

Atmospheric Processes and Weather

We have looked at water flowing over the land in considerable detail. Another key component in the hydrologic cycle is the atmosphere and we will now look at in more detail at the atmosphere and the role water and air play in atmospheric processes and the hazards and benefits of these processes.

Structure of Earth's Atmosphere

The diagram below shows the various layers that exist in the Earth's atmosphere, their typical height above the Earth and the typical temperature in these layers. The air pressure drops with height above the ground as the air thins.

Closest to the ground is the **troposphere**. This is the layer we spend most of our time living in, and in which the Earth's **weather** occurs, including **horizontal winds**. The temperature drops with increasing height in the troposphere. The troposphere is about 18 km deep above the equator, but only 8 km deep above the Earth's Poles. Near the top of the troposphere is the **jet stream** – strong, generally westerly winds in a narrow layer.

The **tropopause** is the boundary between the troposphere and the stratosphere.

Air temperature increases with height in the **stratosphere**. The stratosphere is almost weatherless, extends up to 50 km and contains the ozonosphere. The **ozonosphere**, or **ozone layer**, contains ozone, a form of oxygen which protects life on Earth by screening out harmful UV rays from the Sun. Without the ozone layer, life on Earth would struggle to survive, especially on land.

The **stratopause** is the boundary between the stratosphere and the mesosphere.

Temperature drops with increasing height in the **mesosphere**, dipping to around -70 °C near the top. The mesosphere extends from 50 to 80 km.

The **mesopause** is the boundary between the mesosphere and the thermosphere.

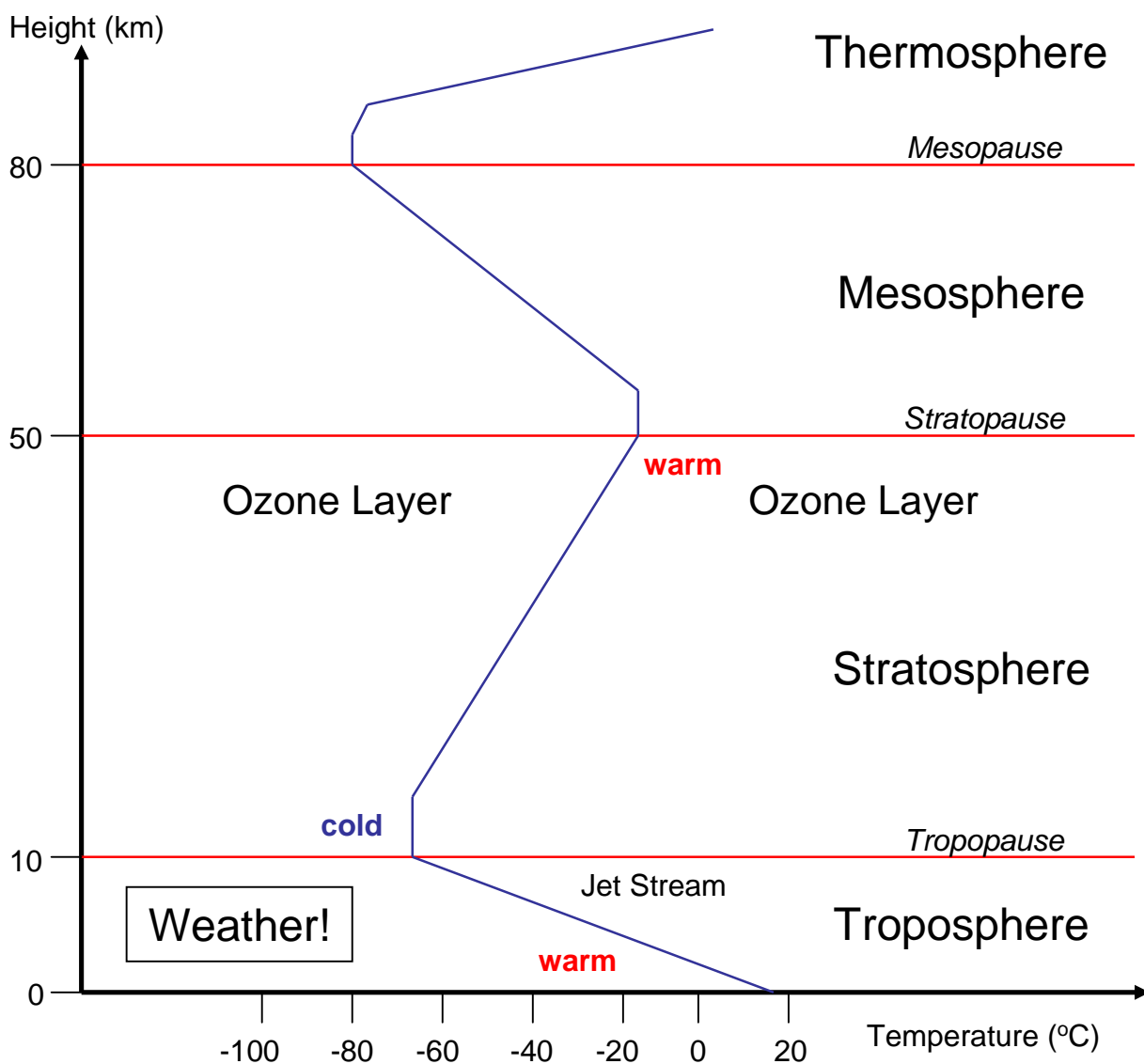
The thermosphere extends from 80 to 800 km and the temperature here varies from about 1300 °C at day, to 150°C at night. The **Aurorae** occur here (the **Northern and Southern Lights**). This layer contains ionised particles (particles carrying electric charge). The **ionosphere** extends from 50 to 300 miles and includes the mesosphere and the lower thermosphere and contains electrically charged ions. These ions reflect radio waves, allowing radio signals to travel further than the horizon by being bounced off the ionosphere which is thus important in radio communications.

