Vulnerability of high latitude soil organic carbon in North America to disturbance

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Motivation + Goals

Definitions

Soil OC pools

High latitudes

North America

Disturbances + Feedbacks

Examples

Status of Projections

Research + data gaps

Core reference list for this presentation:

Grosse et al. (in press, 2011): Vulnerability and feedbacks of permafrost to climate change. *EOS Trans. AGU*.

Grosse et al. (in review, 2011): Vulnerability of high latitude soil carbon in North America to disturbance. *JGR – Biogeosciences*.

McGuire et al. (2009): Sensitivity of the carbon cycle in the Arctic to climate change. Ecological Monographs, 79(4), 2009, pp. 523–555.

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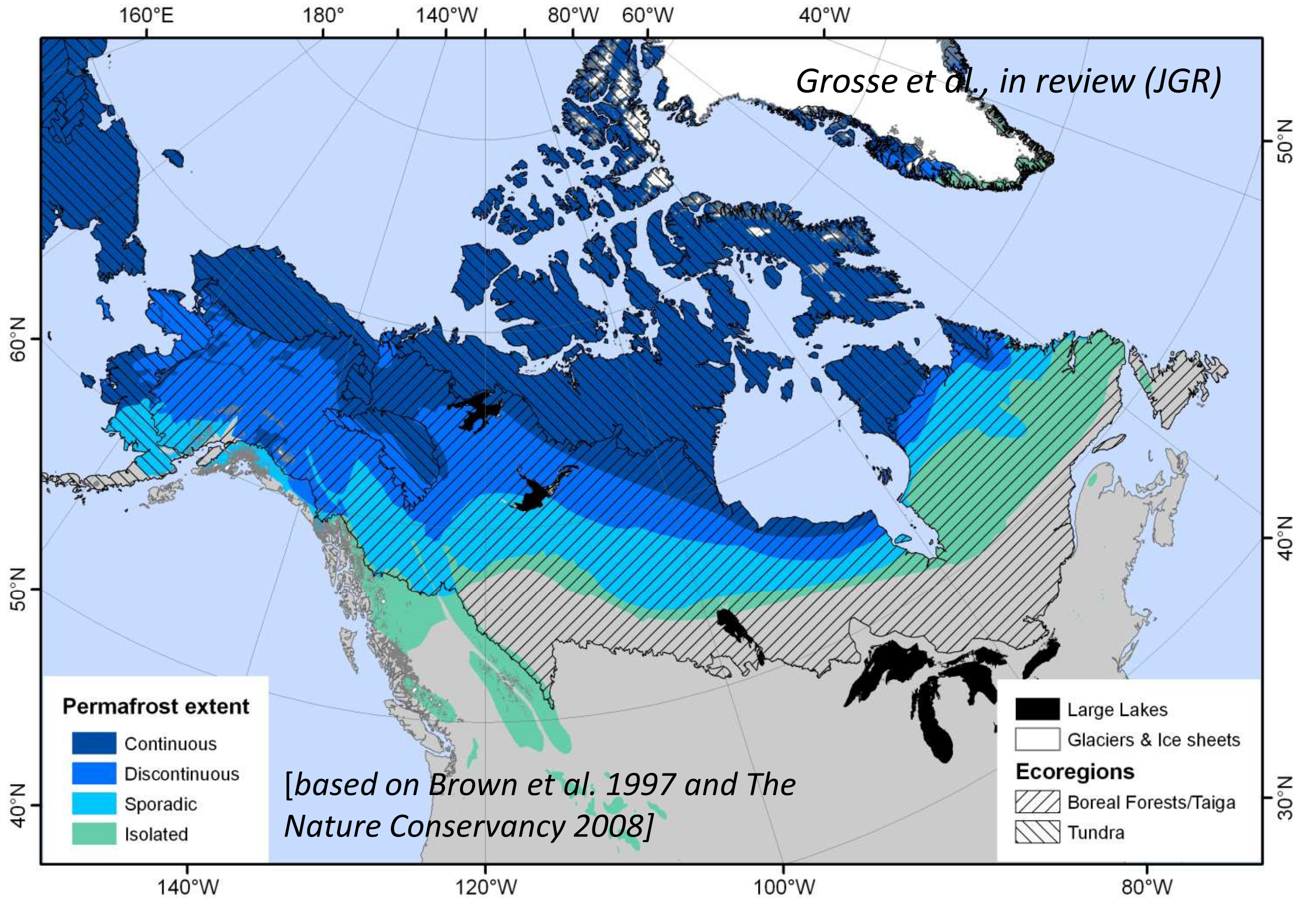
North America high latitudes

