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in der Helmholtz-Gemeinschaft
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Atmosphärische Umweltforschung (IMK-IFU), Garmisch-Partenkirchen

International Symposium on Soil Processes Under Extreme Meteorological Conditions
Bayreuth, Germany, February 25th – 28th, 2007

Importance and frequency of freeze-thaw events for annual N_2O emissions from temperate forest and grassland ecosystems

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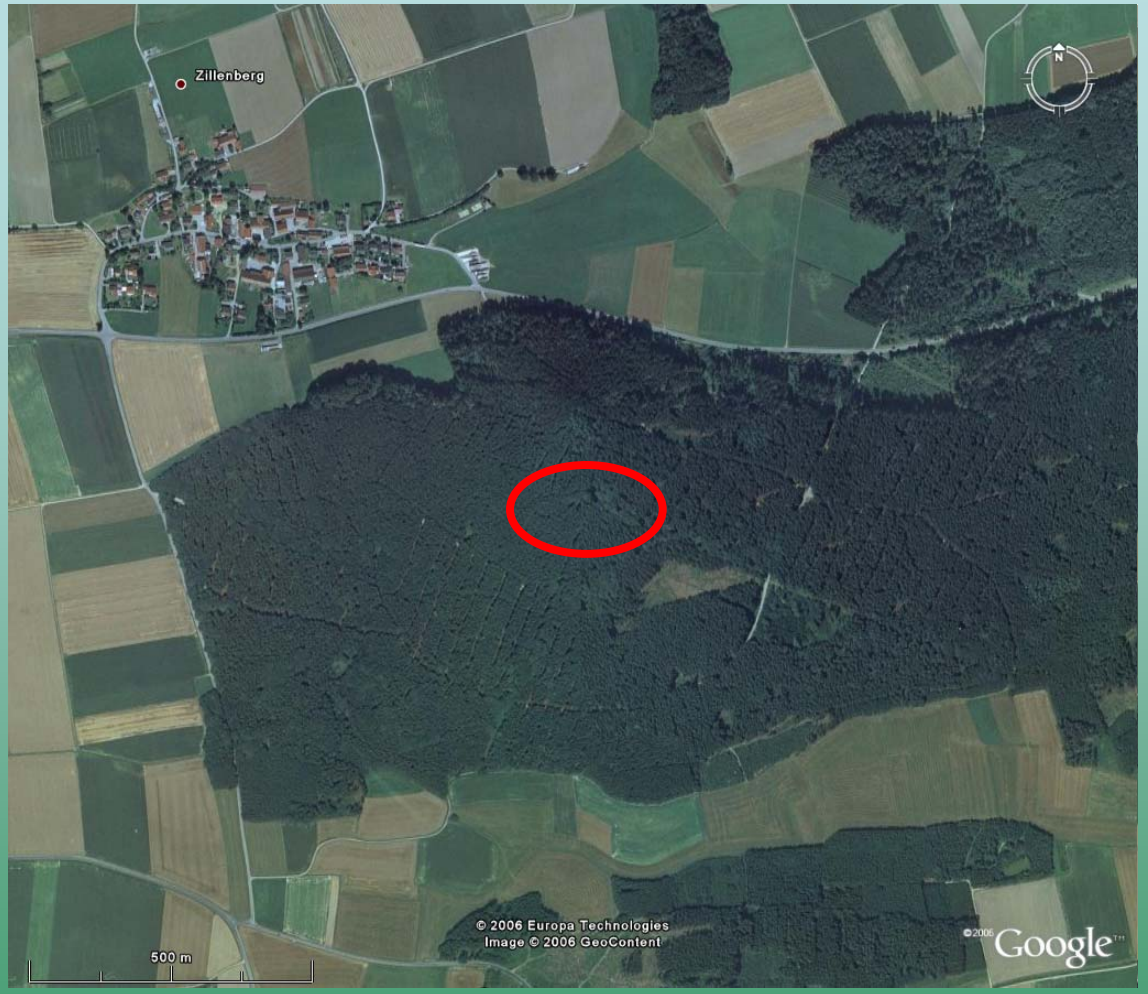
Motivation:

- Enhanced N_2O 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_2O emissions were first shown by Papen & Butterbach-Bahl (1999, *JGR*)
- N_2O emissions during freezing-thawing periods can contribute significantly to the annual N_2O 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:

