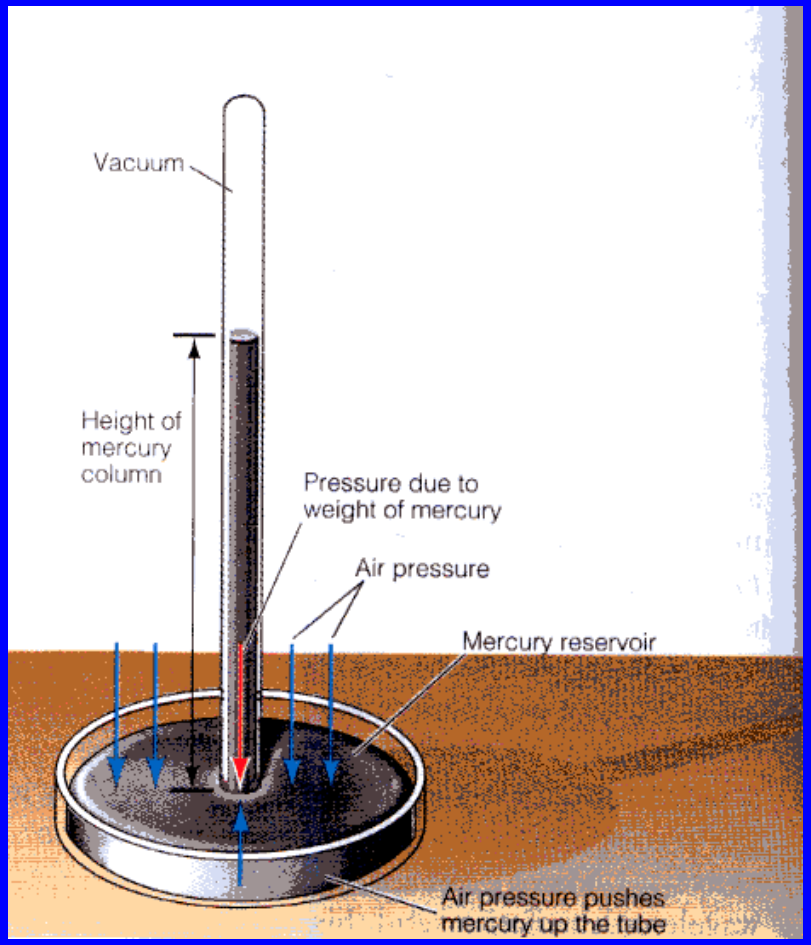
Chapter 4: Pressure and Wind

- Pressure, Measurement, Distribution
- Hydrostatic Balance
- Pressure Gradient and Coriolis Force
- Geostrophic Balance
- Upper and Near-Surface Winds

One Atmospheric Pressure



(from *The Blue Planet*)

- The average air pressure at sea level is equivalent to the pressure produced by a column of water about 10 meters (or about 76 cm of mercury column).
- This standard atmosphere pressure is often expressed as 1013 mb (millibars), which means a pressure of about 1 kilogram per square centimeter (14.7lbs/in^2).

Units of Atmospheric Pressure

- **Pascal (Pa):** a SI (Systeme Internationale) unit for air pressure.

  1 Pa = force of 1 newton acting on a surface of one square meter
  1 hectopascal (hPa) = 1 millibar (mb) [hecto = one hundred =100]

- **Bar:** a more popular unit for air pressure.

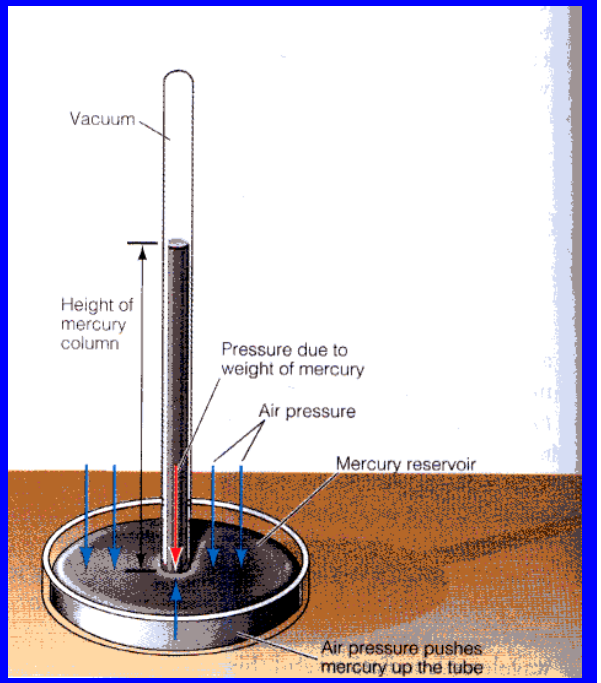
  1 bar = 1000 hPa = 1000 mb

- **One atmospheric pressure** = standard value of atmospheric pressure at lea level = 1013.25 mb = 1013.25 hPa.

Measurement of Atmos. Pressure

Mercury Barometers

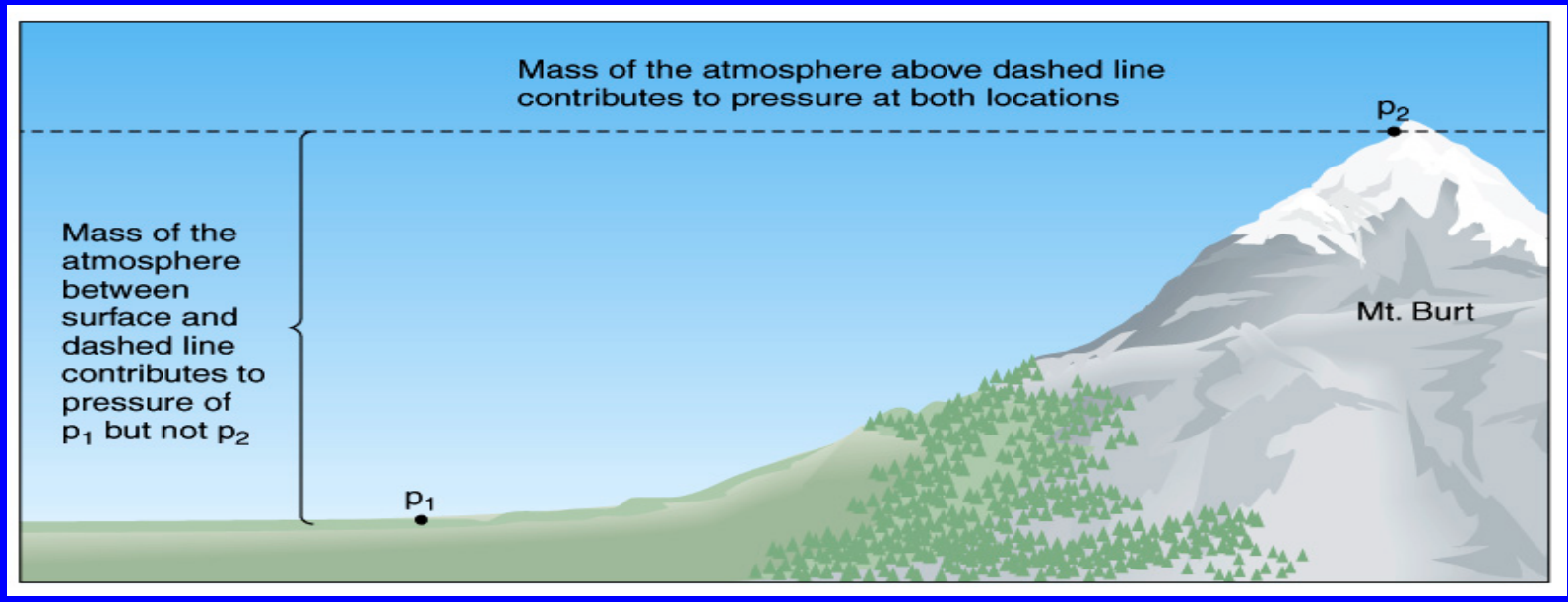
- Height of mercury indicates downward force of air pressure
- Three barometric corrections must be made to ensure homogeneity of pressure readings
- First corrects for elevation, the second for air temperature (affects density of mercury), and the third involves a slight correction for gravity with latitude



Aneroid Barometers

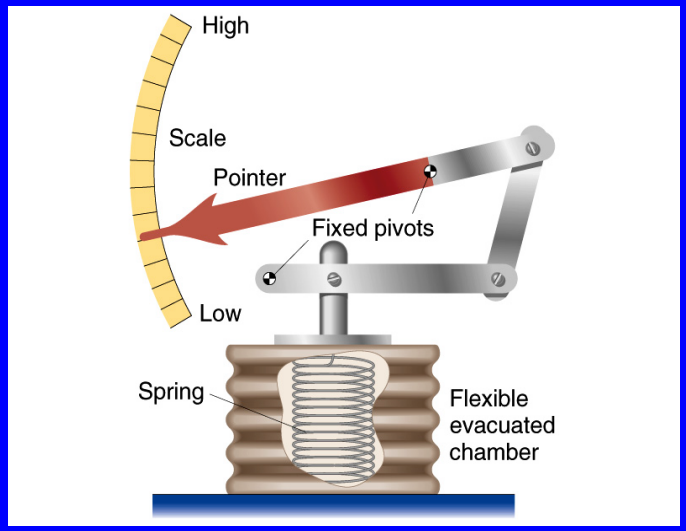
- Use a collapsible chamber which compresses proportionally to air pressure
- Requires only an initial adjustment for elevation

Pressure Correction for Elevation



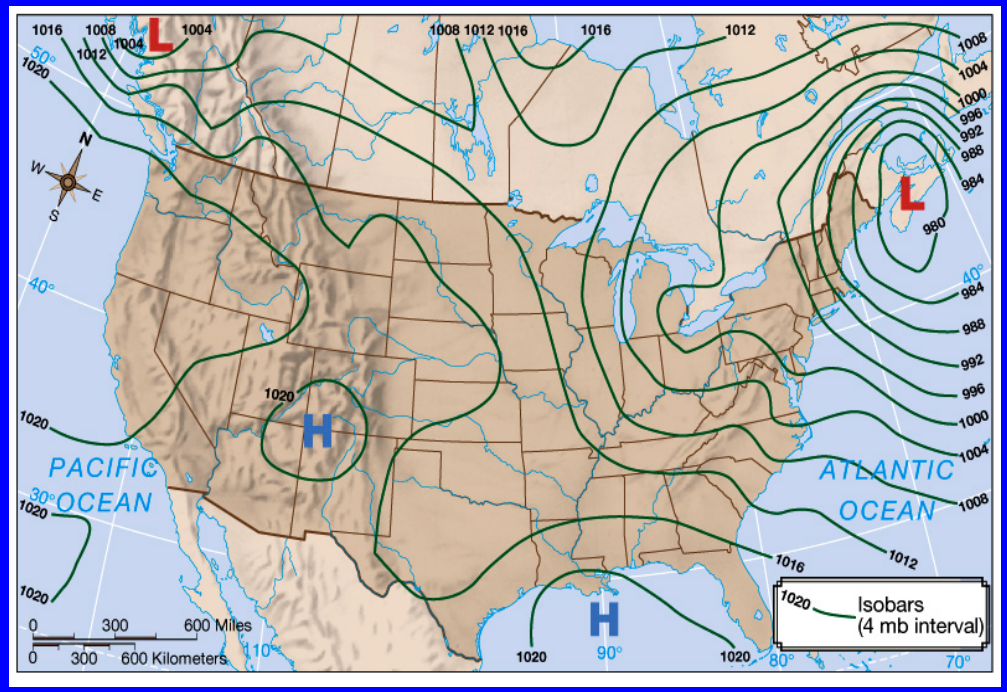
- Pressure decreases with height.
- Recording actual pressures may be misleading as a result.
- All recording stations are reduced to sea level pressure equivalents to facilitate horizontal comparisons.
- Near the surface, the pressure decreases about 100mb by moving 1km higher in elevation.

