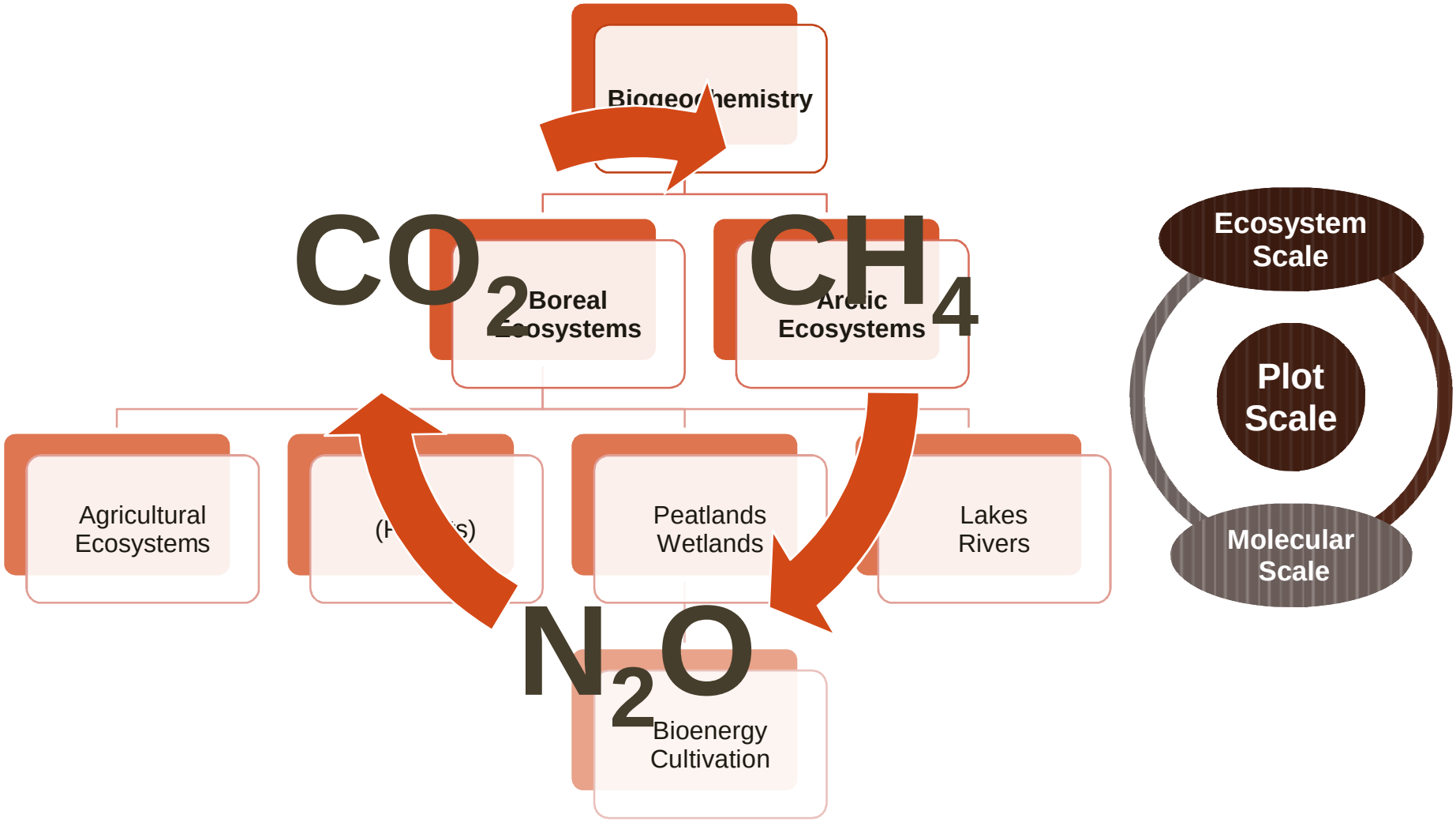
Cultivation of bioenergy crops: A case study from the northern latitudes

Shurpali, N.J., Biasi, C. & Martikainen, P.J.
University of Kuopio, Finland

University of Kuopio

Research Group in Biogeochemistry



Greenhouse gas scenario

- Current CO_2 levels in the atmosphere - 387 ppm.
- This is almost 40 per cent since the industrial revolution.
- From 1970 to 2000, the concentration rose by about 1.5 ppm each year.
- The annual mean CO_2 growth rate for 2007 was 2.14 ppm.
- Primarily because of human intervention - combustion fossil fuels
- Urgent need to reduce these high levels to some lower reference levels.

Mitigation strategies

- Increase the share of renewable energy sources in the total energy consumption.

- Bioenergy from Biomass is one of the renewable sources.

EU targets for Finland

- Increase renewable energy's share of final consumption by about 9.5 per cent compared to 2005.
- In 2005, renewable energy had a 28.5 per cent share. The target for 2020 is 38 per cent.
- Finland must achieve a 16 per cent GHG reduction by 2020, from 2005 levels.

Bioenergy cultivation in Finland

- In Finland, the cultivation of reed canary grass as a bioenergy crop on organic soils is fast increasing.
- Presently cultivated on about 20 thousand hectares.
- Expected to increase to 100 thousand hectares by 2015.
- It thrives well under low temperature, high moisture and humus rich soil conditions.

Land use change issues in Finland

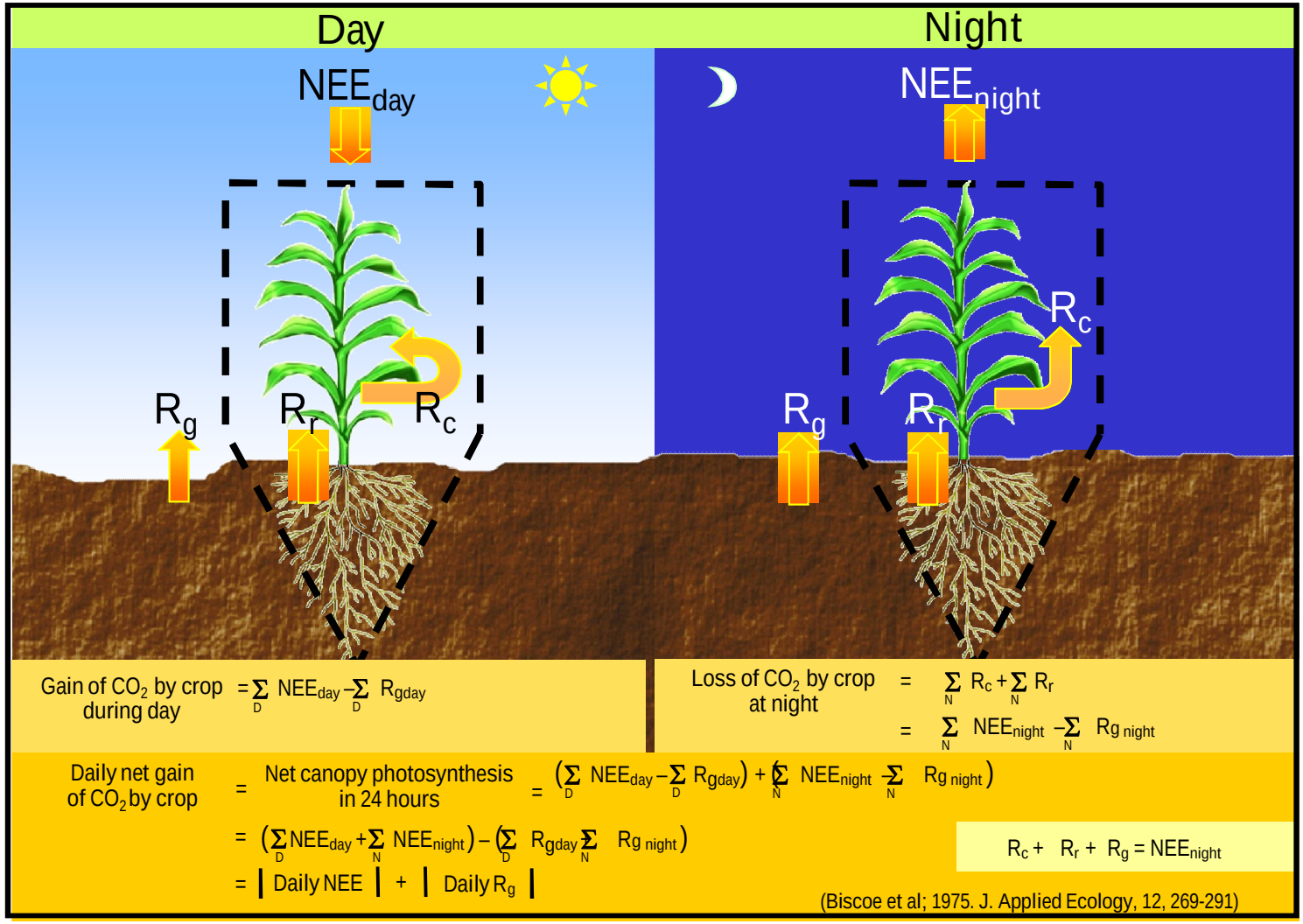
- Natural peatlands drained for forestry, agriculture and peat extraction
- Drained organic soils are environmentally unfriendly.
- They have been known to be persistent sources of CO_2 to the atmosphere.
- Always a source of CO_2 when left abandoned, afforested (nobody knows the full story in this case), cultivated with seasonal crops such as barley, wheat or potato or grasses.
- Some studies have suggested that such soils should be excluded totally from biomass cultivation for bioenergy.

Research Objective

How feasible it is to cultivate RCG on an organic soil?

What climatic impact will the carbon balance resulting from such a cultivation will have on the environment?


