TUESDAY PM: Force balances, geostrophic flow, cyclones, highs and lows

Forces & Moving Air

- What makes the wind blow?
- Why do winds blow counterclockwise around lows and clockwise around highs?

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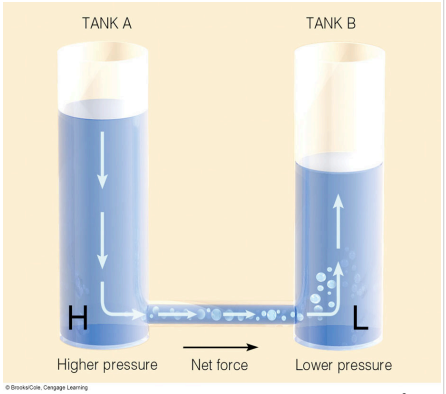
Pressure Gradient Force

- Two tanks filled with water, tank A has more water than tank B
- The pressure at the bottom (the weight of the water above) is higher in tank A than in tank B
- The pressure gradient forces the water to flow from tank A into tank B (high to low pressure)



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Forces and Winds

- Pressure gradients produce air movement/flow: does the wind blow from high to low 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 will remain in motion (and travel at constant speed 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

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Forces expressed as Vectors

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

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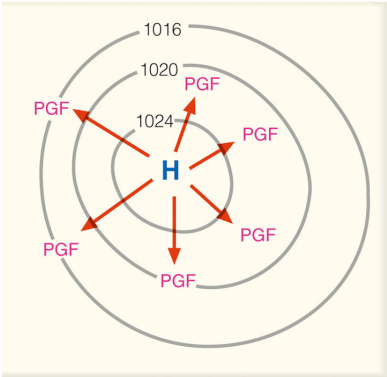
Pressure Gradient Force

- Magnitude
  - Inversely proportional to the distance between isobars (contour lines) – the closer together the stronger the force
- Direction
  - Always directed towards lower pressure



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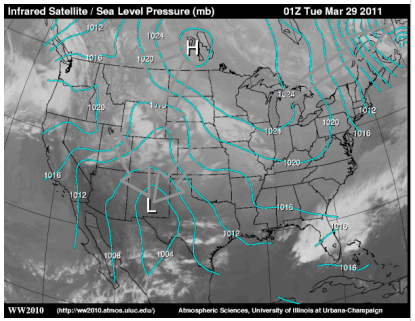
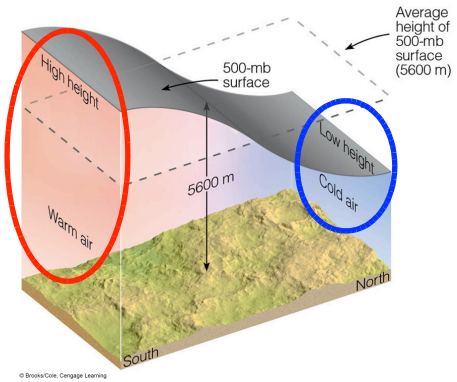


⇨ **Example PGF Vectors**

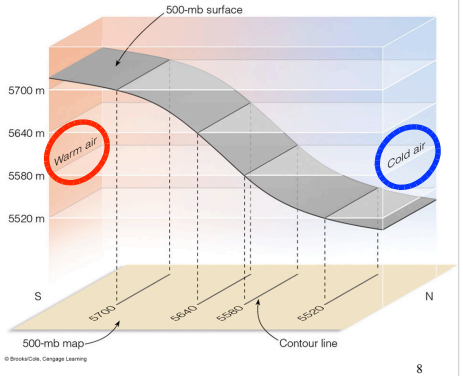
Upper level maps show the height of constant pressure surfaces (isobaric charts/maps)

- Regions of low height correspond to regions of low pressure and vice versa, if you do a horizontal slice across the map
- The height of the pressure surface can be contoured on a map ...



Isobaric maps/charts show the height of constant pressure surfaces

- Warm (cold) air aloft expands (contracts) the atmosphere, lifting (lowering) the 500 mb surface
- Pressure surface slopes downward from warm to cold air
- Height contours are closest together where slope of the pressure surface is steepest