Aneroid barometer (left) and its workings (right)



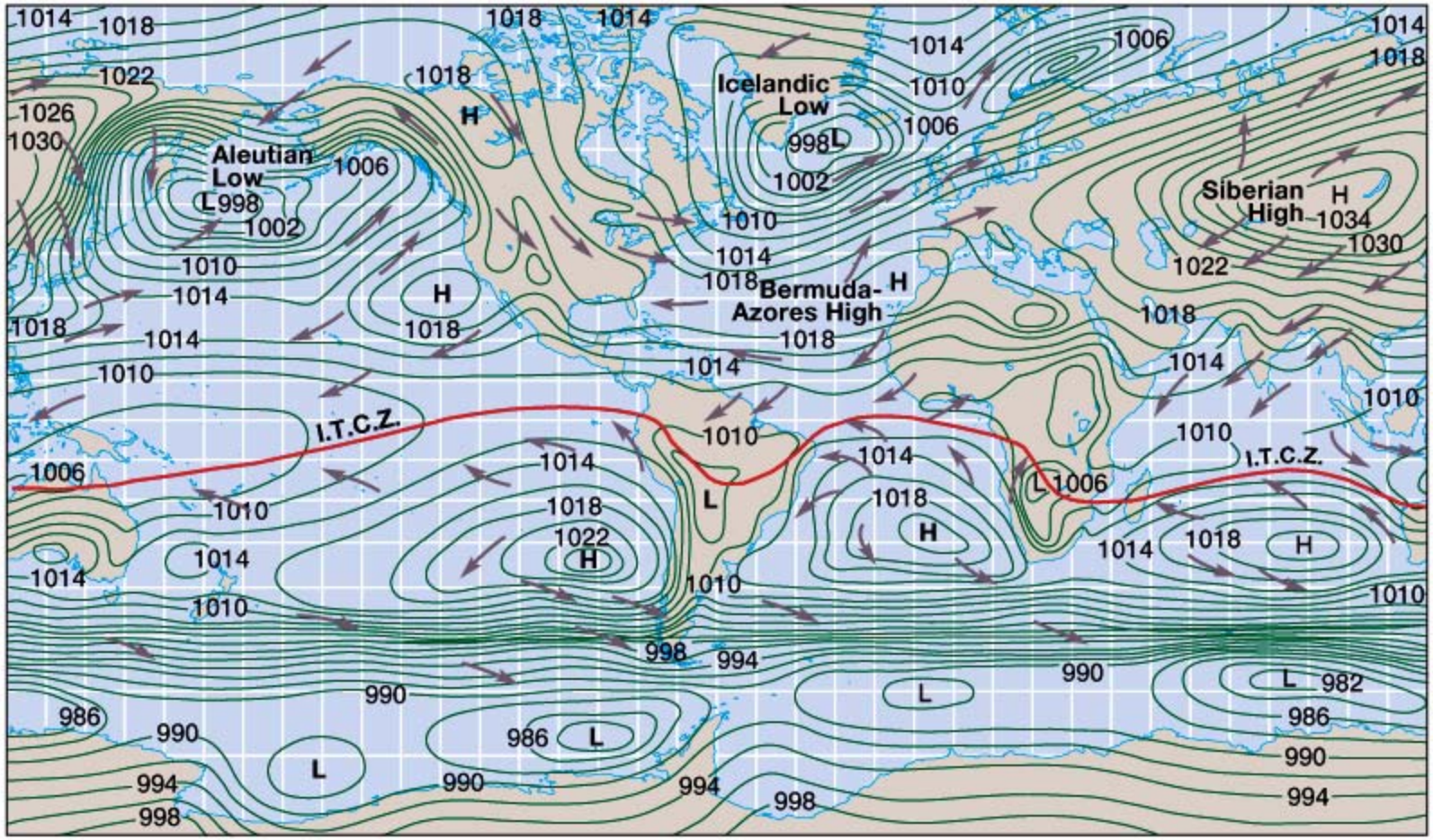
A barograph continually records air pressure through time

Isobar

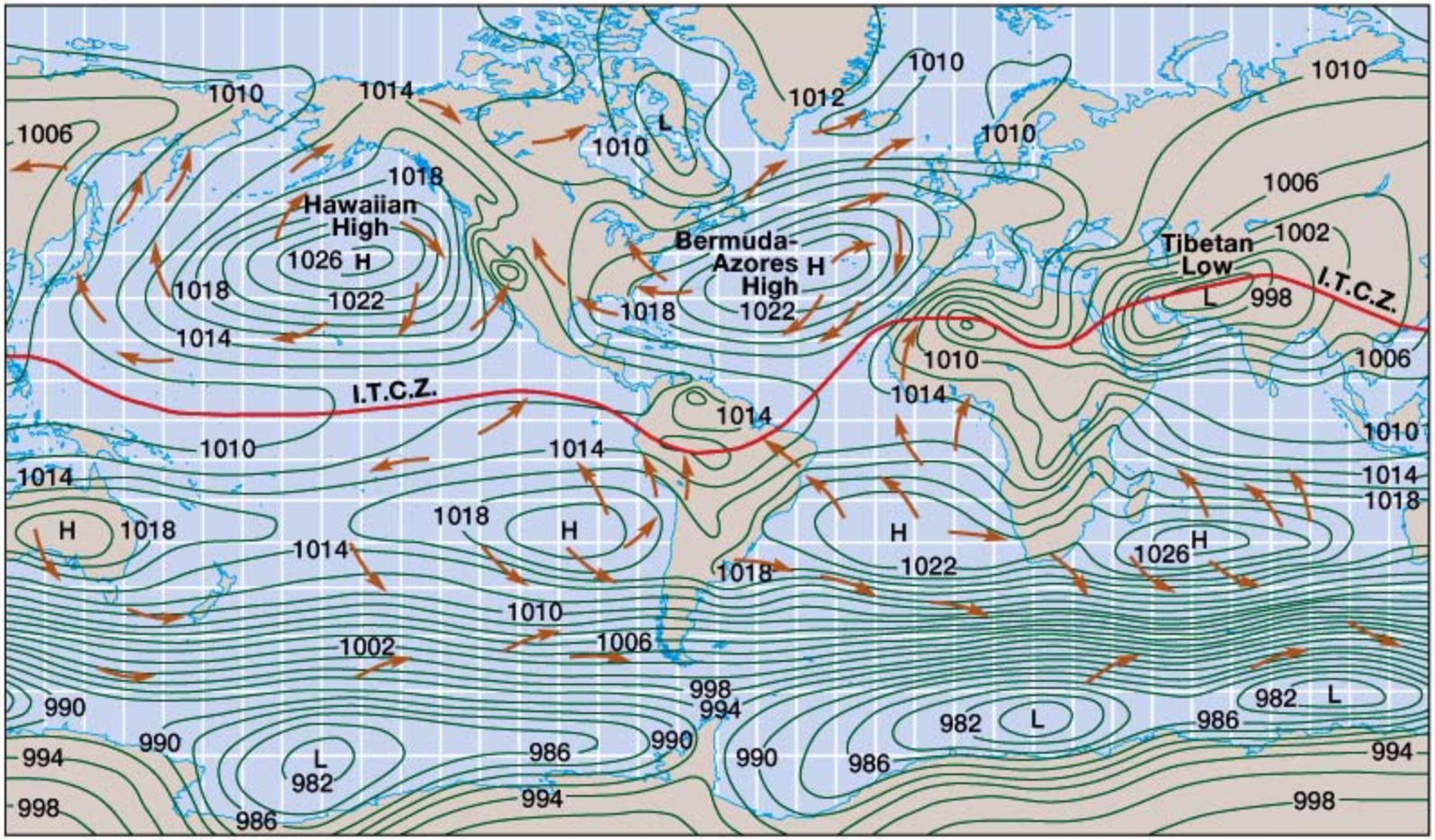


- It is useful to examine horizontal pressure differences across space.
- Pressure maps depict ***isobars***, lines of equal pressure.
- Through analysis of ***isobaric charts***, pressure gradients are apparent.
- Steep (weak) pressure gradients are indicated by closely (widely) spaced isobars.

