

# Importance and frequency of freeze-thaw events for annual N<sub>2</sub>O emissions from temperate forest and grassland ecosystems

Butterbach-Bahl K<sup>1</sup>, Brüggemann N<sup>1</sup>, Papen H<sup>1</sup>, Holst J<sup>1</sup>,  
Liu C<sup>2</sup>, Zheng X<sup>2</sup>

<sup>1</sup>Forschungszentrum Karlsruhe, Institute for Meteorology and  
Climate Research (IMK-IFU), Germany

<sup>2</sup>Institute for Atmospheric Physics, Chinese Academy of Sciences,  
Beijing, China



## Motivation:

- Enhanced N<sub>2</sub>O emission from arable soils during freeze-thaw cycles have been reported as early as 1982 (Duxbury et al., *Nature*) and studied in detail later (e.g. Christensen & Tiedje, 1990, *J. Soil Sci.*)
- For natural ecosystems (forest soils) freezing-thawing effects on N<sub>2</sub>O emissions were first shown by Papen & Butterbach-Bahl (1999, *JGR*)
- N<sub>2</sub>O emissions during freezing-thawing periods can contribute significantly to the annual N<sub>2</sub>O emission of a site
- However, poorly constrained due to
  - lack of measurements in wintertime
  - restriction of measurements to a few sites (generalization problem)
  - lack of process understanding

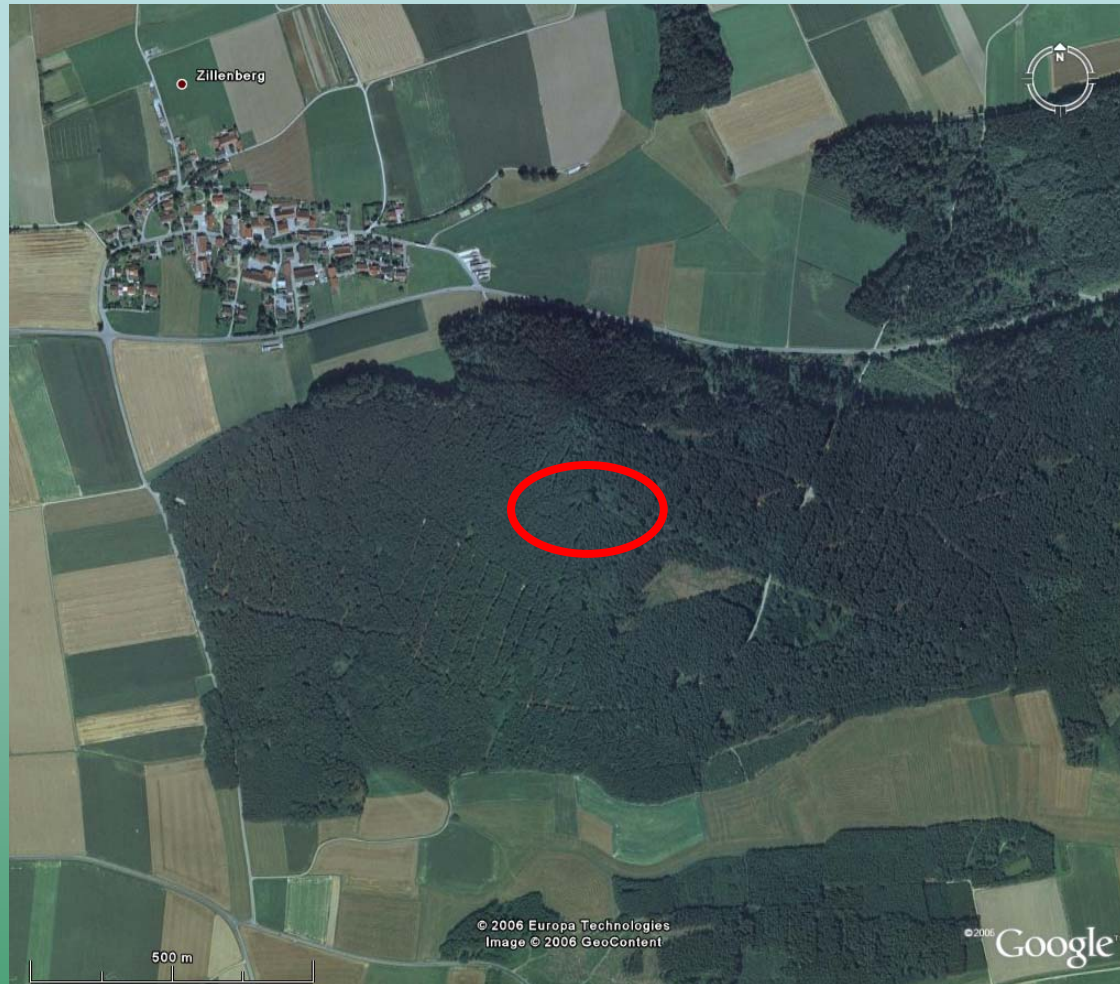


## Goal of the study:

- Quantify importance of N<sub>2</sub>O emissions during freeze-thaw cycles from a temperate forest soils for the annual budget
- Determination of reoccurrence rates
- Portability of results to other natural/ semi-natural systems (forests/ steppe)
- Process identification



