SESSION 2: ATMOSPHERIC FORCES AND WIND

FIRST, WHAT IS WIND?

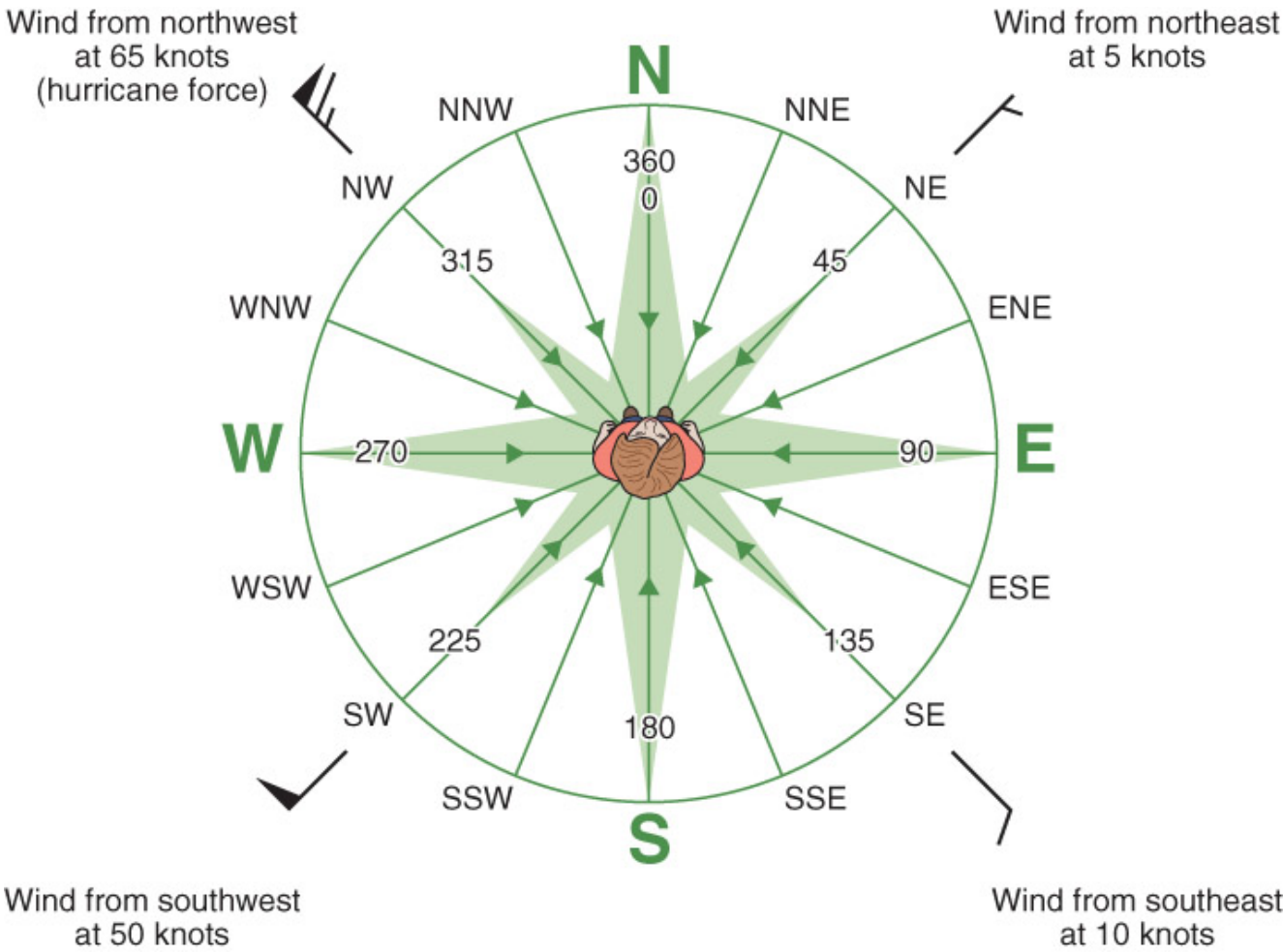
- Wind is simply air in motion

- Wind is a vector: it has a magnitude and a direction
  - For example, you are driving *south* down Main St at *45 mph*

- Wind speed is measured in different ways…
  - Miles per hour (mph)
  - Nautical miles per hour (knots)
  - Meters per second (m/s)

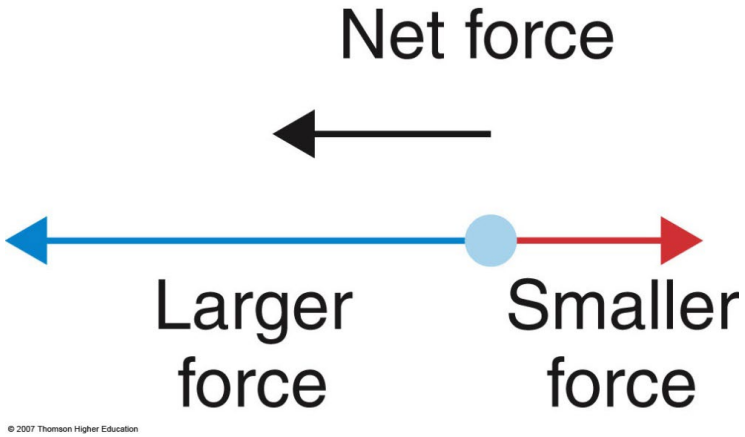
FIRST, WHAT IS WIND?

- Wind direction is described by where the wind is coming from.



How does air move?

- In order for anything to accelerate (move), a force has to be applied. Air molecules are no different.
- Force = Mass x Acceleration
- Acceleration = Force / Mass
- The movement / acceleration of air (wind) is caused by an imbalance of forces.



