NATS 101
Section 13: Lecture 15

Why does the wind blow?
Part I

Newton's First Law of Motion

Sir Isaac Newton

An object at rest will remain at rest and an object in motion will remain at a constant velocity if the net force exerted on it is zero.

Constant velocity =

____

An external force is required to change either the direction or speed of an object (or air in the case of the atmosphere)

Newton's Second Law of Motion

Sir Isaac Newton

The net force exerted on an object is equal to it's mass times acceleration, or change in velocity over time.

FORCE = MASS X ACCELERATION

$$F = ma$$

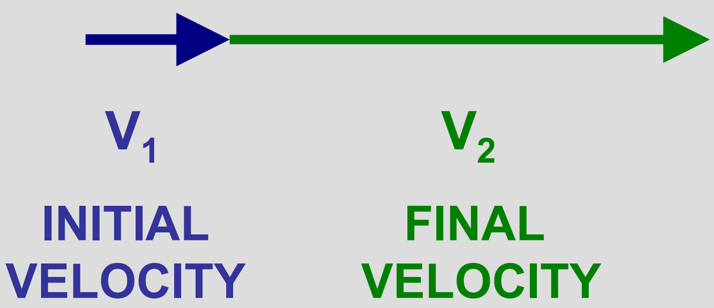
SI Units: Newton (kg m s^{-2})

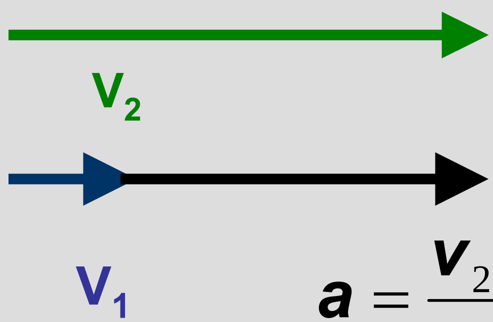
Velocity is a vector property of the object's speed AND its direction, so to change it and cause acceleration either:

1. **Change the speed of the object**
2. **Change the direction of the object.**

Two causes of acceleration

Change in speed (magnitude) over time (*t*).

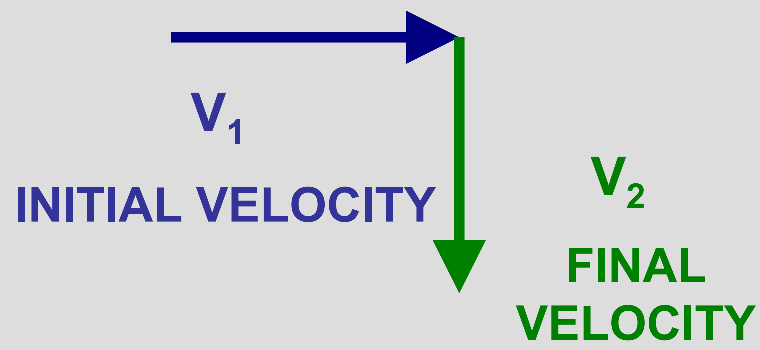


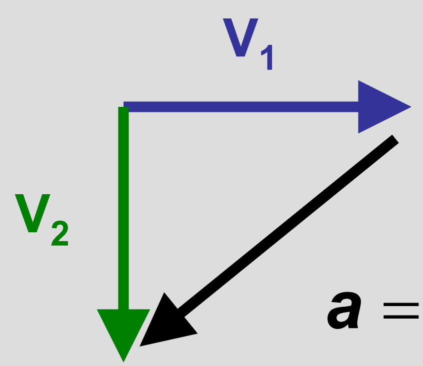


$$a = \frac{\mathbf{v}_2 - \mathbf{v}_1}{t}$$

ACCELERATION

Change in direction over time (*t*) with no change in speed

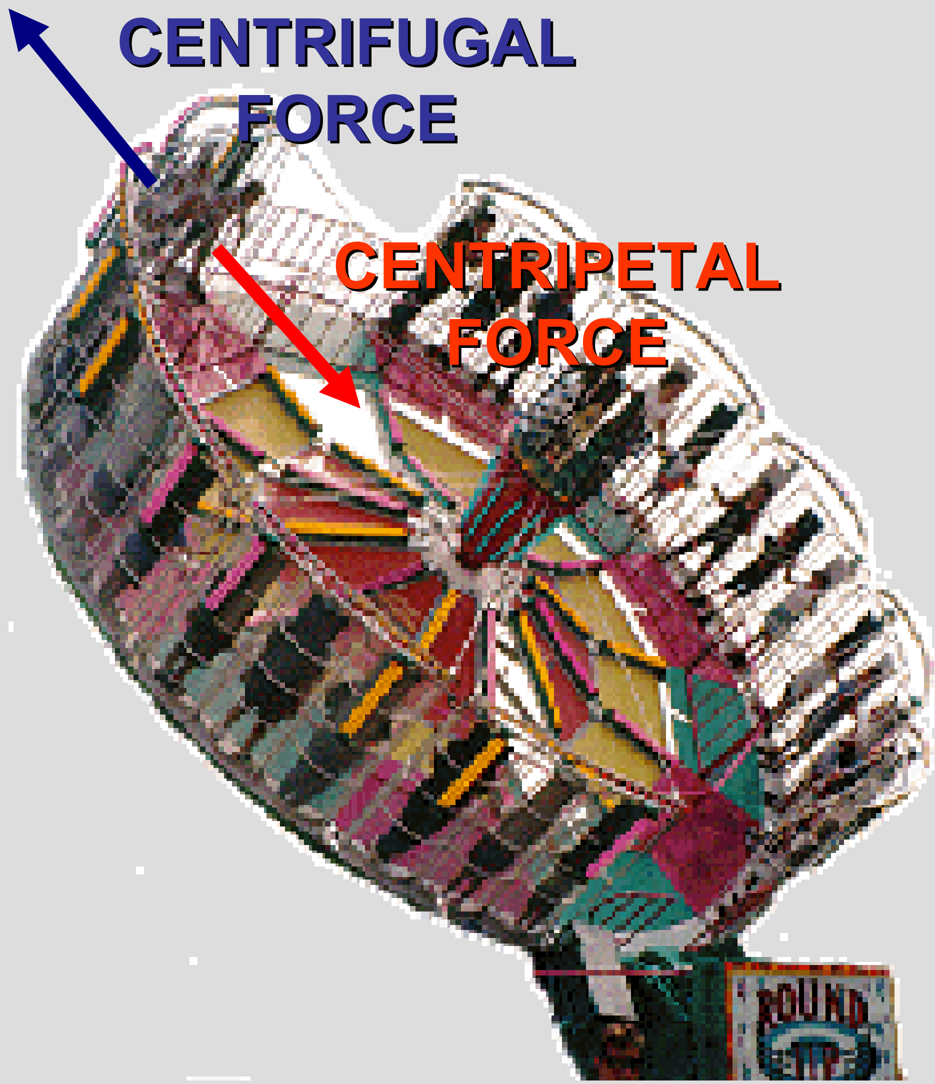




$$a = \frac{\mathbf{v}_2 - \mathbf{v}_1}{t}$$

ACCELERATION

Centripetal Force



You experience acceleration without a change in speed, for example, on a tilt-a-whirl carnival ride.

The force is directed toward the center of the wheel.

An equal an opposite (fictitious) centrifugal force is exerted by the inertia of your body on the wheel—so you stay put and don't fall off even when upside down.

