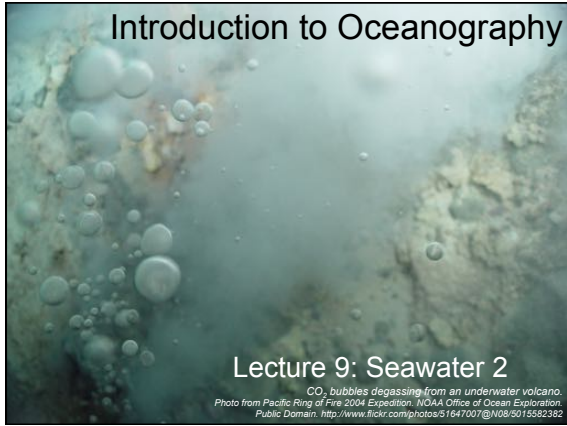


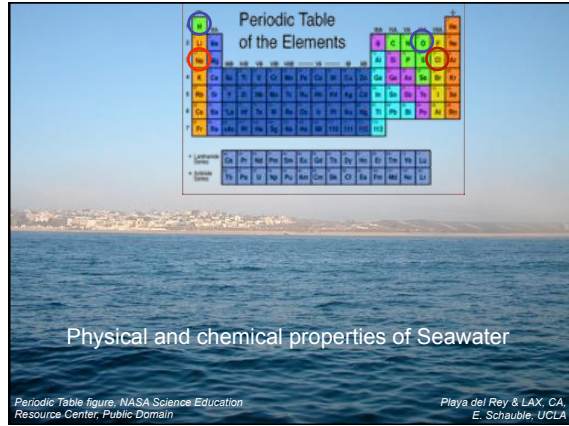
Introduction to Oceanography



Lecture 9: Seawater 2

CO₂ bubbles degassing from an underwater volcano.
Photo from Pacific Ring of Fire 2004 Expedition. NOAA Office of Ocean Exploration
Public Domain. <http://www.flickr.com/photos/1647007@N08/5012582382>

Physical and chemical properties of Seawater



Periodic Table figure, NASA Science Education Resource Center, Public Domain
Playa del Rey & LAX, CA, E. Schauble, UCLA

Chemical Residence Times

Residence Time: the average length of time an element spends in the ocean

$$\text{Res. Time} = \frac{\text{Amount of element in ocean}}{\text{Element's rate of removal (or addition) from the ocean}}$$

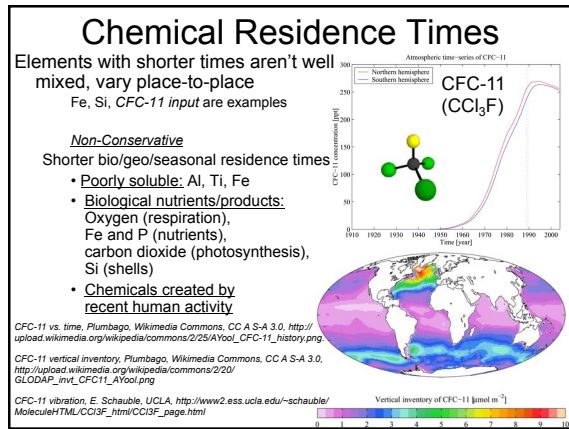
Constituent	Res. Time (yrs)
Chlorine (Cl ⁻)	10 ⁸
Sodium (Na ⁺)	6.8 x 10 ⁷
Silicon (Si)	2 x 10 ⁴
Water (H ₂ O)	4.1 x 10 ³
Iron (Fe)	2 x 10 ²

Chemical Residence Times

Elements with shorter times aren't well mixed, vary place-to-place
Fe, Si, CFC-11 input are examples

Non-Conservative
Shorter bio/geo/seasonal residence times

- **Poorly soluble:** Al, Ti, Fe
- **Biological nutrients/products:** Oxygen (respiration), Fe and P (nutrients), carbon dioxide (photosynthesis), Si (shells)
- **Chemicals created by recent human activity**



