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MEASURING AND MODELING SOIL INTRA-DAY VARIABILITY OF THE $^{13}\text{CO}_2$ & $^{12}\text{CO}_2$ PRODUCTION AND TRANSPORT IN A SCOTS PINE FOREST

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CONTEXT

- Future dynamics of soil CO_2 efflux (F_s) = key question in climate change research.
- Two processes lead to F_s : 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 F_s needs - soil **multilayer approach**
 - fine temporal resolution (intra-day) study
- Use of ^{13}C & ^{12}C improve EF_s origin (partitioning) and pathway (spatiotemporal tracer) knowledge

OBJECTIVE 1: Determine soil horizons P_s and $\delta^{13}P_s$

Based on $^{12}\text{CO}_2$ & $^{13}\text{CO}_2$ 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 $C_i = [^{12}\text{CO}_2]$ or $[^{13}\text{CO}_2]$; ε_i & $thick_i$ = layer i soil porosity & thickness;

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

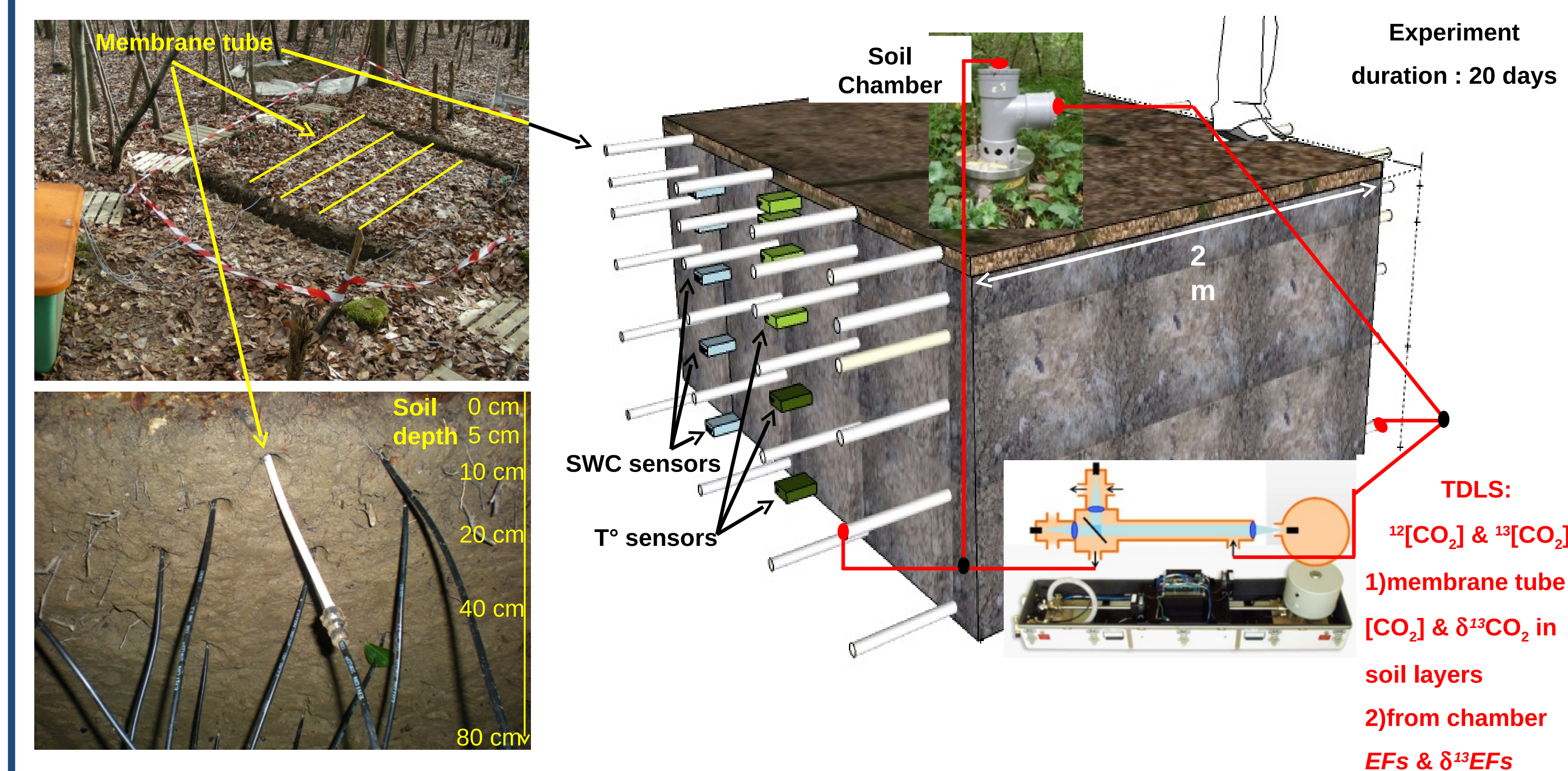
$$P_i = \varepsilon_i * \frac{\Delta C_i}{\Delta t} + \left(D * \frac{\Delta C}{\Delta Z} \right)_{down-i} - \left(D * \frac{\Delta C}{\Delta Z} \right)_{up-i} \quad (\text{Eq. 3})$$

