ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Permafrost

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Universität Potsdam
SEVENTH FRAMEWORK PROGRAMME
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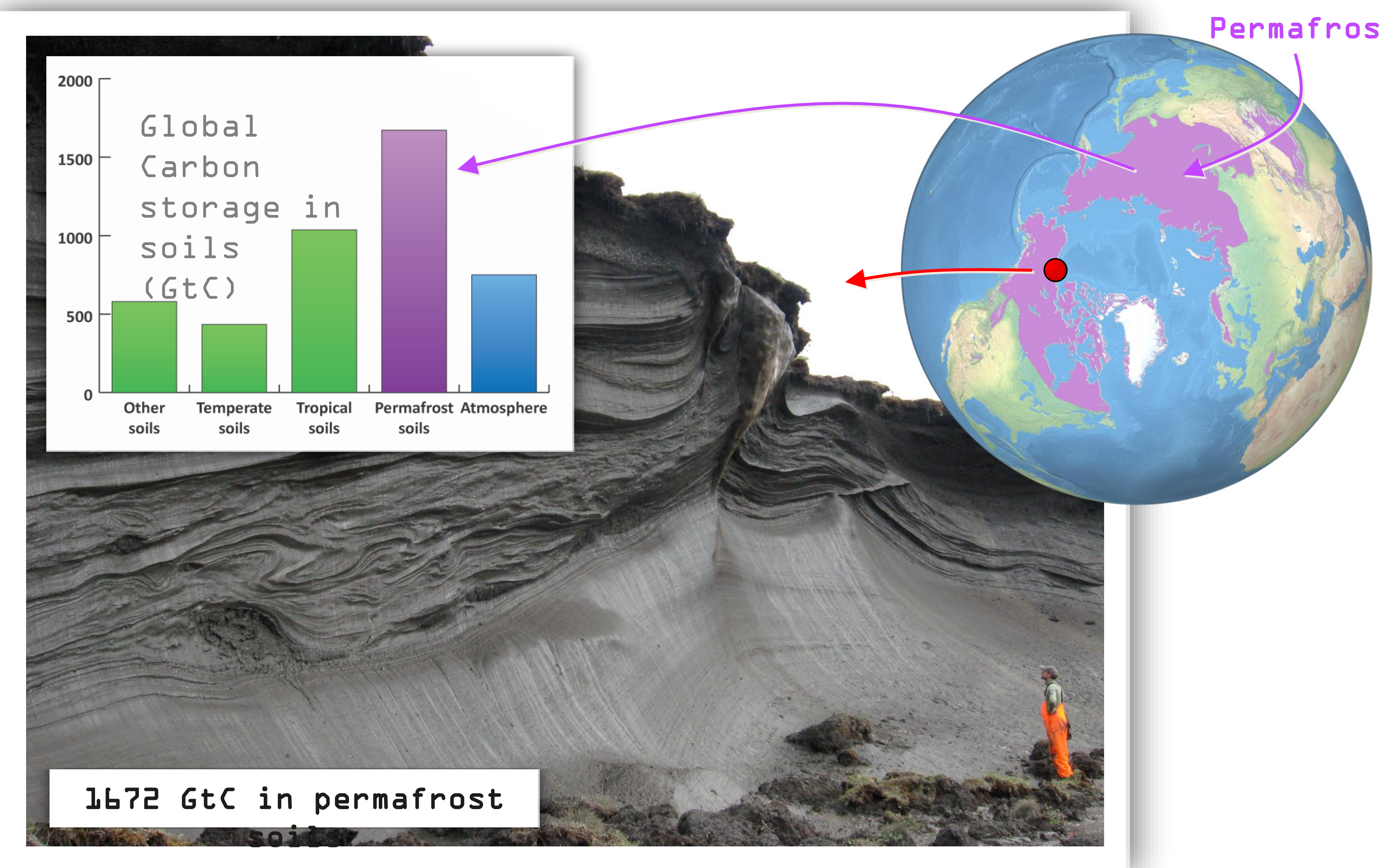
Permafrost



Global Carbon storage in soils (GtC)
2000
1500
1000
500
0
Other soils
Temperate soils
Tropical soils
Permafrost soils
Atmosphere
Permafrost
1672 GtC in permafrost soils

Permafrost distribution

- Underlies 24% of the northern hemisphere
- Can be > 2.5 million years old
- Can be up to 1600 m deep

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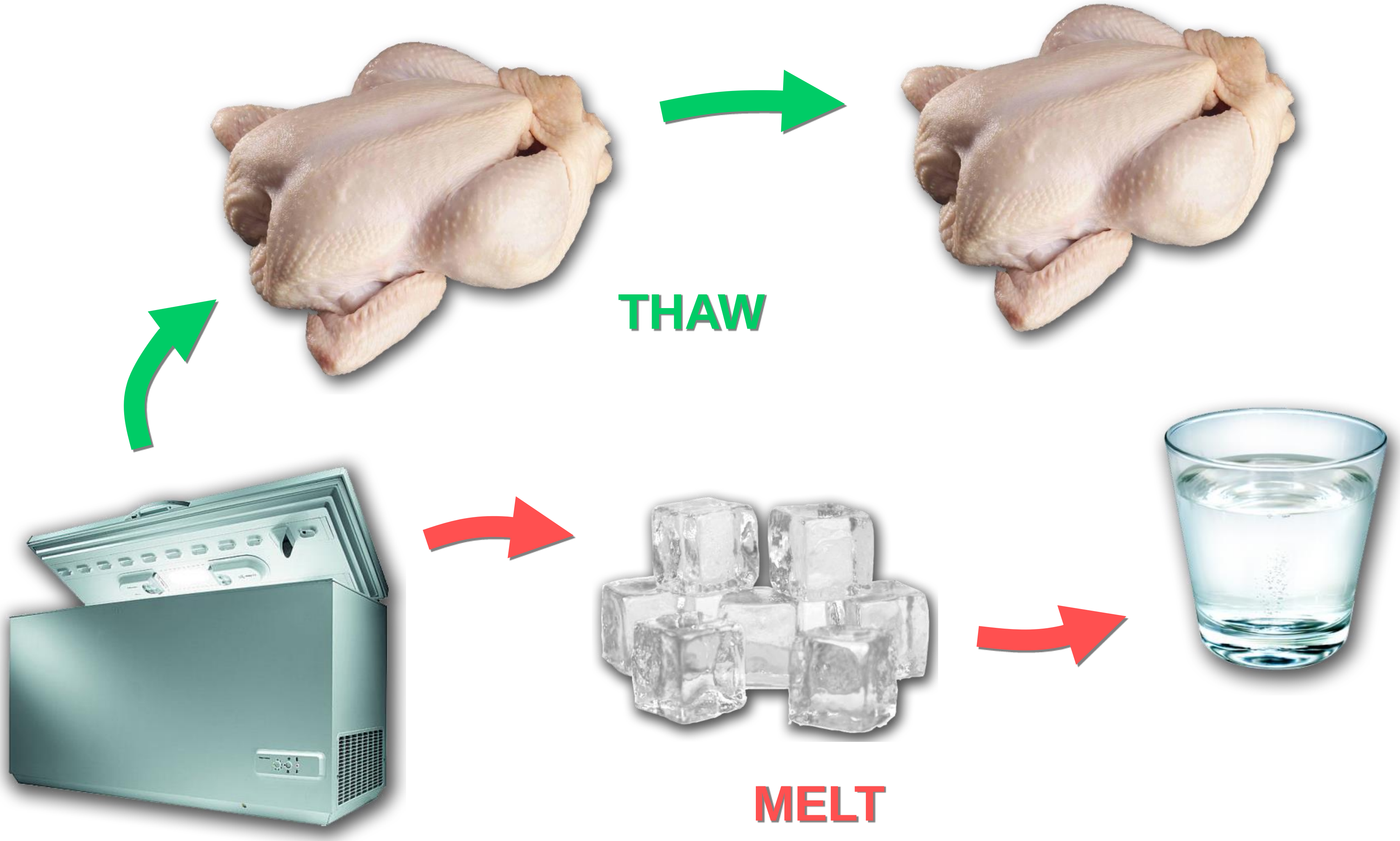
Melt or thaw?



