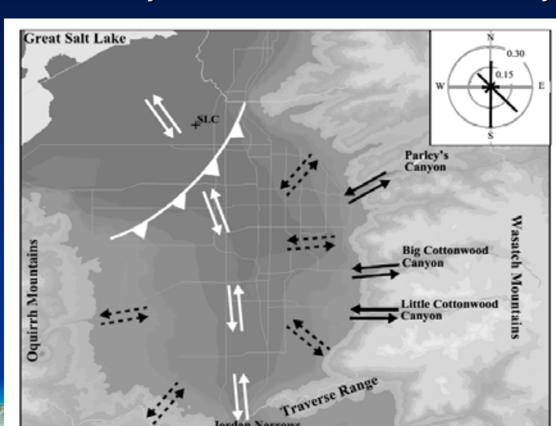
Thermally Driven Circulations

- Mountain winds develop from terrain of all scales
- Circulations arise as a result of differential heating between the ground in regions of complex terrain and free atmosphere at the same elevation
  - During day, higher terrain is an elevated heat source ("lower pressure"
  - During night, higher terrain is an elevated heat sink ("higher pressure")

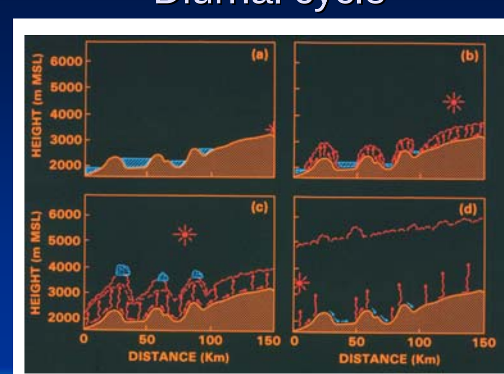
Cold pool haze, Salt Lake City, UT 2001

Whiteman photo

Thermally Driven Flows in the SL Valley

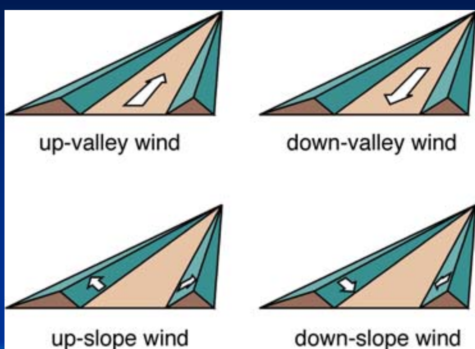


Diurnal cycle

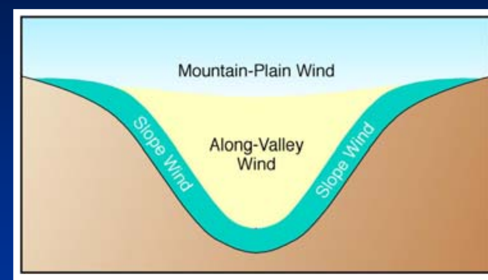


Whiteman

Wind Terminology



Wind regimes

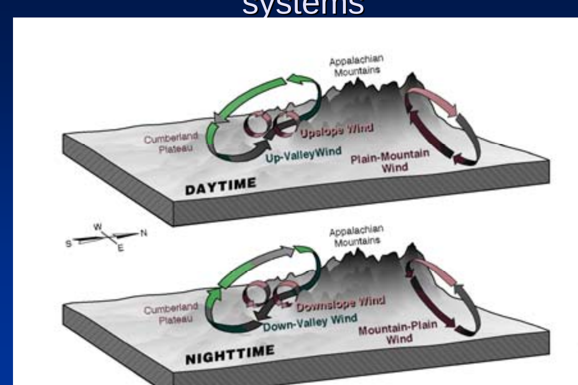


Whiteman (2000)

Wind system terminology

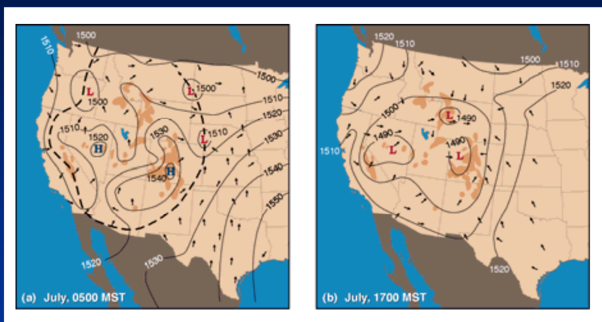
- valley wind = up-valley flow (daytime)
- mountain wind = down-valley flow (nighttime)
- anabatic flow = up-slope wind (daytime)
- katabatic flow = down-slope wind (nighttime)
- mountain-plain circulation
- drainage flows = down-slope and down-valley
- cross-valley flow = toward heated hillside
- anti-winds= away from terrain aloft

Thermally driven mountain wind systems



Whiteman (2000)