CSAT3



Gain of CO_2 by crop during day $= \sum_D NEE_{day} - \sum_D R_{gday}$

Loss of CO_2 by crop at night $= \sum_N R_c + \sum_N R_r$

$= \sum_N NEE_{night} - \sum_N Rg_{night}$

Daily net gain of CO_2 by crop $=$ Net canopy photosynthesis in 24 hours $= \left(\sum_D NEE_{day} - \sum_D R_{gday}\right) + \left(\sum_N NEE_{night} - \sum_N Rg_{night}\right)$

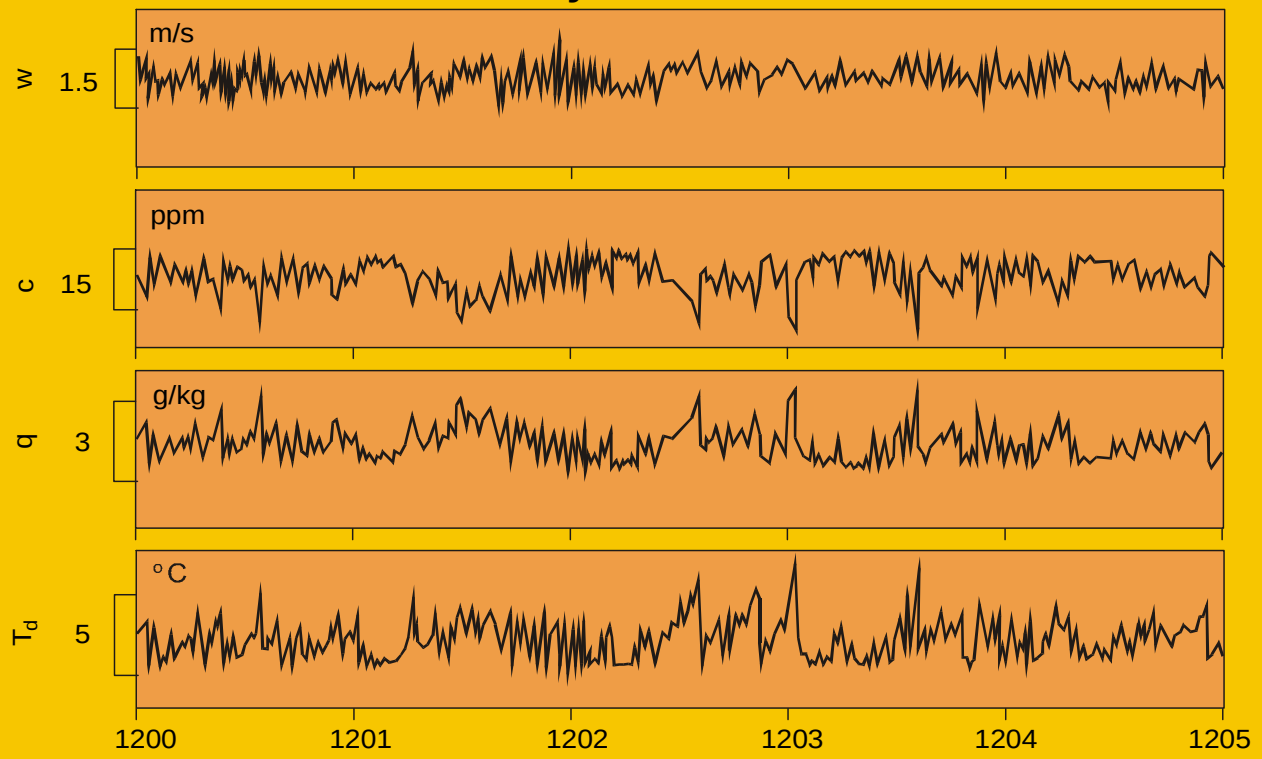
$= \left(\sum_D NEE_{day} + \sum_N NEE_{night}\right) - \left(\sum_D R_{gday} \sum_N Rg_{night}\right)$

$= \left| \text{Daily NEE} \right| + \left| \text{Daily } R_g \right|$

$R_c + R_r + R_g = NEE_{night}$

(Biscoe et al; 1975. J. Applied Ecology, 12, 269-291)

Eddy Covariance



Instantaneous Flux = **ws**

= **wc** *for CO_2*

= **wq** *for water vapor*

= $\rho_a c_p$ **wT** *for sensible heat*

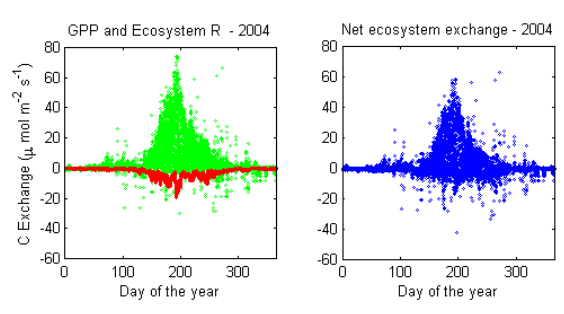
Mean Hourly Flux = Time average of instantaneous flux = $\overline{\mathbf{ws}}$

= $\overline{\mathbf{wc}}$ *for CO_2*

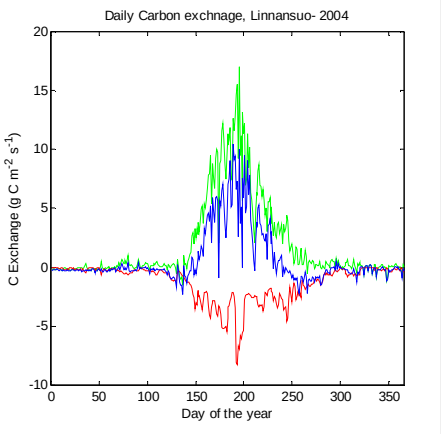
= $\overline{\mathbf{wq}}$ *for water vapor*

= $\rho_a c_p \overline{\mathbf{wT}}$ *for sensible heat*

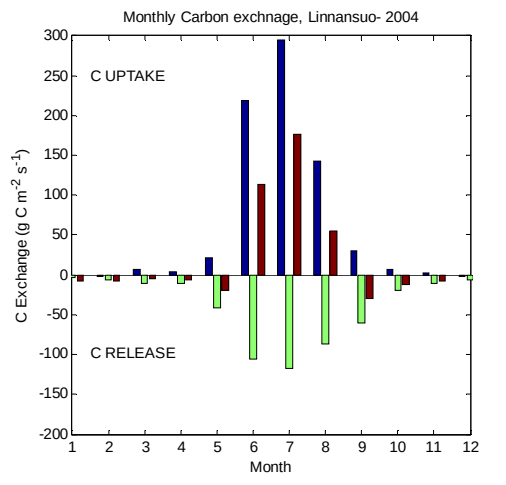
From a fraction of a second to annual and decadal time scales



