Representing permafrost affected ecosystems in the CLM:

An example of incorporating empirical ideas into the CLM

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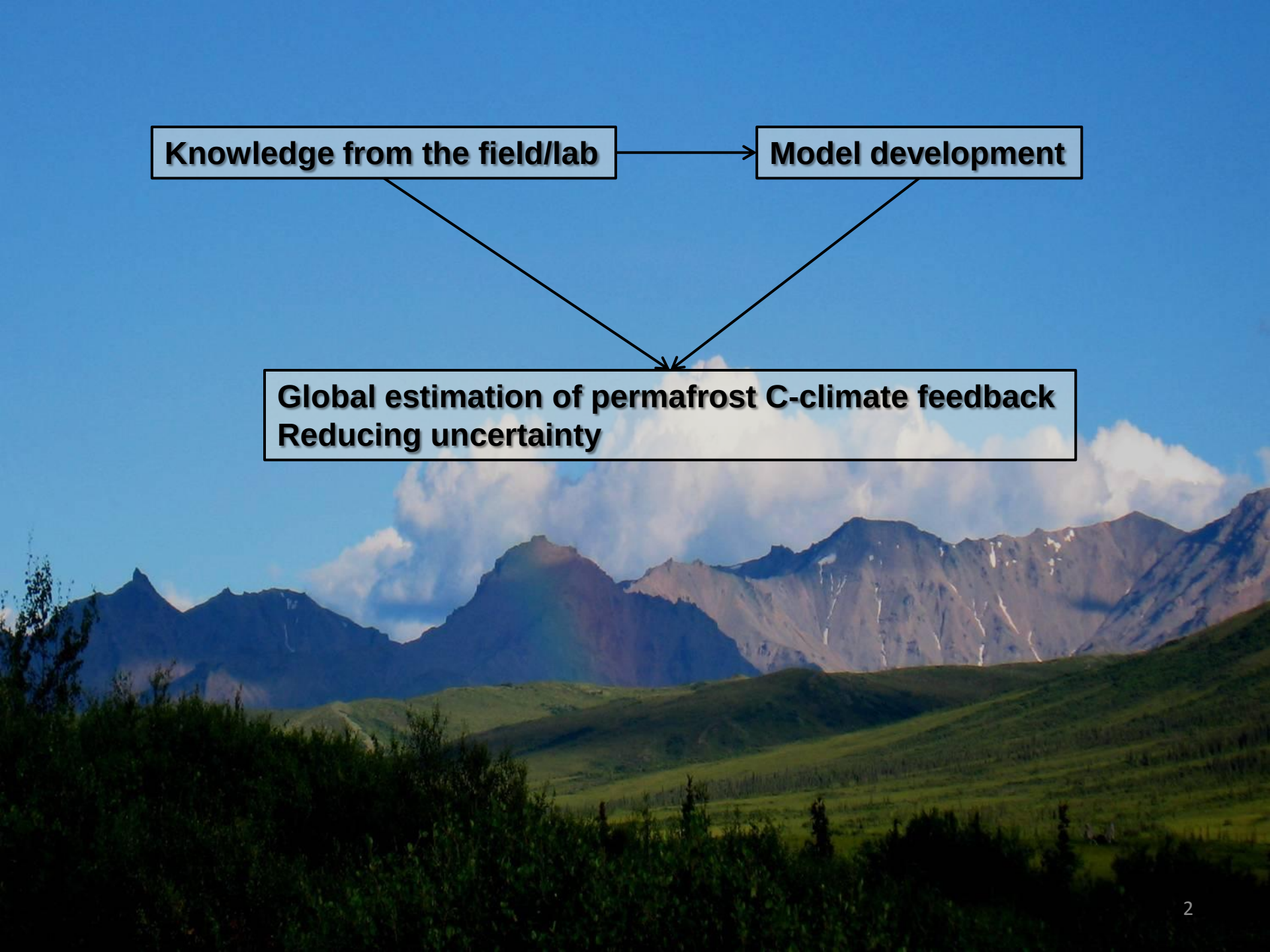

Knowledge from the field/lab
Model development
Global estimation of permafrost C-climate feedback
Reducing uncertainty

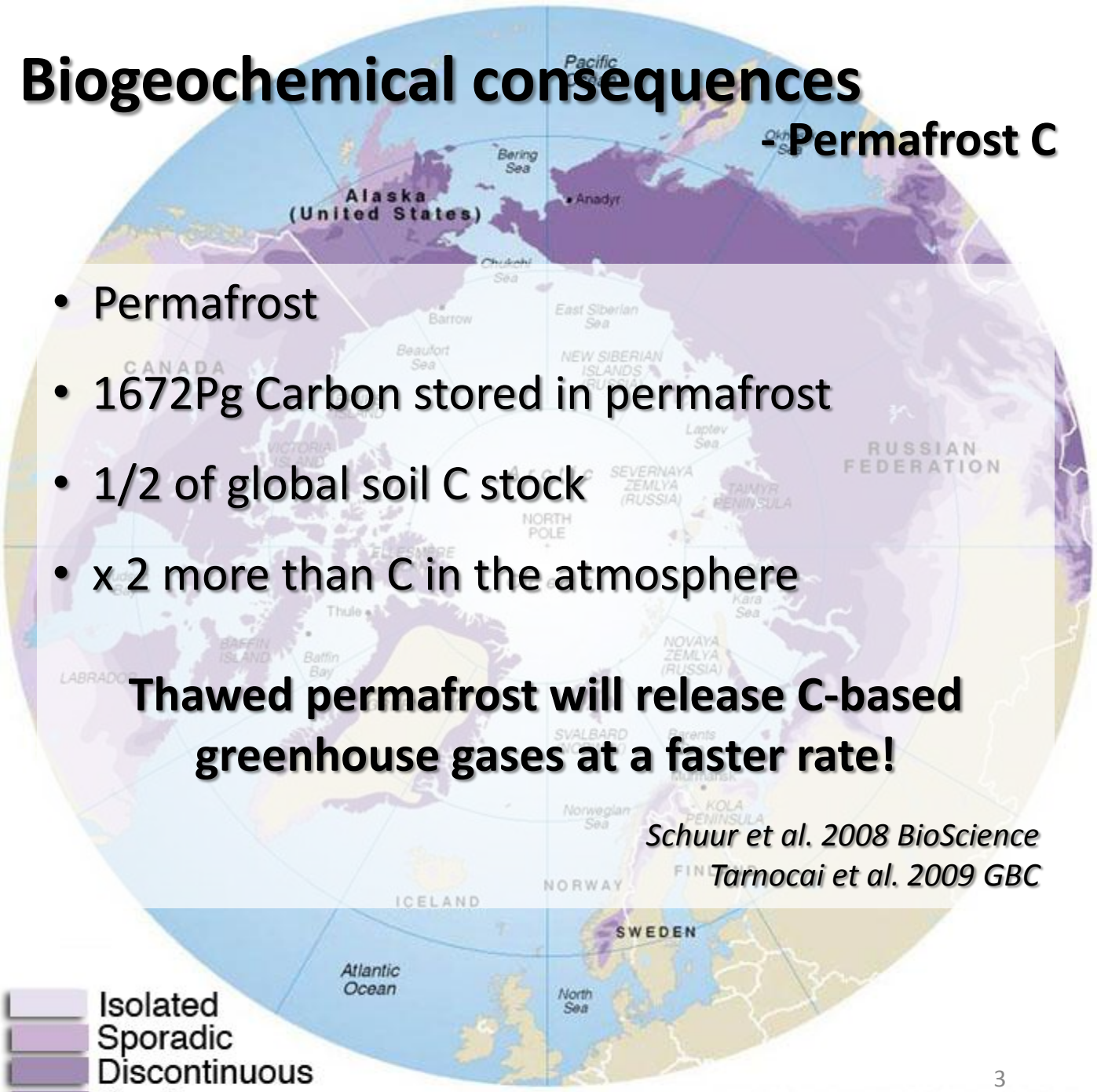
Biogeochemical consequences

-Permafrost C

- Permafrost
- 1672Pg Carbon stored in permafrost
- 1/2 of global soil C stock
- x 2 more than C in the atmosphere

Thawed permafrost will release C-based greenhouse gases at a faster rate!

Schuur et al. 2008 BioScience
Tarnocai et al. 2009 GBC

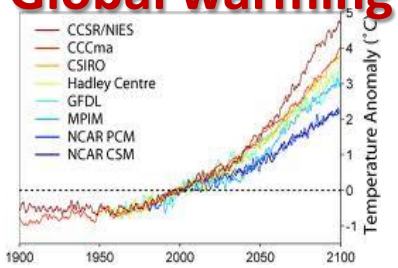


Source:International Permafrost Association, 1998. Circumpolar Active-Layer Permafrost System (CAPS), version 1.0.