The **thermopause** is the boundary between the thermosphere and the exosphere.

The **exosphere** extends from 800 to 1600 km and consists of ionised atomic hydrogen and helium. Temperatures reach about 2500 °C at day and -270°C at night.

As you can see the Earth's atmosphere is complicated, even without mentioning the weather! For this course what you should remember is the ozone layer, the jet stream and the fact that our weather occurs in the lowermost layer, the troposphere. The other terms you do not need to remember, but were included for completeness.

Layers of the Earth's Atmosphere



To help put things into perspective, a passenger plane cruises no higher than about 5.6 km. Military jets can fly at around 17 km. The International space station orbits at an altitude of around 350 km. Mount Everest is about 8.8 km tall.

Climate and Weather

Climate: the weather in some location averaged over some long period of time; "the dank climate of southern Wales";

Weather: the state of the atmosphere at a particular time and place.

What do we mean by "state of the atmosphere"? Well, the state of a system is determined by those large-scale properties that we can measure. For the weather these properties are:

1. Air temperature;
2. Air pressure;
3. Humidity;
4. Clouds;
5. Precipitation;
6. Visibility;
7. Wind.

Air is a mixture of gases and is 78% nitrogen, 21% oxygen and 1% argon, by volume and also contains variable amounts of water vapour (0-4%), traces of carbon dioxide (0.036%), methane, ozone, other gases, aerosols and dust particles.

Meteorology: the scientific study of the atmosphere and its phenomena.

Controls over Climate

Controls over Air Temperature

Temperature is a measure of the amount of heat that an object or quantity of matter, such as the air, contain. The air temperature at a specific geographical location is determined, apart from the obvious effect of altitude, by:

1. The exchange of heat energy between the ground and the air.
2. The movement of air masses.
3. The location relative to a large body of water.

Next we shall look at each of these three controls in turn.

Control 1: Solar Radiation and surface heating

The Sun's radiation is the main source of energy to heat the surface of the Earth. This light radiation hits the ground, heating it, and causing the ground to emit infrared radiation, which is absorbed by the air and heats the air. **The immediate source of energy to heat the air is the surface of the Earth.**

Shortwave electromagnetic (EM) radiation (light and ultraviolet (UV)) passes through the atmosphere and is absorbed by the ground and re-radiated as **longwave EM radiation** or infrared (IR) radiation. It is this long-wave radiation that is absorbed by the air to give the air more heat energy, thus, the immediate source of energy to heat the air is the surface of the Earth!

Daily Cycles of Radiation and Temperature

Solar radiation peaks at noon, and reaches a minimum at sunset. The **insolation** is the amount of solar radiation received at the Earth's surface. Radiation re-emitted from the ground lags behind insolation by 2 to 3 hours, so the ground is emitting most of its heat at 2:00 to 3:00 pm. The air takes a further hour to absorb this heat, and so the maximum air temperature occurs around 4:00 pm. This there is a daily temperature lag (the amount of time between maximum incoming energy and maximum air temperature of the day) of about 4 hours.

The equator receives more solar radiation for the following reasons:

1. Near the equator, the sun is high in the sky all year which means that the solar radiation is concentrated over a smaller surface area of ground. This is illustrated by Figure 1 on p. 50 of BP.
2. Furthermore, the Sun's rays have to travel through less atmosphere to reach the ground and so less of it is absorbed or scattered by the atmosphere before it reaches the ground.
3. The daylength is 12 hours all year round and so the ground does not cool over a winter season.

This results in high rates of insolation in the equator and the tropics, making it hot all year round (average monthly temperature: 27°C).

Temperate zones (at high latitudes) receive less solar radiation for the following reasons:

1. The sun is at a lower angle for most of the year, which spreads the Sun's rays over a larger surface area of ground.
2. The Sun's rays have to travel through more atmosphere to reach the ground (because of the shallower angle they take through the Earth's atmosphere).
3. Summer and winter seasons exist as a result of the tilt of the Earth upon its axis. In winter in the Northern Hemisphere, the Northern Hemisphere is tilted away from the Sun, reducing the angle of the Sun in the sky (increasing the effects of 1 and 2). In summer in the north, the Northern Hemisphere is tilted towards the Sun (reducing the effects of 1 and 2) increasing insolation. In summer daylight exceeds 12 hours and in the winter it is less than 12 hours.