P_i and $\delta^{13}P_i$ can be obtained by measuring the temporal evolution of the $[^{12}\text{CO}_2]$ & $[^{13}\text{CO}_2]$ vertical profiles + Lab.

measurement (on soil samples) of ε and dependence of D on soil water content (vertical profiles)

Boundary conditions : $F_{bottom} = 0$; $F_{top} = F_s$

Experimental device (Parent et al. 2013)



Results

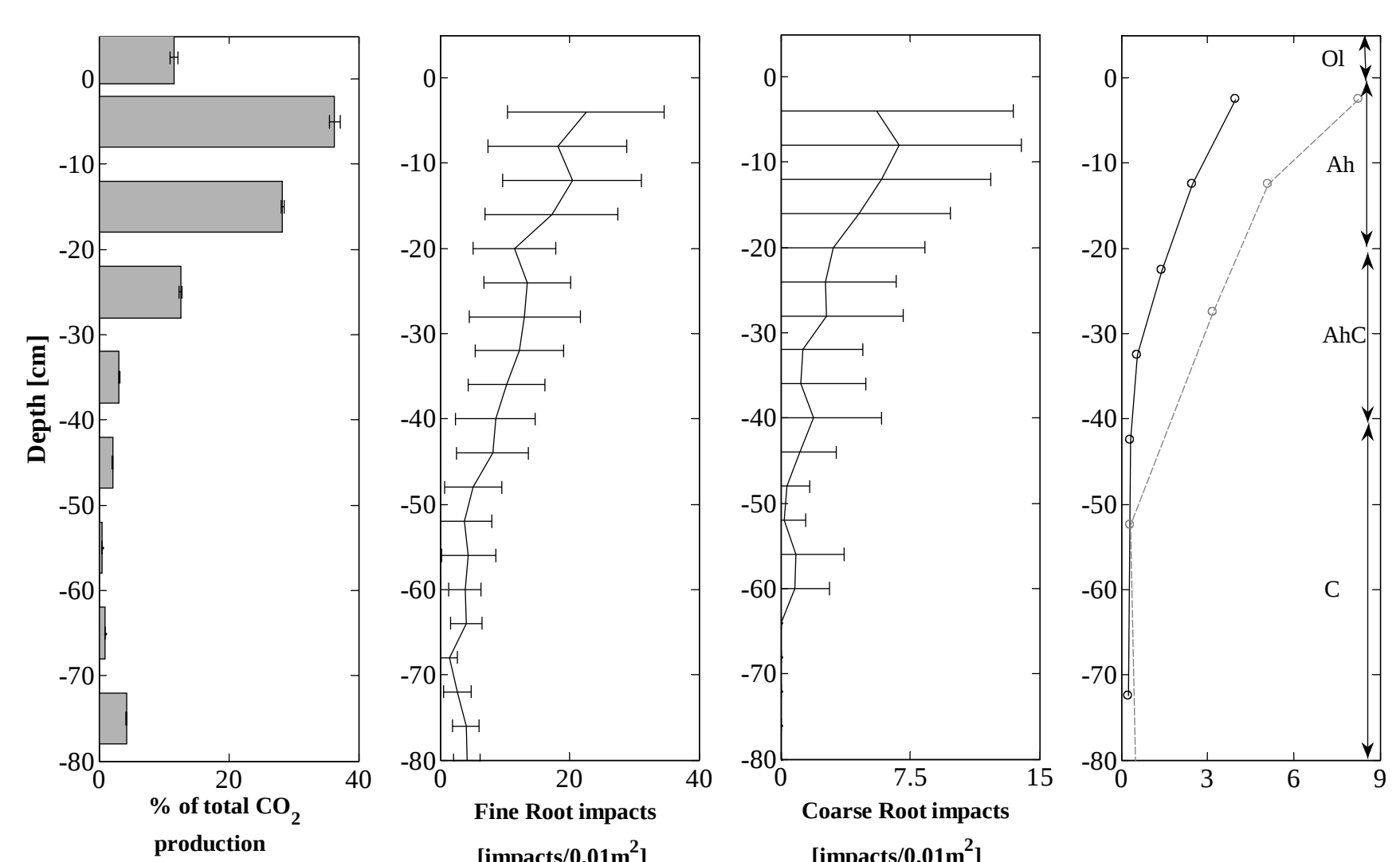


Fig. 1: Mean P_s (over the campaign) of soil horizons (Ol, Ah, AhC, C) in parallel with fine roots and carbon content vertical profiles

- 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 $\delta^{13}P_s$ 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 $\delta^{13}P_s$ in Ah

