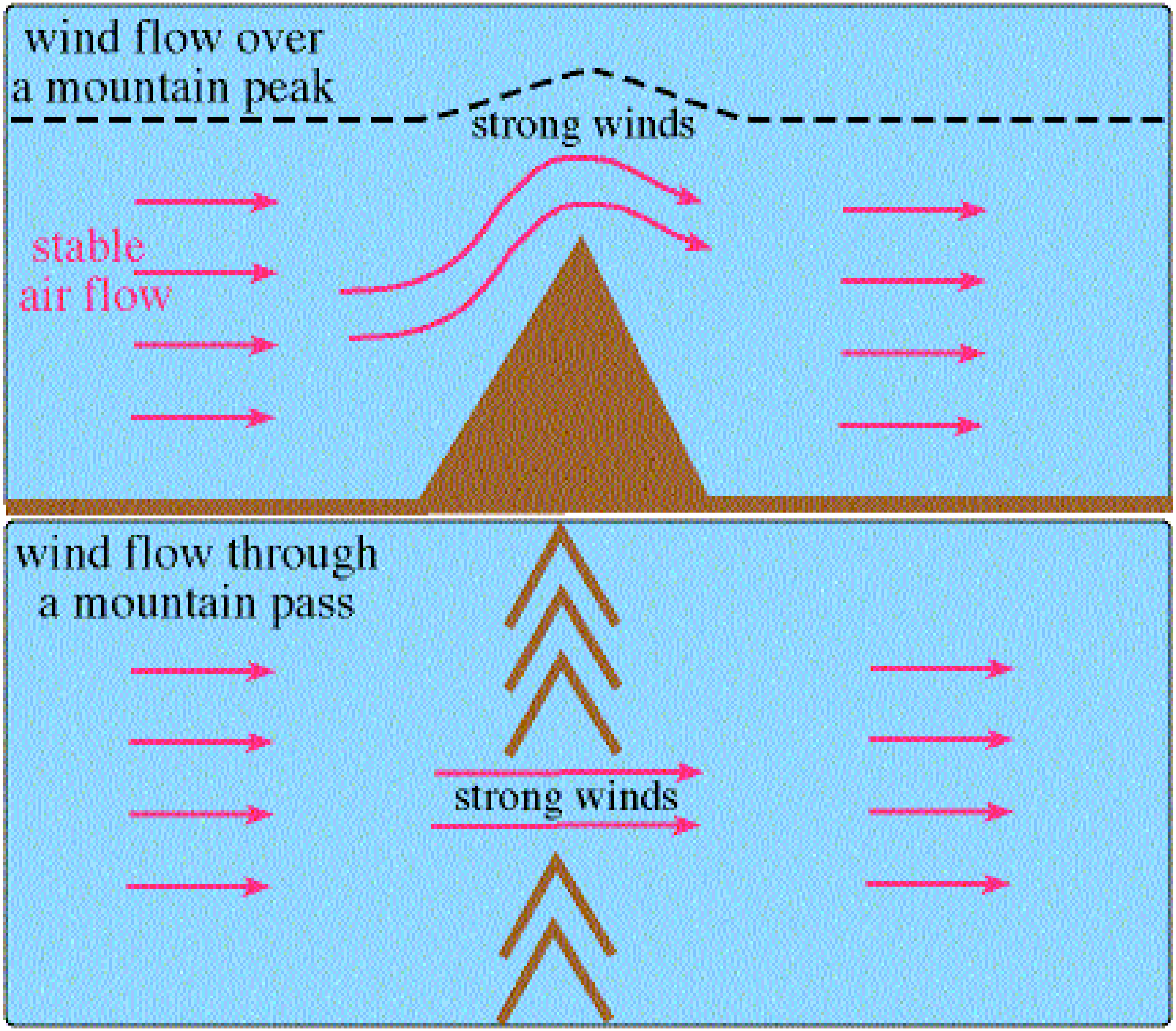
Topography (Climate)

- Regional: 100's of kilometers
  - Chinook winds
  - Mountain waves and resulting clouds
- Mesoscale: 1 to 10's of kilometers
  - Mountain-valley system of winds
- Local Scale: meters to kms

Flow over mountains and through mountain passes

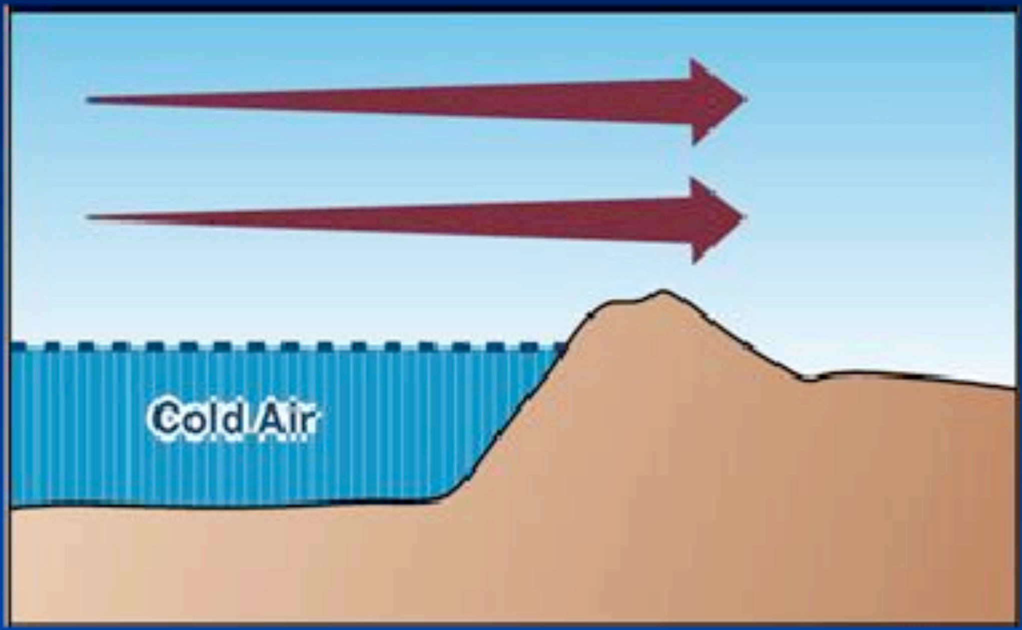
- why is it sometimes very windy:
  - on the peaks of mountains?
  - in a mountain pass?


wind flow over
a mountain peak
strong winds
stable
air flow
wind flow through
a mountain pass
strong winds

Topography: Regional Scale

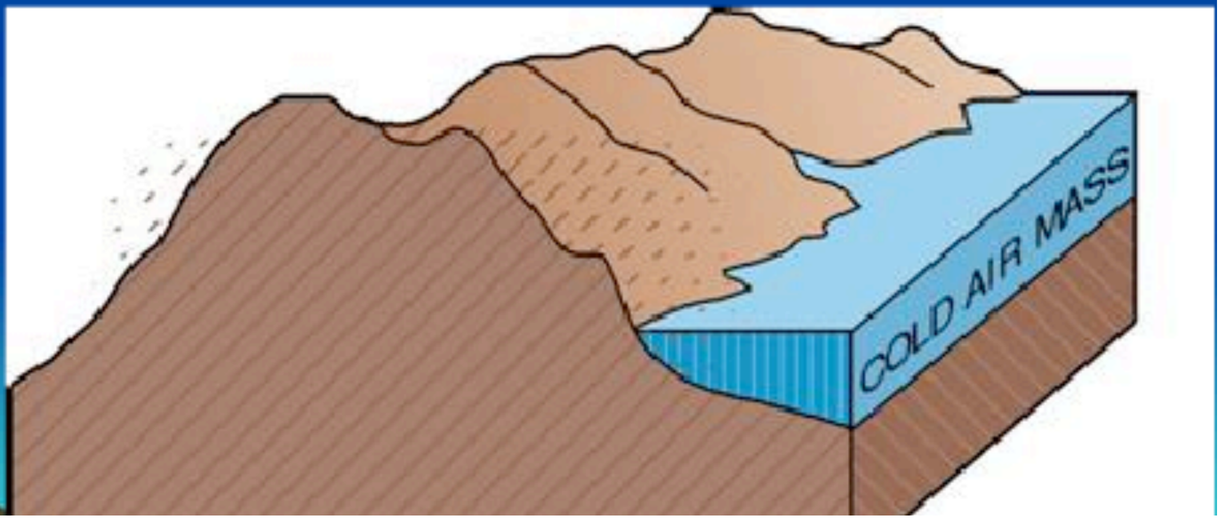
- Mountain Barrier Effect
- Prevailing winds interact with mtns
- They must accelerate to go over mtns,
  - Increasing wind speed on peaks
- The wind “looks” for low places to flow
  - Increasing wind speed in passes

Mountains as flow barriers

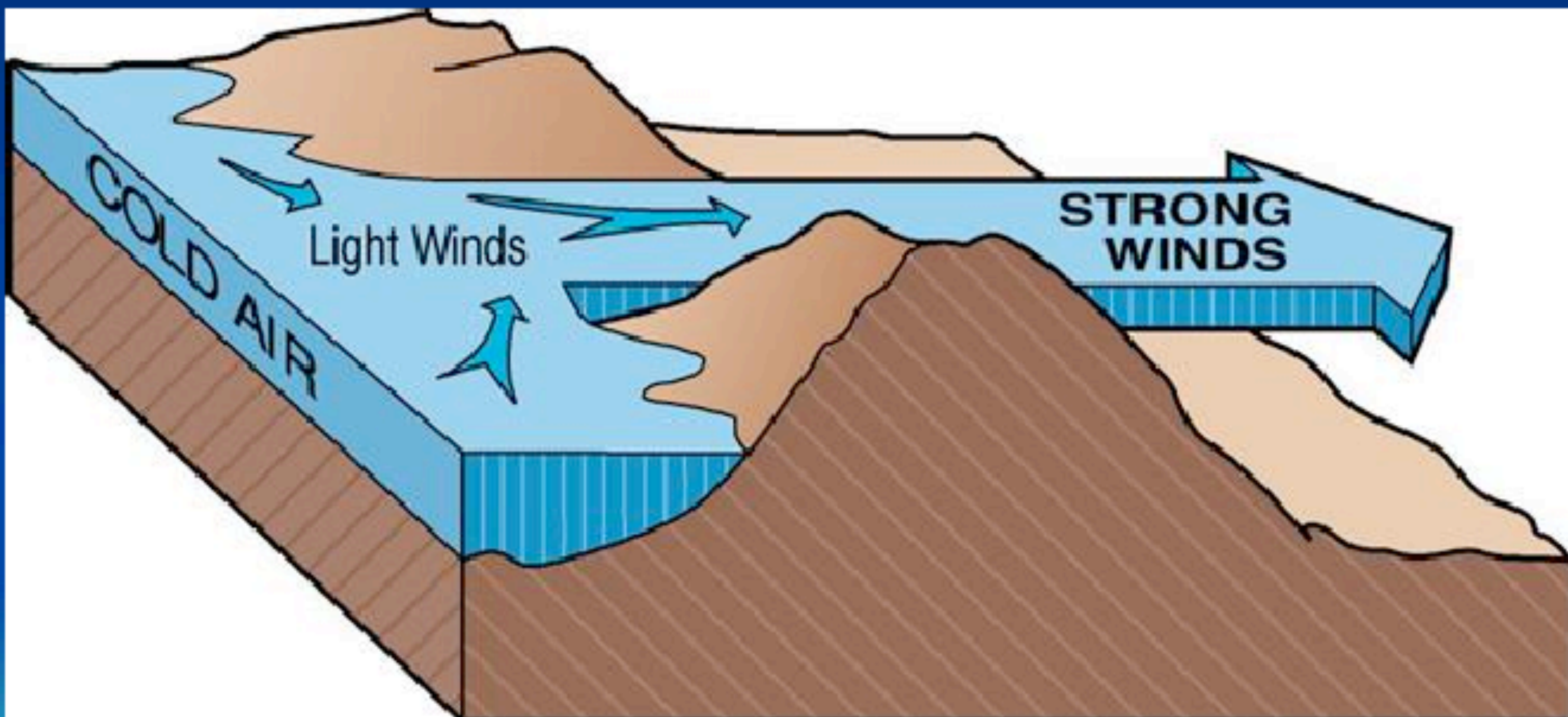


High pressure on windward side
Low pressure on leeward side

Whiteman (2000)