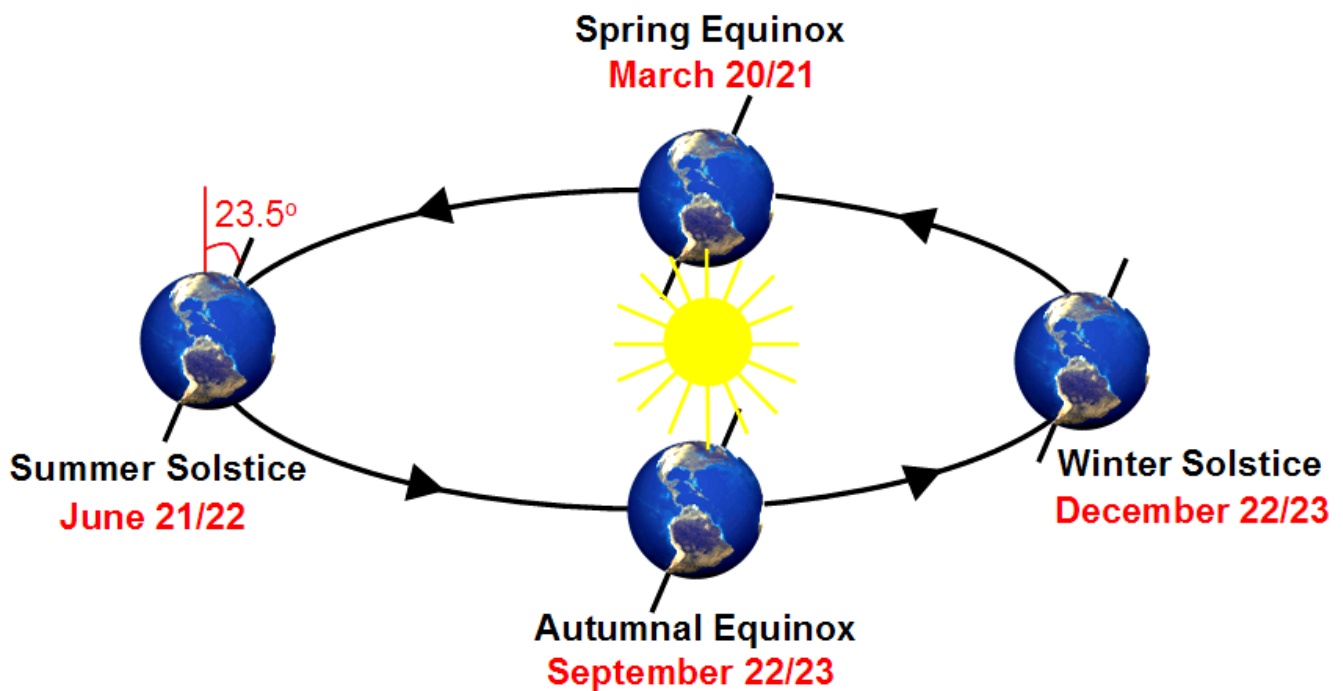
Q. Why does the Southern Hemisphere experience warmer summers than the Northern Hemisphere?

A. When the Northern Hemisphere experiences its winter, the Southern Hemisphere is in summer and vice versa. However, the Earth's orbit around the Sun is not a circle, but an ellipse, and in winter in the north the Earth is actually closer to the Sun, but because the north is tilted away from the Sun it is in winter, whilst the south is tilted toward the Sun and so is in summer. As well as being tilted toward the Sun in summer, the Earth is closer to the Sun and so the Southern Hemisphere experiences especially warm summers.

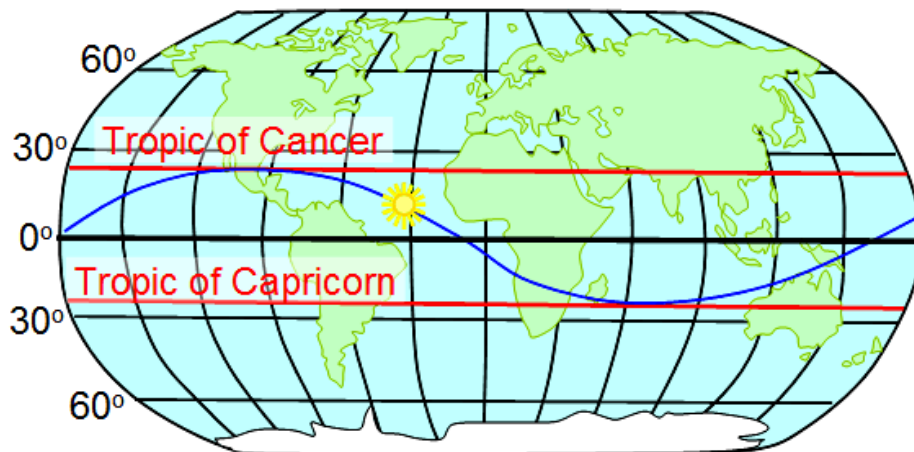


The Earth is tilted on its axis by approximately 23.5 degrees (23 degrees 27 arcminutes) and it precesses around the vertical like a spinning top or gyroscope as its tilted axis traces out a complete circle once every 25 800 years or so.

