# NATS 101
# Section 13: Lecture 16

## Why does the wind blow?

## Part II

**Last time we talked about two of the force terms in the simplified equation for horizontal air motion**

**Geostrophic Balance:**

**_____ = _____**

# 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)

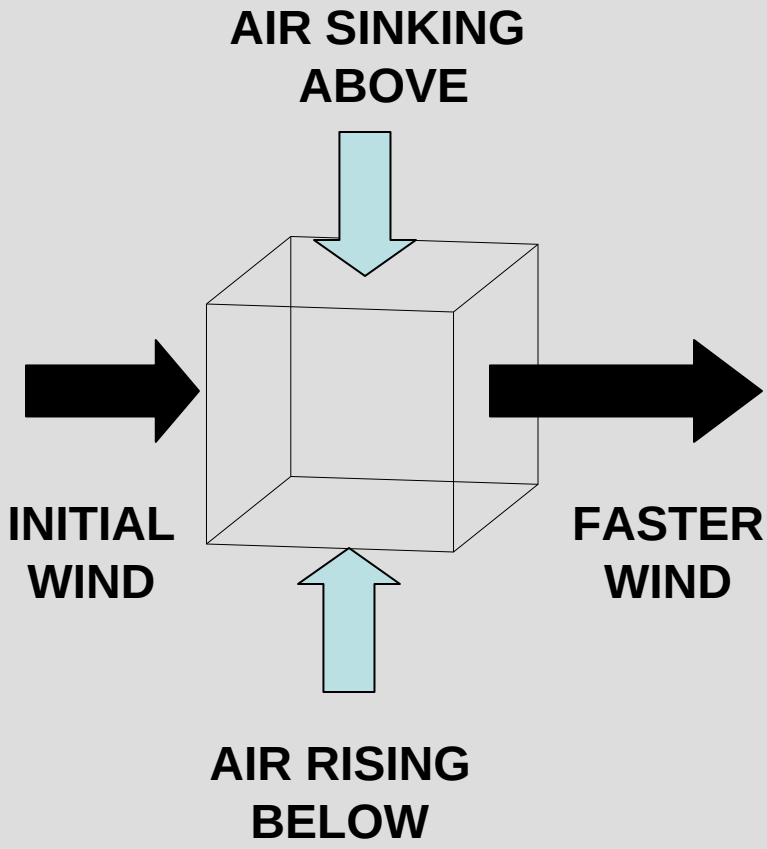
***FOCUS ON LAST TWO THIS TIME…***

| 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 |

**The centripetal force and friction force are typically much smaller, but they are very important for two reasons:**

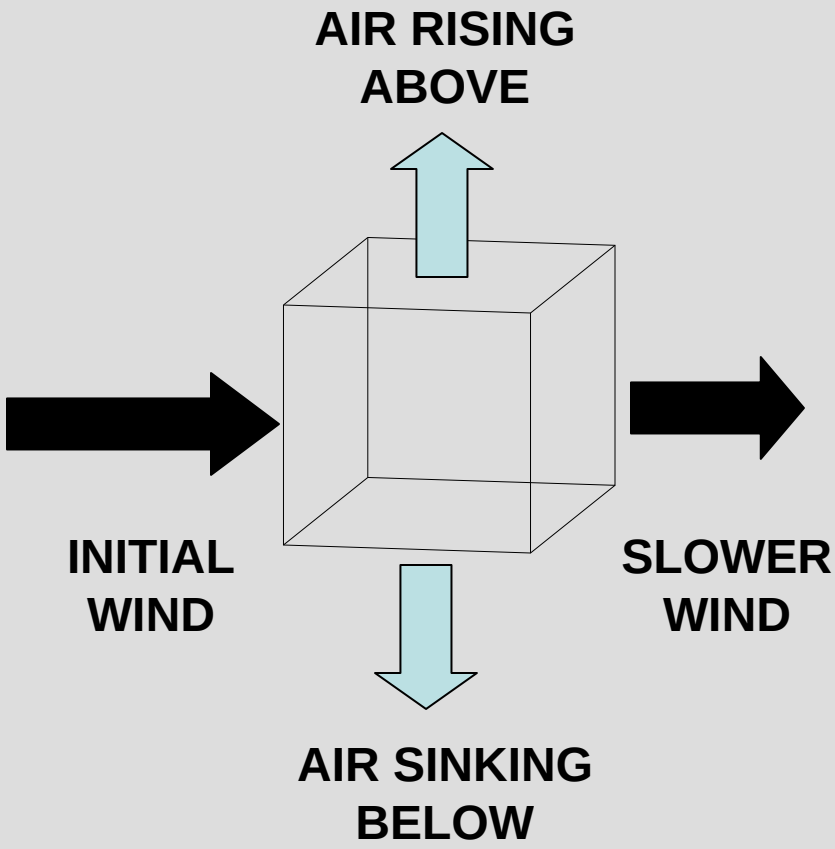
1. **Cause mass divergence and convergence**
2. **Can be relatively large in special cases that are meteorologically important (i.e. cool)**

## MASS DIVERGENCE




**MASS LOST**

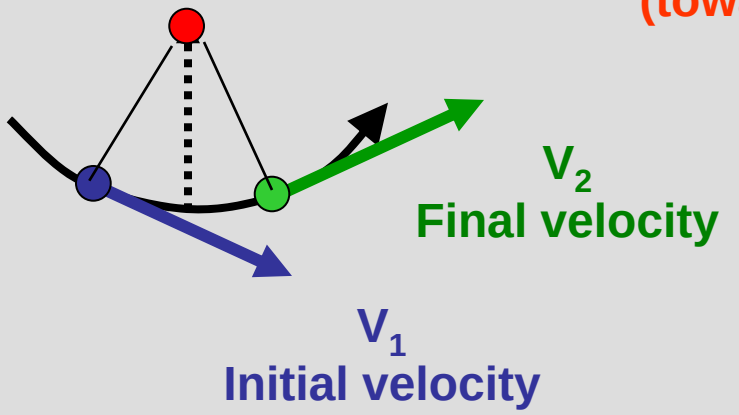
## MASS CONVERGENCE



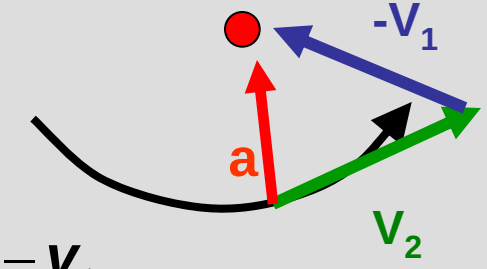

**MASS GAINED**

# Centripetal Force = $\frac{V^2}{r}$

***Arises from a change in wind direction with a constant speed (v) due to the curvature of the flow around a radius (r)***




