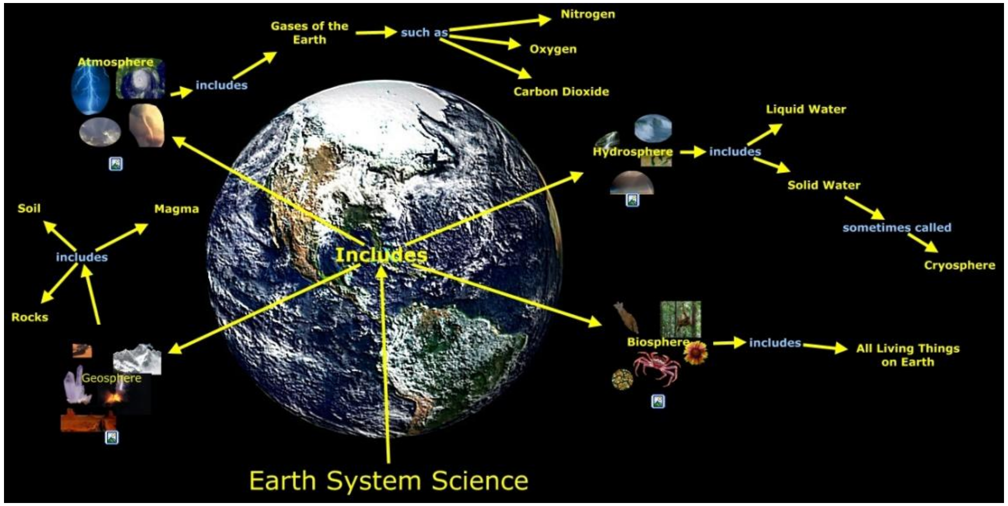


Lecture

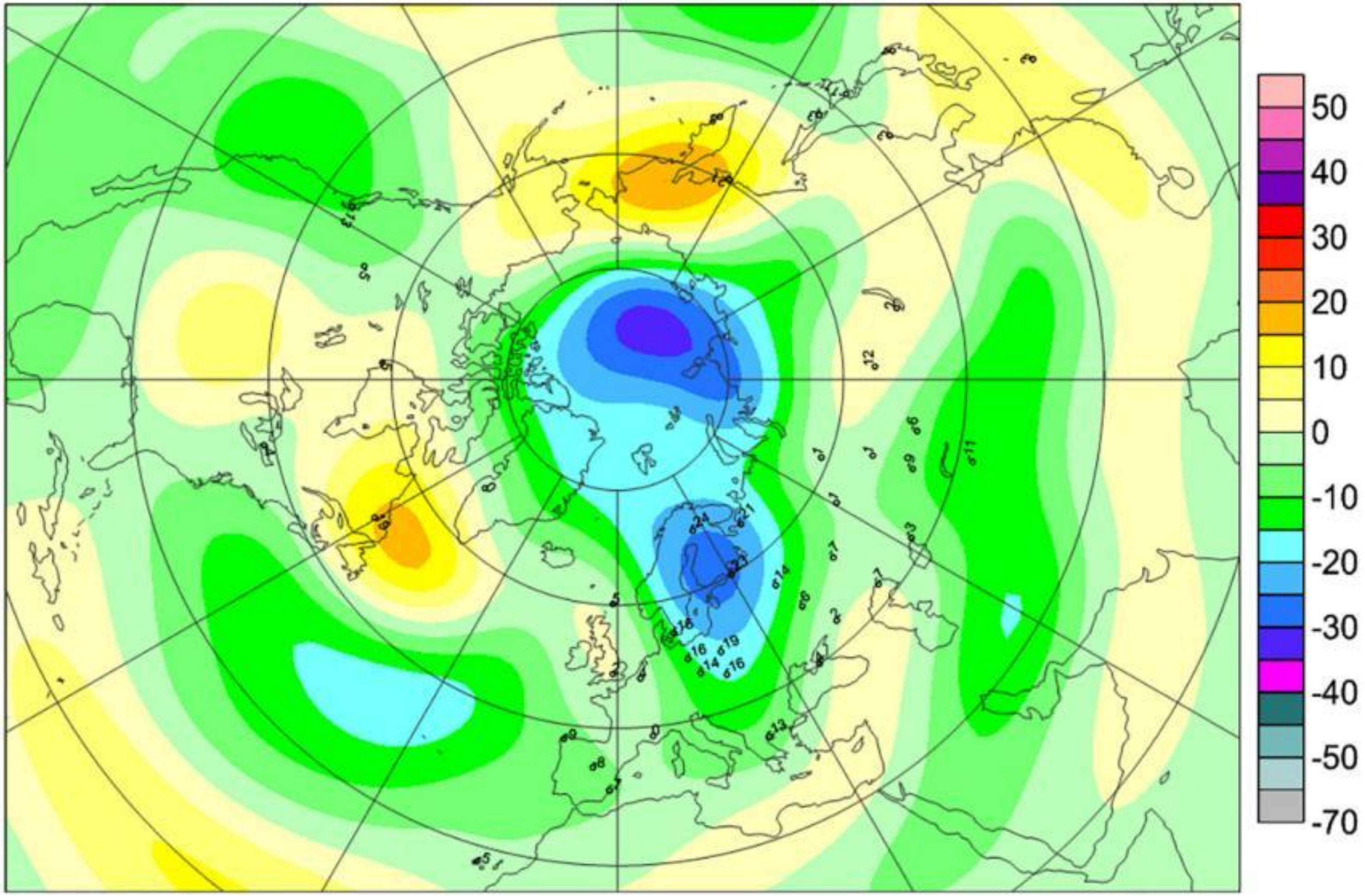
The Ocean – Atmosphere – Land system

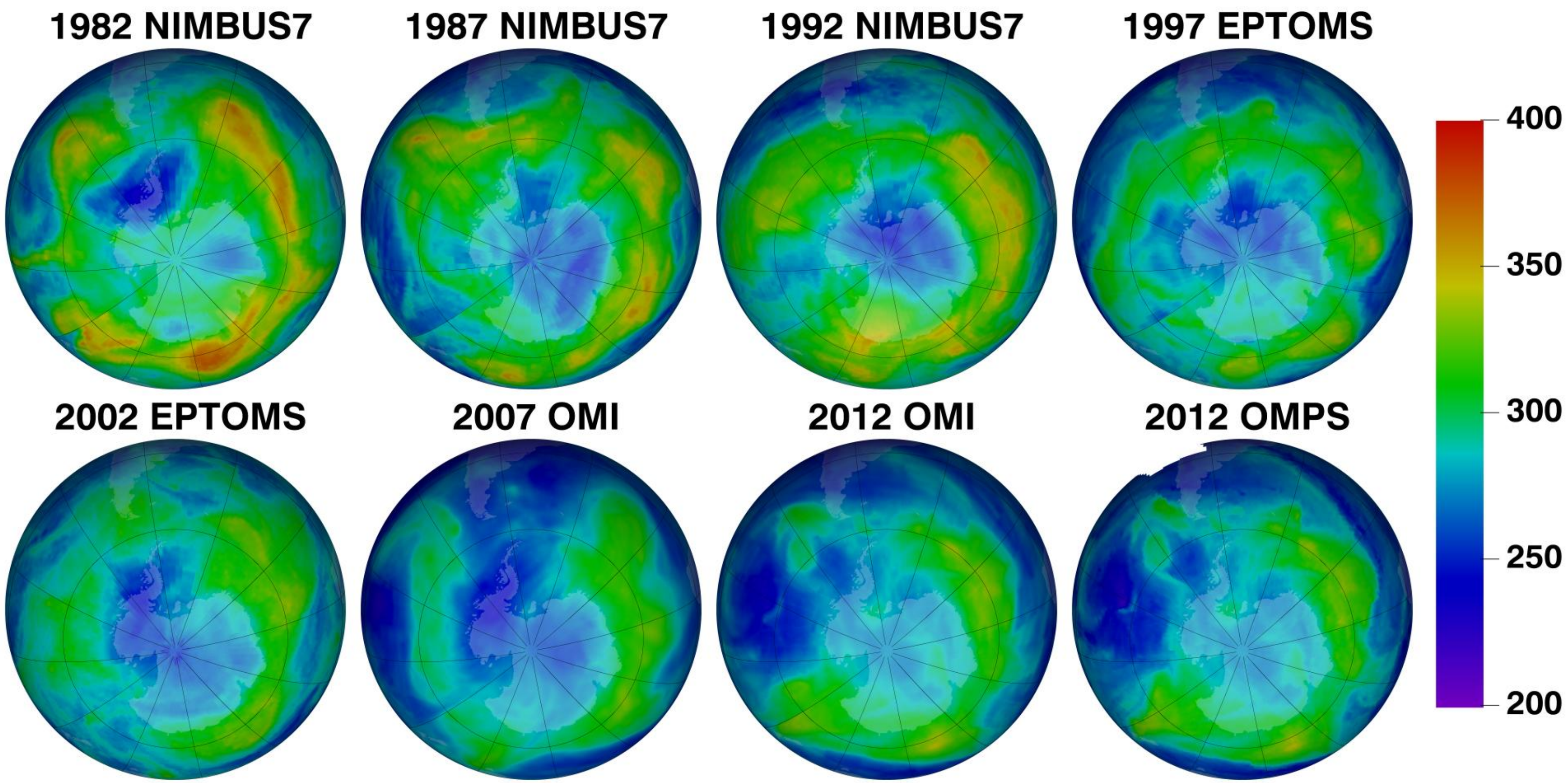
General Circulation in the Atmosphere, Climate Zones

Lecturer: Dr Evangelos GERASOPOULOS
Research Director IERSD/NOA

The importance of understanding atmospheric circulation

Ozone deviation from normal (%), 02/07/2016




1982 NIMBUS7
1987 NIMBUS7
1992 NIMBUS7
1997 EPTOMS
2002 EPTOMS
2007 OMI
2012 OMI
2012 OMPS
400
350
300
250
200

Lecture contents

- Formation of the earth atmosphere
- The "good" Green House Effect
- Vertical structure of the atmosphere
- General Circulation in the Atmosphere
- Vertical patterns of the general circulation
- Main components of the general circulation
- Usual disturbances of the general circulation
- On the time scales involved
- Climate zones

The formation of the earth atmosphere

The **first atmosphere of the Earth** looked like that of the Sun (hydrogen, inactive gases). It disappeared about 4.5 x 10^9 years ago, mainly due to high temperatures and other factors

The emission of several gases from the earth's internal e.g. volcanoes, is responsible for the current state of the atmosphere.

H_2 CH_4 N_2 NH_3 H_2O CO CN … **except O_2**

Then water vapor (H_2O) via condensation lead to the formulation of huge water volumes at the surface of the planet and as a result **intense weather phenomena** started taking place

The **creation of life** was then a result of intense energy sources like ultraviolet radiation and lightnings, supported by the reducing atmosphere.

A **reducing atmosphere** is an **atmospheric** condition in which oxidation is prevented by removal of oxygen and other oxidizing gases or vapours, and which may contain **actively reducing gases** such as hydrogen, carbon monoxide and gases that would oxidize in the presence of oxygen.

The same conditions favored the formulation of amino acids and several other organic compounds, that eventually resulted to the **first DNA and RNA molecules in the water**. Since DNA and proteins are sensitive to UV (2600 Å and 2750-2850 Å, respectively) they could be easily destroyed in conditions other than the water, at that time.

Photodissociation

$$2H_2O + h\nu(uv) \rightarrow 2H_2 + O_2$$

Fortunately …
Saved by oxygen

Photosynthesis

$$H_2O + CO_2 + h\nu(vis) \rightarrow CH_2O + O_2$$

From this first minor oxygen production, **ozone (O_3) was produced** in the atmosphere in quantities adequate to absorb UV (<3000 Å), thus protecting the first living organisms outside the water.

1/1000 of today's O_2 was enough to produce adequate for life protection O_3.

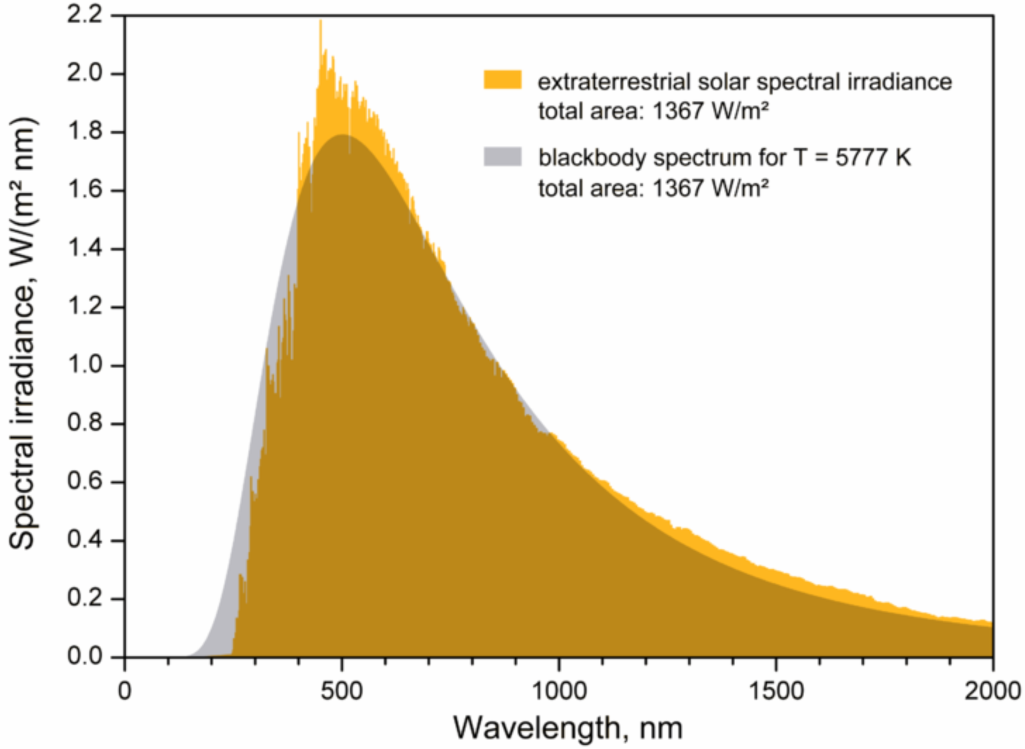
10% of O_2 produced during Earth's life is now at the atmosphere … the rest was used for the various oxides e.g. Fe_2O_3, $CaCO_3$, $MgCO_3$

Since then, H_2O and CO_2 were removed from the atmosphere via several mechanisms, so that the current (last 0.5 billion years) composition of the atmosphere is:

78% NITROGEN
21% OXYGEN

The “good” Green House Effect

The **effective temperature T_{eff}** of a body e.g. a planet is the temperature of a black body that would emit the same total amount (Flux-F) of electromagnetic radiation



To calculate **Teff** of a planet one needs to equate the power received by the planet with the power emitted by a blackbody of temperature *T*.

Absorbed power

Assumptions:

❖ Planet of radius r at a long distance *D* from the star of luminosity L.
❖ The star radiates isotropically
❖ The planet reflects some of the incoming radiation by a values of A (albedo)

$$P_{\mathrm{abs}} = \frac{Lr^2(1-A)}{4D^2}$$

Lr^2/D^2 solar constant
1353 W/m²

Emitted power

Assumptions:

❖ The entire planet is at the same temperature T
❖ The planet radiates as a blackbody.

Stefan–Boltzmann law

$$P_{\mathrm{rad}} = 4\pi r^2 \sigma T^4$$

Stefan–Boltzmann constant
***σ* = 5.670367(13)×10⁻⁸ W m⁻² K⁻⁴**

Equating these two expressions:

$$T = \left(\frac{L(1-A)}{16\pi\sigma D^2}\right)^{\frac{1}{4}}$$

Note that it is independent of the planet's radius.

To calculate **Tsurf** of a planet one needs to modify the previous calculations to account for emissivity and temperature variation

Absorbed power

Additional assumptions:

❖ The area of the planet that absorbs is A_{abs}

$$P_{\mathrm{abs}} = \frac{L A_{\mathrm{abs}}(1-a)}{4\pi D^2}$$

Emitted power

Additional assumptions:

❖ The entire planet is **NOT** at the same temperature T, however, it will radiate as if it had a temperature *T* over an area A_{rad}

❖ There is a factor *ε*, which is the emissivity and represents atmospheric effects. (ε ranges from 1 to 0 with 1 meaning the planet is a perfect blackbody)

Stefan–Boltzmann law

$$P_{\mathrm{rad}} = A_{\mathrm{rad}} \varepsilon \sigma T^4$$

Equating these two expressions:

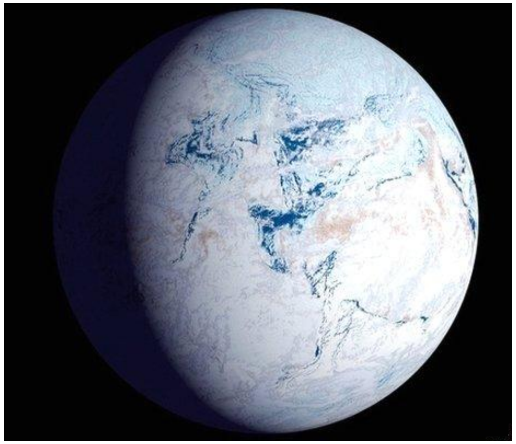
$$T = \left(\frac{A_{\mathrm{abs}}}{A_{\mathrm{rad}}} \frac{L(1-a)}{4\pi\sigma\varepsilon D^2} \right)^{\frac{1}{4}}$$

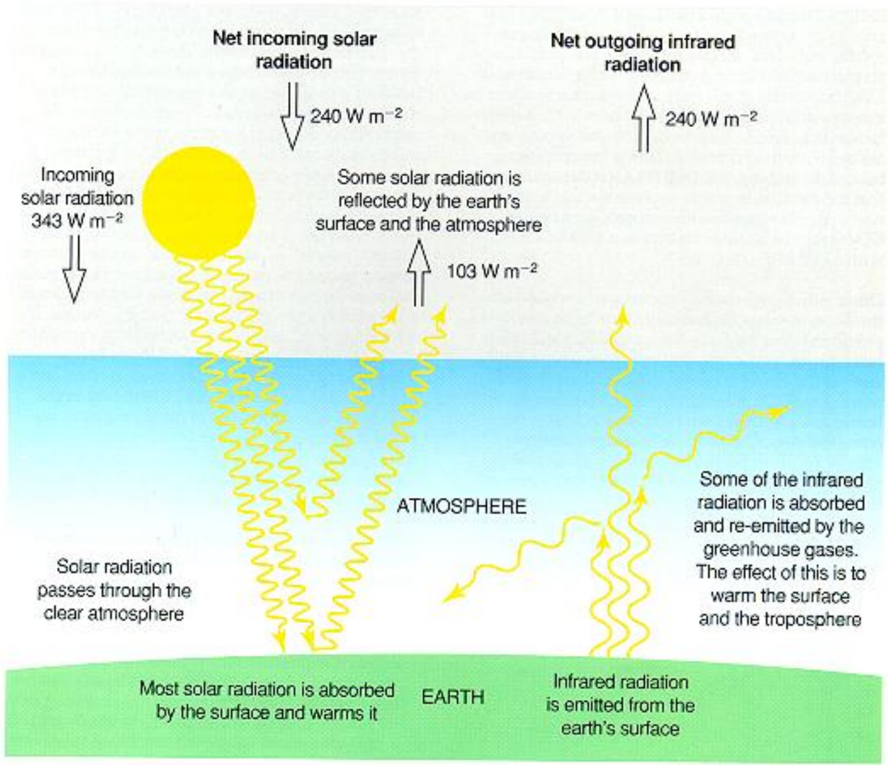
The Earth case

Albedo	~0.37
Emissivity	~0.96
Area ratio (fast rotator)	¼

for a slow rotator this ratio is 1/2

This calculation gives us a **T_{eff} of the Earth of 252K or -21 °C**, when the average temperature of the Earth is 288K or 15 °C.





Green House Effect

The difference between T_{eff} and the actual temperature in the lower atmosphere depends on the mass of the atmosphere and the ability of some of its ***minor atmospheric constituents*** to absorb mainly in the IR range.

These are mainly the triatomic gases CO_2, H_2O and O_3

Through radiative transfer calculations it is shown that the temperature of the atmosphere at an optical depth τ is higher than T_{surf} by a factor:

$$(1/2 + 3\tau/4)^{1/4}$$ Eddington approximation

Optical depth τ(IR)

Assumptions:

- 20 % of IR from the earth surface makes it through the atmosphere
- I_{surf}: IR radiation near the surface
- I_{IR}: the part of IR that escapes the atmosphere

Then

$$I_{IR} = I_{surf} \exp[-\tau(IR)]$$

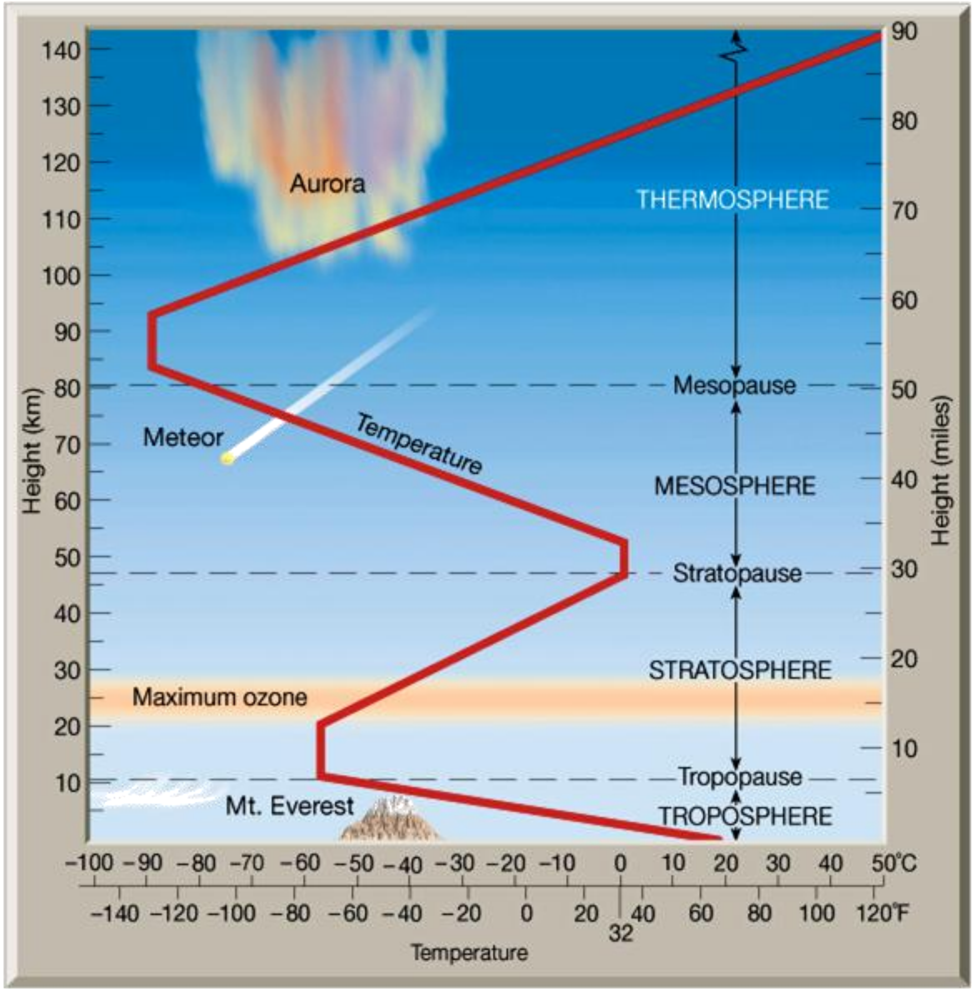
$$\tau(IR) = -\ln(I_{IR} / I_{surf}) = -\ln(0.2) = 1.61$$

Applying this into the Eddington approximation one gets a value of **287K or 15 °C**, which is close to the mean, mid-latitude air temperature near the surface

What is the temperature for the upper atmospheric limit (t=0)? At which height does it correspond in reality?

