6. Atmospheric Circulation and the Major Oceanic Climate Zones

6.1 Factors affecting the circulation of the Atmosphere

The main factors that influence how air moves over the surface of the Earth and in the upper troposphere are:

- The angle of incidence of the insolation reaching the Earth's surface at different latitudes.
- The thickness of the atmosphere through which the insolation must pass before reaching the Earth's surface.
- The inclination of the Earth's axis of rotation which causes the seasons and associated differences in the length of day throughout the year in any location (this increases with latitude).
- The difference in specific heat capacities of the various types of land surfaces e.g. deserts, vegetation cover and sea surfaces.
- The rotation of the Earth which creates wind belts moving around the Earth as a result of the effect of Coriolis.
- The effect of changing declination of the Sun which causes wind belts and areas of maximum surface heating to migrate north and south with the seasons.

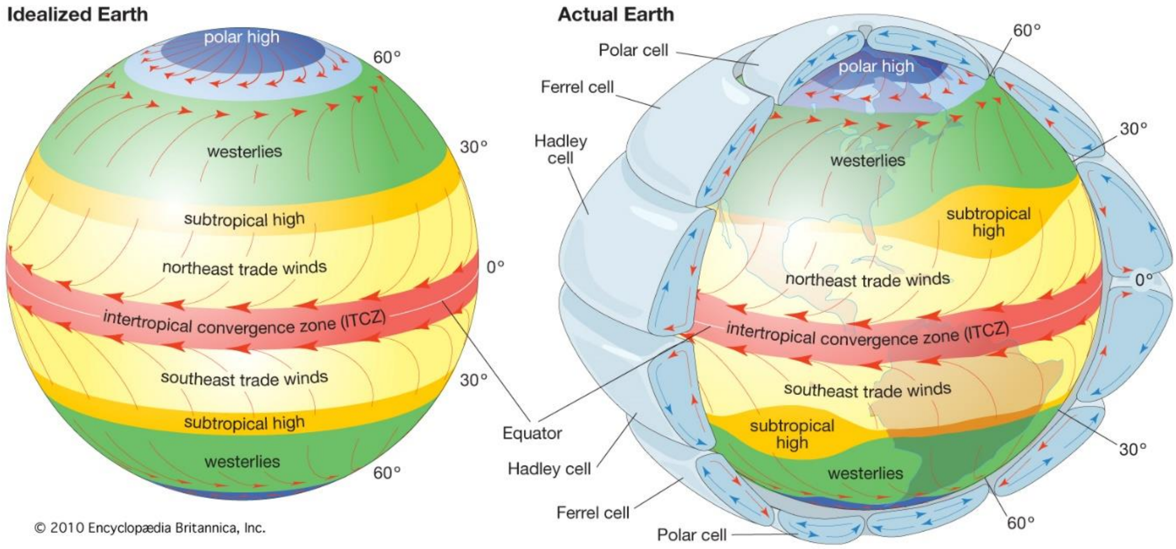

Fig. 6.1 – The general circulation of the atmosphere.
https://www.britannica.com/science/atmospheric-circulation/media/41463/107938

A major influence of atmospheric circulation is the uneven distribution of solar heating across the Earth associated with the uneven distribution of the land masses.

Figure 6.1 shows that in each hemisphere there are three cells or bands of air movement.

Figures 6.2 (a) and (b) show the average pressure distribution for January and July.

