Influence of the atmospheric disturbance on the respiration of a forest soil

C. Wylock, S. Goffin, M. Aubinet, B. Longdoz and B. Haut

COMSOL CONFERENCE ROTTERDAM 2013

October 23 - 25, 2013

WTC Rotterdam

ULB Motivation

- **Assessment of forest soil respiration and its isotopic composition :**
  - important issues for carbon cycling modeling (greenhouse gas emission control)
  - often inaccurate because soil respiration is a complex process :
    - several phenomena coupled

    → highly sensitive to any disturbance
- **Experimental campaign in Harteim (Germany)**
  - Measure of global CO_2 flux F_{CO2} and its isotopic ratio $\delta^{13}[CO_2]$ along time
  - Observation of significant intra-hour fluctuations not explained by current existing model

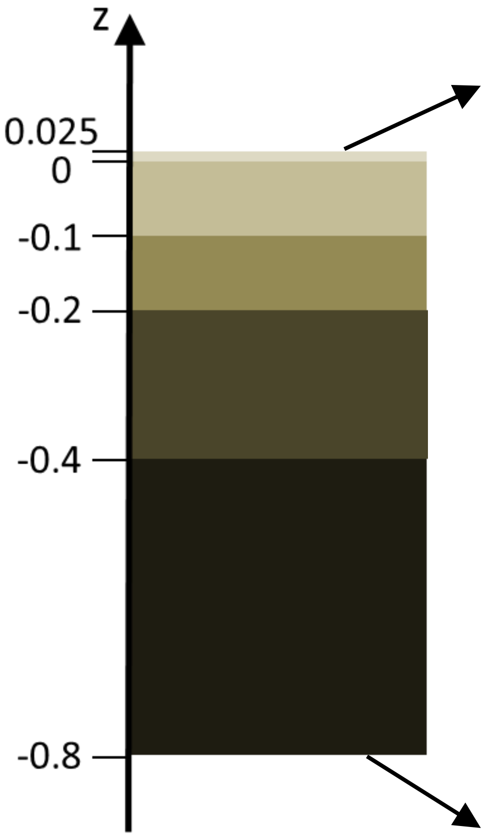
FREEDOM TO RESEARCH

Motivation

- **Where do these intra-hours fluctuations come from ?**
  - Atmospheric pressure fluctuations, i.e. due to wind ?
  - Photosynthesis, i.e. due to variations of the amount of sunshine radiation ?
  - …
- **Mathematical modelling and simulation using COMSOL**
  - Investigation of the influence of pressure fluctuations and photosynthesis on the soil respiration intra-hours fluctuations
  - → what is the role of these two phenomena ?

Mathematical modelling

- **Basic equations**



$[^{12}CO_2]$, $[^{13}CO_2]$ from measurements along time

$$\varepsilon \frac{\partial[^{12}CO_2]}{\partial t} = \frac{\partial}{\partial z}\left(D_{s,12}\frac{\partial[^{12}CO_2]}{\partial z}\right) + S_{12}$$

$$\varepsilon \frac{\partial[^{13}CO_2]}{\partial t} = \frac{\partial}{\partial z}\left(D_{s,13}\frac{\partial[^{13}CO_2]}{\partial z}\right) + S_{13}$$

ε : porosity, determined experimentally for each layer

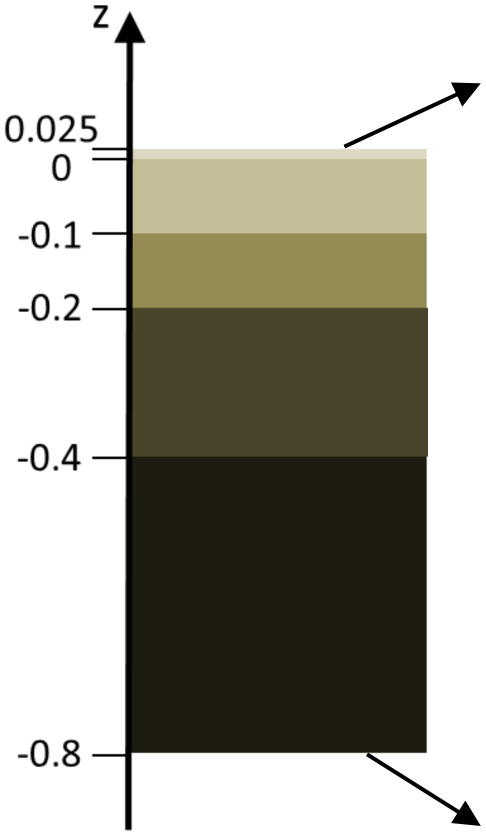
D_S : diffusivity, determined experimentally for each layer

S : production rate by the micro-organisms and roots living in the soil, use of classical laws for soils

$$\frac{\partial[^{12}CO_2]}{\partial z} = \frac{\partial[^{13}CO_2]}{\partial z} = 0$$

