Cold Air Damming

Atmos 6250: Mountain Meteorology

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Learning Objectives

- After this class you should
  - Recognize areas of North America that are prone to cold air damming and its impacts
  - Understand the processes that contribute to the development and maintenance of cold air damming
  - Be prepared to analyze and forecast events

Introduction

Cold Air Damming

- What is it?
  - The phenomenon of cold air becoming entrenched along the slopes of a mountain range
- General characteristics
  - Cold air in the form of a dome
  - Accompanying "U-shaped" ridge in the sea level pressure field

Cold Air Damming

- Impacts
  - Locally low temperatures
  - Sleet, snow, or freezing rain
  - Fog and stratus
  - Local enhancement of gap winds
- Where?
  - East of Appalachians, Rockies, Cascades
  - St. Lawrence Valley
  - South of Alps
  - Uinta Basin

Cold Air Damming

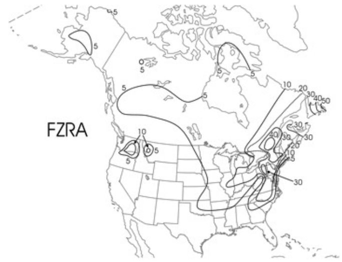
Ice Storm, Cambridge Turnpike, Concord, Mass., Nov. 30, 1921.

Ice Storm, Thoreau Street, Concord, Mass., Nov. 29, 1921.

"In America, the ice storm is an event, and it is not an event which one is careless about"
- Mark Twain

http://www.concordlibrary.org/scollect/fin_aids/dpw.html

Cold Air Damming

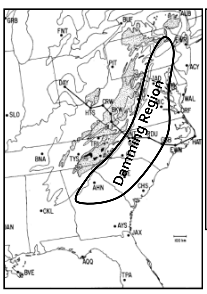


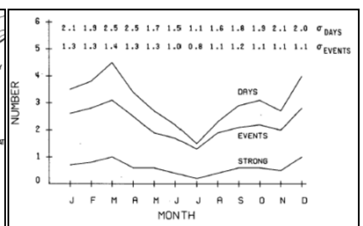
Median annual hours of freezing rain 1976-1990

Cortinas et al. (2004)

Appalachian Cold Air Damming

Appalachian Cold Air Damming

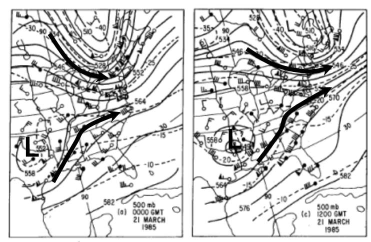




Occurs frequently east of Appalachians
Events most common from Dec-Mar

Bell and Bosart (1988)

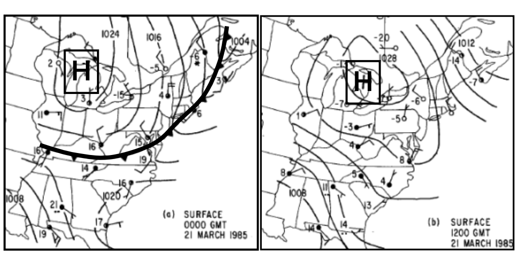
Antecedent Conditions



Large-scale upper-level confluence over eastern US
Northern upper-level trough precedes southern trough

Bell and Bosart (1988)

Antecedent Conditions

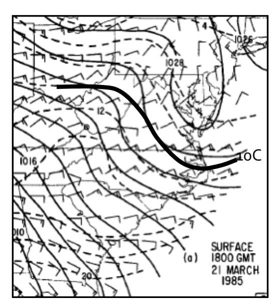


Surface frontal passage & building of cold anticyclone at surface
Result: Cold air becomes entrenched over eastern U.S. prior to a cyclogenesis event over southeast US

Bell and Bosart (1988)

Initiation Phase

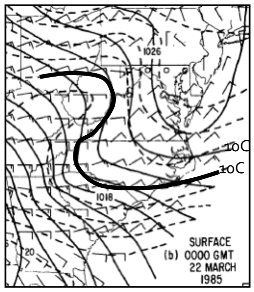
- Initiation phase
  - Low pressure develops over Gulf of Mexico in response to southern upper-level trough
  - High pressure drifts eastward
  - Result
    - Magnitude of easterly flow directed towards mountains increases
    - Along-barrier pressure gradient increases
    - Upslope flow experiences adiabatic cooling



Bell and Bosart (1988)

Initiation Phase

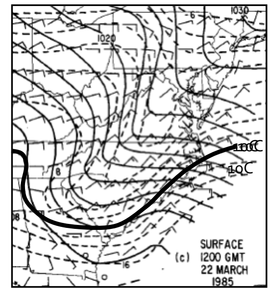
- Initiation phase
  - Terrain-parallel pressure gradient increases
  - Mountain-induced windward ridge and lee trough amplify



