7. Jet streams and Rossby waves

7.1 Introduction

Jet streams are narrow, fast flowing and meandering air currents that occur in the atmospheres of some planets.

On Earth the main jet streams are located near the altitude of the tropopause and are westerly winds where their paths typically have a wavy shape.

They have a major influence in the development and movement of depressions and tropical revolving storms.

Jet streams may start, stop, split into two or more parts, combine into one stream, or flow in various directions including opposite to the direction of the remainder of the jet.

The strongest jet streams are the polar jets, at some 9–12 km (30,000–39,000 ft) above sea level. At a higher altitude are the weaker subtropical jets at some 10–16 km (33,000–52,000 ft).

The northern hemisphere and the southern hemisphere each have a polar jet and a subtropical jet.

The northern hemisphere polar jet flows over the middle to northern latitudes of North America, Europe, and Asia and their intervening oceans.

The southern hemisphere polar jet mostly circles Antarctica all the year round.

Typical jet stream speeds are:

- 60 to 80 knots conventionally the minimum
- 100 to 150 knots frequent
- 150 to 200 knots fairly common
- >200 knots less frequent

The higher wind speeds in the jet streams are not evident at surface level but influence and steer weather systems around the globe, sometimes bringing storms, sometimes bringing very calm and settled weather.

- The jet streams shift north and south according to the seasons.

- In winter time the temperature contrast between the cold polar air and the warm tropical air is greatest so the jet stream is strongest at this time of year.

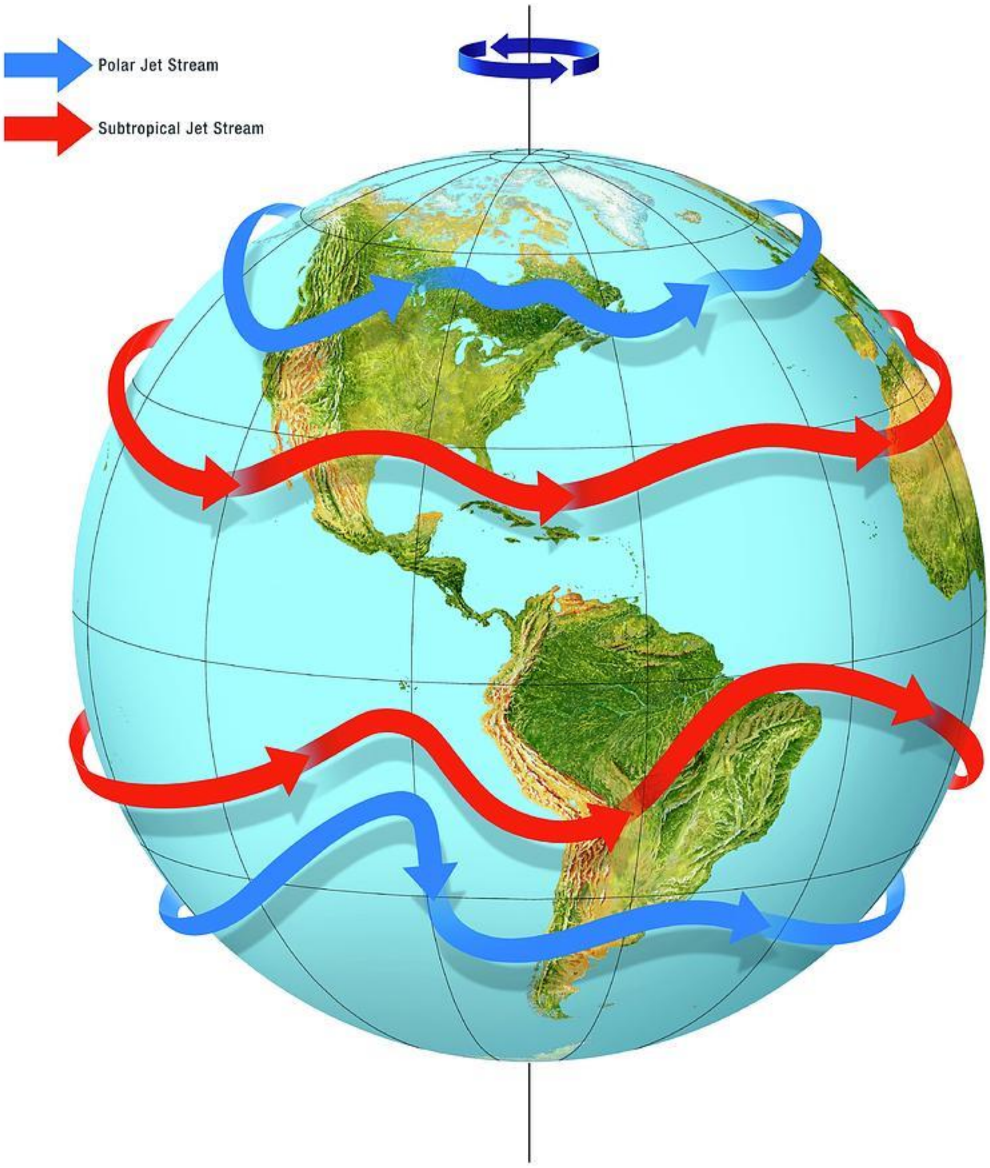


Fig. 7.1 – The polar and subtropical jets streams.
https://images.fineartamerica.com/images-medium-large-5/1-jet-streams-gary-hincks.jpg

The polar jet stream is responsible for influencing the weather in the UK, it is important to understand the cause of the jet stream and why it has such an influence on the weather we experience on the ground.

7.2 Jet stream formation

The three atmospheric circulation cells in each hemisphere circulate the air in the troposphere and the jet streams situated at about the level of the tropopause are driven largely by the differences in temperature that occur in the atmosphere.

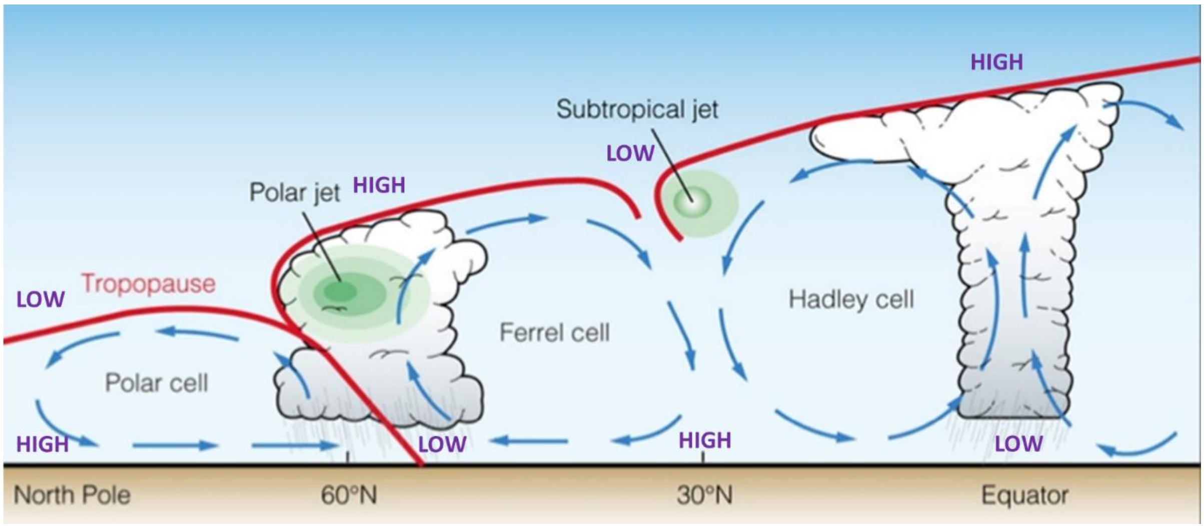


Fig. 7.2 - The Polar and Hadley cells create the circulation within the troposphere and these drive the jet streams.

For the purpose of explanation, we will consider the northern hemisphere only.

The jet streams are caused by a combination of atmospheric heating, which create pressure differences and pressure gradients, and Coriolis effect.

They form and are strongest where variable air temperature gradients are steepest.

This is normally seen in two zones:

- The boundary between the polar and mid latitude air; the Polar Front Jet or Polar jet.
- The boundary between the mid latitude air and tropical air; the Subtropical Jet.

See figure 7.2.

Both these jets are separate entities but they can join up from time to time across an area of the Earth. The polar jet is the strongest as the temperature gradient across Polar and mid latitude regions is greatest; it is fastest in the winter.

Both the subtropical jet and the polar jet travel from west to east and both would travel uniformly and evenly around the Earth if it was not for other influencing factors.

Consider the Polar jet. At altitude near the tropopause in about 60°N in figure 7.2 the air starts to move poleward from the High pressure; as it gathers pace Coriolis effect, which is strong in this latitude deflects the winds to the right causing an eastward flow of air; this is the Jetstream.

The subpolar jet is similarly formed with air moving from the equator at the tropopause towards the low pressure aloft in about 30°N. The effect of Coriolis is not as strong but takes effect as the air moves poleward where it is deflected to the right to cause another band of eastward flowing air. The subpolar jets are weaker because there is a lesser temperature variation between the two air masses aloft.

The same occurs in the southern hemisphere where moving air is deflected to the left to create similar eastward flowing jet streams.

Seasonal differences in the positions of the jet streams occur over the UK because:

- In winter there is a greater temperature difference between the equator and the poles so the jet stream is stronger and flows over the UK. This is why we tend to see wetter weather.

- In summer the temperature difference is less between the equator and the poles. The position of the jet stream moves to the north of the UK and weather is typically calmer and drier.

This will be looked at more closely in the next section.

Figure 7.3 shows a jet stream chart. Note the position of the jet stream in relation to the surface pressure chart features.

Jet stream speeds are given in mph.

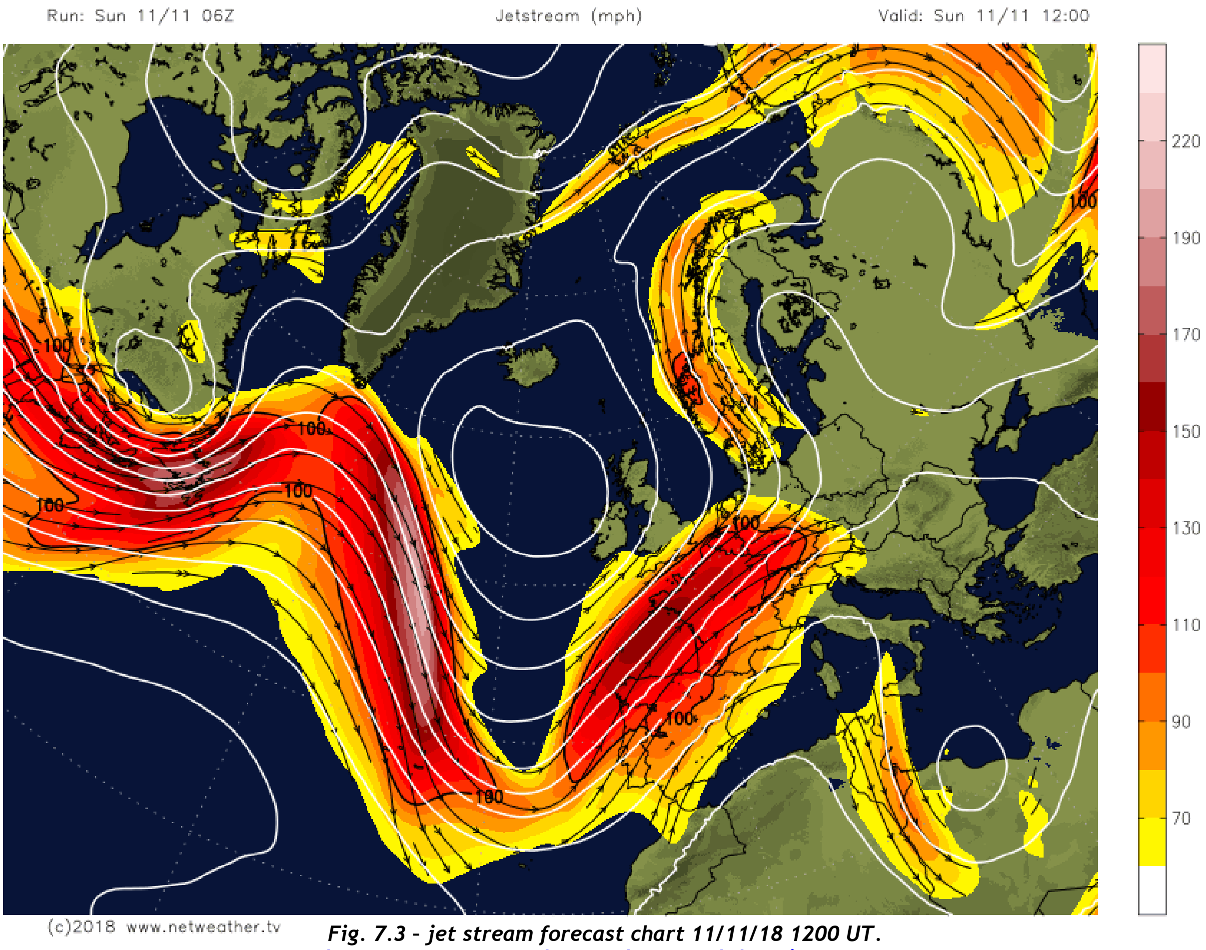


Fig. 7.3 – jet stream forecast chart 11/11/18 1200 UT.
https://www.netweather.tv/charts-and-data/jetstream