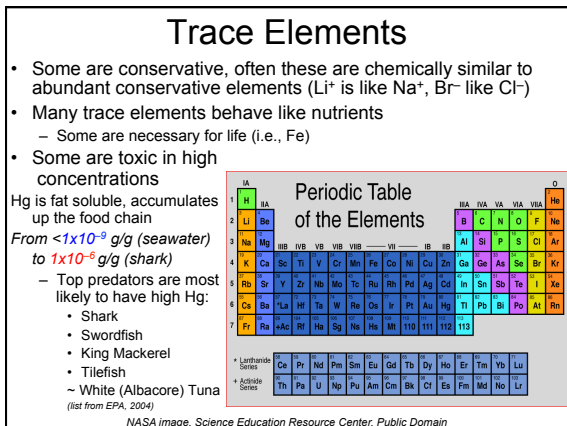
CFC-11 vs. time, Plumbago, Wikimedia Commons, CC A S-A 3.0, http://upload.wikimedia.org/wikipedia/commons/2/28/A'ool_CFC-11_history.png
CFC-11 vertical inventory, Plumbago, Wikimedia Commons, CC A S-A 3.0, http://upload.wikimedia.org/wikipedia/commons/2/20/GLODAP_inv4_CFC11_A'ool.png
CFC-11 vibration, E. Schauble, UCLA, http://www2.ess.ucla.edu/~schauble/MoleculeHTML/CCl3F.html/CCl3F_page.html

Trace Elements

- Some are conservative, often these are chemically similar to abundant conservative elements (Li⁺ is like Na⁺, Br⁻ like Cl⁻)
- Many trace elements behave like nutrients
 - Some are necessary for life (i.e., Fe)
- Some are toxic in high concentrations

Hg is fat soluble, accumulates up the food chain
From 1×10^{-9} g/g (seawater) to 1×10^{-6} g/g (shark)

- Top predators are most likely to have high Hg:
 - Shark
 - Swordfish
 - King Mackerel
 - Tilefish
- White (Albacore) Tuna (list from EPA, 2004)



NASA image, Science Education Resource Center, Public Domain

Biological Nutrients

- N, P, Fe, Si
- More needed for organic processes or skeletal growth than is easily available
- Consumed in photic zone (lots of biological growth)
 - Si used by diatoms for skeletal material
- Enriched in deep waters due to breakdown of organic matter
- Upwelling flows transport nutrients back up to shallower waters

