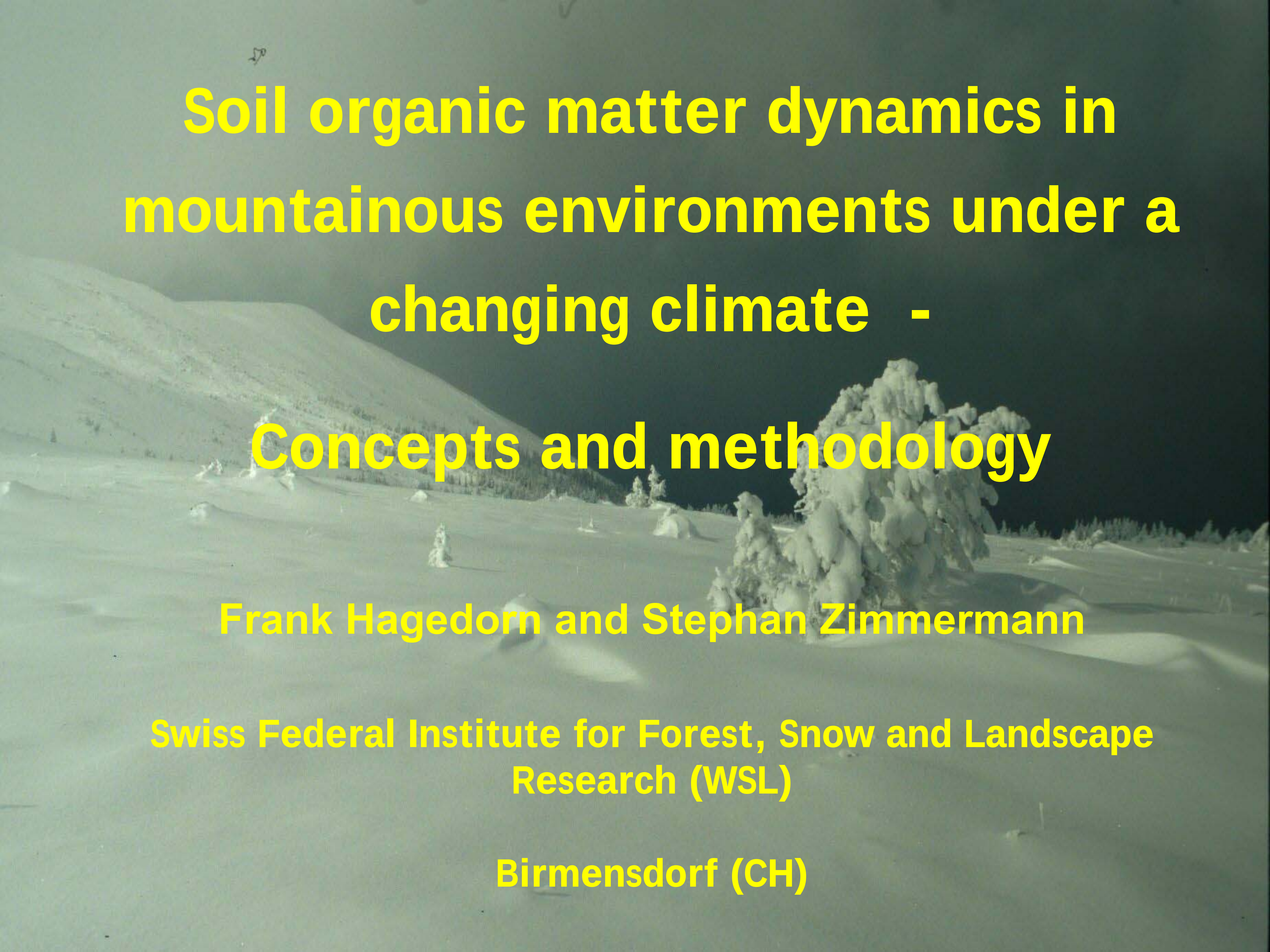


Soil organic matter dynamics in mountainous environments under a changing climate -

Concepts and methodology

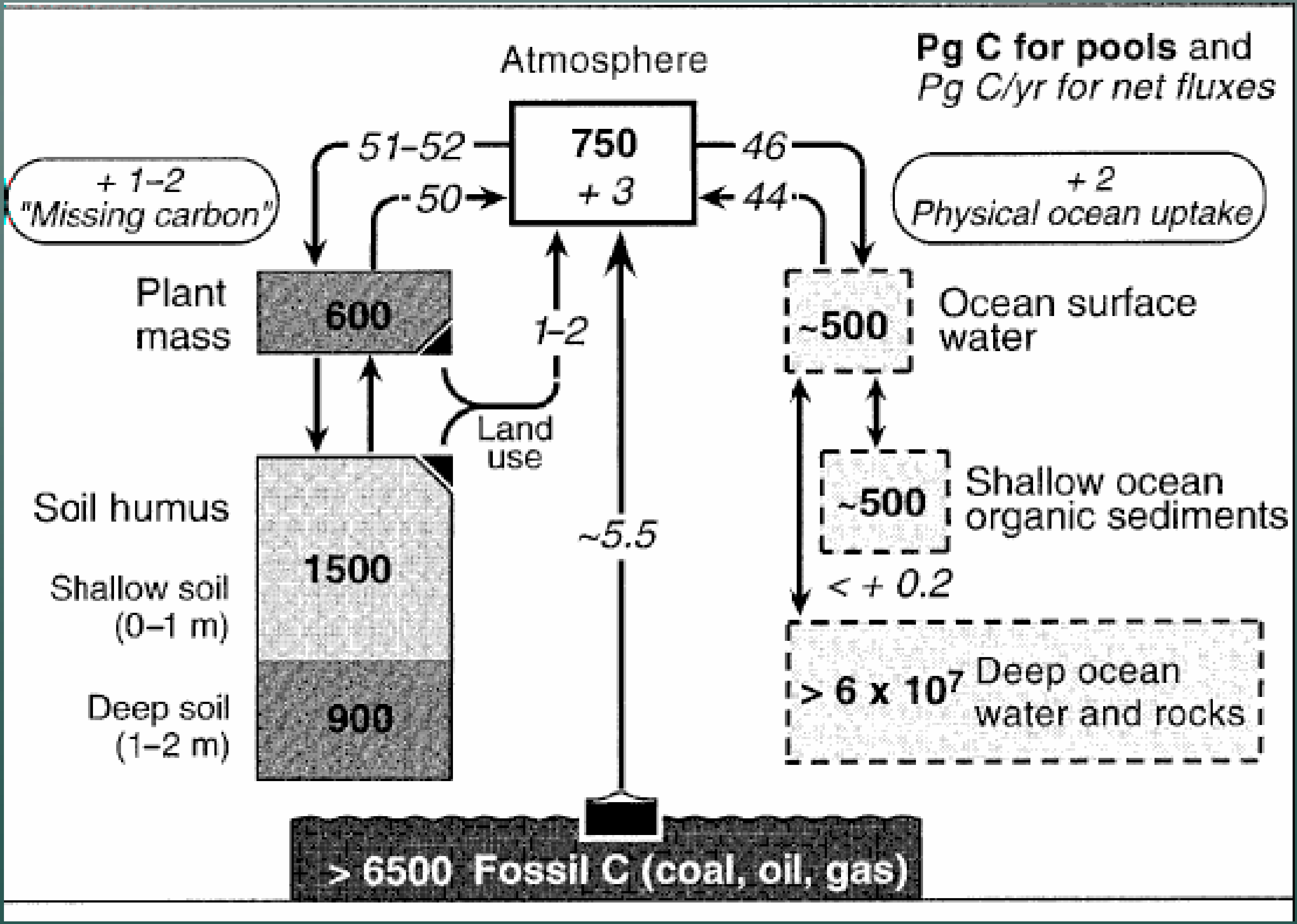
Frank Hagedorn and Stephan Zimmermann

Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)

Birmensdorf (CH)

outline

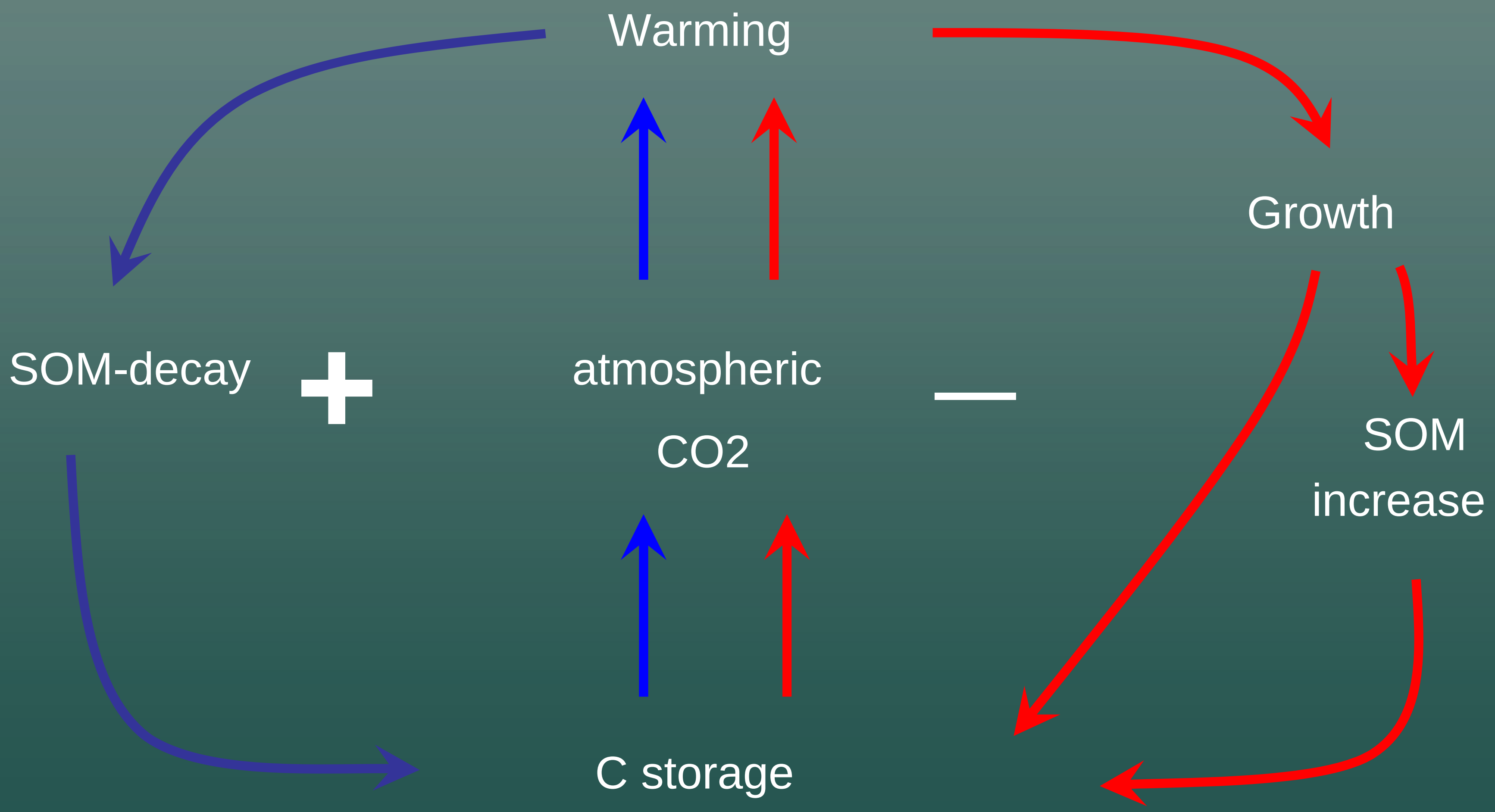
1. Why to look at feedbacks climate change - SOM?
2. Experimental approaches
3. Case study: Treelines in the Ural mountains
4. Case study: Alpine treeline in Stillberg (Switzerland)
5. Learning from the global C distribution and past



Batjes, European Journal of Soil Science, 47, 151-163, 1996

outline

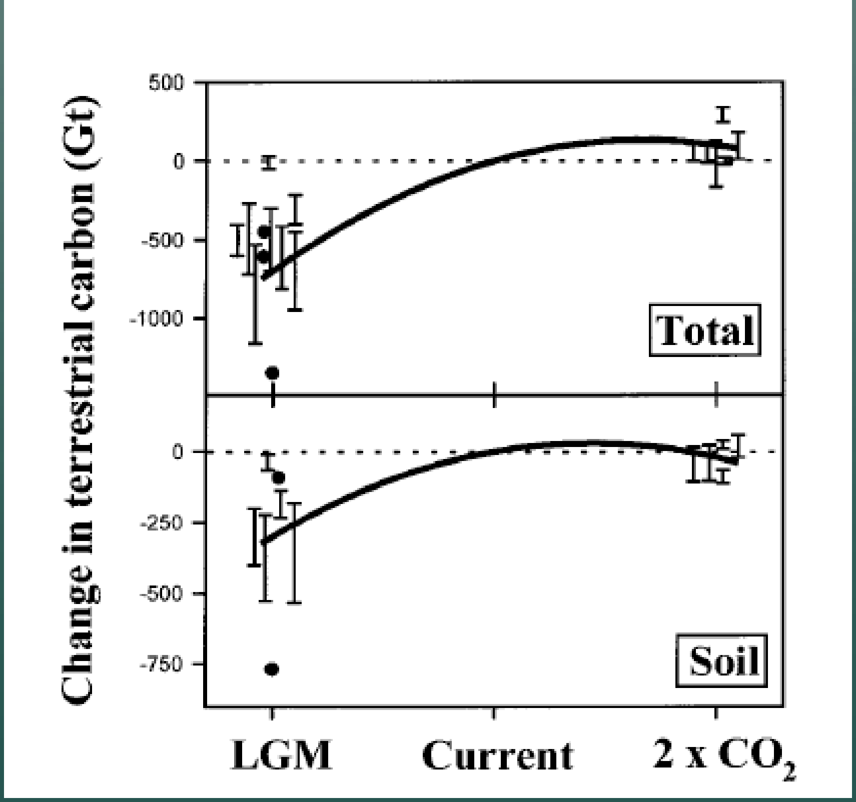
Feedbacks: Warming ⇔ C storage



Feedbacks: SOM ⇕ climate

Will changes in soil organic carbon act as a positive or negative feedback on global warming?

Miko U.F. Kirschbaum
Biogeochemistry 48, 21-51, 2000



LGM: Last Glacial Maximum

Feedbacks: SOM ⇔ climate

roughly equal to natural erosion.

Sparring aside, a recent set of analyses* has helped clarify the link between soil degradation and tapered growth in crop yields. One study, led by Christoffel den Biggelaar of Appalachian State University in Boone, North Carolina, combined erosion rates, estimated by soil type and climate, with data from hundreds of field studies for various crops. The team estimated global average potential yield losses at 0.3% a year, compared to Pimentel's 8% for the United States. Recognizing that most farmers have incentives to counter these losses—for example, by using better tilling methods—the actual decline may be as low as 0.1%, USDA's Wiebe says. But that figure is not trivial, he cautions. Growth rates of global cereal yields, which have grown at a brisk 2% per year since the 1960s, are expected to rise at a slower rate in coming decades. As that happens, Wiebe says, 0.1% "gets to be a more important number."

Moreover, the reasonably rosy global picture glosses over disturbing regional trends. Degradation is clearly cutting into yields in parts of Africa, South Asia, and Latin America, notes Forest Trends analyst Sara Scherr. "The critical issue," she says, "is where are the places in the world" where soil degradation matters most. A USDA analysis found that if struggling regions could reduce degradation and thereby boost crop-yield growth by a mere 0.1% per year, the number of malnourished people would fall by 5%, or 37 million, over a decade.

A fertile future?

There's no lack of technological fixes for reversing soil degradation. In the United States, for instance, no-till farming has helped reduce water erosion by over 40% since 1982, Pimentel notes. And in developing countries, strategies such as sowing cover crops and planting trees have been shown to restore soil fertility and stem erosion. But these solutions can't be imposed top-down (*Science*, 21 November 2003, p. 1356). Terracing, for example, has failed in many places, including Haiti, because it is too expensive for most farmers.

Although the United Nations funds some efforts to disseminate approaches that work, major aid organizations, such as the World Bank, have slashed agricultural budgets over the past 2 decades in favor of addressing urban projects, Scherr says. But the pendulum aims to halve the number of starving people by 2015, says co-chair Pedro Sanchez of Columbia University's Earth Institute. Soil degradation, he says, is "the main constraint to reducing hunger" in Africa.