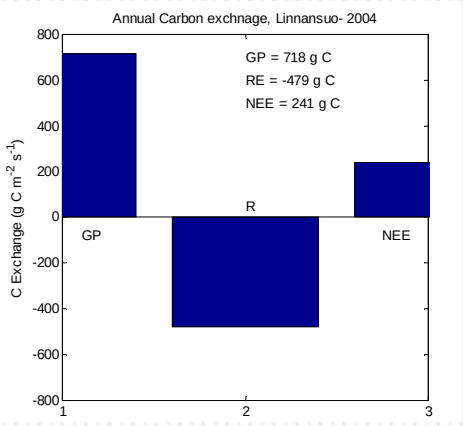
30 min fluxes



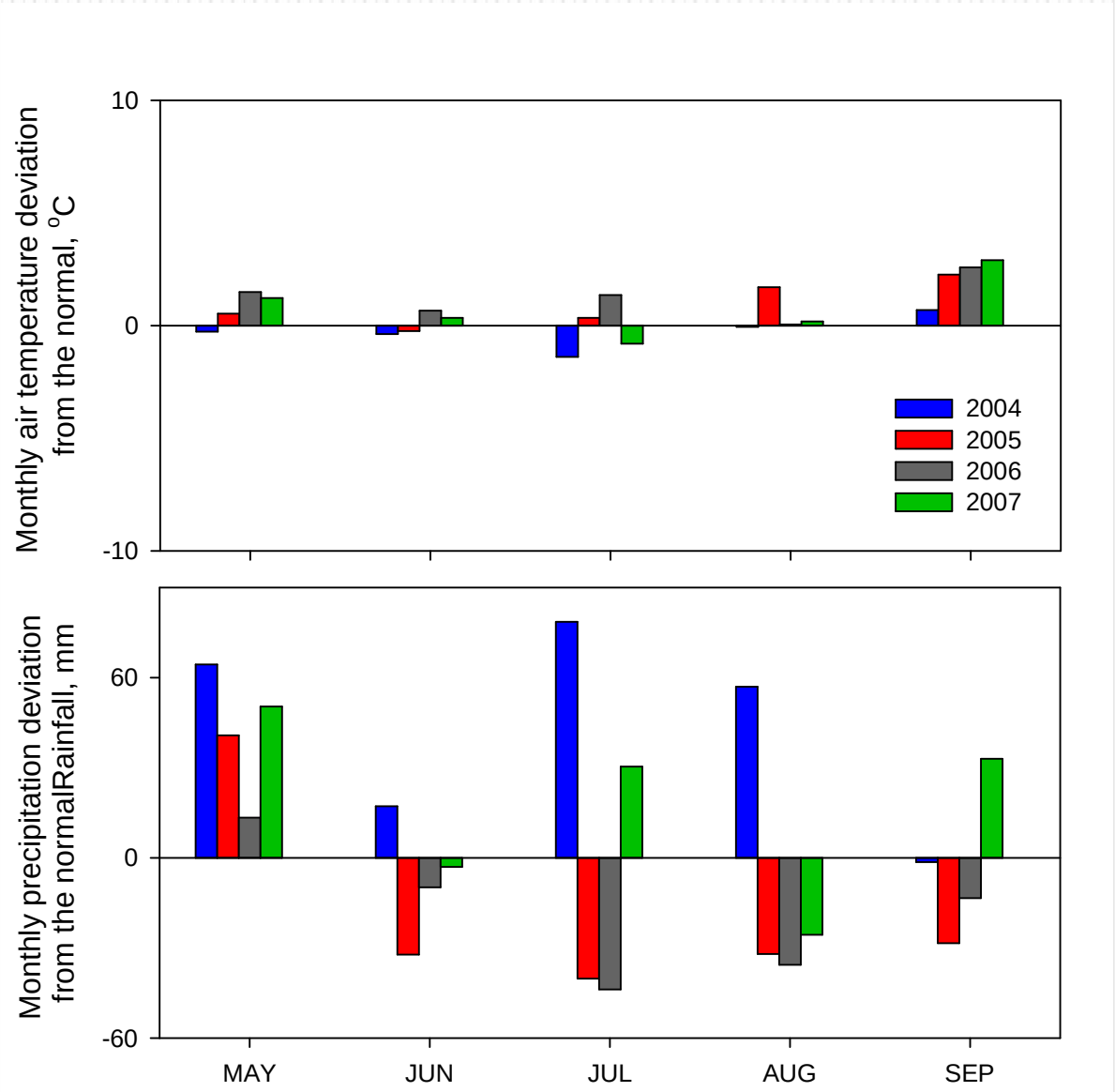
Daily exchange rates

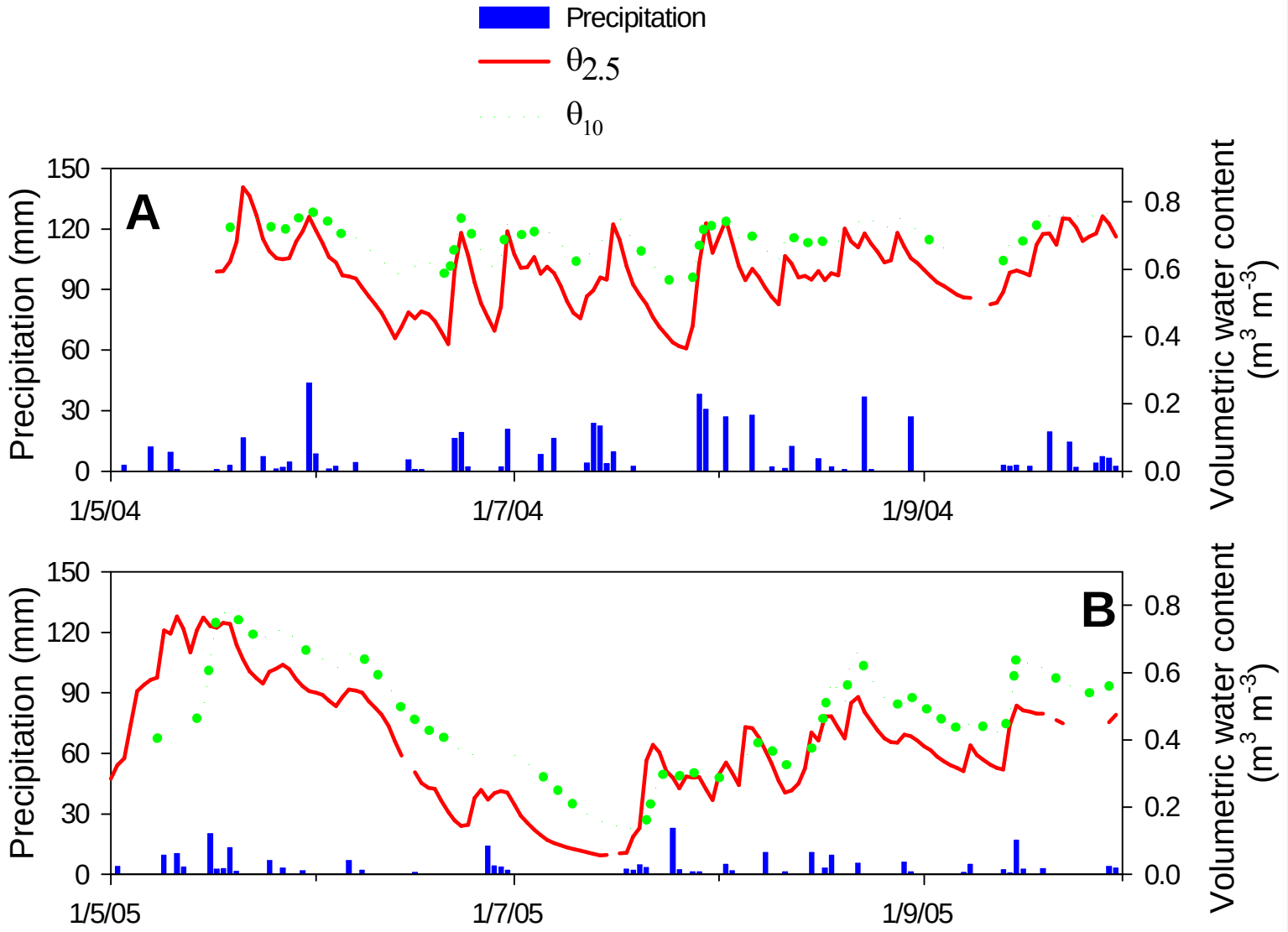


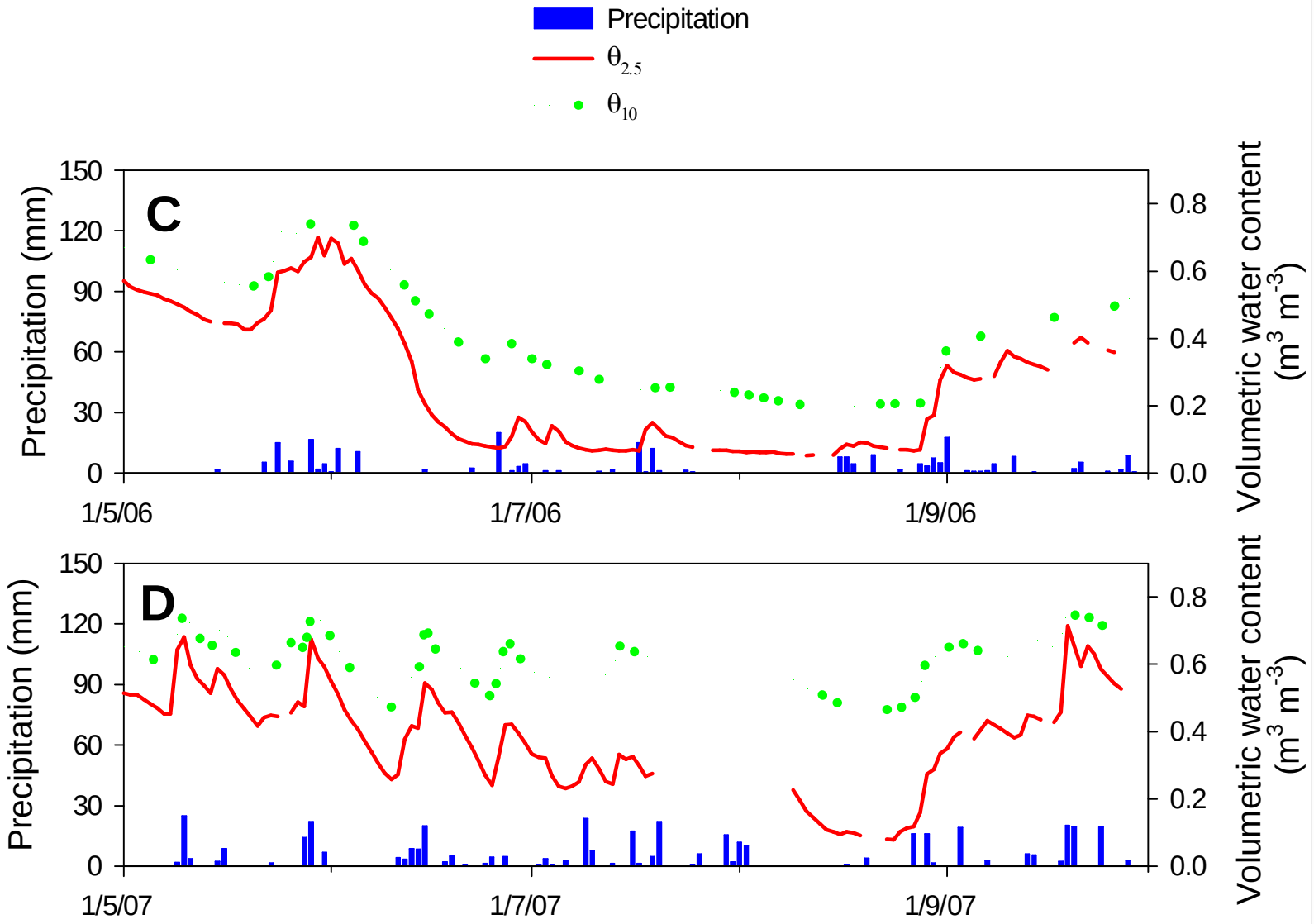
Monthly trends

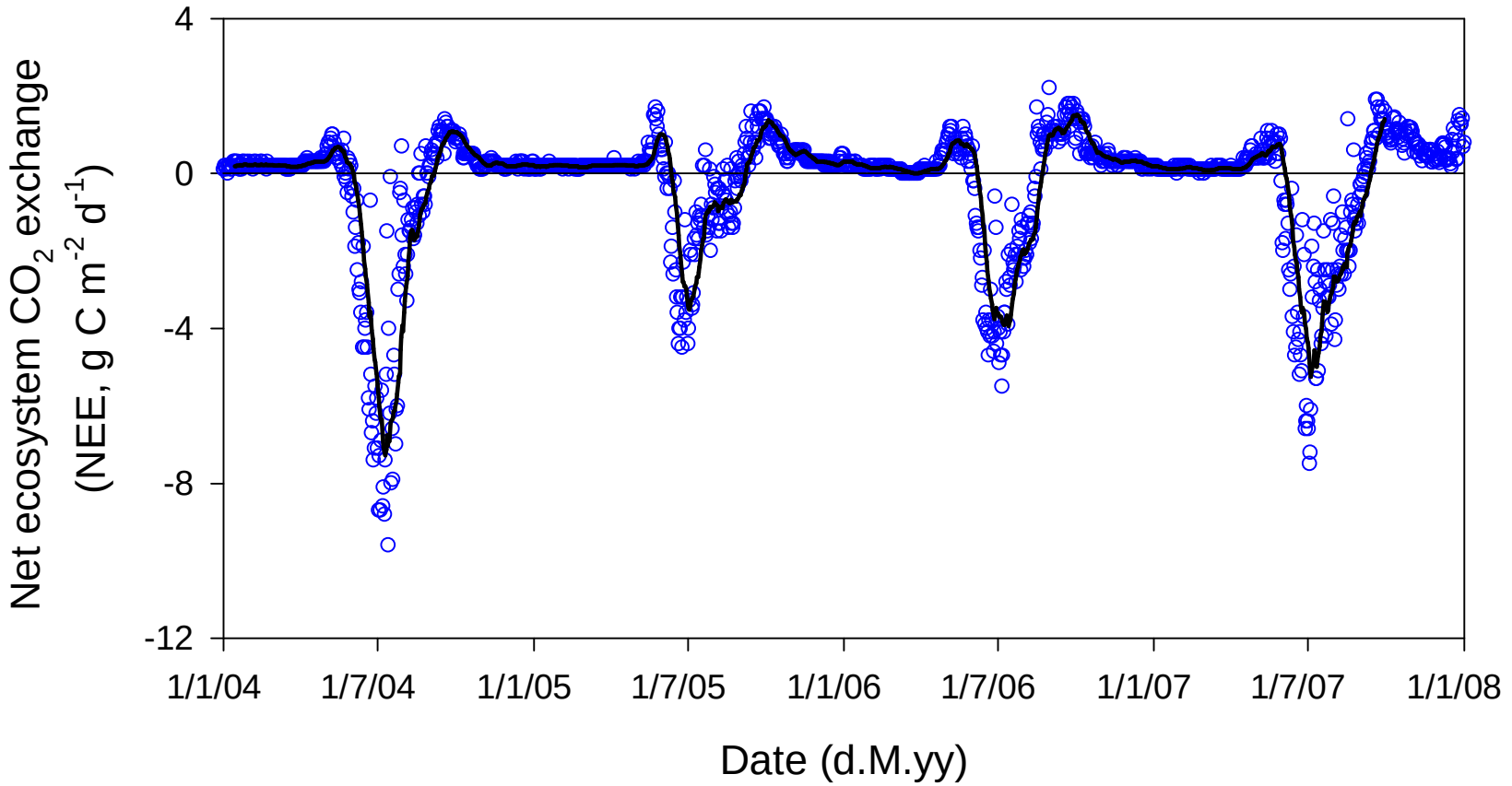


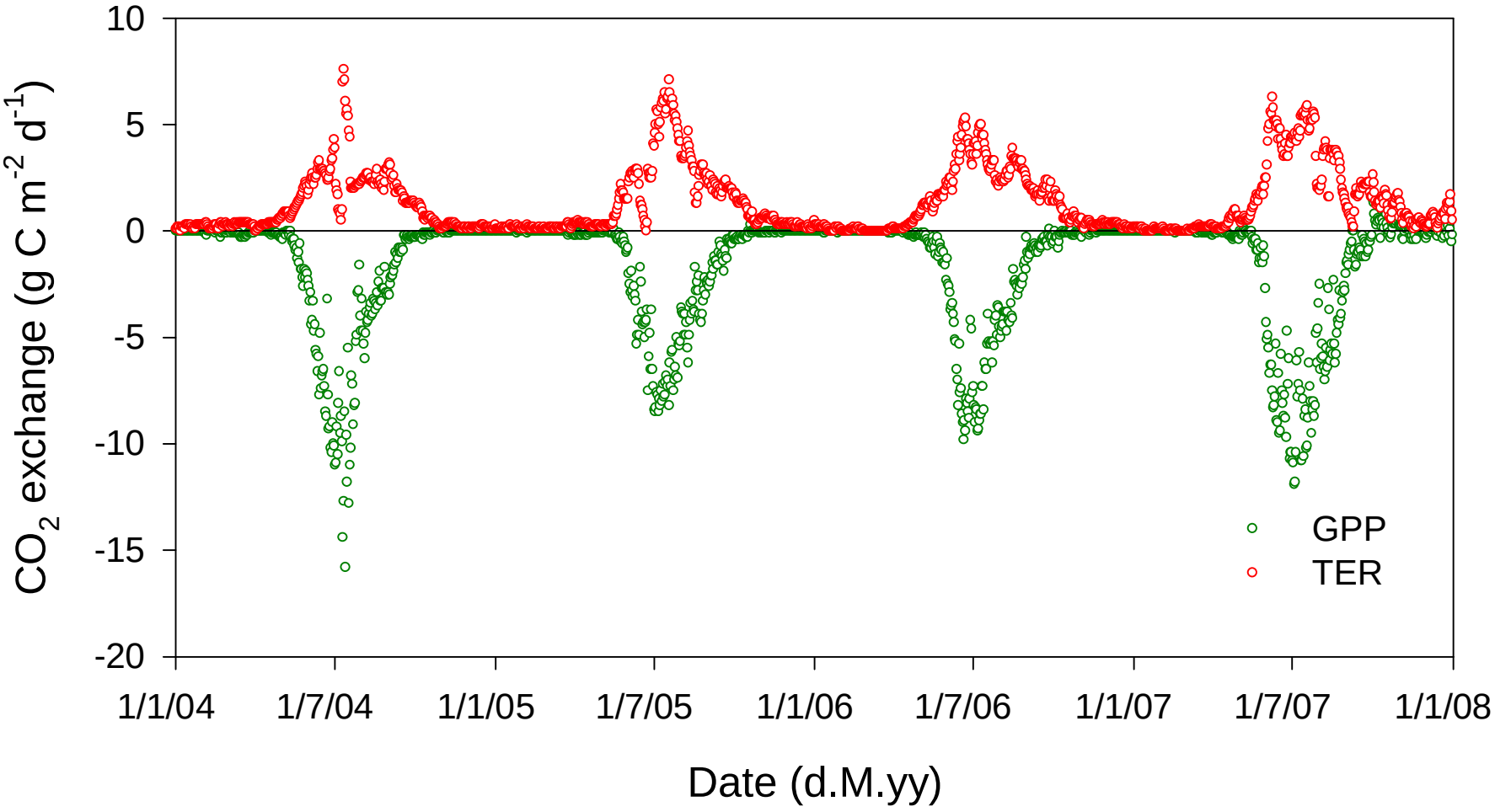
Annual patterns


