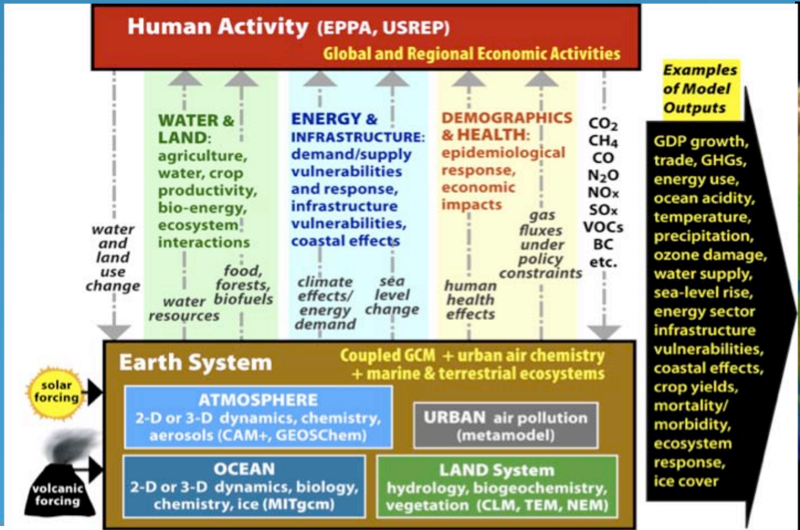
Assessing the Fate/Impact of Potential Thermokarst Expansion Using the IGSM Framework

Adam Schlosser, Xiang Gao, Katey Walter (U. of Alaska), Qianlai Zhuang (Purdue), Eunjee Lee, David Kicklighter (MBL), Jerry Melillo (MBL) and Ron Prinn



Human Activity (EPPA, USREP)
Global and Regional Economic Activities

WATER & LAND: agriculture, water, crop productivity, bio-energy, ecosystem interactions

ENERGY & INFRASTRUCTURE: demand/supply vulnerabilities and response, infrastructure vulnerabilities, coastal effects

DEMOGRAPHICS & HEALTH: epidemiological response, economic impacts

Examples of Model Outputs

GDP growth, trade, GHGs, energy use, ocean acidity, temperature, precipitation, ozone damage, water supply, sea-level rise, energy sector infrastructure vulnerabilities, coastal effects, crop yields, mortality/ morbidity, ecosystem response, ice cover

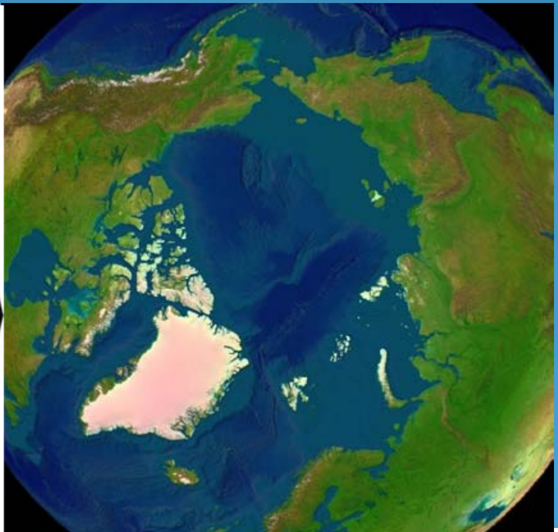
Earth System Coupled GCM + urban air chemistry + marine & terrestrial ecosystems

ATMOSPHERE 2-D or 3-D dynamics, chemistry, aerosols (CAM+, GEOSChem)

URBAN air pollution (metamodel)

OCEAN 2-D or 3-D dynamics, biology, chemistry, ice (MITgcm)

LAND System hydrology, biogeochemistry, vegetation (CLM, TEM, NEM)



Numerical Experiments with IGSM-CLM To Explore the Effect of Thermokarst Expansion on CH_4 Emissions, its Climate Feedback, with Uncertainty

No Policy

TCR	Emission	Time frame	Notes
High (7.0°C)*	Median	1991 ~ 2100	Longer simulation period of median TCR to provide initial condition @1991
Median (5.1°C)		1948 ~ 2100	
Low (3.8°C)*		1991 ~ 2100	
Median (5.1°C)	High	1991 ~ 2100	
	Low		