**Centripetal acceleration (a)**
**(towards the center of circle)**

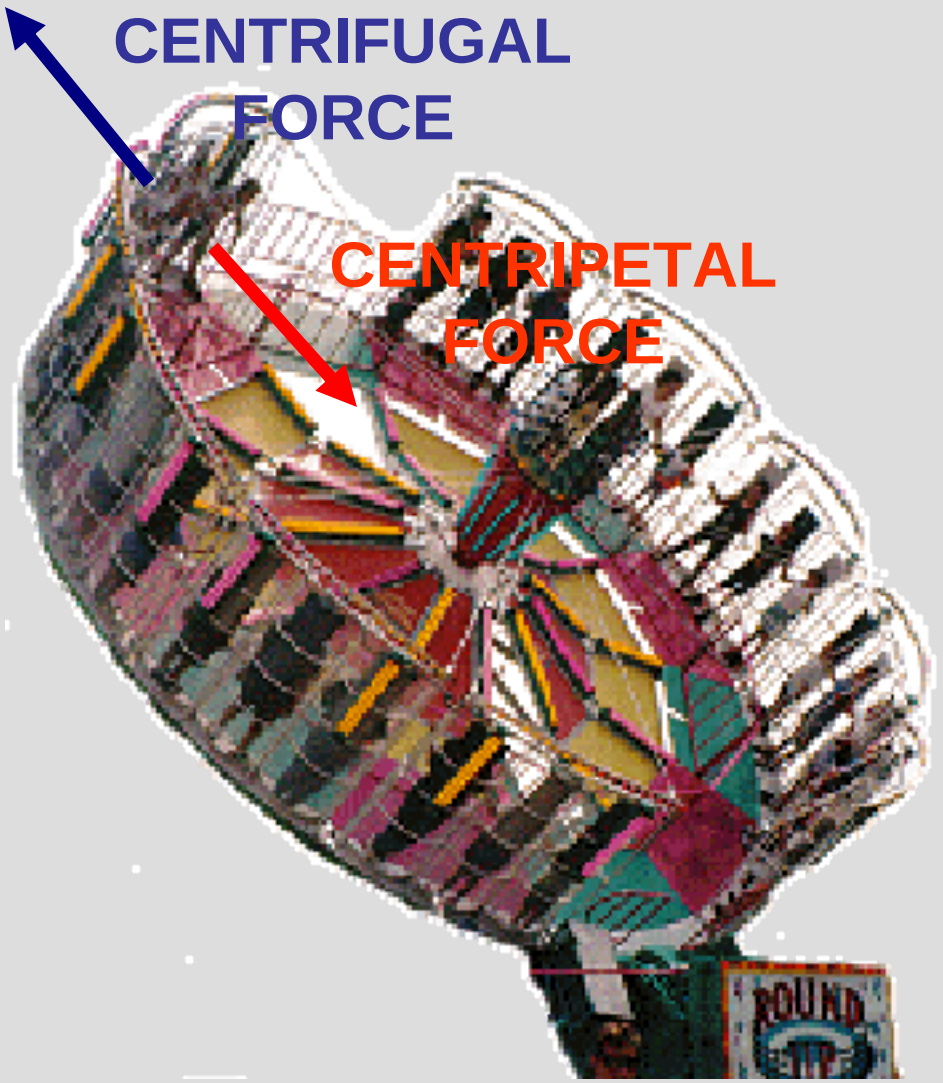



$$a = \frac{v_2 - v_1}{t}$$

**The centripetal acceleration is always directed toward the center of the axis of rotation.**

***Note to be physically correct, the expression should have a negative sign, so $+V^2/r$ is actually the centrifugal acceleration.***

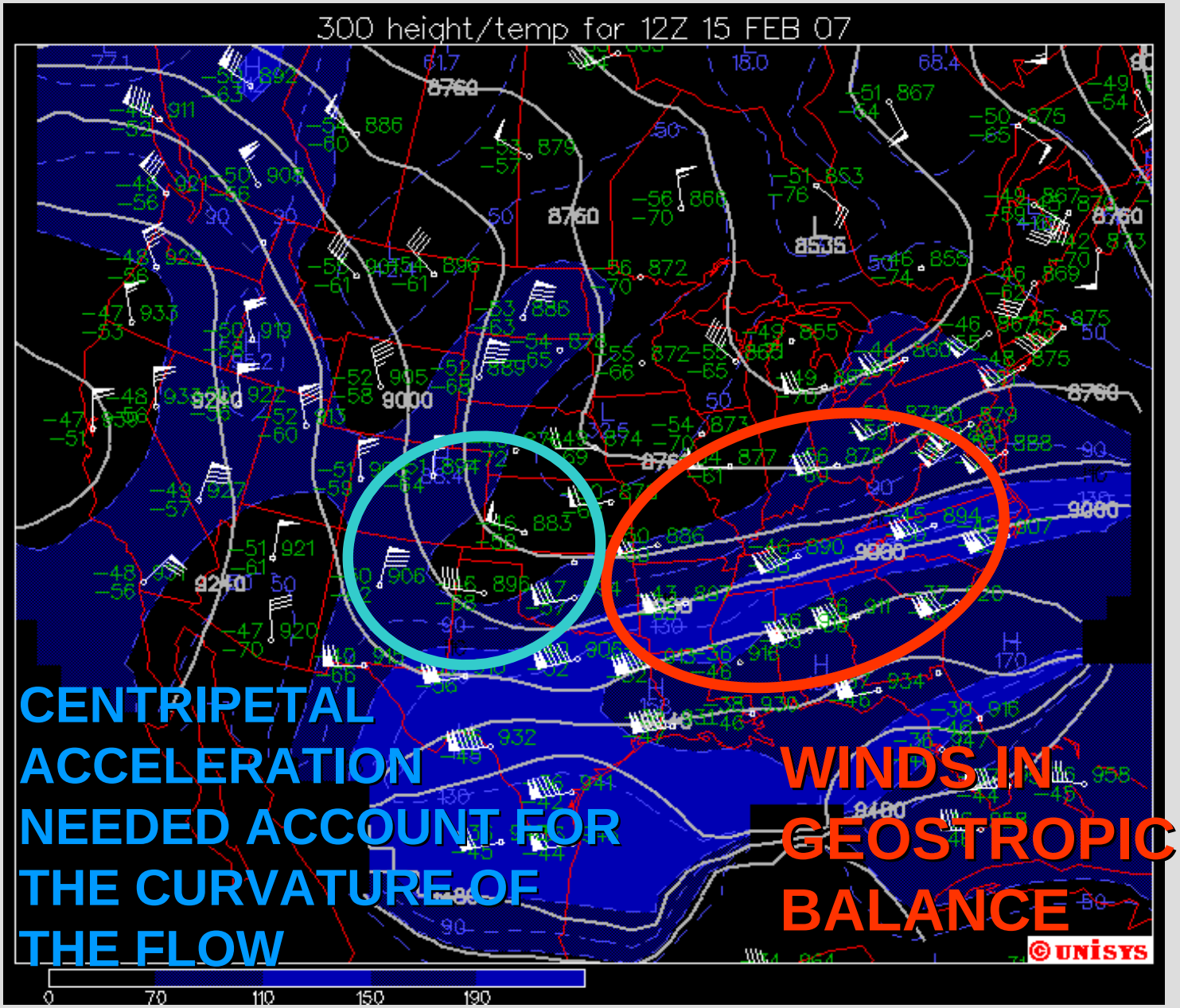
# Centripetal Force




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

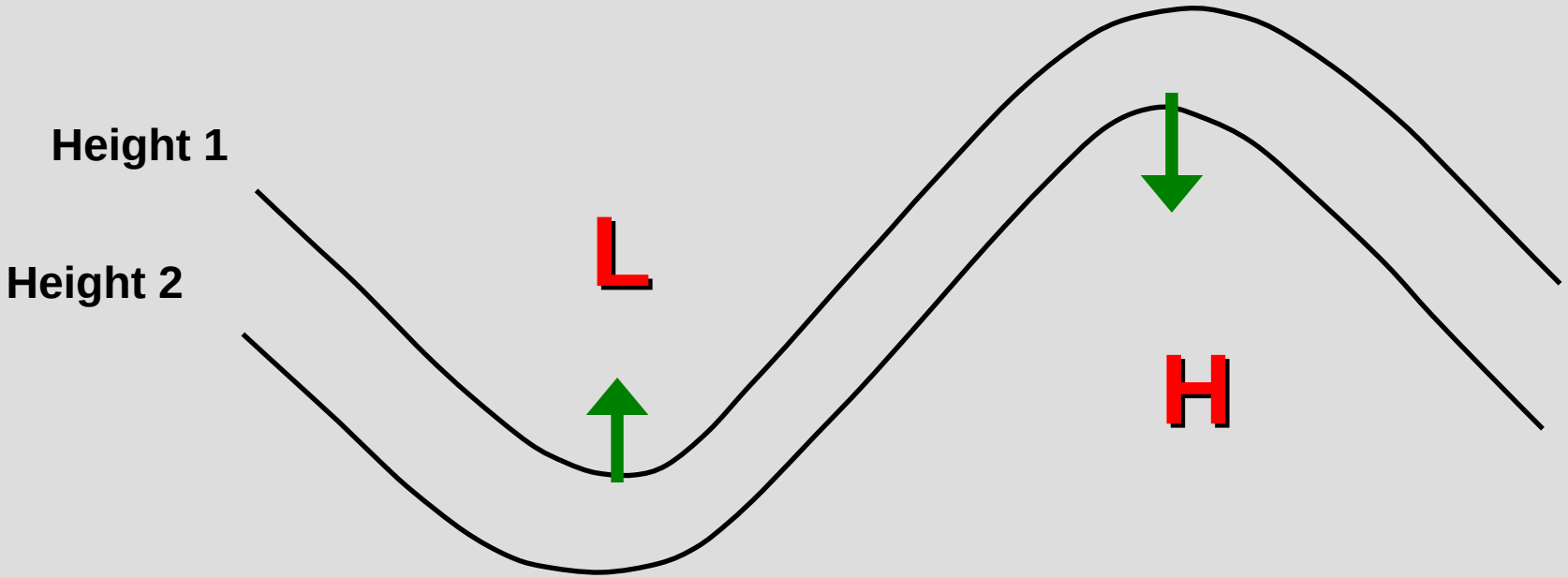
**The force is directed toward the center of the wheel.**

