Announcements

- Friday (Feb 28):
  - Option 1: Abstract #2 due
  - Option 2: First draft due
  - glacial theory test?

MONDAY, 24 FEB, 4:00, 425 OSB
--SPECIAL TERRESTRIAL CARBON SEMINAR - Dr David Schimel, NCAR, "Human impacts on the global carbon cycle: Unraveling the mechanisms with models and observations,"
Sponsored by Program on Climate Change.

TUESDAY, 25 February
-- WX discussion, 12:30, 310 ATG

WEDNESDAY, 26 FEB, 3:40, 14 OTB.
--OCEANOGRAPHY SEMINAR - Dr Don Brownlee, Astronomy, "Life and death of planet Earth: How the new science of astrobiology charts the ultimate fate of our world,"
Coffee and cookies will be available at 3:30.

THURSDAY, 27 FEB, 4:00, 425 OSB
--FEBRUARY SOS MEETING - Dr Paul Quay, Oceanography, "Future climate change: How it involves the CO2 cycle and model predictions of future temperature change,"
Pizza and the official SOS meeting to follow directly afterward.
Concentration of Carbon Dioxide and Methane Have Risen Greatly Since Pre-Industrial Times

Carbon dioxide: 33% rise
Methane: 100% rise
The last 160,000 years (from ice cores) and the next 100 years
Variations of the Earth’s surface temperature; 1000 to 2100
Impact of stabilising emissions versus stabilising concentrations of CO$_2$

- **CO$_2$ emissions (Giga tonnes C per year)**
  - Constant CO$_2$ emissions at 2000 level
  - Emissions path to stabilise CO$_2$ concentration at 550 ppm

- **CO$_2$ concentration (ppm)**
  - Atmospheric CO$_2$ concentrations

- **Temperature change (°C)**
  - Temperature response
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Friday will be a review session with Amy

Orbital parameter test?
Carbon cycle talk yesterday...

Extra credit: Chap 13, Critical Thinking Problems, 1-3 [5 pts each]

TODAY: WX discussion, here, 12:30

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Tues Feb 25: Outline

Today: Carbon budget at present
   - temporary vs permanent transfers
   - "the missing sink"
   - Forest Policy (executive order)
   - Homebuilding as a CO2 reduction scheme

Wed: Carbon fate
    Control strategies

Thurs: Climate forcings
    Climate sensitivity
    Climate modeling and regional effects

Friday: review session with Amy
In-class make-up for Friday, 21 Feb:

http://www.atmos.washington.edu/2003Q1/211

Go to class web site, then "Lectures", then "week7", then slide 15 which shows temperatures of N Hem. for last 1000 yrs. Gray band is the measurement uncertainty.

Answer these questions:

1. Find the maximum 50-yr temperature change in the pre-industrial period. (a) When did it occur? (b) By how much did the temperature change, based on the running average (thick black line)? (c) What is the maximum amount of change that is compatible with the temperature measurements including their uncertainty?

2. What is the amount of change during the industrial period? Is it larger than your answer to 1b and 1c, above?

3. Based on your answers to 2, would you say that global warming due to human activity has been detected? Explain.
- carbon cycle embraces huge range of time scales
  > geological processes (slow)
  > biophysical processes (active)
    atmosphere<>oceans<>land<>biota

- operational definition of "permanent": 10,000 yrs or more
  > burning fossil fuel is "permanent" addition of carbon to the active, biophysical reservoirs
  > reforestation is a temporary sink, not permanent removal
- **terrestrial sink** for large fraction of anthropogenic emissions

> deduced by **inverse modeling** (reasoning from effect to cause)

> occurring in hilly and mountainous terrain of N. America and Eurasia (where not many people live)

> this sink varies greatly from year to year

> variation correlated to ENSO cycle - tropical droughts causes big fires and release of carbon to atmosphere

> storing carbon in forests is almost certainly not stable; hotter, dryer conditions under global warming will very likely cause it to be released
Current Carbon Budget (Gton, C/yr)

Sources:
- Fossil fuel burning (Fig 13-2): 6.0
- Tropical deforestation: 1.5
- Total: 7.5

Accumulating in atmosphere: 3.0

So, total sinks must be 7.5 - 3.0 = 4.5

Sinks:
- Oceans: 2.0
- N. Hemi. forests: 0.5
- Total: 2.5

Missing sink (text p. 257): 4.5 - 2.0 = ~2
Missing sink

> 7.5 Gtons added to atmosphere each year
> We can only account for 5.5 of this

Where is the other 2 Gtons going?