The biggest looming issue may be global warming. Lal notes that erosion already contributes to warming, because some of the carbon in soil-laden water running off fields wafts into the atmosphere. Yet fields could sop up some of this carbon, Lal says, if farmers adopt practices to reduce erosion and retain nutrients, as is encouraged by the Kyoto Protocol on climate change (see p. 1623). Inevitably, "a hotter world is likely to have less organic matter" in its soils, Duke's Schlesinger notes. Such vital nutrients decompose as temperatures rise, releasing carbon. Deserts will also expand as the interiors of continents become drier. Erosion rates could rise if soils dry out and storms increase, Lal says. "The risks of soil degradation are going to go up, but how much, we don't know," he says.

Soil degradation is no longer seen as a matter of "global survival," says Wiebe. But "it's still an issue. It will keep coming back." In a warming world, it could come back to haunt us.

—JOCELYN KAISER

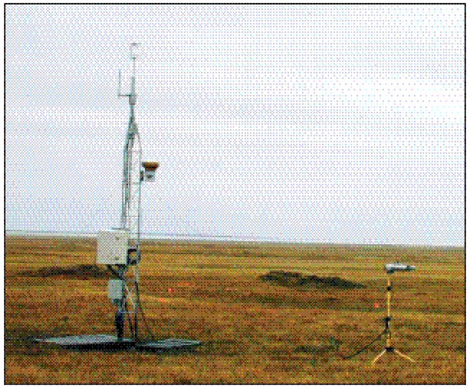
NEWS

Defrosting the Carbon Freezer of the North

The perpetually frozen soils of the Arctic and boreal regions are thawing at unprecedented rates. It's unclear what this bodes for global warming

When Phil Camill goes looking for frozen soil in the spruce forests of northern Manitoba each summer, he finds less and less each year. Instead of rock-hard permafrost, he discovers drenched soil, dying trees, and ever-expanding, mossy bogs. The physicist at the University of Alaska, Fairbanks. The pace has shocked researchers—and it's accelerating. In Manitoba, at the southern edge of Canada's permafrost, the thaw rate has nearly tripled over 4 decades; this patchy permafrost is now receding up to 31 centimeters per year, and in a forthcoming paper in *Climatic Change*, Camill predicts that Manitoba will lose most of its permafrost within a century. Even in the far north, where soil deposits are thicker and colder, much permafrost has warmed to the brink of meltdown. That's a major concern for residents: Settling of the ground has already damaged buildings, pipelines, and other infrastructure in Alaska and Siberia (*Science*, 30 August 2002, p. 1493).

But widespread permafrost melting could have grave consequences well beyond the far

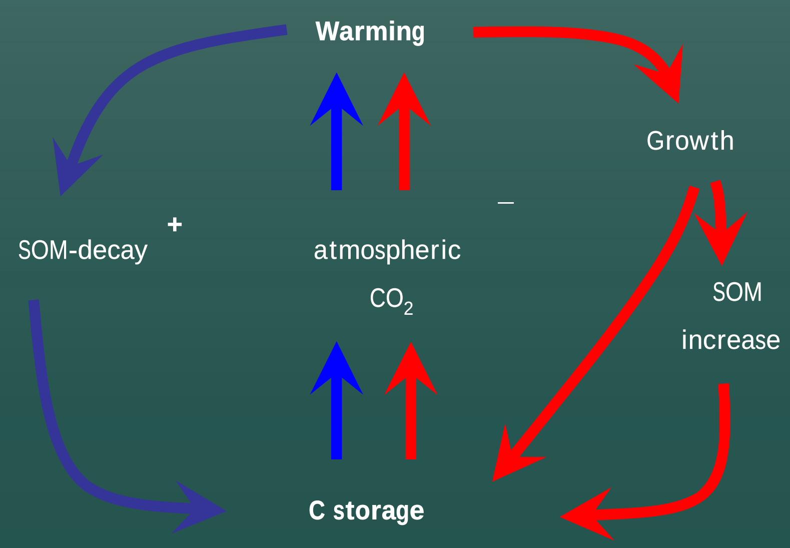


High and dry. Instruments like this eddy tower near Barrow, Alaska, have measured increasing carbon dioxide emissions in places where water can drain out of thawing permafrost.

Temperature dependency

Van't Hoff, 1898: Change of reaction rates across 10K

$$Q_{10} = (k_2 / k_1)^{\frac{10}{(T_2 - T_1)}}$$



Experimental approaches

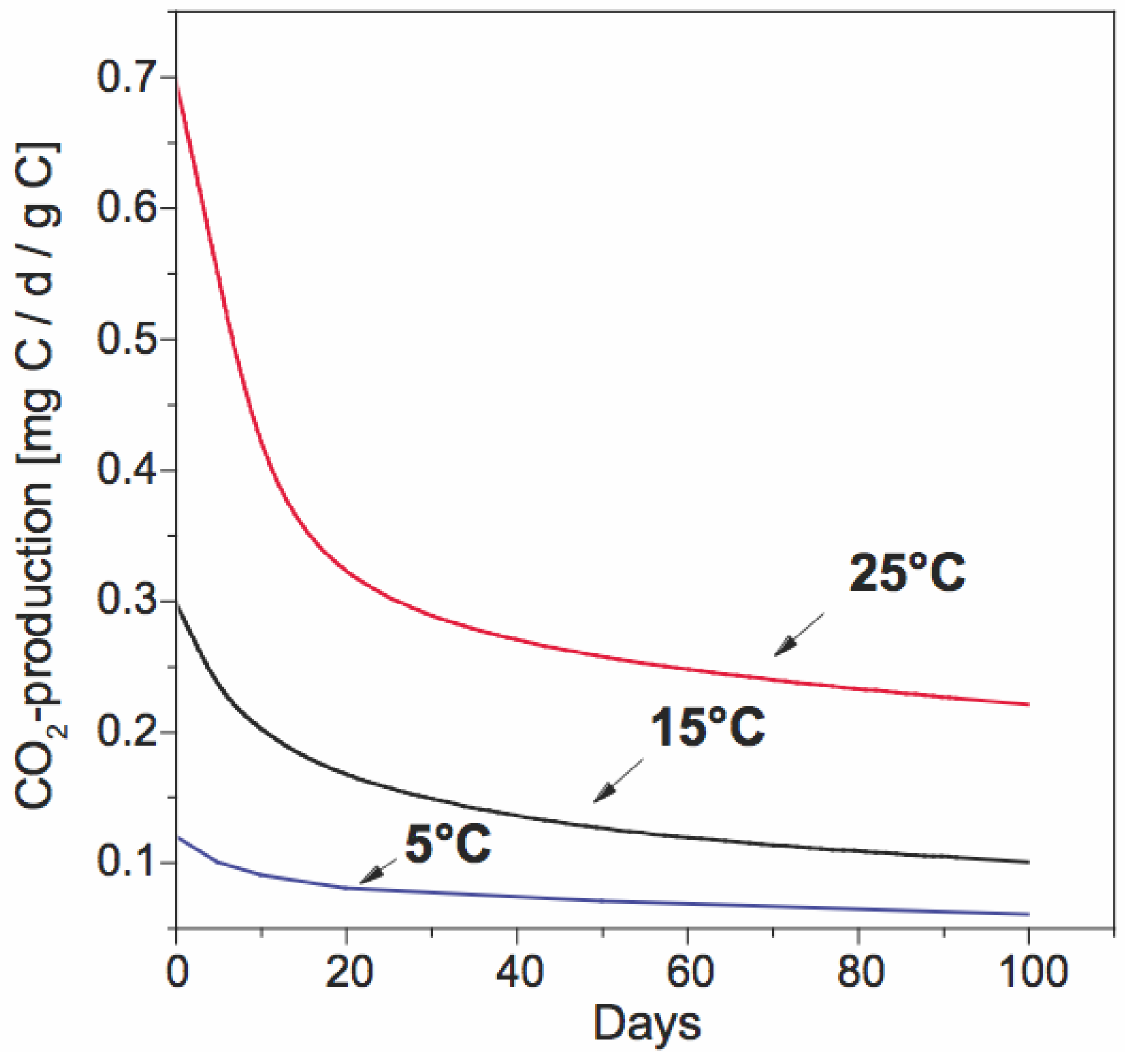
1. Laboratory incubations
2. Soil warming studies
3. Altitudinal/latitudinal transects

Laboratory incubation

DOC-leaching

CO_2-Production

Temperature drives soil respiration



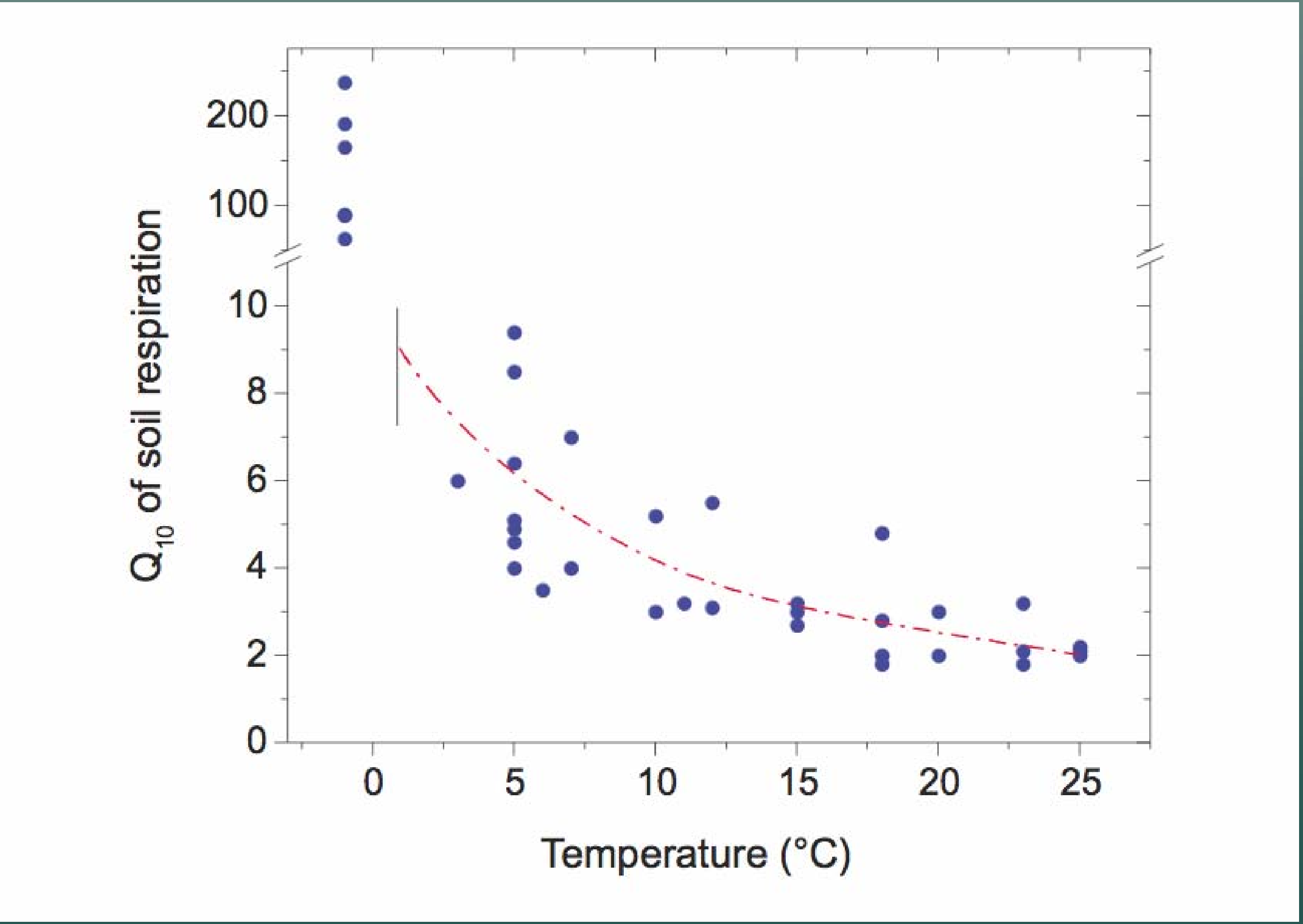
From Reichstein et al. (2000): Soil Biol. Biochem. 32, 947-958

Laboratory incubation

WSL

Q10 - Temperature dependent

Laboratory incubation



Ref.: Kirschbaum (1995): Soil Biol. Biochem. 27, 753-760
Mikan et al. (2002): Soil Biol. Biochem. 34, 1785-1795

Summary laboratory incubation

- Temperature sensitivity greater at lower T

Limitations

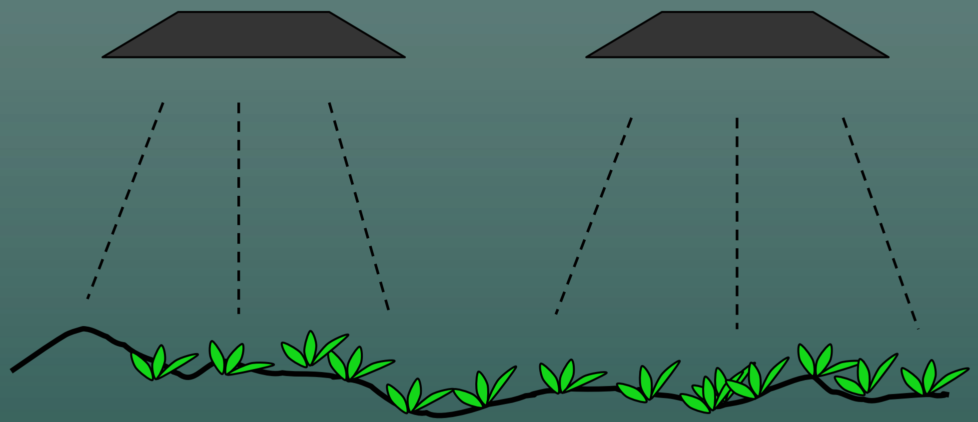
- More rapid losses of labile SOM at high T
- Disturbance, no input

Experimental Warming

Greenhouse-Warming
Val Bercla, Switzerland

Marion et al., Global Change Biology 3 (Suppl.1), 20-32, 1997
Hollister and Webber, Global Change Biology 6, 835-842, 2000