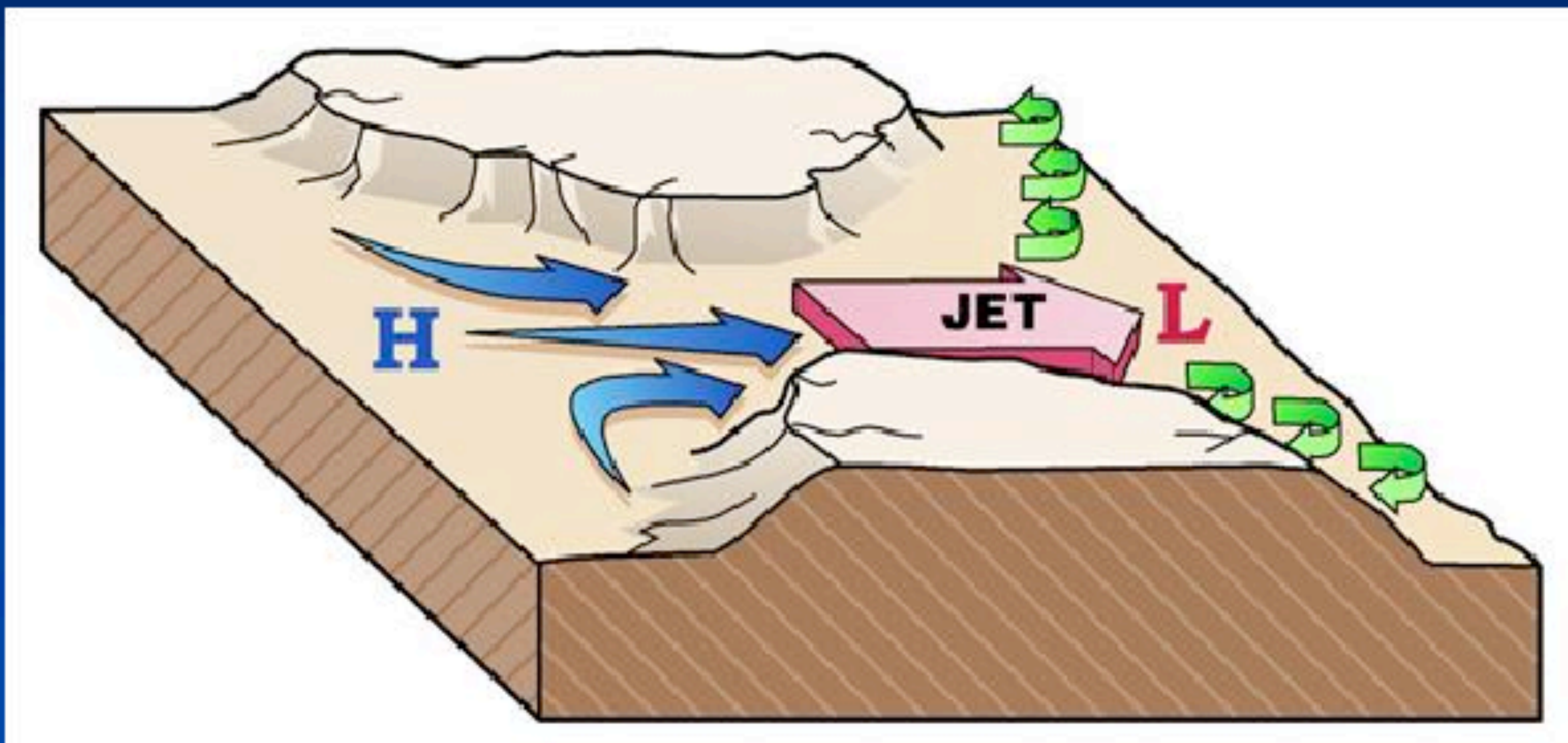


Flow through passes & gaps



Whiteman (2000)

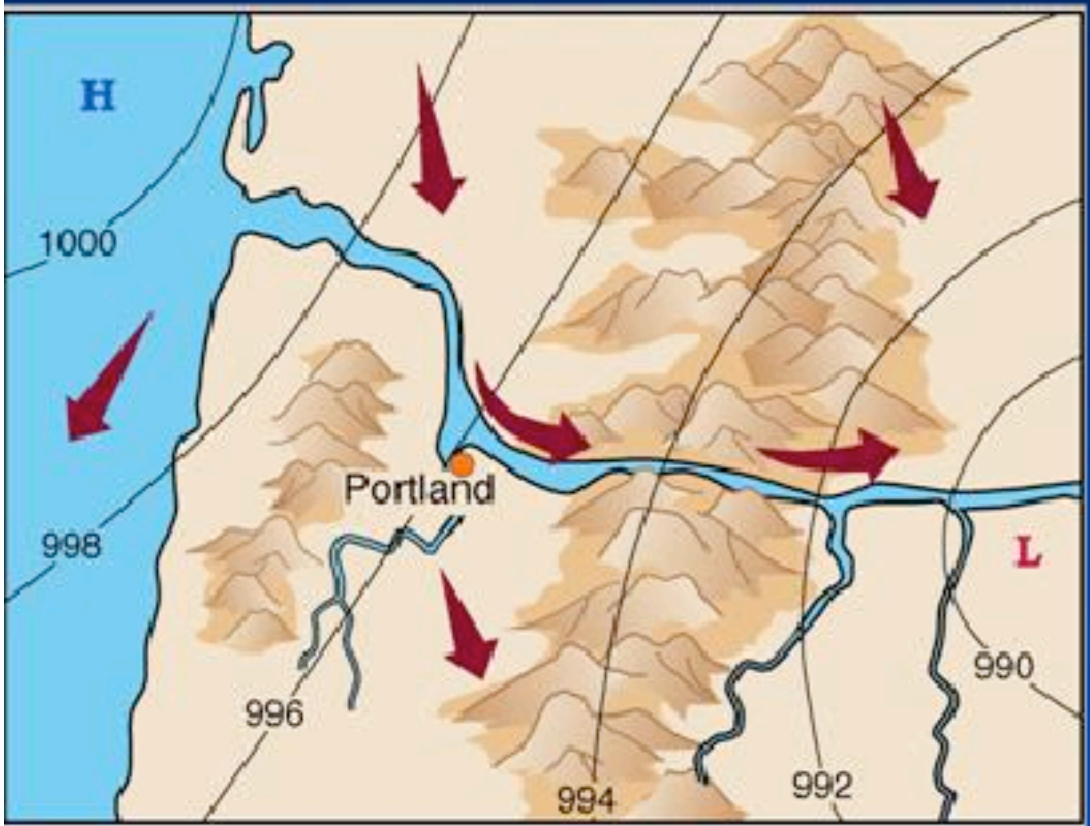
Venturi or Bernoulli effect



Whiteman (2000)

Venturi effect causes a jet to form as winds pass through a terrain constriction and strengthen.

Pressure driven channeling through Columbia Gorge



Whiteman (2000)

Pacific High, heat low in Columbia Basin

Excellent windsurfing as wind blows counter to the river current with high speeds.

Other well-known gap winds:

Caracena Strait, CA

Strait of Juan de Fuca (Wanda Fuca)

Fraser Valley, BC

Stikine Valley (nr Wrangell)

Taku Straits (nr juneau)

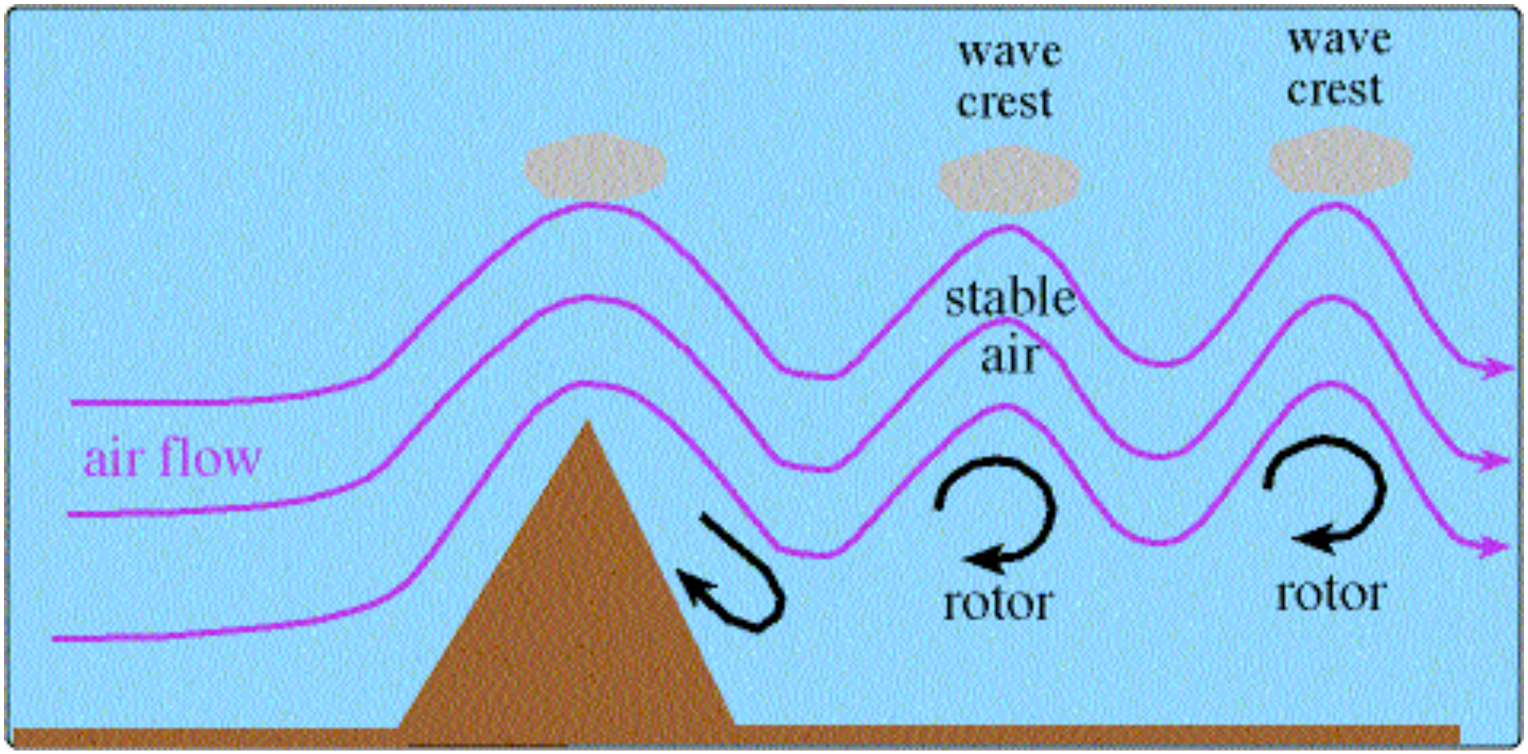
Copper River Valley (nr Cordova)

