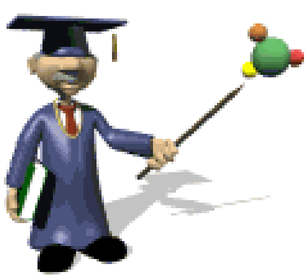
WEATHER AND CLIMATE
ENVS1140

# Chapter 7 –
# Atmospheric Circulations

(pp. 165-195)

# Contents

- scales of motion and turbulence
- local winds
- the General Circulation of the atmosphere
- ocean currents



# Wind Examples

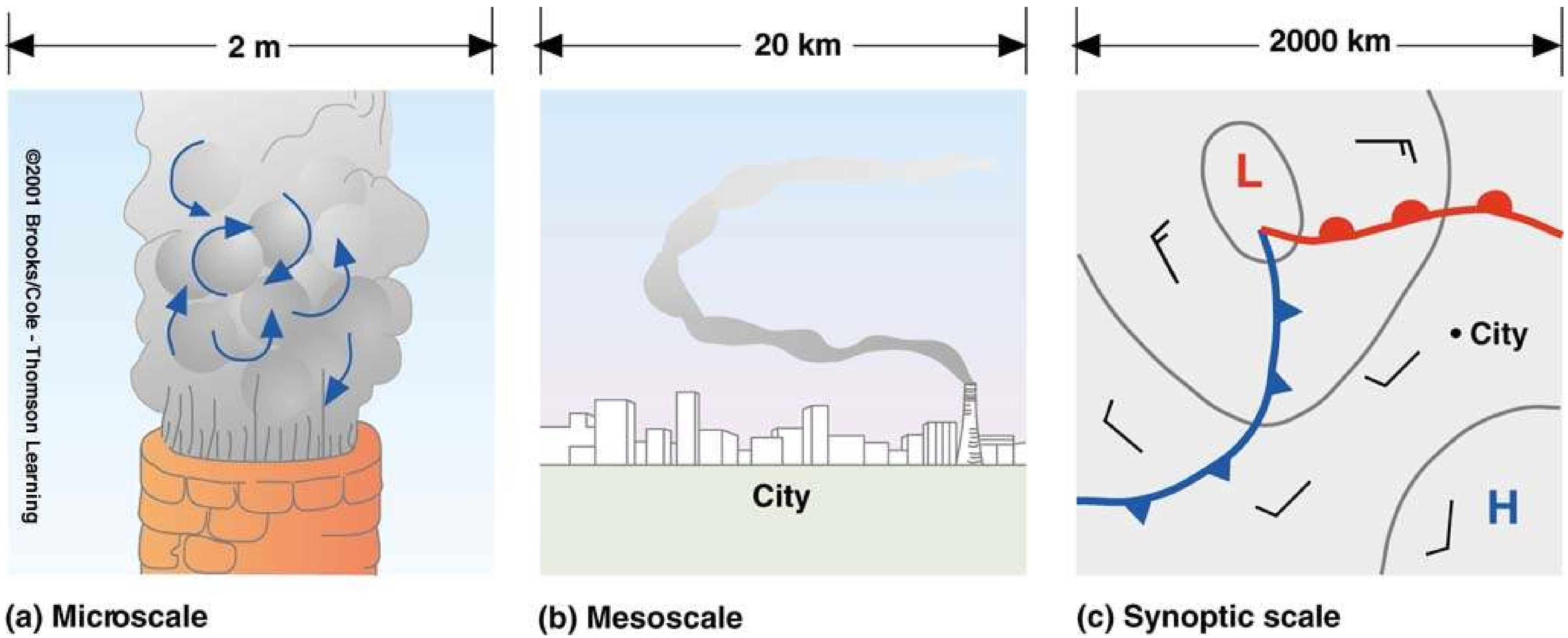



Fig. 7.1: Scales of atmospheric motion.
Microscale → mesoscale → synoptic scale.

# Scales of Motion

- Microscale
  - e.g. chimney
  - Short lived ‘eddies’, chaotic motion
  - Timescale: minutes
- Mesoscale
  - e.g. local winds, thunderstorms
  - Timescale mins/hr/days
- Synoptic scale
  - e.g. weather maps
  - Timescale: days to weeks
- Planetary scale
  - Entire earth

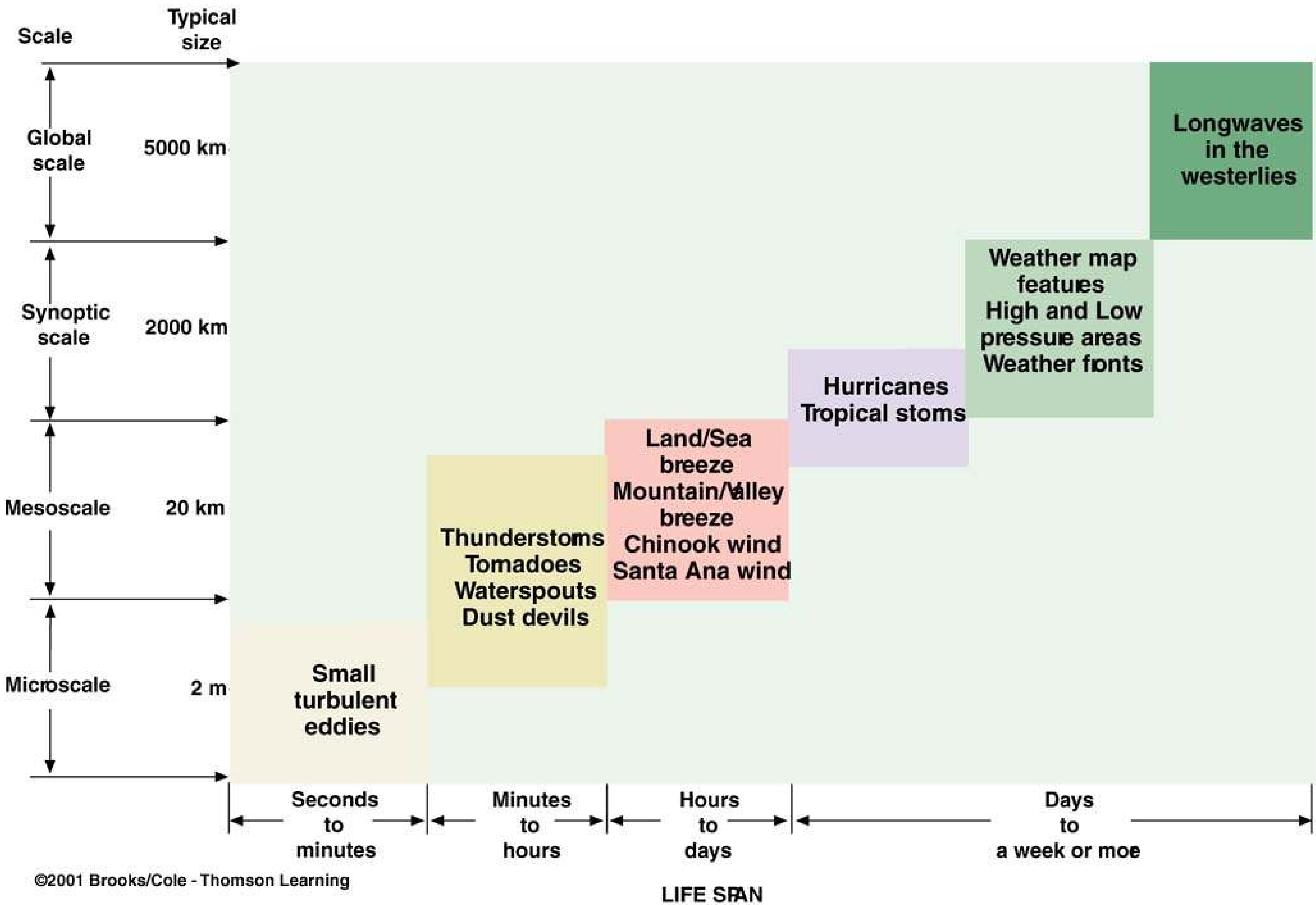



Table 7.1: Scales of atmospheric motion

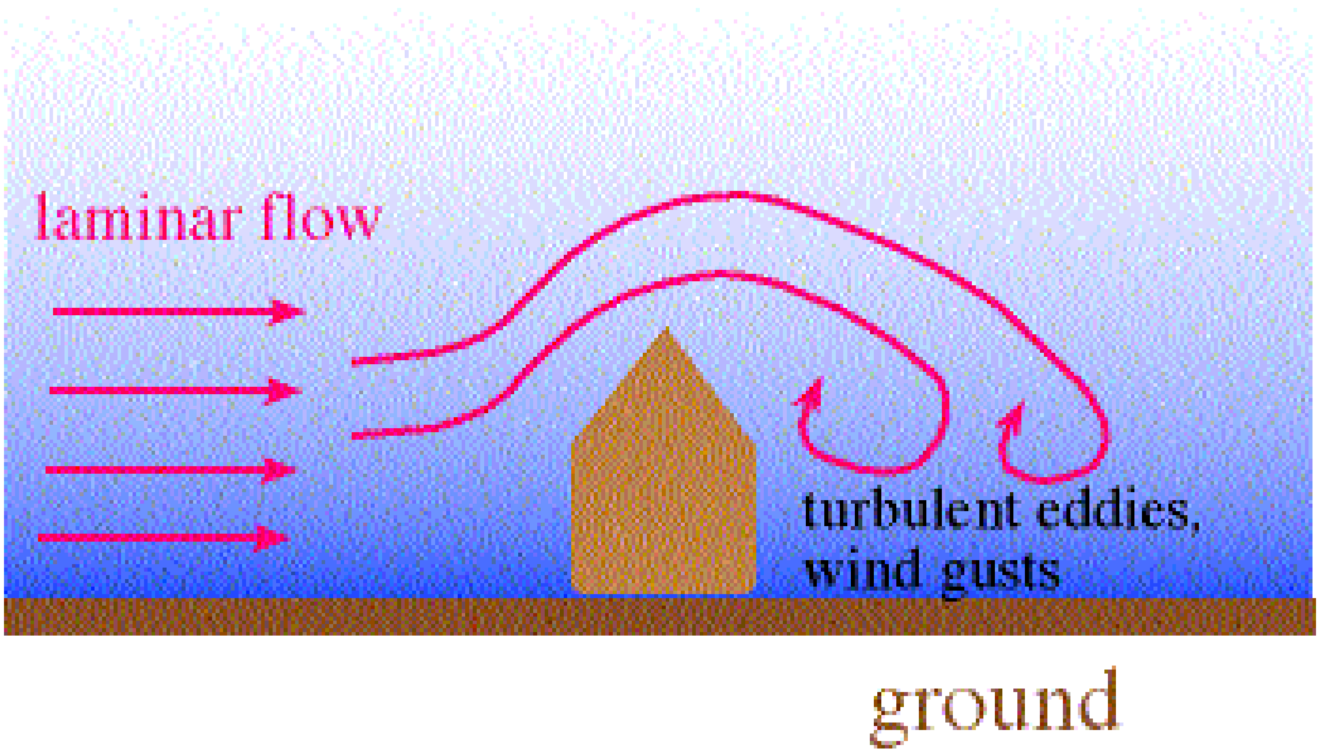
# Turbulence

- Eddies: internal friction generated as laminar (smooth, steady) flow becomes irregular and turbulent
- Most weather disturbances involve turbulence


- 3 kinds:
  - Mechanical turbulence – you, buildings, etc.
  - Thermal turbulence – due to warm air rising and cold air sinking caused by surface heating
  - Clear Air Turbulence (CAT) - due to wind shear, i.e. change in wind speed and/or direction

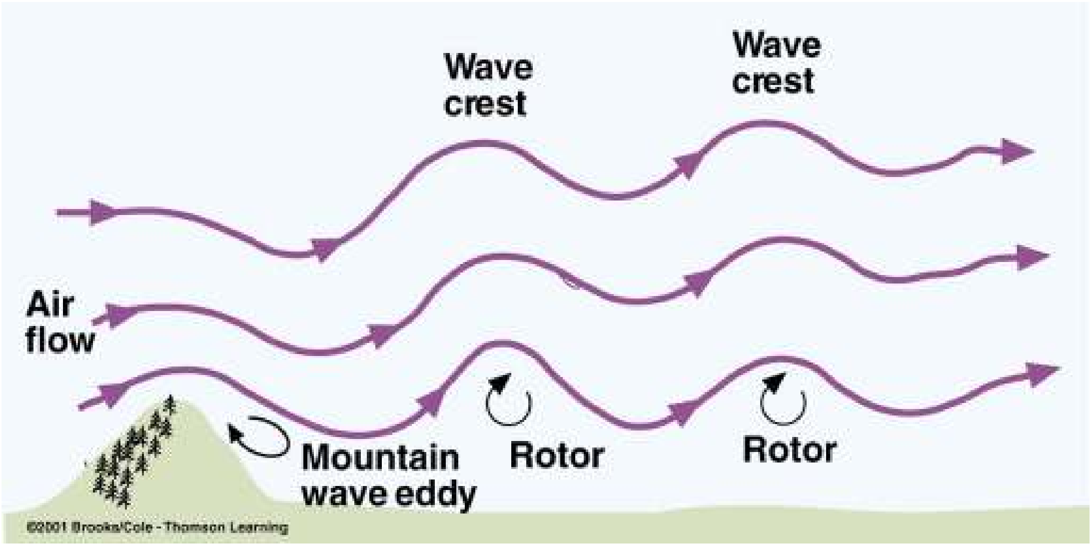
# Mechanical Turbulence

- Mechanical turbulence – due to flow over or around objects (mountains, buildings, etc.)



# Mechanical Turbulence: Wave Clouds

- Flow over a mountain, generating:
  - Wave clouds
  - Rotors, bad for planes and gliders!



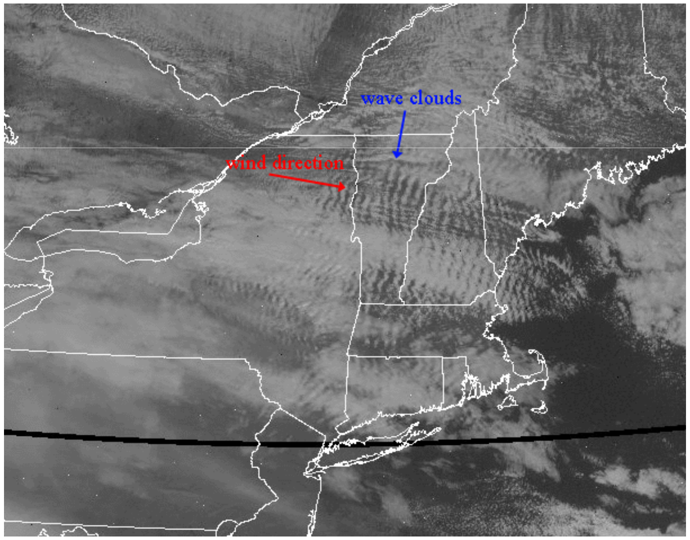
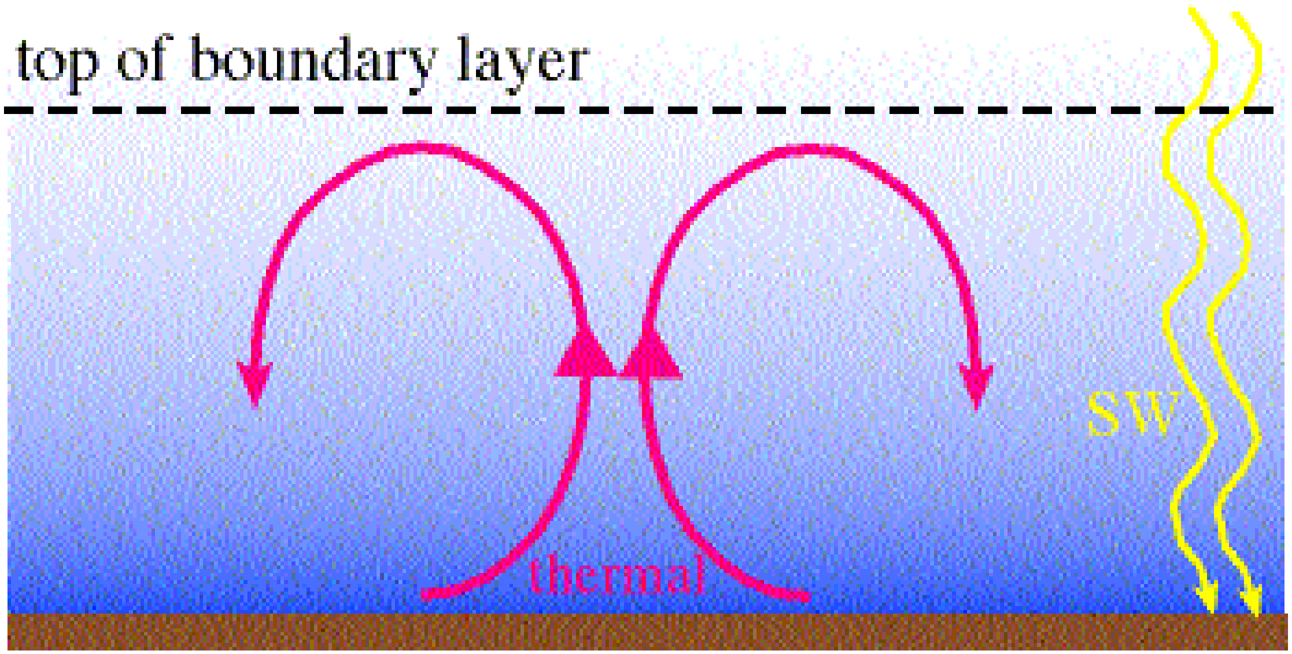
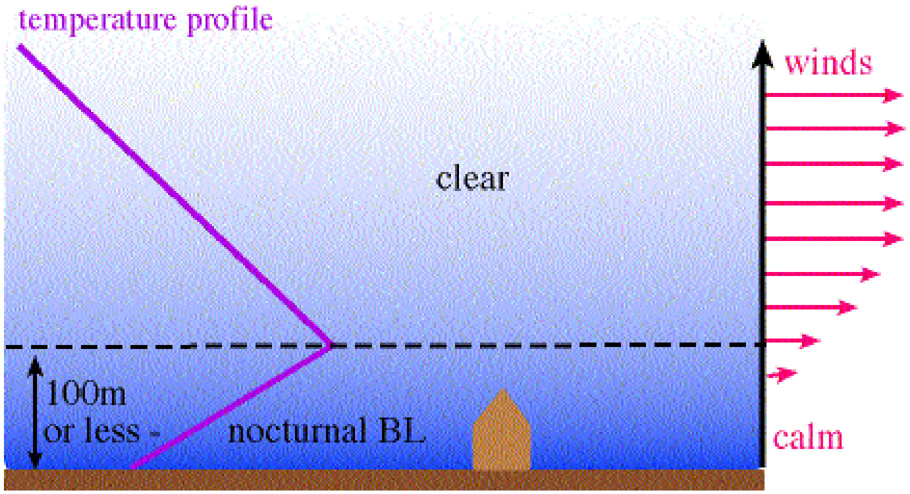




Fig. 7.2: Mechanical turbulence - Air flowing past a mountain range creates eddies hazardous to flying.

