

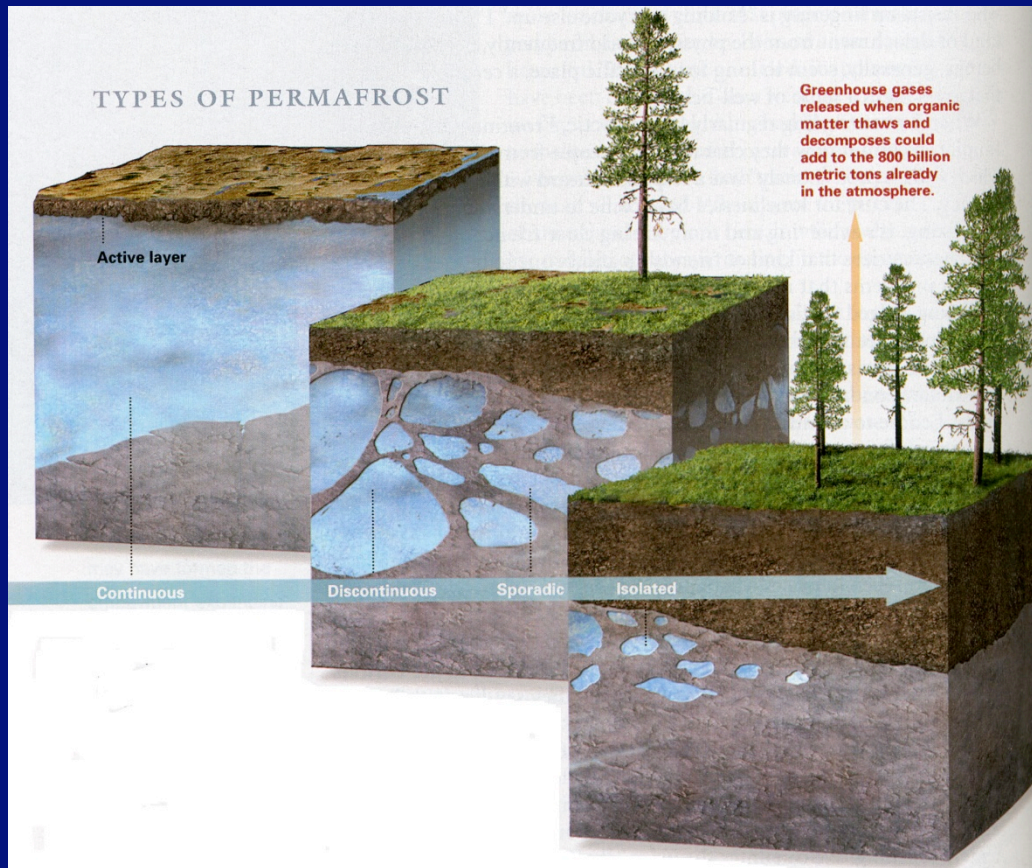
When is the Permafrost Carbon Tipping Point?

Kevin Schaefer¹, Tingjun Zhang¹, Lori
Bruhwiler², Andrew P. Barrett¹, Zhuxiao Li¹

¹National Snow and Ice Data Center, University of Colorado

²NOAA Earth System Research Laboratory

Permafrost Primer



Skiklomanov [2007]

Permafrost: Ground at or below 0°C for at least 2 consecutive years

Active Layer: A layer over permafrost that freezes and thaws annually

Permafrost Degradation: A decrease in permafrost extent; an increase in active layer thickness.

Permafrost Profile

Vegetation

Active Layer

Permafrost



Thermokarst

- *Thermokarst*: subsidence or collapse of ground surface due to melting of ground ice



Thermokarst, Tibet [Zhang, 2007]



Thermokarst, Alaska

Permafrost Distribution

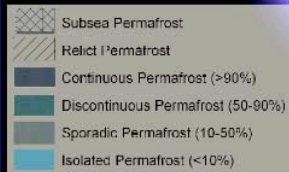
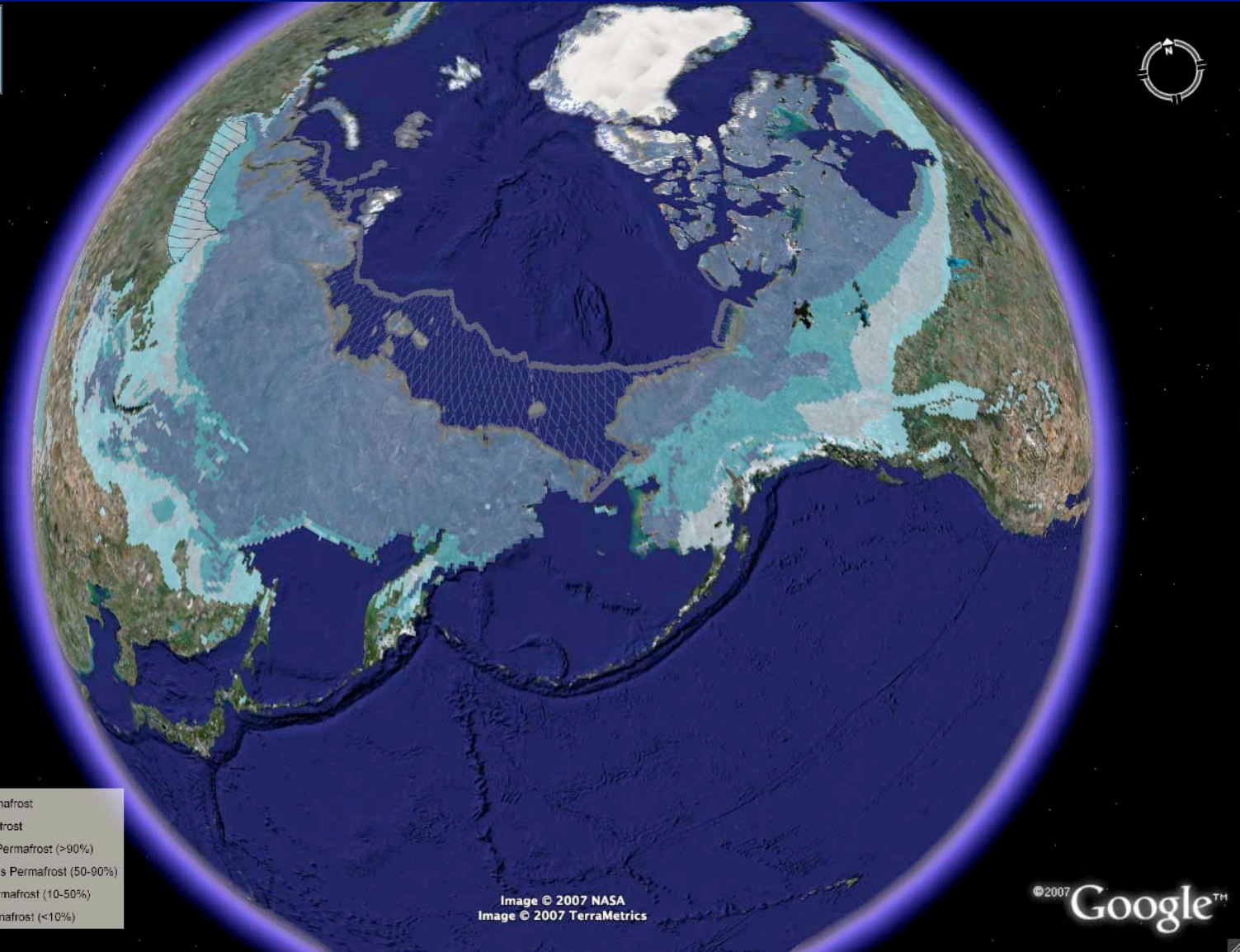
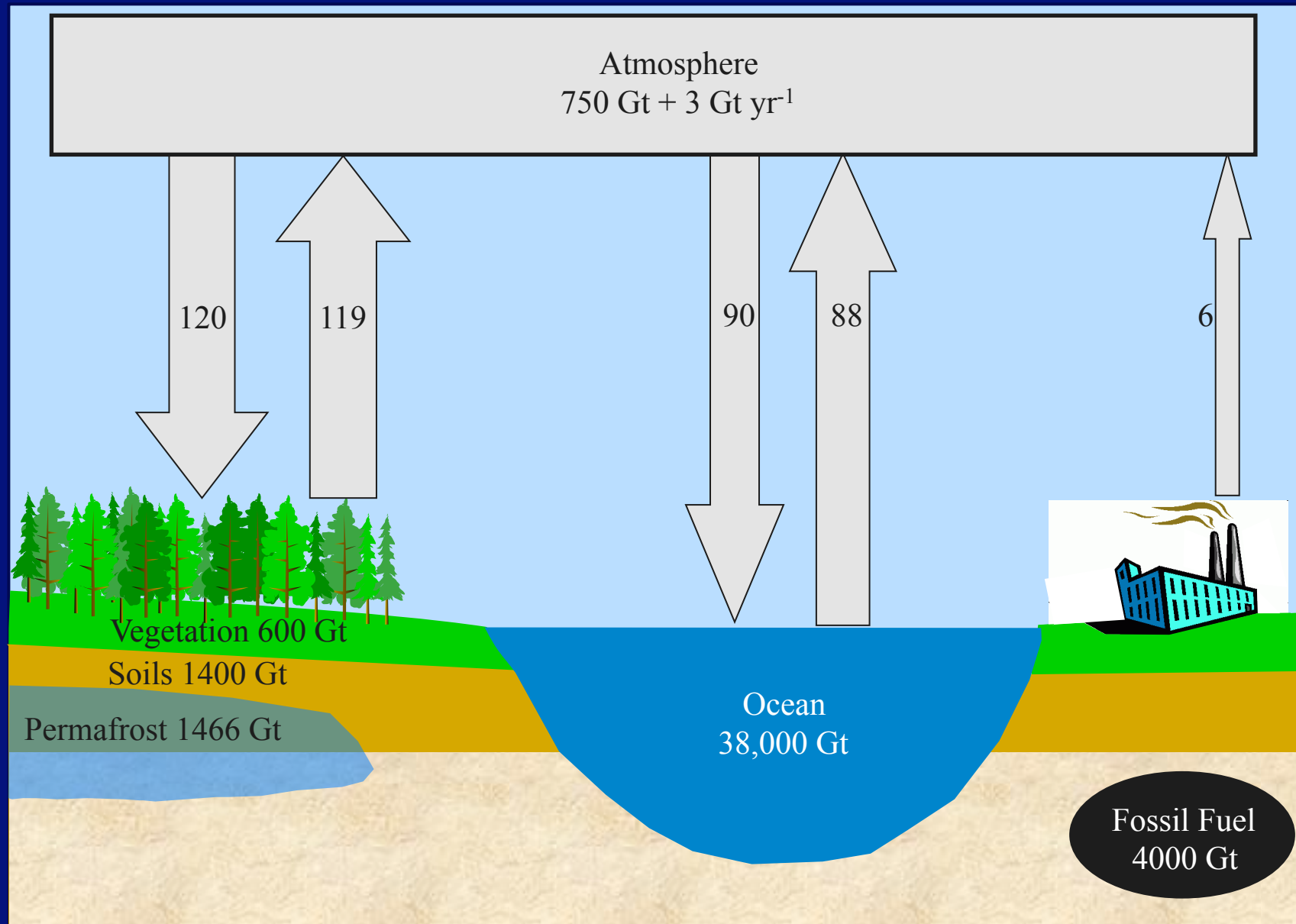