Turnagain Arm (Anchorage)

Flow Over Mountains

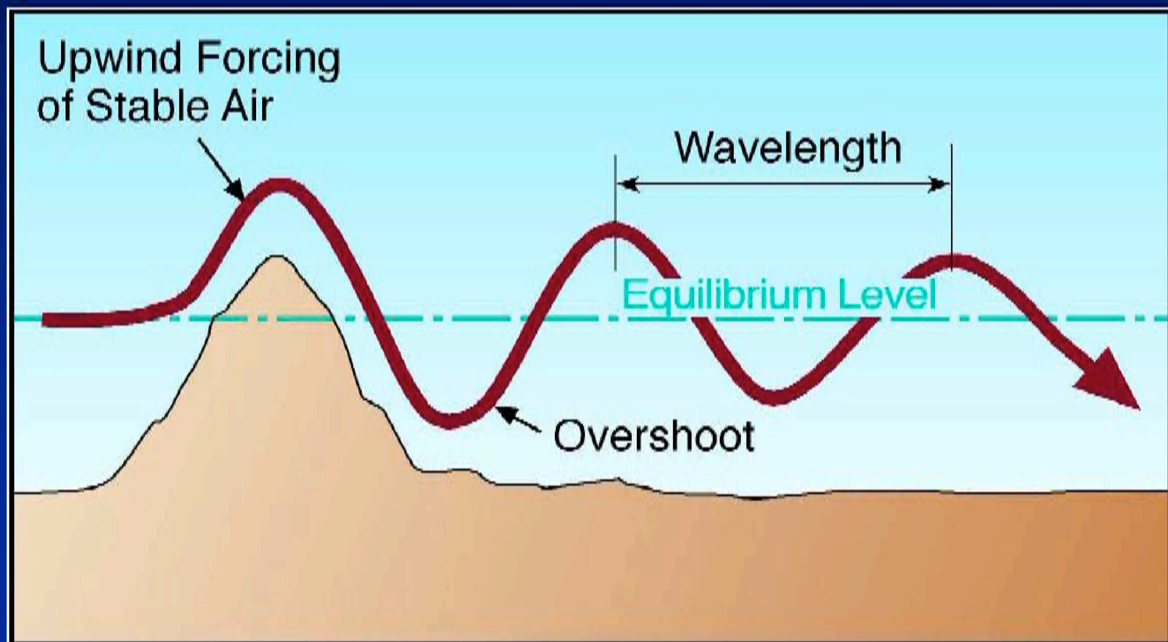
- Approaching flows tends to go over mountains if
  - 1) barrier is long
  - 2) cross-barrier wind component is strong
  - 3) flow is unstable, neutral or only weakly stable
- Common in North American mountain ranges
- Evident by presence of lenticular clouds, cap clouds, banner clouds, rotors, foehn wall, chinook arch, and billow clouds as well as blowing snow, cornice buildup, blowing dust, downslope windstorms, etc.

Downslope winds



Windward slope **Lee slope**

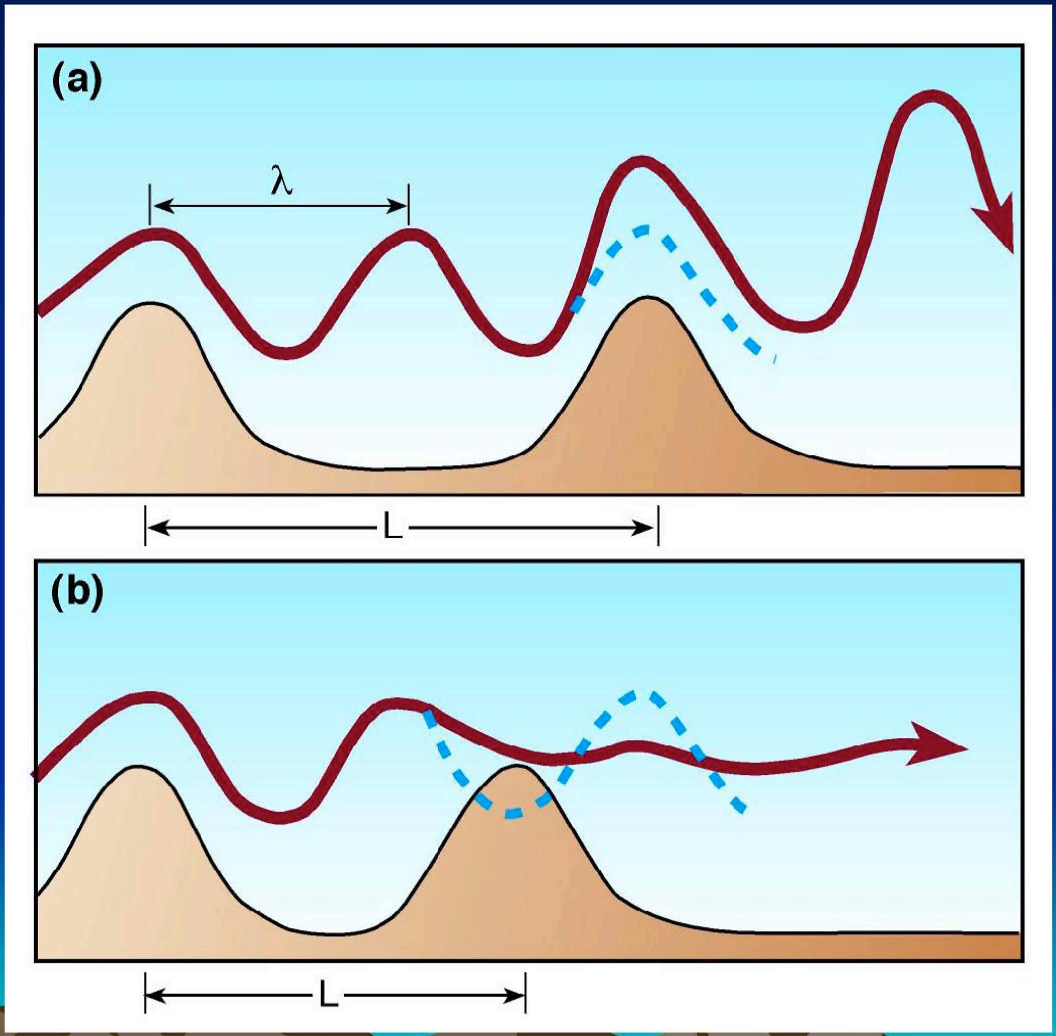
Lee waves



Stull (1995)

Lee waves are *gravity waves* produced as stable air is lifted over a mountain. The lifted air cools and becomes denser than the air around it. Under gravity's influence, it sinks again on the lee side to its equilibrium level, overshooting and oscillating about this level.

Amplification and cancellation of lee waves



If the flow crosses more than one ridge crest, the waves generated by the first ridge can be amplified (a process called *resonance*) or canceled by the second barrier, depending on its height and distance downwind from the first barrier.

Orographic waves form most readily in the lee of steep, high barriers that are perpendicular to the approaching flow.

Eg Rocky Mountains

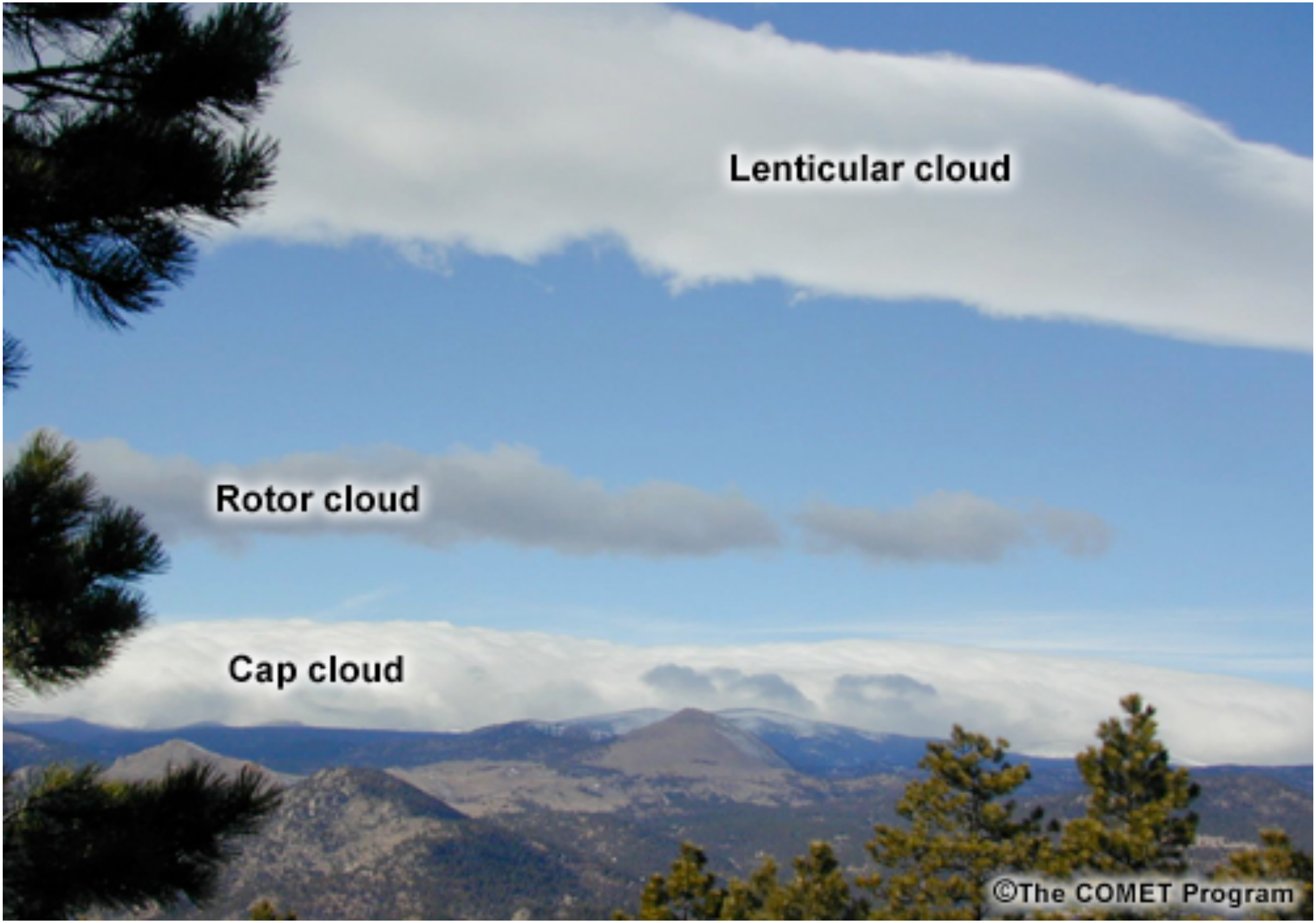
Bérenger &Gerbier (1956)

