Wind

* Movement of air
* Blows from areas of high pressure to low pressure
  * Pressure needs to be balanced
  * Blows side to side not up and down
* Workhouse of Weather
  * Moves storms and large fair-weather systems around the globe
  * Transports heat, moisture, dust, insects, bacteria and pollens from one area to another

Origin of Wind

* What causes Air Pressure Differences
  * By unequal heating of the Earth: Temperature differences
  * Areas receive different amounts of sunlight because:
    * Tilt
    * Sphericity
* Temperature increases/decreases pressure decreases/ increases
* Convergence and Divergence
  * Changes in Continuity
  * Changes in vorticity of air aloft

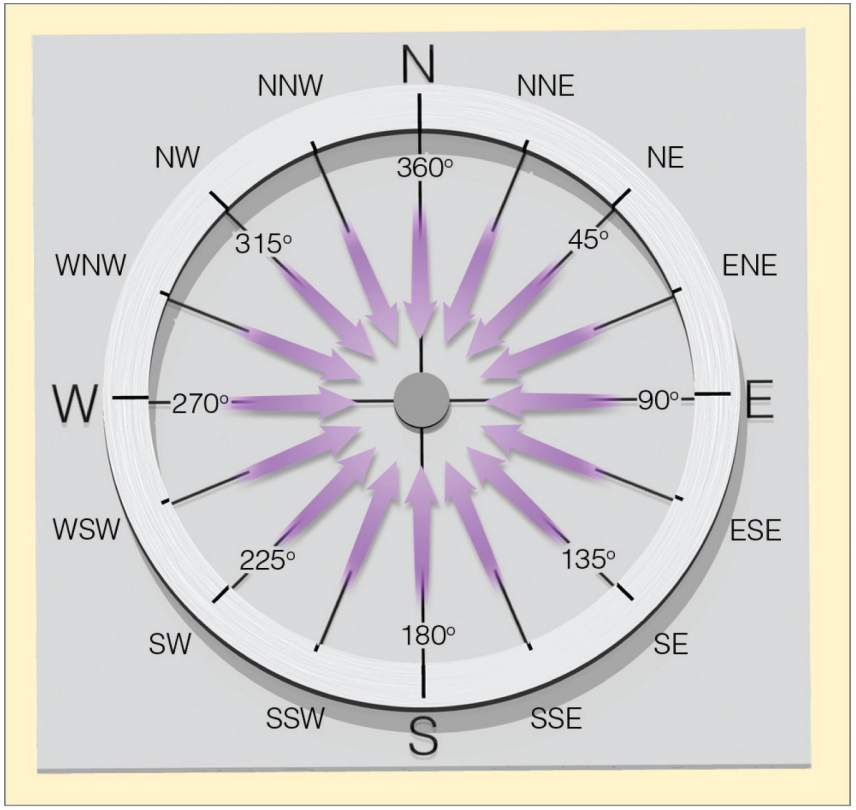
Measuring Wind Speed

© Jan Null

© C. Donald Ahrens

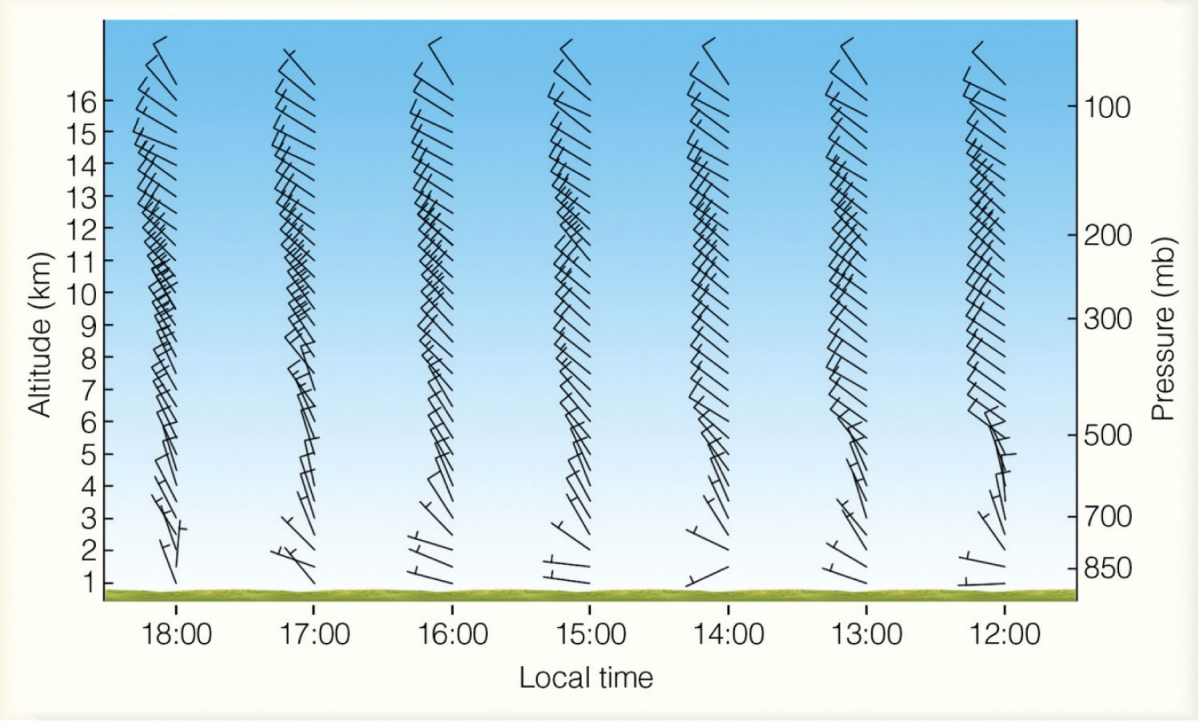
* Speed
  * Anenometer
    * Cups of catch the wind and cause it to spin
* Direction
  * Wind Vane
  * Aerovane
    * Both speed and direction

Wind Direction



* Named for direction in which they come from and not the direction they are blowing to
* North winds come from north and blow toward south

Wind Speed on Weather Maps



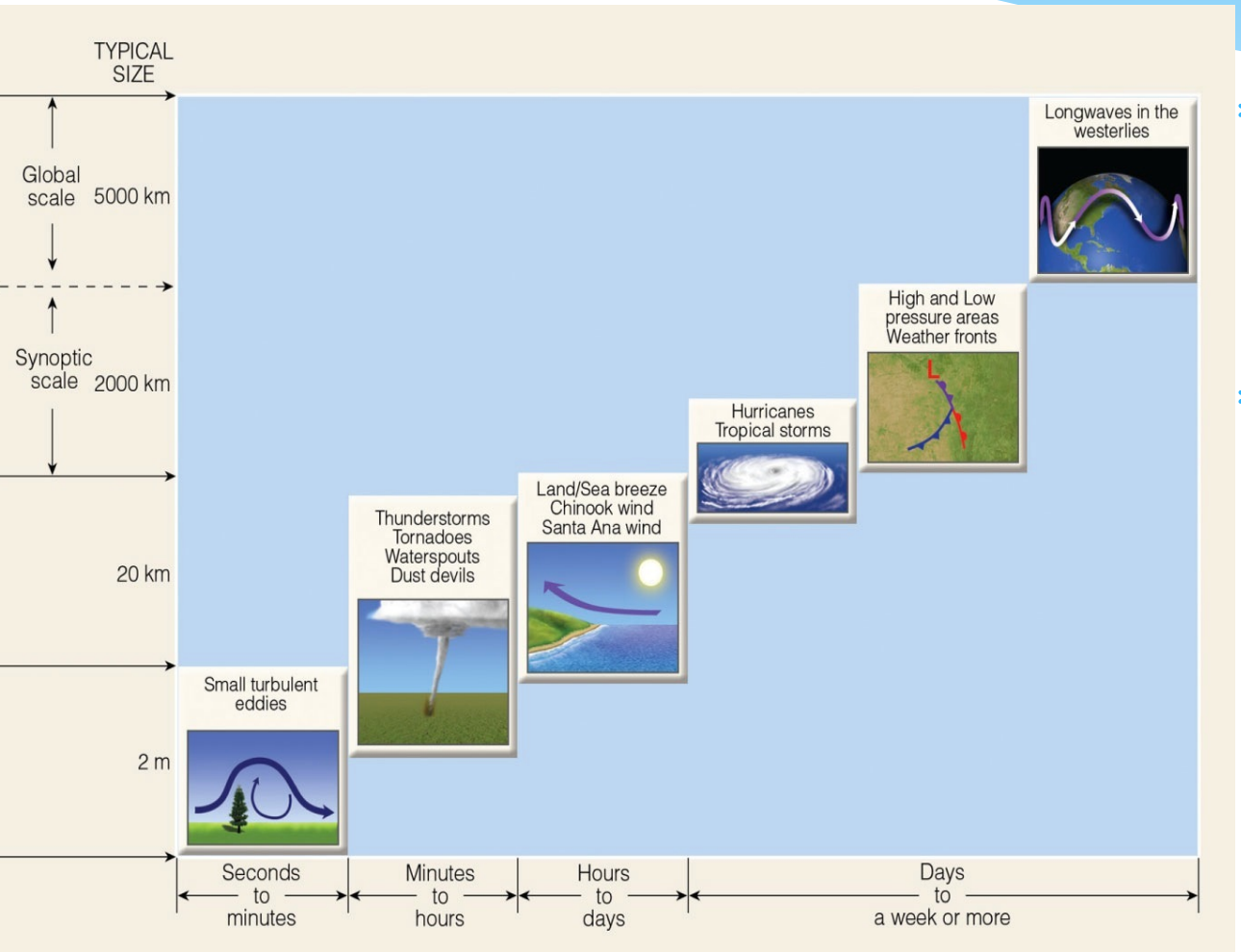
	MILES (STATUTE) PER HOUR	KNOTS	KILOMETERS PER HOUR
	Calm	Calm	Calm
	1–2	1–2	1–3
	3–8	3–7	4–13
	9–14	8–12	14–19
	15–20	13–17	20–32
	21–25	18–22	33–40
	26–31	23–27	41–50
	32–37	28–32	51–60
	38–43	33–37	61–69
	44–49	38–42	70–79
	50–54	43–47	80–87
	55–60	48–52	88–96
	61–66	53–57	97–106
	67–71	58–62	107–114
	72–77	63–67	115–124
	78–83	68–72	125–134
	84–89	73–77	135–143
	119–123	103–107	144–198

Beaufort Wind Scale (Over Land)