Image © 2007 NASA
Image © 2007 TerraMetrics

©2007 Google™

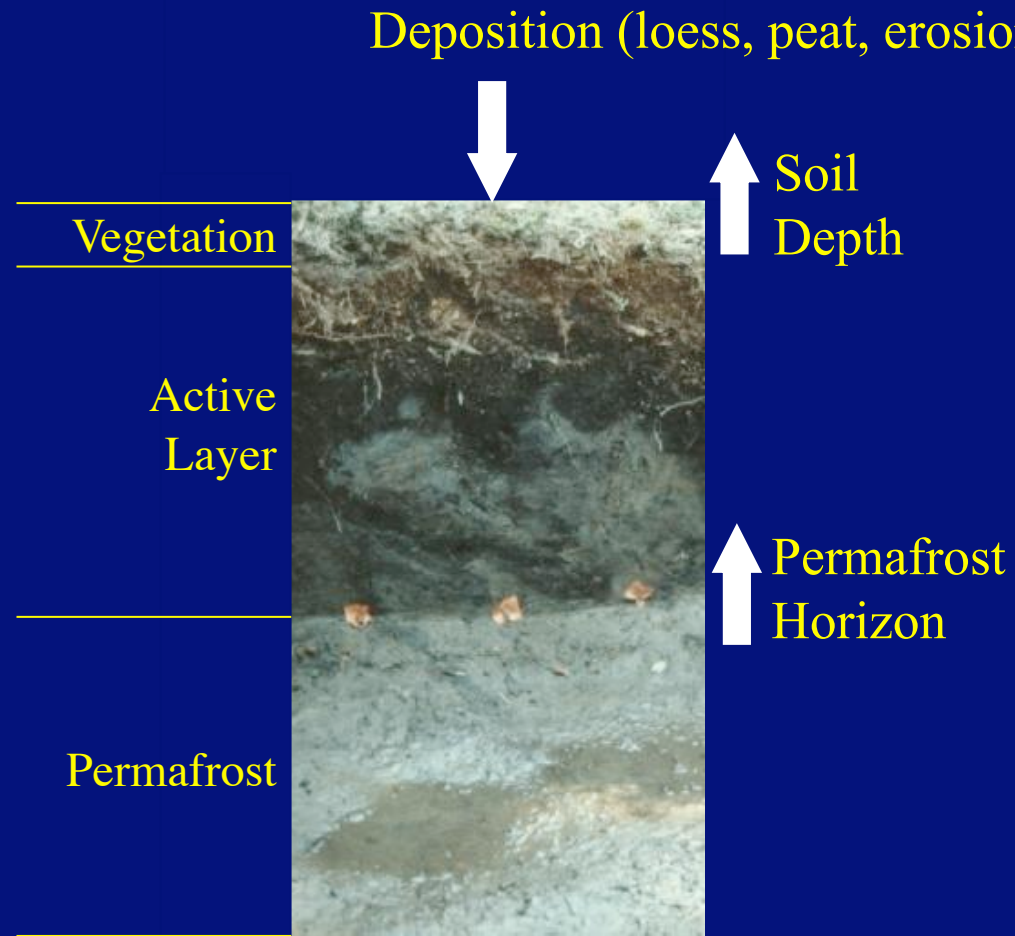


Global Carbon Cycle



Permafrost Carbon Burial

~1466 Gt C in permafrost [*Tarnocai et al., 2009*]



Permafrost Carbon



Ямальский мамонтенок
Mammuthus primigenius

Mammoth, Siberia



30,000 year old roots, Siberia
[Zimov et al., 2006]

