Vertical Pressure Gradients and Circulation

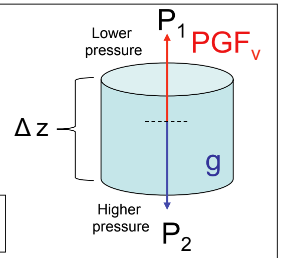
- *Vertical* pressure differences (gradients) in the vertical are nearly balanced by gravity
- This balance is called the *hydrostatic balance*

Vertical

$$\frac{1}{\rho}\frac{\Delta P}{\Delta z} = -g$$

Acceleration due to *vertical* pressure differences (gradients)

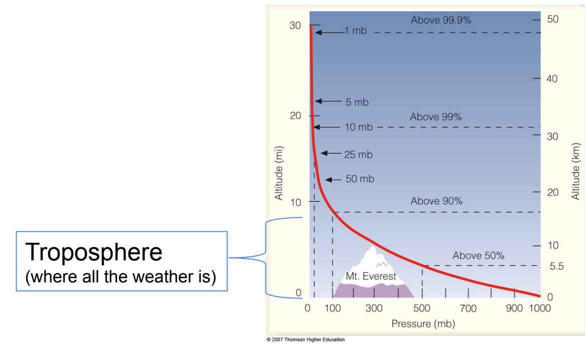
Acceleration due to gravity



- It holds to within 0.01% in the atmosphere and ocean
- Hence, vertical motions are weak

Vertical Pressure Gradients and Circulation

- *Vertical* pressure differences (gradients) in the vertical are nearly balanced by gravity
  - Hence, vertical motions are weak
  - Pressure decreases with increasing height

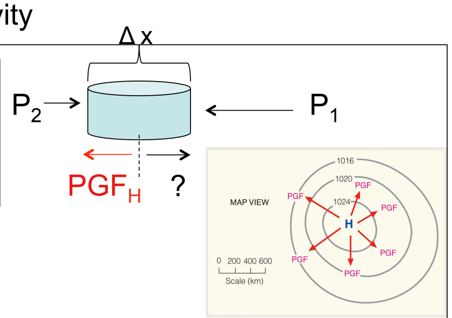


Horizontal Pressure Gradients and Circulation

- *Horizontal* pressure differences (gradients) are weak but *not* balanced by gravity

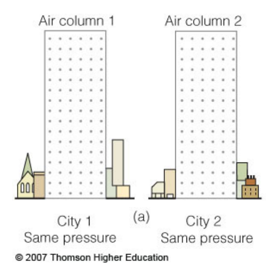
$$\frac{1}{\rho}\frac{\Delta P}{\Delta x} = ?$$

Acceleration due to *horizontal* pressure differences (gradients)

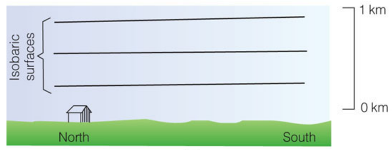


- Hence, horizontal pressure gradients drive winds
  - Air is forced (accelerated) from high towards low pressure
- The larger the pressure difference, the greater the acceleration
- E.g., sea breeze, wind gust, etc.

Sea Breeze driven by horizontal pressure gradients



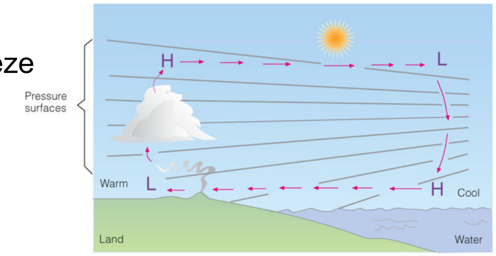
Sea Breeze driven by horizontal pressure gradients



(a)