TABLE F.1 Estimating Wind Speed from Surface Observation

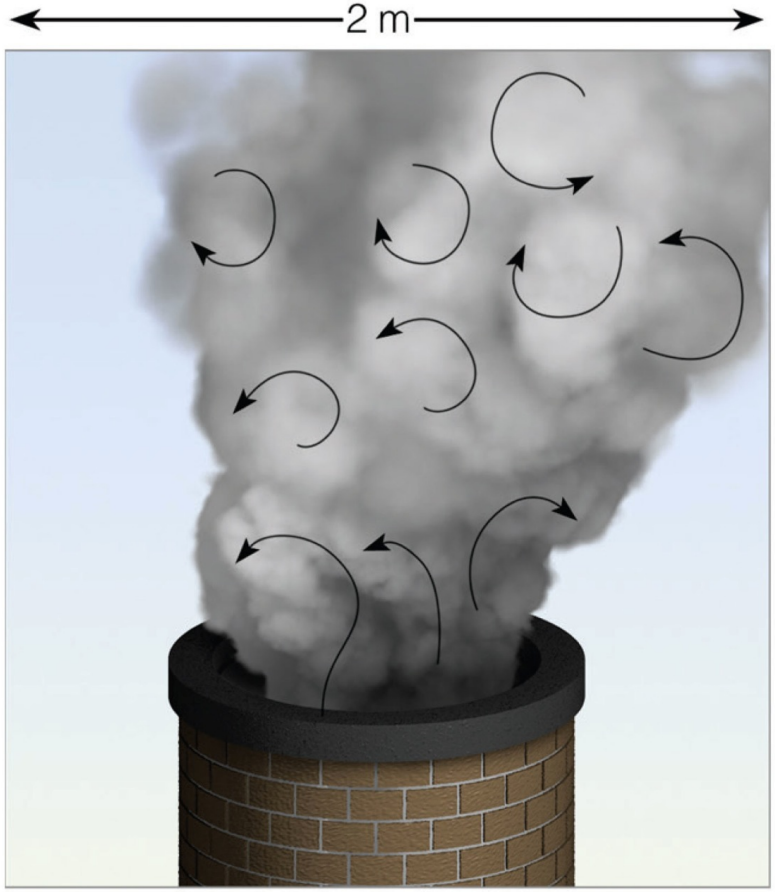
BEAUFORT NUMBER	DESCRIPTION	WIND SPEED MI/HR	WIND SPEED KNOTS	WIND SPEED KM/HR	OBSERVATIONS
0	Calm	0–1	0–1	0–2	Smoke rises vertically
1	Light air	1–3	1–3	2–6	Direction of wind shown by drifting smoke, but not by wind vanes
2	Slight breeze	4–7	4–6	7–11	Wind felt on face; leaves rustle; wind vanes moved by wind; flags stir
3	Gentle breeze	8–12	7–10	12–19	Leaves and small twigs move; wind will extend light flag
4	Moderate breeze	13–18	11–16	20–29	Wind raises dust and loose paper; small branches move; flags flap
5	Fresh breeze	19–24	17–21	30–39	Small trees with leaves begin to sway; flags ripple
6	Strong breeze	25–31	22–27	40–50	Large tree branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty
7	High wind	32–38	28–33	51–61	Whole trees in motion; inconvenience felt walking against wind; flags extend
8	Gale	39–46	34–40	62–74	Wind breaks twigs off trees; walking is difficult
9	Strong gale	47–54	41–47	75–87	Slight structural damage occurs (signs and antennas blown down)
10	Whole gale	55–63	48–55	88–101	Trees uprooted; considerable damage occurs
11	Storm	64–74	56–64	102–119	Winds produce widespread damage
12	Hurricane	≥ 75	≥ 65	≥ 120	Winds produce extensive damage

Scales of Motion



* Circulations of all sizes exist within the atmosphere
  * Meteorologists arrange them according to size
* Hierarchy of motion from tiny gust to giant storms is called Scales of Motion

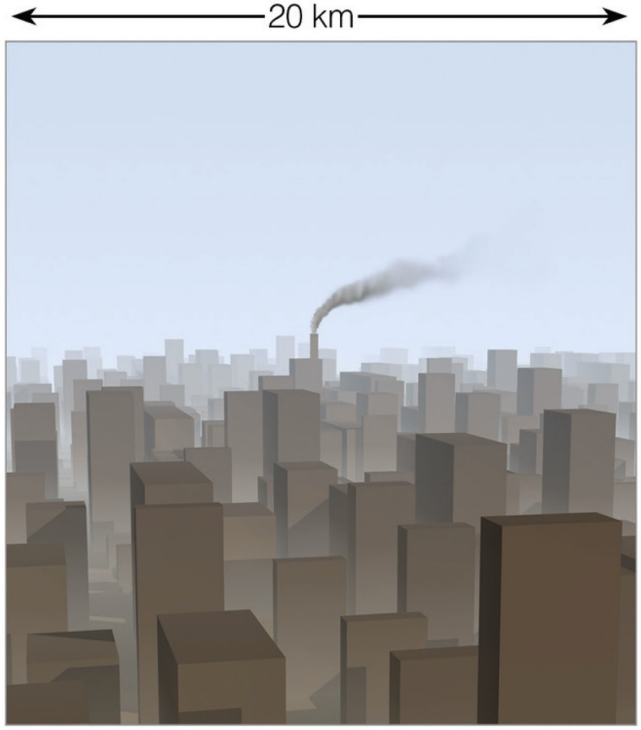
Microscale



(a) Microscale

* Eddies
  * Small chaotic motions
    * Air pocket when on a plane
    * Diameters of a few meters or less
    * Form by
      * Convection
      * Wind blowing past an obstruction
    * Usually short-lived lasting only a few minutes
    * Very unpredictable

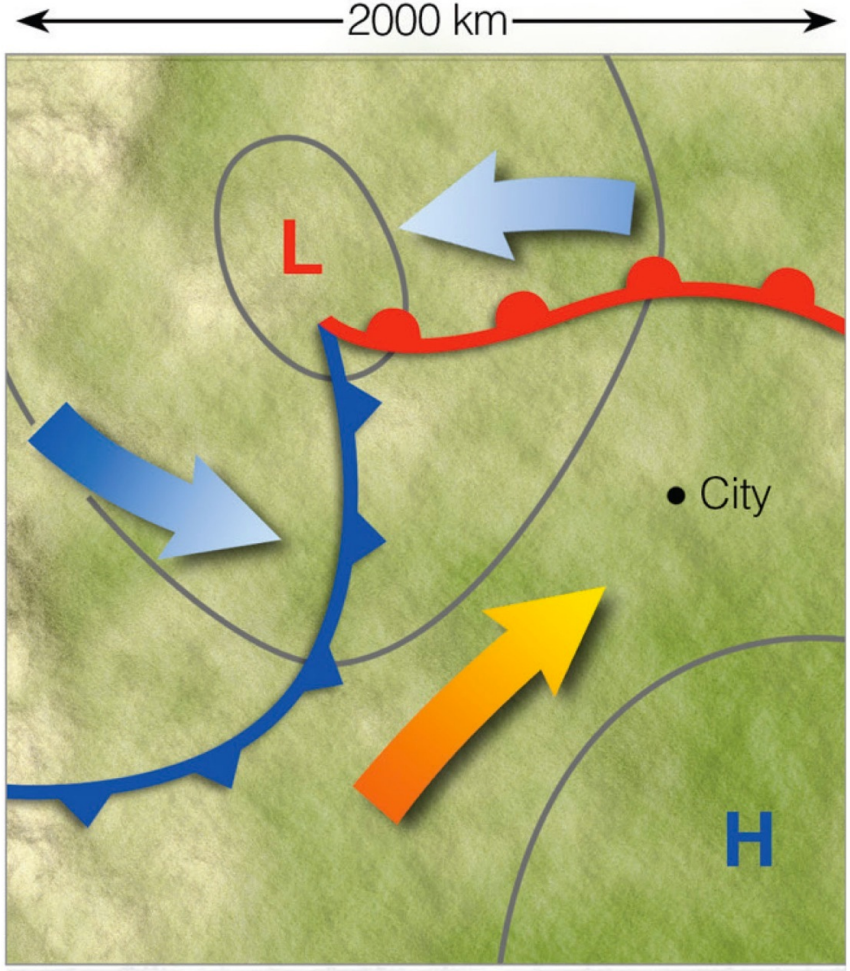
Mesoscale



(b) Mesoscale

* As the smoke rises it drifts toward the center of town : carried many miles downwind
* This circulation of city air is an example of a mesoscale (middle scale) circulation
* Includes local winds (shorelines and mountains) as well as thunderstorms, tornadoes and small tropical storms

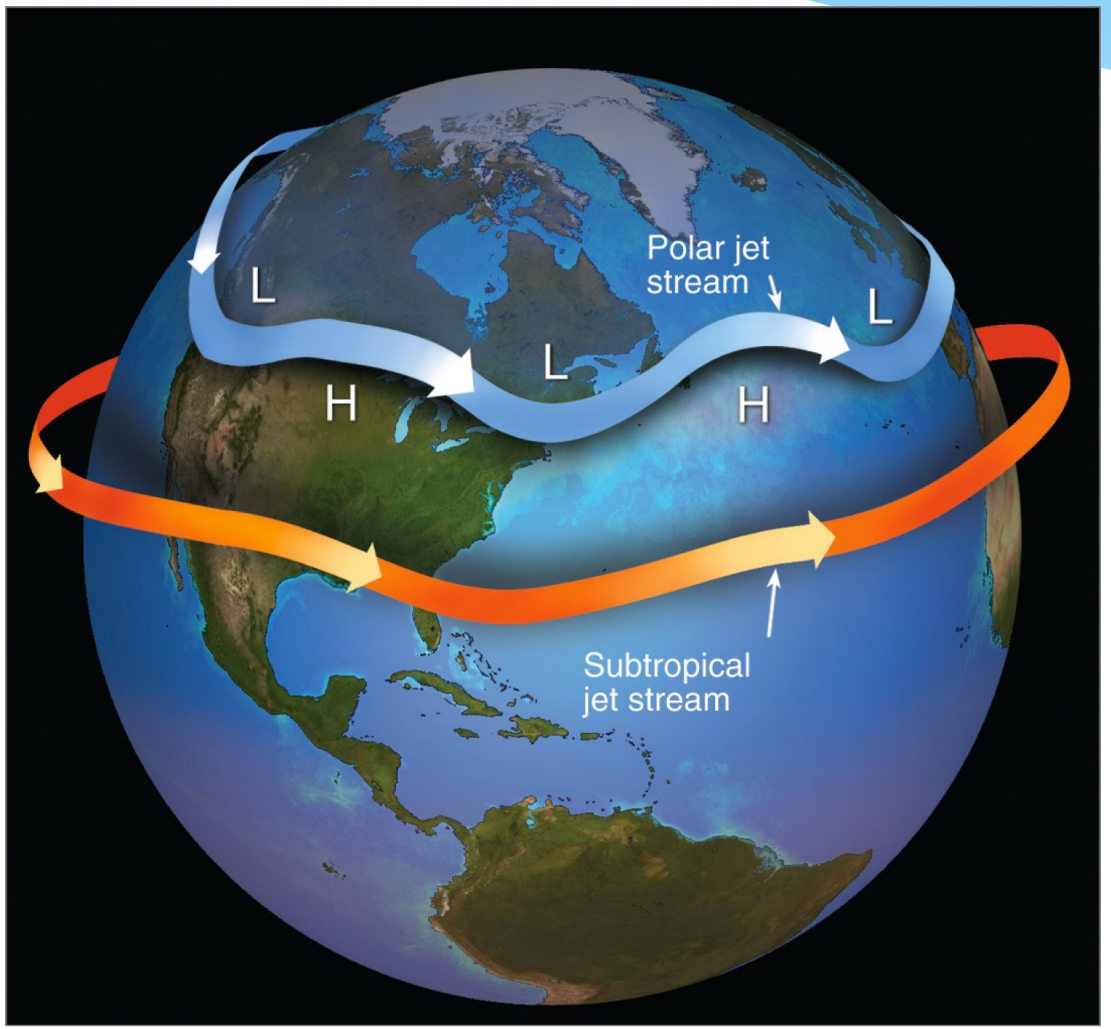
Synoptic Scale



(c) Synoptic scale

* High and low pressure systems
* Cyclones and anticyclones, fronts, air masses, hurricanes

