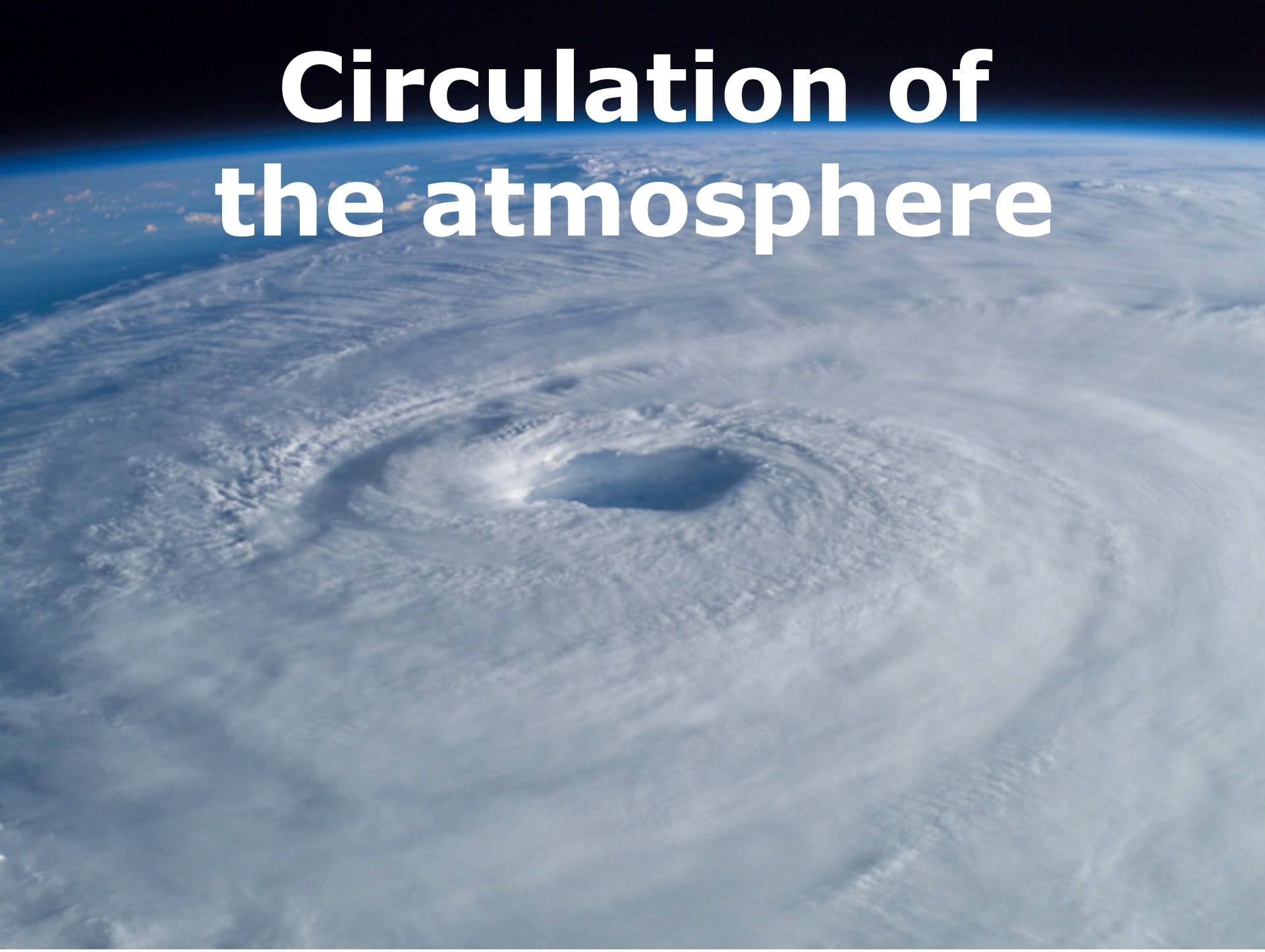
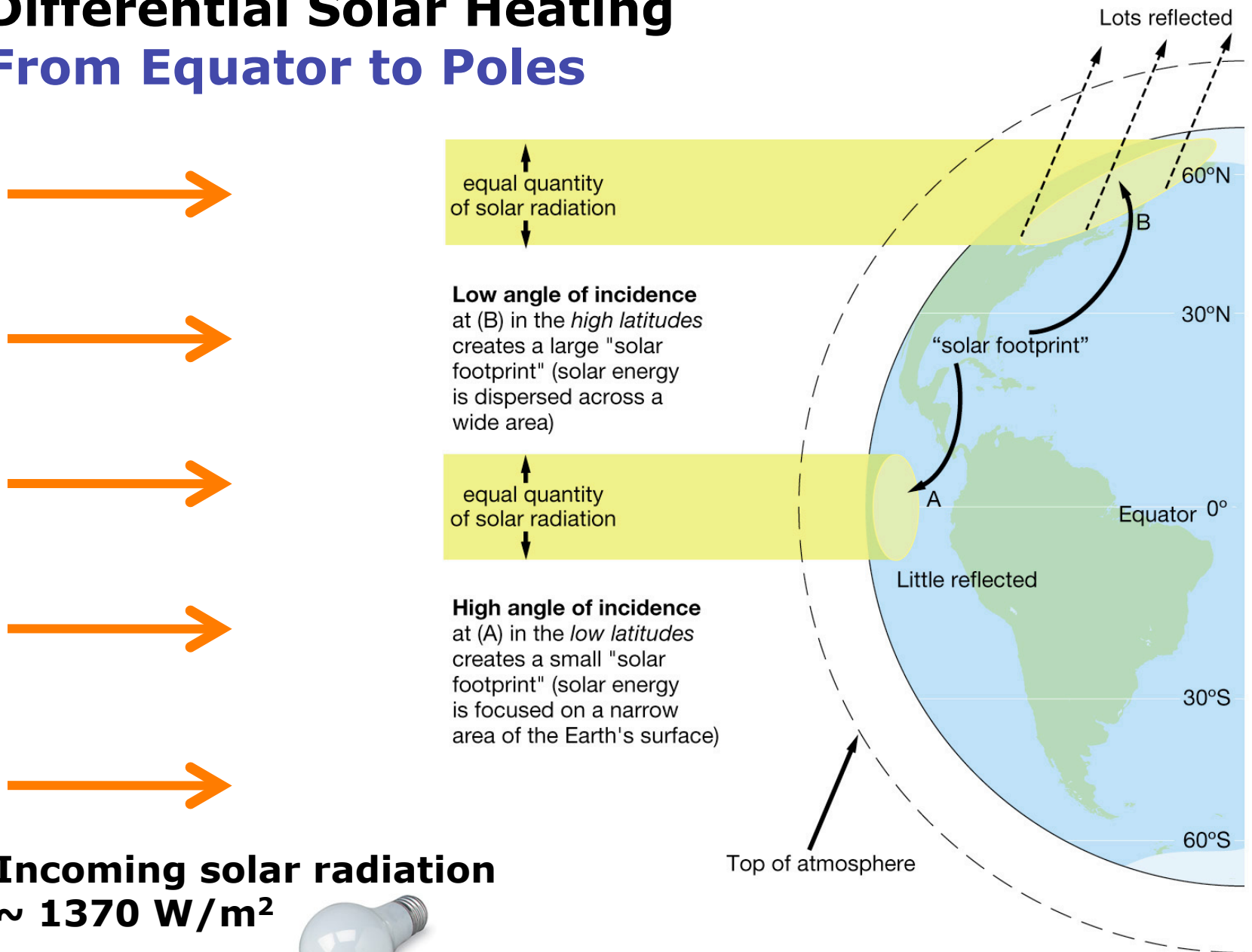
Circulation of the atmosphere



What drives the atmospheric circulation?

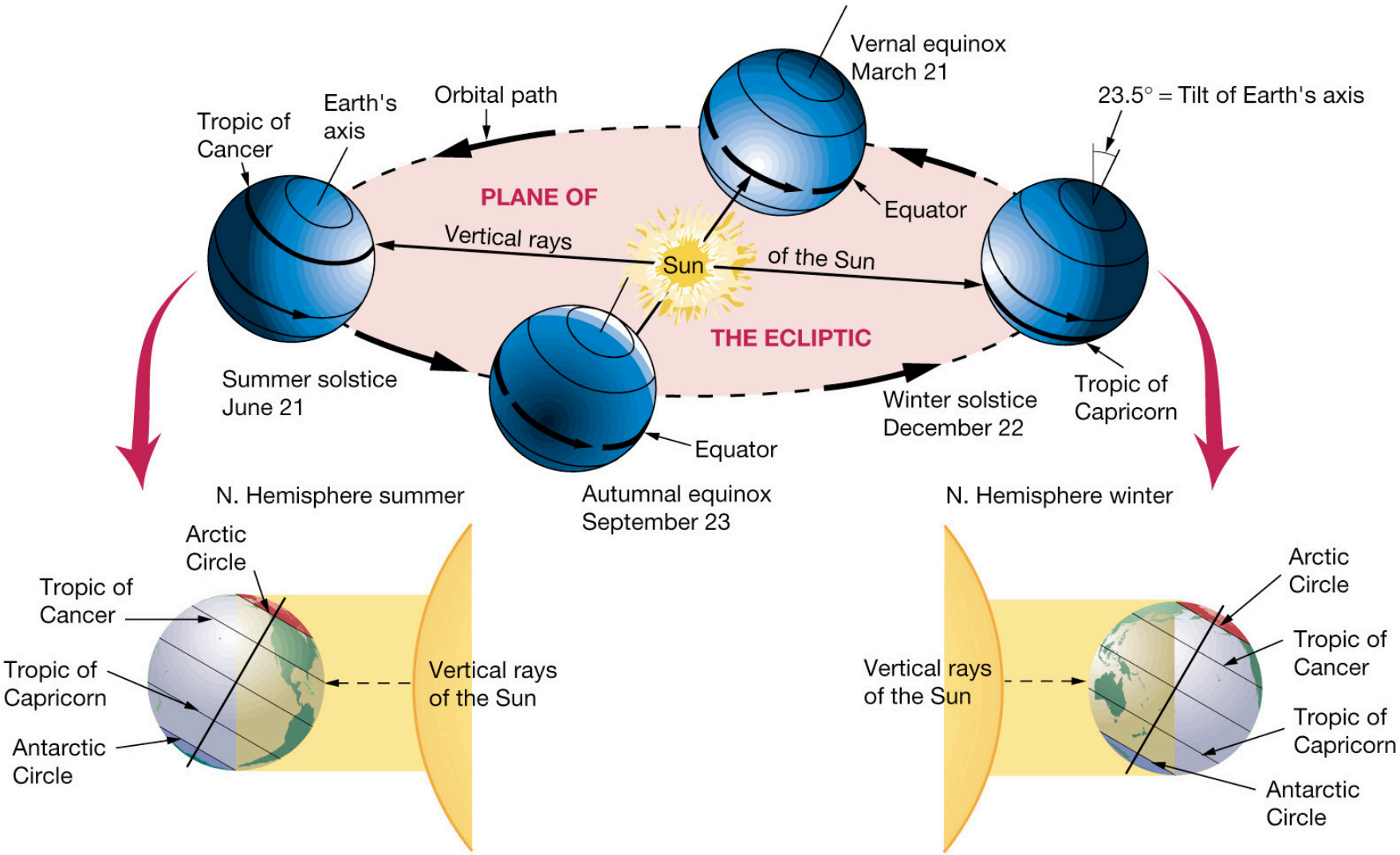
- Two fundamental mechanisms
  - Differential heating by the sun
  - Rotation of the planet

Differential Solar Heating
From Equator to Poles

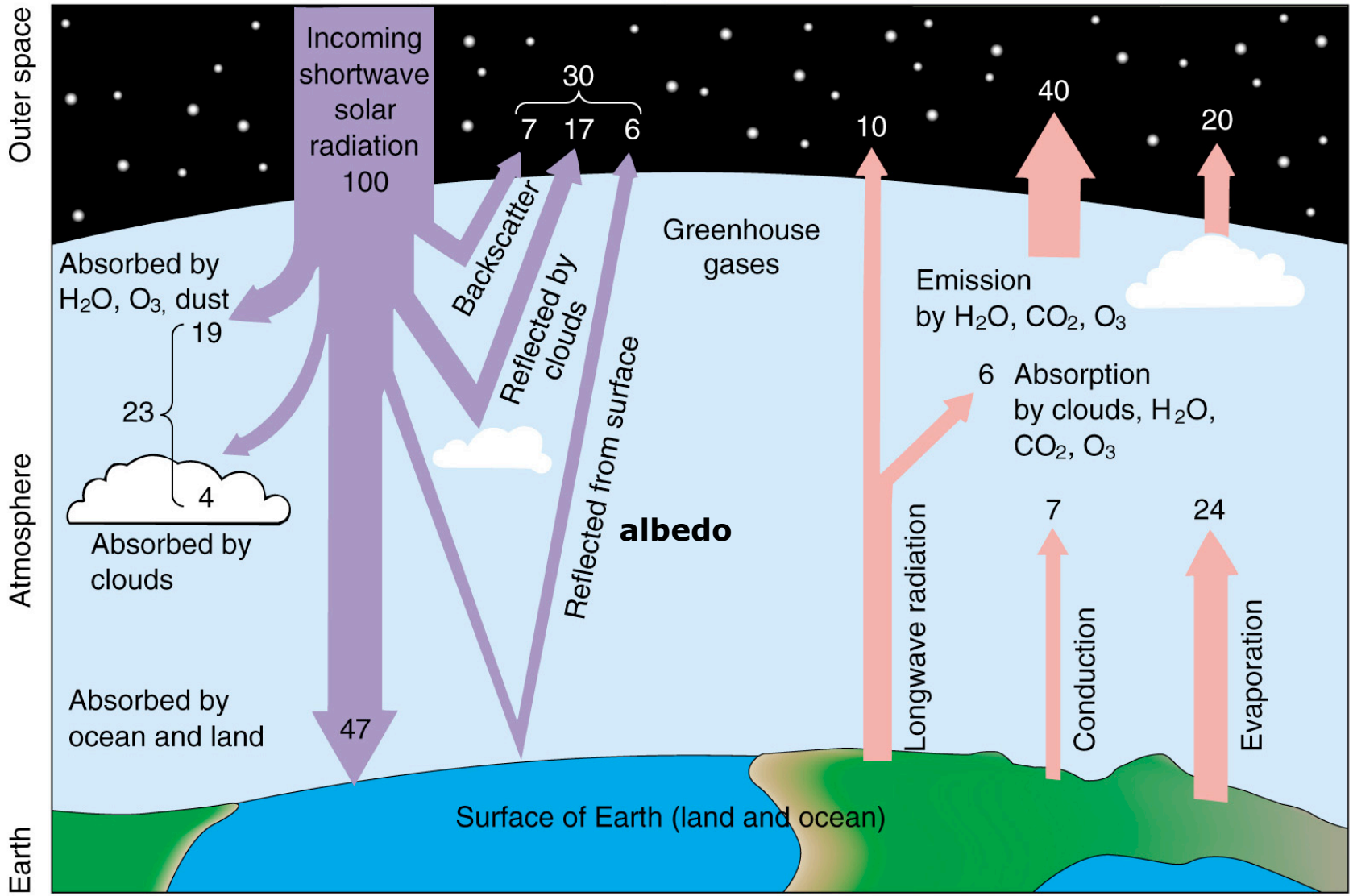


Incoming solar radiation
~ 1370 W/m²

Seasonal Heating

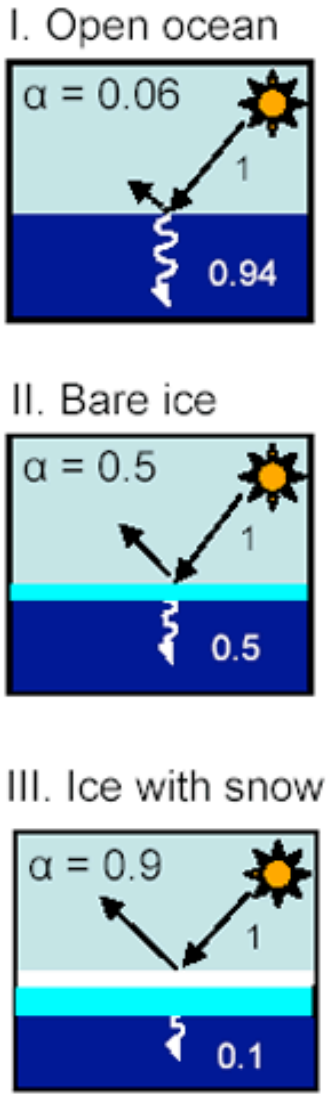


Radiative Budget

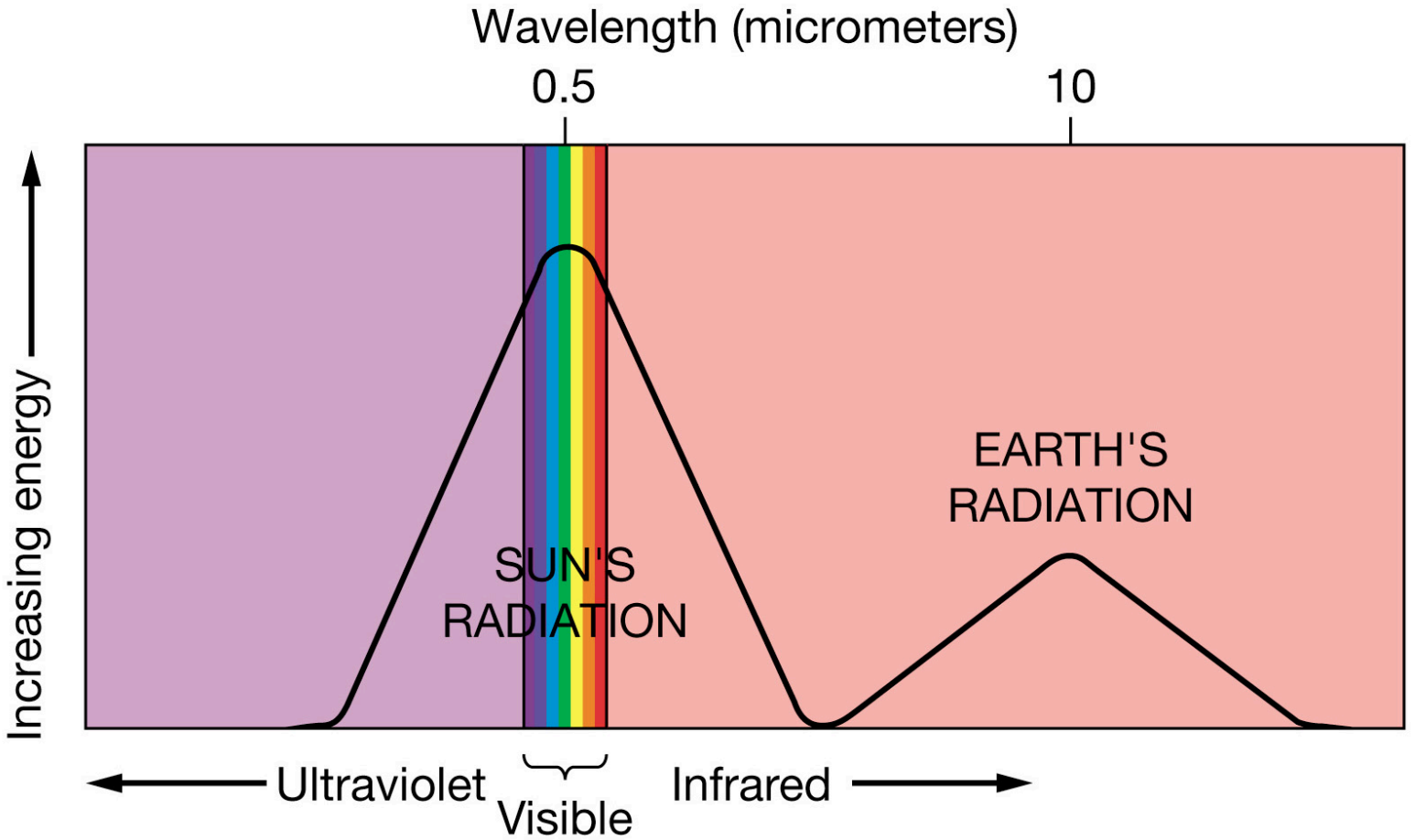


Reflectivity and albedo

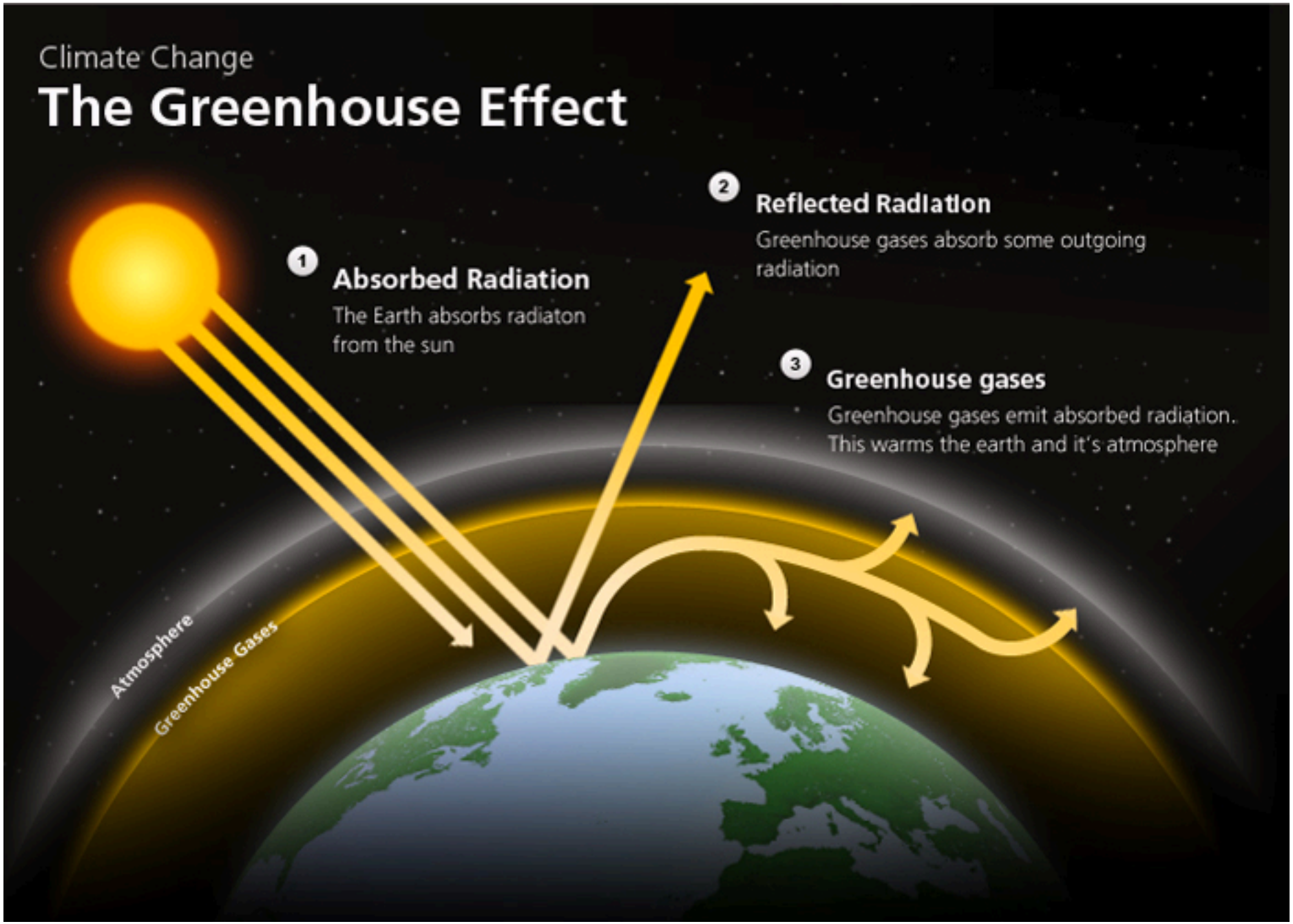
- Albedo = fraction of energy reflected
  - Fully absorbing surface: $\alpha = 0$
    - Black surface ~ sea water
  - Fully reflecting surface: $\alpha = 1$
    - White surface ~ snow
- At high latitudes
  - Cold ice/snow reflects solar radiation, making it even colder
  - Positive ice-albedo feedback



