Quantifying Future Changes in High-Latitude Methane Emissions Under Regional Climate Change Uncertainty

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Background:

Permanently frozen soils in the arctic are susceptible to widespread thaw and degradation (via thermokarst lake formation and wetland expansion) due to rising surface temperatures. Permafrost thaw, particularly in the icy, organic-rich region of yedoma, is expected to release a large amount of methane, which could be potentially significant to the global carbon cycle and also dramatically alter the hydrological cycle and lake and wetland dynamics.

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 may initiate a strong, positive feedback to global climate warming.

Community Land Model (CLM) Permafrost and Lake Extent

- PERMAFROST: Grid in which bottom soil temperature (~3M depth) remains below 0°C for 24 consecutive months.

- LAKE EXTENT DIAGNOSTIC: saturated grid area - fractional area of grid in which water table is at surface.

Offline Simulation Experiments with CLM

- Baseline Simulations (1950~2000): Use observationally-based, bias-corrected forcing – CAS, GOLD, and NCC
- Simulations with IGSM atmospheric forcing:
  - Climatological projection of precipitation (GPCP), temperature (CRU), and radiation across latitude band and kept fixed
  - IGSM atmosphere with various Transient Climate Response (TCR), emission scenarios (from EPPA), and policy
- CLM Version 3.5 @2°x2.5° spatial resolution