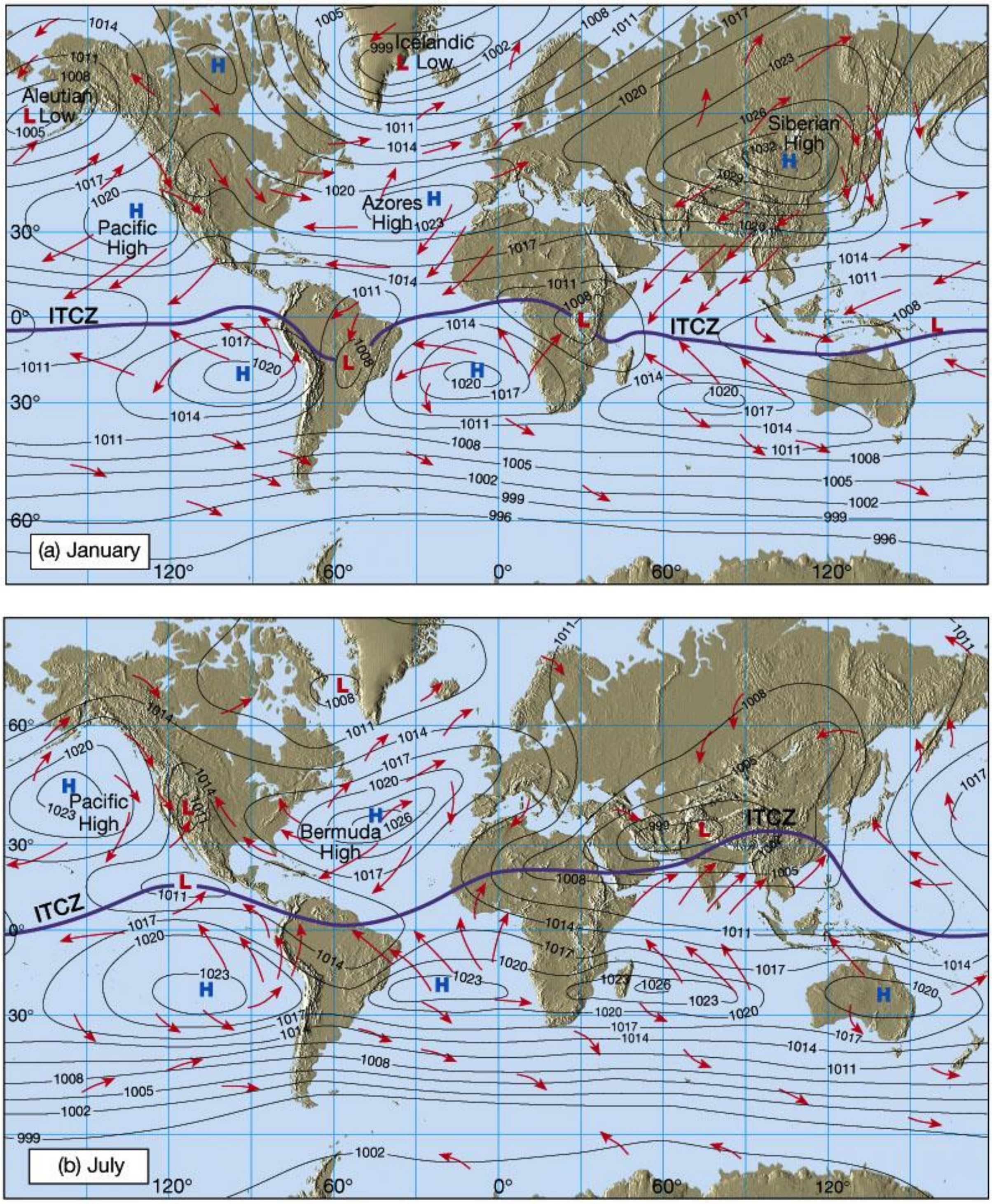

Fig. 6.2 – Average pressure distribution for (a) January and (b) July and the seasonal movement of the ITCZ.
http://www.ux1.eiu.edu/~cfjps/1400/circulation.html

6.2 The Hadley and Polar cells of atmospheric circulation

6.2.1 The Hadley cell

The Hadley cell is a global scale tropical atmospheric circulation in each hemisphere that features air rising near the Equator, flowing poleward at 10–15 kilometres above the surface, descending in the subtropics, and then returning equatorward near the surface.

The Hadley cell creates the NE and SE Trade winds which come together at the Intertropical Convergence Zone (ITCZ) which is a broad belt of low pressure and weak pressure gradient associated with huge cumulonimbus cloud formation, torrential rain, thunderstorms and line squalls.

