TOPIC # 16
GLOBAL WARMING & ANTHROPOGENIC FORCING

TODAY’s 3 KEY CONCEPTS:

- Carbon / Forests / Deforestation
- Computer Model Evidence for Anthropogenic GW Forcing
- Tying it all together w/ RADIATIVE FORCING GRAPHS
Where are we now?

GOAL: Enhanced Understanding of Global Change Science, How It Operates, & What It Means To Me Personally

The Science of Global Change

Understanding Climate Science
- Building on my attained knowledge as semester progresses
- IPCC & peer review
- “Hands on” assignments
- On being a scientist

Climate Science Literacy
- Past & Present Observations
- Future projections
- Models

Physical Science Foundation
- Global Climate processes
- (matter & energy, electromagnetism, laws of thermodynamics & of motion)

How it links to my life
- “Thinking deeply” about course material as the semester progresses
- “Dire Predictions”
- Sustainability segments
- Possible solutions
- GC-Sawy Consumer & other assignments
- Personal awareness

How science is done
- “Hands on” assignments
- Tree Rings!
TOPIC # 16
GLOBAL WARMING & ANTHROPOGENIC FORCING

Part A - CARBON RESERVOIRS & FLUXES: Natural vs. Anthropogenically Enhanced

(or How does all that “C” get into the atmosphere??)

Class Notes pp 83
“I'm extremely concerned that the Earth has a chronic disease, and that chronic disease is CO₂ syndrome, it’s something that's creeping on us.

We have plenty of fossil fuel so it's going to continue to get worse, and it's going to affect every aspect of life on the planet, from food production to drinking water to coastlines to the plight of the poor in the tropics, and so forth.”

~Wally Broecker, Paleoclimatologist
CO₂ & CARBON RESERVOIRS

CO₂ in the atmosphere is one place CARBON resides in the Earth-Atmosphere system.

Where else is carbon located and how does it move (flux) from one reservoir to another?
Major Reservoirs of Carbon at or near the Earth's surface

Gt (C) = gigaton carbon

- Atmospheric CH₄ 10 Gt(C)
- Living biomass 610 Gt(C)
- Atmospheric CO₂ 760 Gt(C)
- Oceanic dissolved CO₂ 740 Gt(C)
- Oceanic carbonate ion 1300 Gt(C)
- Organic carbon in soils/sediments 1600 Gt(C)
- Fossil fuels 4200 Gt(C)
- Oceanic bicarbonate ion 37,000 Gt(C)
- Organic carbon in sedimentary rocks 10,000,000 Gt(C)
- Limestone in sedimentary rocks 40,000,000 Gt(C)
Amount of carbon is expressed in units of Gtons (gigatons) of carbon: GT(C)

Amounts represent the MASS OF CARBON ATOMS ONLY, not other atoms to which C is attached (e.g. CO$_2$)
One gigaton is . . .

• Greater than the mass of all the humans on the planet
Major Reservoirs of Carbon at or near the Earth’s surface

Gt (C) = gigaton carbon

- Atmospheric CH₄: 10 Gt(C)
- Living biomass: 610 Gt(C)
- Atmospheric CO₂: 760 Gt(C)
- Oceanic dissolved CO₂: 740 Gt(C)
- Oceanic carbonate ion: 1300 Gt(C)
- Organic carbon in soils/sediments: 1600 Gt(C)
- Fossil fuels: 4200 Gt(C)
- Oceanic bicarbonate ion: 37,000 Gt(C)
- Organic carbon in sedimentary rocks: 10,000,000 Gt(C)
- Limestone in sedimentary rocks: 40,000,000 Gt(C)
Major Carbon Fluxes IN & OUT of the atmosphere

Vegetation 610
Soils and detritus 1580
2190

Global net primary production and respiration

Volcanism

Atmosphere 760

(Contributes to GH effect)

Surface ocean 1020

Marine biota 3

Dissolved organic carbon <700

Intermediate and deep ocean 38,100

Surface sediment 150

Carbonate rocks $4 \times 10^7$

In Gtons

Fossil fuels 4000–6000

90

62.5

60

62.5

0.06

0.06

1.5

0.5

92.5

519
Biomass = the total mass of organic matter in living organisms in a particular reservoir.

The total amount of carbon in the LIVING BIOMASS = 610 Gt

The total amount of carbon in the ATMOSPHERIC CARBON RESERVOIR = 770 Gt (760 Gt is in CO₂ gas)

(Definition on p 84)
How does CARBON “flux” FROM the biosphere INTO the atmosphere?

