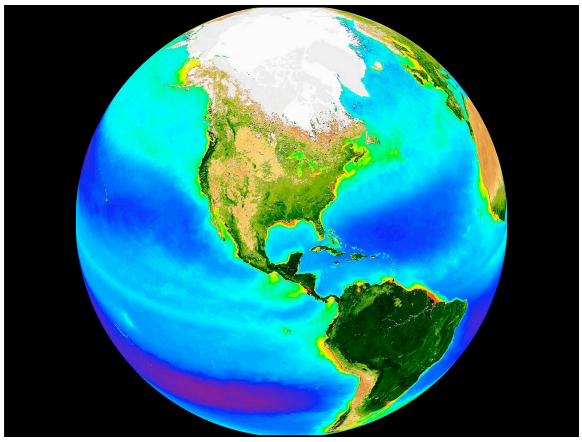


CLIM 101: Global Warming - Weather, Climate and Global Society

Climate, Ecosystems and Humans

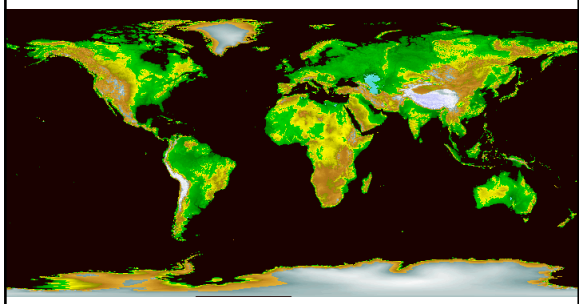
Jim Kinter

Topics

- Tutorial: graphical display of quantitative information
- What is Weather? What is Climate?

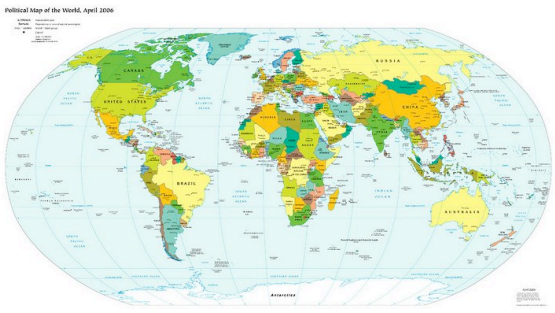
First … A Tutorial on Graphical Display of Quantitative Information

World Topographic Map

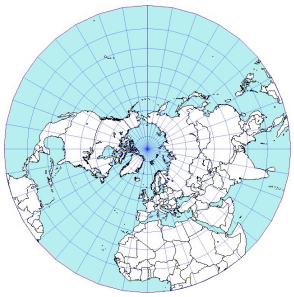


Colors correspond to elevation

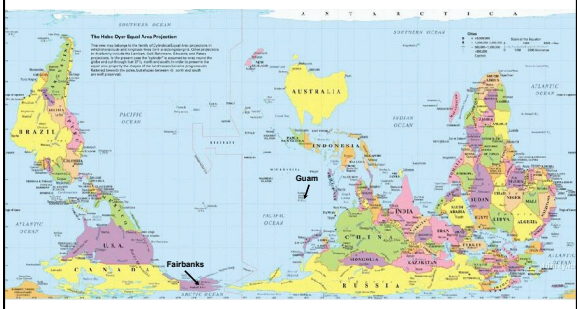
World Political Map



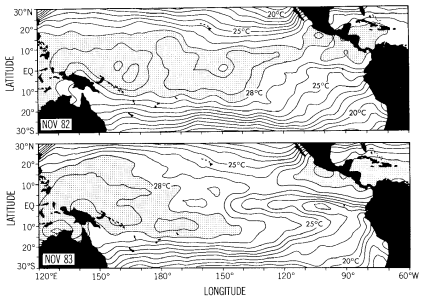
Polar Stereographic Projection



World Political Map
SH world view



Graphical Display of Quantitative Information
Contour Plot



What is Weather?
What is Climate?

Weather is what you get, climate is what you expect.

E. N. Lorenz

Weather = Expected Weather + Unexpected Weather

↓

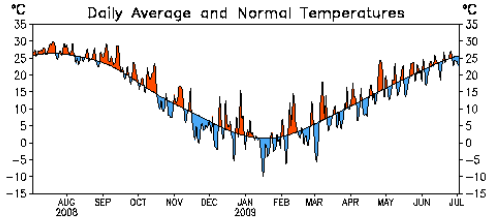
Climate

Questions

- What is "expected" weather? Why do we expect one type of weather in one place and a different type of weather in another?
  - E.g. why does it get cold at night? What determines how cold?
  - E.g. why is Guam warmer on average compared to Fairbanks? Why is the annual cycle of temperature in Guam so small compared to the annual cycle of temperature in Fairbanks?
- What is "unexpected" weather?
  - Why can't we predict the weather forever (like the tides or the movement of planets)?
  - How accurate is the weather forecast?
  - What about the Farmer's Almanac?
  - Is the average departure from normal predictable?
  - What is Global Warming?