WIND COORDINATE SYSTEMS

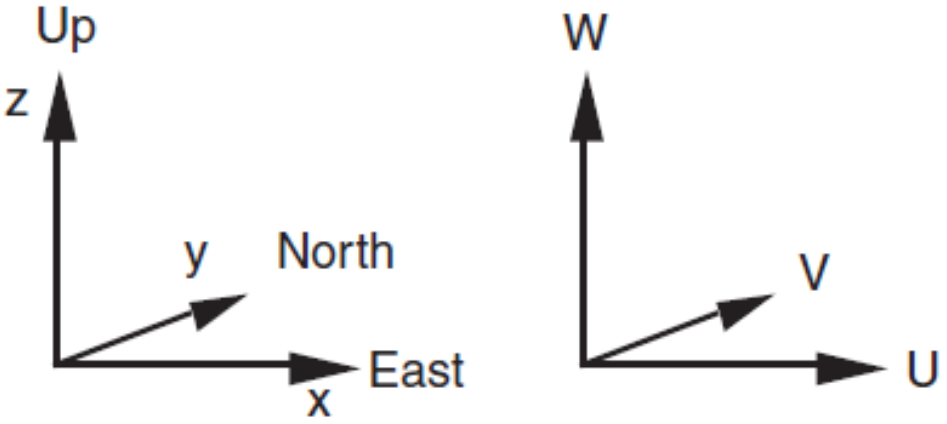
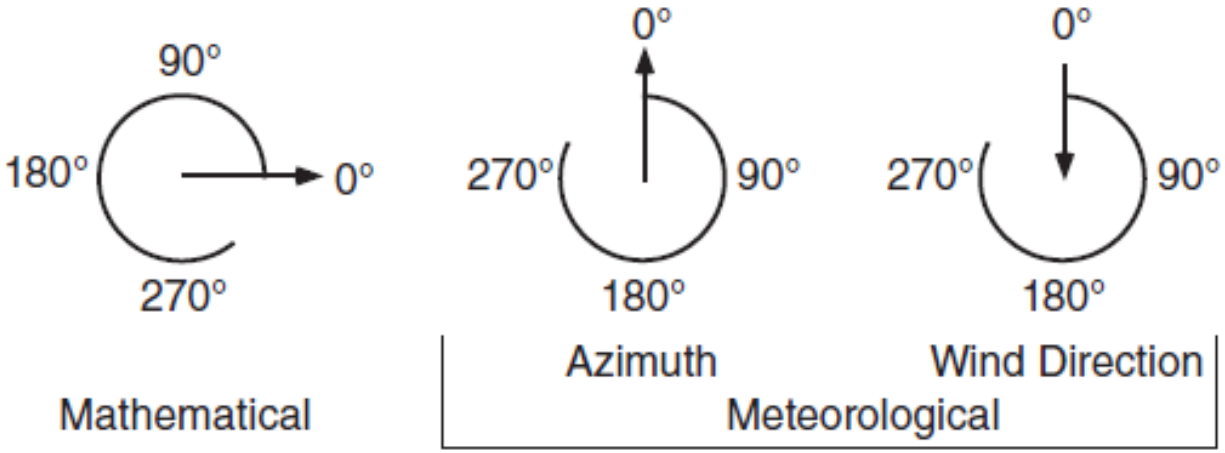


Figure 1.1
Local Cartesian coordinates and velocity components.



WHAT FORCES ARE INVOLVED?

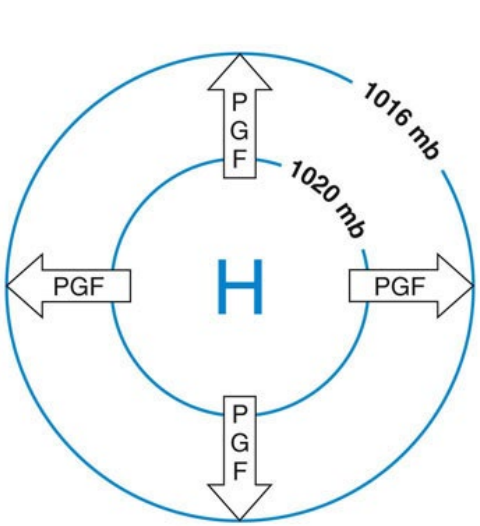
- Forces are responsible for both the magnitude and direction of the wind. We will discuss
  - Pressure Gradient Force
  - Gravity
  - Coriolis Force (due to Earth's rotation)
  - Centrifugal Force
  - Friction

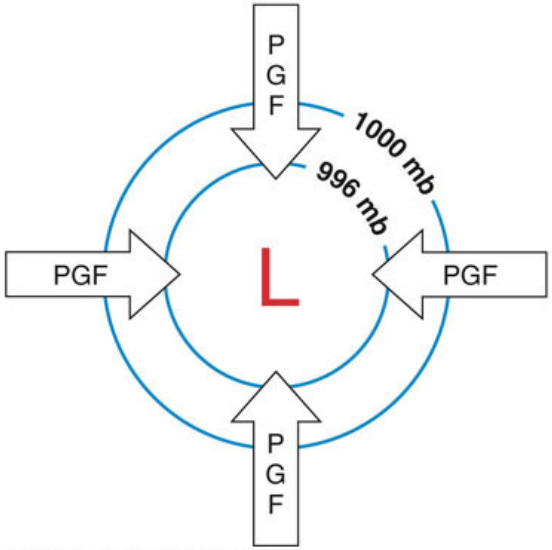
GRAVITY

- Attraction of two objects to each other
- Inversely proportional to the distance between the two objects.
- For us, gravity works downwards towards Earth's surface at 9.8 m/s^2.
- Gravitational Force is balance by another force…