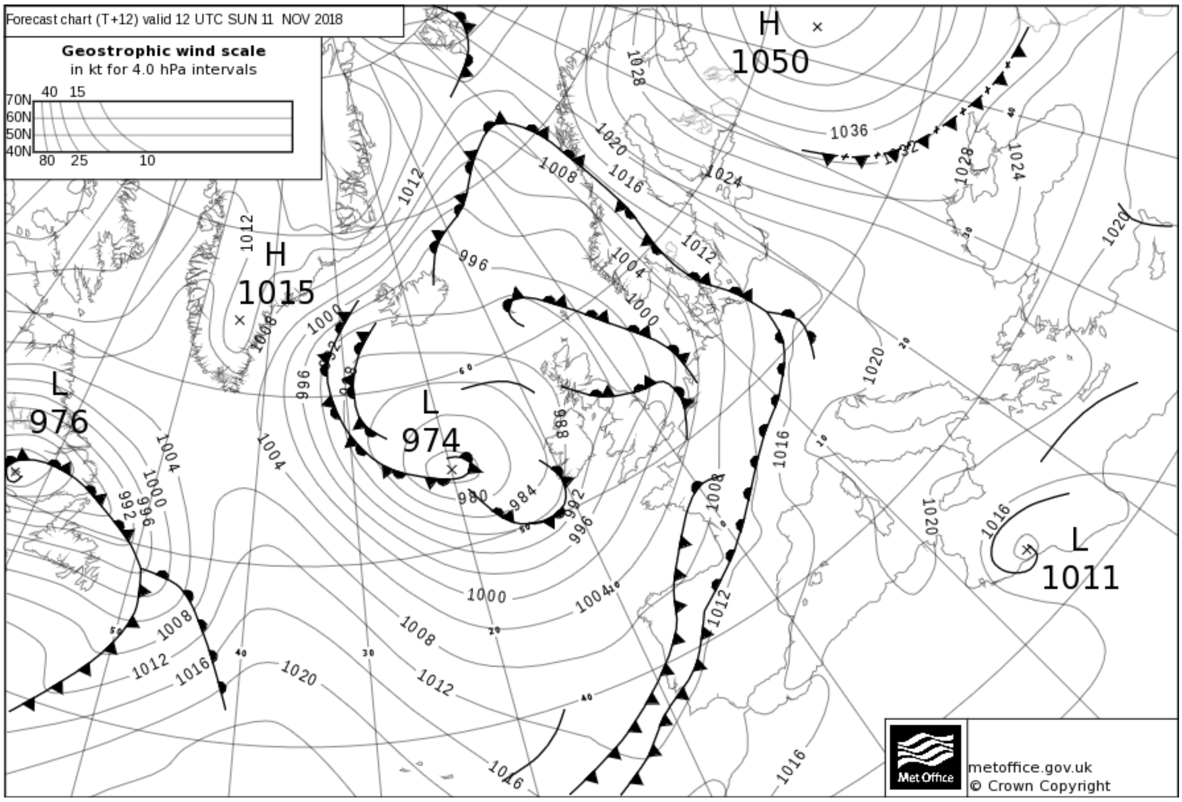


Fig. 7.4 – Forecast chart for same time.

Figure 7.5 shows the jet stream overlaid on a North Atlantic Upper Atmosphere 250 mb chart.

Upper atmosphere charts are covered in the next section.

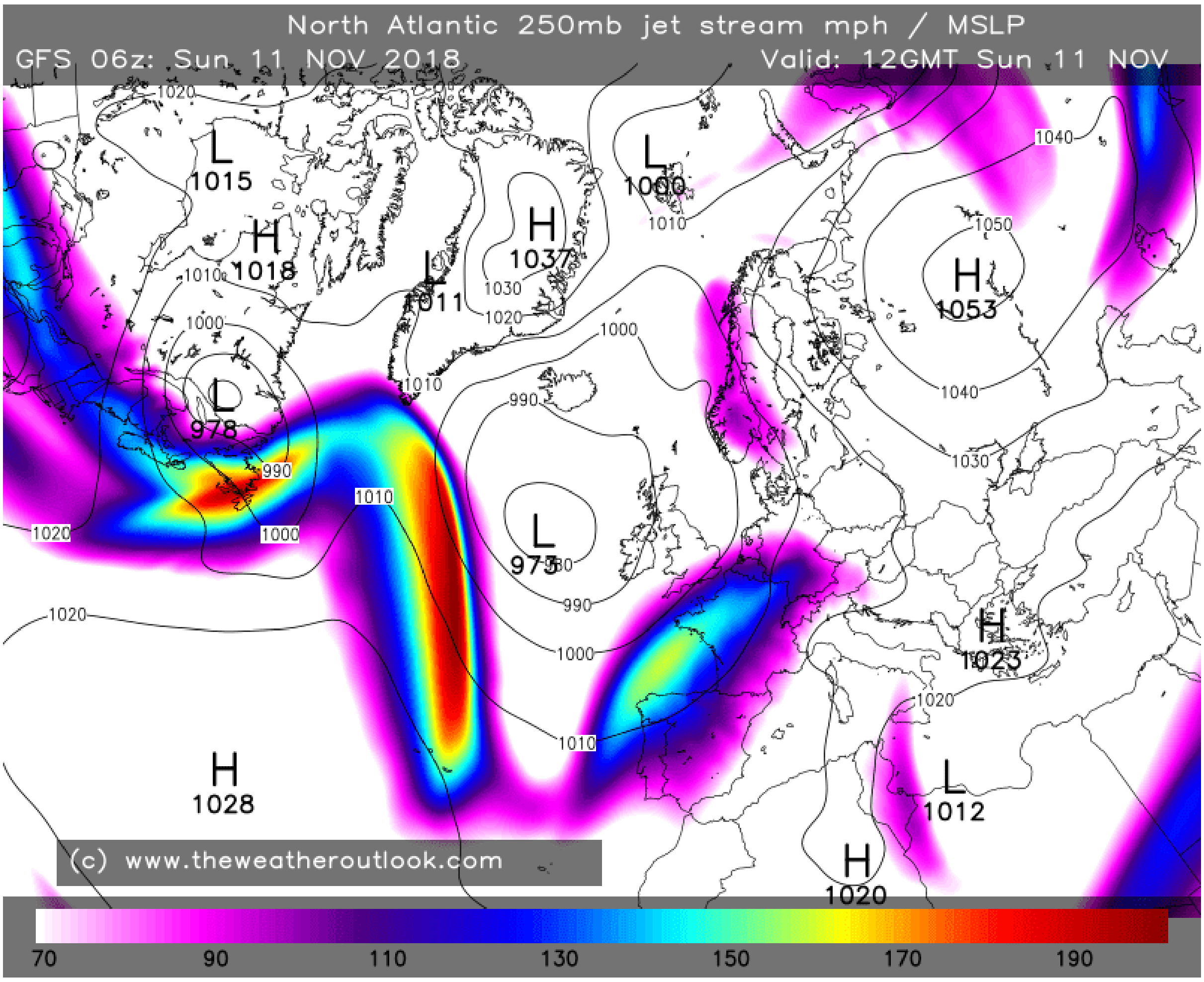


Fig. 7.5 - North Atlantic jets stream forecast chart.
https://www.theweatheroutlook.com/twodata/datukgfshires.aspx?display=jetstream&model=gfs

7.3 Upper air charts

It is important to note that *weather* is like humidity, it is all relative. In many cases absolute values of pressure and temperature are not as important as *change in pressure* or *change in temperature*.

Any change is referred to as a *gradient*.

Any time there is a rapid change in any particular weather feature then the gradient will be large.

Weather is most active in areas where there are large gradients.

Examples of this are seen at cold and warm fronts where there are large changes in pressure and temperature.

7.3.1 Skew-T charts

Skew-T charts are used to plot information from radiosondes. Three measurements are made:

- Temperature
- Dew point
- Wind speed and direction

A typical Skew-T chart is shown below.

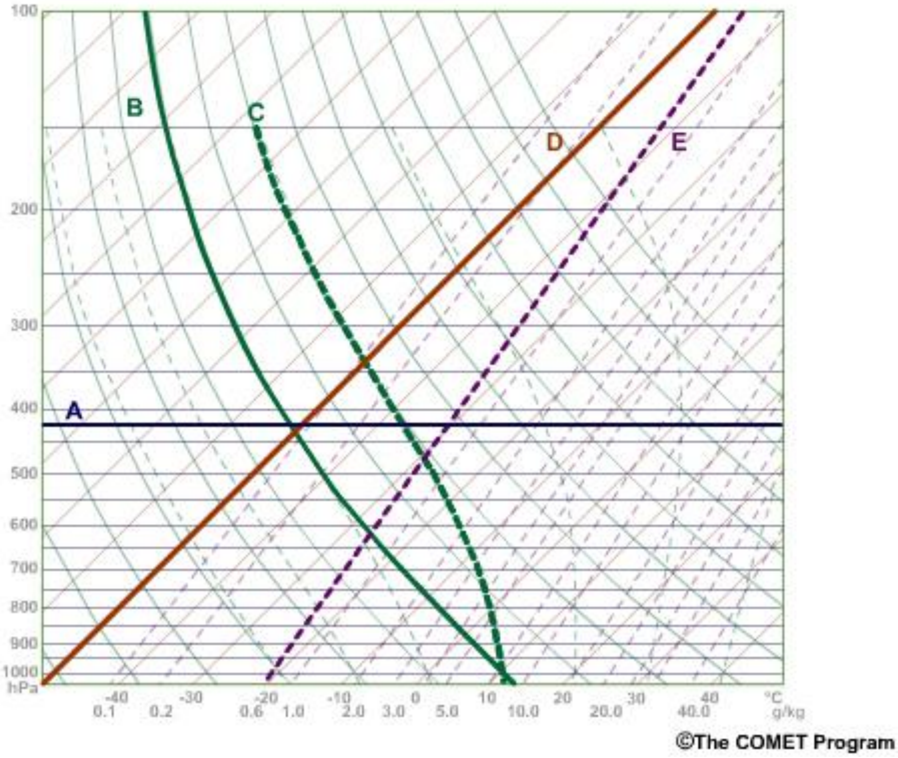


Fig. 7.6 – Skew-T chart; isobars (A), dry adiabats (B), moist adiabats (C), isotherms (D) and saturation mixing ratio lines.
https://weathertogether.net/weather-101/how-to-read-skew-t-charts/

Isobars (A): These are lines of constant pressure. On a Skew-T chart pressure, NOT height is plotted on the Y-axis. Because pressure decreases more slowly with height the higher up you go, pressure is plotted in a logarithmic fashion to keep the scale in manageable proportion.

Dry adiabats (B): These show how much an unsaturated parcel cools when lifted through the atmosphere. The air cools as a result of reducing pressure as the parcel rises (adiabatic process). These adiabats follow the Dry Adiabatic Lapse Rate (DALR which is 10°C/Km.

Moist adiabats (C): When saturated air rises it follows the moist adiabats. When air reaches saturation water vapour condenses into liquid water droplets and this change of state releases 'latent heat' into the atmosphere. Because of this the moist or Saturated Adiabatic Lapse Rate (SALR) is always less than the DALR. The SALR will increase as the parcel continues to rise and less moisture becomes available to condensed out of the parcel.

Note that if air subsides it will ALWAYS warm at the DALR.

Isotherms (D): These are lines of constant temperature. The chart is termed a Skew-T chart because they are skewed 45° to the right. This allows calculation of important atmospheric levels and parameters like the Lifting Condensation Level (LCL), Level of Free Convection (LFC), the Equilibrium Level and other features.

Saturation Mixing Ratio Lines: The saturation mixing ratio is the ratio, in grams of water vapor per kilogram of air, that an air parcel must have at a given pressure and temperature to be considered 'saturated.' Once an air parcel is saturated, it generally cannot hold any more water vapor.

Now that the lines on the chart have been identified the we can see how they are used to calculate important levels of the atmosphere.