Global Scale

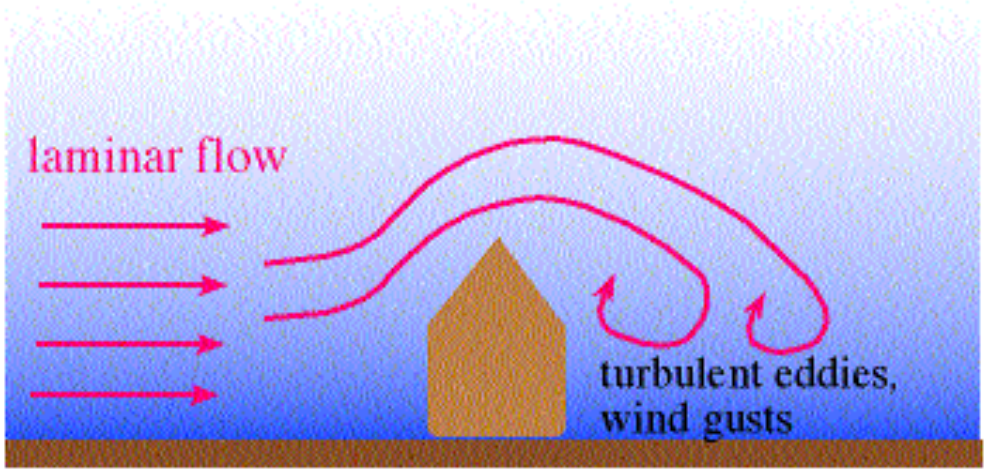


* Jet stream

Microscale Winds

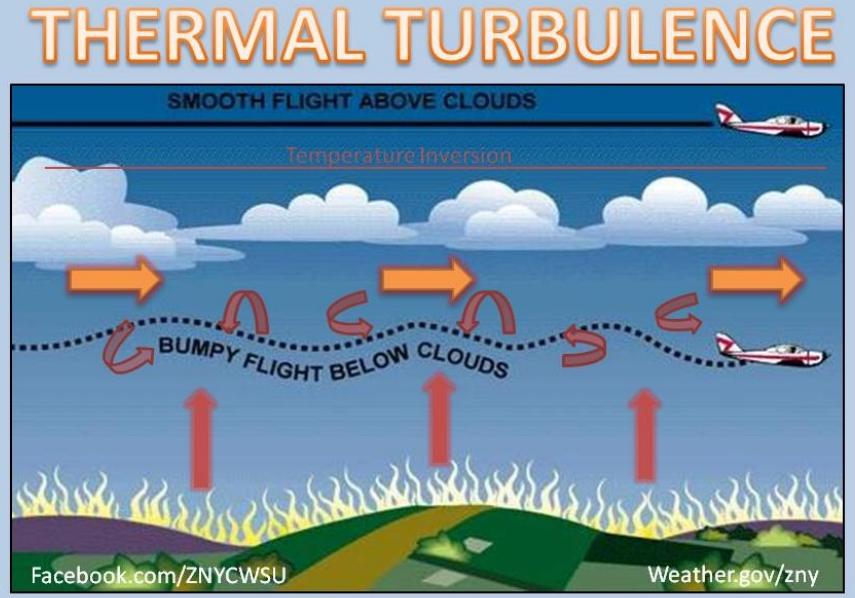
* Atmospheric Turbulence
  * Any disturbed flow of air that produces eddies
  * Eddies
    * For example a rock in a steady flowing (laminar flow) stream.
    * Turbulent whirls
    * Eddies drain energy from the main flow slowing it down
* Wind gusts
  * Within an eddy, the wind speed and direction fluctuate rapidly producing irregular air motion called Wind Gusts

Mechanical Turbulence



* Eddy motion created by obstructions
  * Roughness of the ground
  * Wind blowing over a landscape dotted with trees and buildings

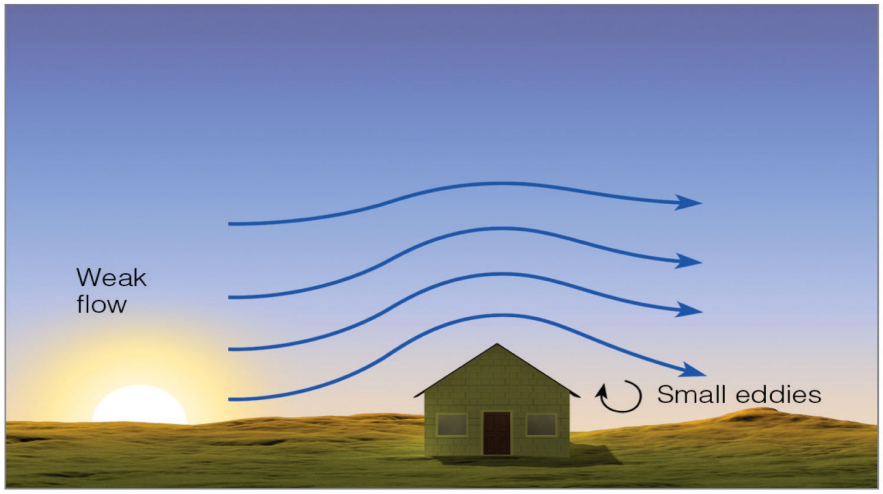
Thermal Turbulence



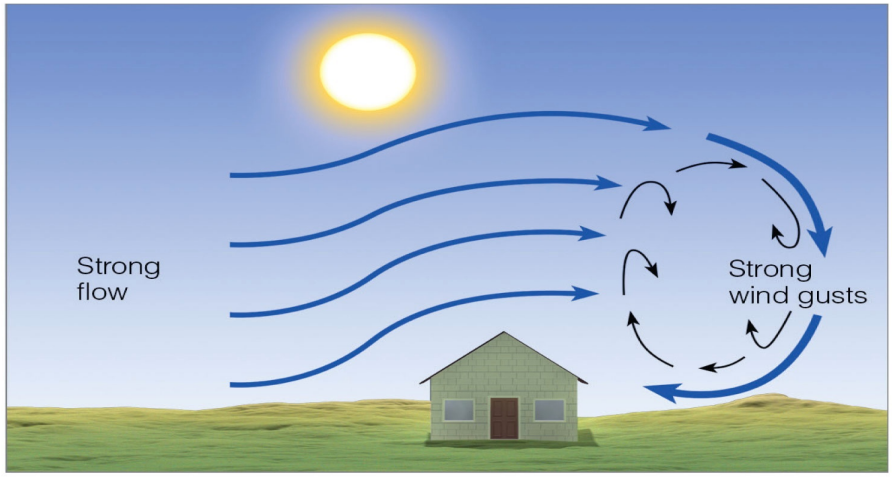
Daytime heating causes thermals to rise, which then interact with the prevailing winds aloft. As the winds deviate around the thermals, turbulent eddies form. The eddies are carried downstream some distance before dissipating, and are what we feel as "bumps", particularly on take off and landing. Stronger prevailing winds and heating (especially in the summer) result in the biggest bumps!

* Rising thermals of air in the boundary layer generated by surface heating (convection cells)
* In the morning thermal turbulence is at a minimum
* As the day goes on and there is more thermal heating thermal turbulence increases- it is at a maximum around 3 PM : **Surface winds are stronger in the afternoon**
* Picture on left
  * As wind speed and surface heating increases more eddies are formed and there are more wind gusts

Thermal and Mechanical Turbulence



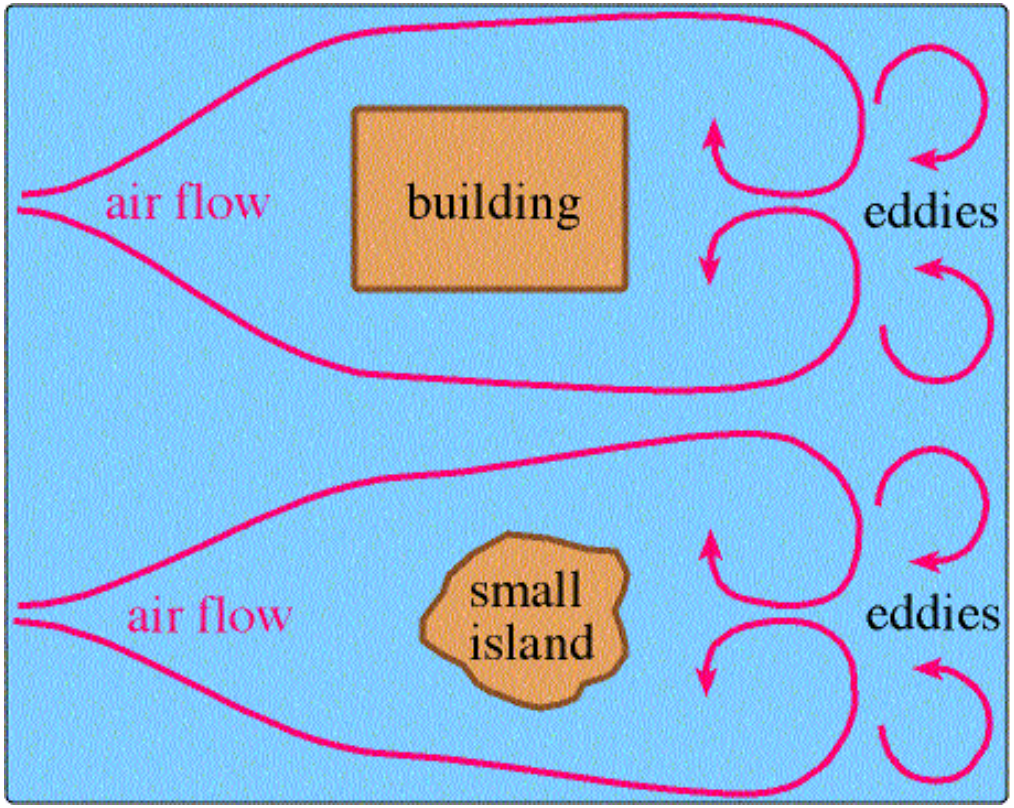
(a) Stable air



(b) Unstable air

* Stable air and weak winds the turbulence is very small
* If the wind speed increases along with the surface heating the turbulence increases
  * More mixing with upper level faster moving air

