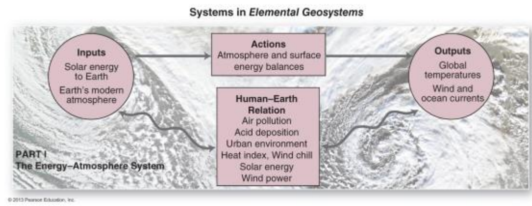
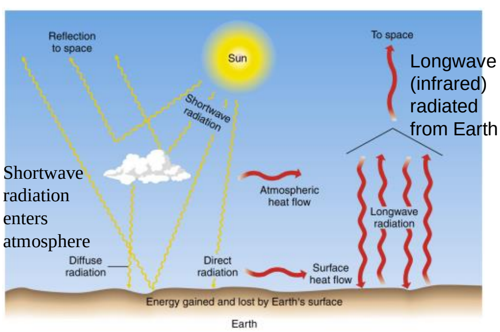
The Energy-Atmosphere System

Atmosphere and Surface Energy Balances

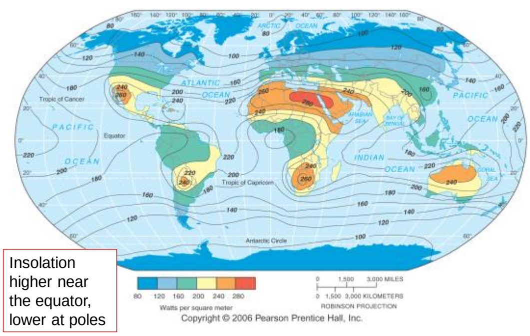
The Energy-Atmosphere System



Energy Pathways: The Transmission Of Energy Through The Atmosphere

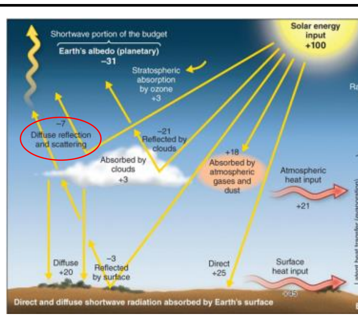


Insolation Input: All Radiation Received At Earth's Surface – Direct And Indirect

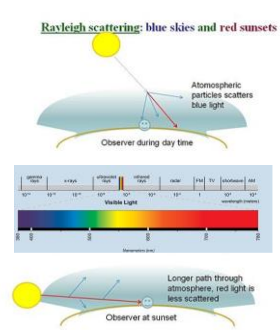


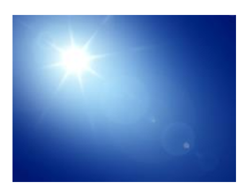
Insolation higher near the equator, lower at poles

Incoming Solar Radiation Is Affected By Atmosphere

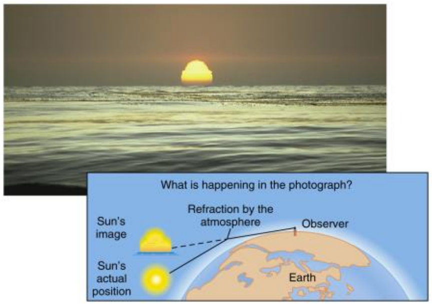


- Scattering: Changing direction of light's movement, without altering its wavelength
- Refraction: Change in speed and direction of light, causing light path to bend

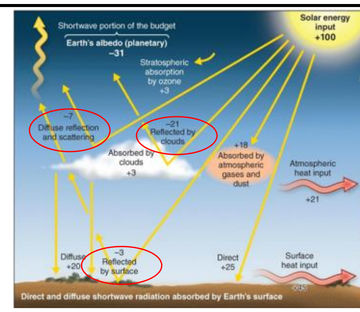




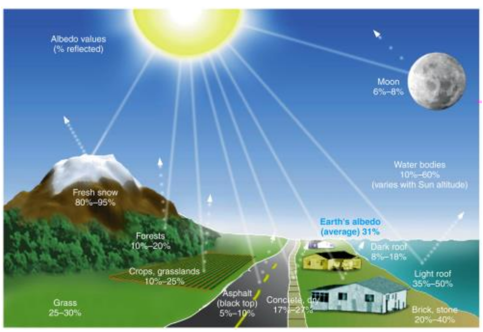
Refraction Is The Bending Of Light Passing Through Atmosphere



