



Measuring and modeling soil intra-day variability of the $^{13}\text{CO}_2$ & $^{12}\text{CO}_2$ production in a scots pine forest

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

Longdoz Bernard, Goffin S., Parent F., Plain C., Epron D., Wylock C.,
Haut B., Maier M., Schack-Kirchner H., Aubinet M.,

Background

Past

today

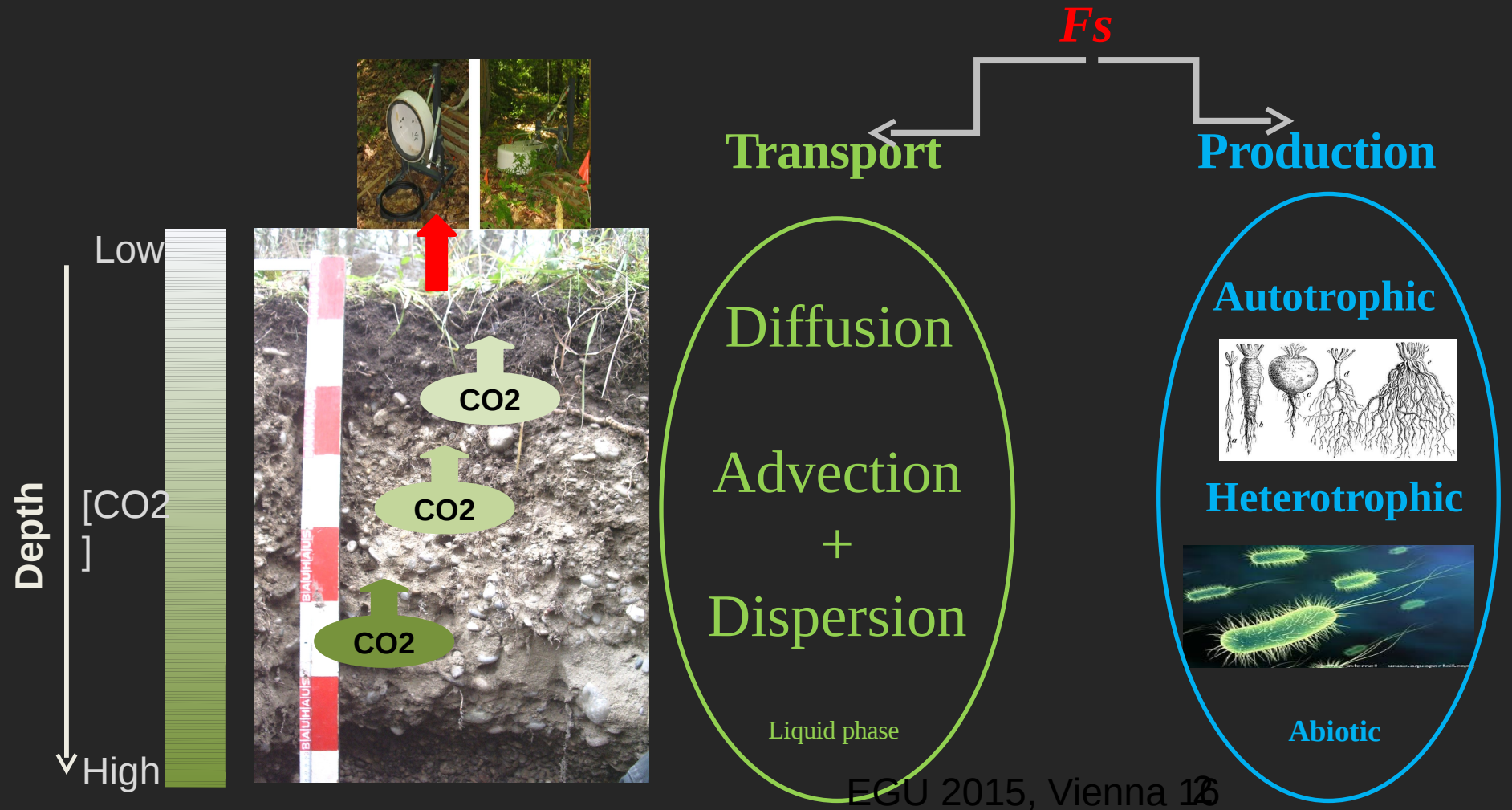
Soil CO₂ efflux (F_s)

Future

Empirical description

Mechanistic understanding

Climate Change Impact & Positive feedback ?

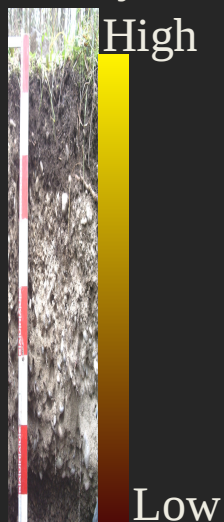


Background & Objectives

Transport

$f(\text{porosity, humidity...})$

Porosity



F_s

$P_s \Leftrightarrow$

CO_2

$P_s \Leftrightarrow$

CO_2

CO_2

$\Leftrightarrow P_s$

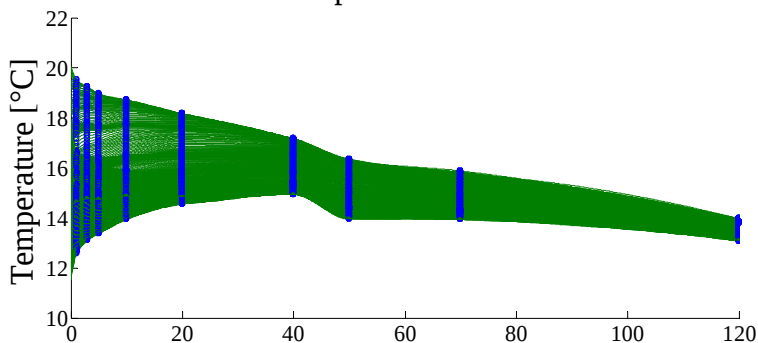
Production P_s

Heterotrophic

Autotrophic

$f(\text{Temperature, humidity, substrate, pH,...})$

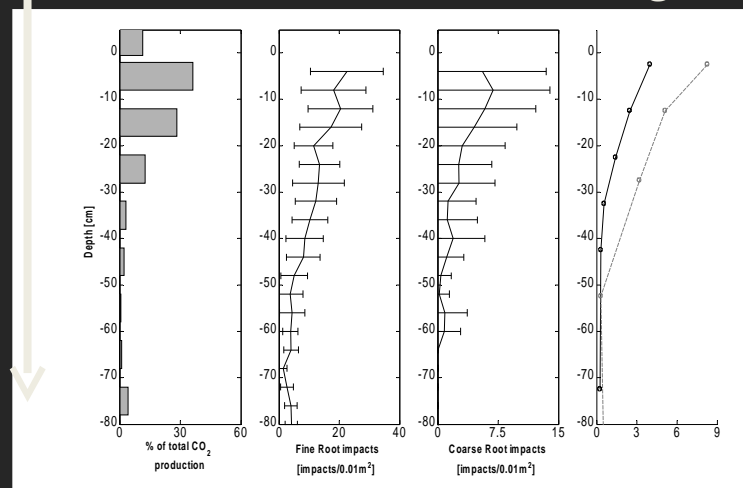
Temperature Profile



\Rightarrow Multilayer Approach needed

Fine and Coarse Roots

Corg



$$\delta^{13}\text{CO}_2 \text{ atm} \approx$$

-8‰

$$\delta^{13}\text{C}_{\text{leaf}} = \delta^{13}\text{CO}_2 \text{ atm} + \Delta\text{photo}(\text{climate}) \approx -27‰$$

$\delta^{13}\text{C}_{\text{phloem}}$

Temporal variation of $\delta^{13}\text{Ps}$ give information about transfer time and pathway of photoassimilates in the