Lifting Condensation Level (LCL): This is the pressure level an air parcel would need to be raised (dry adiabatically) to become saturated.

The LCL is important because it marks location where the air parcel stops rising at the dry adiabatic lapse rate and switches to the moist adiabatic lapse rate.

Level of Free Convection (LFC): This is the pressure level an air parcel would need to be raised so that its temperature is equal with the environmental temperature.

Equilibrium Level (EL): This level only exists if there is an LFC, and it is defined as the level at which the SALR denoting the parcel's path re-crosses the environmental temperature. At the EL, the air parcel is the same temperature as its environment, and above it, it is cooler and denser.

The EL can be found by looking at the anvils on thunderstorms, as these mark the location where a rising air parcel is no longer positively buoyant.

Figure 7.7 shows a typical atmospheric profile represented on a Skew-T diagram.

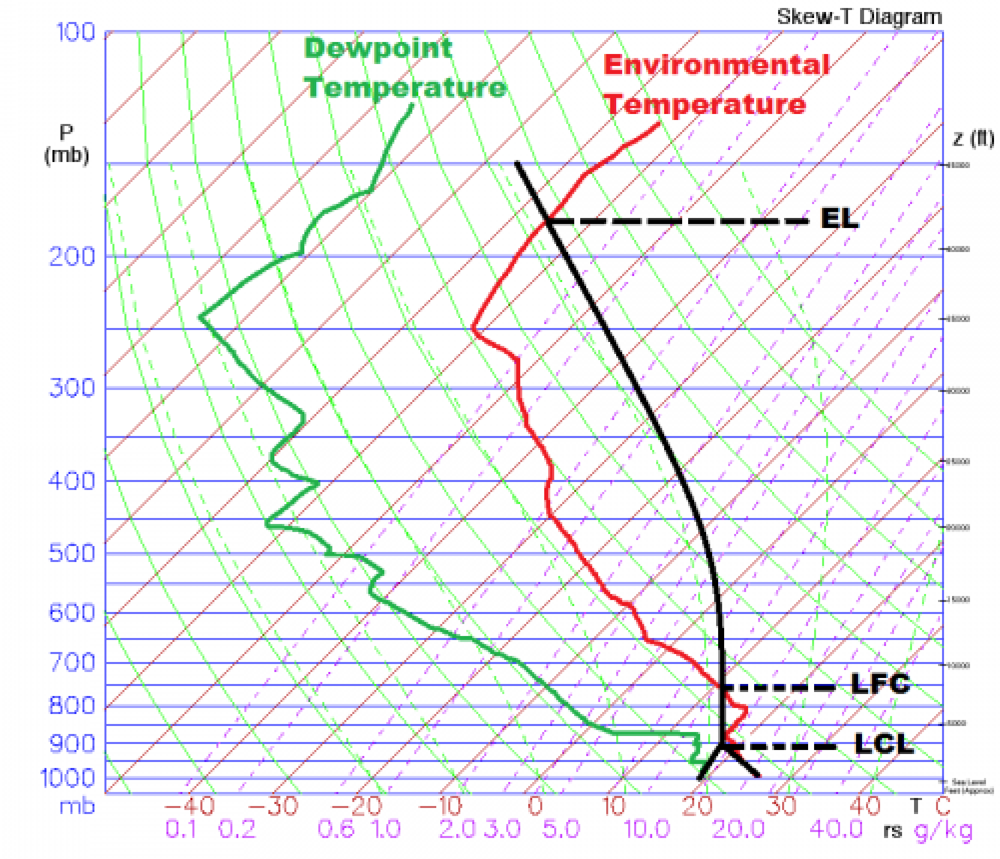


Fig. 7.7 - A Sample Skew-T Diagram.
The slanted red lines are lines of constant temperature, the dotted purple lines are lines of constant mixing ratio, the solid curved green lines are dry adiabats, and the curved green lines are moist adiabats. The Lifting Condensation Level (LCL), Level of Free Convection (LFC), and Equilibrium Level (EL) are labelled.
[*https://weathertogether.net/weather-101/how-to-read-skew-t-charts/*](https://weathertogether.net/weather-101/how-to-read-skew-t-charts/)

Clearly a chart produced from radiosonde balloon data is very useful to the meteorologist but it only gives information as to what is happening in a *single* location!

To provide a complete picture of the atmosphere data must be viewed for many upper air observations. This is achieved by creating constant pressure charts that show changes and gradients in atmospheric conditions for the area under observation.

7.3.2 The concept of upper air charts

Air pressure values reduced to a sea level baseline are required to provide a picture of the weather patterns *at the surface*. Isobars represent locations of equal pressure *along* the lines.

When studying the atmosphere, since air pressure decreases with altitude, the elevation at which any particular pressure value occurs will vary from place to place.

The changes in elevation represent different densities (and ultimately air temperature) in the atmosphere.

The height of any pressure level is determined by the density of the air. As the air temperature *decreases* the density of the air *increases*.

Therefore, the altitude where any particular pressure occurs will be lower in regions of colder air. Conversely, higher air temperatures result in lower densities with the corresponding altitude of various pressure levels being higher.

Consider figure 7.8.

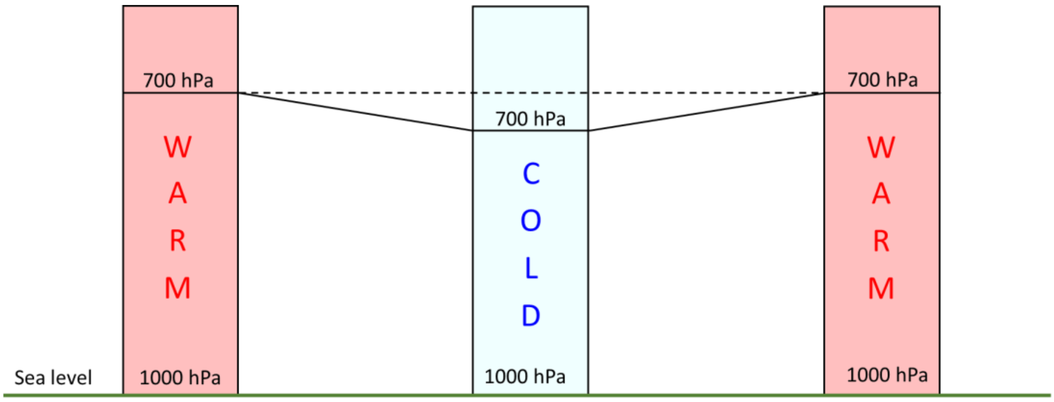


Fig. 7.8 - The height of a particular air pressure value is dependent on the density of the air.

As a rule, the altitude of constant pressure levels decreases from the equator towards the poles simply because it is colder over the poles than over the equator.

Upper air weather maps, instead of looking at the pressure at sea level, they look at the *altitudes* at which *constant pressures* occur.

The lines drawn on constant pressure charts are called *isoheights*, lines of height. For example, on the 700 hPa pressure chart, the air pressure is a constant 700 hPa all across the chart. Therefore, the lines on the chart represent the *altitude* at which the air pressure of 700 hPa was reached.

Essentially, these upper air charts show the atmosphere in three dimensions.

Isoheight lines are simply referred to as contours. By looking at these contours upper air patterns such as ridges of higher heights and troughs of lower heights are observed. It is these ridges and troughs that govern the weather that we experience at the surface.

Analogous to topographic charts, ridges are areas where the elevation of any particular pressure is higher than the surrounding heights of that same pressure level; troughs are like valleys in that they lie along areas of the lowest elevations of any particular pressure value.

Wind flowing from a ridge toward a trough is decreasing in height above the surface; if flowing from a trough toward a ridge it will be increasing in height.

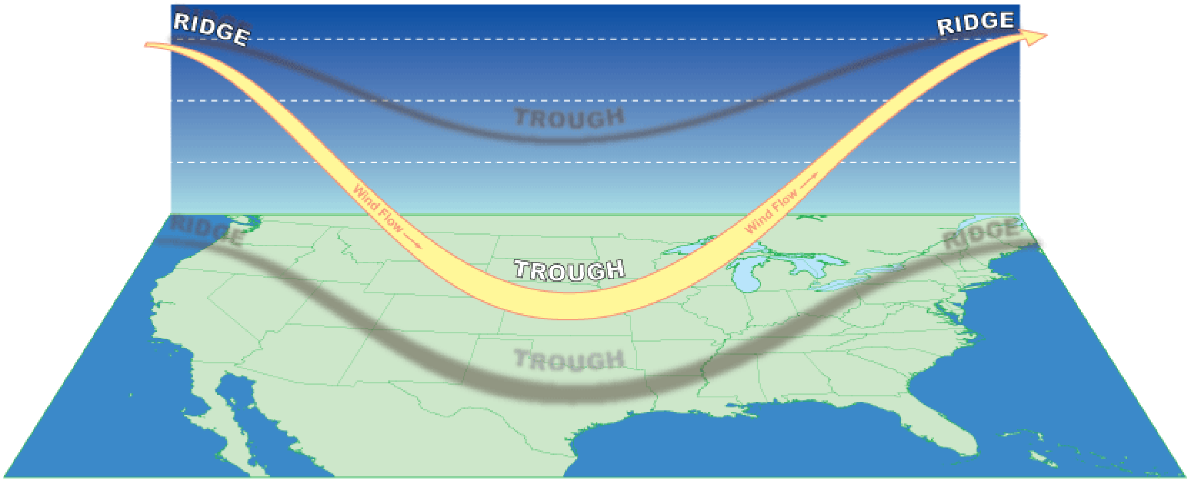


Fig. 7.9 – Troughs are seen on charts as dips in the airflow as well as dip in elevation.
https://www.weather.gov/jetstream/verses

Between the colder, more dense air and the warmer, less dense air is the location of the *greatest change in heights of any particular pressure level*. With change in density comes the change in temperature. Therefore, the wind speed is strongest at this location and indicates where the jet stream is.

Upper air charts are widely available for the following pressure values: 200, 300, 500, 700 and 850 hPa. Charts for other values are also available.

Figures 7.10 and 7.11 shows a surface forecast chart and a 500 hPa forecast pressure chart.

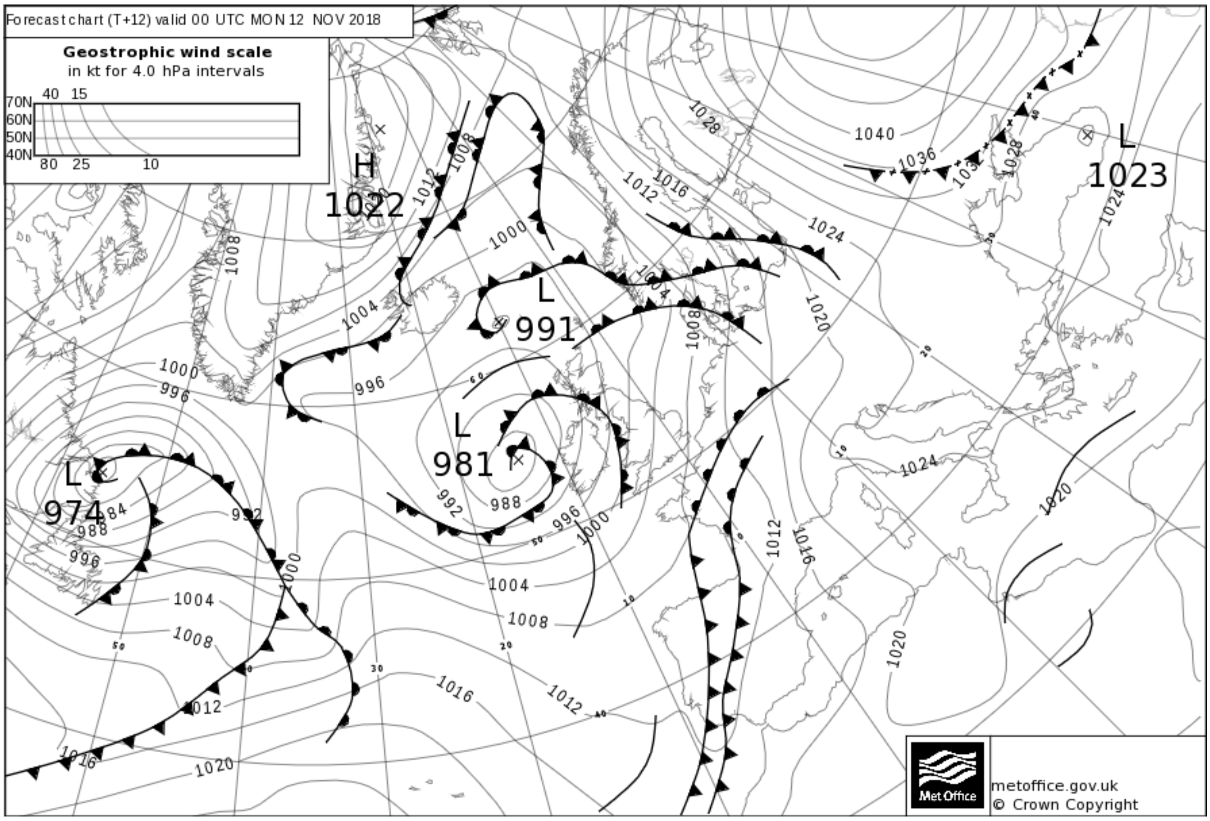


Fig. 7.10 - Forecast (T+12) valid 00 UTC 12 Nov 2018).