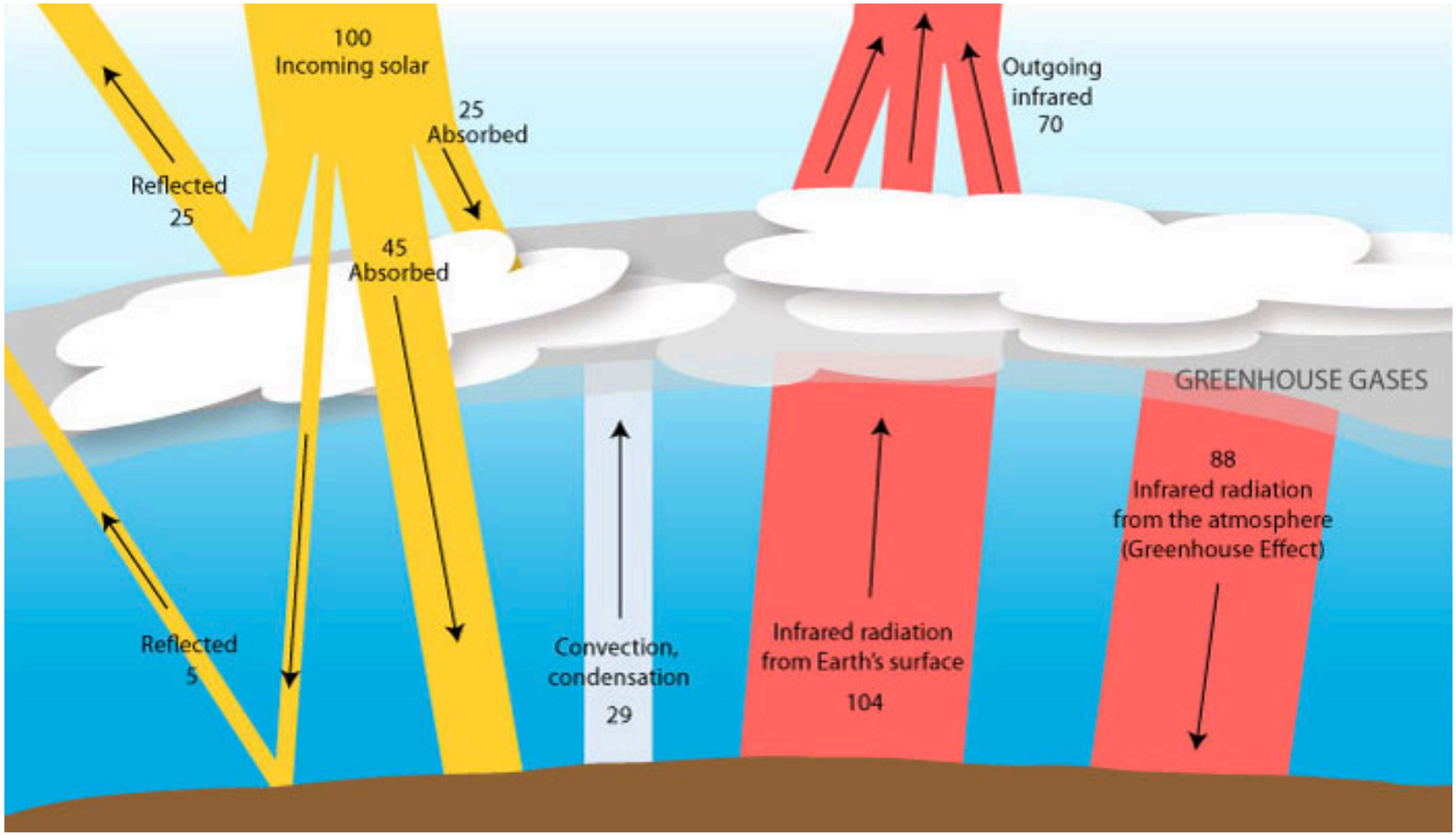
Radiative balance



- Solar radiation is mostly in the visible band
- Earth's radiation is in infrared band
- The type of radiation depends on the temperature of the body


Climate Change
The Greenhouse Effect
1
Absorbed Radiation
The Earth absorbs radiaton from the sun
2
Reflected Radiation
Greenhouse gases absorb some outgoing radiation
3
Greenhouse gases
Greenhouse gases emit absorbed radiation. This warms the earth and it's atmosphere
Atmosphere
Greenhouse Gases

Greenhouse radiative balance



Greenhouse gases

Water vapor (H2O)

Carbon dioxide (CO2)

Methane (CH4)

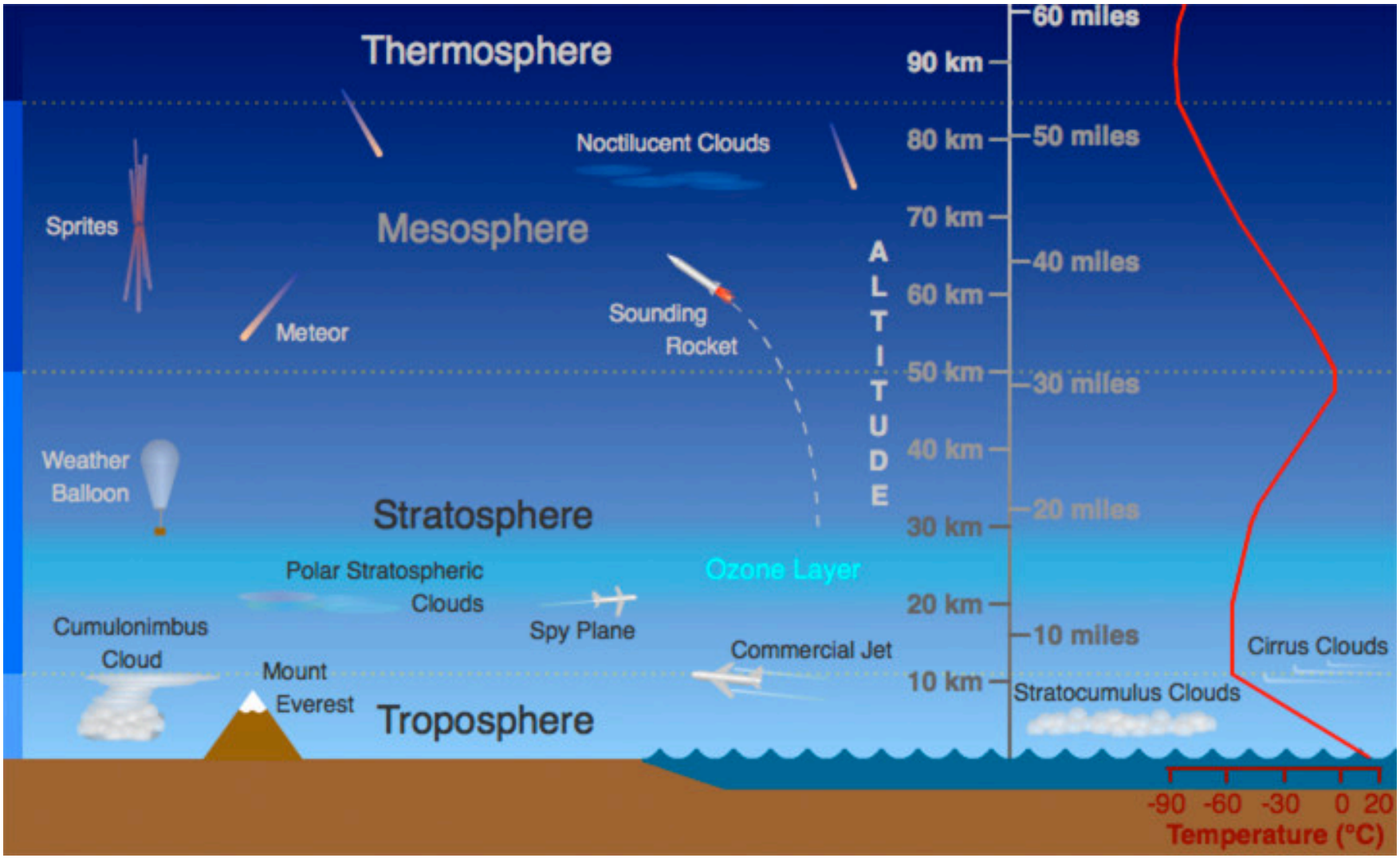
Nitrous oxide (N2O)

Ozone (O3)

Chlorofluorocarbons (CFCs)

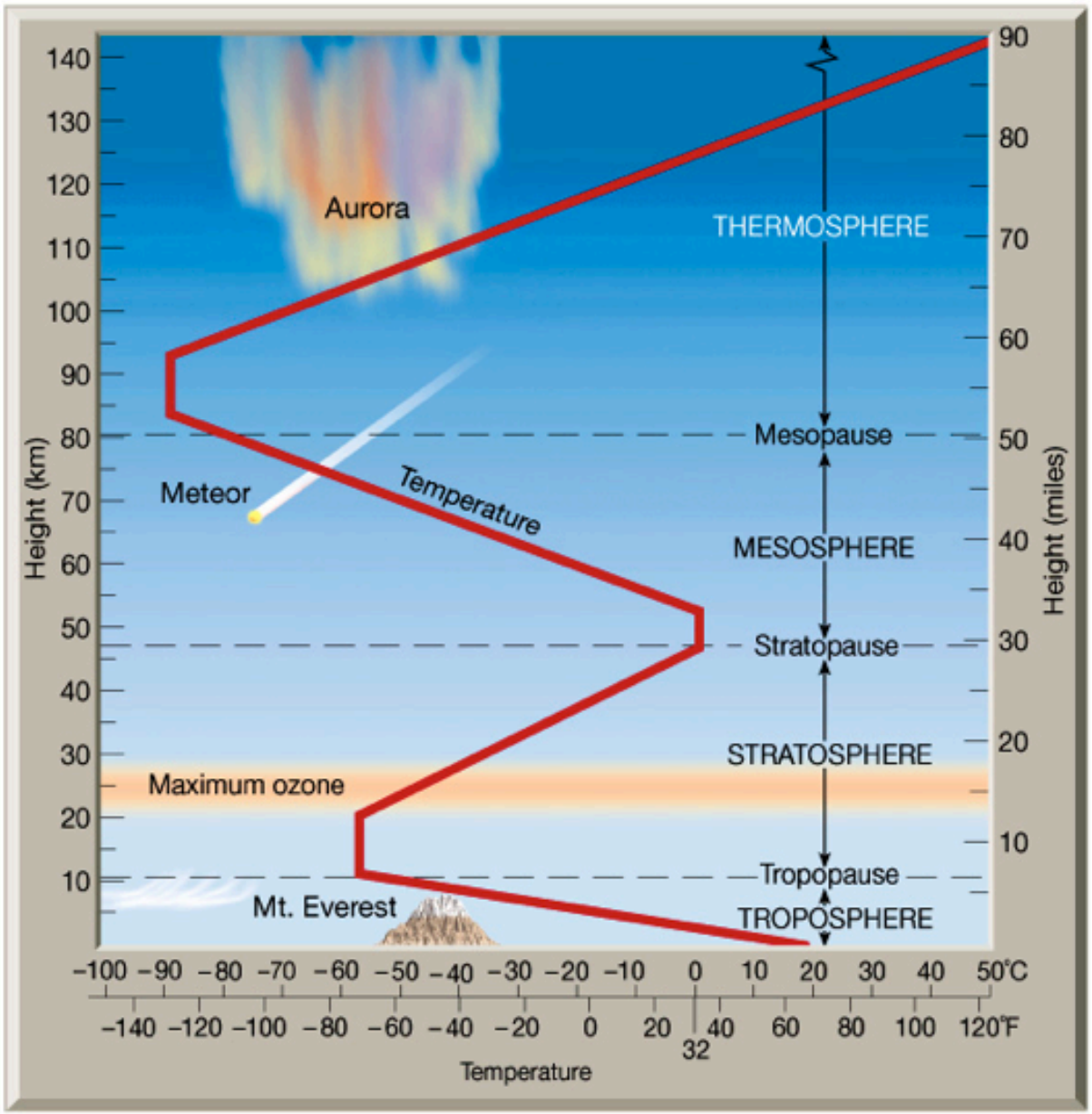
Influenced by human activities

Layers of the Atmosphere



We will focus on the tropopshere

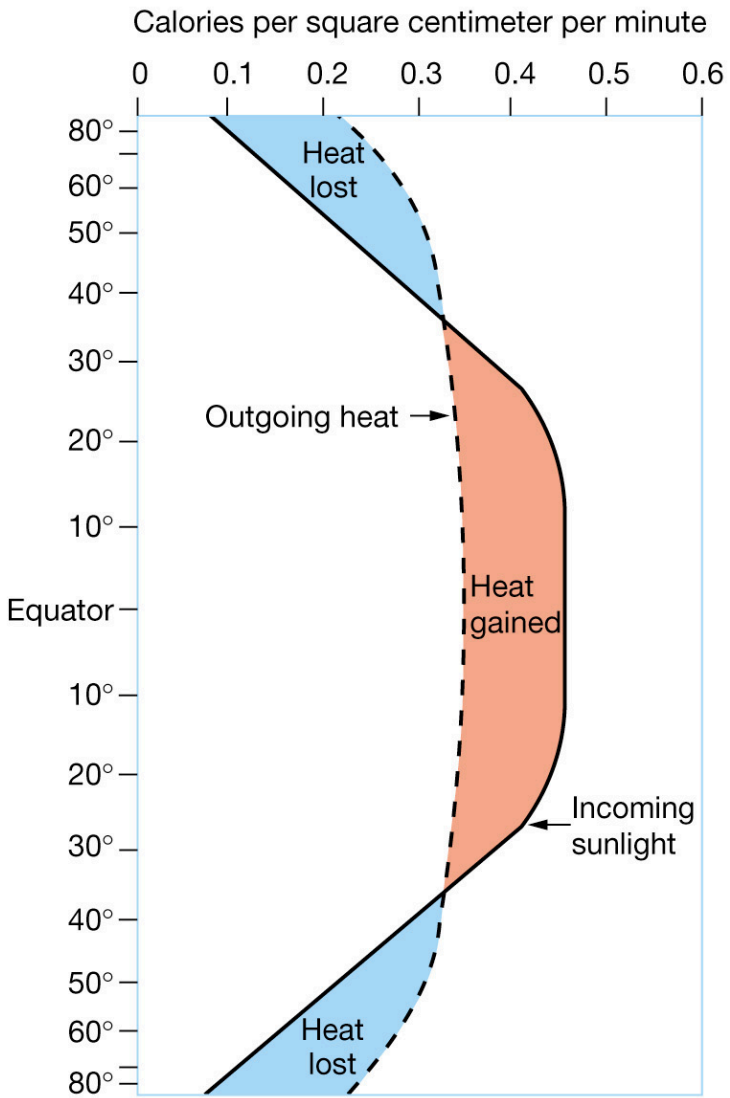
Layers and structure of the Atmosphere



The **Thermosphere** absorbs much of the energy from the sun. It absorbs x rays and ultraviolet radiation from the sun and converts it into heat. The **Thermosphere** doesn't feel warm even though it is at up to 2500 C because it is **so** close to being a vacuum.

http://www.weather-climate.org.uk/02.php

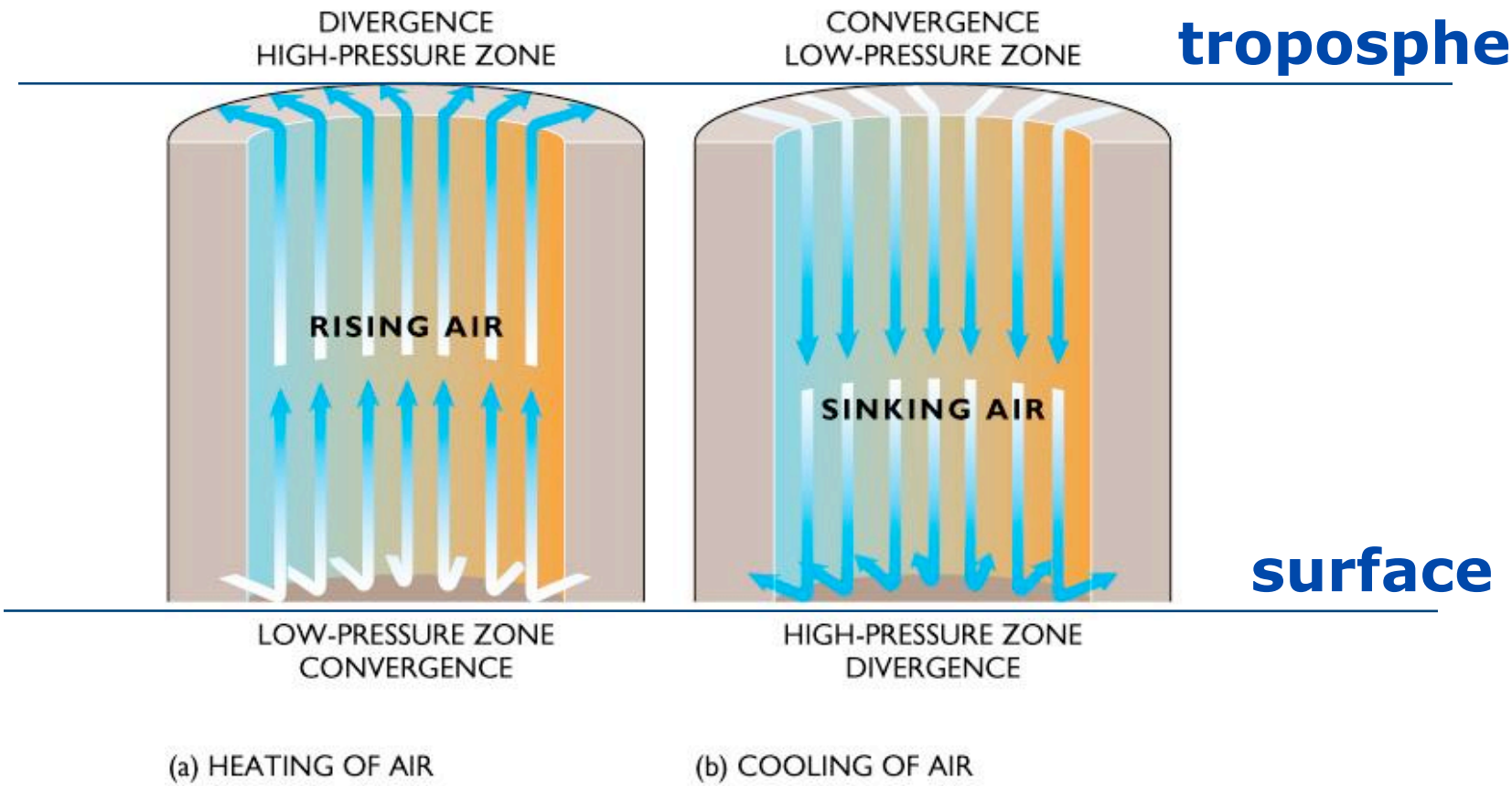
Flow of energy in the atmosphere



- Net heat gain in tropics
- Net heat loss at high-latitudes
- Atmospheric circulation is in part driven by the pole-equator differential heating
- Atmospheric and oceanic circulations transport heat from low to high latitudes

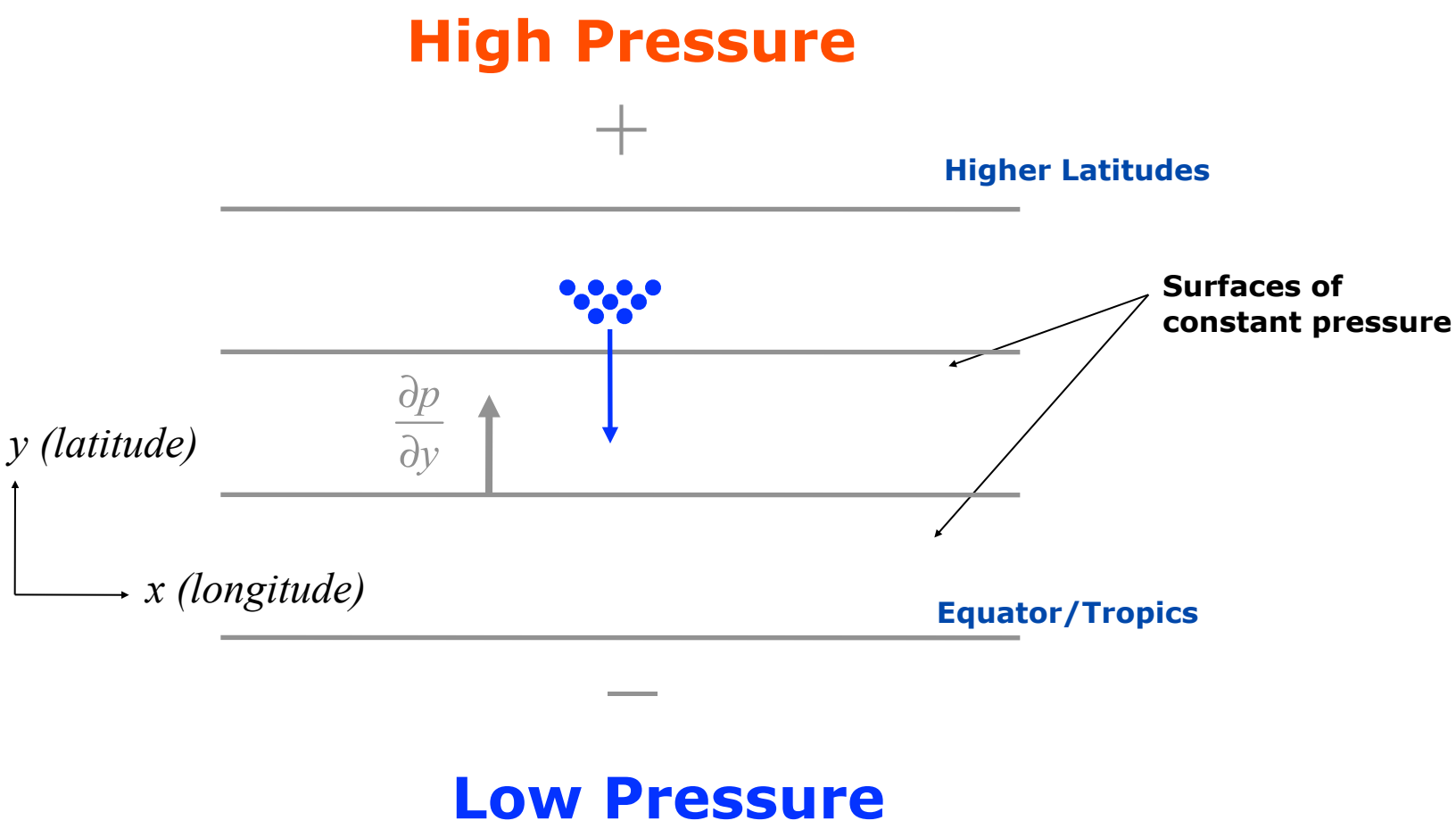
Vertical motions driven by heating / cooling

