SESSION 3: FORCE BALANCES / WINDS

ATMOSPHERIC FORCE BALANCES

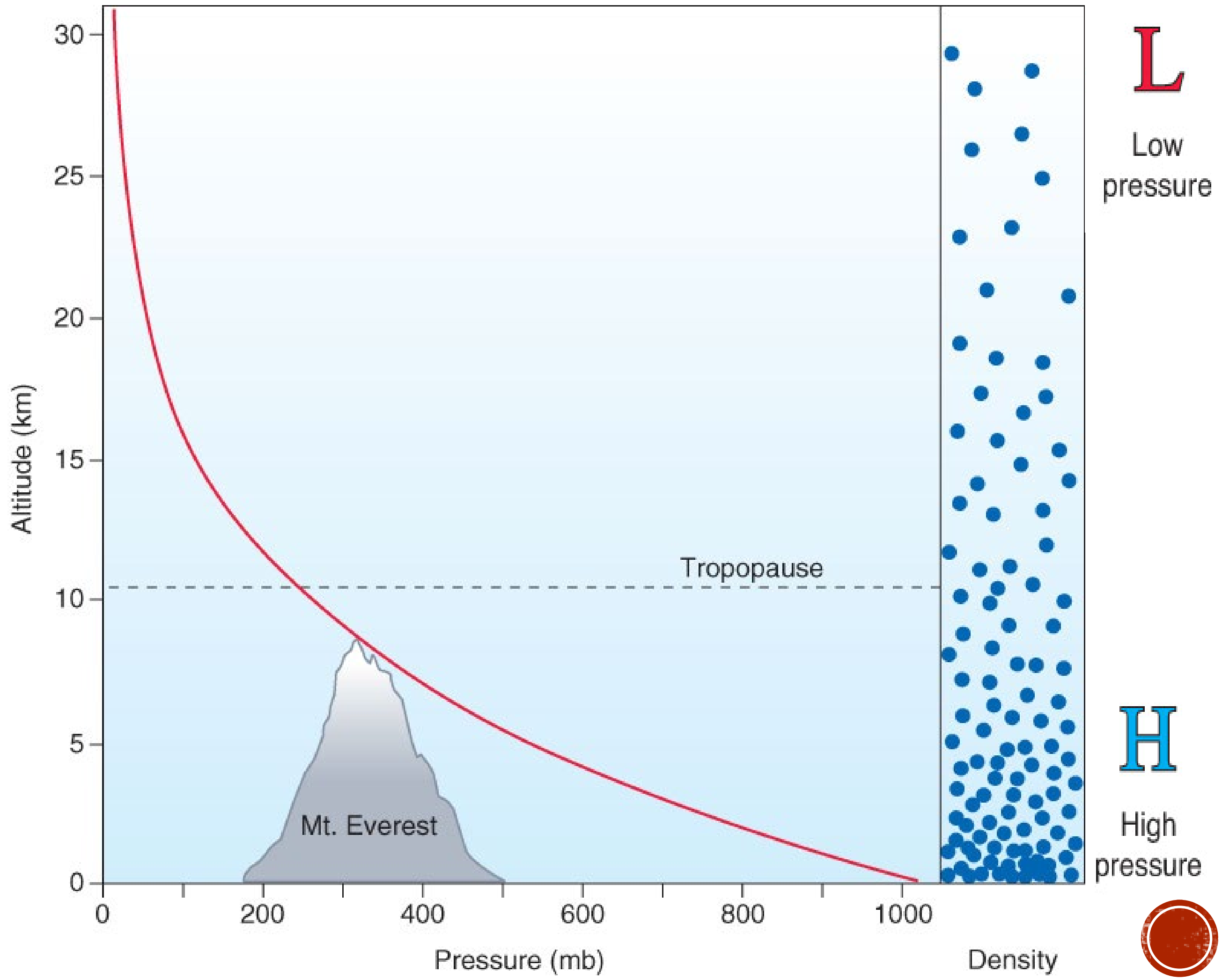
- First, MUST have a pressure gradient force (PGF) for the wind to blow.

- Otherwise, all other forces are irrelevant because they depend on wind having a velocity (or speed).

- Some balances we will examine:
  - Hydrostatic
  - Geostrophic Balance
  - Gradient Balance
  - Cyclostrophic Balance
  - Guldberg-Mohn