**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.**


300 height/temp for 12Z 15 FEB 07
CENTRIPETAL ACCELERATION NEEDED ACCOUNT FOR THE CURVATURE OF THE FLOW
WINDS IN GEOSTROPIC BALANCE
© UNISYS
0
70
110
150
190

# Flow around curved height iso-lines

**Assume PGF constant size along entire channel**

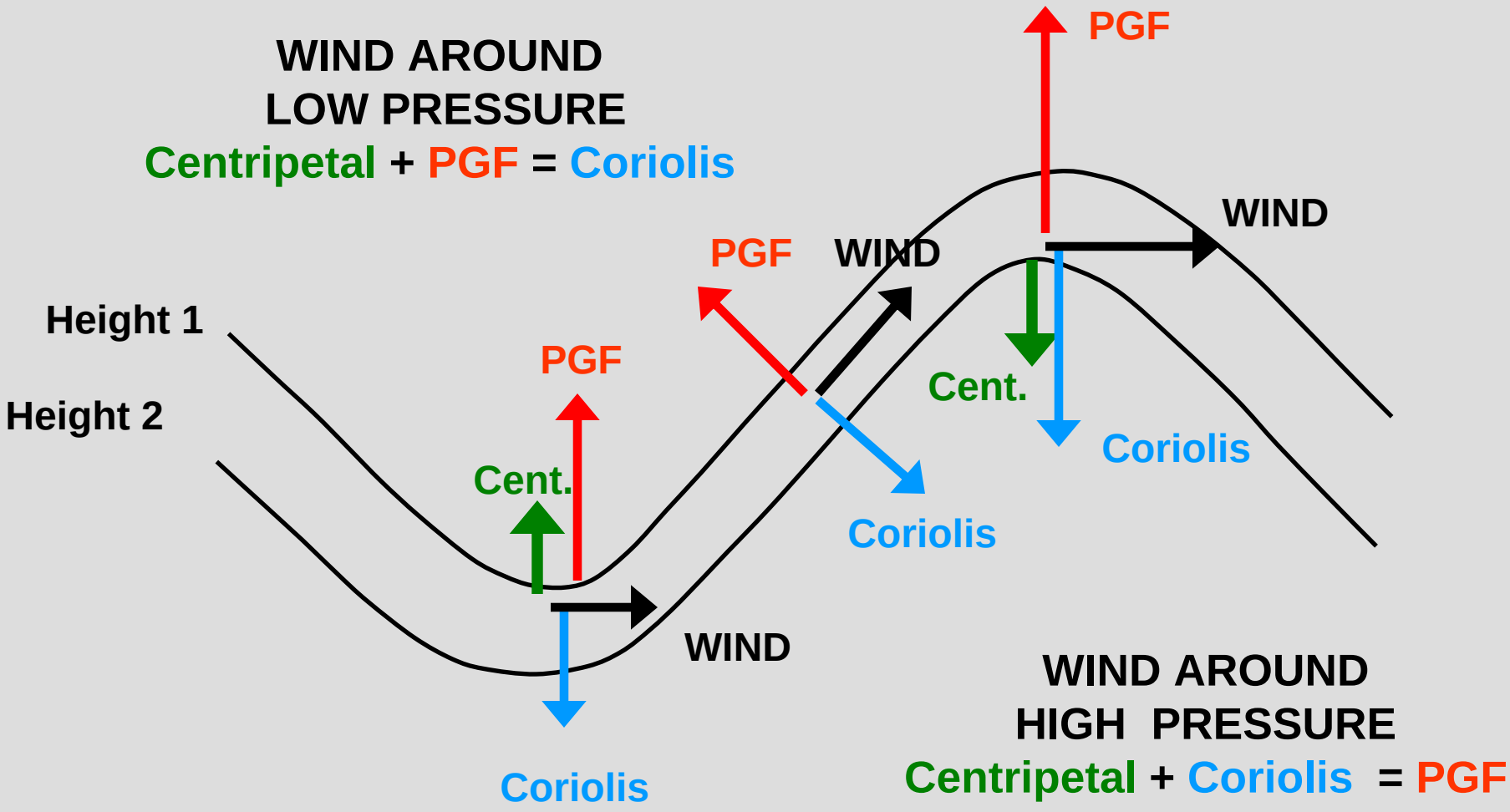



**Centripetal acceleration (towards low pressure)**

**Centripetal acceleration (towards high pressure)**

***When wind curves, it must have an centripetal acceleration towards the axis of rotation, so it is NOT geostrophic.***

# Gradient Balance: Curved Flow



**The effect of curvature has curious—and counter intuitive--implication for winds around high and low pressure, *if the pressure gradient is constant***