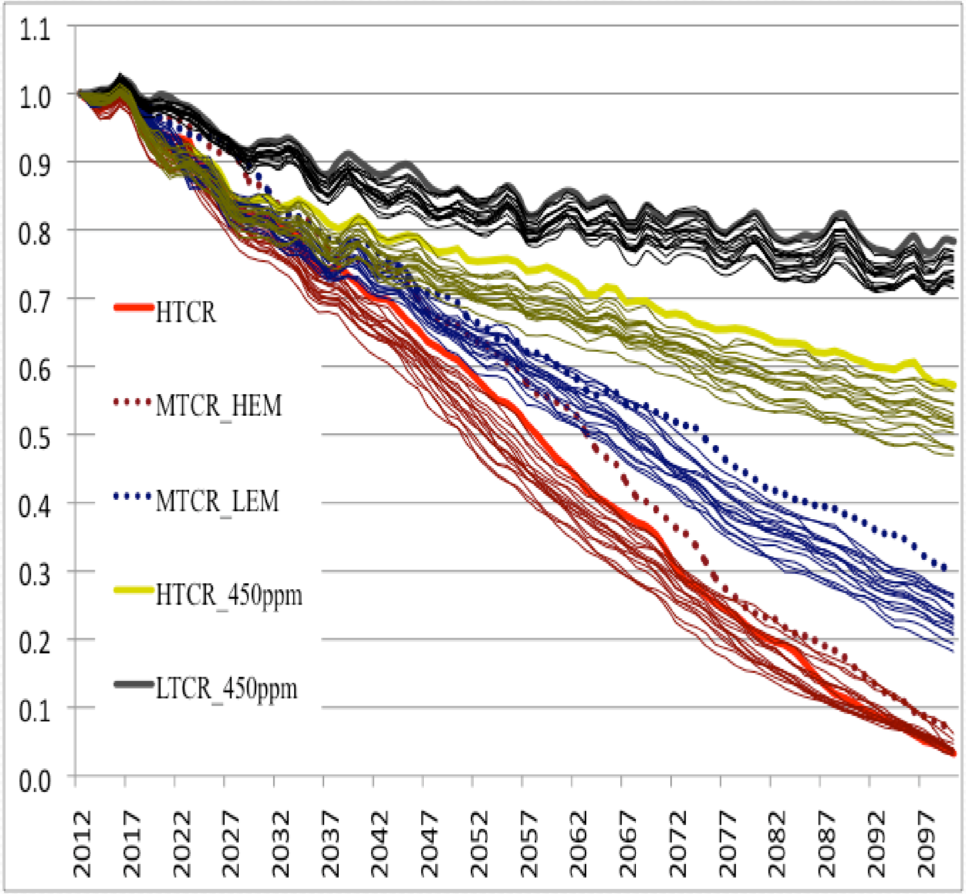
With Policy

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

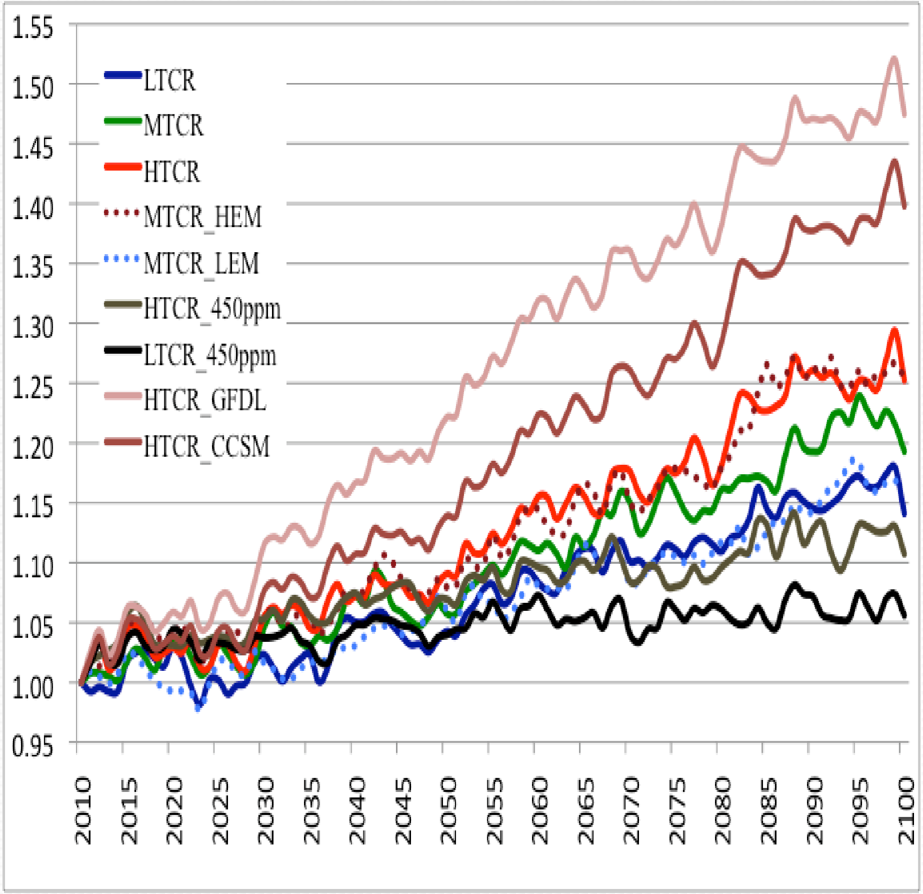
* Nineteen different GCM patterns applied to the high and low TCR in both policy and no-policy scenarios (Schlosser et al., forthcoming)

Fate of Arctic Permafrost and Saturated Area

Relative Change of Permafrost Area



Relative Change of Arctic Saturated Area (North of 45˚N)



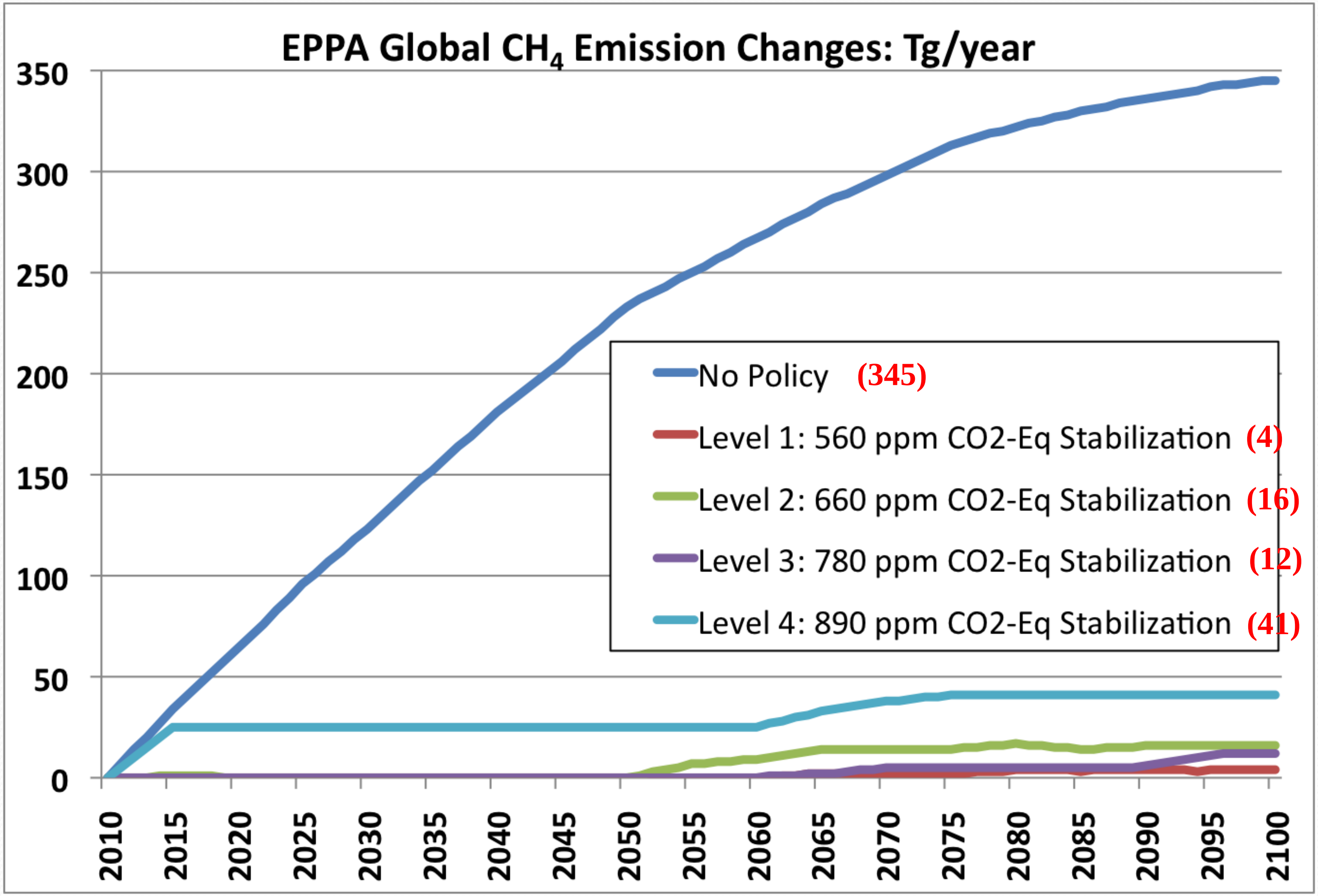
Change in Methane Emission (Tg/yr) due to Implied Thermokarst Expansion (2091~2100 minus 2001~2010)