Incoming Solar Radiation Is Affected By Atmosphere

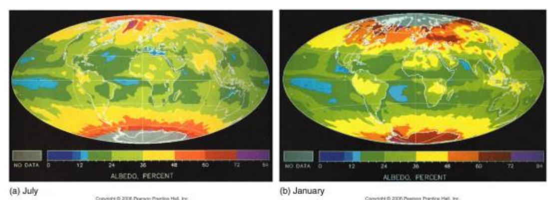


- Reflection is the energy that bounces off surface and is returned:
  - Earth and its atmosphere reflects an average of 31% of all insolation
  - Albedo is the reflective quality of a surface



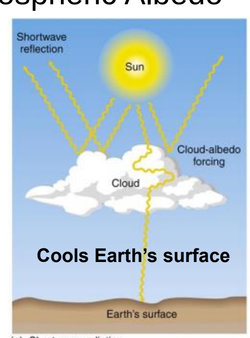
Albedo is the percentage of insolation that is reflected:
- Darker colors have lower albedos (less reflective)
- Lighter colors have higher albedos (more reflective)

July and January Albedos



Clouds and Atmospheric Albedo

Cloud-albedo forcing occurs when clouds cause an increase in albedo:
- Incoming shortwave radiation from Sun is reflected back towards space by clouds
- Industrial aerosols can also reflect incoming radiation



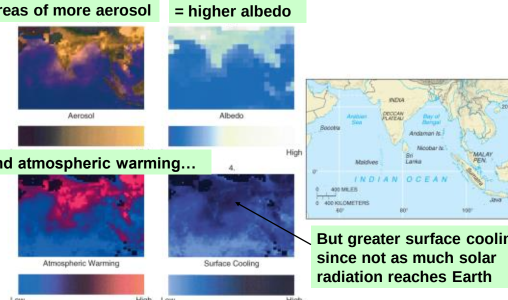
(a) Shortwave radiation

Atmospheric Aerosols

Areas of more aerosol = higher albedo

and atmospheric warming…

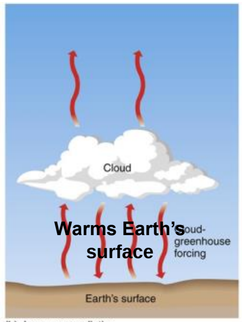
But greater surface cooling since not as much solar radiation reaches Earth



Clouds and Atmospheric Albedo

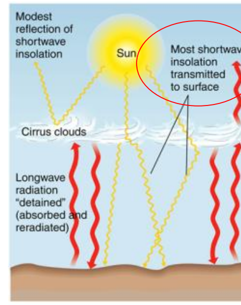
Cloud-greenhouse forcing occurs when clouds act to increase greenhouse warming:

- Inhibits the escape of longwave radiation emitted by Earth's surface



(b) Longwave radiation

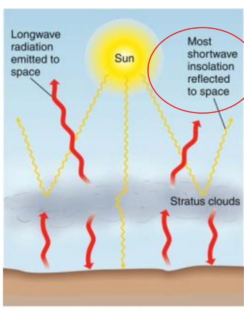
Net Greenhouse Forcing



(a) High clouds: net greenhouse forcing and atmospheric warming

- High, thin clouds allow more incoming shortwave (SW) radiation to reach the surface
- Surface materials absorb SW radiation
- High clouds detain the high flux of longwave radiation emitted by surface materials
- Atmospheric warming results