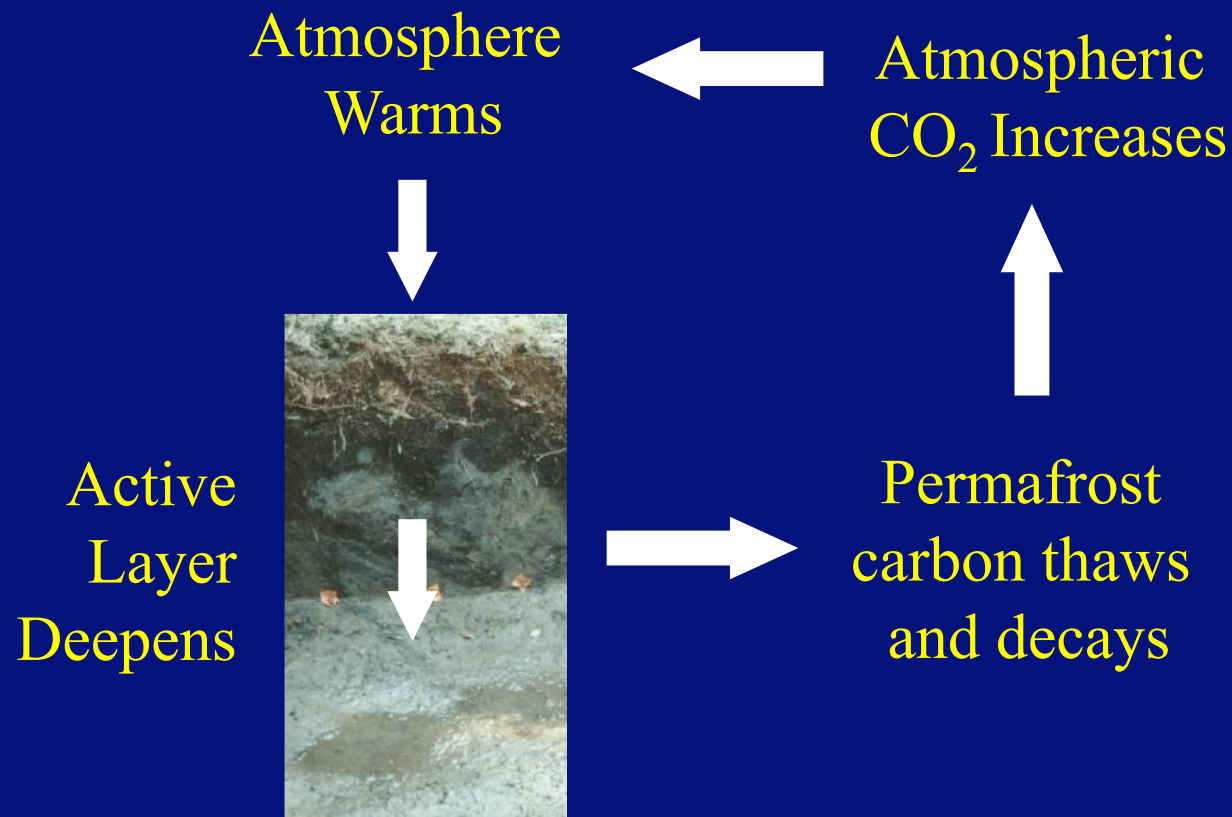
Primarily grass
roots



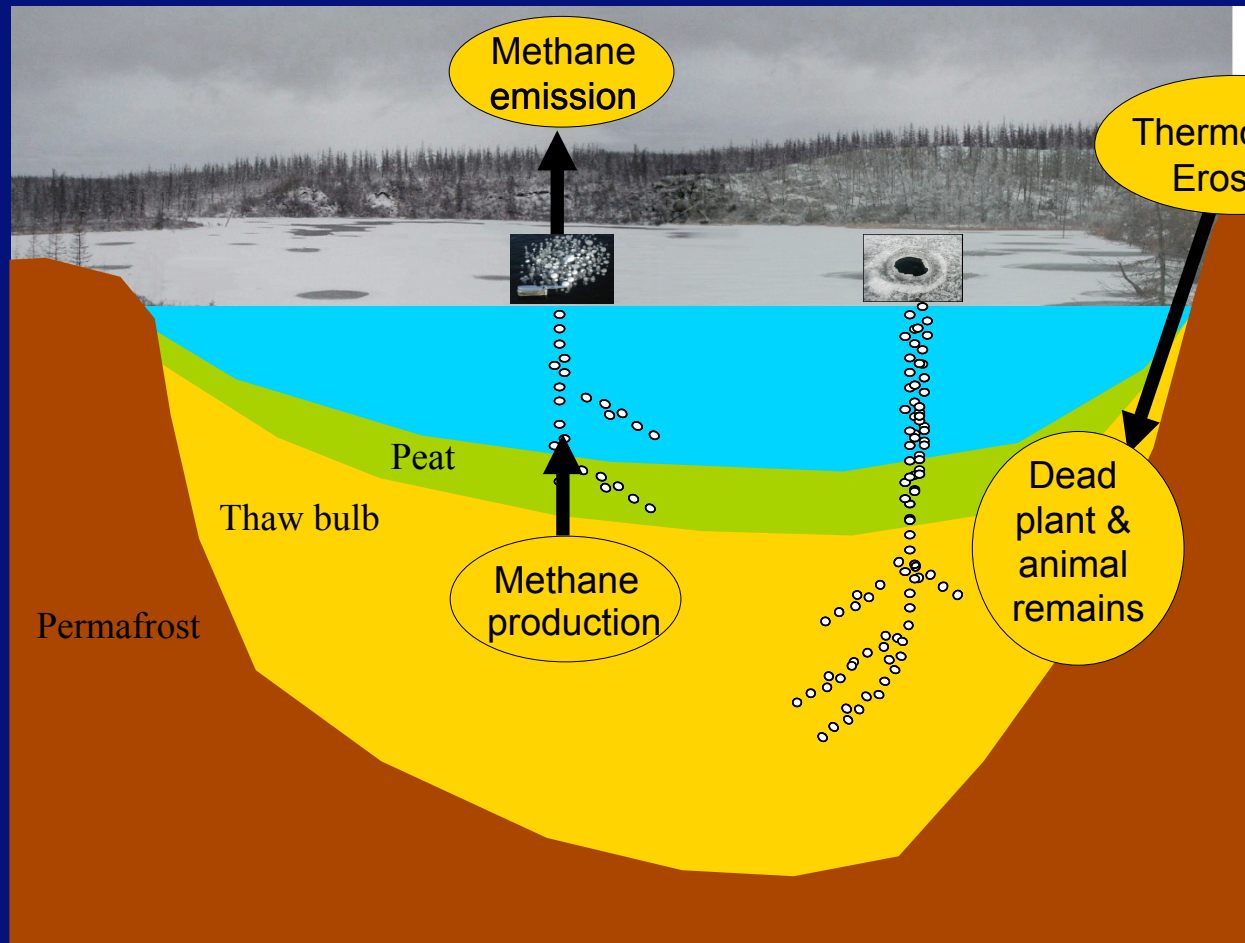
32,000 year old grass, Alaska

Permafrost Carbon Feedback

Amplification of warming due to release of CO₂ and CH₄ from thawing permafrost

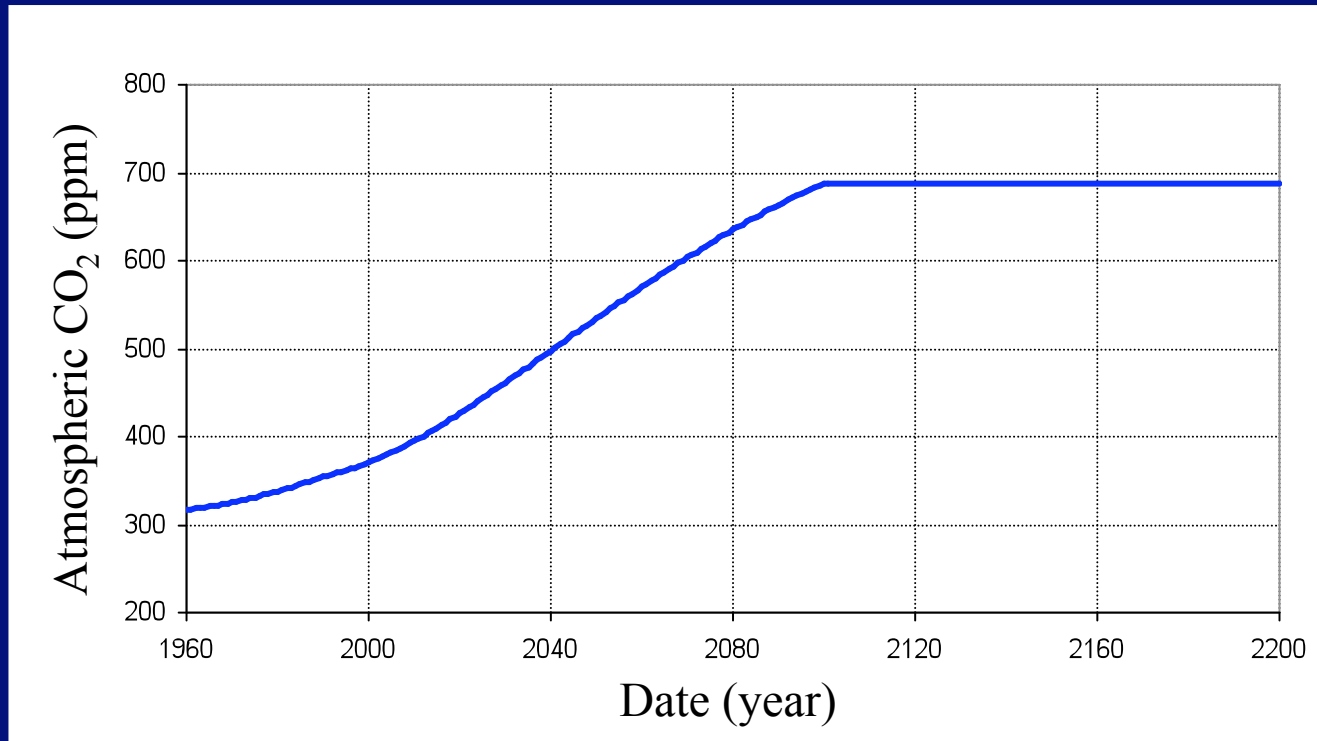


Methane Release from Thawing Permafrost



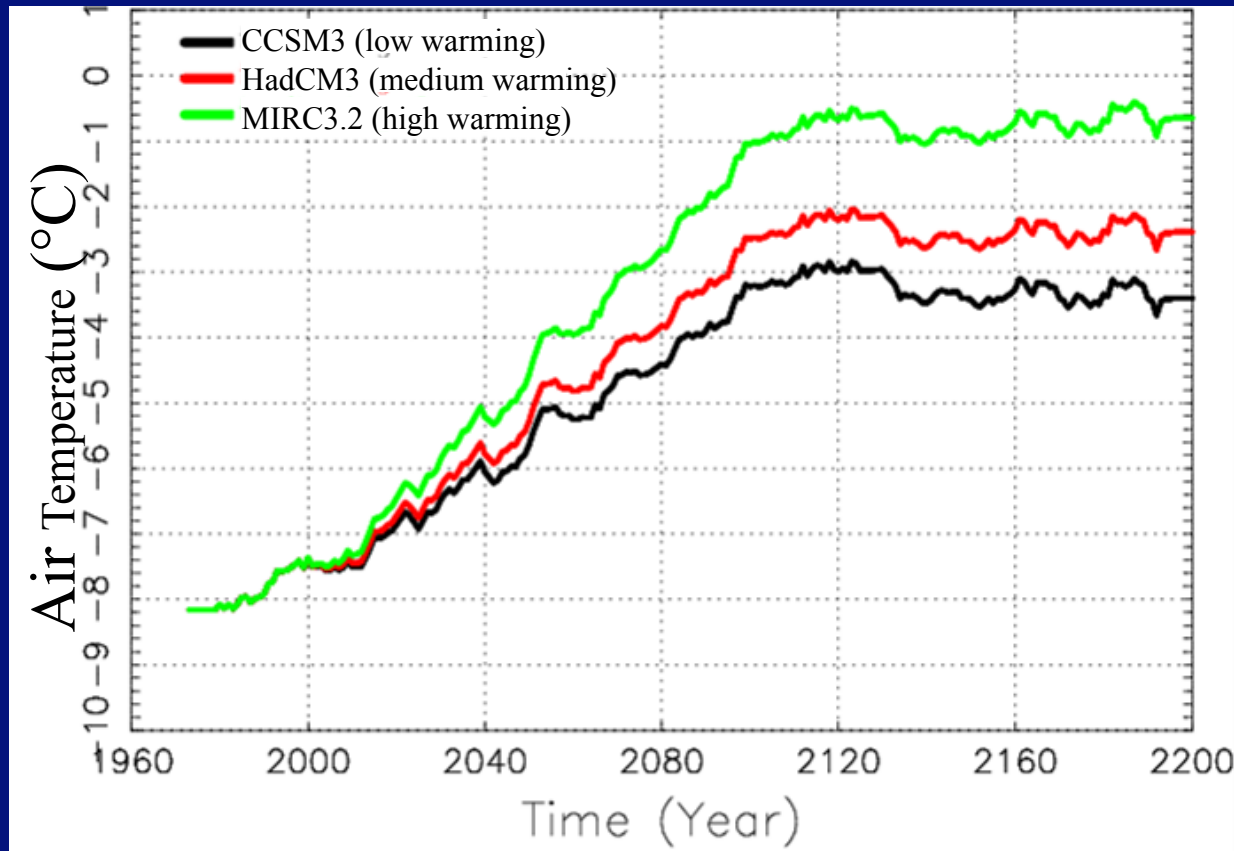
Burning methane over a thermokarst lake in Siberia (K. Walter)

What will happen in the future?



