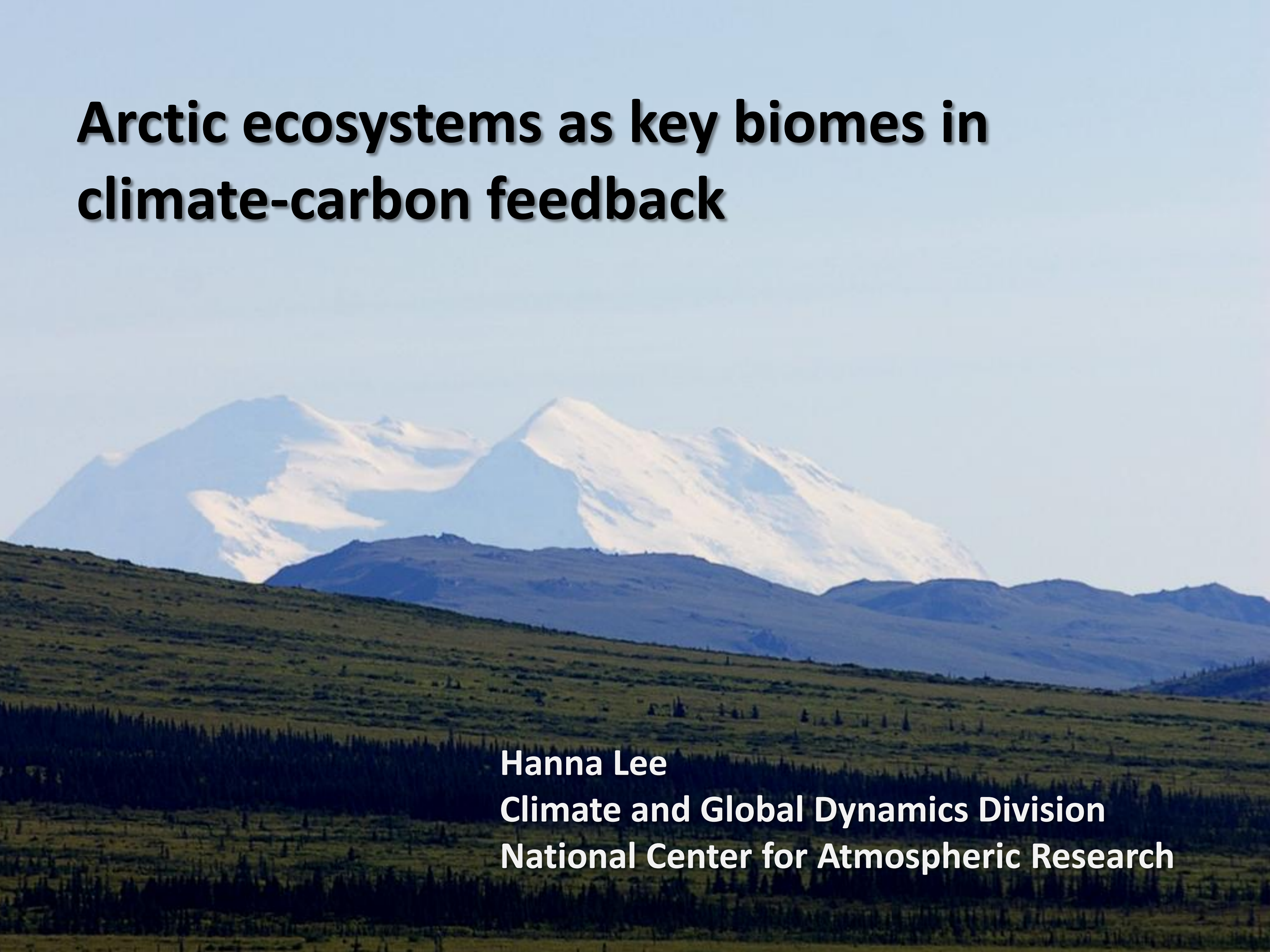
Arctic ecosystems as key biomes in climate-carbon feedback

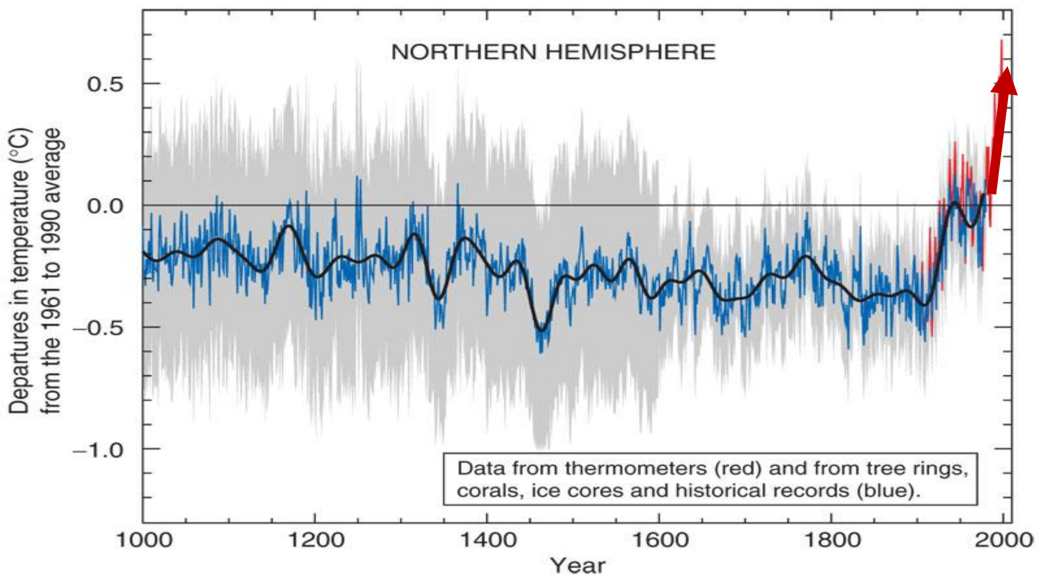


Hanna Lee
Climate and Global Dynamics Division
National Center for Atmospheric Research

Outline

- Permafrost carbon
- Permafrost carbon-climate feedback cycles
- Thermokarst influence on permafrost carbon feedback cycles
- Using CLM to better represent permafrost processes

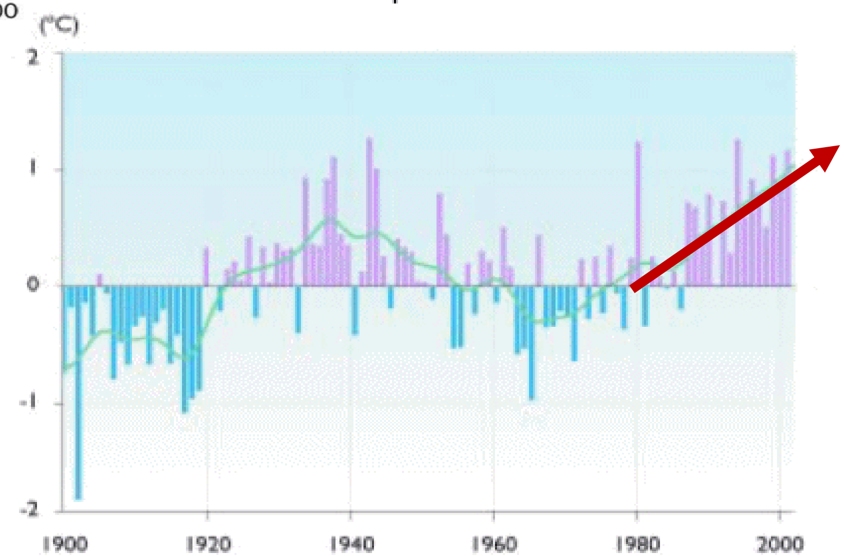
Warming in the Arctic



Northern Hemisphere: **0.4ºC** increase in the past two decades

IPCC (2007)

Observed Arctic Temperature, 1900 to Present



Annual average change in near surface air temperature from stations on land relative to the average for 1961-1990, for the region from 60 to 90°N.

Arctic: **1.2ºC** increase in the past two decades

ACIA (2004)

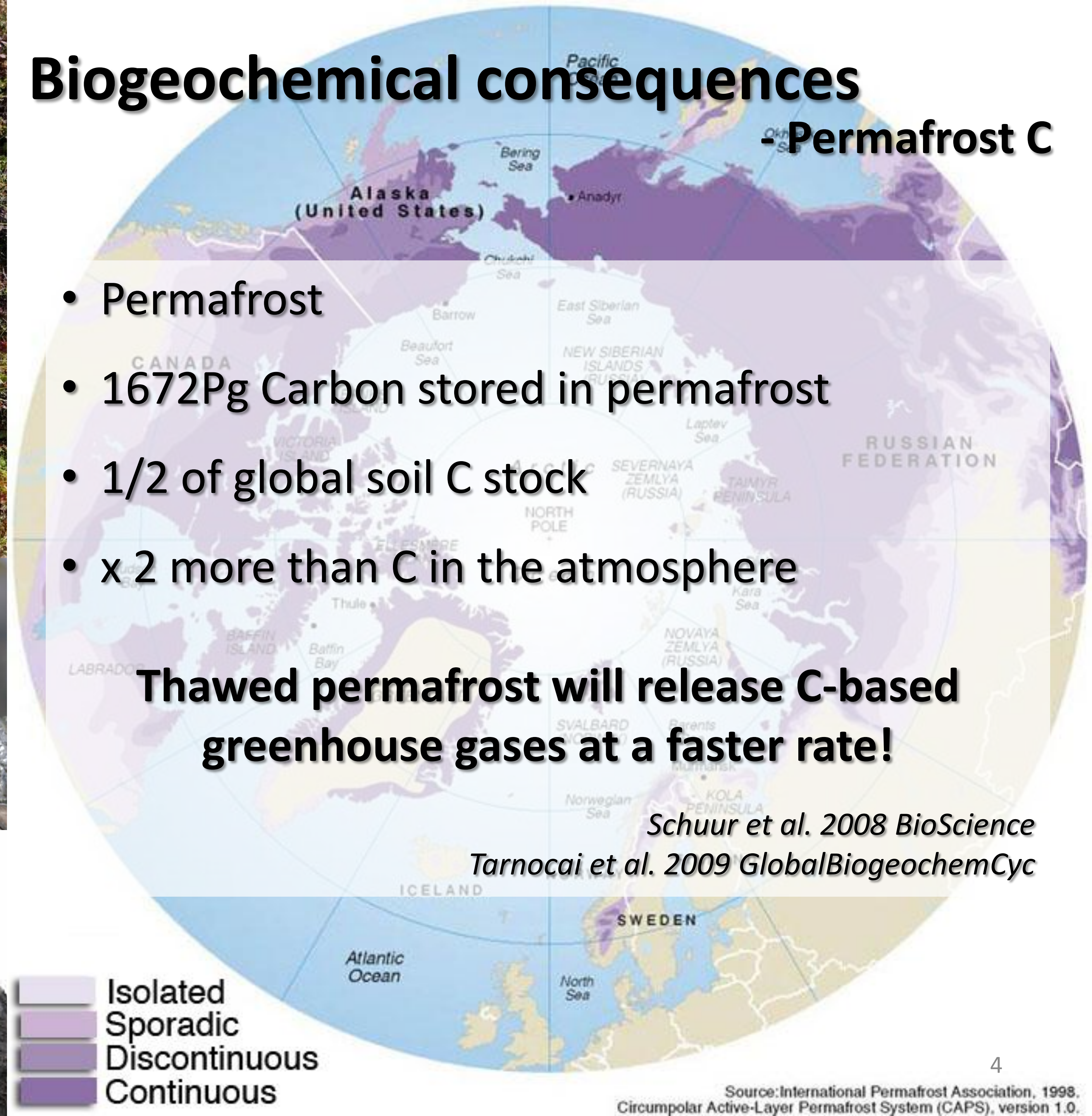
Biogeochemical consequences

- Permafrost C

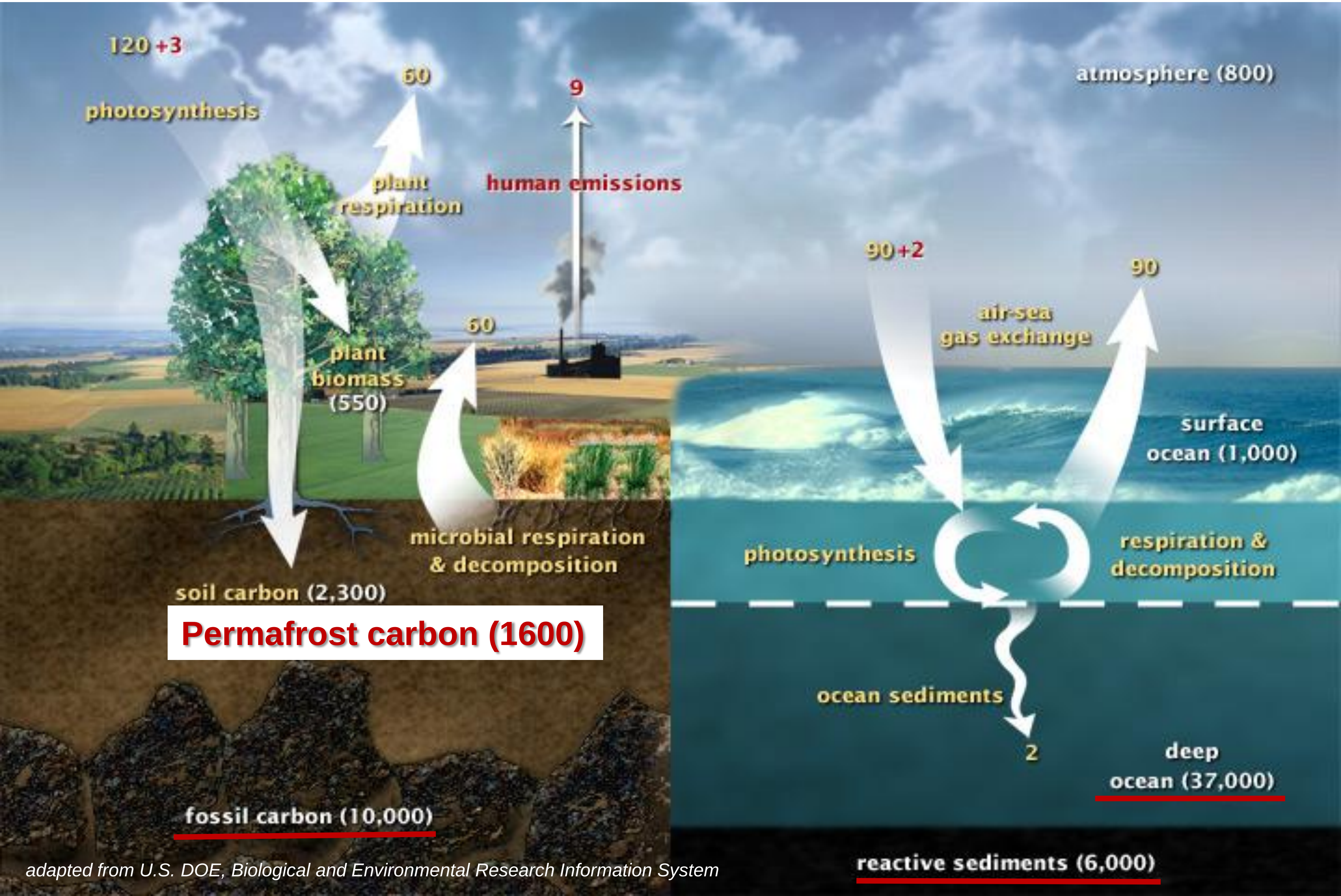
- Permafrost
- 1672Pg Carbon stored in permafrost
- 1/2 of global soil C stock
- x 2 more than C in the atmosphere

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

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



Why permafrost carbon?



adapted from U.S. DOE, Biological and Environmental Research Information System

Vulnerability of permafrost C

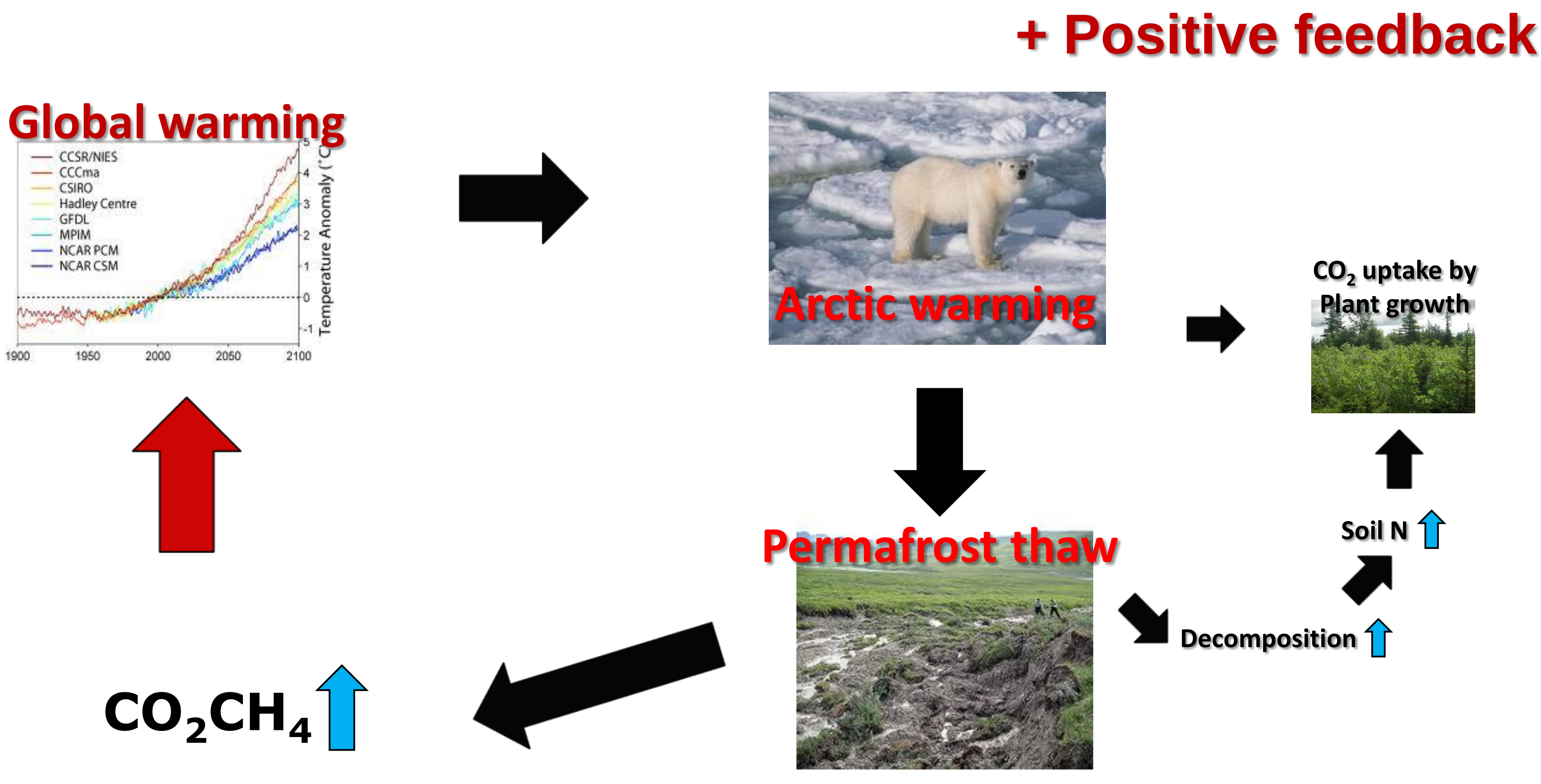
Permafrost Zone Soil C

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 et al. 2009 ***Nature*** *459: 556-559.*

