



OCEANOGRAPHY

6. Air-Sea Interaction

notes from textbook, integrated with original contributions

Alessandro Grippo, Ph.D.

low tide on the North Sea, Mandø, Denmark

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Introduction

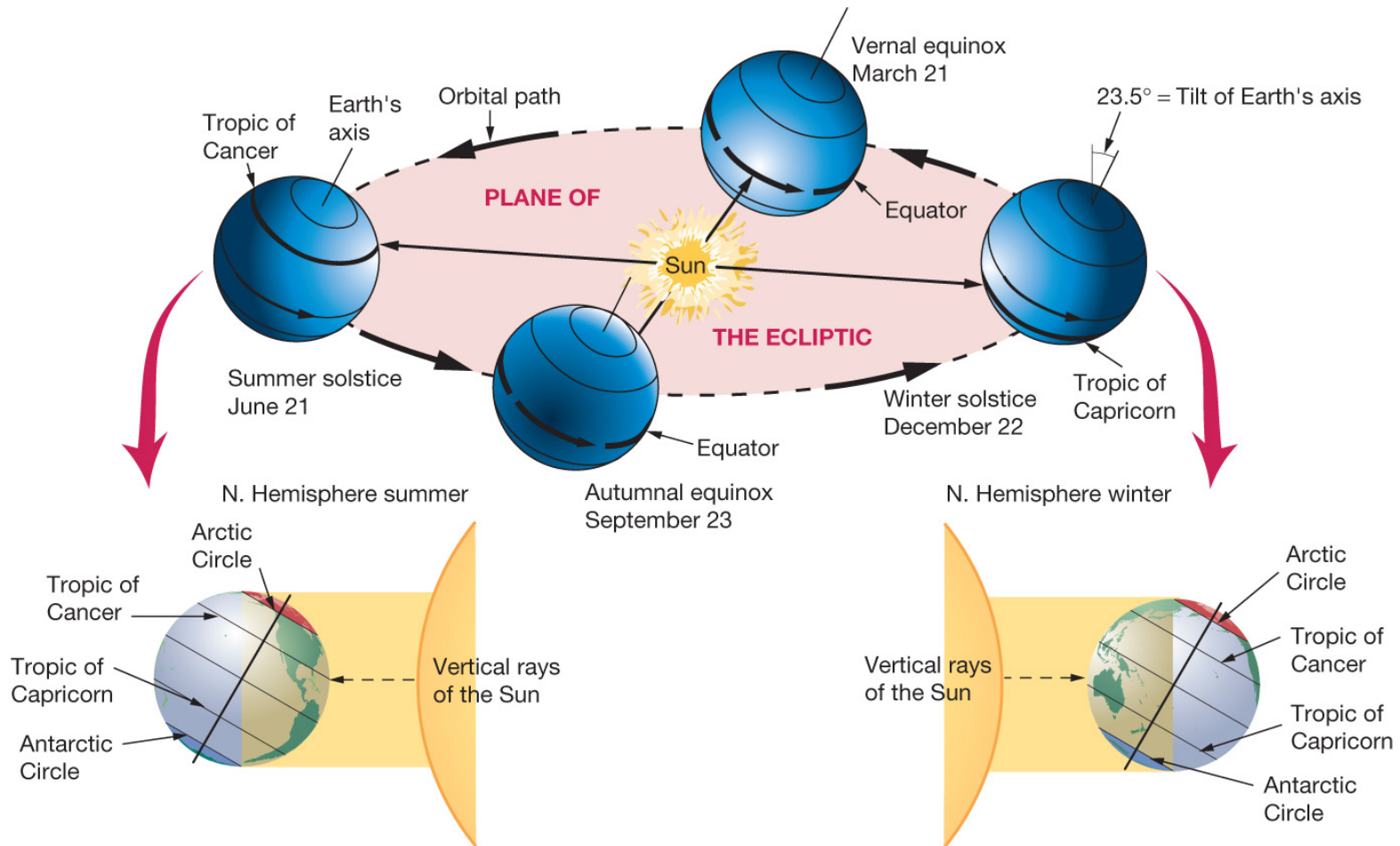
- The atmosphere and the ocean are one interdependent system
- There are complex feedbacks between the atmosphere and the ocean
- Energy from the Sun varies over time
- Energy from the Sun creates winds
- Winds create waves and ocean surface currents

6.1 – What Causes Variations in Solar Radiation on Earth?

- Day/night cycles
- Seasons
 - Earth's seasons are NOT caused by its changing distance from the Sun
 - Earth's seasons are caused by the tilt of Earth's axis
 - Seasonal changes and Earth's rotation cause unequal solar heating of Earth's surface

- Earth's axis of rotation is tilted 23.5° with respect to the **ecliptic**
 - The **ecliptic** is the plane traced by Earth's solar orbit

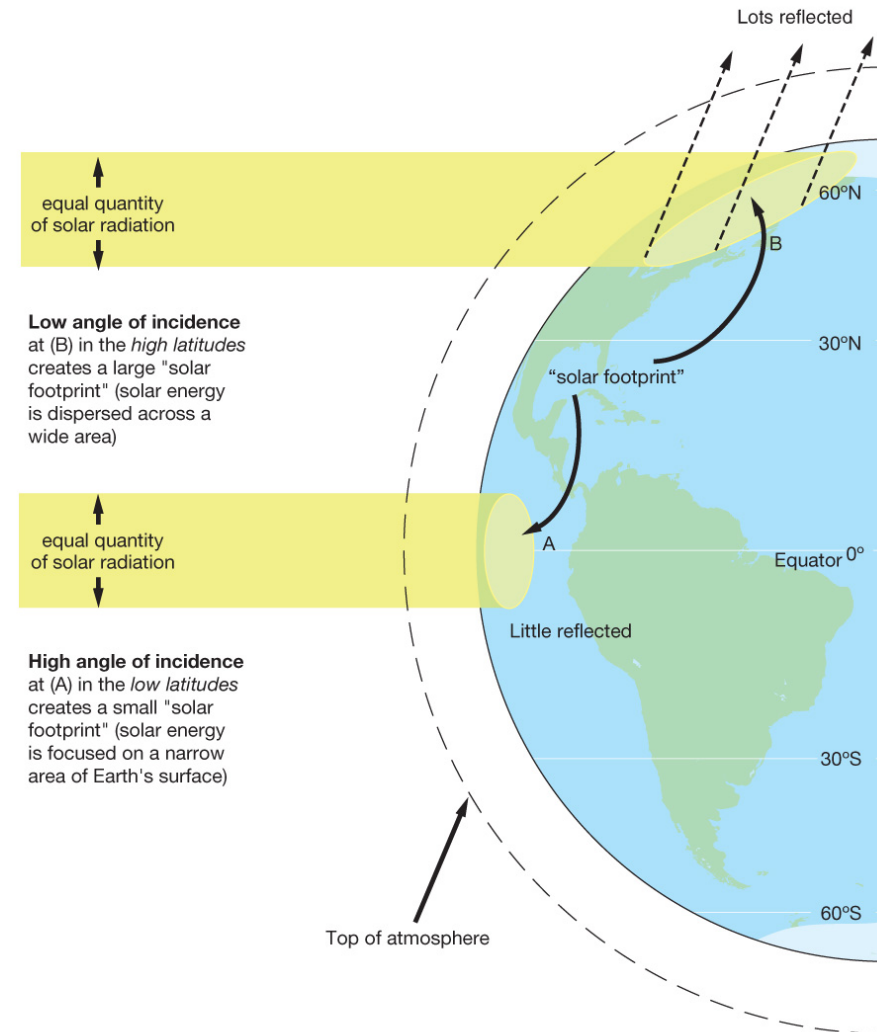
- Vernal (spring) equinox
- Summer solstice
- Autumnal equinox
- Winter solstice



- **Declination** – angular distance of Sun from Earth's equatorial plane
 - Changes between 23.5° North and 23.5° South latitudes during one year
- Most radiation is received between these two latitudes (called **tropics**)
 - Tropic of Cancer
 - Tropic of Capricorn
- Arctic Circle – 66.5° North latitude
- Antarctic Circle – 66.5° South latitude
 - for part of the year, the areas between these **circles** and the poles do not experience daily lights of daylight and darkness

How Latitude Affects the Distribution of Solar Radiation

- Earth as a disk vs. Earth as a sphere
 - amount and intensity of solar radiation received at high latitudes are much less than at lower latitudes
- Besides daily and seasonal variations, *four factors* affect the amount of radiation received at high and low latitudes



- Four factors that affect amount of radiation received at different latitudes:
 - **Solar footprint:** the same amount of radiation is spread over a wider area at high latitudes
 - **Atmospheric absorption:** atmosphere absorbs radiation, and at high latitudes radiation crosses more atmosphere than at lower latitudes
 - **Albedo:** ratio reflected radiation/incident radiation. Depends on materials, white ice has a higher value
 - **Reflection of incoming sunlight:** angle at which sunlight strikes the ocean surface determines how much is absorbed and how much is reflected

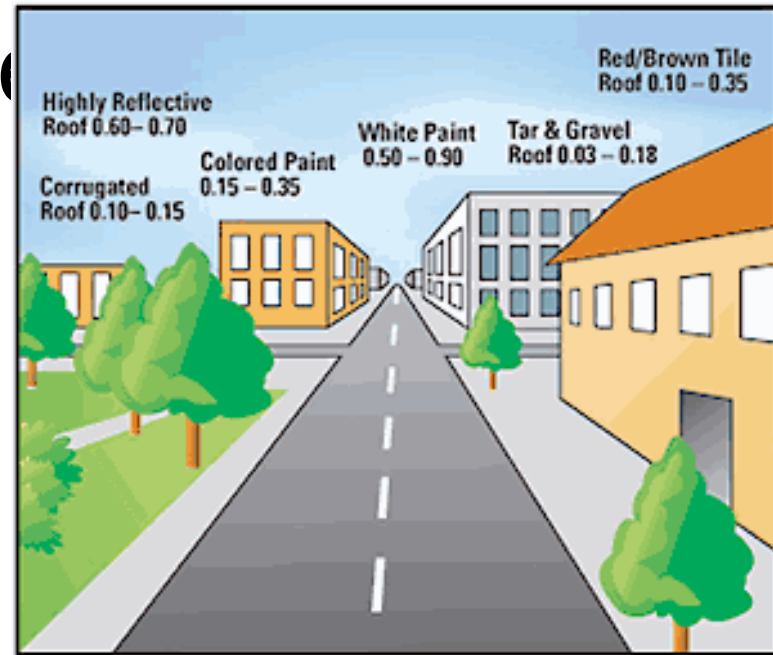
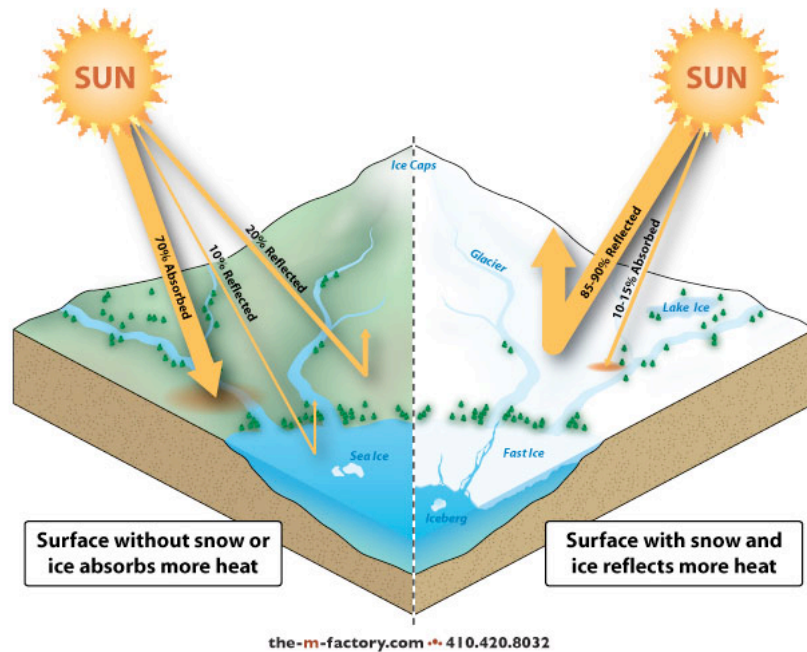


