# Isotope-specific measurements with laser instruments in ecosystem research — results from laboratory and field measurements

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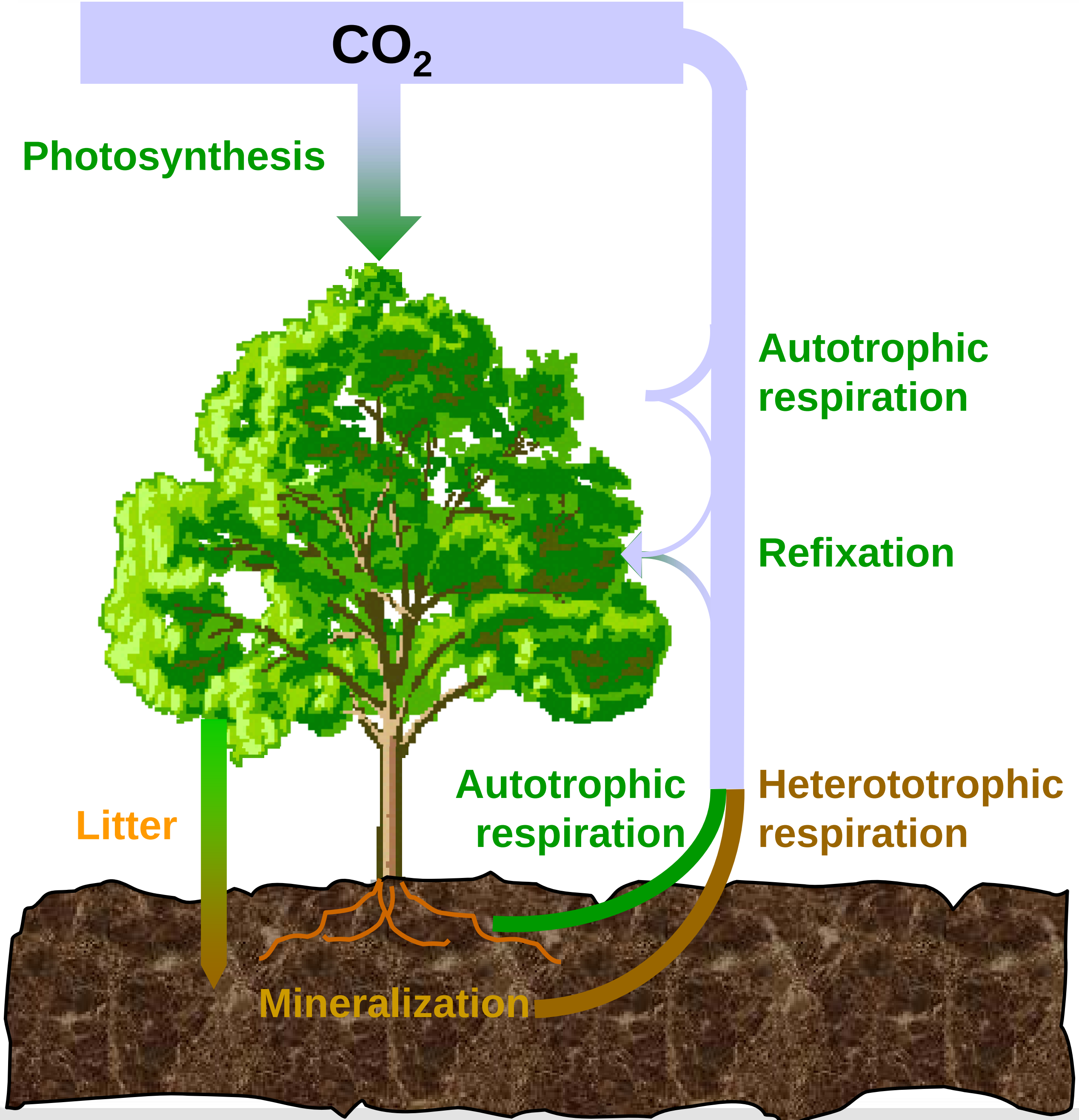


## Challenge

- Disentangling ecosystem $CO_2$ component fluxes
- Understanding short-term dynamics of $CO_2$ exchange between ecosystems and the atmosphere
- Understanding C fluxes into, within and out of ecosystems


KIT – a Cooperation between Karlsruhe Research Center and University of Karlsruhe
Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft
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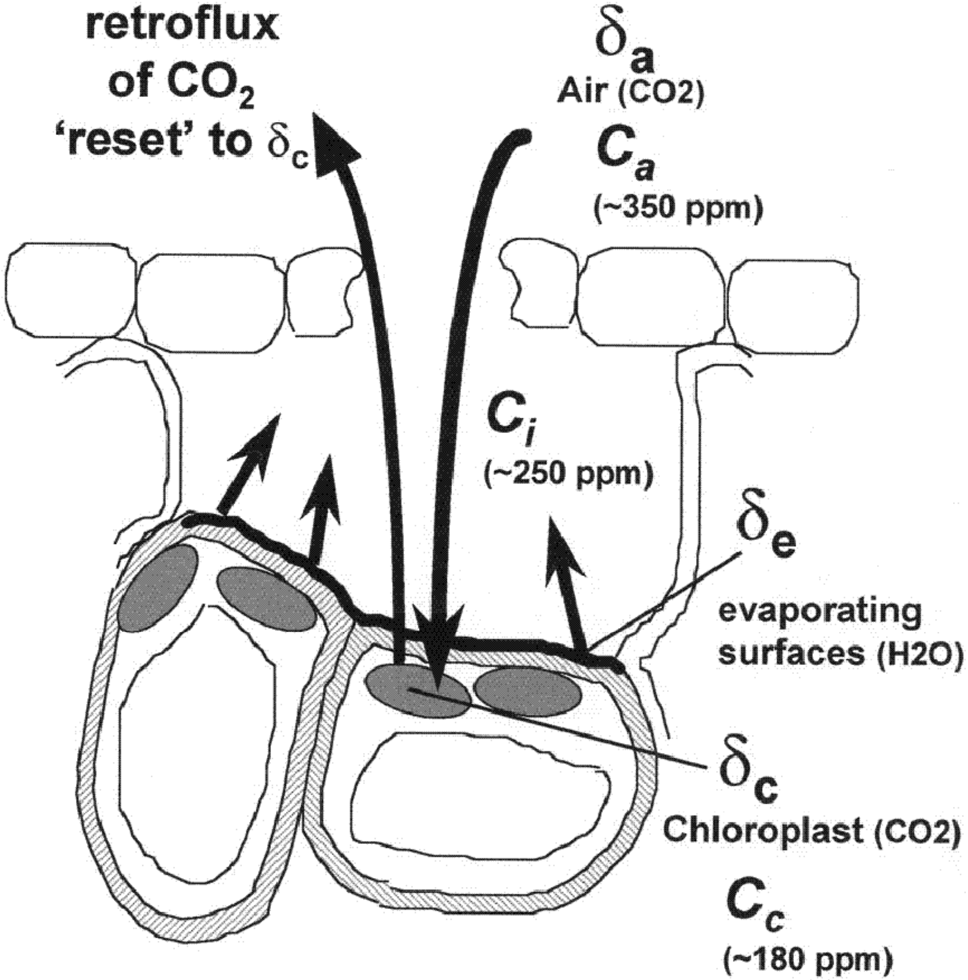
# Major steps involved in the $^{18}O$ isotopic exchange of $CO_2$ between a $C_3$ leaf and the atmosphere