Important when considering curved flows, as well see later…

Simplified equation of horizontal atmospheric motion

$$\textbf{Total Force} = \frac{1}{\rho}\frac{\Delta \boldsymbol{p}}{\boldsymbol{d}} + 2\Omega \boldsymbol{V}\sin\phi + \frac{\boldsymbol{V}^2}{\boldsymbol{r}} + \boldsymbol{F_r}$$

(1) (2) (3) (4)

Term	Force	Cause
1	Pressure gradient force	Spatial differences in pressure
2	Coriolis force	Rotation of the Earth
3	Centripetal force	Curvature of the flow
4	Friction force	Acts against direction of motion due to interaction with surface

Force Balance

What we're looking for in the equation of motion is the condition *where the forces exactly balance—or the sum of the forces is equal to _______.*

When this happens, there is no net ______________and the wind speed is ______________, by Newton's first law.

$$0 = \frac{1}{\rho}\frac{\Delta p}{d} + 2\Omega V \sin\phi + \frac{V^2}{r} + F_r$$

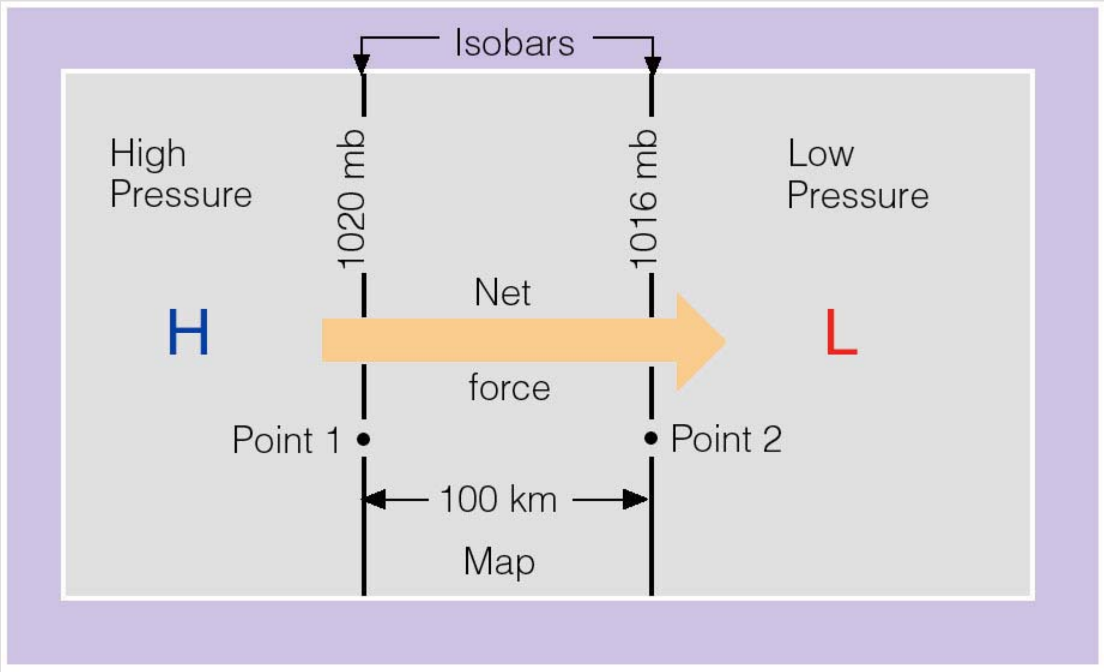
0 = Pressure gradient force + Coriolis force + Centripetal Force + Friction

0 = Pressure gradient force + Coriolis force → Geostrophic Balance

Pressure gradient force

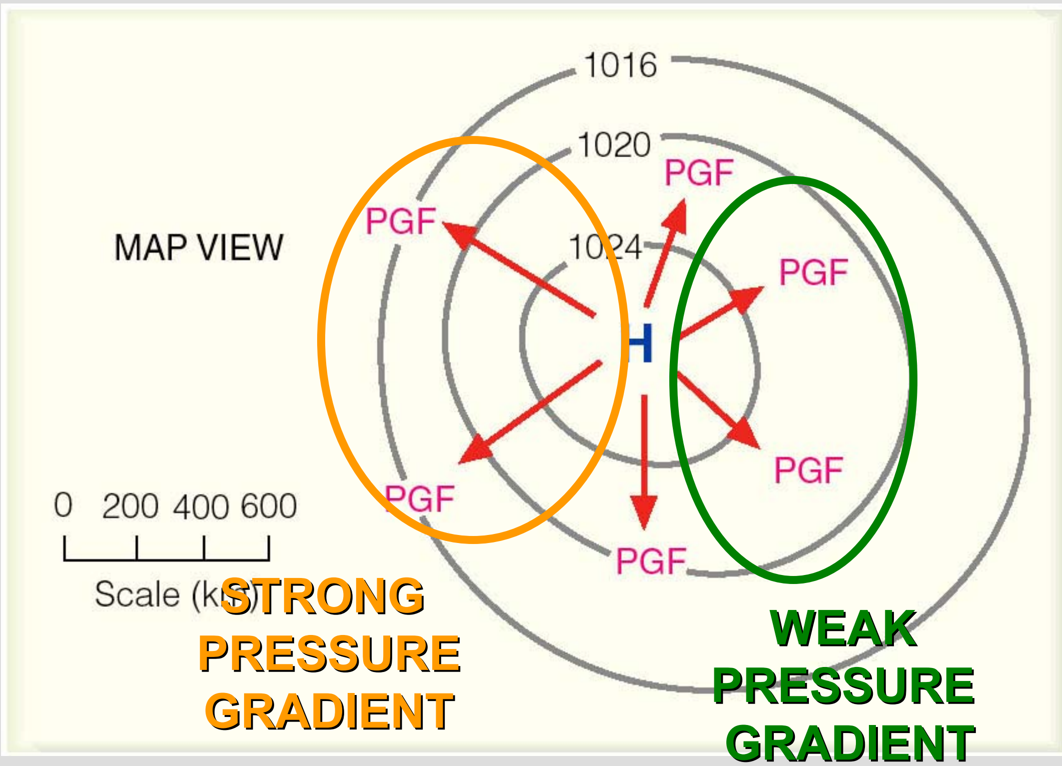
$$\frac{1}{\rho}\frac{\Delta p}{d}$$

Definition: **Force to a the difference in pressure (*Δp*) over a distance (*d*). (In the equation *ρ* is the density of air)**



The pressure gradient force is directed perpendicular to lines of constant pressure (isobars).

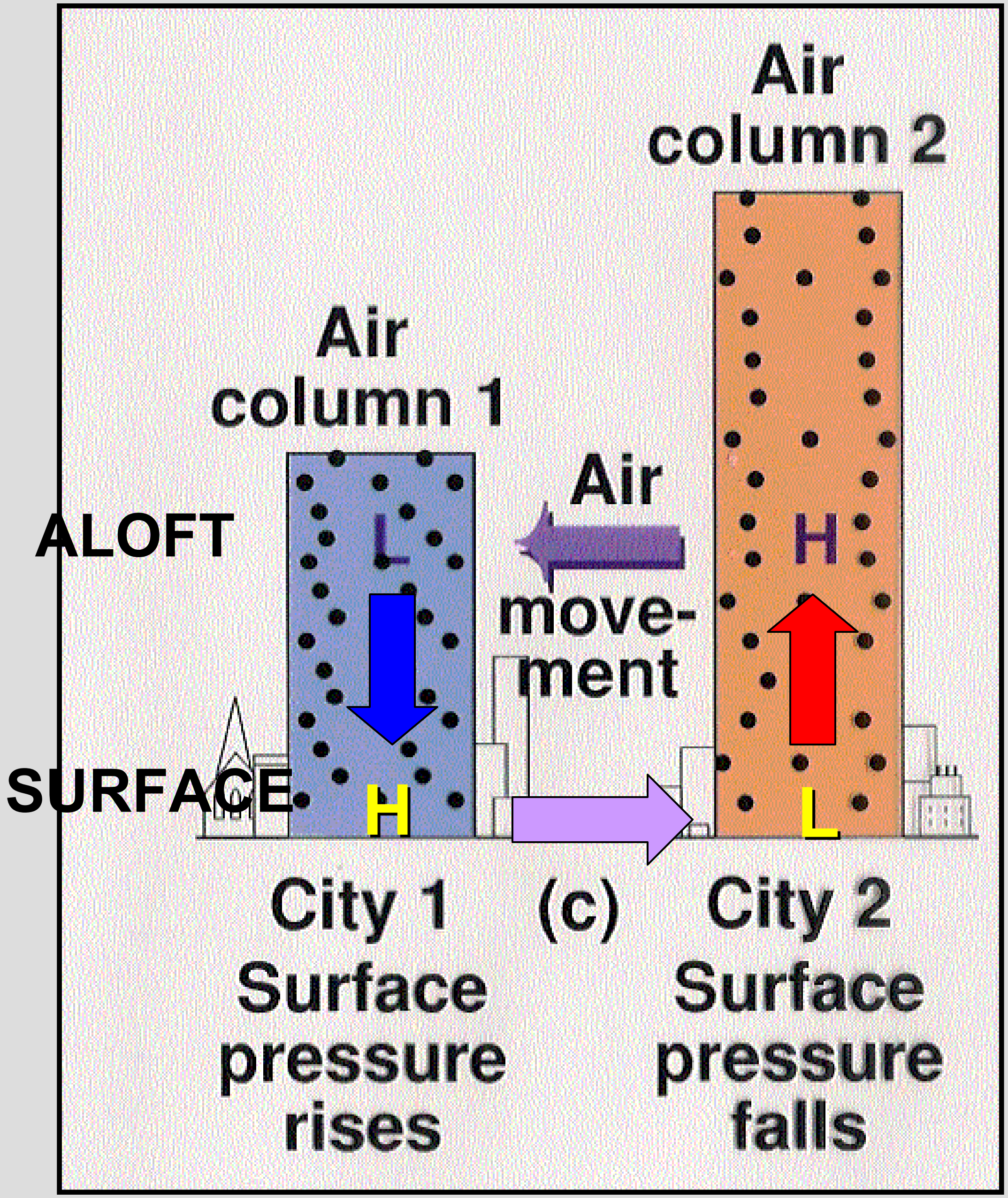
Strength of the pressure gradient force



How strong the pressure gradient force is depends on the distance between the areas of high and low pressure, or how close the lines of constant pressure are.