$\delta^{13}\text{Fs}$

$\delta^{13}\text{P}_{\text{aut}}$

o

$\delta^{13}\text{P}_{\text{s}}$

$\delta^{13}\text{P}_{\text{heter}}$

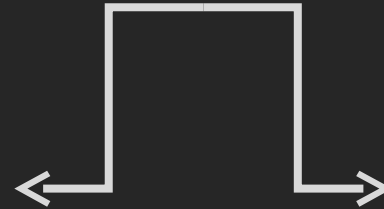
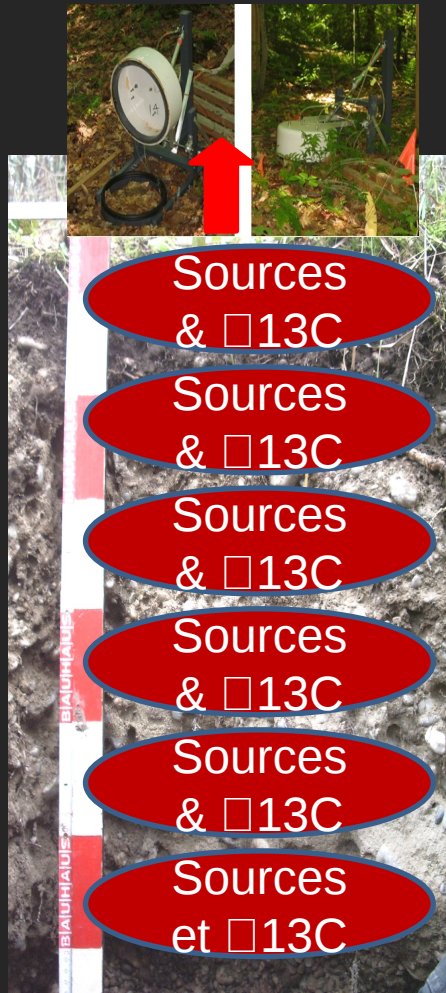
o

$\delta^{13}\text{Ps}$ fluctuations help for source partitioning kinetic

\Rightarrow Quantify the $\delta^{13}\text{Ps}$ temporal fluctuations

Objectives

Improving mechanistic understanding of F_s and P_s

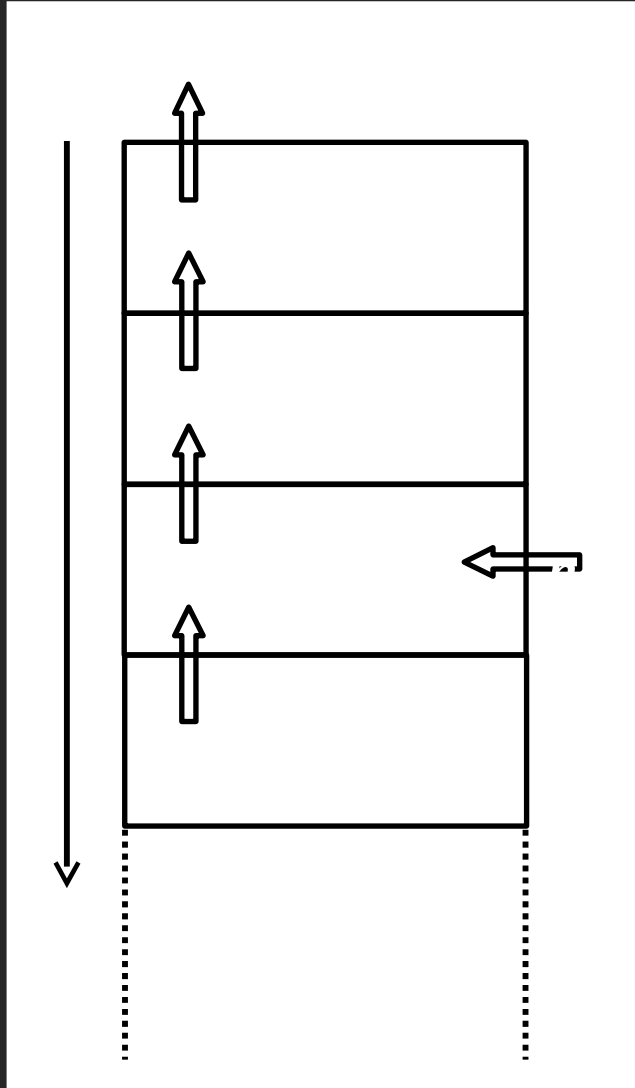


Multilayer Approach

- 1) Determine P_s and $^{13}P_s$ for the different soil horizons.
- 2) Find factors affecting P_s & $^{13}P_s$ intra & inter day fluctuations
- 3) Evaluate by modeling what is the part of P_s in the F_s temporal variability

Isotopic Signal Analysis

1. Determine P_s and $\delta^{13}P_s$ for \neq layers



• $^{12}\text{CO}_2$ & $^{13}\text{CO}_2$ mass balance for the n th layer:

$$\frac{\Delta(\epsilon_n * C_n^{12-13})}{\Delta t} = \frac{F_{n+1}^{12-13} - F_n^{12-13}}{\text{thick}_n} + P_s^{12-13}$$

• Diffusive Flux-Gradient approach :

$$F_{n+1/n} = D_{i+1/n}^{12-13} * \frac{C_{n+1}^{12-13} - C_n^{12-13}}{Z_{n+1} - Z_n}$$

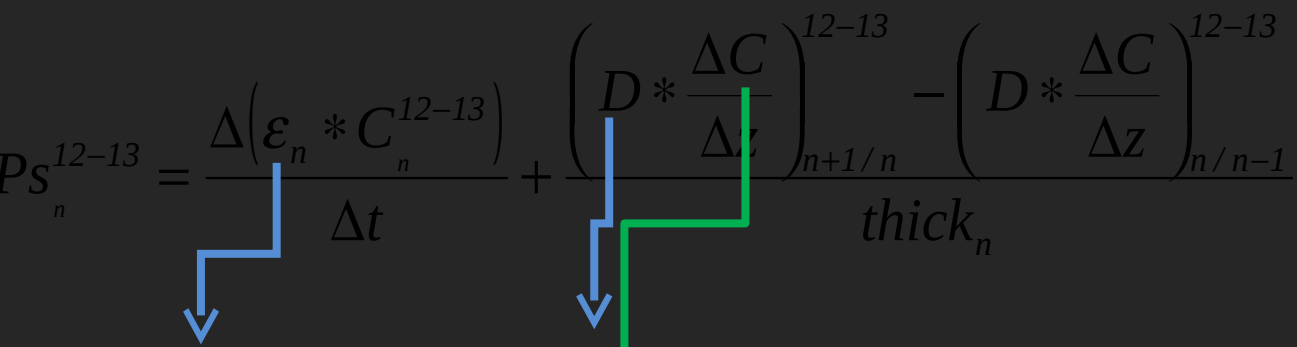
$$= \left(D^{12-13} * \frac{\Delta C^{12-13}}{\Delta Z} \right)_{n+1/n}$$



$$P_s^{12-13} = \frac{\Delta(\epsilon_n * C_n^{12-13})}{\Delta t} + \frac{\left(D * \frac{\Delta C}{\Delta Z} \right)_{n+1/n}^{12-13} - \left(D * \frac{\Delta C}{\Delta Z} \right)_{n/n-1}^{12-13}}{\text{thick}_n}$$

1. Determine P_s and $\delta^{13}P_s$ for \neq layers

Determination of ϵ , D and C :

$$P_{S_n}^{12-13} = \frac{\Delta(\epsilon_n * C_n^{12-13})}{\Delta t} + \frac{\left(D * \frac{\Delta C}{\Delta z} \right)_{n+1/n}^{12-13} - \left(D * \frac{\Delta C}{\Delta z} \right)_{n/n-1}^{12-13}}{thick_n}$$


Soil cores sampled along the vertical profile

Relationship $\epsilon(SWC)$ and $D(SWC)$ determined at the lab



The $D(SWC)$ obtained is the $D_{12}(SWC)$ one, $D_{13} = 1.0044 * D_{12}$

$^{12}CO_2$, $^{13}CO_2$ and SWC vertical profile measured in the field



Boundary conditions : $(F \ \& \ \delta F)_{bottom} = 0$; F_s and $\delta^{13}F_s$ measured