- Tundra and boreal forest ecoregions (45-83° N, 53-170° W)
- Large portion (but not all) is characterized by permafrost, ranging from continuous extent in the north to isolated patches in the southern zones



Motivation + Goals
Definitions
Soil OC pools
High latitudes
North America
Disturbances +
Feedbacks
Examples
Status of
Projections
Research +
data gaps

Goals

(1) Review the current soil organic carbon (SOC) storage in northern high latitude soils of North America

(2) Describe key ecosystem, climate, and soil processes that characterize SOC pools in this region

(3) Discuss major press and pulse disturbances and their impacts on northern high latitude SOC

(4) Evaluate model projections of disturbance impacts on northern high latitude SOC

(5) Discuss research and data gaps that need to be addressed to better predict the near-future trajectory of SOC in the North America high latitude regions

Disturbance and vulnerability of SOC

- Disturbances

- Perturbation of a normal state or regime
- Events or processes that significantly redistribute C among major reservoirs
- Alter key ecosystem factors in ways that affect the dynamics of the northern high latitude SOC pool
- Have always been a natural factor for northern soil C dynamics

- Vulnerability

- SOC pools are vulnerable if disturbance can significantly alter the physical, chemical and/or biological properties of the soil
- Biological origin as well as physical and chemical preservation of organic matter can affect its vulnerability to disturbance

Motivation + Goals

Definitions

Soil OC pools

High latitudes

North America

Disturbances + Feedbacks

Examples

Status of Projections

Research + data gaps

Soil organic carbon pools

- Northern high latitude SOC pool is a dynamic stock

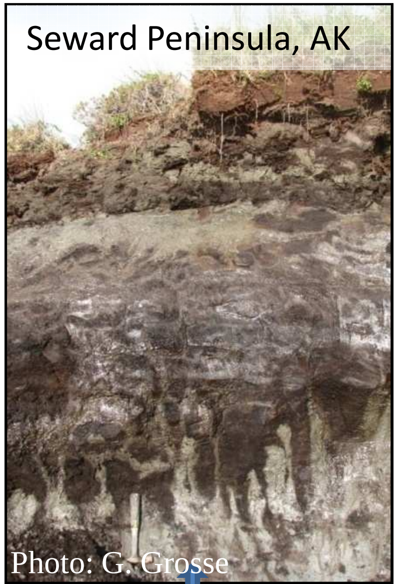
Affected by:
- <u>C inputs</u> (organic litter quality and quantity)
- <u>C stabilization</u> (permafrost aggradation; cryoturbation; peat accumulation; sedimentation)
- <u>C destabilization</u> (microbial decomposition; combustion)
- <u>C exports</u> (via dissolved and particulate organic matter; inorganic and organic state; gas fluxes)

- Northern high latitude soils are often defined by <u>low inputs</u>; However, strong stabilization, decreased destabilization, and low exports result in long-term soil C sinks
- Panarctic SOC pools are very large: 1400-1850 Pg SOC (McGuire et al., 2009) ; 1672 Pg SOC (Tarnocai et al., 2009)

818 Pg in Cryosols from 0-3 m depth (permafrost-affected soils)
277 Pg in frozen and unfrozen peatlands 0 m to full depth
88% of the C pool are in perennially frozen soils + deposits (permafrost)
12% are in seasonally frozen soils + deposits within the permafrost region

