Quantification of Arctic Terrestrial Biosphere Methane Emissions and Their Feedbacks to the Global Climate System

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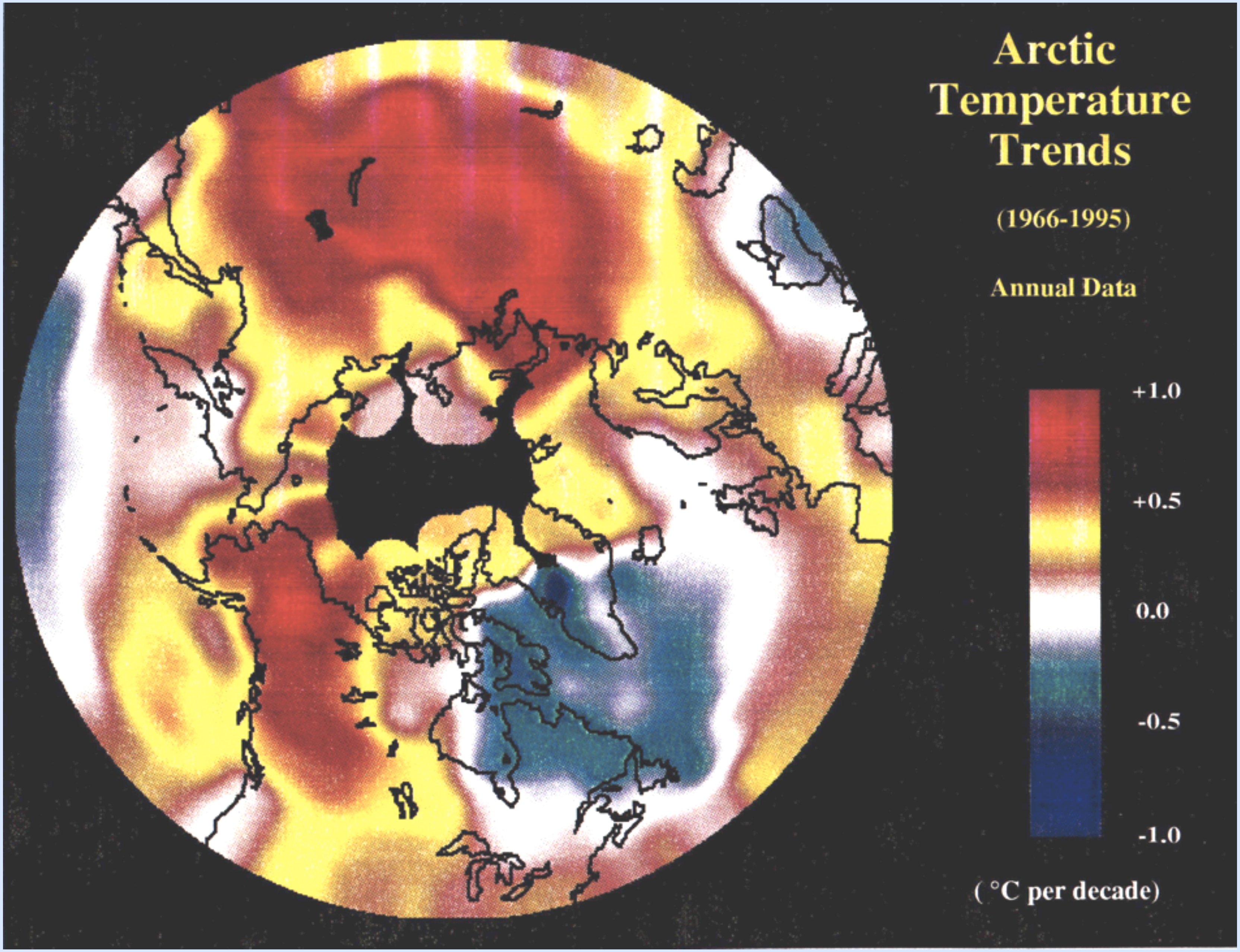


Serreze et al., 2000, Climatic Change

Ecosystems in Northern High Latitudes

- Large vulnerable carbon pool (~1/3 of world soil *C*)
- Large wetland distribution (~1/2 of world wetlands)
- Longer growing season (1-4 days /decade)
- Changing vegetation (e.g., moving treeline)