Inverse modeling points to N. Hemisphere land, especially forests.

That is, removal and storage by terrestrial photosynthesis appears to be much larger (2.5 vs 0.5 Gtons/yr) than what is derived from direct estimates, based on studying forest growth rates.

- CO2 fertilization
- fire suppression
- nitrate fertilization

Will this sink continue to operate?
Is this a stable way to store carbon?

"Almost certainly not." [David Schimel, NCAR]
We need to establish a clear "forest policy".

For your own safety and well-being (especially in this class) please remember it!

"Mature forests are a reservoir of carbon, not a sink."
"Clearing of forests… results in a substantial release of carbon into the atmosphere, both from the trees themselves and from the soil beneath them." [p. 256]

"Curiously, however, the biosphere as a whole is currently acting as a net sink for carbon." [p. 256]

- "sink"?

"Deforestation of North America during the 19th century, the pioneer effect, was responsible for most of the rise in atmospheric CO2 between 1800 and 1850." [p 256]

But now, especially on mountainous regions, "the forests are regrowing and are probably contributing to the Northern Hemisphere CO2 sink." [p 256-7]
Forest Policy:
"Mature forests are a reservoir of carbon, not a source or sink."

Text:
"Most of these [Northern Hemisphere] forests will not reach maturity for another century or more, so this sink should remain active for some time into the future." [p. 256]

Earth in the Balance by Al Gore:
"By rapidly destroying the [tropical] forests..., we are damaging [the earth's] ability to remove excess CO2." [p. 293]

POLICY VIOLATION !!!
Forest Policy:
"Mature forests are a reservoir of carbon, not a sink."

Consider three land owners, each with a mature forest containing 100 units of carbon locked up in the biomass of the trees.

#1: leaves it alone

#2: burns it down and starts a farm

#3: logs it and replants with trees

Which one removes or adds the most CO2 to the atmosphere? (a) Immediate effect? (b) after 100 years?
Announcements

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Friday will be a review session with Amy

WX discussion... ???

Extra credit: Chap 13, Critical Thinking Problems, 1-3 [5 pts each]

TODAY's news: http://www.nap.edu/books/0309088658/html/

TODAY, 26 FEB, 3:40, 14 OTB.
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THURSDAY, 27 FEB, 4:00, 425 OSB
--FEBRUARY SOS MEETING - Dr Paul Quay, Oceanography, "Future climate change: How it involves the CO2 cycle and model predictions of future temperature change,"

WEDNESDAY, 5 MAR, 3:40, 14 OTB
--OCEANOGRAPHY SEMINAR - Dr Farooq Azam, Scripps, "Microbial regulation of oceanic carbon fluxes,"
Coffee and cookies will be available at 3:30.
Wed Feb 26: Outline

CARBON CYCLE and the Human Perturbation

Yesterday… Overall carbon budget
  Storage in forests and soils
    - not well understood ("missing sink")
    - not likely to be sustainable

Today… OCEANS
  response times:  8 yrs to 1000 yrs (bracket the problem)
  mechanisms:
    physical/chemical
      limited by carbonate ion availability
      limited by mixing with deep ocean
      involves dissolving seafloor calcium carbonate
    biological pump (more active?)
    silicate weathering
      permanent sink, but slow

CO₂ FORECASTING and CONTROL STRATEGIES
Over-arching question:
As humans burn up the fossil fuel reserves (4000-6000 Mtons), how will the earth system process all that CO2 added to the atmosphere?

Note: 1 Megaton(C) = $10^9$ metric tons(C) = $10^{15}$ g(C)

1) Photosynthesis is the fastest process for removing CO2 from the atmosphere. But it has little or no net effect.
   > temporary storage in N. Hem. forests occurring presently
     - this is not well understood (thus, called the "missing sink")
     - it is probably not sustainable
     - no significant, long-term sink is available through land biota
   > "biological pump" in oceans moves CO2 to deep ocean
     - see text 7:136 and 11:221
     - Will climate change speed or slow the pump? (not known)
     - Could pump be enhanced as CO2 removal method? (not known)
2) Dissolving CO$_2$ into the ocean

> time scales:

- ocean-atmosphere (OA): $\tau_{OA} = 760 \text{Gton}/(90 \text{Gton/yr}) = \sim 8$ yrs
- surface-deep ocean (SD): $\tau_{SD} = \sim 1000$ yrs

excess CO$_2$ (from fossil fuel emissions) remains in the atmosphere for time scales between these limits