TABLE 6.1

REFLECTION AND ABSORPTION OF SOLAR ENERGY RELATIVE TO THE ANGLE OF INCIDENCE ON A FLAT SEA

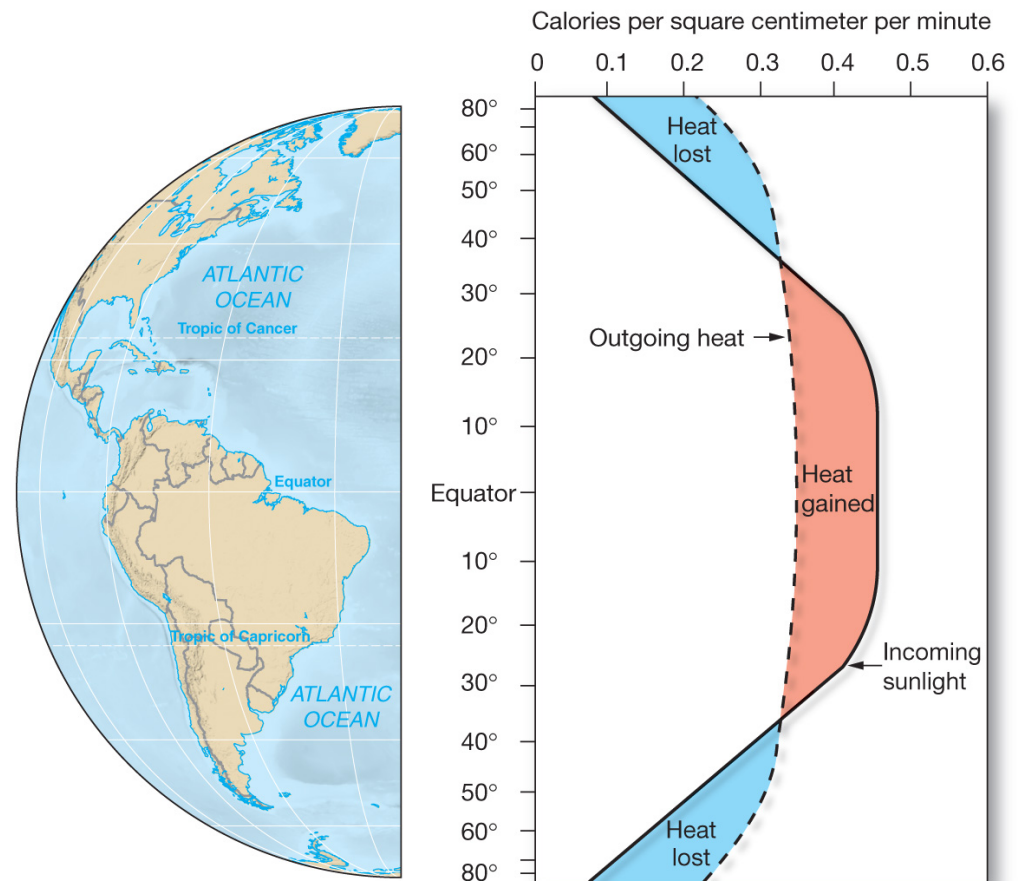
Elevation of the Sun above the horizon

	90°	60°	30°	15°	5°
Reflected radiation (%)	2	3	6	20	40
Absorbed radiation (%)	98	97	94	80	60

oceanic heat flow

- High latitudes:
 - more heat lost than gained
 - Ice has high albedo
 - Low solar ray incidence
- Low latitudes:
 - more heat gained than lost

Heat Gained and Lost



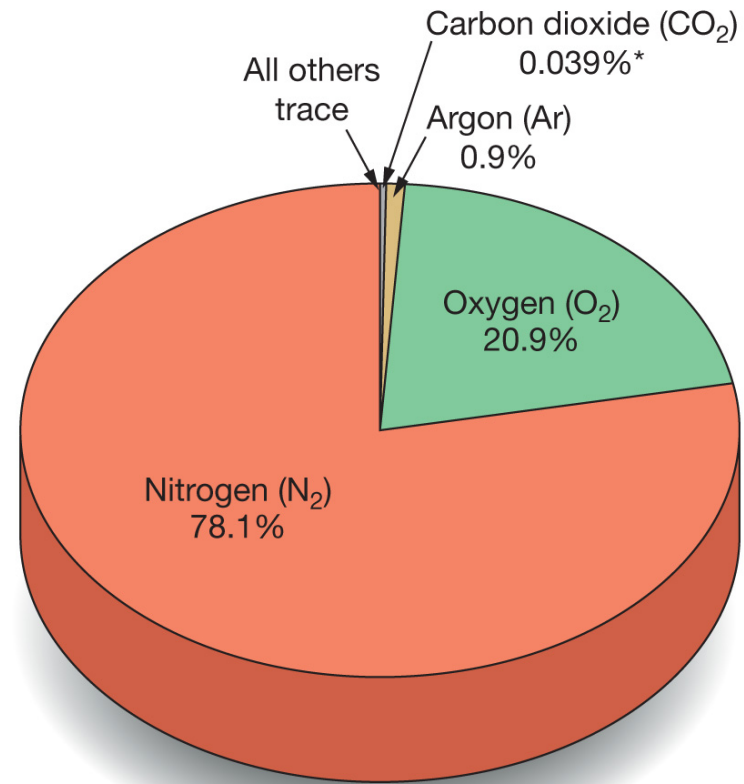
- If equatorial areas gain heat and polar areas lose heat continuously, then the first should be overheating and the second should be freezing
- What happens is that the excess heat from the equator travels towards polar areas, warming them up
- This excess heat is transferred via:
 - air circulation in the atmosphere
 - water circulation in the oceans

6.2 – What Physical Properties Does the Atmosphere Possess?

- Atmosphere transfers heat and water vapor from place to place on Earth
- Complex relationships exist in the atmosphere among air composition, temperature, density, water vapor content, and pressure

Composition of the Atmosphere

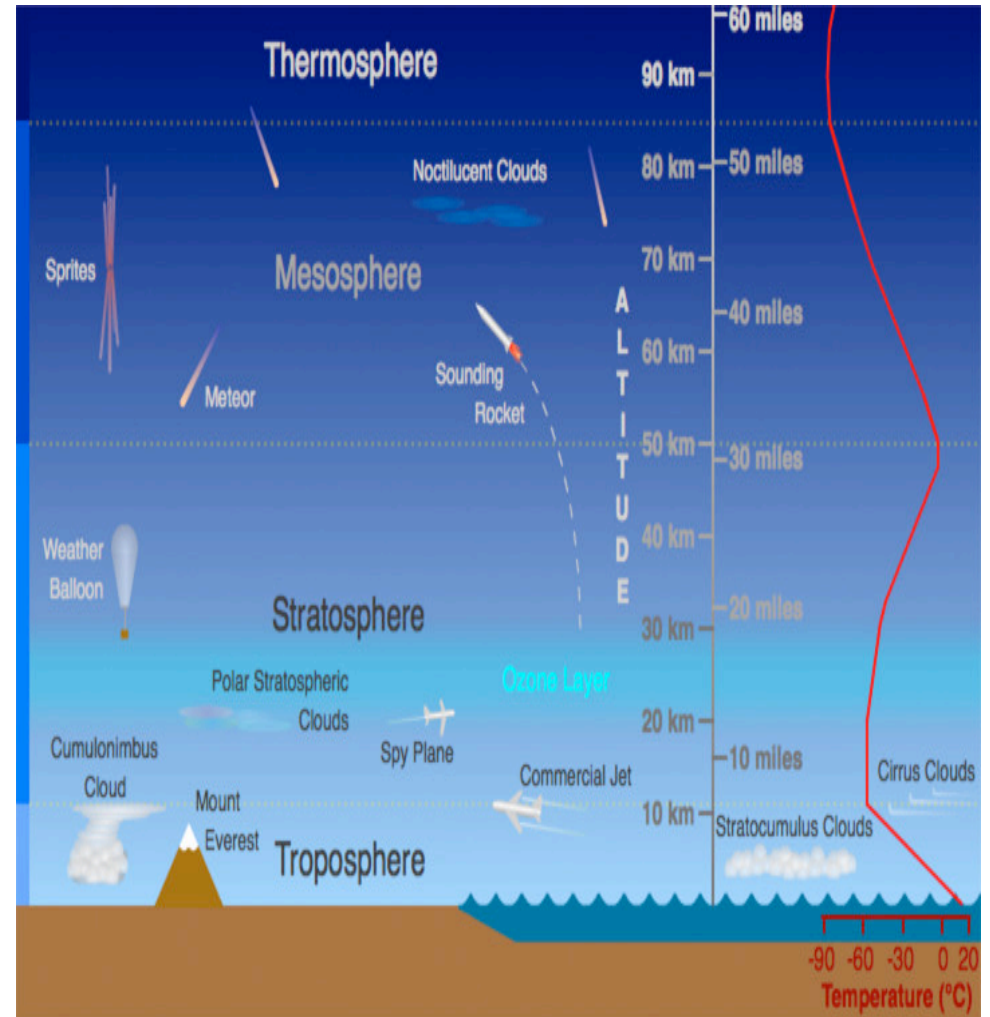
- Mostly nitrogen (N_2) and Oxygen (O_2)
- Other gases are significant because of their heat-trapping properties



*Note that the concentration of carbon dioxide in the atmosphere is increasing by 0.5% per year due to human activities

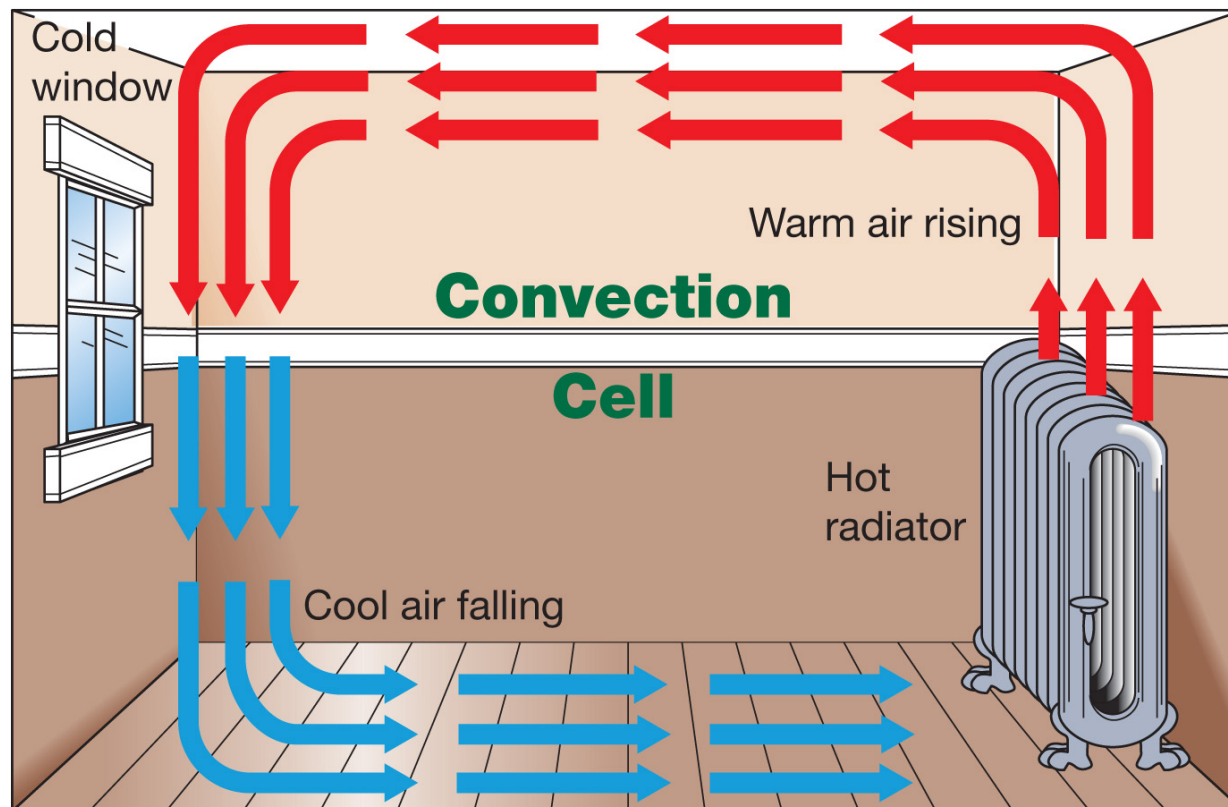
Temperature Variation in the Atmosphere

- The heat we feel at the surface is not directly from the Sun but from Earth radiating Sun's energy back
- Because of this, in the Troposphere (mixed layer) temperatures drop with altitude (away from the source, Earth's surface)
- The Troposphere is where all weather occurs