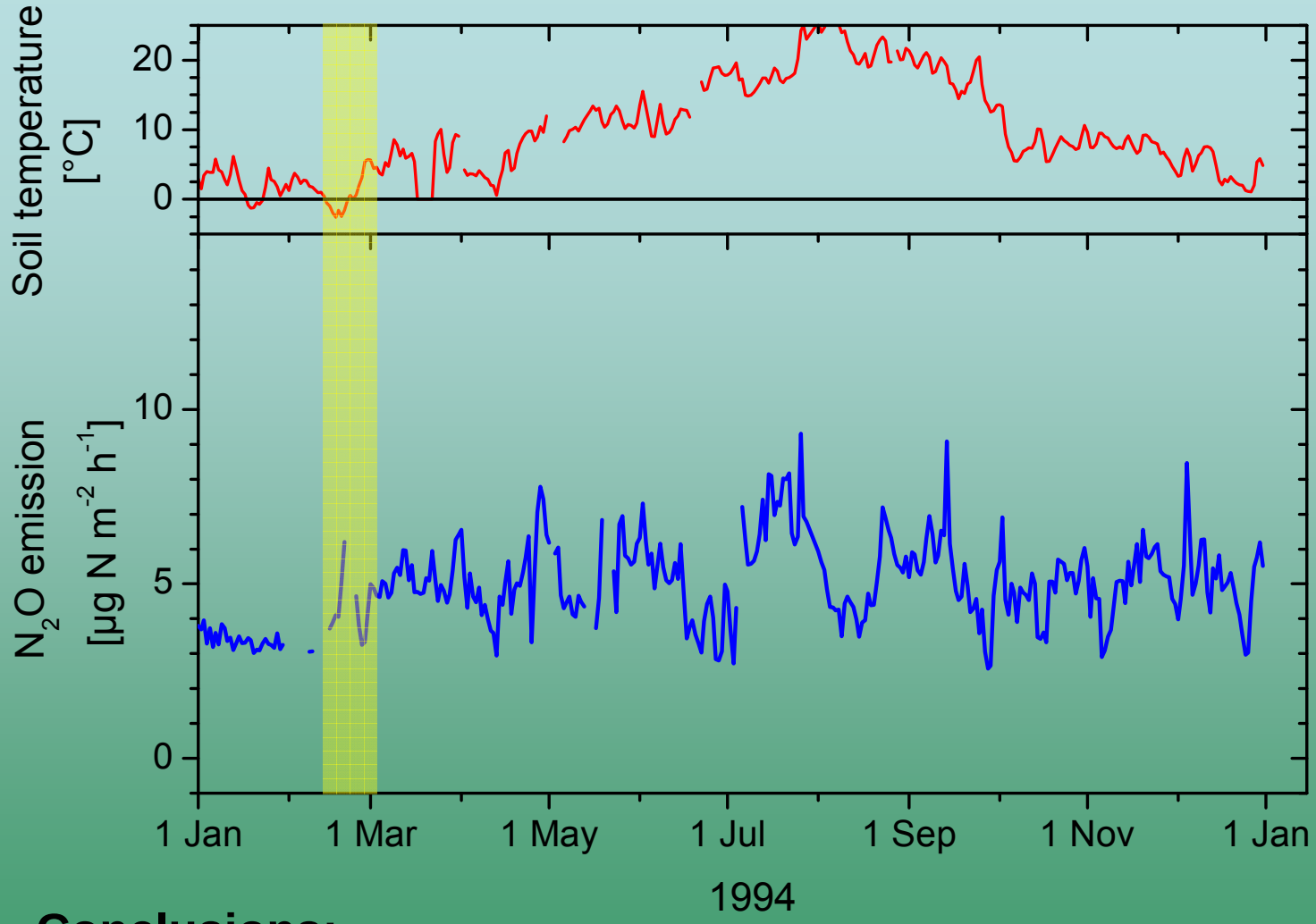
- Quantify importance of N_2O emissions during freeze-thaw cycles from a temperate forest soils for the annual budget
- Determination of reoccurrence rates
- Portability of results to other natural/ semi-natural systems (forests/ steppe)
- Process identification

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

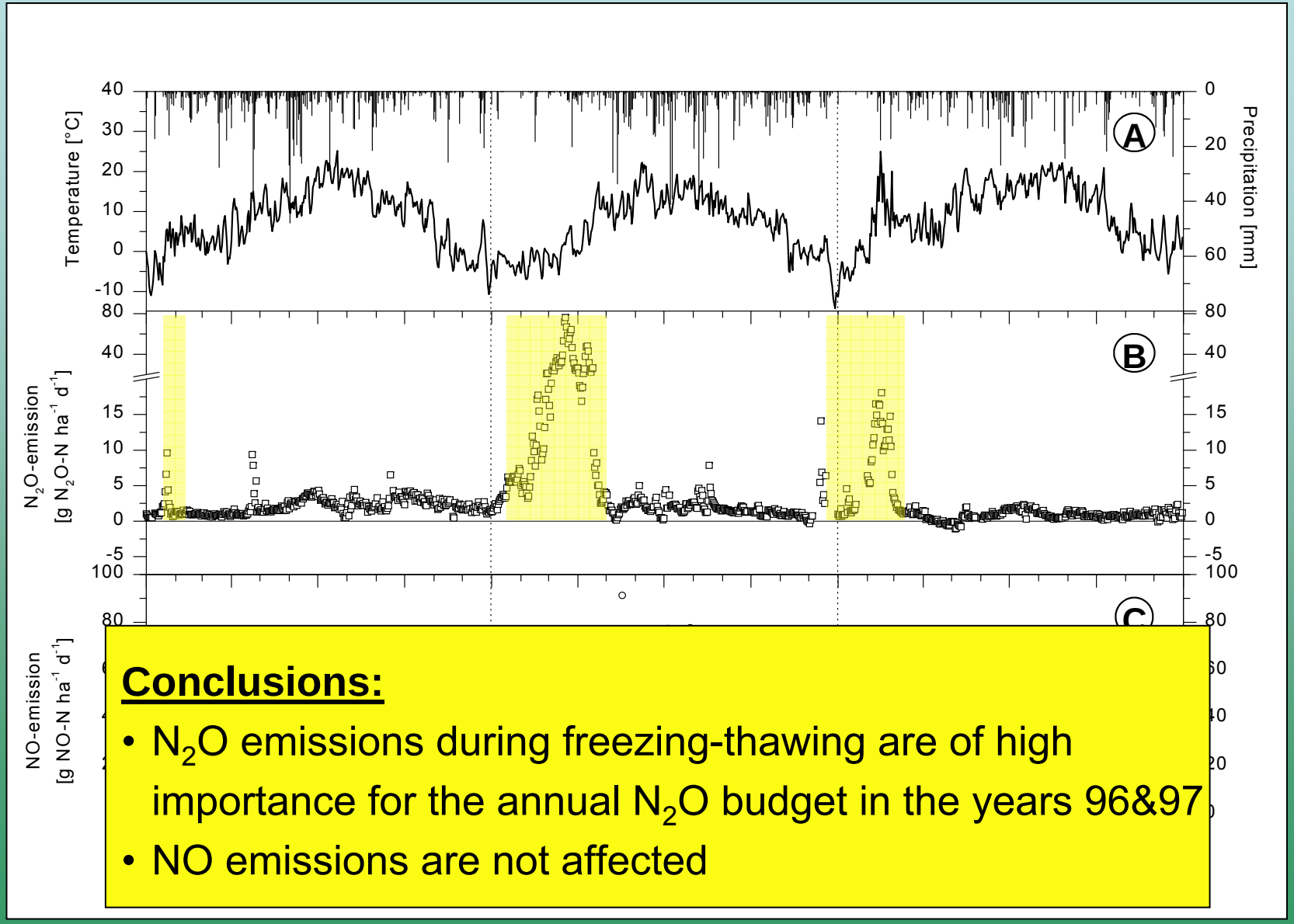
Höglwald: the first full year of measurements