Motivation + Goals
Definitions
Soil OC pools
High latitudes
North America
Disturbances +
Feedbacks
Examples
Status of
Projections
Research +
data gaps

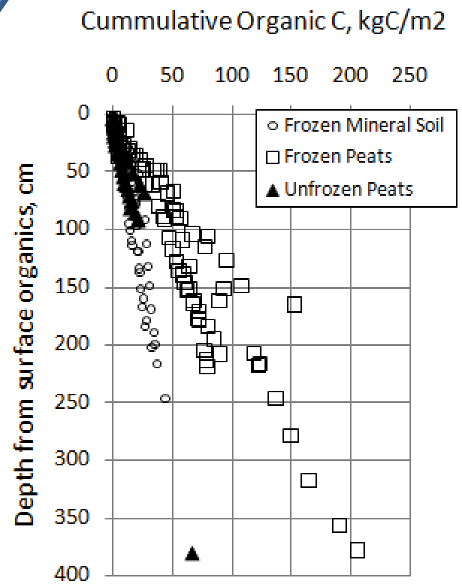
Soil organic carbon pools



Near-surface soil organic carbon in Cryosols

Near-surface and deep soil organic carbon in frozen and unfrozen peatlands

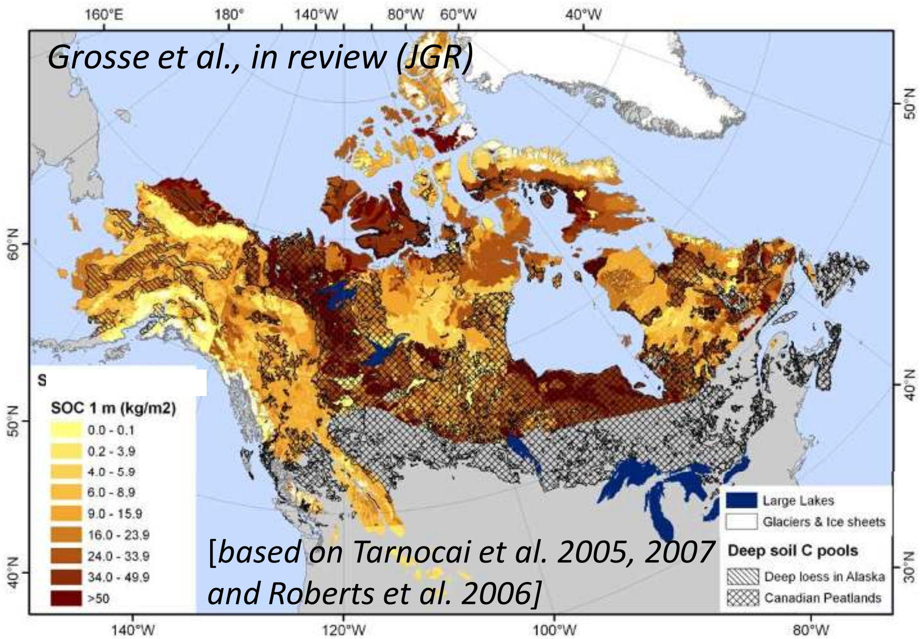
Organic carbon in deep permafrost deposits



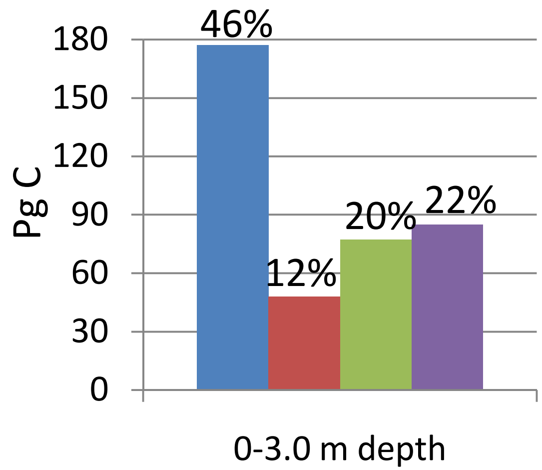
Grosse et al., in review (JGR)