UV-Lamps



Problems: Decreasing air humidity
Non-uniform heating

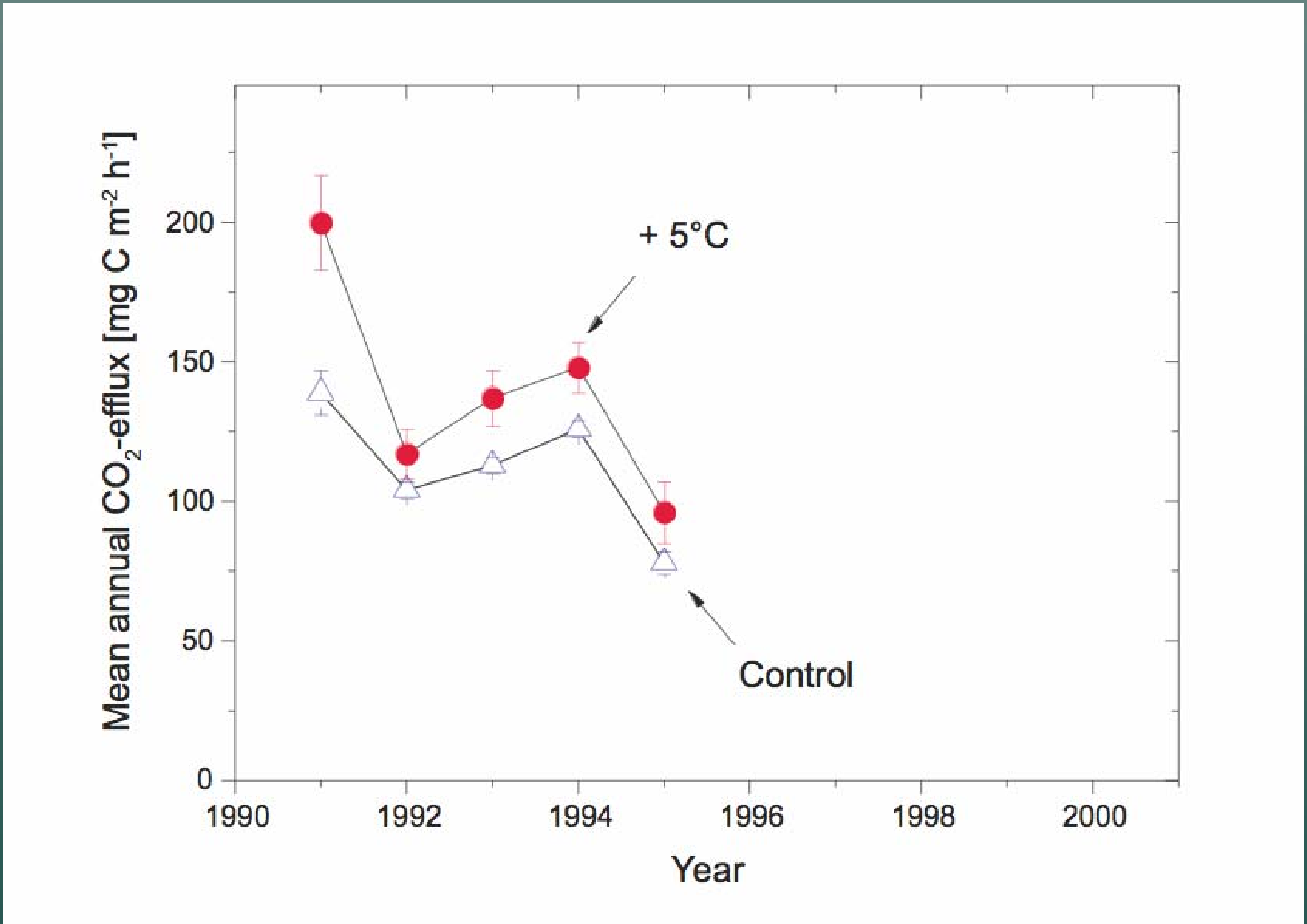
Heating cables

Problems

Soil Disturbance

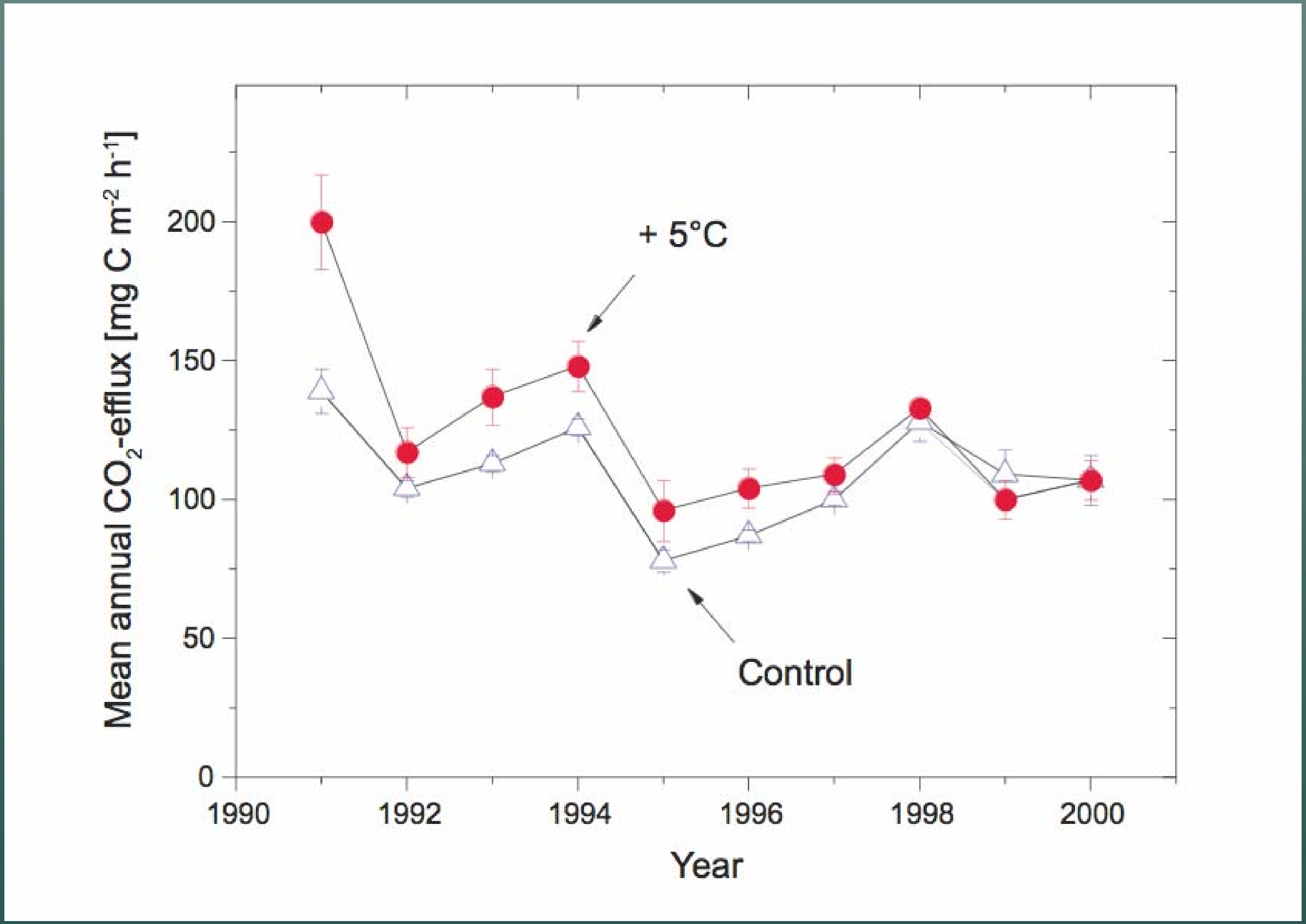
Non-uniform heating

Warming: increased C losses



Ref.: Melillo et al. (2002): Science 298, 2173-2176

Warming: increased C losses



Ref.: Melillo et al. (2002): Science 298, 2173-2176

Soil warming studies

Experimental warming

- Warming = Drying
- Uneven warming: C fluxes respond differently
- Response time dependent

Altitudinal transect

Maly Iremel, Southern-Ural

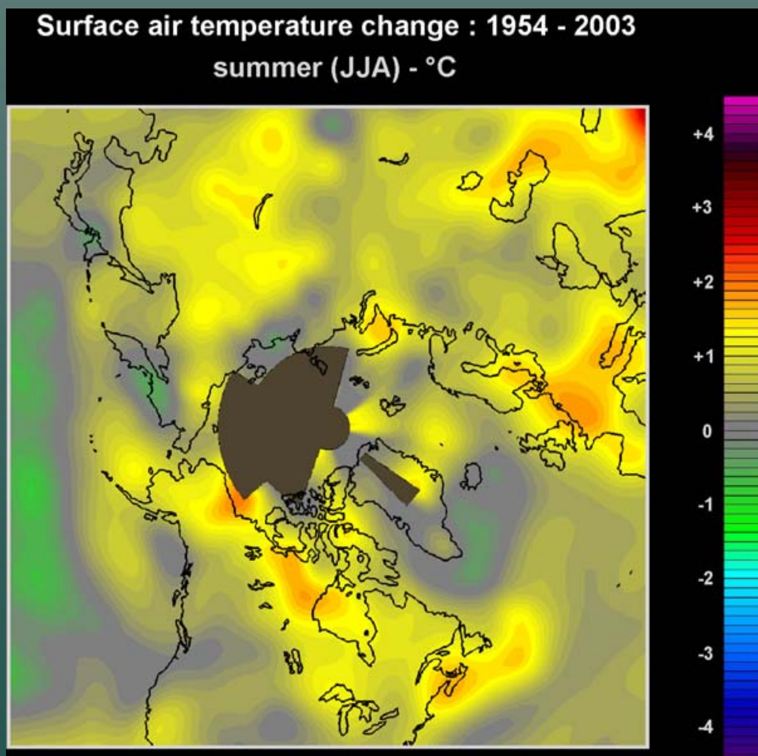
Where to look?

1. Sensitive region
2. Low anthropogenic influence
3. Large areas

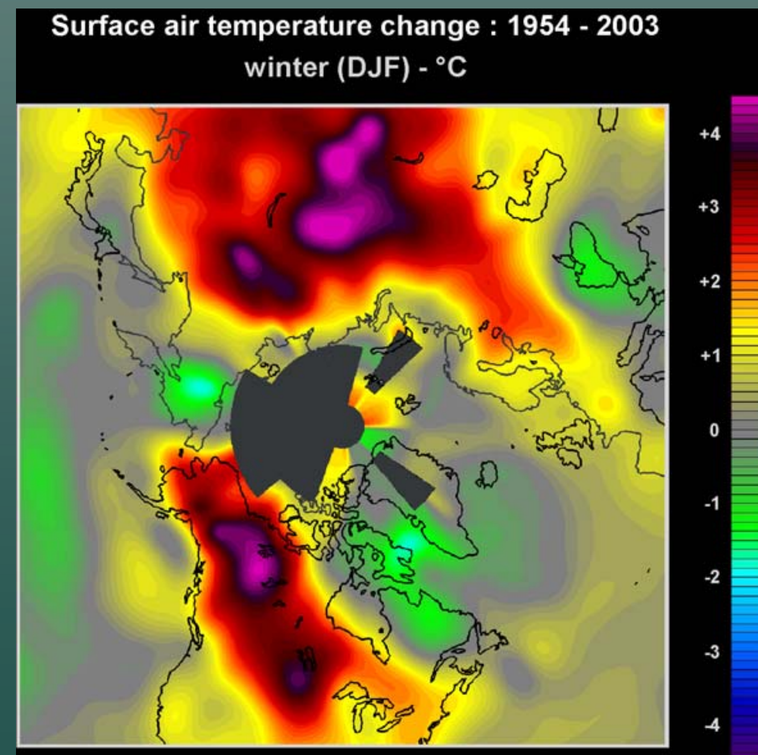
Altitudinal transects

Global Warming - Greater warming in winter

Summer

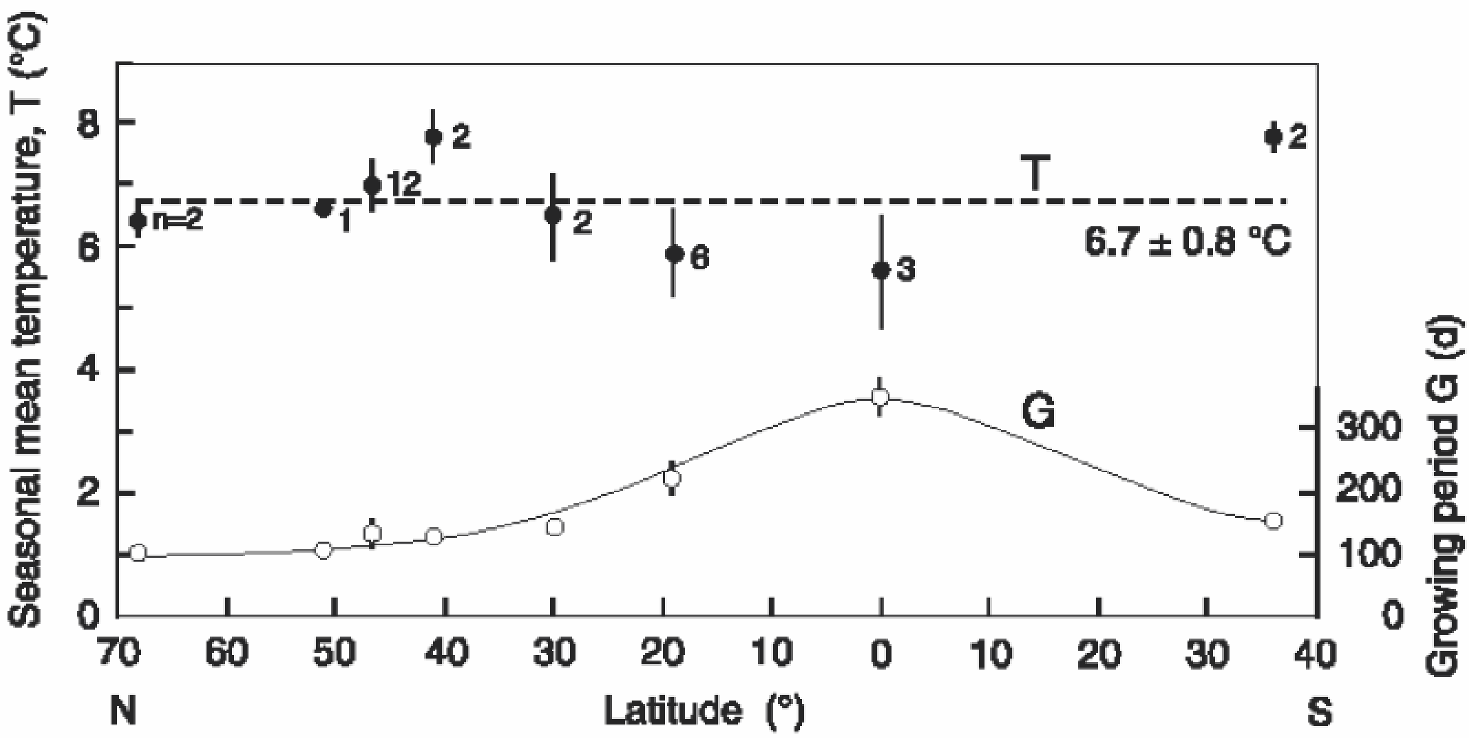


Winter



http://arctic.atmos.uiuc.edu/

Treeline is limited by summer temperature

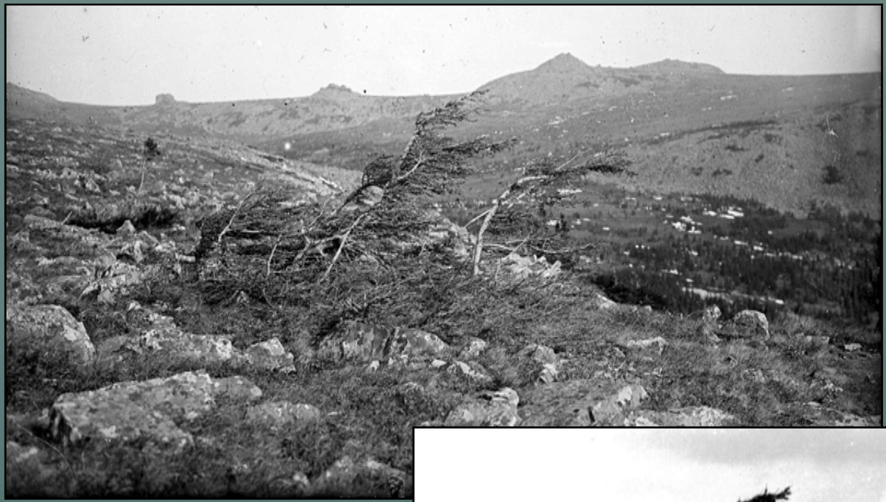


Ref.: Körner & Paulsen (2004): Journal of Biogeography 31, 713-732

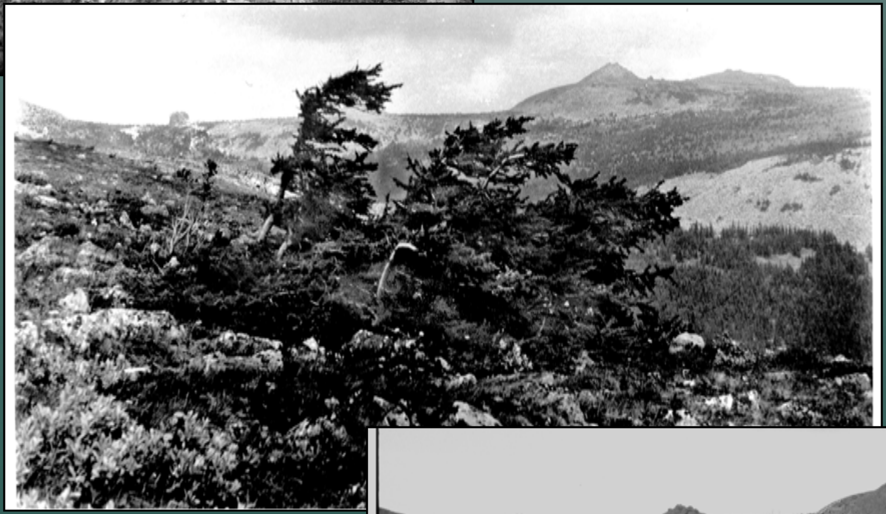
Altitudinal transects

Study Area - Treeline in the Ural mountains

Rising treelines



1929



1976

1999

(Moiseev, Shiyatov, 2003)

