

ESCI 107/109 – The Atmosphere  
Lesson 9 – Wind

**Reading:** *Meteorology Today*, Chapter 8

### ABOUT WIND

- Wind is the motion of the air.
- The direction of the wind is given by which direction it is blowing *from*. For example, a southerly wind means a wind blowing from the South.
- Wind speed is measured in *nautical miles per hour (knots)*. This is close to miles per hour, the conversion being 1 knot = 1.1 miles per hour.
- Wind is depicted on weather charts using a shaft to show the direction of the wind, and barbs to show speed. *A half barb is 5 knots, a full barb is 10 knots, and a filled in triangle barb is 50 knots.*

### FORCES AND MOTION

- The velocity of an object is the combination of its speed and the direction in which it is traveling
- Acceleration is defined as the change in velocity. This can be either
  - A change in speed (either increase or decrease)
  - A change in direction
- If the forces acting on an object are not in balance, then the object will accelerate.
- If the forces acting on an object are in balance (or, if there are no forces acting on the object), then the object's velocity will not change.
  - If it were stopped it would stay stopped
  - If it were moving, it would continue to move in the same direction and at the same speed.
- An object moving at a uniform speed around a circle is still accelerating, because its velocity is changing (the direction is changing). This acceleration is called the centripetal acceleration. Since it is accelerating, the forces on an object moving in a steady circle are not in balance.

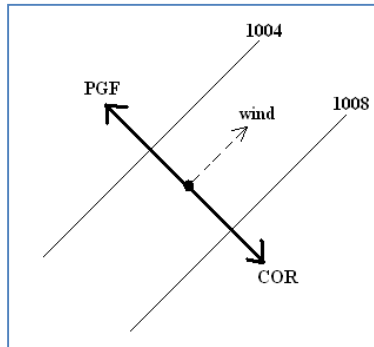
## WHAT CAUSES WIND?

- Wind is caused by pressure differences in the atmosphere, which set the air in motion.
- The forces that act on the air are
  - *Pressure Gradient Force (PGF)* – This is the force caused by the difference in air pressure on opposite sides of the air parcel. This force tries to push the parcel toward lower pressure.
    - The spacing of the isobars is called the *pressure gradient*. A closer spacing means a *tighter* or *steeper* gradient. A greater spacing means a *looser* gradient.
    - The tighter the pressure gradient, the stronger the pressure gradient force will be.
  - *Coriolis Force (CF)* – This force is a result of the fact that we are on a rotating planet. It is proportional to speed, and always acts to the right of the motion in the Northern Hemisphere (and to the left of the motion in the Southern Hemisphere).
  - *Friction (FR)* – Friction always acts to slow the air down, so it is always acting opposite to the direction of motion.
    - Friction is only important within a few kilometers of the earth's surface (in what is known as the *planetary boundary layer*). Above the planetary boundary layer we can assume that there is no friction.

## GEOSTROPHIC BALANCE

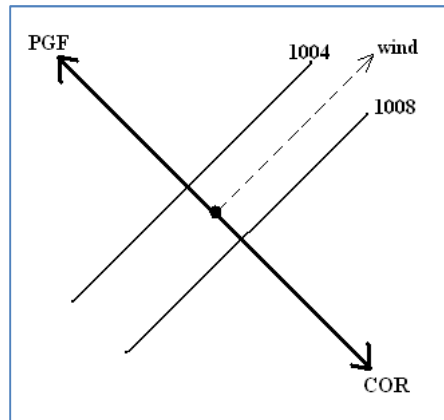
- Above the planetary boundary layer we can ignore friction. This leaves only two forces, PGF and CF.
- These two forces are usually very close to being in balance. This means that they must be acting in opposite directions. Since CF is always to the right of the direction of motion, then the PGF must be to the left. This means that

- **THE WIND BLOWS ALONG LINES OF CONSTANT PRESSURE, WITH LOWER PRESSURE TO THE LEFT.**



**Force balance for geostrophic flow. Note that PGF and COR are equal and opposite.**

- **The balance between pressure gradient force and Coriolis force is called *geostrophic balance*.**
- **If the pressure gradient is tighter, the PGF will be stronger. This means the Coriolis force will also have to be stronger to balance the PGF. The only way to increase the CF is to speed up the wind. Thus**
  - **A TIGHTER PRESSURE GRADIENT MEANS FASTER WINDS.**



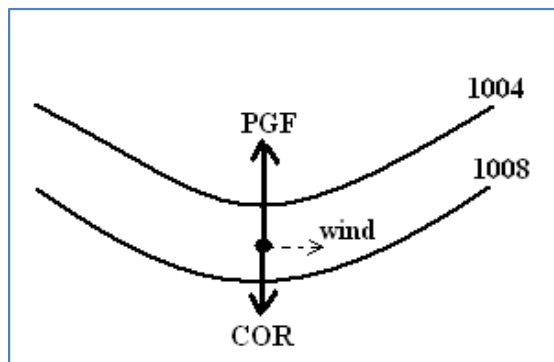
**A tighter pressure gradient means larger PGF which requires larger COR to balance it. Larger COR implies faster wind speed.**

- **Since the atmosphere is close to being in geostrophic balance, we can infer wind direction and relative wind speed just by looking at the isobar pattern.**

- **BUYS BALLOTT'S LAW** – In the northern hemisphere, if you stand with your back to the wind, low pressure will be to your left.