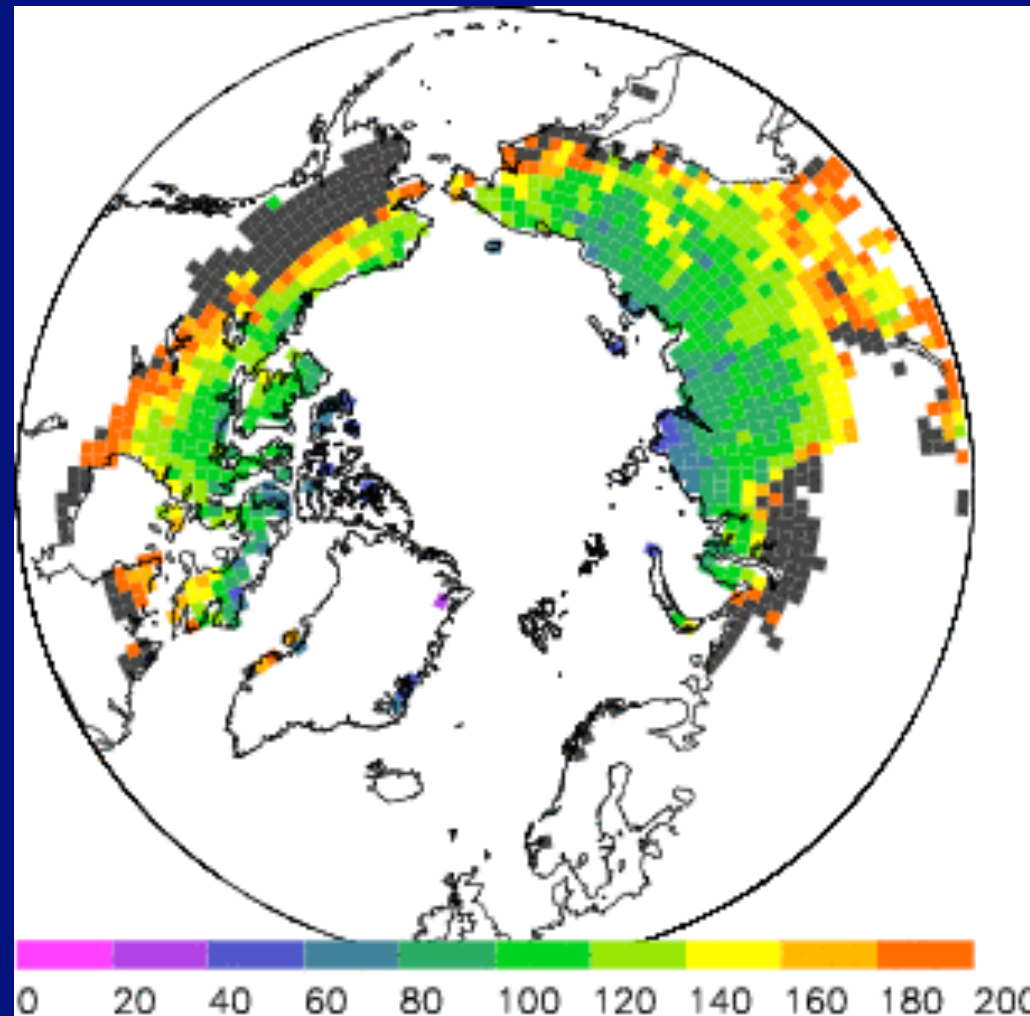
- Projections: SiBCASA & IPCC A1B Scenario

IPCC A1B Arctic Temperatures



Average air temperature for permafrost regions

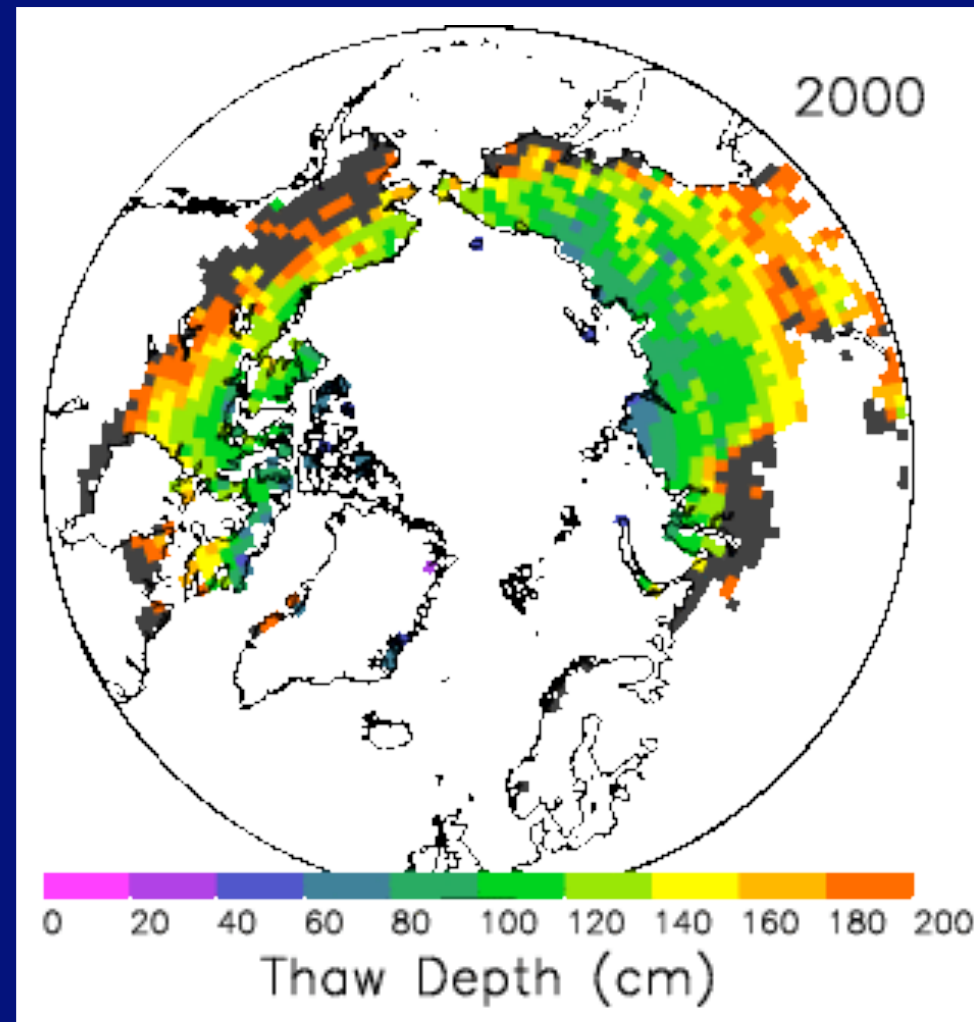
Current Permafrost



Active Layer Thickness ALT (cm)