Yakir & Sternberg (2000), Oecologia 123, 297–311

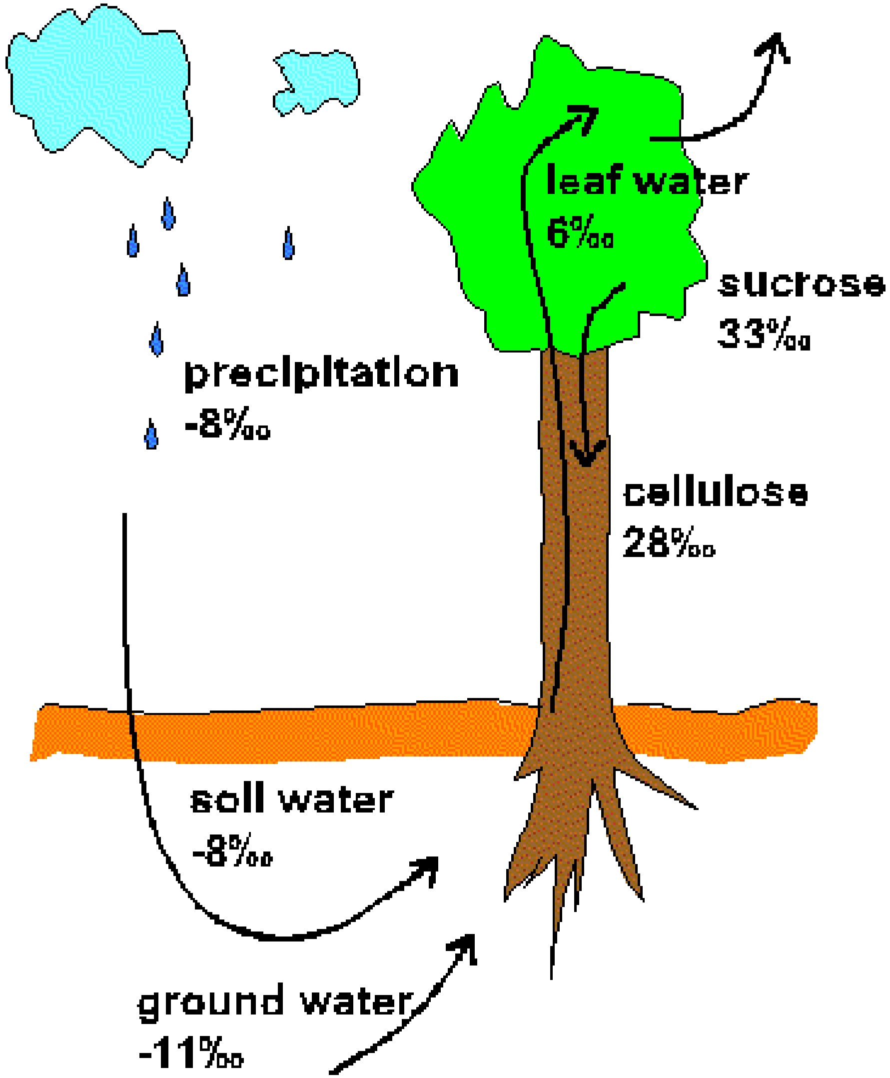
Thermodynamic equilibration

$$H_2{}^{16}O + C^{18}O^{16}O$$

$$\leftrightarrow H_2{}^{18}O + C^{16}O^{16}O$$

catalyzed by carbonic anhydrase

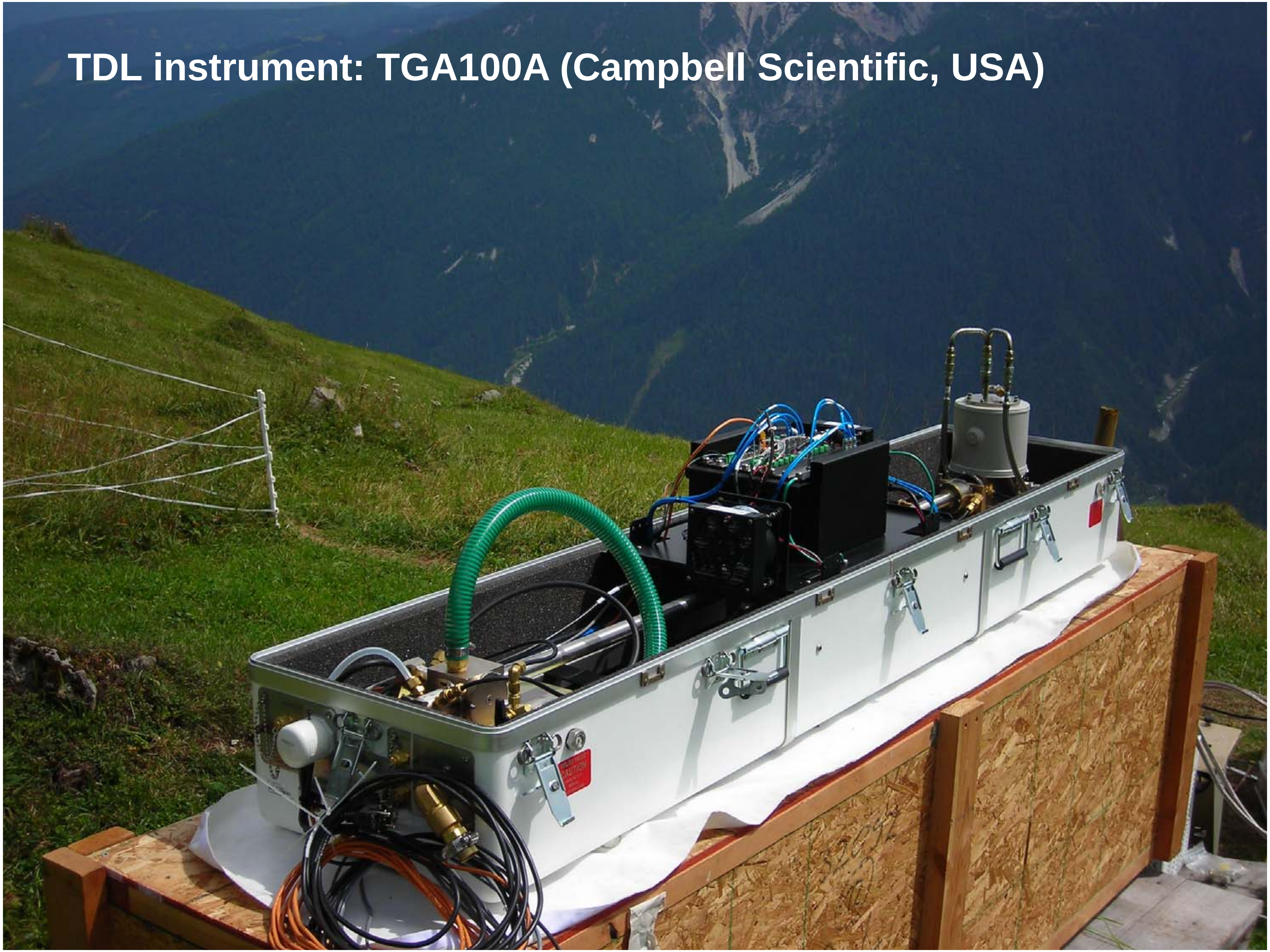
# $\delta^{18}$O values in different compartments of the water-plant system




As soil water and leaf water have significantly different $^{18}O/^{16}O$ ratios, a differentiation between plant and soil $CO_2$ fluxes is possible

Saurer M. et al. (1997), Tellus **49B**, 80-92.

# TDL instrument: TGA100A (Campbell Scientific, USA)



# TDL instrument: TGA100A (Campbell Scientific, USA)

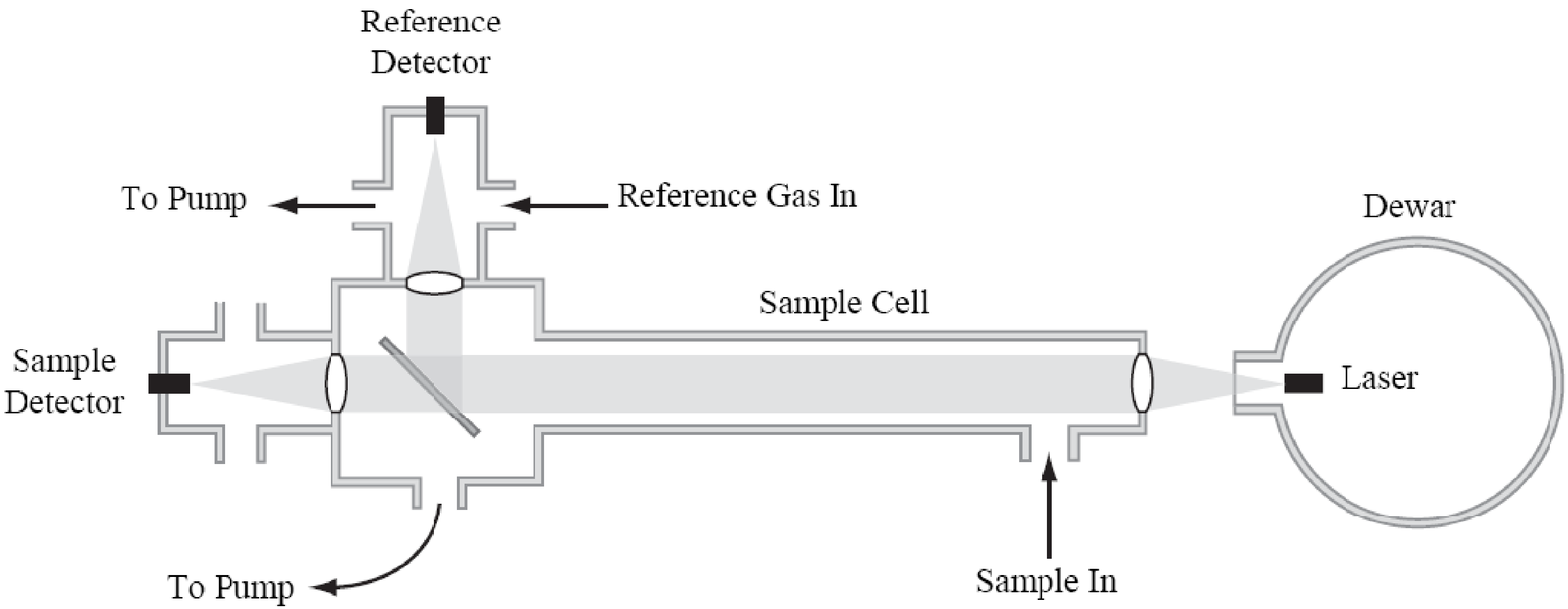



*FIGURE OV2.1-1. Schematic Diagram of TGA100A Optical System*

# Absorption lines and noise of $CO_2$ isotope ratio measurements with the TGA100A

| Gas | Isotope Ratio | Wavenumber ($cm^{-1}$) | 10 Hz Noise | Calibrated Noise |
|---|---|---|---|---|
| Carbon Dioxide, $\delta^{13}C$ only | $CO_2$ | 2293.881 | 0.2 ppm | 0.05 ppm |
| | $\delta^{13}C$ | 2294.481 | 0.5 ‰ | 0.1 ‰ |
| Carbon Dioxide, $\delta^{13}C$ and $\delta^{18}O$ | $CO_2$ | 2308.225 | 0.6 ppm | 0.15 ppm |
| | $\delta^{13}C$ | 2308.171 | 2.0 ‰ | 0.4 ‰ |
| | $\delta^{18}O$ | 2308.416 | 2.0 ‰ | 0.4 ‰ |
| Water, $\delta D$ only | $H_2O$ | 1501.846 | 10 ppm | 2 ppm |
| | $\delta D$ | 1501.813 | 8 ‰ | 2 ‰ |
| Water, $\delta^{18}O$ and $\delta D$ | $H_2O$ | 1500.546 | 10 ppm | 2 ppm |
| | $\delta^{18}O$ | 1501.188 | 2 ‰ | 0.5 ‰ |
| | $\delta D$ | 1501.116 | 20 ‰ | 5 ‰ |