Simulations Experiment with IGSM forcing

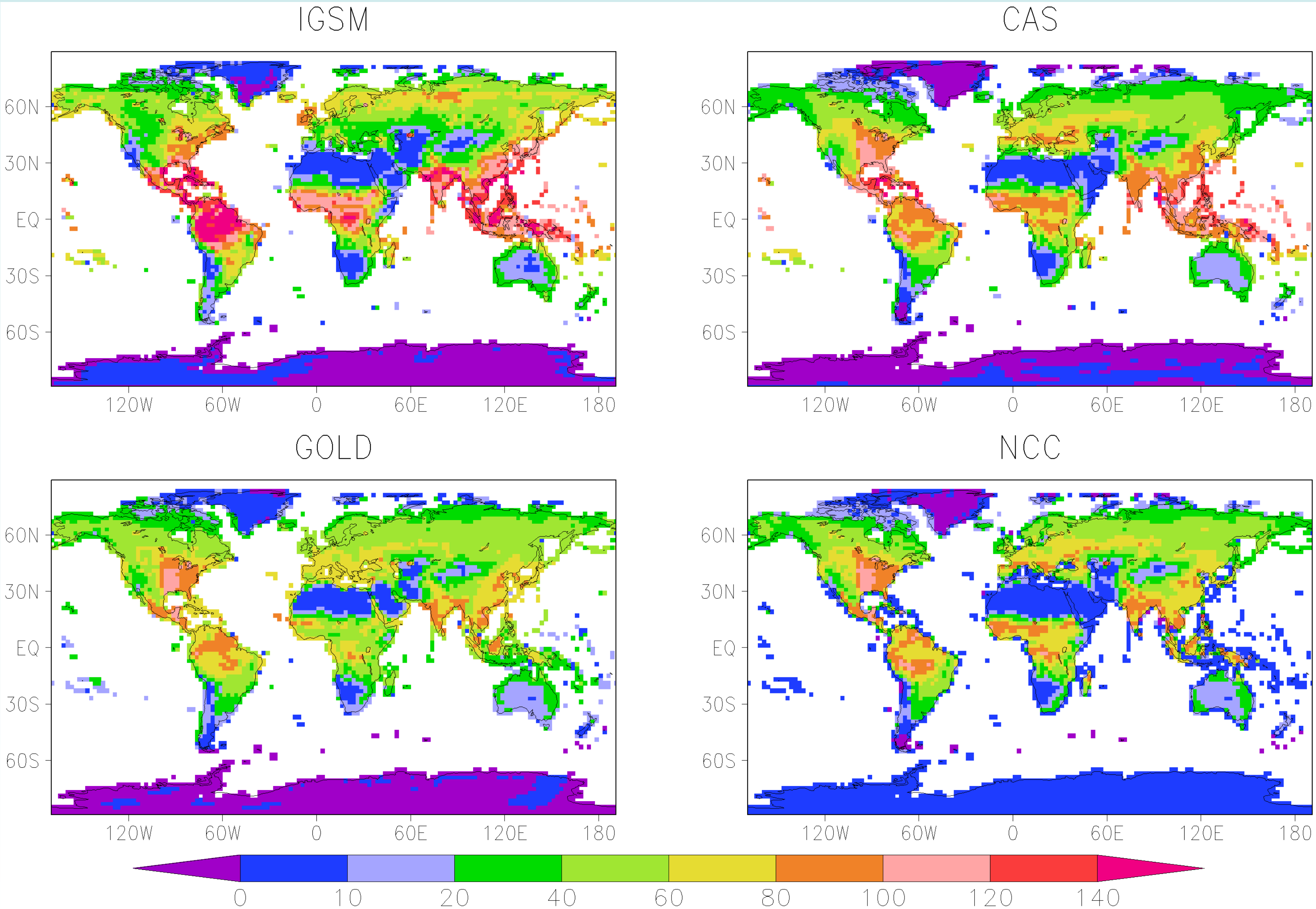
No Policy

TCR	Emission	Time frame	Notes
High (7.0°C)	Median	1991 ~ 2100	Comparable to BAU A2 in IPCC AR4 * To compared with baseline simulations
Median (5.1°C)		1948 ~ 2000*	
Low (3.8°C)		1991 ~ 2100	
Median (5.1°C)	High	1991 ~ 2100	
	Low		