Density Variation in the Atmosphere

- Warm air is less dense, so it rises
- Cool air is more dense, so it sinks

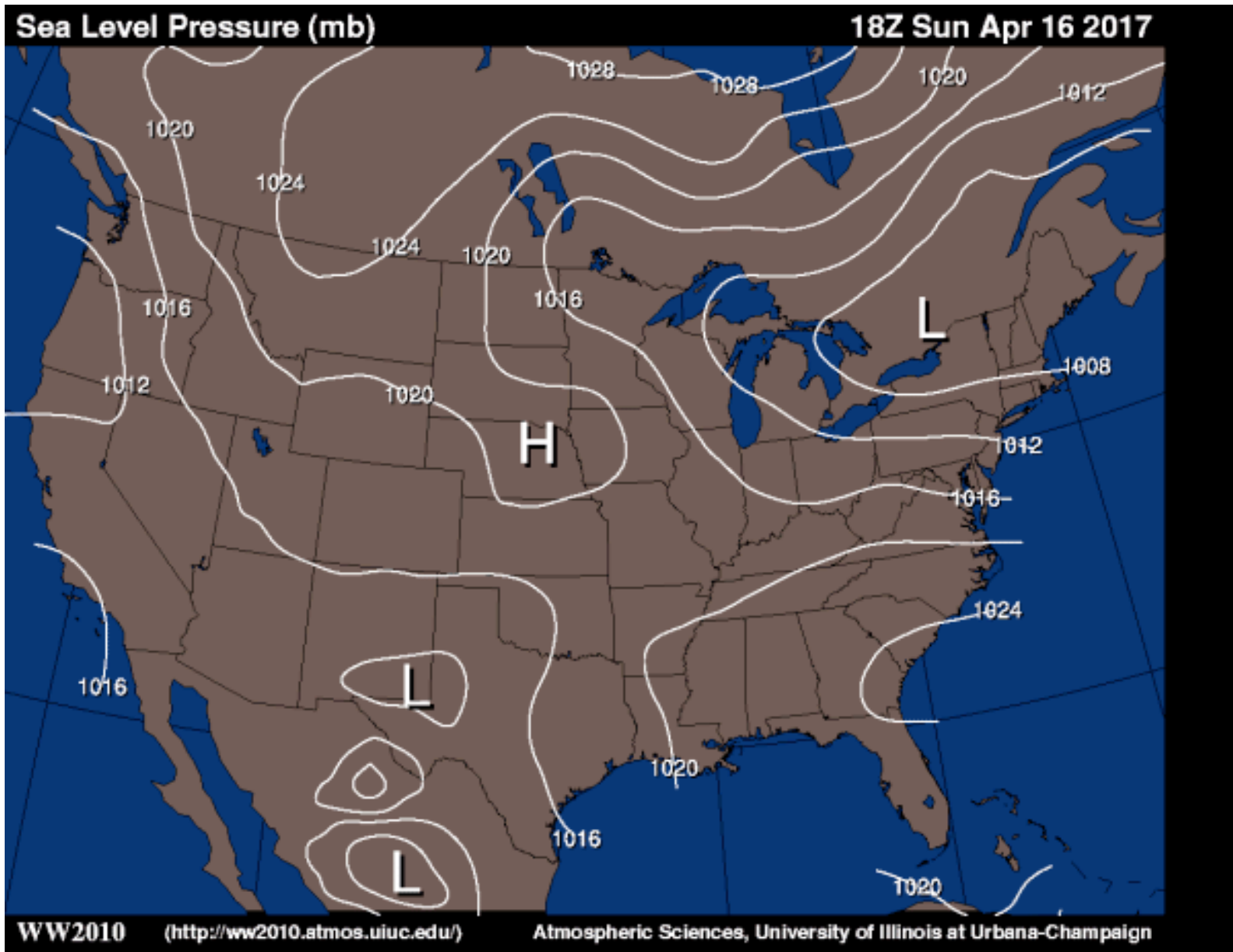


Atmospheric Water Vapor Content

- Warm air can hold more moisture than cold air
 - Air molecules moving at higher speed come into contact with more water vapor
- Warming air would “absorb” moisture (dry conditions in a desert, for instance)
- Cooling air would “lose” moisture (precipitation)
- Water vapor also influences the density of air:
 - Water vapor is less dense than air, so:
 - Moist air rises because it is less dense
 - Dry air sinks because it is more dense

Atmospheric Pressure

- Atmospheric pressure depends on the weight of the column of air above
- This means that atmospheric pressure decreases with elevation (it is higher on the ground)
- The atmospheric unit of pressure is the **standard atmosphere** (atm), defined as 101,325 Pascals, or 1.01325 bars
 - 1.033 kg/cm²
 - 14.7 lb/in²

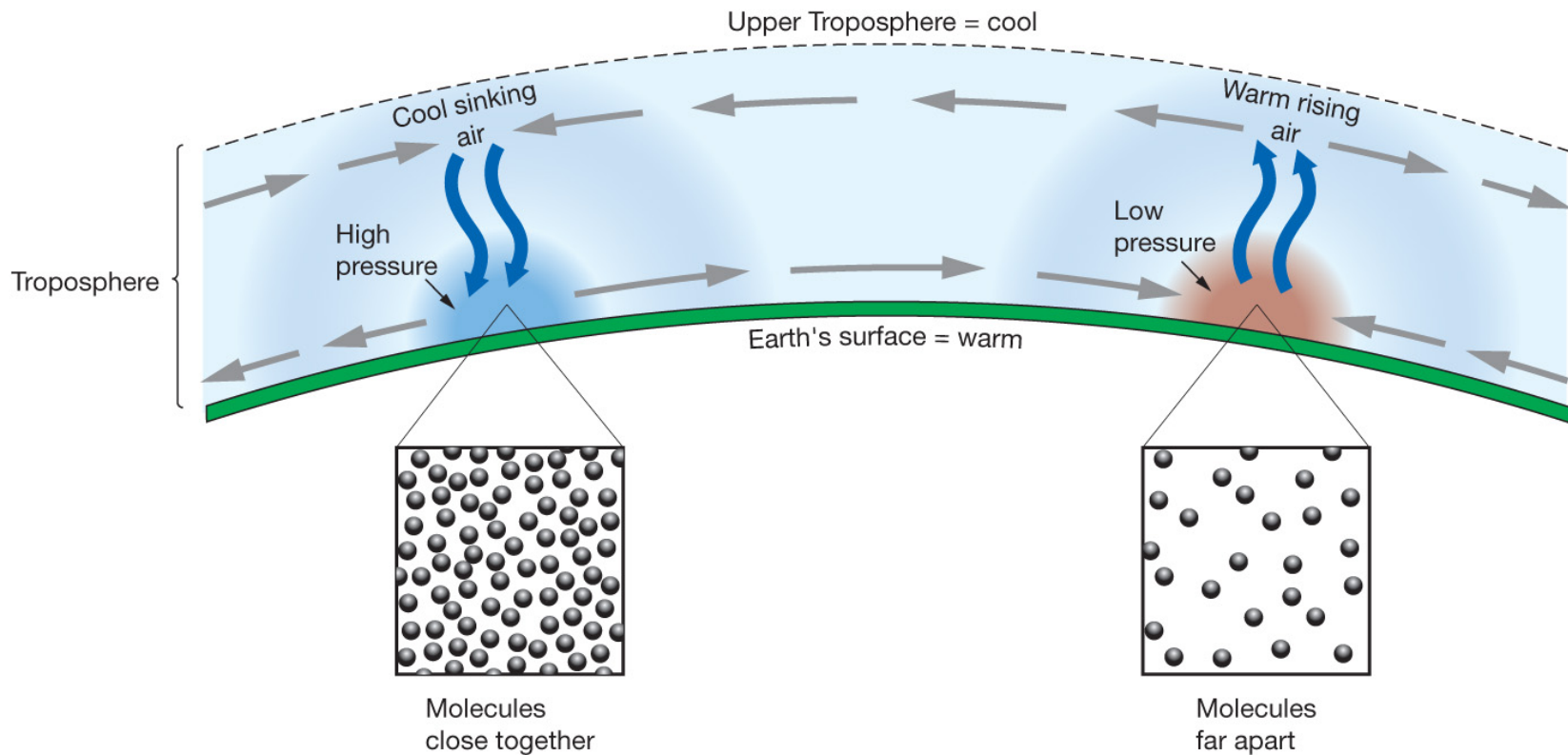


A map showing atmospheric pressure in millibars (mb)

- Temperature affects pressure:
 - Cool temperatures cause air molecules to be closer to each other, and vice versa
- Cool air sinks (high pressure on the surface)
 - sinking cool air warms up in the process: compression
- Warm air rises (low pressure on the surface)
 - rising warm air cools down in the process: expansion

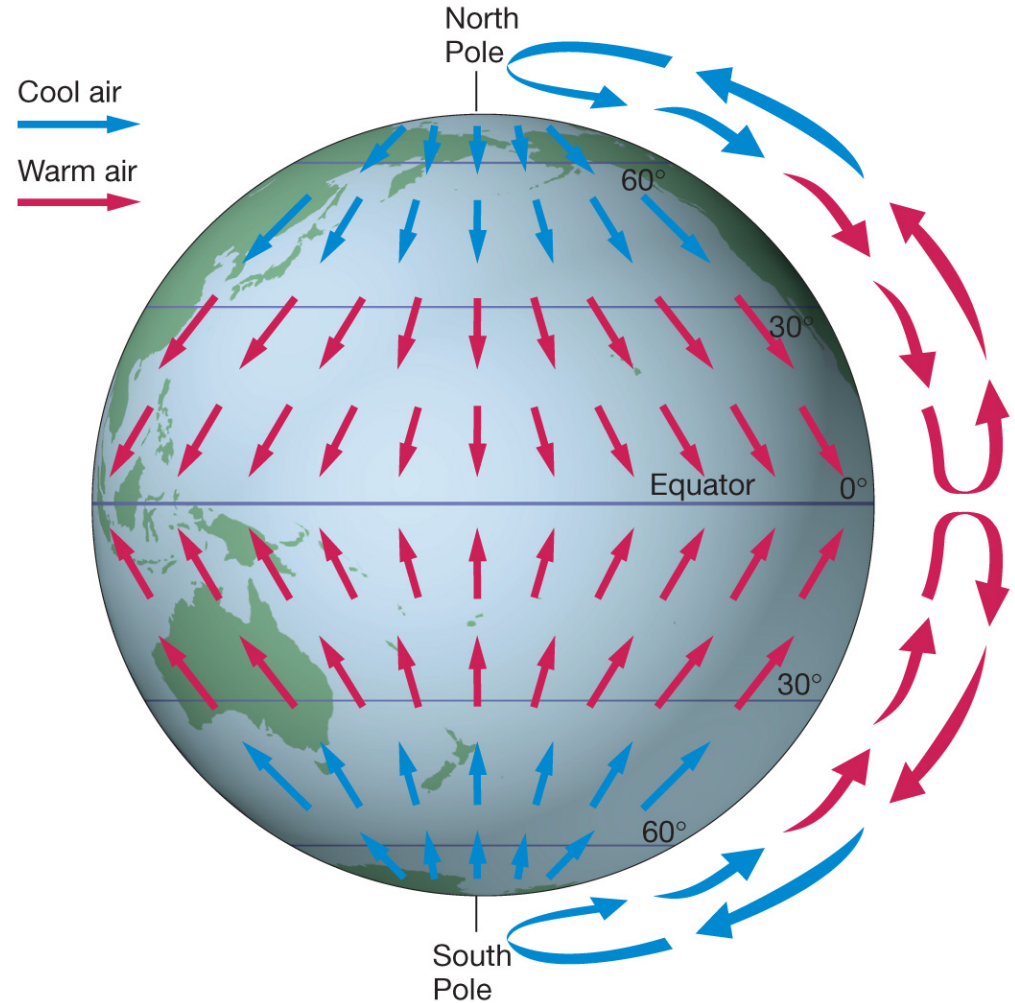
Movement of the Atmosphere

- Air *always* moves from high-pressure regions to low pressure regions
- Movement of air on the ground is called **wind**