Potential Arctic-climate feedback



Arctic shrub growth and tree line expansion

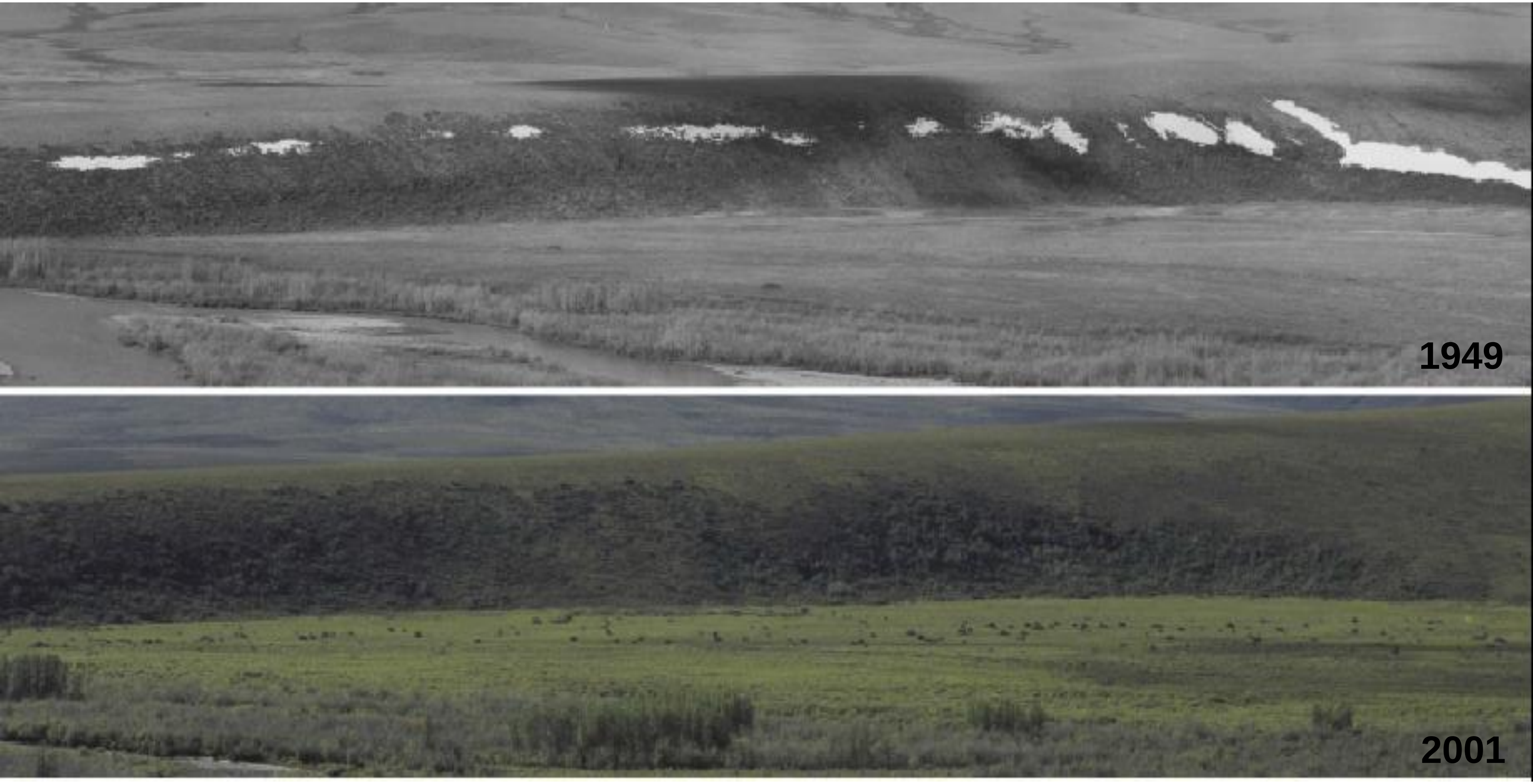
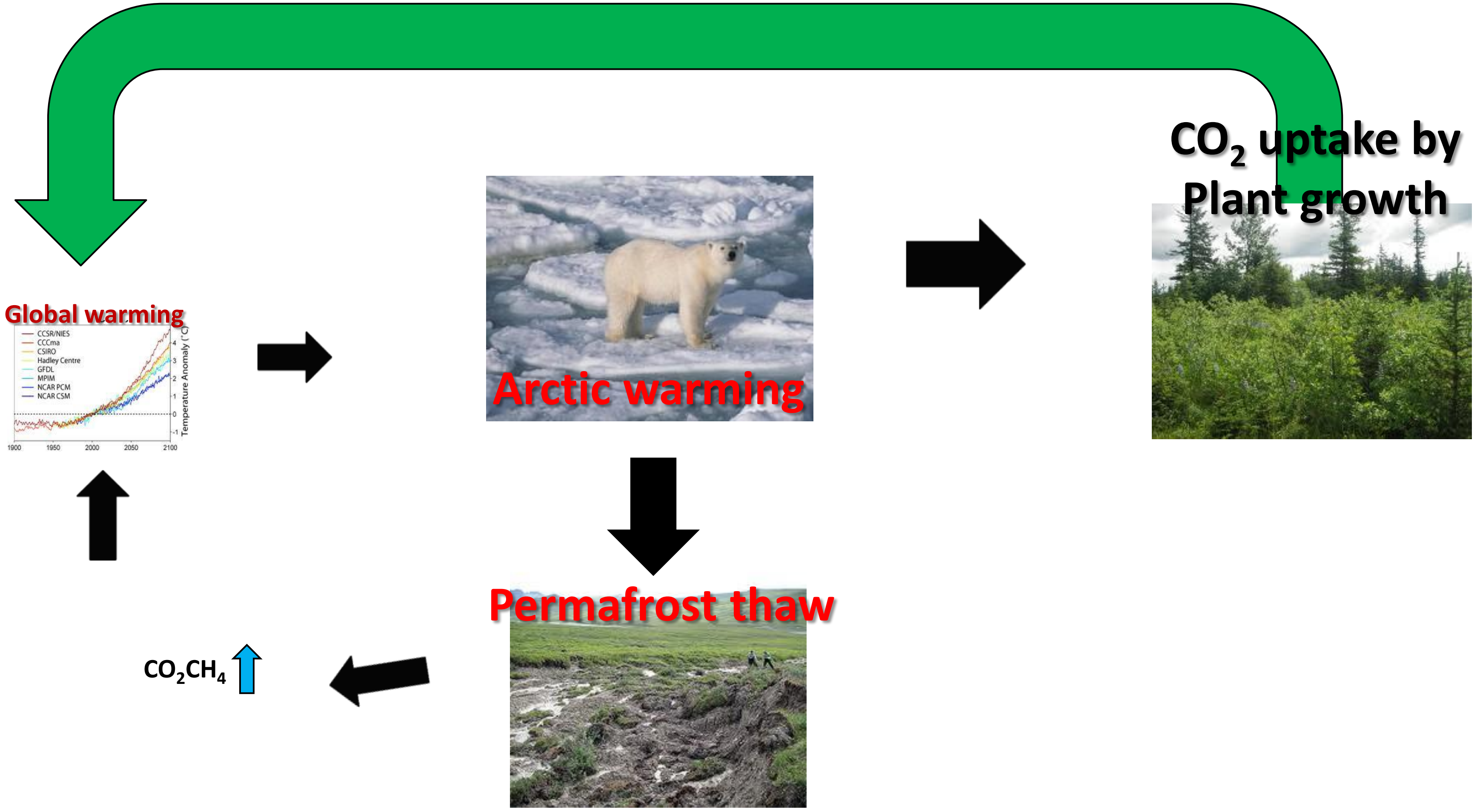
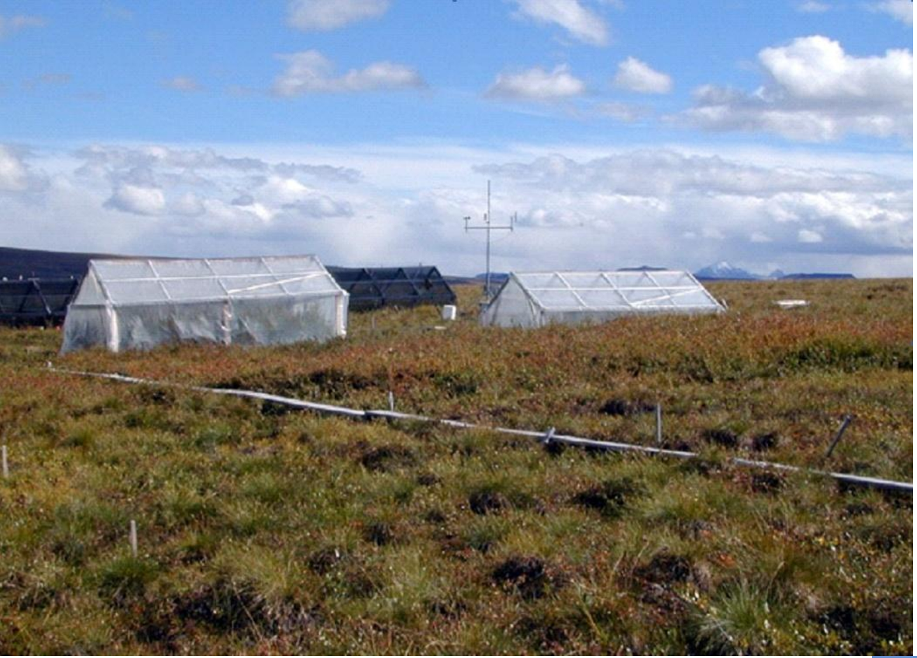


Photo from the Chandler River located at 68° 25.14' N, 161° 15.24' W: 7/4/1948 and 7/29/2001. (Tape et al., 2006).

Potential Arctic-climate feedback

- Negative feedback





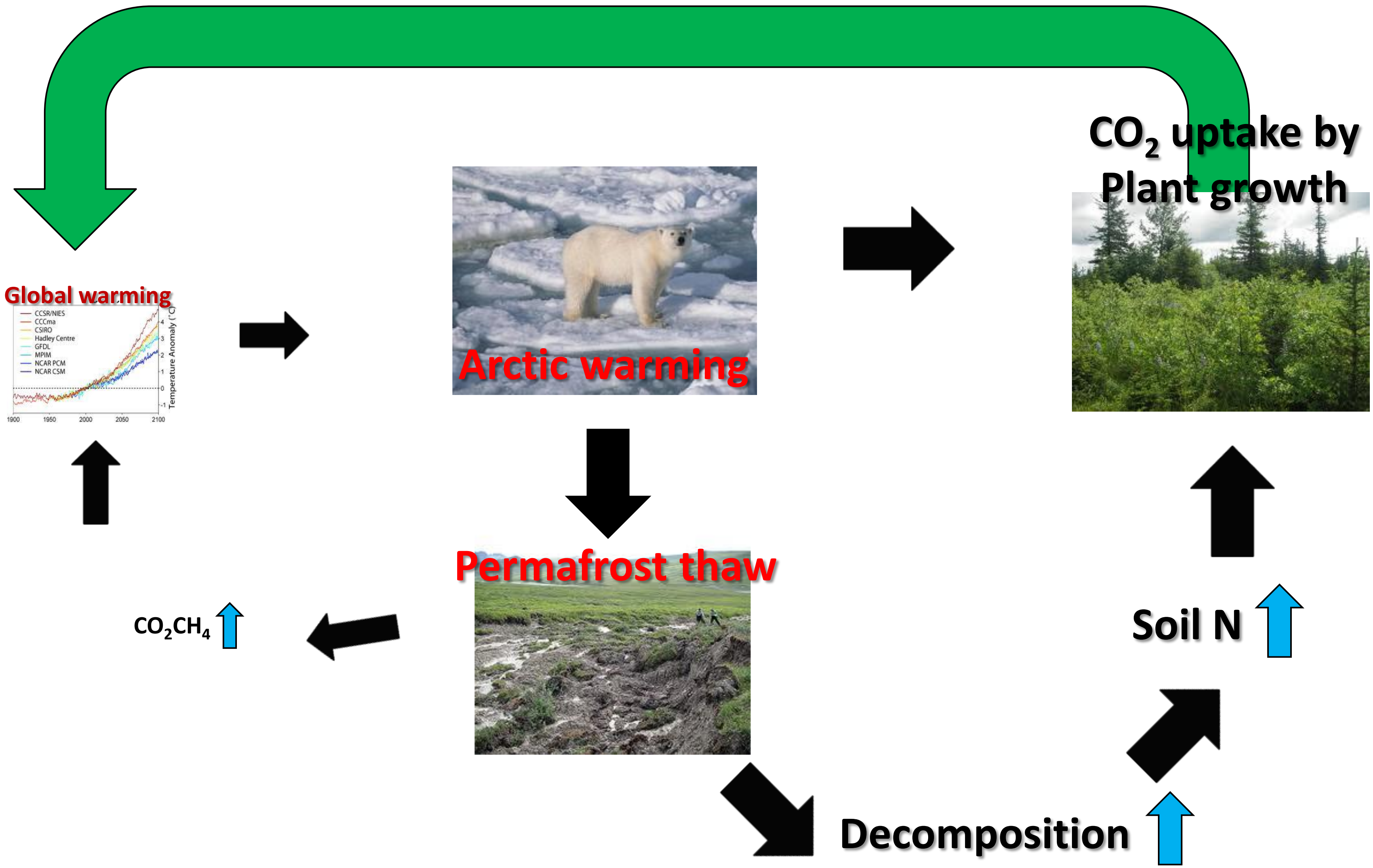
The effects of N fertilization on shrub growth

Toolik lake Long-Term Ecological Research site N fertilization over 20 years

Warming & thawing permafrost stimulated decomposition and release N back to very N limited ecosystem

Potential Arctic-climate feedback

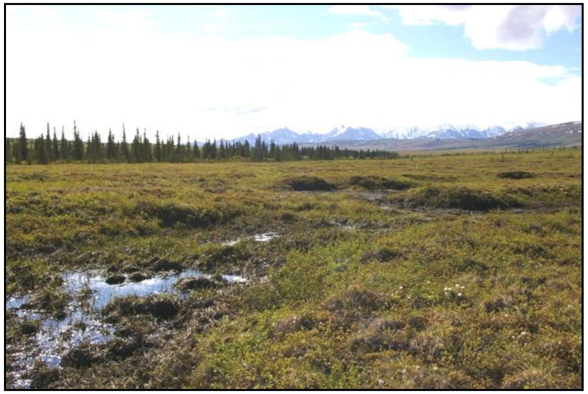
- Negative feedback



Physical consequences

- Thermokarst formation

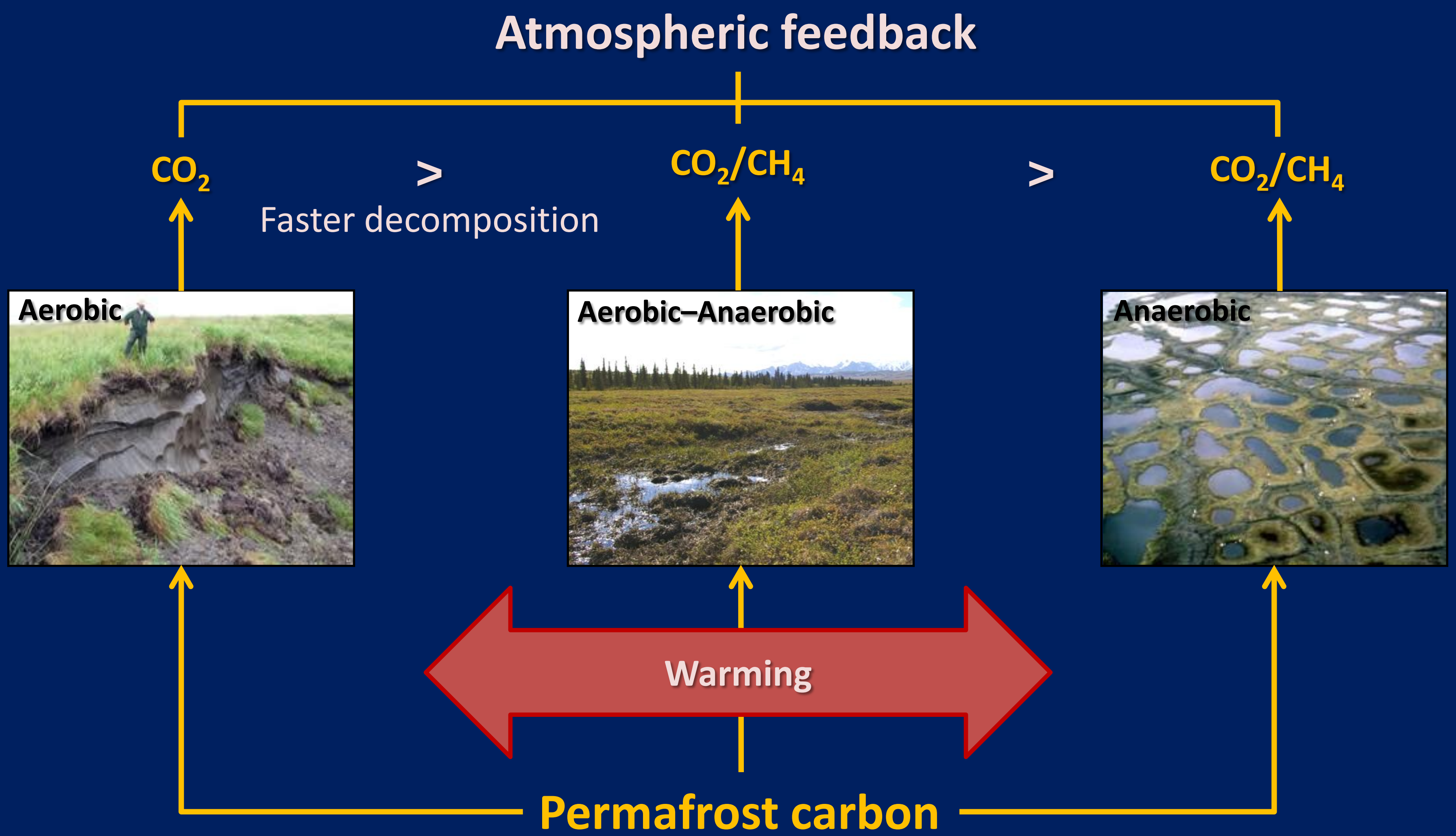
Land surface subsidence created by permafrost thaw



