Global change: Scientific understanding and challenges for the future

KBS GK12 program 3 Oct 2012 Steve Hamilton
Global change, climate change, global warming?

- Warming is the greatest driver of global change
  - But warming will not happen everywhere
- Many other climate changes expected:
  - Hydrological cycle
  - Extreme weather
- Effects extend throughout Earth system:
  - Less snow and ice
  - Ocean acidification by carbon dioxide
Do people understand the challenge?

Alarmed     Concerned     Cautious    Disengaged    Doubtful    Dismissive

March 2012: 13% 26% 29% 6% 15% 10%

Highest Belief in Global Warming  Most Concerned  Most Motivated

July 2010: 14% 31% 23% 10% 12% 11%

Lowest Belief in Global Warming  Least Concerned  Least Motivated

Proportion represented by area

Source: Yale Project on Climate Change Communication
Scientific consensus vs. public confusion

From “Twenty questions and answers about climate change” (Sally Ride Science and Climate Central, 2010)
Scientists are often not even in the public discourse on global change.
International and national scientific consensus on global change

- IPCC – Intergovernmental Panel on Climate Change
  - Latest (2007) report concludes: “Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.”

- AGU – American Geophysical Union
  - 41,000 Earth and space scientists
  - “Human activities are increasingly altering the Earth's climate... Scientific evidence strongly indicates that natural influences cannot explain the rapid increase in global near-surface temperatures...”
First 8 months of 2012 hottest ever recorded (1 deg F warmer than record)

2000-09 was warmest decade on record
- 1990s second warmest

Arctic sea ice, Greenland land ice diminishing faster than expected

Glaciers in retreat worldwide

Antarctic ice shelves degrading
Long term temperature record (to 2011)
Warming is uneven

Land & Ocean Temperature Anomalies Jul 2012
(with respect to a 1981–2010 base period)

Data Source: GHCH-M version 3.1.0 & ERSST version 3b

NOAA's National Climate Data Center

Please Note: Grey areas represent missing data

NOAA
Uneven distribution of warming observed so far in the US

http://www.usda.gov/img/content/EffectofClimateChangeonUSEcosystem.pdf
Arctic Sea Ice

Average September Extent

Data source: Satellite observations.
Credit: NSIDC

Time Series: 1979-2010

Data source: Satellite observations.
Credit: NASA/Goddard Scientific Visualization Studio

climate.nasa.gov/keyindicators/
Land Ice

ANTARCTICA MASS VARIATION SINCE 2002
Data source: Ice mass measurement by NASA's Grace satellites.
Credit: NASA/University of California, Irvine

GREENLAND MASS VARIATION SINCE 2002
Data source: Ice mass measurement by NASA's Grace satellites.
Credit: NASA/University of California, Irvine

Note: In the above charts, mass change is relative to the average during the entire period. (Reference)

climate.nasa.gov/
keyindicators/
Historical sea level record

climate.nasa.gov/keyindicators/
The greenhouse effect

- Heat-trapping gases make the Earth’s surface warm
- Human activities -- fossil fuel combustion, agriculture, deforestation -- increase heat-trapping “greenhouse gases”
  - Carbon dioxide, methane, nitrous oxide, ozone, CFCs
- Heat balance of the land surface also important
The global climate system is complex!
Radiative forcing

- Positive = heating
- Compensating effects
- Net result = heating
- Note uncertainties (error bars)

IPCC 2007
Diverse activities cause climate change

Global Emissions by Sector

- Energy Emissions
  - Power (24%)
  - Transport (14%)
  - Buildings (8%)
- Industry (14%)
- Other energy related (5%)
- Waste (3%)
- Agriculture (14%)
- Land use (18%)
- Non-energy emissions

Total emissions in 2000: 42 GtCO₂e.
What is your carbon footprint?

Your own carbon footprint will be found on the U.S. or industrialized country side. It is easy. Take a look at the table here. It's the amount of carbon (in the form of carbon dioxide, or CO₂) you send into the atmosphere in the process of living your life. The factors that are beyond our personal control.

The average U.S. carbon footprint is 19.9 metric tons of CO₂ per person per year. The average non-U.S. industrialized country's carbon footprint is 8.4 metric tons of CO₂ per person per year. The rest of the world has an average carbon footprint of 2.7 metric tons of CO₂ per person per year.

From “Twenty questions and answers about climate change” (Sally Ride Science and Climate Central, 2010)
World Greenhouse Gas Emissions in 2005
Total: 44,153 MtCO$_2$ eq.

End Use/Activity

- Road 10.5%
- Air 1.7%
- Rail, Ship, & Other Transport 2.5%
- Residential Buildings 10.2%
- Commercial Buildings 6.3%
- Unallocated Fuel Combustion 3.8%
- Iron & Steel 4.0%
- Aluminum/Non-Ferrous Metals 1.2%
- Petrochemicals 1.8%
- Food & Tobacco 1.0%
- Chemicals 4.1%
- Cement 5.0%
- Other Industry 7.0%
- T&D Losses 2.2%
- Coal Mining 1.3%
- Oil/Gas Extraction, Refining & Processing 6.4%
- (tropics only)
  - Deforestation 11.3%
  - Afforestation -0.4%
  - Harvest/Management 1.3%
- Agricultural Energy Use 1.4%
- Agriculture Soils 5.2%
- Livestock & Manure 5.4%
- Rice Cultivation 1.5%
- Other Agriculture 1.7%
- Landfills 1.7%
- Wastewater, Other Waste 1.5%
- HFCs, PFCs, SF$_6$ 1%
- Methane (CH$_4$) 15%
- Nitrous Oxide (N$_2$O) 7%

Sources & Notes: All data are for 2005. All calculations are based on CO$_2$ equivalents, using 100-year global warming potentials from the IPCC (1996), based on a total global estimate of 44,153 MTCO$_2$ equivalent. See Appendix 2 of Navigating the Numbers: Greenhouse Gas Data & International Climate Policy (WRI, 2005) for a detailed description of sector and end use/activity definitions, as well as data sources. Dotted lines represent flows of less than 0.1% percent of total GHG emissions.