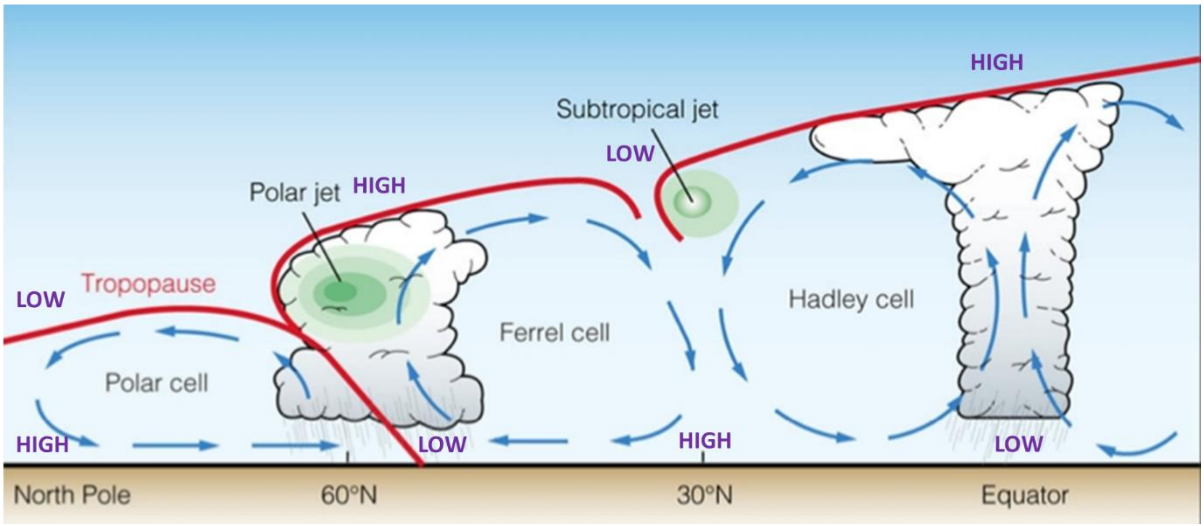

Fig. 6.3 -The north-south tending movement of air in the northern hemisphere.
http://geophile.net/Lessons/atmosphere/images/circulationcells_xsection.fw.png

The two Hadley cells encircle the globe latitudinally and act to transport energy from the equator to about 30°N and S in the upper troposphere. The mechanisms that cause the circulation are as follows:

- The NE and SE Trade Winds bring warm, moist air to meet near the equator to form the ITCZ.
- The converging air rises to create cumulus and cumulonimbus clouds which causes heavy precipitation. This releases latent heat, driving strong rising up draughts.
- The air rises to the tropopause some 10–15 kilometres above sea level, where the air is no longer buoyant.
- Unable to continue rising and with the formation of High pressure aloft this air now moves poleward.
- As air moves poleward it both cools and gains a strong eastward component as it moves away from the equator due to the Coriolis effect. The resulting winds form the subtropical jet streams.

- At about 30° latitude on either side of the equator, the jet streams become so much faster than the surface wind speed that baroclinic instability prevents the Hadley circulation from extending further poleward. This coincides with the beginning of the Ferrel cells.

- At this latitude, the now cool, dry, high altitude air begins to sink. As it sinks, it warms adiabatically, decreasing its relative humidity.

- Near the surface, a frictional return flow completes the loop, absorbing moisture along the way. The Coriolis effect gives this flow a westward component, creating the trade winds.

- Where the NE and SE trade winds meet is a zone of convergence known as the Intertropical Convergence Zone (ITCZ); an area often referred to as being the doldrums.

6.2.2 The weather in the ICTZ

Unlike the polar front in temperate latitudes, where two distinctly different air masses meet, the air masses that converge at the ITCZ are very similar; so much so that the ITCZ is not considered to be a true front but simply a line of air convergence. As a consequence, the convergence zone is likely to disperse in one area and be replaced with new development in another area.

The weather in the ITCZ is summarised below:

- The air, which is very moist and heated by the Sun, tends to expand and rise, maintaining the low pressure of the area.

