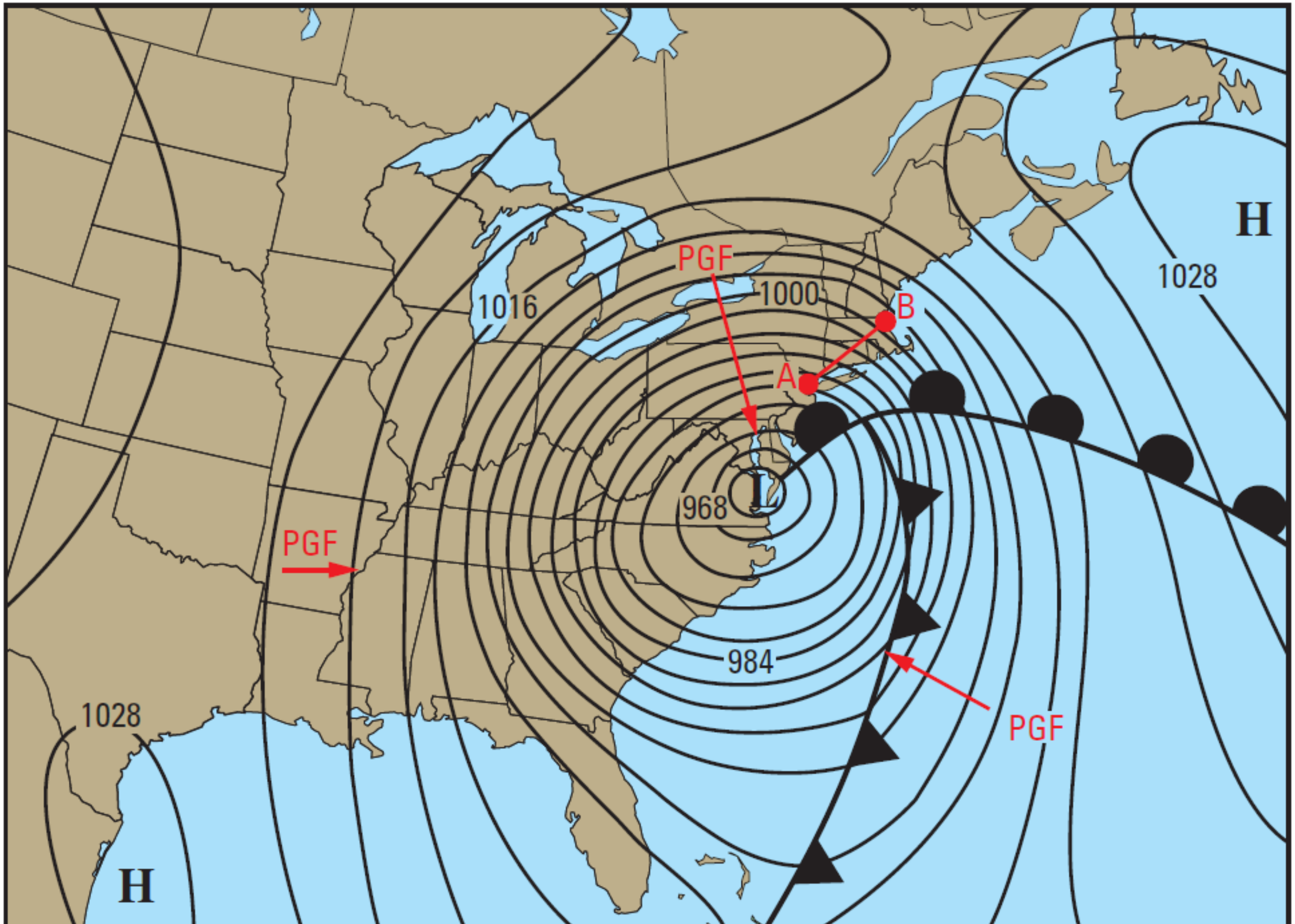
MET 4300/5355

Lecture 7:
Forces & Balanced Motions (CH7)

Why does air move?
Pressure and Wind in the Atmosphere are Coupled



Newton’s Laws of Motion Govern the Wind

1. Every object in a state of uniform motion (or at rest) will remain in that state of motion (or rest) unless an external force is applied.
2. Force is equal to mass times acceleration. Acceleration and force are vectors.

What Forces Act On the Wind?

- Fundamental forces:

  1) Pressure Gradient Force (PGF)

  2) Gravity: point downward

  3) Friction, which always acts to slow moving objects

- Apparent forces:

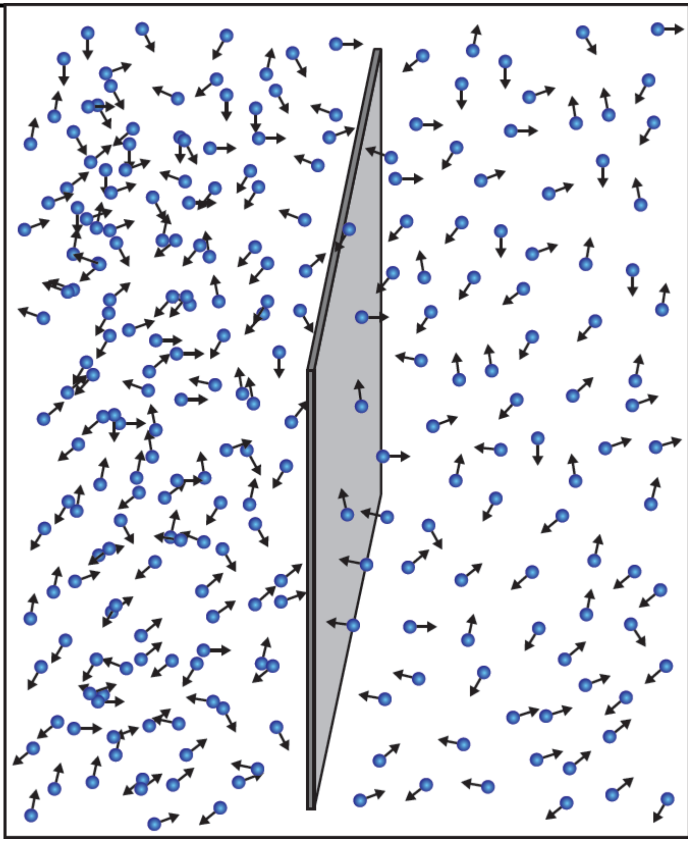
  1) Coriolis force results from Earth's rotation

