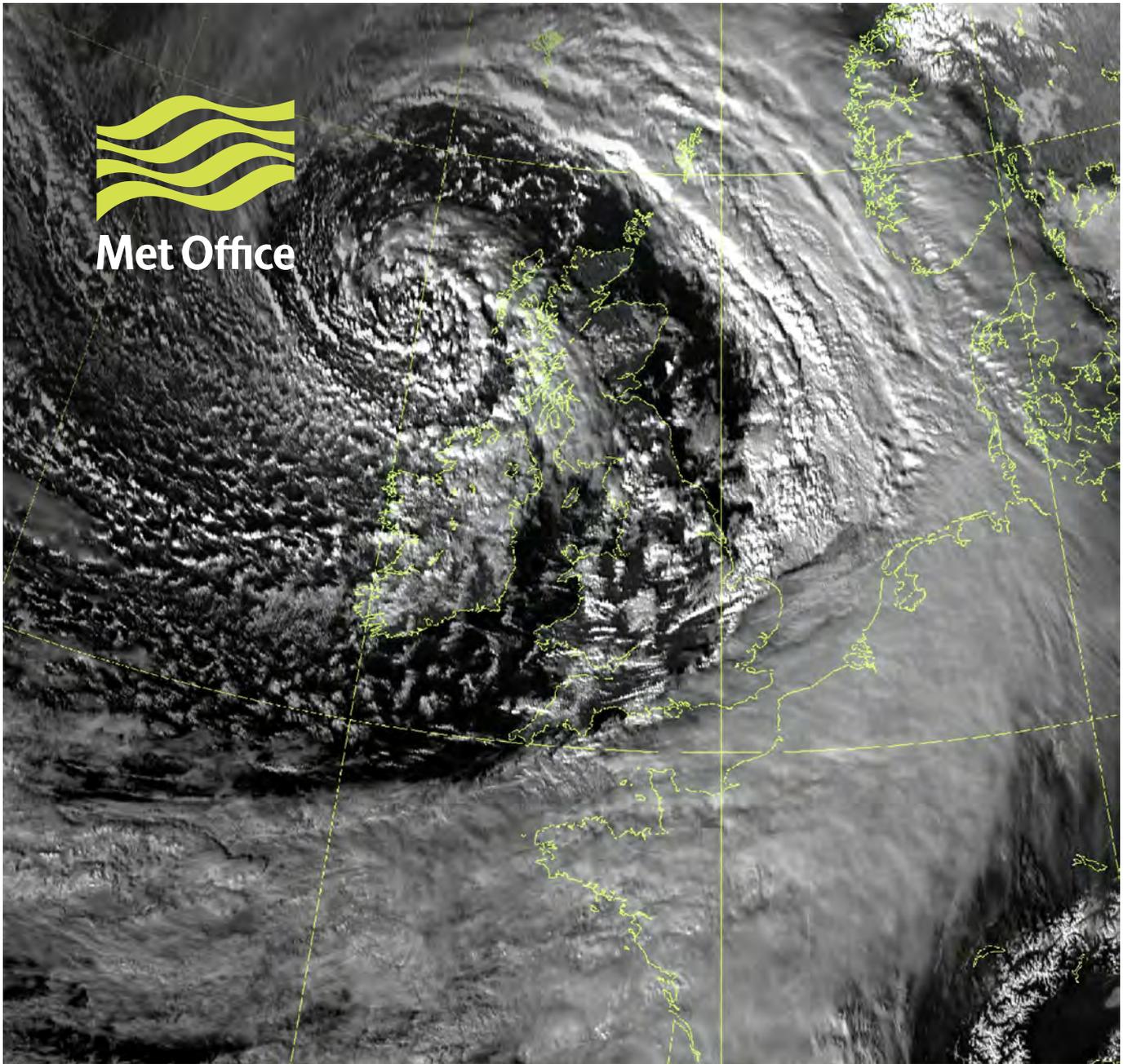




Met Office



# Air mass

National Meteorological Library and Archive  
Fact sheet 10 — Air masses and weather fronts

*(version 01)*

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## Air masses

### Introduction

Air masses are parcels of air that bring distinctive weather features to the country. An air mass is a body or 'mass' of air in which the horizontal gradients or changes in temperature and humidity are relatively slight. That is to say that the air making up the mass is very uniform in temperature and humidity.

An air mass is separated from an adjacent body of air by a transition that may be more sharply defined. This transition zone or boundary is called a front. An air mass may cover several millions of square kilometres and extend vertically throughout the troposphere.

### Sources of an air mass

The temperature of an air mass will depend largely on its point of origin and its subsequent journey over the land or sea. This might lead to warming or cooling by the prolonged contact with a warm or cool surface.

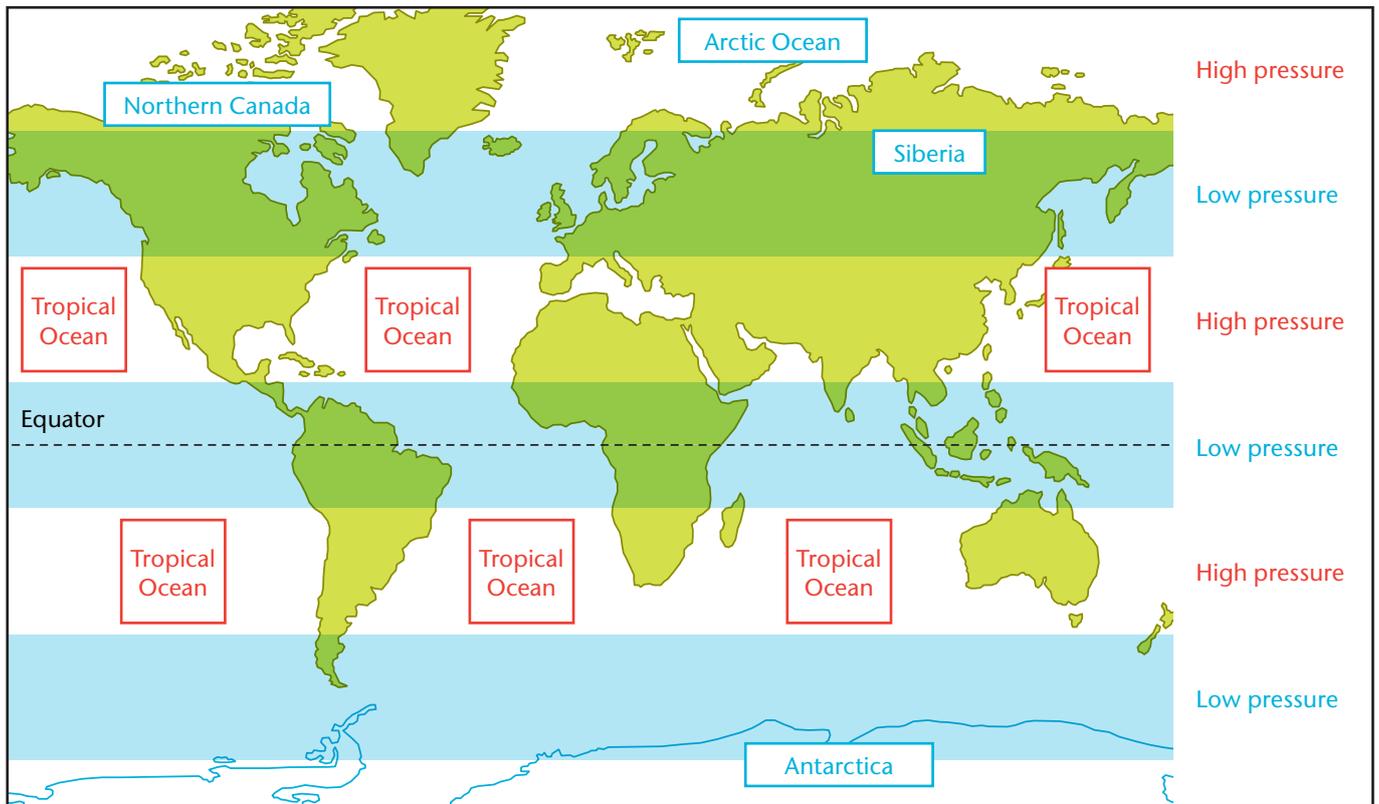


Figure 1. Air mass source regions.

The processes that warm or cool the air mass take place only slowly, for example it may take a week or more for an air mass to warm up by 10 °C right through the troposphere. For this to take place, an air mass must lie virtually in a stagnant state over the influencing region. Hence, those parts of the Earth's surface where air masses can stagnate and gradually attain the properties of the underlying surface are called **air mass source regions**.

The main source regions are the high pressure belts in the subtropics, which produce tropical air masses, and around the poles, that are the source of polar air masses.

Examples of source regions are:

Warm regions (tropical air masses)	Cold regions (polar air masses)
<ul style="list-style-type: none"> <li>• Sahara Desert – warm and dry</li> <li>• Tropical Oceans – warm and moist</li> </ul>	<ul style="list-style-type: none"> <li>• Arctic Ocean – cold and moist</li> <li>• Siberia – cold and dry</li> <li>• Northern Canada – cold and dry</li> <li>• Southern Ocean – cold and moist</li> <li>• Antarctica – cold and dry</li> </ul>

### **Air mass modification**

As we have seen, it is in the source regions that the air mass acquires distinctive properties that are the characteristics of the underlying surface. The air mass may be cool or warm, or dry or moist. The stability of the air within the mass can also be deduced. Tropical air is unstable because it is heated from below, while polar air is stable because it is cooled from below.

As an air mass moves away from its source region towards the British Isles, the air is further modified due to variations in the type or nature of the surface over which it passes. Two processes act independently, or together, to modify an air mass.

An air mass that has a maritime track, i.e. a track predominantly over the sea, will increase its moisture content, particularly in its lower layers. This happens through evaporation of water from the sea surface. An air mass with a long land or continental track will remain dry.

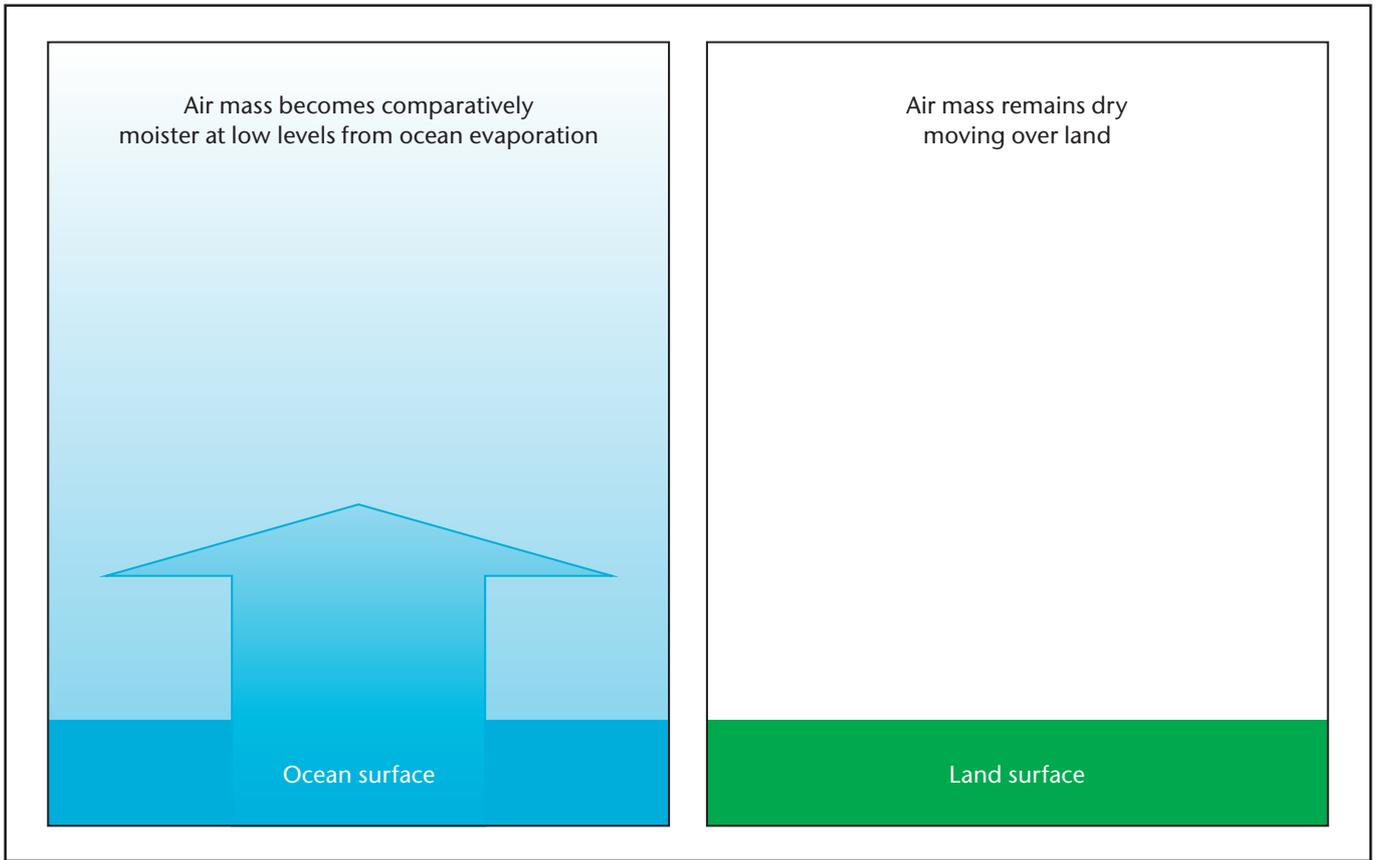
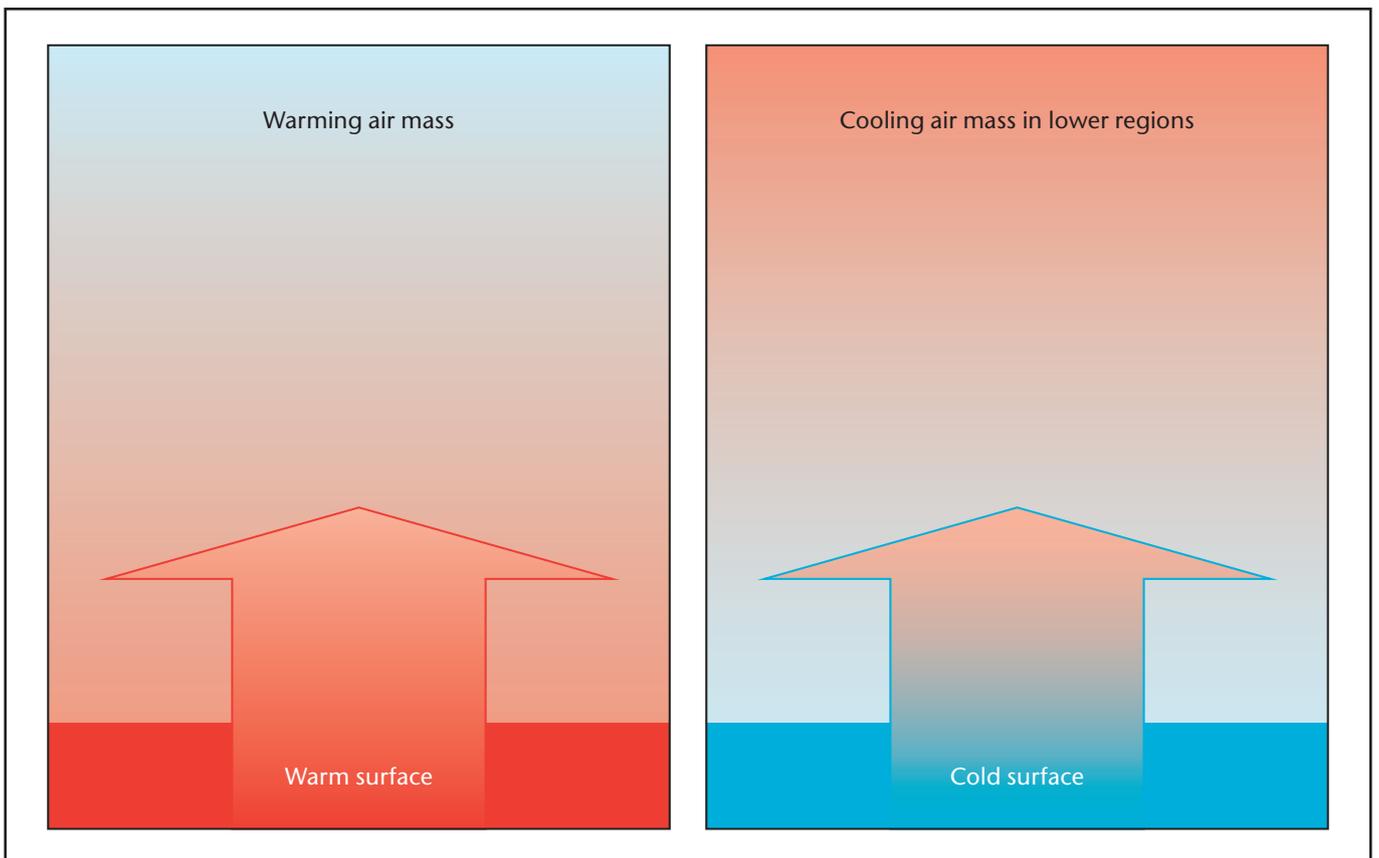