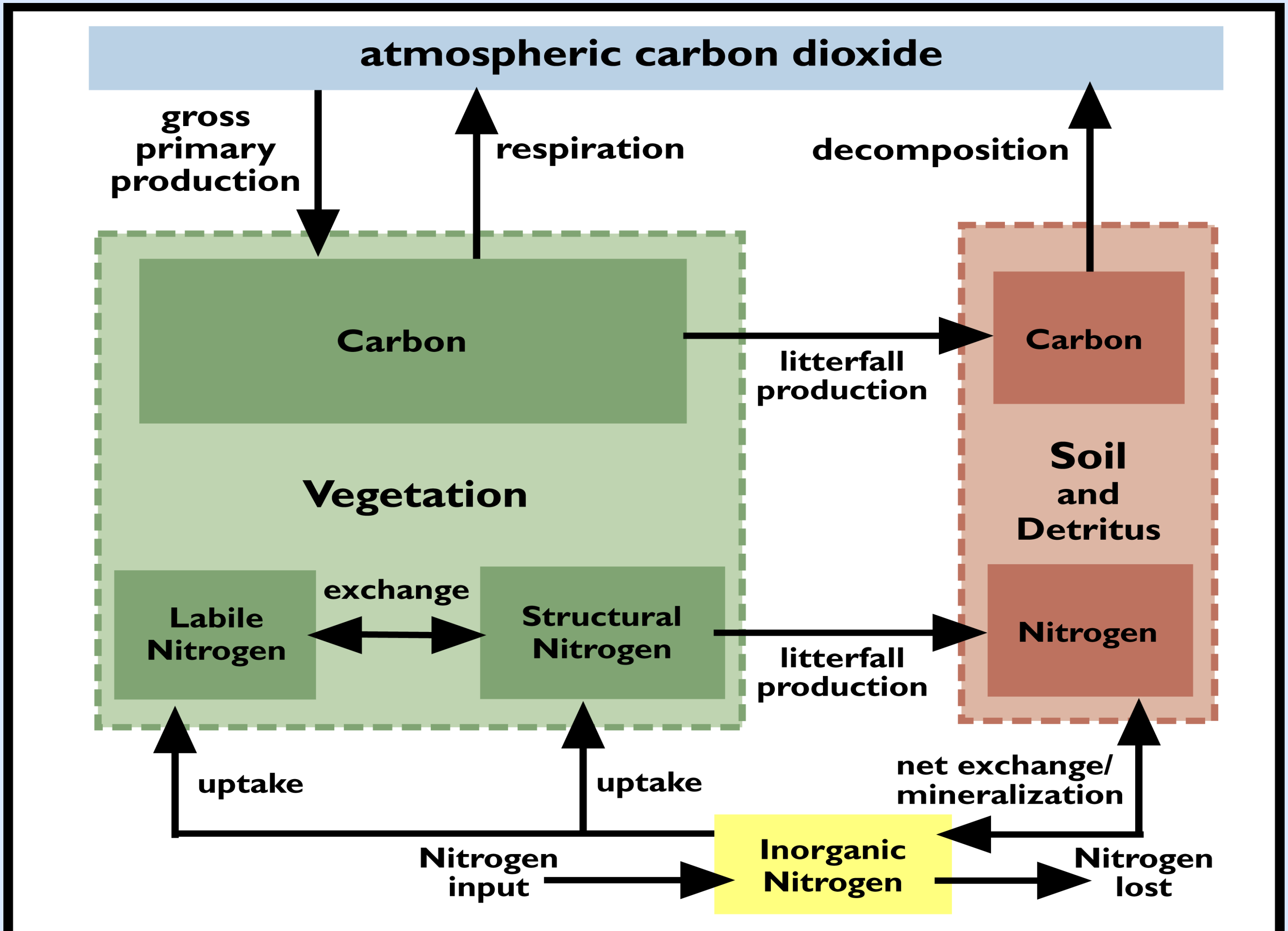
Large-Scale Processes in the Region

- Permafrost thawing (~1/4 of areas underlain by permafrost)

- Fire disturbance increase (~1% yr^{-1})

Questions

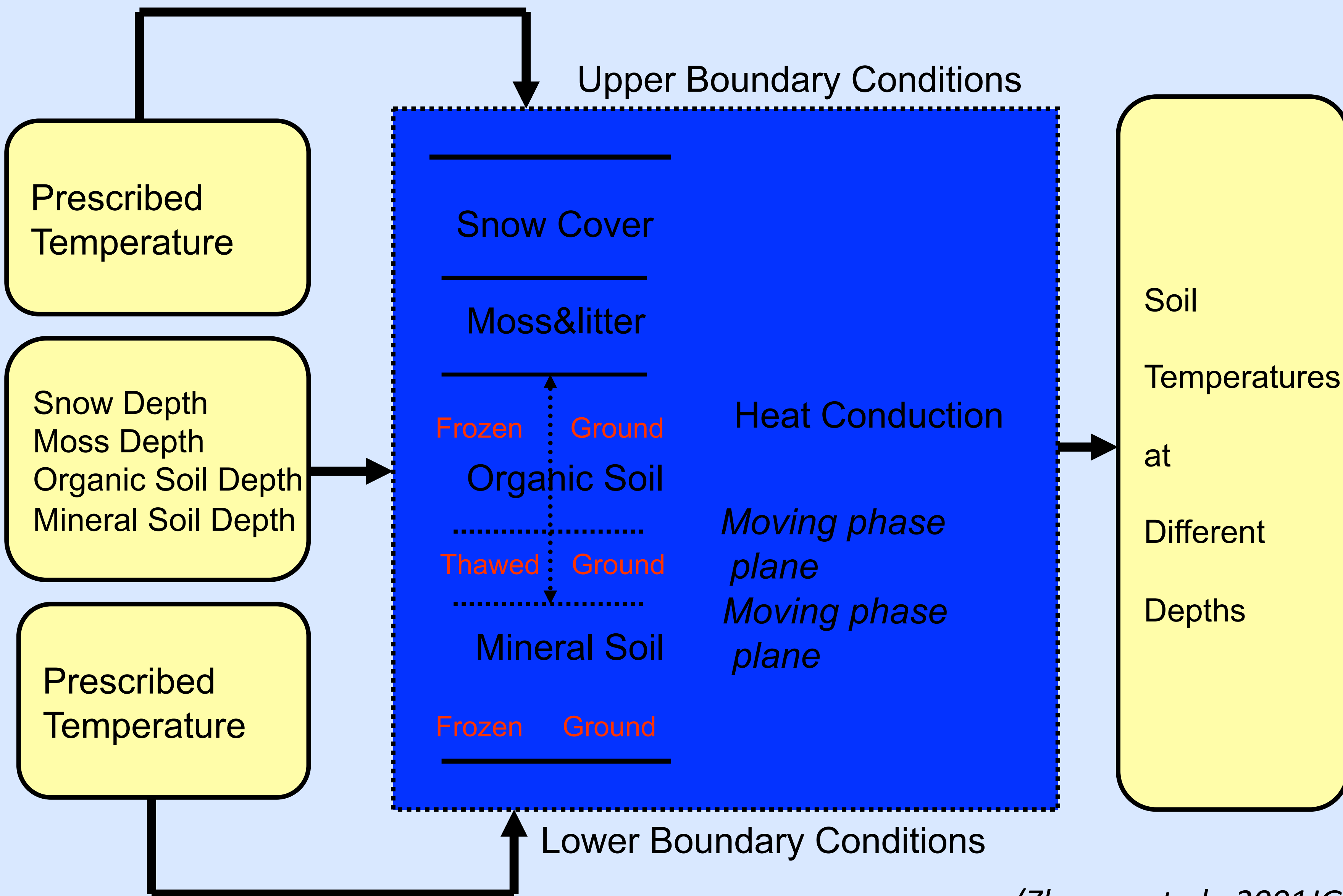
- What is the current GHG budget (CO_2 and CH_4) for the region?
- How will net CO_2 and CH_4 fluxes change over the 21st century?
- How will the GHG budget change and affect the global climate system over the 21st century?