Conclusions:

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

Höglwald: 1995 onwards - it becomes interesting

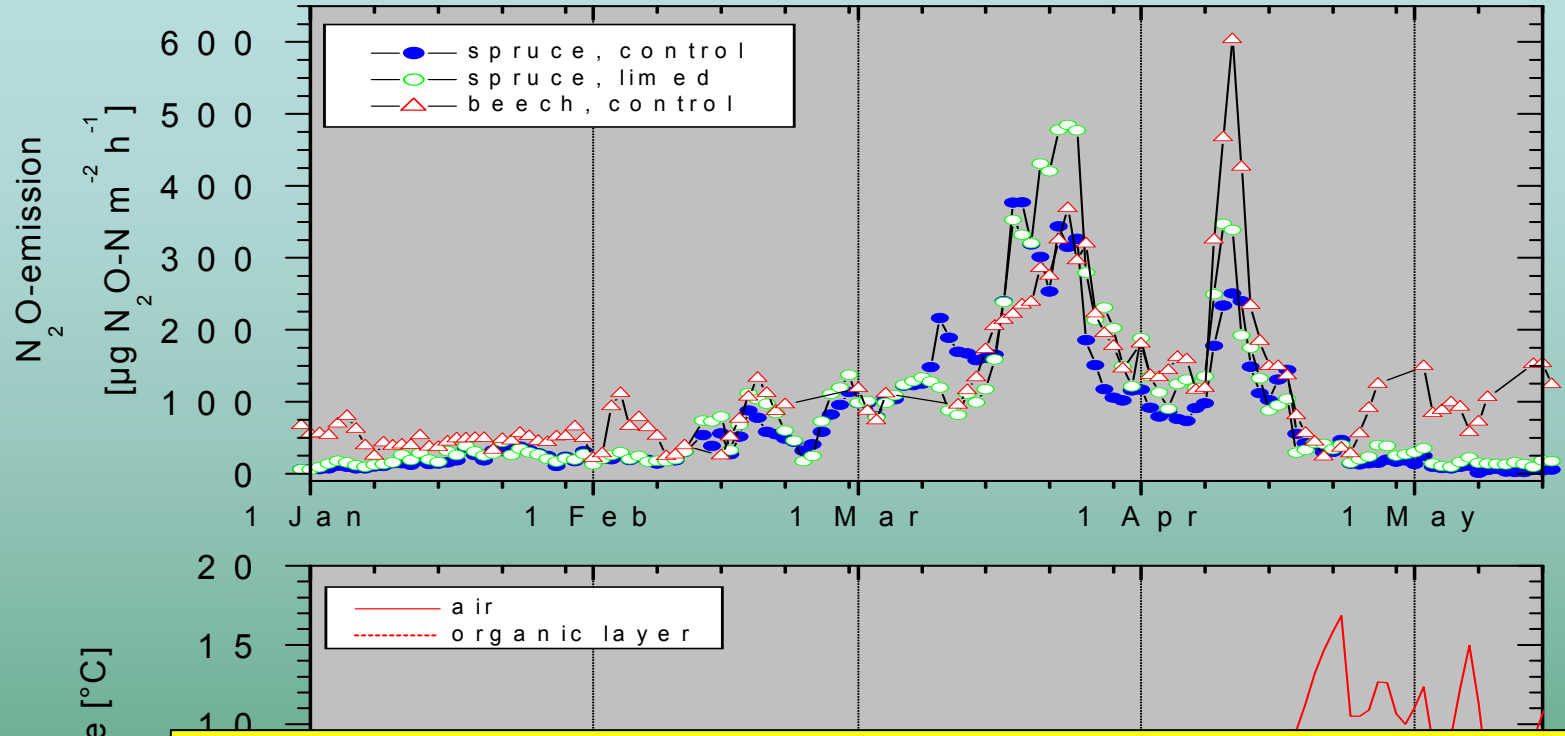


Conclusions:

- N_2O emissions during freezing-thawing are of high importance for the annual N_2O budget in the years 96&97
- NO emissions are not affected

Papen and Butterbach-Bahl, JGR 104, 18487-18503,1999; Butterbach-Bahl et al.,JGR 106, 34155-34166, 2001