PRESSURE GRADIENT FORCE (PGF)

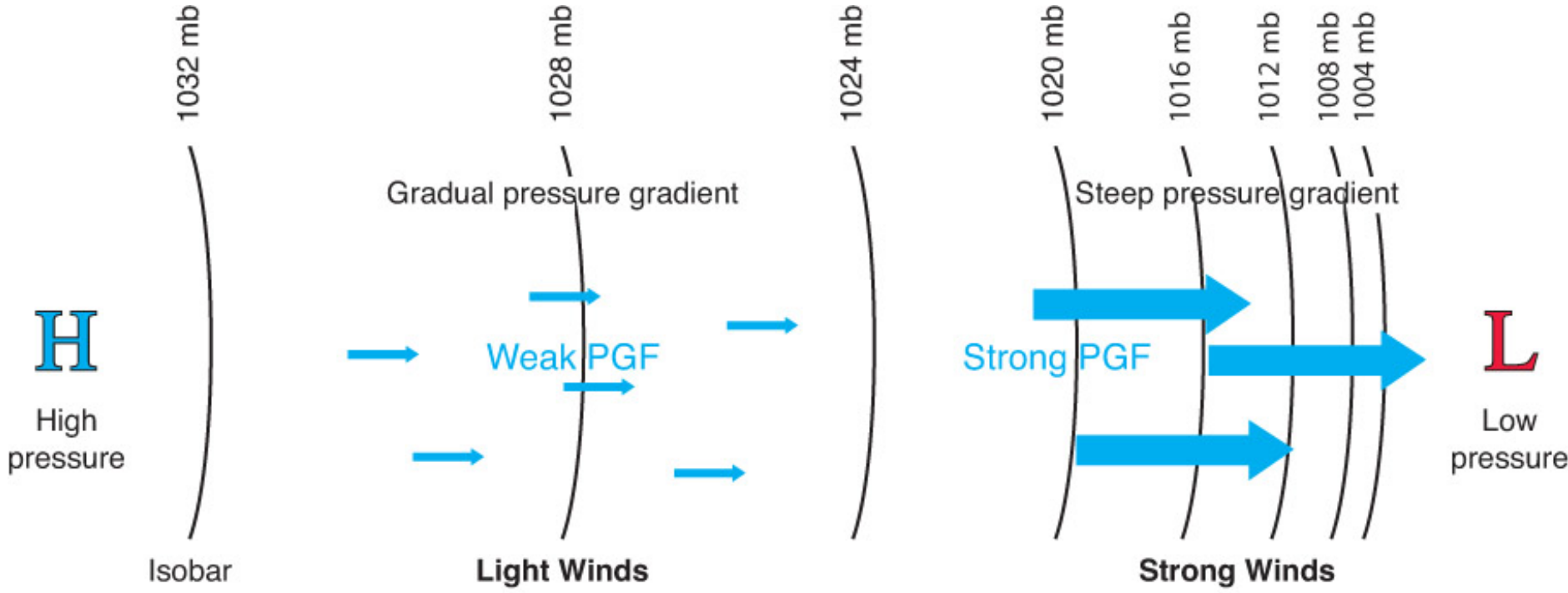
- The force due to a change in pressure over some distance.
- Always directed from higher pressure to lower pressure:





- The greater the pressure difference over some distance, the greater the force. The greater the force, the faster the wind blows.

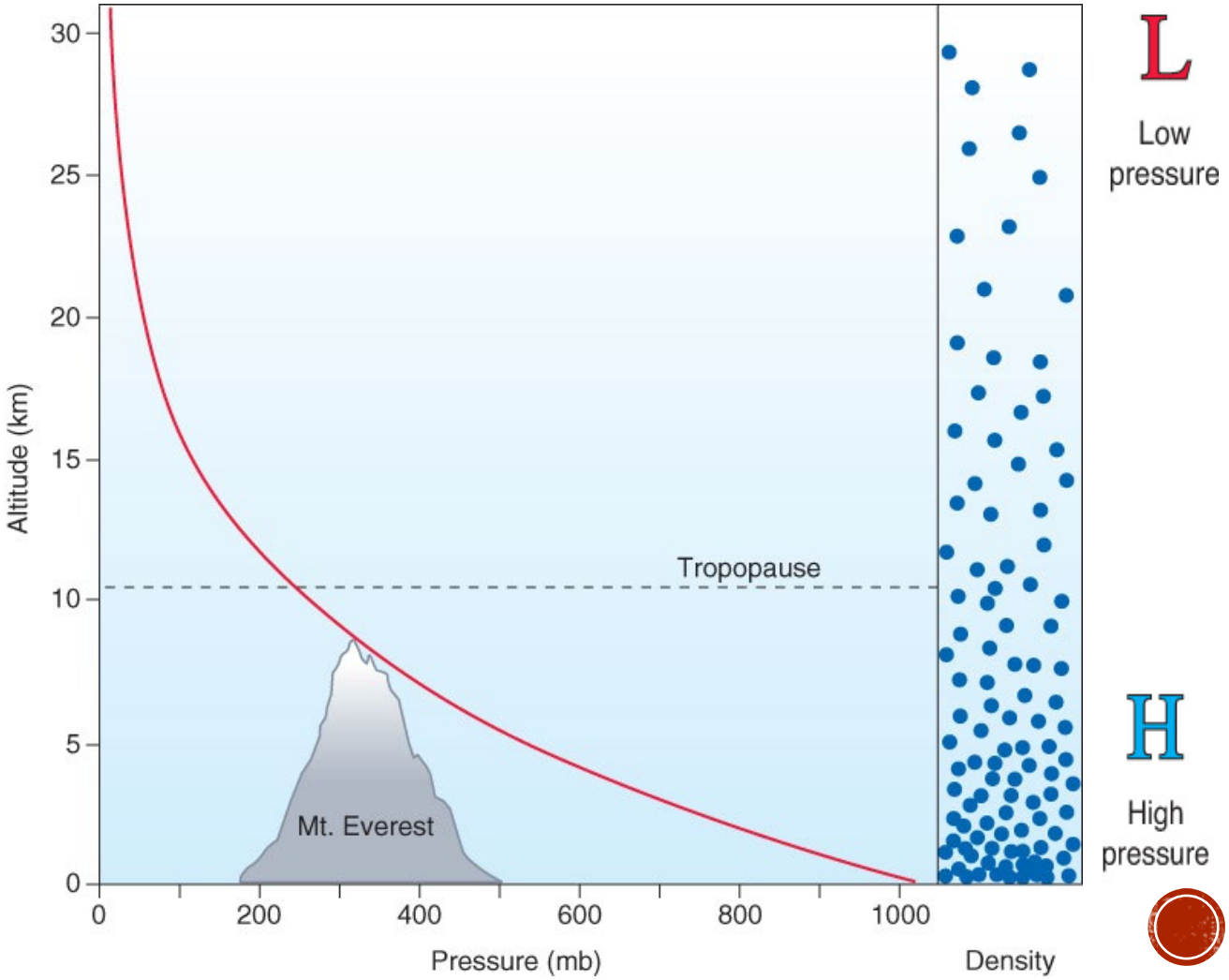
PRESSURE GRADIENT FORCE (PGF)