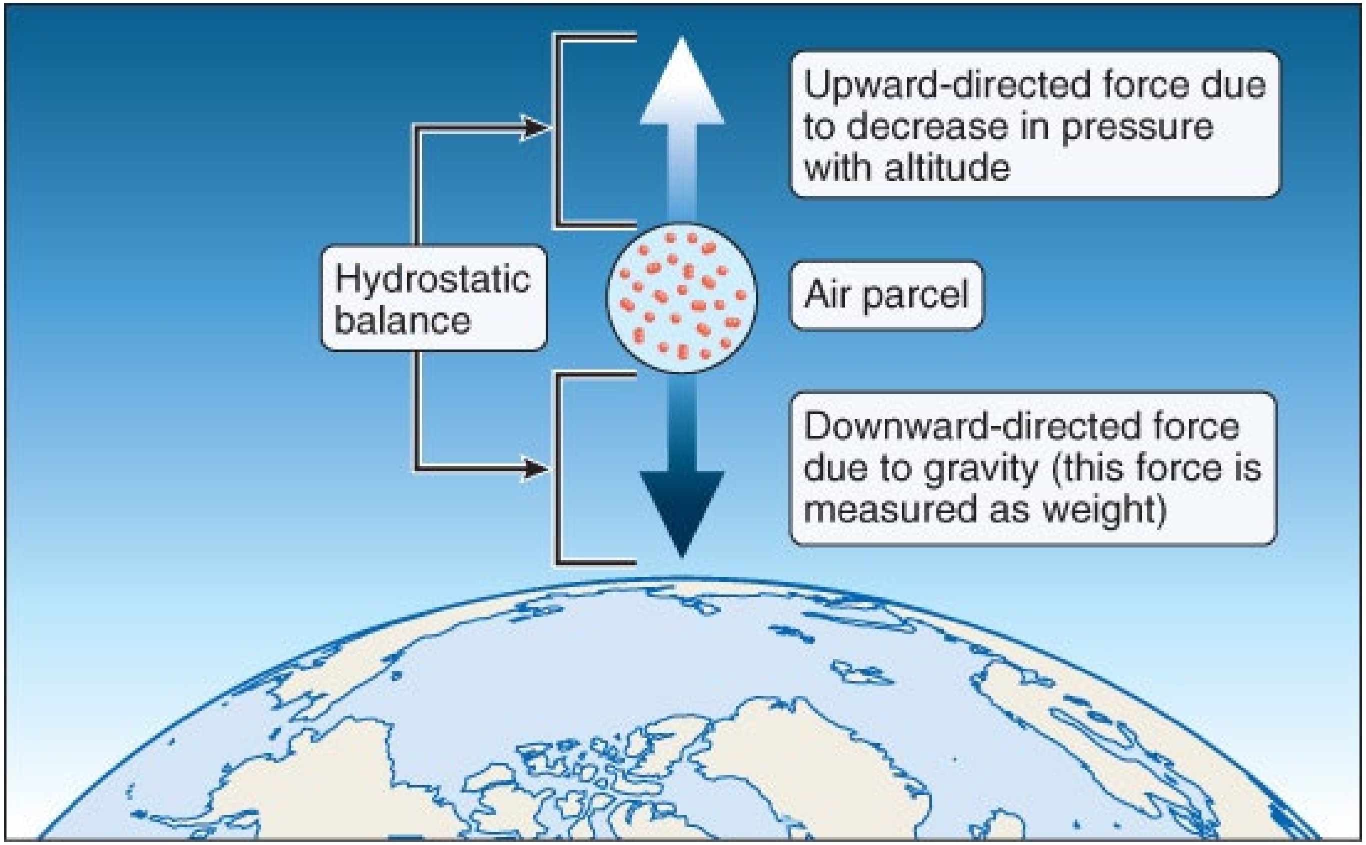
HYDROSTATIC BALANCE

- Recall the <u>vertical</u> pressure gradient force.
- Why doesn't the air get sucked up into outer space?



HYDROSTATIC BALANCE

- Answer…GRAVITY!! The gravitational force BALANCES the vertical pressure gradient force:



THE HYDROSTATIC EQUATION

- Vertical PGF and gravity are roughly equal in magnitude, but opposite in direction. Thus, they act to keep the vertical velocities minima (not zero!).

$$\frac{\partial p}{\partial z} = -\rho g$$

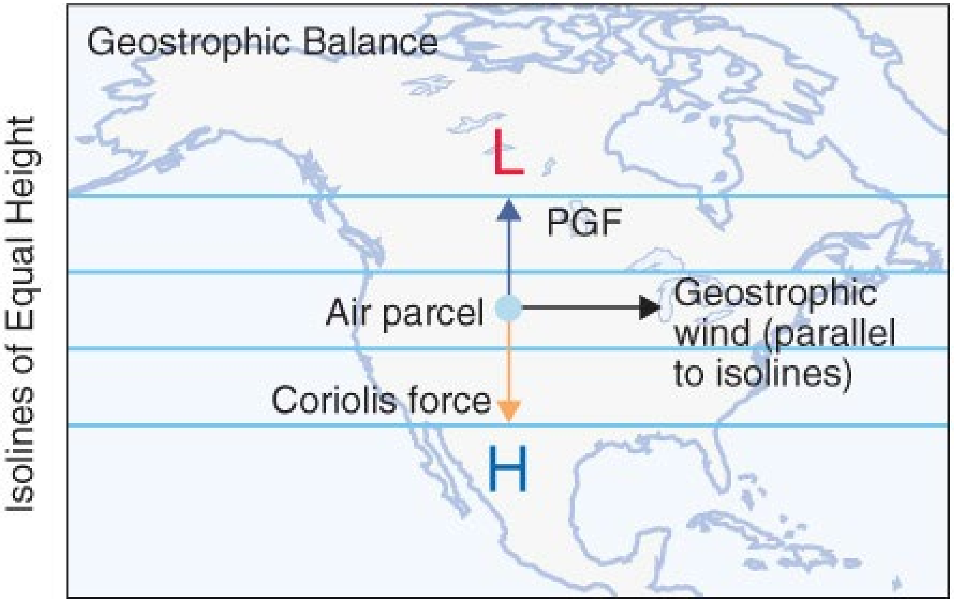
- There MUST be vertical motion to get precipitation and clouds.

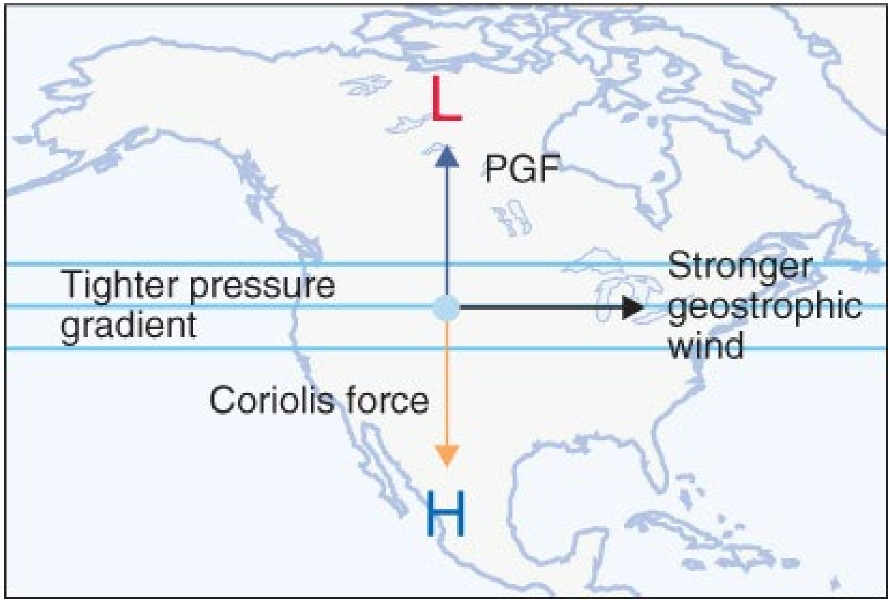
THE HYDROSTATIC EQUATION

- Most global NWP models (like the GFS) are hydrostatic.
- They don't solve for vertical momentum (velocity) explicitly.
- Two additional methods to get vertical motions:
  - Kinematic method (Continuity Equation)
  - Thermodynamic method (Based on first law)