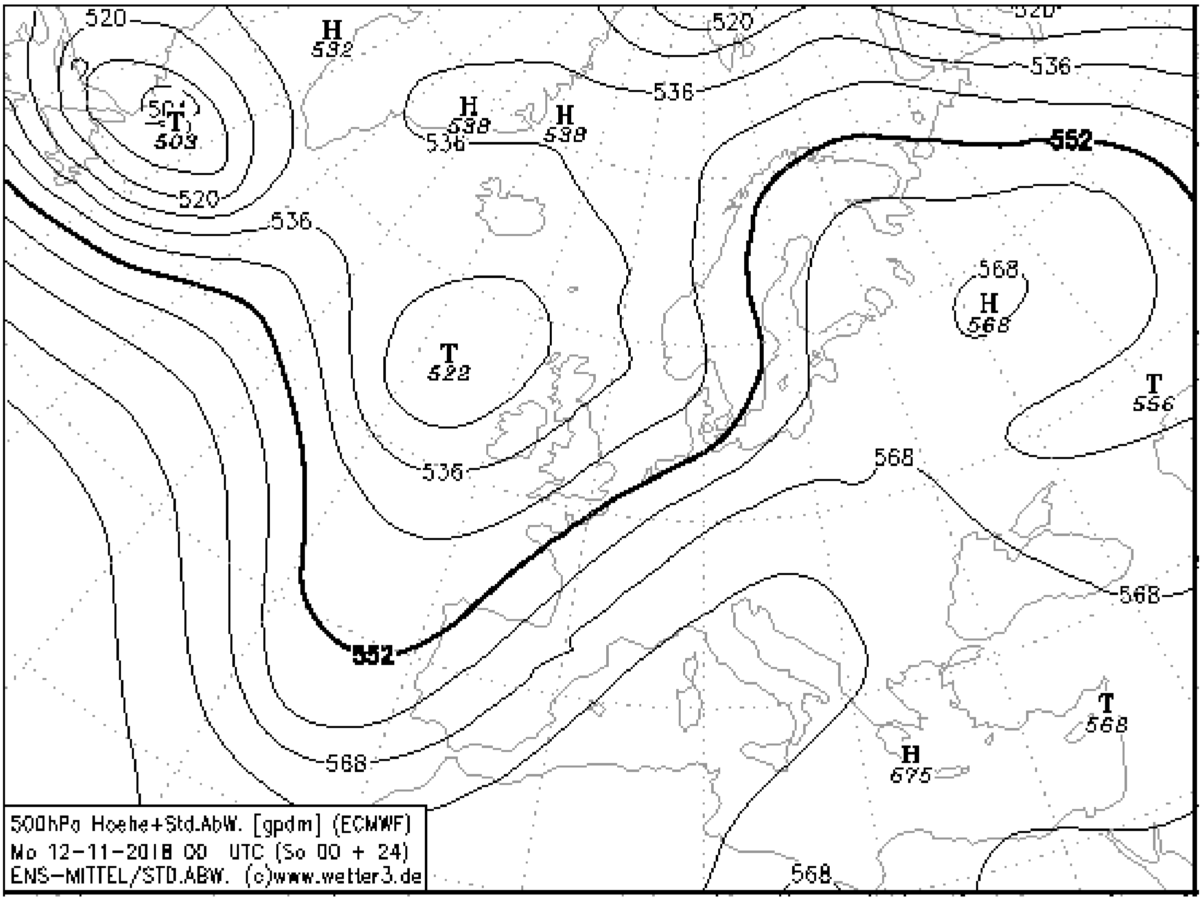


Fig. 7.11 - 500 hPa upper air chart (Forecast 12 Nov 2018 00+24). The numbers on the contour lines give the heights of the constant 500 hPa pressure: 568 = 5680 metres (the last zero is not shown). H = High or Ridge; T = Low or Trough.

7.3.3 The 500 hPa constant pressure chart

The 500 hPa constant pressure charts are the most useful charts for meteorologists because they show the situation at near the middle level (or average mean level) in the troposphere, the vertical extent up to which our weather exists being the tropopause.

Height contours

Ranging in elevation from 16,000 feet (4,980 metres) to nearly 20,000 feet (6,000 metres) they consider the middle of the vertical range of the atmosphere. It is based on the assumption that 500 hPa is one-half of 1000 hPa (at sea level) and the top of the atmosphere, being zero hPa, which occurs at 30+ miles (50 kilometres) high.

For the 500 hPa level constant pressure chart heights, the last digit, 0 (zero), is omitted from the chart. Adding a zero to the end of the four-digit height value reveals the actual height in metres.

For example, a height value of 564 means that the actual height is 5,640 metres (18,503 feet).

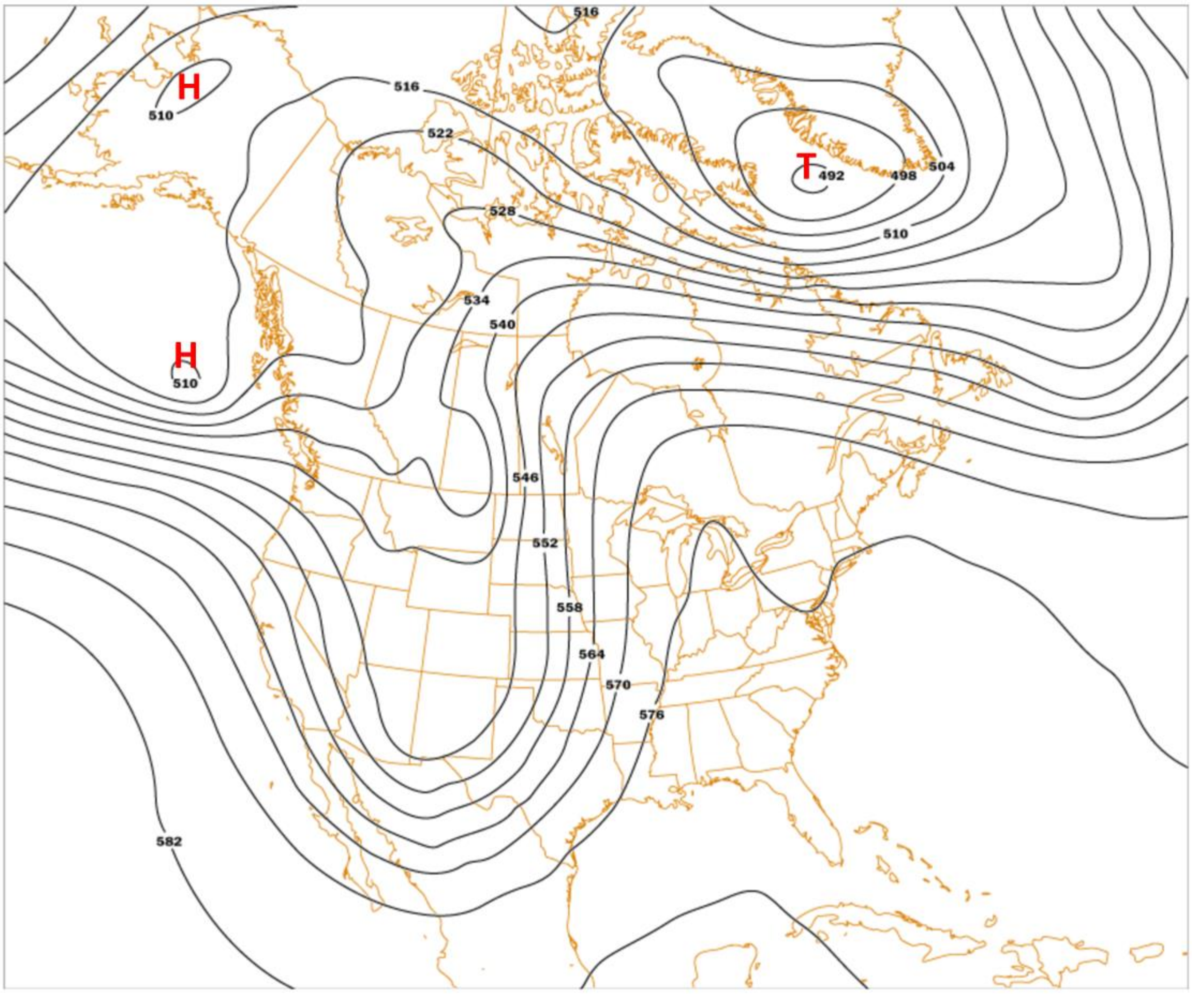


Fig. 7.12 - A typical representation of the 500 hPa upper air chart; the ridges and troughs have been added in. H = High or Ridge; T = Low or Trough.

7.3.4 The 200 hPa (250 hPa and 300hPa) constant pressure chart

This chart (and sometimes the 250 or 300 hPa chart) is primarily used to locate the jet stream. An air pressure of 200 hPa occurs at altitudes of the order 39,000 feet (12,000 m) but can range from near 35,000 to 41,000 feet (10,800 to 12,300 metres).

This level is very close to the upper troposphere and level of the tropopause where the jet streams are located.

An example 200 hPa chart is shown.

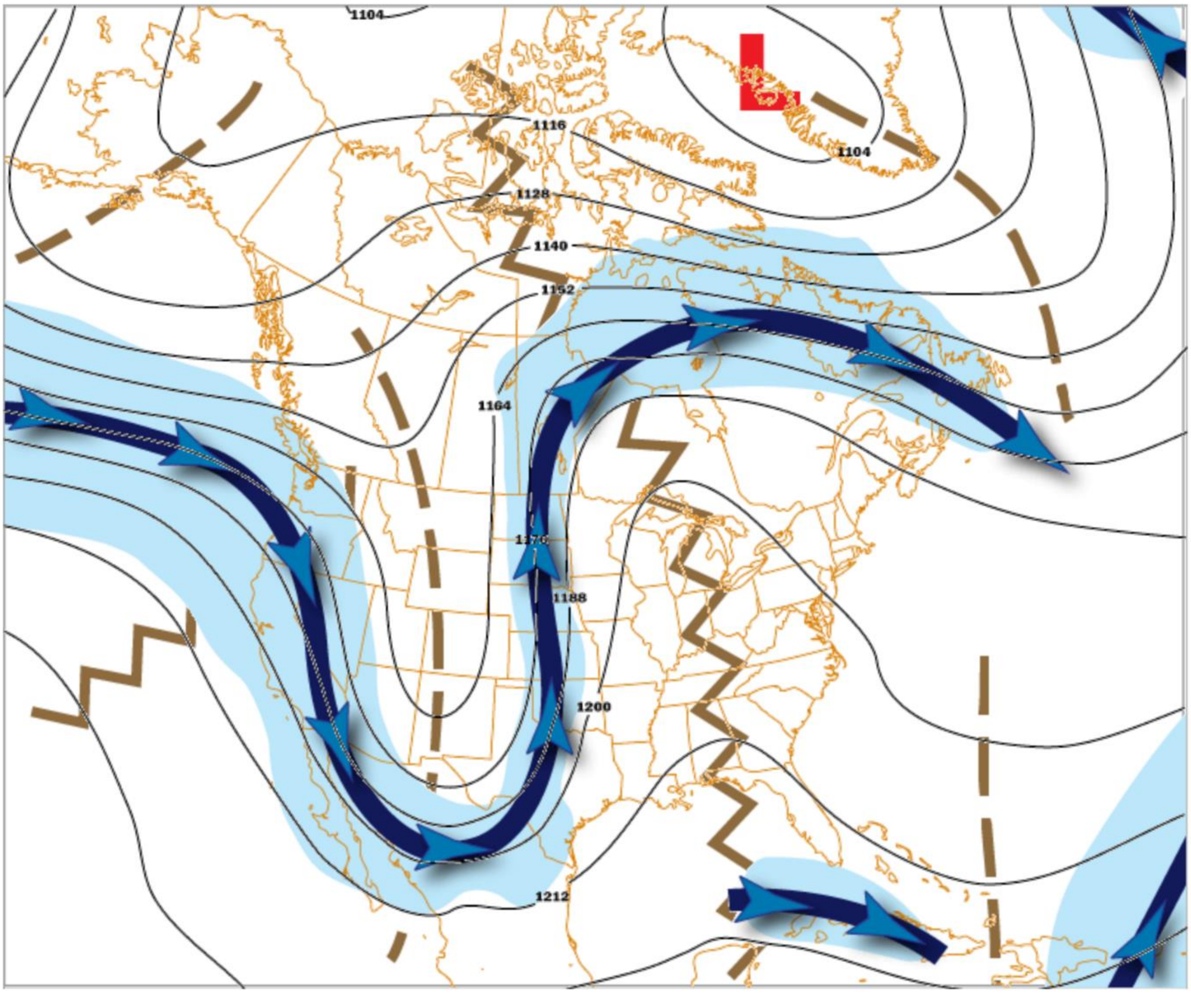


Fig. 7.13 - 200 hPa chart showing the location of the jet stream; dashed line = Low pressure trough; zig-zag line = High pressure ridge.
https://www.weather.gov/jetstream/basic

A 250 hPa chart is available which serves the same purpose. Figure 7.14 shows such a chart which illustrates the position of the jet stream.