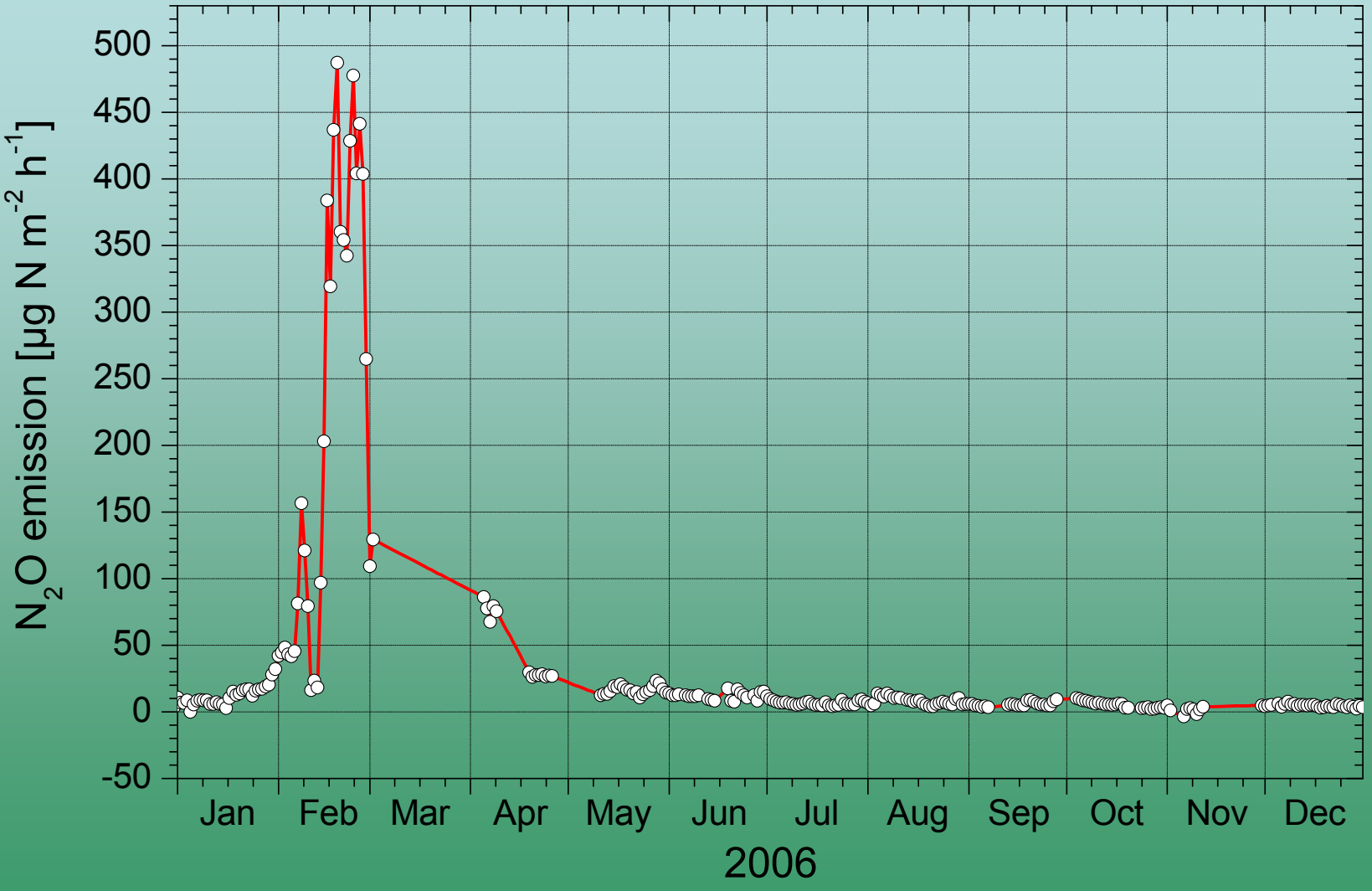
Höglwald: 1996 – details



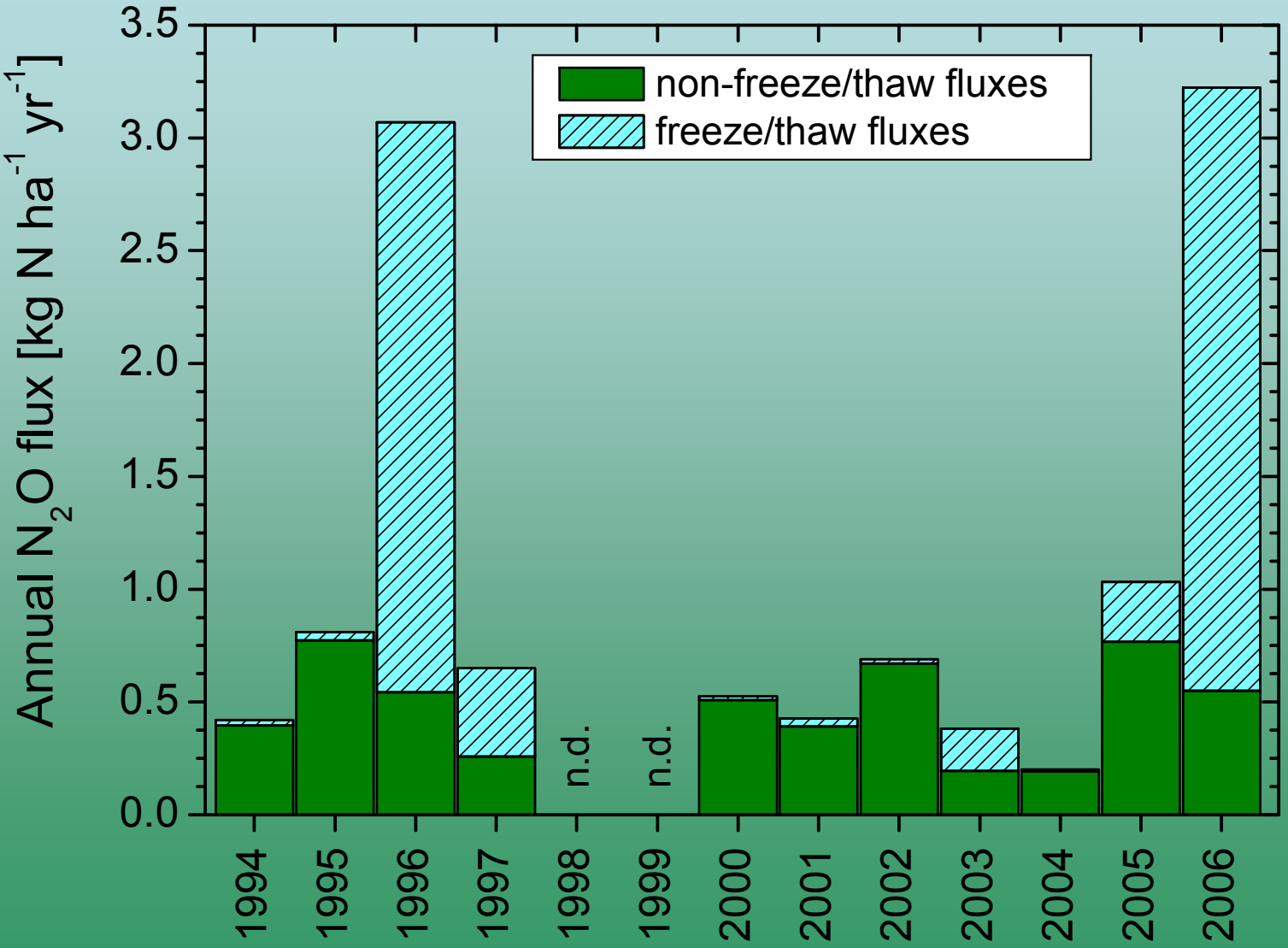
Results:

- Evidence of microbial activity at T<0°C, but
- freezing caused dieback of microbial biomass
  - 50 kg N ha^{-1} → 30 kg N ha^{-1}
  - ≈ 700 µg N m^{-2} h^{-1} easily degradable substrate
- No significant tree-species effect

