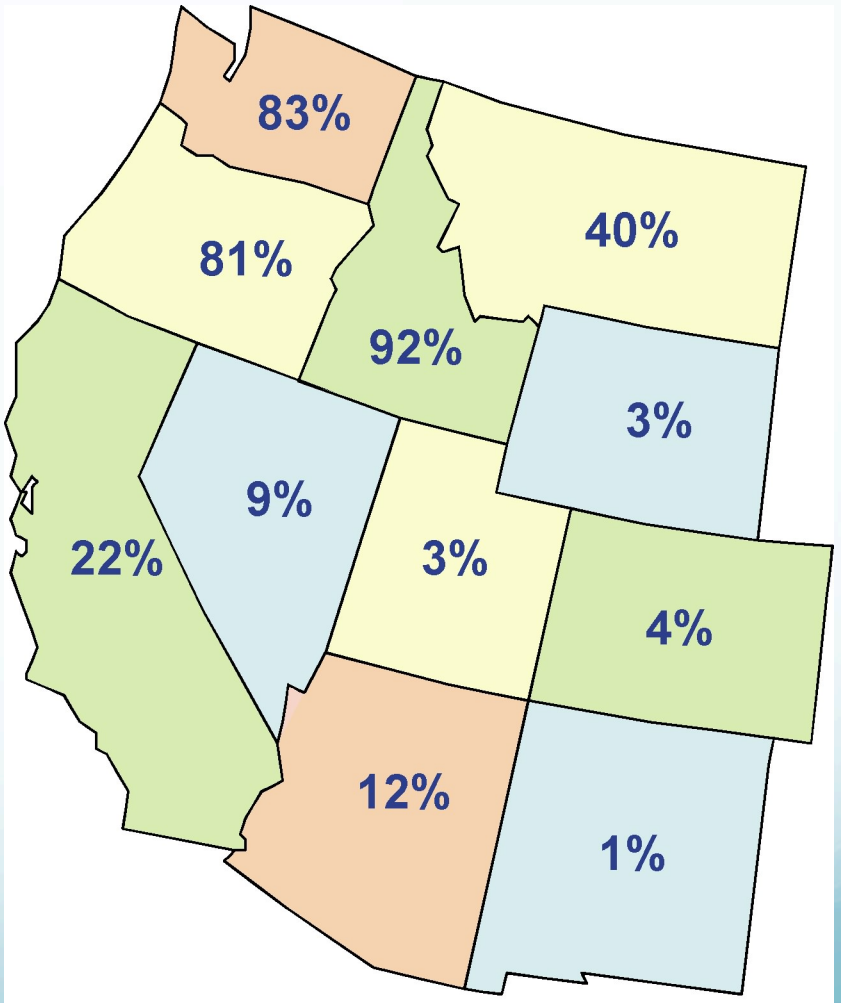
Chapter 16
Mountain Snowstorms

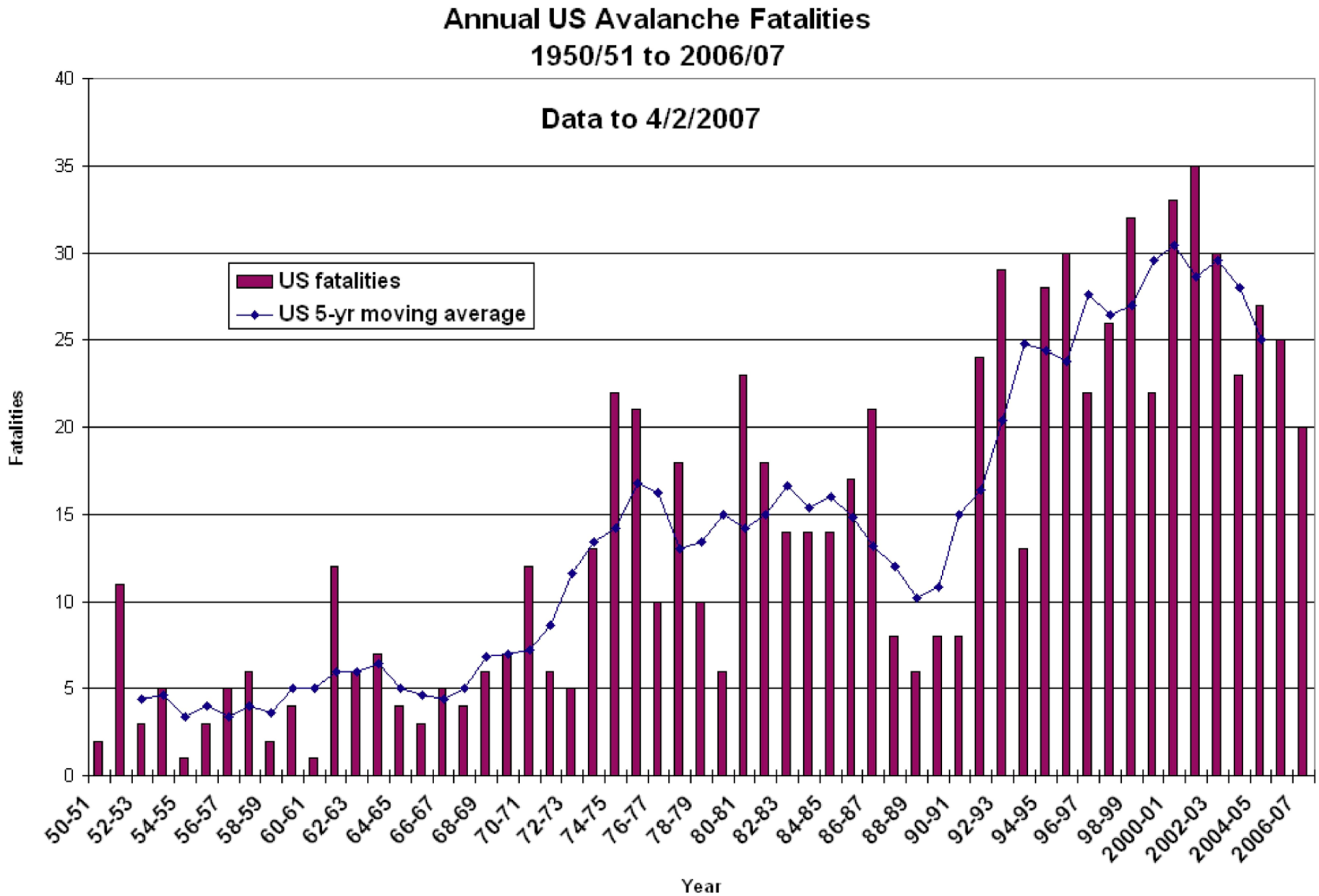
courtesy of the California Department of Transportation

Why do we care about mountain snowstorms?