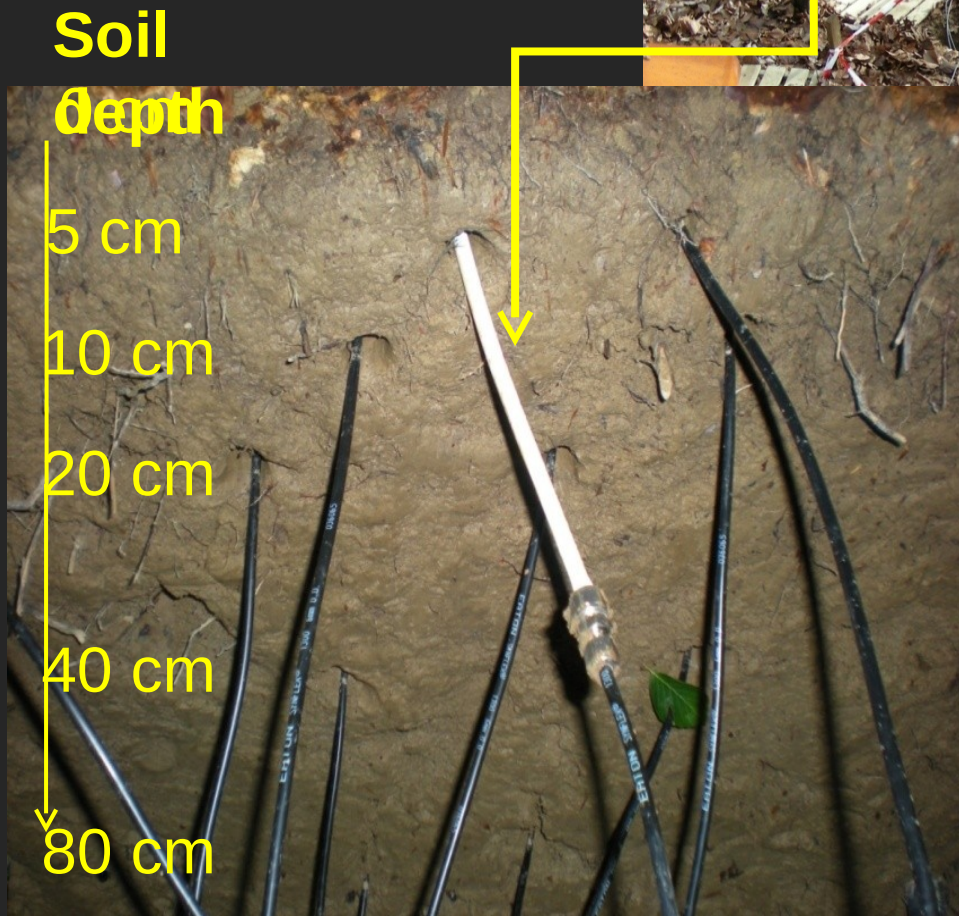


➔ P_s and δP_s for each layer

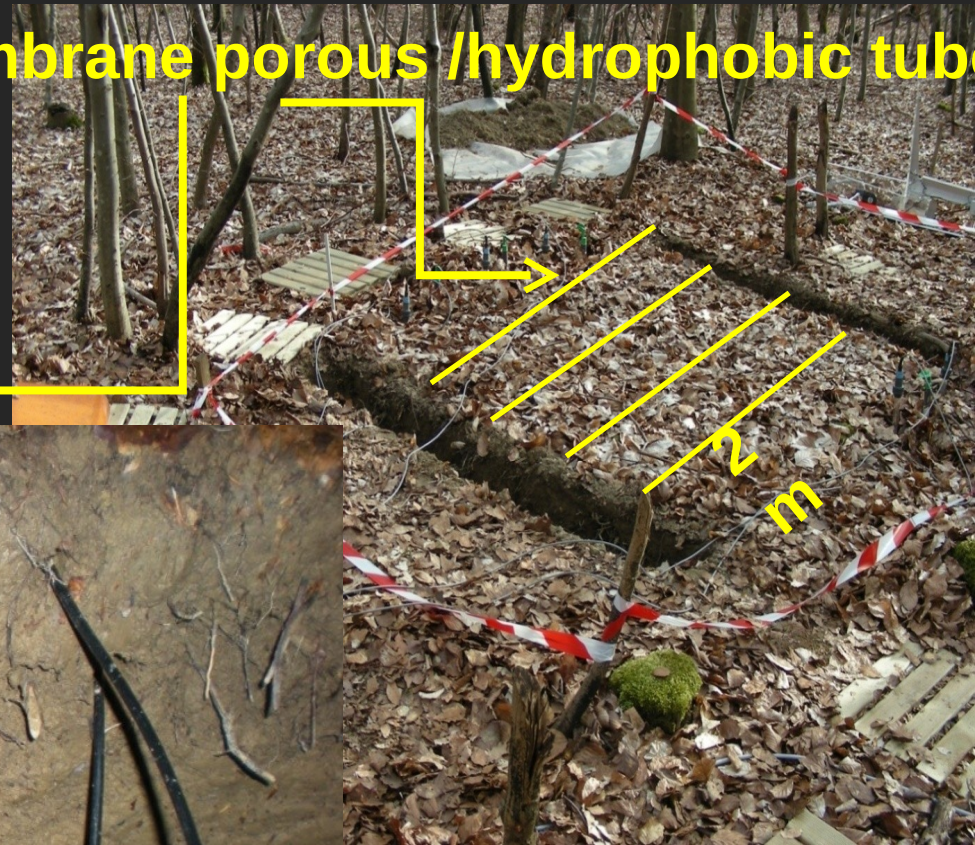
1. Determine P_s and $\delta^{13}P_s$ for \neq layers

Field experimental device

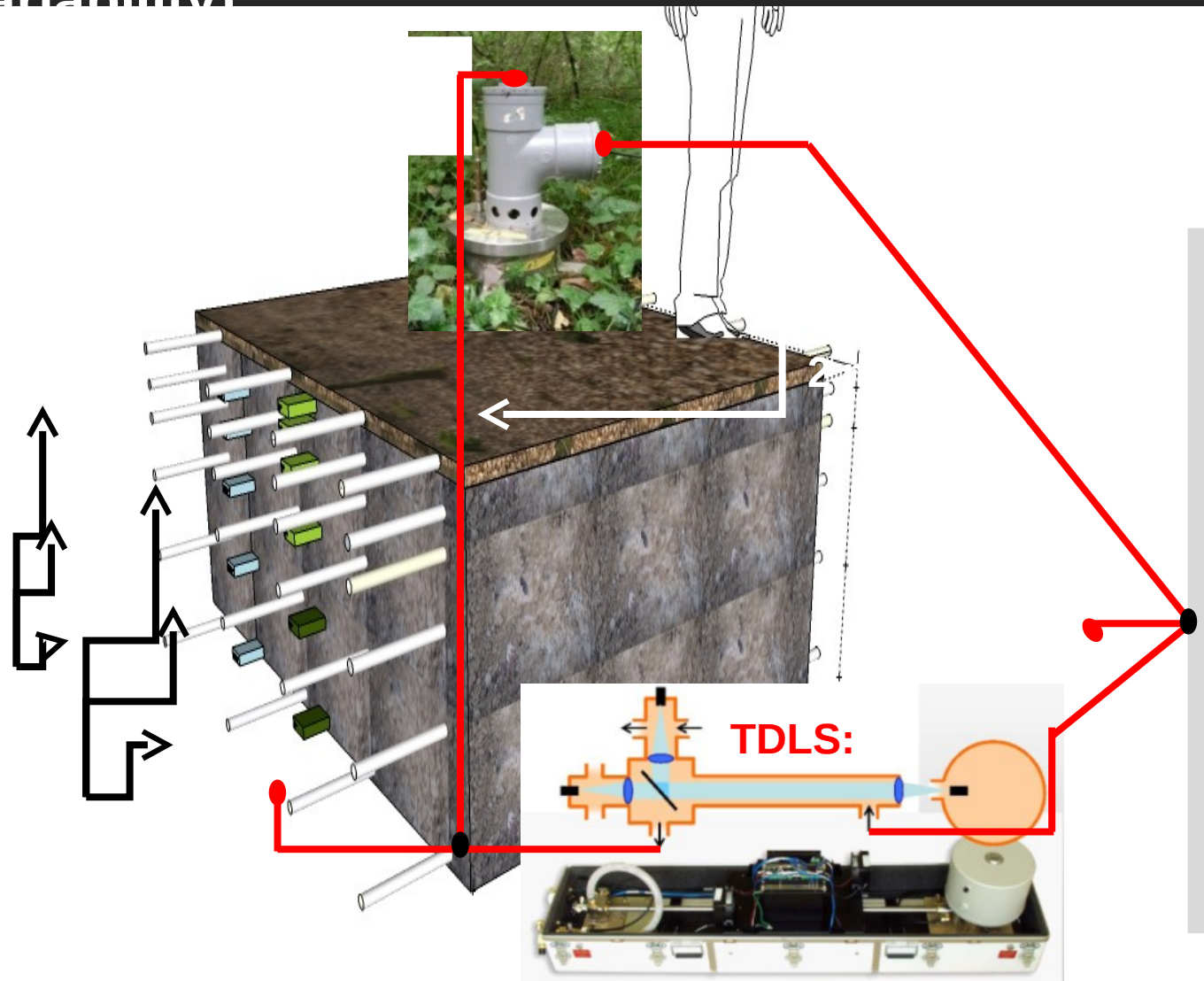
(Parent et al. 2013)



