Terrain-forced vs. Thermally Driven Flows

Thermally Driven Circulations

– produced by temperature contrasts that form within mountains or between mountains and surrounding plains

Terrain-forced flows

– produced when large-scale winds are modified or channeled by underlying complex terrain

Over or Around?

- Terrain forcing can cause an air flow approaching a barrier to be carried over or around the barrier, to be forced through gaps in the barrier or to be blocked by the barrier.
  - See http://meted.ucar.edu/mesoprim/flowtopo/
  - See http://meted.ucar.edu/mesoprim/gapwinds/
  - See http://meted.ucar.edu/mesoprim/mtnwave/

Critical Factors

- Three factors determine the behavior of flow approaching barrier
  - Stability of approaching air
    - Unstable or neutral stability air can be easily forced over a barrier
    - The more stable, the more resistant to lifting
  - Wind speed
    - Moderate to strong flows are necessary
  - Topographic characteristics of barrier

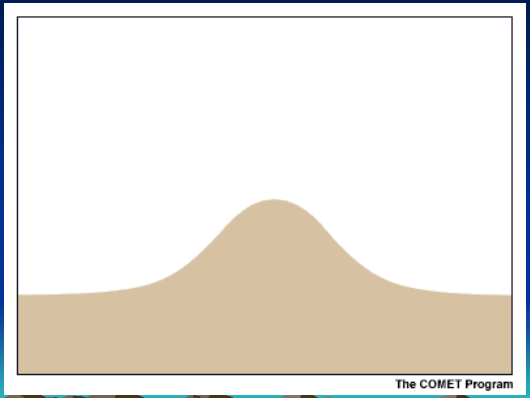
Kinetic Energy vs. Potential Energy

- Kinetic energy
  - Energy due to motion of air
  - $\frac{1}{2} U^2$
- Potential energy
  - Energy due to location of air parcel in gravitational field
  - Greater the stability (N-Brunt-Vaisala frequency), stronger the restoring force due to gravity
  - Higher the obstacle (h_m), greater the displacement required
  - Weaker horizontal wind, then stronger potential energy
  - $\frac{1}{2} N h_m / U$

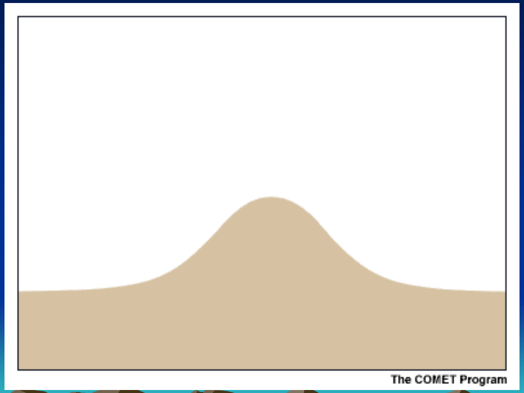
Froude Number

- Froude Number
  - Ratio of kinetic energy to potential energy
  - $U/(N h_m)$
  - U: Speed of wind approaching mountain
  - N: stability of atmospheric flow
  - h_m: height of obstacle
- FR<1: KE<PE; upstream flow blocked by terrain
- FR= 1: KE=PE; upstream flow reaches crest
- FR>1: KE>PE; upstream flow continues over mountain

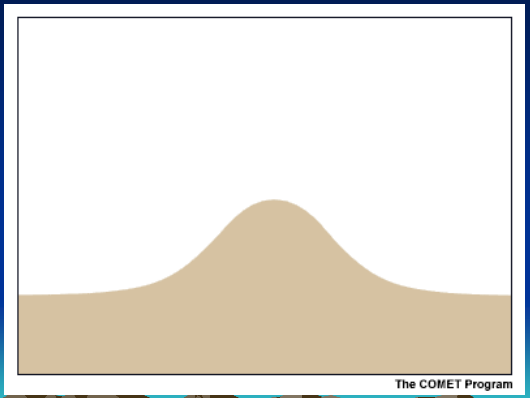
KE=PE; FR=1



KE<PE; FR<1



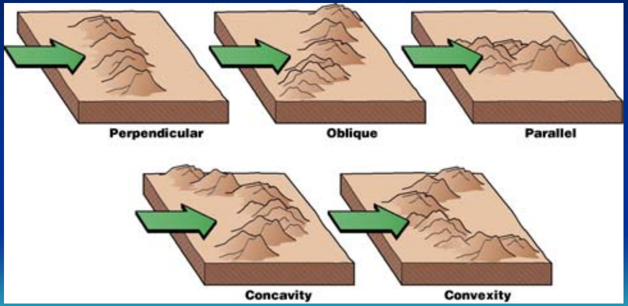
KE>PE; FR>1



The Intermountain West

Whiteman (2000)

