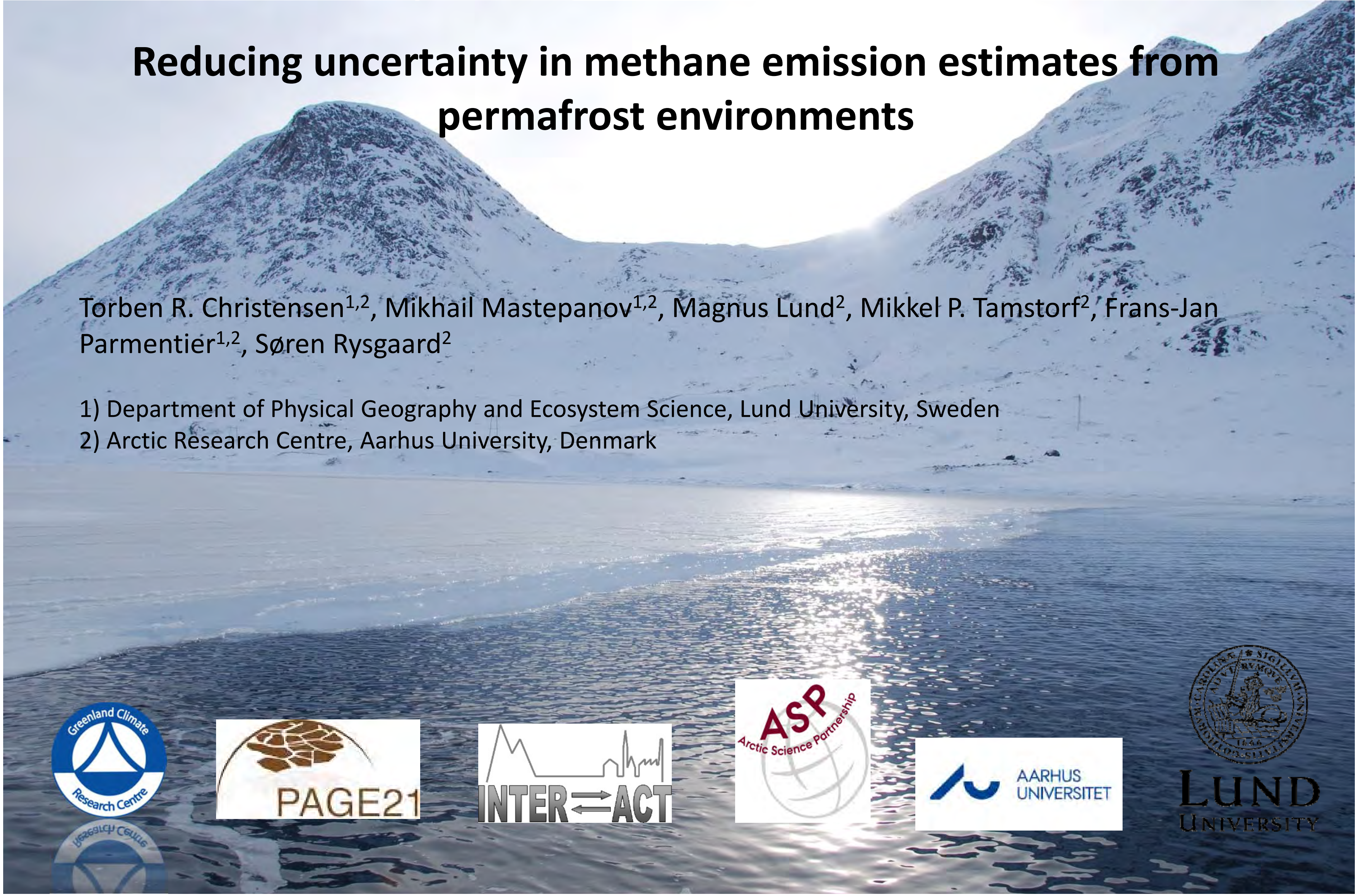


Reducing uncertainty in methane emission estimates from permafrost environments

Torben R. Christensen[1,2], Mikhail Mastepanov[1,2], Magnus Lund[2], Mikkel P. Tamstorf[2], Frans-Jan Parmentier[1,2], Søren Rysgaard[2]

1) Department of Physical Geography and Ecosystem Science, Lund University, Sweden
2) Arctic Research Centre, Aarhus University, Denmark

Outline

- Global picture
- Arctic Council initiated Arctic methane assessment under the auspices of the AMAP SLCF initiative
- Monitoring methane emission variability in space and time combined with experimental field work
- Permafrost sensitivity and impacts on ecosystem productivity

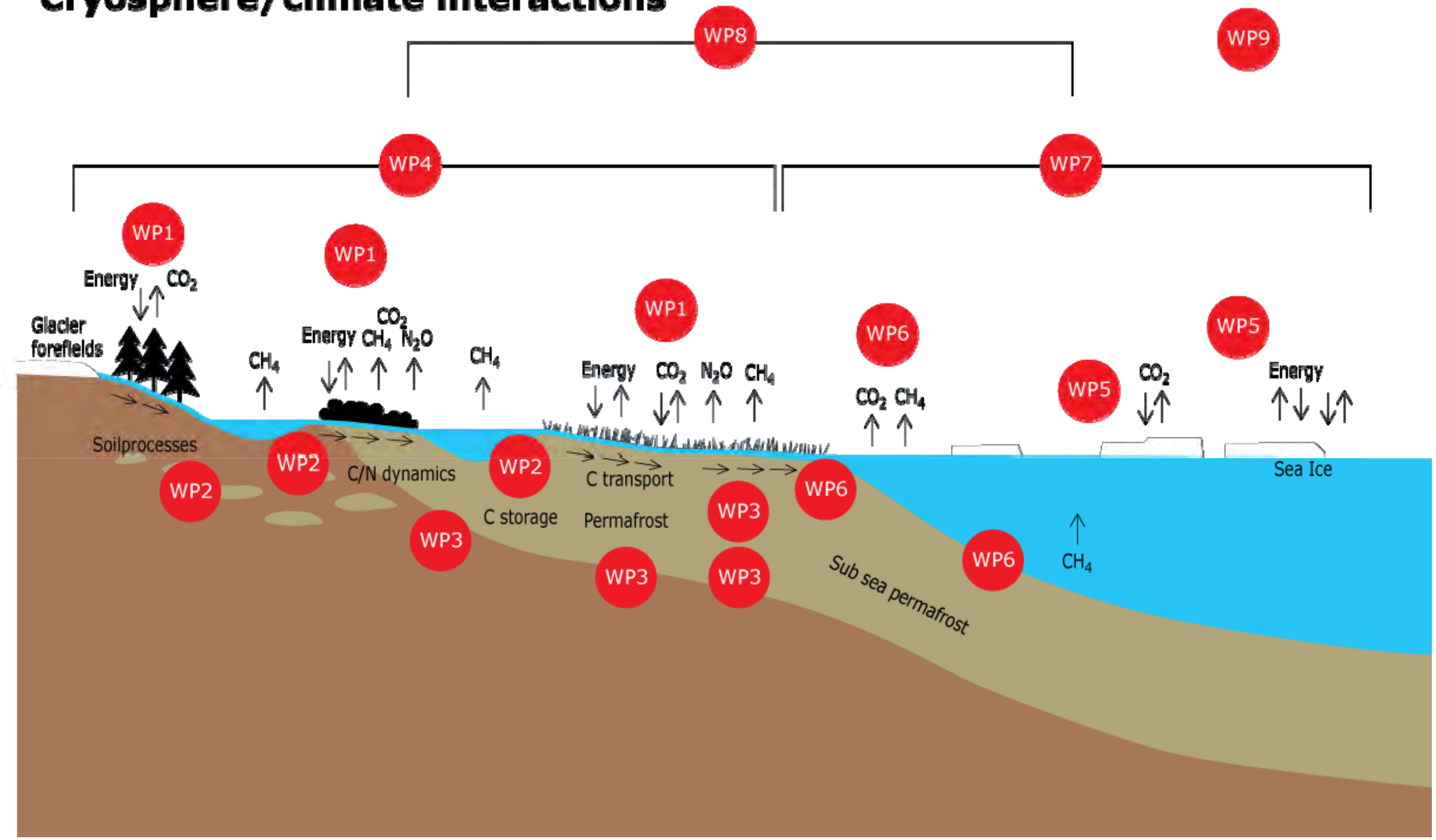
norden

Top-level Research Initiative

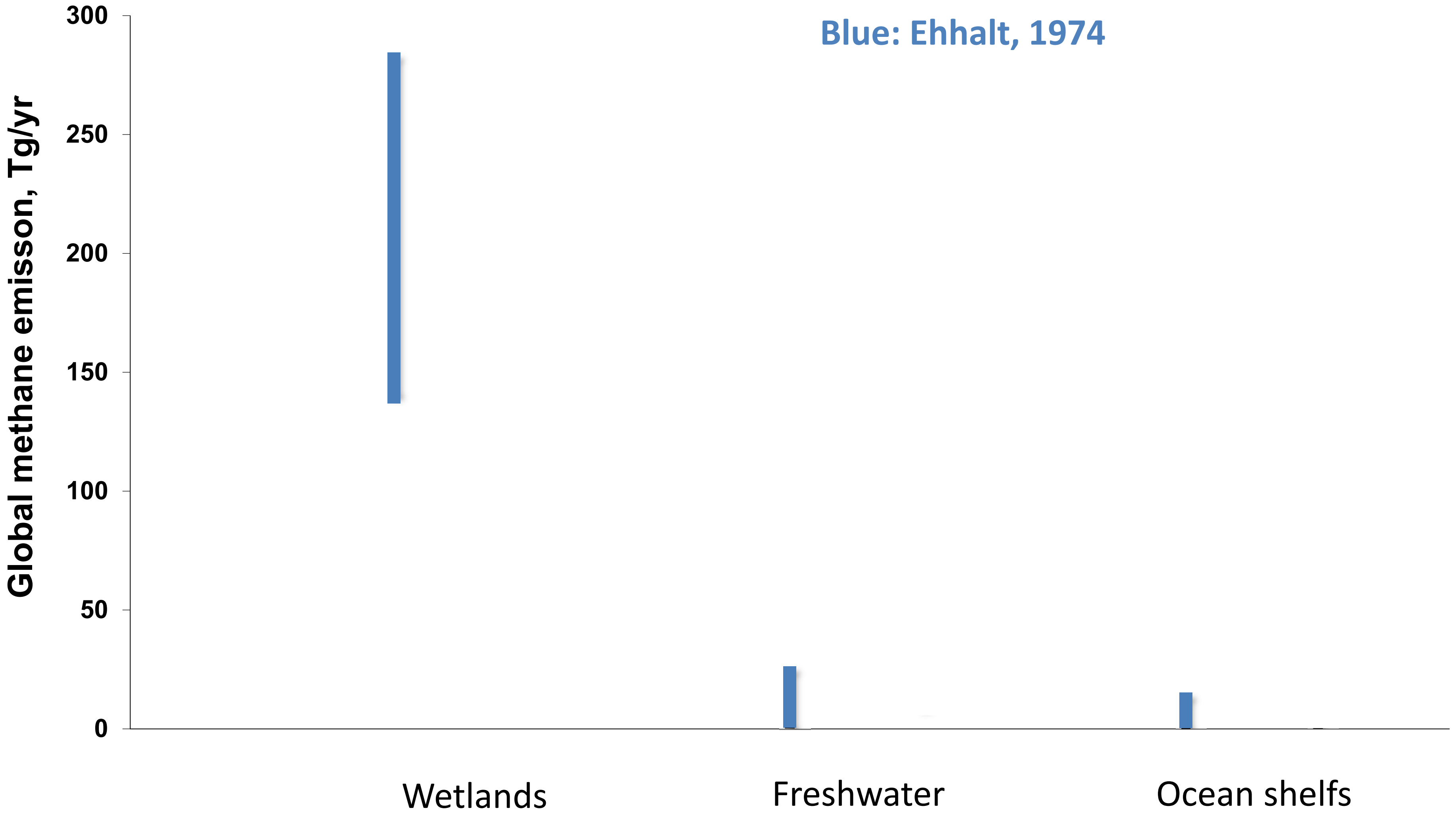
DEFROST

Impacts of a changing cryosphere-
Depicting ecosystem-climate feedbacks from permafrost, snow and ice

