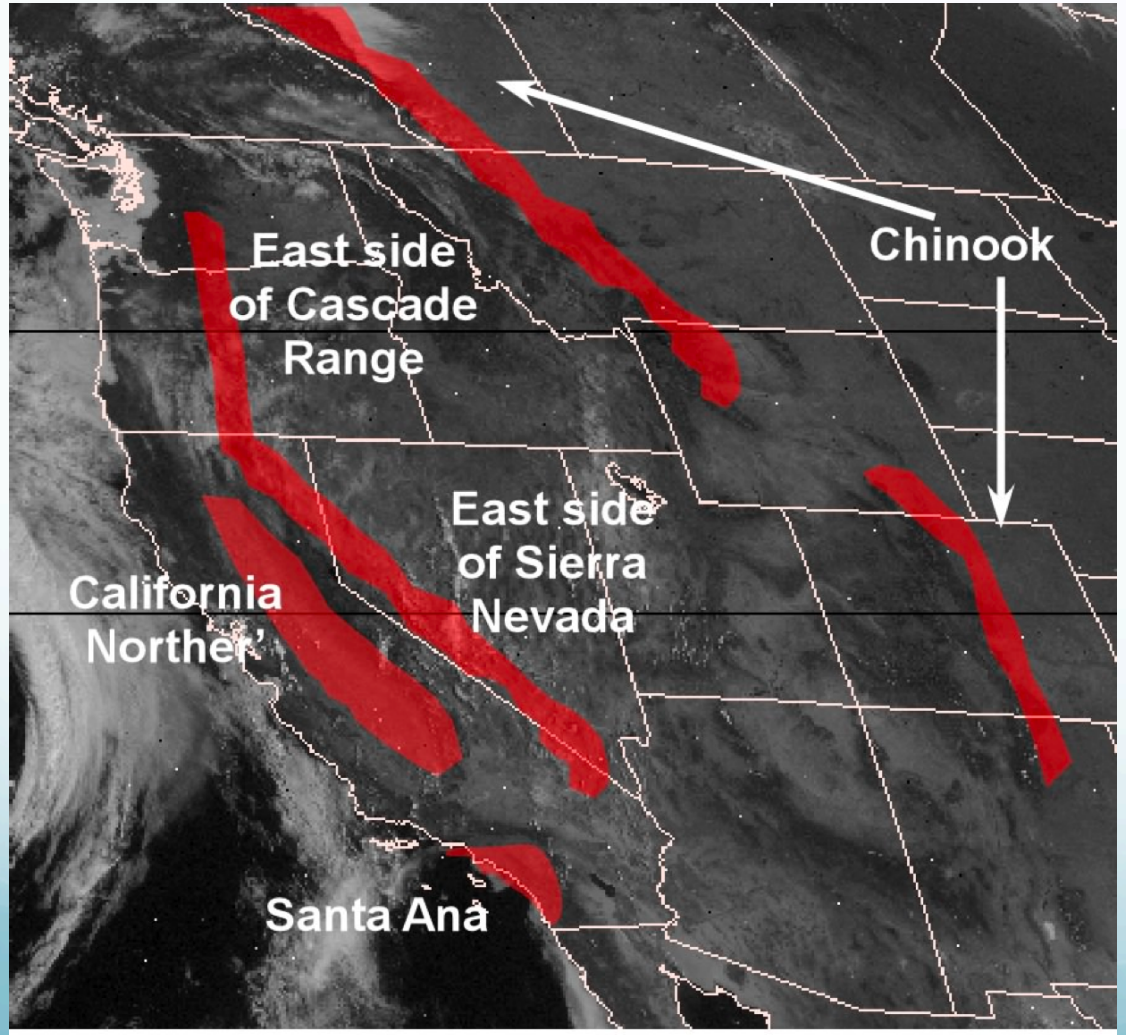
Chapter 17: Mountain Windstorms

Downslope winds

- **Foehn** – Alps (**warm**)
- **Bora** – Adriatic Sea (**cold**)
- **Chinook** – Rocky Mountains (**warm**)
- **Santa Ana** – Southern California (**warm**)
- **Katabatic** – Antarctica and Greenland (**cold**)