- This force can act <u>horizontally</u> (HPGF) or <u>vertically</u> (VPGF)

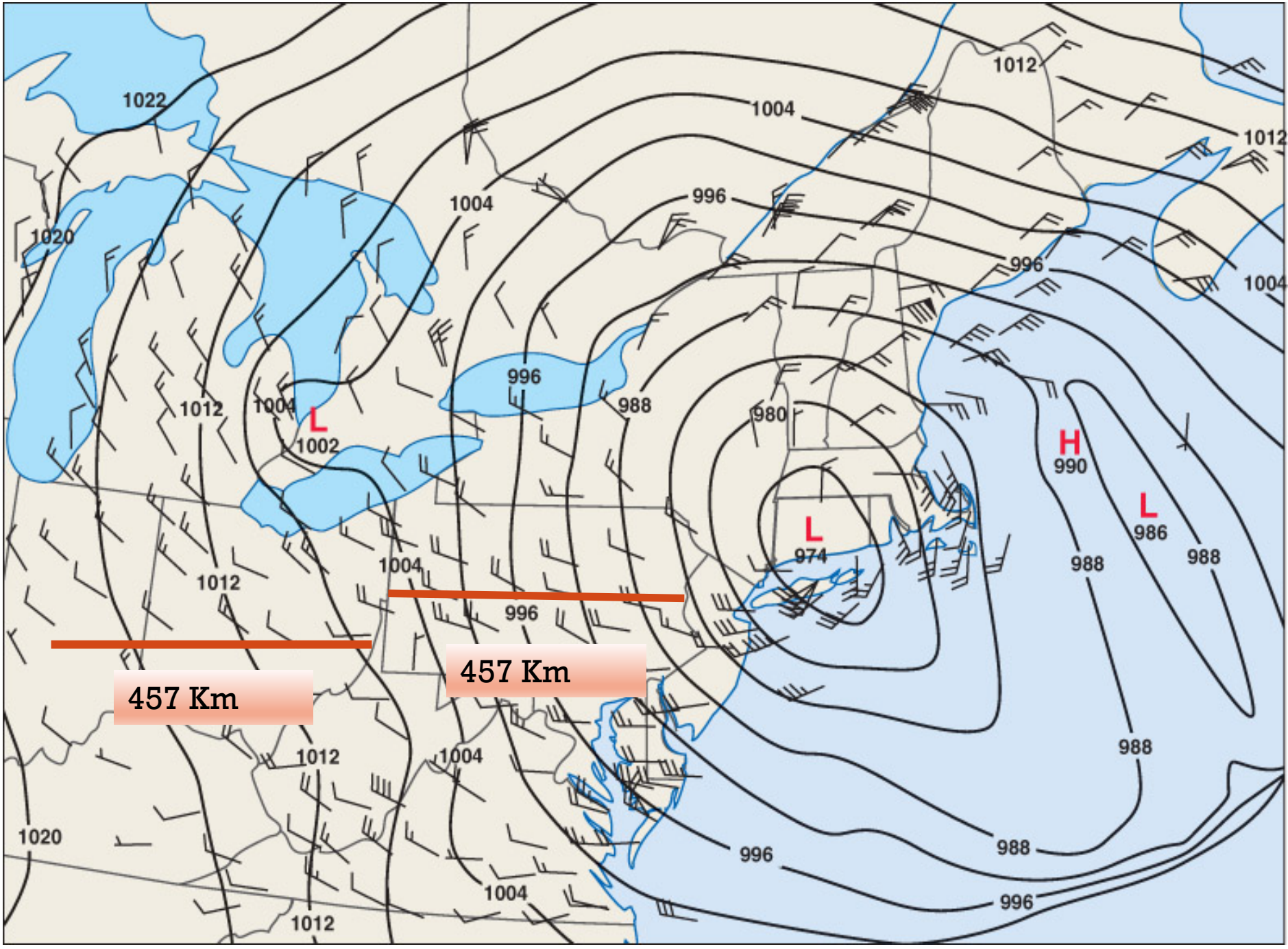
VERTICAL PGF

- How is the vertical pressure gradient oriented?
- What should this pressure gradient do?