Movements in the Air: an example from a non-spinning Earth

- Warm air rises at equator (low pressure)
 - it cools down and releases moisture → precipitation
- Air sinks at poles (high pressure)
 - it warms up and absorbs moisture → dry condition
- Air flows from high to low pressure
- One giant **convection cell** or **circulation cell**



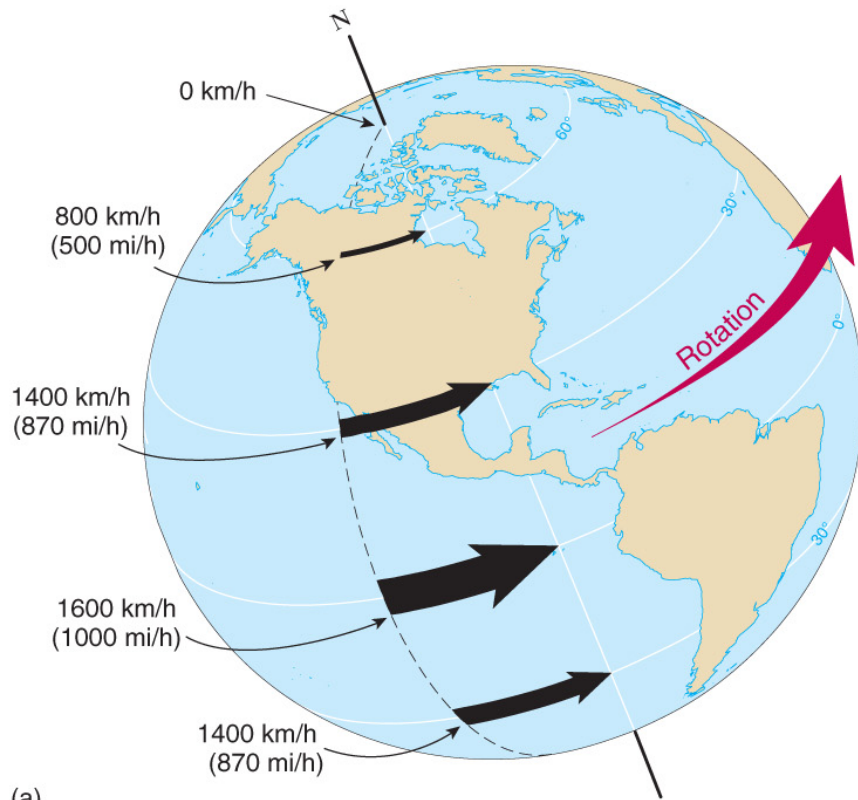
Was that model a good approximation? No

- The previous model used the correct principles that drive air circulation
- Reality is more complicated than this because Earth is spinning and because the angle of incidence of Sun's radiation varies during seasons

Coriolis Effect

- Objects moving on Earth follow a curved path
 - deflected to the right in the Northern Hemisphere
 - deflected to the left in the Southern Hemisphere
- This is due to Earth's rotation

- The Coriolis effect is greatest at the poles
- Change in Earth's rotating velocity with latitude
 - 0 km/hour at poles
 - More than 1600 km/hr (1000 mi/hr) at equator
- The greatest effect is on objects that move long distances across latitudes



(a)

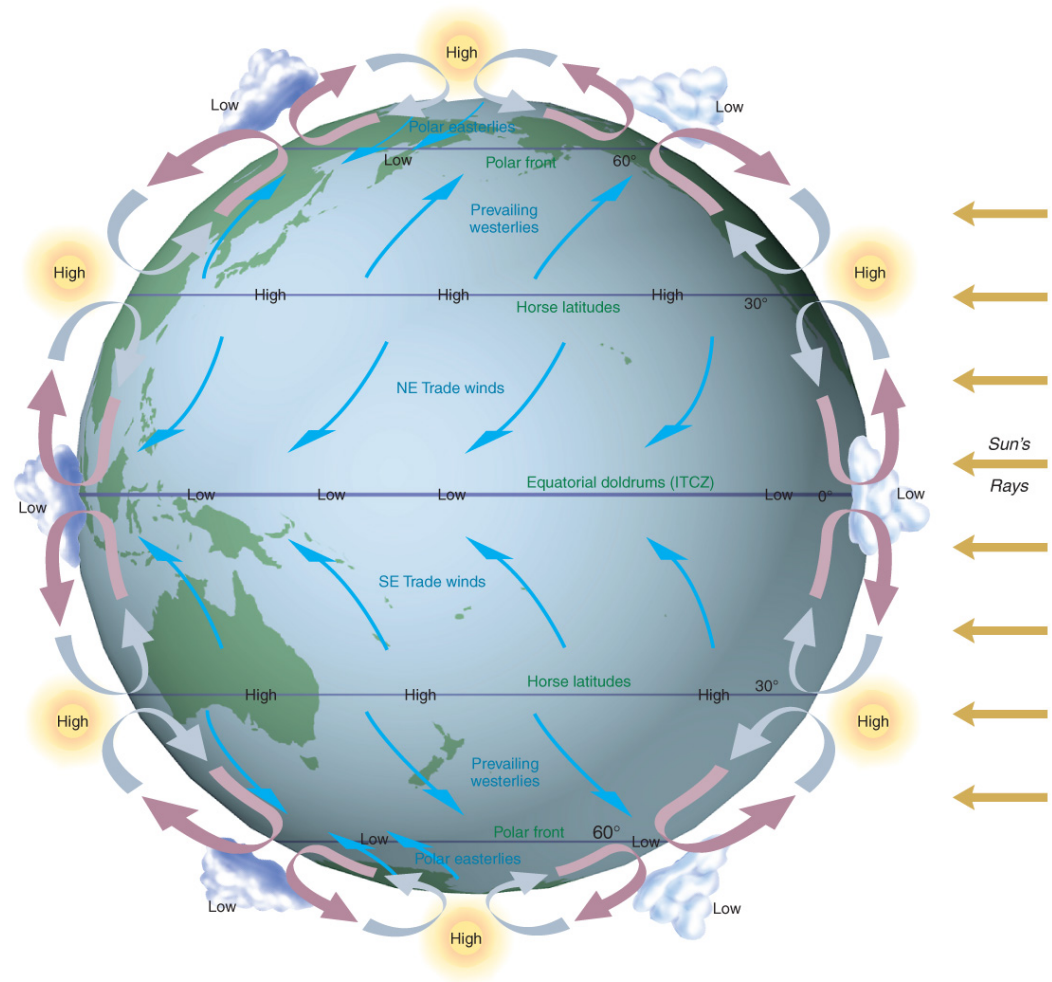
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(b)

6.4 – What Global Atmospheric Circulation Patterns Exist?

- Circulation cells
- Pressure
- Wind belts
- Boundaries



- Circulation Cells – one in each hemisphere
 - **Hadley Cell**: 0–30 degrees latitude
 - **Ferrel Cell**: 30–60 degrees latitude
 - **Polar Cell**: 60–90 degrees latitude
- High pressure zones – descending air
 - **Subtropical highs** – 30 degrees latitude
 - **Polar highs** – 90 degrees latitude
 - Clear skies
- Low pressure zones – rising air
 - **Equatorial low** – equator
 - **Subpolar lows** – 60 degrees latitude
 - Overcast skies with lots of precipitation

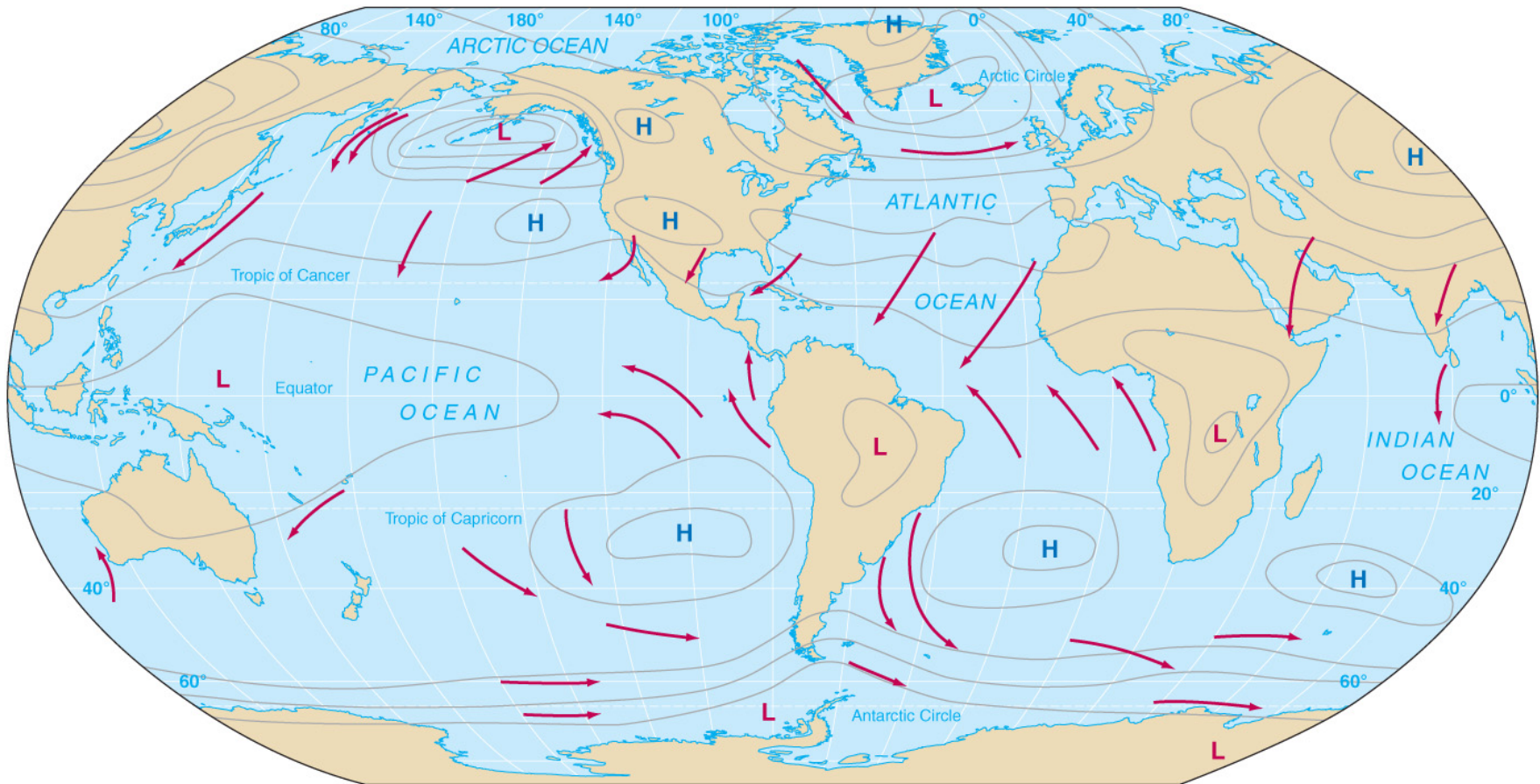
- **Trade winds** – From subtropical highs to equator
 - Northeast trades in Northern Hemisphere
 - Southeast trades in Southern Hemisphere
- **Prevailing westerlies** – from 30–60° N/S latitude
- **Polar easterlies** – 60–90° N/S latitude

- **Boundaries between wind belts**
 - **Doldrums or Intertropical Convergence Zone (ITCZ)** – at equator
 - **Horse latitudes** – 30° N/S
 - **Polar fronts** – 60° N/S

Circulation Cells: Idealized or Real?