# Laser scanning and concentration calculation

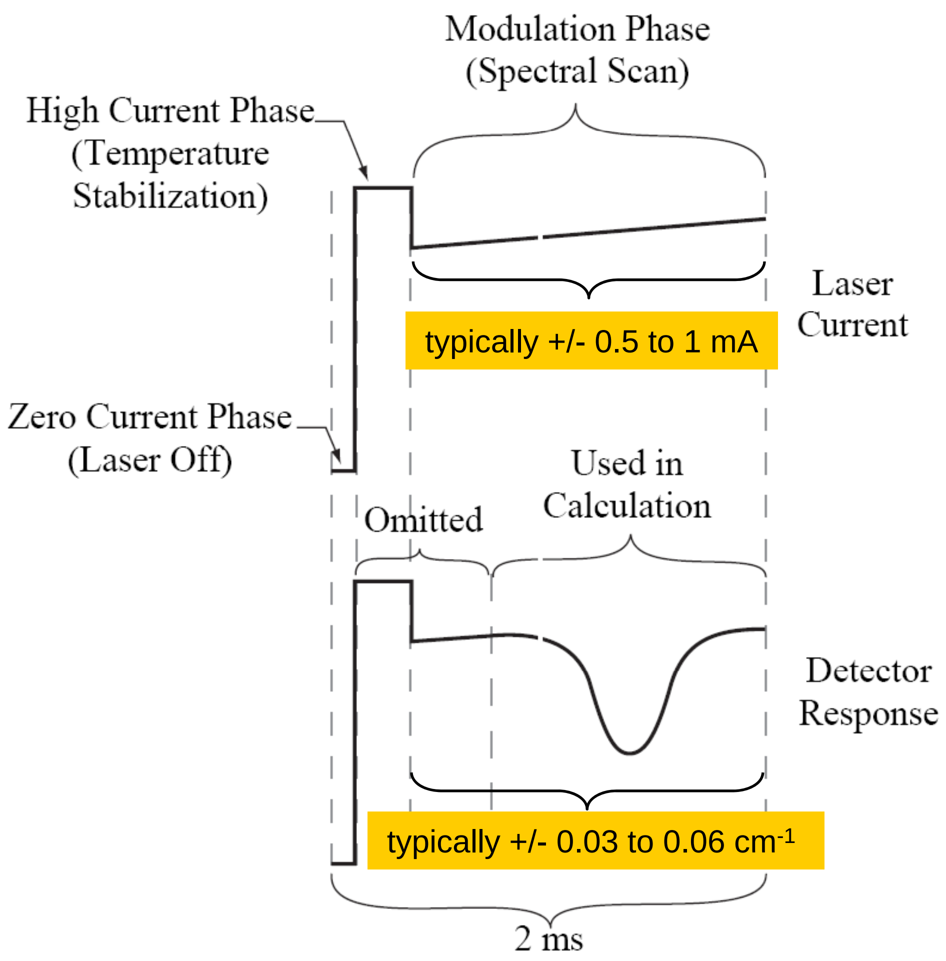



*FIGURE OV2.2-1. TGA100A Laser Scan Sequence*

$$C_s = \frac{(C_R)(L_R)(D)}{L_S + L_A(1-D)}$$

where

$C_S$ = concentration of the sample, ppm

$C_R$ = concentration of reference gas, ppm

$L_R$ = length of the short reference cell, cm

$L_S$ = length of the short sample cell, cm

$L_A$ = length of the long sample cell, cm

$D$ = ratio of sample to reference absorbance

# Instrumental setup for $CO_2$ isotope measurements

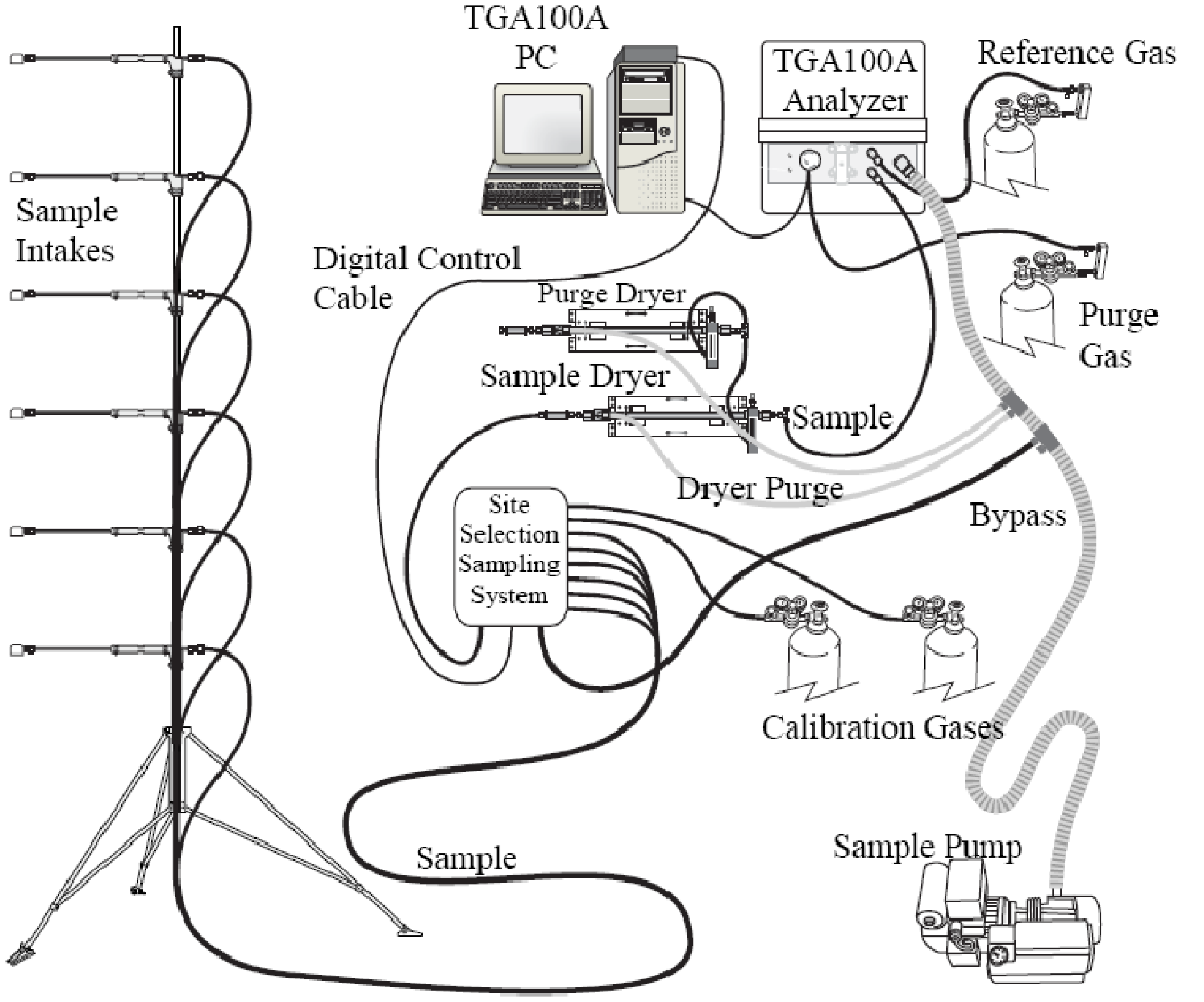
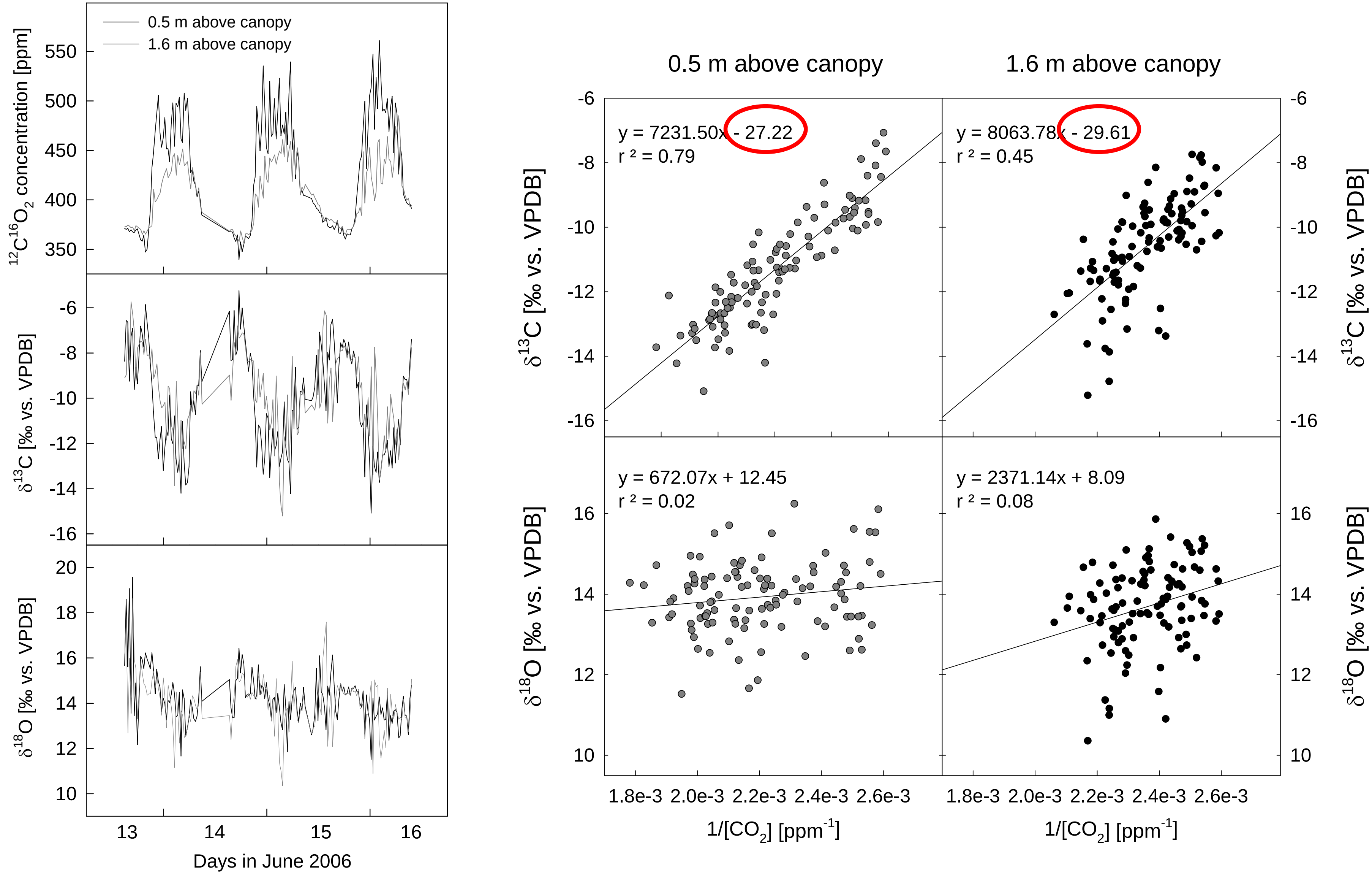



*FIGURE OV6.4-1. Example $CO_2$ Isotope Application*

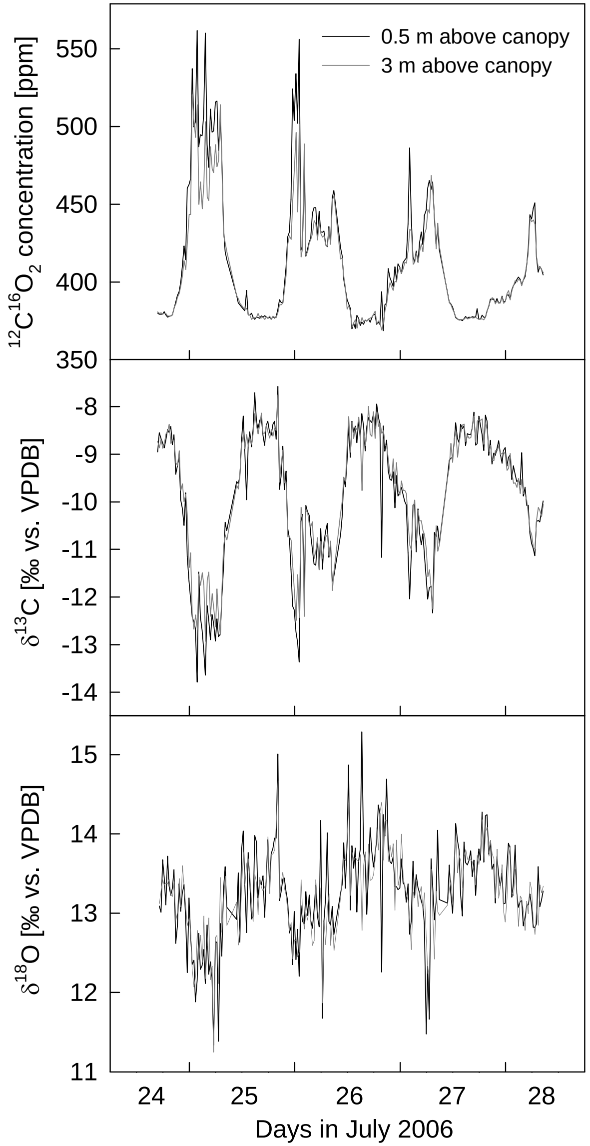
# $CO_2$ isotope measurements above wheat ($C_3$) and maize ($C_4$)

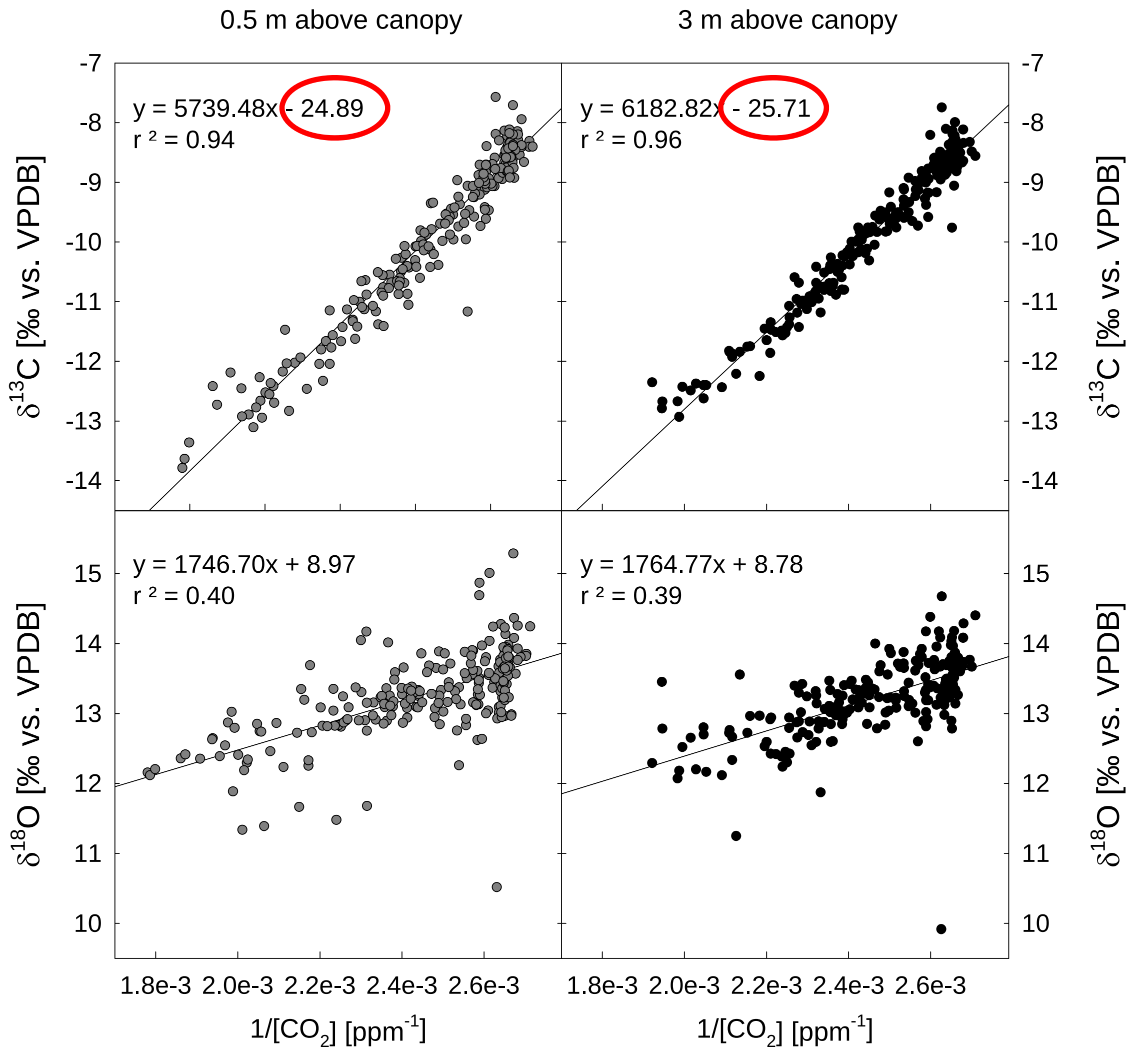
- **Measurements at natural abundance level**
- **Wheat and maize grown on field exclusively planted with $C_3$ crops in the past**
- **Continuous measurements in different heights above the ground over several days**