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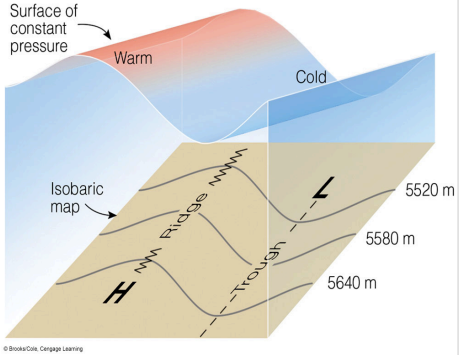
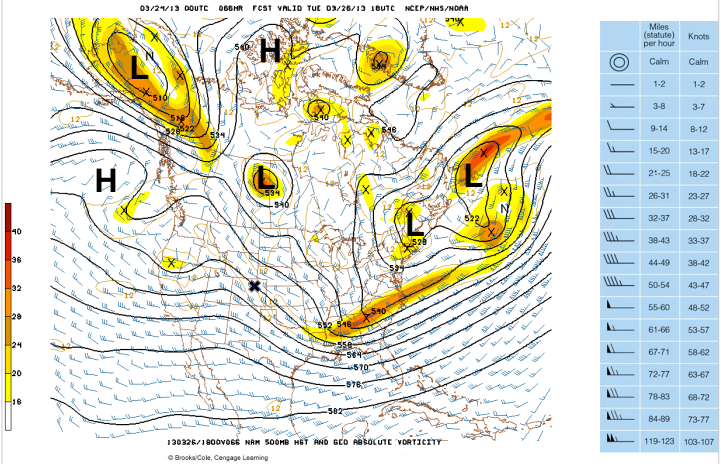
Troughs and Ridges

- Temperature gradients generally produce pressure gradients
- Isobars (lines of constant pressure) usually decrease from equator to pole (south to north in our hemisphere)

- But contour lines are usually not straight:
  - Ridges (elongated highs) occur where air is relatively warm
  - Troughs (elongated lows) occur where air is relatively cold



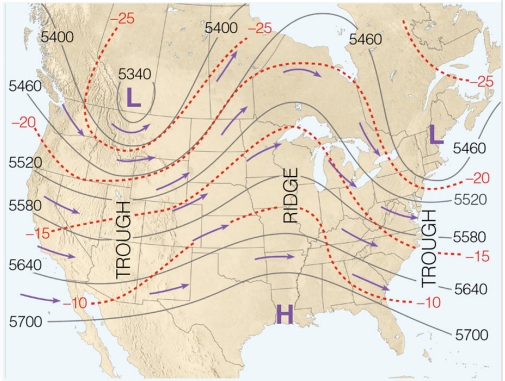
Pressure / height patterns (500 mb) & winds aloft: Example



Pressure / height patterns & winds aloft

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

Winds are deflected counterclockwise around lows and clockwise around highs.



(b) Upper-air map (500 mb)

This is northern hemisphere!

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

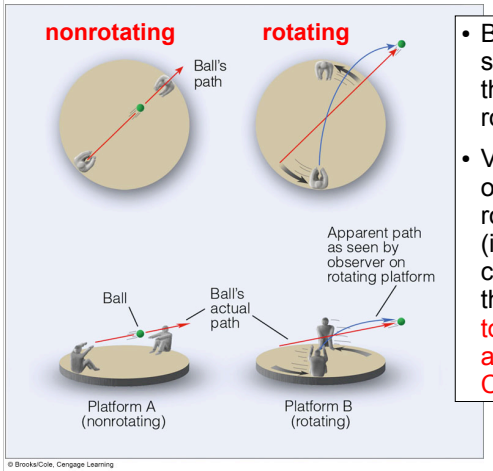
Forces controlling the wind

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

- Coriolis and Centrifugal are "*apparent*" forces, i.e. they only *apparently* exist because of our specific choice of a rotating coordinate system (attached to the surface of our rotating planet)
- If the sum of all forces acting is zero, we speak of a force balance – no acceleration (BUT: steady motion is still possible)

Thomas Birner, ATS, CSU

Coriolis Force



- Ball is going in a straight line for both the nonrotating and rotating case!
- Viewed from the observer on the rotating platform (inside the rotating coordinate system) the ball is deflected to the right by an apparent force – the Coriolis force

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Coriolis Force

- Magnitude
  - Depends on the latitude and the speed of movement of the air parcel
    - The higher the latitude, the stronger the Coriolis force (zero at the equator, maximum at the poles)
    - The faster the speed, the stronger 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

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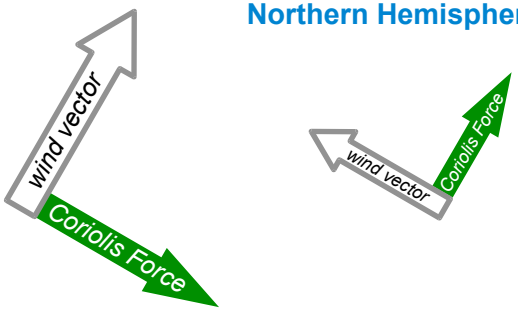
Northern Hemisphere (NH)



- Magnitude
  - The faster the speed, the stronger the Coriolis force
- Direction
  - The Coriolis force *always* acts at right angles to the direction of movement
    - To the right in the northern hemisphere

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Southern Hemisphere (SH)

- Magnitude
  - The faster the speed, the stronger the Coriolis force
- Direction
  - The Coriolis force *always* acts at right angles to the direction of movement
    - To the left in the southern hemisphere