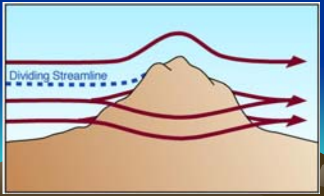
Angle of attack

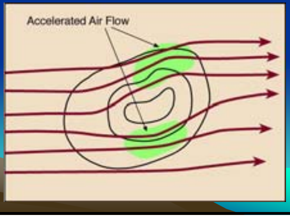


Whiteman (2000)

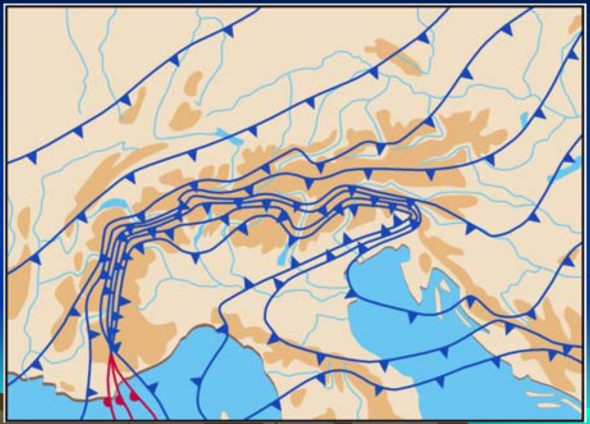
Wind variations with topo characteristics

- Height and length of barrier contribute to whether air goes around barrier
- To carry air over a high mountain range or around an extended ridge requires strong winds (or weak stability)
- When stable air splits around an isolated peak, the strongest winds are usually on the edges of the mountain tangent to the flow



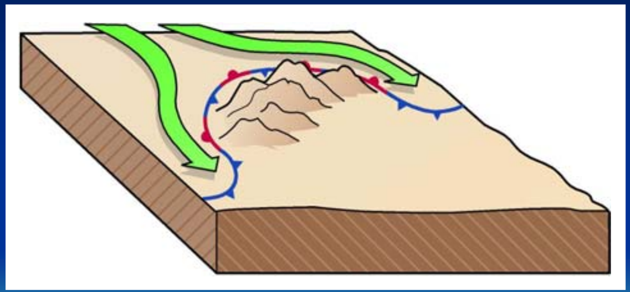


Successive 3-hrly positions as front approaches Alps



Steinacker (1987)

Flow splitting around an isolated mountain range



Convergence zones often form on the back side of isolated barriers (Ex: Puget Sound convergence zone)

Whiteman (2000)

Landforms assoc'd with strong winds

Expect high winds at sites:
Located in gaps, passes or gorges in areas with strong pressure gradients
Exposed directly to strong prevailing winds (summits, high windward or leeward slopes, high plains, elevated plateaus
Located downwind of smooth fetches

Landforms assoc'd with weak sfc winds

Expect low wind speeds at sites:
Protected from prevailing winds (low elevations in basins or deep valleys oriented perpendicular to prevailing winds)
Located upwind of mountain barriers or in intermountain basins where air masses are blocked by barrier
Located in areas of high surface roughness (forested, hilly terrain)

Wind variations with topo characteristics

- Wind increases at the crest of a mountain (more so for triangular than for rounded or plateau-like hilltops)
- Speed is affected by orientation of ridgeline relative to approaching wind direction (concave, convex)
- Winds can be channeled through passes or gaps by small topographic features

Wakes and eddies

Eddy

•swirling current of air in direction different from main current

Wake

•eddies shed off an obstacle cascading to smaller and smaller sizes

•Characterized by low wind speeds and high turbulence

Wakes and eddies are common in mountains

Vertical and horizontal dimensions are a function of stability

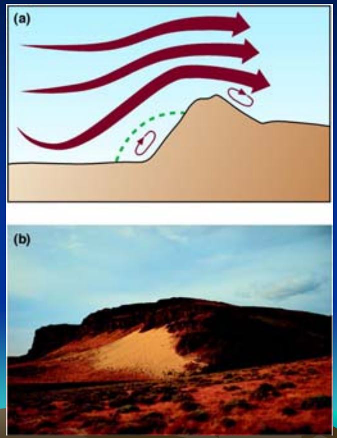
Wakes and eddies

Eddy examples

- rotors
- rotor clouds
- drifts behind snow fences, trees and other obstacles
- cornices

Winds are slowed to distances of 15 (sometimes 60) times obstacle height.