# $CO_2$ isotope measurements above a wheat field ($C_3$)



# $CO_2$ isotope measurements above a maize field ($C_4$)



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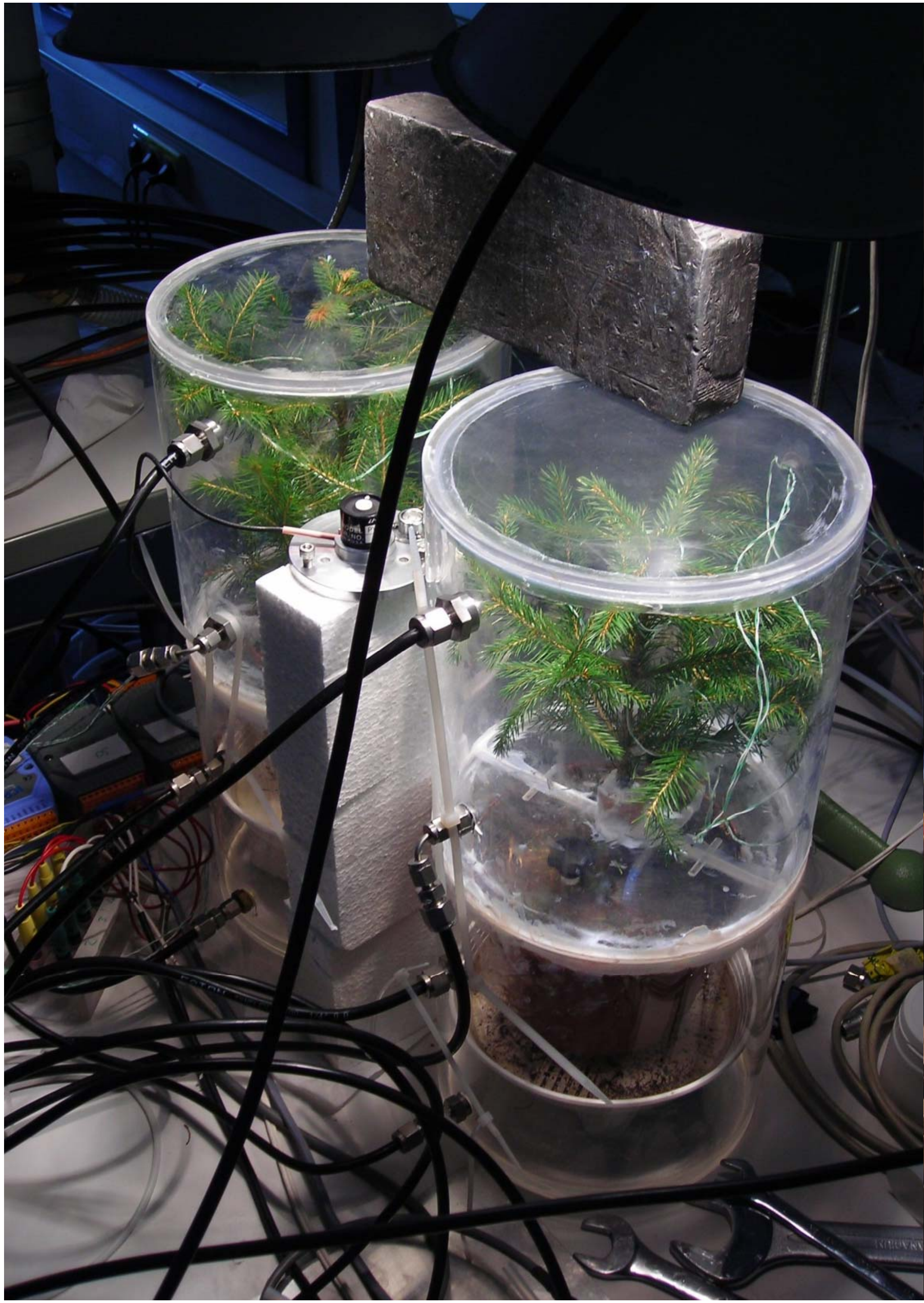
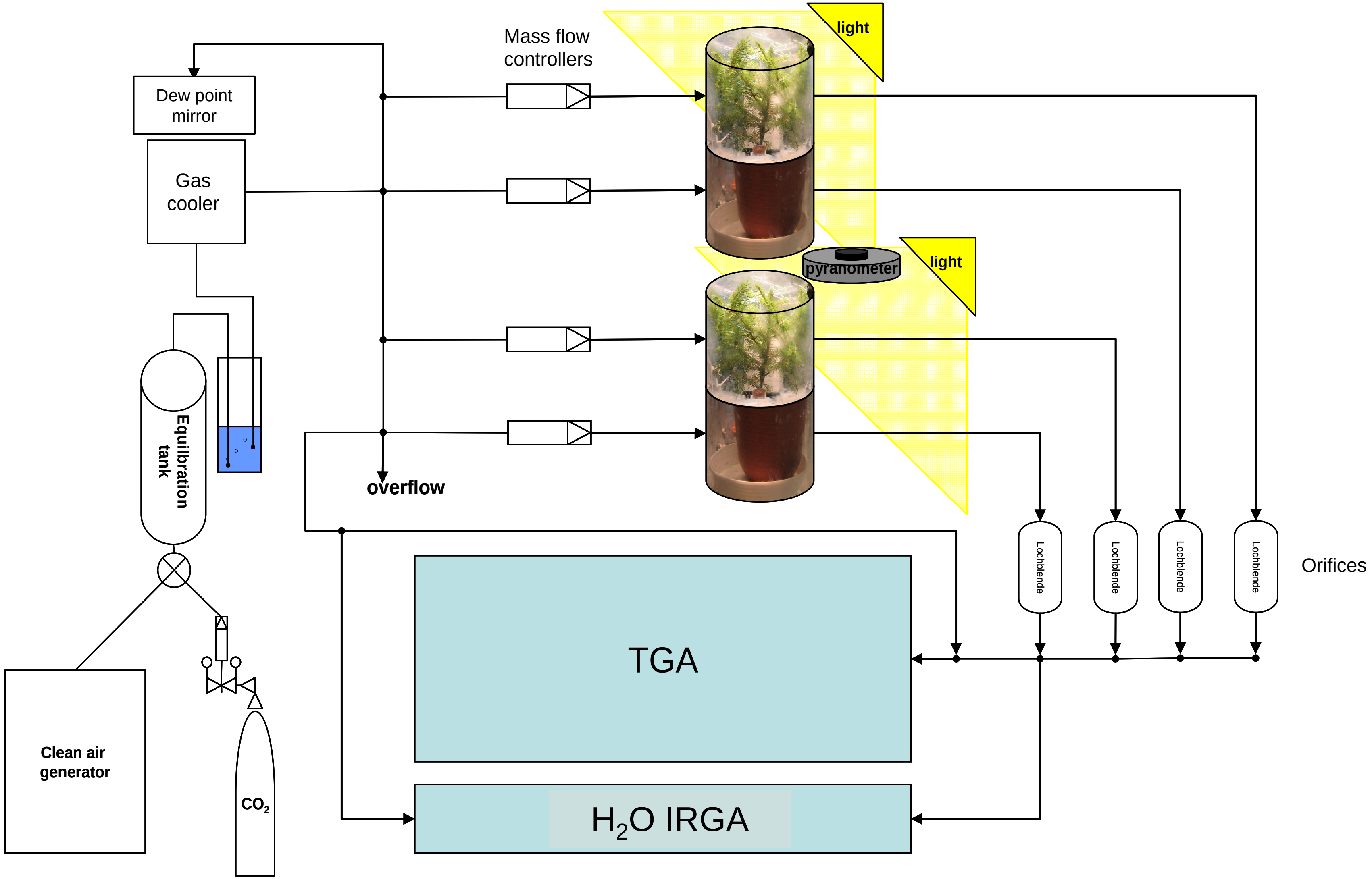
# $CO_2$ isotope measurements on Norway spruce saplings

- **Measurements at natural abundance level**
- **Above-ground (needle) and below-ground (root) compartment separated gas-tight**
- **Flushed with ~380 ppm $CO_2$, $\delta^{13}C = -30.5‰$**
- **Continuous measurements over several days**