DEFROST
Cryosphere/climate interactions

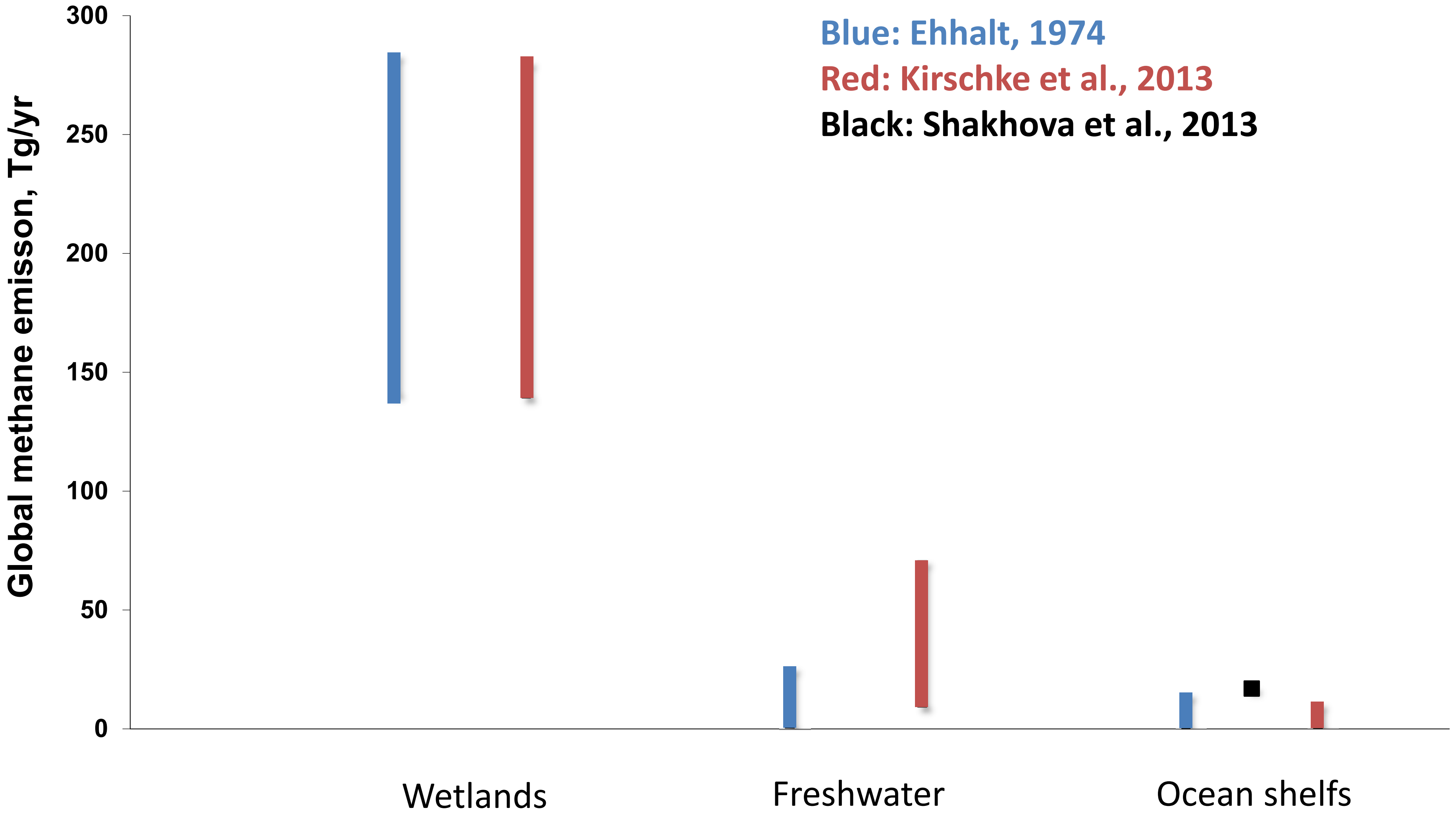


Natural methane sources with a distinct high northern latitude contribution



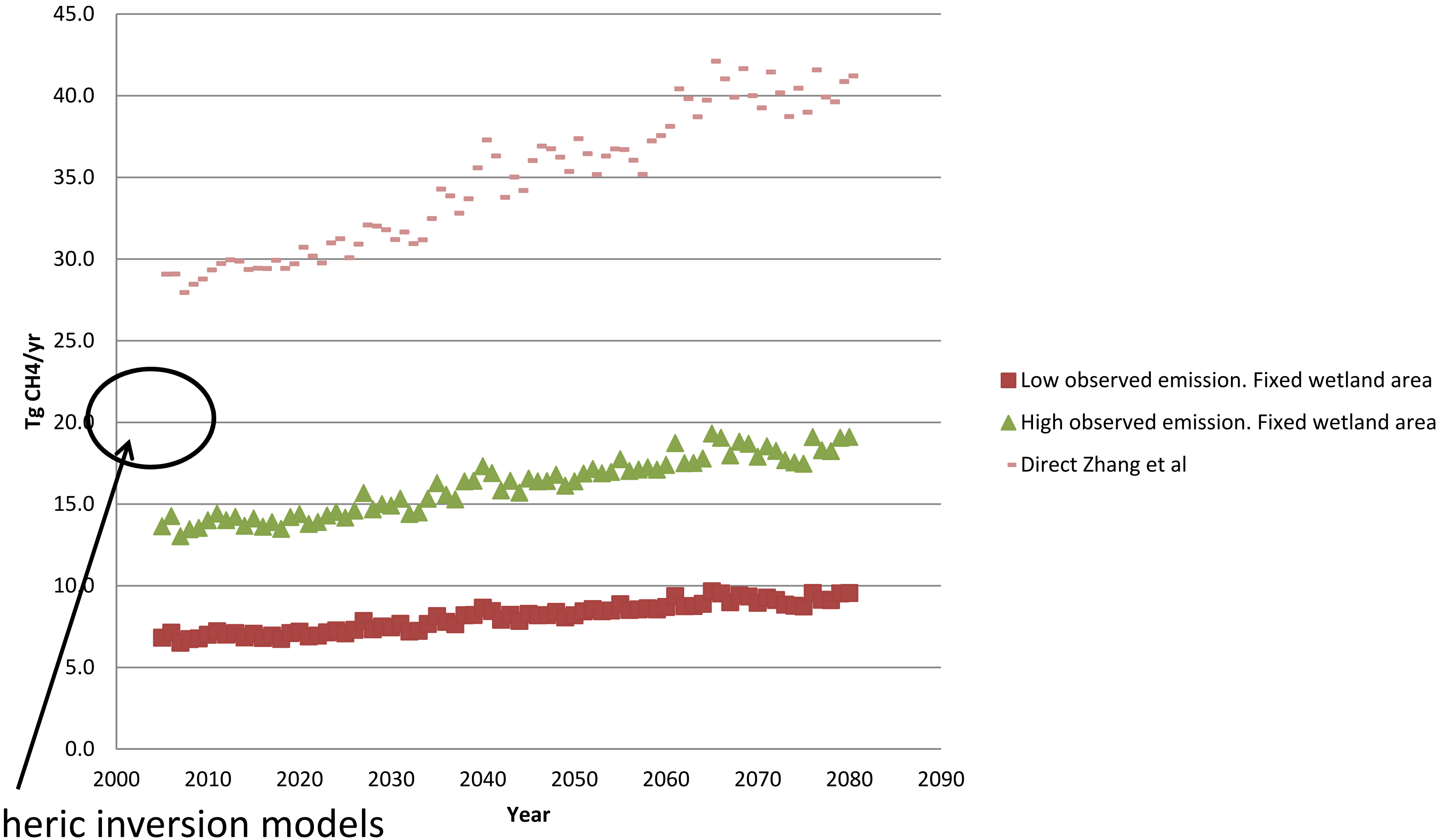
Christensen, *Nature* 2014

Natural methane sources with a distinct high northern latitude contribution



Christensen, *Nature* 2014

LPJ-GUESS WhyMe forward run, circumpolar Arctic



Atmospheric inversion models

Zhang et al., 2013 and Christensen, Huissteden, Sachs and the AMAP CH_4 expert team, in press.

For AMAP technical report

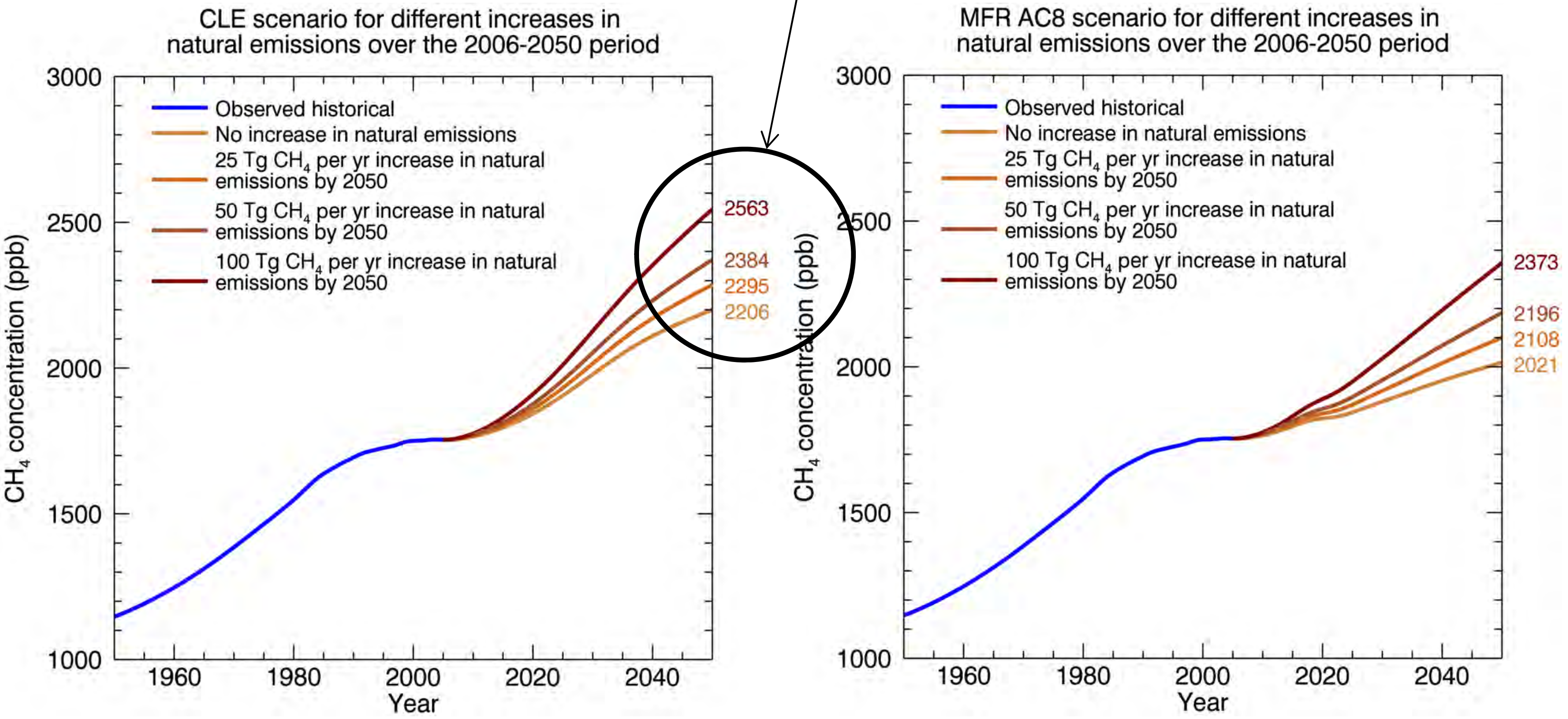
A medium (25 Tg CH_4/yr)
A large (50 Tg CH_4/yr)
An extreme (100 Tg CH_4/yr)

- scenario for natural emission change by 2050 was used.

This assessed in relation to global-mean concentrations until 2050 assuming different scenarios for anthropogenic emissions. Future concentrations are calculated by a Box model, using the CLE (left panel) or MFR-AC8 (right panel) scenarios for anthropogenic emissions, and the different (linear) increases above in natural emissions, in addition to the baseline natural emissions of 202 Tg(CH_4)/yr.

Natural emission change impact

Extra global warming < 0.1 °C



CLE scenario for different increases in natural emissions over the 2006-2050 period

MFR AC8 scenario for different increases in natural emissions over the 2006-2050 period

Gauss, Avorek, and the AMAP CH_4 expert team, in press.

nature
climate change

PUBLISHED ONLINE: 21 SEPTEMBER 2015 | DOI: 10.1038/NCLIMATE2807

Economic impacts of carbon dioxide and methane released from thawing permafrost

Chris Hope[1]* and Kevin Schaefer[2]

The Arctic is warming roughly twice as fast as the global average[1]. If greenhouse gas emissions continue to increase at current rates, this warming will lead to the widespread thawing of permafrost and the release of hundreds of billions of tonnes of CO_2 and billions of tonnes of CH_4 into the atmosphere[2]. So far there have been no estimates of the possible extra economic impacts from permafrost emissions of CO_2 and CH_4. Here we use the default PAGE09 integrated assessment model[3] to show the range of possible global economic impacts if this CO_2 and CH_4 is released into the atmosphere on top of the anthropogenic emissions from Intergovernmental Panel on Climate Change scenario A1B (ref. 4) and three other scenarios. Under the A1B scenario, CO_2 and CH_4 released from permafrost increases the mean net present value of the impacts of climate change by US$43 trillion, or about 13% (5–95% range: US$3–166 trillion), proportional to the increase in total emissions due to thawing permafrost. The extra impacts of the permafrost CO_2 and CH_4 are sufficiently high to justify urgent action to minimize the scale of the release.

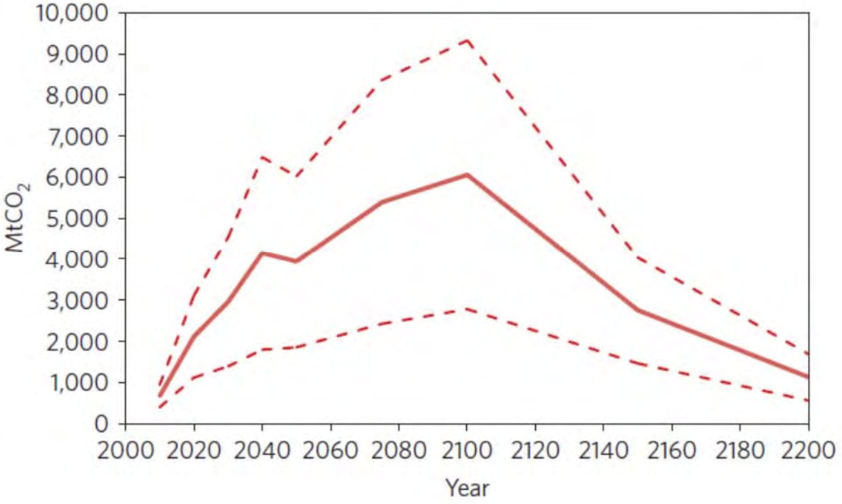


Figure 1 | Estimated annual emissions of CO_2 from thawing permafrost for the A1B scenario from the IPCC AR4. The solid line shows the mean values and the dashed lines are the 5 and 95% confidence intervals.

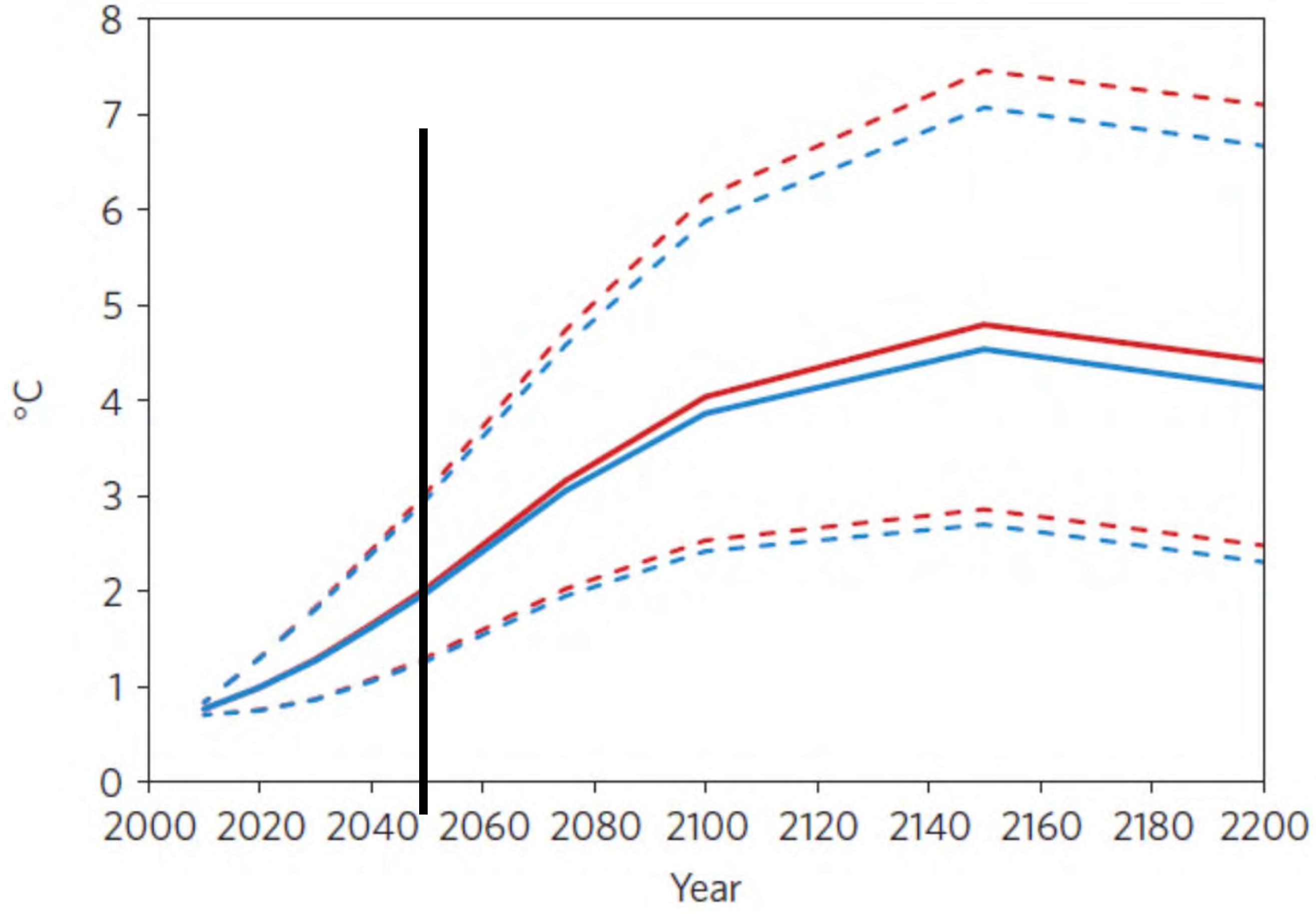


Figure 3 | Global mean temperature rise relative to pre-industrial conditions by date, with and without permafrost CO_2 and CH_4 emissions for the IPCC AR4 A1B scenario. The solid lines represent the ensemble mean of the 100,000 default PAGE09 simulations and the dashed lines represent the 5 and 95% confidence intervals. The red lines are with the permafrost emissions and blue lines without.