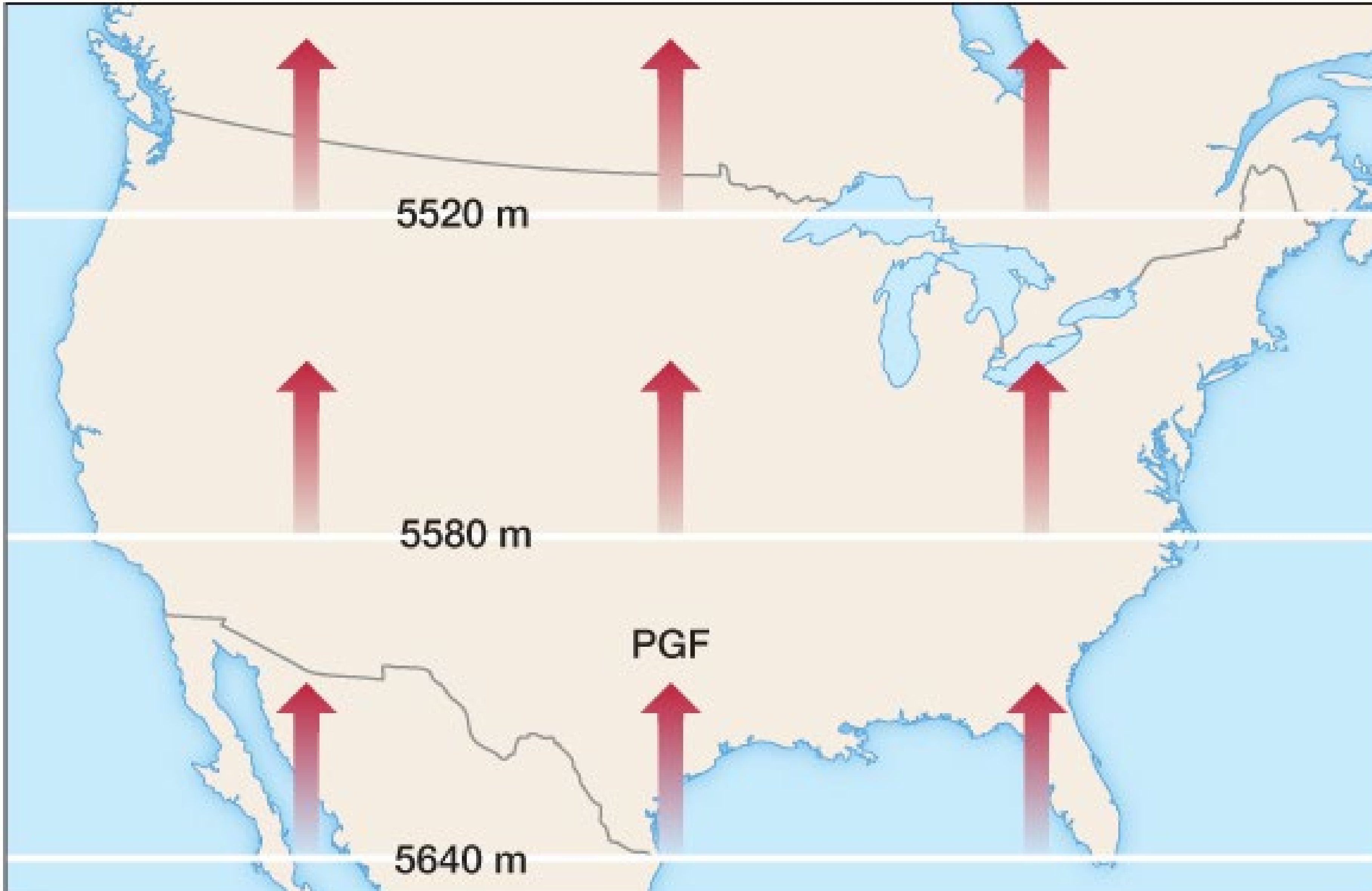
GEOSTROPHIC BALANCE

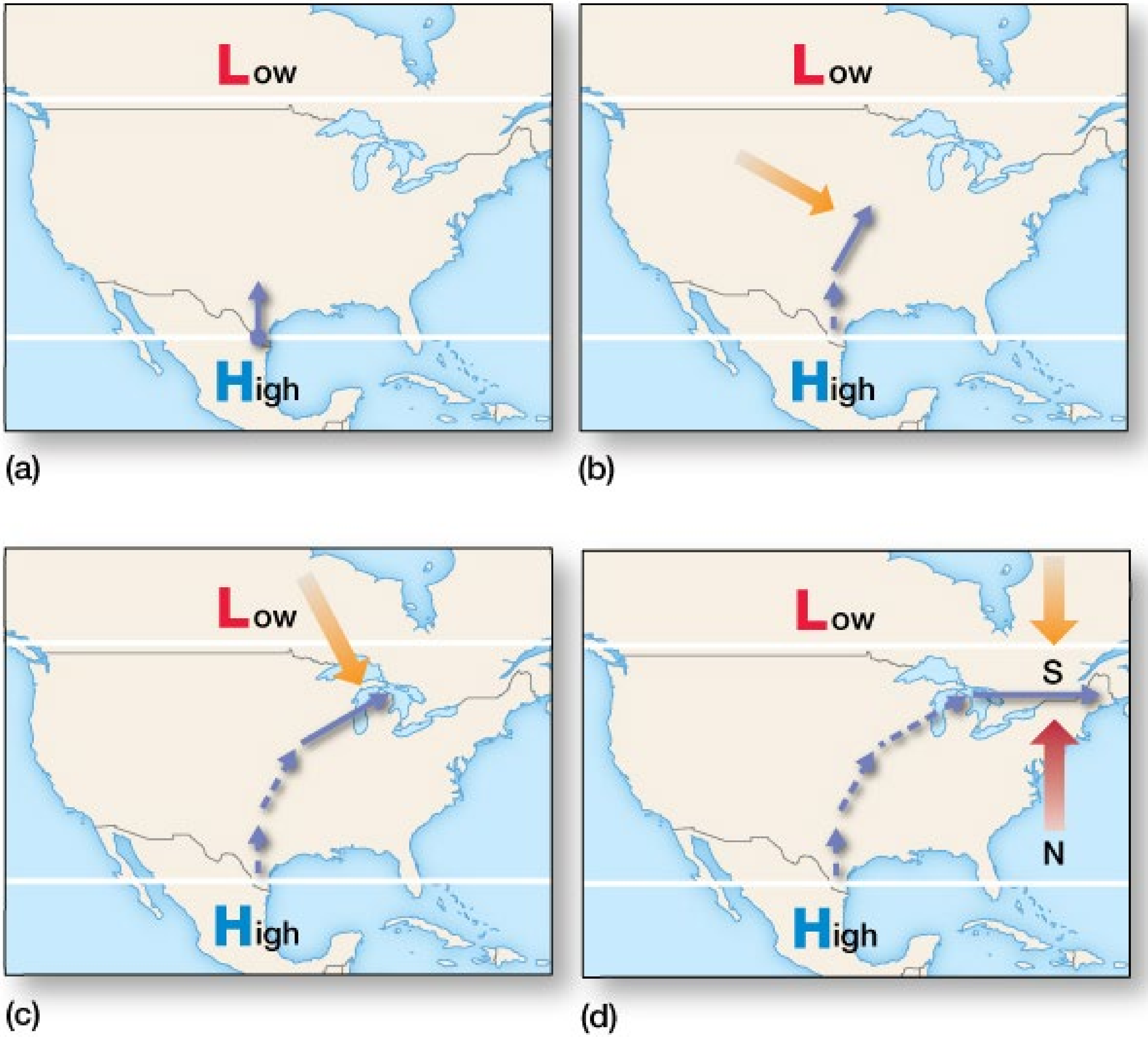
Balance between the pressure gradient force and the Coriolis force :