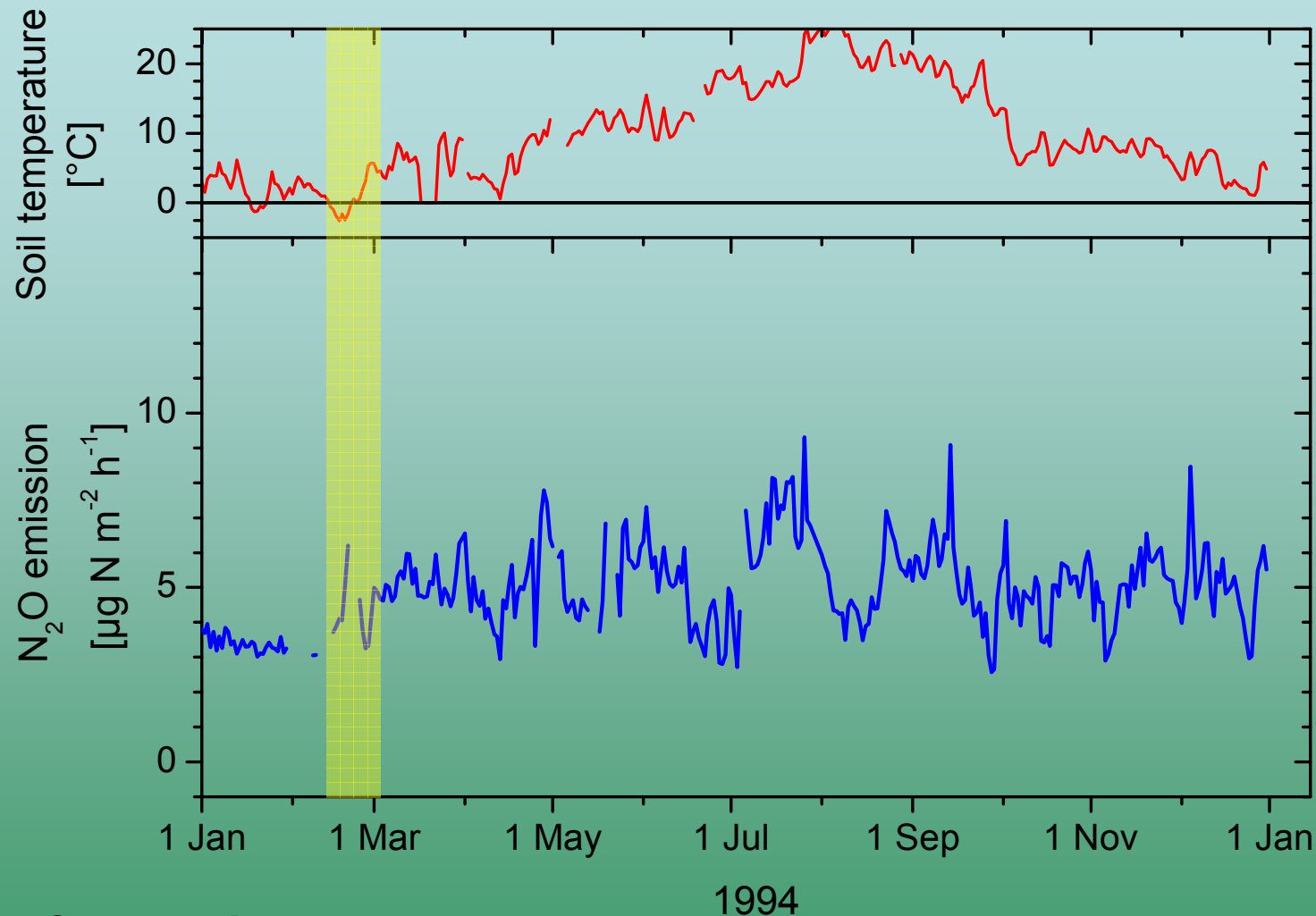
## Location of the Höglwald field site



- Continuous measurements of  $N_2O$  emissions 1994-1997 and 1999-present
- N deposition 20-30 kg N
- Loamy soil texture



## Höglwald: the first full year of measurements

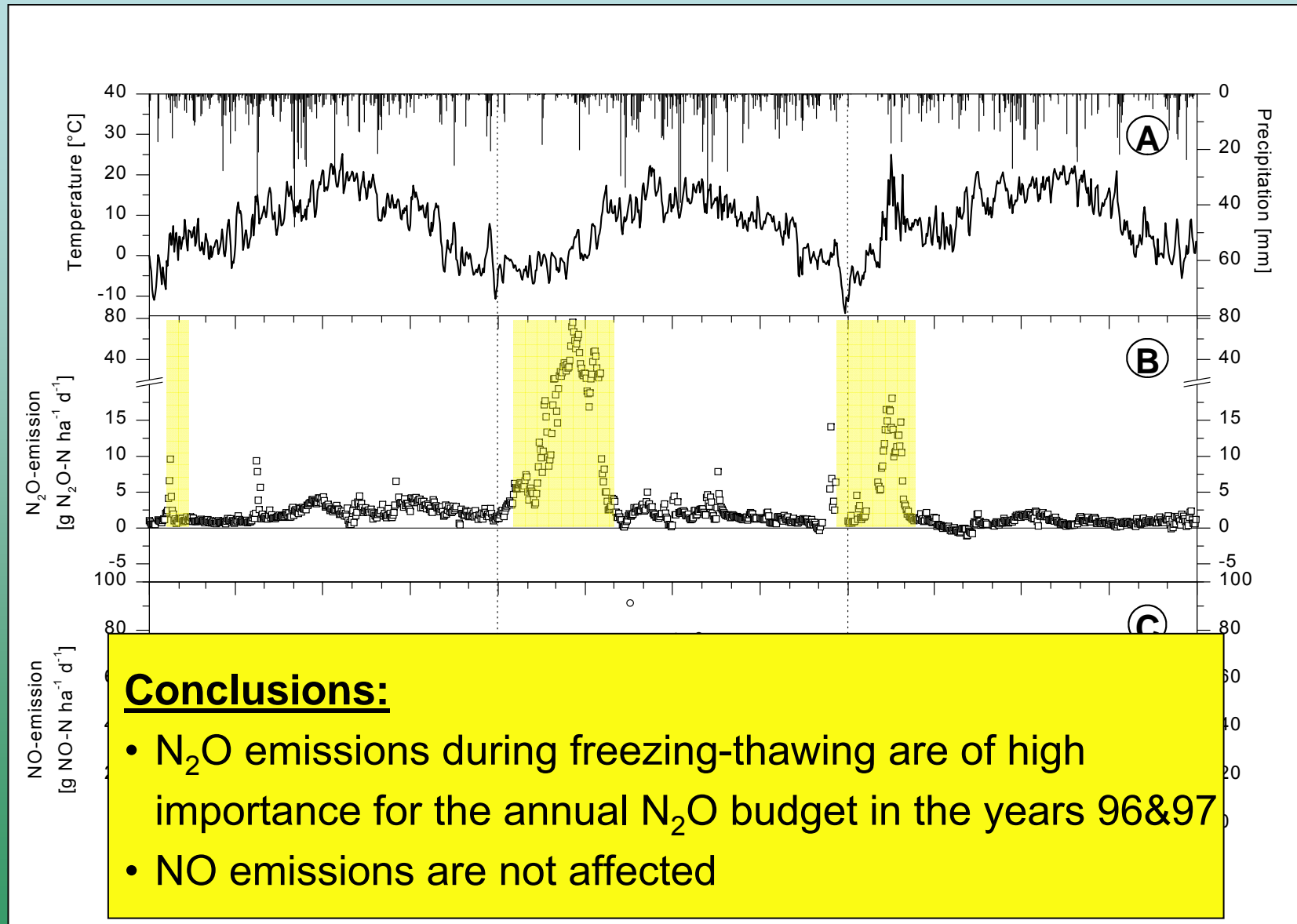


### Conclusions:

- Annual emissions approx. 0.5 – 0.6 kg N ha<sup>-1</sup> yr<sup>-1</sup> (spruce, control)
- Freezing-thawing can be neglected at the Hoeglwald site in 1994