- There are periods of variable light or calm winds alternating with thunderstorms and squalls.

- Conditions will be worst when the Trade winds are at their strongest where they reach their maximum strength in the spring in each hemisphere.

- The region is also referred to as the doldrums since during calm periods when the winds disappear altogether, sailing ships would be becalmed for periods of days or even weeks.

The ITCZ migrates seasonally as the declination of the Sun changes. Greatest migration tends to be over large land masses in the northern hemisphere where land area of continents is greater and the effects of surface heating are much greater than over the oceans.

Variation in the location of the ITCZ significantly affects rainfall in many equatorial nations, resulting in the wet and dry seasons of the tropics rather than the cold and warm seasons of higher latitudes.

Longer term changes in the ITCZ can result in severe droughts or flooding in nearby areas.

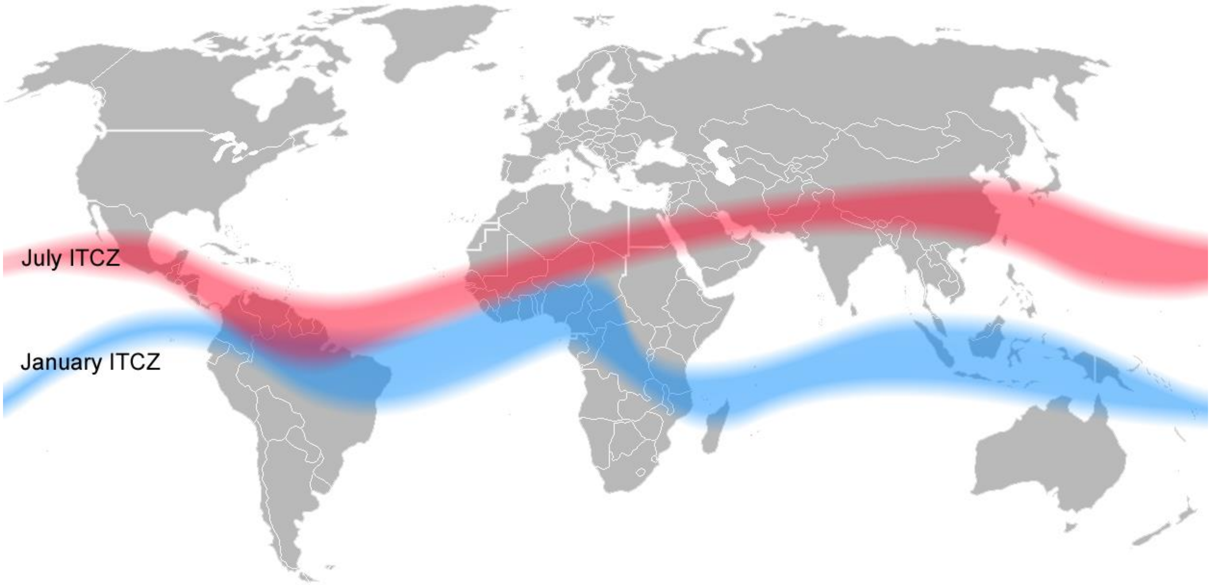

Fig. 6.4 – The ITCZ moves further away from the equator during the Northern summer than the Southern summer due to the north-heavy arrangement of the continents.
https://en.wikipedia.org/wiki/Intertropical_Convergence_Zone#/media/File:ITCZ_january-july.png

6.2.3 The weather in the trade wind belts

The trade winds are prominent over all the major oceans except in the Arabian Sea, Bay of Bengal and China Seas where the Asian monsoons predominate.

The typical weather in the trade wind belts is summarised below:

- Winds tend to blow consistently, direction is NE in the northern hemisphere and SE in the southern hemisphere.
- The average wind strength is force 3-4.
- Maximum wind strength is reached at the end of winter and early spring in each hemisphere with the SE trade winds being considerably stronger with the highest average wind speeds of force 5 being found in the southern Indian Ocean.
- Winds tend to weaken as they approach the ITCZ.
- On the western sides of the oceanic highs the winds tend to turn poleward, becoming SE in the northern hemisphere and NE in the southern hemisphere.
- Weather is generally fair with cloudless sky, occasional small cumulus.
- Visibility may be impaired on the eastern side of oceans due to fog and mist over cold currents or by dust carried offshore by the wind.
- Cloud amounts increase towards the ITCZ and on the western sides of oceans in the summer.