- Water supply
- Hydroelectric power
- Transportation problems
- Avalanches
- Tourism



% of electricity derived from hydroelectric power in 2006 by state



Courtesy of the Northwest Weather Avalanche Center, US Forest Service

Cloud Seeding

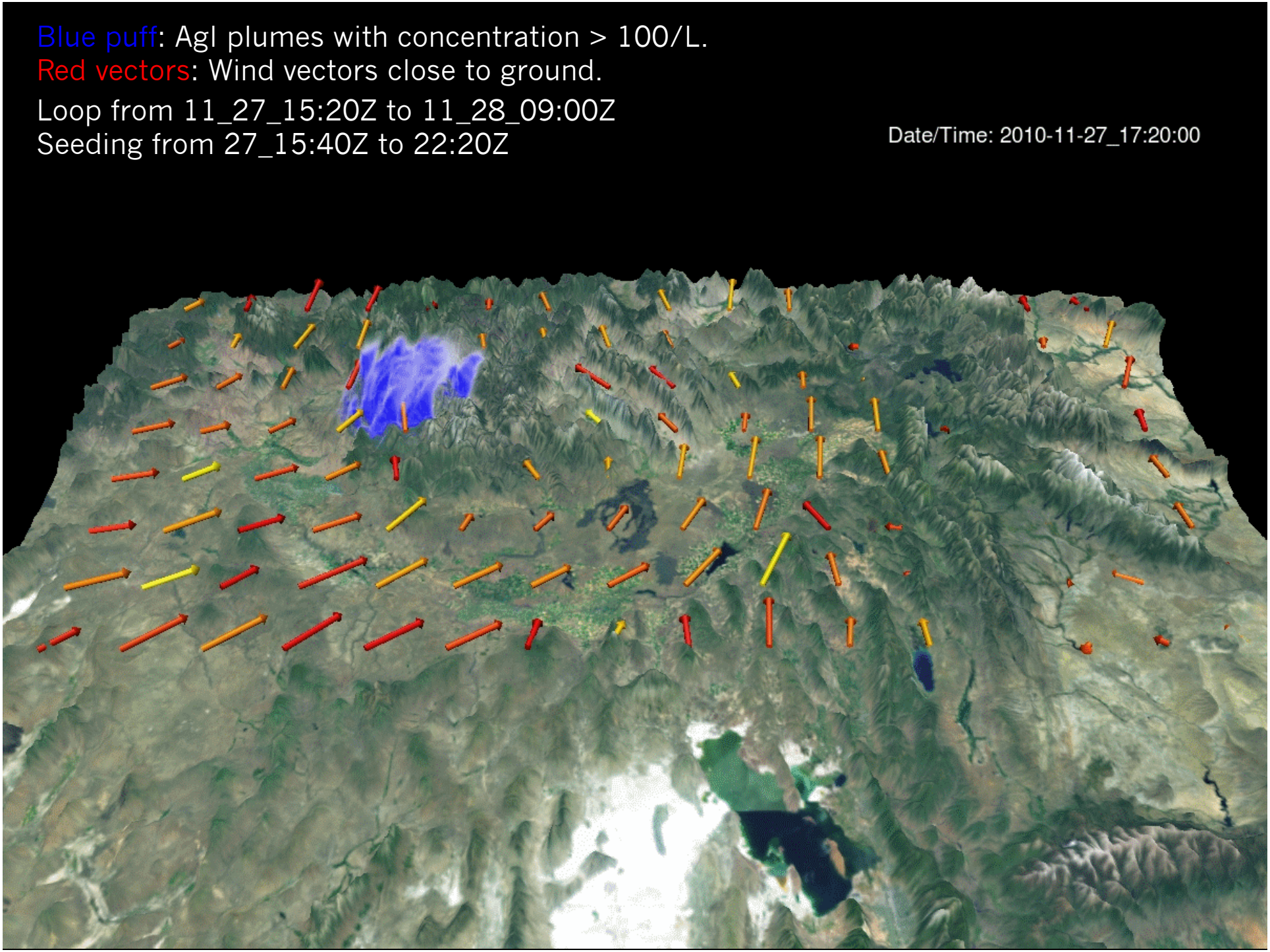
- A method of adding particles to a cloud to aid in the development of precipitation
- To make more snowfall, silver iodide (AgI) particles are often added to clouds that contain supercooled liquid water
  - **Supercooled water** – is water that has not frozen yet exists at temperatures colder than the freezing temperature of water (0°C)
  - AgI is used because it has a structure much like that of a real ice crystal and serves as good ice nuclei (the particles ice can form on when there is supercooled water)

http://www.youtube.com/watch?v=_9N-Y2CyYhM&NR=1

Cloud seeding

- Many power companies and local water resource management organizations use AgI seeding in the winter to enhance snowfall in their region
  - Ground generators
  - Aircraft
- Some of the research I do is to evaluate cloud seeding methods using observations and numerical cloud models

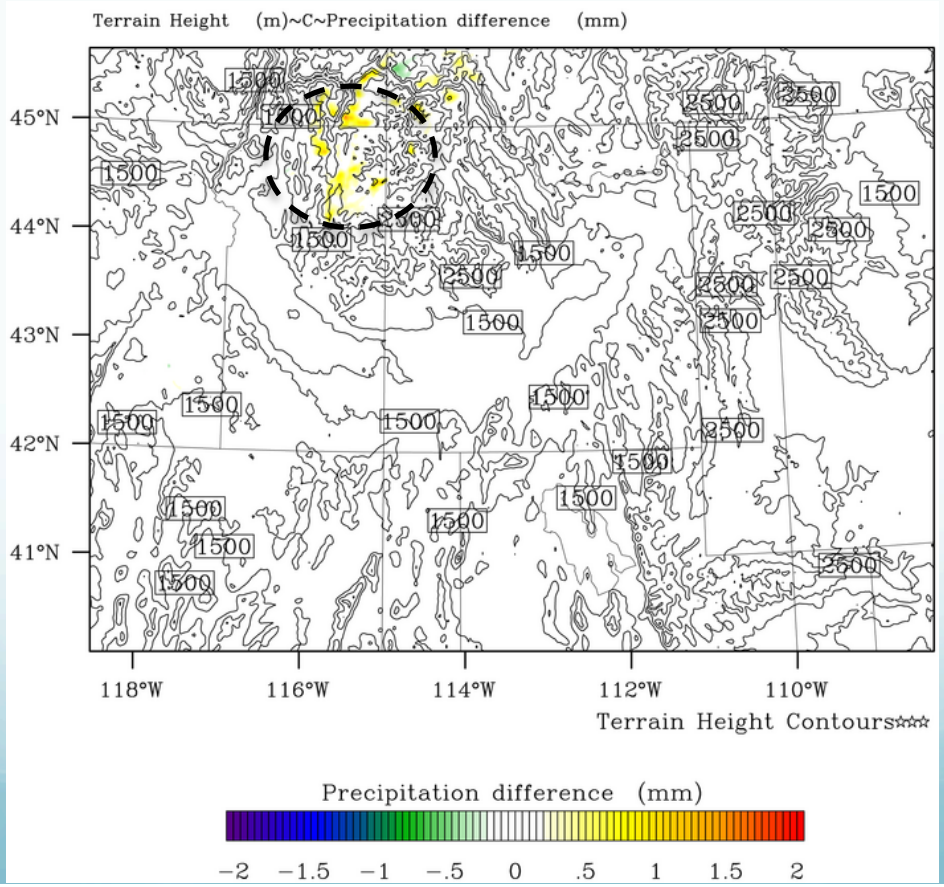
Courtesy of the Desert Research Institute
University of Nevada