HORIZONTAL PGF

- This force is mostly responsible for the wind.
- Remember, this force is based on differences in pressure.
- We display these difference in pressure with isobars – or lines constant pressure.
- The closer the isobars → the greater the pressure difference → the stronger the wind.


1022
1020
1012
1004
996
988
980
1002
974
990
986
457 Km
457 Km

WHAT FORCES ARE INVOLVED?

- These forces are responsible for both the magnitude and direction of the wind. We will discuss:
  - ~~Pressure Gradient Force~~
  - ~~Gravity~~
  - Coriolis Force (due to Earth's rotation)
  - Centrifugal Force
  - Friction

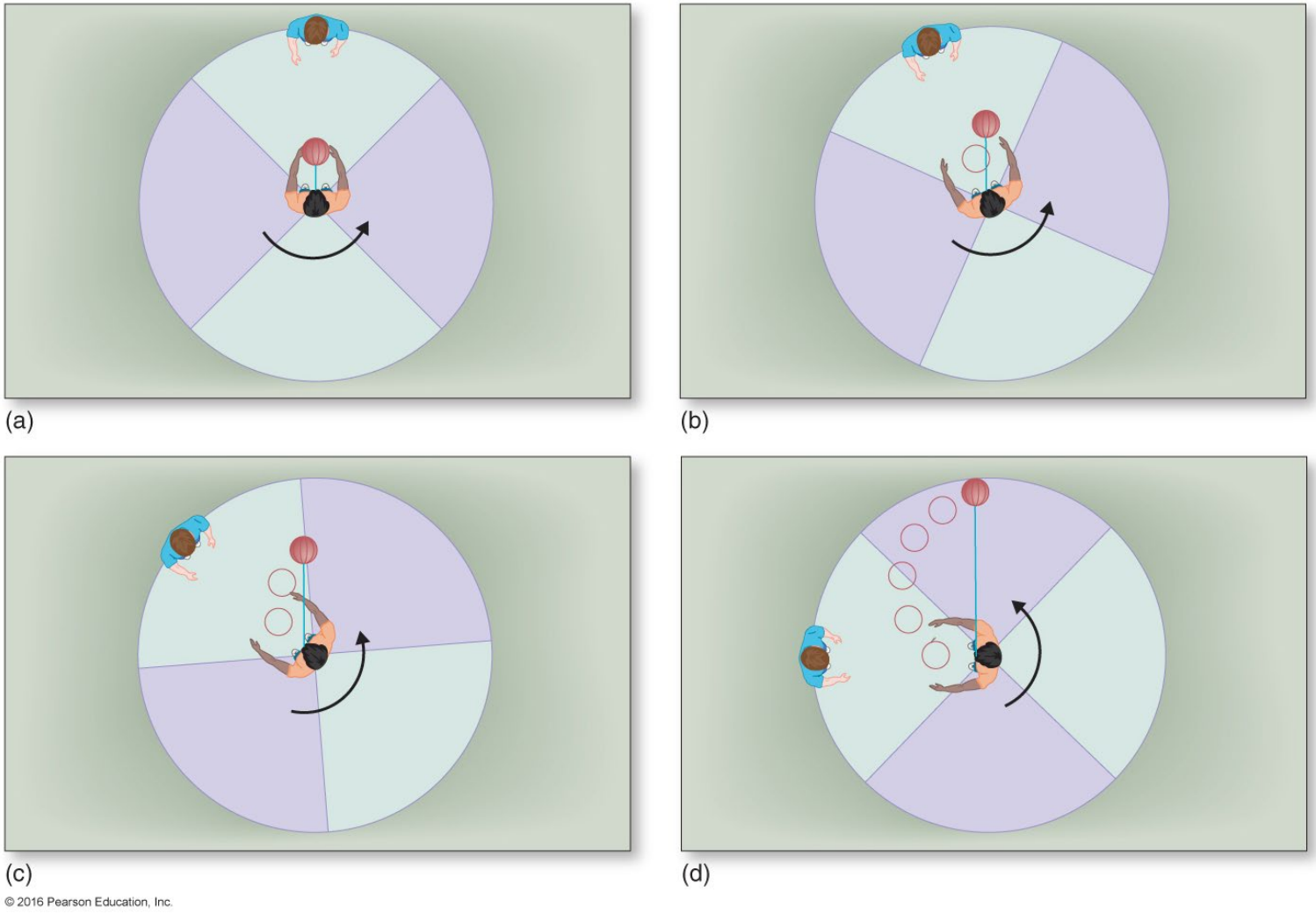
CORIOLIS FORCE: APPARENT FORCE

- The apparent turning, or deflection, of the wind due to Earth's rotation.

- Called an "apparent" because it depends on your frame of reference. We are standing on a rotating earth observing wind that above the rotating earth.

- Called a force because it causes an acceleration: a change in the wind direction.