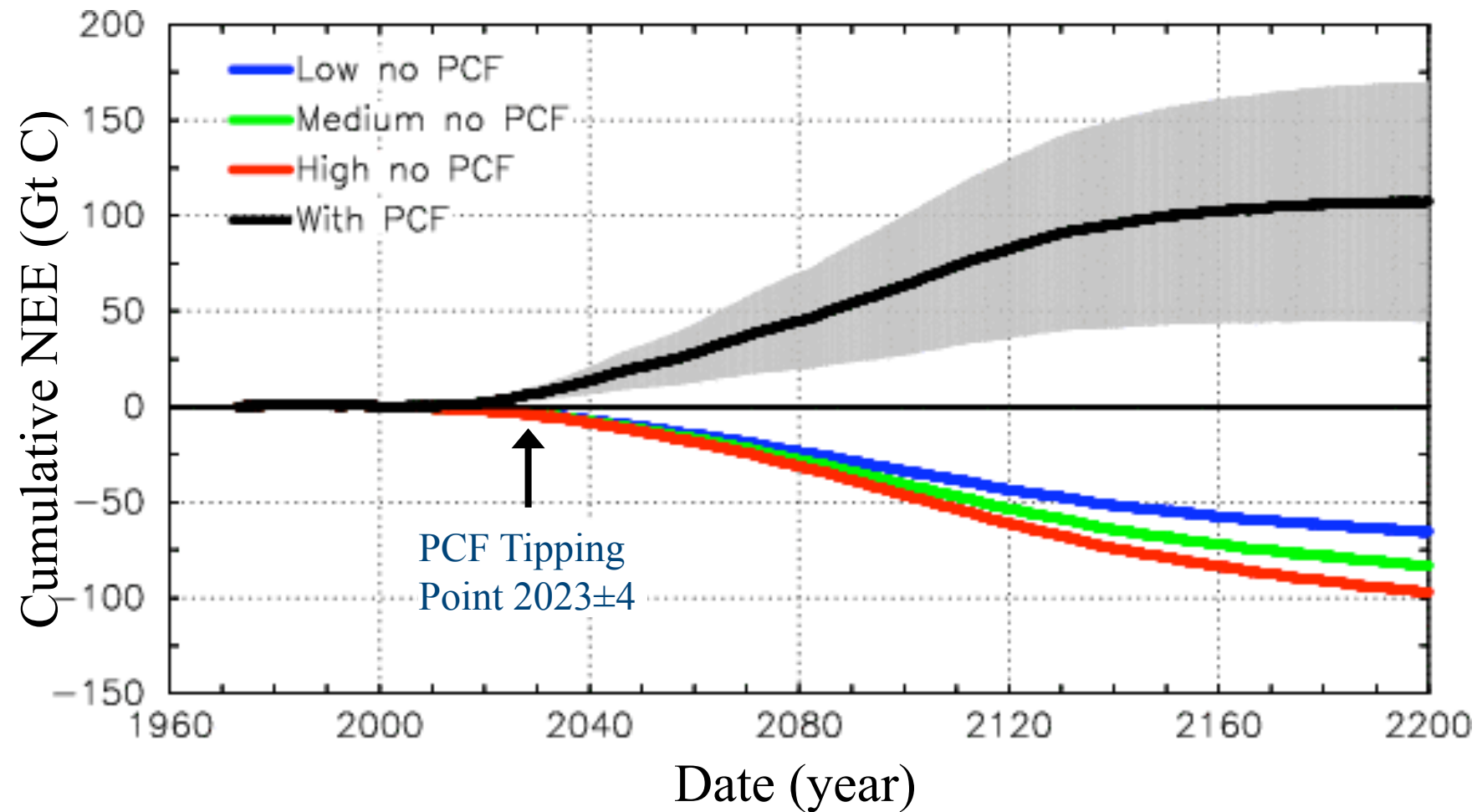
Projected Permafrost Degradation

HadCM3 (med)



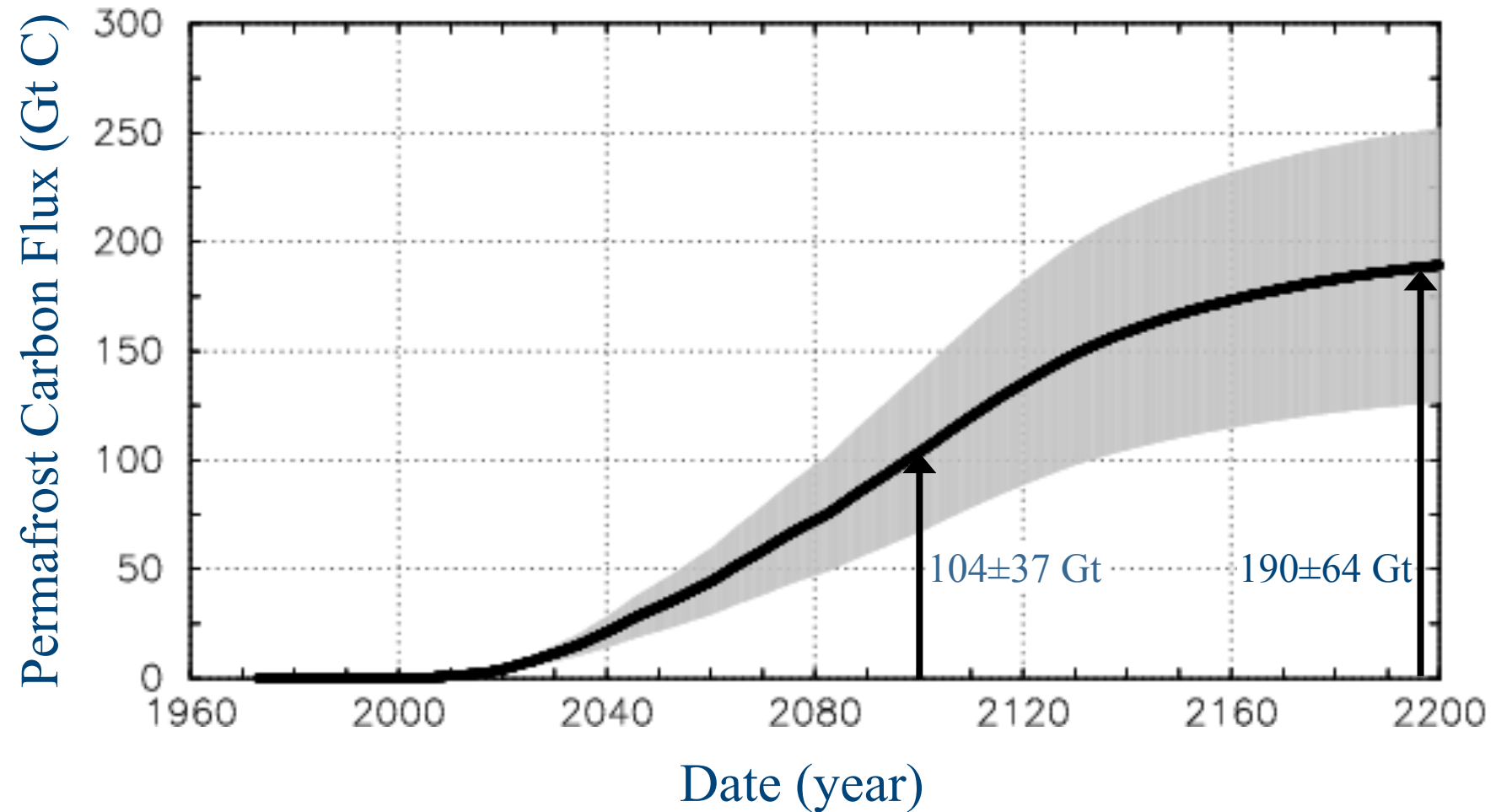
Active Layer Thickness ALT (cm)

Permafrost Carbon Tipping Point



Arctic switches from a sink to a source

Cumulative Permafrost Carbon Flux



65±23% of cumulative to 2100 (~160 Gt C)

PCF and Fossil Fuel Emissions

- Both inject old carbon into atmosphere
- Both irreversible
- A1B scenario: 700 ppm by 2100
 - 1345 Gt C total emissions
 - 190 Gt C permafrost carbon flux
 - 1155 Gt C fossil fuels
- Need a 15% allocation for permafrost carbon

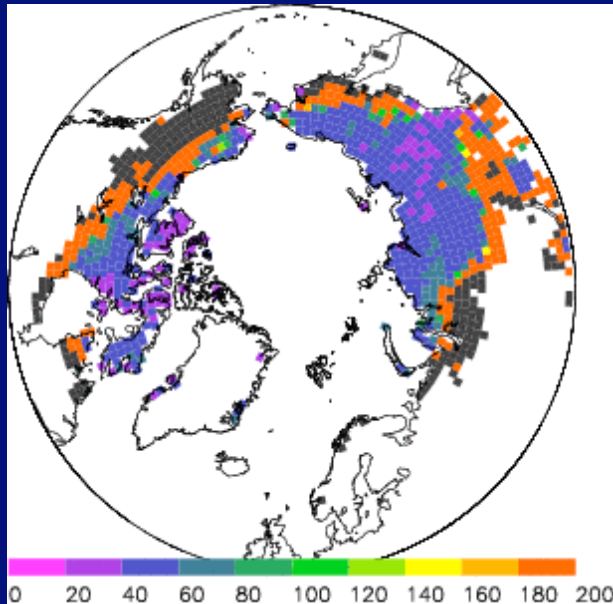
Conclusions

- PCF tipping point in 2020s
- PCF is strong (190 ± 64 Gt C by 2200)
- Include PCF in emission reduction strategies

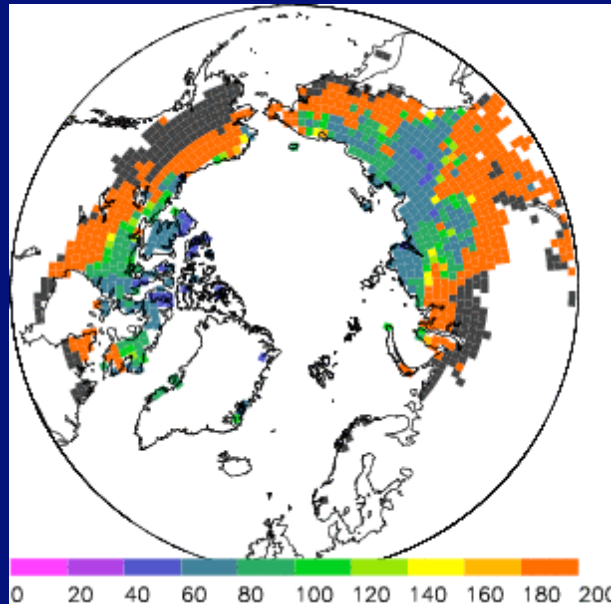
Thank You!