Hope and Schaefer, 2015

Basic message

Natural Arctic methane emission change is still marginal in importance for climate over the coming 50-100 years compared with anthropogenic emissions

We have no evidence to say we are looking towards an “apocalypse” based on natural emission changes..

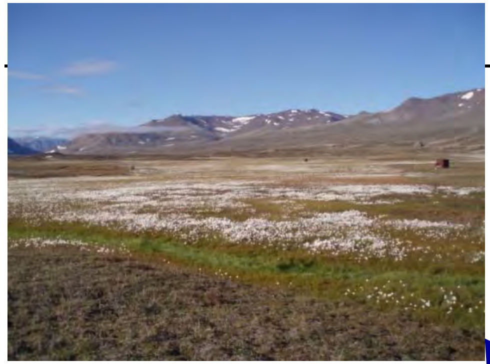
Anthropogenic emissions rule the changing climate and these emissions are far more powerful than any of the natural ecosystem processes.

But this does not mean we do not have some important unknowns and interesting basic science issues to address in the natural arctic environments

Basic science

Explain natural variability in space and time

Study sites



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

Summarising Arctic carbon fluxes

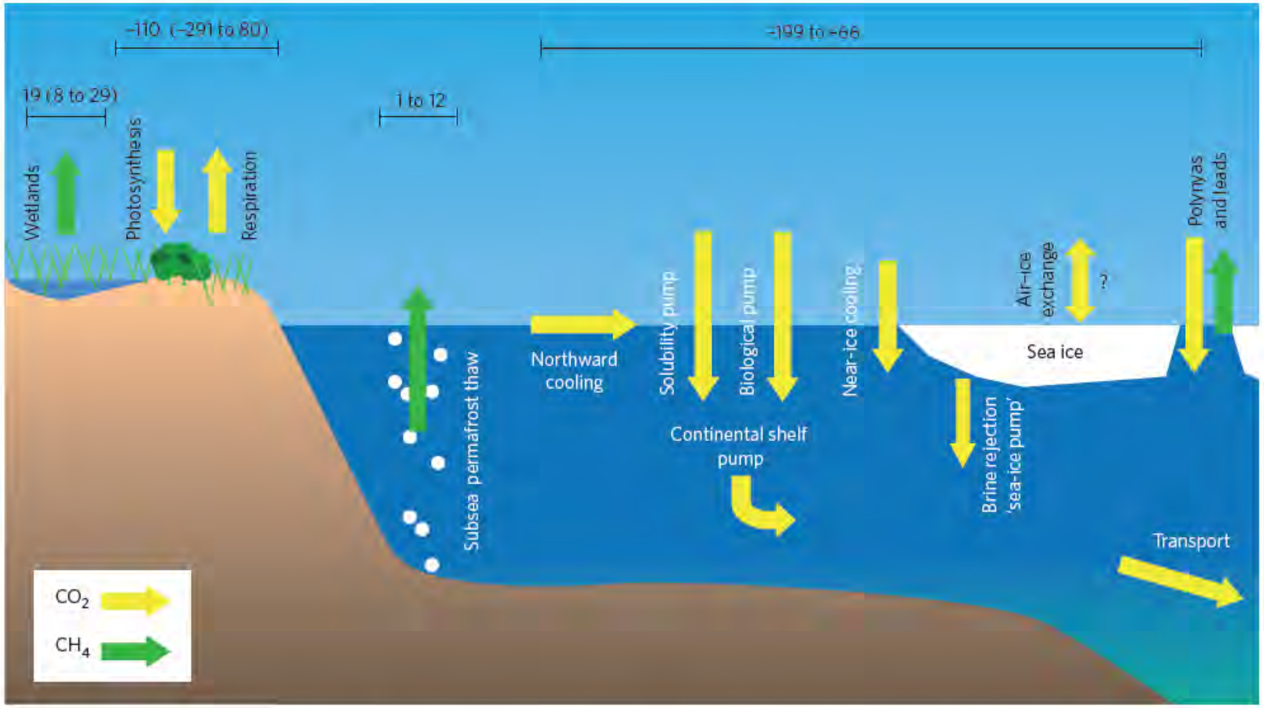
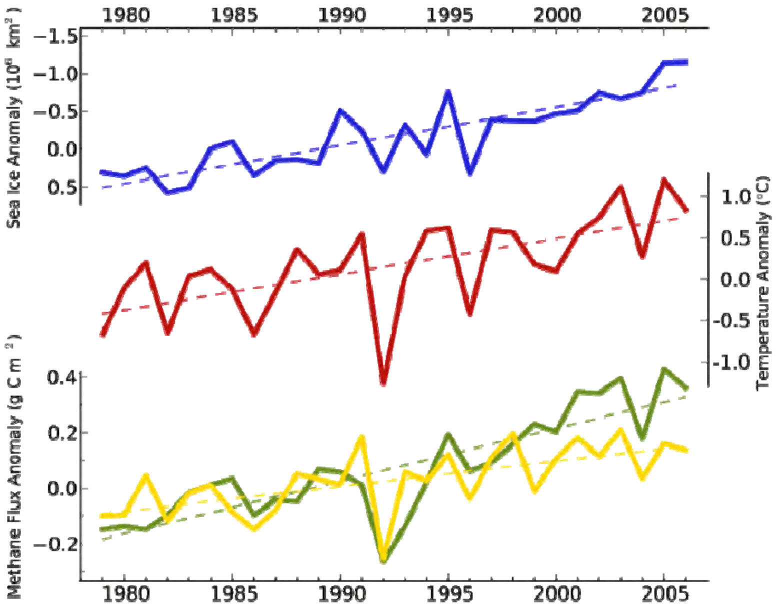
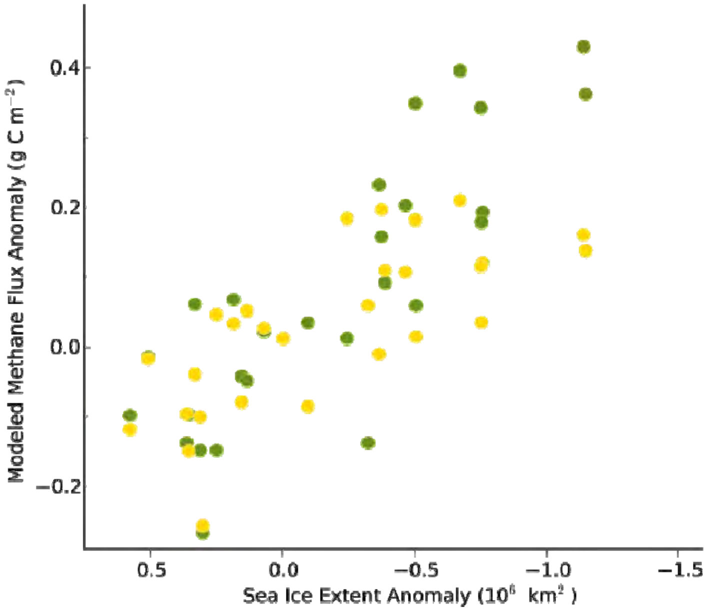


Figure 3 | Simplified representation of Arctic carbon fluxes that are possibly influenced by sea ice retreat. On land, plants take up carbon while microorganisms in the soil produce methane and respire CO_2. In the ocean, methane is released from thawing subsea permafrost, while CO_2 is absorbed due to an undersaturation of CO_2 in the water compared with the atmosphere. CO_2 is then photosynthesized into organic carbon, or converted into $CaCO_3$ by the biological and solubility pumps, maintaining low p_{CO2} levels. Near the ice edge, cooling induces sinking of the surface water, and with it CO_2. Above the ice, the air–ice exchange depends on the carbonate chemistry and temperature of the ice. CO_2 can also be discharged into brine channels in the ice, where transport is downwards due to the density difference. In polynyas and leads, CO_2 can be taken up from the atmosphere, but methane can also be produced in surface waters. Transport into the deeper and interior waters of the Arctic Ocean ensures storage of carbon. Current best estimates of sink/source strengths are given in Tg C yr^{-1}, where available[9,50,91,100]. The uncertainty ranges of the terrestrial fluxes are shown in brackets. The arrows in this figure do not represent the strength of each flux.

Parmentier et al. *Nature Climate Change* 2013

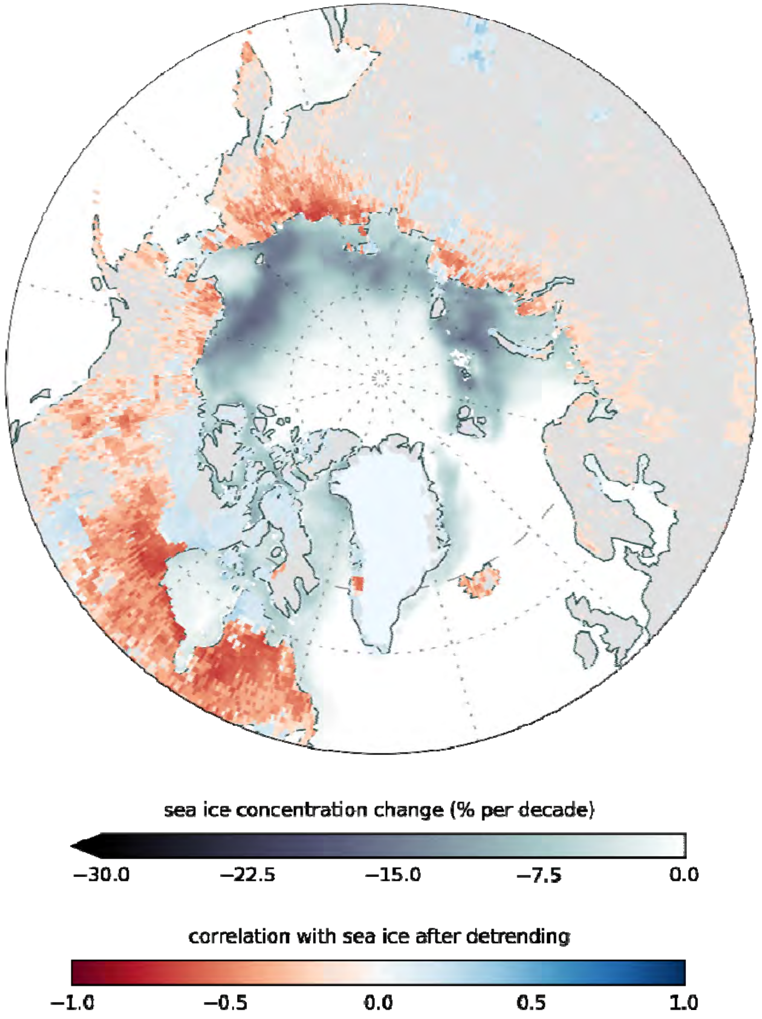
Sea Ice Connections to Methane





Parmentier et al., *Nature Climate Change*, 2013

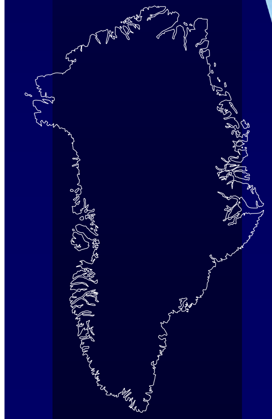
Sea ice correlation with terrestrial methane emissions

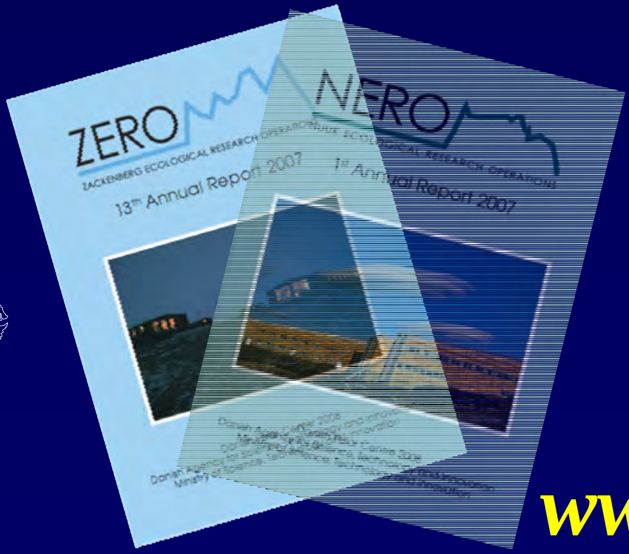


Parmentier et al., GRL, 2015

Greenland Ecosystem Monitoring

"The overall purpose is to collect long-term data quantifying seasonal and interannual variations and long-term changes in the biological and geophysical properties of the terrestrial, freshwater and marine ecosystem compartments in relation to local, regional and global climate variability and change"





www.g-e-m.dk

Monitoring and research platforms, year of start, all ongoing

Zackenberg

Terrestrial - 1996

Marine - 2002 (1994)