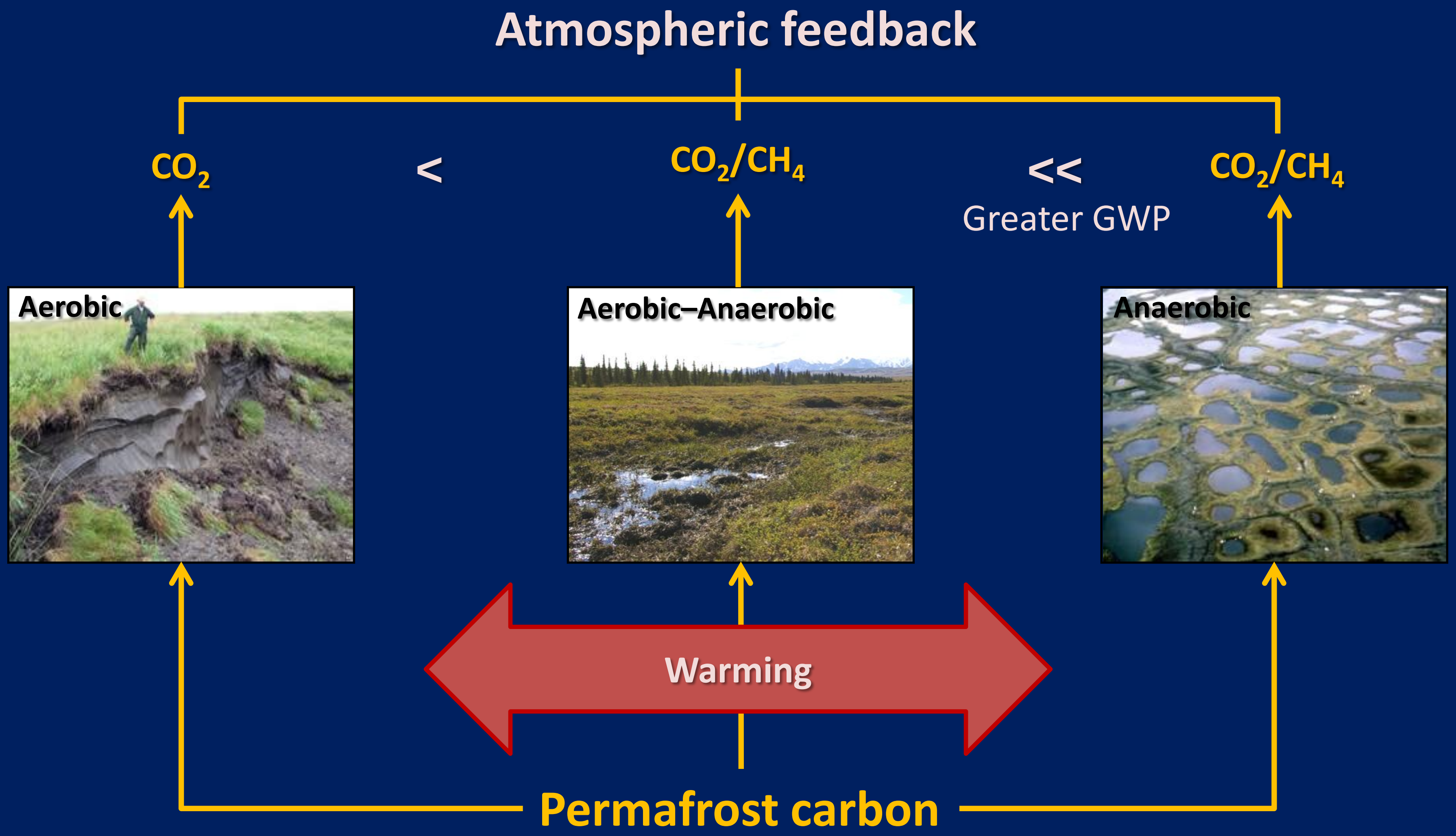



Changes in local hydrology: Aerobic vs. Anaerobic -> C cycling

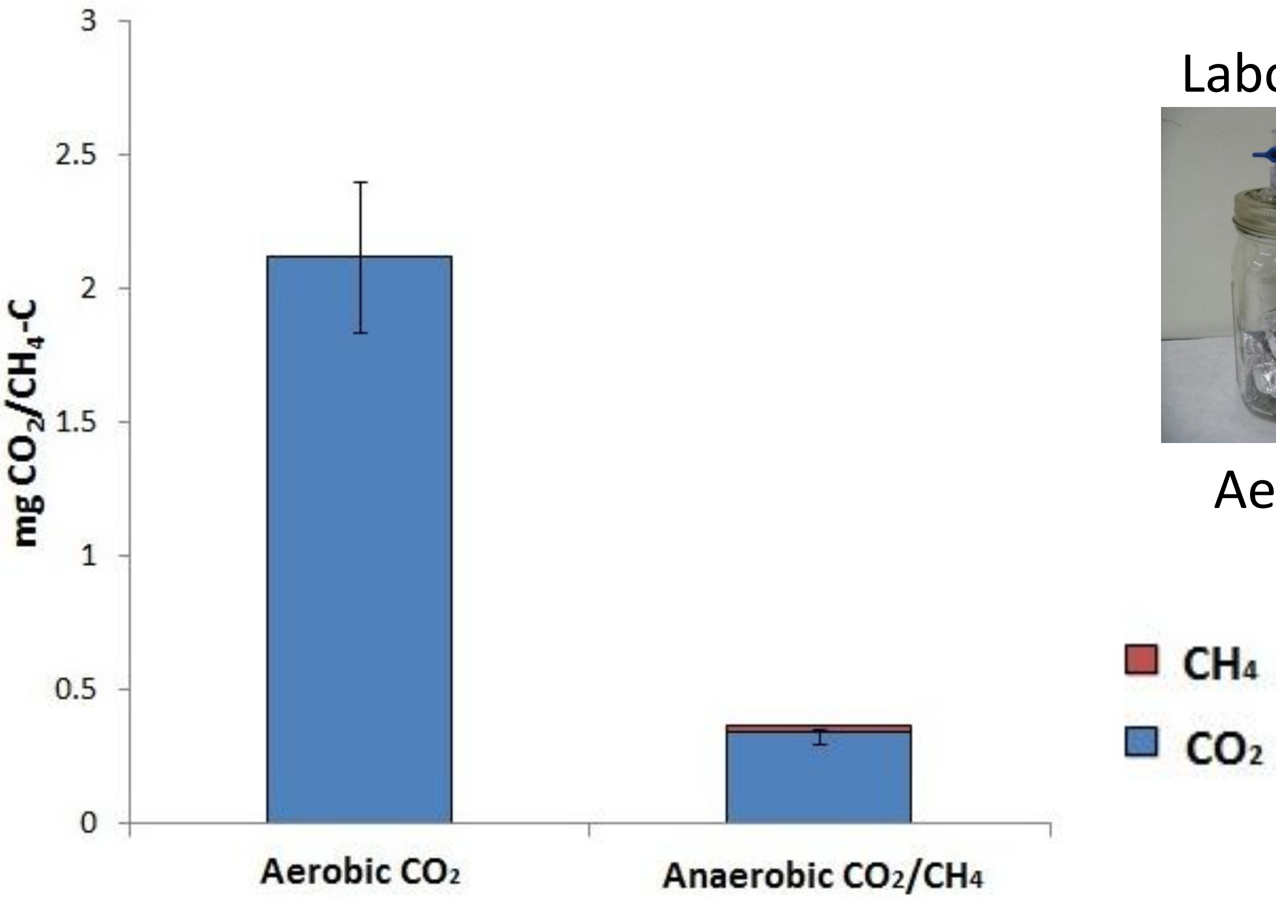
Aerobic/Anaerobic influence on permafrost carbon and climate feedback



Aerobic/Anaerobic influence on permafrost carbon and climate feedback



Climate effects from permafrost C release



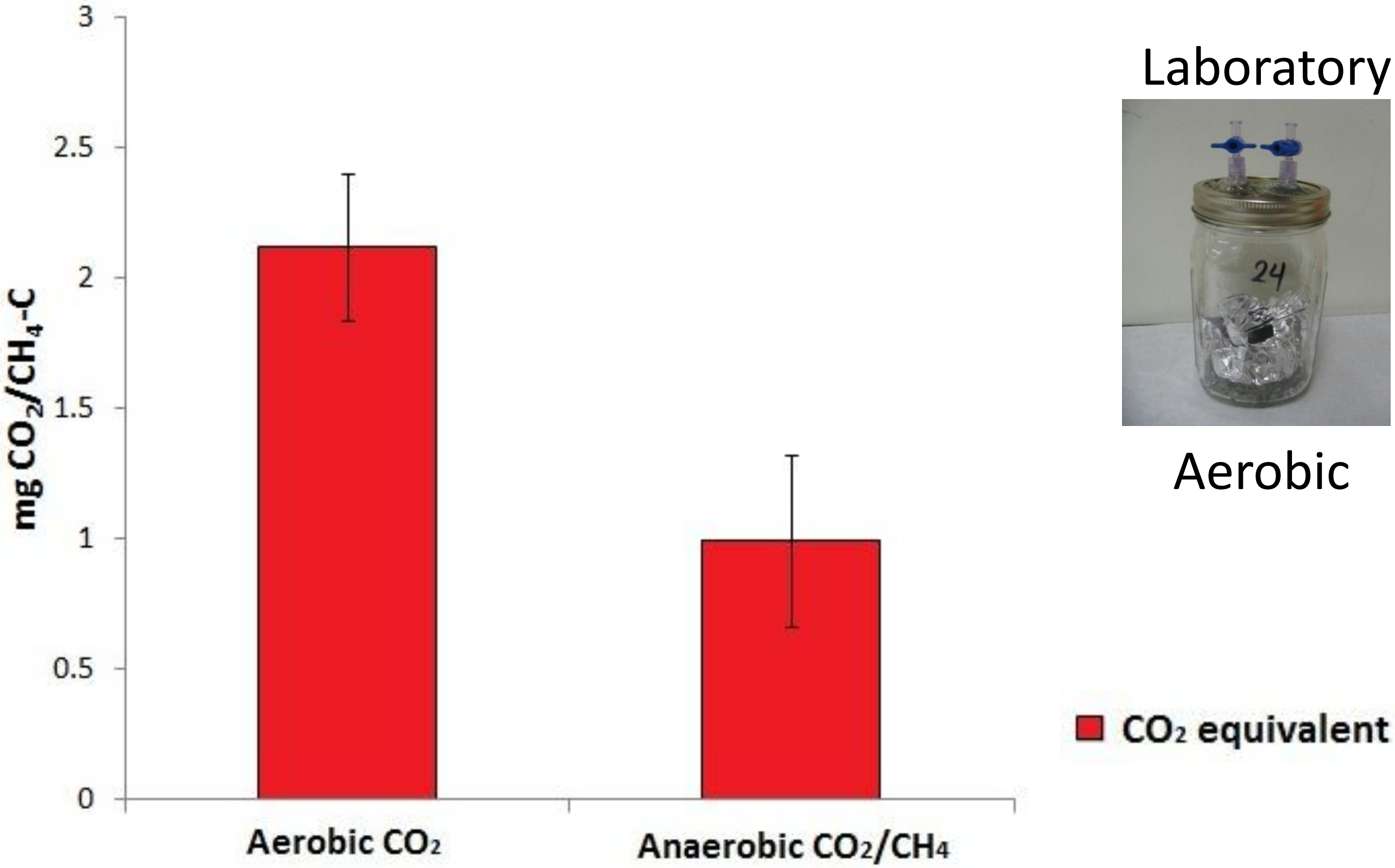
Laboratory incubation

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 Questions

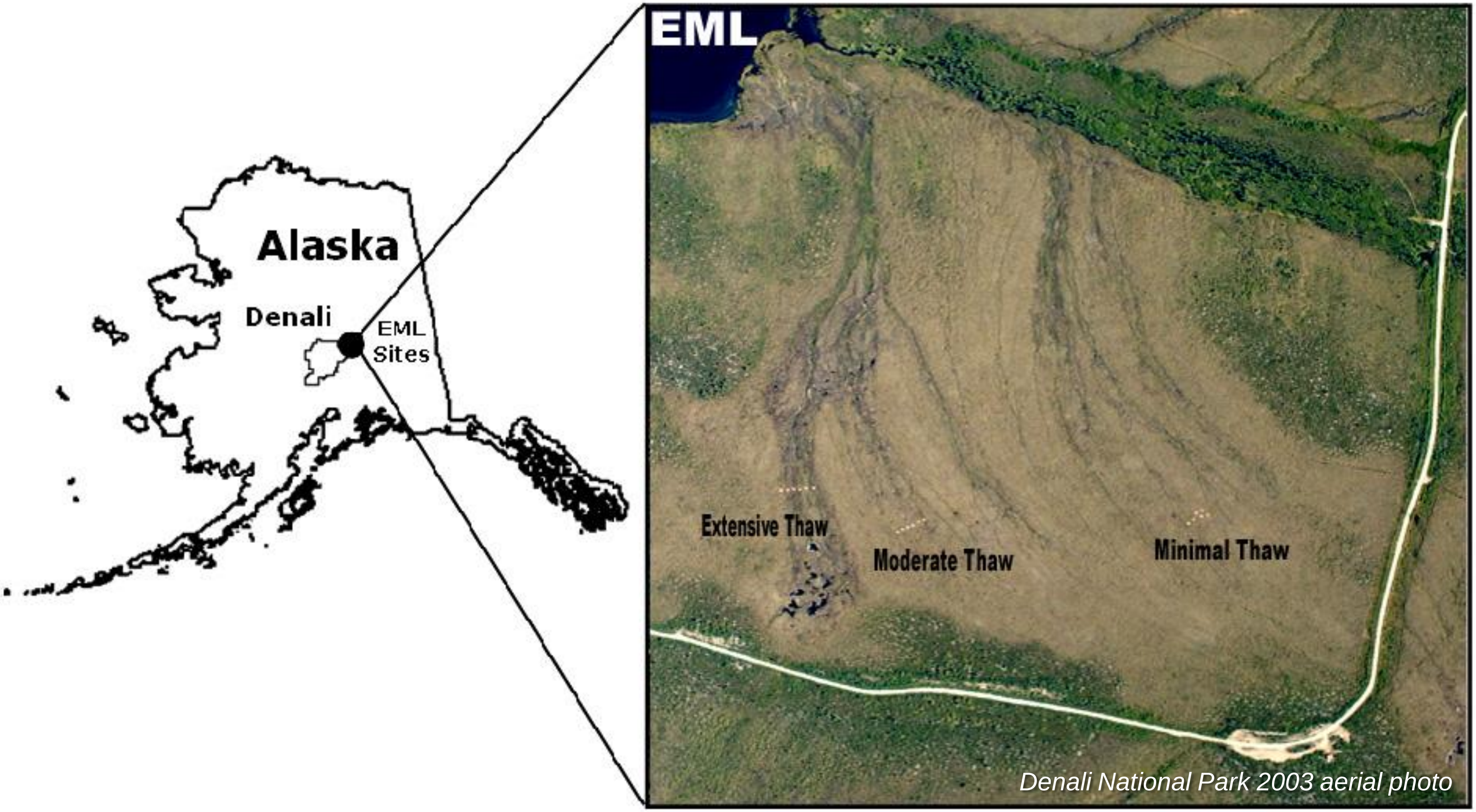
- **How does permafrost thaw influence ecosystem carbon balance under warmer world?**

- **What is the climate feedback from permafrost C?**

Research Question 1.

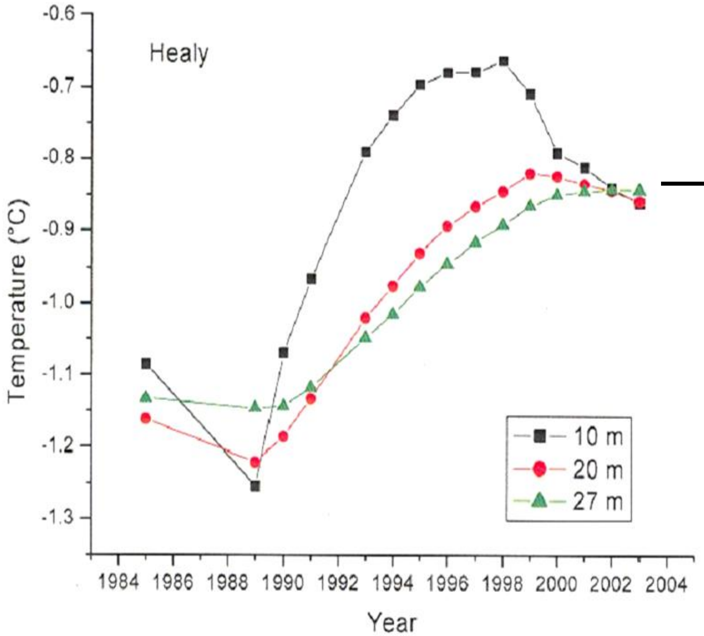
- **How does permafrost thaw influence ecosystem carbon balance under warmer world?**