  2) Centrifugal force: is usually combined with gravity

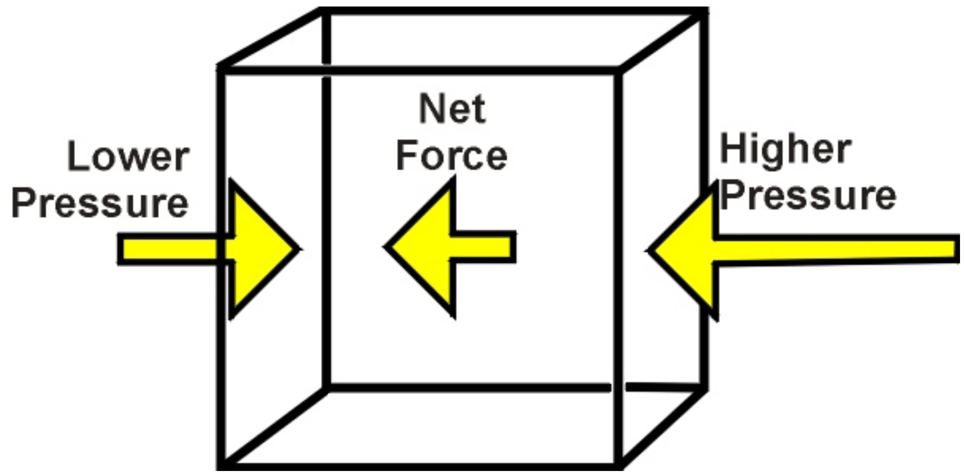
- PGF and Coriolis forces are most important…

Pressure Gradient Force

Pressure difference can result from a difference in air density (more molecules), air temperature (more energy per collision, in this case there must be no volume change, i.e. in a closed system), or both.