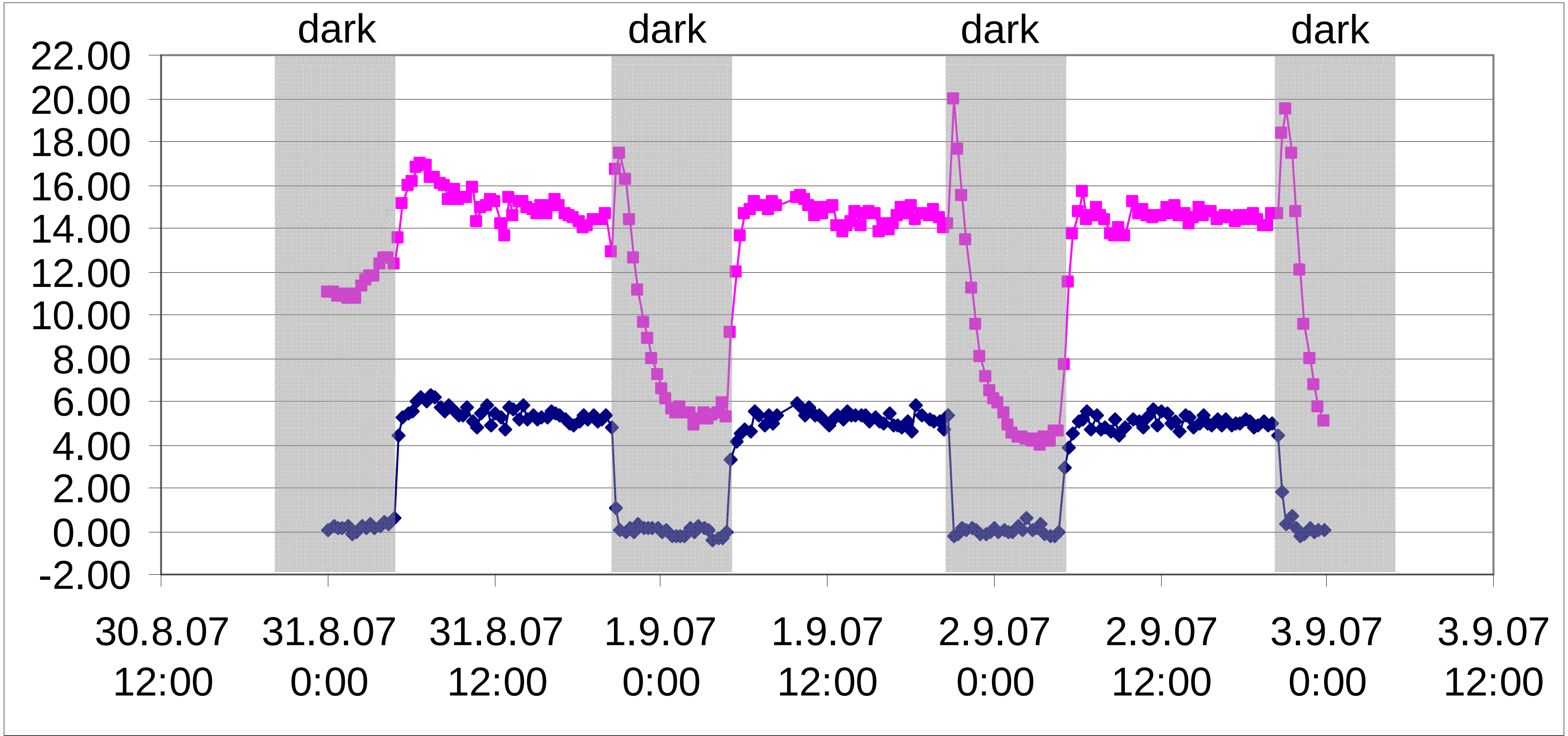


# Experimental setup



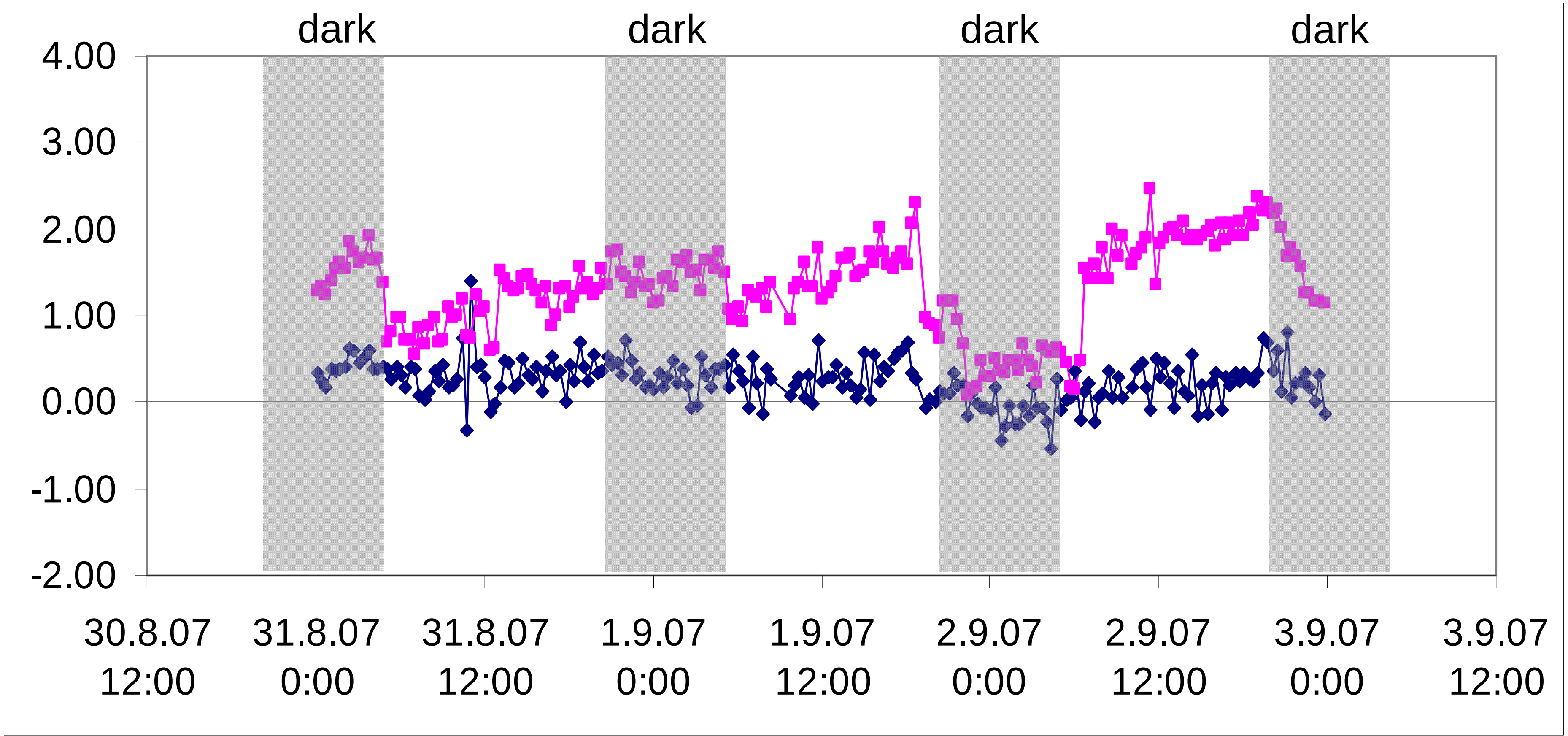
# Potted Norway spruce (*Picea abies*): above-ground $CO_2$

## $\Delta\delta^{13}C$ and $\Delta\delta^{18}O$ of $CO_2$ of needle compartment [outlet–inlet]

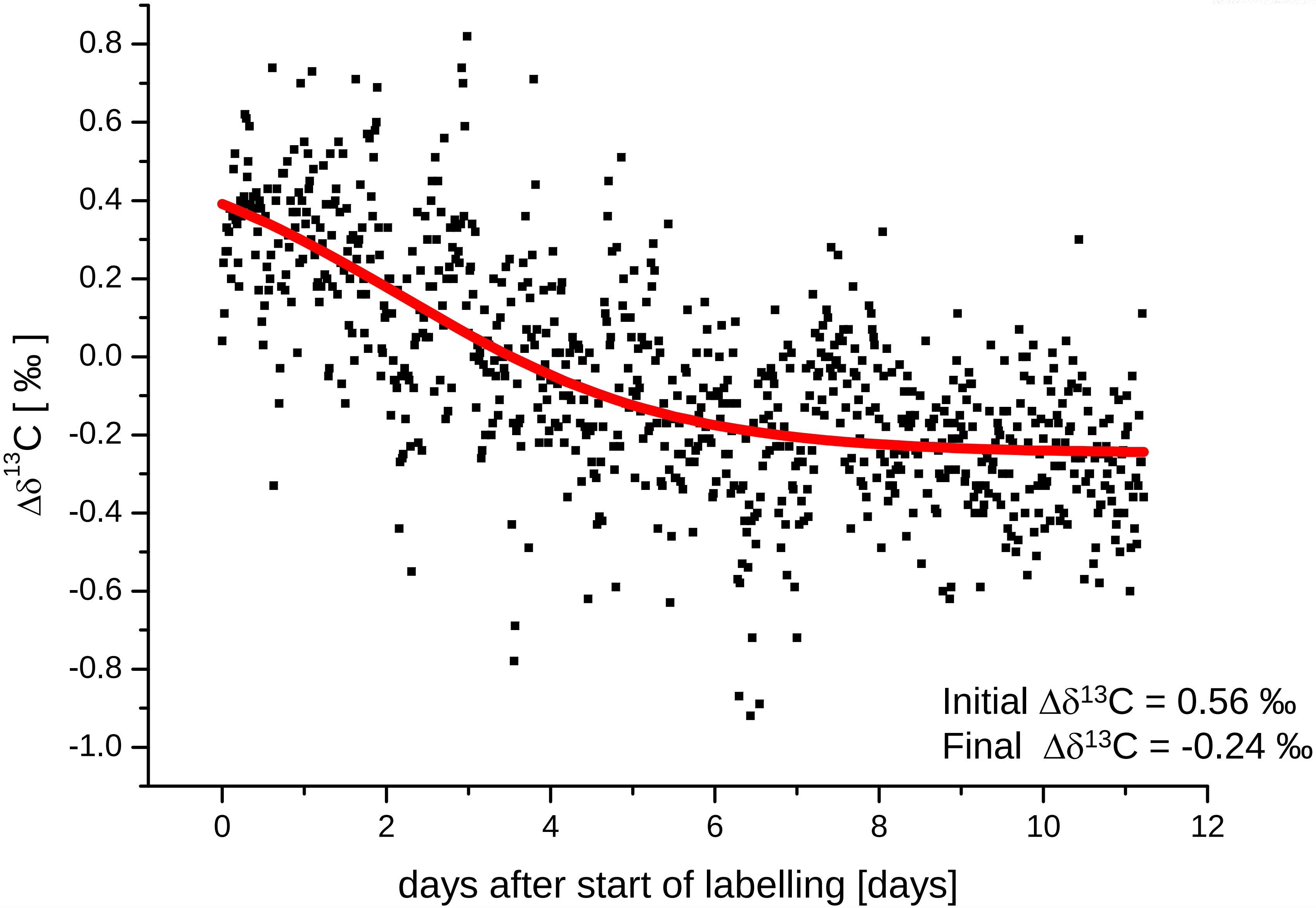


# Potted Norway spruce (*Picea abies*): below-ground $CO_2$

## $\Delta\delta^{13}C$ and $\Delta\delta^{18}O$ of $CO_2$ of root compartment [outlet–inlet]



# $\Delta\delta^{13}C$ of root-respired $CO_2$ in spruce



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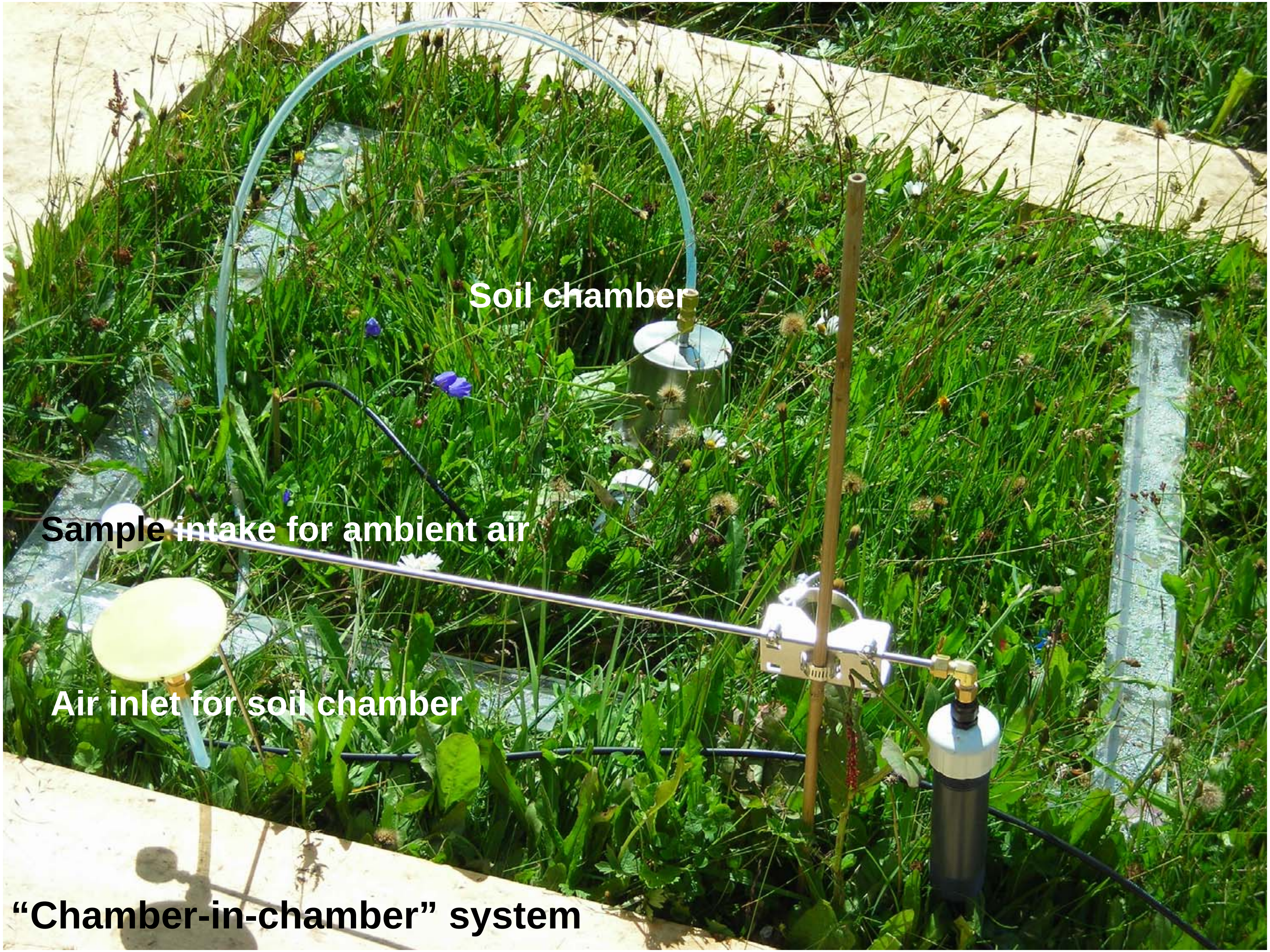
# $CO_2$ isotope measurements in alpine grassland, Austrian Alps (Stubaital)