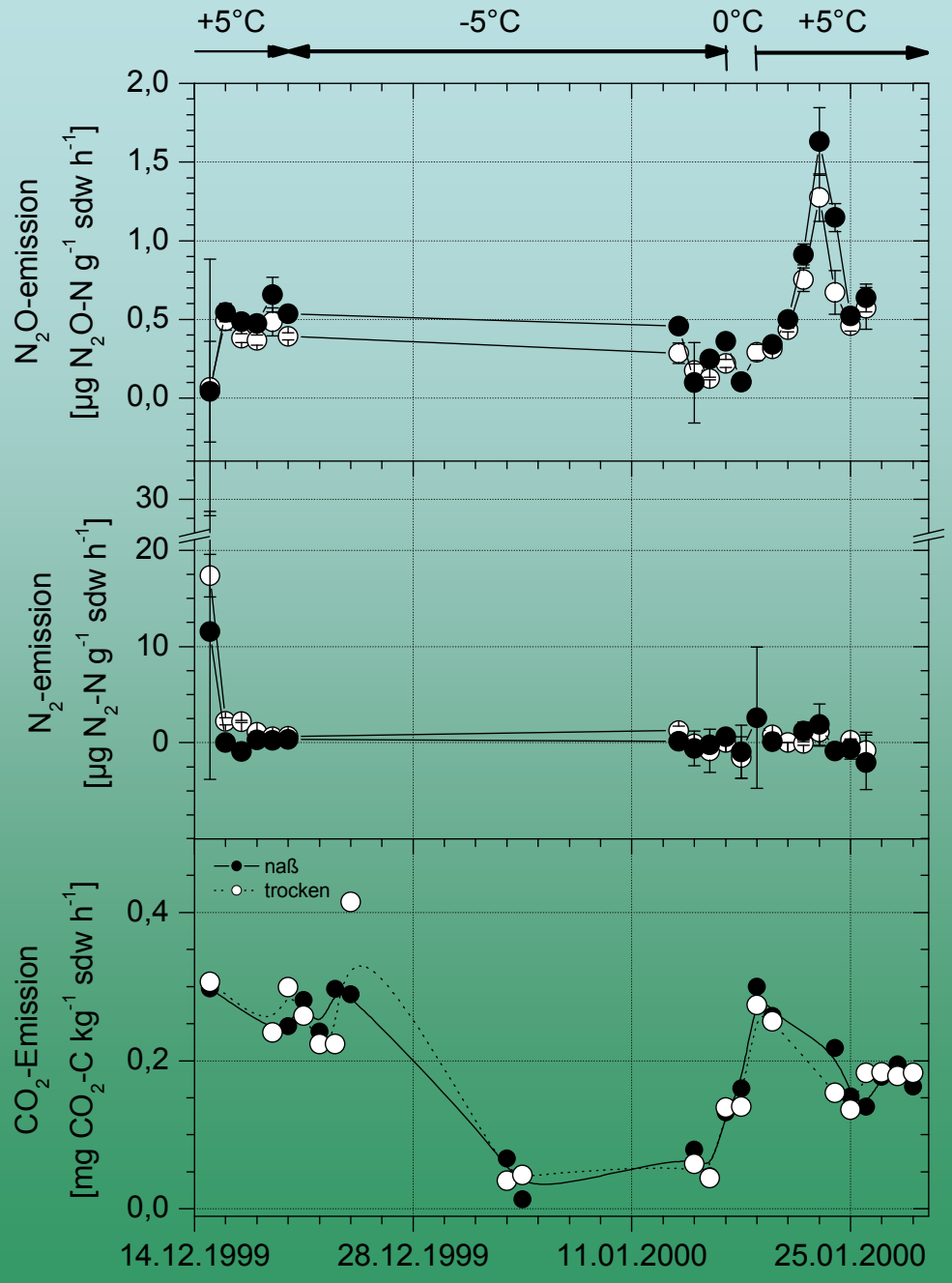
Höglwald: Also strong freezing-thawing effect in 2006



Höglwald: Importance of freezing/thawing events



Höglwald: intact soil core studies (N≥3)