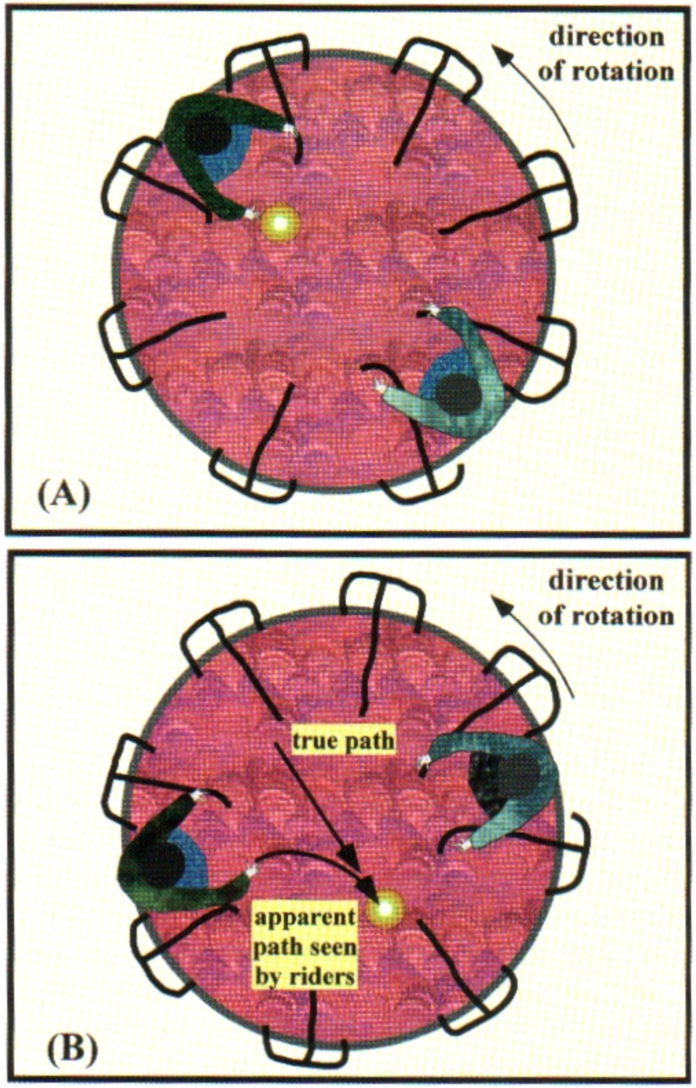


A wall with higher pressure on its left side



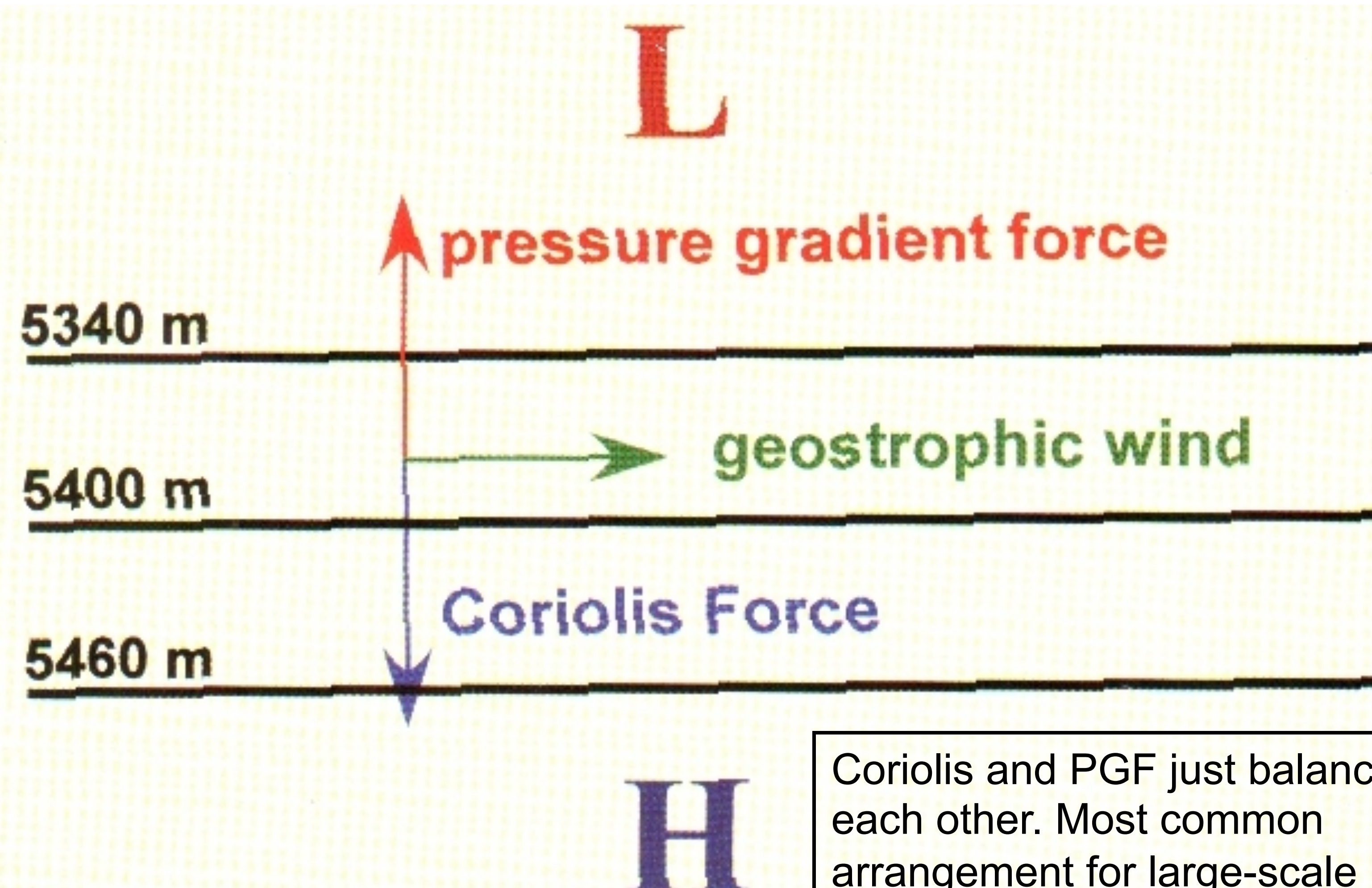
PGF tries to squeeze air toward lower pressure

Coriolis Force



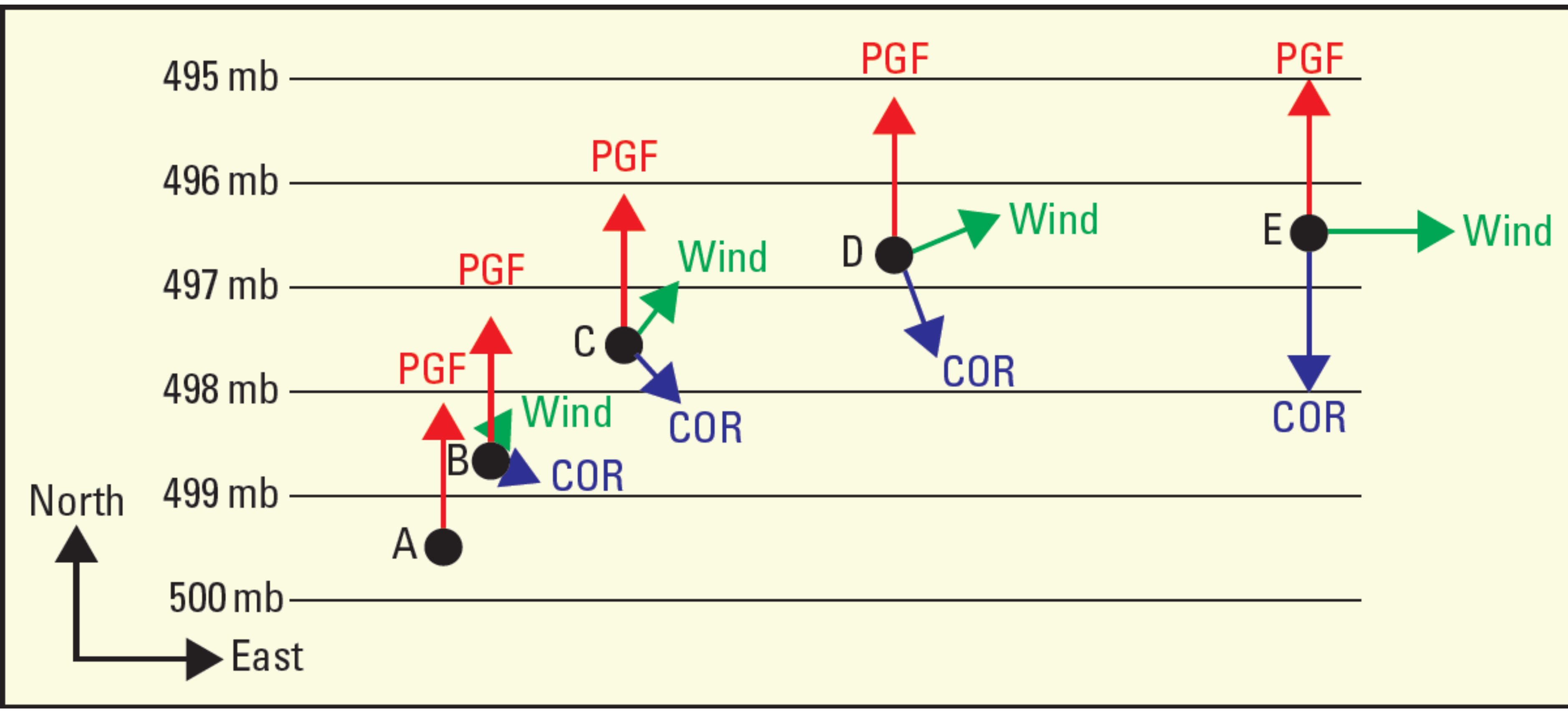
- **In a rotating reference frame, objects following straight paths appear to move in curved paths.**
- **This leads to the "Coriolis Force" which is an apparent force that lets us forget that we are on a rotating planet once we take it into account.**
- **In the northern hemisphere, it deflects moving objects to the right of their motion**
- **To the left in the southern hemisphere**
- **Affects the direction when an object moves, but has no effect on its speed**
- **The Coriolis force's magnitude is proportional to the object's speed of motion and the trigonometric sine of the latitude: strongest for fast moving objects, zero for stationary objects**
- **The Coriolis force is zero at the equator, and maximum at the poles**