Potential Arctic-climate feedback

+ Positive feedback

Global warming



CO_2 uptake by Plant growth

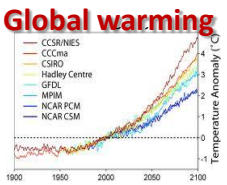
Soil N ↑

Decomposition ↑

$CO_2 CH_4$ ↑

Potential Arctic-climate feedback

- Negative feedback



$CO_2 CH_4$

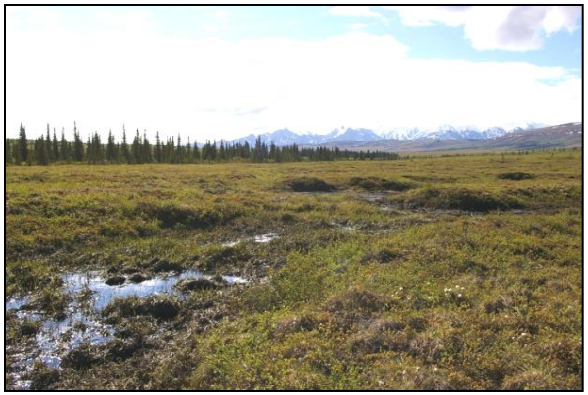
Soil N

Decomposition

Physical consequences

- Thermokarst formation

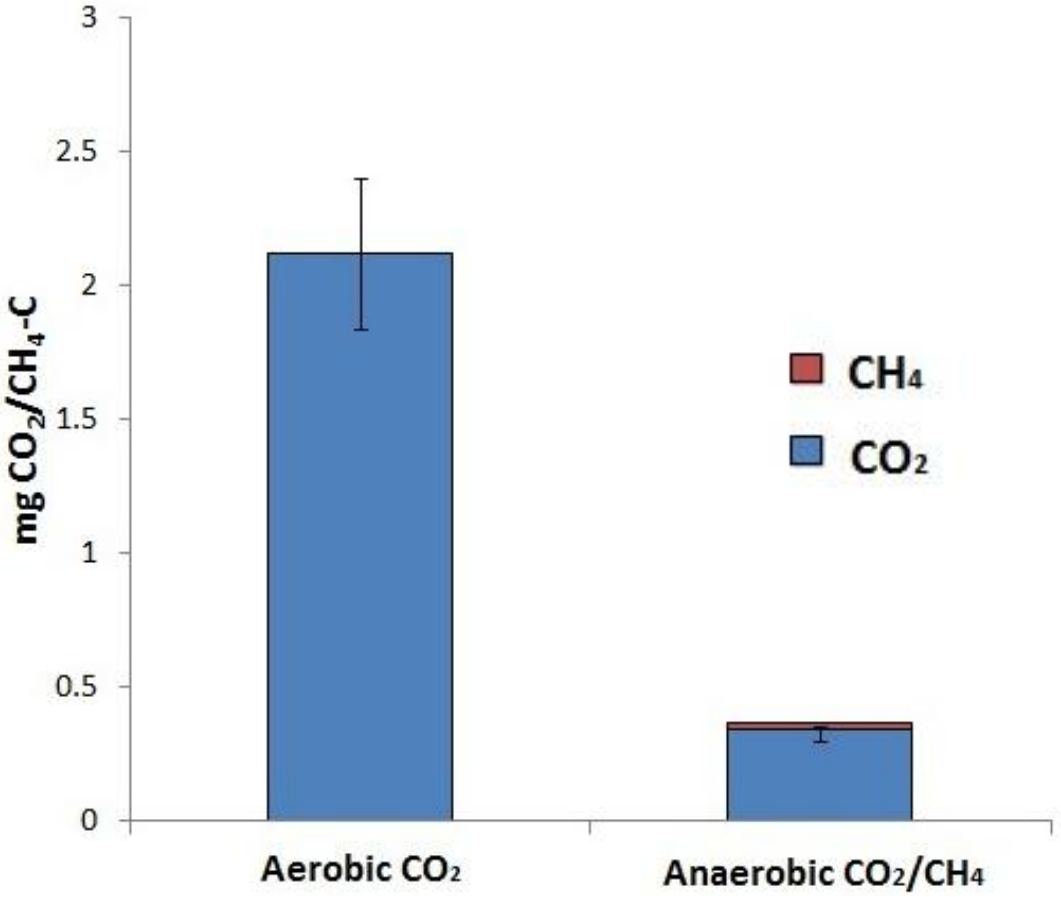
Land surface subsidence created by ice rich permafrost thaw






Changes in local hydrology: Aerobic vs. Anaerobic -> C cycling

Climate effects from permafrost C release



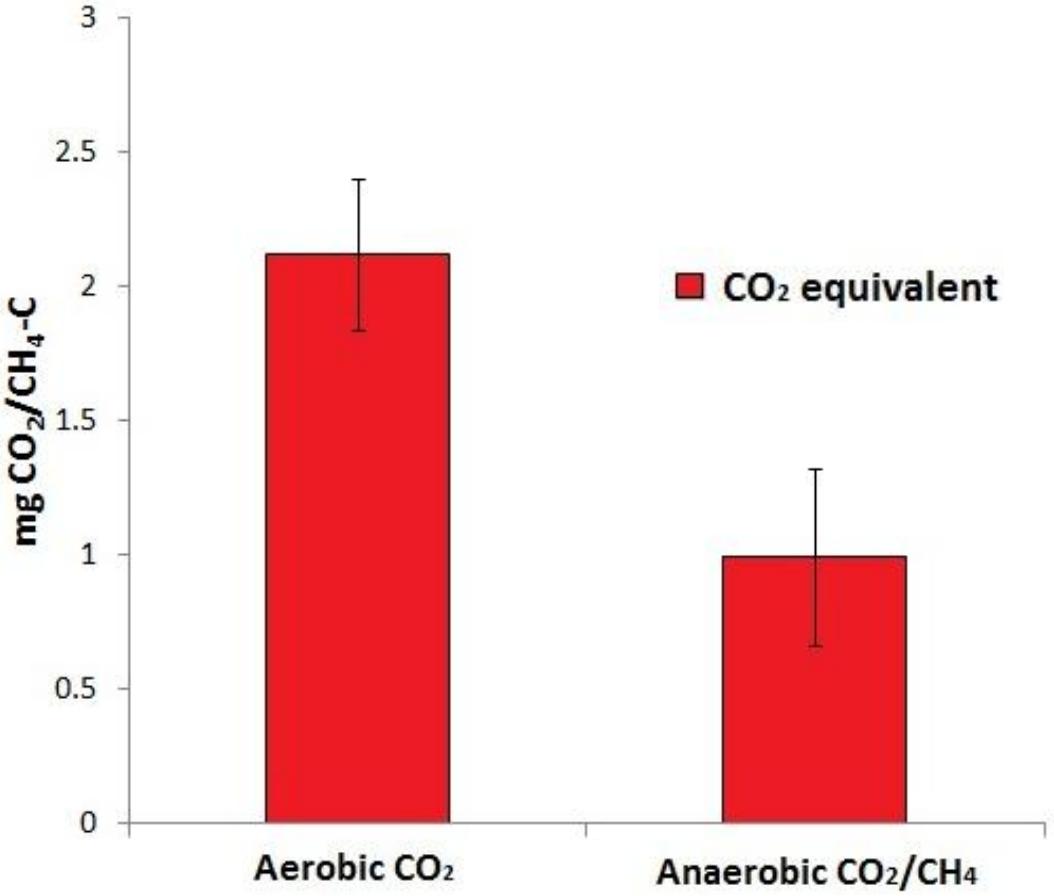
Laboratory incubation

Aerobic Anaerobic

Deep permafrost C release under aerobic and anaerobic conditions
: Faster C release under aerobic conditions