Membrane porous /hydrophobic tube



In situ measurements during 21 days (intra-day variability)



TDLS:

$^{12}[\text{CO}_2]$ &

$^{13}[\text{CO}_2]$

1) **Membrane**

tubes $\Rightarrow [\text{CO}_2]$ &

$\delta^{13}\text{CO}_2$ in soil

layers

2) **Chambers**

$\Rightarrow F_s$ & $\delta^{13}F_s$

1. Determine P_s and $\delta^{13}P_s$ for \neq layers

Site
Description

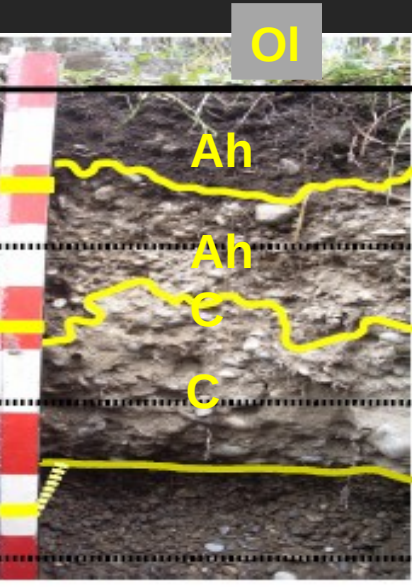


Hartheim experimental site

Slow growing 46 year old Scots Pine Forest (*Pinus sylvestris* L.)

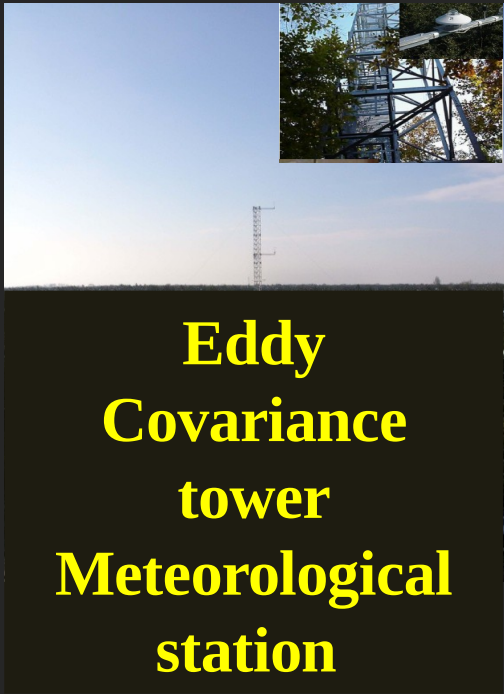
Mean annual air Temp: 10.3°C

Mean annual precip: 642 mm



Haplic Regosol (calcaric, humic) (FAO, 2006)

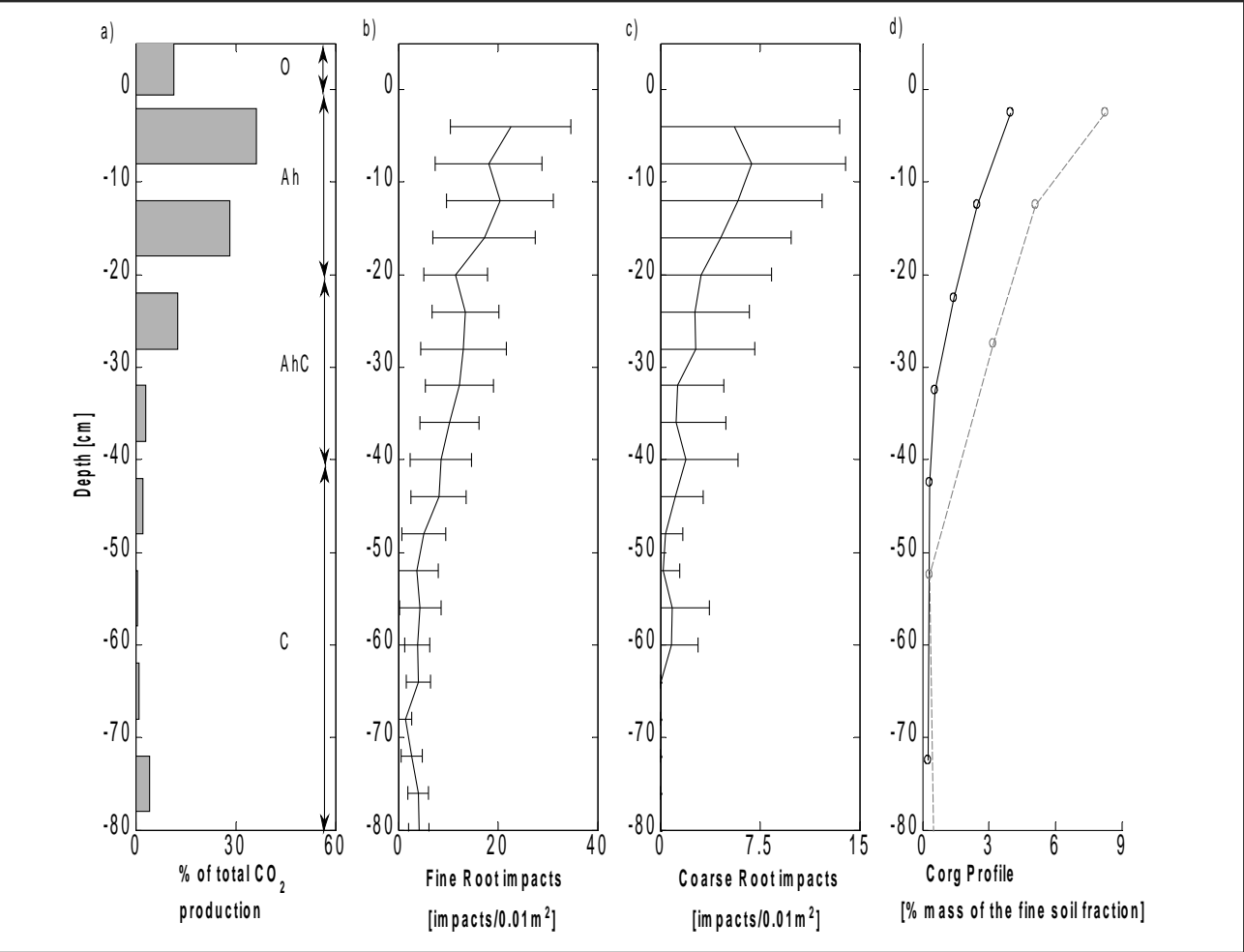
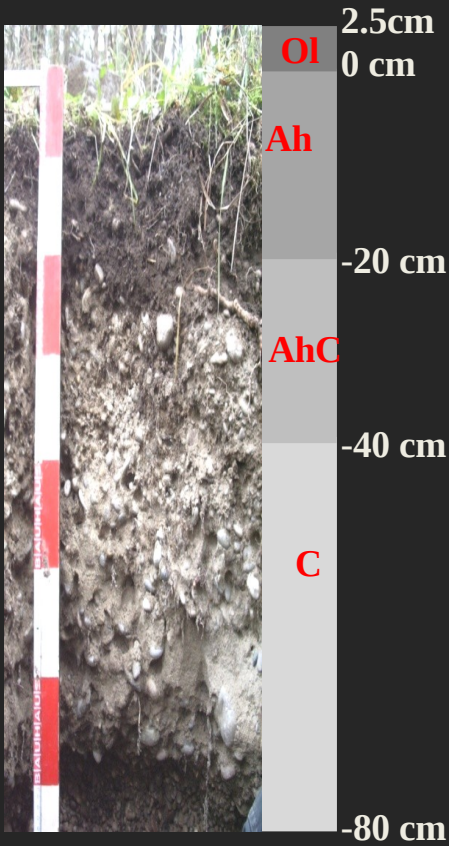
Humus type is mull (1-3 cm thick)