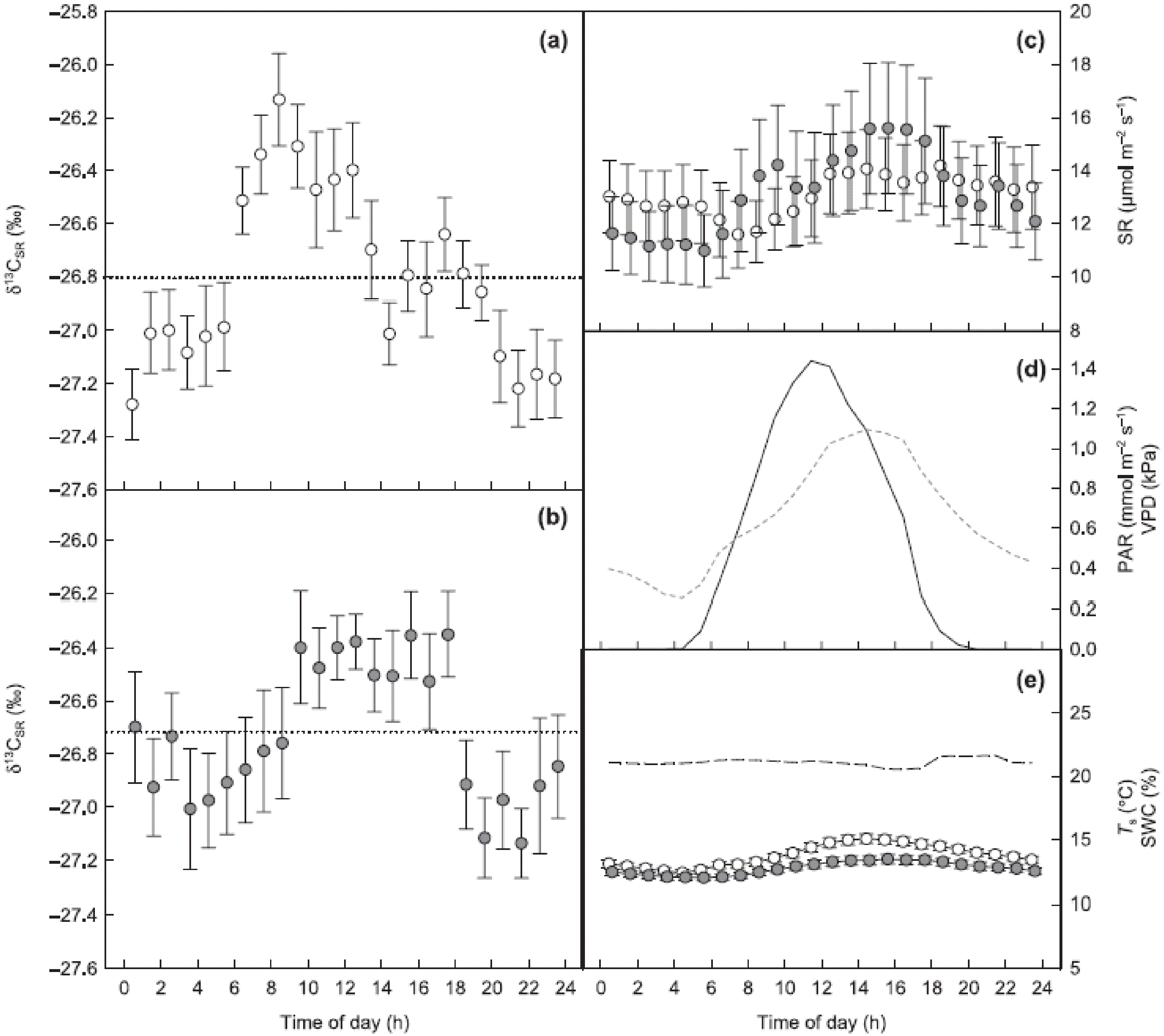
- $^{13}CO_2$ pulse labelling of 1m x 1m plots
- One half of the plots shaded (–90% light reduction) immediately after labelling, the other half unshaded (3 replicates and 3 controls each)
- Continuous measurements of soil-respired $CO_2$ over several days

# $^{13}CO_2$ labelling of alpine grassland, Stubaital, Austria, July-August 2007


Soil chamber
Sample intake for ambient air
Air inlet for soil chamber
“Chamber-in-chamber” system

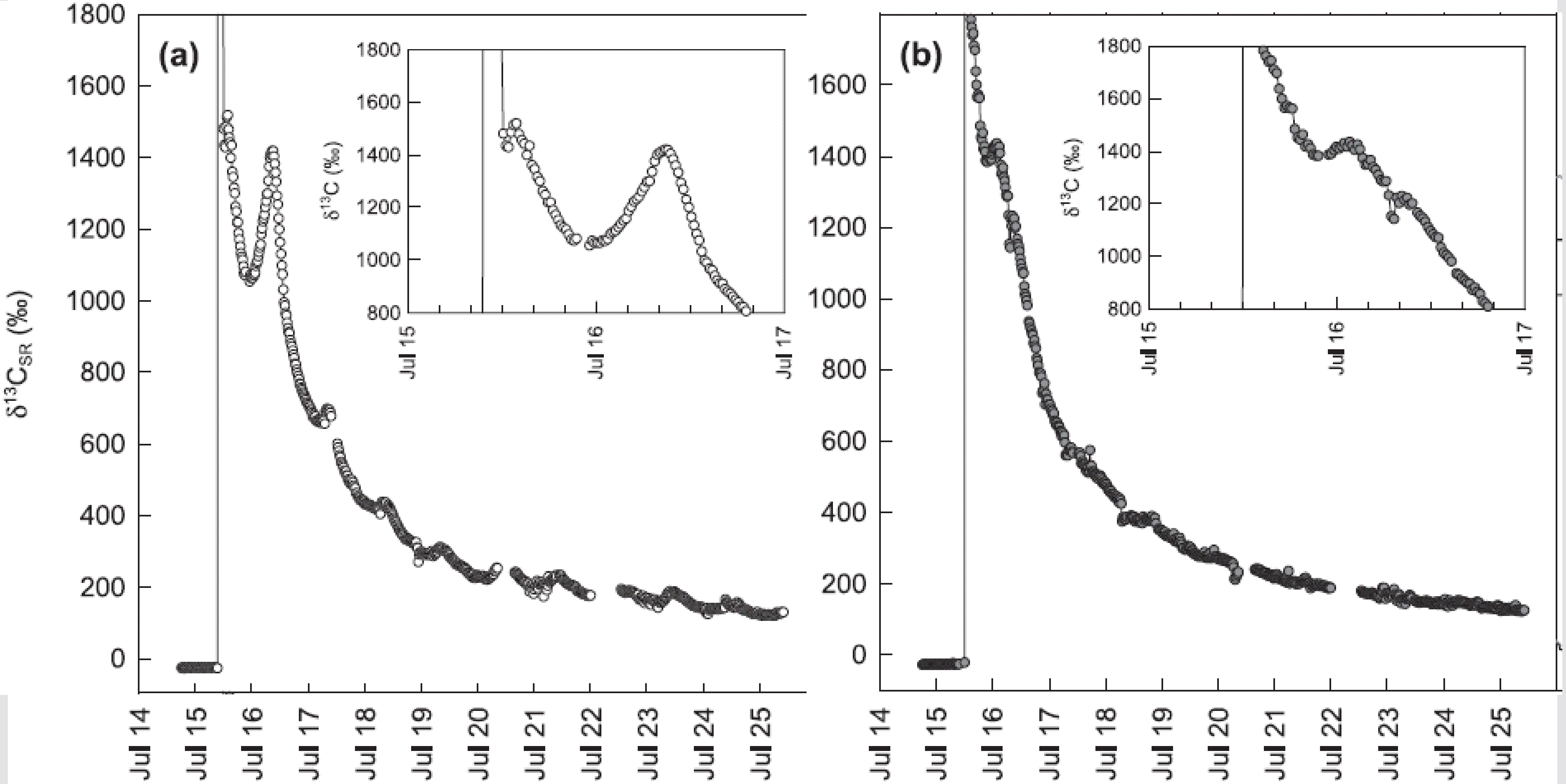

Custom-made stainless steel
soil respiration chambers,
i.d. 10 cm, height 13 cm
3/8“ inlet, ¼“ outlet

# $\delta^{13}C$ of soil-respired $CO_2$ in shaded and unshaded alpine grassland after $^{13}CO_2$ pulse labelling: unlabelled control



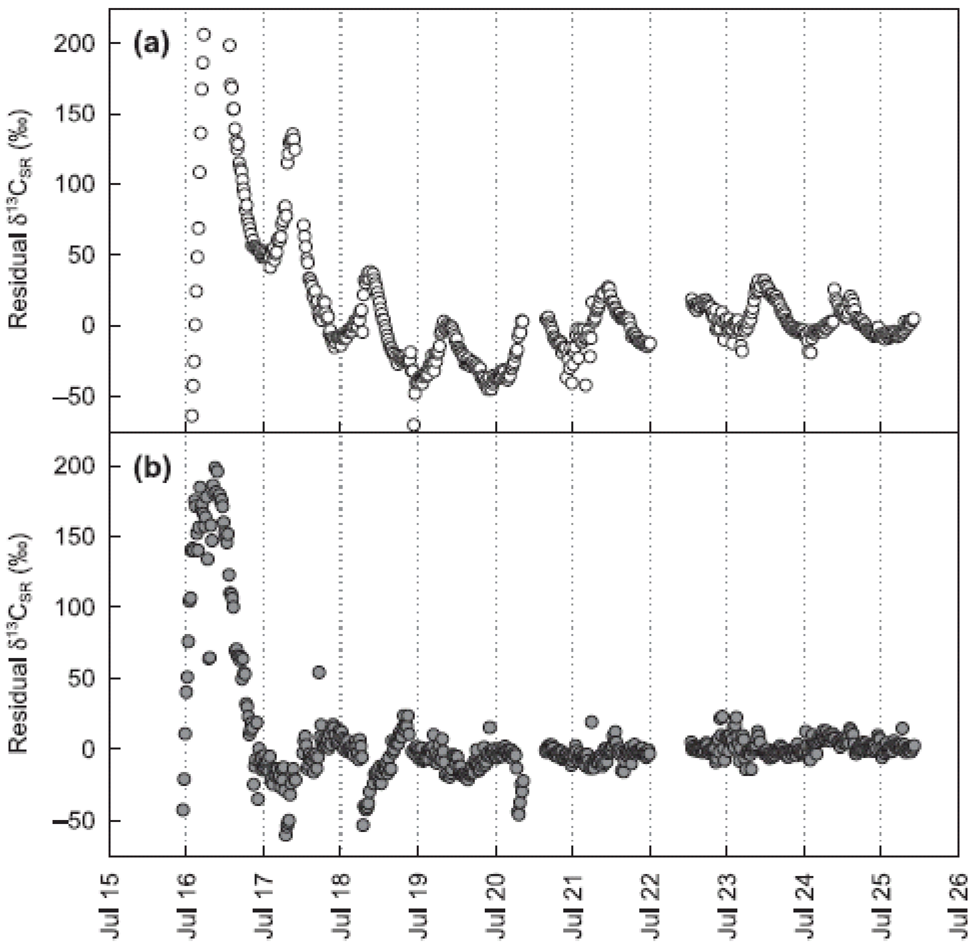

Bahn et al. (2009)
*New Phytologist* **182: 451–460**

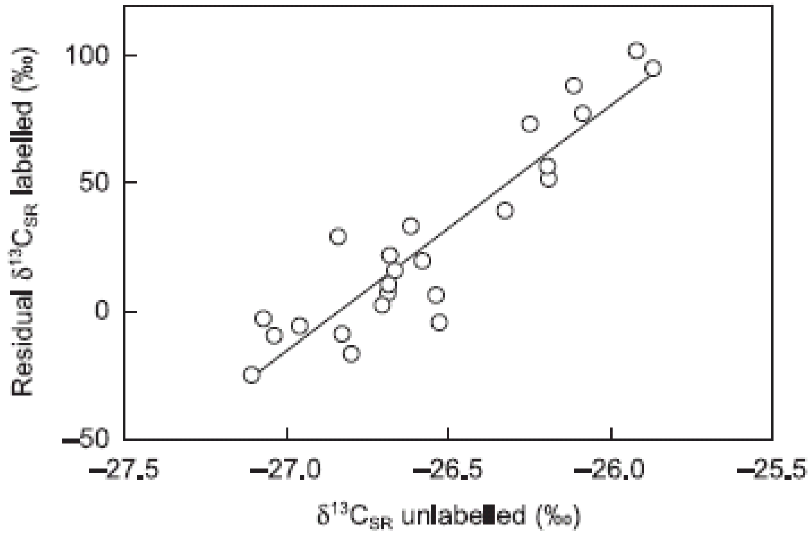
# $\delta^{13}C$ of soil-respired $CO_2$ in shaded and unshaded alpine grassland after $^{13}CO_2$ pulse labelling: labelled plots