Strong pressure gradient: Isobars close together

Weak pressure gradient: Isobars far apart.



ALOFT

Cold column → relatively _________air above. LOW PRESSURE.

Warm column → relatively_______ above. HIGH PRESSURE

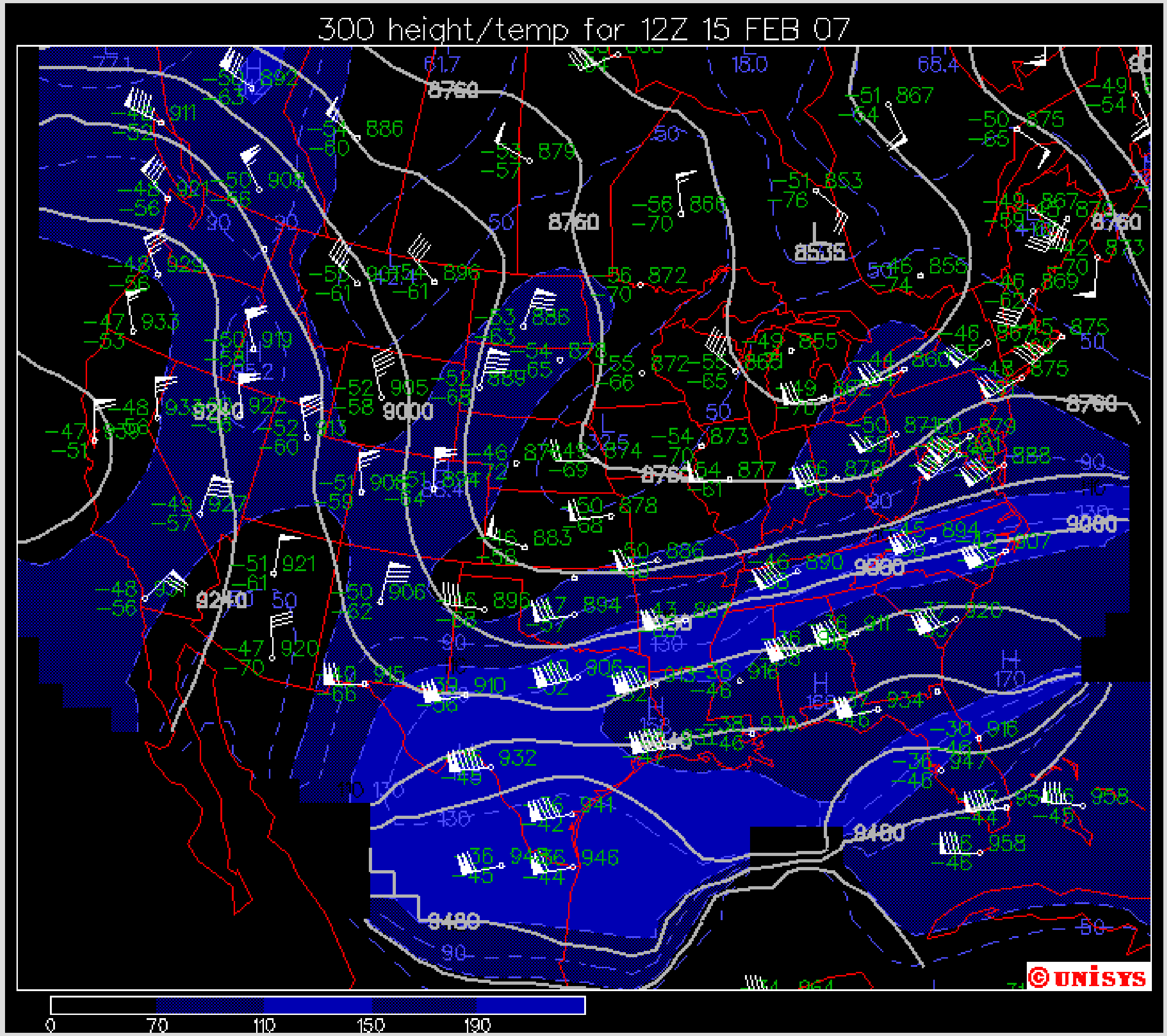
Result:

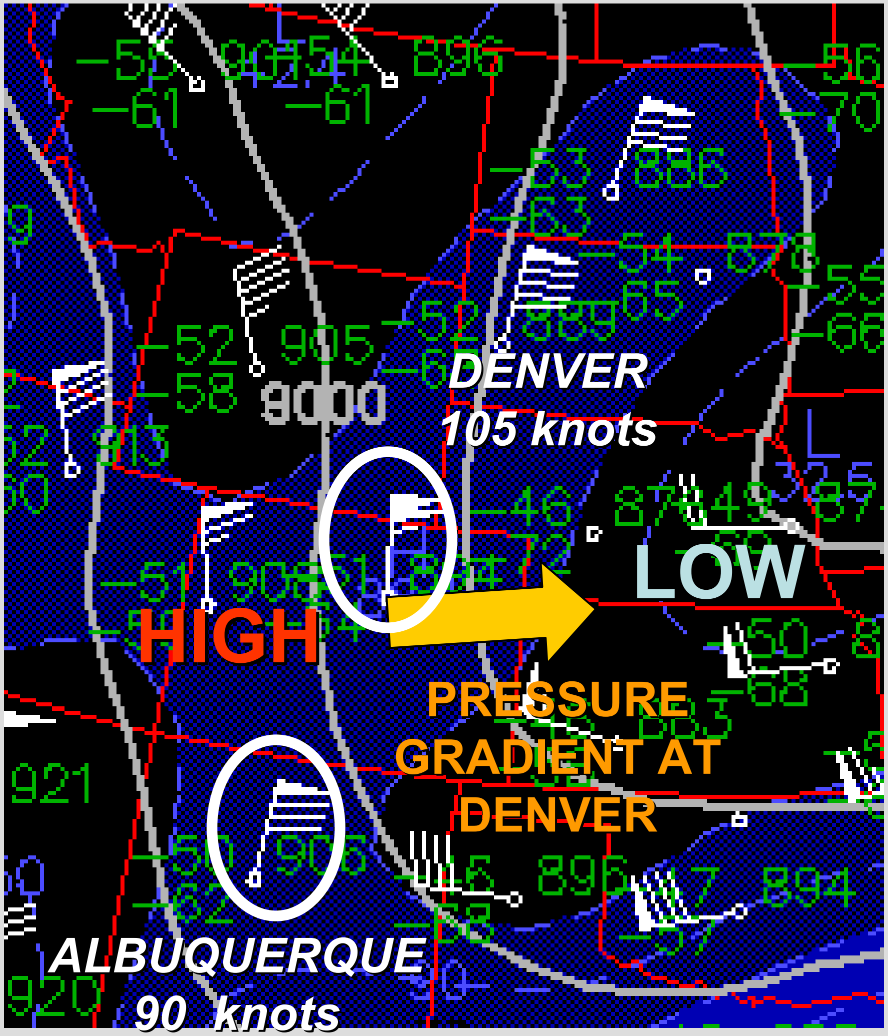
SURFACE

Cold column → ________ mass above. HIGH PRESSURE

Warm column → ________ mass above. LOW PRESSURE.

Upper Level Chart for Surface Arctic High Example (300-mb)





Observations for upper level winds:

Wind DOES NOT follow the pressure gradient.

Wind runs parallel to the lines of constant height (i.e. isobars).

Strength of the wind IS related to the closeness, or *packing*, of the isobars.