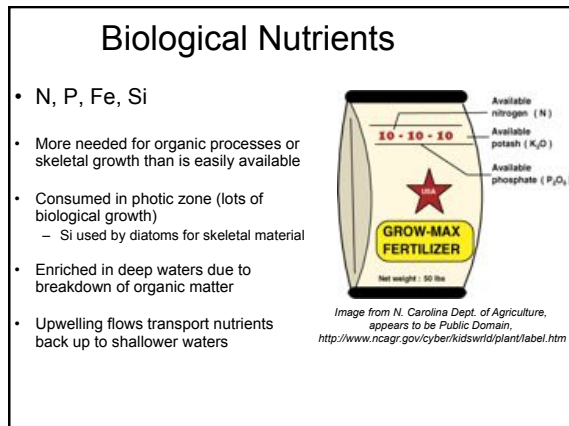
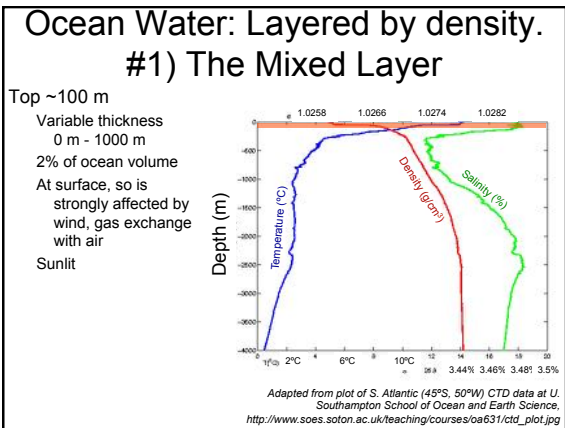
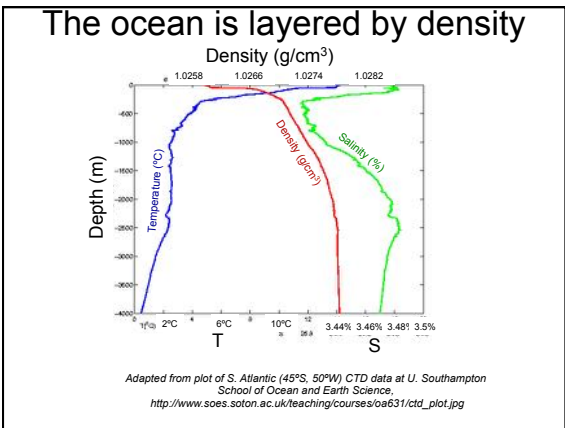
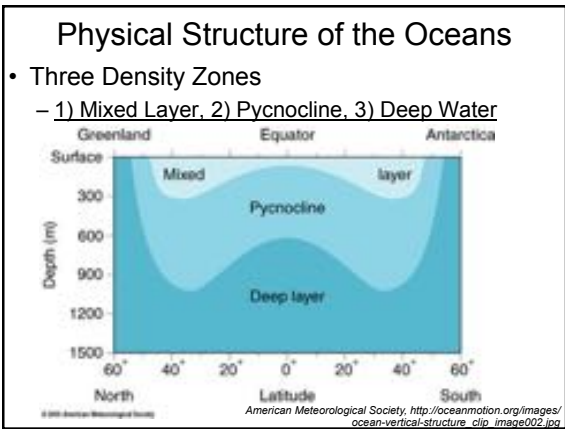
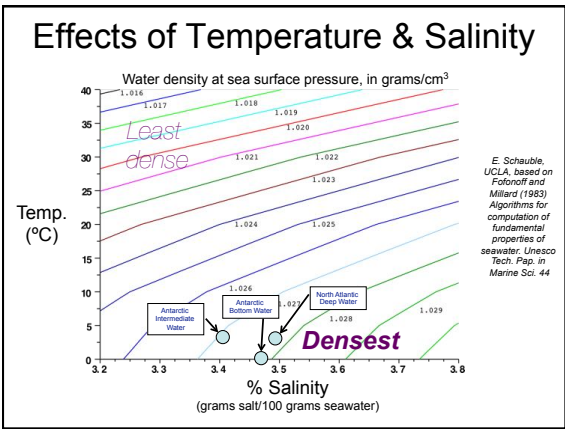
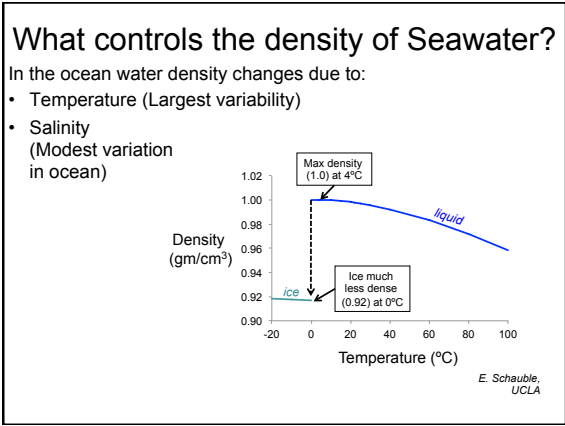
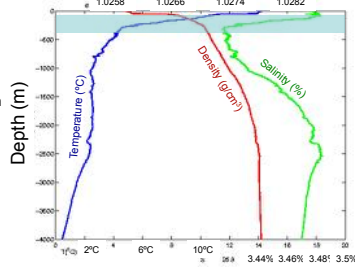


Image from N. Carolina Dept. of Agriculture, appears to be Public Domain, <http://www.ncagr.gov/cyber/kidswrld/plant/label.htm>



Layer #2) The Pycnocline

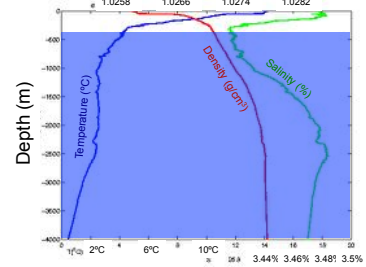
- Density gradient between Mixed Layer and Deep Water
- 18% ocean volume
- Mostly due to temperature change (deeper water is colder)
- At poles, surface water is also cold, so pycnocline caused mostly by change in salinity (i.e. halocline).



