MET 4300

Lecture 16
Mountain Snowstorms (CH16)

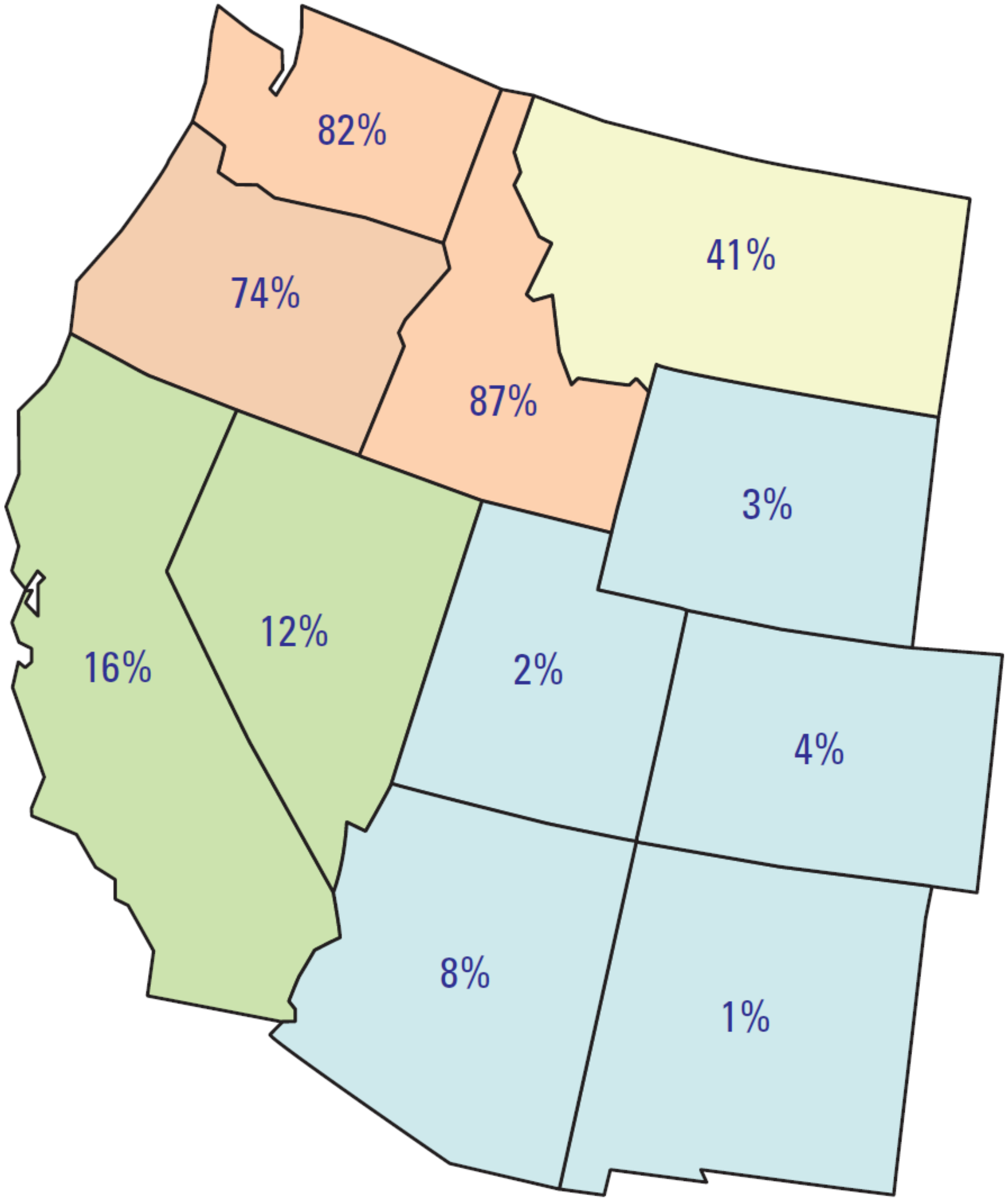
Learning Objectives

- Provide an overview of the importance and impacts of **mountain snowstorms in the western US**
- Describe how **topography** influence precipitation regimes of the West
- Summarize the precipitation scenario of a Pacific storm crossing the western mountain ranges
- Identify the factors that contribute to snowstorms on the **eastern slopes of the Rockies**

MOUNTAIN SNOWSTORMS

- **Good:** Provide water for agriculture, urban water supplies, hydroelectric generation and recreational snow (tourist industry);
- **Bad:** But they can lead to close roads and cause some deaths.

Snow plow, on I-80's Donner Pass California



Percent of total power generation from hydroelectric sources

- *Over 1/3 of the 200 billion KW hours of power generated in the western states are hydroelectric*
- *½ in Pacific Coast states*
- *Over 75% in Oregon, Washington, and Idaho*

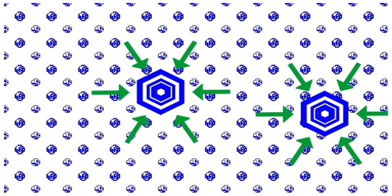
Cloud Seeding (weather modification)

- Heavy snow are welcome in the West (CA, NE, UT)
- Cloud seeding is designed to increase snowpack
- Ice clouds are very efficient at producing precipitation, while supercooled water clouds are not (Ice crystals grow very rapidly while supercooled water droplets do not grow at all at T=-10C, sometimes they even evaporate while ice grow.)
- Use silver iodide (AgI) aerosols or dry ice pellets
  - Ground based silver iodide generator (Figure here)
  - Flares dropped from aircraft
- Introduces some ice/ice nuclei into supercooled clouds
- Ice crystals grow at the expense of water droplets
- Increasing precipitation efficiency
- Otherwise, clouds with only supercooled water will

be carried over the mountain and evaporate downwind

More About Cloud Seeding

- Cloud formation general requires both freezing and condensation
- Natural clouds have plenty of condensation nuclei (CCN, 100,000/liter) but few ice/freezing nuclei (IN, 10-100/liter)
- The ice forming nuclei (IN) are water insoluble particle (e.g Ag, PbI2, CuS) against to the CCN and their structure has hexagonal symmetry similarly to the ice crystals. Other types of IN can include bacteria, leaf fragments, and even in certain cases soot and pollen. However, the IN activity of these particles can be suppressed or inhibited by coatings of soluble species, such as sulfate coatings on dust or soot. Then, these can actually serve as giant cloud condensation nuclei (CCN).
- CCN on the other hand are smaller, semi- or fully soluble species such as particles from pollution plumes (organic, sulfate, nitrate), fires, and sea salt. Sea salt actually serves as a giant CCN.
- Consequently clouds colder than 0C contain supercooled liquid H_20 that has not yet frozen.
- May be as cold as -20C
- When some ice does form,
  - the ice crystals grow
  - Stealing H_2O from the liquid droplets
  - Bergeron-Findeisen process or "cold-rain process": a process of ice crystal growth that occurs in mixed phase clouds (containing a mixture of supercooled water and ice)