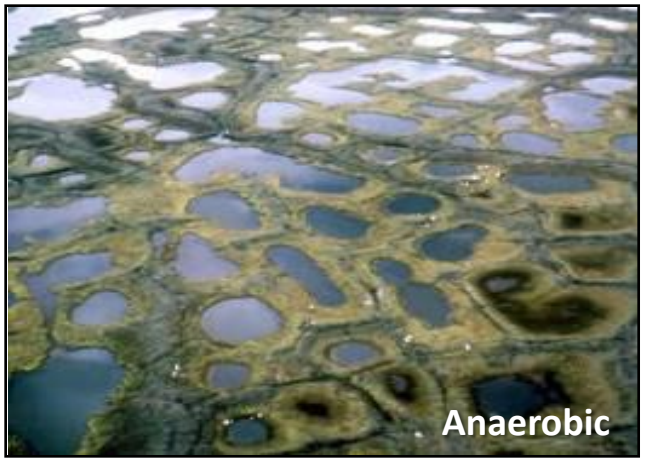
Modified from Lee et al. 2012 GCB

Climate effects from permafrost C release



Laboratory incubation

Aerobic Anaerobic

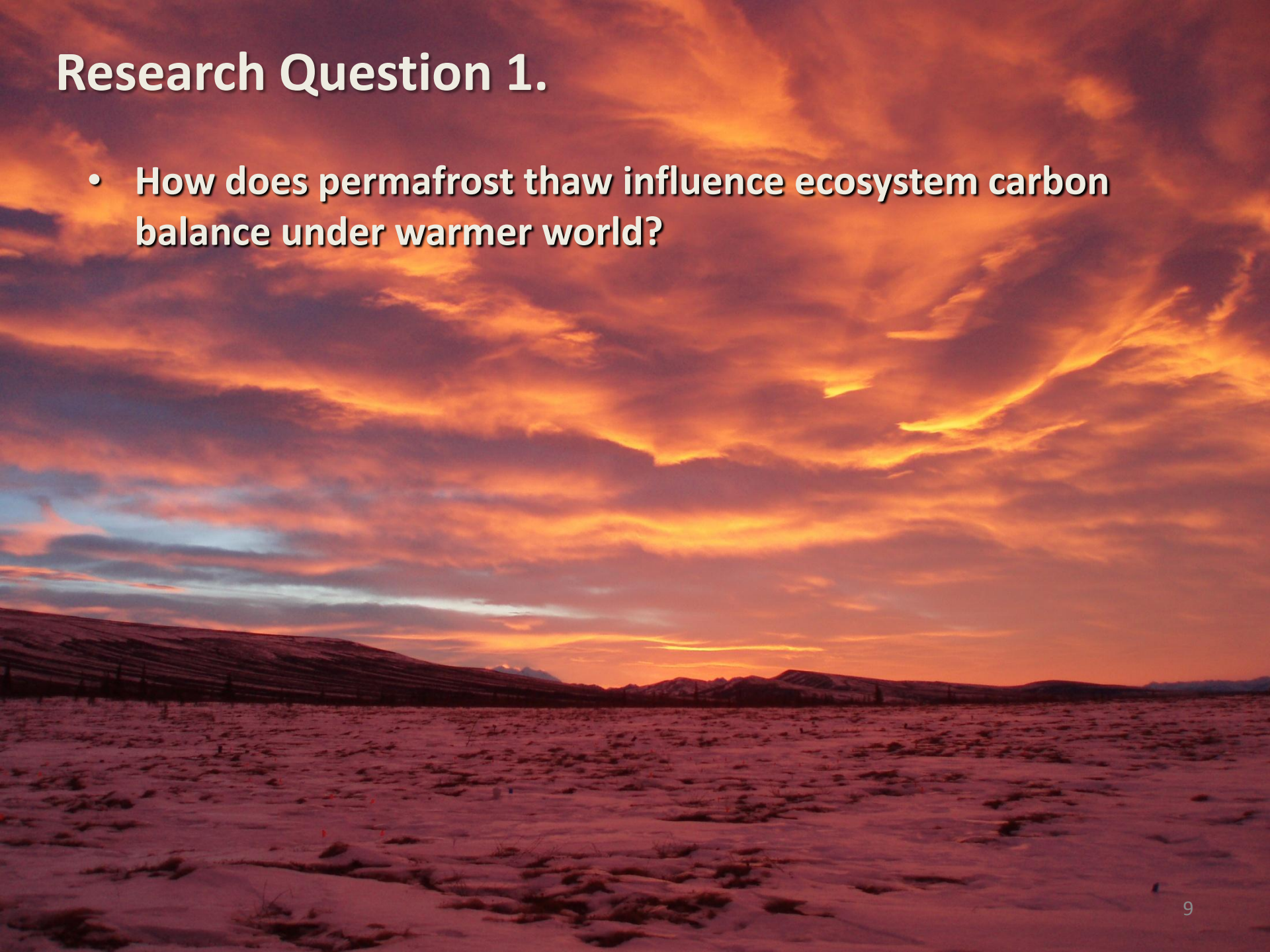


Deep permafrost C release under aerobic and anaerobic conditions : Comparable in atmospheric forcing with CH_4 effect

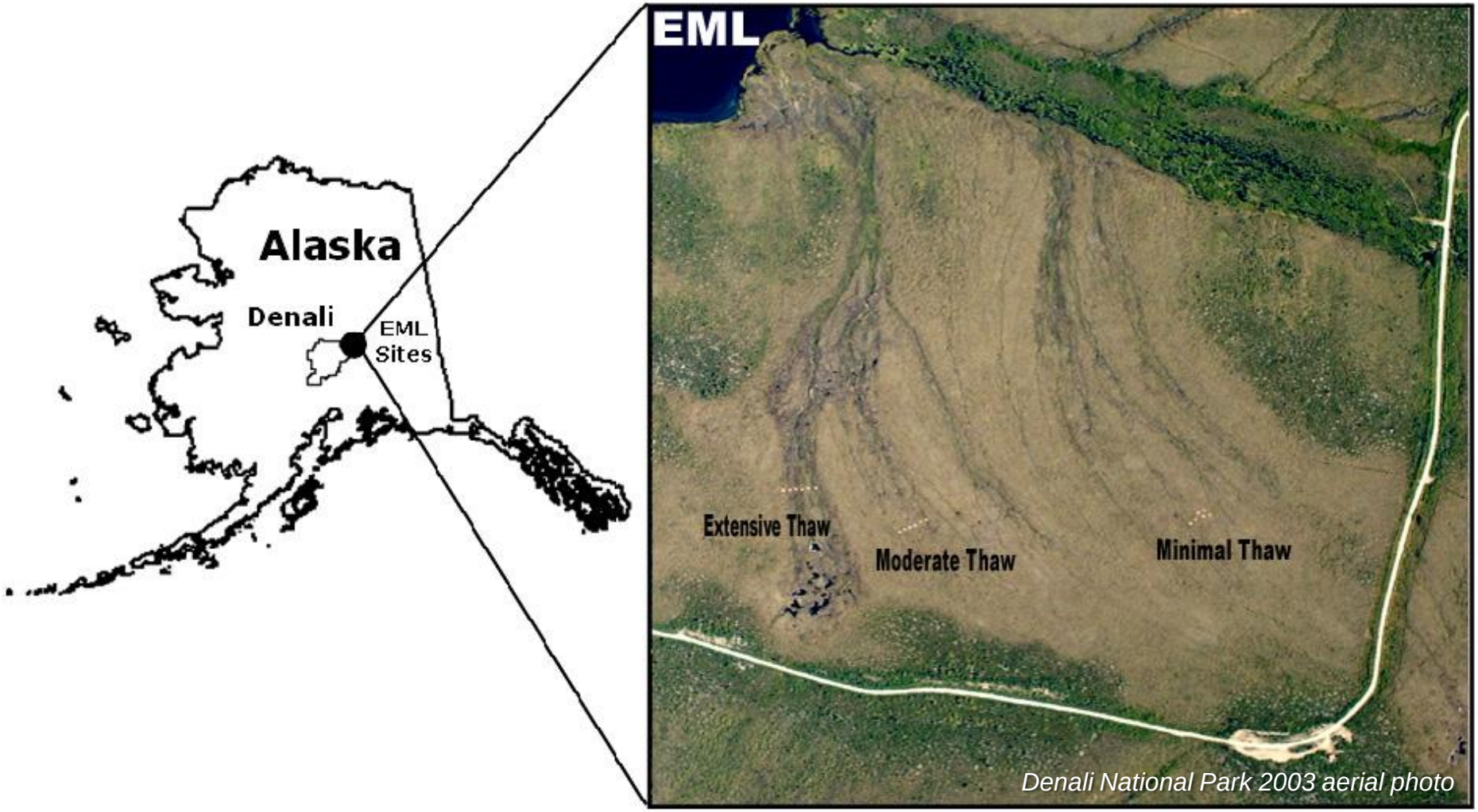
Modified from Lee et al. 2012 GCB

Research Question 1.

- How does permafrost thaw influence ecosystem carbon balance under warmer world?

