"It is difficult to get a man to understand something, when his salary depends upon his not understanding it."

- Upton Sinclair

(Passed along to me from Facebook by my facebook friend and cyber-colleague, Dr. Marshall Shepard, Professor of Meteorology, University of Georgia.)

Climate Change - Life in the Greenhouse

Natural Climate Change

What is the Greenhouse Effect?

Climate Change and the Future

Graphic: See Garrison, Fig. 18.27.

Measuring Climate Change

Scientists can monitor past climate

using natural climate recorders

Examples

- chemical composition of coral

skeletons

- air bubbles trapped in polar ice caps

Graphics: (above) Diver drills for

coral samples, courtesy of NOAA,

(right) Banding in coral skeletons

NOAA Coral Paleoclimate slide set.

Atmospheric Composition

The atmosphere is a mixture of gases, but mostly nitrogen and oxygen

Gases present in small concentrations can have a large influence on climate

Examples: carbon dioxide (CO_2), Methane (CH_4), water vapor (H_2O)

Graphic: Blue Planet Fig. 12.2, composition of the dry atmosphere.

Earth's Radiative Budget
What Makes a Gas a "Greenhouse Gas"?

The type radiation that can be absorbed or emitted by a molecule depends on the molecule's structure

"Greenhouse gases" absorb and emit infrared radiation

These gases trap heat in the atmosphere, increasing planetary temperatures and causing variations in climate

Graphics: Kump et al., Figs. 3-12, 3-14.

Life in the Greenhouse

The greenhouse effect is a

natural part of how the

atmosphere works

Natural sources of greenhouse gases:

- **volcanoes**
- **burning and decay of organic matter**
- **respiration and other biological processes**

Graphic: Oldoinyo Lengai, erupts explosively in 1966. Photography by G.Davies, courtesy of C.Nyamweru, St. Lawrence University, Canton NY.

The Greenhouse Effect

"Greenhouse gases" in the atmosphere trap heat, resulting in higher surface temperatures

Graphic: See Garrison, Fig. 8.3.

A Planetary Comparison

Venus, Earth and Mars are all warmed by greenhouse gases in their atmospheres

Without the greenhouse effect average Earth surface temperatures would be -

18°C (0°F)

Actual average surface temperatures were 16°C (61°F) prior to industrialization

What is different about recent climate change?

Anthropogenic (Human induced changes):

Carbon dioxide - fossil fuels, deforestation

Water vapor - changes in land use, ocean warming

Methane - rice farming, ranching

CFCs - cleaning agents, refrigerants

‘05 & ‘07 Top 20 nations for carbon emissions

Components of the cryosphere

- Mtn glaciers and ice caps - fast response
- Sea ice and ice shelves - fast response
- Ice sheets – slow response

Atmospheric CO_2, 1950-present

Atmospheric CO_2 can be measured directly from air samples

Measurements at Mauna Loa, Hawaii show an increase in atmospheric CO_2 of ~80 parts per million (ppm) over the past 50 years

Data source: Keeling, D.C., and T.P. Whorf, 1998: Atmospheric CO_2 records from sites in the SIO air sampling network. In "Trends: A Compendium of Data on Global Change", Carbon Dioxide Information Analysis Center, US Dept. of Energy. Lower picture: CO2 monitoring station on Mauna Loa, courtesy of NOAA.

Atmospheric CO_2, 1000-present

Air bubbles within polar and glacial ice are analyzed to determine CO_2 levels in the past (yellow squares)

Atmospheric CO_2 has increased from 280 ppm in the 1740's to about 390 ppm in 2009 (red squares)

Other greenhouse gases have also increased

CO2 Data : Law Dome Antarctica: Etheridge et al , 1996, Mauna Loa: Keeling and Whorf, 2005.

Selected Greenhouse Gas Concentrations Over the Past 10,000 Years

600,000 years of greenhouse gases

Just how unusual is today's CO_2 level?

Many paleoclimatologists believe that a doubling of today's CO_2 level (to ~ 800 ppm) last occurred ~20-40 million years ago

ΔpCO_2 ~ 100 ppm

in 20,000 years =

0.005 ppm/yr

in 200 years =

0.5 ppm/yr

So ~100x faster than natural variation

Recent global temperature trend

Source: http://data.giss.nasa.gov/gistemp/2010july/

Spatial pattern of warming

Source: http://www.giss.nasa.gov

Opening the northeast passage

- During the age of expansion, European explorers died trying to find a safe sea route from Europe to the Orient.
- For the first time in hundreds of years this passage is open.

(Source NY Times)

The "Ice-Albedo" feedback trend

- As ice melts, patches of open water develop

- These patches absorb energy and heat

- This heats the ocean, further melting the ice

- Trends as high as 4% per year are observed

Source: CRREL Synthesis Project http://www.donperovich.com/sunlight.htm

Sea Ice Trends

Sea ice:

- cools climate by reflecting solar energy back to space

- is an important habitat for many marine animals

- is decreasing in summer by 8.7% per decade

Analyses indicate a seasonally ice-free Arctic by 2050

Graphic: (top) Sea ice coverage, 1979 and 2003 based on satellite data, courtesy of "Impacts of a Warming Arctic: Arctic Climate Impact Assessment", Cambridge University Press, 2004, (inset) Sea ice trends as measured by satellite, courtesy of National Snow and Ice Data Center.

What About the Melting of Ice on Greenland?

Graphics: (left) Meltwater flowing into a moulin, courtesy R.J. Braithwaite, University of Manchester, UK, (top right) seasonal meltwater zone around Greenland, as measured by satellite. Courtesy of "Impacts of a Warming Arctic: Arctic Climate Impact Assessment", Cambridge University Press, 2004, (bottom right) glacial melt processes, NASA GSFC.