# Changes in wind speed around highs and lows due to gradient balance

**WIND AROUND LOW PRESSURE**

**Centripetal + PGF = Coriolis**

**OR, better to think…**

**PGF = Coriolis – Centripetal**

**Effectively REDUCES the pressure gradient force**

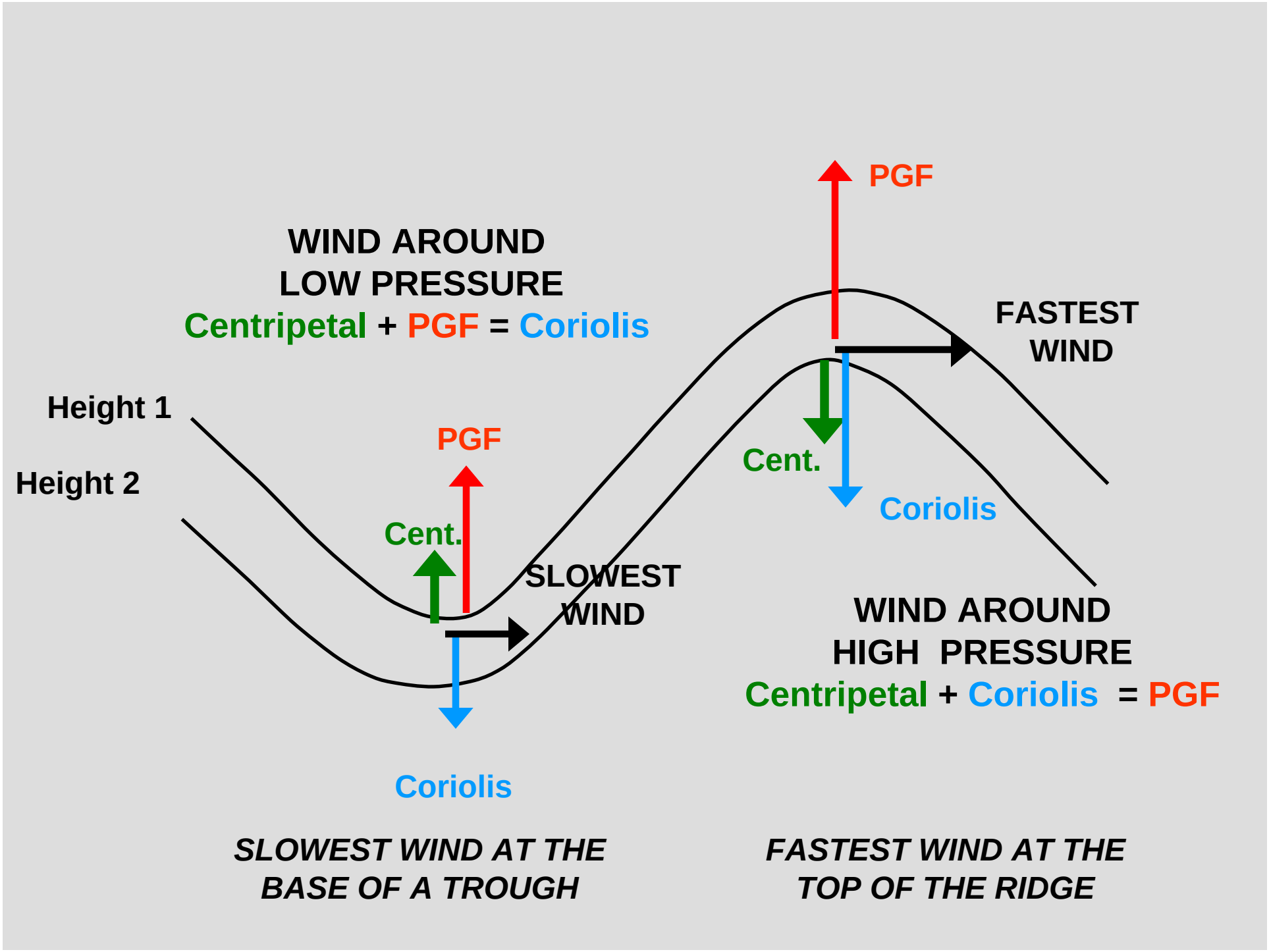
***Wind* _____.**

**WIND AROUND HIGH PRESSURE**

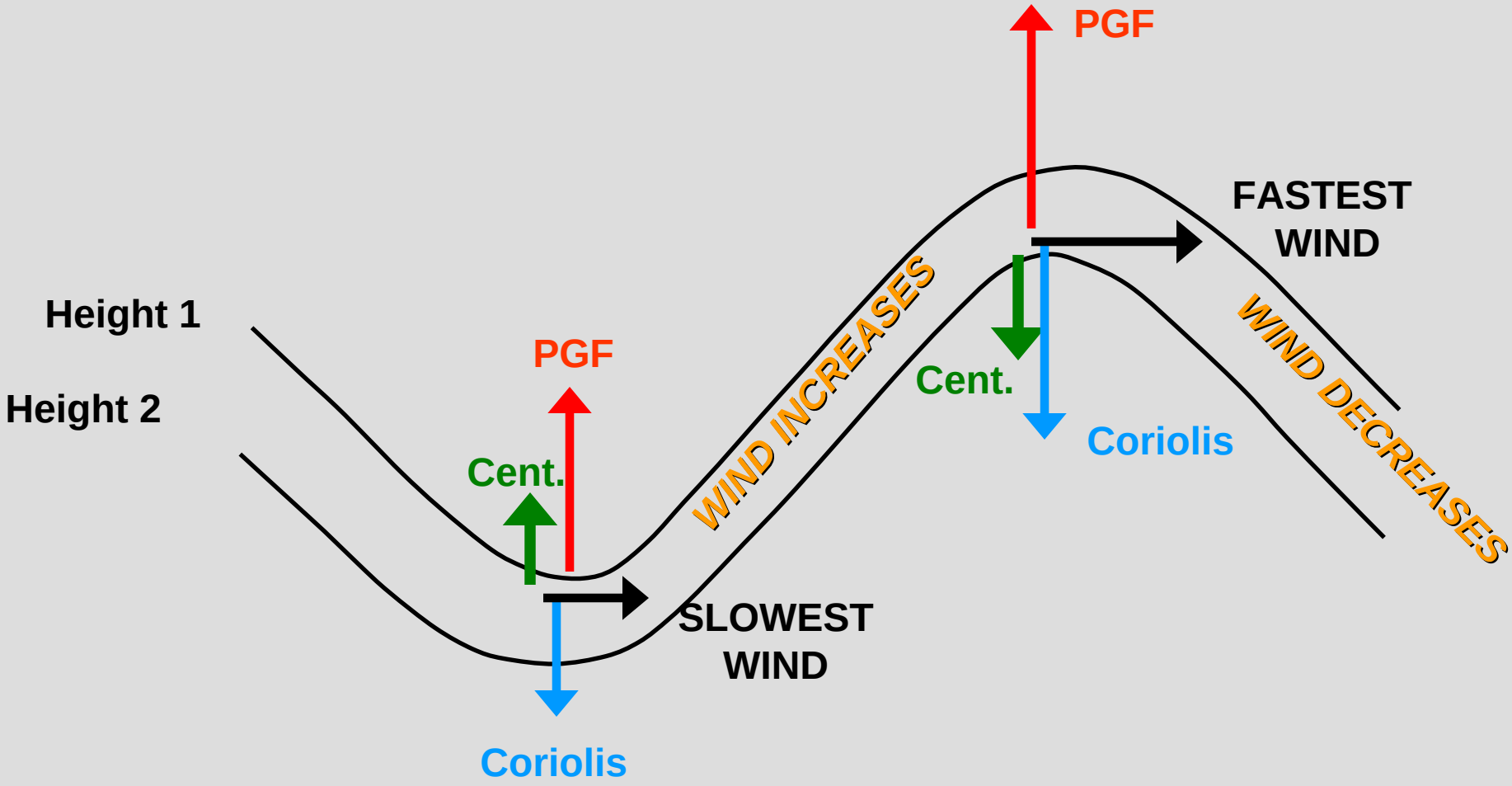
**PGF = Centripetal + Coriolis**

**Effectively INCREASES the pressure gradient force,**

***Wind* _____.**


WIND AROUND
LOW PRESSURE
Centripetal + PGF = Coriolis
Height 1
Height 2
PGF
Cent.
SLOWEST
WIND
Coriolis
SLOWEST WIND AT THE
BASE OF A TROUGH
PGF
FASTEST
WIND
Cent.
Coriolis
WIND AROUND
HIGH PRESSURE
Centripetal + Coriolis = PGF
FASTEST WIND AT THE
TOP OF THE RIDGE

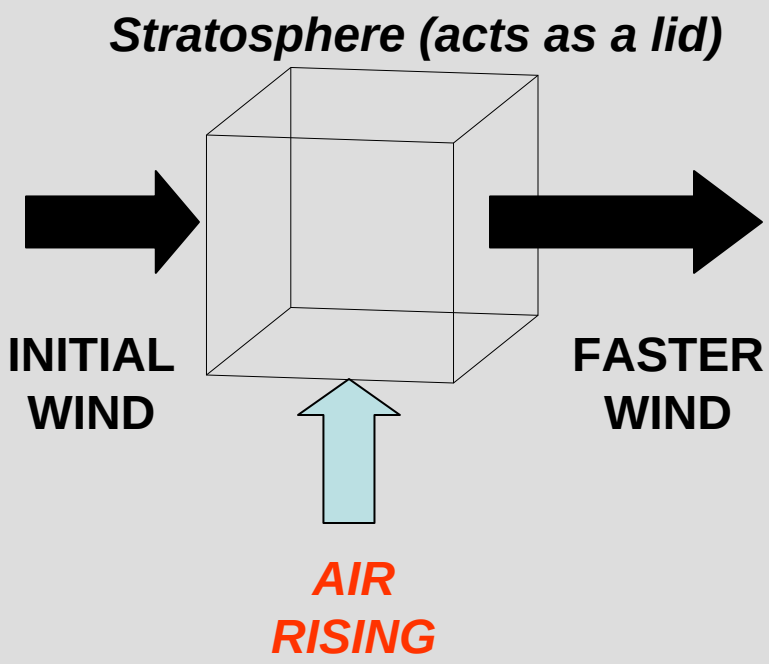
***Because of the effect of centripetal force, winds increase to the east of trough and decrease to the east of a ridge.***




***THERE MUST BE COMPENSATING VERTICAL MOTION DUE TO CHANGES IN WIND SPEED AHEAD OF THE TROUGH AN RIDGE.***

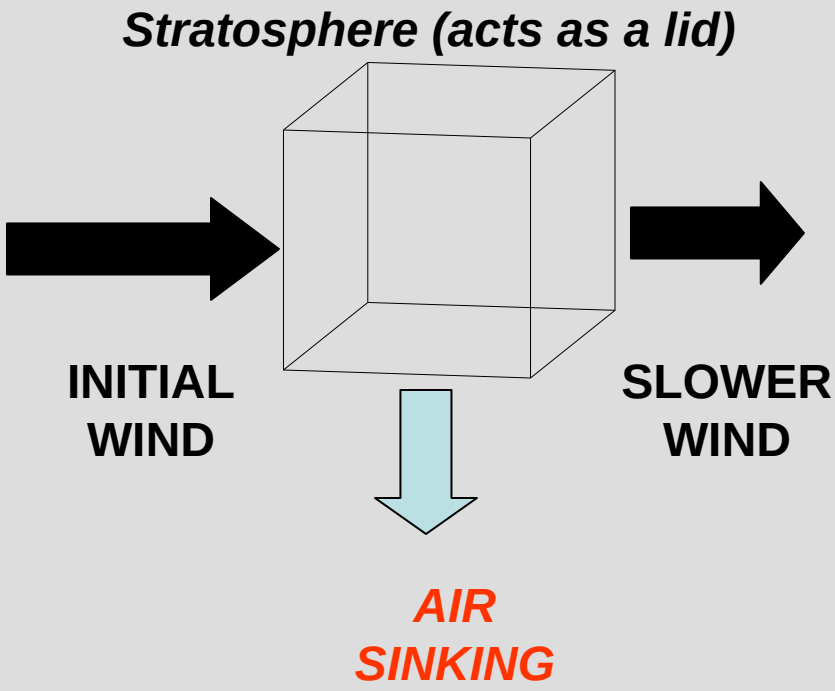
# MASS DIVERGENCE AND COVERGENCE AT UPPER LEVELS (DUE TO CURVATURE OF THE FLOW)