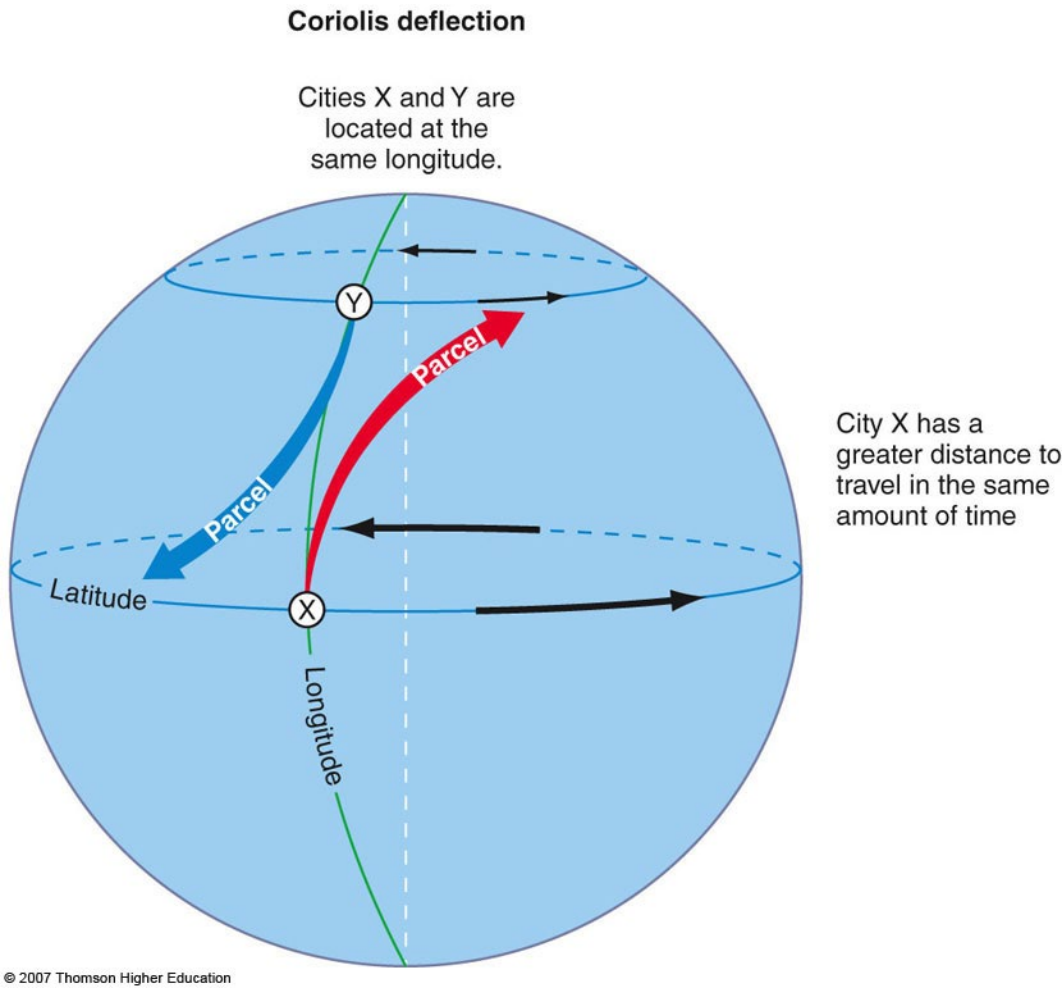
FRAME OF REFERENCE EXAMPLE



CORIOLIS FORCE

- Objects appear to be deflected to the <u>right</u> (following the motion) in the Northern Hemisphere

- Opposite in the Southern Hemisphere



CORIOLIS FORCE

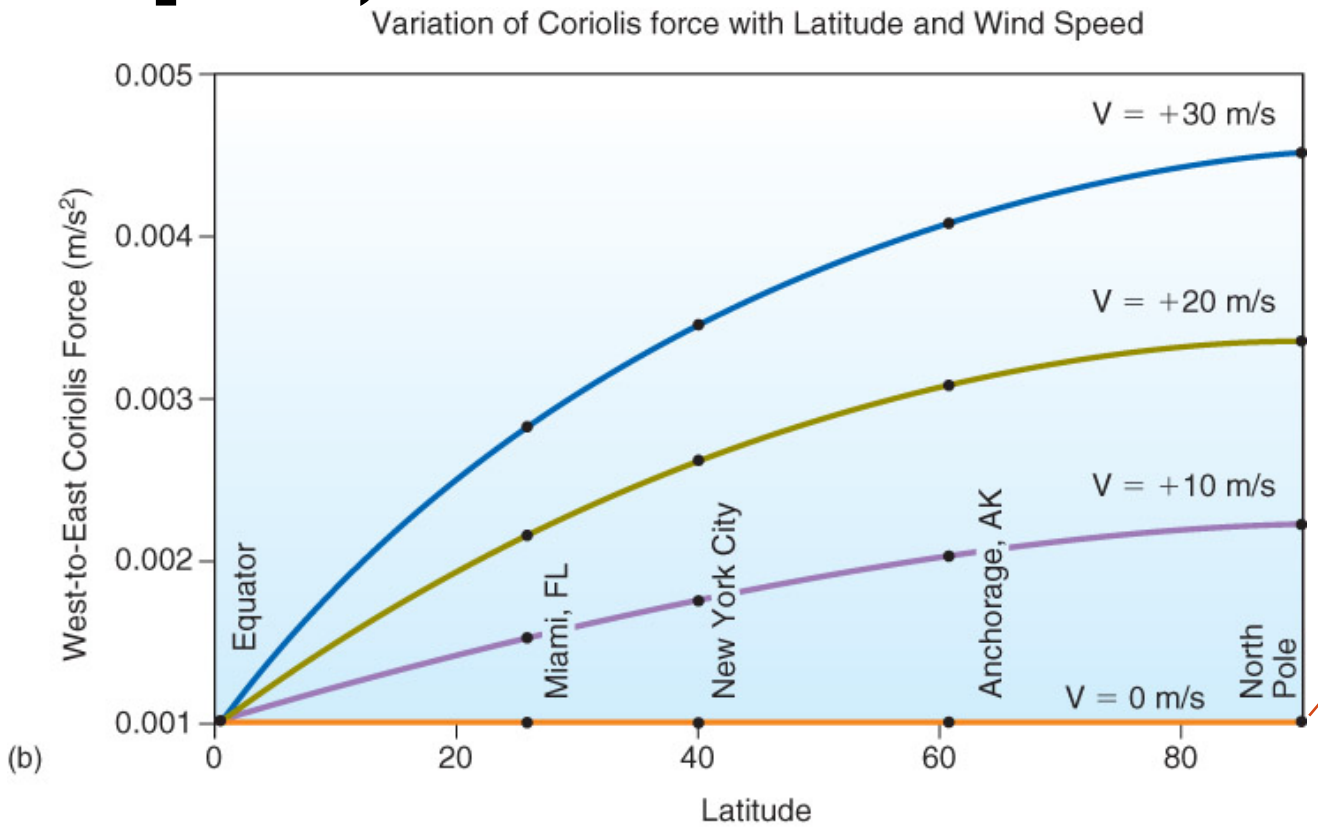
- Acts at a right angle to the wind
- In the Northern Hemisphere, air is deflected to the right of the direction of motion.
- Only changes the direction of moving air, not the wind speed
- Depends on 2 things :
  - Latitude
  - Wind speed