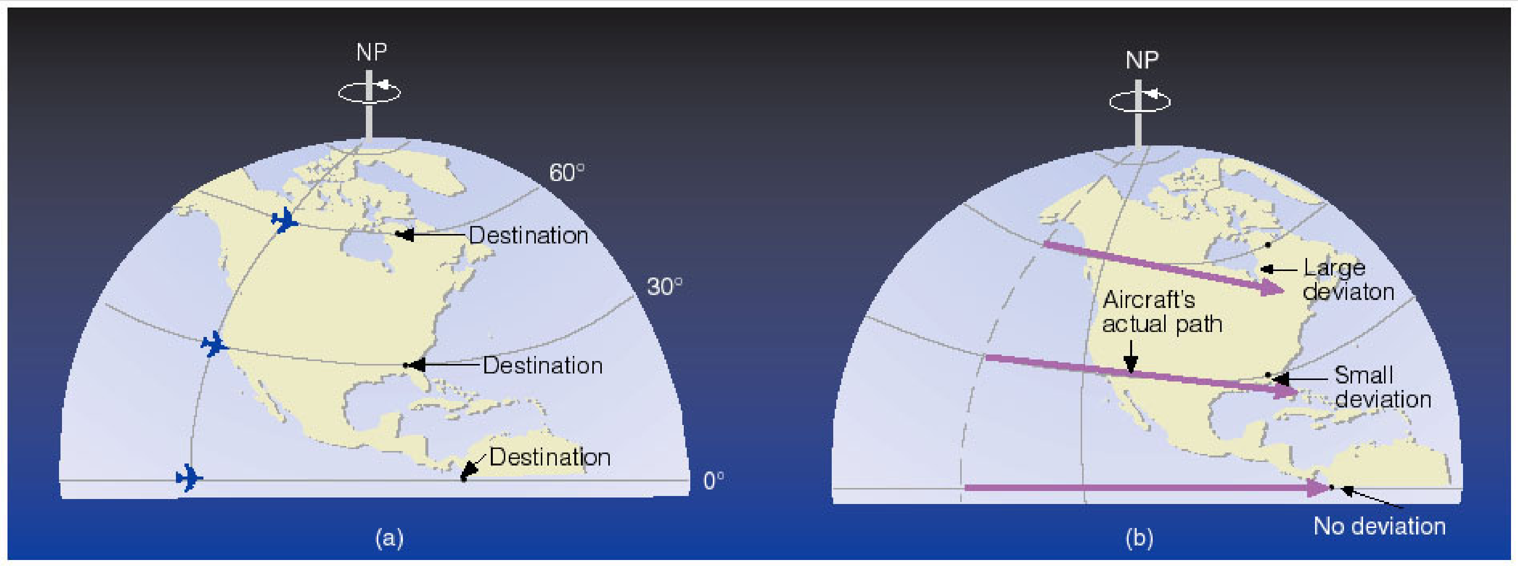
For example, compare the wind speed at Denver (105 knots) to some of the surrounding upper air observations, like Albuquerque.

NEED AT LEAST ONE OF THE OTHER THREE FACTORS TO ACCOUNT FOR WIND MOTION

Coriolis Force $2\Omega V \sin\phi$

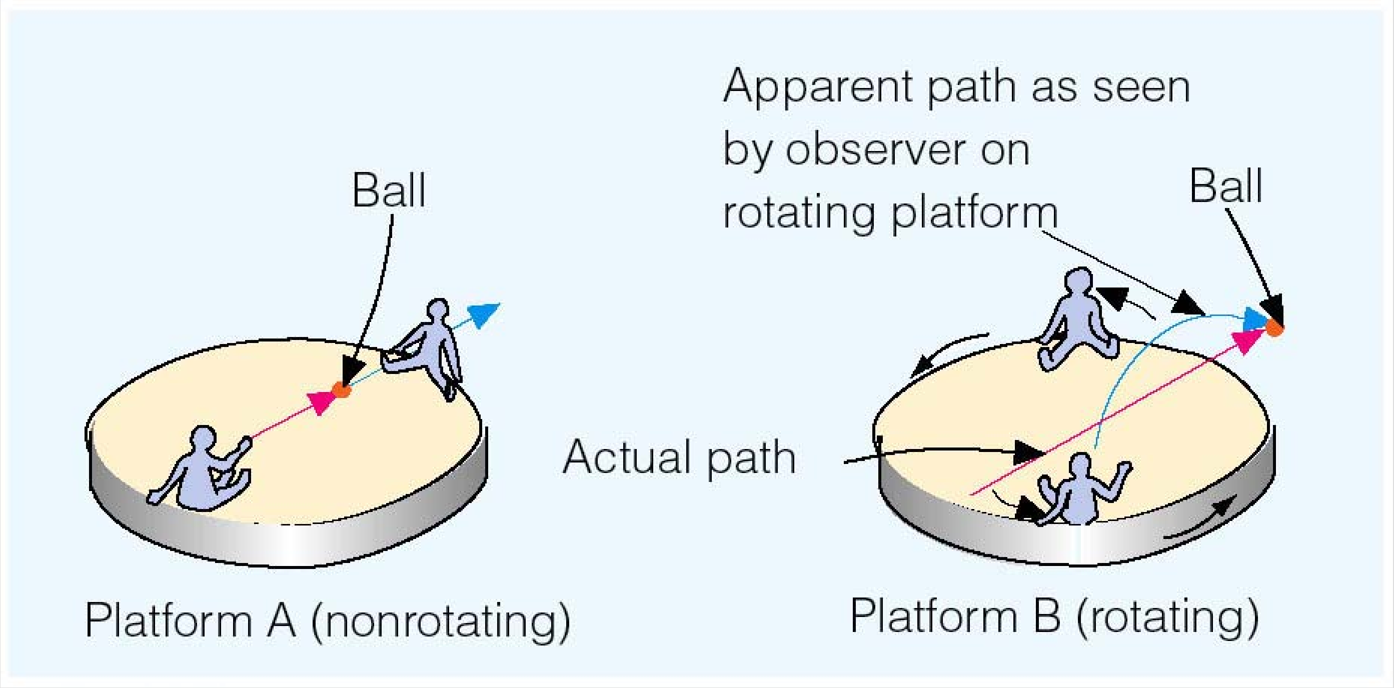
Gaspard Coriolis

Definition: **Apparent force due to rotation of the Earth (Ω). Depends on the speed (V) and the latitude (*Φ*).**



Causes apparent deflection in reference from of an observer at a fixed point on Earth

Coriolis force on a merry-go-round



From perspective of person NOT on merry-go-round, path of ball is straight.

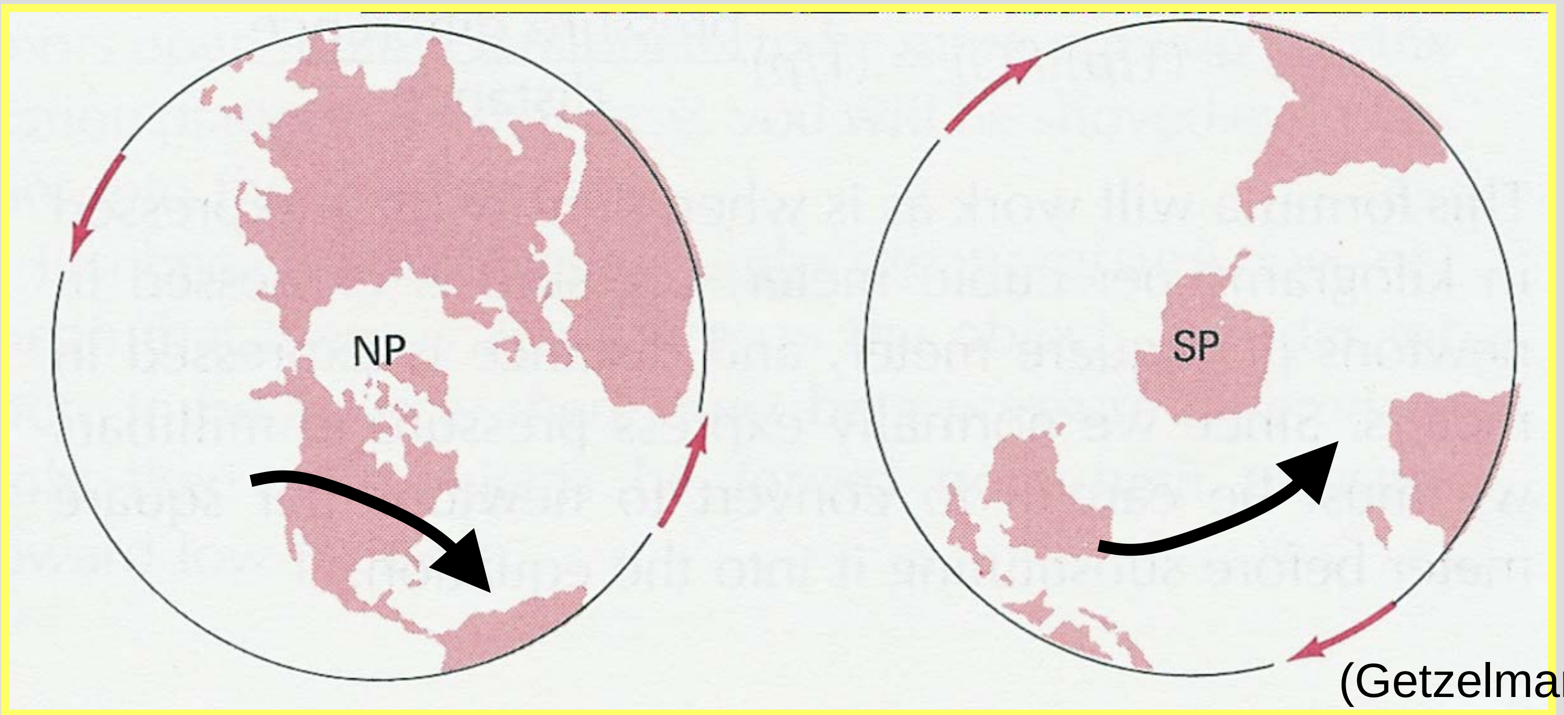
From perspective of person on merry-go-round, path of ball deflects. This is an apparent (or fictitious force).