Permafrost alliance

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IPA

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ADAPT
Arctic Development and Adaptation to Permafrost in Transition

INTER ⇄ ACT

CAPEC
Korea Polar Research Institute

GRENE-TEA

Source: Brown et al., 1998

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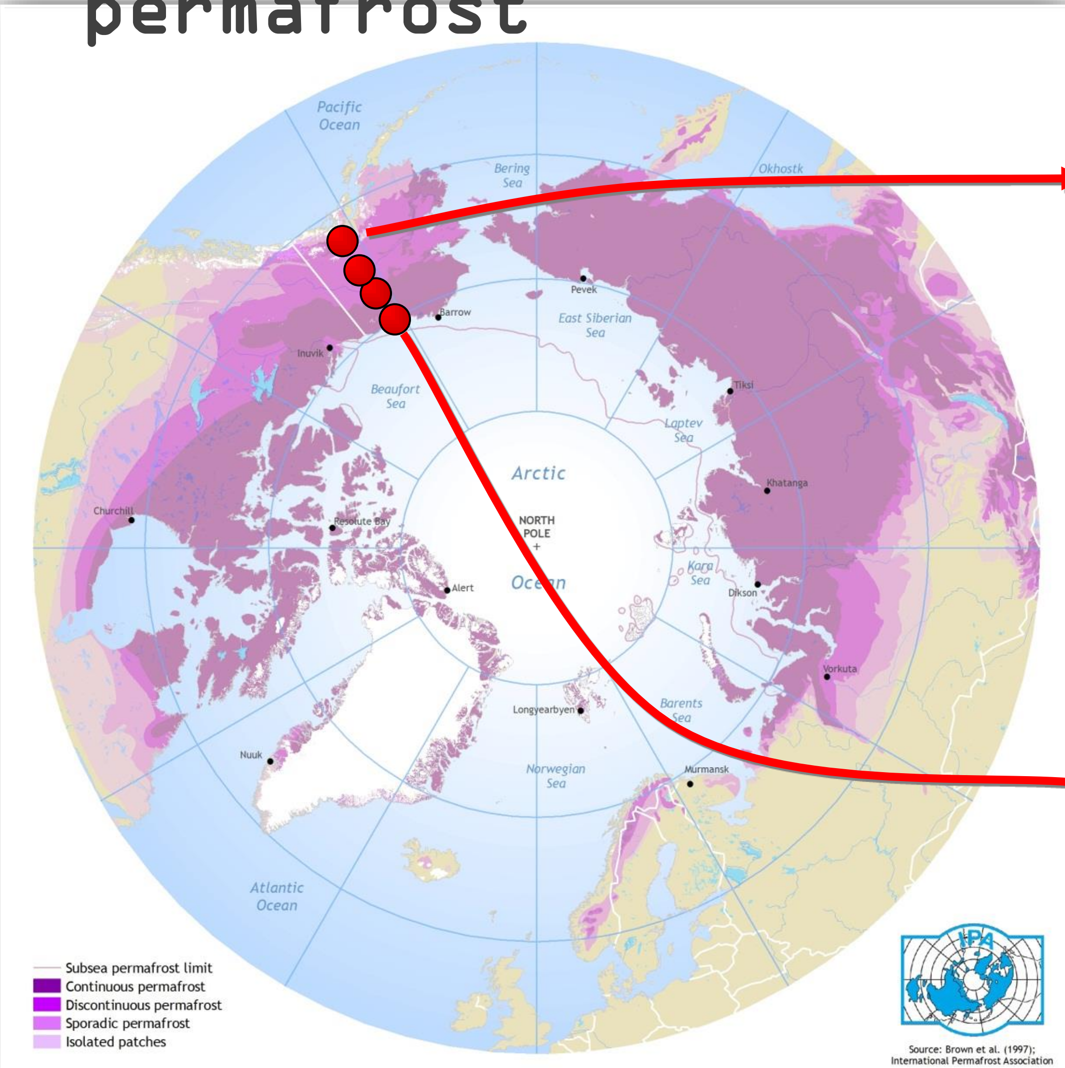
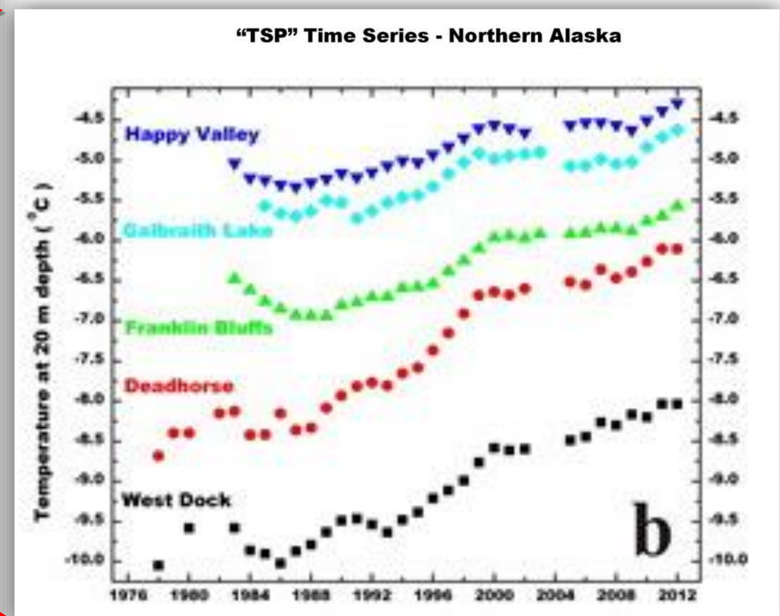
Observed temperature evolution of Alaska's permafrost