Heating by the sun → AIR PRESSURE

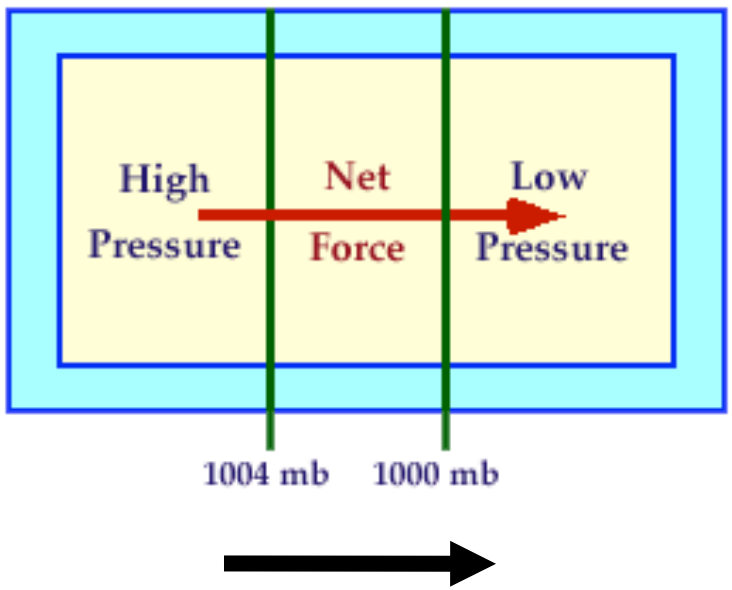


Equator/Tropics **Higher Latitudes**

Horizontal view of air pressure at the surface

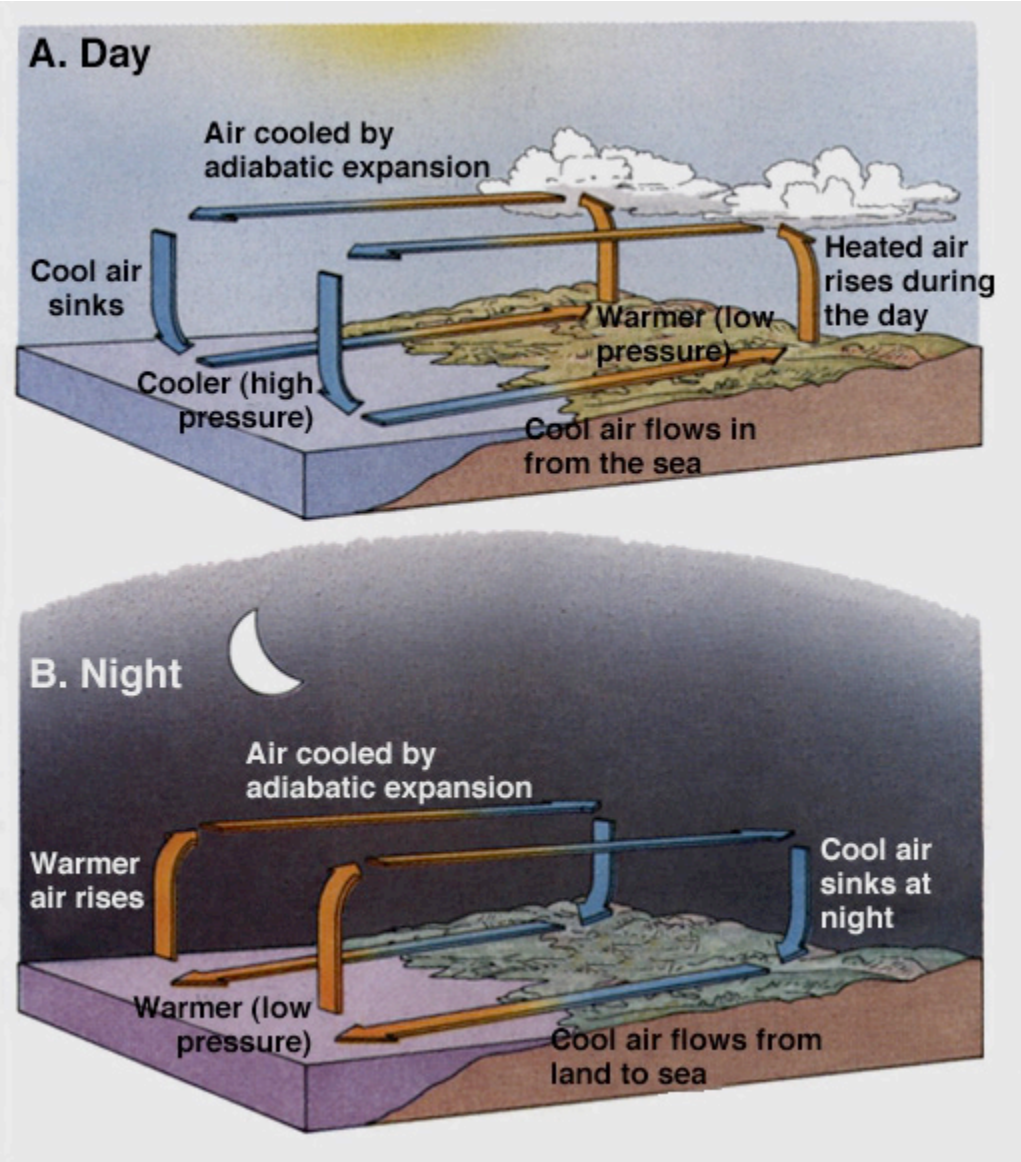


Fluid accelerates towards low pressure regions



$$-\nabla p$$

Land-Sea Breeze

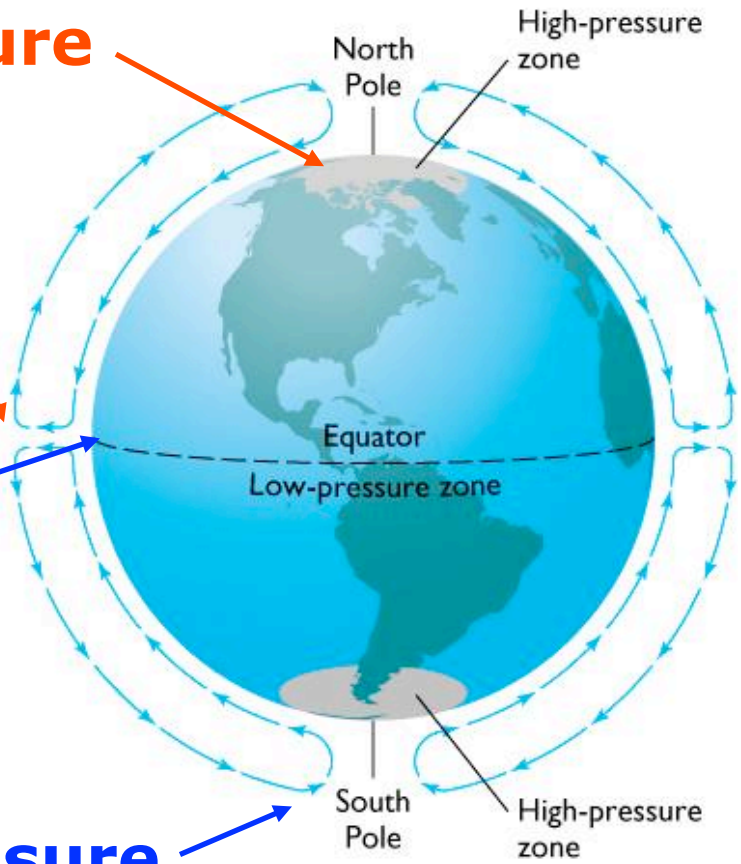


Vertical view of air pressure (horizontal convection)

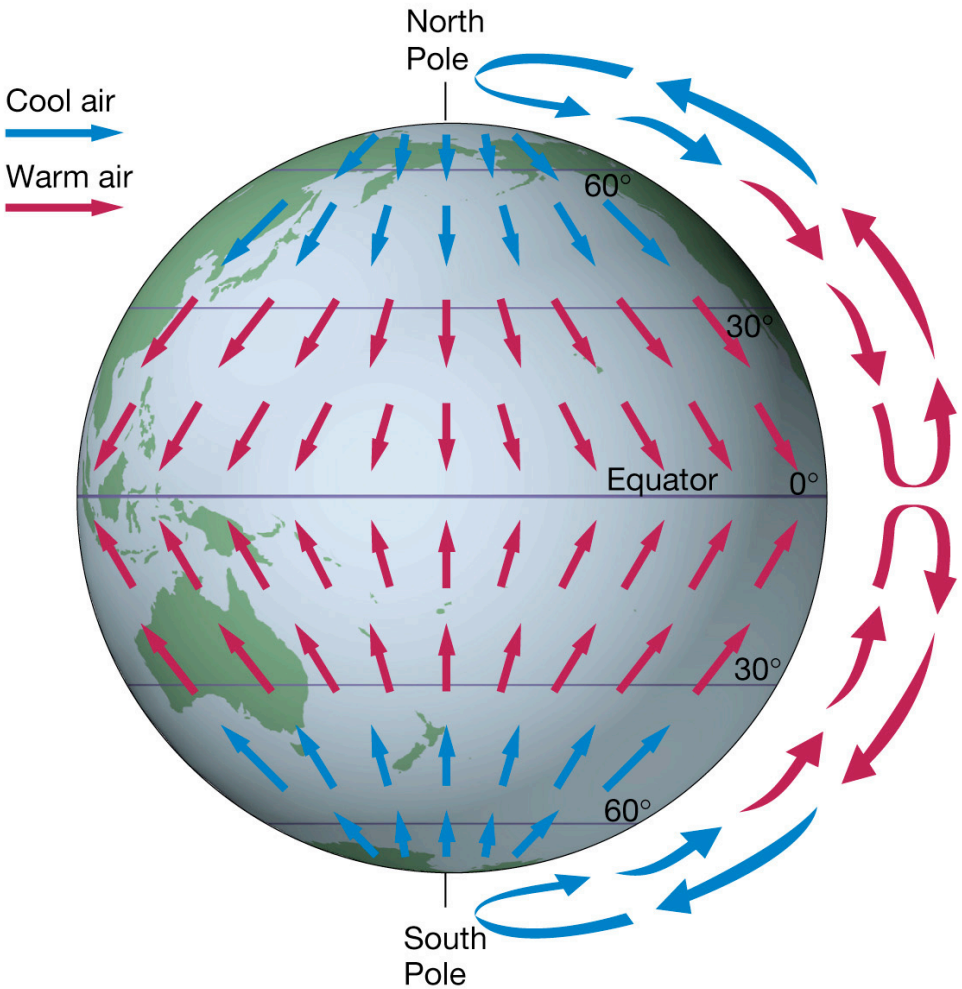
High Pressure

Low Pressure

Low Pressure

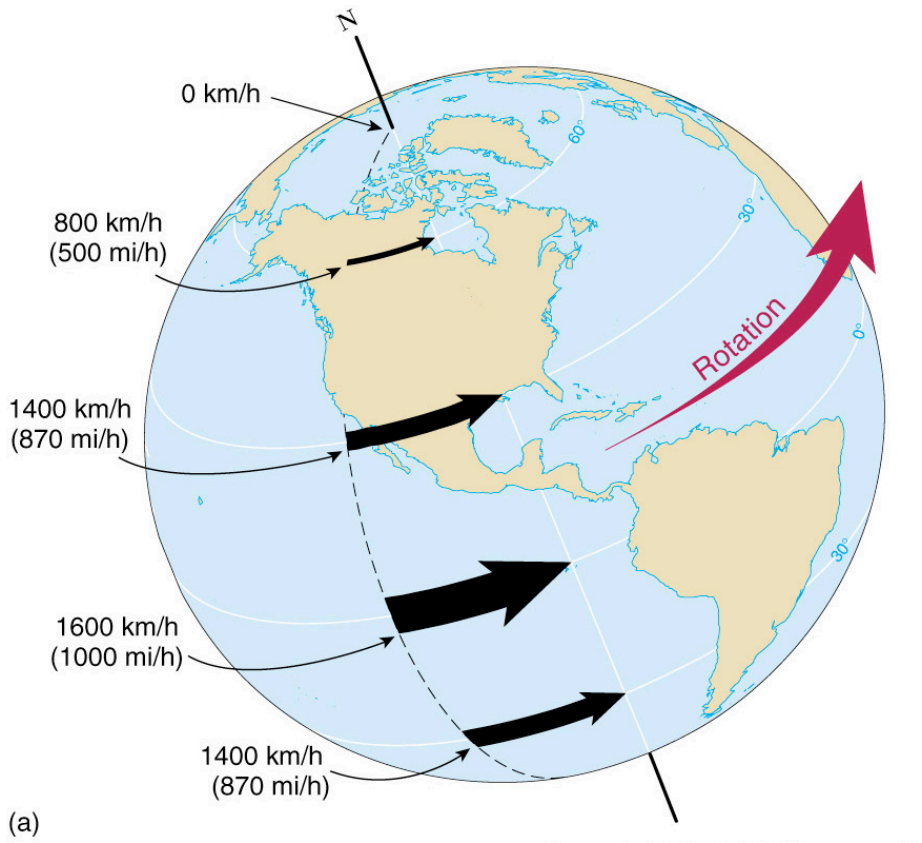


Non-rotating view of Atmospheric Circulation



Hadley circulation: Tropics

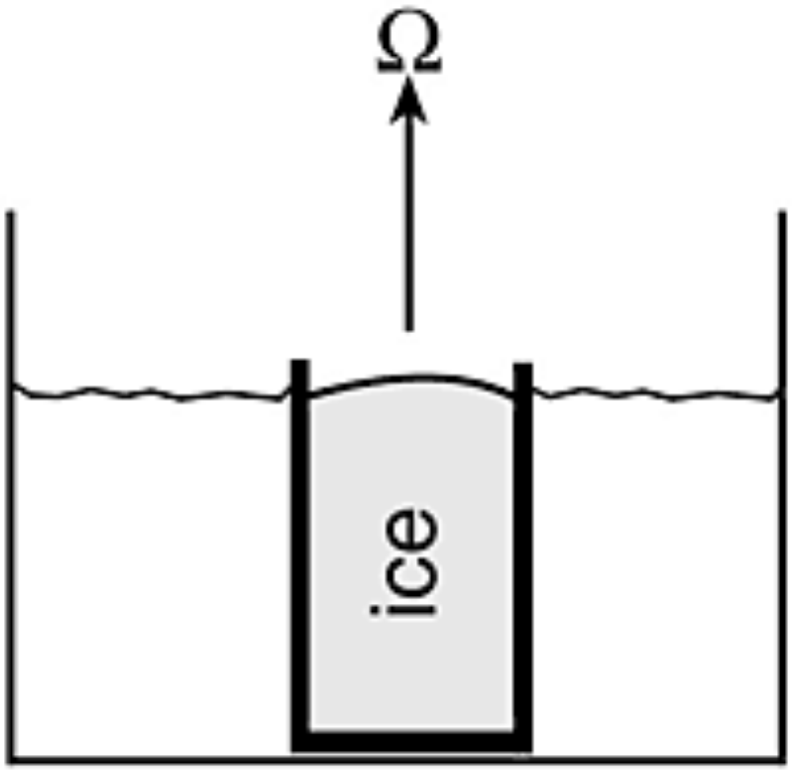
Rotation effect



We are in the rotating frame of reference

Tank demo

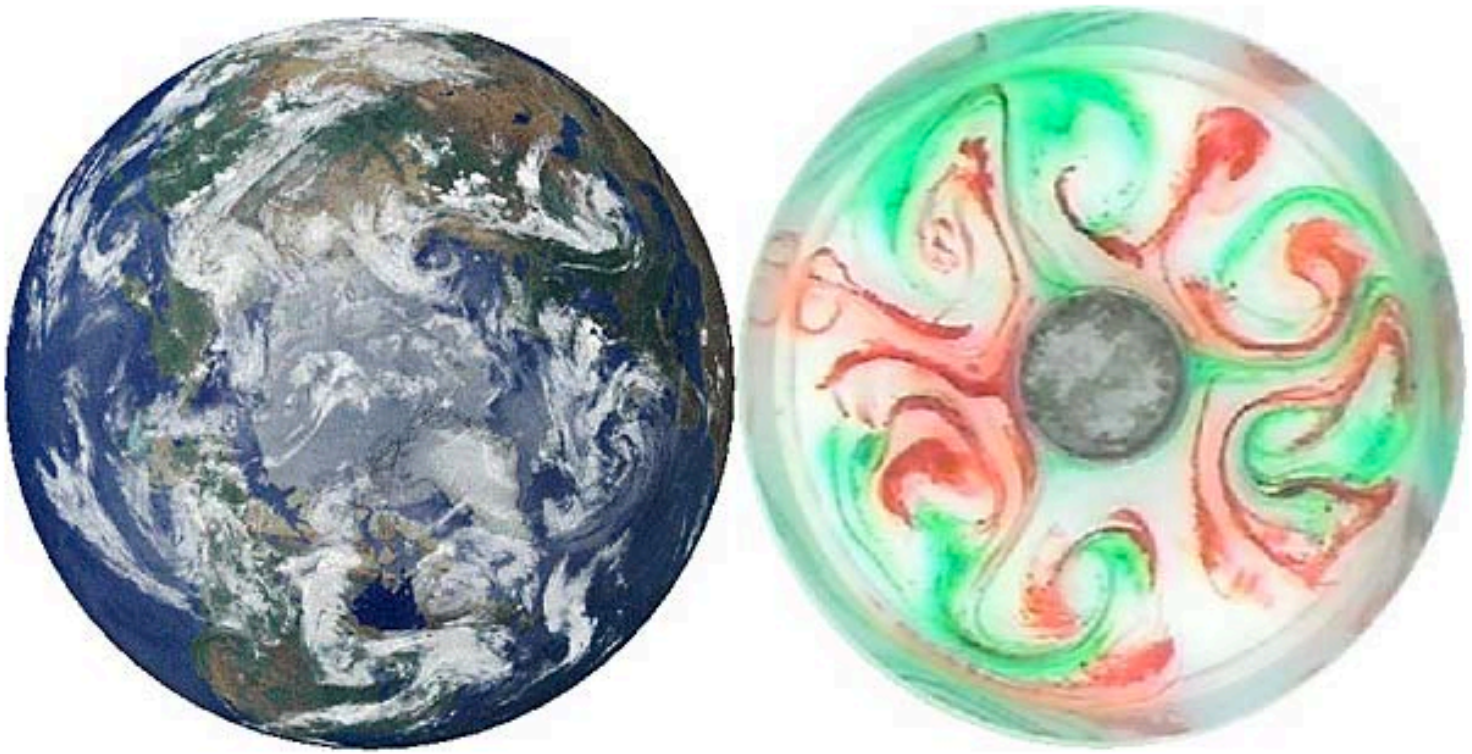
Differentially heated annulus experiment



Low lat. **"Pole"** **Low lat.**

Differentially heated, rotating flow

Baroclinic wave/vortices → "Weather events"



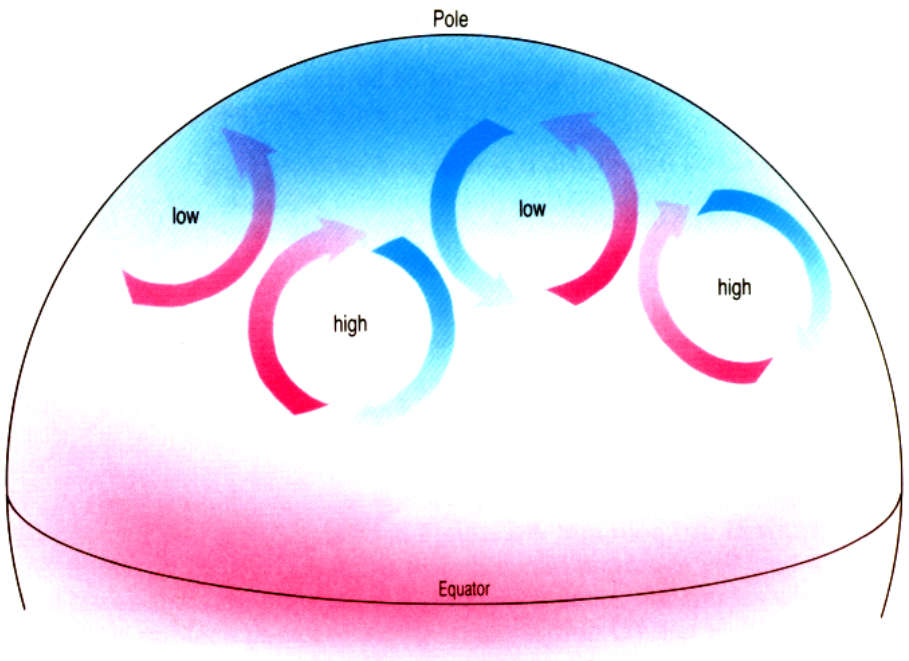
Look at the IR satellite images

http://www.meteo.psu.edu/~gadomski/SAT_NHEM/atlanim16wv.html

Differentially heated, rapidly rotating flow

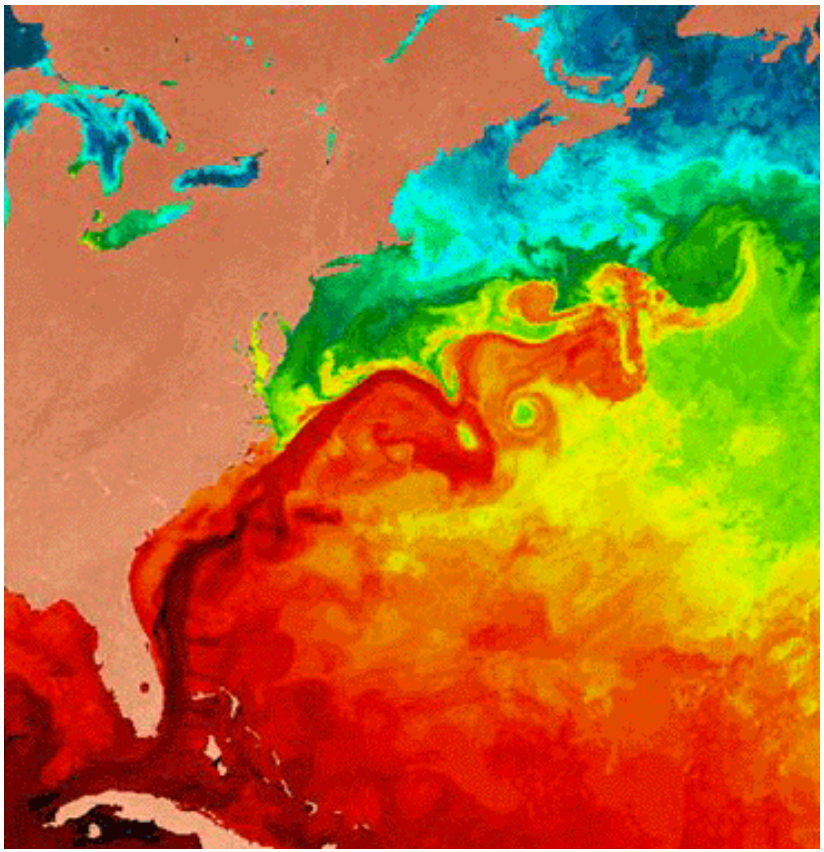
Wave/vortex motion naturally emerges:

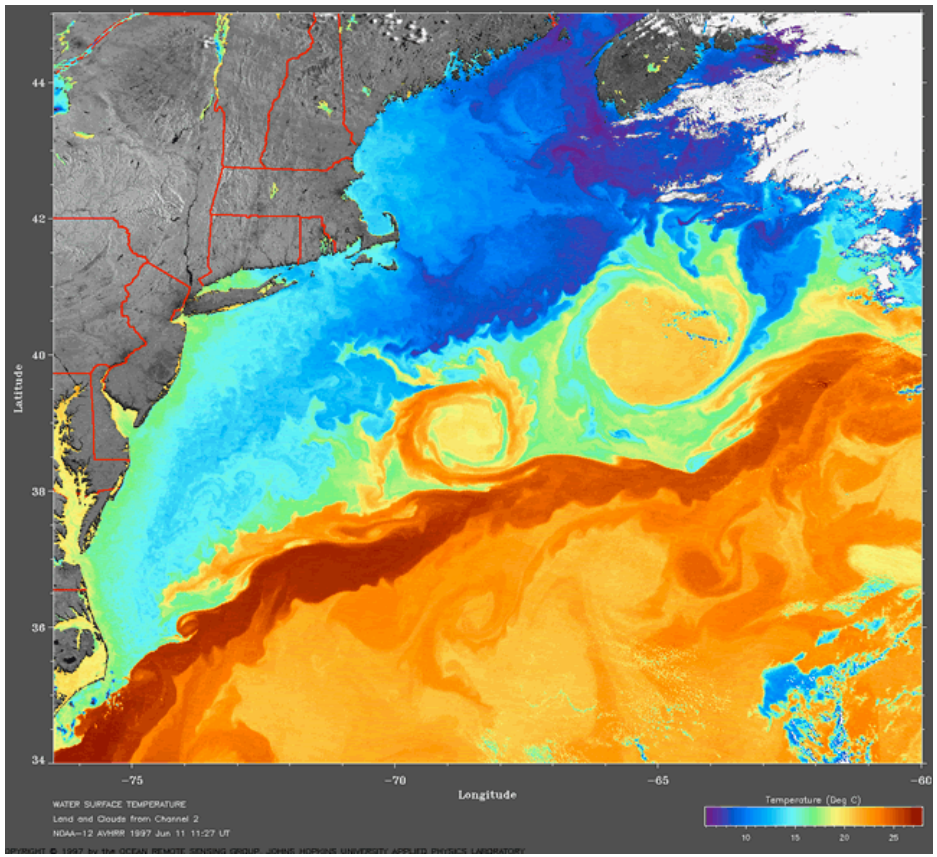
→ Mid-latitude cyclones: weather events



Ocean eddies

Same mechanism: planetary rotation +
temperature gradient

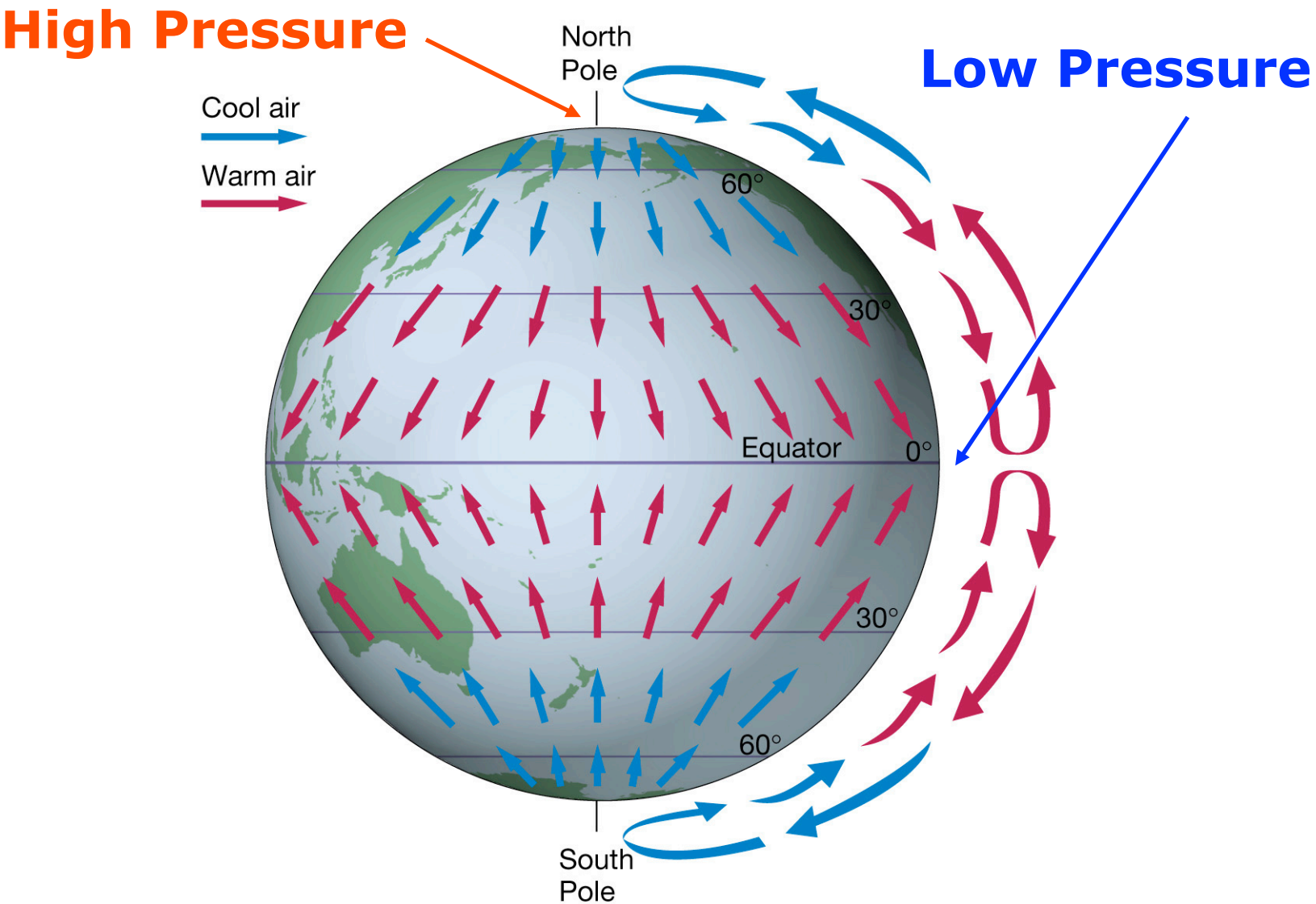




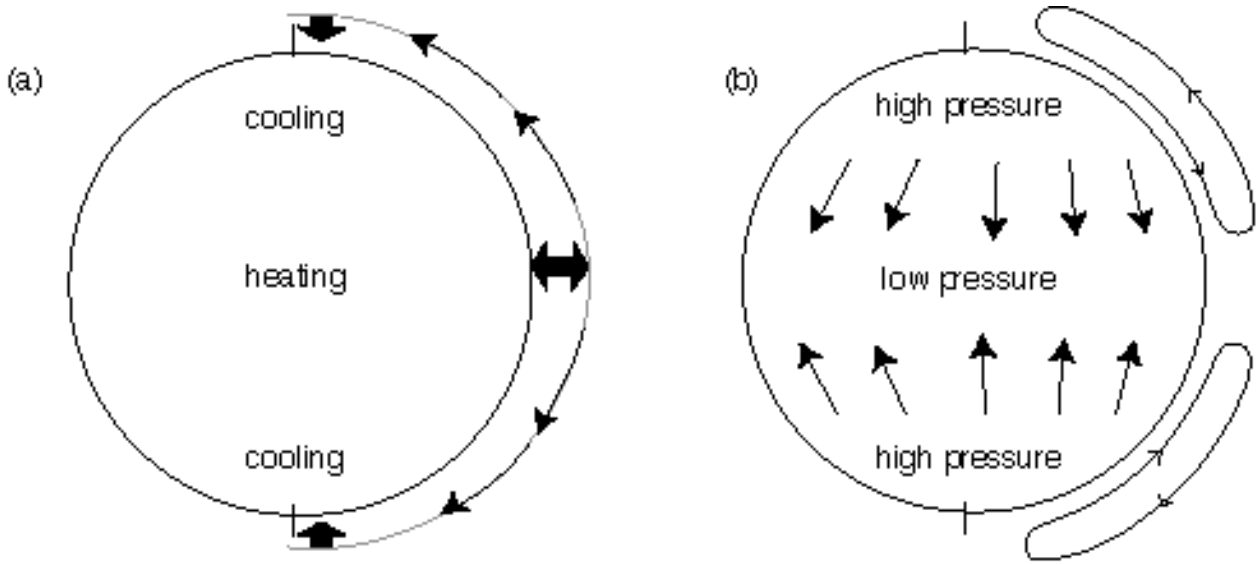
Circulation of the atmosphere

- The effects of Earth Rotation
- The role of friction
- Conservation of angular momentum

Non rotating view of Atmospheric Circulation



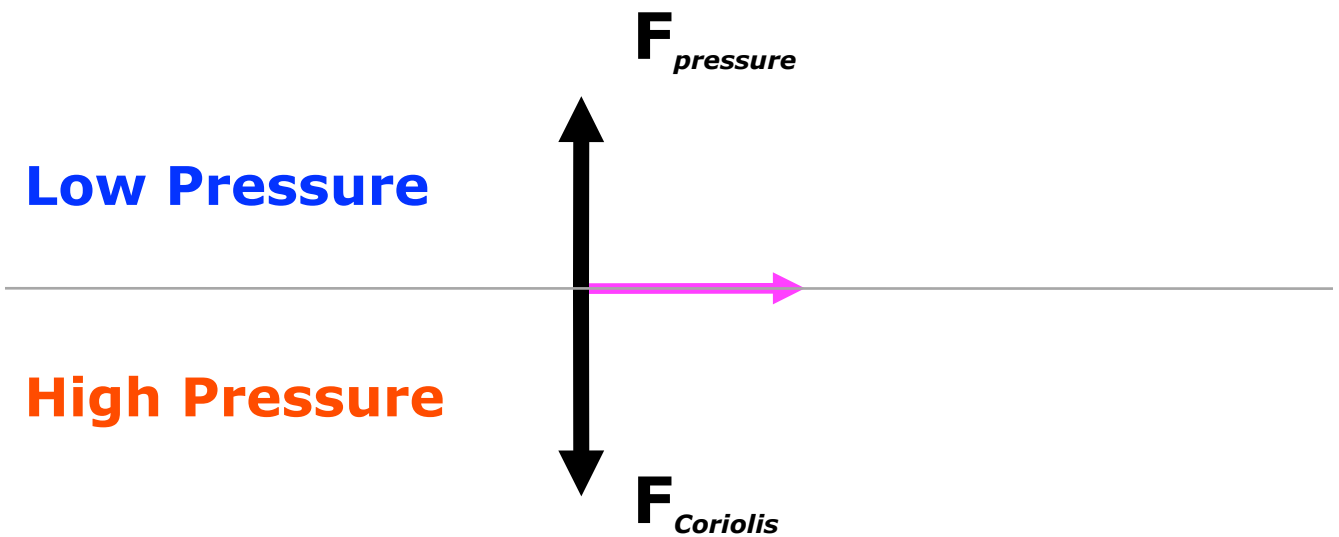
Schematic depiction of the development of the atmospheric circulation, starting from a state of rest



Redistribution of Heat
– Large scale convective Cells

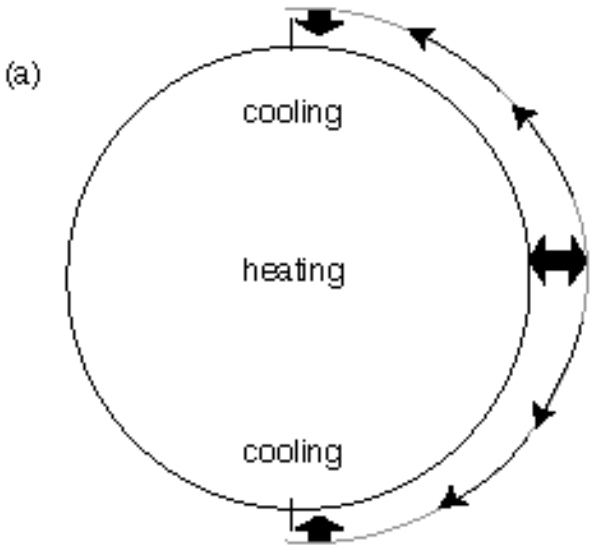
Rotation effects, the Coriolis Force

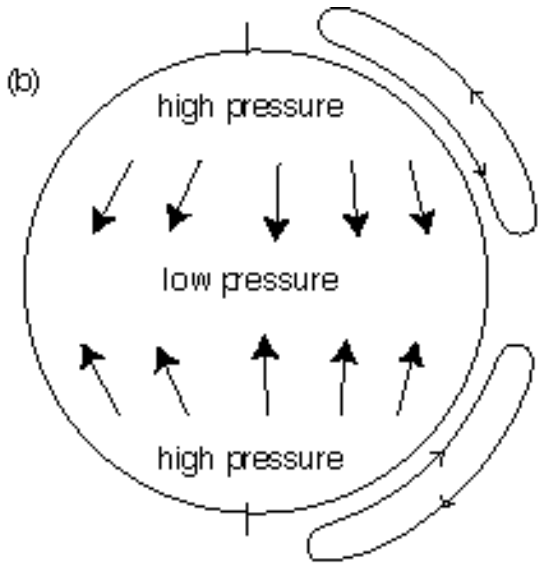
Some practical rules to remember:



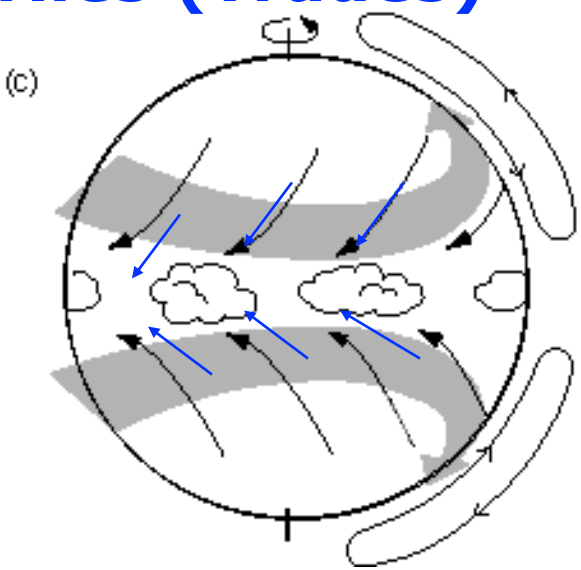
1) Particle will have the Coriolis force 90 degrees to the right
2) Particles will tend to move along line of constant pressure
3) Particles will have the high pressure on their right (same as Coriolis)

Schematic depiction of the development of the atmospheric circulation, starting from a state of rest

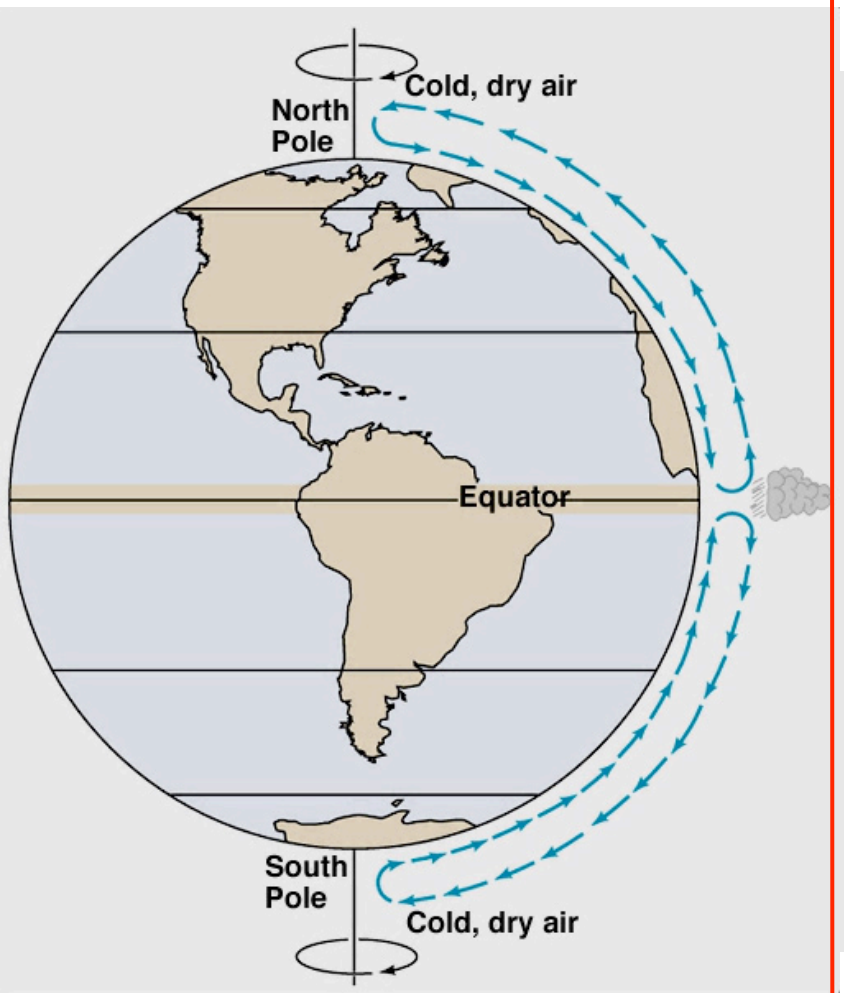


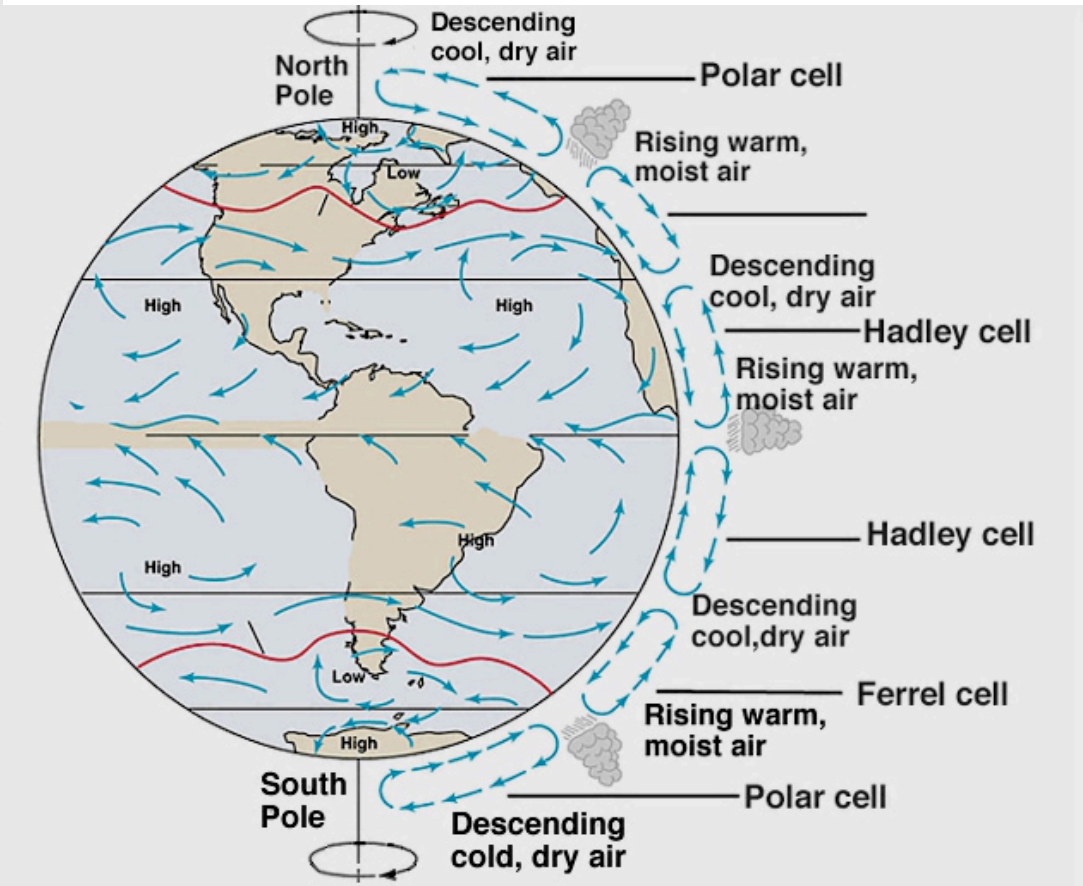


Easterlies (Trades)



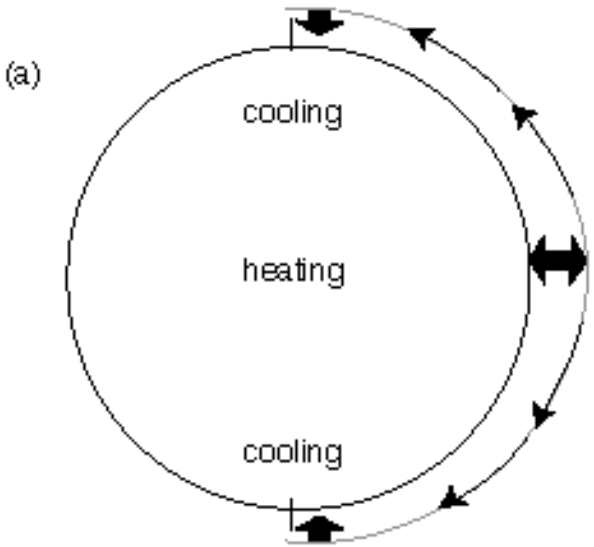
Problem?