Merry-go-round example

Rotation of the Earth
(from the polar perspective)

NORTHERN HEMISPHERE

SOUTHERN HEMISPHERE



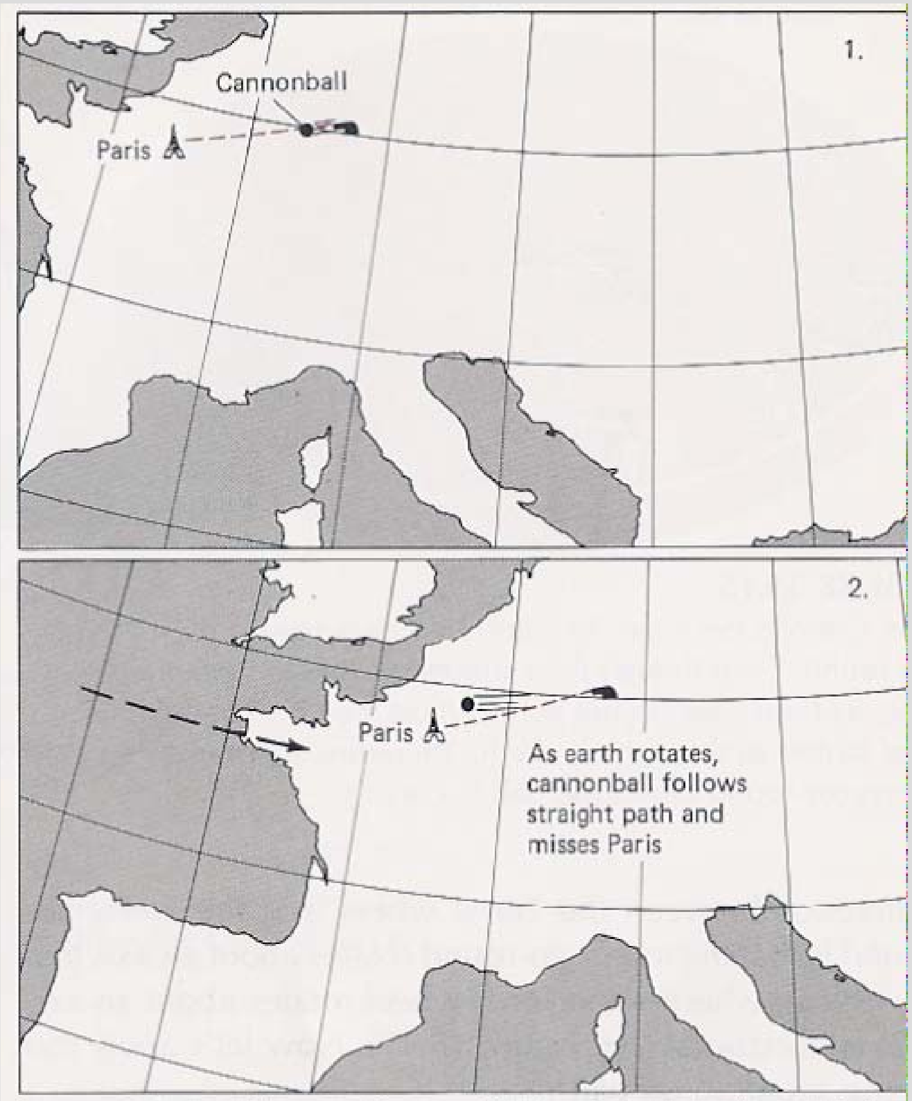
(Getzelman)

COUNTERCLOCKWISE ROTATION
Deflection to the right

CLOCKWISE ROTATION
Deflection to the left

SAME IDEA AS THE MERRY-GO-ROUND!

Coriolis Effect: An Apparent Force

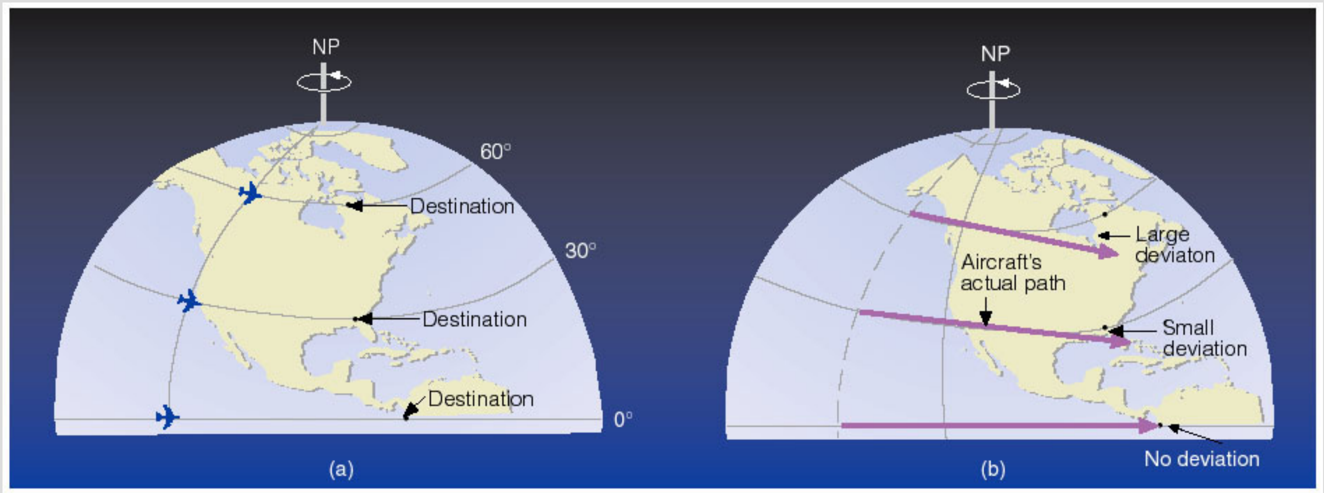


Cannonball follows a __________________ to an observer in space

Earth rotates counter-clockwise underneath cannonball
(in Northern Hemisphere)

Cannonball appears to deflect to the ___________ to an observer on earth

Coriolis Force and Latitude



All three airplanes travel in a straight line with respect to an outside observer (from space).