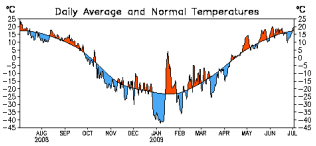
Temperature for July 2008 to June 2009

WASHINGTON D. C.,

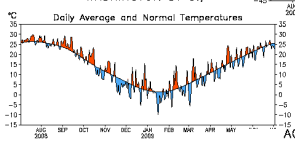


Temperature for July 2008 to June 2009

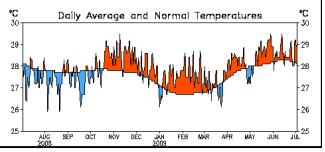
FAIRBANKS, ALASKA



WASHINGTON D. C.,



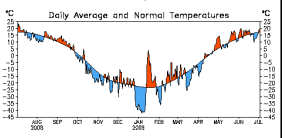
AGANA NAS, GUAM, MARIANA ISLANDS



Temperature for July 2008 to June 2009

GUAM

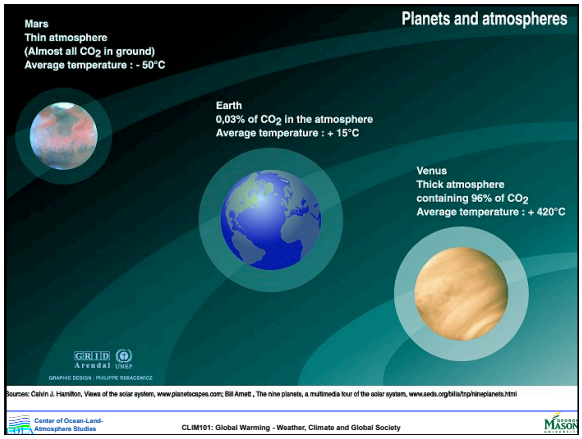
FAIRBANKS, ALASKA



The Climate of a Planet Depends On …

1. Energy from the Sun (energy from the interior)	S (depends on Sun itself and distance from Sun)
2. Planetary Albedo	α
3. Speed of Planet's Rotation	Ω
4. Mass of the Planet	M
5. Radius of the Planet	a
6. Atmospheric Composition	H_2O, CO_2, O_3, clouds
7. Ocean-Land, Topography	h*

Note: 1, 3, 4, 5, 7 are effectively "givens" that cannot be influenced by weather, climate or life (including humans, so far)

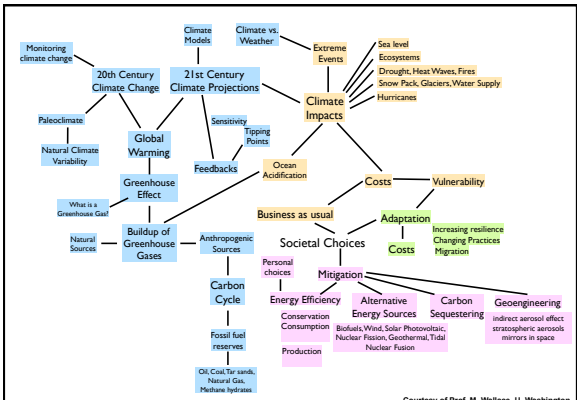


Weather, Climate and Global Society

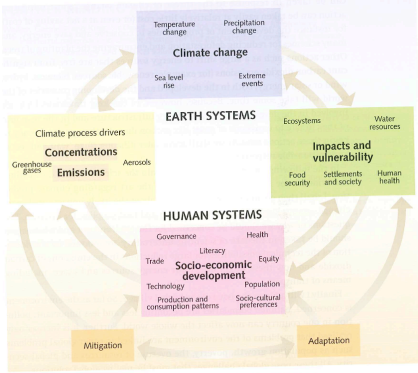
General Principles and Evidence from the Past

Topics

- **READING**:
  - *Rough Guide* pp 3-19; 193-226
  - *Global Warming* Chapter 4
- Climate, Ecosystems and Humans
- Weather, Climate and Global Society – General Principles and Evidence from the Past

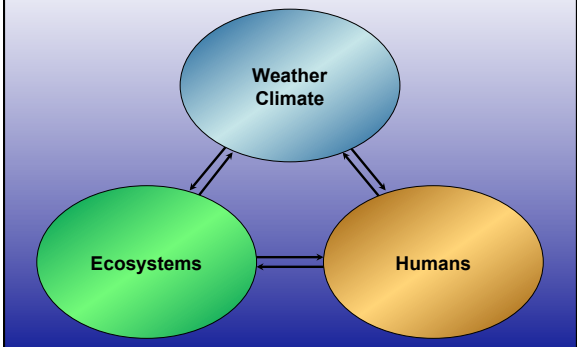


Courtesy of Prof. M. Wallace, U. Washington



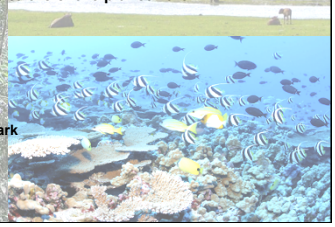
Houghton: Global Warming – The Complete Briefing (2009; Fig. 1.5)

