Coriolis and Transport

SEA2004F

Week 4 Lecture 4

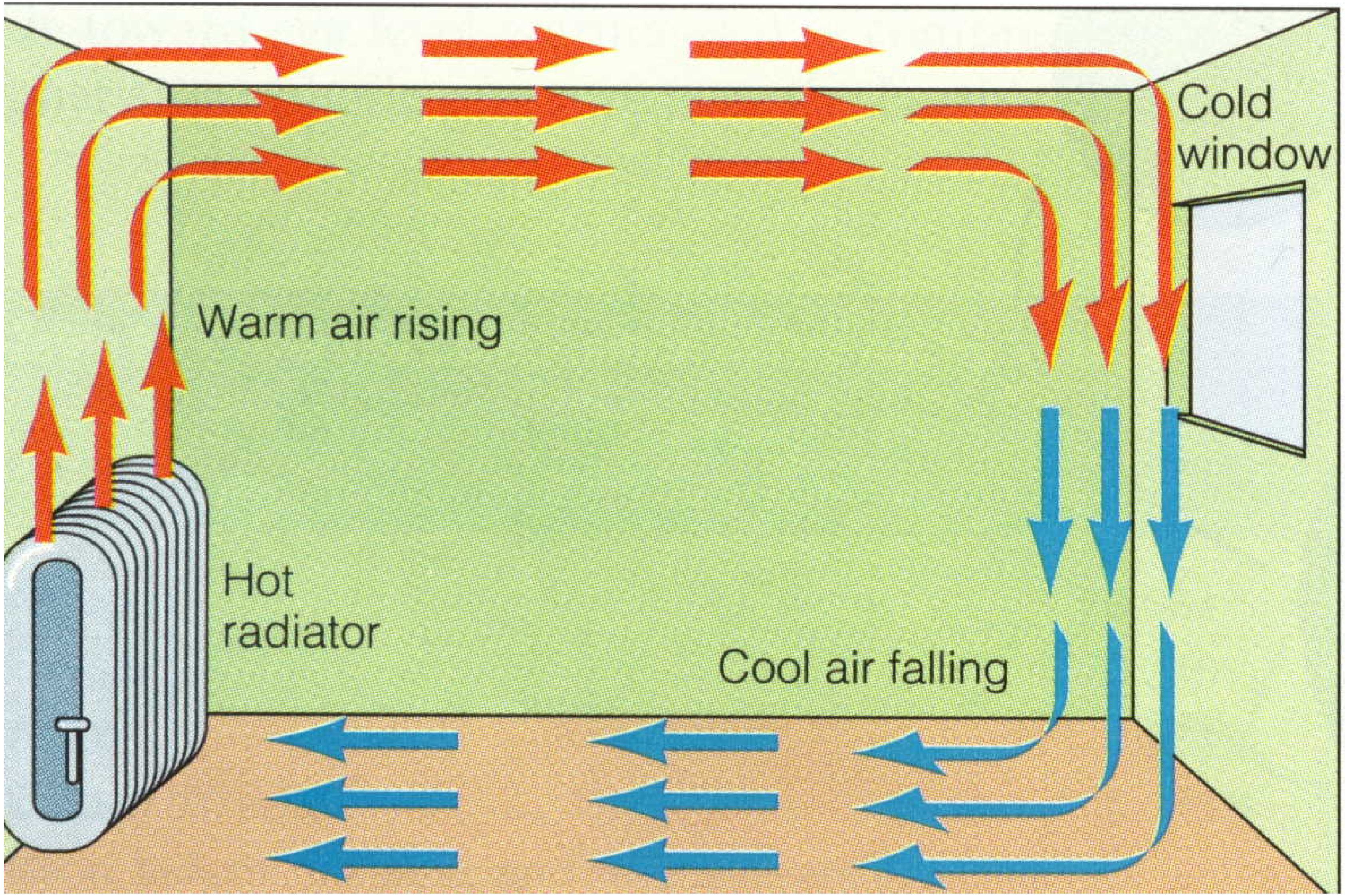
Katye Altieri

Katye.altieri@uct.ac.za, R.W. James, Level 1, Room 113

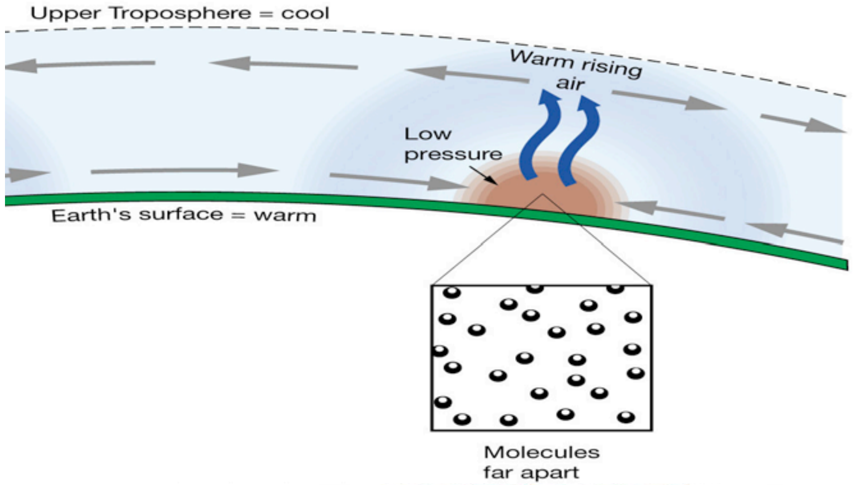
Coriolis and Atmospheric Forces

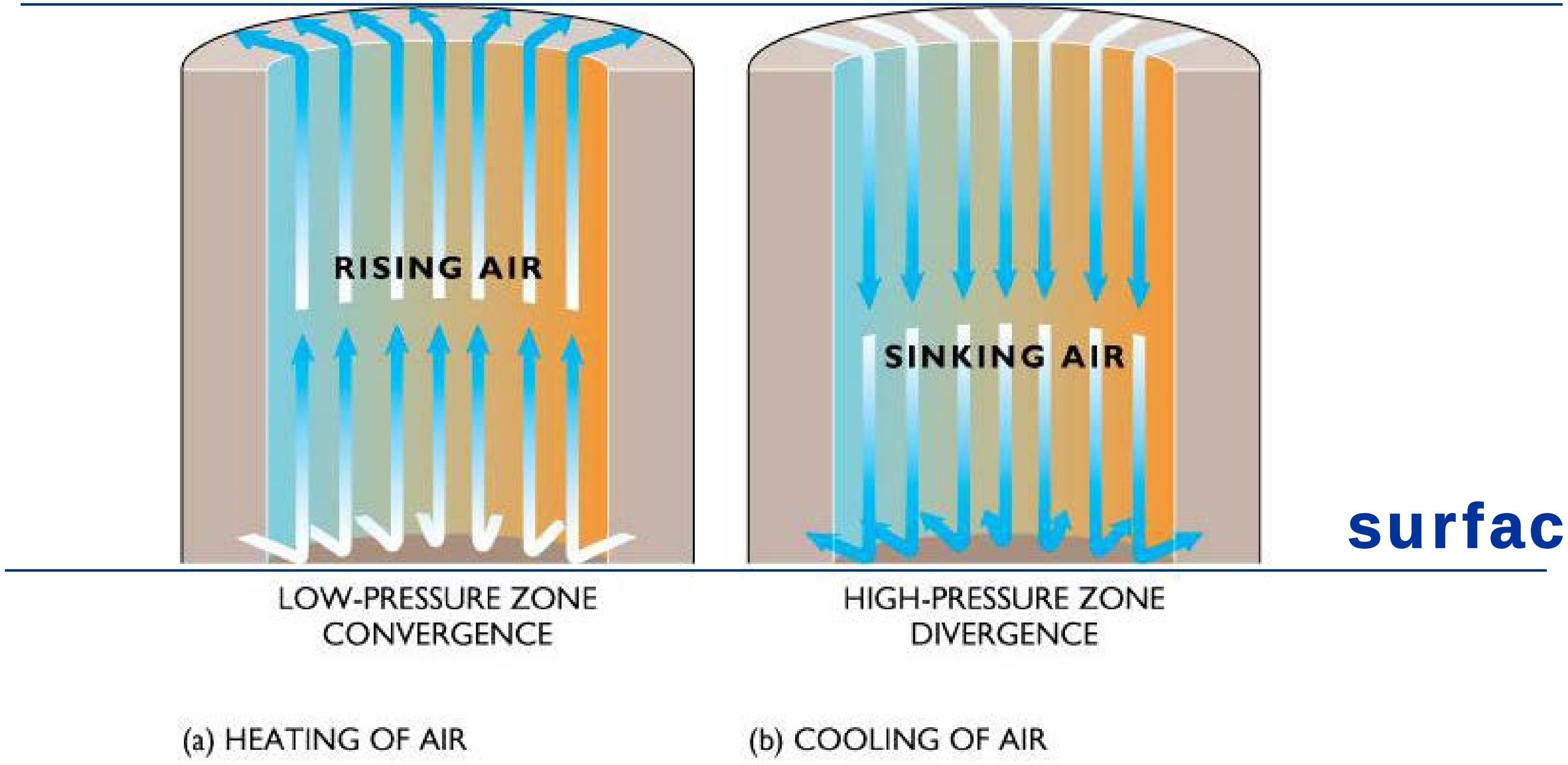
Recap from Lecture 3

- At the large scale (1000–10,000 km), air flows around low and high pressure areas, creating wave-like patterns.
- Troughs and ridges in the pressure field are analogous to valleys and mountains in terrain.
- Air converges into low pressure areas and diverges away from high pressure areas – with corresponding vertical motion for mass continuity.
- Vertical motion leads to adiabatic temperature change, thus the location of high and low pressures give us information about expected cloudiness and precipitation.
- Rising motion in low pressure leads to expansion, adiabatic cooling, and condensation while sinking in high pressures leads to adiabatic compression, warming, and dry conditions.



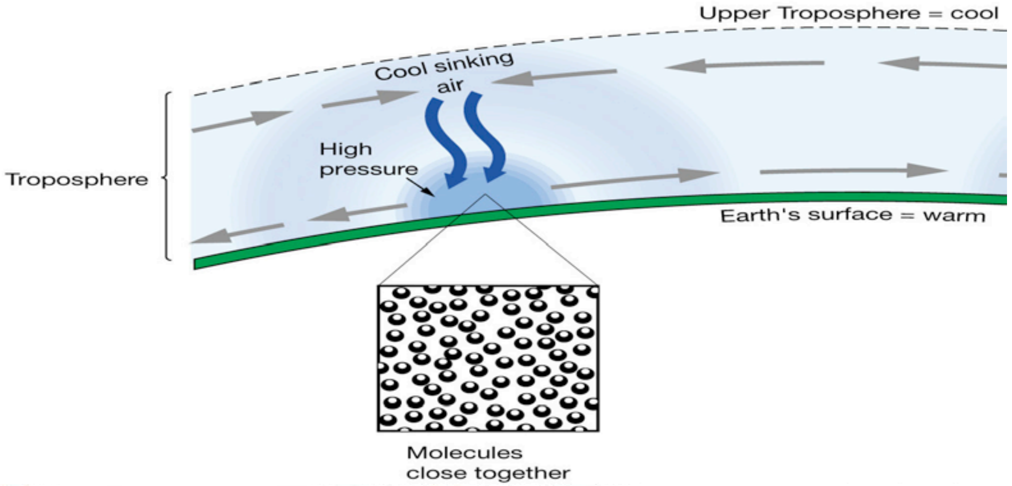
Simplified!! Warm air rises and cool air sinks; a convection current forms in a room resulting from uneven heating and cooling.