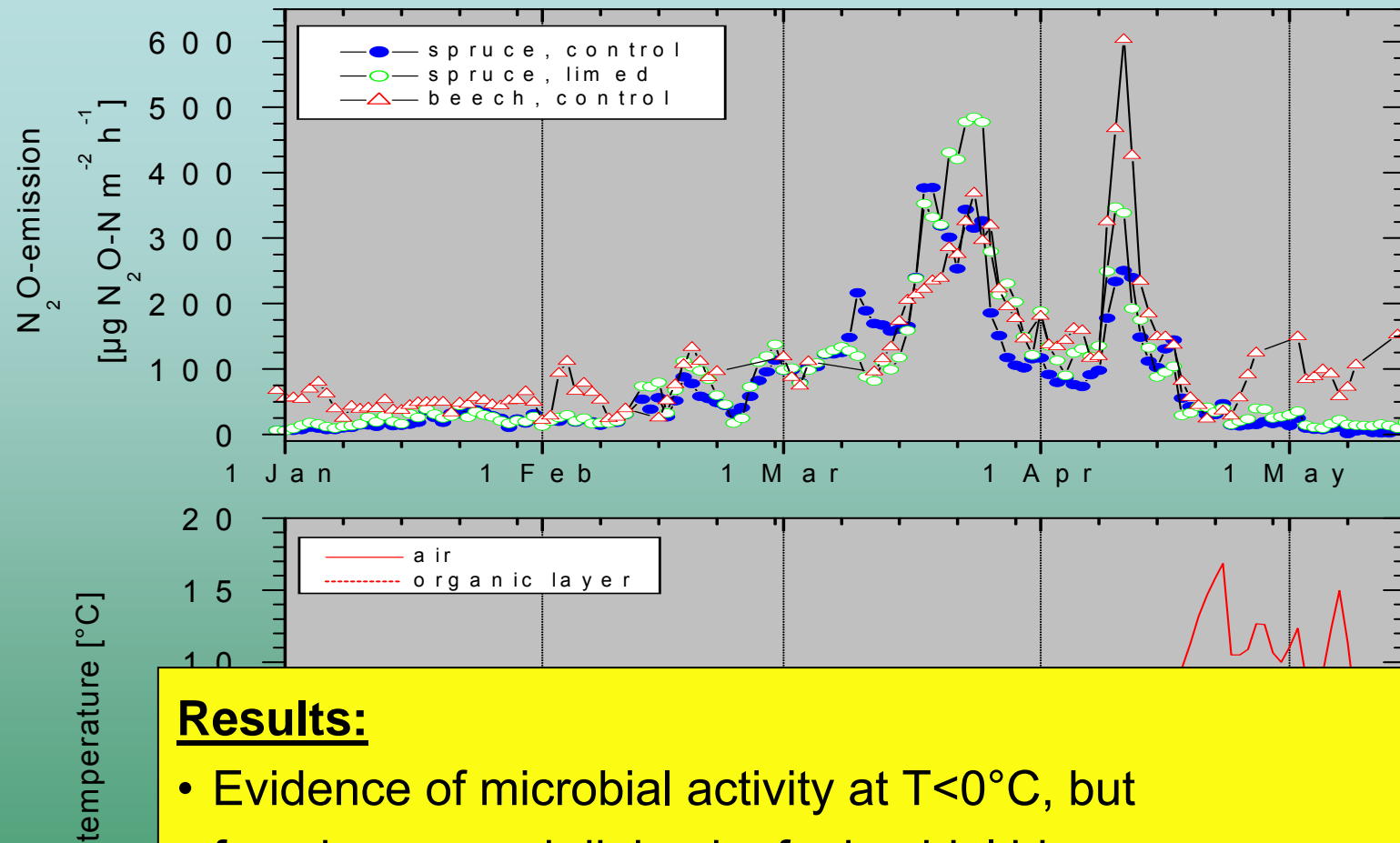


## Höglwald: 1995 onwards - it becomes interesting





## Höglwald: 1996 – details

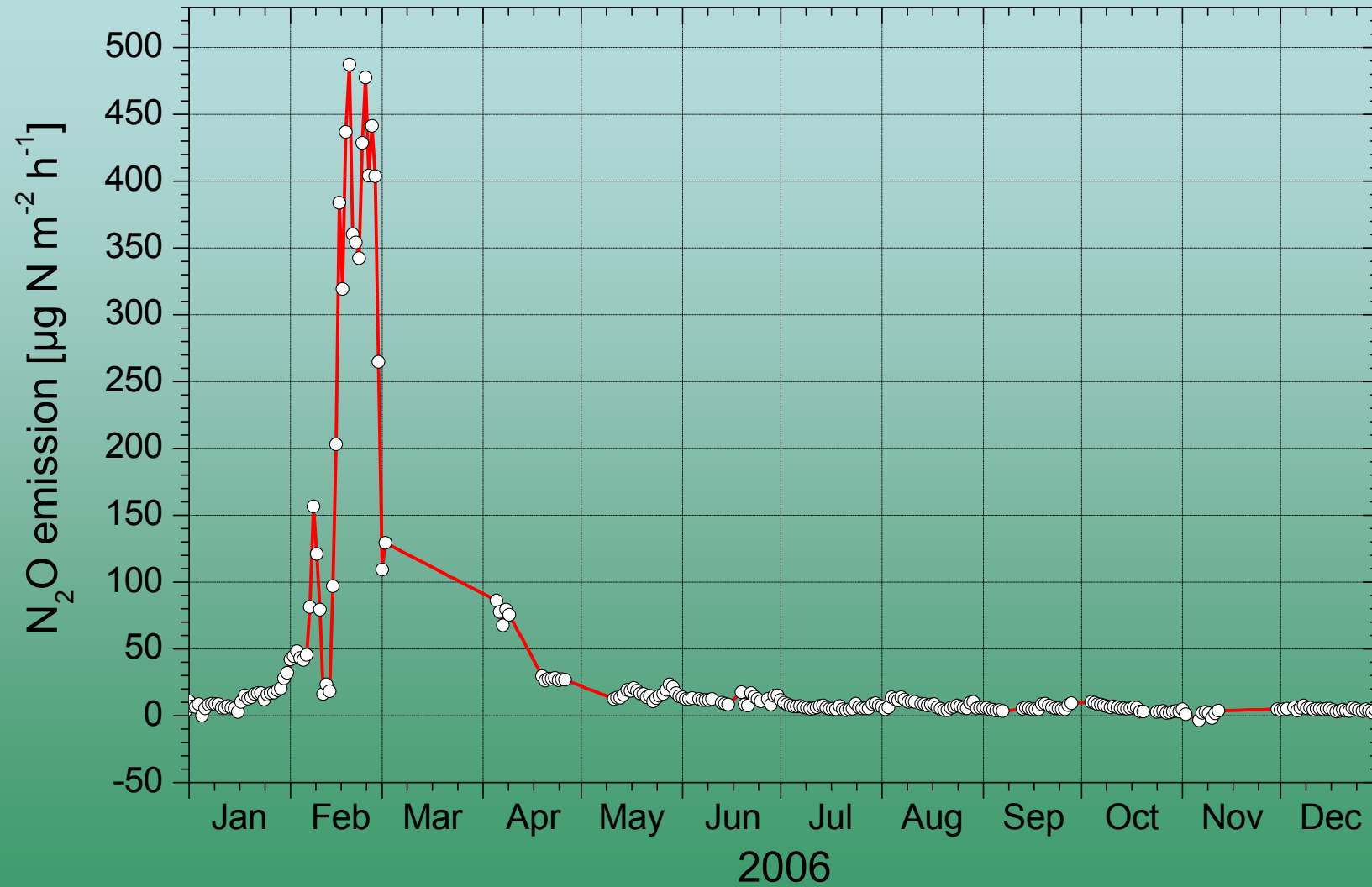


### Results:

- Evidence of microbial activity at  $T < 0^{\circ}\text{C}$ , but
- freezing caused dieback of microbial biomass