Terrestrial Ecosystem Model (TEM)

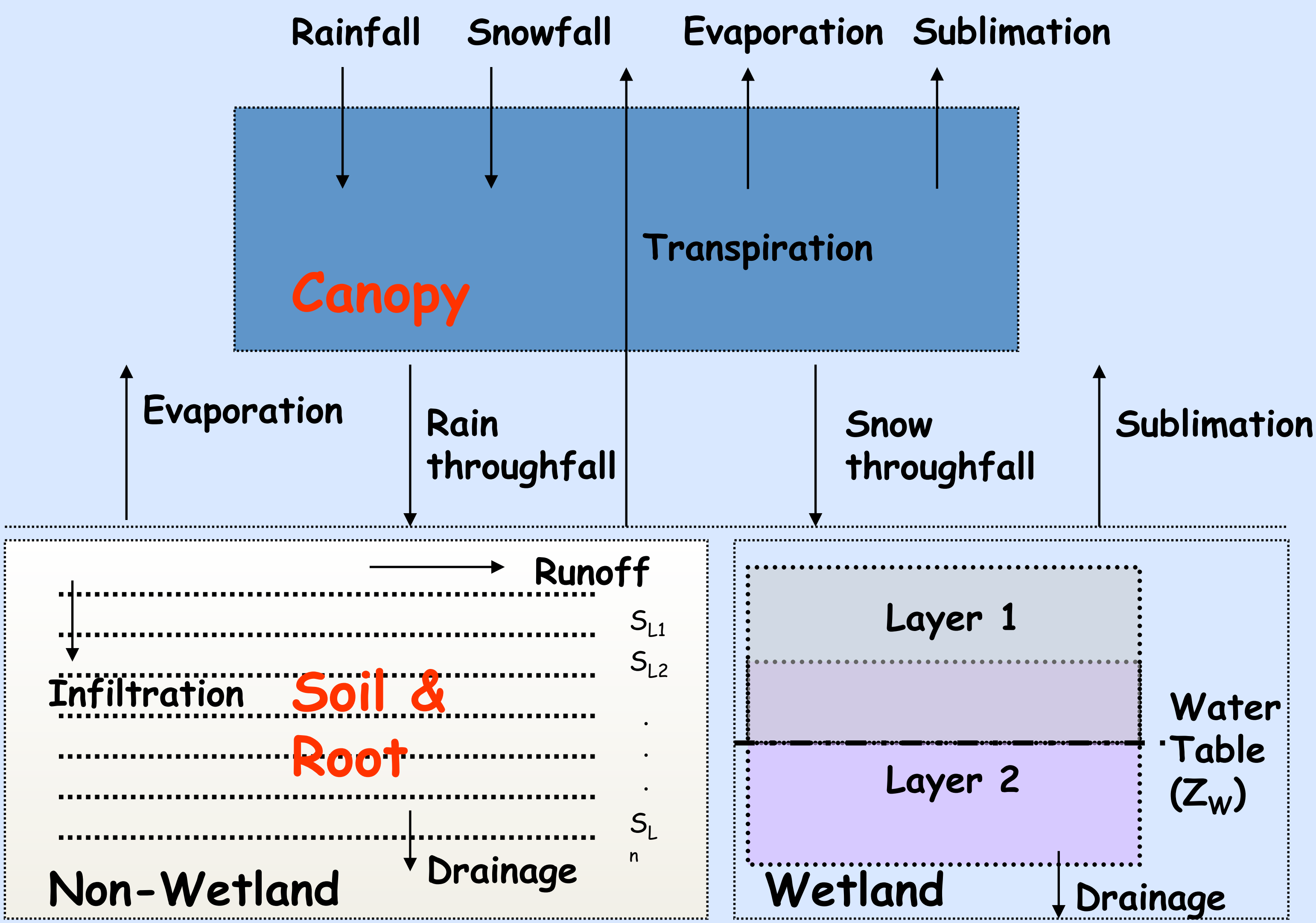
The Ecosystems Center, Marine Biological Laboratory (Woods Hole, Massachusetts)

Soil Thermal Model



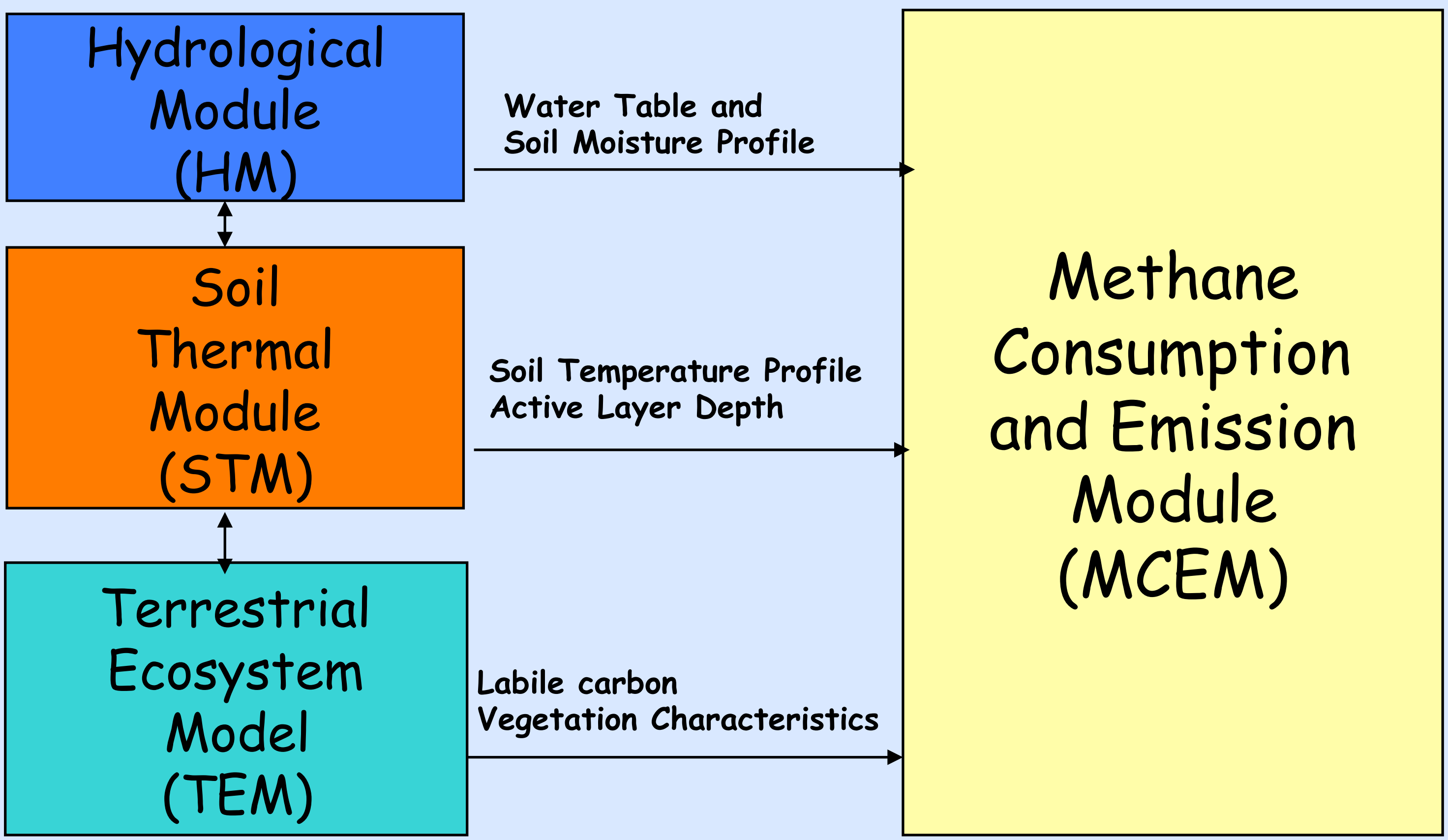
(Zhuang et al., 2001JGR)