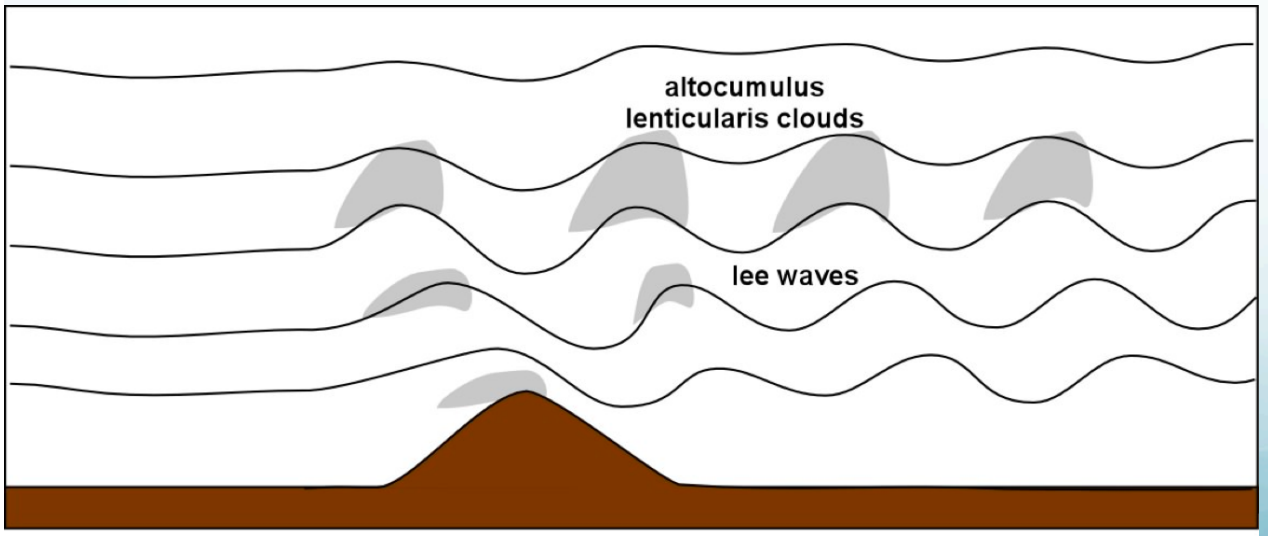
Where do they occur in western North America?



Strong Chinook downslope windstorms occur every winter in Boulder.

Dynamics of downslope winds

- Recall:
  - **Windward side** – upwind side of a mountain range
  - **Leeward (or lee) side** – downwind side of a mountain range
    - As air encounters a mountain range it must rise on the windward side and then descend on the leeward side.