Figure 2. Modification of air mass by land and ocean surfaces.

A cold air mass flowing away from its source region over a warmer surface will be warmed from below making the air more unstable in the lowest layers. A warm air mass moving over a cooler surface is cooled from below and becomes stable in the lowest layers.

Figure 3. Modification of air mass due to surface temperature.



If we look at the temperature profiles of the previous example, the effects of warming and cooling on the respective air masses are very different.

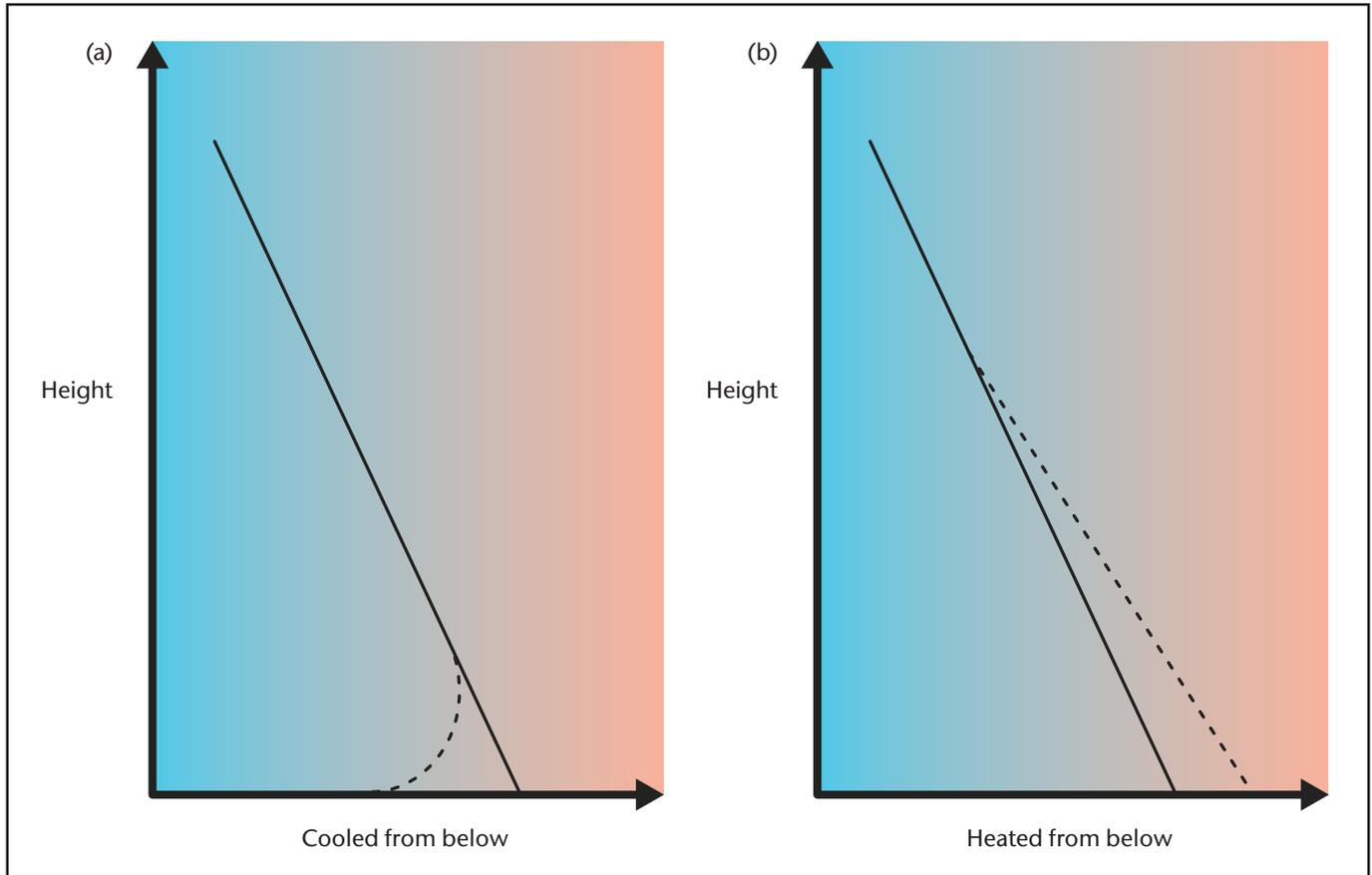


Figure 4. Modified vertical temperature profiles (----- line) typical of: a) tropical air cooled from below and b) polar air heated from below on its way to the British Isles. Note that where the air is heated from below the effect is spread to a greater depth of the atmosphere.

### Air mass types

Air masses are classified into groups designated as 'polar' (P) or 'tropical' (T), 'maritime' (m) or 'continental' (c), defining the basic temperature and humidity characteristics, respectively; more generally, a twofold classification in terms of both elements, e.g. Tm or Pc, is used. Further divisions are sometimes made into Arctic or Antarctic (A) air and into classes of more local significance, e.g. Mediterranean air.

The Britain Isles can be affected by six major air masses from both warm (tropical) regions and cold (polar) regions. These six air masses are:

- Tropical continental (*Tc*)
- Polar continental (*Pc*)
- Tropical maritime (*Tm*)
- Polar maritime (*Pm*)
- Returning polar maritime (*rPm*)
- Arctic maritime (*Am*)

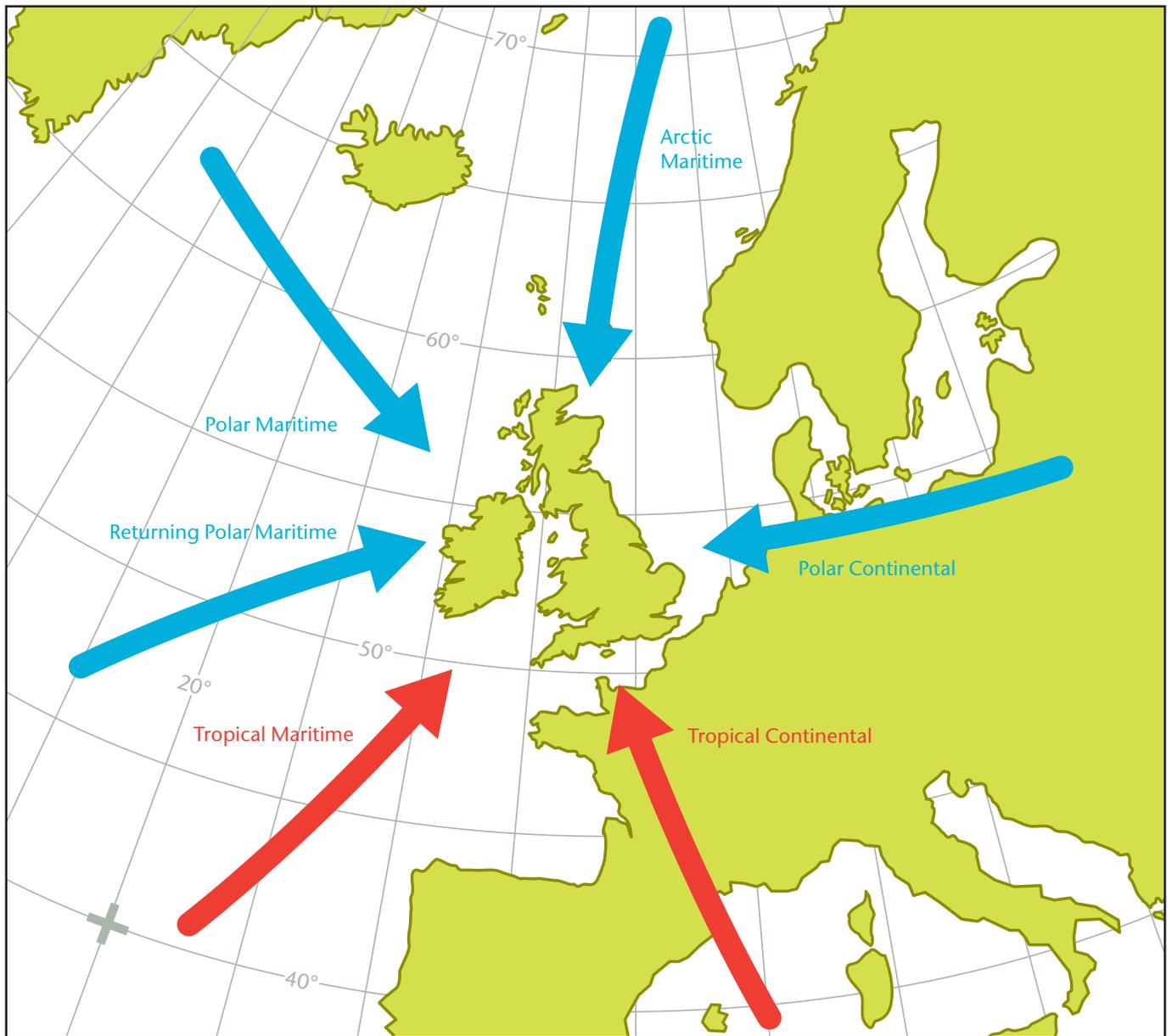


Figure 5. Air masses affecting the British Isles.

Each of these air-mass types has its own distinctive combination of properties in terms of:

- temperature
- moisture content (relative humidity)
- change of lapse rate
- stability
- weather
- visibility

## Principal air masses affecting the British Isles.

- Tropical continental (Tc)

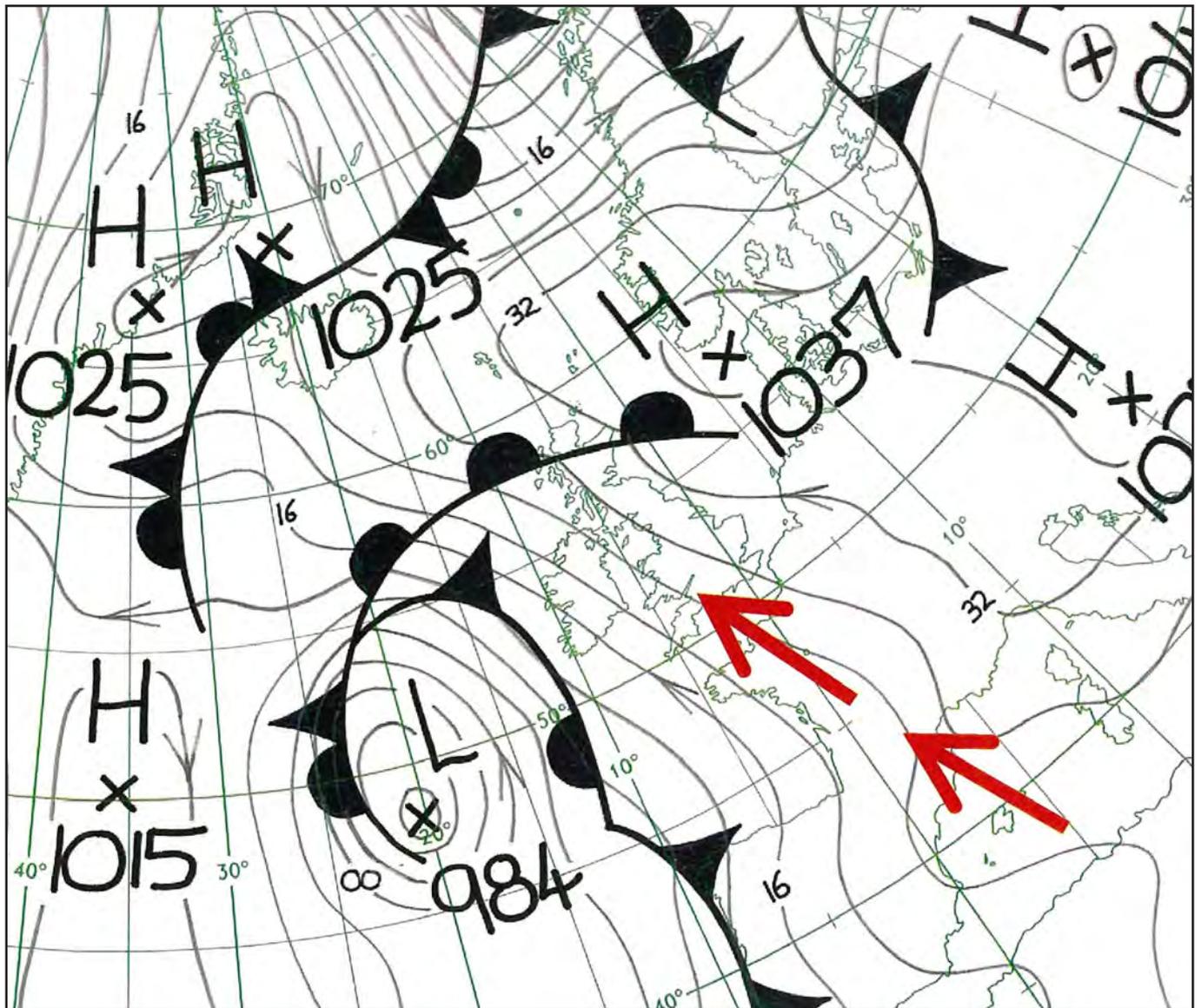


Figure 6. Typical synoptic situation for the British Isles to be affected by a tropical continental air mass.