Interior Alaska tundra site

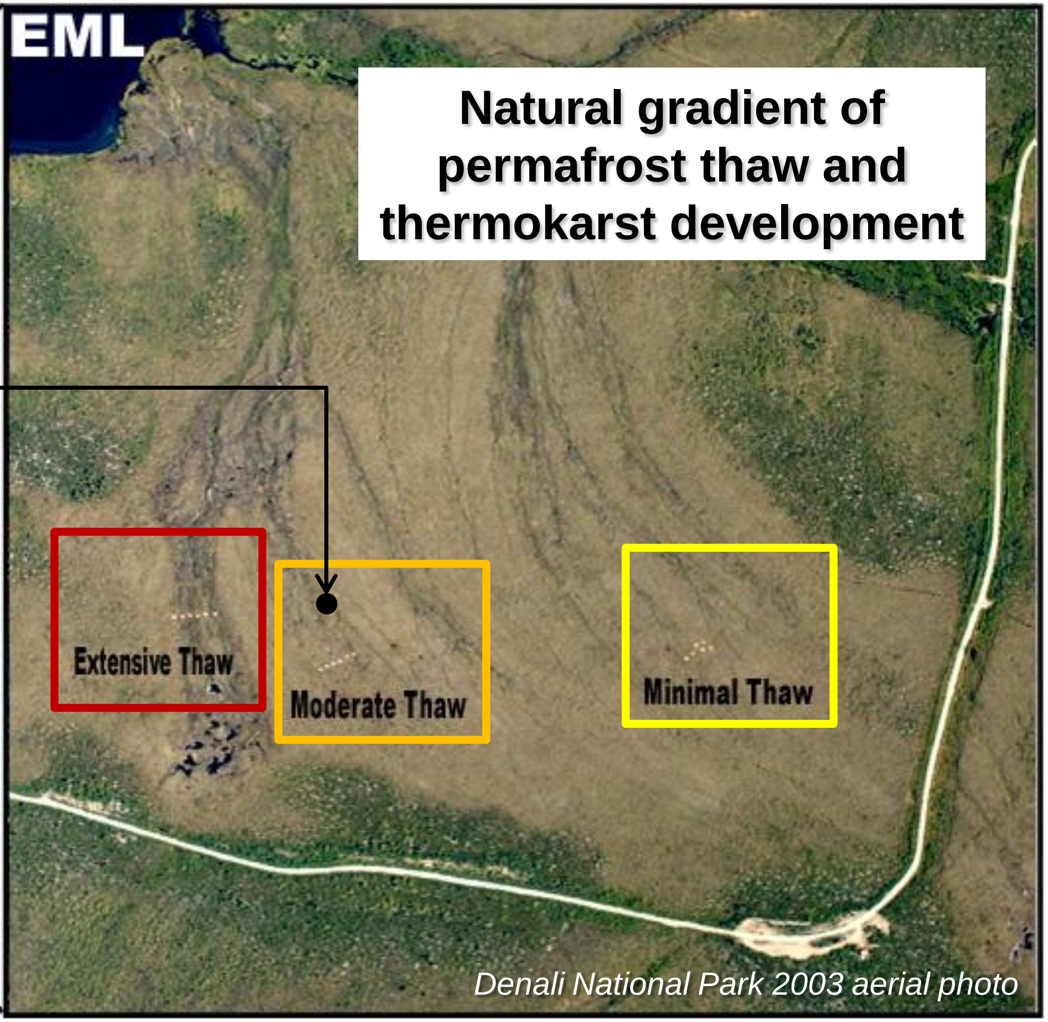


Interior Alaska tundra site

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

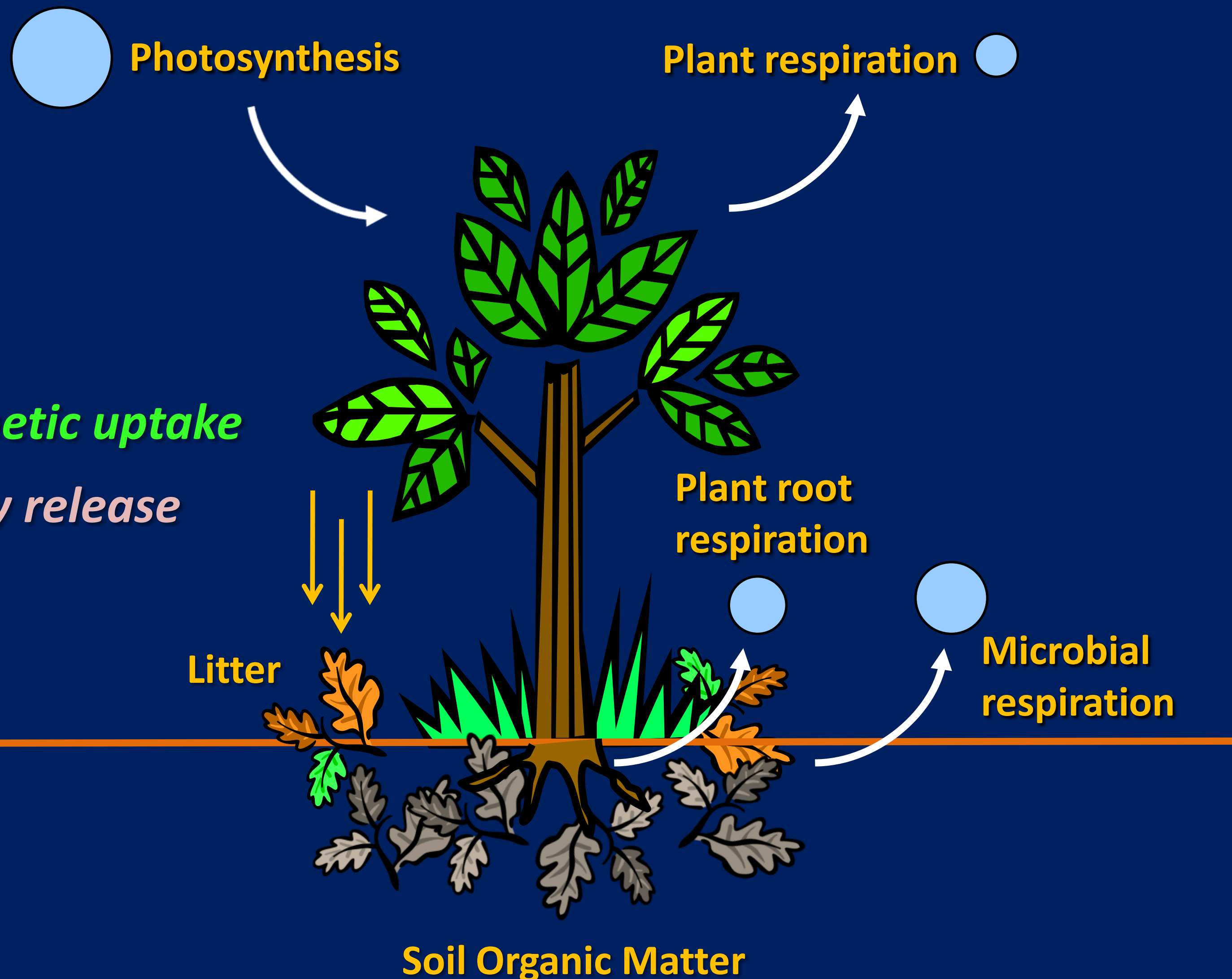
Extensive Thaw: over 50 yrs of thaw and deep thermokarst

Ecosystem carbon cycling

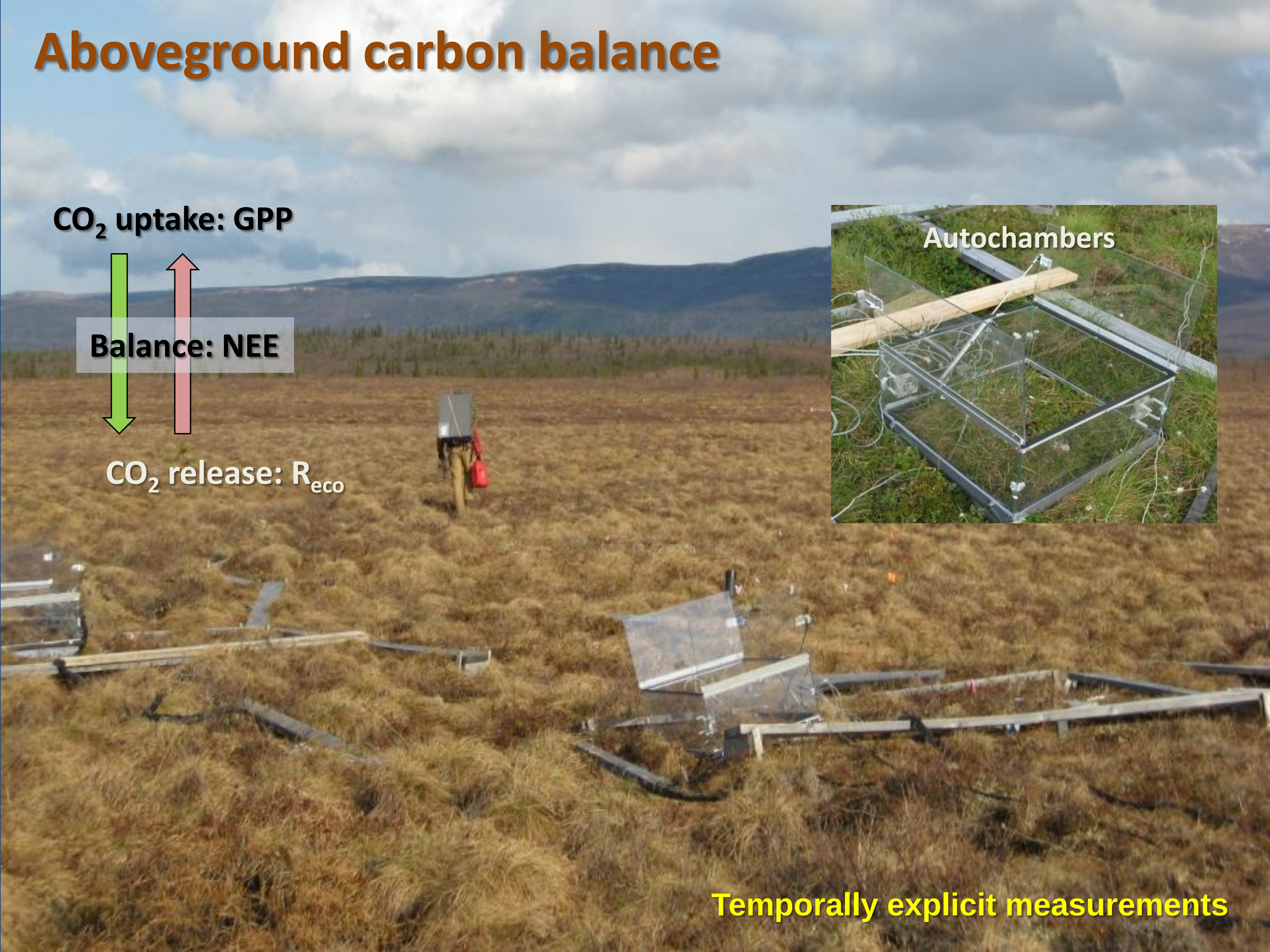
GPP: photosynthetic uptake

Reco: respiratory release

NEE: GPP - Reco

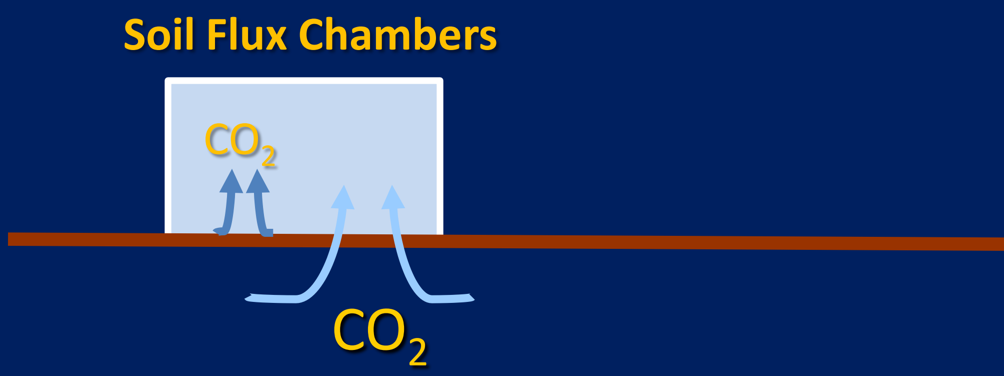


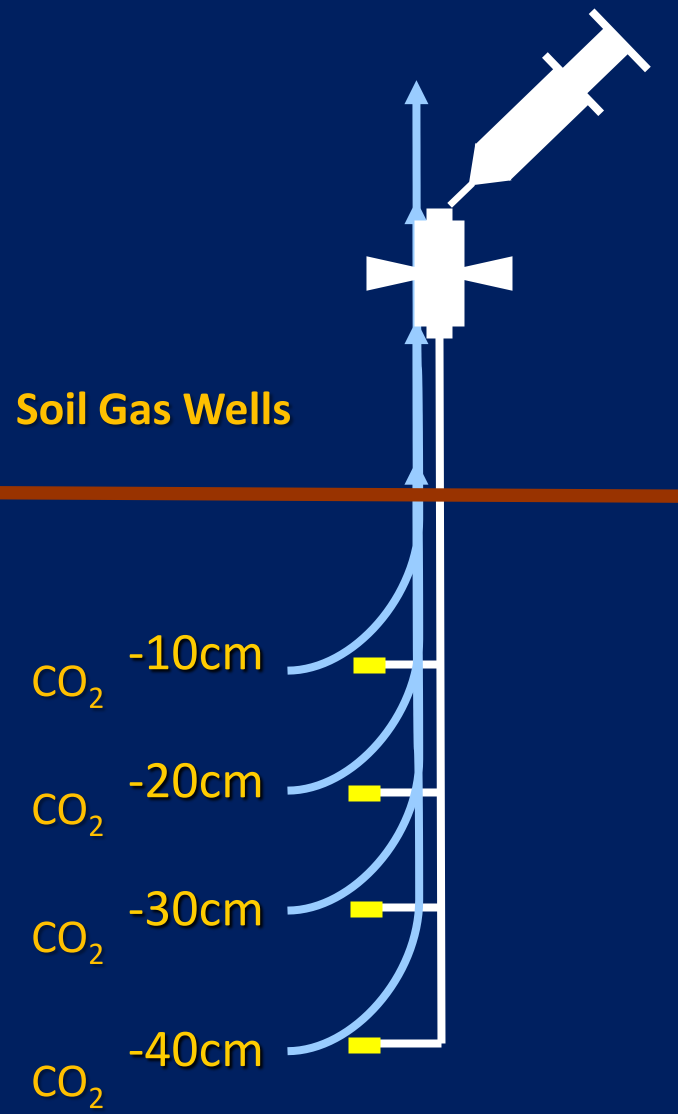
Aboveground carbon balance



Belowground permafrost carbon release

Aboveground CO_2 flux measurement



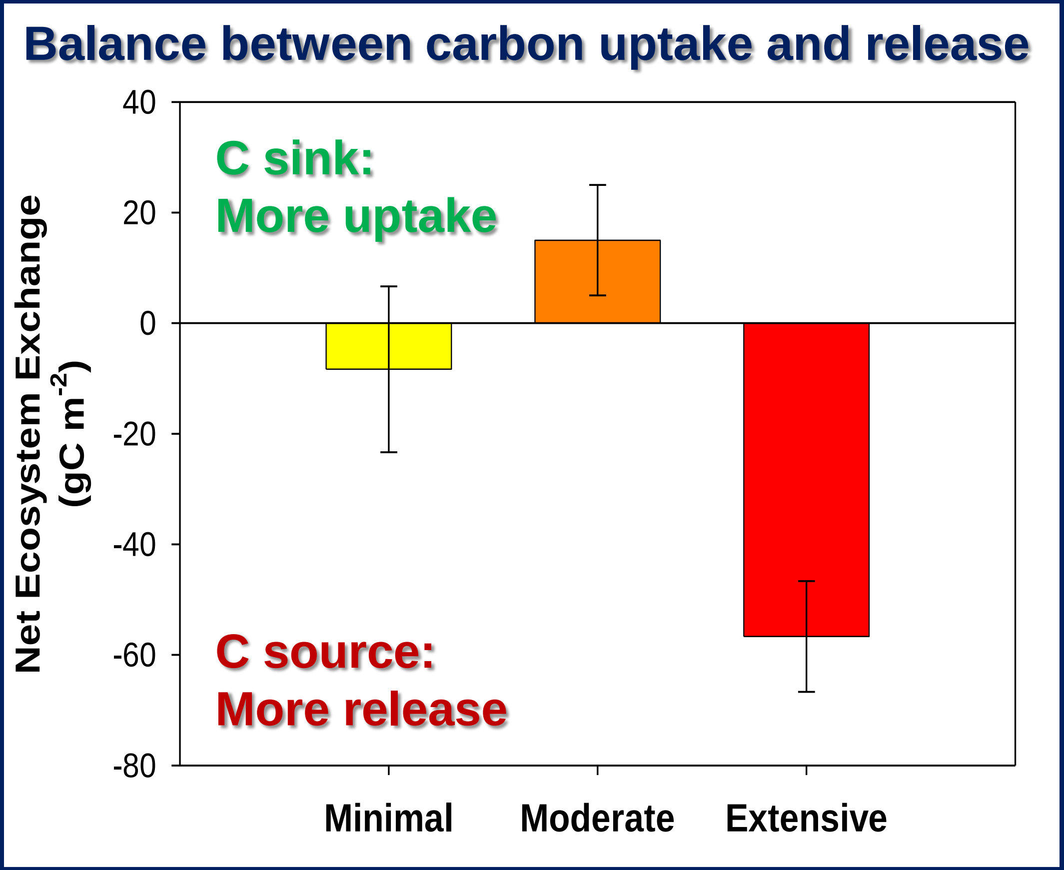


Chambers:
Photosynthetic uptake
Plant respiration
Permafrost carbon release

Gas wells:
Root respiration
Permafrost carbon release

Belowground CO_2 measurement

Aboveground Net Ecosystem Exchange of carbon



Over 3 years:

Minimal ≈ neutral

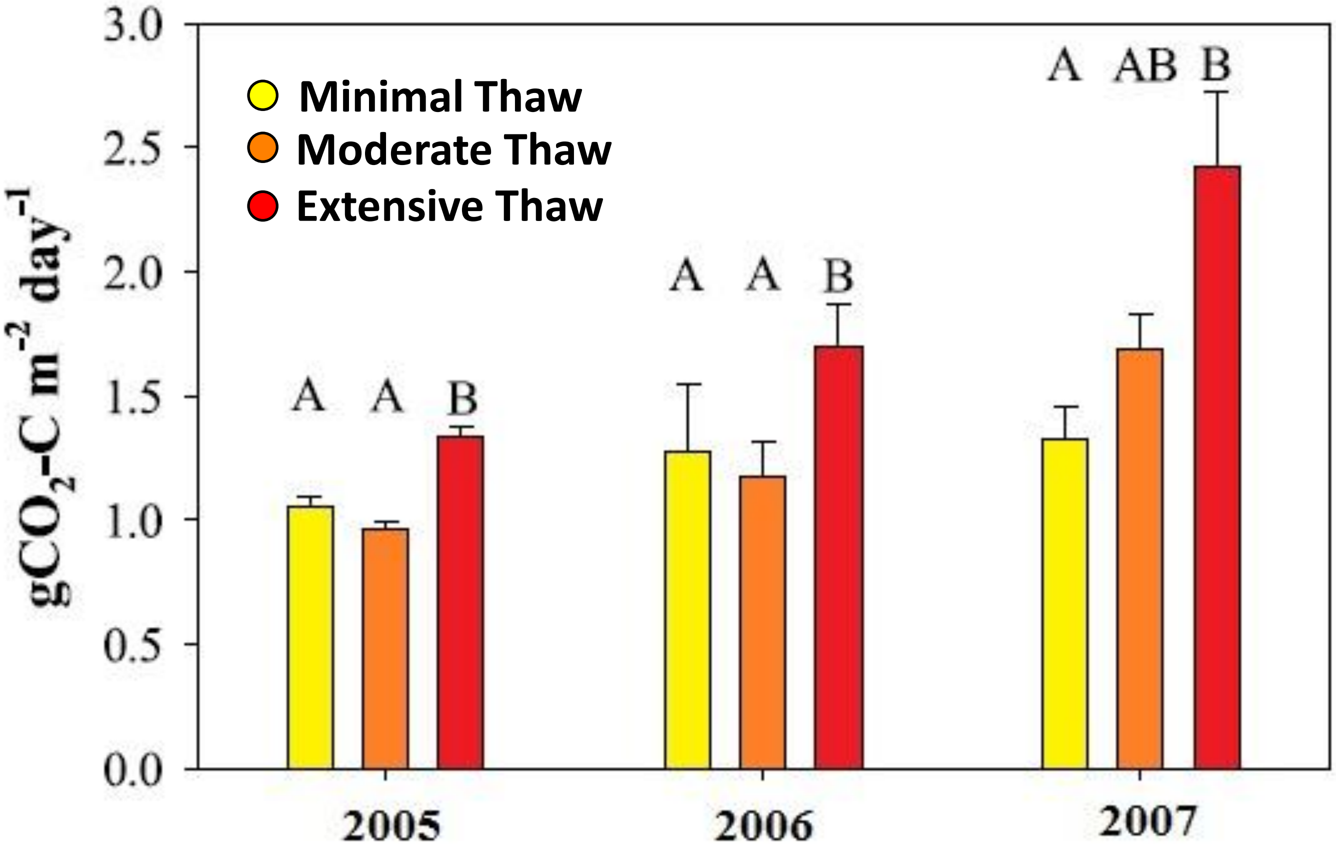
Moderate = sink
(↑GPP, ↑R_{eco})