  - $50 \text{ kg N ha}^{-1} \rightarrow 30 \text{ kg N ha}^{-1}$
  - $\approx 700 \mu\text{g N m}^{-2} \text{ h}^{-1}$  easily degradable substrate
- No significant tree-species effect



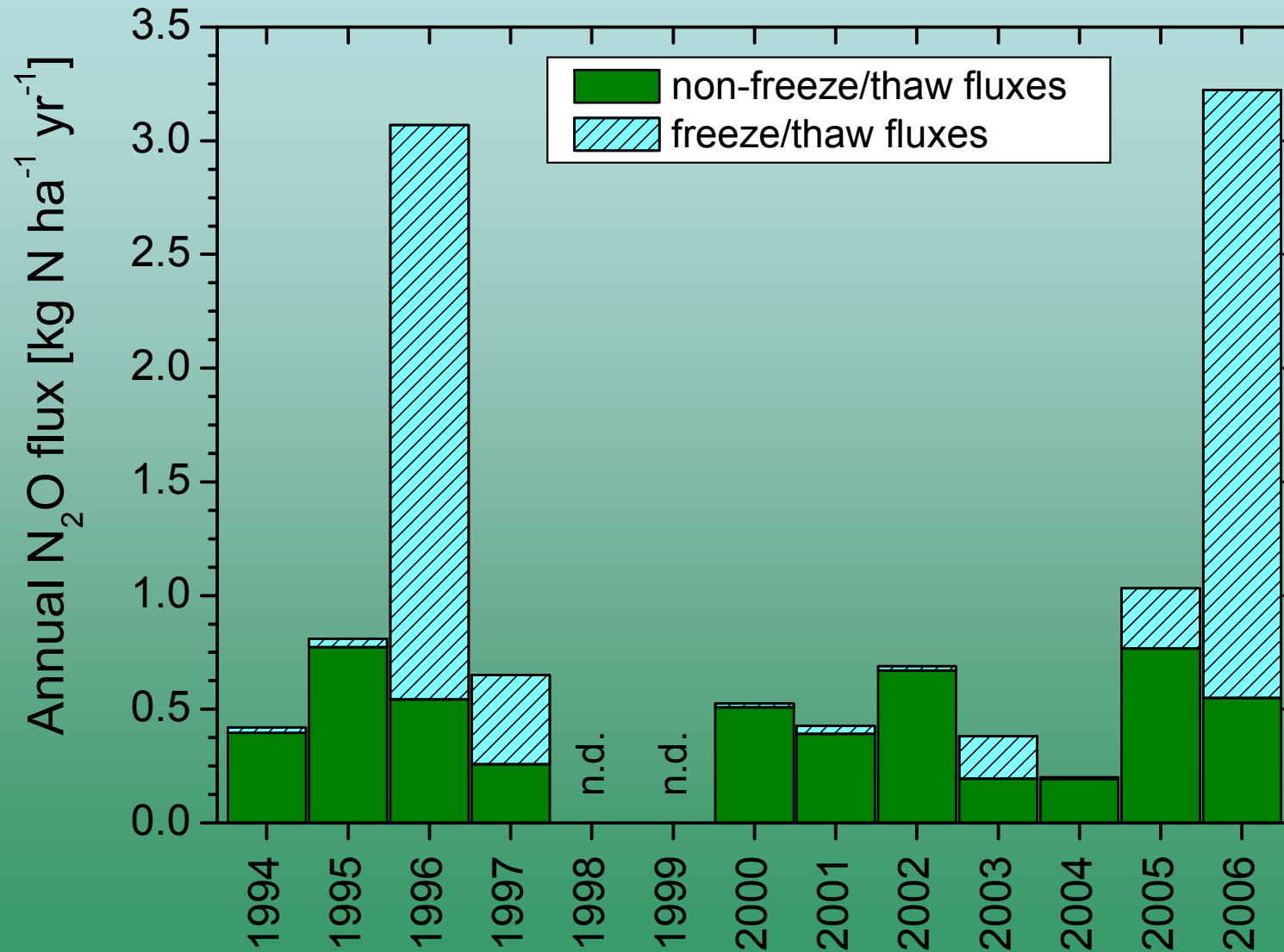
## Höglwald: Also strong freezing-thawing effect in 2006