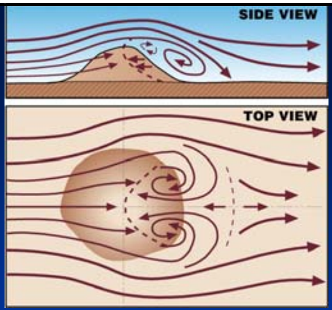
Separation eddies

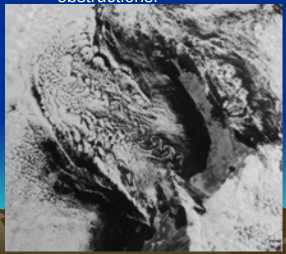


Whiteman (2000)

Wakes

Large, generally isotropic vertical-axis eddies can be produced by the flow around mountains or through gaps as eddies are shed from the vertical edges of terrain obstructions.





Orgill (1981)

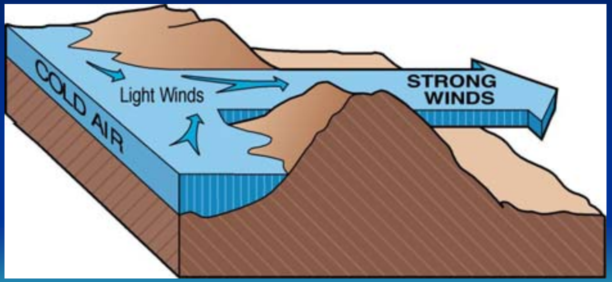
Flow through Passes, Channels and Gaps

Gaps - major erosional openings through mountain ranges
Channels - low altitude paths between mountain ranges

Strong winds in a gap, channel or pass are usually pressure driven - I.e., caused by a strong pressure gradient across the gap, channel or pass.

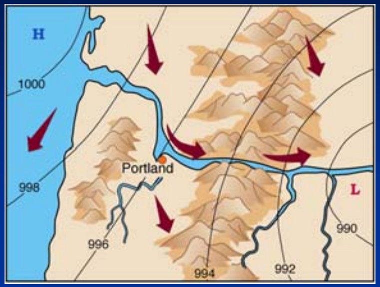
Regional pressure gradients occur frequently across coastal mountain ranges because of the differing characteristics of marine and continental air. These pressure gradients usually reverse seasonally.

Flow through passes & gaps



Whiteman (2000)

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)

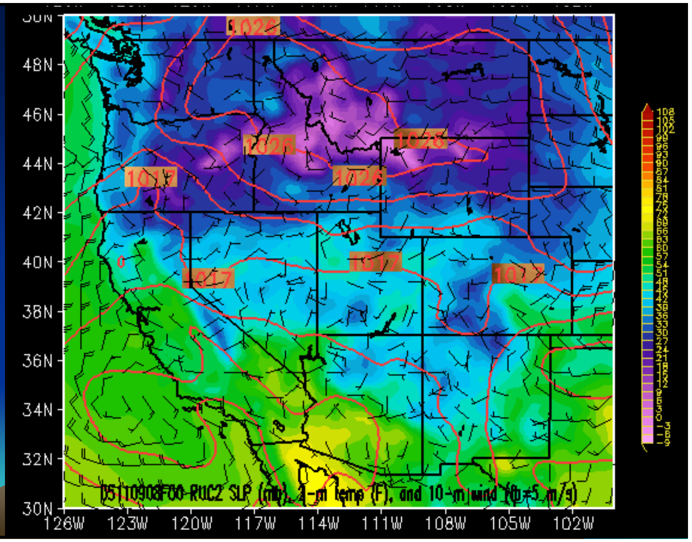
Taku Straits (nr juneau)

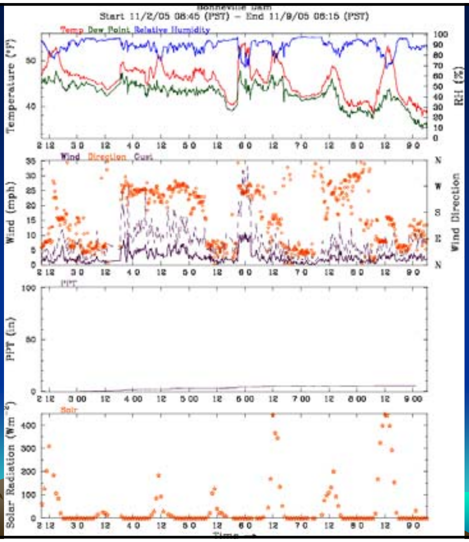
Copper River Valley (nr Cordova)

Turnagain Arm (Anchorage)

