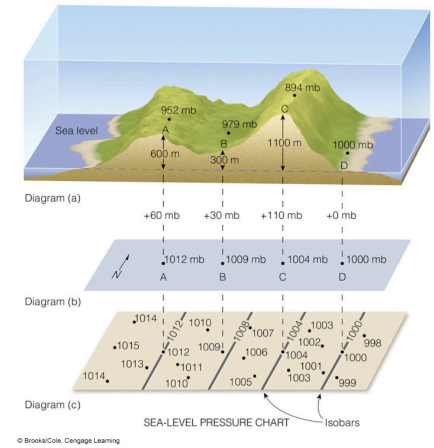
Pressure and winds (chapter 9)….

Pressure

- Recall that
  - Pressure is force per unit area
  - Air pressure is determined by the weight of air above
- A change in pressure over some distance (pressure gradient) causes air to move
- What is the difference between surface pressure and sea level pressure?

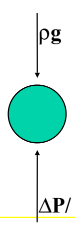


Remember: hydrostatic balance

What keeps air from always moving downwards due to gravity?

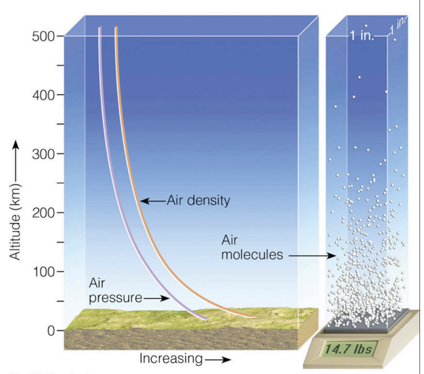
A balance between gravity and the pressure gradient force.

$\Delta P / \Delta z = \rho g$



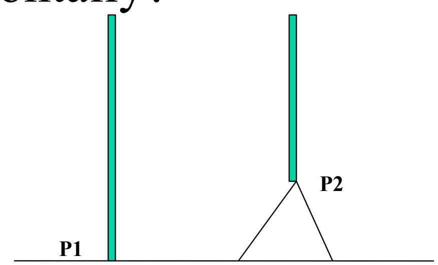
So:

$\Delta P = \rho g \Delta z$

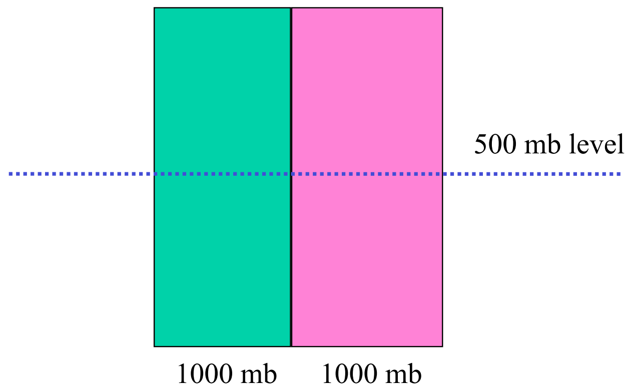


Why does pressure vary horizontally?

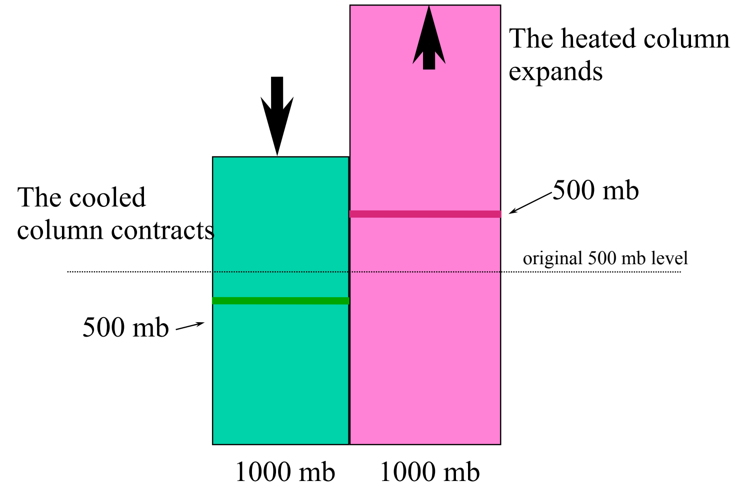
- Elevation changes cause pressure differences
- But why does pressure vary between locations which are at the same elevation?



