Carbon, climate, and forests:
How the land links the past, present, and future

Nov 2012
Prof. Ankur Desai
University of Wisconsin-Madison
Acknowledge

• My lab: Jonathan Thom (scientist), Malgorzata Golub (PhD), Ke Xu (PhD), Tommy Jasmin (MS/scientist), Sean DuBois (MS), Dong Hua (postdoc), Ben Sulman (postdoc), Justin Bagley (postdoc)

• Collaborators: Penn State, U Illinois, U Minnesota, Boston U, CalTech, NOAA

• Funding: NSF, DOE

• Hosts: Sarah Paquette, Cody Martin, CMN and SDI!
Willow Creek - NetCam SC IR - Thu Sep 20 11:31:17 2012
Temperature: 36.0 °C internal, 9.0 °C outside
RH: 0%, Pressure: 944.0 millibars
Exposure: 400
Human population increase (in red) from 10,000 BCE to 2000 CE

• Source: UCAR Quarterly, Summer 2007
CARBON
Atmospheric CO\textsubscript{2} at Mauna Loa Observatory

Scripps Institution of Oceanography
NOAA Earth System Research Laboratory

PARTS PER MILLION

YEAR


320 340 360 380 400

October 2012
Let’s Play a Game!

- Red = 1 GTC of fossil fuel carbon
- Blue = 10 GTC non-fossil carbon
- White = 100 GTC Carbon
- Dark Blue = 1000 GTC Carbon
- 1 GTC = Gigaton of Carbon = Billion metric tons = 2,200,000,000,000 pounds
Global Carbon Cycle

Atmospheric CO₂
750 (@360 ppm)
(+ 3.2 per year)

Stock = Billion metric tons
Flow = Billion metric tons per year

Vegetation 610
Soils 1580
Ocean 39000

Fossil fuels
+7.9 per year

6.3
1.6 Land-use
1.1 Plant synthesis
50 Plant respiration
60 Soil respiration

92
90

1.4 Net flux
1.7 Net flux
Where Is The Carbon Going?

Houghton et al. (2007)

Ecosystem Carbon Sink
CLIMATE
Figure TS.20. (Top) Records of Northern Hemisphere temperature variation during the last 1300 years with 12 reconstructions using multiple climate proxy records shown in colour and instrumental records shown in black. (Middle and Bottom) Locations of temperature-sensitive proxy records with data back to AD 1000 and AD 1500 (tree rings: brown triangles; boreholes: black circles; ice core/ice boreholes: blue stars; other records including low-resolution records: purple squares). Data sources are given in Table 6.1, Figure 6.10 and are discussed in Chapter 6.
Technical Summary

Chemically stable and persist in the atmosphere over time scales of a decade to centuries or longer, so that their emission has a long-term influence on climate. Because these gases are long lived, they become well mixed throughout the atmosphere much faster than they are removed and their global concentrations can be accurately estimated from data at a few locations. Carbon dioxide does not have a specific lifetime because it is continuously cycled between the atmosphere, oceans and land biosphere and its net removal from the atmosphere involves a range of processes with different time scales.

Short-lived gases (e.g., sulphur dioxide and carbon monoxide) are chemically reactive and generally removed by natural oxidation processes in the atmosphere, by removal at the surface or by washout in precipitation; their concentrations are hence highly variable. Ozone is a significant greenhouse gas that is formed and destroyed by chemical reactions involving other species in the atmosphere. In the troposphere, the human influence on ozone occurs primarily through changes in precursor gases that lead to its formation, whereas in the stratosphere, the human influence has been primarily through changes in ozone removal rates caused by chlorofluorocarbons (CFCs) and other ozone-depleting substances.

Short-lived gases (e.g., sulphur dioxide and carbon monoxide) are chemically reactive and generally removed by natural oxidation processes in the atmosphere, by removal at the surface or by washout in precipitation; their concentrations are hence highly variable. Ozone is a significant greenhouse gas that is formed and destroyed by chemical reactions involving other species in the atmosphere. In the troposphere, the human influence on ozone occurs primarily through changes in precursor gases that lead to its formation, whereas in the stratosphere, the human influence has been primarily through changes in ozone removal rates caused by chlorofluorocarbons (CFCs) and other ozone-depleting substances.