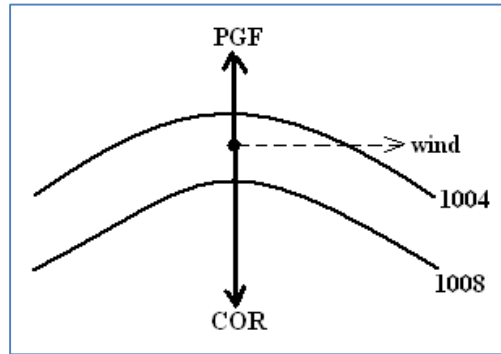
### CURVED FLOW (THE GRADIENT WIND)

- In geostrophic flow the pressure gradient force exactly balances the Coriolis force.
- However, if the atmosphere were exactly in geostrophic balance, then the flow would always be in a straight line. This is because curved flow is accelerating (changing directions).
- We know that flow in the atmosphere is often curved. There is counterclockwise flow around low-pressure systems, and clockwise flow around high-pressure systems.
- Counterclockwise flow is known as *cyclonic flow*, so low-pressure systems are known as cyclones.
- Clockwise flow is known as *anticyclonic flow*, so high-pressure systems are known as anticyclones.
- In curved flow, there must be a net force toward the center of the curvature. The pressure gradient force and Coriolis force can't balance in curved flow.
- The larger of the two forces must point toward the center of the curvature.
- In cyclonic flow the pressure gradient force is stronger than the Coriolis force.



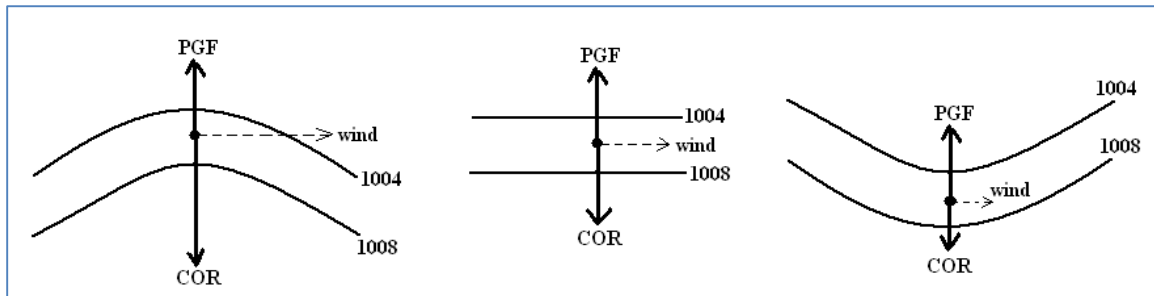
Force balance in cyclonic flow. Larger force must point toward center of curve. Therefore, in cyclonic flow the PGF is larger than the COR.

- In anticyclonic flow the pressure gradient force is weaker than the Coriolis force.



Force balance in anticyclonic flow. Larger force must point toward center of curve. Therefore, in anticyclonic flow the COR is larger than the PGF.

- The flow around curved isobars is called *gradient flow*.
- Assuming that the pressure gradient remains the same, the flow around an anticyclone will be stronger than straight flow, and the flow around a cyclone will be weaker than for straight flow.



Comparison of force balance and wind for anticyclonic, straight (geostrophic), and cyclonic flow. Note that the PGF is the same in all three cases, since the isobar spacing is the same. But, the COR (and hence, the wind speed) is different in each case.

## UPPER AIR CHARTS

- Instead of mapping the pressure distribution at a constant altitude, meteorologists prefer to work on surfaces of constant pressure, and draw lines of constant height.

- On a constant pressure chart the rules for determining wind direction and speed are identical to those on a constant height chart. You just replace the word “pressure” with “height.” Therefore,
  - THE WIND BLOWS ALONG LINES OF CONSTANT HEIGHT, WITH LOWER HEIGHTS TO THE LEFT.
  - A TIGHTER HEIGHT GRADIENTS MEAN FASTER WINDS.
- Thus, whether you are using a constant height chart or a constant pressure chart, all the rules are the same, so you don’t need to get confused.

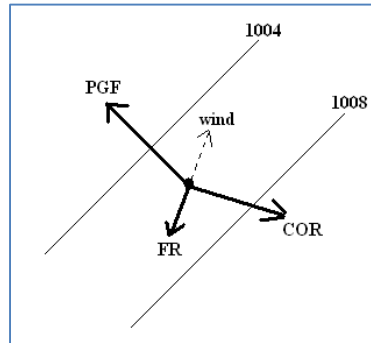
### TROUGHS AND RIDGES

- Isobars and height contours don’t always formed closed circles (highs and lows). Instead, they are just “kinked” and form “troughs” and “ridges” instead.
- To see whether a kink is a trough or ridge, you need to look at how the values of pressure or height change as you approach the axis of the kink.
  - If the numbers get smaller, it is a trough.
  - If the numbers get larger, it is a ridge.
- The flow around a trough is cyclonic.
- The flow around a ridge is anticyclonic.

### SURFACE WINDS AND THE ROLE OF FRICTION

- Near the surface of the Earth we have to include the effects of friction. This adds a third force to the balance of forces.
- Friction always acts opposite to the direction of motion.
- Friction slows-down the wind. This causes the wind to be lighter than it would be in either geostrophic or gradient flow.

- *In order for the three forces to be in balance the wind must point slightly toward lower pressure and slightly away from higher pressure.*



Force balance in straight flow with friction (FR). In order for the three forces to balance, the wind must blow slightly across the isobars toward low pressure.

- Since friction causes the flow to blow slightly toward lower pressure, a surface low (or cyclonic circulation) will have converging winds and a surface high will have diverging winds.
- This is why lows are associated with upward motion, clouds, and bad weather, while highs are associated with downward motion (*subsidence*), clear skies, and fair weather.