	LTCR		**MTCR**		**HTCR**		**LEM**		**HEM**		**L450**		**H450**	
	ΔA	ΔE	ΔA	ΔE	ΔA	ΔE	ΔA	ΔE	ΔA	ΔE	ΔA	ΔE	ΔA	ΔE
Y	0.70	0.46	0.81	0.54	1.09	0.72	0.66	0.43	1.00	0.66	0.28	0.19	0.48	0.32
N-Y	13.2	1.99	16.6	2.50	18.8	2.82	13.7	2.05	18.7	2.80	4.61	0.69	9.11	1.37
T		2.45		3.03		**3.54**		2.48		3.46		0.88		**1.68**

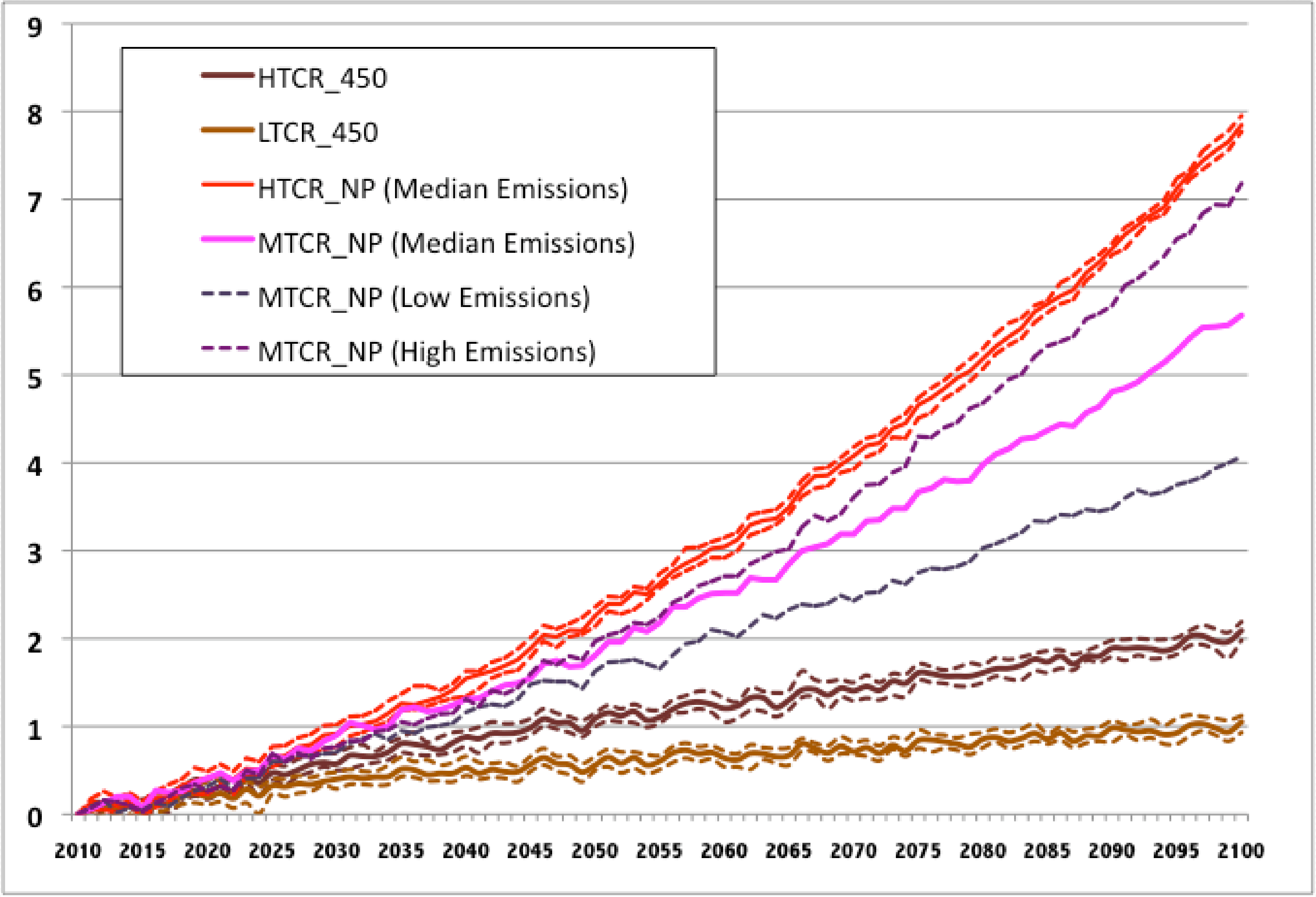
	HTCR(ΔE)			**LTCR(ΔE)**			**H450(ΔE)**			**L450(ΔE)**		
	ccsm	gfdl	miroc	ccsm	gfdl	miroc	ccsm	gfdl	miroc	ccsm	gfdl	miroc
Y	0.81	1.98	1.33	0.52	1.49	0.84	0.26	0.90	0.48	0.11	0.44	0.20
N-Y	3.75	4.33	3.74	2.41	3.19	2.33	1.38	2.00	1.25	0.54	0.85	0.49
T	**4.56**	**6.31**	**5.07**	2.93	4.68	3.16	**1.64**	**2.90**	**1.73**	0.66	1.29	0.69