Monthly air temperature deviation from the normal, °C
10
0
-10
2004
2005
2006
2007
Monthly precipitation deviation from the normalRainfall, mm
60
0
-60
MAY
JUN
JUL
AUG
SEP

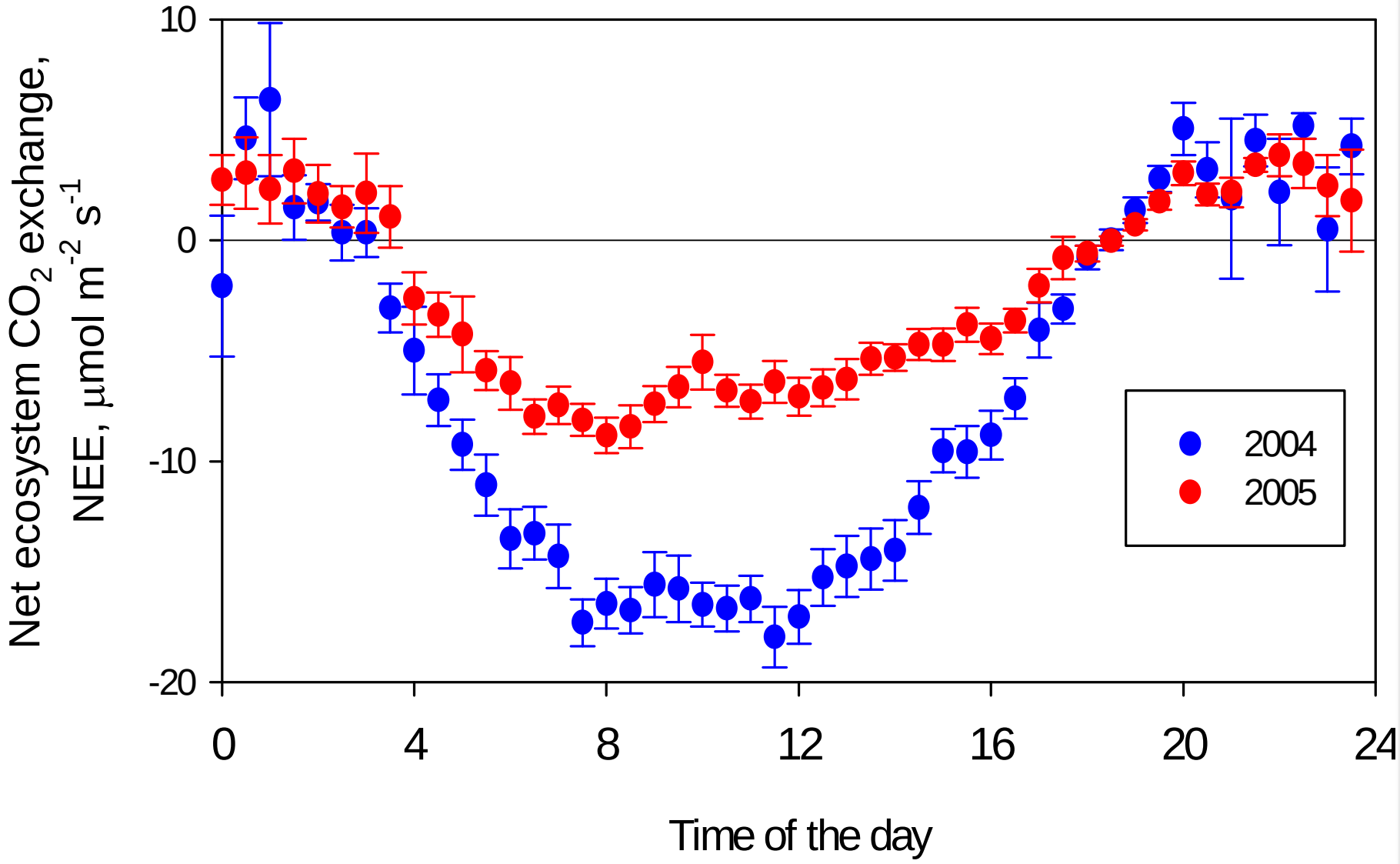

Precipitation
θ2.5
θ10
A
B
Precipitation (mm)
Volumetric water content (m3 m-3)
150
120
90
60
30
0
0.8
0.6
0.4
0.2
0.0
1/5/04
1/7/04
1/9/04
1/5/05
1/7/05
1/9/05