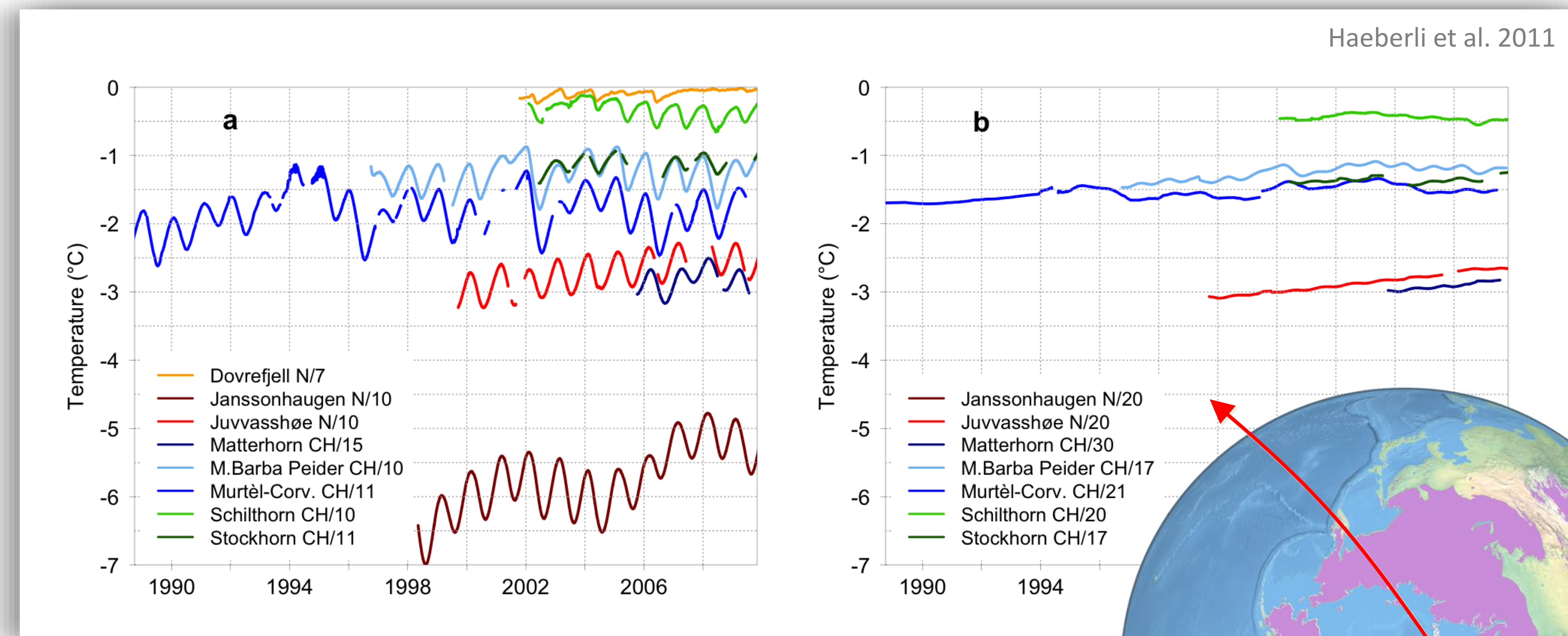


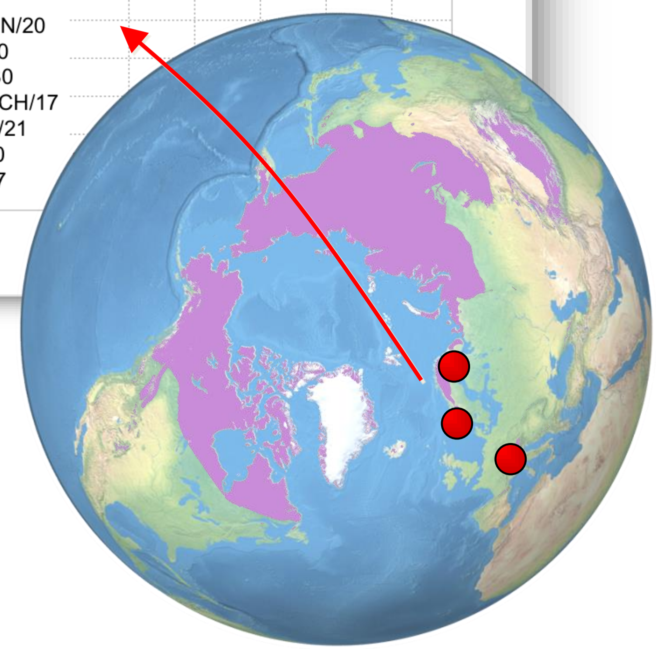


Temperatures at 20 m depth

Romanovsky et al. 2010,
Christiansen et al, 2013

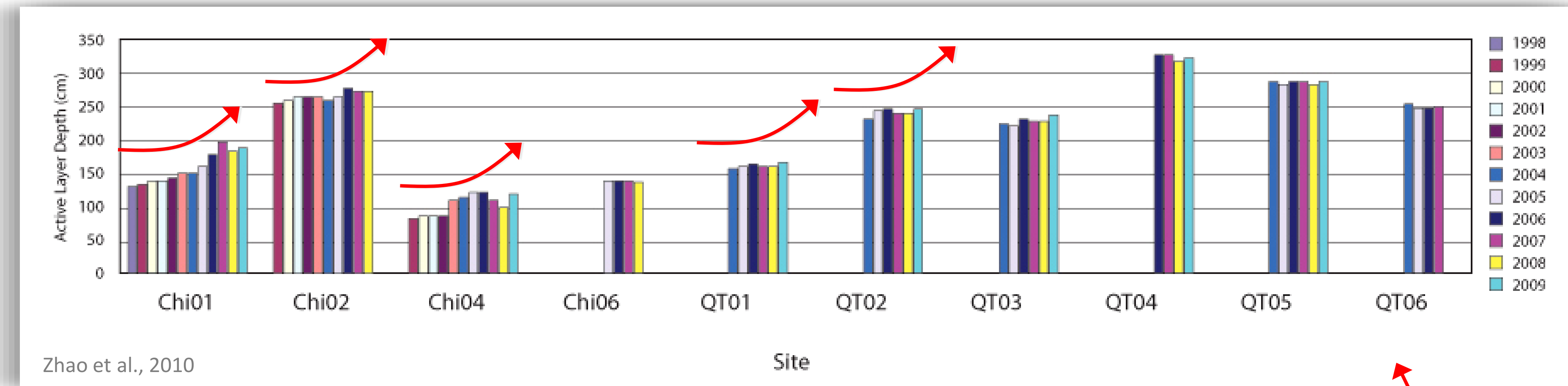
Mountain permafrost

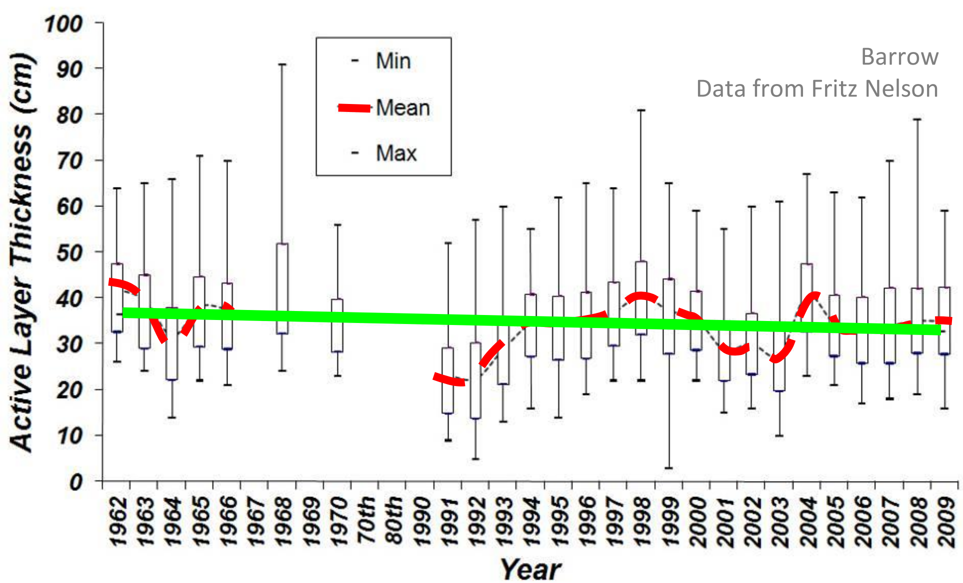


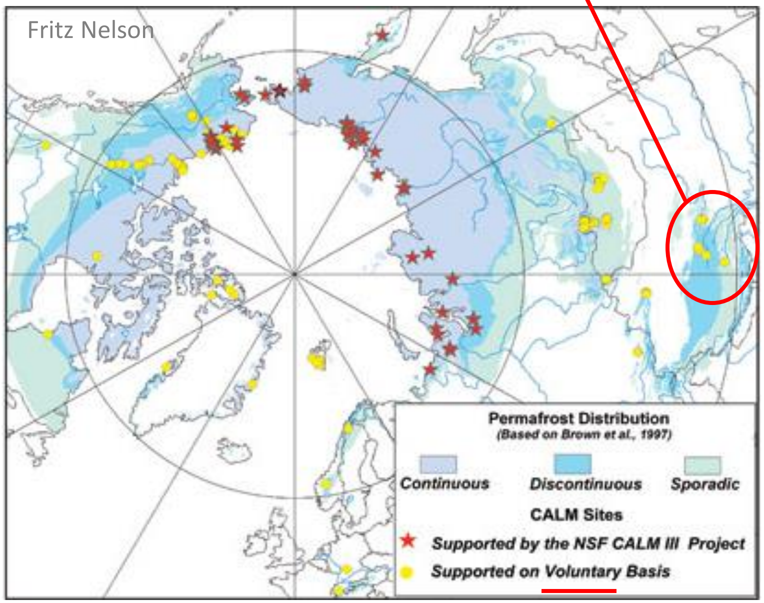


- Mountain permafrost time series are shorter
- Trends difficult to assess because of strong environmental gradients