Coriolis Force and Latitude:

This force is greater at higher latitude. Maximum at the poles and 0 at the equator.

CORIOLIS FORCE AND WIND SPEED :

- The faster the wind speed, the greater the effect of this force. In other words, the faster the wind speed, the more the wind turns to the right (northern hemisphere)



If there is no wind, there is no Coriolis!

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  - Friction

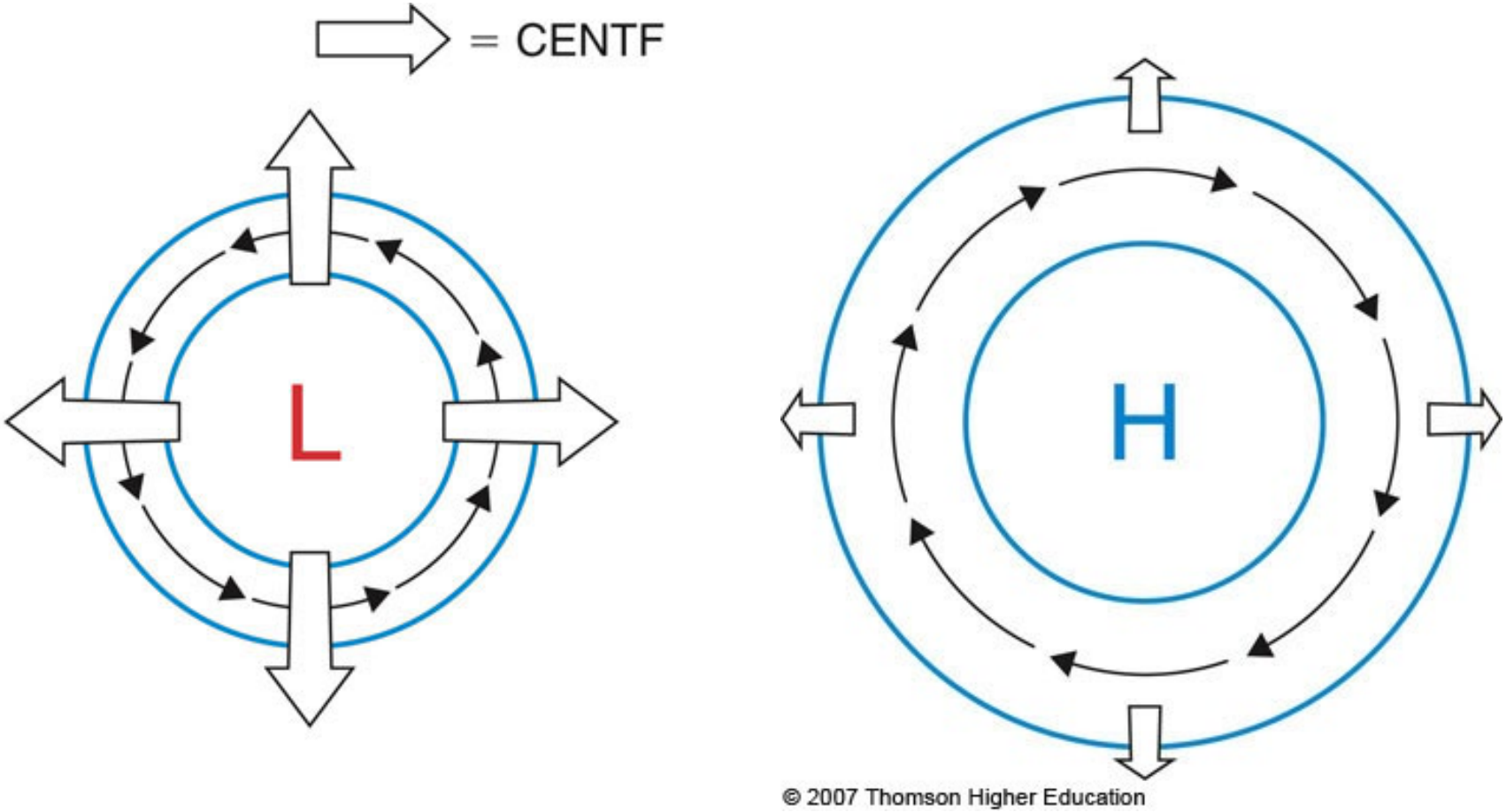
CENTRIFUGAL FORCE

- Similar to Coriolis, in that it is an apparent force.