Updated Hydrological Model



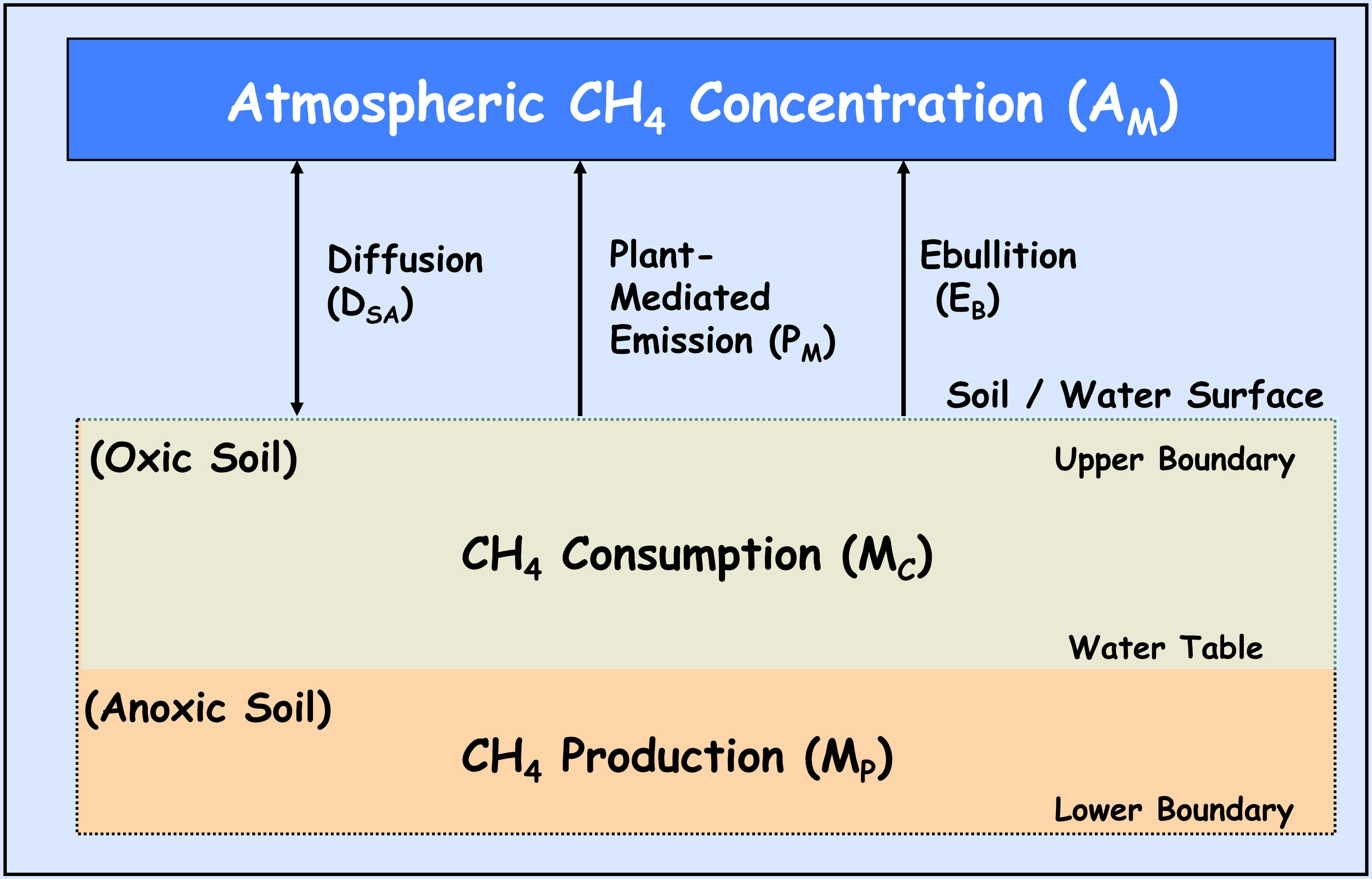
(Zhuang et al., 2002JGR, 2004GBC)

Methane Model Framework



(Zhuang et al., 2004GBC)