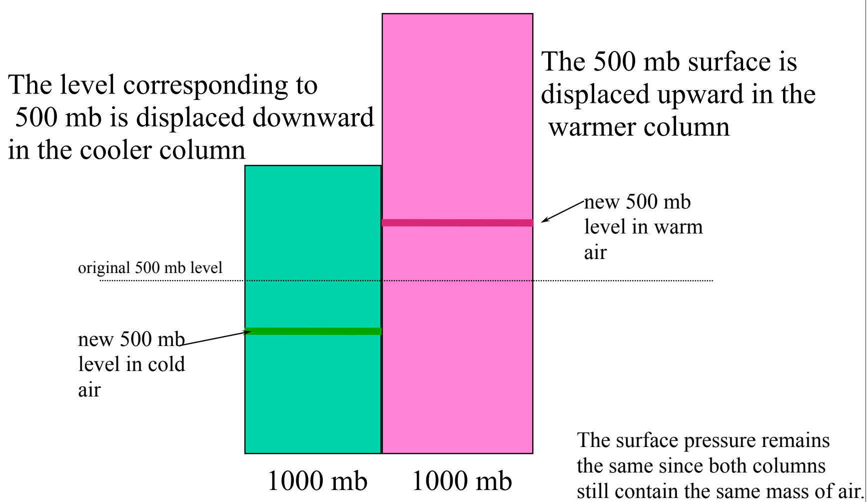
Two columns - same temperature



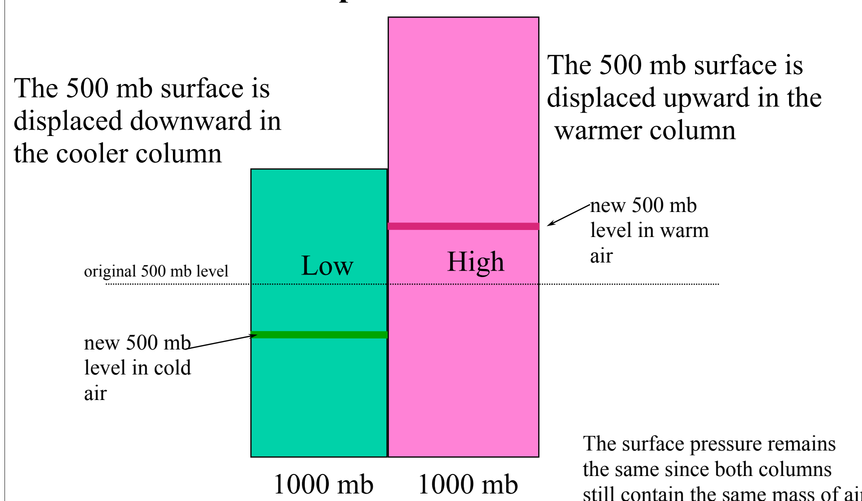
Cool the left column; warm the right column



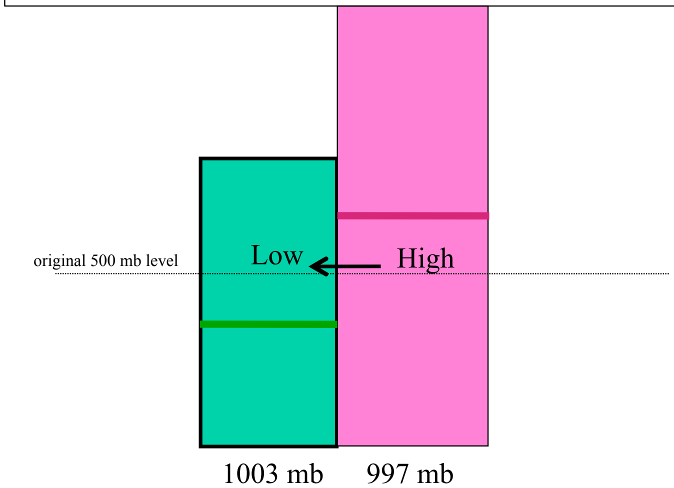
The level of the 500 mb surface changes; the surface pressure remains unchanged