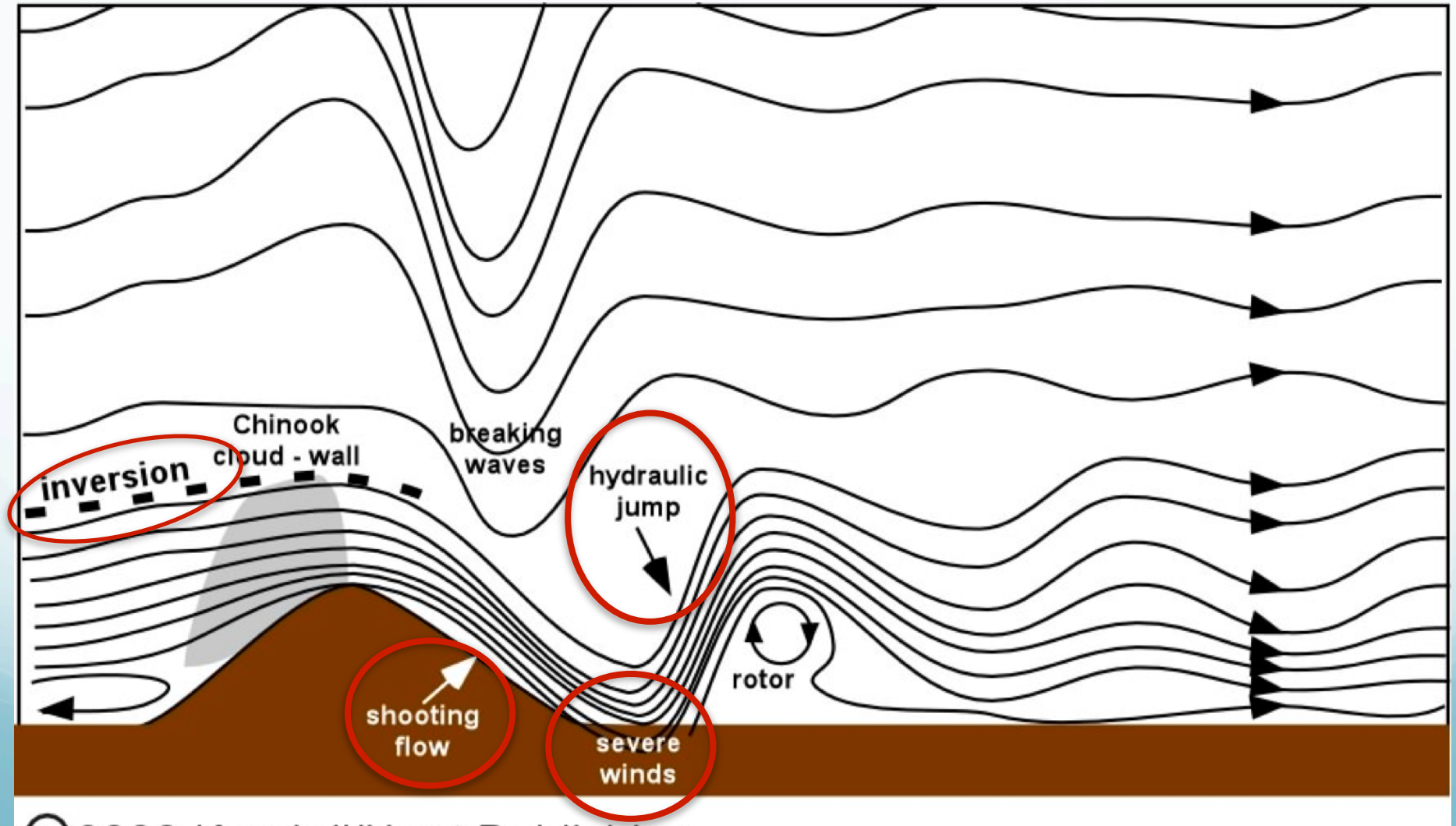
Lee waves – a series of waves in the flow downstream from a mountain

What type of clouds form in lee waves?

Altocumulus lenticularis

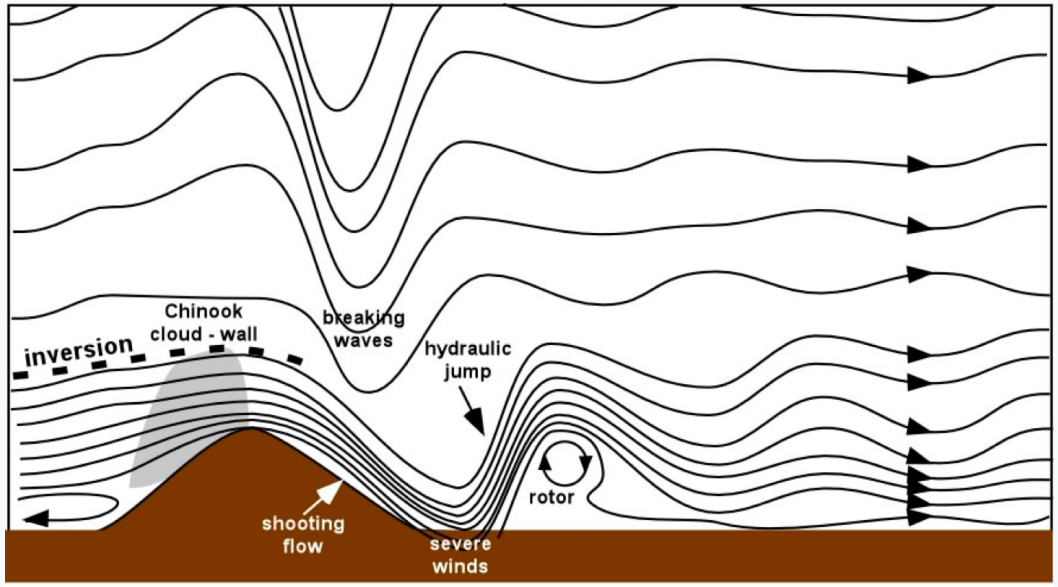
- “Lenticular” clouds, lens shaped clouds