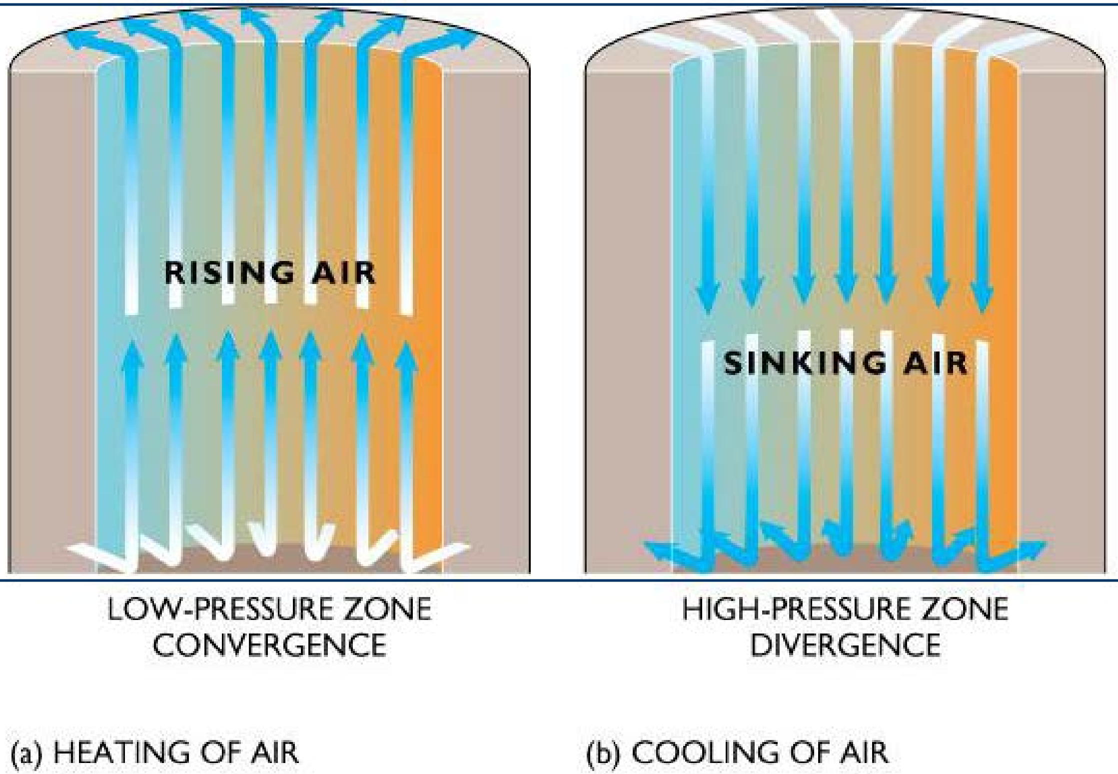




surface

Equator / Tropics **Higher Latitudes**



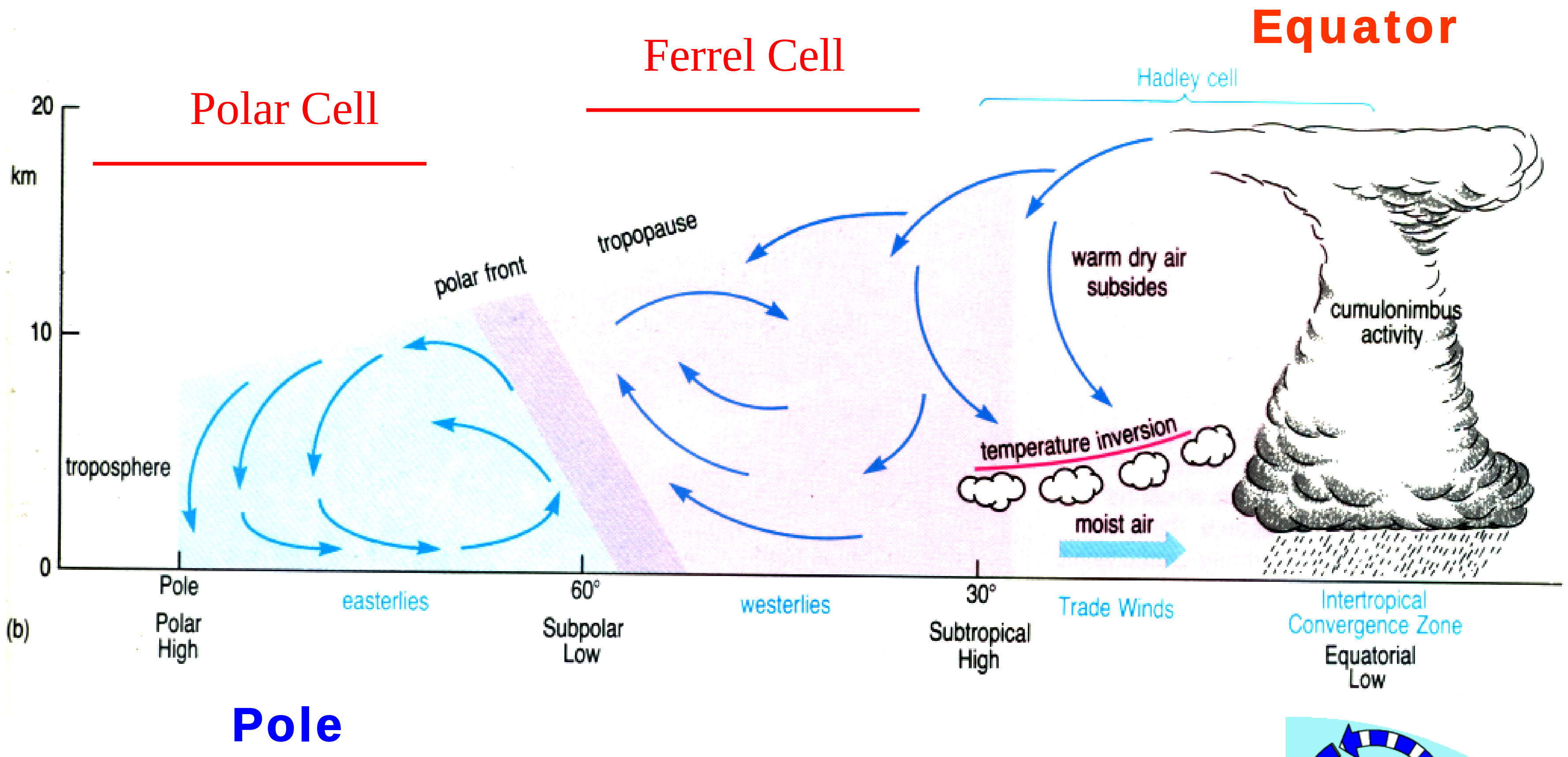


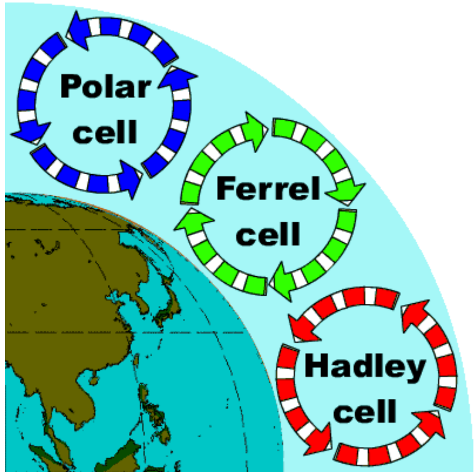
surface

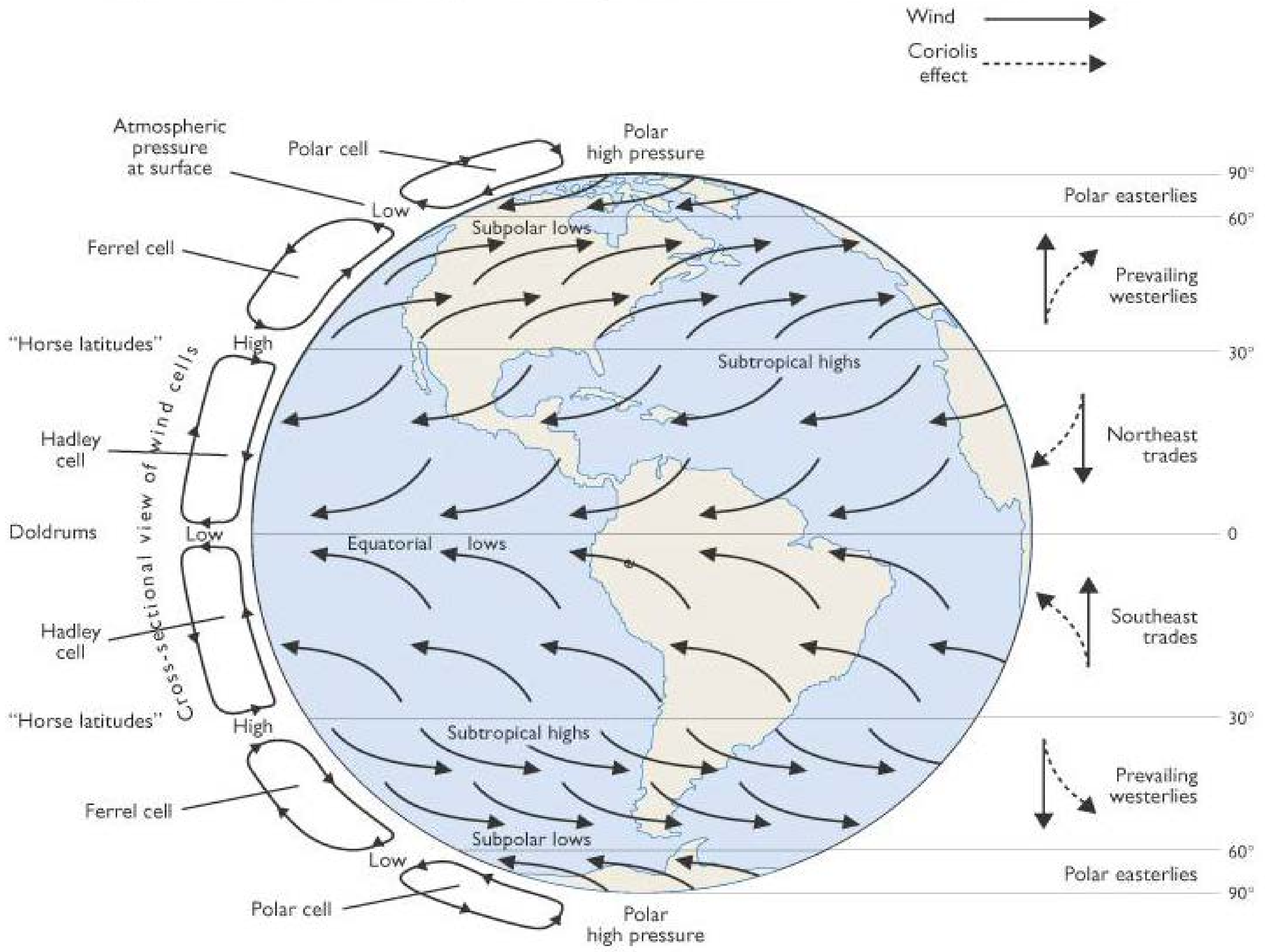
Equator / Tropics

Higher Latitudes

Vertical view of the atmosphere



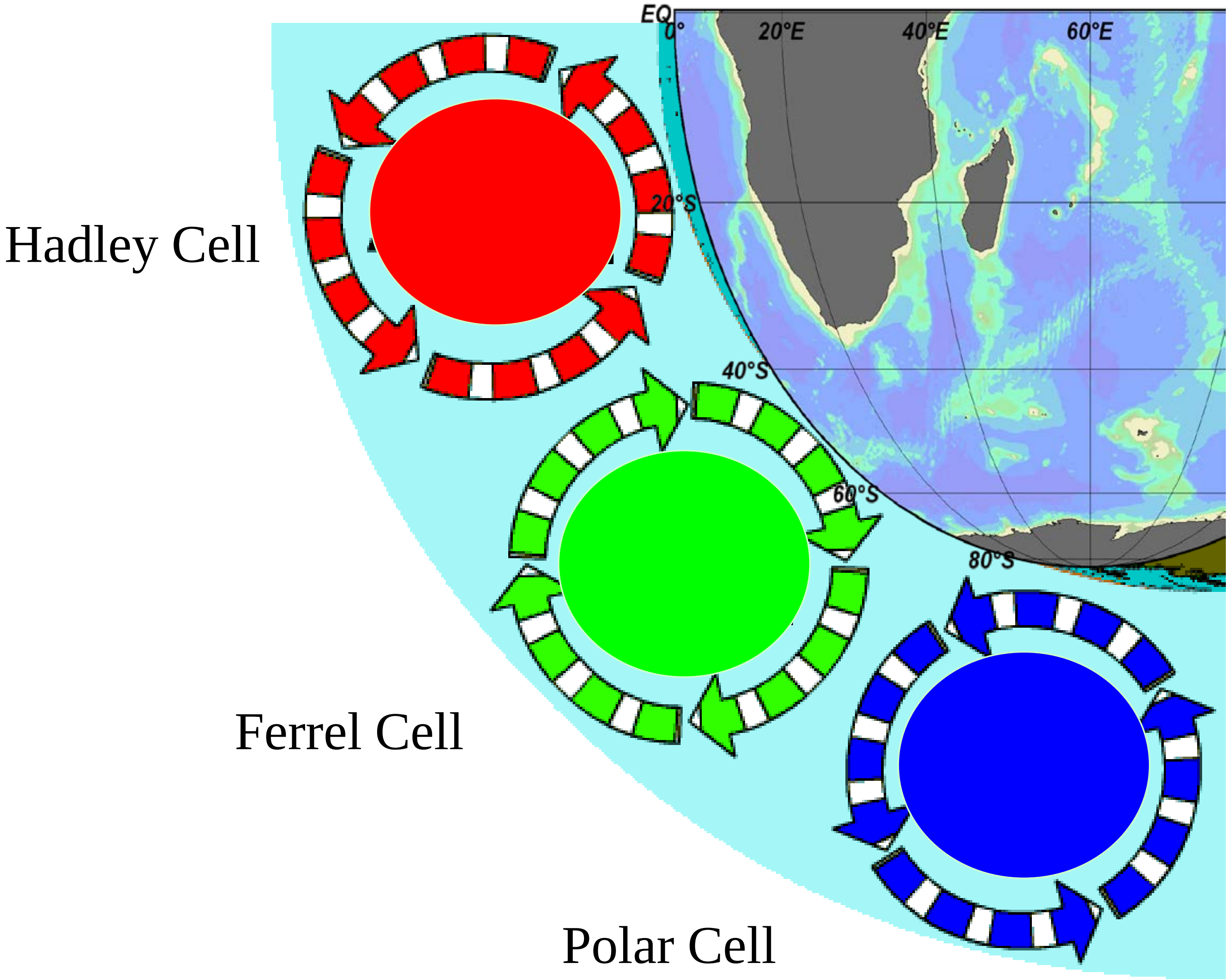




(a) GLOBAL WIND PATTERN

..so that's the role of solar heating covered… BUT…

Unequal heating of the Earth's surface and the Coriolis deflection cause a zonal wind system to develop, arranged in three circulation cells.



- For an object travelling on earth in the northern hemisphere the Coriolis force will deflect to the right of its path and to the left of its path in the southern hemisphere. At the equator the force is zero.

- There are two reasons for this phenomenon:
- (1) the Earth rotates eastward
- (2) the velocity of a point on the Earth is a function of latitude

$$F=2\omega\sin(\phi)$$

ω = rotation of earth = $7.292E^{-5}\ s^{-1}$

- The Coriolis deflection is therefore related to the motion of the object, the motion of the Earth, and the latitude.

- ....importance of coriolis force..

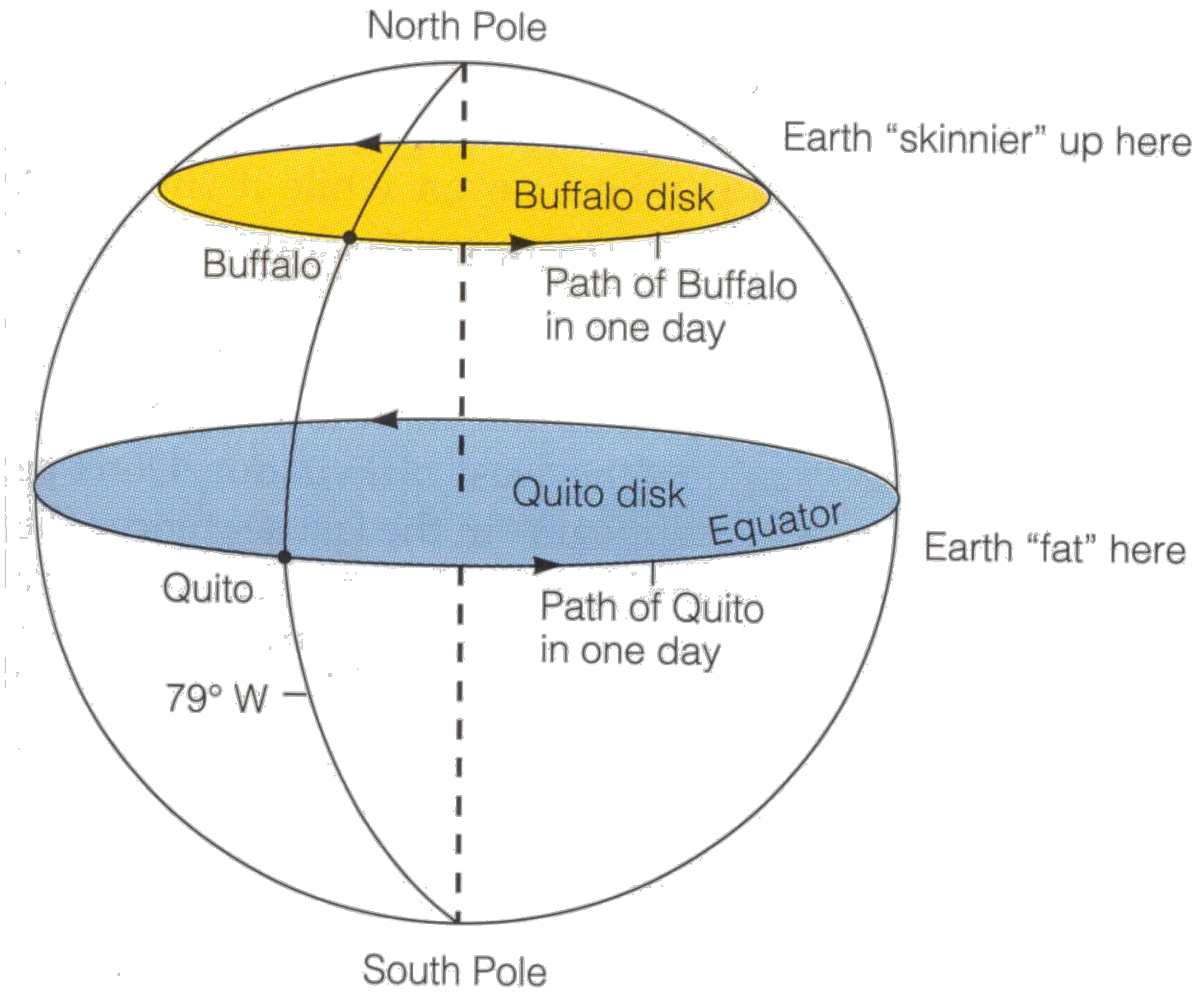
- Two important reasons:
- (1) the Earth rotates eastwards
- (2) the velocity of a point on the Earth is a function of latitude

Coriolis parameter $f = 2\omega\sin(\phi)$

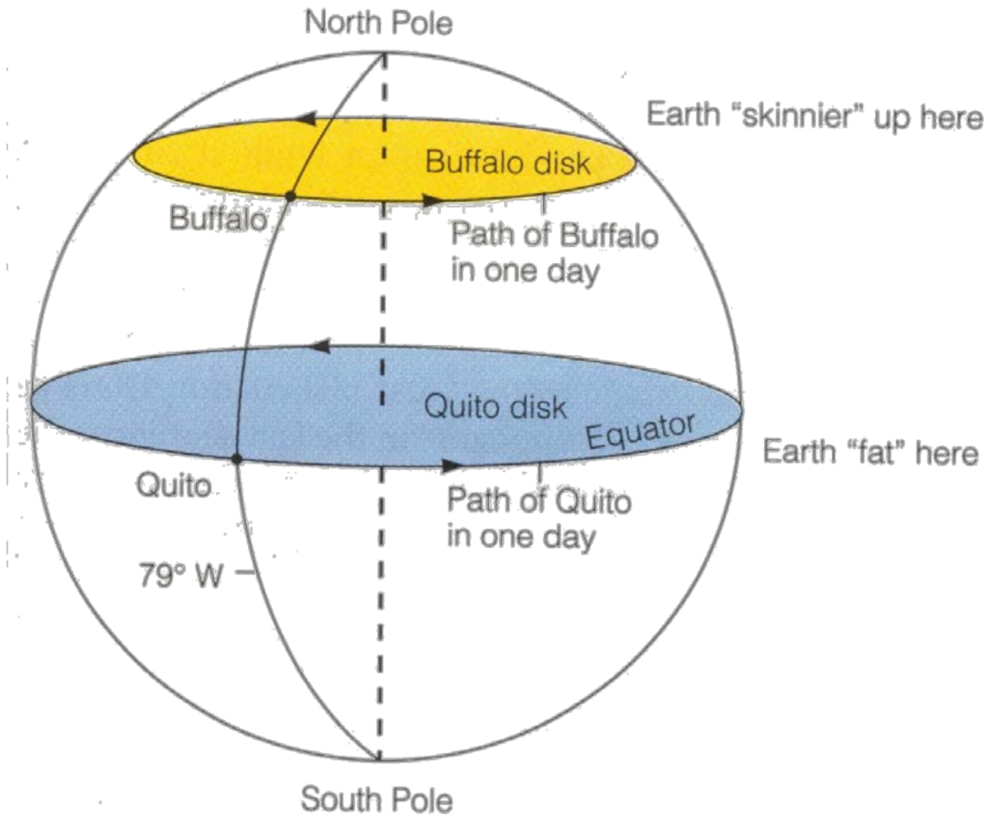
ω = rotation of earth = $7.292E^{-5}\ s^{-1}$

- The Coriolis deflection is therefore related to the latitude.

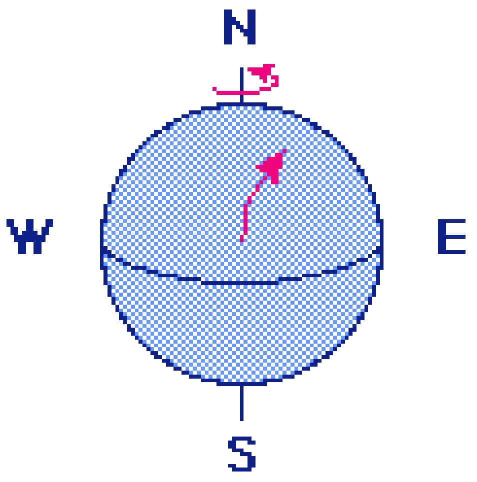
- Circumference of the Earth at the **Equator** = **40,000 kilometers**
- Time to complete one Rotation = **24 hours**
- Speed of Rotation = Distance/Time = 40,000 km / 24 hr = **1670 km/hr**



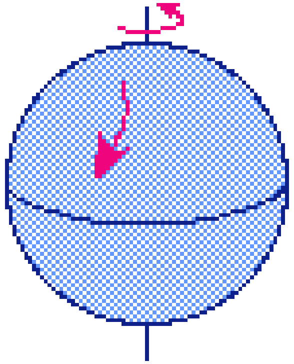
- Circumference of the Earth at the **Equator** = **40,000 kilometers**
- Time to complete one Rotation = **24 hours**
- Speed of Rotation = Distance/Time = 40,000 km / 24 hr = **1670 km/hr**



Circumference of the Earth **at 40°N** = **30,600 kilometers**
Time to complete one Rotation = **24 hours**
Speed of Rotation at 40° North = Distance/Time = 30,600 km / 24 hr = **1280 km/hr**

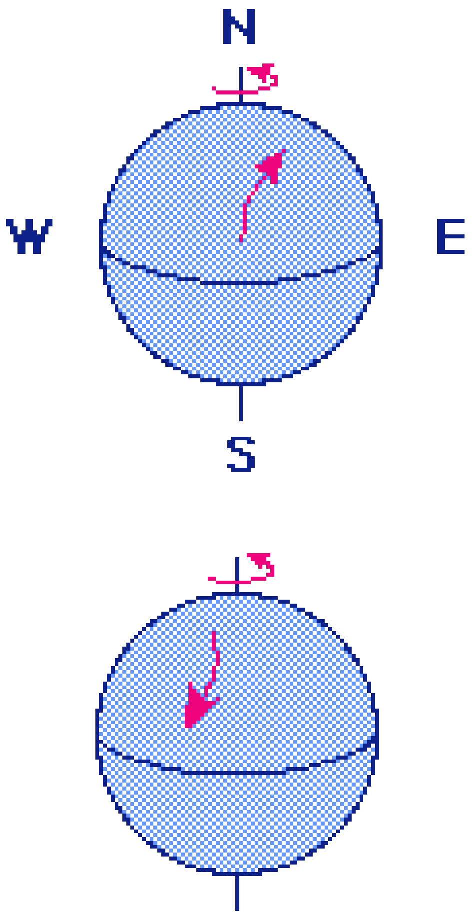


i.e. if a cannon was fired northwards from the Equator, the projectile would land to the east of its due north path because the cannon is moving eastward faster at the Equator than was its target farther north.

