Linkages among climate variability, terrestrial ecosystems, and the global atmospheric CO_2 budget as determined from atmospheric observations

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Motivating questions:
- What governs the C dynamics of terrestrial ecosystems?
- Why does the global atmospheric CO_2 budget vary from year-to-year?
- Can we project net ecosystem-atmosphere exchange (NEE) of CO_2 into the future?
- How does the atmospheric boundary layer (ABL) respond to land surface fluxes?
- How does the interaction among the ABL, clouds, and the land surface influence NEE of CO_2 and climate/clouds/storms?

Tools for observing earth-atmosphere interactions:
- Globalview-CO_2, global flask network
- AmeriFlux/Fluxnet network (http://www-eosdis.ornl.gov/FLUXNET/).
- Chequamegon Ecosystem-Atmosphere Study (ChEAS! - http://cheas.psu.edu).
- Airborne eddy-covariance flux measurements (e.g. BOREAS, FIFE)
- Airborne LIDAR (Light Detection and Ranging) (e.g. BOREAS, SGP97), a good tool for looking at the atmospheric boundary layer.

In order to determine terrestrial CO_2 flux one can observe the flux directly (micrometeorological approach) or derive it by observing concentrations and modeling transport (inversion approach). The scales of the two approaches are vastly different.

Conclusions from the inversion approach:
- A large and highly variable global sink of atmospheric CO_2 exists.
- The interannual variability in the sink is likely governed by climate. The mechanisms are unknown.
- The sensitivity of the global CO_2 budget to climate change is potentially large.
- Northern terrestrial ecosystems are a major contributor to the sink and its interannual variability.
- Northern ecosystems' gross CO_2 exchanges are increasing.

- Our ability to resolve continental-scale NEE of CO_2 is marginal.

No anthropogenic land-use change enters directly into these points. Surface energy balance is largely conserved.

Problems with this approach include the fact that continental CO_2 mixing ratio data is lacking and spatial resolution, and hence connection to governing mechanisms, is poor, and that atmospheric transport models show significant differences.

Conclusions from the micrometeorological approach:

- NEE of CO_2 is observed to be quite large.
    - Transient? Systematic error? Unanticipated large potential for sequestration? Result of site selection?
- Interannual variability in NEE of CO_2 is also large.
- Some links between flux-tower NEE of CO_2 and climate have been made.
    - Growing season length, soil thaw, drought, spatial coherence, forest age?
- Universal factors governing network-wide NEE of CO_2 are uncertain.
    - NEE vs. T, NEE (or RE) vs. latitude, NEE vs. dryness
- Great similarity in NEE of CO_2 exists among "plant functional types" (deciduous, conifer, grass, crop).
    - AmeriFlux results, BOREAS airborne fluxes

Problems with this approach include the fact that flux tower NEE observations are troubled with concerns about systematic errors, and that the footprints of eddy covariance flux measurements are very small compared to biomes and continents (the scale at which we know there is a missing terrestrial sink).

The figures below show daily and annual patterns of CO_2 emission and uptake.

[Ken - which figures would you suggest?]

typical net values: 2-3 tons C per hectare per year
interannual variability: 1 ton C/h/yr

Problems: did not pay attention to stand age in selecting sites, disturbance regimes, etc.

Conclusions: Surface Energy Budget

- Great similarity in the surface energy budget (SEB) exists among plant functional types.
  - AmeriFlux results, BOREAS airborne fluxes
- Mean ABL depth and the SEB are closely coupled.
  - WLEF seasonal results, fluxes and ABL depth
- Clouds form when
  - evapotranspiration (latent heat flux) is large?
  - atmospheric warming (sensible heat flux) is large?
  - upper atmospheric structure can determine which is true
- Convective ABL structure is not strongly influenced by small-scale (< 10km) surface heterogeneity. Larger scales (~ 100km) are needed. Significance of these mesoscale features is a topic for research.

It is important to look at the stand age rather than the forest age because C flux is very different between different age stands.

Research Needs

Link the flux and inverse approaches. Determine mechanisms governing NEE of CO_2.

- Increase the density of continental CO_2 observations
- Add flux observations in tropical ecosystems
- Improve coupled ecosystem-atmosphere models and atmospheric transport models

Reduce uncertainty in tower-based NEE of CO_2.
Link large-scale climate and tower flux data.
Find governing parameters for NEE of CO_2.