6.2.4 The Polar cell

Refer to figure 6.3.

The Polar cell in each hemisphere is a simple system driven by strong convection. Though cool and dry relative to equatorial air, the air masses at around 60° are still sufficiently warm and moist to undergo convection and drive a thermal loop.

The mechanisms that cause the polar cell circulation are as follows:

- At 60°N/S the air converges on the polar front and rises to the tropopause (about 8 km) and moves poleward.
- As it moves poleward, the upper level air mass deviates toward the east by Coriolis.
- When the air reaches the polar areas, it has cooled and is considerably denser than the underlying air.
- It descends, creating a cold, dry high-pressure area.
- At the polar surface the mass of air is driven by surface PGF towards 60°N/S to replace the air that rises from there and the polar circulation cell is complete.

The polar easterlies meeting the prevailing westerlies form the polar front, a significant frontal zone where two very contrasting air masses meet. This front is responsible for the formation of wave depressions that form in the western ocean areas and travel eastward to create very changeable weather conditions.

It is not possible to generalise about the typical weather experienced on the polar front because it is so changeable. This was the topic of Outcome 1 where the formation of depressions and other features of synoptic charts was considered.

6.2.5 The prevailing westerlies

On the polar sides of the oceanic highs the winds are predominantly from the west. Unlike the trade wind belts the zones are very mobile and lie generally N of 40°N and S of 40°S.

The continual formation of depressions on the western sides of oceans, their eastward movement along the polar front and decay causes wind, temperature and weather to vary greatly with gales being common.

The *Roaring Forties* are strong westerly winds found in the southern hemisphere, generally between the latitudes of 40 and 50°S. The strong west-to-east air currents are caused by the combination of air being displaced from the Equator towards the South Pole, the Earth's rotation, and the scarcity of land masses to serve as windbreaks; hence the name.

Notably fog is very common on the western sides of oceans in the summer.

6.2.6 The subpolar polar easterlies

Pressure is consistently high throughout the year at the poles and the prevailing easterly winds blow from the polar regions to the subpolar low-pressure systems.

Located north of 60 degrees latitude in each hemisphere, subpolar zones are characterised by low rainfall and cold temperatures. Sea ice forms in these areas during winter months, creating high salinity water beneath the ice as salts do not get incorporated into ice.

In summer months, ice melts creating a low salinity layer at the surface.

As the polar air moves southward towards the Polar front weather becomes mostly cloudy as the cold air with moisture is heated from below as it moves over the ocean.

Katabatic winds are an important feature of the local weather in many places in Arctic and Antarctic regions, being particularly frequent and severe where ice- or snow-covered land lies close to a straight coast.