High latitude SOC pools in North America

Motivation + Goals
Definitions
Soil OC pools
High latitudes
North America
Disturbances + Feedbacks
Examples
Status of Projections
Research + data gaps



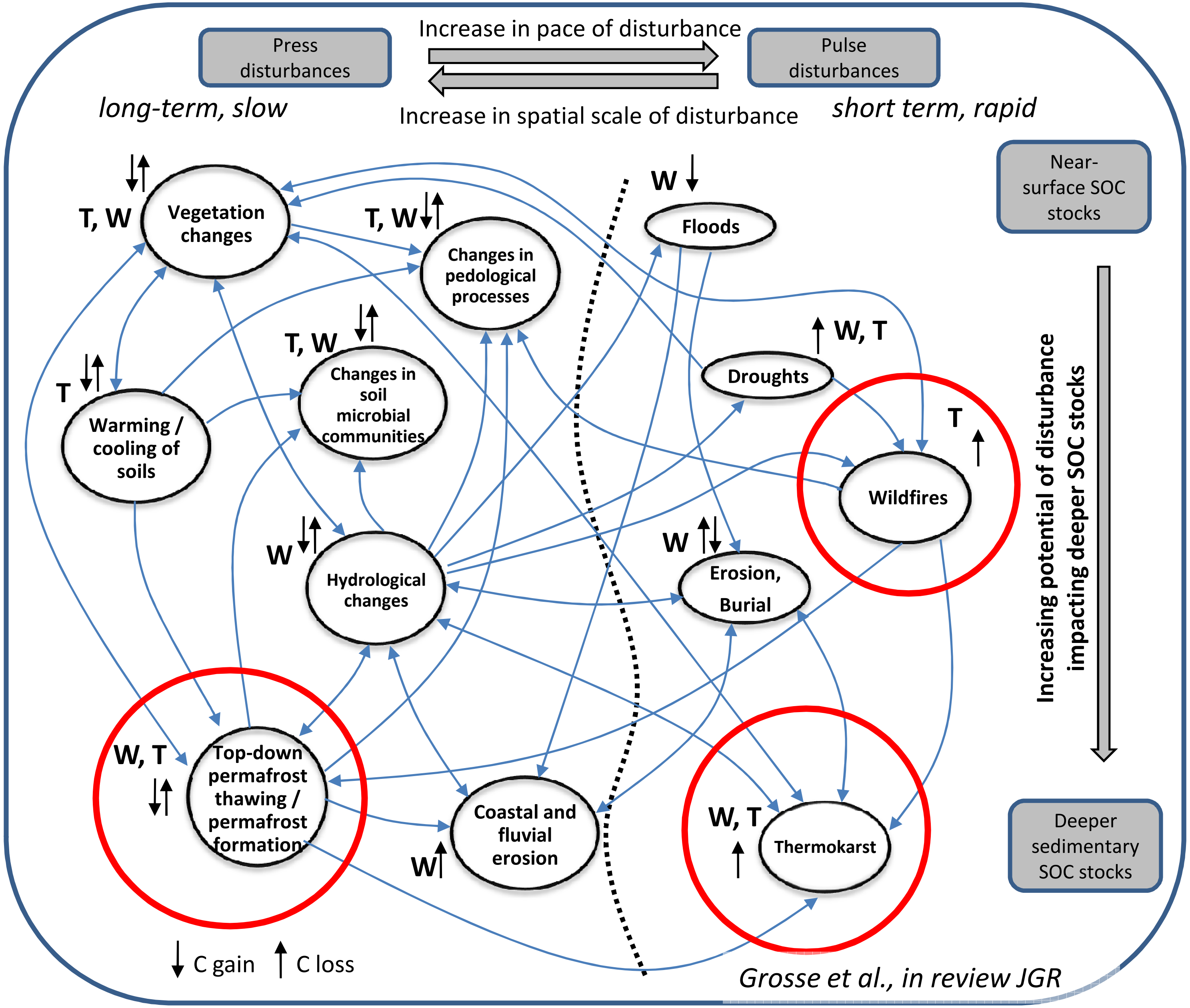
Permafrost region:
5.17×10^6 km^2 mineral soils
1.04×10^6 km^2 organic soils