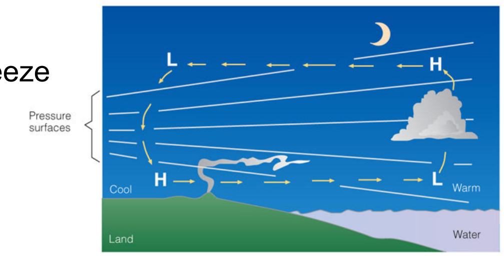
Sea Breeze driven by horizontal pressure gradients

Sea Breeze



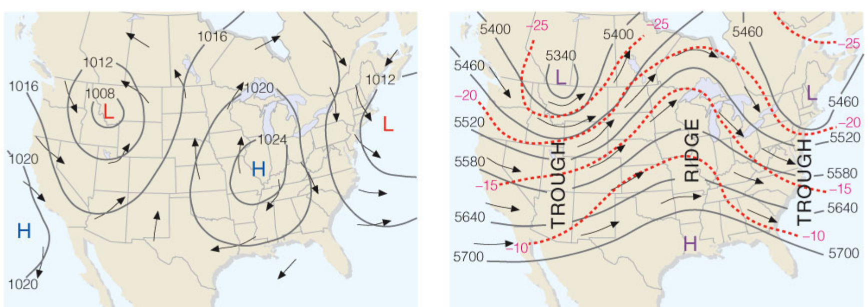
(a) Sea breeze

Land Breeze



(b) Land breeze

Horizontal Forces & Circulation

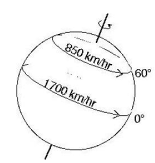


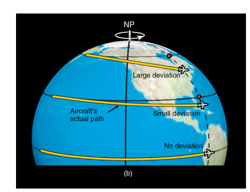
(a) Surface map (b) 500-millibar map

- **On a weather map (or on any map of atmospheric flows last longer than a few hours)**
  - The wind is not accelerating in the direction of the horizontal pressure gradient! In fact, the wind blows along a line of constant pressure.
  - E.g.,mid-latitude cyclones, jet stream
- **Why?**

Coriolis Effect

- If the *horizontal* pressure gradients last long enough (longer than several hours) or the air displacement is large enough (1000 of km) rotation of the earth greatly affects the motion
- In these cases, the air experiences the Coriolis Effect (or Force) which is a frame-of-reference effect: the combined effect of
  - Observers reference frame (on earth) is rotating
  - Gravity acting to keep air on the spherical Earth

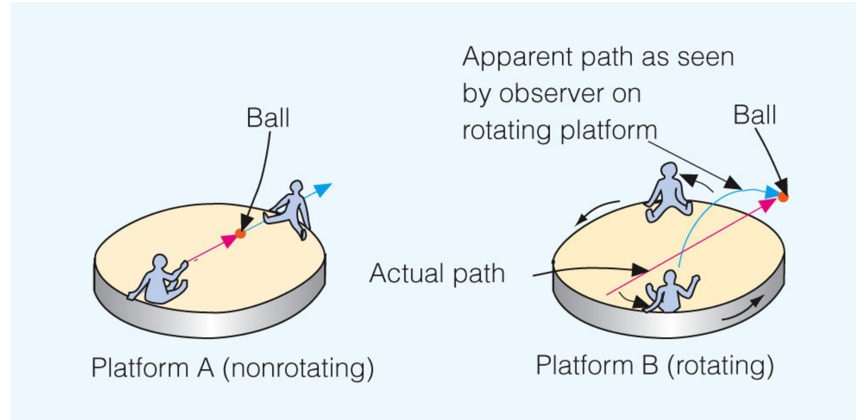




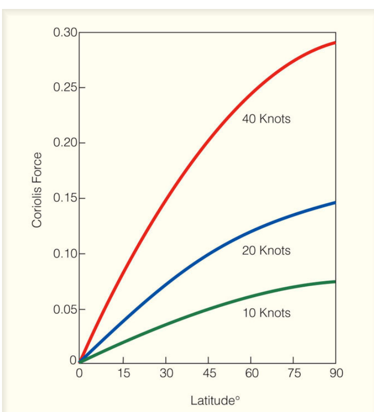
In the net, air moving in the northern hemisphere experiences an *apparent force* to the right of motion