- initially, $\sim 8$ yrs, eventually, due to limiting factors, $\sim 1000$ yrs
- (presently, the effective atmosphere residence time is $\sim 60$ yrs)

> mixing limitation

- atmosphere is only in contact with surface ocean
- mixing throughout entire ocean takes around 1000 yrs

> chemical limitation

- removal of CO$_2$ into the oceans is limited by the availability of carbonate ion, CO$_3^{2-}$ (or other buffering agent)
- surface ocean has only small amount of carbonate ion, thus mixing with the deep ocean is required and this is slow

(see text p.258, box "The Chemistry of CO2 Uptake")
3) Dissolving carbonate sediments on the ocean floor
   > carbonate ion limitation (again, see Box on p. 258)
   fossil fuel carbon is ~6000 Gton
   carbonate in surface ocean is just 60 Gton, so surface ocean could
   only take up 0.1% of fossil fuel carbon
   carbonate in deep ocean is about 1500 Gton, so entire ocean
   could still only take up only about 25% of fossil fuel carbon
   thus, to take up all the carbon requires an additional source
   of carbonate ion
   > dissolving calcium carbonate sediments at the ocean floor would
   provide the needed carbonate
   > requires bringing high-CO2 (relatively acidic) water into contact with
   ocean bottom - again, very slow

NOTE: Even after all fossil fuel carbon is dissolved in the ocean by this
mechanism, it is still not permanently "gone". It now exists (mainly)
as bicarbonate ion in the ocean and could potentially be re-emitted
to the atmosphere if chemical conditions change.
4) Weathering of silicate rocks
   > The carbonate-silicate cycle (7:147-148) constitutes a permanent removal of fossil-fuel carbon back into the geological reservoir
   > Of course, this takes millions of years

5) Putting it all together (box on p.261, "Long-term CO2 projections")
   > assume we continue along our present course and burn all available fossil fuels over the next couple centuries
   > CO2 would peak at about 8 times the pre-industrial value
   > CO2 would remain massively perturbed (more than triple pre-industrial) for the next several thousand years
   > CO2 would remain significantly perturbed (well above pre-industrial value) for the next million years
   > elevated CO2 might prevent glaciations over the next several glacial cycles (potentially, a nice benefit)
   > [Note: other theories suggest that CO2 increases may trigger an ice-age within the next century or so]
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  - Option 2: First draft due
Tomorrow will be a review session with Amy

Extra credit:
1) Chap 13, Critical Thinking Problems, 1-3 [5 pts each]
2) http://www.nap.edu/books/0309088658/html/
   Planning Climate and Global Change Research: A Review of the Draft
   U.S. Climate Change Science Program Strategic Plan (2003)

Brownlee seminar????

TODAY, 27 FEB, 4:00, 425 OSB
--FEBRUARY SOS MEETING - Dr Paul Quay, Oceanography, "Future climate
change: How it involves the CO2 cycle and model predictions of future
temperature change,"

NEXT WEEK:
WEDNESDAY, 5 MAR, 3:40, 14 OTB
--OCEANOGRAPHY SEMINAR - Dr Farooq Azam, Scripps, "Microbial regulation
of oceanic carbon fluxes,"
  Coffee and cookies will be available at 3:30.
**Week 9, March 3-7: The Great Global Warming Debate**

<table>
<thead>
<tr>
<th><strong>approximate schedule...</strong></th>
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<tr>
<td><strong>Monday</strong></td>
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<td><strong>Tues</strong></td>
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**Homework for the week:**
- for each day, write a one-paragraph summary [2 pts] and a set of questions and/or comments [2 pts]
- 4 pts max per day, 16 pts max for the week
- turn in by Monday, March 10
Don Brownlee: End of Earth
book: The Life and Death of Planet Earth

Motivation:
Search for life and "Earth-like" planets. What is "Earth-like"?

What's to come (it ain't pretty, but it's pretty spectacular)
- glaciations ("short-term")
- new super-continent (250 million yrs)
- solar brightening takes Earth out of habitable zone in ~1 billion yrs. Why? No CO2 then no oceans.
- as Earth warms, silicate weathering gets more efficient and draws down CO2. Below ~10ppm, all plant life and photosynthesis stops. Starvation.
- warmer planet causes water to be lost to space. No oceans. Earth becomes a giant salt-flat.
- at about 8 billion yrs, sun flares violently and Earth fries.