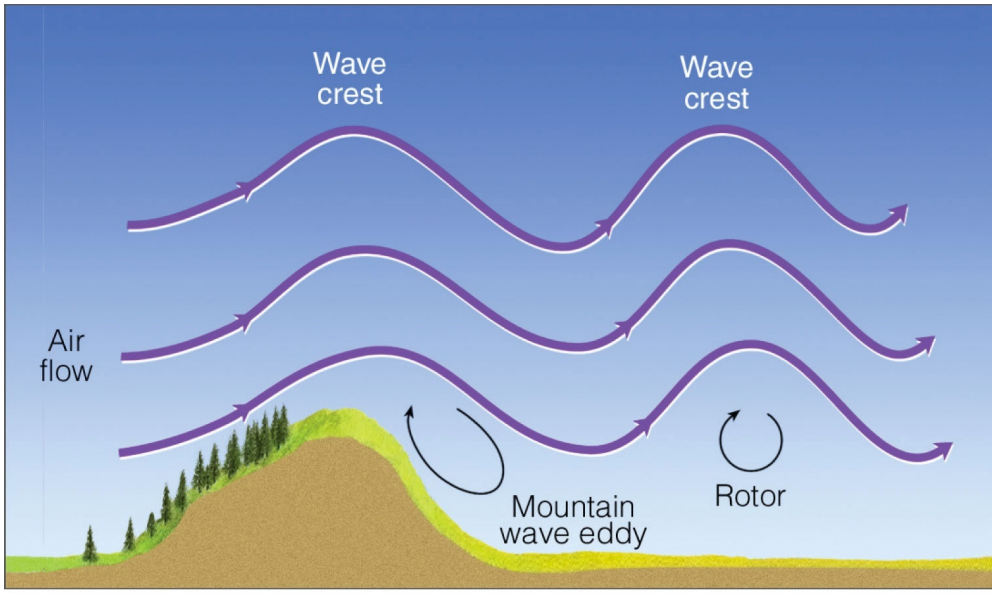
Small Scale EDDIES



* Examples: Flow around a building and an island
* When the wind encounters a solid object, an eddy (whirl of air) forms on the leeward side
* The eddie often depends on
  * Size and shape of object
  * Speed of the wind
* Examples
  * Drop apiece of paper on a windy day only to have it carried away by a swirling eddy as you try to pick it up
  * Strong winds blowing over a stadium can produce eddies that may rotate in such a way to create surface winds on the playing field in an opposite direction
* Wind blowing over a fairly smooth surface produces few eddies, but when the surface is rough ,many eddies form

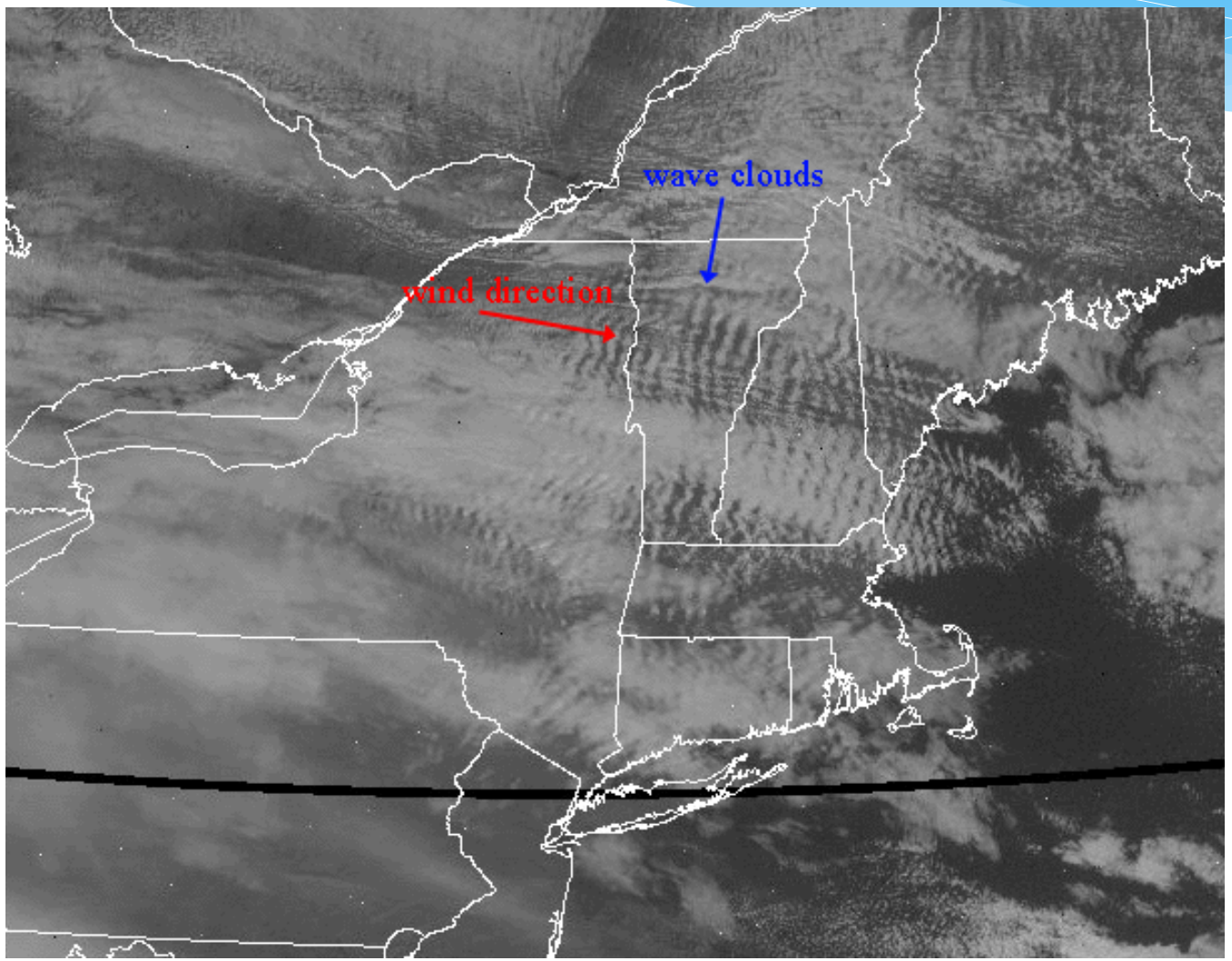
Roll Eddies or Rotors

Brooks Martner--www.cloudphotos.net



* Wind moving over a mountain range with a speed greater than 40 knots
  * Generates wave clouds
  * Rotor circulations (eddies) on the leeward side of the mountain - bad for airplanes and gliders!!
  * Rotors can have strong vertical motions

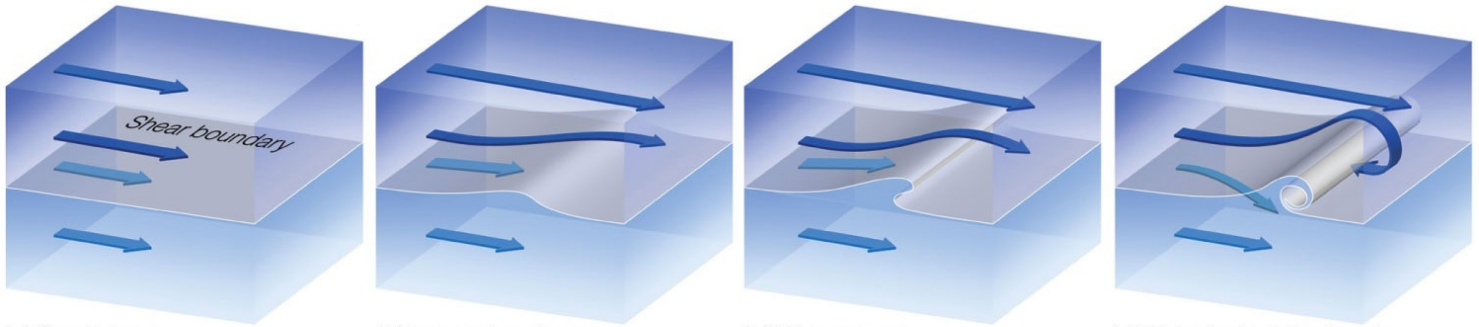
Wave Clouds on a Satellite Photo



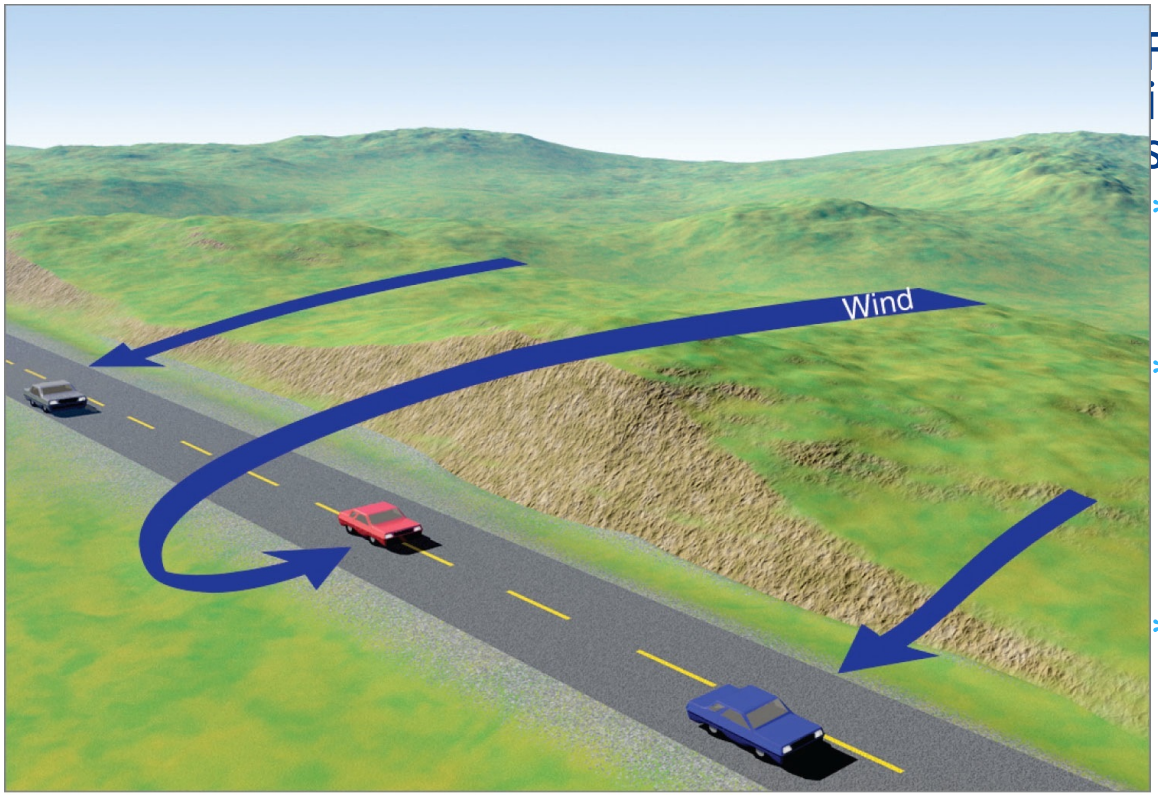
Why is it dangerous during hang gliding to enter the leeward side of the hill when the wind speed is strong?

Wind Shear

* Wind Shear
  * Changing wind speed with height or altitude
* Turbulent Eddies can form aloft as well as near the surface
  * When the wind changes direction or speed or both abruptly
  * Eddies can be a few meters to several hundred meters in diameter
  * Air Pocket: Aircraft that flies into one of these eddies may drop suddenly or there may be bumps, vibrations, etc.



