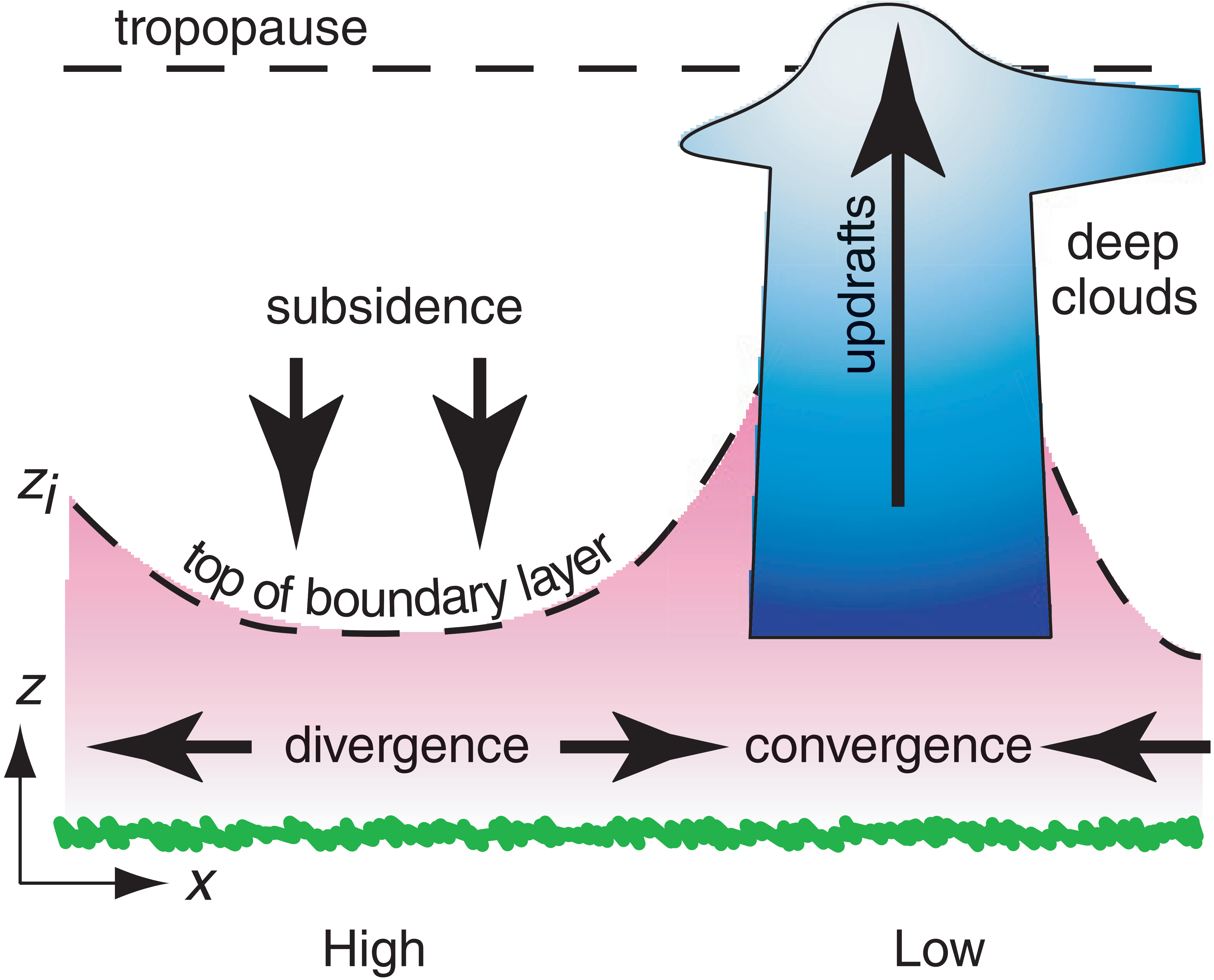
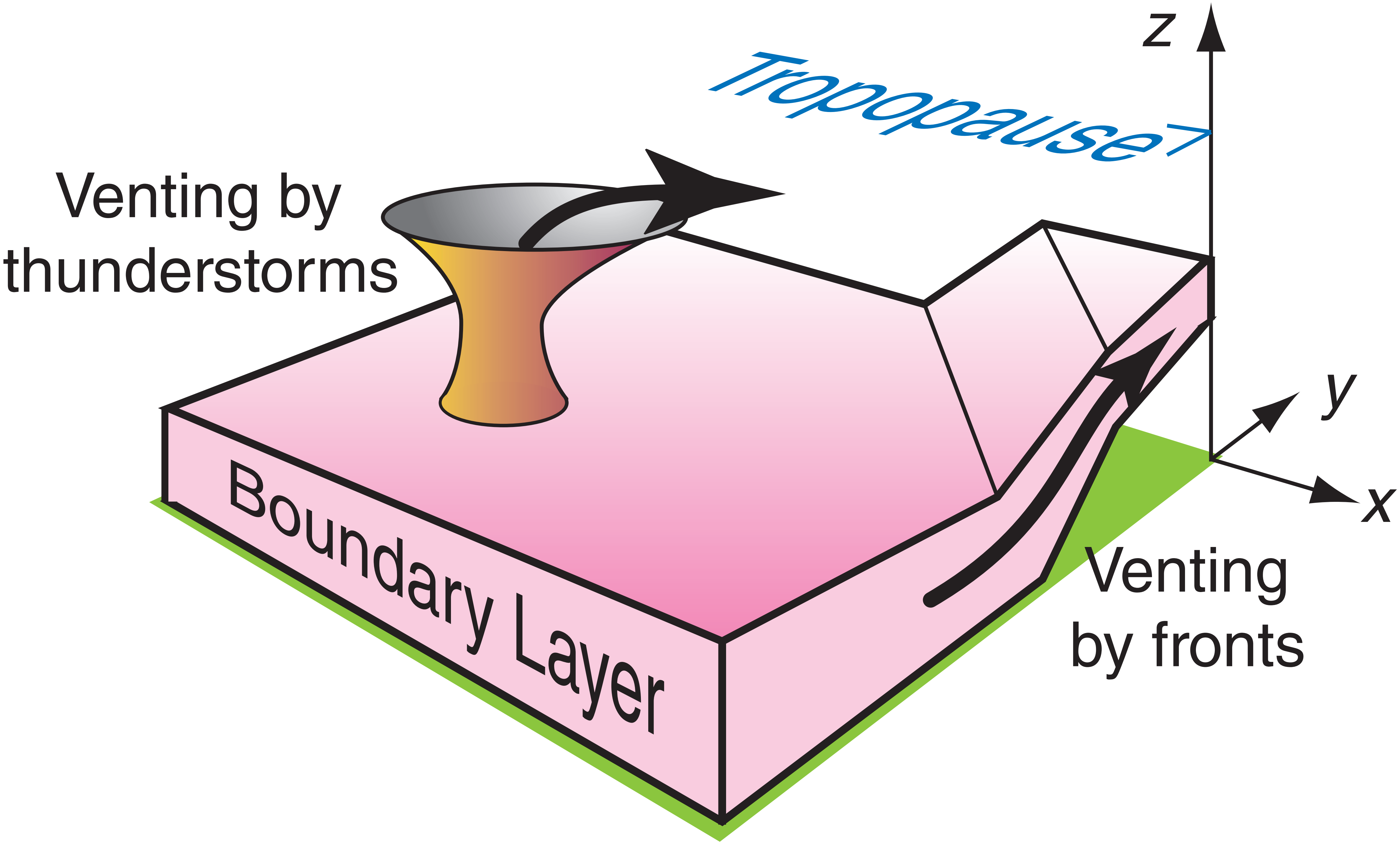
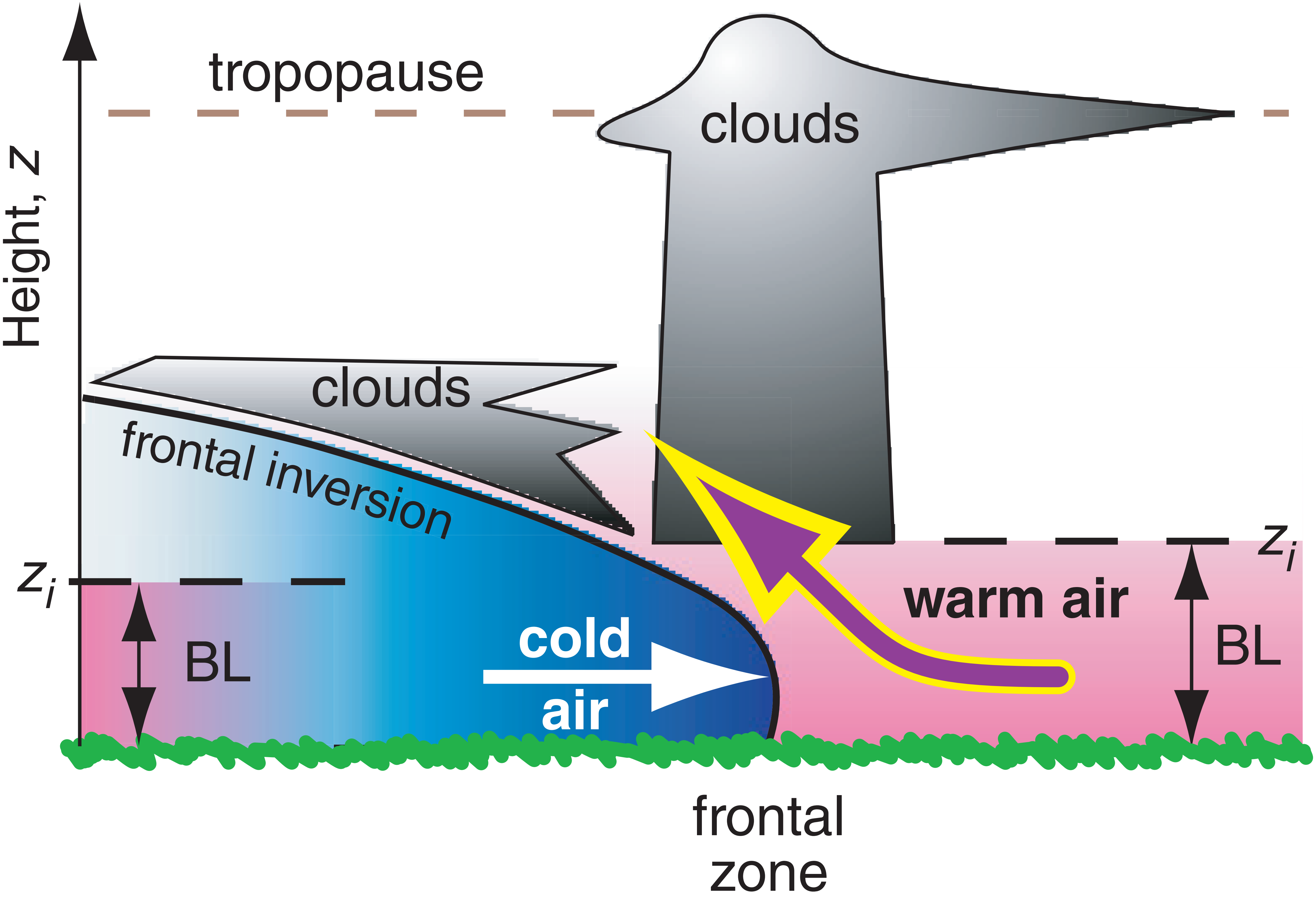
Stormy Weather



Stormy Weather



Stormy Weather



The Atmospheric Boundary Layer

- Turbulence (9.1)
- The Surface Energy Balance (9.2)
- Vertical Structure (9.3)
- Evolution (9.4)
- ***Special Effects (9.5)***
- The Boundary Layer in Context (9.6)

Diurnal Mountain Winds

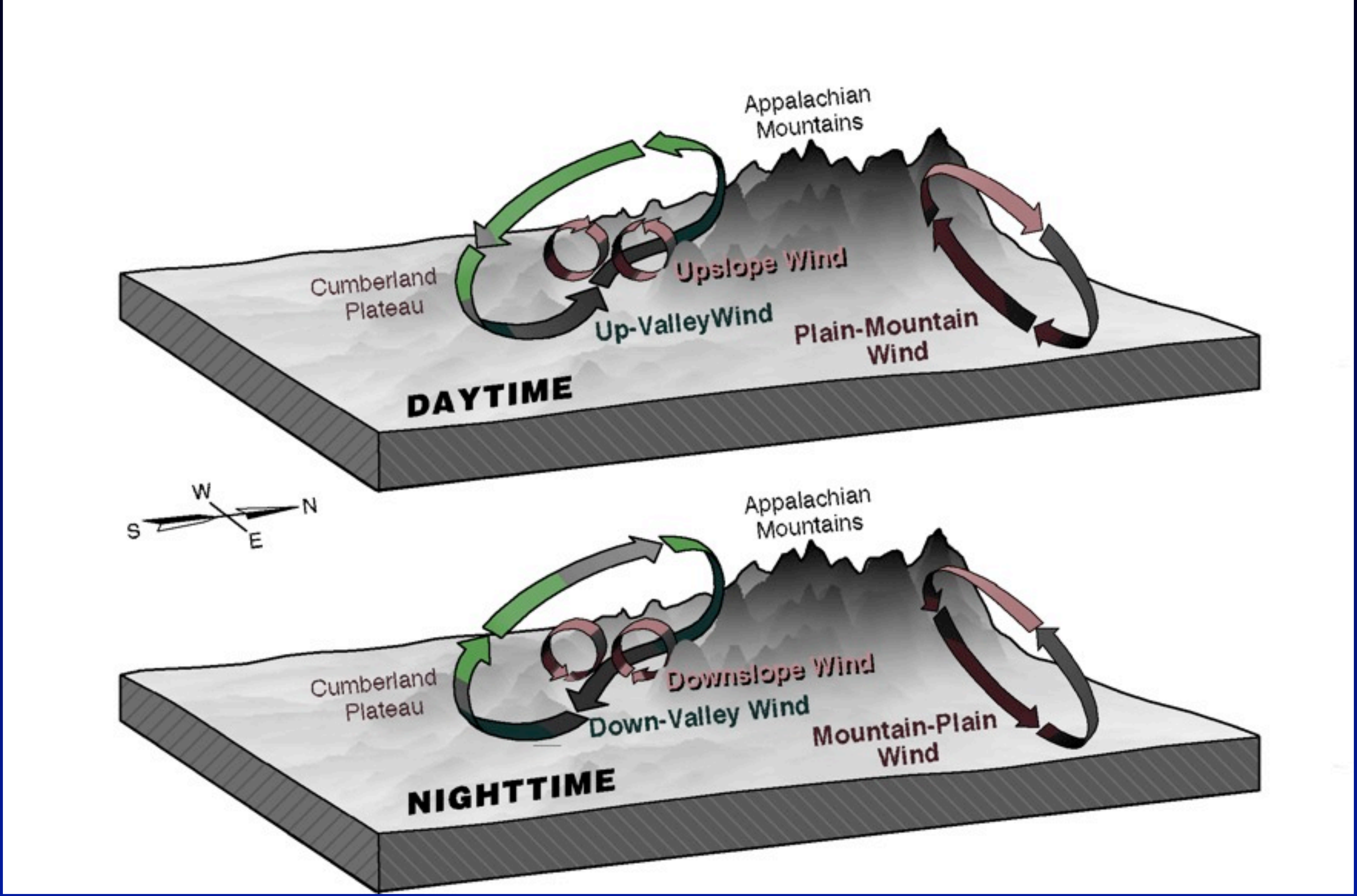
C. David Whiteman

Meteorology 3000
Mountain Weather and Climate
Spring 2005

The mountain wind system

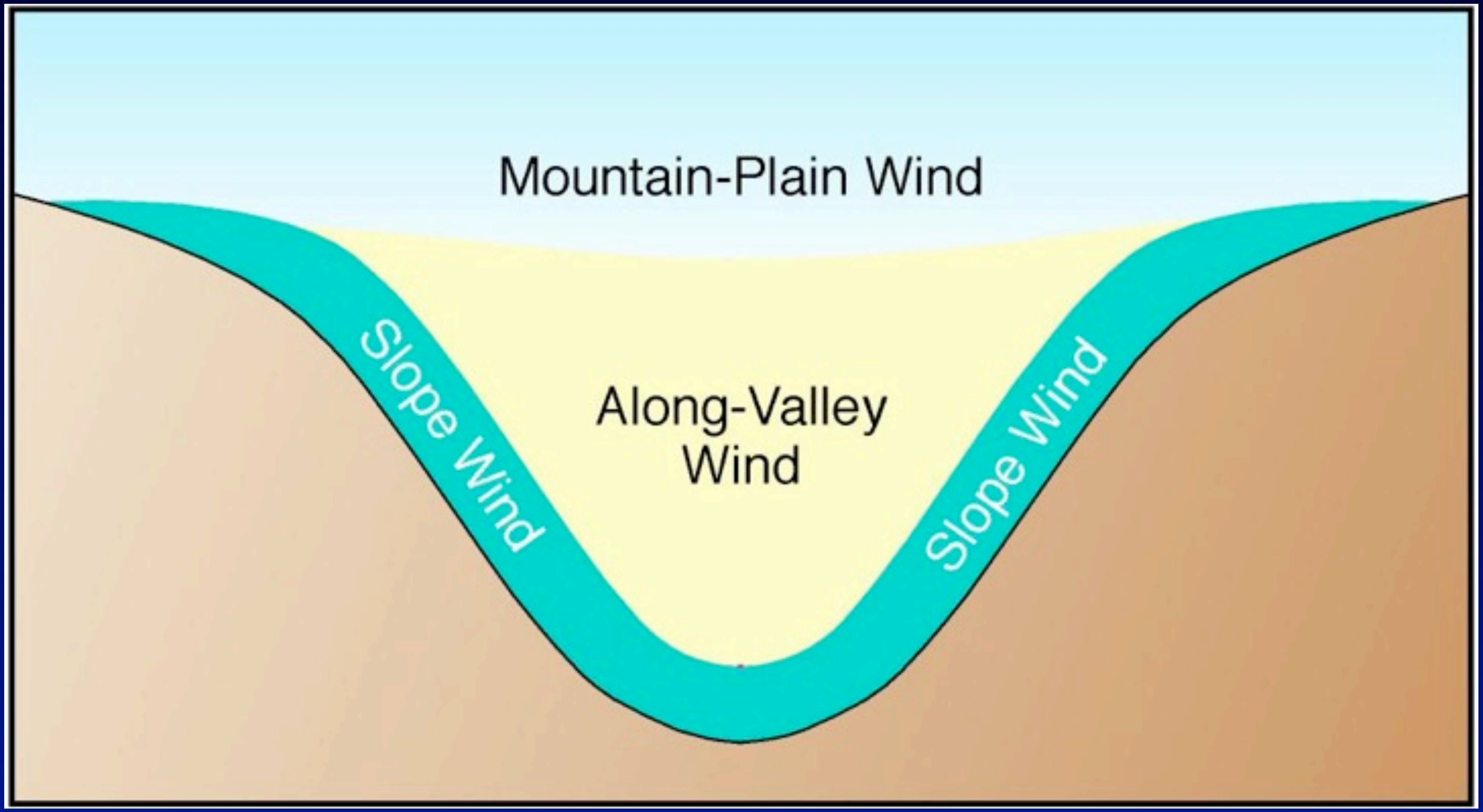
- Four interacting wind systems are found over mountain terrain:
  - Slope wind system (upslope and downslope winds)
  - Along-valley wind system (up-valley and down-valley winds)
  - Cross-valley wind system (from the cold to warm slope)
  - Mountain-plain wind system (plain-mtn and mtn-plain winds)
- Because diurnal mountain winds are driven by horizontal temperature differences, the regular evolution of the winds in a given valley is closely tied to the thermal structure of the atmospheric boundary layer within the valley, which is characterized by a diurnal cycle of buildup and breakdown of a temperature inversion.

Thermally driven mountain wind systems



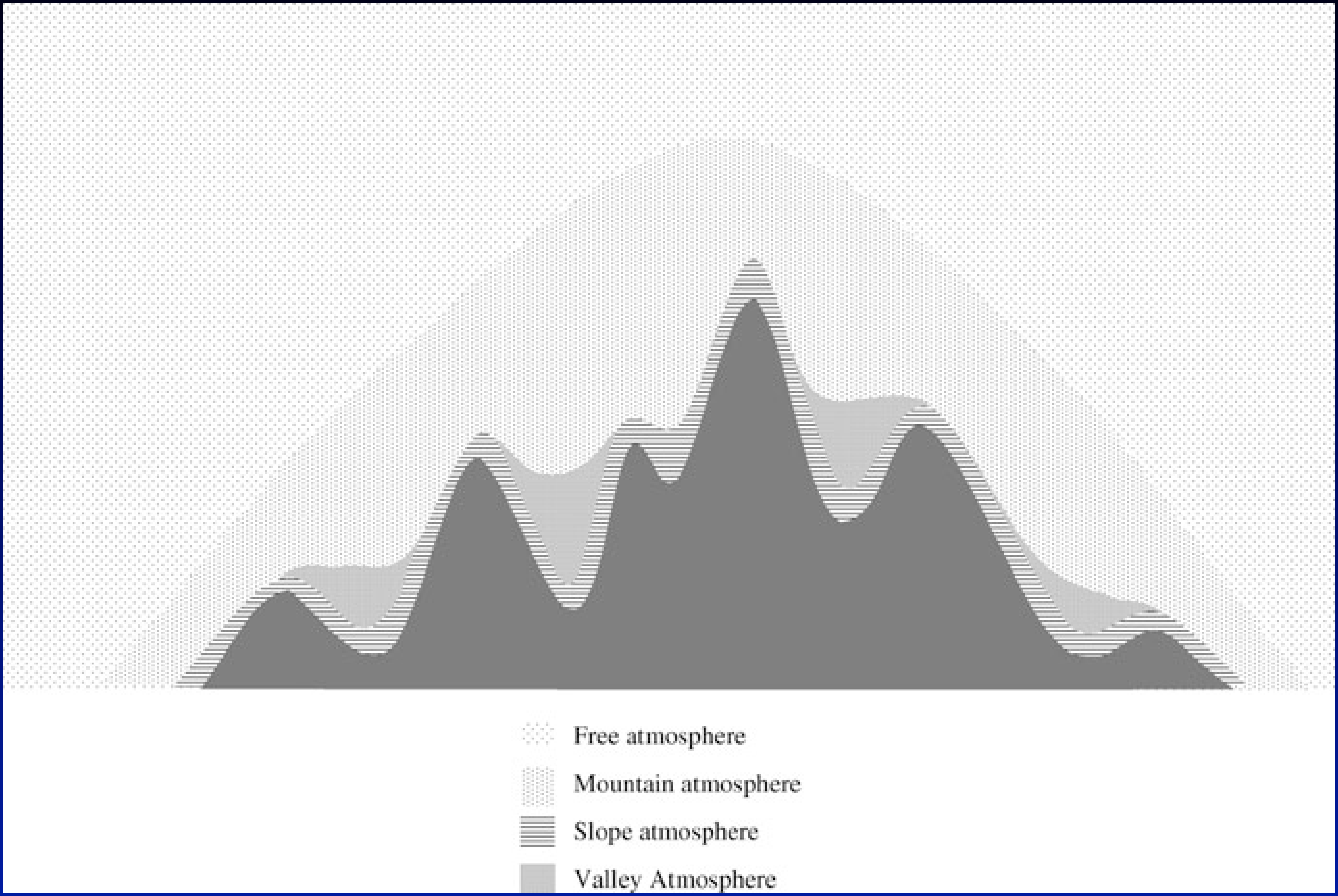
Whiteman (2000)

Wind regimes



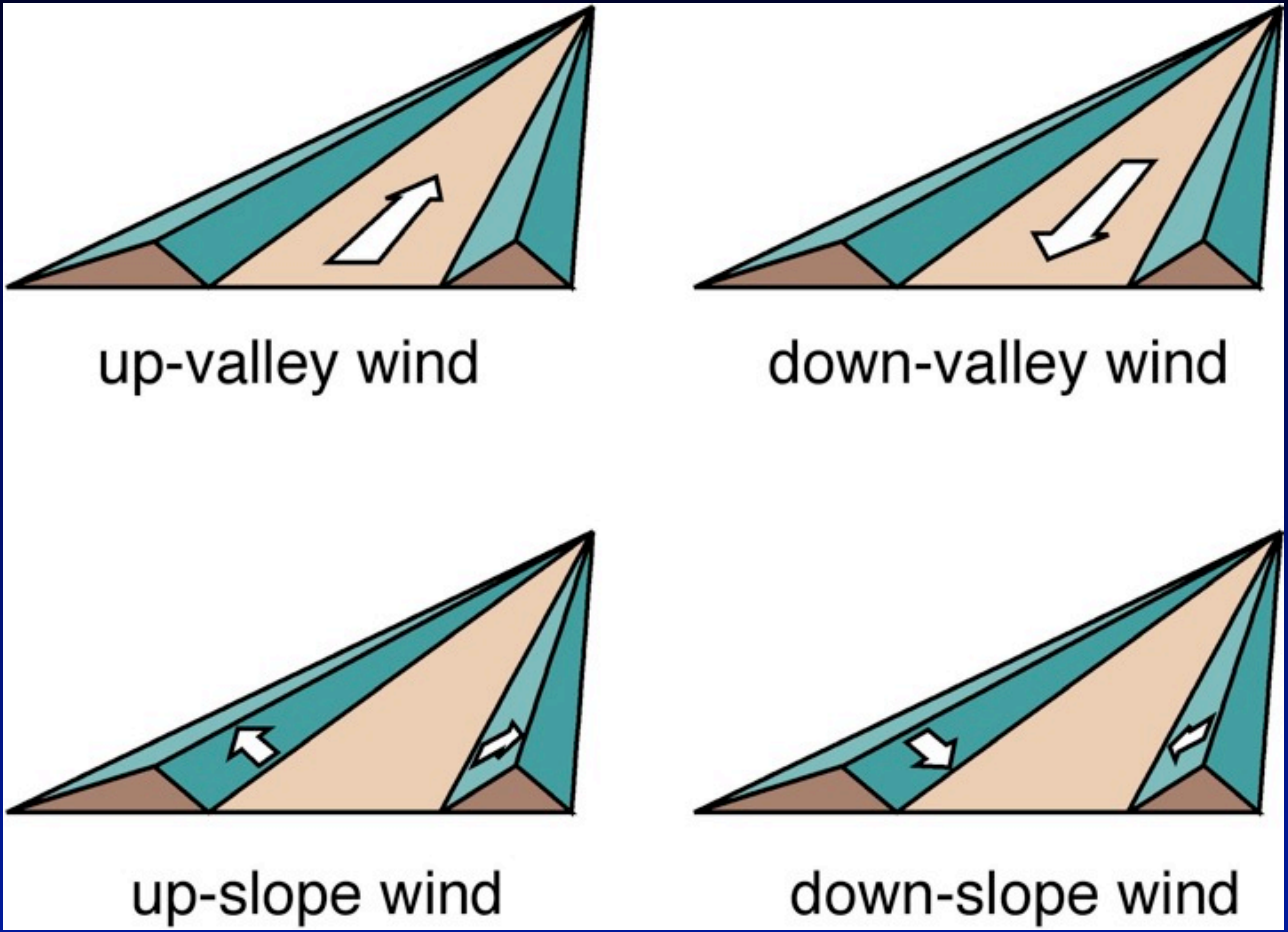
Whiteman (2000)

Wind regimes



Zardi and Whiteman (2012)