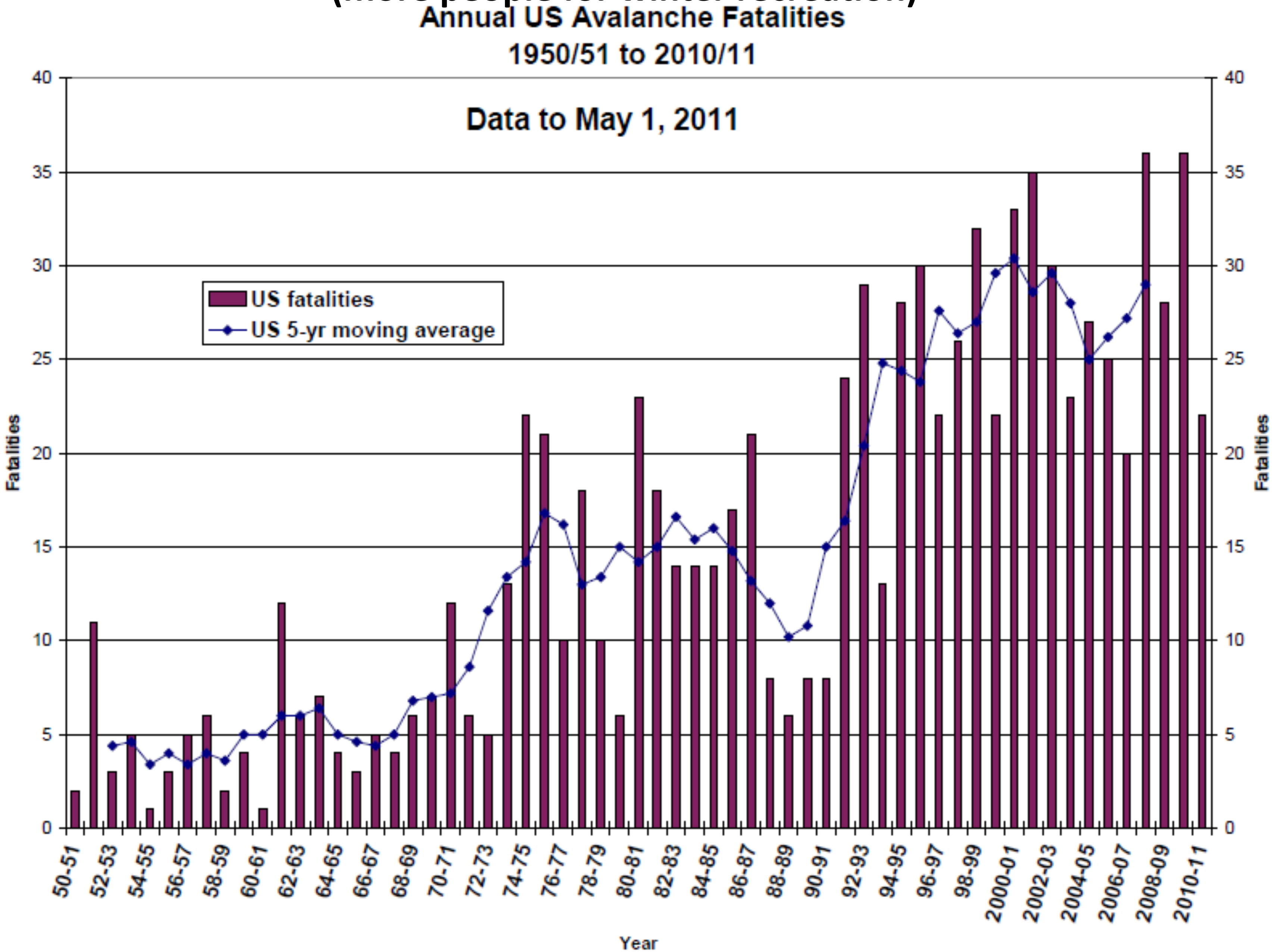
- Artificial freezing nuclei <u>can</u> promote growth of snow

Impacts of heavy Mountain Snowstorms

- ***Highways closures:*** *Donner Pass (Sierra Nevada) on I-80; Eisenhower tunnel (summit of the Rockies) on I-70*
- ***Traffic accidents***
- ***Avalanches:*** *Little Cottonwood Canyon → 9 miles with 42 avalanches paths*
- ***Measurement:*** *routine observations, satellite data, snow gauges and human observers;*
- ***Radars are not very useful*** *because 1) dBZ-snow rates relationship is not reliable due to ice shape and density variations; 2) mountains block radar beams, limiting coverage.*

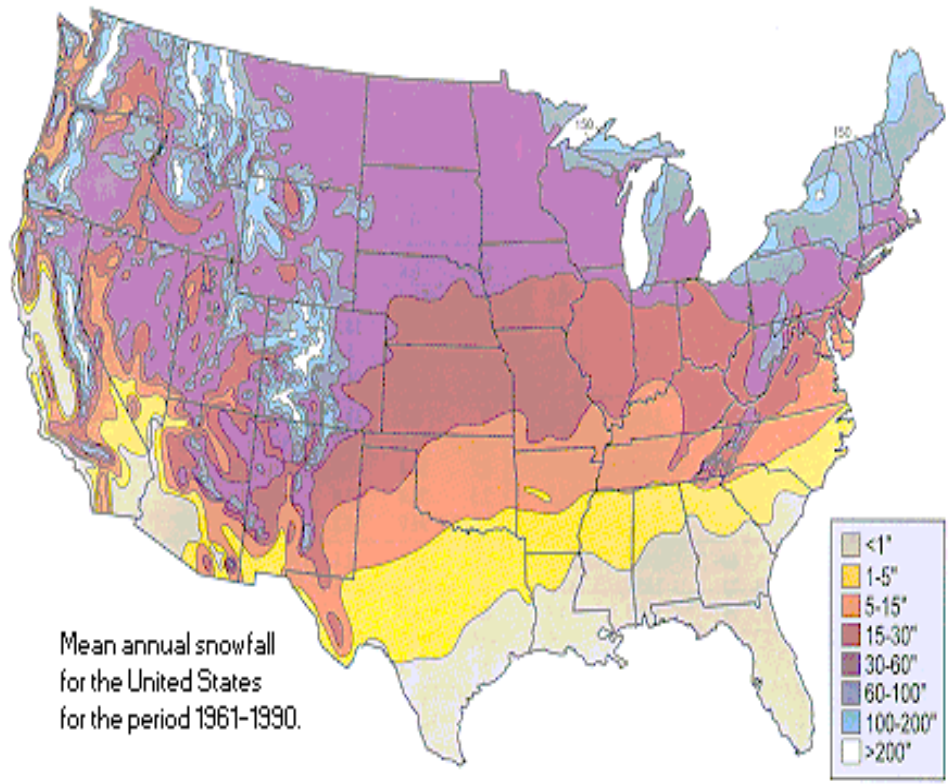
60-yr climatology: # of fatalities has increased

(more people for winter recreation)