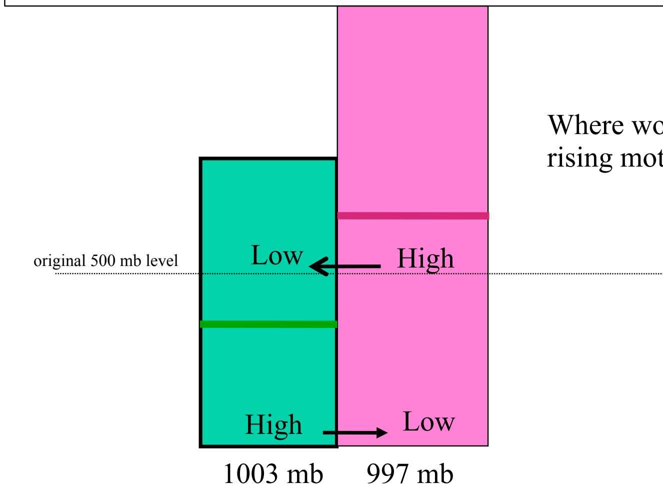
A pressure difference in the horizontal direction develops above the surface



Air moves from high to low pressure in middle of column, causing surface pressure to change.



Air moves from high to low pressure at the surface…



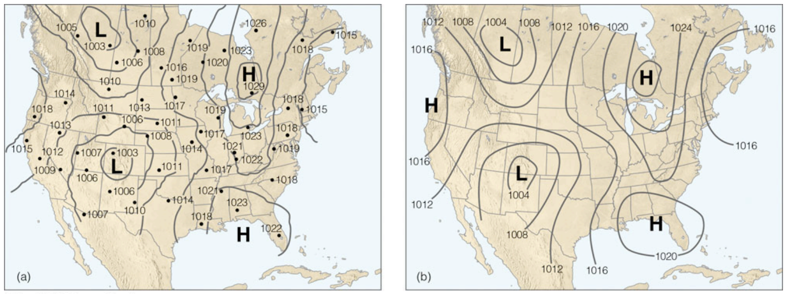
Where would we have rising motion?

What have we just observed?

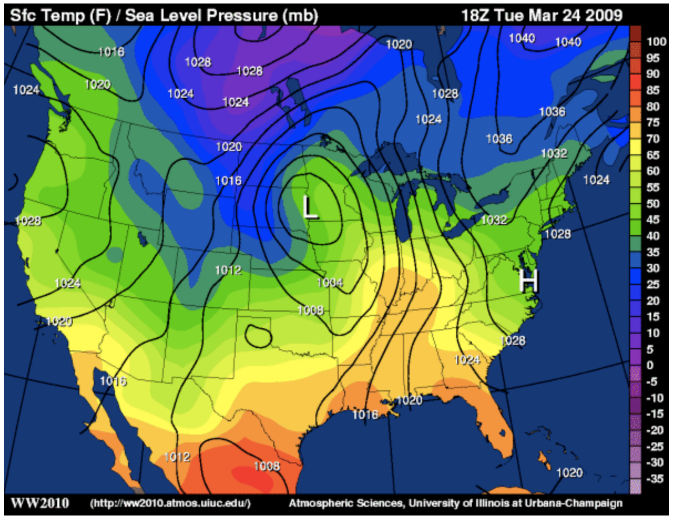
- Starting with a uniform atmosphere at rest, we introduce differential heating
- The differential heating causes different rates of expansion in the fluid
- The differing rates of expansion result in pressure differences along a horizontal surface aloft.
- The pressure differences induce horizontal flow aloft and at the surface
- This is a microcosm of how the atmosphere converts heating into motions

Surface Pressure Maps

- Altitude-adjusted surface station pressures are used to construct sea level pressure contours