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.*

Belowground permafrost carbon release

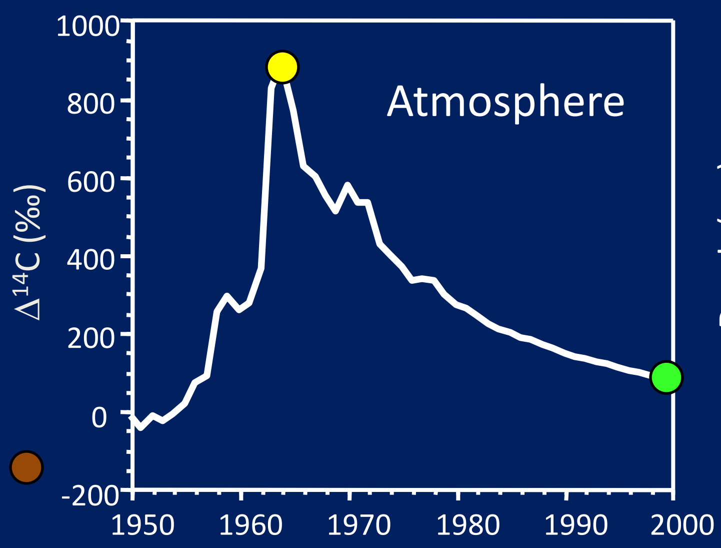
More CO_2 release in Extensive thaw

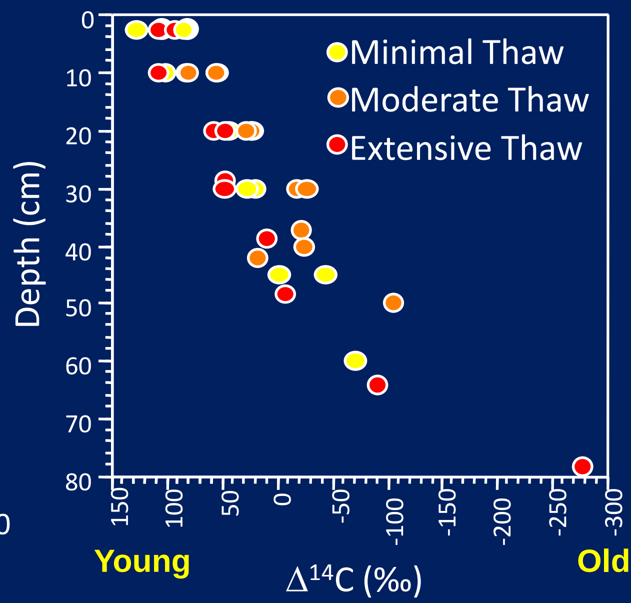


Permafrost C release greater with more permafrost thawing

Lee et al. 2010 JGR

Respiration Partitioning using ^{14}C



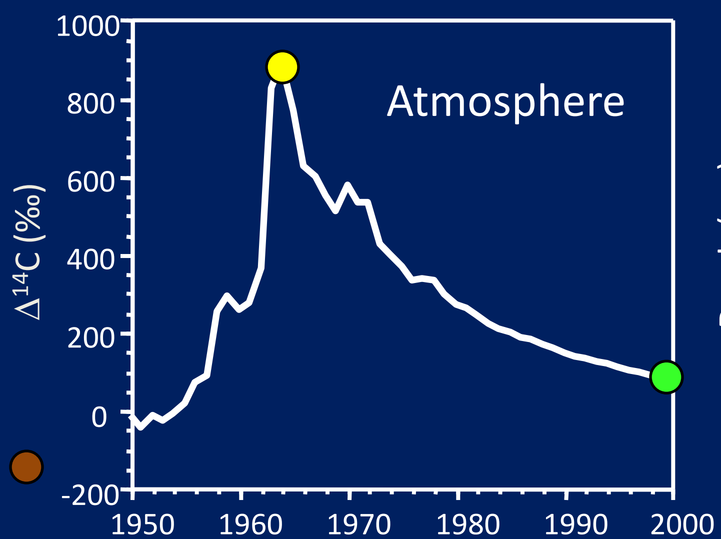


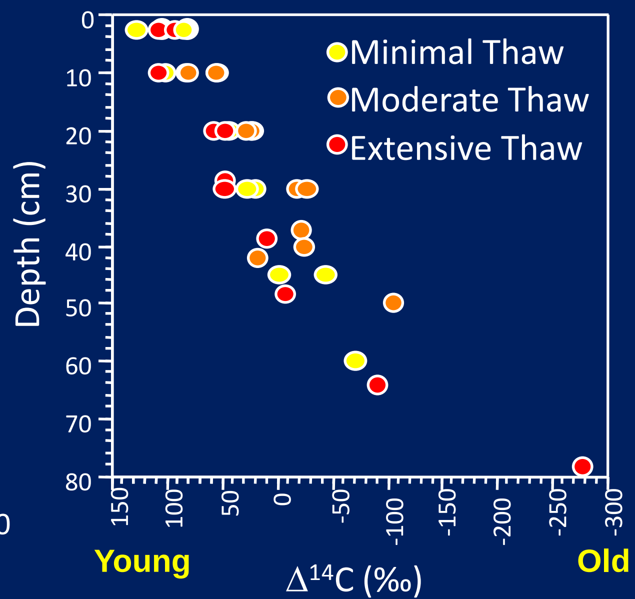
Bomb signature

Natural decay

Organic matter deposit

Respiration Partitioning using ^{14}C

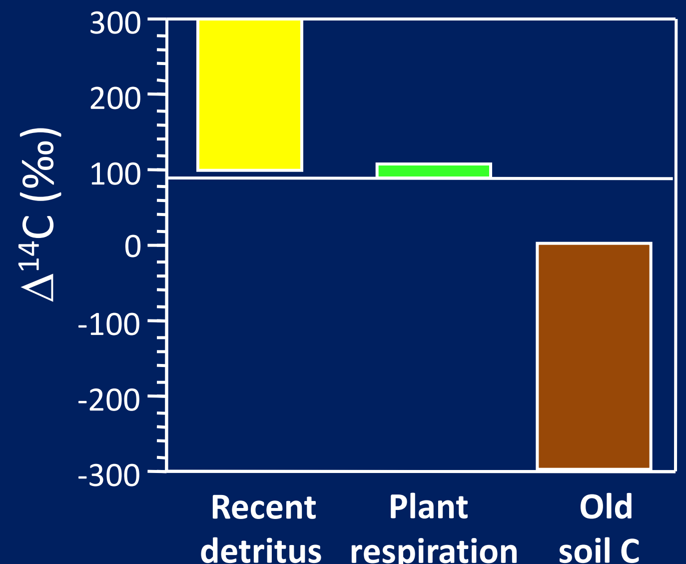




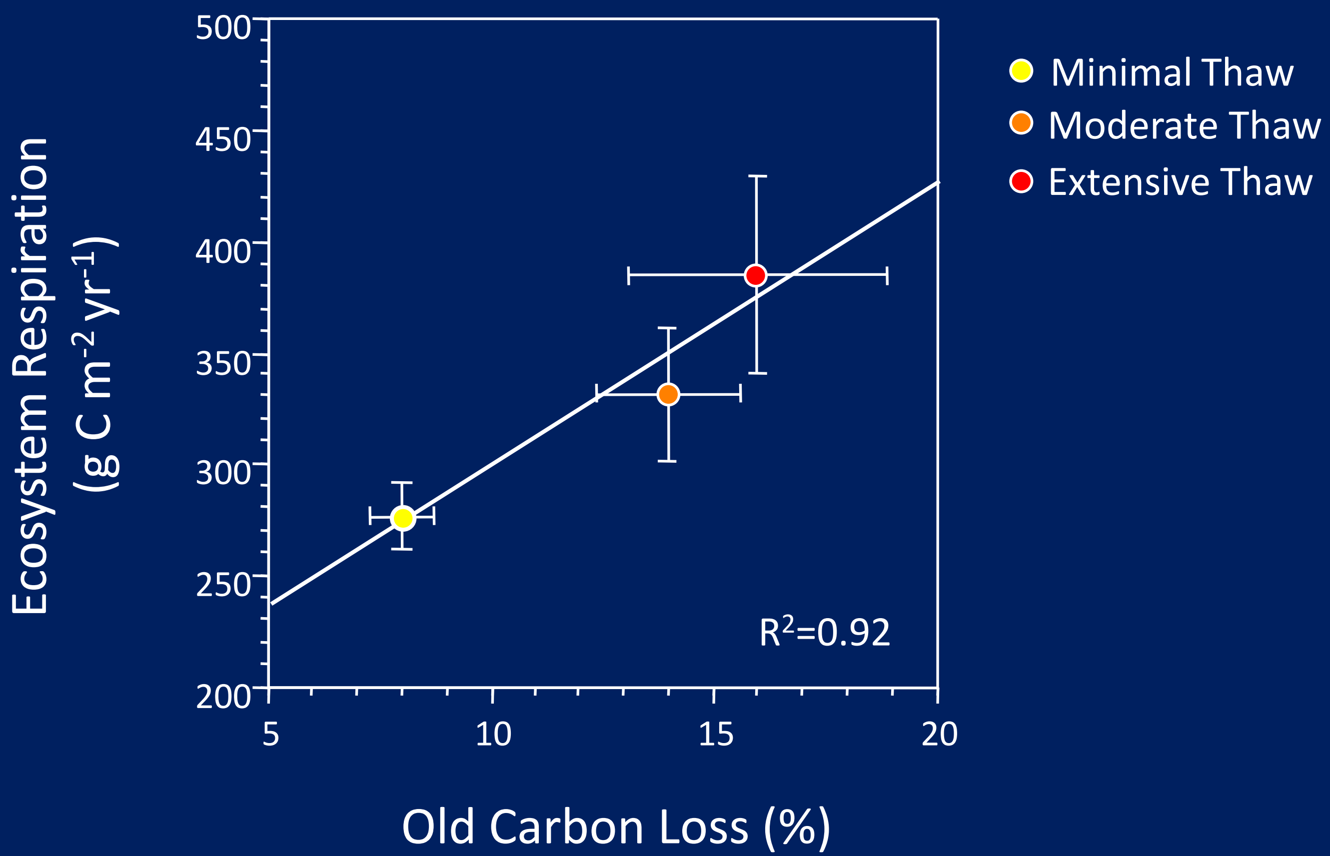
Bomb signature

Natural decay

Organic matter deposit



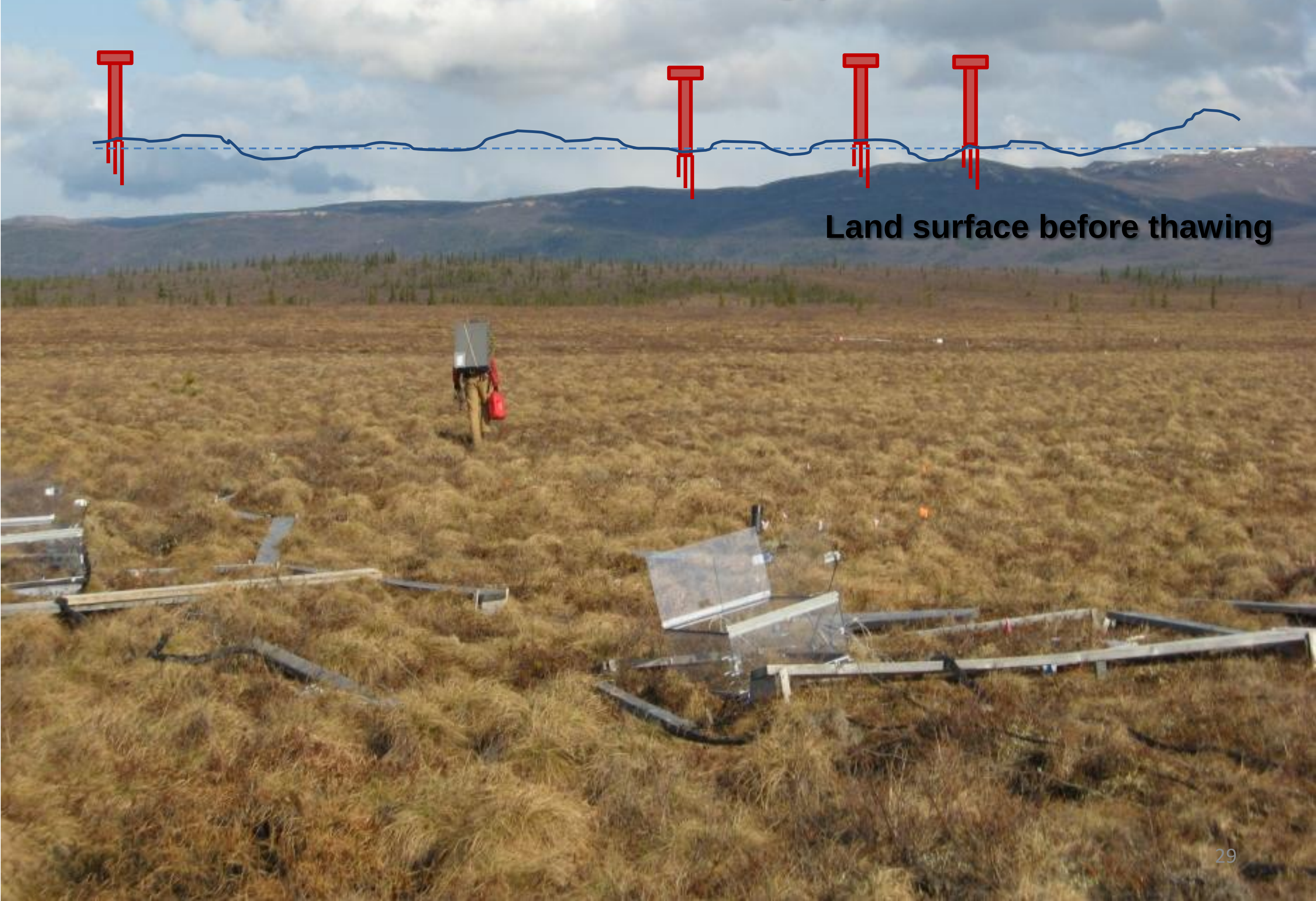
More old carbon loss with permafrost thaw



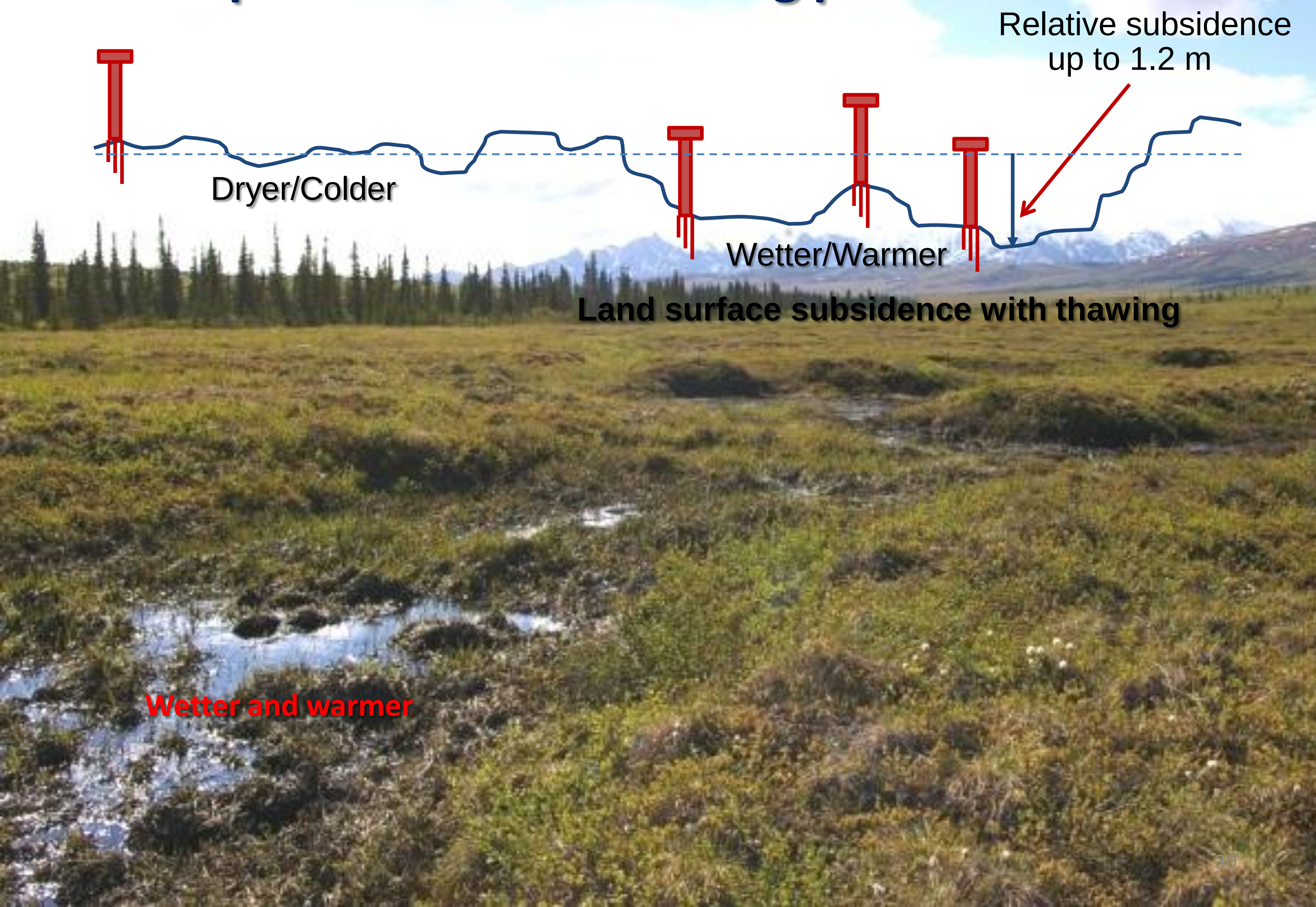
Contribution of permafrost C in total ecosystem C release greater with more thawing.

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

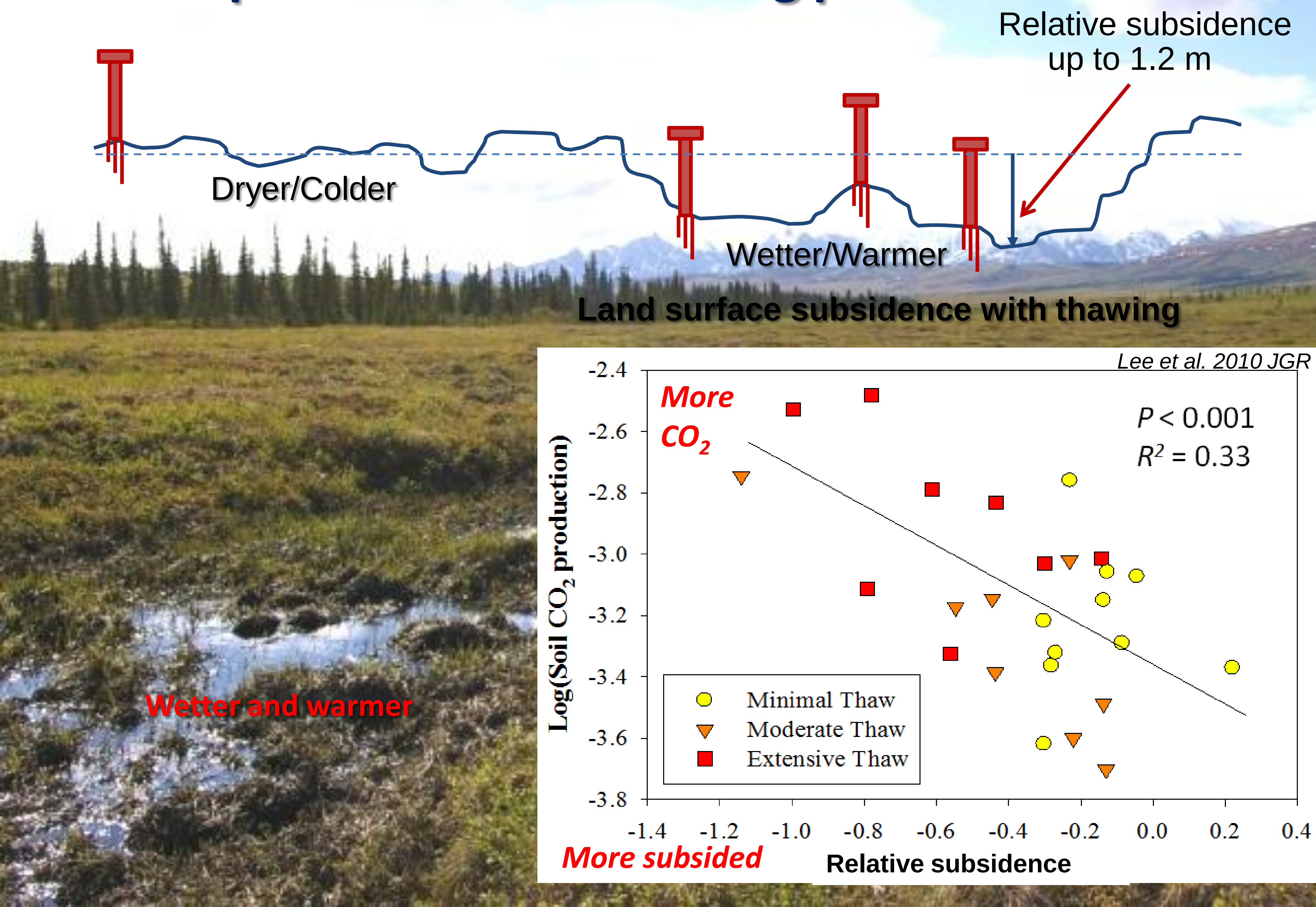
Surface patterns under thawing permafrost



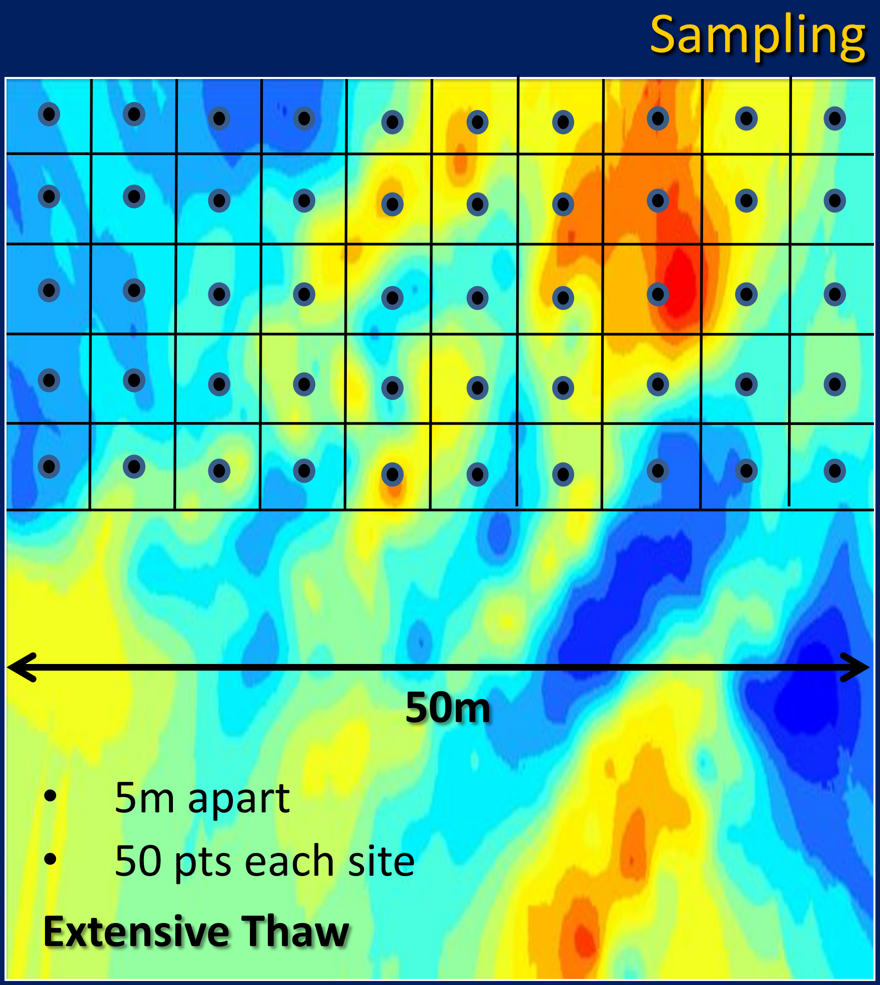
Surface patterns under thawing permafrost



Surface patterns under thawing permafrost



How can we model ecosystem C dynamics with thermokarst?