ΔA: Change in saturated area between two periods; unit is 1.0E+10 m^2, assuming all region is lake-based (no wetland); **ΔE**: Change in methane emission between two periods; unit is Tg/yr; 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)

Emissions Predictions



Impact of Thermokarst-Expansion CH_4 Emission
21st Century Annual Surface-Air Temperature (˚K)



Summary

Under range of uncertainty in TCR, permafrost degradation occurs linearly between 75% (Low TCR) to nearly 100% (high TCR) at 2100 for no policy case. Increase in saturated area occurs between 20% to 30% for the low and high TCR, respectively.

Stabilization policy could prevent permafrost degradation (between 20% to 40%) and saturation area expansion (between 5% and 15%).

GCM patterns usually speed up degradation and thawing process more or less, but act differently for permafrost versus saturated area.

Yedoma permafrost usually does not start to thaw around 2020, but does show different onset of thawing for various scenarios. The lag of thawing among different GCM patterns could reach 5~10 years.

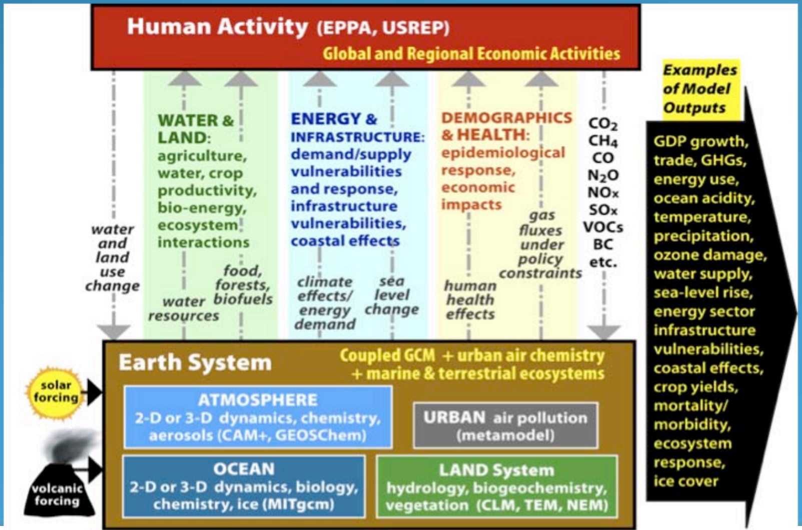
Stabilization policy could effectively reduce the methane emission increase more than half for various scenarios. For no-policy case, increase in methane emission is negligible compared with global CH_4 emission change (~ 345 Tg). However, it could be potentially important for stabilization case (1.7 Tg for HTCR and 3.0 Tg with GCM patterns versus 4 Tg).

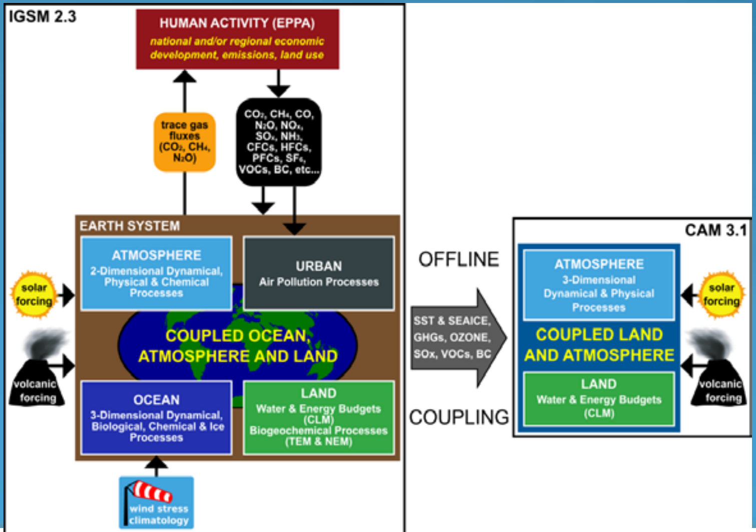
Under the uncertainty of climate sensitivity, emissions, and regional climate changes, our modeled evidence indicates that the increase in CH_4 emission due solely to the expansion of the thermokarst ch4-emitting areas has little (if any)

Impact of Emissions, Land-Use, and Energy Policies on Climate (The Equilibrium Response)

Willow Hallgren, Adam Schlosser, and Erwan Monier

With help/insights from: Andrei Sokolov, Jerry Melillo, David Kicklighter, John Reilly, Angelo Gurgel, Sergey Paltsev, Ben Felzer, and Yongxia Cai





Background

Melillo et al. (2009), based on the IGSM development work of Gurgel et al. (2007), considered future land-use scenarios based on different economic/energy/emissions policies:

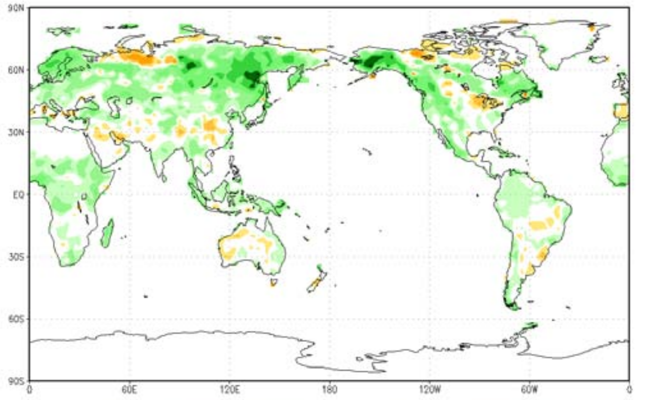
- Pure Conversion Cost Response (PCCR): Allows the conversion of natural areas to meet increased demand for land, as long as the conversion is profitable; a.k.a. "Extensification" – involves less constraint in land supply, price is only factor.
- Observed Land Supply Response (OLSR): Driven by more intense use of existing managed land. a.k.a "Intensification" - involves more constraint (legal, environmental to get new land to convert to agricultural production.
- Both of these land-use trajectories consider two energy-policies: ***With and without the inclusion of cellulosic biofuel penetration*** into the global energy resource portfolio.
- These linked ecologic-econometric scenarios were driven by a climate forced under a modest stabilization policy (~650 ppm CO_2-eq stabilization by 2100).