Depth	Soil carbon mass (Pg) in North American permafrost region						
	Mineral soils			Organic soils (peatlands)			All soils
	Perennially frozen	Unfrozen	Total	Perennially frozen	Unfrozen	Total	Total
0–0.3 m	33	16	49	9	9	18	67
0–1.0 m	75	29	104	31	30	61	165
0–3.0 m	177	48	225	77	85	162	387

[Tarnocai et al., 2007, 2009]

Motivation + Goals
Definitions
Soil OC pools
High latitudes
North America
Disturbances + Feedbacks
Examples
Status of Projections
Research + data gaps



Motivation + Goals
Definitions
Soil OC pools
High latitudes
North America
Disturbances +
Feedbacks
Examples
Status of
Projections
Research +
data gaps

Press disturbance: Top-down permafrost thawing

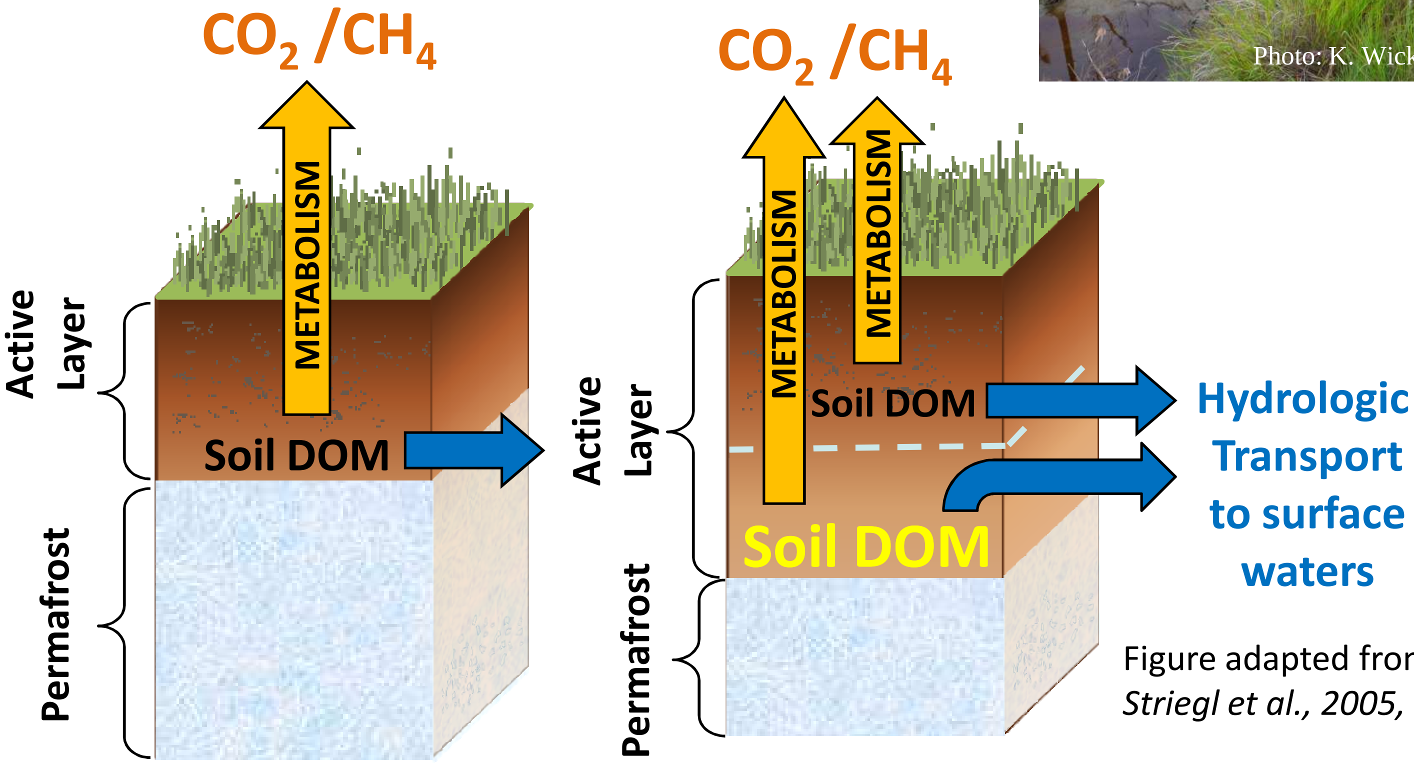


Figure adapted from *Striegl et al., 2005, GRL*

Motivation + Goals

Definitions

Soil OC pools

High latitudes

North America

Disturbances +

Feedbacks

Examples

Status of

Projections

Research +

data gaps

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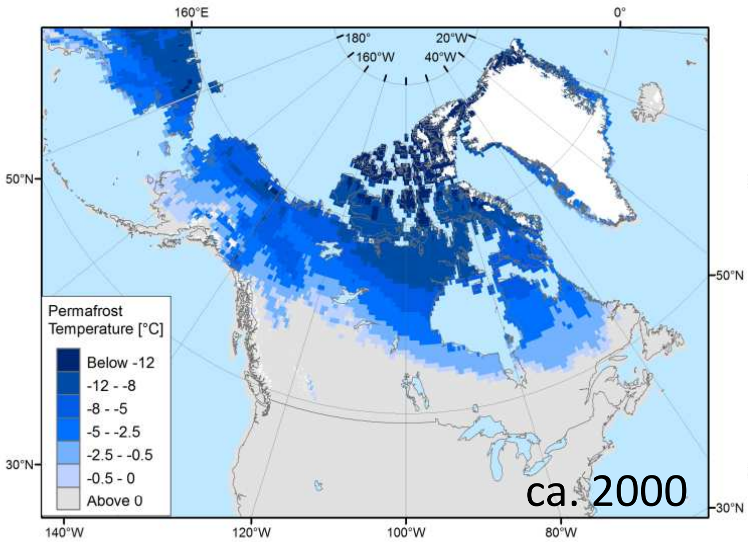
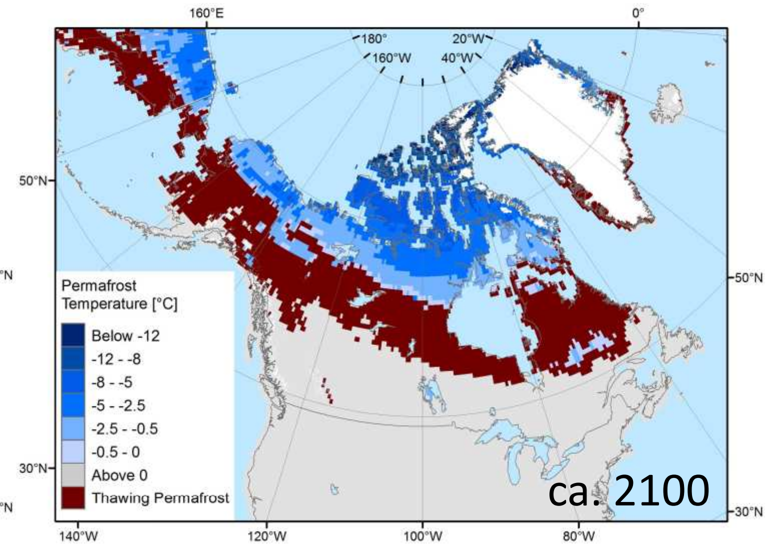




