Measuring and modeling soil intra-day variability of the 13CO2 & 12CO2 production and transport in a scots pine forest

Stephanie Goffin, Florian Parent, C. Plain, Daniel Epron, Christophe Wylock, Benoit Haut, Martin Maier, Helmer Schack-Kirchner, Marc Aubinet, Bernard B. Longdoz

MEASURING AND MODELING SOIL INTRA-DAY VARIABILITY OF THE $^{13}CO_2$ & $^{12}CO_2$ PRODUCTION AND TRANSPORT IN A SCOTS PINE FOREST

Goffin Stéphanie [(1)], Parent F. [(2)], Plain C. [(2)], Epron D. [(2)], Wylock C. [(3)], Haut B. [(3)], Maier M. [(4)], Schack-Kirchner H. [(4)], Aubinet M. [(1)], Longdoz Bernard [(2)] (bernard.longdoz@nancy.inra.fr)

(1) University of Liege - GxABT, Unit of Biosystem Physics, Gembloux, Belgium; (2) INRA Centre de Nancy - Henri Poincare University, UMR 1137, Forest Ecology and Ecophysiology, France; (3) University of Bruxelles, Transfers, Interfaces and Processes, Belgium; (4) Institute of Soil Science and Forest Nutrition University of Freiburg, Germany

CONTEXT

- Future dynamics of soil CO_2 efflux (***Fs***) = key question in climate change research.
- Two processes lead to ***Fs***: CO_2 production ***P*** (heterotrophic + autotrophic) + transport ***F*** to surface
- Factors affecting ***P*** & ***F*** (t°, moisture, substrate…) vary vertically and temporally.
- Better understanding of the mechanisms controlling ***Fs*** needs - soil **multilayer approach**

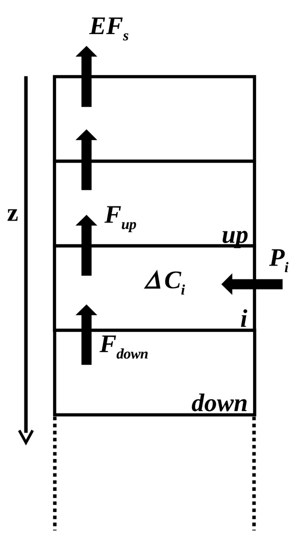
  - fine temporal resolution (intra-day) study
- Use of **^{13}C & ^{12}C** improve *EFs* origin (partitioning) and pathway (spatiotemporal tracer) knowledge

OBJECTIVE 1: Determine soil horizons *Ps* and *δ¹³Ps*

Based on $^{12}CO_2$ & $^{13}CO_2$ balances for layer i & Diffusive Flux-Gradient approach

$$\varepsilon_i * \frac{\Delta C_i}{\Delta t} = \frac{F_{down} - F_{up}}{thick_i} + P_i \quad \text{(Eq. 1)}$$

$$F_x = D_{x\_i} * \frac{C_x - C_i}{z_x - z_i} = \left(D * \frac{\Delta C}{\Delta z} \right)_{x\_i} \quad \text{(Eq. 2)}$$



where C_i = [$^{12}CO_2$] or [$^{13}CO_2$]; ε_i & $thick_i$ = layer i soil porosity & thickness;