Blue puff: AgI plumes with concentration > 100/L.
Red vectors: Wind vectors close to ground.
Loop from 11_27_15:20Z to 11_28_09:00Z
Seeding from 27_15:40Z to 22:20Z
Date/Time: 2010-11-27_17:20:00

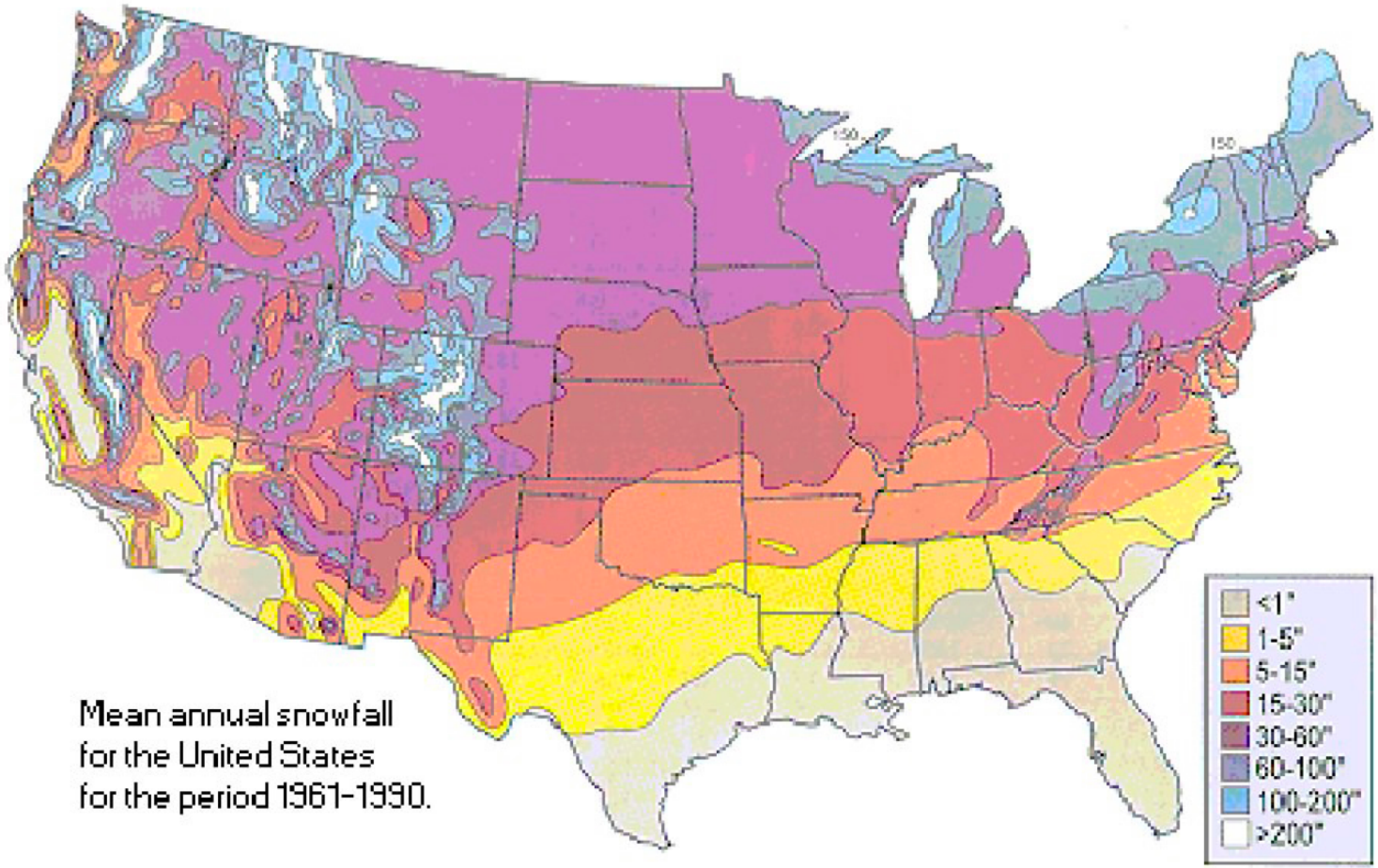
Precipitation difference between seeding case and control run

Control case has no AgI.
Plots show precipitation and precipitation difference at the end of simulation.

Up to 6mm precipitation simulated in control run,
Up to 1 mm increase in seeding simulation



Annual snowfall trends



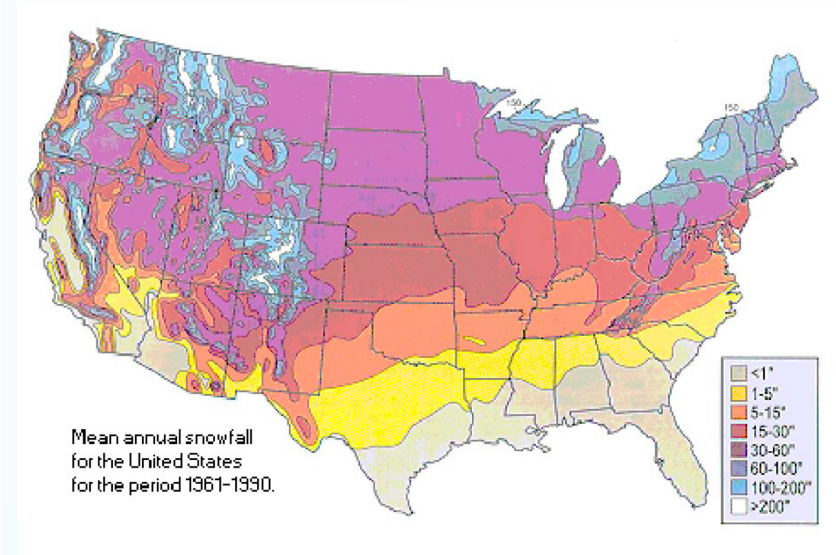
How does the mean annual snowfall change as you move from south to north in the Great Plains?