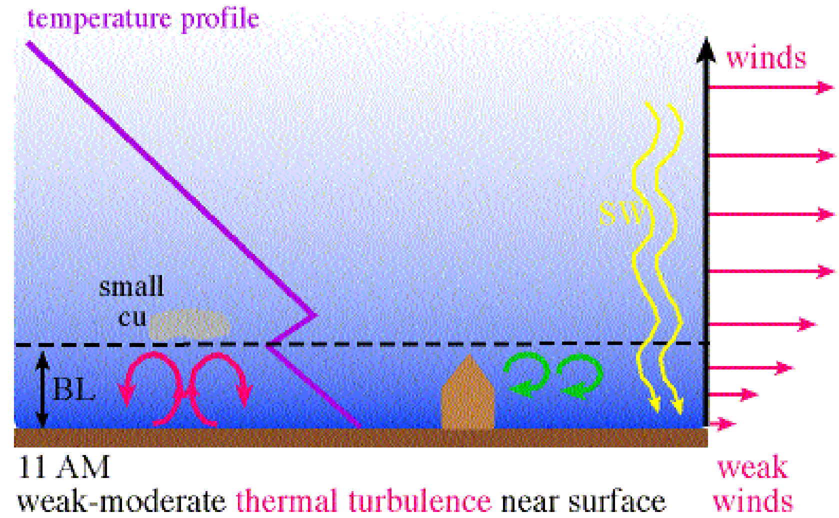
# Thermal Turbulence

- Thermal turbulence - essentially rising thermals of air generated by surface heating
- Thermal turbulence is maximum during max surface heating - mid afternoon

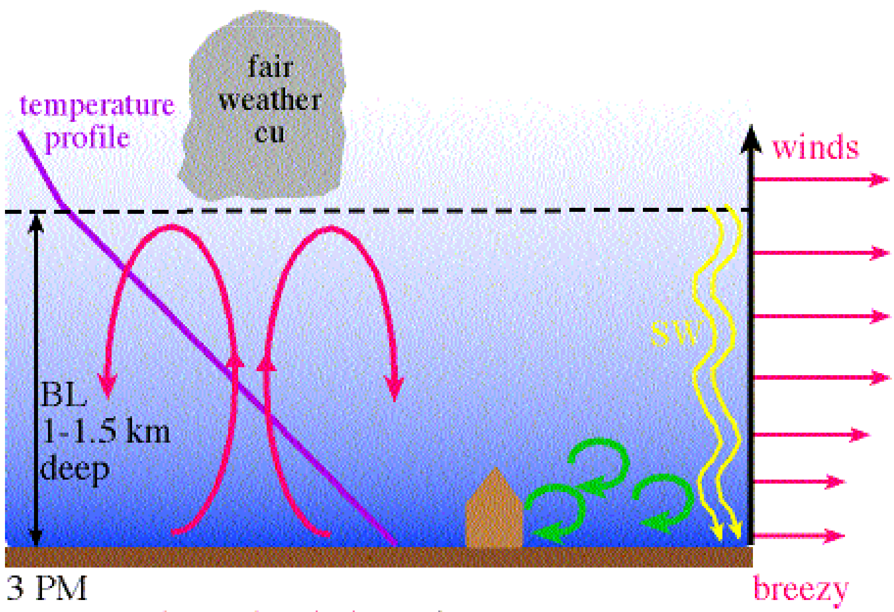




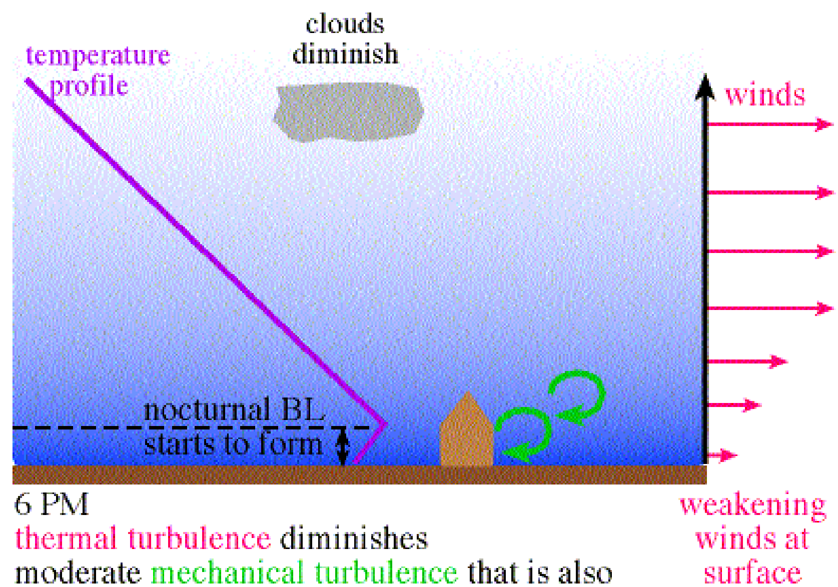

6 AM
No thermal turbulence
Little/no mechanical turbulence




11 AM
weak-moderate thermal turbulence near surface
weak-moderate mechanical turbulence near surface




3 PM
strongest thermal turbulence in BL
strongest mechanical turbulence in BL

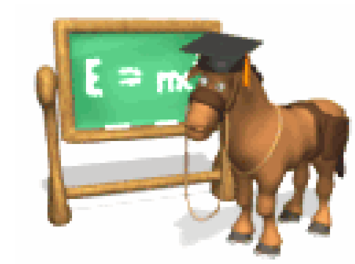



6 PM
thermal turbulence diminishes
moderate mechanical turbulence that is also diminishing

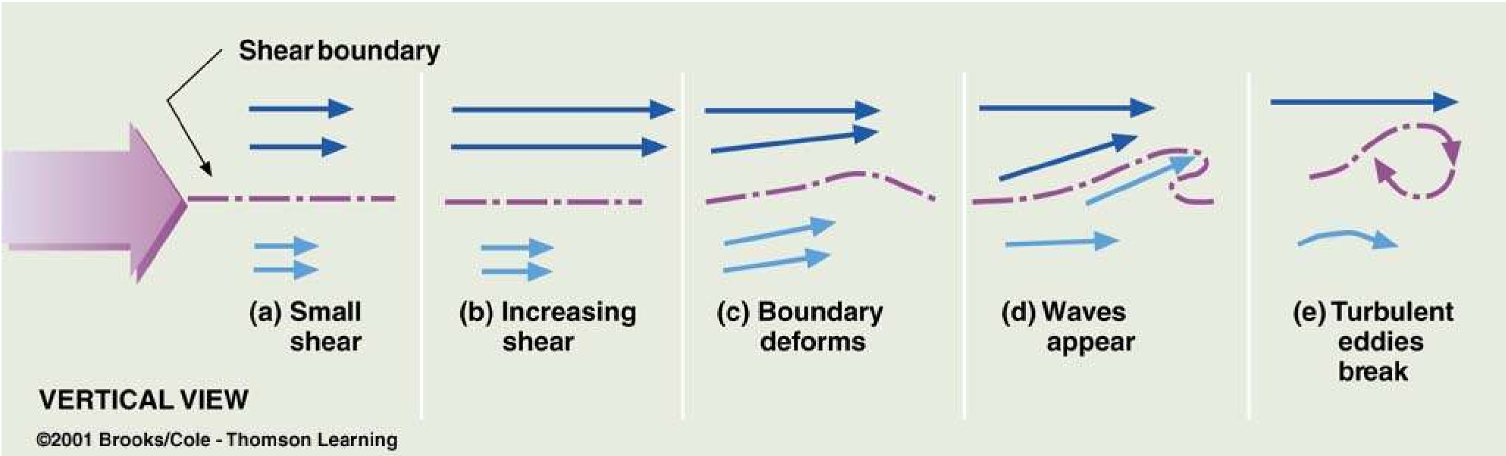
# Questions

1. A pilot enters the weather service office and wants to know what time of the day she can expect to encounter the least turbulent winds at 760 m above central Kansas. If you were the weather forecaster, what would you tell her?

2. Why is the difference in surface wind speed between morning and afternoon typically greater on a clear, sunny day than on a cloudy, overcast day?



# Turbulence Aloft (Wind Shear)




Formation of clear air turbulence (CAT), responsible for 'air pockets'

Wind shear occurs at all altitudes and it can be horizontal or vertical

At high altitudes, shear is encountered at the jet stream with the wind increasing from less than 50 mph to 150 mph over a few miles.

# Local Winds

- Many mesoscale phenomena are the result of a thermal circulation:
- Thermal circulation - a circulation generated by pressure gradients produced by differential heating
- Thermal circulations tend to be shallow - **do not** extend up through the depth of the troposphere

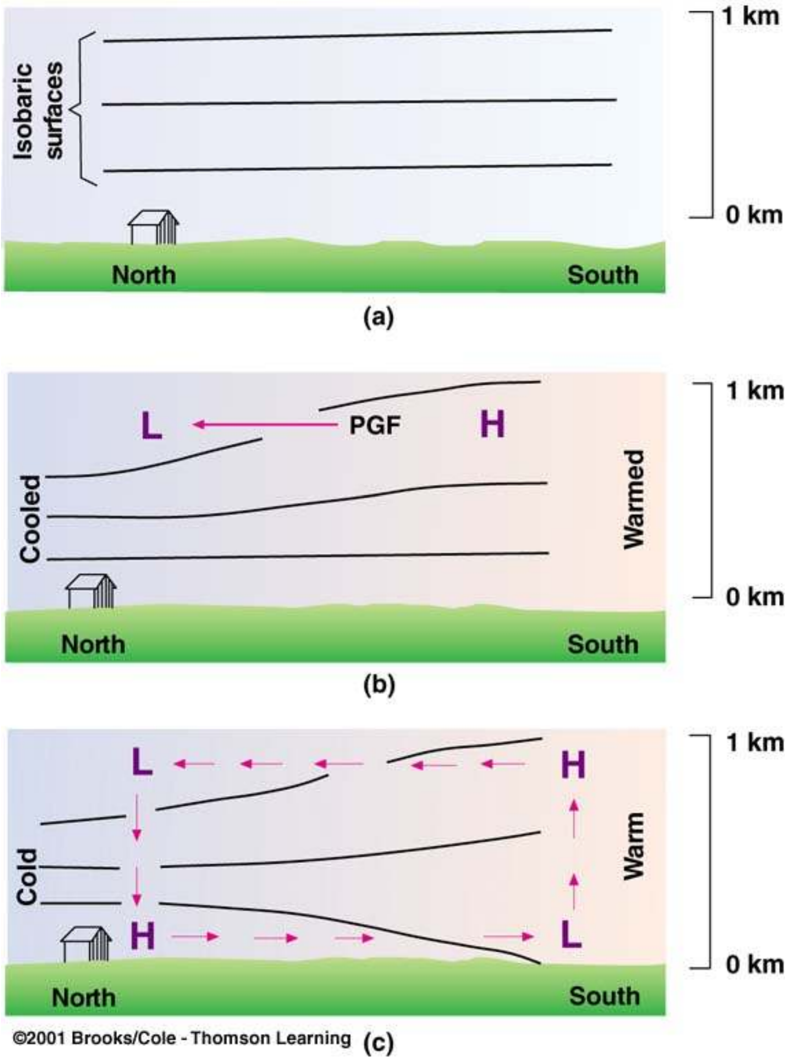
  – Sea and Land Breezes
  – Monsoon
  – Mountain + Valley
  – Katabatic Winds
  – Chinook
  – Santa Ana
  – Desert Winds

Thermal circulation (Sea and Land Breezes, Monsoon)

Downslope winds (Mountain + Valley, Katabatic Winds, Chinook, Santa Ana)

All mesoscale phenomena

# Thermal Circulations




No horizontal P or T variation

Cool the N and warm the S

Complete the circulation

Fig. 7.3: Thermal circulation produced by heating and cooling of the ground.

# Thermal Circulations: Sea and Land Breezes

- Consider the land/sea interface in the morning
- Assume that the ocean and land surfaces have the same temperature
- Also assume that synoptic-scale phenomena are absent
- As solar heating increases during the morning, which surface heats quicker and why?

# Thermal Circulations: Sea and Land Breezes

- Uneven heating of land and water
- Diurnal wind coming from sea ('sea breeze') during daytime and from land ('land breeze') at night
- Why is the land breeze weaker than the sea breeze?

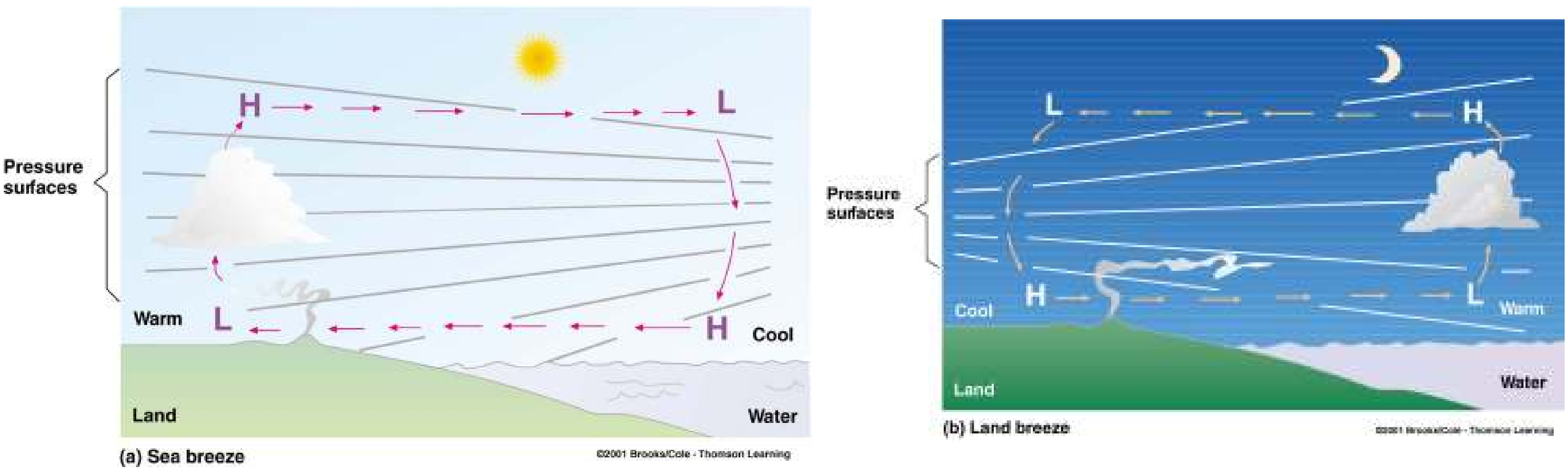
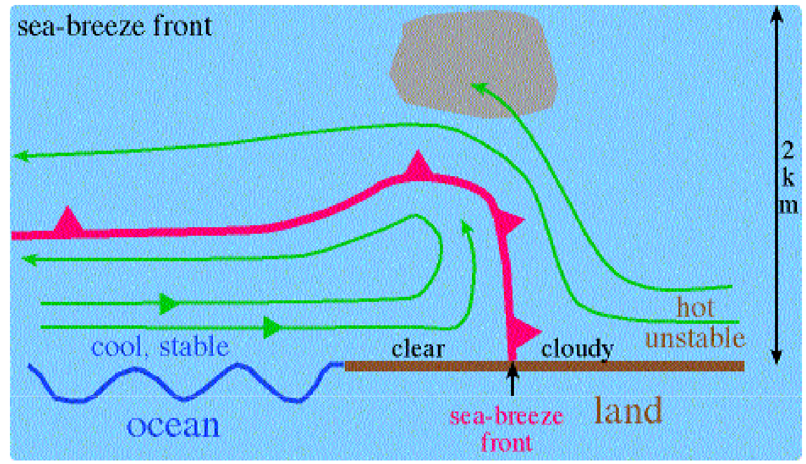
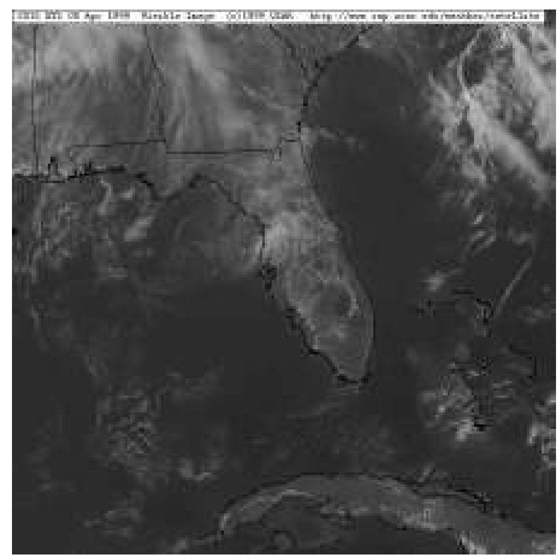