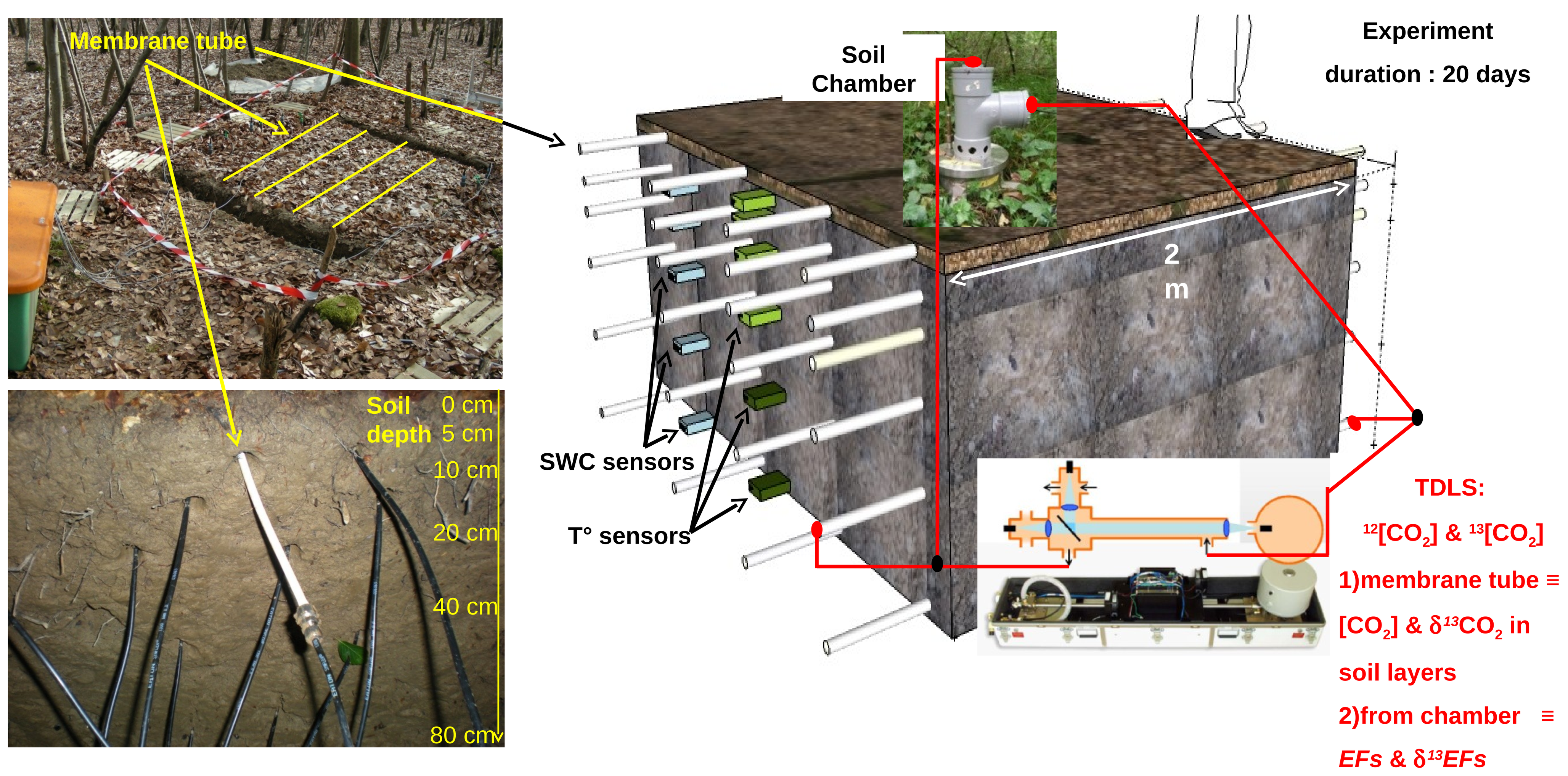
D_{x_i} = soil diffusivity at the x-i boundary

$$P_i = \varepsilon_i * \frac{\Delta C_i}{\Delta t} + \frac{\left(D * \frac{\Delta C}{\Delta z} \right)_{down\_i} - \left(D * \frac{\Delta C}{\Delta z} \right)_{up\_i}}{thick_i} \quad \text{(Eq. 3)}$$

P_i and $\delta^{13}P_i$ can be obtain by measuring the temporal evolution of the [$^{12}CO_2$] & [$^{13}CO_2$] vertical profiles + Lab. measurement (on soil samples) of ε and dependence of *D* on soil water content (vertical profiles)

Boundary conditions : F_{bottom} = 0; F_{top} = *Fs*

Experimental device (Parent *et al*. 2013)