Sermilik

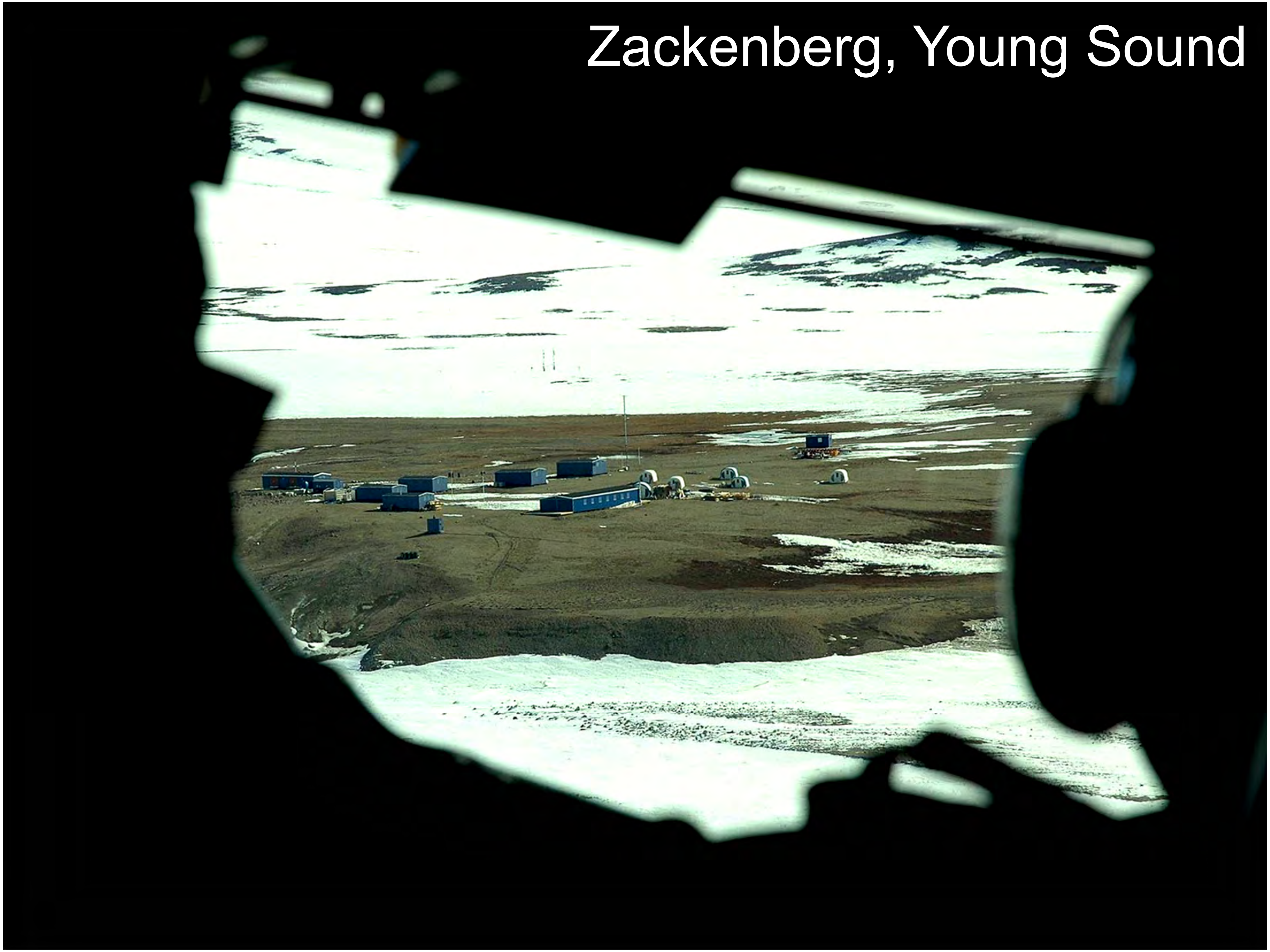
Qeqertarsuaq

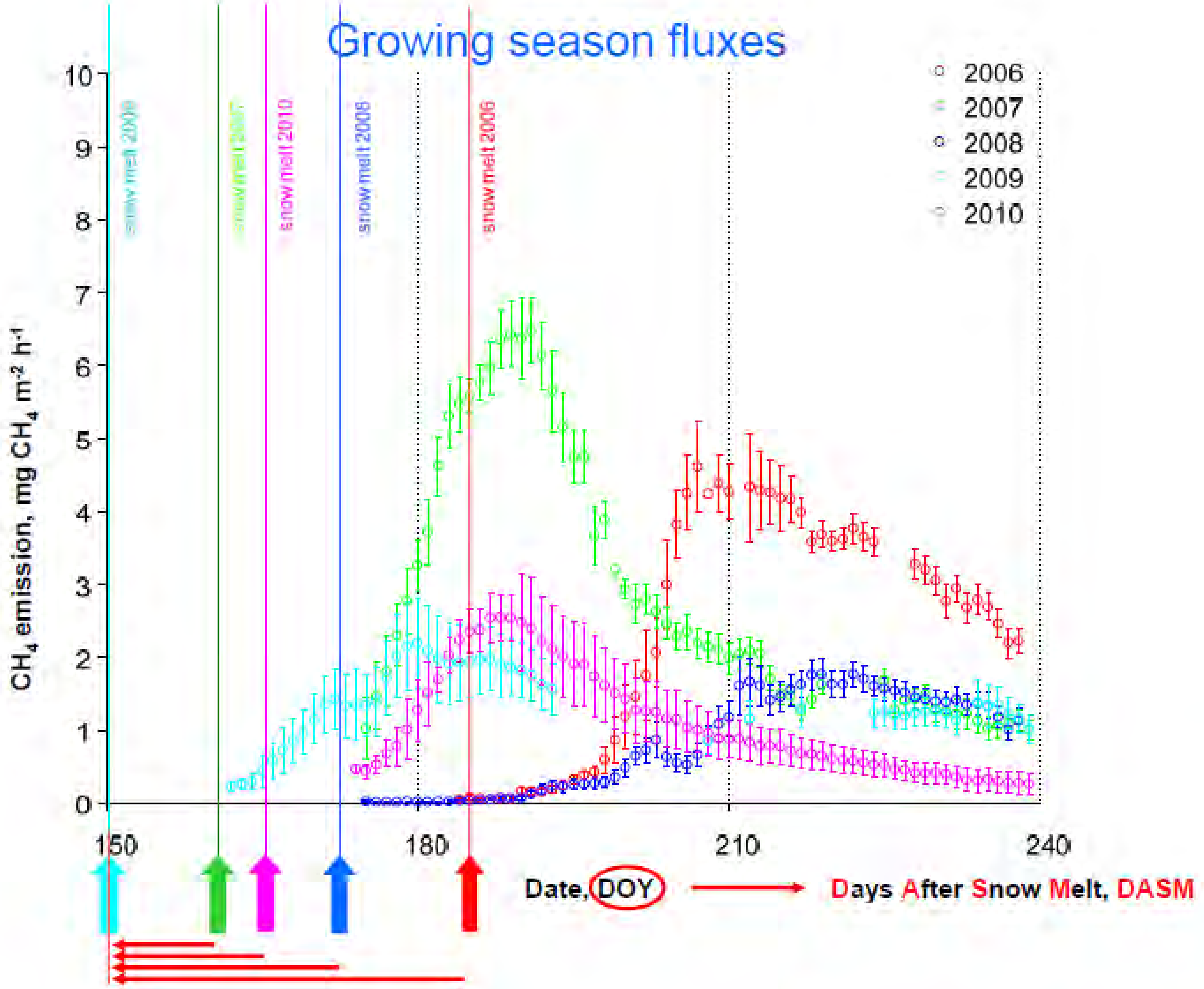
Nuuk

Terrestrial - 2007

Marine - 2005

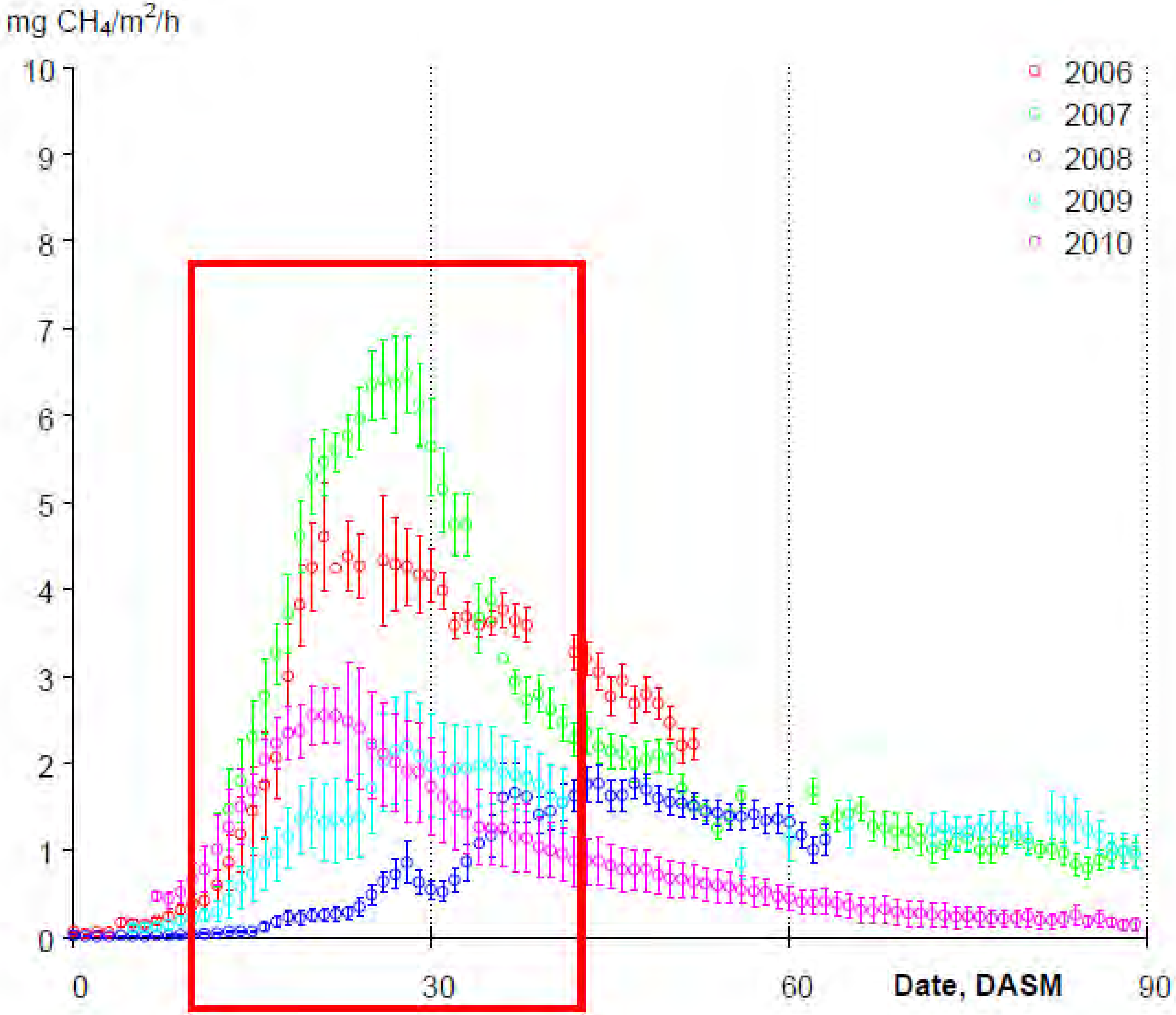
Zackenberg, Young Sound



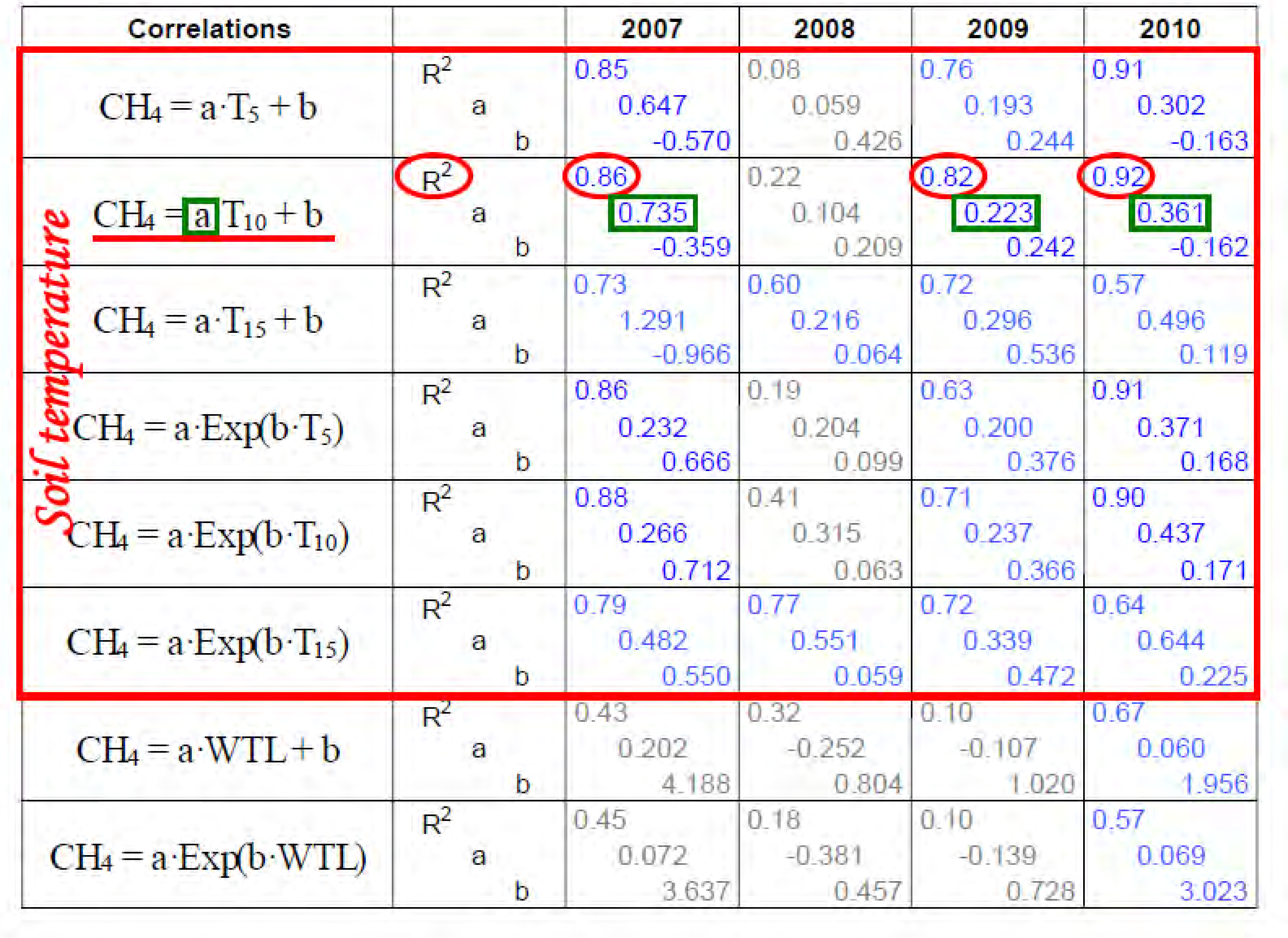


Date, DOY → Days After Snow Melt, DASM

Mastepanov, Christensen et al., 2013. *Biogeosciences*



Mastepanov, Christensen et al., 2013. *Biogeosciences*

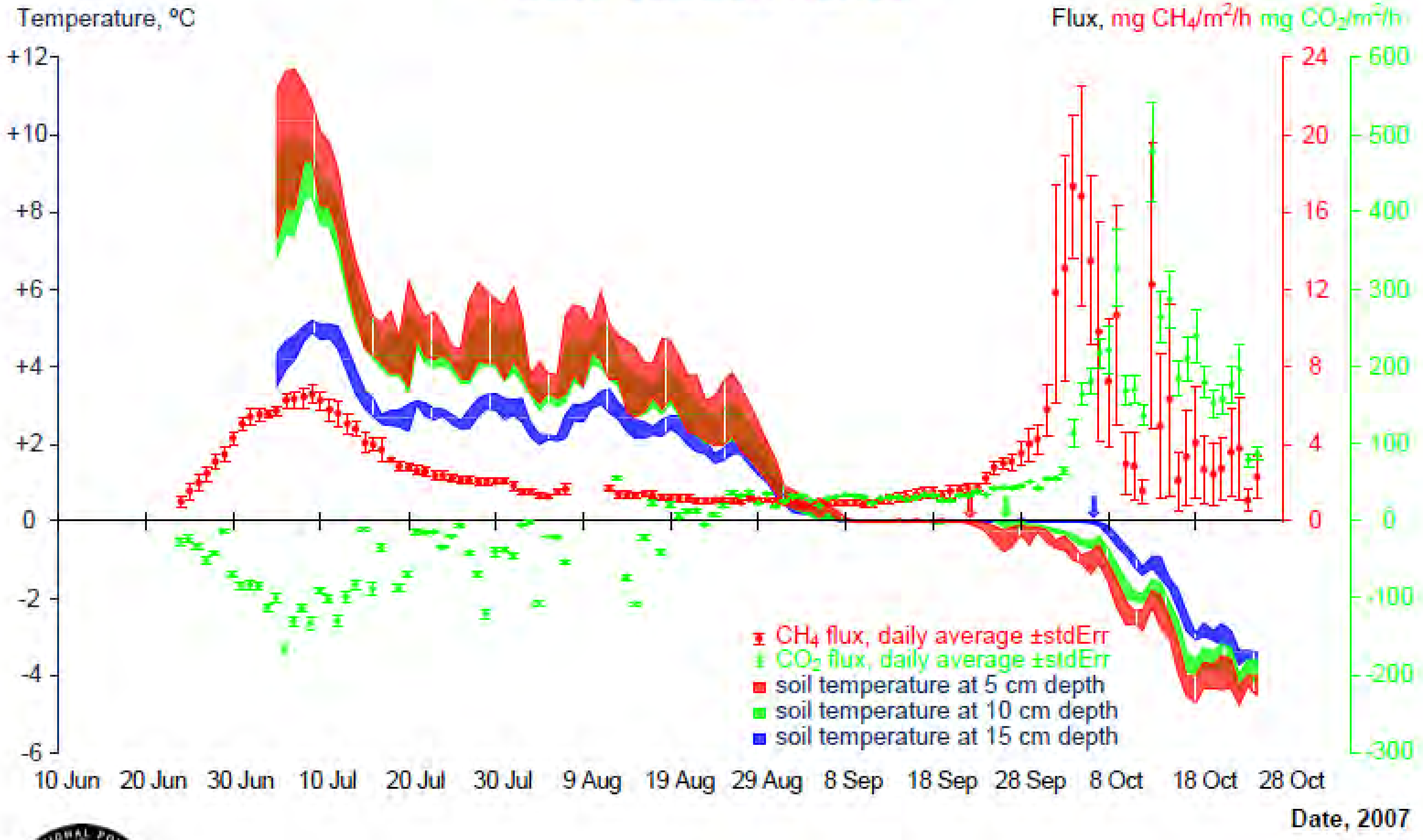


Soil temperature

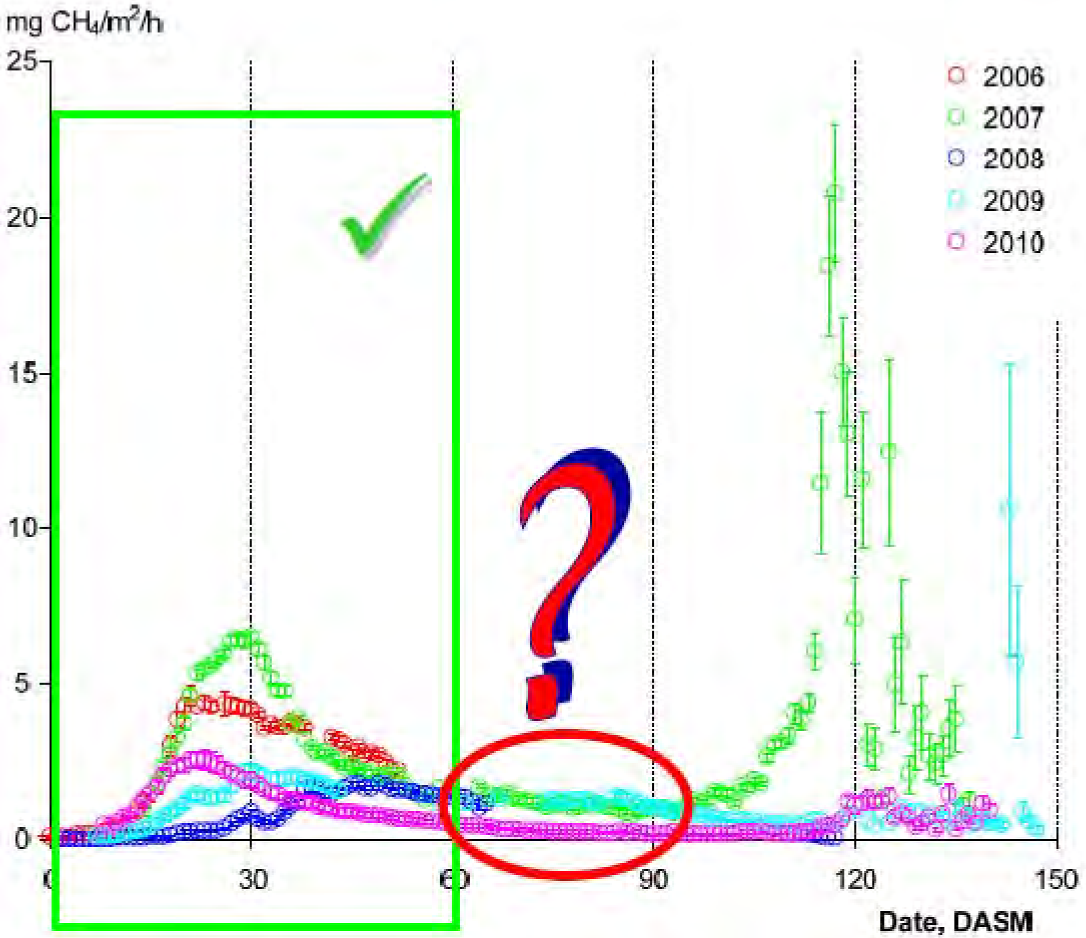
Correlations		2007	2008	2009	2010
$CH_4 = a \cdot T_5 + b$	R^2	0.85	0.08	0.76	0.91
	a	0.647	0.059	0.193	0.302
	b	-0.570	0.426	0.244	-0.163
$\underline{CH_4 = \boxed{a} T_{10} + b}$	R^2	0.86	0.22	0.82	0.92
	a	$\boxed{0.735}$	0.104	$\boxed{0.223}$	$\boxed{0.361}$
	b	-0.359	0.209	0.242	-0.162
$CH_4 = a \cdot T_{15} + b$	R^2	0.73	0.60	0.72	0.57
	a	1.291	0.216	0.296	0.496
	b	-0.966	0.064	0.536	0.119
$CH_4 = a \cdot Exp(b \cdot T_5)$	R^2	0.86	0.19	0.63	0.91
	a	0.232	0.204	0.200	0.371
	b	0.666	0.099	0.376	0.168
$CH_4 = a \cdot Exp(b \cdot T_{10})$	R^2	0.88	0.41	0.71	0.90
	a	0.266	0.315	0.237	0.437
	b	0.712	0.063	0.366	0.171
$CH_4 = a \cdot Exp(b \cdot T_{15})$	R^2	0.79	0.77	0.72	0.64
	a	0.482	0.551	0.339	0.644
	b	0.550	0.059	0.472	0.225
$CH_4 = a \cdot WTL + b$	R^2	0.43	0.32	0.10	0.67
	a	0.202	-0.252	-0.107	0.060
	b	4.188	0.804	1.020	1.956
$CH_4 = a \cdot Exp(b \cdot WTL)$	R^2	0.45	0.18	0.10	0.57