Coriolis Effect (“Force”)

An imperfect analog to understanding frame of reference



The Coriolis Force (CF) depends on latitude and wind speed



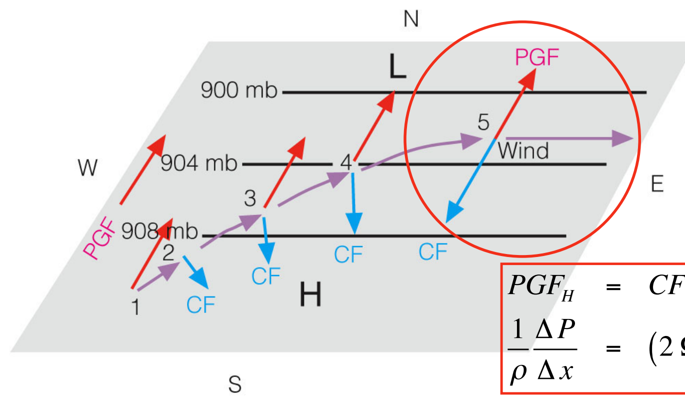
$$CF = (2\,\Omega \sin\phi) * V$$

where Φ is latitude and Ω is a constant and V is the speed of the air relative to the rotating Earth (ie, as seen by an observer rotating with the earth)

Stronger wind => Stronger CF
Higher latitude => Stronger CF

Fig. 8-21, p. 205

When the horizontal pressure gradient balances the Coriolis Force the air is said to be in *geostrophic balance*

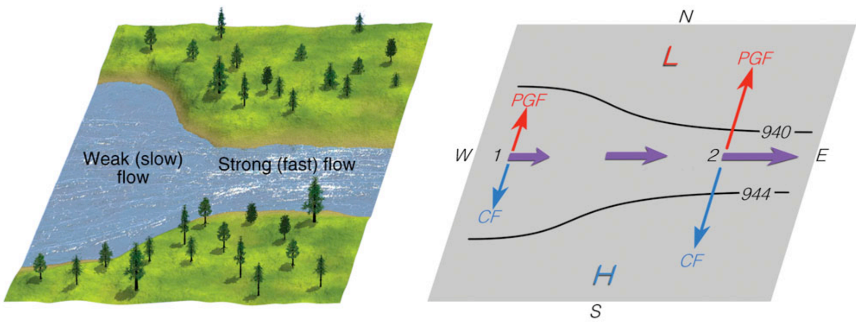


$$PGF_H = CF$$

$$\frac{1}{\rho}\frac{\Delta P}{\Delta x} = (2\,\Omega \sin\phi) * V$$

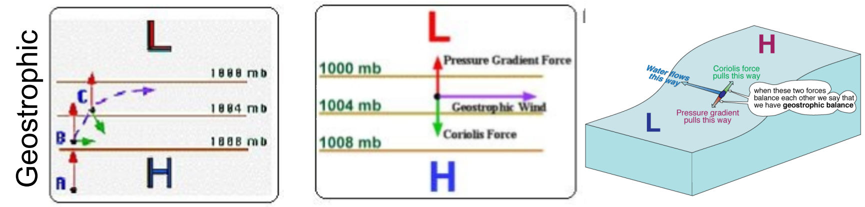
In geostrophic balance, the wind blows *along* a line of constant pressure (an isobar)

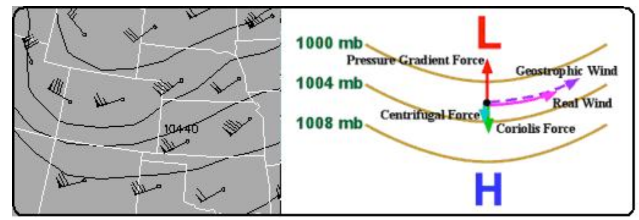
Geostrophic Wind



The stronger the PGF_v, the stronger the CF
(hence, the stronger the wind)