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Coriolis Deflections

- 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

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Gaspard-Gustave Coriolis (1792–1843)

- French mathematician, mechanical engineer
- Coined term "work" (= force acting through a distance)
- One of the first to formulate correct expression for kinetic energy (½mv^2)

- His work on (apparent) forces in rotating systems did not address any atmospheric science problems
- Contemporary scientists working on atmospheric problems were not aware of his work on rotating systems

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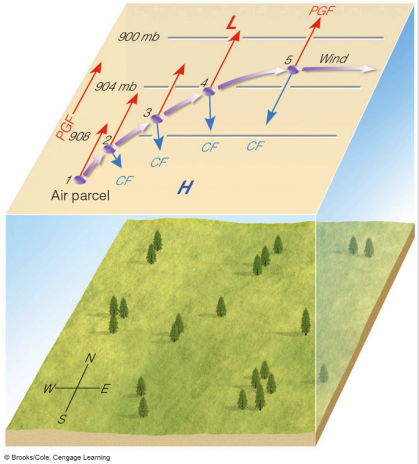
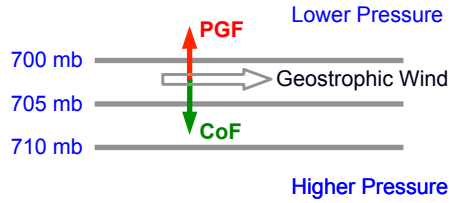
Coriolis Force & Geostrophic Wind

- Coriolis force acts to the right in the northern hemisphere and is stronger for higher wind speed
- Pressure gradient points from high to low pressure
- When Coriolis and pressure gradient force balance → no net force and wind is on a straight line with constant speed



Geostrophic Wind

- Geostrophic Wind = Flow in which the pressure gradient force balances the Coriolis force → flow along lines of constant pressure (isobars)
- often a good approximation at upper levels (e.g. 500 mb)



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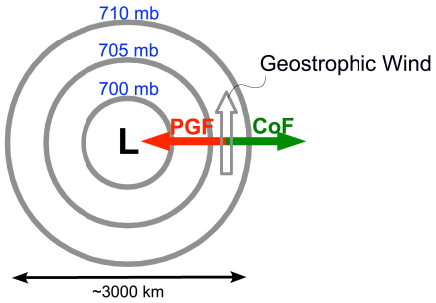

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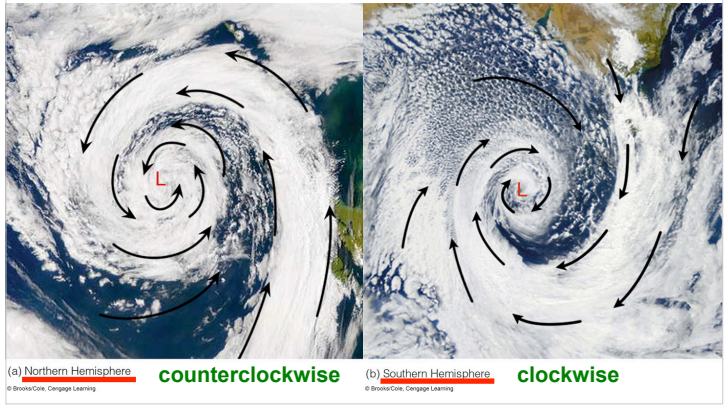
Remark about Hemispheric Difference

Coriolis acts to the right in the Northern Hemisphere → counterclockwise flow around lows; in the Southern Hemisphere Coriolis acts to the left → clockwise flow around lows. Vice versa for highs.



Coriolis Force – Angular Momentum Perspective

- Angular Momentum ~ Rotational Momentum
  - is conserved (does not change), unless rotational forces (torques) are acting (e.g. friction, or your legs pushing the pedals of your bike)
  - for the same angular momentum, the closer to the axis of rotation the faster you rotate – this is why a figure skater pulling her arms in will spin up
- On the rotating Earth, moving closer to the poles means moving closer to the axis of rotation – as with the figure skater this results in spin up → deflection to the right in the NH, deflection to the left in the SH
- Likewise, moving eastward (in the direction of rotation) equals a spin up on the rotating planet – this has to be compensated by moving farther away from the axis of rotation → deflection to the right/left in the NH/SH

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Coriolis Force – Angular Momentum Perspective

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  - for the same angular momentum, the closer to the axis of rotation the faster you rotate – this is why a figure skater pulling her arms in will spin up
- Moving farther away from the poles means moving farther away from the axis of rotation – as with the figure skater this results in slow down → deflection to the right in the NH, deflection to the left in the SH
- Likewise, moving westward (against the direction of rotation) equals a slow down on the rotating planet – this has to be compensated by moving closer to the axis of rotation → deflection to the right/left in the NH/SH

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