1. Determine P_s and $\delta^{13}P_s$ for \neq layers

Vertical Profile of P_s

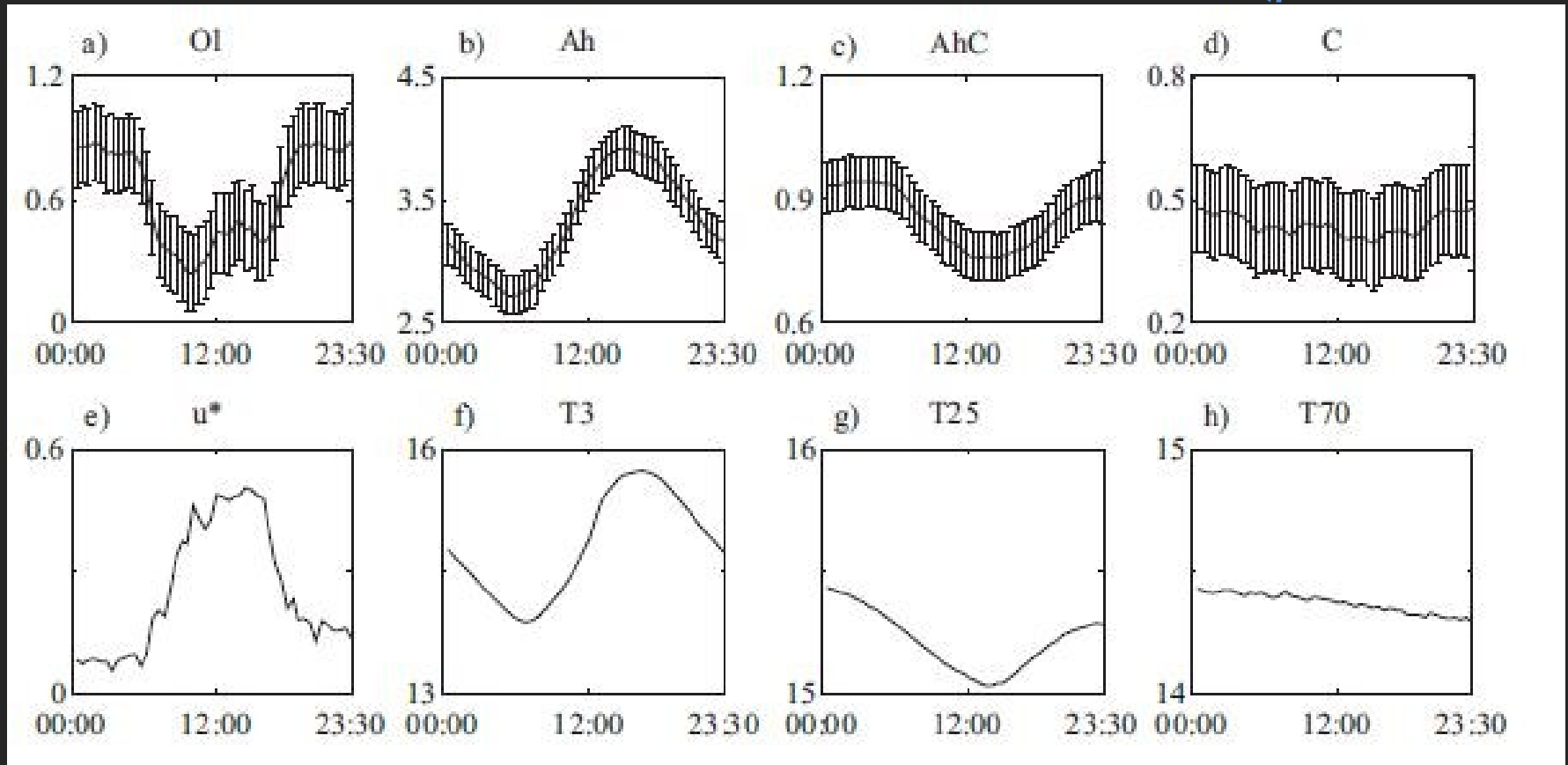
Horizon	%CO ₂ Prod
Ol	11.5
Ah	64.7
AhC	15.8
C	8



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

Intra-day P_s variability

P_s mean diel evolution ($\mu\text{mol m}^{-2} \text{s}^{-1}$)



Mean diel evolution of drivers

- Positively correlated to **LOCAL T°** in Ah & AhC
- Negatively correlated to u^* in litter layer ???

Oh layer

u^* is the driver of advective and dispersive fluxes !

⇒ because of the total diffusive assumption

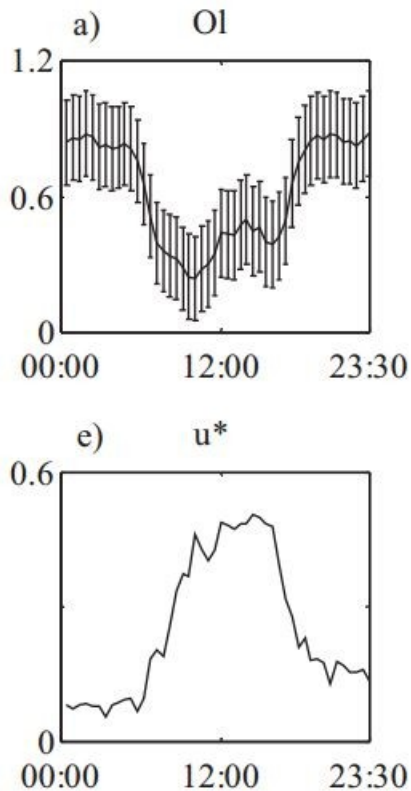
$$P_{s_{computed}} = \text{Storage} + \text{Diffusion} + \text{Adv} / \text{Disp}$$

$$P_{s_{real}} = \text{Storage} + \text{Diffusion} + \text{Adv} / \text{Disp}$$

$$\Rightarrow P_{s_{computed}} = P_{s_{real}} - \text{Adv} / \text{Disp}$$

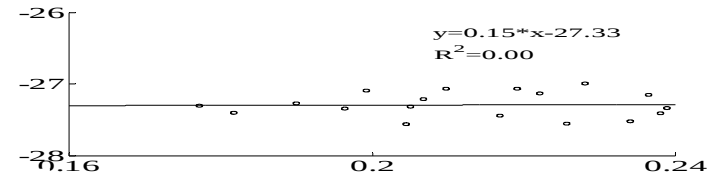
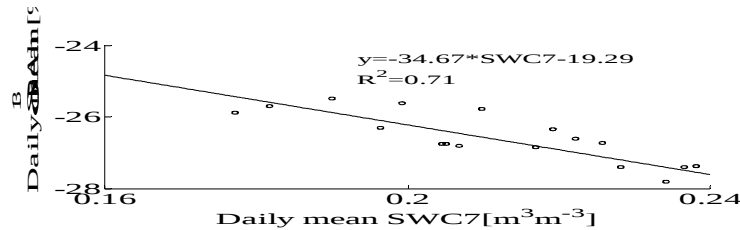
T° dependence

u^* dependence



Inter-day $\delta^{13}P_s$ variability

- Significant day to day variations in $\delta^{13}P_s$ of Ah ($> 2.5\text{‰}$)