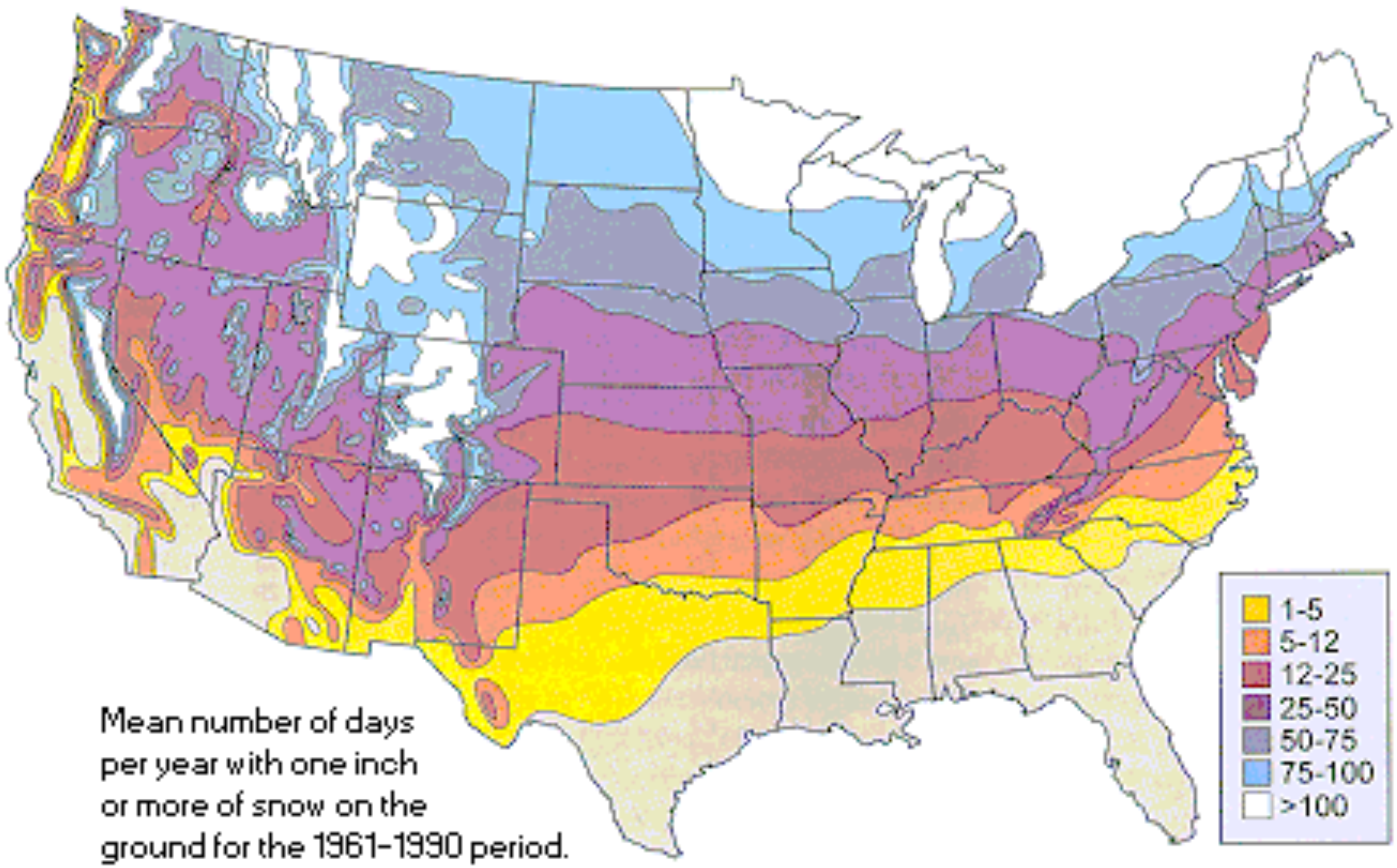


Mean Annual Snowfall (inches) in the US

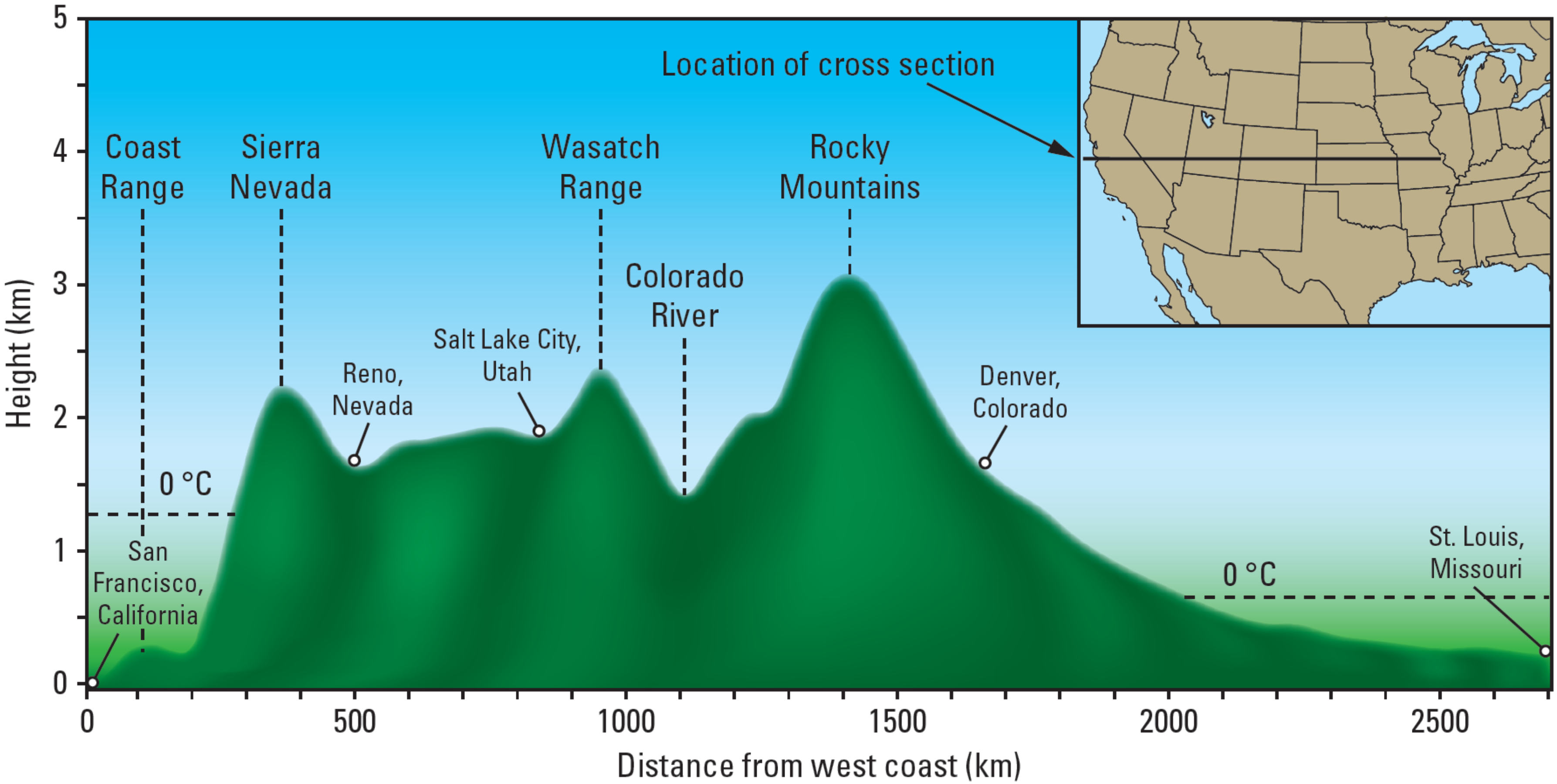
- East of the Rockies, snowfall increases from S to North (controlled by latitude and temperature)
- West of the Rockies, snowfall is controlled by elevation and mountains (their location, height, and steepness)
- All mountain ranges appear as regions of heavy snow