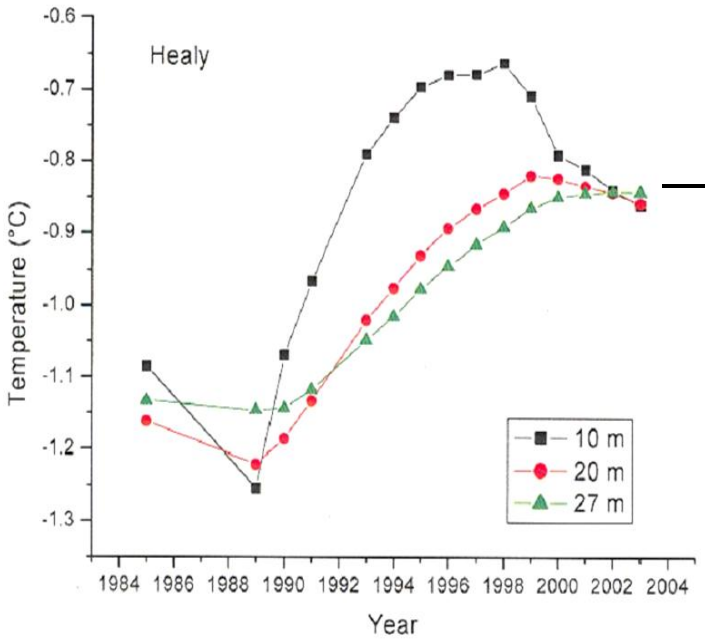


Interior Alaska tundra site

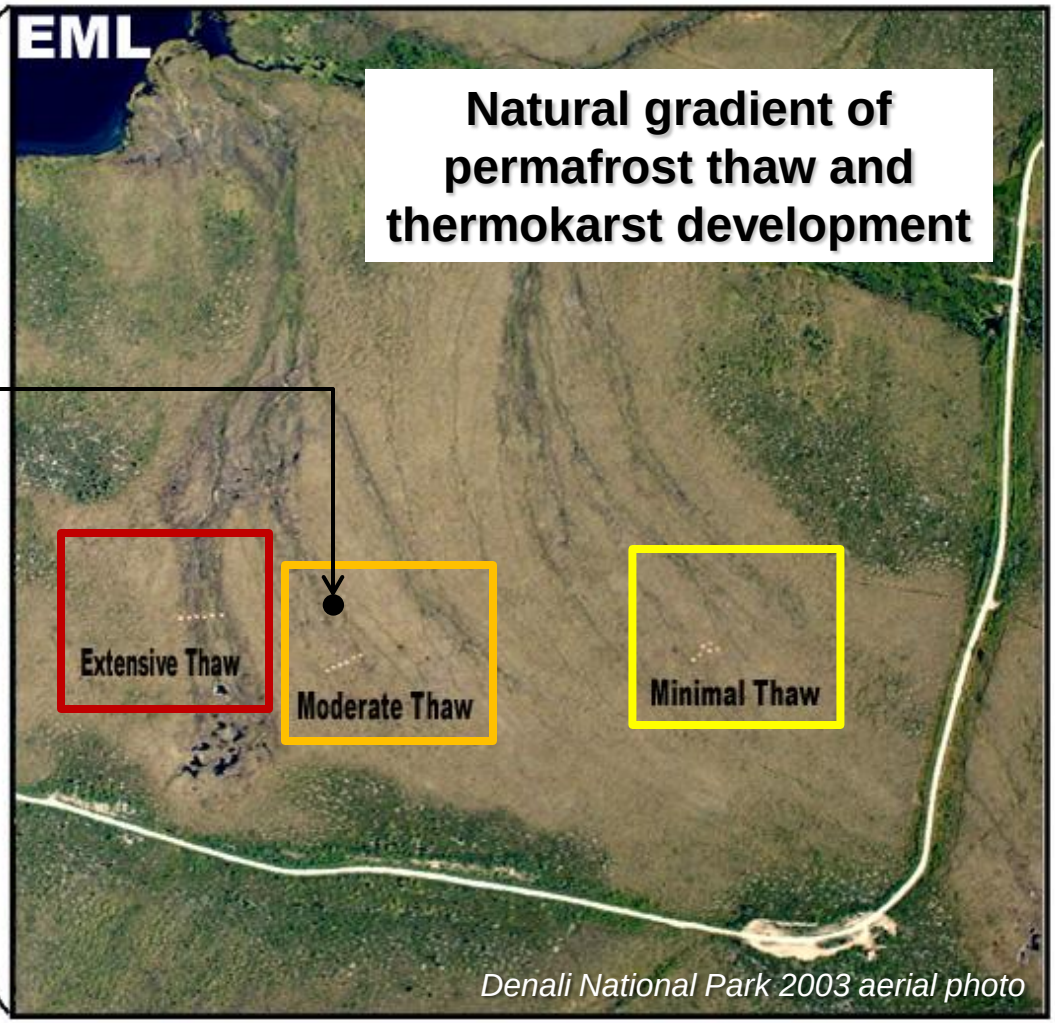


Interior Alaska tundra site

Deep permafrost T increase



Osterkamp & Romanovsky 1999 PPP



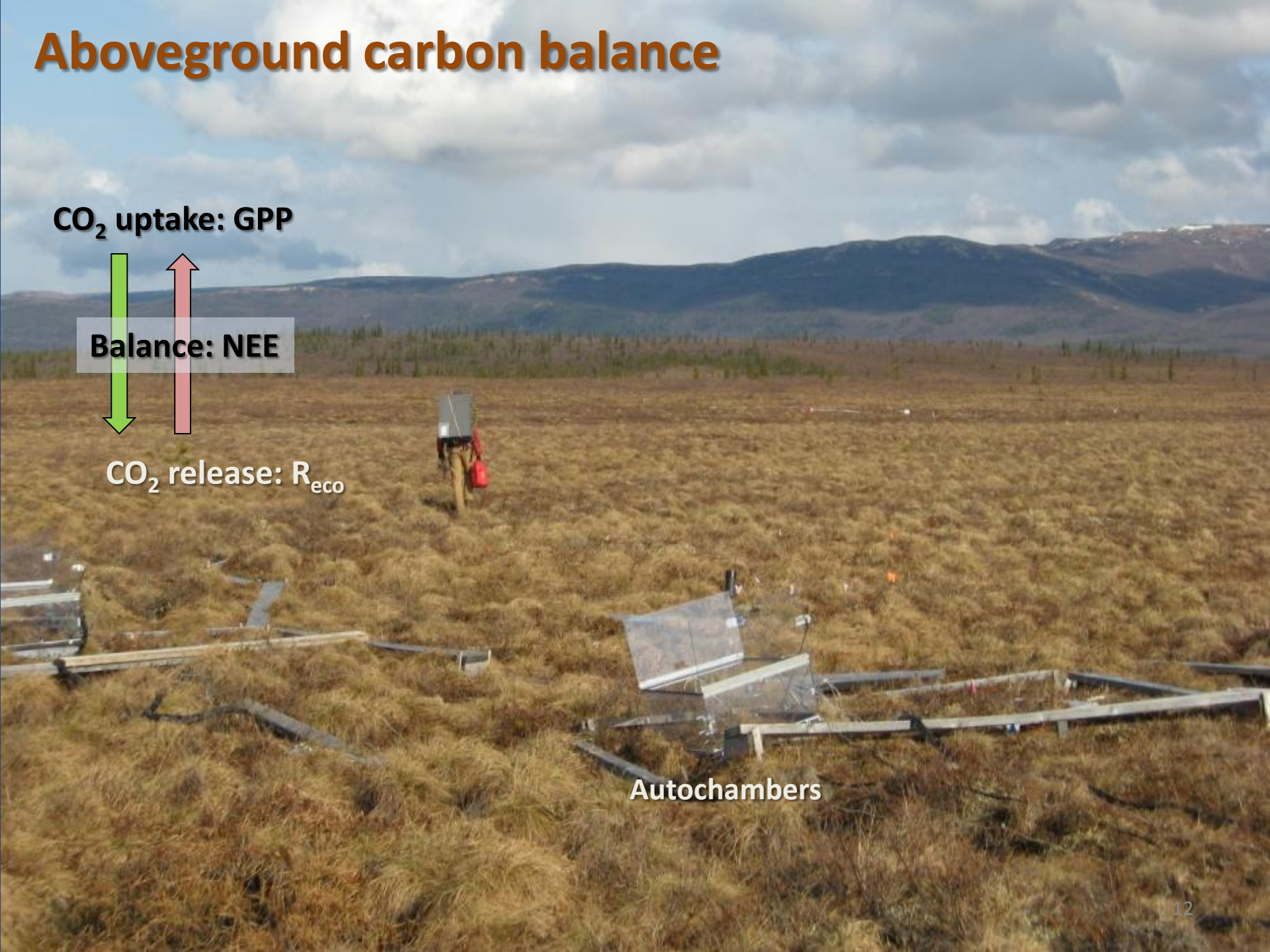
Three sites:

Minimal Thaw: Typical tussock tundra before thawing

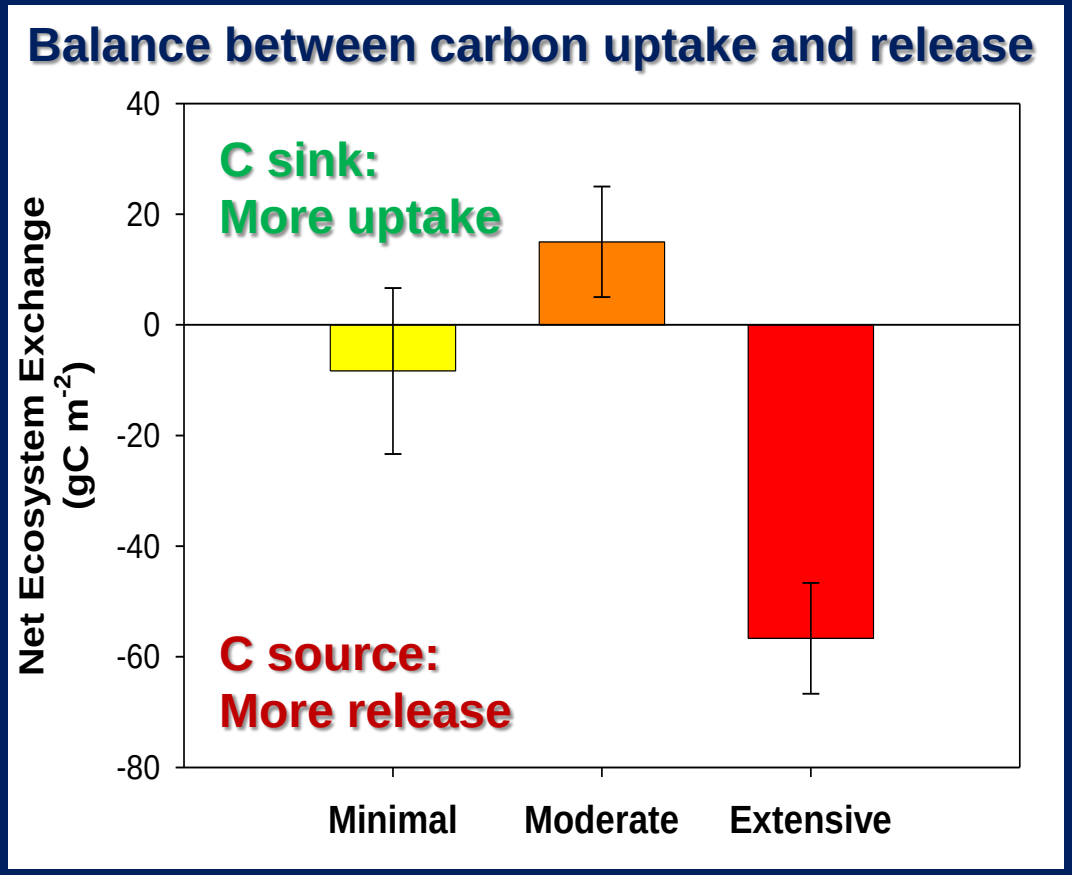
Moderate Thaw: 15-20 yrs of permafrost thaw

Extensive Thaw: over 50 yrs of thaw and deep thermokarst

Aboveground carbon balance



Aboveground Net Ecosystem Exchange of carbon



Over 3 years:

Minimal ≈ neutral

Moderate = sink
(↑GPP, ↑R_{eco})

Extensive = source
(↑GPP, ↑↑R_{eco})