Equilibrium Simulations with CAM3.1 coupled to a slab ocean model:

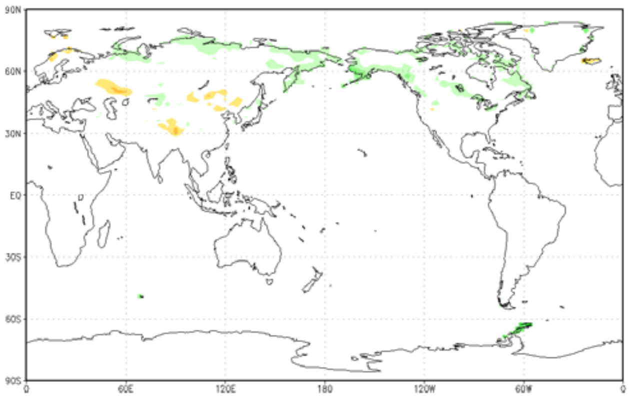
- Ran CAM-SOM-CLM for 50 years (after spin-up) for both 1990 and 2050 trace-gas concentrations (taken from the Melillo et al. results) with corresponding land conditions (@ 1990 or 2050) taken from the above land-use scenarios.
- A run was also performed at 2050 trace-gas conditions with no land-use change.
- A run was also performed at 1990 trace-gas conditions with default CLM

ALBEDO Changes: PCCR Case

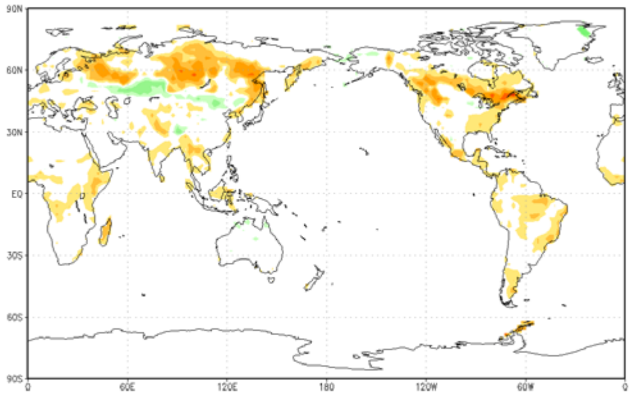
1990 Trace-Gas Forcing
IGSMVeg-CLM 1990 Land Cover



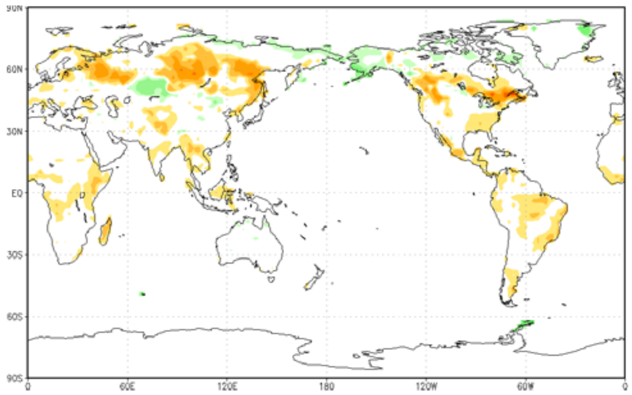
2050-1990 Trace-Gas Forcing
No Land-Cover Change

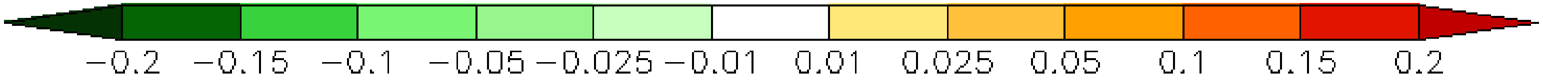


2050 Trace-Gas Forcing
2050-1990 Land Cover Change



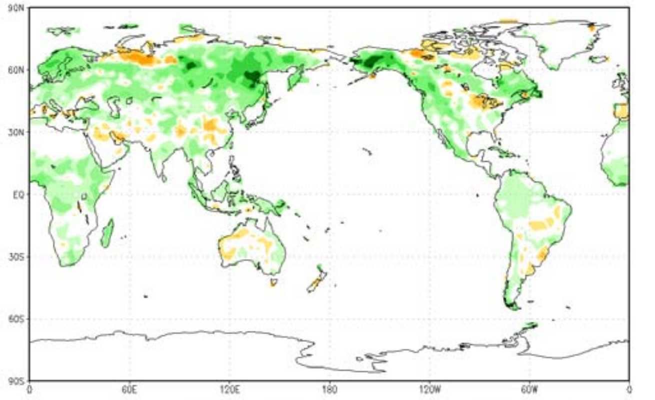
2050-1990 Trace-Gas Forcing
2050-1990 Land Cover Change



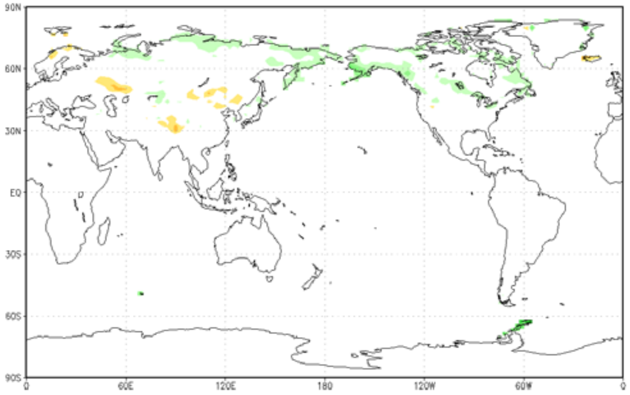


ALBEDO Changes: OLSR Case

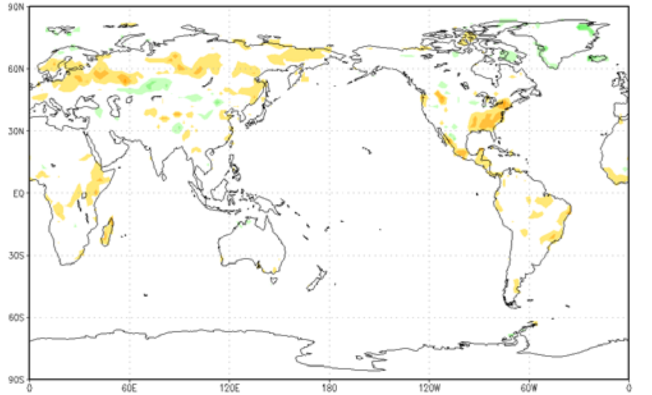
1990 Trace-Gas Forcing
IGSMVeg-CLM 1990 Land Cover