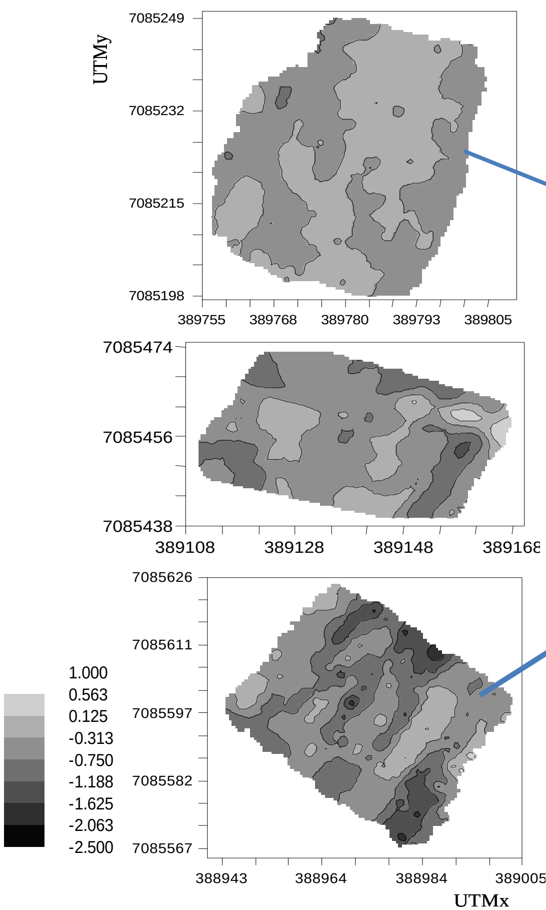
Spatially explicit measurements

- Land surface patterns
- Ecosystem C balance
- Vegetation
- Soil environment

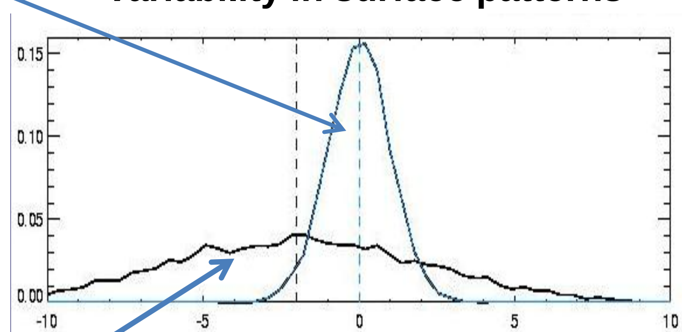
How can we model ecosystem C dynamics with thermokarst?

Lee et al. 2011 GCB

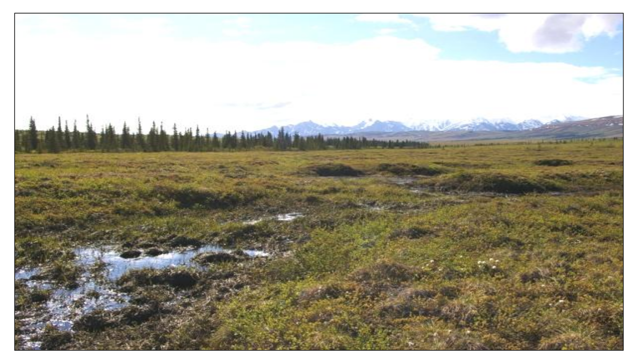
Land surface patterns



Variability in surface patterns



Low relief land surface pattern

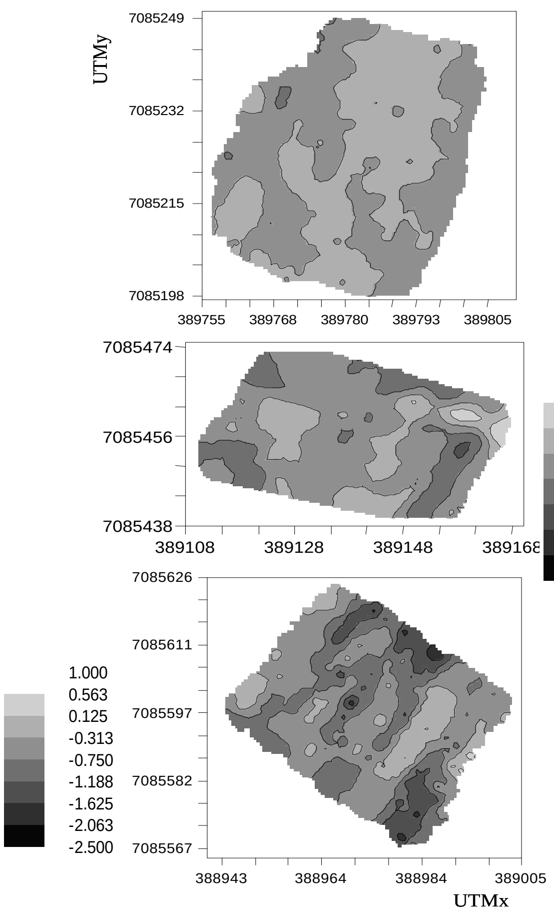


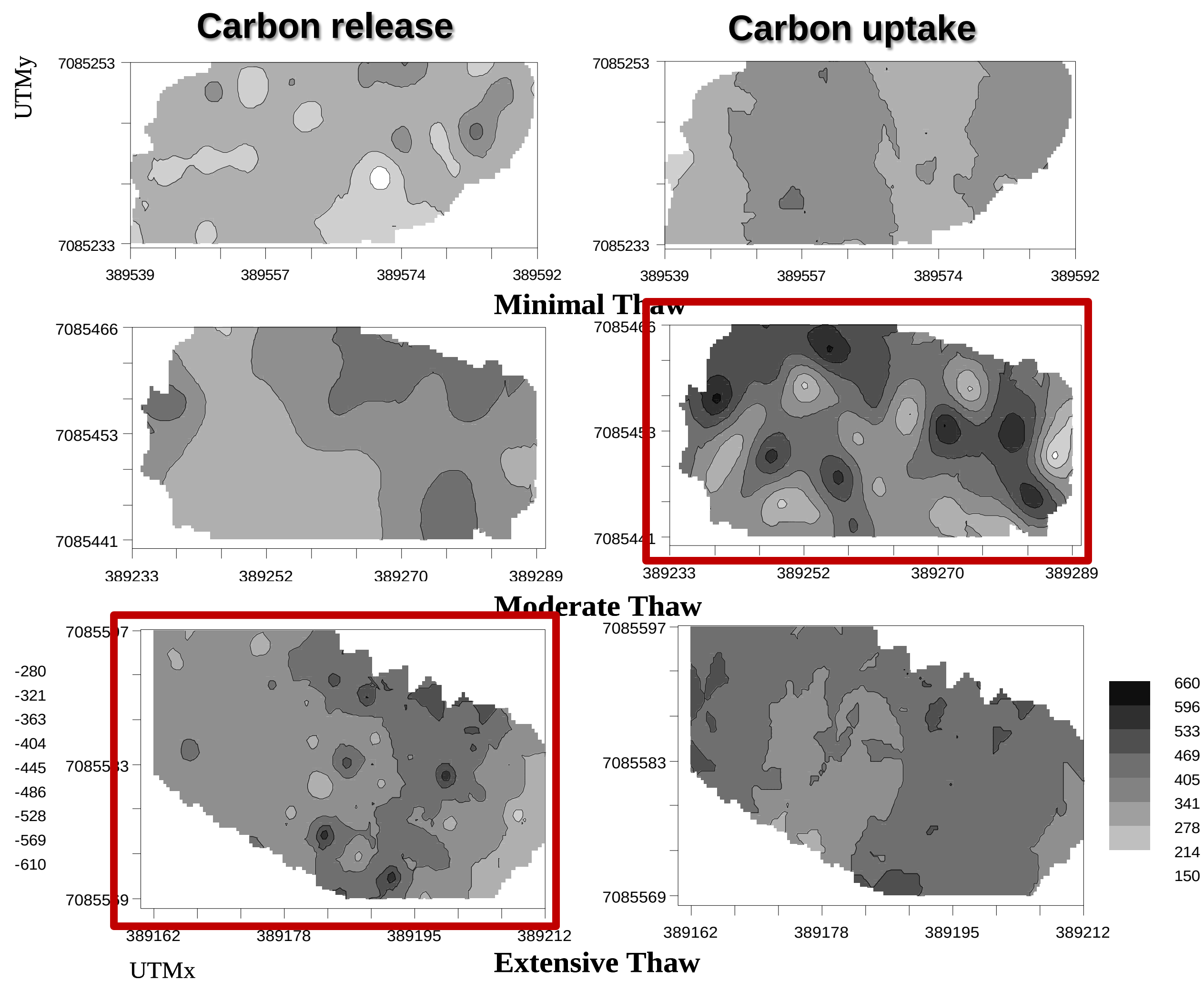
High relief land surface pattern

How can we model ecosystem C dynamics with thermokarst?

Lee et al. 2011 GCB

Land surface patterns





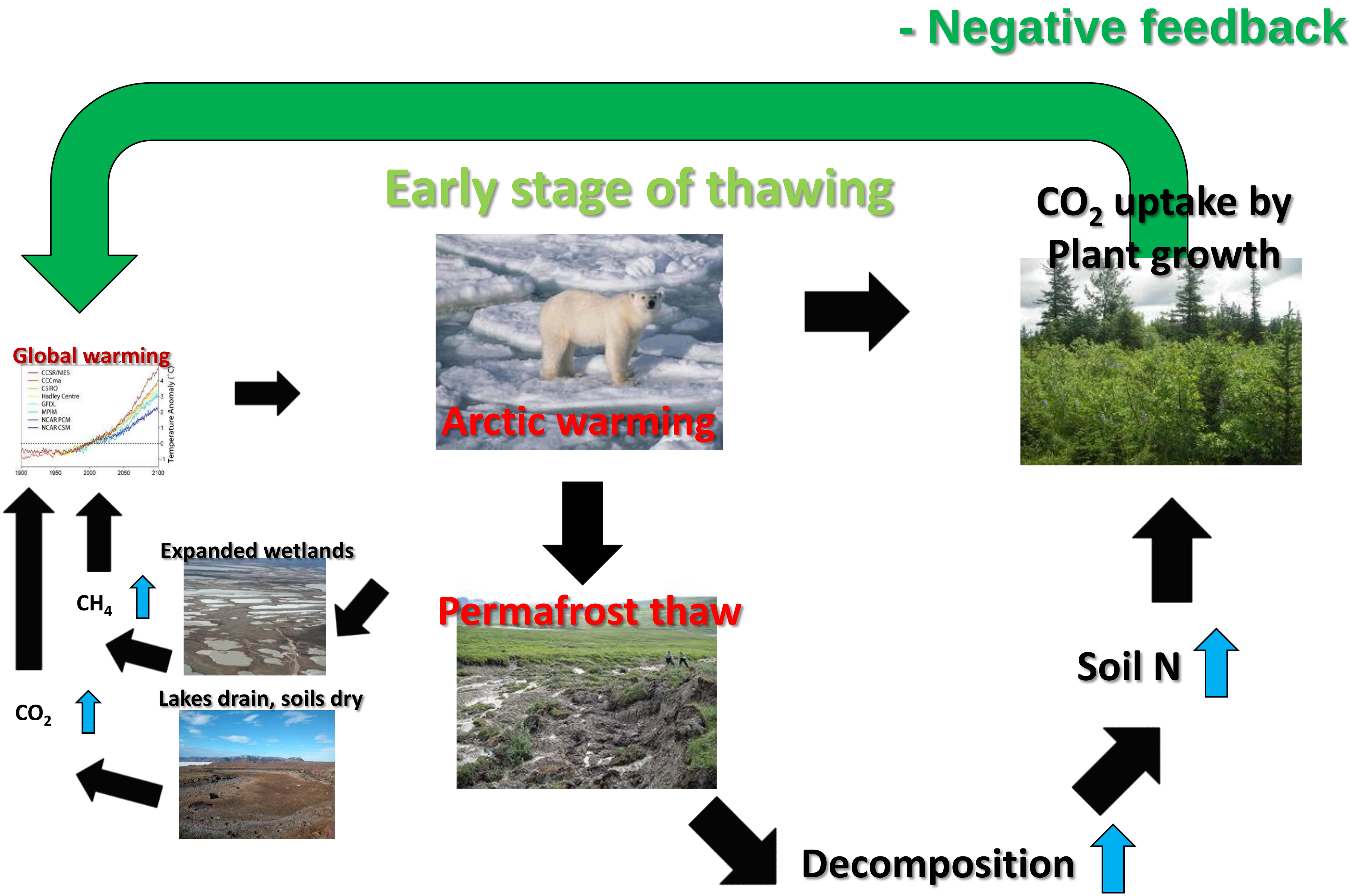
Land surface patterns explain ecosystem carbon balance in the landscape!

Insights from Observations

- Permafrost thaw increase C uptake, but increase C release at a greater rate over time

- Land surface subsidence (thermokarst) can be used as a proxy for understanding ecosystem C balance on a landscape scale