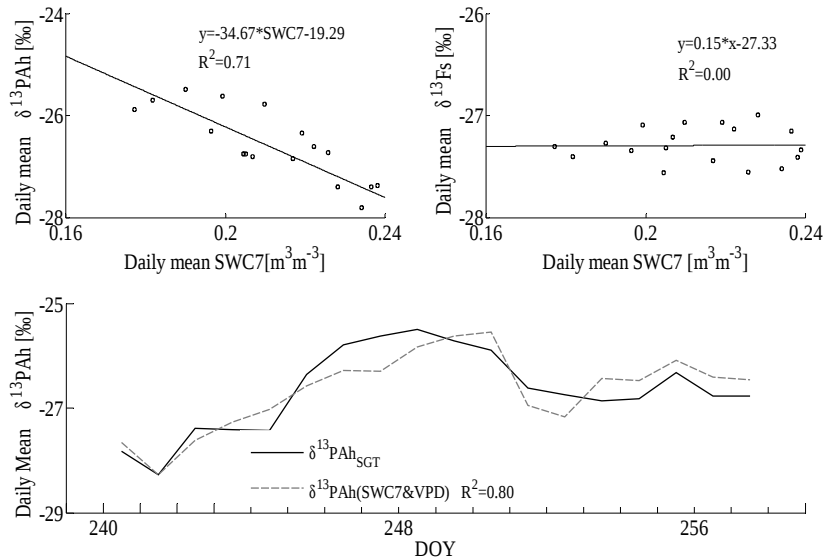


(SWC)

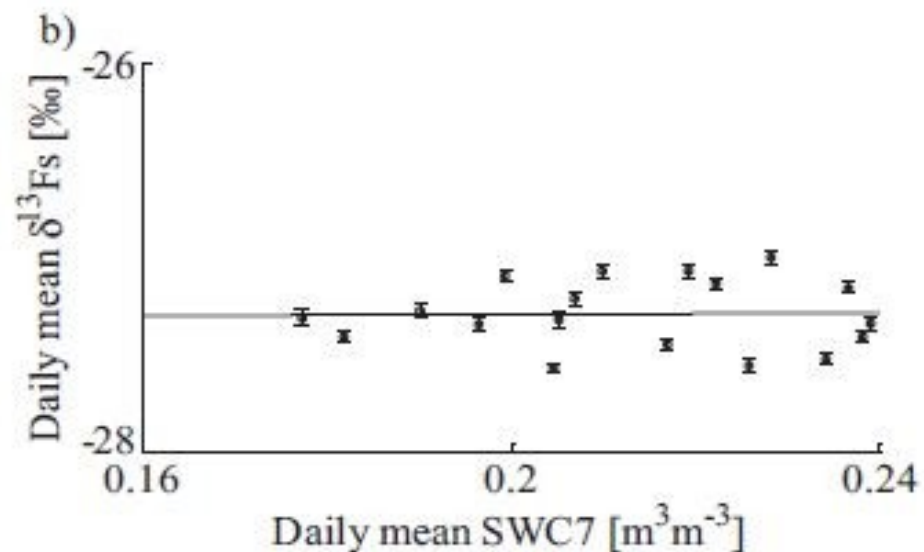
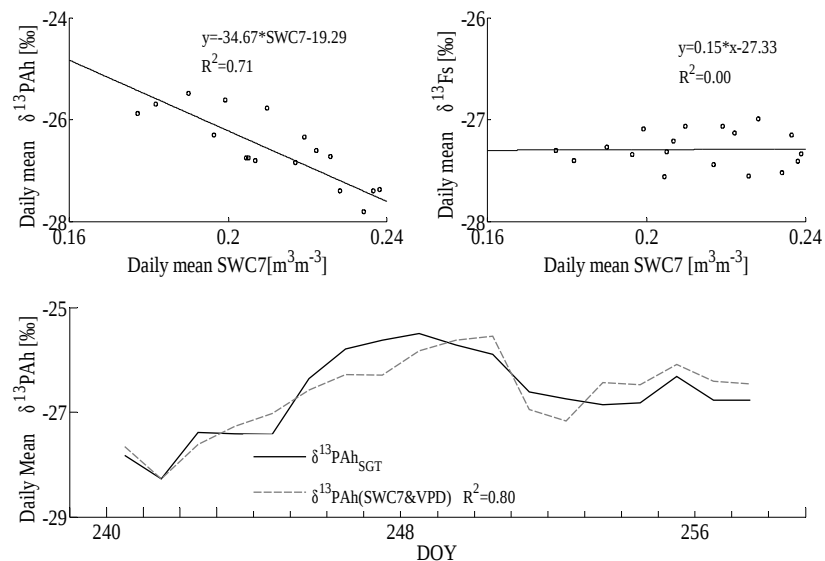
Julian
day

- **Best explained by soil moisture**

SWC decrease \Rightarrow enrichment
Same impact as for
photosynthesis discrimination !!!



2. Factors affecting P_s and $\delta^{13}P_s$



• Enrichment not observed in chamber efflux measurements

- Mixing of \neq layers contributions
- Perturbation of soil climate below the chambers ?

3. Who (transport or production) is responsible for P_s and $\delta^{13}P_s$ temporal variability ?

(Goffin et al. 2015)

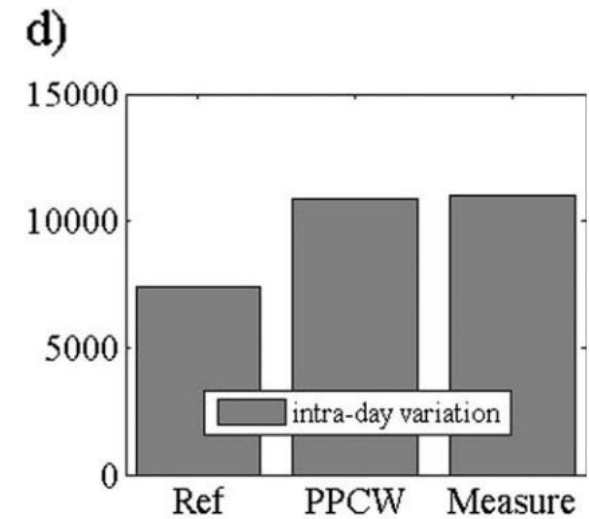
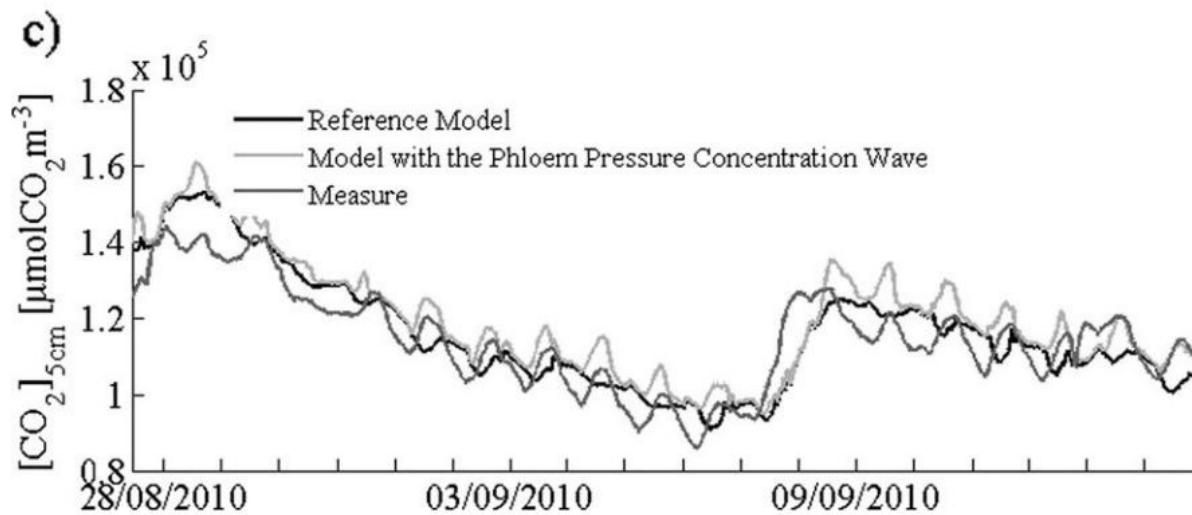
3 model versions simulating CO₂ production and transport