As the diagram below shows, the North Pole always points in the same direction (shown at the top of the globe and slightly tilted) throughout the year as the Earth orbits the Sun. During the spring and autumnal equinoxes in the Northern hemisphere there is exactly 12 hours of daylight in the day. During the winter solstice the daylight is shortest and at the summer solstice we have the longest day of the year. Note also that the Earth is closest to the Sun during our winter, which corresponds to summer in the Southern Hemisphere.



Below: as the part of the Earth's surface directly pointing toward the Sun changes over the year, the position at which the Sun is directly overhead also changes. The furthest north that the Sun can be directly overhead occurs during the summer solstice and is marked by the **Tropic of Cancer** (23° 26' 22" N of the equator). The Sun is directly overhead at the **Tropic of Capricorn** on the winter solstice (23° 26' 22" S). During the rest of the year it oscillates between these positions.



Control 2: Air Pressure and Winds

The equator receives more solar radiation throughout the year than do higher latitudes. The equator receives 12 hours daylight every day of the year, during which the Sun is always directly overhead at mid-day. Northern temperate and southern temperate zones may receive as much sunlight as the equator during their summer, when the Sun climbs directly overhead, but at winter the Sun stays at a shallower angle, lower in the sky and so the temperate zones receive less solar radiation than the equator in winter.

If there was no transport of heat around the globe, then the equator would get hotter and hotter and the higher latitudes would become colder and colder. Heat naturally flows from hot regions to cold regions. To transport heat efficiently, the Earth has to use water and air currents. **Less than half the heat is transported by ocean currents**, for example the **Gulf Stream** which flows from the Equator to Britain, Ireland and Scandinavia transports heat and makes these NW European countries warmer than they would otherwise be. (The North Atlantic Drift is a branch of the Gulf stream).

You can see the Gulf Stream in figure 3 on p.51 of BP, it is shown by the purple arrows, labeled "Warm ocean currents" traveling from the east coast of the USA to NW Europe.

However, **more than half of the heat is transported in air currents** – wind. Hot air expands, becoming less dense than cold air and so rises, causing an area of **low pressure**. Heating at the equator produces lots of warm rising air. As this air rises, colder air rushes in underneath from higher latitudes. The warm air moves out from the equator, north and south, until it cools and sinks again, creating a region of **high pressure**. This cool air moves to the equator to replace the warm air that has come from there. In effect a conveyor belt is established, transporting hot air from the equator to the poles, and, underneath this, cold air from the poles to the equator. This circular mass movement of air creates the winds, and is called a **convection cell**.

Convection: the circulation of water or gas driven by large temperature differences. Also refers to the transport of heat by this mechanism. In this instance it refers to the rising of warm air at an area of low pressure. This air may rise 10 000 m or more and **cumulus clouds** may form.

Convergence is the movement of air masses toward an area of low pressure. We have seen how rising warm air at the equator, lowers the pressure, sucking in cold air from the poles, which converges on the equator.

Divergence is the movement of air masses away from an area of high pressure, such as the movement of cold dense air away from the poles.

Uplift is the upward movement of air and **subsidence** is the downward movement of air.

So far we have a simple model with two convection cells, one carrying warm air from the equator northwards and the other from the equator southwards. In reality the situation is made more complicated by the rotation of the Earth. The rotation of the Earth produces a force on fluids moving across the Earth (a fluid can be a gas or a liquid) called the **Coriolis force**. The effect of the Coriolis force is to **deflect moving objects to the right in the Northern Hemisphere** and to deflect them to the left in the Southern Hemisphere. The force gets stronger further from the equator, so winds close to the poles are deflected more. Stronger winds are also deflected more.

Convection Belts and Prevailing Winds

The end result of the Earth's rotation and the Coriolis force is to break up the two convection cells into 6 belts or cells that girdle the Earth. These are the two **Hadley cells**, closest to the equator, the two **Polar cells** closest to the poles and the two **Ferrel cells** in-between at mid-latitudes. Note the complexity of the ferrel cell, some air flows over the Ferrel cell from the Hadley cell to the Polar cell. *Take careful note of the direction of the arrows in this figure.* The Hadley cell is the strongest, since it is driven by the radiation that it receives from the Sun.

Go to <http://www.school-portal.co.uk/GroupDownloadFile.asp?GroupID=12426&ResourceID=40425> Click the buttons and watch the animations!

The net effect of these 6 convection cells is still to transport warm air from the equator to the poles and cold air from the poles to the equator.

The **Intertropical Convergence Zone (ITCZ)** is situated at the equator and is where warmed air converges and uplifts.