Mountain/Plain System

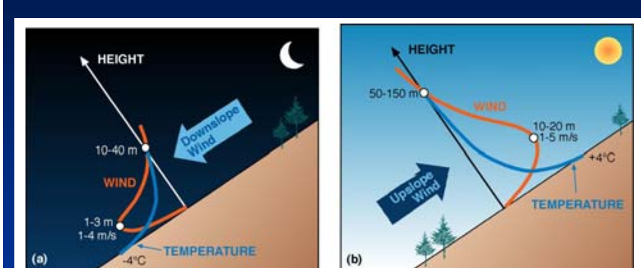


Reiter & Tang (1984)

Slope winds

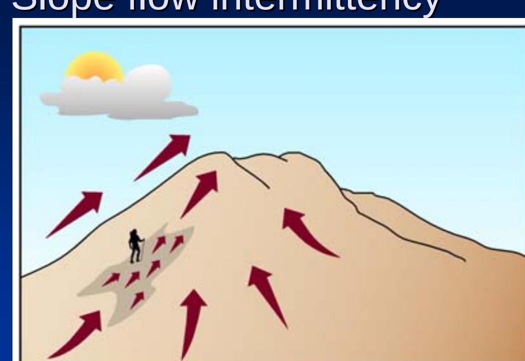
- Gravity or buoyancy currents following the dip of the underlying slope
- Caused by differences in temperature between air heated or cooled over the mountain slopes and air at the same altitude over the valley center
- Best-developed in clear, undisturbed weather- Difficult to find in a pure form.

Along-slope flows



Whiteman (2000)

Slope flow intermittency



Whiteman (2000)

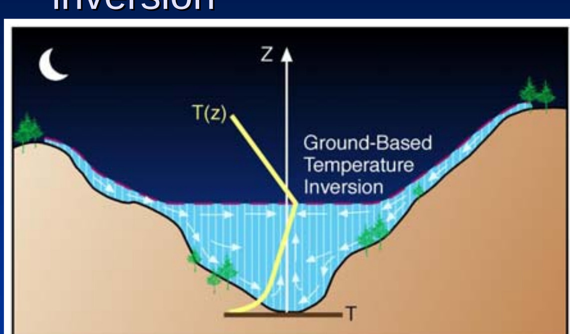
Upslope Flow above Forest

Whiteman (2000)

Slope flows

- Closed circulation driven by horizontal temperature contrasts between the air over the slope and the air at the same level over the center of the valley
- Speeds- 1-5 m/s with maximum a few meters above the ground
- Increase in speed as length of slope increases (Antarctica 14-30 m/s)
- Strongest downslope at sunset; strongest upslope in midmorning
- Depth of downslope ~5% of drop in elevation from top
- Upslope flows increase in depth as move upslope
- Stronger the stability, shallower the slope flows
- Downslope flows converge into gullies; upslope flows converge over higher ground between gullies

Temperature inversion



Whiteman (2000)

Relationship between slope and valley winds

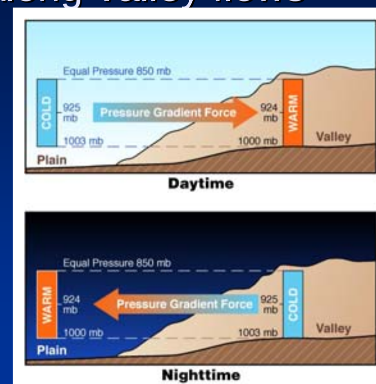
1. The vertical motion necessary for the development of the horizontally moving valley wind is taken care of by the slope winds, and
2. the circulation of the slope winds makes possible the relatively large diurnal temperature range in the valley. Vertical motions over the valley center that compensate for the mass carried up or down the slopes by the slope wind system transfer heat throughout the valley cross section.

Whiteman

Valley Winds

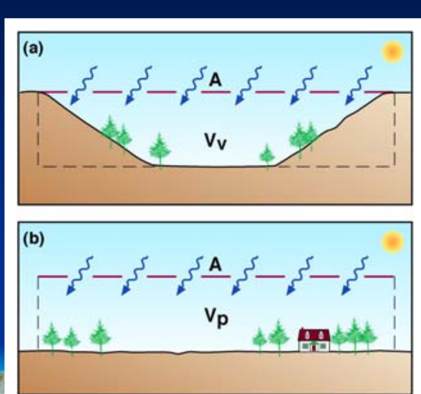
- Air currents trying to equalize horizontal pressure gradients built up hydrostatically between valley and plain
- Caused by the stronger heating and cooling of the valley atmosphere as compared to the adjacent plain
- Best-developed in clear undisturbed weather

Along-valley flows



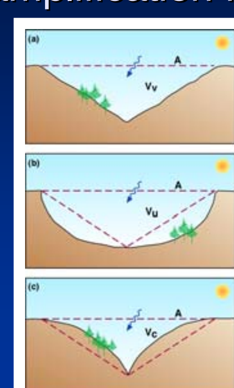
Hawkes (1947)