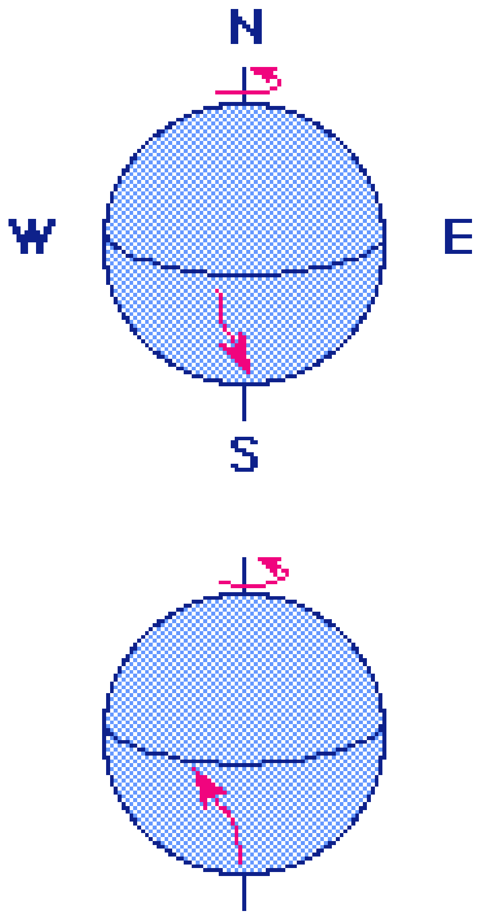


Deflection to the right in the Northern Hemisphere

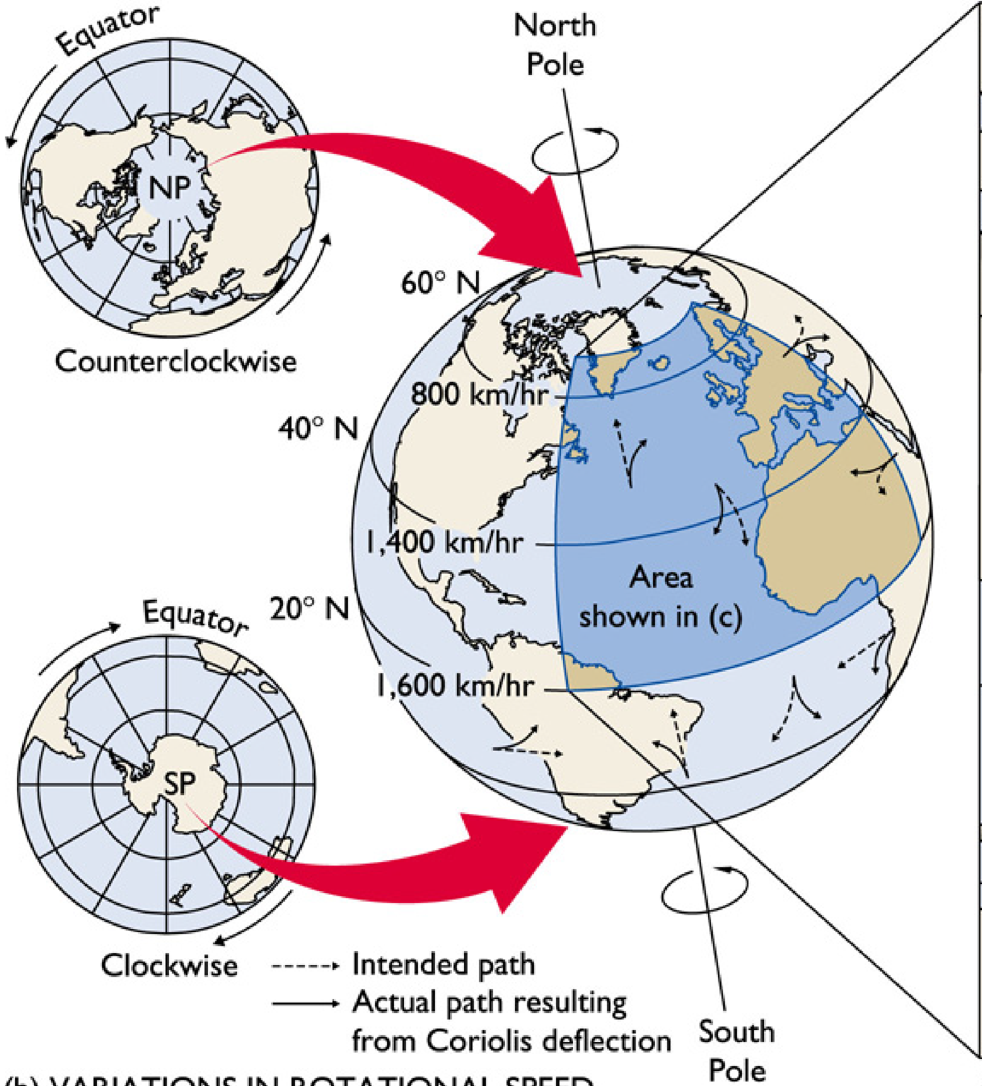
Similarly, if the weapon were fired from the equator southwards to the South Pole, the projectile would again land to the right of its true path. In this case, the target area would have moved eastward before the shell reached it because of its greater eastward velocity.



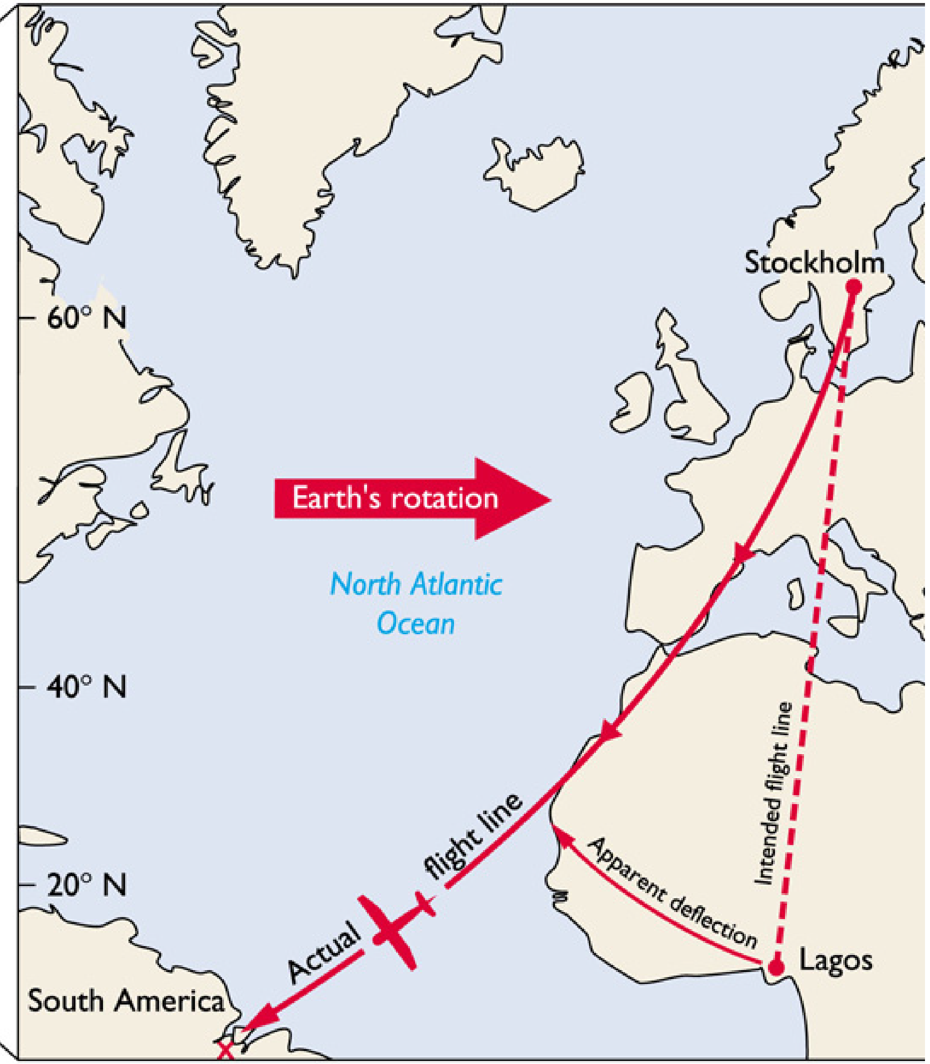
Deflection to the right in the Northern Hemisphere