Adapted from plot of S. Atlantic (45°S, 50°W) CTD data at U. Southampton School of Ocean and Earth Science. http://www.so.es.soton.ac.uk/teaching/courses/oa631/ctd_plot.jpg

Layer #3) The Deep Layer

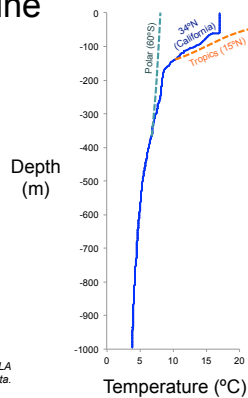
- Water originates at high latitude (cold)
- Cold ~4° C waters
- 80% of ocean's volume
- Completely dark (aphotic) and relatively unaffected by surface conditions



Adapted from plot of S. Atlantic (45°S, 50°W) CTD data at U. Southampton School of Ocean and Earth Science. http://www.so.es.soton.ac.uk/teaching/courses/oa631/ctd_plot.jpg

Thermocline

- Region where temperature changes with depth.
- Typically ~100 - 1000 m
- Strong near equator (hot surface water)
- Weak at poles (surface water almost as cold as deep water)



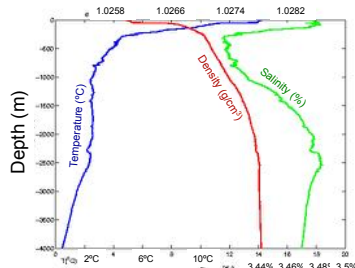
Plot E. Schauble, UCLA from NOAA CTD data.

Halocline

- Changing salinity instead of temperature
 - Sharp gradient in salinity with depth
 - Strongest near river mouths, regions with high rainfall. Why?

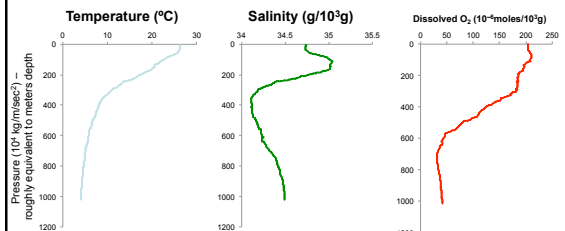
Pycnocline

- Depth interval with strong vertical density gradient
- Caused by thermocline & halocline



Adapted from plot of S. Atlantic (45°S, 50°W) CTD data at U. Southampton School of Ocean and Earth Science. http://www.so.es.soton.ac.uk/teaching/courses/oa631/ctd_plot.jpg

Questions



CTD data from ALOHA station, Hawaii, July 7, 1997

Dissolved Gases in the Ocean

- Atmospheric gases dissolved in seawater
 - Mainly N₂, O₂
 - CO₂
- Relative Solubilities:
 - Gases are most soluble in **COLD** water
 - Polar waters: cold, rough waters = gas rich
 - Less soluble in salty water ("salting out")
 - Not quite the same process as Mentos+Diet Coke




Photo by Michael Murphy, Wikimedia Commons. GFDL/Creative Commons-BY-SA 3.0, http://commons.wikimedia.org/wiki/File:Diet_Coke_Mentos.jpg

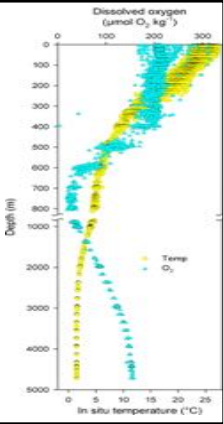
Photo by JD (Kinchan1), Creative Commons Attribution-NonCommercial-NoDerivs 2.0 Generic <http://www.flickr.com/photos/jdbaskin/5334126513>

Dissolved Gases in the Ocean

Gas	Atmosphere (Volume %)	Dissolved in Ocean (Volume %)
Nitrogen (N ₂)	78.08%	48%
Oxygen (O ₂)	20.95%	36%
Carbon dioxide (CO ₂)	0.039%	15%

Oxygen (O₂)

- Produced in the *photic zone* (top 200 m) where photosynthesis occurs
- Also dissolves from atmosphere
- Consumed below photic zone by
 - Animal respiration
 - Bacterial oxidation of organic detrital matter
 - Mainly at sea floor
- Oxygen minimum in region below photic zone (200 - 1000 m)
 - Also depleted bottom water zone



Plot from Station ALOHA, N. of Hawaii, from Dore et al. (2009) PNAS doi: 10.1073/pnas.0906044106

Carbon Dioxide

- Like N₂ and O₂, dissolves from the atmosphere at the ocean surface
- Also produced by respiration (digestion) of organic matter
- Consumed by photosynthesis
- CO₂ combines chemically with H₂O
 - VERY soluble in seawater---1000x solubility of nitrogen or oxygen

$$\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \rightleftharpoons 2\text{H}^+ + \text{CO}_3^{2-}$$