Organizing Schema



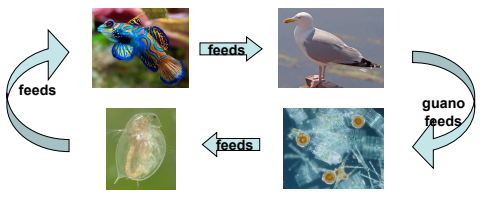
What is an Ecosystem?

- **A system of living organisms, consisting of all plants, animals and micro-organisms (biotic factors) in an area interacting with each other and their physical environment.**
- **The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of study, ranging from the very small scale to the entire planet Earth.**
- **Examples:**
  - **Coral reef**
  - **River catchment**
  - **Rain forest**
  - **Estuary**
  - **Desert**
  - **Yellowstone National Park**



Example: Hypercycle

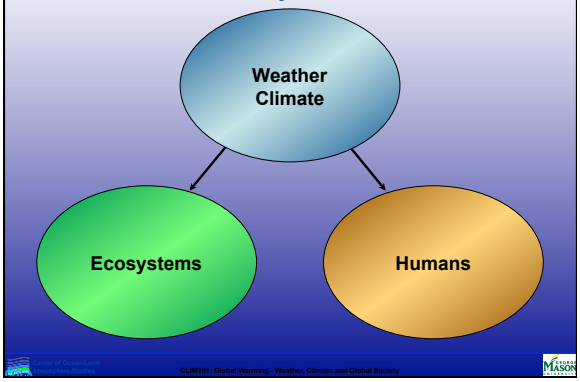
- Each member of an ecosystem may depend on the presence or actions of another element, so that the members thrive in each others' presence
- For example, fish eat water fleas. Birds eat fish. Birds provide guano, which assists the blooms of algae on which water fleas flourish.



Climate, Ecosystems and Humans

- **Organizing schema**
- **How do weather/climate affect humans and ecosystems?**
  - Ice ages
  - Origin of agriculture
  - Distribution of (natural) vegetation
  - Temperature and income
  - Extremes → disruptions
- **How do ecosystems affect weather/climate?**
  - Albedo
  - Storage of water
  - Storage of carbon
- **How do humans affect weather/climate and ecosystems?**
  - Deforestation
  - Dams and irrigation
  - Energy consumption and emission
  - Pollution
  - Carrying capacity and collapse

Ways that Weather & Climate Affect Humans, Ecosystems



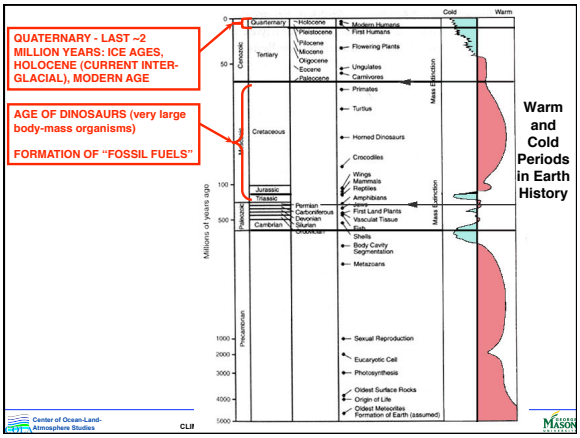
Ways that Weather & Climate Affect Humans, Ecosystems

Features of climate:

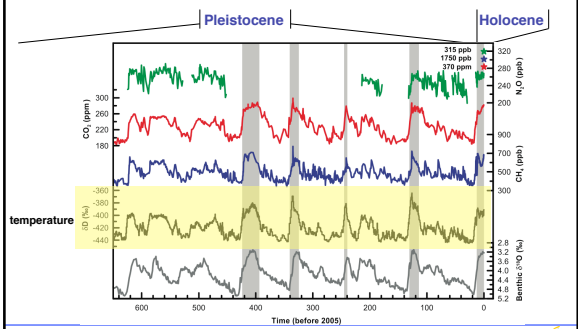
- Annual mean and annual cycle of
  - Temperature (e.g. warm vs. cold climate; frost/freeze dates)
  - Rainfall (abundant/regular vs. sparse/irregular)
  - Sunshine
  - Wind (magnitude, intermittency)
- Frequency, severity, duration of storms
- Frequency, severity, duration of floods, droughts

Affect:

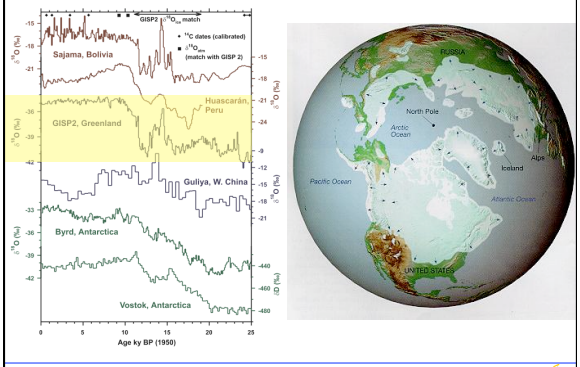
- Body size and shape (thermoregulation by increasing/decreasing body surface-area/ mass ration in hot/cold climate)
- Culture (viz. indigenous populations in Arctic, deserts etc.)
- Location, robustness of agriculture
- Plant/animal species ranges
- Plant, animal and human health
- Human economic systems: energy use, transportation, etc. (next class!)

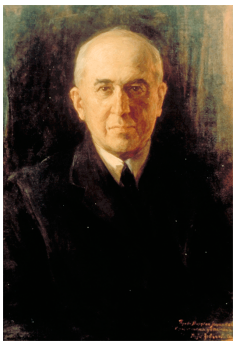


Quaternary Era (last ~2 million years)



Ice Cores from the Tropics Greenland and Antarctica

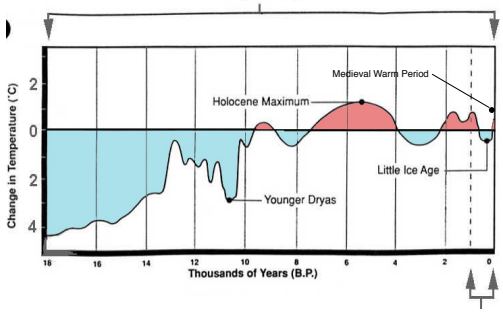




Milutin Milankovitch (1879-1958)

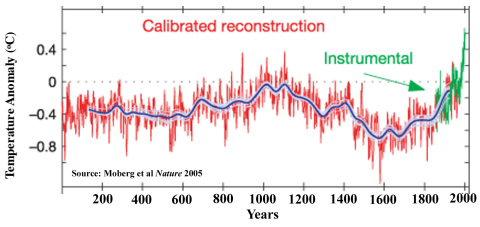
- Leading proponent of an astronomical theory of climate change in the 20th century.
- Worked in Serbia under extreme duress including incarceration in 1914 by the Austro-Hungarian Army and the bombing of Belgrade (and his publisher!) in 1941.
- Mathematically calculated the timing and influence at different latitudes of changes in orbital eccentricity, precession of the equinoxes, and obliquity of the ecliptic.
- This theory was confirmed in 1976 in the paleoclimatic proxy record, so Milankovitch cycles became known as the pacemaker of the ice ages.

18 ka

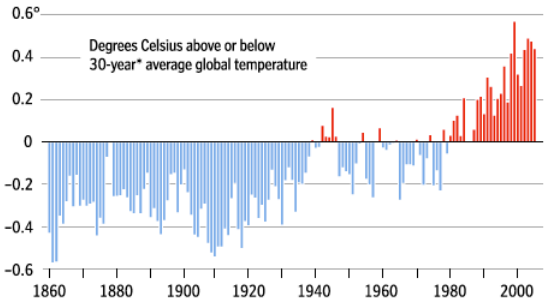


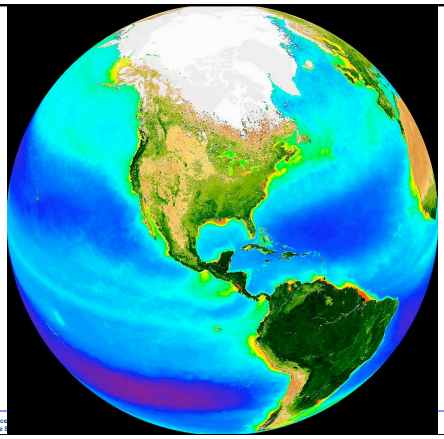
LAST TWO MILLENIA OR SO …

2000 Year Northern Hemisphere Reconstruction of Surface Air Temperatures



LAST CENTURY OR SO …





Origin of Agriculture (~8 ka)