Altitudinal transects

Rising treelines

Altitudinal transects

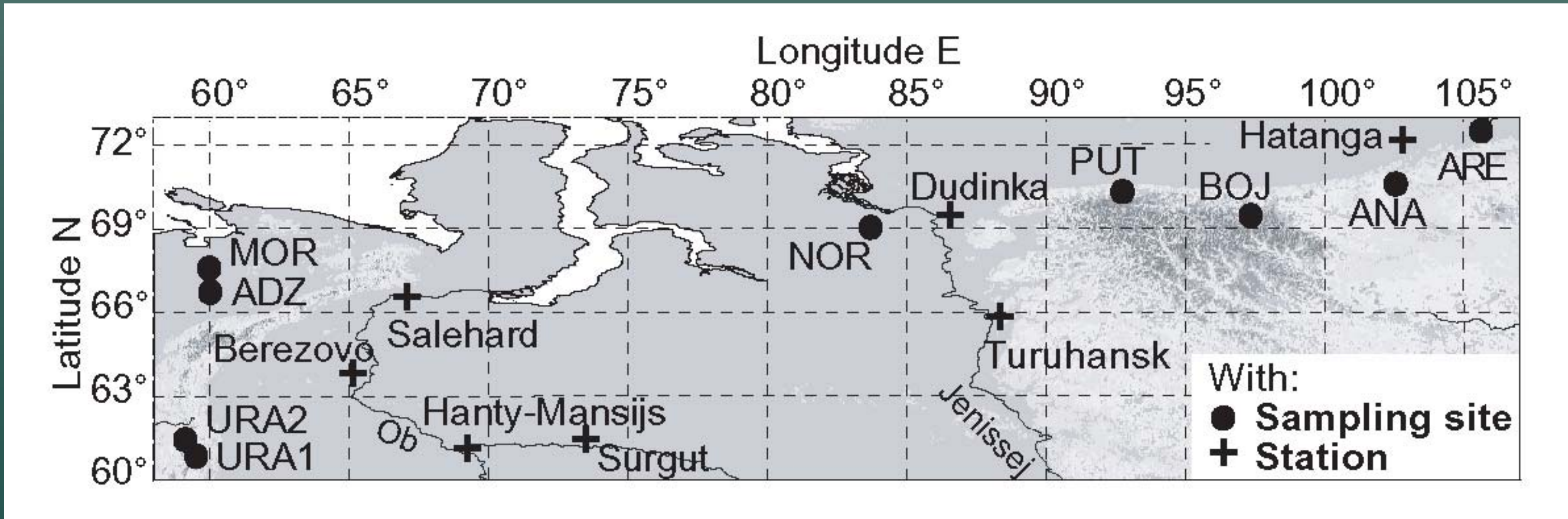
Northern treeline

GEOPHYSICAL RESEARCH LETTERS, VOL. 31, L06202, doi:10.1029/2003GL019178, 2004

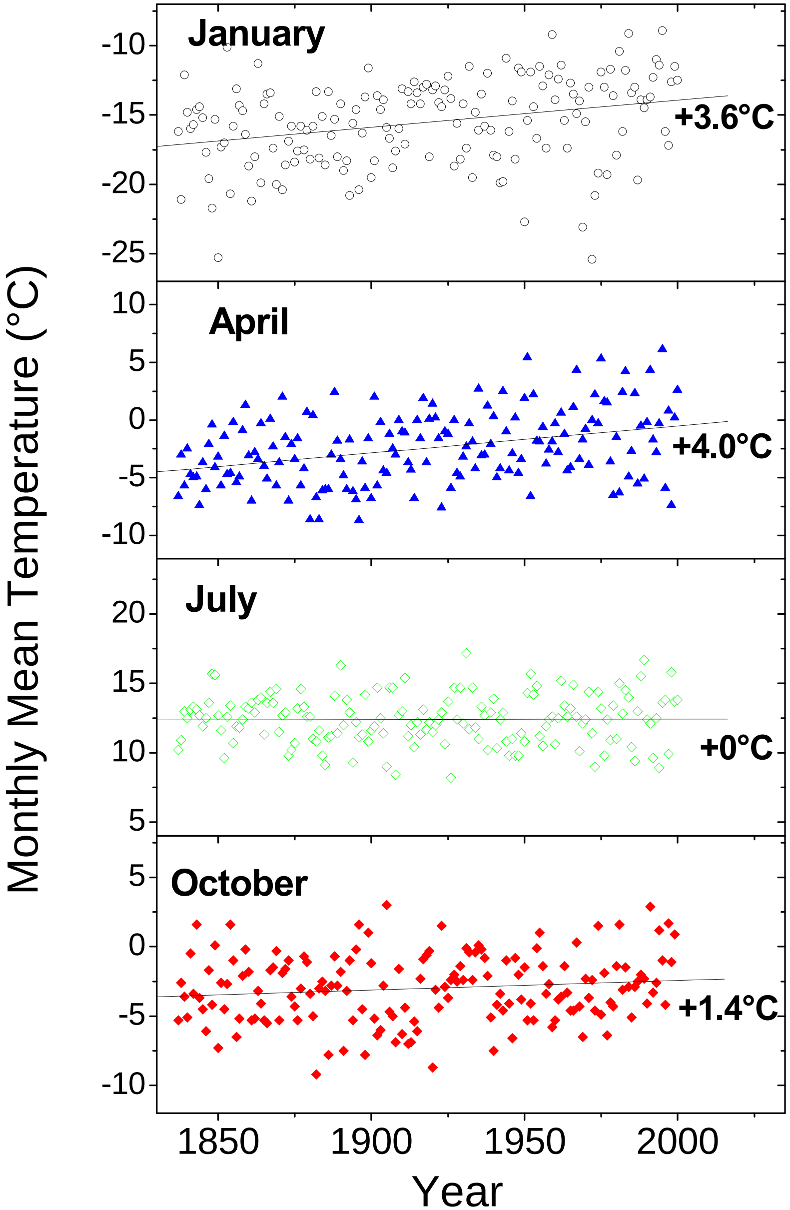
Large-scale treeline changes recorded in Siberia

Jan Esper and Fritz H. Schweingruber
Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

Received 27 November 2003; revised 30 January 2004; accepted 10 February 2004; published 16 March 2004.



Altitudinal transects



South-Ural
Taganai,1100 m
Data from
Fomin, Moiseev

1. **Treeline sensitive to temperature**
2. **Large scale changes of treelines in remote regions**
3. **Warming particular in winter (?)**

Case study Ural

Early Response Areas for Climate Change in Eurasia -

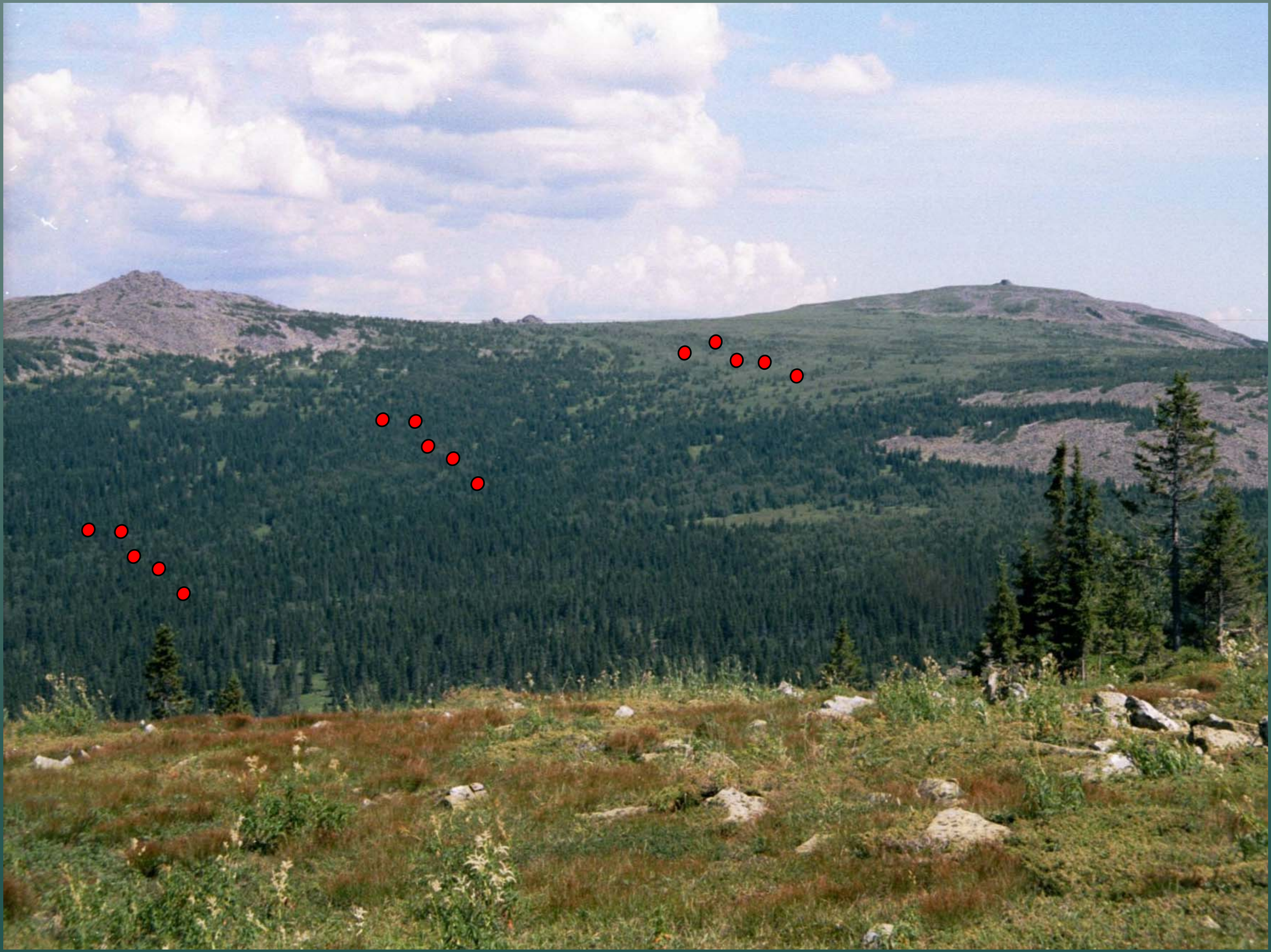
Spatio-Temporal Dynamics of the Upper Tree-line in the Ural Mountains and Implications for Carbon Sequestration

IPAE, USFEU Ekaterinburg
SB RAS Krasnojarsk
ETH Zürich
Uni Halle
WSL Birmensdorf

EU-INTAS

Diploma thesis of Adrian Kammer under the supervision of Dr. Frank Hagedorn, WSL Birmensdorf

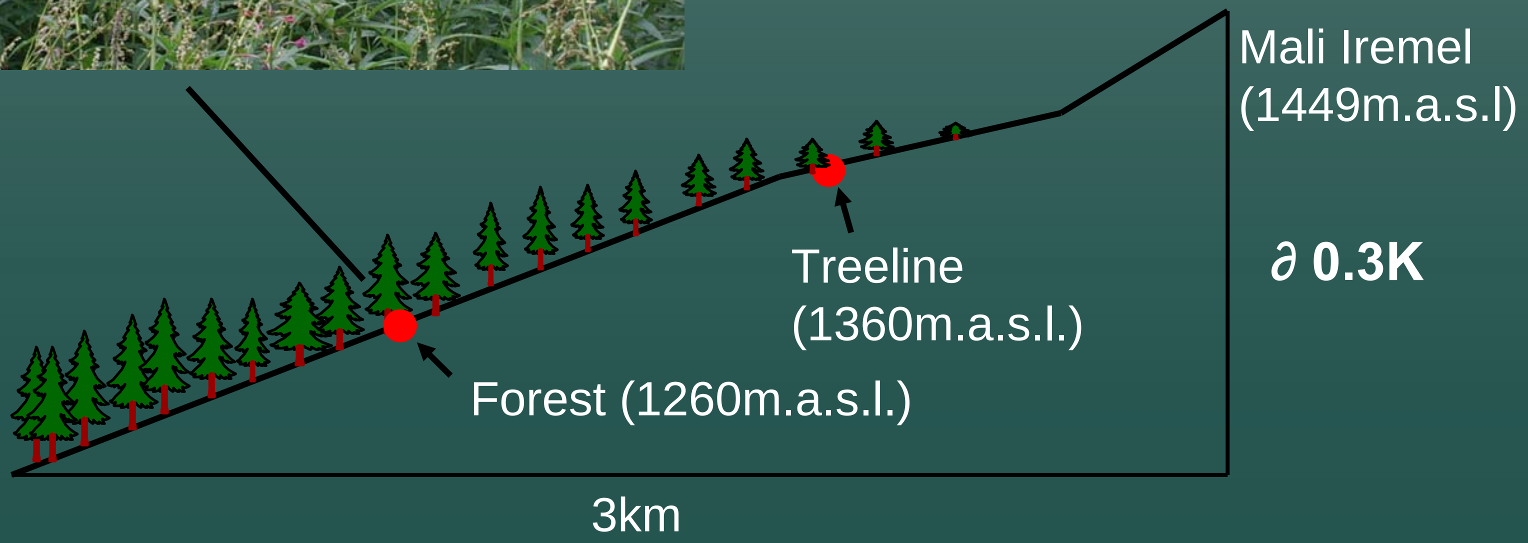
Altitudinal Gradient: ‚Space for time and climatic change‘