Wavelength

- directly proportional to wind speed
- Inversely proportional to stability
- Intermountain West - averages 4 miles
- Appalachia Wave - averages 10 miles

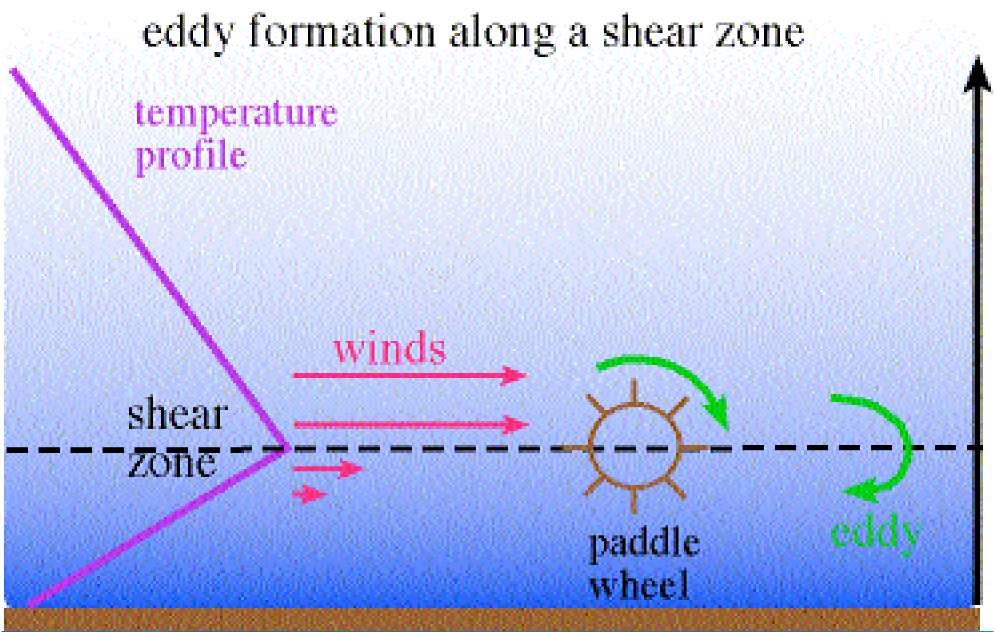
Conditions

- Diurnal variation: in the summer early morning or late afternoon is best for formation
- Seasonal variation: winter is the best time for formation (jet stream, snow covered ground = no convection, stable layer aloft)


Lenticular cloud
Rotor cloud
Cap cloud
©The COMET Program

Shear zone and clouds

- a shear zone is where the winds change speed and/or direction rapidly over a given distance
- wind shear along the shear zone can generate eddies that are sometimes visible as billow clouds



Shear Waves

Shear waves, Mt Shasta

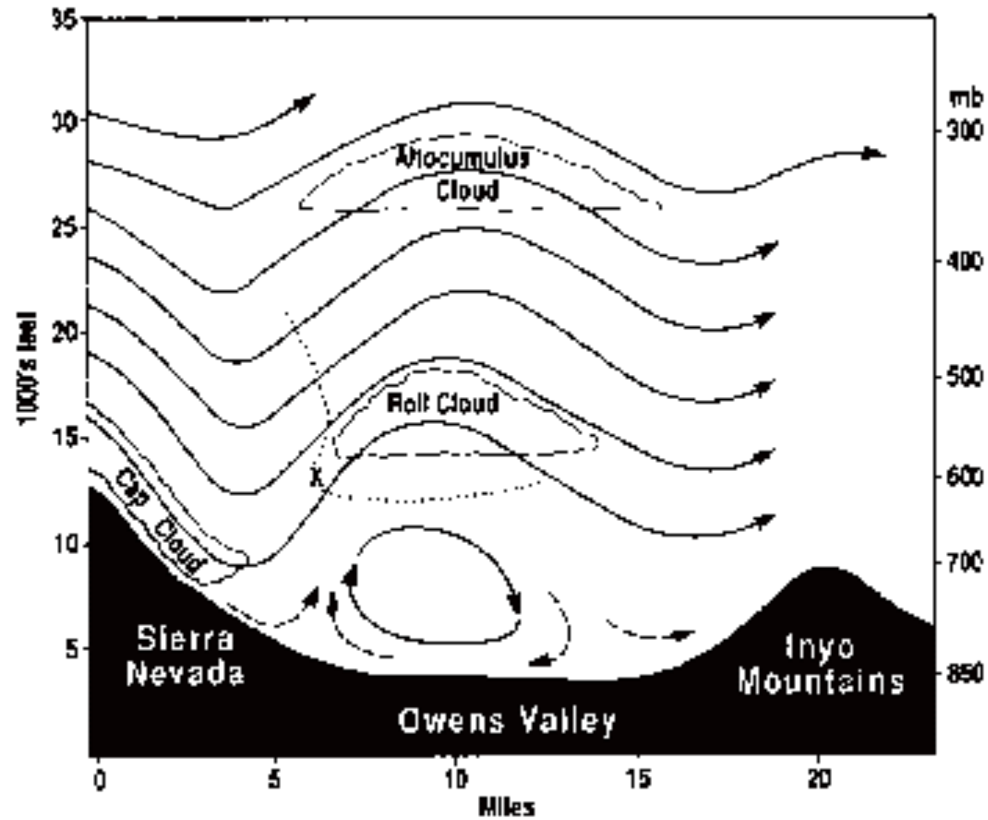
Wind direction

Sierra wave
http://www.met.utah.edu/whiteman/T_REX/

View is toward south from 11 km height. Airflow is from right to left. The cloud mass on the right is plunging down the lee slope of the Sierra Nevada; the near-vertical ascending cloud wall of the mountain wave is on the left. The turbulent lower part of the cloud wall is a "rotor"; the smooth upper part is the "lenticular" or "wave cloud". The cloud mass to the right is a "cap cloud" (= Föhn-Mauer); the cloud-free gap (middle) is the "Foehn gap" (= Föhn-Lücke).

Kuettner/
Klieforth 1952

Sierra Nevada Example

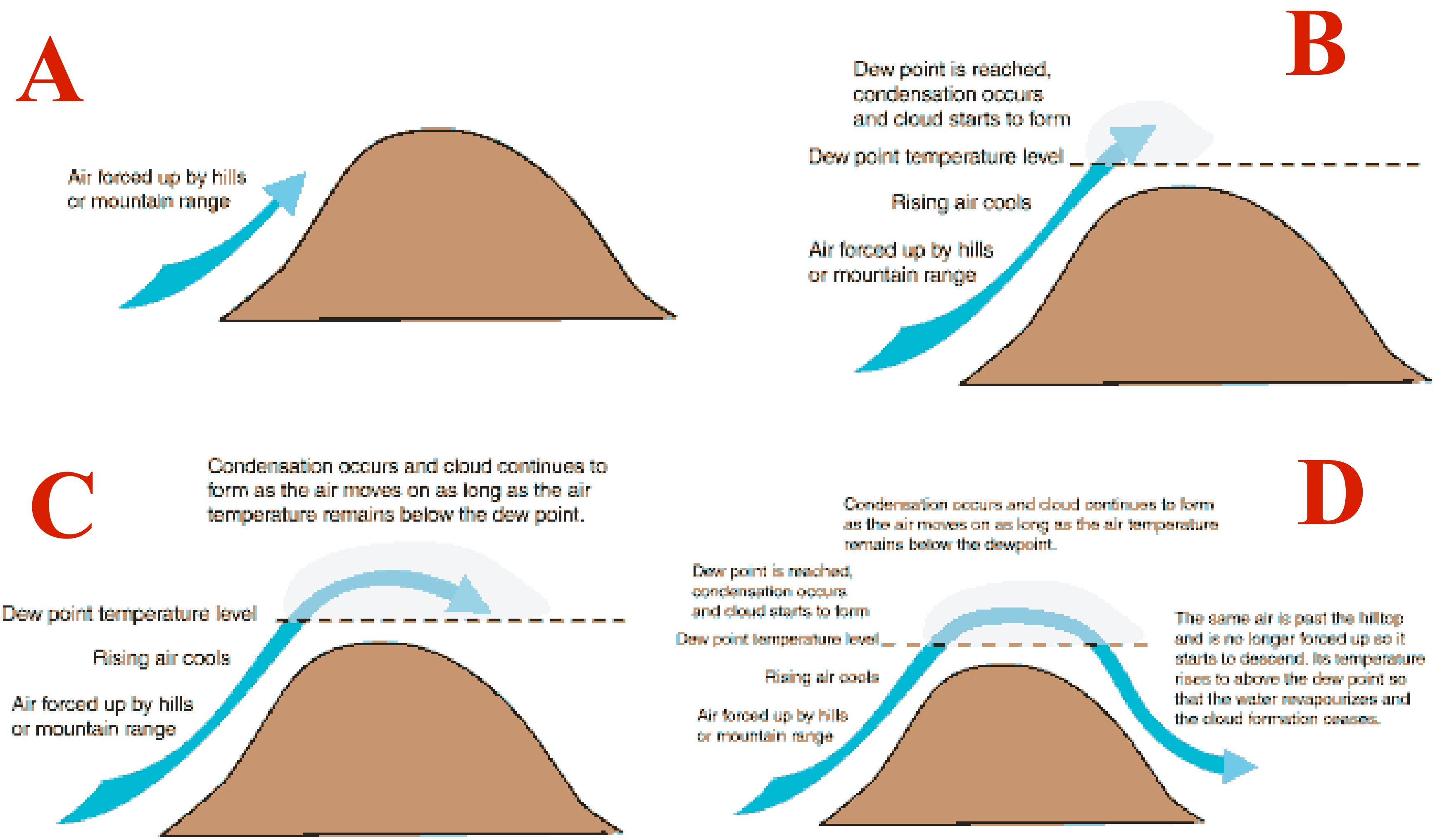


Lenticular Cloud Formation

- Technically known as altocumulus standing lenticularis
- stationary lens-shaped clouds that form at high altitudes
- normally aligned at right-angles to the wind direction.
- Occur where stable moist air flows over a mountain or a range of mountains, forming large-scale standing waves
- Lenticular clouds sometimes form at the crests of these waves.

