Energy, Greenhouse Gases and the Carbon Cycle

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Concepts for today

• Greenhouse Effect
• Grand Cycles
• Reservoirs and flows
• Why worry about the carbon cycle?
• Carbon stocks and flows in a human-altered landscape
• Details of the stocks and flows
• The carbon cycle and global warming
• Uncertainties and case studies of positive and negative feedbacks
• What can we do?
Energy budget and climate change

• Without the atmosphere present, the temperature of the surface of the earth would be approximately -20°F
• The Greenhouse Effect warms the planet to the more moderate climate that we have today

How much of a good thing?
Why is it called a greenhouse effect?

- The glass in a greenhouse is transparent at visible wavelengths but opaque at infrared wavelengths
- Re-radiated wavelengths are unable to escape the greenhouse

Greenhouse effect

- Frequency of electromagnetic radiation released by an object depends on its temperature
- Sun releases radiation in the visible portion of the spectrum
- Earth releases energy in the infrared portion of the spectrum
- Gases can absorb radiation depending on its wavelength
Greenhouse gas molecules

Carbon dioxide
\[ \text{CO}_2 \]

Water
\[ \text{H}_2\text{O} \]

http://www.ucar.edu/learn/1_3_1.htm

What are the greenhouse gases?

- Long lifetime in the atmosphere
- Absorb infrared radiation at key frequencies
- Some compounds are more potent than others as greenhouse gases
The greenhouse gas molecule absorbs IR energy. The molecule can go back to a normal (non-vibrational) state by emitting energy back to Earth.
If we change this system, we get feedbacks, both positive and negative

Positive or negative feedbacks?

- Planet warms, glaciers melt
- More sunlight absorbed, rather than reflected
- Does atmosphere increase or decrease in temperature?

http://www.nsidc.org/data/glacier_photo/special_collection.html
Positive or negative feedbacks?

• Greenhouse gases “fertilize” vegetation, causing more carbon to be sequestered in vegetation
• Atmospheric concentrations of greenhouse gases decrease
• Does atmosphere increase or decrease in temperature?

Radiation budget

(Fig. 3.2, p. 42)
Why care about Grand Cycles?

Understanding carbon flows: Basic Concepts

• The amount of carbon on earth is fixed
• Carbon resides in many places and takes different forms, but these are **not** fixed. Movement between places (reservoirs) and changes in composition are described using a "cycle"
• Humans activity changes the **distributions** of where carbon resides and the form that it takes (we influence the cycles)
Chemical forms of carbon

- Gaseous carbon dioxide and methane in the atmosphere (CO$_2$, CH$_4$)
- Carbon in vegetation and other living organisms
- Carbonates in water
- Organic material in soils
- Buried geologic reservoirs (e.g., fossil fuels and rocks)

Carbon reservoirs and flows

http://www.windows.ucar.edu/tour/link=/earth/Water/co2_cycle.html&edu=high
Carbon reservoirs, flows

- Reservoirs
  - Oceans, rivers
  - Soils
  - Atmosphere
  - Biota

- Flows (fluxes) between reservoirs
  - Uptake by vegetation
  - Ocean-atmosphere exchanges
  - Releases by vegetation
  - Methane producing bacteria

Human activities and the carbon cycle

- Human activities cause increased carbon releases in a variety of ways, including
  - burning of both fossil fuels and forests, which releases carbon into the atmosphere
  - Destruction and planting of vegetation
  - Modification of soils
• Flows include the preindustrial (black) and anthropogenic (red) ocean-atmosphere and land-atmosphere exchanges. The anthropogenic fluxes are average values for the 1980s and 1990s.

http://www.pmel.noaa.gov/co2/ccstudies/

A look at two of the flows

• Photosynthesis
• Ocean atmosphere exchange and ocean circulation
Photosynthesis

- Photosynthesis is the process by which autotrophs (self-feeders) convert water, carbon dioxide, and solar energy into sugars and oxygen.

- The reverse process, used by animal life and other heterotrophs, is respiration.

http://www.windows.ucar.edu/tour/link=/earth/Life/photosynthesis.html&edu=high

Ocean-Atmosphere exchanges and the ocean carbon cycle

- The oceans contain about 50 times more carbon than the atmosphere and 10 times more than the plant and soil carbon reservoirs.

- Over millennial time-scales, the ocean has the potential to take up much of the anthropogenic CO$_2$ that is released to the atmosphere.

http://www.pmel.noaa.gov/co2/gcc.html
Back to our overview

History of Atmospheric Carbon Dioxide

Mauna Loa

Antarctic ice core
Annual cycling of atmospheric carbon dioxide concentrations

Down in summer, up in winter, amplitude of variation is increasing

Test your knowledge

• Craft a hypothesis, explaining why atmospheric carbon dioxide goes down in summer (May-October) and up in winter (November-April)

• Craft a hypothesis, explaining why the magnitude of the oscillation is increasing
Quantitative interpretation of Grand Cycles

- Mass balances and accumulation
- Residence time
- Response time

Back to our overview: What are the reservoirs? What are the fluxes? Are they in mass balance?
In-Out=Accumulation

- Into the atmosphere:
- Out of the atmosphere:
- Accumulation:

How long does a carbon atom stay in any one place (residence time)?