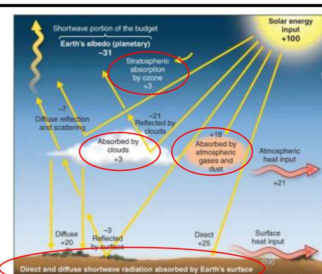
Net Albedo Forcing



(b) Low clouds: net albedo forcing and atmospheric cooling

- Low clouds reflect more incoming shortwave radiation back into space
- Less shortwave radiation reaches Earth's surface
- Less longwave radiation is emitted and detained at surface
- Atmospheric cooling results

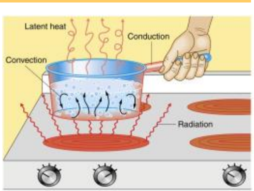
Absorption

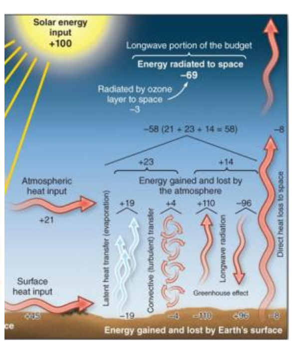


- Absorption is the assimilation of radiation and its conversion from one form to another
  - Absorption occurs in atmospheric gases, dust, clouds, stratospheric ozone, and surface materials including rock and soil
  - Some insolation also absorbed by plants via photosynthesis
  - Temperature of absorbing surface increases

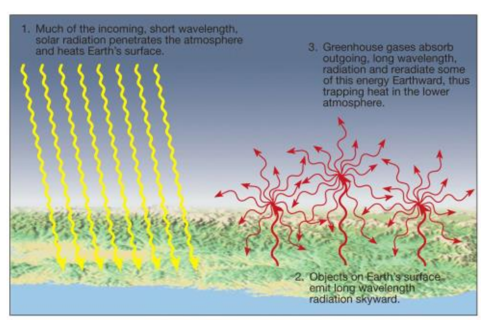
Heat Transfer

- Advection (horizontal transfer)
- Conduction (surface soil and rock)
- Latent heat transfer (evaporation)
- Atmospheric convection
- Atmospheric radiation:
  - Greenhouse effect

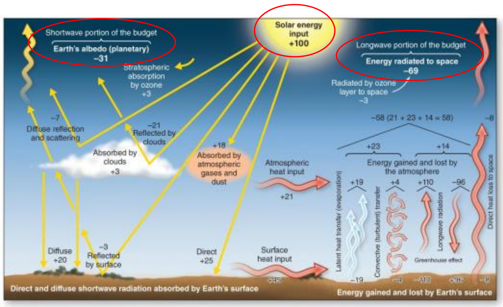




The Greenhouse Effect and Atmospheric Warming



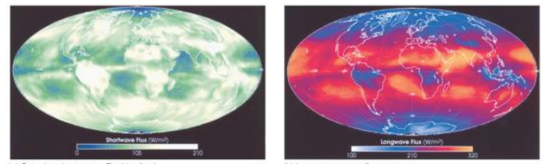
All Solar Radiation Received By The Atmosphere And Surface Is Eventually Returned To Space



Shortwave and Longwave Energy

Incoming solar energy reflected back into space

Energy radiated into space by Earth materials



(a) Outgoing shortwave – Earth's albedo.

(b) Longwave energy flux to space.

Heat & Heat Storage

- Sensible heat:
  - Heat that we can feel
  - Determined by heat capacity (cal/gm/ °C) of a substance
- Latent heat:
  - Heat that is absorbed or released due to phase changes
  - Ice to water (80 cal/gm absorbed)
  - Water to vapor (540 cal/gm absorbed)

Energy Storage and Heating

- When you heat a substance, it stores heat by getting hotter
- Different substances have different heat capacities:
  - Some substances can store more heat than others