Deflection to the left in the Southern Hemisphere



(b) VARIATIONS IN ROTATIONAL SPEED



(c) CONSEQUENCES OF CORIOLIS DEFLECTION

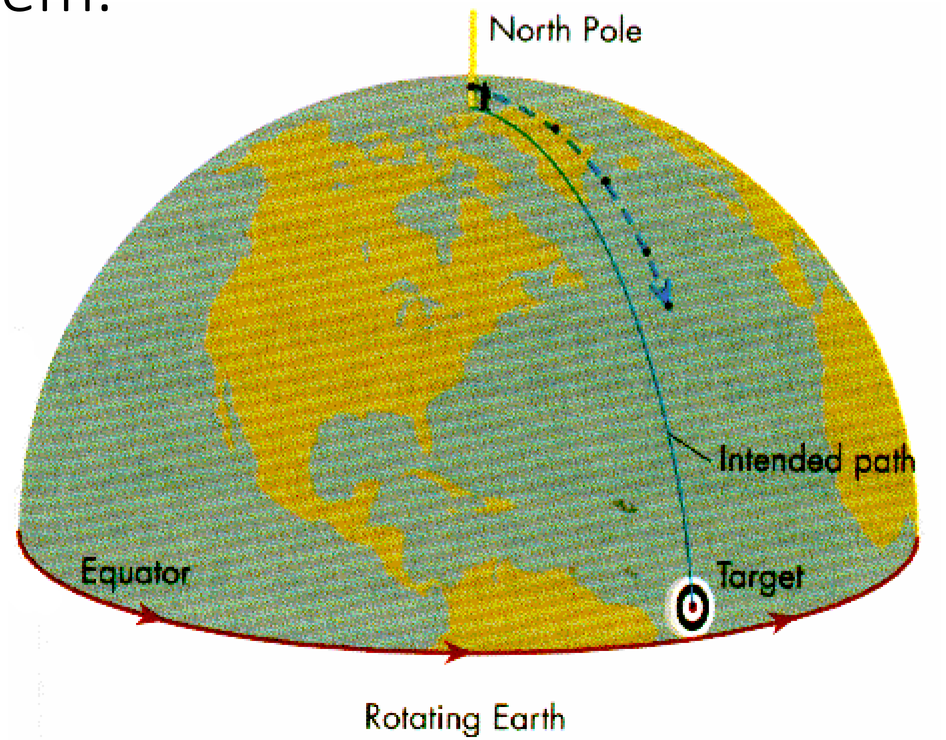
Coriolis Effect

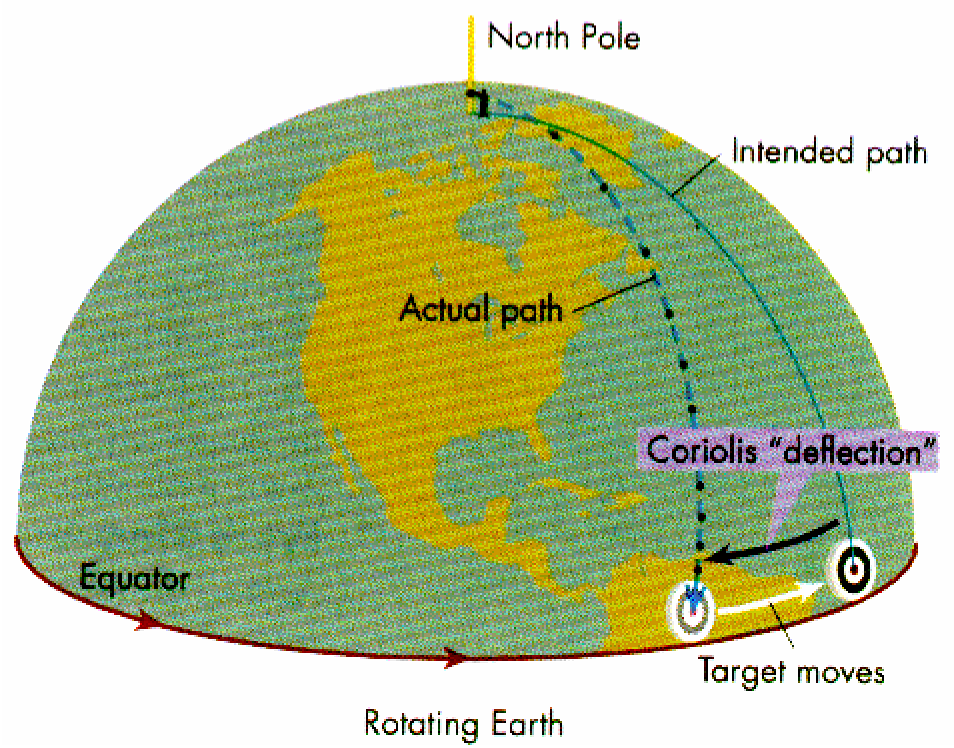
- Winds blow across the Earth from high-pressure systems to low-pressure systems. However, winds don’t travel in a straight line. The actual path of winds—and of ocean currents, which are pushed by wind—are partly a result of the Coriolis effect.
- The key to the Coriolis effect lies in the Earth’s rotation. The Earth rotates faster at the Equator than it does at the poles. This is because the Earth is wider at the Equator. A point on the Equator has farther to travel in a day.

Coriolis force deflects winds and currents to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

Coriolis Effect

An apparent deflection of the path of an object that moves within a rotating coordinate system. The object does not actually deviate from its path, but it appears to do so because of the motion of the coordinate system.





1. The Earth is rotating eastward
2. The tangential velocity of a point on Earth is a function of latitude

Coriolis Effect

- Dependent on latitude

The coriolis parameter: $f = 2\Omega \sin\theta$

where Ω is the angular velocity in radians per second; for Earth it is 7.27×10^{-5} rad s^{-1}

and where θ is latitude

$f > 0$ in the N. Hem. and $f < 0$ in the S. Hem.

What is f at the equator?

Units and Conversions

SI unit for angles → *radian* (rad)

Other units = *degree* (°)

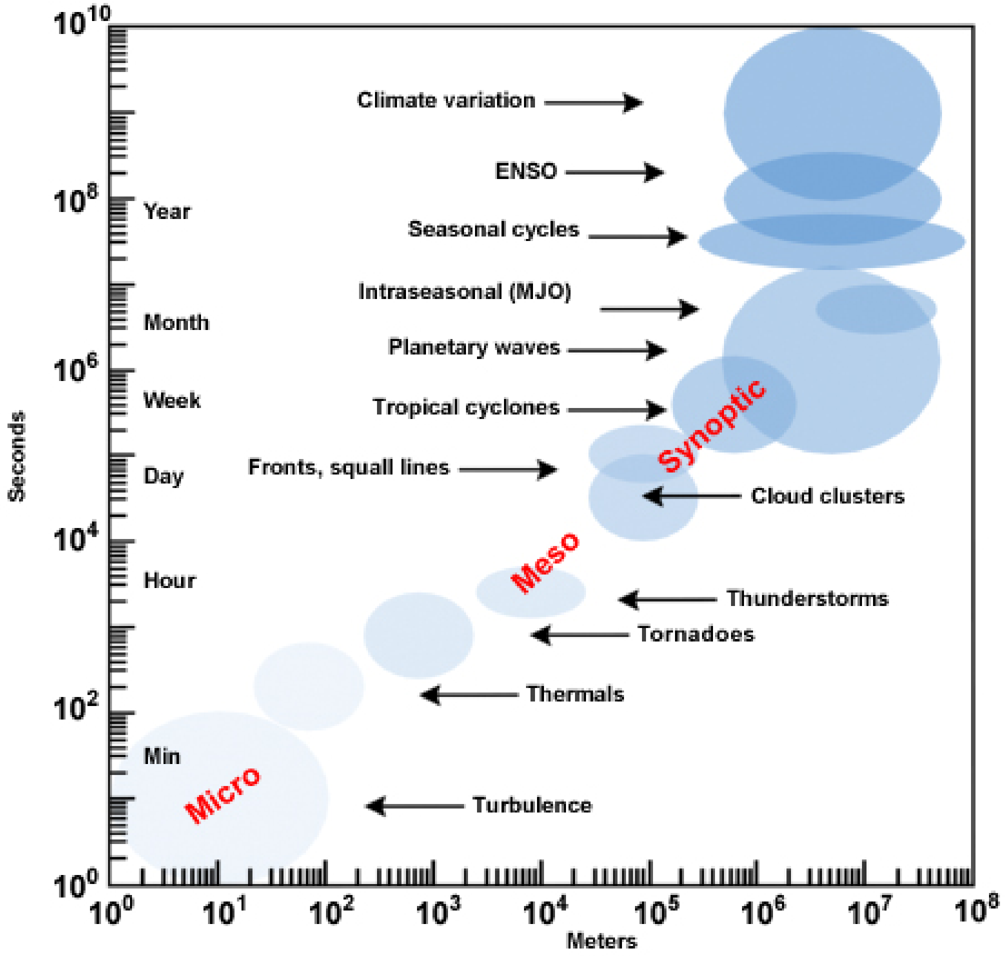
1 rad = degrees * π / 180

Latitude of Cape Town is
-33.9° = -0.592 rad = -0.1833 πrad

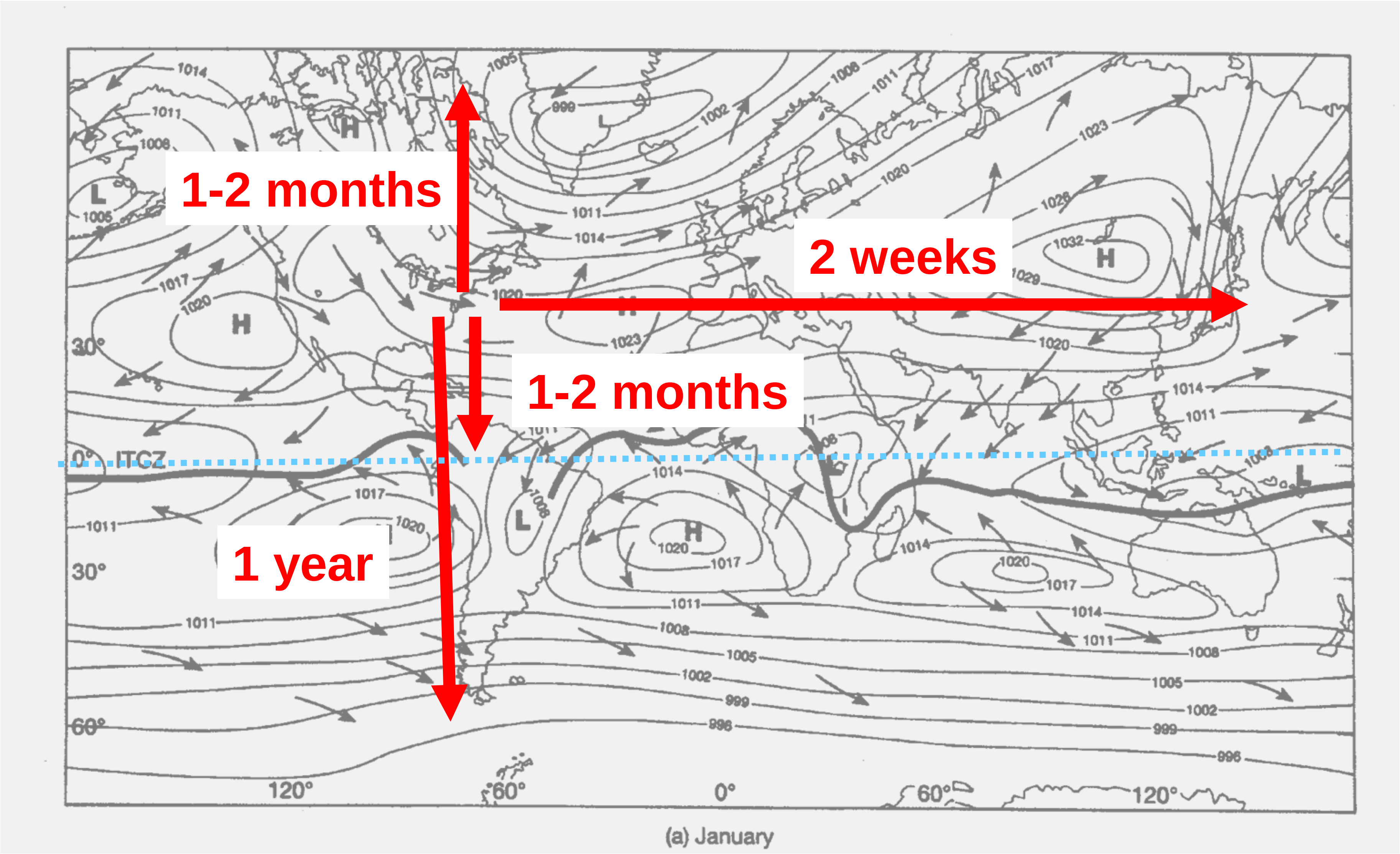
Scale Analysis

Dynamical processes in the atmosphere classified by their space and time scales

Symbol	Variable	Units
U	Horizontal velocity	m s^{-1}
W	Vertical velocity	m s^{-1}
L	Length	m
H	Height or depth	m
T=L/U	Time	s