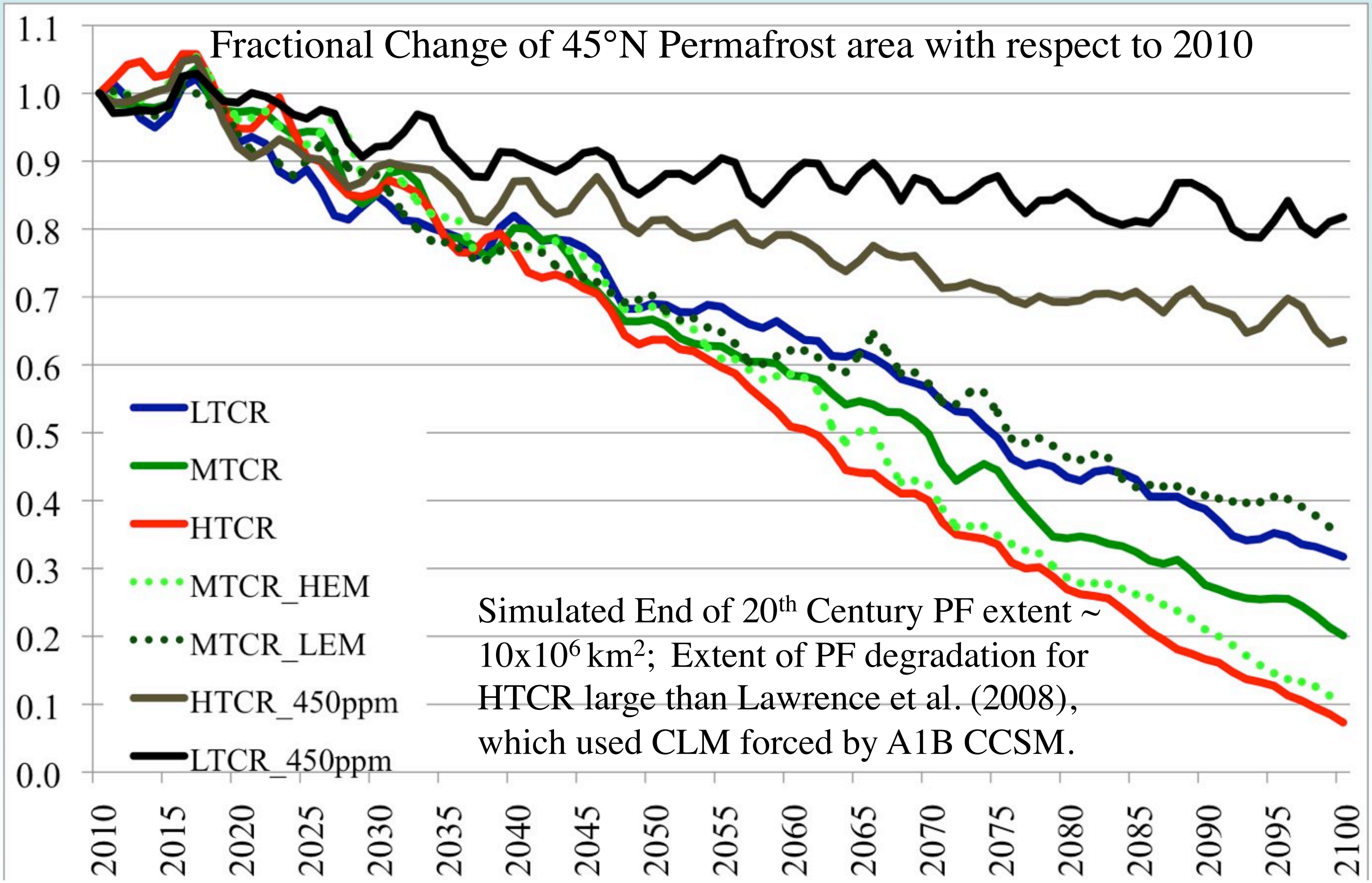
With Policy

TCR*	Emission	Time frame	Notes
High	Stabilization @ 450PPM	1991 ~ 2100	Comparable to B2 in IPCC AR4 * TCR is different from that in no policy
Low			

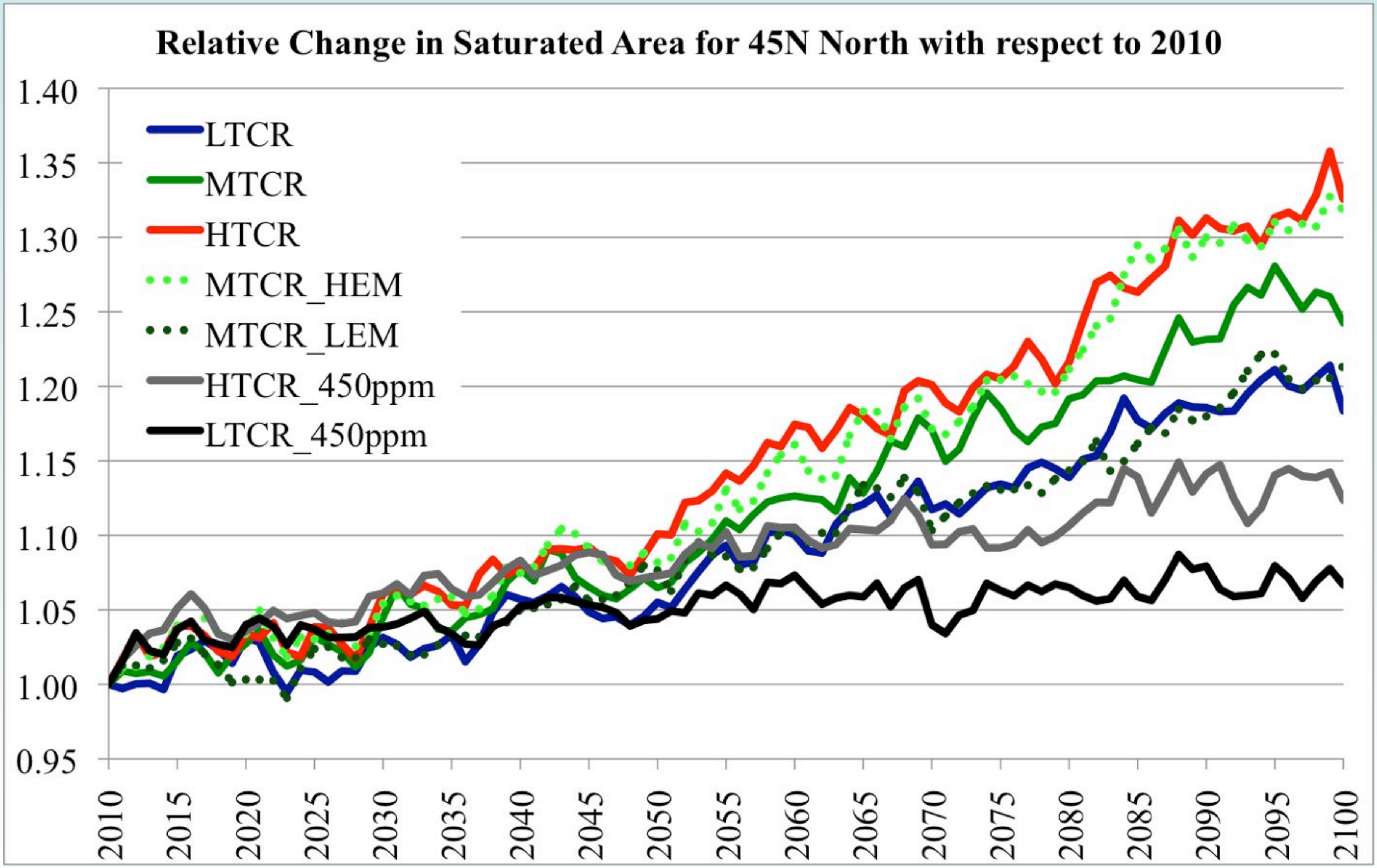
Consistency Between Forcings
JJA Latent Heat Flux (1971-2000)