This balance describes the geostrophic wind

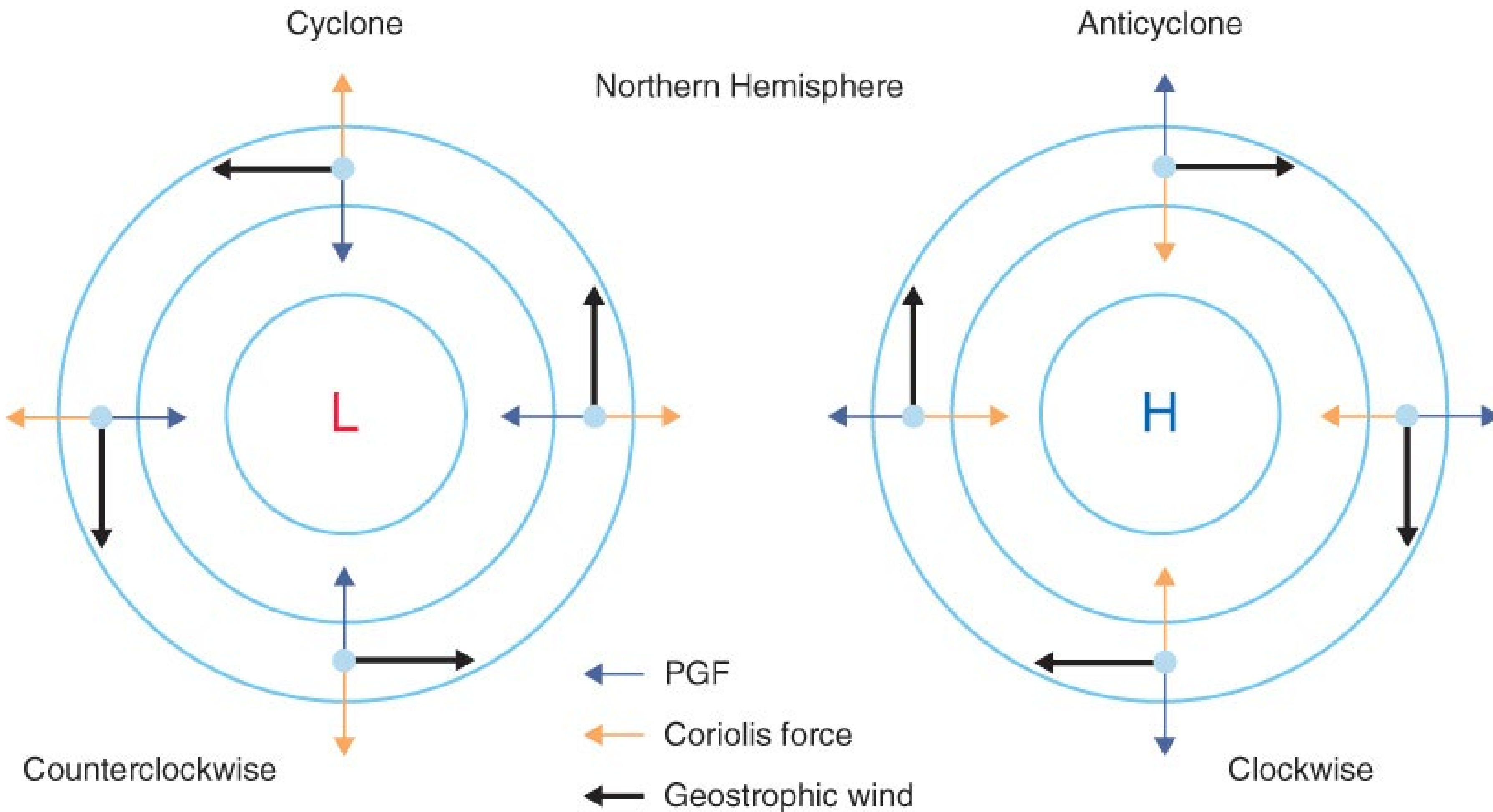

5520 m
5580 m
PGF
5640 m


Low
High
(a)
Low
High
(b)
Low
High
(c)
Low
S
N
High
(d)

GEOSTROPHIC WIND

- Winds in upper atmosphere are largely geostrophic.
- Therefore, wind blows parallel to isobars (or isoheights), which is useful to consider when looking at weather maps.
- If low pressure is always to the left of motion, this means:
  - Wind must move counterclockwise around low pressure areas
  - Wind must move clockwise around high pressure.

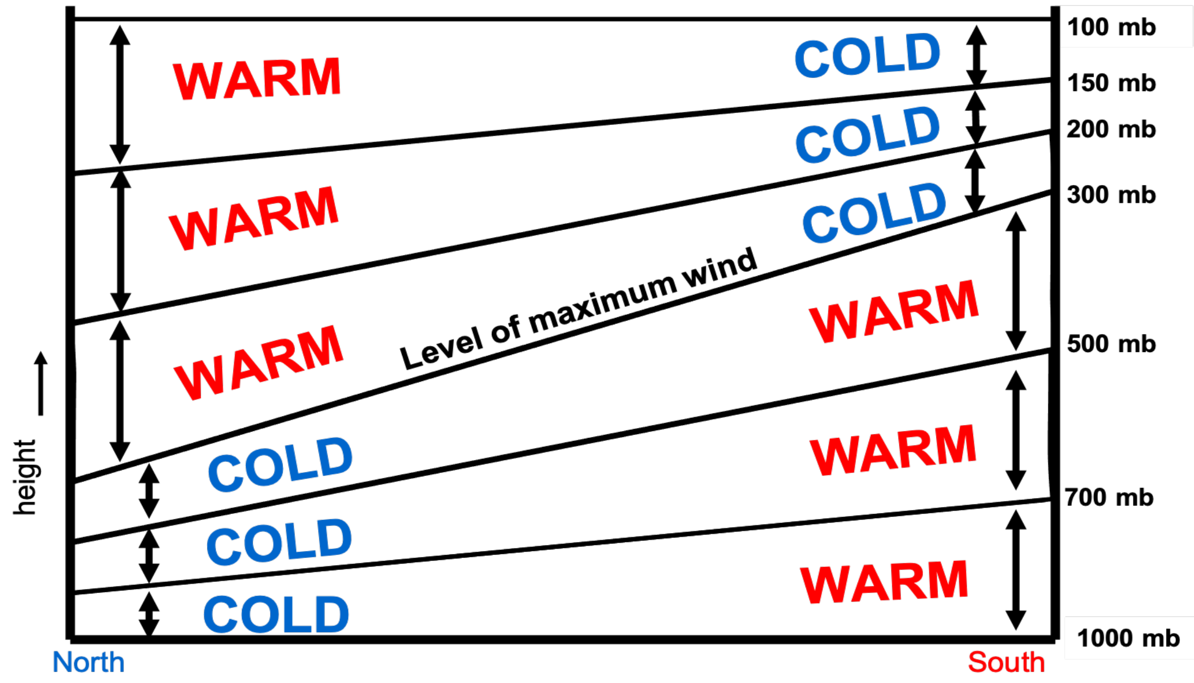
GEOSTROPHIC WIND



TEMPERATURE AND WIND

- The strength of the geostrophic wind will be proportional to the gradient (slope) in temperature.
- Thus, geostrophic winds increase with height up to the 300 mb level.
- Cold air on left.

Fig. 1.5



THERMAL WIND

- This increase in geostrophic wind with height is known as the *thermal wind*.

