ESM 202

Effect of Catchment Disturbances on Biogeochemistry

Catchment Disturbances
- Global warming - a carbon cycling issue
  - Terrestrial ecosystem carbon cycling can both influence atmospheric CO2 concentrations and in turn, be influenced by atm. CO2 and associated climate change
- Human Caused Land Cover Change (deforestation, afforestation)
  - Changes carbon sources and sinks
- Fires
  - A primary natural type of disturbance in the carbon cycle - that is also influenced by both human activities (fire suppression/land use change) and climate

Relevance
- Frequency, magnitude and duration of disturbances to natural system are all increasing
- Additional disturbances can have a major effect on carbon and nutrient storage
- Management Practices can influence outcomes

Global Carbon Cycle
- Human impact on the carbon cycle from 1989 to 1998
- Released by
  - Fossil fuel burning
  - Deforestation and land use change.
- Taken up by
  - Oceans
  - Atmosphere
  - Land Ecosystems
- Recent 2007 IPCC Report
  - Fossil fuel emissions 7.2 (6.9 to 7.5) GtC per year for 2000-2005
  - Deforestation 1.6 GtC (high uncertainty 0.5 to 2.7)

Another look: Carbon sink/sources

Emission Sources
Climate change and ecosystem carbon cycling
- Changes in temperature and precipitation alter NEP (positive or negative feedback with climate change)
- Human can alter ecosystem carbon cycling through management and change the magnitude of terrestrial sinks/sources
- Fire dramatically changes terrestrial carbon cycling and is linked with climate change

Climate change and high latitude carbon cycling
- Greatest climate changes occur in high latitudes
- Previous research suggests 0.6 to 2.3 PgC/year in a terrestrial sink in Northern Hemisphere
- Arctic 90% of terrestrial carbon is in soils; Boreal forest 55% is in soils
- 250 to 455 PG carbon in permafrost/seasonally thawed layers (1/2 world pool of soil carbon)
- Boreal Forest total store 700Pg Carbon vs Tropical 375Pg carbon

Changing carbon cycling in northern ecosystems
- Warming may increase NPP in northern latitudes due to longer growing season
- Warming may increase soil carbon respiration and DOC losses (due to thawing of permafrost)
- Balance? Complex feedbacks - thaw releases nutrients which may also stimulate production, warming and drainage increases drought, evidence of increased fire, DOC losses, increase pest outbreaks (2004 largest fire year on record in Alaska)

Recent Observations of high latitude NPP
Suggest gains in warming may be overshadowed by declines due to drought, fire and insect (bark beetle) outbreaks

Goetz et al., Woods Hole Research Center
Changing carbon cycling in water-limited ecosystems

- Greater water stress due to higher ET rates
- Greater water use efficiency due to greater atmospheric CO2 concentrations
- Increased fire frequency

Plant response

- CO2 uptake is through same stomata that control water transpiration
- Balance between using more CO2 or losing water
- Differences in Water Use Efficiency (WUE)
- Studies inconclusive on gains in productivity due to increases in WUE with higher atm. CO2 - typically short term and influenced by nutrient availability

FACE Experiments

http://www.bnl.gov/face/

- Free-air CO2 enrichment
- Experimental increase of atm. CO2 for intensively monitored ecosystems
- Current finding show complex, variable responses depending on length of time, adaptation and nutrient availability

Human Disturbances

Deforestation

- Land cover change is a significant source of carbon loss to atmosphere (although smaller than fossil fuel emissions)
- Primarily conversion of forest (90%)
- Also leads to land degradation - erosion, nutrient leaching - limits future ability to store carbon

Afforestation

- In US, changing land use has lead to significant afforestation, particularly in northeast - farming shifted to Midwest and West
- EPA estimates US Forests are a net carbon sink of 170TgC (1990-2004)
- Russia forests account for almost 40% of biomass carbon sequestration
### Change in forest in US

![Forest Land Percentages](chart.png)

Source: US Global Change Research Program 2000

### Change in forest in Amazon

- In tropics, Africa rapid deforestation
- For example ~6% of Brazilian Amazon has been deforested
- (source FAO and NASA)

### Reforestation/ Deforestation

- Upper bounds on impacts on global carbon cycle (from 2001 IPCC report)
  - Estimate of carbon losses due to land use change ~200 PgC (cumulative to year 2000)
  - Estimate of anthropogenic emissions ~500 PgC (cumulative to year 2000)
  - Maximum potential deforestation (all world forests converted to grasslands, with 20 to 50 % soil carbon lost) - would produce 400 to 800 PgC

### C sequestration through forest management

- All fluxes in PgC/yr
- Adapted from Woods Hole Research Center
  - [http://whrc.org/carbon/forestseq.htm](http://whrc.org/carbon/forestseq.htm)

### Forest Management for Carbon Storage

![Carbon balance from a hypothetical forest management project](chart.png)

### Soil Carbon Sequestration

- Soil organic matter includes a variety of compounds that decay at rates from days to centuries
- When soil decays it releases carbon back to the atmosphere - in wetlands, anaerobic decomposition releases methane
- Climate, soil texture and moisture influences the rates of decay
- Land management practices can alter soil carbon sequestration
Changes in SOC

- Spatial distribution patterns of soil organic carbon (SOC) stocks, net primary production (NPP), and SOC change in the northwestern Great Plains (portions of Montana, Nebraska, North Dakota, South Dakota, and Wyoming) between 1972 (a,c) and 2001(b,d):

Fires and Carbon

- See animations at
- Role of fire in carbon sequestration
  - http://earthobservatory.nasa.gov/Observatory/runqt.php3
  - Illustrates frequency of fire in tropical regions

Fire and Carbon

- Fire: removes terrestrial carbon to atmosphere; followed by recovery
- Peak sequestration occurs during regrowth after fire
- Long-term fires may actually increase sequestration due to creation of burned material that decays more slowly

Fire and soil biochemistry

- More severe fires can burn litter and soil carbon stores
- After fires
  - hydrophobicity (water repellency)
  - increased pH
  - increases in erosion
  - leaching of nutrients, including DOC and POC (dissolved and particulate organic carbon)

Other possibilities for sequestration

- Geologic
- Ocean
- SOM (soil organic matter)

How will changes in vegetation water use under a combination of projected climate change alter river flows and carbon sequestration in chaparral ecosystems?
Combined RHESSys Modeling / remote sensing based approach for developing projections of the impact of climate change on river flow and chaparral post-fire recovery rates

Opportunity to adapt and test RHESSys in Semi-arid chaparral ecosystem

• Many hydrologic based models of climate change impacts do not incorporate feedbacks between carbon cycling and hydrology
• Changes in plant water use under different climate regimes can not be assessed

Climate change scenarios

All scenarios show significant increases in precipitation

Post-fire recovery trajectories under different climate scenarios

• Recovery trajectory characteristics depend on the start date used
• Inter-annual variability is therefore a stronger control post-fire NPP and water fluxes than projected climate change
• This variability, however, decreases for more extreme climate change scenarios

Results are averaged over 20 different climate trajectories (start date varied by 1 year)

Modeled LAI (leaf area index - measure of above ground biomass) recovery trajectories show increases in peak and stable LAI values for the more extreme scenarios

Time to peak does not change