1. Trees **take in** carbon dioxide during **photosynthesis**.

2. Trees **release** carbon dioxide during **photosynthesis**.

3. Trees **release** carbon dioxide into the atmosphere during **respiration**.
NATURAL FLUXES INTO & OUT OF THE ATMOSPHERIC CARBON RESERVOIR related to BIOMASS = respiration & photosynthesis

**FLUX from PLANT INTO ATMOSPHERE:**

Respiration: \[ \text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}. \]

(carbohydrate oxygen carbon dioxide water)

**FLUX OUT OF ATMOSPHERE into PLANT:**

Photosynthesis: \[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2. \]

(Primary Production) carbon dioxide water carbohydrate oxygen gas
The Atmospheric Carbon Reservoir

showing inflows and outflows (fluxes)

Inflow: 60 Gton(C)/yr
Respiration and decomposition

Atmospheric CO₂
760 Gton(C)

Outflow: 60 Gton(C)/yr
Photosynthesis
... leads to a **STEADY STATE**

In the atmospheric CO$_2$ “reservoir”

Where have we a **STEADY STATE** before?
**SOME DEFINITIONS:**

Respiration =
- biochemical process
- living organisms take up $O_2$, consume organic matter,
- RELEASE $CO_2$, heat, & $H_2O$

Decomposition =
- breakdown of organic matter
- by bacteria and fungi,
- RELEASES $CO_2$ to the atmosphere
Photosynthesis =

 manufacture of carbohydrates & $O_2$
 from $CO_2$ and $H_2O$
in the presence of chlorophyll
sunlight as the energy source.

Oxygen is released in the process.

Solar energy $\rightarrow$ chemical energy

(Part of chemical energy is stored in living tissues &
used by other organisms (consumers) that cannot use
solar energy directly.)
Photosynthesis

Respiration, Burning of Biomass, & Decomposition
WHAT ABOUT THOSE ZIG-ZAGS IN THE KEELING CURVE?

Mauna Loa Observatory, Hawaii
Monthly Average Carbon Dioxide Concentration
Data from Scripps CO₂ Program   Last updated October 2009

(p 84)
CLOSE-UP VIEW:

Seasonal fluctuations in CO₂ (ppm)

Year


Trend due to anthropogenic increases has been removed.
Oscillations represent seasonal fluctuations driven by the balance between respiration & photosynthesis (dominated by Northern Hemisphere forests)
The largest forested areas are in the Northern Hemisphere.
“Breathing” -- ANIMALS vs. PLANTS

Respiration

\[ \text{O}_2 \rightarrow \text{CO}_2 \]

Photosynthesis

\[ \text{CO}_2 \rightarrow \text{O}_2 \]

Respiration & Decomposition

\[ \text{O}_2 \rightarrow \text{CO}_2 \]
Tick marks are at January of each year:

- **Photosynthesis > Respiration**
  (CO₂ goes down in SUMMER as forests “breathe in” more CO₂)

- **Respiration > Photosynthesis**
  (CO₂ levels rise in FALL/WINTER as forests “breathe out” more CO₂)

- **Photosynthesis > Respiration**
  (CO₂ goes down in summer)

- **Respiration > Photosynthesis**
  (CO₂ levels rise in fall/winter)
Mauna Loa Observatory, Hawaii
Monthly Average Carbon Dioxide Concentration

Data from Scripps CO₂ Program   Last updated October 2009

CO₂ Concentration (ppm)

350 ppm CO₂

Year


review
BUT IS ALL THE EXTRA CO$_2$ A BAD THING???

PLANTS DEPEND ON CO$_2$!!!

Photosynthesis: $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2$.  

