The GHG Balance of Terrestrial Ecosystems in North America in the early 2010s

Hanqin Tian (Auburn University), Wilfred M. Post, Steve Wofsy, Xiaofeng Xu, Deborah N. Huntzinger, Yaxing Wei, Andy Jacobson, Chaoqun Lu, Guangsheng Chen, Mingliang Liu and NACP Regional-Interim Synthesis Participants
The three GHGs \((CO_2, CH_4\text{ and } N_2O)\) together contribute to more than 90% of anthropogenic climate warming (Forster et al., 2007)
Do CH$_4$ and N$_2$O matter?

Comparing to their concentrations in the pre-industrial period,

- The atmospheric CH$_4$ has increased more than 100%;
- The atmospheric N$_2$O has increased 18%,
  (Forster et al., 2007; Solomon et al., 2007).
The North American CO$_2$ Problem:

• Current understanding of state of the North American Carbon Cycle (e.g., SOCCR; King et al., 2007):
The North American CO$_2$ Problem:

NACP Regional Interim Synthesis

Across model mean net flux; 2000-2005

NEP $= 0.66$ PgC/yr (-1.8 to +0.25 Pg C/yr)

NPP $= 9.2$ PgC/yr (6.2 to 13.8 Pg C/yr)

GPP $= 18.4$ PgC/yr (9.9 to 31.7 Pg C/yr)

Rh $= 8.6$ PgC/yr (5.8 to 13.1 Pg C/yr)
Mean average annual NEE (Tg C yr\(^{-1}\)), 2000 to 2006, NACP Regional Interim Synthesis

- FORTRAN DATA: -282 Tg C yr\(^{-1}\)
- FORWARD MODELS: -511 Tg C yr\(^{-1}\)
- INVERSE MODELS: -931 Tg C yr\(^{-1}\)
Can we simulate all these three GHGs together?
Dynamic Land Ecosystem Model

INPUT

Driving Factors
- Climate
  - Temperature
  - Precipitation
  - Radiation
  - Relative Humidity
- Atmospheric Compositions
  - CO₂
  - O₃
  - Nitrogen Deposition
- Land Use
  - Deforestation
  - Urbanization
  - Harvest
  - Fertilization
  - Irrigation
- Other Disturbances
  - Wildfire
  - Disease
  - Climate Extremes

Controlling Factors
- Soil
  - Physical Properties
  - Chemical Properties
  - Depth
- Geomorphology
  - Elevation
  - Slope
  - Aspect
- River Network
  - Flow Direction
  - Accumulative Area
  - River Slope
  - River Length
  - River Width
- Vegetation Functional Type
- Cropping System

MODEL

OUTPUT

CO₂ Related:
- Carbon Storage
- Harvest
- Ecosystem Respiration
- Net Primary Productivity
- Net Ecosystem Exchange
- Export of DOC and POC

Non-CO₂ GHG:
- CH₄ Emissions
- N₂O Emissions

Water Related:
- Surface Runoff
- Subsurface Flow
- Evapotranspiration
- Soil Moisture
- River Discharge

Nitrogen Related:
- Nitrogen Storage
- Mineralization Rate
- Nitrofication Rate
- Denitrification Rate
- Export of TN
Model validation

CH$_4$ flux in Durham Forest (42°N, 73°W); Modeled = 0.9389 * observed, $r = 0.562$, $P < 0.001$ for A

Tian et al., 2010, Biogeosciences
Model validation

CH$_4$ flux in Alaska wetland (64.8°N, 147.7°W);
Modeled = 0.5882 * observed, r = 0.628, P < 0.001

Tian et al., 2010, Biogeosciences
Model validation

CH\textsubscript{4} flux in Hubbard Brook Forest (43.95°N, 71.74°W) (Groffman et al., 2009; Groffman et al., 2006); The error bars in Fig. 4d represents the standard deviations of four or five replicated observations; Modeled = 0.7937 * observed, r = 0.595, P < 0.001 for D)

Tian et al., 2010, Biogeosciences
Model validation

CH$_4$ flux in Sallie fen (43.21°N, 71.05°W); Modeled = 0.8795 * observed, r = 0.502, P < 0.001
Model validation

Sanjiang in Northeast China

Xu and Tian, GBC, in review
Model validation

Ruoergai in Southwest China

Xu and Tian, GBC, in review
Model validation

Regional comparison of simulated CH$_4$ across China

Xu and Tian, GBC, in review
$\text{N}_2\text{O}$ flux in Sallie fen (43.21°N, 71.05°W);
Modeled = 0.7042 * observed, $r = 0.633$, $P < 0.001$

Tian et al., 2010, Biogeosciences
Comparison of simulated CH$_4$ flux with inverse results

CH$_4$ flux in 2003 derived by inverse method (Kort et al., 2008)

CH$_4$ flux in 2003 simulated by DLEM
Multiple Environmental Drivers:

- Climate (Temperature, Precipitation, Solar radiation, humidity)
- Atmospheric chemistry (CO$_2$, O$_3$, N deposition)
- Land use and land cover change
- Land management practices (N fertilization, irrigation, rotation etc.)
Mean annual CH$_4$ fluxes: 15.0 (12.35-18.48) Tg C yr$^{-1}$
Mean annual $\text{N}_2\text{O}$ fluxes: 1.91 (1.67-2.07) Tg N yr$^{-1}$
Temporal variation of accumulated terrestrial CH₄ fluxes caused by global change factors

Xu, Tian et al., 2010, Biogeosciences
Temporal variation of accumulated terrestrial N$_2$O fluxes caused by global change factors

Xu et al., In prep.
N-induced GHG balance in conterminous US

Lu , Tian et al., Poster: I-197

Offset percentage

-54%

-43%

N deposition-driven GWP

N fertilization-driven GWP
Partition of CO$_2$-driven cooling effect offset by CH$_4$ and N$_2$O emissions:

- 135%
- 75%
- 41%
Summary

• From both scientific and policy perspectives, it is of critical importance to take multiple greenhouse gases into consideration.

• 41%-135% of the cooling effects caused by atmospheric CO$_2$ sequestration could be offset by CH$_4$ and N$_2$O emissions from North America’s terrestrial ecosystems.

• Nitrogen input and climate variability played important role in this offsetting effect. It is important to improve nitrogen use efficiency, instead of increasing N input levels.
Future Research Needs

• Data needs for model development, validation and regionalization

• Consideration of additional levels of complexity, including coupled biogeochemical cycles (e.g. C-N-P interactions) and hydrological cycle.

• Mechanistic links between small- and large-scale processes, between short- and long-term processes.

• Integration of multiple approaches.
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