## MASS DIVERGENCE



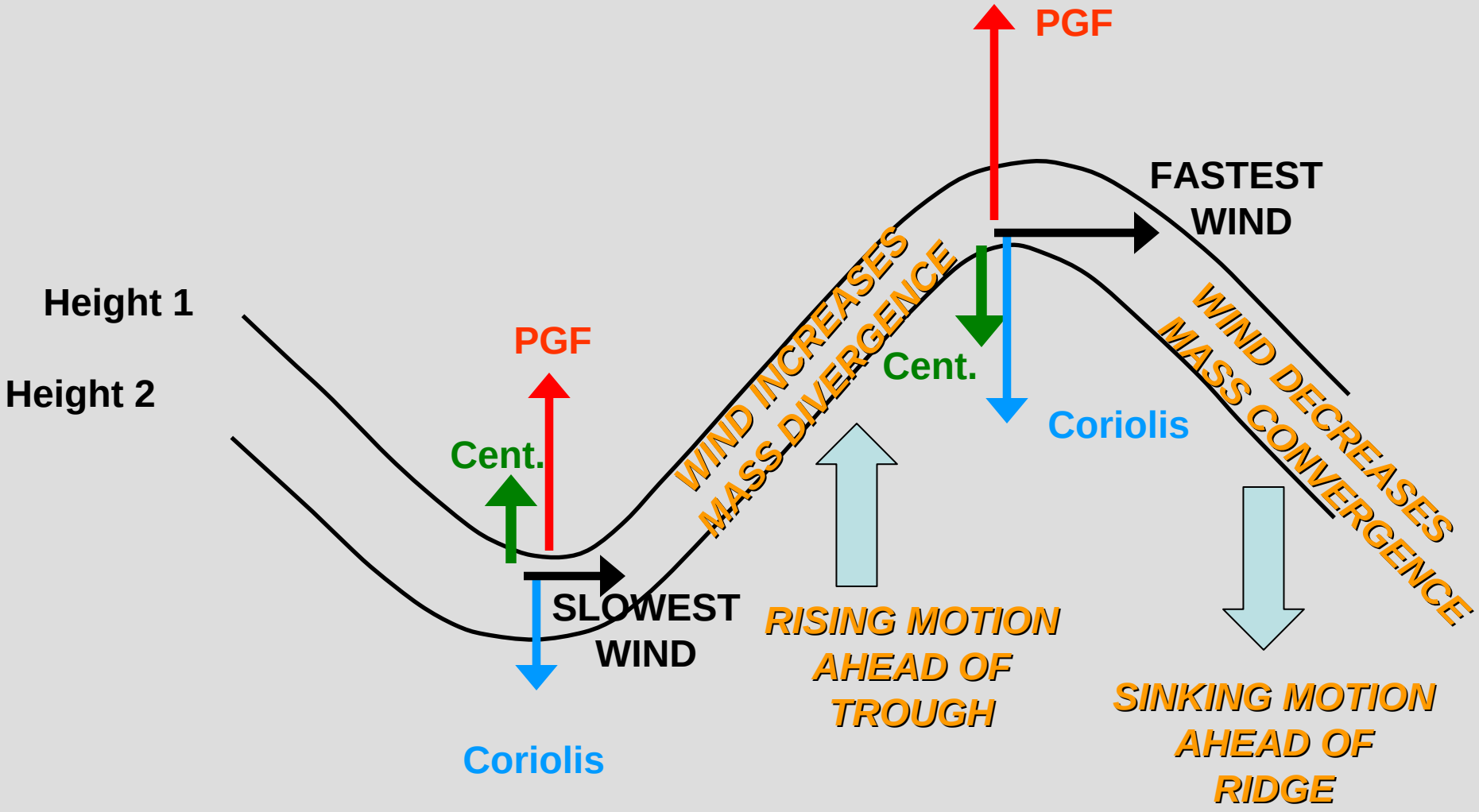

AHEAD OF A _____

## MASS CONVERGENCE

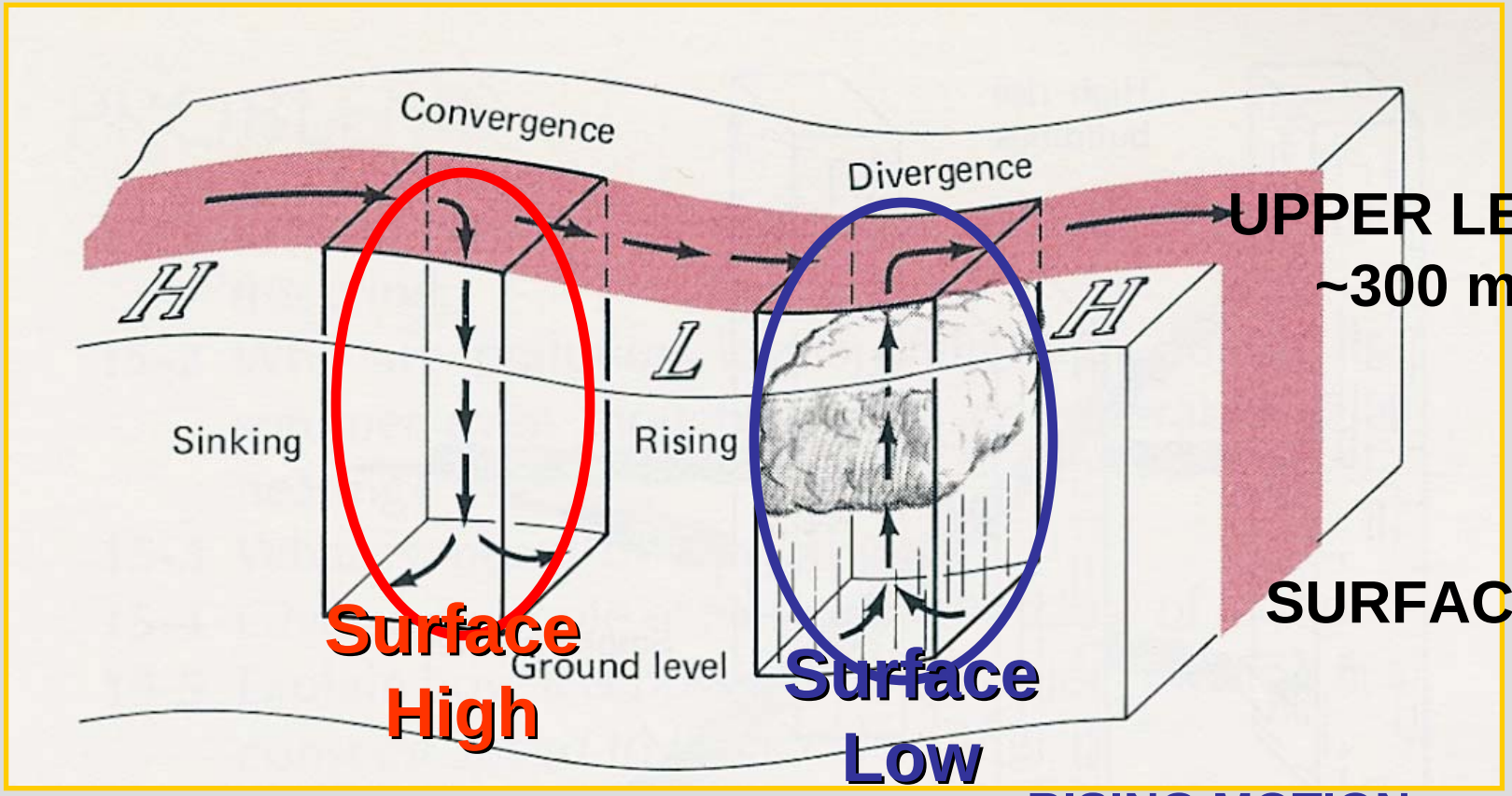



AHEAD OF A _____

# Relationship between upper level troughs and ridges and vertical motion

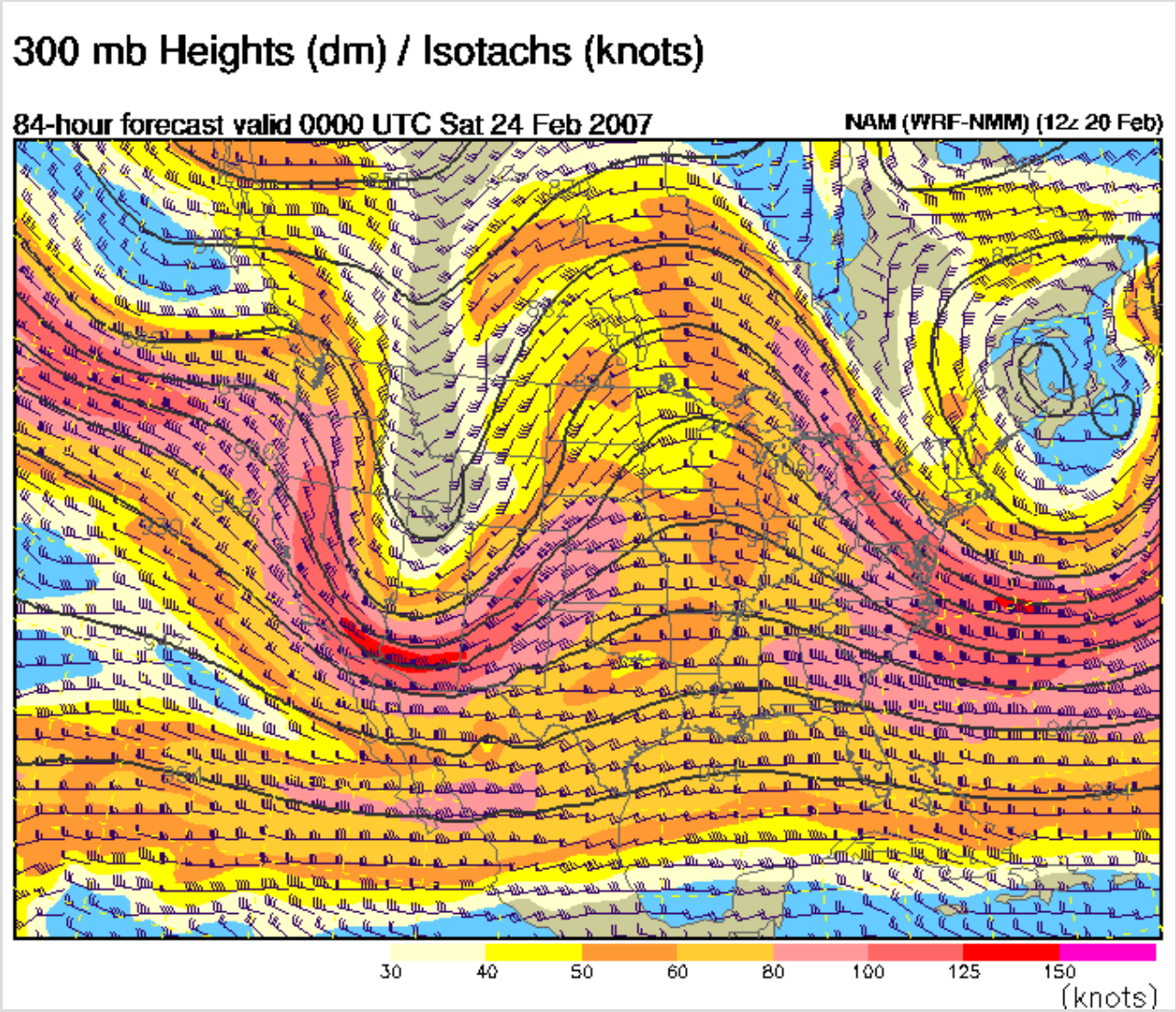


# Relationship between upper level troughs and ridges and vertical motion



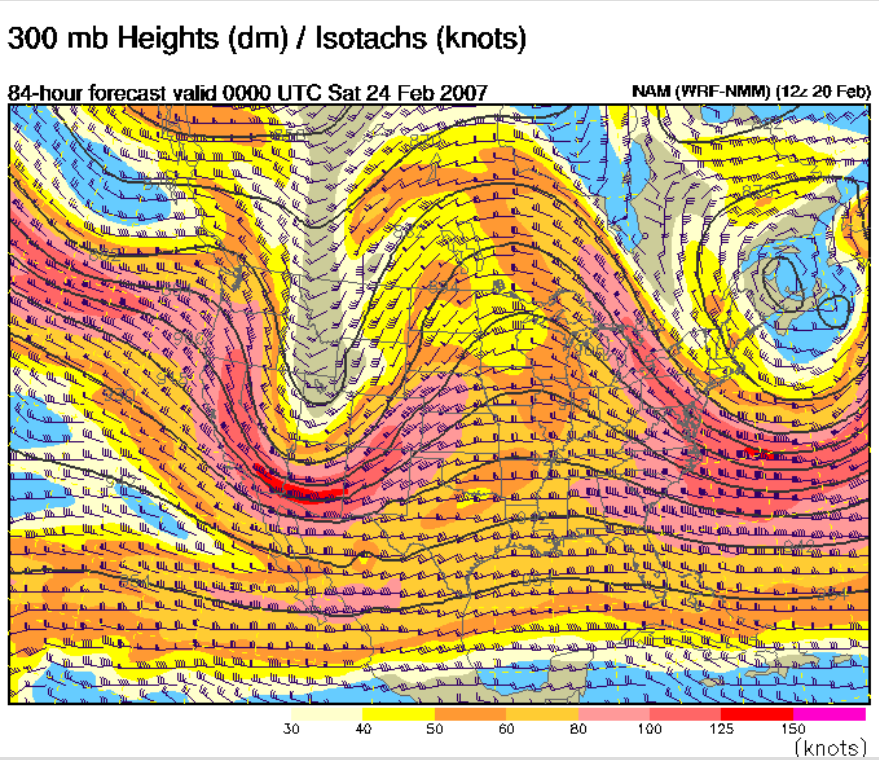

**SINKING MOTION**
**TYPICALLY STABLE**

**RISING MOTION**
**MAY BE CONDITIONALLY