What happens if the atmosphere becomes able to absorb an additional 1% of the Earth's IR?

The vertical structure of the atmosphere



Composition

Homosphere(0-100 km)

Eterosphere(>100 km)

Thermosphere(100-400 km)

Exosphere(>400 km)

Temperature

Troposphere(0-12±4 km)

Stratosphere

(Stratopause 45-50 km)

Mesosphere

(Mesopause 80 km)

Other criteria

Ionosphere(70-300 km)

Magnetosphere

(1000 km-10 R_{Γ})

The homosphere and heterosphere

✓ Defined by whether the atmospheric gases are well mixed.
✓ The surface-based homosphere includes the troposphere, stratosphere, mesosphere, and the lowest part of the thermosphere, where the chemical composition of the atmosphere does not depend on molecular weight because the gases are mixed by turbulence.
✓ This relatively homogeneous layer ends at the turbopause found at about 100 km, which places it about 20 above the mesopause.
✓ Above this altitude lies the heterosphere, which includes the exosphere and most of the thermosphere.
✓Here, the chemical composition varies with altitude. This is because the distance that particles can move without colliding with one another is large compared with the size of motions that cause mixing.
✓ This allows the gases to stratify by molecular weight, with the heavier ones, such as oxygen and nitrogen, present only near the bottom of the heterosphere.
✓ The upper part of the heterosphere is composed almost completely of hydrogen, the lightest element.

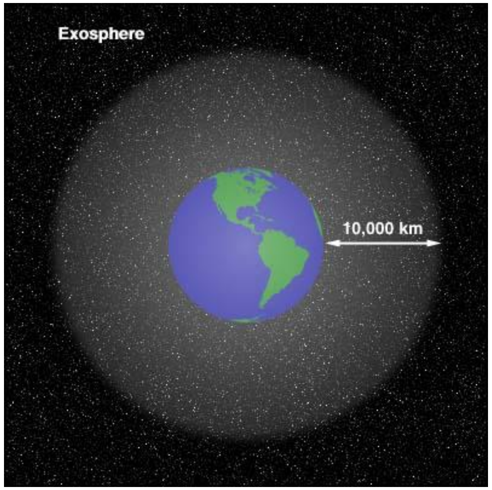
Exosphere

✓ Isothermal

✓Extremely low densities of H_2, He and several heavier molecules including N, O_2 and CO_2 closer to the exobase.

✓ They can travel hundreds of kilometers without colliding with one another.

✓ The exosphere contains most of the satellites orbiting Earth.



Thermosphere

✓ The inversion in the thermosphere occurs due to *the extremely low density of its molecules, the lack of triatomics, solar radiation <1750 Å, exothermal chem. Reactions, cooling only by downwards convection.*

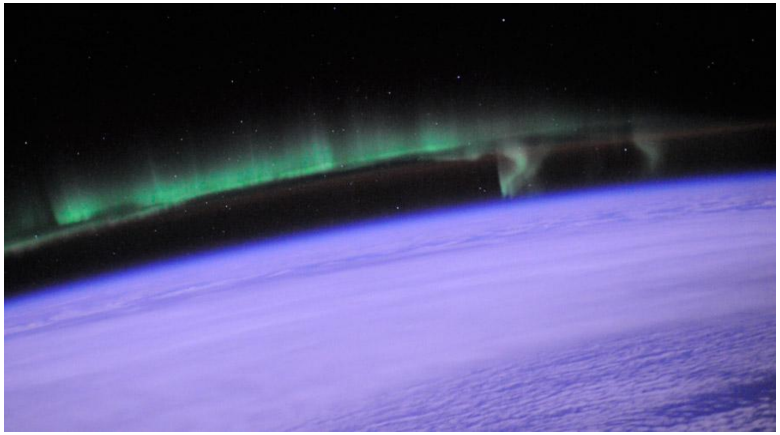
✓ Temperature as high as 1500 °C.

✓ Air so rarefied that an individual molecule travels an average of 1 km between collisions.

✓ Completely cloudless and free of water vapor.

✓ Non-hydrometeorological phenomena such as the aurora borealis and aurora australis are occasionally seen in the thermosphere.

✓ The International Space Station orbits in this layer, between 320 and 380 km.



Mesosphere

✓ Average temperature around −85 °C.
✓ Cooled by convection and gases radiation (O_3, CO_2)
✓ Just below the mesopause, the air is so cold that even the very scarce water vapor at this altitude can be sublimated into polar-mesospheric noctilucent clouds.
✓ The layer where most meteors burn up upon atmospheric entrance.
✓ It is too high above Earth to be accessible to aircraft and balloons, and too low to permit orbital spacecraft.
✓ The mesosphere is mainly accessed by sounding rockets.

Ionosphere

✓ Ionized by solar radiation.
✓ It is responsible for auroras.
✓ During daytime hours, it stretches from 50 to 1,000 km and includes the mesosphere, thermosphere, and parts of the exosphere.
✓ Ionization in the mesosphere largely ceases during the night, so auroras are normally seen only in the thermosphere and lower exosphere.
✓ It has practical importance because it influences, for example, radio propagation on Earth.

Stratosphere

✓ The atmospheric pressure at the top of the stratosphere is roughly 1/1000 the pressure at sea level.

✓ The rise in temperature is caused by the absorption of ultraviolet radiation (UV 2000-3000 Å) radiation from the Sun by the ozone layer.

✓ Although the temperature may be −60 °C at the tropopause, the top of the stratosphere is much warmer, and may be near 0 °C.

✓ The stratospheric temperature profile creates very stable atmospheric conditions, so the stratosphere lacks the weather-producing air turbulence that is so prevalent in the troposphere.

✓ Almost completely free of clouds and other forms of weather.

✓ Polar stratospheric or nacreous clouds are occasionally seen in the lower part of this layer of the atmosphere where the air is coldest.

✓ This is the highest layer that can be accessed by jet-powered aircraft.

Ozone layer

✓ Ozone concentrations are about 2 to 8 parts per million, which is much higher than in the lower atmosphere but still very small compared to the main components of the atmosphere.

✓ It is mainly located in the lower portion of the stratosphere from about 15–35 km, though the thickness varies seasonally and geographically.

✓ About 90% of the ozone in Earth's atmosphere is contained in the stratosphere.

Troposphere

✓ Although variations do occur, the **temperature usually declines with increasing height (-6.5 °C/km)** because the troposphere is mostly heated through energy transfer from the surface.

✓ This promotes vertical mixing. Heat transfer is conducted by water vapour (absorb IR from the Earth's surface).

✓ The troposphere contains roughly 80% of the mass of Earth's atmosphere.

✓ The troposphere is denser than all its overlying atmospheric layers because a larger atmospheric weight sits on top of the troposphere and causes it to be most severely compressed.

✓Nearly all atmospheric water vapor or moisture is found in the troposphere, so it is the layer where most of Earth's weather takes place.

✓ It has basically all the weather-associated cloud genus types generated by active wind circulation, although very tall cumulonimbus thunder clouds can penetrate the tropopause from below and rise into the lower part of the stratosphere.

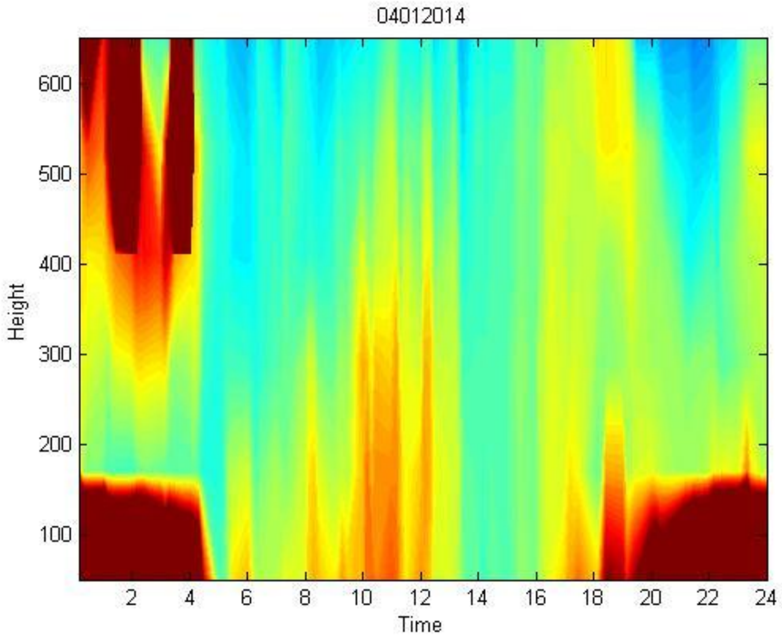
✓ Most conventional aviation activity takes place in the troposphere, and it is the only layer that can be accessed by propeller-driven aircraft.

Planetary boundary layer

✓ Closest to Earth's surface and directly affected by it, mainly through turbulent diffusion.

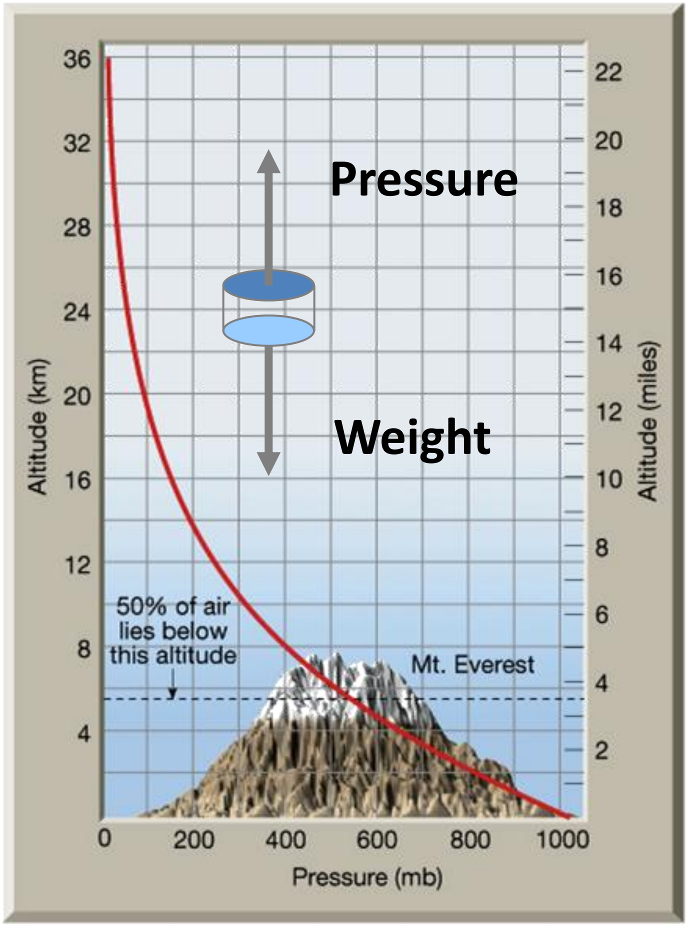
✓ During the day it is usually well-mixed, whereas at night it becomes stably stratified with weak or intermittent mixing.

✓ The depth of the planetary boundary layer ranges from as little as about 100 meters on clear, calm nights to 3000 m or more during the afternoon in dry regions.



➢ Study of the vertical structure of the atmosphere

Pressure, temperature, density, composition



Powers on an air mass

Weight=m.g=d.V.g=d.A.g.Δz

Pressure=A.ΔP

hydrostatic equilibrium-Equation

$\Delta P/\Delta z=-d.g$

Isothermal Atmosphere

(assumption – ideal gas ok for h>strat)

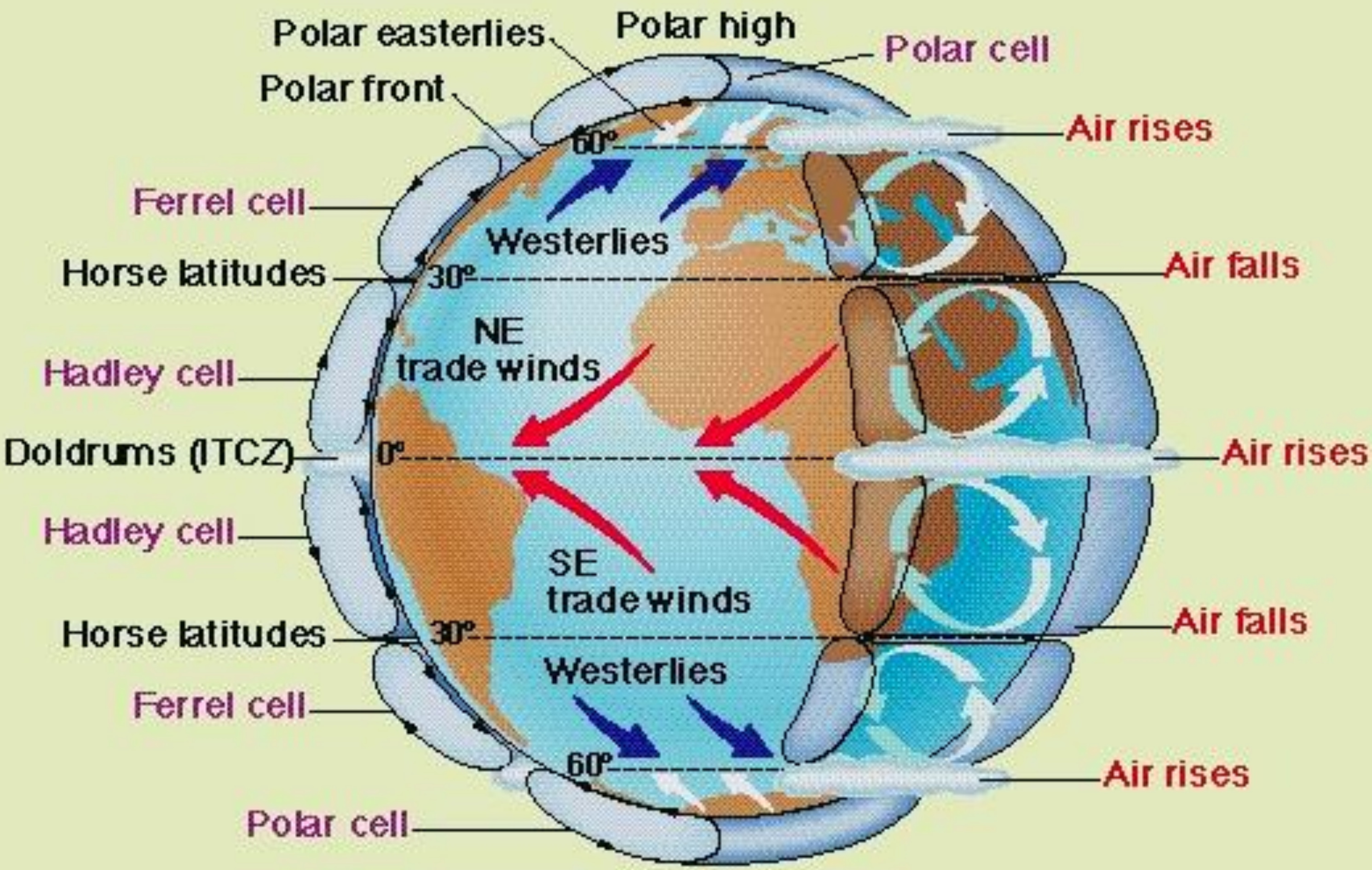
$P=n.R^{*}.T/V=(d.V/MW).R^{*}.T/V=d.R.T$

(mean MW=28.96)

$P_{(z)}=P_{(0)}.e^{-g.z/R.T}$ $P_{(0)}=1013.25$ mb=1 Atm

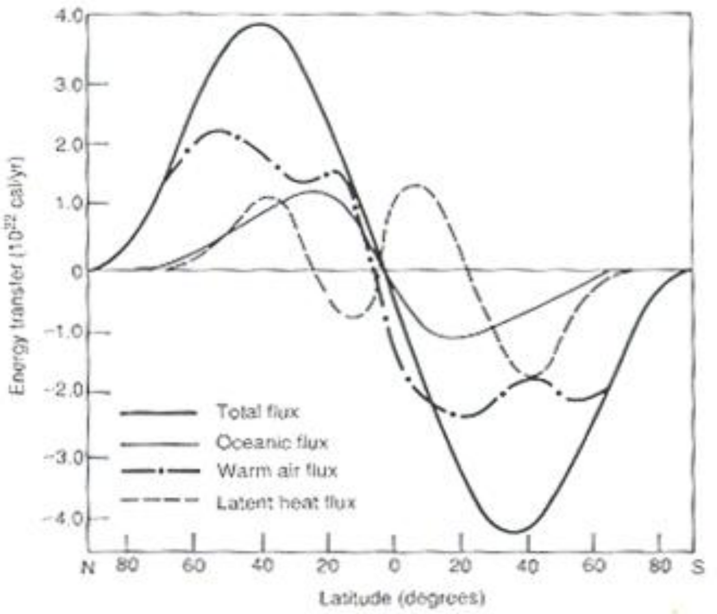
The general circulation of the atmosphere

The Patterns in Global Air Circulation



The General Circulation (GC) describes the large scale behavior of winds and pressure that dominates year round or seasonally.

*Understanding the general circulation of the atmosphere and the motion of global winds is very important since it enables us to understand how and why Earth is divided into **different zones**, and to interpret the findings from Earth Observations*



The equator is warmer than higher latitudes and as a result a continuous energy flux takes place from low latitudes to higher, through both the atmosphere and the oceans

- This unequal heating would create a two-cell circulation pattern.
  - Rising air at the equator and descending air at the poles.
  - Surface winds → from the poles toward the equator
  - Winds aloft → from the equator toward the poles.

- But the Earth is rotating and its surfaces are not inform and this creates a much more complex atmospheric circulation.

Navier-Stokes equation describes air motion via 3 components:

$$\frac{d\vec{V}_h}{dt} = -\frac{1}{\rho}\nabla p - f\hat{k}\times\vec{V} + F\vec{r}\left(\frac{1}{\rho}\nabla\cdot\tau\right)$$

Pressure gradient force

Coriolis force

Friction force

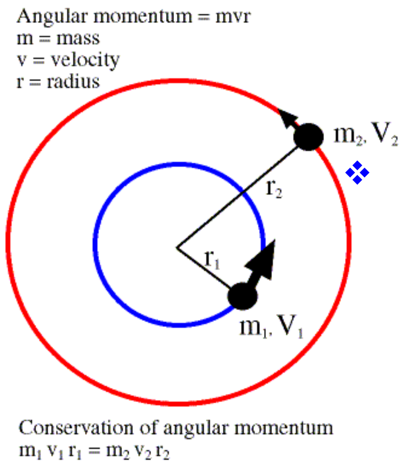
In one page GC is due to the following:

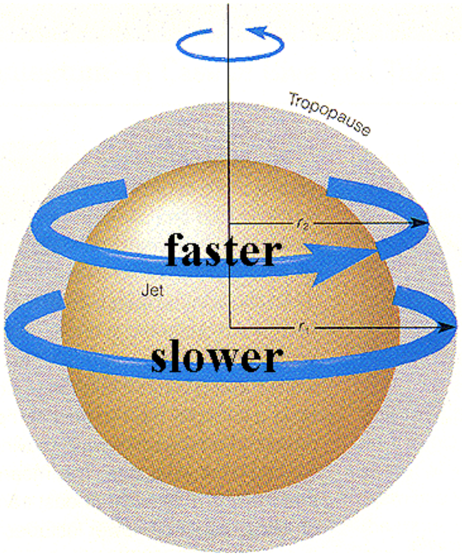
- Differential heating: The energy difference between low and high latitudes
- Differential rotation: The fact that the atmosphere rotates together with the Earth

  (angular momentum) ~ ωr^2

  ω= angular velocity,

  r= air distance from Earth's rotation axis
- Differential gravity: Gravitational acceleration is larger at the poles than at the equator





Angular Momentum Conservation:

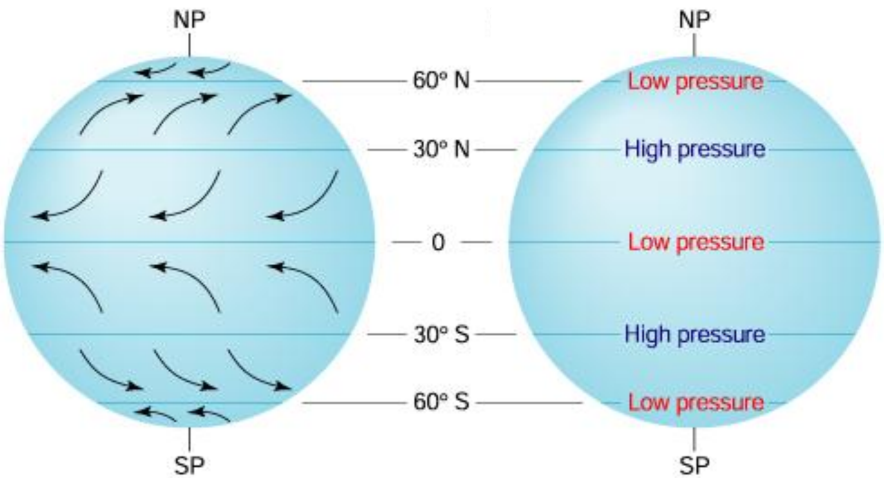
a) Max rotation at the equator

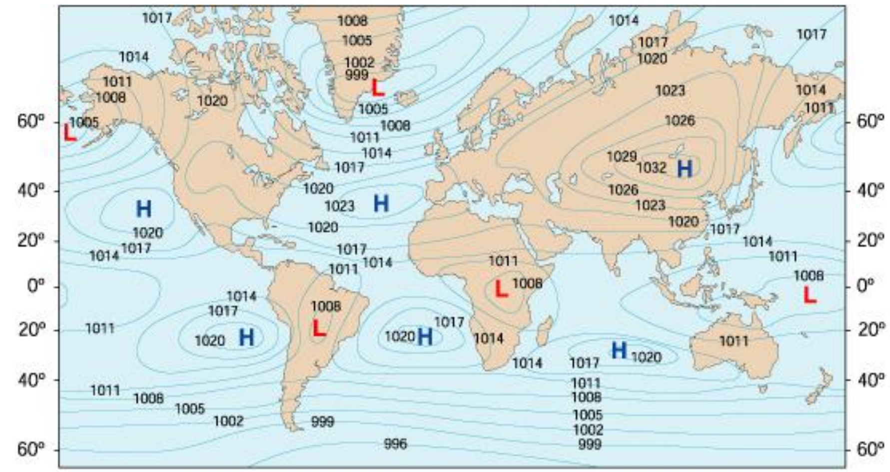
b) Zero at the poles

e.g. air parcels moving from lat 42° to 46° and conserves its angular momentum, it increases its velocity by 29m/s.