- Geostrophic wind shear:

$$\overrightarrow{V_T} = \vec{V}_{g\ upper} - \vec{V}_{g\ lower}$$

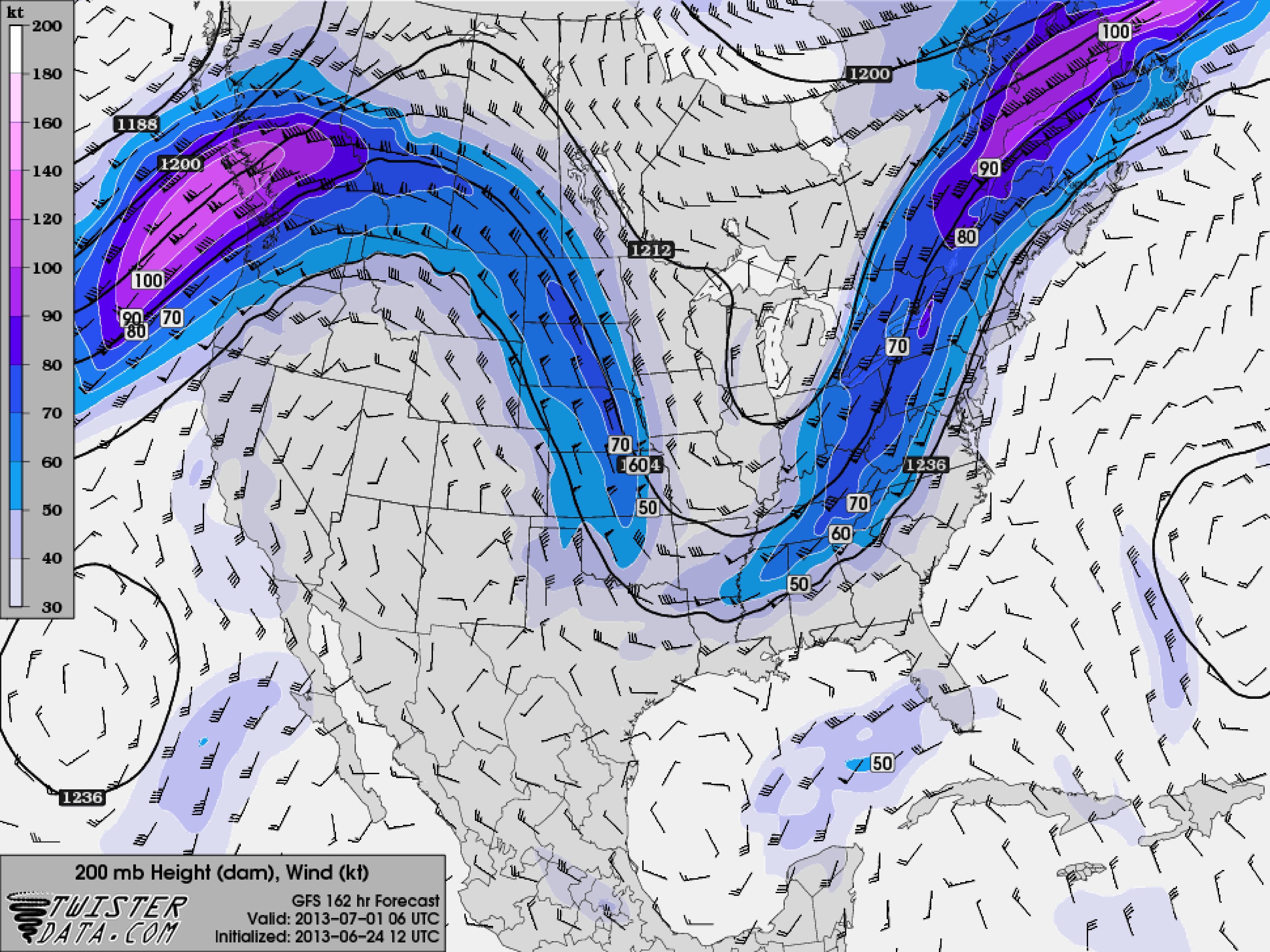
- ***Vertical shear of geostrophic wind (thermal wind)*** directly related to ***horizontal (virtual) temperature gradient***

THERMAL WIND

- The thermal wind assumes hydrostatic and geostrophic balance.
- ***This relationship explains the general west – east motion of mid-latitude weather and the jet stream.***
- ***Example***

GRADIENT BALANCE

- TECHNICALLY, geostrophic balance only applies to flows with no curvature.
- If there is curvature, then the centrifugal force should be included.
- The result is the gradient wind -- > flows along gradients (isobars / isoheights).
- In reality, CF contributes only a little. Not really worth the trouble to include.


kt
200
180
160
140
120
100
90
80
70
60
50
40
30
1188
1200
1212
1236
100
90
80
70
60
50
1604
200 mb Height (dam), Wind (kt)
TWISTER DATA.COM
GFS 162 hr Forecast
Valid: 2013-07-01 06 UTC
Initialized: 2013-06-24 12 UTC

GRADIENT WINDS

- Used in wind engineering to represent winds above the boundary layer
  - Gradient height, for example.

- The winds around a hurricane are also typically modeled as gradient winds / flow.

- Coriolis still important here.