Fig. 7.4: Development of a sea breeze and a land breeze

# The Sea-breeze Front

- The boundary between the cool, stable sea-breeze flow and the hot, unstable winds over land
- Passage is noted by:
  - change of wind speed/direction
  - rapid temperature decrease
  - moisture increase
  - change in air quality
- Max temperature occurs much earlier than inland cities
- Clouds often form along the front



# Sea-breeze

- Convergence in Fl produces large summertime rainfall

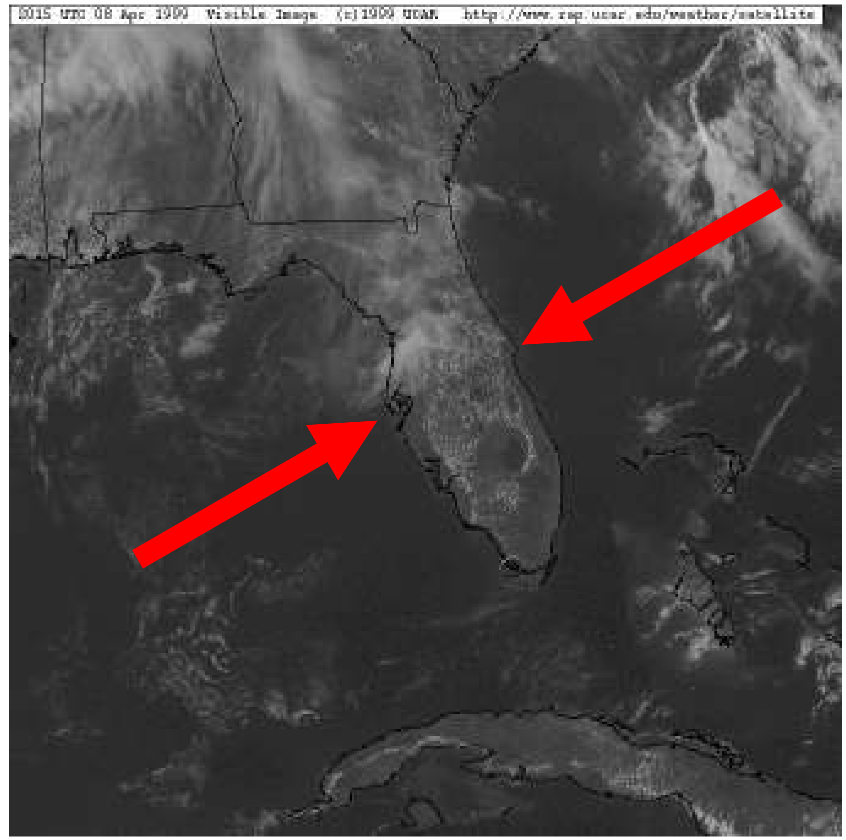


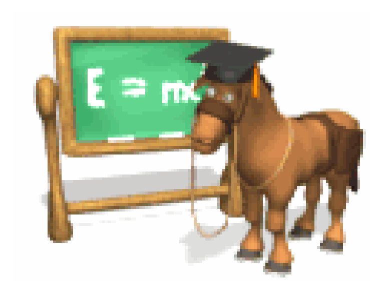

Fig. 7.5: Surface heating and lifting air along a sea breeze form thunderstorms almost daily during summer in S. Florida.

Convergence of a sea breeze from Atlantic and Gulf sides. Lack of convergence in 98' caused fires.

# Questions

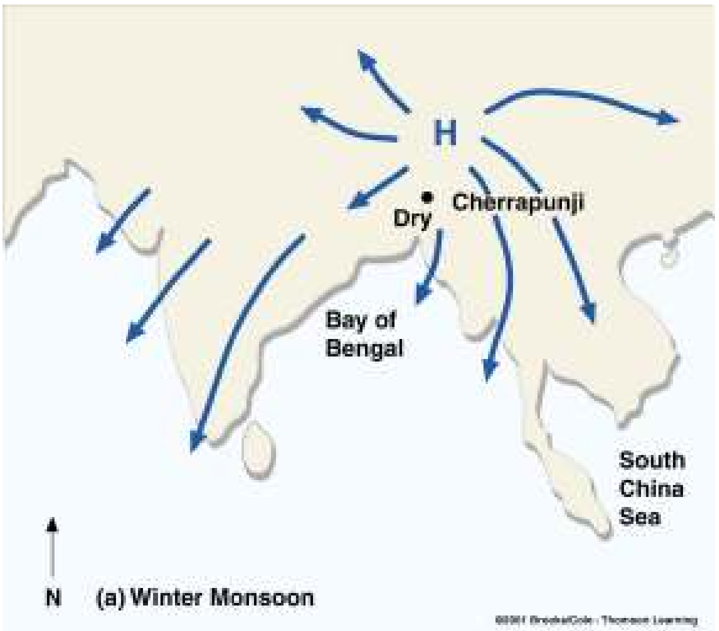
1. Explain why cities near large bodies of cold water in summer experience well-developed sea breezes, but only poorly-developed land breezes.

2. The prevailing winds in southern Florida are northeasterly. Knowing this, would you expect the strongest sea breezes to be along the east or west coast of southern Florida? What about the strongest land breezes.

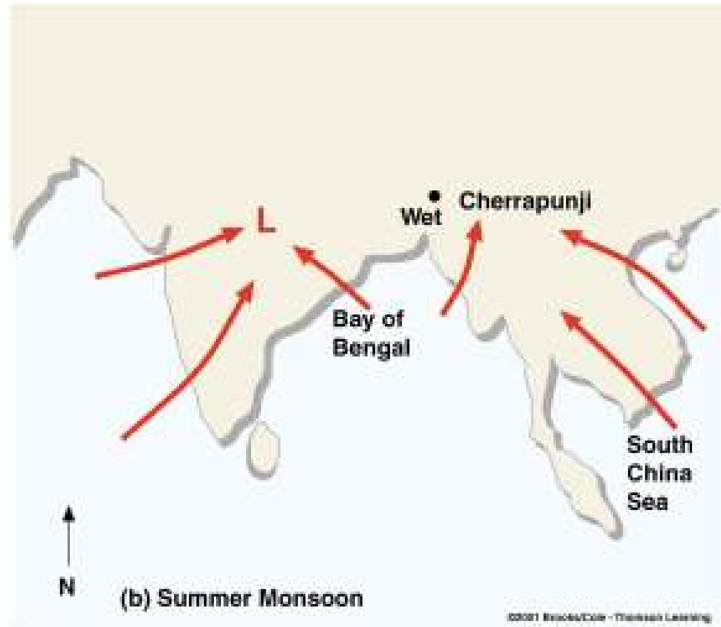


# Monsoon

- Like sea/land breeze but seasonal




Winter: Land cool - Dry season




Summer: Land warm - Wet season (425” of rain/yr at *) +uplift by Himalayas

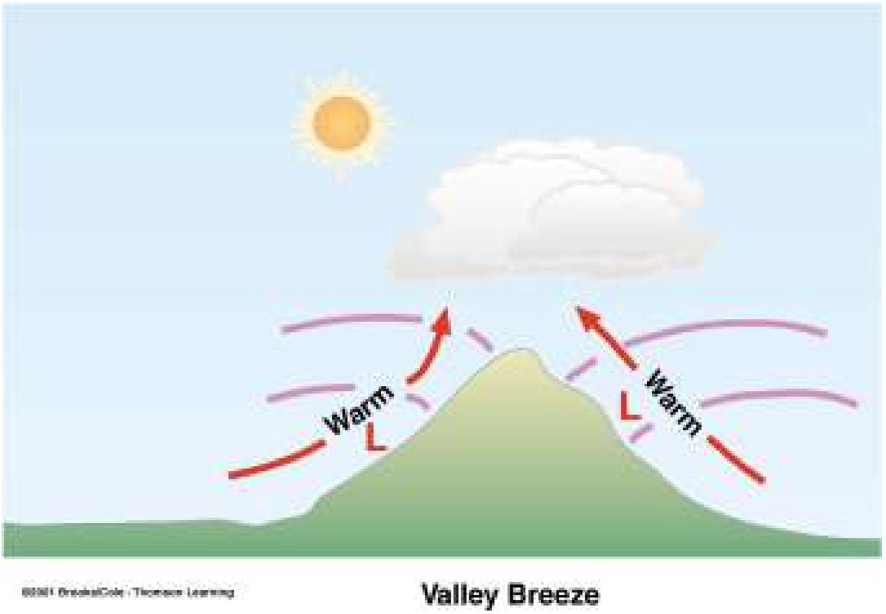
Fig. 7.6: Changing annual wind patterns associated with winter and summer Asian monsoon (linked to El Niño) Many people depend on it for drinking water/irrigation.

# Downslope Winds

- Mountain breezes belong to a group of winds more generally as Katabatic winds.
- These are winds driven by cold air flowing down a slope

# Mountain Breezes

- Day: sunlight warms valley walls – valley breeze
- Night: valley walls cool – mountain breeze



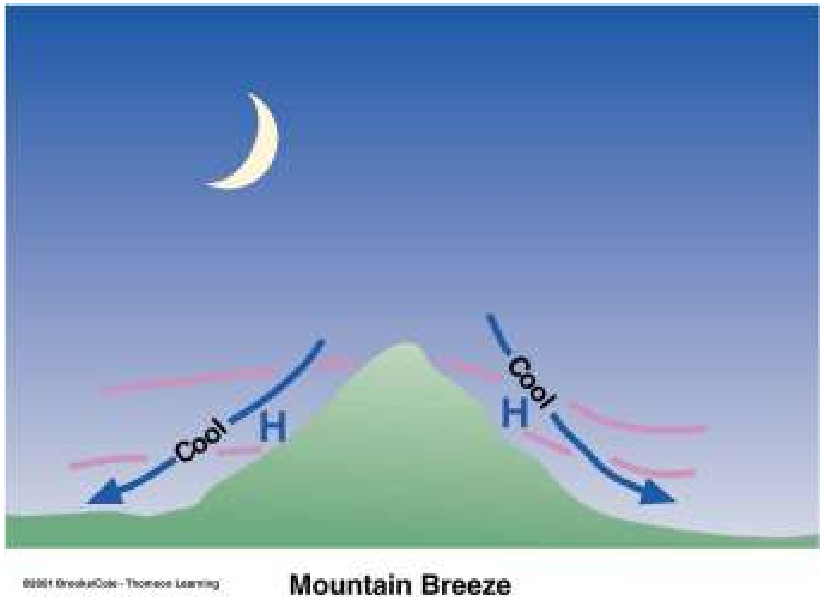



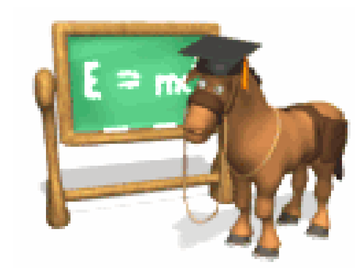

Fig. 7.7: Valley breeze: uphill during day

Mountain breeze: downhill at night

# Question

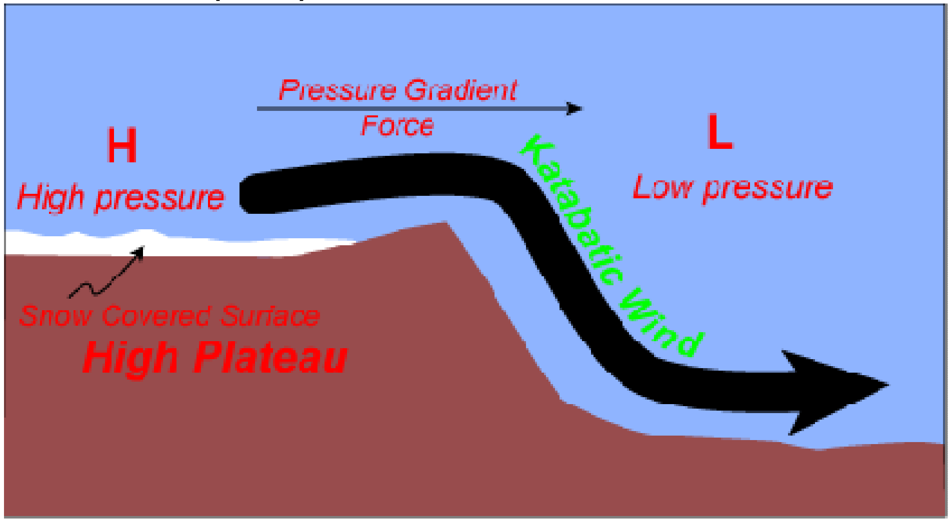
If campfire smoke is blowing uphill along the east-facing side of the hill and downhill along the west-facing side of the same hill, are the fires cooking breakfast or dinner?

From the drift of the smoke, how were you able to tell?



# Katabatic Wind

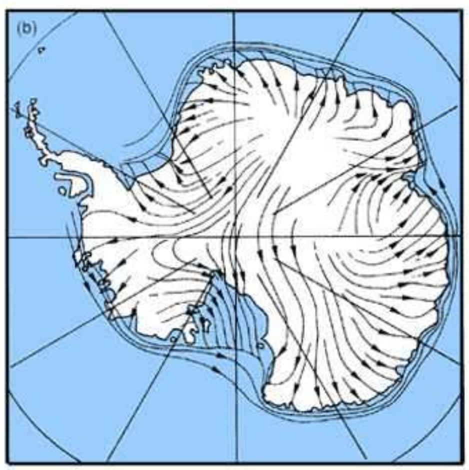
- Katabatic or 'fall' winds (cold air)
  - Down slope wind (stronger than a mountain breeze)
  - Usually a plateau surrounded by mountains with opening sloping downhill
  - e.g. the *bora* (Adriatic coast), *mistral* (Rhone valley), *coho* (Columbia Gorge wind), *Santa Ana* (CA)




- Optimal conditions:
  - Snow covered plateau cools
  - Generates large PGF
- Causes frost damage to vineyards
- Winds can exceed 100 knots

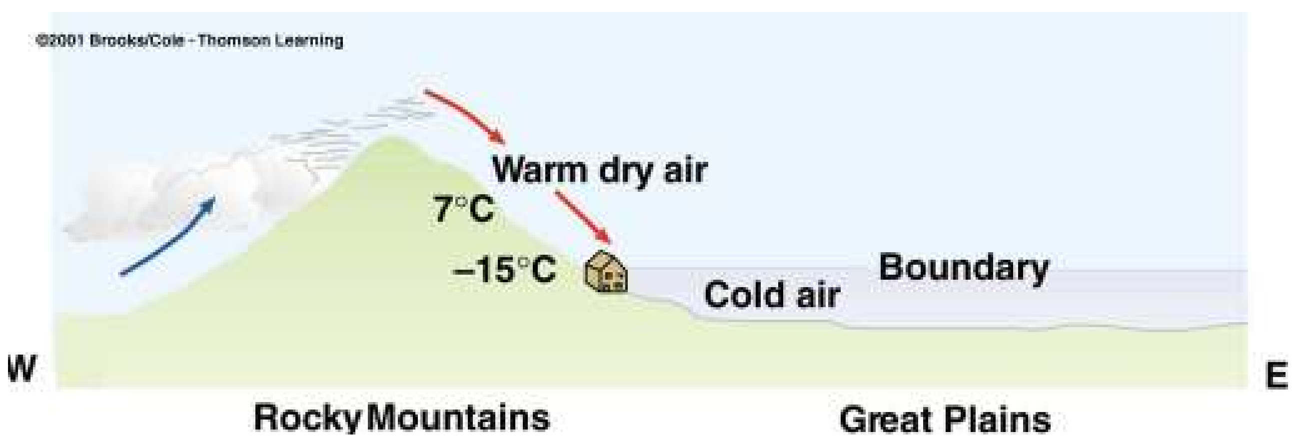
# Question

Where on Earth would we find the strongest Katabatic winds? Why?



# Chinook

- Chinook: warm, dry wind flowing from east side of Rockies.
- Indian word meaning 'snow eater'.
- Similar phenomena exist elsewhere in the world and have their own names (Alps =foehn)
- Temperature may rise as much as 36 ° F (20 °C) in 1 hr, plus sharp drop in RH
- Two kinds of chinook: with and without rain



# Pros and Cons

- Pros: relief from winter cold (main source is compressional heating), uncovers prairie grass, railroads
- Cons: fire hazard, crop failure (parched soil), high speed wind may do damage, human behavior?