（Primary Production）

- carbon dioxide
- water
- carbohydrate
- oxygen gas

😊
YOU TUBE!

http://www.youtube.com/watch?v=0_VmMlbWKoo
With rising CO2 levels:

- Some plant species continue to increase photosynthesis (C3)
- Some plants can respond readily to higher CO2 levels
- Others do NOT (C4)
- Other plants can make only limited responses

Hence with Increased CO2:

- Some plant species will be stronger, more prolific, and may overwhelm those less able to benefit

WE ARE ALREADY SEEING POLLEN INCREASES FROM RAGWEED & OTHER PLANTS

And . . . there may be consequences we don't yet know !!
Greater atmospheric CO₂ concentration
→ enhanced photosynthesis (due to “CO₂ Fertilization”)
→ more CO₂ being assimilated by plant from the atmosphere
→ less atmospheric CO₂

What kind of FEEDBACK LOOP?

Negative & self-regulating!

... but the jury is still out on how well this negative feedback loop can counteract HUGE anthropogenic influxes of CO₂
LAND USE CHANGES:
Deforestation practices increase burning & decomposition of large areas of forest
CARBON DIOXIDE: Trends

Data from ice cores
Time Series Graph comparison of two ways CARBON gets into atmosphere:

http://www.whrc.org/science/carbon/carbon.htm

- Combustion of Fossil Fuels
- Land Use Change

Annual Emissions to the Atmosphere (Pg C)

1850 1870 1890 1910 1930 1950 1970 1990

p 85
“Imagine if you took all the cars, trucks, planes, trains and ships in the world and added up their exhaust every year. The amount of carbon dioxide, or CO2, all those cars, trucks, planes, trains and ships collectively emit into the atmosphere is actually less than the carbon emissions every year that result from the chopping down and clearing of tropical forests in places like Brazil, Indonesia and the Congo. “

“We are now losing a tropical forest the size of New York State every year, and the carbon that releases into the atmosphere now accounts for roughly 17 percent of all global emissions contributing to climate change. “

Much of increase in China due to **AFFORESTATION** = planting new forests in places where preceding vegetation or land use was not a forest.

**Highest rates of DEFORESTATION** in red

Data Source: UN / FAO Global Forest Assessment Report

Figure on p 175 in *Dire Predictions*
Forest carbon emissions INTO the atmosphere (+)

- Forest uptake of carbon OUT OF the atmosphere (-)

Since ~1950, USA & EUROPE have become net carbon SINKS (rather than sources) due to reforestation and palm oil plantations!

from pp 174-175 in *Dire Predictions*
Some good news?...

Amazon deforestation at record low

By Richard Reynolds

Posted Fri Nov 13, 2009 2:35pm AEDT

Brazil has announced that deforestation in the Amazon basin has fallen to its lowest level since records began 21 years ago.

The report comes from Brazil’s space agency, which monitors deforestation with satellites.

The organisation is considered credible and often contradicts the Brazilian Government when it makes outlandish claims about deforestation.

The agency claims that in the year to August, only 7,000 square kilometres of forest has been cut down.

That level is a 45 per cent reduction on the previous year.

Brazilian President Lula da Silva has promised a reduction in deforestation and is using that to pressure the leaders of major nations to reduce greenhouse gas emissions.

This comes ahead of the UN conference on climate change next month in Copenhagen.

TOPIC # 16, PART B:
Evidence from Natural Archives
(Covered in class last Thursday)

Class Notes pp 86
TOPIC # 16, PART C: Evidence from Natural vs. Anthropogenic Model Comparisons

Class Notes pp 87
Modeling The Climate System: A Brief Look

[Diagram showing interactions within the climate system including changes in solar inputs, atmospheric composition, terrestrial radiation, human influences, and changes in the cryosphere, hydrosphere, and biosphere.]
MULTIPLE FEEDBACKS
(e.g., snow / ice, water vapor, clouds, etc.)

[Diagram showing feedback loops involving surface temperature, atmospheric H₂O, greenhouse gases, planetary albedo, and snow and ice cover.]