- *0.5° x 0.5° GIPL model by Romanovsky et al. 2007*
- *Zone of thawing permafrost is defined as reaching a seasonal thaw depth in excess of 2 m*

See also: Marchenko et al. (2011)

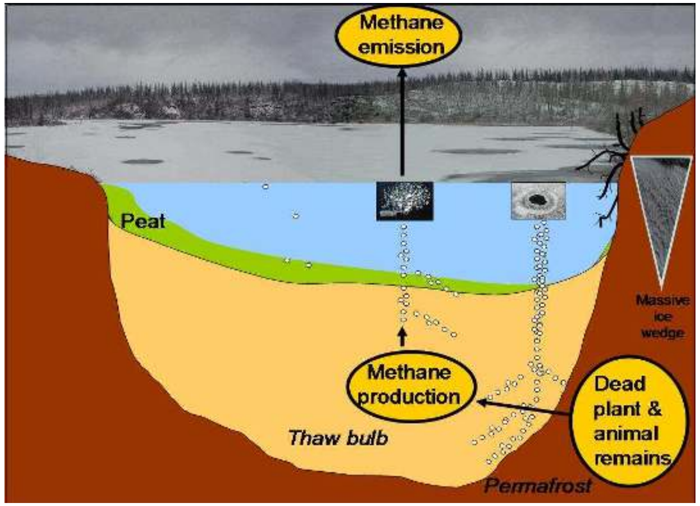
	Zone of thawing surface permafrost by 2050	Zone of thawing surface permafrost by 2100
Cryosol area within zone of thawing surface permafrost*	385,000 km^2	1,132,000 km^2
SOC mass upper 1 m*	9.7 Pg C	28.6 Pg C

Grosse et al., in review JGR

* *Based on Tarnocai et al., 2007*

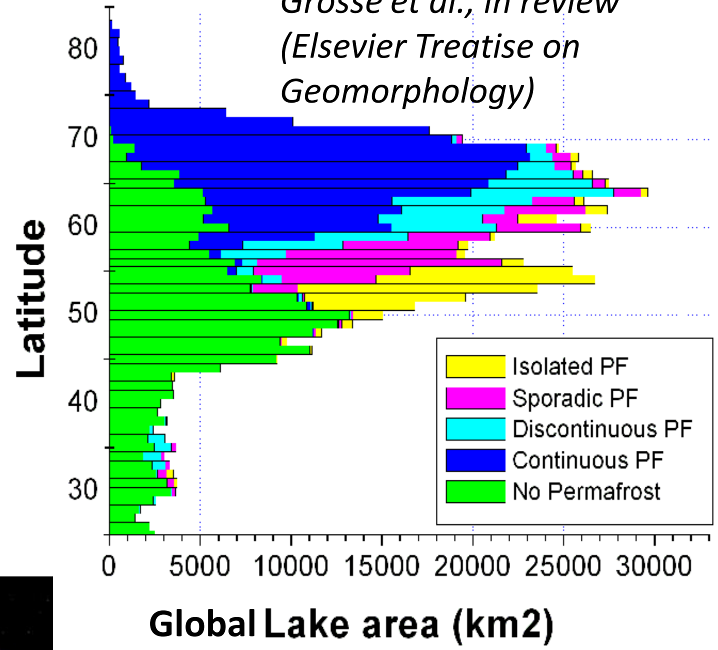
Pulse disturbance: Thermokarst lakes

- *Motivation + Goals*
- *Definitions*
- *Soil OC pools*
  - *High latitudes*
  - *North America*
- *Disturbances + Feedbacks*
- *Examples*
- *Status of Projections*
- *Research + data gaps*