Northern Winter (January)



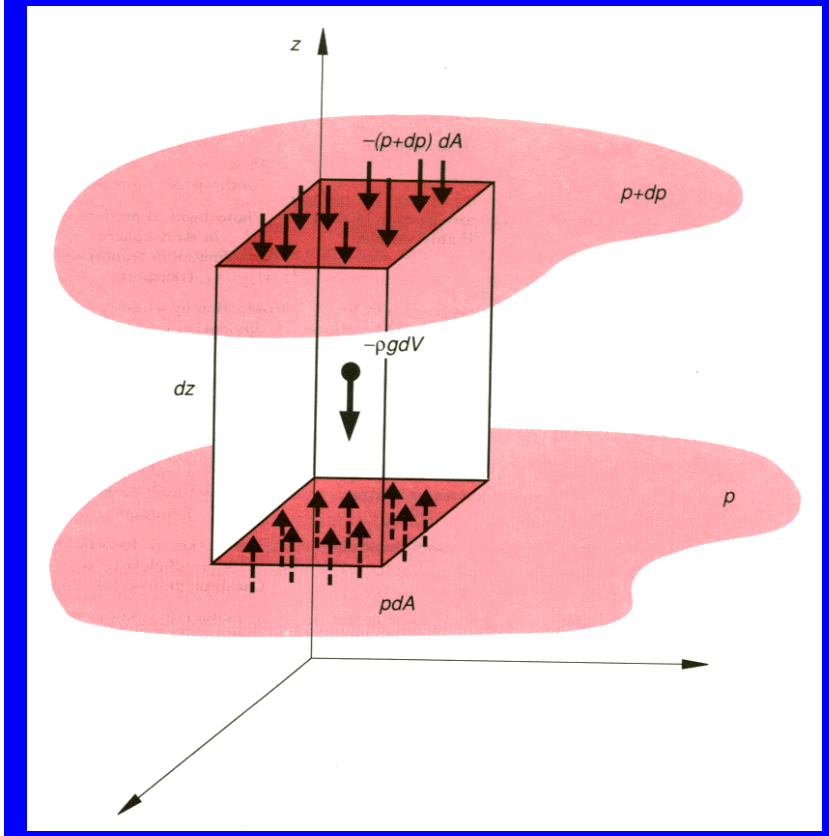
Northern Summer (July)



Pressure Gradients

- Pressure Gradients
  - The pressure gradient force initiates movement of atmospheric mass, wind, from areas of higher to areas of lower pressure
- Horizontal Pressure Gradients
  - Typically only small gradients exist across large spatial scales (1mb/100km)
  - Smaller scale weather features, such as hurricanes and tornadoes, display larger pressure gradients across small areas (1mb/6km)
- Vertical Pressure Gradients
  - ***Average vertical pressure gradients are usually greater than extreme examples of horizontal pressure*** gradients as pressure always decreases with altitude (1mb/10m)

Hydrostatic Balance in the Vertical



(from *Climate System Modeling*)

- vertical pressure force = gravitational force

$$-(dP) \times (dA) = \rho \times (dz) \times (dA) \times g$$

$$dP = -\rho g dz$$

$$\boxed{dP/dz = -\rho g}$$

The hydrostatic balance !!

What Does Hydrostatic Balance Tell Us?

- The hydrostatic equation tells us how quickly air pressure drops wit height.

➔The rate at which air pressure decreases with height ($\Delta P/ \Delta z$) is equal to the air density (ρ) times the acceleration of gravity (g)

The Ideal Gas Law

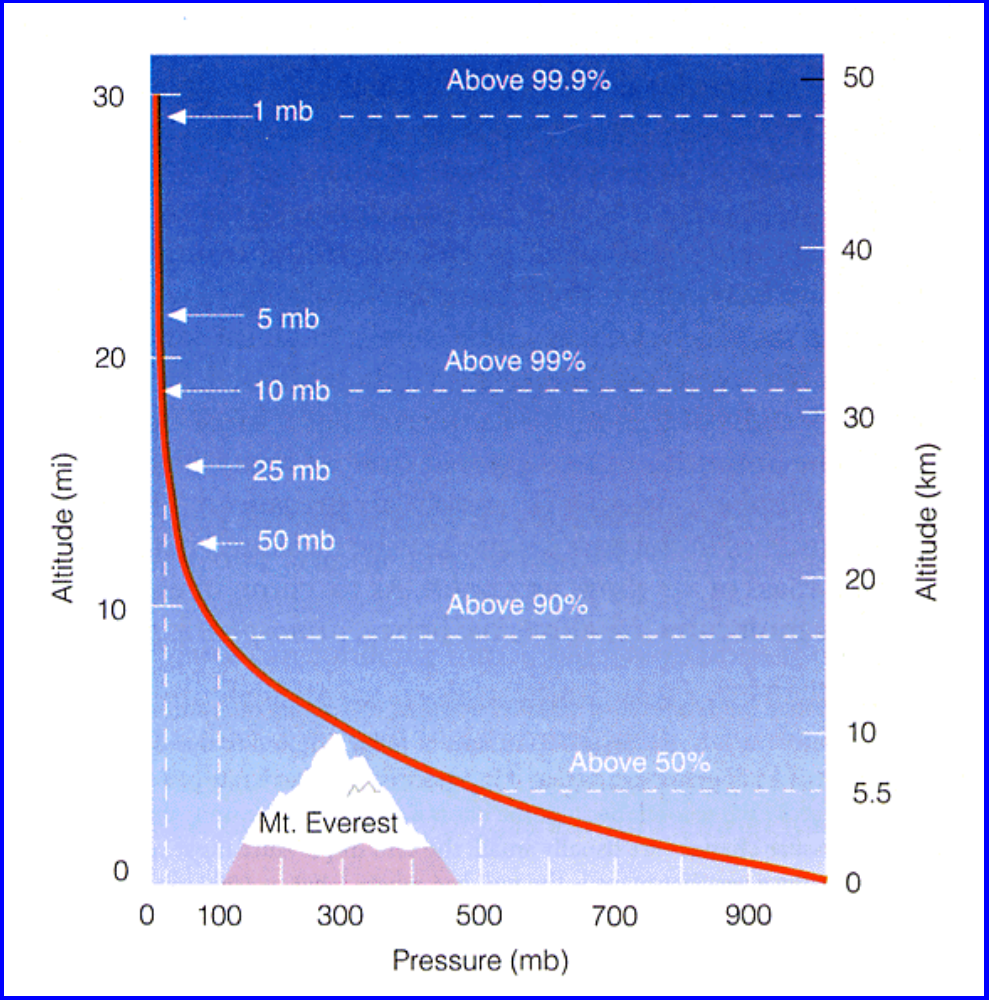
- An ***equation of state*** describes the relationship among pressure, temperature, and density of ***any material***.
- All gases are found to follow approximately the same equation of state, which is referred to as the ***"ideal gas law (equation)"***.
- Atmospheric gases, whether considered individually or as a mixture, obey the following ideal gas equation:

$$P = \rho R T$$

pressure P *Density=m/V* ρ *temperature* T *(degree Kelvin)*

gas constant R *(its value depends on the gas considered)*

Hydrostatic Balance and Atmospheric Vertical Structure



(from *Meteorology Today*)

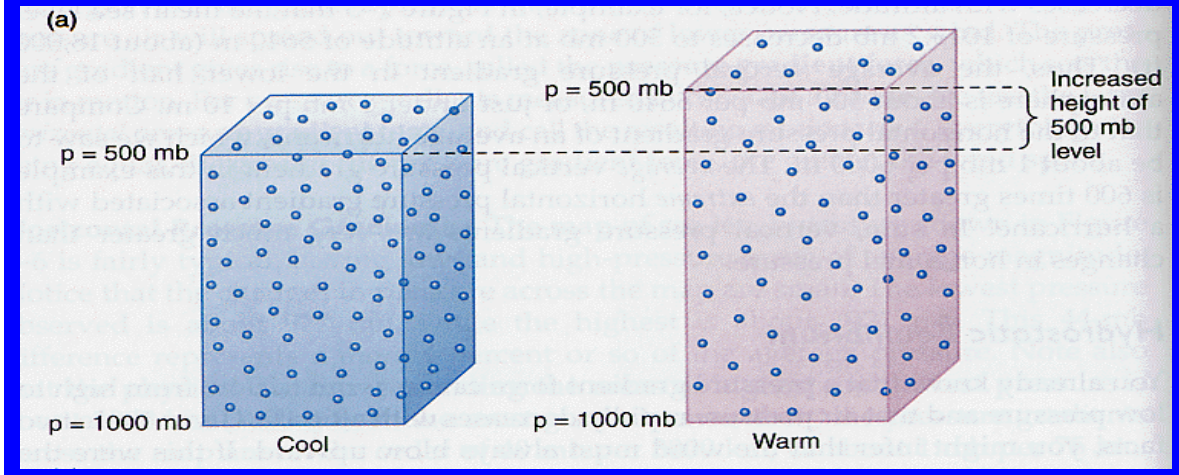
- Since P= ρRT (the ideal gas law), the hydrostatic equation becomes:

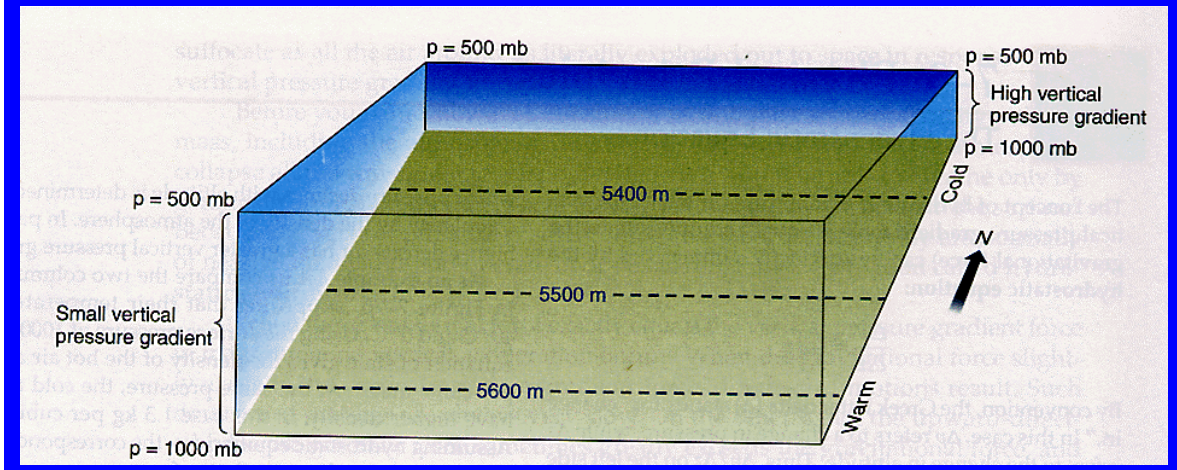
  $dP = -P/RT \times g dz$

- ➔ $dP/P = -g/RT \times dz$
- ➔ **$P = P_s \exp(-gz/RT)$**
- ➔ $P = P_s \exp(-z/H)$