Maly Iremel, Southern-Ural

Case study Ural

Altitudinal Gradient

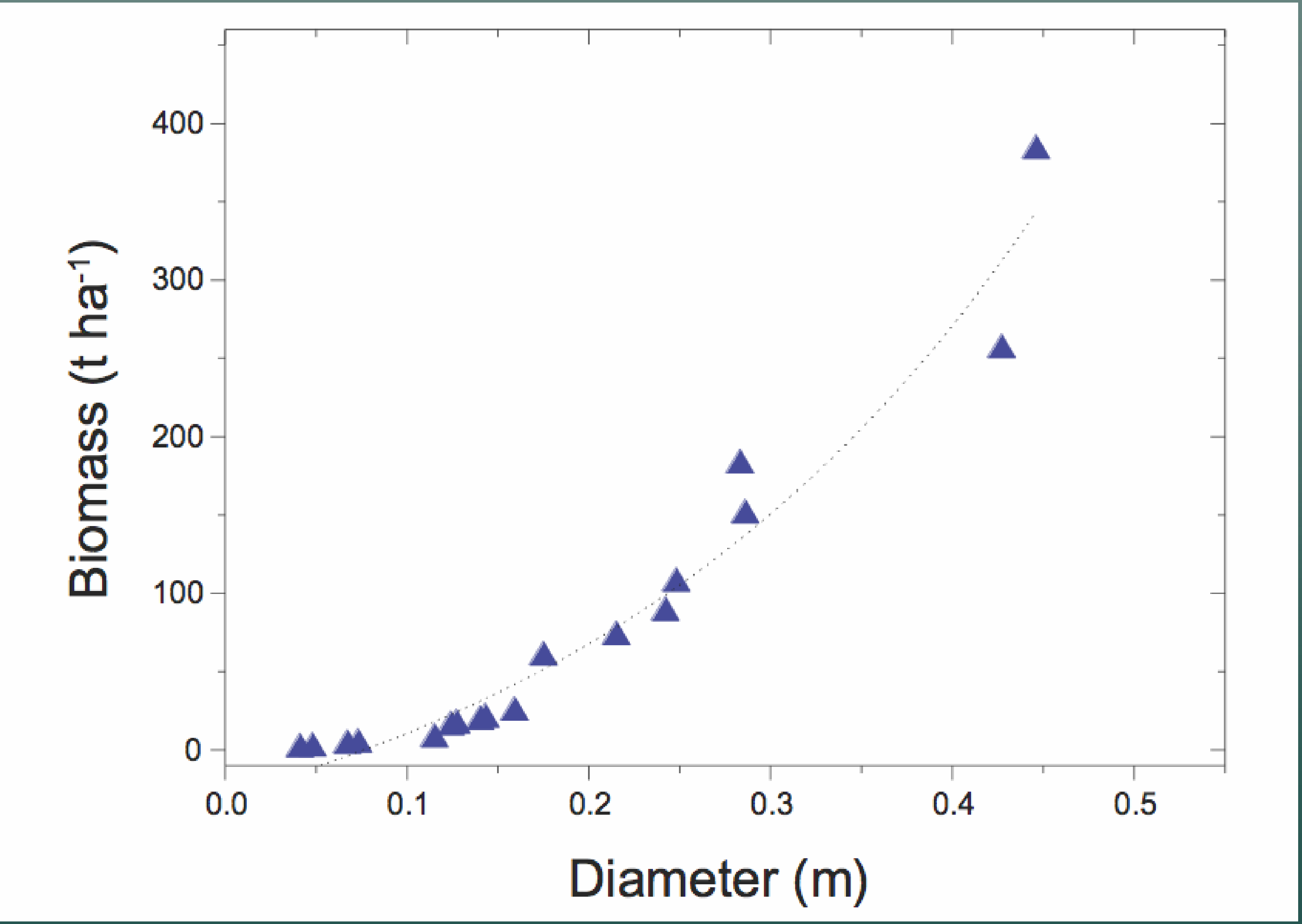


Case study Ural

C-pool estimates

Case study Ural

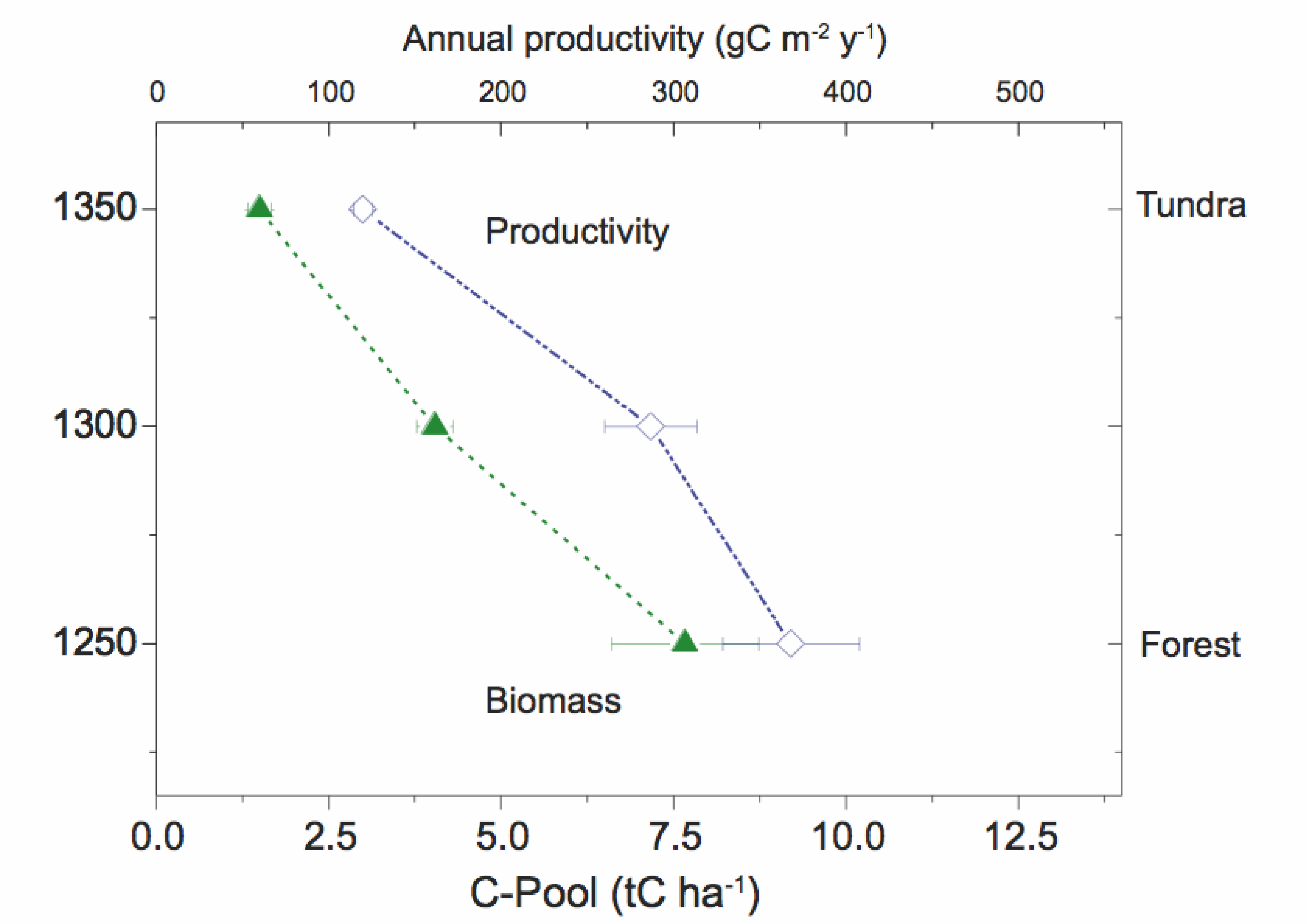
C-pool estimates: C-Allocation



Case study Ural

Devy, Mazepa, Hagedorn, Rigling unpublished data

Transect: ‚Space for time and climate change‘ C-pools and productivity



Maly Iremel, Southern-Ural

Case study Ural

Rising treeline and soil carbon: mechanisms

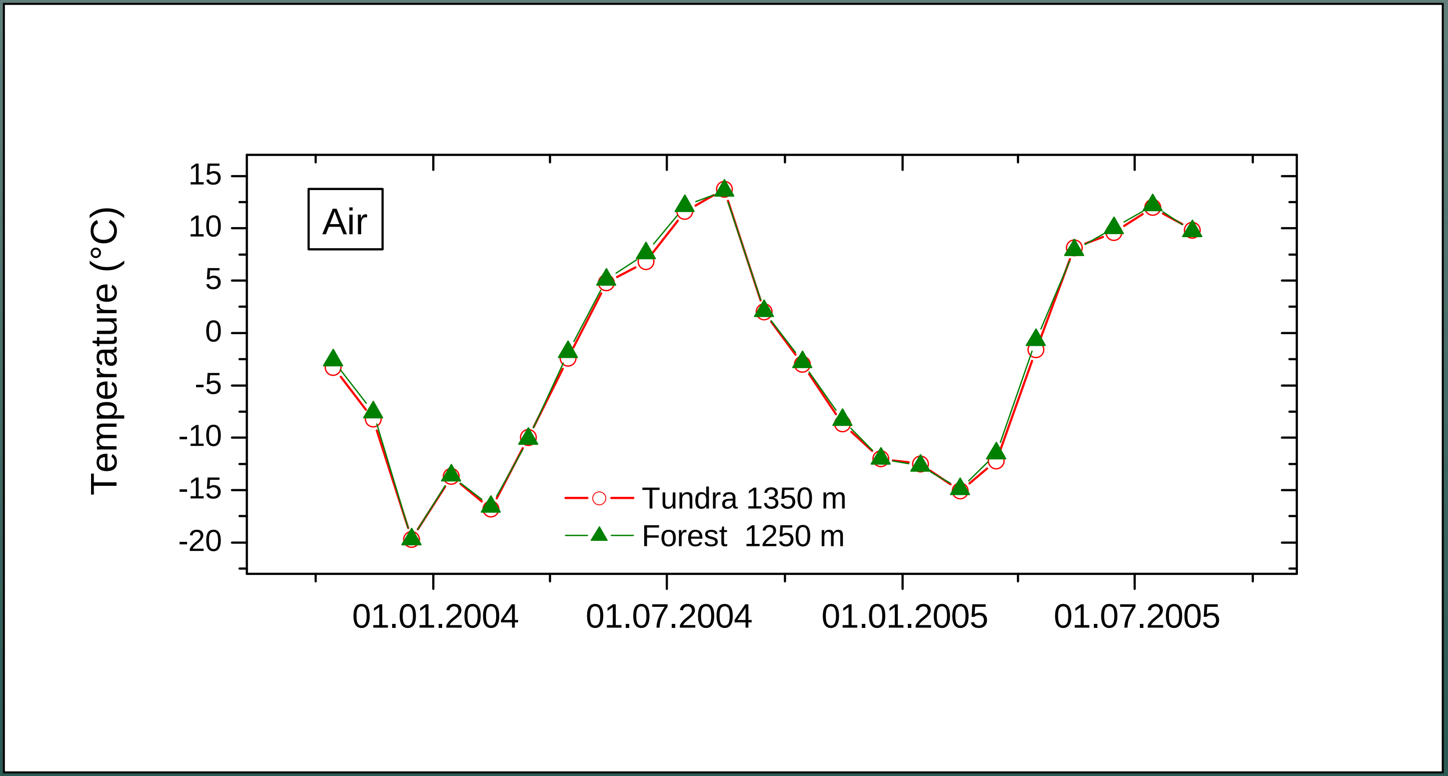
1. Greater C-Input through more biomass ↑

   (above-ground: 180 vs. 60 g C $m^{-2}y^{-1}$)

2. Greater decomposition through warming ? ↓

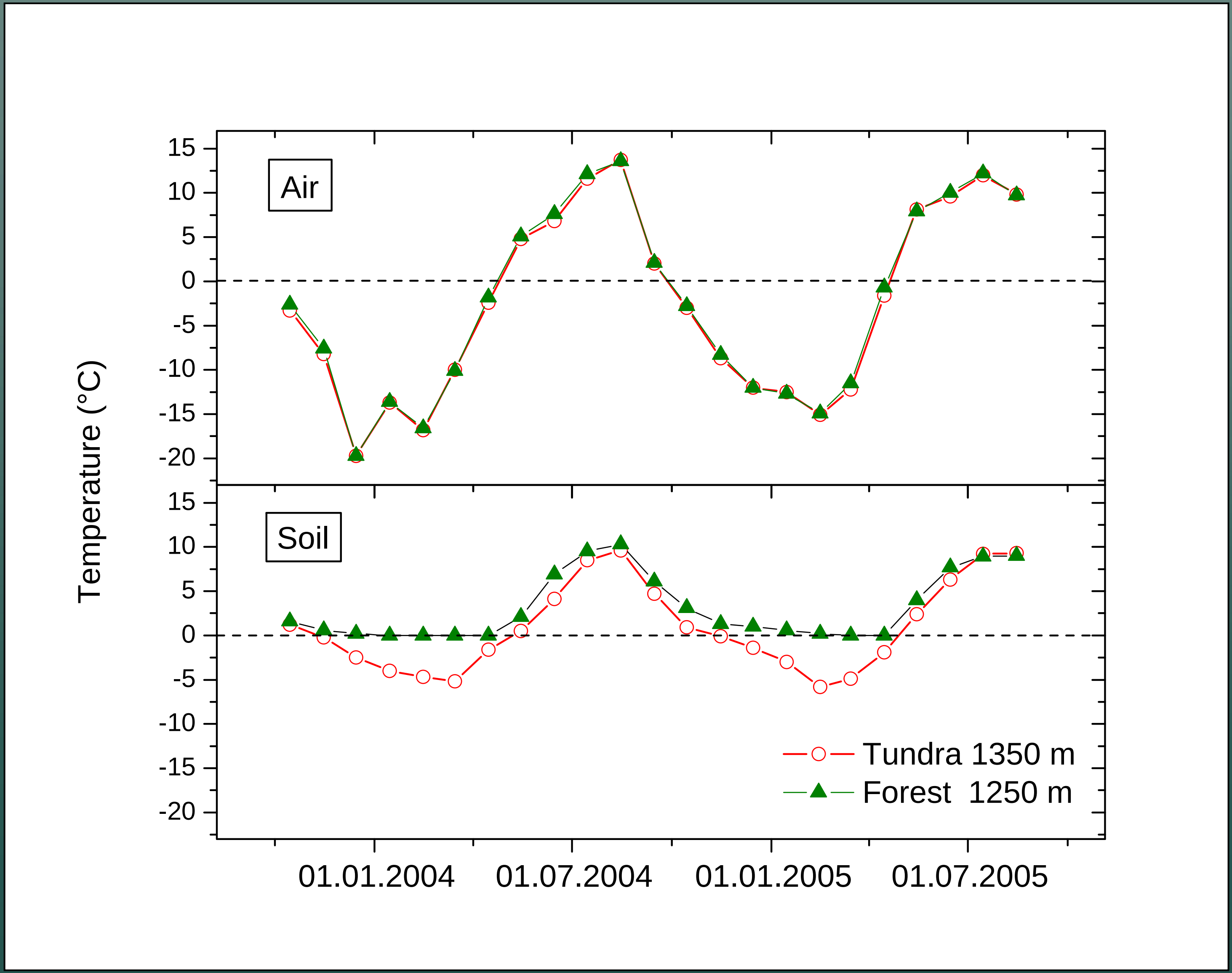
Case study Ural

Micro climate: air temperature



Case study Ural

Micro climate: soil temperature



Case study Ural

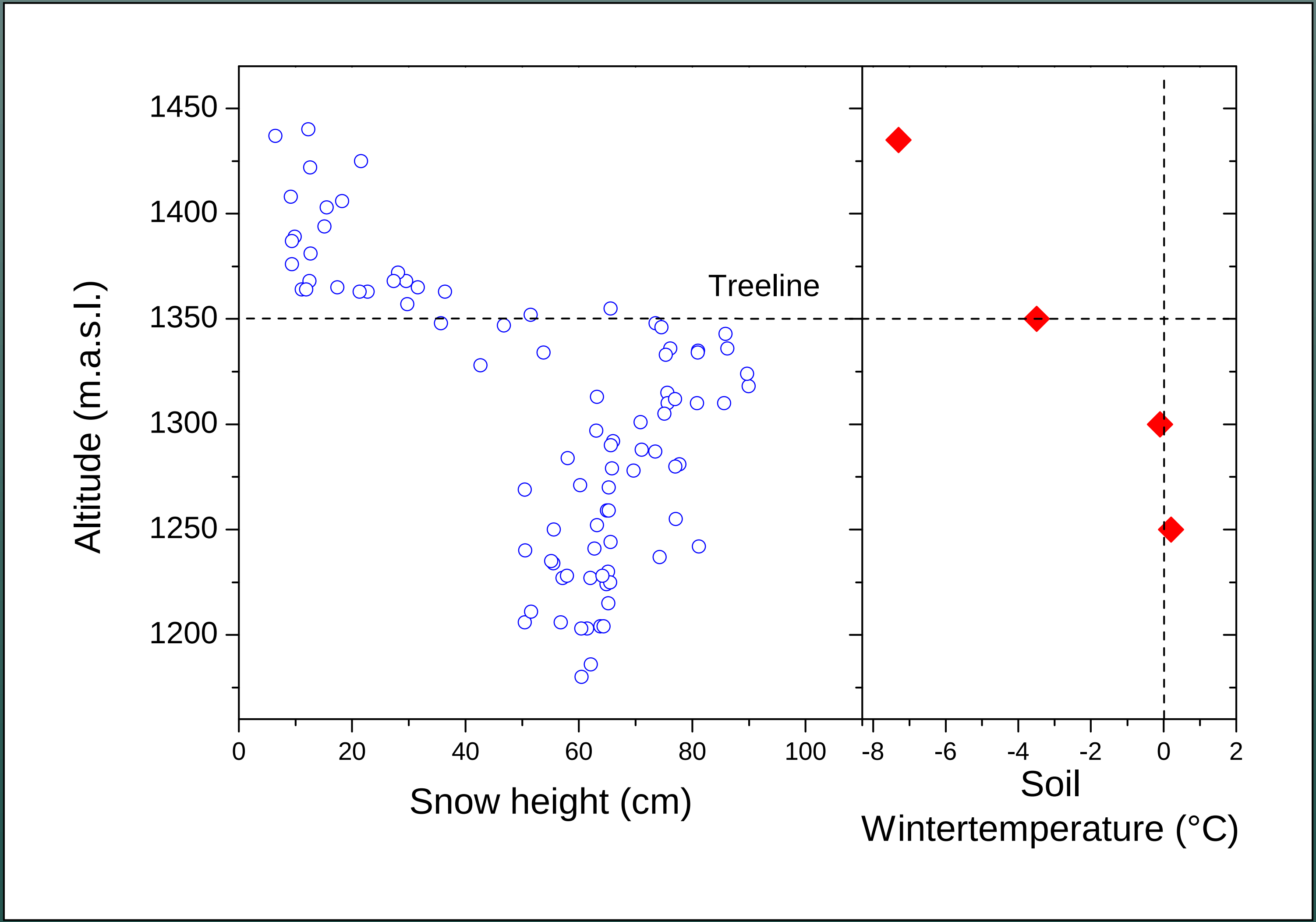
Winter climate

1360 m

1300 m

Case study Ural

Winter climate: Snow height and temperature



Case study Ural

Case study Ural

Sampling: soil C pools

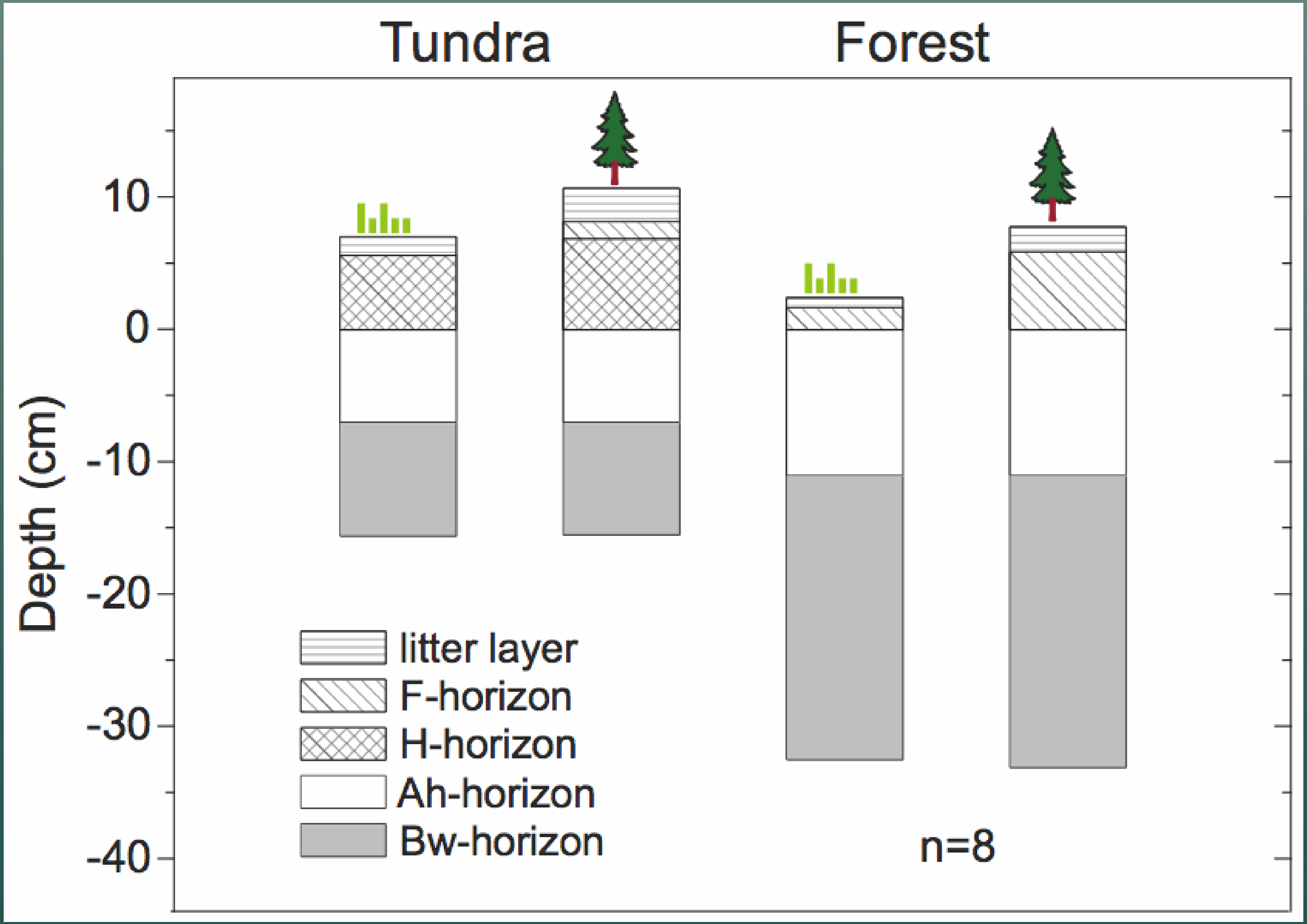
- 3 altitudes
- 4 trees
- 2 profiles under trees and ‚open' land
- L, F, H, 0-7cm, 7-25cm, 25-C
- additional topsoil sampling
- areal and volume based sampling

Soils: Cambisols

Tundra 1360 m a.s.l.