Current concentrations of atmospheric CO$_2$ and CH$_4$ far exceed pre-industrial values found in polar ice core records of atmospheric composition dating back 650,000 years. Multiple lines of evidence confirm that the post-industrial rise in these gases does not stem from natural mechanisms (see Figure TS.1 and Figure TS.2). {2.3, 6.3–6.5, FAQ 7.1}

The total radiative forcing of the Earth's climate due to increases in the concentrations of the LLGHGs CO$_2$, CH$_4$ and N$_2$O, and very likely the rate of increase in the total forcing due to these gases over the period since 1750, are unprecedented in more than 10,000 years (Figure TS.2). It is very likely that the sustained rate of increase in the combined radiative forcing from these greenhouse gases of about +1 W m$^{-2}$ over the past four decades is at least six times faster than at any time during the two millennia before the Industrial Era, the period for which ice core data have the required temporal resolution. The radiative forcing due to these LLGHGs has the highest level of confidence of any forcing agent. {2.3, 6.4}
July 2012

- Report added new indicators to better understand changes in the global climate
- Same bottom line conclusion – climate continues to change

State of the Climate in 2011

- La Niña in the eastern equatorial Pacific kept global surface temperatures cooler during the year compared with the record warmth of 2010, but still remained above the average of the past 30 years.

Long-term trend:
- Temperatures at the Earth’s surface and lower atmosphere continue to warm, while the stratosphere continues to cool.

- Sea ice extent was 2nd smallest since the satellite era began.
- Old ice (4–5 years) reached record low: 81% below average.

- Greenland ice sheet: Above average air temperatures and declining albedo (reflectivity) caused extreme melting and mass loss in 2011.

- March: when maximum ice extent occurs
- September: when minimum ice extent occurs

- Globally averaged carbon dioxide concentrations in the atmosphere surpassed 390 parts per million for the first time. Four data sets show global surface temperatures continue to rise; temperature has increased at a rate of about 0.31 °F per decade since 1980.
Summary for Policymakers

Geographical pattern of surface warming

Figure SPM.6. Projected surface temperature changes for the late 21st century (2090-2099). The map shows the multi-AOGCM average projection for the A1B SRES scenario. Temperatures are relative to the period 1980-1999. {Figure 3.2}

Some systems, sectors and regions are likely to be especially affected by climate change.

Systems and sectors:
- particular ecosystems: terrestrial: tundra, boreal forest and mountain regions because of sensitivity to warming; mediterranean-type ecosystems because of reduction in rainfall; and tropical rainforests where precipitation declines
- coastal: mangroves and salt marshes, due to multiple stresses
- marine: coral reefs due to multiple stresses; the sea ice biome because of sensitivity to warming
- water resources in some dry regions at mid-latitudes and in the dry tropics, due to changes in rainfall and evapotranspiration, and in areas dependent on snow and ice melt
- agriculture in low latitudes, due to reduced water availability
- low-lying coastal systems, due to threat of sea level rise and increased risk from extreme weather events
- human health in populations with low adaptive capacity.

Regions:
- the Arctic, because of the impacts of high rates of projected warming on natural systems and human communities
- Africa, because of low adaptive capacity and projected climate change impacts
- small islands, where there is high exposure of population and infrastructure to projected climate change impacts
- Asian and African megadeltas, due to large populations and high exposure to sea level rise, storm surges and river flooding.

Within other areas, even those with high incomes, some people (such as the poor, young children and the elderly) can be particularly at risk, and also some areas and some activities.

Ocean acidification

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units. Increasing atmospheric CO$_2$ concentrations lead to further acidification. Projections based on SRES scenarios give a reduction in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century. While the effects of observed ocean acidification on the marine biosphere are as yet undocumented, the progressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species.

Identified on the basis of expert judgement of the assessed literature and considering the magnitude, timing and projected rate of climate change, sensitivity and adaptive capacity.

Including arid and semi-arid regions.