- What is the average residence time of a carbon atom in the atmosphere?
Residence time

- Residence time: Content of Reservoir divided by flows

Mass in reservoir/flow (mass per time) = residence time

Response time

Response time = Reservoir volume change divided by difference between in-flow and out-flow
Response time versus response time

Response time of atmosphere:

- In-out (without fossil fuels) =
- Change = 161 Pg
- Response time =

If the input of carbon to the atmosphere from burning of fossil fuels were to stop, and all other flows remained constant, the time it would take to reduce the carbon in the atmosphere to 590 Pg (reduced by 161 Pg) is:
- about 5 years
- about 50 years
- about 500 years
- the level of carbon in the atmosphere would not decrease
What about uncertainties? What effect would a 10% change in the ocean-atmosphere flows have?

Effects of changes in the carbon cycle on the atmosphere

Primary anthropogenic drivers are fossil fuel combustion, cement production, and land use changes
If fuel burning doubles, what happens to carbon in the atmosphere? How fast does it happen?
What fuels are we using?

So, how much will all of these greenhouse gases warm the planet, and what are the likely impacts?

Summary for Policy-makers from the IPCC
• Greenhouse gases cause a positive radiative forcing (warming); uncertainty is low
• Aerosols (particles) cause a negative radiative forcing (cooling); higher uncertainty

Over the past century:
• Temperatures have increased about 1 degree centigrade
• Sea level has risen about 15 cm
• Snow cover in the northern hemisphere has decreased
Annual precipitation trends: 1900 to 2000

Indicators: Arctic sea ice shrinking & thinning

NCDC, 2000
What temperature rise will this cause and what are the uncertainties?

Uncertainties in predicting future temperature rises are due to:
- Scientific uncertainties (smaller)
- Uncertainties in how societies will respond to this challenge (larger)
Even if we stop emissions now, how long will it take for the system to respond?

Largest temperature rises are predicted near the poles (bad for ice caps) and in the interior of continents.
Effects on rainfall vary around the globe; greatest decreases predicted at mid-latitudes (expansion of deserts?)

What’s expected: sea-level rise to 2100

What should we do?

There are only three options:

- **Mitigation**, meaning measures to reduce the pace & magnitude of the changes in global climate being caused by human activities.

- **Adaptation**, meaning measures to reduce the adverse impacts on human well-being resulting from the changes in climate that do occur.

- **Suffering** the adverse impacts that are not avoided by either mitigation or adaptation.
Mitigation: What do we do?

Since the problem is driven by our use of fossil energy, let’s start there.

Fuel Combustion and Carbon Dioxide Emissions

- Burn less fuel
- Burn less carbon intensive fuels
- Sequester the carbon dioxide
- Use renewable fuels
Burn different fuels?

- Fossil fuels are hydrocarbons – compounds containing carbon and hydrogen
- When we burn hydrogen, we make water
- When we burn carbon, we make carbon dioxide
  - Coal: 1 hydrogen for each carbon
  - Oil: 2 hydrogens for each carbon
  - Natural gas: 4 hydrogens for each carbon
  - Hydrogen*: No carbon (at least directly)
  - Nuclear: No carbon (at least directly)

Sequester the carbon dioxide?

- In oceans
- In salt domes
- In oil reservoirs
- In coal beds
- React in geological media

Plant trees?

- Vegetation takes up carbon dioxide
- Feedbacks include changes to soil
- Decomposition of plant matter
- Changing the reflectivity of the surface
- Example: In one year, 4 square meters of temperate forest takes up the amount of carbon in one gallon of gasoline. Driving 12,500 miles a year consumes half an acre – more if we have grassland, less if we have rainforest

At current driving rates the US would need to reforest about half of the country’s cropland to offset passenger vehicles.

What is the likely cost?

IPCC
What is the likely cost?

- $60-200 per ton carbon marginal cost
- A barrel of oil contains about 200 pounds of carbon, so a ton of carbon is about 10 barrels of oil (~$600-700 per ton), but a ton of coal from the Powder River Basin is about $10 per ton
How much would it cost to reduce all of the fossil fuel carbon emissions?

Global engineering?

- Fertilize the ocean?
- Inject sulfur high into the atmosphere?
- Satellite sun screens?
Adaptation possibilities include...

- Changing cropping patterns
- Developing heat-, drought-, and salt-resistant crop varieties
- Strengthening public-health & environmental-engineering defenses against tropical diseases
- Building new water projects for flood control & drought management
- Building dikes and storm-surge barriers against sea-level rise
- Avoiding further development on flood plains & near sea level

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References and additional information

- [http://www.ipcc.ch/](http://www.ipcc.ch/)
- [http://www.windows.ucar.edu/tour/link=/earth/Water/co2_cycle.html&edu=high](http://www.windows.ucar.edu/tour/link=/earth/Water/co2_cycle.html&edu=high)
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