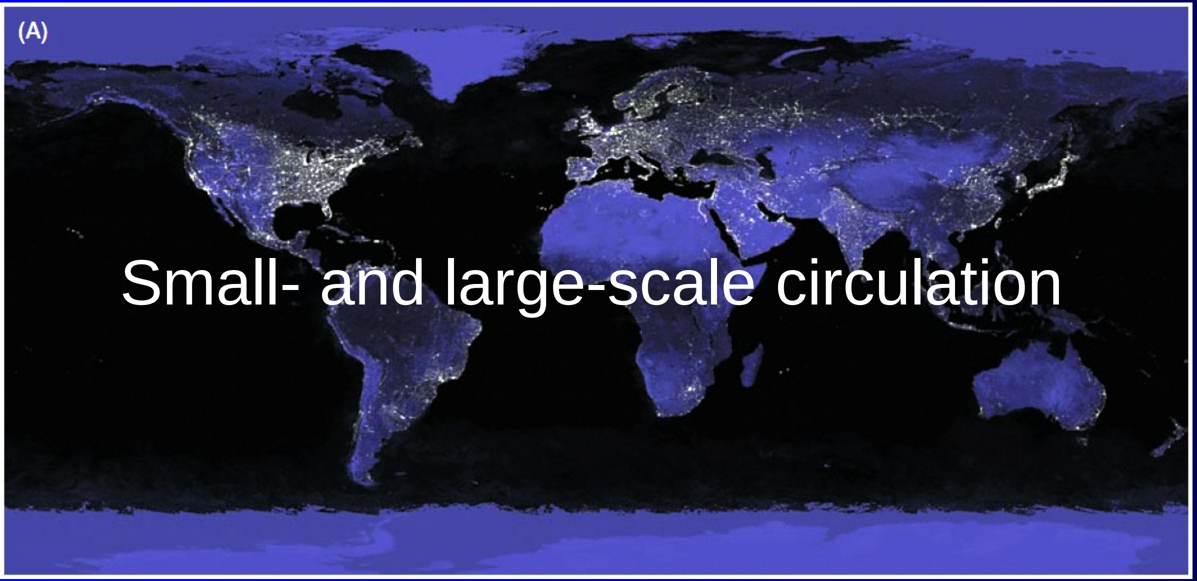
The Earth System - Atmosphere II



Small- and large-scale circulation

Atmospheric Circulation

1. Global atmospheric circulation can be thought of as a series of deep rivers that encircle the planet.

2. Imbedded in the main current are vortices of varying sizes including hurricanes, tornadoes and mid-latitude cyclones

Scales of Atmospheric Motion

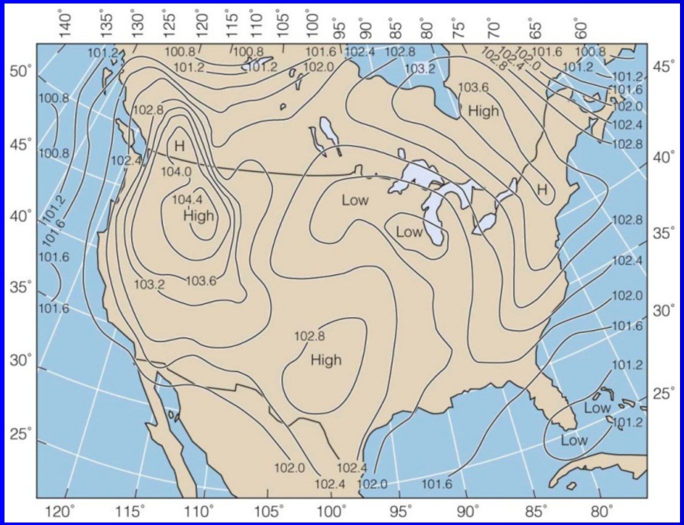
1. We sort weather events by size
2. The larger the event, the longer it lasts
3. Three major categories of atmospheric circulation - macroscale, mesoscale and microscale

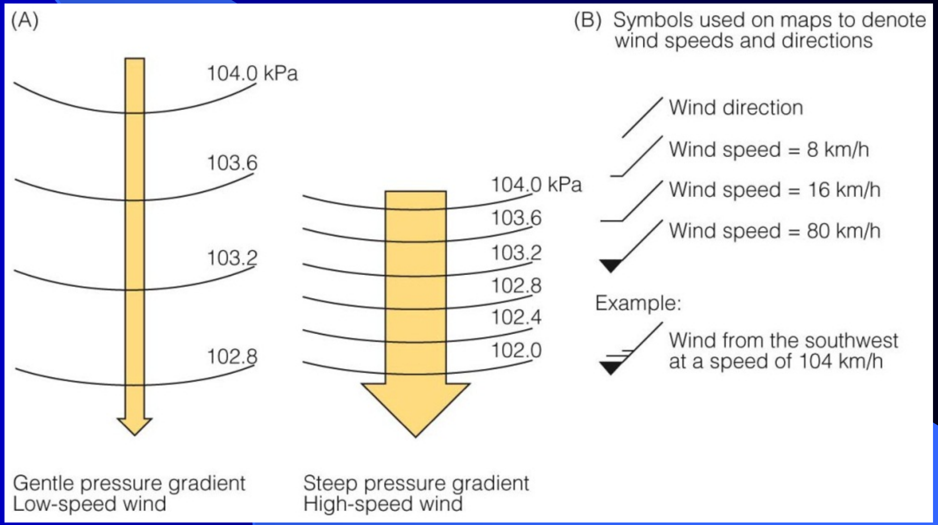
TABLE 7-1 Time and space scales for atmospheric motions