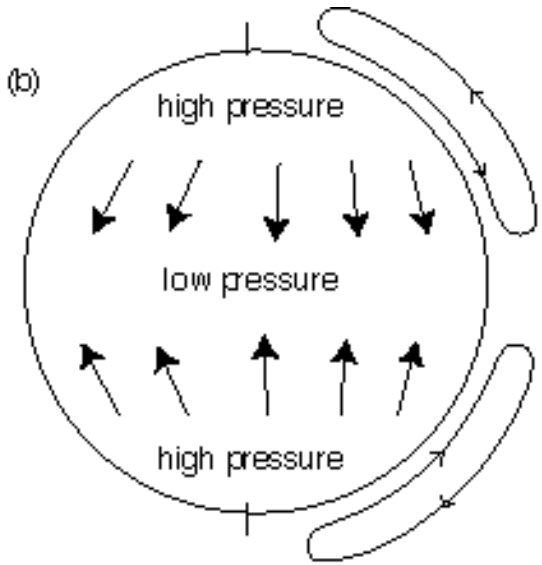

Cold, dry air
North Pole
Equator
South Pole
Cold, dry air


Descending cool, dry air
North Pole
Polar cell
High
Low
Rising warm, moist air
Descending cool, dry air
Hadley cell
High
High
Rising warm, moist air
Hadley cell
High
High
Descending cool,dry air
Low
Ferrel cell
Rising warm, moist air
High
South Pole
Polar cell
Descending cold, dry air

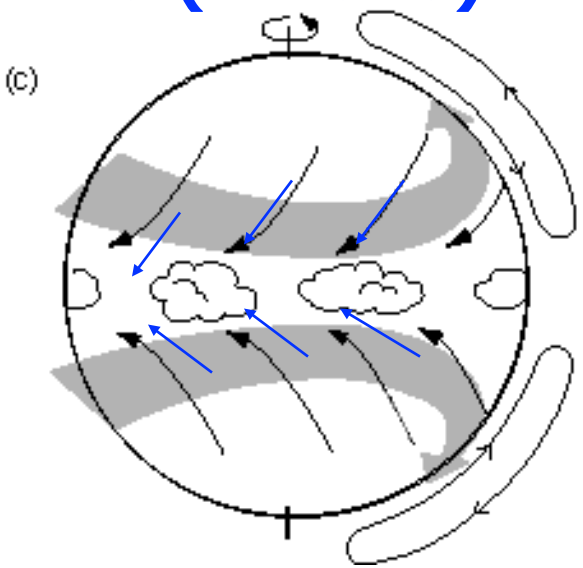
Role of Friction

Schematic depiction of the development of the atmospheric circulation, starting from a state of rest





Easterlies (Trades)



Westerlies

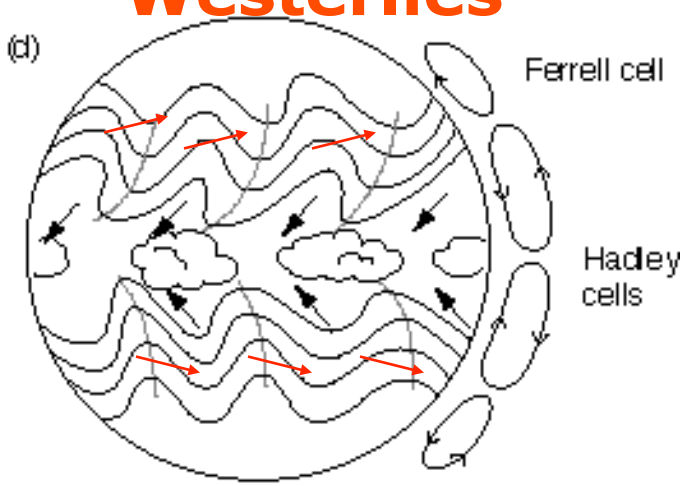
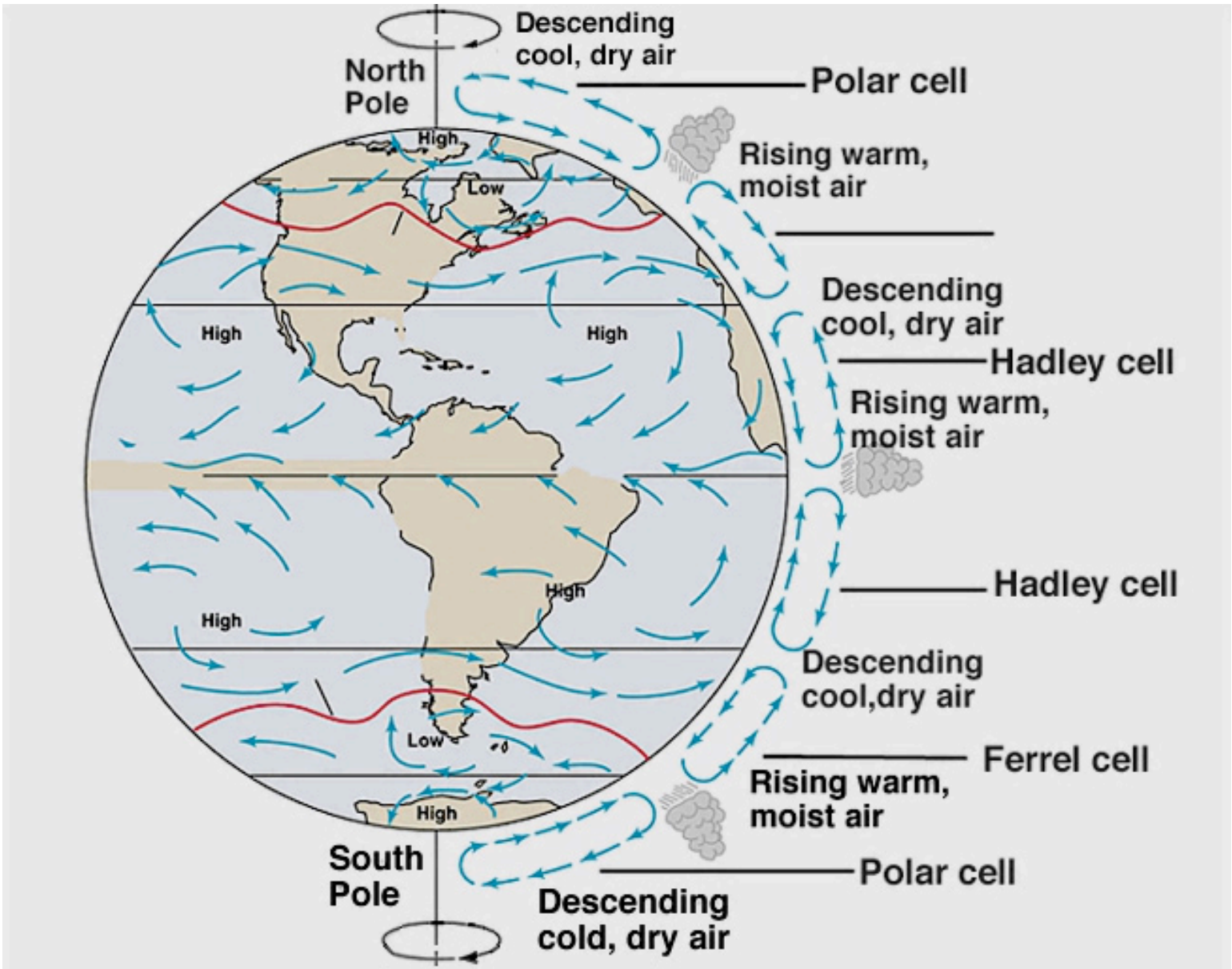
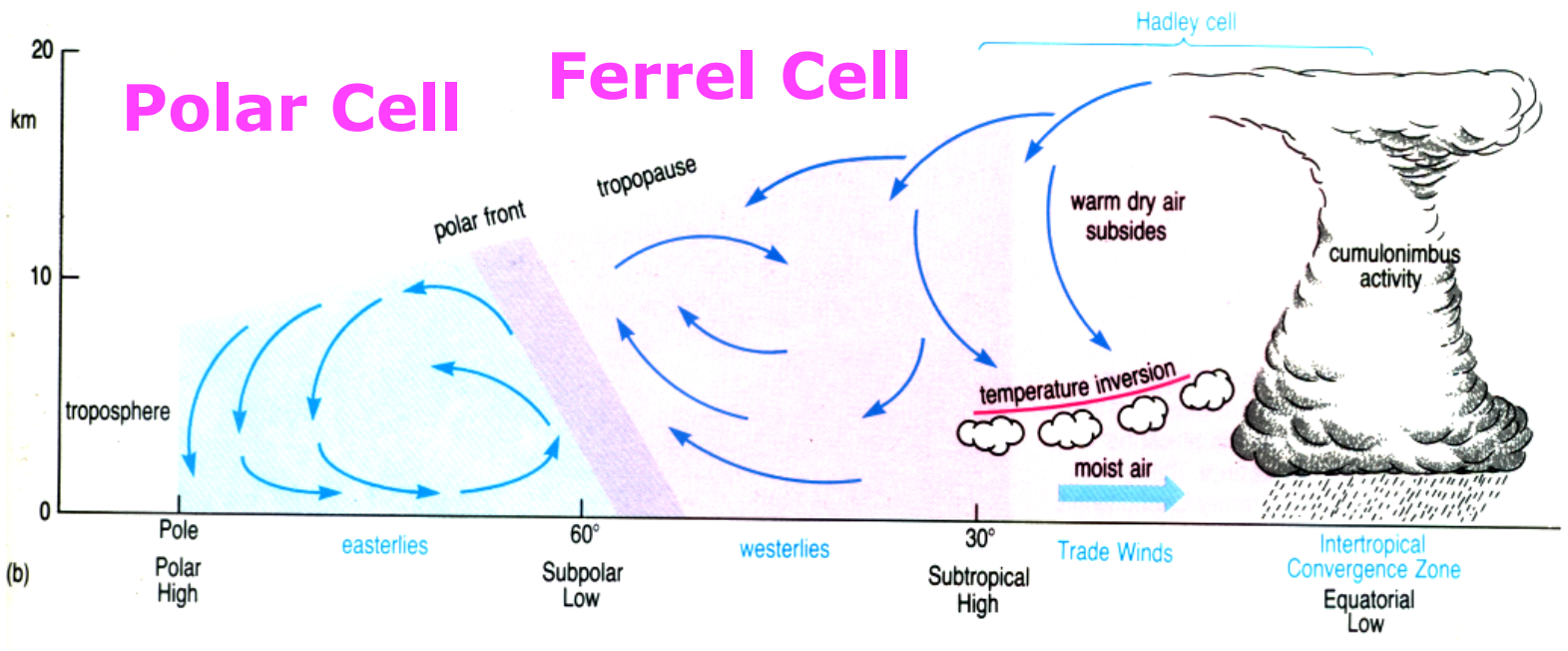
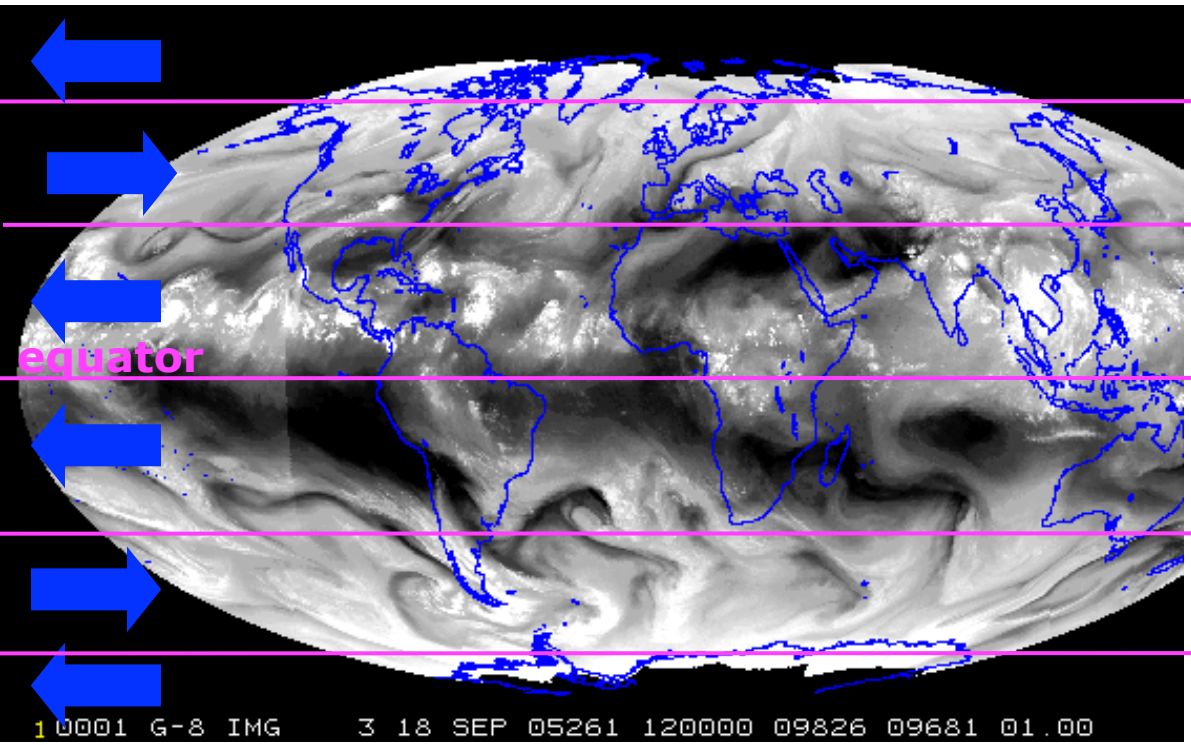


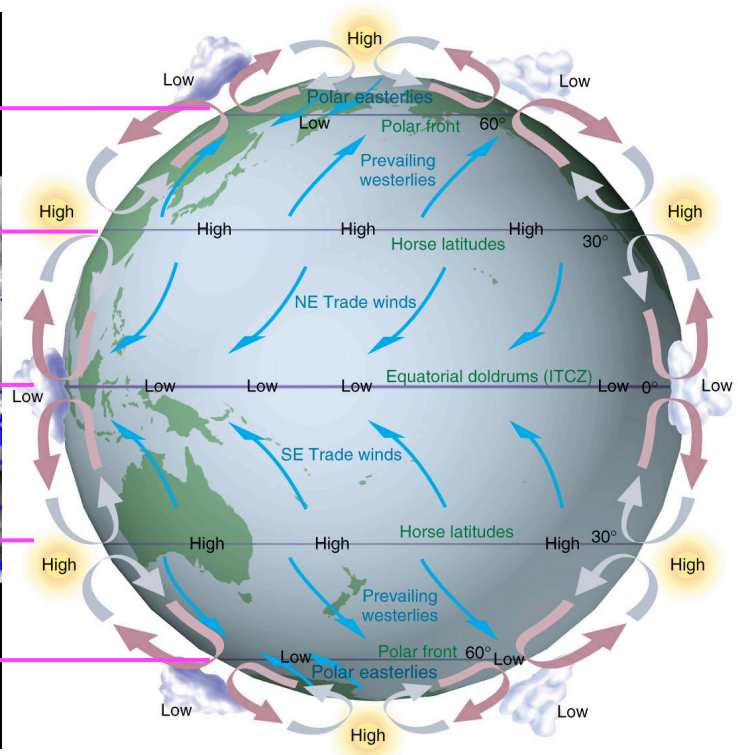
Diagram of Atmospheric Circulation



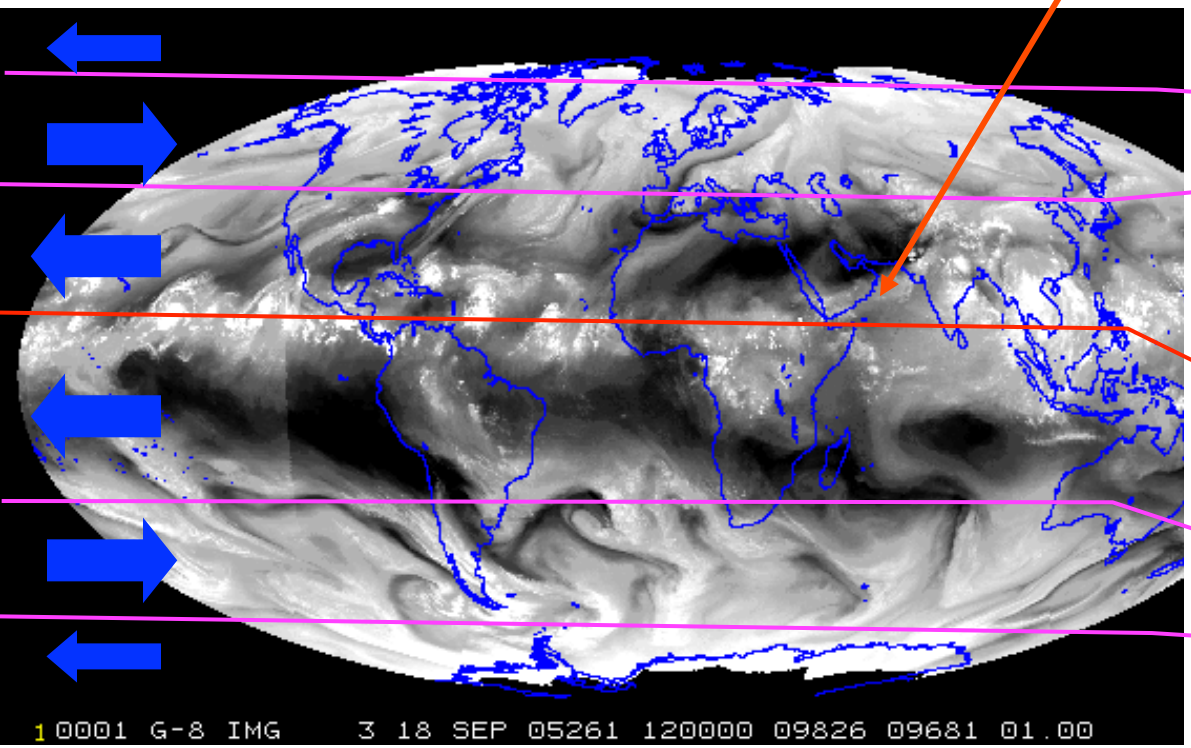
Vertical view of the atmosphere and Poleward Transport of Heat

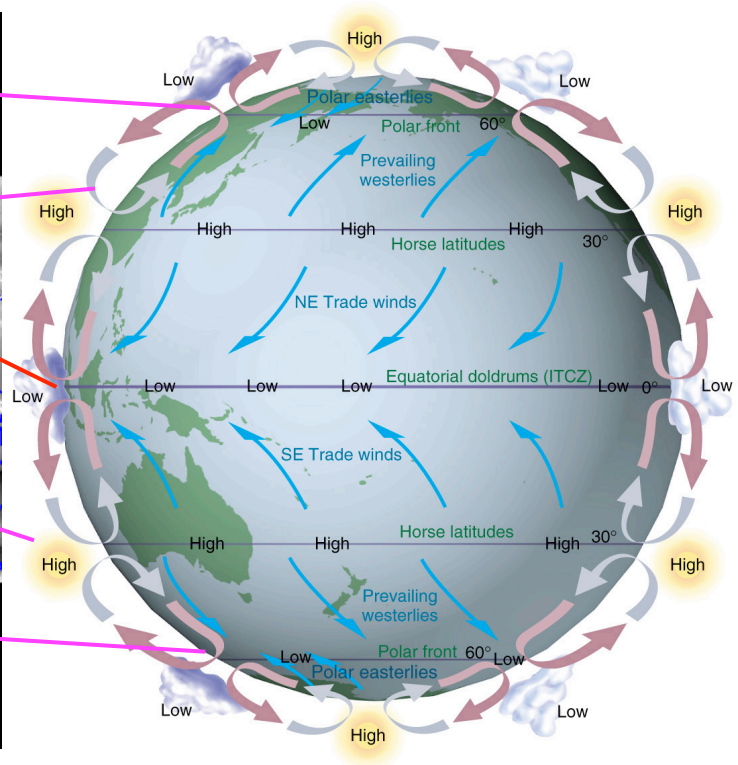



equator
1 0001 G-8 IMG 3 18 SEP 05261 120000 09826 09681 01.00

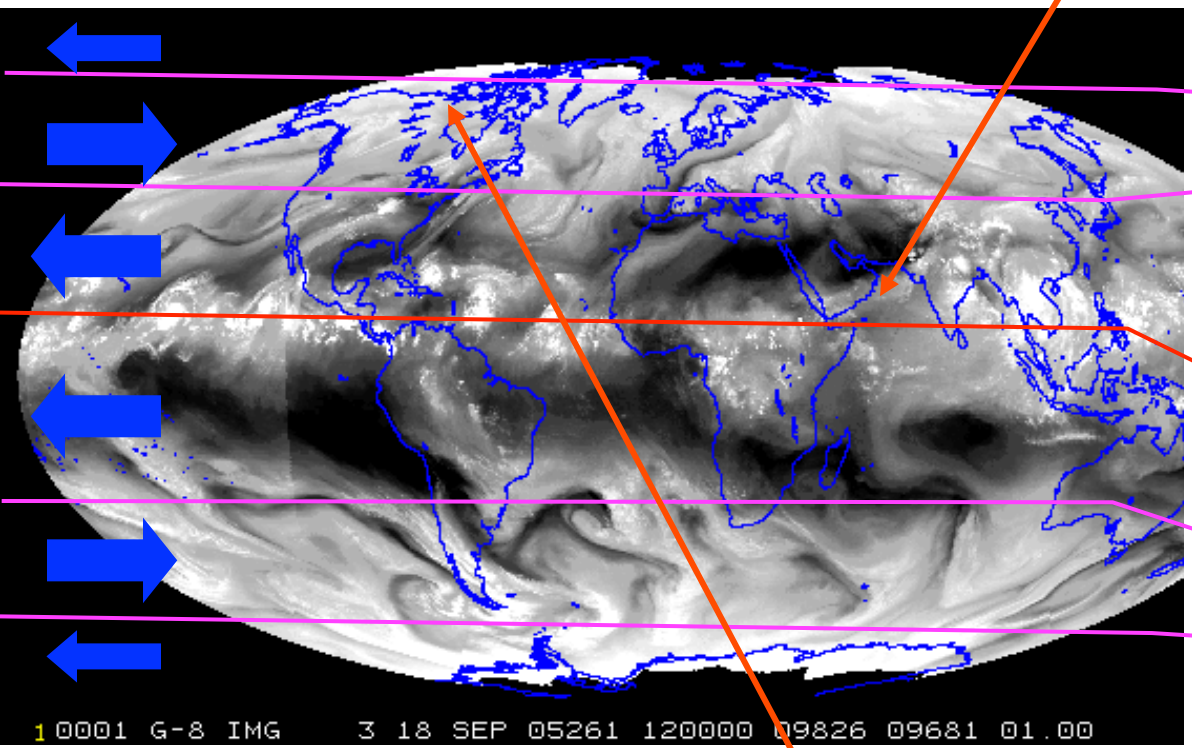

High
Low
Low
Polar easterlies
Low
Polar front
60°
Prevailing
westerlies
High
High
High
High
High
Horse latitudes
30°
NE Trade winds
Low
Low
Low
Low
Equatorial doldrums (ITCZ)
Low
0°
Low
SE Trade winds
High
High
High
Horse latitudes
High
30°
High
Prevailing
westerlies
Low
Polar front
60°
Low
Polar easterlies
Low
Low
High