- While basically correct, the 3-cells model is idealized
- That is particularly true for location and direction of motion of the Hadley and Polar Cells
- Complexity also comes from:
 - tilt of Earth's axis, producing seasons
 - uneven distribution of land masses and ocean basins (particularly in the Northern Hemisphere)
 - differences in heat capacity between continents and oceans
 - air over continents is warmer in summer and colder in winter, when compared to air over adjacent oceans. This difference triggers local changes to the general circulation pattern
 - examples: Monsoons in the Indian Ocean

January Atmospheric Pressures and Winds



6.5 – How Does the Ocean Influence Global Weather Phenomena and Climate Patterns?

- because of its huge extent over Earth's surface, and because of water's unusual thermal properties, the **ocean exerts a very strong influence on Earth's global weather phenomena and climate patterns**
-
- **Weather**: the conditions of the atmosphere at a particular time and place
- **Climate**: the long-term average of weather

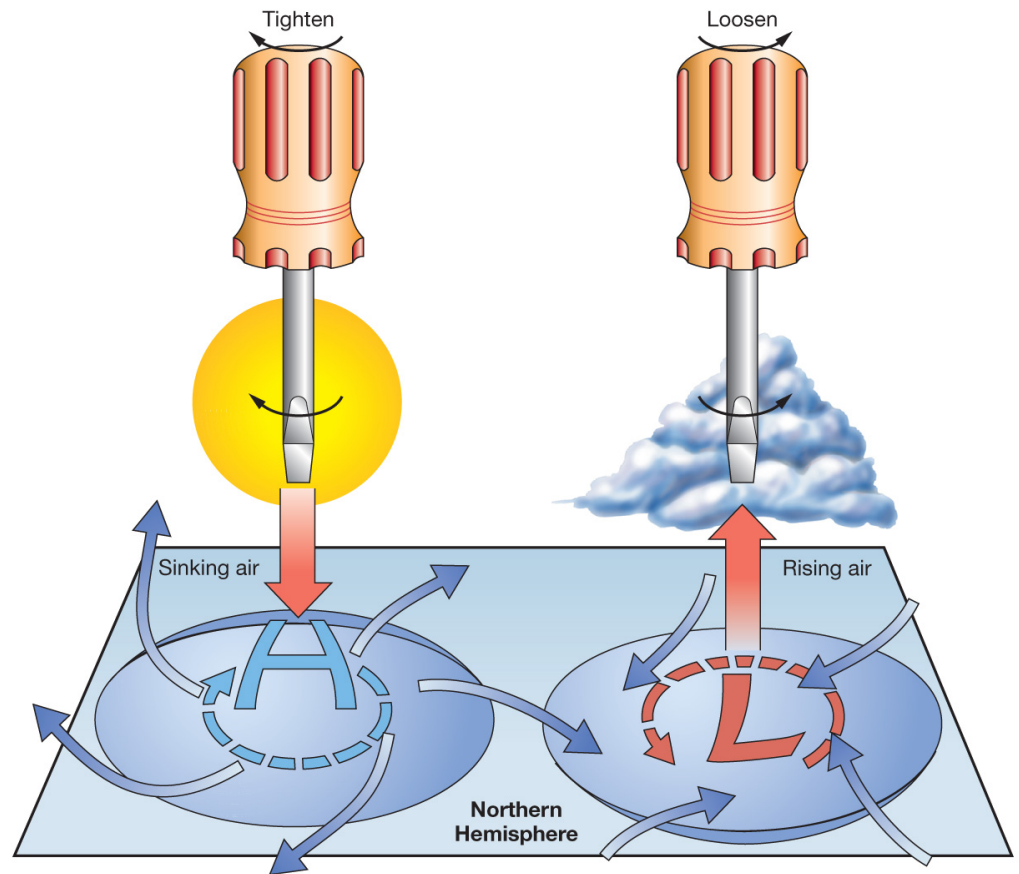
Winds

- **Cyclonic flow**

- Counterclockwise around a low in Northern Hemisphere
- Clockwise around a low in Southern Hemisphere

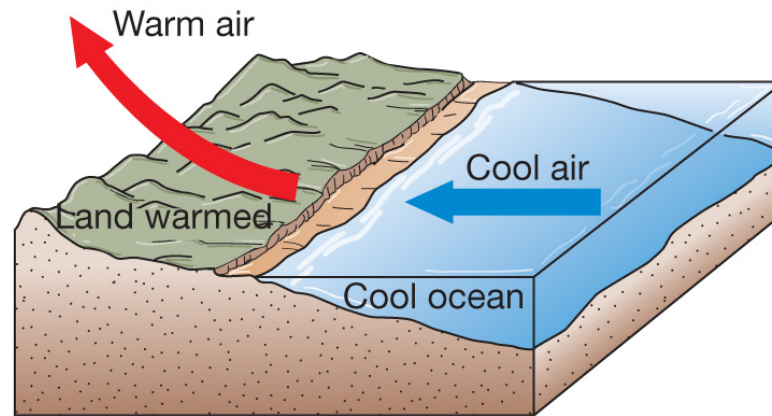
- **Anticyclonic flow**

- Clockwise around a low in Northern Hemisphere
- Counterclockwise around a low in Southern Hemisphere



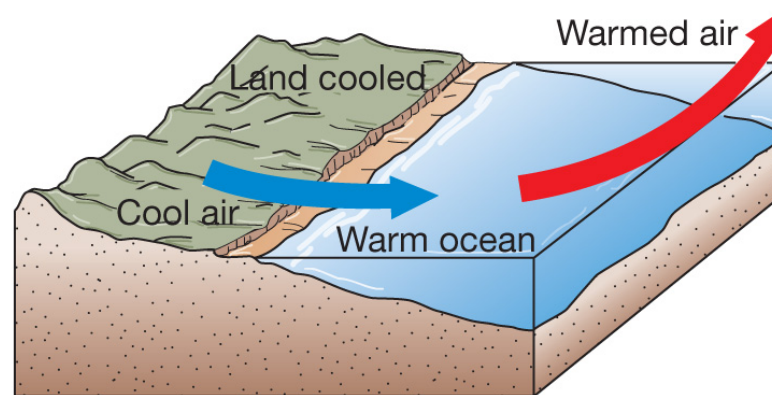
Sea and Land Breezes

- Differential solar heating is due to different heat capacities of land and water.



(a) Sea breeze

- **Sea breeze**
 - From ocean to land
- **Land breeze**
 - From land to ocean

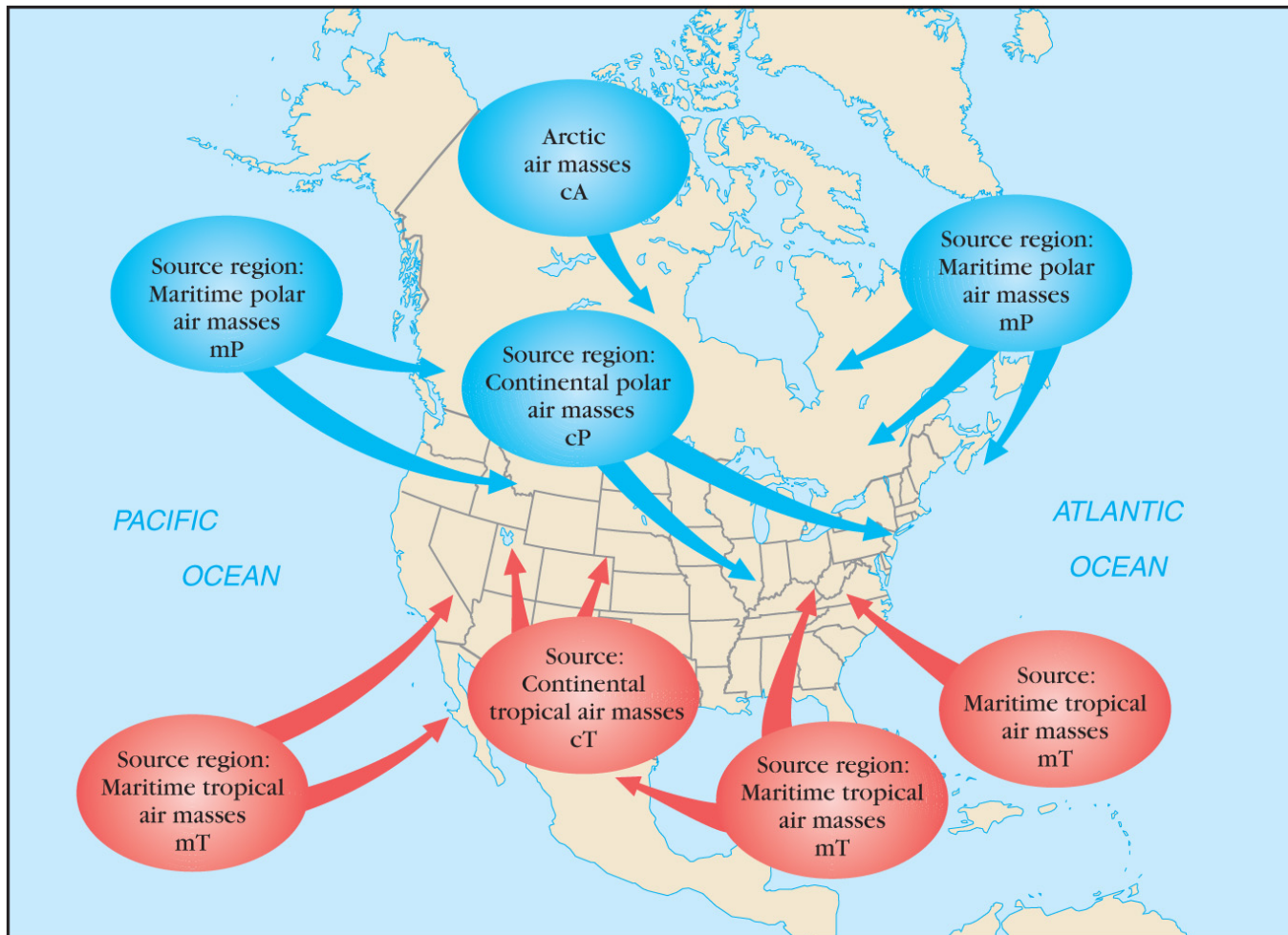


(b) Land breeze

Storms and Fronts

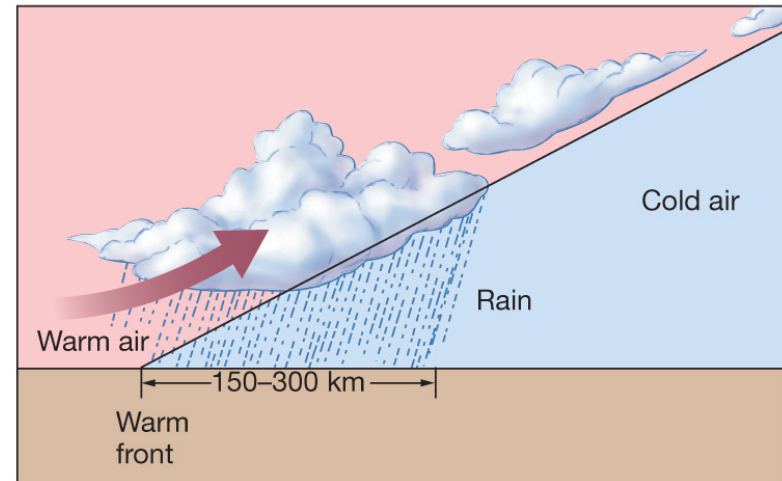
- At high and low latitudes there is little minor seasonal change in weather
- It is in mid-latitudes that storms are common (where there is more variation)
- **Storms** are atmospheric disturbances characterized by strong winds, precipitation, thunders, lightning
- **Air Masses** are large volumes of air with distinctive origin and characteristics