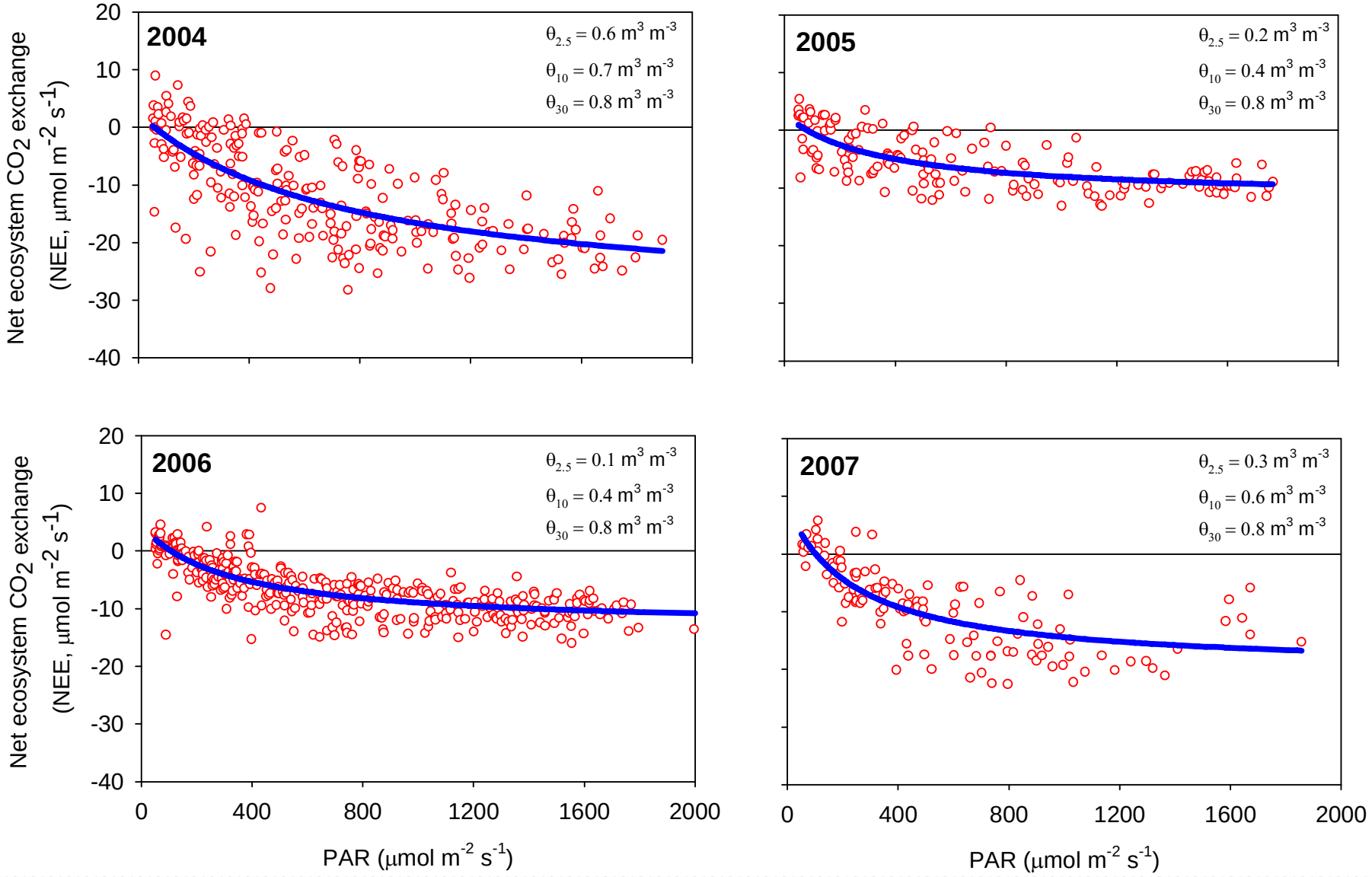

Precipitation
θ2.5
θ10
C
D
Precipitation (mm)
Volumetric water content (m3 m-3)
150
120
90
60
30
0
0.8
0.6
0.4
0.2
0.0
1/5/06
1/7/06
1/9/06
1/5/07
1/7/07
1/9/07

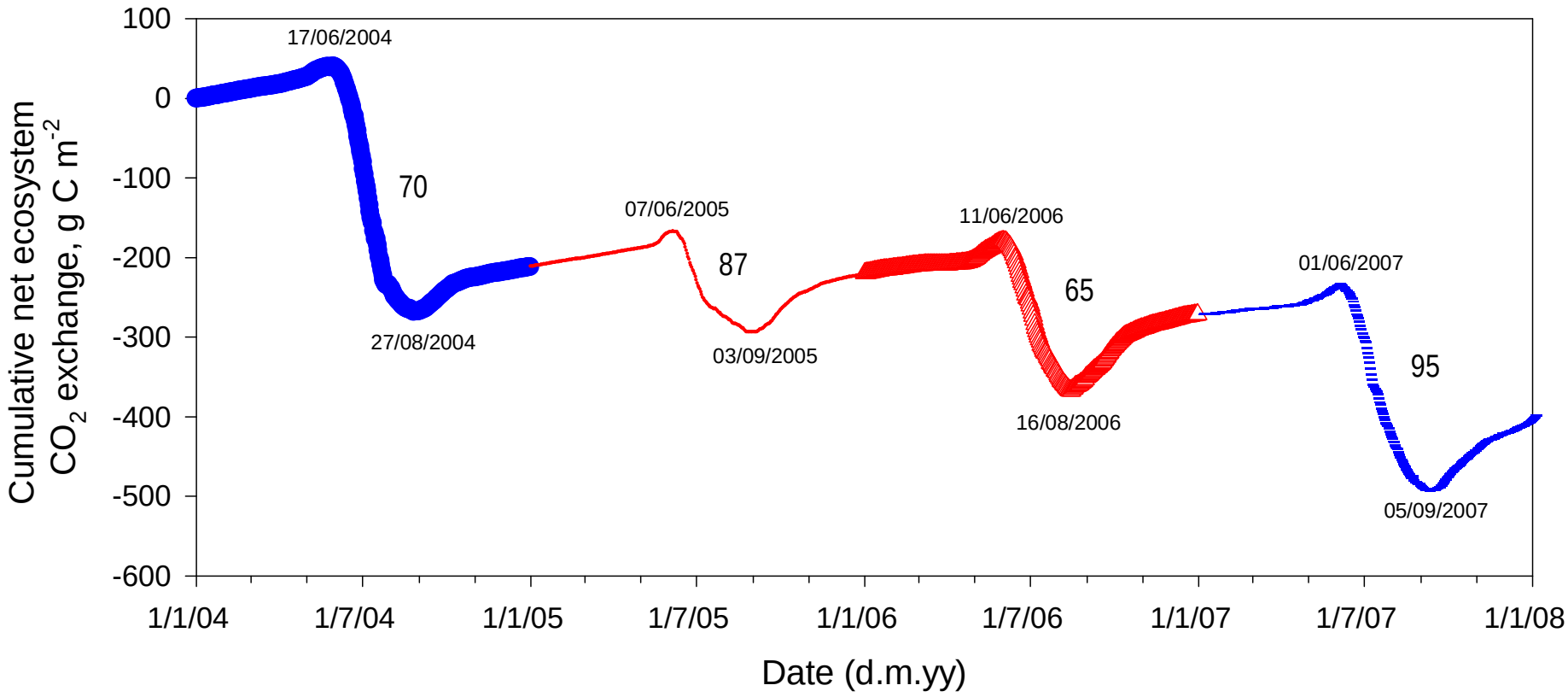

Net ecosystem CO_2 exchange
(NEE, g C m^{-2} d^{-1})
4
0
-4
-8
-12
1/1/04
1/7/04
1/1/05
1/7/05
1/1/06
1/7/06
1/1/07
1/7/07
1/1/08
Date (d.M.yy)


10
5
0
-5
-10
-15
-20
CO_2 exchange (g C m^{-2} d^{-1})
1/1/04
1/7/04
1/1/05
1/7/05
1/1/06
1/7/06
1/1/07
1/7/07
1/1/08
Date (d.M.yy)
GPP
TER