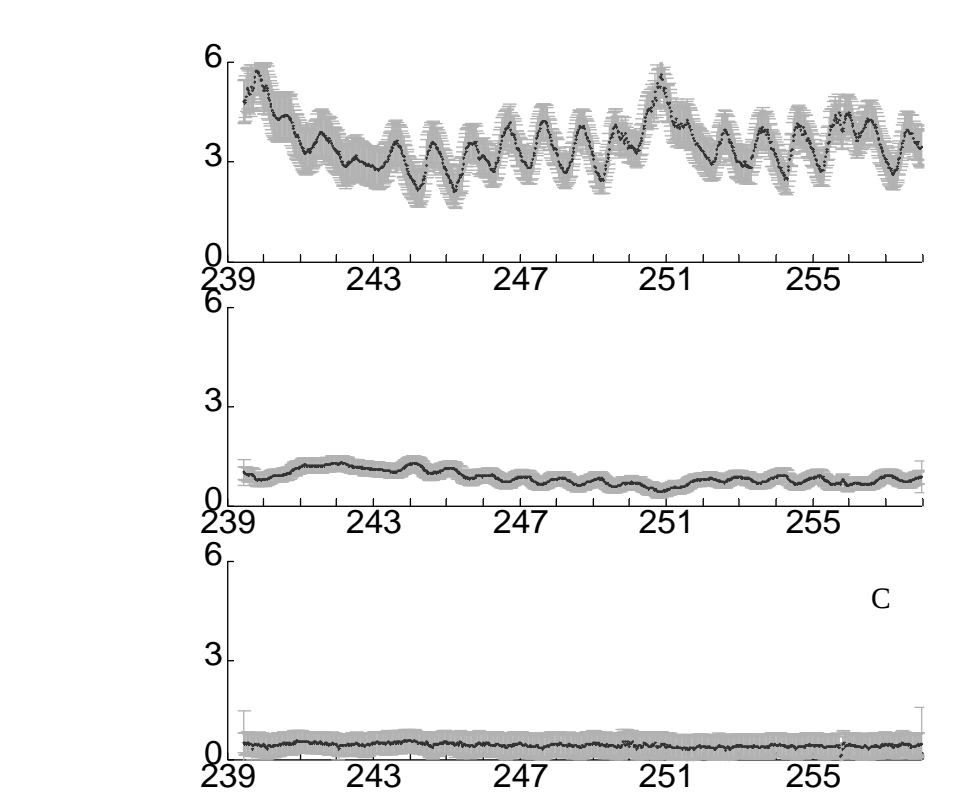
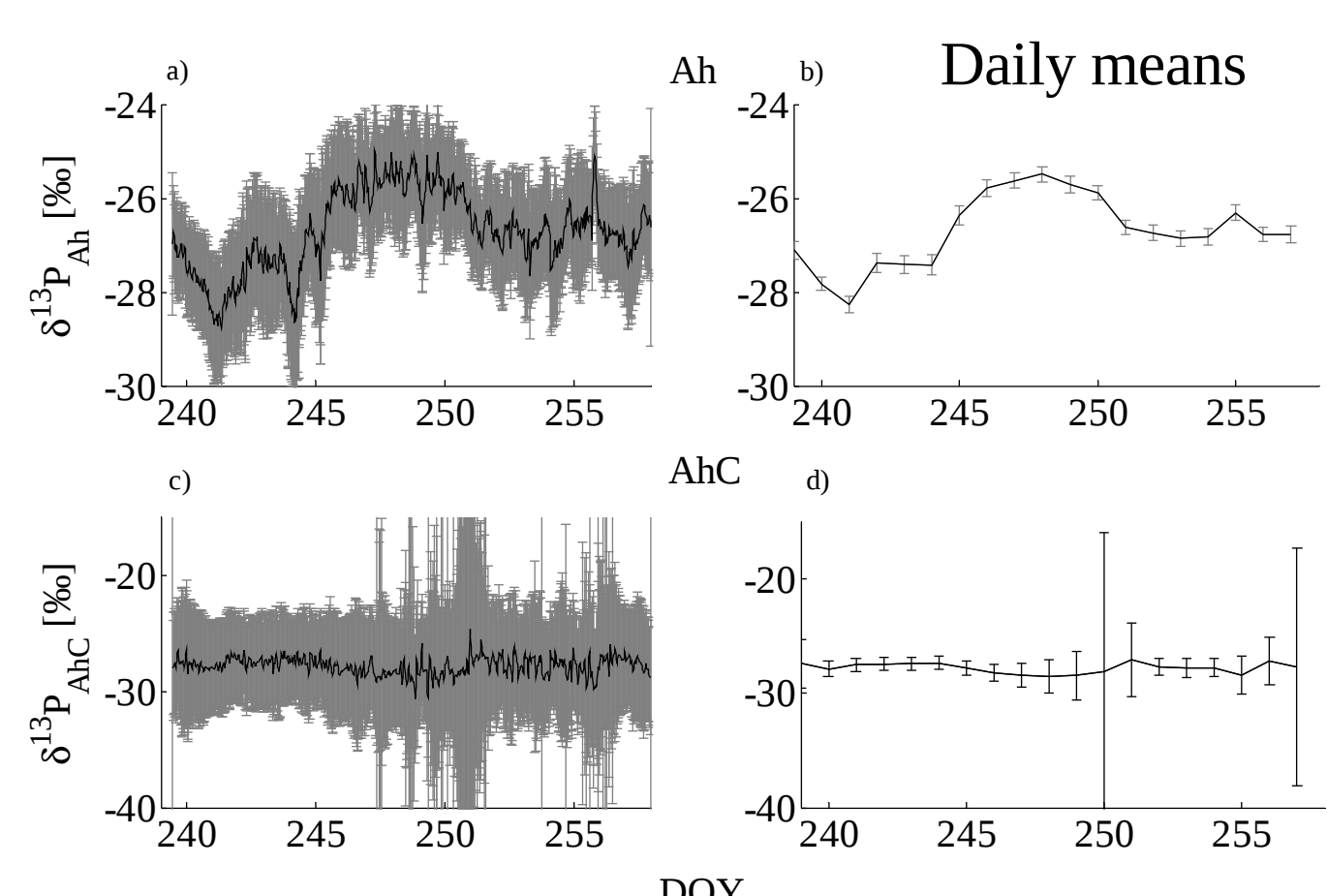