Results

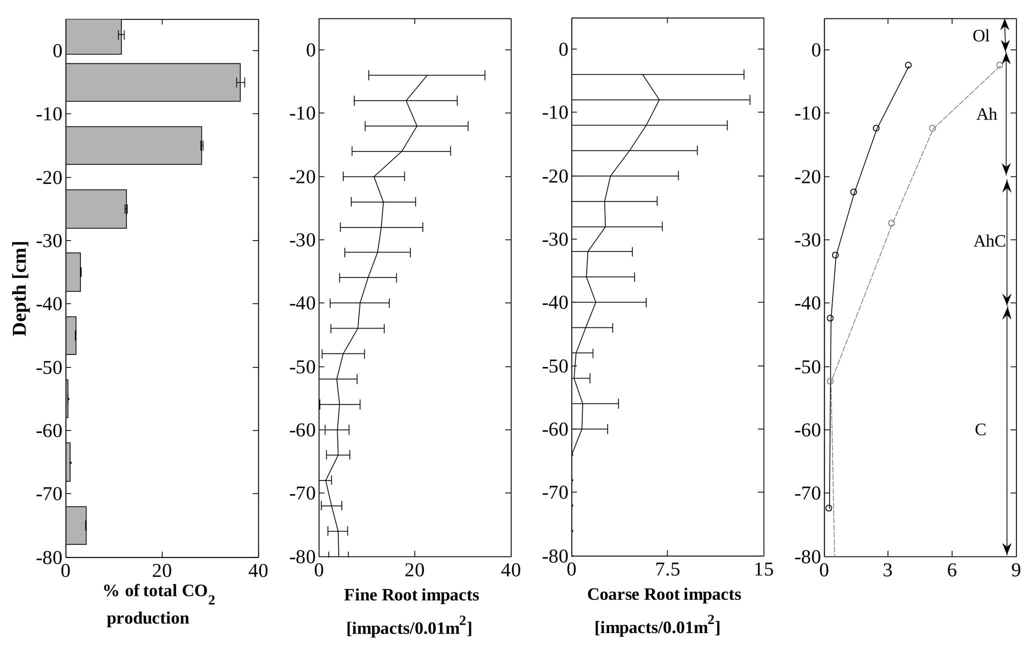


Fig. 1: Mean *Ps* (over the campaign) of soil horizons (Ol, Ah, AhC, C) in parallel with fine roots and carbon content vertical profiles

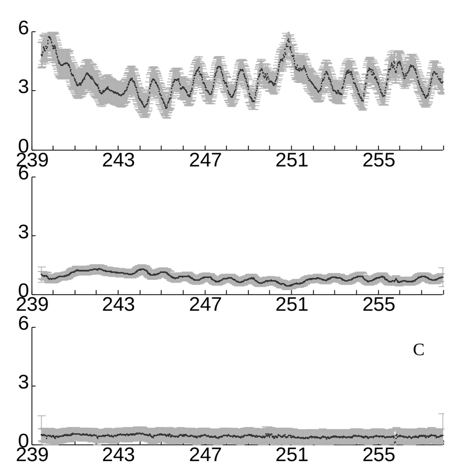


Fig. 2: Temporal evolution of the CO_2 production for the different horizons

- **CO_2 production decrease with depth as fine roots & carbon contents**
- **Clear intraday variability in Ol, Ah & AhC horizons**
- **Not plausible negative CO_2 production (consumption) in Ol ! (see explanation in Objective 2 section)**

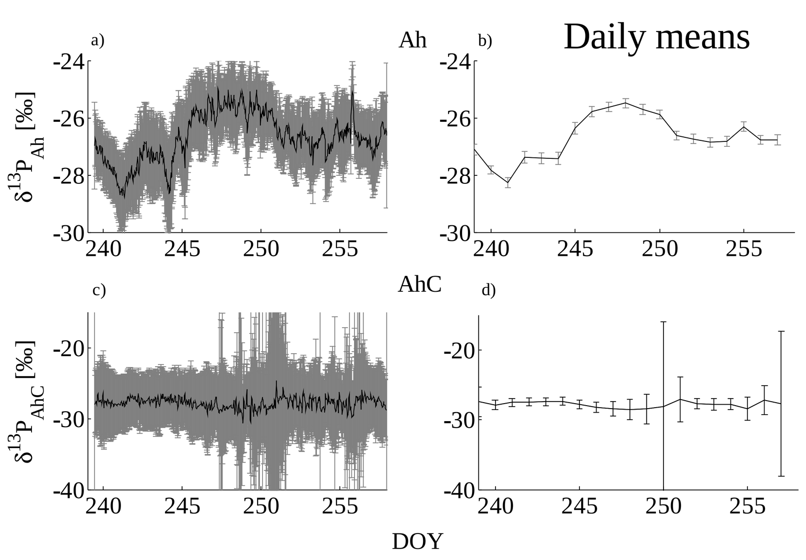


Fig. 3: Temporal evolution of δ^{13}*Ps* for Ah (a & b) and Ahc (c & d). Hourly variability (a & c) and daily means (b & d) are presented