Geostrophic Balance



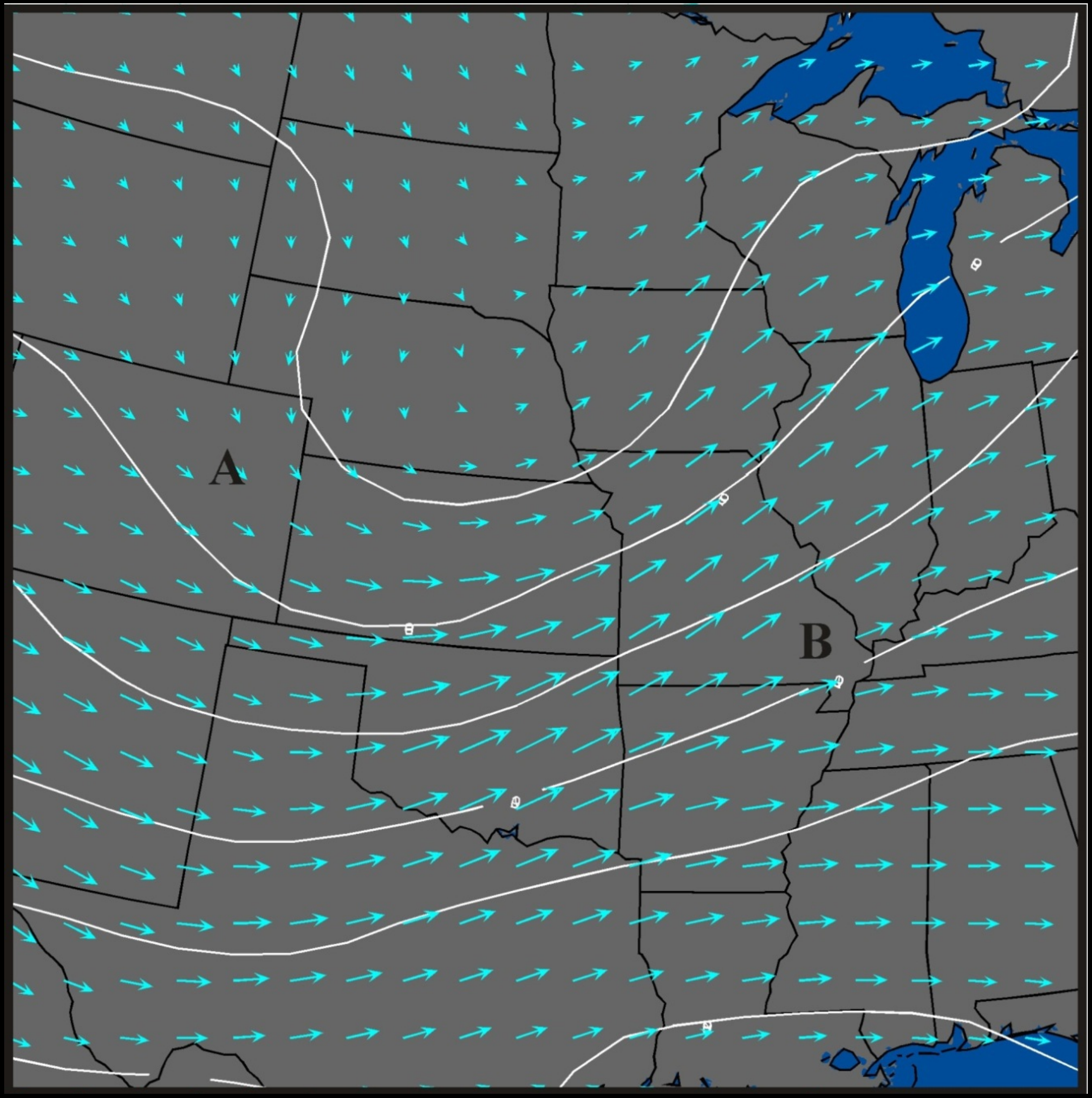
Coriolis and PGF just balance each other. Most common arrangement for large-scale atmospheric motions

How does the wind get to be balanced?