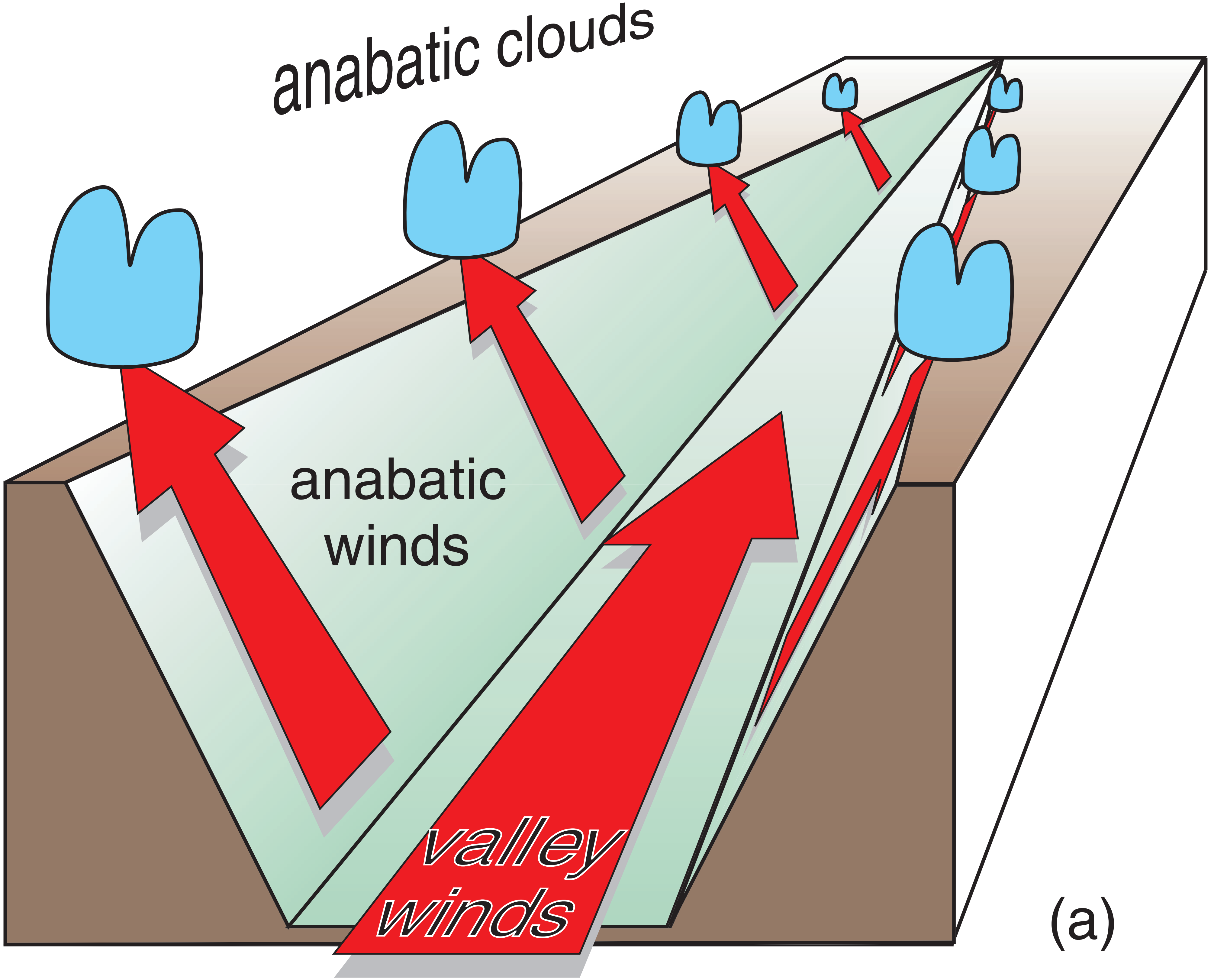
Wind Terminology



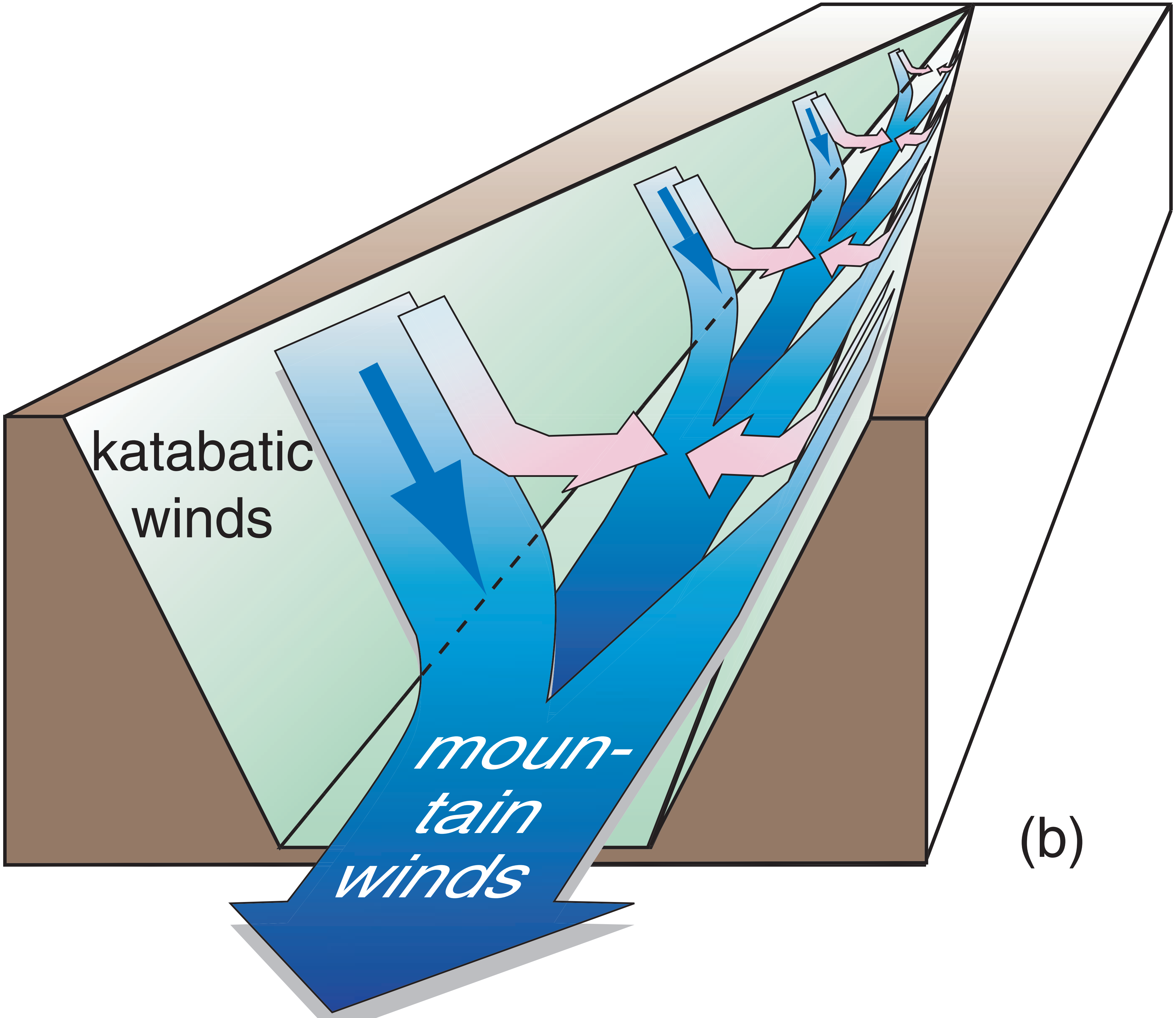
Wind system terminology

- 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

Terrain Effects



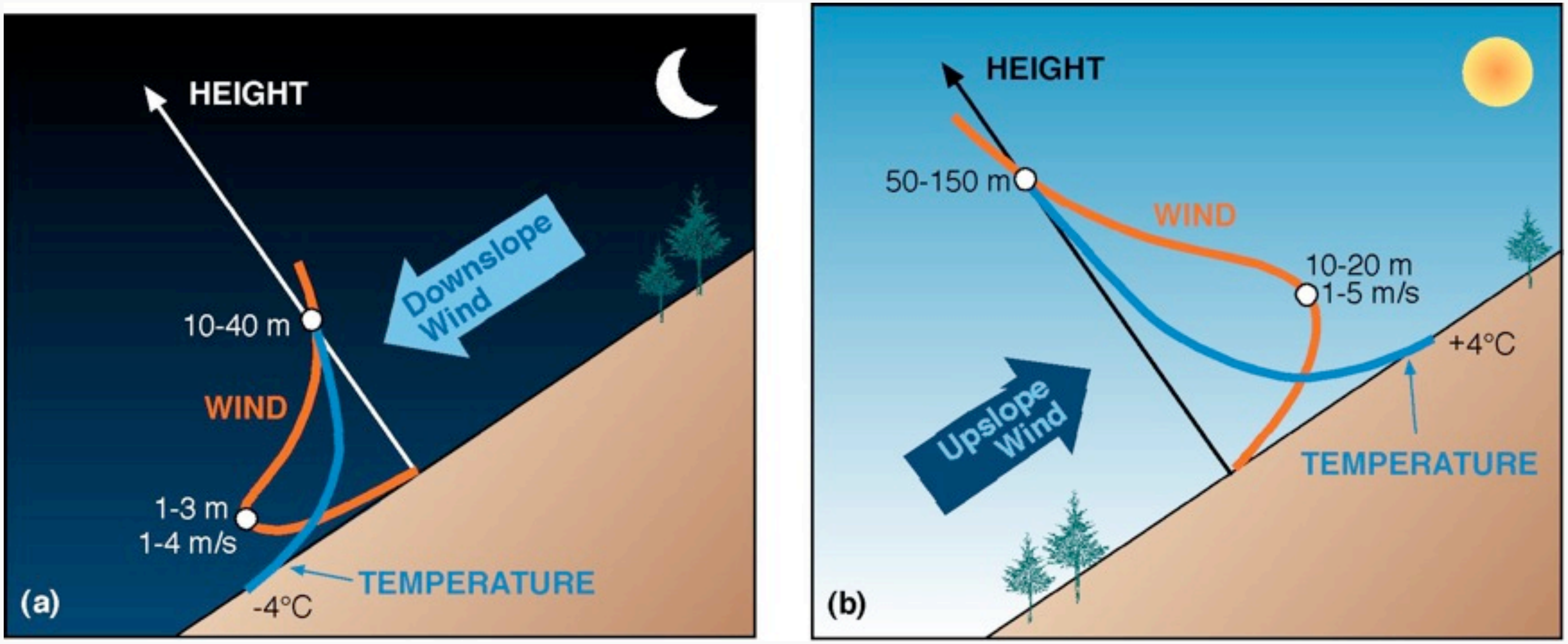
Terrain Effects



Slope winds

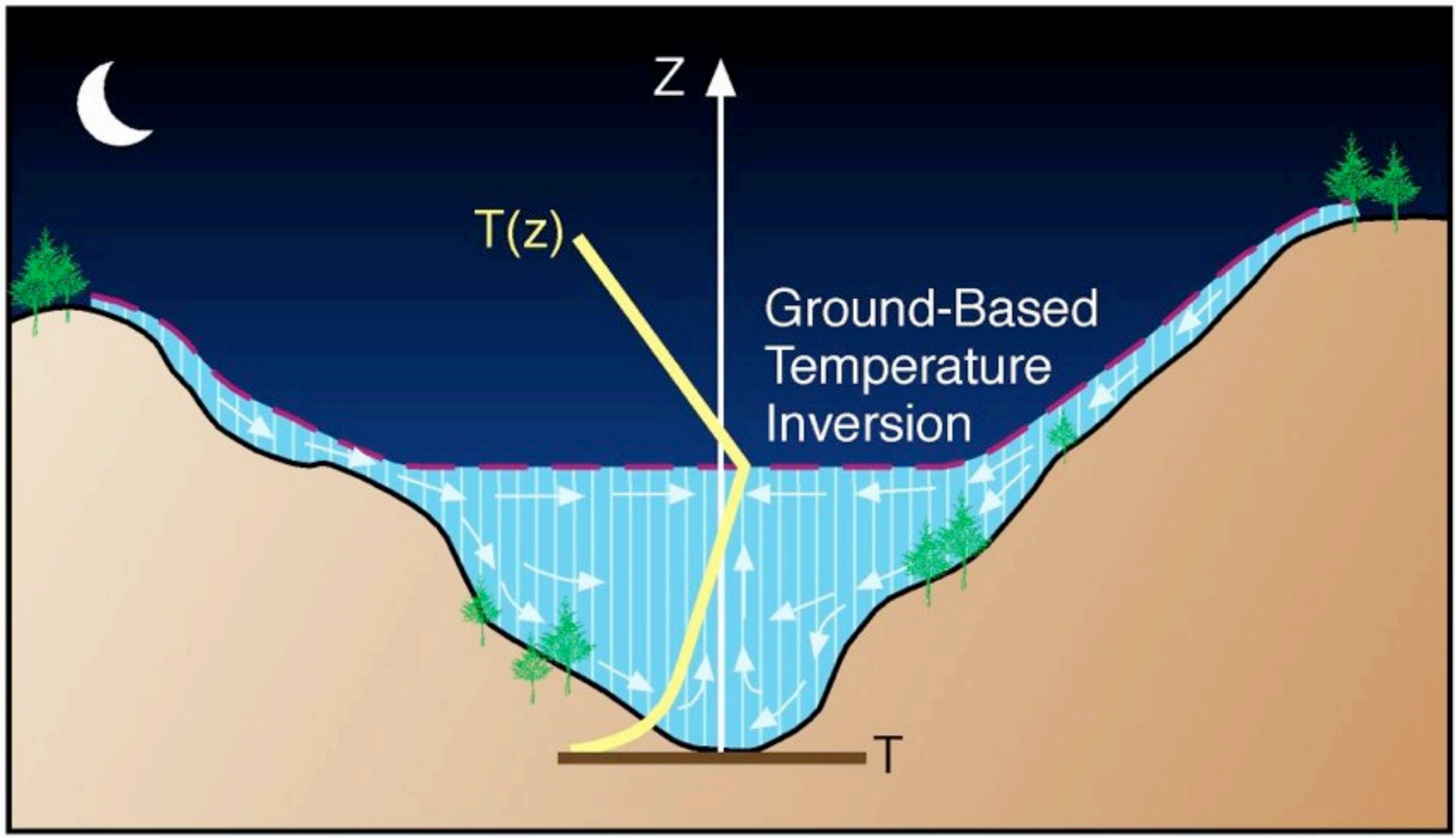
- Gravity or buoyancy currents following the dip of the underlying slope
- Caused by differences in temperature between air heated or cooled over the mountain slopes and air at the same altitude over the valley center
- Best-developed in clear, undisturbed weather
- Difficult to find in a pure form. Affected by along-valley wind system, weather (radiation budget, ambient flows), changing topography or surface cover

Slope flows



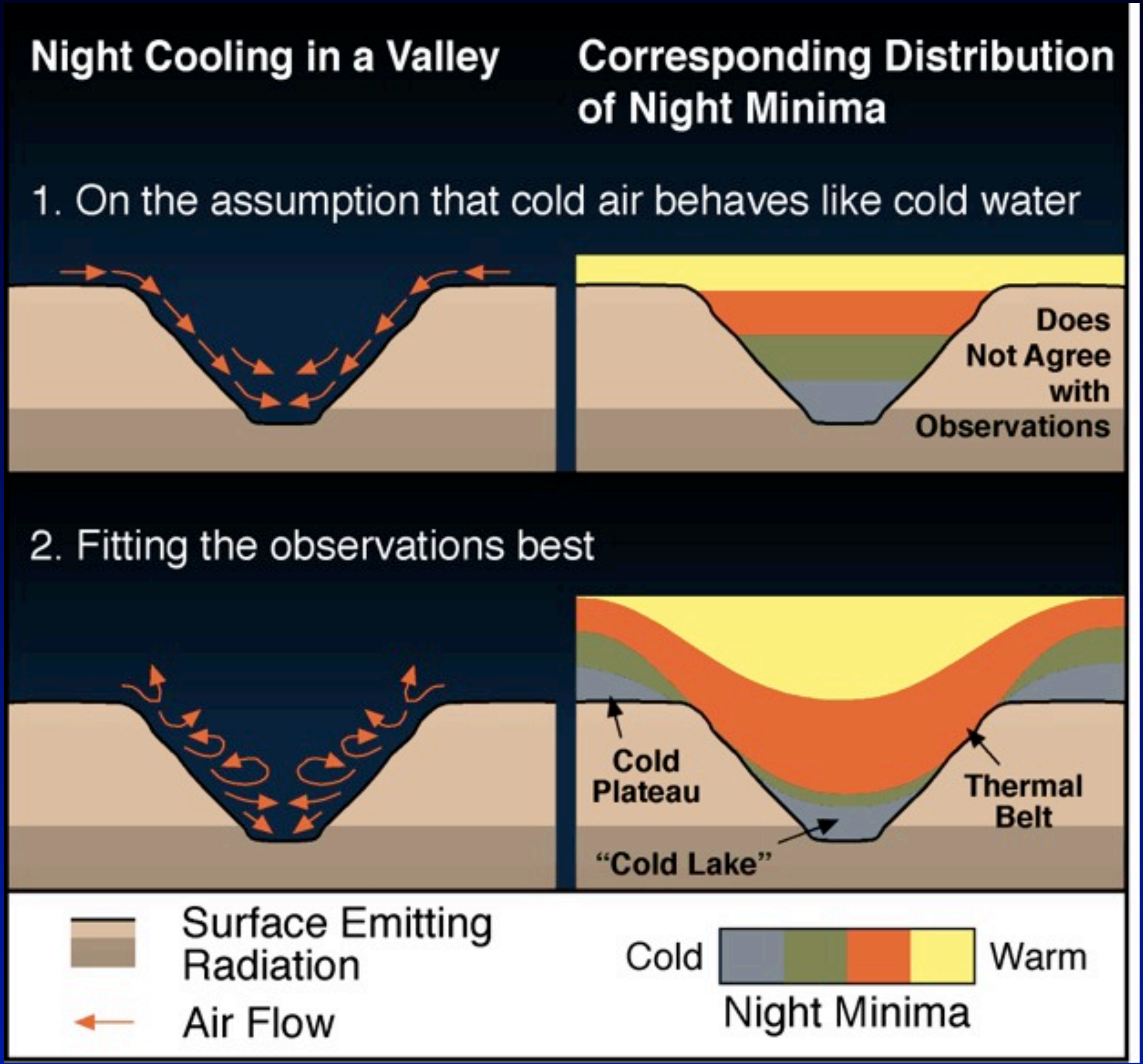
Whiteman (2000)

Temperature inversion



Whiteman (2000)

Thermal belt

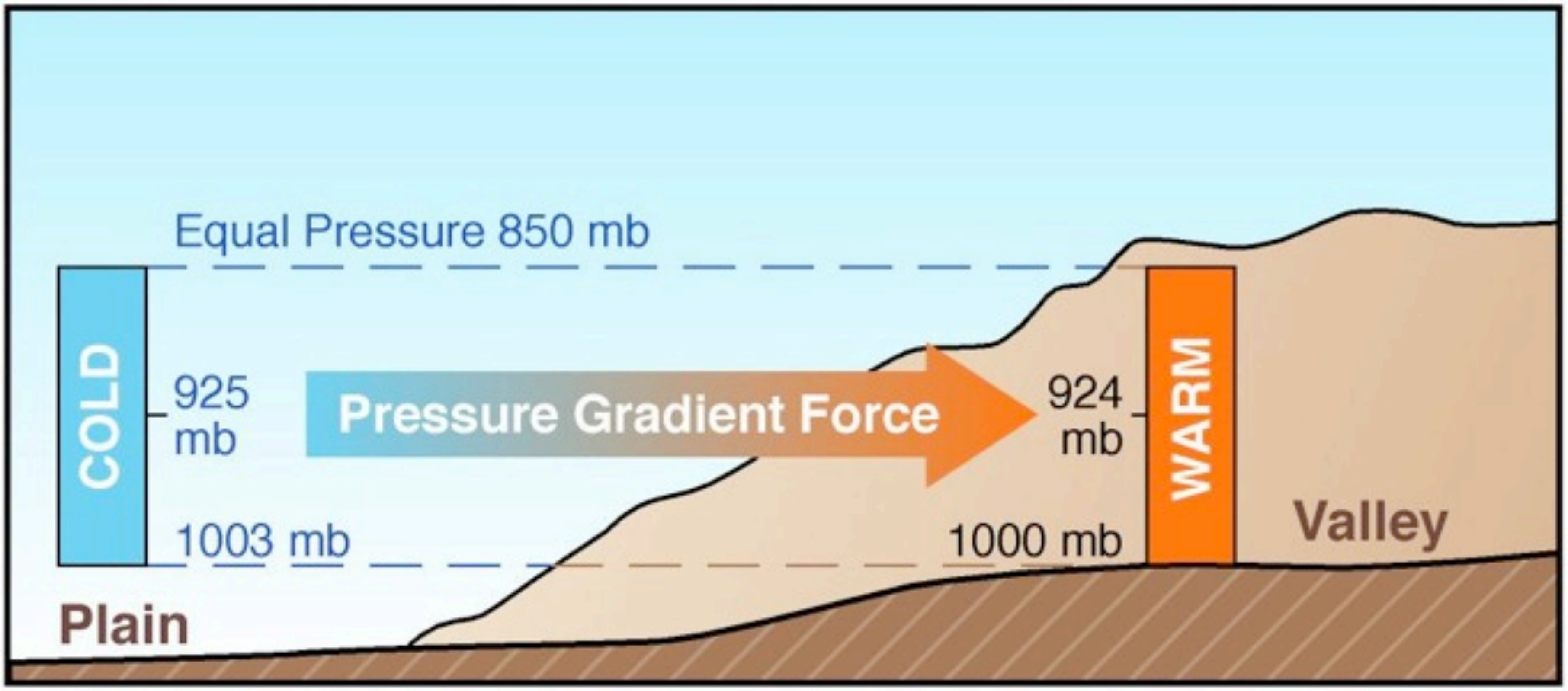


Geiger et al. (1995)

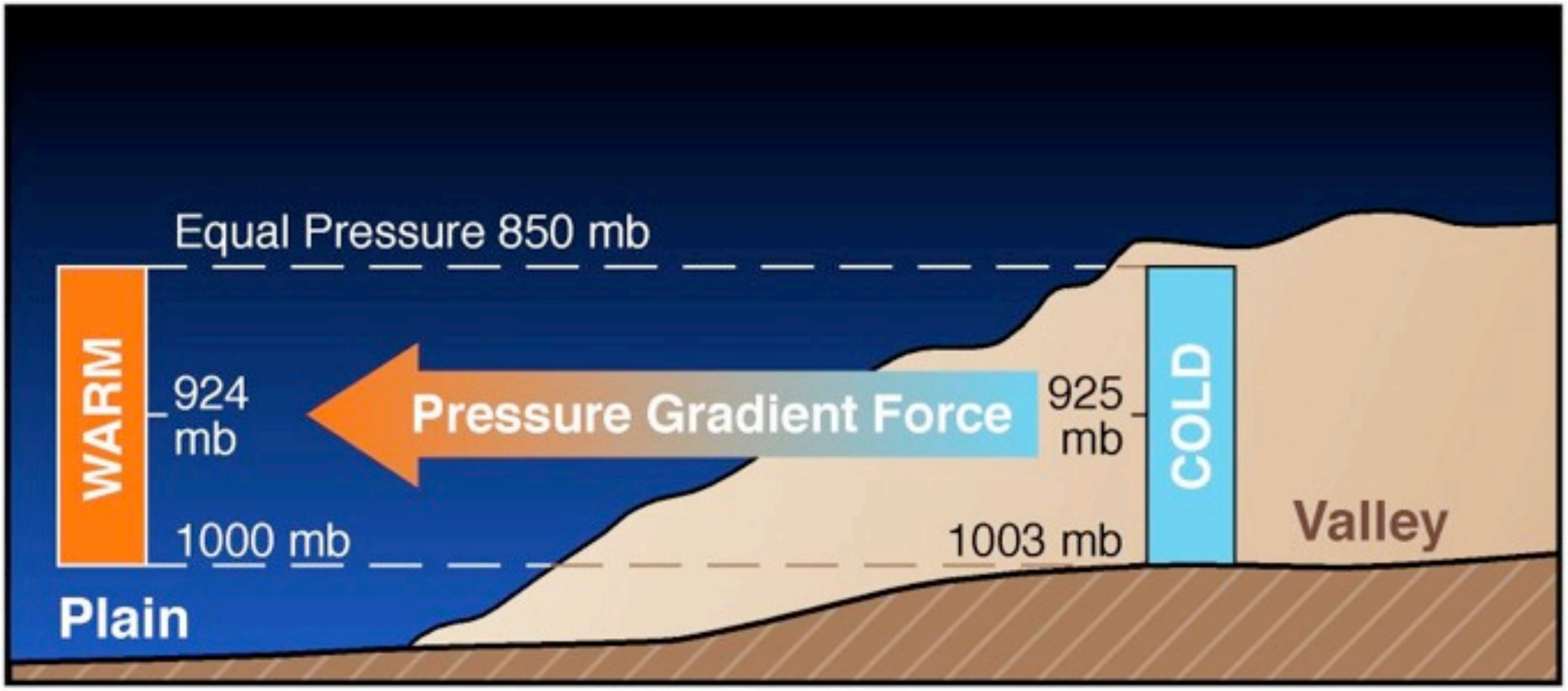
Valley Winds

- 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

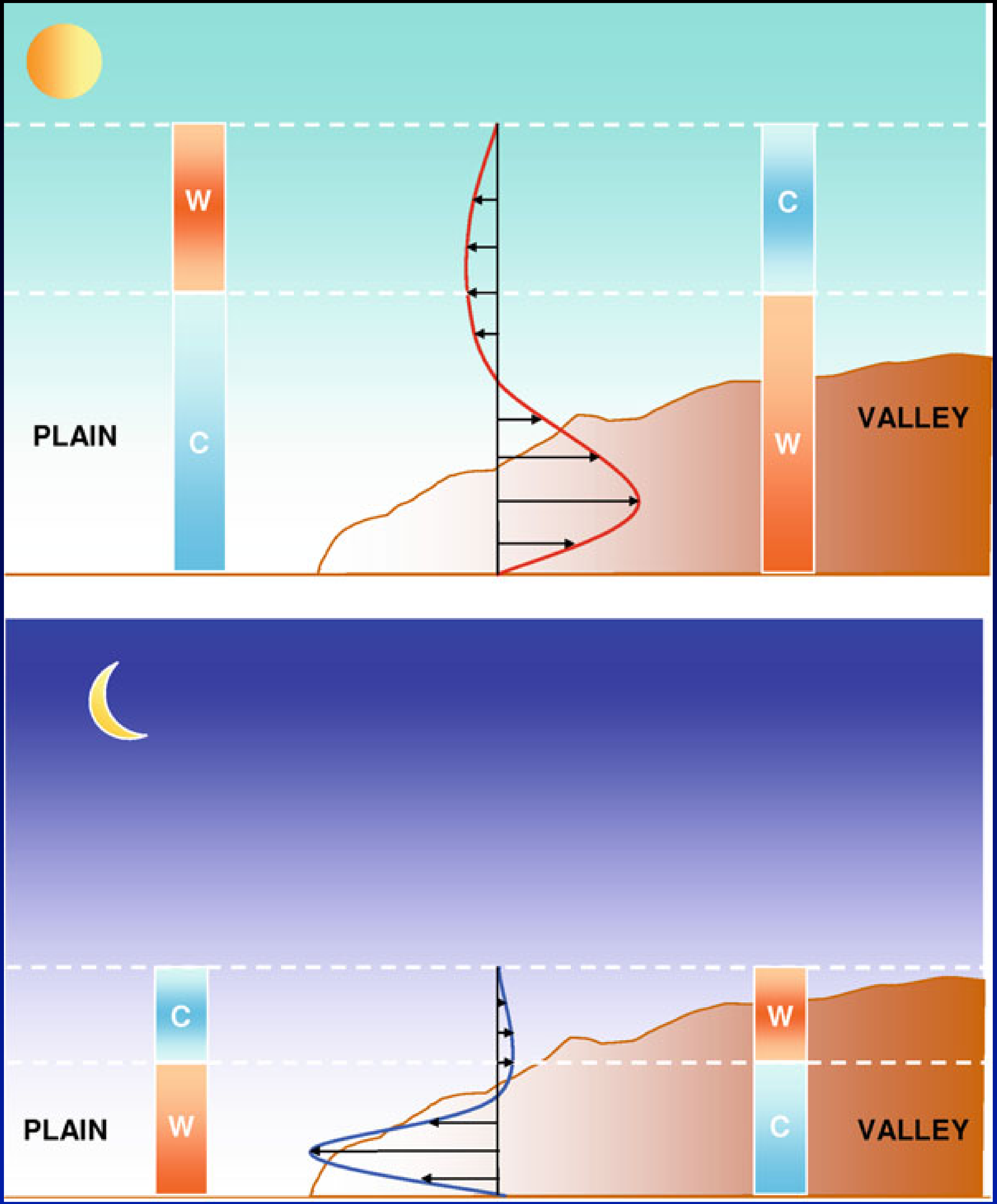


Daytime



Nighttime

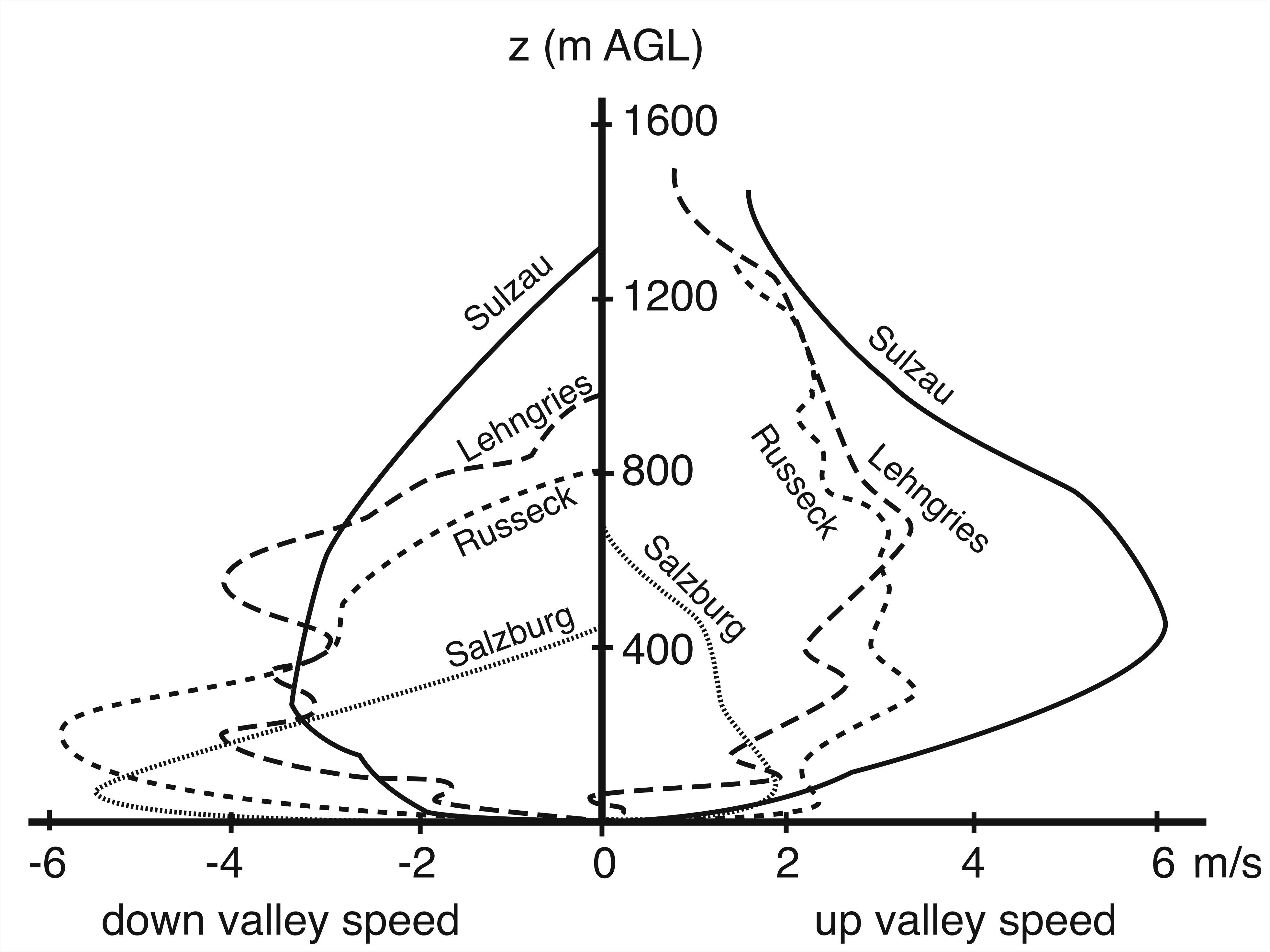
Hawkes (1947)