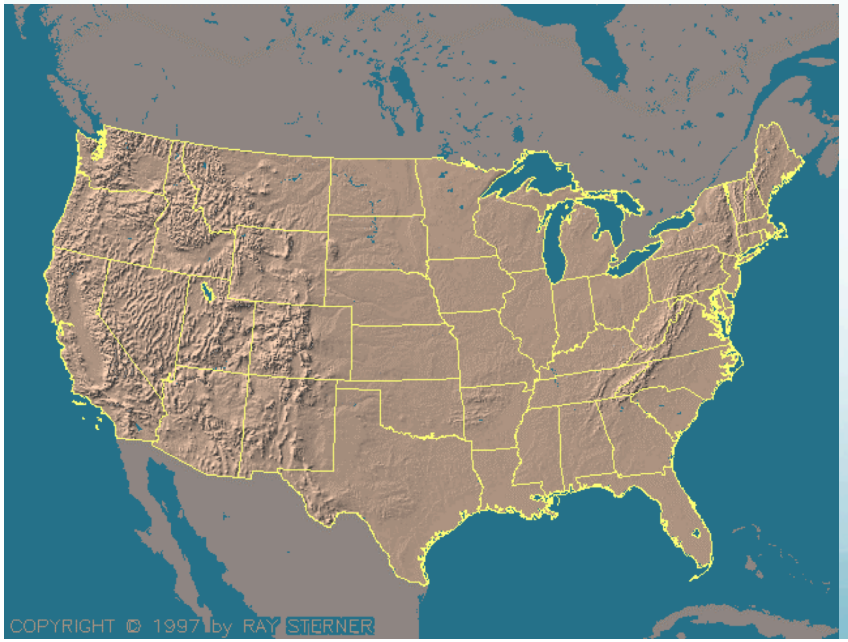
What factors control the annual snowfall on the Great Plains?

Does mean annual snowfall change smoothly from south to north in the western US?

What factors control the annual snowfall in the western US?

Influence of topography

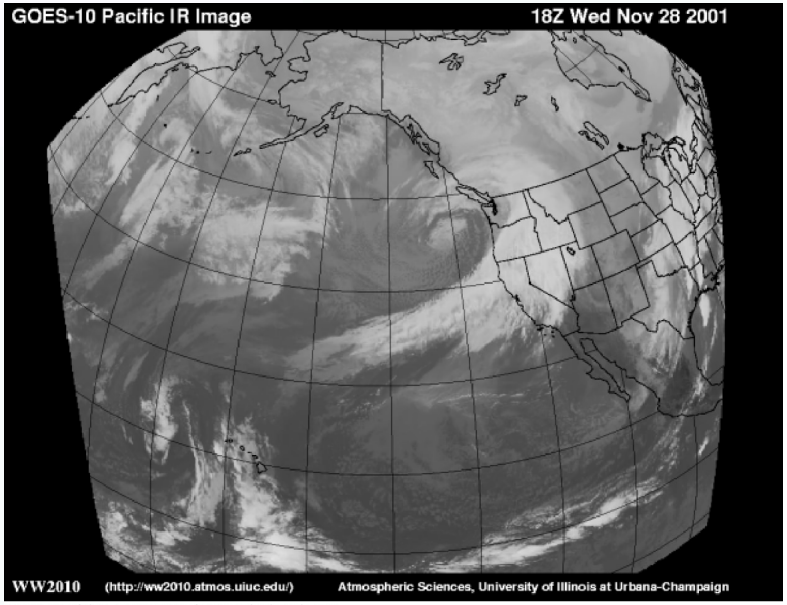




- East of the Rocky Mtns, the influence on snowfall is latitude and temperature
- In the western U.S., snowfall is influenced by elevation and mountains
  - The topography has a strong influence on snowfall!
  - Heaviest snowfalls in highest mountains, and snow may last year round in some of those highest elevations