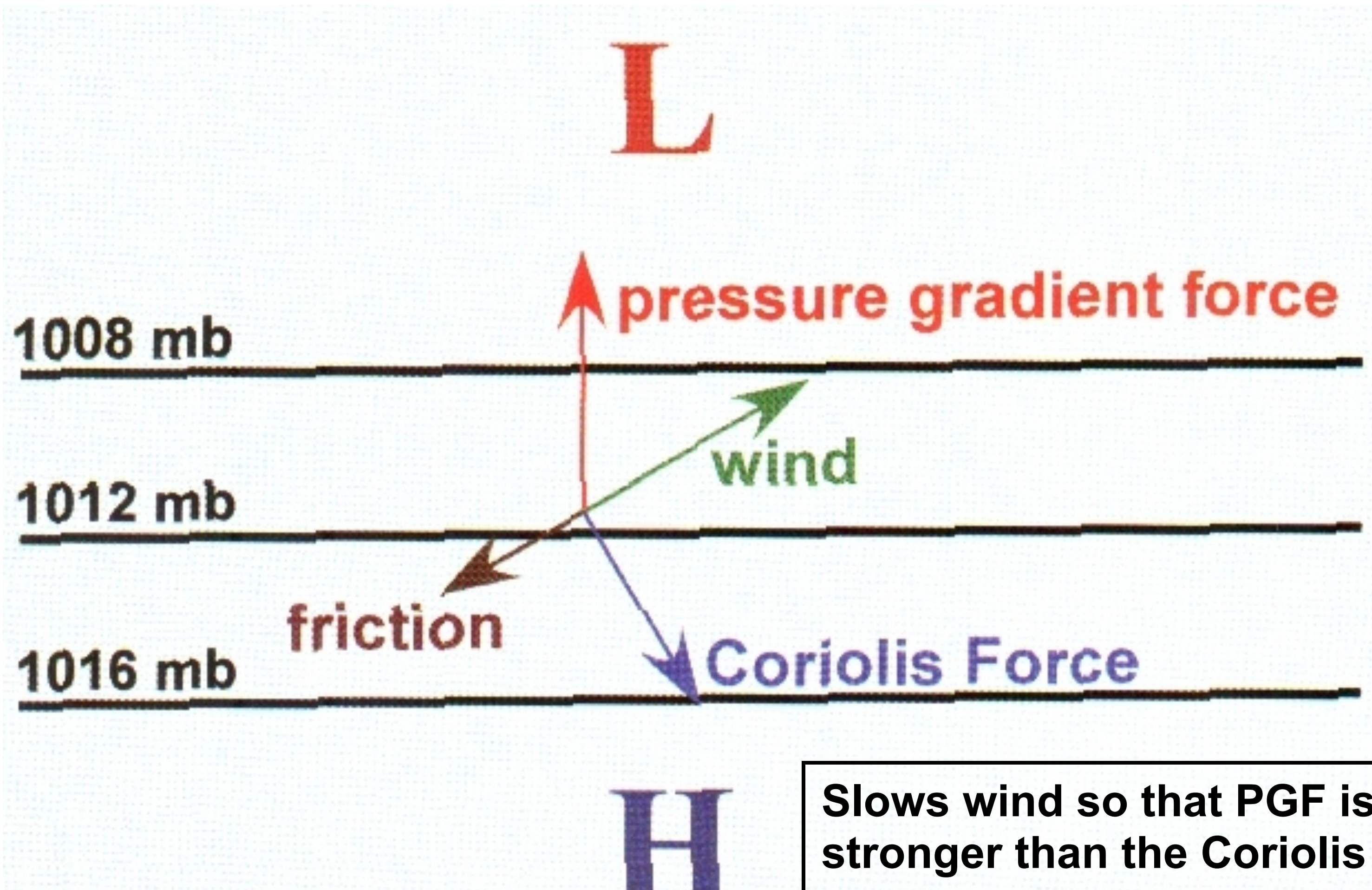


Balanced Winds at 500 mb

- Geostrophic winds flow parallel to straight isobars (or height contours)
- The higher the pressure gradient (less spacing between isobars), the stronger the geostrophic winds.
- In NH, the higher pressures (heights) are to the right of the geostrophic winds.