UNSTABLE**
**(if clouds form and air is saturated)**

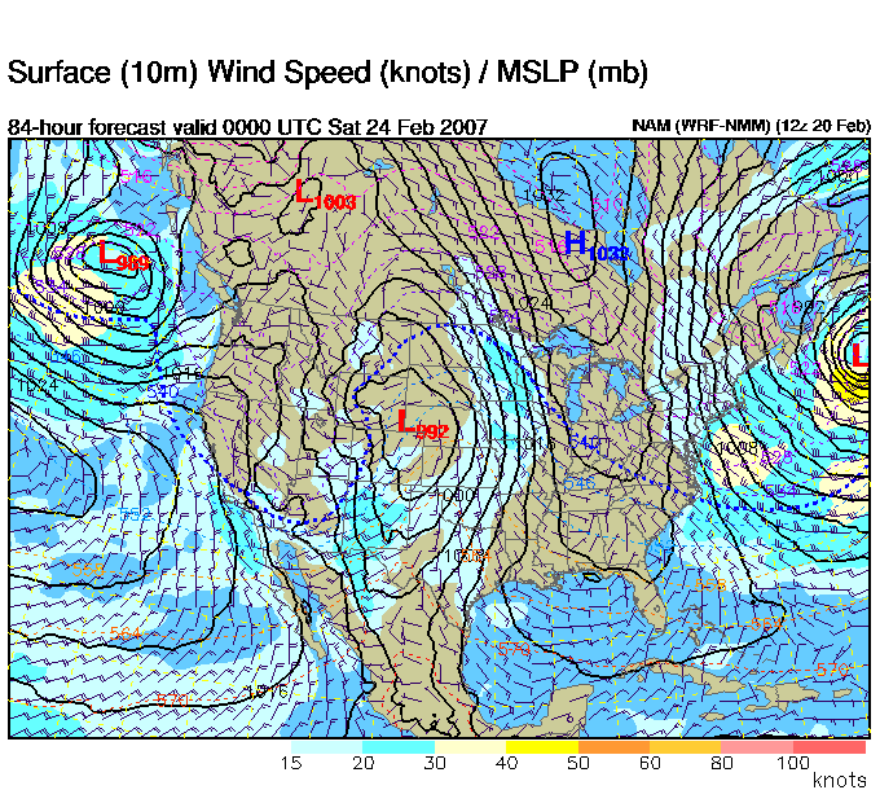



**Where would you expect to find rising and sinking air in relation to the troughs and ridges on this map?**

# UPPER LEVEL

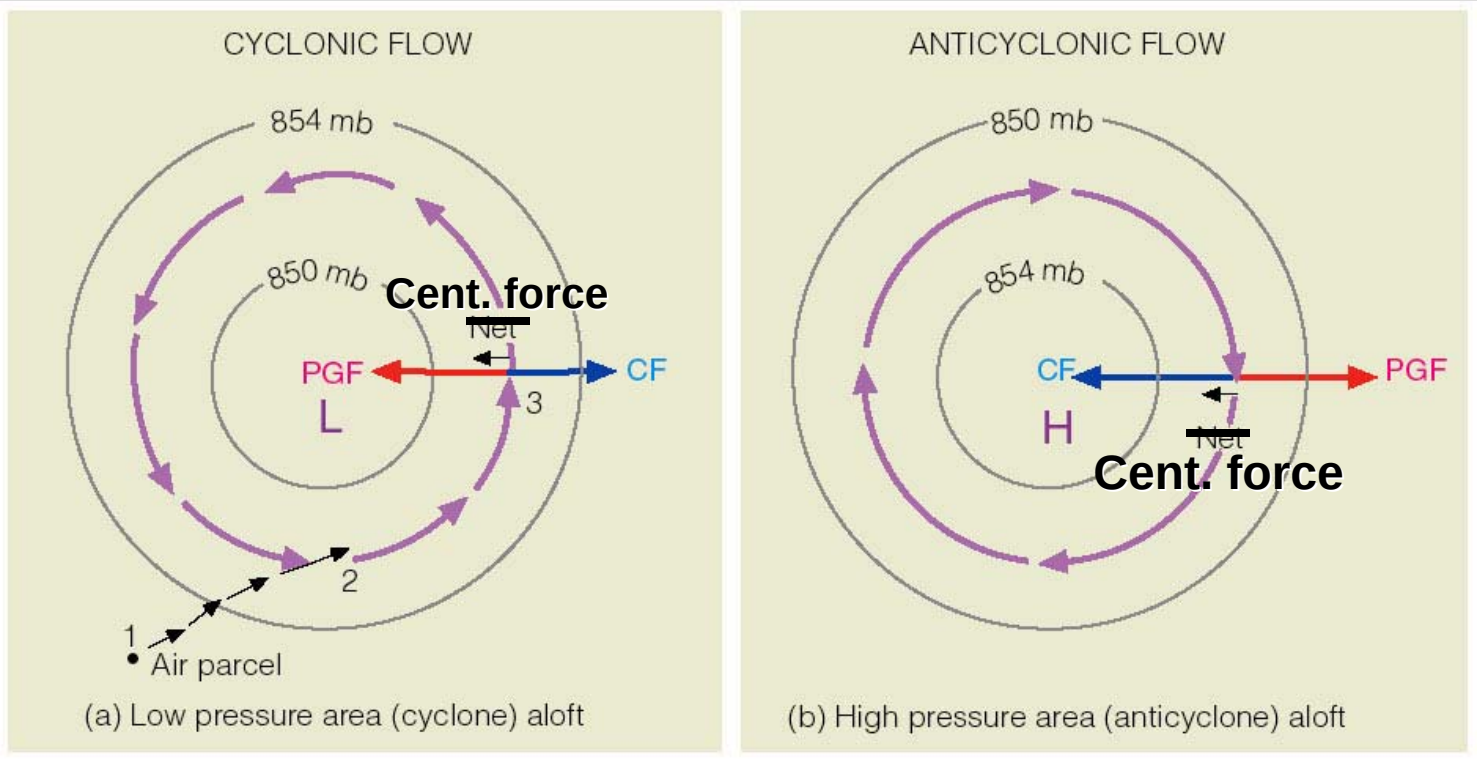



# SURFACE




**SURFACE LOW (in Colorado) IS LOCATED _____ OF TROUGH AT 300-MB, BECAUSE AIR IS _____ AHEAD OF THE TROUGH**

# Gradient balance and flow around lows and highs (Northern Hemisphere)




**Counterclockwise