# Chinook With Rain

- Air flows up a mountain. Air expands and cools as it moves into lower pressure.
- Cooled air reaches saturation and water vapor condenses, releasing L.H. into air on uphill side

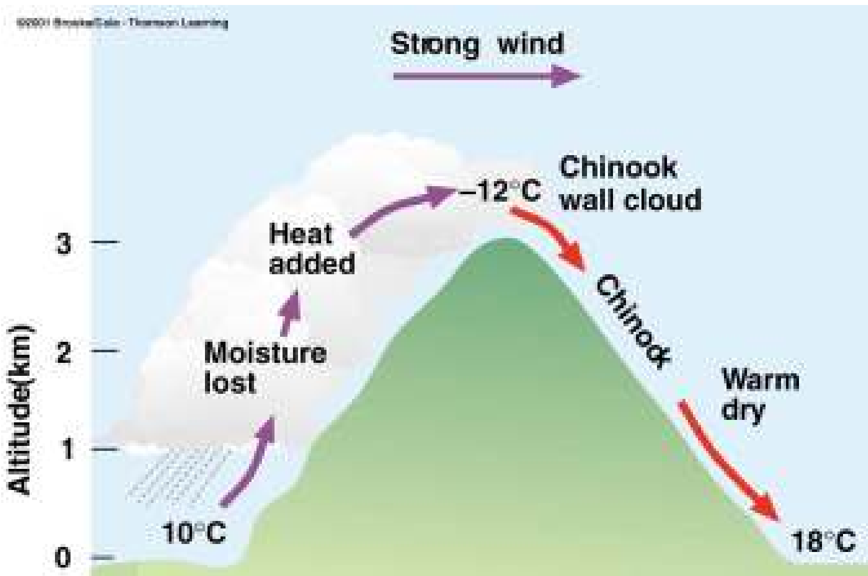



Fig. 7.9: Conditions that may enhance a chinook

# Chinook With Rain

- Cooling on upwind side is reversed as air is compressed downwind - compressional heating

- Net effect on the air after passing over the mountain:
  - Air is fairly dry since moisture lost on upwind side
  - Air is warm (sometimes a great deal warmer) because of L.H. released + compressional heating

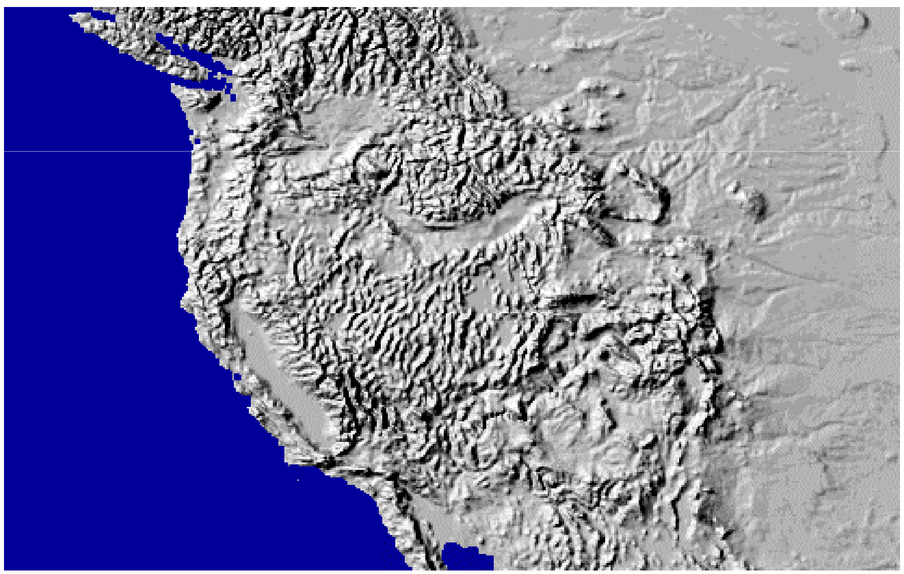
# Chinook Without Rain

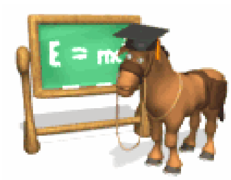
- Sometimes air to W of mountain only flows over if it is above the mountain top
- Air below stays on W side
- As upper level air flows over mountain it is compressed and warms


Fig. 7.10: A chinook wall cloud over the rockies

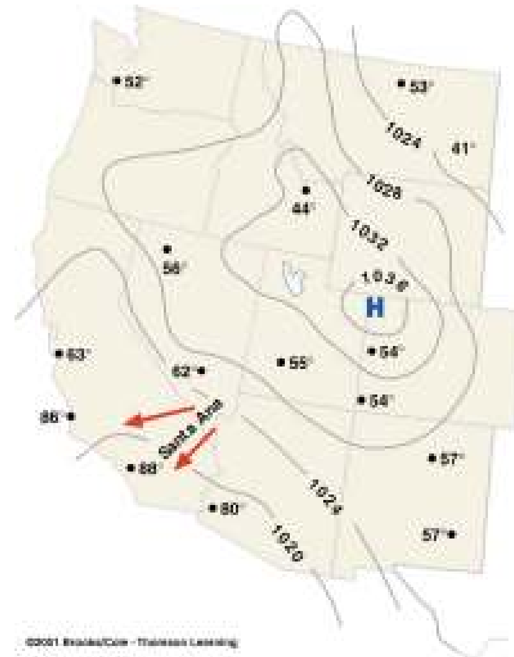
# Question

Why don't chinook winds form on the east side of the Appalachians?





# Santa Ana Wind




- Hot dry wind that often sweeps through the L.A. Basin in the fall and winter.
- Need a strong H over S. USA
- winds descend from the higher desert terrain down in to the L.A. Basin - parcels become warmer and drier due to compressional heating
- wind speeds are enhanced as the flow channels through the mountain passes
- Especially in fall, these hot dry winds fan fires that threaten LA

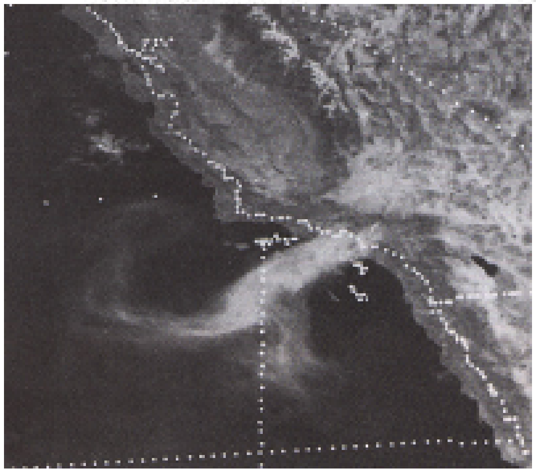
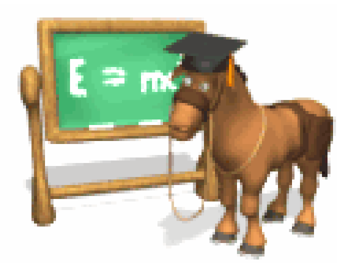


Fig. 7.11: Surface map showing Santa Ana in January.
Downslope winds into S. CA raised temperatures into the 80's

# Question

In what ways is the Santa Ana similar to the Chinook wind?



# Dust Devil

- Usually forms on a hot sunny day in a desert
- VERY unstable conditions
- Looks like a small tornado but is not
- Typically taller, weaker and shorter lived than a tornado

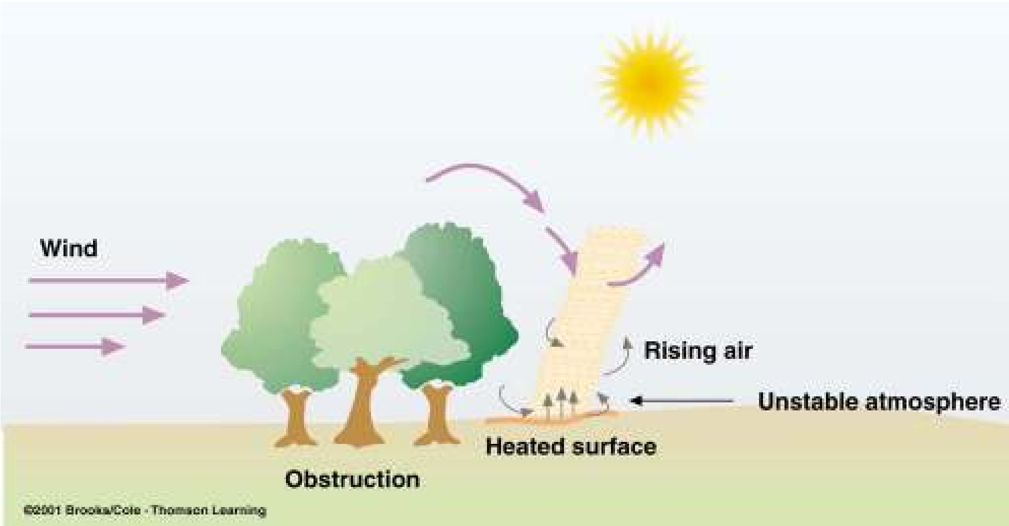




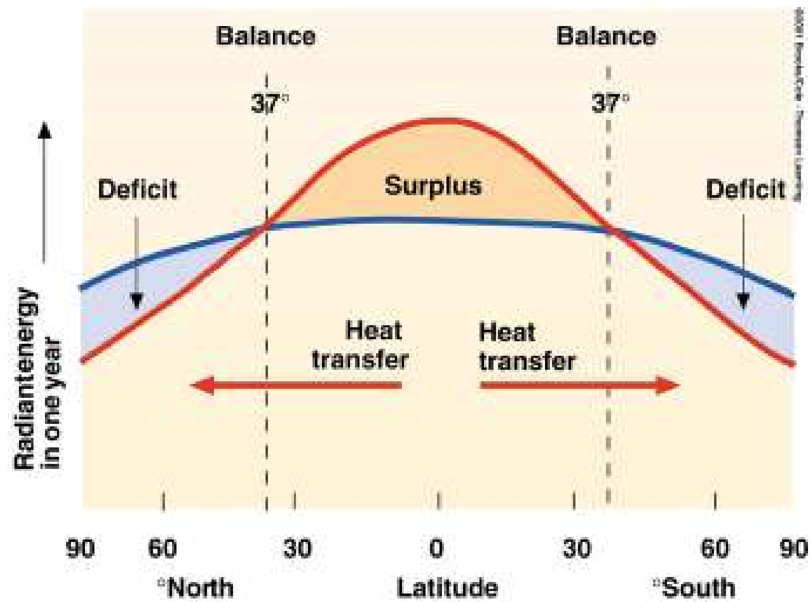
Fig. 7.12: Formation of a dust devil. Unstable atmosphere (hot/dry day). Heated air rises, wind blowing past obstruction twists the rising air

# Global Scale Winds

- Wind is determined by pressure
  - Fast wind where isobars are close (lg. PGF)
  - High to Low pressure, deflection to right in N. hemisphere with CCW flow around lows, CW around highs
  - High to Low pressure, deflection to left in S. hemisphere with CW flow around lows, CCW around highs
- Upper-level pressure distribution is determined by temperature
  - Upper-level high pressure where warm, because warm air expands
  - Upper-level low where cold

# General Circulation of the Atmosphere

- Why? NE in Honolulu, W in New York?
- Represents average air flow around the globe
- Is created by unequal heating at earth's surface
- General circulation's function is to transport heat poleward



# Simplest Model

- If you assume:
  - earth is uniformly covered with water (no land!)
  - sun is directly over equator (no seasons!)
  - no rotation
- You will end up with a single-cell pattern
  - called the Hadley Cell
  - warm air rises at the equator, cold air sinks at the poles

# Simplest Model

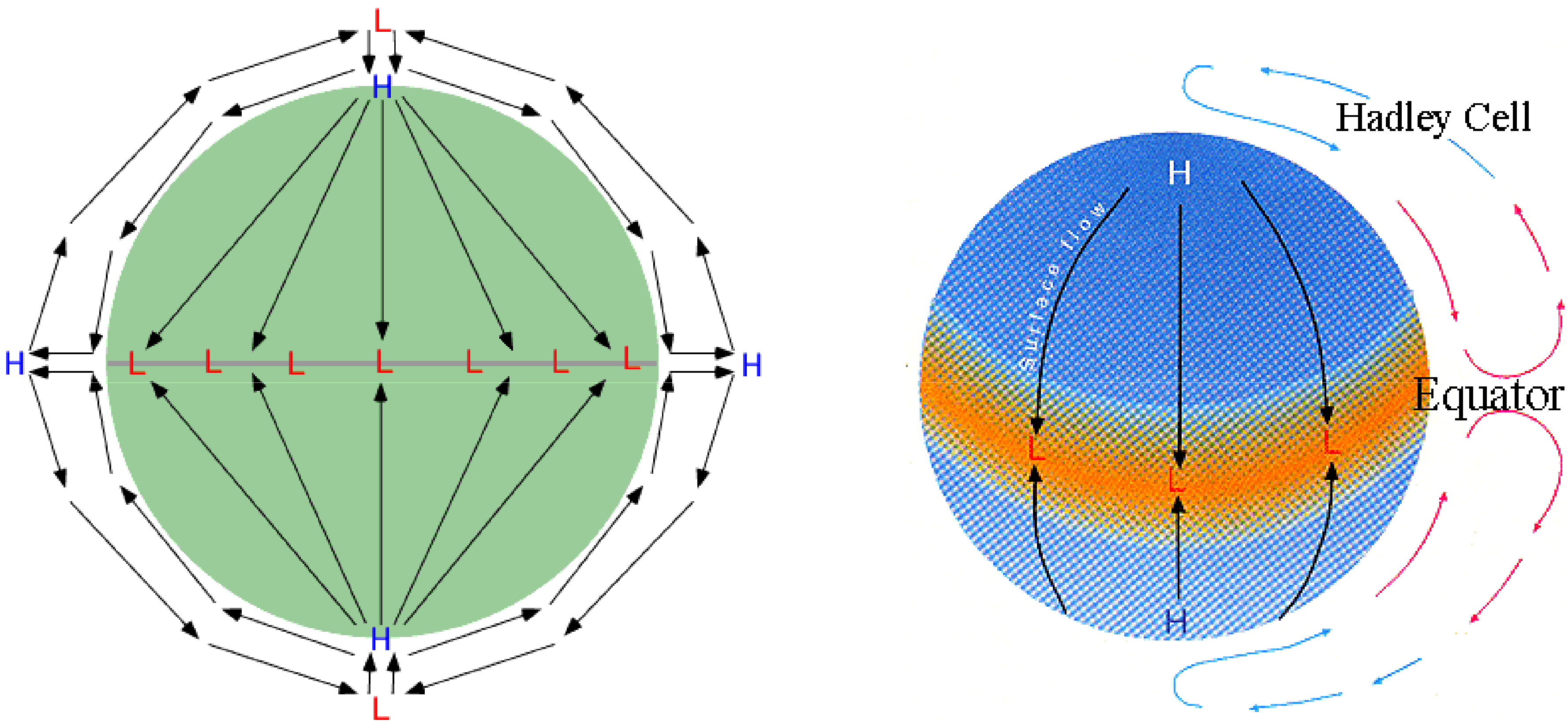
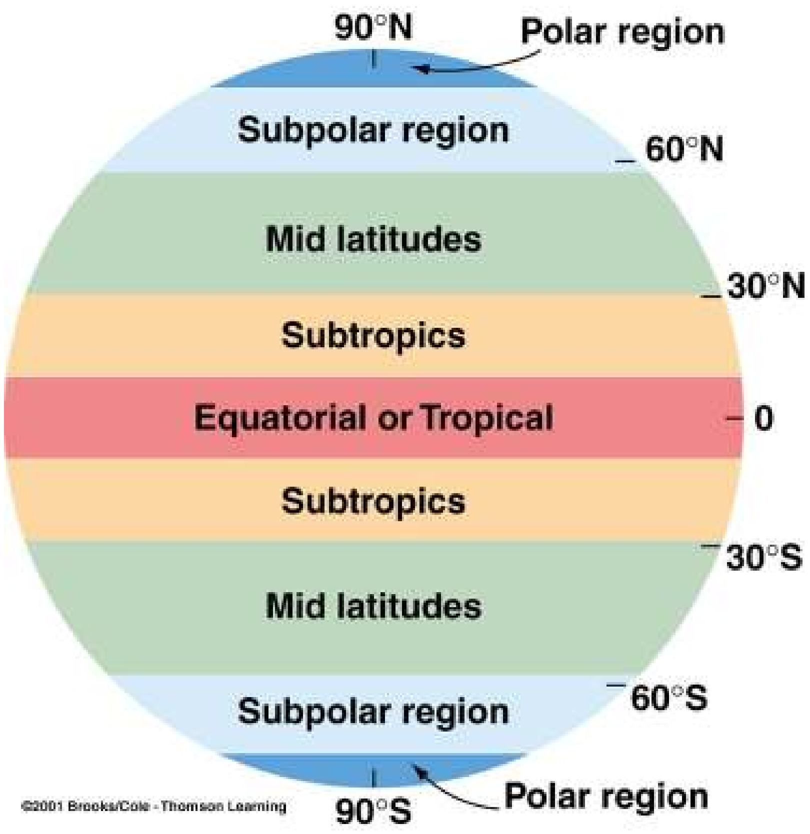