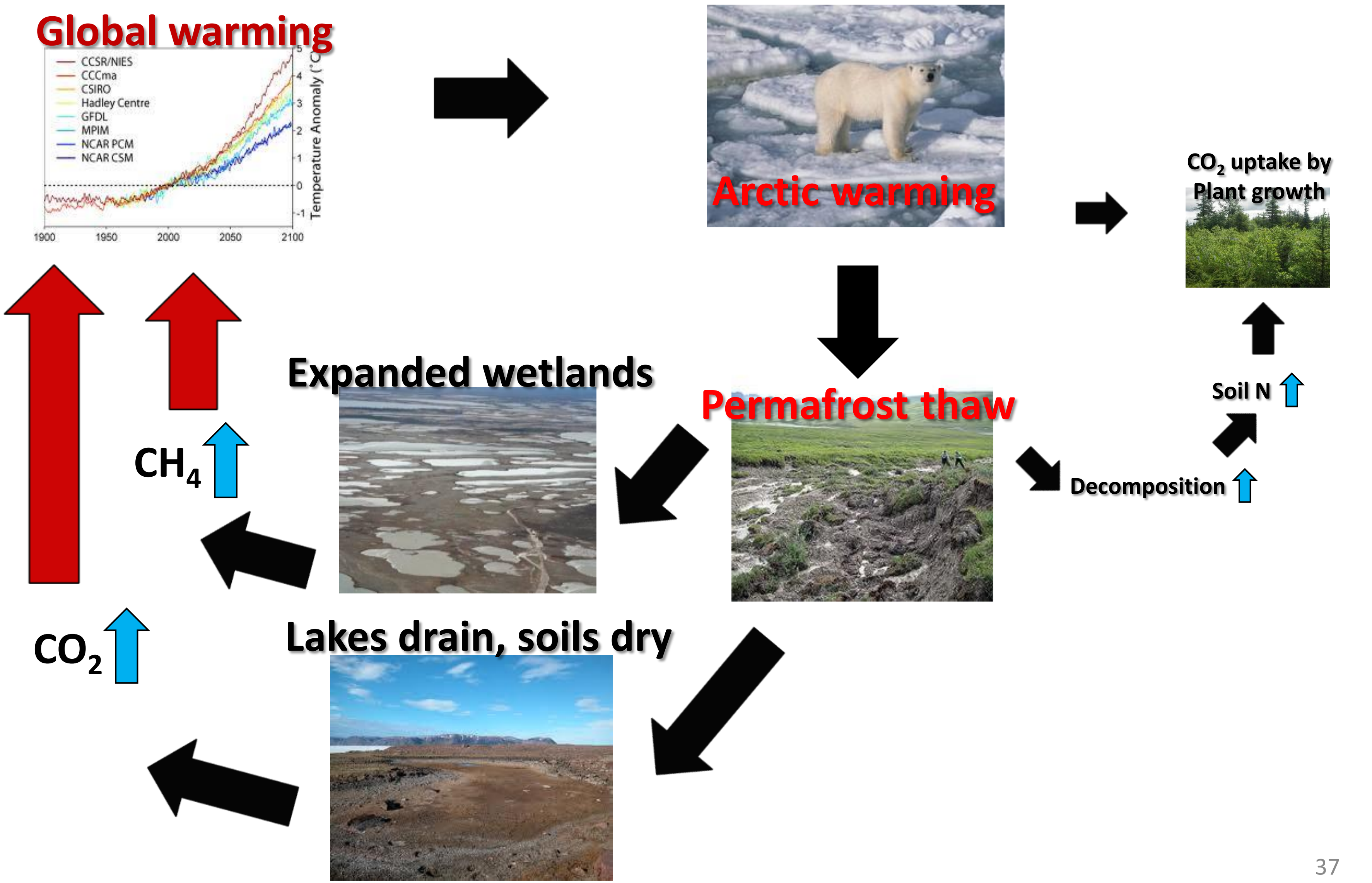
Potential Arctic-climate feedback



Potential Arctic-climate feedback

Later stage of thawing

+ Positive feedback



Permafrost Carbon Loss in global carbon context

Using the three sites as representatives of permafrost thaw…

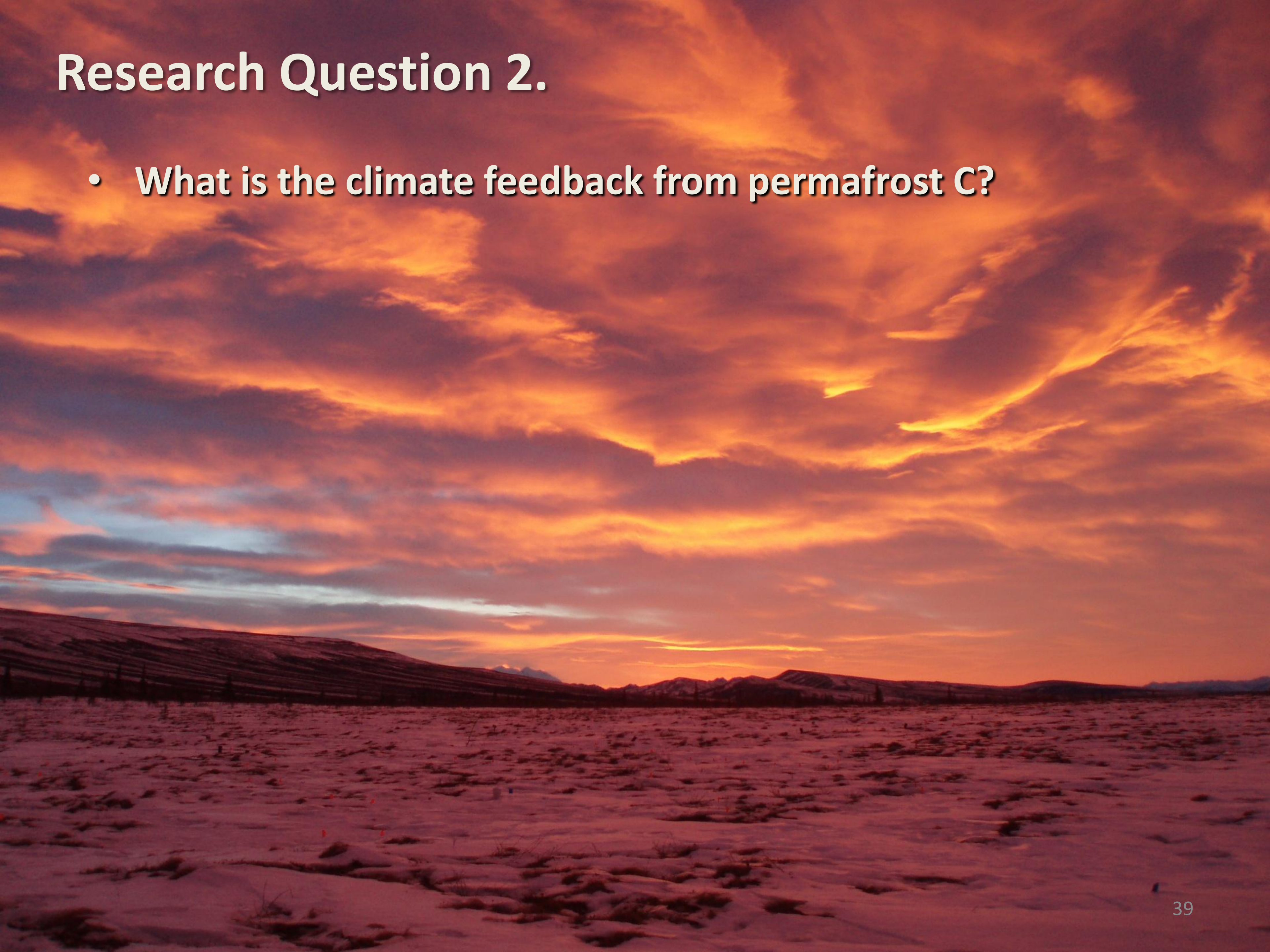
Permafrost Zone Soil C

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)

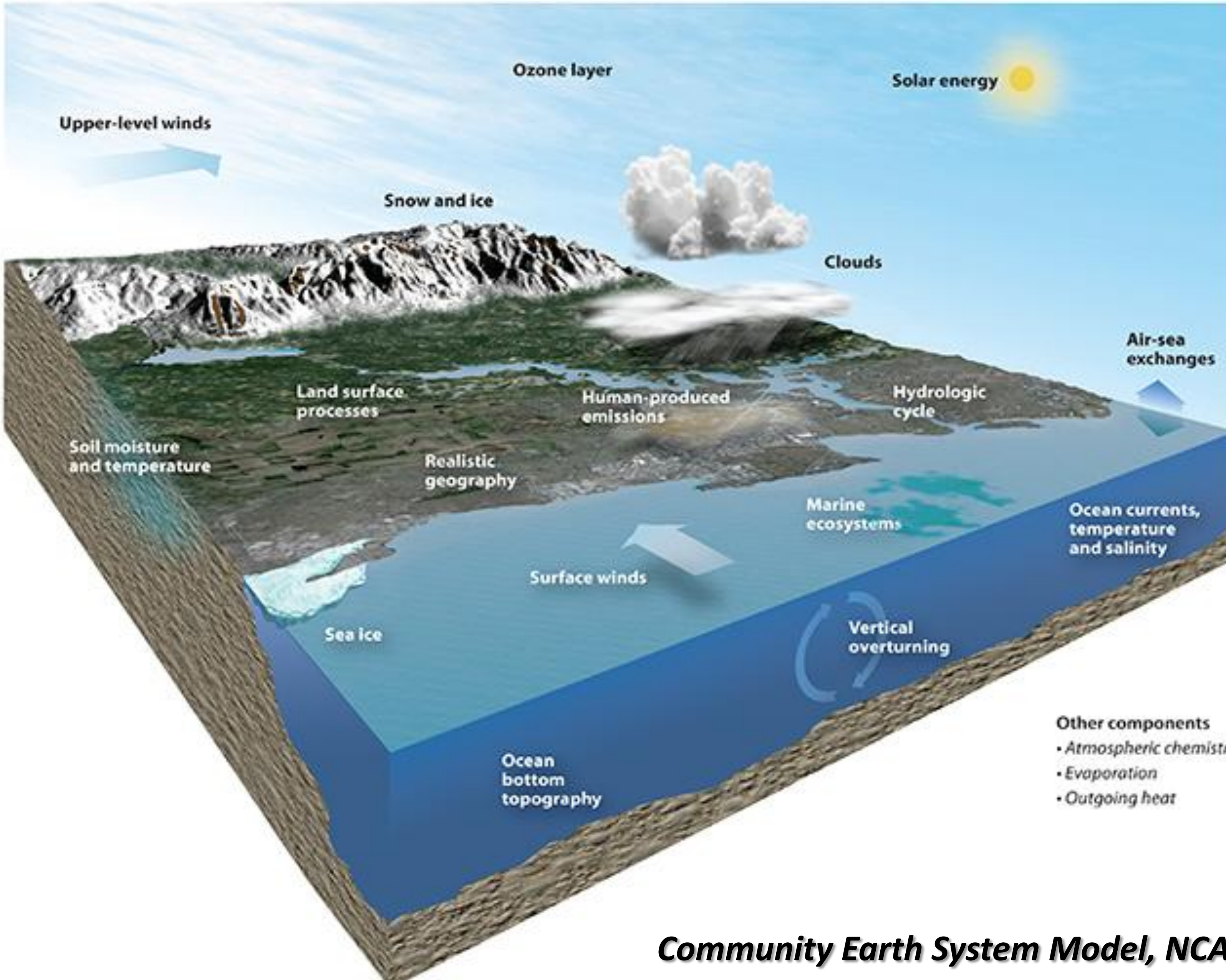
*Schuur, Vogel, Crummer, **Lee**, Sickman, Osterkamp 2009 **Nature** 459: 556-559.*

Research Question 2.

- **What is the climate feedback from permafrost C?**

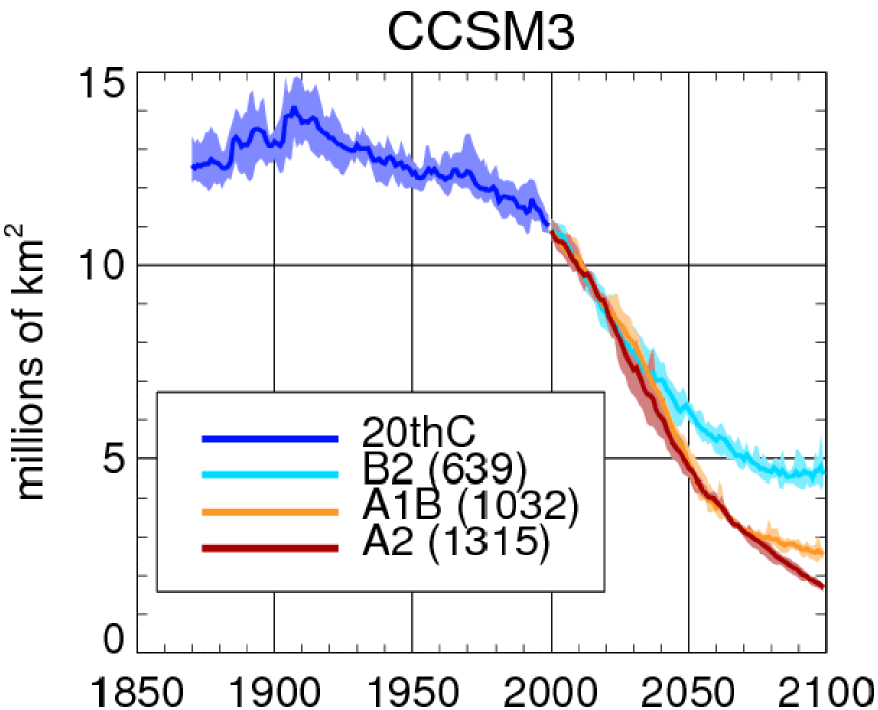


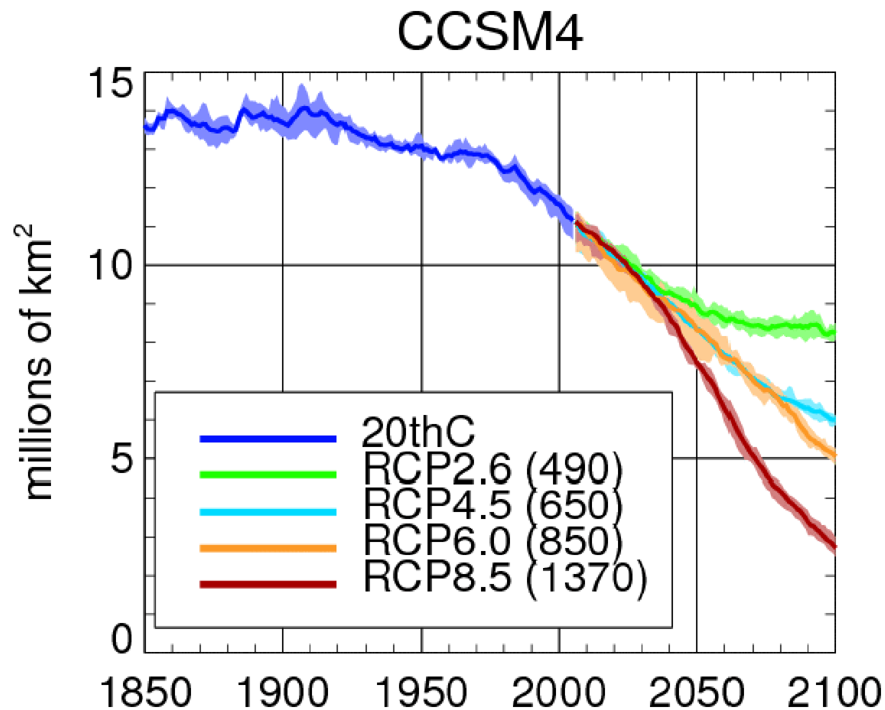
Using Earth System Models



Community Earth System Model, NCAR

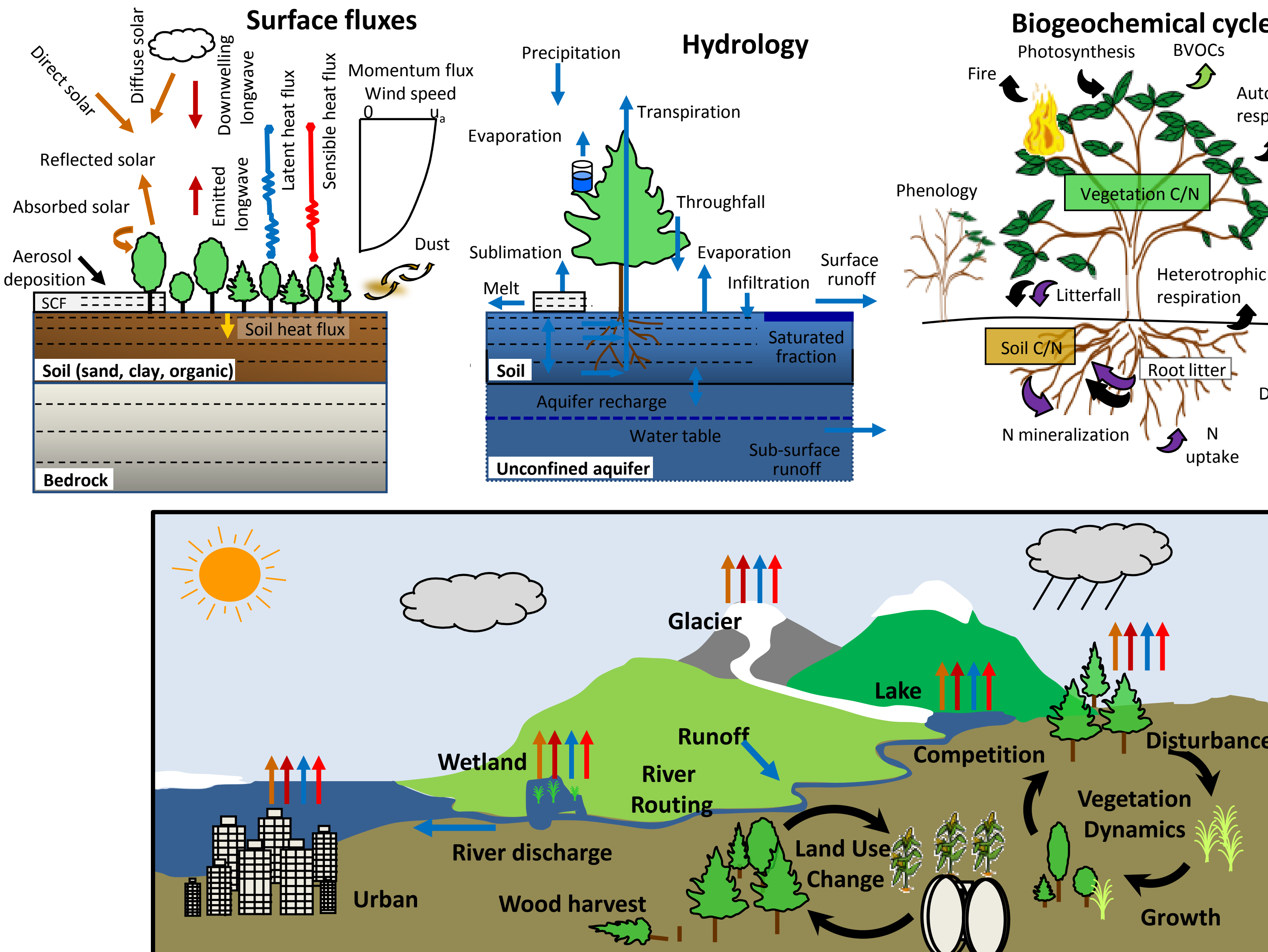
Near surface permafrost extent



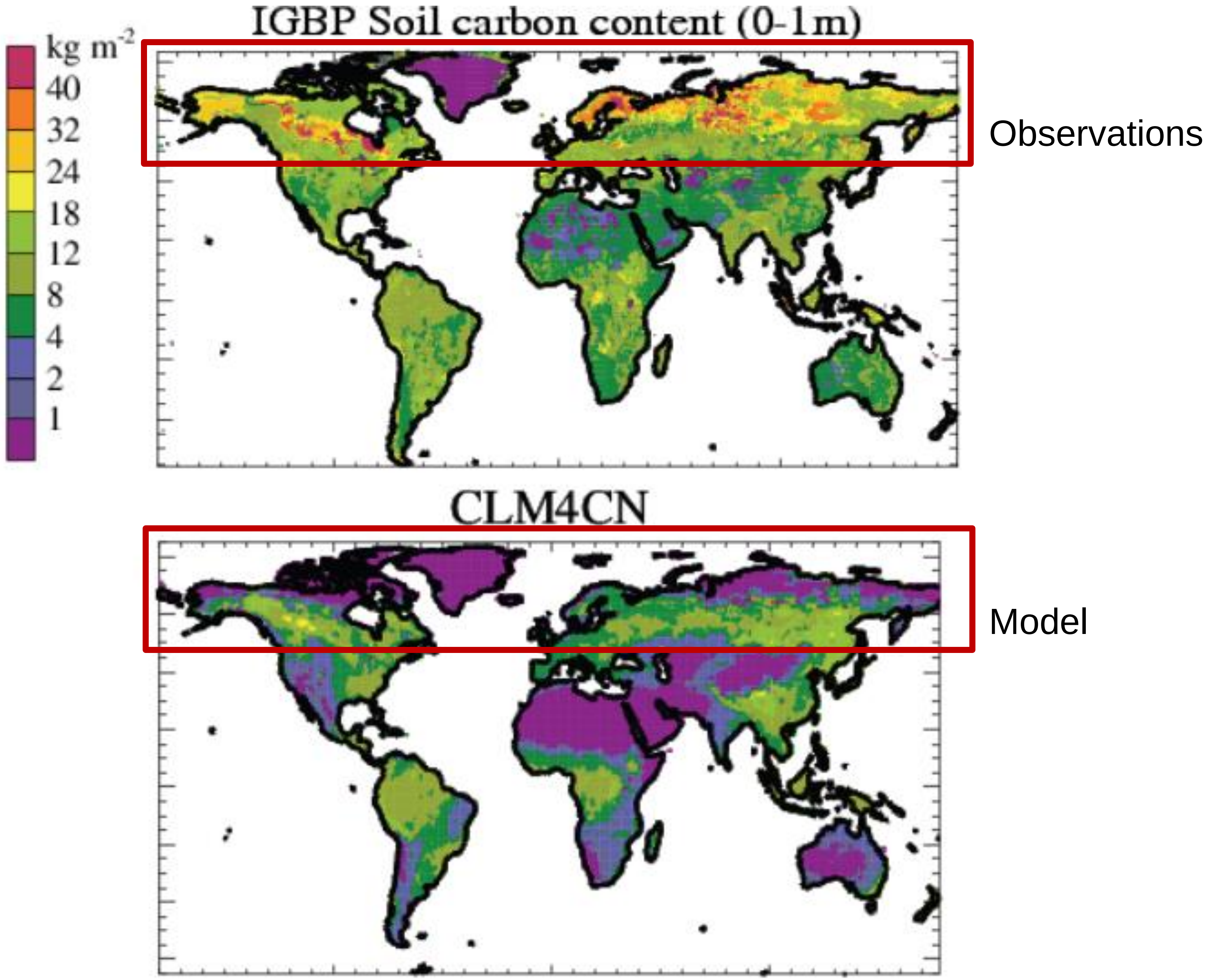


Lawrence and Slater 2005
Lawrence, Slater, Swenson 2012

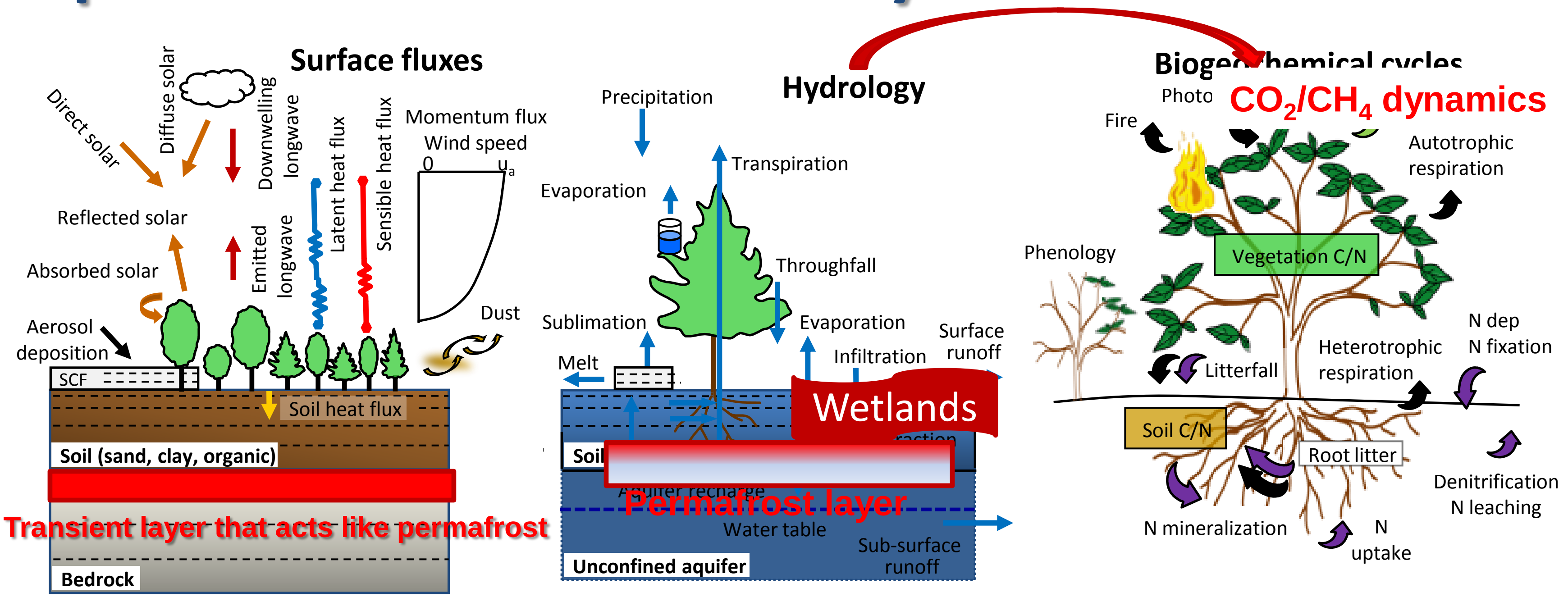
Conceptual diagram of Community Land Model 4.0