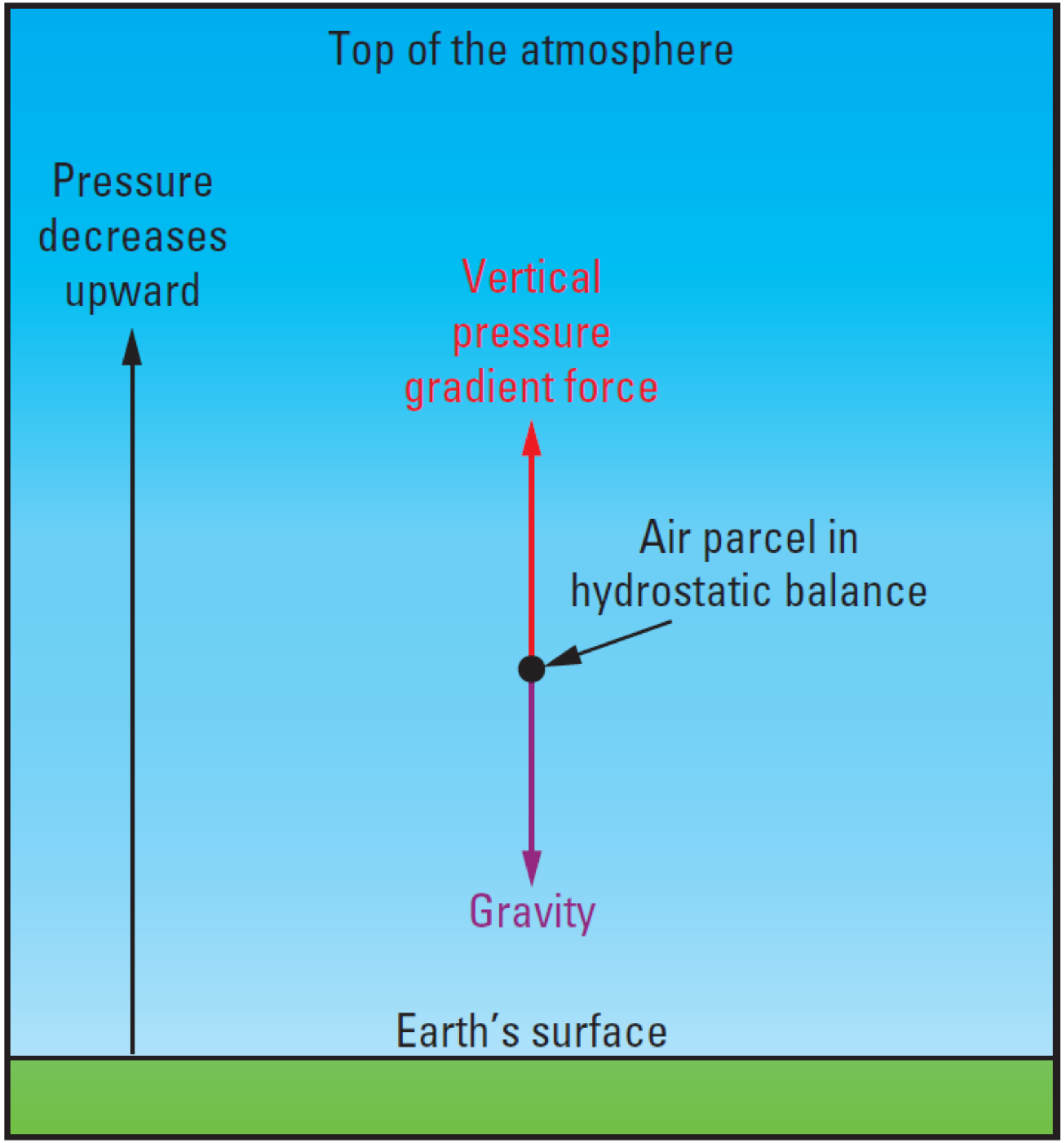


Effect of Friction



Slows wind so that PGF is stronger than the Coriolis force causing near-surface winds to blow toward lower pressure: convergent cyclonic flow!

Hydrostatic Balance



Not in thunderstorms

TABLE 7.1 Newton's Second Law for Horizontal and Vertical Motions (PGF denotes the Pressure Gradient Force)

Type of Motion	Newton's Second law
Horizontal motions above the boundary layer	Acceleration = Horizontal PGF + Coriolis Force
Horizontal motions within the boundary layer	Acceleration = Horizontal PGF + Coriolis Force + Friction
Vertical motions	Acceleration = Vertical PGF + Gravity

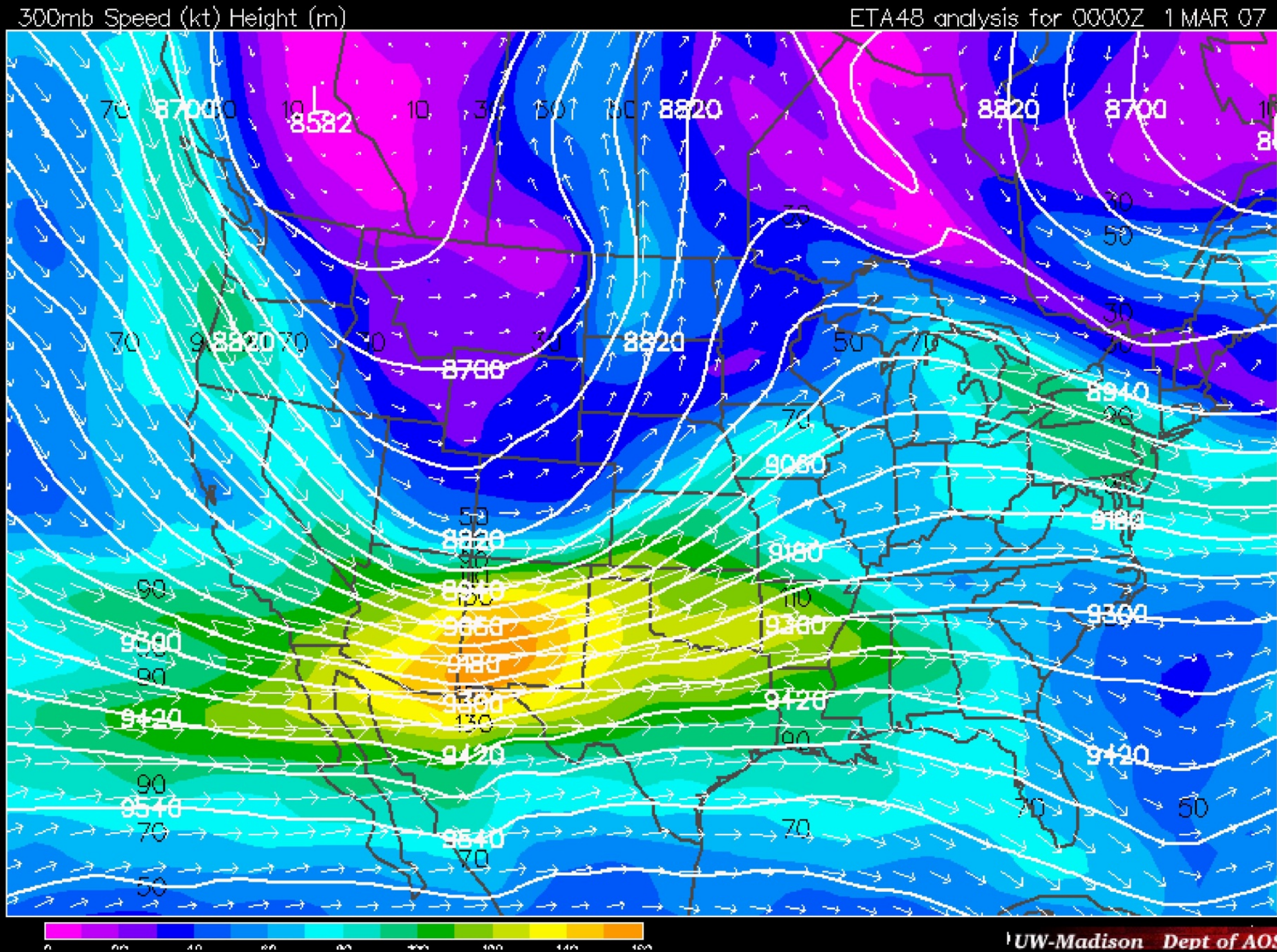
TABLE 7.2 Summary of the Properties of Forces Acting on Air in the Earth's Atmosphere