Wind Force

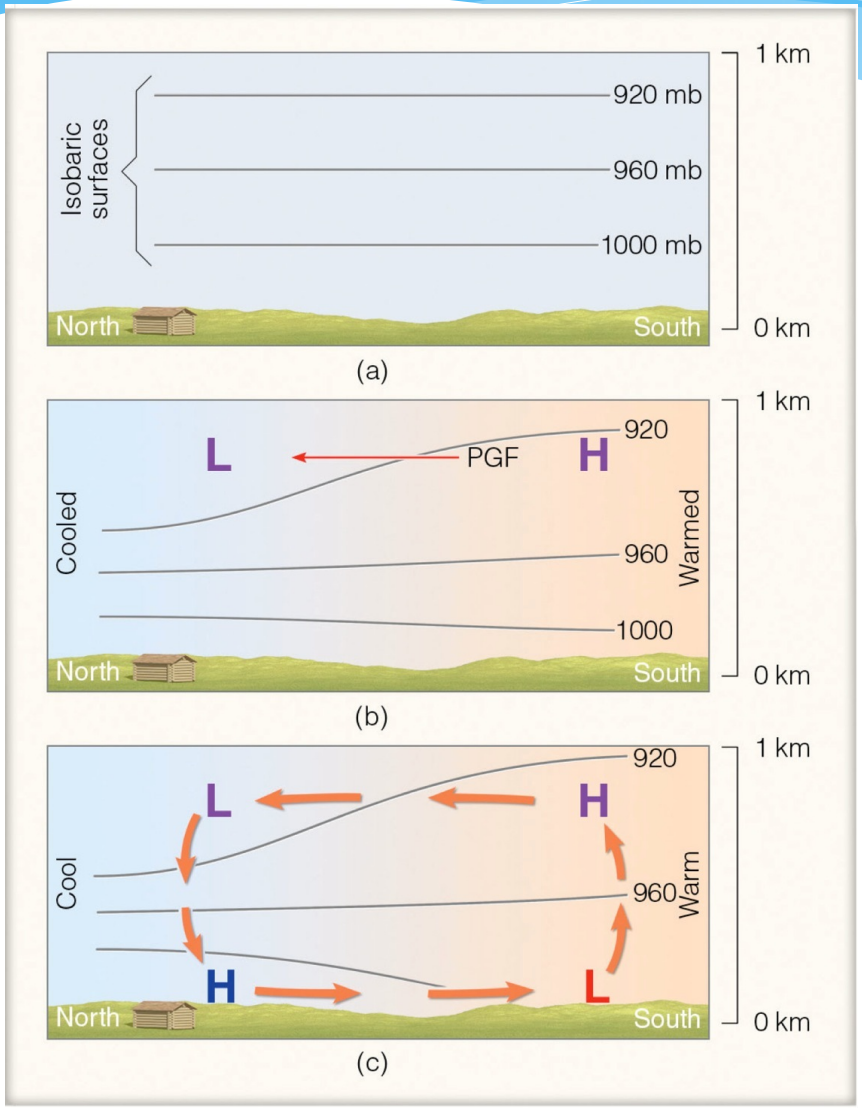


* Force of the wind on an object is proportional to the speed squared
  * A small increase in speed results in a large increase of force
  * Top of a bridge – less friction from ground – wind speed increases –eddies form around obstructions such as guard railing and posts
  * Similar effect where the wind moves over low hills that parallel the highway

Thermal Circulations

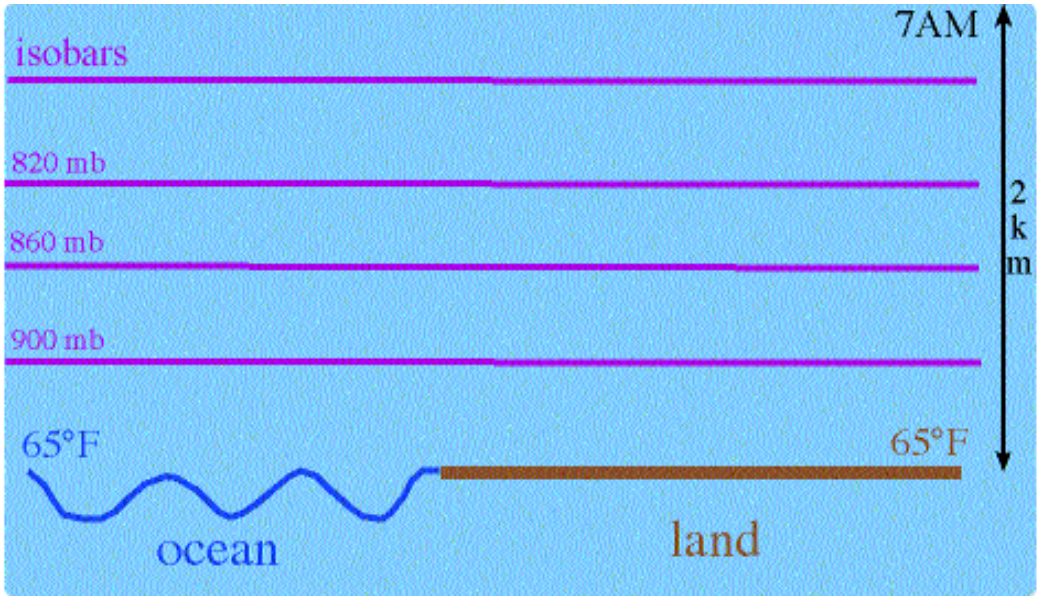
* Many mesoscale phenomena are the result of a *thermal circulation:*
* *thermal circulation* - a circulation generated by pressure gradients produced by *differential heating*
* Thermal circulations tend to be shallow - **do not** extend up through the depth of the troposphere
* examples of thermal circulations:
  * sea breeze
  * land breeze
  * mountain and valley breezes
  * monsoons

Thermal Circulations



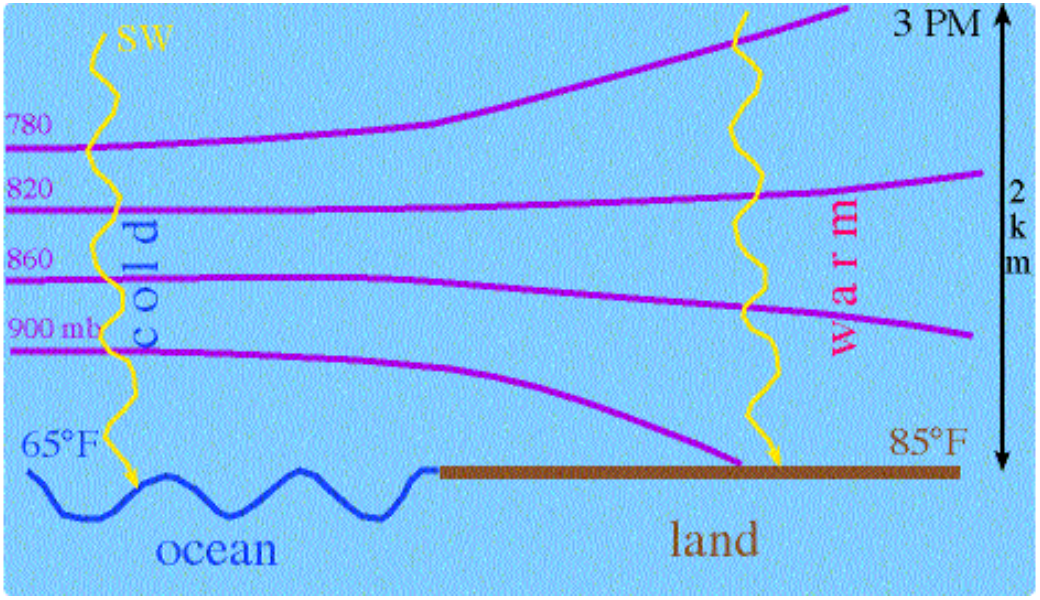
* A circulation generated by pressure gradients produced by *differential heating*
* Thermal circulations tend to be shallow - **do not** extend up through the depth of the troposphere. Only a few kilometers
* Maintained by local surface heating and cooling
* Surface pressure changes at the surface when air aloft moves from south to north
* Examples of thermal circulations:
  * sea breeze
  * land breeze
  * monsoons
  * mountain and valley breezes
* Thermal Highs and Thermal Lows

Sea and Land Breeze Formation Early morning



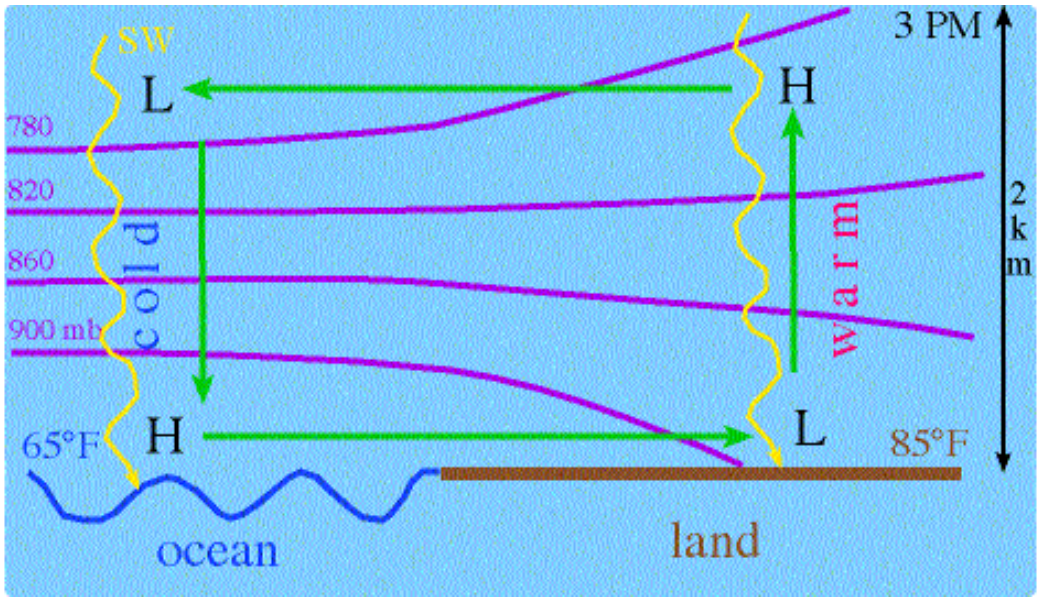
* In the morning assume that the ocean and land surfaces have the same temperature
* No other weather events occurring
* Sea Breeze
  * From sea to land
* Land Breeze
  * From land to sea

Sea and Land Breeze Formation
Late afternoon



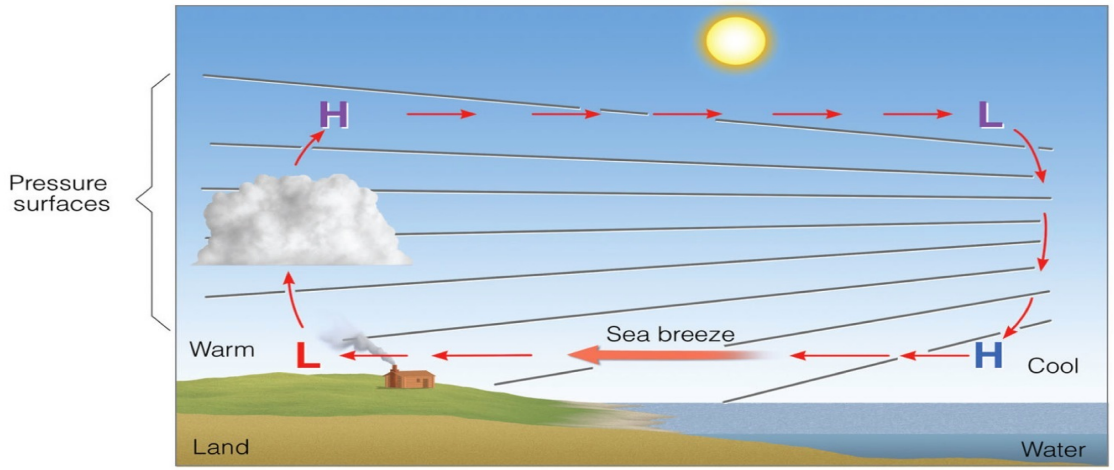
* By afternoon (3 PM), the land is much warmer than the ocean surface
* The air over the land will be warmer - will have expanded in response to the surface heating
* Hence, at low levels, there is a cold column of air over the ocean, warm column of air over the land
* This *differential heating* generates the pressure distribution to the right
* **Why is there differential heating?**
  * **specific heat capacity is higher for water than land**