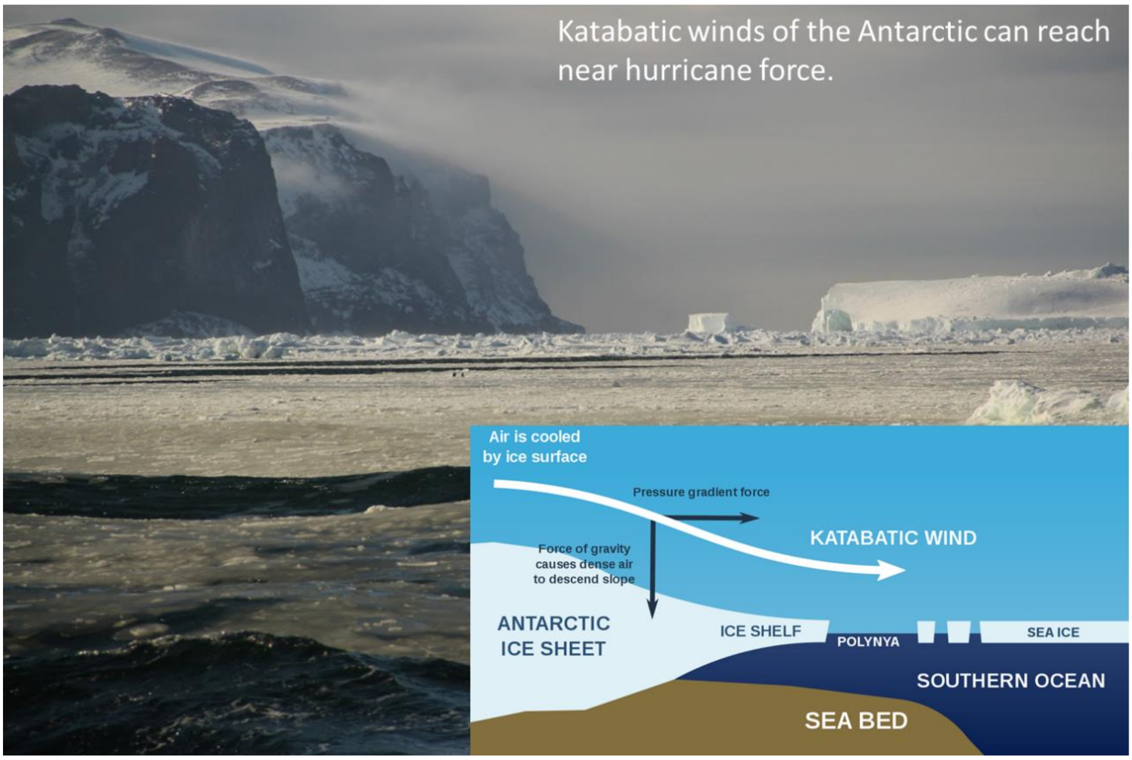

Fig. 6.5 - Katabatic winds in the Antarctic.
http://3.bp.blogspot.com/-U_YpHo_5xhl/UclwEl9CMFI/AAAAAAAADxE/HB4A90cl3hE/s1600/IMG_6581.JPG

6.2.7 The Polar front

Formed by the meeting of two very different air masses winds can be highly variable, blowing at times with great speed and intensity.

When the cold air flowing out of the polar regions and the warmer air moving in the path of the westerlies meet, they do not mix well. The denser, heavier cold air pushes the warm air upward, forcing it to rise rapidly. The line along which these two wind systems meet is the polar front.

The weather that results from the meeting of the cold polar air and the warmer air from the subtropics can be very changeable and at times stormy. Weather is very much influenced by the development of waves to the west that form into depressions that drive eastward and the intervening ridges of high pressure.

The front migrates north and south frequently as families of depressions form.

6.2.8 Polar regions

Located near the polar regions of each hemisphere, the polar zone is characterised by low rainfall and light winds. Pressure is high all the year round but high pressure is more prominent in winter. Most of this zone is covered by ice all year and water temperatures below ice cover are near freezing.

6.3 The Ferrel cells and the Horse Latitudes

6.3.1 The Ferrel cell

Part of the air rising at 60° latitude diverges at high altitude toward the poles and becomes part of the polar cell. The rest moves toward the equator where it collides at 30° latitude with the high-level air of the Hadley cell. There it subsides and strengthens the high-pressure ridges beneath.