Mean Number of Days per year with 1 inch or more of snow on the ground



Topography of The Mountain West



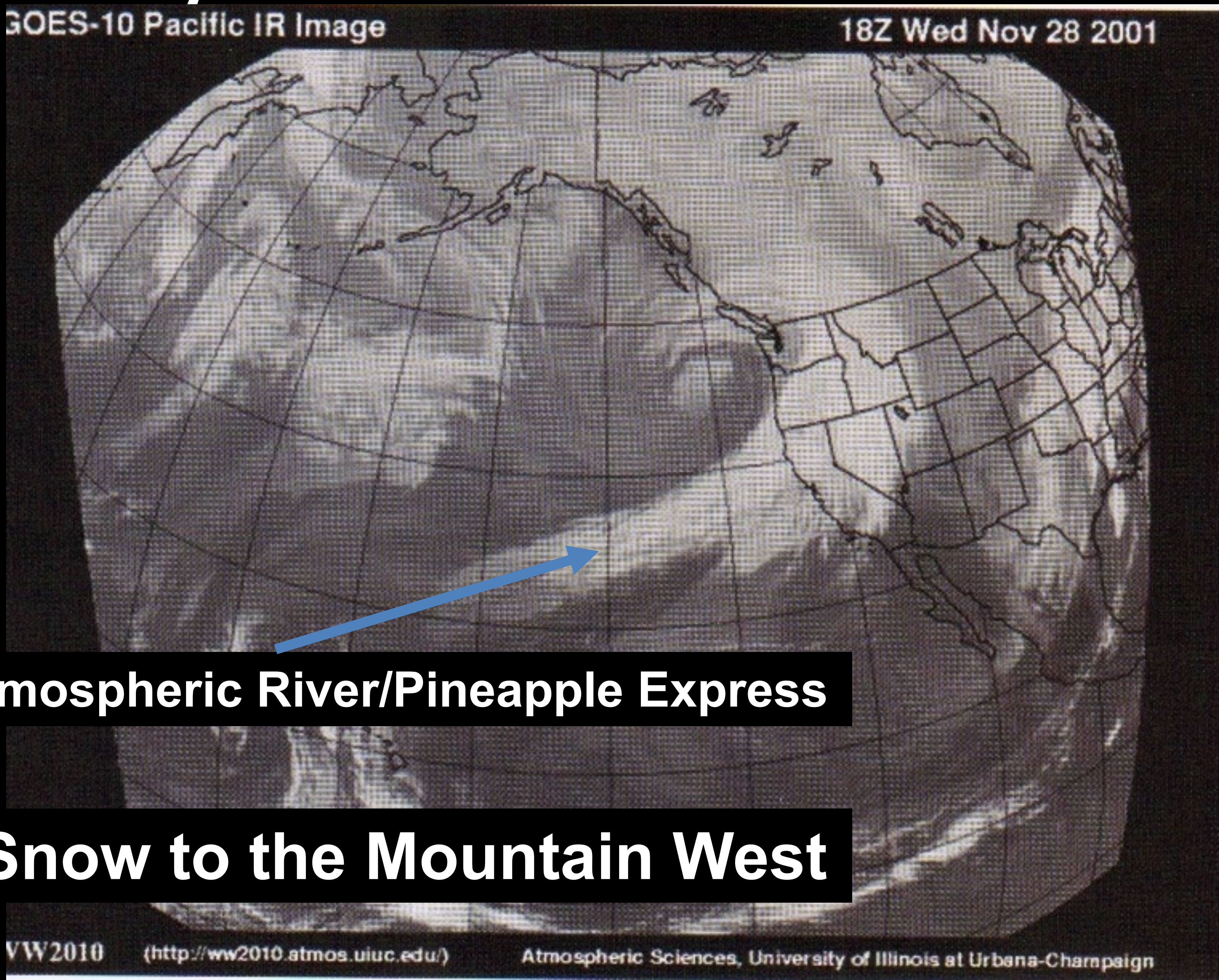
Source of Mountain Snowstorms

- ***Large-scale weather systems over the mountain ranges:*** *extratropical cyclones, fronts, and upper-level troughs;*
- ***Many of these weather systems are originated over central and western Pacific Ocean:*** *air arriving at the west coast (having traversed the Pacific Ocean from as far away as Asia) is moist and well-above freezing*
- ***Moisture streams or atmospheric river (e.g. Pineapple Express):*** *moisture along the frontal system associated with extratropical cyclones*

Pacific Cyclones

- ***Originates at Gulf of Alaska*** *(south and east of the Aleutian Islands)*
- ***Life cycle of these cyclones occurs mostly over open water***
- ***Most cyclones arrives the West Coast during occluded stage***
- ***Winds and pressure gradients can be very strong***
- ***Thunderstorms are rare*** *because air is not warm enough to cause buoyancy-induced convection*
- ***Only clouds from air lifting along surface and upper-level fronts***

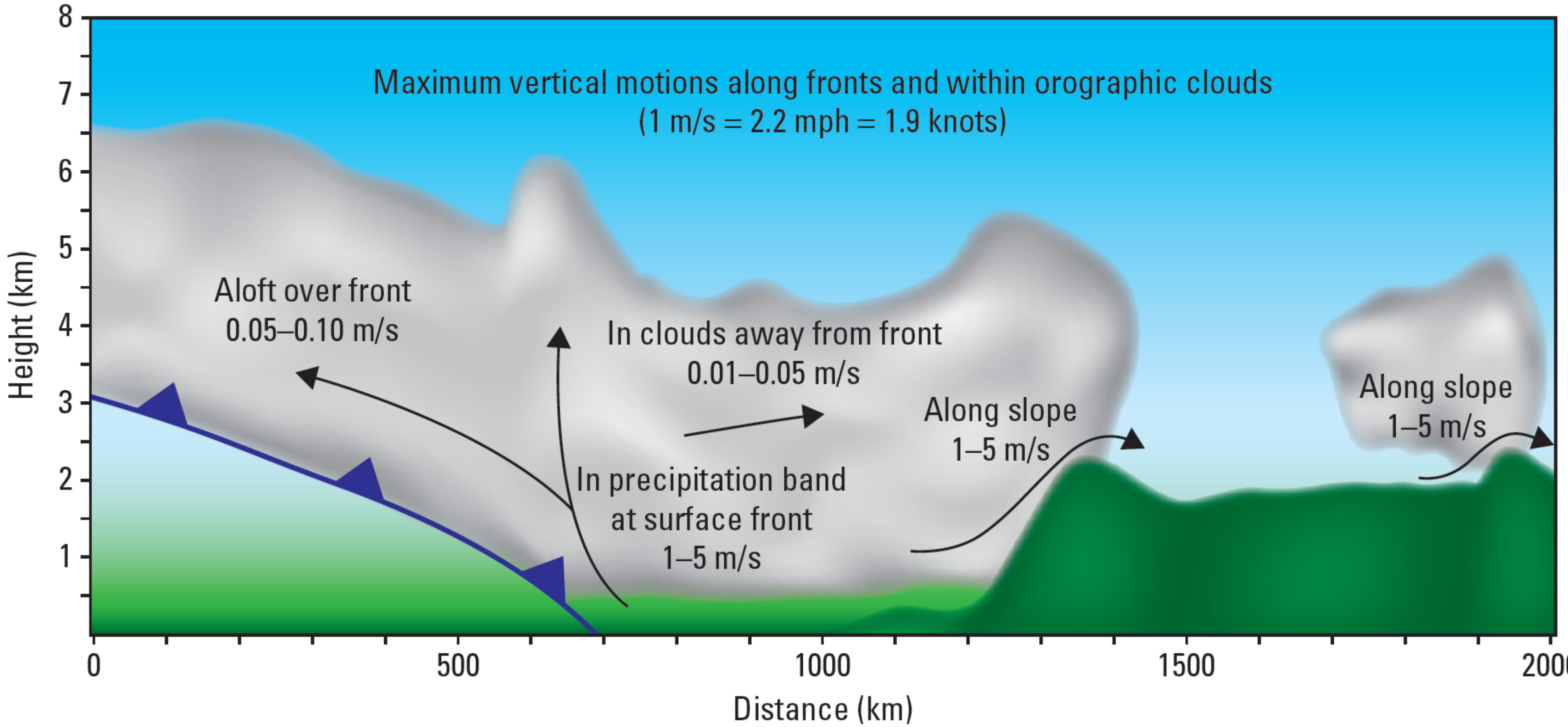
Occluded Cyclones From the North Pacific



Atmospheric River/Pineapple Express

Bring Snow to the Mountain West

Wintertime Orographic Rain on the Pacific Coast



Orographic lifting: moutains block the flow within large weather systems, forcing air to rise sharply along their windward slopes