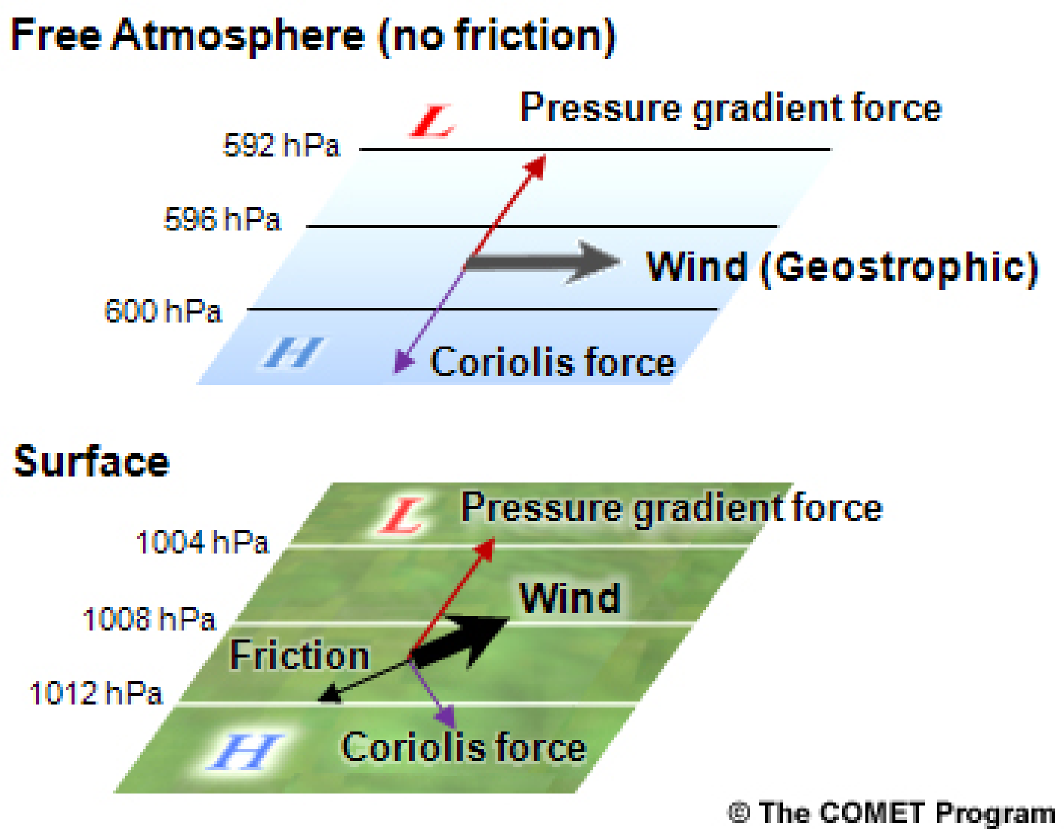
TIME SCALES FOR HORIZONTAL TRANSPORT (TROPOSPHERE)



Motion in the atmosphere and ocean

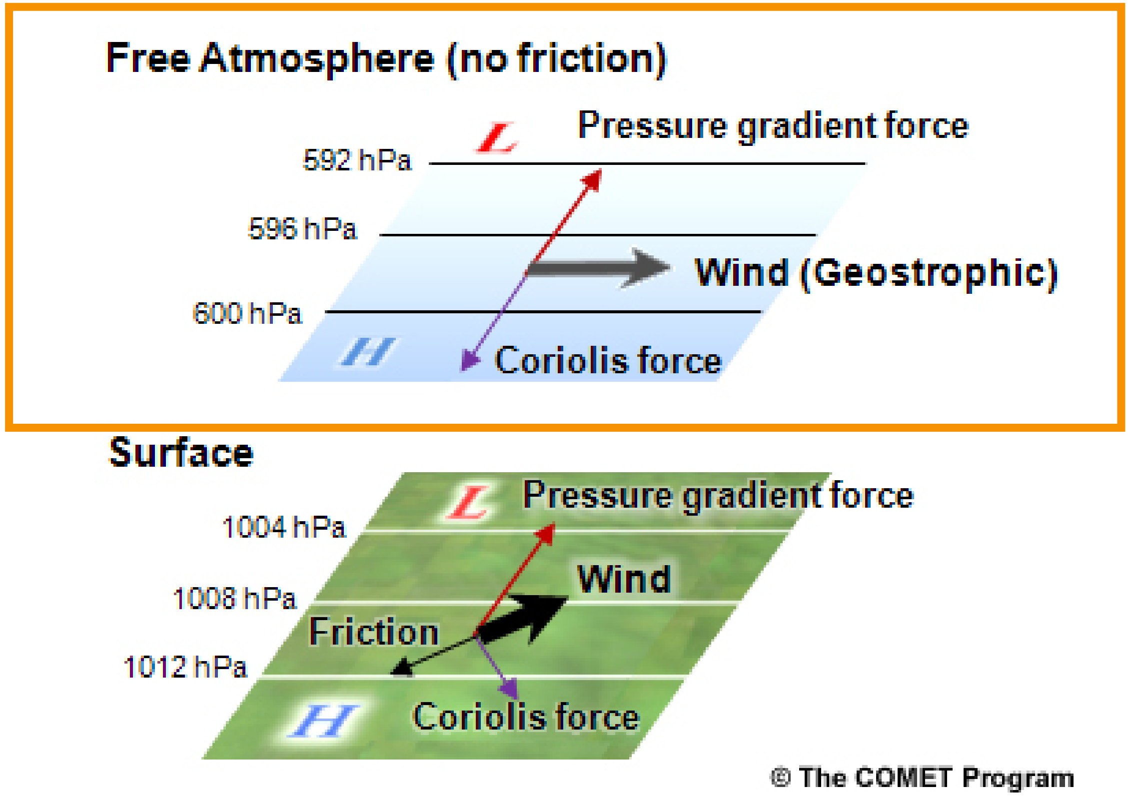
- The pressure gradient force moves fluid from high to low pressure. When rotation, friction, and gravity are added, the acceleration of motion following a fluid on a rotating planet can be written as:

Acceleration = pressure gradient + Coriolis + effective gravity + frictional forces



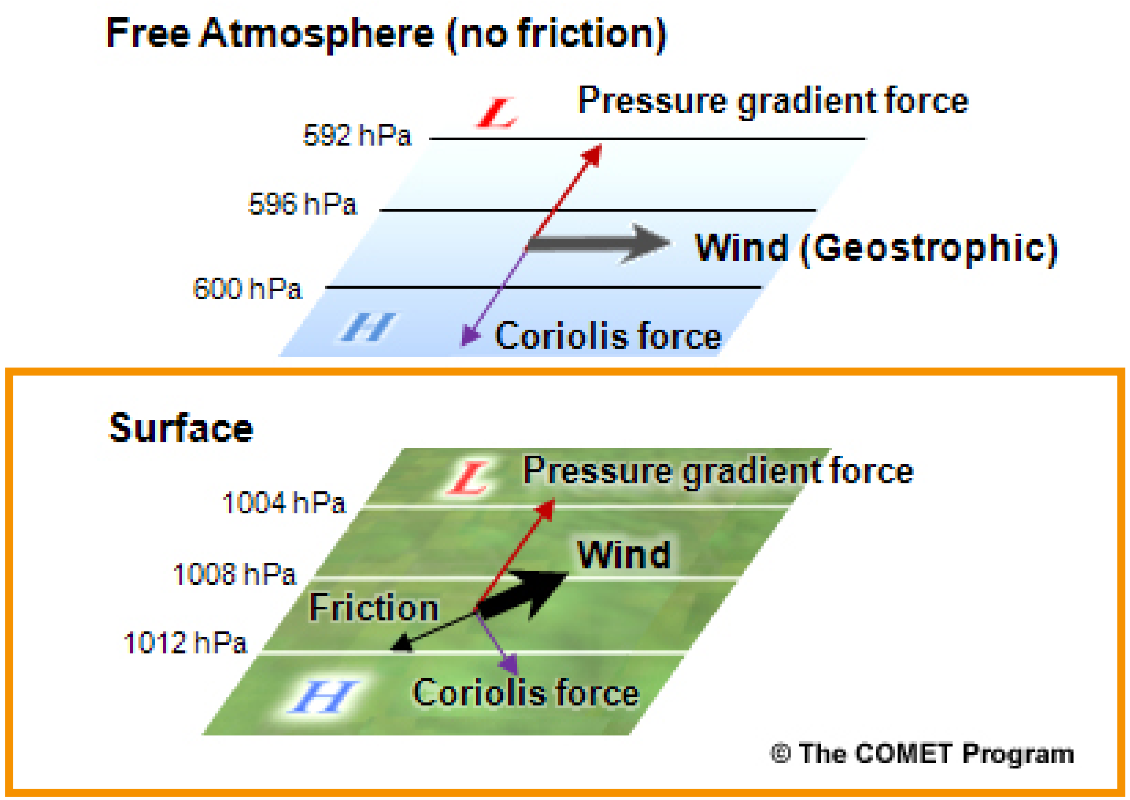
Motion in the atmosphere and ocean

- Above the friction layer, balance is between the pressure gradient and the Coriolis force
- The wind in geostrophic balance blows parallel to the isobars, which means that these winds are parallel to the other mass fields (density, temperature).
- This geostrophic approximation holds for large-scale motion away from the equator.



Motion in the atmosphere and ocean

Moving downwards to the surface, frictional forces increase and the surface winds are no longer parallel to the pressure field but angled toward lower pressure

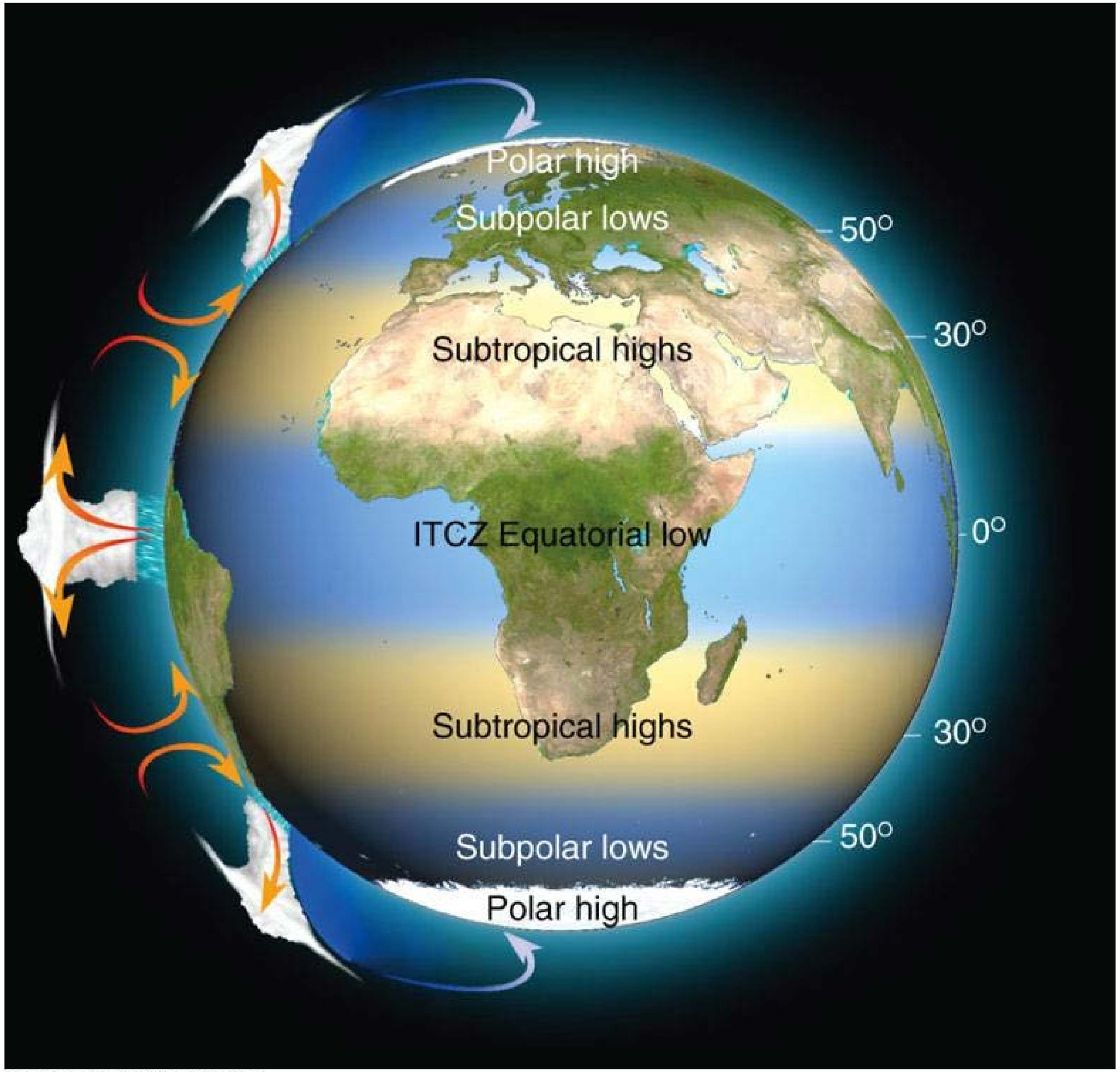


Motion in the atmosphere and ocean

- Flow that is parallel to the isobars around high and low pressure areas results from balance between pressure gradient, Coriolis, and centripetal (negative centrifugal) forces.
- In these regions near circulation centers the geostrophic wind is not a good enough balance to the observed wind because of the curved flow. The wind calculated from this three force balance is referred to as the gradient wind.