Active Layer Depths

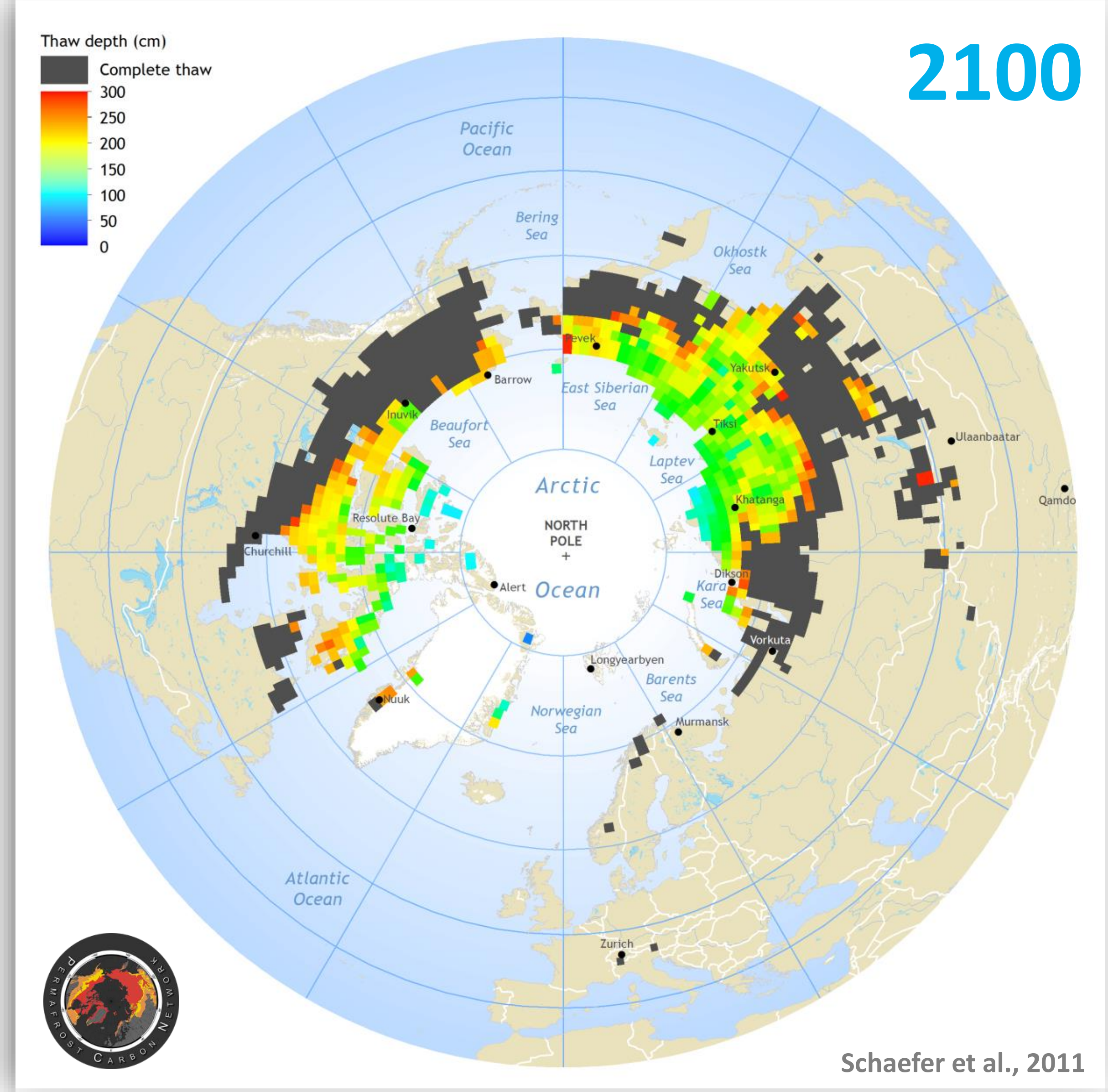






Active Layer

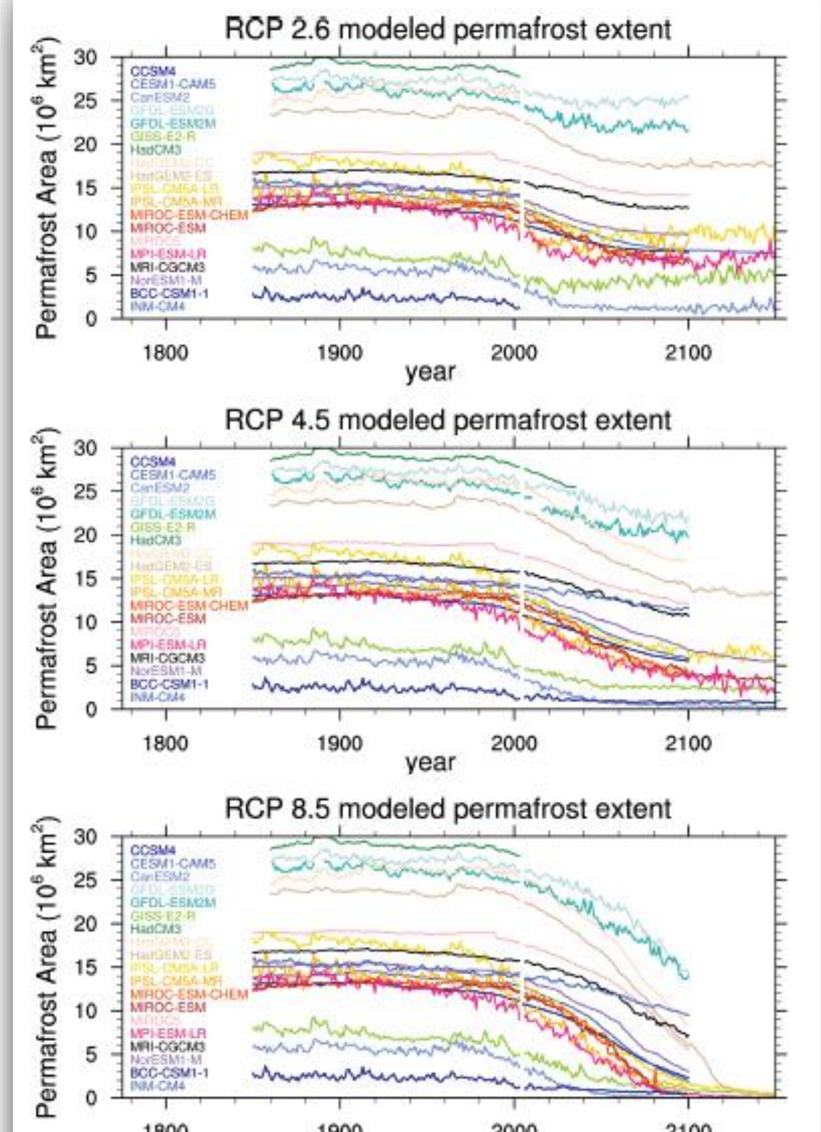
- Thaw in the subarctic
- Deeper active layer in carbon-rich regions



Thermal modeling

Permafrost in CMIP5 models

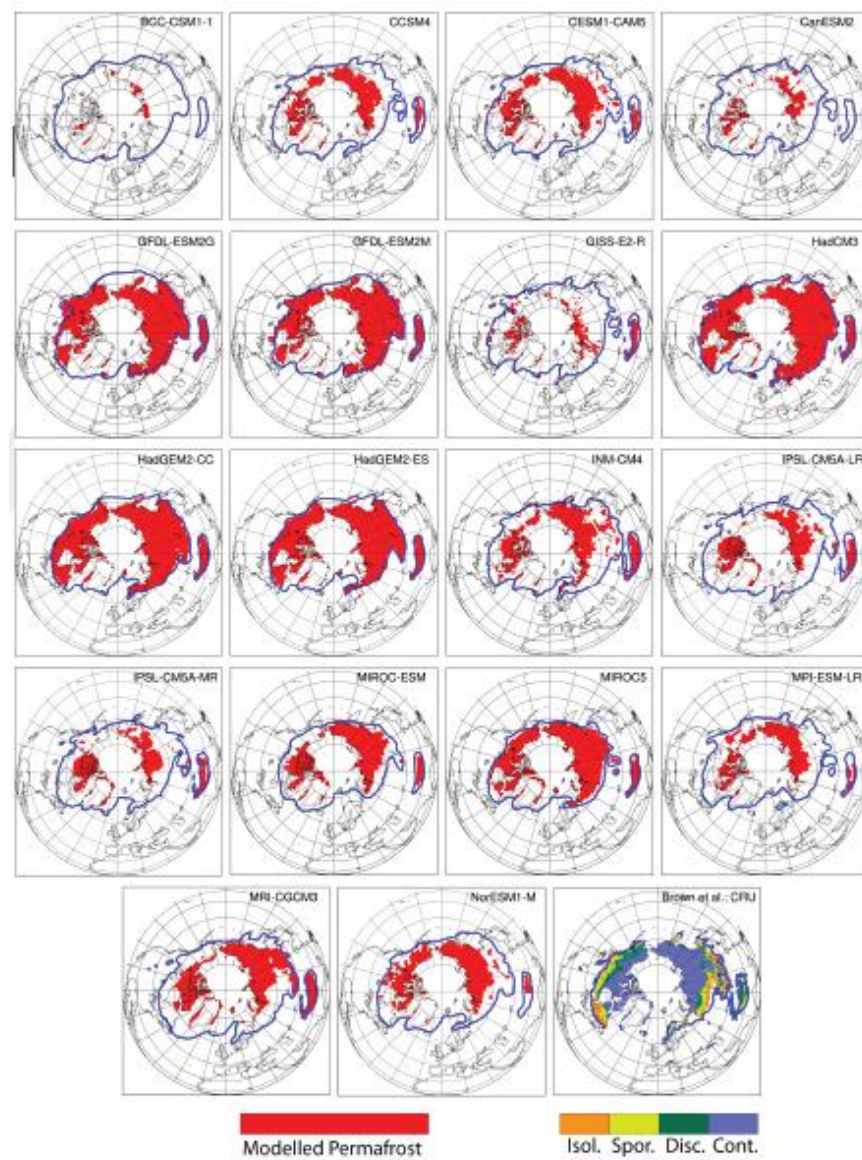
- Large uncertainty on current estimate
- Agreement on decrease in the future (obvious)
- Somehow simulated change is more consistent than simulated present-day distribution…



Koven et al., 2012

Permafrost extent in CMIP5

- The present day estimate remains a major issue
- More model development and evaluation is critical.