Flow with severe downslope winds



Hydraulic Jump

Hydraulic Jump —
Where the flow abruptly rises and becomes turbulent as it adjusts within the deeper layer over the plains downstream of the mountain

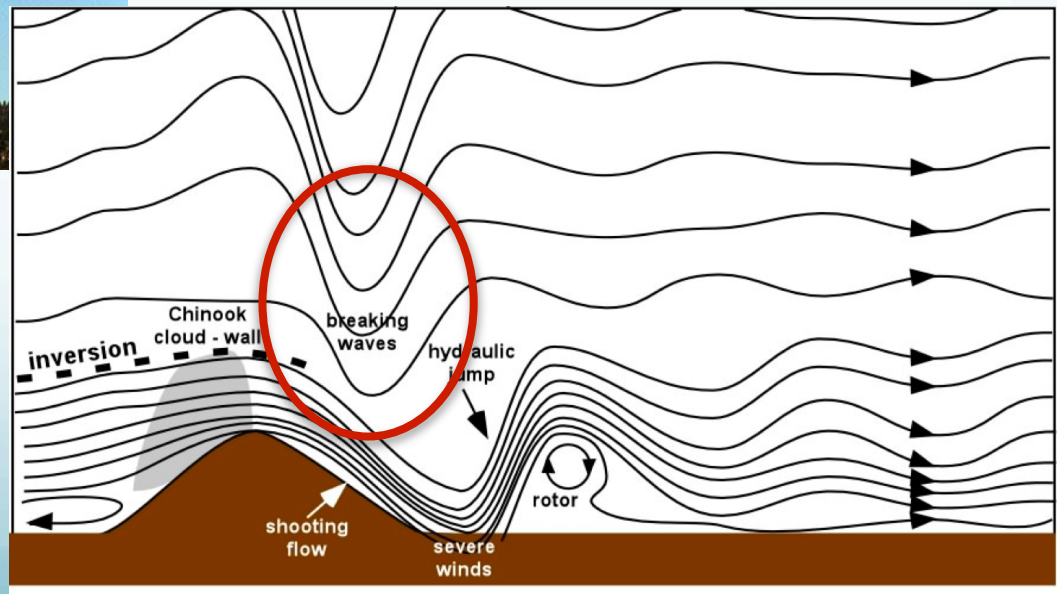


- The hydraulic jump marks the transition from strong winds upstream of the jump to weaker winds downstream of the jump.
- Strong vertical winds and turbulence occur at the hydraulic jump, creating dangerous conditions for aircraft.