Force	Direction in Which Force Acts	Strength Depends on	Effect on Air	Balances
Vertical Pressure Gradient Force	Upward, from higher to lower pressure	Magnitude of the vertical pressure gradient	Accelerates air vertically toward lower pressure	Hydrostatic balance when equal and opposite to gravitational force
Horizontal Pressure Gradient Force	Horizontally, from higher to lower pressure	Magnitude of the horizontal pressure gradient	Accelerates air horizontally toward lower pressure	Geostrophic balance when equal and opposite to Coriolis force
Coriolis Force	To the right (left) of the wind direction in the Northern (Southern) Hemisphere	Wind speed and latitude	Affects wind direction, but no effect on wind speed	Geostrophic balance when equal and opposite to horizontal pressure gradient force
Frictional force	Opposite the direction of the flow	The roughness of the underlying surface	Reduces air velocity, important primarily in boundary layer	________
Gravitational force	Toward the center of the Earth	Essentially constant in the troposphere	Accelerates air downward	Hydrostatic balance when equal and opposite to vertical pressure gradient force.

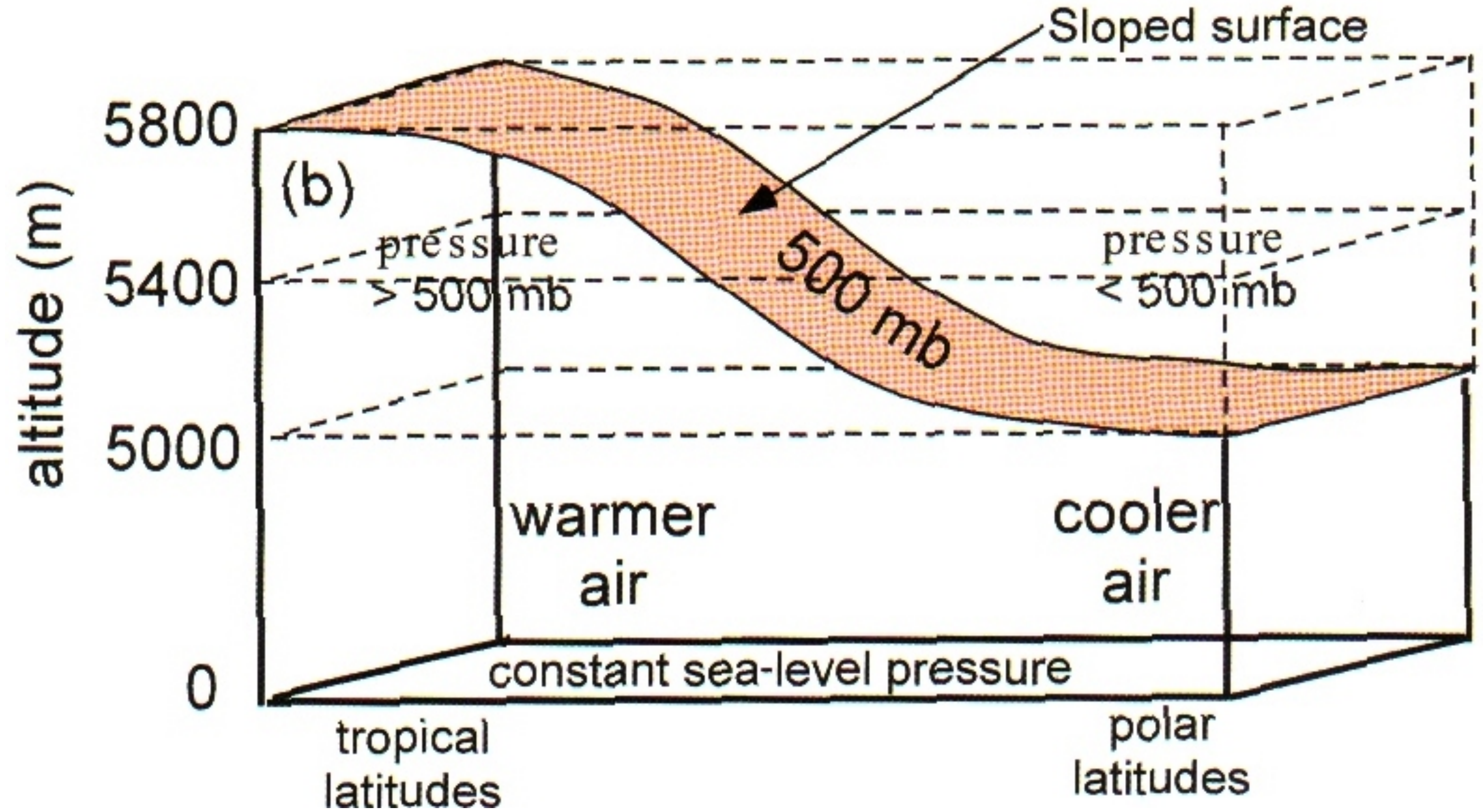
Jetstream

- A narrow band of strong winds that encircles the Earth in the mid-latitudes.
- Typically 300-500km wide
- Located near the tropopause at 250 mb, sometime down to about 500mb
- Three jetstreams: Subtropical, polar, and arctic (they often merge & interact)
- Jetstreaks: Regions of exceptionally strong winds within the jetstream.

