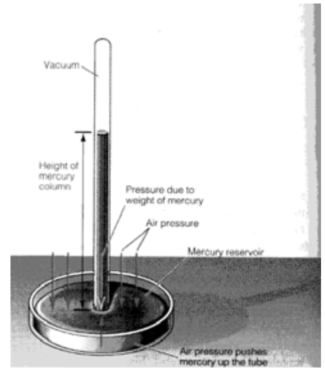
Chapter 4: Pressure and Wind

- ❑ 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.

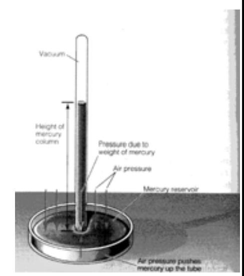
1 bar = 1000 hPa = 1000 mb

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

Measurement of Atmos. Pressure

❑ Mercury Barometers

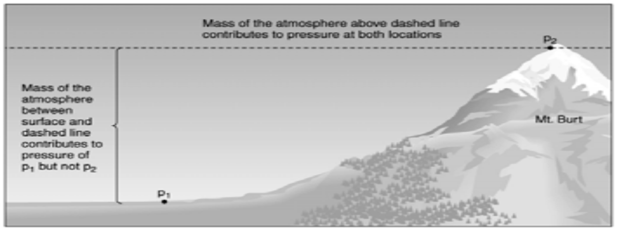
- Height of mercury indicates downward force of air pressure
- Three barometric corrections must be made to ensure homogeneity of pressure readings
- First corrects for elevation, the second for air temperature (affects density of mercury), and the third involves a slight correction for gravity with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



❑ Aneroid Barometers

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

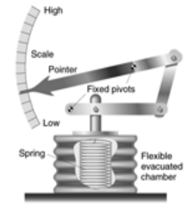
Pressure Correction for Elevation



- 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.

ESS5
Prof. Jin-Yi Yu

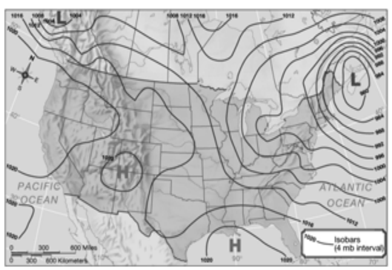
Aneroid barometer (left) and its workings (right)



A barograph continually records air pressure through time

ESS5
Prof. Jin-Yi Yu

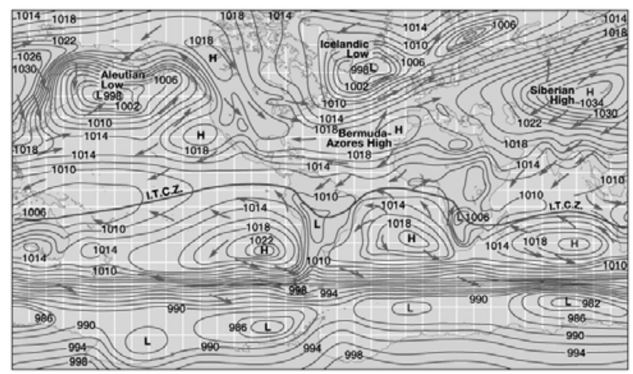
Isobar



- 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.

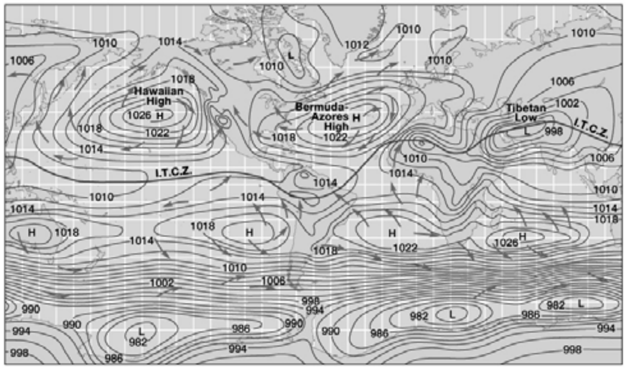
ESS5
Prof. Jin-Yi Yu

Northern Winter (January)



ESS5
Prof. Jin-Yi Yu

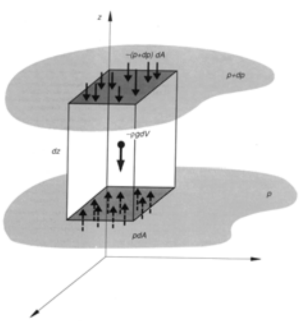
Northern Summer (July)