- The atmospheric pressure decreases exponentially with height

Temperature and Pressure

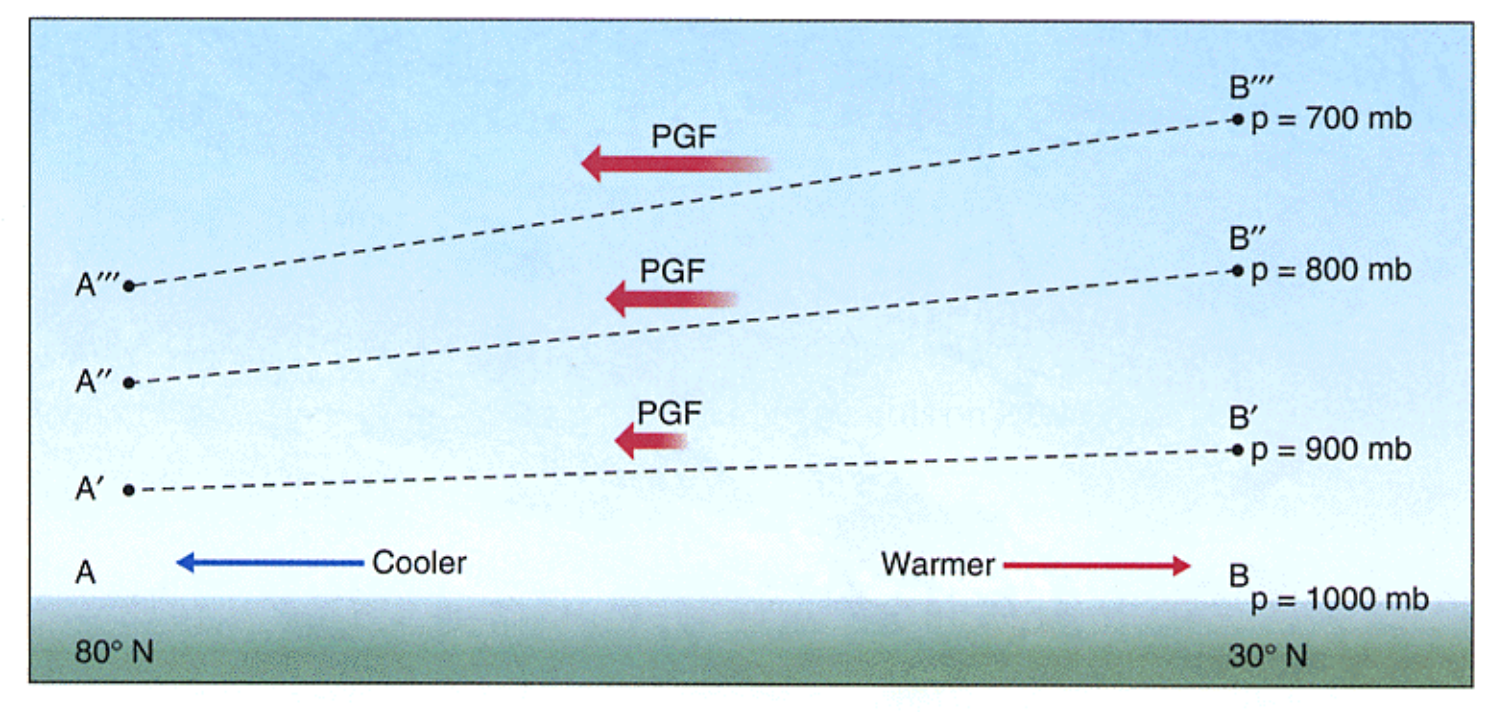




(from Understanding *Weather & Climate*)

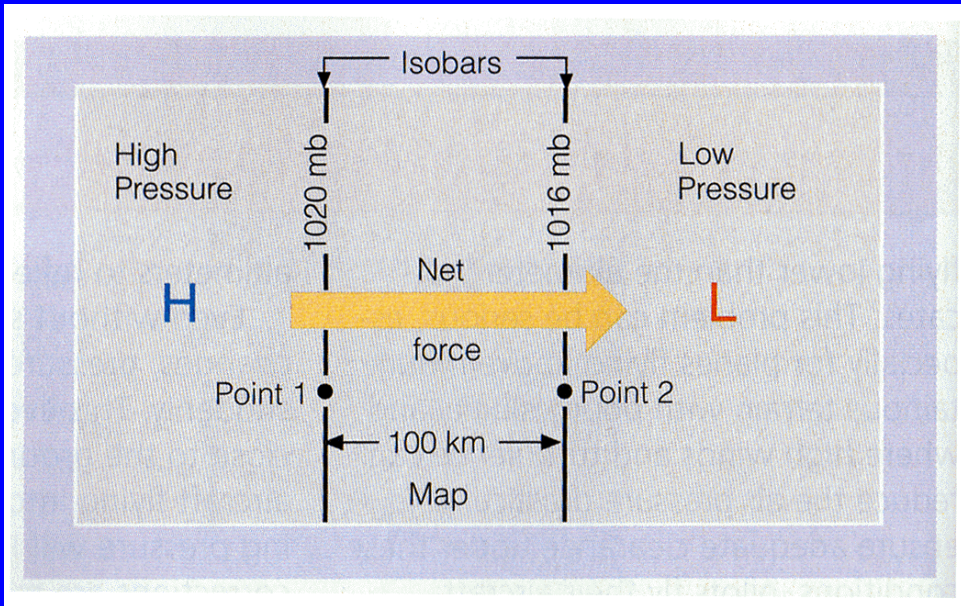
- Hydrostatic balance tells us that the pressure decrease with height is determined by the temperature inside the vertical column.
- Pressure decreases faster in the cold-air column and slower in the warm-air column.
- Pressure drops more rapidly with height at high latitudes and lowers the height of the pressure surface.

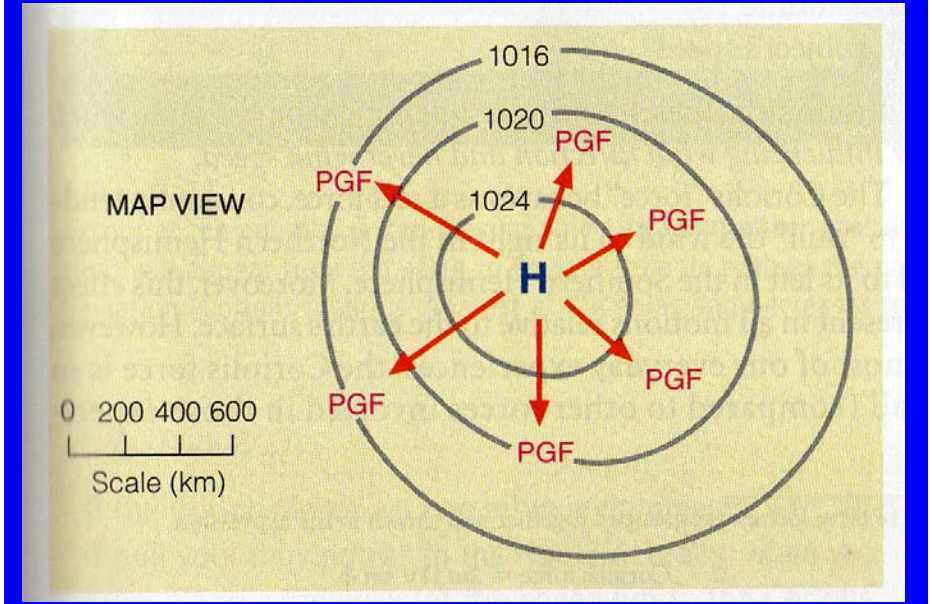
Wind Changes with Height



(from *Weather & Climate*)

Pressure Gradient Force





(from Meteorology Today)

- PG = (pressure difference) / distance
- Pressure gradient force goes from high pressure to low pressure.
- Closely spaced isobars on a weather map indicate steep pressure gradient.

Balance of Force in the Horizontal

H (high pressure)

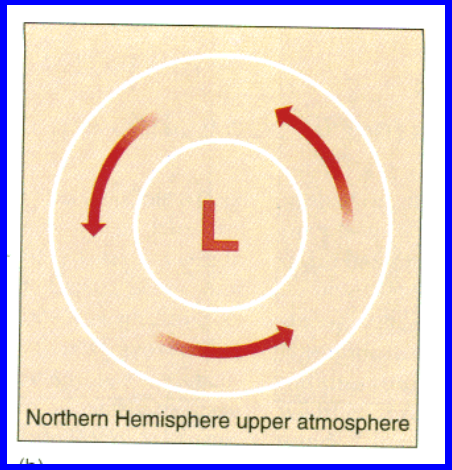
pressure gradient force

L (low pressure)

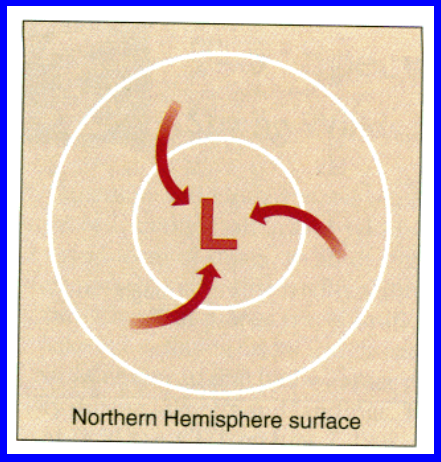
Can happen in the tropics where the Coriolis force is small.

geostrophic balance

geostrophic balance plus frictional force



Upper Troposphere (free atmosphere)



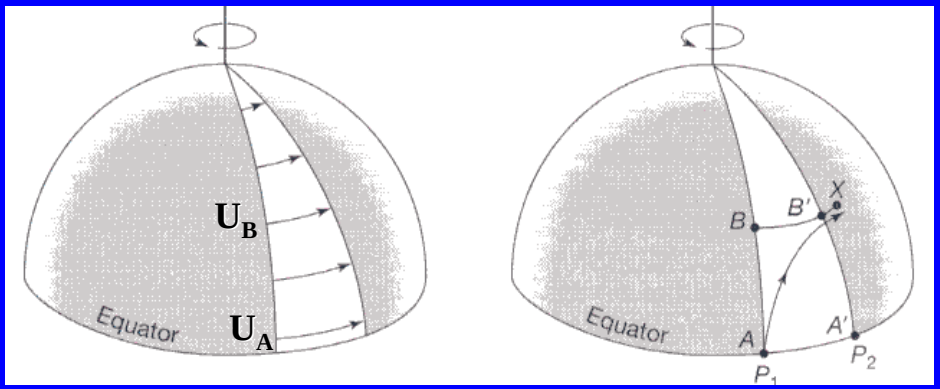
Surface

(from *Weather & Climate*)

Force that Determines Wind

- Pressure gradient force
- Coriolis force (Earth's Rotation)
- Friction (near Earth's surface)
- Centrifugal force