The Horizontal Wind is nearly Geostrophic

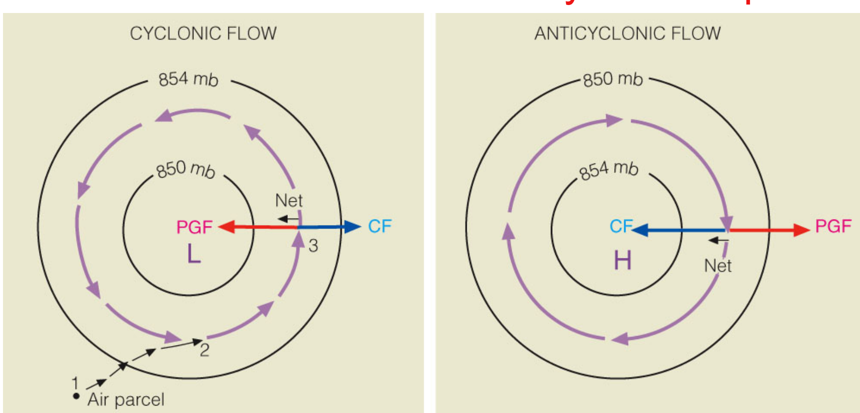




Nearly Geostrophic Flow
(it is curved)

Northern Hemisphere

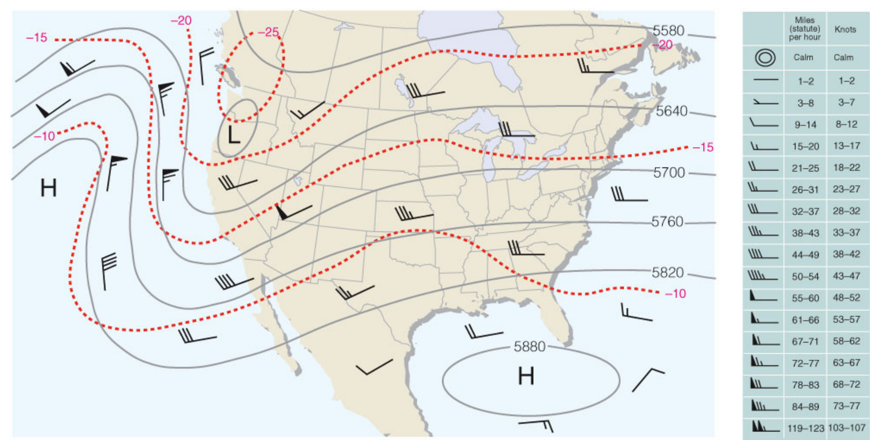
The Horizontal Wind is nearly Geostrophic



(a) Low pressure area (cyclone) aloft
(b) High pressure area (anticyclone) aloft

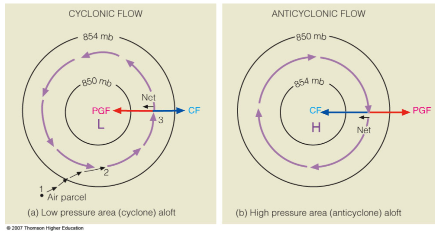
Northern Hemisphere

The flow at ~ 5.6km is nearly Geostrophic

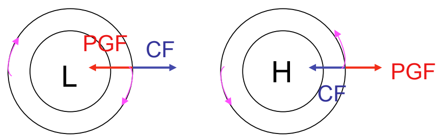


- **The flow is nearly perfect *geostrophic balance***
  - the *horizontal* pressure gradients are balanced by Coriolis Force, and the wind blows along a line of *constant* pressure
- **E.g.,day to day weather, mid-latitude storms, jet stream, monthly flows , seasonal flows ..**