Methane Consumption and Emission Module



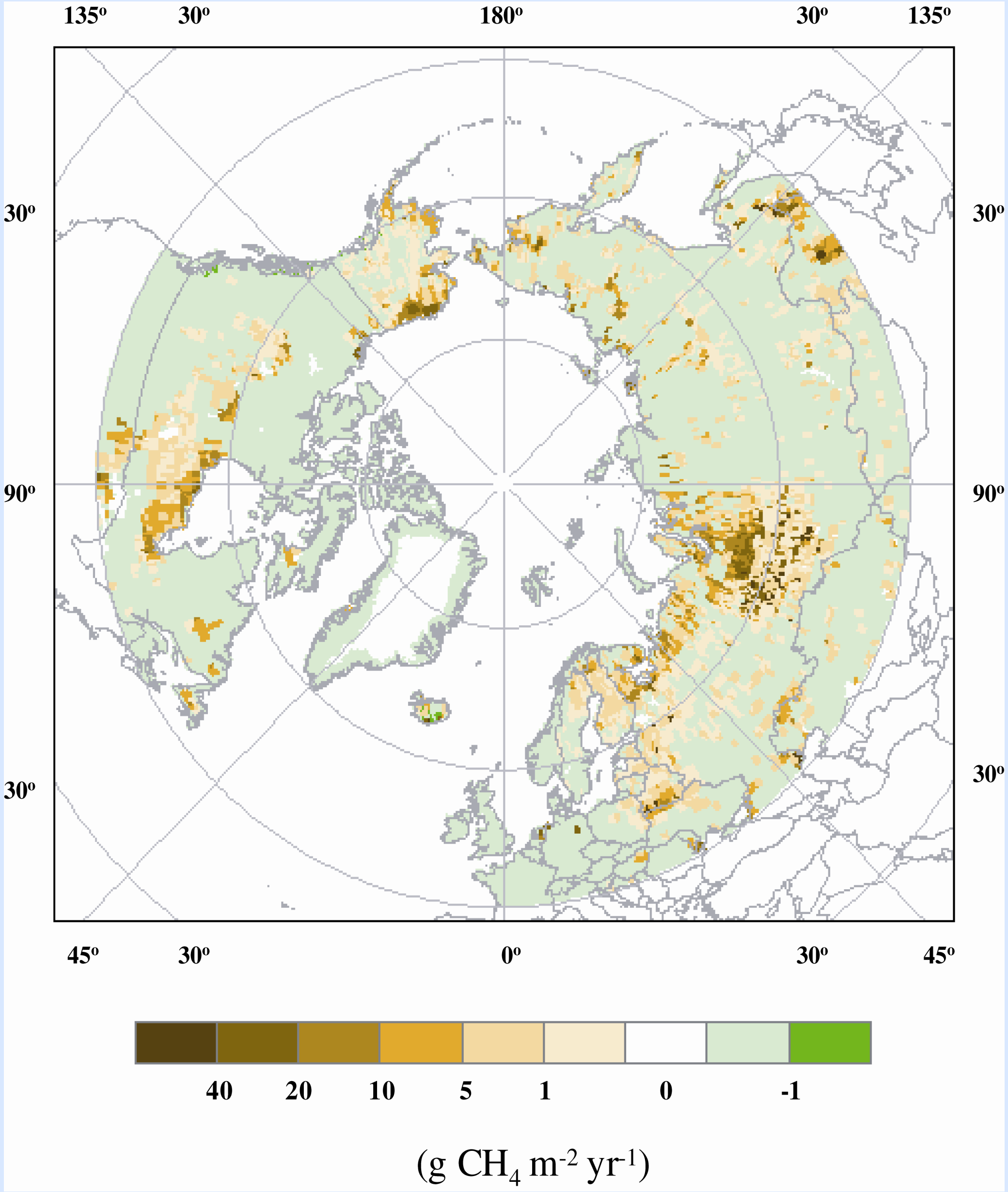
(Zhuang et al., 2004 GBC)

Net Methane Fluxes in the 1990s

Emissions
= 56 Tg CH_4 yr^{-1}

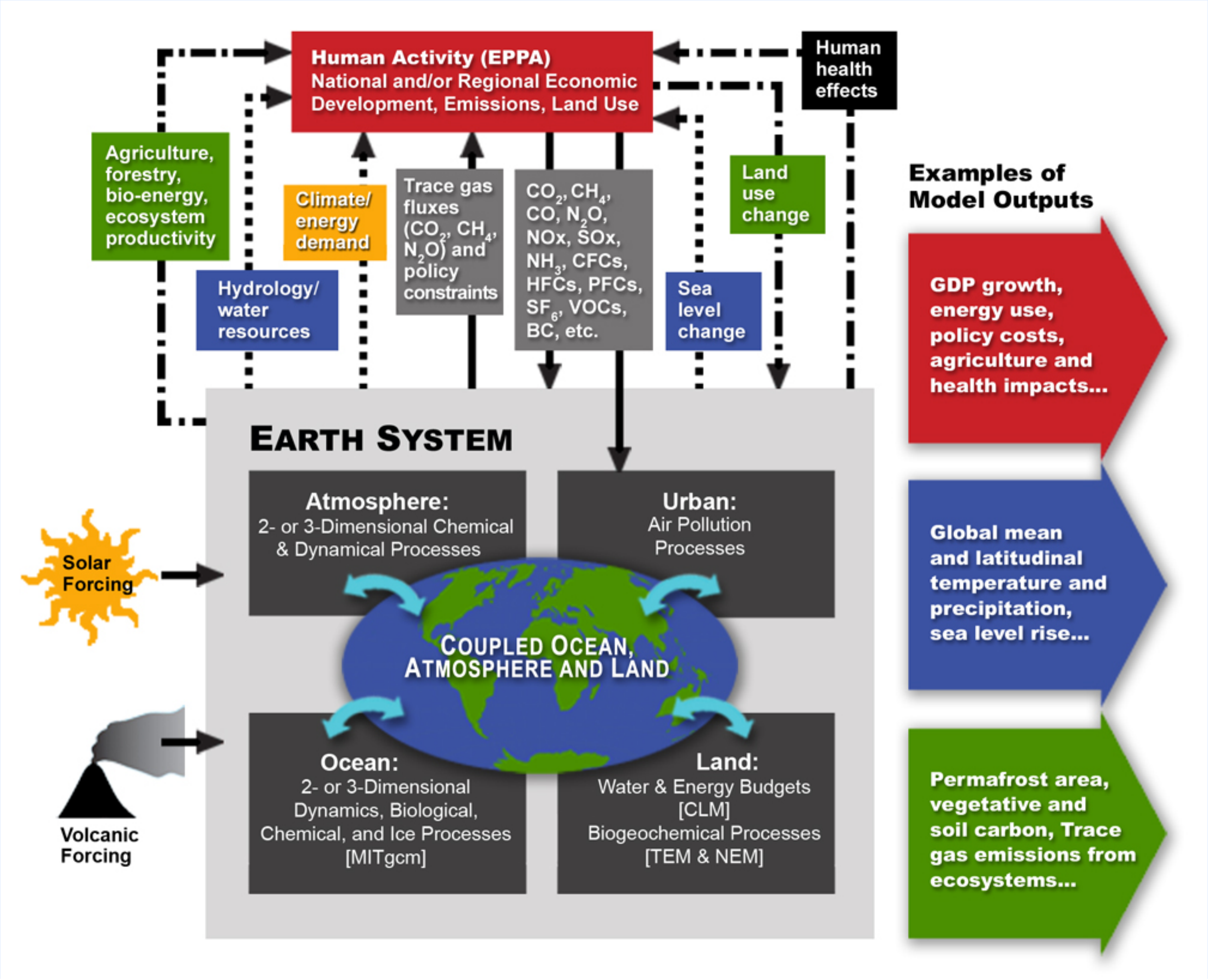
Consumption
= -7 Tg CH_4 yr^{-1}

Net Methane Fluxes
= 49 Tg CH_4 yr^{-1}



(Zhuang et al., 2004GBC)