- **Significant day to day variation of δ^{13}*Ps* in Ah**

OBJECTIVES

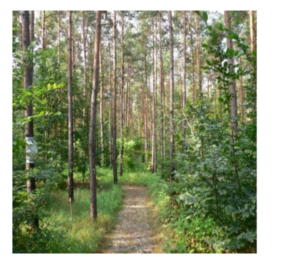
1)Determine ***Ps*** and its isotopic signature **δ^{13}*Ps*** for the different soil horizons.

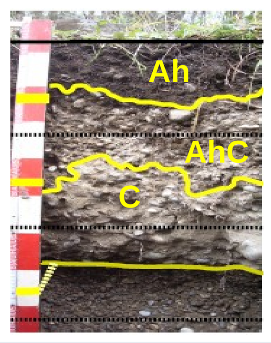
2)Find factors affecting ***Ps*** & **δ^{13}*Ps*** intra & inter day fluctuations

3) Evaluate by modeling which processes (those linked to production or transport) drive ***Fs*** temporal variability

EXPERIMENTAL SITE: HARTHEIM FOREST

- 46 year old Scots Pine Forest (Pinus sylvestris L.)
- Mean annual Air Temp/Prec: 10.3°C/642 mm
- Haplic Regosol (calcaric, humic)
- Humus type is mull (1-3 cm thick)





OBJECTIVE2: Factors affecting *Ps* and *δ¹³Ps* (Goffin *et al*. 2014)

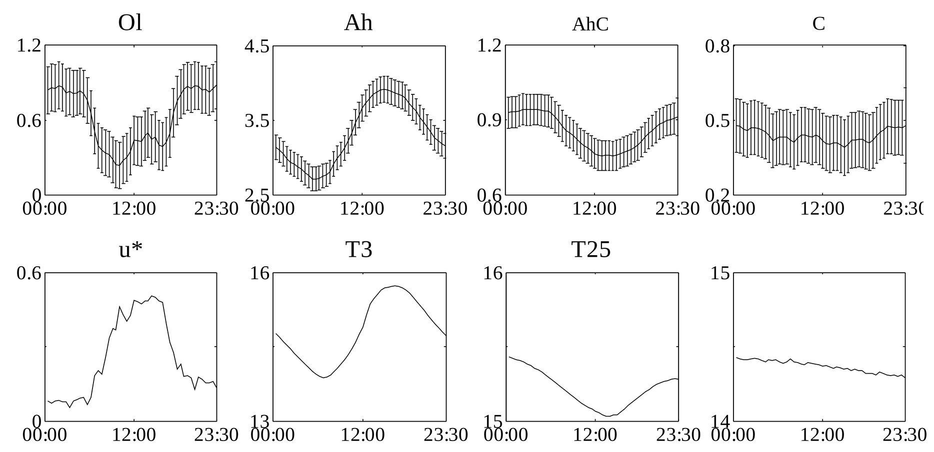


Fig. 4: Mean diurnal evolution of the *Ps*, soil temperature (3, 25, 70 cm depth) and friction velocity (u*)

- ***Ps* in Ah and AhC are correlated to their local temperature**
- **No diurnal evolution of *Ps* in C (t° ≃ constant over the campaign)**
- ***Ps* in Ol (litter) is correlated to u*. The CO_2 transport processes due to turbulence are not represented in Eq. 1 & 3 when they are actually present in the litter layer. Consequently their influences are reflected back in the *Ps* term (≡ Eq. 3 output). This point explains also negative value of *Ps* in Ol met in Fig. 2**

- **Significant dependence of δ^{13}*Ps* in Ah on SWC (enrichment with drought) could be imputed to change in the substrate / microbial communities involved in C mineralization when SWC decreases.**