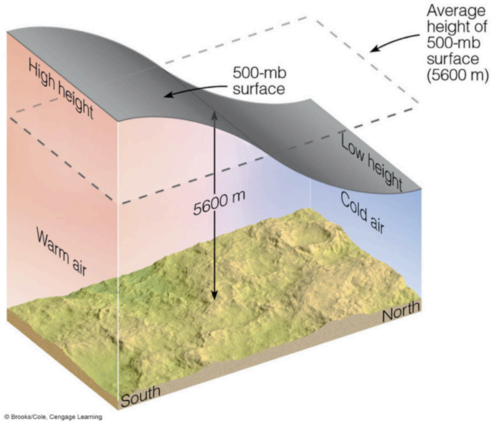


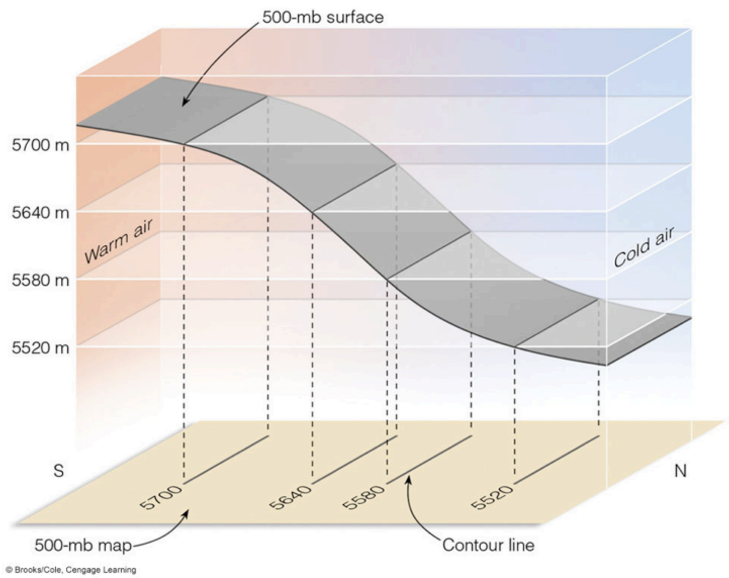
Surface Pressure Maps



Constant pressure charts

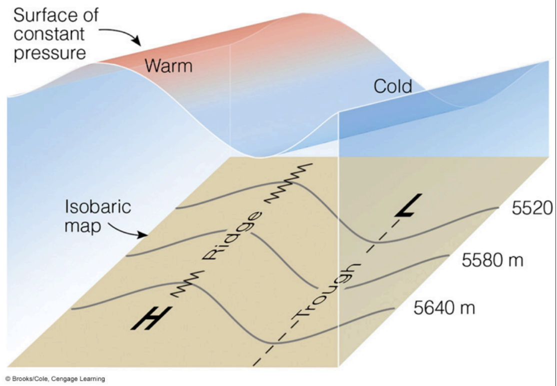
- Constant pressure (isobaric) charts are often used by meteorologists
- Isobaric charts plot variation in height on a constant pressure surface (e.g., 500 mb)
- In this example a gradient between warm and cold air produces a sloping 500 mb pressure surface
  - Pressure decreases faster with height in a colder (denser) air mass
- Where the slope of the pressure surface is steepest the height contours are closest together





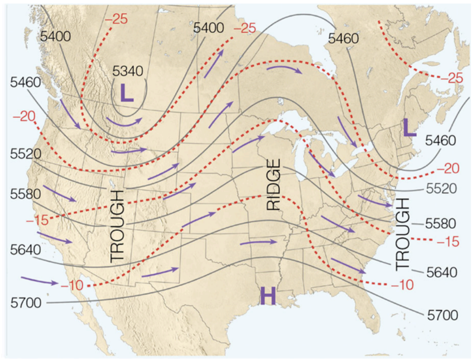
Troughs and ridges

- Temperature gradients generally produce pressure gradients
- Isobars usually decrease in value from south to north (cooler temperatures)
- But contour lines are usually not straight.
  - **Ridges** (elongated highs) occur where air is warm
  - **Troughs** (elongated lows occur where air is cold



Pressure patterns and winds aloft

- At upper levels, winds blow parallel to the pressure/height contours

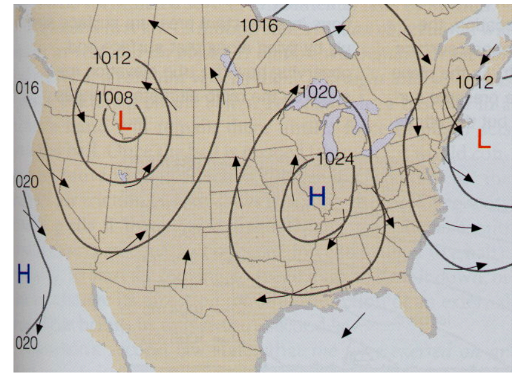


(b) Upper-air map (500 mb)

Surface pressure patterns and winds

Near the surface in the northern hemisphere winds blow

- counterclockwise around and in toward the center of low pressure areas
- clockwise around and outward from the center of high pressure areas



Why doesn't the wind blow from high to low pressure?

Forces and winds

- Pressure gradients produce air movement
- Multiple forces act simultaneously to cause the wind direction to differ from the direction of decreasing pressure
- Newton's laws of motion describe the relationship between forces and motion
  - 1st Law: an object at rest will stay at rest and an object in motion will remain in motion (and travel at a constant velocity along a straight line) as long as no force is exerted on the object
  - 2nd Law: the force exerted on an object equals its mass times the acceleration produced (F = ma)

Air accelerates in the presence of a force (a=F/m).