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:

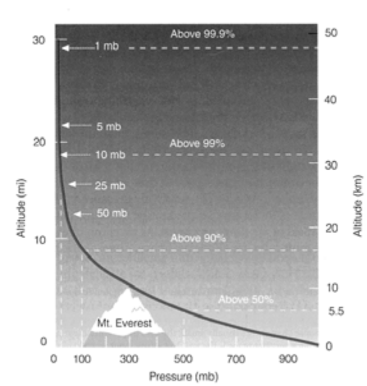
$$\boxed{P = \rho R T}$$

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

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

ESS5
Prof. Jin-Yi Yu

Hydrostatic Balance and Atmospheric Vertical Structure



(from *Meteorology Today*)

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

  dP = -P/RT x gdz

  ➔ dP/P = -g/RT x dz

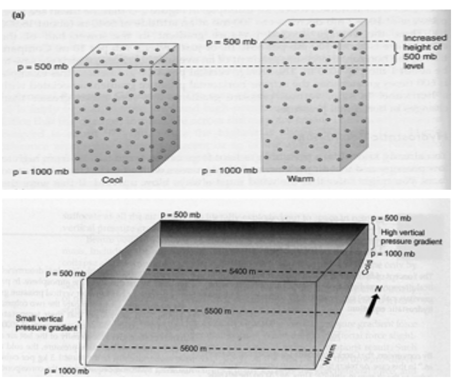
  ➔ $\boxed{\mathbf{P = P_s\ exp(-gz/RT)}}$

  ➔ $P = P_s\ exp(-z/H)$

- The atmospheric pressure decreases exponentially with height

ESS5
Prof. Jin-Yi Yu

Temperature and Pressure

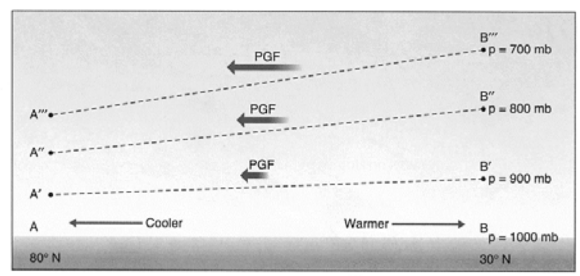


(from Understanding *Weather & Climate*)

- 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.

ESS5
Prof. Jin-Yi Yu

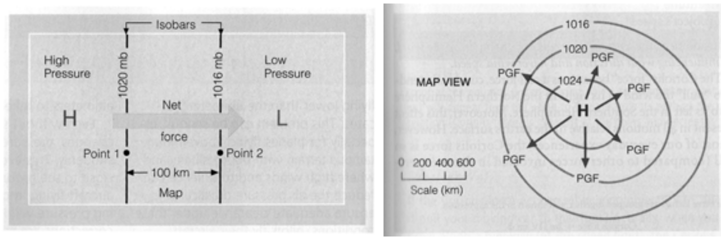
Wind Changes with Height



(from *Weather & Climate*)

ESS5
Prof. Jin-Yi Yu

Pressure Gradient Force

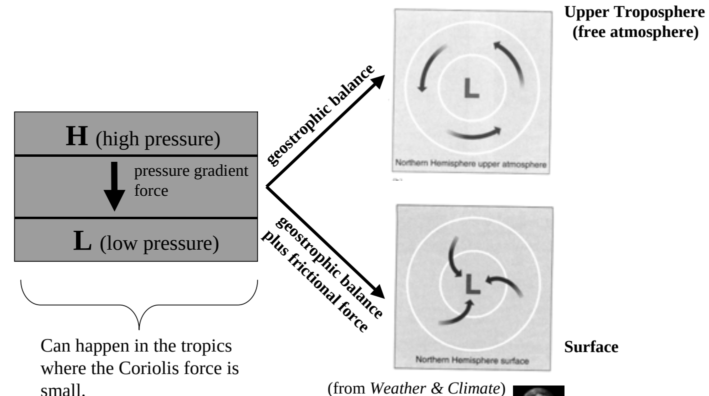


(from Meteorology Today)

- ❑ 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.