MIT Integrated Global System Model

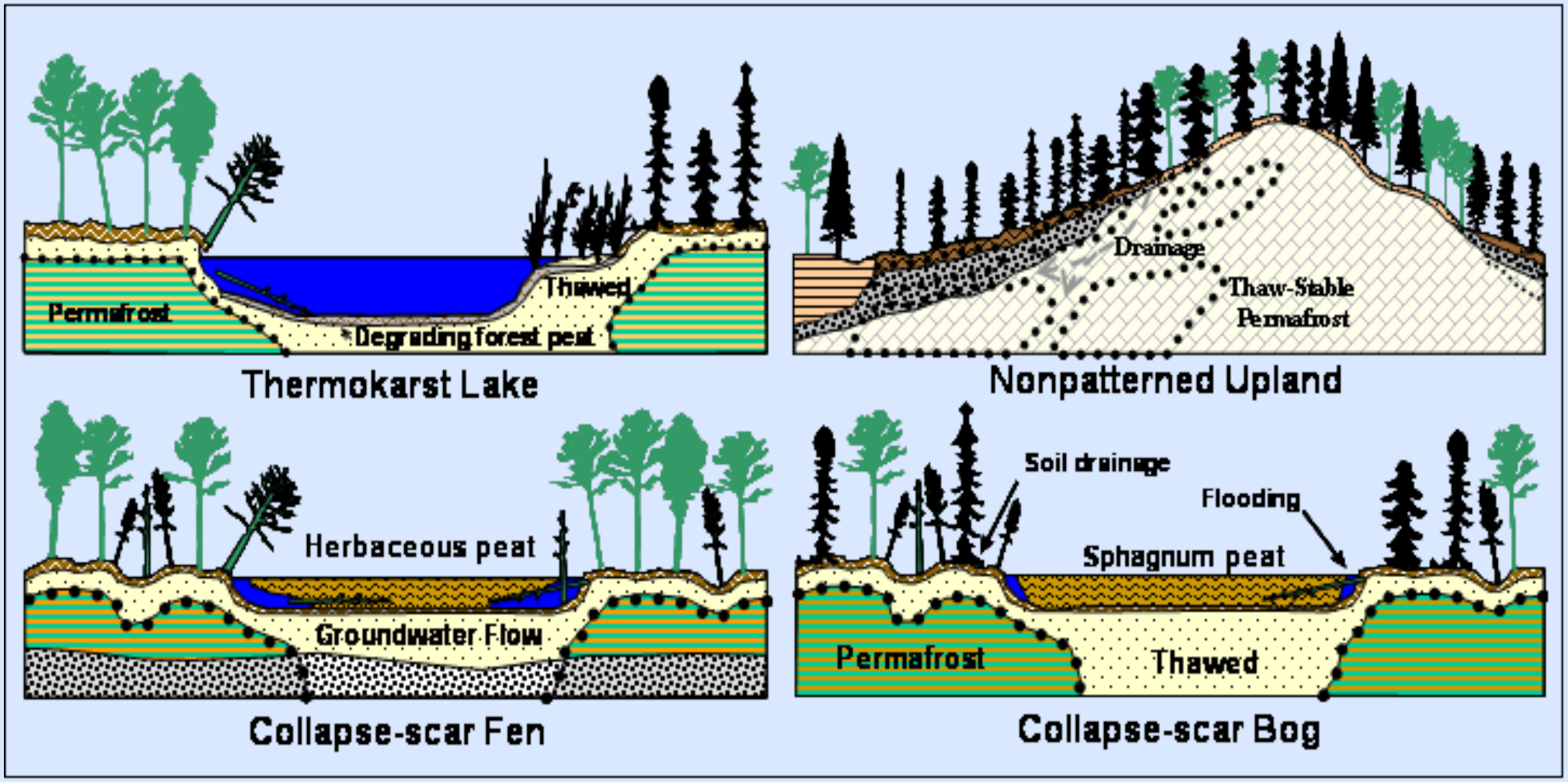


GHG Changes and Their Global Radiative Forcing over the 21st Century

Anthropogenic Emissions	CO_2 fertilization effect			No CO_2 fertilization effect		
	$\Delta[CH_4]$ (ppm)	$\Delta[CO_2]$ (ppm)	ΔF (W/m^2)	$\Delta[CH_4]$ (ppm)	$\Delta[CO_2]$ (ppm)	ΔF (W/m^2)
High	0.35	-19	-0.065	0.25	0.7	0.047
Intermediate	0.18	-5.1	-0.006	0.15	3.3	0.073
Low	0.06	-1.6	-0.005	0.05	2.1	0.044

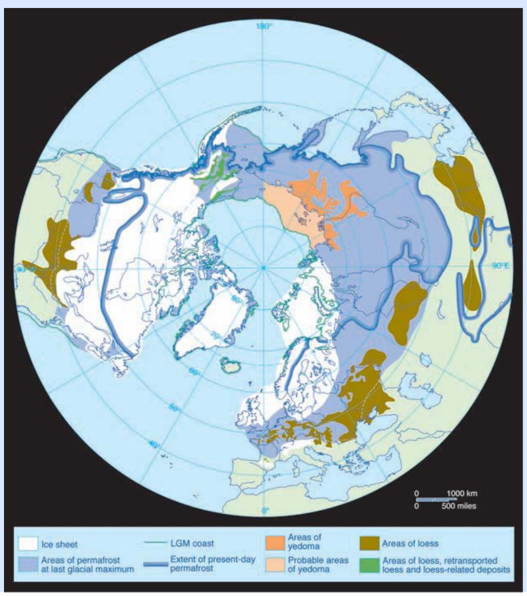
(Zhuang et al., 2006 GRL)

Changes in Hydrology, Soils, and Vegetation with Varying Modes of Permafrost Degradation