Sea and Land Breeze Formation Air Flow

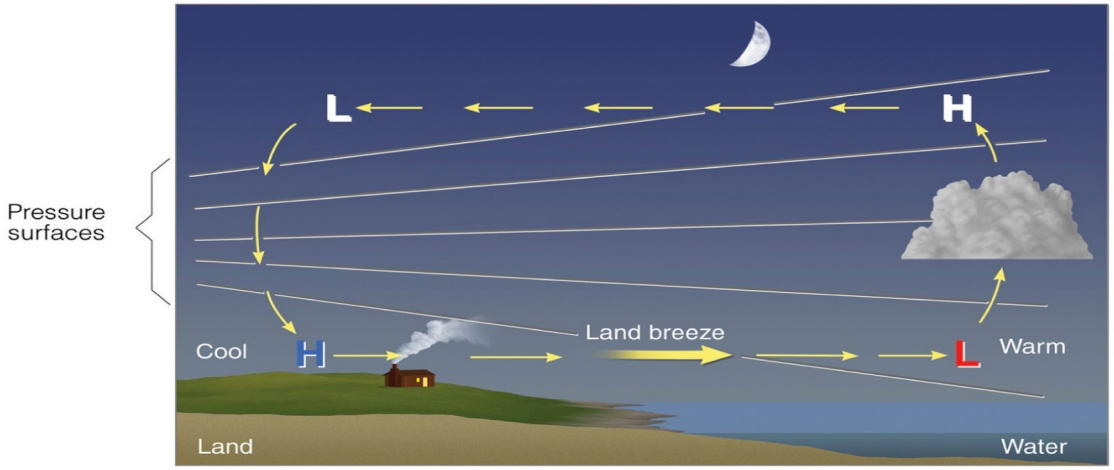


* Onshore flow at low levels - *sea breeze*
* Offshore flow at upper levels - *return flow*
* Rising air over land - due to *convection* and lifting over the *sea-breeze front (RECC)*
* Sinking motion over the ocean
* NOTE: the surface low pressure over land is often referred to as a *warm core thermal low,* surface high over ocean is often referred to a *cold core thermal high*

Sea and Land Breeze

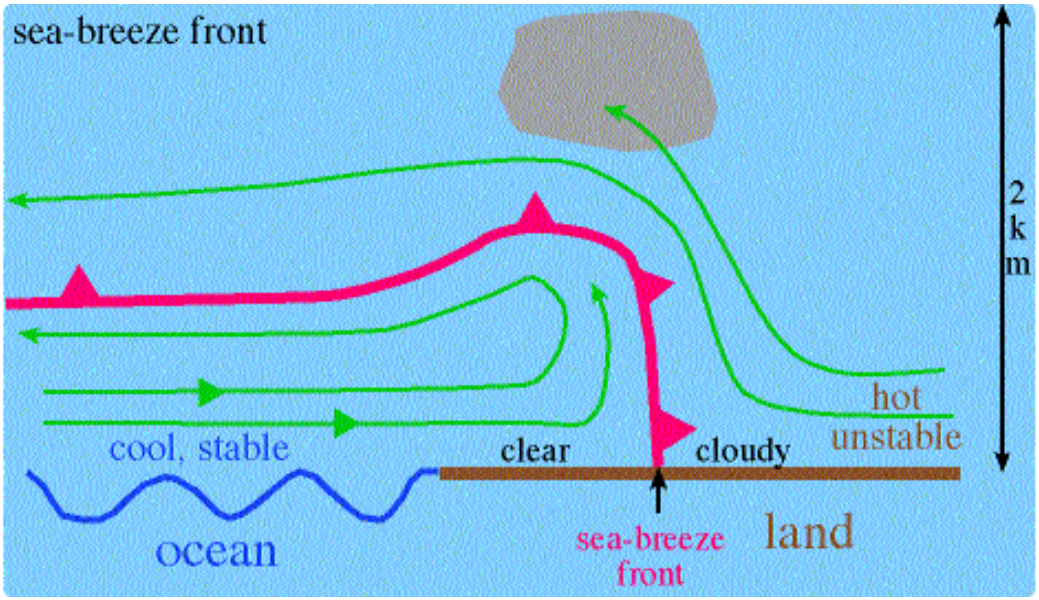


(a) Sea breeze



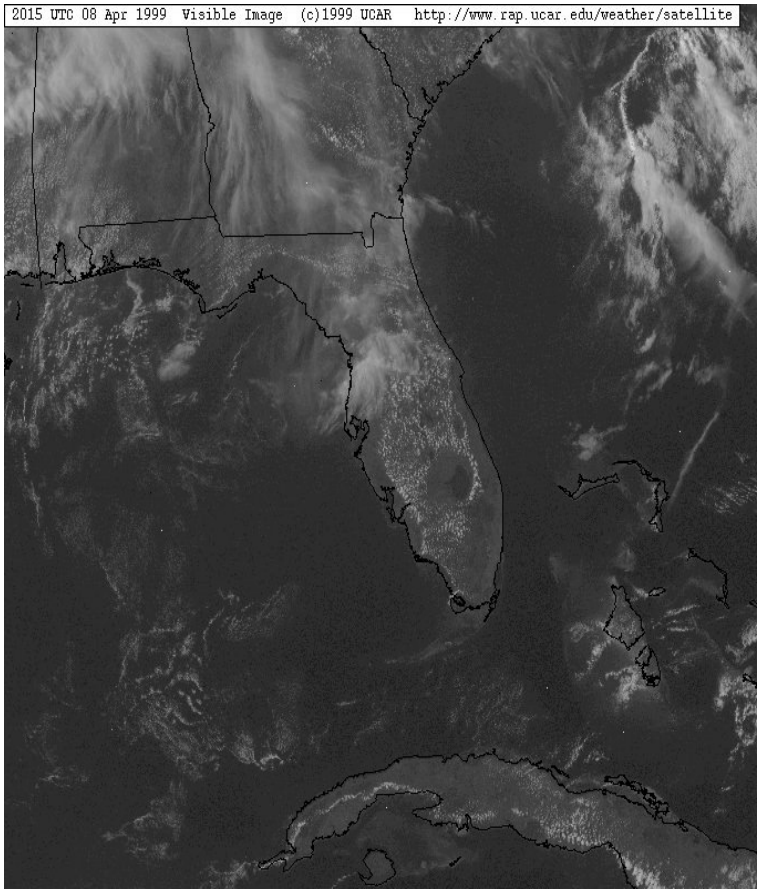
(b) Land breeze

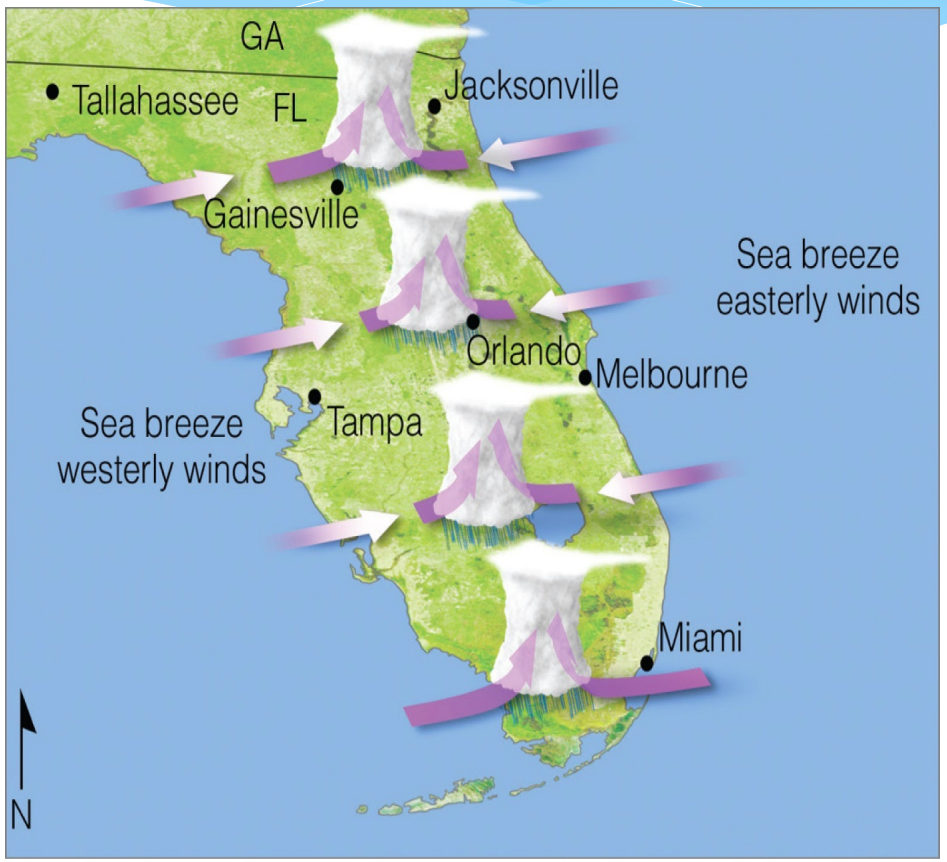
Sea Breeze Front



* The *sea-breeze front* is the boundary between the cool, stable sea-breeze flow and the hot, unstable winds over land
* Sea-breeze frontal passage is noted by:
  * change of wind speed and direction
  * temperature decrease
  * moisture increase
  * change in air quality
  * max temperature at a station is often realized just before frontal passage
* Clouds often form along the front