Bell and Bosart (1988)

Mature Phase

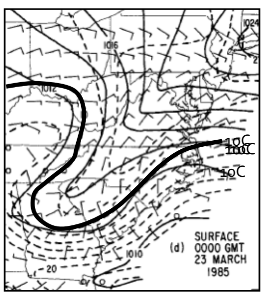
- Mature phase
  - Windward (east side) flow veers and becomes terrain parallel
  - Cold advection becomes stronger near mountains (in this case, warm advection occurs off coast)
  - Equatorward movement of cold air is most rapid east of mountain slopes



Bell and Bosart (1988)

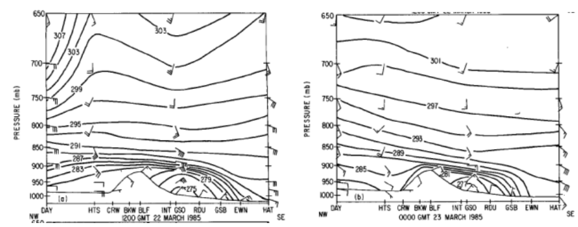
Mature Phase

- Mature phase
  - Pronounced cold dome and U-shaped mesoscale pressure ridge



Bell and Bosart (1988)

Vertical Structure

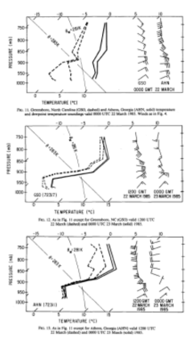


- Cold-dome extends to near crest height of Appalachians
- Near-surface winds are terrain parallel within dome and veer with height (warm advection above cold dome)

Bell and Bosart (1988)

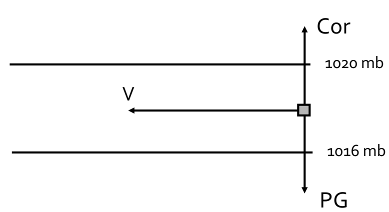
Soundings

- During development of damming event, a shallow-layer of cold air deepens and becomes surmounted by an inversion



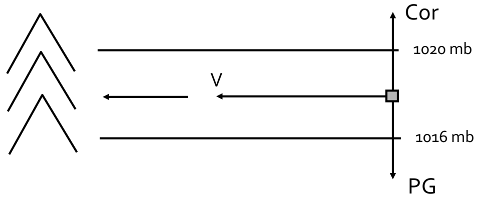
Bell and Bosart (1988)

Basic Dynamics



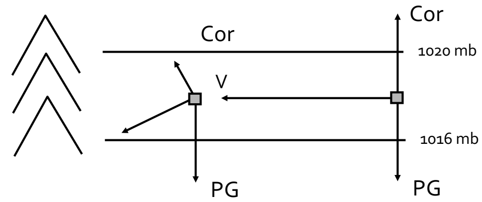
In the absence of topography and friction, the flow exhibits geostrophic balance

Basic Dynamics



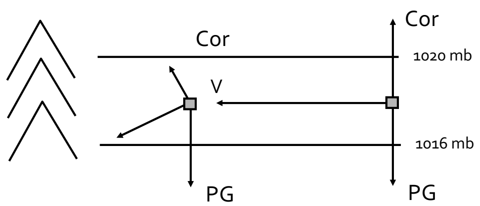
If flow is characterized by a low Froude number (U/NH < 1), the the low-level flow will be blocked and decelerate as it approaches mountains

Basic Dynamics



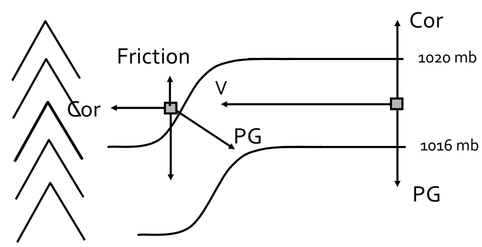
Flow is deflected toward lower pressure

Basic Dynamics



Flow deceleration results in a piling up of mass and development of a mesoscale pressure ridge near the mountains (mutual adjustment of mass and momentum)

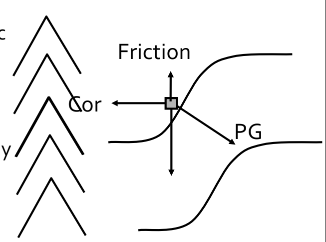
Basic Dynamics



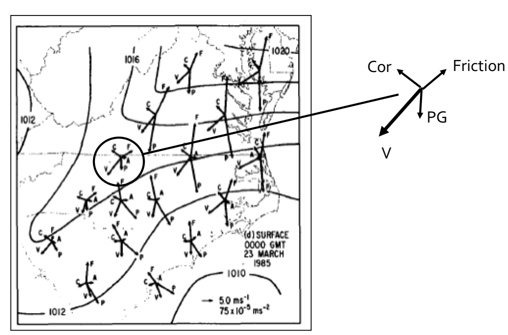
The final near-barrier force balance

Mature Force Balance

- Along-barrier antitripitic
  - Pressure gradient is balanced by friction
- Cross-barrier geostrophy
  - Pressure gradient is balanced by Coriolis