Coriolis Force



(from *The Earth System*)

- First, Point A rotates faster than Point B ($U_A > U_B$)

➔ $U_A > U_B$

➔ A northward motion starting at A will arrive to the east of B

➔ It looks like there is a "force" pushing the northward motion toward right

➔ This apparent force is called "Coriolis force":

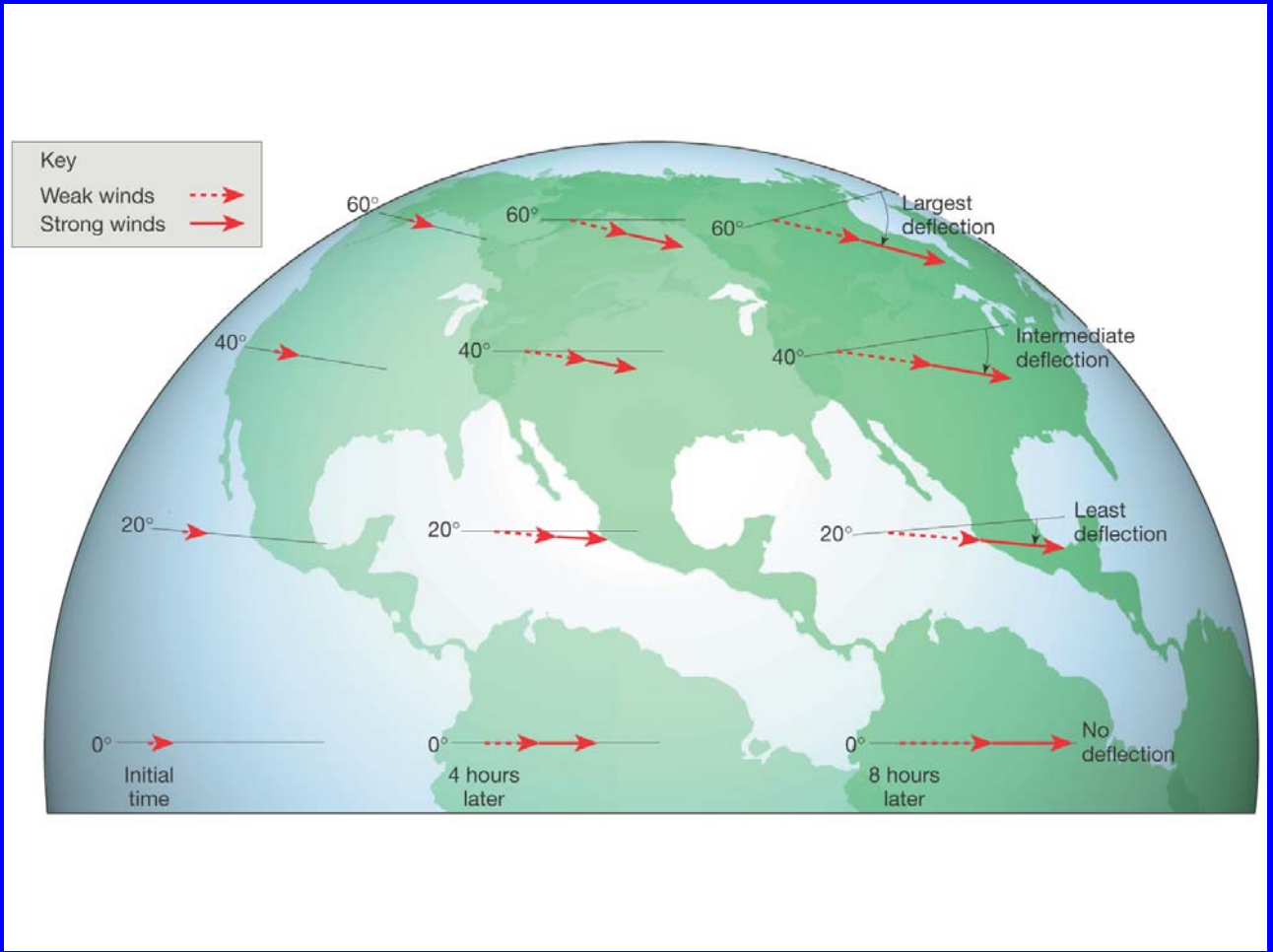
Coriolis Force = *f V*

where *f* = 2*Ω*Sin(lat) and Ω=7.292x10^{-5} rad s^{-1}

Coriolis Force

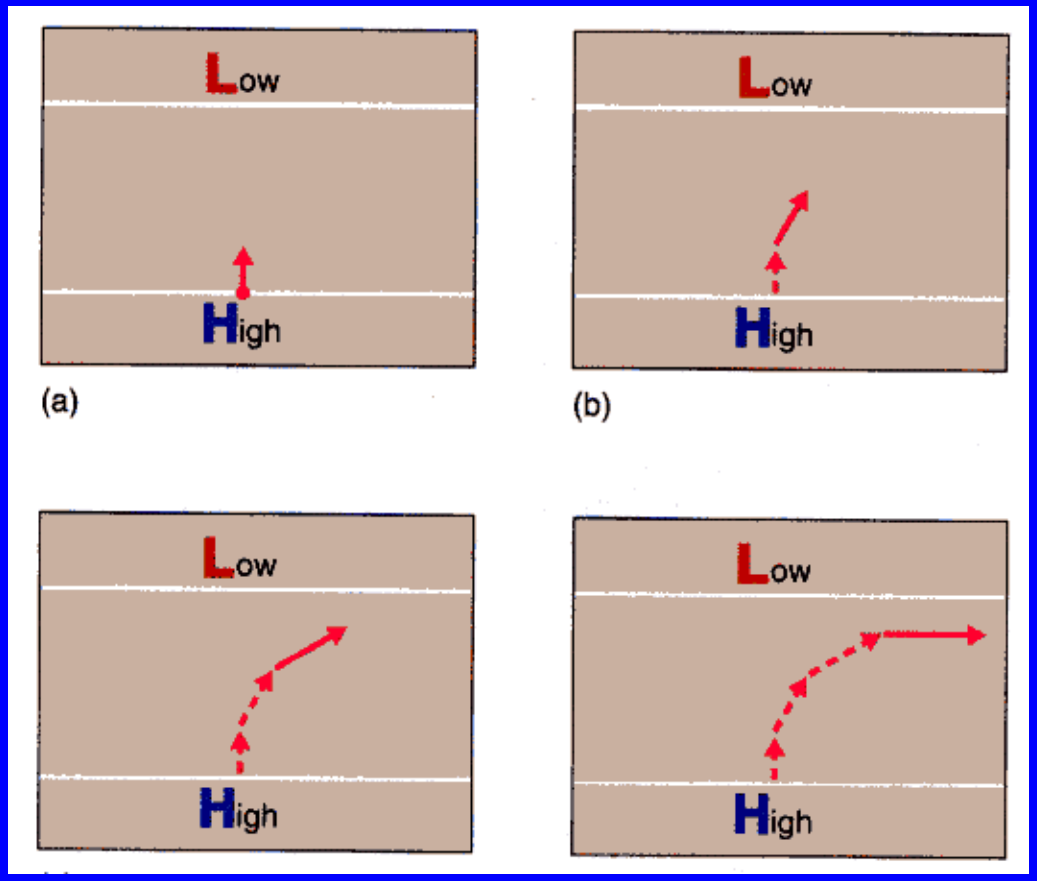
- Coriolis force causes the wind to deflect to the right of its intent path in the Northern Hemisphere and to the left in the Southern Hemisphere.
- The magnitude of Coriolis force depends on (1) the rotation of the Earth, (2) the speed of the moving object, and (3) its latitudinal location.
- The stronger the speed (such as wind speed), the stronger the Coriolis force.
- The higher the latitude, the stronger the Coriolis force.
- The Corioils force is zero at the equator.
- Coriolis force is one major factor that determine weather pattern.

Coriolis Force Change with latitudes



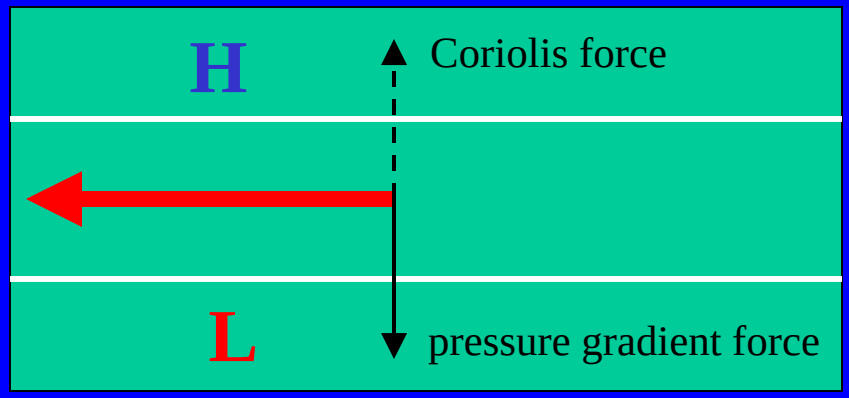
(from *The Atmosphere*)

Upper Atmospheric Winds



(from *Weather & Climate*)

Geostrophic Balance

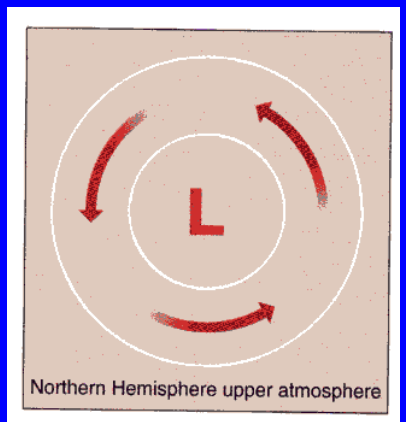


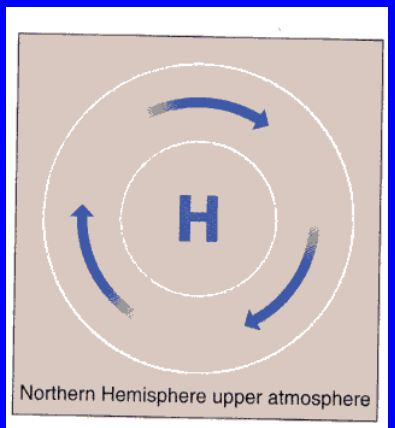
- By doing scale analysis, it has been shown that large-scale and synoptic-scale weather system are in geostrophic balance.
- Geostrophic winds always follow the constant pressure lines (isobar). Therefore, we can figure out flow motion by looking at the pressure distribution.