Air masses affecting United States weather

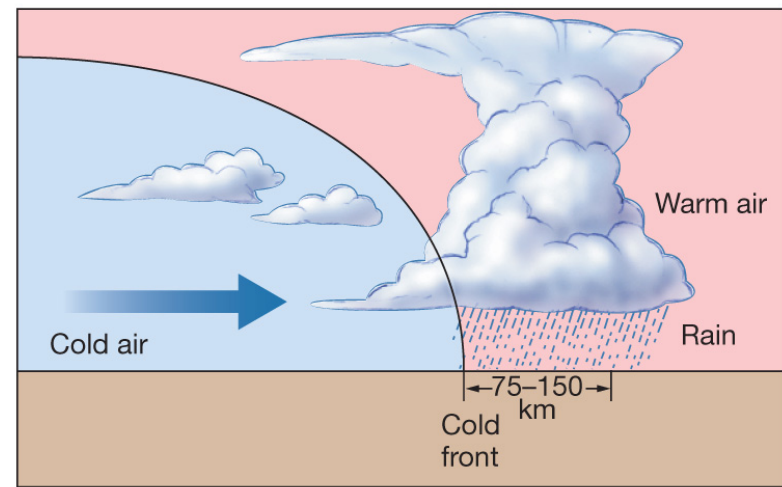


Fronts

- As polar and tropical air masses move into middle latitudes, they also move gradually eastwards
- When air masses meet they create a front
- A **front** is the boundary between air masses, and it can be either warm or cold
- Typically, **storms** develop at fronts



(a)



(b)

Jet Streams

- Jet Streams are narrow, fast, easterly flowing air masses that exist at about 10 km of altitude
- They follow a wavy pattern that can cause occasional unusual weather by steering polar or tropical masses into mid-latitudes
- Regardless of what happens, warm air will always rise above cold air
 - Warm front: minor temperature changes and gentle rain
 - Cold front: major temperature changes and heavy rains

Tropical Cyclones (Hurricanes)

- Large rotating masses of low pressure
- Characterized by strong winds, and torrential rain
- Largest storm systems on Earth
- Not associated with any front
- The energy contained in a single tropical cyclone is greater than that generated by all energy sources in the U.S. over the past 20 years
 - called hurricanes in the Americas
 - called typhoons in the western Pacific Ocean
 - called cyclones in the Indian Ocean

origin of tropical cyclones

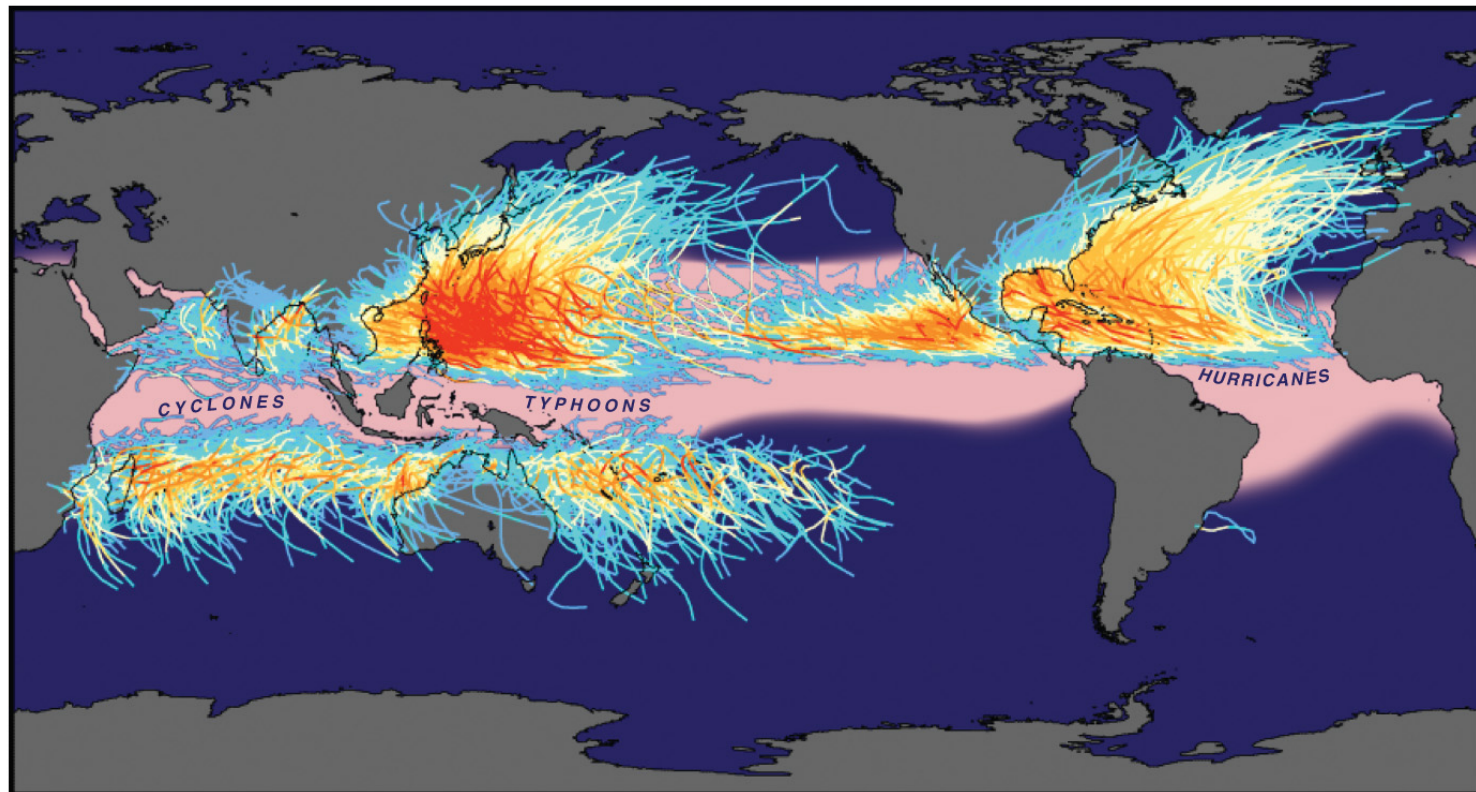
- Low pressure cell
- Winds feed water vapor – latent heat of condensation
- Air rises, low pressure deepens
- Storm develops
 - Winds less than 61 km/hour (38 miles/hour) – tropical depression
 - Winds 61–120 km/hour (38–74 miles/hour) – tropical storm
 - Winds above 120 km/hour (74 miles/hour) – tropical cyclone or hurricane

TABLE 6.3

THE SAFFIR-SIMPSON SCALE OF HURRICANE INTENSITY

Category	Wind speed		Typical storm surge (sea level height above normal)		Damage
	(km/hr)	(mi/hr)	(meters)	(feet)	
1	120–153	74–95	1.2–1.5	4–5	Minimal: Minor damage to buildings
2	154–177	96–110	1.8–2.4	6–8	Moderate: Some roofing material, door, and window damage; some trees blown down
3	178–209	111–130	2.7–3.7	9–12	Extensive: Some structural damage and wall failures; foliage blown off trees and large trees blown down
4	210–249	131–155	4.0–5.5	13–18	Extreme: More extensive structural damage and wall failures; most shrubs, trees, and signs blown down
5	>250	>155	>5.8	>19	Catastrophic: Complete roof failures and entire building failures common; all shrubs, trees, and signs blown down; flooding of lower floors of coastal structures

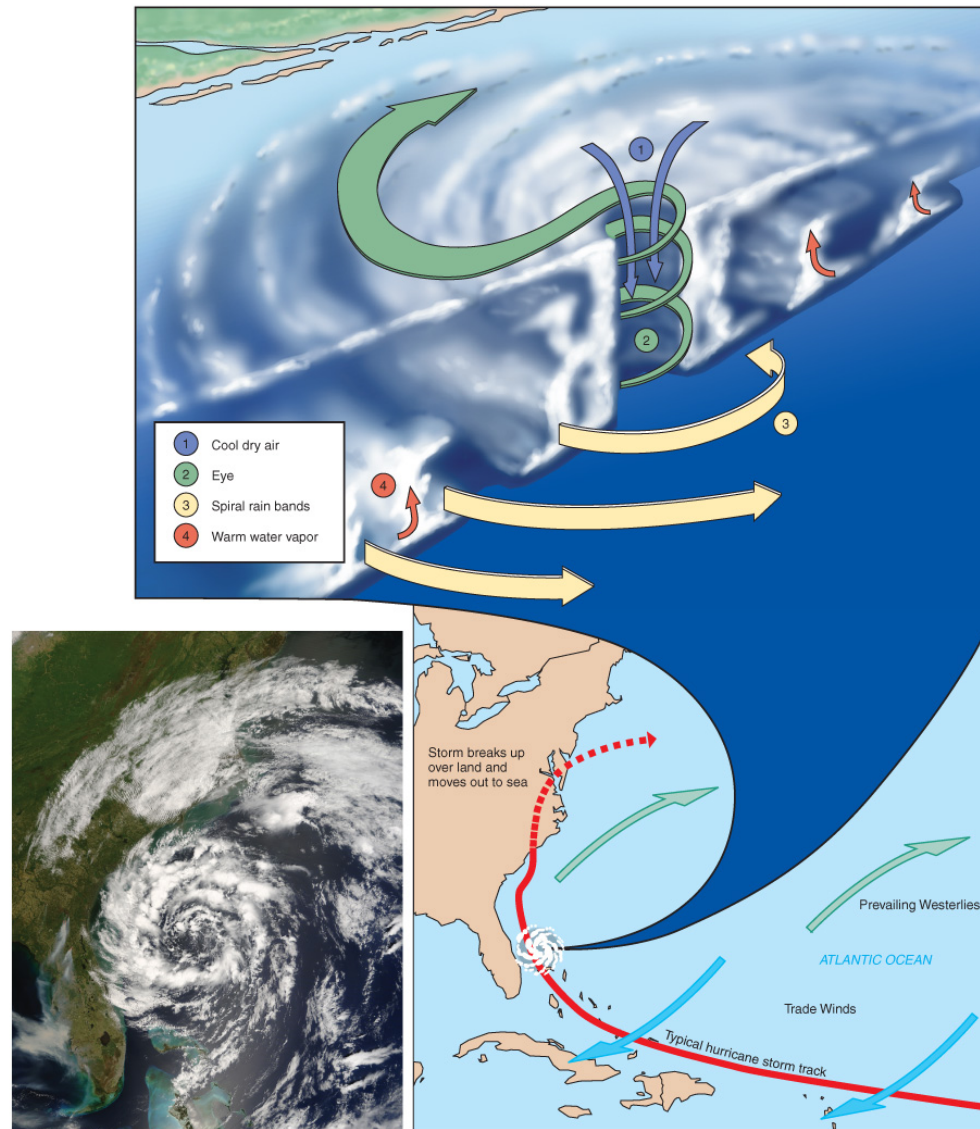
- About 100 worldwide per year
- Require
 - Ocean water warmer than° 25°C (77°F)
 - Warm, moist air
 - The Coriolis Effect
- Hurricane season is June 1 – November 30