Bahn et al. (2009), *New Phytologist* **182: 451–460**

# Relationship between $\delta^{13}C$ of soil-respired $CO_2$ in labeled and unlabeled plots




Bahn et al. (2009), *New Phytologist* **182: 451–460**

# $CO_2$ isotope measurements in a Norway spruce forest (Höglwald close to Augsburg, Germany)

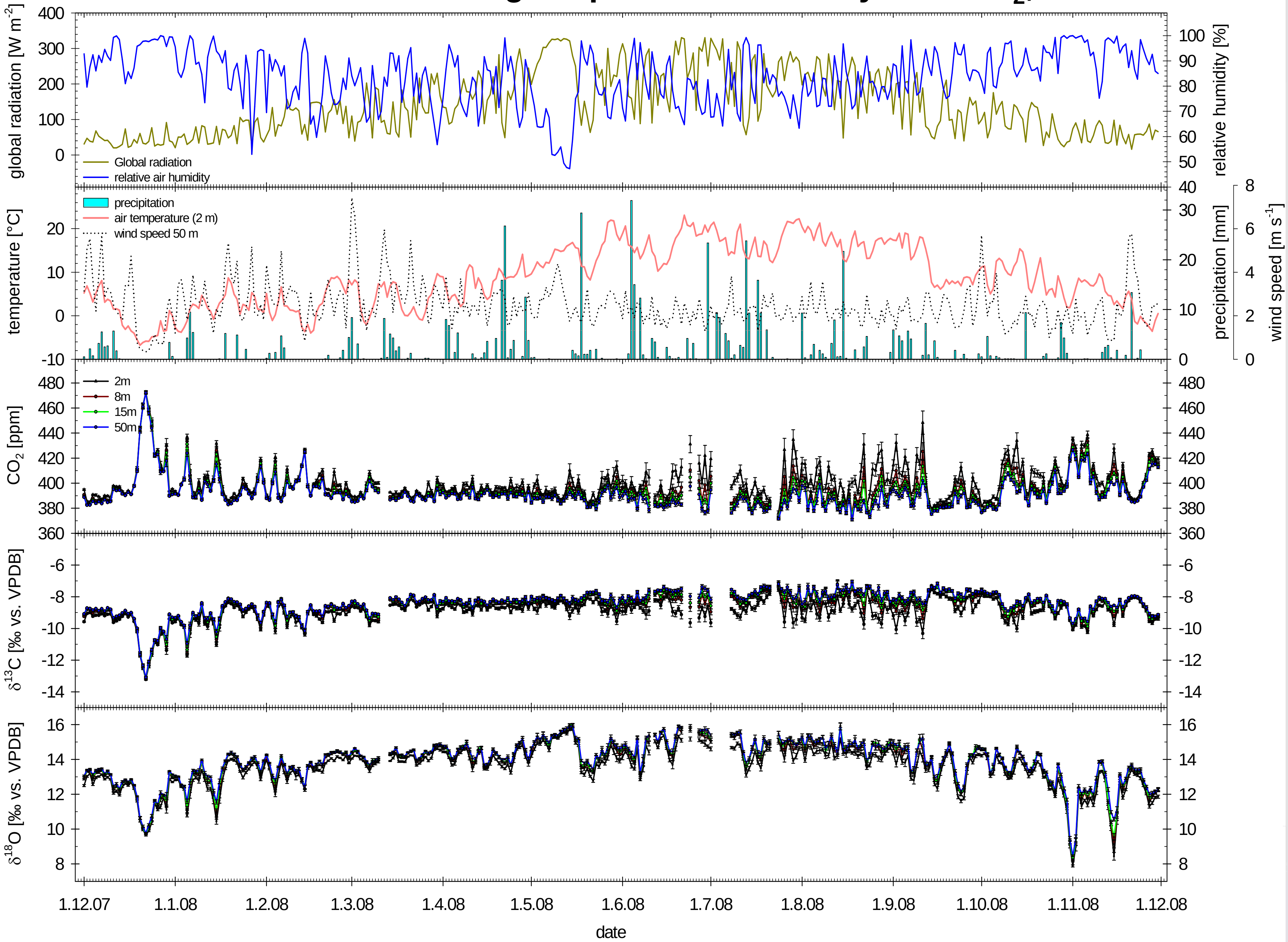
- **Profile measurements of mixing ratios and C and O isotopic ratios of $CO_2$ along a tower (2, 8, 15, 50 m) over one year**
- **Continuous measurements of soil-respired $CO_2$ over six months with 6 dynamic chambers**
- **Differentiation between total (3 replicates) and heterotrophic (3 replicates) soil respiration with chambers on stainless steel collars of different depth (2 cm, 30 cm)**

# Isotope-specific measurements of

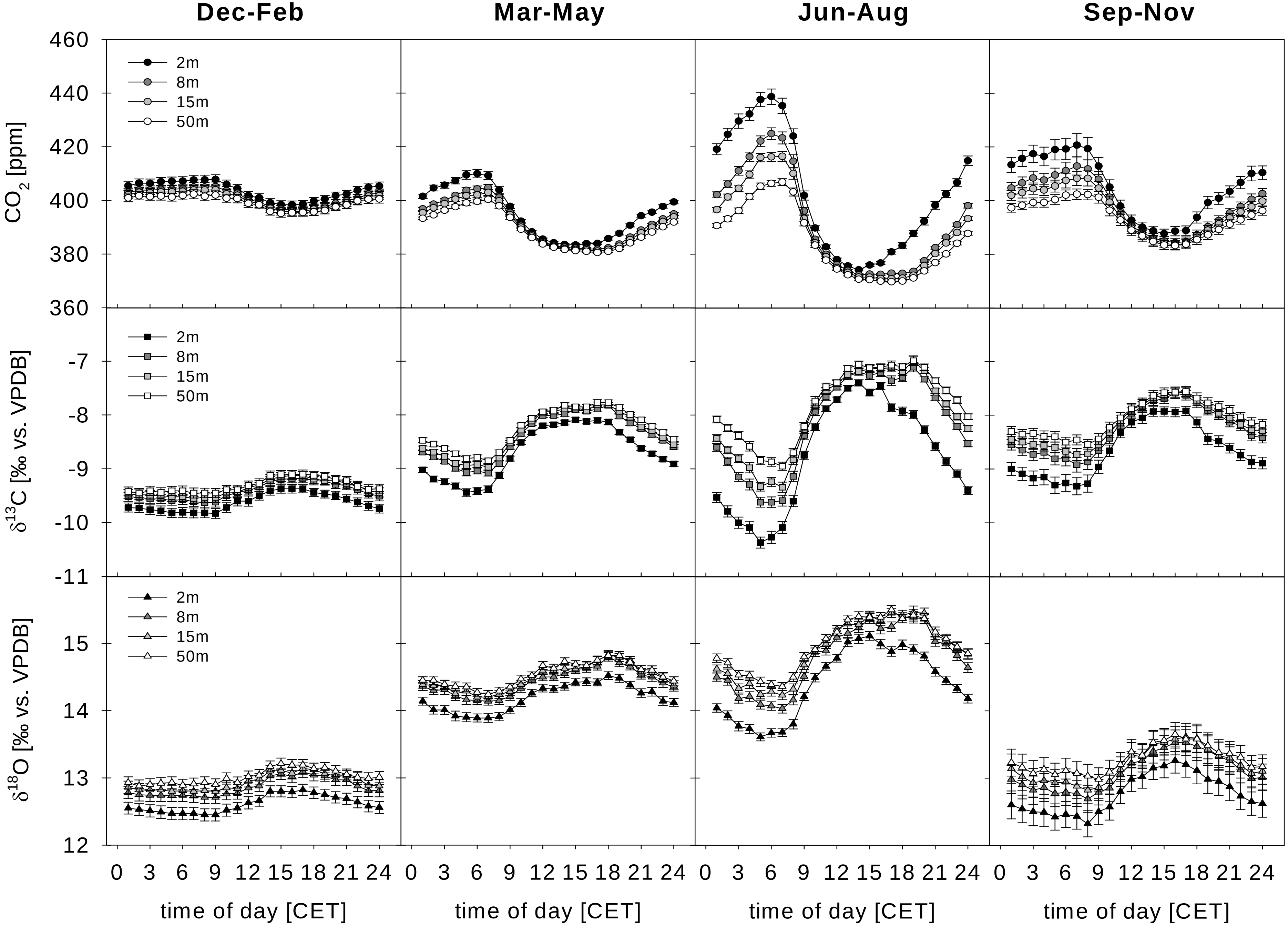
$CO_2$ profiles

soil respiration

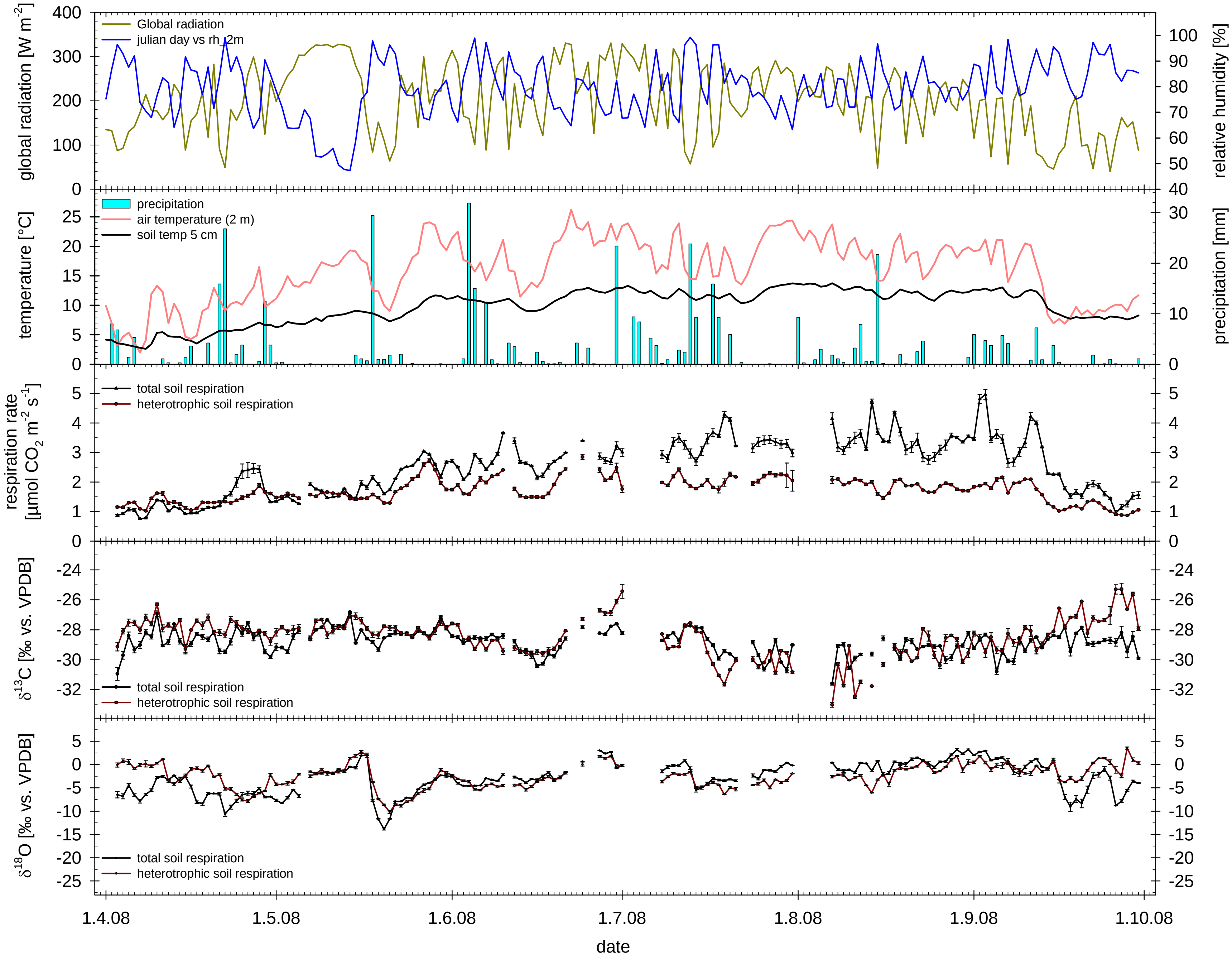
# Seasonal courses of meteorological params and ecosystem $CO_2$, $\delta^{13}C$ & $\delta^{18}O$