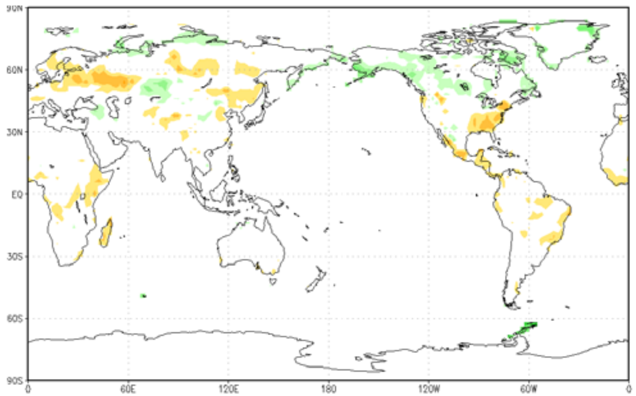
2050-1990 Trace-Gas Forcing
No Land-Cover Change

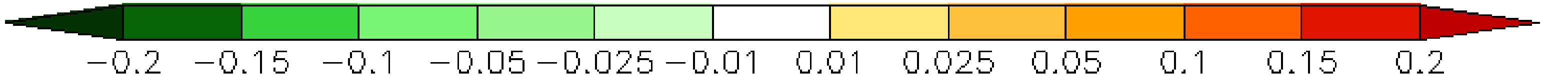


2050 Trace-Gas Forcing
2050-1990 Land Cover Change



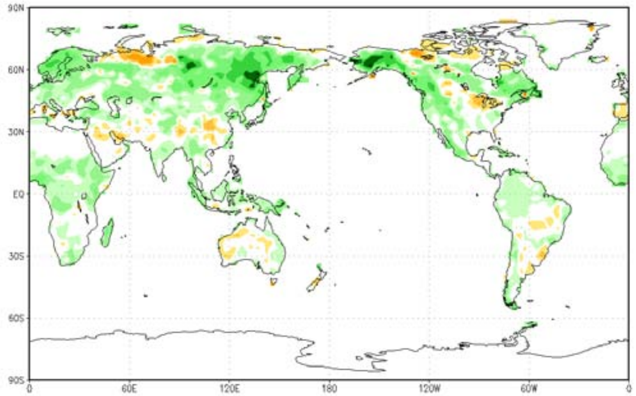
2050-1990 Trace-Gas Forcing
2050-1990 Land Cover Change



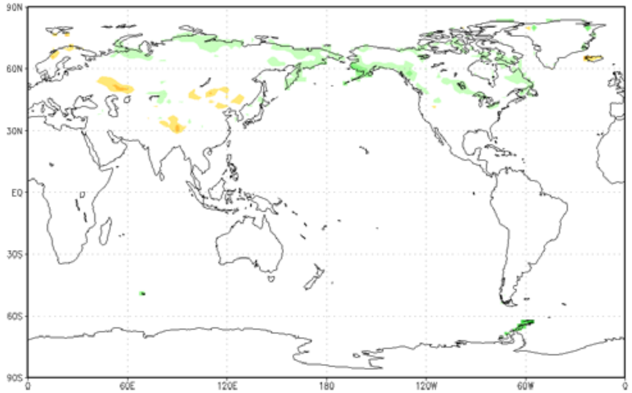


ALBEDO Changes: OLSR-NB Case

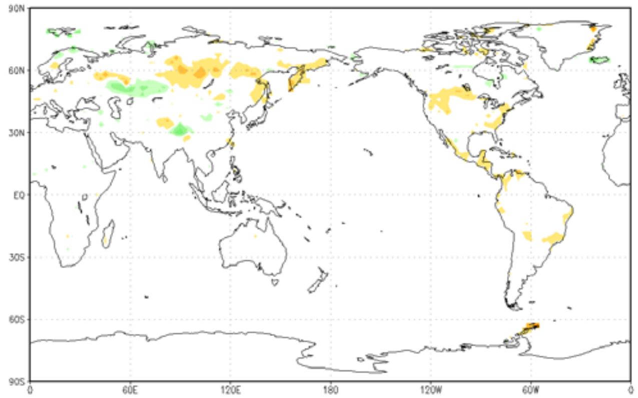
1990 Trace-Gas Forcing
IGSMVeg-CLM 1990 Land Cover



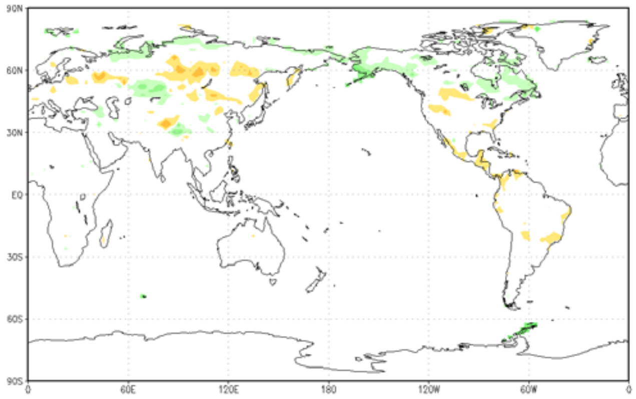
2050-1990 Trace-Gas Forcing
No Land-Cover Change