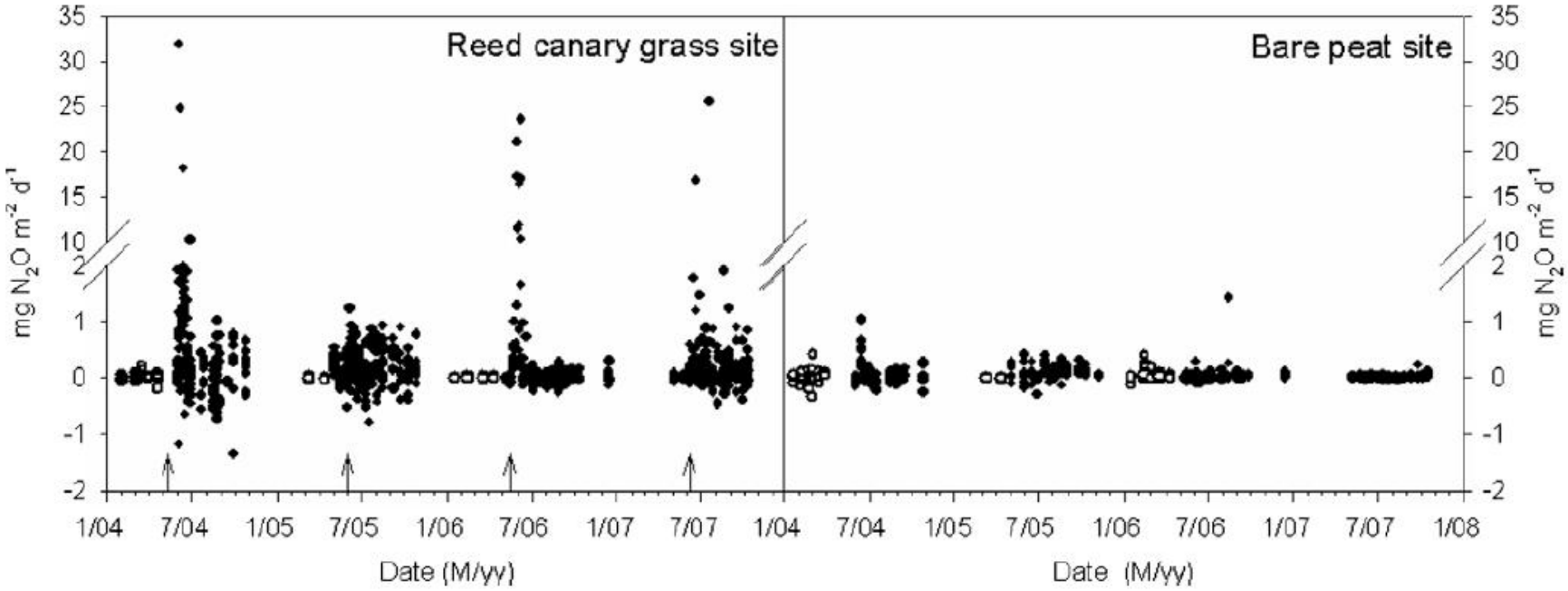
NEE diurnal patterns

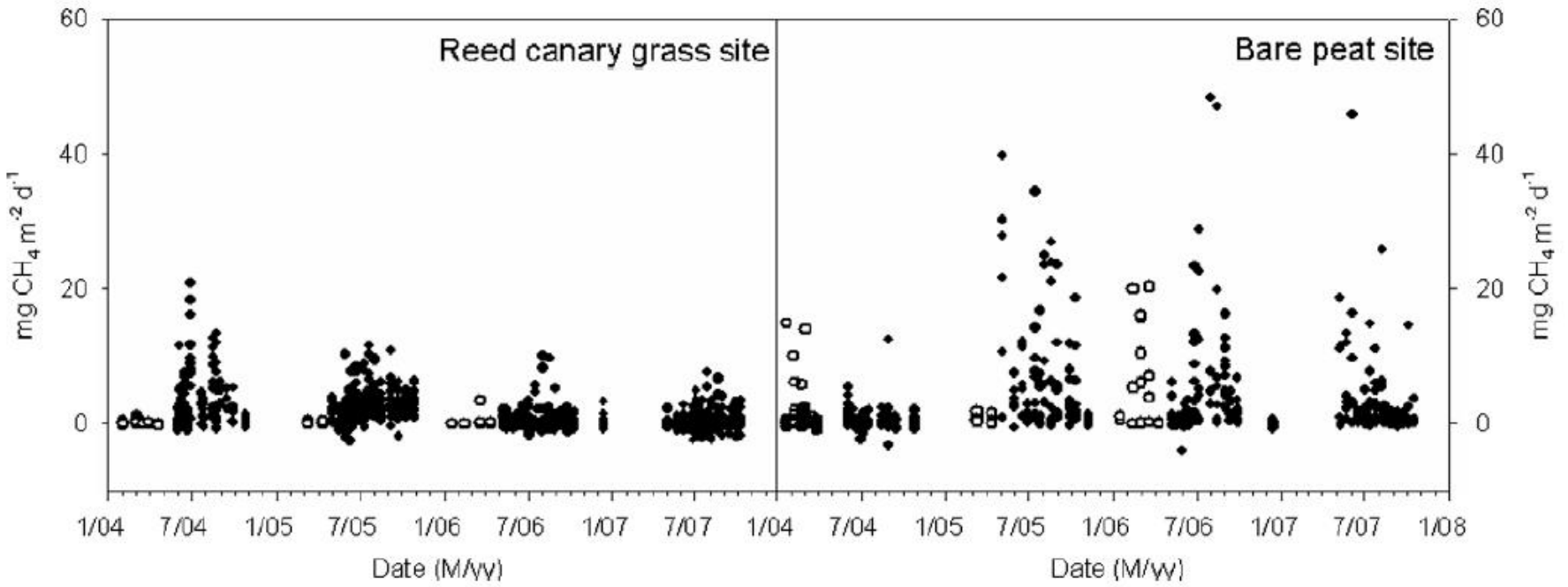



2004
$\theta_{2.5}$ = 0.6 m^3 m^{-3}
θ_{10} = 0.7 m^3 m^{-3}
θ_{30} = 0.8 m^3 m^{-3}
2005
$\theta_{2.5}$ = 0.2 m^3 m^{-3}
θ_{10} = 0.4 m^3 m^{-3}
θ_{30} = 0.8 m^3 m^{-3}
2006
$\theta_{2.5}$ = 0.1 m^3 m^{-3}
θ_{10} = 0.4 m^3 m^{-3}
θ_{30} = 0.8 m^3 m^{-3}
2007
$\theta_{2.5}$ = 0.3 m^3 m^{-3}
θ_{10} = 0.6 m^3 m^{-3}
θ_{30} = 0.8 m^3 m^{-3}
Net ecosystem CO_2 exchange (NEE, µmol m^{-2} s^{-1})
PAR (µmol m^{-2} s^{-1})
20
10
0
-10
-20
-30
-40
0
400
800
1200
1600
2000