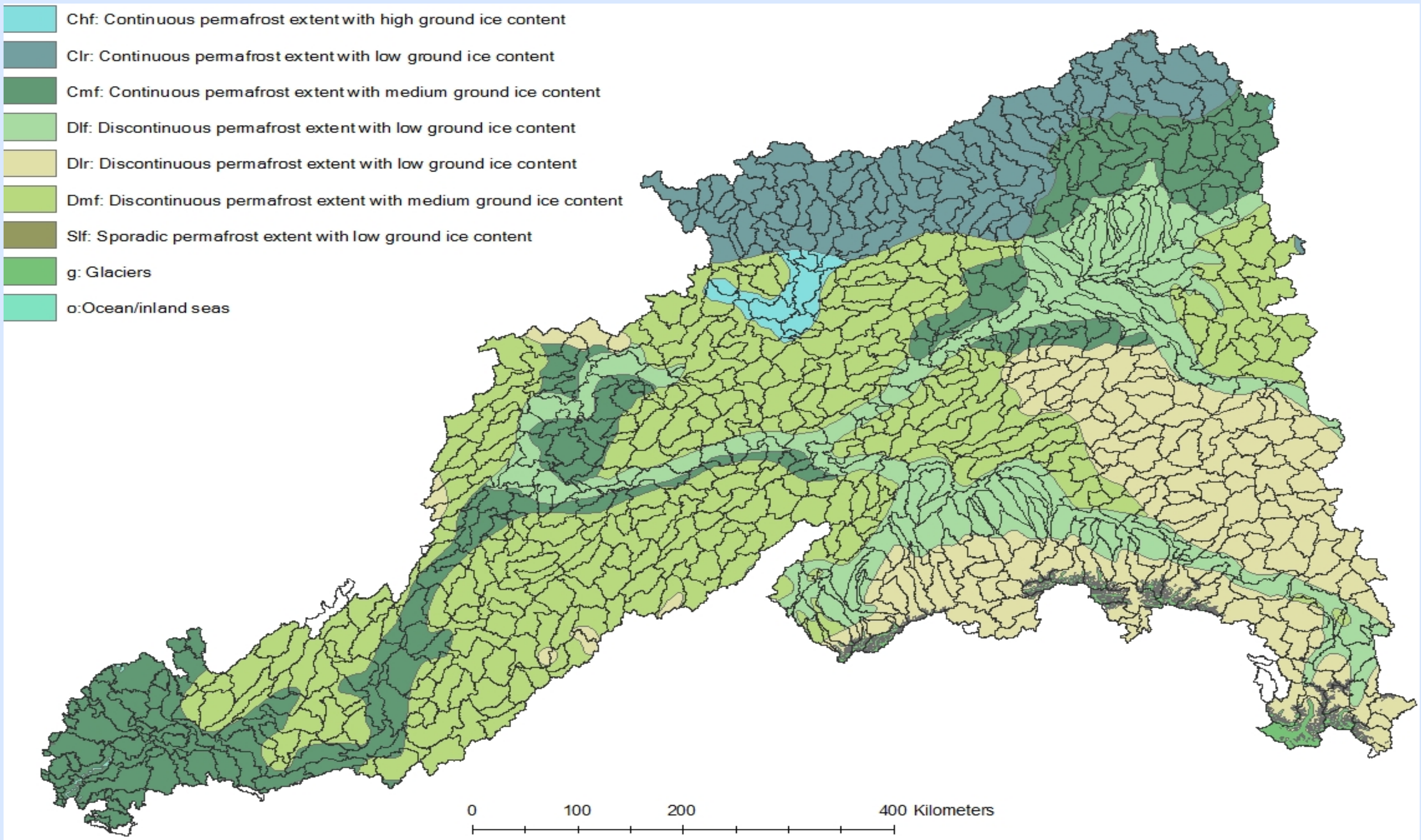

Innoko Flats
Lateral Degradation
Water redistribution:
Impoundments
Drier uplands

Sergey Zimov, director of the Northeast Science Station in Siberia, examining a cross-section of yedoma, carbon trapped in permafrost, along the bank of the Kolyma River in Siberia.
The shiney surface of the cliff represents massive ice wedges.
The dark sections in between are soil inclusions which contain ice-age organic carbon, left over from the Pleistocene steppe-tundra ecosystem.
Organic carbon when deposited into lake bottoms provides food for bacteria that produce methane.
Some scientists believe that as this organic matter becomes exposed to the air it will accelerate global warming faster than even predicted in the most pessimistic forecasts.
Photo: Nature, Katey Walter



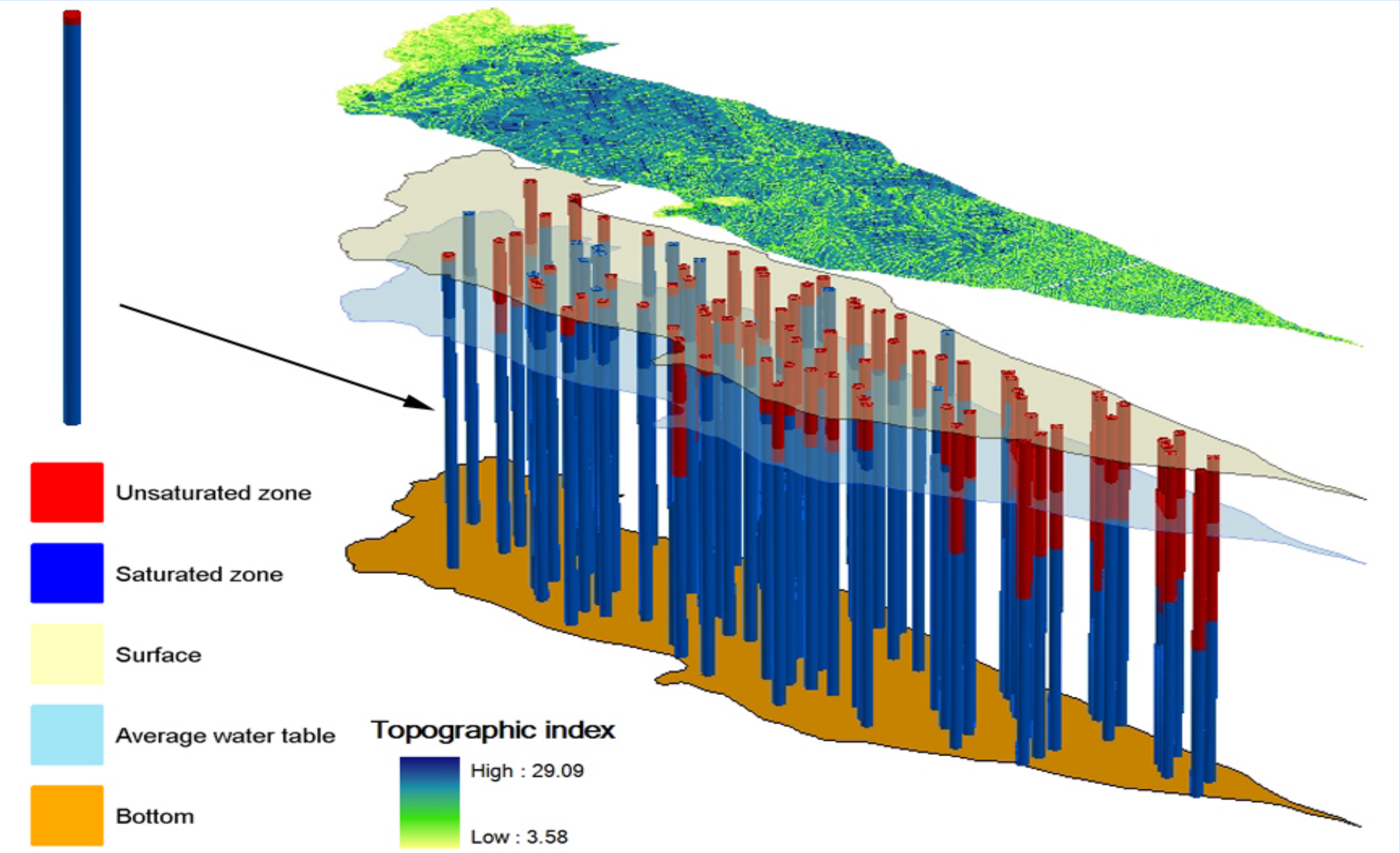
Areas of Permafrost,loess (brown), and yedoma (orange) contain a large amount of carbon in northern high latitudes (Walter et al., 2007).