Along-valley flows

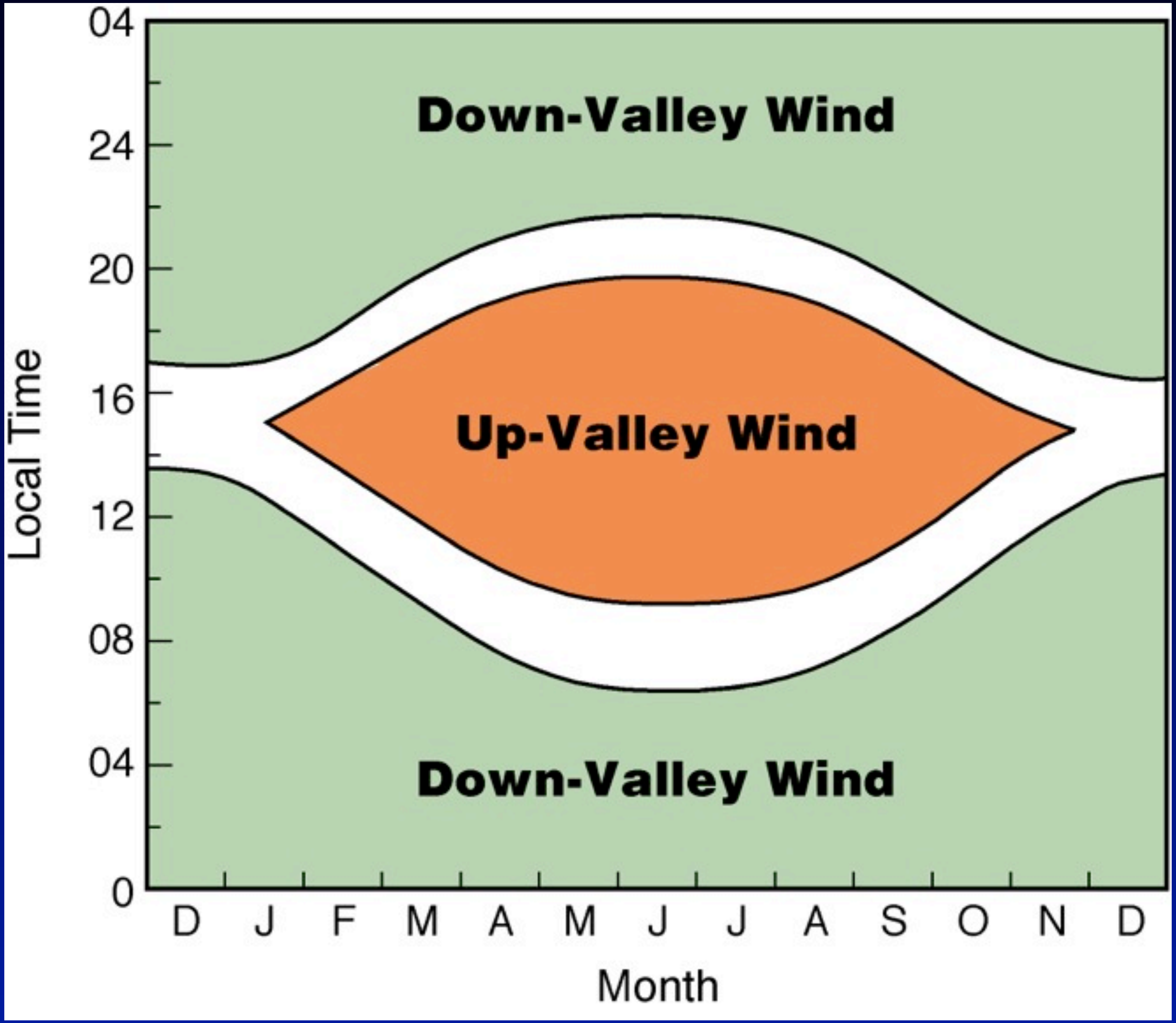
Zardi and Whiteman (2012)

Along-valley flows



Zardi and Whiteman (2012)

Valley wind regimes



Reiter et al. (1983)

Terrain Effects

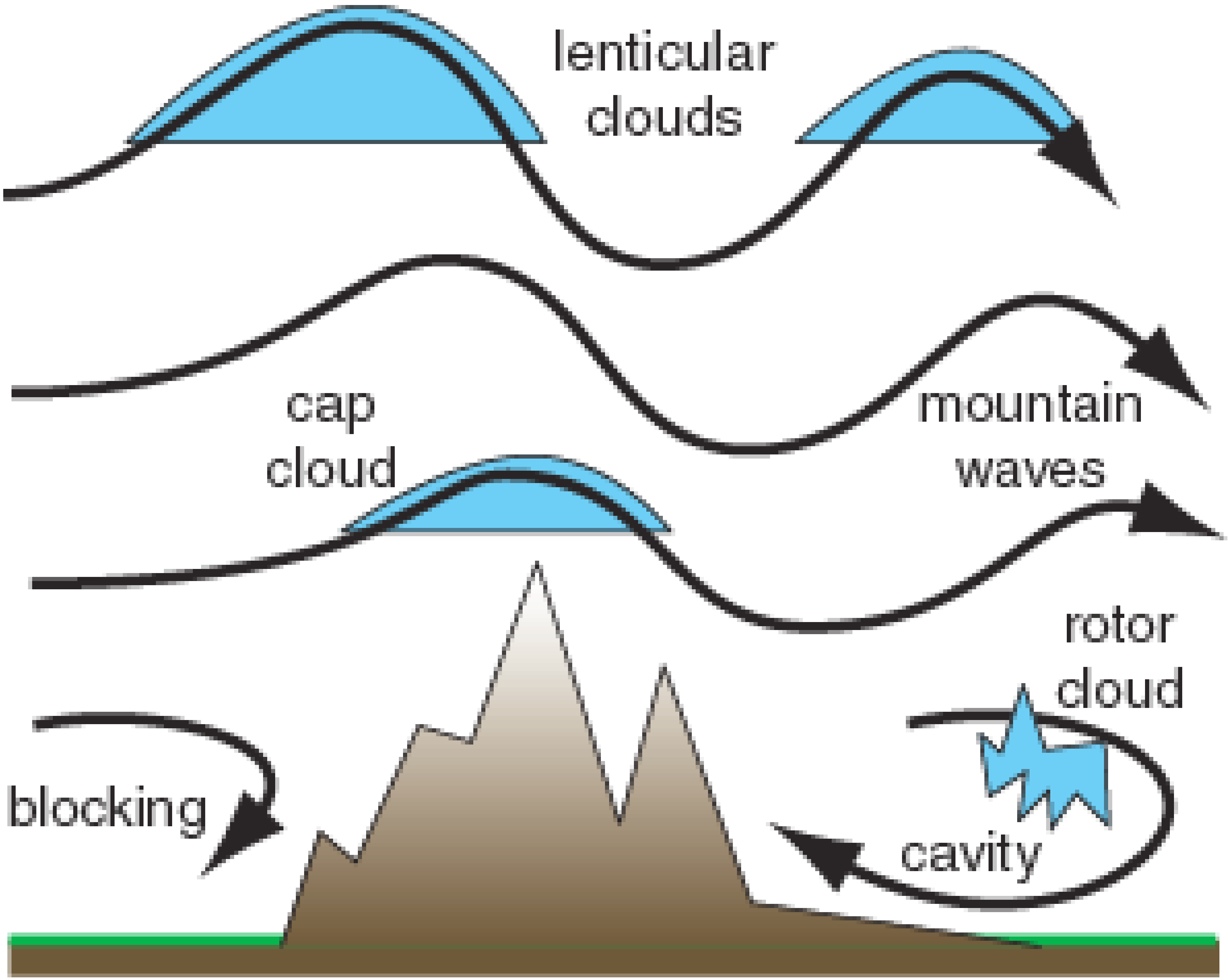
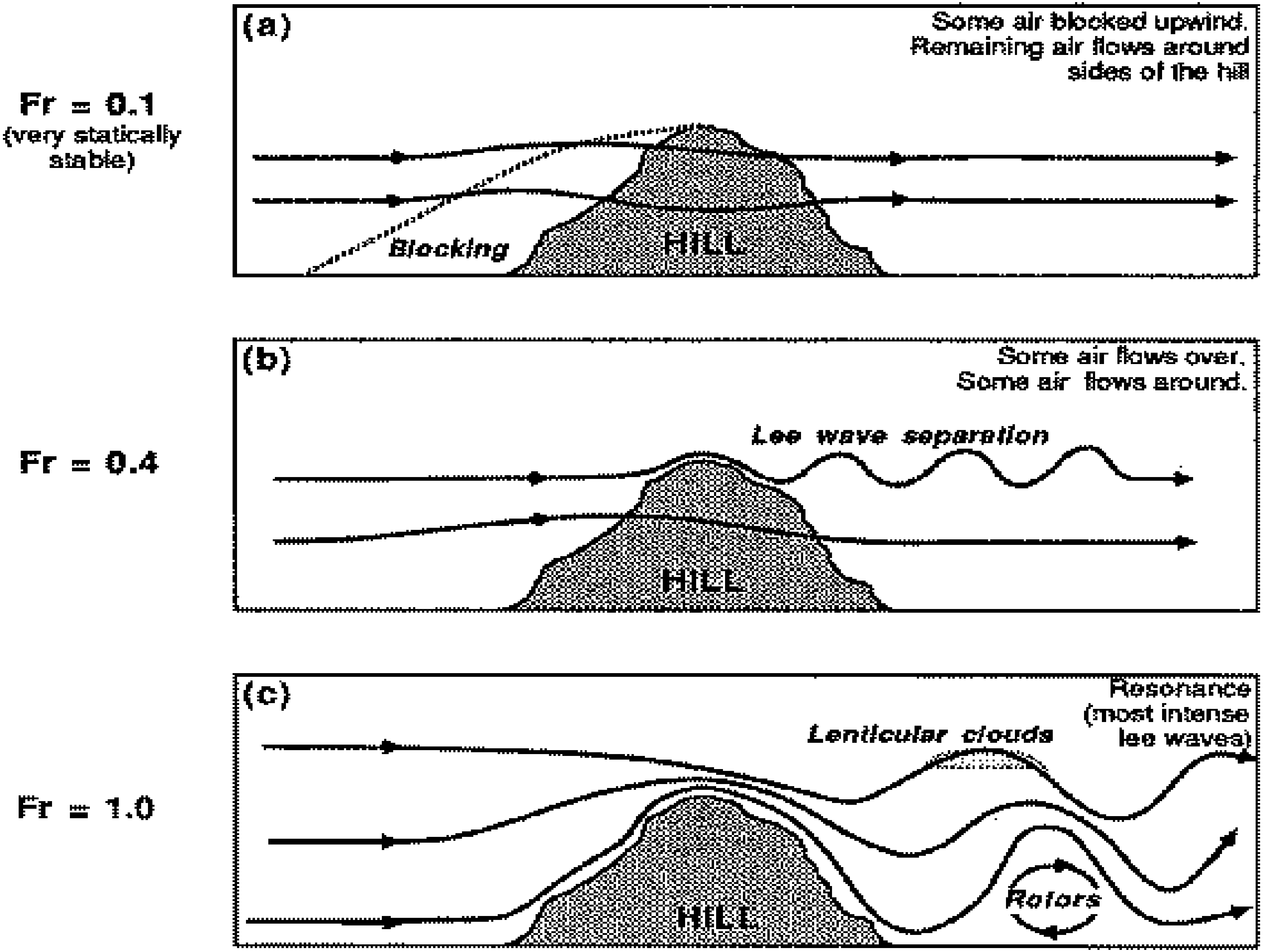
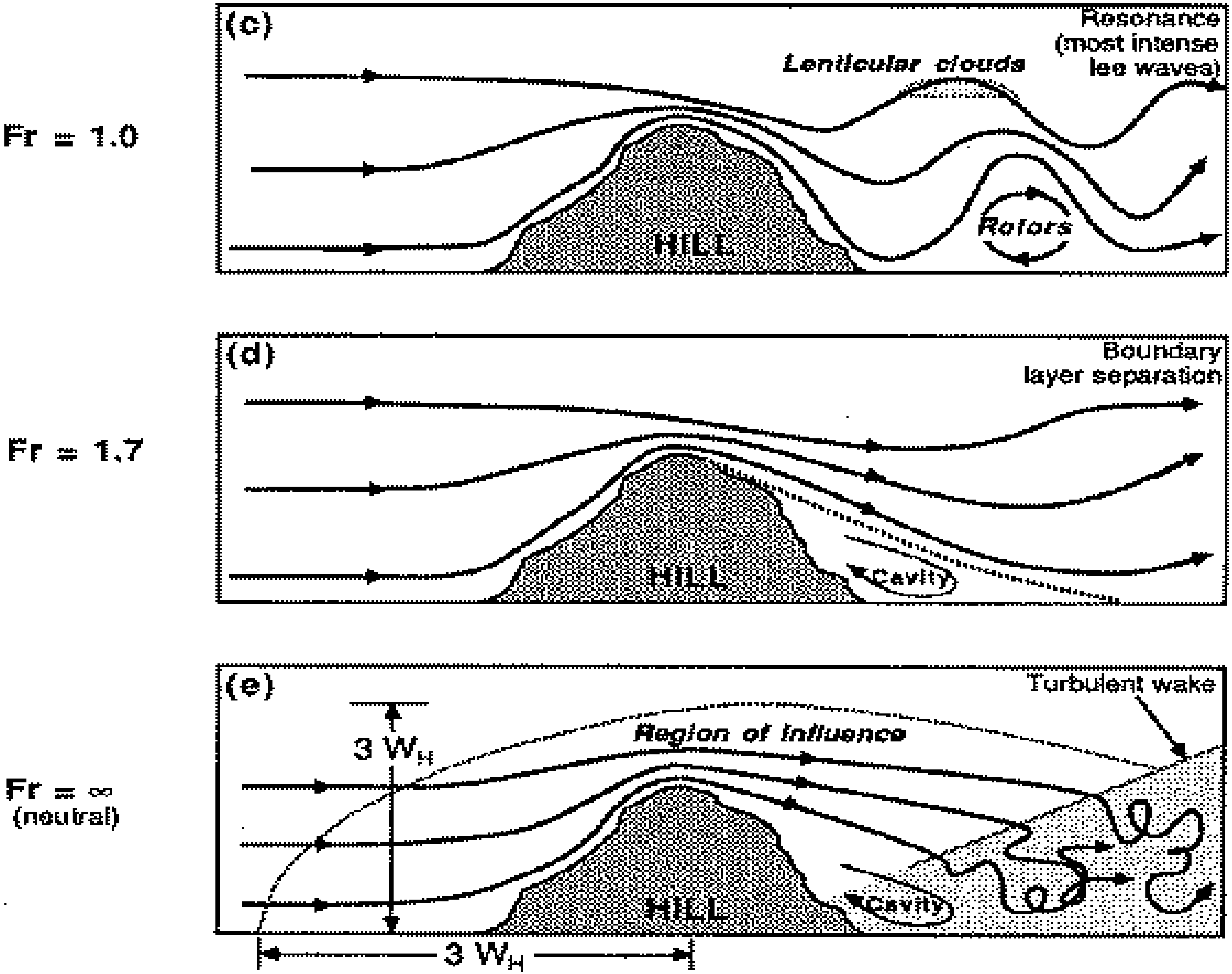
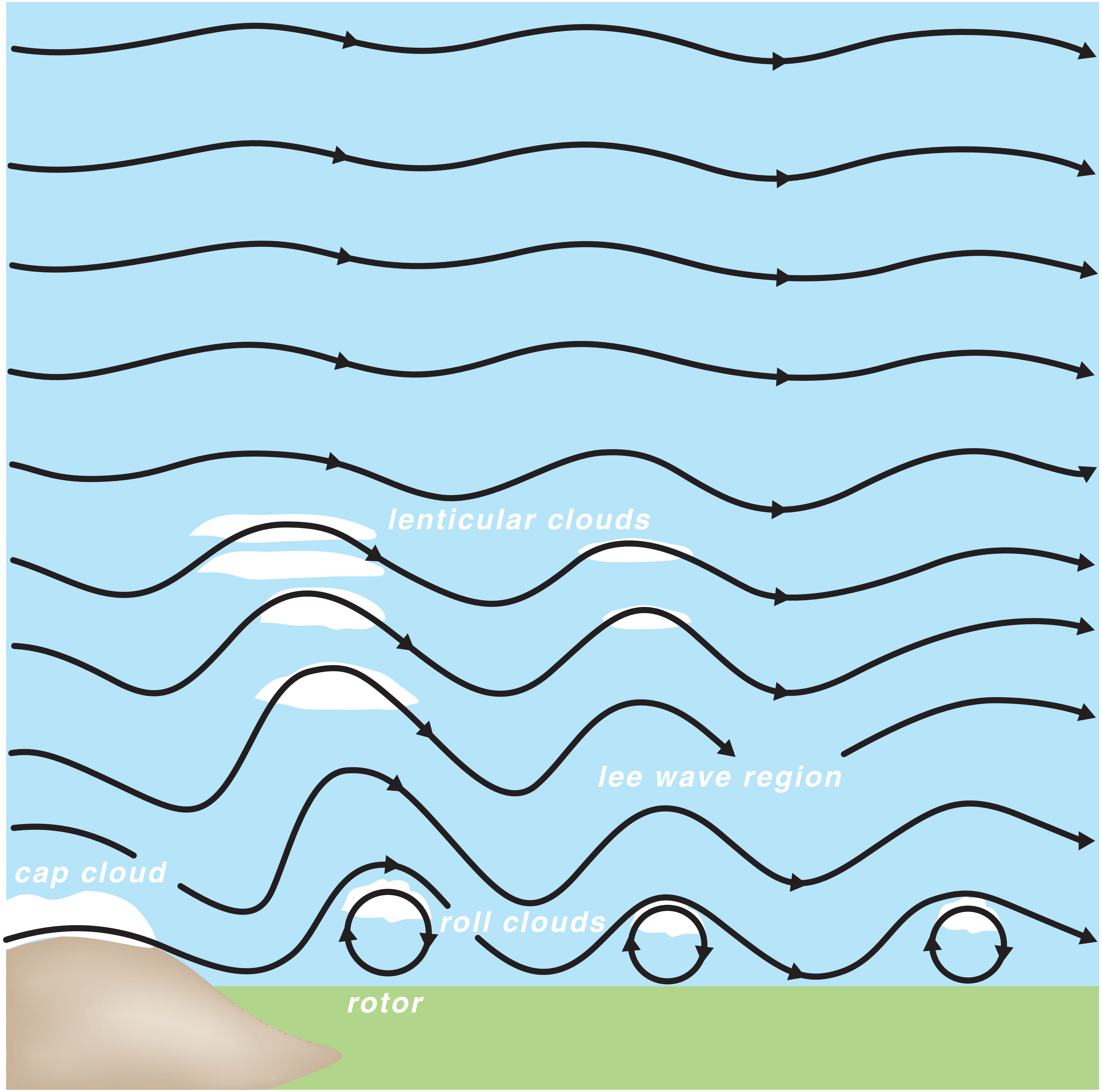


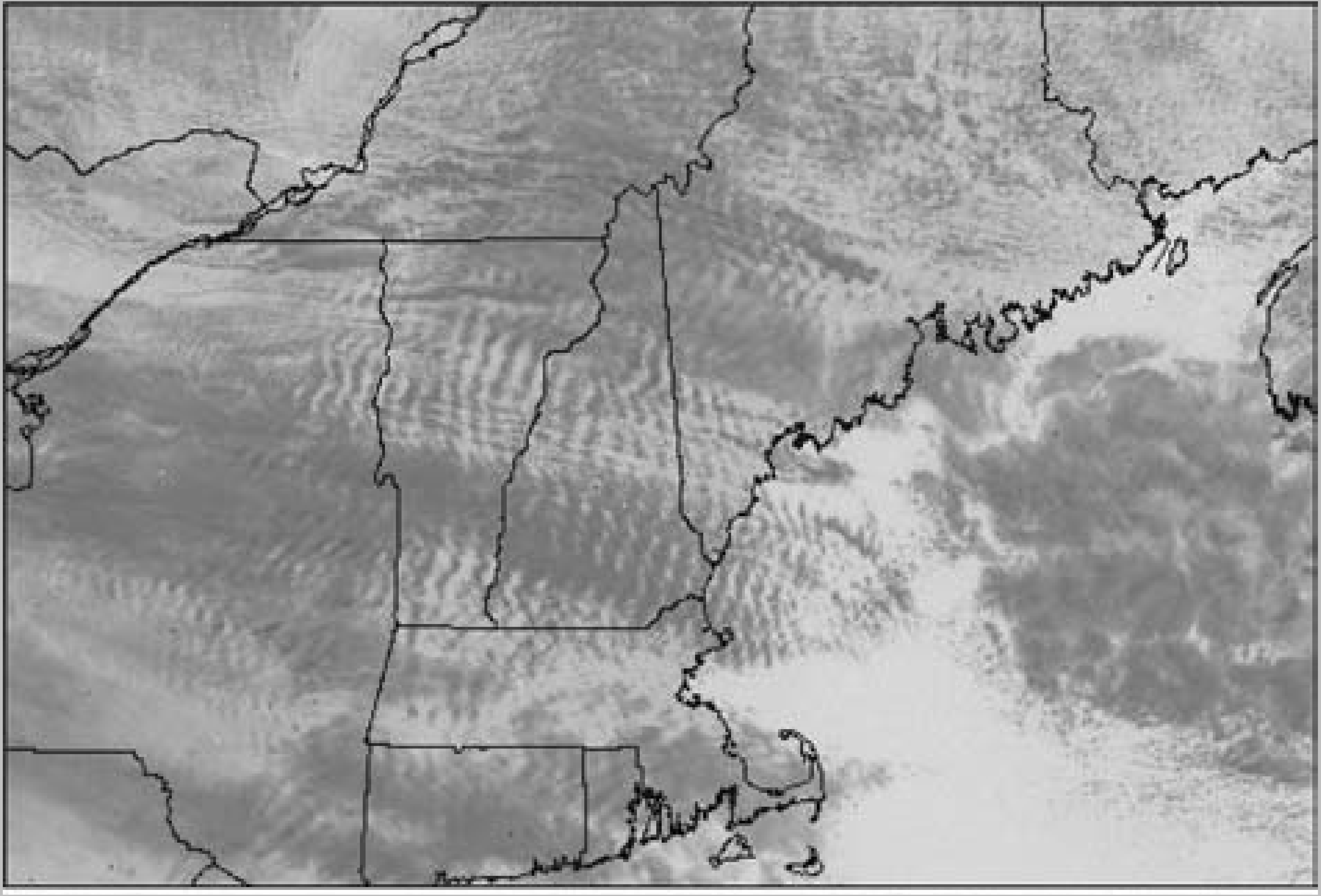
Figure 3: Idealized flow over an isolated hill. Different stability conditions are defined by the values of the Froude number Fr=U/(NL), where U is the wind speed, N the Brunt-Vaisala frequency and L is the length scale of the hill (from Stull, 1988, p. 602, fig. 14.4). [Reprinted with kind permission from Kluwer Academic Publishers]

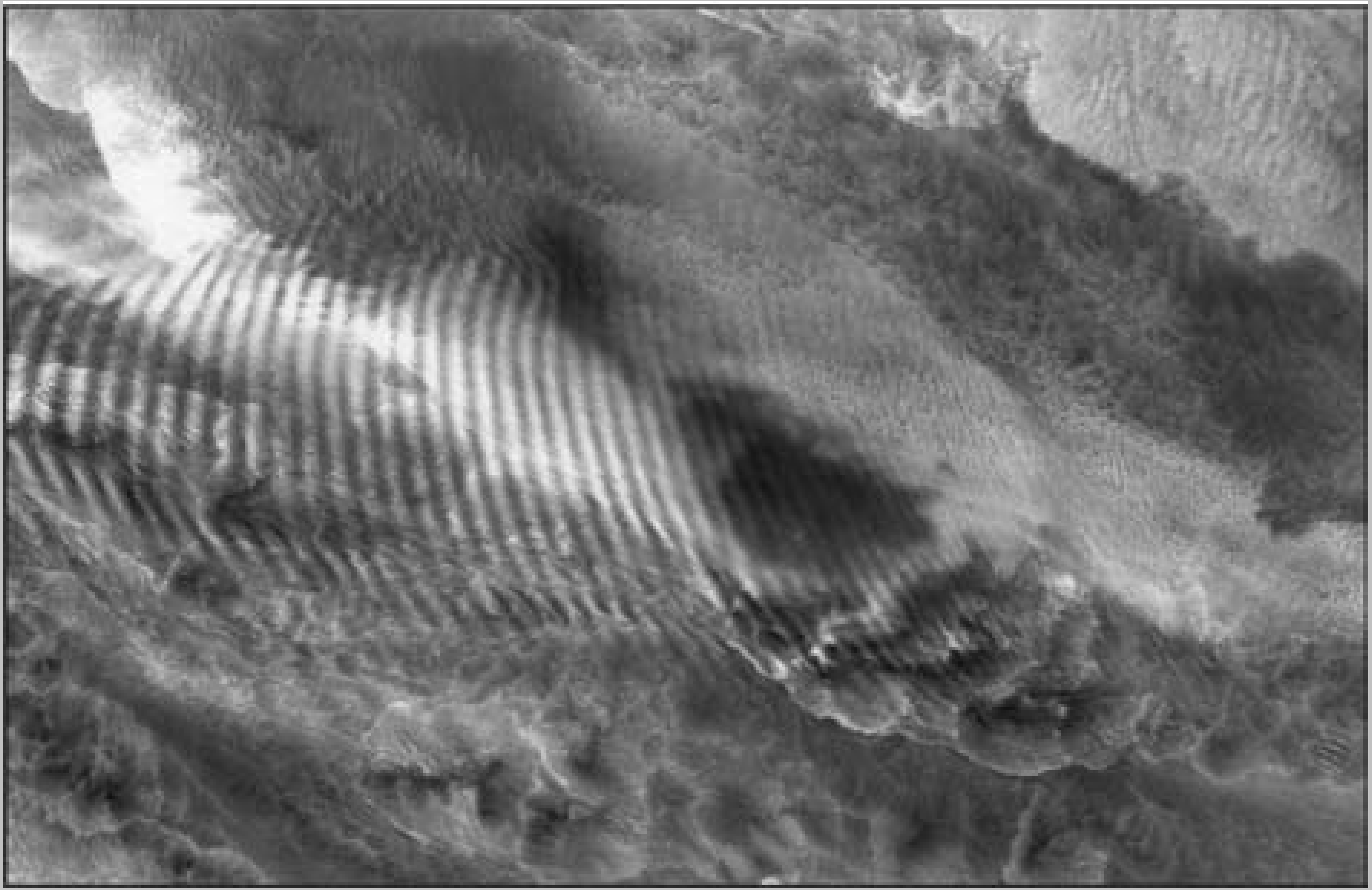

Fr = 0.1
(very statically stable)
(a)
Some air blocked upwind.
Remaining air flows around
sides of the hill
Blocking
HILL
Fr = 0.4
(b)
Some air flows over.
Some air flows around.
Lee wave separation
HILL
Fr = 1.0
(c)
Resonance
(most intense
lee waves)
Lenticular clouds
Rotors
HILL