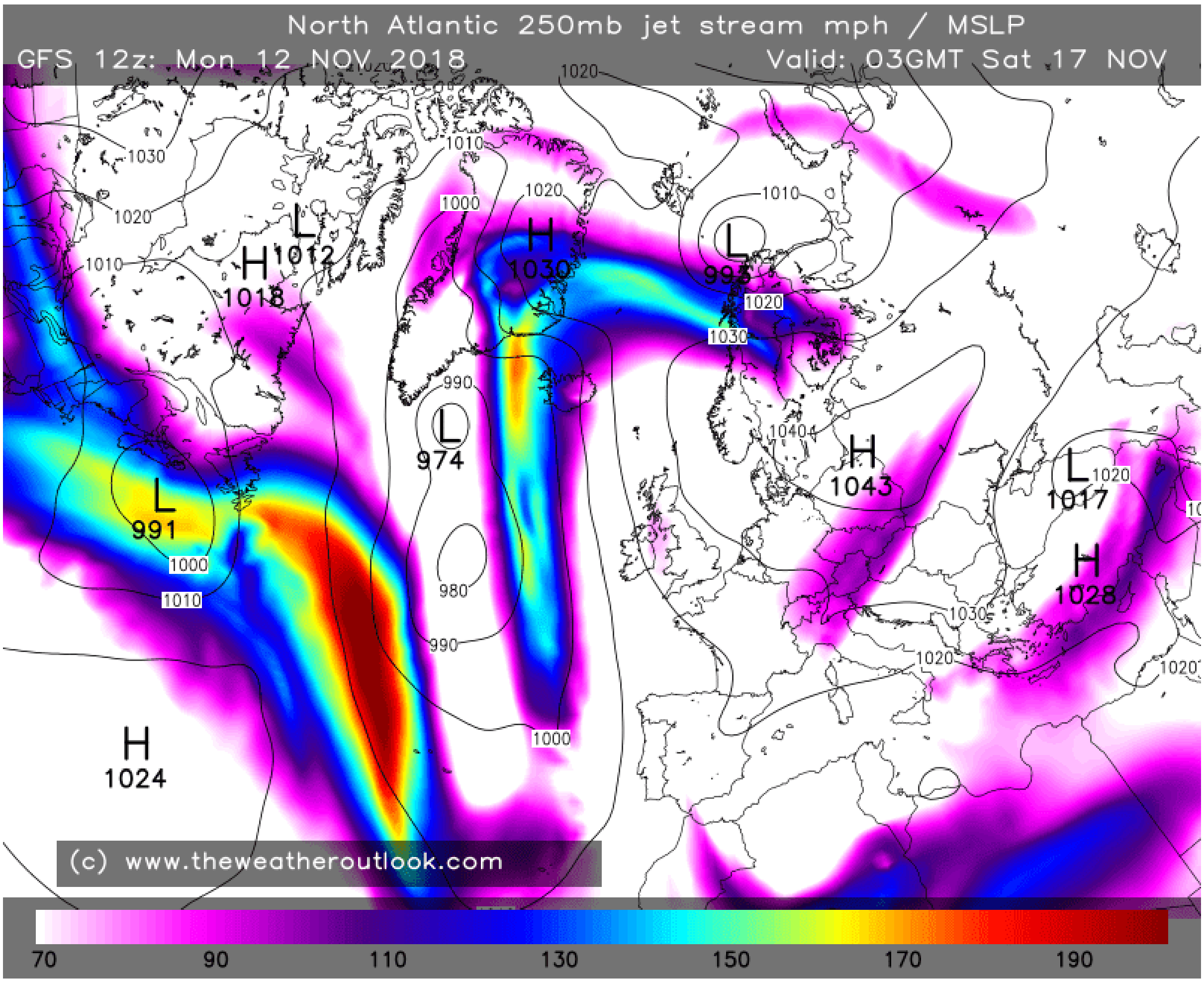


Fig. 7.14 – 250 hPa chart showing the location of the jet stream.
https://www.theweatheroutlook.com/twodata/datukgfshires.aspx?display=jetstream&model=gfs

7.4 Rossby waves

7.4.1 Long waves

Weather patterns are governed by the mid-latitude polar and subtropical jet streams which are fast westerly winds which move in large wavy patterns around the Earth. Known as planetary waves, these long waves are also called Rossby waves, named after Carl Rossby who discovered them in the 1930's.

Rossby waves form primarily because of the Earth's geography.

- The Earth's heating from the Sun is uneven due to the different shapes and sizes of land masses (differential heating.
- The air cannot travel through mountain barriers so it must rise up and over or go around them.

In both cases the disruption of the air flow creates imbalances in temperature distribution both vertically and horizontally. The wind responds by seeking a return to a 'balanced' atmosphere and changes speed and/or direction. However, as long as the Sun keeps heating the Earth those imbalances continue to develop so the wind will constantly be changing directions and develop into wave-like patterns.

The length of long waves can vary from around 3,700 miles (6000 Km) to 5,000 miles (8000 Km) or more. The waves generally move very slowly from east to west but occasionally they will become stationary or move east to west.

Note that the jets streams flow within the waves!

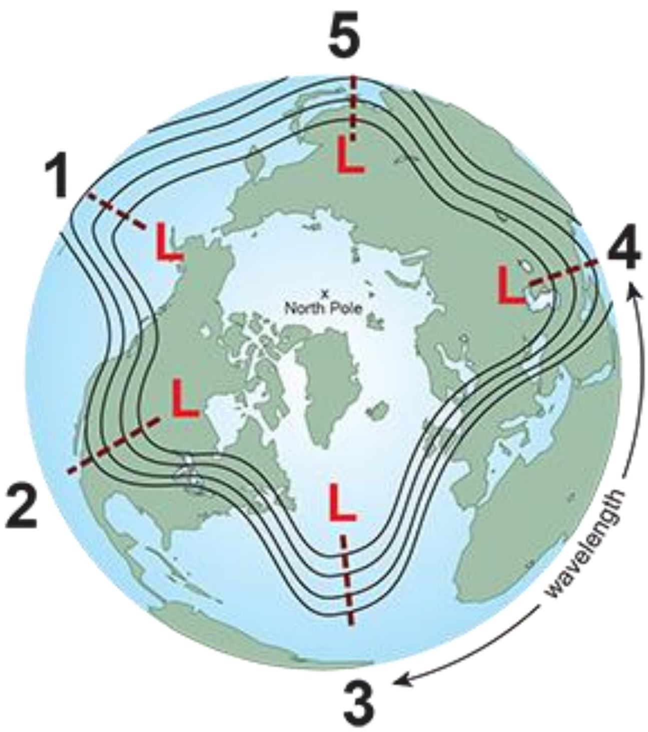


Fig. 7.15 - An example of a five-planetary wave pattern.
https://www.weather.gov/jetstream/longshort

Rossby waves help to transfer heat from the tropics toward the poles and cold air toward the tropics in order to return the atmosphere to a balance. They also help locate the jet stream and mark out the track of surface low pressure systems. The number of long waves at any one time varies from three to seven but it is typically four or five.

Their slow motion often results in fairly long persistent weather patterns.

7.4.2 Short waves

These are waves that are embedded within the long waves and move much faster *through* the long waves. Short waves move east on average 23 mph (20 knots, 37 Km/h) in summer and 35 mph (20 knots, 55 Km/h) in winter. This motion causes long waves to distort and change shape such as deepening long wave troughs and flattening long wave ridges.

7.4.3 Basic upper level chart wave patterns and their influence on surface weather

Basic wave patterns can be identified on upper level charts and influence the type of weather that will be experienced at the surface.

Open waves

Whether long or short wave, these are the most common pattern seen in upper air charts and are plain troughs and ridges. These waves and troughs are considered 'open' as, mostly, there is no closed circulation associated with the waves.

They progressively move from west to east.

The majority of inclement weather occurs between the trough and the downwind (eastward) ridge while fair weather occurs between the ridge and the downwind trough.

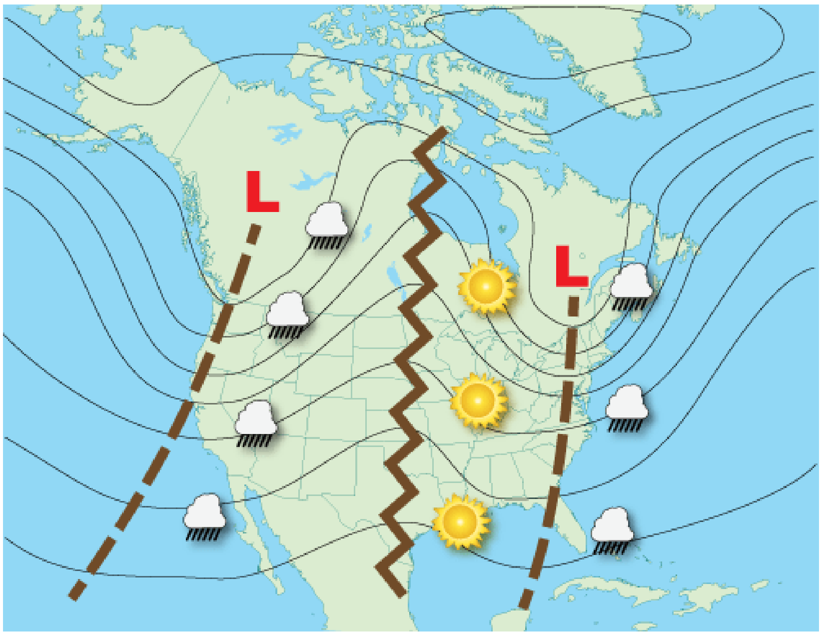


Fig. 7.16 - Open wave pattern; dashed line = Low pressure trough; zig-zag line = High pressure ridge.
https://www.weather.gov/jetstream/basic

Positive tilted troughs

The axis of a trough is usually not in a north-south direction and will have some tilt in direction relative to the poles. Positive tilted troughs extend from the lowest pressure NE to SW in the northern hemisphere (SE to NW in the southern hemisphere).

Positive troughs tend to produce the least amount of severe weather.

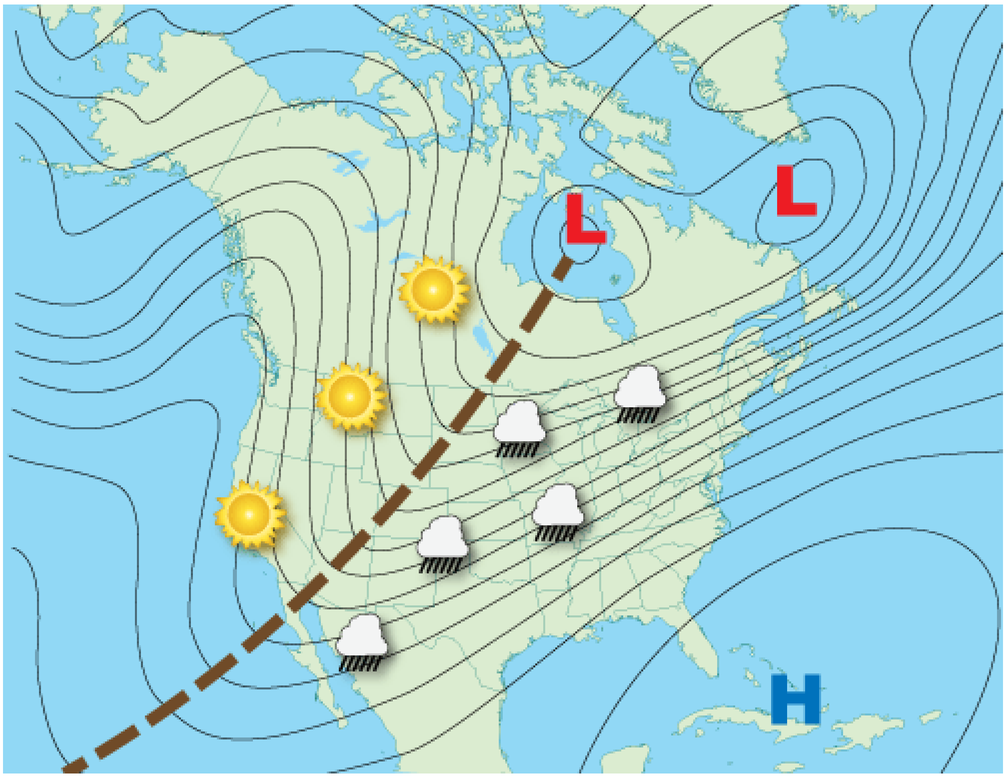


Fig. 7.17 - Positive tilted trough.
https://www.weather.gov/jetstream/basic

Negative tilted troughs

These usually begin as positive tilted troughs. As the short-wave energy races east through the long wave it distorts its shape from positive to neutral and then to a negative NW/SE orientation.