	a	0.072	-0.381	-0.139	0.069
	b	3.637	0.457	0.728	3.023

Mastepanov, Christensen et al., 2013. *Biogeosciences*

Late season fluxes

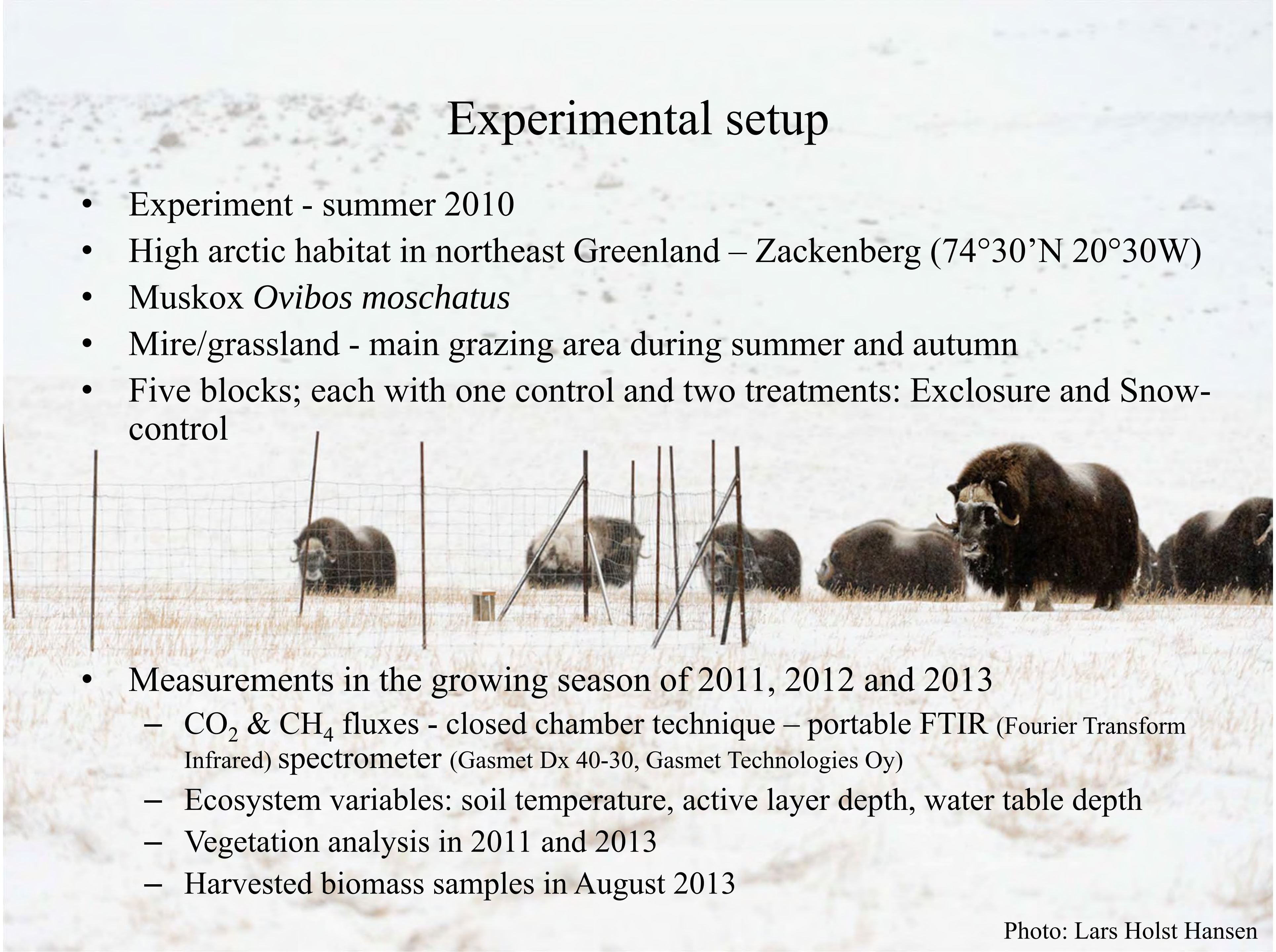


Adapted from Mastepanov et al, *Nature*, 2008



Mastepanov, Christensen et al., 2013. *Biogeosciences*

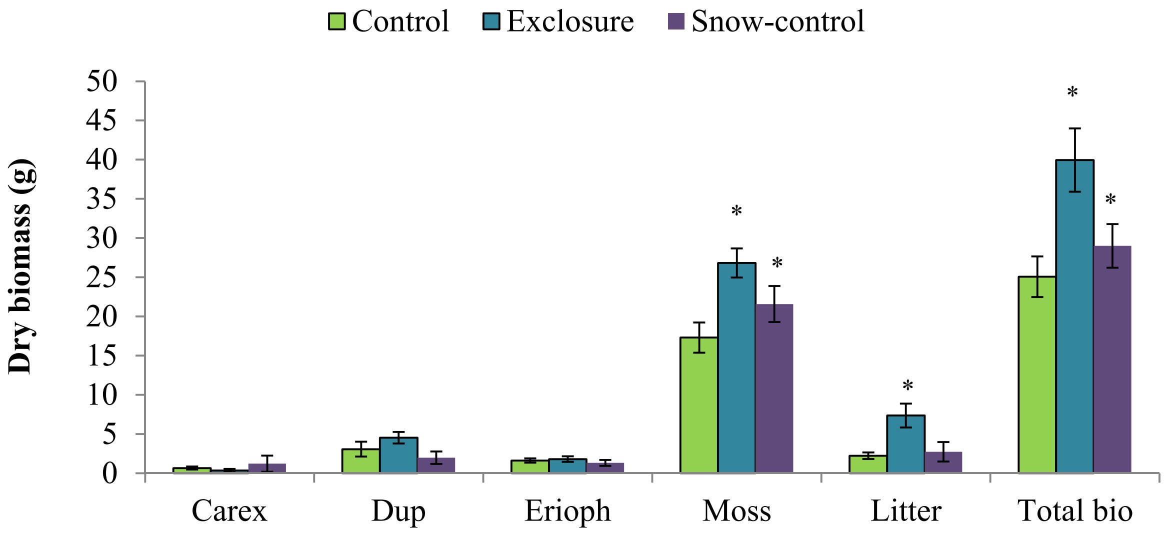
Experimental setup



- Experiment - summer 2010
- High arctic habitat in northeast Greenland – Zackenberg (74°30’N 20°30W)
- Muskox *Ovibos moschatus*
- Mire/grassland - main grazing area during summer and autumn
- Five blocks; each with one control and two treatments: Exclosure and Snow-control
- Measurements in the growing season of 2011, 2012 and 2013
  - CO_2 & CH_4 fluxes - closed chamber technique – portable FTIR (Fourier Transform Infrared) spectrometer (Gasmet Dx 40-30, Gasmet Technologies Oy)
  - Ecosystem variables: soil temperature, active layer depth, water table depth
  - Vegetation analysis in 2011 and 2013
  - Harvested biomass samples in August 2013

Photo: Lars Holst Hansen

Three years after initiation of the exclosures vegetation structure had changed



Litter 70 % ↑

Mosses 35 % ↑

Fig: g ± SE of samples harvested (20*20 cm) in 2013. Sign. differences, * $p \leq 0.05$

The height of *Dupontia fisheri ssp. Psilosantha*, *Eriophorum scheuchzeri* and mean height of all vascular leaves were significantly higher in ungrazed areas (approximately 27 %)