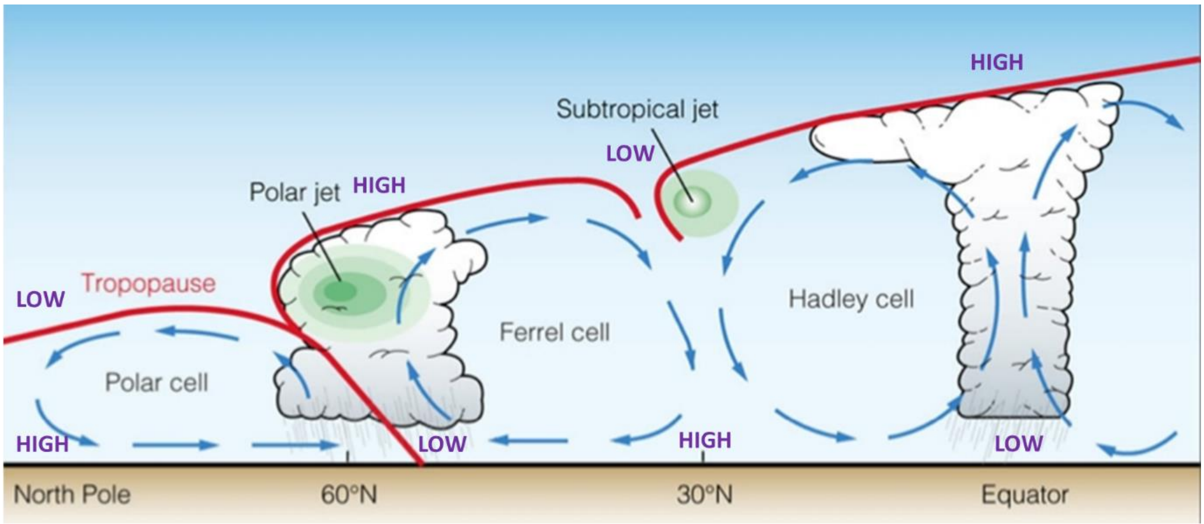

Fig. 6.6 – The Ferrel cell is driven by the Polar and Hadley cells and is not strictly a convective cell as it is driven by convergence and divergence.

A large part of the energy that drives the Ferrel cell is provided by the polar and Hadley cells circulating on either side.

The Ferrel cell is therefore a secondary circulation feature the existence of which depends upon the Hadley and Polar cells on either side of it.

6.3.2 The subtropical anticyclones and the Horse latitudes

The Horse latitudes are in the subtropical highs in the subtropical latitudes between 30-35°N and S where the air subsides which suppresses the formation of cloud and rain. Winds here are calm to light and variable.

The term horse latitudes originate from when the Spanish transported horses by ship to their colonies in the West Indies and Americas. Ships often became becalmed in mid-ocean in this latitude, thus severely prolonging the voyage; the resulting water shortages made it impossible for the crew to keep the horses alive and they would throw the dead or dying animals overboard.

The typical weather in the region is summarised below:

- Subsiding air and consistently high pressure.
- Clear skies.
- Low rainfall, predominantly dry especially over the eastern portions of the oceans where the high-pressure cells are more prominent.
- Winds are light and variable.

The consistently warm, dry and sunny conditions of the Horse latitudes are the main cause of the existence of the major deserts such as the Sahara Desert in Africa, the Arabian and Syrian deserts in the Middle East, the Mojave and Sonoran deserts in the southwestern United States and Northern Mexico, all being in the Northern hemisphere; and the Atacama Desert, the Kalahari Desert and the Australian Desert in the Southern hemisphere.

Fig. 6.7 – Principal desert regions.
https://permaculturenews.org/2013/09/04/the-atacama-desert-chile-the-driest-desert-on-earth-five-reasons-why/

6.4 Principal frontal zones

The principal frontal zones are shown for both January and July for the Atlantic Ocean. These frontal positions are much generalised; the greatest range in positions and movement occur in temperate latitudes.

Similar seasonal variations occur in the Pacific and Indian Oceans too.

	February	**August**
Atlantic doldrums	0° - 2°N	5°N - 10°N
NE trade	2°N - 25°N	10°N - 30°N
E trade	0° - 30°S	5°N - 25°S
Pacific doldrums	4°N - 8°N	8°N - 12°N
NE trade	8°N - 25°N	12°N - 30°N
SE trade	4°N - 30°S	8°N - 25°S
Indian SE trade	15°S - 30°S	0° - 25°S

Table 6.1 - Annual migration north and south of the predominant wind regions.

Figure 6.8 shows the principal frontal zones of the Atlantic Ocean.