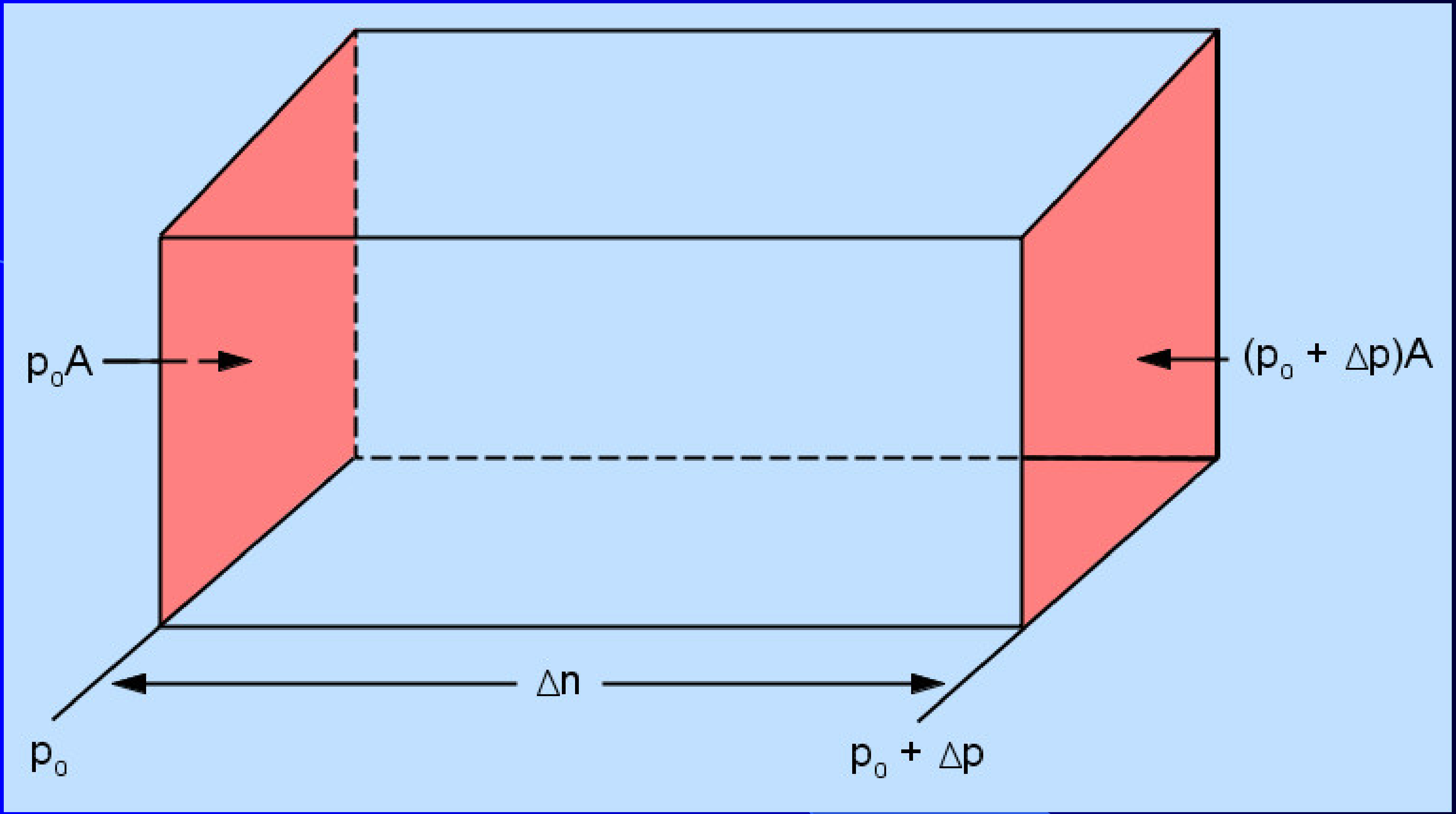
Scale	Time scale	Distance scale	Examples
Macroscale			
Planetary	Weeks or longer	1000–40,000 km	Westerlies and trade winds
Synoptic	Days to weeks	100–5000 km	Mid-latitude cyclones, anticyclones, and hurricanes
Mesoscale	Minutes to hours	1–100 km	Thunderstorms, tornadoes, and land–sea breeze
Microscale	Seconds to minutes	<1 km	Turbulence, dust devils, and gusts

- Wind is air movement that arises from differences in air pressure
  - Flowing from an area of high pressure to an area of low pressure
- Most places have wind speeds that average between 10 and 30 km/hr
- In places where temperatures drop below freezing, the windchill factor is reported
  - This is a measure of the heat loss from exposed skin due to low temperature and wind

- Pressure-gradient force
  - Air always moves from an area of high pressure to an area of low pressure, the stronger the pressure gradient, the stronger the resulting flow of air
  - Places of equal air pressure are shown on weather maps by lines called isobars
    - Analogous to contour lines on topographic maps
    - Isobars close together show a steep gradient
    - Isobars far apart show a low gradient







$F_M = p_o A - (p_o + \Delta p)A = -\Delta p \cdot A$

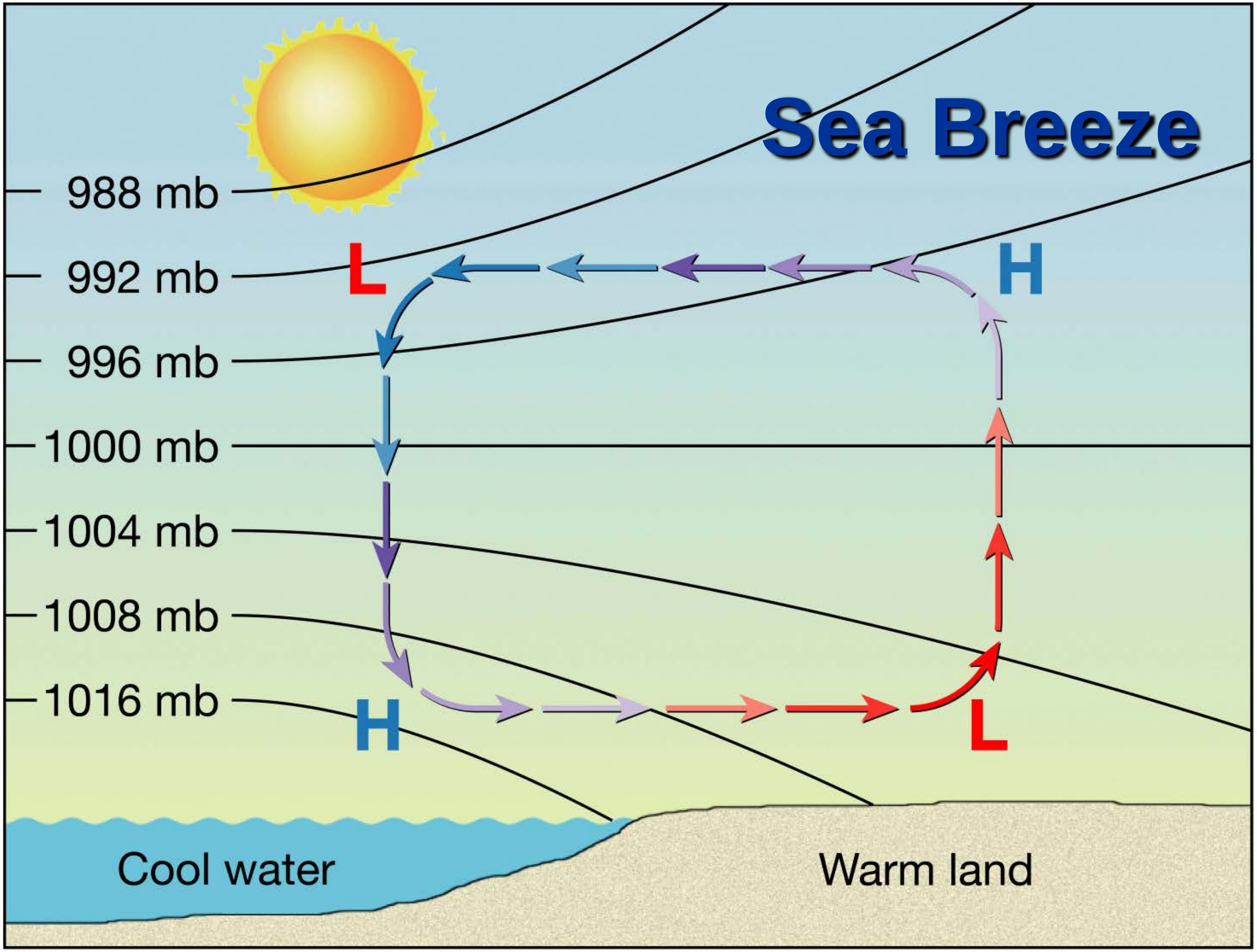
$M = \rho(A \cdot \Delta n)$

$$a = \frac{F}{m} = \frac{-\Delta p \cdot A}{\rho(A \cdot \Delta n)} = -\frac{\Delta p}{\rho \Delta n} = -\frac{1}{\rho}\frac{\Delta p}{\Delta n} = -\alpha\frac{\Delta p}{\Delta n}$$