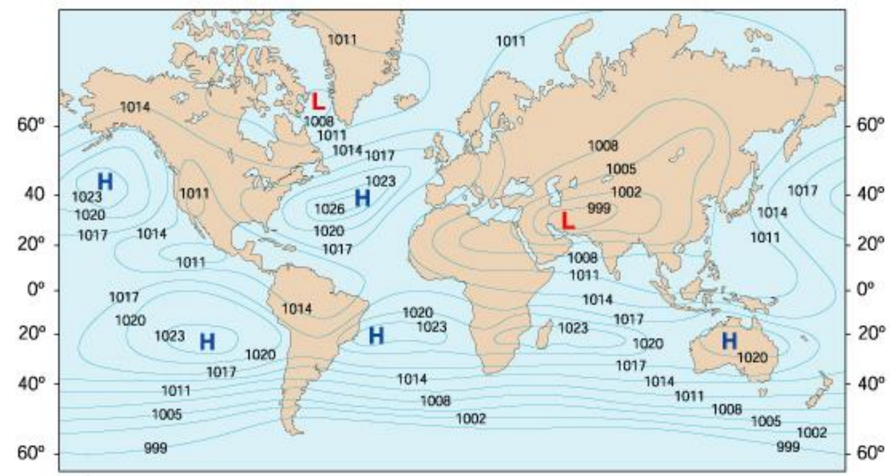
c) In low lats, friction with the surface forces trade winds to gain west relative angular momentum and this is further channeled towards the poles nearby the jet stream.

Global wind patterns are driven by global pressure patterns



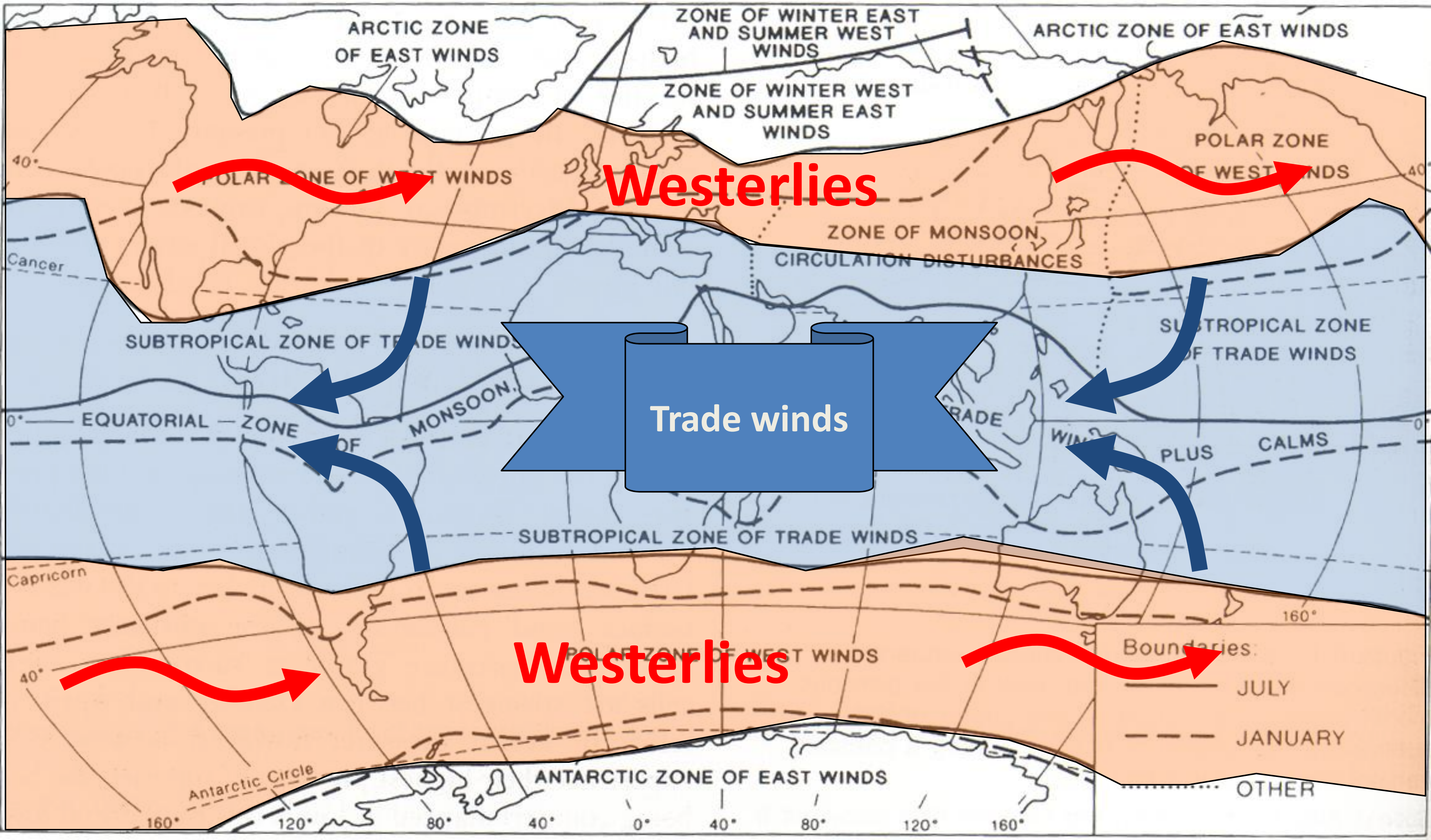


January

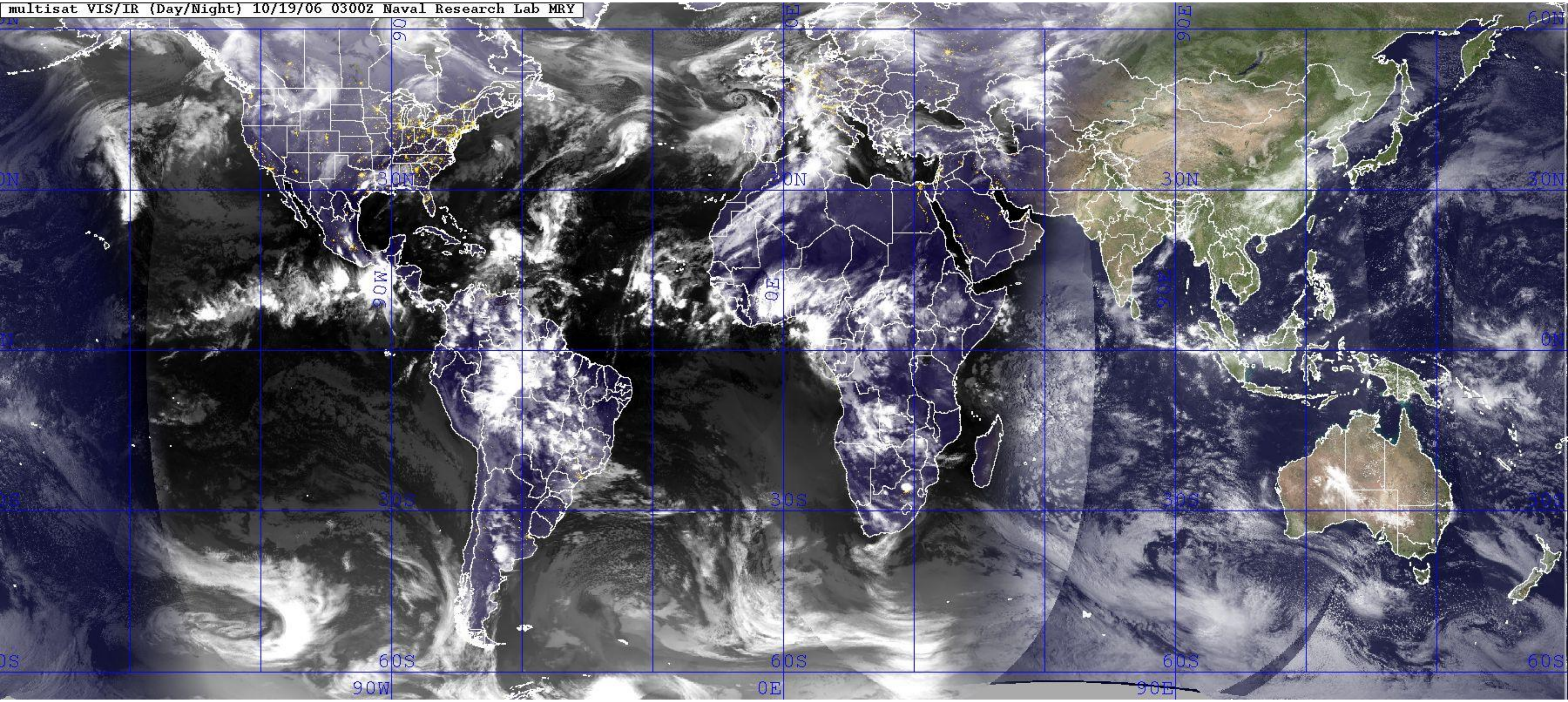


July

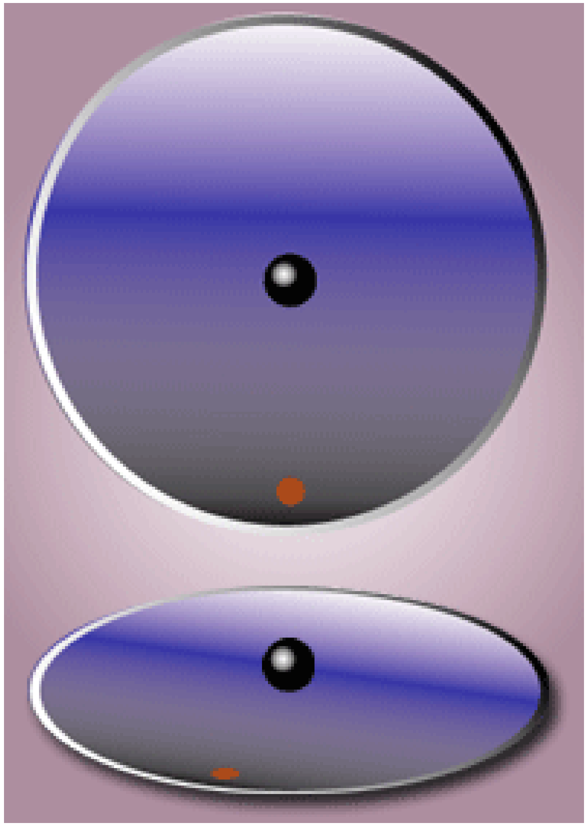
(July – continuous line, January – dashed line)

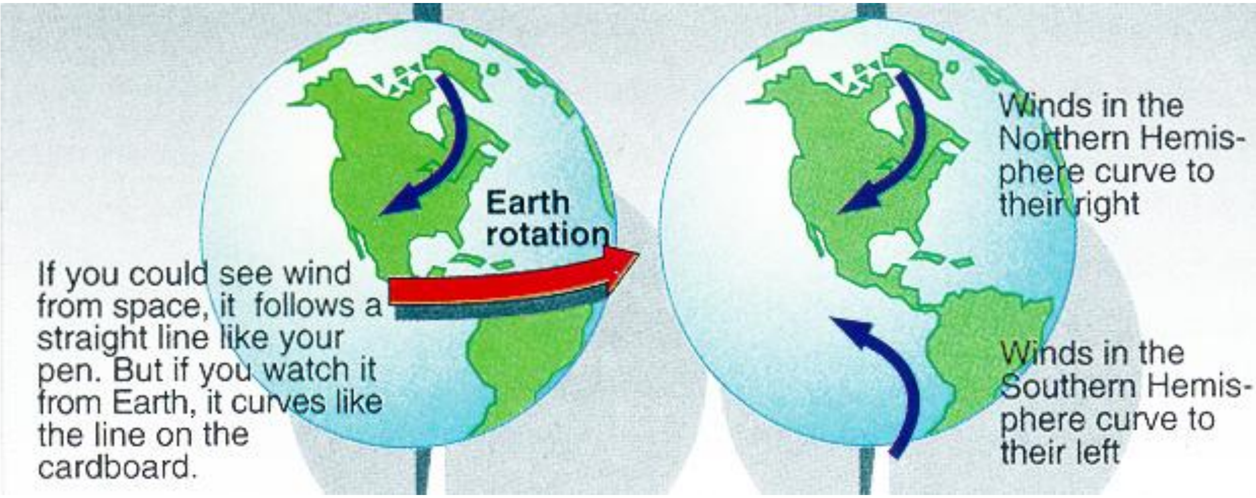


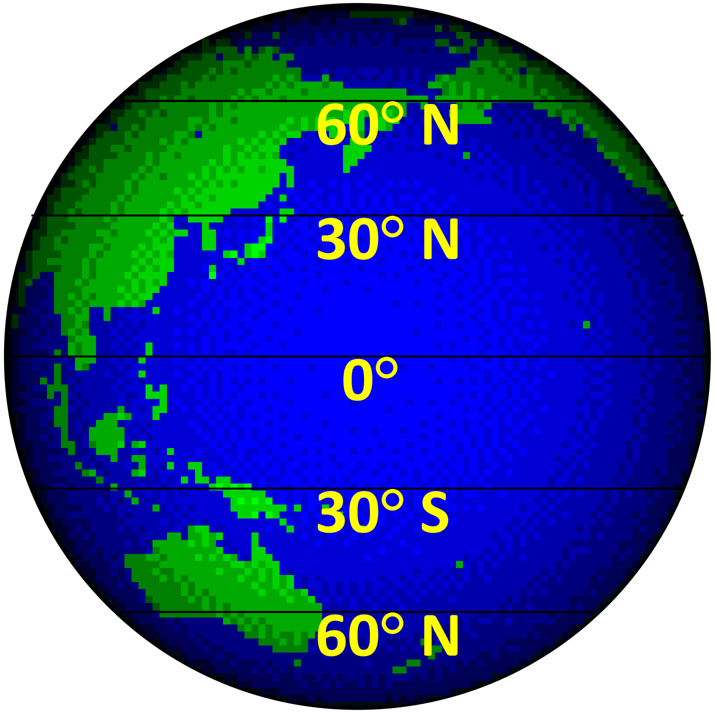
Global (visible + infrared) satellite image



Trade winds





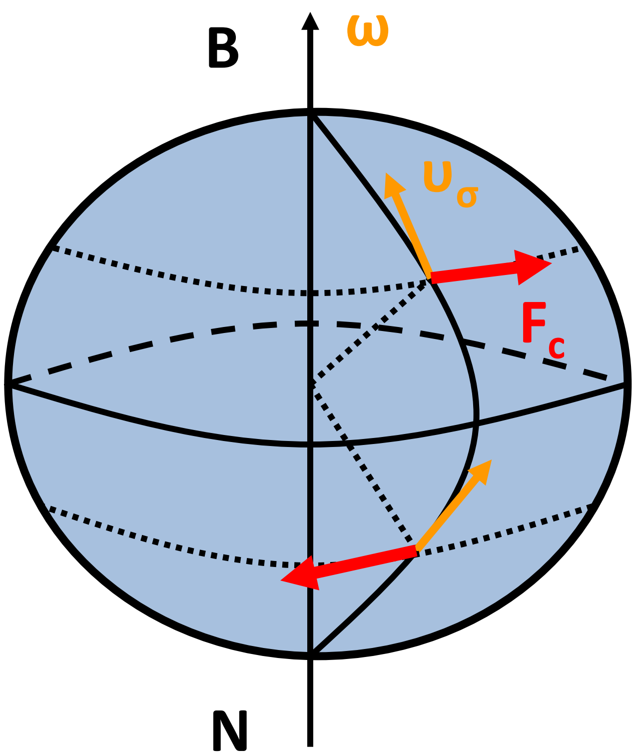


Because of rotation, surface air blows increasingly to the west the closer we approach the equator, as a result of Coriolis effect.

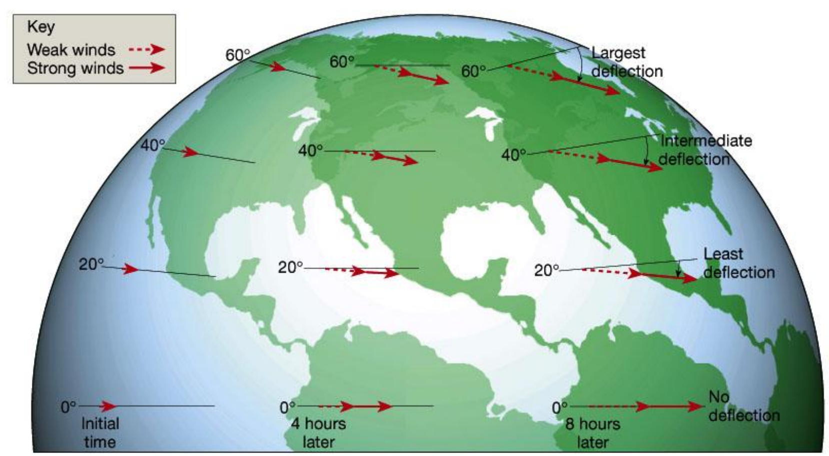
Coriolis force

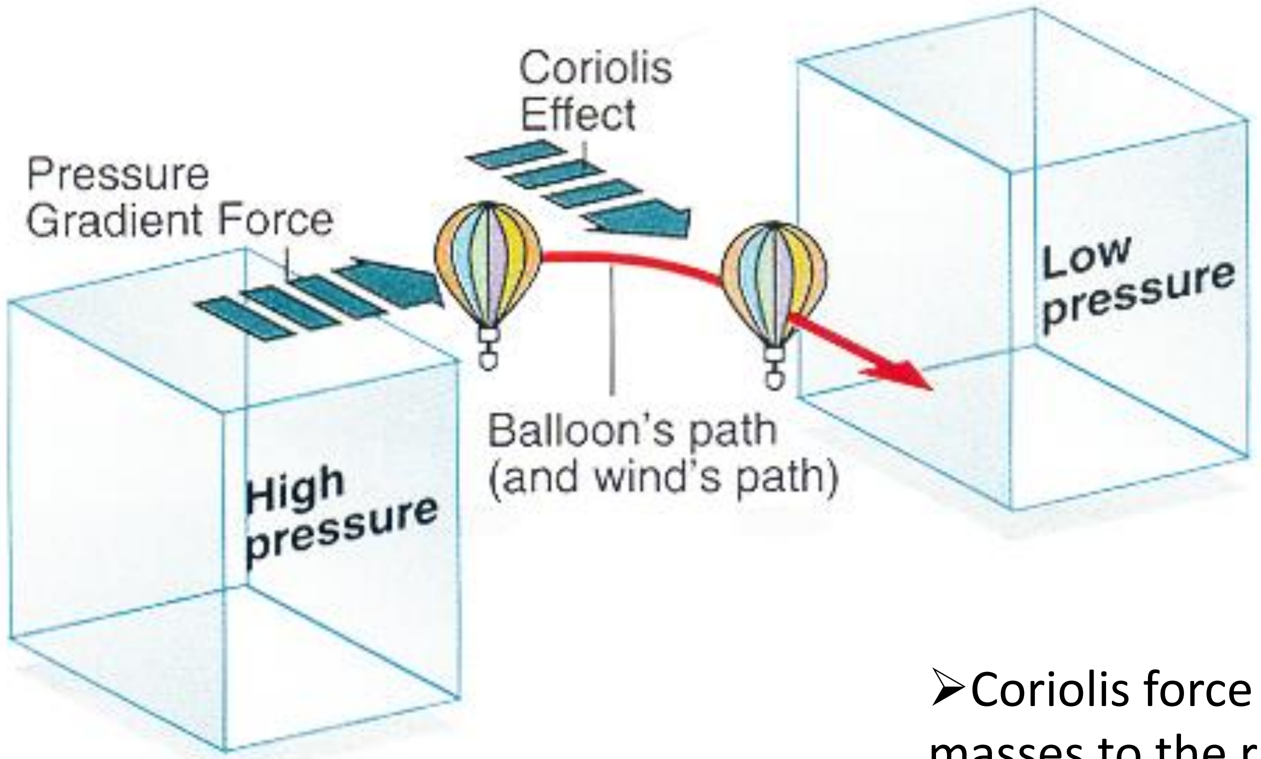
$$F_c = -2m\ \boldsymbol{\omega} \times \boldsymbol{u}_\sigma$$

➢ Coriolis force is an inertia force to be taken into account when a body possesses relative velocity in a rotating reference system

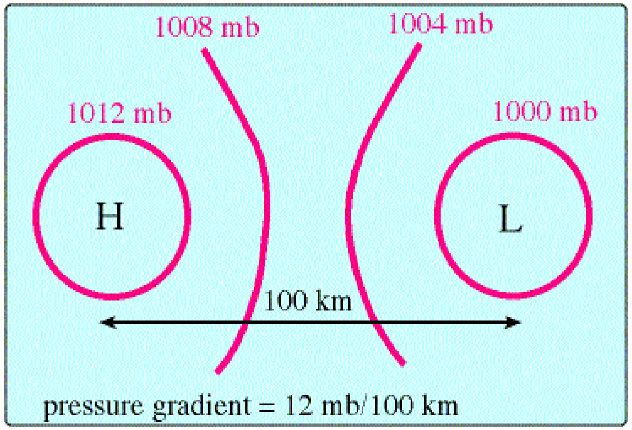


- All objects away from the equator deflect to:
  - the right of the direction of move in the North Hemisphere
  - the left in the South Hemisphere
- Its impact is zero at the equator and maximizes over the poles