flow around lows**

**Clockwise flow Around highs**

# Flow around low pressure

**NORTHERN HEMISPHERE**

**SOUTHERN HEMISPHERE**


**Counterclockwise flow**

**Clockwise flow**
**(because Coriolis force reverses with respect to wind direction)**

**There is another force balance possibility *if the Coriolis force is very small or zero, so it's negligible.***

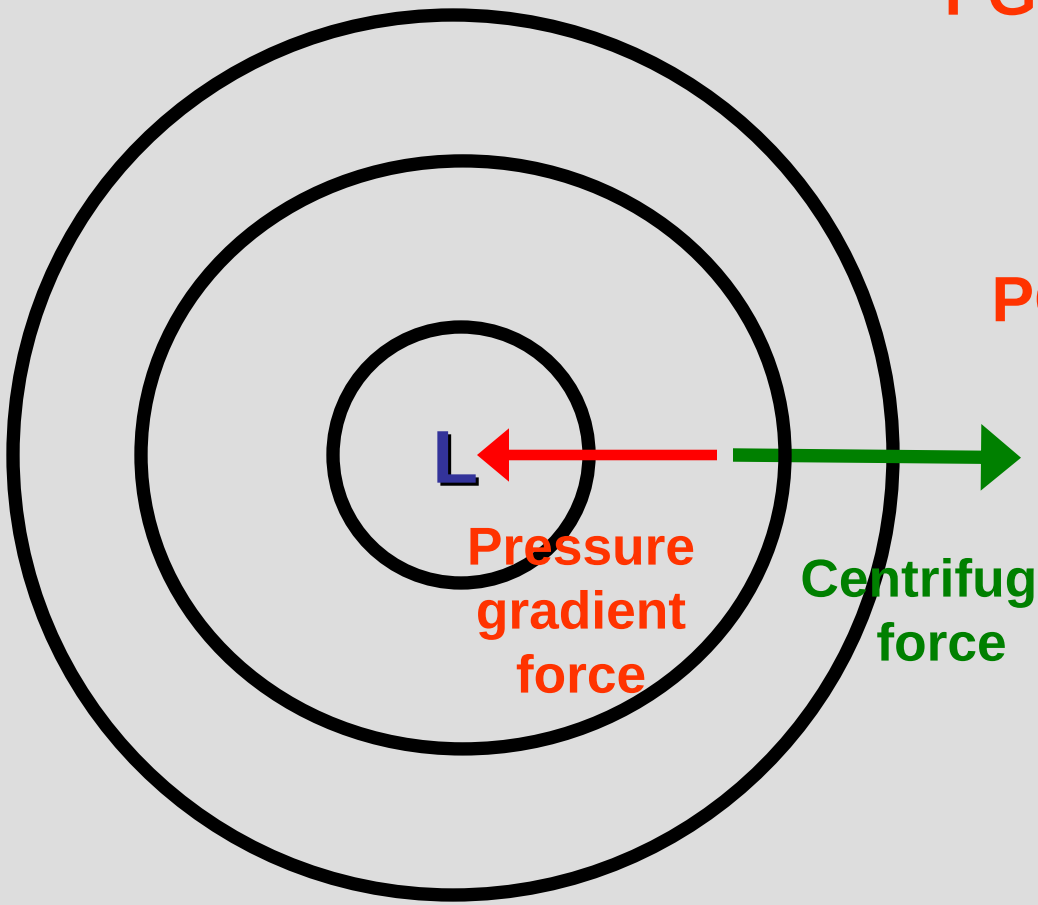
**In that case, the pressure gradient force would balance the centripetal force.**