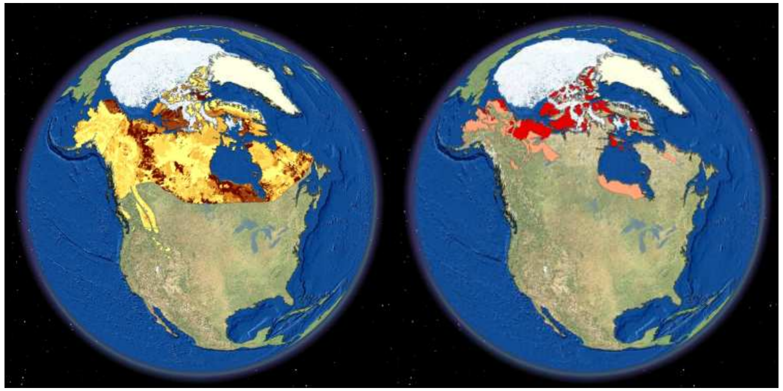


Walter et al., 2007 (Phil. Trans. Royal Soc. A)

Grosse et al., in review (Elsevier Treatise on Geomorphology)



(based on Lehner & Döll, 2004)



Ground ice content*	Medium	High
Area of Cryosols#	714,000 km^2	887,000 km^2
SOC mass upper 1 m#	21.4 Pg C	33.2 Pg C

**Brown et al., 1997*
#Tarnocai et al., 2007

Motivation + Goals

Definitions

Soil OC pools

High latitudes

North America

Disturbances + Feedbacks

Examples

Status of Projections

Research + data gaps

Pulse disturbance: Fires

- Combustion of soil organic matter
- Fire severity, size, duration
- Complex post-fire feedbacks: albedo, soil thermal regime, permafrost thaw, hydrology, vegetation succession

<u>Future trend</u>: increased fire severity; extended fire season; accelerated fire repeat cycles; increased likelihood of tundra fires

Photo: B. Jones

Photo: S. Marchenko

Post-disturbance fate of northern high latitude SOC

- **Fate of SOC in a post-disturbance setting depends on**
  1) whether the SOC remains in unaffected layers or becomes exposed to disturbances (depth)
  2) whether the SOC is perennially frozen or subject to freeze-thaw cycles (temperature)
  3) whether the ice or water content is high or low (water content)
  4) soil organic matter quality as determined by botanic origin and long-term decomposition trajectories (lability)

Status of projecting SOC disturbances

- Much progress over the last decade in integrating soil freeze-thaw dynamics, hydrology, and biogeochemistry in large-scale ecosystem models that simulate northern high latitude SOC dynamics
- No models are yet able to fully consider how changes in hydrology and soil thermal dynamics associated with disturbance influence soil carbon dynamics at high latitudes
- Main obstacles are implementation of complex feedback dynamics and sub-grid factors and processes
- Example: Permafrost modeling can successful project top-down permafrost thawing; however, highly dynamic and local-scale feedbacks with ground ice distribution, hydrology, and vegetation succession are not sufficiently implemented to factor in thermokarst and -erosion

Motivation + Goals

Definitions

Soil OC pools

High latitudes

North America

Disturbances +

Feedbacks

Examples

Status of

Projections

Research +

data gaps

Research and data gaps

1. Uncertainties in SOC spatial distribution, i.e. deep stocks
2. Uncertainties in distribution and physical properties (thermal state, ground ice content) of permafrost
3. Enhancement of process understanding: post-disturbance SOC dynamics; vegetation succession; cryoturbation; time scales; hydrology
4. Modeling of SOC disturbances, feedbacks, and subgrid processes on various scales
5. Further development of remote sensing methods for quantifying disturbances
6. How will disturbance frequencies + intensities and successional trajectories change in the future?
7. Integration of disturbances in dynamic Earth system models

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Grosse et al. (in press, 2011): Vulnerability and feedbacks of arctic permafrost to climate change. *EOS Trans. AGU*.