Breaking waves

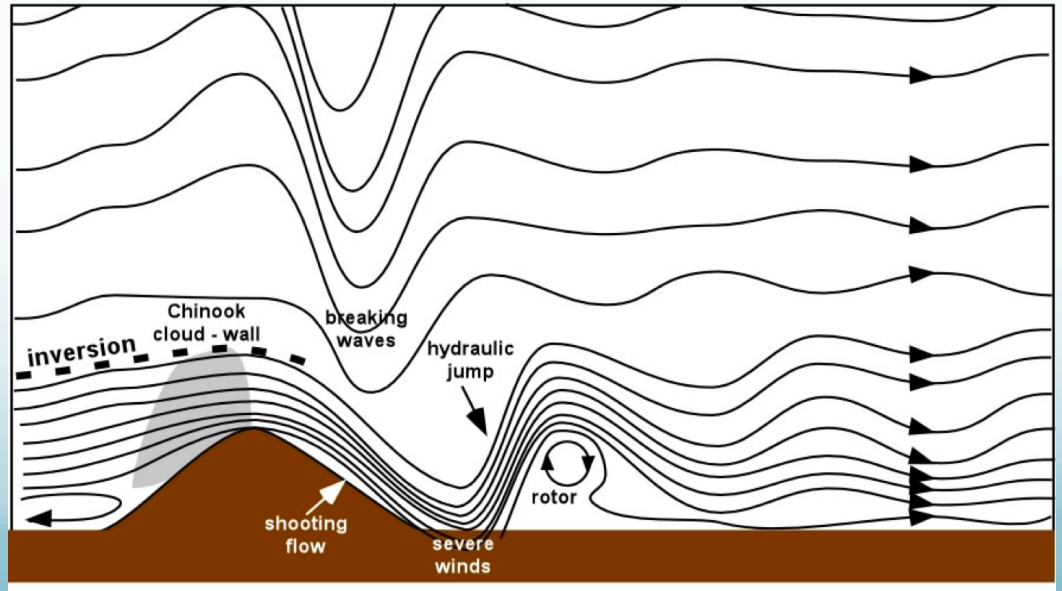
- Kelvin-Helmholtz wave clouds

Waves break similar to those in the ocean



Recap

- This type of flow can form when winds are strong upstream of the mountain and an inversion layer is present above the top of the mountains.
- Changes in the upstream wind speed and inversion cause this flow to change, resulting in gusty winds on the leeward side of the mountains.



Demo

- http://nimbus.colorado.edu/1050/PAGES/Contents/Experiments/channel.htm

Clicker Question

- You would expect air to _____ on the windward side of a mountain range resulting in _____ skies.
  A. Rise, mostly sunny
  B. rise, mostly cloudy
  C. Sink, mostly sunny
  D. sink, mostly cloudy

Clicker Question

- For west winds across the Rocky Mountains you would expect lee waves to form on the _____ side of the Rocky Mountains.