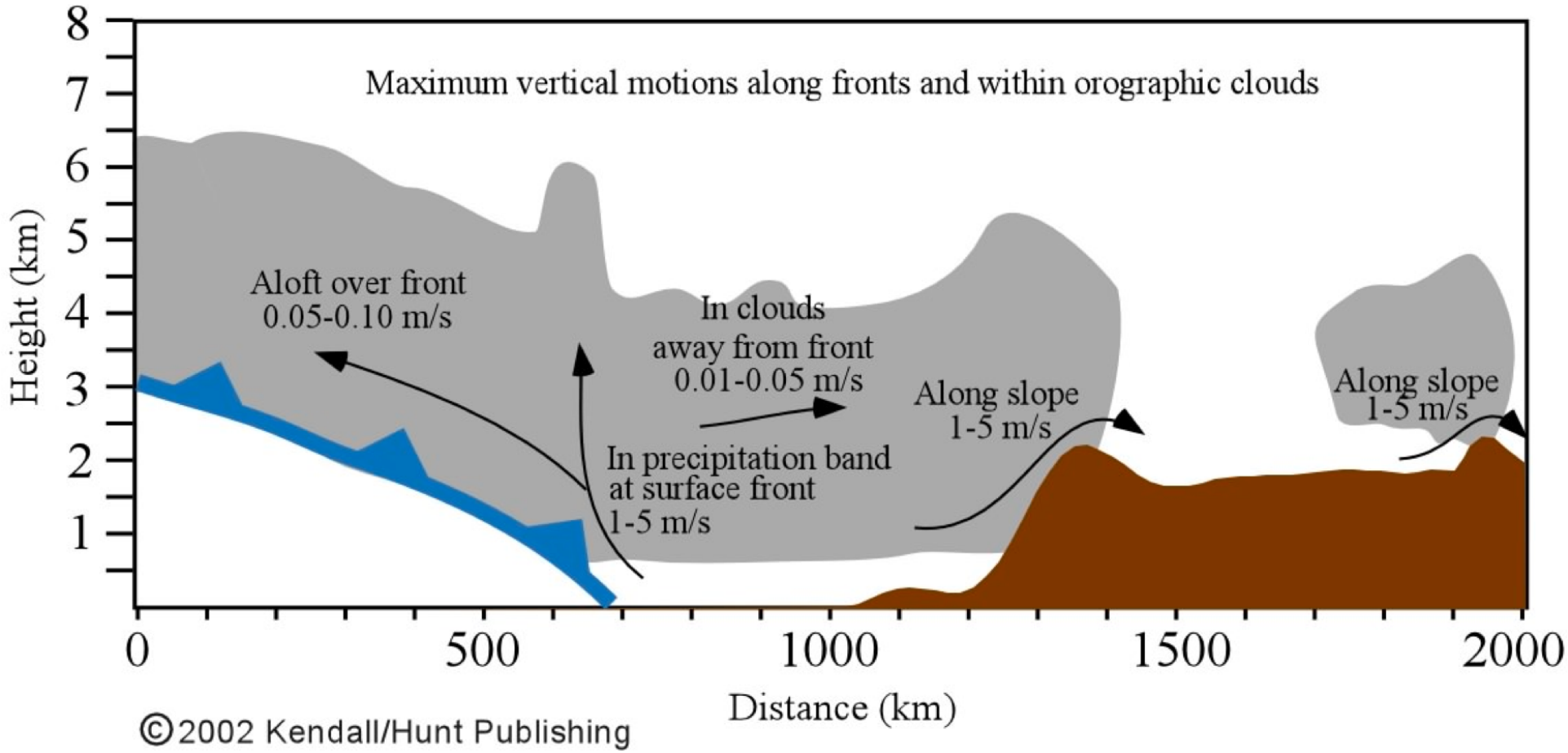
Source of Mountain Snowstorms

- What weather elements are responsible for mountain snowstorms in the western US?
  - Large-scale weather systems, like extratropical cyclones, fronts, and upper-level troughs
- Storms develop in the Pacific Ocean and come ashore in western North America.
  - Associated with streams of moisture from the ocean, called atmospheric rivers



Courtesy of the Department of Atmospheric Sciences
University of Illinois at Urbana-Champaign

What happens when these storms encounter the mountains of North America?



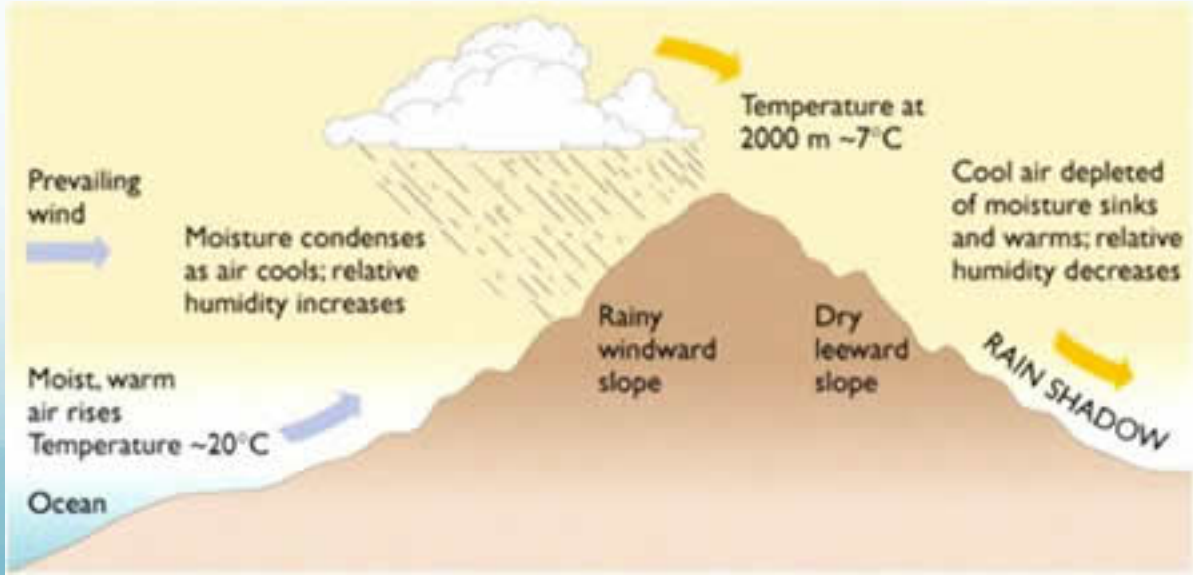
- How does the lifting of air over mountains compare to the lifting of air along a front?
- Why are local precipitation amounts often larger in the mountains than along a front?

Frontal is more spatially distributed, while orographic is localized and falls continuously in one location

Orographic Lifting

- **Orographic lifting** – air is forced to rise as it encounters a mountain
  - **Windward side** – the upwind side of a mountain
  - **Leeward side** – the downwind side of a mountain
- How do precipitation totals differ between the windward and leeward side of a mountain range?

What happens to air parcel as it is lifted on windward side?



What happens to air parcel that flows down leeward side? Especially if it rained out moisture on windward side?

Clicker Question

- True or false: Mean annual snowfall in the western United States always increases from south to north.

  A. True

  B. False

Clicker Question

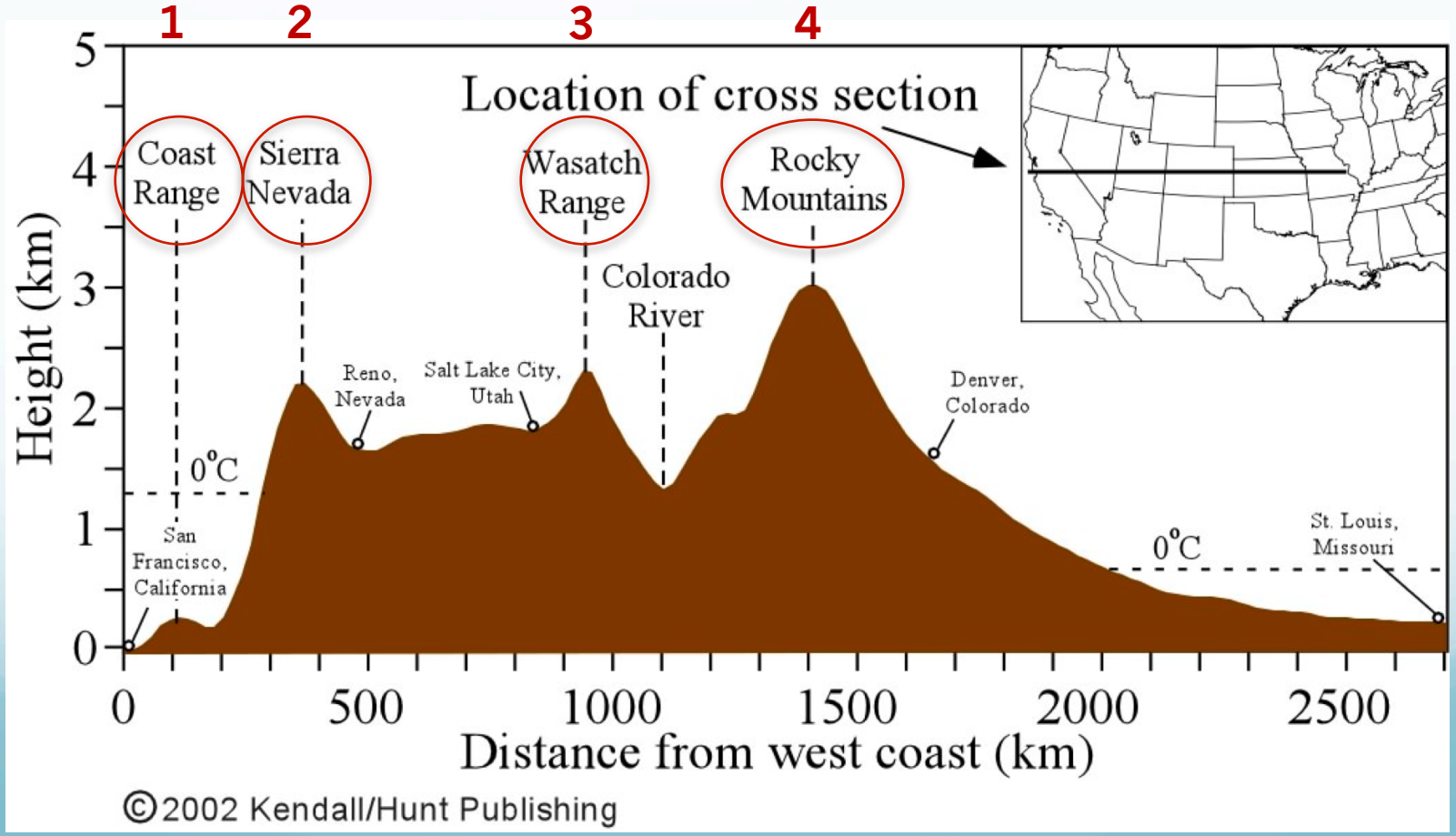
- Total precipitation amounts are often _____ on the windward side of a mountain compared to along a front.
  A. Less
  B. About the same
  C. Greater