ESS5
Prof. Jin-Yi Yu

Balance of Force in the Horizontal



(from *Weather & Climate*)

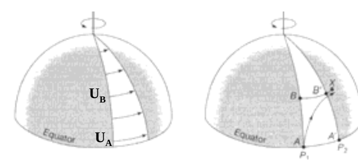
ESS5
Prof. Jin-Yi Yu

Force that Determines Wind

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

ESS5
Prof. Jin-Yi Yu

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 $f = 2*\Omega*\mathrm{Sin(lat)}$ and $\Omega = 7.292\times10^{-5}$ rad s^{-1}

ESS5
Prof. Jin-Yi Yu

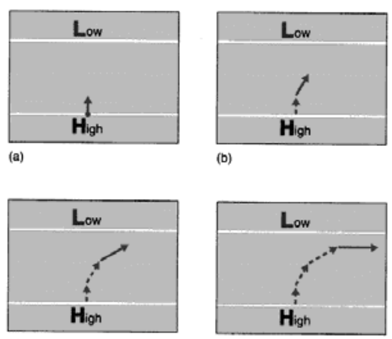
Coriolis Force

- ❑ 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

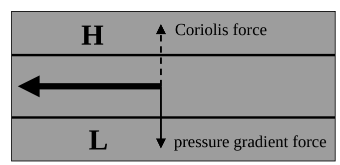
(from *The Atmosphere*)

Upper Atmospheric Winds



(from *Weather & Climate*)

Geostrophic Balance



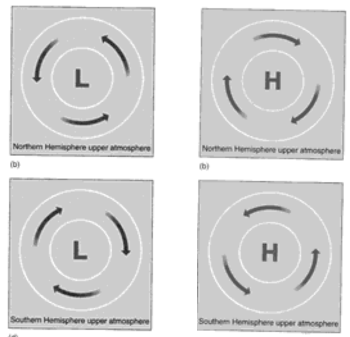
- ❑ By doing scale analysis, it has been shown that large-scale and synoptic-scale weather system are in geostrophic balance.
- ❑ Geostrophic winds always follow the constant pressure lines (isobar). Therefore, we can figure out flow motion by looking at the pressure distribution.

Upper Atmosphere Geostrophic Flow

Cyclonic Flow | **Anticyclonic Flow**

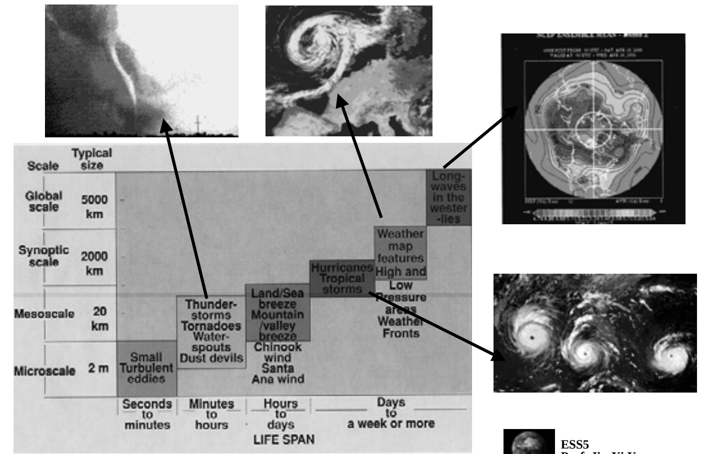
Northern Hemisphere

Southern Hemisphere



(figures from *Weather & Climate*)