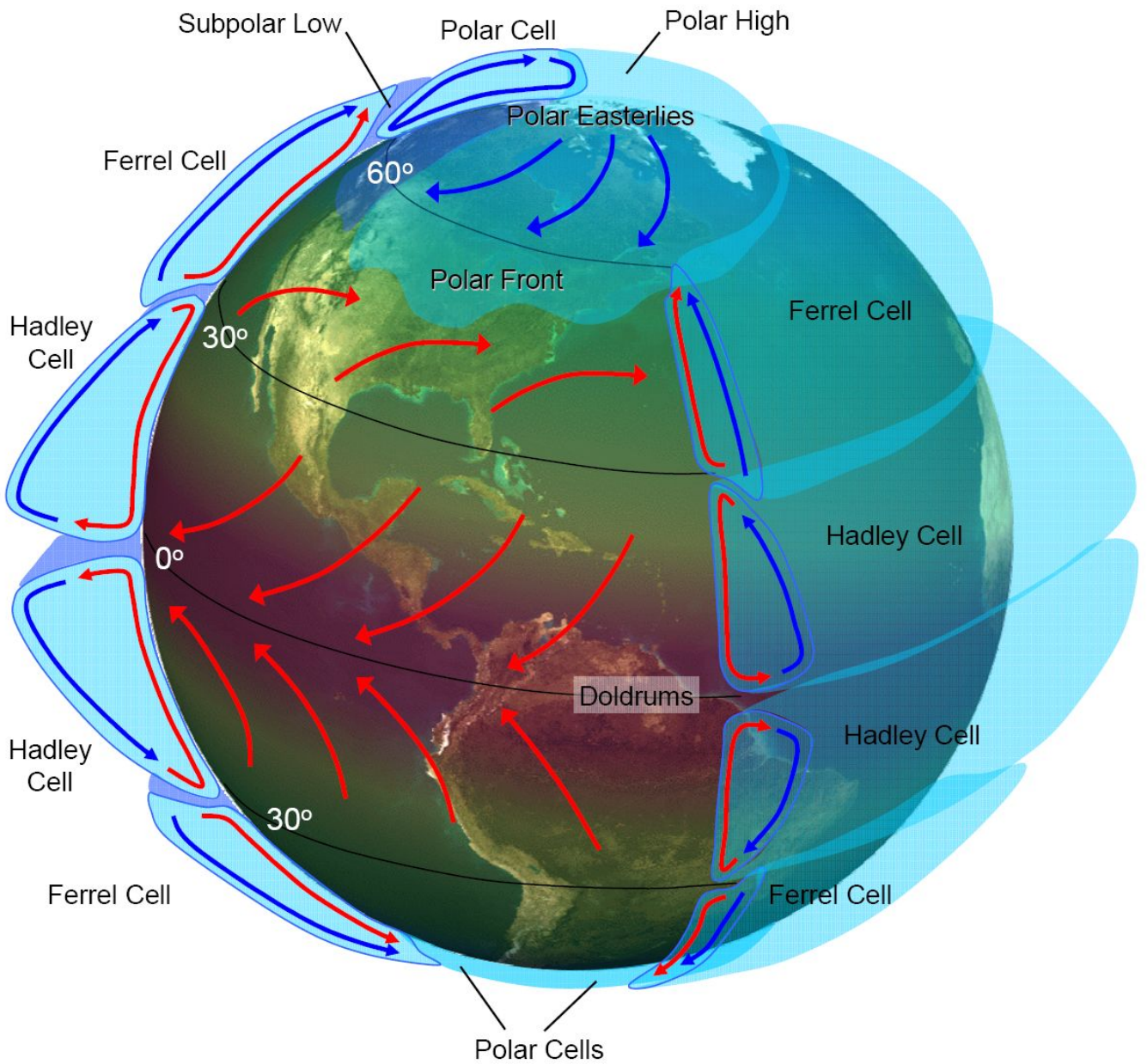
A second effect of the Coriolis force is to skew the flow of air in these convection belts, so that the winds are not simply northerly or southerly. Now the prevailing wind directions are the NE Polar Winds from the North Pole (and SE Polar Winds from the South Pole); **SW winds** in northern mid-latitudes (30° N to 60° N) (NW in southern mid-latitudes); and the **NE trade winds** from 30° N to the equator (SE trade winds from 30° S to the equator). These are the **prevailing winds**.

Remember that you have a low P where air rises, and a high P where air subsides. Thus, there is a low pressure near to the equator (the **Equatorial Low**), low pressures at about 60° N and 60° S (the **Temperate Lows**) and high pressures at 30°N and 30°S (called the **Subtropical Highs**).