Heat Capacity of Various Substances

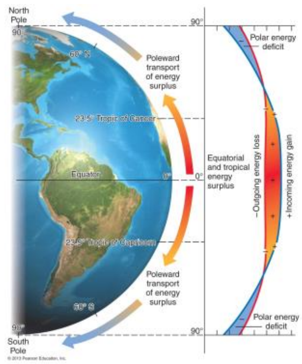
- Substance and heat capacity (cal/gm/°C)
  - Water 1.0
  - Wet mud 0.60
  - Ice 0.50
  - Sandy clay 0.33
  - Dry air 0.24
  - Quartz sand 0.19
  - Granite 0.19

Energy Storage and Heating

- Example:
  - Water has a heat capacity of 1.0 cal/gm/°C
  - Land has a heat capacity of 0.2 cal/gm/ °C
  - Question? If I put one calorie (cal) of heat into 1 gram (gm) of water or land, how does the temperature of each change?
    - Water temperature increases 1 °C
    - Land temperature increases 5 °C

Net Radiation (NET R)

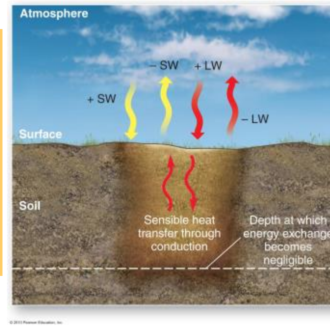
- Net radiation is the balance between incoming and outgoing radiation
- There is a latitudinal energy imbalance in net radiation:
  - Positive values at low latitudes (energy surplus)
  - Negative values poleward of 36º north and south latitudes (energy deficits)
- Energy surplus at low latitudes is transported poleward via air and ocean currents



Surface Energy Balance

Net radiation at Earth's surface is a balance between incoming and outgoing radiation:

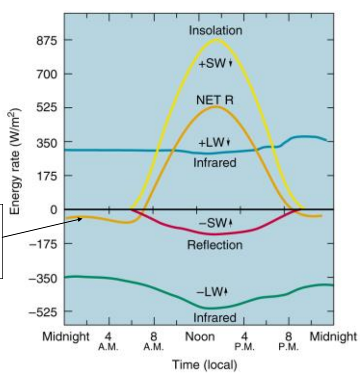
- Surface receives visible shortwave (+SW) and longwave (+LW) radiation
- Surface also reflects visible (-SW) and radiates longwave (-LW) radiation



Simplified Surface Energy Balance

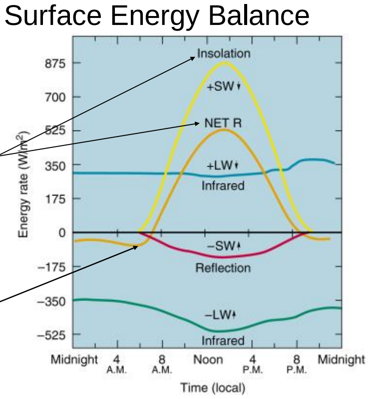
- NET R =
  +SW (insolation)
  –SW (reflection)
  +LW (received)
  –LW (radiated)

Surface NET R varies throughout the day



Simplified Surface Energy Balance

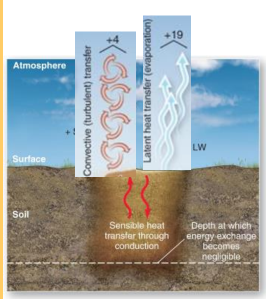
- NET R is highest midday when insolation is at its maximum
- NET R is lowest early morning when insolation is at its minimum



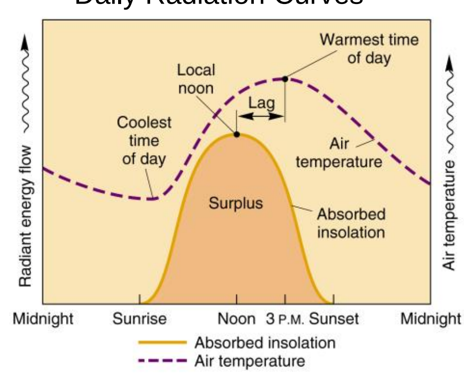
Net Radiation (NET R) At Surface

After heating of a non-vegetated surface (land and water), NET R at the surface gradually decreases (surface cools) via three pathways of heat removal:

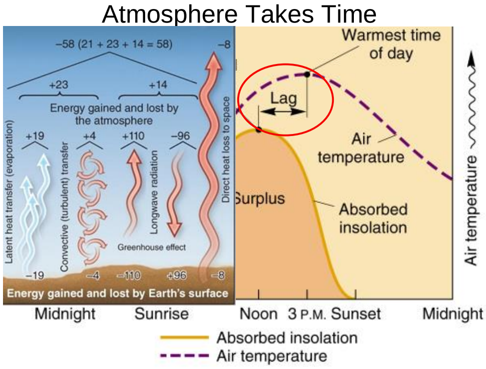
- Sensible heat within bedrock and soil is drawn up to the ground surface by conduction
- Atmospheric convection removes sensible heat from the surface via rising air masses to higher altitudes
- Latent heat of evaporation removes heat energy from the surface by converting liquid water to vapor



Daily Radiation Curves



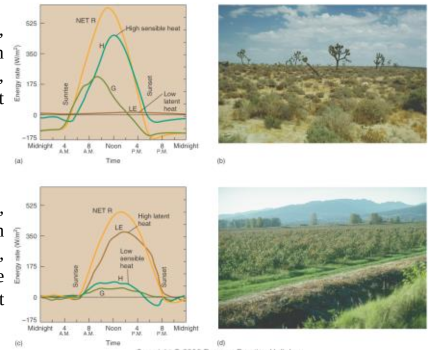
Transfer Of Heat From Surface To Atmosphere Takes Time



Radiation Budgets

El Mirage, CA: High sensible heat, low latent heat

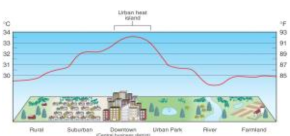
Pitt Meadows, BC: High latent heat, low sensible heat

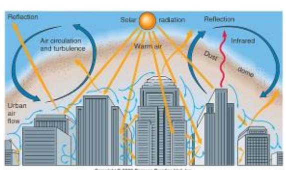


Urban Heat Islands

Why urban areas are warmer than nearby rural settings:

- Surfaces typically metal, glass, asphalt, etc.
- Irregular geometric shapes cause incoming insolation to be caught in maze-like reflection and radiation 'canyons'
- Human activity such as electricity production, burning of fossil fuels, and heating during winter
- Sealed so that water does not reach soil; more runoff, less long-term moisture and fewer vegetation
- Urban air pollution absorbs more infrared radiation





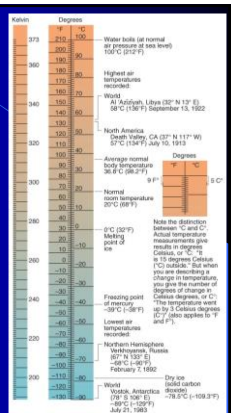
Thermal-infrared image of Sacramento, CA, June 29, 1998

Sacramento urban heat island in the distance

Hotter: Reds and white
Cooler: Greens and blues

Temperature Scales

- **Fahrenheit:**
  - **Melting point of ice 32º F**
  - **180 divisions to the boiling point water at 212º F**
- **Celsius:**
  - **Melting point of ice 0º C**
  - **Boiling temperature water at sea level 100º C**
- **Kelvin:**
  - **Proportional to actual kinetic energy of molecules in material**
  - **Starts at absolute zero temperature**
  - **Melting point for ice 273 K**
  - **Boiling point of water 373 K**



Measuring Temperature

- Mercury thermometer or alcohol thermometer:
  - Fluid stored in sealed glass tube
  - Fluid expands when heated, contracts when cooled
  - Calibrations measure amount of expansion or contraction