Modified from
*Schuur, Vogel, Crummer, **Lee**, Sickman, Osterkamp 2009 **Nature** 459: 556-559.*
*Vogel, Schuur, Trucco, **Lee** 2009 **J Geophys Res** 114, G4, doi:10.1029/2008JG000901.*

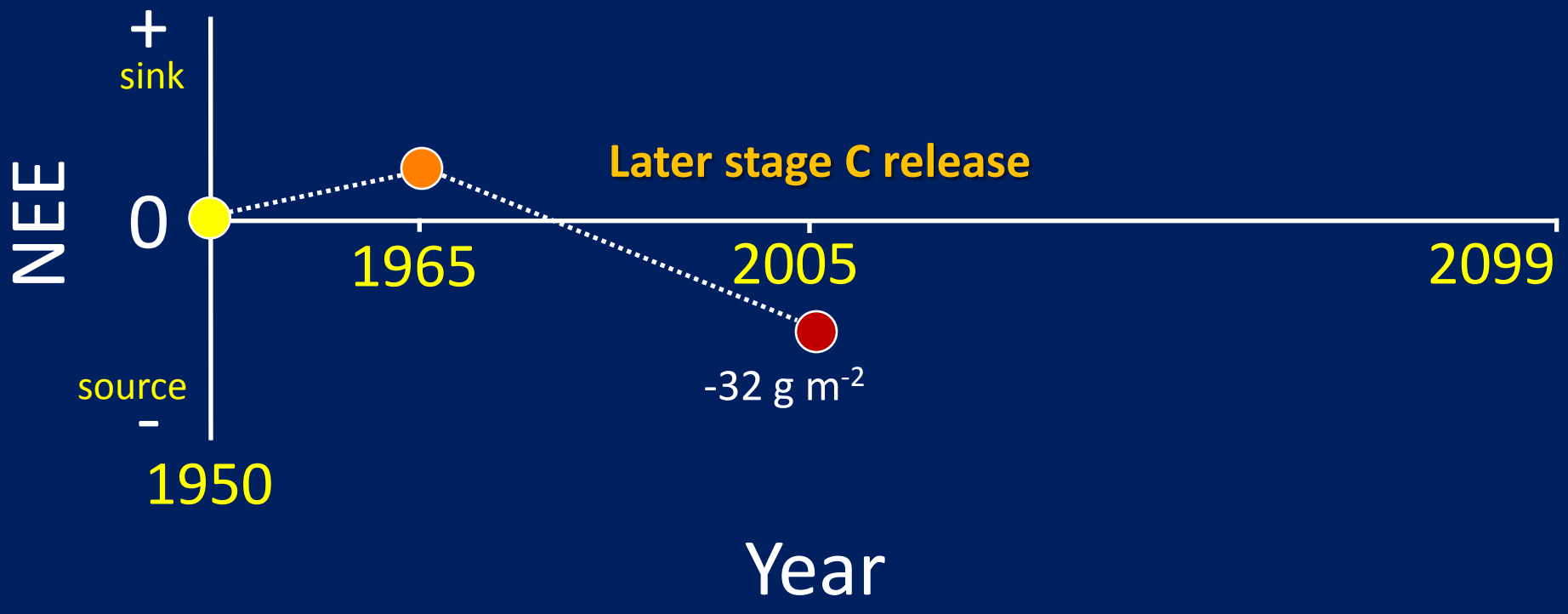
Net Carbon Exchange Projections

Carbon neutral when thawing started

Net Carbon Exchange Projections

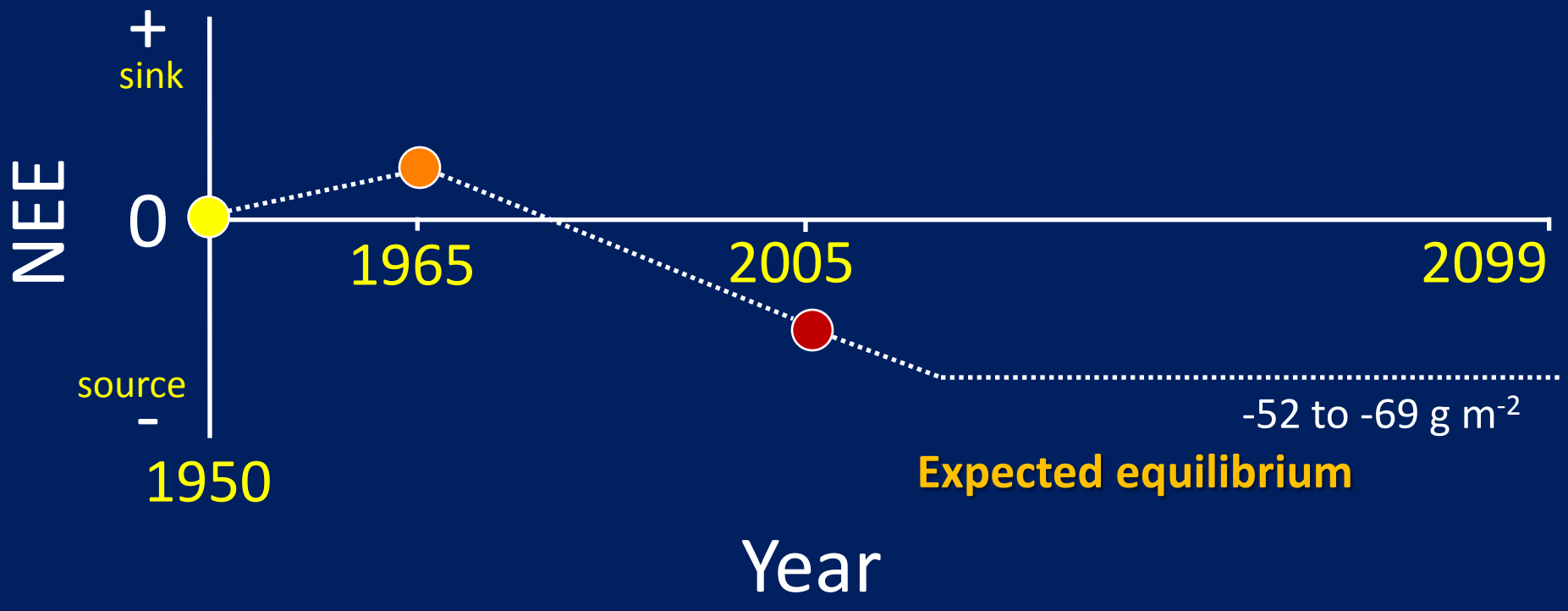
Carbon uptake of ~25 g m^{-2} in the early stage of thawing

Net Carbon Exchange Projections



Carbon release of ~32 g m^{-2} in the later stage of thawing

Net Carbon Exchange Projections



Carbon loss by 2099: 4.4-6.0 kg m^{-2} (9.4-12.9%)

Permafrost Carbon Loss in global carbon context

Using the three sites as representatives of permafrost thaw…

Permafrost Zone Soil C

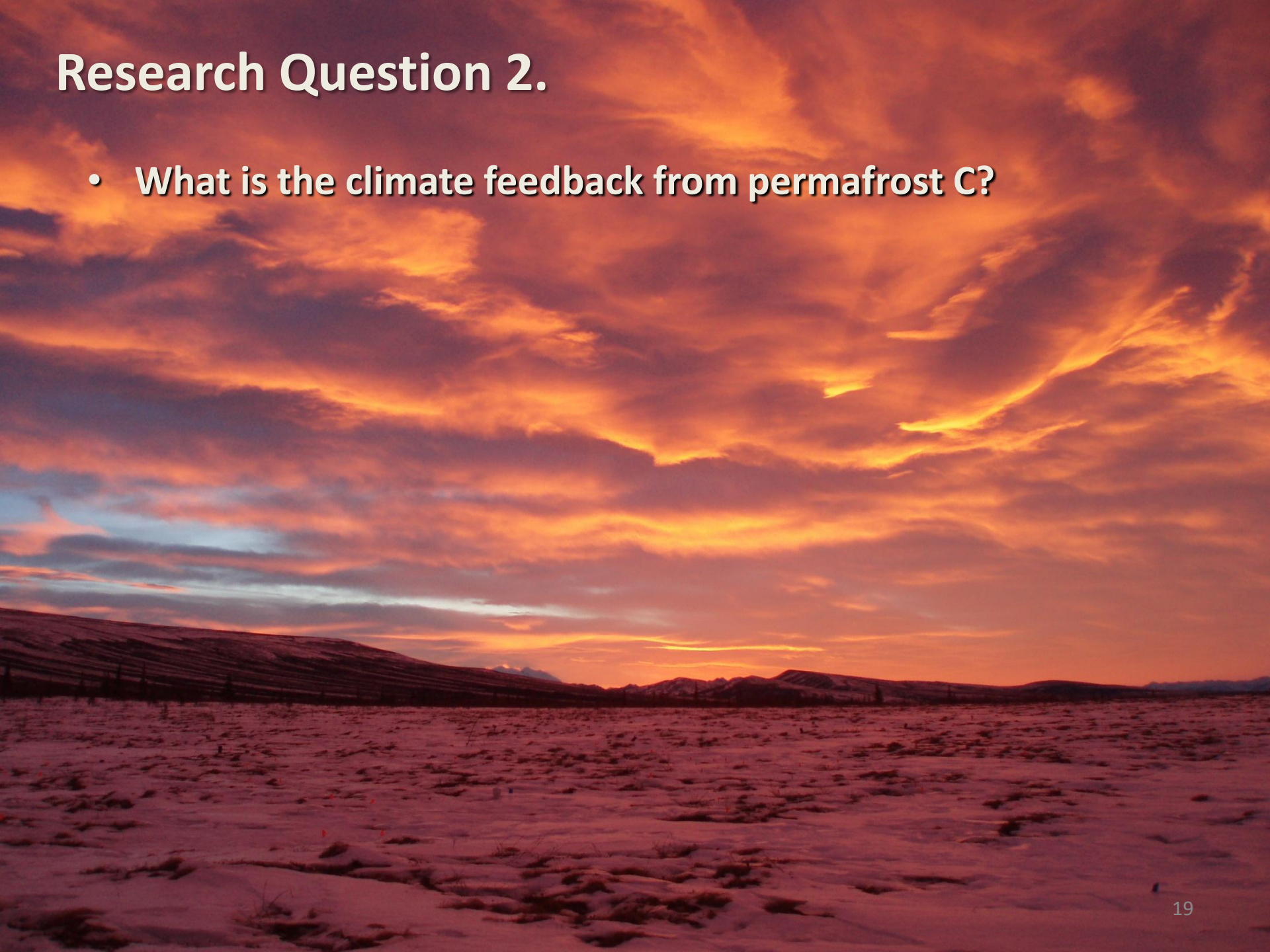
Gelisol Soil Order (3m)	818 Pg
	x 9.4-12.9%
	77-106 Pg