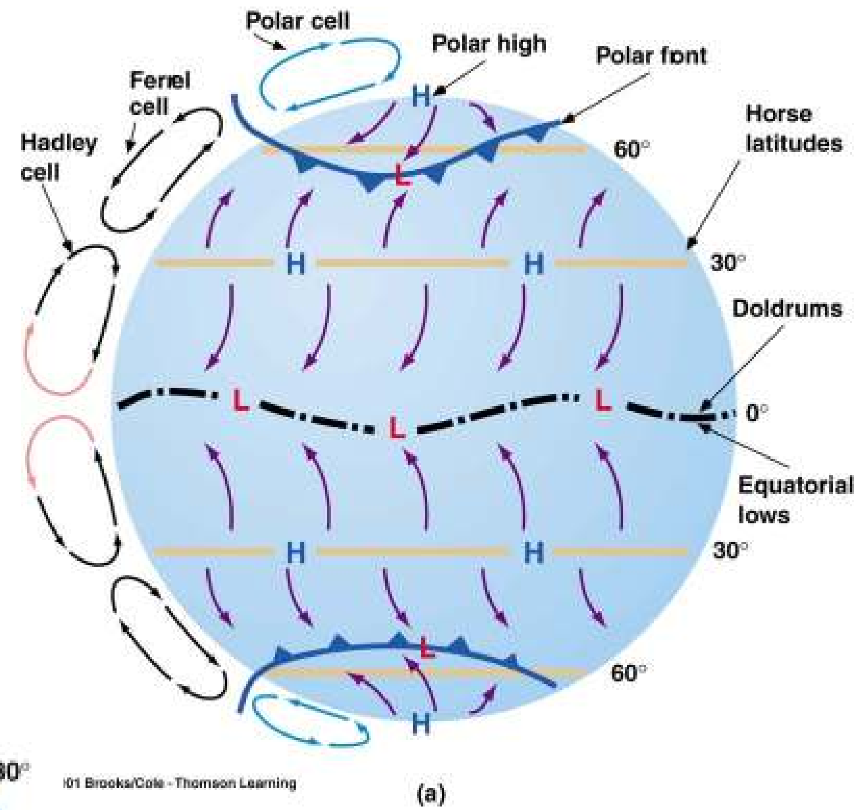

Fig. 7.14: General circulation on a non rotating earth, sun over equator (no land masses)

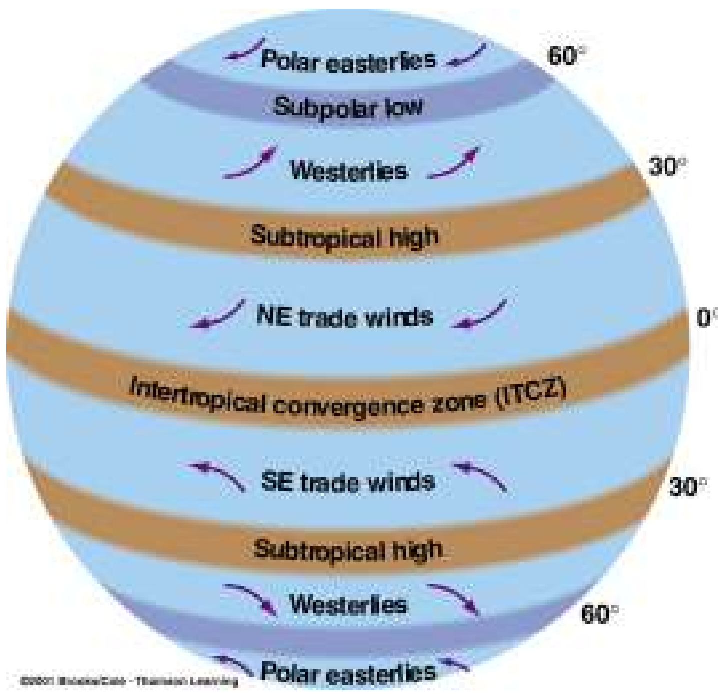
# Single Cell Model

- This single-cell pattern is not observed
- What we have is more complicated
- .... what important process have we neglected??



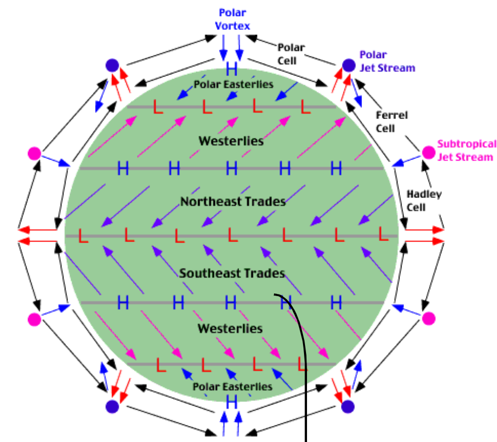
- Three-cells
- surface pressure
- surface winds
- comparison to real world???




**+ ROTATION (CF)**

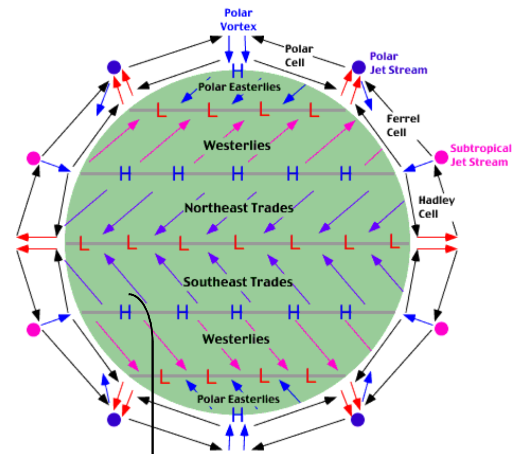
# Three Cell Model




- Equator:
  - warm air
  - center of P system gradient is zero - light winds – doldrums
  - thunderstorms provide latent heat to drive Hadley cell
  - at tropopause air moves N, CF deflects right ‘westerlies aloft’
  - cools and piles up at mid-lattitudes
- 30º:
  - P at surface increases - subtropical highs
  - dry air warms by compression
  - clear skies and warm T’s – deserts
  - center of P system gradient is zero - Weak winds over the ocean – horse latitudes
  - Some air moves back to equator from the NE – trade winds
- ITCZ
  - NE trades converge with SE trades
  - Sensible+latent heat

Hadley Cell

# Three Cell Model




- 30º:
  - Air moves N, CF deflects right – westerlies
  - N hemi: Not constant since H and L's break up this flow
  - S hemi: more steady
- 60 º:
  - Warm air meets cold – polar front
  - Convergence zone of L pressure – subpolar Low
  - Air returns to horse latitudes

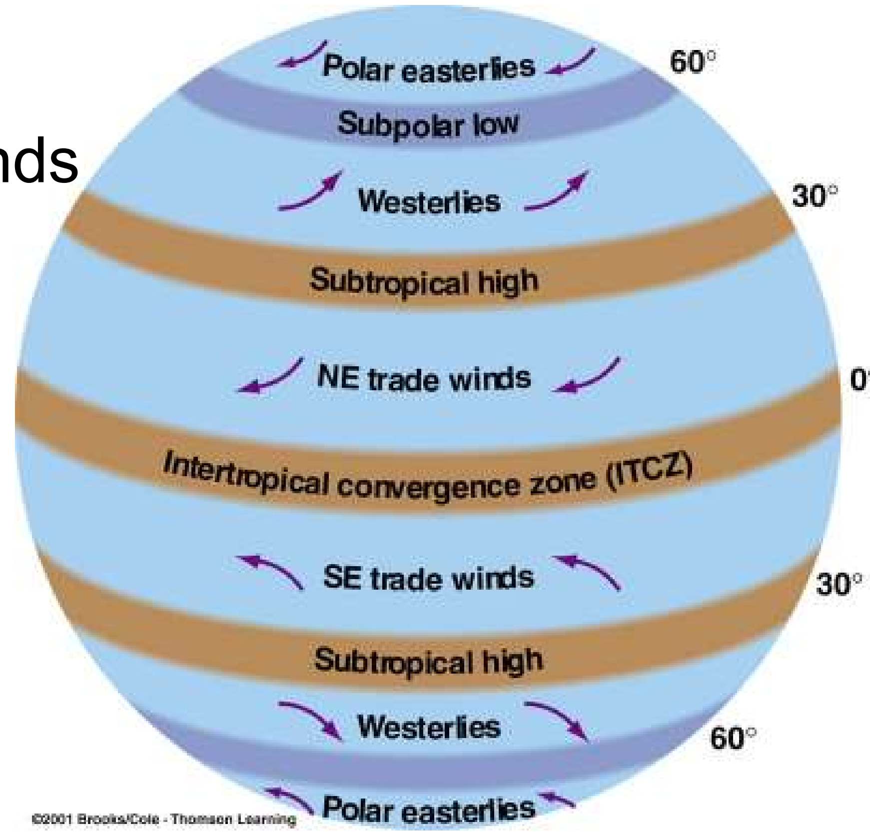
Ferrel cell

- Polar front
  - Cold air from pole deflected by CF – polar easterlies
  - Moves into middle and subtropical areas in winter –cold
  - At the front rising air moves poleward – westerlies aloft

Polar cell

# Understanding Average Surface Pressure and Wind

- Conclusion:
  - Works well with surface winds
- Summary:
  - 2 high (30°, 90°)
  - 2 low (0°, 60°)
  - trade winds,
  - westerlies,
  - polar easterlies



# Problems With the 3-Cell Model

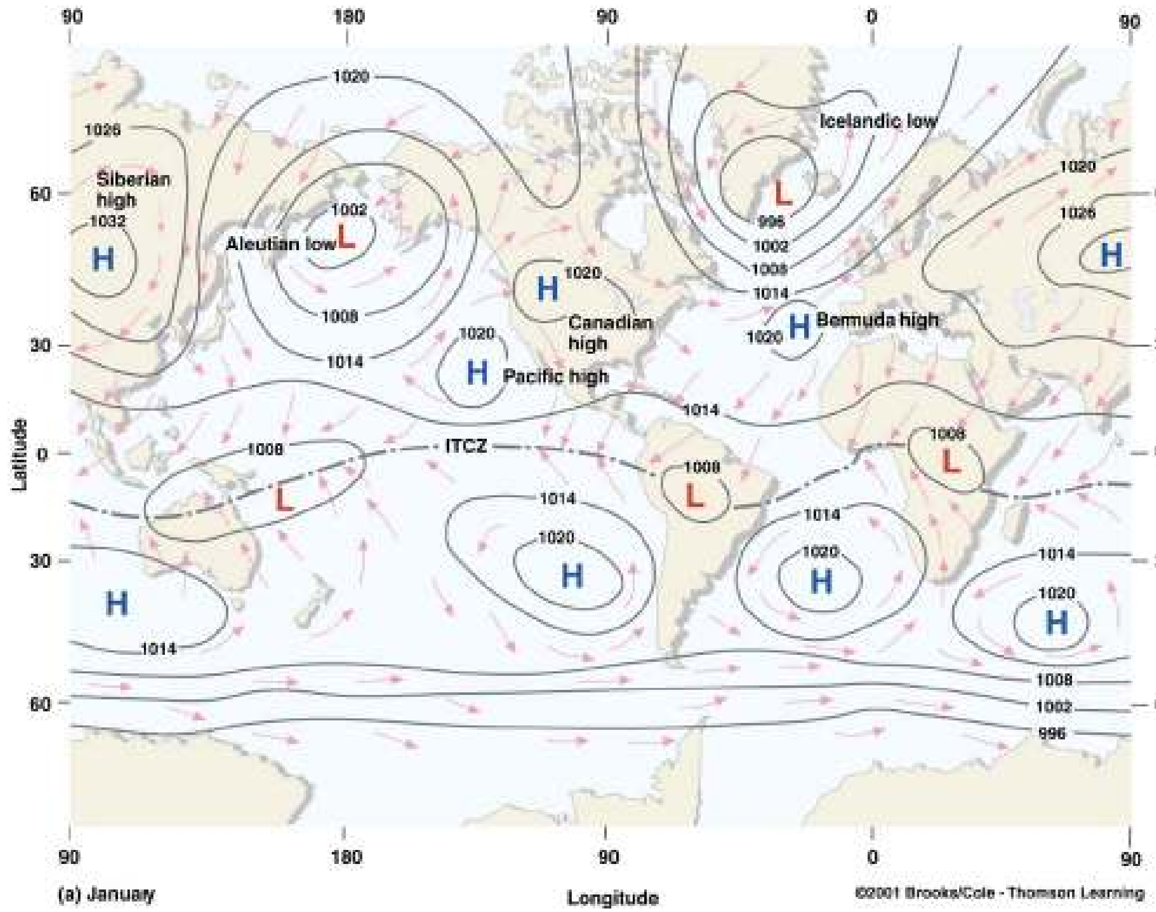
- Middle and high latitudes dominated by migrating frontal cylones (L) and anticyclones (H)   (Chp8)

- Features change in intensity and location with seasons

- Land and sea temperature contrasts

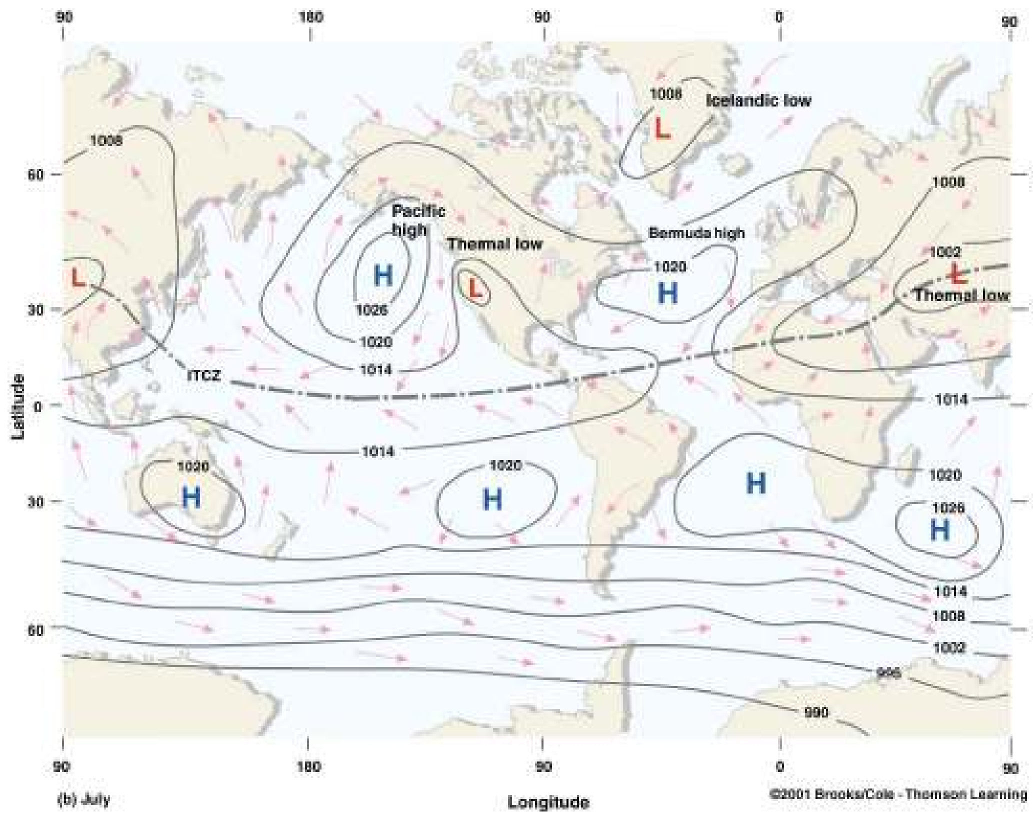
# Average Surface P and Winds During January

- **Semi-permanent pressure areas:**
  - Bermuda High
  - Pacific High
  - Aleutian Low
  - Icelandic Low
- **Seasonal pressure areas:**
  - Siberian High
  - Canadian High