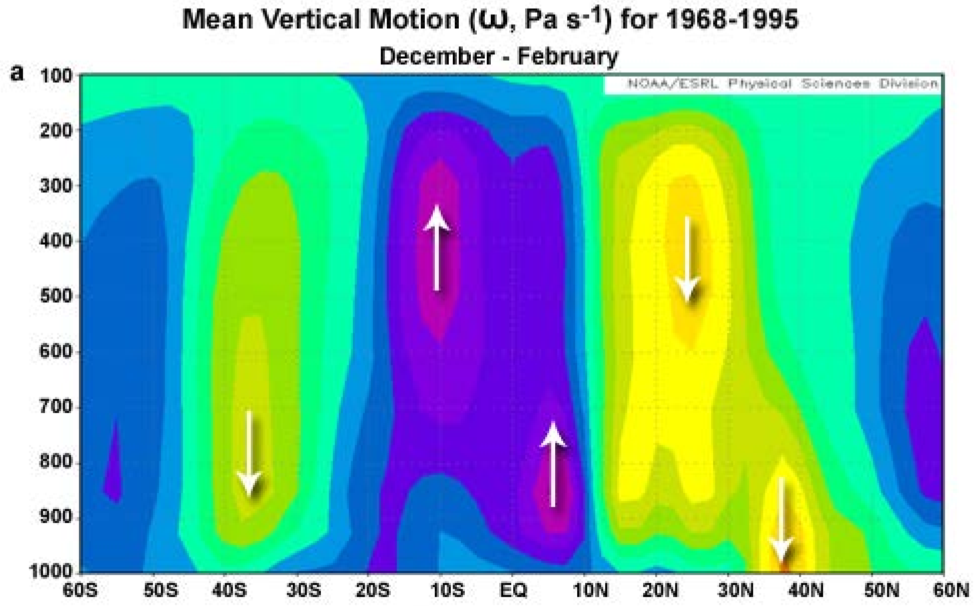
Zonal distribution of precipitation

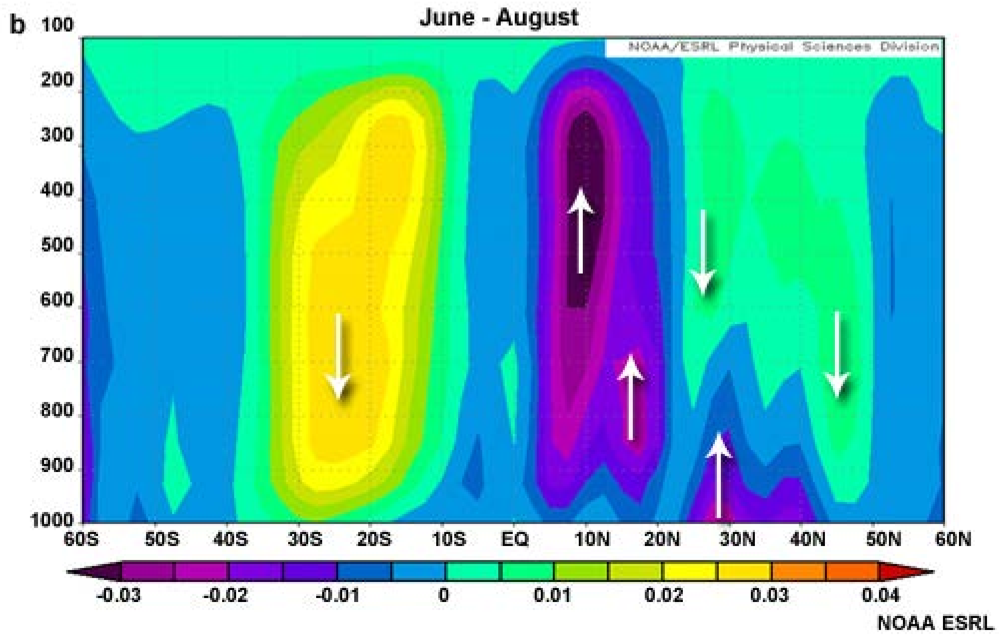
- 0 N – low pressure – cloudy
- 30 N – high pressure – sunny
- 45 – 60 N – low pressure – cloudy
- Polar latitudes – high pressure - clear



Mean meridional circulation

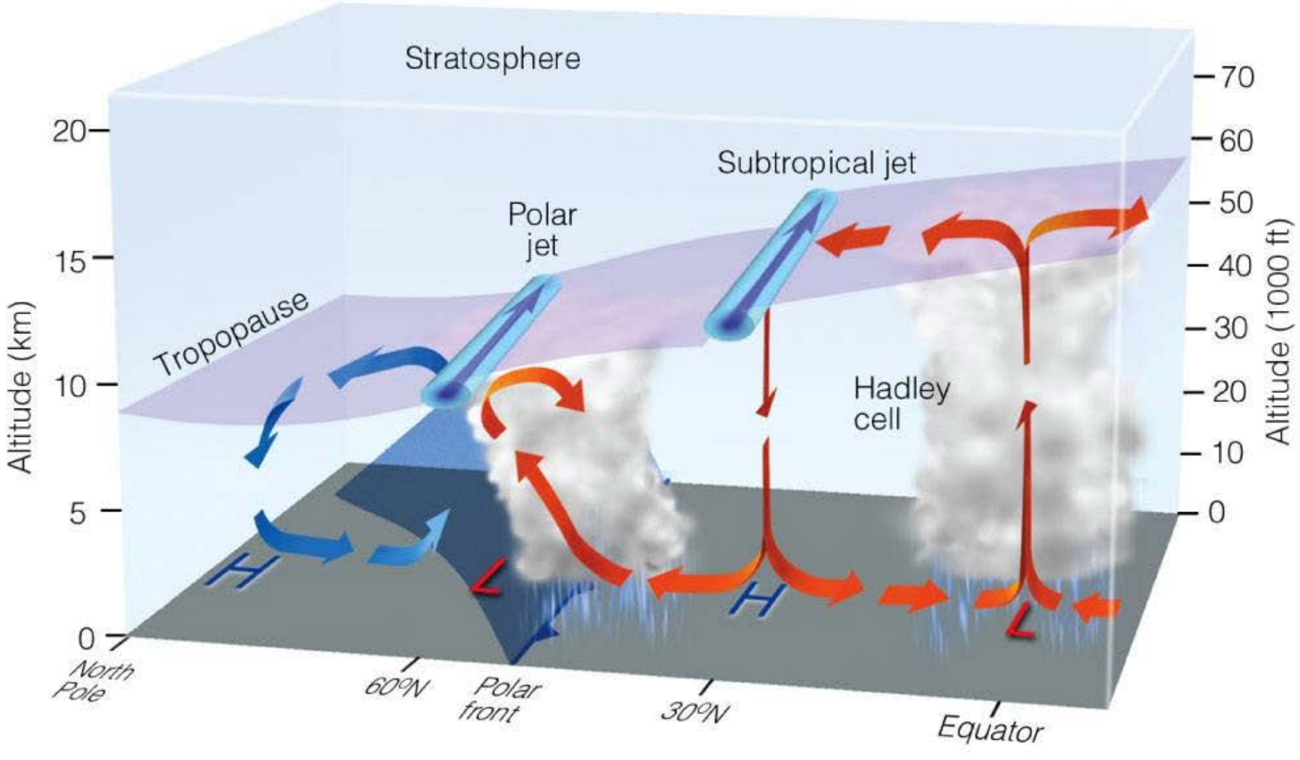
- Upward motion in the tropics – sinking motion in the subtropics → Hadley cell
  - Pattern of rising motion flanked by dual areas of sinking motion occurs only during S. Hem. Summer
  - Continental effects in N. Hem. lead to strong sinking motion in lower troposphere during winter
  - Maximum upward motion occurs during summer over N. Hem
  - Continental effects in N. Hem. lead to strong upward motion in lower troposphere during summer





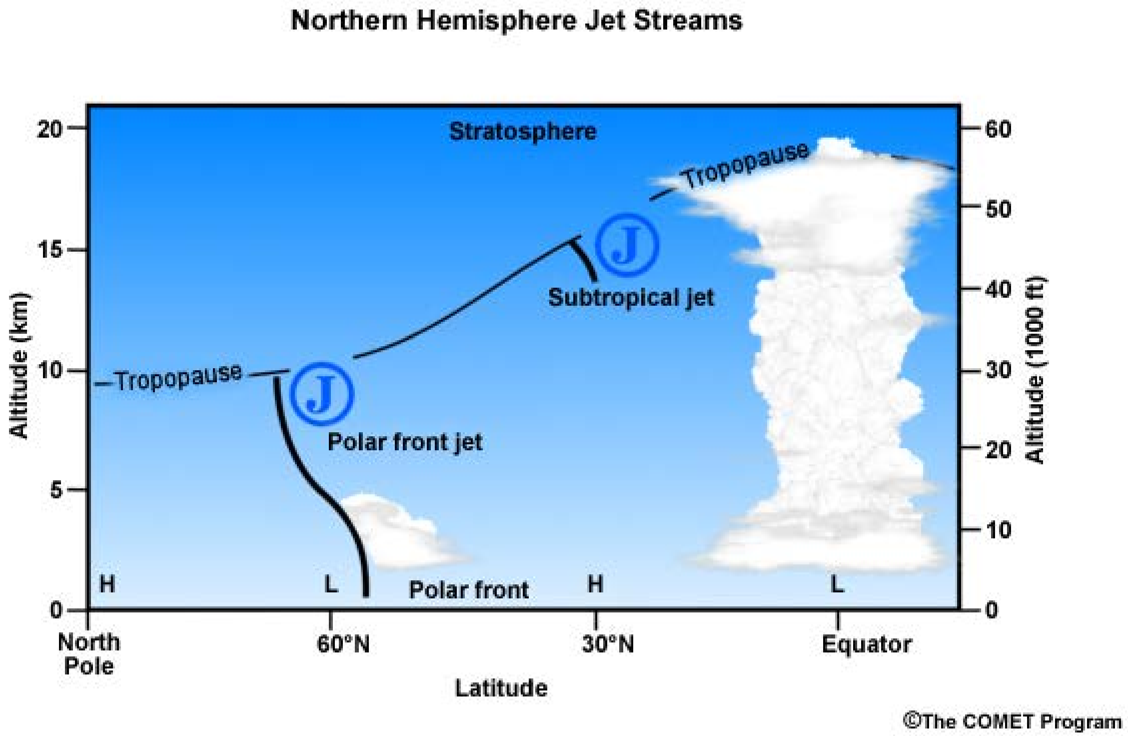
Subtropical jet formation

- Above the surface, away from friction, winds are generally faster.
- Near the tropopause, are corridors of very strong winds called jetstreams.
- The STJ at about 30° latitude results from the air flowing upward and poleward in the Hadley cell
- As air parcels move to a smaller latitude circle, their velocity must increase in order to conserve angular momentum.
- large-scale eddies (e.g., cyclones) transport some of the momentum from the Hadley cell to the midlatitudes and air parcels are slowed by small scale turbulence.