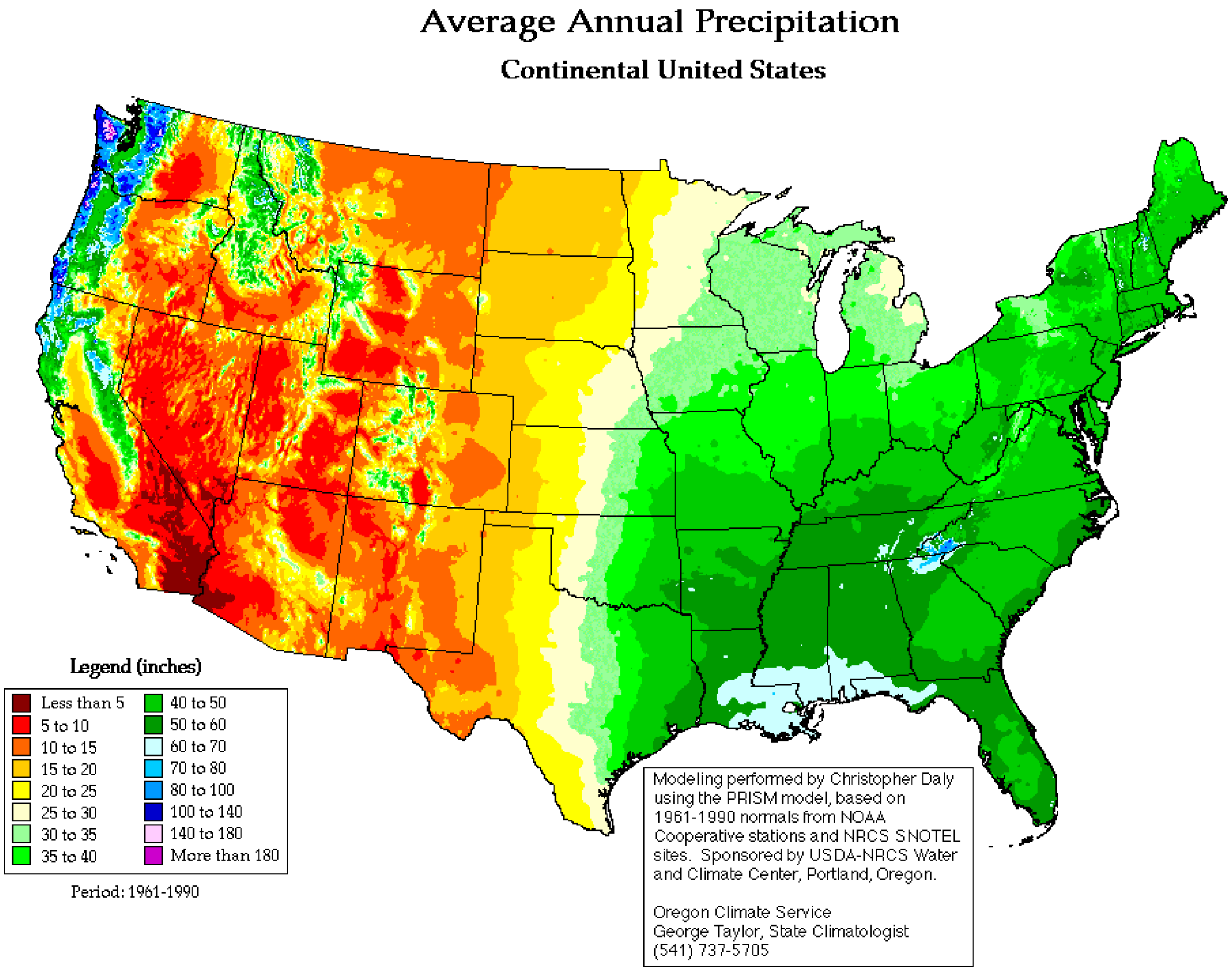
Except at the leading edge of the sfc front, vertical motion in air rising over a front is much weaker than that along a mountain slope.

Precipitation associated cyclones will be enhanced by mountains; Precipitation can be generated directly by orographic lifting

Orographic clouds often form well in advance of a large-scale weather system and linger for a day or more after the system passes

How do mountains modify storms coming onshore from the Pacific Ocean?

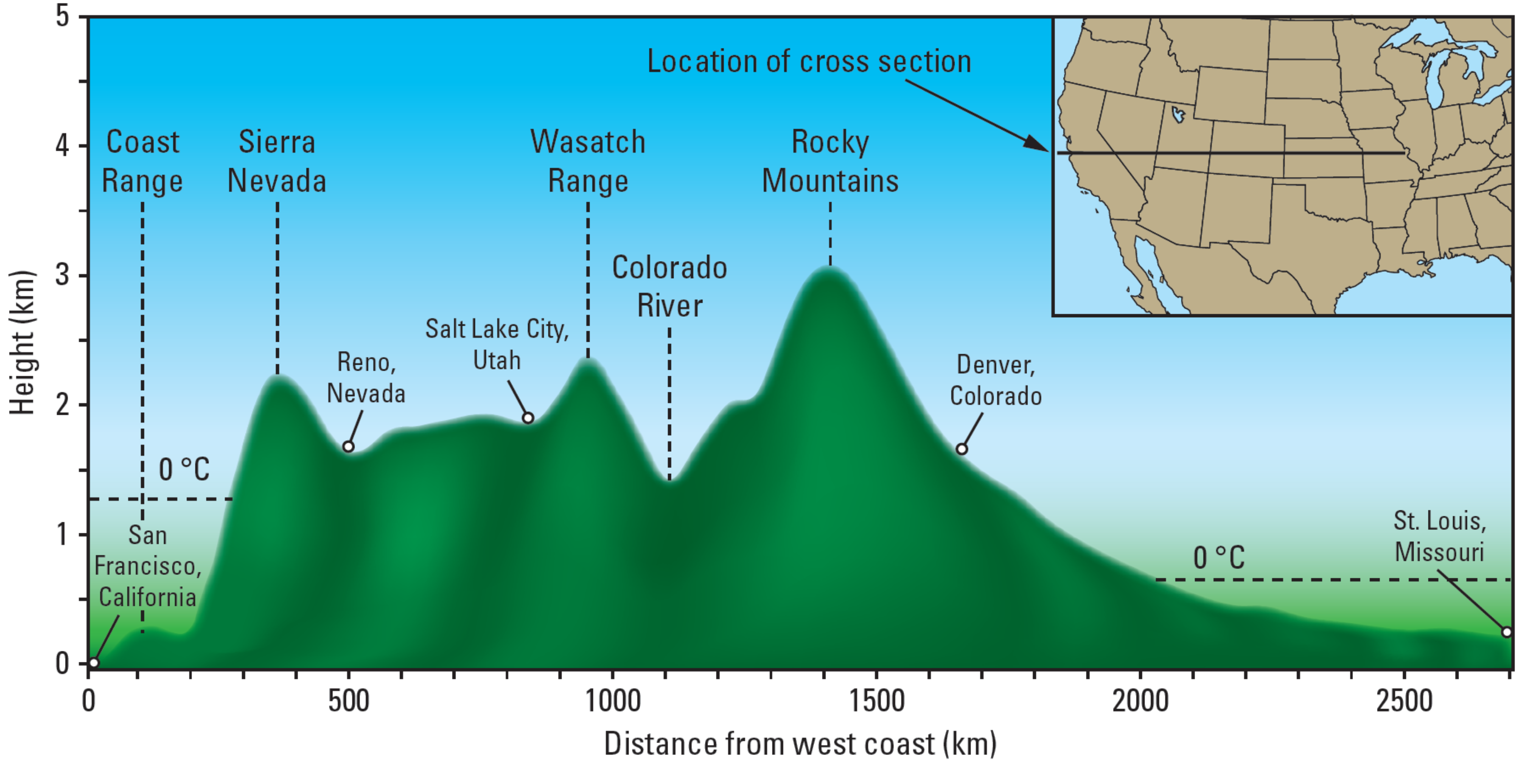
- *Low-level storm structure is disrupted*
- *Upper-level troughs and jetstreams are still effective, triggering cloud formation*
- *Reduce the moisture content of air*
- *Orographic lifting is the primary forcing for precipitation formation*