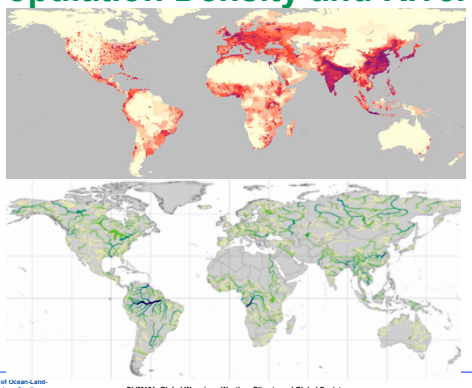
- *Hypothesis 1*: Agriculture was impossible during the last glacial (ice age; ended ~12 thousand years ago - 12 ka)
  - Climate very dry, highly variable over large areas
  - Low atmospheric CO_2 (might inhibit photosynthesis)
  - Very large climatic swings on decadal to centennial time scales with frequent extremes
- *Hypothesis 2*: Agriculture is compulsory in the Holocene (since last glacial)
  - Relatively warm, wet climate
  - Prehistoric population rapidly increases to carrying capacity set by environment and prevailing subsistence system
  - Local communities that develop more intense subsistence strategy have competitive advantage
  - agriculture out-competes hunting/gathering and evolves rapidly under competitive pressure

Richerson et al., *American Antiquity*, 2001

Agriculture

- Revolutionized interaction between humans and the rest of the biosphere
- For example: many major population centers have grown in the great river systems
  - **Asia**: Indus, Ganges, Brahmaputra, Ayeyarwaddy (Irriwaddy), Mekong, Yangtze, Yellow, Salween
  - **Middle East**: Tigris, Euphrates
  - **Europe**: Rhine, Danube, Seine, Loire, Po
  - **North America**: St. Lawrence, Mississippi/Missouri/Ohio
  - **South America**: Amazon, Parana/La Plata, Orinoco
  - **Africa**: Nile, Congo, Niger

Population Density and Rivers



Ways that Weather & Climate Affect Humans, Ecosystems

Features of climate:

- Annual mean and annual cycle of
  - Temperature (e.g. frost/freeze dates)
  - Rainfall
  - Sunshine
  - Wind
- Frequency, severity, duration of storms
- Frequency, severity, duration of floods, droughts

Affect:

- Body size and shape (thermoregulation by increasing/decreasing body surface-area/mass ration in hot/cold climate)
- Culture (viz. indigenous populations in Arctic, deserts etc.)
- Location, robustness of agriculture
- **Plant/animal species ranges**
- Plant, animal and human health
- Human economic systems: energy use, transportation, etc. (next class!)

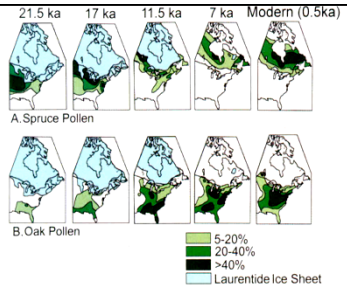
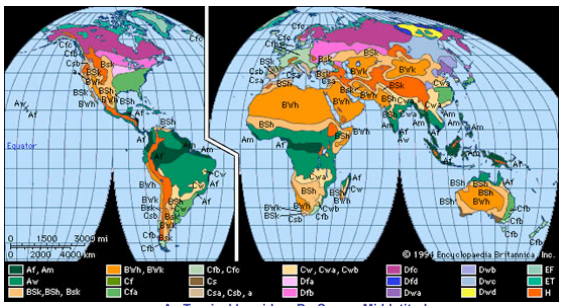


Fig. 1. Ranges, as indicated by pollen percentages in sediment, of spruce and oak in eastern North America at intervals of about 5000 years during the late Quaternary (65). Dates are calibrated equivalents of radiocarbon years before present. The continental ice sheet is shown in blue; pollen proportions are shown in shades of green. The shoreline is not drawn to reflect changes in sea level. (**A**) Spruce (*Picea*) pollen representing three extant species plus the extinct *P. critchfieldii*. More recent data show that spruce was abundant farther south in the Mississippi valley during the Last Glacial Maximum than shown here (*3*, *4*). Both southern and northern range boundaries of spruce shifted northward. (**B**) Oak (*Quercus*) pollen representing some or all of the 27 extant species in eastern United States. Oak expanded from the southeast but continued to grow near the locations of full-glacial refuges.

Davis et al., *Science*, 2001

Köppen Climate Classification



A - Tropical humid
B - Dry
C - Mild Mid-latitude
D - Severe Mid-latitude
E - Polar
H - Highland

Temperature and Economy

- Dell et al. (MIT; 2009 article in *American Economic Review Papers and Proceedings*) showed that a negative relationship between income and temperature exists across countries, when looking within countries, and even when looking within states within countries
- Each additional 1° C is associated with a statistically significant reduction of 8.5% per-capita GDP
- Temperature, precipitation, elevation, slope, and distance to the sea together explain 61% of the variation in municipal income
- A poor country's growth in a given year is 1.1% lower when its temperature is 1° C higher that year
- The persistent effect of temperature shocks suggests that temperature affects the growth rate, not simply the level of income, at least over 10- to 15-year time horizons

Dell, M., B. F. Jones and B. A. Olken, 2009: Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates. *Amer. Econ. Rev. Papers Proc. (in press)*.