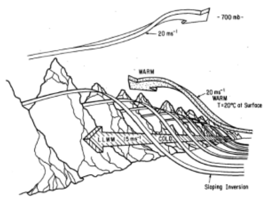
Real World Example



Bell and Bosart (1988)

Conceptual Model

- Terrain-parallel low-level wind maximum within cold dome
- Easterly (or SE) flow above cold dome associated with strong warm advection
- Southerly to southwesterly flow aloft



Bell and Bosart (1988)

Discussion

Other than terrain driven flows, what other processes contribute to the development and maintenance of cold-air damming?

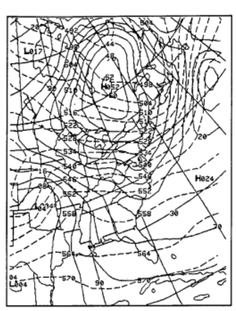
Event Types

- Morphology based on
  - Three-dimensional scale variations
  - Relative roles of synoptic-scale and diabatic processes
- Types
  - Classic damming
  - Hybrid damming
  - In situ damming
  - "Look alikes"

Hartfield (1999)

Classic Damming

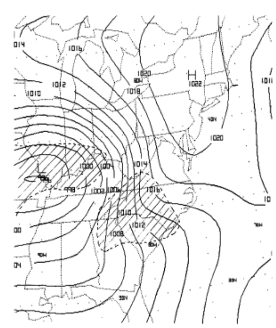
- Strong forcing by synoptic-scale features
- Interaction of large-scale flow with topography results in upslope adiabatic cooling and along-barrier cold advection east of Appalachians
- Diabatic processes not needed to initiate event, but can strengthen it



Hartfield (1999)

Hybrid Damming

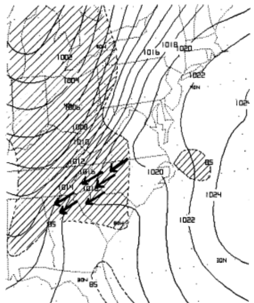
- Synoptic-scale and diabatic processes play nearly equal roles
- Parent high may be:
  - In a good position but weak
  - Progressive (limited CAA)
- Diabatic processes
  - Cool low levels
  - Enhance low-level stability
  - Ultimately enhance upslope cooling, high-pressure, and along-barrier cold advection



Hartfield (1999)

In-Situ Damming

- Surface high is unfavorably located
- Little or no CAA initially; cool dry air in place east of Applachians
- Damming is initiated by sub-cloud evaporation and reduced solar heating



Hartfield (1999)

Erosion

- Not handled well by current NWP models
- Rules of thumb
  - Strong events require cold-front passage to mix out cold dome (particularly during winter)
  - Shallow, weak events with only fog or low cloud cover are susceptible to erosion by insolation and mixing from aloft

Hartfield (1999)

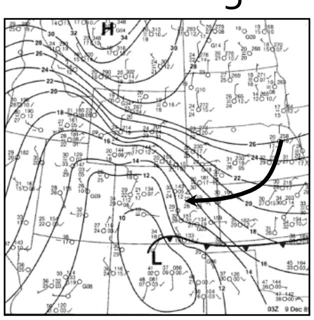
Discussion

How could our understanding of cold air pools help us to understand the erosion of cold air damming?

Could observations collected during PCAPS and other cold pool projects be used to advance understanding of damming maintenance and erosion?

Damming in Other Regions

Front Range

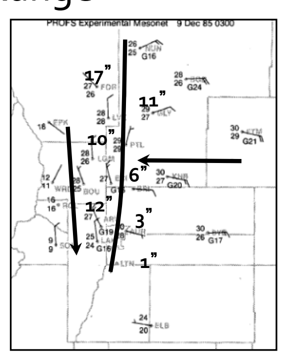


Develops when stable easterly flow impinges on Front Range

Dunn (1987)

Front Range

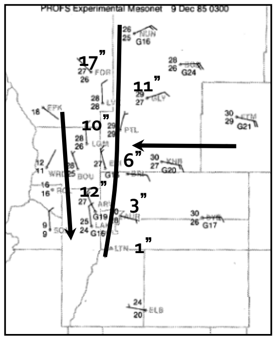
- Along-barrier flow develops near barrier, resulting in a narrow zone of cold-air damming
- Mesoscale front on eastern boundary of damming region
- Heavy precip (possibly snow) west of mesofront