Saffir-Simpson Hurricane Intensity Scale

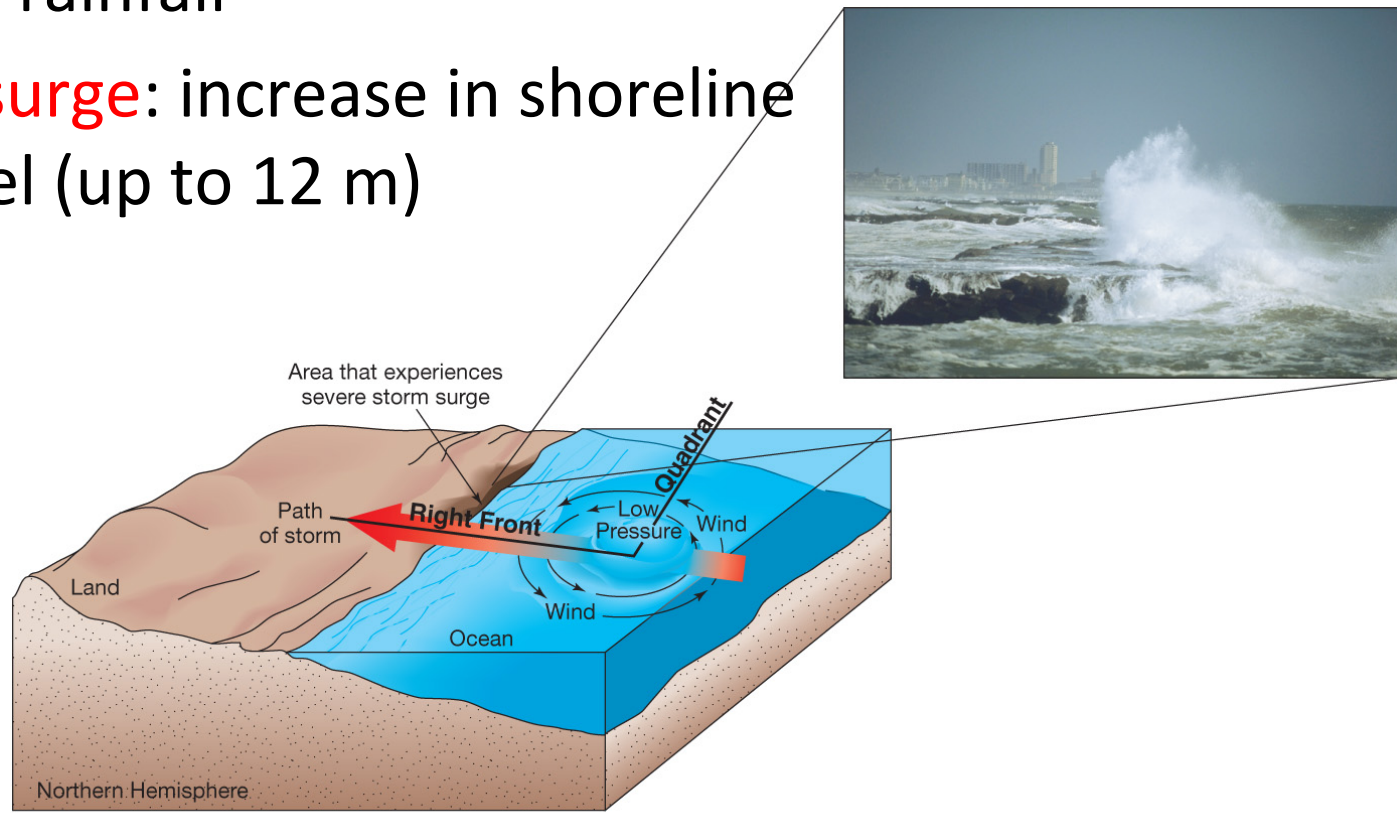


Tropical cyclone (hurricane) anatomy and movement



hurricane destruction

- High winds
- Intense rainfall
- **Storm surge**: increase in shoreline sea level (up to 12 m)



Historic destruction in the U.S. mainland

- Historically destructive storms

- Galveston, TX, 1900
- Andrew, 1992
- Mitch, 1998
- Katrina, 2005
- Ike, 2008
- Sandy, 2012



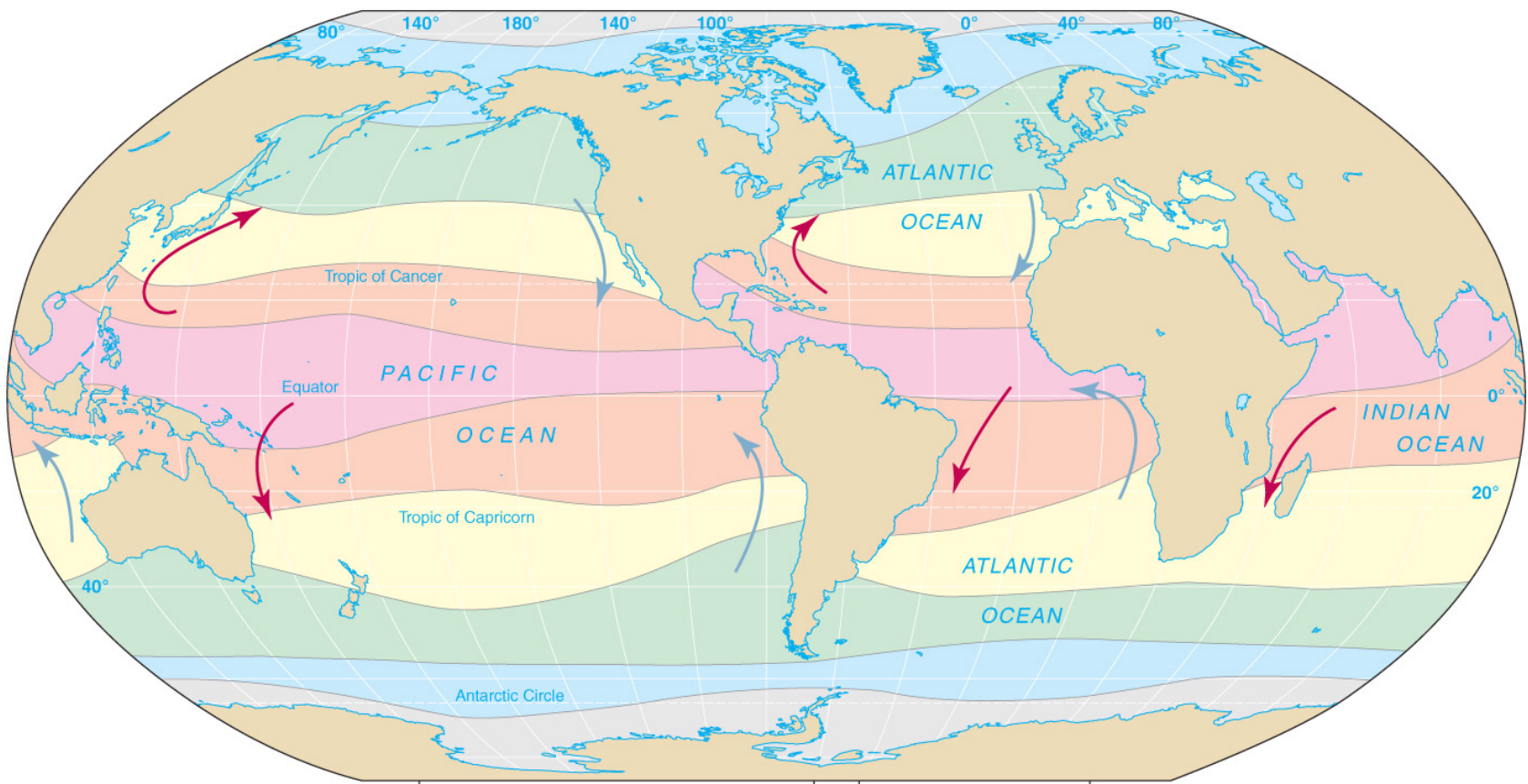
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Ocean's Climate Patterns

- Like land, oceans have climate patterns
- Open ocean's climate regions are parallel to latitude lines
- Boundaries between these regions may be modified by surface ocean currents
- Equatorial, tropical, subtropical, temperate, subpolar, polar



	Equatorial		Temperate		Warm currents
	Tropical		Subpolar		Cool currents
	Subtropical		Polar		

- **Equatorial**
 - Rising air
 - Weak winds
 - Doldrums
- **Tropical**
 - North and south of equatorial zone
 - Extend to Tropics of Cancer and Capricorn
 - Strong winds, little precipitation, rough seas
- **Subtropical**
 - High pressure, descending air
 - Weak winds, sluggish currents
- **Temperate**
 - Strong westerly winds
 - Severe storms common
- **Subpolar**
 - Extensive precipitation
 - Summer sea ice
- **Polar**
 - High pressure
 - Sea ice most of the year

6.6 – How Do Sea Ice and Icebergs Form?

- Low temperatures in high-latitude regions cause a permanent or nearly permanent ice cover on the sea surface
- Frozen seawater is defined as **sea ice** (**icebergs** instead are calved from freshwater glaciers originating on land)
- Sea ice is found around Antarctica, in the North Atlantic, in the Arctic Ocean

- Sea ice has been decreasing over the last few years in the Arctic Ocean opening up, for the first time in human history, the Northwest Passage north of Canada and Alaska

SHRINKING ICE CAPS



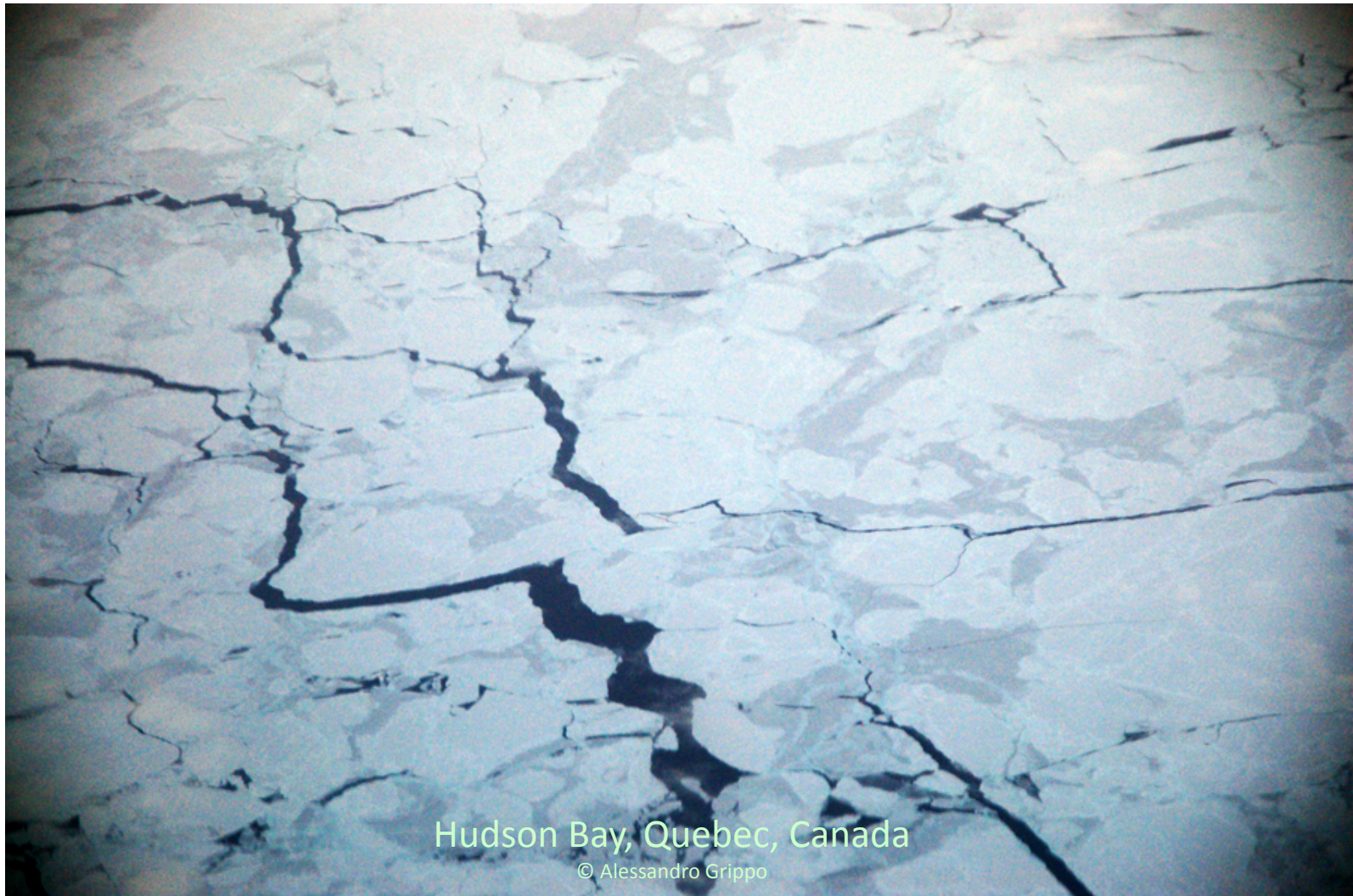
Sea ice formation

- *Sea ice* is ice that forms directly from seawater
- At first, small *needle-like crystals* form
- They can become so numerous that a *slush* develops
- The slush forms a thin sheet that is broken by wind and waves into disk-shaped pieces called *pancake ice*
- Pancakes merge together to form larger *ice floes*
- Over time, ice floes further merge to create large sheets of ice, moved by ocean currents and winds, which would produce *pressure ridges* along their margins



(a)