Permafrost C Loss	(0.8-1.1 Pg/yr)
Current Land Use Change	(1.5±0.5 Pg/yr)

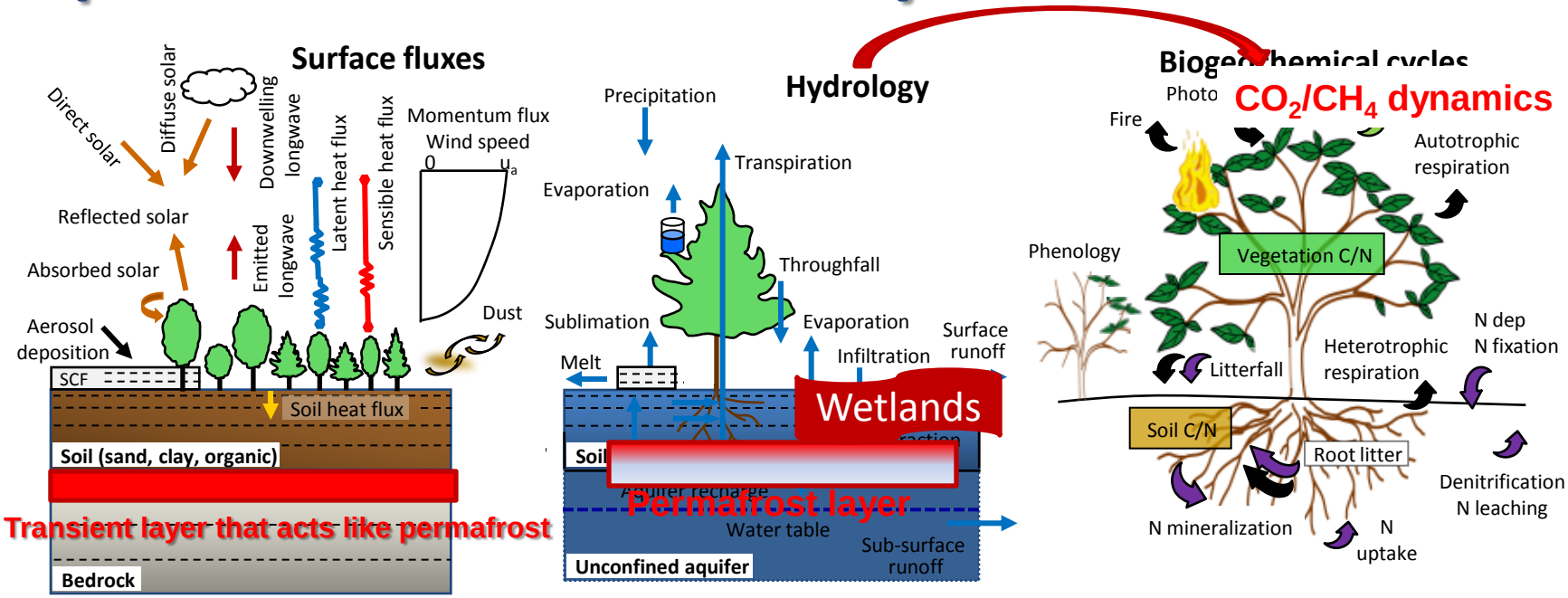
*Schuur, Vogel, Crummer, **Lee**, Sickman, Osterkamp 2009 **Nature** 459: 556-559.*

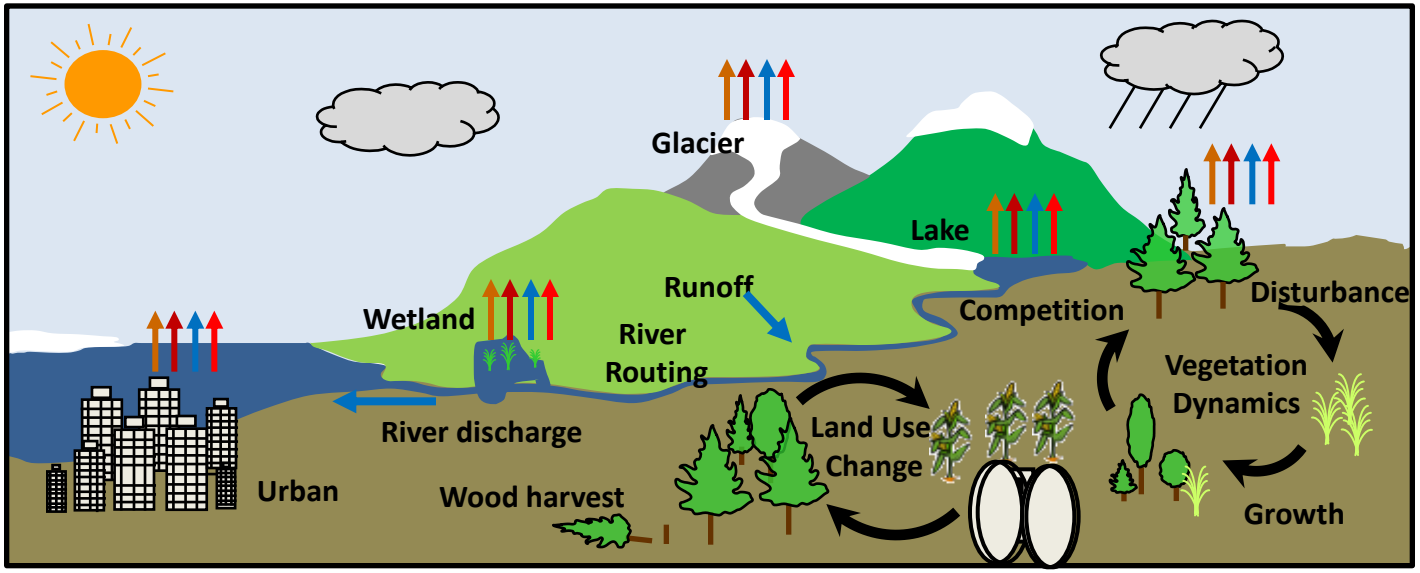
Research Question 2.

- What is the climate feedback from permafrost C?