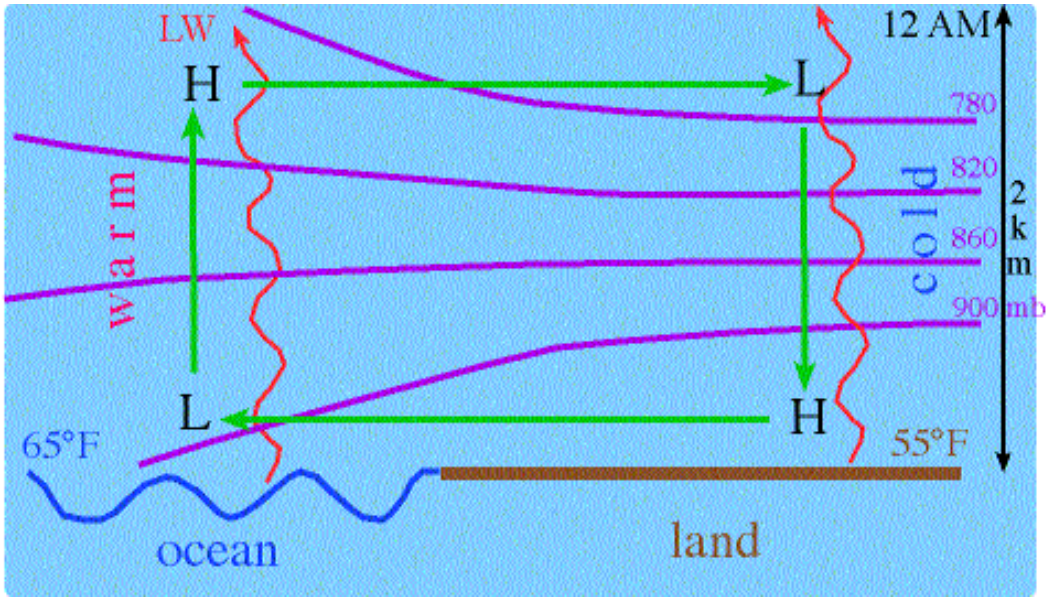
Converging Sea Breezes in Florida





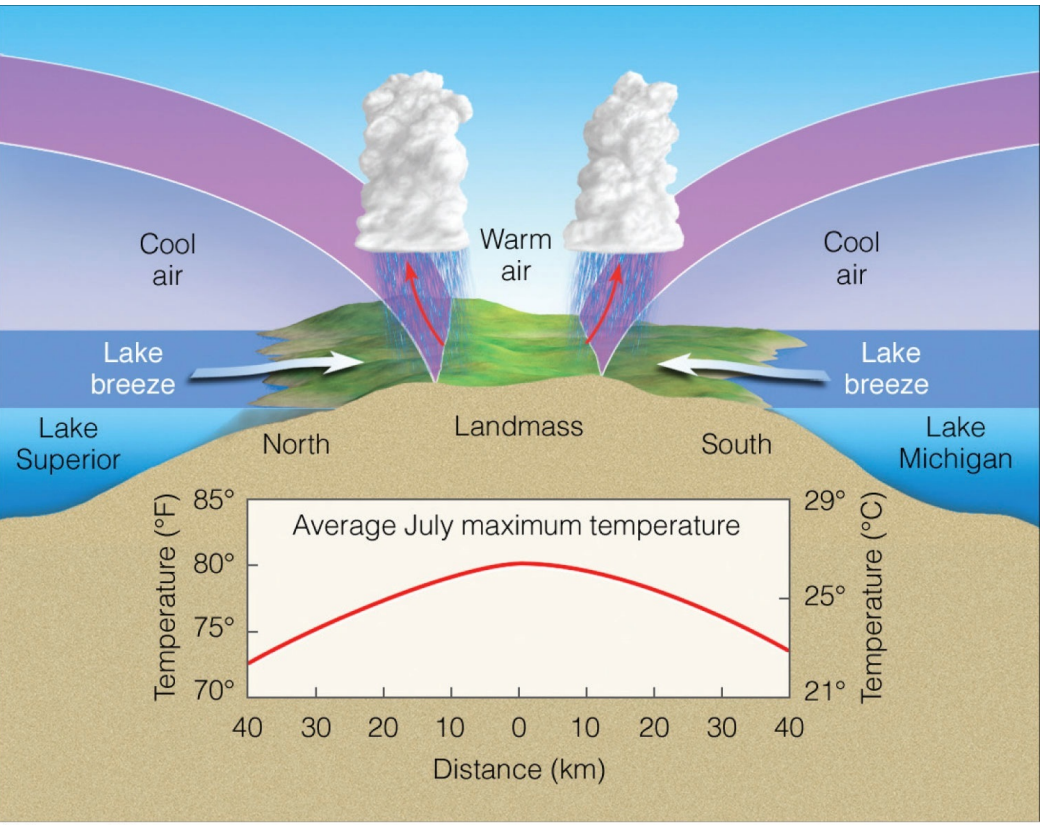
Thunderstorms in Florida

Land Breeze



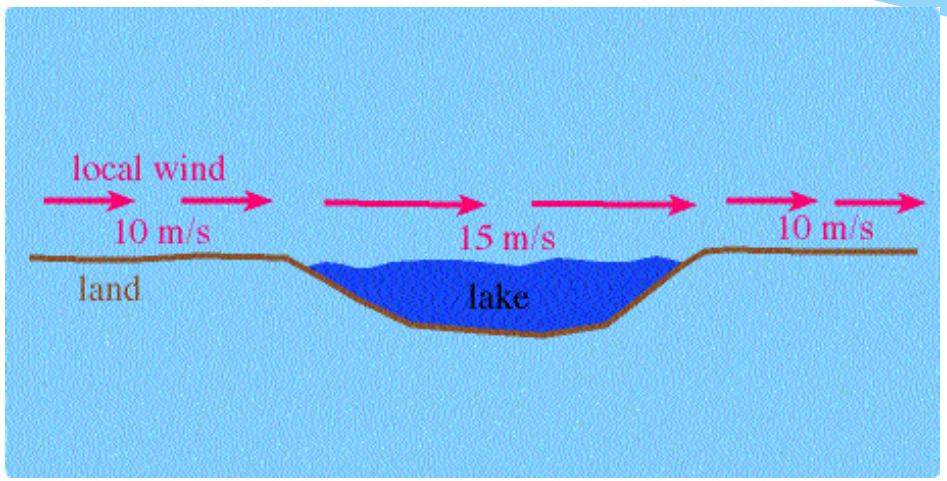
* Forms at night as the land cools radiatively more rapidly than the ocean surface, again due to the specific heat difference

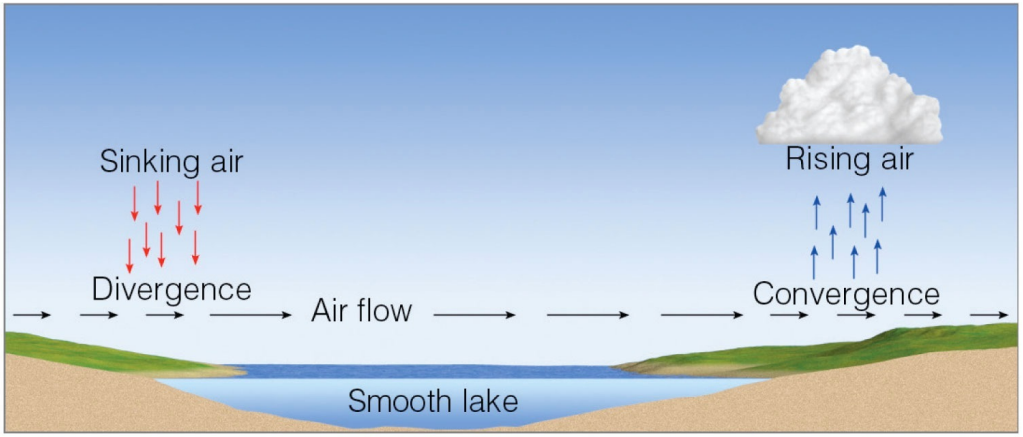
Lake Breezes



* Large lakes (Lake Superior and Lake Michigan) can produce strong lake breezes
* In upper Michigan these lakes are separated by about 50 miles of land
* Two breezes push inland and converge near the center of the peninsular creating afternoon clouds and showers while the lake shore area remains sunny and pleasant

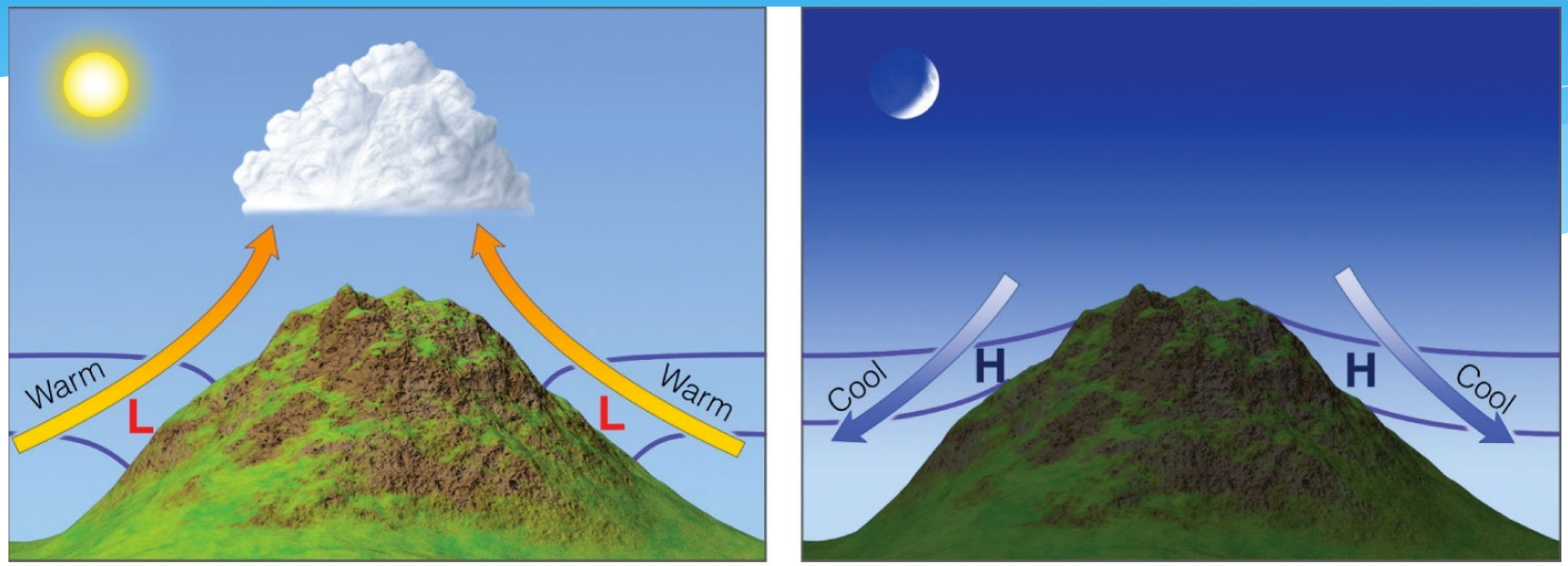
Local Winds





* Winds often change speed and direction when moving from land to water or water to land (less friction)
  * Land to water – speed up
  * Water to land – slow down
* Where the winds speed up as the air moves from the land to water, an area of divergence and *sinking motion* is generated
* Where the winds slow down as the air moves from the water to land, an area of convergence and *rising motion* is generated
* If the rising motion is strong enough, clouds may be generated