Clicker Question

- The leeward side of a mountain is the _____ side of a mountain.
  A. Upwind
  B. Downwind
  C. Both (a) and (b)
  D. None of the above

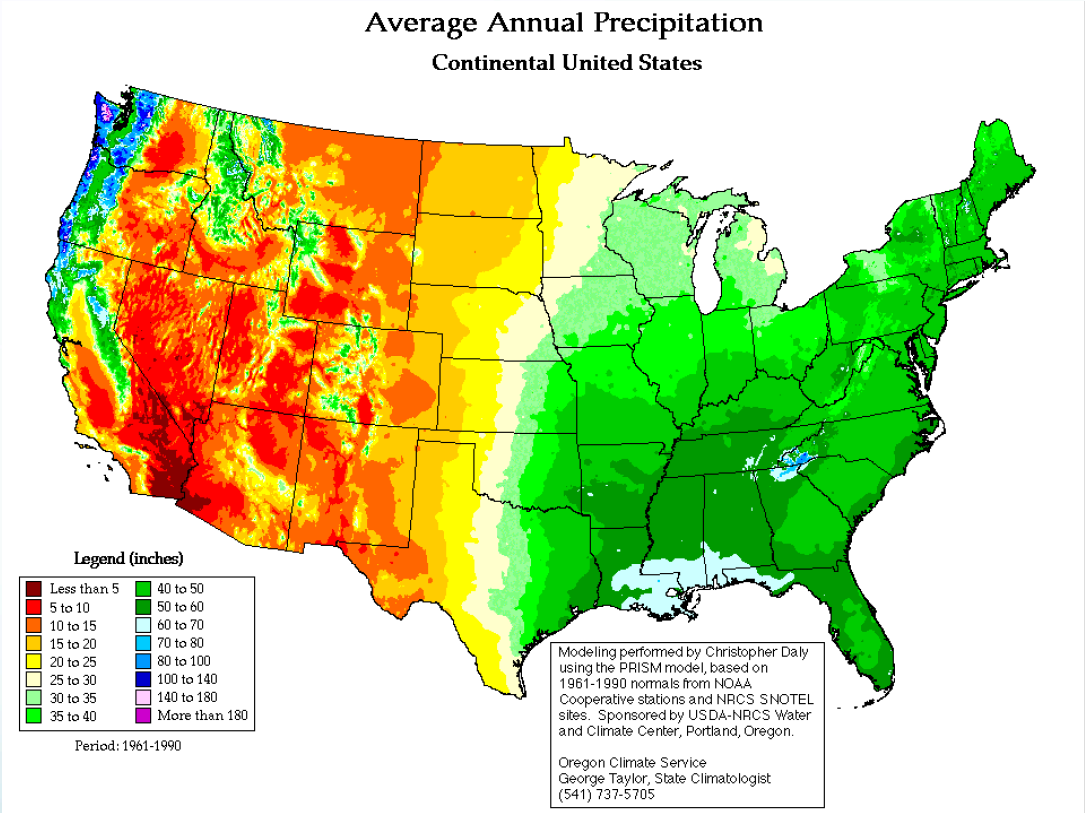
Individual Mtn Ranges

- What mountains does air coming from the Pacific Ocean encounter in the western US?



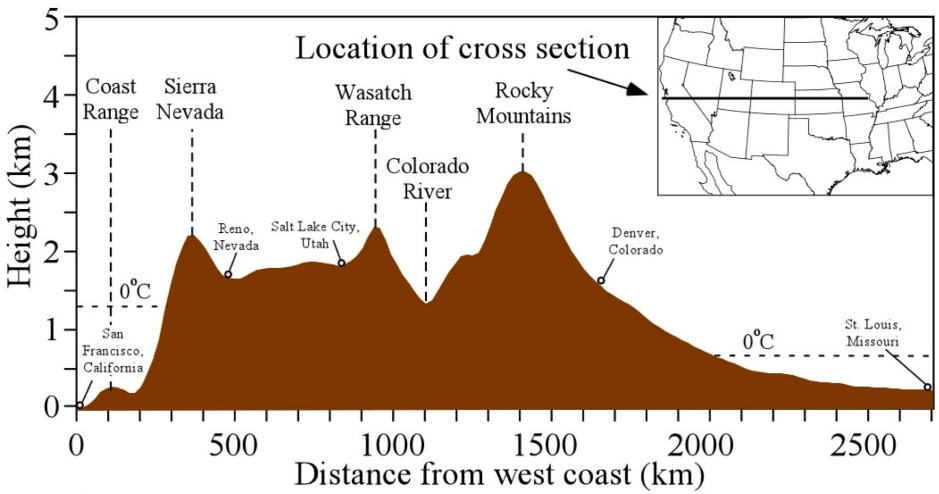
Coast Range

- These are the first mountains encountered as air comes ashore from the Pacific Ocean.
- Does the precipitation that falls in the Coast Range fall mainly as snow or as rain?
  - Rain, because peak altitudes of mountains in the Coast Range are below melting level
- **Melting level** – the altitude in the atmosphere where the temperature = 0 degrees C.