Fig. 2: Temporal evolution of the CO_2 production for the different horizons

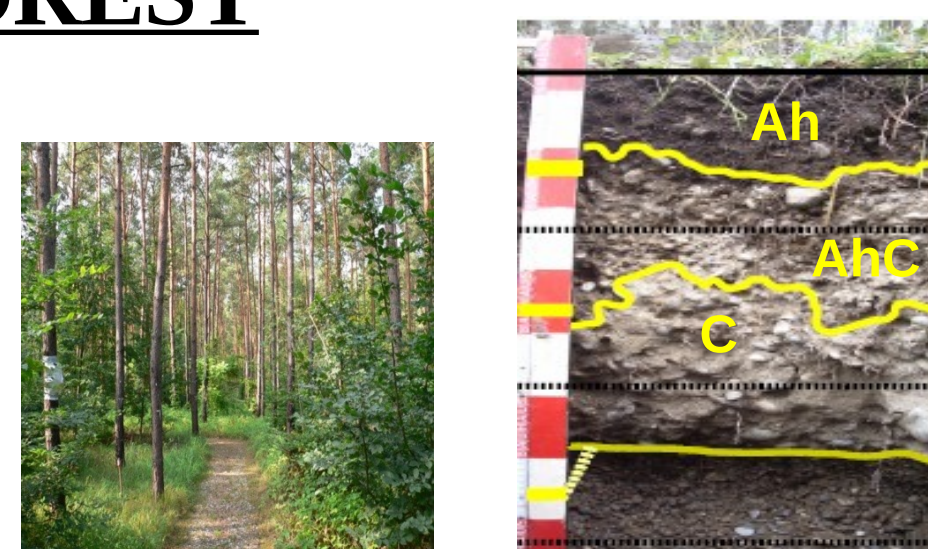


OBJECTIVES

- Determine P_s and its isotopic signature $\delta^{13}P_s$ for the different soil horizons.
- Find factors affecting P_s & $\delta^{13}P_s$ intra & inter day fluctuations
- Evaluate by modeling which processes (those linked to production or transport) drive F_s 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)



OBJECTIVE 2: Factors affecting P_s and $\delta^{13}P_s$ (Goffin et al. 2014)