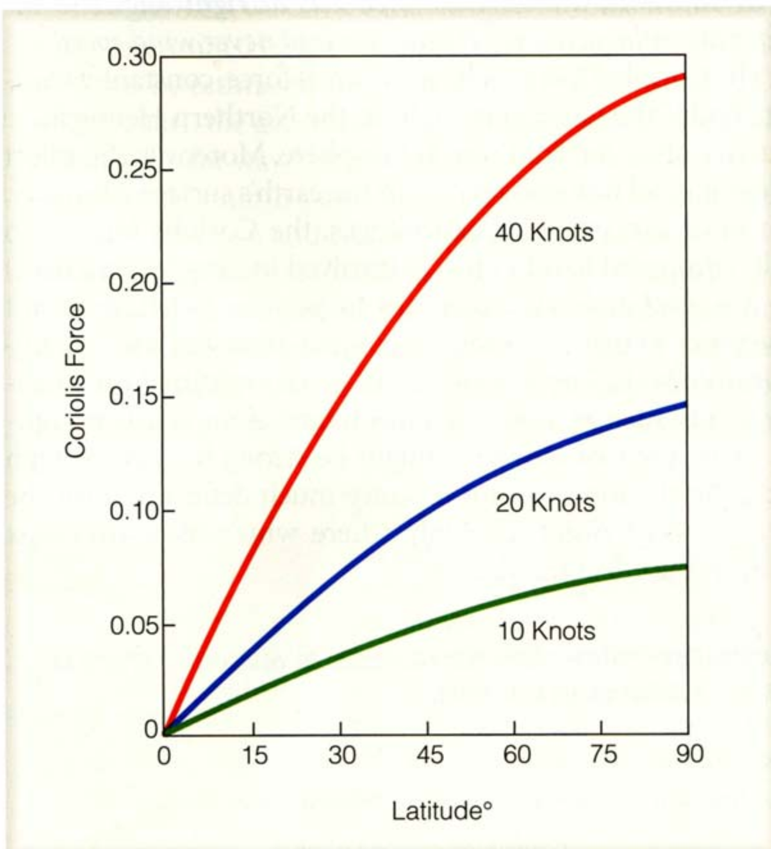
The largest deviation, or deflection to the _______, with respect to an observer on Earth occurs for the one traveling closest to the________.

The higher the latitude, the greater the Coriolis force. **Accounted for by the sine term in the mathematical expression.**

Zero at equator (sin 0° = 0)

Maximum at poles (sin 90° = 1)

Coriolis force and speed



● FIGURE 8.21
The relative variation of the Coriolis force at different latitudes with different wind speeds.

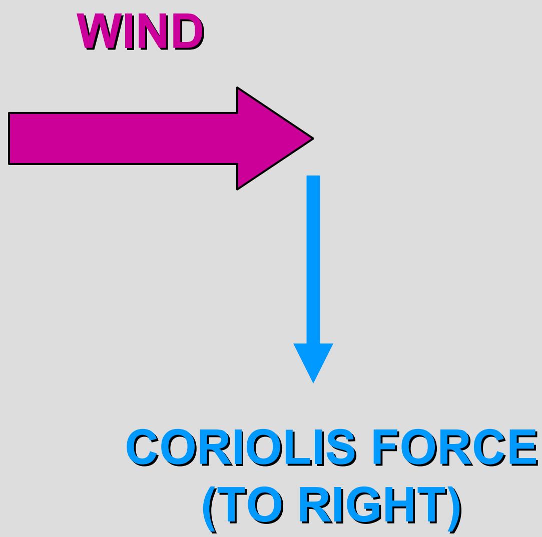
The Coriolis force is proportional to the wind speed.

The faster the speed (or velocity), the greater the amount of Coriolis force.

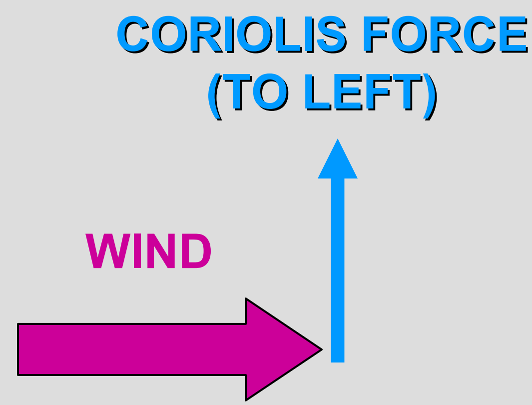
Note also the dependence on latitude here.

Coriolis Force vs. Wind Direction

NORTHERN HEMISPHERE

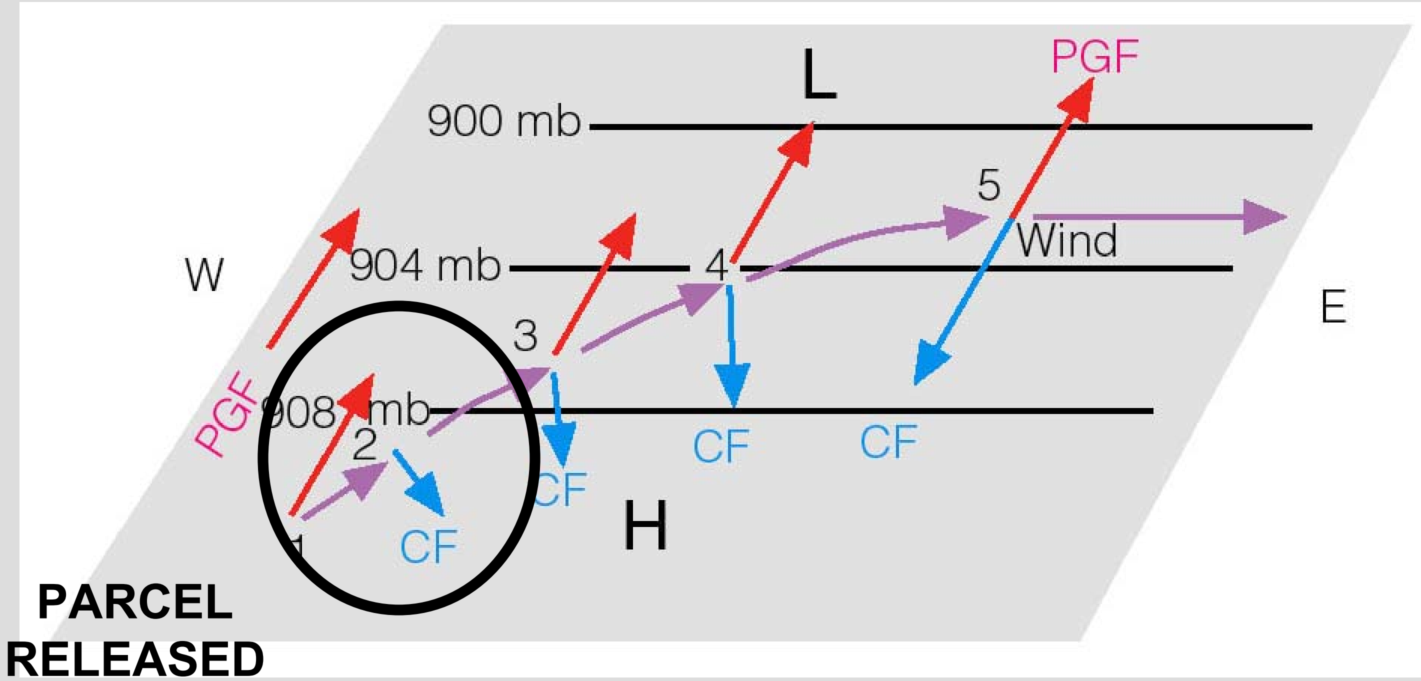


SOUTHERN HEMISPHERE



Coriolis force acts perpendicular (____________) to the wind direction, to the right or left depending on which hemisphere.