GULDBERG-MOHN BALANCE

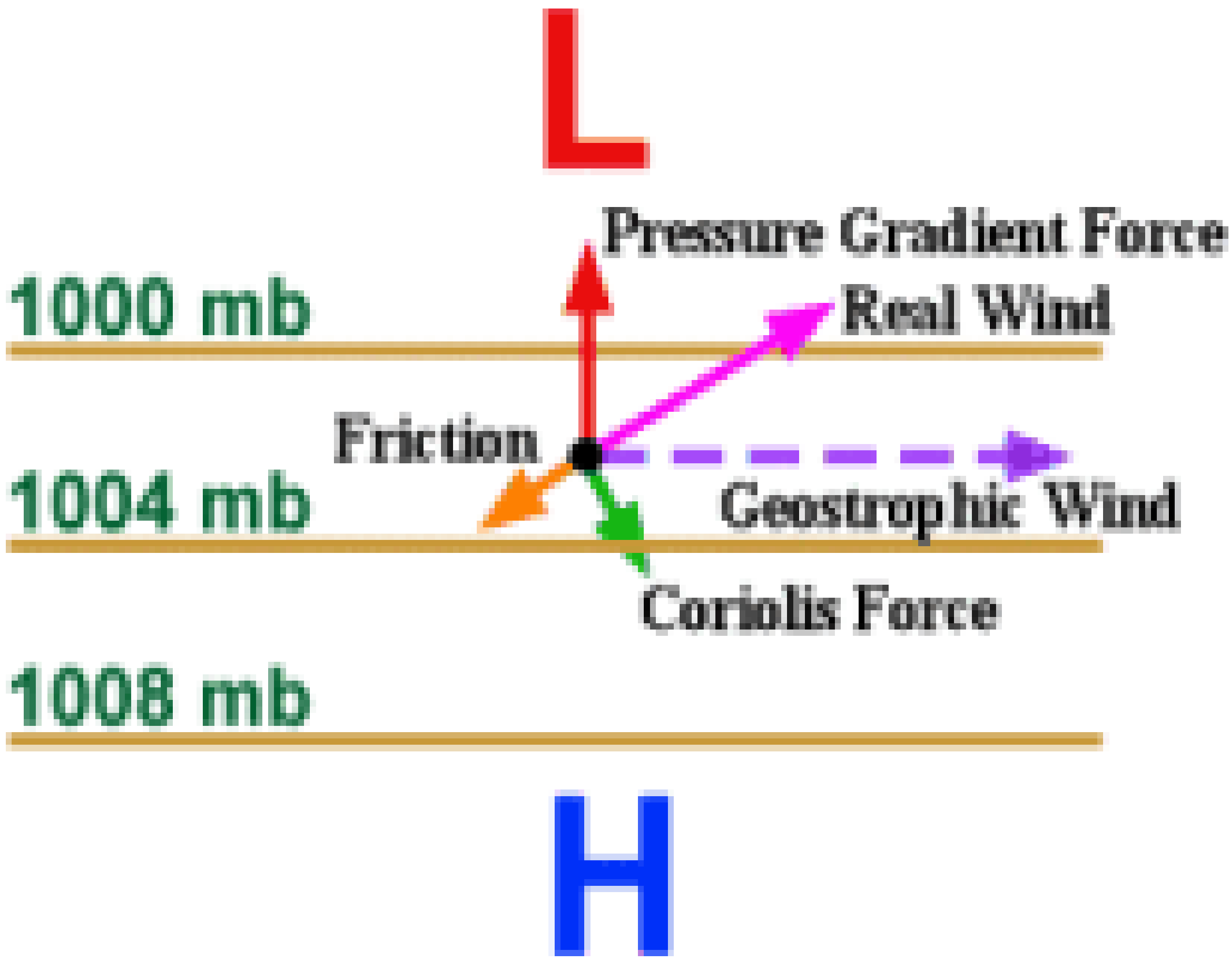
Friction slows the wind

Coriolis force (dependent on wind speed) is therefore reduced

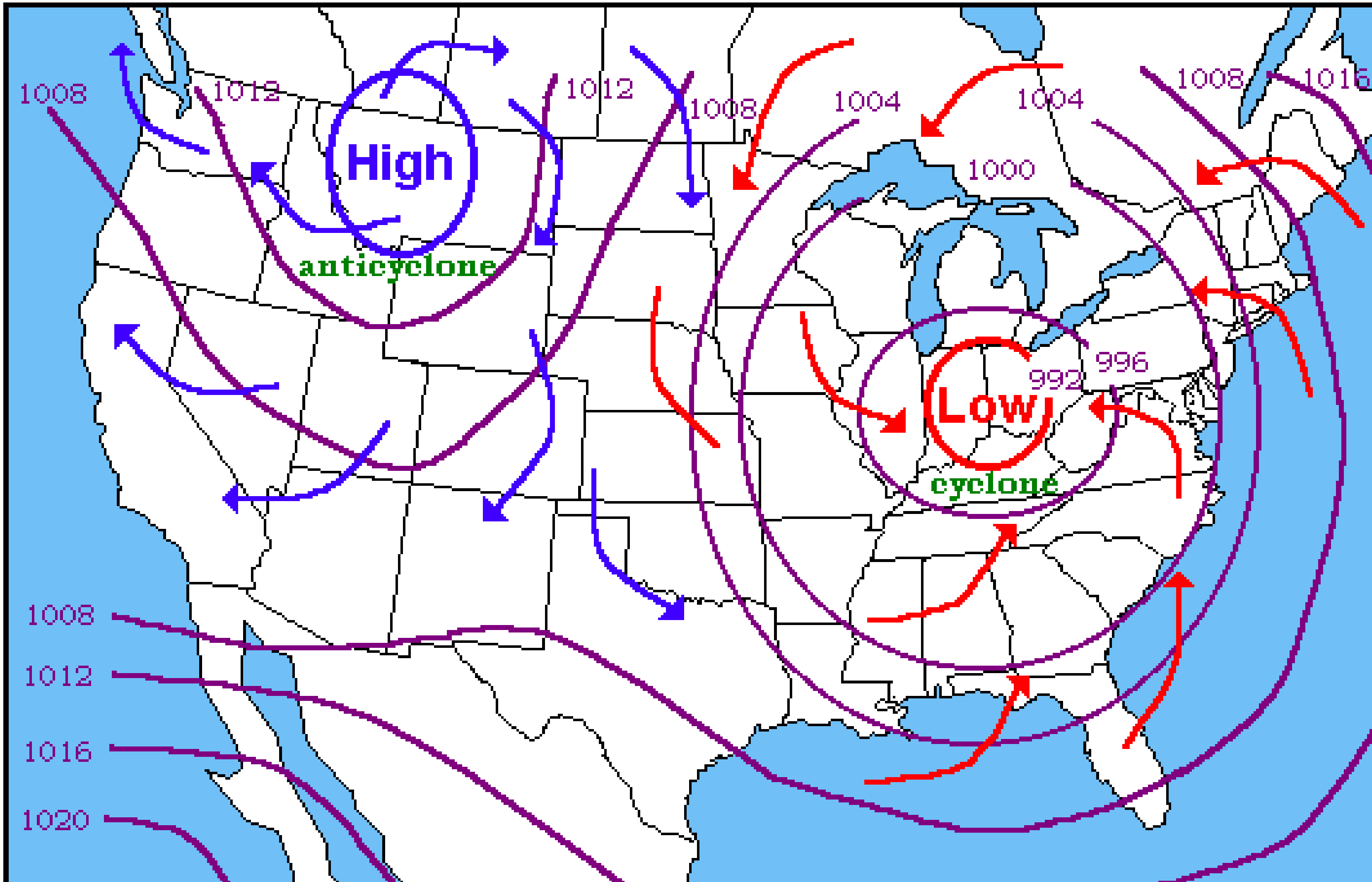
Pressure gradient force now exceeds Coriolis force