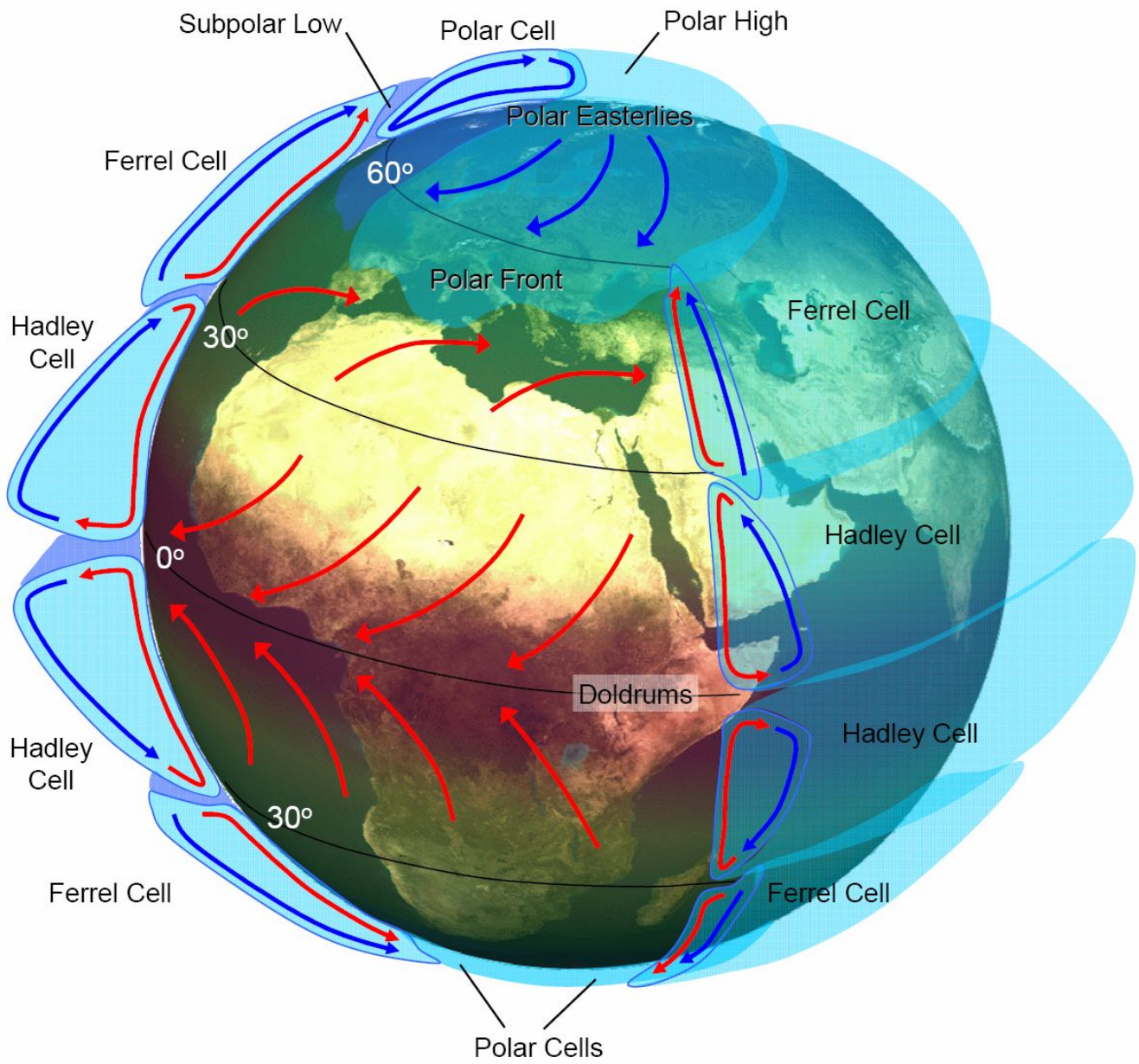
What is the Jet stream?

So far we have considered the winds near to the Earth's surface. The Jet Stream is the high altitude winds (about 10 000 m above the ground) that are free of the surface and are not dragged around by friction with the Earth's surface, as the Earth rotates, as are the surface winds, but is free to flow straight from high pressure to low pressure, along the isobars. Surface winds cross the isobars at an angle.

Isobar: an imaginary line joining points in the atmosphere of equal pressure. Differences in pressure create the winds – air moves from (cold) high pressure zones to (warm) low pressure zones.



Above: A model of the Earth's atmosphere showing the three pairs of convection belts responsible for prevailing winds.



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Atmospheric Pressure and its Effects on Climate

We have already talked about atmospheric pressure – we have seen how unequal illumination of the Earth by the Sun, creates pressure differences or pressure gradients along which air moves as wind – forming the 6 convection belts.

In the rising air low pressure zones (the Equatorial Low and the Temperate Lows there is heavy annual precipitation. As the air rises it cools and water vapour it carries condenses out and forms clouds. Once the water droplets and ice crystals are large enough they fall out of the cloud as precipitation.