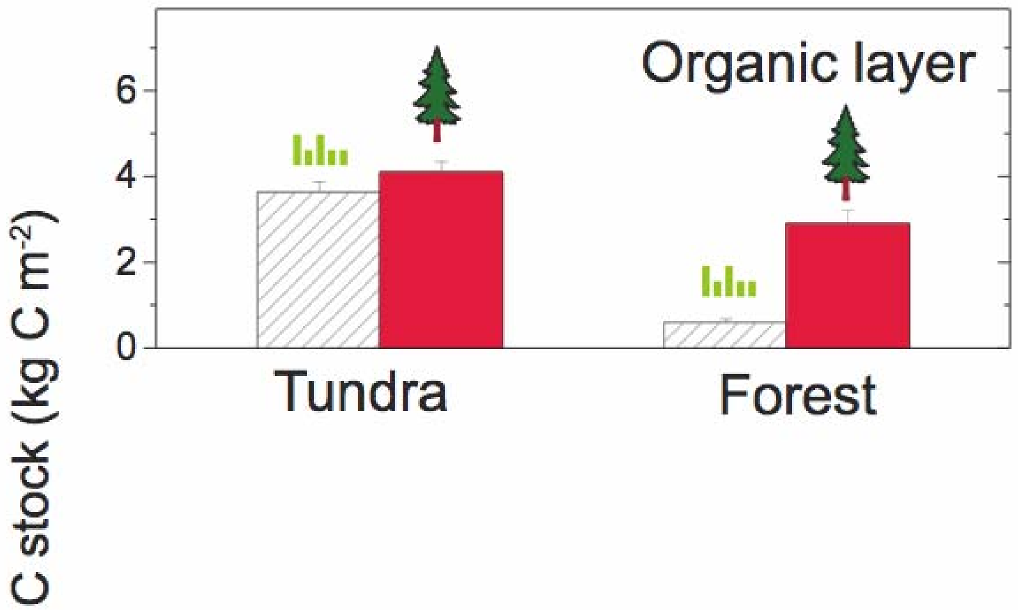
Forest 1260 m a.s.l.