2. July 2013

Falk *et al.*, ERL 2015

Three years after initiation of the exclosures vegetation structure had changed

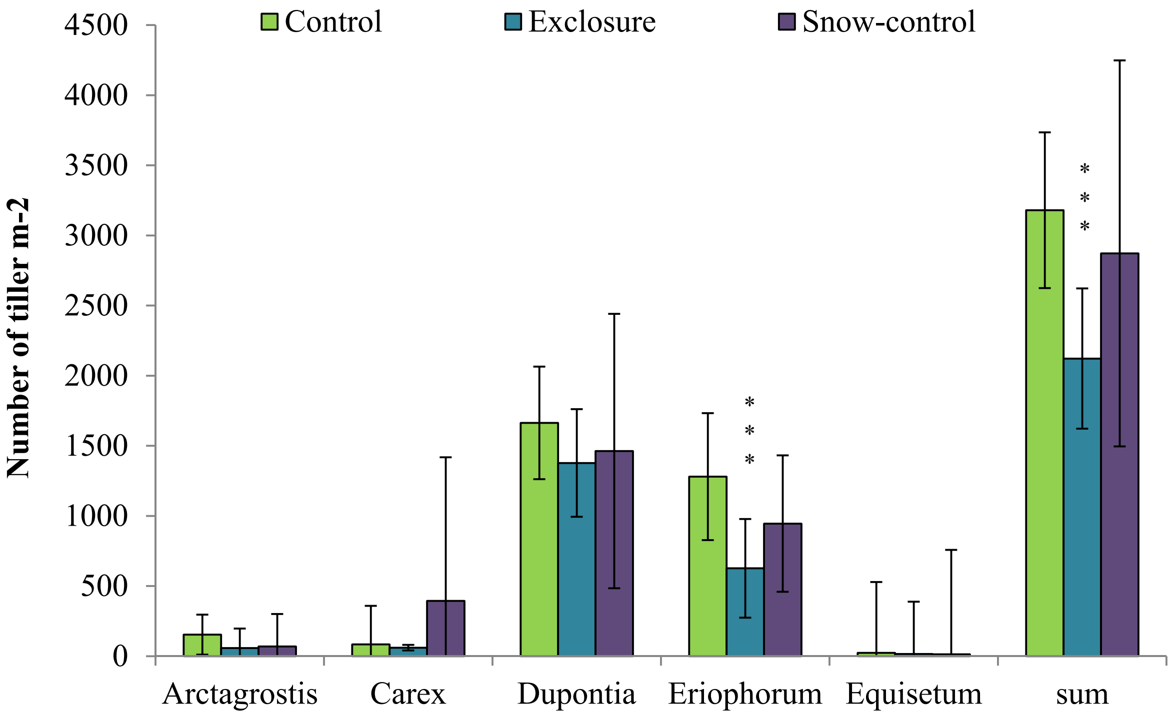


Fig: Values ± SE for all plots. Sign. differences, *** p ≤ 0.001, * p ≤ 0.05.

Vascular plants 33 % ↓

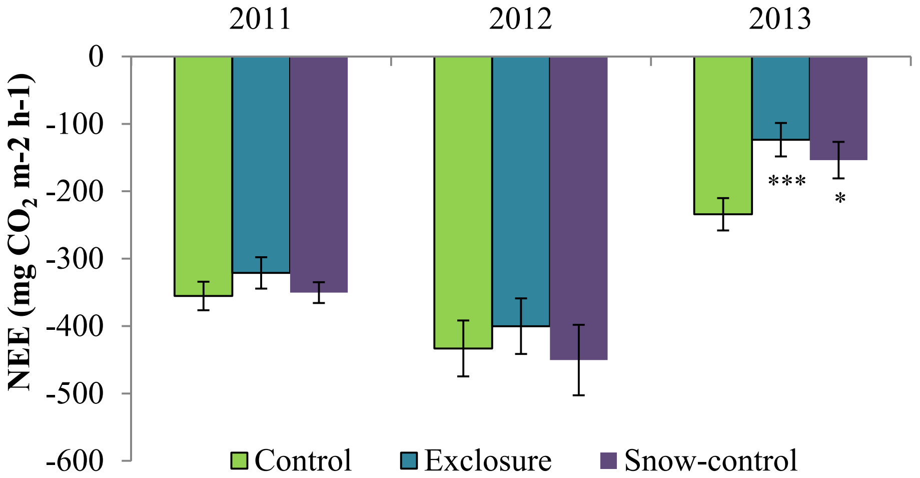
Eriophorum 51 % ↓

The vascular plants (counting for 99% of the species composition)

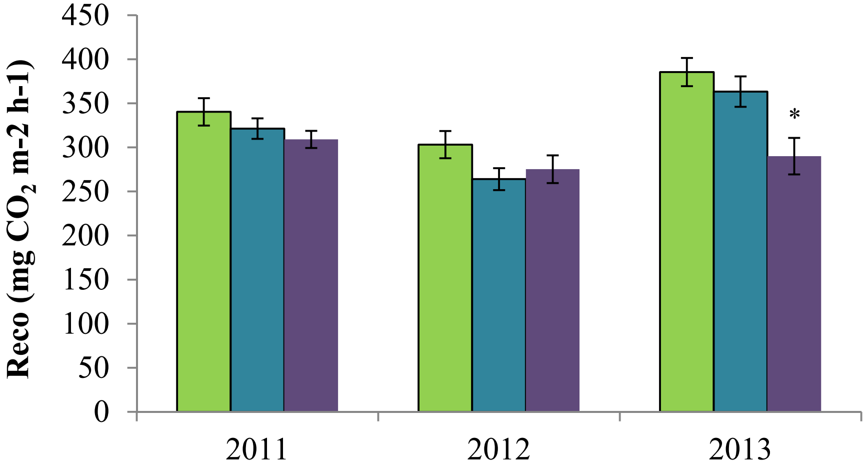
- *Arctagrostis latifolia,*
- *Carex sp*
- *Dupontia fisheri ssp. psilosantha*
- *Eriophorum scheuchzeri*
- *Equisetum sp*

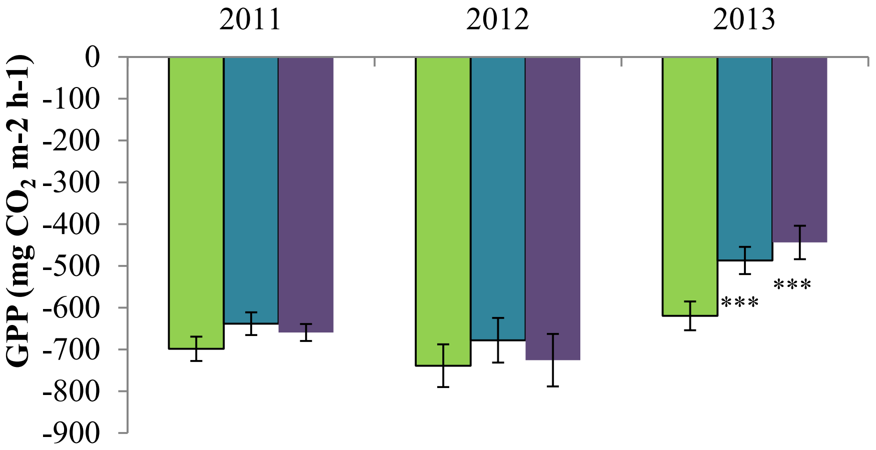
Falk *et al.,* ERL 2015

Three years after initiation of the exclosures CO_2 fluxes had changed



NEE 47 % ↓

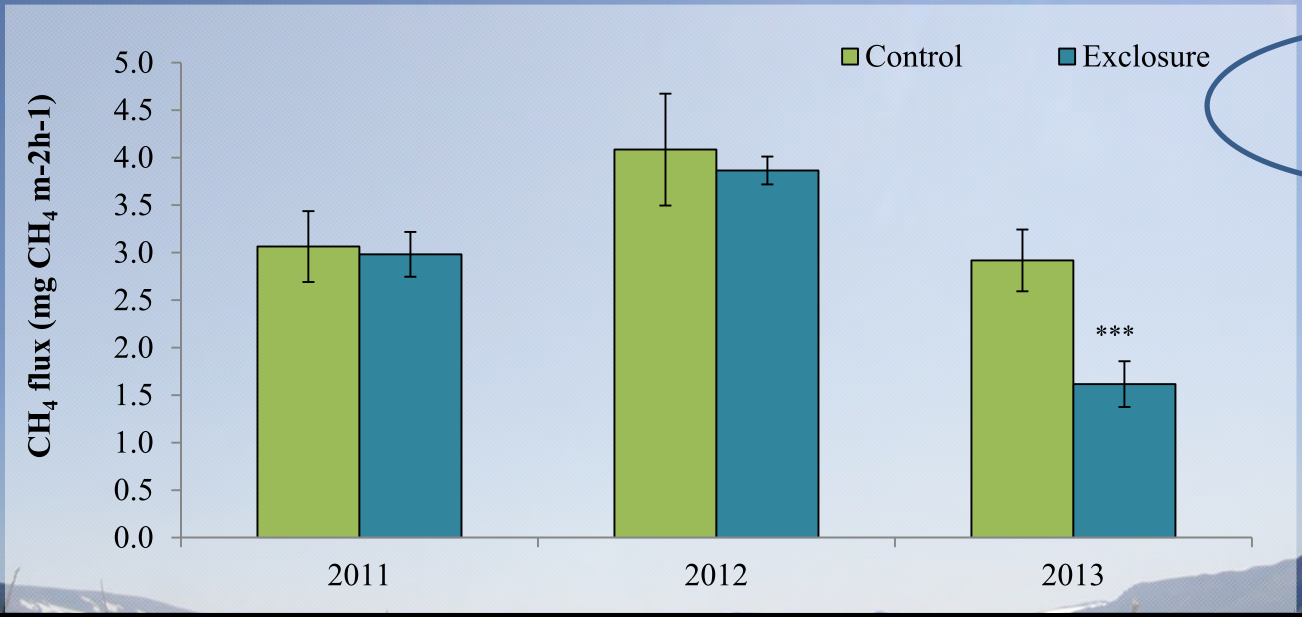




Figs: mean flux ± SE in all blocks, *** $p \leq 0.001$, * $p \leq 0.05$

Falk *et al.*, ERL 2015

Three years after initiation of the exclosures CH_4 fluxes had changed



CH_4 44 %↓

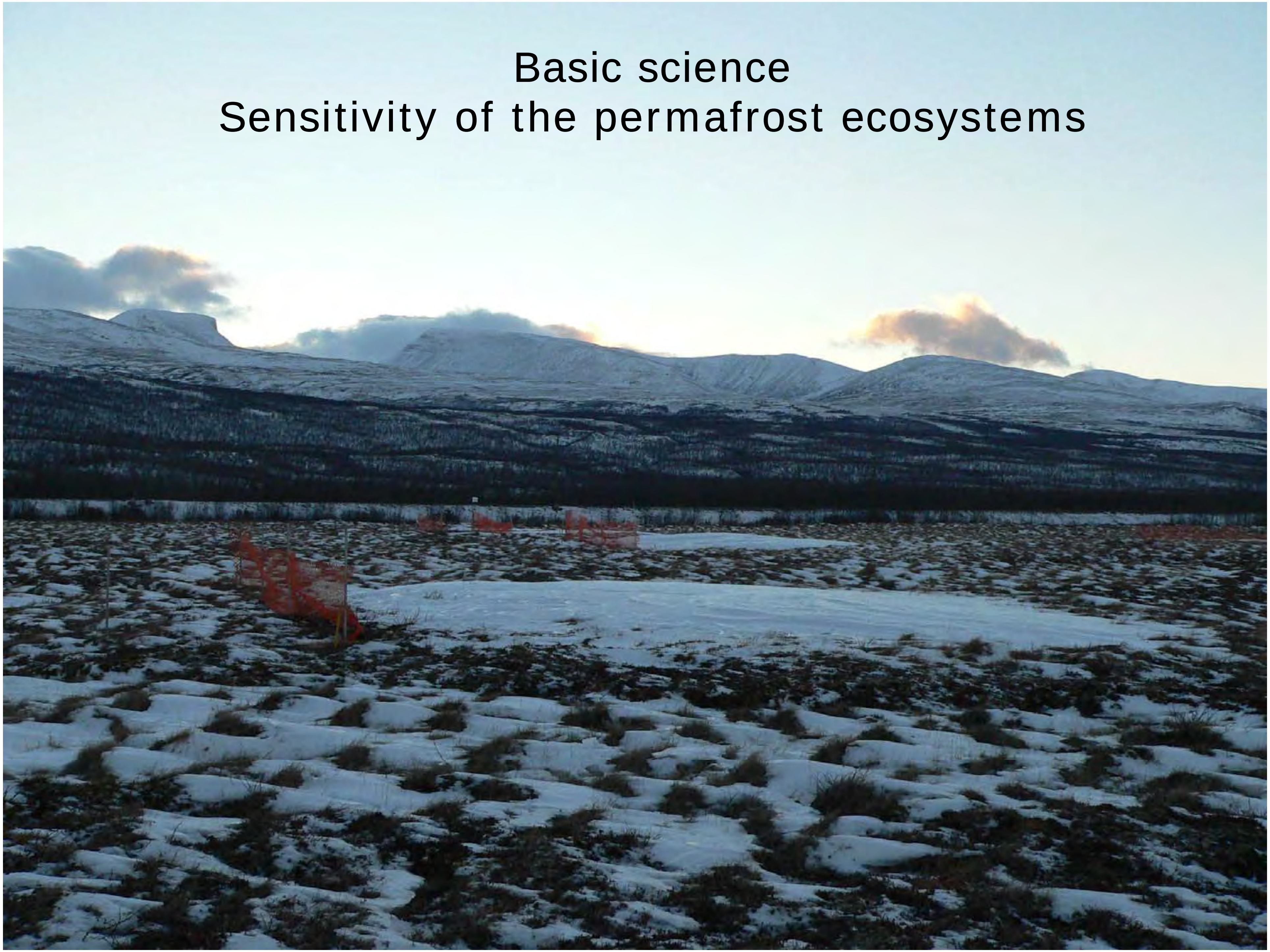
Fig: Mean CH_4 flux ± SE in wet blocks *** p ≤ 0.001

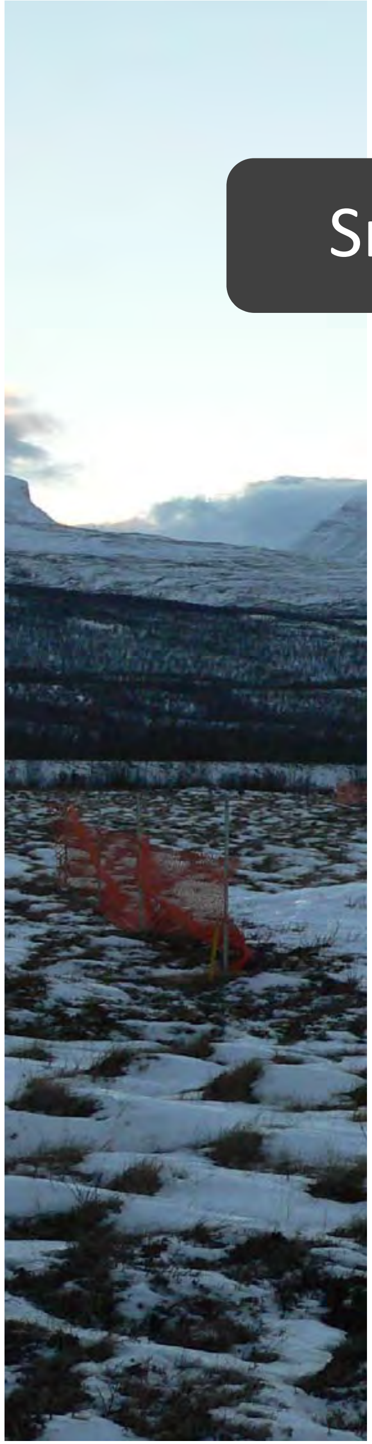
Year		Arctagrostis		Dupontia		Eriophorum		Equisetum		Sum	
		C	EX	C	EX	C	EX	C	EX	C	EX
2011	**Mean**	340 ± 220	96 ± 76	3450 ± 148	3546 ± 162	3123 ± 526	2175 ± 386	166 ± 91	266 ± 192	6913 ± 664	5818 ± 379
	Max	1588	550	4131	4038	5219	3544	594	1419	8869	7456
	Min	0	0	2994	2763	1375	900	0	19	4756	4775
	p		0.316		0.666		0.172		0.648		0.184
2013	**Mean**	185 ± 122	13 ± 10	1993 ± 159	1746 ± 83	1371 ± 196	**623 ± 47**	38 ± 34	2 ± 2	3548 ± 220	**2381 ± 109**
	Max	881	69	2813	2019	2306	825	244	13	4163	2844
	Min	0	0	1450	1375	756	444	0	0	2763	2044
	p		0.208		0.194		0.008		0.33		0.001

Table: No of vascular plants tillers per m^{-2} ±SE, Sign. differences bold.