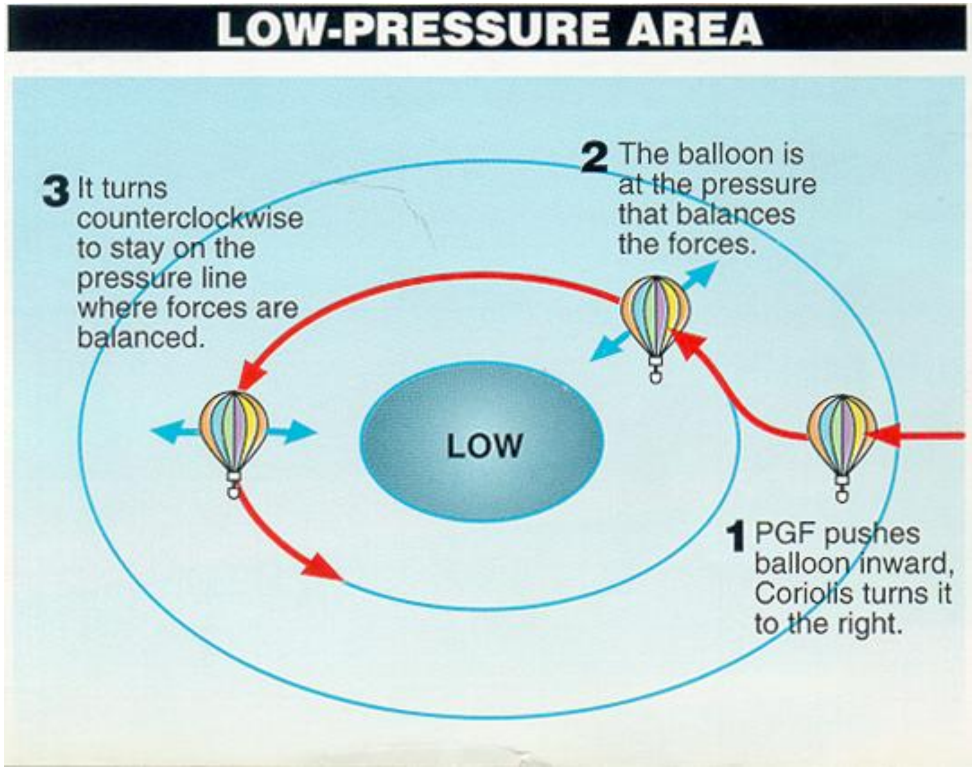


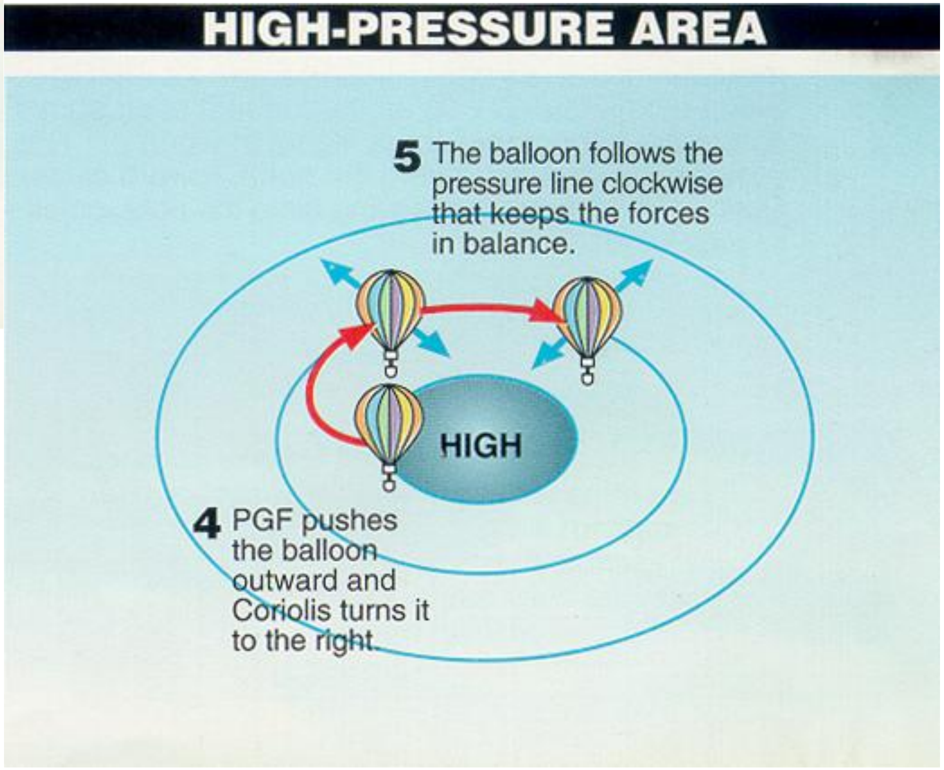


- Pressure gradient forces air masses to move from areas of high to areas of low pressure



- Coriolis force deflects air masses to the right (N. Hemipshere) untill forces are balanced out (geostrophic balance) and then this geostrophic wind blows parallel to pressure contours

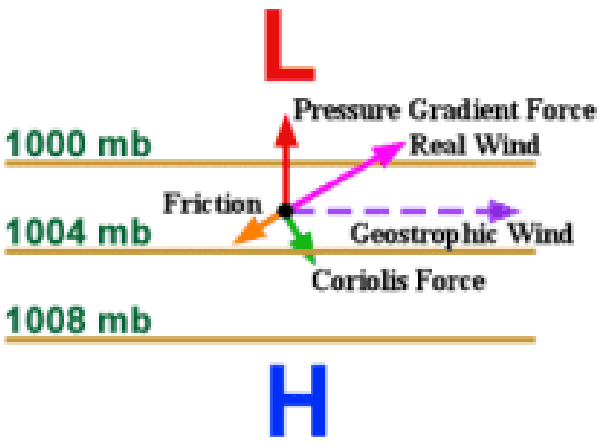

LOW-PRESSURE AREA
3 It turns counterclockwise to stay on the pressure line where forces are balanced.
2 The balloon is at the pressure that balances the forces.
LOW
1 PGF pushes balloon inward, Coriolis turns it to the right.


HIGH-PRESSURE AREA
5 The balloon follows the pressure line clockwise that keeps the forces in balance.
HIGH
4 PGF pushes the balloon outward and Coriolis turns it to the right.

BUT NOT IN REAL LIFE!

Friction at the surface induces imbalance between the pressure gradient and Coriolis forces.

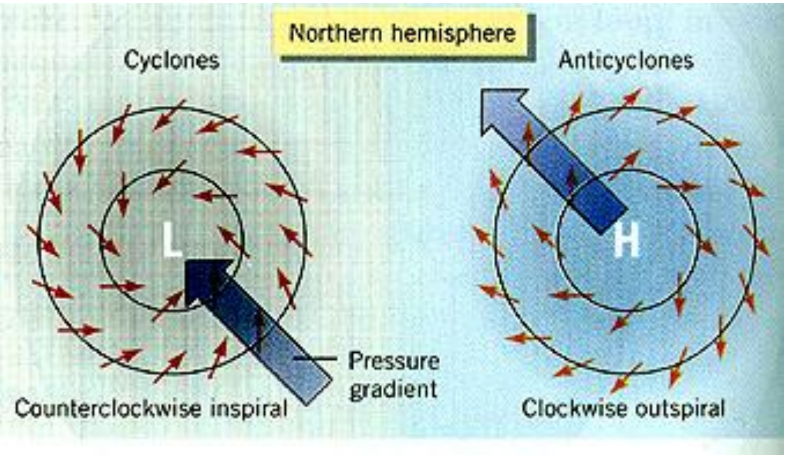
As a result real wind crosses isobars, diverging from high and converging into low pressure



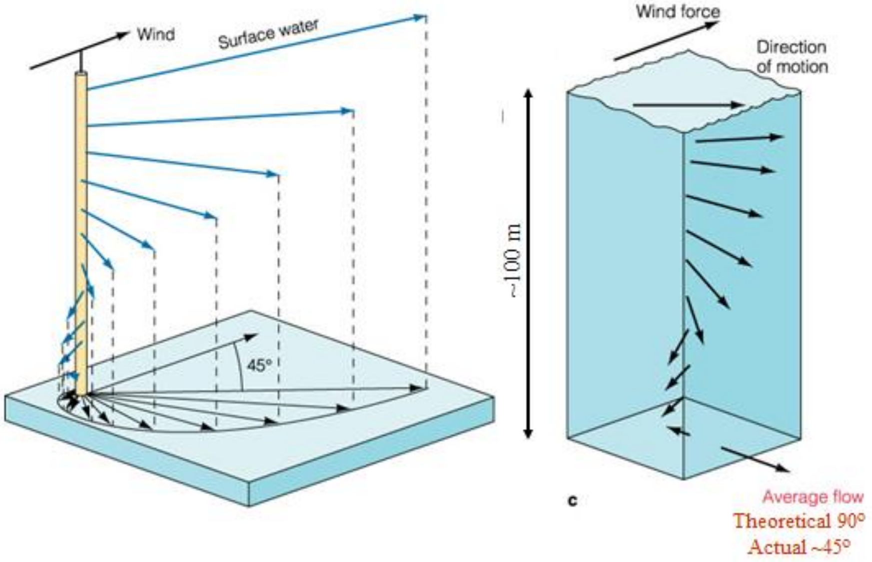
When surface winds cross isobars , this is called **"Ekman turning"**. It has two results:

A. Winds spiral cyclonic *into* Low Pressure and anticyclonic *out of* High Pressure

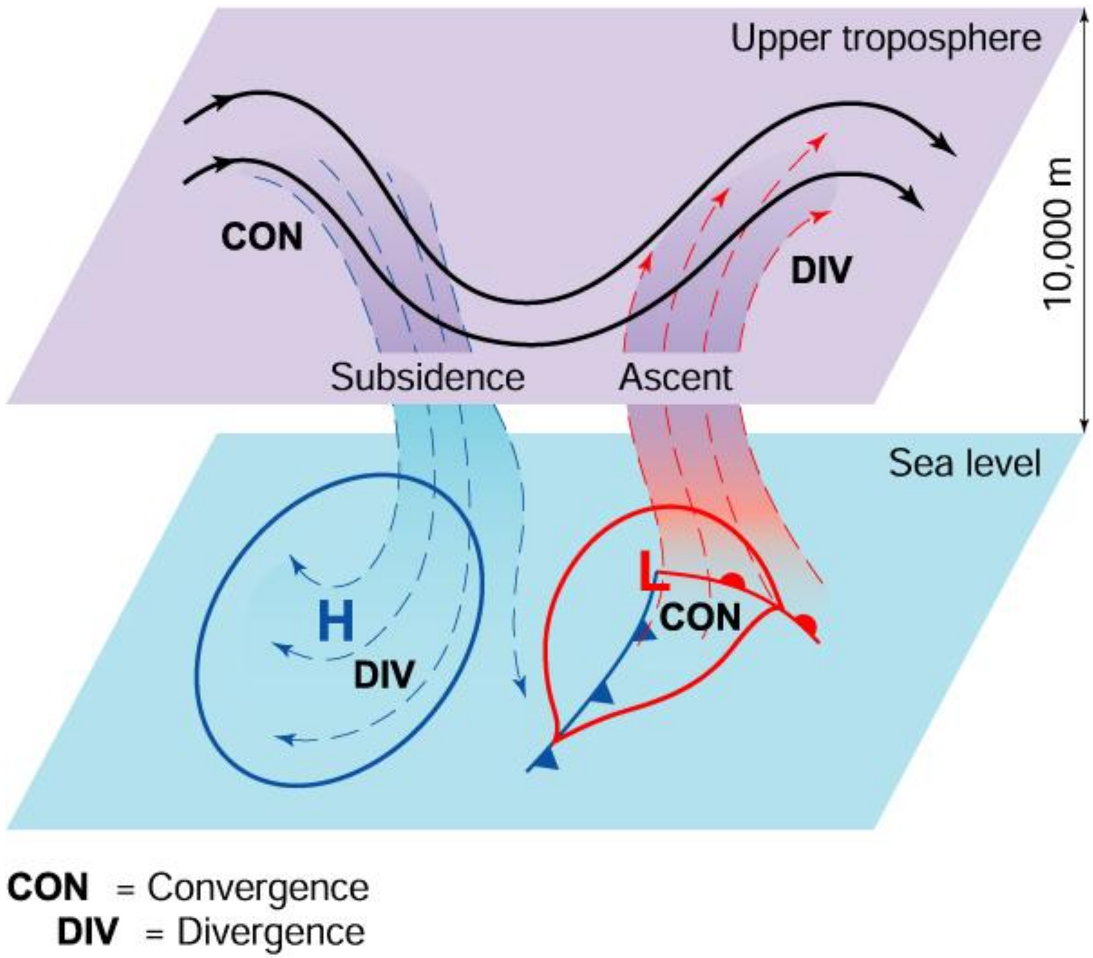
B. Surface winds are oriented approximately 45° to right of geostrophic wind at surface. Top of "Ekman layer" is defined where ***v*** wind component is zero. (And thus wind is now geostrophic).

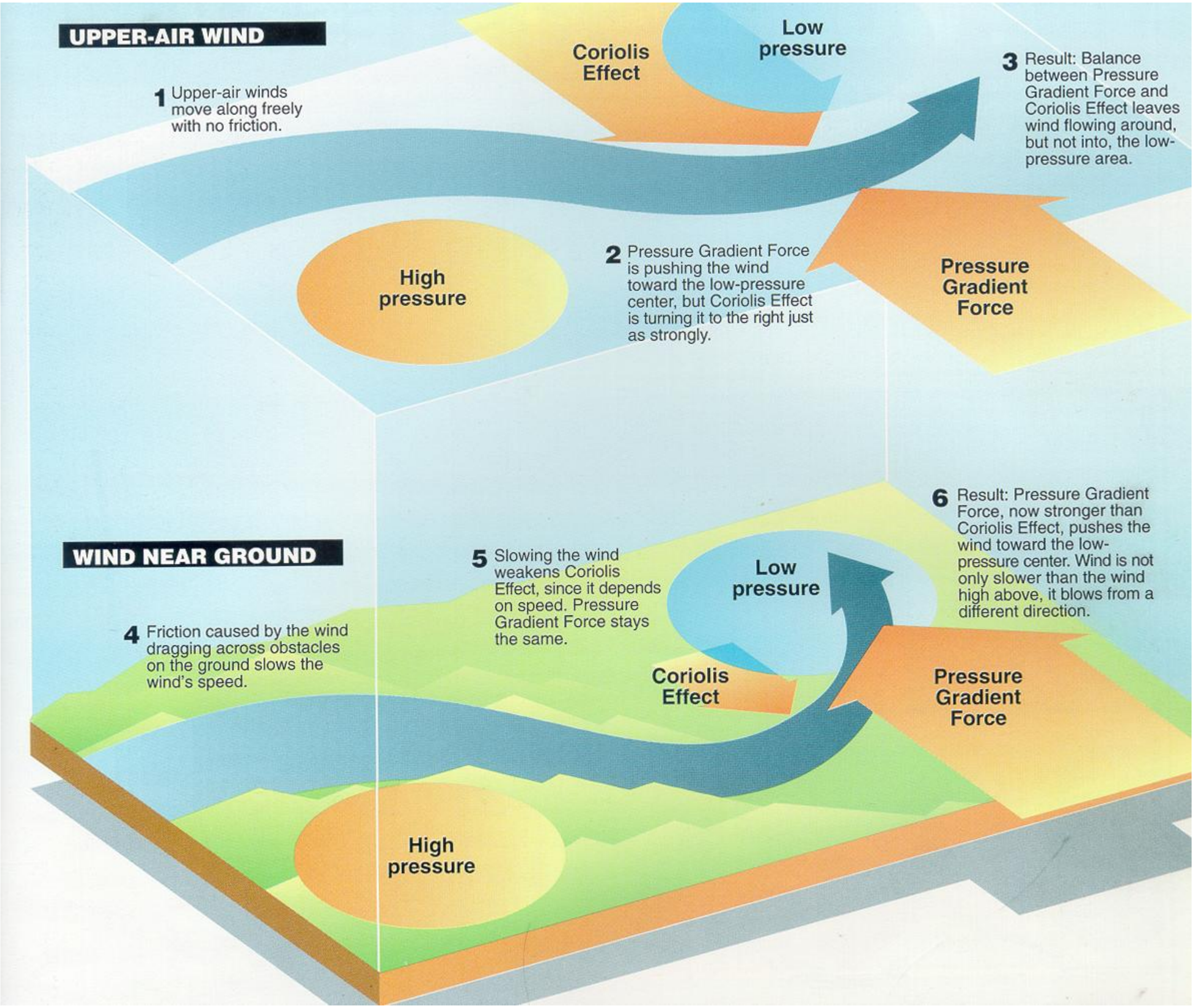


Ekman Spiral



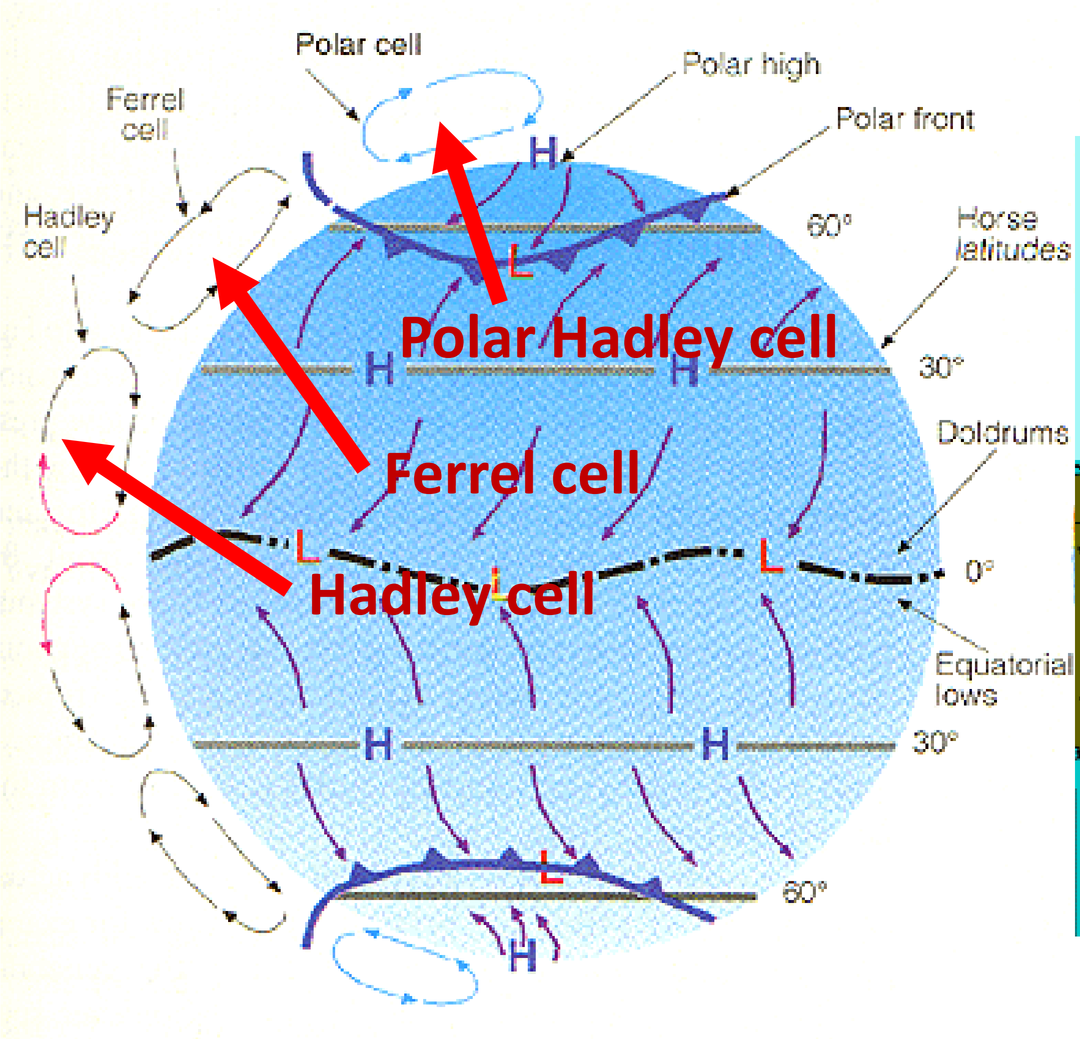
Another consequence of Ekman turning is the response of the upper-atmosphere to the low-atmosphere surface layer.