Altitudinal transect Ural: Soil profiles



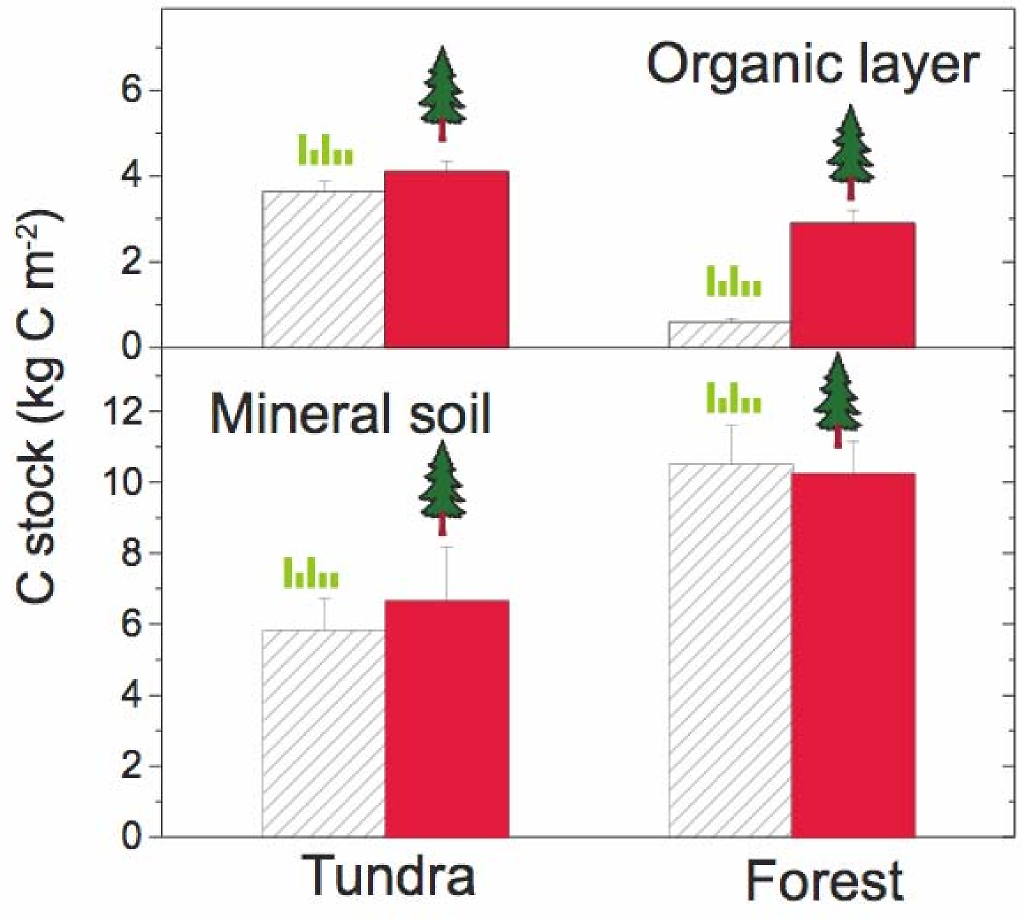
Case study Ural

Altitudinal transect Ural: Soil C pools



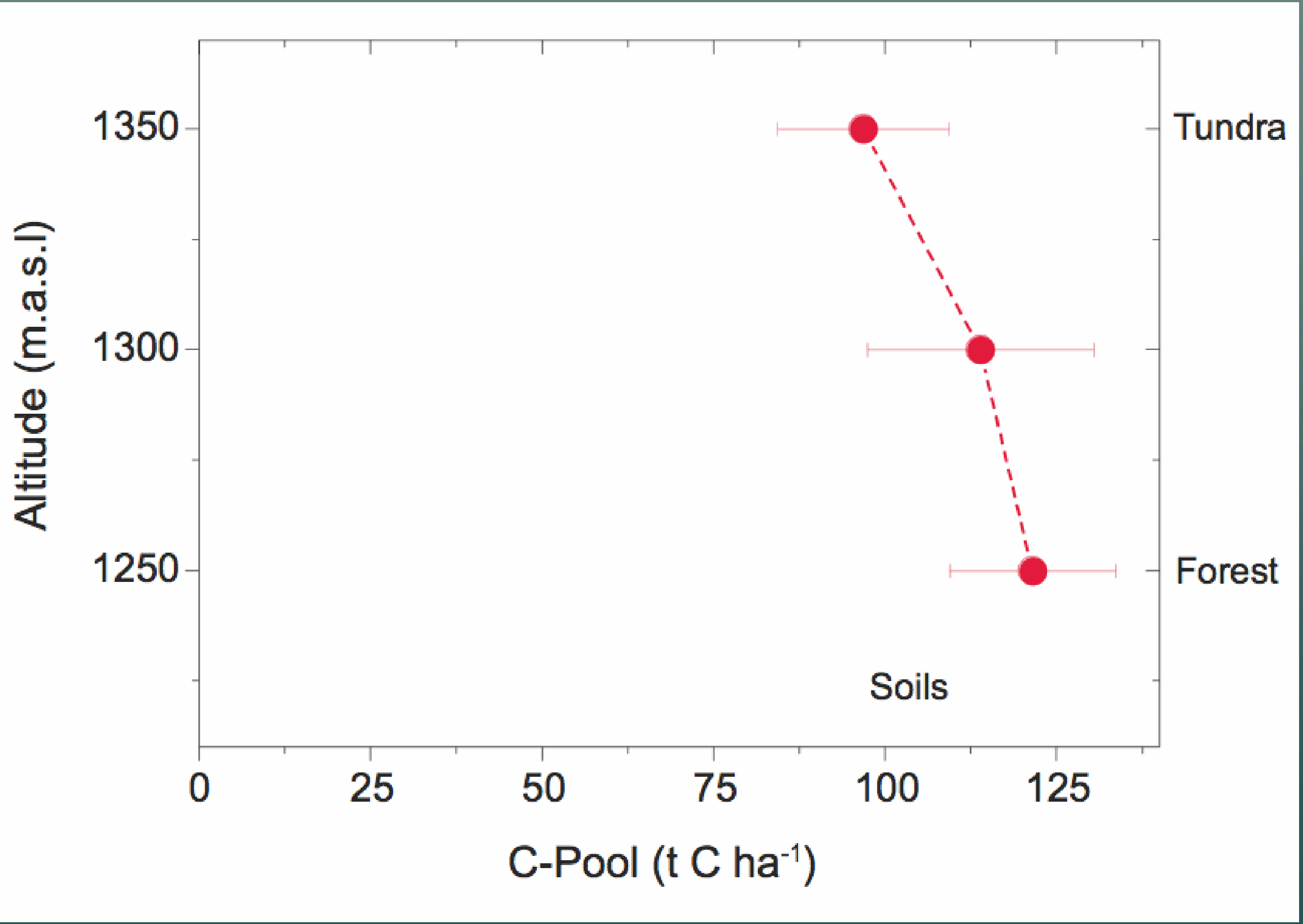
Case study Ural

Altitudinal transect Ural: Soil C pools



Case study Ural

Altitudinal transect Ural: Soil C-Pools

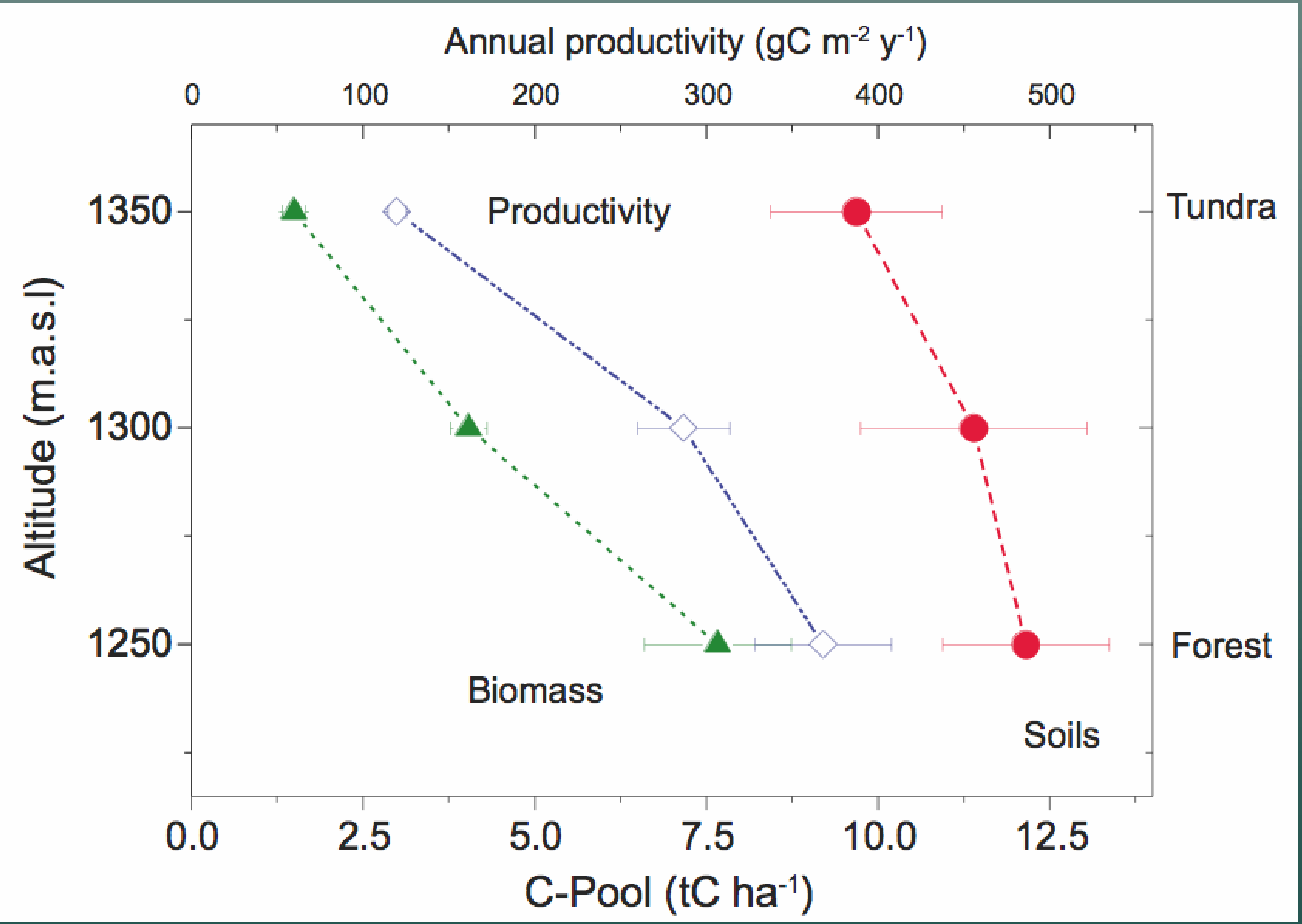


Case study Ural

Maly Iremel: Southern-Ural

Kammer, Hagedorn unpublished data

Altitudinal transect Ural: Soil C-Pools and producitivity

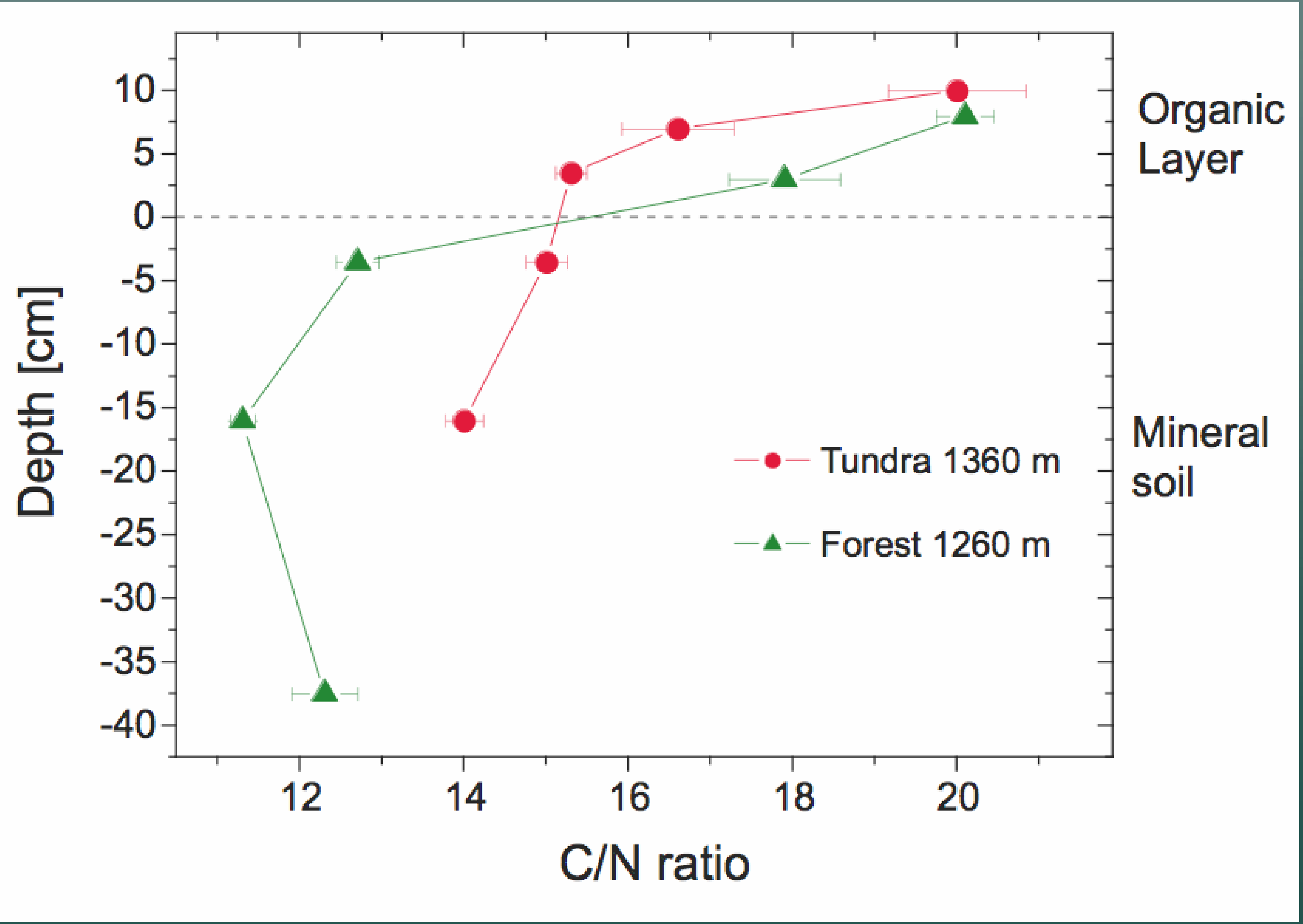


Case study Ural

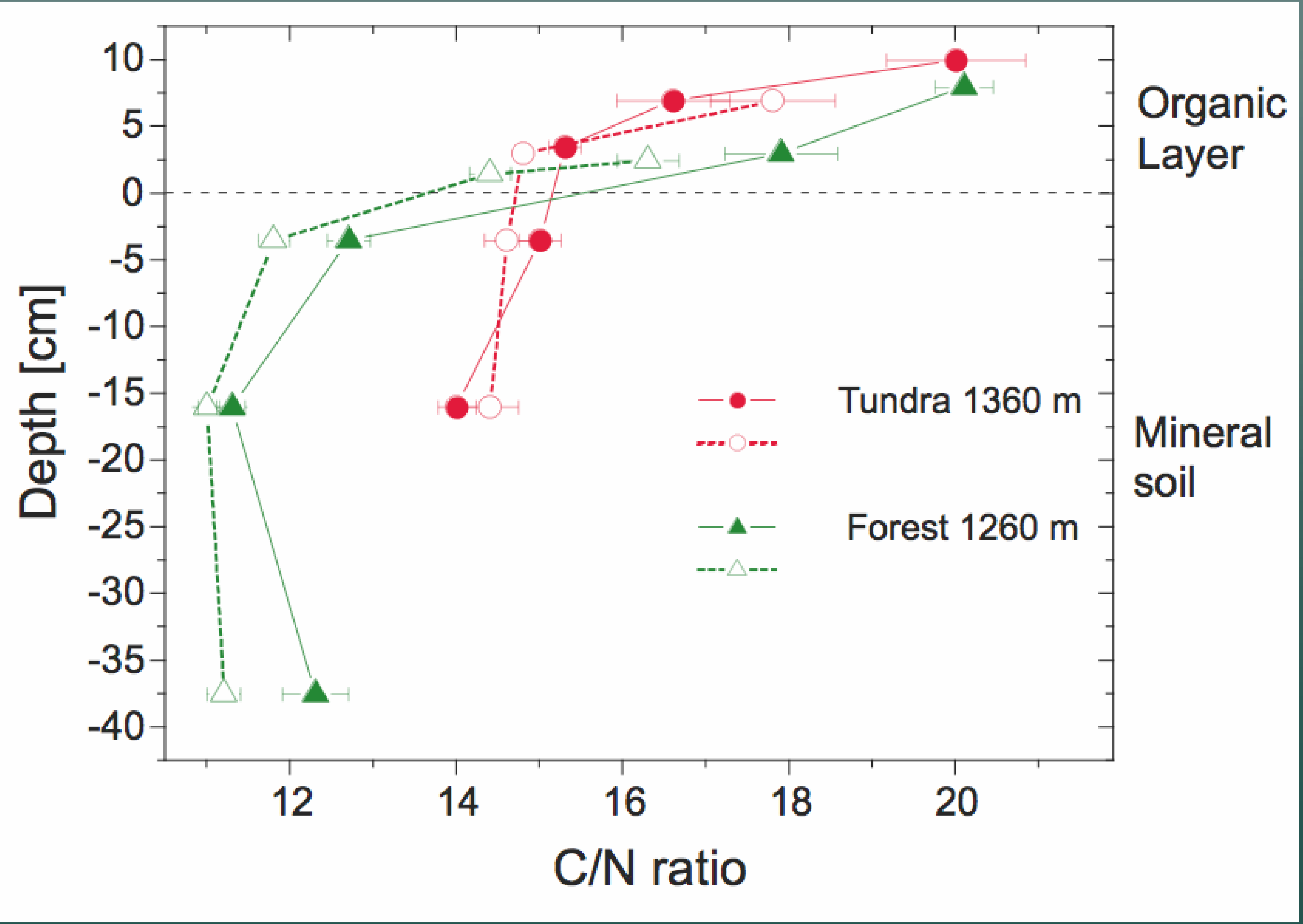
Maly Iremel: Southern-Ural

Kammer, Hagedorn unpublished data

Altitudinal transect Ural:
SOM quality changes from tundra to forest



Altitudinal transect Ural:
SOM quality changes from tundra to forest



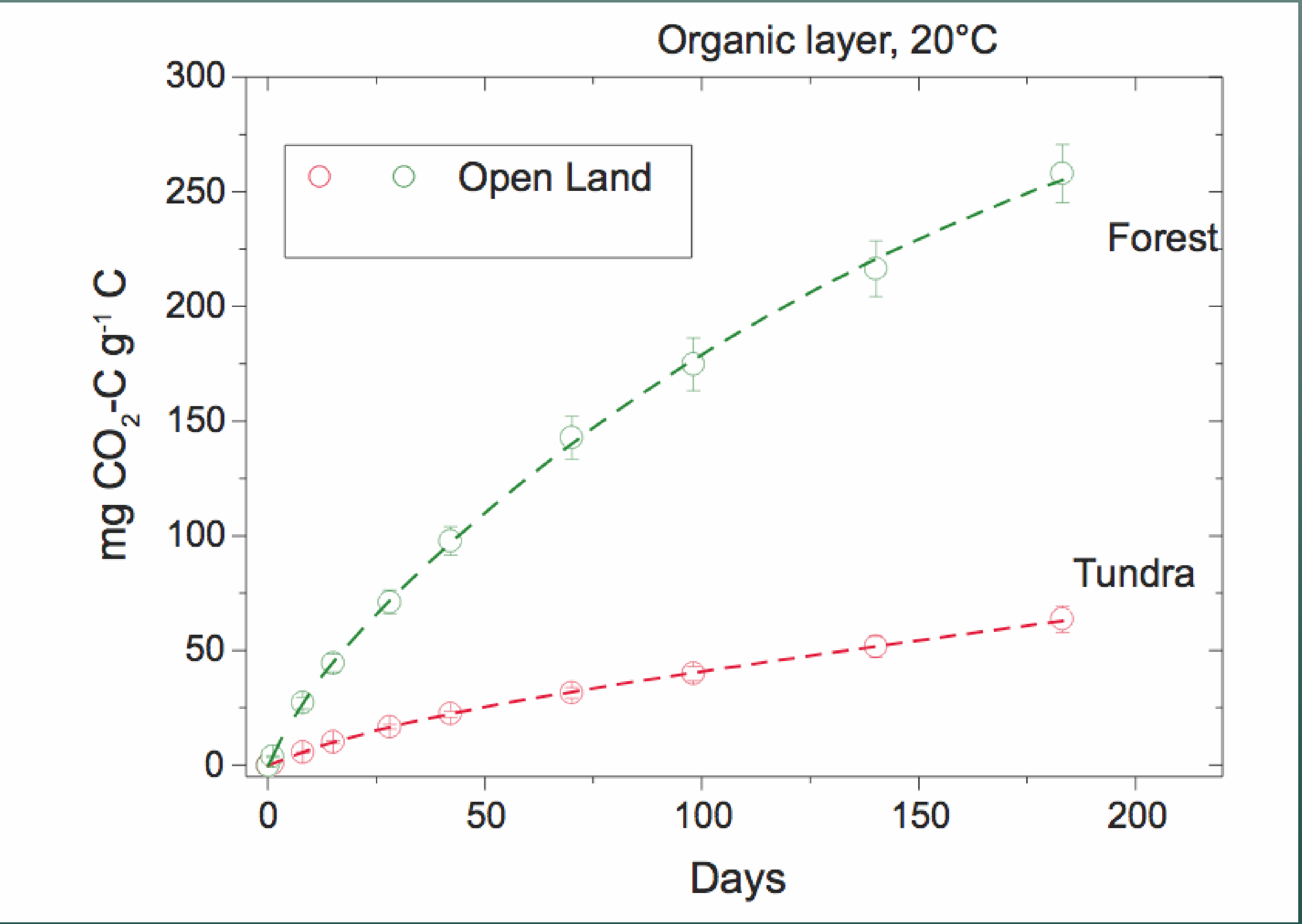
Case study Ural

SOM <–> climate change

Rising treelines and C pools

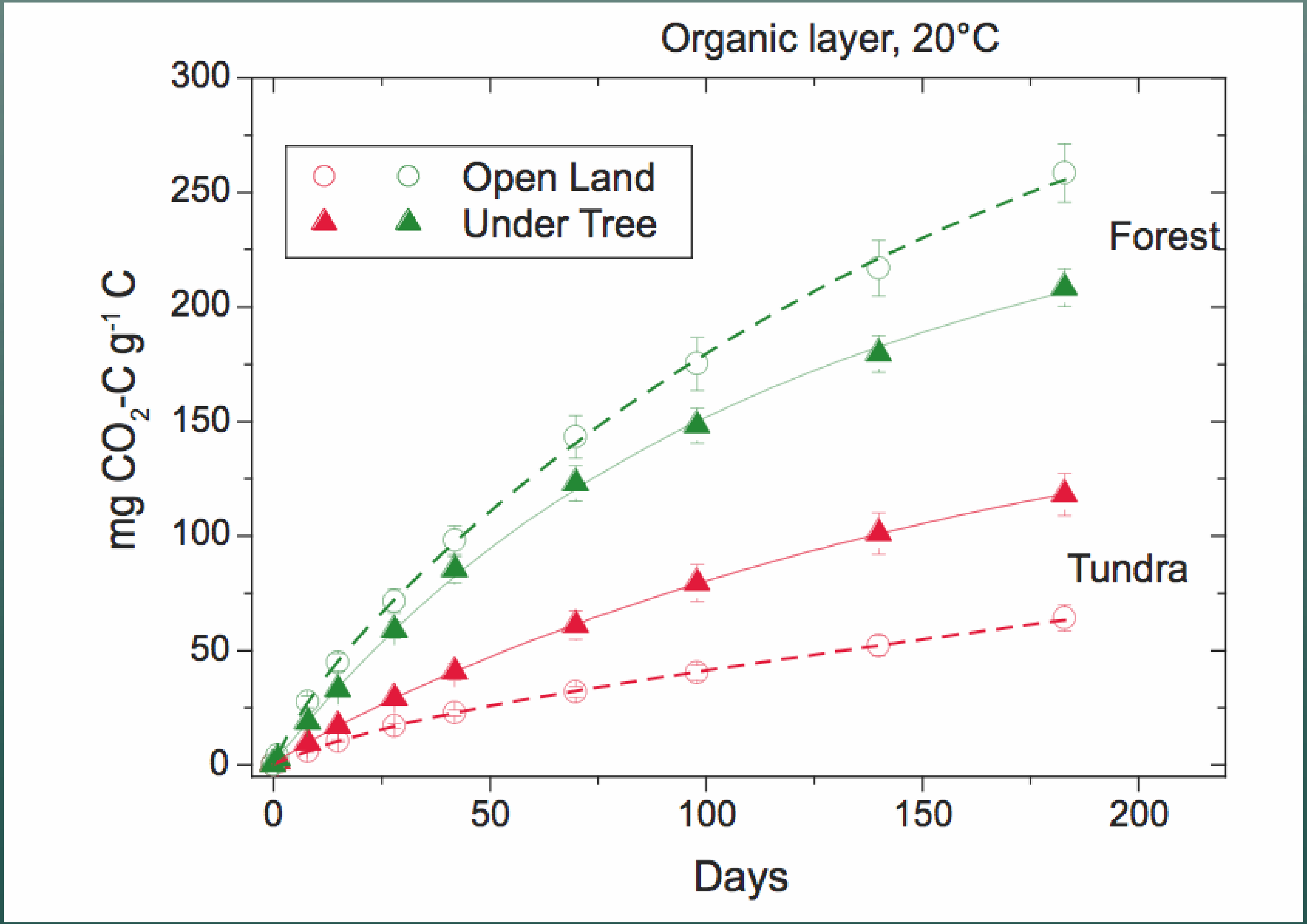
1. Increasing biomass: 15 tC/ha → 75 tC/ha
2. Tripling of litter input
3. 20-40%-increase of soil C pool → + 20-40 t C ha^{-1}
4. SOM quality increases

C-Mineralisation (SOM → CO_2)



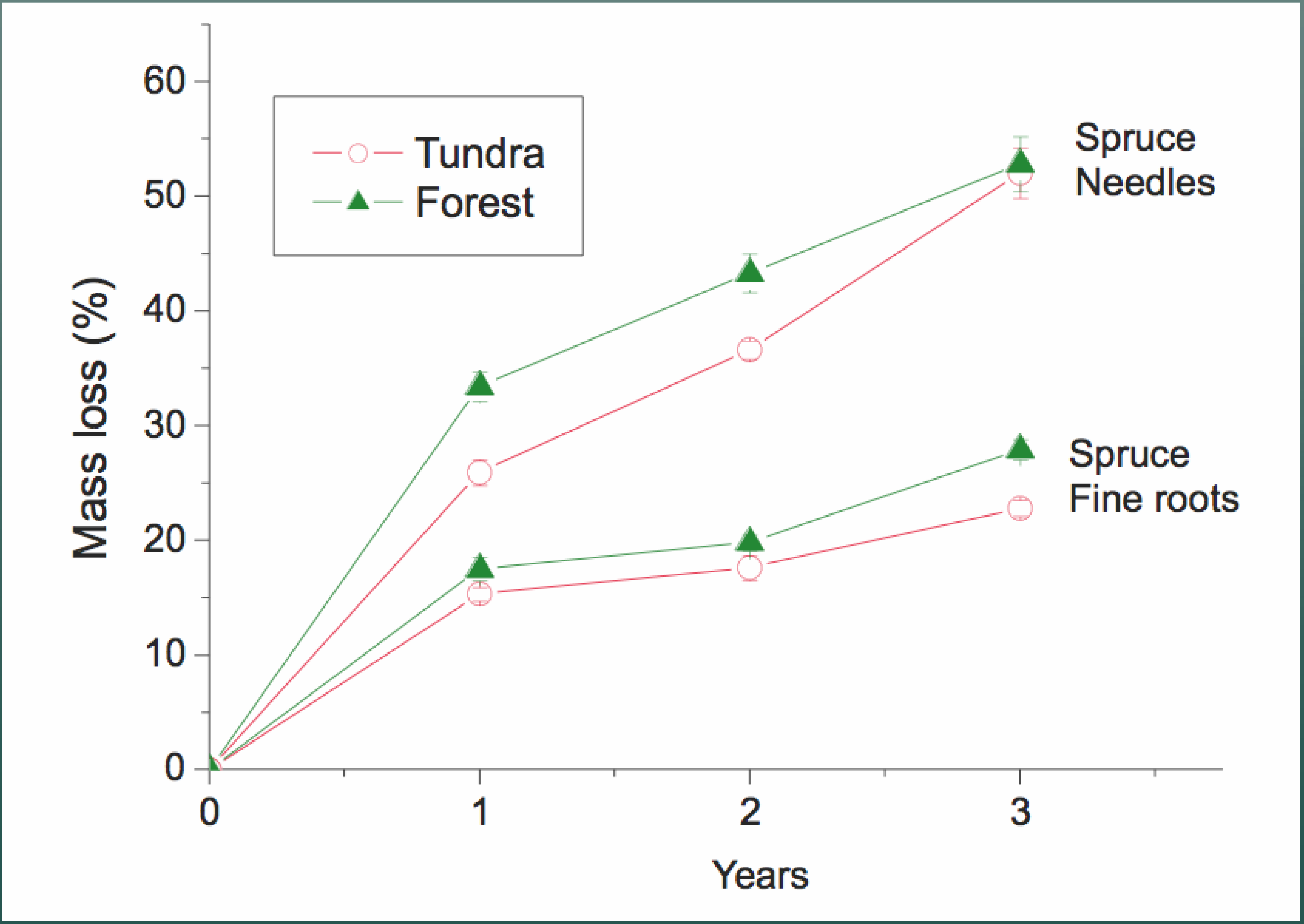
Case study Ural

C-Mineralisation (SOM → CO_2)