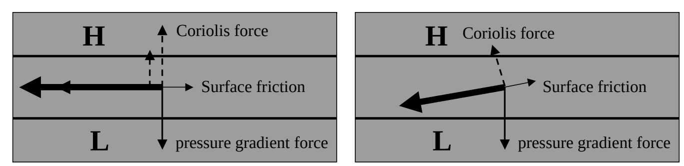
Scales of Motions in the Atmosphere



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.***

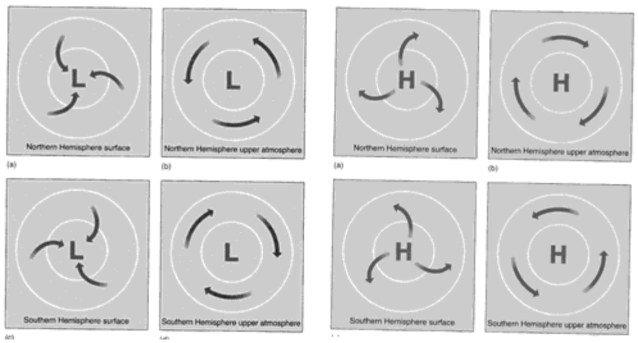
Surface Winds



- 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

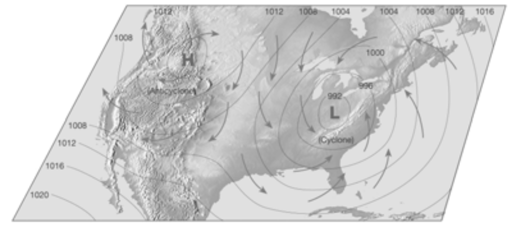
Cyclonic Flow **Anticyclonic Flow**



(figures from *Weather & Climate*)

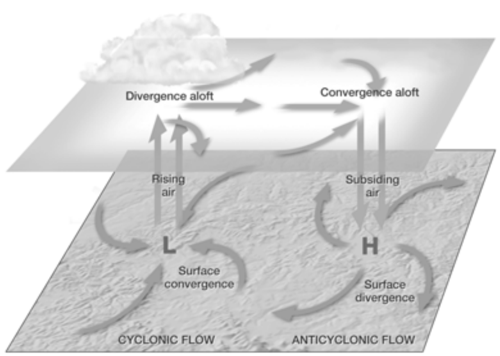
ESS5
Prof. Jin-Yi Yu

Surface High and Low Pressure Systems



(from *The Atmosphere*)

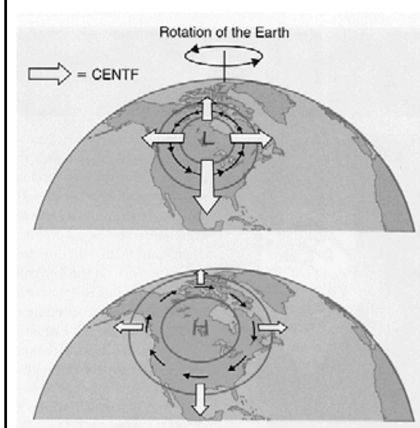
ESS5
Prof. Jin-Yi Yu



(from *The Atmosphere*)

ESS5
Prof. Jin-Yi Yu

Centrifugal Force



❑ 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

(from *The Atmosphere*)

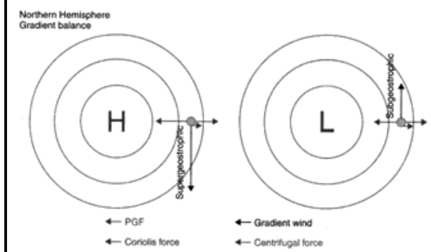
ESS5
Prof. Jin-Yi Yu

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.

ESS5
Prof. Jin-Yi Yu

Super- and Sub-Geostrophic Wind

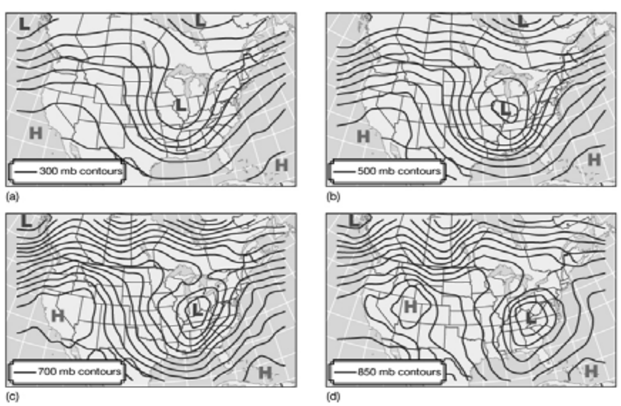


(from *Meteorology: Understanding the Atmosphere)*

- ❑ For high pressure system
- ➔gradient wind > geostrophic wind
- ➔supergeostropic.
- ❑ For low pressure system
- ➔gradient wind < geostrophic wind
- ➔subgeostropic.

ESS5
Prof. Jin-Yi Yu

Troughs, Ridges, Cyclones, and Anticyclones



ESS5
Prof. Jin-Yi Yu

Measuring Winds

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

ESS5
Prof. Jin-Yi Yu