Quantifying Climate Feedbacks from Abrupt Changes in High-Latitude Trace-Gas Emissions

**Project Objective:**
Quantify the potential for threshold changes in natural emission rates of trace gases, particularly methane and carbon dioxide, from pan-arctic terrestrial systems under the spectrum of anthropogenically forced climate warming, and the extent to which these emissions provide a strong feedback.

**Tested Hypothesis:**
There exists a climate warming threshold beyond which permafrost degradation becomes widespread and thus instigates strong and/or sharp increases in methane emissions (via thermokarst lakes and/or wetland expansion). These would outweigh any increased uptake of carbon (e.g. from peatlands) and would result in a strong, positive feedback to global climate warming.

**Project Investigators:**
- MIT: C. Adam Schlosser, Xiang Gao, and Ron Prinn
- Penn State: Chris E. Forest
- Marine Biological Laboratory: Jerry Melillo and David Kicklighter
- Purdue: Qianlai Zhuang
- University of Alaska: Katey Walter

**Support:**
DOE Abrupt Climate Change Program
The MIT Integrated Global System Model Version 2


IGSM2 Integrated Assessment model
Designed for analyzing the global environmental changes that may result from anthropogenic causes, quantifying the uncertainties associated with the projected changes and assessing the costs and environmental effectiveness of proposed policies to mitigate risk.

Includes an economic model for analysis of greenhouse gas and aerosol emissions and mitigation proposals, a coupled atmosphere-ocean-land surface models with interactive chemistry and of natural ecosystems.
IGSM Scenarios
(Sokolov et al., 2009, and Webster et al., 2010)

No Policy (Reference):
- Climate & EPPA Samples

Policy Scenarios:
Representative Concentration Pathways (RCPs)
- U.S. CCSP Level 4
- U.S. CCSP Level 3
- U.S. CCSP Level 2
- U.S. CCSP Level 1

Run 400 member ensembles using Latin Hypercube sampling for each policy.
Research Tasks

- **Task 1**: Implement Methane Dynamics Model (MDM) and Terrestrial Ecosystems Model (TEM) associated with changing wetland conditions (as calculated from CLM).
- **Task 2**: Formulate thermokarst-lake effect into the IGSM2.
- **Task 3**: Numerical Experiments within Integrated Global Systems Model (IGSM) framework.

**Knowing there’s uncertainty in regional climate change... project zonal patterns of the IGSM2 atmosphere onto the longitudinal grids of a land model system.**

Walter et al., 2007

Figure 1
Merging Regional Climate Uncertainty in the IGSM Framework

Use observed variables for $C_{x,y}$ climatology of:
- Temperature (CRU: surface air temperature)
- Precipitation (GPCP: satellite and ground)

Use AR4 archive of $2\times CO_2$ runs to estimate:
- $C_{x,y}$ trends
- 19 GCM simulations available

**Construct probabilistic sample of potential future $C_{x,y}$ trends from AR4 projections**

$$V_{IGSM}^{x,y} (\Delta T_{IGSM Global}) = C_{x,y}^{OBS} V_{IGSM}^{y} + \left[ \frac{dC_{x,y}^{AR4}}{dT_{Global}} \Delta T_{IGSM Global} \right] V_{IGSM}^{y}$$
CLM Simulation Experiments

• **Three “baseline” simulations with observationally-based bias-corrected forcing:** CAS, GOLD, NCC
  - All runs span ~1950 to ~2000.

• **Simulations with IGSM forcing:**
  - IGSM atmosphere with low, median, & high climate sensitivity ($C_s$), and median emission scenarios (from EPPA).
  - Runs start in 2010 thru 2100, except for median climate sensitivity run - begins 1948.
  - Climatological projection of precipitation (GPCP) and temperature (CRU) across latitude band kept fixed.

• **CLM Version 3.5 @ 2°x2.5° spatial resolution.**
Consistency Between Forcings
Consistency Between Forcings

30-yr mean of spatial correlation between evaporation forced by various forcing

- IGSM-CAS
- IGSM-GOLD
- IGSM-NCC
- CAS-GOLD
- CAS-NCC
- GOLD-NCC

LMWG/BGCWG Meeting, Feb. 9, 2010
Consistency Between Forcings

spatial correlation between interannual variations of evaporation forced by various forcing
Trends in Near-Surface Permafrost

Fractional Change of NH Permafrost area with respect to 2010

2010: SIMULATED PERMAFROST EXTENT ~15x10^6 KM^2
REGIONAL CLIMATE-CHANGE UNCERTAINTY
Trends in Saturated Area

Relative Change in Total Saturated Area for High NH Latitudes

2010: SIMULATED TOTAL EXTENT ~4x10^6 KM^2
REGIONAL CHANGES AND UNCERTAINTY
Change in Saturated Area over 21st Century
High Climate Sensitivity Run
Regional Climate Change Uncertainty

Normalized Derivative of June Precipitation Coefficient Due to Doubling of CO$_2$

Implement these uncertain climate change patterns of the AR4 GCMs into the IGSM2 framework.

LMWG/BGCWG Meeting, Feb. 9, 2010
Precipitation and Temperature 2xCO₂ Responses
Yedoma Region

AR4 Model Scatter

Units in % of Zonal Mean

Summer
Autumn

WARMER

COOLER

DRIER

WETTER

Units in % of Zonal Mean
Closing Remarks and Looking Ahead

- **Under range of uncertainty in climate sensitivity, extent of permafrost degradation about a factor of 2.5.**

- **Widespread decreases in saturated area at high latitudes, with a range of 30% to ~45% reduction for the low and high climate sensitivity cases, respectively.**

- **Continue evaluation of CLM climatological simulations with IGSM and C_x,y... Looking forward to CLM4 (for upgrades in soil carbon and permafrost treatment).**

- **Regional climate change uncertainty: simulations with ΔC_x,y based on AR4 archive underway. Build ensembles that span the No-Policy and Policy IGSM runs.**

- **Upgrade methane dynamics module (Q. Zhuang). Total lake emissions will be extrapolated from latest field emission observations (K. Walter).**