Carbonic Acid
Bicarbonate ion
Carbonate ion

Carbon Dioxide


- > 90% stored in bicarbonate ions, HCO₃⁻
 - At 10° C, Salinity = 3.43% and pH = 8.0:

CO ₂	(HCO ₃) ⁻	(CO ₃) ²⁻
1%	94%	5%

- Consumed in photic zone (photosynthesis)
- Produced by respiration, decomposition of organic matter

Photosynthesis

- Plants and phytoplankton make simple organic compounds (sugars) from H₂O, CO₂ and light energy
 - Energy stored in compounds
 - O₂ formed as byproduct
 - Occurs in the photic zone



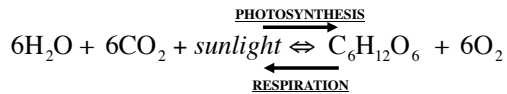
$$6\text{H}_2\text{O} + 6\text{CO}_2 + \text{sunlight} \rightleftharpoons \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$$

PHOTOSYNTHESIS
RESPIRATION

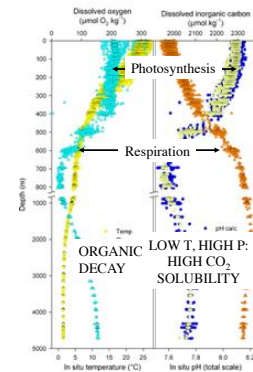
Photo by Wikiwatcher1, Wikimedia Commons. Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Seaweed_Rocks2_wiki.jpg

Respiration

- Plants and animals oxidize sugars to release energy
 - Water and carbon dioxide are by products
 - Occurs throughout the water column



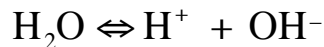
O₂ and CO₂ vs. Depth



Plot from Station ALOHA, N. of Hawaii, from Dore et al. (2009) PNAS doi: 10.1073/pnas.0906044106

Acid-Base Balance

- H₂O occasionally splits into H⁺ and OH⁻
 - 1 molecule in 5.5x10⁸ dissociates at 25° C



J. W. Pang(?), UCLA Chemistry, www.chem.ucla.edu/~gchemlab/ph-paper.jpg

pH Scale

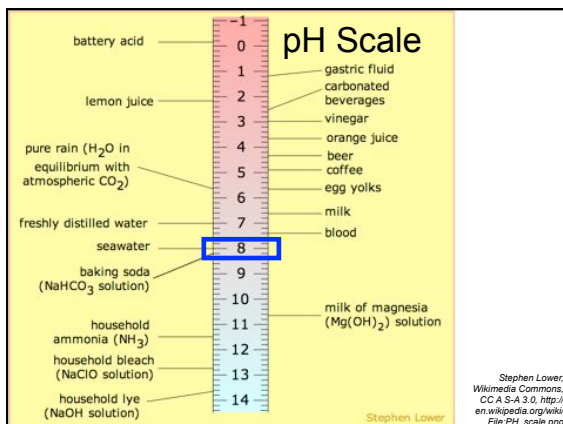
- pH scale = Logarithmic scale

$$\text{pH} = -\log_{10}(\text{H}^+)$$
- Neutral (pure) water:
 - 1/(5.5x10⁸) water molecules is disassociated
 - there are about 55 moles of water per liter

Concentration of H⁺=

$$55/(5.5 \times 10^8) = 10^{-7} \text{ moles/liter}$$

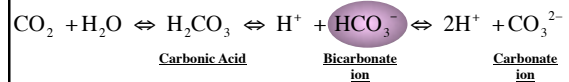
- Neutral water pH = 7
 - lower pH = acid, higher pH = base



Stephen Lower, Wikimedia Commons, CCA SA 3.0, http://en.wikipedia.org/wiki/File:PH_scale.png

The Carbonate Buffer System

- Seawater pH = ~8.0 (slightly basic)
- Maintained by carbonate buffer system:

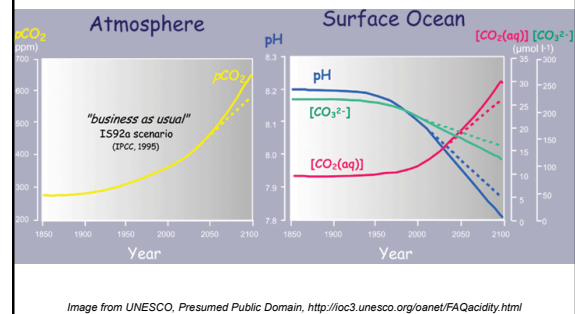


- Increase CO₂ in water, acidity increases
What happens to pH?
- Add acid and CO₂ is produced