Mountain and Valley Breezes



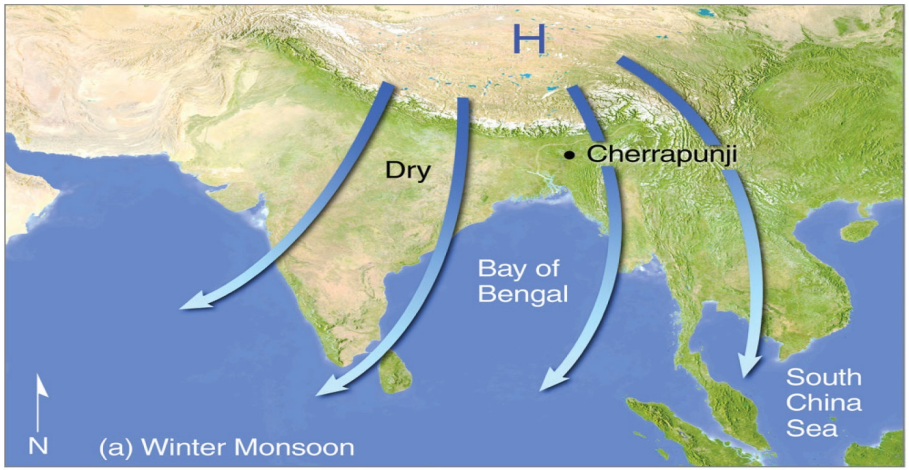
Valley breeze

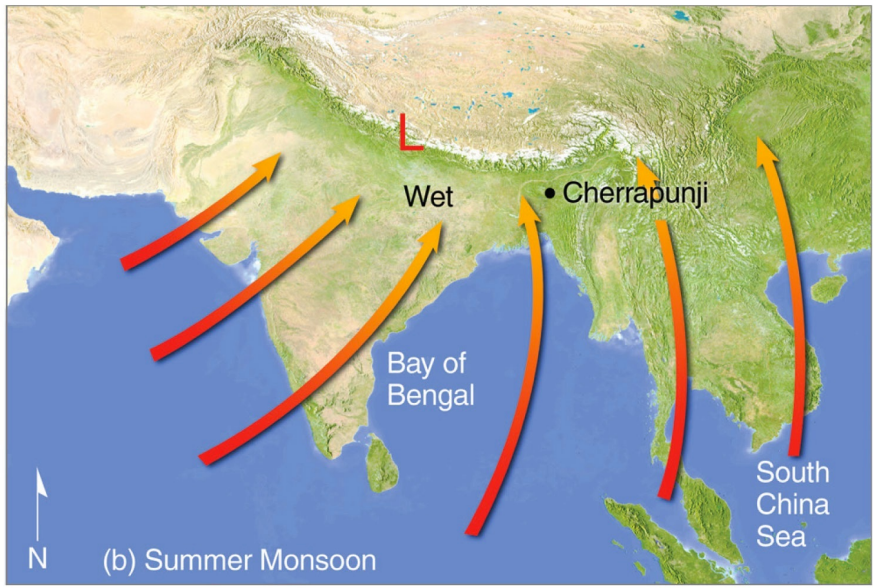
Mountain breeze

* Upslope/valley breezes
  * Form as solar radiation heats the mountain slope
  * This lowers the air pressure adjacent to the mountain slope
  * A PGF is created and directed towards the mountain
  * The air moves up the mountain slope, sometimes producing clouds
  * Often cumulus clouds are formed
  * Valley breezes reach max strength in the afternoon and often result in thunderstorms
* Mountain Breeze
  * At night the process is reversed (PGF is opposite direction) and wind flows down the mountain

Clouds from Valley Breezes

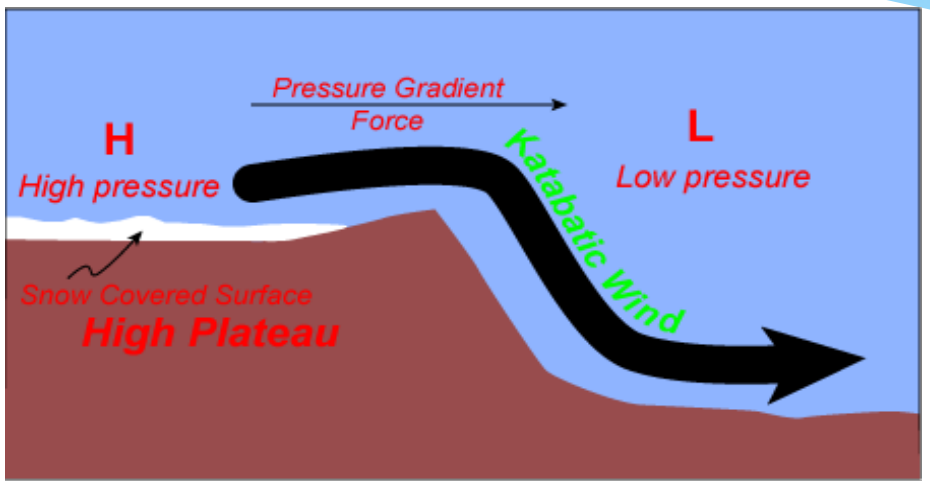
Monsoons





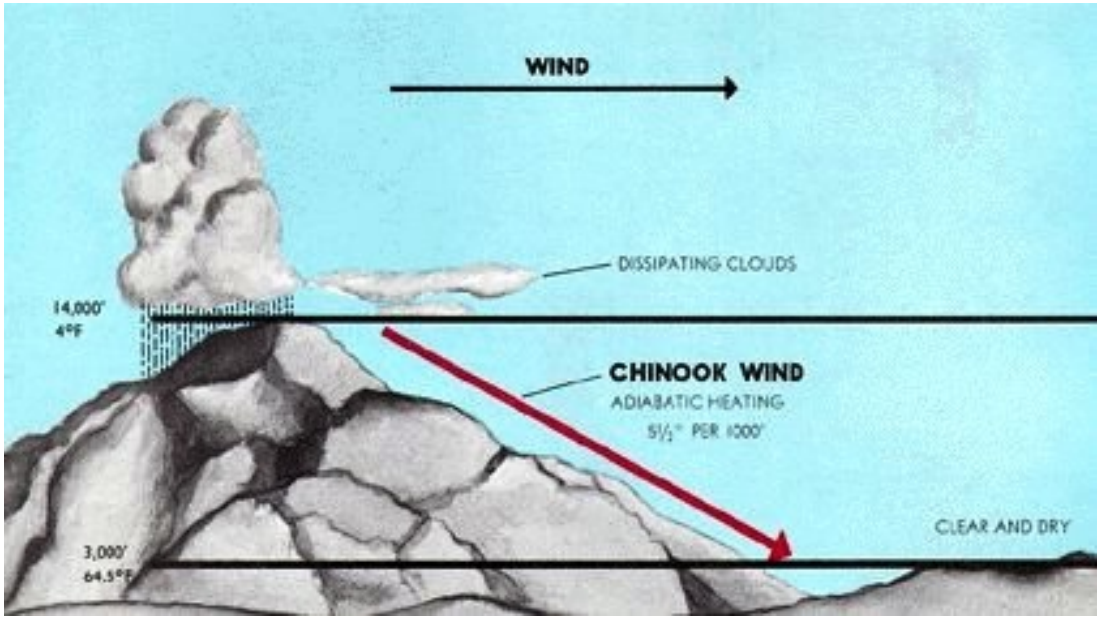
* Very large thermal circulation Monsoon winds – change direction seasonally
  * Blows from one direction in the summer and another in the winter
* Summer water becomes warmer than land
* Winter land becomes warmer than water
* Due to ITCZ band shift
* Strength related to El Nino

Katabatic Winds



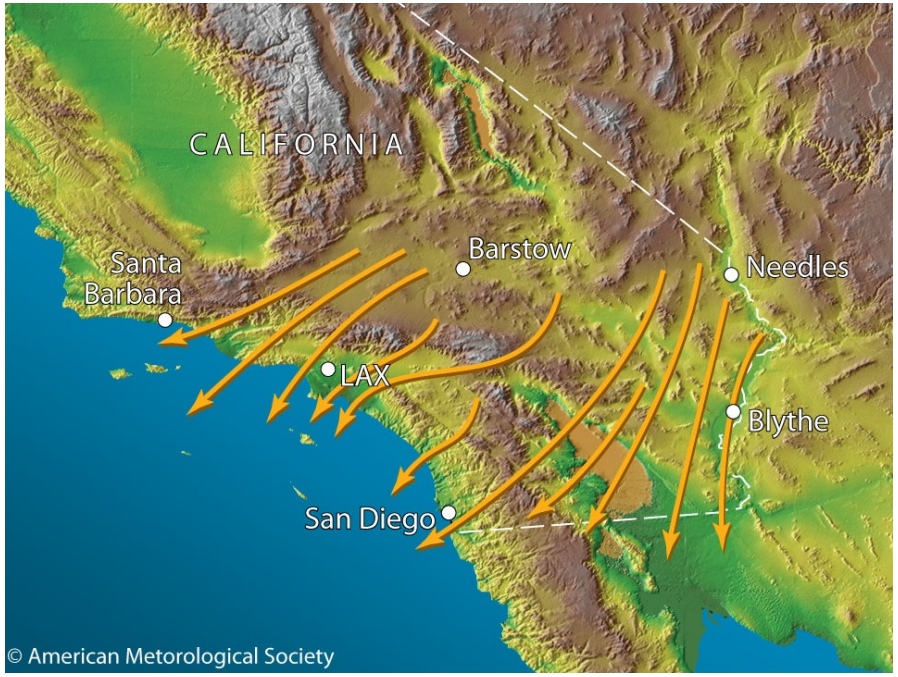
* Down-slope wind that are stronger than mountain breezes and can occur during daytime . Very Cold
  * Ideal setting is an elevated plateau with snow
  * Cold air forms a high pressure
  * PGF is toward lower ground
  * Air warms as it descends but start out very cold (-25c) and end up cold (-4)
  * The Columbia River Gorge, the largest gap through the Cascades, is not only known for its spectacular beauty, but its persistent, sometimes damaging, cold easterly winter winds
    * Winds are channeled through this narrow gap and concentrated into fierce onslaughts that blast the Portland-Vancouver areas with chilly, high speed winds several times each winter. These winds sometimes reach speeds of 80 miles-per-hour, causing structural damage and blowing trucks off Interstate-84.

Chinook Winds



* Occurs with West winds flowing over a N-S mountain range (Rockies)
  * Wind loses moisture and becomes denser and flows down leeward side
  * Adiabatic or compressional warming
  * Snow eaters

Santa Ana Wind



Typical paths followed by Santa Ana winds.

* Hot, dry wind usual blowing from the northeast to east that impacts portions of southern California from fall into early winter (October-March).
* Wind originates in Great Basin and high Mojave Desert
  * Air is cool and dry
* Gravity initiates downslope flow, helped by a strong pressure gradient
  * Adiabatic compression produces hot, dry winds

Desert Winds

* Without water, vegetation or evapotranspiration, absorbed radiation goes into sensible heating; hot surfaces generate superadiabatic lapse rates in the lowest levels of the atmosphere
  * Great instability, vigorous convection, gusty surface winds, no water vapor or clouds
  * Dust devil – whirling mass of dust-laden air formed by localized hot spot
    * Air is heated, rises rapidly; cooler surface winds converge on the hot spot
    * Horizontal wind shear causes the column of rising hot air to spin about vertical axis
    * Dust and debris collected, made visible to altitudes topping 900 m
    * May have winds as higher than 75 km per hr

Desert Winds

* Desert winds
  * Haboob – dust storms generated by strong thunderstorm downdrafts
    * Rain from thunderstorm evaporates, cooling counteracts warming by compression
    * Thunderstorm downdraft exits cloud base, hits ground as cool gusty air, lifts dust off ground creating a huge ominous black cloud