  A. east
  B. south
  C. west
  D. north

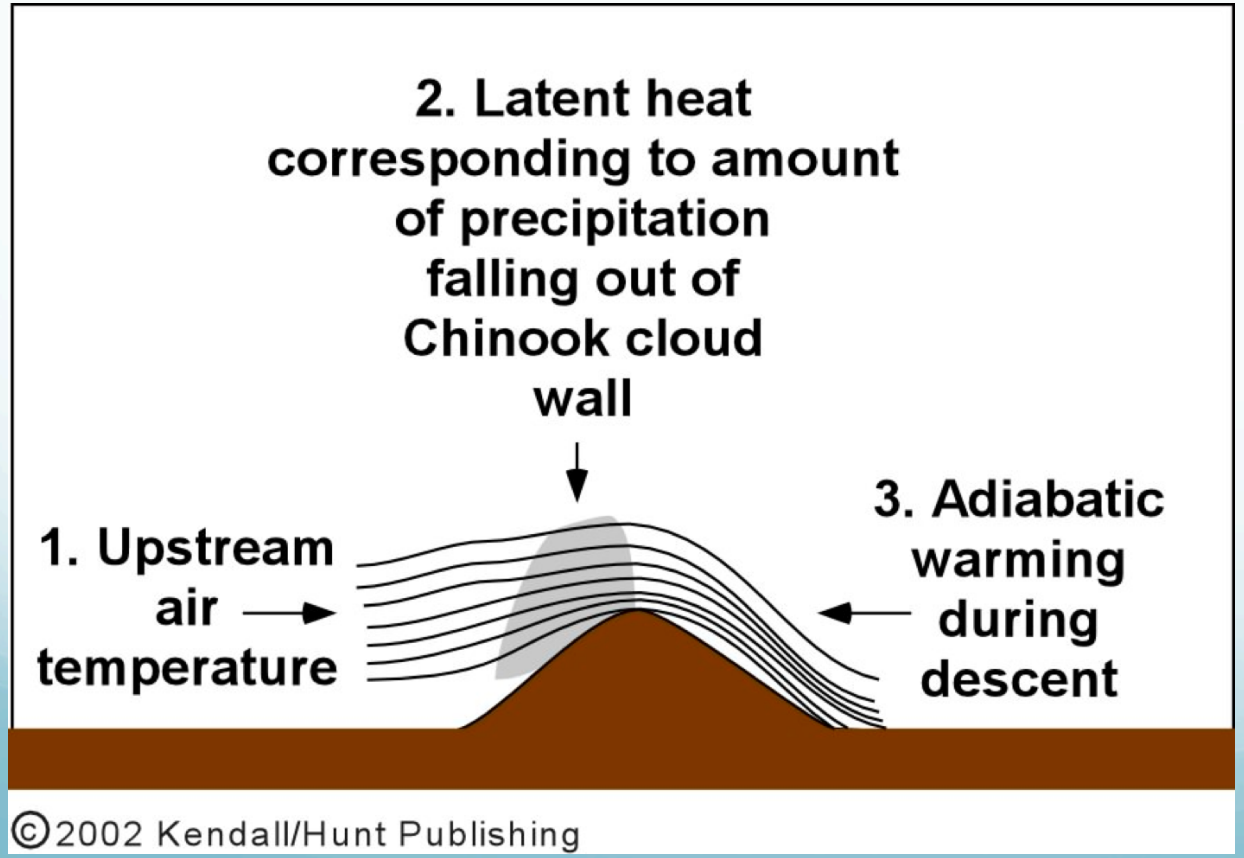
Clicker Question

- A hydraulic jump may form downstream of a mountain range if the winds are _____ upstream of the mountain and an inversion layer is present _____ the top of the mountains.

  A. weak, above
  B. strong, above
  C. weak, below
  D. strong, below

Cold vs Warm downslope winds

- 3 factors that determine the temperature of the air in downslope winds



"Chinook wall"

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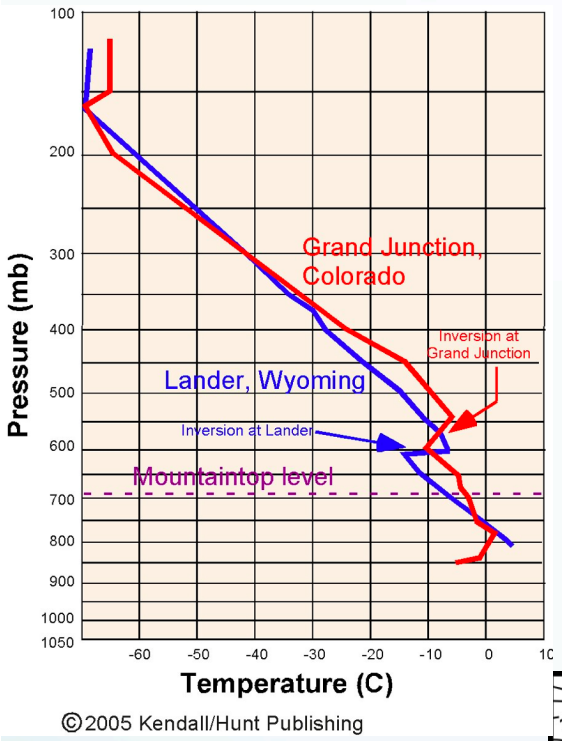
- What determines the upstream air temperature for downslope winds in Colorado?
  - Origin of air upstream (from Pacific = warm, from western Canada = cold)
- How much adiabatic warming does air experience as it descends from the crest of the Rocky Mountains to Boulder, CO?
  - Dry adiabatic lapse rate = 10 deg C / km
  - 1.5 to 2 km decrease in height **15 to 20°C warming!**
- What happens to the relative humidity of air as it descends and warms dry adiabatically on the leeward side of a mountain range? **Decreases!**
- What determines if a downslope wind will be warm or cold in Boulder?