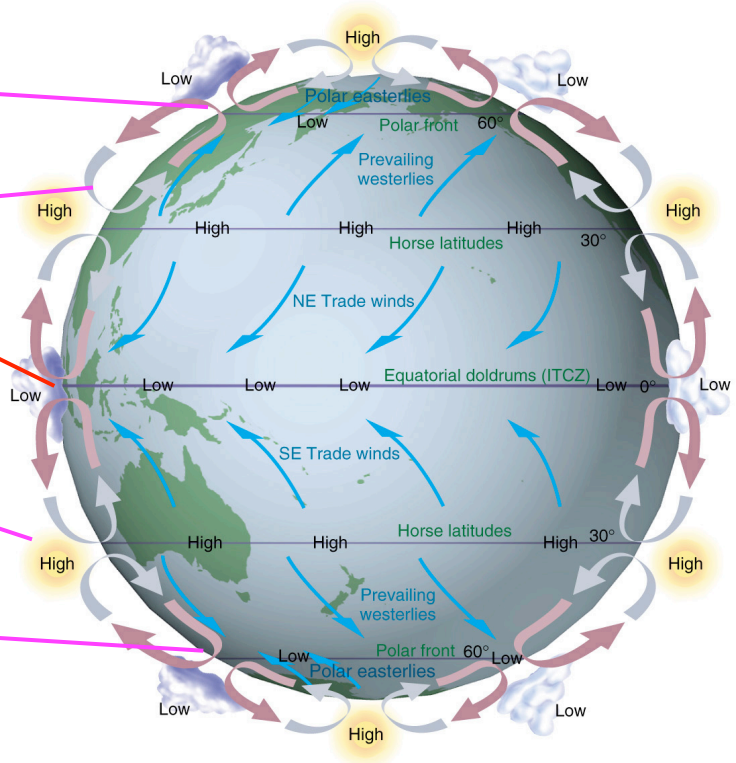
ITCZ: Inter-Tropical Convergenze Zone





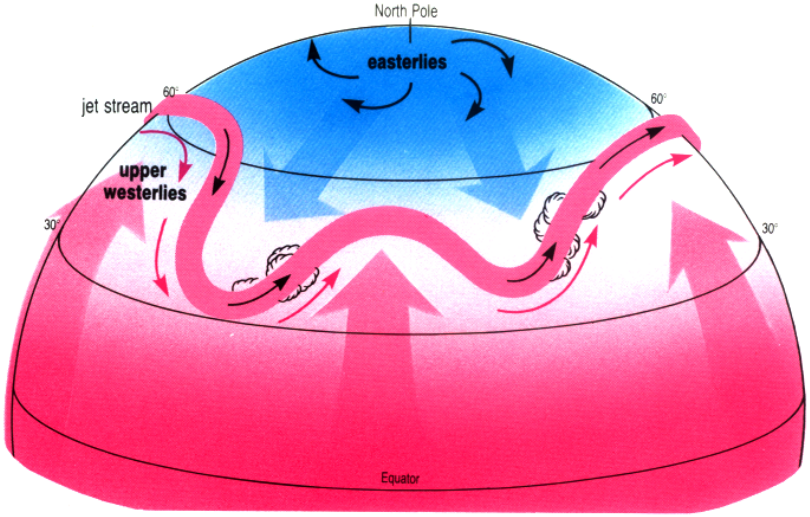
ITCZ: Inter-Tropical Convergenze Zone



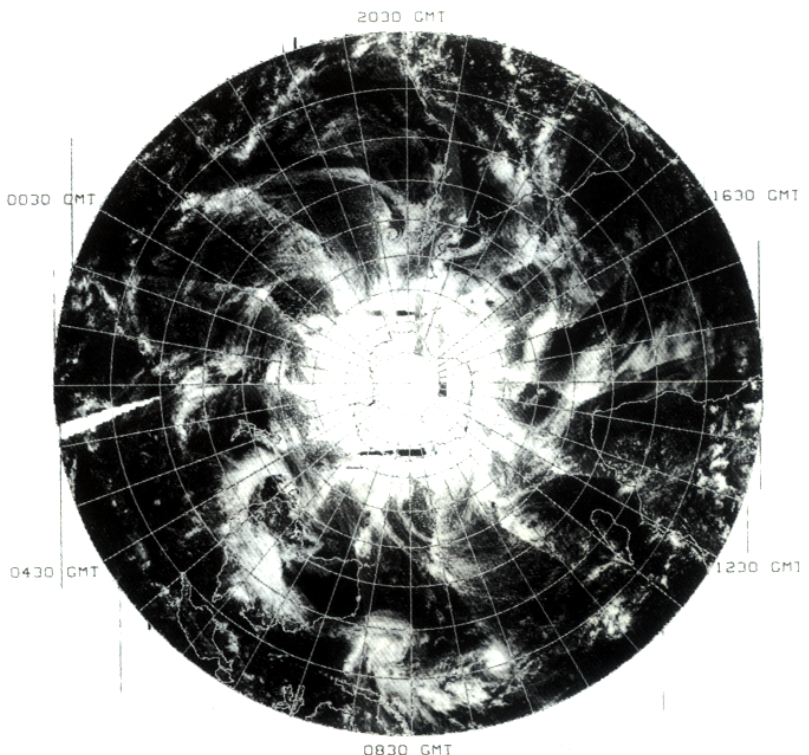


Midlatitude Instabilities

http://
www.atmos.washington.edu/
~ovens/loops/wxloop.cgi?ir_central
+/48h/3h

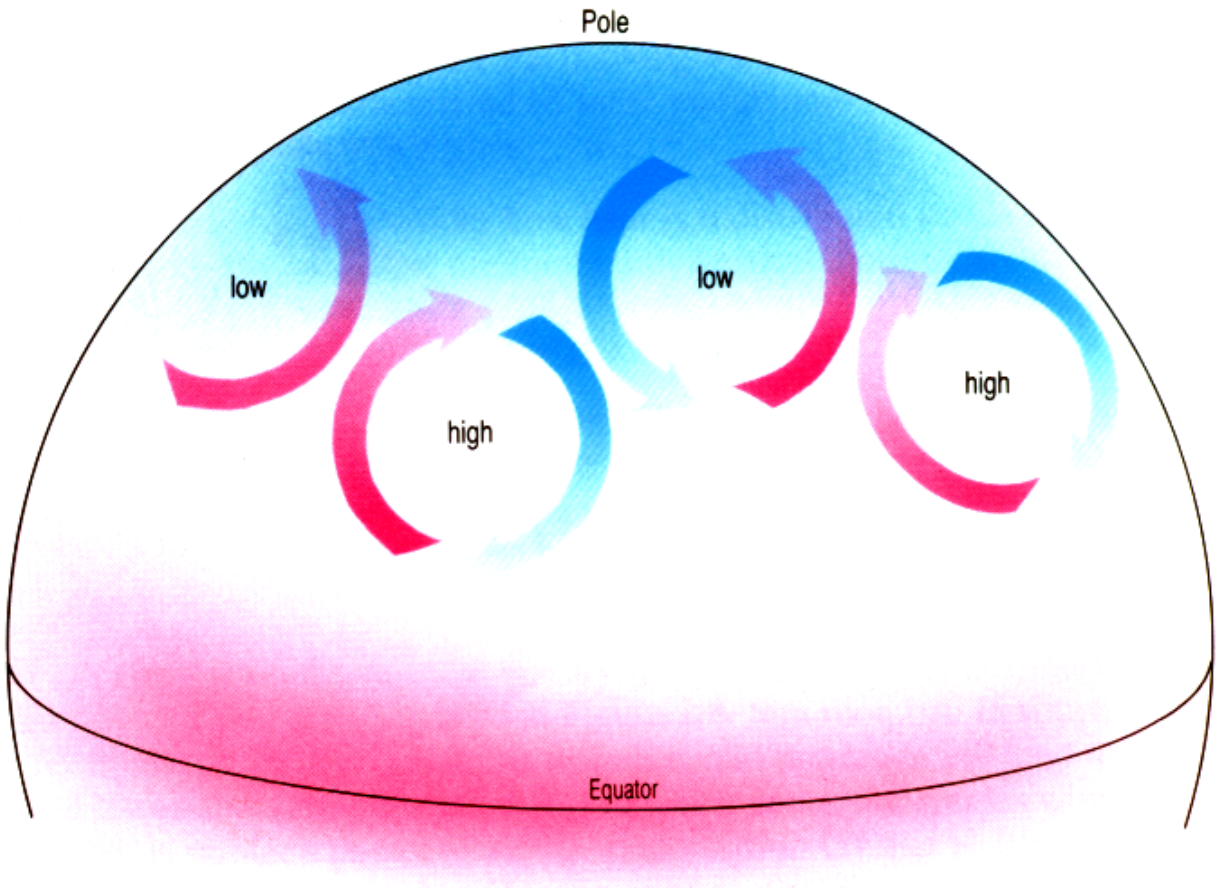

North Pole
easterlies
jet stream
60°
60°
upper
westerlies
30°
30°
Equator

(b)

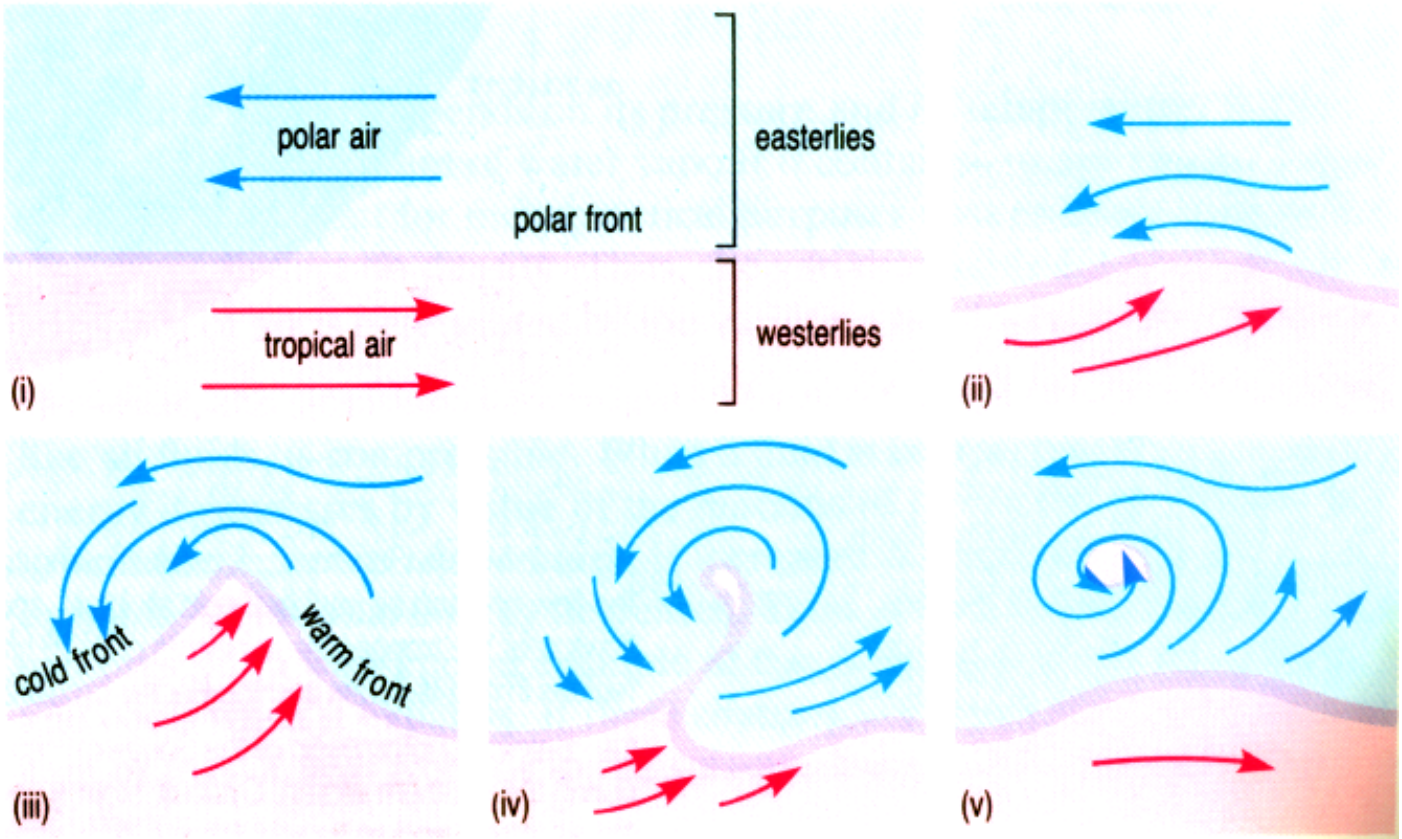

2030 GMT
0030 GMT
1630 GMT
0430 GMT
1230 GMT
0830 GMT

(c)

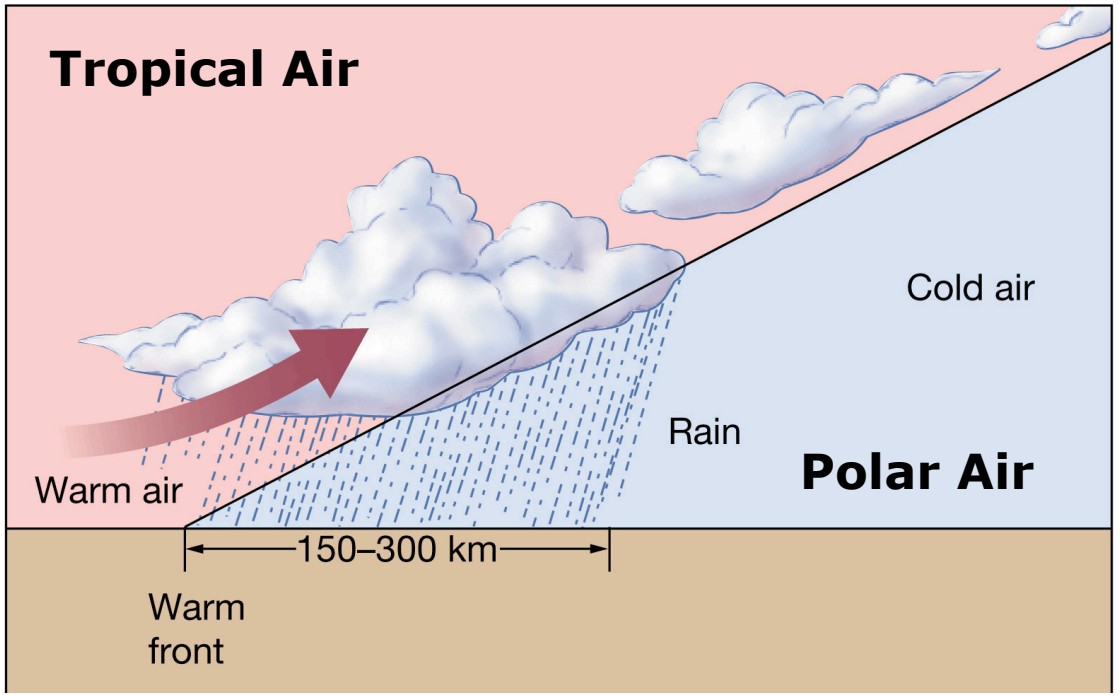
Poleward Heat Transport



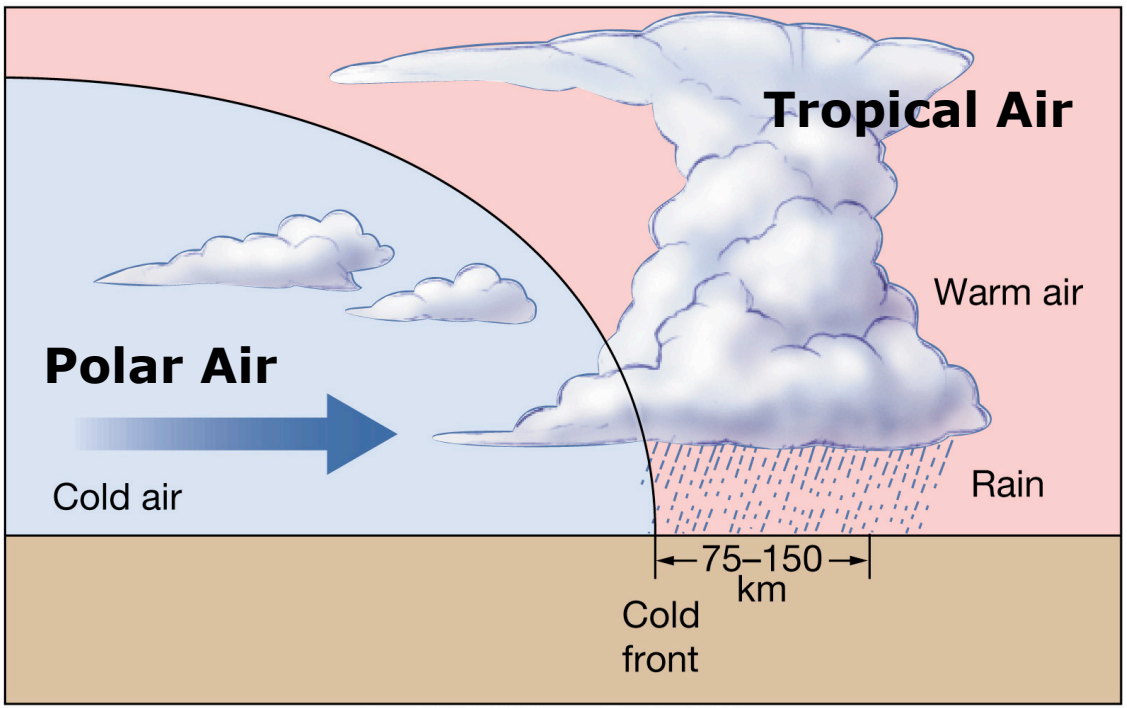
Midlatitude Cyclones



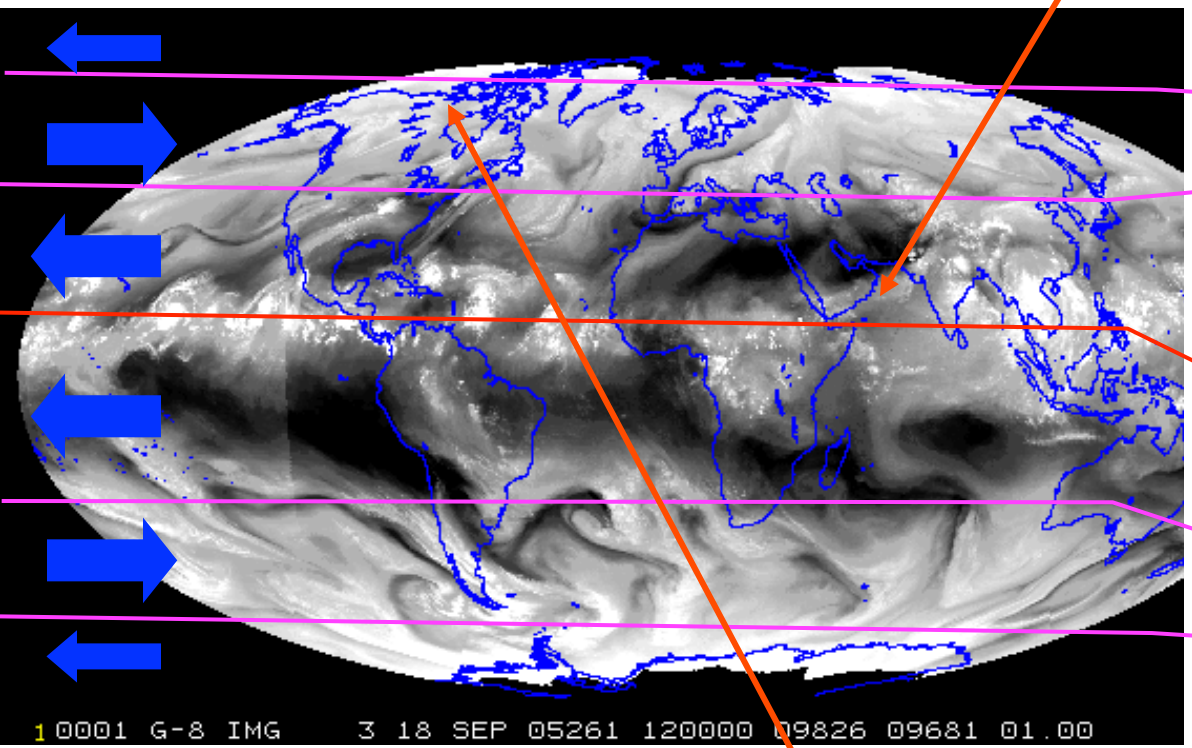
Warm Front

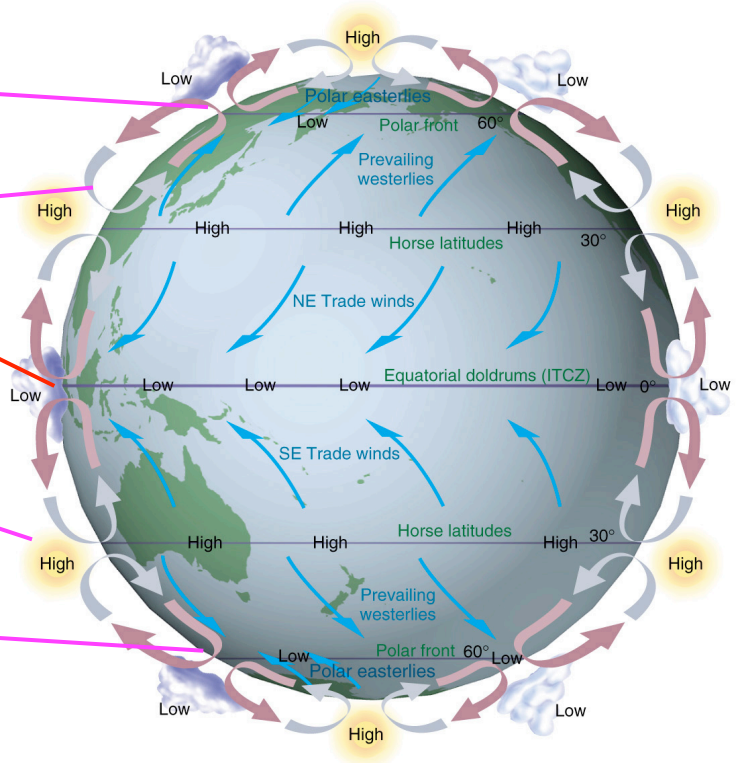


Cold Front



ITCZ: Inter-Tropical Convergenze Zone





Midlatitude Instabilities

http://
www.atmos.washington.edu/
~ovens/loops/wxloop.cgi?ir_central
+/48h/3h

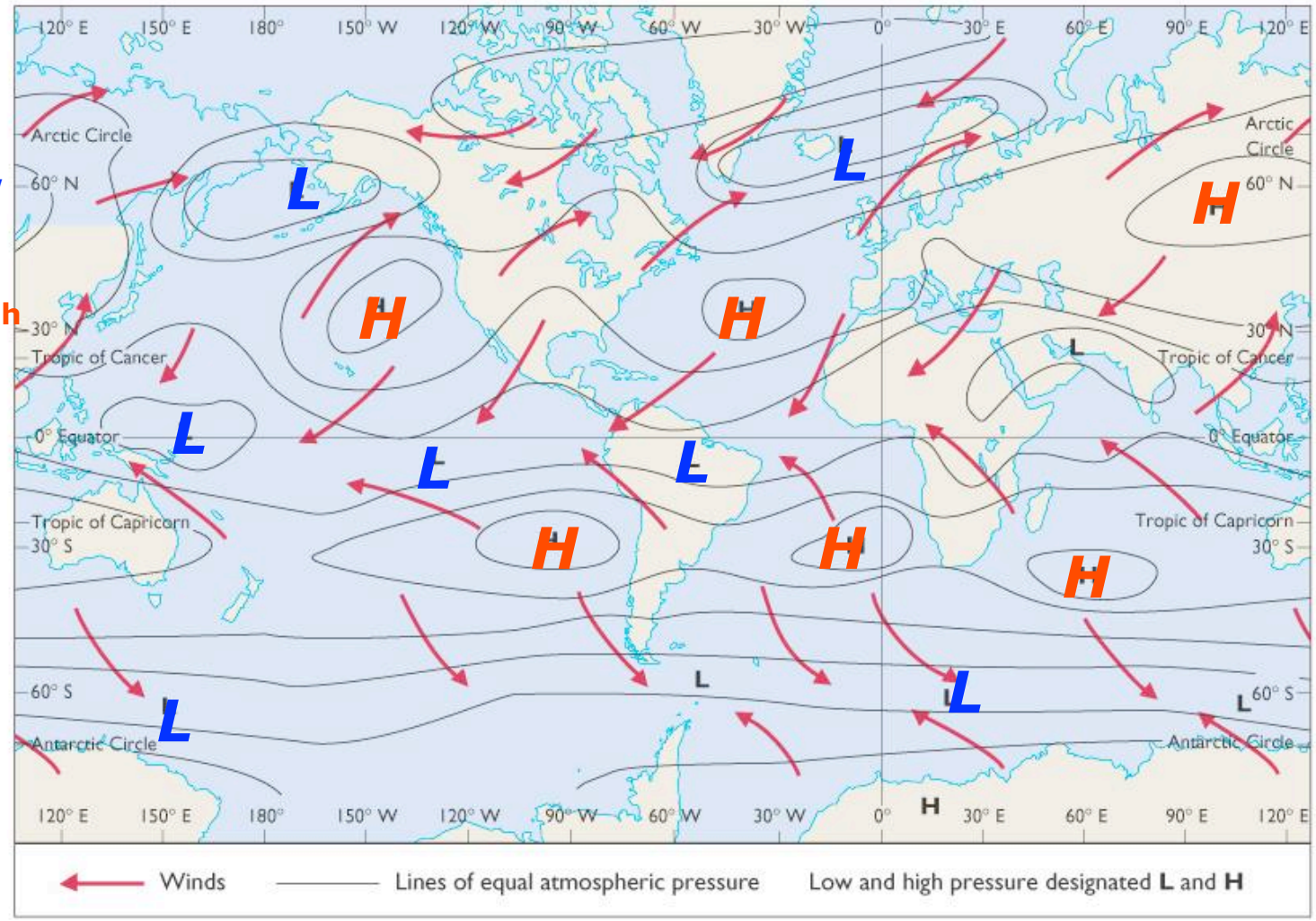
The plotting of prevailing winds on an air-pressure map of the world reveals that winds flow from high-pressure zones to low-pressure zones at an angle to the regional pressure gradients.