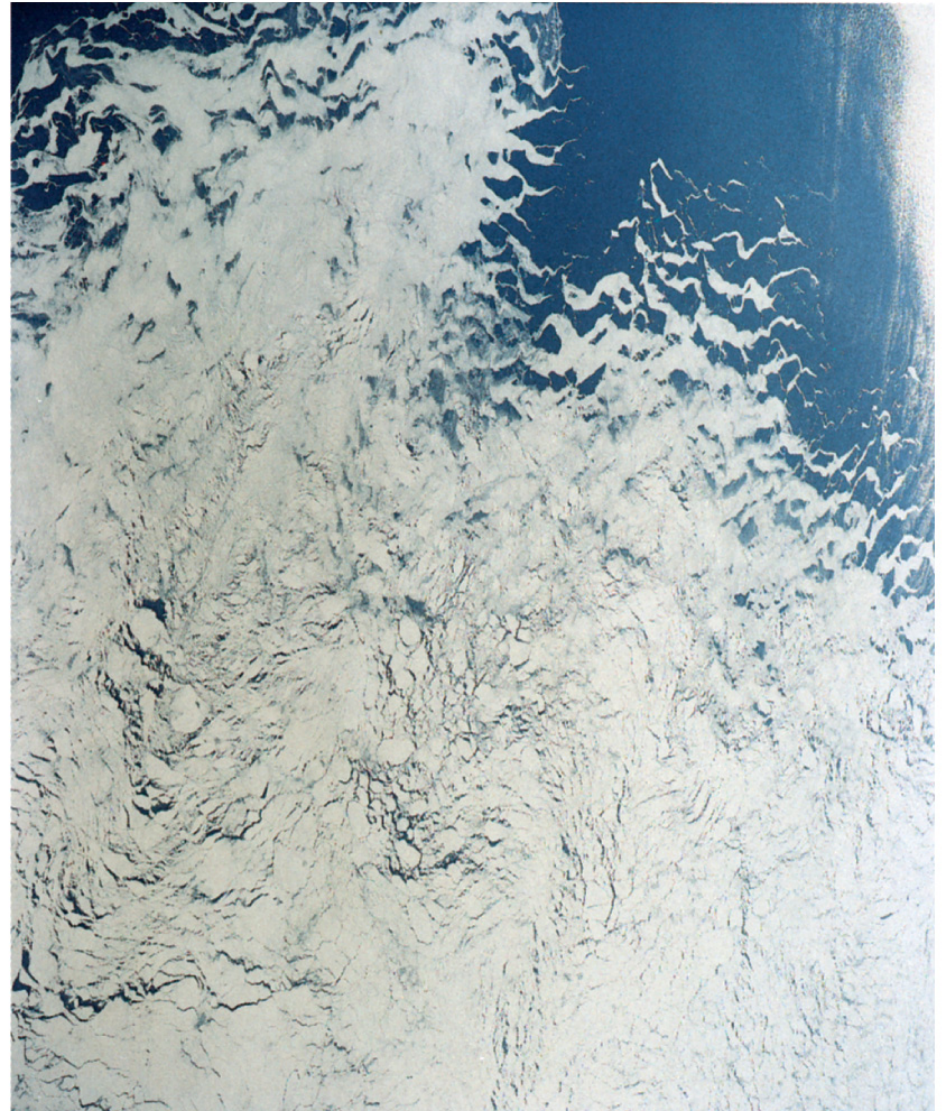
Ice floes starting to merge and break again



Hudson Bay, Quebec, Canada

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- The rate of formation of sea ice depends on temperature
- Self-perpetuating system: when sea water freezes most salt can not become part of ice
- Sea water becomes saltier, which makes it more difficult for ice to form
- Sea water also is more dense, so it starts to sink
- When dense water sinks (**downwelling**), it is replaced by seawater at a lower salinity)
- Without the formation of sea ice, there would be no downwelling



(b)

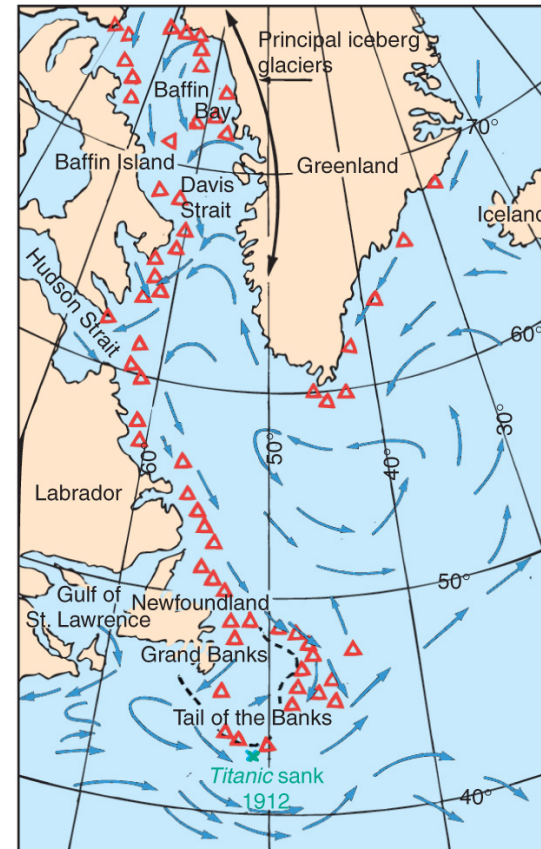
Formation of Icebergs

- An **iceberg** is a body of floating ice that has broken away from a glacier



(a)

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(b)

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- Ice in glaciers forms on land because of snow precipitation
- Glaciers slowly move towards lower elevation (the ocean) under their own weight
- Once a glacier reaches the ocean, it can either
 - breakup (and form an iceberg) or
 - float on the water for a great distance before breaking
- Most icebergs in the Arctic come from Greenland
- “Iceberg Alley”

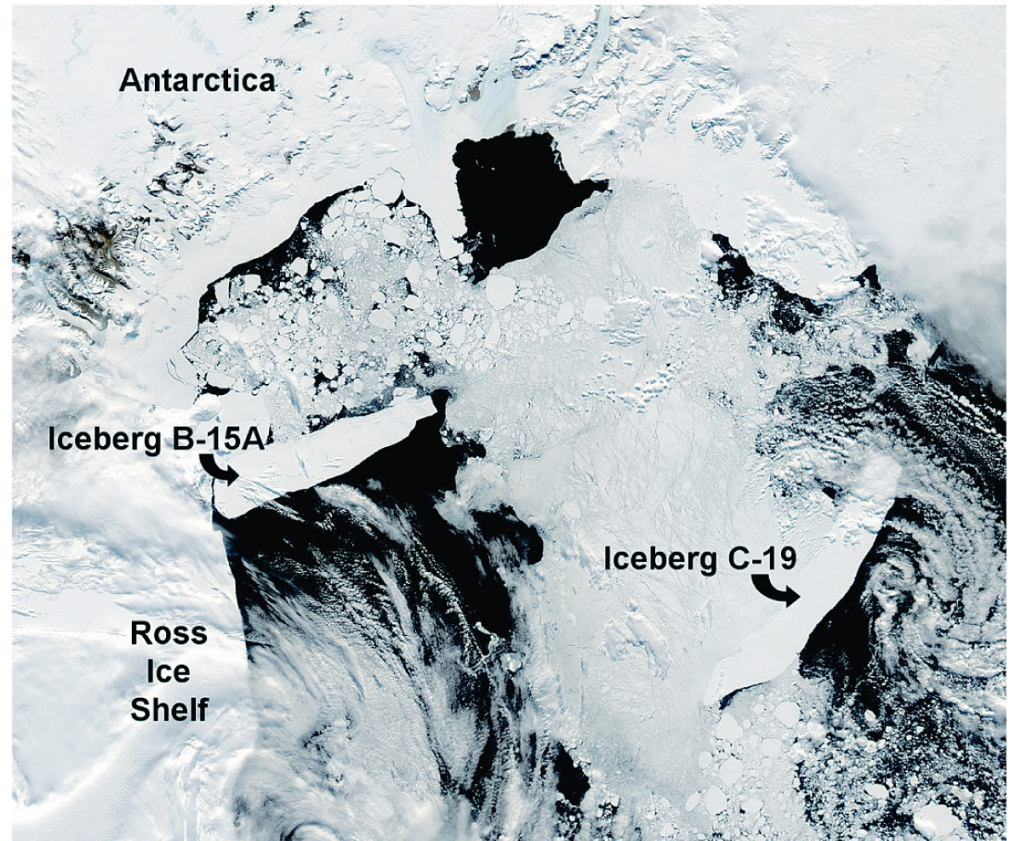
“iceberg alley”, April 19, 2017
Ferryland, Newfoundland, Canada



Icebergs in the Arctic

Shelf Ice in Antarctica

- In Antarctica, the edge of glaciers forms thick floating sheets of ice called **shelf ice**
- Shelf ice breaks off and creates plate-like icebergs
- Their flat top can be up to 200 m above sea level, but 90% of the iceberg mass is below the waterline



(d)

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6.7 – Can Power from Wind Be Harnessed as a Source of Energy?

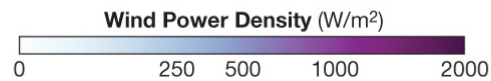
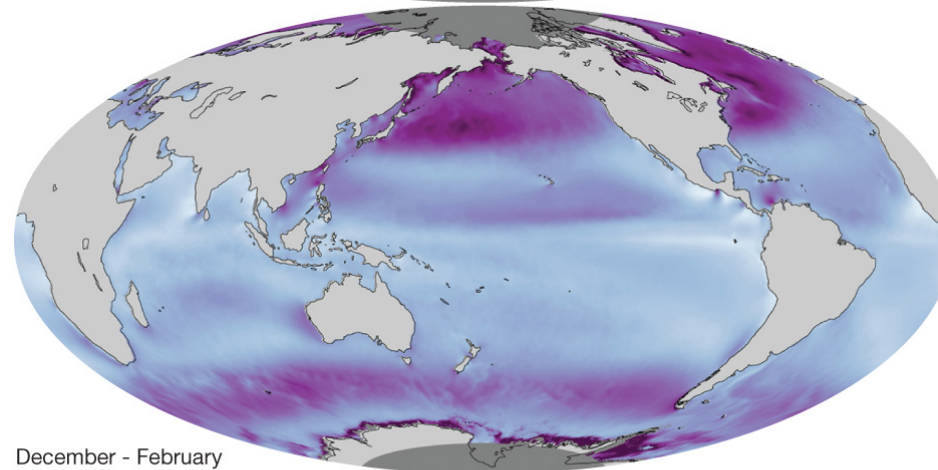
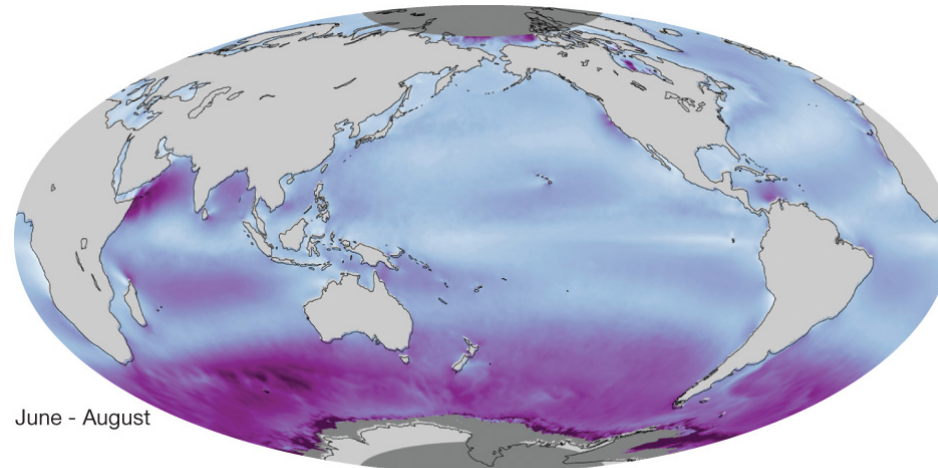
- Uneven solar heating of Earth generates winds
- Turbines or windmills harness wind energy
- “Wind farms” are common on land
- Offshore “wind farms” can also generate electricity
- Problems:
 - winds are not constant
 - difficult to store electricity, tap it and carry it when and where needed

wind farms on land and at sea



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Global Ocean Wind Energy



end of CHAPTER 6

Air-Sea Interaction