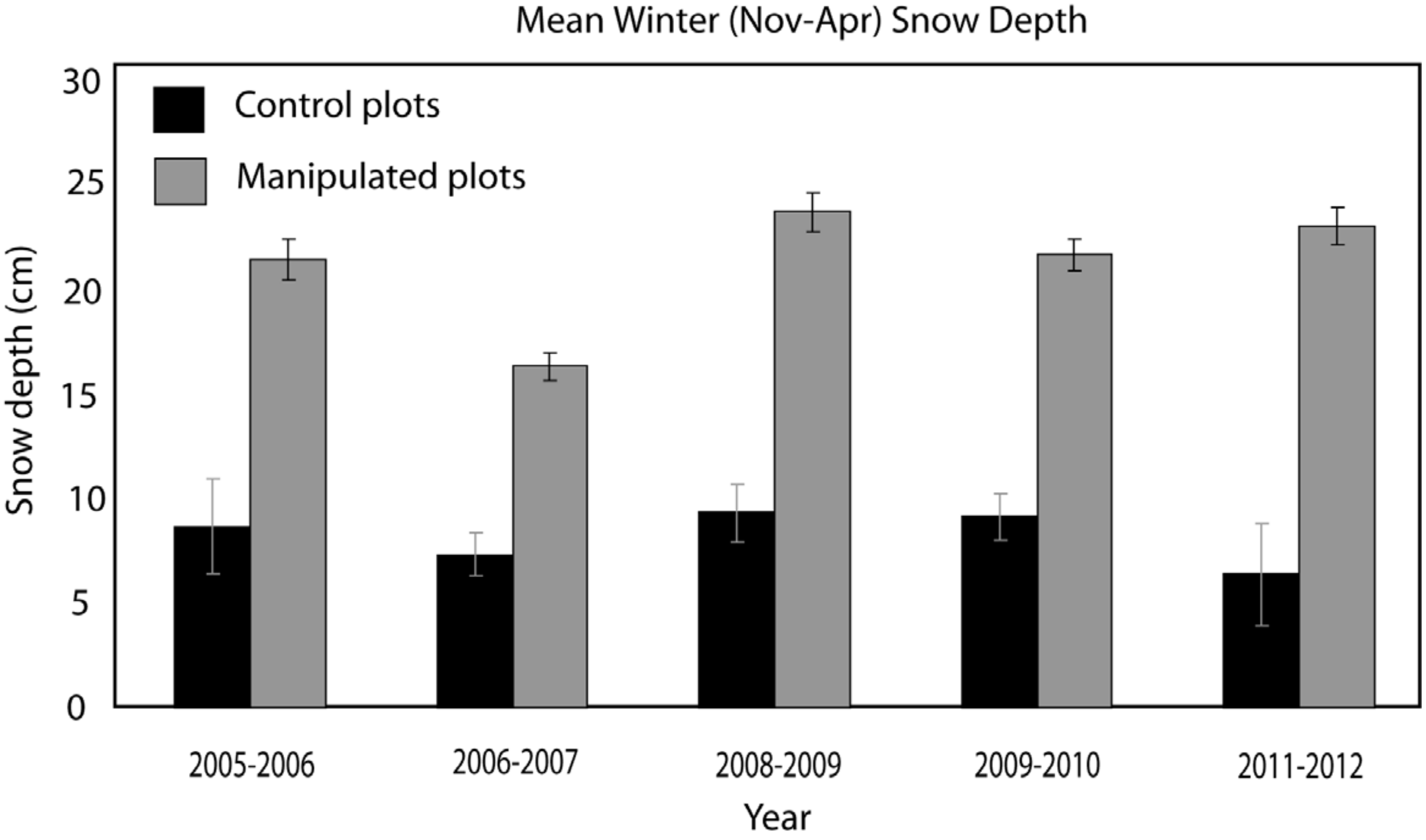
Falk *et al.*, ERL 2015

Basic science
Sensitivity of the permafrost ecosystems



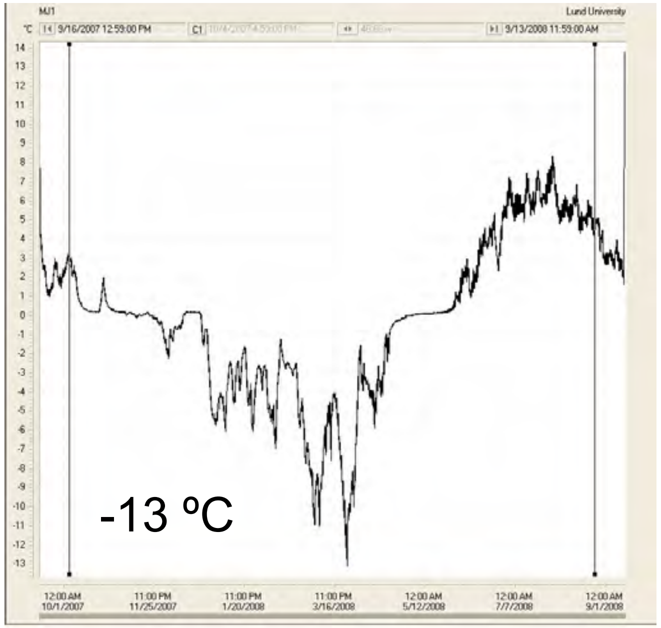


Snow depth



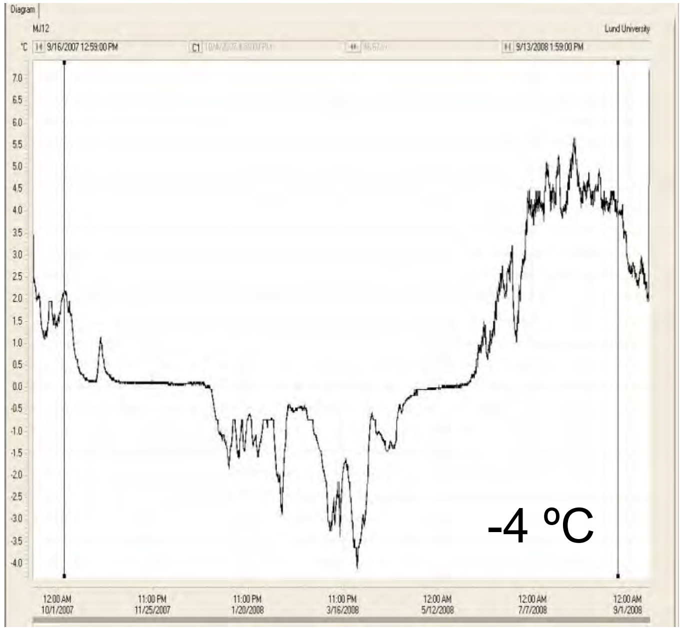
Johansson et al. 2013

Mininum temperature varies greatly



-13 ºC

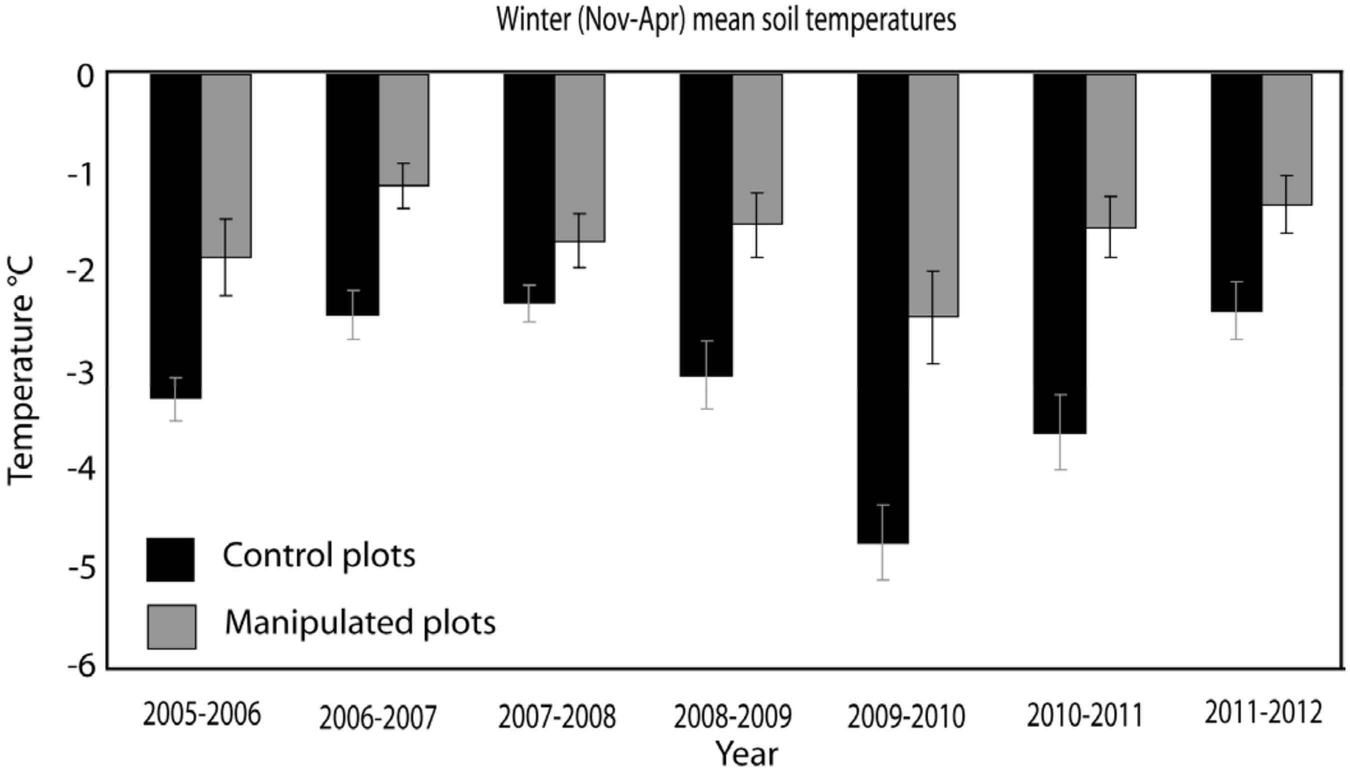
Control



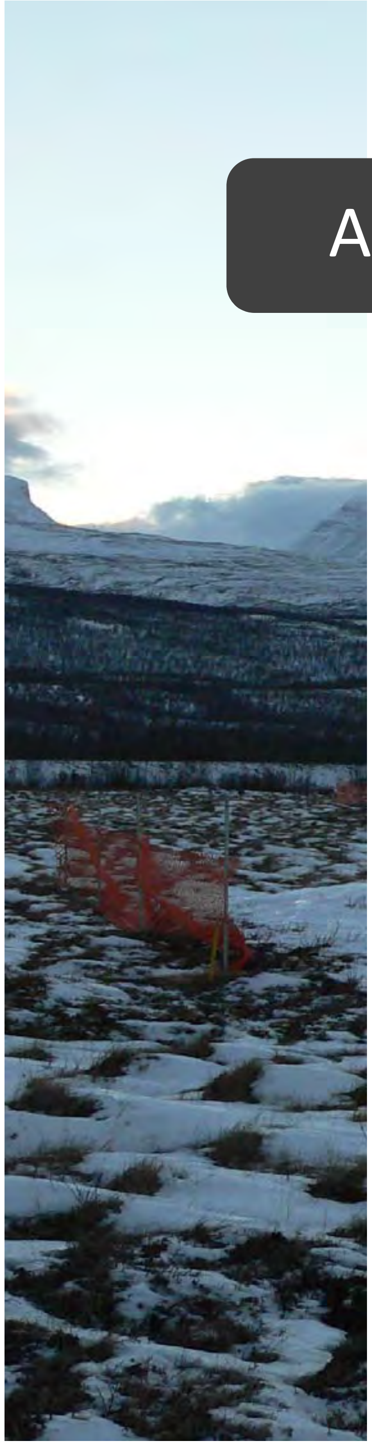
-4 ºC

Snow fences

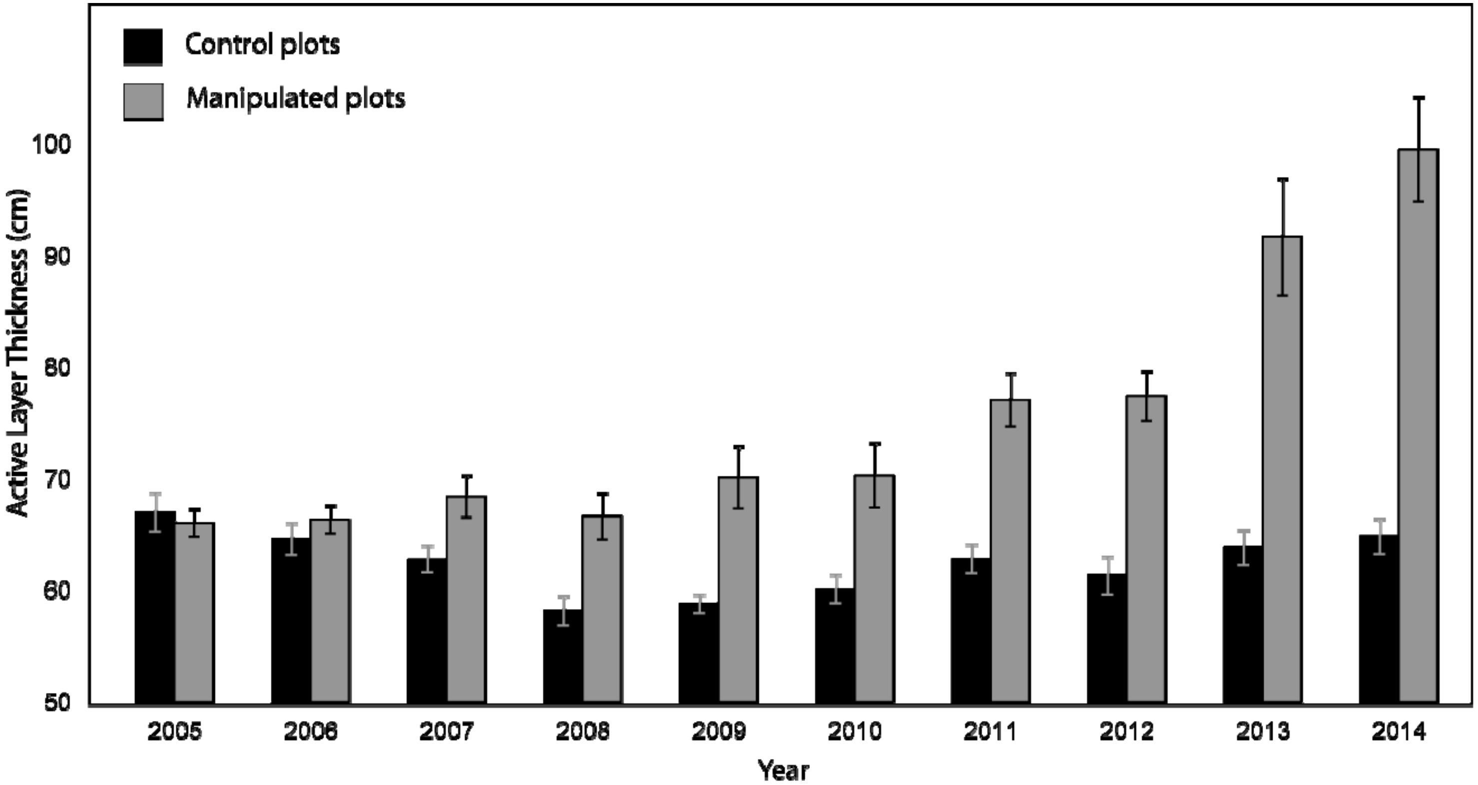
Winter (Nov-Apr) temperatures at 15 cm



Johansson et al. 2013



Active layer thickness



Updated from Johansson et al. 2013

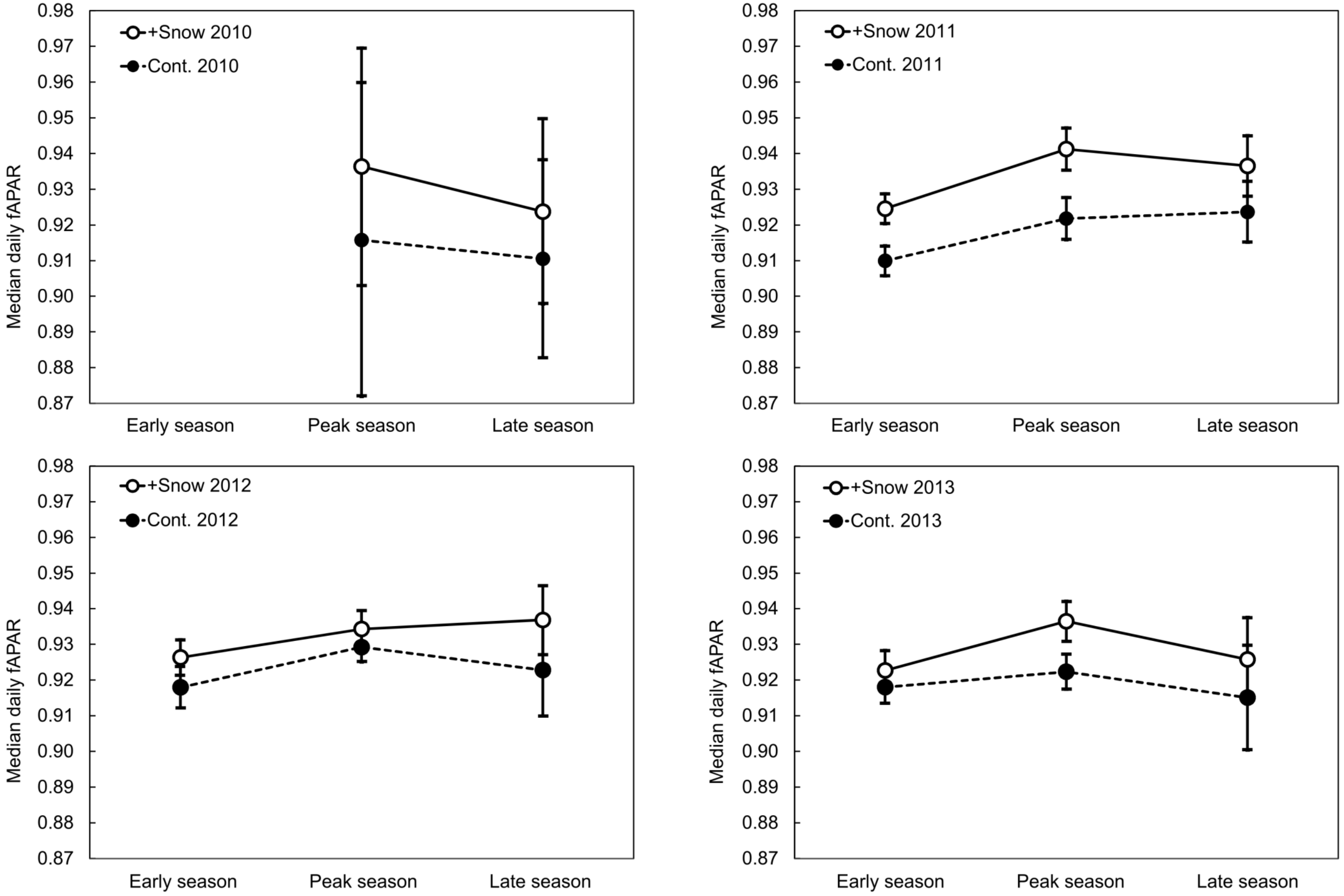


Fig. 2:
Median daily fAPAR for early, peak and late season from 2010 to 2013. Filled circles indicate median values for control plots, empty circles indicate treatment plots. Bars show the median absolute deviation (MAD)

Bosiö et al. 2014

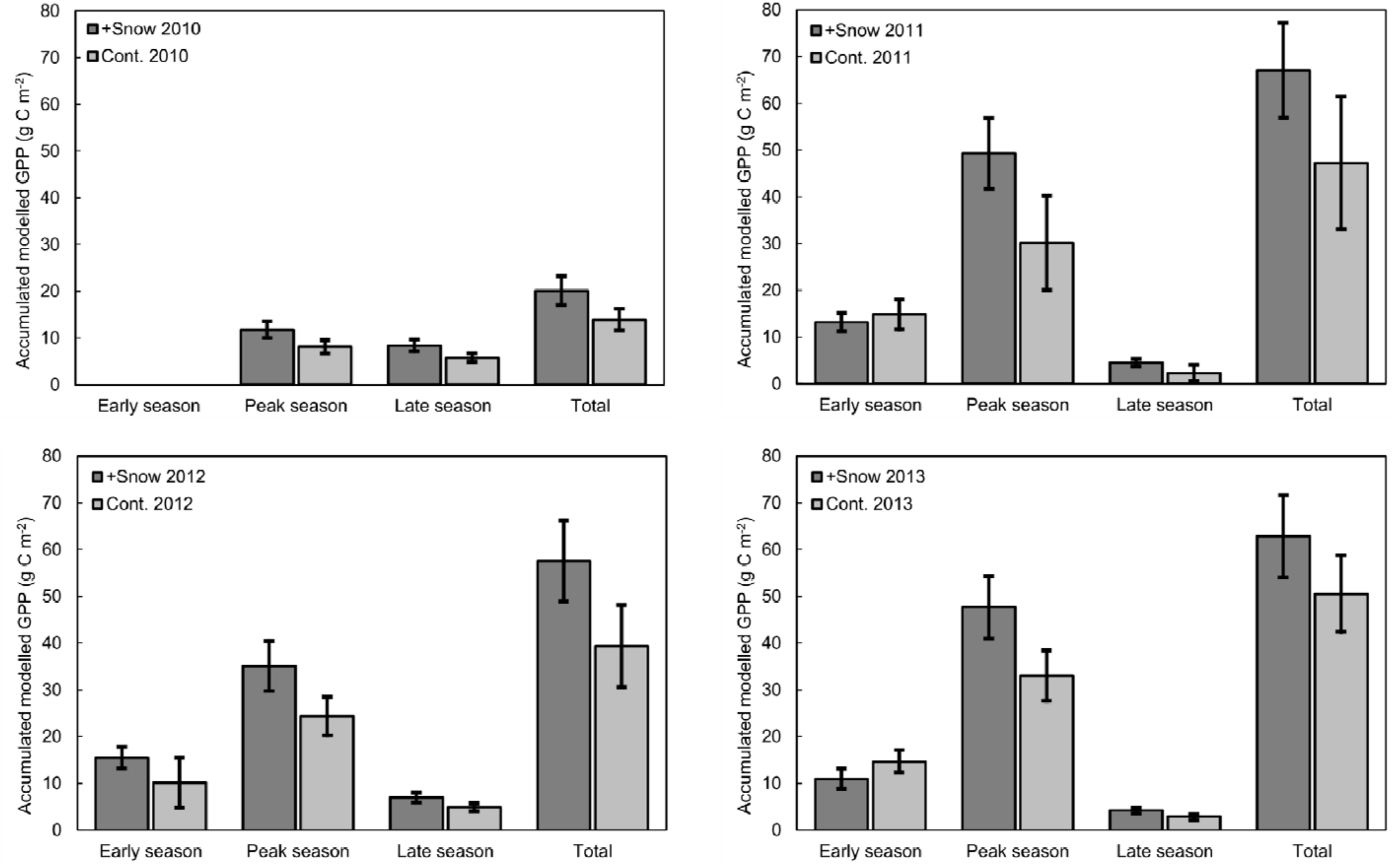
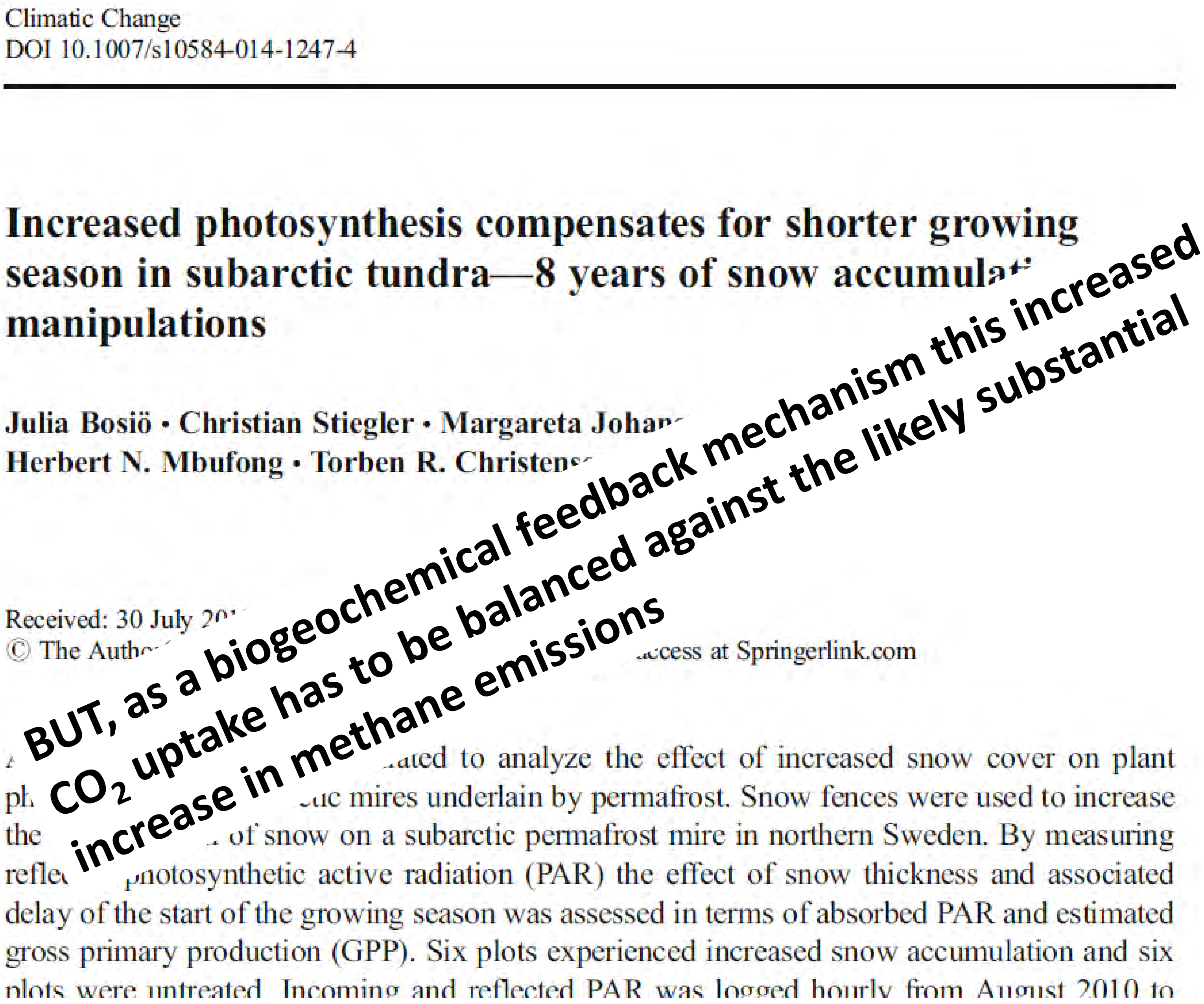


Fig. 3:
Modeled GPP_{accum} for control (Cont.) and treatment (+Snow) plots for early, peak and late season from 2010 to 2013. Bars show the standard deviation

Bosiö et al. 2014



Climatic Change
DOI 10.1007/s10584-014-1247-4

Increased photosynthesis compensates for shorter growing season in subarctic tundra—8 years of snow accumulat manipulations

Julia Bosiö • Christian Stiegler • Margareta Johan
Herbert N. Mbufong • Torben R. Christens

Received: 30 July 20

ated to analyze the effect of increased snow cover on plant
ph tic mires underlain by permafrost. Snow fences were used to increase
the of snow on a subarctic permafrost mire in northern Sweden. By measuring