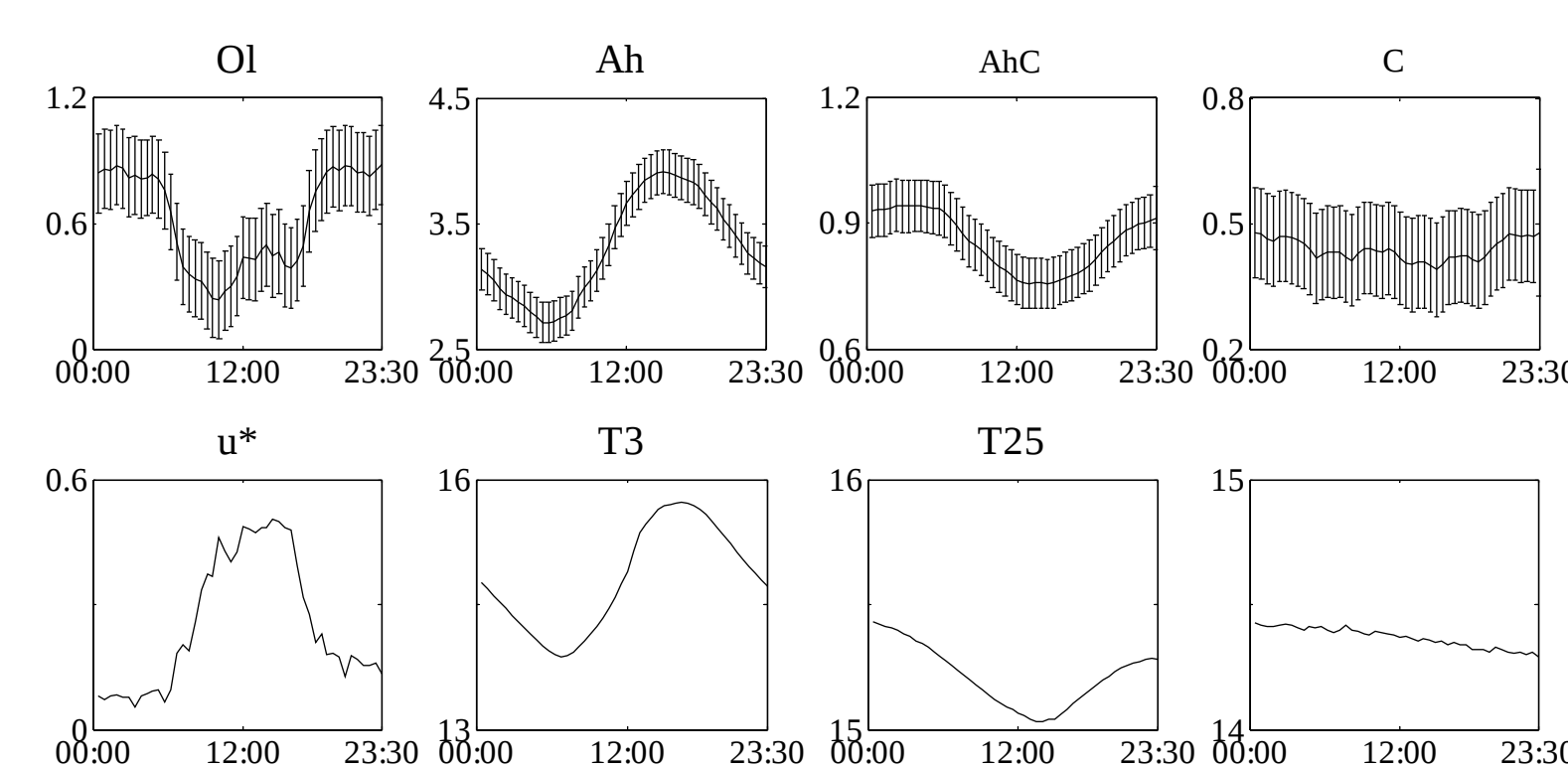


Fig. 4: Mean diurnal evolution of the P_s , soil temperature (3, 25, 70 cm depth) and friction velocity (u^*)

- P_s in Ah and AhC are correlated to their local temperature
- No diurnal evolution of P_s in C ($t^\circ \approx$ constant over the campaign)
- P_s 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 P_s term (\equiv Eq. 3 output). This point explains also negative value of P_s in Ol met in Fig. 2