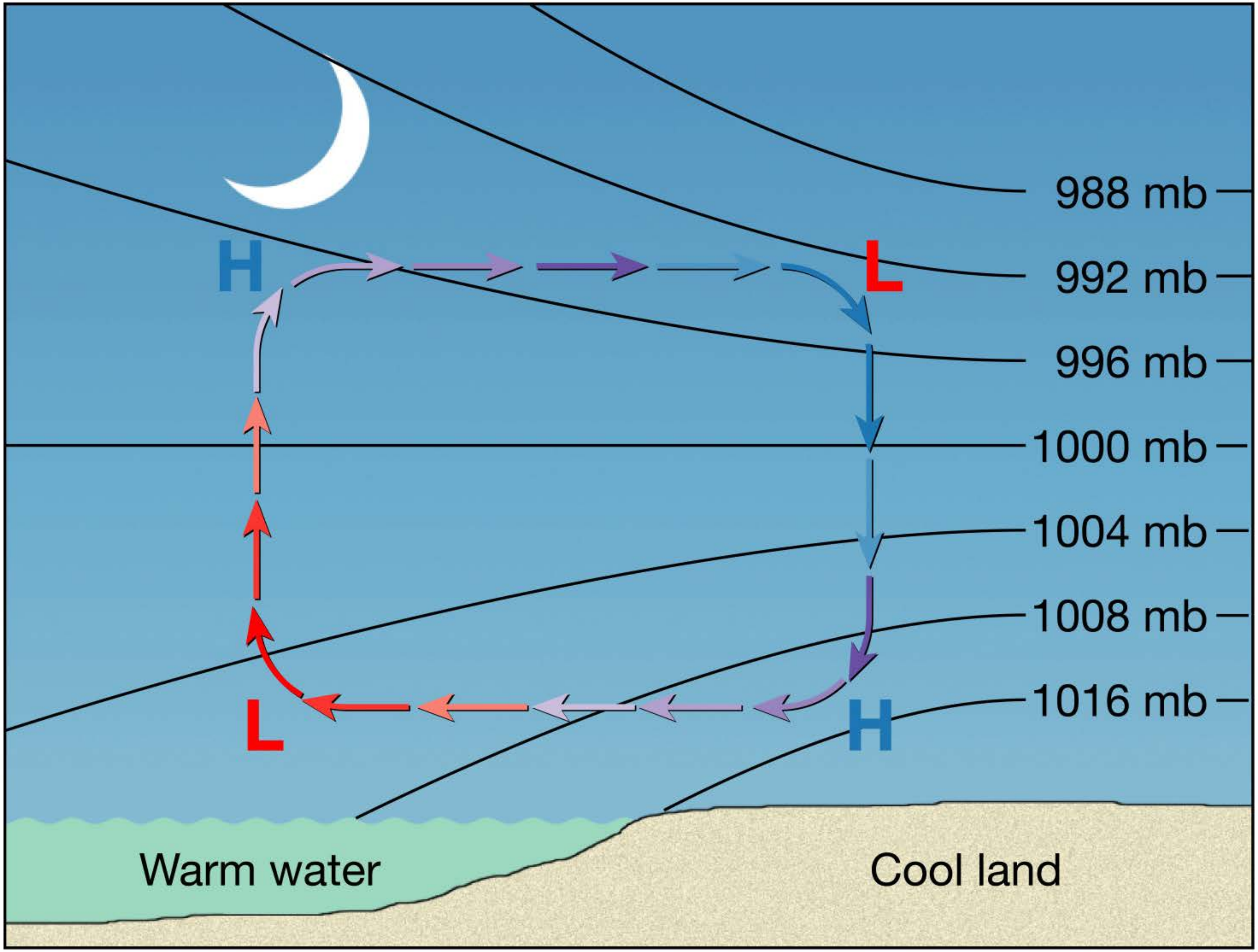
Local Winds

1. Local winds are medium-scale winds produced by a locally produced pressure gradient.
2. Winds are named for the direction **from** which they blow. e.g., sea breezes flow from the sea.
3. Have moderating effect. Reach only 50 to 100 km inland.
4. Smaller-scale sea breezes can develop along shores of large lakes.

Sea Breeze



(a) Sea breeze



(b) Land breeze

Local Winds

1. Sea breezes also affect amount of cloud cover. e.g., Florida. Convergence of sea breezes from two coasts causes convergence and leads to a summer maximum in rainfall.

2. Tropical regions experience stronger sea breezes than mid-latitude regions.

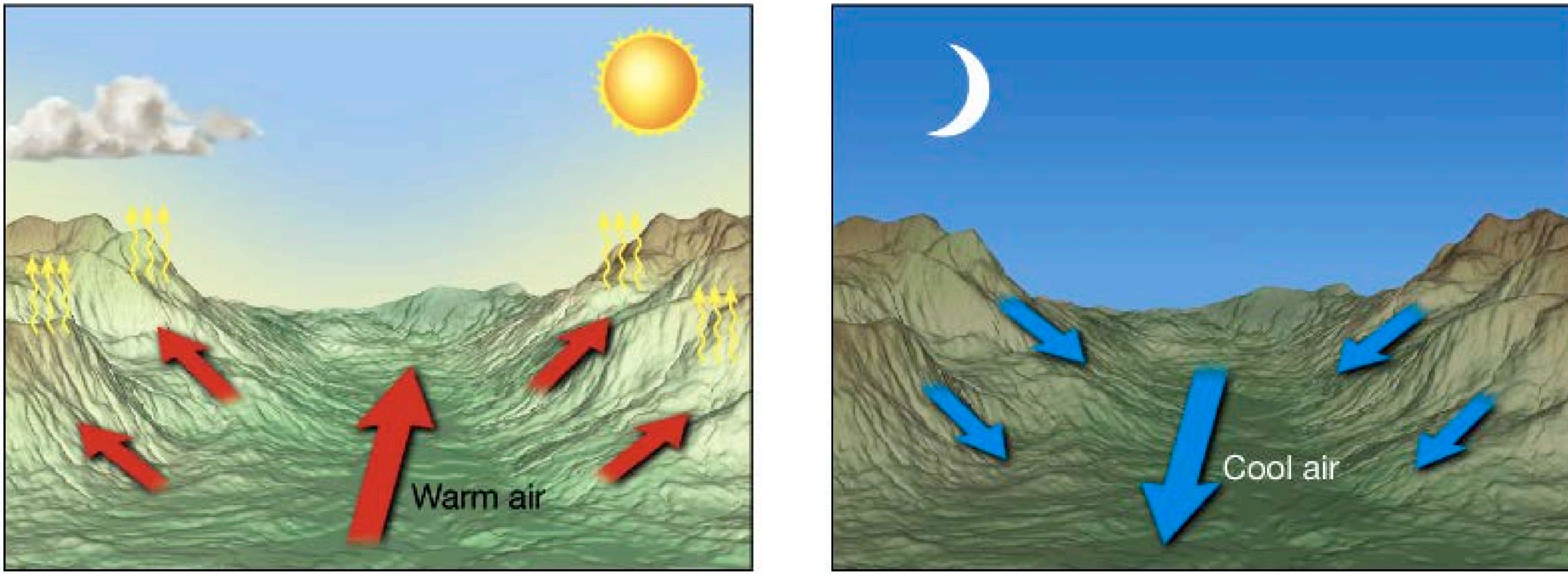
3. Cool ocean currents enhance the effect in tropical regions.