Geostrophic Wind

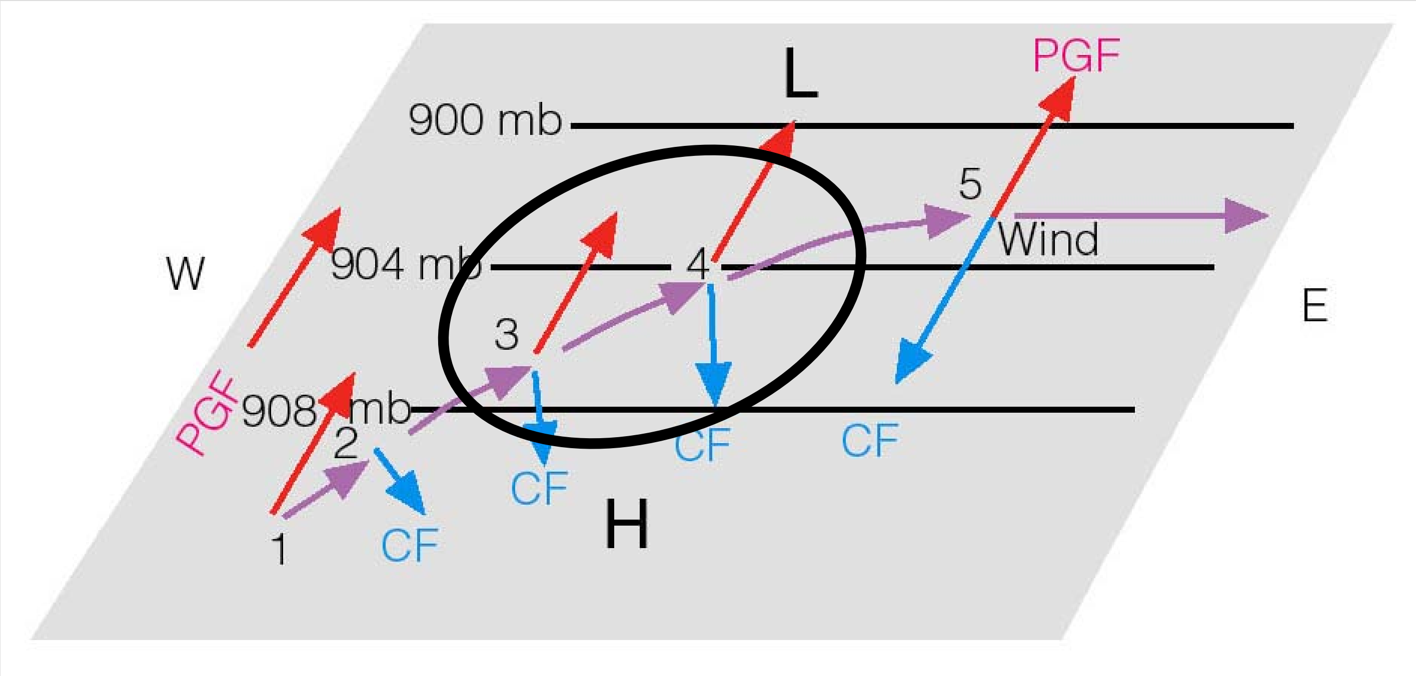


<u>**Positions 1 and 2**</u>:

Pressure gradient force accelerates the parcel towards the low pressure.

Coriolis force acts to the right of the velocity of the parcel, making it curve to the right.

Geostrophic Wind

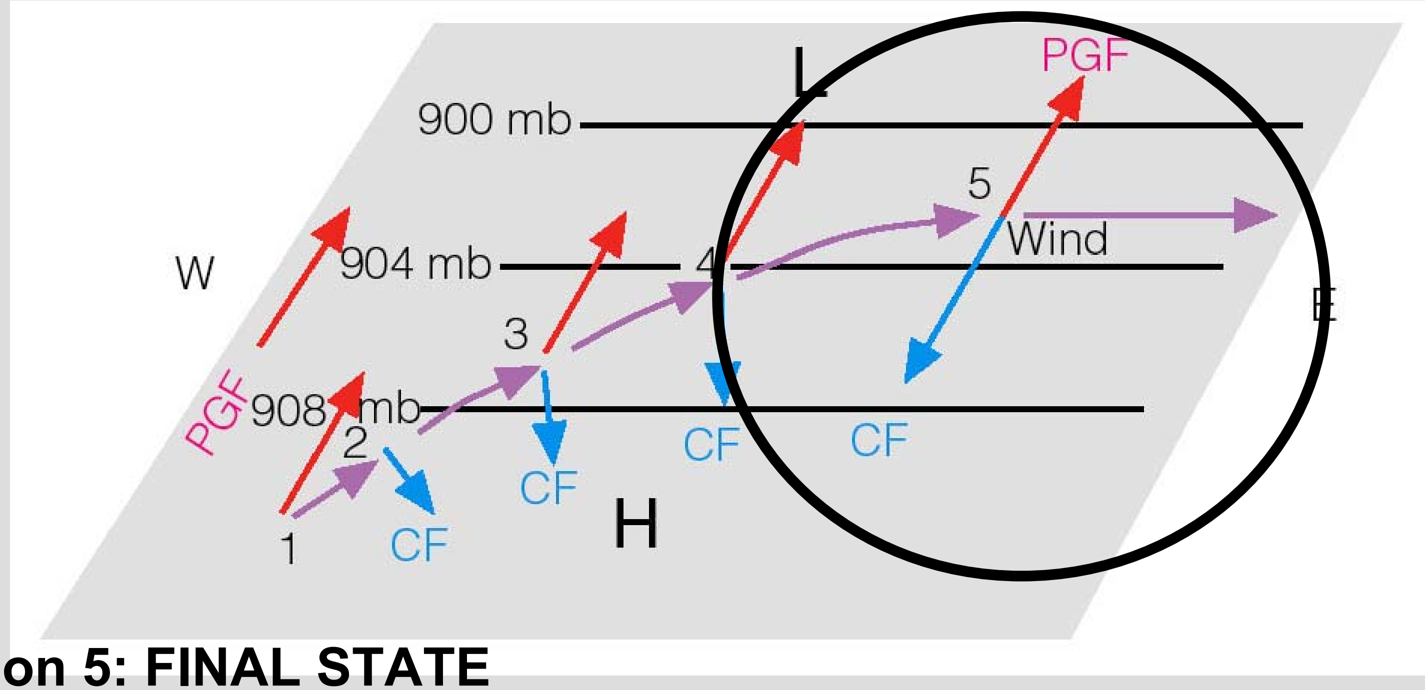


Positions 3 and 4:

Pressure gradient force continues to accelerate the parcel towards the low pressure.

As the velocity of the parcel increases, the Coriolis force increases, making the parcel continue to curve to the right.

Geostrophic Wind



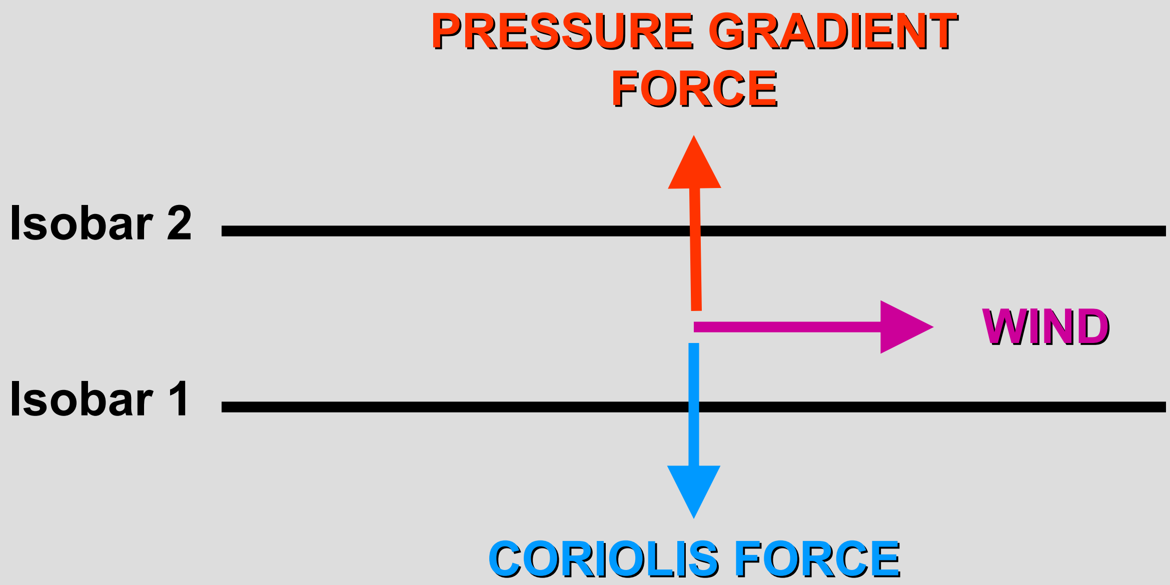
Position 5: FINAL STATE

Pressure gradient force is balanced by the Coriolis force.

Velocity of the parcel is constant (no acceleration). Direction is parallel to the isobars.

FINAL STATE is called __________________________.