This air mass originates over North Africa and the Sahara (a warm source region). It is most common during the summer months June, July and August, although it can occur at other times of the year. It is caused by high pressure over northern or Eastern Europe with surface winds blowing from a south-easterly direction.

Our highest temperatures usually occur under the influence of tropical continental air (over 30 °C by day and around 15 to 20 °C at night). Visibility is usually moderate or poor due to the air picking up pollutants during its passage over Europe and from sand particles blown into the air from Saharan dust storms. Occasionally, the Saharan dust is washed out in showers producing coloured rain and leaving cars covered in a thin layer of orange dust.

During winter months, tropical continental air is more difficult to identify, but may reach the British Isles on south or south-easterly winds ahead of slow-moving Atlantic fronts. When high pressure prevails during the winter, strong cooling near the surface makes the air stable, rather than cold and moist. Low cloud and poor visibility may be very persistent under such conditions.

- The record breaking temperatures of August 2003 were caused by a tropical continental air mass.

	Summer	Winter
Temperature:	Very warm or hot	Average
Humidity:	Relatively dry	Rather moist
Stability:	Generally unstable	Stable
Weather:	Clear, occasional thundery showers	Usually cloudy
Visibility:	Moderate or poor	Moderate or poor

- Polar continental (Pc)

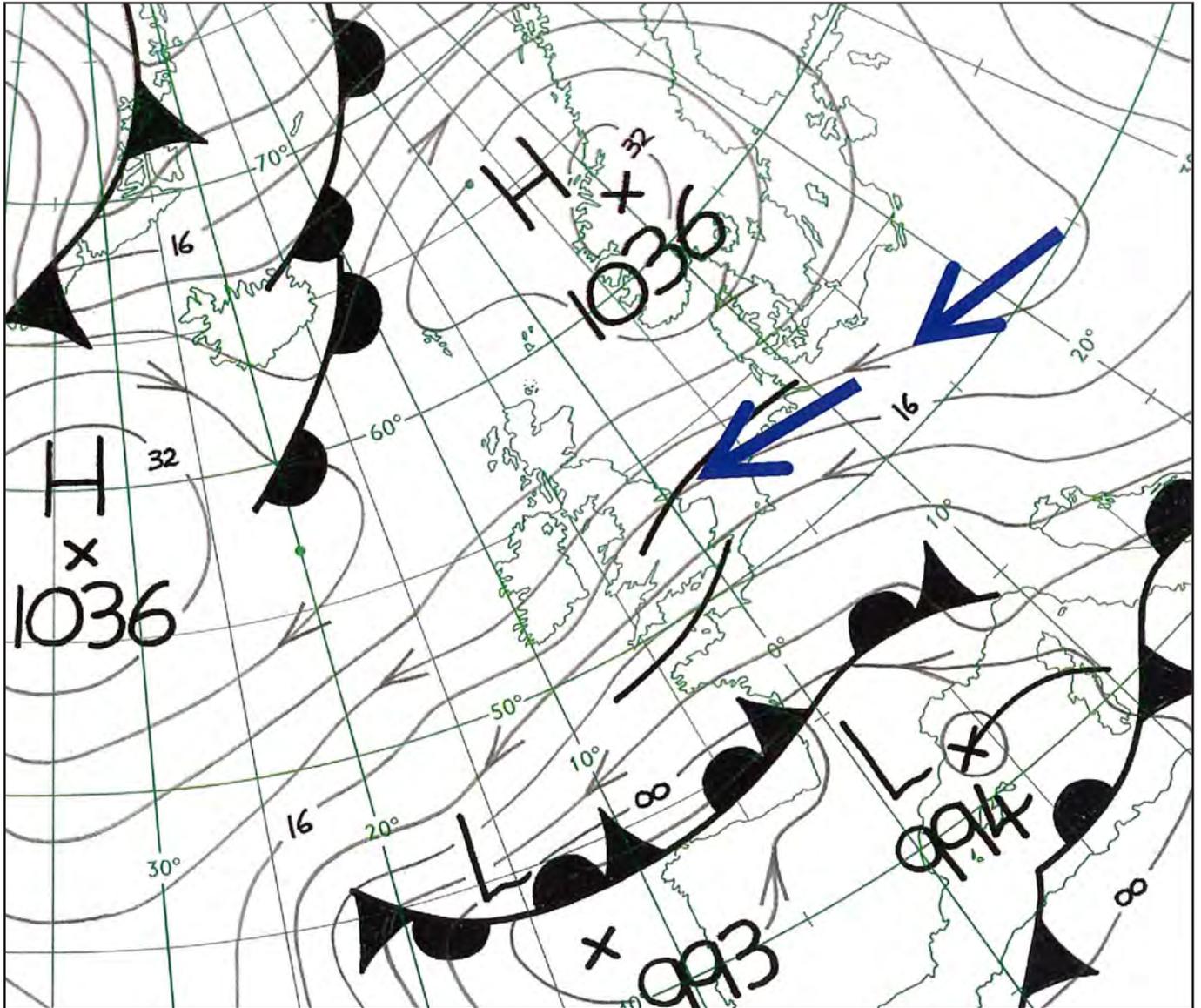


Figure 7. Typical synoptic situation for the British Isles to be affected by a polar continental air mass.

This air mass has its origins over the snow fields of Eastern Europe and Russia and is only considered a winter (November to April) phenomena. During the summer with the land mass considerably warmer, this air mass would be classed as a tropical continental.

Polar continental air affects the British Isles when pressure is high over Scandinavia with surface winds from an easterly point.

The weather characteristics of this air mass depend on the length of the sea track during its passage from Europe to the British Isles: this air is inherently very cold and dry and if it reaches southern Britain with a short sea track over the English Channel, the weather is characterised by clear skies and severe frosts; with a longer sea track over the North Sea, the air becomes unstable and moisture is added giving rise to showers of rain or snow, especially near the east coast of Britain. The lowest temperatures across the British Isles usually occur in this air mass, lower than -10 °C at night, and sometimes remaining below freezing all day.

This air mass was responsible for the record low temperatures across Scotland during January 1982 and December 1995 and for the exceptionally cold spell during November and December 2010.

	Long sea track	Short sea track
Temperature:	Cold	Very cold
Humidity:	Moist in lowest layers	Very dry
Stability:	Unstable	Stable
Weather:	Rain or snow showers	Clear
Visibility:	Good	Moderate or poor

- Tropical maritime (*Tm*)

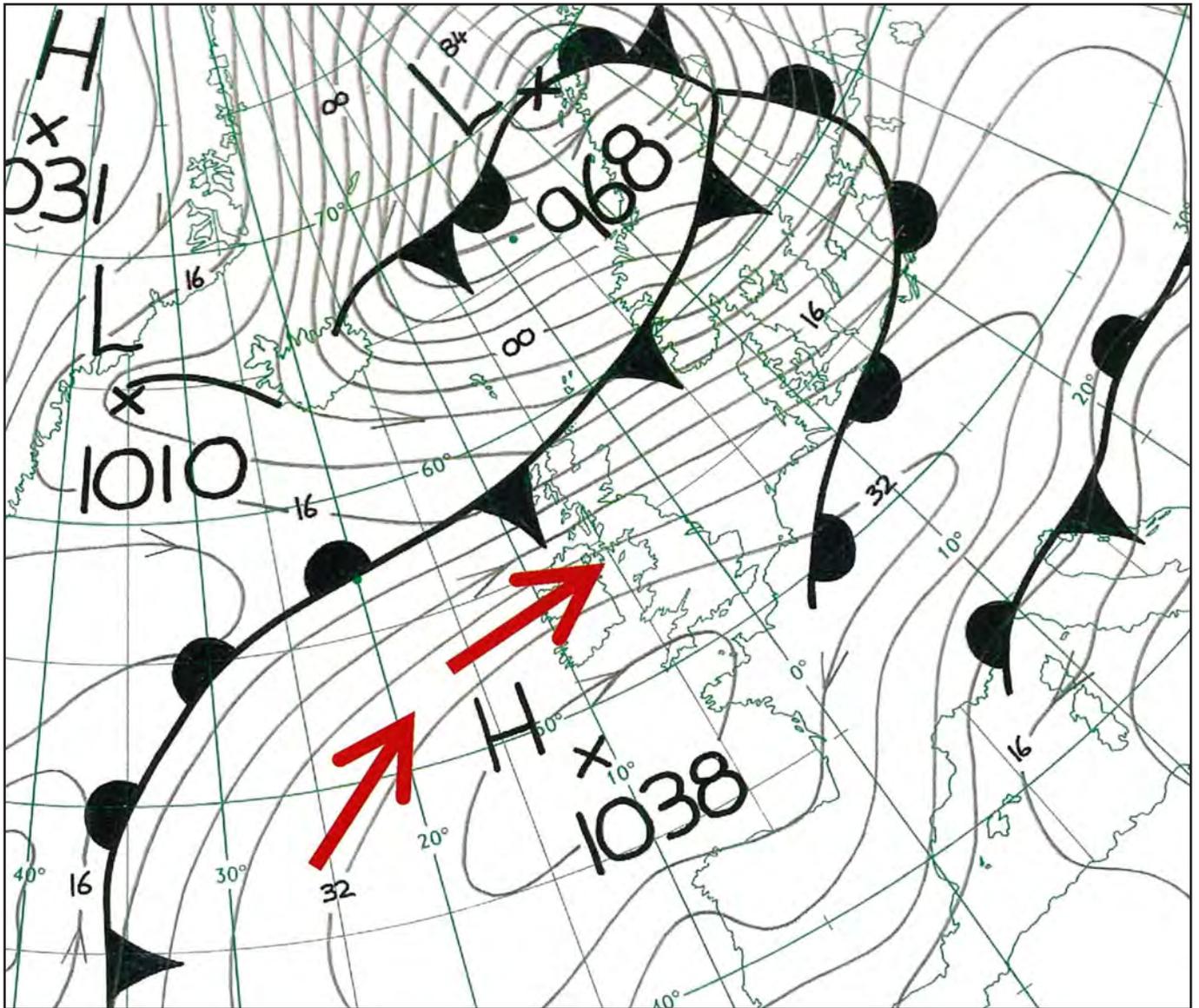


Figure 8. Typical synoptic situation for the British Isles to be affected by a tropical maritime air mass.

The source region for this air mass is warm waters of the Atlantic Ocean between the Azores and Bermuda. The predominant wind direction across the British Isles, in a tropical maritime air mass, is south-westerly. This air mass usually occurs in warm sectors of depressions.

Tropical maritime air is warm and moist in its lowest layers and, although unstable over its source region, during its passage over cooler waters becomes stable and the air becomes saturated. Consequently when a tropical maritime air mass reaches the British Isles it bring with it low cloud and drizzle, perhaps also fog around windward coasts and across hills. To the lee of high ground though, the cloud may break up and here the weather, particularly in the summer months, can be fine and sunny.

This is a mild air stream and during the winter month in particular, can raise the air temperature several degrees above the average.