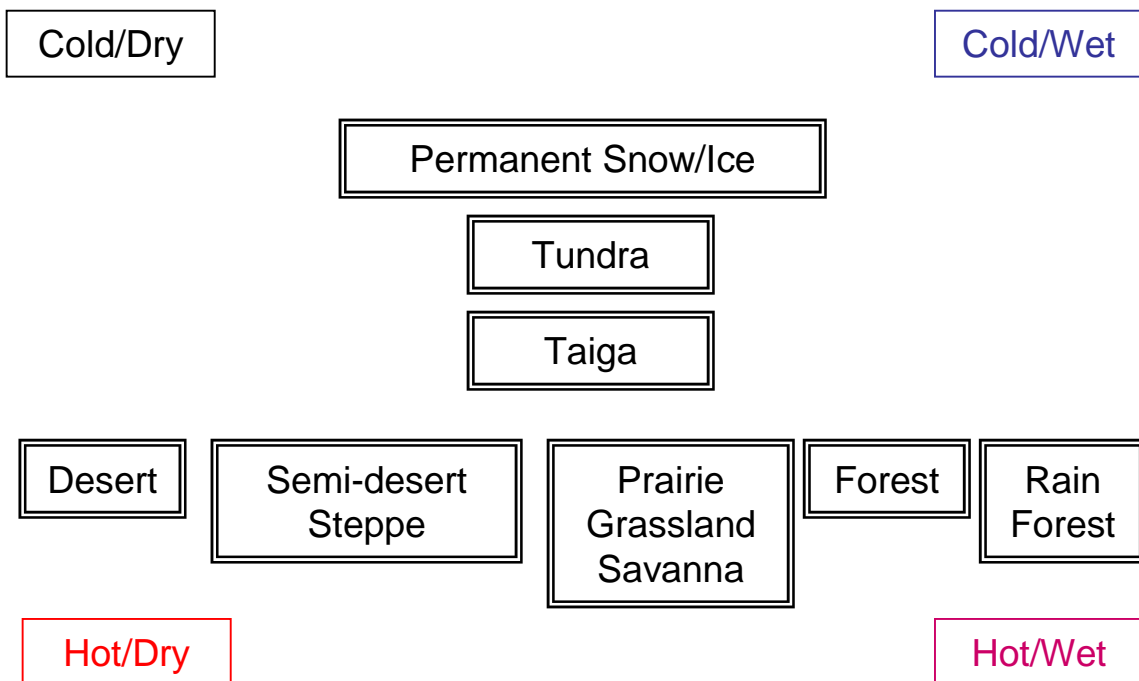
E.g. **The British Isles** lies in a Temperate Low pressure zone where warm tropical air, transported by warm south-westerly winds meets cold polar air, transported by north-easterly winds. Where these two air masses collide along the polar front, frontal depressions are formed which move across the Atlantic toward the British Isles, throughout the year.

A **depression** is a local area of low pressure.

Where air descends at the Polar highs and Subtropical Highs there is little precipitation. Below the Subtropical Highs are the **hot deserts** of the World, and below the Polar Highs are the **cold deserts**, such as those found in Antarctica.

Climate Types of The World

The diagram below illustrates the major climatic types on Earth, as characterised by their degree of heat, moisture and vegetation type.



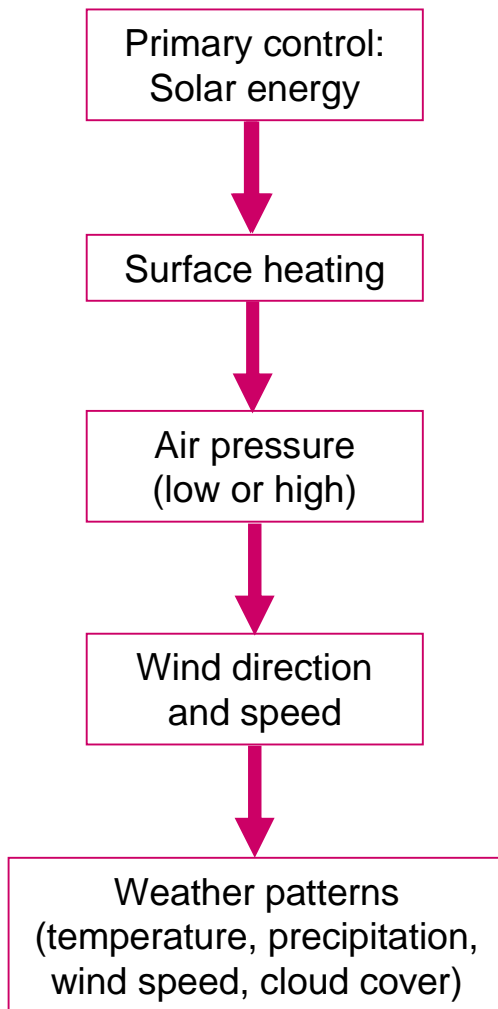
Tundra: a treeless plain characteristic of arctic and subarctic regions.

Taiga: a moist subarctic coniferous forest that begins where the tundra ends – dominated by spruces and firs.

Steppe: temperate, semiarid treeless grassland.

Prairie: a treeless grassy plain.

Savanna: a grassland with scattered trees.



The diagram on the left shows how the controls we have discussed so far link together to affect climate. The main control is solar energy – this energy drives the climate systems of the Earth. The Sun’s energy heats the ground which heats the air, generating areas of low pressure, and high pressure where that air cools and sinks again. These pressure differences create the winds that bring moisture to the land from the sea, which condenses into clouds to bring us rain and snow.

This diagram shows the main controls: solar energy, air pressure and wind. What control is missing from this scheme? The effects of large bodies of water is missing. We shall discuss this below, after saying a bit more about clouds.

The Classification of Clouds

Clouds are grouped into types, based on their altitude and appearance.

Cumulus clouds are piled-up, accumulated and fluffy in appearance.

Stratus clouds are layered.

Nimbus clouds are dark and gray and carry rain.

Alto clouds are high clouds.

Cirrus clouds are very high altitude clouds of ice crystals.

High Altitude Clouds (7000 m or higher)

1. **Cirrus**: thin, wispy clouds, made up of ice crystals, form above 8000 m.
2. **Cirrocumulus**: thin, patchy, form in wave patterns, uncommon, give a **mackerel sky**, made of ice crystals and form at 7000 to 8000 m.
3. **Cirrostratus**: patchy, form a fine veil, form Sun and Moon halos, made of ice crystals and form at 7000 to 8000 m.