Distribution of Permafrost and Ground-ice Conditions and Watersheds in the Yukon River Basin

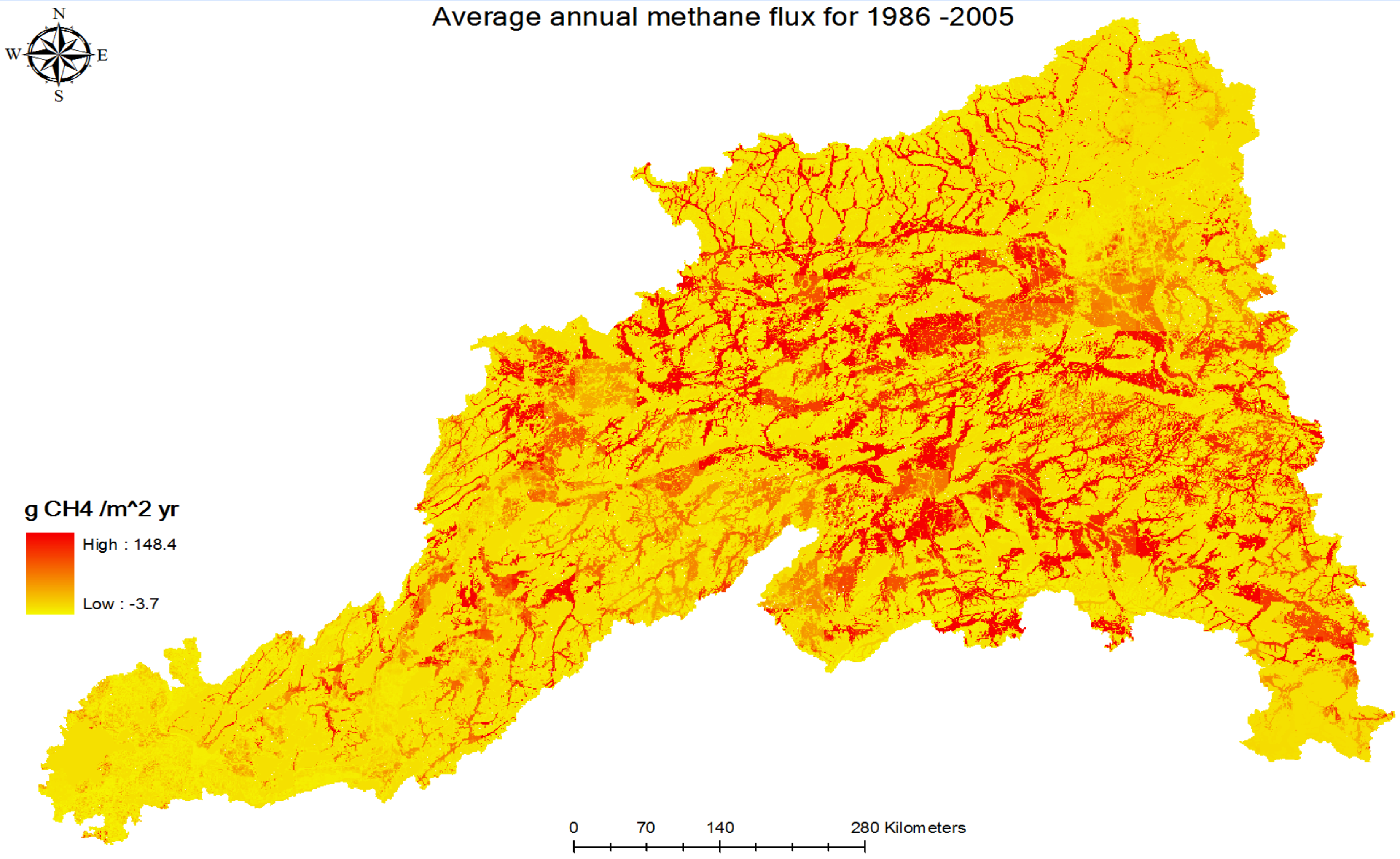


(Lu and Zhuang, 2011JGR-Biogeoscience in review)

Water Table Distribution of a Watershed on August 2, 2004



Annual Methane Fluxes in the Yukon River Basin during 1986-2005



(Positive values are emissions and negative values are oxidation)

Conclusions and Next Steps

- The Arctic GHG feedback is more complex than previously thought – the net feedback is the balance between a set of negative and positive feedbacks
- Positive feedbacks might include the enhanced aerobic and anaerobic decomposition of organic carbon and the fire effects
- Negative feedbacks include the CO2 and nitrogen fertilization effects
- Deep recalcitrant and labile carbon and yedoma carbon should be considered to adequately quantify the GHG dynamics
- Complex dynamics of hydrology and landscape due to permafrost degradation should be incorporated into the biogeochemistry modeling

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