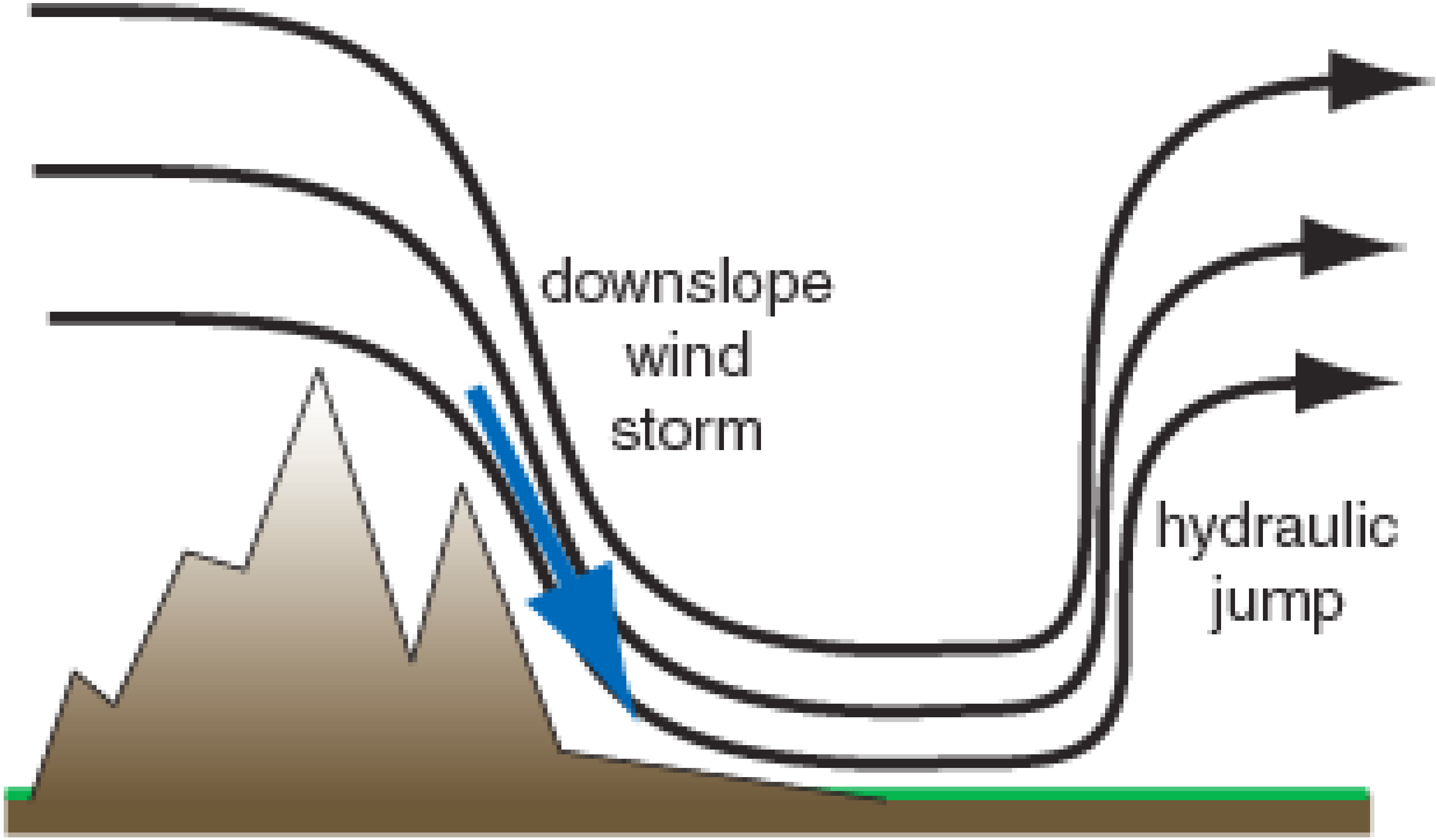
Fr = 1.0
(c)
Resonance (most intense lee waves)
Lenticular clouds
Rotors
HILL
Fr = 1.7
(d)
Boundary layer separation
Cavity
HILL
Fr = ∞ (neutral)
(e)
Turbulent wake
Region of influence
3 W_H
Cavity
HILL
3 W_H


lenticular clouds
lee wave region
cap cloud
roll clouds
rotor





Terrain Effects



Turbulent rotor cloud downwind (left-hand side of the photo) of the
Sierra Nevada mountain range in the Owens Valley near Bishop, California.
Downslope winds gather dust on the valley floor and serve as a tracer of the
air rising suddenly into the cloud. Over the mountains themselves (upper right)
a portion of a Föhn wall cloud is seen.
(Photo taken by pilot Robert Symons, while flying a P-38 fighter.
Photo courtesy of Morton G. Wurtele.)

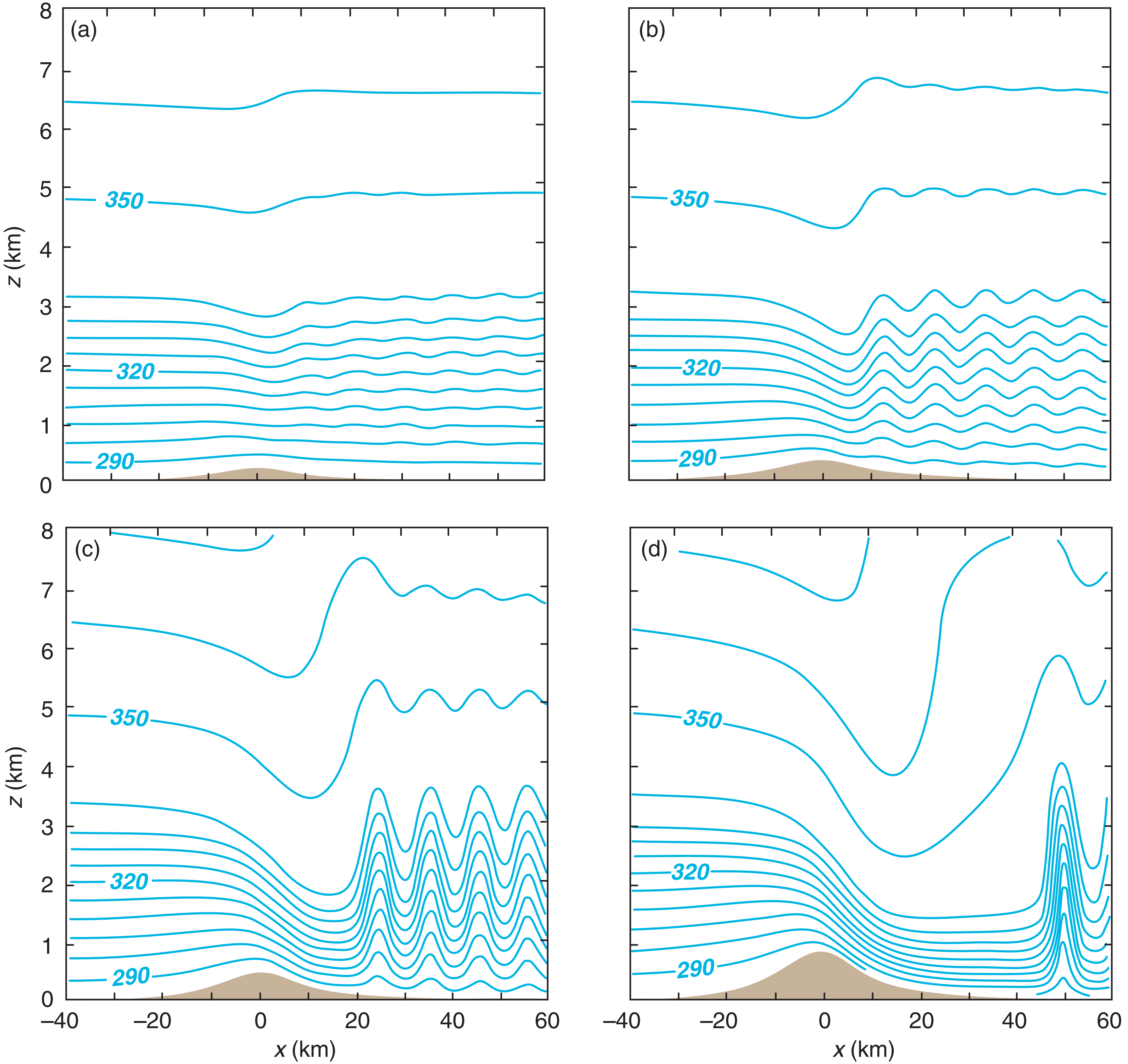


Figure 12.14 Isentropes for the airflow in a two-layer atmosphere when the interface is fixed at 3000 m, and the mountain height is (a) 200, (b) 300, (c) 500, and (d) 800 m. (From Durran [1986b].)

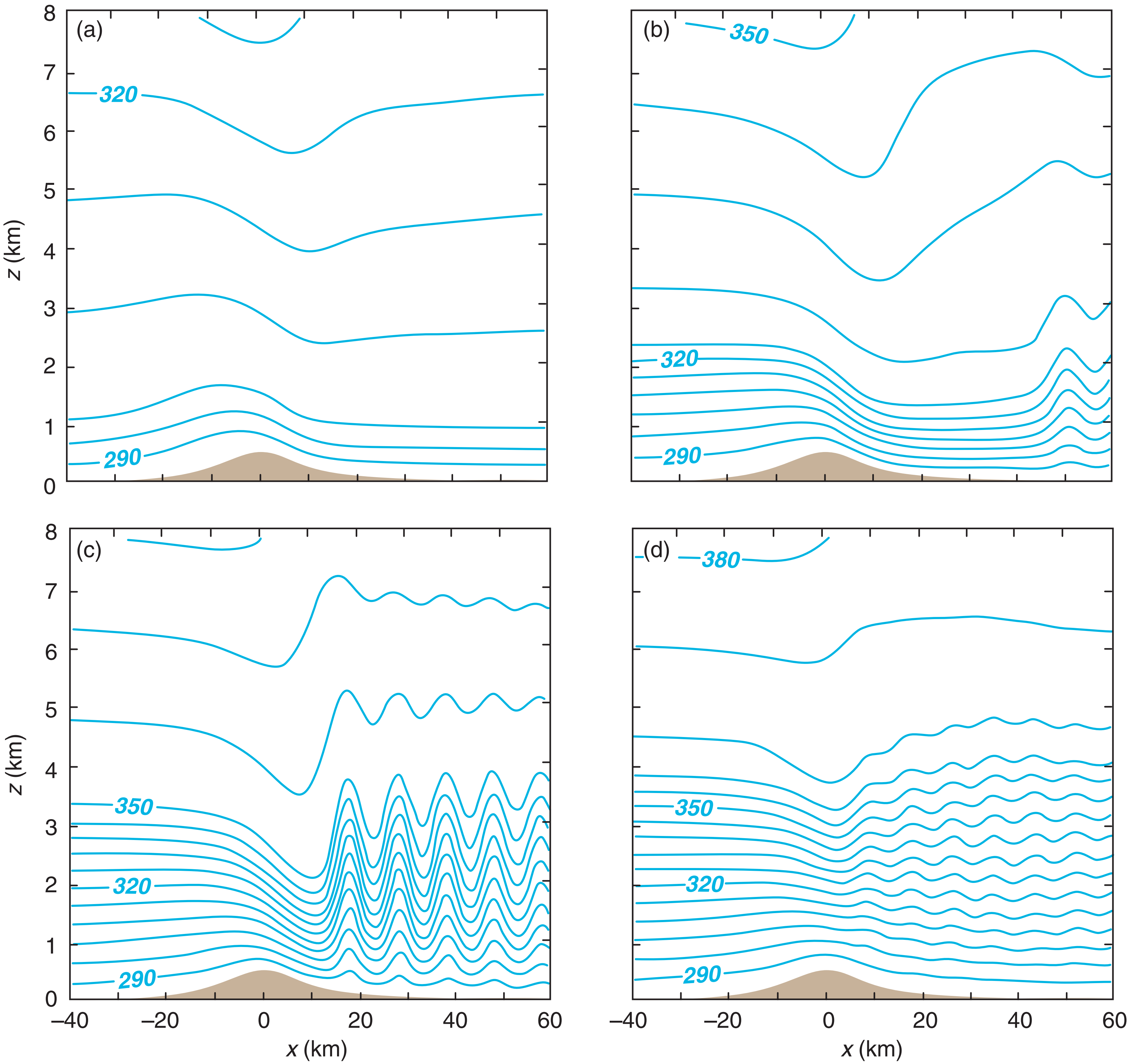
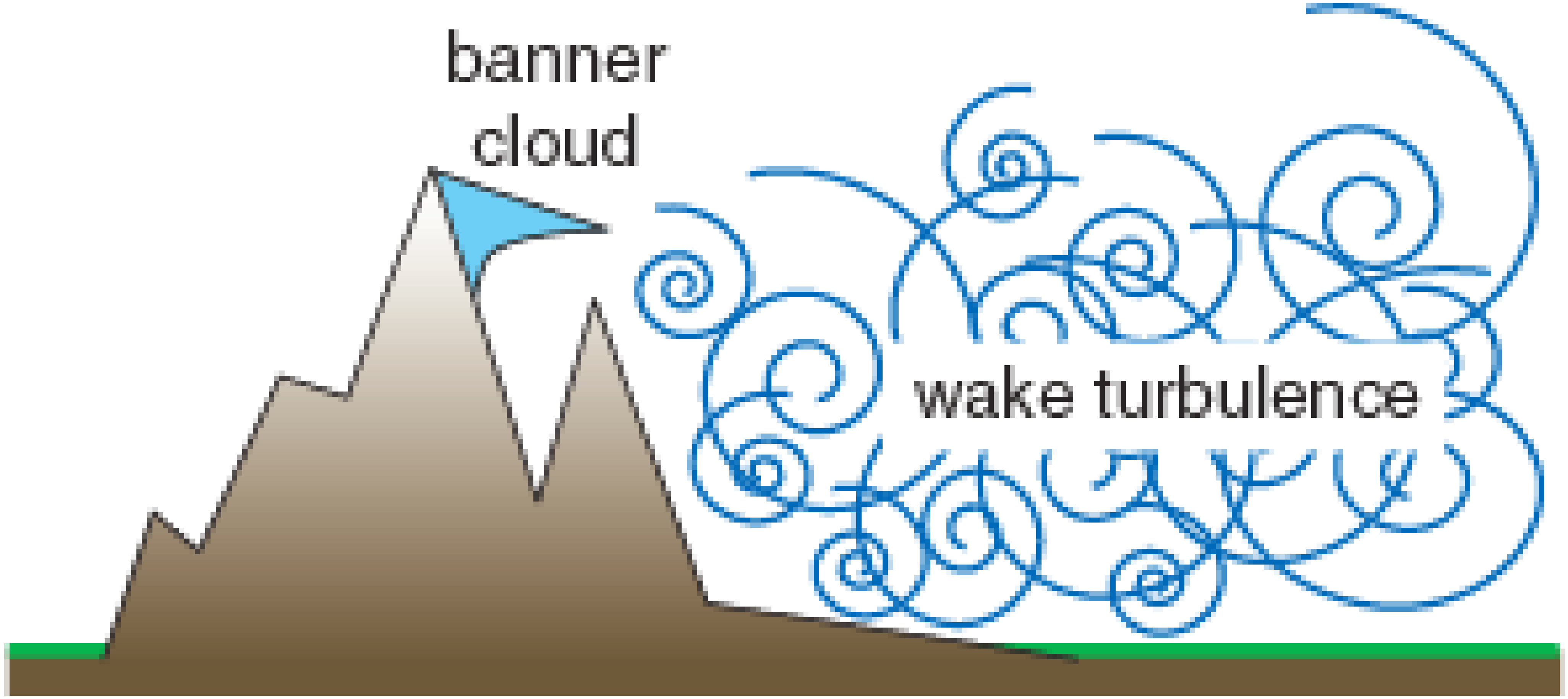
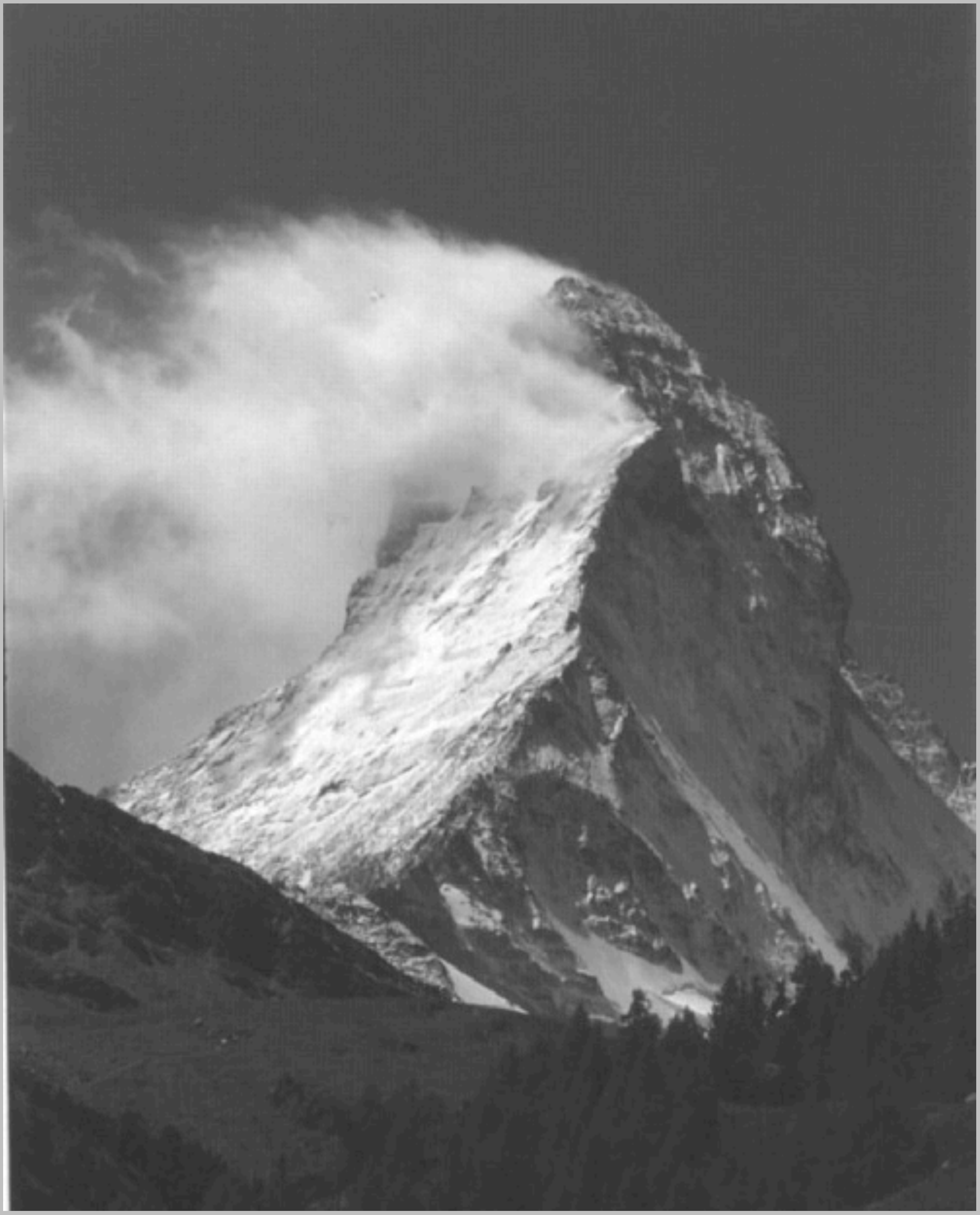


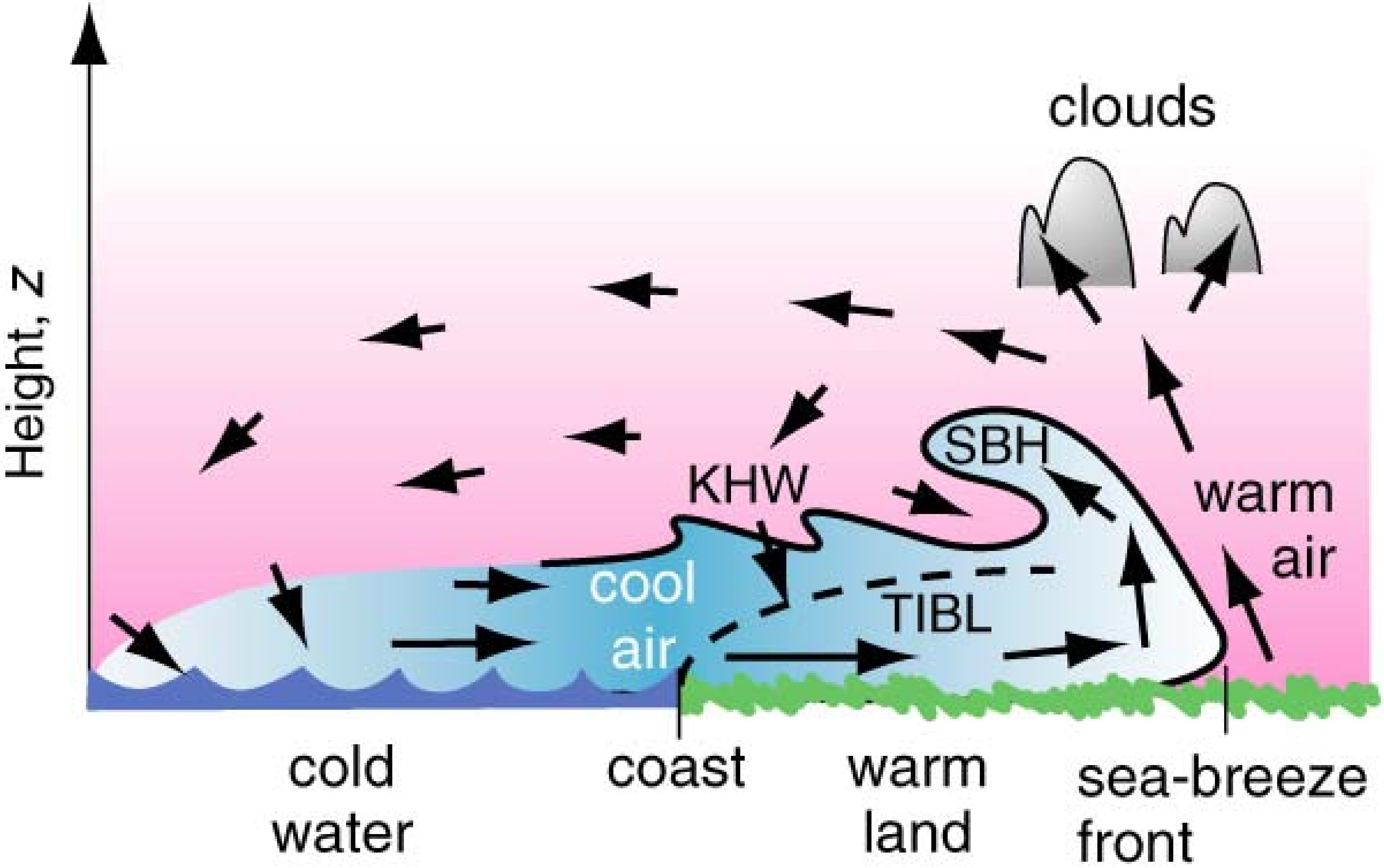
Figure 12.15 Isentropes for the airflow in a two-layer atmosphere when the mountain height is fixed at 500 m, and the interface is at (a) 1000 m, (b) 2500 m, (c) 3500 m, and (d) 4000 m. (From Durran [1986b].)