- Considering going around a sharp turn in a car. Your body wants to keep going forward, but it is forced to turn by the car. Which way do you lean in your seat?

- Centrifugal force acts in the direction away from the center of the curve

CENTRIFUGAL FORCE



CENTRIFUGAL FORCE

- Like Coriolis, centrifugal force is greater for faster wind speeds
  - Again, think about going around a sharp curve really fast vs. going around a sharp curve very slow.
- Centrifugal force is also greater for "shaper" curves. Put another way, the smaller the radius of the curve, the greater the centrifugal force
- If there is no curvature (or wind speed), no centrifugal force!

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FRICTION

- This force causes a slowing, or deceleration, of the wind near the surface of the Earth .

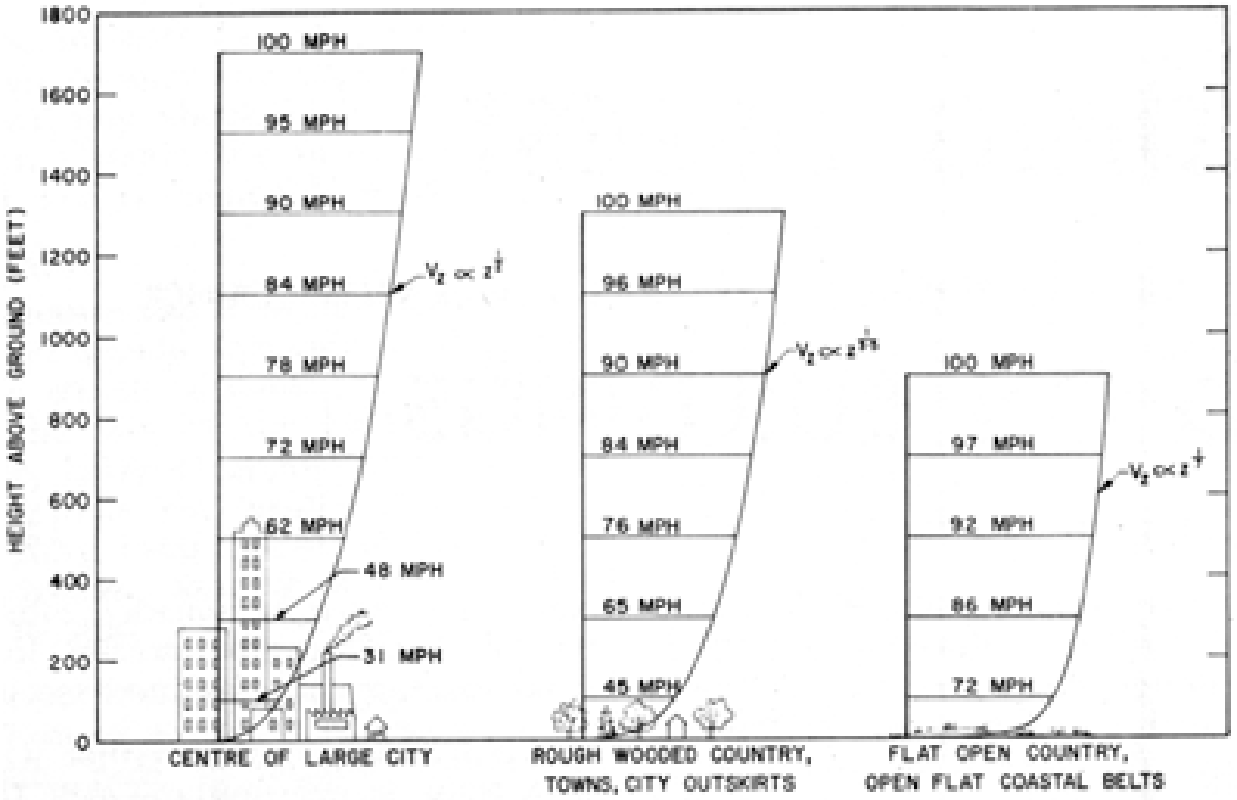
- This force is based on wind speed and the roughness of the underlying surface.

  - Magnitude of the deceleration increases with increasing wind speed

  - Frictional force going to be stronger over a forest of tall trees than over a large, smooth body of water .

FRICTION

- Quantified via:
  - Drag Coefficient
  - Roughness length



SURFACE DRAG AND ROUGHNESS

- Drag – The frictional force between two objects (e.g. the air and the ground).
- One way we quantify that is through the aerodynamic roughness length, z_o.
- Roughness varies based on surface type.

Table 18-1. The Davenport-Wieringa roughness-length z_o (m) classification, with approximate drag coefficients C_D (dimensionless).

z_o (m)	Classification	C_D	Landscape
0.0002	sea	0.0014	sea, paved areas, snow-covered flat plain, tide flat, smooth desert
0.005	smooth	0.0028	beaches, pack ice, morass, snow-covered fields
0.03	open	0.0047	grass prairie or farm fields, tundra, airports, heather
0.1	roughly open	0.0075	cultivated area with low crops & occasional obstacles (single bushes)
0.25	rough	0.012	high crops, crops of varied height, scattered obstacles such as trees or hedgerows, vineyards
0.5	very rough	0.018	mixed farm fields and forest clumps, orchards, scattered buildings
1.0	closed	0.030	regular coverage with large-sized obstacles with open spaces roughly equal to obstacle heights, suburban houses, villages, mature forests
≥ 2	chaotic	≥0.062	centers of large towns and cities, irregular forests with scattered clearings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