The Horizontal Wind is nearly Geostrophic



Northern Hemisphere



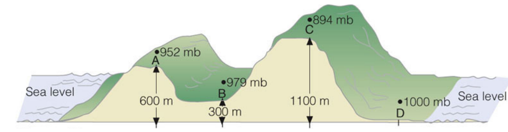
Southern Hemisphere

The CF acts to accelerate the air to the left of the motion in the Southern Hemisphere

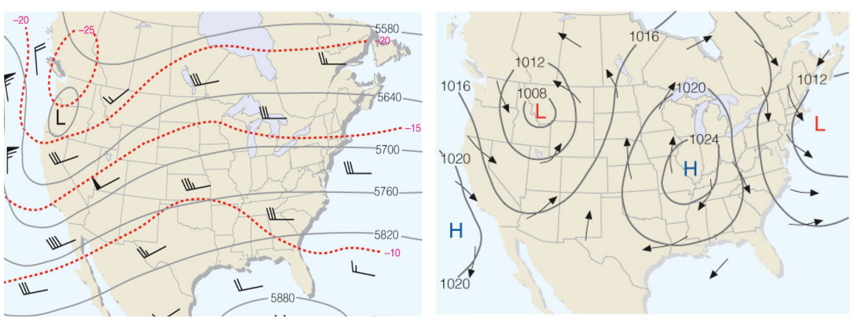
Sea Level Pressure

To determine horizontal pressure gradients that drive winds, we need to compare pressures at the same elevation

Surface Pressure



Horizontal Forces & Circulation

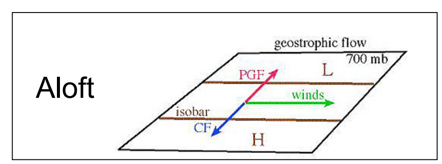


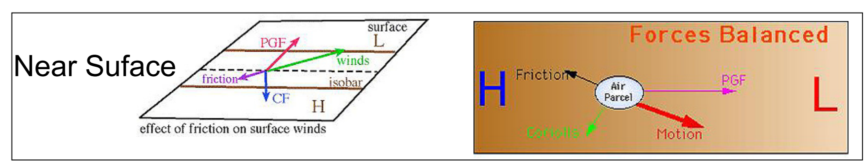
(a) Surface map

- Aloft, the flow is nearly in perfect geostrophic balance (PGF balanced by CF, so the flow is along an isobar (line of constant pressure)
- What about the flow near the surface? Is it in geostrophic balance?

Near Surface Winds

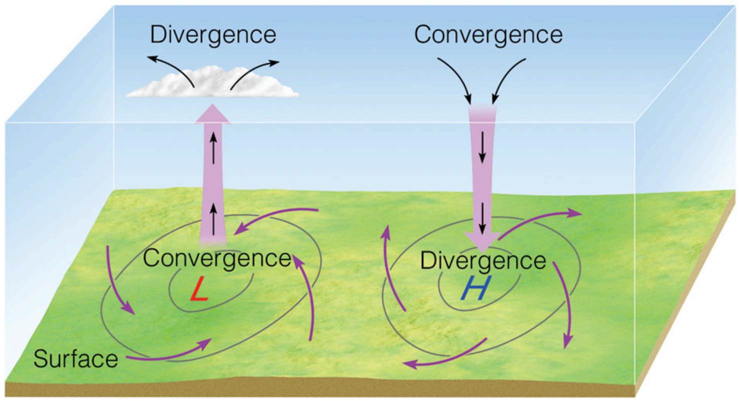
They feel PGF_H, CF *and* friction from the rough surface





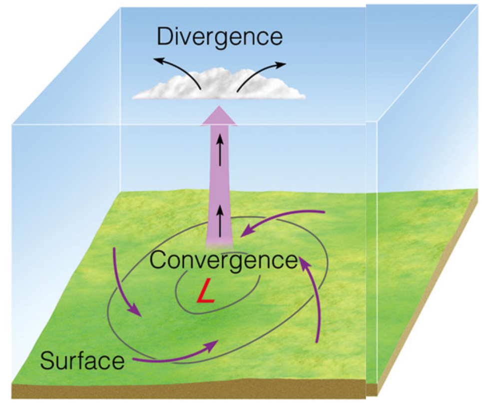
Averaged over many hours, the net force balance is zero and so at the surface there is a small component to the wind that blows toward the low pressure.