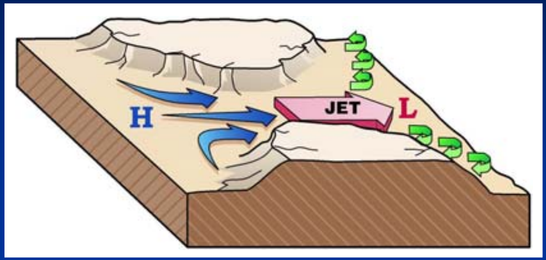
http://www.iwindsurf.com

Bonneville Locks BNDW





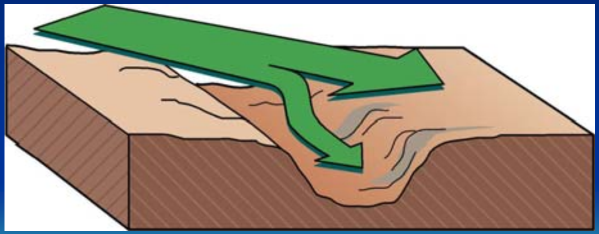
Venturi or Bernoulli effect



Whiteman (2000)

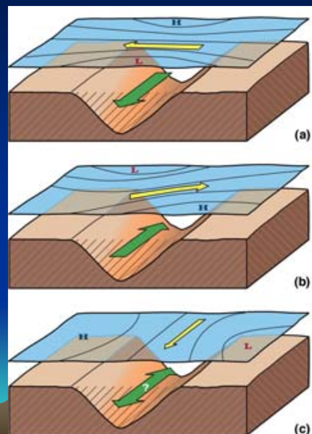
Venturi effect causes a jet to form as winds pass through a terrain constriction and strengthen.

Forced channeling



Whiteman (2000)

Pressure driven channeling



Whiteman (2000)

Blocking, Cold air Damming and Obstruction of Air Masses

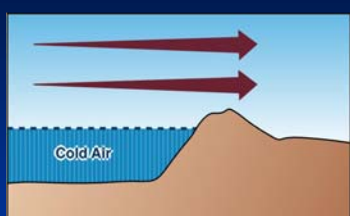
-These processes affect stable air masses and occur most frequently in winter.

-The blocked flow upwind of a barrier is usually shallower than the barrier depthOnset and cessation of blocking may be abrupt.

-Cold air damming - a process in which a shallow cold air mass is carried up the slope of a mountain barrier, but with insufficient strength to surmount it

-The cold air, trapped upwind of the barrier alters the effective terrain configuration of the barrier to larger-scale approaching flows.

Mountains as flow barriers



Whiteman (2000)

Blocked flow - New Zealand

Whiteman photo

Flow Around Mountains

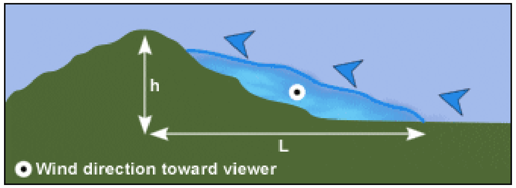
A flow approaching a mountain barrier tends to go around rather than over a barrier if:

-ridgeline is convex on windward side
-mountains are high
-barrier is an isolated peak or a short range
-cross barrier wind component is weak
-flow is very stable
-approaching low-level air mass is very shallow
-Kinetic energy due to wind directed towards barrier is less than potential energy due to stability and height of obstacle (Froude number less than 1)

Because Rockies and Appalachians are long, flow around them is uncommon. But these types of flows are seen in the Aleutians, the Alaska Range, the Uinta Mountains, the Olympics and around isolated volcanoes.

How Far Upstream L is flow blocked?

- Depends on
  - Latitude (f-Coriolis parameter)
  - Stability (N-Brunt Vaisala frequency)
  - Height of object (h_m)
  - Upstream flow speed (U)

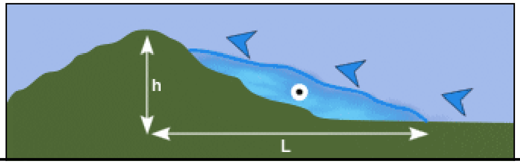


How Far Upstream L is flow blocked?

$L = (Nh_m - U)/f$

Blocked further upstream when

- low latitude (f small)
- Large stability (N big)
- Large obstacle (h_m)
- Small Upstream flow speed (U)



Barrier jet

They form when stably stratified low-level flow approaches a limited-length mountain barrier with an edge or low pass on its left side (N Hemisphere). The flow, unable to surmount the barrier, turns left (because of Coriolis force) to blow along the barrier.

In US, barrier jets have been noted on W side of Cascades and Sierras, on E side of Rockies and Appalachians, and on N side of Brooks Range. They probably occur elsewhere in N America.