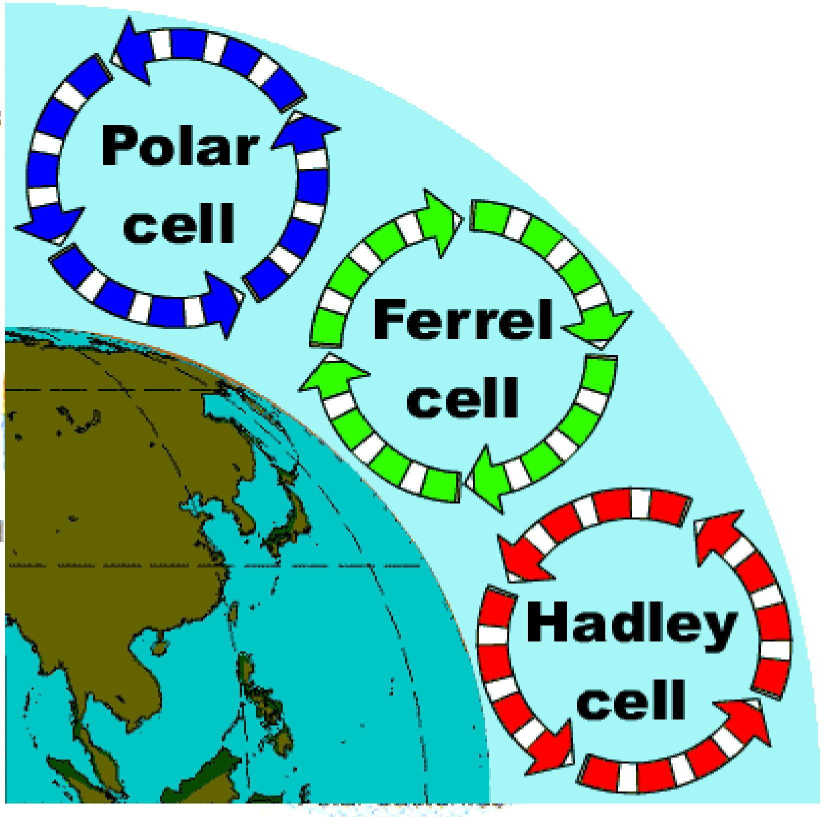

UPPER-AIR WIND
1 Upper-air winds move along freely with no friction.
Coriolis Effect
Low pressure
3 Result: Balance between Pressure Gradient Force and Coriolis Effect leaves wind flowing around, but not into, the low-pressure area.
High pressure
2 Pressure Gradient Force is pushing the wind toward the low-pressure center, but Coriolis Effect is turning it to the right just as strongly.
Pressure Gradient Force
WIND NEAR GROUND
5 Slowing the wind weakens Coriolis Effect, since it depends on speed. Pressure Gradient Force stays the same.
6 Result: Pressure Gradient Force, now stronger than Coriolis Effect, pushes the wind toward the low-pressure center. Wind is not only slower than the wind high above, it blows from a different direction.
Low pressure
4 Friction caused by the wind dragging across obstacles on the ground slows the wind's speed.
Coriolis Effect
Pressure Gradient Force
High pressure

Vertical patterns of the general circulation

Vertical winds structure

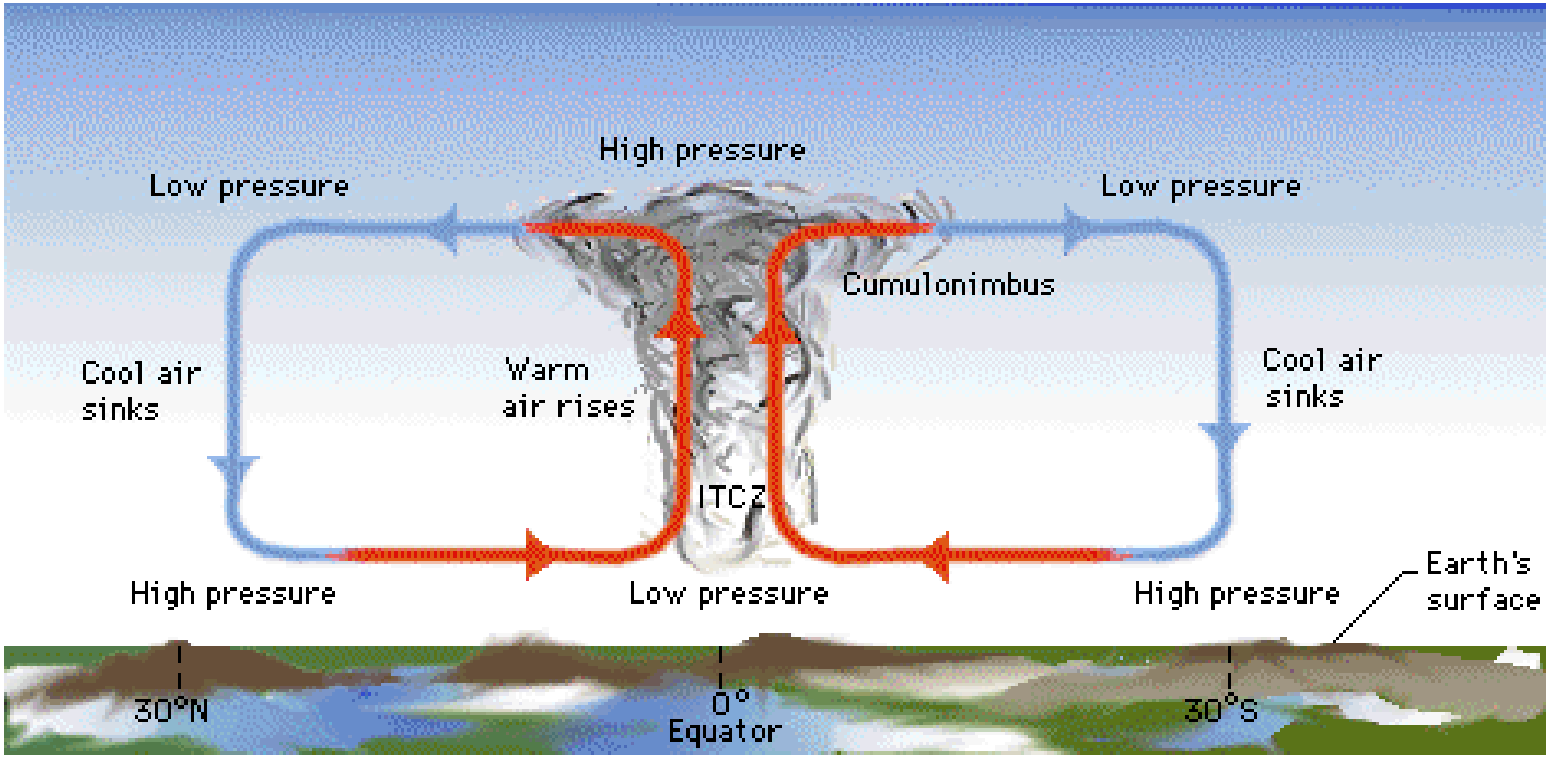


(a)



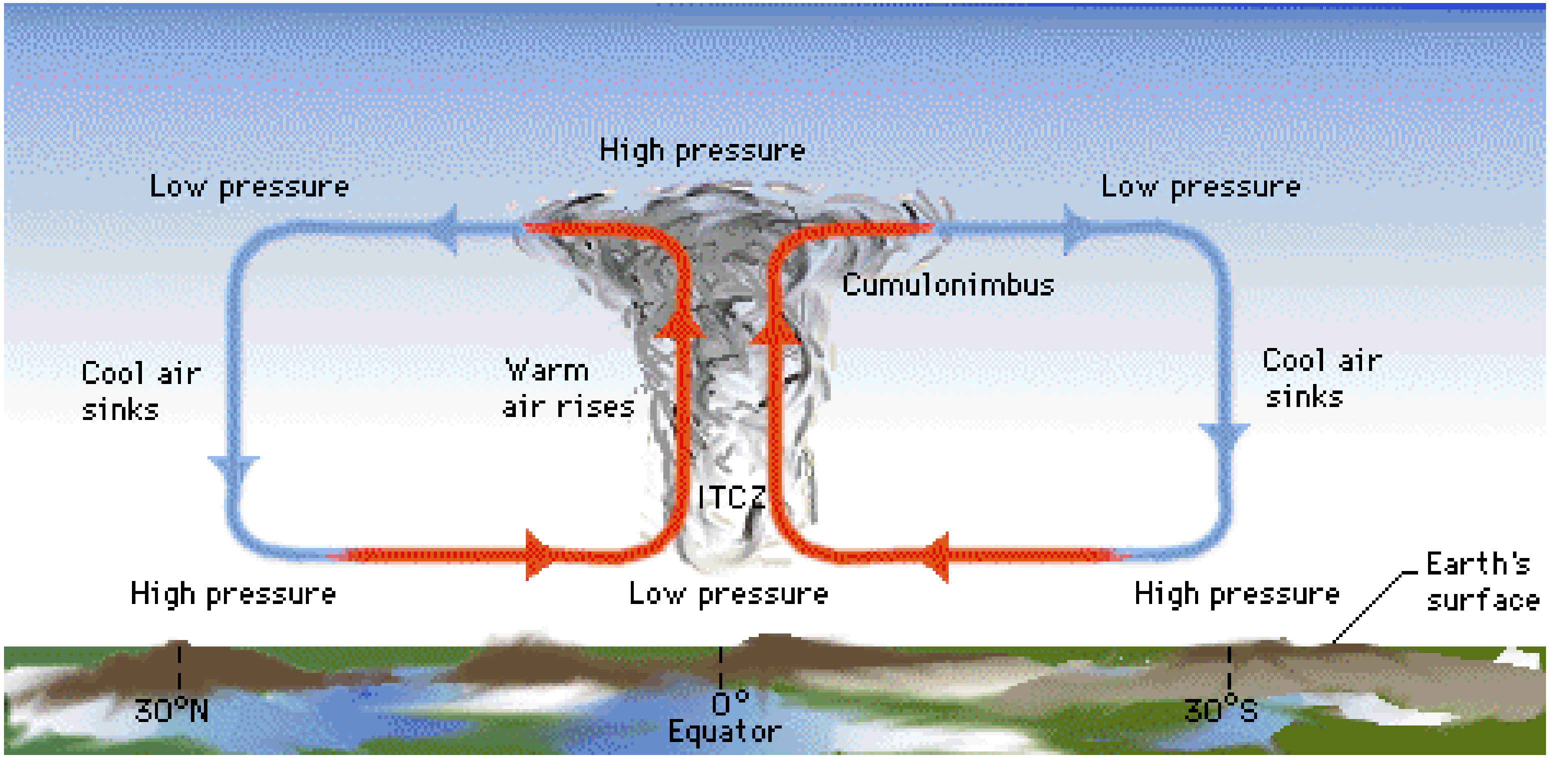
(b)

Hadley cell

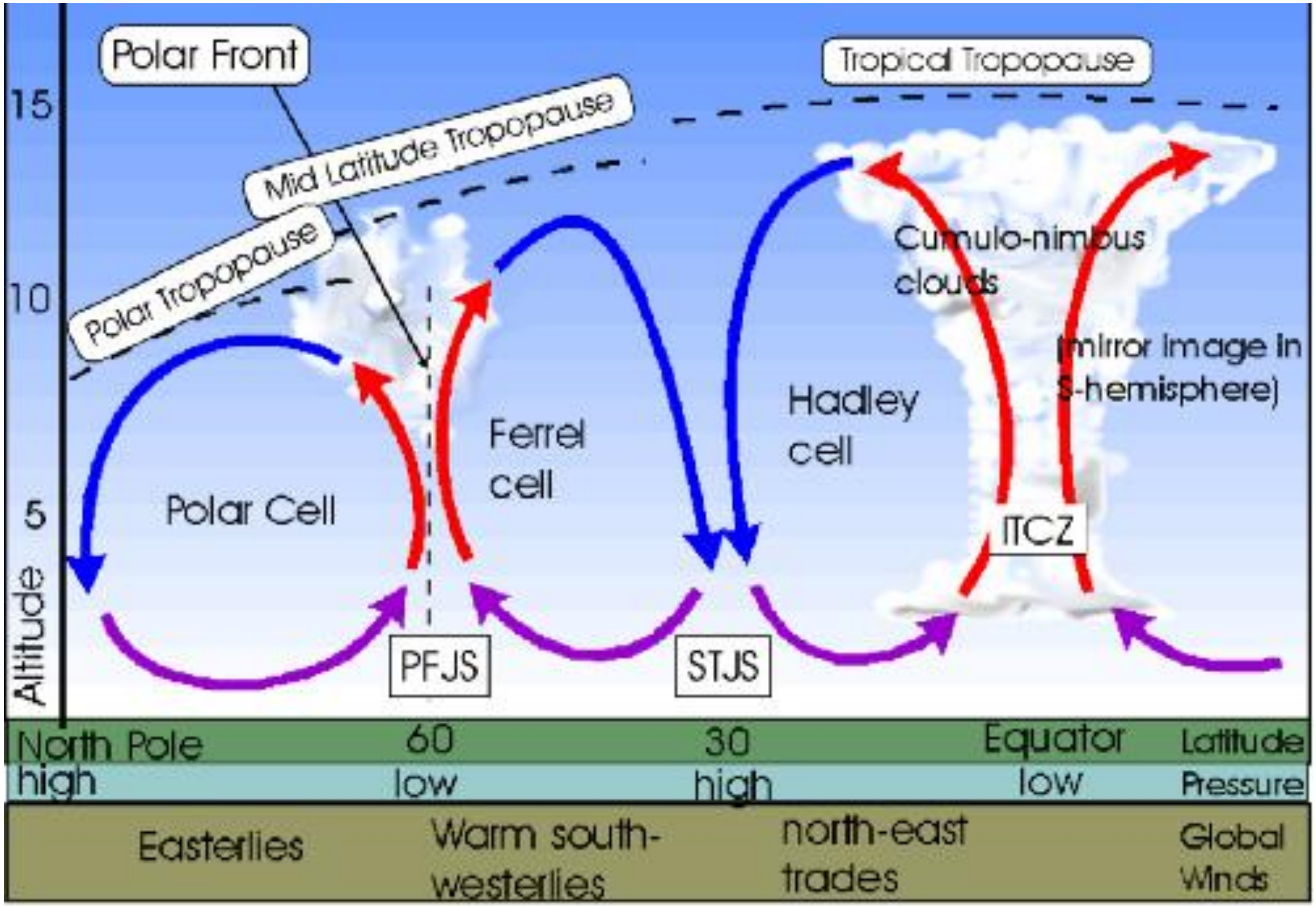


- Air ascending due to equatorial heating
- This defines the Intertropical Convergence Zone (ITCZ) were great amounts of latent heat are released
- The ascending air is replaced at the surface by air coming from higher latitudes – trade winds
- In ITCZ intense tropical storms are encountered (reviving for the areas)

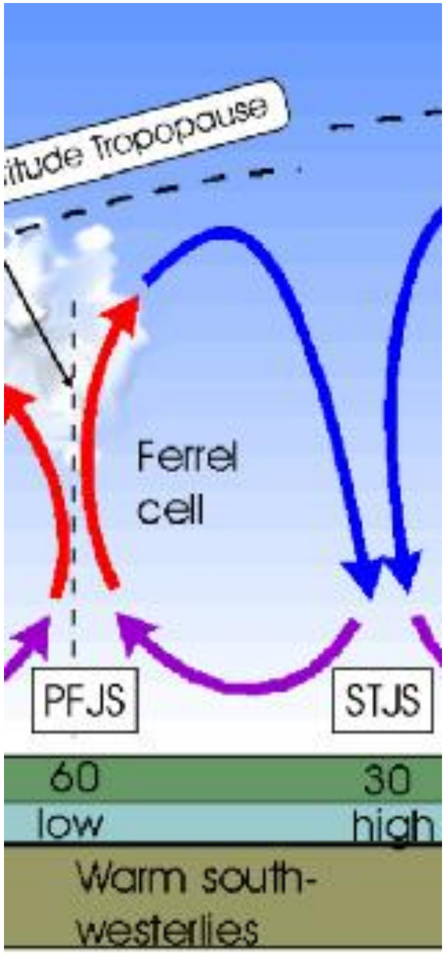
Hadley cell



- The zone of weak winds at the ITCZ is called «doldrums»
- Descending air at subtropical lats is responsible for the respective high pressure systems
- In these systems winds are also weak and the whole zone is called «horse latitudes» (transfer of horses towards west Indies by Spanish ships … due to low speeds and water scarcity they used to throw horses in the ocean !!!
- At horse latitudes: Good weather high pressure systems, with dry and warm air

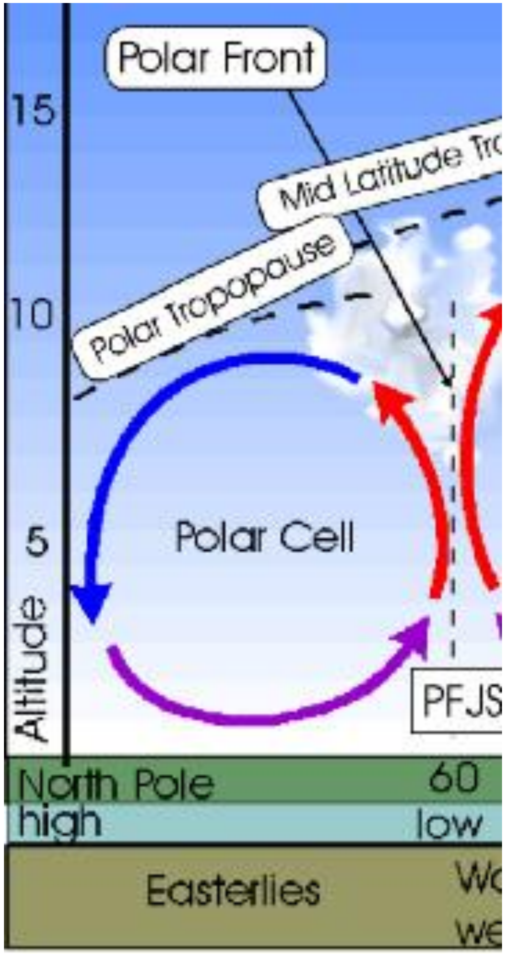

Polar Front
Tropical Tropopause
Mid Latitude Tropopause
Polar Tropopause
15
10
5
Altitude
Cumulo-nimbus clouds
(mirror image in S-hemisphere)
Hadley cell
Ferrel cell
Polar Cell
ITCZ
PFJS
STJS
North Pole
60
30
Equator
Latitude
high
low
high
low
Pressure
Easterlies
Warm south-westerlies
north-east trades
Global Winds

Ferrel cell



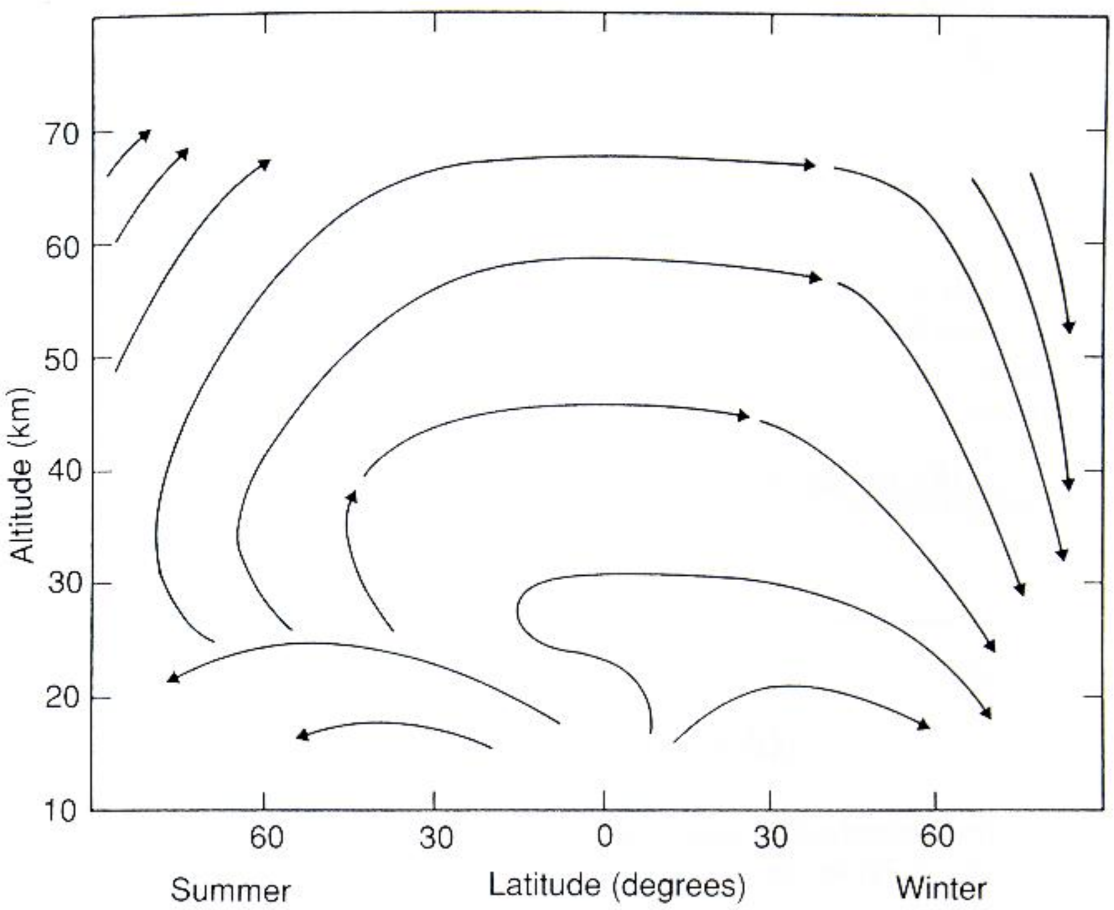
- These cells do not actually exist, however right ascending and descending branches of the winds are observed as well as the response of surface winds
- Warm and wet air at low altitudes moves towards the subtropical high pressure systems. This motion gives birth to the thermal fronts of mid-latitudes.
- At 50-60° there is ascend of air and creation of fronts responsible for cloudiness, rains and snow in these lats

Polar cell



- Slow descend of air at high latitudes accompanied by surface high pressure systems
- Surfacial flow toward the equator. The cold polar air meets warmer masses in mid-latitudes, creating the polar front

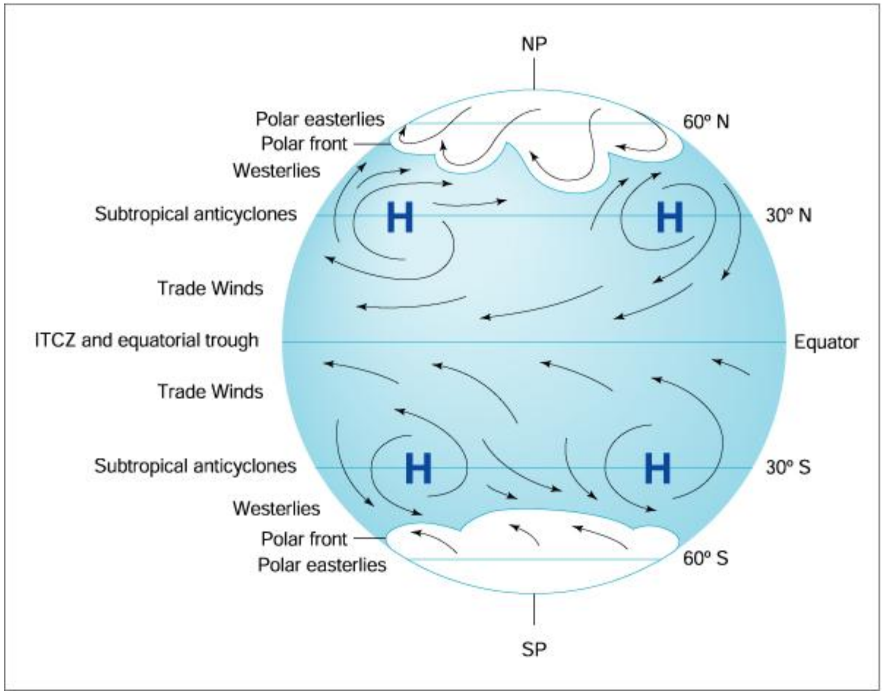
Stratospheric circulation



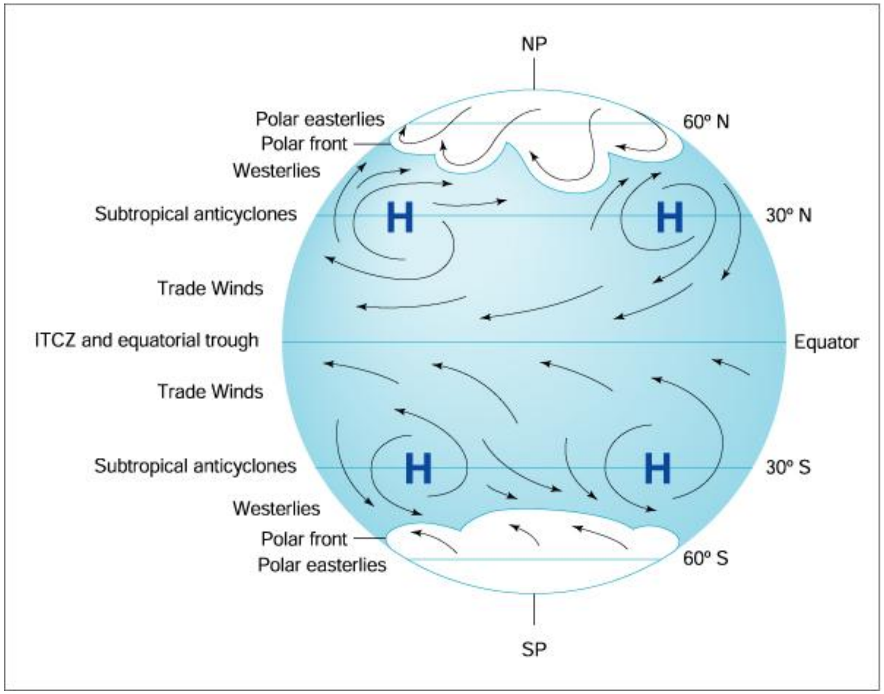
- Mainly due to inhomogeneity in temperature distribution and the expansion of Hadley cells in the lower stratosphere
- Ascending (descending) flow in the summer (winter) hemispheres