	Exposed	Sheltered
Temperature:	Near sea temperature	Warm
Humidity:	Very moist	Moist
Stability:	Stable	Stable aloft
Weather:	Low cloud, drizzle, fog	Broken cloud, dry
Visibility:	Often poor with coastal fog	Moderate

- Polar maritime (*Pm*)

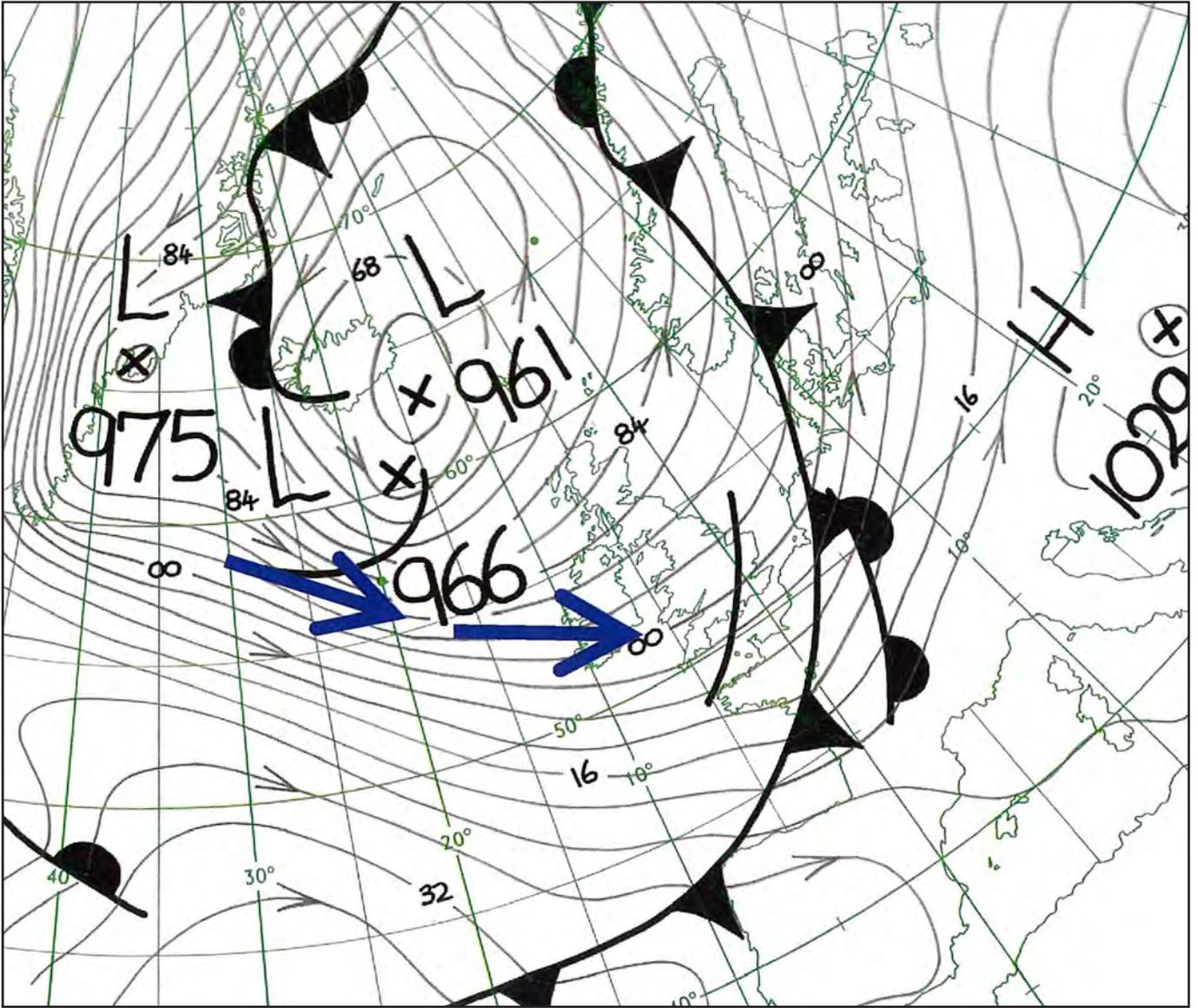


Figure 9. Typical synoptic situation for the British Isles to be affected by a polar maritime air mass.

This air mass has its origins over northern Canada and Greenland and reaches the British Isles on a north-westerly air stream.

Polar maritime is the most common air mass to affect the British Isles. It is normally the air mass found behind a cold front what has come in off the Atlantic Ocean.

This air mass starts very cold and dry but during its long passage over the relatively warm waters of the North Atlantic its temperature rises rapidly and it becomes unstable to a great depth.

This air mass is characterised by frequent showers at any time of the year. In the winter months when convection is most vigorous over the sea, hail and thunder are common across much of the western and northern side of the British Isles. However, eastern Britain may see fewer showers as here the surface heating is reduced. During the summer, the reverse is true, land temperatures are higher than sea temperatures and the heaviest showers occur over eastern England.

	Summer	Winter
Temperature:	Cool	Rather cold
Humidity:	Moist	Moist
Stability:	Unstable	Unstable
Weather:	Showers in eastern England	Heavy showers, sometimes with hail and thunder mainly in exposed western and hilly areas
Visibility:	Good	Good

- Arctic maritime (*Am*)

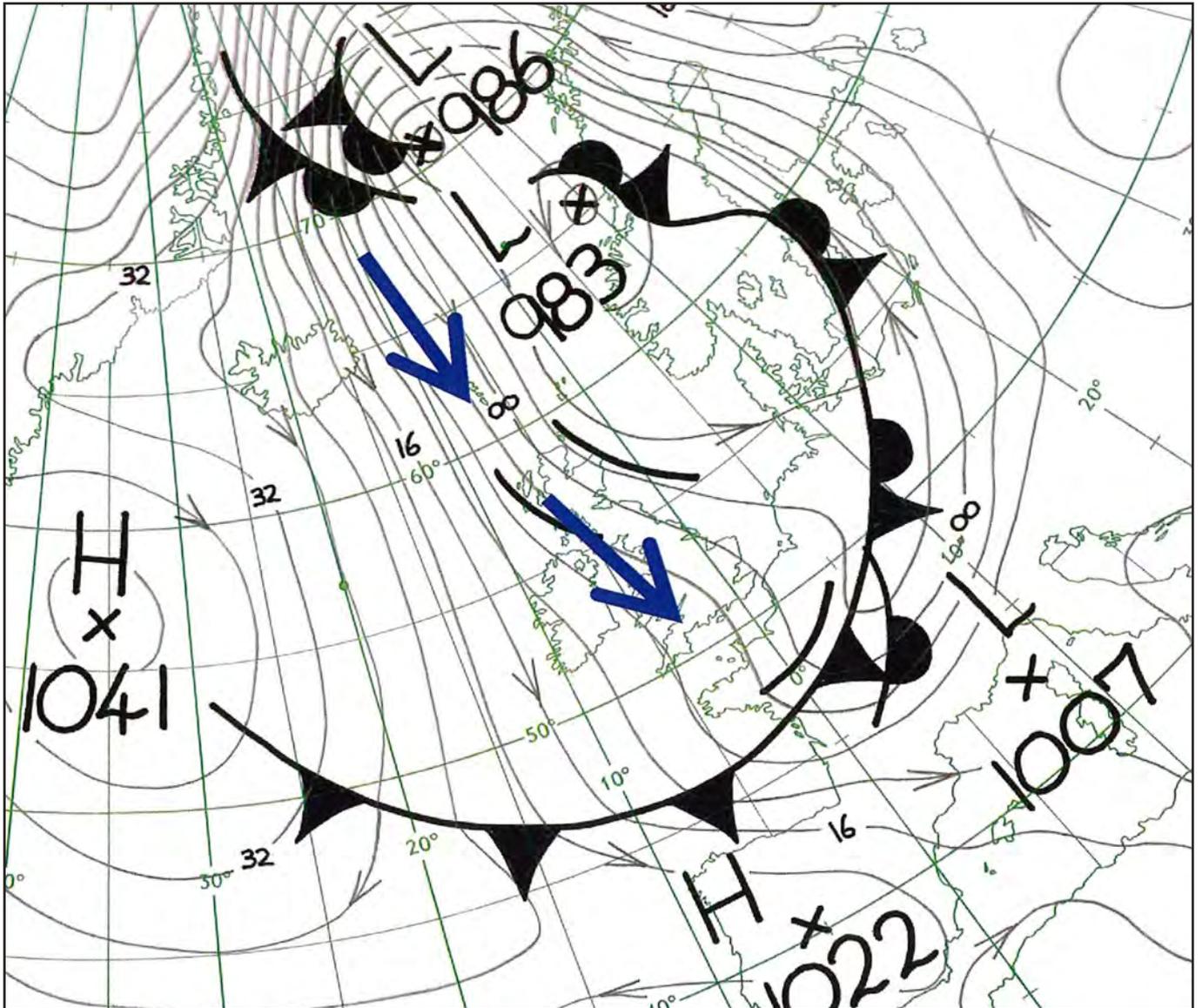


Figure 10. Typical synoptic situation for the British Isles to be affected by an arctic maritime air mass.

An arctic maritime air mass has similar characteristics to a polar maritime air mass, but because of the shorter sea track the air is colder and less moist. Arctic air is uncommon during the summer, but when it does occur it may bring heavy showers or thunderstorms and unseasonably low temperatures. Between October and May, the air is cold enough to produce hail showers or snow, and these are most frequent over Scotland and along the coasts exposed to northerly winds.

An arctic maritime air mass has its origins over the North Pole and the Arctic Ocean. The synoptic situation needed for this type of air mass is high pressure over or to the west of Ireland and low pressure over Eastern Europe and southern Scandinavia.

Polar low-pressure systems forming in this air mass can sometimes lead to widespread and heavy snowfall, but otherwise inland areas remain free of cloud in the winter months. In northern Scotland, arctic maritime is usually the coldest air mass, but over the rest of Britain, this air mass is not as cold as polar continental.

	Summer	Winter
Temperature:	Cold	Cold (colder than polar maritime)
Humidity:	Fairly moist	Moist (not as moist as polar maritime)
Stability:	Unstable	Unstable
Weather:	Heavy showers or thunderstorms	Heavy showers, sometimes with snow, hail and thunder mainly in northern Scotland and exposed coastal areas.
Visibility:	Very good	Very good

- Returning polar maritime (rPm)

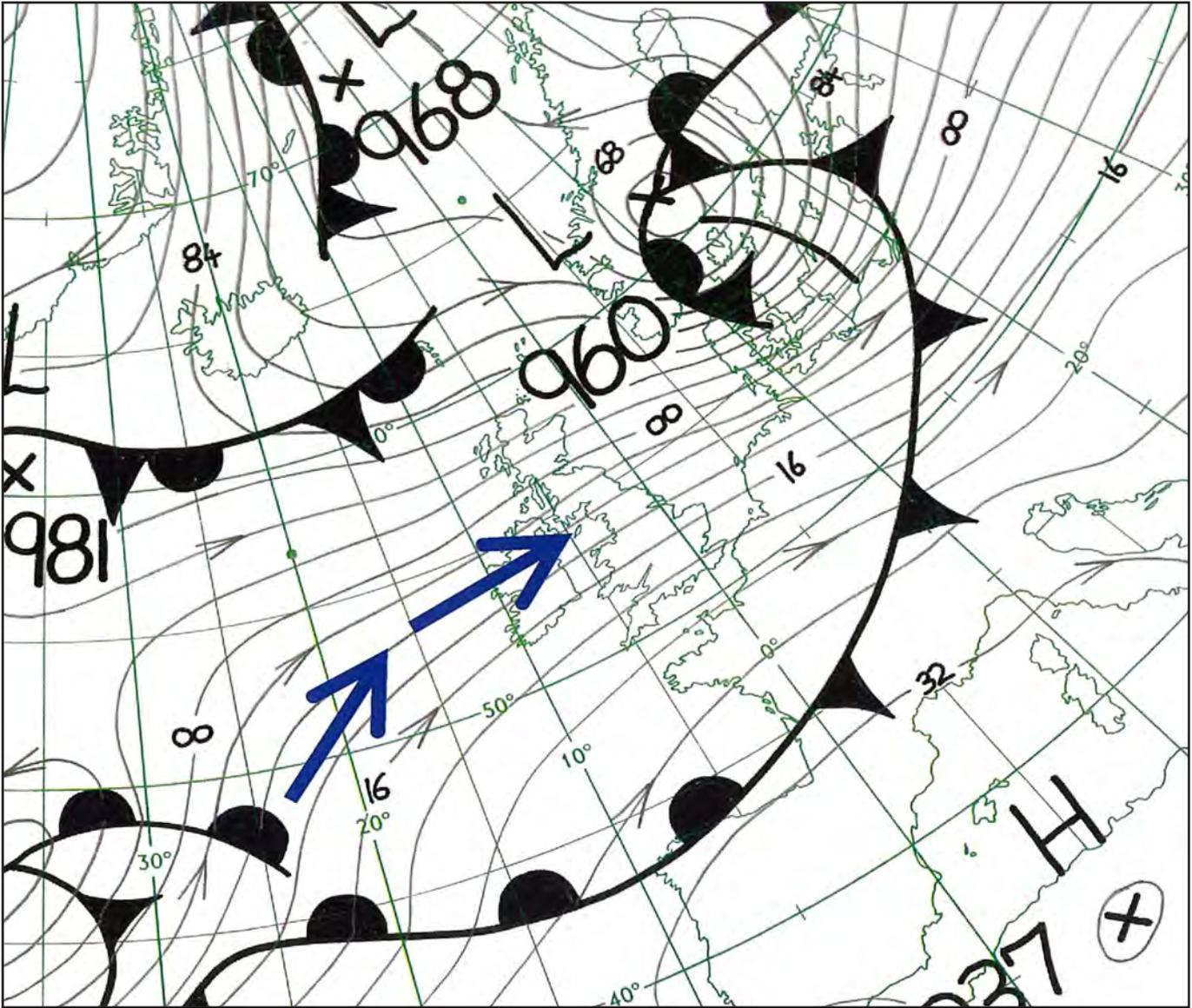


Figure 11. Typical synoptic situation for the British Isles to be affected by a returning polar maritime air mass.

A typical synoptic situation associated with this air mass would be a slow moving depression in mid-Atlantic.

During its passage south, the air becomes unstable and moist but on moving north-east it passes over cooler water making it stable in its lowest layers. Although the weather across the British Isles in this air mass is largely dry, there can be extensive stratocumulus cloud.

This air mass is basically another variation of polar maritime, in so far as it has its origins over Greenland and northern Canada. However, this time the sea track is much longer having taken the air first southwards over the North Atlantic, then north-eastwards across the British Isles.

	All year
Temperature:	Warm (warmer than polar maritime)
Humidity:	Moist (moister than polar maritime)
Stability:	Stable at low levels; unstable aloft
Weather:	Variable cloud, possible showers
Visibility:	Mainly good

## Weather fronts

### Introduction

We have looked at the individual types of air masses in some detail, but what is just as, or perhaps, even more important for weather forecasting is what happens in the immediate region where the air masses meet. As we have seen, the air masses have quite different properties so when they meet, perhaps one is cold and dry and the other is relatively very warm and moist. These differences produce a reaction in a zone known as a front.

Definition of a weather front: a weather front is simply the boundary between two air masses.

### A brief history

The idea of weather fronts first appeared in 1919 when the Norwegian Meteorologist Wilhelm Bjerknes identified that the area associated with weather fronts was the battle ground between two opposing air masses. As the First World War had just finished, Bjerknes decided to call this area a 'front'.

The idea that the boundary between a warm air mass and advancing cold air mass was called a cold front and likewise the boundary between a cold air mass and an advancing warm air mass is called a warm front has today been acknowledged as originating from the Bergen School of meteorology.

In 1919 Bjerknes published a weather map with these fronts on them — these were simple line drawings with no symbols. The colours used are quite interesting, the warm front was coloured blue, instead of red, to represent the boundary between the cold air mass immediately in front of the warm air and correspondingly, the cold front was coloured red.

During the summer of 1919, another meteorologist at the Bergen School suggested that it would be better if these colours were reversed so that the cold front was coloured blue and the warm front red. This is the colour scheme that we know today. One of the big problems with this colour representation was the fact that most publishing in the early 20th Century was in black and white, thus making this representation useless. Another representation was needed.