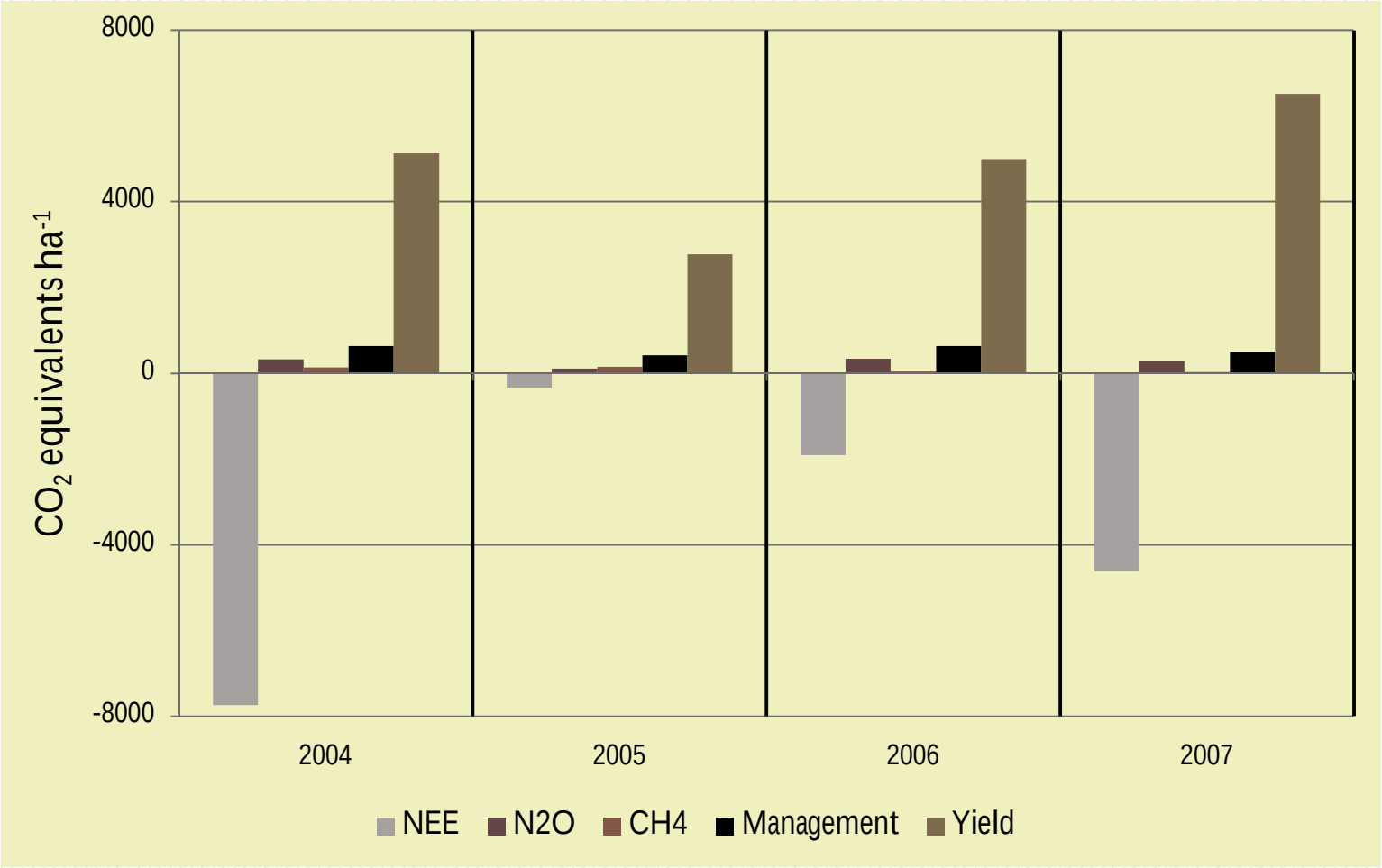


Daily cumulative RCG CO_2 balance

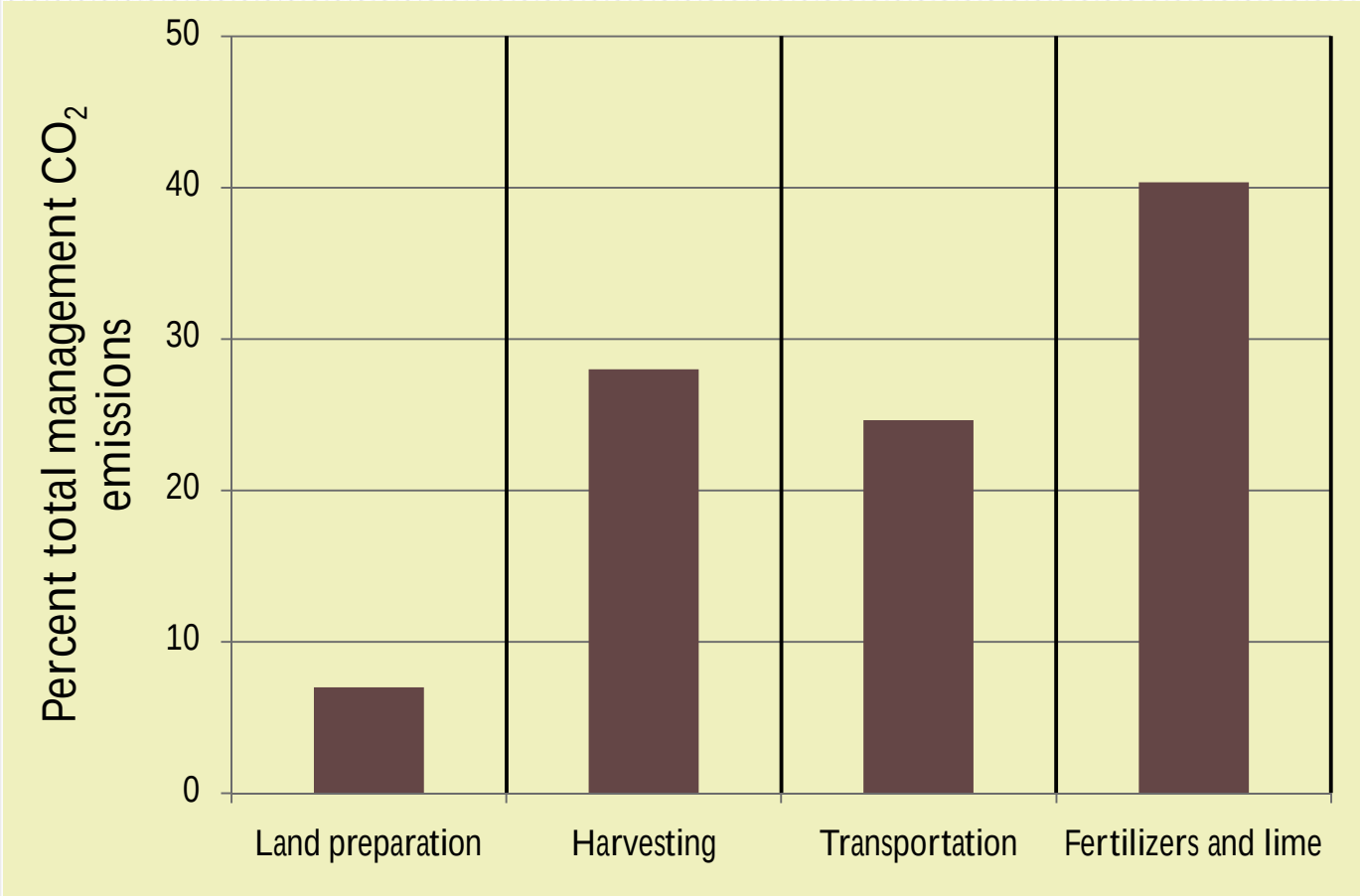

Reed canary grass site
Bare peat site
mg N_2O m^{-2} d^{-1}
35
30
25
20
15
10
2
1
0
-1
-2
1/04
7/04
1/05
7/05
1/06
7/06
1/07
7/07
1/08
Date (M/yy)


Reed canary grass site
Bare peat site
60
40
20
0
mg CH4 m-2 d-1
1/04
7/04
1/05
7/05
1/06
7/06
1/07
7/07
1/08
Date (M/yy)

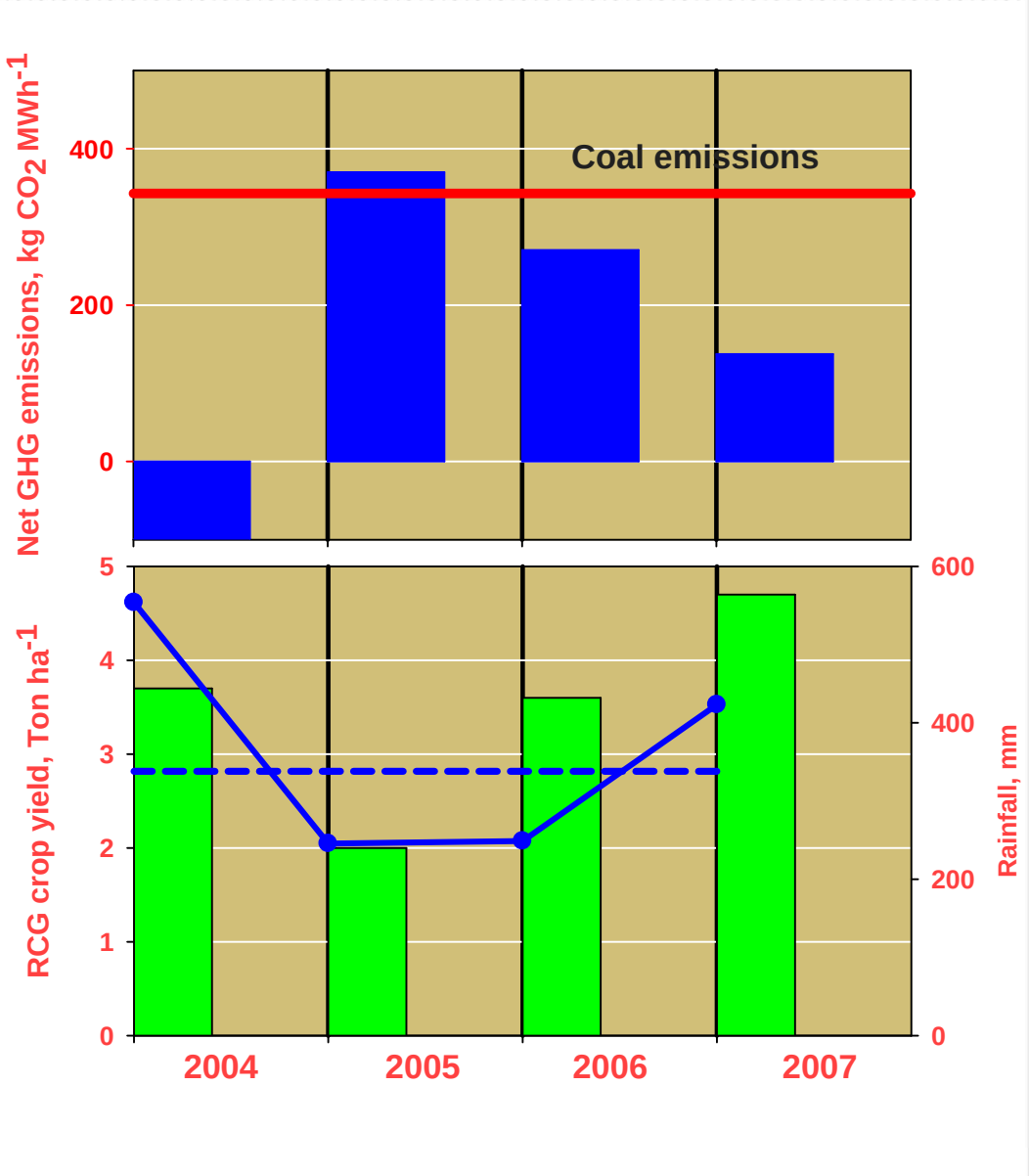
Components of the reed canary grass life cycle analysis (LCA)



Different crop management operations considered in the LCA of RCG cultivation system and their percent contribution to the total management related CO_2 emissions



A comparison of Net GHG emissions (kg, CO_2 equivalents per MWh of energy) from RCG cultivation and Coal



Soil Carbon Dynamics

Question:

Does RCG cultivation increase soil carbon loss as CO_2? (is there a priming effect?)

Soil carbon sequestration is an important component in bioenergy systems

Problem:

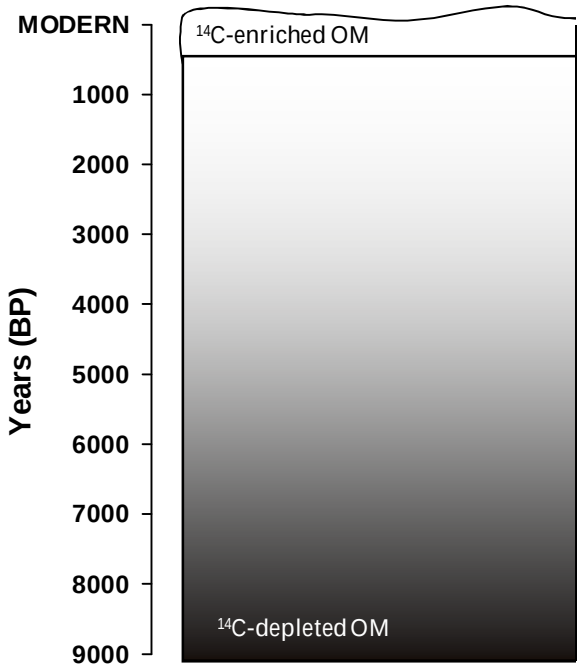
- Against huge background of carbon in soils small changes are difficult to detect
- Analysis of soil respiration is complicated by the contribution of roots

Solution:

- Cultivated cut-away peat offers a unique natural tracer to partition sources of respiration (soil vs. plant)