4. Mid-latitudes - sea breezes dominated by migration of low & high pressure systems.

Local Winds

1. Mountain & Valley Breezes - slopes are heated more than valley air, at same elevation, during the day. Heated air glides up mountain slopes - ***valley breeze***. Can cause clouds & thunders showers. *More common in summer than mountain breezes*.

2. After sunset, slopes cool more than valley floor. Cooler air flows down into the valley - ***mountain breeze***. *More common than valley breezes in winter*.



(a) Valley breeze

(b) Mountain breeze

Daytime upslope (valley) breeze leads to cloud development

Local Winds

1. ***Dust devils*** - few meters in diameter, < 100m tall. Last only minutes. Form on clear days. Occur mostly in the afternoon. Surface heating causes surface air to rise, and air is drawn in. Conservation of Angular Momentum leads to rotation.
2. ***Chinook (Foehn) winds*** - warm, dry winds that sometimes move down the east slope of the Rockies. (Called Foehn in the Swiss Alps)

A Dust Devils start at the hot surface

Local Winds

- ***Chinook winds*** often created when a pressure system like a cyclone pulls air over the mountains. As the air descends on the leeward side, it is heated adiabatically by compression. Descending air will be warmer & drier than on the windward side. Winds are relatively warm. Both good and bad side effects. Chinook = snow eater.

- ***Santa Ana*** - clockwise flow of air in anticyclone over the great basin (centered on Nevada) draws hot & dry desert air to the sea. Air becomes even warmer & drier as it descends.

- ***Country breeze*** - Hot urban air rises, and cooler air flows from country into the city.

Santa Ana winds & Wild fires

Katabatic (fall) Winds

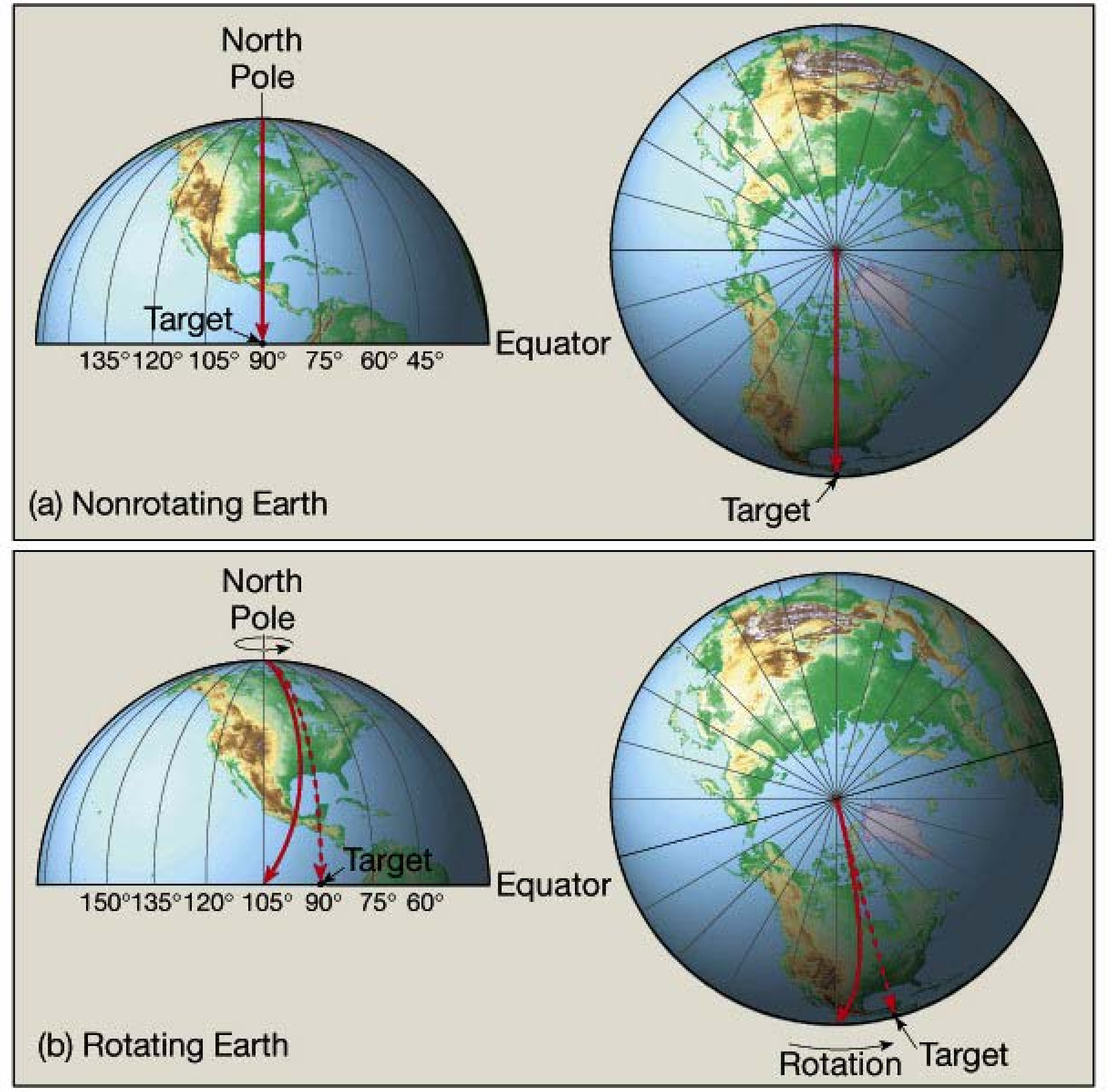
- Very cold air "falls off" a highland area, is heated adiabatically, but is still colder than the air at lower altitudes (else it would not fall).
- Such winds originate in places like the Greenland and Antarctica ice shelves.
- If the air is channeled into valleys, high wind speeds are generated
- Examples: ***Mistral*** blows from French Alps to the Mediterranean Sea; ***Bora*** blows from mountains of Yugoslavia to the Adriatic Sea.