# Cyclostrophic Balance

**PGF** + **centripetal force** = 0

**OR**

**PGF** = **Centrifugal force**




**Pressure gradient balances the centrifugal force.**

***Occurs where flow is on a small enough scale where the Coriolis force becomes negligible.***

***Why is this special type of balance important?***

# Examples of Cyclostrophic Flow

***HURRICANES***

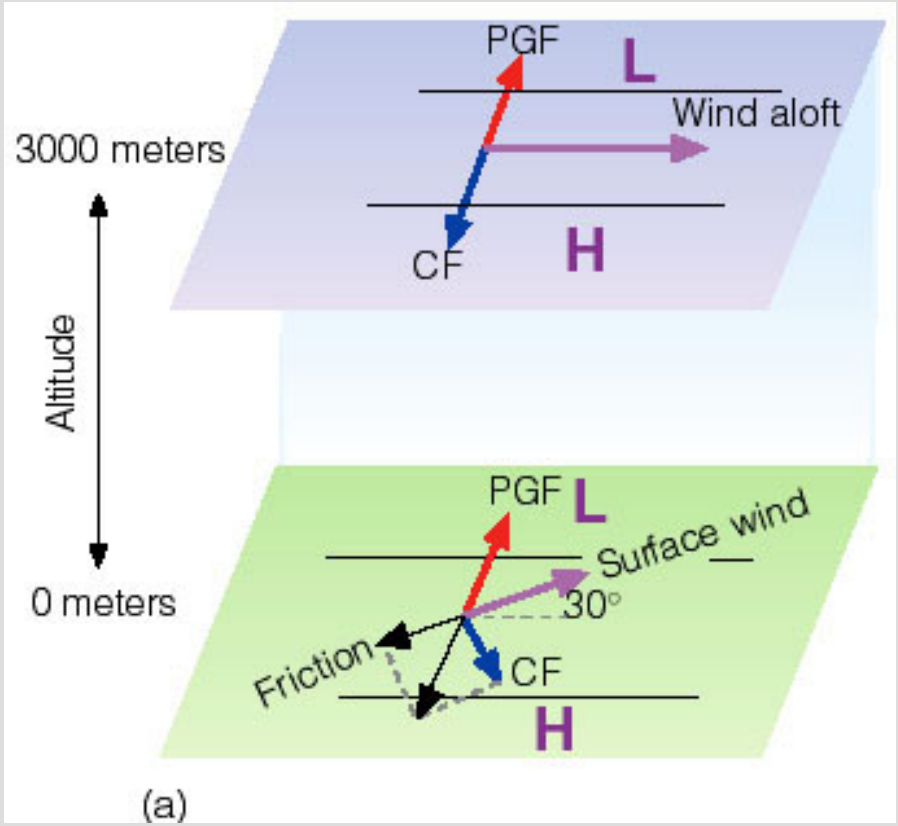

***TORNADOES***

***What about this one??***

**One last force to consider…**

**Friction**

# Effect of Friction Force (at the surface)



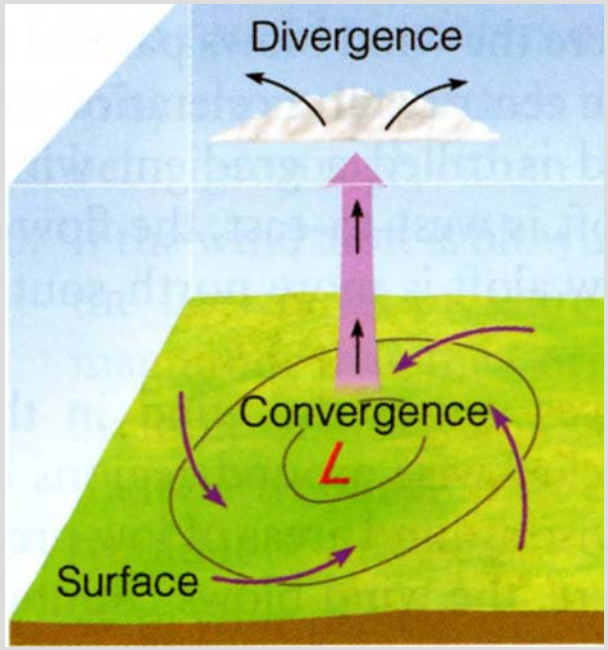

**Friction acts to slow the wind at the surface**

**The slower wind decreases the magnitude of the Coriolis force.**

**Weaker Coriolis force no longer balances the pressure gradient force.**

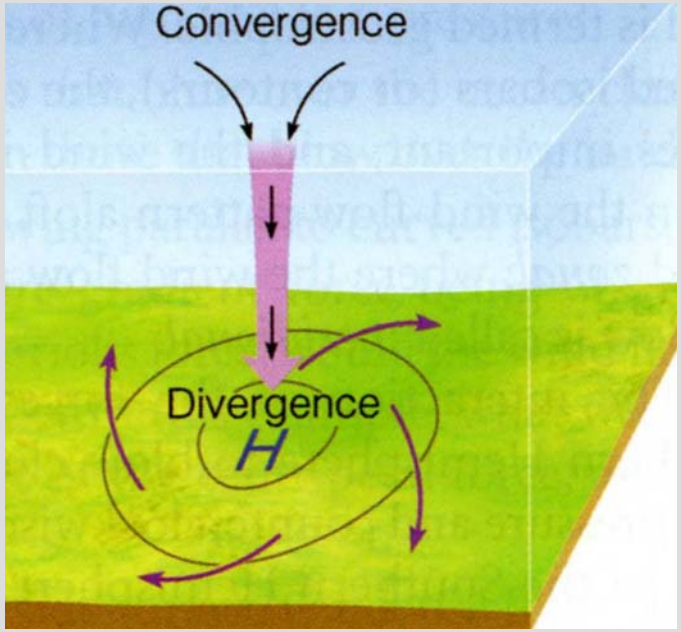
**Wind crosses the isobars, more toward the pressure gradient.**

# Surface friction and flow around surface highs and lows



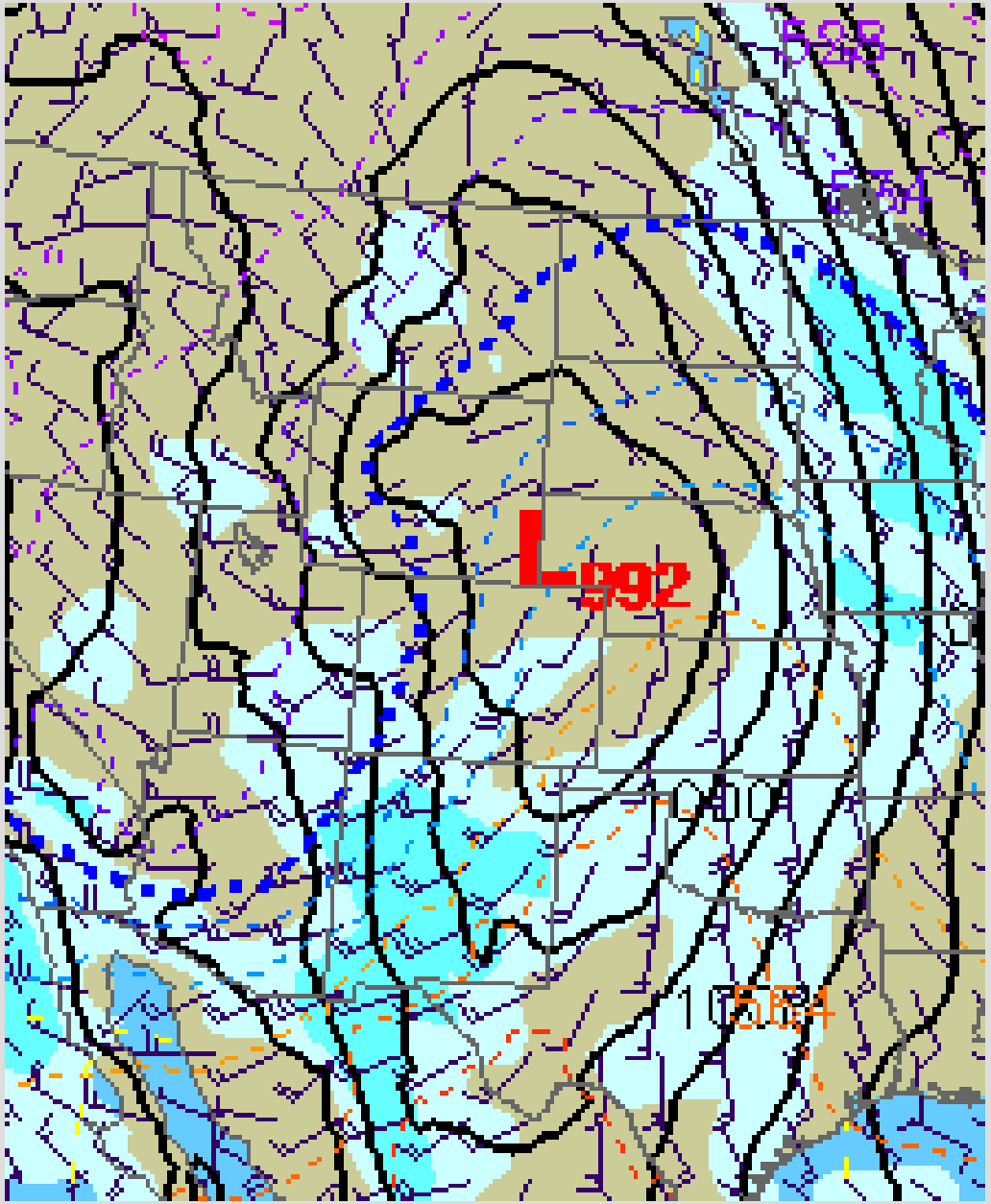

Air curves inward toward surface low pressure.

Mass convergence and rising motion




Air curves outward away from surface high pressure

Mass divergence and sinking motion.




**Zoom-in on surface low in Colorado from earlier.**

# Summary of Force Balances: Why the wind blows

| Force Balance | Forces Involved | Where it happens |
|---|---|---|
| Geostrophic | Pressure gradient and Coriolis | Winds at upper levels (with no curvature) |
| Gradient | Pressure gradient, Coriolis, and centripetal (or centrifugal) | Winds at upper levels with curvature. |
| Cyclostrophic | Pressure gradient and centrifugal | Smaller-scale, tight rotations like tornadoes and hurricanes |
| Gradient + Friction | Pressure gradient, Coriolis, centripetal, and friction | Surface winds |

# Reading Assignment and Review Questions

**Reading: Chapter 9**