Principle of the Isotopic tracer method

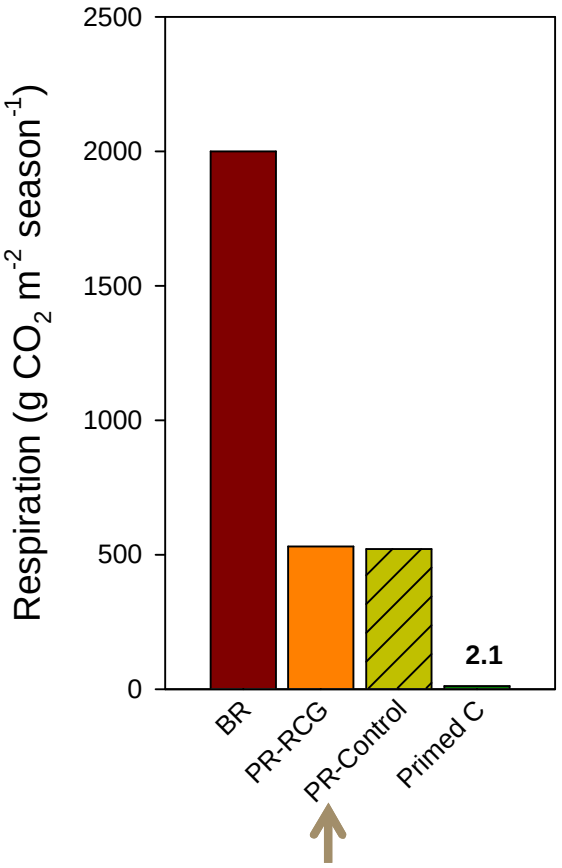
Natural peatland



Huge difference in age (^{14}C content) between plants and soil!!

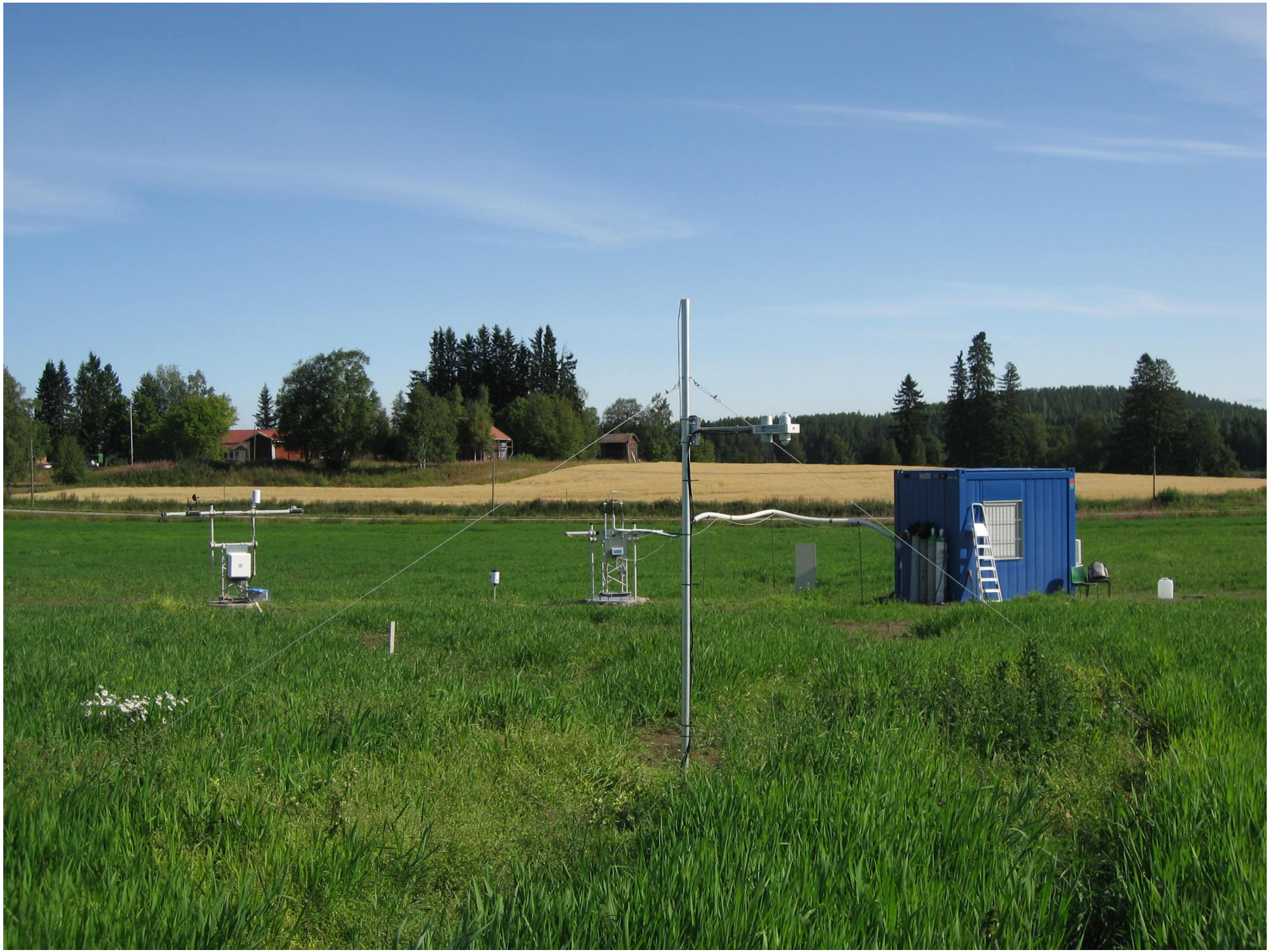
Ideal opportunity to partition plant vs. soil-derived CO_2 with radiocarbon dating

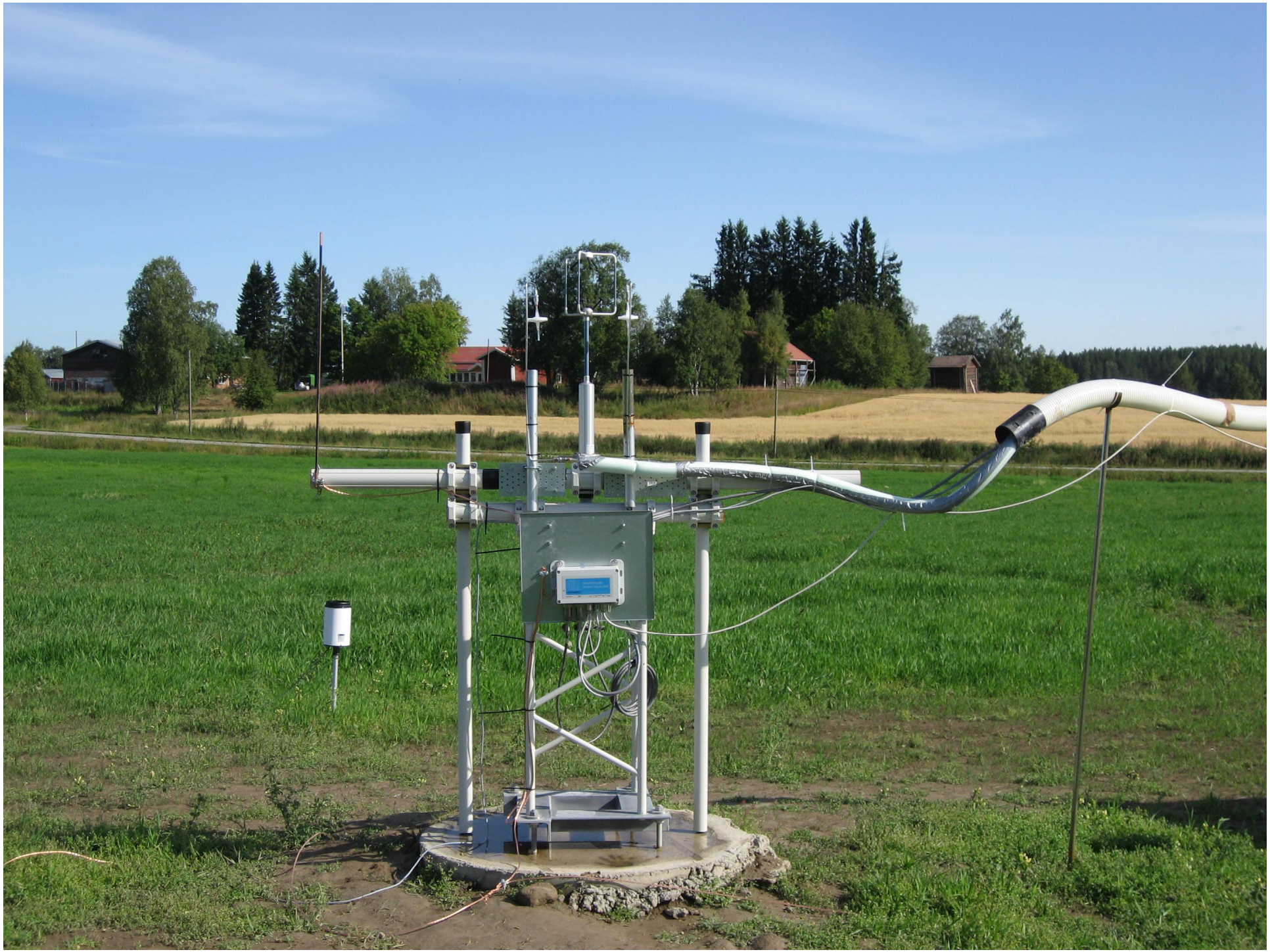
CO_2 emissions from peat are not increased due to cultivation



- Priming effect is negligible over the season!!
- RCG does not stimulate the decomposition of peat
- Potential for soil carbon sequestration is very high in RCG cultivations with conservative management practice and no-tillage
- High value as a bioenergy crop

The cut-away peatland functions as the control site to compare soil CO_2 emissions between cultivated and non-cultivated site





Vielen Dank

Picture taken by: Dr. Mark Zahniser, Aerodyne Research - Puijo Tower in Kuopio, Finland - August 4, 2009