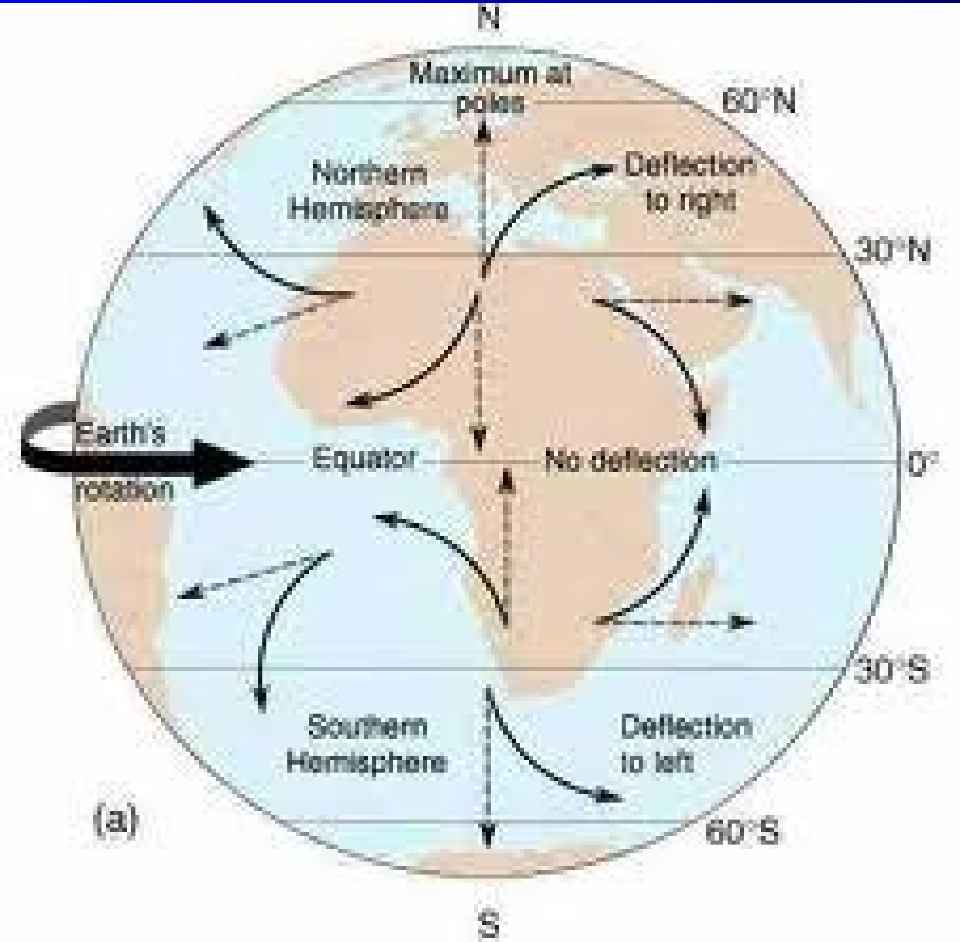
Winds

Coriolis force

- Affects all freely moving objects on the surface of a rotating planet - such as wind
- The directions of all winds, like ocean currents, are subject to this force

Coriolis Effect





$F_C = 2(\Omega \sin\varphi)v = fv$

Ω = radial velocity of the earth (rad/s)

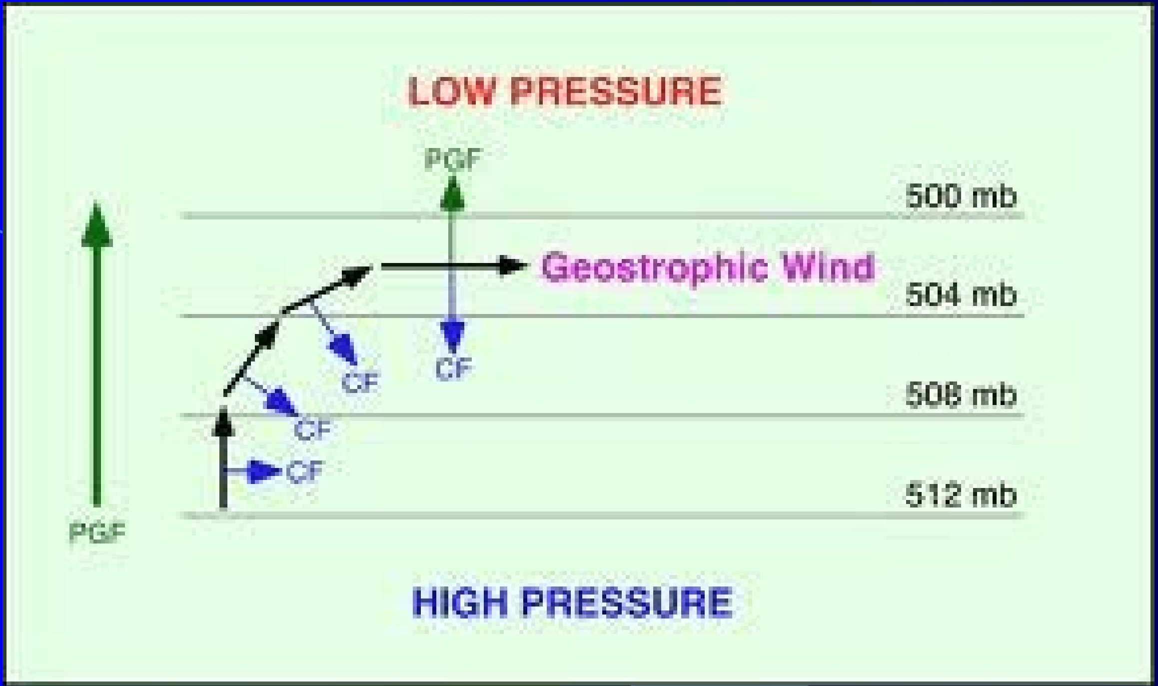
φ = latitude

v = velocity

f = coriolis parameter

Geostrophic winds

- Winds are always subject to more than one factor, even the least complicated example
- A high-altitude wind, not in contact with the ground, starts to flow due to air pressure gradient, the Coriolis effect deflects the wind so that it is no longer perpendicular to the isobars
- Eventually the pressure-gradient force and the Coriolis effect are in balance, and the wind flows parallel to the isobars
- This is a geostrophic wind

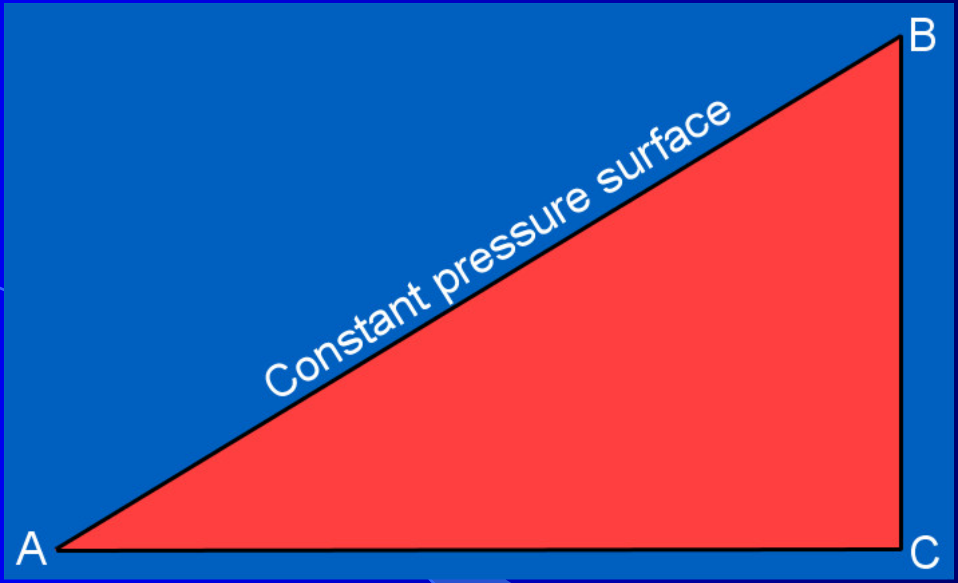


$$F_C = F_P$$

$$fv_g = -\alpha\frac{\Delta p}{\Delta n}$$

$$V_g = \left|\frac{\alpha}{f}\frac{\Delta p}{\Delta n}\right|$$

Calculating Geostrophic Flow from Upper-Level Charts



Wind velocity perpendicular to AC:

$$v_g = \left|\frac{g}{f}\frac{P_C - P_A}{AC}\right| = \left|\frac{g}{f}\frac{BC}{AC}\right|$$