Jet Stream


300mb Speed (kt) Height (m)
ETA48 analysis for 0000Z 1 MAR 07
UW-Madison Dept of AOS

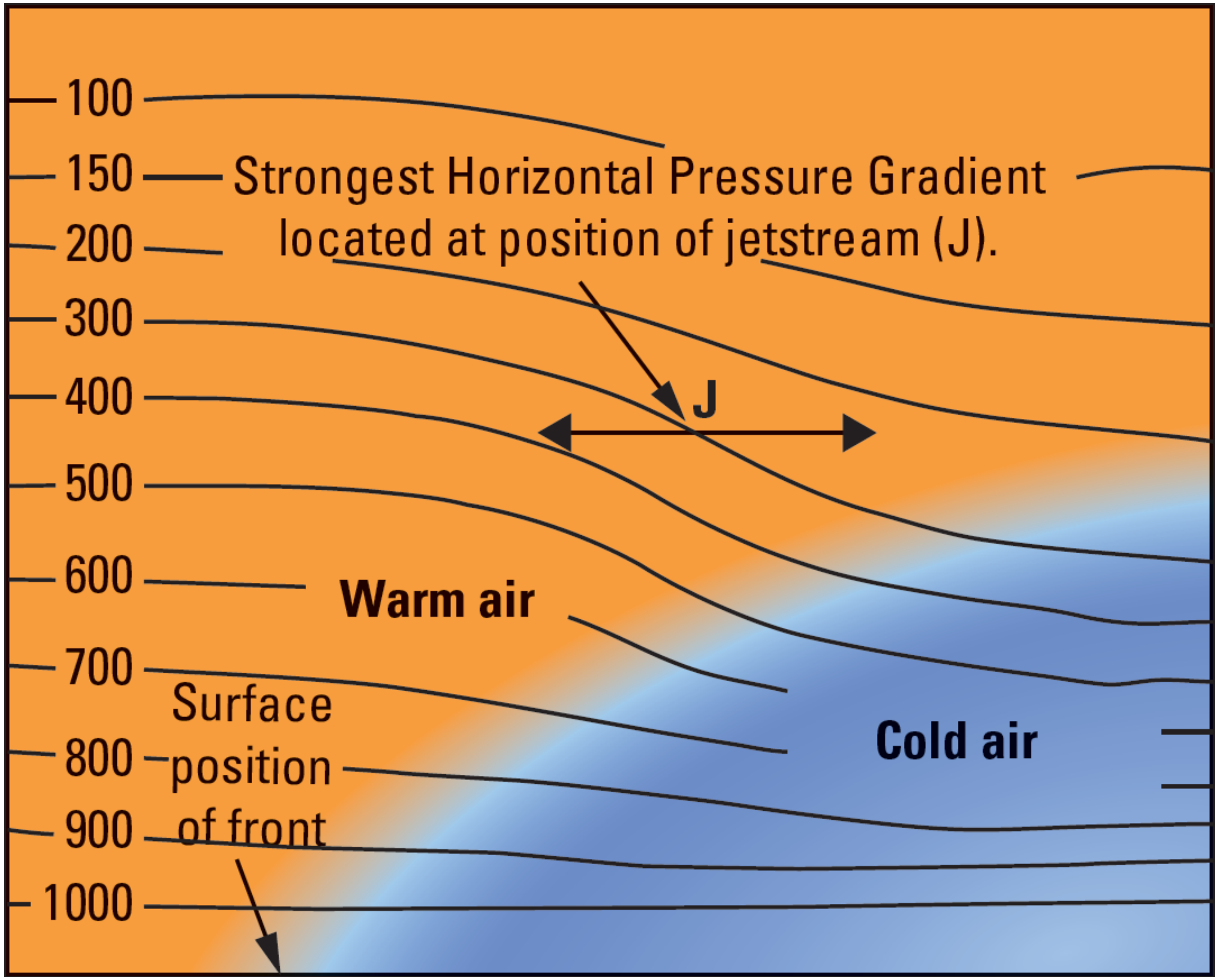
Temperature Gradients and Thermal Wind: how does the jetstream form?



1. Winds increase with height in the troposphere: because pressure surfaces at higher altitudes slope more steeply than those at lower altitudes.

2. Upper troposphere winds have a west to east component: geostrophic balance; PGF is directed poleward toward cold air.

Pressure Surfaces Across A Front



1. Pressure surfaces slope downward toward cold air in regions of strong temperature gradients.
2. The strongest slope occur over the front.
3. The horizontal PGF and strongest winds (e.g. jet stream) occur where the slope of the pressure surfaces is steepest.
4. Winds are directed out of the page in NH.
5. Fronts and jet streams are closely related.

Summary

- Newton’s laws of motion
- Forces: Pressure Gradient, Coriolis, Friction, “Centrifugal”…
- Geostrophic balance between PGF & Co
- Friction causes cross-isobar flow to low pressure
- Hydrostatic balance: Vertical pressure gradient balances gravity
- Thermal wind: Horizontal temperature gradients lead to increasing height gradients aloft and shear of geostrohic wind
- Strong temperature gradients along (surface & upper) fronts cause jet streams.