2090 (IPCC 4th Assessment)
• Climate changes with:
  – A change in forcing (sun strength, Earth’s orbit, volcano frequency, greenhouse gases)
  – Is amplified by positive feedbacks
The carbon cycle feedback is large and hard to predict

Atmospheric CO$_2$ change: Historic and A1B

Booth et al., 2012
Locally: Warmer winters, drier summers

Temperature

Precipitation

Source: Center for Climatic Research & Center for Sustainability and the Global Environment, Nelson Institute, University of Wisconsin-Madison

http://www.wicci.wisc.edu/
FORESTS
For-CLIMATE: Forest and Climate Leaders In Menominee And The Environment
Global change science research involves:

- **Analysis of observations** of air, water, land, humans over space and time
- **Lab and field experiments** of these quantities
- **Theory and math** about the physics, chemistry, biology, geology, and economics of the Earth System
- **Computational simulation** of various Earth system models to test hypotheses against observations
- **Synthesis, communication, and application** of findings from all of the above

All require:

- good questions, precise observations, and working in diverse teams!
Wikipedia!
from May to October. While the gap-filling algorithm used a one-month moving window for computing ER, the curves shown in Fig. 5a represent the average response curve for the entire growing season. At Willow Creek, the soil temperature to ER relationship did not significantly change from 2002 to 2003. However, at Sylvania, there was significantly smaller ER in 2003 compared to 2002 for soil temperatures above 15°C. Sylvania ER is greater than Willow Creek for all temperatures above 5.0°C in both years.

The data suggest that while the respiration base rate at Sylvania is greater than Willow Creek, the slope of the response curves are roughly similar. The ratio of ER from 20 to 10°C ($Q_{10}$) was found to be 2.8 in 2002 and 1.9 in 2003 at Sylvania and 2.5 in 2002 and 2.3 in 2003 at Willow Creek, similar to typical $Q_{10}$ value of 2.0 observed for forests (Ryan, 1991). $Q_{10}$ at both sites decreased from 2002 to 2003, suggesting a coherent response to change in growing season climate; however, the change at Willow Creek was small.

ER at Sylvania was much larger than Willow Creek from June to October in both years (Fig. 5b); however, the uncertainty is larger than the difference for June. ER peaks at both sites in June and steadily declines afterwards. ER from June to September was smaller in

Fig. 6. Weekly cumulative (a) NEE, (b) ER, and (c) GEP. Gray background represents uncertainty in the cumulative values.

Desai et al., 2006
The mismatch between pool sizes and current rates points to widely disparate mean C turnover times among wetlands, lakes, and forests of the region. Assuming current rates are representative of long-term rates, the estimated average time required to build up each major regional C pool was 65 years for forest, 1775 years for peat wetlands, and 7364 years for lake sediments.

Spatial distribution of C pools and fluxes on the landscape

Pools and fluxes of C were spatially heterogeneous at a range of spatial scales in the NHLD landscape. The most dense pools of C were peat in peatlands and sediments in lakes (Fig. 3b). Patches of relatively young coniferous forest gave by far the greatest local rates of influx of C into the land surface, while lakes gave rise to patches of C evasion, with smaller lakes having the highest evasion rates (Fig. 3c).

Discussion

Implications of magnitude and spatial variability of C pools and fluxes

By constructing a C budget we incorporated surface freshwaters, wetlands, and upland forests into a single framework. This framework establishes a context for C cycling research in this and other surface-water rich regions. An integrated view like this is needed to target research and management strategies in a parsimonious way.

We determined that the largest current-day annual land–atmosphere fluxes in the NHLD region are found in forests, which are aggrading. This rate is an order of magnitude higher than surface–atmosphere exchange in wetlands or surface waters (Fig. 2, Table 2). Thus the current behavior of the NHLD in terms of annual C

Forests: 64,000
Wetlands: 158,000
Surface Waters: 162,000

Buffam et al., 2011
Big Questions About Our Forests

• **PAST**: How has the legacy of land management influence the trajectory of carbon uptake?

• **FUTURE**: What changes to the land should we expect to see with warmer, wetter winters and drier summers for this area?

• **PRESENT**: How might we manage the land to mitigate future climate change and how do we adapt our relationship with land to sustain forest production, biodiversity, recreation, culture?
We need smart people

• Menominee have managed forests in a sustainable way for a long time – what lessons can the rest of society learn here?

• What do the Menominee need to know about climate change but don’t know today?

• How do we best train future scientists, engineers, foresters, teachers to gain and apply wisdom about sustainability in face of global change?
Waewaunen!