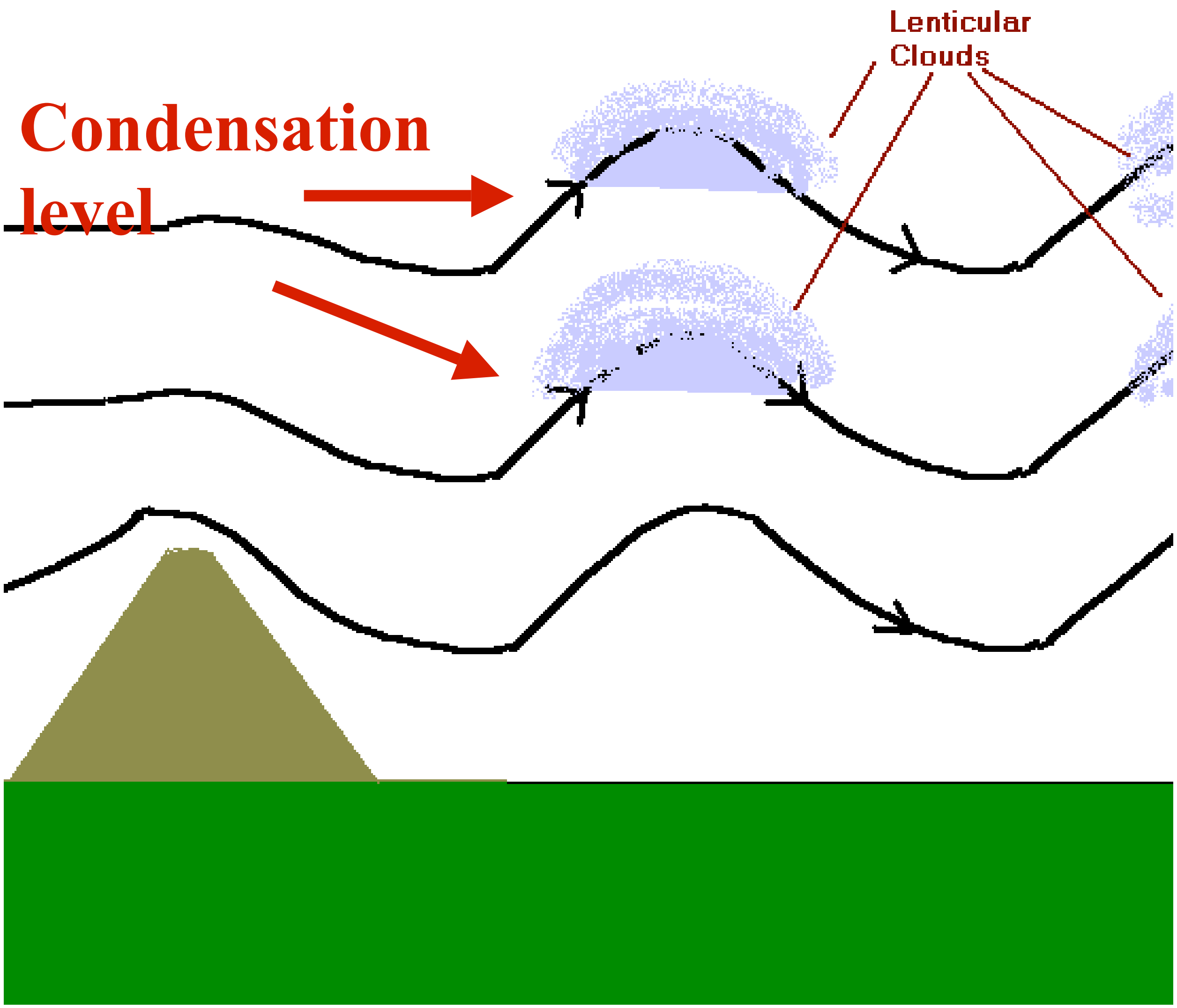
http://www.sgisland.org/pages/environ/c_clouds.htm

Lenticular Cloud Formation



http://www.no-big-bang.com/process/lenticularcloud.html

Lenticular Cloud Formation

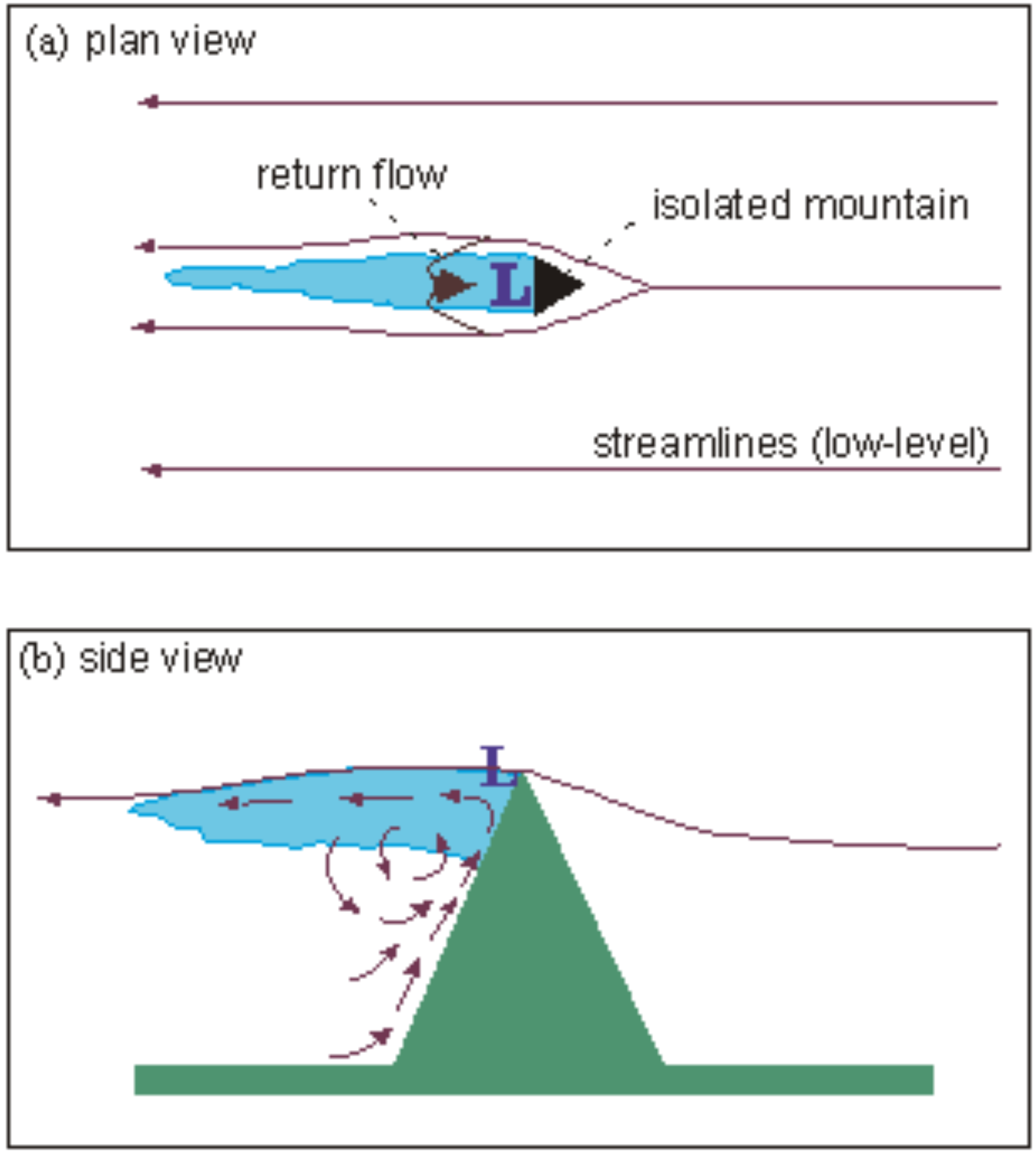


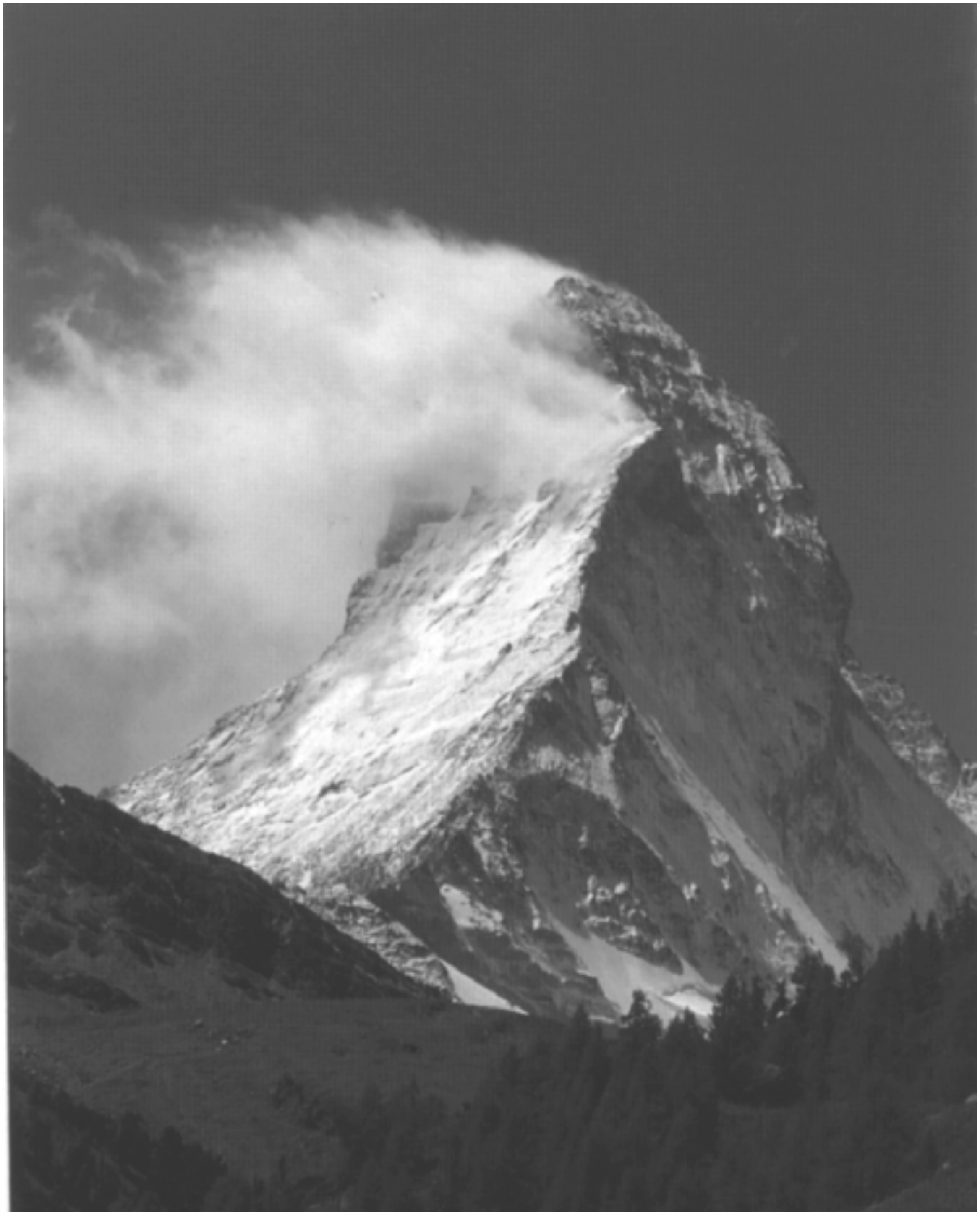
Stacked lenticular clouds

Banner or Cap Clouds

- A cloud plume often observed to extend downwind from isolated, sharp, often pyramid-shaped mountain peaks, even on otherwise cloud-free days.
- Air ascends in an upslope flow, condenses, and forms a triangular- shaped cloud, the banner cloud, to the lee of the peak.
- Physics not well-known

formation of banner clouds





Banner Cloud Matterhorn

Formed on downwind side (lee side)

Cap Cloud, Mt Rainier

Mt Shasta

Hiding UFO's?