Koven et al., 2012

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Solutions

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Borehole distribut i

GTN-P
Global Terrestrial Network for Permafrost

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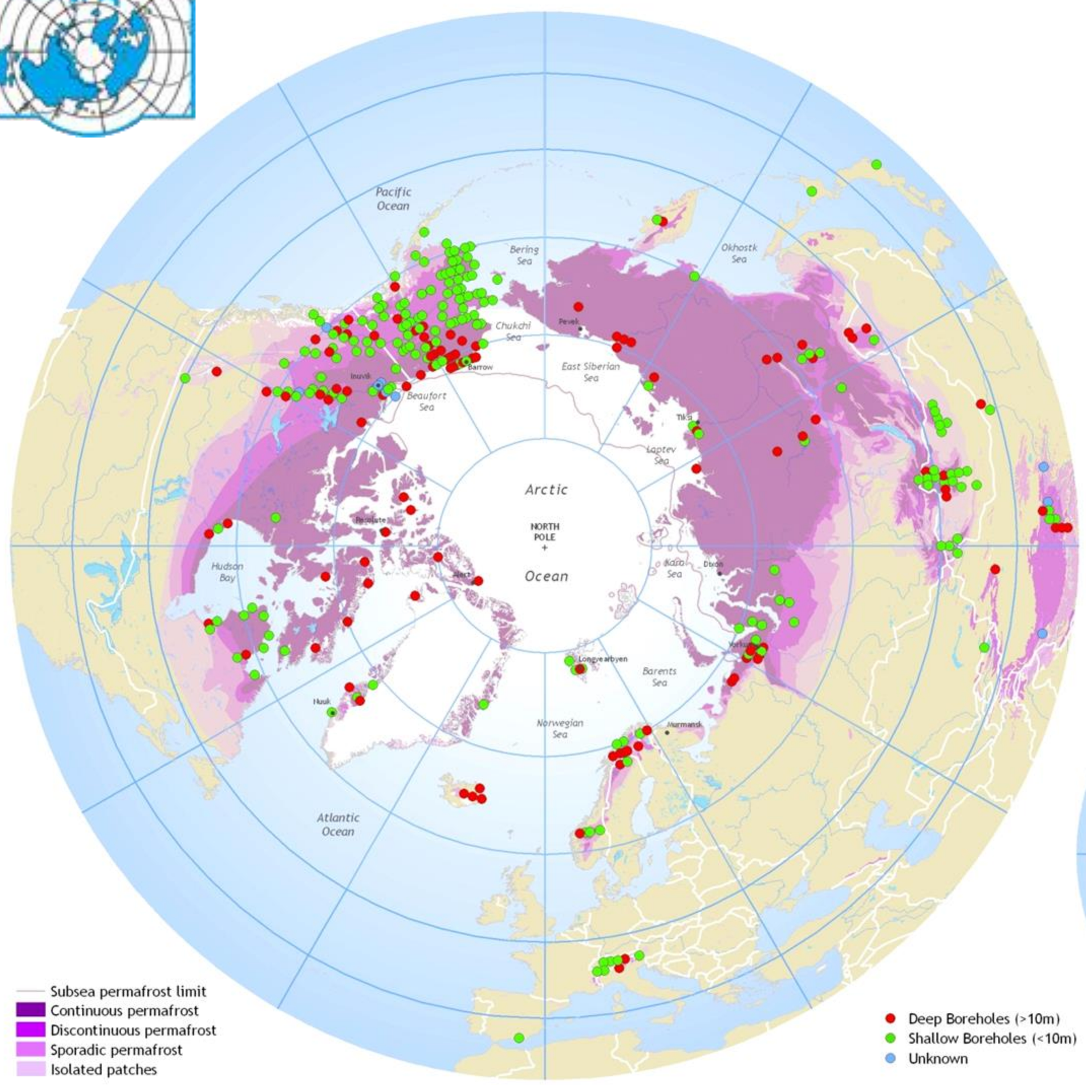

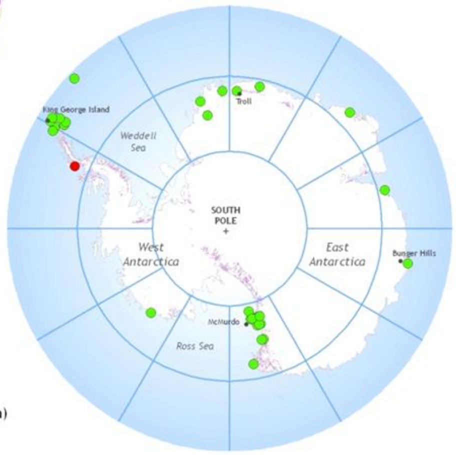

IPA, 2010

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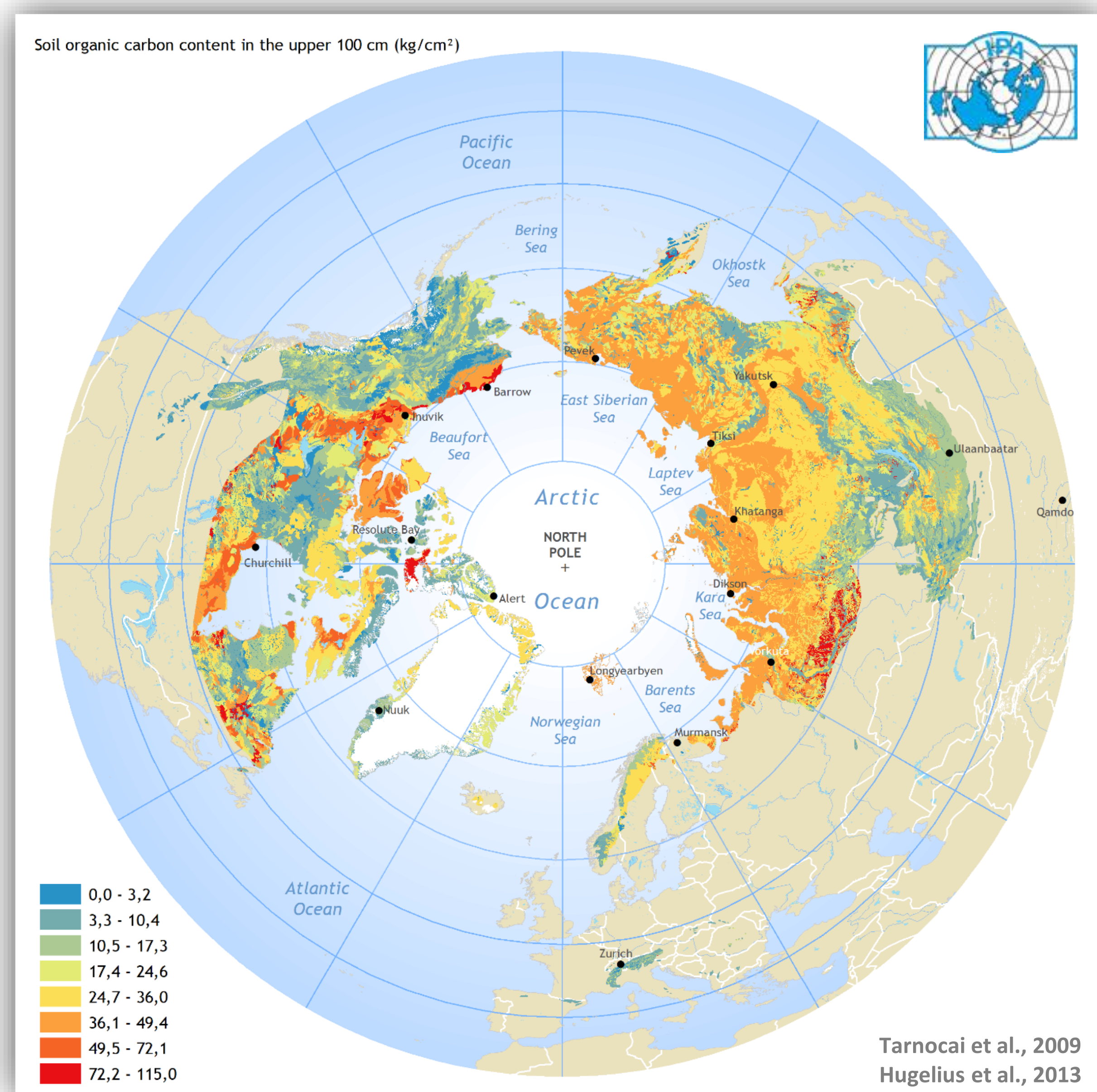
Carbon pools