These types of troughs produce the most severe weather because often there will be a strong southerly surface wind with its warm air underneath the incoming cold air in the upper atmosphere creating very unstable conditions.

Also, there is a large change in wind direction from the surface into the upper atmosphere (wind shear) which aids the formation of thunderstorms.

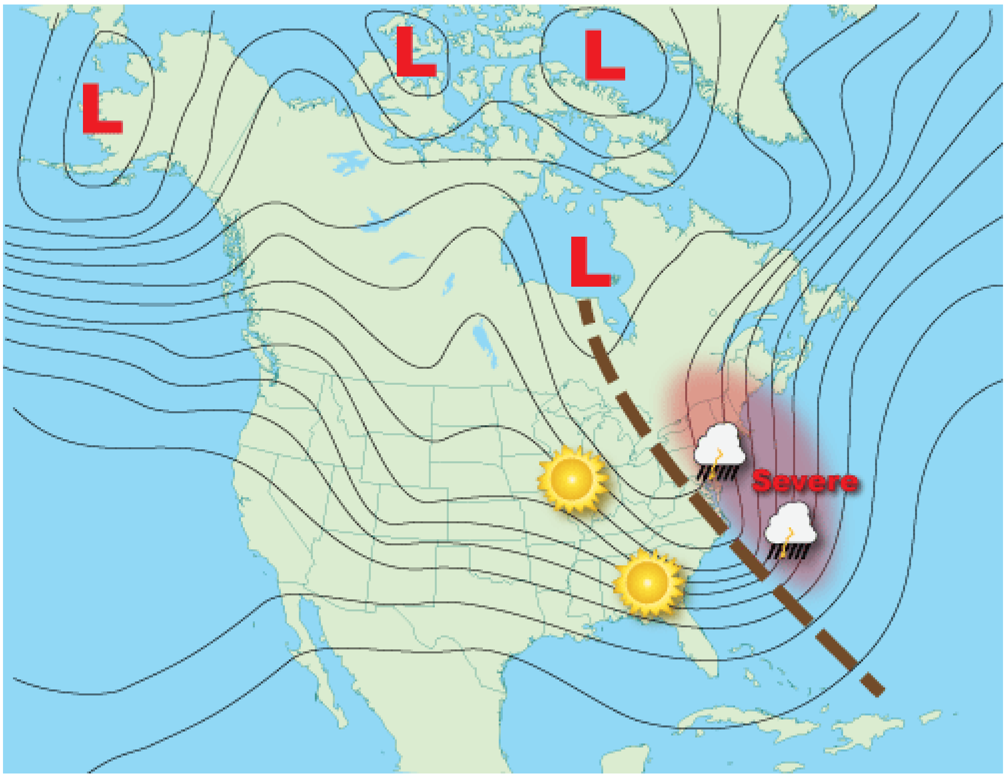


Fig. 7.18 - Negative tilted trough.
https://www.weather.gov/jetstream/basic

Zonal flow
When the air flow is parallel or nearly parallel to parallels of latitude then it is considered to be a zonal flow. Surface level storm systems and associated fronts move very fast from east to west but little north to south or south to north movement.

This results in locations to poleward of a zonal flow will remain cool or cold while those towards the equator remain mild and warm. There is usually a positively and negatively tilted trough at each end of a zonal flow.

The strength of the zonal flow between latitudes 35° and 55° N/S is termed the *zonal (or circulation) index*.

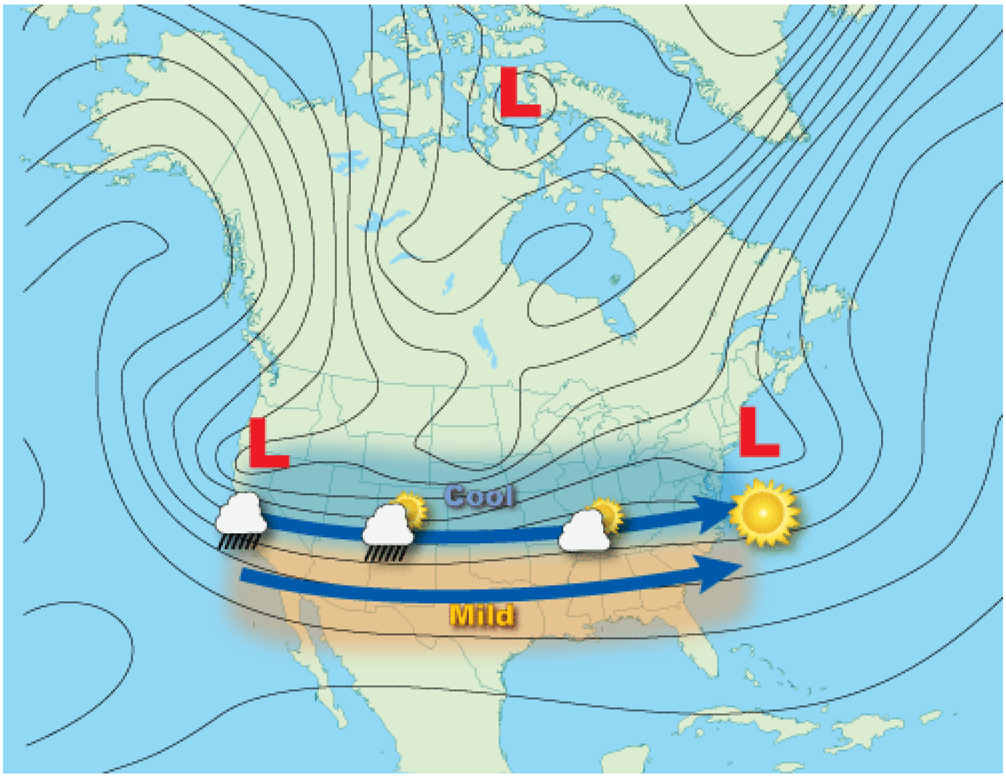


Fig. 7.19 – Zonal flow.
https://www.weather.gov/jetstream/basic

Cut-off low

These are persistent low-pressure areas that have become isolated or cut-off from the main air flow. They usually result from a strong short wave moving south on the western side of troughs that extended the trough toward the equator. The momentum of the short wave pulls the trough out of the main air flow and forms a closed, low pressure circulation.

The low can be very slow moving and they can occur at any time of year. Unsettled weather occurs over the eastern half of the cut-off low though there can be precipitation wrapping around the north end of the low affecting the northwest quadrant.

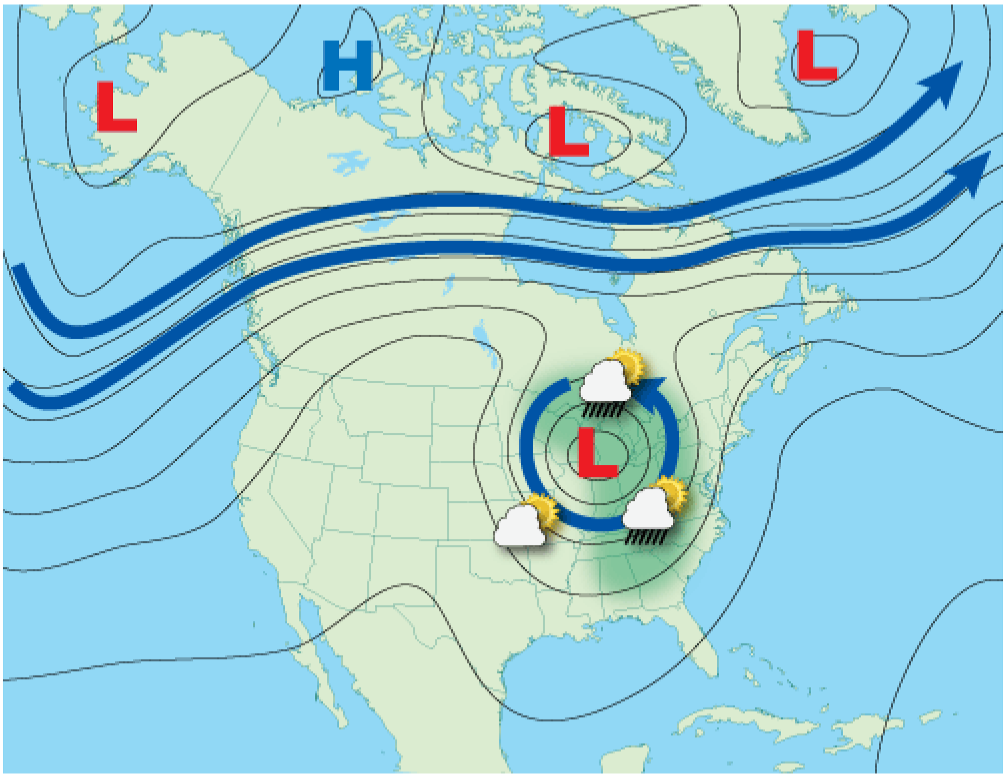


Fig. 7.20 - Cut-off low.
https://www.weather.gov/jetstream/basic

Blocking patterns

Blocking patterns occur when centres of high pressure and/or low pressure set up over a region in such a way that they prevent other weather systems from moving through. Other systems are forced to go around the block.

Blocking patterns can remain in place for several days resulting in long spells of persistent weather for locations under the influence of the block.

There are a number of different types of blocking patterns.

(1) Blocking High

This is typically a summer occurrence and can be responsible for heatwave weather conditions. Any precipitation is usually diverted around the edges of the high-pressure area.

Skies are usually clear due to the downward motion of air.

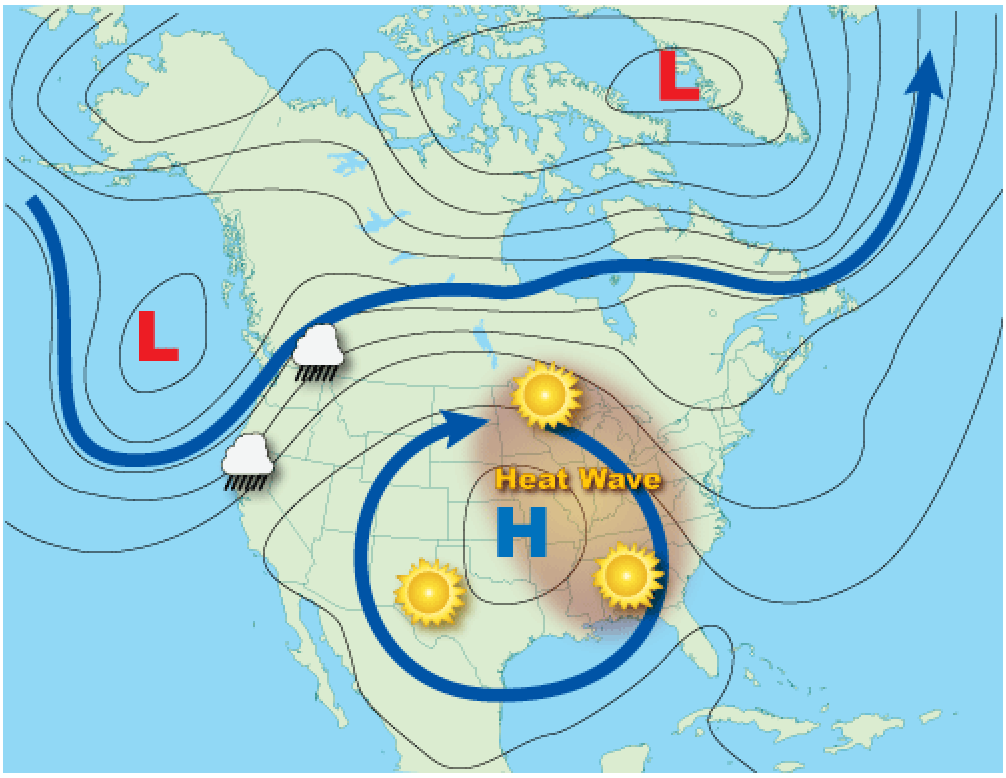


Fig. 7.21 - Blocking high.
https://www.weather.gov/jetstream/basic

(2) Omega block (meridional flow)
Named because the upper air pattern looks like the Greek letter (Ω). Omega blocks are a combination of two cut-off lows with one blocking high in between.