Main components of the general circulation

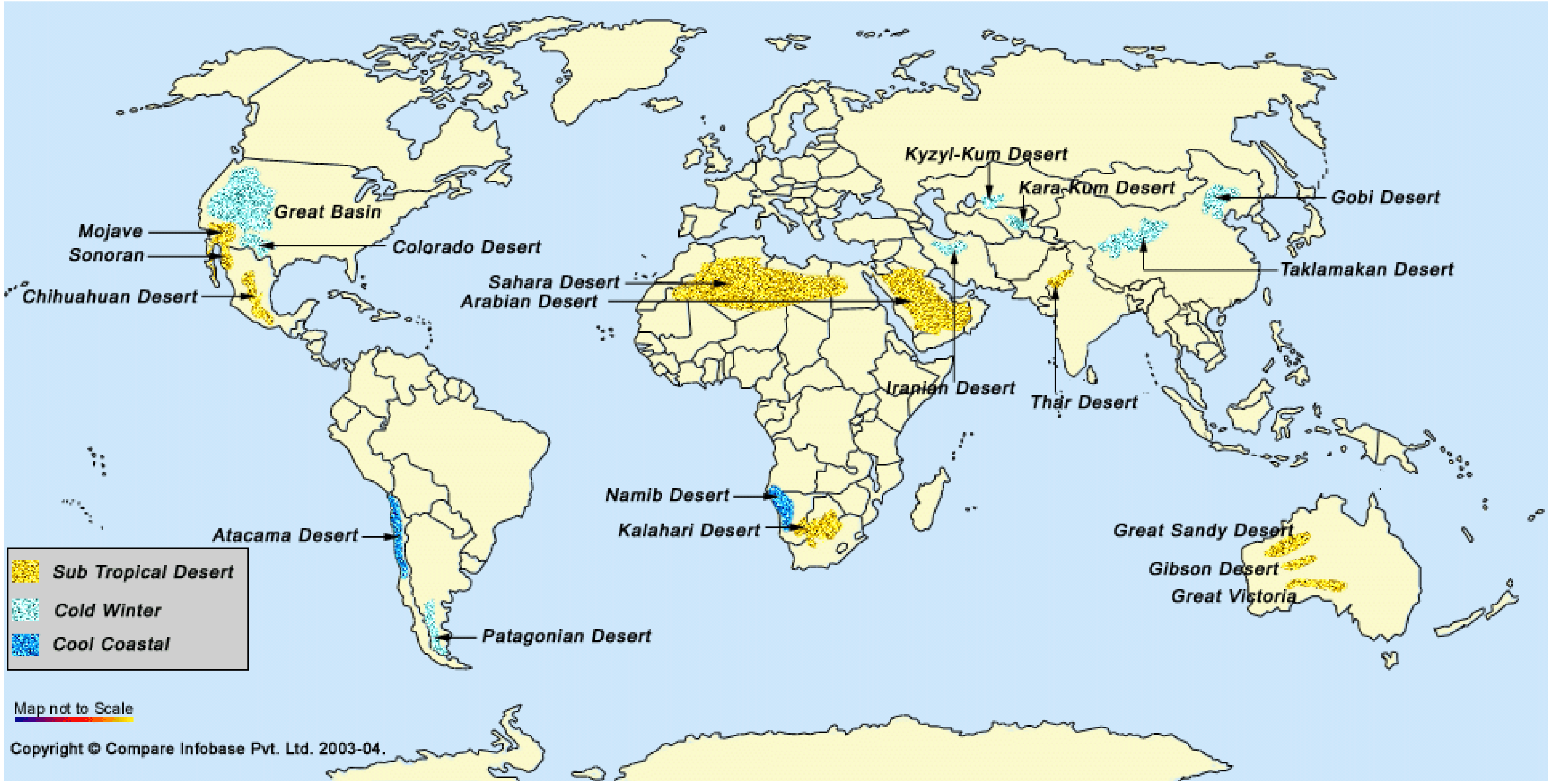
- ✓ Subtropical highs
- ✓ Intertropical convergence zone
- ✓ Polar highs
- ✓ Subpolar lows
- ✓ Trade winds
- ✓ Midlatitude westerlies
- ✓ Polar easterlies



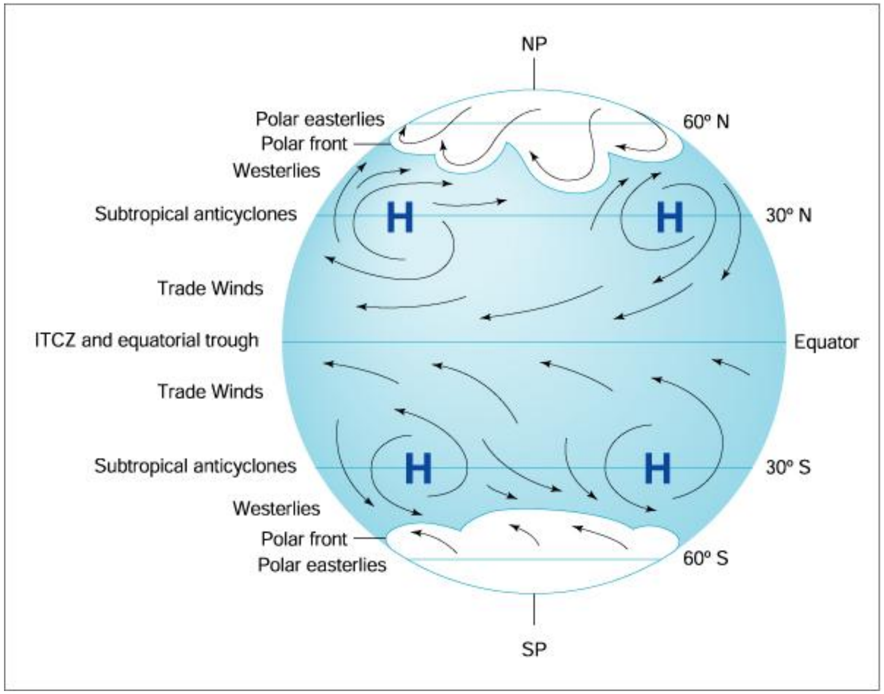
- ✓ Subtropical highs
- ✓ Intertropical convergence zone
- ✓ Polar highs
- ✓ Subpolar lows
- ✓ Trade winds
- ✓ Midlatitude westerlies
- ✓ Polar easterlies



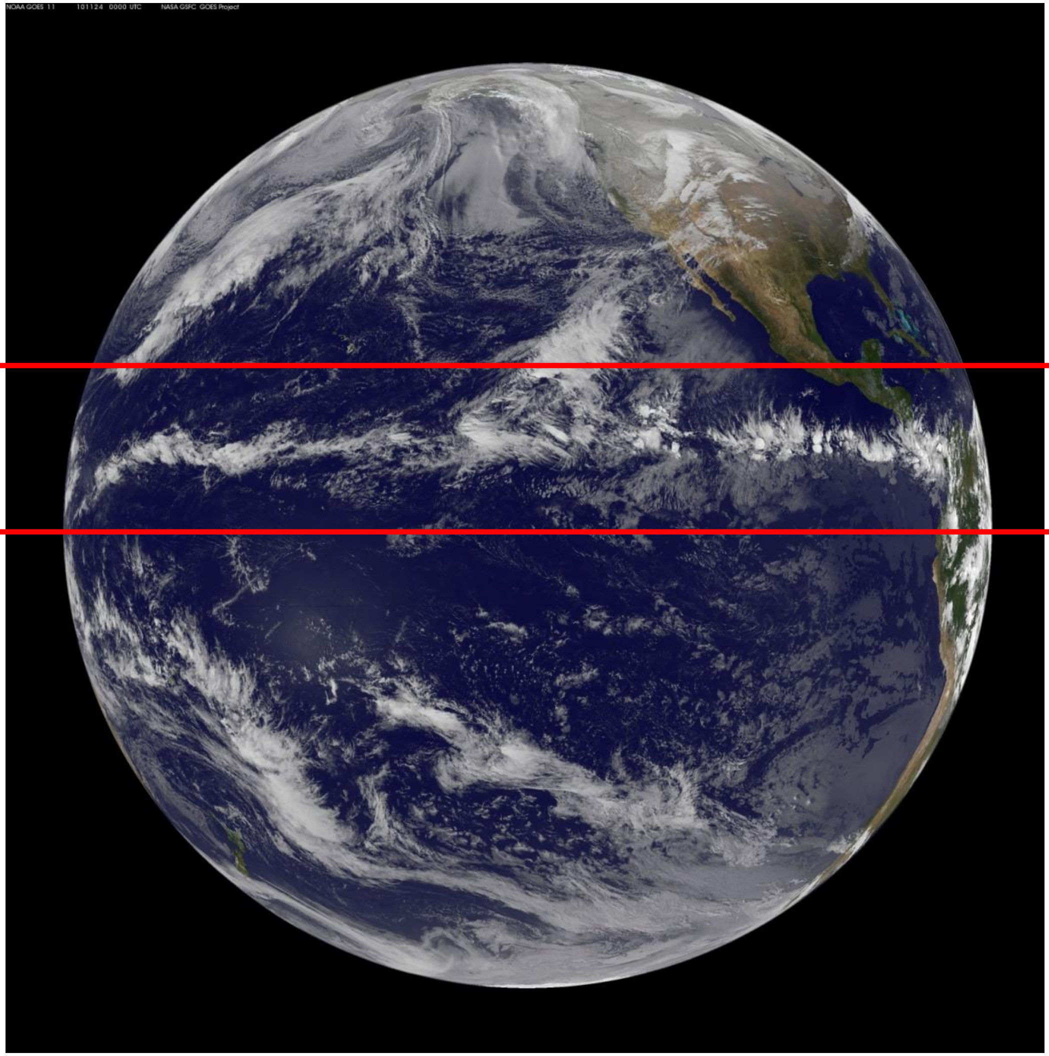
- ❖ These latitudes are the “source” of the major surface winds
- ❖ The average diameter of the subtropical highs is about 3.200 km centered at about 30° latitude over the oceans
- ❖ They develop from the descending limbs of Hadley cells
- ❖ Their location coincide with most of the world’s major desert areas.

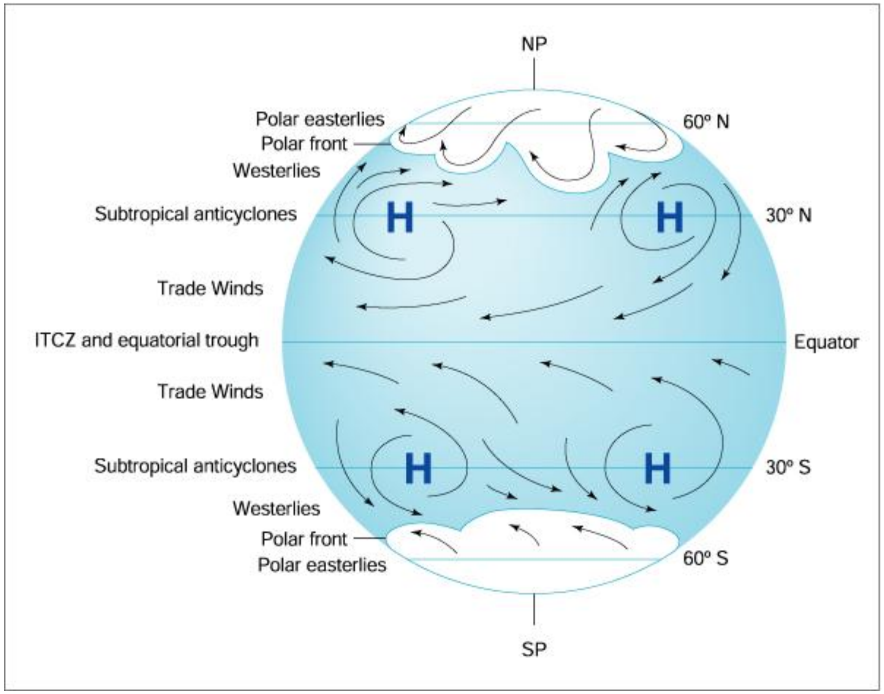

Kyzyl-Kum Desert
Kara-Kum Desert
Gobi Desert
Great Basin
Mojave
Sonoran
Colorado Desert
Taklamakan Desert
Sahara Desert
Arabian Desert
Chihuahuan Desert
Iranian Desert
Thar Desert
Namib Desert
Kalahari Desert
Great Sandy Desert
Atacama Desert
Gibson Desert
Great Victoria
Sub Tropical Desert
Cold Winter
Cool Coastal
Patagonian Desert
Map not to Scale
Copyright © Compare Infobase Pvt. Ltd. 2003-04.

- ✓ Subtropical highs
- ✓ Intertropical convergence zone
- ✓ Polar highs
- ✓ Subpolar lows
- ✓ Trade winds
- ✓ Midlatitude westerlies
- ✓ Polar easterlies



- ❖ The ITCZ is a belt of calm air where the NE trades and SE trades converge
- ❖ Also called the equatorial front, the intertropical front, and the doldrums.
- ❖ Its thunderstorms provide the updrafts where all the rising air in of the tropics ascends
- ❖ Often appears as a narrow band of clouds over oceans, but it is less distinct over continents


NOAA GOES 11
101124 0000 UTC
NASA GSFC GOES Project



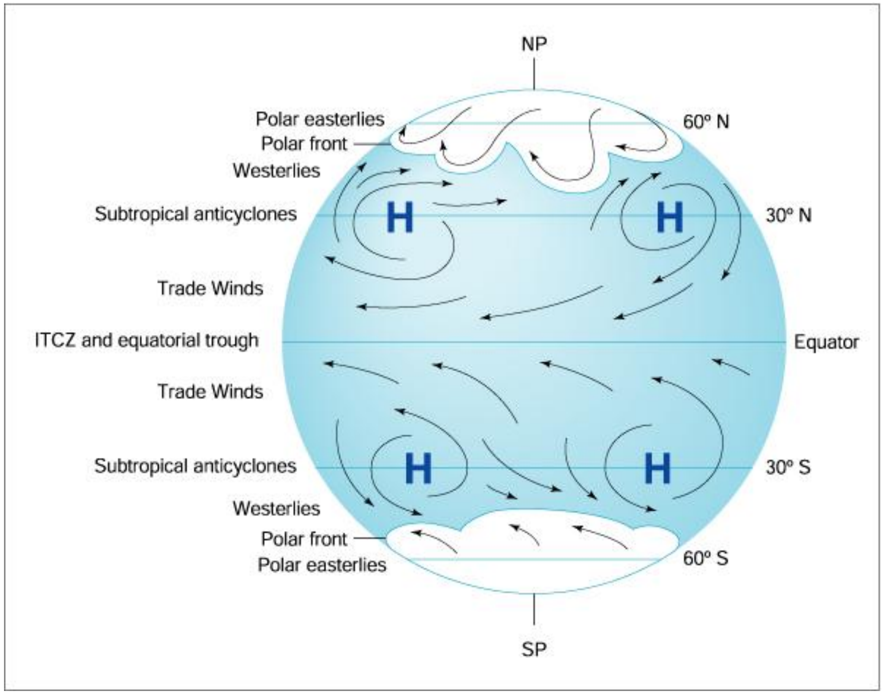
- ✓ Subtropical highs
- ✓ Intertropical convergence zone
- ✓ Polar highs
- ✓ Subpolar lows
- ✓ Trade winds
- ✓ Midlatitude westerlies
- ✓ Polar easterlies

❖ The difference between Antarctic and Arctic highs is due to the fact that the first forms over a high-elevation and cold continent, while the latter over sea ice

❖The Antarctic high is strong, persistent and almost permanent, while the Arctic high is much less pronounced and more ephemeral

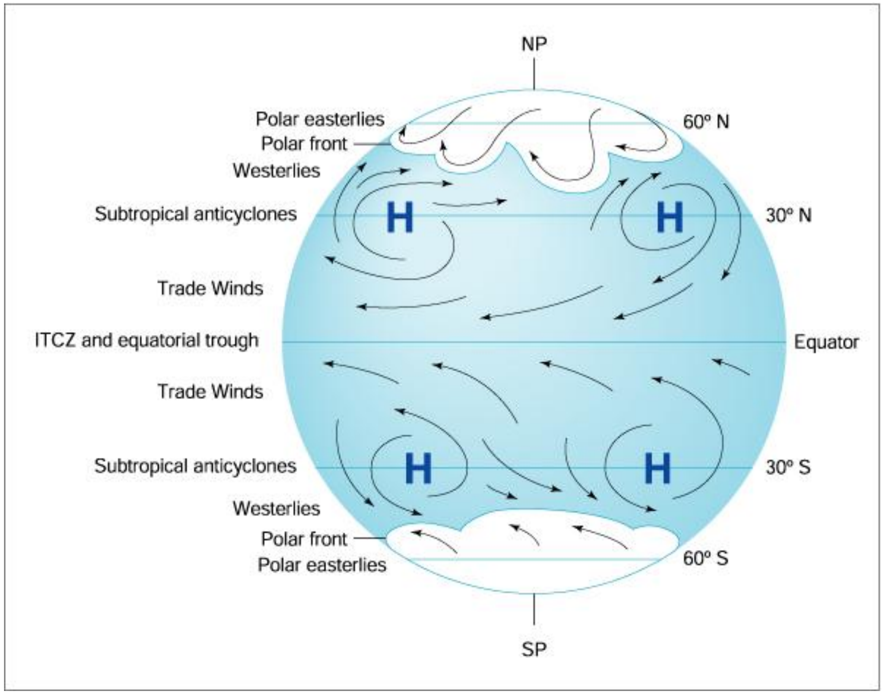
❖They are the source of the polar easterlies, which blow toward the equator and west

- ✓ Subtropical highs
- ✓ Intertropical convergence zone
- ✓ Polar highs
- ✓ Subpolar lows
- ✓ Trade winds
- ✓ Midlatitude westerlies
- ✓ Polar easterlies

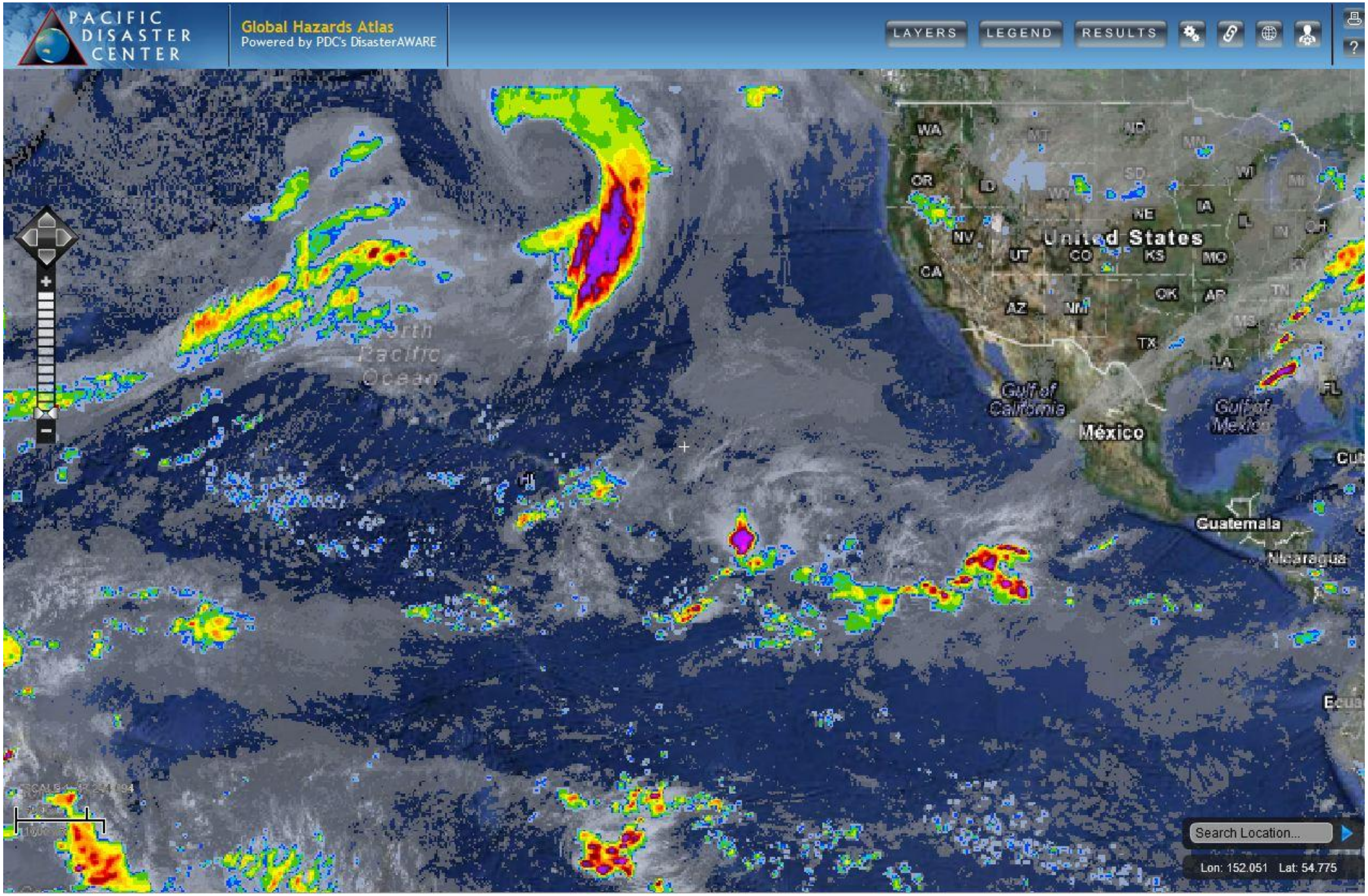


- ❖ A zone of low pressure at about 50° to 60° latitude in both hemispheres
- ❖ They often contain the polar front
- ❖ Different in each hemisphere since the continents of the N versus the oceans of the S modify circulation
- ❖ The polar front is the meeting ground of the cold polar easterlies and the warm mid-latitude westerlies, and is the site of genesis of many mid-latitude weather systems.