Permafrost carbon

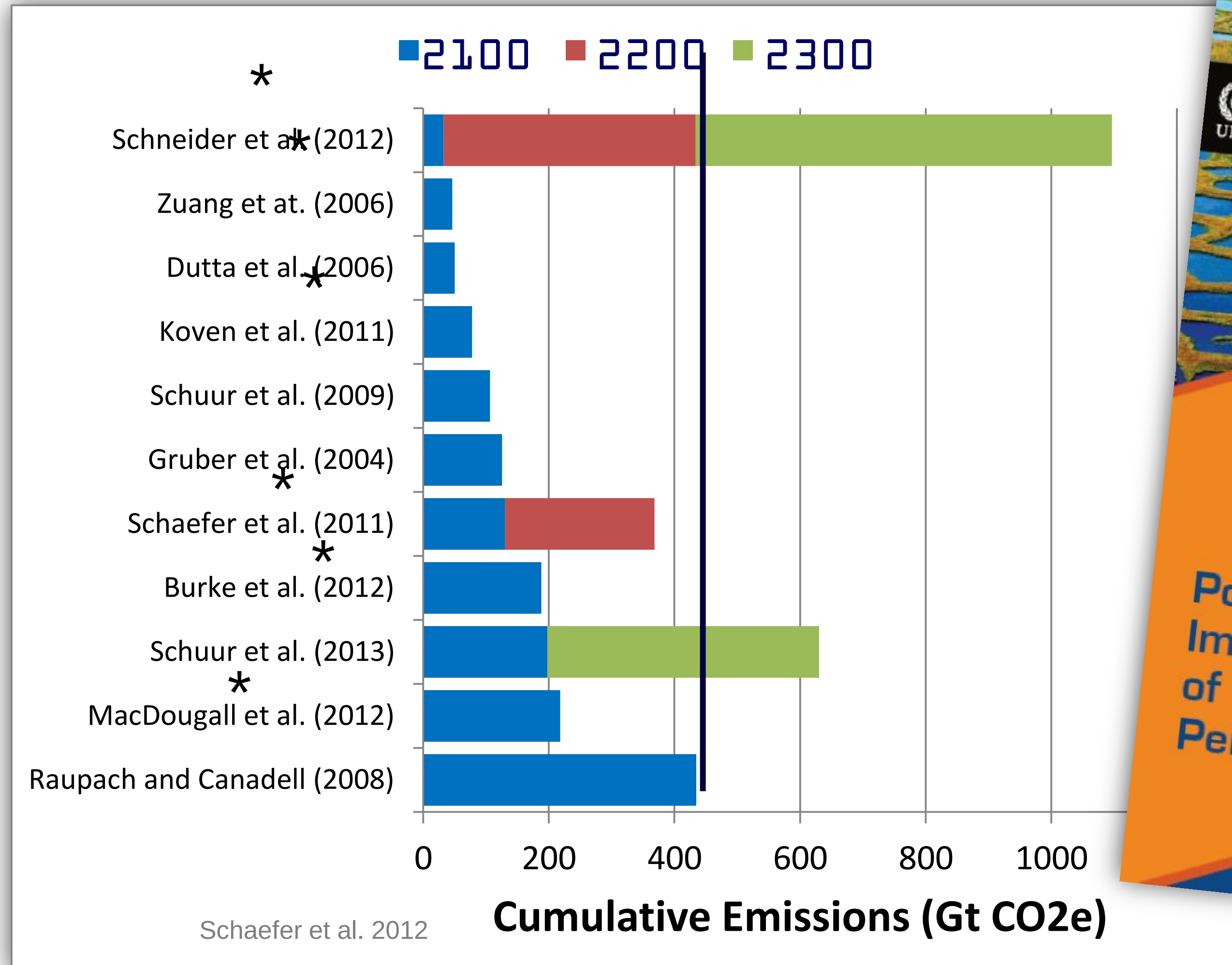
- Fluxes of carbon from thawing permafrost by 2100: between **1.2 and 1.6 Gt C/yr**
- equivalent to **half of all fossil fuel emissions from the dawn of the industrial age to today**