Upper Atmosphere Geostrophic Flow

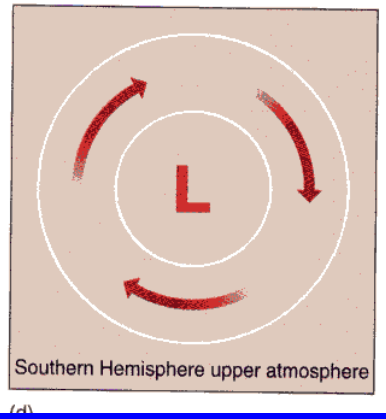
Cyclonic Flow **Anticyclonic Flow**

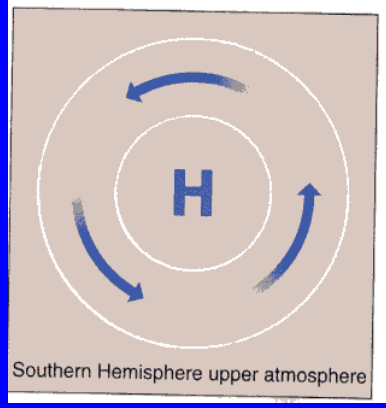
Northern Hemisphere





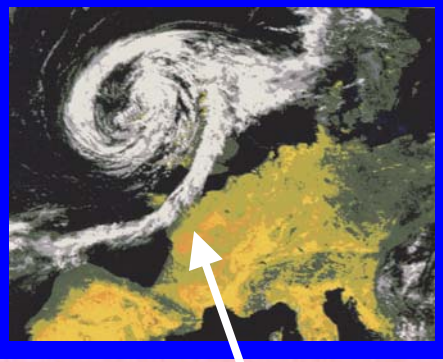
Southern Hemisphere

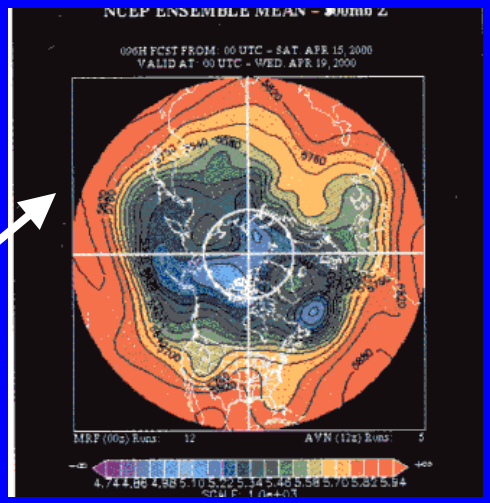


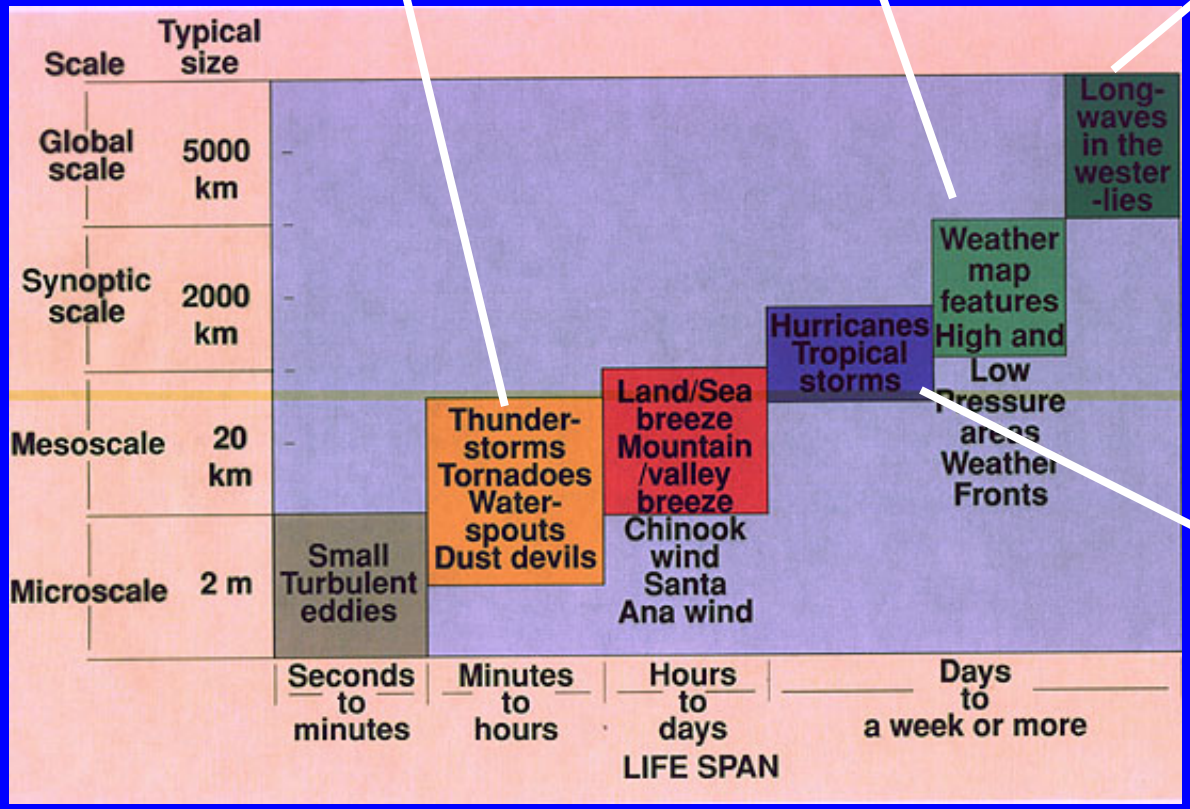


(figures from *Weather & Climate*)

Scales of Motions in the Atmosphere





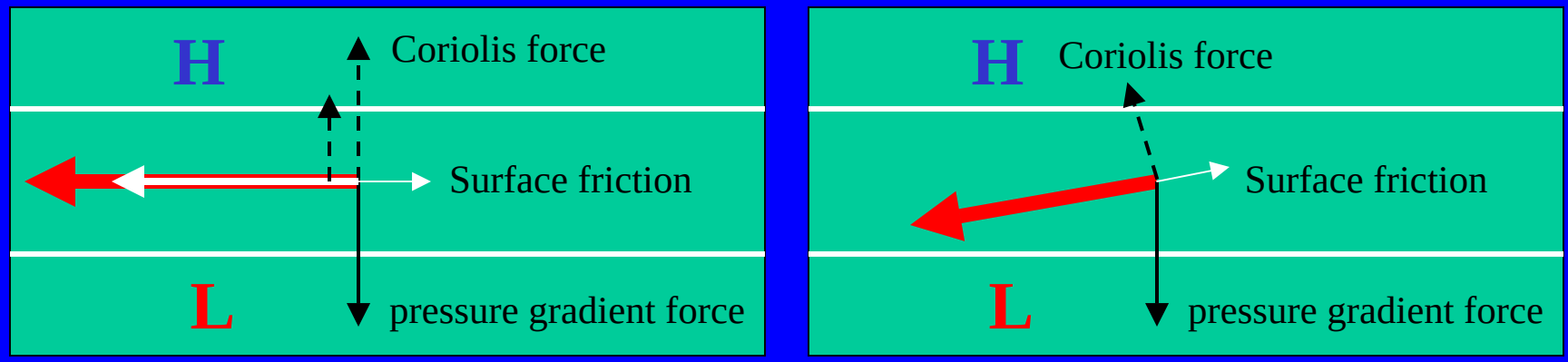


ESS5
Prof. Jin-Yi Yu

Frictional Force

- A force of opposition which slows air in motion.
- Initiated at the surface and extend, decreasingly, aloft.
- Important for air within 1.5 km (1 mi) of the surface, the ***planetary boundary layer.***
- Because friction reduces wind speed it also reduces Coriolis deflection.
- Friction above 1.5 km is negligible.
- Above 1.5 km = the ***free atmosphere.***