On the 8th January 1924, another Bergen School meteorologist named Tor Bergeron, who worked with Bjerknes on his theory, sent Jack Bjerknes, Wilhelm's son, a simple post card from Leipzig. In it he proposed a monochromatic representation of weather fronts to be used on weather maps. He suggested that the cold front should be represented by a line with triangles printed on it. The triangles should be on the side of the line showing the direction the front is moving in. The warm front should be represented with semi-circles on it; again these symbols should be on the side of the line showing its direction of movement. The triangle was picked as it looked like an icicle and the semi-circle because it looked like the sun rising bringing warmth. These fronts could then be drawn in black so as to identify each one on a black and white chart.

## Types of weather front

There are three different types of weather front. These are:

- Cold front
- Warm front
- Occluded front (also called an occlusion)

### Cold front

This is the boundary between warm air and cold air and is indicative of cold air replacing warm air at a point on the Earth's surface.

On a synoptic chart a cold front appears blue and is symbolised thus:

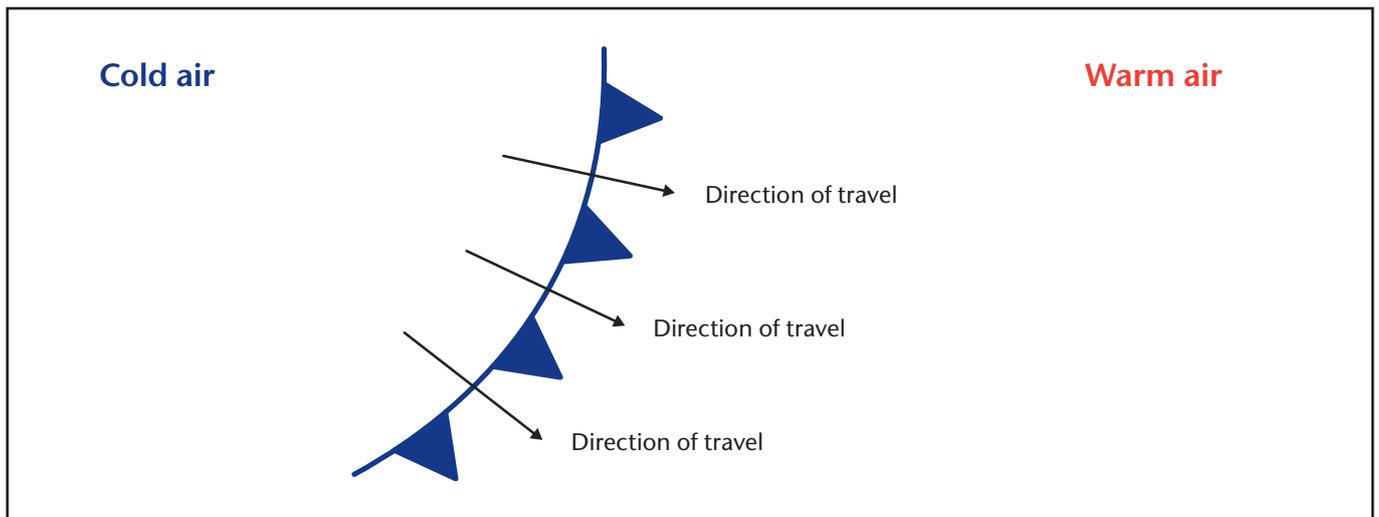


Figure 12. Cold front.

The presence of a cold front means that cold air is advancing and pushing underneath warmer air. This is because the cold air is 'heavier' or denser, than the warmer air. Cold air is thus replacing warm air at the surface. The symbols on the front indicate the direction the front is moving.

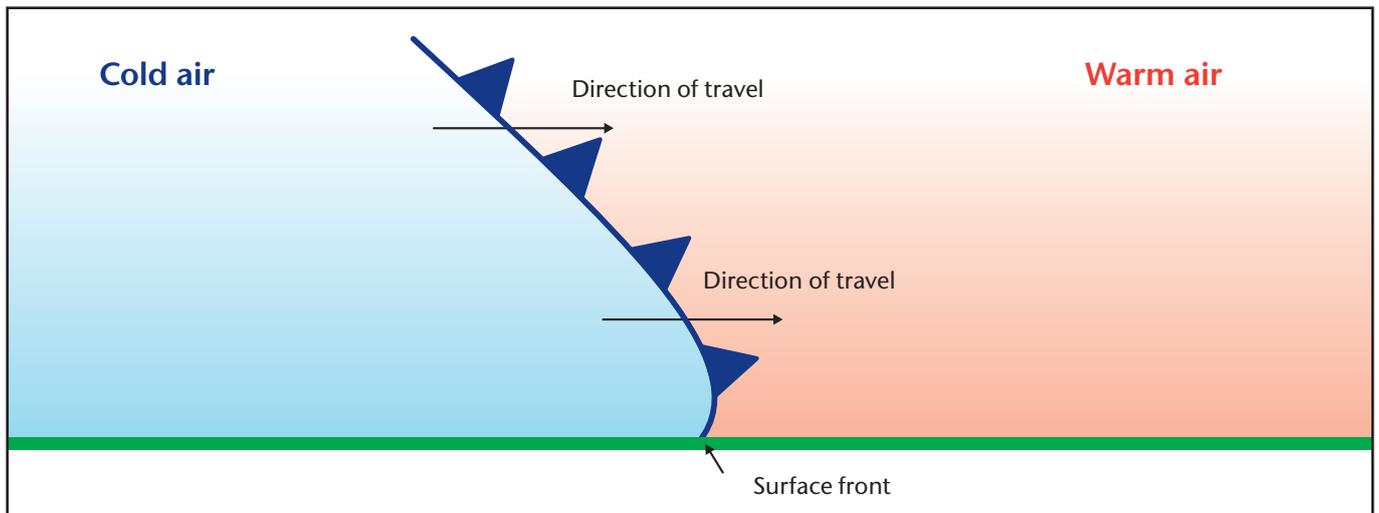


Figure 13. Slope of a cold front.

The average slope of a cold-frontal surface is about 1 in 50. A cold front moves, on average, at about the speed of the **geostrophic wind** component normal to the front and measured at it. The passage of a cold front is normally marked at the earth's surface by a rise of pressure, a fall of temperature and dew-point, and a veer of wind (in the northern hemisphere). Rain occurs in association with most cold fronts and may extend some 100 to 200 km ahead of or behind the front. Some cold fronts give only a shower at the front, while still others give no precipitation. Thunder, and occasionally a line squall, may occur at a cold front.

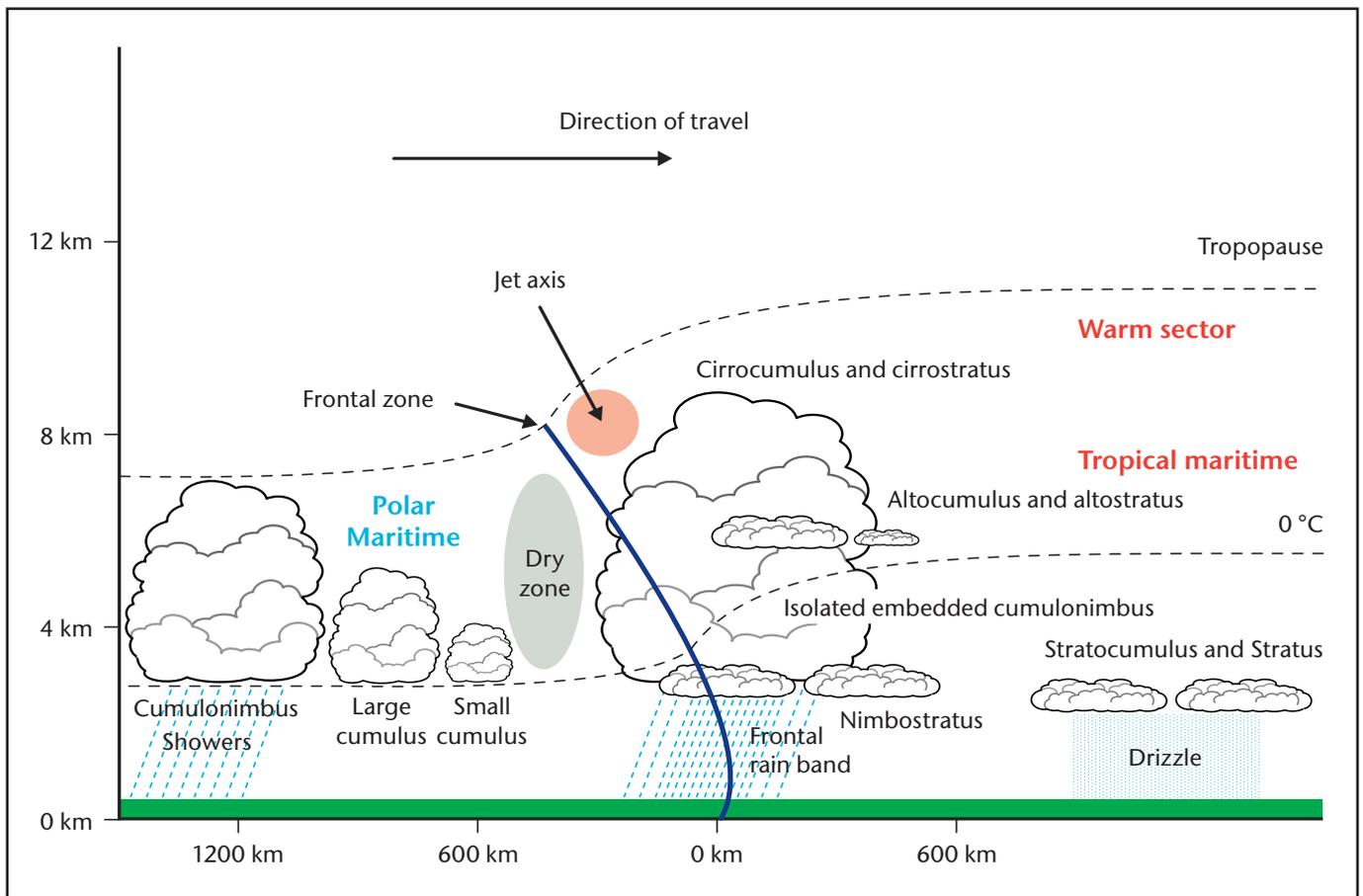


Figure 14. Cross sectional view of a cold front.

Slope:	1:30 to 1:100, steeper slope for more active fronts. Average 1:70
Cloud:	Thick layers of stratiform cloud. Some active cold fronts have occasional embedded cumulonimbus and some are composed principally of convective cloud, though this tends to be more a feature of cold fronts at lower latitudes than the British Isles. Cloud becoming convective and well-broken behind the front. Slope of front usually about double that of frontal surface
Weather:	A fairly narrow band of rain around the surface frontal position, some heavy, especially on the front. Risk of hail and thunder if cumulonimbus are present
Temperature:	Usually falls, but may actually rise due to insolation in clearer air behind front
Dewpoint:	Fall on passage of front
Visibility:	Moderate in precipitation, improves rapidly to good or excellent behind front
Pressure:	Starts to fall as front approaches, rising quickly on and behind front
Surface wind:	Backs slightly (anticlockwise) ahead of front. Veers sharply (clockwise) on passage
Upper winds:	Backs with height
Movement:	With the geostrophic component normal to the front

## Warm front

This is the boundary between cold air and warm air and is indicative of warm air replacing cold air at a point on the Earth's surface.

On a synoptic chart a warm front appears red and is symbolised thus:

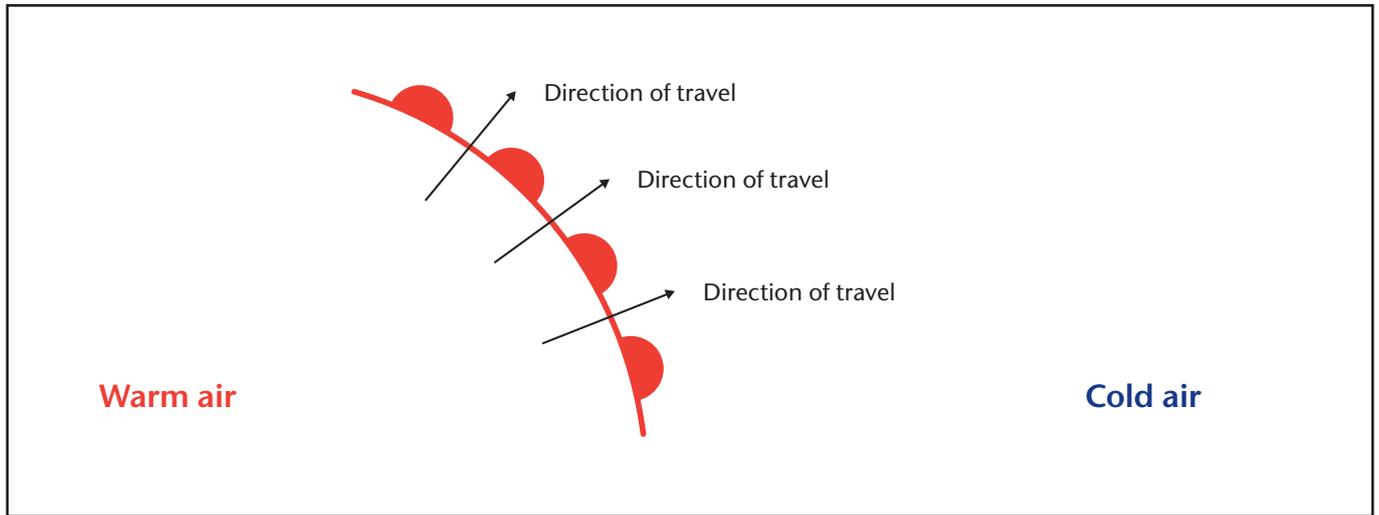


Figure 15. Warm front.

The presence of a warm front means that warm air is advancing and rising up over cold air. This is because the warm air is 'lighter' or less dense, than the colder air. Warm air is thus replacing cold air at the surface. The symbols on the front indicate the direction the front is moving.