Projected Permafrost Loss

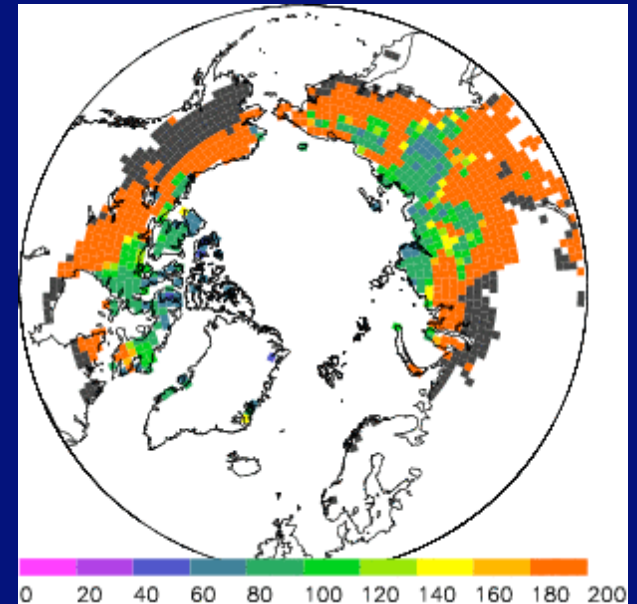
Increase in ALT by 2200 (cm)



CCSM3 (low)
29% loss



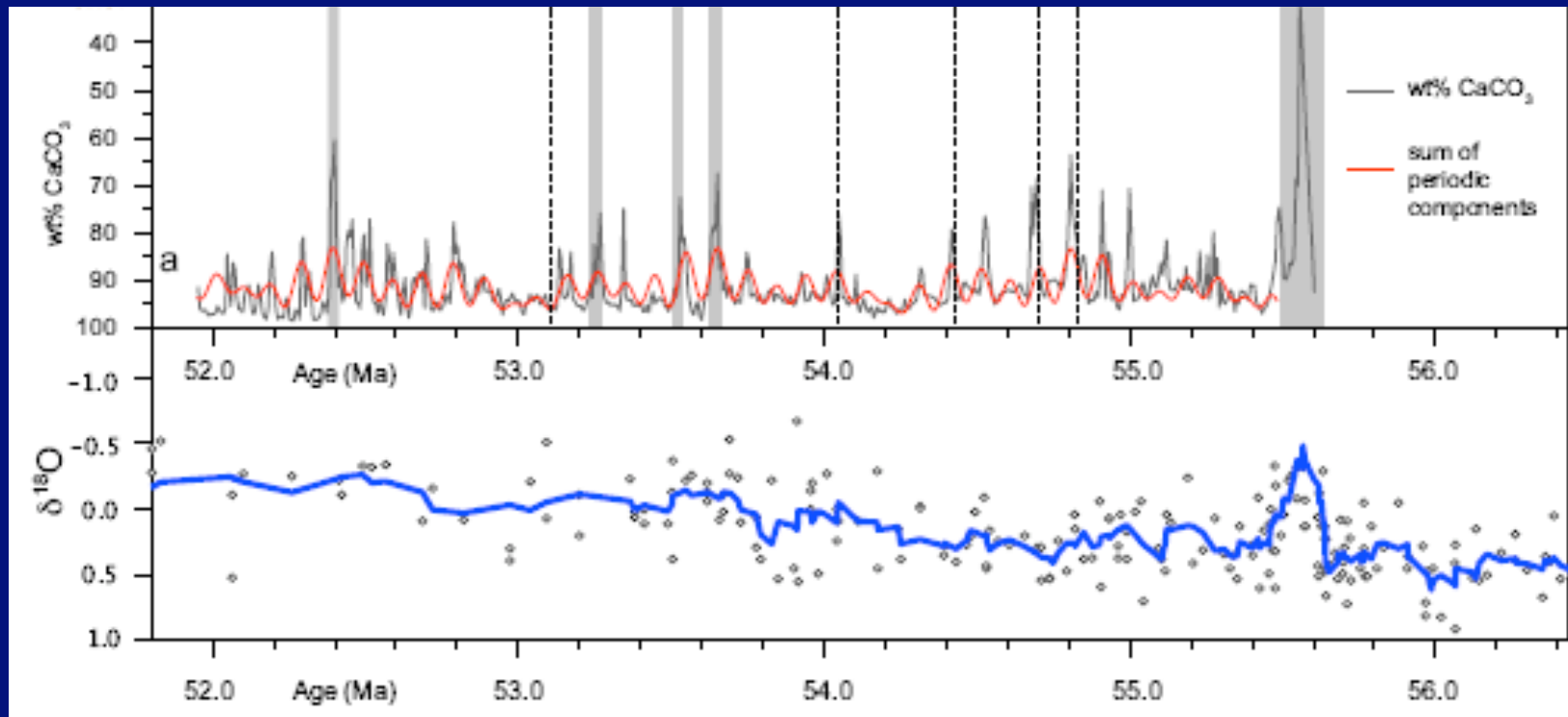
HadCM3 (med)
50% loss



MIROC3.2 (high)
59% loss

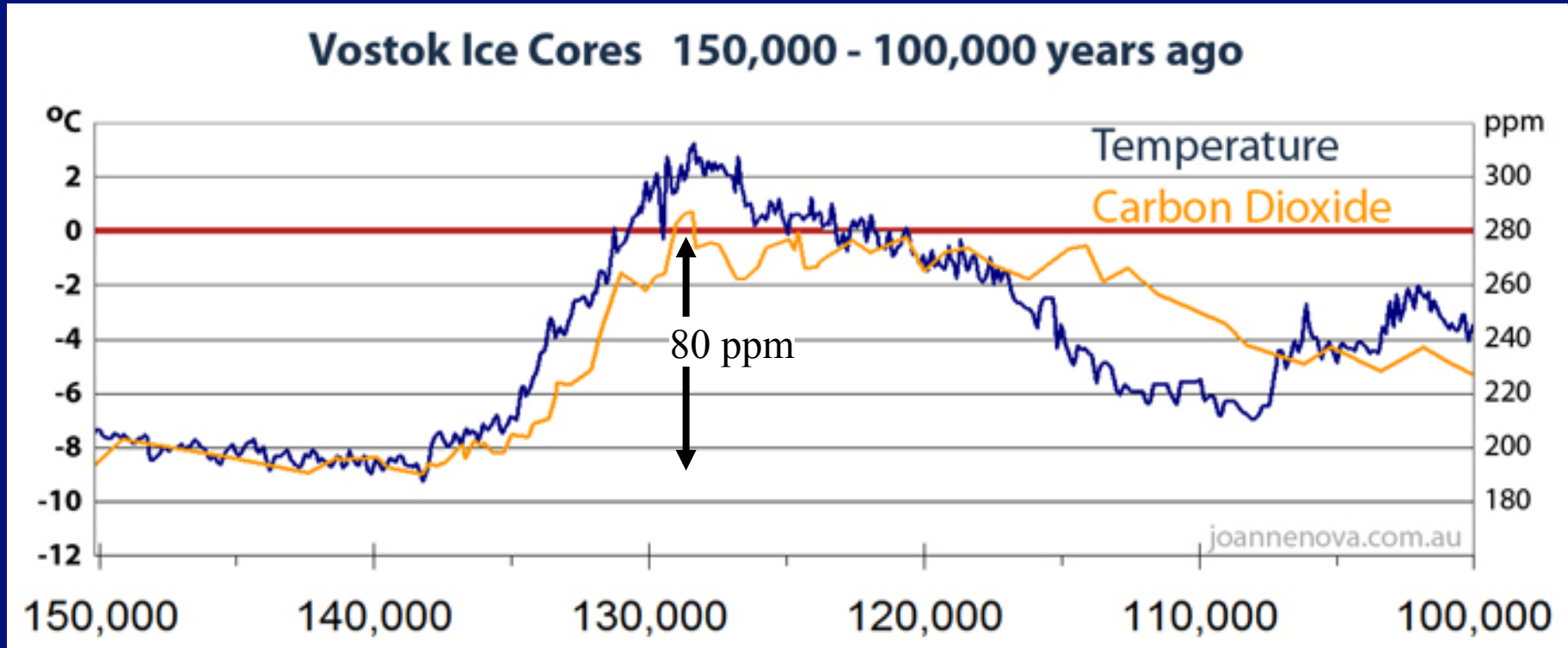
Paleo-Permafrost Carbon Feedback

Palaeocene-Eocene Thermal Maximum (PETM) ↓



Orbit perturbations trigger Antarctic permafrost thaw
[DeConto et al. 2011, in review]