* Land Use Change includes both emissions and absorptions, and is based on analysis that uses revised methodologies compared to previous versions of this chart. These data are subject to significant uncertainties.
Recent carbon dioxide record
Long-term carbon dioxide record
Atmospheric carbon dioxide increase

- Combustion of fossil fuels is main source
- Land use change, causing reduction in organic carbon stocks, is also important
- Accounts for ~70% of greenhouse forcing to date

IPCC (2007)
Atmospheric methane, nitrous oxide increases

- Methane mainly from rice paddies, ruminant livestock, natural gas, landfills
- Nitrous oxide mainly from agriculture
- Rates of increase are greater than carbon dioxide
- Both are more potent greenhouse gases

IPCC (2007)
Global climate projections

IPCC (2007)
Global average temperatures could increase from 4-7°F
- The difference between the Ice Age and now was only 9-11°F!
- Rate of warming will be faster than at any time in the past 10,000 years
- High latitudes including Great Lakes region will warm more
- Arctic warming may exceed range over the past *million* years

**Does this projected temperature change matter?**

Future warming will be unevenly distributed
Projected rise in sea level

- Already increased ~20 cm (8 inches)
- Thermal expansion, glacier melting
- Delay to equilibrate

IPCC (2007) data; chart from skepticalscience.com
Recent rise in sea level vs. projections

- Our models may be too conservative

IPCC (2007) and Allison et al. (2009) data; chart from skepticalscience.com
Sea level rise and coastal ecosystems

- IPCC (2007) sea level projections do not account for possibility of massive loss of land ice.
- 6 m rise is possible with loss of much of the susceptible ice in either Greenland or Antarctica.

Overpeck and Weiss 2009
We’re already committed to a warmer world

- Impacts of greenhouse gases are long-lasting
- Oceans delay to warm
- Even with immediate stabilization of greenhouse gas emissions, warming would continue for decades
Our irreversible commitment to climate change

- Models illustrate what would happen if emissions ceased after reaching certain peaks.
- Long lifetime of CO$_2$ plus ocean heat exchange largely explain these results.

Solomon S et al. PNAS 2009;106:1704-1709
All models agree on warming
Specific details are more uncertain at regional to local scales
Most likely:
  - Wetter winters and springs
  - Warmer nighttime temperatures
  - Less snow and ice
  - More extreme weather
Migrating climate

Michigan’s Climate Migrates South

Changes in average summer “heat index”—a measure of how hot it actually feels based on a specific combination of temperature and humidity—could strongly affect Midwesterners’ quality of life in the future. For example, the red outlines track what summers in Michigan could feel like under the higher-emissions scenario; the yellow outlines track what summers could feel like under the lower-emissions scenario.
New studies show greater probability ("loaded dice" analogy)
- Heavy precipitation
- Droughts
- Damaging storm events
- Hurricanes?

Still cannot attribute a particular event to climate change
- Only its probability
Ecosystem impacts of global change

- Massive changes in ecosystems are possible, such as:
  - Distributions of plants and animals
  - Loss of entire ecosystems (e.g., coral reefs, montane rain forests)
  - Activity of pests and pathogens (e.g., bark beetles)
- Magnitude and rate of change are important, as are interactions with human activities
Ecological feedbacks could potentially alter the course of global environmental change, but remain poorly understood.

Examples:

- The CO$_2$ fertilization effect on forests (reduces climate change)
- Higher temperatures may stimulate respiration rates more than photosynthetic rates (enhances climate change)
- Higher temperatures may stimulate methane production in high-latitude wetlands (enhances climate change)
- Human activities in response to ecosystem changes (??)
Will humanity succeed in stemming the rate of climate change?

- Kyoto agreement as an example of the political challenges that lie ahead
- The war for public opinion
  - Role of special interest groups
- Rising likelihood of action => rising resistance to defend the status quo
Is climate stabilization too costly? (If yes, for whom and over what timescale??)

See more detailed figure in IPCC 2007 Summary for Policy-makers
Geoengineering: Technology to the rescue?

- No geoengineering method “can provide an easy or readily acceptable alternative solution…” (Royal Society of London, 2009)
- Yet we should be studying options in case we need them!

A suite of solutions is the best choice

From “Twenty questions and answers about climate change” (Sally Ride Science and Climate Central, 2010)
“What kind of world will our grandchildren inherit?”

- We can moderate the pace and severity of climate change!
- Stabilization of greenhouse gas emissions is a start
- *Reductions* are imperative in the long term
- No single silver bullet…
  - Conserve
  - Invent
  - Mitigate
  - Adapt
Professors, graduate students, and K-12 teachers all have important roles

- Educate yourself on the subject!
- If challenged, seek help!
- Scientists of all fields are trained to recognize and seek out reliable sources of information
- We would be remiss in our duty if we ignore or downplay global change…