Terrain Effects

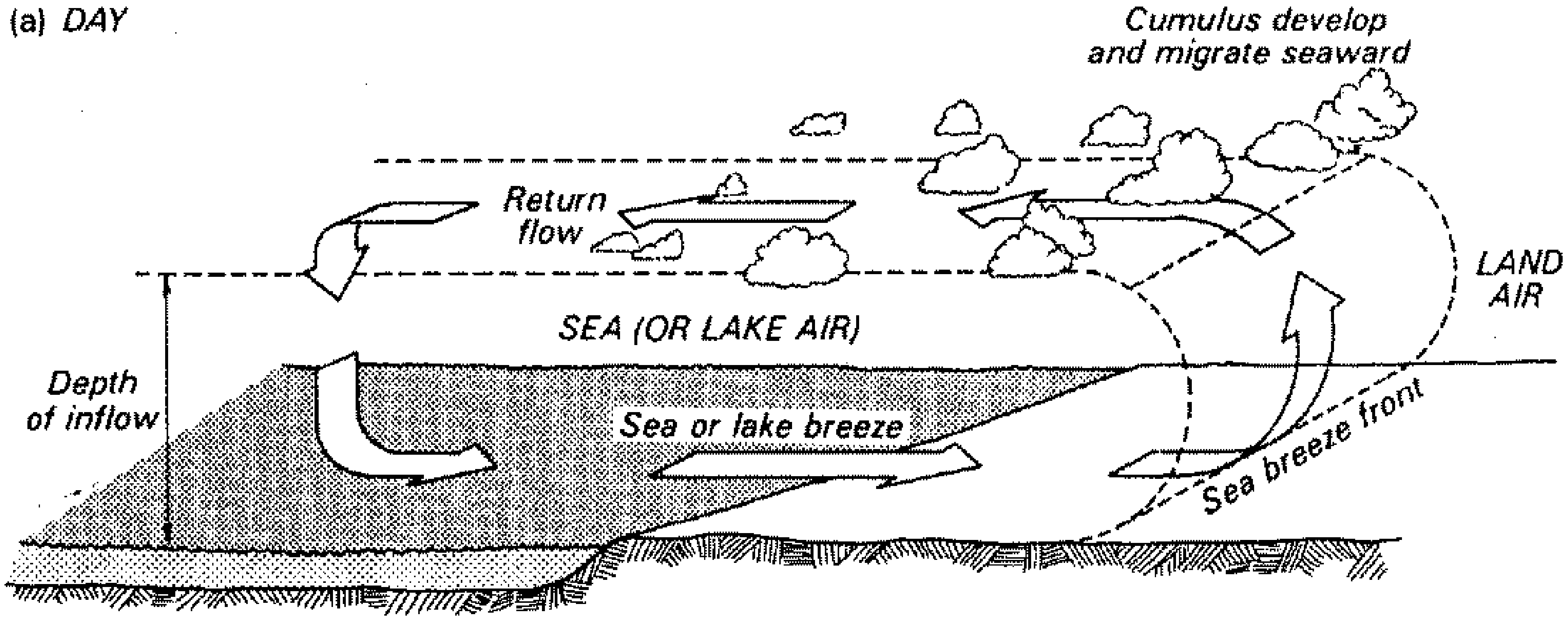




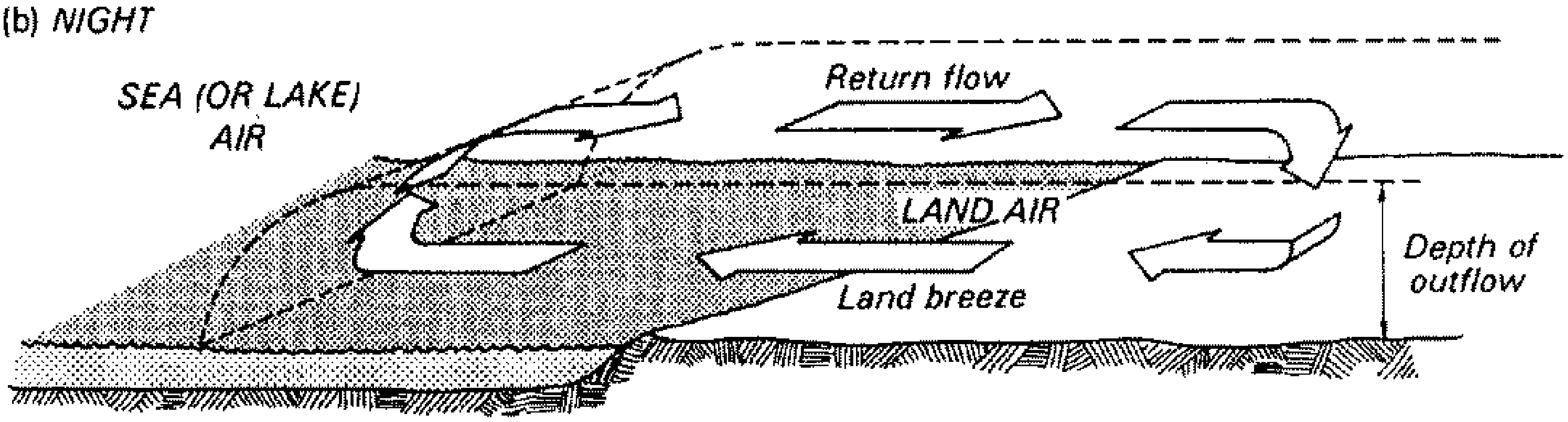
Terrain Effects



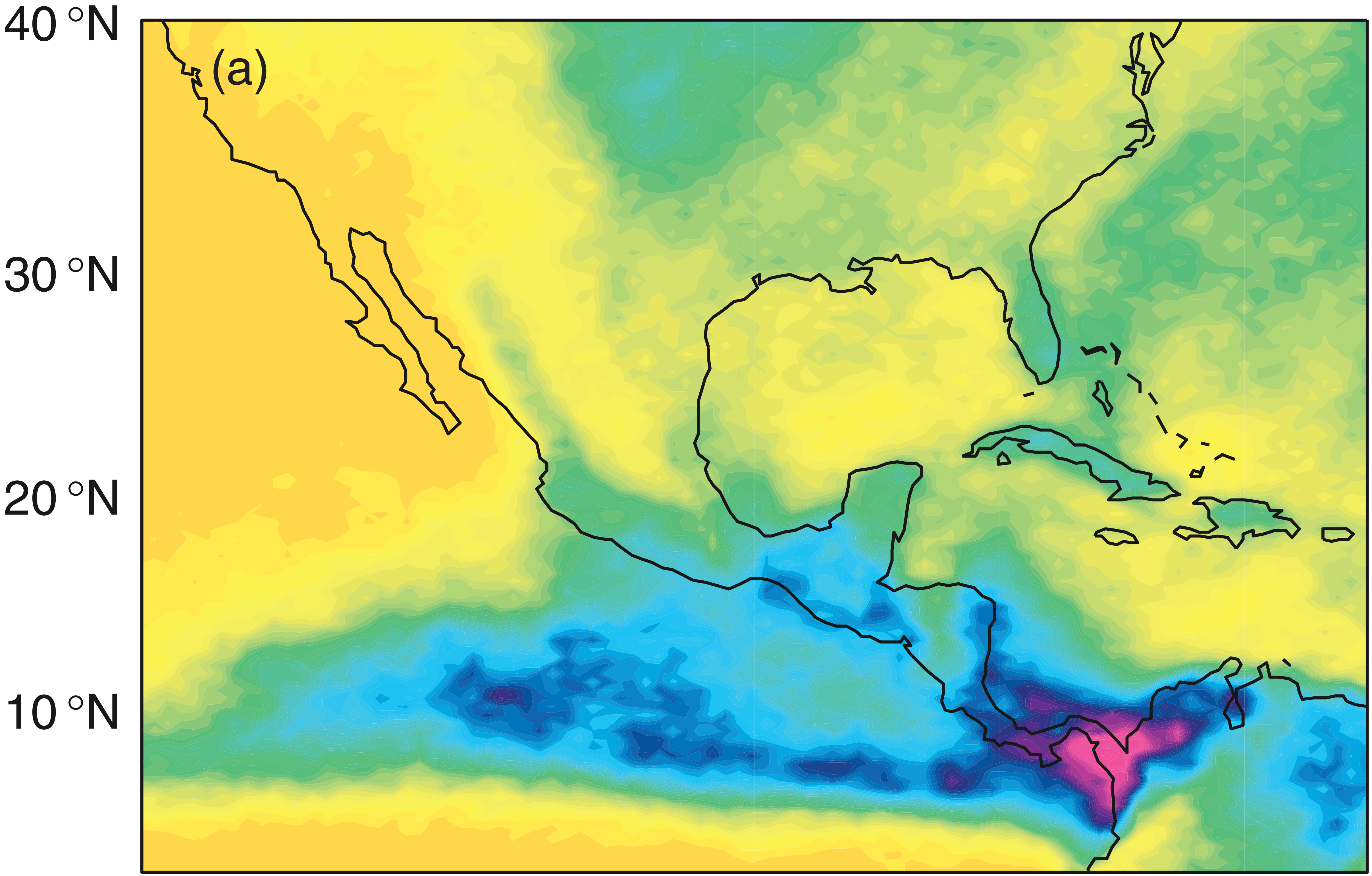
Terrain Effects



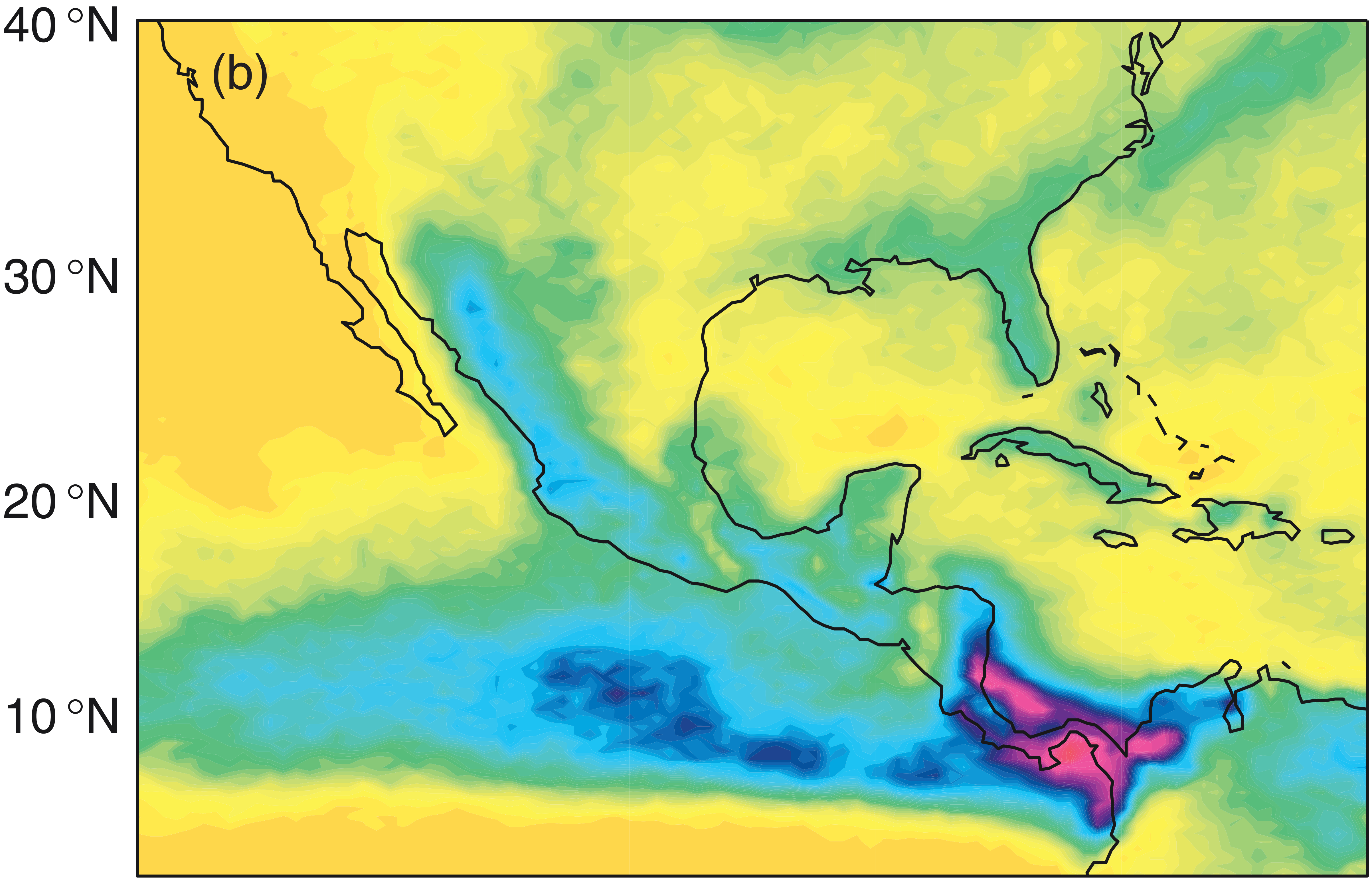
Terrain Effects



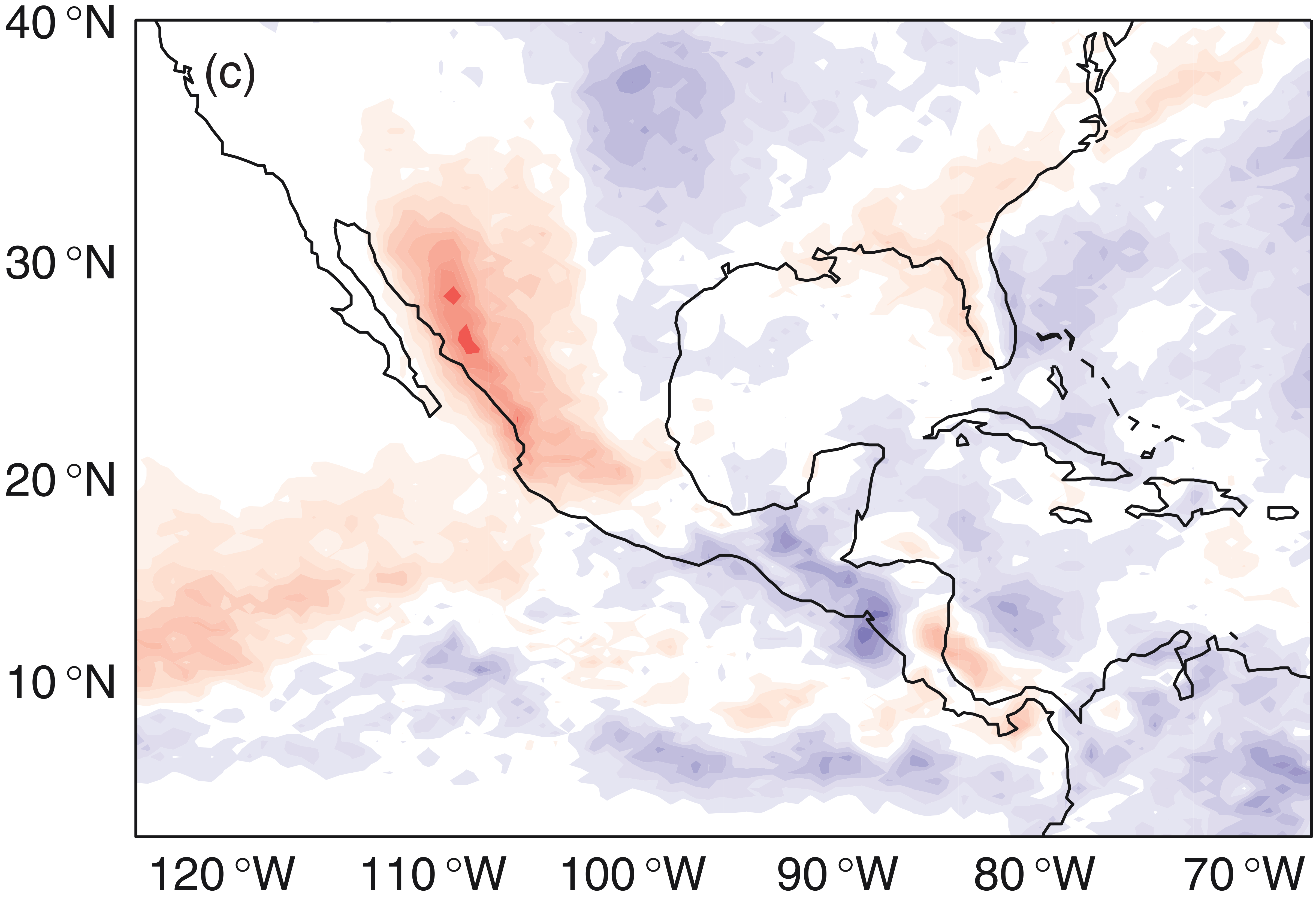
Terrain Effects



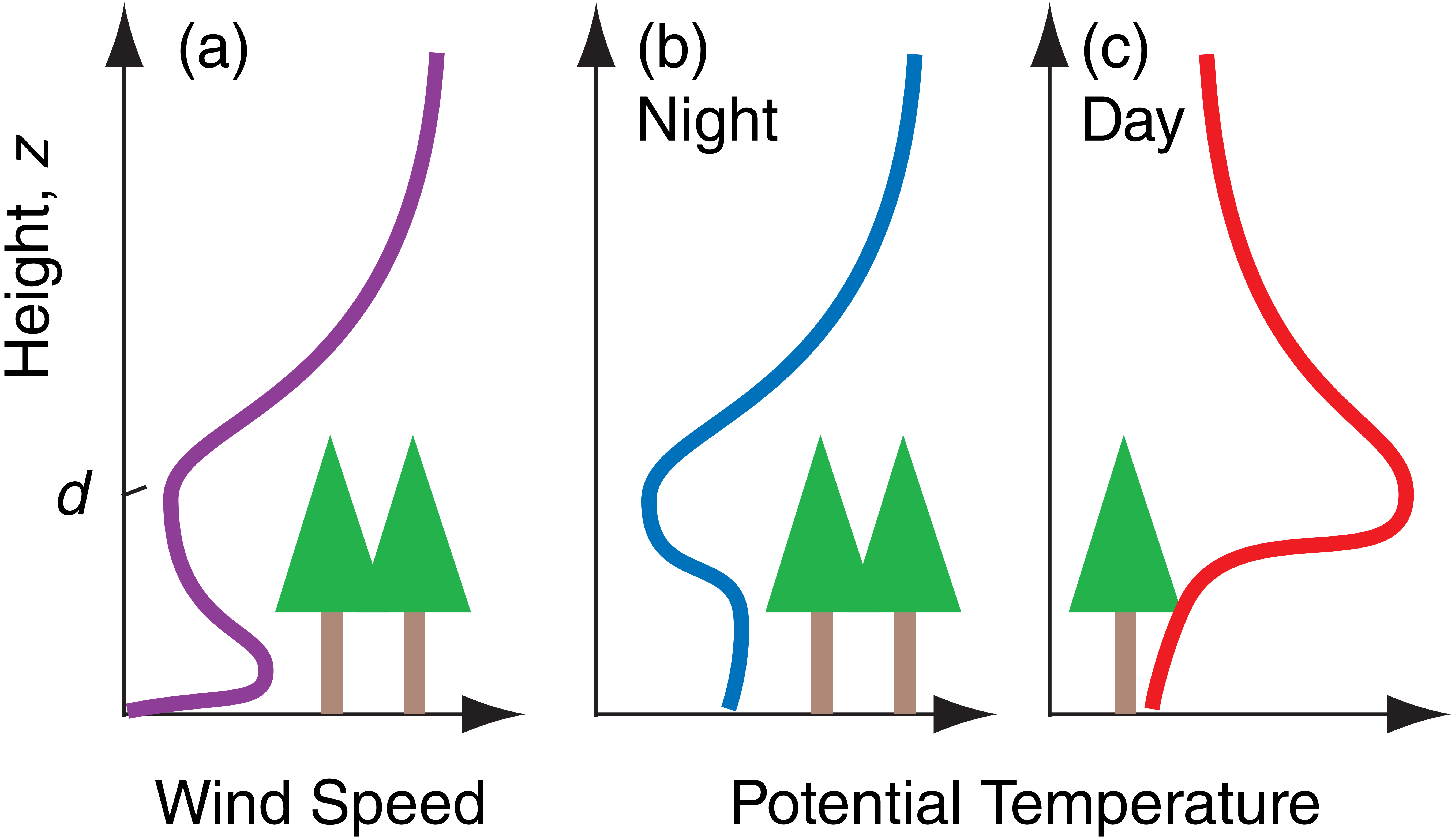
Terrain Effects



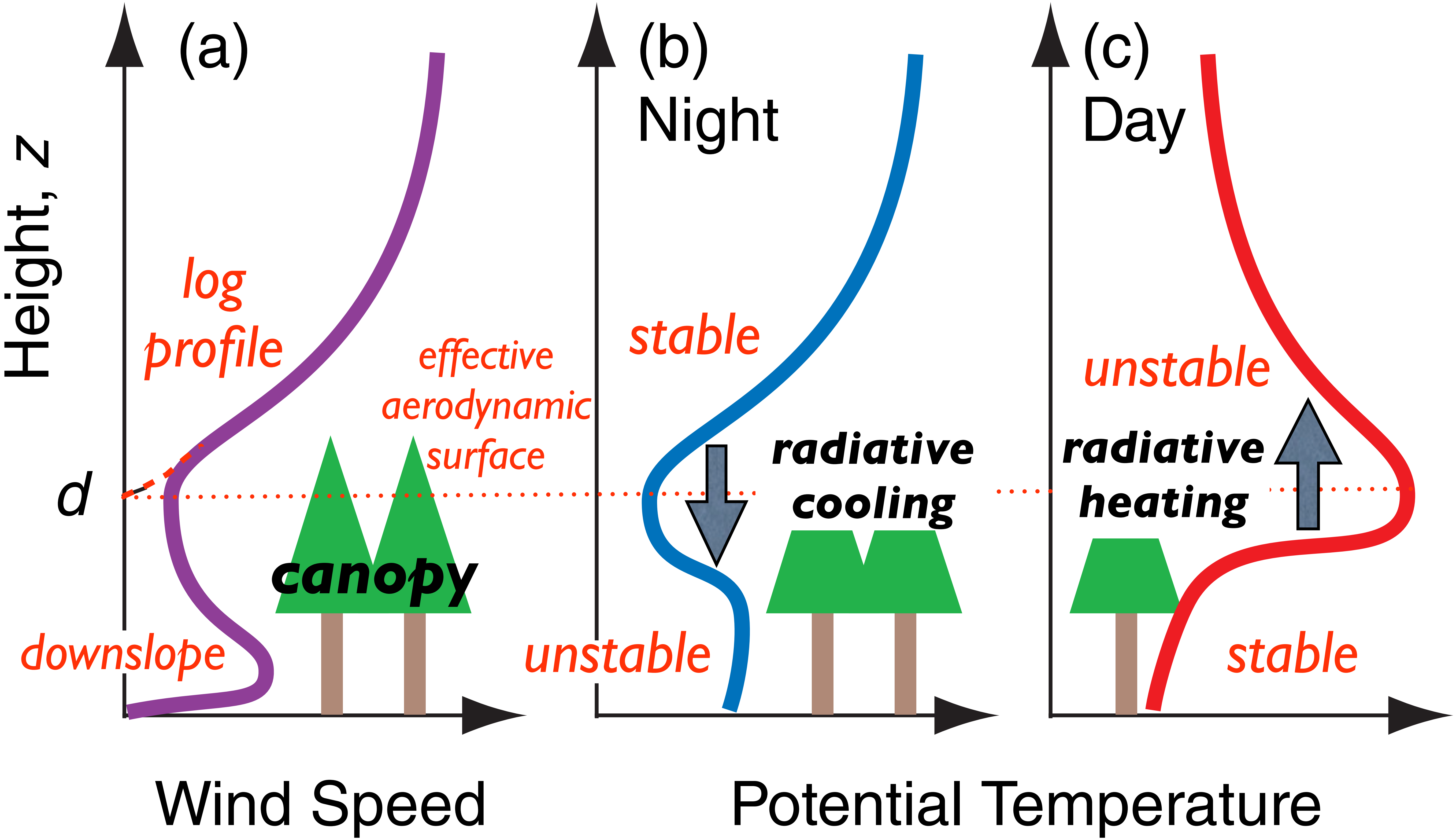
Terrain Effects



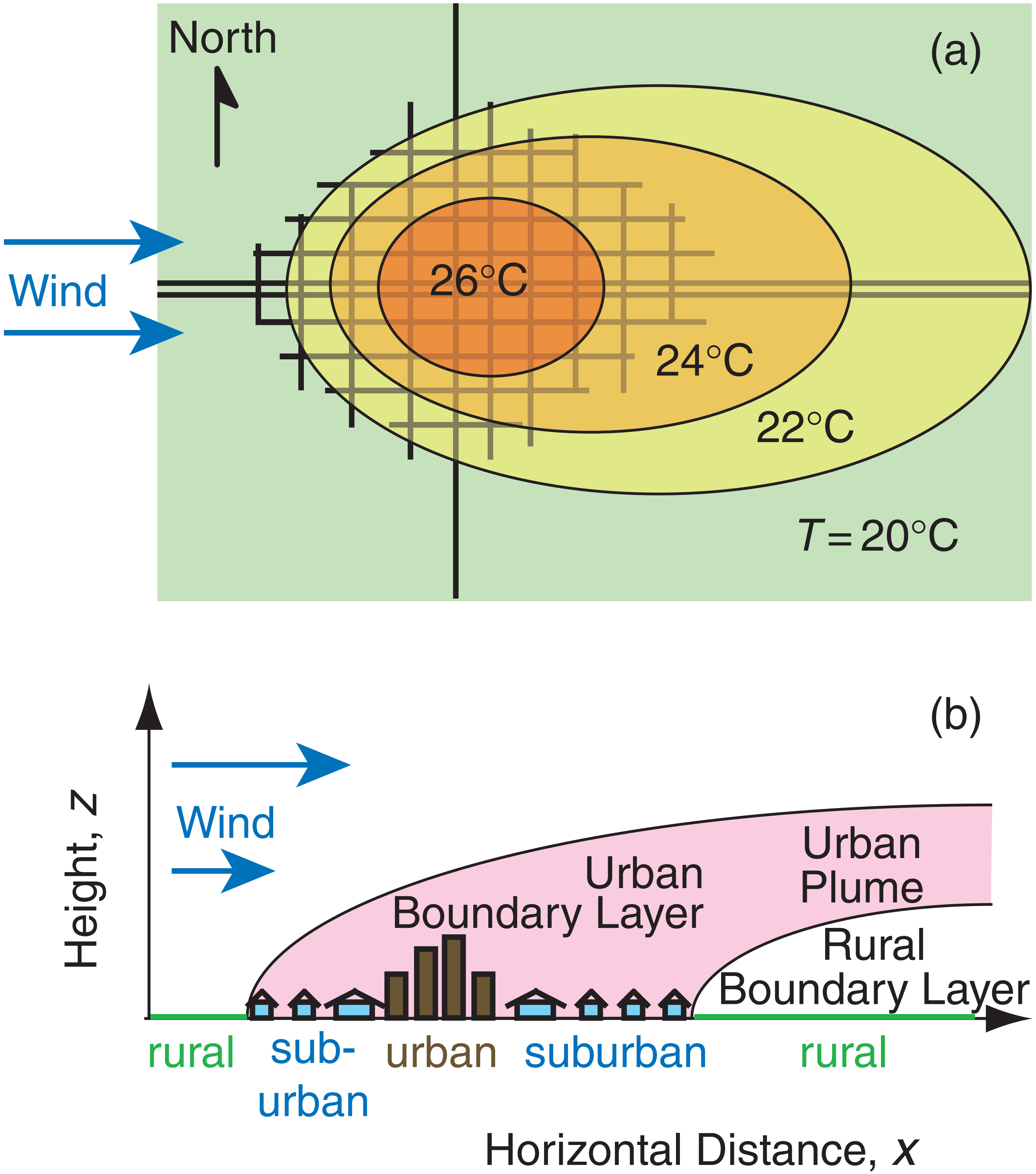
Forest Canopy Effects



Forest Canopy Effects



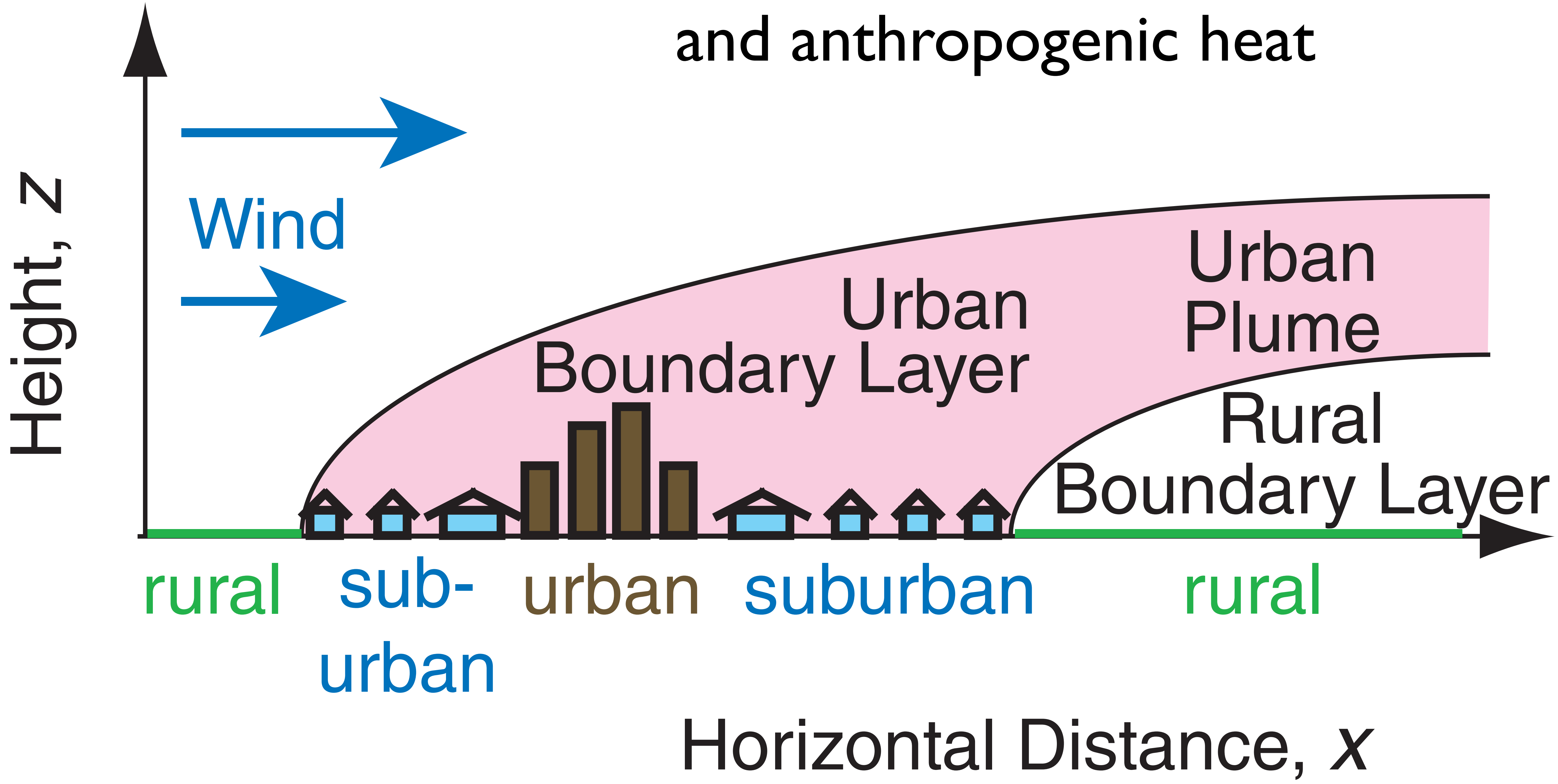
Urban Effects



Urban Effects

- More drag
- Drier surface
- Less vegetation
- Different albedo

- Albedo depends strongly on sun position
- Different heat capacity
- Greater emissions of pollutants and anthropogenic heat