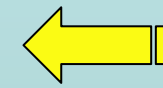
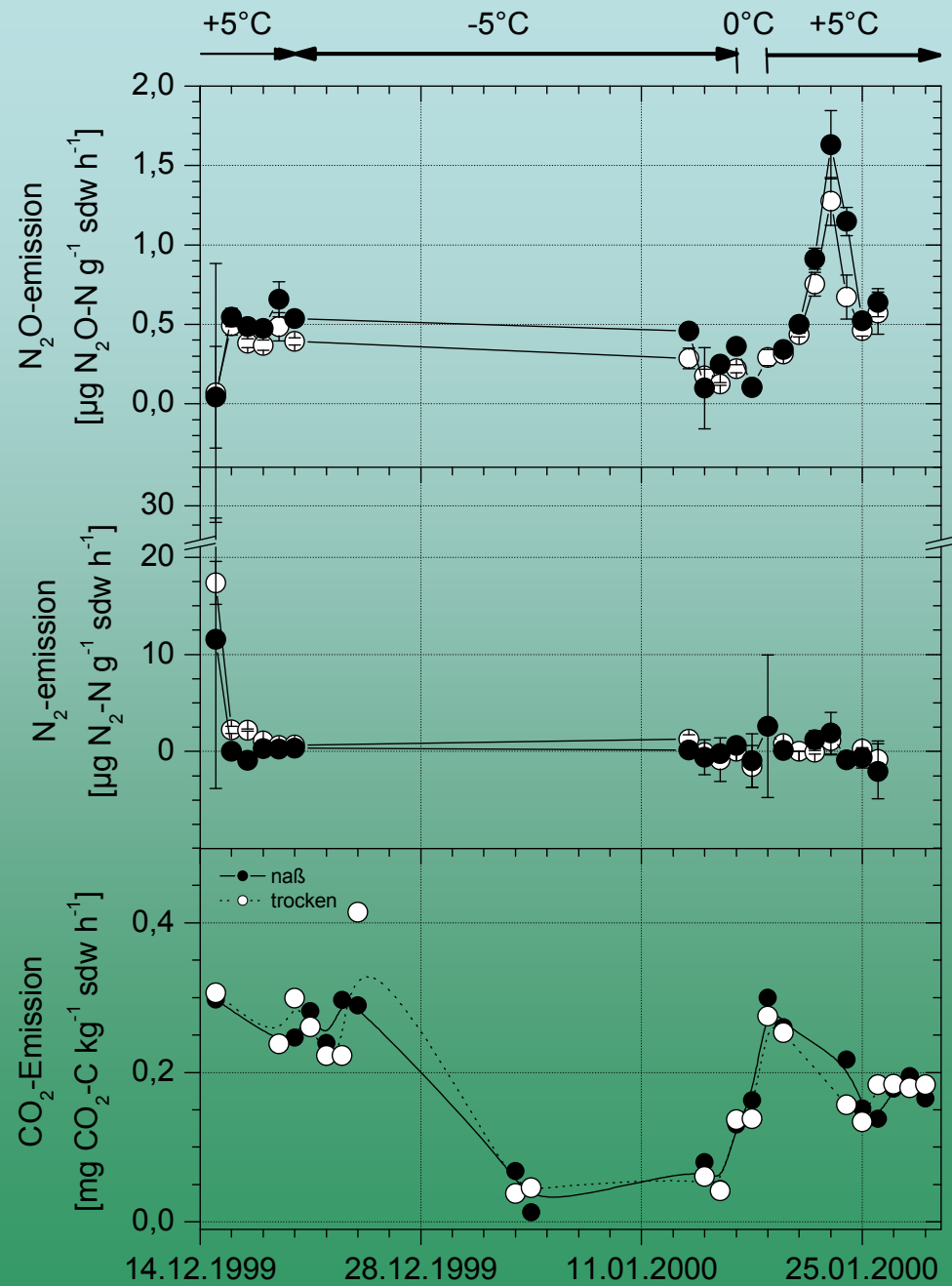


## Höglwald: Importance of freezing/thawing events

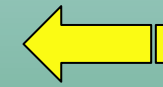




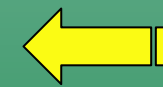
# Höglwald: intact soil core studies (N $\geq$ 3)



N<sub>2</sub>O emission pulse  
after 4 weeks  
freezing



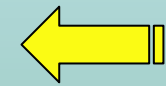
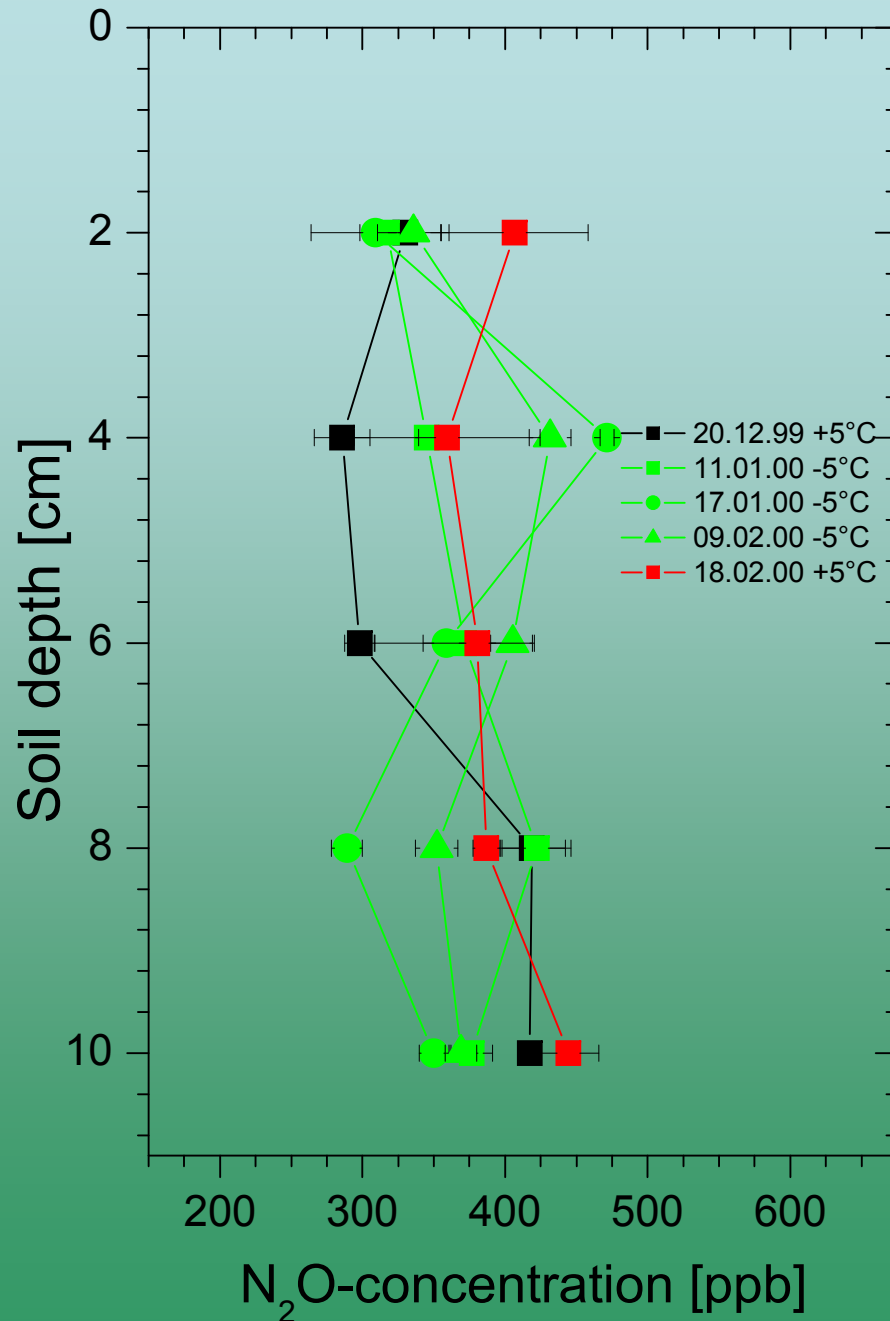
N<sub>2</sub>-emission are close  
to the detection limit