See image 1 and image 2 in http://www.gsfc.nasa.gov/topstory/20020606greenland.html and see http://www.amap.no/acia/Files/GISMeltExt_150.jpg

Evidence for accelerated melting

Seismologists have noted an increase in the frequency and intensity of ice quakes, arising from sudden motion of ice along Greenland's outlet glaciers

Graphic: Seasonality (top) and interannual changes (bottom) of glacial earthquakes on Greenland as compared with conventional, non-glacial earthquakes. Ekstrom et al., Science (2006).

Locations of Greenland's Icequakes

Icequakes are occurring where glaciers flow into the sea

Graphic: (top) From Ekstrom et al., Science (2006), (bottom) Jakobshavn Isbrae, Greenlands largest glacier, image courtesy of National Snow and Ice Data Center

Scientific Predictions of Future Warming

Graphic: Projected surface temperature changes for early and late 21st century relative to 1999. Scenarios: (top) B1-shift to sustainable fuels, population peaks mid-century, (middle) A1B-rapid future economic growth, fossil and non-fossil fuels, (bottom) A2-fossil fuel intensive, regional responses with increasing global population. Fig. SPM-6, IPCC Working Group 1 Executive Summary, 2007. Graphic: http://www.ipcc.ch/SPM2feb07.pdf Fig. SPM-6, pg 15.

Potential Climate Changes

Primary effects:

- Warmer temperatures

- Higher sea level

- Reduced seasonal snowpack

- Retreating glaciers

- Reduced permafrost

- More intense, longer droughts

- Increase in intense tropical cyclones (hurricanes and typhoons)

<u>Types of changes:</u>

- changes in average conditions

- changes in variability

- rapid changes

- "surprises"

Graphic: (top) Hurricane Floyd, Sept. 14, 1999. Courtesy of NASA, (bottom) sea level rise measured from 1992-2005 from satellite altimeters, current estimates of sea level rise are >3.4 mm/yr.

Global Impacts of Sea Level Rise

- Damage to housing and high-value infrastructure

- Altered patterns of damage by storm waves

- Potential refugee issues involving low-lying coastal nations

Graphics: (left) Impact of a 1 meter rise in sea level on Florida. In relatively flat coastal areas, a small rise in sea level can flood large areas (right). Graphics from "Impacts of a Warming Arctic: Arctic Climate Impact Assessment", Cambridge University Press, 2004. http://www.amap.no/acia/Files/ObsSeaIceNASA1979_03_150.jpg http://www.amap.no/acia/Files/SeaLvlRise-Coastline_150.jpg

Ocean Acidity (pH) and the Future

Shell-building organisms form an important part of many marine food webs – many of these can survive in only a narrow range of pH

Compared to pre-industrial levels, the pH of the surface ocean has fallen by 0.1 units. As the ocean continues to absorb CO_2, pH may fall by an additional 0.14-0.35 units by 2100*

<u>Potential impacts:</u> Lower pH makes it difficult for marine organisms to build calcium carbonate shells and skeletons, potentially impacting marine food webs

Photos: (top) Micrograph of a coccolithophore, courtesy of NASA, (bottom) Red Sea coral reef, courtesy of NOAA,

* = From Climate Change 2007: The Physical Science Basis, IPCC Working Group I, Summary for Policymakers, 2007.

Potential Impacts on Coral Reefs

Graphic: Impacts of Ocean Acidification on Coral Reefs and Other Calcifiers, Workshop Report (NSF, NASA, USGS), see http://www.ucar.edu/communications/Final_acidification.pdf, pg 10.

Potential Impacts of Climate Change on Society

Many sectors of society may be affected...

- **Agriculture and fisheries**
- **Infrastructure**
- **Water resource management**
- **Human health**
- **Ecosystems/biodiversity**

Climatologists, economists, sociologists, politicians and others are studying the potential impacts of climate change on these sectors and on individual countries

Graphic: (top) Sunrise, courtesy of NOAA, (bottom) wheat harvest, at ARS Central Great Plains Research Station, Akron, Colorado. Photo by S.Bauer, courtesy of US Dept. of Agriculture.

Predicting Future Climate

Uncertainties:

- **Interactions between different elements of the climate system (e.g., ice on Greenland and Antarctica and future sea level rise)**
- **Future CO_2 emissions are unknown**
- **Potential impacts of mitigation technologies**
- **Unforeseen surprises**

Graphic: Climate change feedbacks, courtesy of United Nations Environmental Program, World Meteorology Office.

What Does the Future Hold?

Options being studied and pursued include:

Mitigation to reduce emissions:

- **using fewer fossil fuels**
- **energy efficiency**

- substitution of technologies
- removing CO_2 once it's produced ("sequestration")

Adaptation to a new climate

- may require sweeping changes in key sectors of society (e.g., farming, insurance)
- success depends on available capital and other resources

Graphics: (top left) Engine from a Toyota Prius, photo courtesy of Oak Ridge National lab, (top right) Cool change logo, courtesy of USEPA, (center) Toyota Prius, photo courtesy of NPS, (bottom) wind farm, photo courtesy of US DOE.

The bottom line

- Climate varies in response to physical, chemical, and biological laws.
- Climate change is <u>not a political question.</u>
- Scientific consensus now states that with 90% certainty, humans have and continue to modify climate due to fossil fuel burning, land use change, and industrial activities.
- How we <u>decide to react</u> to climate change is a political question.

You can make a difference!

~50% drop in electricity usage in our household!

Preview of Next Lecture

Oceans – Powering Hurricanes

Review for Exam 2

Reading: 8.17-8.24

Graphic: Cyclones Olaf (cat 5) and Nancy, in the vicinity of Samoa, February 22, 2005, courtesy of MODIS Rapid Response Team, NASA/GSFC.