Polar High

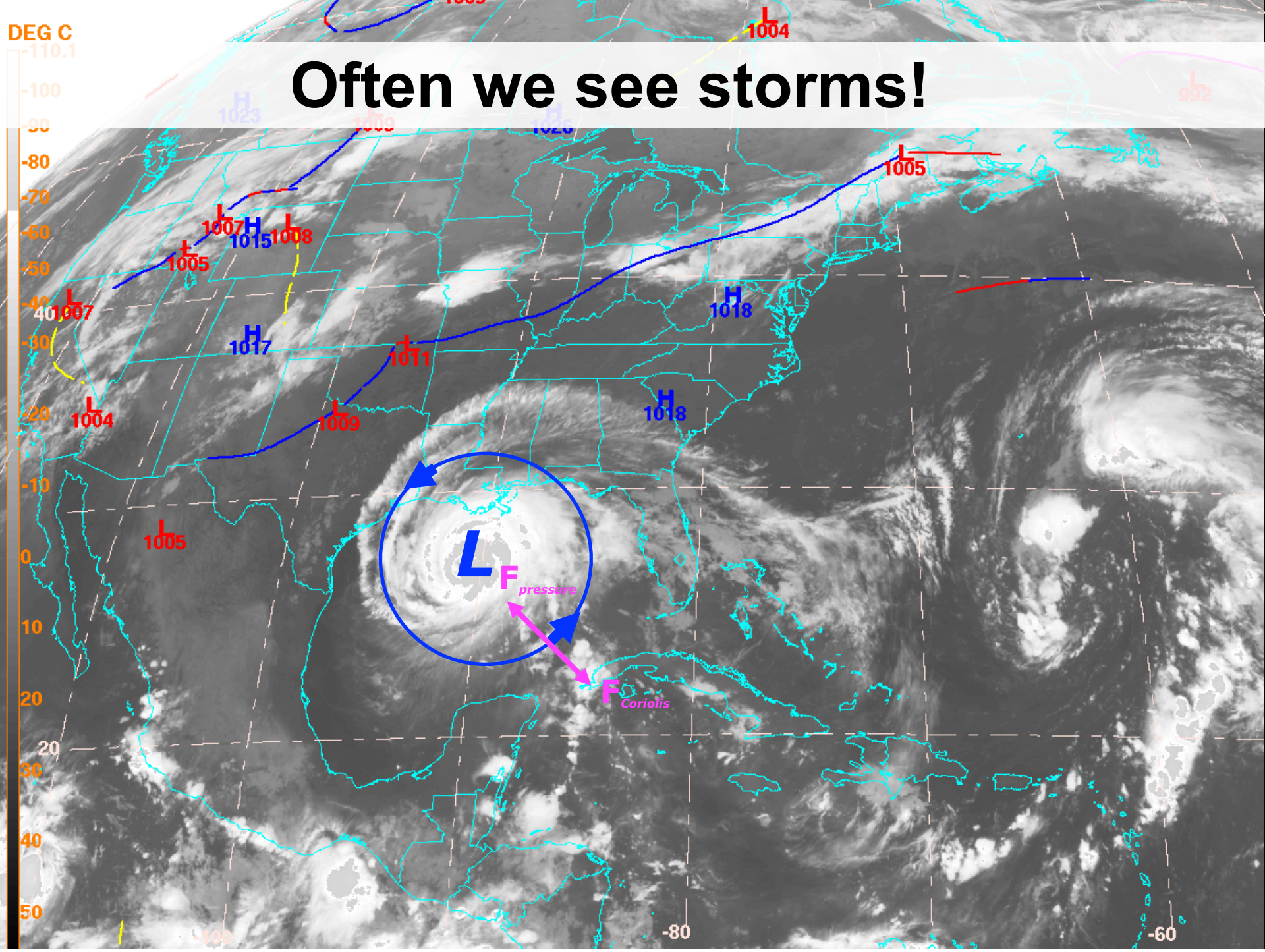
Subpolar Low

Subtropical High

Eq. Low



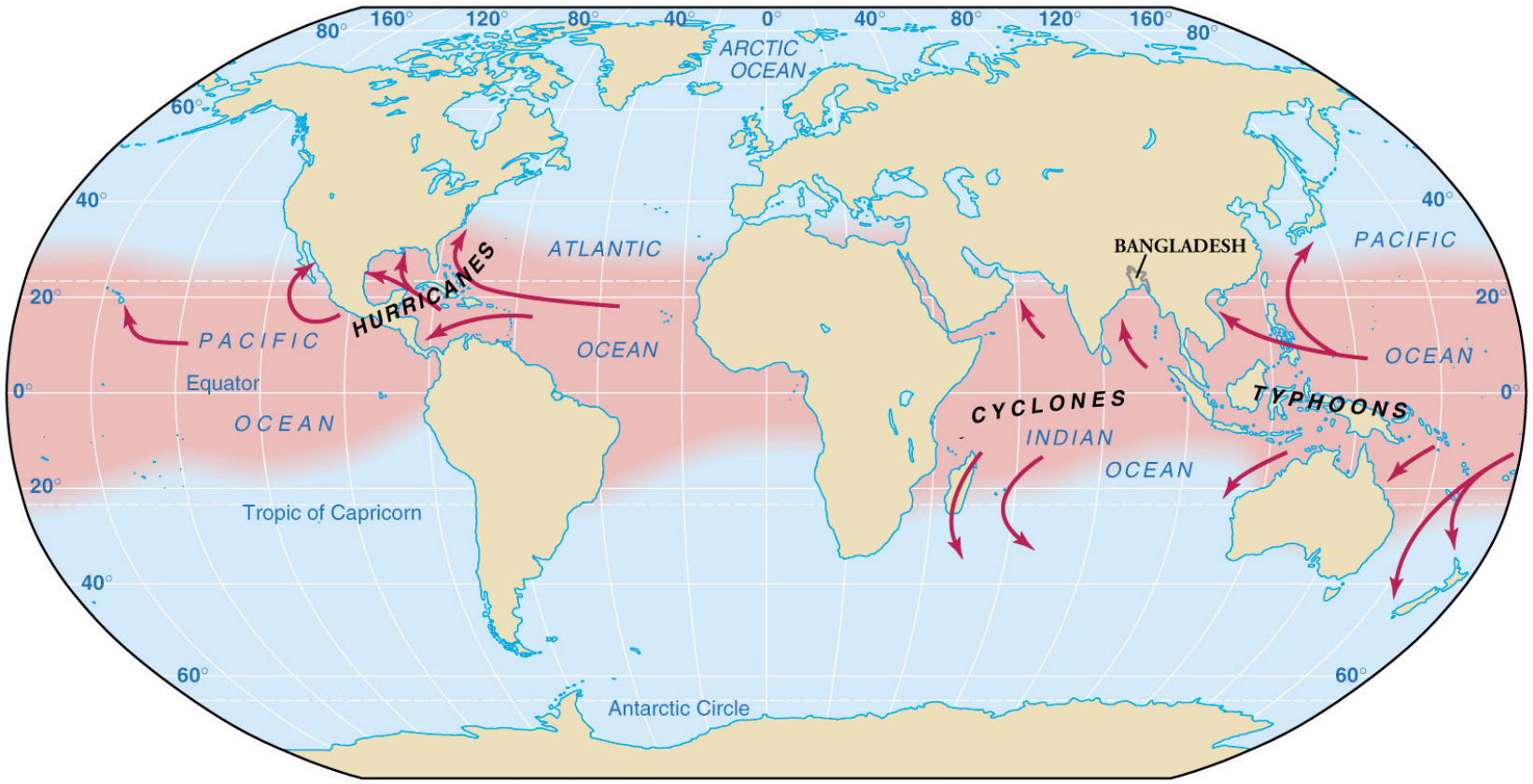
Often we see storms!



Friday, September 16, 16

Tropical Cyclones

RITA http://www.atmos.washington.edu/~ovens/loops/wxloop.cgi?fronts_ir_east+/48h/

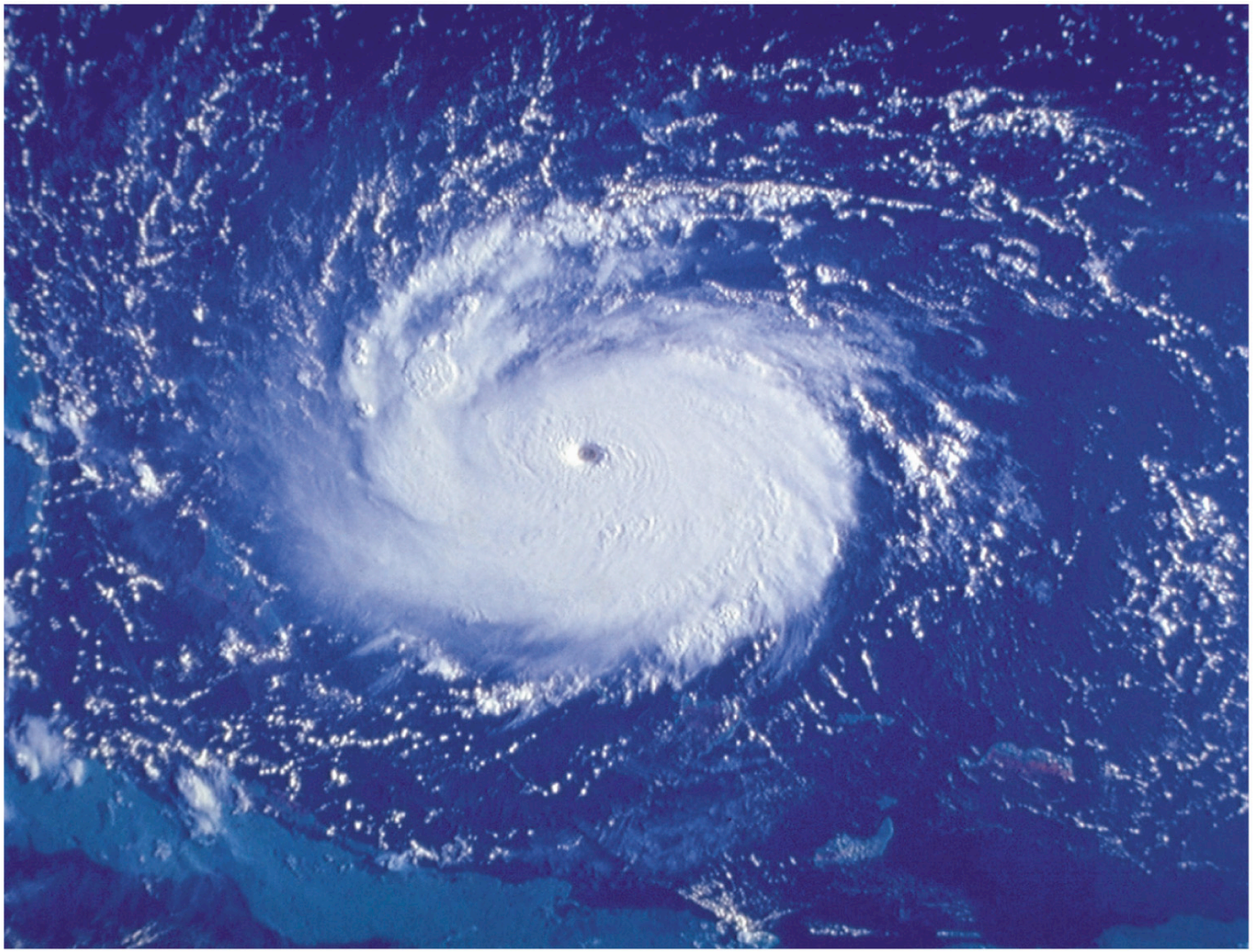


Articles

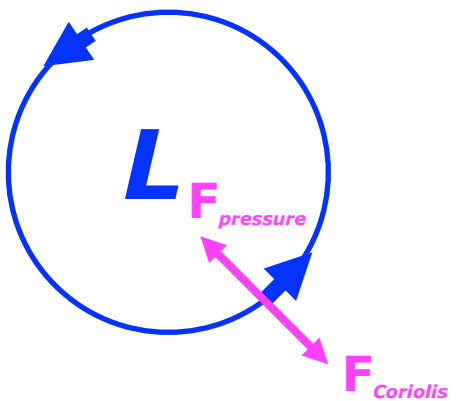
Webster P.J , G. J. Holland, J. A. Curry, H.-R. Chang (2005) Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment, *SCIENCE*

Emmanuel, K. (2004) Increasing destructiveness of tropical cyclones over the past 30 years, *NATURE*

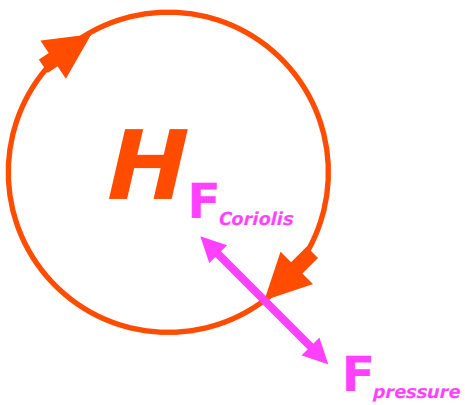
Why do tropical storms intensify?



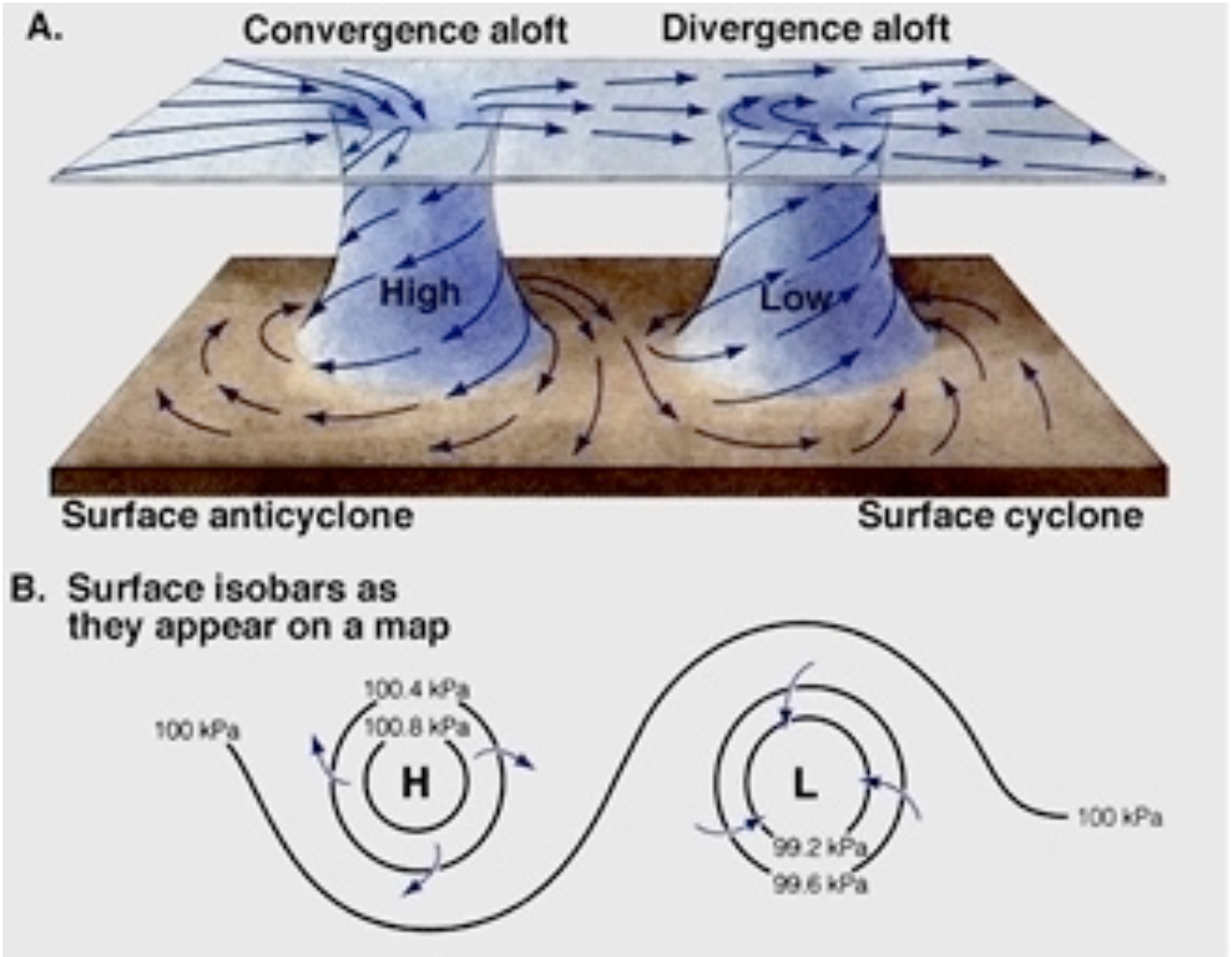
Vortices



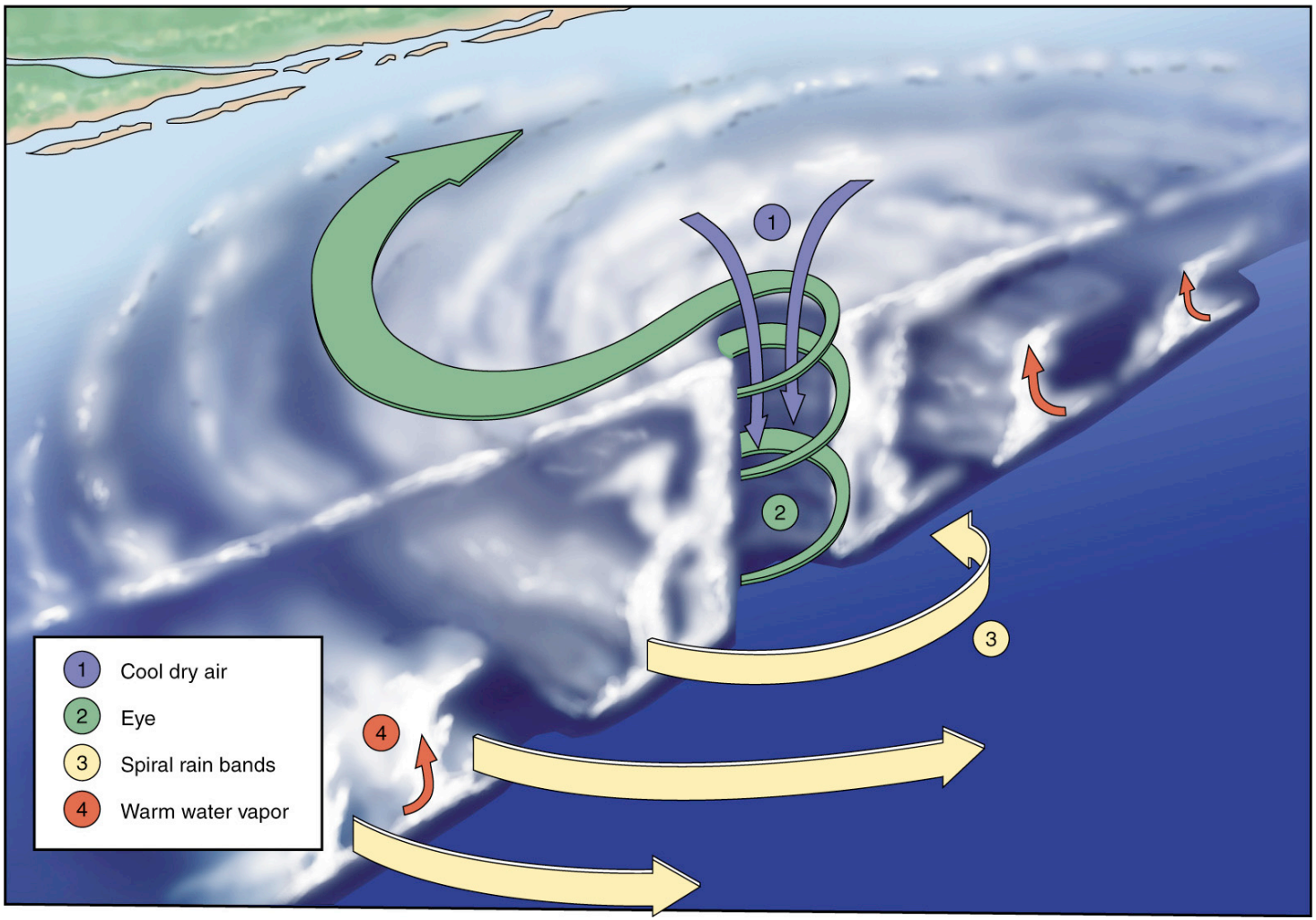
Low Pressure System



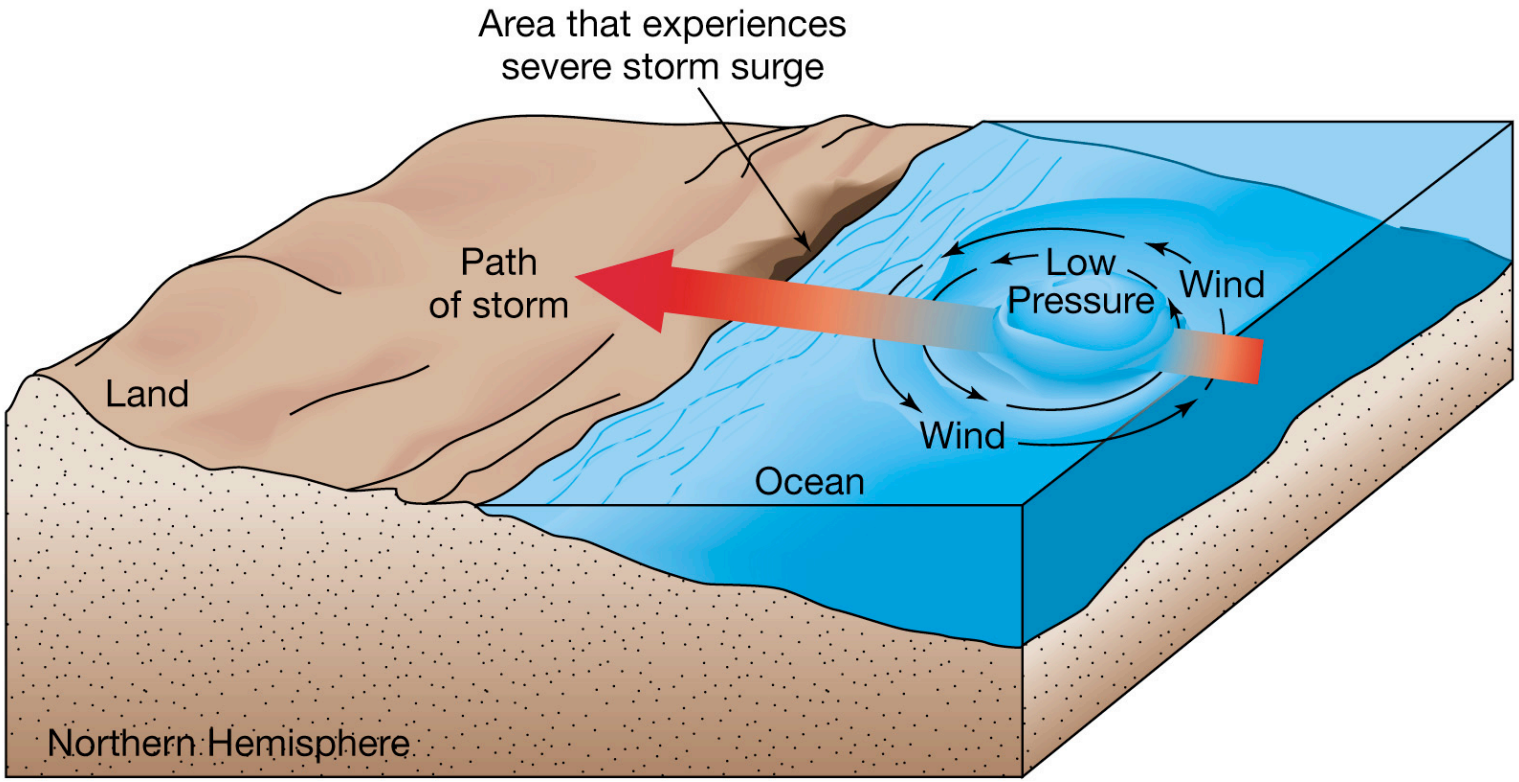
High Pressure System


A.
Convergence aloft
Divergence aloft
High
Low
Surface anticyclone
Surface cyclone
B. Surface isobars as they appear on a map
100 kPa
100.4 kPa
100.8 kPa
H
L
99.2 kPa
99.6 kPa
100 kPa

Tropical cyclone have an eye of anticyclonic circulation!