Mid Altitude Clouds (3000 to 700 m)

1. **Altostratus**: dense, grey clouds formed of water droplets, translucent – the Moon shines through them.
2. **Alto cumulus**: patchy, puffy layers, grey-white, formed from water droplets.

Low Altitude Clouds (below 3000 m)

All made mostly of water droplets

1. **Stratus**: low, uniform sheet, grey, base above the ground, produces drizzle.
2. **Nimbostratus**: dark, thick rain clouds.
3. **Stratocumulus**: irregular, puffy layered, grey, do not produce rain.
4. **Cumulonimbus**: towering, tops extend to 2700 m – thunderclouds, produce lightning and can produce tornadoes.
5. **Cumulus**: puffy, white, form during the day and disperse at night, towering, but not as tall as cumulonimbus clouds.

Use Google image search to find photographs of all the cloud types mentioned in **magenta** on this page.

Control 3: Air Temperature, Water Bodies and Continentality

Continentality: the effect of continent location on weather and climate.

Most of the heat energy absorbed by water gets absorbed over a certain depth, since water is transparent, and mixing of the water carries much of this heat down to greater depths. Much of the heat that remains near the surface is carried off in water vapour when water evaporates. This gives water a relatively cool surface, even on a warm day, and so the air above large bodies of water is kept cooler.

In contrast, think what happens when the land absorbs heat energy. The land is opaque and there is no mixing between the layers, and so the surface traps most of the heat, and just beneath the surface it stay quite cool. The warmer surface heats the air above the land and so the **air above a large land mass tends to be warmer than that above a large body of water.**

In coastal areas, the **cooler maritime air** comes ashore, causing a temperature drop over the land, which tends to keep the coast cooler in summer than inland areas. Water also takes much longer to heat up and cool down than the land does. In winter, the water remains quite warm and takes about a month to cool, this helps keep the coast warmer in winter. As a result, seasonal temperature changes at coastal areas lag behind those inland by about a month, and temperature changes are less severe. The effects of seasonal temperature change is effectively less severe at the coast. For example, Californian coastal cities barely experience any seasonal temperature changes, e.g. Los Angeles, San Francisco.

In contrast, areas far inland suffer more extreme seasonal temperature changes, since soil and rocks warm up and cool down much more quickly than water, and areas far inland are without the moderating effects of the ocean. **Continentality** is the degree to which a local climate typifies that of the interior of a large land mass. More continental climates are further from the sea and less insulated by the sea and so experience harsher seasonal extremes of climate.

So to summarise, continentality causes large seasonal variations in temperature and rainfall but gives rise to relatively dry climates far inland. For example, Siberia, Central Russia and parts of North America, experience up to a 40°C difference in summertime and wintertime temperatures.

In contrast the UK has a maritime climate, influenced by the sea. There is a 10°C average temperature range, but continental polar air in winter may lower the temperature further and pick up moisture over the North Sea and bring snow. The Gulf Stream warms the UK over winter, keeping it warmer than it otherwise would be. Next we shall look at the UK climate in more detail.

The north wind doth blow,
And we shall have snow,
And what will poor robin do then,
Poor thing?
He'll sit in a barn,
And keep himself warm,
And hide his head under his wing,
Poor thing.

Control 3: The proximity of large bodies of water: Maritime effects and Continentality

Water warms up much more slowly than land in summer, but also cools much more slowly and so helps maintain the land at a warmer temperature several months after the air has begun to cool. In this way warm water insulates the land from the extremes of winter temperatures.

In a large continent, the central land area is far from the oceans and so is not so insulated by the sea. As a result large land masses experience very low winter temperatures (e.g. Siberia). In summer the cooler water does not keep the land cool and temperatures soar. Thus central land areas on large land masses have large annual temperature ranges. This effect that large land masses have on temperature is called **continentality** and these regions have **continental climates**. Areas dominated by winds that have travelled far over continents will be dry, such as the vast Sahara Desert in Africa.

Coastal areas and smaller land masses, such as the British isles, experience more moderate climates. The slow cooling of the sea in winter keeps the land warmer than it otherwise would be and the cool sea in summer keeps the land cooler. Thus, these areas experience narrow annual temperature changes. For example, in the UK the annual change in temperature from summer to winter is only 10°C. These effects of the oceans on land are called **maritime effects** and such regions have **maritime climates** (also called oceanic climates, marine west coast climates or **western maritime climates**). The 'western' refers to the prevailing westerly winds in the Northern Hemisphere (south-westerly in the Britain) which bring **warmer wet weather** from the oceans to the western coasts. In Britain, the west country (Devon and Cornwall) experience much warmer winters. These climates are found in small land areas, like Britain, and along the western coasts of larger land masses, such as North America and Canada.

In temperate regions, the cool summers give these climates their alternative name of: **cool temperate western maritime climates**, e.g. Britain. Temperate regions have no extremes of temperature and rainfall. Britain's climate is both temperate and western maritime. However, as we shall see in the next sections, Britain's climate is a little more complicated since it is affected by both maritime air masses and continental air masses from nearby continents.