Increased microbial  
respiration during  
thawing



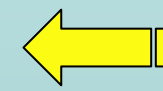
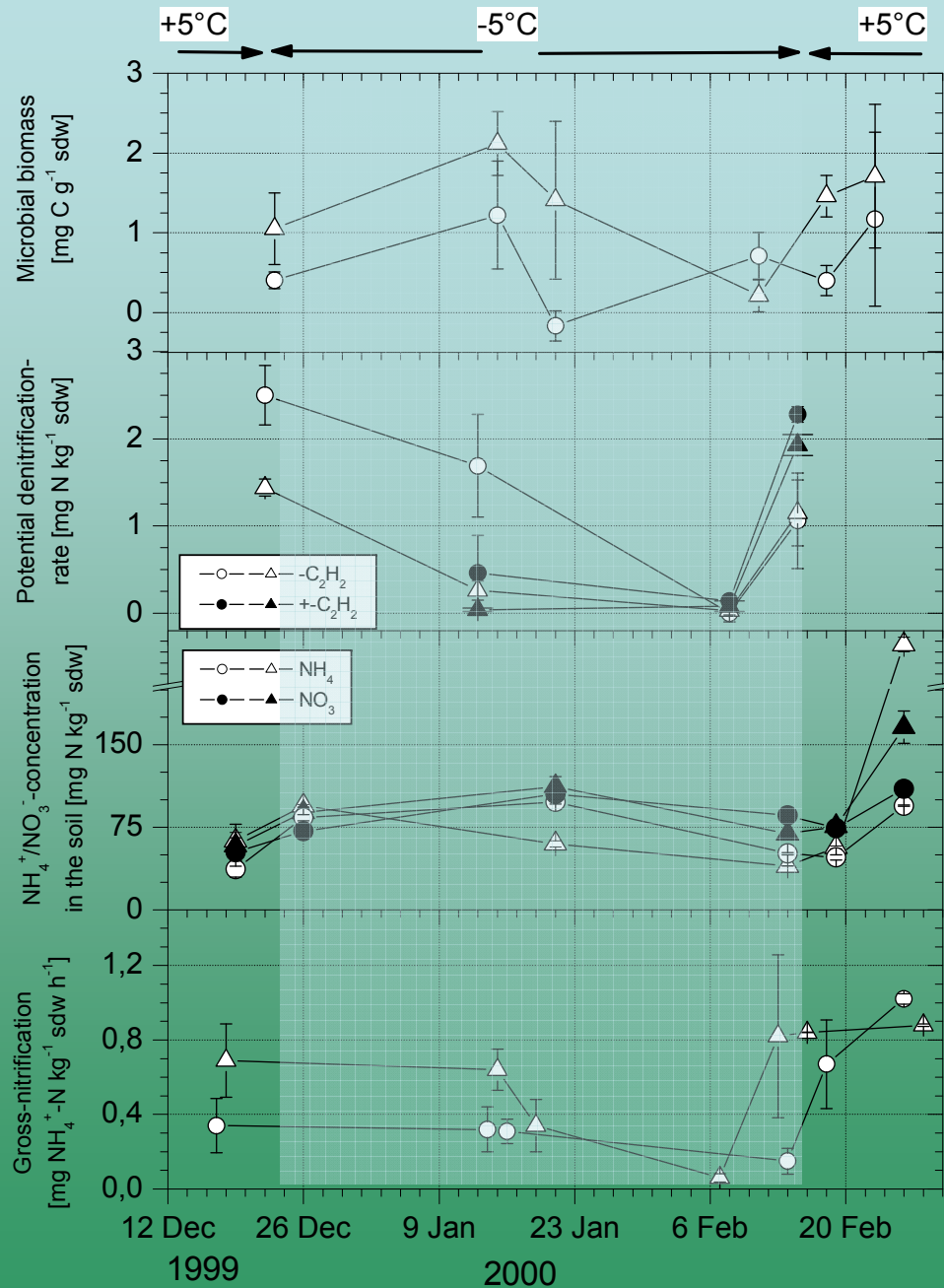
## Höglwald: intact soil core studies (N $\geq$ 3)



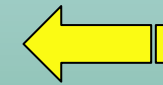
No major changes in soil N<sub>2</sub>O concentrations during freezing, i.e. → Pulse of N<sub>2</sub>O at thawing cannot come from stored N<sub>2</sub>O



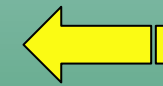
# Höglwald: intact soil core studies (N $\geq$ 3)



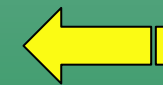
Microbial biomass dieback during freezing