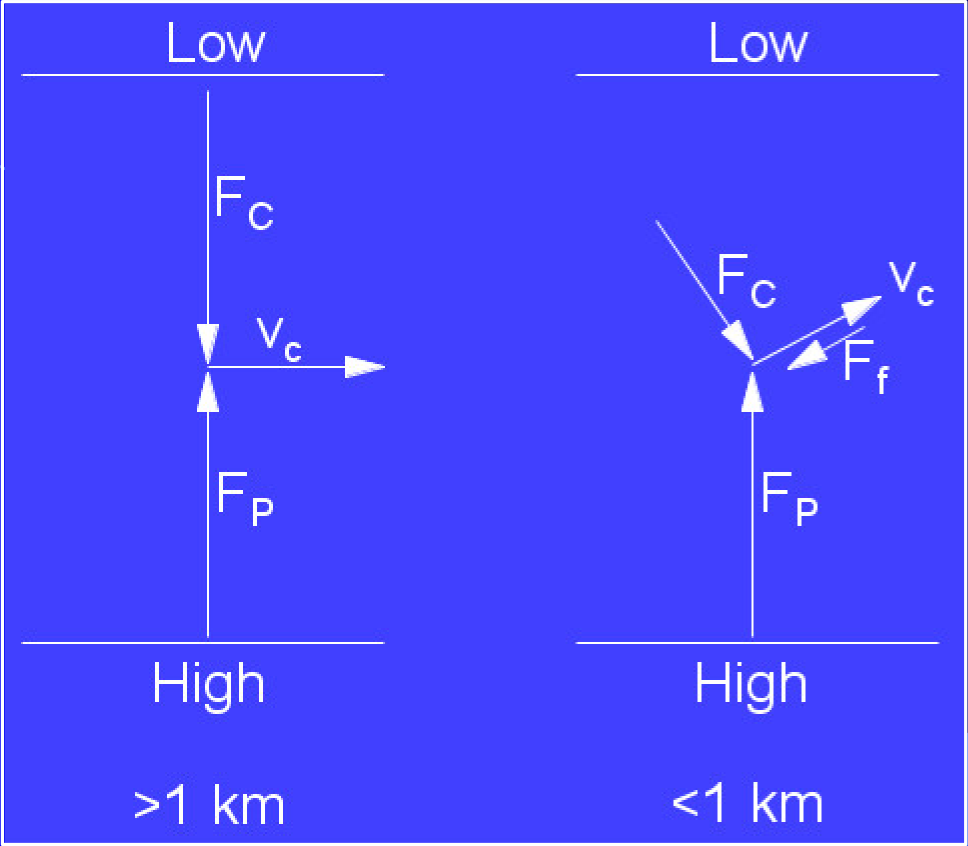
v_g = geostrophic velocity

f = coriolis parameter

$\frac{BC}{AC}$ = slope of the constant pressure surface

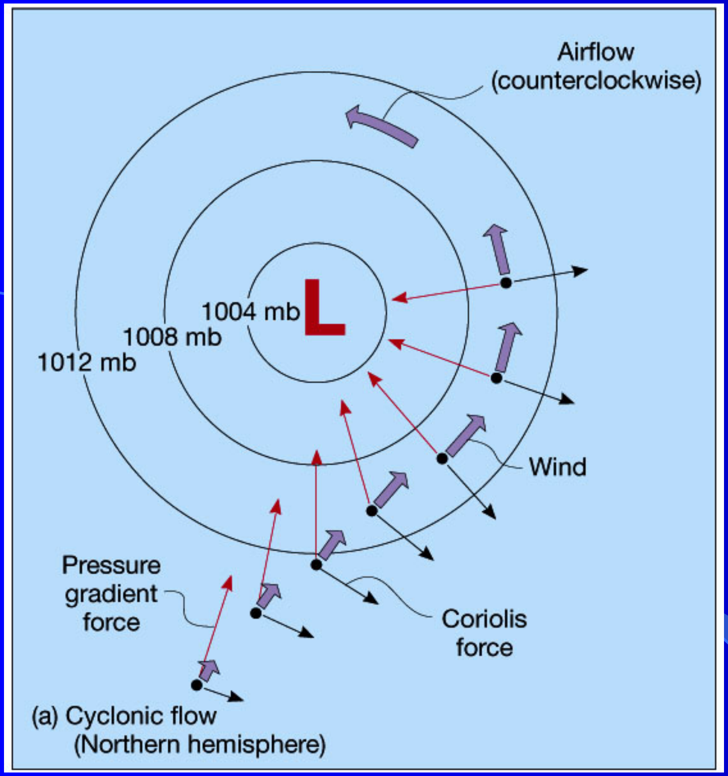
Friction

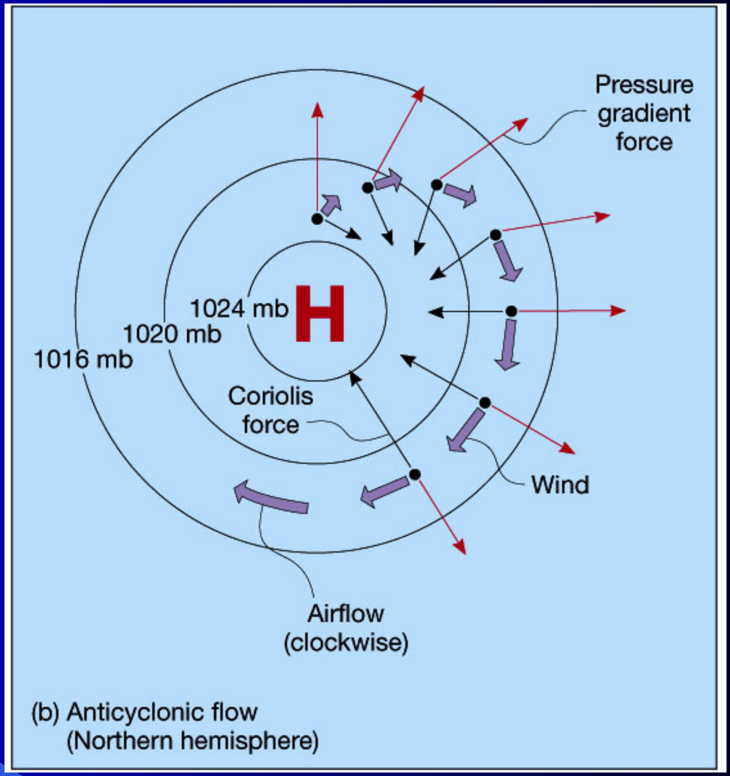
From topography, trees, and other solid objects, friction slows the speed of wind



A decrease in wind speed leads to a decrease in the Coriolis force, and the moving air deflects towards low pressure.