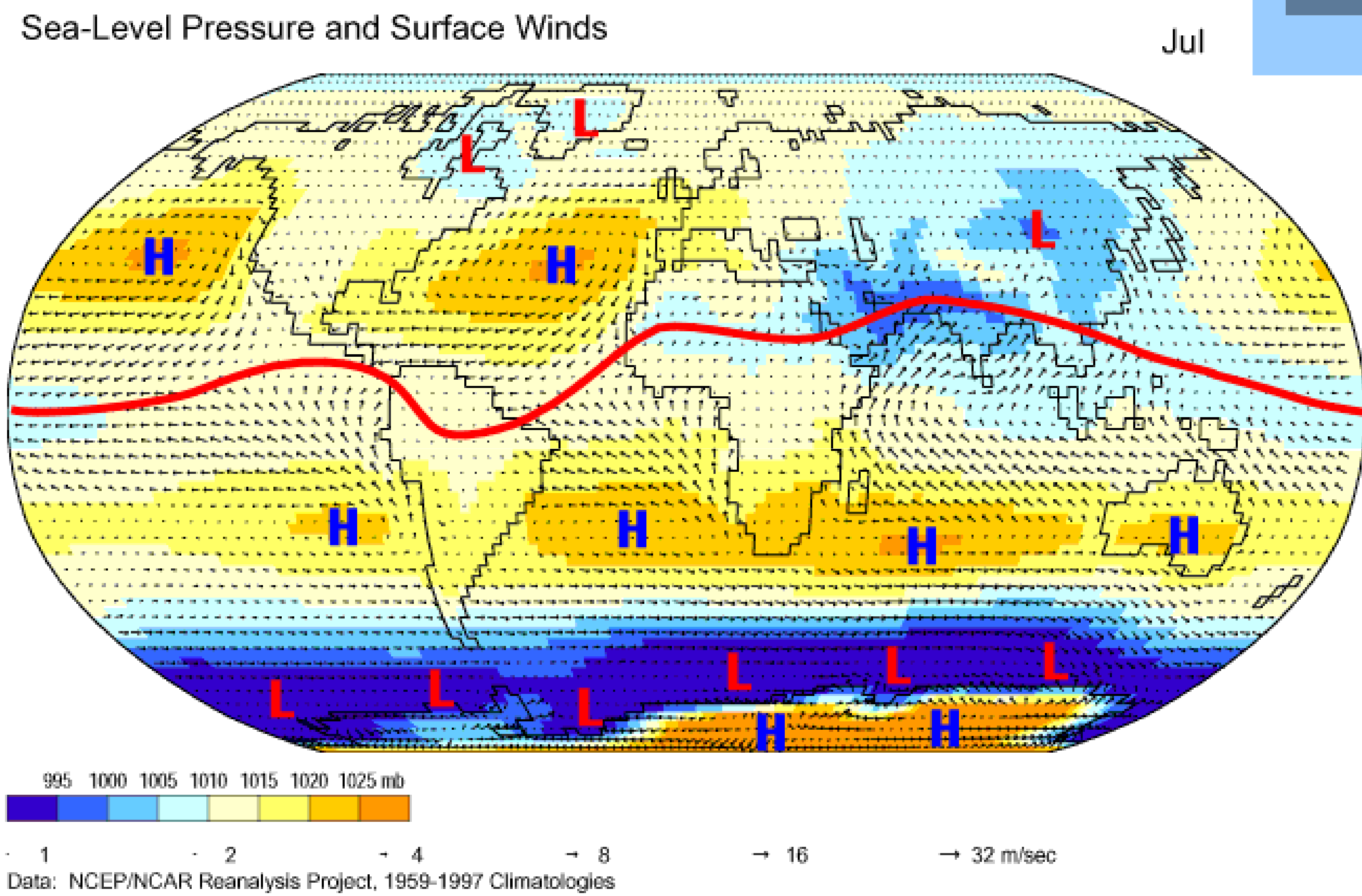


# Average Surface P and Winds During July

- **Semi-permanent pressure areas:**
  - Bermuda High
  - Pacific High
  - Icelandic Low
- **Seasonal pressure areas:**
  - Monsoon Low
  - Thermal Low over SW US

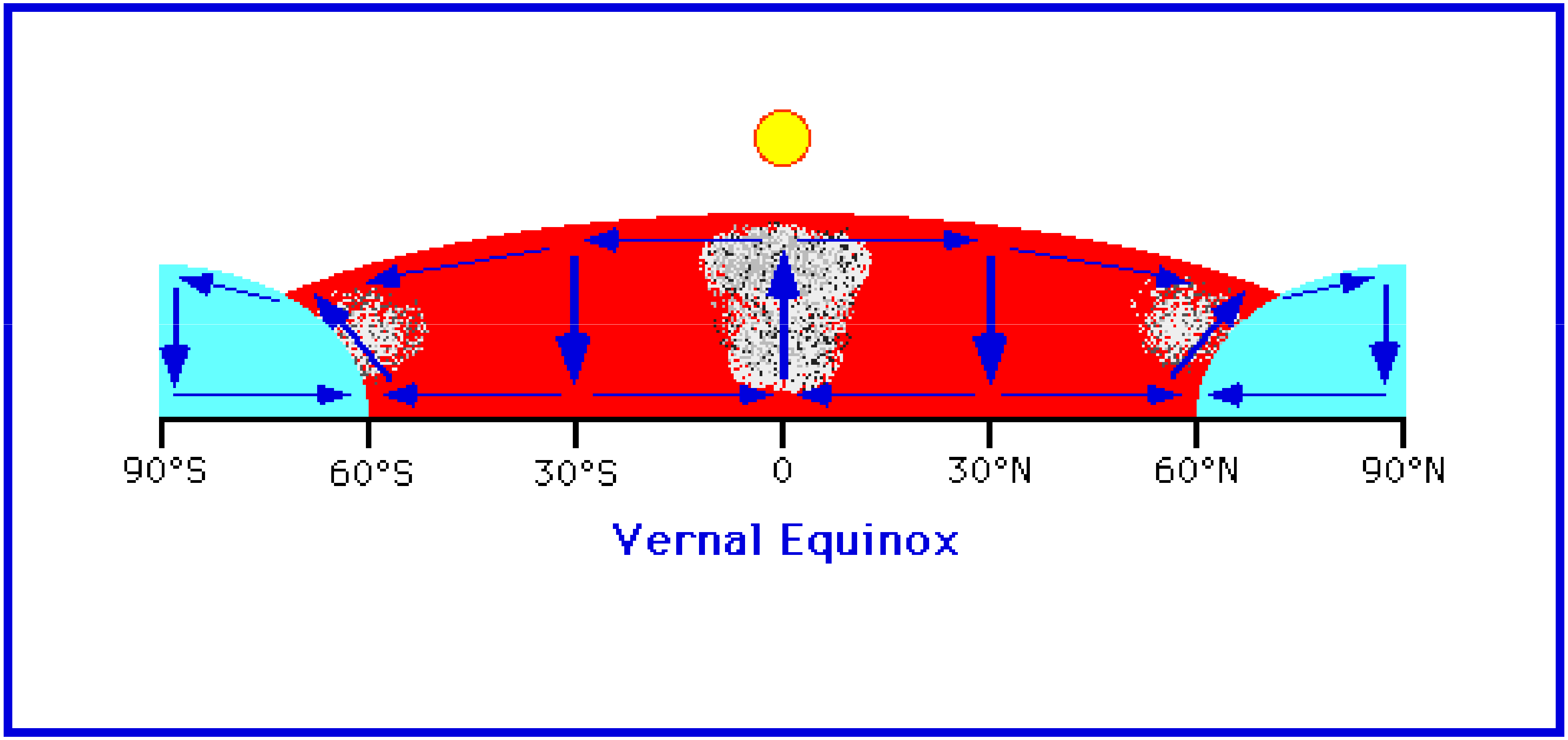



Sub-tropical H pressure belt breaks up: surface heating forms L's over land




Mean July prevailing surface winds and centers of atmospheric pressure

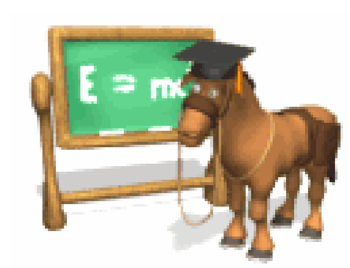
# ITCZ Movement



# Questions

How do the strength and position of these feature differ from July to January? Why?

Why is the ITCZ further North in July than January?



# Global Rainfall

- High where air rises:
  - tropics (ITCZ)
  - polar front
- Low where air sinks:
  - subtropical highs and poles

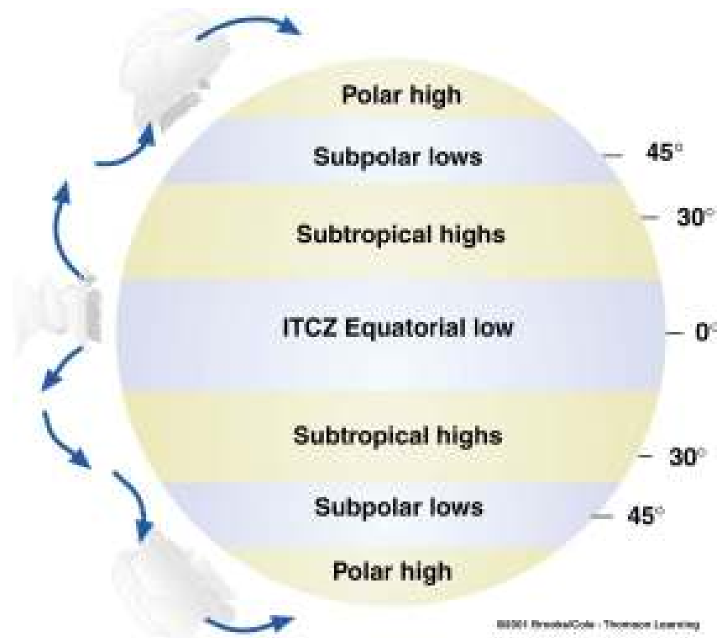



Fig. 7.17: Major pressure systems and idealized motions and precipitation patterns of the general circulation

# Latitudinal Displacement

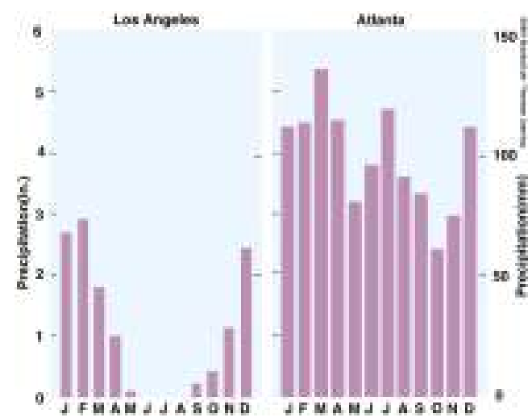
- 10- 15º Latitudinal displacement of major features
- Affects climate

# Pacific and Bermuda Highs

- Pacific high - moves northward during summer
  - Sinking air (subsidence) on E side keeps weather dry
  - During winter, it moves south over warmer ocean, pushed by polar front to bring rain to SW US
- Bermuda high - transports warm, moist subtropical air to US and southern Canada
  - This air can be unstable

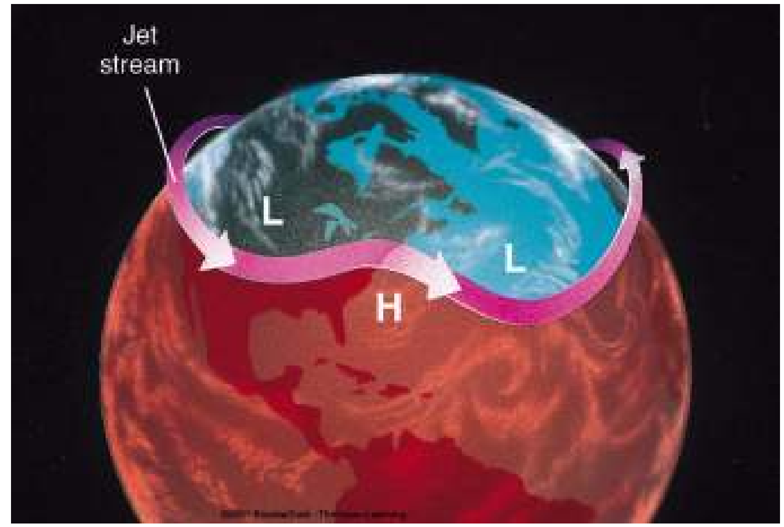
- Weather associated with subtropical highs can vary dramatically depending on where you are located!
  - Depends on amount of subsidence





# Jet Streams

- Concentration of upper-level winds
- > 100 knots, 33-46,000 ft
- Form due to horizontal pressure differences aloft
  - e.g. Polar Front Jet and Subtropical jet
- Steer weather systems
- The jet streams exhibit a "wavy" pattern around the globe....



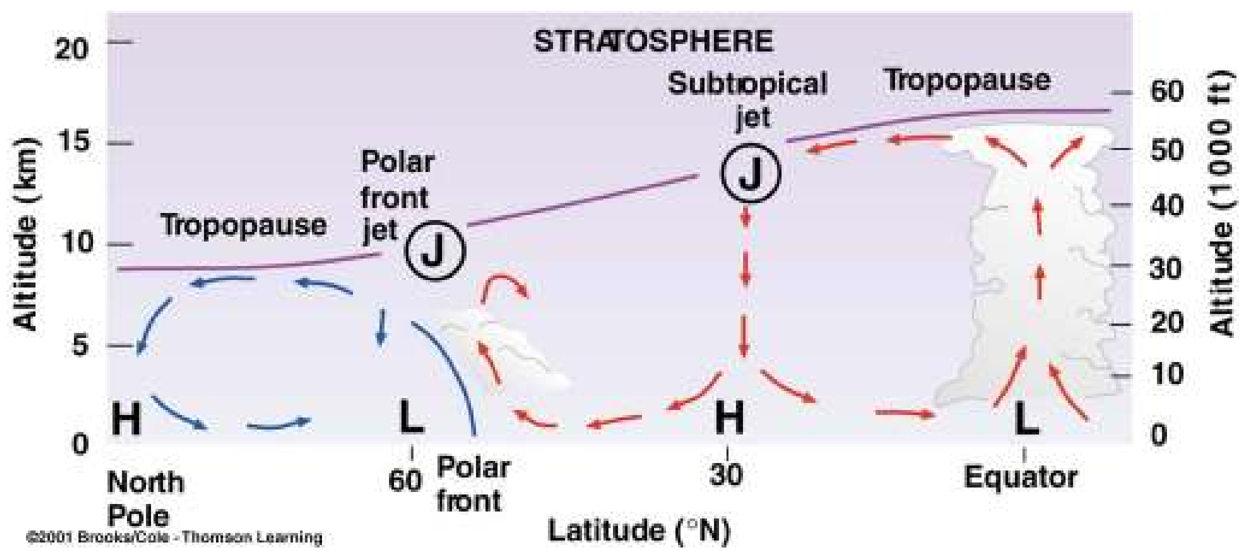
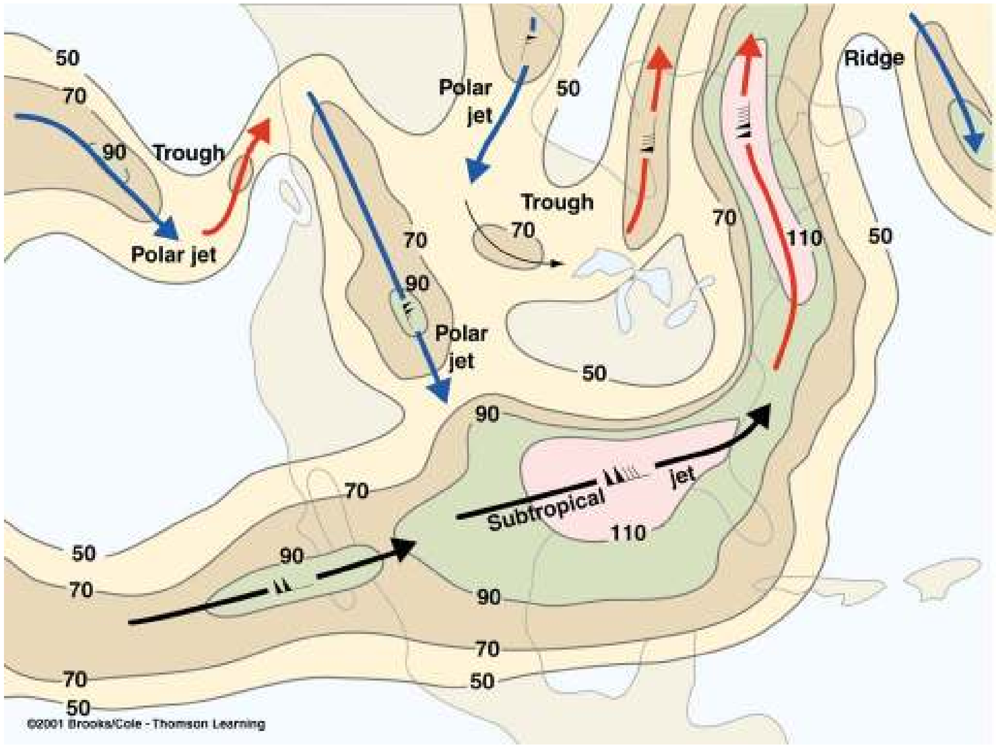




Fig. 7.20: Jet stream

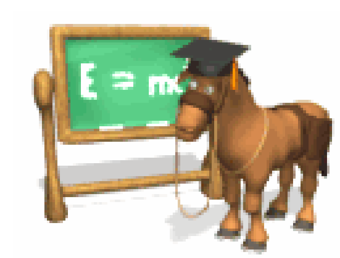
# Jet Stream Waves

- Often have troughs and ridges
- Generally have a jet maximum (jet streak) in the base of the trough
- Transport heat poleward (cold air south and warm air north)



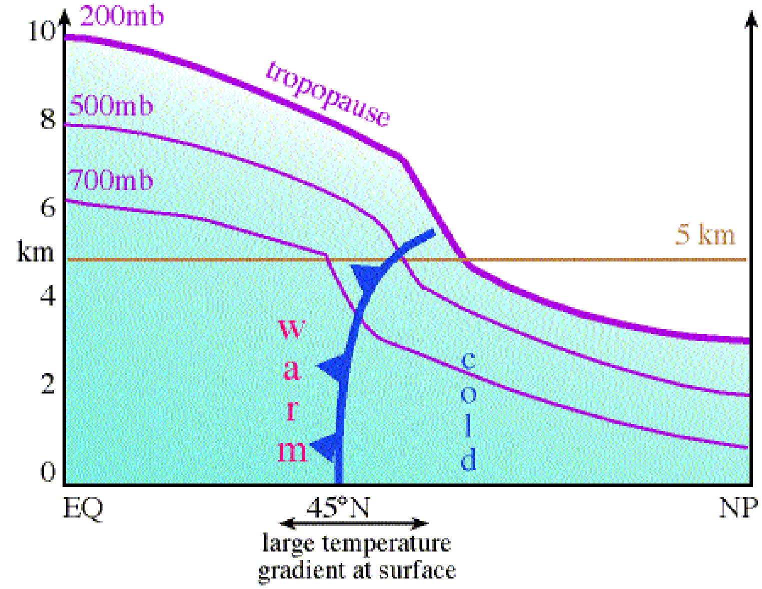
# Question

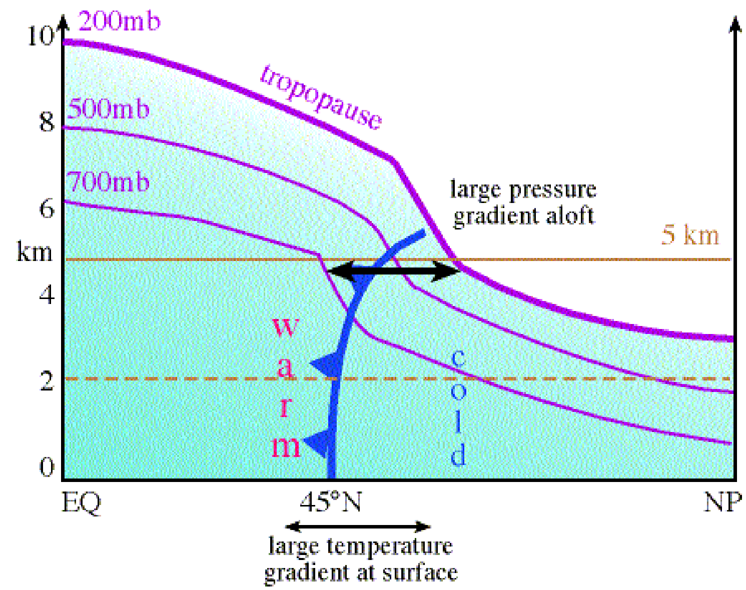
How is the polar jet stream formed????