Vostok Ice Core Records



- CO₂ lags behind temperature by 600 ± 400 yr

Permafrost is Like Concrete



Wickland



Schaefer

Permafrost Features



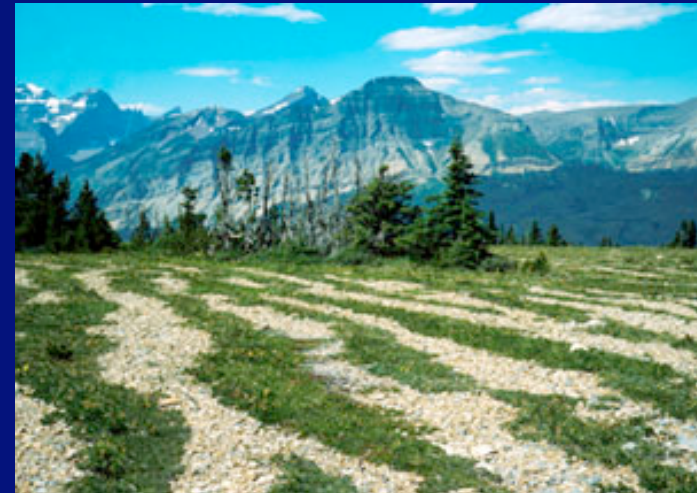
Frost Heave, Yamal



Stone Circles, Svalbard



Stone Circles, NW Territories



Stripes, Glacier NP

Impacts of Degradation



Alaska Road Heaves



**Foundation Settling
in Chersky**



Qinghai-Xizang Highway Bridge



Thermokarst in Yakutsk [Skiklomanov, 2005]

Impacts of Degradation



Coastal Erosion, Alaska



Drying lake, Tibet [Zhang, 2007]

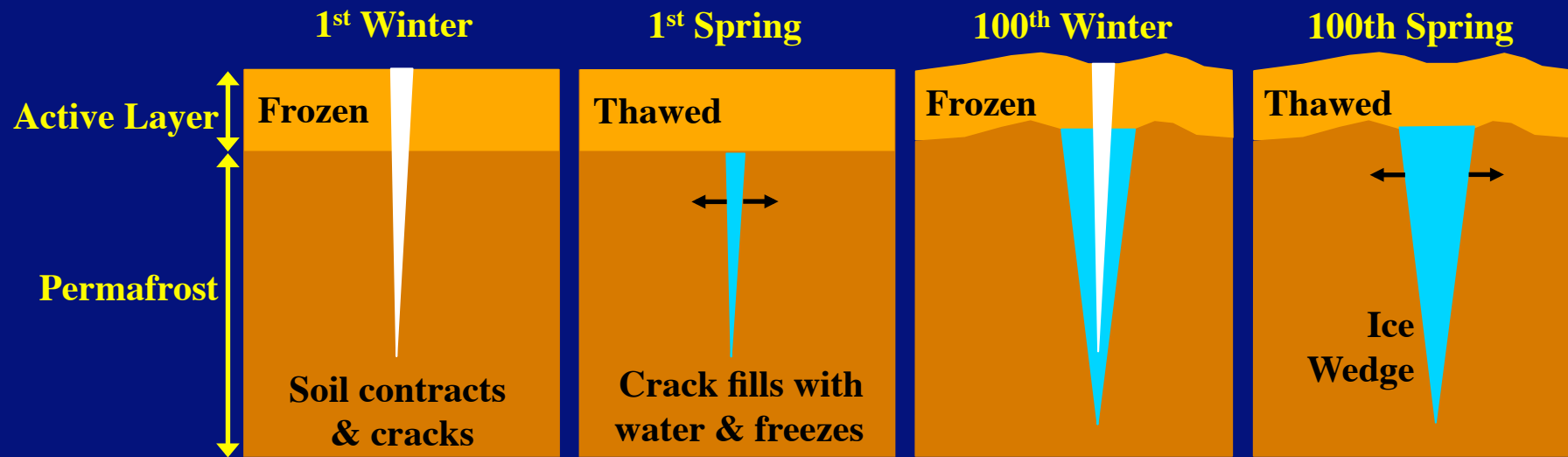


Rockfall, Matterhorn [Gruber, 2003]



Ice-wedge thaw, Alaska [Davis, 2000]

Ice Wedges and Polygons



Polygons, Yena



Polygons, Prudhoe Bay [Zhang, 2009]

Cryoturbation

- Movement of soil or rock due to repeated freezing and thawing

Vegetation

Active
Layer

Permafrost

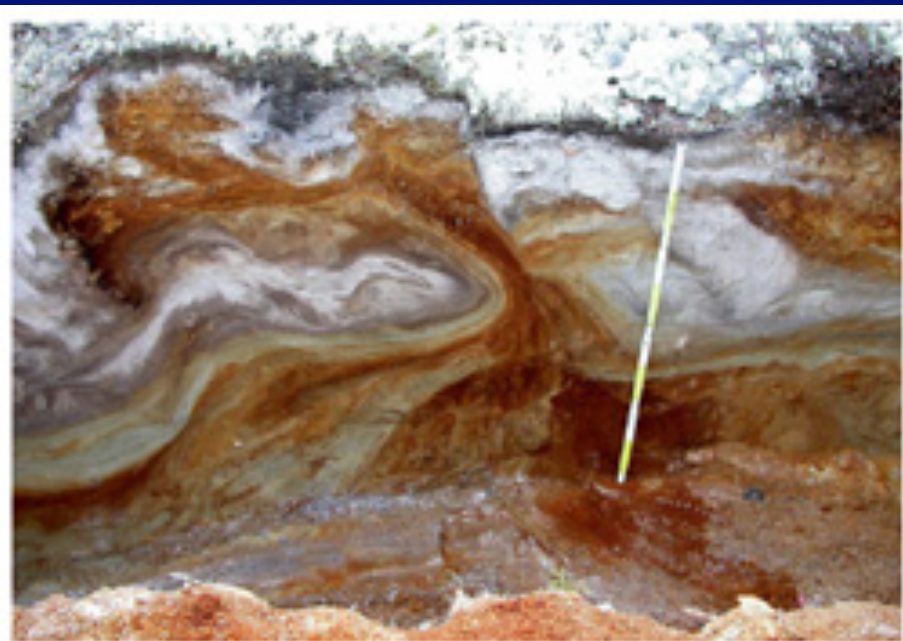
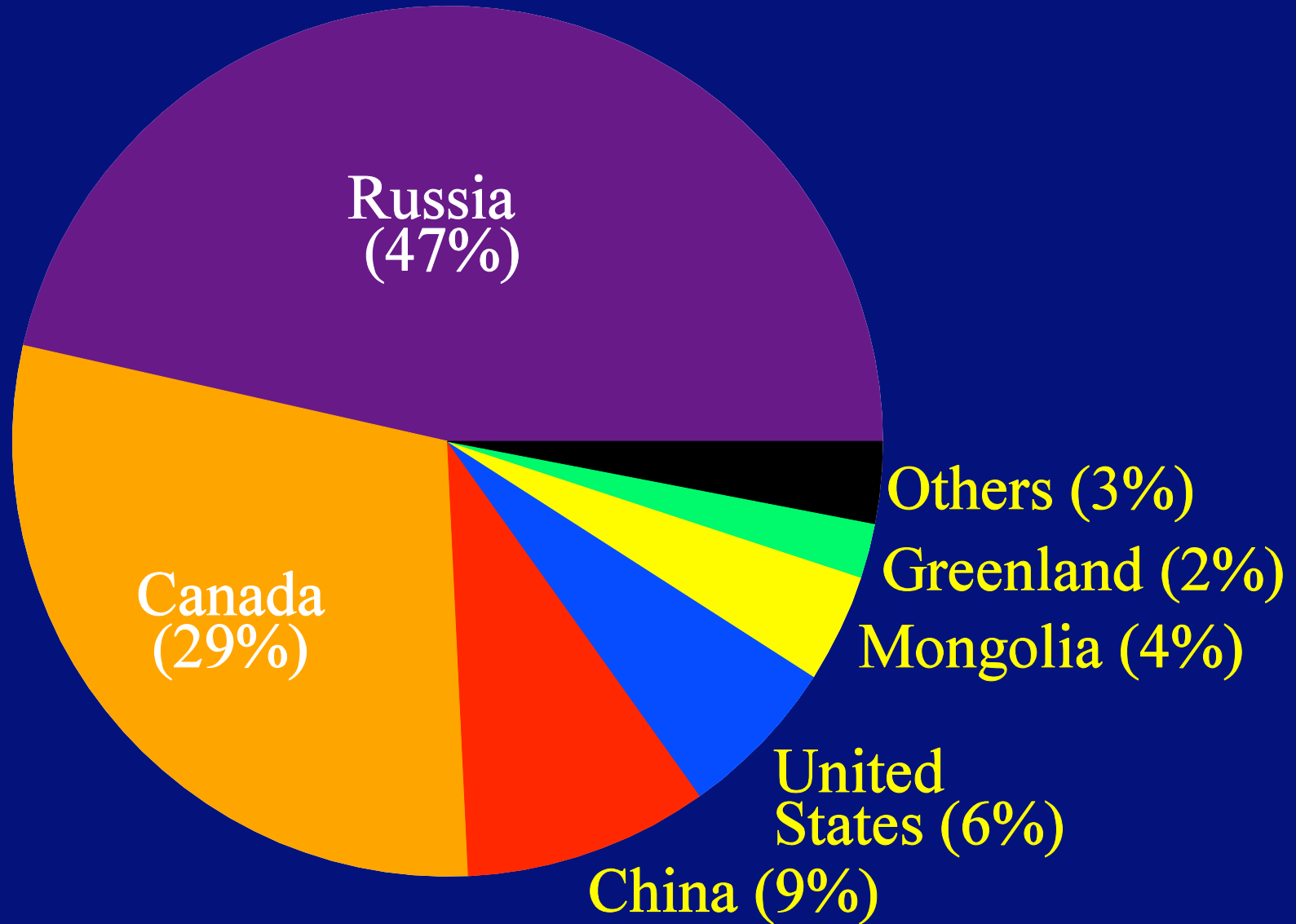