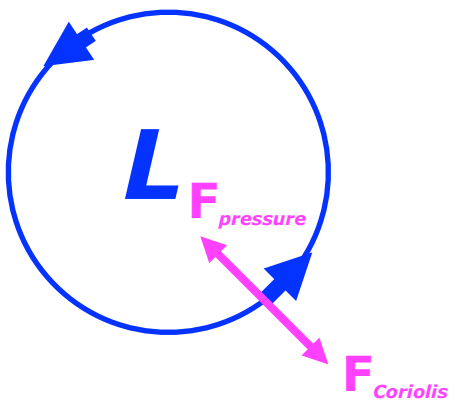


Storm Surge: sea level rises because of the low atmospheric pressure system

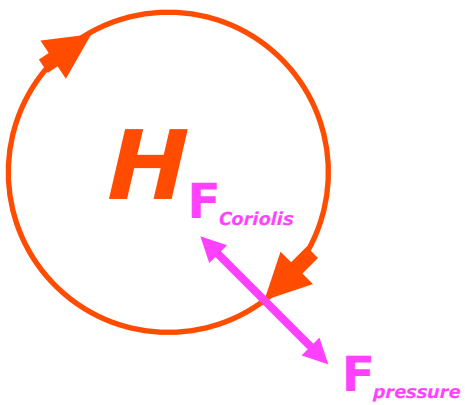


Role of Friction on synoptic scales

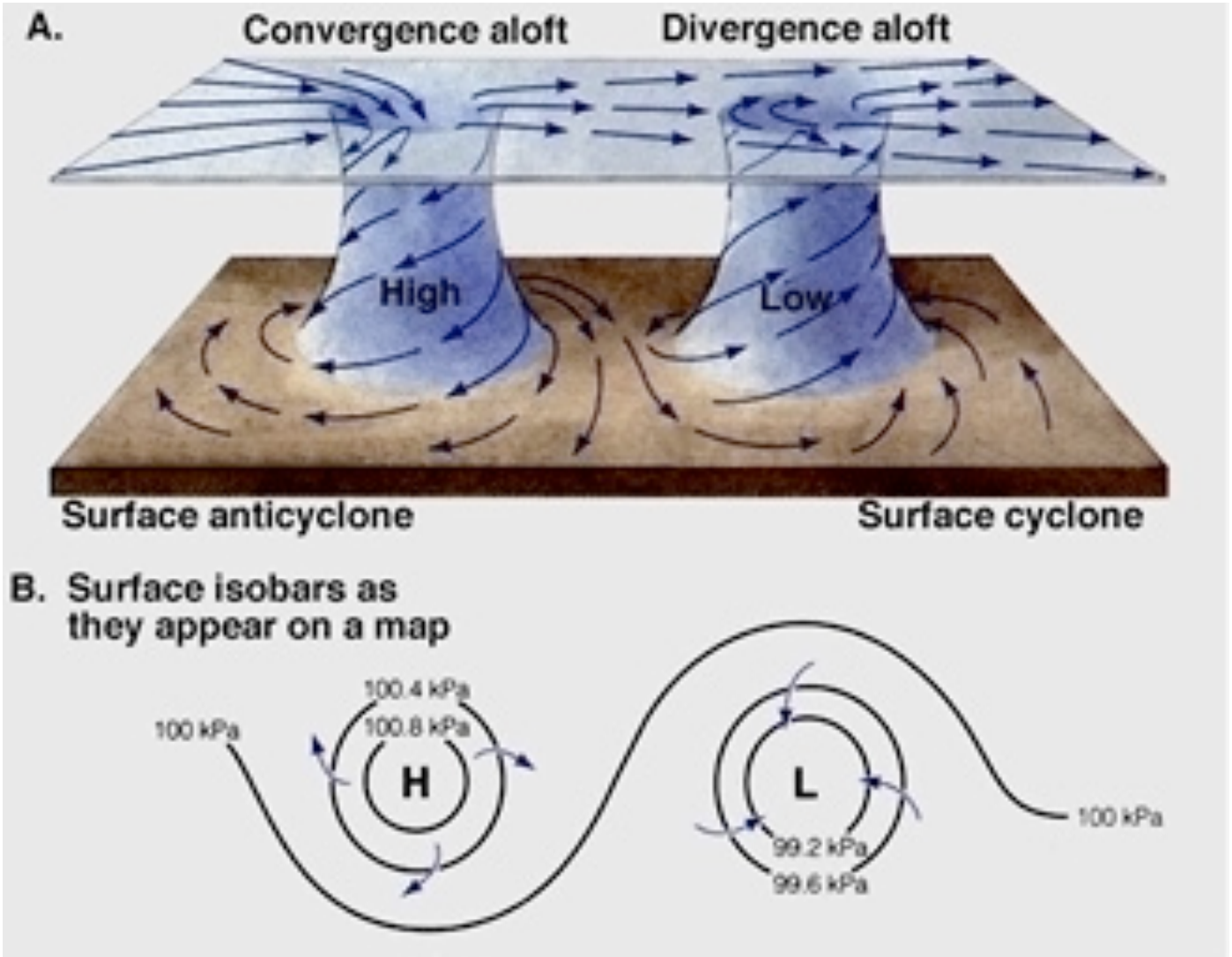
Vortices



Low Pressure System



High Pressure System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H
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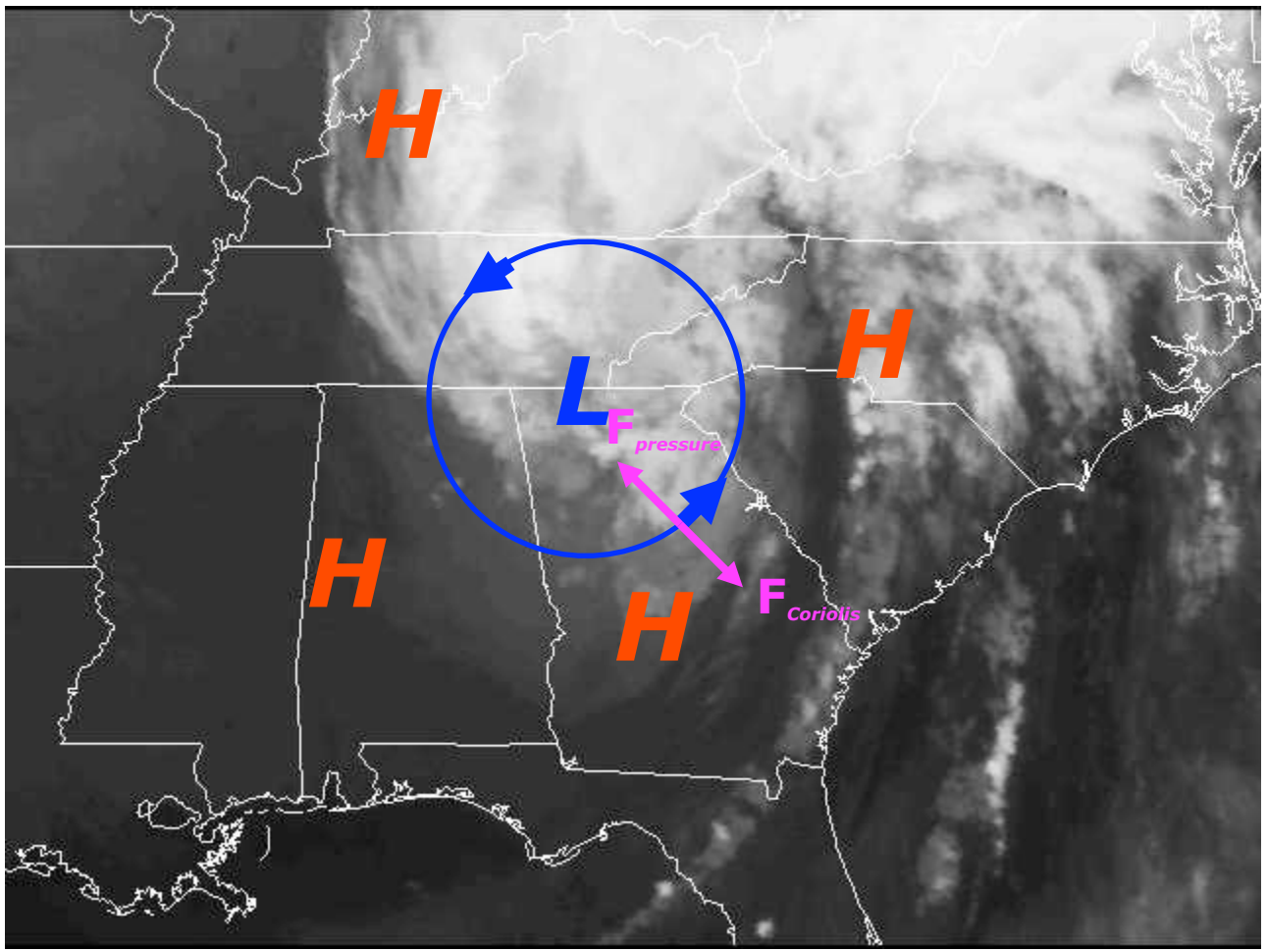
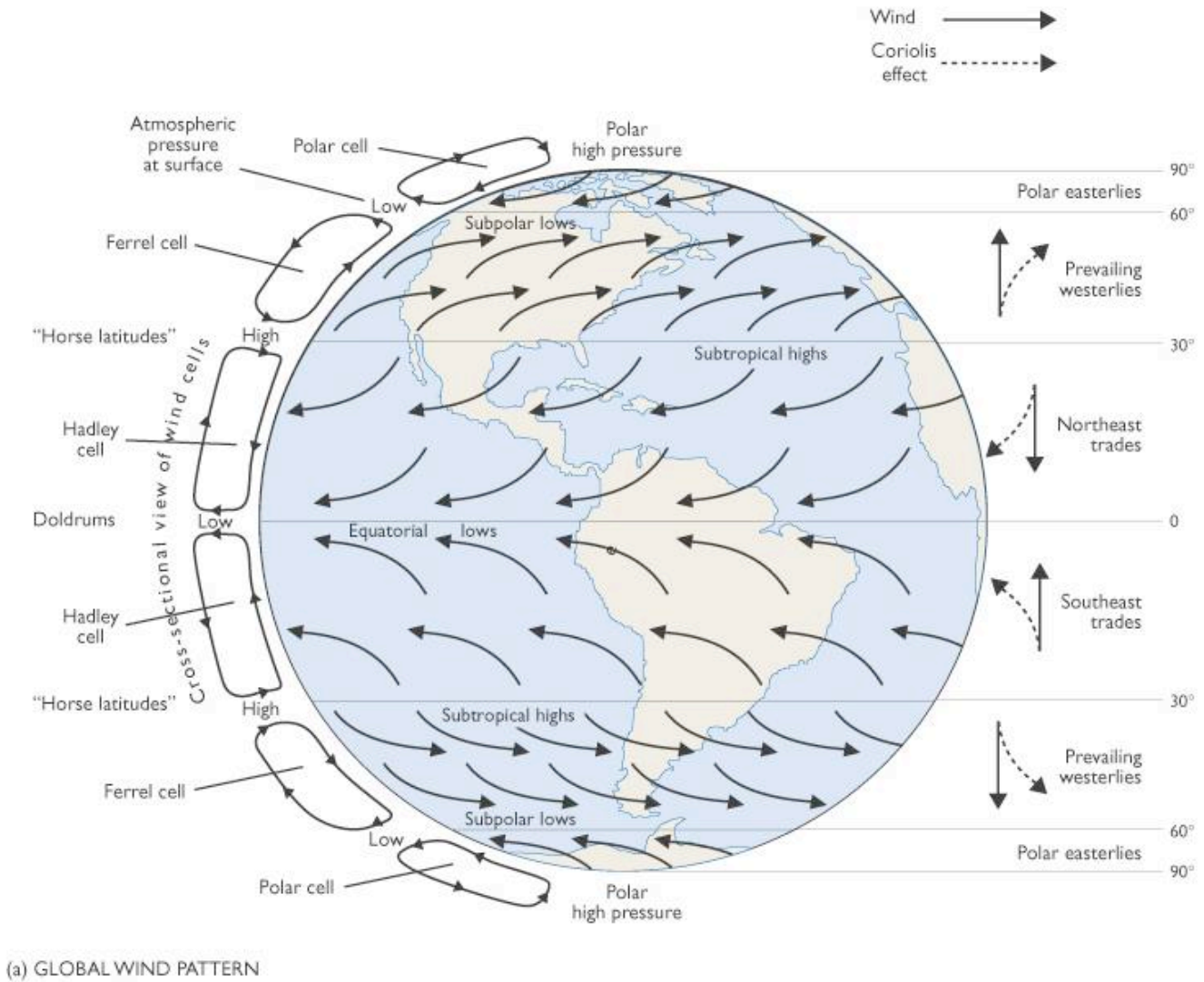
100 kPa

Hurricane IVAN



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



(a) GLOBAL WIND PATTERN

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Polar High

Subpolar Low

Subtropical High

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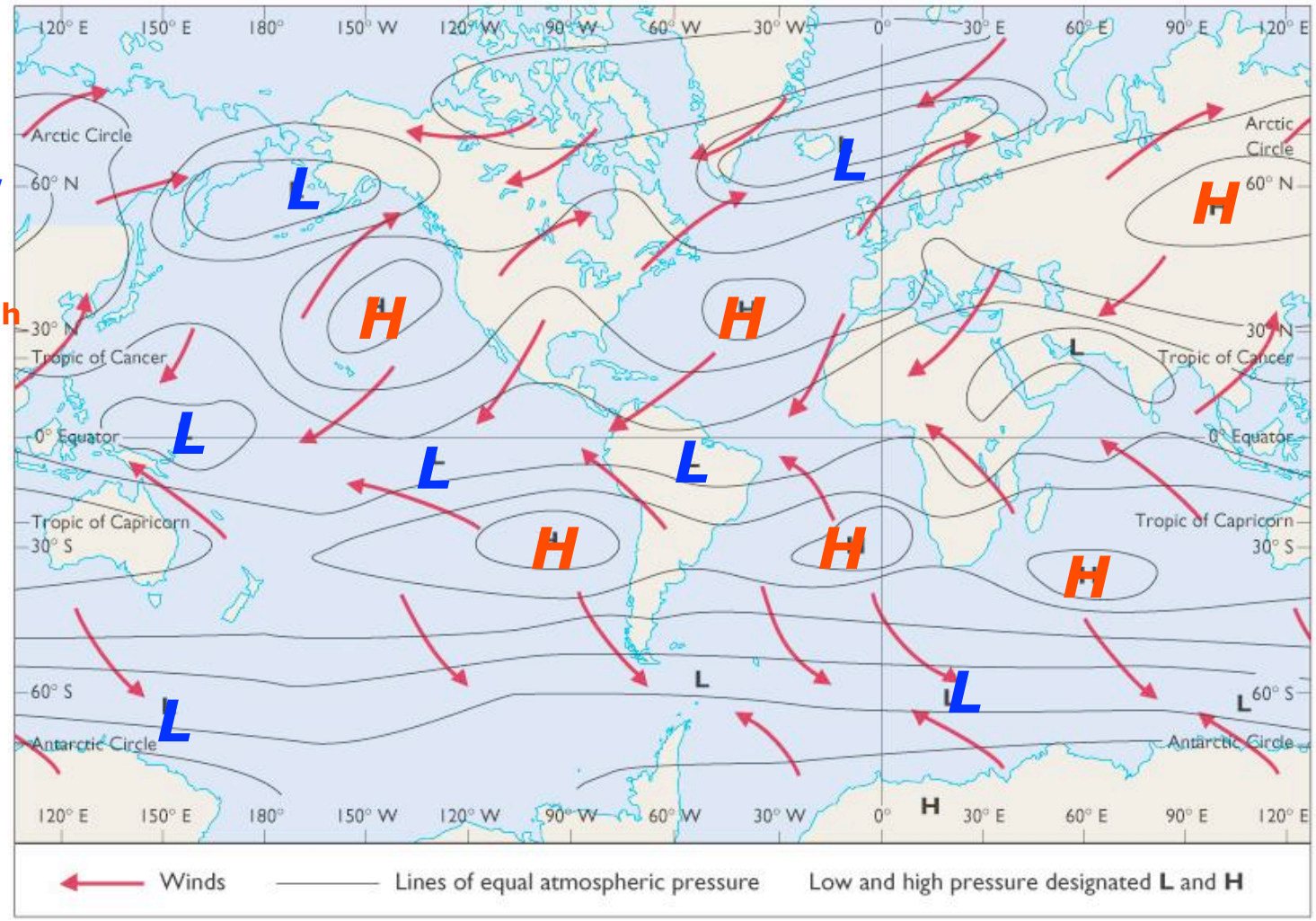
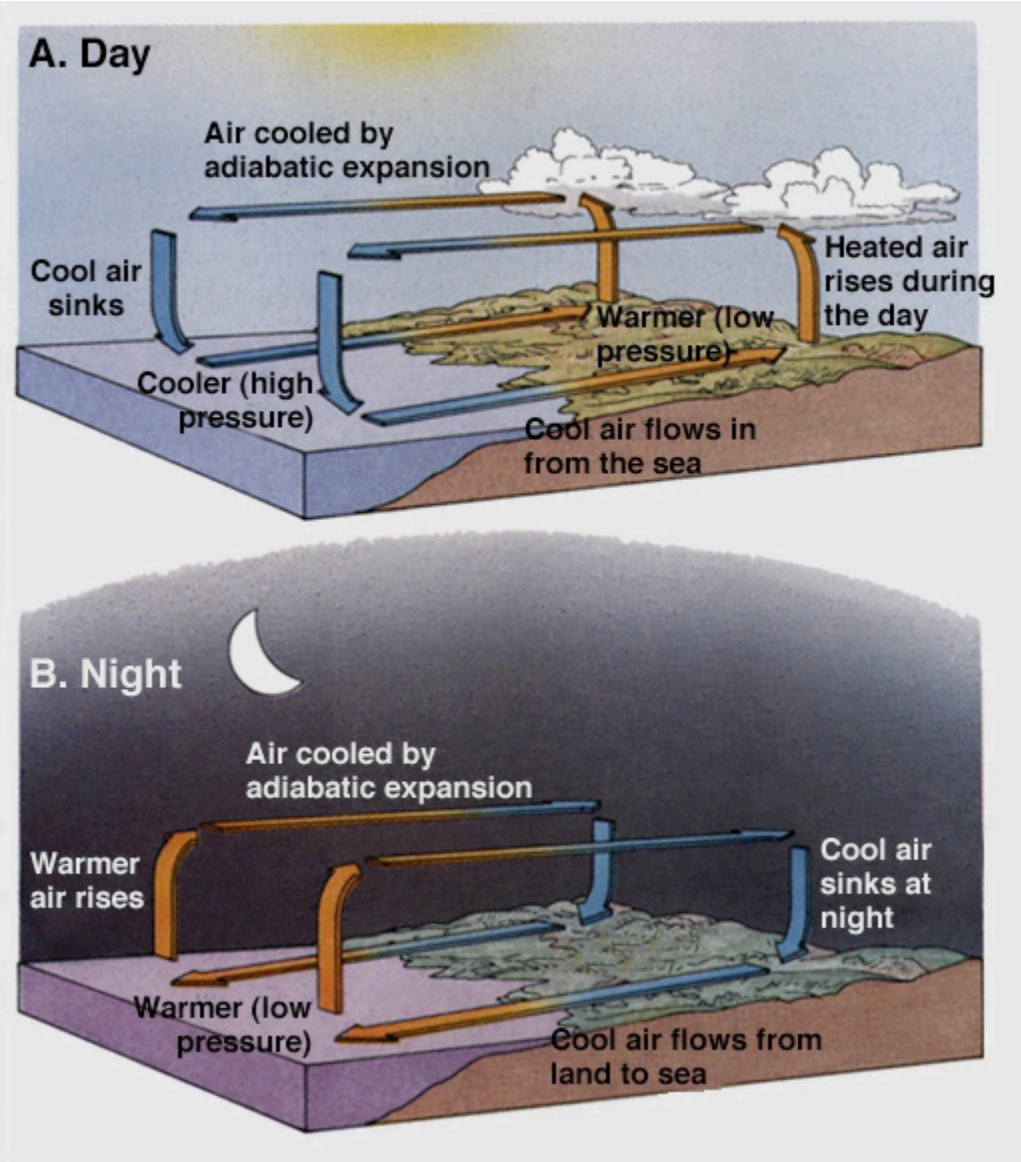


Rotation effects are not always important

Land-Sea Breeze



Moonsoons, a continental scale land-sea breeze