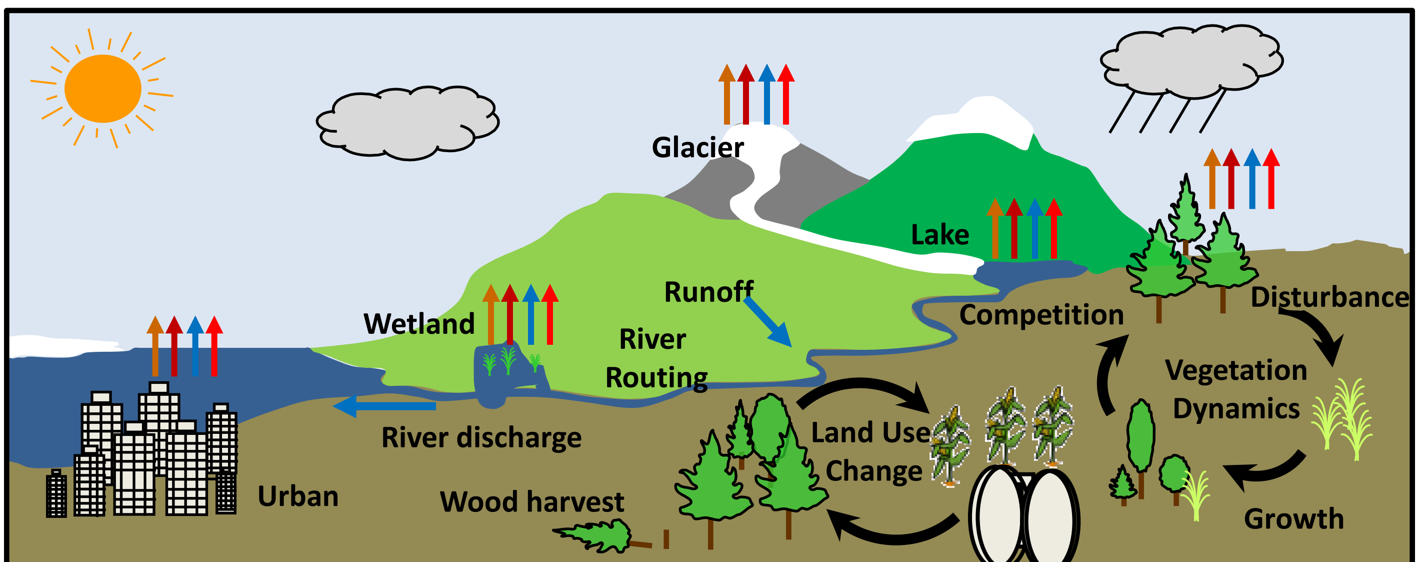


Lawrence et al., Journal Advances Modeling Earth Systems, 2011


IGBP Soil carbon content (0-1m)
kg m-2
40
32
24
18
12
8
4
2
1
Observations
CLM4CN
Model

Improvements in Community Land Model 4.5

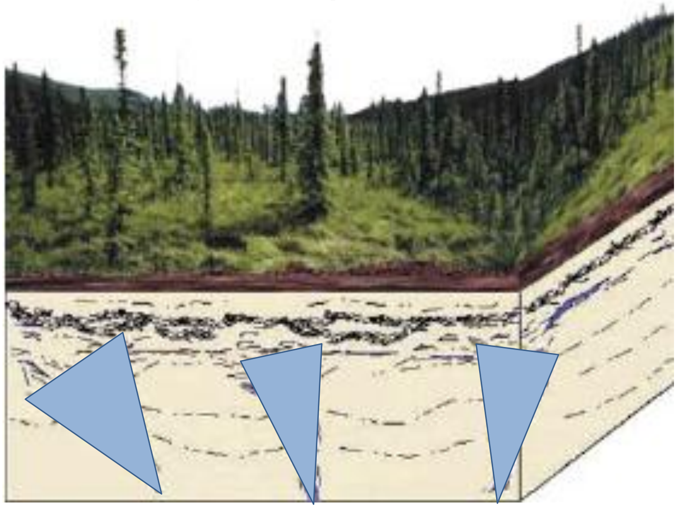




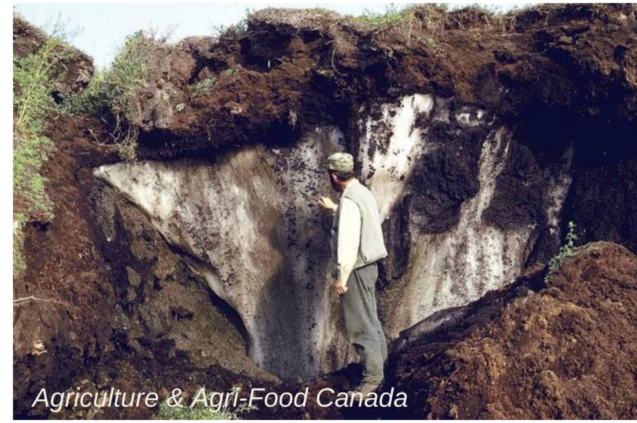
Lawrence et al., Journal Advances Modeling Earth Systems, 2011

Excess ice and thermokarst parameterization

Ice wedges in permafrost soil

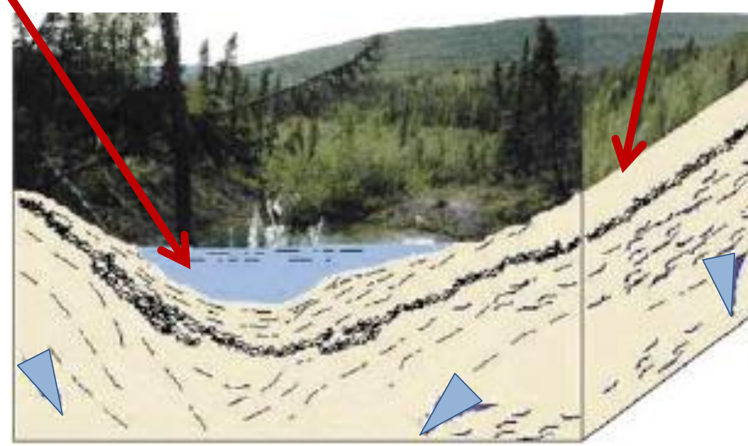


Problem in CLM



Anaerobic environment
CO_2/CH_4 emissions

Exposed permafrost
CO_2 emissions

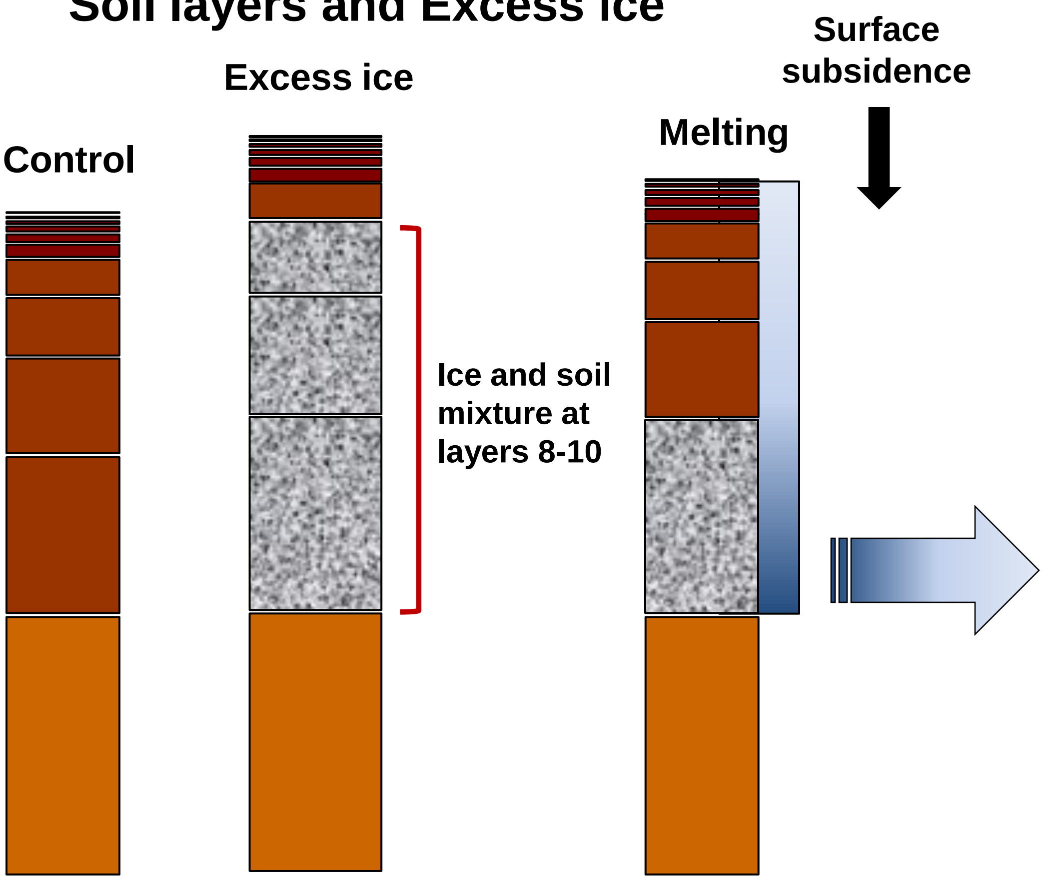


Thermokarst development

Excess ice and permafrost parameterization

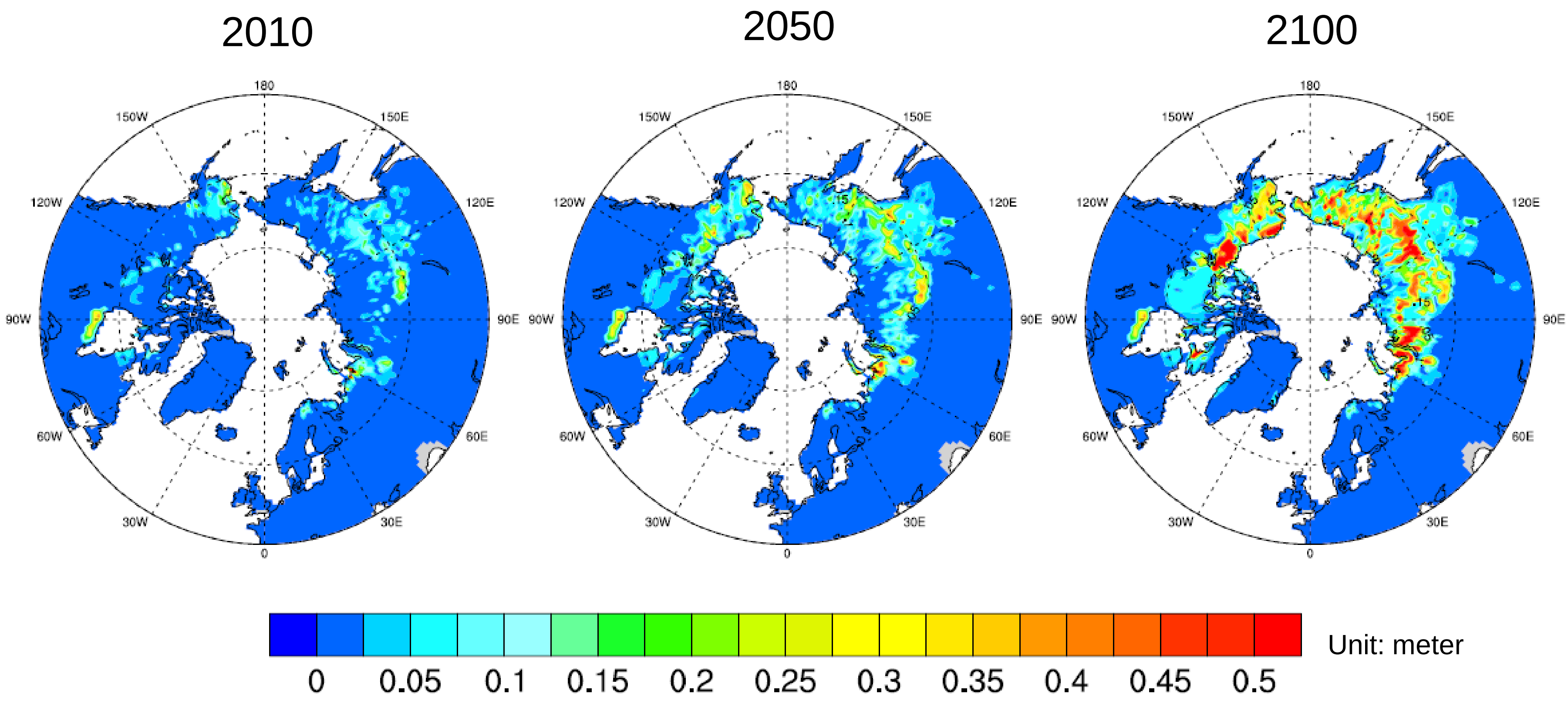
CLM4.5

Soil layers and Excess ice



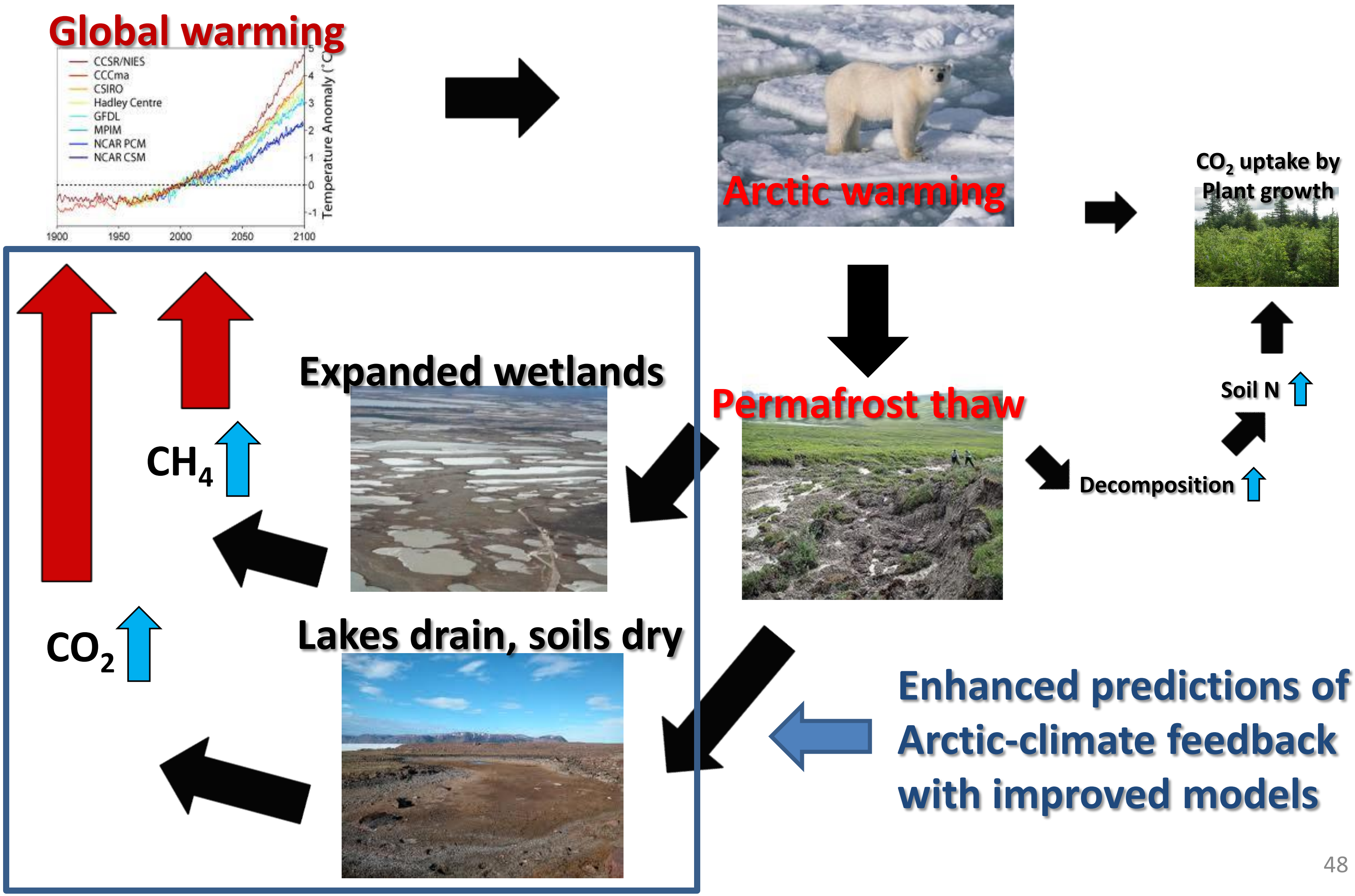
Control: Regular CLM soil layers

Thermokarst predictions under future climate projections



Lee et al. in prep Env Res Lett

Improved model and climate feedback



Conclusions

- Permafrost C important and underestimated source of C in terrestrial-climate feedback
- Thermokarst development can influence the rate and types of C release
- Models are improving to better represent permafrost processes under changing climate