Hence, air tends to flow out of a surface high, causing sinking motion and convergence aloft (fair weather)



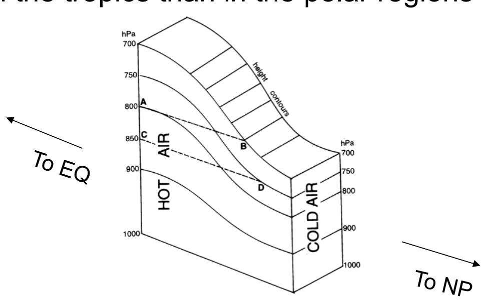
Conversely, air tends to flow into of a surface low, causing convergence and rising motions aloft (cloudy)

A very good analog for the Surface Low



Jets

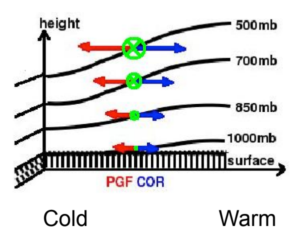
- The air column in the tropics is warmer than that at the poles. Hence, the density is less in the tropics so going up into the atmosphere, pressure drops more slowly in the tropics than in the polar regions

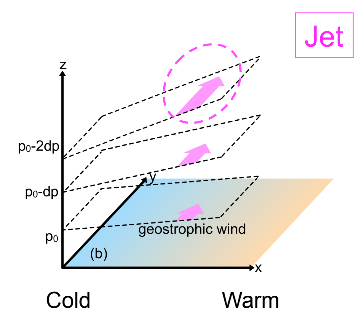


- Hence, a poleward pressure gradient develops as you go up from the surface

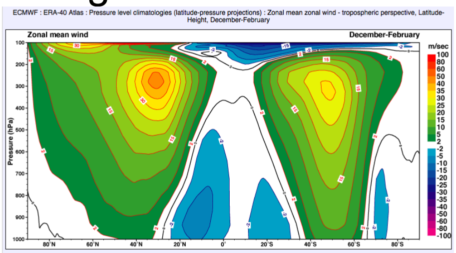
Jets

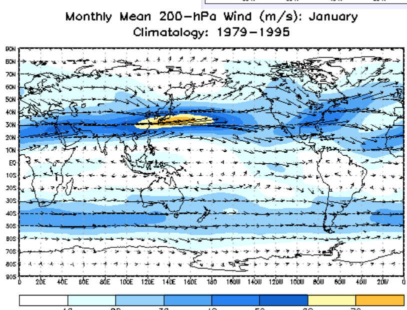
- A poleward horizontal pressure gradient develops and strengthens as you go up
- Air density decreases too, so the PGF_H becomes huge. Hence, the winds increase as you go up.

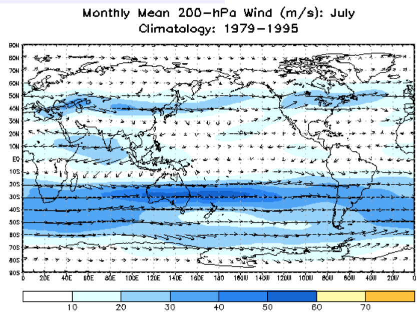




Climatological Winds at 200mb up







Movie http://www.cpc.ncep.noaa.gov/products/precip/CWlink/climatology/200wind/200windloop.gif