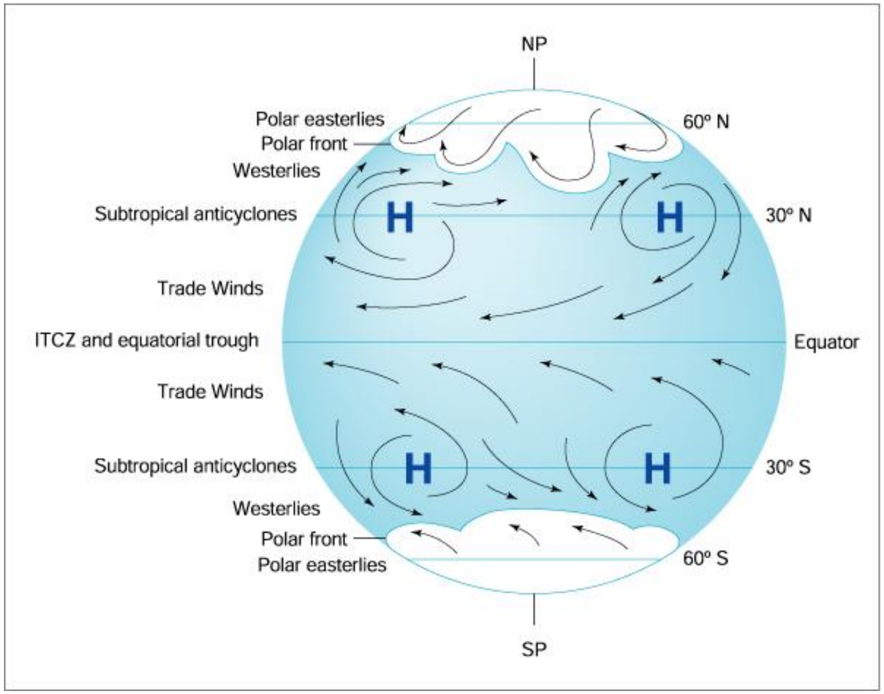
✓ Subtropical highs
✓ Intertropical convergence zone
✓ Polar highs
✓ Subpolar lows
✓ Trade winds
✓ Midlatitude westerlies
✓ Polar easterlies



- The major wind system of the tropics
- Originate from the nearest to equator sides of the subtropical highs and blow towards the west and the equator
- They are the most reliable of all winds in terms of both direction and speed
- They are warming, drying winds capable of holding enormous amounts of moisture
- They release moisture when forced by a topographic barrier or a pressure disturbance


PACIFIC DISASTER CENTER
Global Hazards Atlas
Powered by PDC's DisasterAWARE
LAYERS
LEGEND
RESULTS
North Pacific Ocean
WA
OR
ID
NV
CA
UT
CO
AZ
NM
NE
KS
MO
OK
AR
TX
LA
IA
WI
MN
ND
SD
United States
Gulf of California
México
Gulf of Mexico
Guatemala
Nicaragua
HI
Search Location...
Lon: 152.051 Lat: 54.775

- ✓ Subtropical highs
- ✓ Intertropical convergence zone
- ✓ Polar highs
- ✓ Subpolar lows
- ✓ Trade winds
- ✓ Midlatitude westerlies
- ✓ Polar easterlies



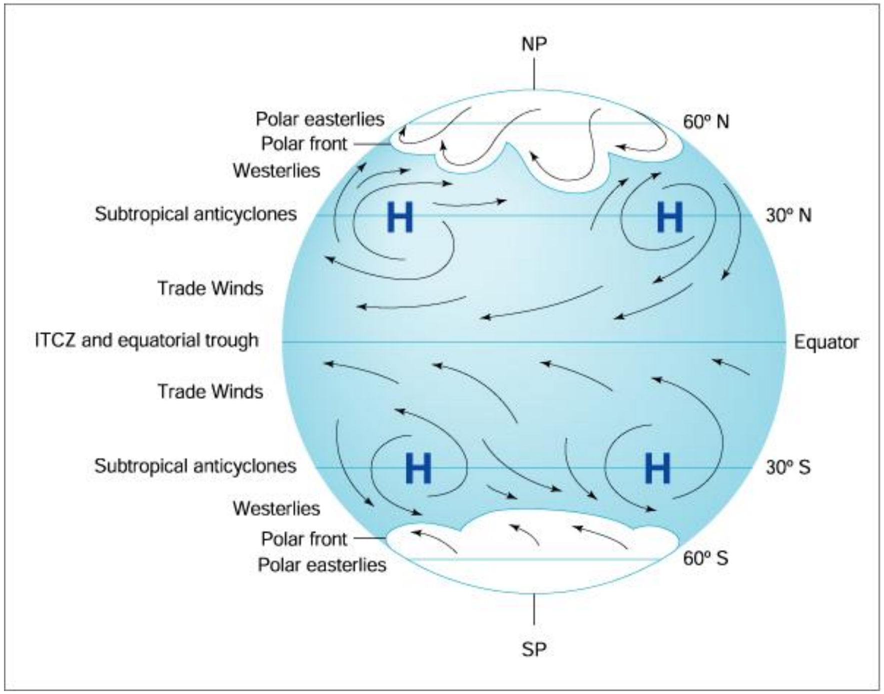
❖ They are found in a latitudinal zone between about 30° and 60˚. They originate from the poleward side of the subtropical highs, blowing toward the poles and the east.

❖There are two cores of high-speed winds at high altitudes in the westerlies, the polar front jet stream and the subtropical front jet stream

❖ A major feature are the Rossby waves, sweeping north-south undulations that frequently develop aloft. Coupled with the migratory pressure systems and storms associated with the westerlies, give the middle latitudes more short-run weather variability than any other place on Earth

❖ Anticyclonic circulation at the surface is associated with ridges in the waves, while cyclonic circulation is associated with troughs in the waves.

- ✓ Subtropical highs
- ✓ Intertropical convergence zone
- ✓ Polar highs
- ✓ Subpolar lows
- ✓ Trade winds
- ✓ Midlatitude westerlies
- ✓ Polar easterlies



- ❖ They are a global wind system that occupies most of the area between the polar highs and about 60° of latitude
- ❖ Typically cold and dry

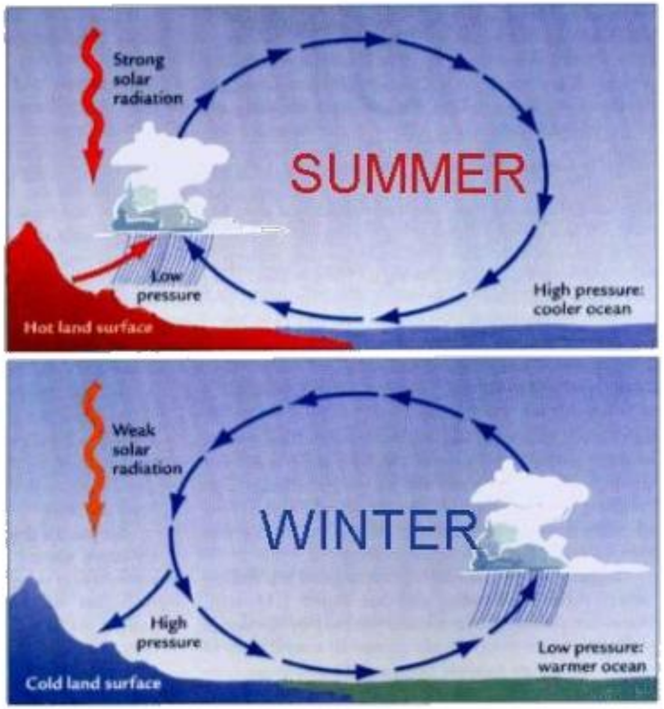
Usual disturbances of the general circulation

Monsoons

Differential heating

Summer: Intense heating of land mass. Oceans take longer to warm. This generates pressure differences leading to SW winds (Em and Tm air masses).

Winter: Land cools rapidly. Ocean retains warmth. Pressure change is reversed and winds move from NE (Tc and Pc from desert).



❖ **Significance:** Their failure or late arrival of monsoonal moisture causes widespread starvation and economic disaster

❖ Brings about long drought periods from September to March. It is hard to grow crops during this period due to the lack of water

❖ The summer monsoon is known to do the opposite, bringing huge amounts of moisture from the Indian Ocean causing massive flooding in many areas

❖ *They control the climate of areas were almost more than half of the global population lives in*

Monsoons

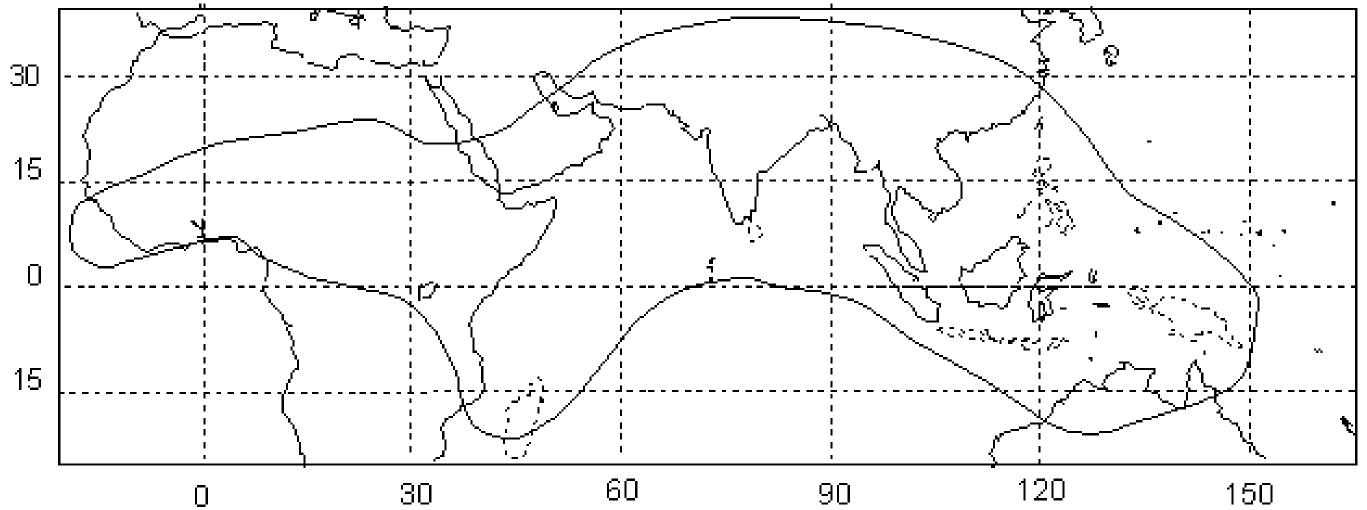


Figure 1. Monsoon areas (enclosed by solid line)
From: The Encyclopedia of Climatology (Oliver & Fairbridge, 1987)

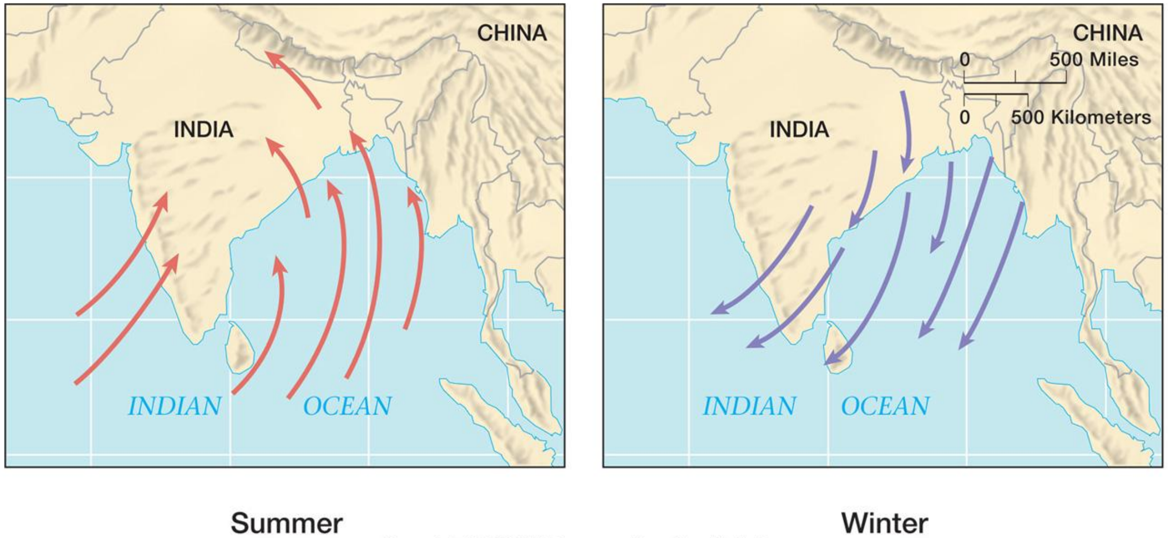
❖ **Significance:** Their failure or late arrival of monsoonal moisture causes widespread starvation and economic disaster

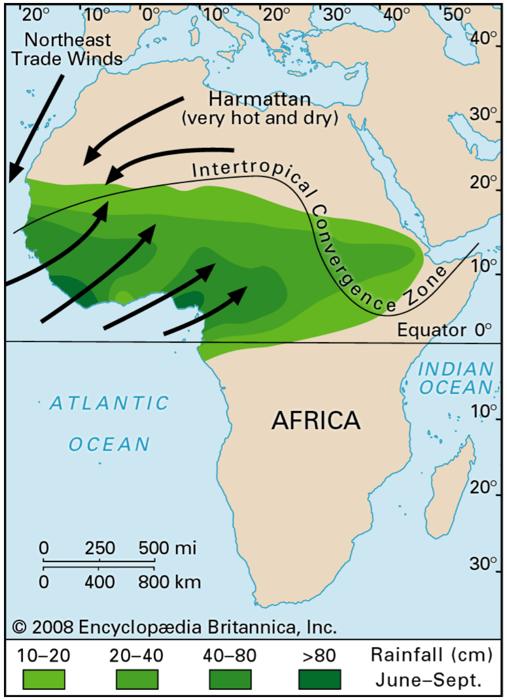
❖ Brings about long drought periods from September to March. It is hard to grow crops during this period due to the lack of water

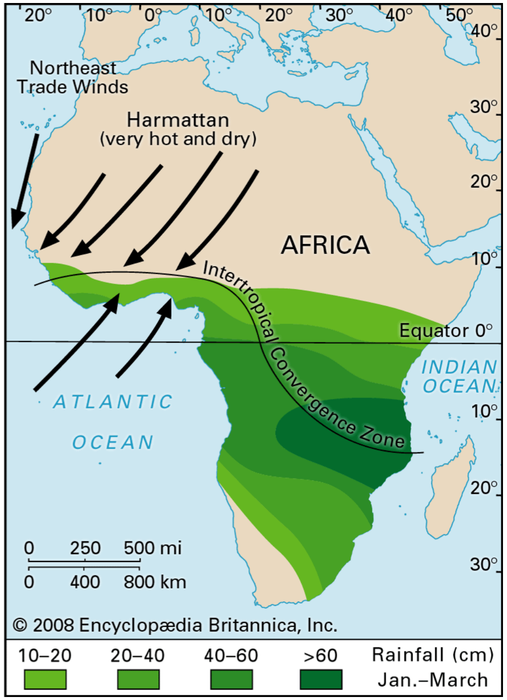
❖ The summer monsoon is known to do the opposite, bringing huge amounts of moisture from the Indian Ocean causing massive flooding in many areas

❖ *They control the climate of areas were almost more than half of the global population lives in*

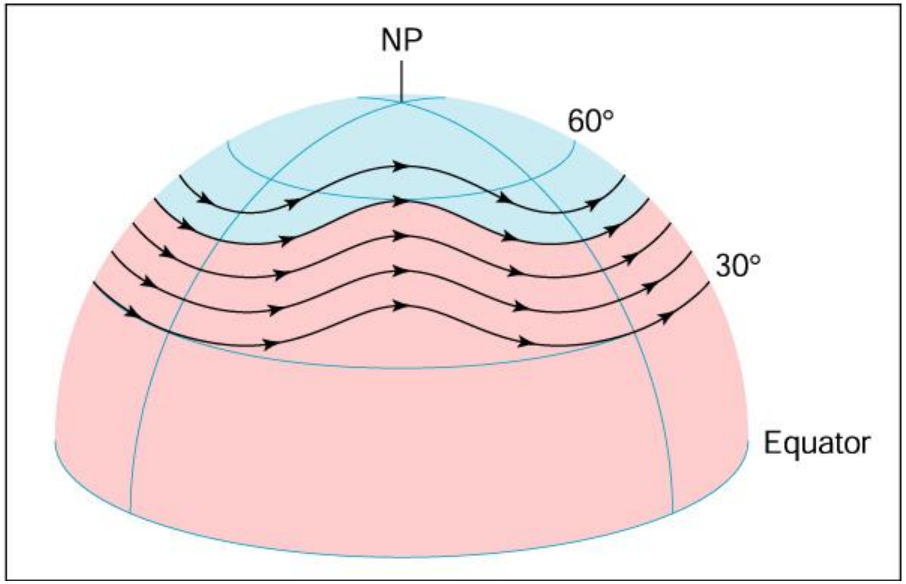
Monsoons


CHINA
INDIA
INDIAN OCEAN
Summer
CHINA
0 500 Miles
0 500 Kilometers
INDIA
INDIAN OCEAN
Winter


Northeast Trade Winds
Harmattan (very hot and dry)
Intertropical Convergence Zone
Equator 0°
ATLANTIC OCEAN
INDIAN OCEAN
AFRICA
0 250 500 mi
0 400 800 km
© 2008 Encyclopædia Britannica, Inc.
10–20 20–40 40–80 >80 Rainfall (cm) June–Sept.

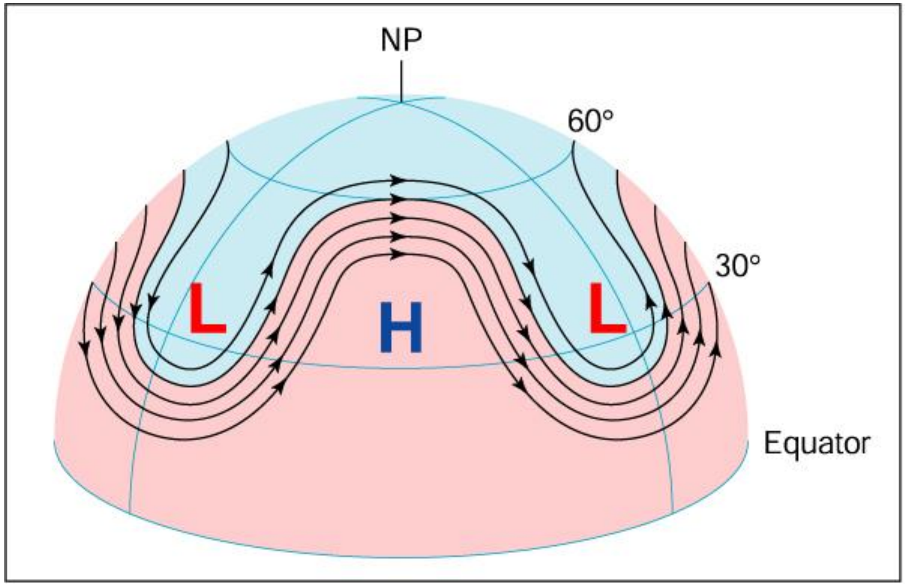

Northeast Trade Winds
Harmattan (very hot and dry)
AFRICA
Intertropical Convergence Zone
Equator 0°
ATLANTIC OCEAN
INDIAN OCEAN
0 250 500 mi
0 400 800 km
© 2008 Encyclopædia Britannica, Inc.
10–20 20–40 40–60 >60 Rainfall (cm) Jan.–March

Rossby waves



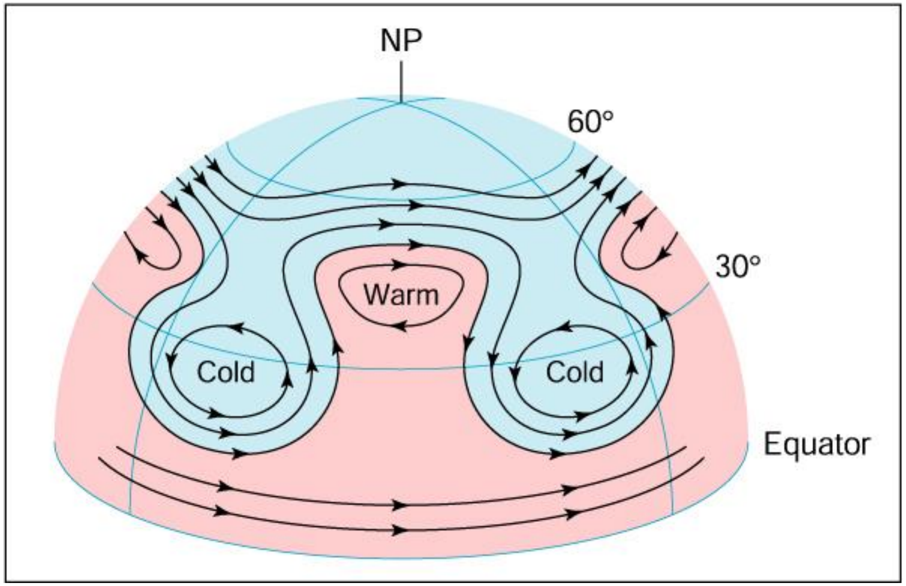
- Typically 2-5 waves in a hemisphere at any given time
- Winds exhibit anticyclonic flow in the ridges, and cyclonic flow in the troughs
- Wave characteristics: wavelength, amplitude, wave number
- Zonal flow occurs when there is a minimal north-south component (minimal amplitude) in the Rossby waves.

Rossby waves



❖ Meridional flow occurs when there is a considerable north-south component (considerable amplitude) in the Rossby waves.