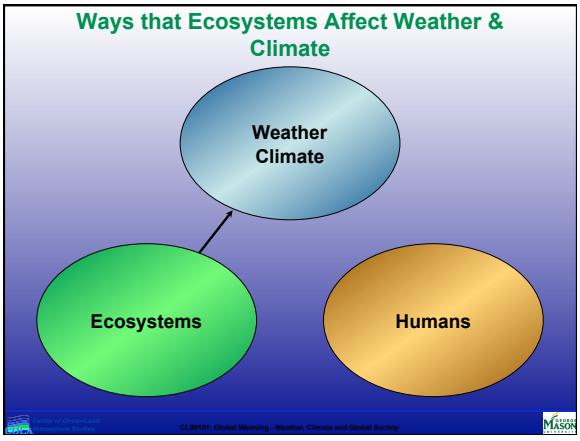

Monsoon Floods in India 2007
South Asian Adaptation


Monsoon Floods in India 2007
Monsoon Drought in 2009
South Asian Adaptation


Monsoon Floods in India 2007
Extreme Pakistan Floods in 2010
South Asian Adaptation

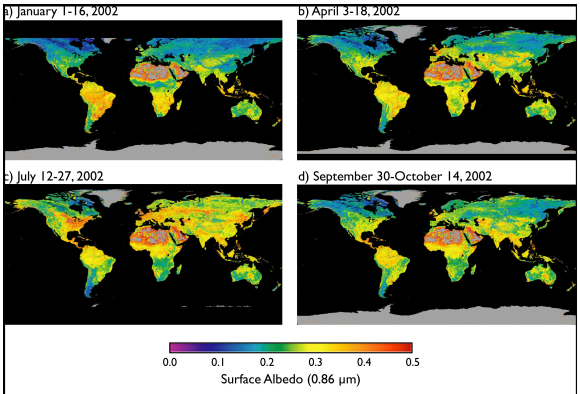

UK Floods: July 2007
POLICE


Irish Adaptation: Floods of July 2007
Crowds panic as flooding threatens Ireland...

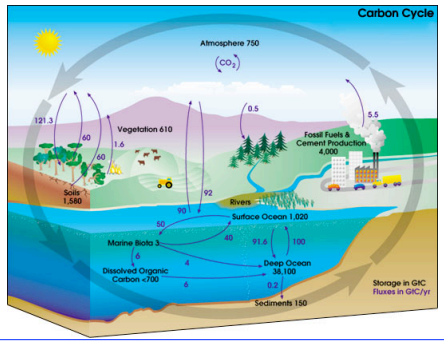

Ways that Ecosystems Affect Weather & Climate
Weather
Climate
Ecosystems
Humans

Ways that Ecosystems Affect Weather & Climate

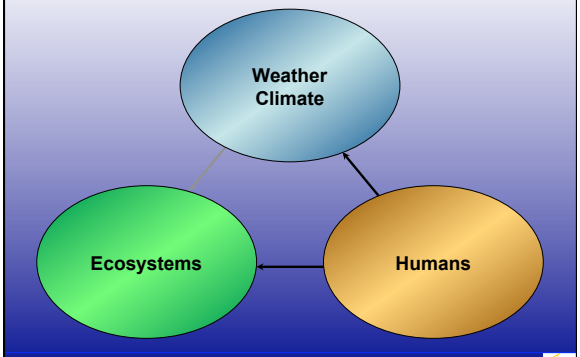
- Albedo of land surface
- Retention of freshwater
- Cycling of components (carbon, nitrogen, OH, etc.) of radiatively-active species (H_2O, CO_2, N_2O, etc.)
- Absorption and latent re-emission of energy (radiation, heat)

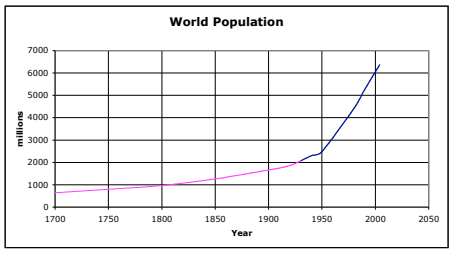


Global Carbon Cycle



Ways that Humans Affect Climate, Ecosystems





Growth rate increased by 3.2X between 1700-1930 and 1930-2004

Doubling time: 134 years 42 years

Ways that Humans Affect Climate, Ecosystems

- Forest fires - in many places, the majority of forest fires have been anthropogenic since the time of significant settlement
- Deforestation - clearing natural landscapes for settlement or transportation
- Dams, irrigation - changes in habitat, geography, water flow and water availability (e.g. for irrigation)
- Energy consumption
- Roads, settlements (e.g., habitat fragmentation)
- Over-fishing, over-hunting
- Pollution - toxicity level, behavior change (e.g. peppered moths in the UK), dead zones (next class!)
- Atmospheric composition leading to climate change and ocean acidification (next class!)