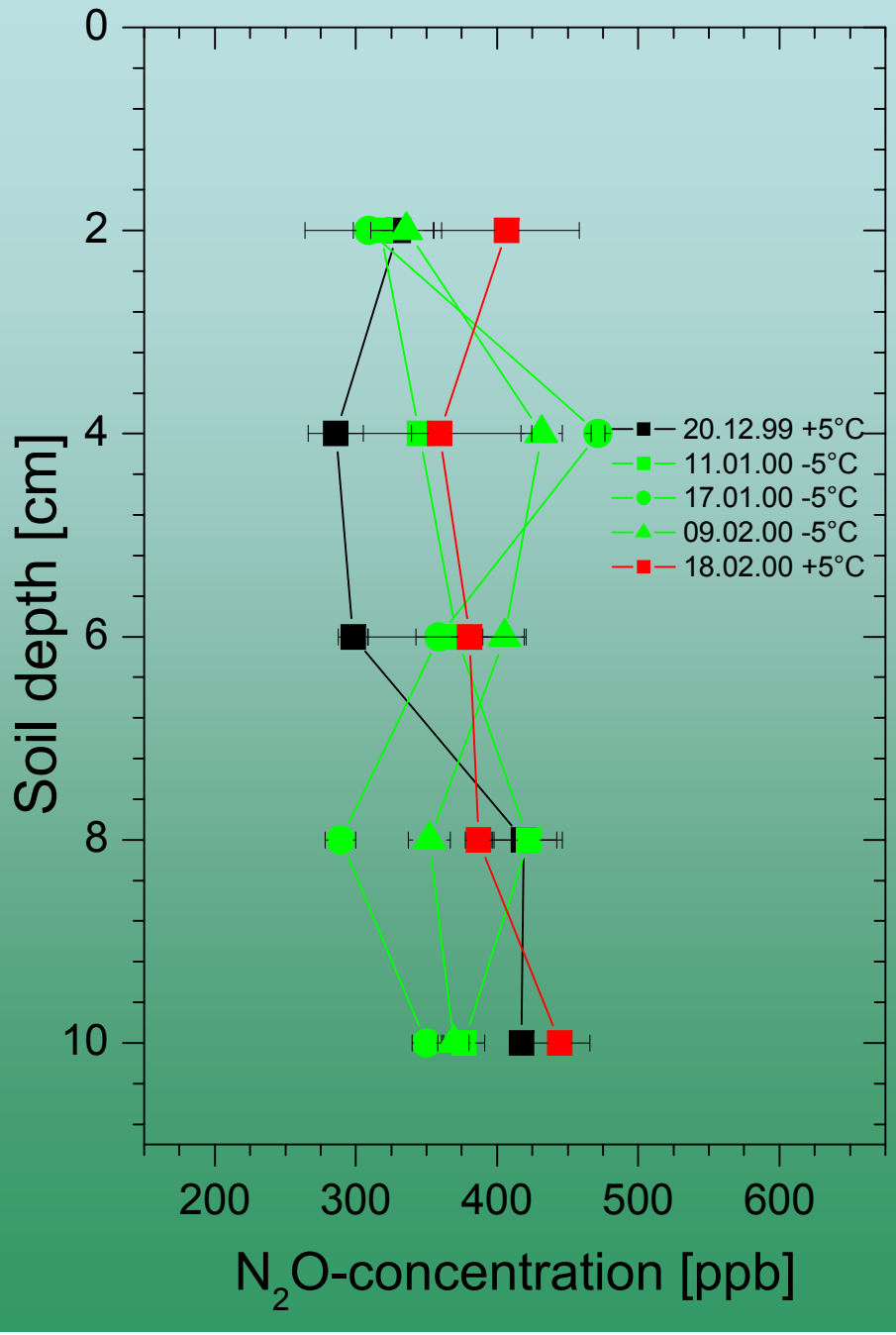


N_2O emission pulse after 4 weeks freezing

N_2-emission are close to the detection limit

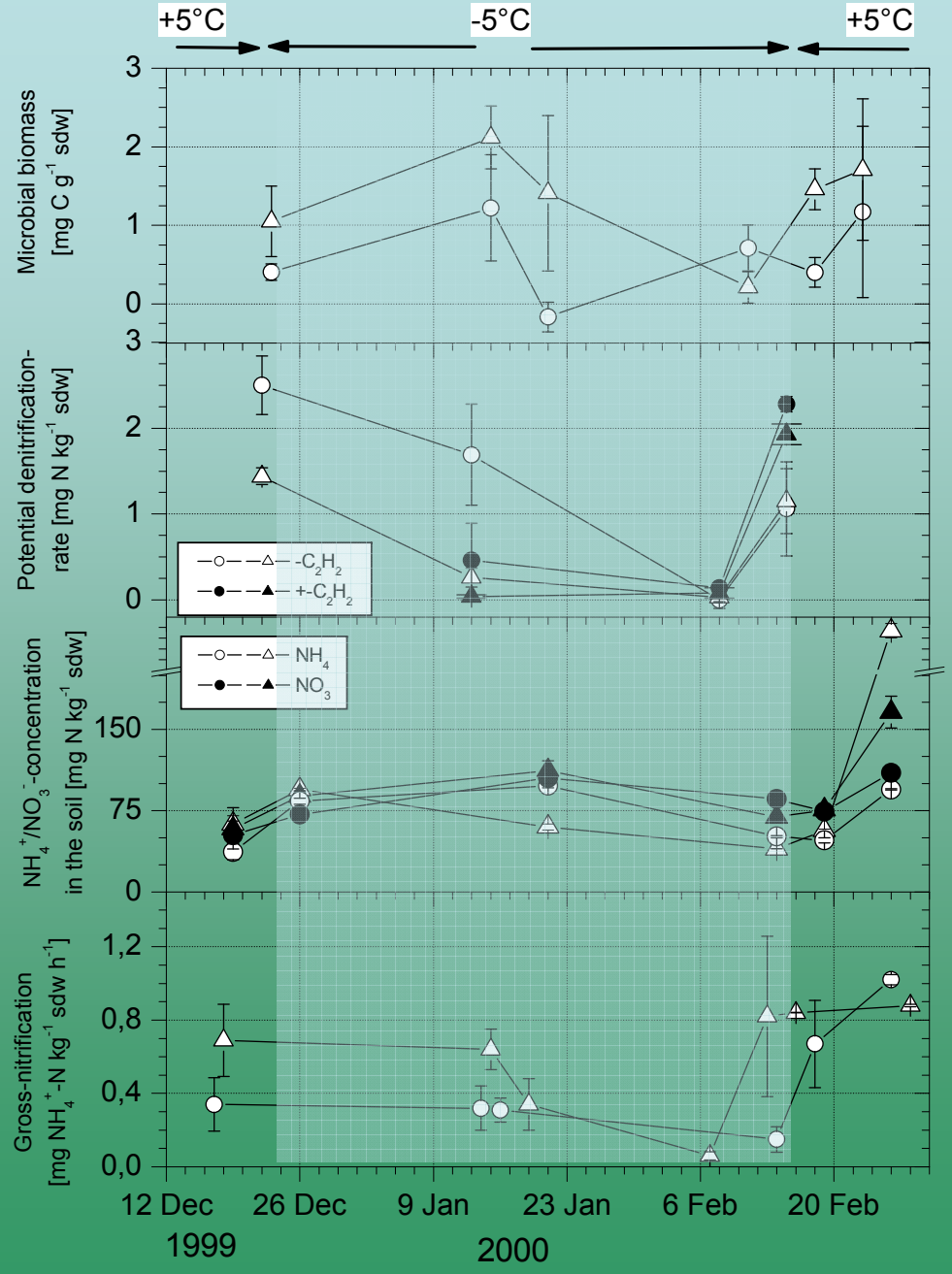
Increased microbial respiration during thawing

Höglwald: intact soil core studies (N≥3)



No major changes in soil N_2O concentrations during freezing, i.e. → Pulse of N_2O at thawing cannot come from stored N_2O

Höglwald: intact soil core studies (N≥3)