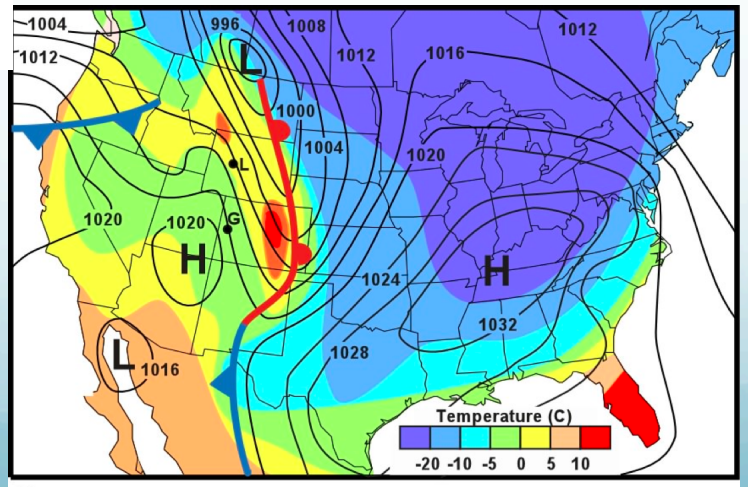
  Upstream air origin, amount of latent heat released on windward side, and current temperature on plains

3 weather features for a Chinook



- Stable layer upstream of mountains (inversion just above mountaintop level)
- Strong surface pressure gradient across the mountain
  - **Lee trough** – an area of low pressure on the lee side of the mountains
- Mountaintop air flow (~700mb) is strong and westerly

Inversions ~600 mb
Mountaintop
~700 mb



How does the sea-level pressure change from west to east across Colorado?

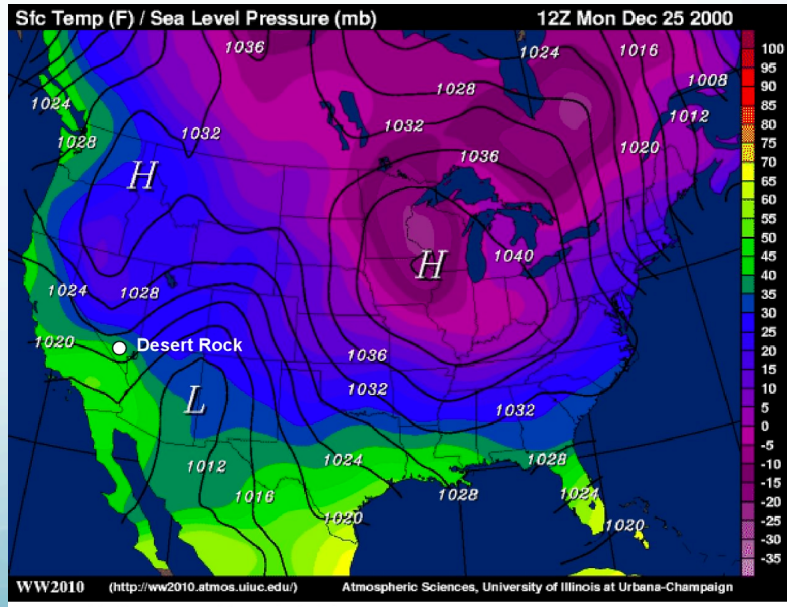
How do the temperatures along the Front Range compare to those further east?

Santa Ana winds

- **Santa Ana winds** – the name given to downslope windstorms in Southern California
  - Santa Ana winds are easterly winds that blow from the desert of the Great Basin across the San Bernadino and San Gabriel Mountains and into Southern California.

- What weather conditions are required for Santa Ana winds to form?

1. Strong high pressure over the Great Basin
2. Strong north-south pressure gradient over southern California
3. An inversion layer above mountaintop level may also be needed