Mt Rainier: Cap cloud and lenticulars

Lenticular Clouds over Mt. Erebus in Antarctica

Rotor Cloud

Re-circulating air on lee side of mountain

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

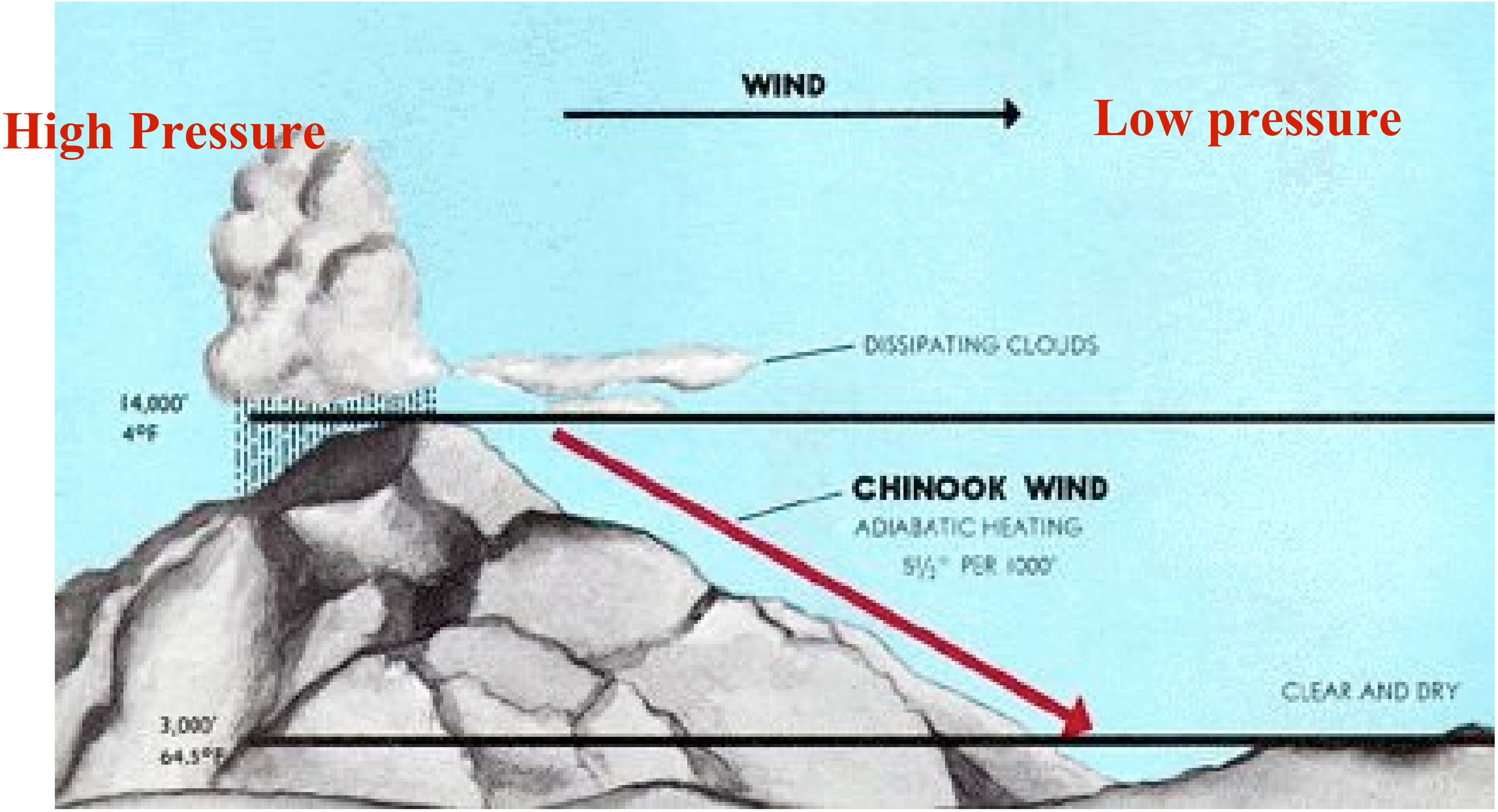
Rotors

Can extend to ground: fatal for aircraft

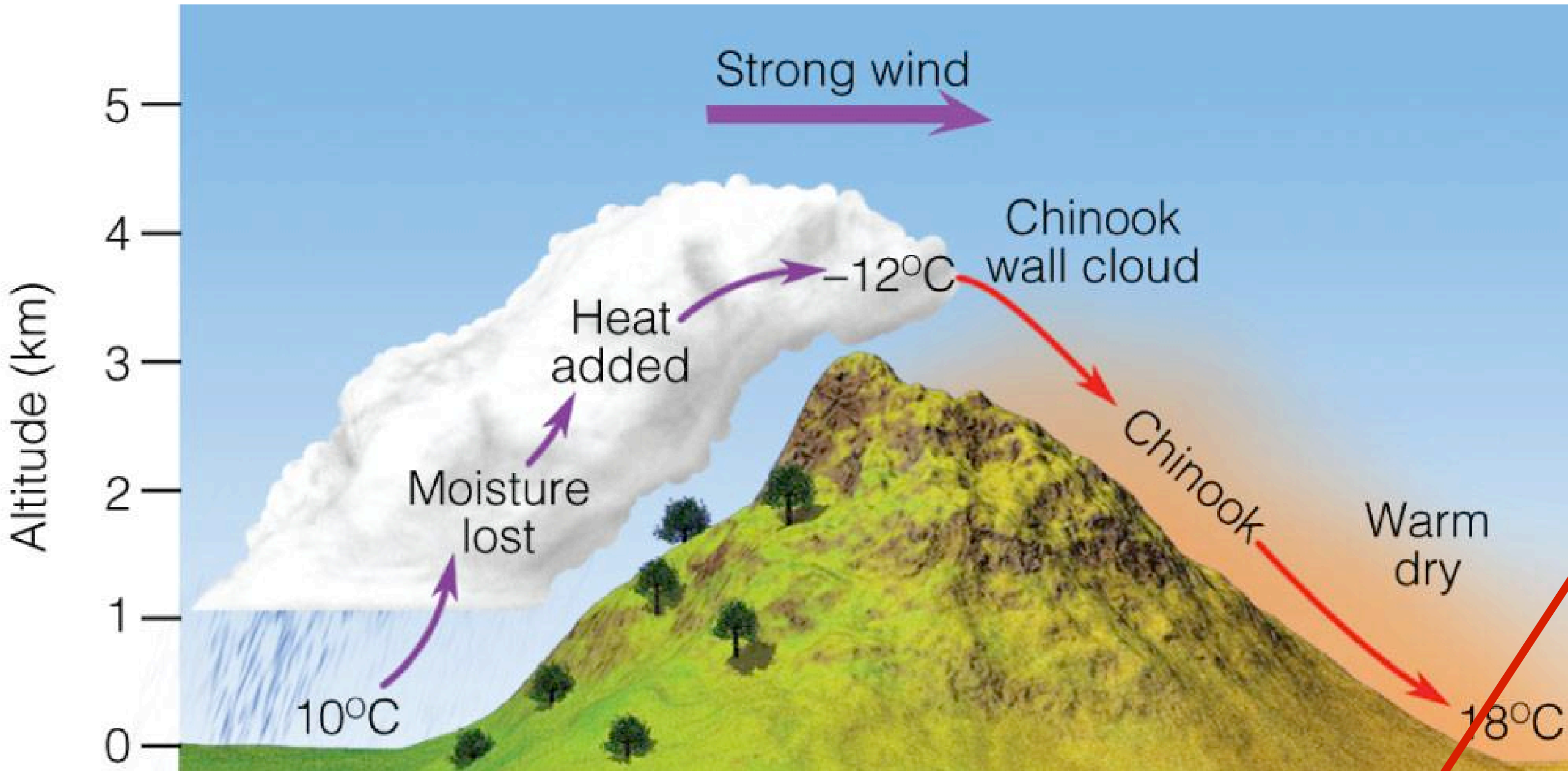
Arikaree Glacier, Colorado

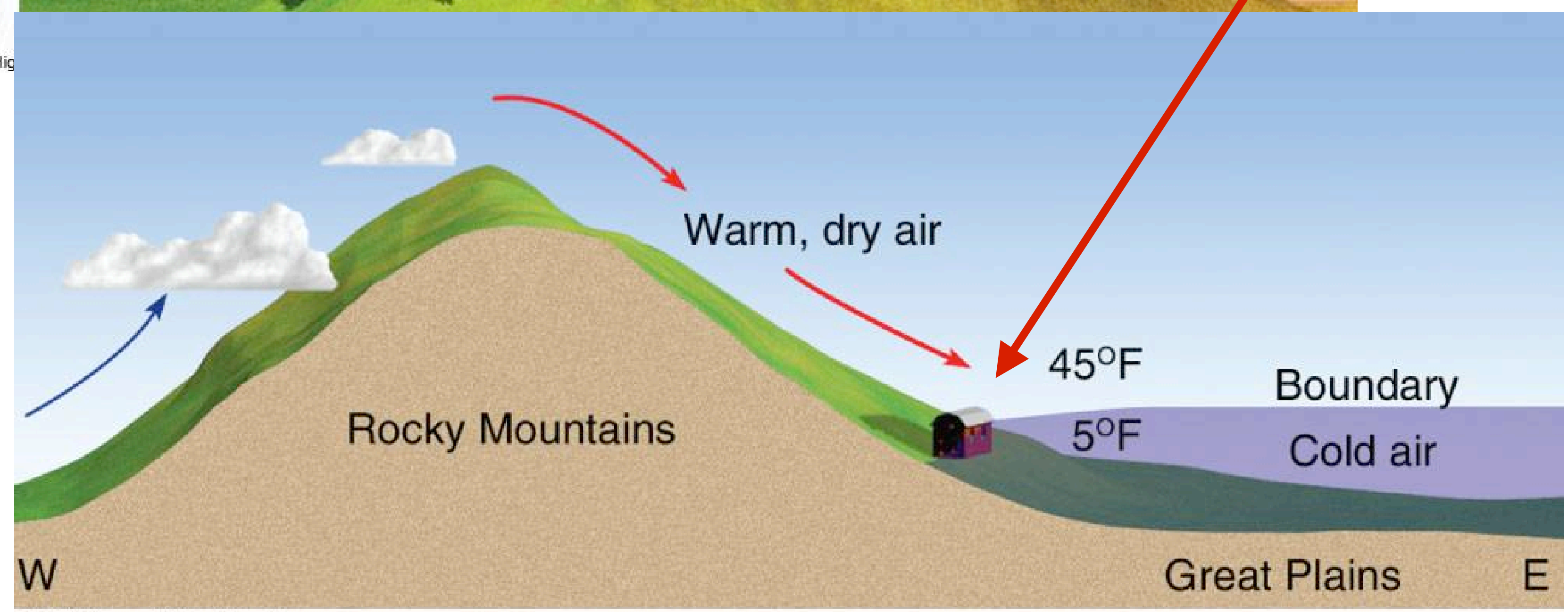
Annual snow accumulation about 15 meters because of rotor effect