Because of their size, Omega blocks are often persistent and weather is dictated by location in the weather system pattern.

Cooler temperatures and precipitation accompany the lows while warm and clear conditions prevail under the highs.

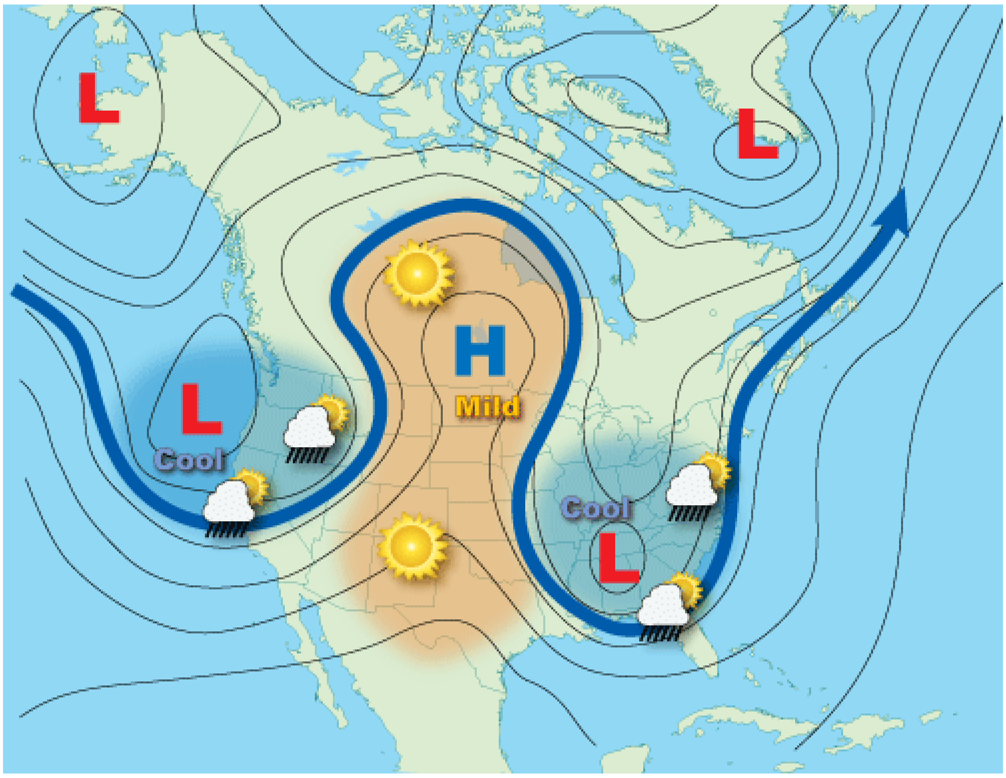


Fig. 7.22 – Omega block.
https://www.weather.gov/jetstream/basic

(3) Rex block

These are characterised by a high-pressure system located poleward of a low-pressure system. The block will remain nearly stationary until one of the height centres (trough or high) changes intensity, unbalancing the pattern.

Unsettled, stormy weather is usually found near the low pressure while dry conditions are typical with the high pressure.

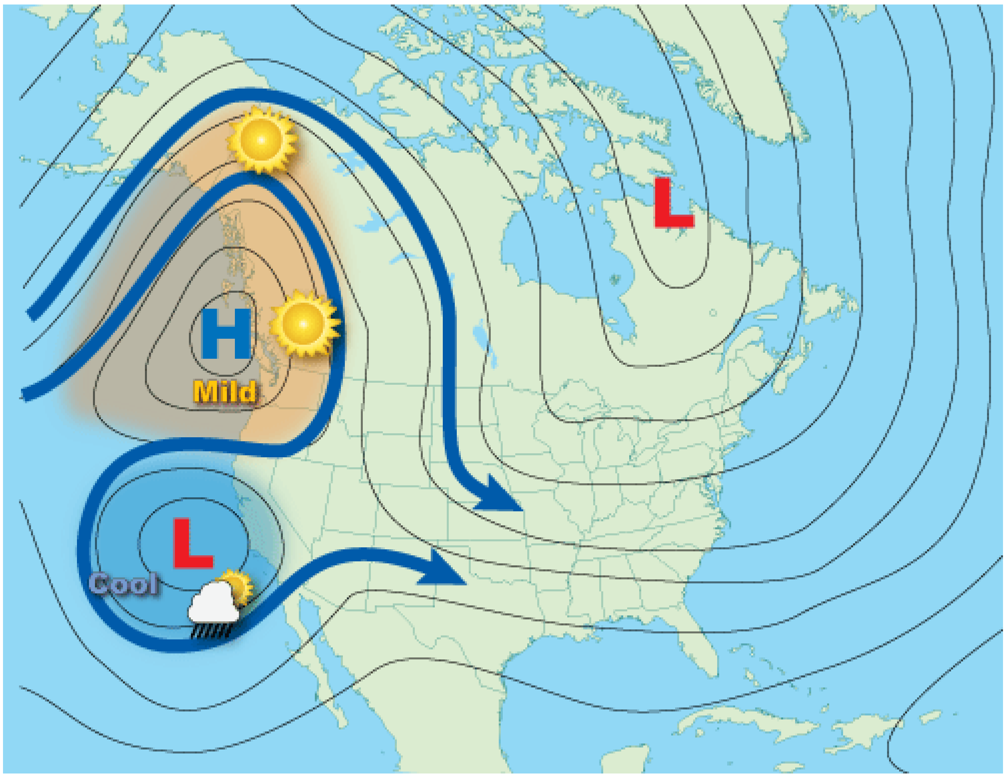
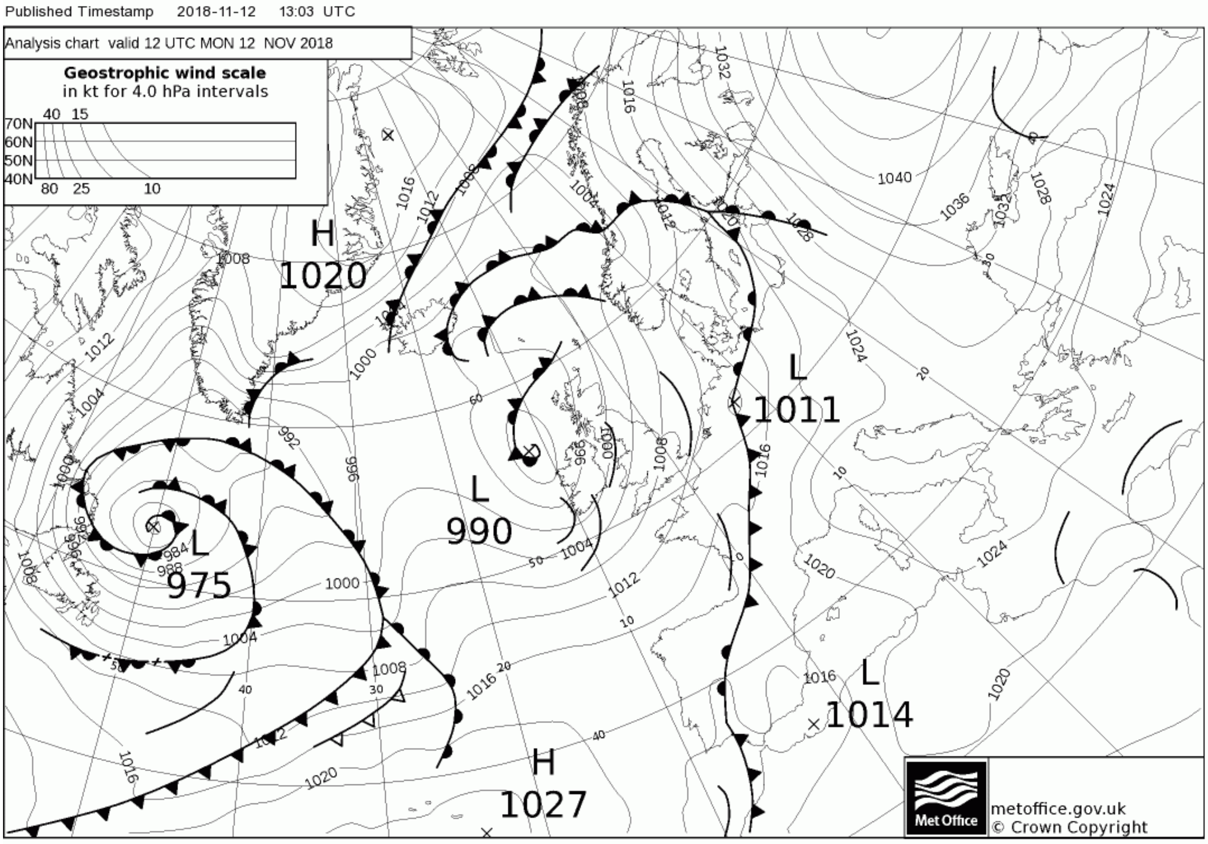
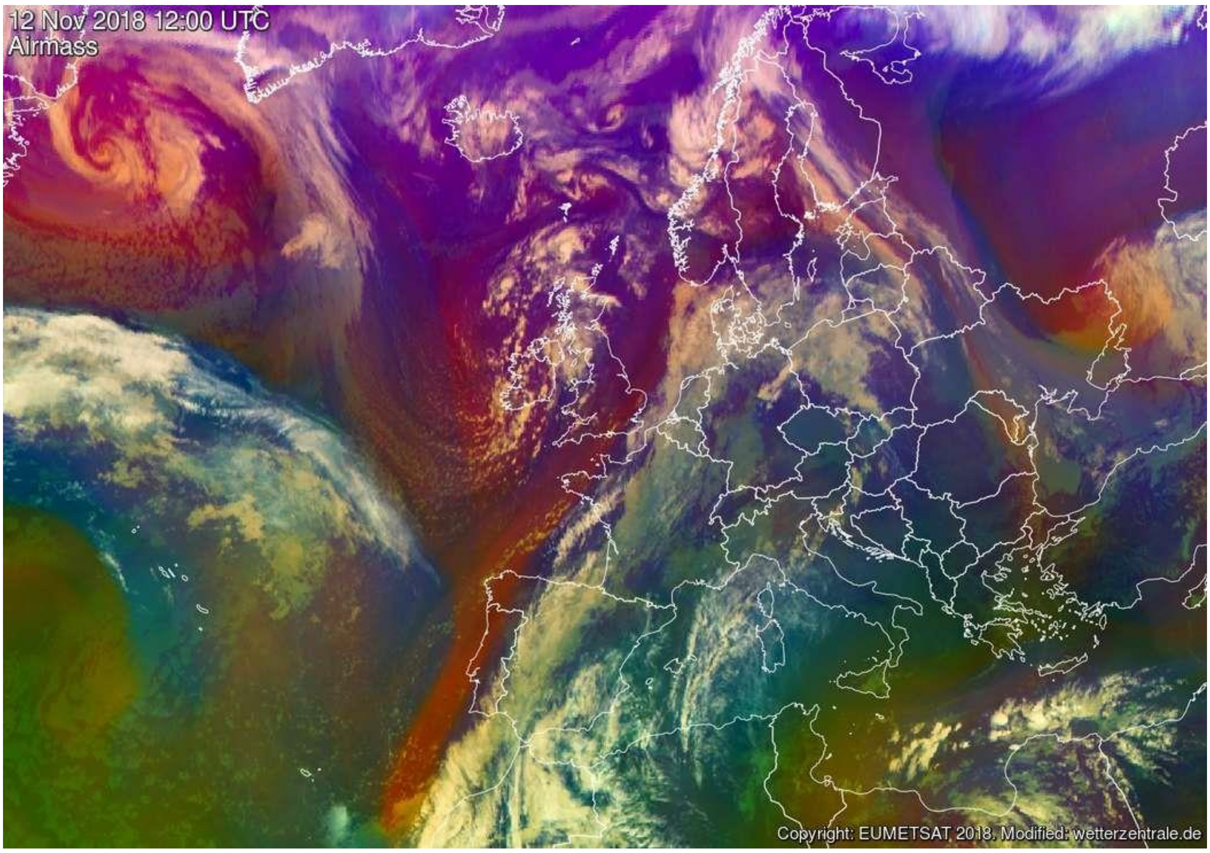