Improvements in Community Land Model 4.5



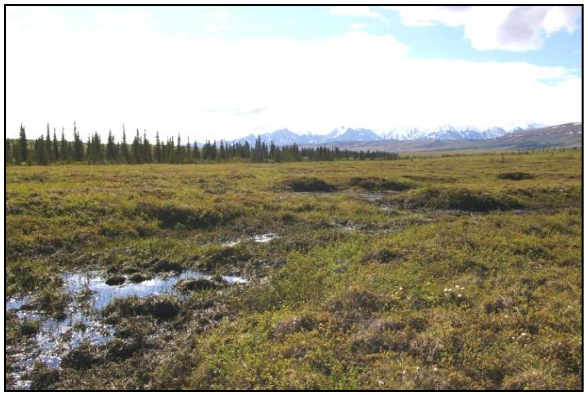


Lawrence et al., Journal Advances Modeling Earth Systems, 2011

Physical consequences

- Thermokarst formation

Land surface subsidence created by ice rich permafrost thaw






Changes in local hydrology: Aerobic vs. Anaerobic -> C cycling

Excess ice and permafrost parameterization

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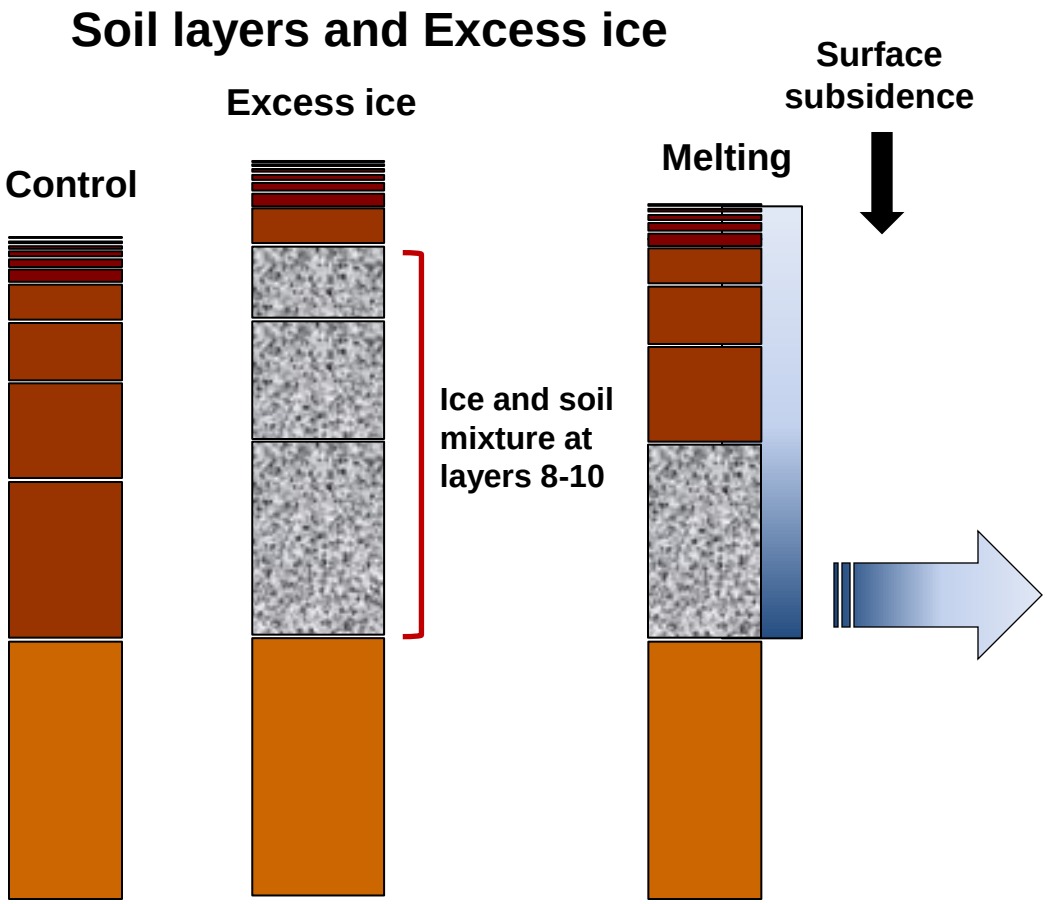
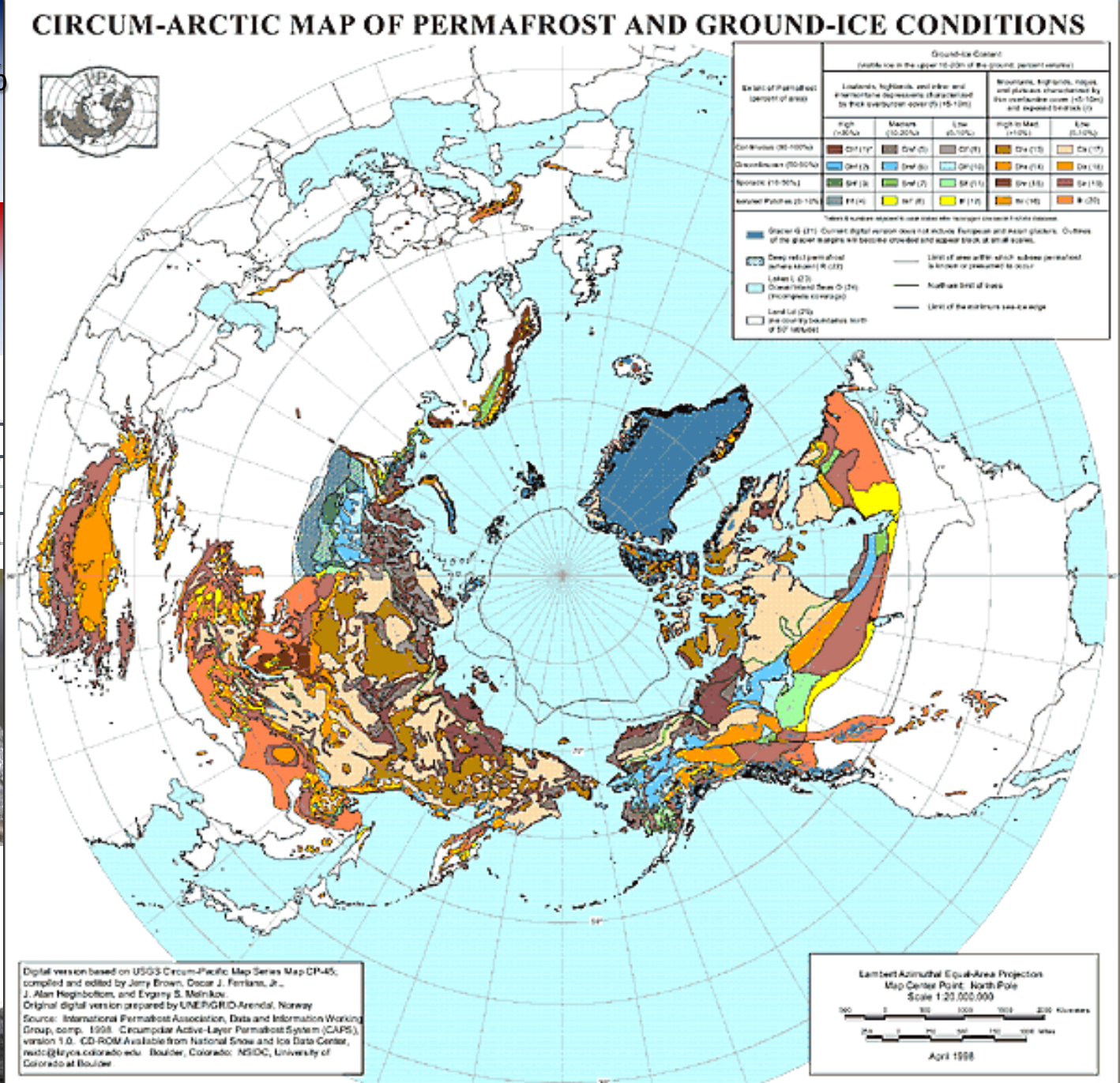


Control: Regular CLM soil layers

Used ground ice data from NSIDC

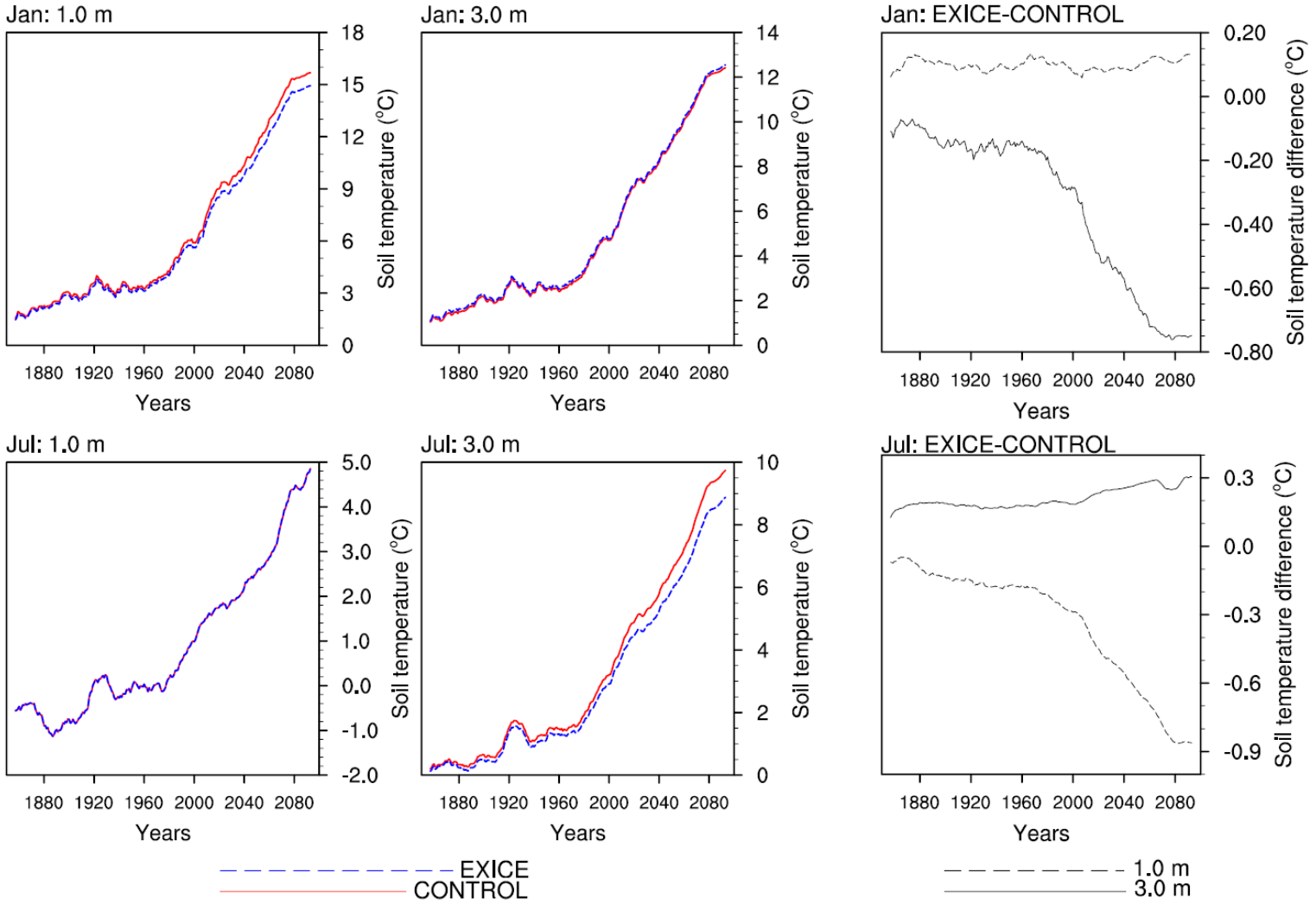
Continuous: 90-100%
Discontinuous: 50-90%
Sporadic: 10-50%
Isolated: 0-10%