“Chinook” type winds



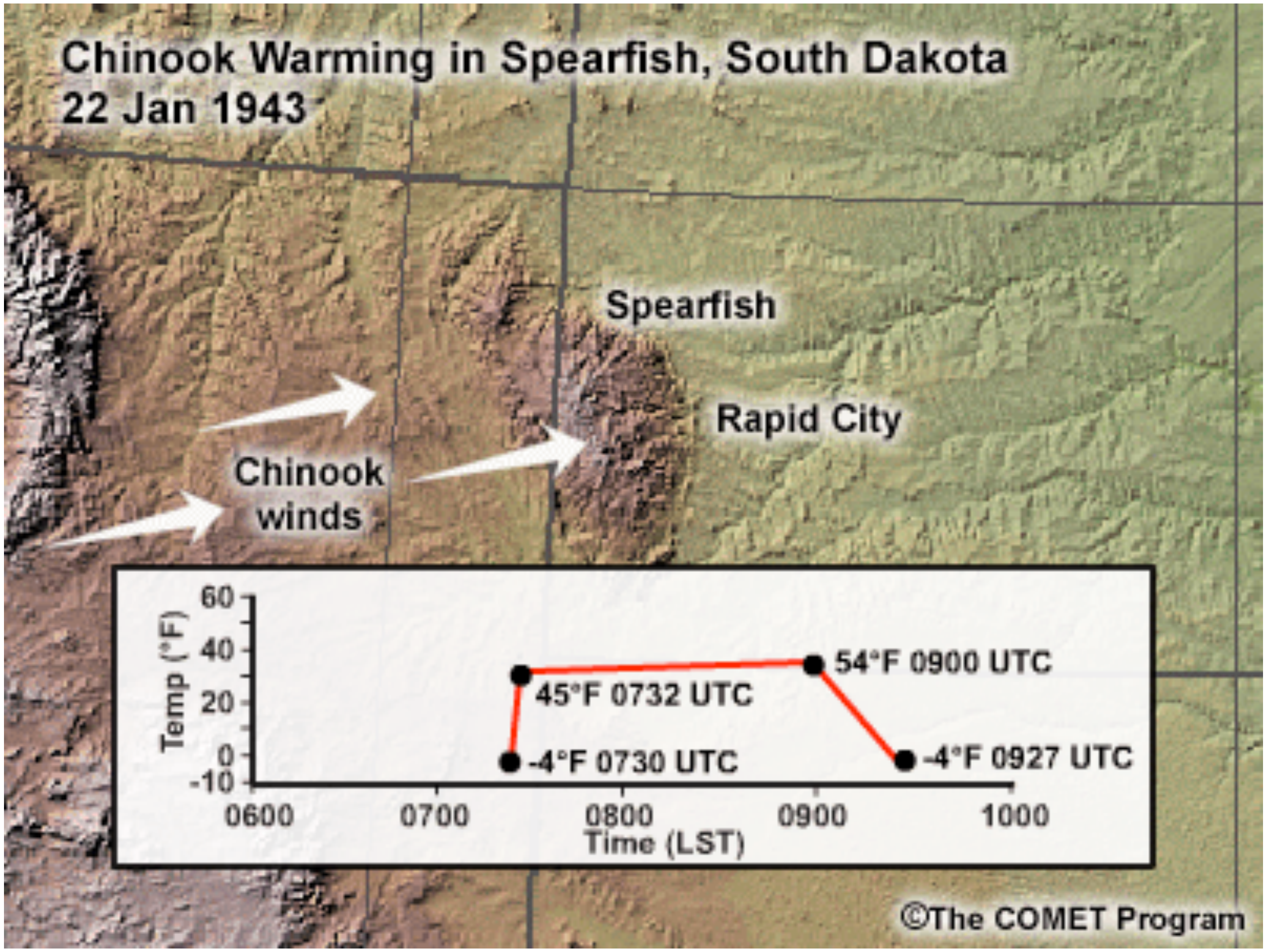
Boulder Banana zone





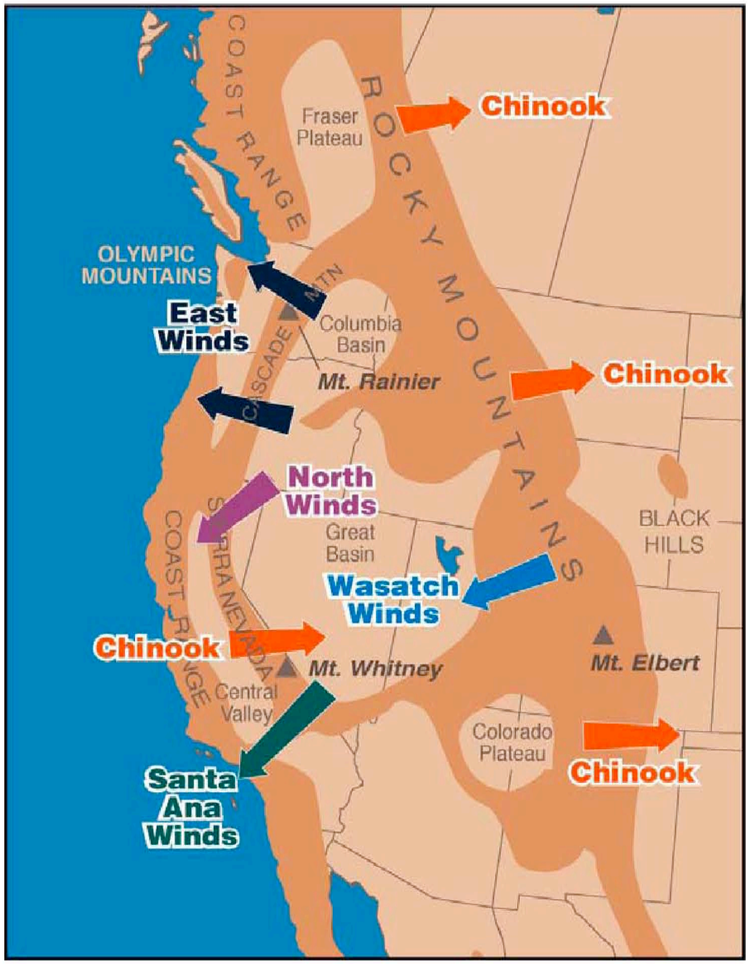
Process

- A deep layer of prevailing wind is forced over a mountain range (Orographic lifting).
- As the wind moves upslope, it expands and cools, causing water vapor to precipitate out.
- As the wind descends to lower levels on the leeward side of the mountains, the air temperature increases adiabatically as it comes under greater atmospheric pressure creating strong, gusty, warm and dry winds.
- Föhn winds can raise temperatures by as much as 30°C (54°F) in just a matter of hours.
- Winds of this type are called "snow-eaters" for their ability to make snow melt rapidly. This ability is based not only on high temperature, but also the low relative humidity of the air mass.



Air temp increased from -4 degrees F to +45 degrees F in 2 minutes from Chinook wind!

Foehn winds of the intermountain west



Schroeder & Buck (1970)

Chinook winds usually occur on the east side of N American mountain ranges since winds aloft are usually westerly. But, they can occur on the west sides when upper-level winds are from the east (Ex: Santa Ana and Wasatch winds).

Santa Ana winds - late Fall and Winter, cause horrendous wildfires.

Wasatch downslope winds - affect a more or less contiguous zone immediately adjacent to the foothills. These are produced by hydraulic jumps and interaction with flows in vicinity of canyon mouths

Synonyms

- Zonda winds in Argentina
- Diablo winds in the San Francisco Bay Area
- Santa Ana winds in Southern California
- The Nor'wester in Canterbury and Otago, New Zealand
- Halny in the Carpathian Mountains, Eastern Europe
- Fogony in the Catalan Pyrenees
- Bergwind in South Africa
- Föhn in Austria, southern Germany and German language parts of Switzerland