Wind flows across the isobars toward lower pressure

ANOTHER PERSPECTIVE…

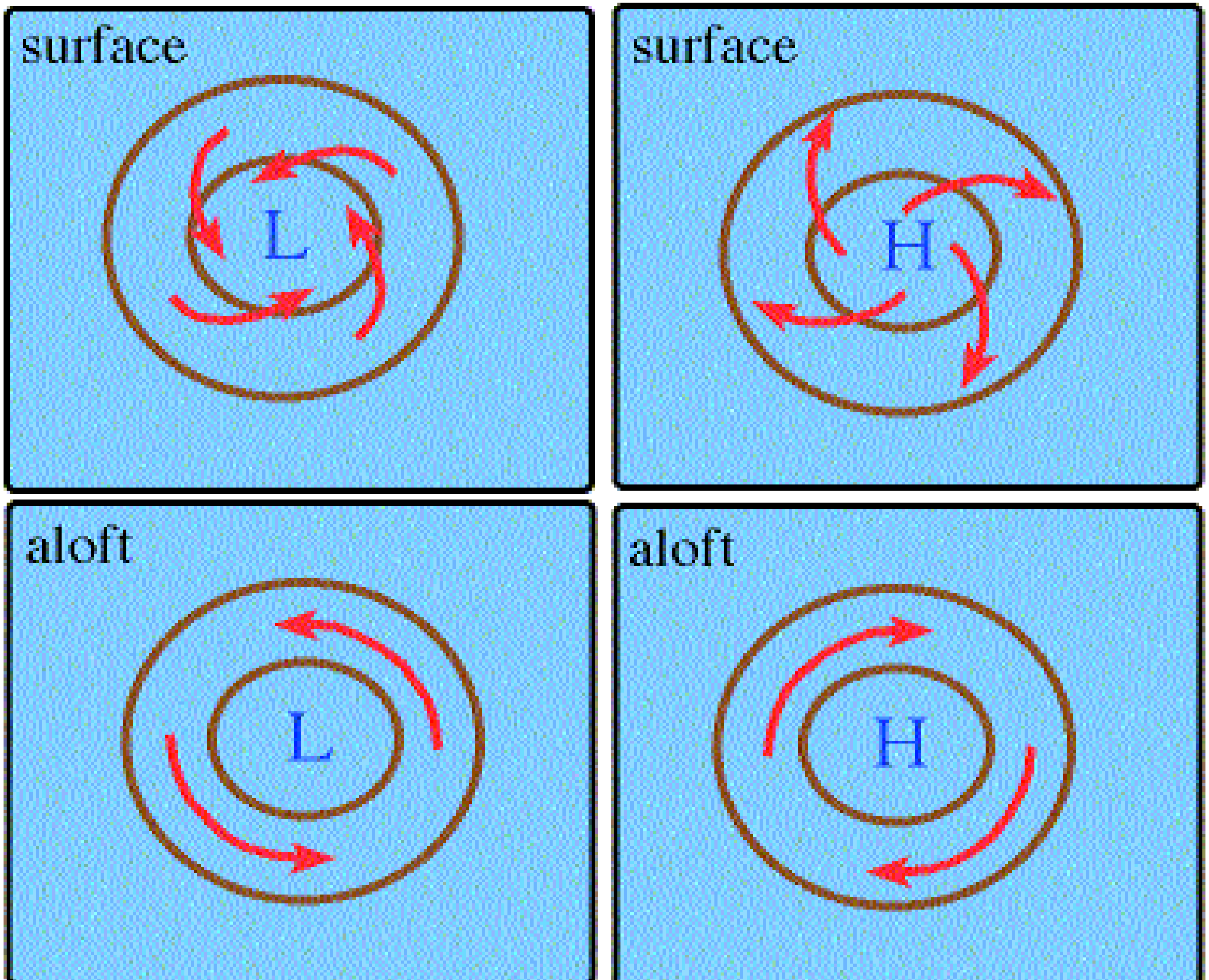


SURFACE WINDS AND PGF



Cyclonic and anticyclonic winds in northern hemisphere

SURFACE WINDS VS. UPPER AIR



SURFACE WINDS AND VERTICAL MOTION

- Horizontal movement of air can result in convergence or divergence.
  - Convergence = winds coming together; colliding
  - Divergence = winds separating

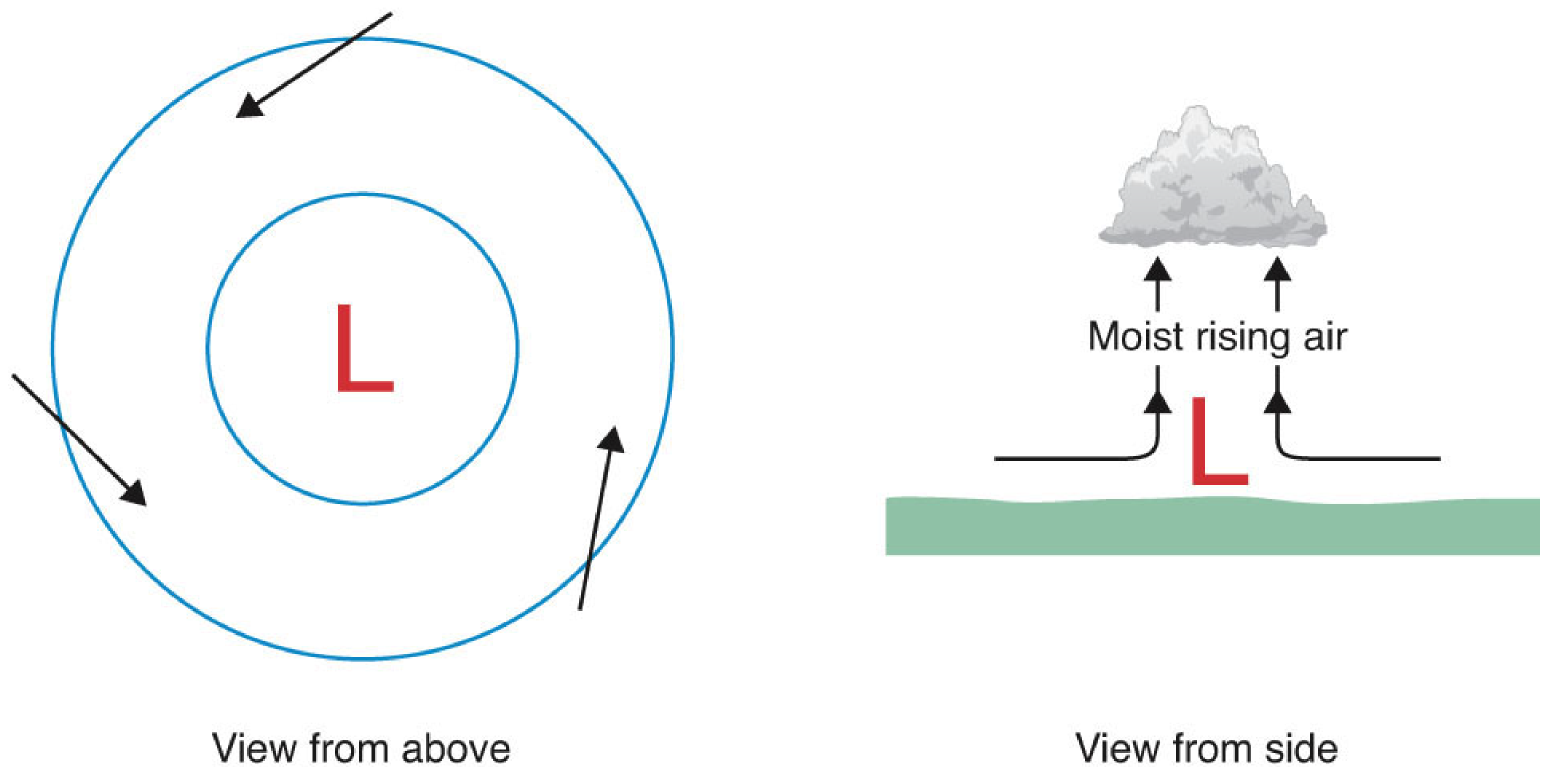
- Areas of ***convergence*** are areas of *rising* air
- Areas of ***divergence*** are areas of *sinking* air

- Rising air (upward vertical motion) is needed to form clouds and precipitation.

CONVERGENCE

- Convergence associated with areas of low pressure at the surface. Therefore areas of low pressure are associated with rising air.