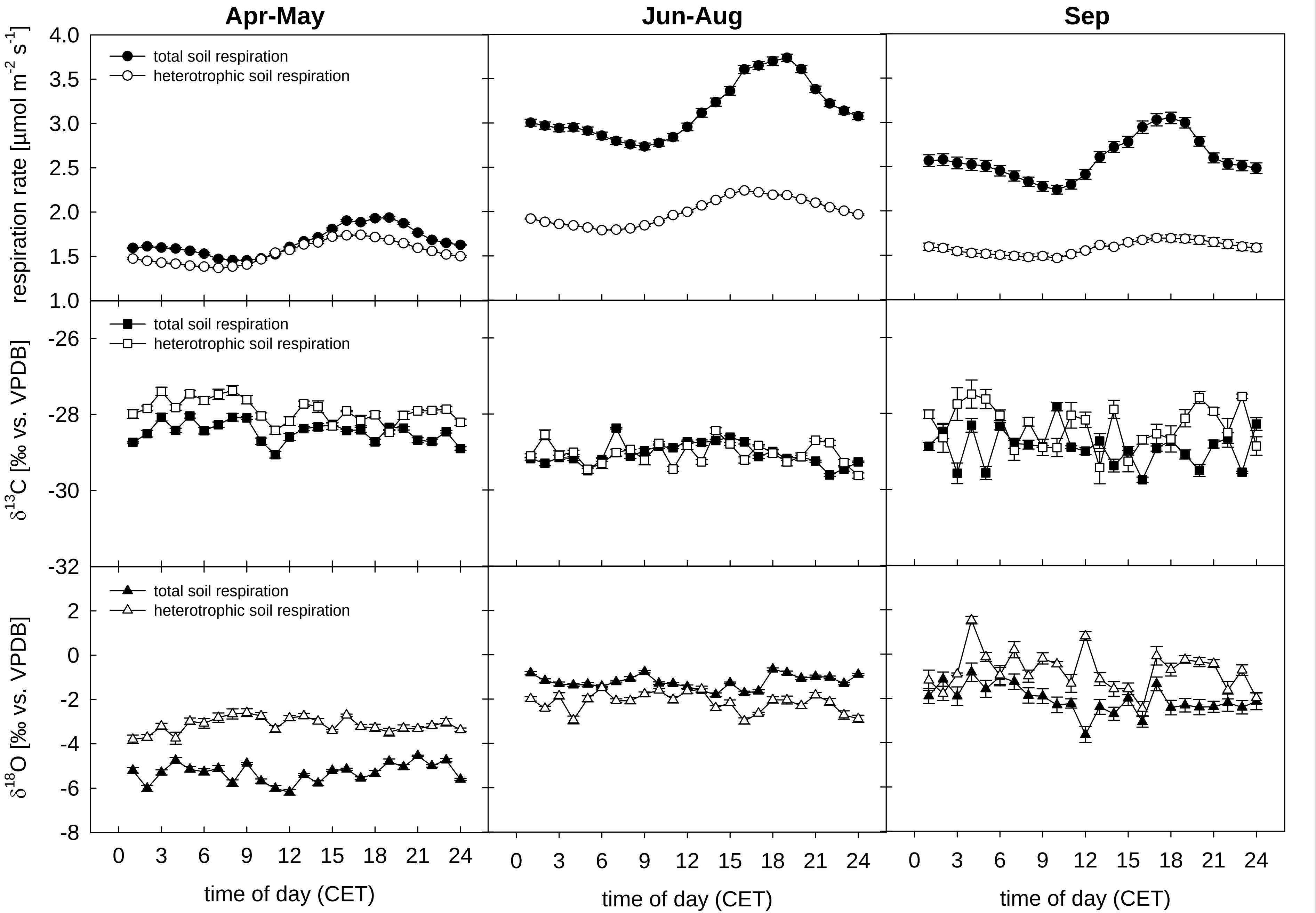
# Seasonal variability of diurnal cycles of ecosystem $CO_2$, $\delta^{13}C$ & $\delta^{18}O$



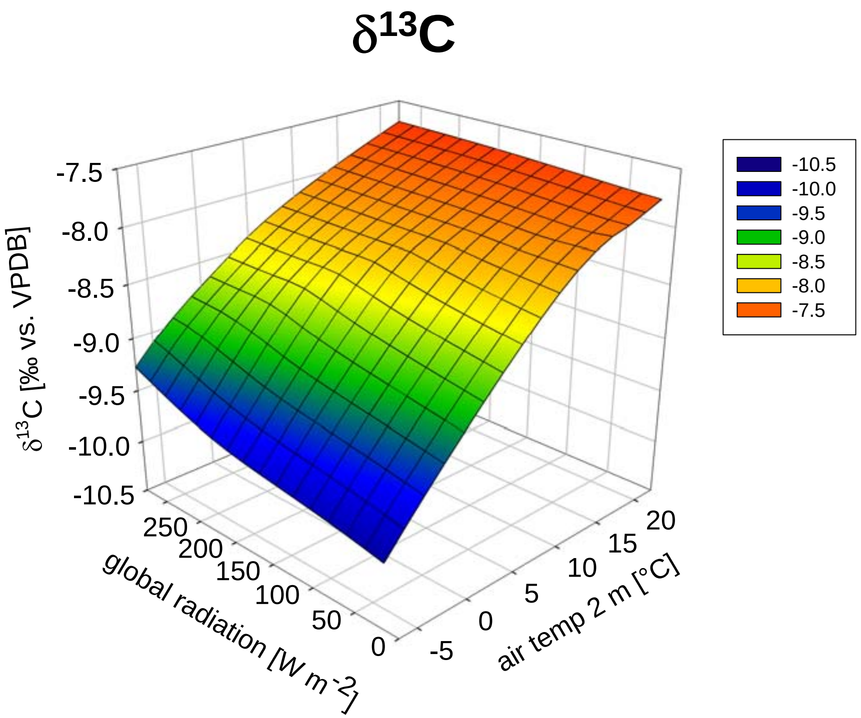
# Seasonal courses of meteorological params and soil $CO_2$, $\delta^{13}C$ & $\delta^{18}O$

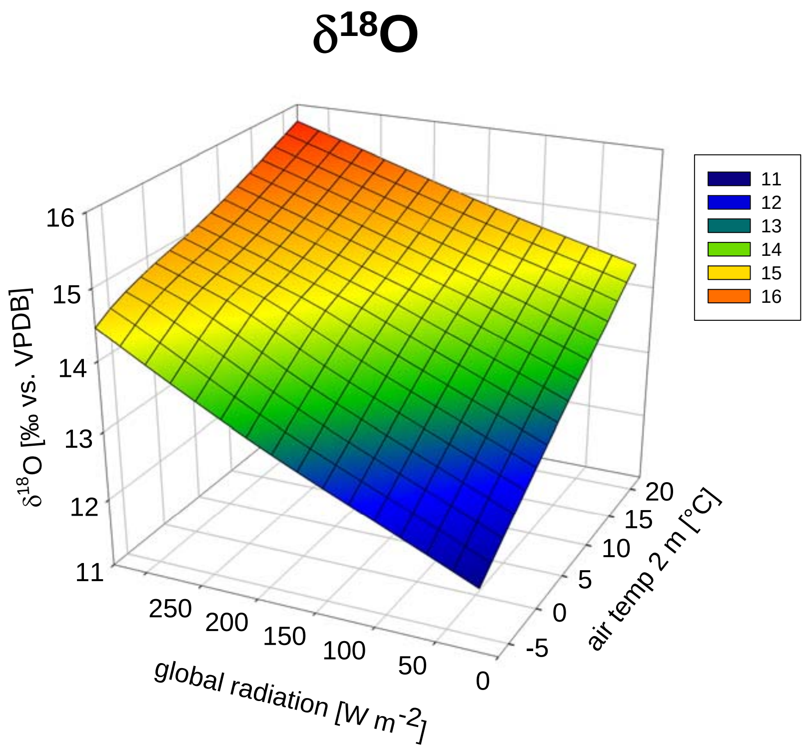


# Seasonal variability of diurnal cycles of soil $CO_2$, $\delta^{13}C$ & $\delta^{18}O$

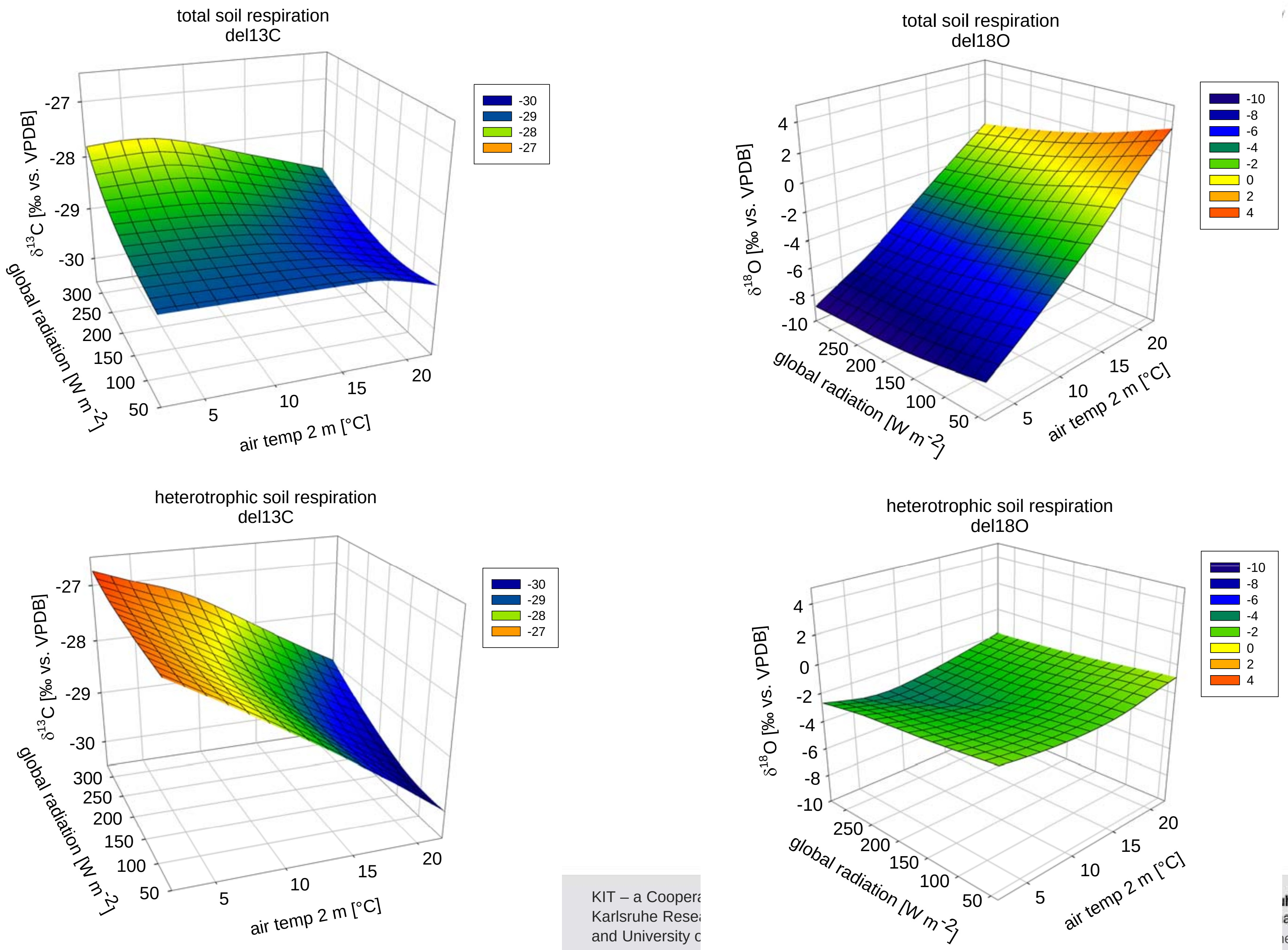


# Dependency of $\delta^{13}C$ & $\delta^{18}O$ of ecosystem $CO_2$ on air temperature & global radiation



# Dependency of δ¹³C & δ¹⁸O of total and heterotrophic soil respiration on air temperature & global radiation



# Conclusions

- Isotope-specific laser absorption spectroscopy is an extremely powerful tool for short-term laboratory and field experiments, not only on the natural abundance level but also in labeling experiments
- Isotope-specific TDL measurements provide invaluable insight into the short-term dynamics of plant, soil and ecosystem processes and fluxes that are inaccessible with isotope-ratio mass spectrometer measurements alone
- Long-term monitoring of C and O isotope ratios of $CO_2$ and of H and O isotopes with high time resolution has become possible

## Outlook

- Combination of isotope-specific laser absorption measurements of $CO_2$ (TGA200, Campbell Scientific) and $H_2O$ (Picarro) in laboratory cuvette and field experiments as well as in long-term monitoring of the atmosphere

- Waiting for isotope-specific $N_2O$ and $CH_4$ laser instruments for C and N trace gas process studies

# Acknowledgments



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- Dominik Steigner, IMK-IFU
- ...