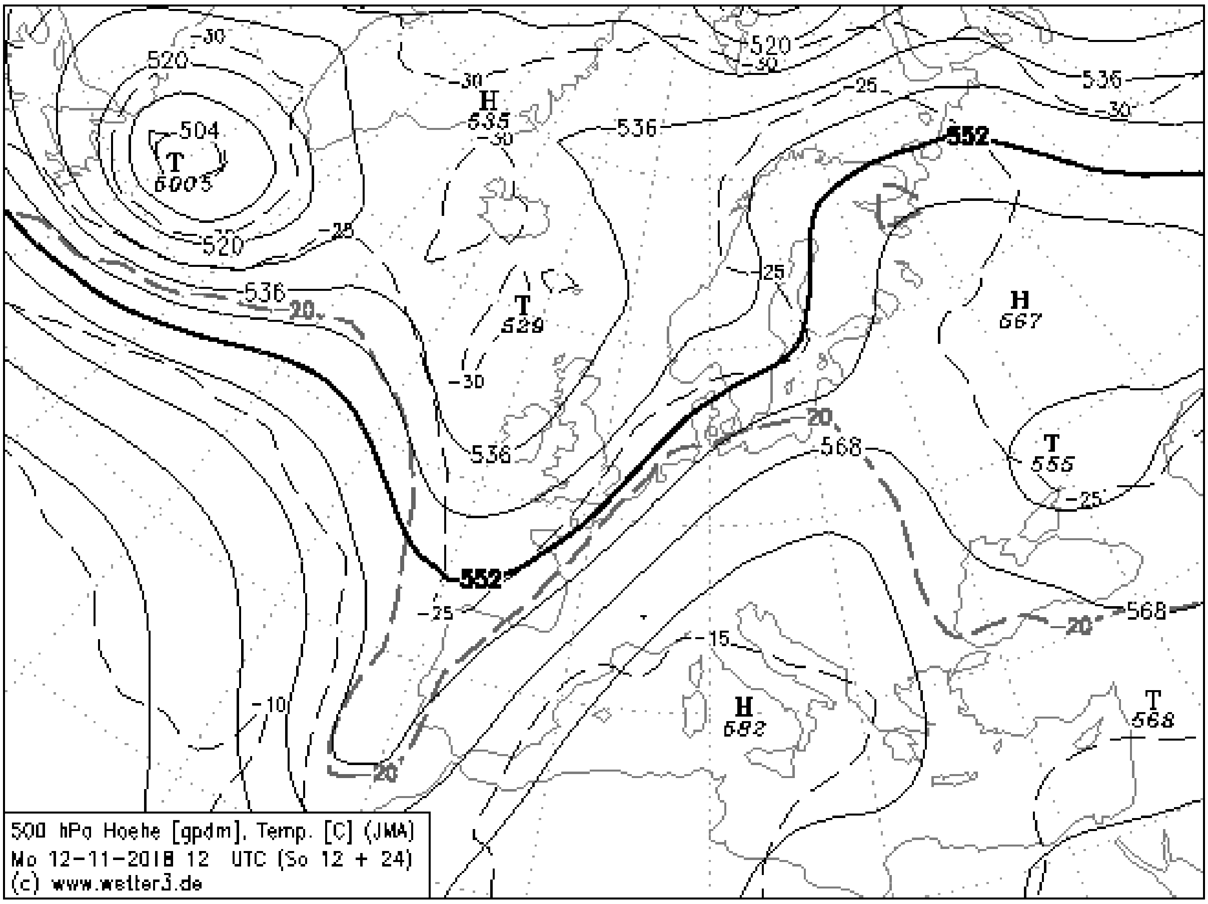
Fig. 7.23 – Rex block.
[*https://www.weather.gov/jetstream/basic*](https://www.weather.gov/jetstream/basic)

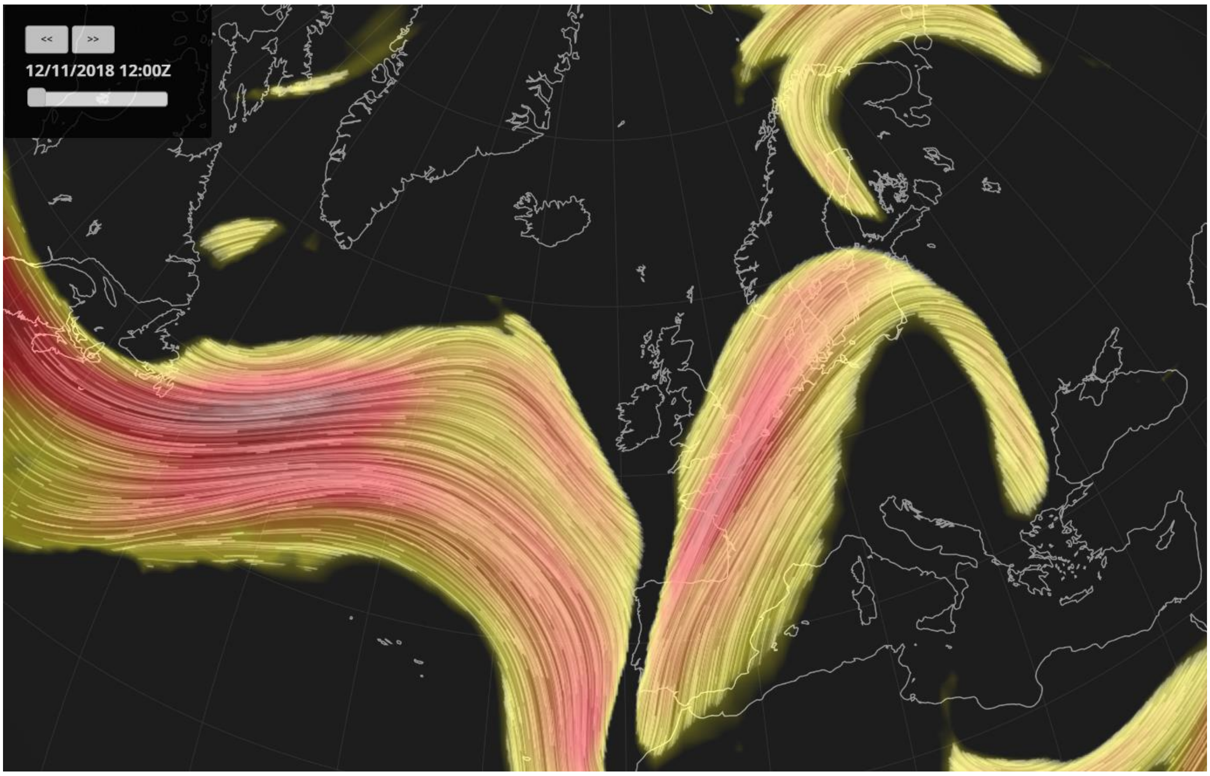
7.5 Example

Case 1 – 12 UTC MON 12 NOV 2018






500 hPa Hoehe [gpdm], Temp. [C] (JMA)
Mo 12-11-2018 12 UTC (So 12 + 24)
(c) www.wetter3.de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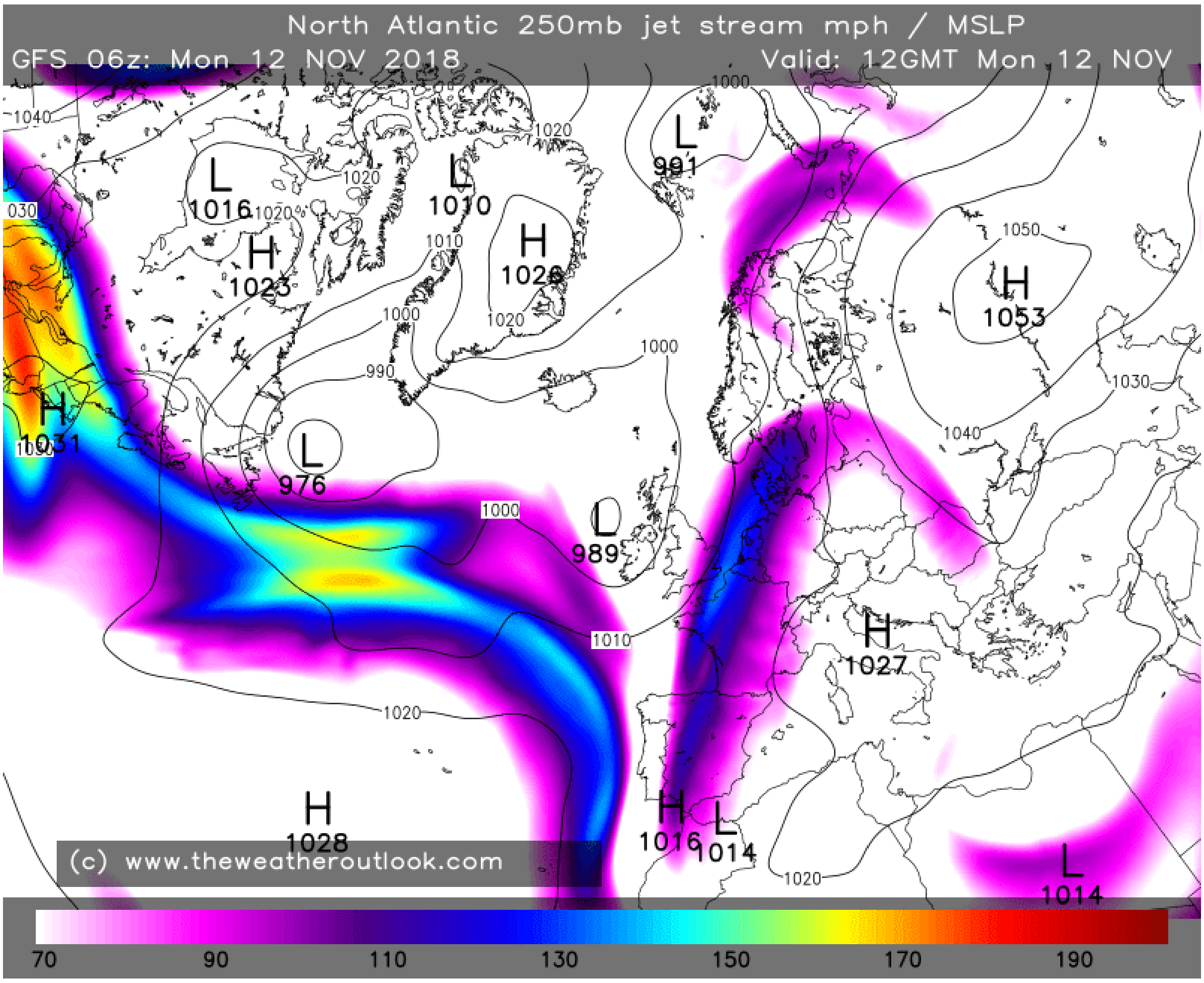
North Atlantic 250mb jet stream mph / MSLP
GFS 06z: Mon 12 NOV 2018
Valid: 12GMT Mon 12 NOV
L
1016
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989
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1027
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1028
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1016
L
1014
L
1014
1040
1030
1020
1010
1000
990
1050
(c) www.theweatheroutlook.com
70
90
110
130
150
170
190

7.6 Summary of using jet streams for forecasting

The 200, 250 or 300 hPa chart is the most appropriate for locating the position of the jet stream, levels being very close to tropopause.

The positioning and strength of the jet stream determines where ridges and troughs are associated and this in turn influences the surface weather.

7.6.1 Zonal flow and meridional flow

During periods when the jet stream is flat and strong with little amplification or meandering, the UK is likely to experience weather that is driven straight in from the Atlantic.

This is characterised by wet and windy weather with temperatures near to average. This condition is termed zonal flow as the warm and cold air masses are clearly defined by a straight fast flowing jet stream.

During periods when the jet stream wave is amplified the pattern will be different. This is termed meridional flow with polar air travelling further south than usual and warmer subtropical air travelling further north. The exact positioning of the amplification of the jet stream will determine whether or not the UK is in cold polar air or warmer air from lower latitudes. If a meridional pattern becomes stagnant then the UK may experience either of these conditions for a period of time and the pattern may be known as blocked.

7.6.2 Summary of the Jet Stream and the weather it creates

- The position of the jet stream over the UK determines the type of weather we experience.

- If the polar front jet is situated significantly to the south of the UK we will experience colder than average weather.

- If the polar front jet is situated to the north of the UK we will experience warmer than average weather.

- If the polar front jet is situated over the UK we will experience wetter and windier than average weather.

- If the polar front jet has a large amplification then cold air will travel further south than average and warm air will travel further north than average.

- The direction and angle of the jet stream arriving at the UK will determine the source of air and air mass that the UK will experience.