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

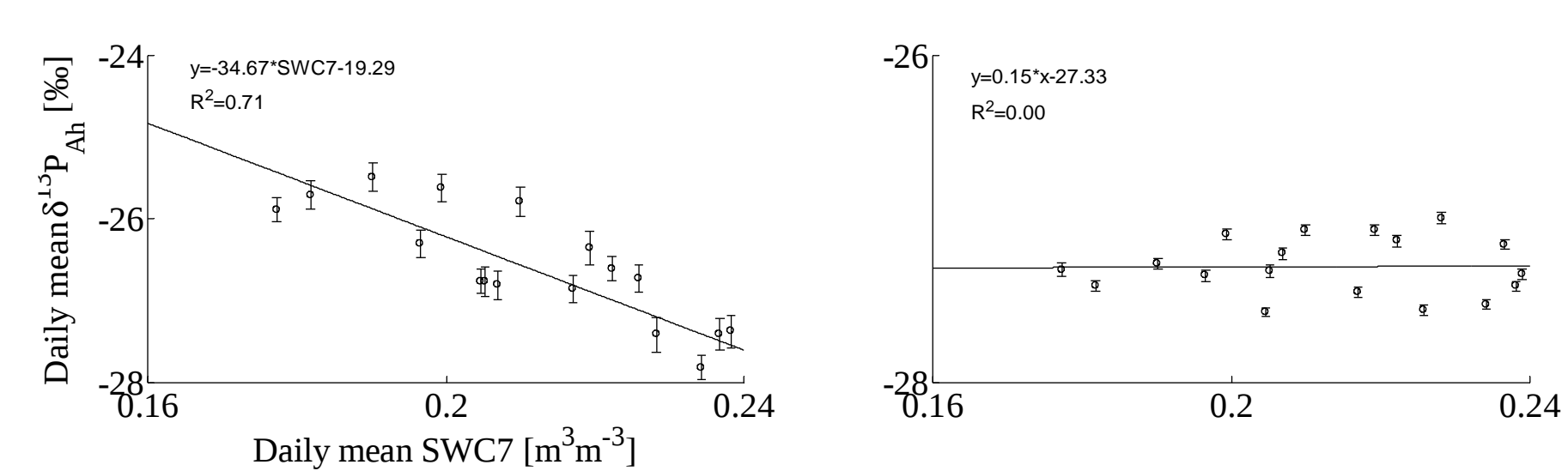


Fig. 5: Dependence of daily mean (a) $\delta^{13}P_s$ in Ah and (b) $\delta^{13}F_s$ on soil water content (SWC) at 7 cm depth

- This dependence is not observed for efflux ($\delta^{13}F_s$) because F_s is a mixed of \neq layer contributions with \neq 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 $[\text{CO}_2]_{\text{soil}}$ & F_s temporal variability (Goffin et al. under review).

