Exploring the Sensitivity of Terrestrial Ecosystems and Atmospheric Exchange of $CO_2$ to Global Environmental Factor

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Acknowledgements
US DOE, NASA-LCLUC
ISAM Estimated Net Ecosystem Exchange (NEE)

**Summer (JJA)**

**Winter (DJF)**

- 1996-1997
- 1999-2000
- 1990s

Negative is net C gain by the terrestrial ecosystems.
Environmental Factors Impacting the Exchange of CO2 between Terrestrial Ecosystems and Atmosphere
Terrestrial Ecosystems and Environmental Factors

- CO₂
- Climate
- Land Use Change
- N Fertilizer, Deposition
- Biomass Burning
- Atmospheric Chemistry
Questions?

• What are the relative contributions of
  - Land use
  - natural ecosystem dynamics
  - climate variability
  - N deposition
  - agriculture management
  - fire

  on ecosystems and carbon dynamics

  What are their synergistic effects?

• What are their potential future trends?
Methods

- We use the terrestrial component of the Integrated Science Assessment Model (ISAM), which simulates C and N fluxes within the terrestrial biosphere.

- The model includes feedback processes such as CO2 fertilization, climate effects on photosynthesis and respiration and increased carbon fixation by nitrogen deposition.

- Changes in land cover classifications are driven by clearing forest for cropland, reforestation and abandonment (reforestations), pasturelands, wood harvest.

- Mineral nitrogen deposition rates are based on chemical transport model.

- Changes in temperature and precipitation, and CO2 are based on observation data.

- Soil carbon sequestration in soils is estimated using empirically-based sequestration estimates coupled with ISAM.
Global Terrestrial C-N ISAM

- 18 Biome types
- 0.5 x 0.5 degree resolution
- Carbon cycle
- Nitrogen cycle
- Feedbacks: Climate-C-N-LUC...

Biome Types
- Tropical Evergreen
- Tropical Deciduous
- Temperate Evergreen
- Temperate Deciduous
- Boreal Forest
- Savanna
- Grassland
- Shrubland
- Tundra
- Desert
- Polar Desert
- Cropland
- Pastureland
- Sec. Tropical Evergreen
- Sec. Tropical Deciduous
- Sec. Temperate Evergreen
- Sec. Temperate Deciduous
- Sec. Boreal Forest

Yang et al. (2009, GBC)
Model Evaluation

- **Long-term Inter-site Decomposition Experiment (LIDET)** and other site-specific data

- Leaf, wood and root litter decomposition data
  - C:N
  - Lignin:N
  - Climate

Yang et al. (2009)
Use of FLUXNET and Other Ground-Based Data in the ISAM Land Surface Model Development
Modeled vs. Measured Data

Monthly GPP

Monthly LH

11:05 AM - 11:20 AM
B22D-04. Studying Uncertainties in Climate-Terrestrial Biogeochemical Feedbacks in the Northern High Latitudes using a Flexible Earth System Modeling Framework

Rahul Barman; Forrest M. Hoffman; David M. Lawrence; Yang Song; Prasanth Meiyappan; Atul K. Jain; Robert L. Jacob; Mariana Vertenstein
Experiments Performed

- ISAM run to equilibrium with $[\text{CO}_2] \sim 280$ ppm and climate for early 1900s
- NEE is calculated with accounting all environmental factors (Case 1)
- Five scenarios examined without following changes (1765-2010) (Case 2)
  - Increasing CO2
  - Changes in N deposition
  - Climate variability (Temp. and Precip.)
  - Changes in land cover and land use (LCLUC)
  - Forest Fires
- The contribution of individual factor to NEE is calculated by subtracting Case2 from Case 1.
- Above five scenarios are extended until 2050 based on two IPCC scenarios: RCP 4.5 and RCP 8.5
Historical Data for Environmental Factors

- Climate Data (i.e., Temperature and precipitation) - Climate Research Unit Time series (CRU-TS) observation data
- CO2 Concentrations: CO$_2$ concentrations from the Mauna Loa (Hawaii) (CDIAC, 2011)
- LCLUCs: Sustainability and the Global Environment (SAGE), History Database (IPCC, AR5)
  - Cropland, Pastureland & Wood-harvest
- N Deposition: Both wet and dry atmospheric depositions (Galloway et al., 2004)
Estimated NEE
Average for 2000-2009

negative is net C gain by the terrestrial ecosystems
Estimated NEE
Average for 2000-2009

negative is net C gain by the terrestrial ecosystems
Contribution of Different Environmental factors to NEE (gC/m²/yr) (Average 2000-2009)

- **CO₂**: Climate
- **LCLUC**: negative is net C gain by the terrestrial ecosystems
- **N Deposition**
Regional Contribution of Different Environmental Factors to NEE (gC/m²/yr) (Average 2000-2009)
Regional Contribution of Different Environmental Factors to NEE (gC/m²/yr) (Average 2000-2009)

- Higher CO2 increase in plant-derived carbon input into soils from leaf and root detritus.
- No N-limitation
- No Land use change, but abandonment and reforestation
- Climate change: warm and moist climate leads to rapid litter decomposition
Contribution of Various Environmental Factors to NEE

- CO2
- Climate
- Land Use Change
- N Deposition

negative is net C gain by the terrestrial ecosystems
Contribution of Various Environmental Factors to NEE

negative is net C gain by the terrestrial ecosystems

Jain et al. (2011, GBC)
Net Land Use Emissions Based on Three Different Data sets
10-yr Mean (GtC/Yr)

SAGE: Ramankutty et al. (2008)
HYDE: Goldewijk et al. 2011
Net Land Use Emissions Based on Three Different Data Sets (gC/m²/yr) Average for 2000-2009

negative is net C gain by the terrestrial ecosystems

Jain et. al. (2011, GBC)
Estimated Impact of N Dynamics on Terrestrial C Uptake (gC/m²/yr)

Average for 2000s

- N dynamics reduces CO₂ fertilization effect
- Climate change increase mineral N available to the plants
  - Less of a source with N dynamics
- N dynamics result in less C storage

Jain et. al. (2009, GBC)
The Net Exchange of C for the 2000s in Secondary Forests (SAGE Data)

C fluxes are not constrained by N dynamics

- In some regions accumulation of carbon is reduced where nitrogen is a limiting nutrient or enhanced if the additional N is deposited in the forest regrowing regions

Yang et. al. (2010, Biogeosciences)
Management: Soil Carbon Sequestration
Modeled Soil Carbon Sequestration Potential
(Conventional Tillage to No Tillage)
Averaged Over the Period 1981-2000
(MgC/ha/yr)

Jain et al. (GRL, 2005)
Estimated Distribution of Net C Exchange Attributed to Biomass Burning ($gC/m^2/\text{year}$)

Positive fluxes represent a net loss of CO2 to the atmospheric
Terrestrial Response to Changes in CO2, Climate, LUC, N Deposition

2000s NEE

Negative flux is net C gain by the terrestrial ecosystem
Conclusions

• Global ecosystems and soils absorbed about 1.1 GtC/yr during the 2000s compared to the 8 GtC/yr release of C due to fossil fuel burning.

• The dominated sink is located in the secondary temperate forests along the East Coast in the US and Latin America and Africa.
  - Uncertainty in these estimates are large, because the uncertainty in the input data for environmental factors.

• CO2 fertilization accounts for a major portion of today’s carbon sink.

• Other factors such as forest regrowth (secondary forest), agriculture soils and N deposition also contributed to the net C sink.
Thank you..