Forces controlling the wind

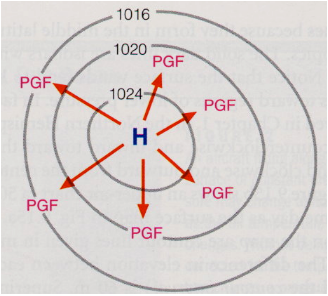
- Pressure Gradient Force
- Coriolis Force
- Centrifugal force
- Friction

Forces expressed as vectors

- Forces have two properties
  - Magnitude or Size
  - Direction
- Vectors have same two properties
  - Length of arrow denotes magnitude
  - Direction of arrow denotes direction

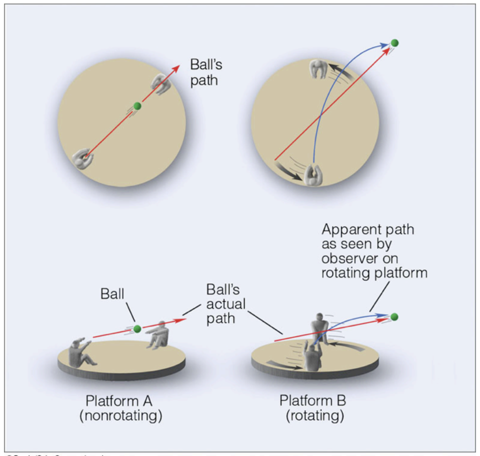
Pressure Gradient Force

- Magnitude
  - Inversely proportional to the distance between isobars or contour lines
    - The closer together, the stronger the force
- Direction
  - Always directed toward lower pressure



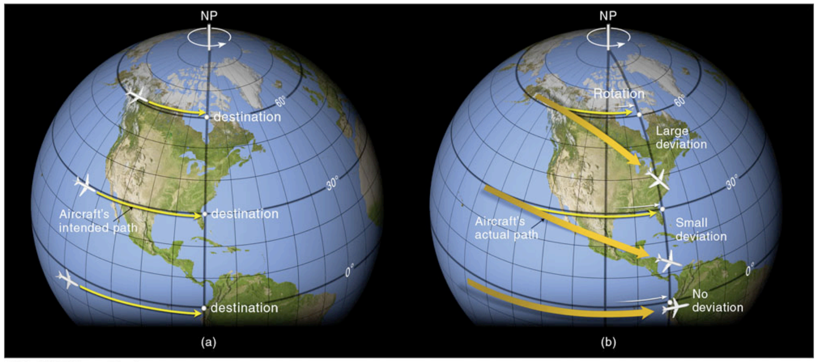
Coriolis Force

Apparent force due to rotation of the earth



Coriolis Force

Apparent force due to rotation of the earth

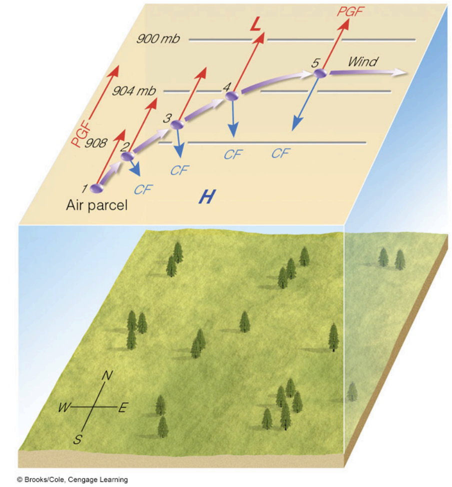


Coriolis Force

- Apparent force due to rotation of the earth
- Magnitude
  - Depends upon the latitude and the speed of movement of the air parcel
    - The higher the latitude, the larger the Coriolis force
      - zero at the equator, maximum at the poles
    - The faster the speed, the larger the Coriolis force
- Direction
  - The Coriolis force always acts at right angles to the direction of movement
    - To the right in the Northern Hemisphere
    - To the left in the Southern Hemisphere

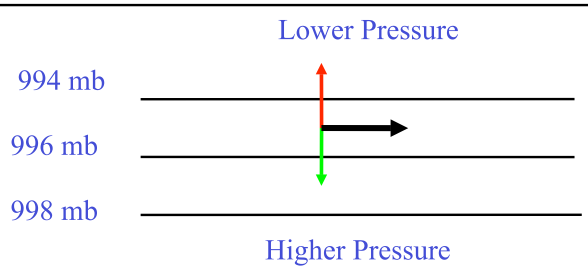
Coriolis Force

- Acts to right in northern hemisphere
- Stronger for faster wind



Geostrophic Wind

- The Geostrophic wind is flow in which the pressure gradient force balances the Coriolis force.