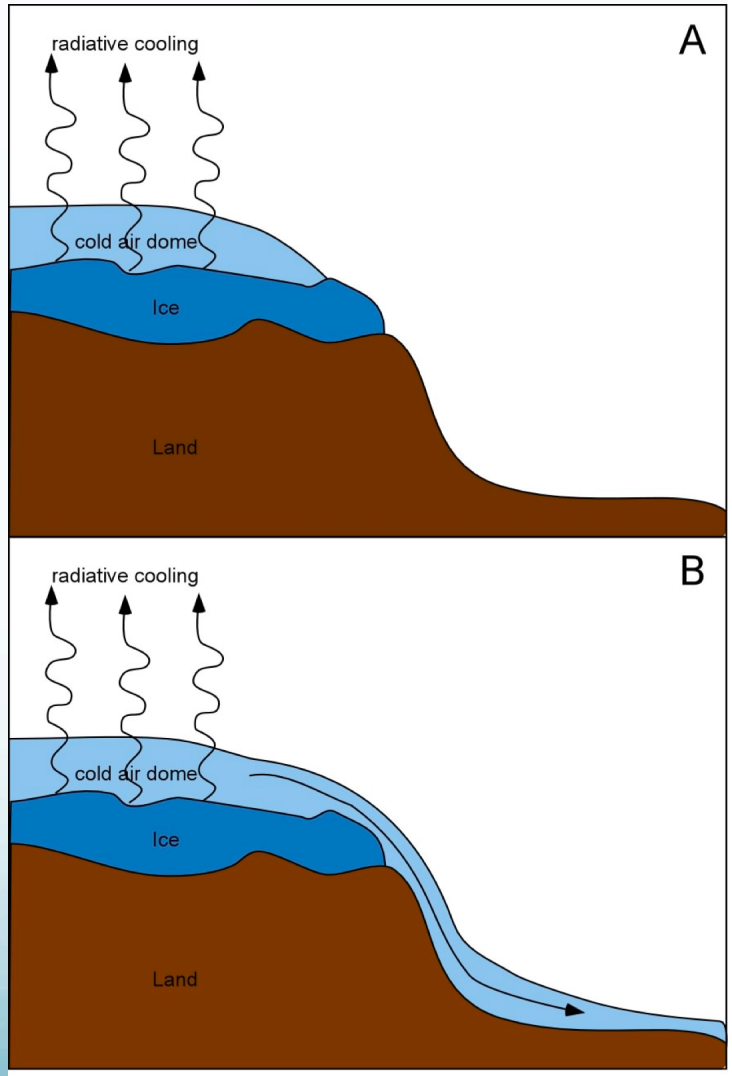
Courtesy of the Department of Atmospheric Sciences
University of Illinois at Urbana-Champaign

Effects of Santa Ana winds

- How do Santa Ana winds compare to Chinook winds in Colorado?
  - Easterly flow (out of desert), yet not as strong as Chinooks
- When do the strongest Santa Ana winds typically occur?
  - Conditions occur Sept-April
- What hazards are associated with Santa Ana winds?
  - Wet season occurs Dec-Mar
  - By late fall (Sept-Nov), end of long dry season, fires are easily sparked and the Santa Ana winds can spread fires quickly

Katabatic winds

- **Katabatic wind** – a cold, downslope wind that is the result of cold air flowing downslope under the force of gravity
  - As opposed to Chinook and Santa Ana winds that are driven by strong pressure gradient forces
  - They occur in cold, high elevation regions of the world with vast ice sheets (Antarctica, Greenland coast)
  - Severe winds result (>100 kts)



Clicker Question

- Which of the following is a cold downslope wind?
  A. Foehn
  B. Chinook
  C. Katabatic
  D. Santa Ana

Clicker Question

- You would expect the warmest downslope winds in Boulder, CO if the air originated over _____ and a _____ amount of latent heat was released on the windward side of the mountains.

  A. Canada, large
  B. Canada, small
  C. the Pacific Ocean, large
  D. the Pacific Ocean, small

Clicker Question

- For west winds across the Rocky Mountains Boulder would be located on the _____ side of the mountains and you would expect _____ skies in Boulder.

  A. windward, mostly sunny
  B. leeward, mostly sunny
  C. windward, mostly cloudy
  D. leeward, mostly cloudy

Clicker Question

- Santa Ana winds will occur when there is strong _____ pressure over the Great Basin and a _____ north-south pressure gradient over Southern California.

  A. high, strong
  B. high, weak
  C. low, strong
  D. low, weak

Clicker Question

- Santa Ana winds are most likely to occur in _____.

  A. Spring
  B. Summer
  C. Fall
  D. Winter
  E. Both c and d