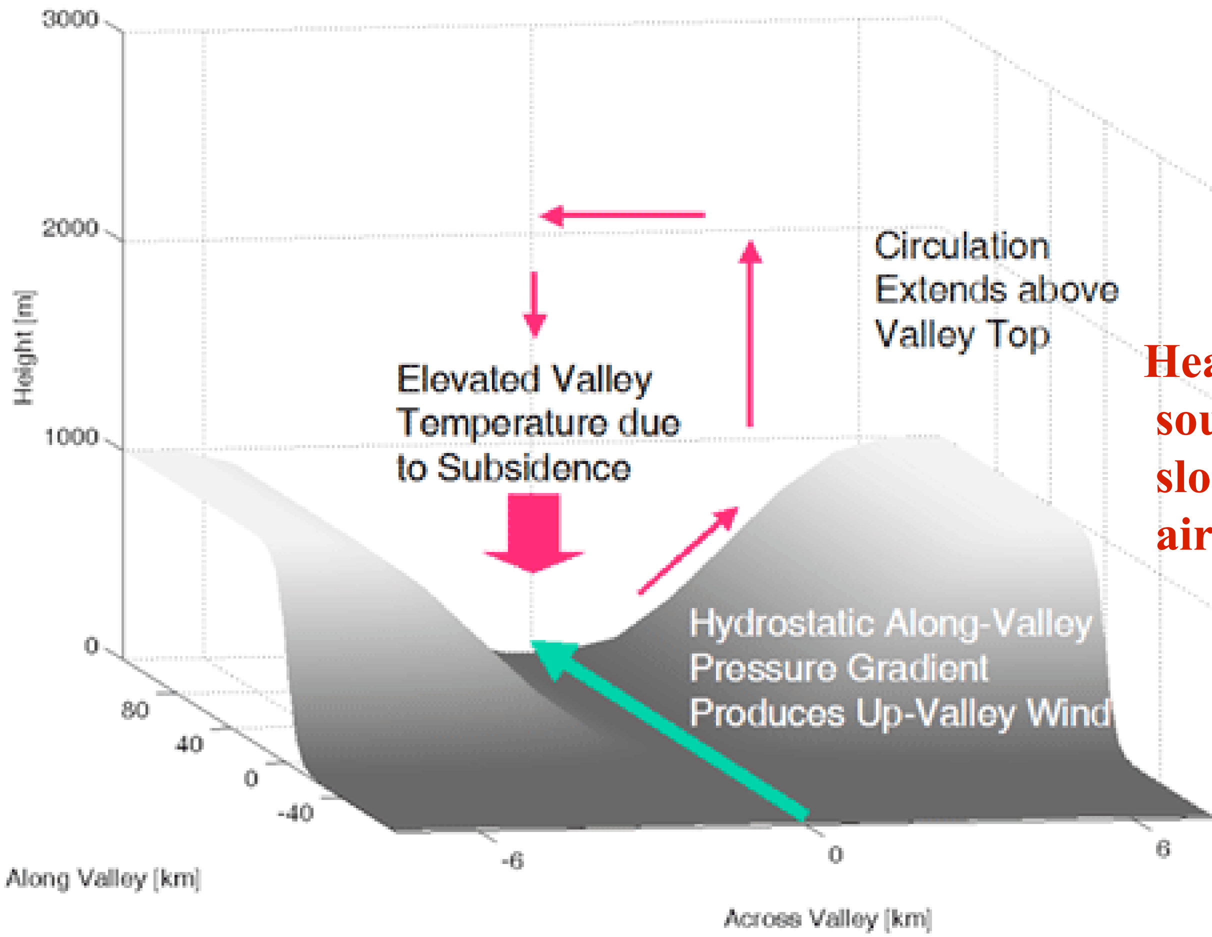
Mountain Valley Wind Systems

- The diurnal cycle of local winds in a mountain valley during mostly clear periods
  - The traditional components of the cycle are upslope (anabatic) daytime upvalley wind
  - downslope (katabatic) winds
  - and the nighttime downvalley wind (Defant,1951).
- In this traditional view, each component has corresponding compensatory currents aloft, presumably to form a closed circulation.

Mountains Breathe

- Differential heating of the earth’s surface
- Daytime: upslope, or valley breeze, summer thunderstorms near the tops of peaks
- Nighttime: cold air drainage into valley

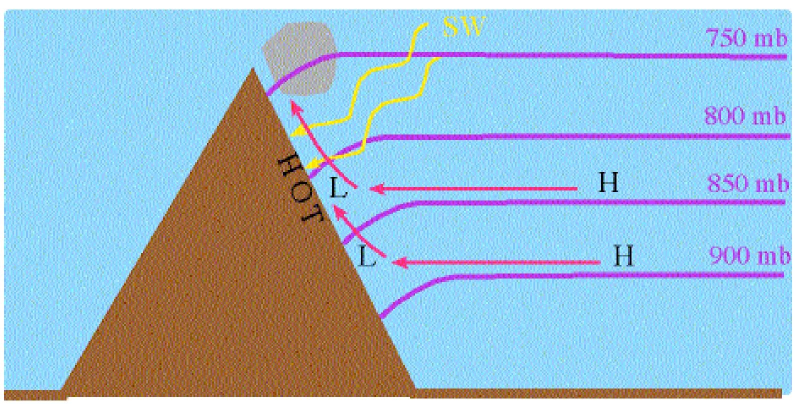
Closed circulation: davtime



Heats up along south-facing slopes. Less dense air rises

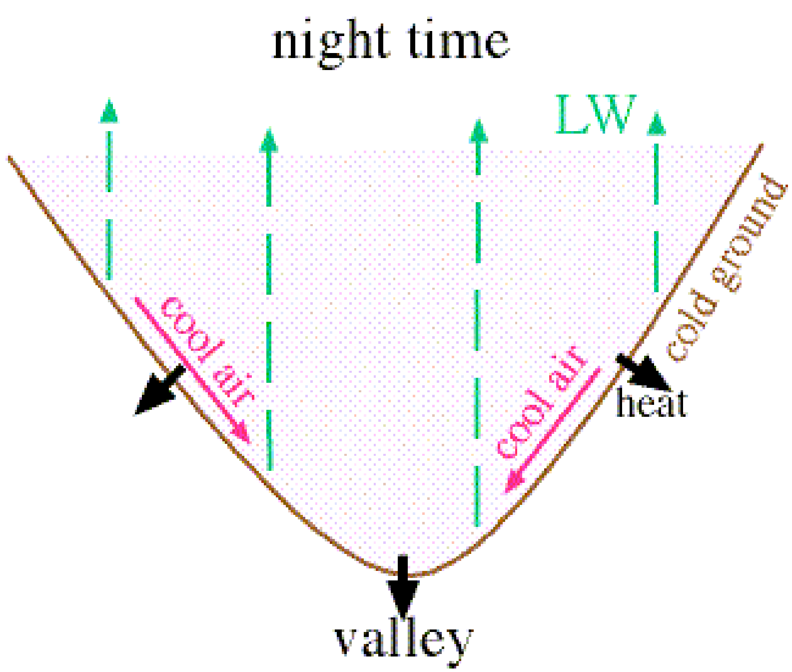
Mountain inhaling

Daytime: Upslope wind



- upslope/valley breezes form as solar radiation heats the mountain slope
- this lowers the air pressure adjacent to the mountain slope
- hence a PGF is created and directed towards the mountain
- the air moves up the mountain slope, sometimes producing clouds

Night Time



- the earth's surface cools as it emits LW radiation
- heat conducts from the warm air to the cold ground
- the resultant cool air is pulled to the bottom of the valley by gravity
- generating a mountain/drainage breeze

Mountain exhaling

What mountain environment would you find consistent down-valley winds?

Continentality

- The degree to which a point on the earth's surface is in all respects subject to the influence of a landmass. Compare *oceanicity*.
- Continental locations experience larger diurnal and seasonal temperature changes than locations on or near large bodies of water because land surfaces heat and cool more quickly than oceans.
- Interior locations experience more sunshine, less cloudiness, less moisture and less precipitation than coastal areas.
- Precipitation is especially heavy on the *windward* side of coastal mountain ranges oriented perpendicular to prevailing winds from the ocean. Marine air lifted up a mountain range releases much of its moisture as precipitation. As a result, far less precipitation is received on the *leeward* side.

Mountain Land Mass Affect

- Warmer
- Clearer
- Dryer
- More sunshine
- Colder at night
- Larger diurnal temperature changes
- The bigger the mountain, the larger the effect

Mountain Land Mass Affect: Why?

Snow lines and timberlines

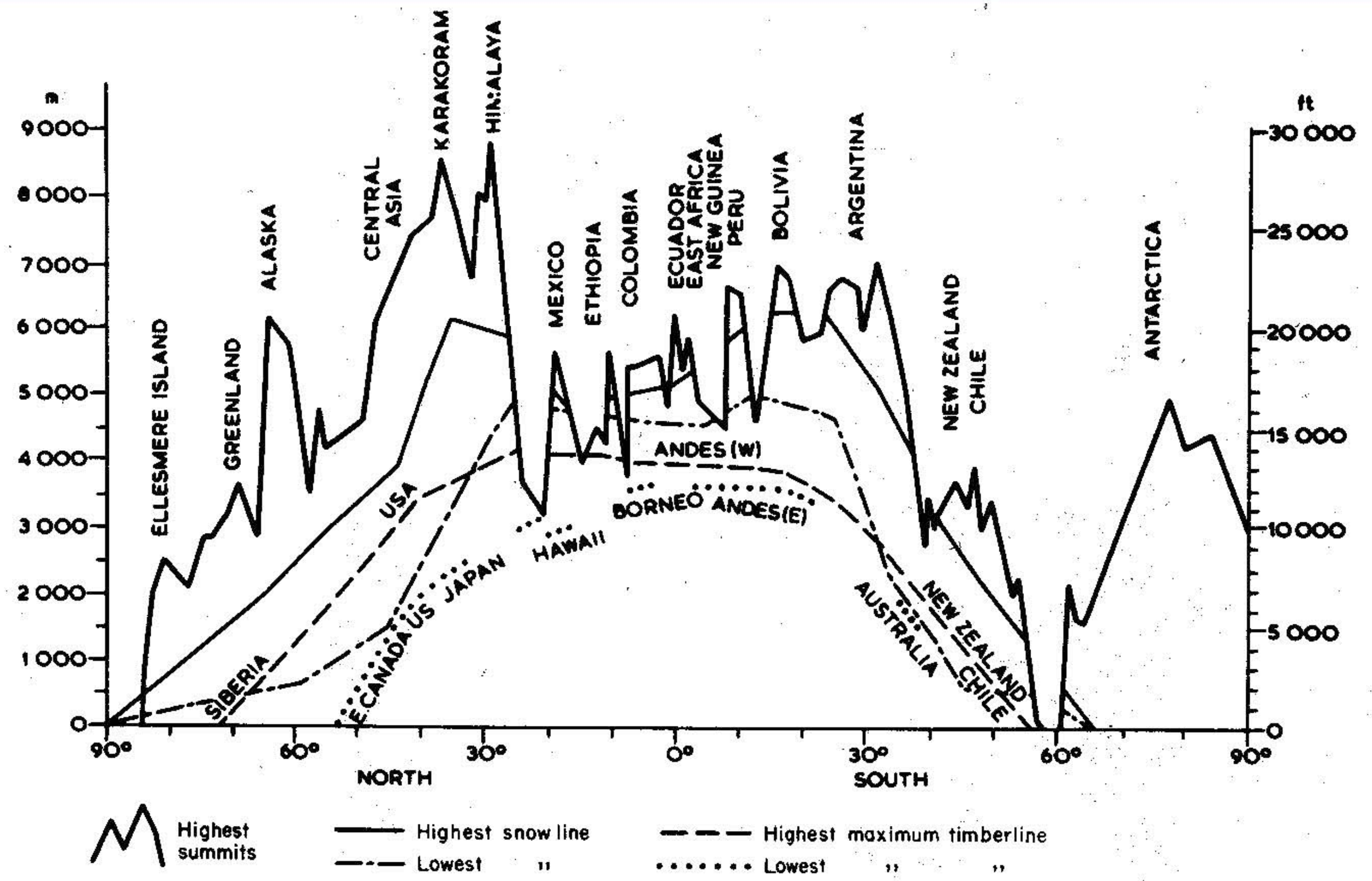


Figure 1.1 Latitudinal cross-section of the highest summits, highest and lowest snow lines, and highest and lowest upper limits of timber line. (From Barry and Ives, 1974.)

Local scale: m to km

- Separation eddies driven by small changes in topography and surface roughness
- Particularly important because of snow redistribution
  - Increased snow in lee zones
  - Less snow on windward sides

Separation eddies