Schaefer et al., 2011



Tarnocai et al., 2009
Hugelius et al., 2013

Permafrost carbon emissions



5% to 39% of anthropogenic emissions

*dynamic model estimates

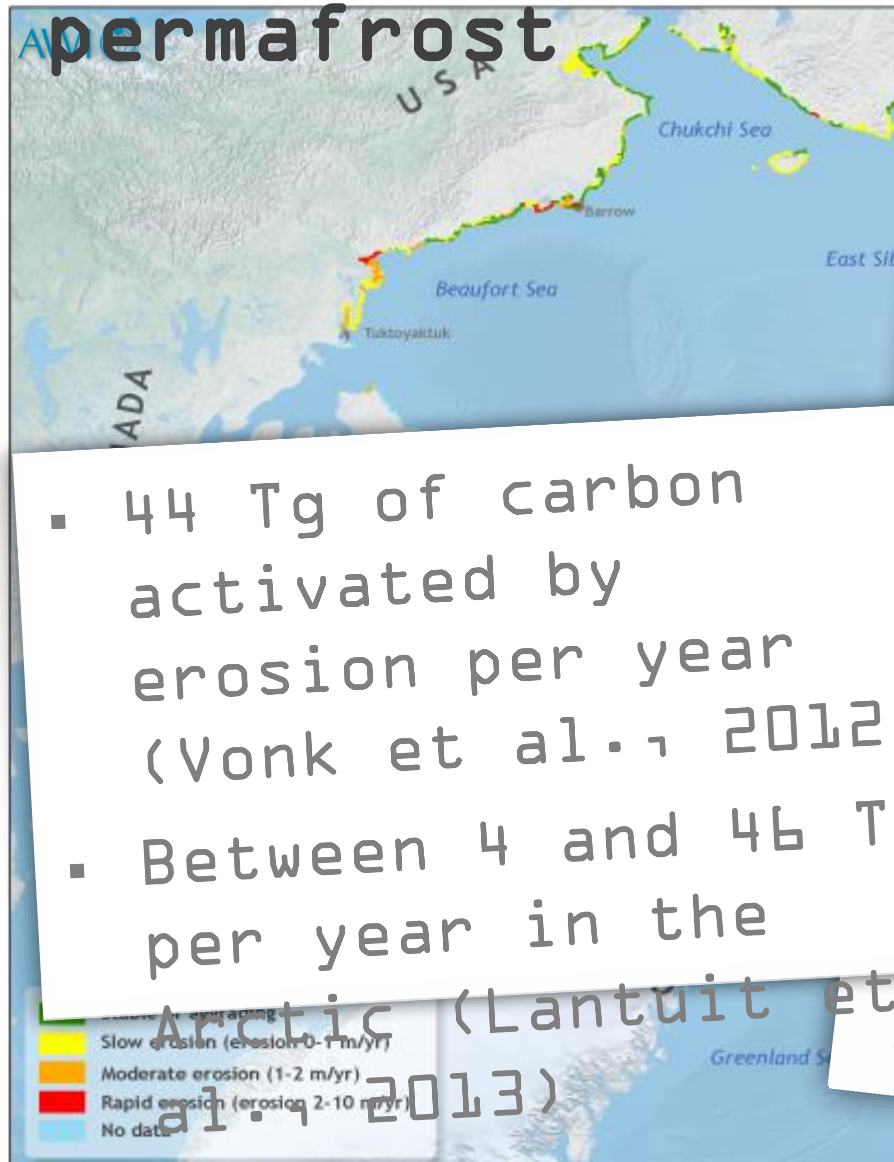
www.unep.org/pdf/permafrost.pdf

Coastal erosion of permafrost

Courtesy Ben Jones

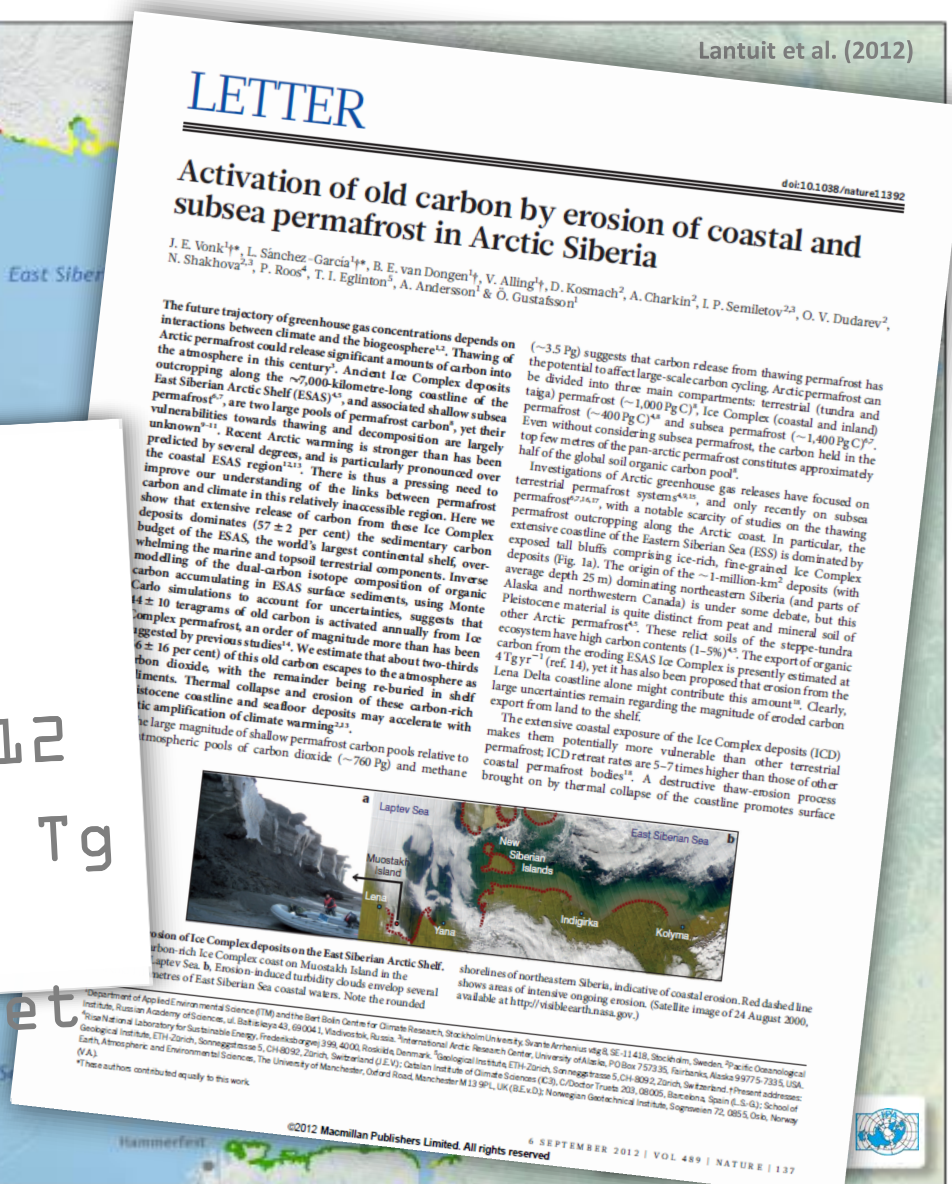
Coastal erosion of permafrost

- 44 Tg of carbon activated by erosion per year (Vonk et al., 2012
- Between 4 and 46 Tg per year in the Arctic (Lantuit et al., 2013)



Map by Lantuit, H., Overduin, P. P., 2008. Data used with permission from the Arctic Coastal Dynamics Project GIS v 1.0 beta

Lantuit et al. (2012)



LETTER

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Activation of old carbon by erosion of coastal and subsea permafrost in Arctic Siberia

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The future trajectory of greenhouse gas concentrations depends on interactions between climate and the biogeosphere[1,2]. Thawing of Arctic permafrost could release significant amounts of carbon into the atmosphere in this century[3]. Ancient Ice Complex deposits outcropping along the ~7,000-kilometre-long coastline of the East Siberian Arctic Shelf (ESAS)[4,5], and associated shallow subsea permafrost[6,7], are two large pools of permafrost carbon[8], yet their vulnerabilities towards thawing and decomposition are largely unknown[9–11]. Recent Arctic warming is stronger than has been predicted by several degrees, and is particularly pronounced over the coastal ESAS region[12,13]. There is thus a pressing need to improve our understanding of the links between permafrost carbon and climate in this relatively inaccessible region. Here we show that extensive release of carbon from these Ice Complex deposits dominates (57 ± 2 per cent) the sedimentary carbon budget of the ESAS, the world's largest continental shelf, overwhelming the marine and topsoil terrestrial components. Inverse modelling of the dual-carbon isotope composition of organic carbon accumulating in ESAS surface sediments, using Monte Carlo simulations to account for uncertainties, suggests that 44 ± 10 teragrams of old carbon is activated annually from Ice Complex permafrost, an order of magnitude more than has been suggested by previous studies[14]. We estimate that about two-thirds (66 ± 16 per cent) of this old carbon escapes to the atmosphere as carbon dioxide, with the remainder being re-buried in shelf sediments. Thermal collapse and erosion of these carbon-rich Pleistocene coastline and seafloor deposits may accelerate with Arctic amplification of climate warming[2,13].

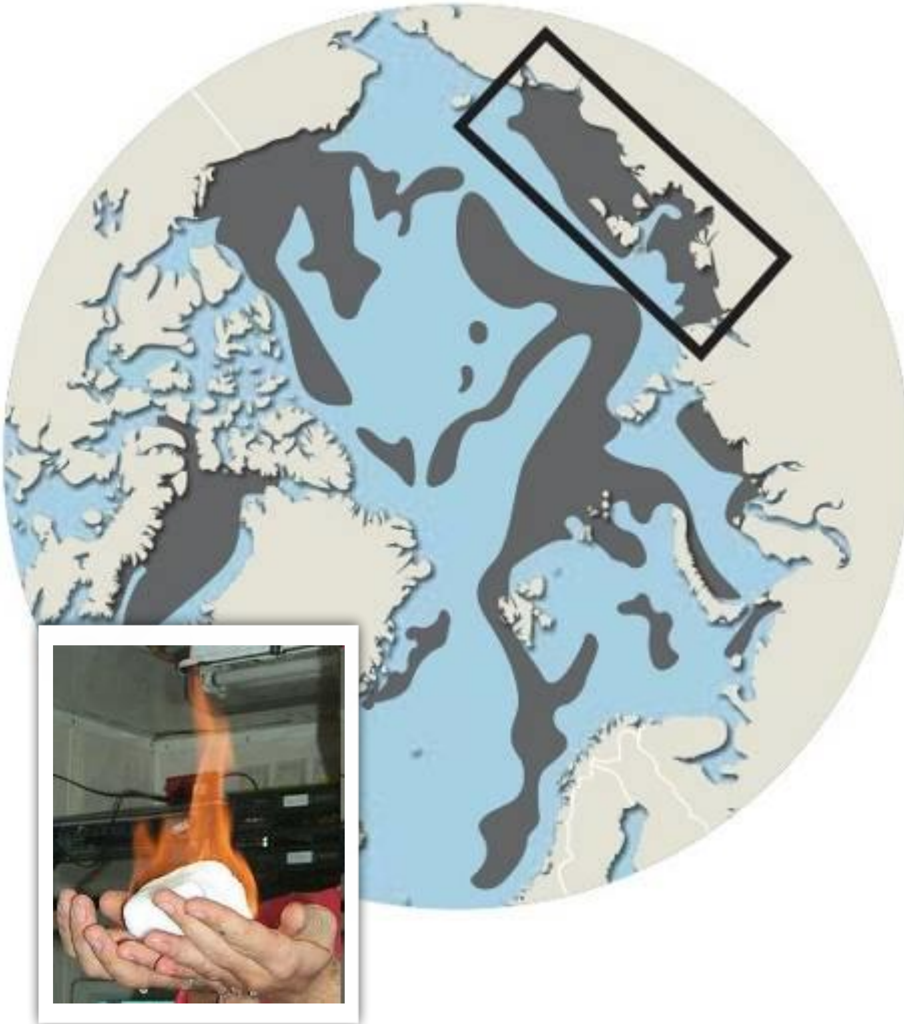
The large magnitude of shallow permafrost carbon pools relative to atmospheric pools of carbon dioxide (~760 Pg) and methane (~3.5 Pg) suggests that carbon release from thawing permafrost has the potential to affect large-scale carbon cycling. Arctic permafrost can be divided into three main compartments: terrestrial (tundra and taiga) permafrost (~1,000 Pg C)[3], Ice Complex (coastal and inland) permafrost (~400 Pg C)[4,8] and subsea permafrost (~1,400 Pg C)[6,7]. Even without considering subsea permafrost, the carbon held in the top few metres of the pan-arctic permafrost constitutes approximately half of the global soil organic carbon pool[8].