Case study Ural

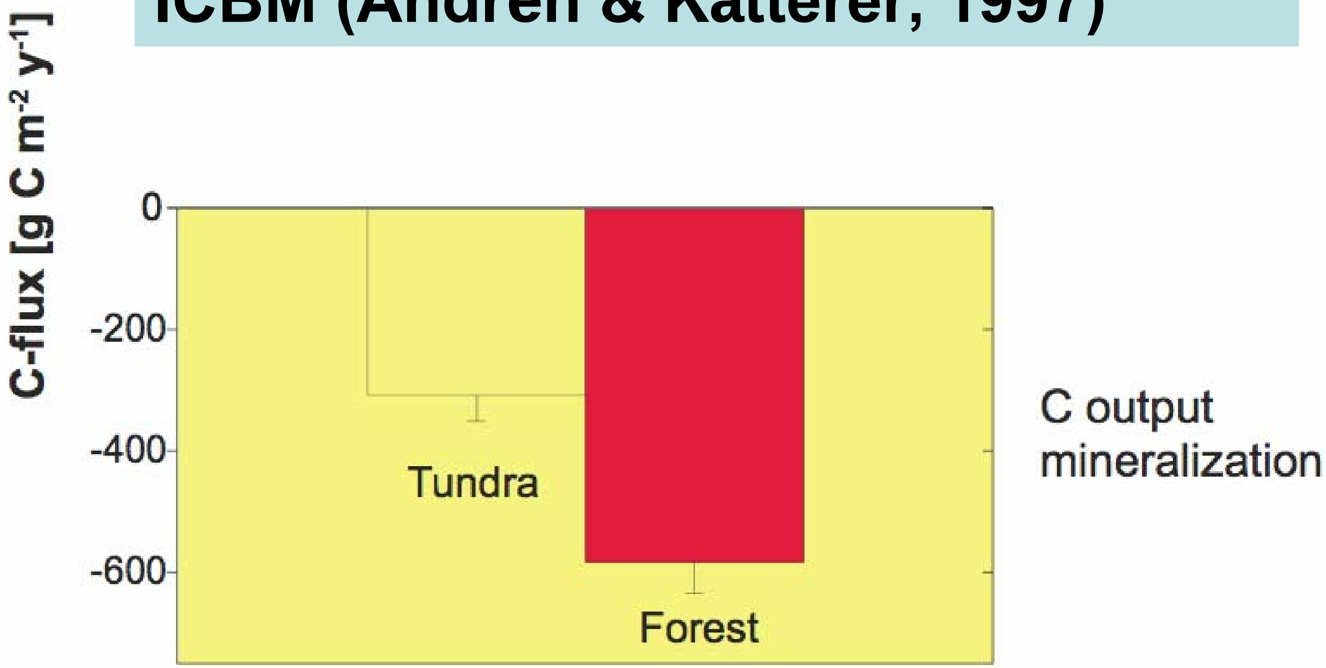
In situ decomposition (litter bags)



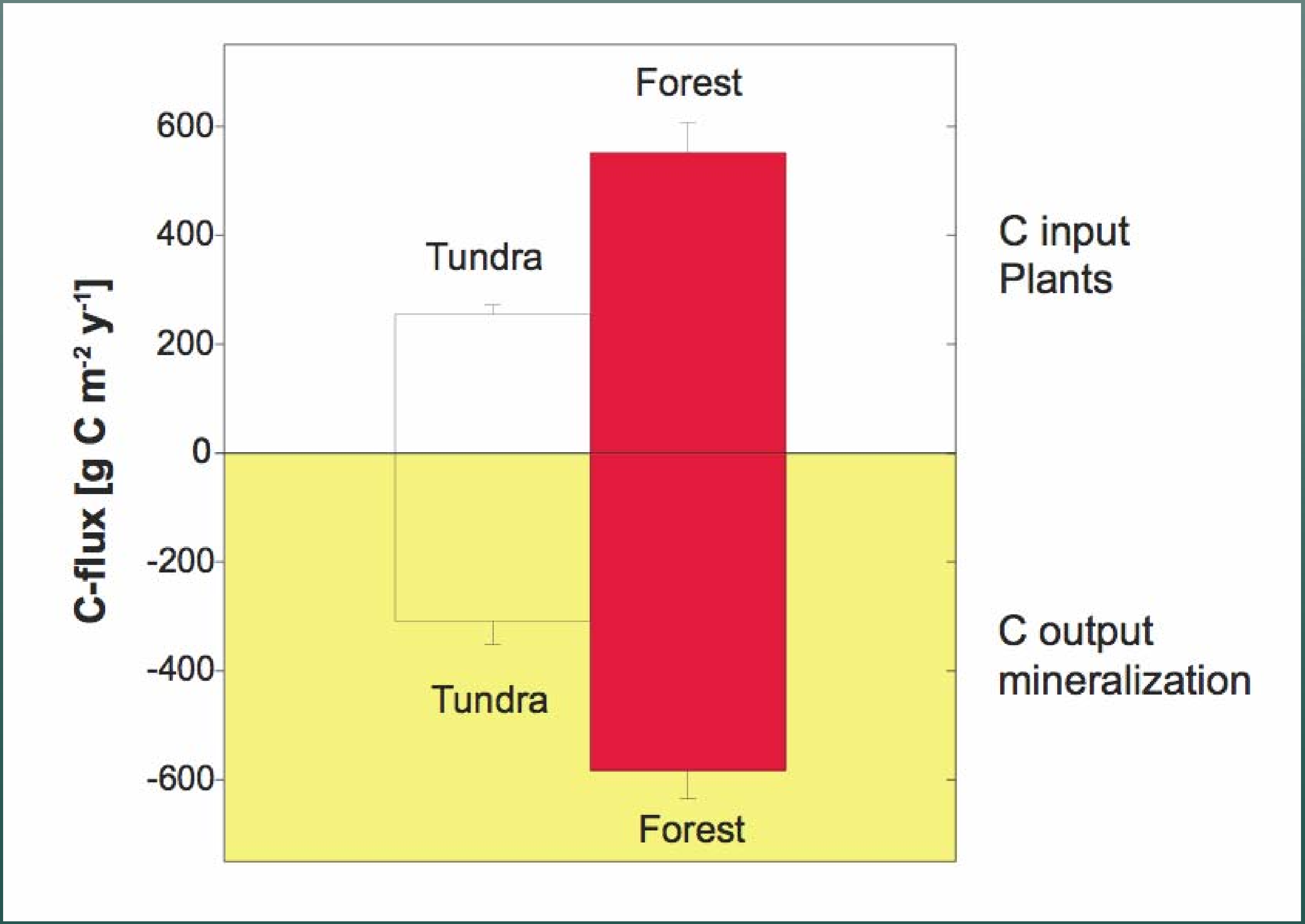
Case study Ural

Annual C mineralization

Modelling with soil temperatures and SOM pools
ICBM (Andrén & Kätterer, 1997)

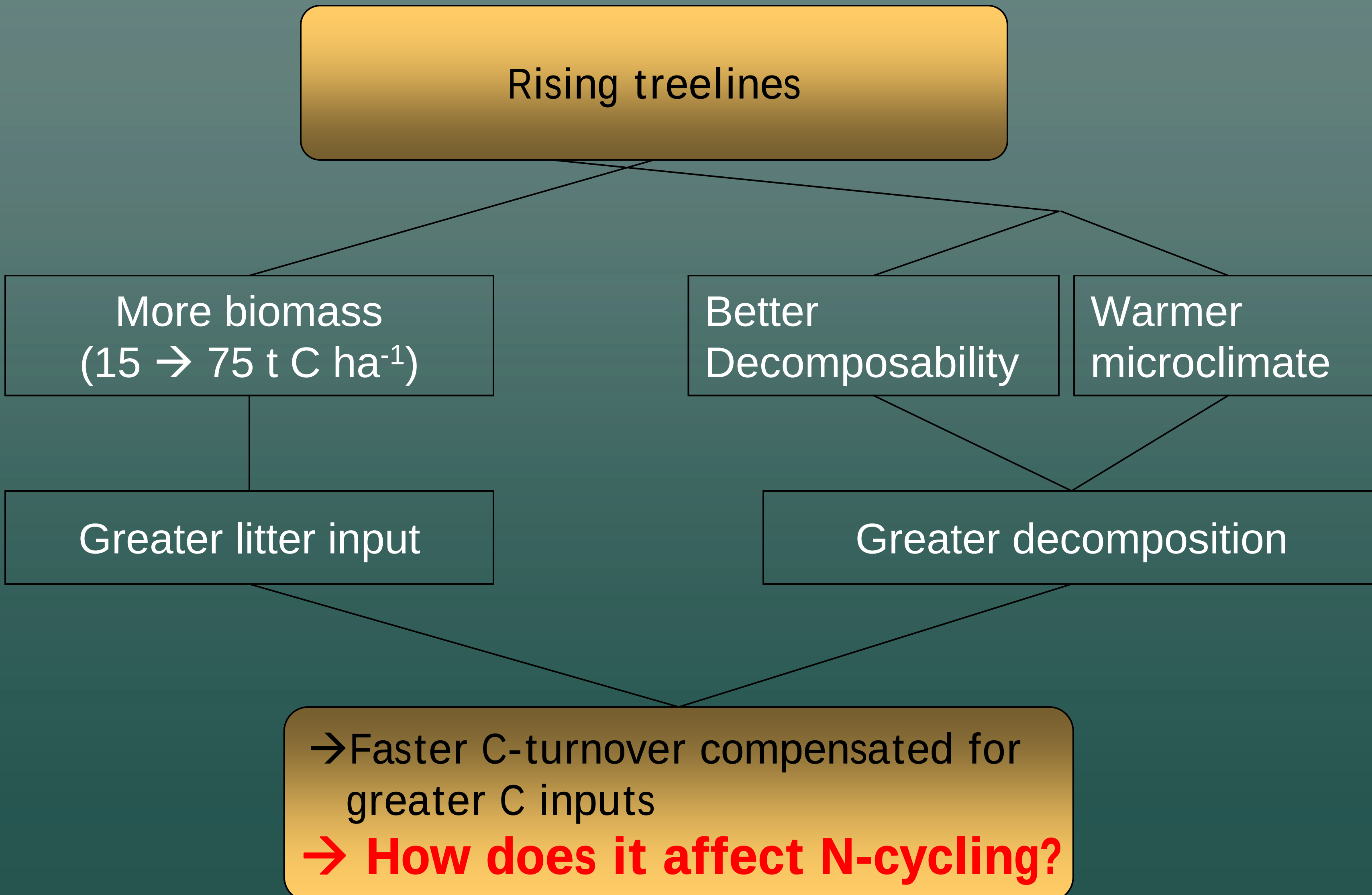


Annual C in- and outputs

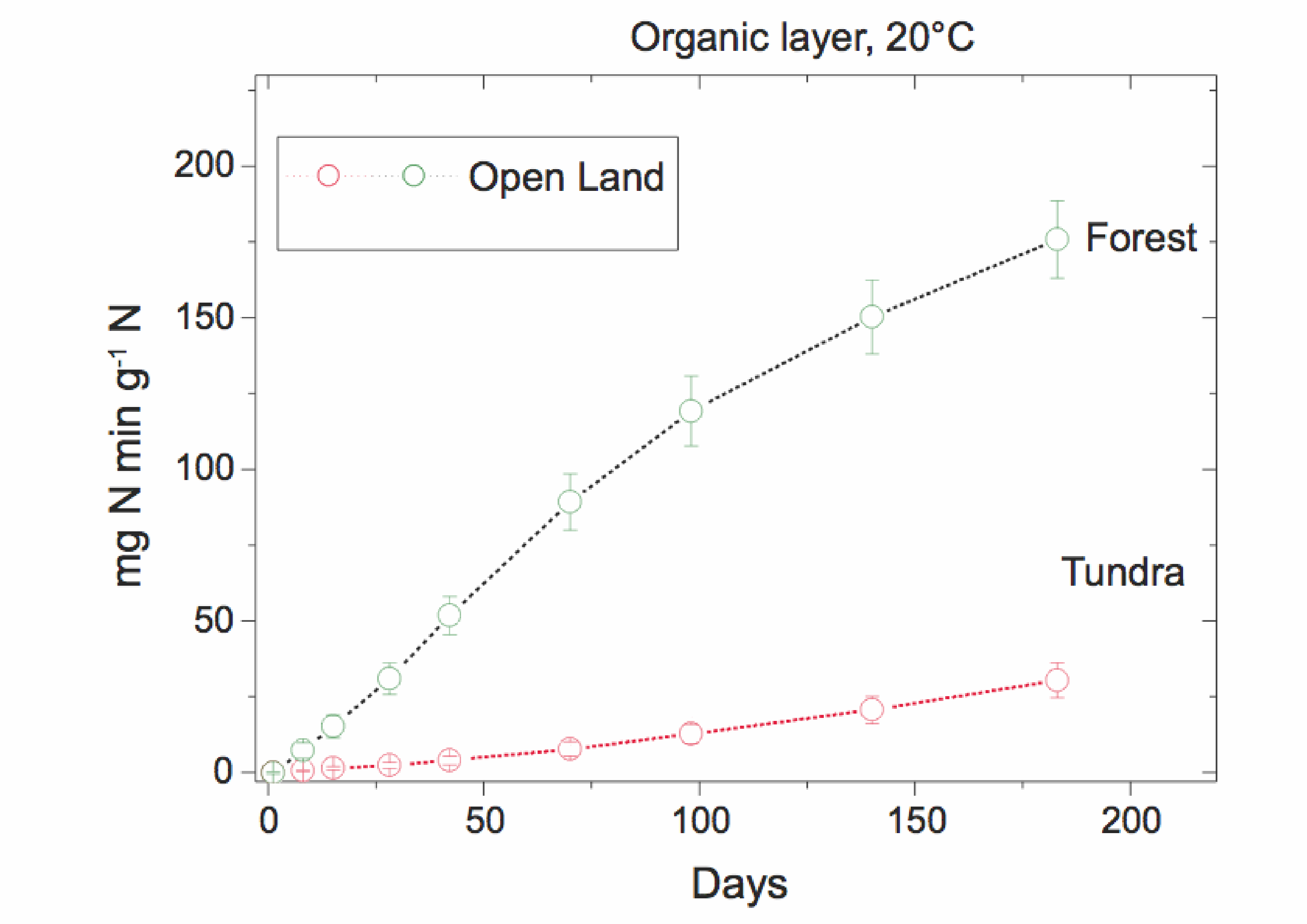


Case study Ural

Summary


Rising treelines
More biomass
(15 → 75 t C ha^{-1})
Better
Decomposability
Warmer
microclimate
Greater litter input
Greater decomposition
→Faster C-turnover compensated for
greater C inputs
→ How does it affect N-cycling?

N-Mineralisation



Case study Ural

Case study Ural

Feedbacks: Winterwarming - Rising Treeline

[1]Devi et al., Global Change Biology 14, 1581-1591, 2008

SOM <-> climate change: Summary

Climatic change likely affects C in- and outputs in similar ways

→ Total SOM pool (=C sink) remains unchanged

→ SOM turnover increases

Thanks!

M. Bauer, P. Egli, T. Handa, S. Hättenschwiler, J. Hutzler, T. Hollmann, A. Kammer, R. Köchli, Ch. Körner, W. Landolt, P. Moiseev, A. Rigling, M. Saurer, R. Siegwolf, D. Spinnler, D. Tarjan, A. Zürcher,…

Schweizer Nationalfonds, BAFU, EU-INTAS