Sierra Nevada and the Cascade Mountains

- These are the second range of mountains encountered by air coming ashore from the Pacific Ocean.
- How does the elevation of the Sierra Nevada compare to the elevation of the Coast Range?
  - Much higher!
- What effect does this have on the type and amount of precipitation that falls in the Sierra Nevada?
  - Most falls as snow!
  - Very high snow amounts!
  - 100s to >1000 inches/yr



Wasatch Range and the Rocky Mountains

- These are interior mountain ranges that are further from the Pacific Ocean.
  - How does the amount of snow that falls in the interior mountains compare to the amount of snow that falls in the Sierra Nevada mountains?
    - Less because moisture has been precipitated out, and colder temperatures yield lower density snow crystals
- **Snow water equivalent** – the depth of water that would be obtained by melting snow
  - This is often expressed as the number of inches of snow per inch of water.
- What are typical and extreme values for the number of inches of snow per inch of water?
  - Typically 11-14 inches of snow per inch water
  - High density snowflakes as low as 4:1, Low density snowflakes as high as 25-30:1
  - One measurement in Alaska of 75-100 inches snow to 1 inch water! Very low density snow!
- What factors cause this variability?
  - Temperature, moisture supply in cloud, how crystals grow and behave as they fall

Storms on the East Slope of the Rockies

- **Upslope storm** – a winter storm that occurs along the eastern slope of the Rocky Mountains when the low-level winds have an easterly component
- As air comes from the east it rises from near sea level along the Mississippi River valley to near 5,000 feet in Denver and Boulder, and rises another 6,000+ feet as it rises up the Rocky Mountains.
- What happens to the air is it is forced to rise?
  - Temperature Decreases adiabatically as parcel expands
  - Relative humidity Increases as temperature decreases
  - Formation of clouds and precipitation

    Clouds form when air becomes saturated (RH>= 100%)

Upslope weather patterns

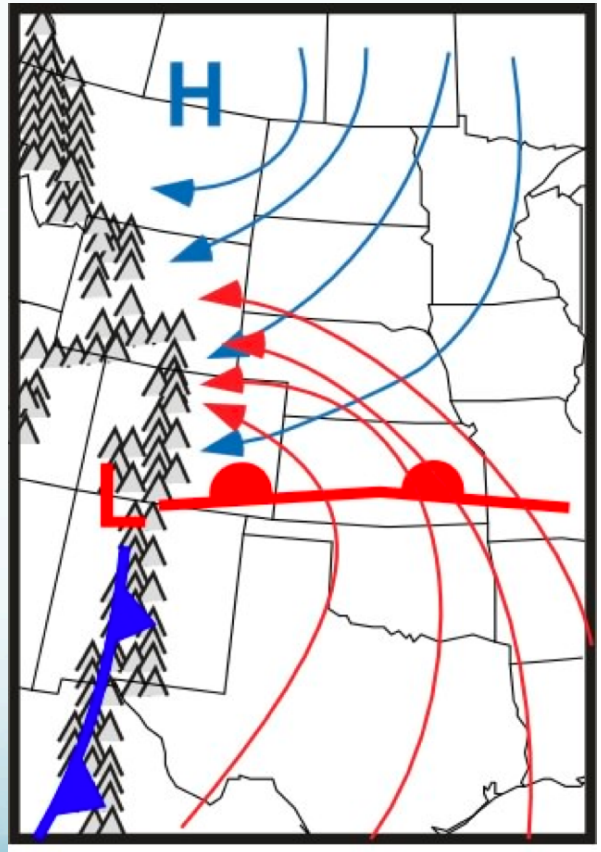
- What weather patterns can create upslope (easterly) flow in Colorado?
  - 1. High pressure north of Colorado
  - 2. Low pressure south of Colorado

Where does the air that ends up in Colorado come from for these two weather patterns?

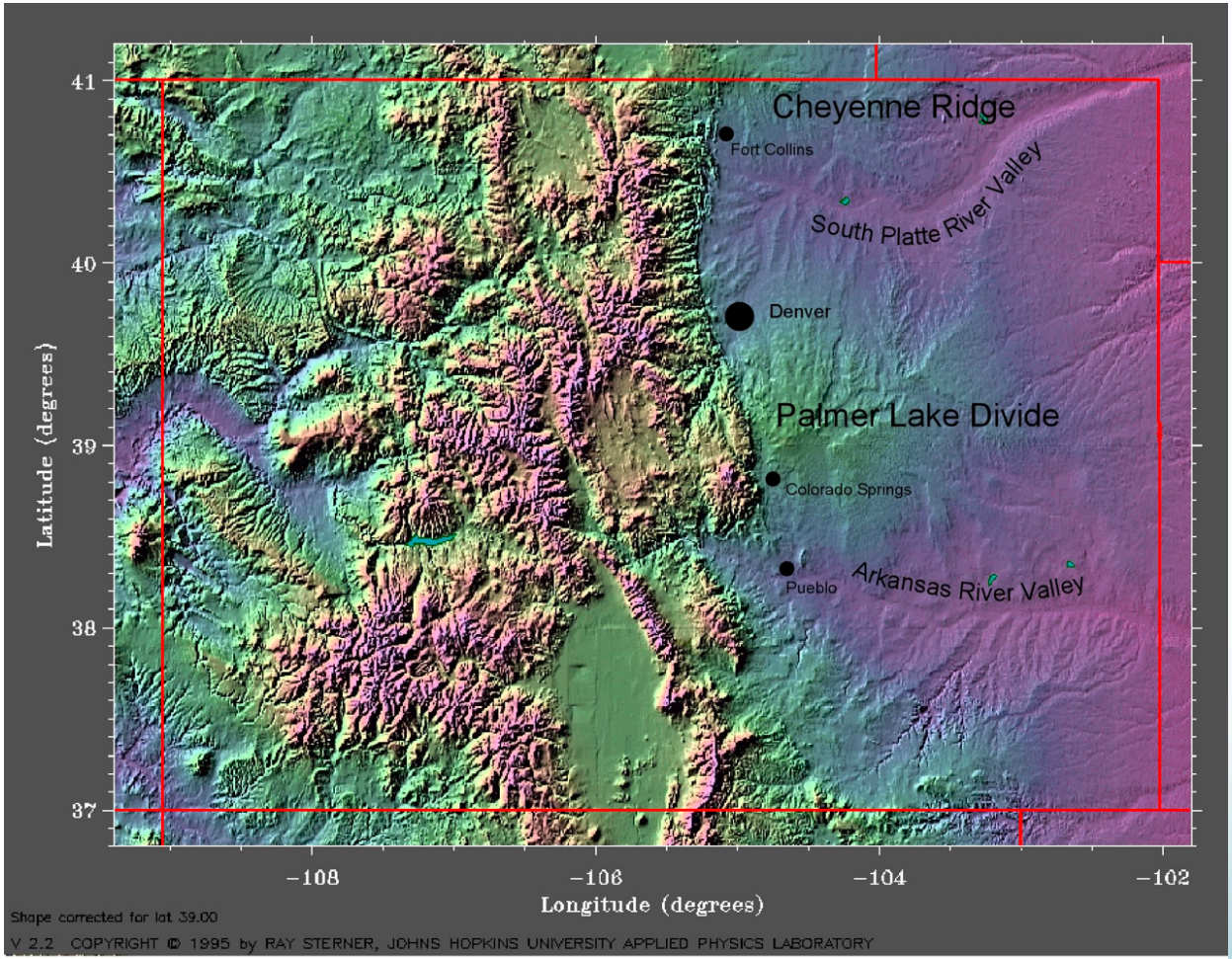
How does the amount of moisture and temperature in the air vary for these different weather patterns?