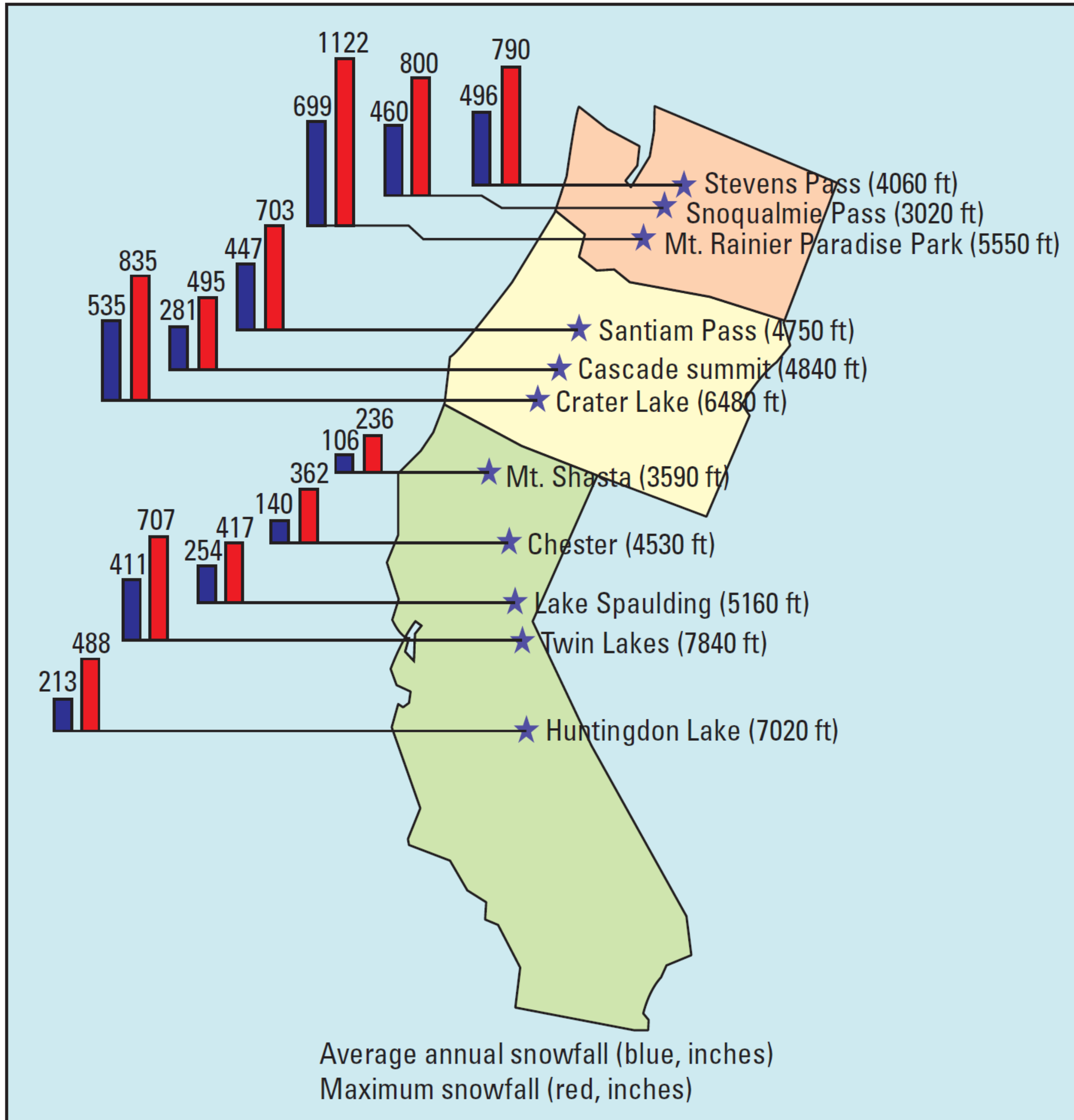
- ***In the western US, mountains receives 5 to 7 times precipitation falling in the neighboring valleys***

Storms along the Western Slopes of the US

- ***Coastal Range:*** *heaviest precipitation (over 180 inches on Washington's Olympic Peninsula– mostly rain though– mountain peaks are below melting level)*
- ***Sierra Nevada (CA) and Cascades (OR & WA):*** *2 miles rising, moisture condensed, rain at low level, and snow above; snow in feet*
- ***Interior mountain ranges:*** *Wasatch Range, Bitterroot mountains, and the Rockies; precipitation amounts is lower due to less moisture; lower density snow due to colder temperatures*

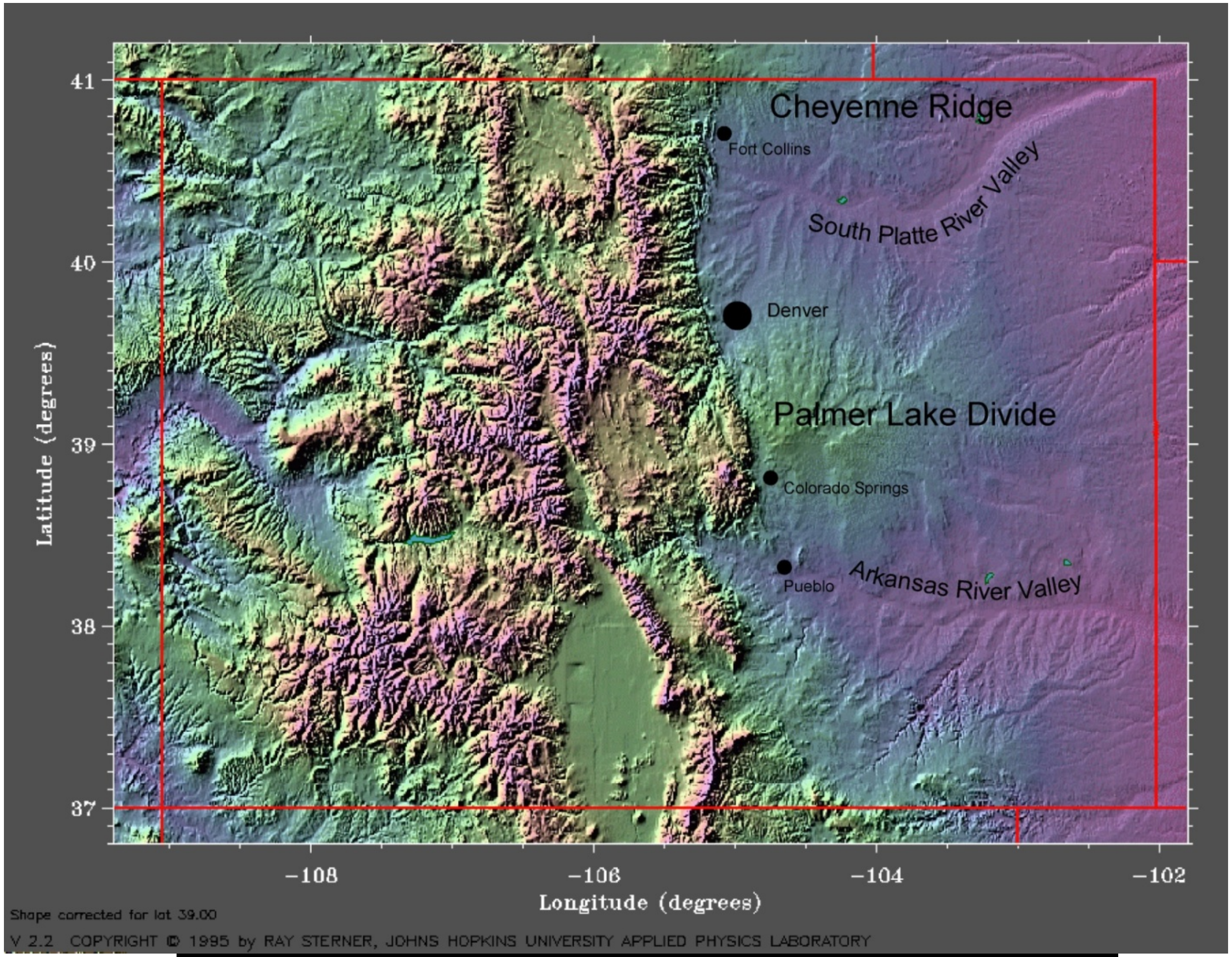


Average and Maximum Snow fall on the Sierra Nevada and Cascade Mountains (in)