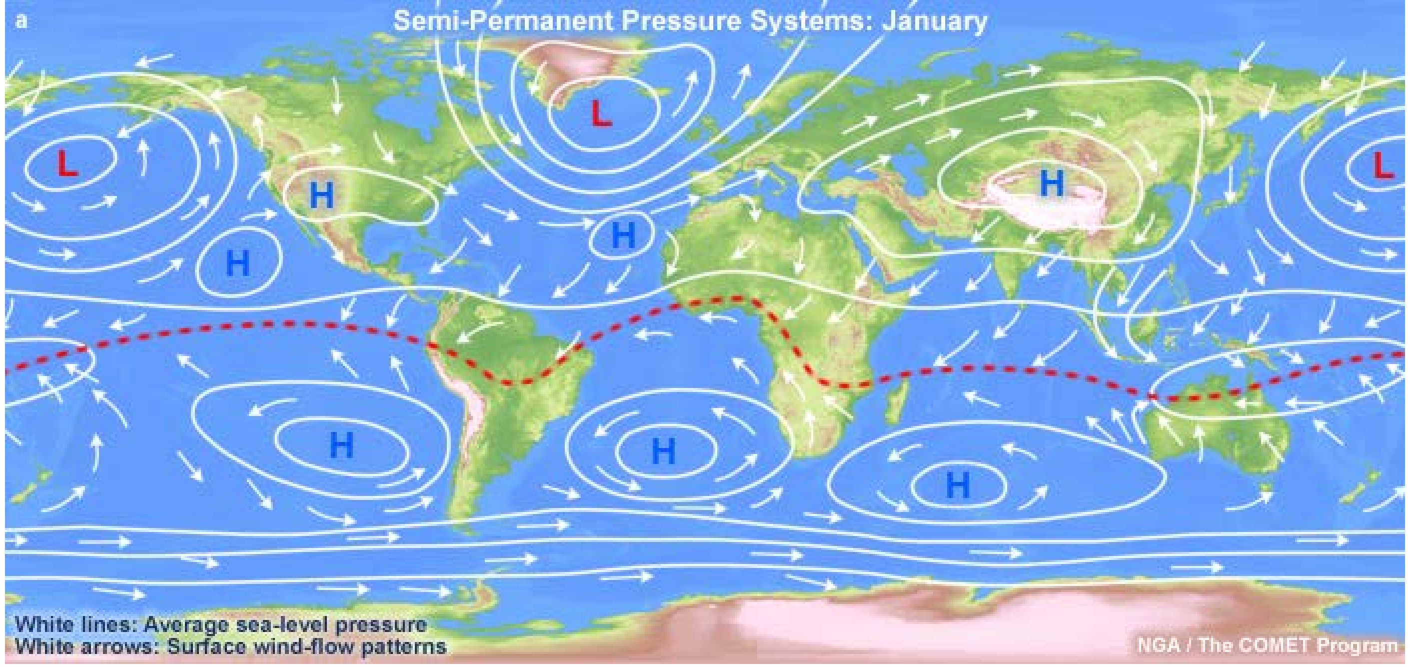
Northern Hemisphere jet streams

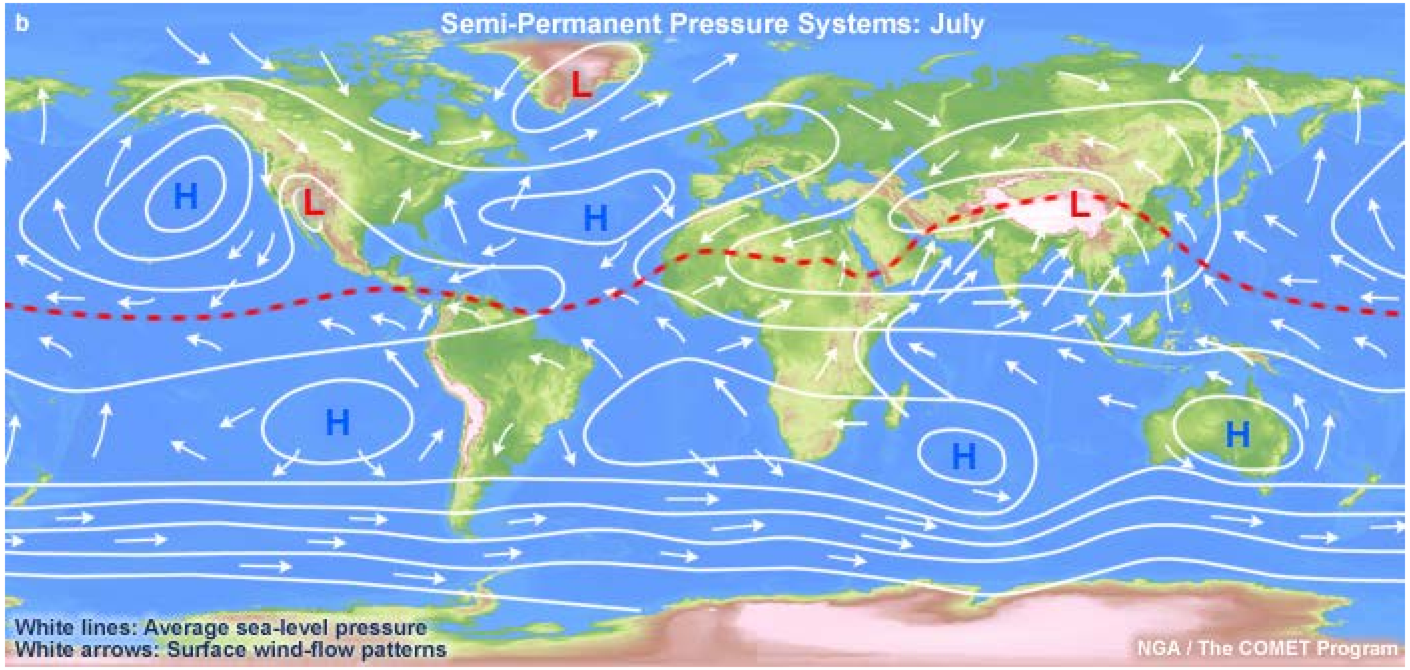
- Equator to pole profile showing the mean positions of the subtropical and polar jet, ITCZ convection, and clouds along the polar front.
- The Polar Jet forms in the region of strongest temperature contrast between cold, polar air and warmer air masses on the equatorward side of the polar front.
- The Polar Jet is strongest during winter when it can, occasionally, migrate to tropical latitudes.



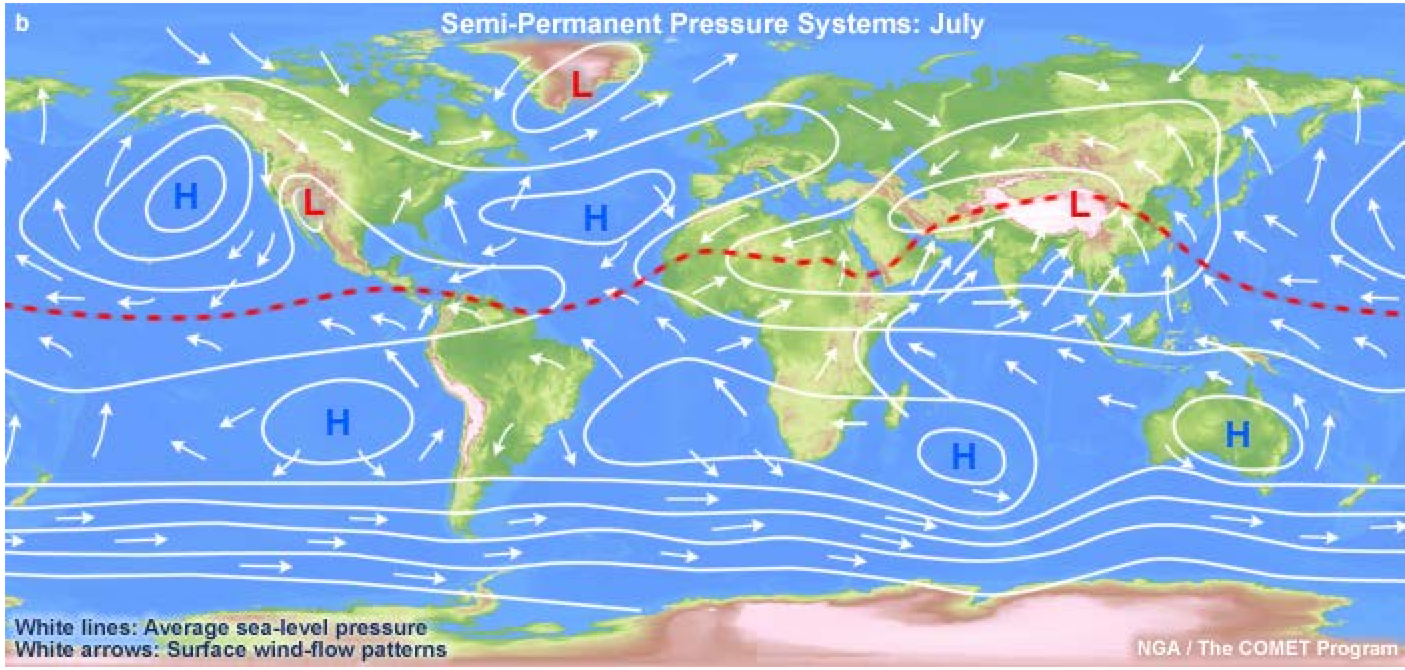
Mean pressure systems and representative wind vectors at the surface of January (top) and July (bottom)

- Equatorial trough – zone of low pressure that forms in response to net heating and rising air

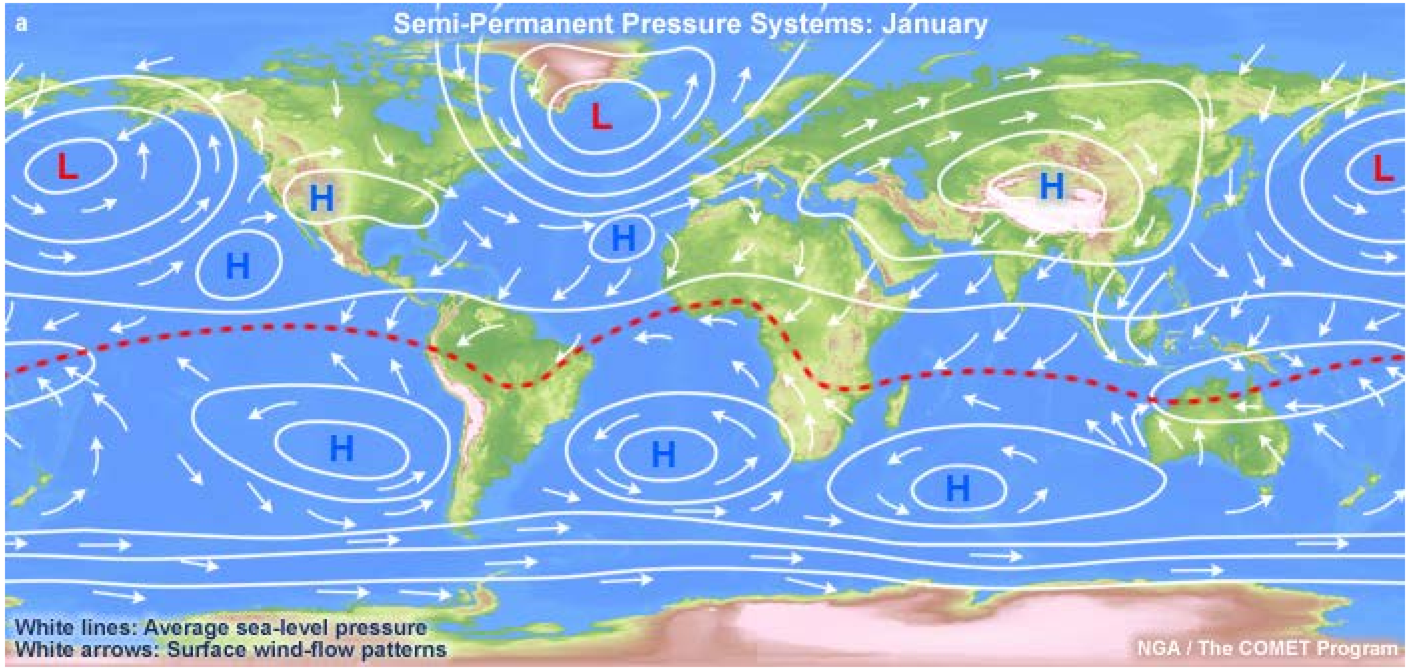




- During the boreal summer (July), the most prominent low pressure centers are the thermal lows over India, the Sahara Heat Low over Africa, and the Sonora Low over North America



- The austral summer (January) has prominent lows over the subtropics of South America, southern Africa, and Australia-Indonesia
- The subtropics are dominated by the Pacific-Hawaiian High and Bermuda-Azores High of the Northern Hemisphere and their counterparts over the Southern Hemisphere all of which have mean pressure of about 1020 hPa but are strongest during their respective summers.



Note the more zonal nature and less dramatic seasonal changes in the southern hemispheric because it has less land.