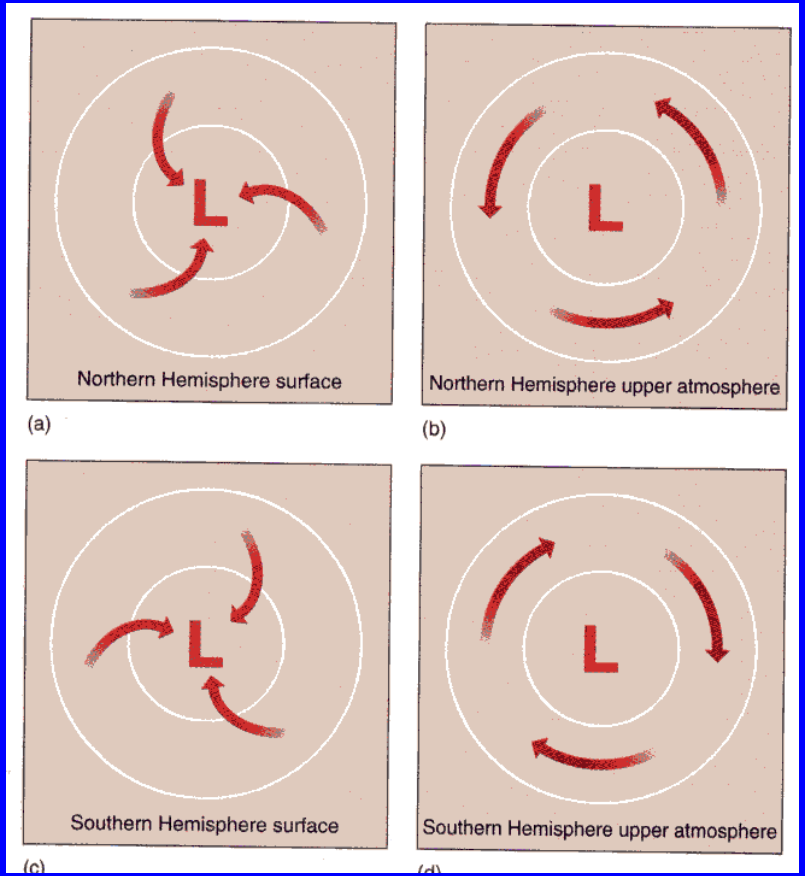
Surface Winds



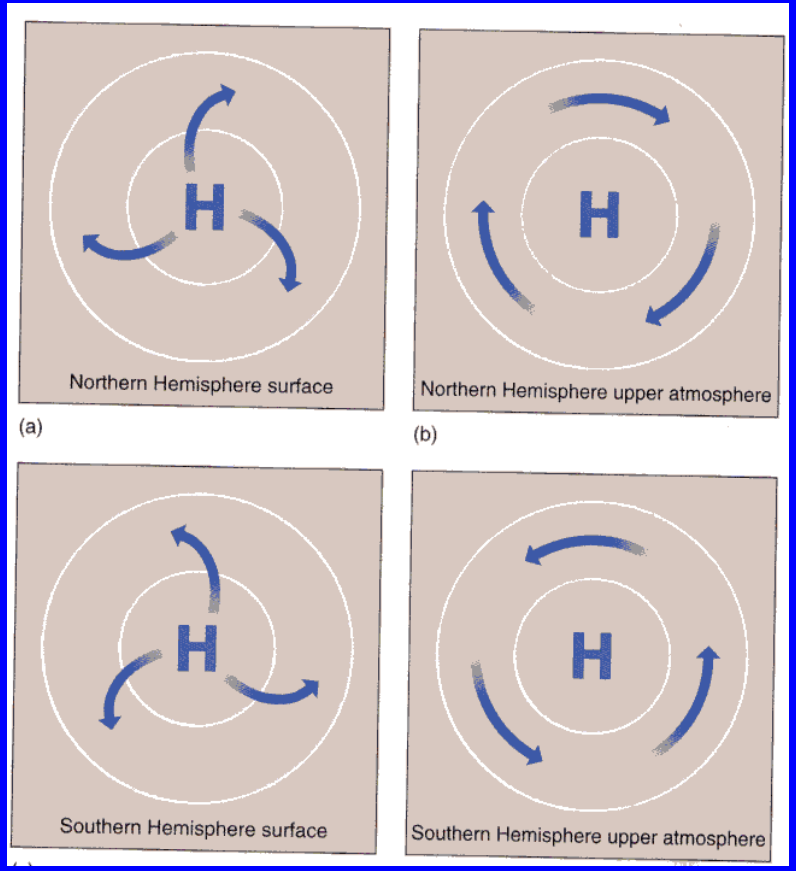
- Surface friction force slows down the geostrophic flow.
- The flow turns into (out of) the low (high) press sides.
- Convergence (divergence) is produced with the flow.

Surface Geostrophic Flow

Cyclonic Flow

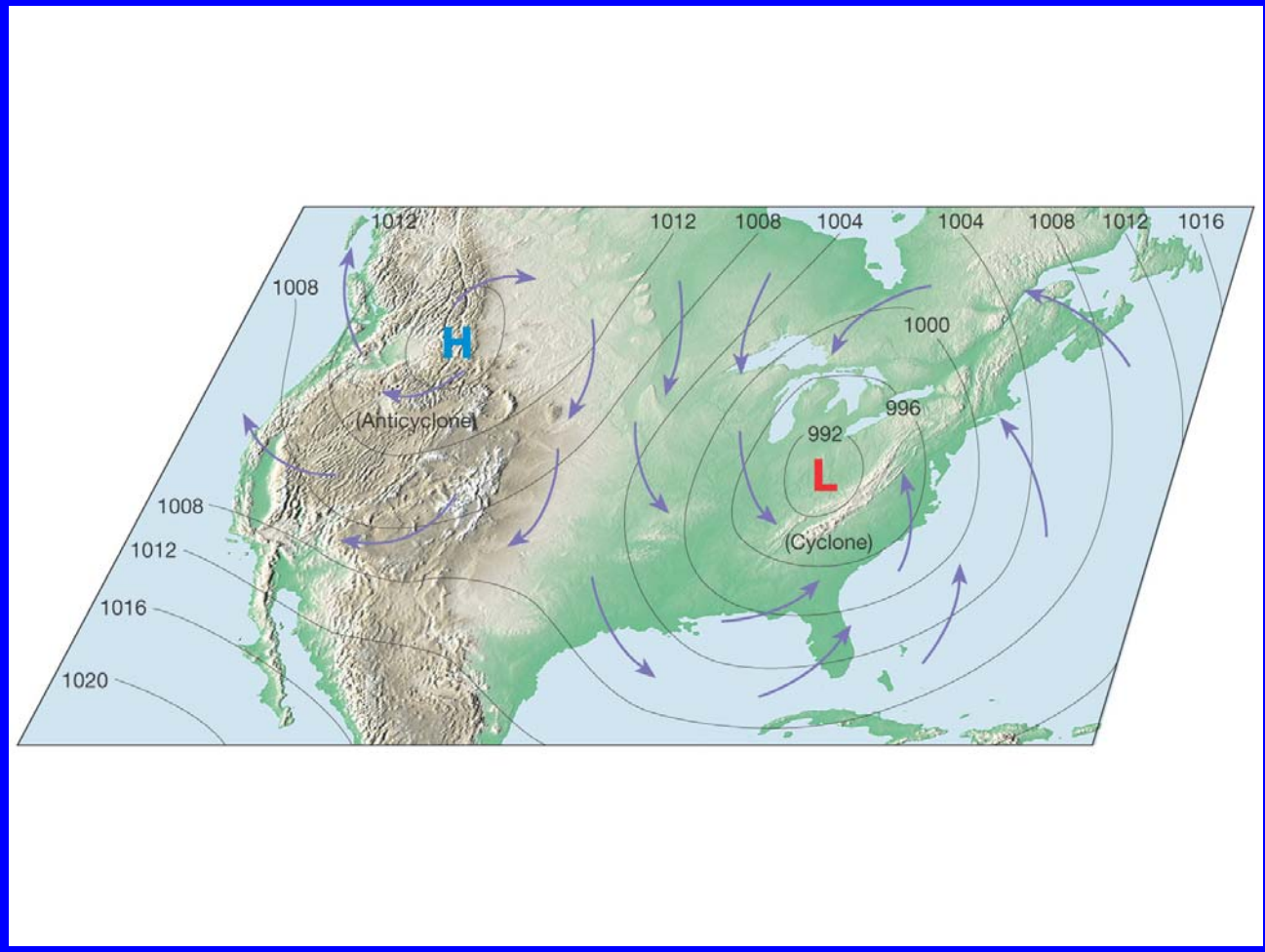


Anticyclonic Flow

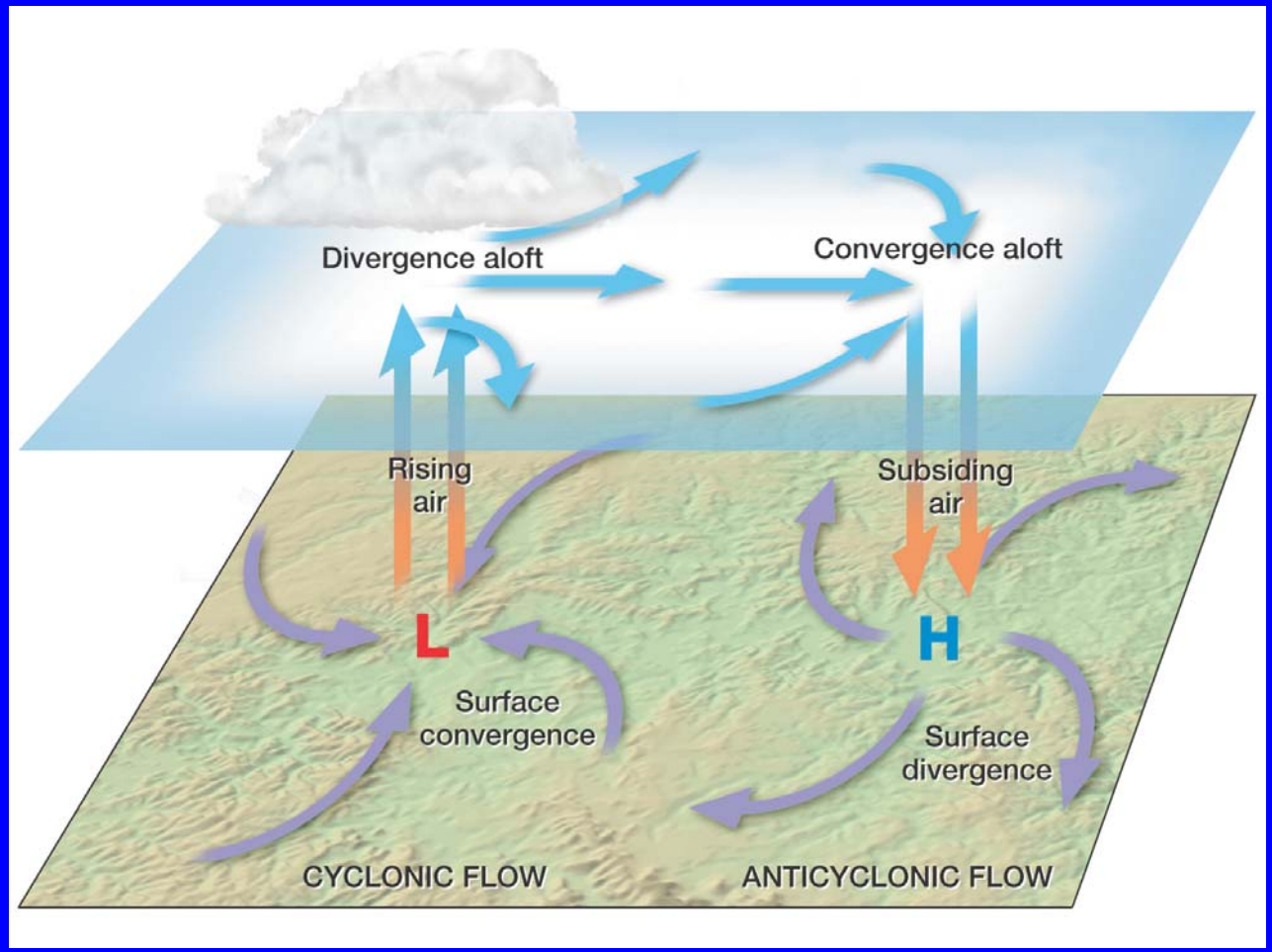


(figures from *Weather & Climate*)