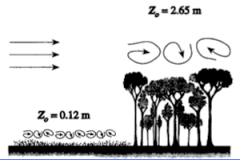
Ways that Humans Affect Climate, Ecosystems

- Forest fires - in many places, the majority of forest fires have been anthropogenic since the time of significant settlement
- Deforestation - clearing natural landscapes for settlement or transportation
- Dams, irrigation - changes in habitat, geography, water flow and water availability (e.g. for irrigation)
- Energy consumption
- Roads, settlements (e.g., habitat fragmentation)
- Over-fishing, over-hunting
- Pollution - toxicity level, behavior change (e.g. peppered moths in the UK), dead zones (next class!)
- Atmospheric composition leading to climate change and ocean acidification (next class!)

Deforestation

Grassland
- Albedo = 20%
- Roughness = 0.12 m
- Bowen ratio = 81% (evaporation = 45% of R_{net})

Rain Forest
- Albedo = 12%
- Roughness = 2.65 m
- Bowen ratio = 43% (evaporation = 30% of R_{net})



Christopher Columbus and the European Settlement of Hispaniola

Effects of Tropical Deforestation

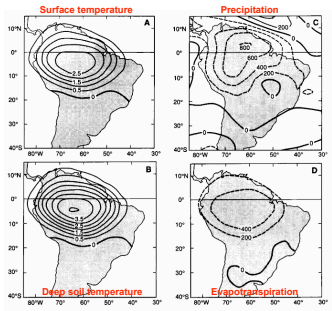


Fig. 2. Differences between 12-month means (1 January to 31 December) of deforestation and control cases (deforested − control) for the South American sector: (**A**) surface temperature increase in degrees centigrade; (**B**) deep soil temperature increase in degrees centigrade; (**C**) total precipitation changes (dashed lines indicate a decrease) in millimeters; and (**D**) evapotranspiration decrease in millimeters. Model results were smoothed before plotting.

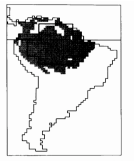


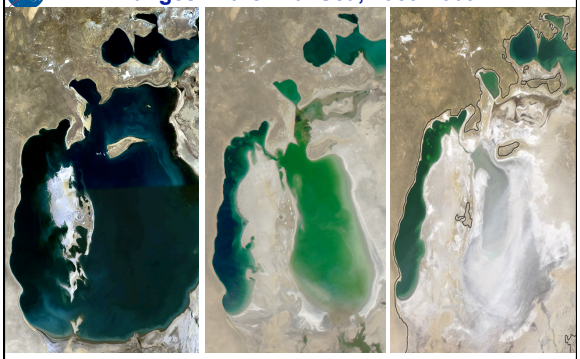
Fig. 1. The South American region. Stippling depicts the area covered by the tropical forest in the control simulation. The area marked with bold lines was used for the areal averages of Fig. 3 and for Tables 1 and 2.

Shukla et al., *Science*, 1990

Ways that Humans Affect Climate, Ecosystems

- Forest fires - in many places, the majority of forest fires have been anthropogenic since the time of significant settlement
- Deforestation - clearing natural landscapes for settlement or transportation
- Dams, irrigation - changes in habitat, geography, water flow and water availability (e.g. for irrigation)
- Energy consumption
- Roads, settlements (e.g., habitat fragmentation)
- Over-fishing, over-hunting
- Pollution - toxicity level, behavior change (e.g. peppered moths in the UK), dead zones (next class!)
- Atmospheric composition leading to climate change and ocean acidification (next class!)

Changes in the Aral Sea, 1989-2009



July - Sep 1989, from Landsat | 12 Aug 2003, from MODIS-Aqua | 3 May 3 2009, from MODIS-Terra

Aral Sea

Aral Sea - Recovering?

Environmental New Service:

ASTANA, Kazakhstan, August 1, 2008 (ENS) - **Water is returning** to the North Aral Sea in Central Asia that had shrunk to a quarter of its former size during the last half of the 20th century. **Fish, sea birds and reptiles have begun to repopulate the Aral Sea and surrounding area**.

…

This week the government of Kazakhstan announced that its US$260 million rescue program for the Northern Aral Sea is working.

Launched in 2001 by Kazakhstan President Nursultan Nazarbayev and supported by the World Bank, the program has **increased the North Aral Sea's surface by about 30 percent since** the last assessment was conducted in **2003**, according to a statement Wednesday by the Kazakh Foreign Ministry.

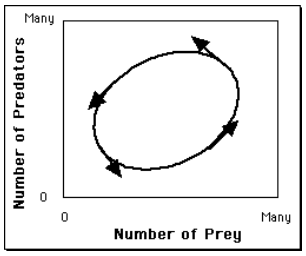
The North Aral Sea's surface increased from 2,550 square kilometers (985 square miles) in 2003, the ministry said, to 3,300 square kilometers (1,275 square miles) in 2008.