Dunn (1987)

Front Range

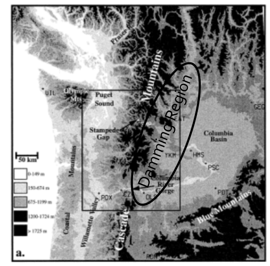
- Not the same as a cold surge, which advects through region
- Instead convergence zone forms in place from stable, cross-barrier flow impinging on mountains



Dunn (1987)

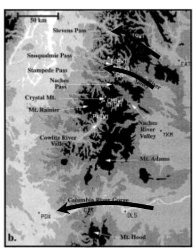
Cascades

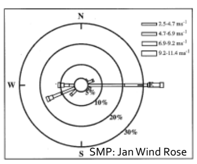
- Cold, continental air dams along east slopes of Cascades
- Along-barrier cold advection not as pronounced as with Rockies/Appalachians
- With approach of a cyclone cold air remains entrenched along Cascades, but mixes out along southern and eastern periphery of Columbia Basin
- Cold pooling also common east of Cascades

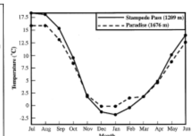


Steenburgh et al. (1997)

Cascades





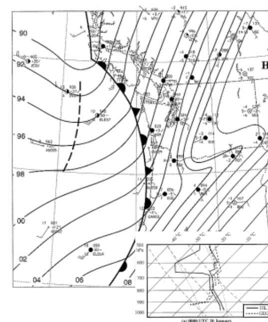


- Cold air from damming region tends to channel through mountain gaps during cool season
- Locally lowers temperatures and snow levels while increasing snowpack
- During the cool season, it is climatologically colder at 3800' in Stampede Pass than 5400' on Mt. Rainier

Steenburgh et al. (1997)

Cascade Example

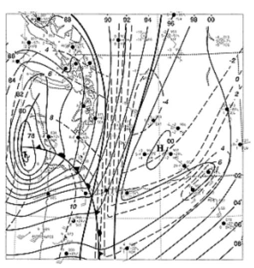
- Antecedent conditions
  - Cold air moves into and/or a period of persistent ridging establishes a cold pool over the Columbia Basin (Whiteman et al. 2001)
- Initiation
  - Front or frontal cyclone approaches from Pacific
  - Cold air begins to mix out along southern and southeastern Columbia Basin
  - U-shaped mesoscale ridge develops east of Cascades



Steenburgh et al. (1997)

Cascade Example

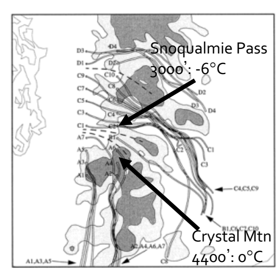
- Downslope flow develops north of Blue Mountains
- Cold air remains entrenched along Cascades and over central Columbia Basin
- Cross-barrier pressure and temperature gradients increase



Steenburgh et al. (1997)

Cascade Example

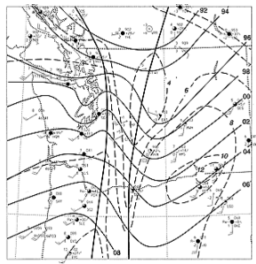
- Cold air channels through mountain gaps, producing locally lower temperatures and snow levels compared to sites west of Cascade Crest



Steenburgh et al. (1997)

Cascade Example

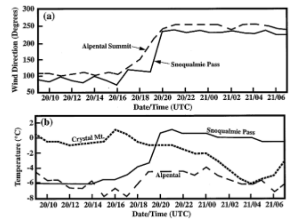
- Cold air begins to mix or be advected out as front moves across Cascades
- Cold air may remain entrenched along eastern slopes and in passes well after passage of front aloft
- Eventually, westerly flow develops in passes and eastern Cascades



Steenburgh et al. (1997)

Cascade Example

- Development of westerly flow results in movement of mild maritime air into passes
  - Rapid temperature rise
  - Snow may change to rain
  - Dangerous avalanche conditions may develop
- Effects are most dramatic at pass level
- Sites west of crest and away from passes may see a more "typical" fropa



Steenburgh et al. (1997)

Summary

- Cold-air damming is the phenomenon of cold air becoming entrenched along the slopes of a mountain range
- Contributing mechanisms
  - Windward adiabatic cooling
  - Along-barrier cold advection (enhanced by blocked low-Froude number flow)
  - Cooling due to evaporation/melting
  - Reduced insolation due to cloud cover
- Event erosion
  - Need cold/occluded front passage to mix out most strong events during winter
  - Solar insolation or turbulent mixing more effective if dammed airmass is shallow or during the fall/spring

References

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