Review
DIFFERENT TYPES OF MODELS:

- Energy Balance Model (EBM)
- Radiative Convective Model (RCM)
- General Circulation Model (GCM)

Increasing complexity
The Development of Climate models, Past, Present and Future

Mid-1970s
Atmosphere
Land surface
Ocean & sea-ice

Mid-1980s
Atmosphere
Land surface
Ocean & sea-ice
Sulphate aerosol

Early 1990s
Atmosphere
Land surface
Ocean & sea-ice
Non-sulphate aerosol

Late 1990s
Atmosphere
Land surface
Ocean & sea-ice
Sulphate aerosol
Non-sulphate aerosol
Carbon cycle

Present day
Atmosphere
Land surface
Ocean & sea-ice
Sulphate aerosol
Non-sulphate aerosol
Carbon cycle

Early 2000s?
Atmosphere
Land surface
Ocean & sea-ice
Sulphate aerosol
Non-sulphate aerosol
Carbon cycle
Dynamic vegetation
Atmospheric chemistry

- Ocean & sea-ice model
- Sulphur cycle model
- Land carbon cycle model
- Ocean carbon cycle model
- Atmospheric chemistry
- Non-sulphate aerosols
- Dynamic vegetation
- Atmospheric chemistry
GCM models compute atmospheric pressure, velocity, density, and water vapor as functions of time for EACH GRID BOX in a latitude-longitude grid covering the entire Earth in the horizontal dimension, and as many as 20 LAYERS(!) of the atmosphere in the vertical dimension.
GCM’s can predict not only HOW MUCH CHANGE IN TEMPERATURE might occur due to an enhanced greenhouse effect but also WHERE the changes are likely to manifest themselves.
All of the calculations are based on physical principles such as the 1st law of thermodynamics and Newton’s 2nd law of motion.

Some models “couple” the ocean and atmosphere for better results.

The models are so complex that they require hundreds of hours of computing time on a supercomputer!
But even such sophisticated models cannot predict processes, such as cloud feedback mechanisms, that occur at scales smaller than a grid box.

Hence the inability to model processes like cloud radiational effects in detail, leads to UNCERTAINTIES and differences in the estimates produced by different GCMs.
However, even with their uncertainties, GCMs can give good results and fairly reliable estimates of the RANGE of EXPECTED CHANGE in the atmosphere (e.g. global temperature increase) due to GHG forcing.
How Good are the Models?

GLOBAL MEAN TEMPERATURE from OBSERVATIONS = black line
Model simulations = yellow lines (58 runs from 14 different models!)
Mean of model runs = red line

Temperature anomaly (°C)

Volcanic eruption years

Santa Maria
Agung
El Chichon
Pinatubo
Modeled Temperature with Natural Forcing Only

PREDICTED/OBSERVED CLIMATE TRENDS
Predicted temperature trends from models, taking into account the impacts of natural forces alone

PREDICTED/OBSERVED CLIMATE TRENDS
Comparison of the average of the model results in graph 1 to actual observations

From Dire Predictions pp 68-69
Modeled Temperature with Natural & Anthropogenic Forcing

PREDICTED/OBSERVED CLIMATE TRENDS
Predicted temperature trends from models taking into account the impacts of both natural and human forces

PREDICTED/OBSERVED CLIMATE TRENDS
Comparison of the average of the model results in graph 3 to actual observations

From Dire Predictions pp 68-69
COMPUTER MODEL “FORCING” EXPERIMENT
1000-year Reconstruction of Northern Hemisphere temperatures
w/ Modeling Results of an Energy Balance Model
Forced in Different Ways

Forced with orbital variations &
volcanic eruptions

Forced with orbital variations,
volcanic eruptions, &
greenhouse gas concentrations

p 87
SEPARATING OUT NATURAL vs. ANTHROPOGENIC FORCING

From SGC-II Ch. 9

(a) Natural
Gray = Model-derived temperatures based on forcing by solar variations and volcanism only
Red = Observed temperatures

(b) Anthropogenic
Gray = Model-derived temperatures based on forcing by human emissions of GHGs and pollution only
Red = Observed temperatures

(c) All forcings
Gray = Model-derived temperatures based on forcing by BOTH natural and anthropogenic factors
Red = Observed temperatures
Regional Model Runs showed the same results!