refle photosynthetic active radiation (PAR) the effect of snow thickness and associated delay of the start of the growing season was assessed in terms of absorbed PAR and estimated gross primary production (GPP). Six plots experienced increased snow accumulation and six plots were untreated. Incoming and reflected PAR was logged hourly from August 2010 to

BUT, as a biogeochemical feedback mechanism this increased CO_2 uptake has to be balanced against the likely substantial increase in methane emissions

Conclusions

- Natural methane emissions and their dynamics both in the terrestrial and near-coastal Arctic domain remain poorly understood. But the climate impact of a wide range of possible changes in the emissions have been quantified and shown as of marginal importance compared with anthropogenic carbon dioxide emissions.

- The carbon cycling in terrestrial ecosystems will according to most models develop to be a stronger (but still minor) sink for atmospheric CO_2 over the coming decades. This disregards the possible extra releases from thawing organic material.

- The balance of evidence shows that in the global picture the Arctic will carry a small amplifying warming effect caused by increasing methane emissions, but also an opposite increasing carbon dioxide sink strength and most importantly a significant change in radiative energy exchange related with changes relating to changes in sea ice, snow and vegetation cover.

norden
Top-level Research Initiative

eSTICC

norden
NordForsk

DEFROST
Impacts of a changing cryosphere-
Depicting ecosystem-climate feedbacks from permafrost, snow and ice

Thank you for your attention