High: > 20%
Medium: 10-20%
Low: 0-10%



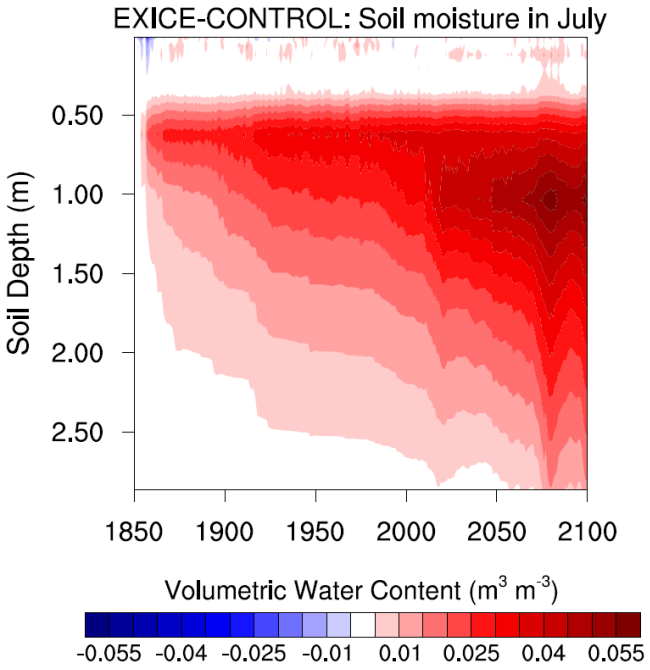
Brown, J., O.J. Ferrians, Jr., J.A. Heginbottom, and E.S. Melnikov.. 2002. *Circum-Arctic Map of Permafrost and Ground-Ice Conditions*. Version 2. [indicate subset used]. Boulder, Colorado USA: National Snow and Ice Data Center.

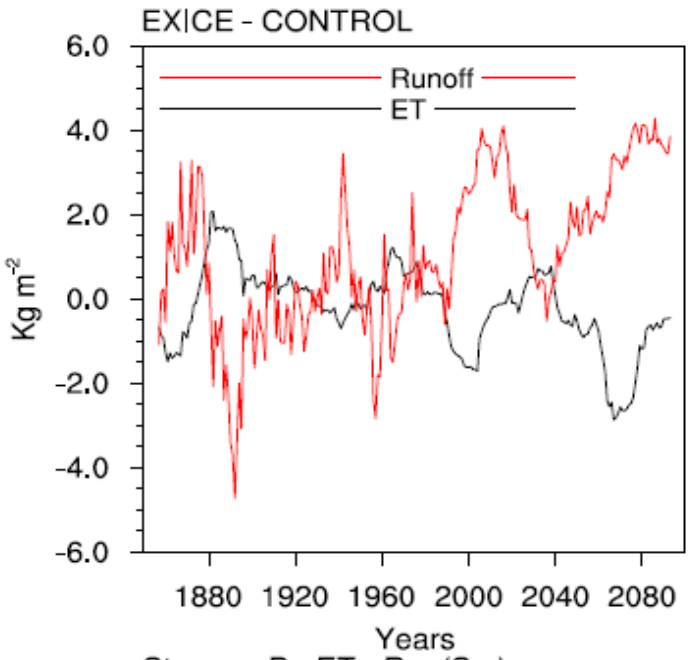
Soil temperature patterns: Annual variability

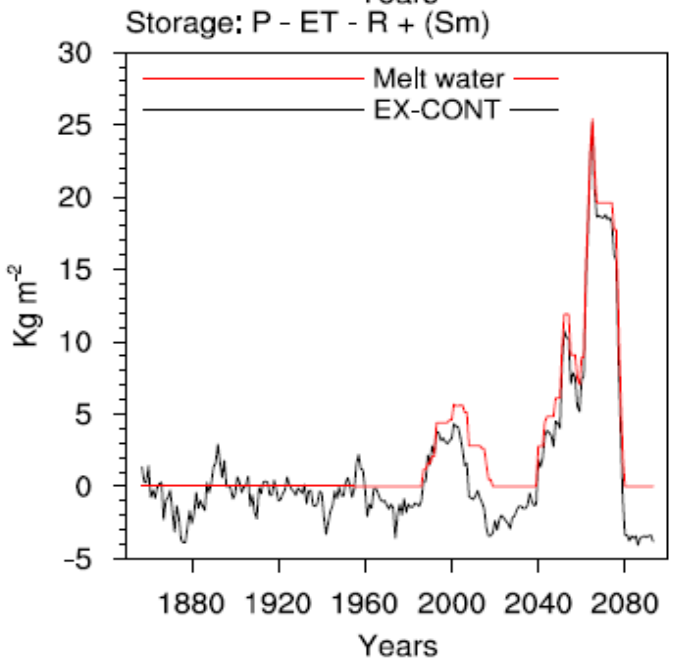


- Soil warming slowed ~1°C by the end of the century

Soil moisture patterns



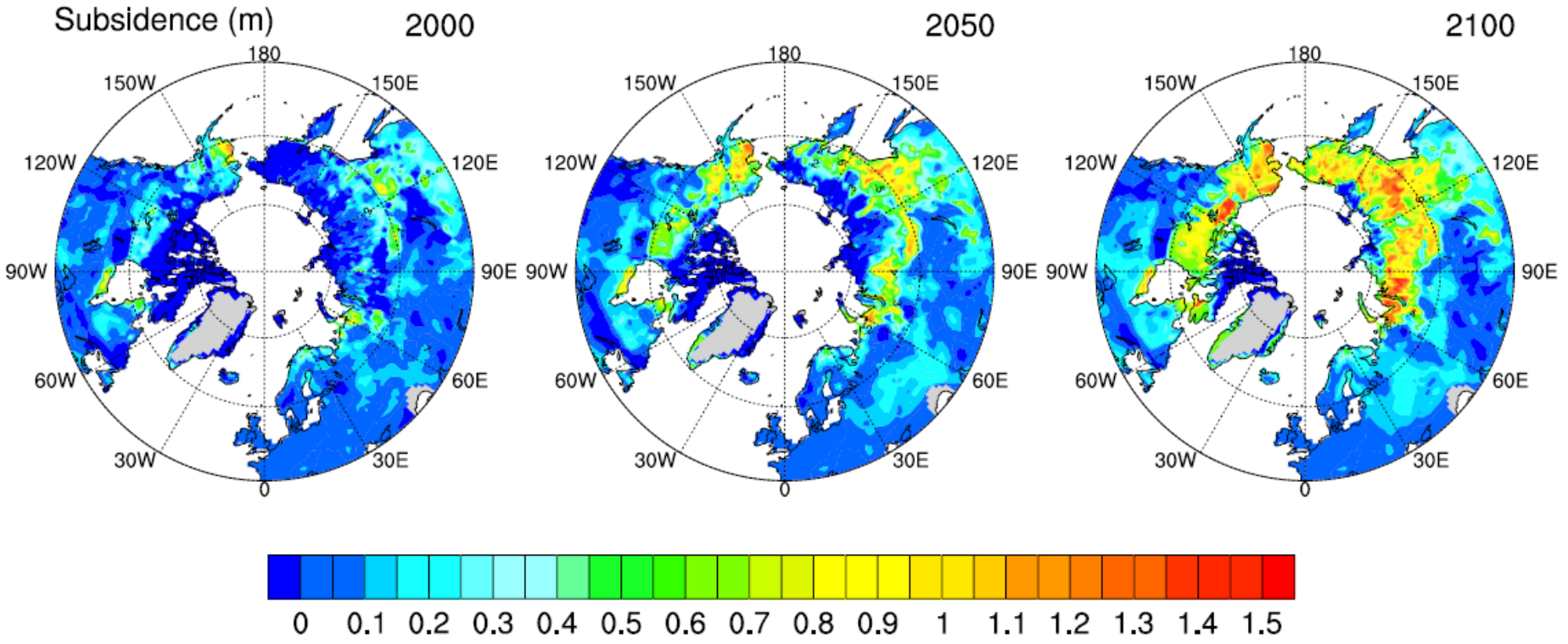




- Soil moisture increases
- Soil water storage increases
- Most of excess ice melt water goes to soil water storage

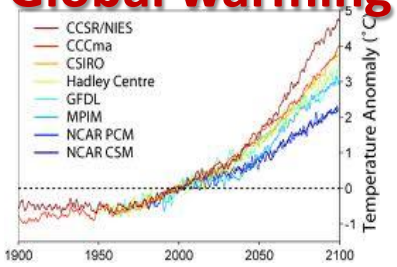
Surface subsidence simulations (Recent/RCP8.5)

- Land surface subsidence as a function of excess ice melting
- Grid cell mean

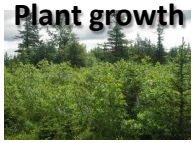


Improved model and climate feedback

Global warming



CO_2 uptake by Plant growth



Soil N

Permafrost thaw

Decomposition

Expanded wetlands

CH_4

CO_2

Lakes drain, soils dry

Enhanced predictions of Arctic-climate feedback with improved models