Microbial biomass dieback during freezing

Increased de-nitrification potential during thawing

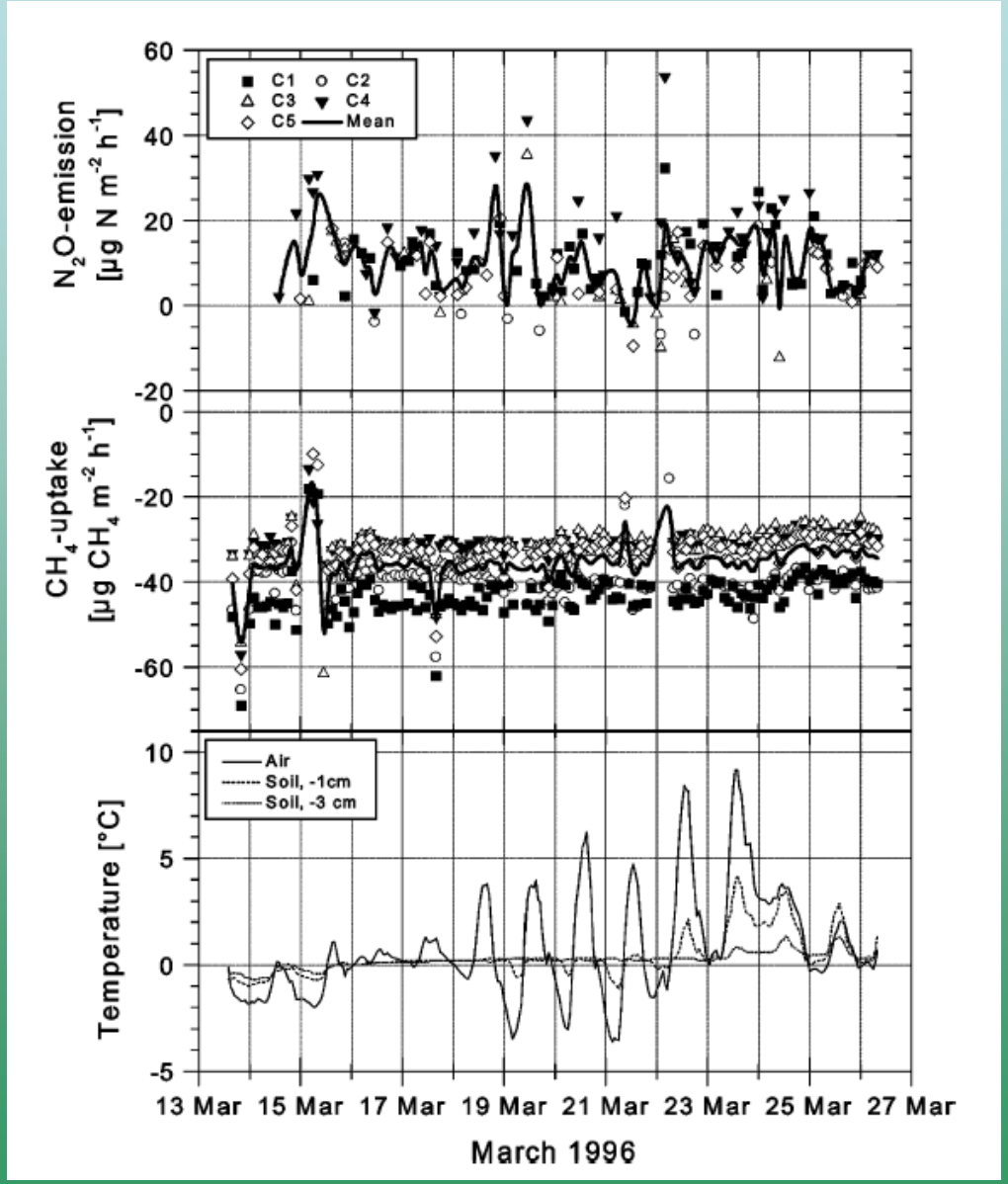
Increased availability of inorganic N after thawing

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_2 emissions, indicating quick recovery of microbial respiration
- During and after thawing N_2O emissions, but not N_2 emissions are elevated
- Magnitude of the effect of freezing/thawing on N_2O 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_2O emissions

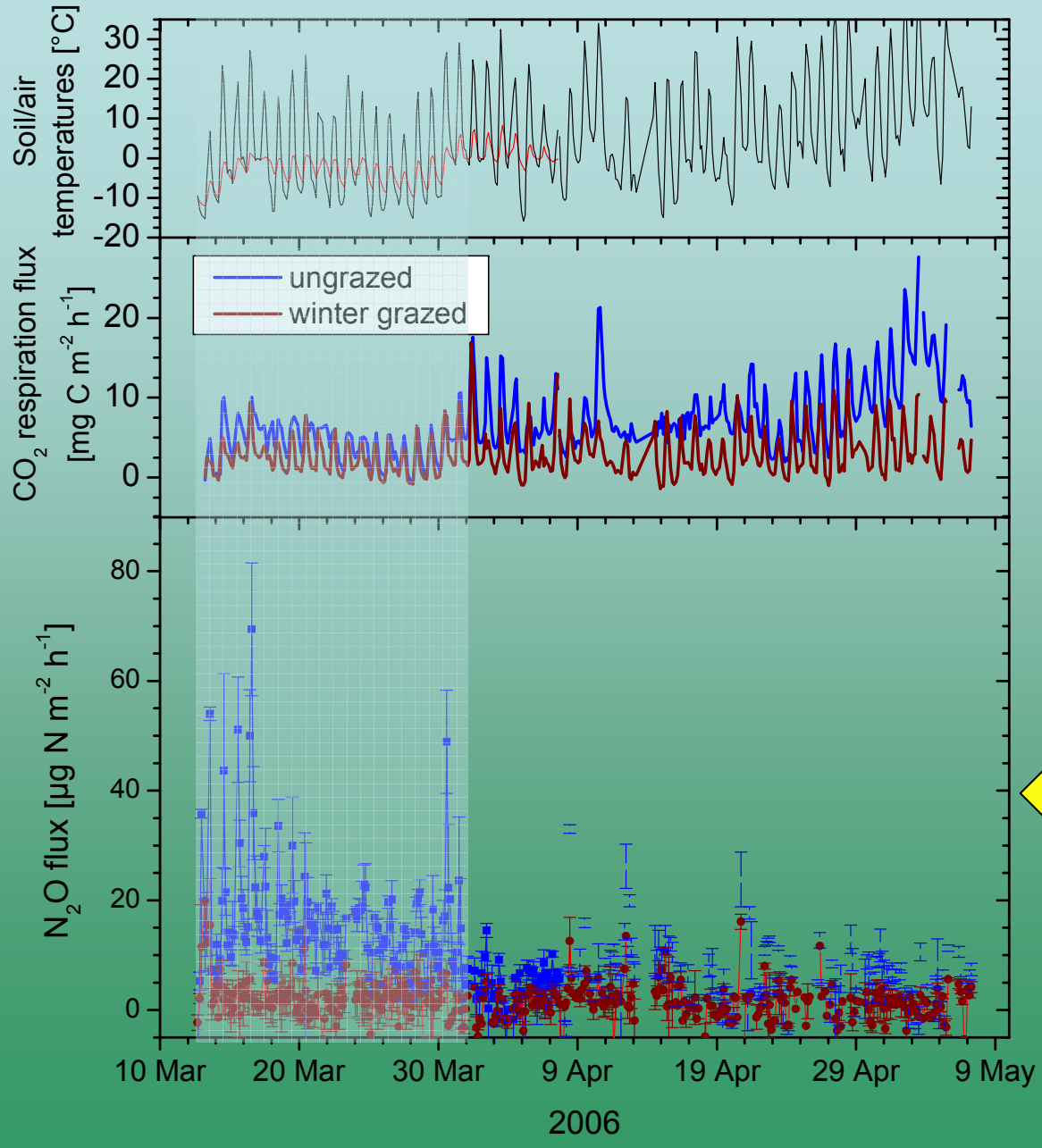
Missing of freezing/thawing effect due to differences in texture and, thus, soil moisture:
Höglwald: loamy texture
Eberswalde: sandy texture