- Reference model (RM):
 - P_{sn} simulated with Q10 relationship using t° of the nth layer
 - Diffusion is the only transport process
- Transport Version (TV):
 - Advection and dispersion are added to diffusion
- Production Version (PV):
 - In addition to T° , simulated production depend on VPD reflecting Phloem Pressure Concentration Wave (PPCW)

Comparison of RM, TV and PV outputs with soil [CO₂] and F_s measurements

3. Who (transport or production) is responsible for P_s and $\delta^{13}P_s$ temporal variability ?

RM: Relatively good reproduction of the general trend but intra-day variability too low and not in phase



- No significant improvement with TV
 - PPCW : Not perfect but diurnal fluctuations are better reproduced and difference in phase is reduced
- ➔ **Working on production description before transport is a better option to improve soil CO_2 model**

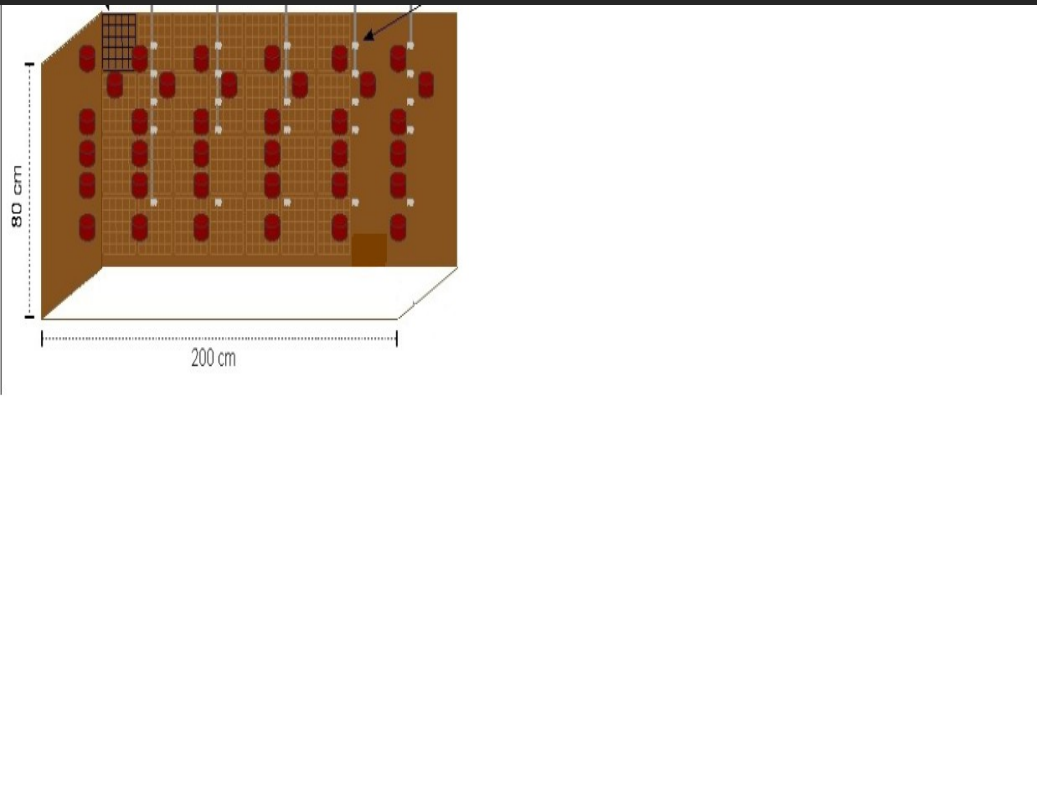
Key points

- Set up of an experimental *in-situ* device to obtain vertical profile of P_s and δP_s
- Identify a dependence of horizons to their own temperature
- Observe enrichment of P_s with soil drought in Ah horizon
- Soil CO₂ model should develop production description before transport to simulate hourly/daily variability

The End

Materials & Method

4. Laboratory Measurements



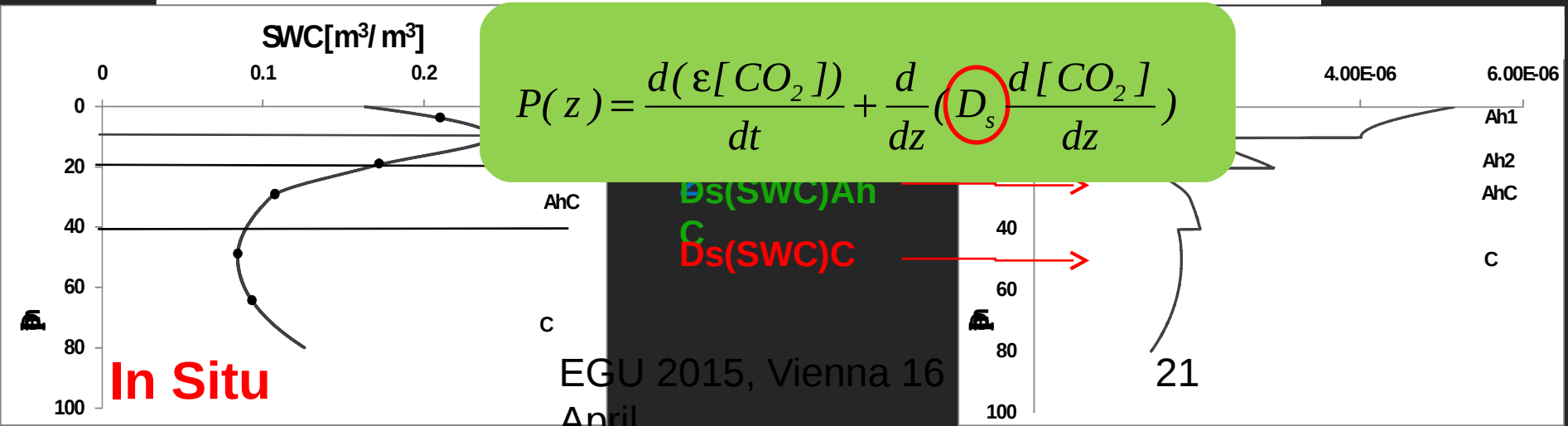
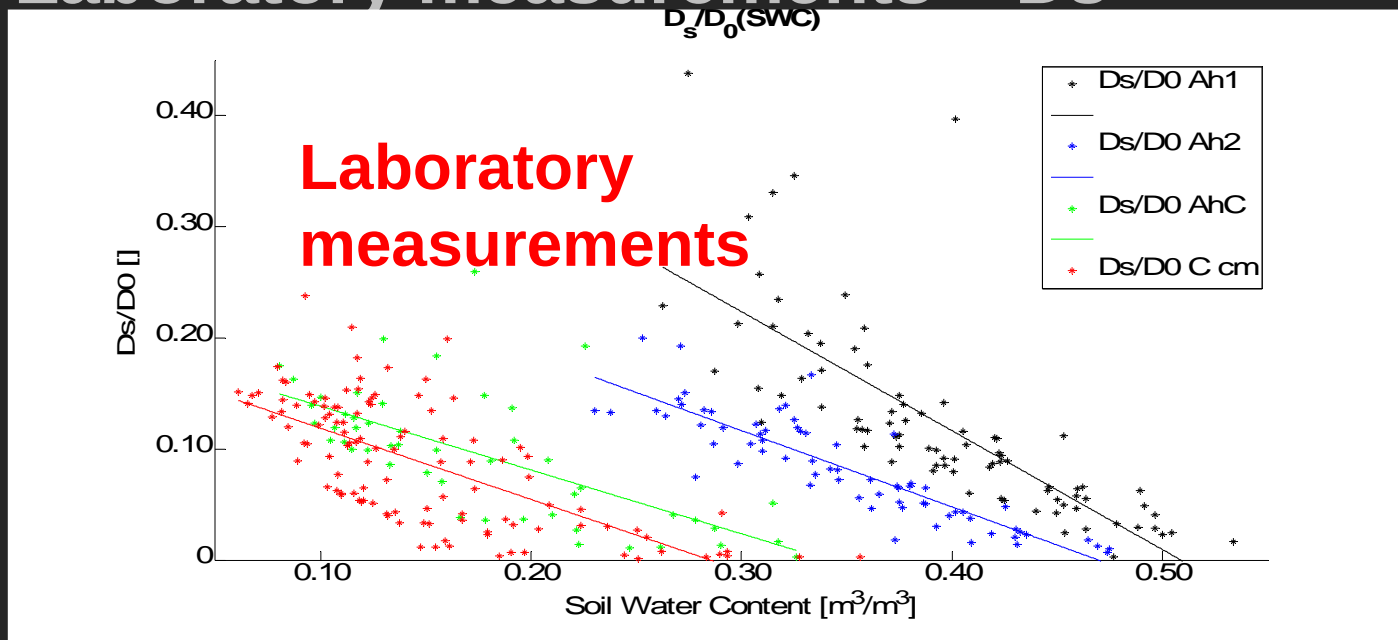
- Undisturbed soil cores of 200 cm³ collected in each horizon