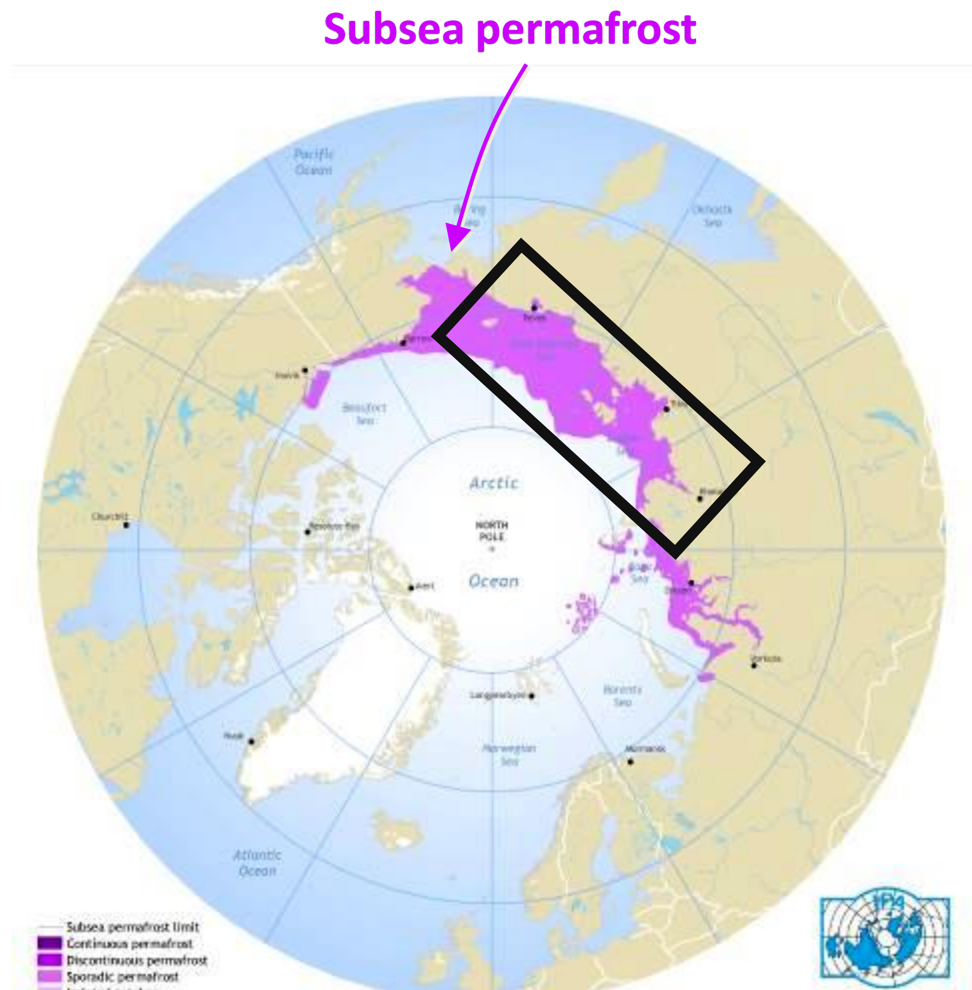
Investigations of Arctic greenhouse gas releases have focused on terrestrial permafrost systems[4,9,15], and only recently on subsea permafrost[6,7,16,17], with a notable scarcity of studies on the thawing permafrost outcropping along the Arctic coast. In particular, the extensive coastline of the Eastern Siberian Sea (ESS) is dominated by exposed tall bluffs comprising ice-rich, fine-grained Ice Complex deposits (Fig. 1a). The origin of the ~1-million-km^2 deposits (with average depth 25 m) dominating northeastern Siberia (and parts of Alaska and northwestern Canada) is under some debate, but this Pleistocene material is quite distinct from peat and mineral soil of other Arctic permafrost[4,5]. These relict soils of the steppe-tundra ecosystem have high carbon contents (1–5%)[4,5]. The export of organic carbon from the eroding ESAS Ice Complex is presently estimated at 4 Tg yr^{-1} (ref. 14), yet it has also been proposed that erosion from the Lena Delta coastline alone might contribute this amount[18]. Clearly, large uncertainties remain regarding the magnitude of eroded carbon export from land to the shelf.

The extensive coastal exposure of the Ice Complex deposits (ICD) makes them potentially more vulnerable than other terrestrial permafrost; ICD retreat rates are 5–7 times higher than those of other coastal permafrost bodies[18]. A destructive thaw-erosion process brought on by thermal collapse of the coastline promotes surface

…osion of Ice Complex deposits on the East Siberian Arctic Shelf. …rbon-rich Ice Complex coast on Muostakh Island in the …aptev Sea. b, Erosion-induced turbidity clouds envelop several …metres of East Siberian Sea coastal waters. Note the rounded shorelines of northeastern Siberia, indicative of coastal erosion. Red dashed line shows areas of intensive ongoing erosion. (Satellite image of 24 August 2000, available at http://visibleearth.nasa.gov.)

Gas hydrate





Source: Brown et al. (1997); International Permafrost Association

Maps: UNEP, IPA

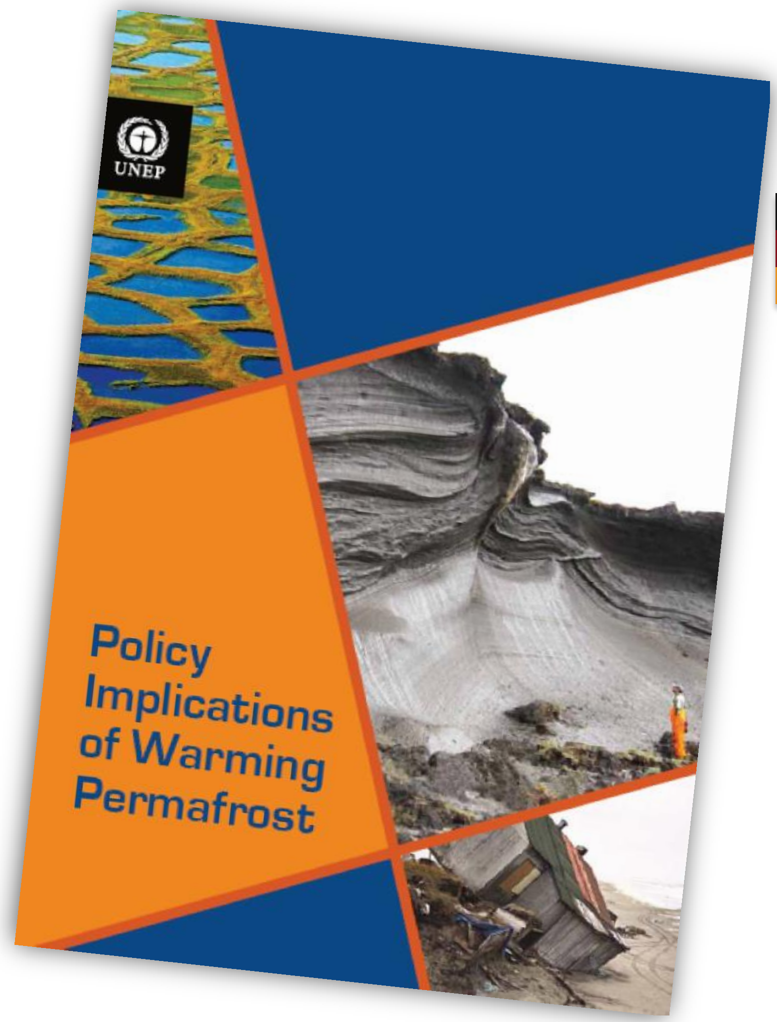
The way forward

UNEP recommendations

1. Special IPCC assessment on permafrost emissions

2. National permafrost monitoring networks

3. National Adaptation Plans



Research needs

1. Model validation
2. Common framework for assessment of carbon bioavilability
3. Lateral fluxes from permafrost areas (coastal and rivers)
4. „between-reservoirs“ degradation of permafrost
5. Subsea permafrost and in situ vs. Gas hydrate methane emission
6. Role of nitrogen and phosphorus

More collaboration

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AWI

United Nations
Framework Convention on Climate Change ?

IASC

WCRP
World Climate Research Programme

Global Carbon Project

CliC
Climate and Cryosphere

IPA

THE INTERNATIONAL COUNCIL FOR SCIENCE • SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH
SCAR

GCOS
GLOBAL CLIMATE OBSERVING SYSTEM

PERMAFROST CARBON NETWORK

UNEP

GTOS

GTN-P
Global Terrestrial Network for Permafrost

Permafrost Carbon Project

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