- Wind speed and direction are affected by three factors
  1. Pressure-gradient force: drop in air pressure per unit of distance
  2. Coriolis force: the deviation from a straight line of the path of a moving body as a result of Earth's rotation
  3. Friction: the resistance to movement that results when two bodies are in contact
- The three effects interact such that winds around a low-pressure center develop an inward spiral motion (convergence, cyclone)
- By the same process, winds around a high-pressure center develop an outward spiral motion (divergence, anticyclone)
- In the northern hemisphere, convergent centers rotate counterclockwise and divergent centers rotate clockwise - the reverse is true for the southern hemisphere





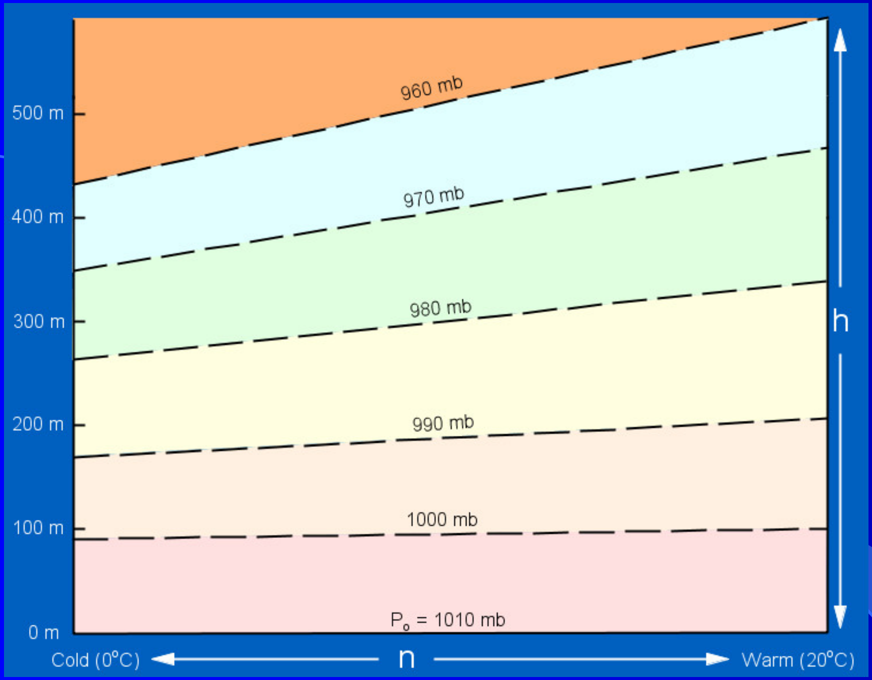
The gradient wind:

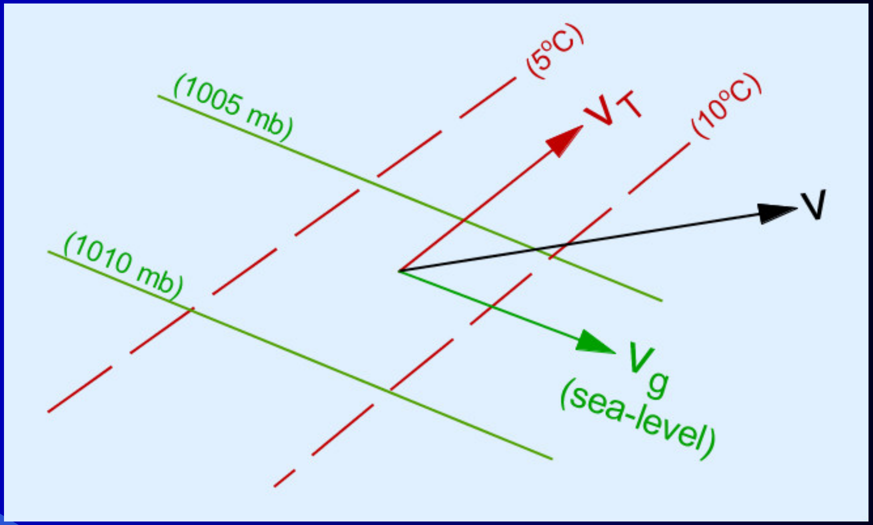
$$v_G = \frac{2v_g}{1 + \sqrt{1+(\frac{4v_g}{fr})}}$$

v_G = gradient wind speed v_g = geostrophic wind speed

f = Coriolis parameter   r = radius of curvature (+ cylcone, - anticyclone)

The Thermal Wind





$$v_T = \left| \frac{g}{fT} \left(\frac{\Delta T}{\Delta n_T} \right) \right| \Delta h$$

T = mean temperature of the air column (K)

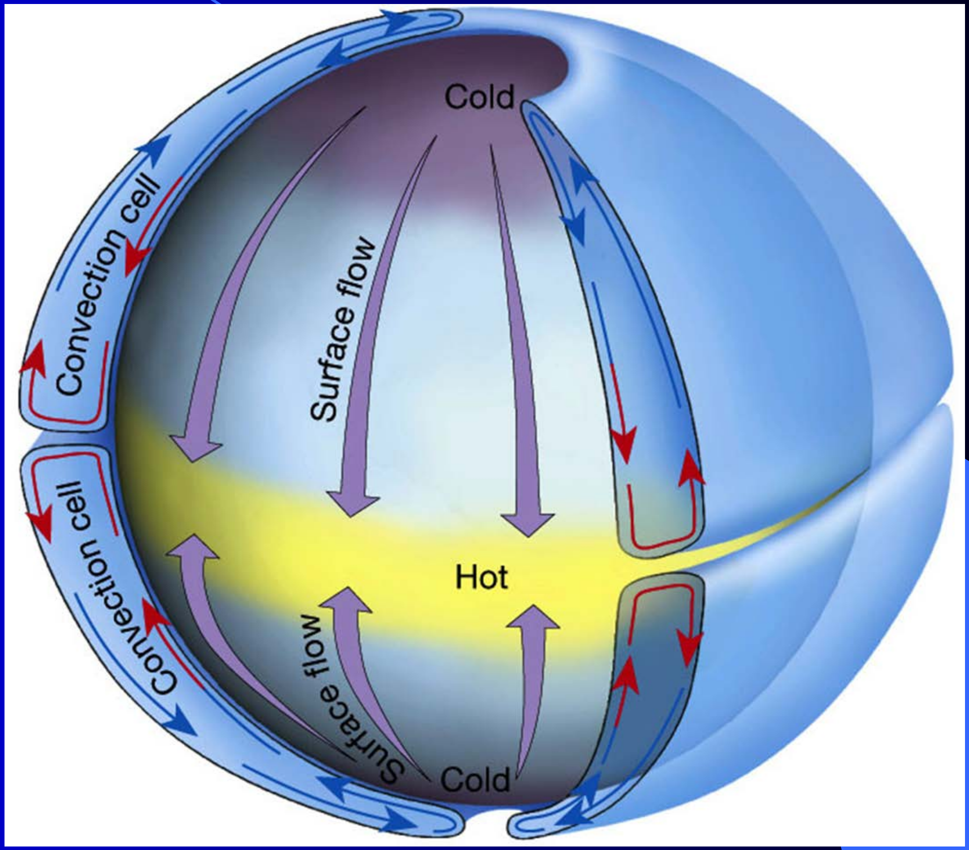
$\frac{\Delta T}{\Delta n_T}$ = horizontal temperature gradient