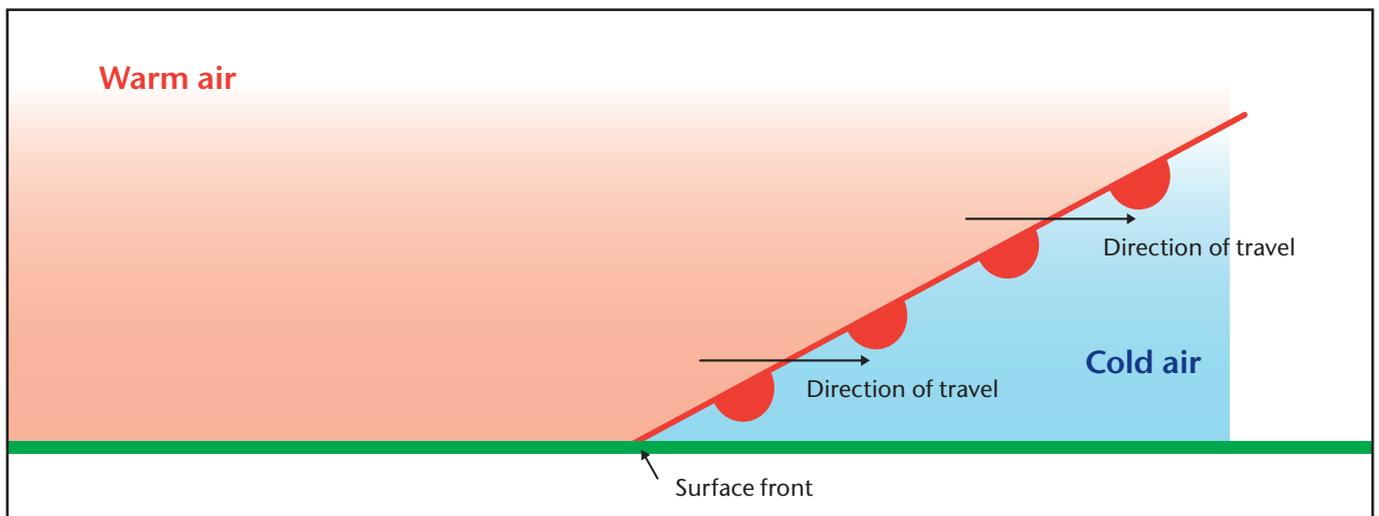


Figure 16. Slope of a warm front.

The average slope of a warm-frontal surface is about 1 in 150. A warm front moves, on average, at a speed some two-thirds of the component of the geostrophic wind component normal to the front and measured at it.

Behind a warm front and in front of the cold front lies the warm sector. As the warm front moves slower than the cold front, due to friction, the warm sector gradually gets smaller until it ultimately disappears (at the surface) resulting in an occluded front or occlusion for short.

As a warm front approaches, temperature and dew-point within the cold air gradually rise and pressure falls at an increasing rate. Precipitation usually occurs within a wide belt some 400 km in advance of the front. Passage of the front is usually marked by a steadying of the barometer, a discontinuous rise of temperature and dew-point, a veer of wind (in the northern hemisphere), and a cessation or near cessation of precipitation.

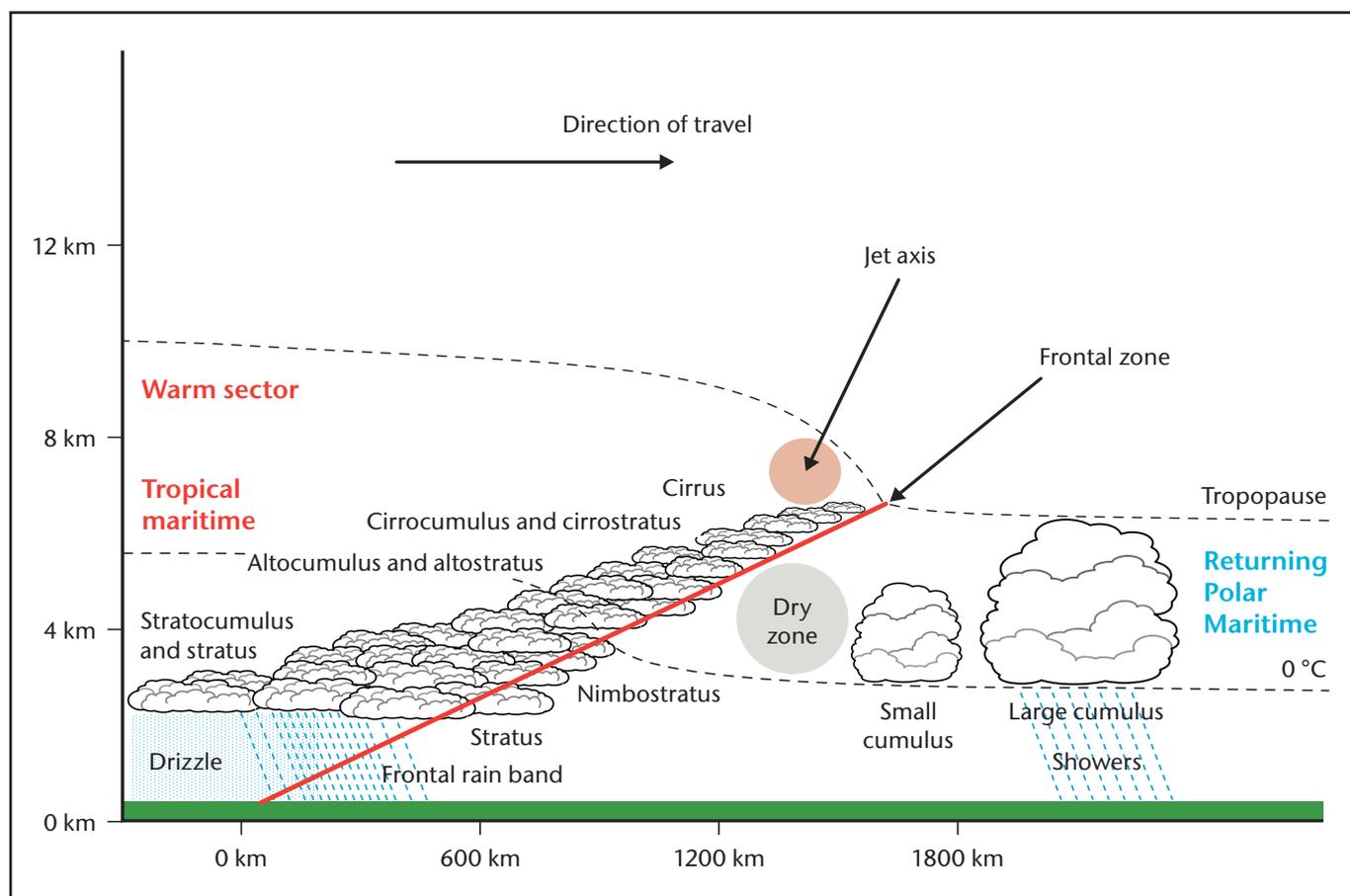


Figure 17. Cross sectional view of a warm front.

Slope:	1:100 to 1:200, steeper slope for more active fronts. Average 1:150
Cloud:	Increasing amounts of upper cloud, thickening and lowering with approach of front. Leading edge of upper cloud about 800km ahead of surface front. Slope of cloud usually about double that of frontal surface
Weather:	Slight rain approximately 200 – 400 km ahead of surface front becomes moderate close to surface front, ceasing after passage. Scattered outbreaks of slight rain or drizzle may occur in warm sector
Temperature:	May rise on passage of front, but not necessarily as rain depresses temperature
Dewpoint:	Starts to rise ahead of front, levelling off on passage of front
Visibility:	Good ahead of front, becoming moderate in precipitation, occasionally poor in warm sector
Pressure:	Falls increasingly as front approaches. Generally becomes steady in warm sector, but continues to fall if depression is deepening
Surface wind:	Tends to back (anticlockwise) and increase ahead of front. Veers (clockwise) on passage
Upper winds:	Veer with height
Movement:	Over sea $\frac{4}{5}$ – $\frac{5}{6}$ geostrophic component normal to the front. Over land $\frac{1}{2}$ – $\frac{2}{3}$

### Occluded front

These are slightly more complex than cold or warm fronts. An occluded front (also known as an occlusion) is formed when a cold front catches up with a warm front. The slope of a cold front is angled at about 1 in 70 (this is the average) whereas a warm front is angled at 1 in 150 (average). Consequently, a warm front has more contact with the ground and is therefore slower moving than a cold front, mainly due to friction.

When a cold front catches up with a warm front the warm air in the warm sector is forced up from the surface.

On a synoptic chart an occluded front appears purple and is symbolised thus:

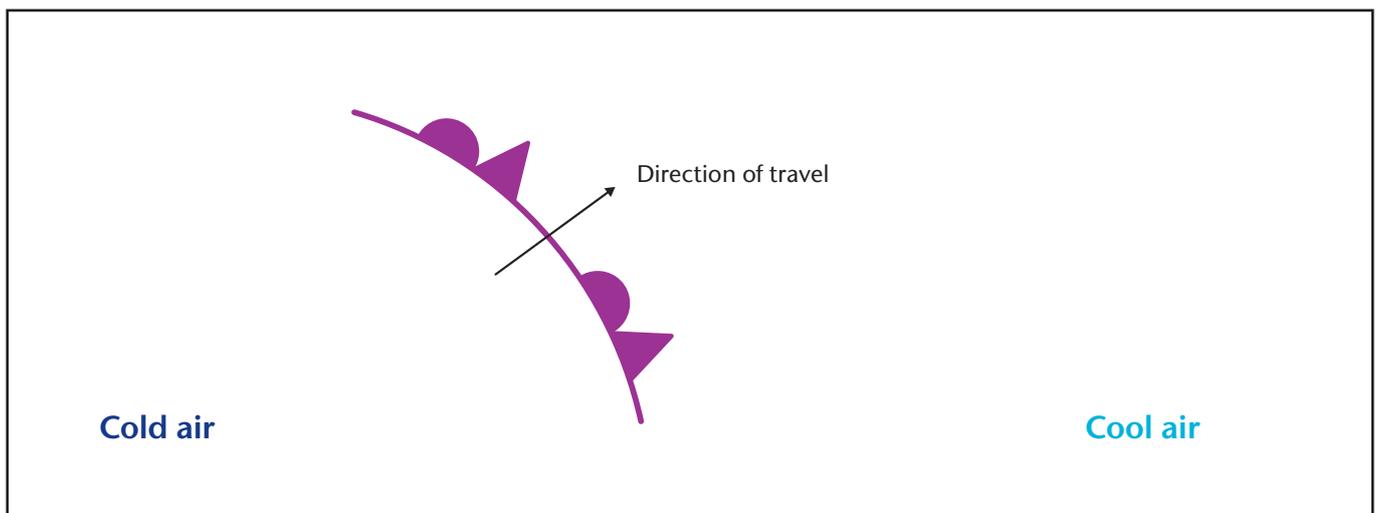


Figure 18. Occluded front.

The symbols on the front indicate the direction the front is moving.

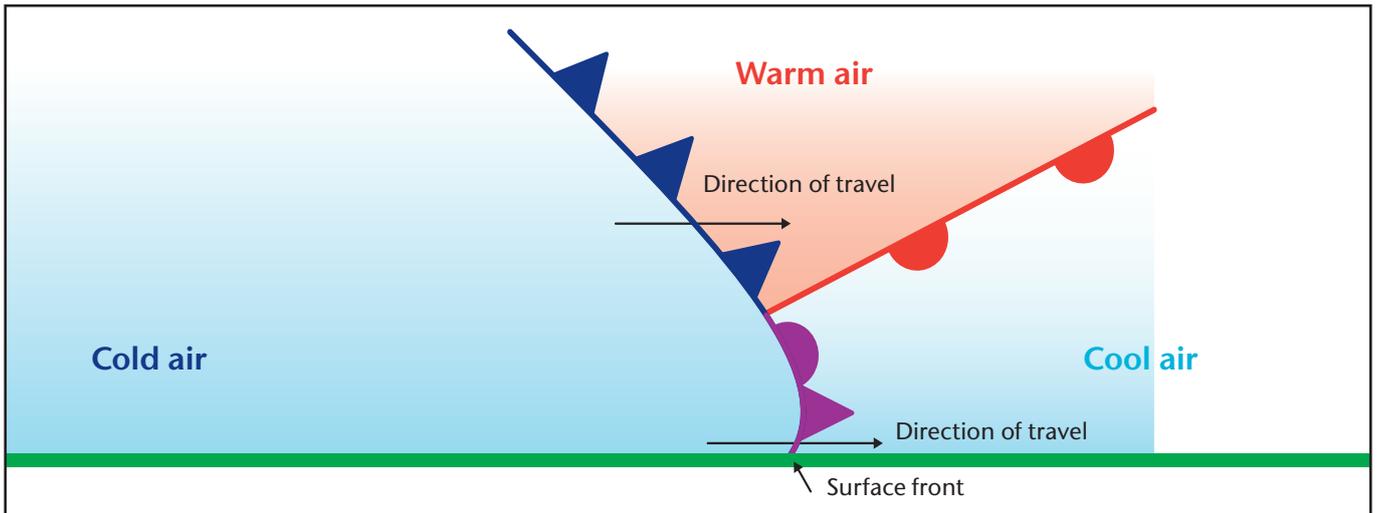


Figure 19. Slope of an occluded front.

As convergence takes place at the fronts and in the warm sector of the depression, the cold front closes in on the warm front. The warm sector is thus reduced to a trough line called the line of occlusion and is substantially lifted from the surface of the earth. The trough line is marked by a belt of cloud and precipitation and by a wind shift.

In those cases where there is a substantial temperature difference between the cold air mass in advance of the warm front and that behind the cold front a 'warm occlusion' (less cold air behind) or 'cold occlusion' (less cold air in advance) forms; the effect is to extend the cloud and precipitation well in advance of the surface occlusion in the former case, and behind the occlusion in the latter case. Occlusions are common in north-western Europe, the warm type being more common in winter, the cold type in summer.

## Formation of a mid-latitude depression

The Bergen School, led by Bjerknes, devised a simple model that shows how depressions, or low pressure systems, develop in mid-latitudes as warm and cold air masses meet. Their model has the following stages:

- Origin and infancy — a warm air mass, such as tropical maritime or tropical continental meets a cooler air mass, such as polar maritime or polar continental.