Rossby waves



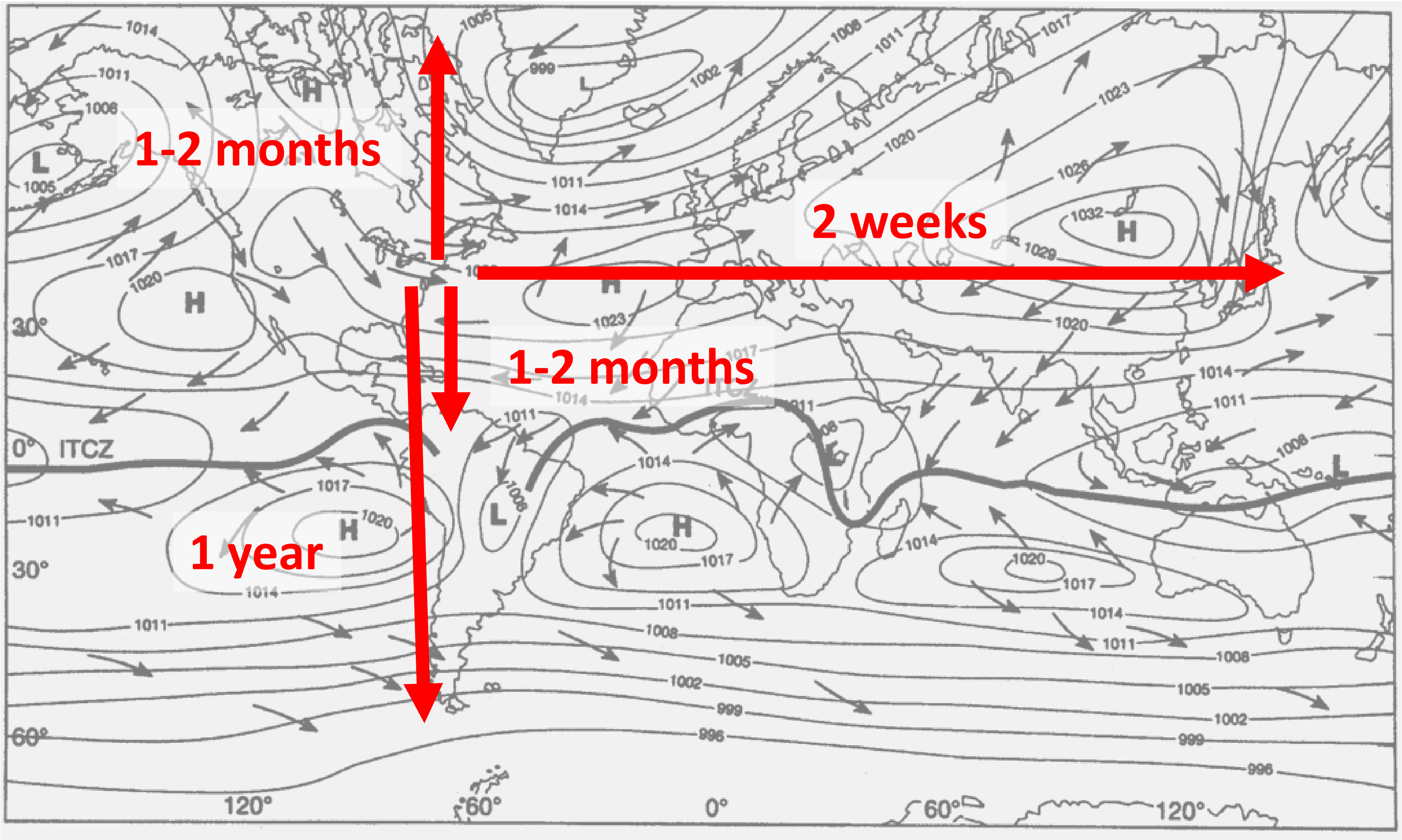
❖ When Rossby circulation is strongly meridional, whirling masses of air separate from the main westerly flow

❖Such cutoff air may prevent the usual east-west flow of the westerlies, thus setting up blocking systems

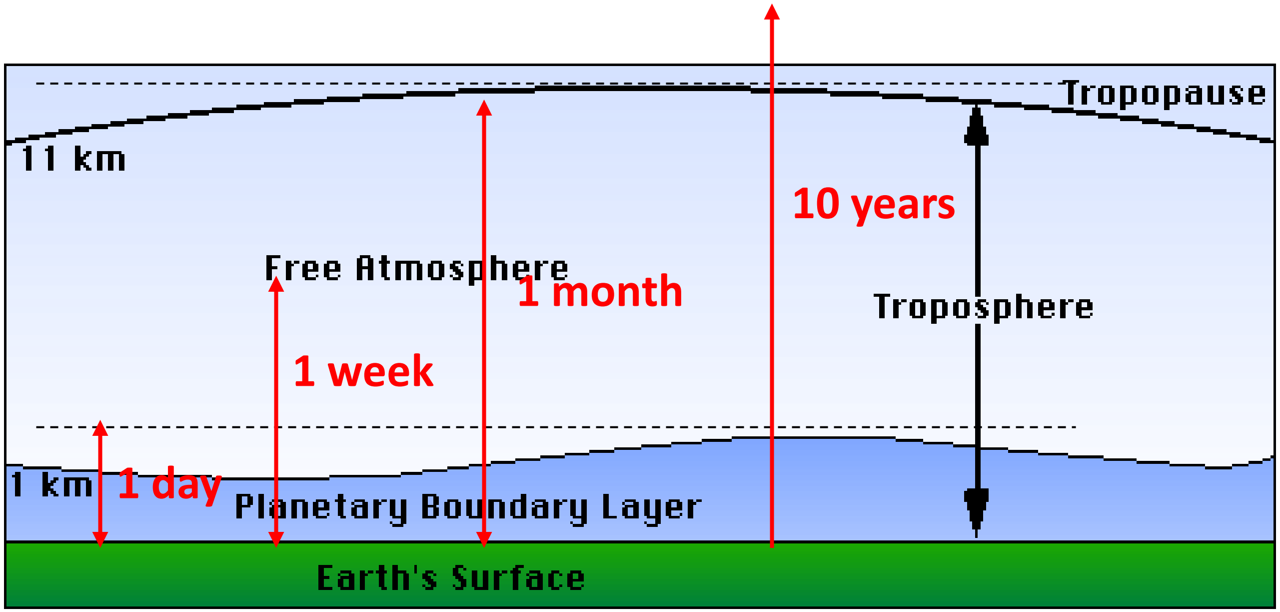
❖These blocking systems are often responsible for extreme weather patterns (e.g. droughts or floods) but also for stratospheric air intrusions into the troposphere

On the time scales involved

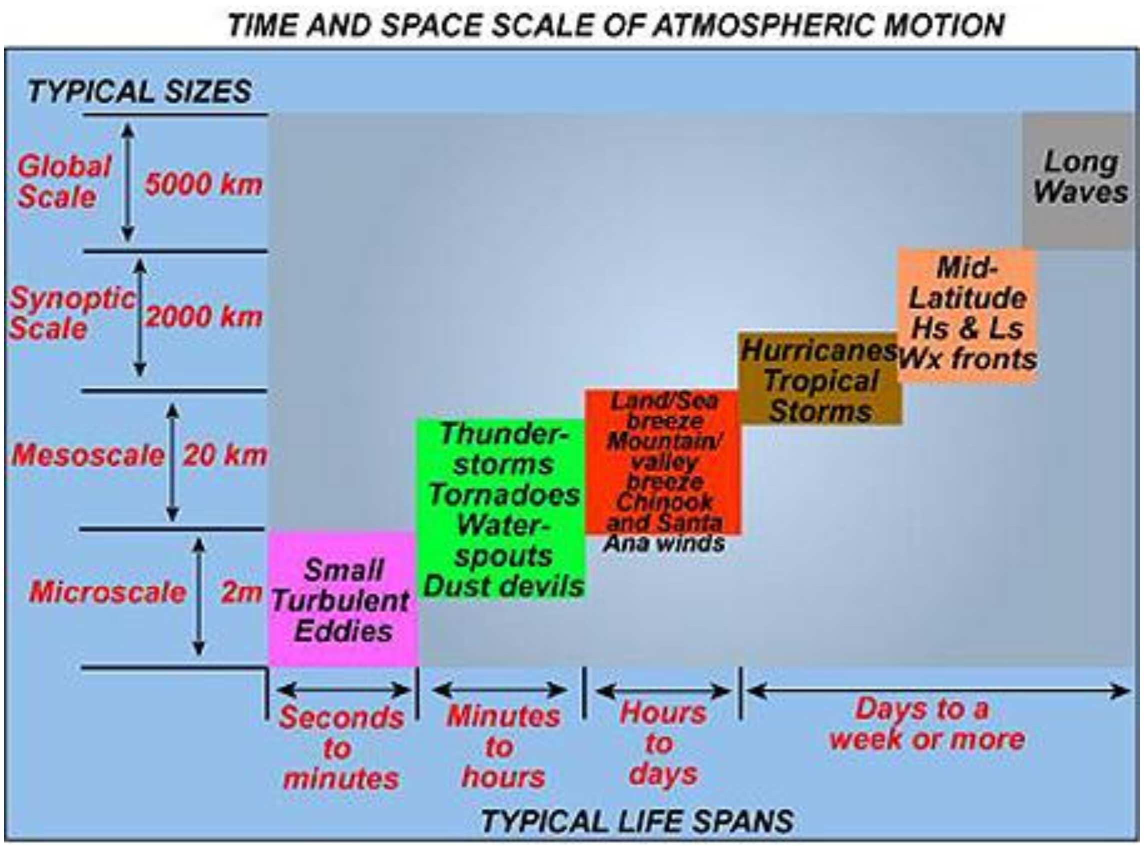
TIME SCALES FOR HORIZONTAL TRANSPORT (TROPOSPHERE)



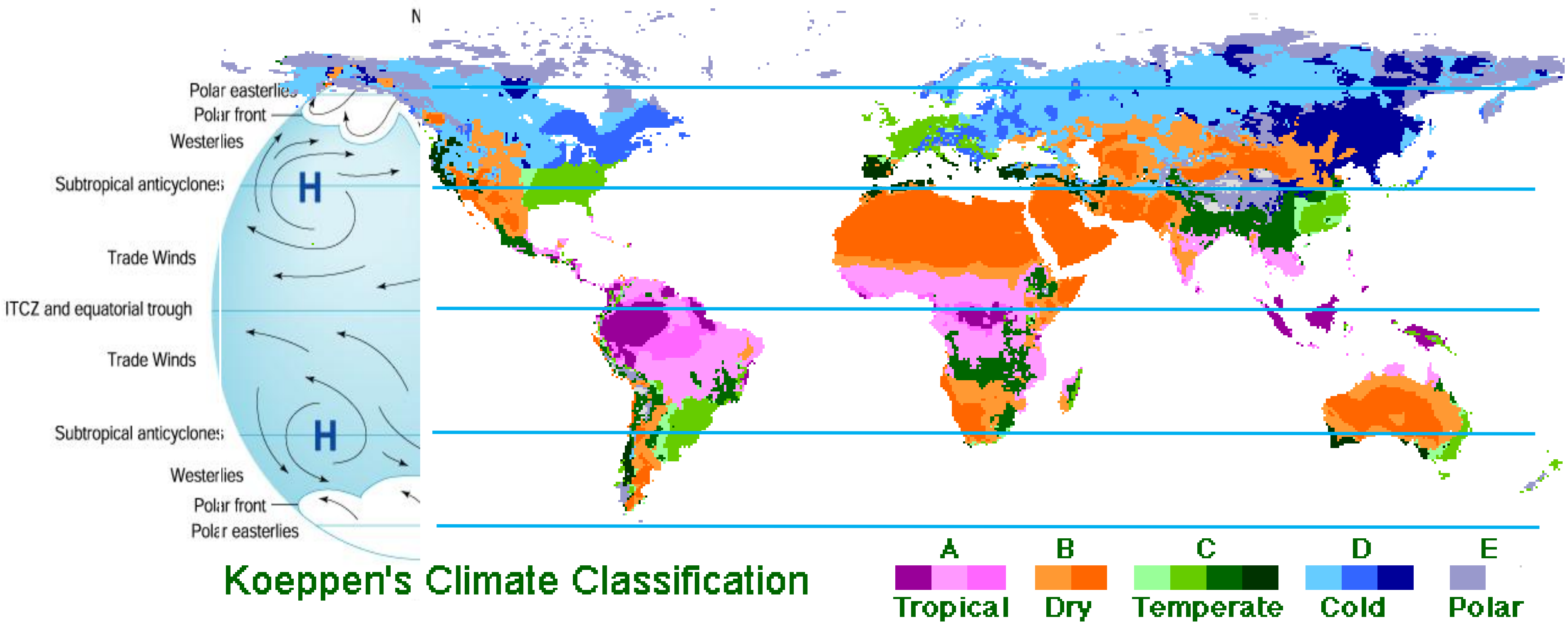
TYPICAL TIME SCALES FOR VERTICAL MIXING

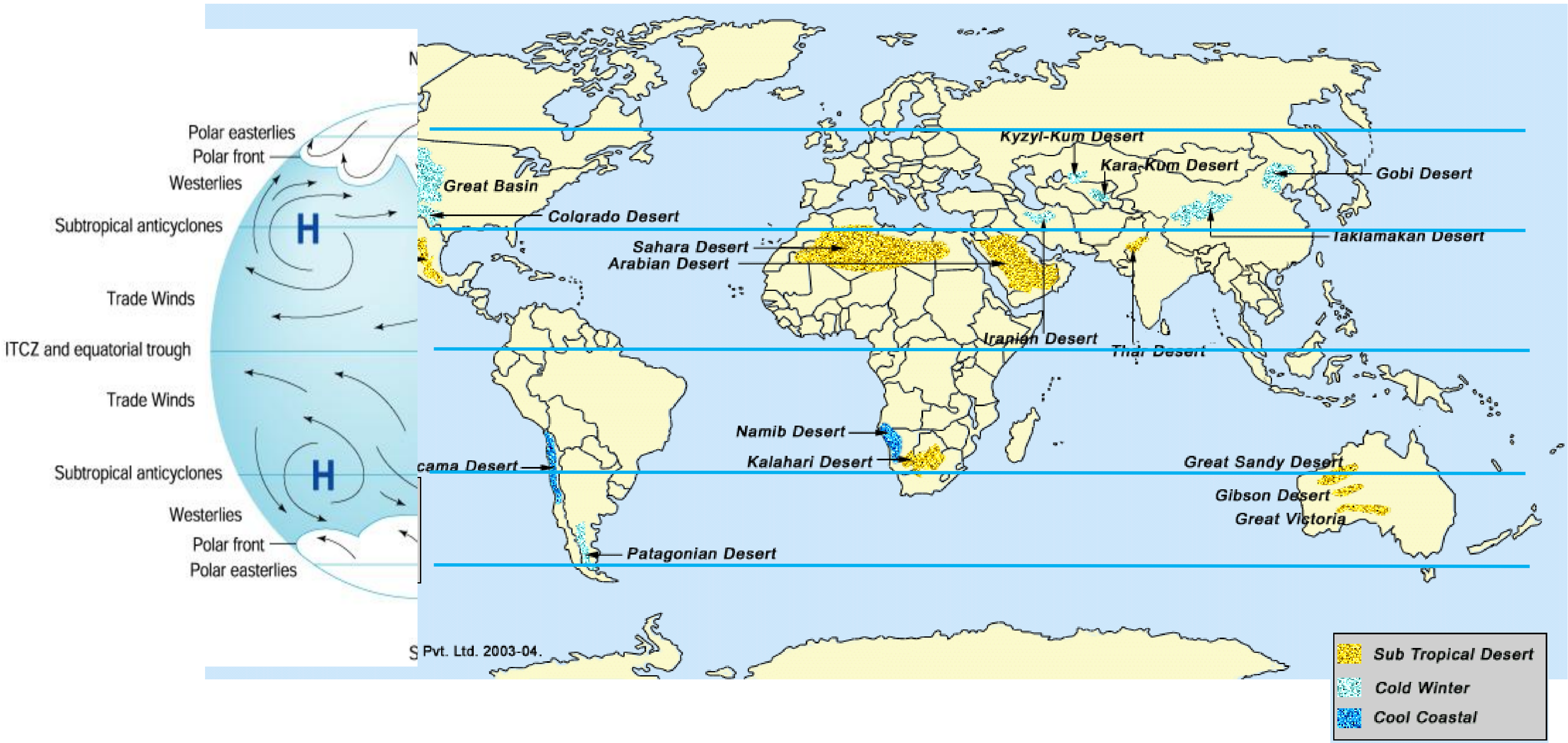


Weather phenomena categorization by size and time in order to understand typical timescales of air motion

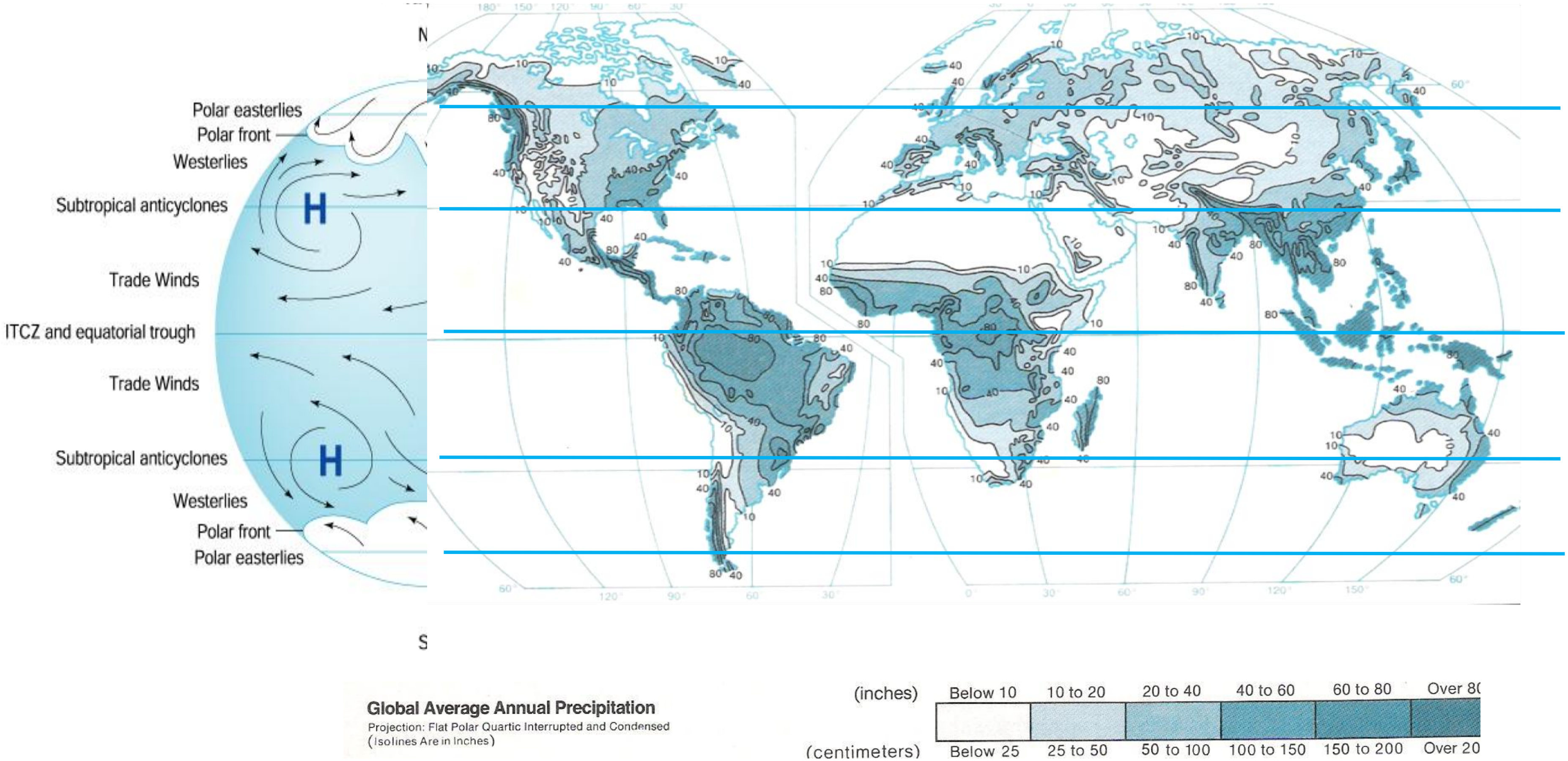


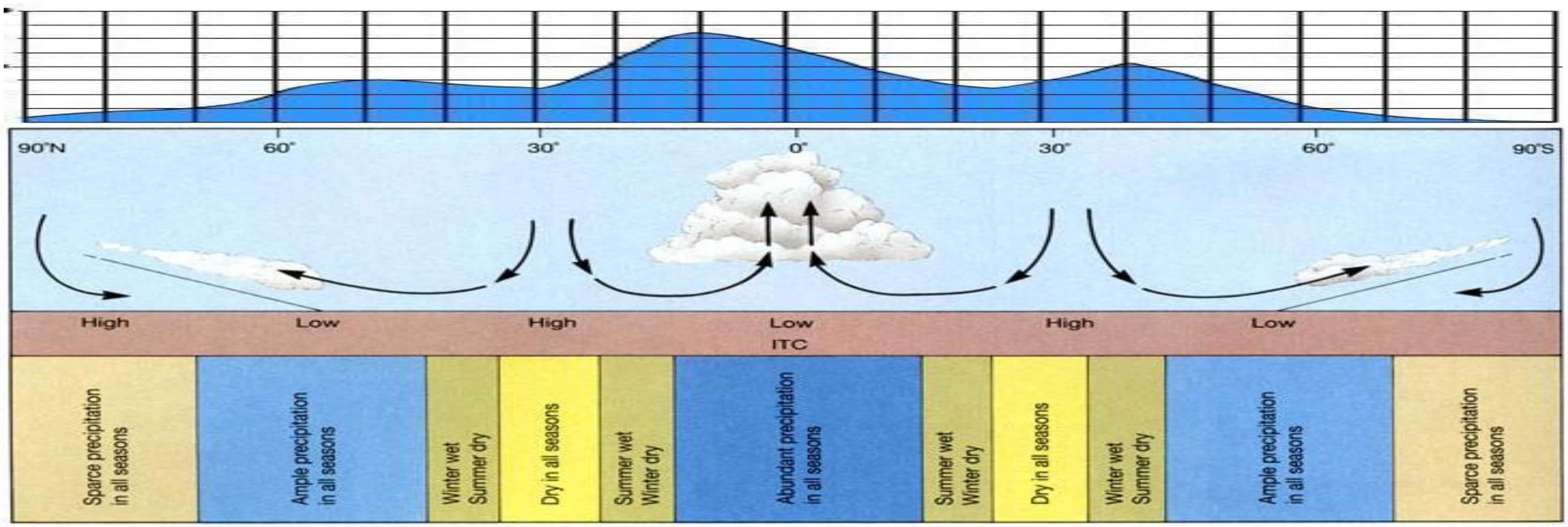
Climate zones


N
Polar easterlies
Polar front
Westerlies
Subtropical anticyclones
H
Trade Winds
ITCZ and equatorial trough
Trade Winds
Subtropical anticyclones
H
Westerlies
Polar front
Polar easterlies
Koeppen's Climate Classification
A
B
C
D
E
Tropical
Dry
Temperate
Cold
Polar



Polar easterlies
Polar front
Westerlies
Subtropical anticyclones
H
Trade Winds
ITCZ and equatorial trough
Trade Winds
Subtropical anticyclones
H
Westerlies
Polar front
Polar easterlies
Kyzyl-Kum Desert
Kara-Kum Desert
Gobi Desert
Great Basin
Colorado Desert
Sahara Desert
Arabian Desert
Taklamakan Desert
Iranian Desert
Thar Desert
Namib Desert
Kalahari Desert
Great Sandy Desert
Gibson Desert
Great Victoria
Patagonian Desert
Pvt. Ltd. 2003-04.
Sub Tropical Desert
Cold Winter
Cool Coastal


Polar easterlies
Polar front
Westerlies
Subtropical anticyclones
H
Trade Winds
ITCZ and equatorial trough
Trade Winds
Subtropical anticyclones
H
Westerlies
Polar front
Polar easterlies
N
S
Global Average Annual Precipitation
Projection: Flat Polar Quartic Interrupted and Condensed
(Isolines Are in Inches)
(inches)
Below 10
10 to 20
20 to 40
40 to 60
60 to 80
Over 80
(centimeters)
Below 25
25 to 50
50 to 100
100 to 150
150 to 200
Over 20



90°N
60°
30°
0°
30°
60°
90°S
High
Low
High
Low
ITC
High
Low
Sparce precipitation in all seasons
Ample precipitation in all seasons
Winter wet Summer dry
Dry in all seasons
Summer wet Winter dry
Abundant precipitation in all seasons
Summer wet Winter dry
Dry in all seasons
Winter wet Summer dry
Ample precipitation in all seasons
Sparce precipitation in all seasons