SOURCE: IPCC 2007 WG-1 Synthesis Report Summary for Policymakers
The Key To It All:

RADIATIVE FORCING OF CLIMATE

Class Notes pp 90
NATURAL FORCING

Solar output variations, sunspots

GHG’s, soot, SO₂

Volcanic eruptions

Surface Albedo Changes

ANTHROPOGENIC FORCING

Fossil Fuel Combustion

Land Use
FORCING = a persistent disturbance of a system

(a longer term disturbance than a perturbation)
Now we will focus on:

**RADIATIVE FORCING**

(linked to Radiation Balance!)

\[ R_{NET} = \downarrow_{SW} + \downarrow_{SW} - \uparrow_{SW} - \downarrow_{LW} + \uparrow_{LW} \]

(expressed in Watts per square meter (Wm\(^{-2}\))

(def) a measure of the influence a factor has in altering the balance of incoming & outgoing energy in the Earth-atmosphere system
RADIATIVE FORCING
(linked to Radiation Balance!)

\[ R_{\text{NET}} = \downarrow_{\text{SW}} + \downarrow_{\text{SW}} - \uparrow_{\text{SW}} - \uparrow_{\text{LW}} + \downarrow_{\text{LW}} \]

It’s an index of the importance of the factor as a potential climate change mechanism!
Curve A or Curve B can move Up or Down due to a radiative forcing in SW or LW

ENERGY BALANCE CHANGES IN THE TROPOSPHERE
Smaller Surplus

Larger Deficit

TROPOSPHERIC COOLING

If incoming energy represented by Curve A is reduced (A curve goes down)

HOW? Albedo increases due to Eruption, Deforestation, Sulfur Aerosols, etc.
If Curve B moves down, the energy flux can be affected. If outgoing energy represented by Curve B is reduced (B curve goes down), the system will require a larger surplus to keep more LW in.

**HOW?**
GHG's increase & keep more LW in!
If incoming energy represented by Curve A is increased (A curve goes up) and/or solar input increases, Albedo decreases.
If outgoing energy represented by Curve B is increased (B curve goes up)

HOW?
GHG's decrease & allow more LW out!

TROPOSPHERIC COOLING

If CURVE B moves up:

LW

Larger Deficit

Smaller Surplus
Radiative forcing of climate between 1750 and 2005

SOURCE: IPCC 2007 WG-1 Synthesis Report Summary for Policymakers
The figure shows that the forcing mechanism that is \textit{BEST} understood by scientists is also the one that leads to the greatest climatic impact.

1. True
2. False
If the forcing is **NEGATIVE** (to left of line) it means that an increase in that gas or factor contributes to **COOLING** in the troposphere.

If the forcing is **POSITIVE** (to right of line) it means that an increase in that gas or factor contributes to **WARMING** in the troposphere.
ALL of the forcing mechanisms shown here (X, Y, & Z) are linked to anthropogenic activity in some way: **1. TRUE**  **2. FALSE**
The figure shows that forcing mechanism Z (Land-use as indicated by albedo) leads to COOLING.

... The reason for this is that cooling occurs when surface albedo increases and hence MORE energy is absorbed.

TRUE or FALSE?

LESS energy is absorbed!
A COMMON MISCONCEPTION!

ONE MORE THING, SIR... HAVE YOU CONSIDERED HOW MUCH OF THE FLOOD-PRONE OCEANFRONT PROPERTY BELONGS TO MEMBERS OF YOUR PARTY?

GLOBAL WARMING

OZONE THINNER

SUN'S RAYS STRONGER

ICECAPS MELT

SEA LEVELS RISE

POLITICAL SCIENCE
OZONE’S DUAL PERSONALITY!
According to the figure which forcing mechanism has a GREATER influence on global temperature?

- Stratospheric OZONE
- Tropospheric OZONE

The OZONE HOLE IS NOT THE MAIN CAUSE FOR GLOBAL WARMING!
FAQ 2.1

How do Human Activities Contribute to Climate Change and How do They Compare with Natural Influences?

Climate Change 2007 - IPCC The Physical Science Basis Working Group 1 Report
Study hard for Test #4!

See you on Thursday . . . .