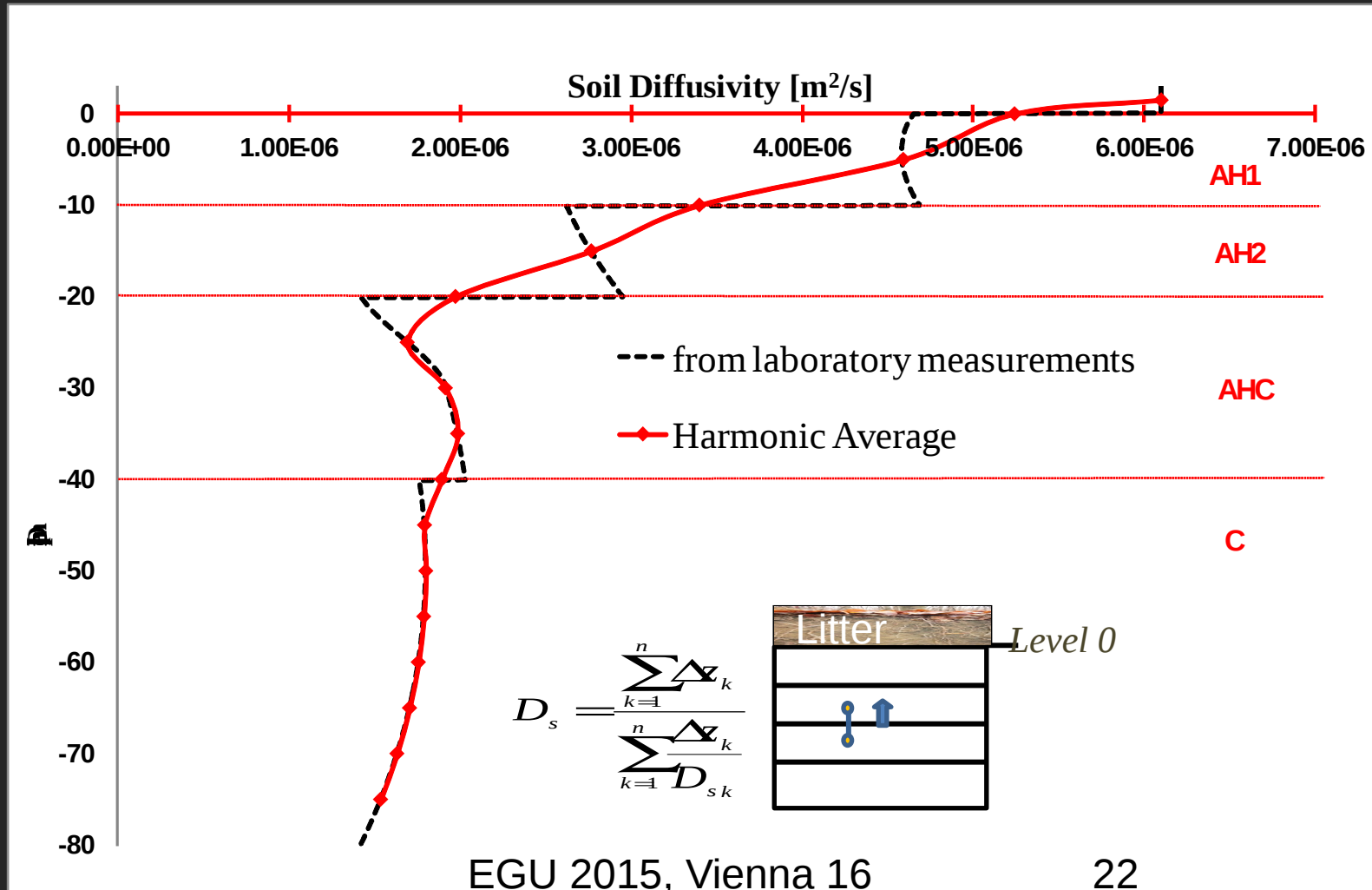
- Soil horizon specific physical parameters :
 - Porosity, pF curves
 - Relationships between $D_s(SWC)$

Material & Method

4. Laboratory measurements – Ds



4. Laboratory Measurements– Parametization



1. Determine P_s and $\delta^{13}P_s$ for \neq layers

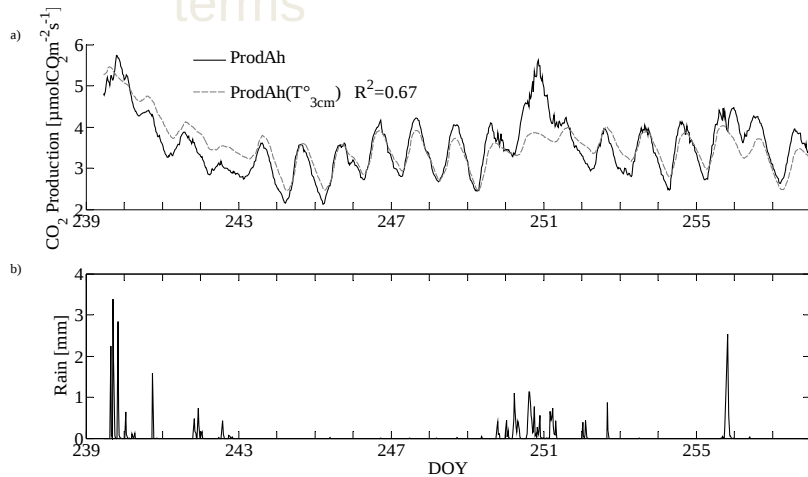
Day to day variation

Vertical Profile of CO₂

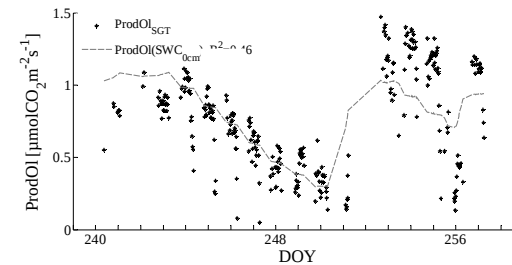
sources

Ah Production

terms



Litter Production terms



- Soil production shows clear diel and daily fluctuations in **Ah**
- The diel and daily fluctuations are best explained by the T measured in the topsoil
temperature is the most important driver of soil CO₂ production

- Unlike other horizons, Ol production was best explained by surface soil water content (SWC) ($R^2=0.46$)