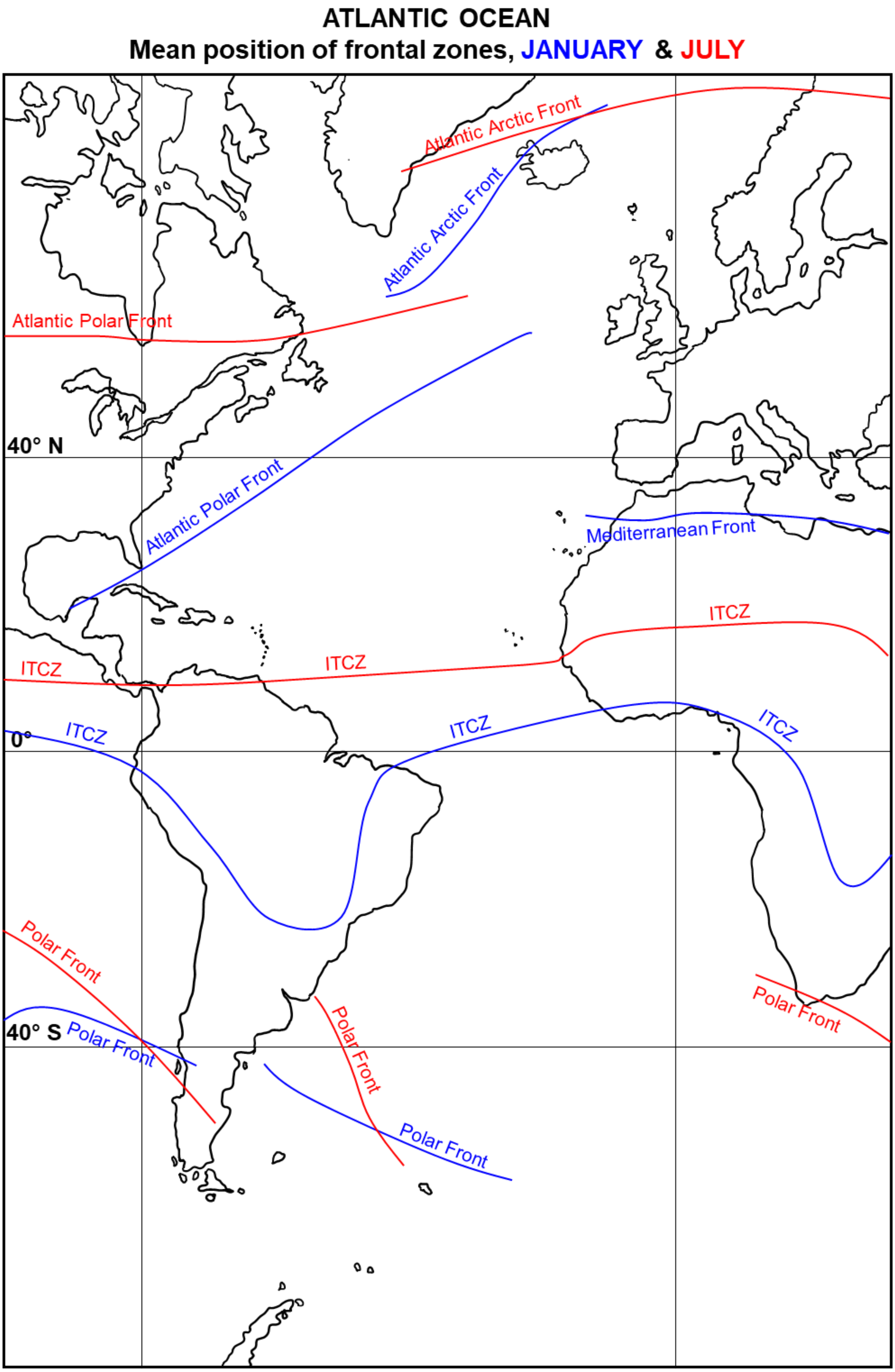

Fig. 6.8 – Principal frontal zones of the Atlantic Ocean.