Measuring Temperature

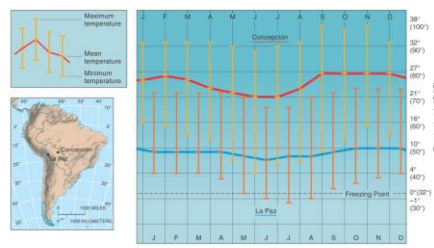
- Thermistor:
  - Measures temperature by sensing electrical resistance of a semiconducting material
  - Resistance changes 4% per °C

Weather Instrument Shelters

Principal Temperature Controls

- **Latitude:**
  - **Affects insolation - more diffuse (cooler) at higher latitudes**
- **Altitude:**
  - **Higher altitudes have a greater daily range of temperatures**
  - **Higher altitudes have lower annual average temperatures**
- **Cloud Cover:**
  - **Moderates surface temperatures – cooler days, warmer nights**

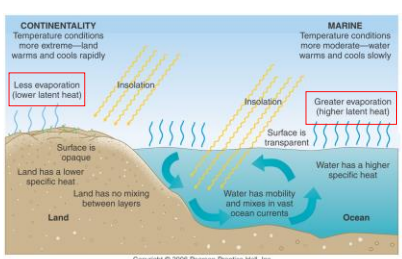
Temperature Effects of Altitude



	Station	
	Concepción, Bolivia	La Paz, Bolivia
Latitude/longitude	16° 15′ S 62° 03′ W	16° 30′ S 68° 10′ W
Elevation	490 m (1608 ft)	4103 m (13,461 ft)
Avg. ann. temperature	24°C (75.2°F)	9°C (48.2°F)
Ann. temperature range	5 C° (9 F°)	3 C° (5.4 F°)
Ann. precipitation	121.2 cm (47.7 in.)	55.5 cm (21.9 in.)
Population	10,000	810,300 (Administrative division 1.6 million)

Two locations at the same latitude but different elevations

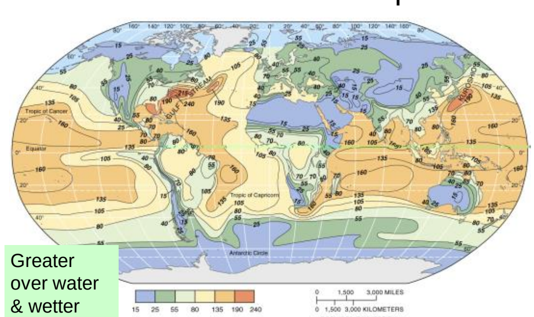
Land–Water Heating Differences



Evaporation and Latent Heat:

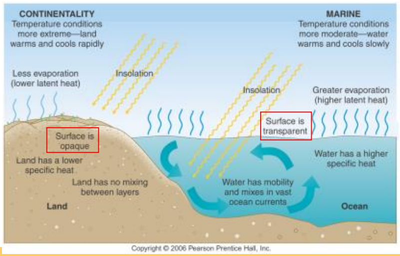
- An estimated 84% of all evaporation on Earth is from the oceans
- When water evaporates, heat energy is absorbed as latent heat
- This evaporative heat loss causes cooling
- Evaporation moderates temperatures at marine locations

Global Latent Heat of Evaporation



Greater over water & wetter land areas

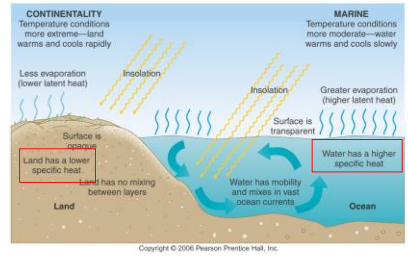
Land–Water Heating Differences



Transparency:

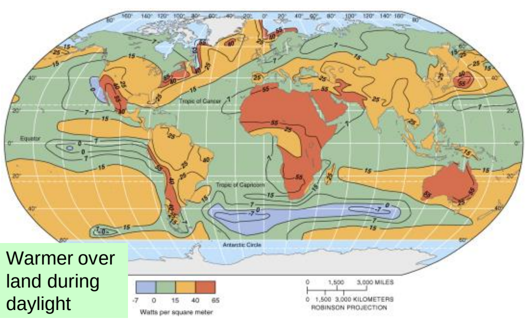
- Solid ground is opaque and absorbs solar energy
  - Ground surface heated
  - Accumulated energy rapidly lost at night or in shadows
- Water is transparent and transmits light
  - Heat energy distributed over much greater depth and volume
  - Water is thus a larger energy reservoir than is land

Land–Water Heating Differences



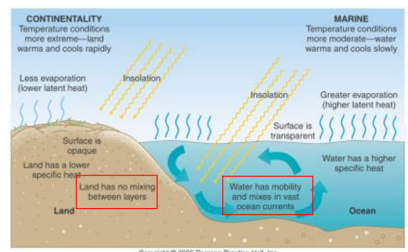
- Water has a higher specific heat and requires far more energy to increase its temperature than does soil or rock:
  - Changing water temperature thus a slow process
- Land has a lower specific heat and requires less energy to increase its temperature:
  - Land temperature can change quickly

Global Sensible Heat at Surface Level



Warmer over land during daylight

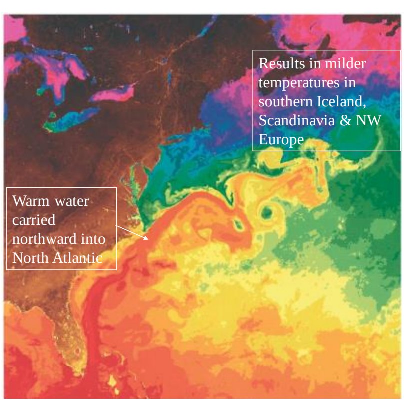
Land–Water Heating Differences



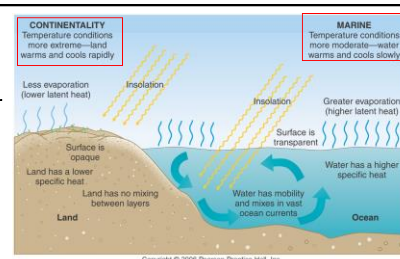
Movement:

- Land is rigid and solid, whereas water is fluid and capable of movement
- Oceans thus are able to mix cooler and warmer regions effectively

The Gulf Stream

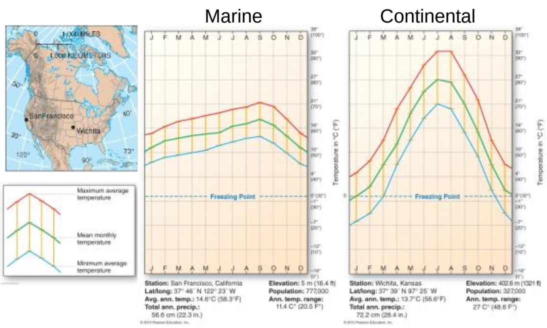


Land–Water Heating Differences



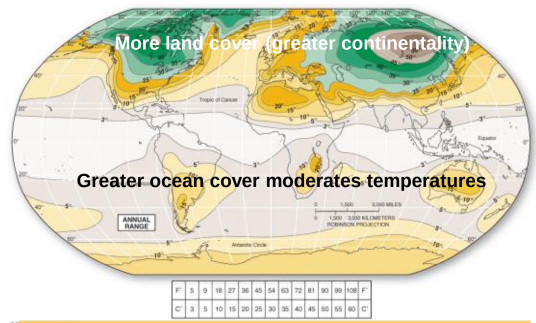
Oceans moderate atmospheric temperatures through negative feedback:

- Increasing ocean temperatures result in greater evaporation and more cloud cover
  - Greater cloud cover reflects more incoming solar radiation, lowering surface temperatures (cloud-albedo forcing)
- Lower ocean-surface temperatures reduce evaporation rate and cloud cover, allowing more incoming solar radiation to heat surface



Both locations at the same latitude

Global Annual Temperature Ranges (ºC)



Why are annual temperature ranges greater in Northern Hemisphere?