Note: Geostrophic flow is often a good approximation high in the atmosphere (>500 meters)

Centrifugal Force

- When viewed from a fixed reference frame, a ball swung on a string accelerates towards to center of rotation (centripetal acceleration).
- When viewed from a rotating reference frame, this inward acceleration (caused by the string pulling on the ball) is opposed by an apparent force (centrifugal force).

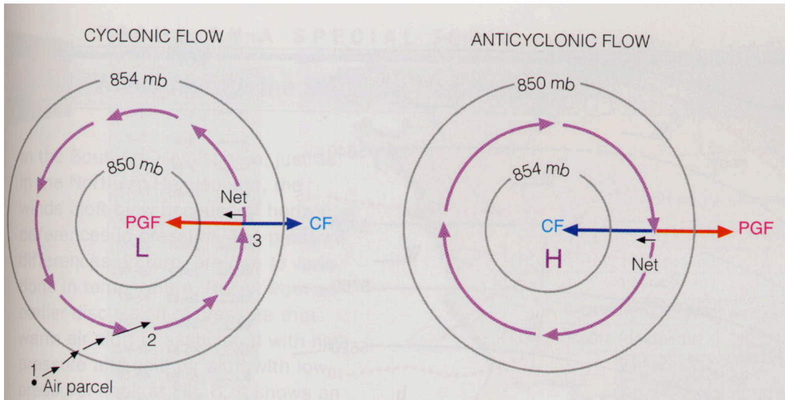
Centrifugal Force

- Magnitude
  - depends upon the radius of curvature of the curved path taken by the air parcel
  - depends upon the speed of the air parcel
- Direction
  - at right angles to the direction of movement

Gradient Wind

- The Gradient Wind is flow around a curved path where there are three forces involved in the balance:
  - 1. Pressure Gradient Force
  - 2. Coriolis Force
  - 3. Centripetal Force
- Important near high or low pressure centers

Gradient Wind



(a) Low pressure area (cyclone)

(b) High pressure area (anticyclone)

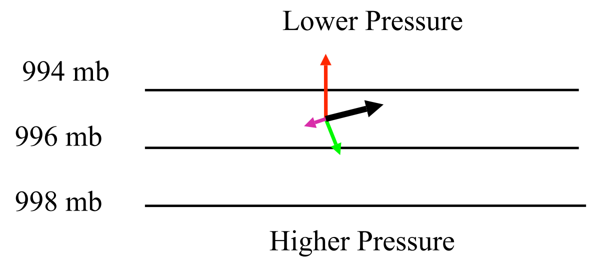
Friction is important near Earth's surface

- Frictional drag of the ground slows wind down
  - Magnitude
    - Depends upon the speed of the air parcel
    - Depends upon the roughness of the terrain
    - Depends upon how uniform the wind field is
  - Direction
    - Always acts in the direction opposite to the movement of the air parcel
  - Important in the ***friction layer*** (planetary boundary layer)
    - ~lowest 1000 m of the atmosphere

What happens when we add friction?

- Friction can only slow wind speed, not change wind direction
- Therefore, in the northern hemisphere, if the wind speed is decreased by friction, the Coriolis force will be decreased and will not quite balance the pressure gradient force
  - Force imbalance (PGF > CF) pushes wind in toward low pressure
  - Angle at which wind crosses isobars depends on surface roughness
    - Average ~ 30 degrees

Geostrophic wind plus friction



The wind no longer blows parallel to the isobars, but is deflected toward lower pressure; this happens close to the ground where terrain and vegetation provide friction

Winds and vertical air motion

- Surface winds blow
  - In toward center of low pressure (convergence)
  - Out from center of high pressure (divergence)
- Air moves vertically to compensate for surface convergence or divergence
  - Surface convergence leads to divergence aloft
  - Surface divergence leads to convergence aloft

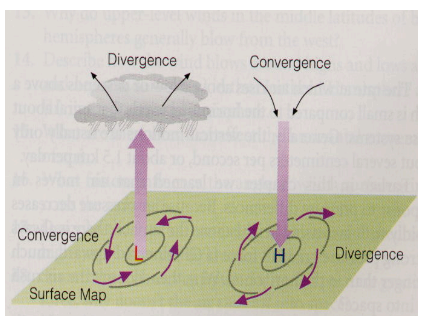


FIGURE 9.32
Winds and air motions associated with surface highs and lows in the Northern Hemisphere.