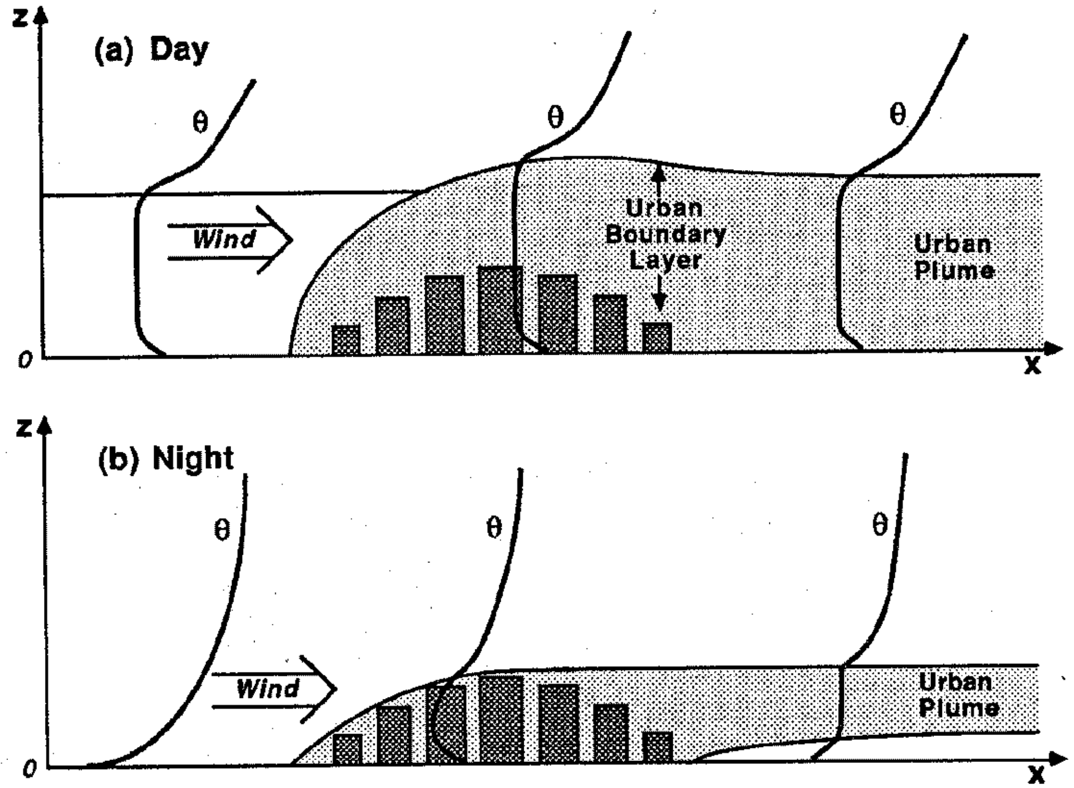


Figure 2: Sketch of the urban boundary layer and urban plume for a windy day (a), and night (b) (from Stull, 1988, p. 611, fig. 14.22). [Reprinted with kind permission from Kluwer Academic Publishers]

Urban Effects

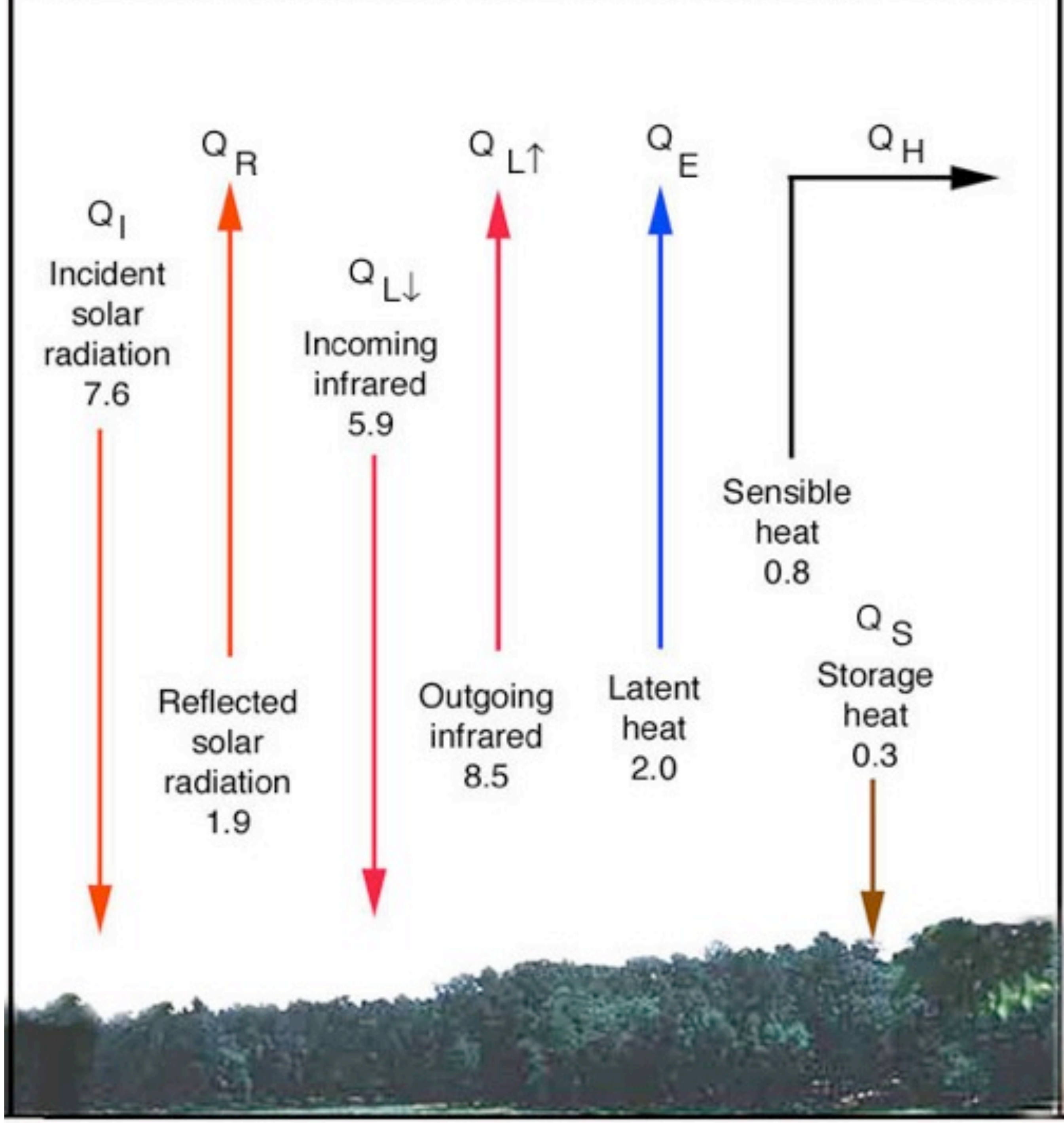


Figure 3a: Typical Daily Summer Rural Energy Balance

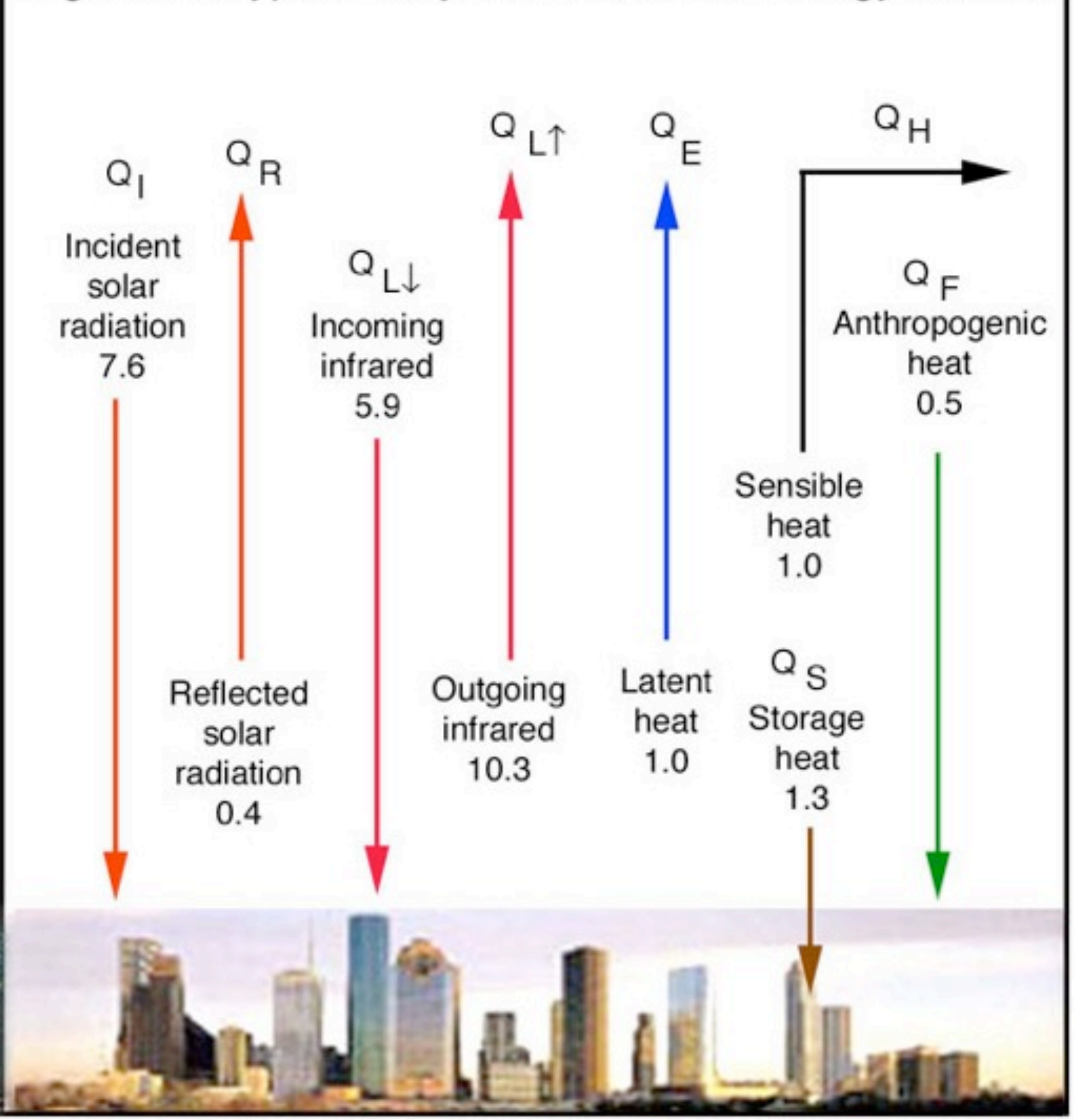
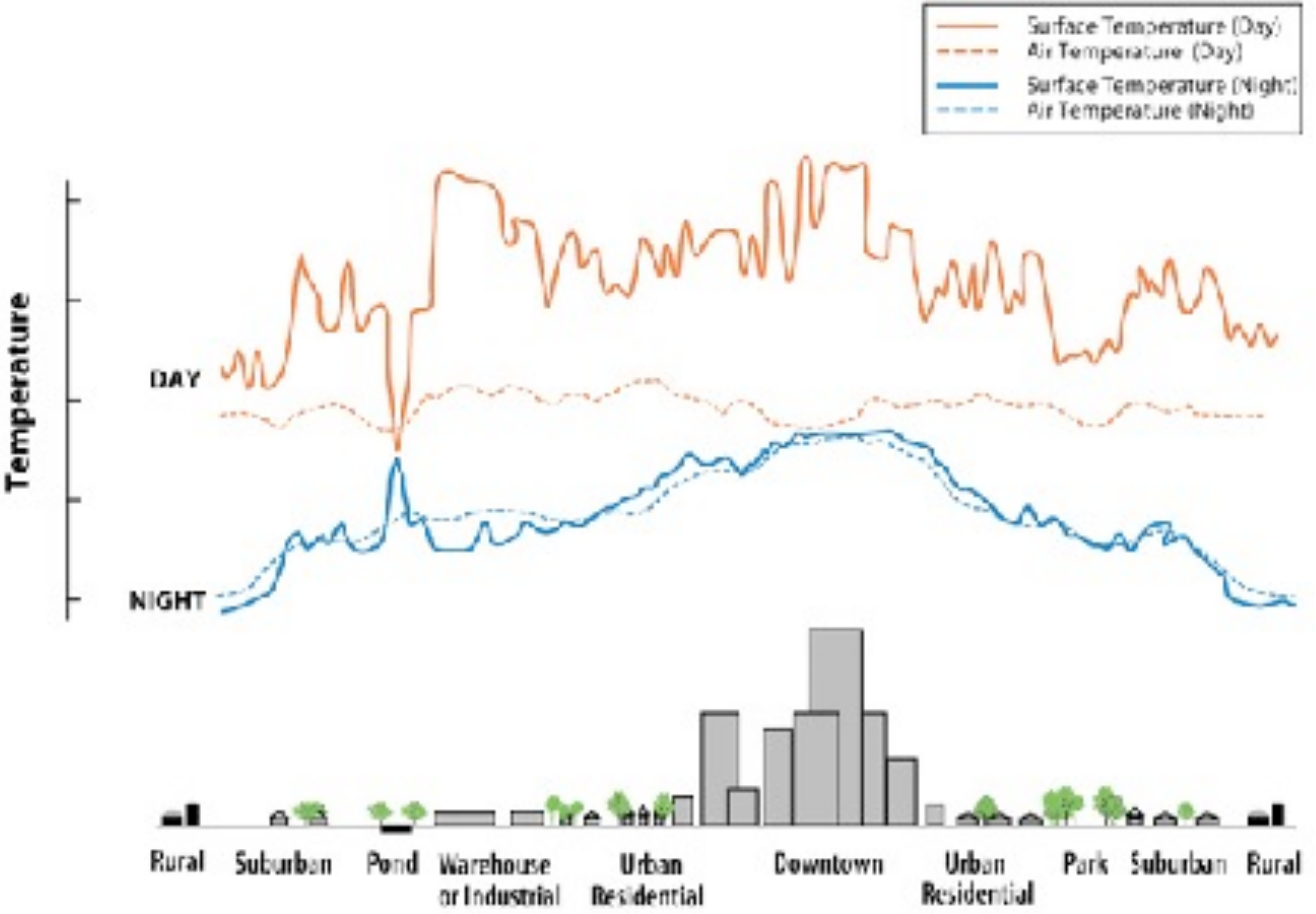
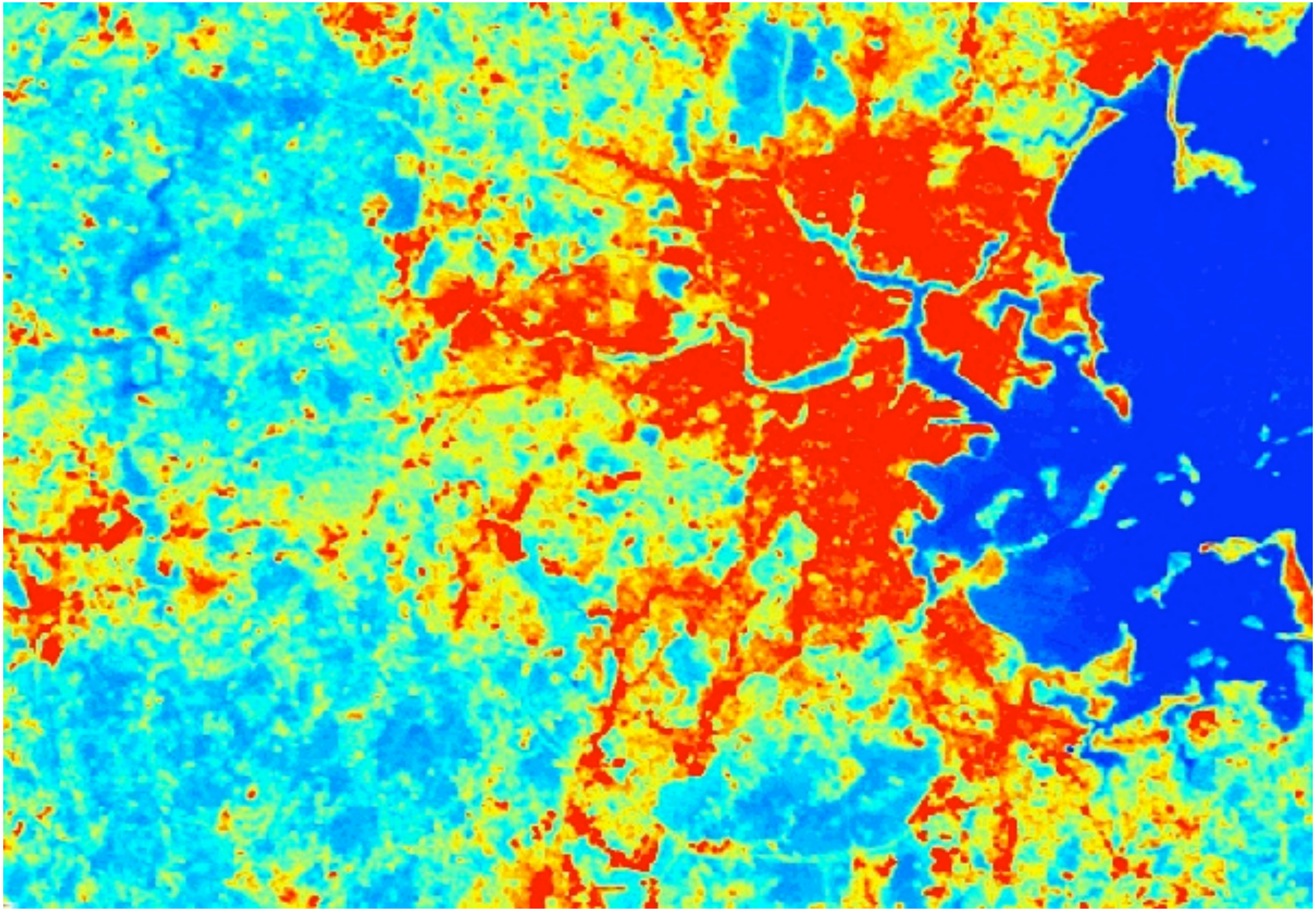