And the **sea's depth increased from 30 meters (98 feet) in 2003 to 42 meters (138 feet) in 2008**.

Ways that Humans Affect Climate, Ecosystems

- Forest fires - in many places, the majority of forest fires have been anthropogenic since the time of significant settlement
- Deforestation - clearing natural landscapes for settlement or transportation
- Dams, irrigation - changes in habitat, geography, water flow and water availability (e.g. for irrigation)
- Energy consumption
- Roads, settlements (e.g., habitat fragmentation)
- Over-fishing, over-hunting
- Pollution - toxicity level, behavior change (e.g. peppered moths in the UK), dead zones (next class!)
- Atmospheric composition leading to climate change and ocean acidification (next class!)

Predator-Prey Relationship



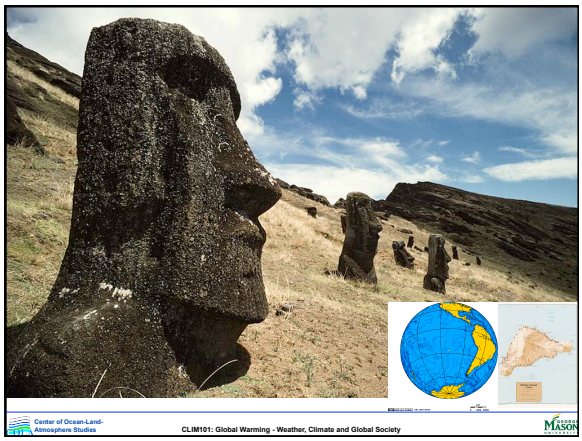
Carrying Capacity

- The supportable population of an organism, given the food, habitat, water and other necessities available within an environment is known as the environment's **carrying capacity** for that organism.
- For the human population, more complex variables such as sanitation and medical care are sometimes considered as part of the necessary infrastructure.
- Carrying capacity is the number of individuals an environment can support without significant negative impacts to the given organism and its environment. A factor that keeps population size at equilibrium is known as a regulating factor.
- A common model of population growth:
  - the rate of reproduction is proportional to the existing population, all else being equal
  - the rate of reproduction is proportional to the amount of available resources, all else being equal. This models the competition for available resources, which tends to limit the population growth.
- **Humans can overcome natural predator-prey limits to growth through technological efficiency; however, technology cannot necessarily overcome limits imposed by carrying capacity.**

Factors Contributing to Societal Collapse in the Past

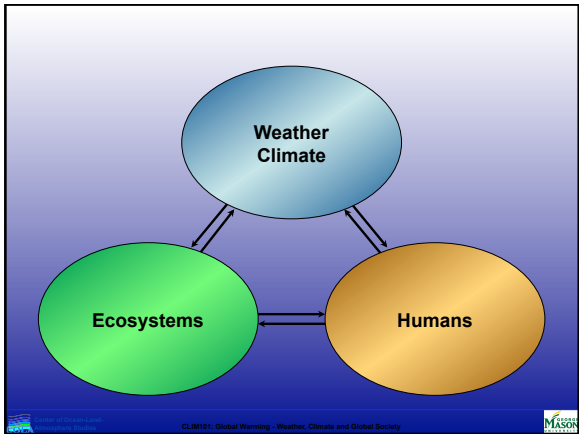
1. Deforestation and habitat destruction
2. Soil problems (erosion, salinization, and soil fertility losses)
3. Water management problems
4. Overhunting
5. Overfishing
6. Effects of introduced species on native species
7. Human population growth
8. Increased per-capita impact of people

Diamond, *Collapse*, 2005



The Collapse of Easter Island Human Habitation (~900-1700 AD)

- Huge statues built (for unknown purposes)
- Raw materials quarried and carved at far end of island
- Roads built to transport rocks - log rolling method and rope tows
- Huge population needed to carve, transport and erect statues
- Inhabitants used indigenous trees for road and rope materials
- Result - total deforestation and extinction of flora



How Should We Characterize these Relationships?

- **Cause and Effect** - changes may occur on either side of the arrow … which is the cause and which is the effect? More specifically, what is the proximate cause and the ultimate cause of any given phenomenon?
  - Example: Does deforestation change the climate or does climate change alter the trees (or both … see "feedback" below)?
- **Magnitude** - to what degree does one system affect another?
  - Example: How large a change in climate is required to change the flora or fauna in a given location?
- **Time Scale** - do changes in one system respond on the same time scale as changes in another?
  - Example: How long must a heat wave persist in order to result in human fatalities?
- **Feedback** - does a change in one system, that results in a change in another, in turn cause the first system to respond?
  - Positive feedback: the cycle of changes tends to amplify the responses
  - Negative feedback: the responses in one system tend to reverse the changes in the forcing system
  - Example: Deforestation may reduce the precipitation in a given region making it unlikely that the forest will grow back

REMINDER

Last Day to Add a Class:

14 September 2010