Trend in Near-Surface Permafrost (PF)



Trend in Saturated Area



Change in Methane Emission (2091~2100 minus 2001~2010)

	LTCR		MTCR		HTCR		LEM		HEM		L450		H450	
	ΔA	ΔE	ΔA	ΔE	ΔA	ΔE	ΔA	ΔE	ΔA	ΔE	ΔA	ΔE	ΔA	ΔE
Y	0.40	0.26	0.44	0.29	0.58	0.38	0.36	0.24	0.55	0.36	0.16	0.11	0.27	0.18
N-Y	12.9	1.93	16.0	2.40	19.3	2.90	13.0	1.95	18.7	2.80	4.34	0.65	8.24	1.24
T		2.19		2.69		3.28		2.19		3.17		0.76		1.41

Y: Yedoma region; **N-Y**: Non-Yedoma region; **T**: Yedoma + Non-Yedoma region – assuming all region is lake-based (no wetland);

ΔA: Change in saturated area between two periods; unit is 1.0E+10 m^2

ΔE: Change in methane emission between two periods; unit is Tg

Ebullition flux rates for yedoma and non-yedoma lakes take the values of 66±17 and 15±2 $gCH4m^{-2}yr^{-}1$ (from Katey Walter)

LTCR, MTCR, and **HTCR** are different TCR with median emission;

LEM and **HEM** are different emission with median TCR

L450 and **H450** are different TCR for stabilization of 450 ppm.

Closing Remarks and Looking Ahead (1)

- With no policy applied, under range of uncertainty in transient climate response, extent of permafrost degradation occurs anywhere between 70% (Low TCR) to 90% (high TCR). But this sensitivity is not evident until 2050.
- Increase in saturated area at high latitudes, with a range of 20% to 30% for the low and high TCR, respectively, but difference is not evident until later part of this century.
- The degree of the impact from the changing TCR and emission (low versus high) is similar when no policy is applied.
- 450ppm stabilization can well prevent the extent of permafrost degradation anywhere between 20% (Low TCR) to 30% (high TCR) and the increase of saturated area from 5% (low TCR) and 15% (high TCR).
- Though increase in methane emission (~ 3Tg) from the expanded saturated area with HTCR or high emission scenarios is in small quantities, compared with total natural (270 Tg) and total anthropogenic (~300 Tg), it could be potentially important if stabilization of 450 ppm policy is applied.

Closing Remarks and Looking Ahead (2)

- Looking forward to CLM4 (with upgrades in soil carbon and permafrost treatment)
- Continue evaluation of CLM simulations with climatologically projected IGSM forcings.
- Regional climate change uncertainty: simulations based on AR4 patterns underway.
- Build ensembles that span more no-policy and policy IGSM simulations.
- Updated thermokarst emissions from field-based surveys and flux measurements, which will provide information specific to lake types and regions (Katey Walter by August 2010).