Air Temperature and the Human Body

- Wind chill
  - Correlates cold and wind speed
- Heat index
  - Correlates heat and humidity

Wind Chill Table

Holding actual air temperature constant, higher wind speed results in higher wind chill

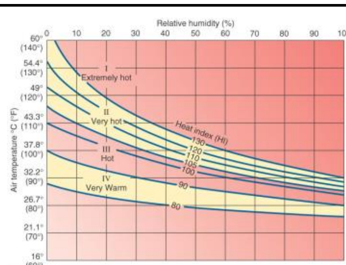
Actual Air Temperature in °C (°F)

Wind speed, kmph (mph)									
Calm	4° (40°)	−1° (30°)	−7° (20°)	−12° (10°)	−18° (0°)	−23° (−10°)	−29° (−20°)	−34° (−30°)	−40° (−40°)
8 (5)	2° (36°)	−4° (25°)	−11° (13°)	−17° (1°)	−24° (−11°)	−30° (−22°)	−37° (−34°)	−43° (−46°)	−49° (−57°)
16 (10)	1° (34°)	−6° (21°)	−13° (9°)	−20° (−4°)	−27° (−16°)	−33° (−28°)	−41° (−41°)	−47° (−53°)	−54° (−66°)
24 (15)	0° (32°)	−7° (19°)	−14° (6°)	−22° (−7°)	−28° (−19°)	−36° (−32°)	−43° (−45°)	−50° (−58°)	−57° (−71°)
32 (20)	−1° (30°)	−8° (17°)	−16° (4°)	−23° (−9°)	−30° (−22°)	−37° (−35°)	−44° (−48°)	−52° (−61°)	−59° (−74°)
40 (25)	−2° (29°)	−9° (16°)	−16° (3°)	−24° (−11°)	−31° (−24°)	−38° (−37°)	−46° (−51°)	−53° (−64°)	−61° (−78°)
48 (30)	−2° (28°)	−9° (15°)	−17° (−1°)	−24° (−12°)	−32° (−26°)	−39° (−39°)	−47° (−53°)	−55° (−67°)	−62° (−80°)
56 (35)	−2° (28°)	−10° (14°)	−18° (0°)	−26° (−14°)	−33° (−27°)	−41° (−41°)	−48° (−55°)	−56° (−69°)	−63° (−82°)
64 (40)	−3° (27°)	−11° (13°)	−18° (−1°)	−26° (−15°)	−34° (−29°)	−42° (−43°)	−49° (−57°)	−57° (−71°)	−64° (−84°)
72 (45)	−3° (26°)	−11° (12°)	−19° (−2°)	−27° (−16°)	−34° (−30°)	−42° (−44°)	−50° (−58°)	−58° (−72°)	−66° (−86°)
80 (50)	−3° (26°)	−11° (12°)	−19° (−3°)	−27° (−17°)	−35° (−31°)	−43° (−45°)	−51° (−60°)	−59° (−74°)	−67° (−88°)

Frostbite times: 30 min. 10 min. 5 min.

Heat Index Table

Holding actual air temperature constant, higher humidity results in higher heat index



Level of concern	Category	Heat Index Apparent Temperature	General Effect of Heat Index on People in High-Risk Groups
Extreme danger	I	54°C (130°F) or higher	Heat/sunstroke highly likely with continued exposure
Danger	II	41° – 54°C (105° – 130°F)	Sunstroke, heat cramps, or heat exhaustion likely and heatstroke possible with prolonged exposure and/or physical activity
Extreme caution	III	32° – 41°C (90° – 105°F)	Sunstroke, heat cramps, and heat exhaustion possible with prolonged exposure and/or physical activity
Caution	IV	27° – 32°C (80° – 90°F)	Fatigue possible with prolonged exposure and/or physical activity