Photo : http://131.130.57.239/sibirien/Taiga_Nord.htm

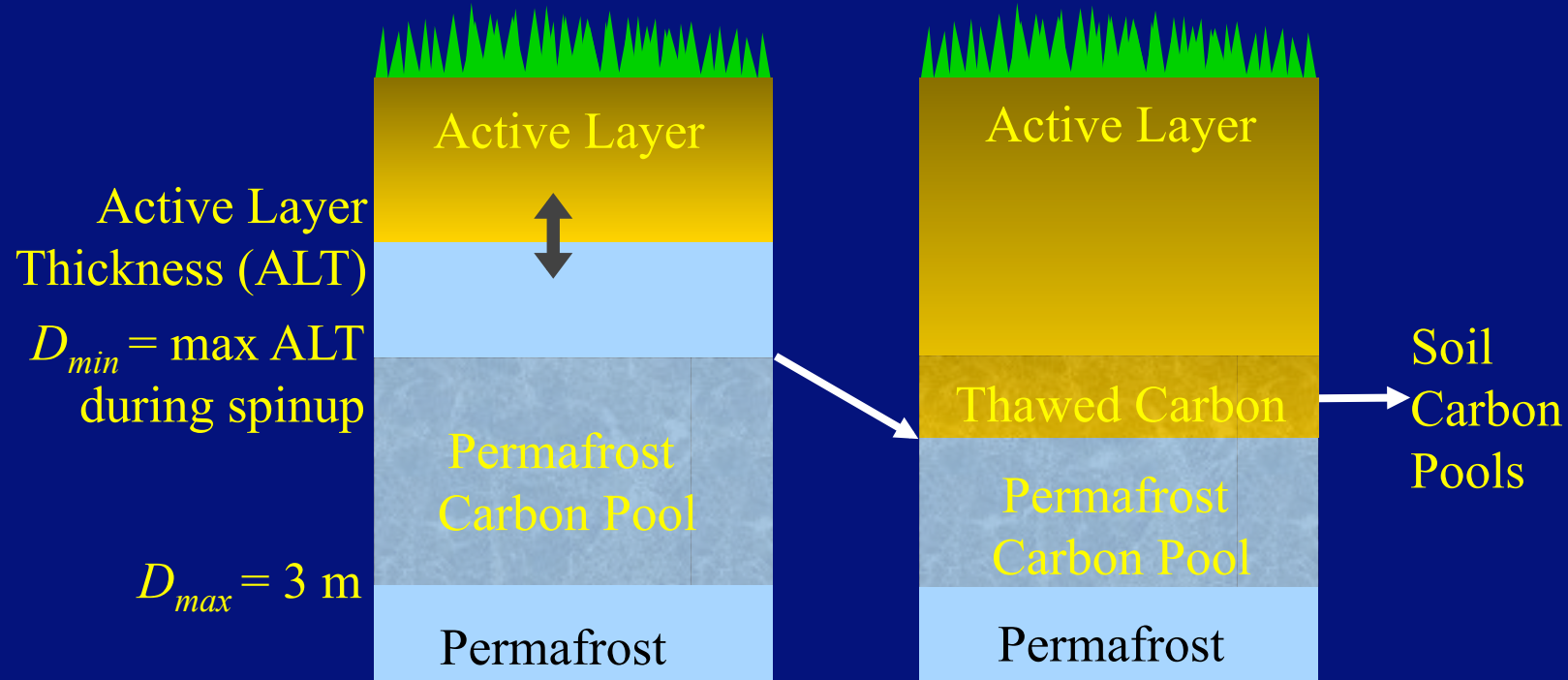
adapté de Pech 1998

Pleistocene Cryoturbation, France

Permafrost Distribution by Country



Permafrost Carbon in SiBCASA



- 313 Gt C in permafrost carbon pool
- 91 Gt C in active layer
- 414 Gt C in top 3 m (575 Gt C estimated*)

*Tarnocai et al. [2009]

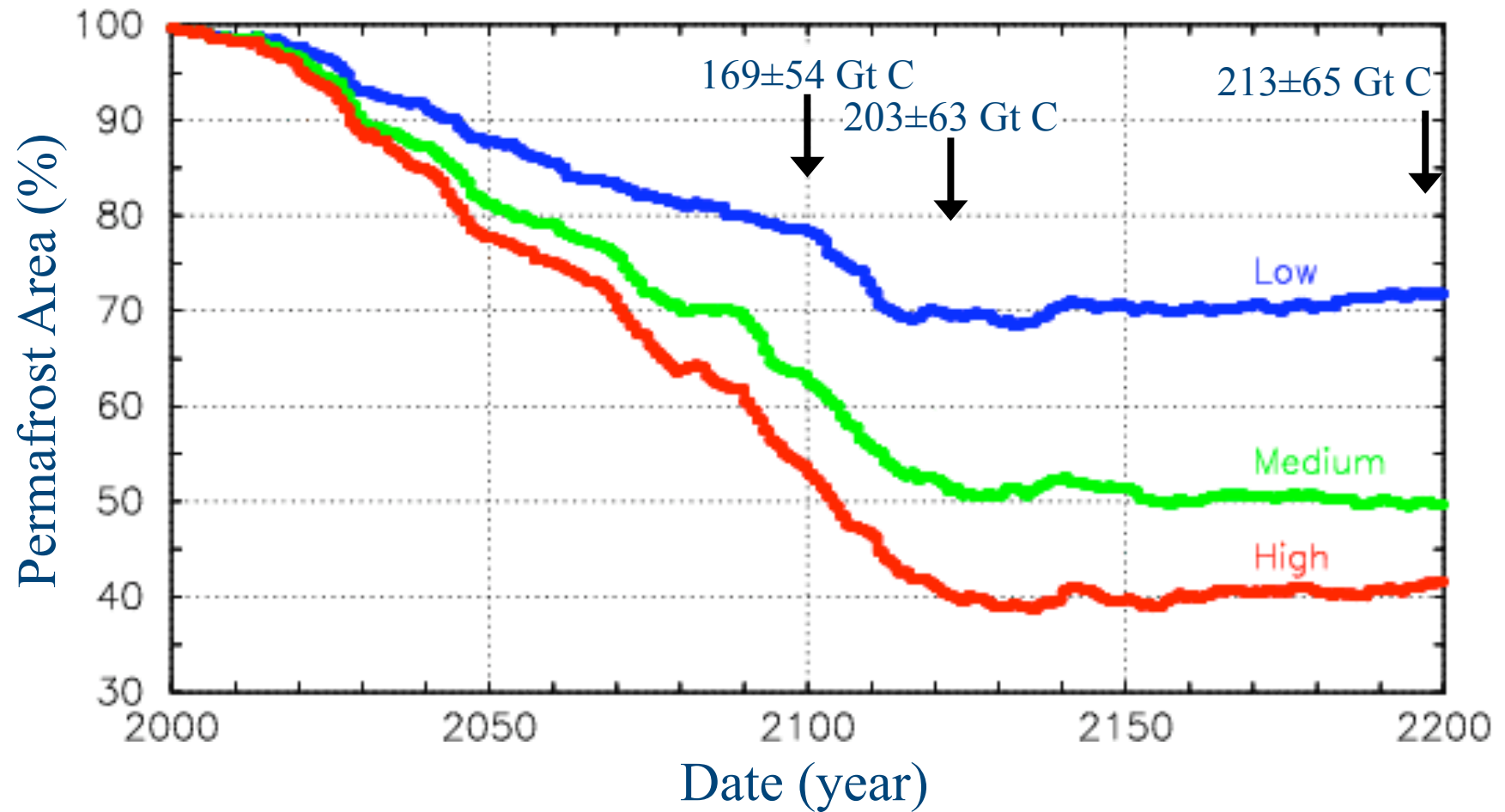
Experiment Setup

- SiBCASA + ERA40 + A1B scenario
- Continuous/discontinuous permafrost
- 1973-2001: “spin up”
- 2002-2200: random ERA40 + linear trend
 - MIROC3.2 (high)
 - HadCM3 (med)
 - CCSM3 (low)

Estimating Uncertainty

- 18 ensemble members
 - 3 warming rates
 - 3 permafrost carbon densities
 - 2 sub-grid permafrost extents
- Best estimate: ensemble mean
- Uncertainty: ensemble standard deviation

Permafrost Area Loss



Permafrost Features



Frost Heave, Yamal



Stone Circles, Svalbard



Stone Circles, NW Territories



Stripes, Glacier NP