# Polar

- Polar Jet Stream
  - boundary between warm air to the S and cold air to the N at the polar front
  - location of a large T gradient near the surface
  - Hence, the large *T gradient* at the surface across the polar front creates a large *pressure gradient* aloft

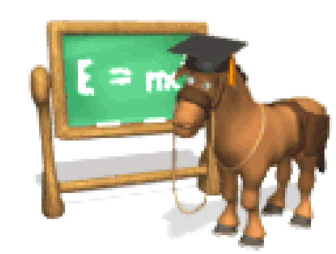


# Question

1. During which season is the jet stream stronger, winter or summer?

2. Why does the polar jet stream shift northward during the summer?



# Question

When they are hitting the beaches in Southern California in January, they are probably digging out in New York City **True or False?**

# Review

- The two major semi-permanent subtropical highs that influence the weather of N. America are the _________ high situated off the W coast and the __________ high situated off the SE coast
- The ________ front is a zone of low pressure where storms often form. It separates the mild westerlies of the middle latitudes from the cold, polar easterlies of the high latitudes
- In equatorial regions, the intertropical convergence zone (ITCZ) is a boundary where air rises in response to the convergence of the northeast trades and the southeast trades
- In the N. hemisphere, the major global pressure systems and wind belts shift northward in summer and southward in winter
- The northward movement of the Pacific high in summer tends to keep summer weather along the west coast of North America relatively dry
- Jet streams exist where strong winds become concentrated in narrow bands. The polar-front jet stream meanders in a wavy, west-to-east pattern, becoming strongest in winter when the contrast in temperature between high and low latitudes is greatest

# Ocean Currents

- Ocean currents are generally CW in N. hemisphere and CCW in S. hemisphere
- Reason why: ocean water is pushed by water flowing around high pressure

# Some Important Ocean Currents

1- gulf stream
3- laborador current
7- north equatorial current
8- north equatorial. counter current
9- south equatorial current
10- south equatorial counter current
11- equatorial counter current
12- kuroshio current
14- Alaska current
16- California current

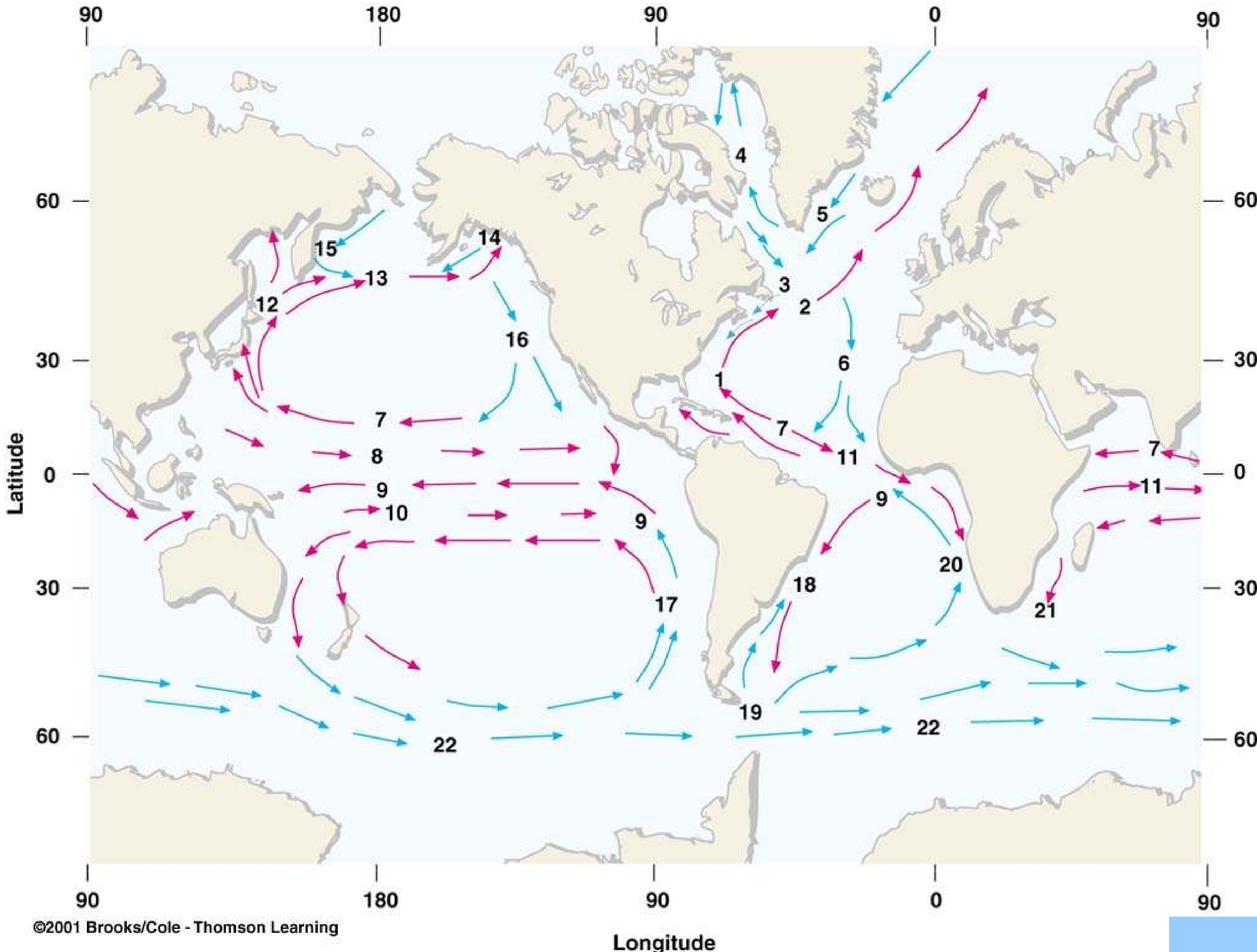




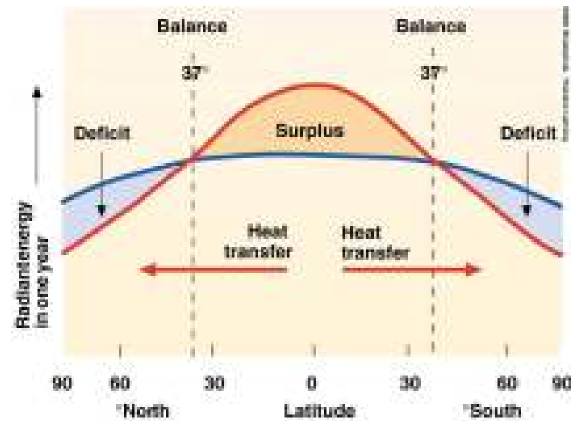
Fig. 7.23: Major surface ocean currents

# Gulf Stream

- Provides heat+moisture for mid-latitude cyclones
- Westerlies steer Gulf Stream towards Europe
- Compare position of UK to Canada. Winter temperatures are warmer than expected at this latitude
- Because of the Gulf Stream?
  - New thinking…
  - the surrounding ocean stores heat in the summer and gradually releases it in winter. Where winds blow from west to east, as across the North Atlantic, the heat released in winter preferentially warms the land areas to the east of the ocean. + effect of Rocky Mountains pushing westerlies from the SW.

# Circulations

- Atmospheric and ocean circulations are closely linked
- Currents and wind help transfer heat from equator to the poles
- If there was an imbalance yearly T differences would increase and climate would change…



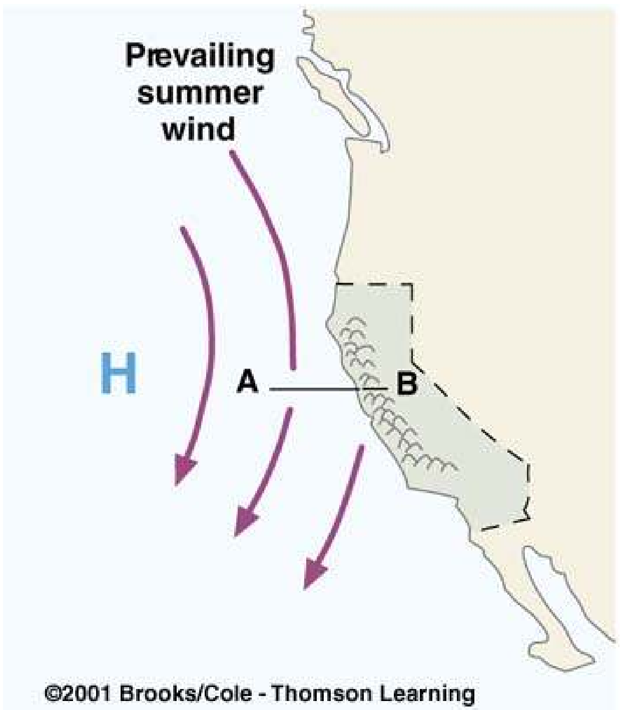

# Upwelling

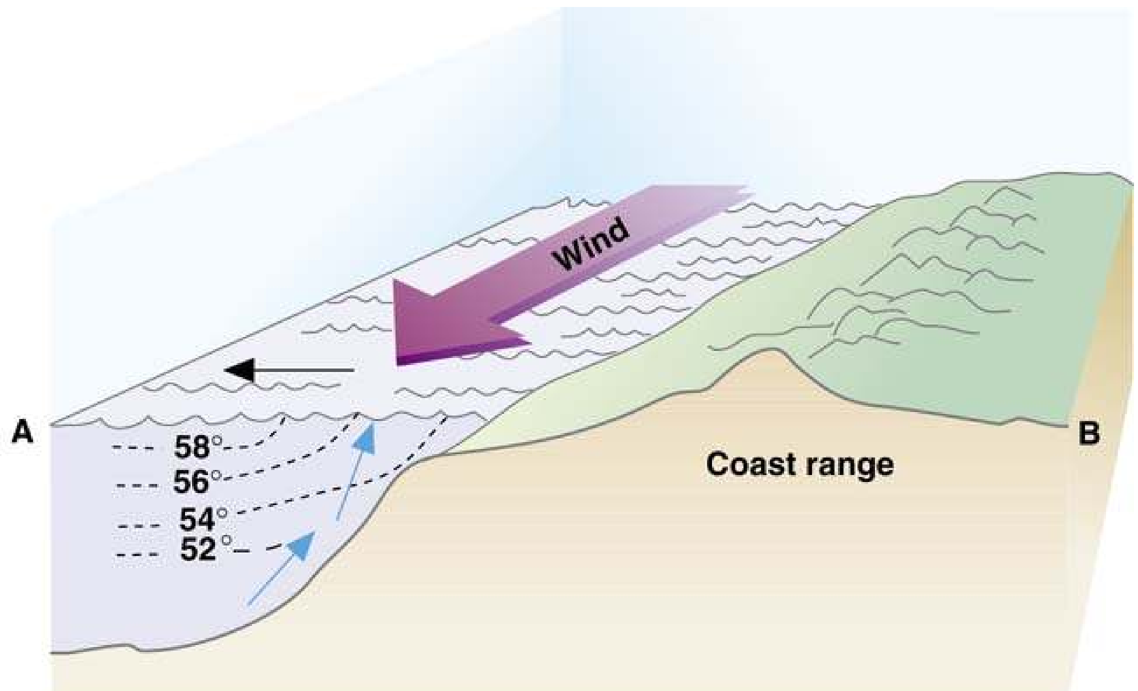
- Cold California current flows parallel to W coast
- May expect cool ocean temp. at Washington, warming as move south…but not the case!


Fig. 7.24: Average sea surface temperature along W coast during august

# Upwelling

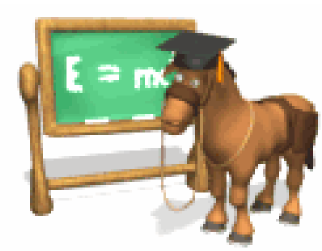
- Water pushed away from land brings up deeper water
  - N surface winds create offshore flow.
  - Cold, nutrient-rich water rises to replace the surface water (good for fishing- Peru)



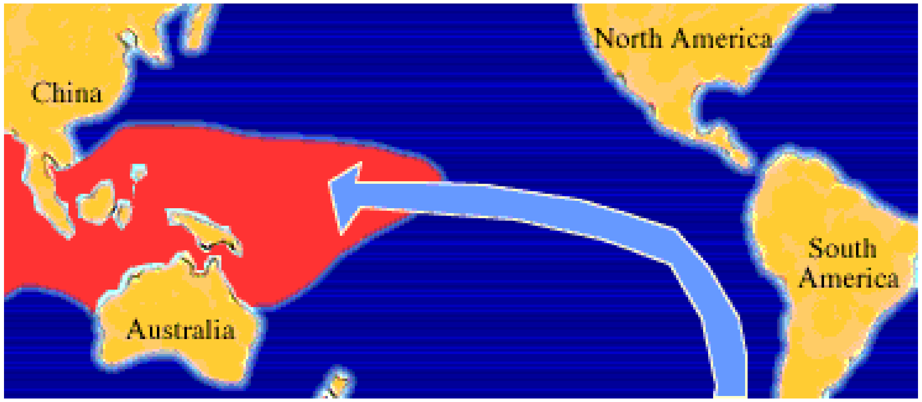
# Question

Why do the major ocean currents in the North Indian Ocean reverse direction between summer and winter?



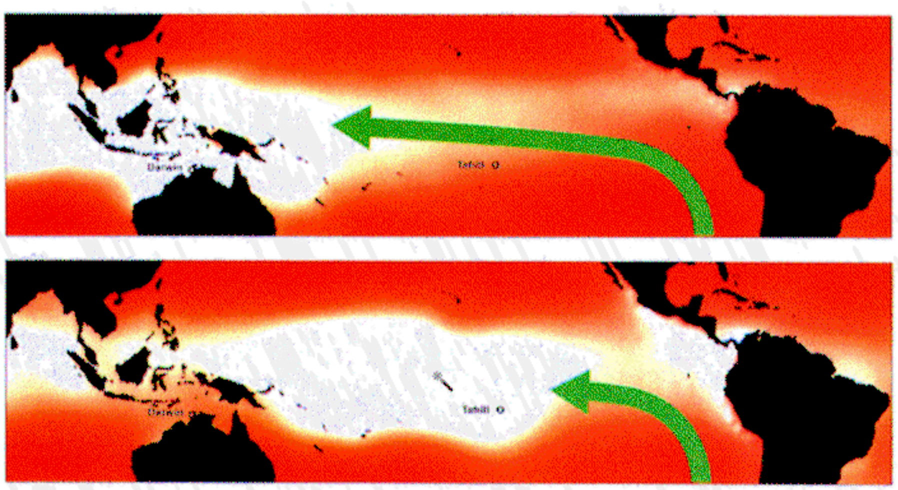
# El Niño

- El Niño refers to the E movement of warm water from the W equatorial pacific to the E equatorial pacific.
- Initially referred to a weak, warm current appearing annually around Christmas time along the coast of Ecuador and Peru (not good for their fishing industry)
- Can produce significant economic and atmospheric consequences worldwide
- Occur every 3-7 years, lasting about one year
- Last event (1997-1998) was largest ever recorded



# Southern Oscillation

- Observation:
  - air pressures at sea level in the South Pacific seesaws back and forth between two distinct patterns.
- “High index" (upper map) pressure is higher to the east of Tahiti than to the west near Australia.
  - The pressure difference along the equator causes surface air to flow westward, as indicated by the long arrow.