Which of these patterns can cause the largest snowfall amounts? Why?

What happens if both weather patterns occur at the same time?

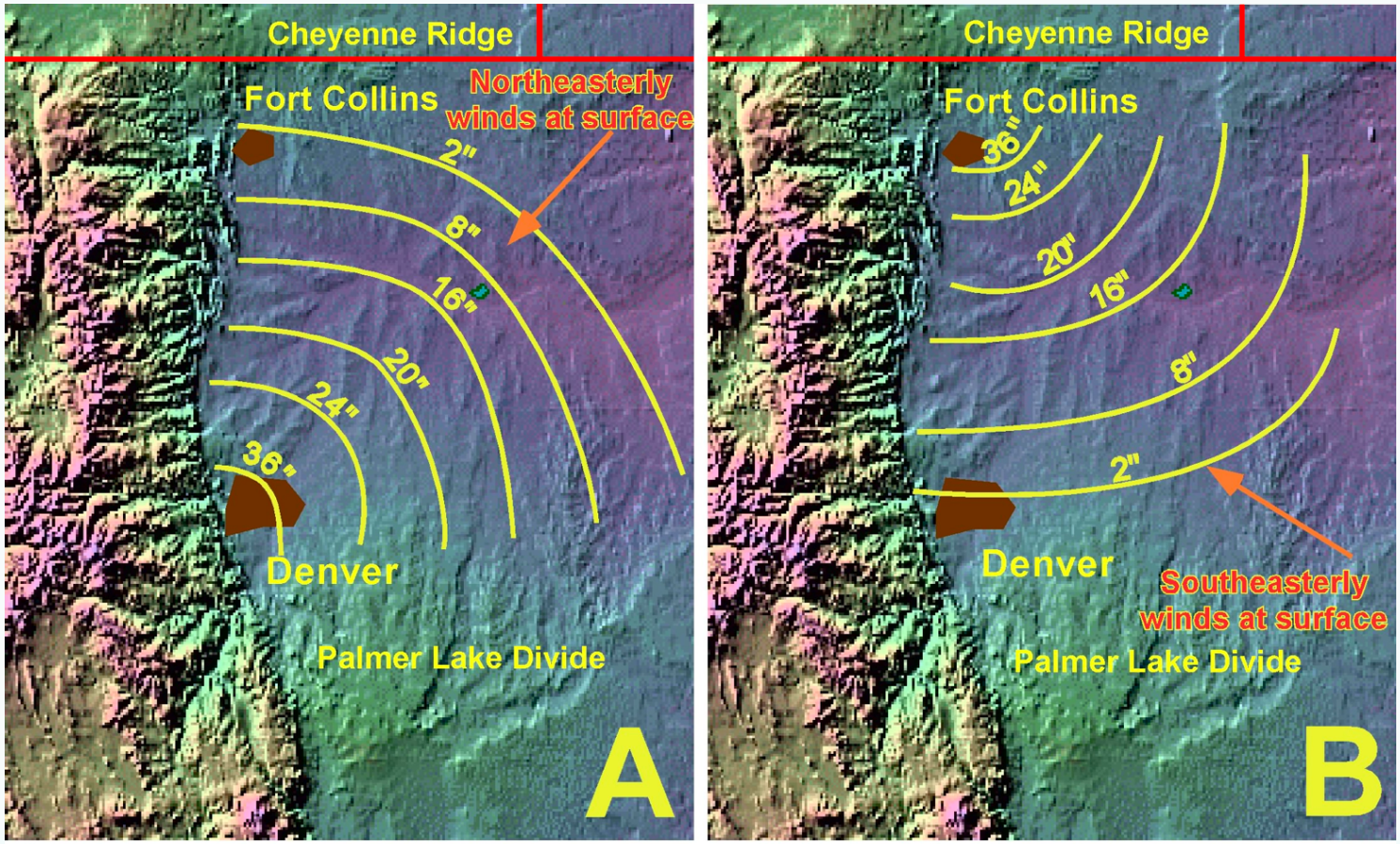


Variable local snow amounts



Courtesy of Ray Steiner, Johns Hopkins University

- What local topographic features are important for upslope snowstorms along the Front Range?
  - Palmer divide
  - Cheyenne ridge



- Where would you expect the heaviest snowfall for northeasterly or southeasterly surface winds? Why?
  - A) Northeasterly winds yields upslope along Palmer divide
  - B) Southeasterly winds yields upslope along Cheyenne ridge

Clicker Question

- The elevation of the Coast Range is _____ than the Sierra Nevada, yielding more precipitation in the form of _____ over the Sierra Nevada.

  A. Higher, snow
  B. Higher, rain
  C. Lower, snow
  D. Lower, rain

Clicker Question

- A snow water equivalent of 12 inches of snow per 1 inch of water would be considered _____.
  A. Low
  B. High
  C. Typical

Clicker Question

- Upslope flow in Boulder, CO occurs if there is high pressure _____ of Colorado and/or low pressure _____ of Colorado.
  A. South, south
  B. South, north
  C. North, north
  D. North, south

Clicker Question

- For a surface high pressure center north of Colorado you would expect the air that arrives at the Front Range to be _____ resulting in _____ in the winter.

  A. cold and dry, heavy snow
  B. cold and dry, light snow
  C. mild and moist, heavy snow
  D. mild and moist, light snow