Overall
- sun goes for ~12 billion years; higher life on Earth is possible from about 4 to 5 (presently, 4.6)
Words of wisdom for scientists

Never say, “oops!”. Always say, “Ah, interesting!”

If you can’t beat your computer at chess, try kickboxing.
Global warming overview / review

Human perturbation of the Carbon Cycle (13:254-262)
> fundamental basis for "global warming" concern
  - it all began with observation that CO2 is increasing
  - natural climate changes in past linked to CO2
> knowledge of carbon cycle is critical to control strategies
> atmosphere, ocean, biota are all involved
> plays out over a very, very long time scale

Other forcing agents (13:262-264)
> other greenhouse gases
> aerosols (mostly negative forcings)
> short-lived warming agents: soot and methane
Global warming overview / review

**Climate Response** (13:262-273)
- climate modeling
- lag-time (thermal inertial) and climate sensitivity (feedbacks)
- regional forecasts (what we really care about)
- sea level changes
- ecosystem changes

**Testing the theory** (not in text)
- detection and attribution
  - has warming been detected?
  - is it beyond natural variability?
  - does it fit the pattern predicted by climate models?
- counter-arguments (the skeptics)
Industrial-era forcings of climate

Note: short-lived positive forcing agents
Vulnerability to Sea-Level Changes
Ice-sheet calving, Antarctica
Testing the Global Warming Theory

The current paradigm

Detection:
Has it warmed? Is the warming "unnatural"?
(i.e. beyond natural variability)

Attribution:
Can we explain the warming in terms of anthropogenic causes?

Projection:
For various emission scenarios (policy options)
what further climate changes will occur?

Control requirements:
Reduce CO2 emissions dramatically in order to stabilize CO2 concentration and thereby "prevent dangerous interference" with the climate system.
Variations of the Earth’s surface temperature for the past 1,000 years

Detection

Data from thermometers (red) and from tree rings, corals, ice cores and historical records (blue).
**Attribution:** Yes, it has warmed. But does the pattern of warming fit the theory of forcing by GHGs?
Simulated annual global mean surface temperatures

(a) Natural
(b) Anthropogenic
(c) All forcings

Figure 4: Simulating the Earth’s temperature variations, and comparing the results to measured changes, can provide insight into the underlying causes of the major changes.

Source: IPCC 2001, Summary for Policymakers, Fig 4
Projection
But wait... Is there a problem with the current paradigm?
IPCC, 2001: Forcing projection...

Figure 19: Simple model results: estimated historical anthropogenic radiative forcing up to the year 2000 followed by radiative forcing for the six illustrative SRES scenarios. The shading shows the envelope of forcing that encompasses the full set of thirty five SRES scenarios. The method of calculation closely follows that explained in the chapters. The values are based on the radiative forcing for a doubling of CO₂ from seven AOGCMs. The IS92a, IS92c, and IS92e forcing is also shown following the same method of calculation. [Based on Figure 9.13a]
Industrial-era forcings of climate

What's missing from this analysis ???

*Figure 3: Many external factors force climate change.*
TOTAL Industrial-era forcing (with uncertainty)

What is troubling about this plot for the global warming theory?

Boucher and Haywood, 2001 (narrowest) result
IPCC, 2001: Forcing projection…

with uncertainty in current forcing

Figure 19: Simple model results: estimated historical anthropogenic radiative forcing up to the year 2000 followed by radiative forcing for the six illustrative SRES scenarios. The shading shows the envelope of forcing that encompasses the full set of thirty five SRES scenarios. The method of calculation closely follows that explained in the chapters. The values are based on the radiative forcing for a doubling of CO$_2$ from seven AOGCMs. The IS92a, IS92c, and IS92e forcing is also shown following the same method of calculation. [Based on Figure 9.13a]
Conclusions re Climate Forcing Uncertainty

1. It is possible (though not likely) that total industrial-era forcing of climate has been small or even negative.

2. If so, then our current understanding of past climate changes is seriously flawed. Something is wrong with the climate models.

3. However, a strong, positive forcing is coming in the near future (if it isn't here already). This is because CO2 is building up in the atmosphere and takes centuries to go away.

4. How does the climate respond to a strong, positive forcing? We had better figure this out (and decide if we like it).

5. Research to reduce the huge uncertainties in climate forcing should be a high priority. This is our most effective way to constrain and improve climate models.

6. Decision-making cannot wait for research to be complete. We have to learn to make decisions in the face of uncertainty.