- Model run with a reference version simulating production in the \neq layers (rate depending on local t°) and diffusion as the only CO_2 transport process
- Model runs with testing versions where (a) advection, (b) dispersion and (c) production regulated by phloem pressure concentration waves (PPCW) are successively added
- Comparison of the reference and testing versions outputs with $[\text{CO}_2]_{\text{soil}}$ & F_s

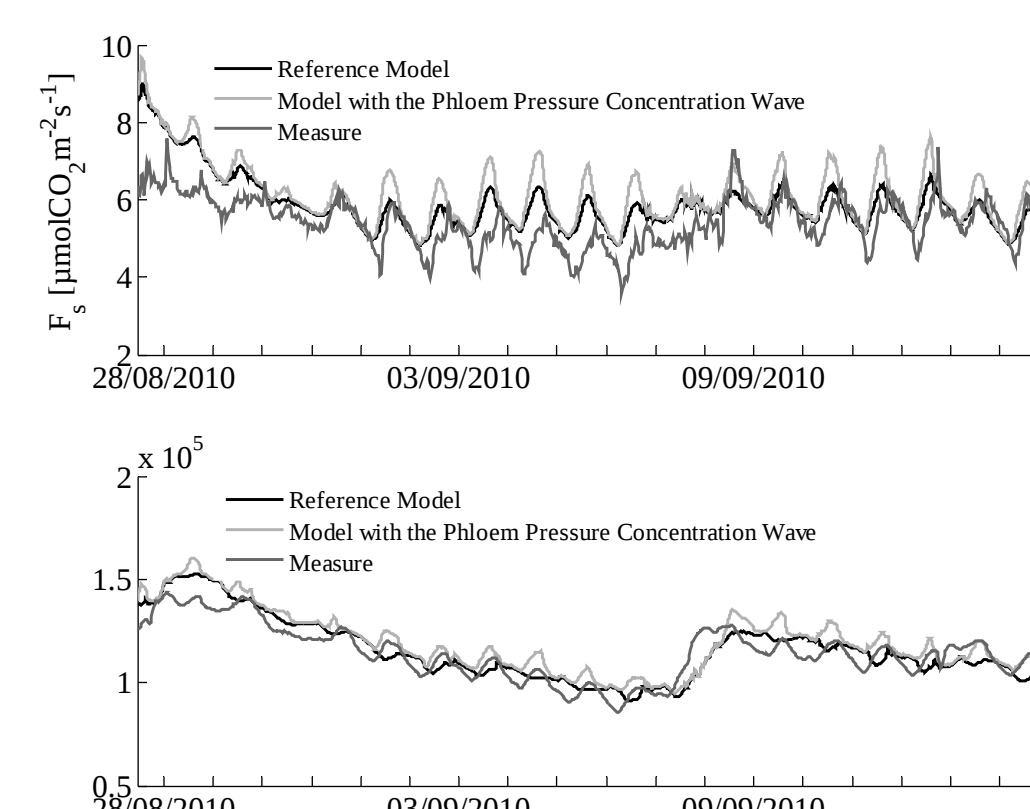


Fig. 6 a & c: Time evolutions of F_s and $[\text{CO}_2]_{\text{soil}}$ obtained with reference model, model including the phloem pressure concentration wave (PPCW) and measurements

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

Adding PPCW

- Improve significantly the simulation of F_s & $[\text{CO}_2]_{\text{soil}}$ amplitude and phase
- Best way to reproduce the intra-day F_s & $[\text{CO}_2]_{\text{soil}}$ variations

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 $[\text{CO}_2]_{\text{soil}}$ but no benefit for the phase