Global Circulation

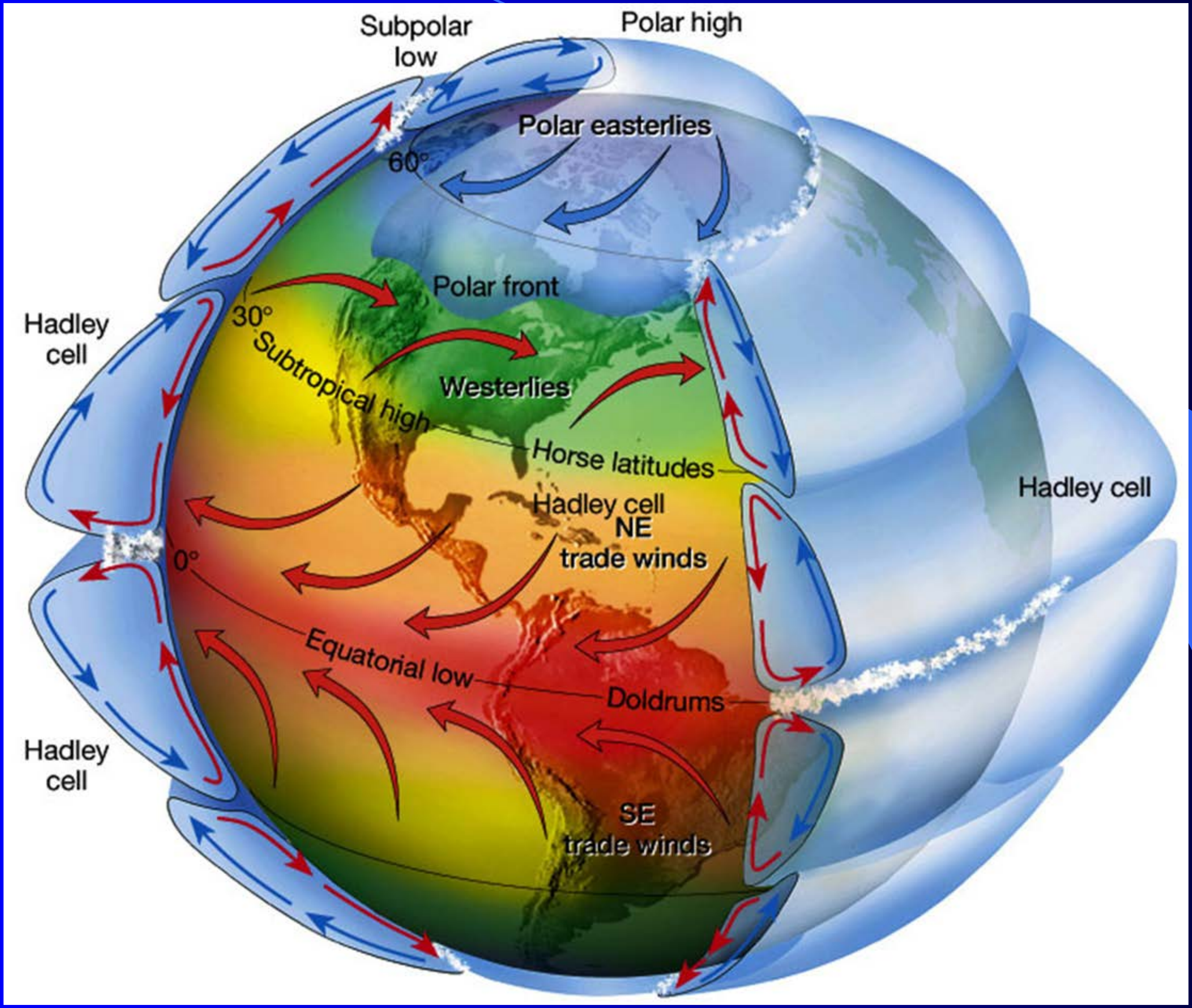
Single cell model is the ***Hadley*** model.

- Proposed one single large convection cell. Tropical air rises into tropopause and spreads towards the poles. There cooling causes it to sink, and to spread out (diverge) at the surface as cool equator-ward winds that close the circulation loop.

- Hadley model ignores the Earth's rotation.

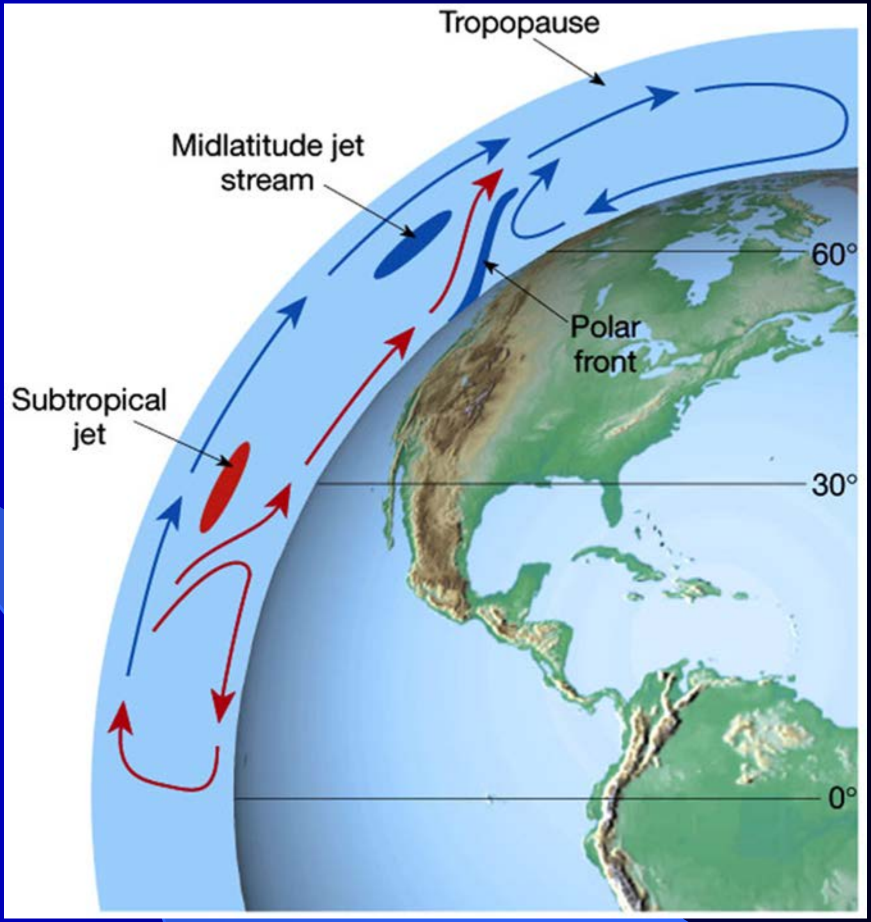


Three-Cell model - splits at latitudes of 30 and 60 degrees.



- Hadley cells and the ITCZ
  - Major circulatory cell that stretches from the equator to 30° N and S latitude
  - Warm air rises in the tropics and creates a low-pressure zone of convergence (ITCZ)
  - Air piles up here, creating two belts of high-pressure air sinking towards the surface, and creating a zone of divergence and completing the convection cells
  - Contains high-level winds: the westerlies and low-level winds: the trade winds
- Ferrel cells
  - On the poleward side of the Hadley cells are midlatitude convection cells
  - Surface winds are westerlies

- Polar fronts and Jet streams
  - On the poleward side of the Ferrel cells, meeting along a zone called a polar front
  - Dry, high-altitude air descends near the pole, creating a zone of divergence
  - Surface air then moves toward the equator, forming the polar easterlies
  - High-level winds in the polar cells are westerly
  - Upper atmosphere westerlies associated with steep pressure gradient are called jet streams



Relationship between the global circulation pattern and climate.