Storms on the East Slope of the Rockies

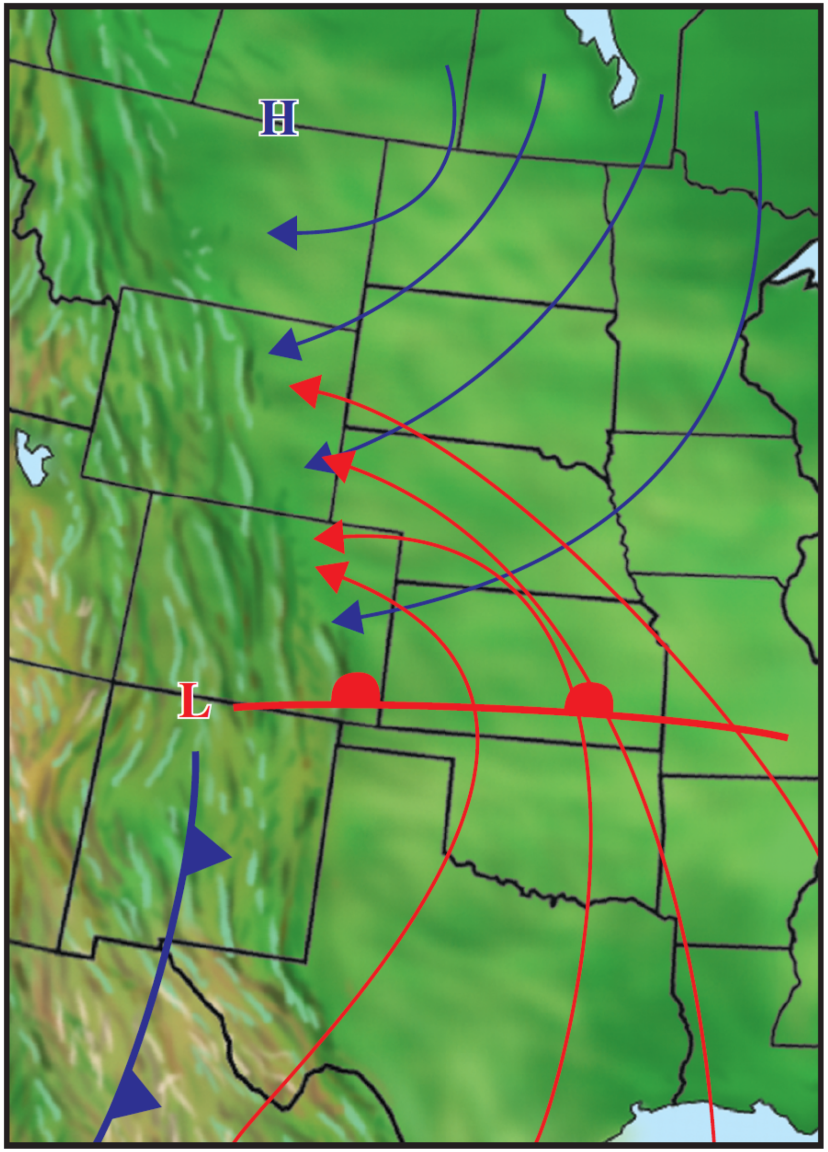
- ***Upslope storm:*** *a winter storm that occurs along the eastern slope of the Rockies*
- ***Low-level winds are easterly*** *(less common)*
- ***Can occur from Canada to New Mexico, but we focus on Colorado.***
- ***Moist air rising from Mississippi to Colorado (5000ft****): cooler temperature, higher humidity, produce enormous amounts of snow (3 ft in one single event)*



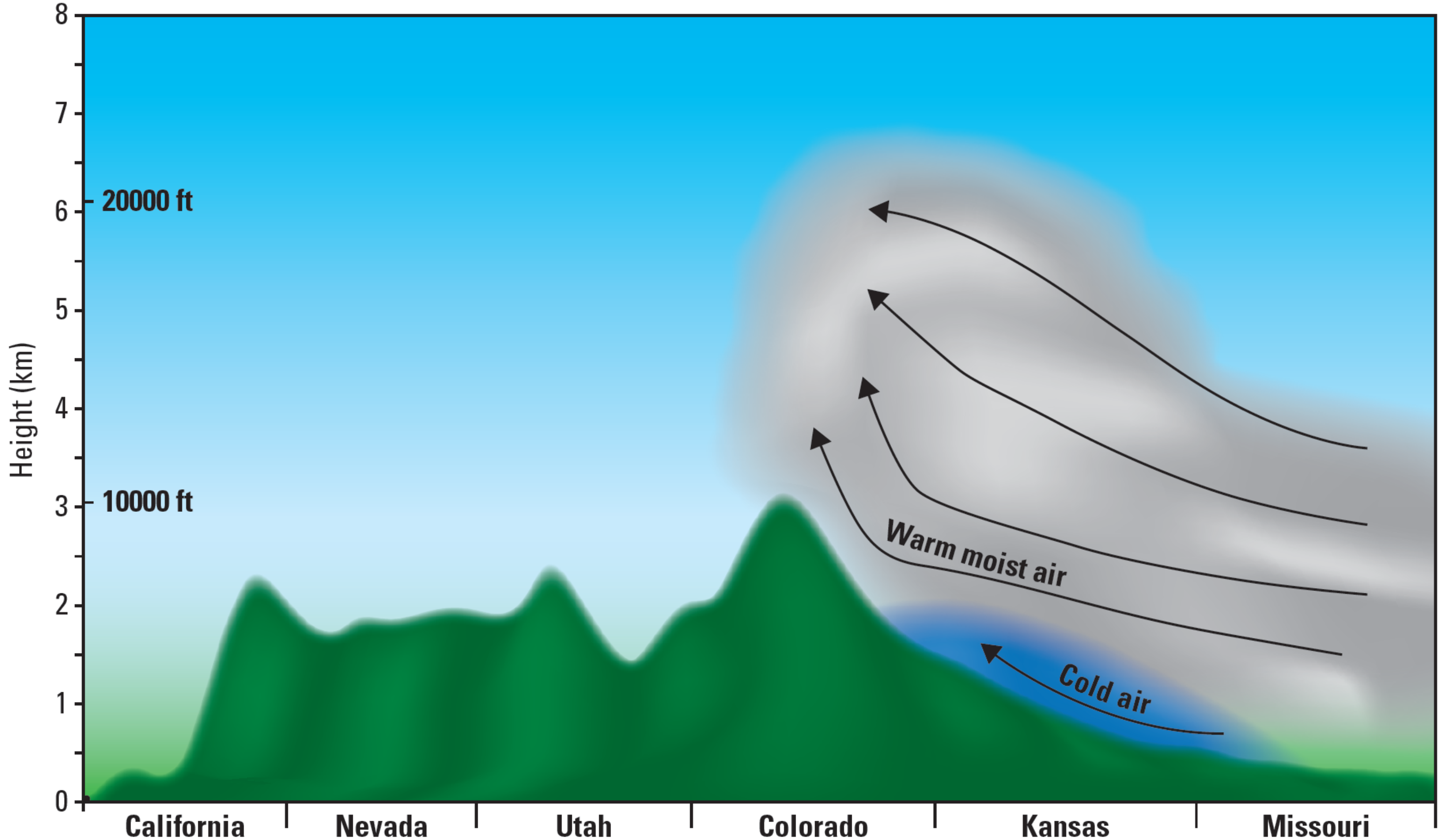
Topography of the Colorado Rockies

Upslope Snowstorms

- Two pressure patterns can produce **Easterly** winds
  - High to the north near Canadian border: cold, less moisture, light snow (< 4 in)
  - Low center to the south near the four corners (Az,Nm,Ut,Co): warm moist air from Gulf of Mexico, deep snow (~ 1 ft) with higher water equivalent
- Exceptional blizzards occur when both pressure pattern occur simultaneously with a cutoff low aloft