Increased denitrification potential during thawing



Increased availability of inorganic N after thawing



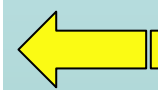
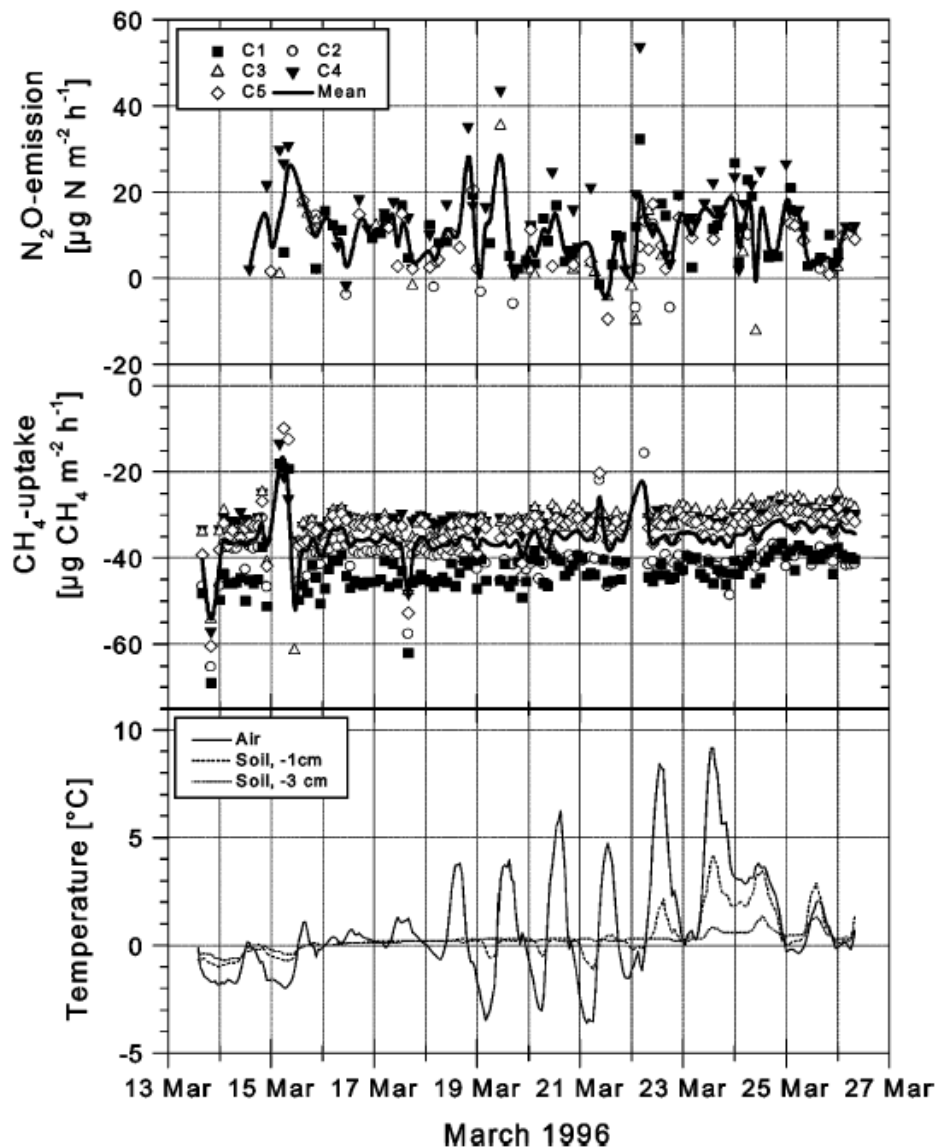
Increased gross nitrification during and after thawing



## Höglwald: Summary

- Microbial biomass dies back during freezing
- During thawing inorganic N accumulates
- Gross nitrification and potential denitrification rates start to increase at thawing
- Thawing is accompanied with a pulse of CO<sub>2</sub> emissions, indicating quick recovery of microbial respiration
- During and after thawing N<sub>2</sub>O emissions, but not N<sub>2</sub> emissions are elevated
- Magnitude of the effect of freezing/thawing on N<sub>2</sub>O emissions depends on the length of the freezing period

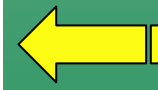
# Portability of Höglwald results to other forest sites: Pine forests in East Germany



But no significant freezing/ thawing effect on N<sub>2</sub>O emissions

Missing of freezing/thawing effect due to differences in texture and, thus, soil moisture:

Höglwald: loamy texture  
Eberswalde: sandy texture



Same period as Höglwald peak emissions



# Can freezing/thawing effects on N<sub>2</sub>O emissions be observed elsewhere?

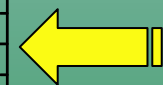
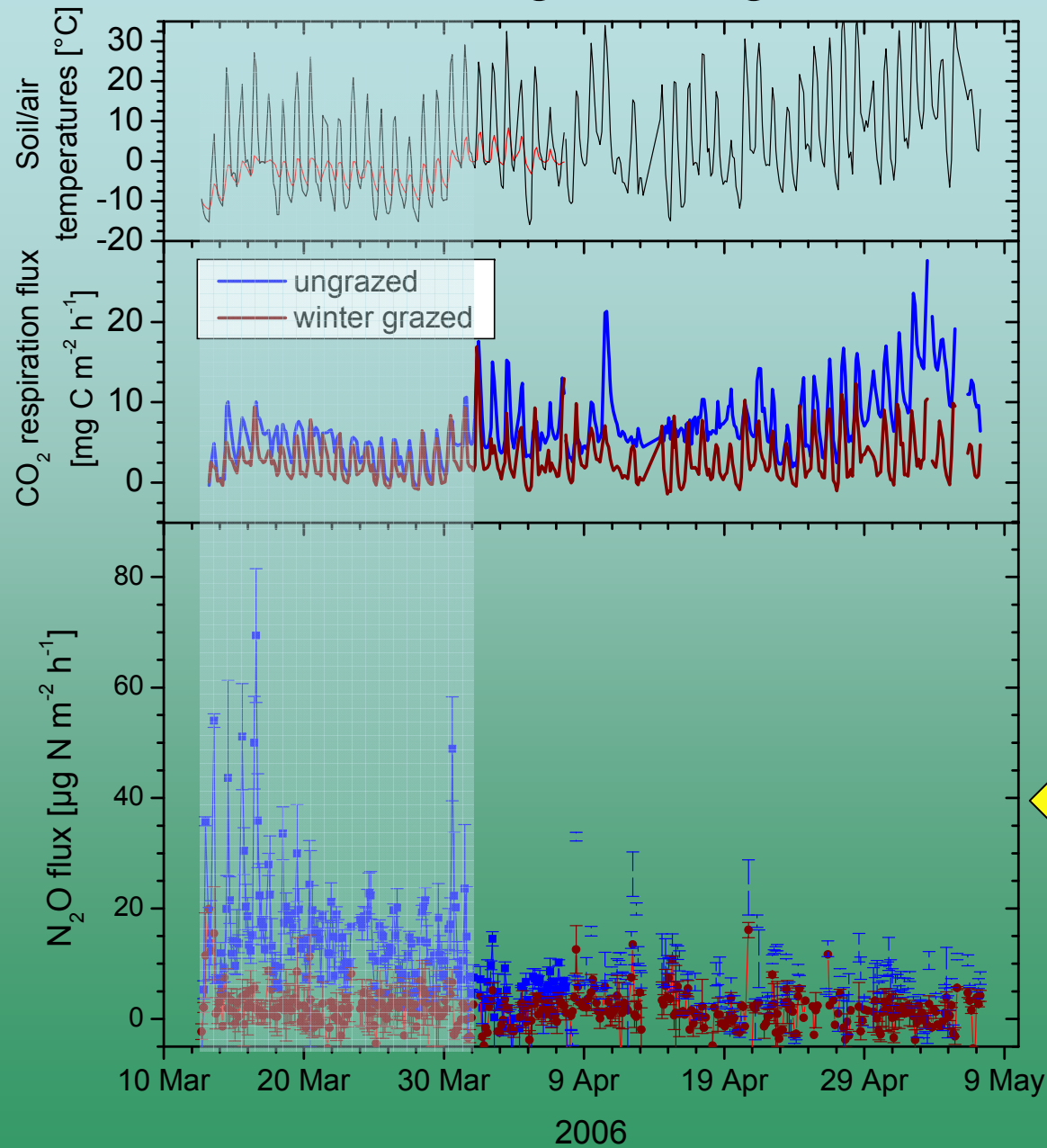