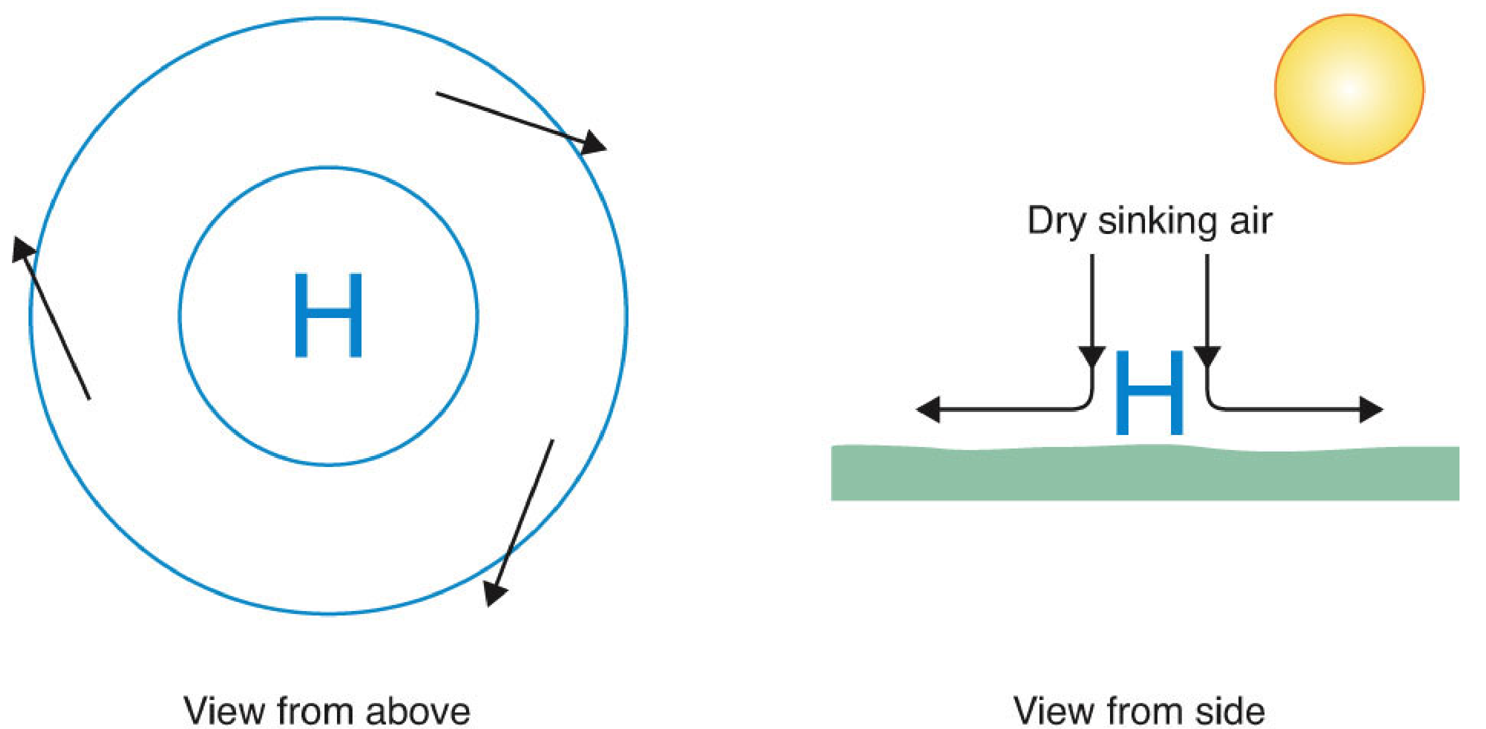
Surface winds blow counterclockwise around a cyclone (low pressure) and converge.



DIVERGENCE

- Divergence is associated with areas of high pressure at the surface. Therefore areas of high pressure are associated with sinking air.

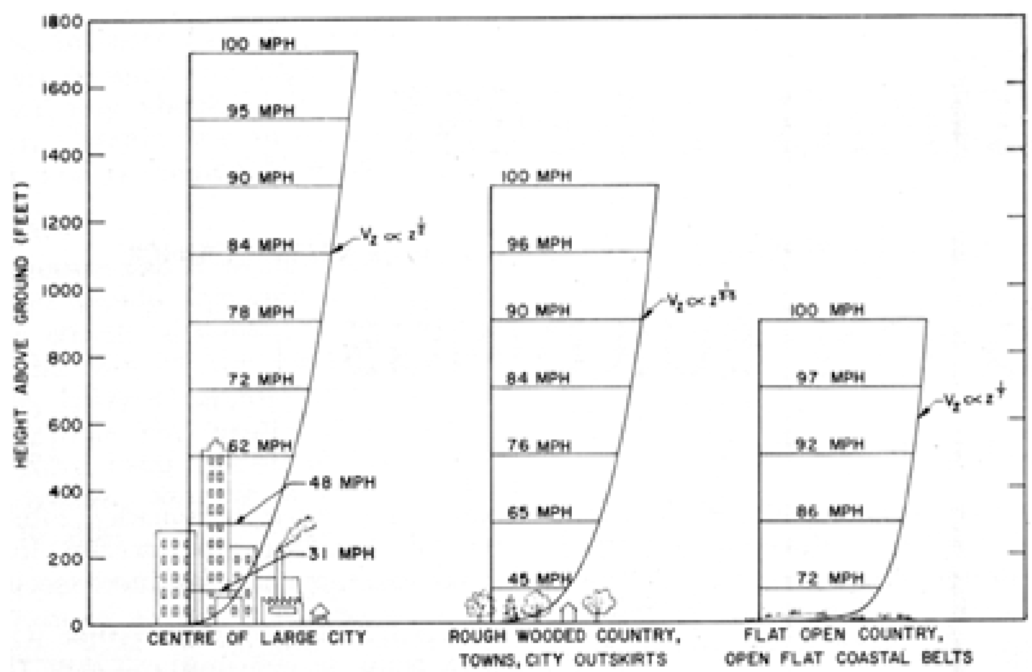
Surface winds blow clockwise around an anticyclone (high pressure) and diverge.



SURFACE AND VERTICAL PROFILE

- The consideration of both friction (surface) and gradient winds leads to the standard wind profile above the surface.

- Typically modeled as logarithmic profile (or a power law)



EQUATIONS OF MOTION

- Separate into equations for horizontal and vertical momentum as well as zonal and meridional components:

$$\frac{du}{dt} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + fv + F_x$$

$$\frac{dv}{dt} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + F_y$$

PGF

Coriolis

Friction

- In vector form:

$$\frac{d\vec{V}}{dt} = -\frac{1}{\rho}\nabla_h p - f\hat{k} \times \vec{V} + \vec{F_r}$$

- Also called the Navier-Stokes of Motion

EQUATIONS OF MOTION

- Expanding the total derivative:

$$\frac{\partial \vec{V}}{\partial t} = -\vec{U} \cdot \nabla \vec{V} - \frac{1}{\rho} \nabla_h p - f \hat{k} \times \vec{V} + \vec{F}_r$$

- In words, the local time rate of change of the wind at a fixed location is due to:
  - Horizontal advection
  - The PGF
  - The Coriolis force projected into the vertical
  - The resultant friction (molecular stress term)

- But do all of these terms really matter? It depends.