Surface High and Low Pressure Systems

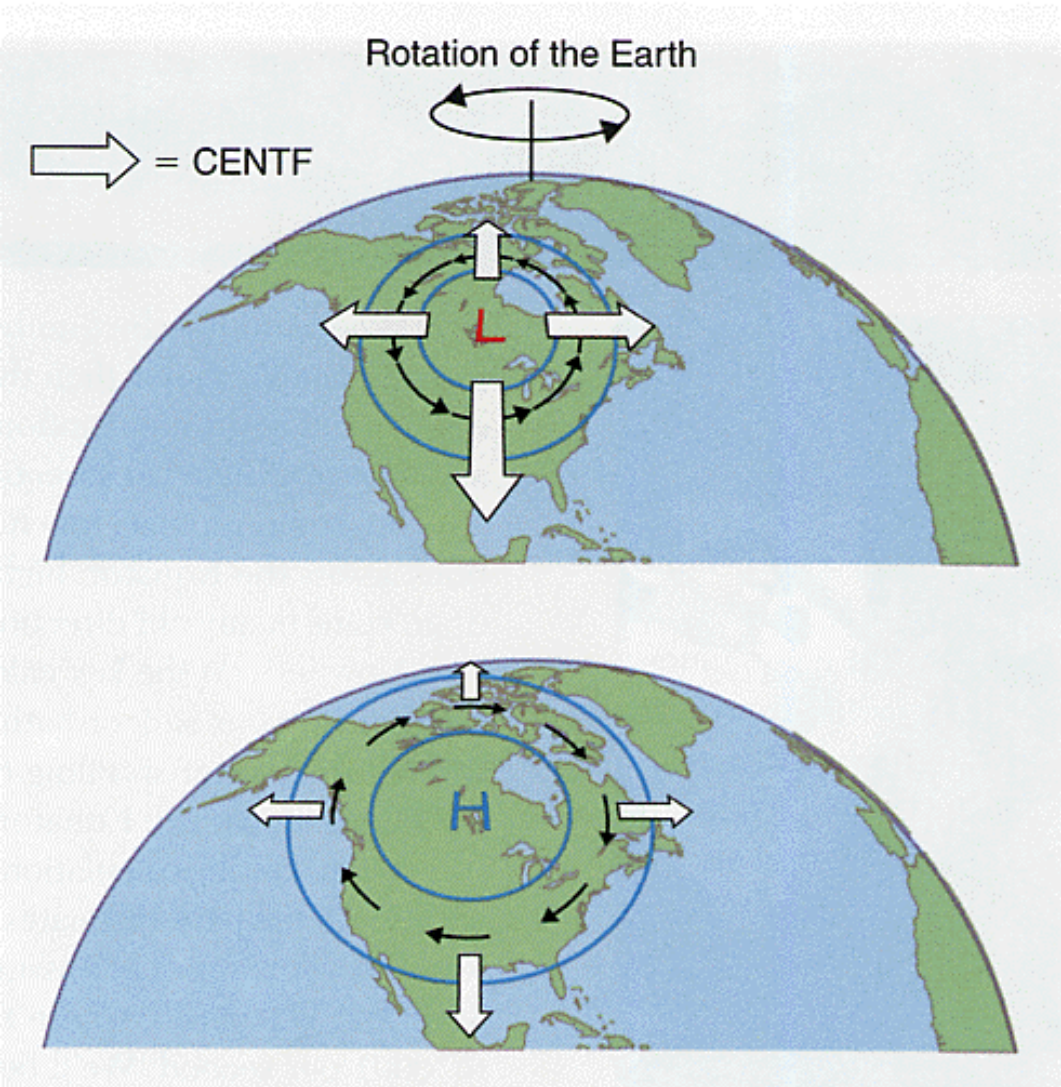


(from *The Atmosphere*)



(from *The Atmosphere*)

Centrifugal Force



(from *The Atmosphere*)

- The force that change the direction (but not the speed) of motion is called the centrifugal force.

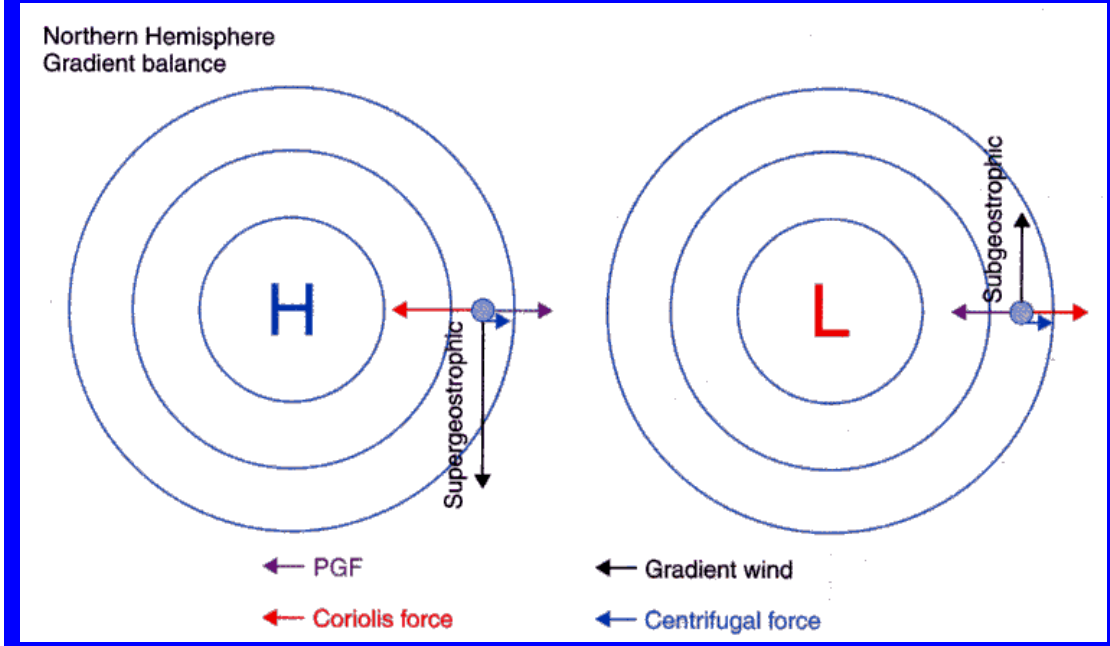
- Centrifugal Force = V^2 / R.
  V = wind speed
  R = the radius of the curvature

Gradient Wind Balance

- The three-way balance of horizontal pressure gradient, Coriolis force, and the centrifugal force is call the ***gradient wind balance***.

- The gradient wind is an excellent approximation to the actual wind observed above the Earth's surface, especially at the middle latitudes.

Super- and Sub-Geostrophic Wind



(from *Meteorology: Understanding the Atmosphere*)

- For high pressure system

➔gradient wind > geostrophic wind

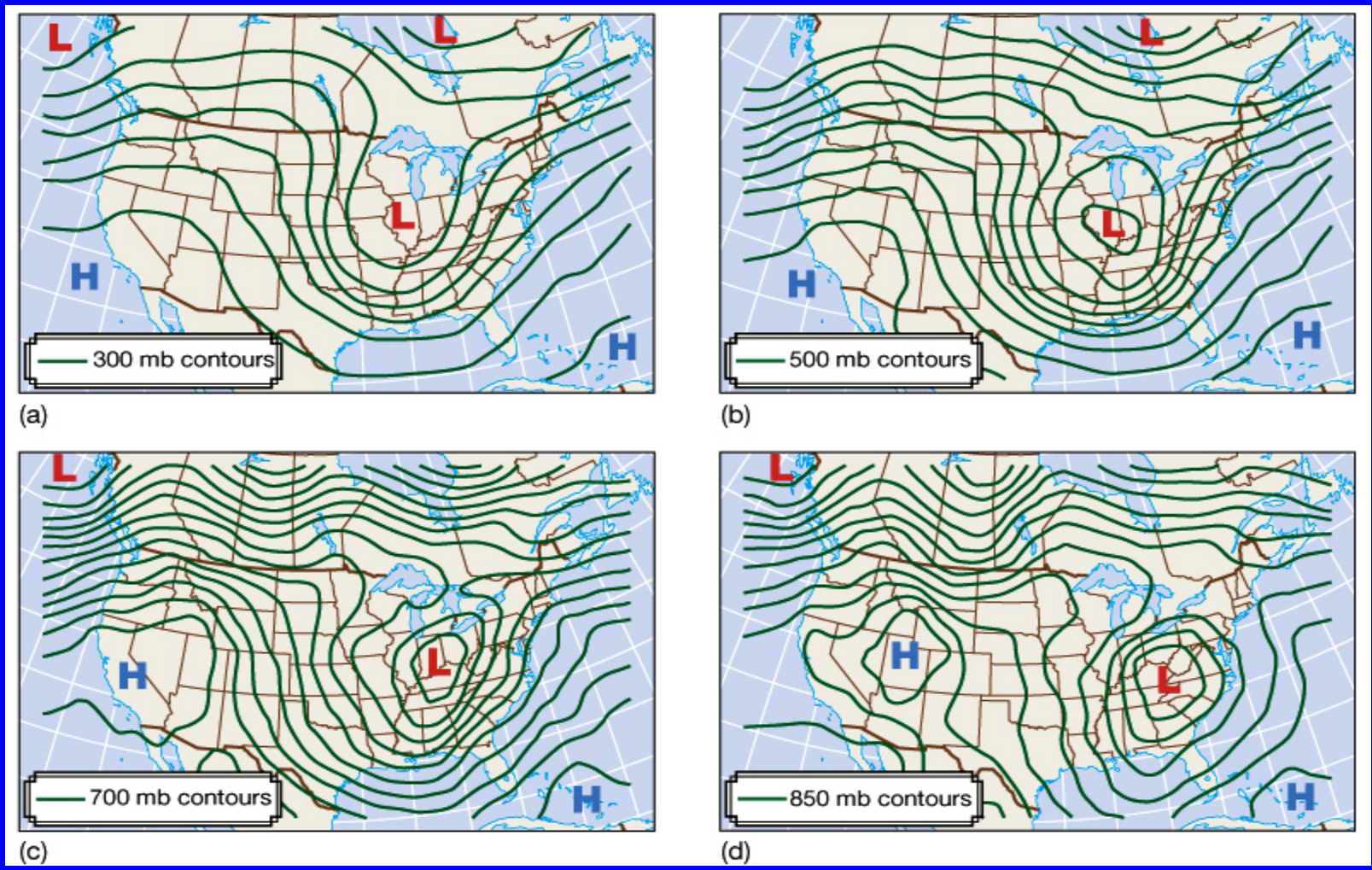
➔supergeostropic.

- For low pressure system

➔gradient wind < geostrophic wind

➔subgeostropic.

Troughs, Ridges, Cyclones, and Anticyclones



Measuring Winds

- Wind direction always indicates the direction from which wind blows.
- An ***aerovane*** indicates both wind speed and direction.