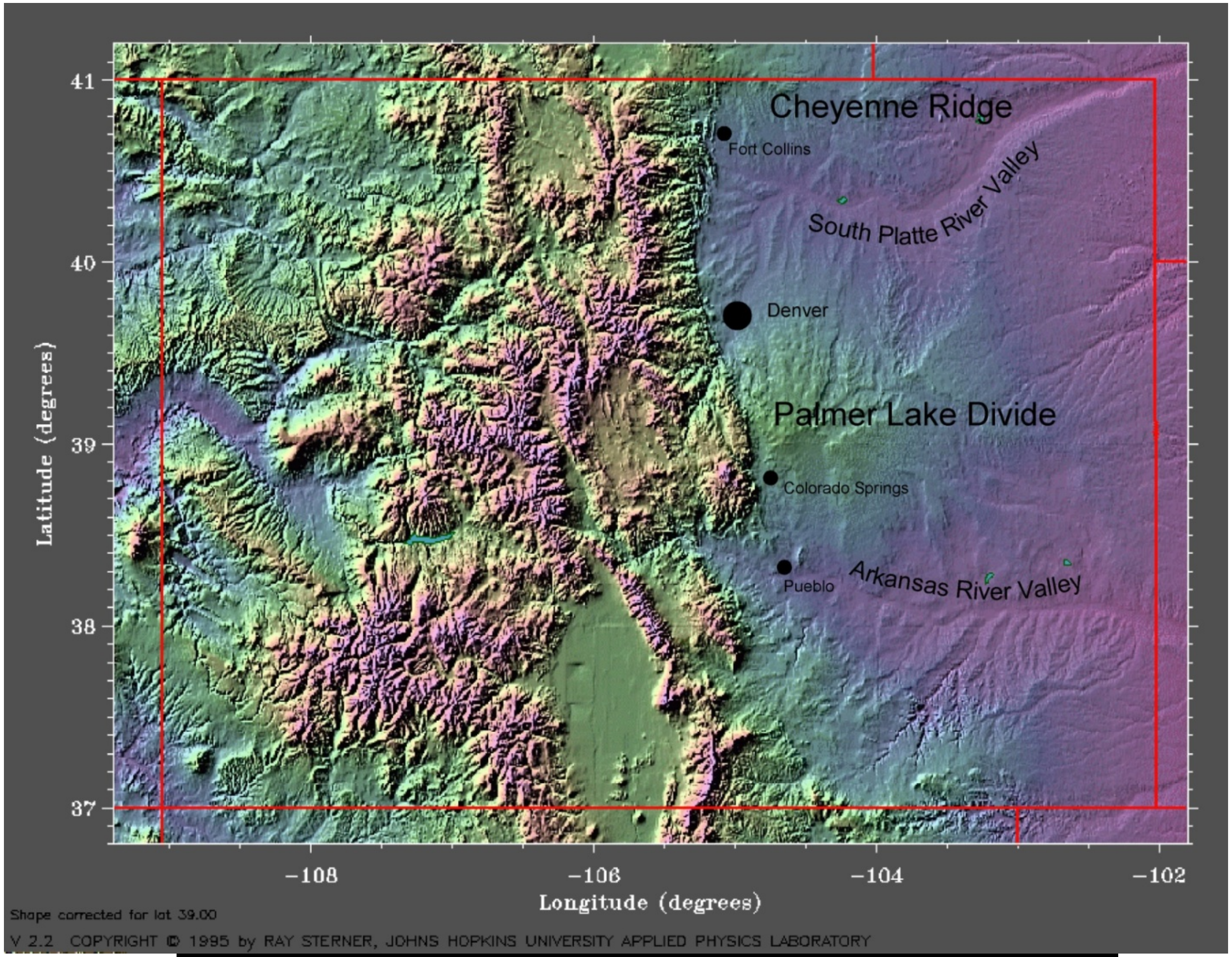
Profile of an Upslope storm



- Warm air from the Gulf of Mexico must rise, not only over the topography, but also over the cold air
- Blizzard conditions on the plains can extend well east of the mountains.
- Clouds can be as much as 6-9km deep
- Snowfall is often reported in feet.

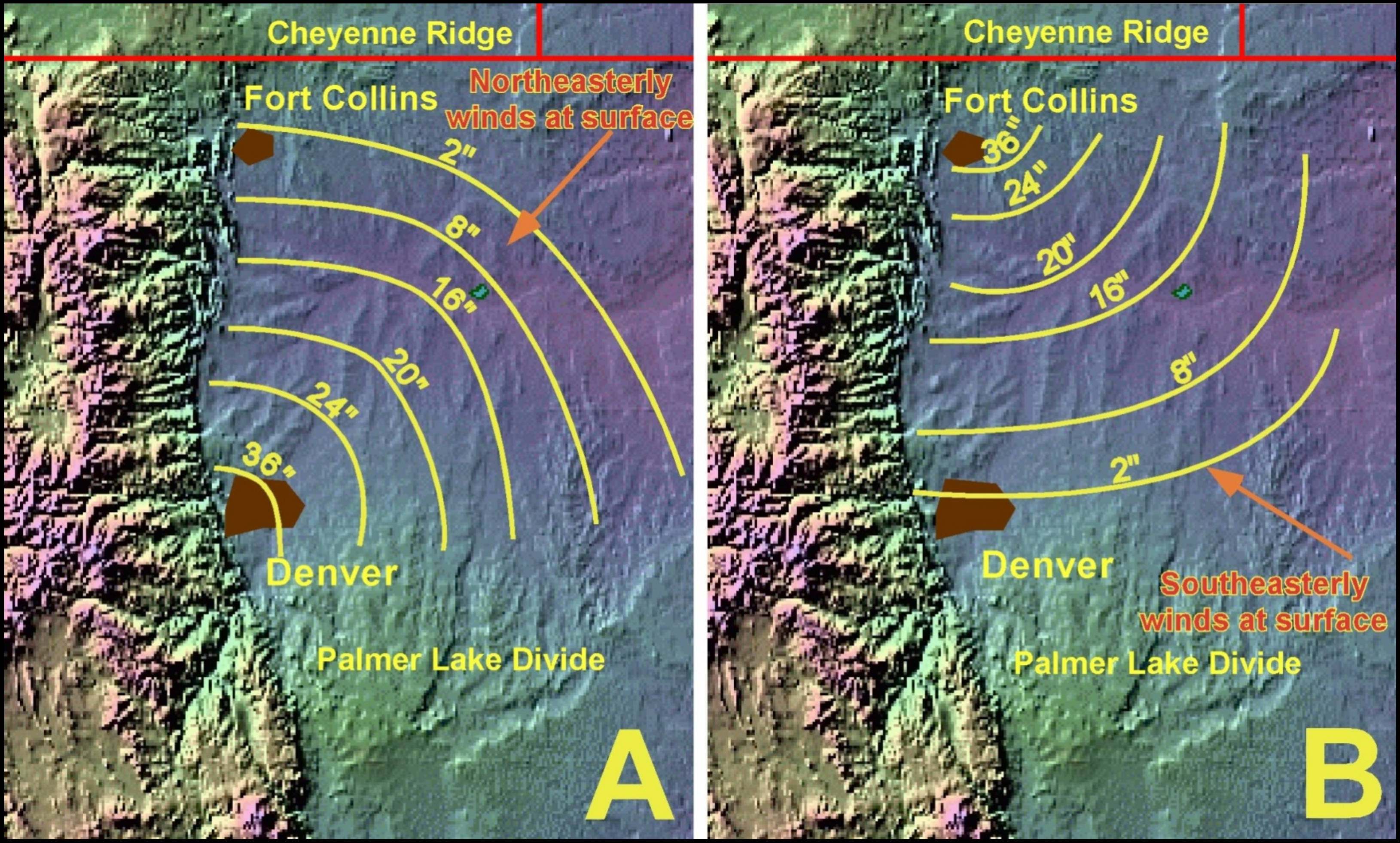
Variability of Snowfall Amounts Over Short Distance

- ***South Platt River Valley: between Denver & Fort Collins: ~1,500m***
- ***Two ridges:***
  - ***1) Cheyenne Ridge: north of Fort Collins: 2,100m;***
  - ***2) Palmer Lake Divide: south of Denver***



Topography of the Colorado Rockies

Effect of Wind Direction on Upslope Snowfall along the Denver-Fort Collins urban corridor



Wind downslope, then upslope
More snow in Denver (upslope region)

Wind downslope, then upslope
More snow in Fort-Collins (upslope region)

Some Facts

- **Water equivalent of snowfall**: is the depth of water that would be obtained if snow is melted.
  - In the mountains of the western US, fresh snow is typical 11-14 inches of snow per inch of water.
  - However, at low elevations, it can be as low as 4 inches. While at higher elevations of the interior mountains, the snow density is so low, it can reach 30 inches of snow per inch of water.
- **The chain law in western US**: it requires that vehicles use tire chains or adequate snow tire on mountain passes during heavy snow conditions

Summary

- Mountain snowfall provides essential water for agriculture, hydroelcetric generation, recreation … in the generally arid west
- Pacific occluded cyclones
  - Produce orographic rain over the coast ranges from Southern California to Alaska
- Upslope snowfall on the east Side of the Rockies
  - In Colorado combined effect of Arctic High near Canadian Boarder and a low near the Four Corners
  - Cold air blows south along the front range
  - Moist air glides up over it from the SE
  - Patterns of snowfall depend in detail upon interactions of the airflow with topography