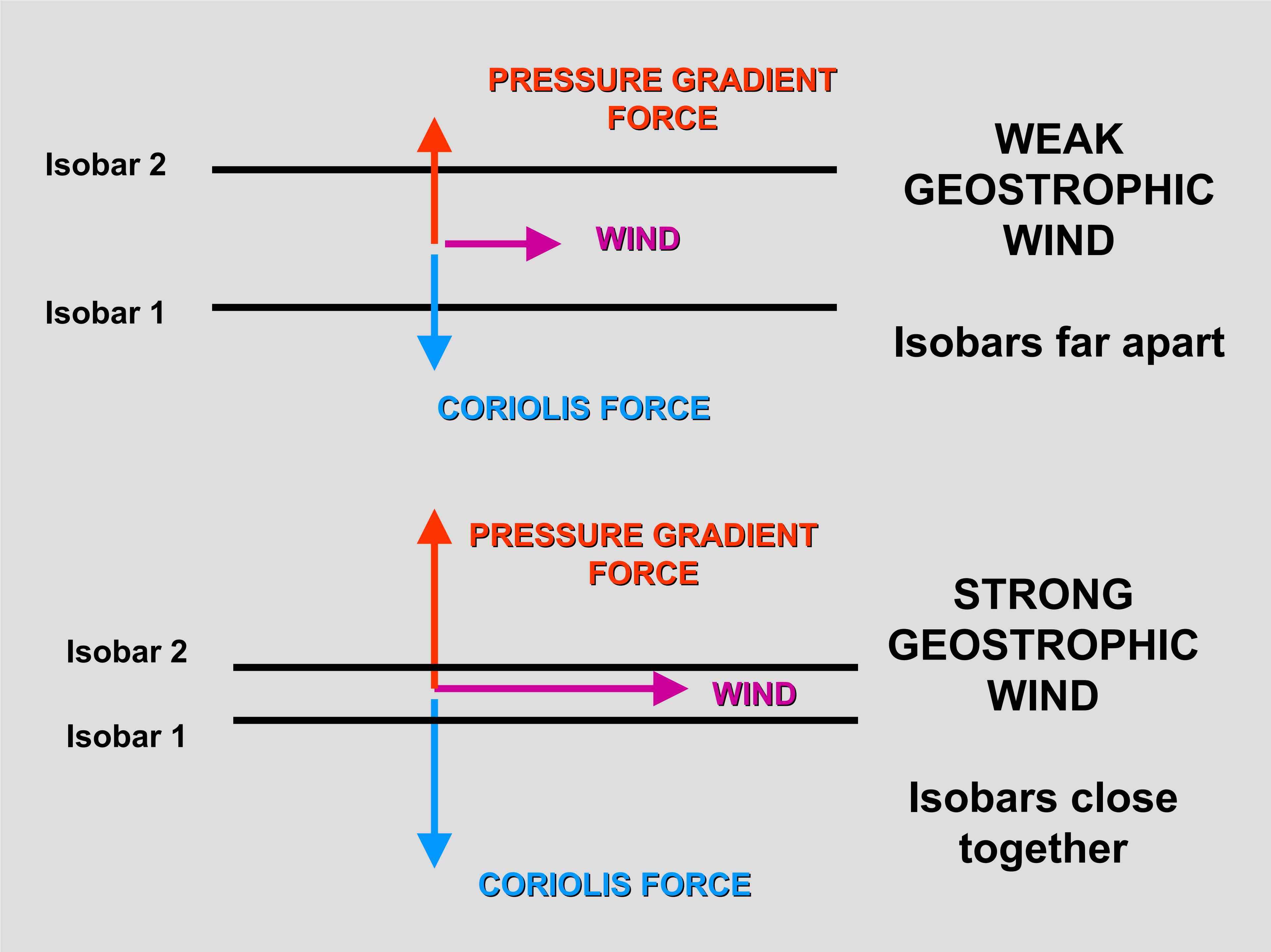
Geostrophic Wind



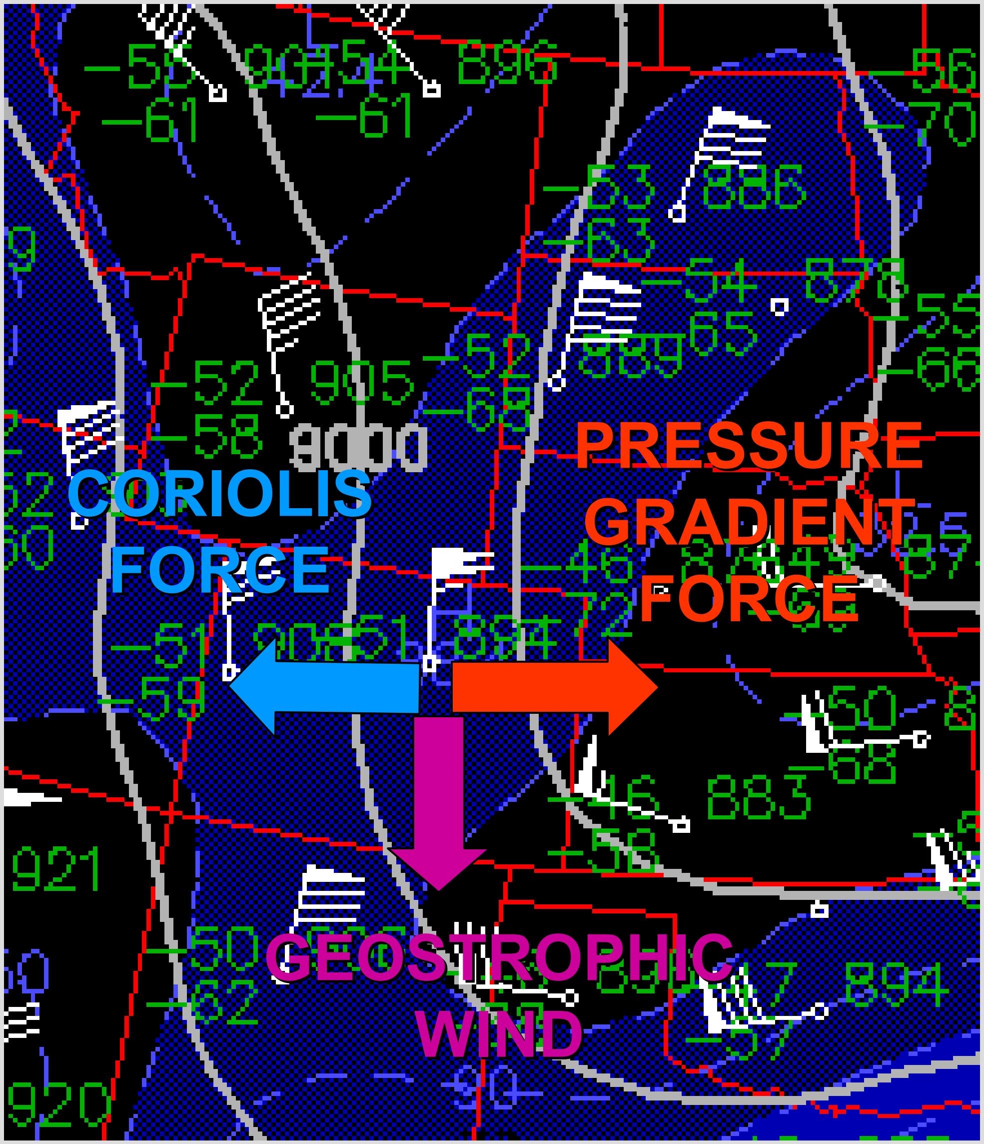
Pressure gradient force is equally balanced by the **Coriolis force**, so net force is zero.

Wind speed and direction (velocity) is constant (no acceleration).

Direction of wind is _______________ to the isobars, or lines of constant pressure.


PRESSURE GRADIENT FORCE
Isobar 2
WIND
Isobar 1
CORIOLIS FORCE
WEAK GEOSTROPHIC WIND
Isobars far apart
PRESSURE GRADIENT FORCE
Isobar 2
WIND
Isobar 1
CORIOLIS FORCE
STRONG GEOSTROPHIC WIND
Isobars close together

Geostrophic Wind and Upper Level Charts



Winds at upper levels are pretty close to being geostrophic:

Wind is ________ to isobars

Wind strength dependent on how close together isobars are

Simplified equation of horizontal atmospheric motion

$$\text{Total Force} = \frac{1}{\rho}\frac{\Delta p}{d} + 2\Omega V \sin\phi + \frac{V^2}{r} + F_r$$

(1) (2) (3) (4)

GEOSTROPHY:

No centripetal force or friction

Term	Force	Cause
1	Pressure gradient force	Spatial differences in pressure
2	Coriolis force	Rotation of the Earth
3	Centripetal force	Curvature of the flow
4	Friction force	Acts against direction of motion due to interaction with surface

Summary of Lecture 15

Newton's first law of motion: an object will remain at rest and an object in motion will maintain a constant velocity if the net force is zero.

Newton's second law of motion: F = ma. Change acceleration by a change in speed or direction.

The simplified equation of horizontal atmospheric motion has four force terms: pressure gradient force, Coriolis force, centripetal force, and friction.

The pressure gradient force is due to the difference in pressure over a distance.

The Coriolis force is an apparent force due to the rotation of the Earth, and depends on speed (of the wind) and latitude. It causes deflection from the reference point of an observer in a rotating frame.

Coriolis force deflects the wind to the right or left depending on which hemisphere.

Geostrophic wind occurs when the pressure gradient force balances the Coriolis force and the wind is parallel to the isobars. A good approximation for upper level winds.

Reading Assignment and Review Questions

Reading: remainder of Chapter 8.