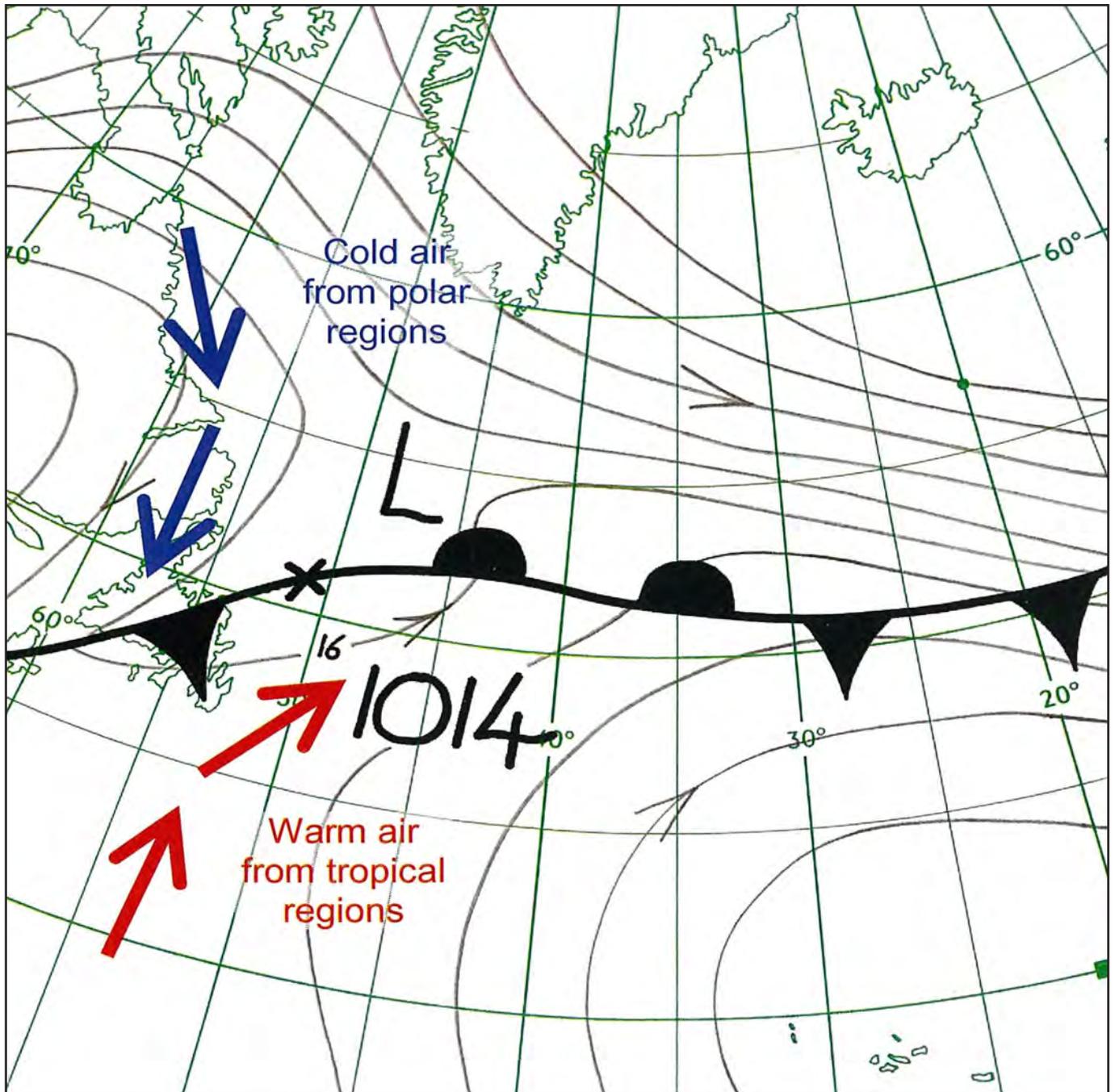


Figure 20. Origin and infancy of a mid-latitude depression.

- Maturity — the warm air rises and spirals up in an anticlockwise manner over the sinking cold air. A distinctive warm sector exists between the warm and cold fronts.

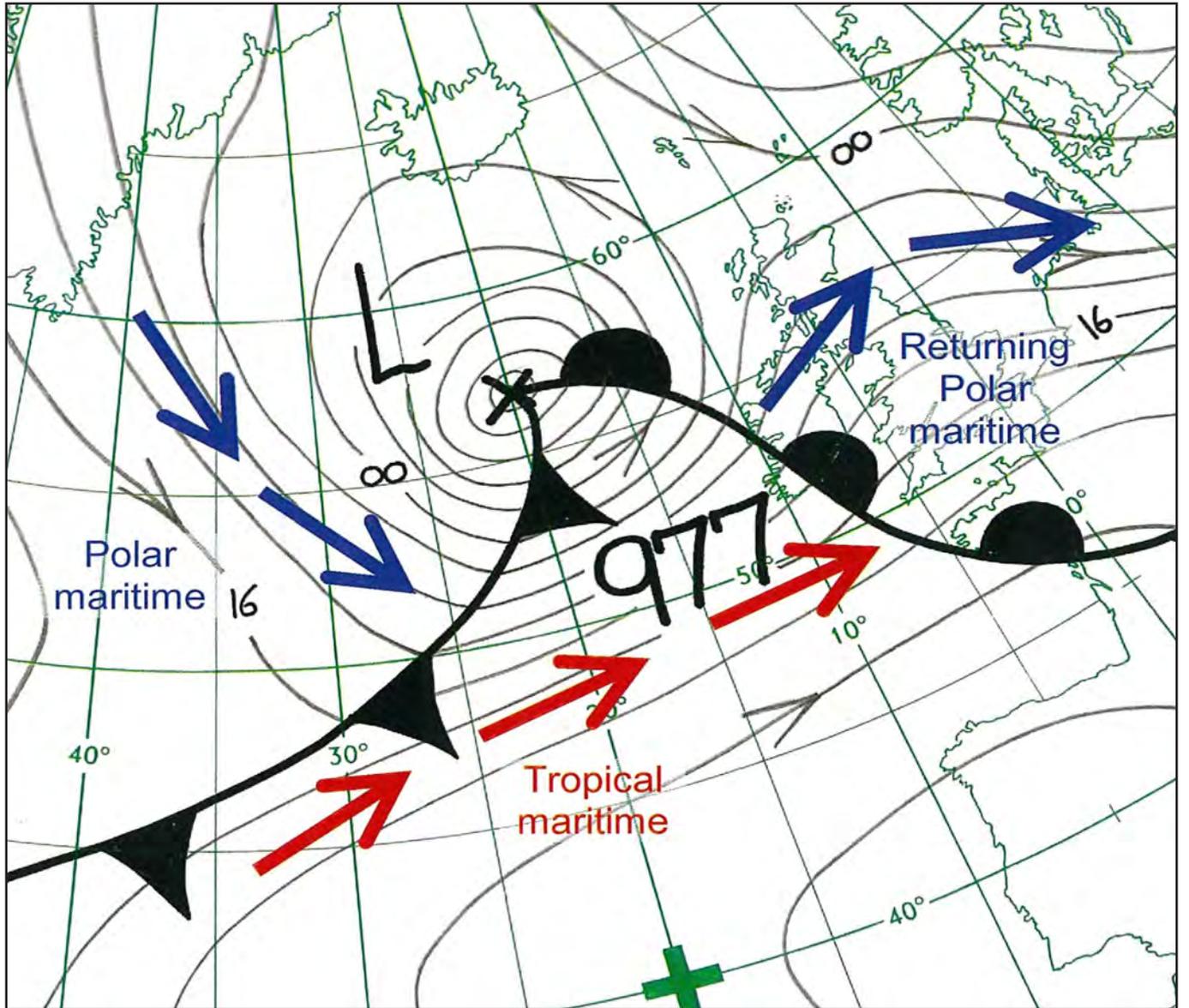


Figure 21. Maturity stage of a mid-latitude depression.

- Occlusion — the warm sector disappears, as the cold front quickly advances. Its faster movement is because the cold front is the leading edge of cold, denser air, pushing up the warmer lighter air. It is harder for the warmer, lighter air at the warm front to cause the cooler, denser air to sink. Hence, the warm front advances at 20 to 30 miles per hour, while the cold front can move forward more quickly at 40 to 50 miles per hour.

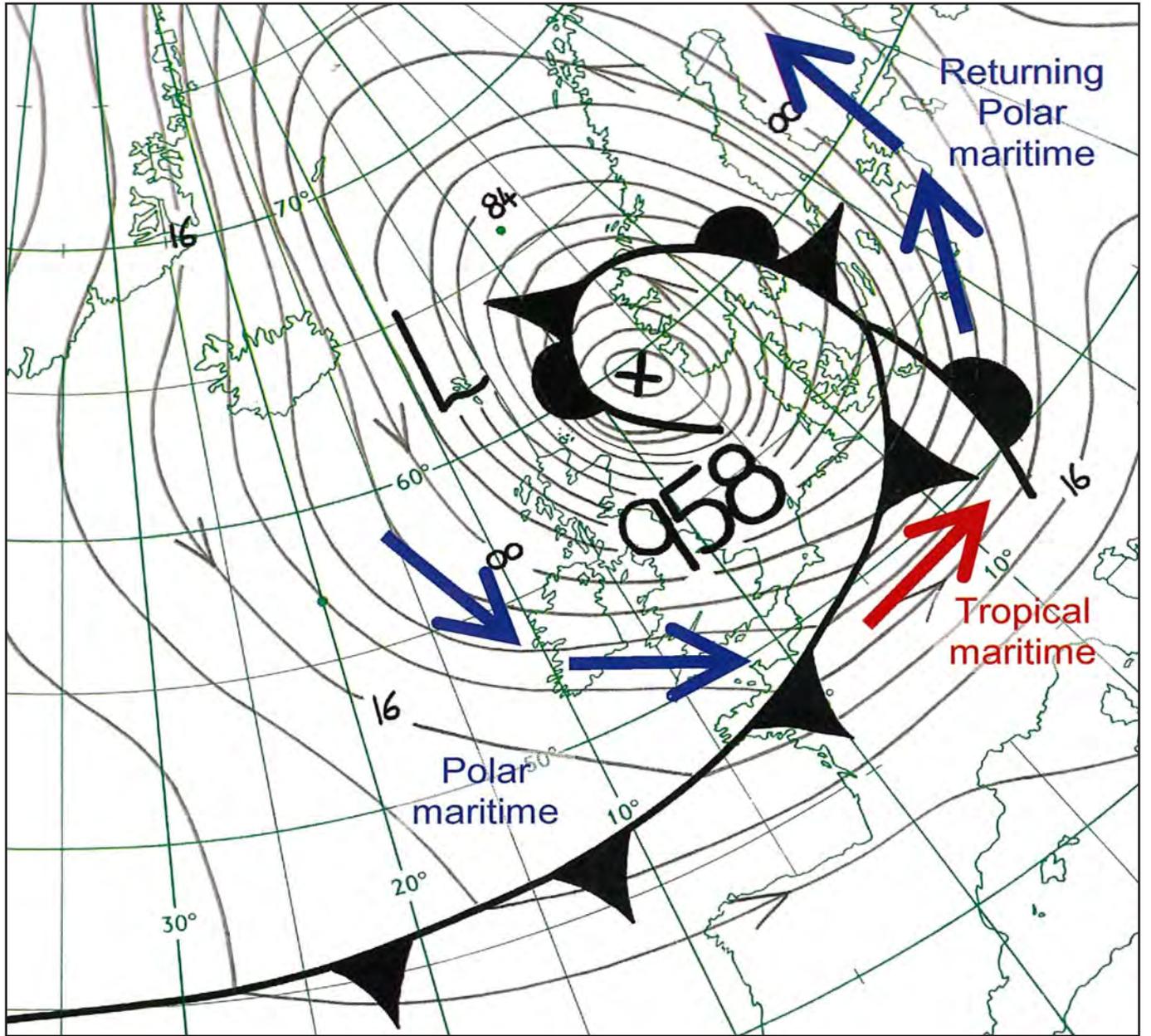


Figure 22. Occlusion stage of a mid-latitude depression.

- Death — the frontal system dies as the warm air has completely risen and cooled, and is now underlain by the cold air. The differences in temperature have therefore been equalled out, and the occluded front disappears.

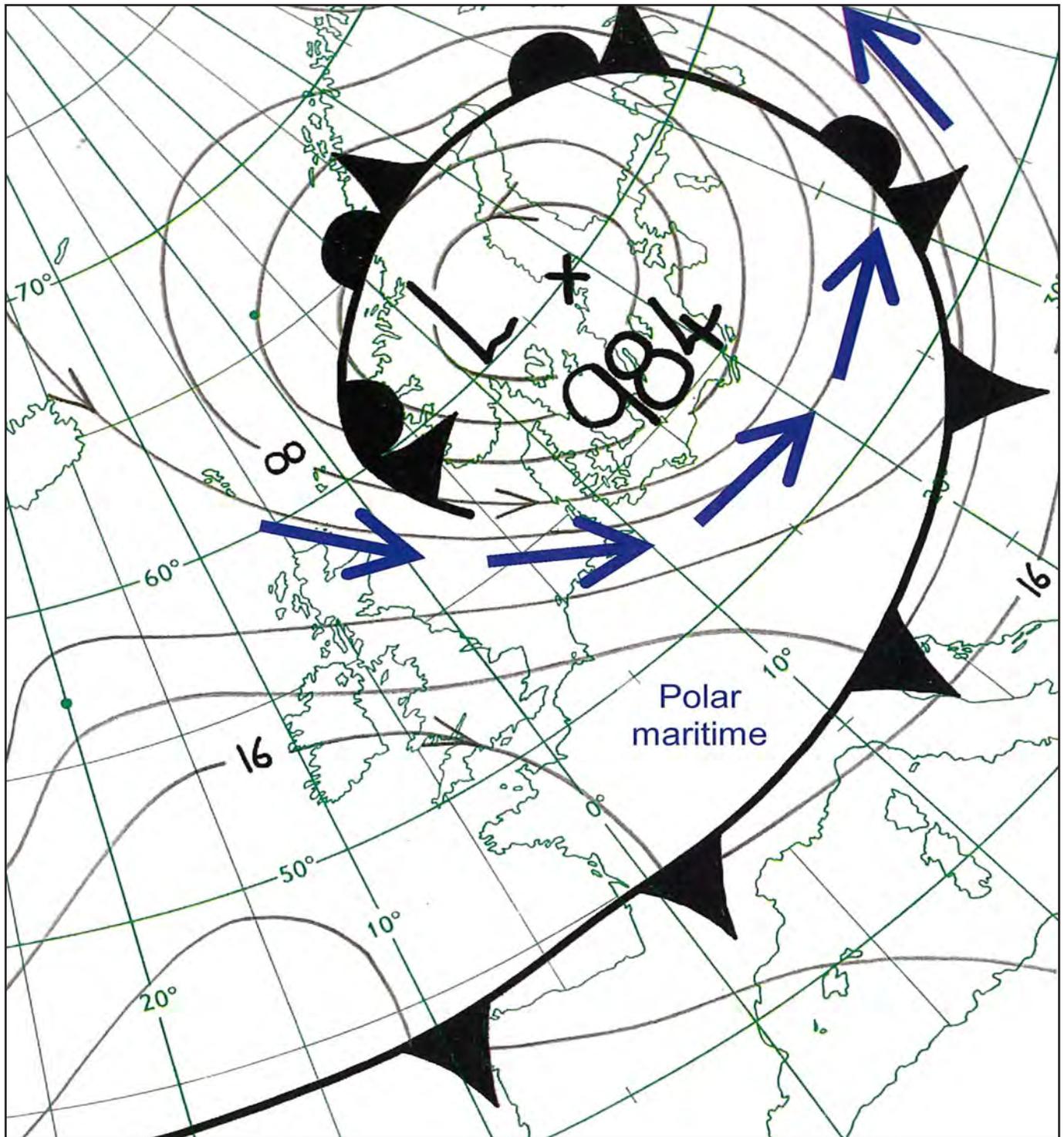


Figure 23. Death stage of a mid-latitude depression.