- “Low index" phase (lower map for November 1982)
  - barometers rise in the west and fall in the east, a reduction or even a reversal of the pressure difference between Australia and Tahiti.
  - The flattening of the seesaw causes the easterly surface winds to weaken and retreat eastward as shown.
  - We now know that the "low index" phase is usually accompanied by El Nino conditions.

http://www.pmel.noaa.gov/toga-tao/figure9.html

# Normal, Non El Niño Conditions

- Normal, non El Niño conditions
- Extreme of this is La Nina

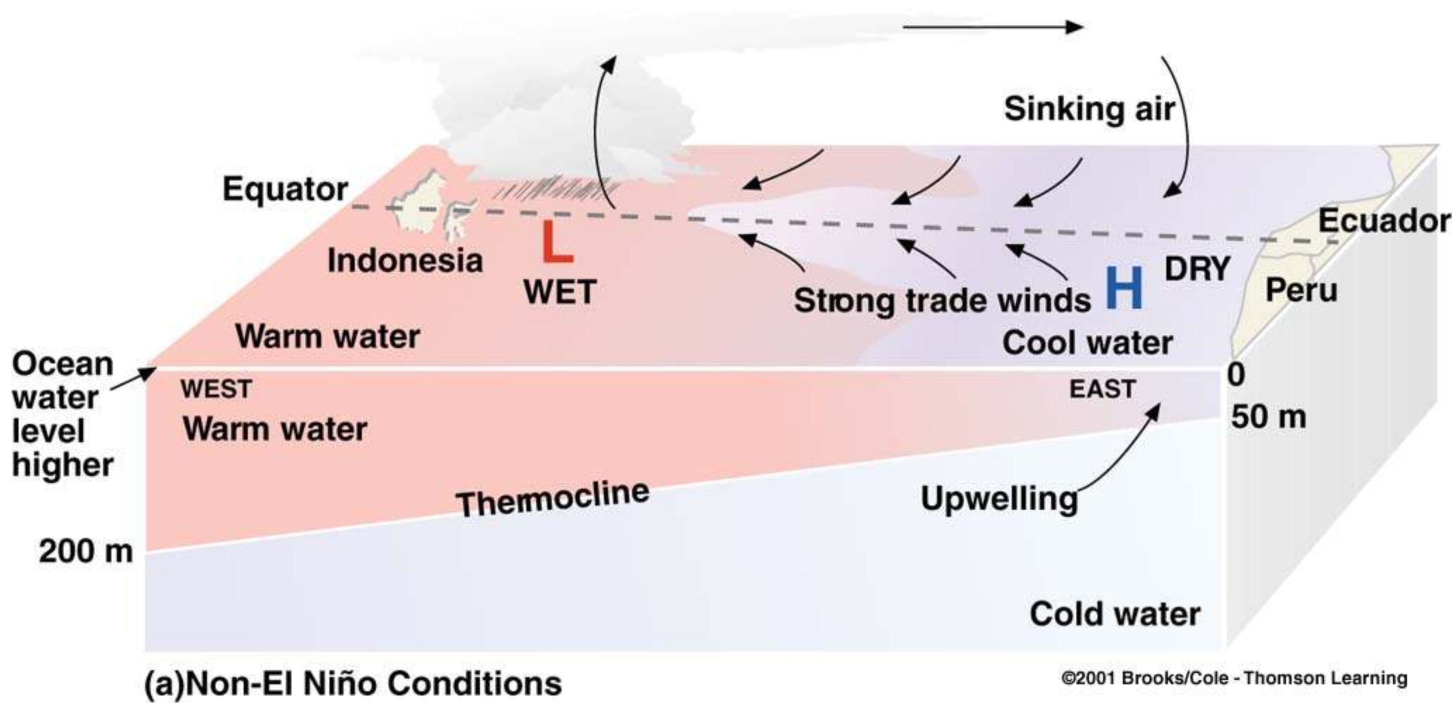



Fig. 7.26: Cold water from upwelling moves west and is warmed by sunilight

# Onset of El Niño

- During a normal year, there is a large pool of warm water in the W pacific.
- Winds relax, allowing water from W pacific to slosh along

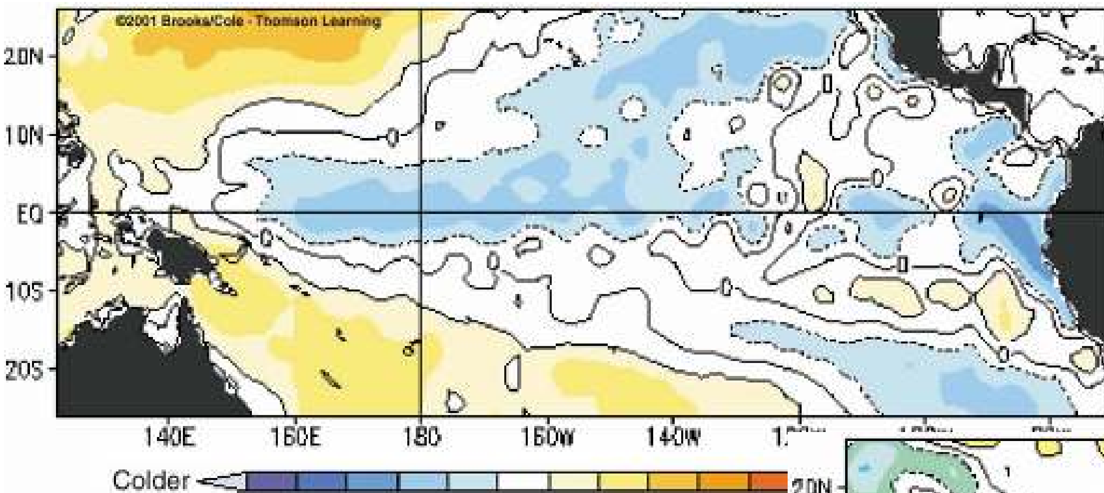



Fig. 7.27: (a) upwelling along equator and S. Amer. Coast keeps water cool

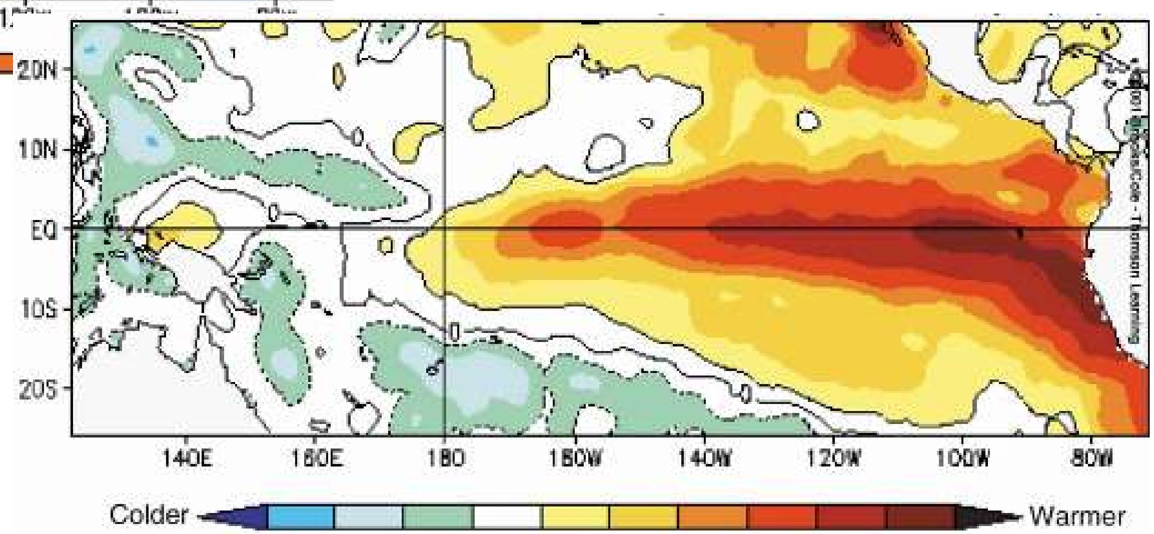
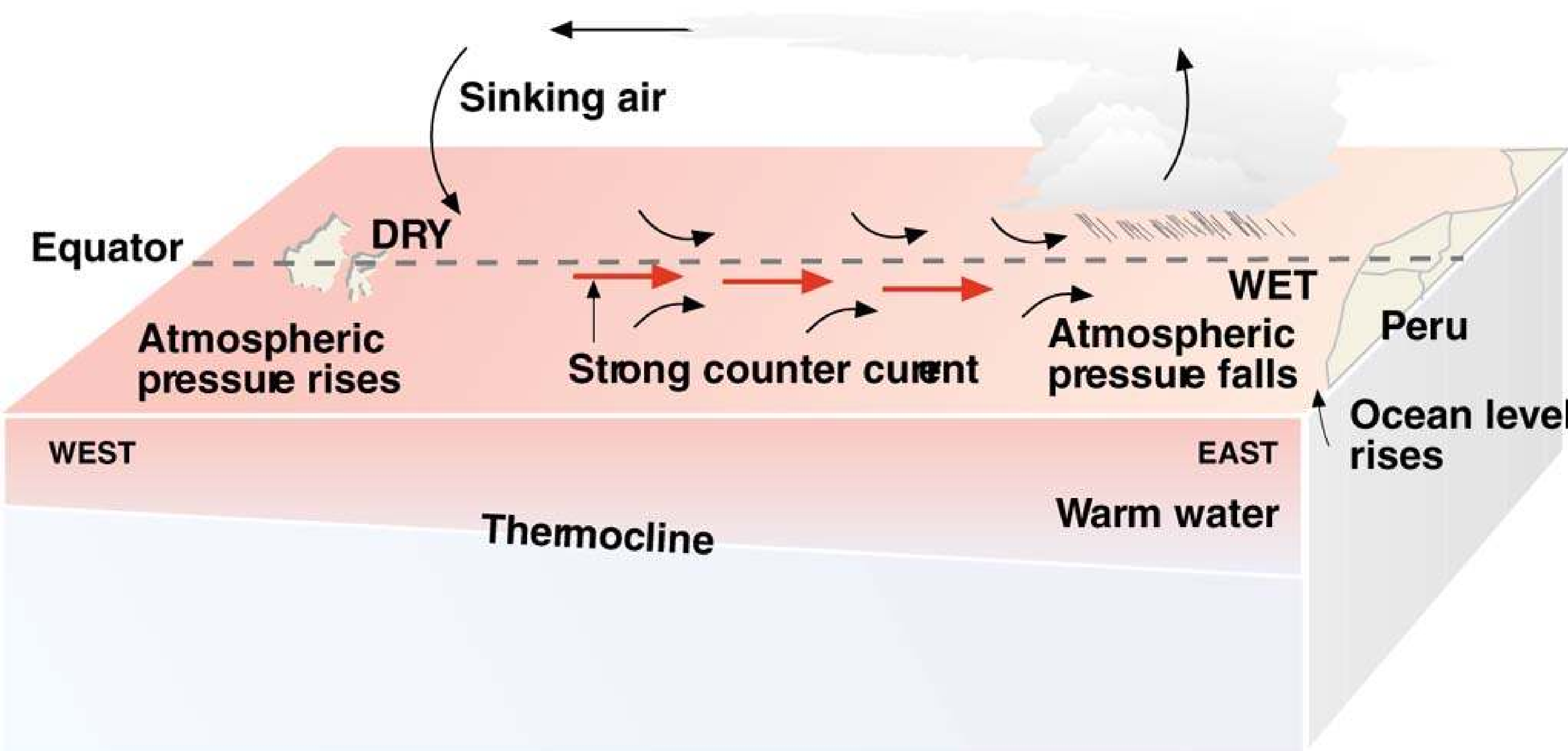



Fig. 7.27: (b) El Niño sea surface temperatures (from satellites)

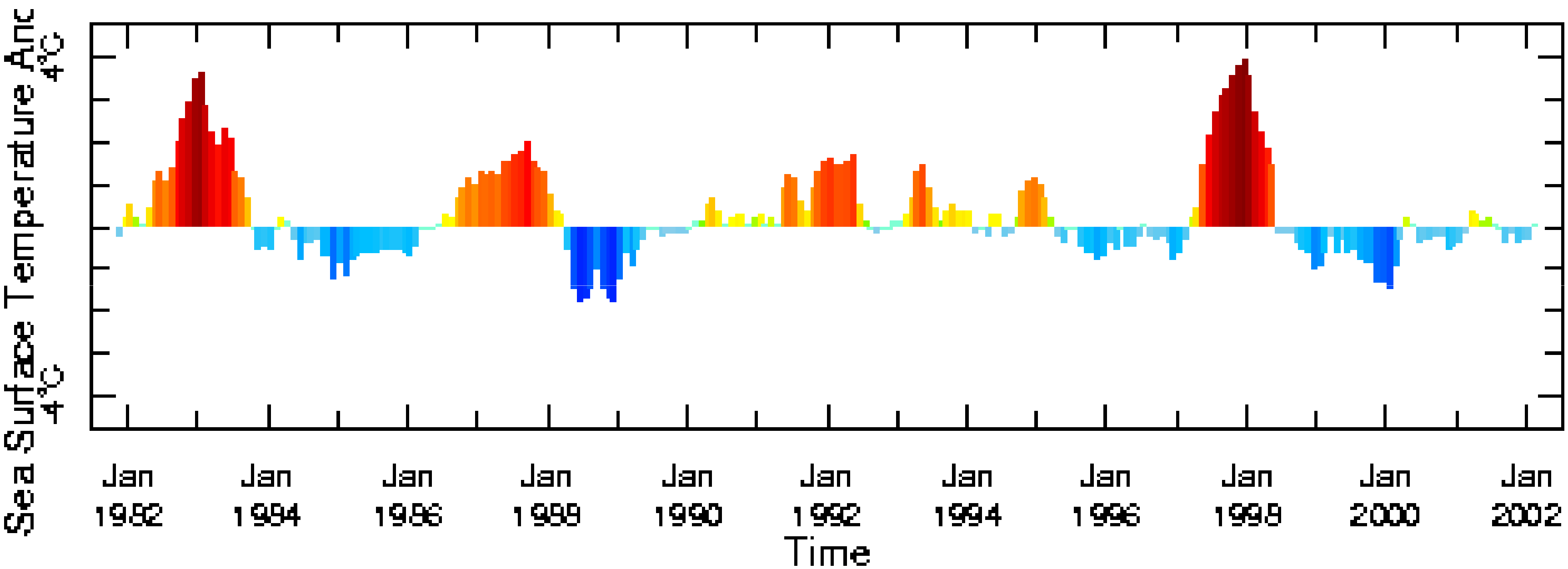
# El Niño

- El Niño conditions




(b)El Niño Conditions

# Duration of El Niño



# Effects of El Niño

- Abnormally warm water fuels the atmosphere with additional warmth and moisture

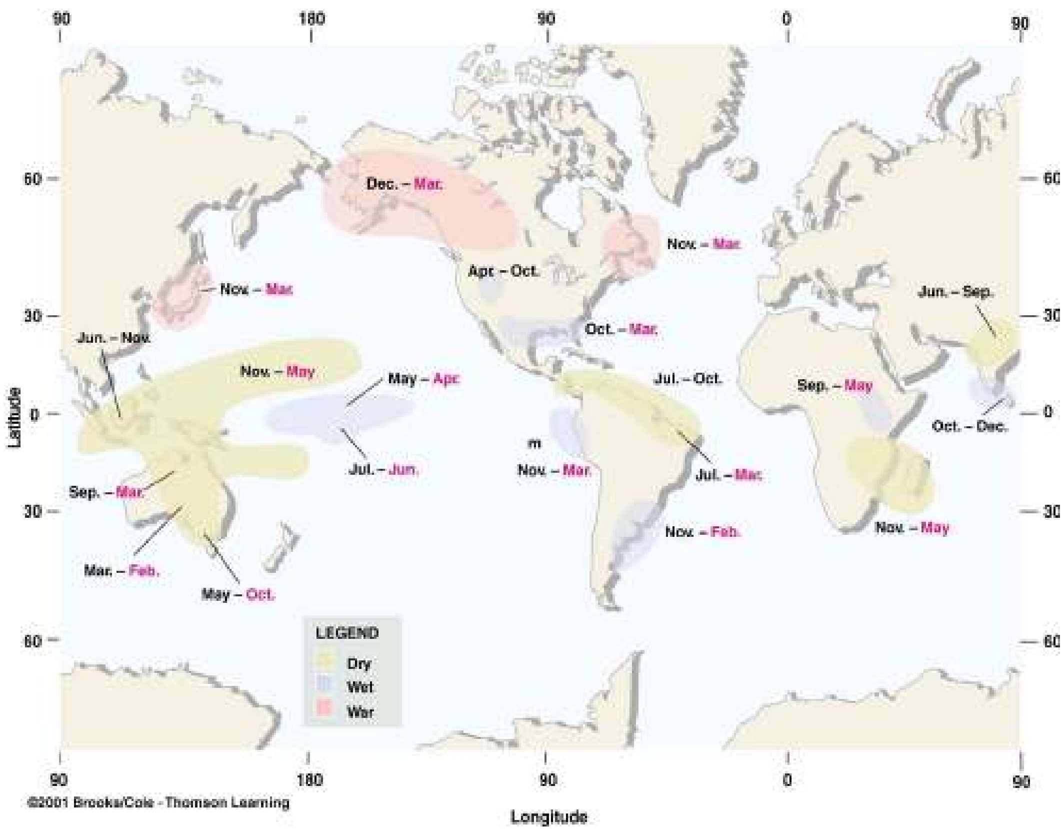



Fig. 7.28: Regions of climatic abnormalities associated with El Niño – Southern Oscillation conditions.

# Question

- Adisappointing fishing season in the normally rich fishing region off Peru can mean flooding rains for Florida and mudslides in California True or False?

- The failure of the monsoon in India can mean a mild winter is coming for the United States True or False?

# Web Sites of Interest

- www.ElNino.noaa.gov
- www.pmel.noaa.gov
  (Pacific Marine Env. Lab.)
- www.coaps.fsu.edu
  (Center for Ocean-Atmosphere Prediction Studies)
- http://www.pmel.noaa.gov/tao/jsdisplay/plots/mpeg/TAO_SST_Wind.mpeg
  (Movie)