Air volume is smaller in valley x-section than in a plains x-section, for the same area at the top



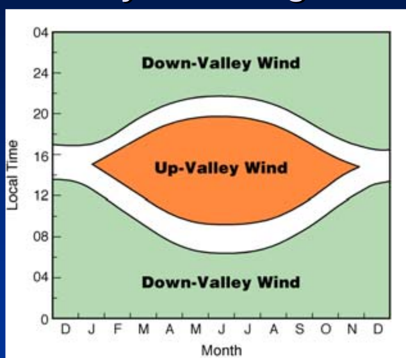
Whiteman (2000)

Valley shape and topographic amplification factor



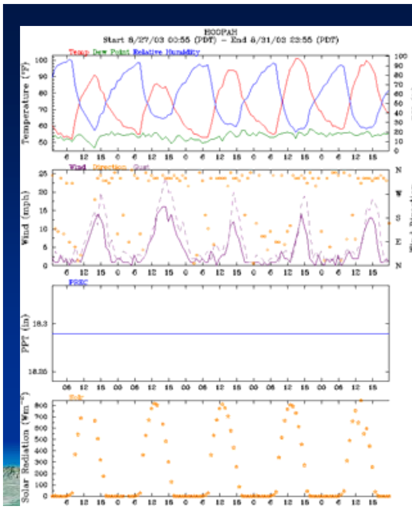
Whiteman (2000)

Valley wind regimes



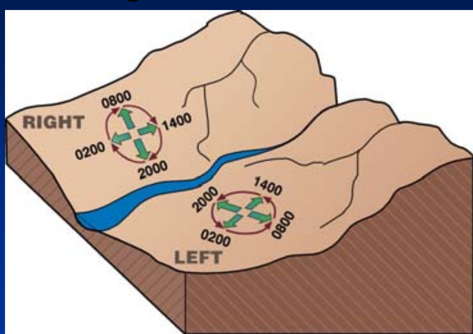
Reiter et al. (1983)

HOOPA RAWS



Hoopa, CA

Wind turning: Left bank - CCW, right bank - CW



Hawkes (1947)

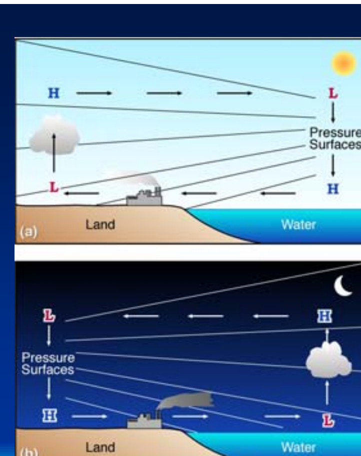
Summary: Valley wind characteristics (Whiteman)

- Direction of movement
  - Simultaneous initiation, parallel to valley axis, shift 180° day to night. Reversal takes several hours and is delayed relative to SR/SS depending on valley size Gradual extension in vertical plane.
- Depth
  - ~ridge height, often UV > DV depth. Deep valleys generate better P gradient. Shallow valleys and basins usually have weak valley winds.
- Velocity
  - Variable from valley to valley, in time with p-grad changes, often UV > DV, velocities strongest at lower levels (without friction, would be strongest at floor), DV velocities strongest at valley exits.
- Valley shape
  - Occur in valleys of all shapes. Best in U-shaped valleys opening into foreland. Weaker in narrow, v-shaped valleys.

Valley wind characteristics and development factors: continued

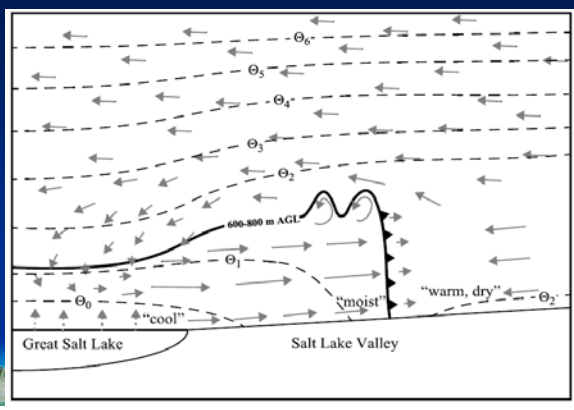
- Valley orientation
  - Timing and strength not dependent on orientation. S-opening valleys not noticeably favored.
- Valley floor inclination
  - Valley winds move horizontally and do not depend on slope of valley floor (can occur in flat floored valley).
- Season and weather
  - Length of day/night affects UV/DV wind phasing. DV winds may blow all day in winter. Clear, undisturbed days are best.

Sea/Lake breeze



Ahrens (1994)

Schematic Lake-Breeze Front (Zumpfe and Horel 2006)



Lake Breeze Front

Zumpfe and Horel(2006)