Continuous measurement  
of N and C trace gas  
emissions from  
March to July 2006





# Freezing/thawing effects in steppe

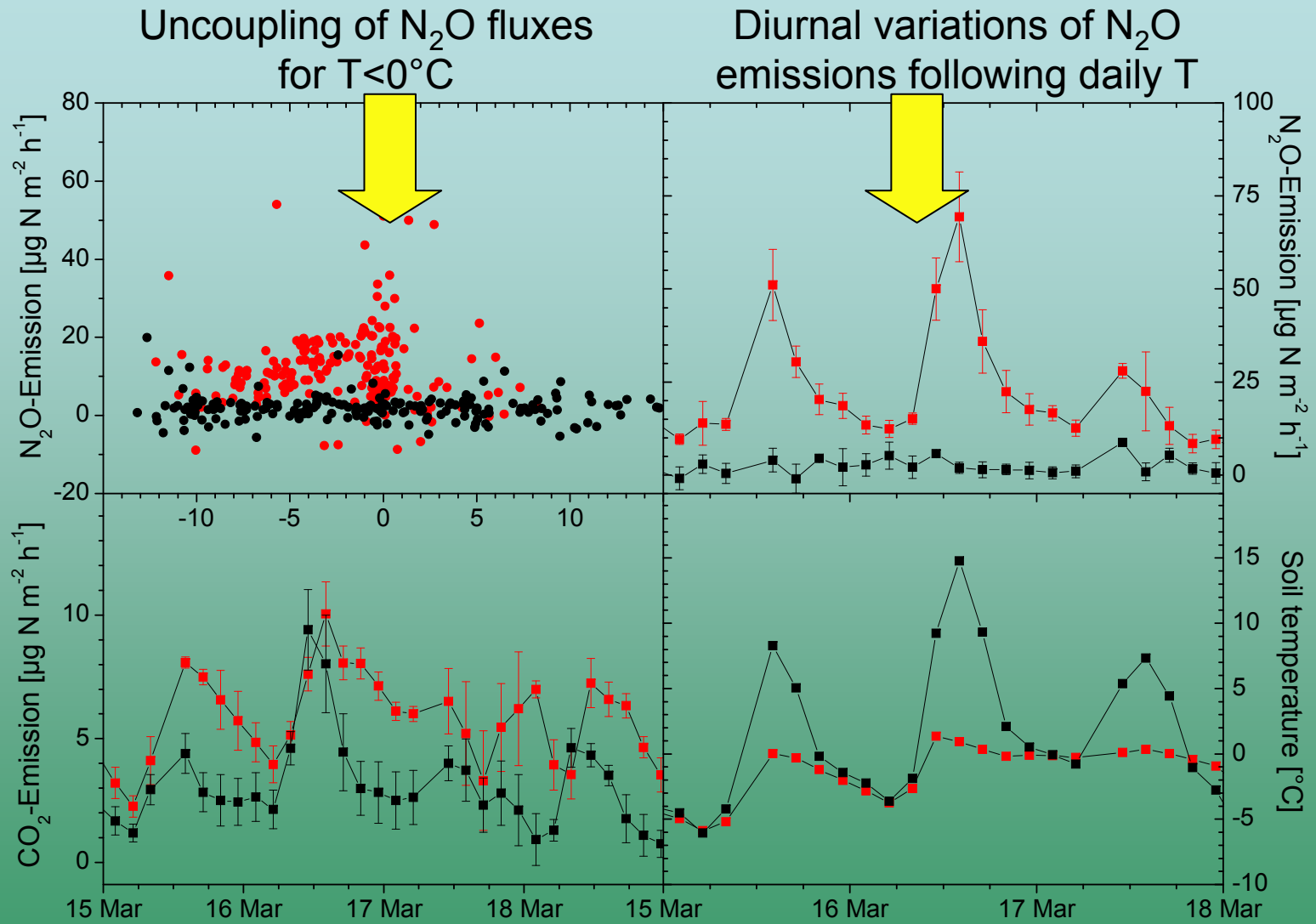


Freezing/ thawing effect on  $\text{N}_2\text{O}$  emissions only in ungrazed steppe





# Freezing/thawing effects in steppe





## Conclusions

- freeze/ thaw effects are caused by
  - dieback of microbial biomass
  - stimulated nitrification/ denitrification
- freeze/ thaw effects
  - occur after prolonged freezing periods
  - need sufficient moisture (also texture effects)
  - are surface phenomena (top few millimeters)
  - only affect  $N_2O$ , but not  $NO$  and  $N_2$  emissions
- freeze/ thaw effects on  $N_2O$  emissions can be of high significance for the annual  $N_2O$  budget of a site
- can occur in a wide variety of natural/ semi-natural ecosystems