Frontal systems tend to occur in 'families', which migrate in an easterly direction across the Atlantic. Sometimes as many as four or five mature depressions may make their way across the British Isles, before a ridge of high pressure builds up to prevent any more from advancing over the country. The origin stage tends to occur over the mid-Atlantic, with the mature stage occurring over the British Isles. The death stage usually occurs over the European mainland and Scandinavia. The depressions follow the zigzag path of the fast jet streams in the upper troposphere. The jet streams may blow at 120 miles per hour in the upper troposphere, but the weather systems below it will usually move more slowly, often at about 40 miles per hour.

Britain's changeable and damp climate is largely the result of the frequent movement of the rain-bearing fronts across the country. The regularity of their passage, and the standard sequence of changes they produce, allow quite accurate forecasts to be made.

### **The passage of a mid-latitude depression across the British Isles**

The passage of a mature depression across the British Isles will produce the following sequence of weather changes:

- Ahead of the depression in the cold sector

High cirrus clouds may occur in long feather-like streaks. Some cirrostratus may also occur up to 600 miles ahead of the surface position of the warm front. As the front approaches, temperatures start to rise, and barometric pressure falls steadily.

- The warm front passes over

Drizzle and then rain will usually start to fall from altostratus and nimbostratus clouds. The amount of cloud will increase and the cloud base will fall. Continuous rain will persist as pressure carries on falling.

- In the warm sector

Pressure stabilises and the amount of cloud falls as the clouds start to thin out. The precipitation also stops, and the weather is generally fine, with a little stratus or stratocumulus. As the cold front approaches, pressures slightly rise and temperatures start to fall slightly.

- The cold front passes over

Large, towering cumulonimbus clouds develop as the cold front passes over. This produces heavy downpours of rain and fierce squalls, sometimes with hail and thunder. Pressures rise steadily and air temperatures start to drop as the cold front passes over.

- Behind the cold front

There is an end to the heavy rain as the cumulonimbus clouds move away. Barometric pressure continues to rise in a steady fashion. A few showers may occur from some small cumulus clouds, but it is generally fine and cool behind the cold front.

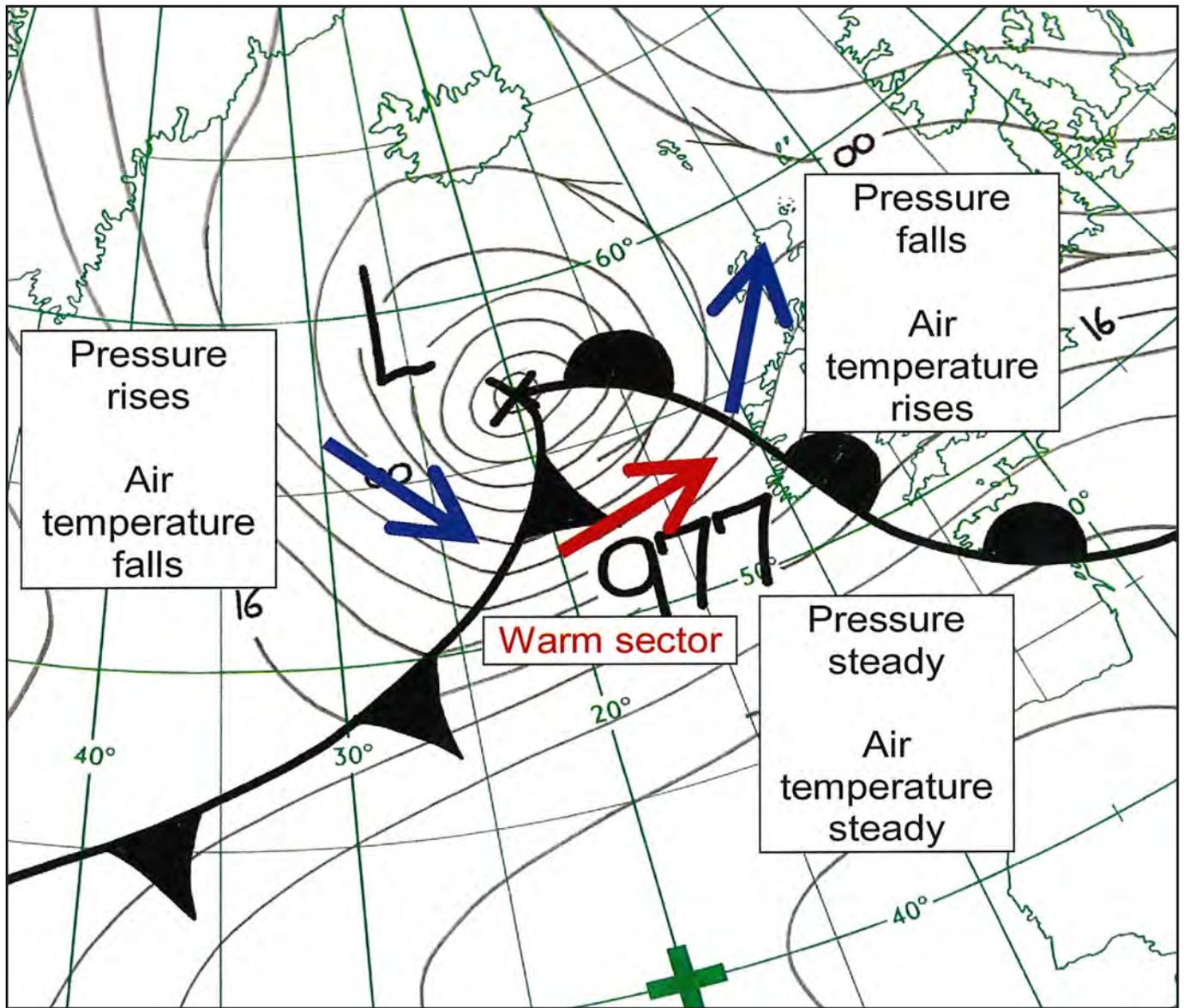


Figure 24. Passage of a mature depression across the British Isles.

Relationship between weather fronts and air masses

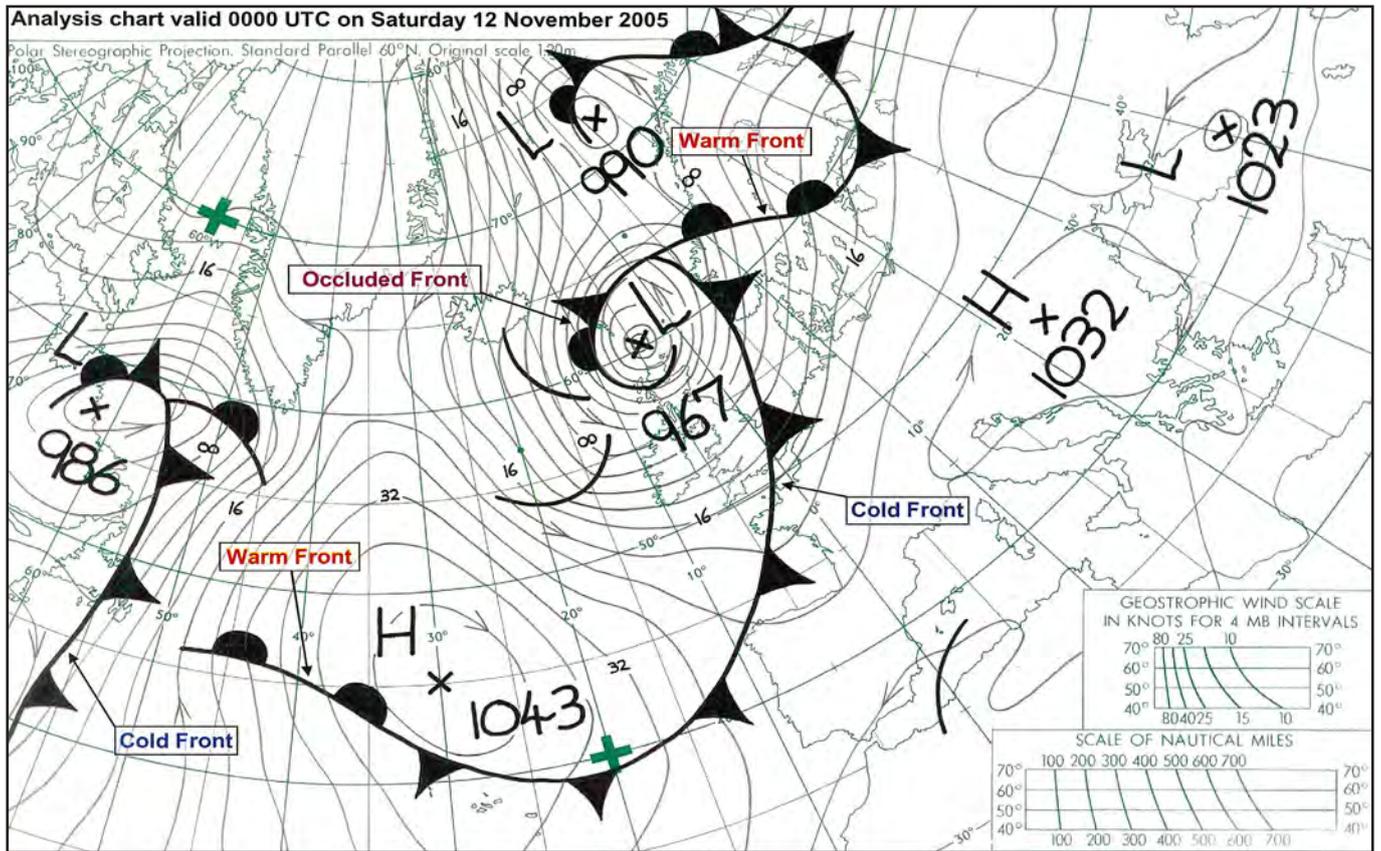


Figure 25. Synoptic chart showing weather fronts.

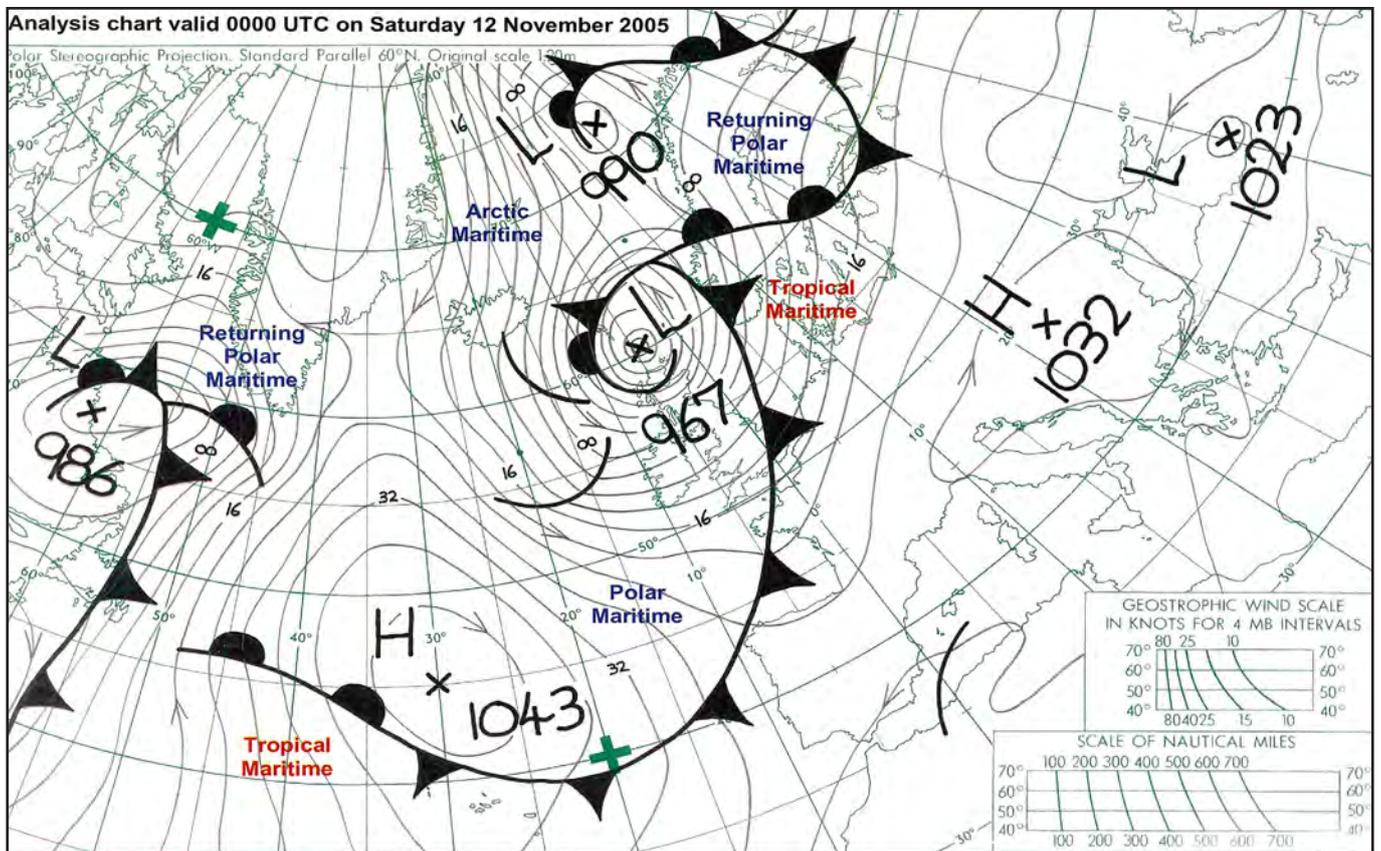


Figure 26. Same synoptic chart showing the weather fronts and air masses.

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