Same period as Höglwald peak emissions

Can freezing/thawing effects on N_2O emissions be observed elsewhere?

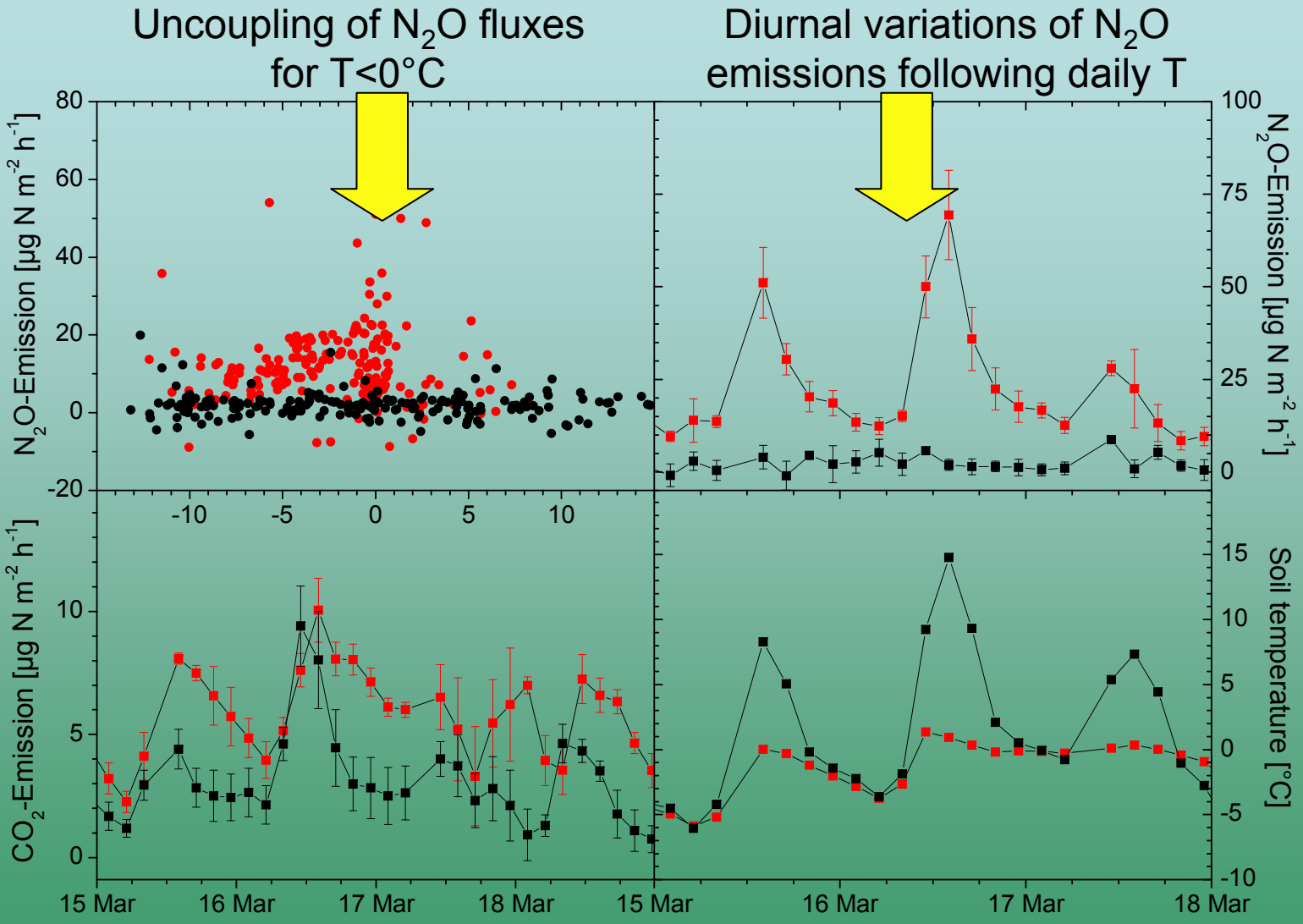
Continuous measurement of N and C trace gas emissions from March to July 2006

Freezing/thawing effects in steppe



Freezing/ thawing effect on N_2O 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