The CO₂ system and carbonate

- Deep waters form at the poles: High CO₂ and therefore acidic
- Acidity interacts to dissolve calcium carbonate (CaCO₃) deposits on the deep sea floor
 - Acidity and temperature control carbonate compensation depth (CCD)

Questions



Wind

Wind sea, N. Pacific, Winter 1989, M/V NOBLE STAR/NOAA, Public Domain, <http://commons.wikimedia.org/wiki/File:Wea00816.jpg>



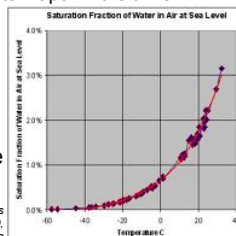
Atmosphere-Ocean Coupling

- Why study atmospheric circulation?
 - Atmosphere & ocean processes are intertwined
 - Atmosphere-ocean interaction moderates surface temperatures, weather & climate
 - Weather: local atmospheric conditions
 - Climate: regional long-term weather
 - Atmosphere drives most ocean surface waves and currents (our next topic)

Composition of the Atmosphere

- Dry Air: 78% Nitrogen, 21% Oxygen
- BUT it is never completely dry
 - Typically contains about 1% water vapor
 - Chemical residence time of water vapor in the air is about 10 days
 - (liquid water residence time in ocean: 3x10³ years!)
 - Liquid evaporates into the air, then is removed as dew, rain, or snow
 - **Warm air** holds **much** more water vapor than **cold air**

Figure by Greg Benson, Wikimedia Commons Creative Commons A S-A 3.0, <http://en.wikipedia.org/wiki/File:Dewpoint.jpg>



Density of Air

- Typical air density ~ 1 mg/cm³
 - About 1/1000th the density of water
- Temperature and **pressure** affect the density of air
- **Temperature**: Hot air is less dense than cold air
- **Pressure**: Air expands with elevation above sea level
 - Air is much easier to compress than water

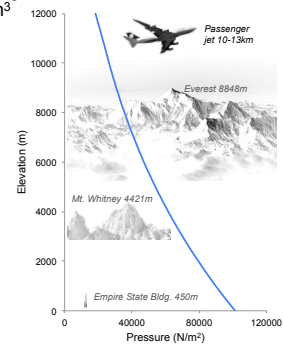


Figure by E. Schauble, using NOAA Standard Atmosphere data.

Density & temperature of Air

- Rising air expands & cools
 - Vapor condenses into clouds, precipitation
- Sinking air is compressed and warms
 - Clear air

Figure adapted from Nat'l Weather Service/NOAA, Public Domain, <http://ocenservice.noaa.gov/education/yos/resource/letStream/synoptic/clouds.htm>

Expanding Air Cools and Condenses

- Like opening a pressurized bottle of soda
- Air expands and cools
- Water vapor condenses -- cloud formation

Movies by J. Aurnou, E. Schauble, UCLA

Questions

Figure adapted from Nat'l Weather Service/NOAA, Public Domain, <http://ocenservice.noaa.gov/education/yos/resource/letStream/synoptic/clouds.htm>

Solar Heating of the Earth

- Solar energy absorbed unevenly over Earth's surface
- Energy absorbed / unit surface area varies with:
 - Angle of the sun
 - Reflectivity of the surface (i.e., ice v. ocean)
 - Transparency of the atmosphere (i.e., clouds)

Przemyslaw "Blueshade" Idzikiewicz, Creative Commons A S-A 2.0, http://commons.wikimedia.org/wiki/File:Earth-lighting-winter-solstice_EN.png

Solar Heating of the Earth

Sunlight heats the ground more intensely in the tropics than near poles

Figure by William M. Connolley using HadCM3 data, Wikimedia Commons, Creative Commons A S-A 3.0, <http://commons.wikimedia.org/wiki/File:Insolation.png>

Solar Heating & the Seasons

Not to scale!

Background image: Iau'olina, Creative Commons A S-A 2.5, http://en.wikipedia.org/wiki/File:North_season.jpg

- Seasons are caused by Earth's 23.5° tilt
- Northern summer: north hemisphere points at sun