Figure 3b: Typical Daily Summer Urban Energy Balance

Urban Effects



Urban Effects

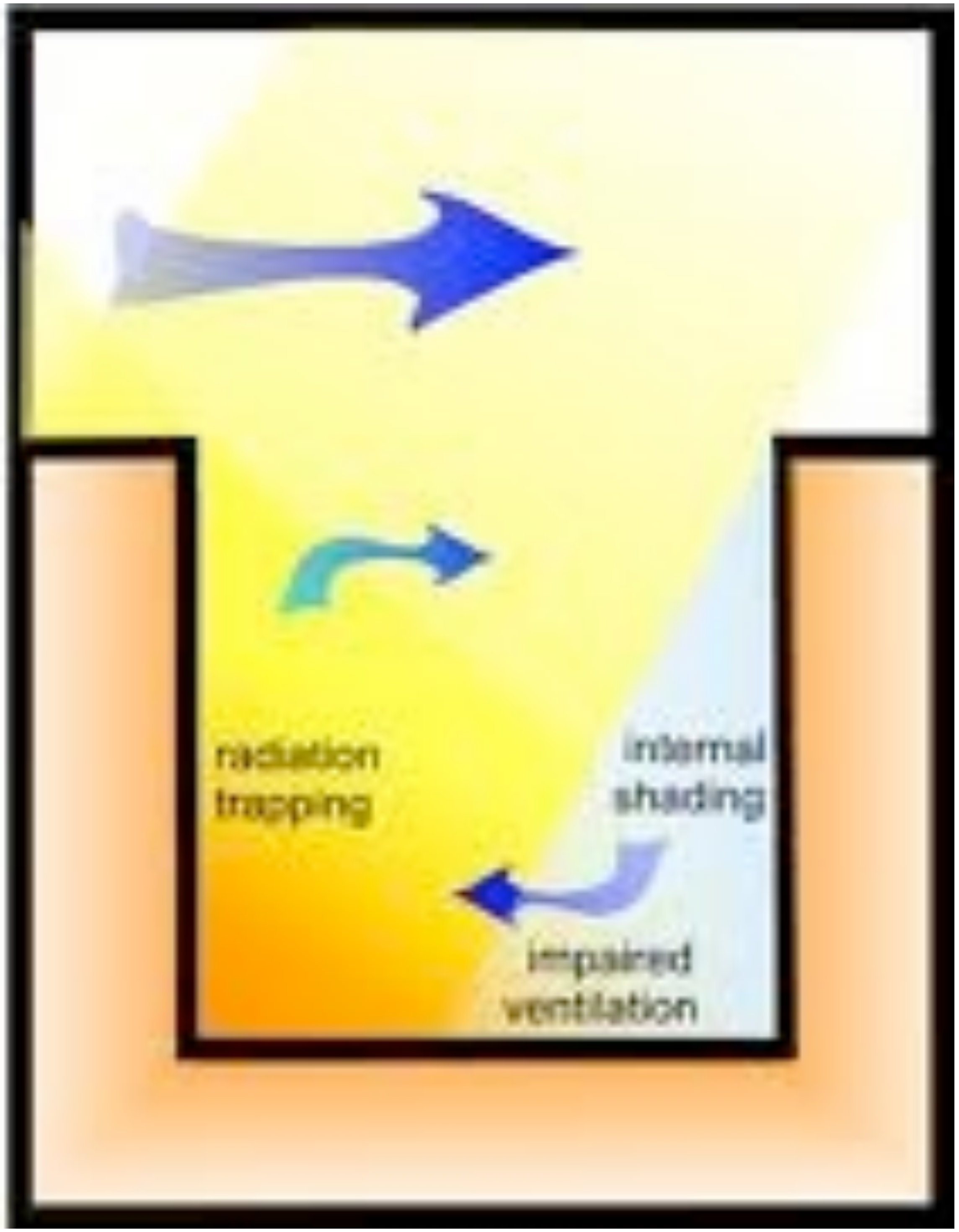


surface radiating temperature

Urban Effects

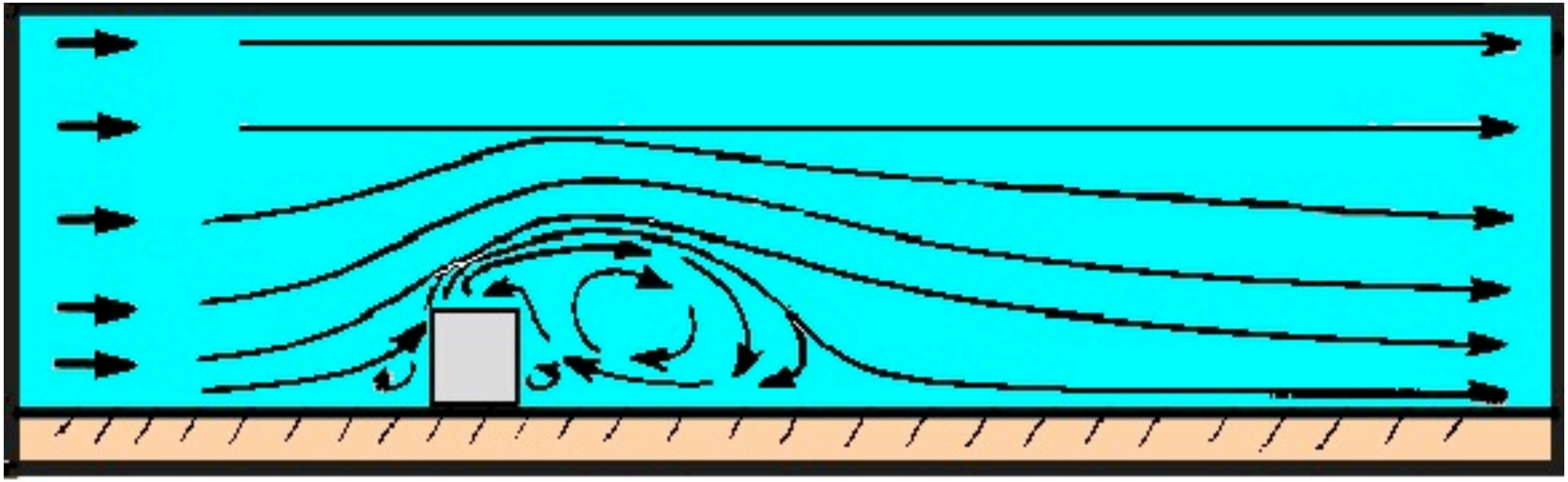
urban street canyon

Urban Effects

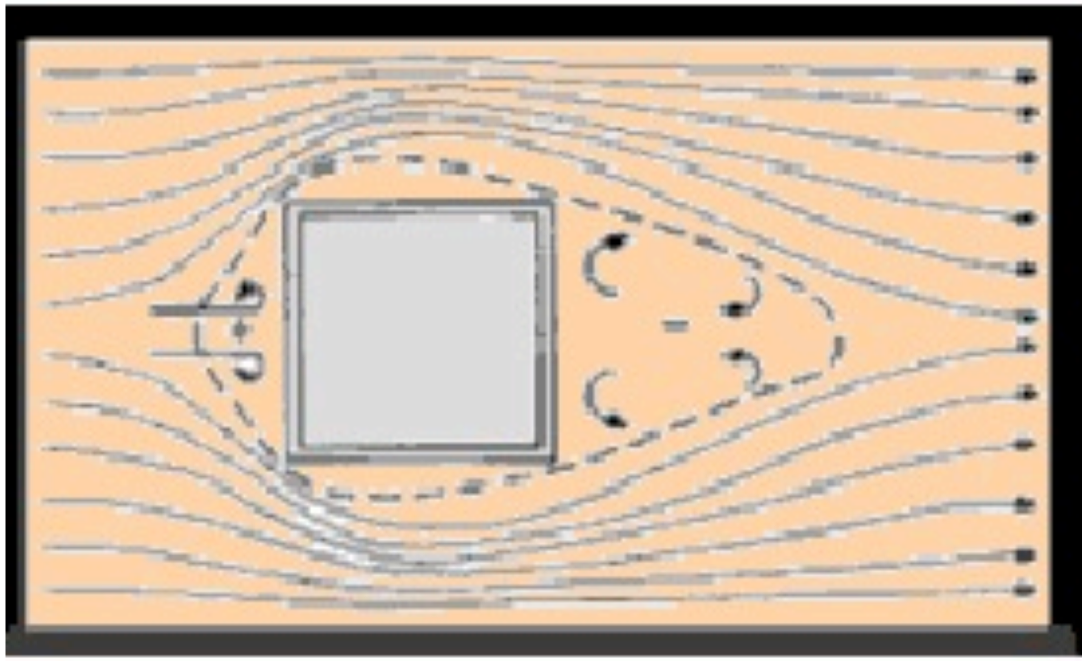


urban street canyon

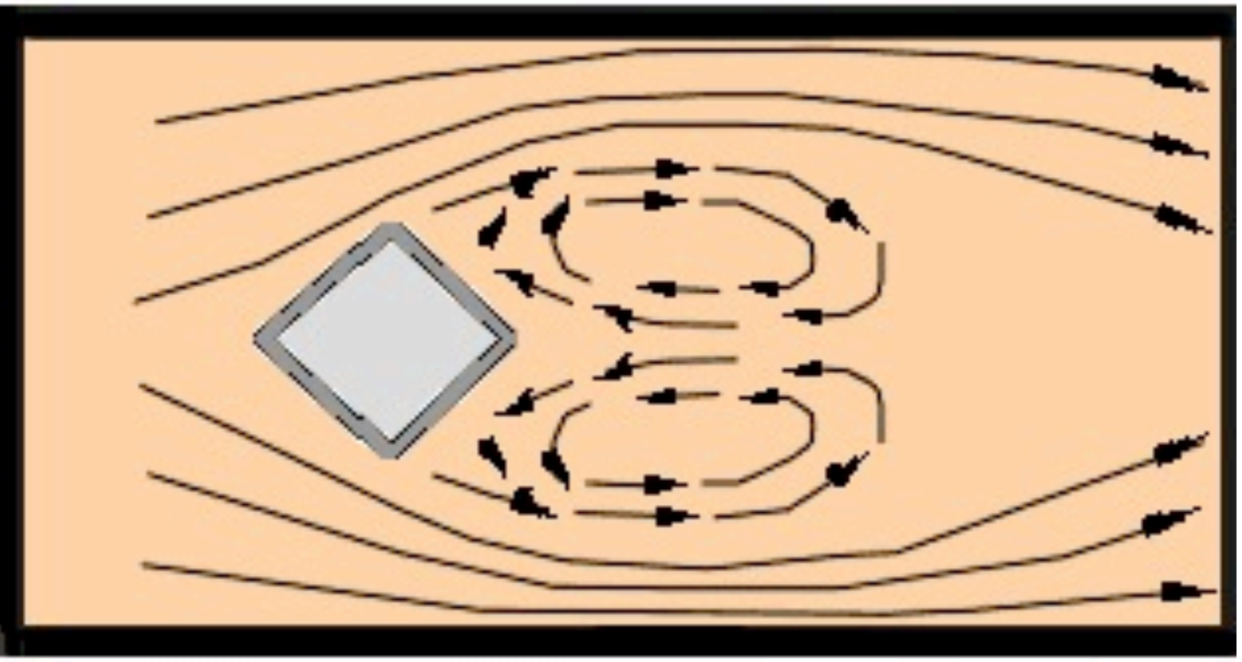
Urban Effects



Flow Pattern: Side View Wind Against Face

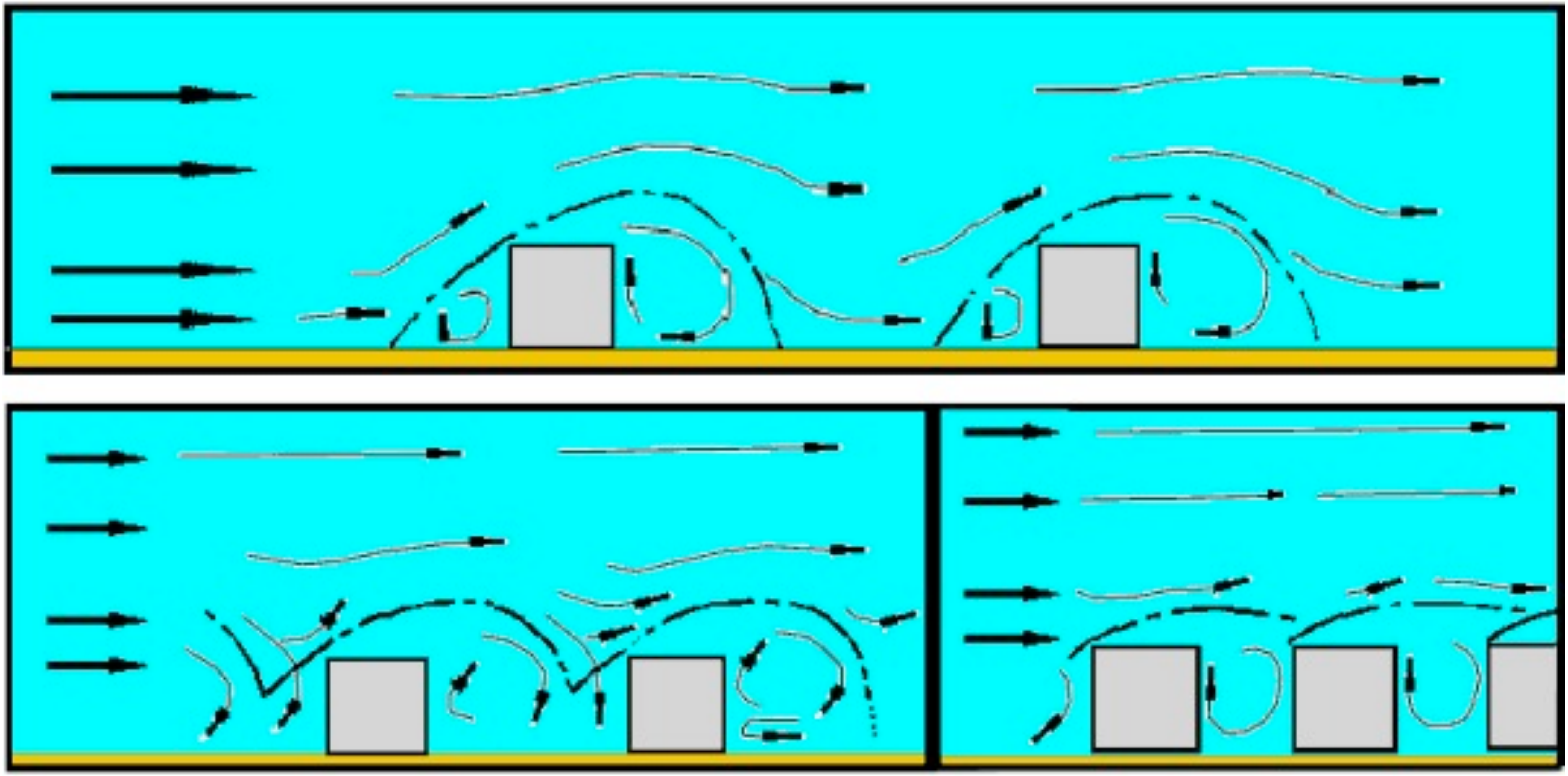


Flow Pattern: Top View
Wind Against Face



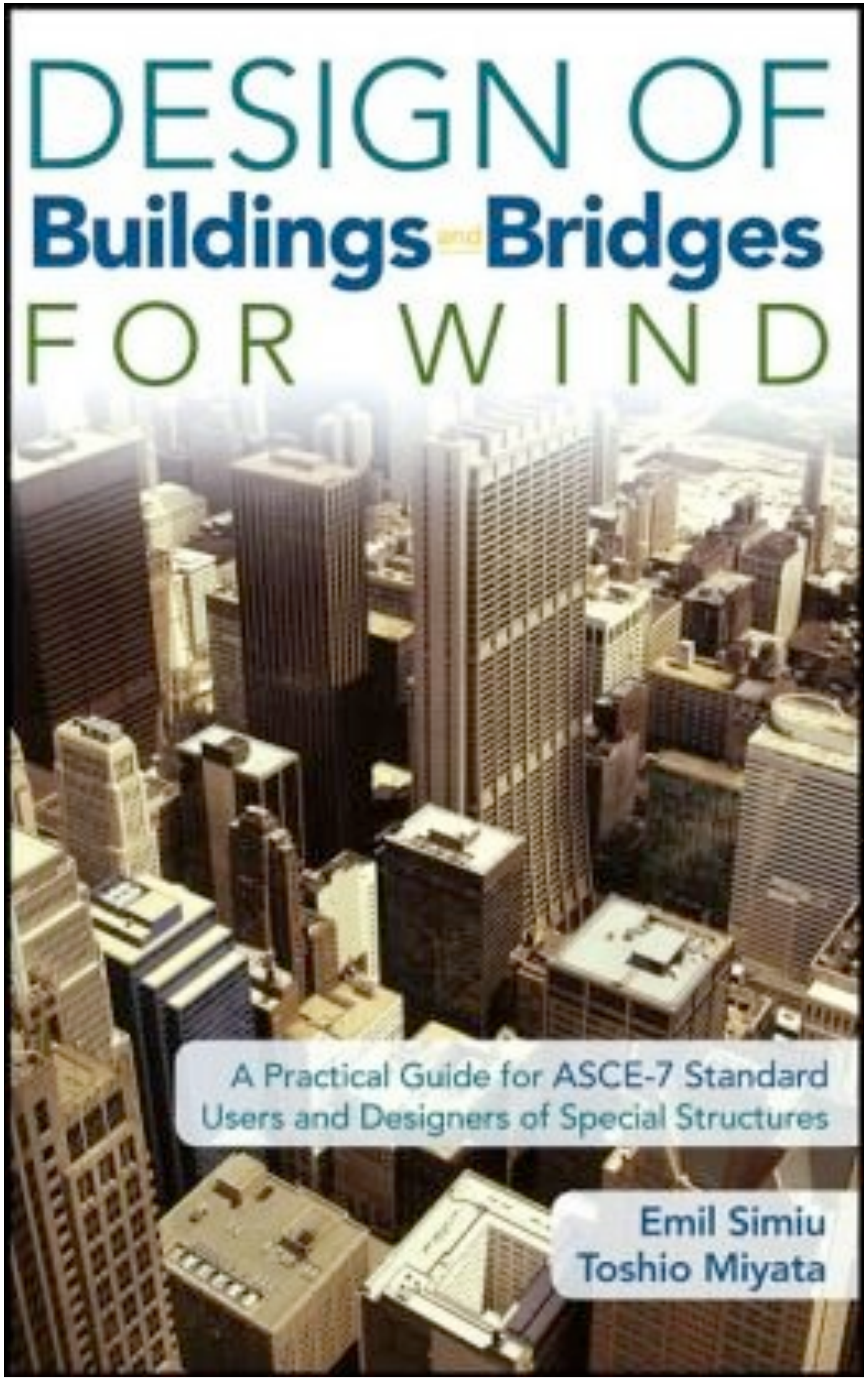
Flow Pattern: Top View
Wind Against Edge

Urban Effects



Urban Wind Flow Patterns With Various Simple Building Shapes and Spacings

Wind Engineering

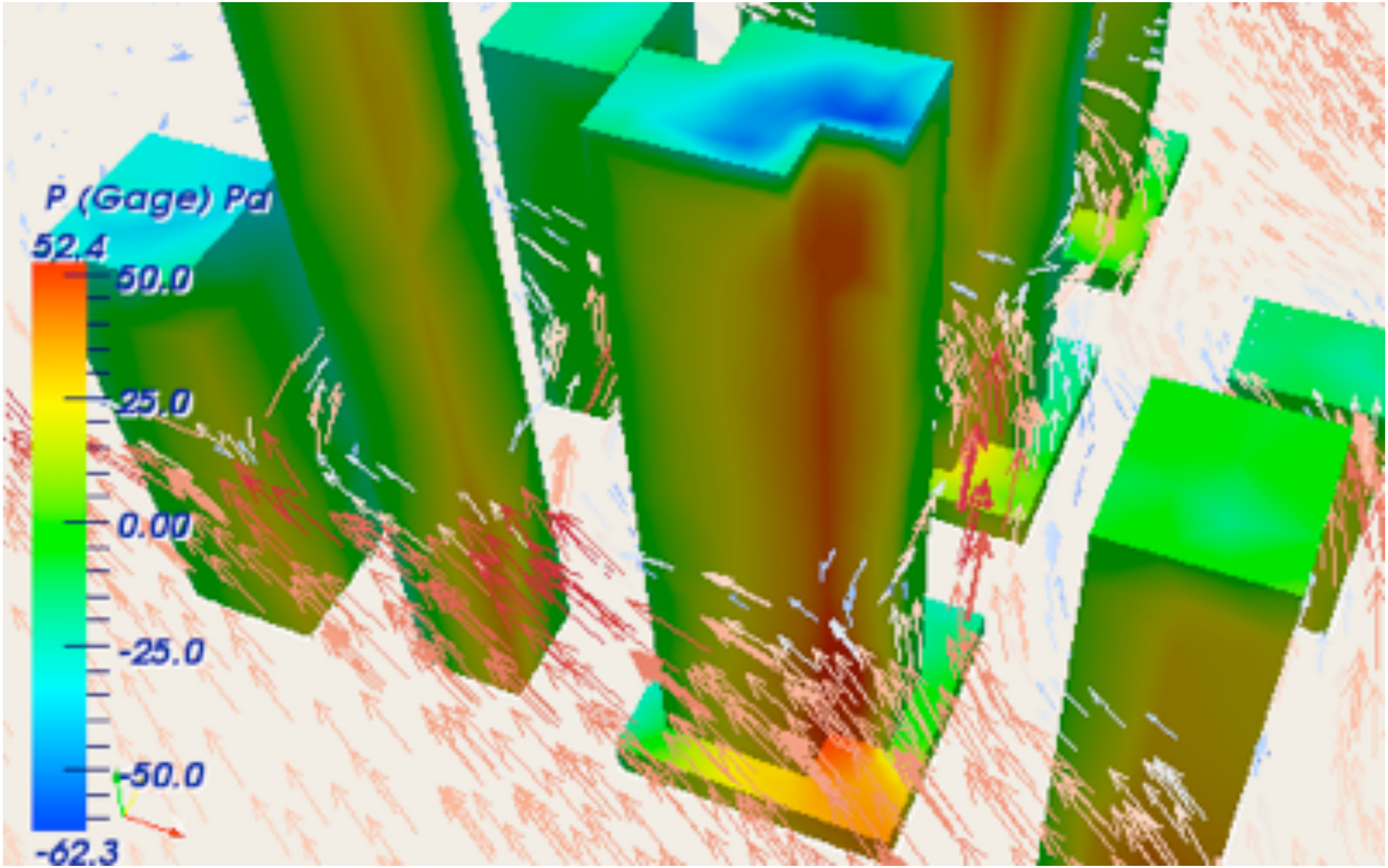


DESIGN OF
Buildings and Bridges
FOR WIND

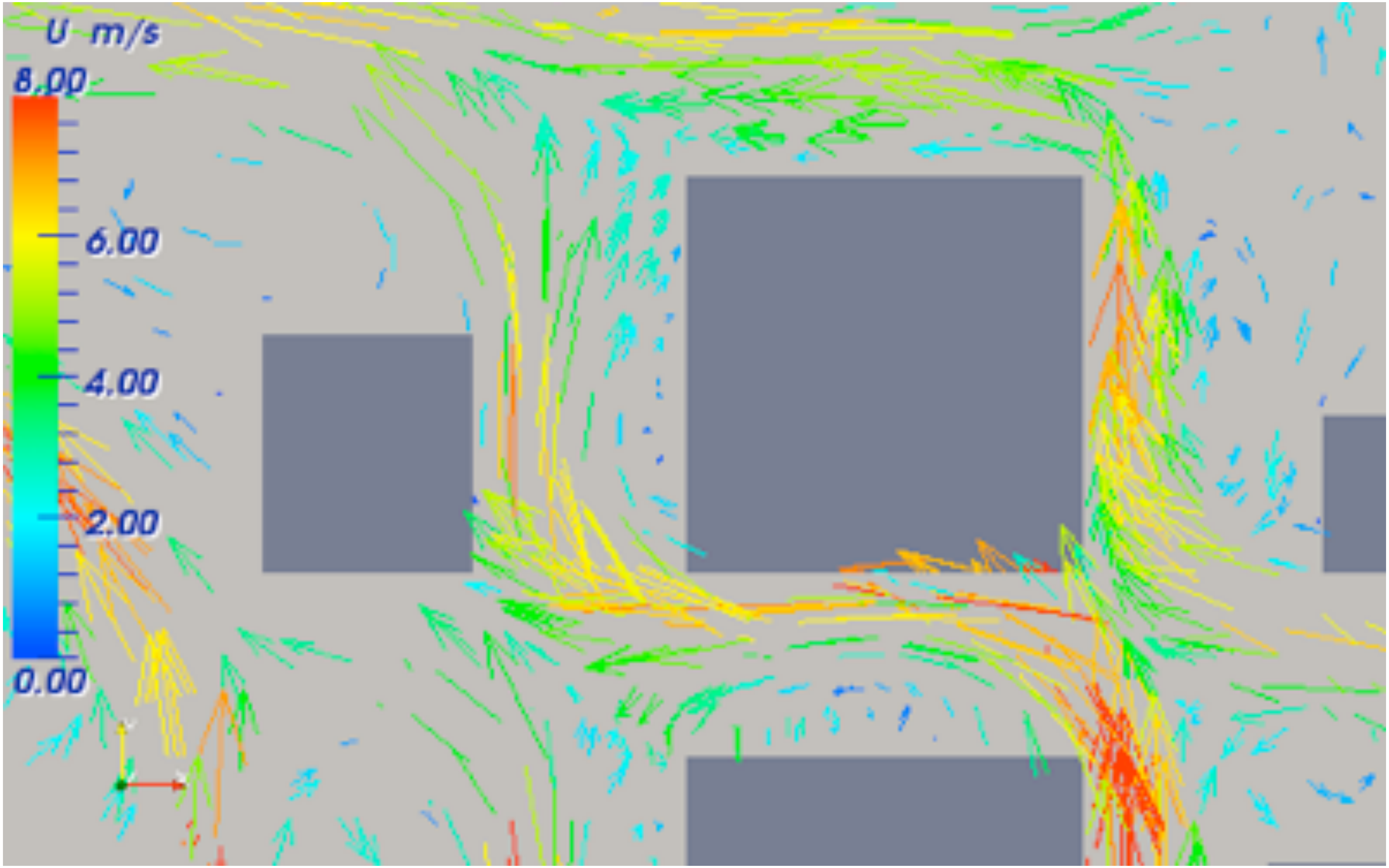
A Practical Guide for ASCE-7 Standard Users and Designers of Special Structures

Emil Simiu
Toshio Miyata

Wind Engineering

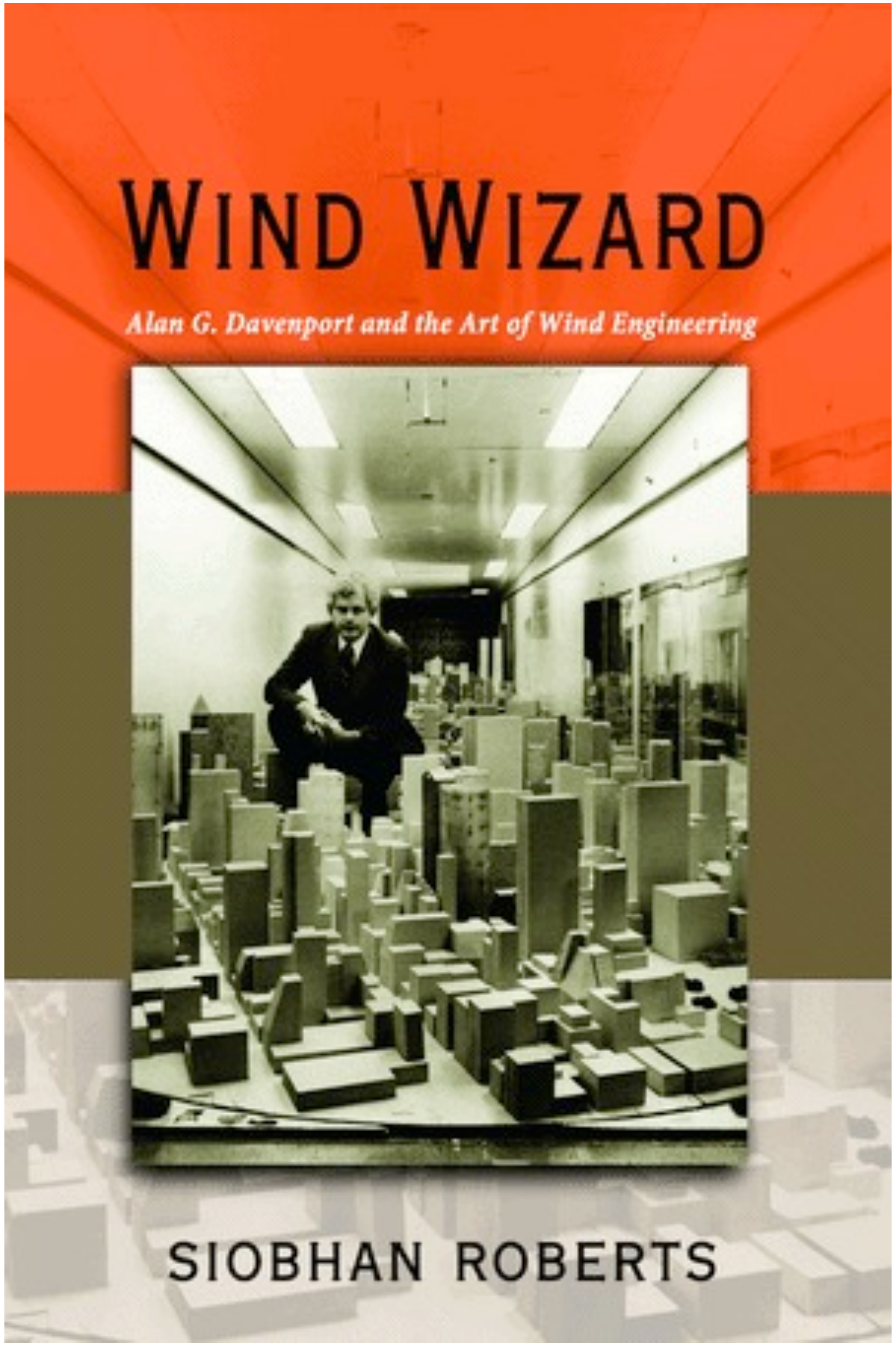


Wind Engineering



Wind Engineering

Wind Engineering



Alan G. Davenport, with a model of New York City in 1980.

DUST STORMS IN THE EASTERN GREAT BASIN

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Department of Atmospheric Sciences

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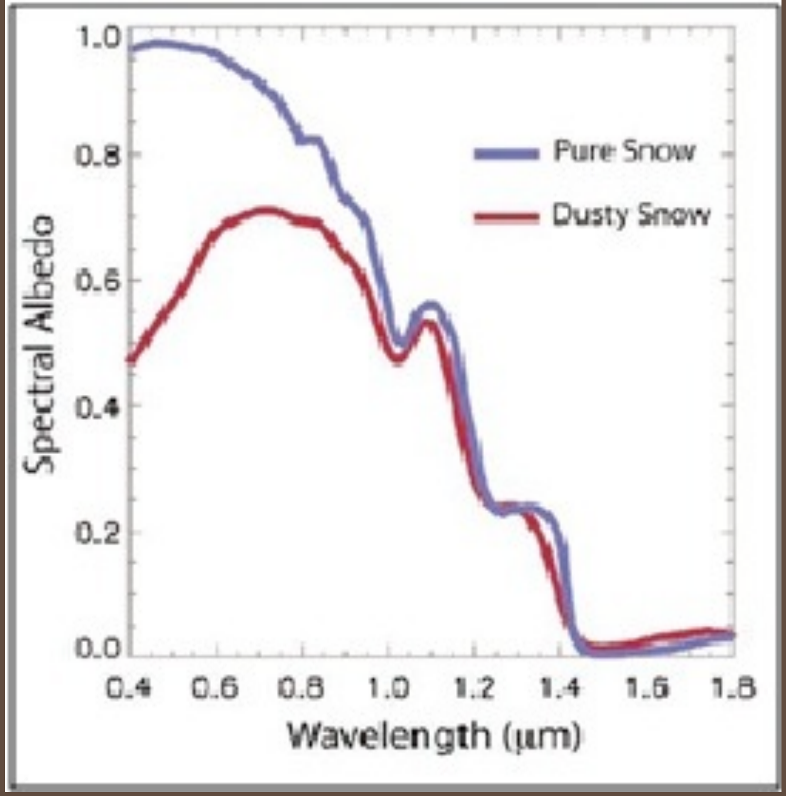
Twitter: @Maura_Science

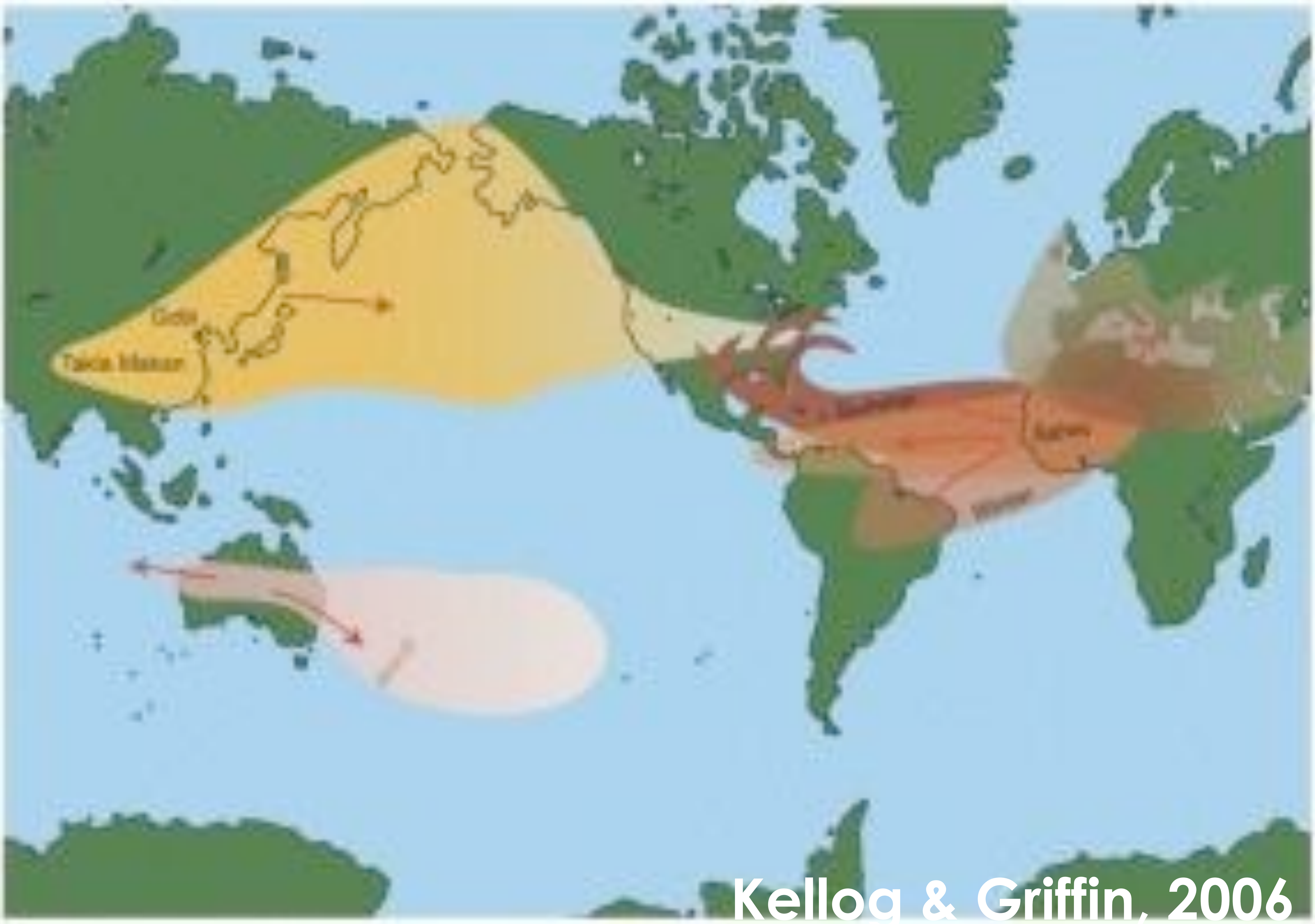
Dust on Snow



- Reduces albedo of snow
- Increases snow melt rate causing
  - Snow free day to be 18-35 days earlier (Painter et al 2007)
- Dusty snow causes
  - Peak runoff 3 weeks earlier at Lee's Ferry
  - Reduces runoff by 5% (Painter et al. 2010)
- Leads to phenological changes in plants (Steltzer et al. 2009)

Health Impacts of dust

- Increases in mortality: Spain (Perez et al. 2008)
- Increases in hospitalization for respiratory ailments: Texas (Grineski et al. 2011)
- Coarse particles:
  - Deposited in bronchial passages leading to respiratory conditions
- Fine particles:
  - Reach alveoli leading to cardiovascular events

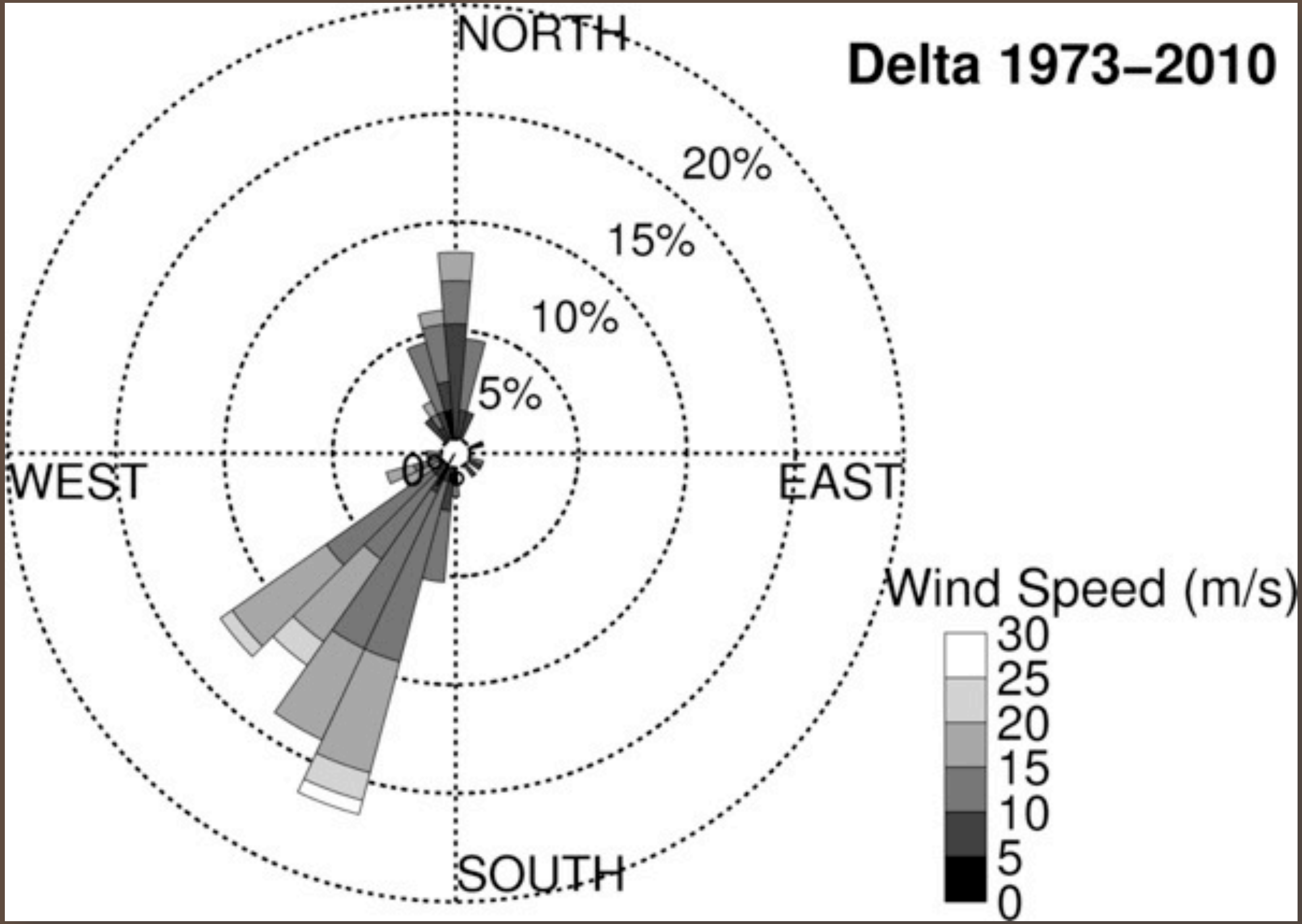


Kellog & Griffin, 2006

Utah dust storms sometimes:

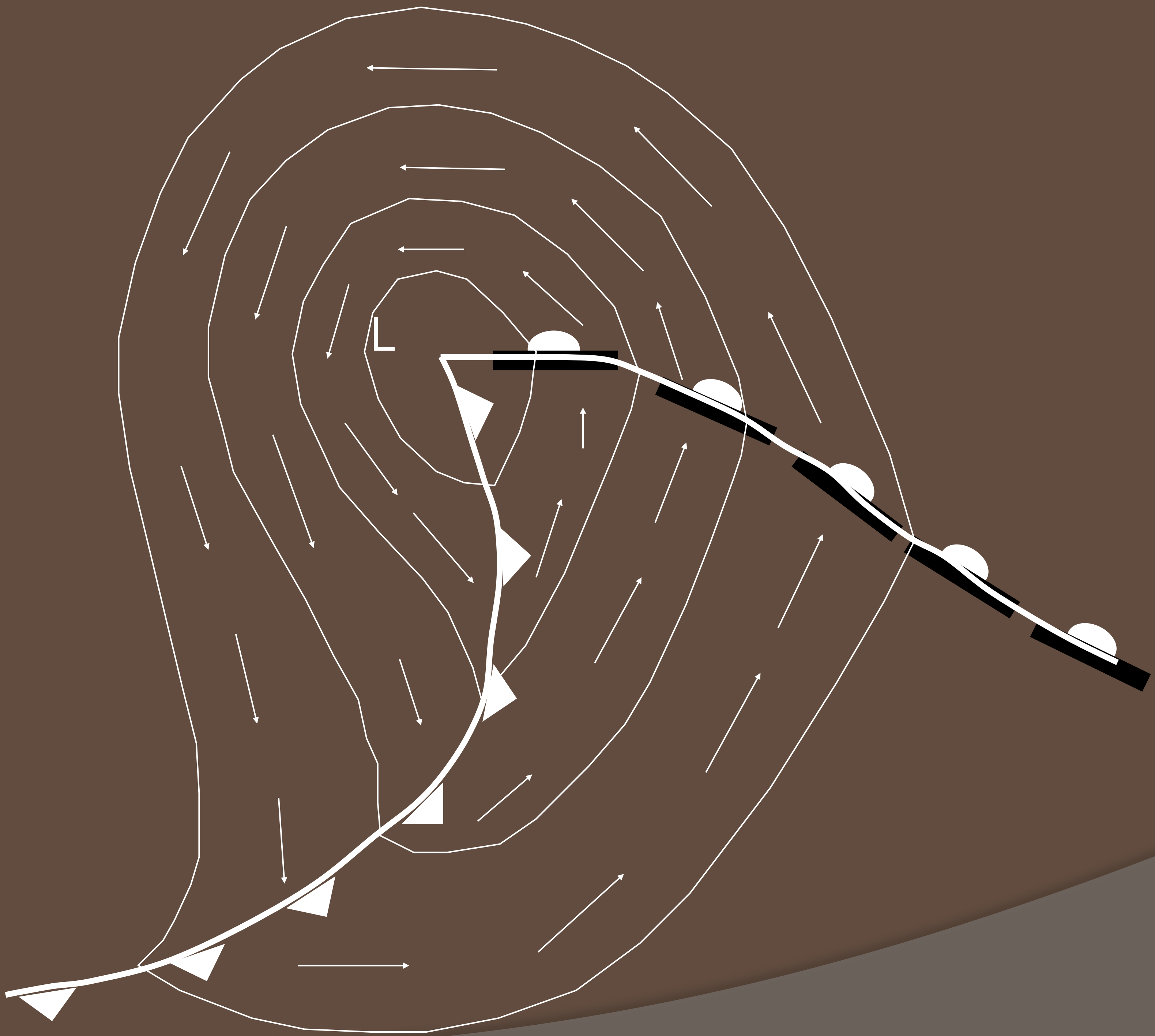
- Occur in March and April
- Occur during clear sky conditions
- Dense enough to totally obscure the sun and reduce visibility
- Accompanied by strong damaging winds
- Formed by winds from the south and southwest
- Followed by a wind shift to the northwest ending the dust storm
- Followed by muddy rain or snow washing out the dust
- Negatively impact human health and welfare
- Cause damage to crops and property

What wind speeds and directions are associated with the Dust Storms?



- Southwest winds
- Occasionally with northerly winds
- Usually speeds from 10-20 m/s (22-45 mph)

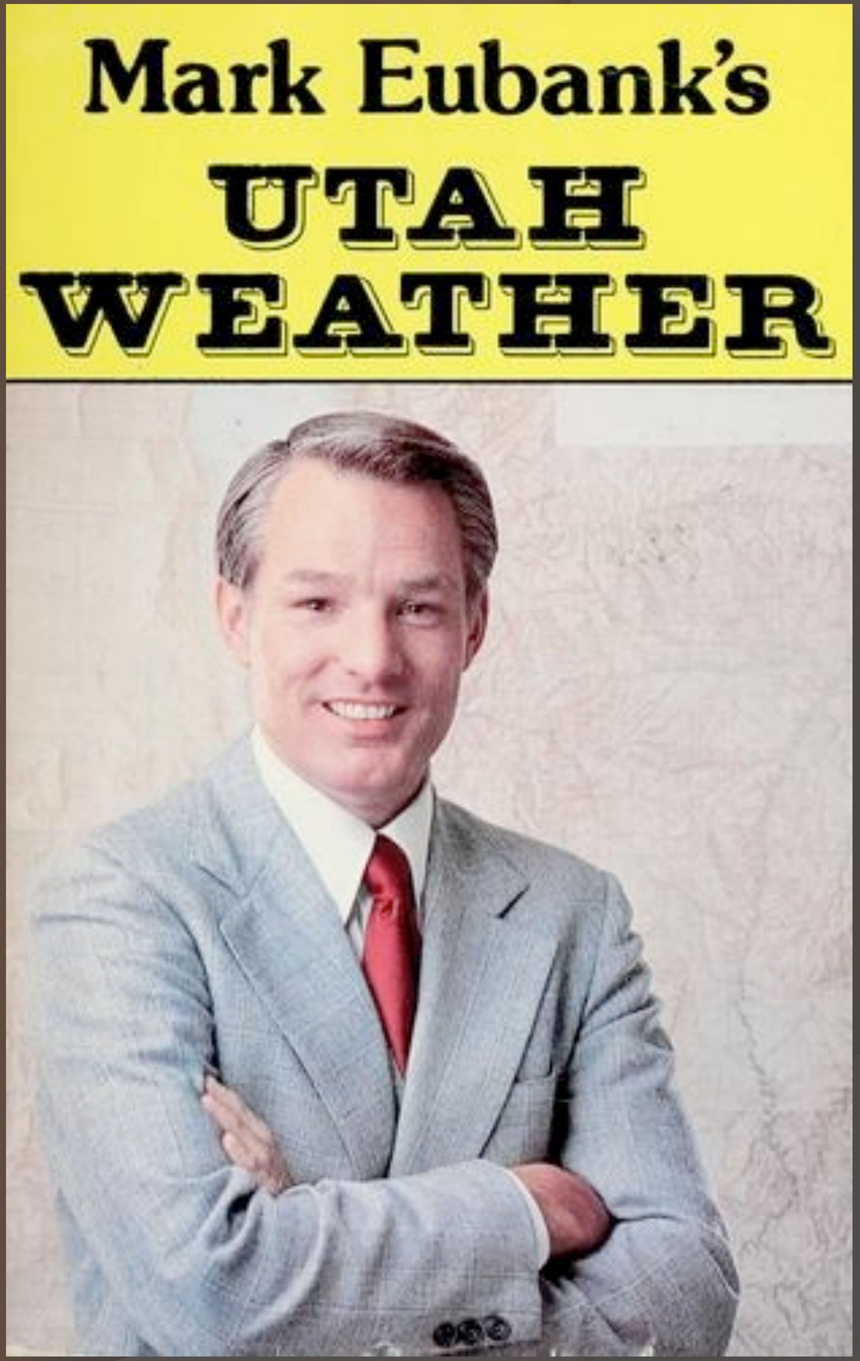
When do we get South winds?



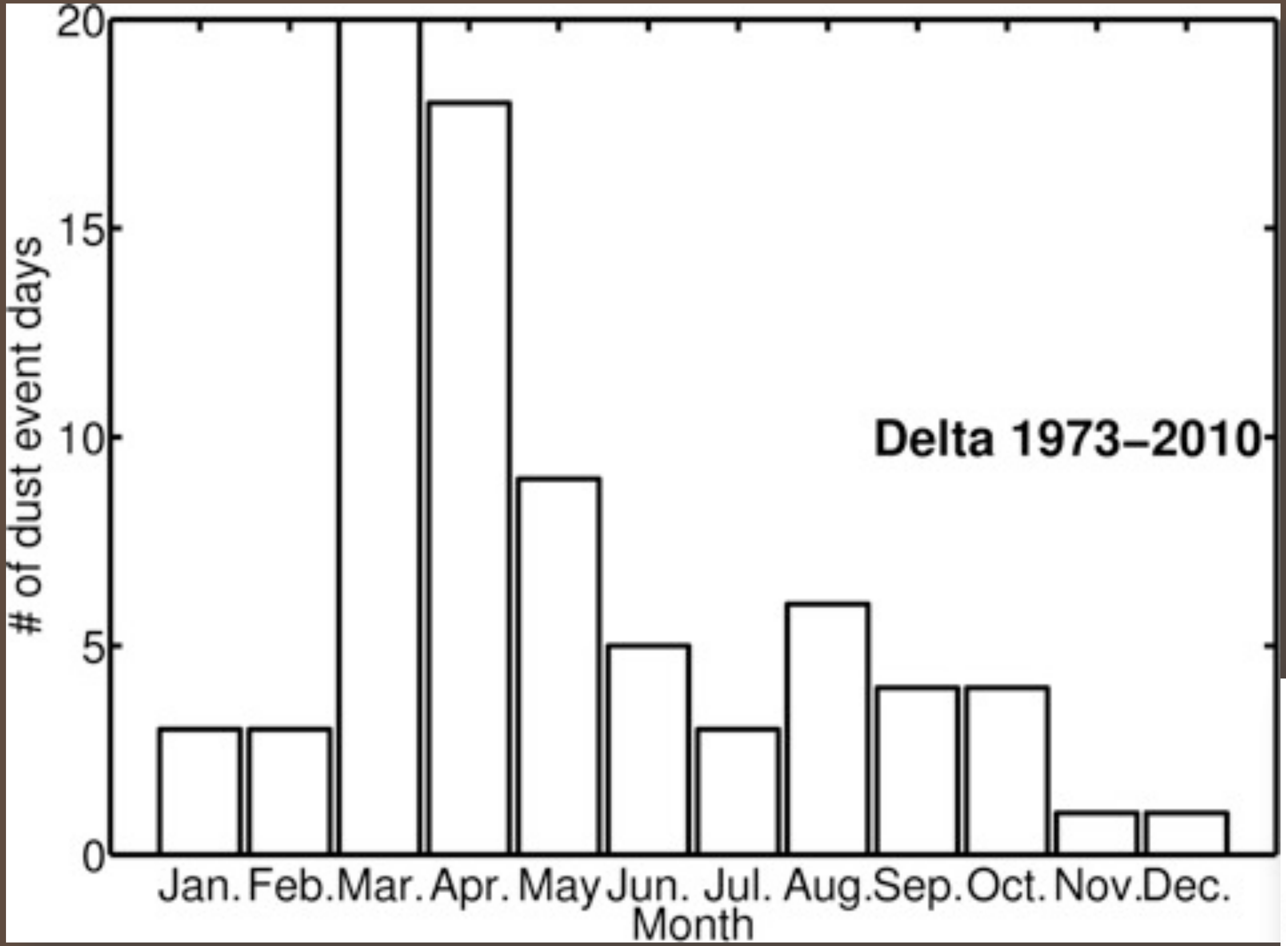
The "Hatu" Winds

- "Hatu" is "Utah" spelled backward
- "Warm winds coming from the south that occur ahead of an approaching storm."
- Pre-frontal dry winds
- These types of winds are a known producer of regional dust transport in arid regions.

(Goudie 1978; Rivera Rivera et al. 2009; Strong et al. 2010)

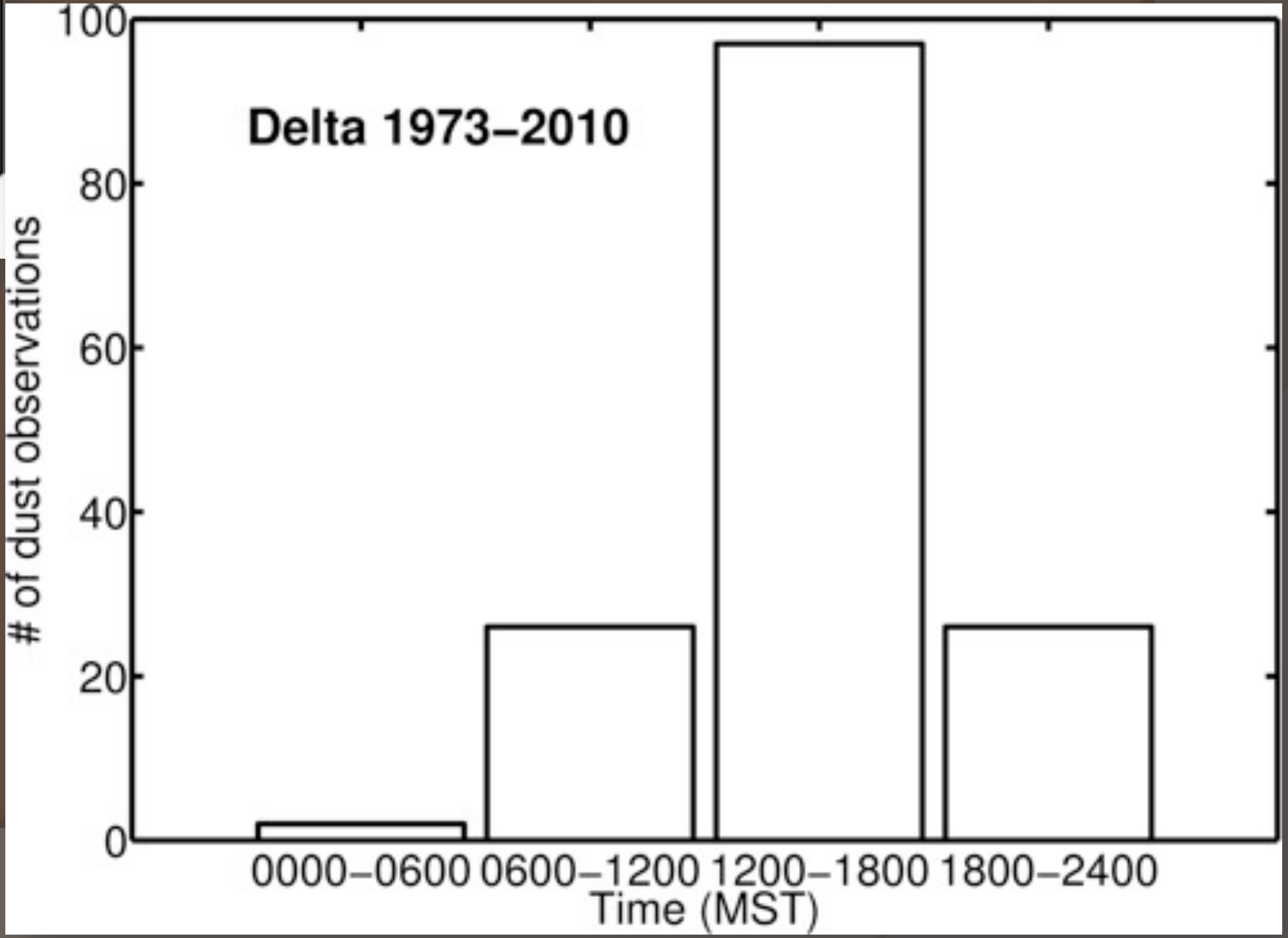


When do Dust Storms occur in the Eastern Great Basin?



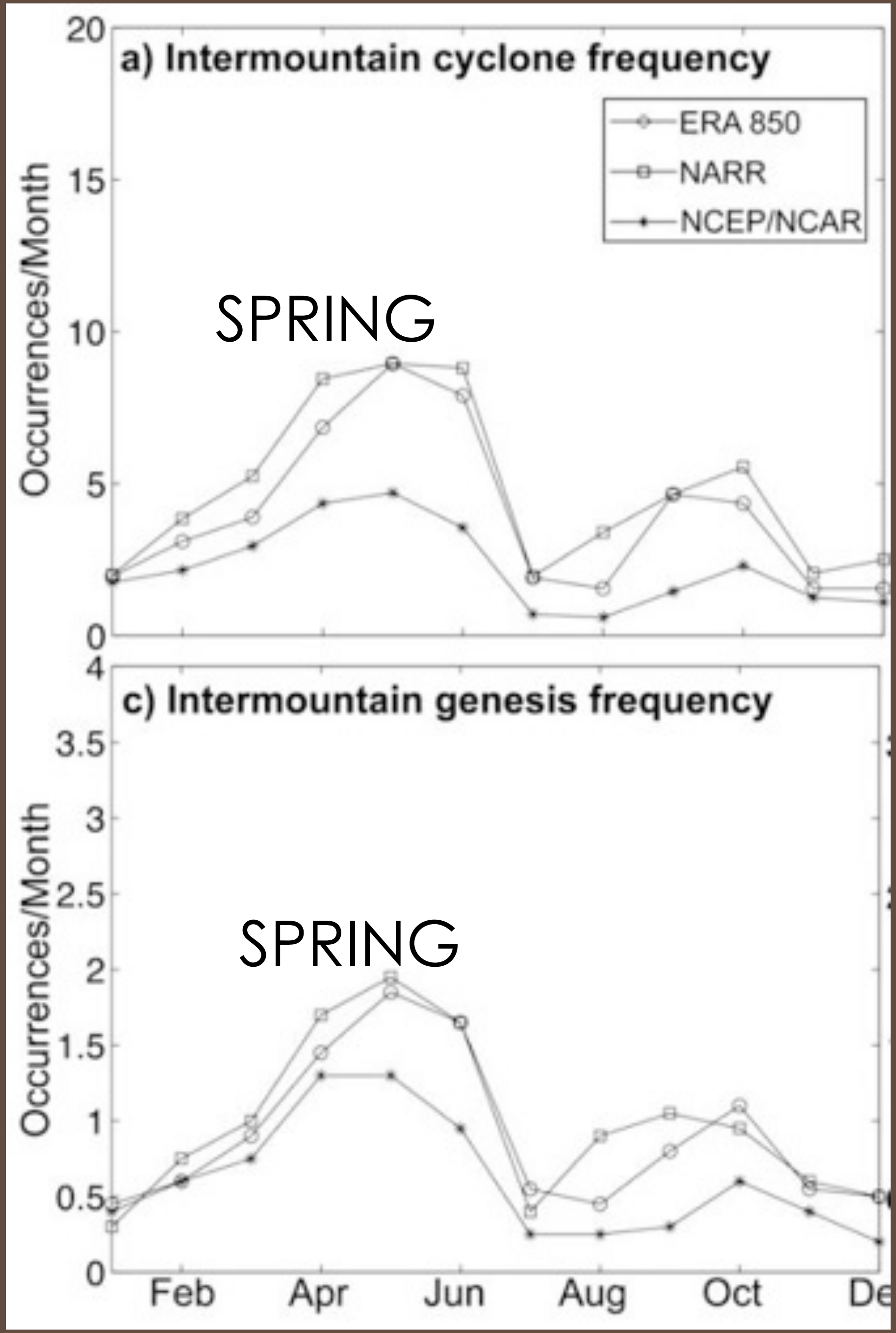
In the spring, with a much weaker peak in the fall.

In the afternoon.



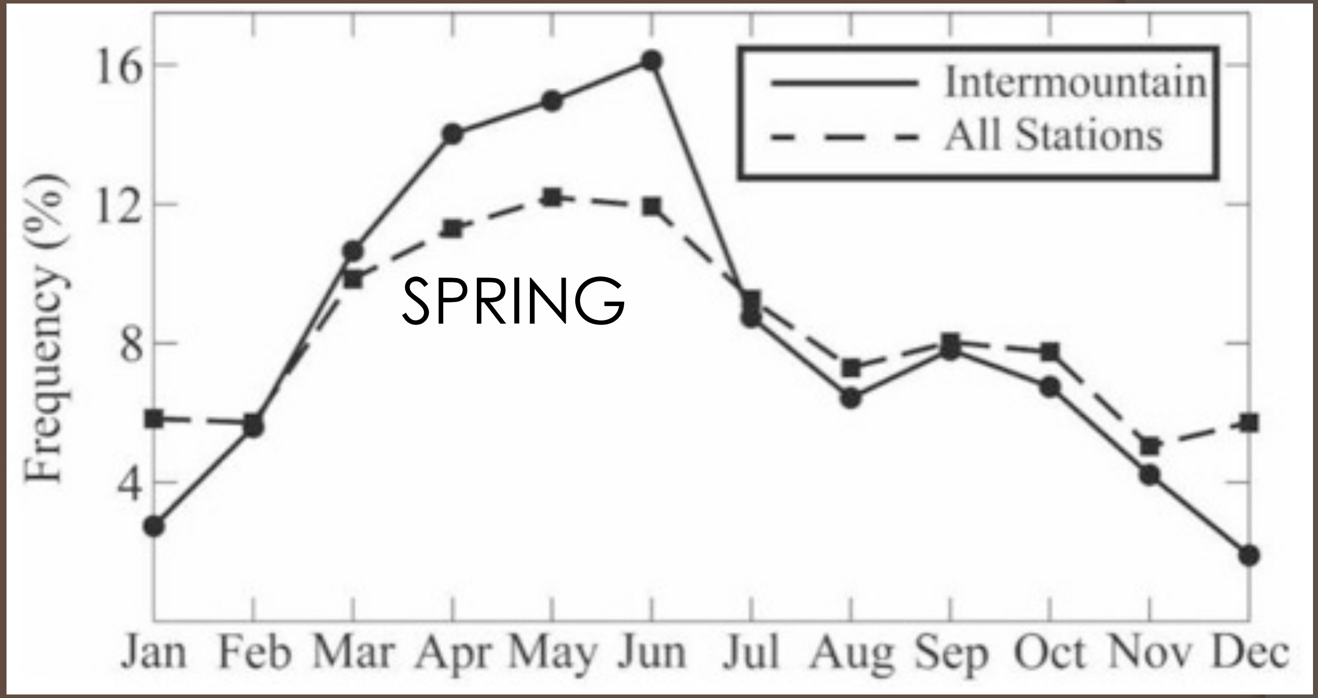
Cyclo and Frontogenesis in the Great Basin

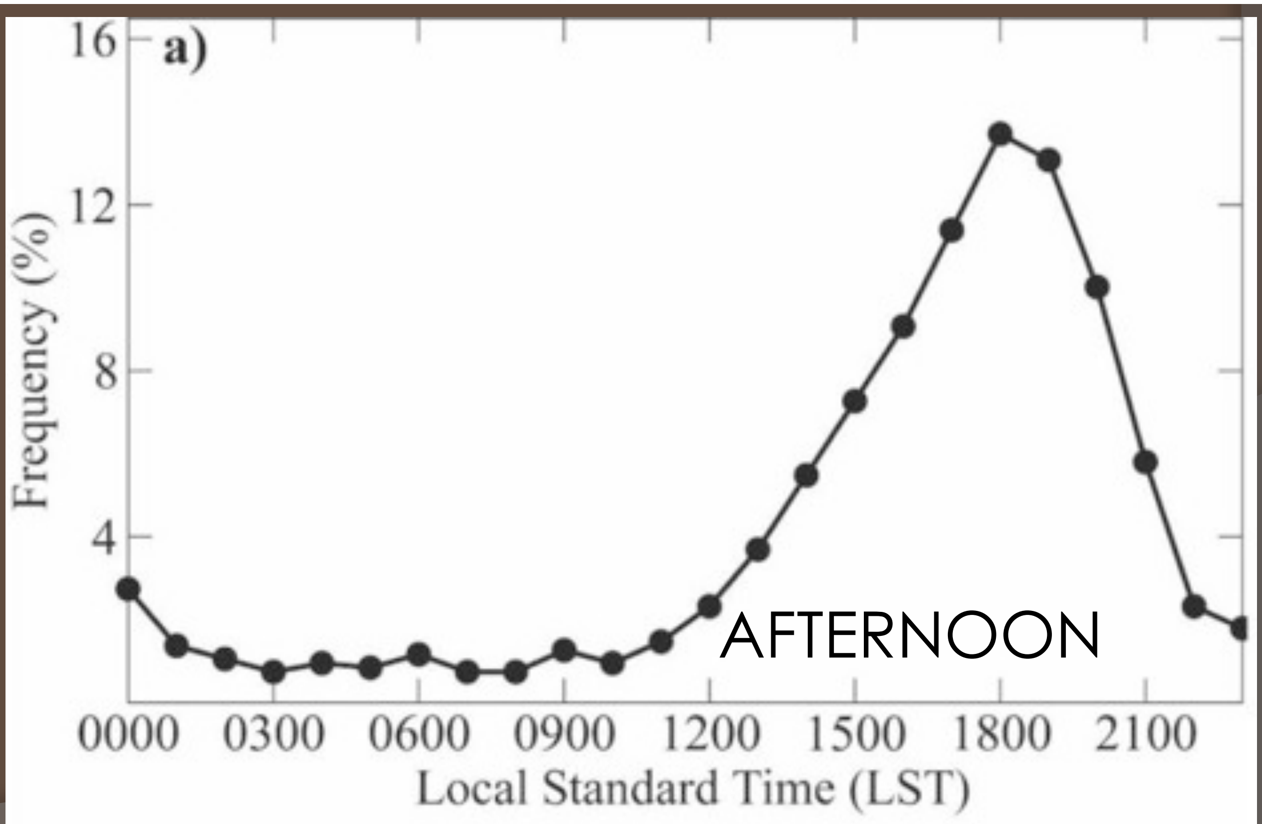
Intermountain Cyclones



(Jeglum et al., 2010)

Strong Frontal Passages





(Shafer and Steenburgh, 2008)

Summary of Meteorology

- Strengthening cyclonic systems over the northern Great Basin are the main driver of dust events in this region
  - With the dust event occurring in the pre frontal southerly wind environment
- Dust events occur mostly in spring and sometimes in fall
  - Matches the climatology of strong fronts and cyclogenesis in this region
- Dust events have a diurnal pattern peaking in the afternoon
  - Which is coincident with the maximum boundary layer depth
- Dust events have a clear impact on air quality in the SLC region
  - Elevated particulate levels during most dust events and many days exceeding NAAQS for PM10

(Hahnenberger and Nicoll, 2012, Atmospheric Environment)

Summary of Source Areas

- Most dust plumes originate from:
  - Dry Lake Beds (Playas)
  - Disturbed areas
- Anthropogenic influence on most sources
- Drought helps drive dust production
- Human activities can directly alter dust production…
  - Must take landscape, soils, and climate into account

(Hahnenberger and Nicoll, submitted, Geomorphology)