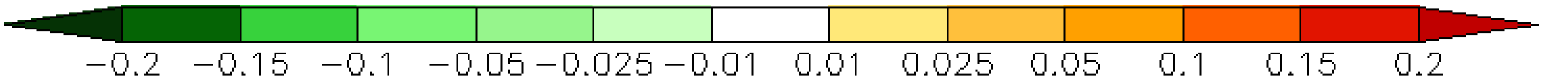


2050 Trace-Gas Forcing
2050-1990 Land Cover Change

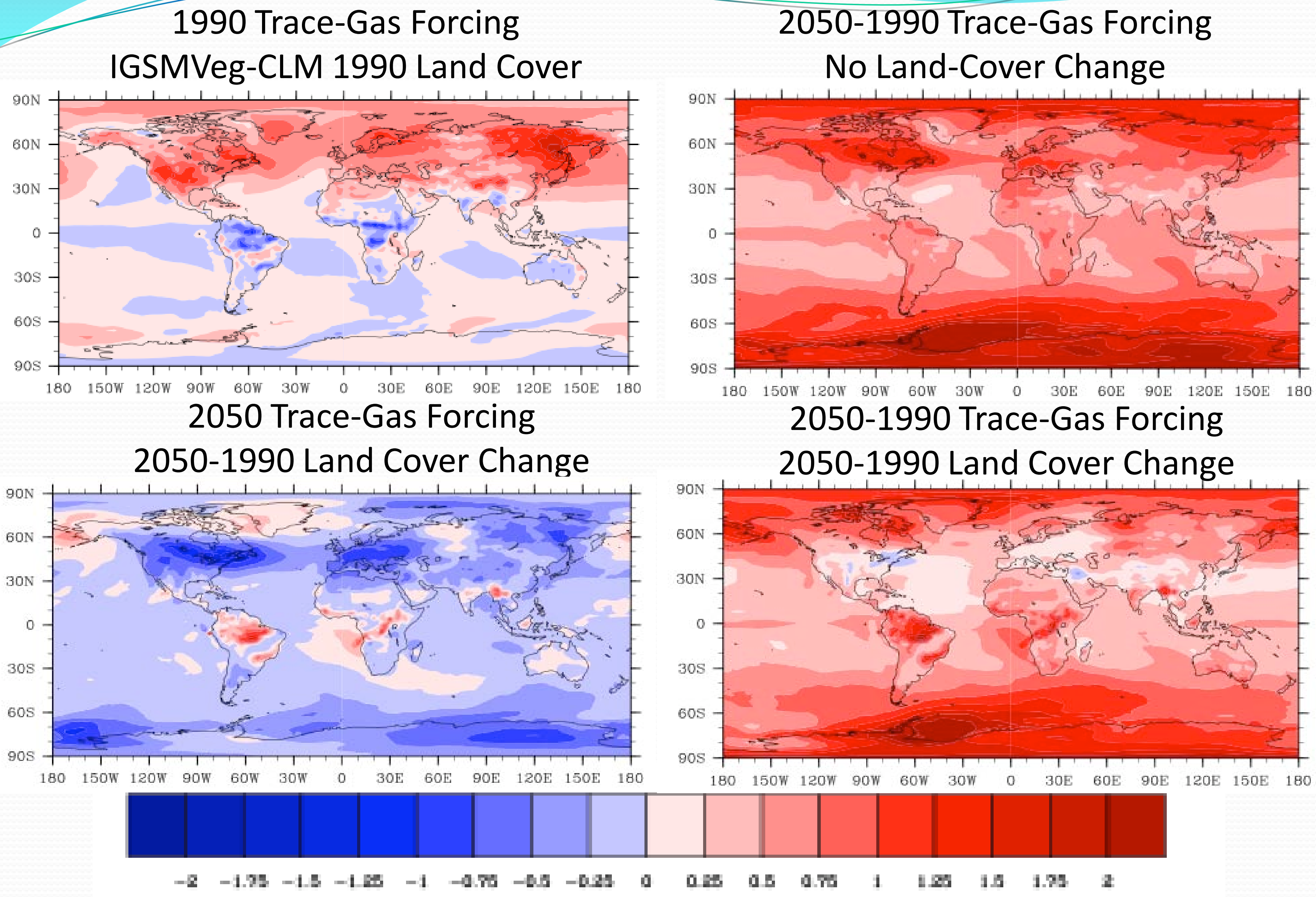


2050-1990 Trace-Gas Forcing
2050-1990 Land Cover Change





Surface-Air Temperature Changes (˚K): PCCR Case



1990 Trace-Gas Forcing
IGSMVeg-CLM 1990 Land Cover

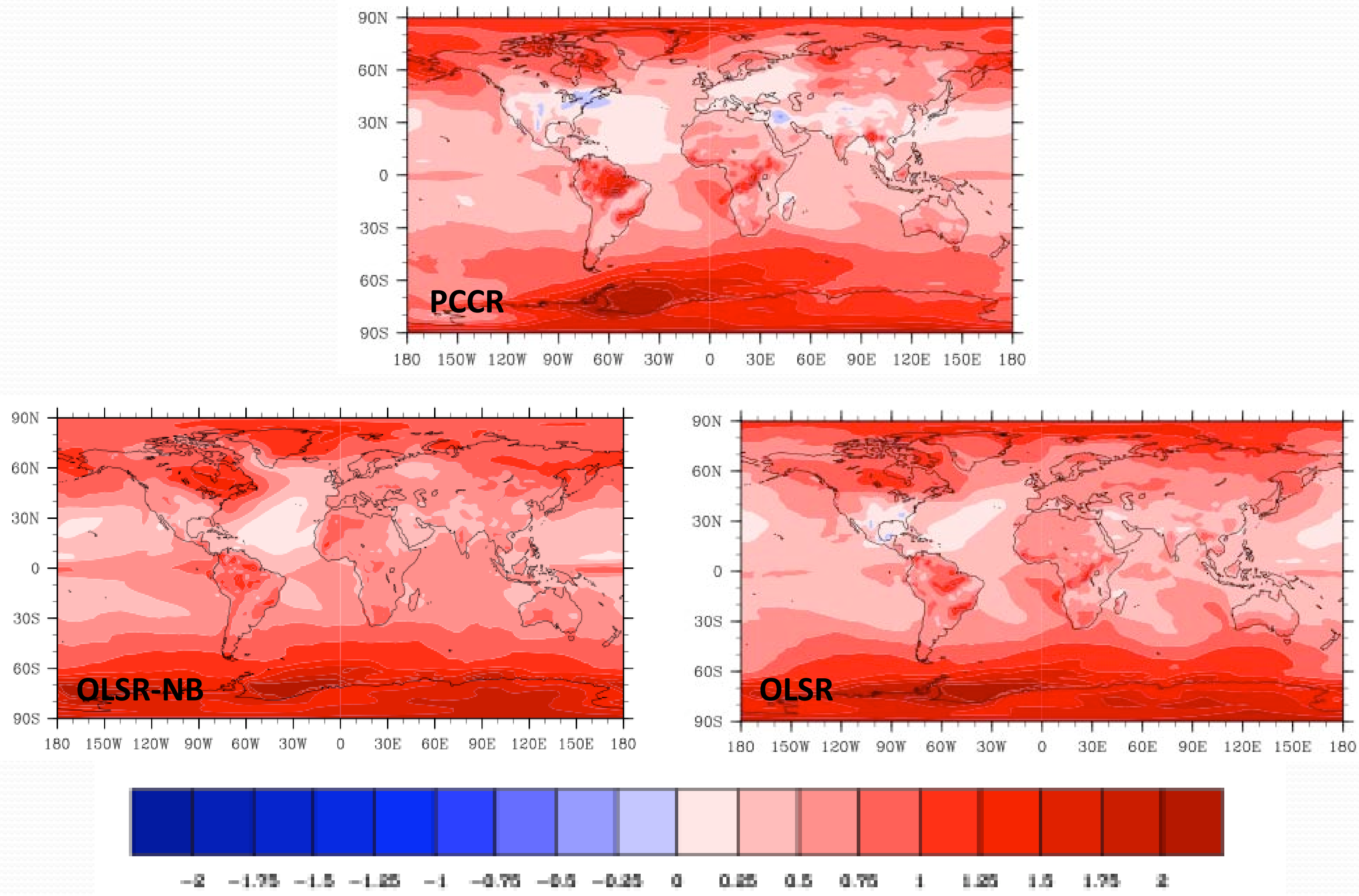
2050-1990 Trace-Gas Forcing
No Land-Cover Change

2050 Trace-Gas Forcing
2050-1990 Land Cover Change

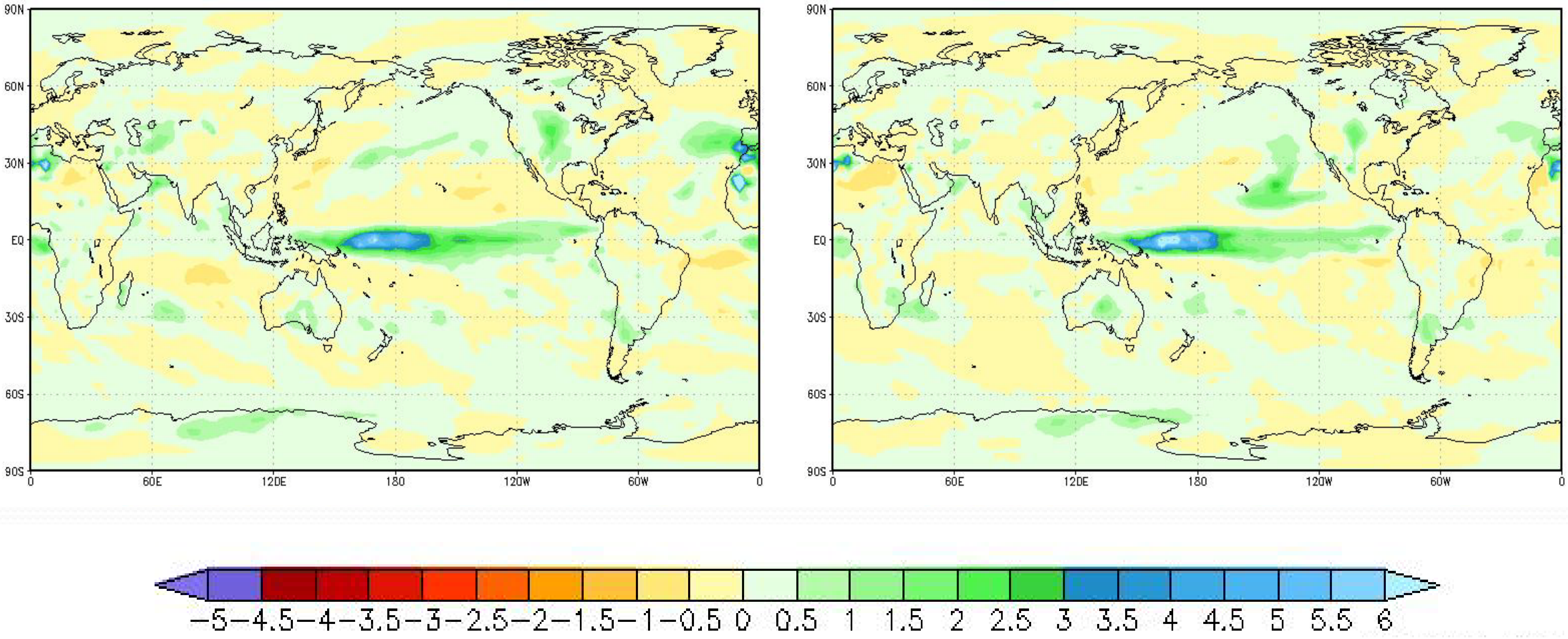
2050-1990 Trace-Gas Forcing
2050-1990 Land Cover Change

Surface-Air Temperature Changes (˚K)

2050-1990 Trace-Gas Forcing and 2050-1990 Land Cover Change



Precipitation Changes (mm/day)



OLSR

PCCR

Remarks/Caveats

- No explicit crop treatment
    - Physiology
    - Phenology
    - Irrigation
- TEM vs. CLM4 (or CLM-CN or whatever…)
    - NPP response
- Quasi-linked framework between IGSM land-use scenarios and CAM-SOM equilibrium runs.
    - Follow-up runs will address the more egregious features.
- Uncertainty in regional climate
    - Adopt framework used for thermokarst study