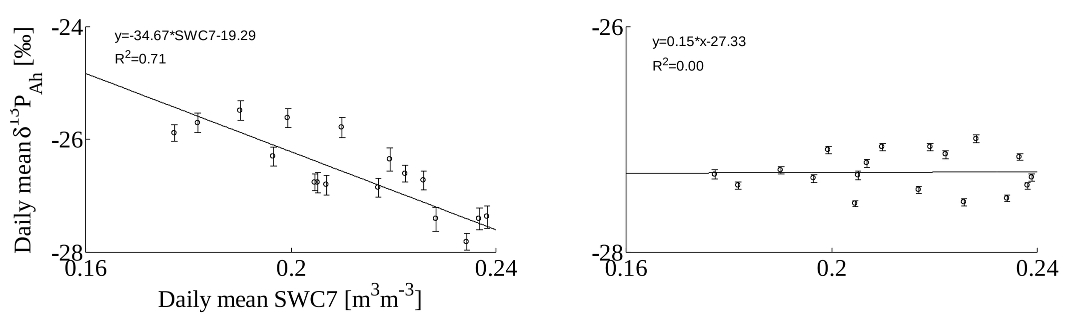


Fig. 5: Dependence of daily mean (a) δ^{13}*Ps* in Ah and (b) δ^{13}*Fs* on soil water content (SWC) at 7 cm depth

- **This dependence is not observed for efflux (δ^{13}*Fs*) because *Fs* is a mixed of ≠ layer contributions with ≠ dependences and the presence of soil chamber can have induced difference between SWC below them and the SWC measuring points.**

OBJECTIVE 3: Model applications to evaluate the part of production and transport processes in the $[CO_2]_{soil}$ & *Fs* temporal variability (Goffin et al. *under review*).

1) Model run with a reference version simulating production in the ≠ layers (rate depending on local t°) and diffusion as the only CO_2 transport process
2) Model runs with testing versions where (a) advection, (b) dispersion and (c) production regulated by phloem pressure concentration waves (PPCW) are successively added
3) Comparison of the reference and testing versions outputs with $[CO_2]_{soil}$ & *Fs*

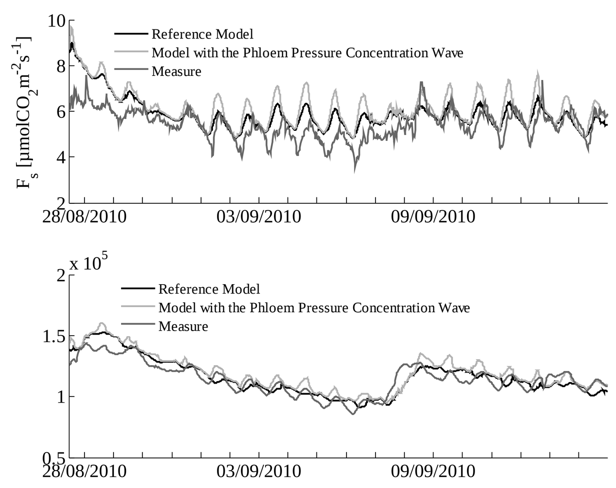


Fig. 6 a & c: Time evolutions of *Fs* and $[CO_2]_{soil}$ obtained with reference model, model including the phloem pressure concentration wave (PPCW) and measurements

Fig. 6 b & d: Corresponding averaged intra-day variability

Ref. model

- **Inter-day variation relatively well reproduced**
- **Bad simulation of the intra-day variability (amplitude too low, not in phase)**

Adding Advection

- **Affect only outputs at very small temporal scale (few seconds), no impact on half-hour average**

Adding Dispersion

- **Brings intra-day amplitude for $[CO_2]_{soil}$ but no benefit for the phase**

Adding PPCW

- **Improve significantly the simulation of *Fs* & $[CO_2]_{soil}$ amplitude and phase**
- **Best way to reproduce the intra-day *Fs* & $[CO_2]_{soil}$ variations**

References: Parent *et al*., 2013, *European Journal of Soil Science*, 64, 516-525

Goffin *et al*., under review, *Plant and Soil*

Goffin *et al*., 2014, *Agricultural and Forest Meteorology*, 188,