Mathematical modelling

- **Basic equations + atmospheric pressure fluctuations**



$[^{12}CO_2]$, $[^{13}CO_2]$, p from measurements along time

$$\varepsilon \frac{\partial[^{12}CO_2]}{\partial t} = \frac{K}{\eta}\frac{\partial}{\partial z}\left([^{12}CO_2]\frac{\partial p}{\partial z}\right) + \frac{\partial}{\partial z}\left(D_{s,12}\frac{\partial[^{12}CO_2]}{\partial z}\right) + S_{12}$$

$$\varepsilon \frac{\partial[^{13}CO_2]}{\partial t} = \frac{K}{\eta}\frac{\partial}{\partial z}\left([^{13}CO_2]\frac{\partial p}{\partial z}\right) + \frac{\partial}{\partial z}\left(D_{s,13}\frac{\partial[^{13}CO_2]}{\partial z}\right) + S_{13}$$

$$\varepsilon \frac{\partial p}{\partial t} = \frac{K}{\eta}\frac{\partial}{\partial z}\left((p + p_{\mathrm{ref}})\frac{\partial p}{\partial z}\right)$$

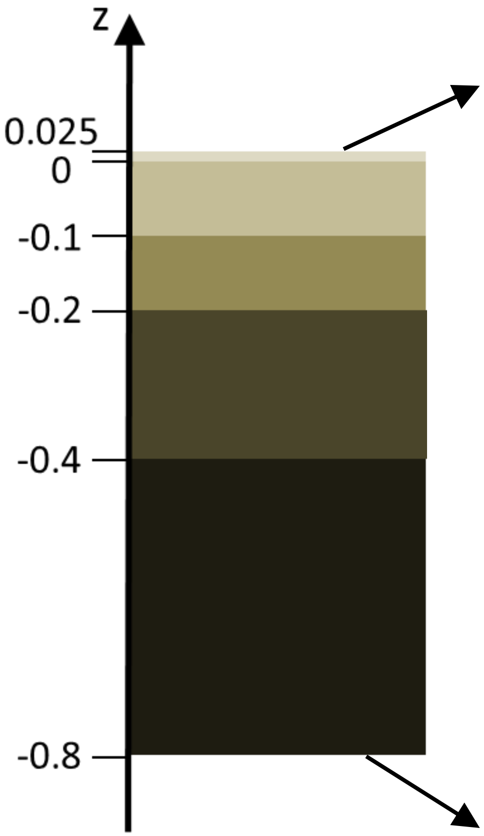
η: air viscosity

K: permeability, determined experimentally for each layer

$$\frac{\partial[^{12}CO_2]}{\partial z} = \frac{\partial[^{13}CO_2]}{\partial z} = \frac{\partial p}{\partial z} = 0$$

Mathematical modelling

- **Basic equations + photosynthesis**



$[^{12}CO_2]$, $[^{13}CO_2]$ from measurements along time

$$\varepsilon \frac{\partial [^{12}CO_2]}{\partial t} = \frac{\partial}{\partial z}\left(D_{s,12} \frac{\partial [^{12}CO_2]}{\partial z}\right) + S_{12} + P_{12}$$

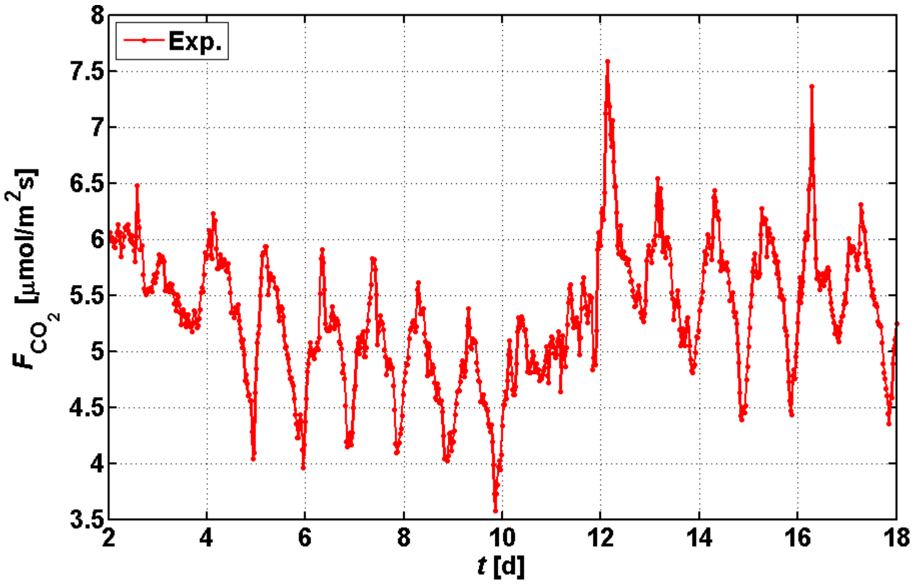
$$\varepsilon \frac{\partial [^{13}CO_2]}{\partial t} = \frac{\partial}{\partial z}\left(D_{s,13} \frac{\partial [^{13}CO_2]}{\partial z}\right) + S_{13} + P_{13}$$

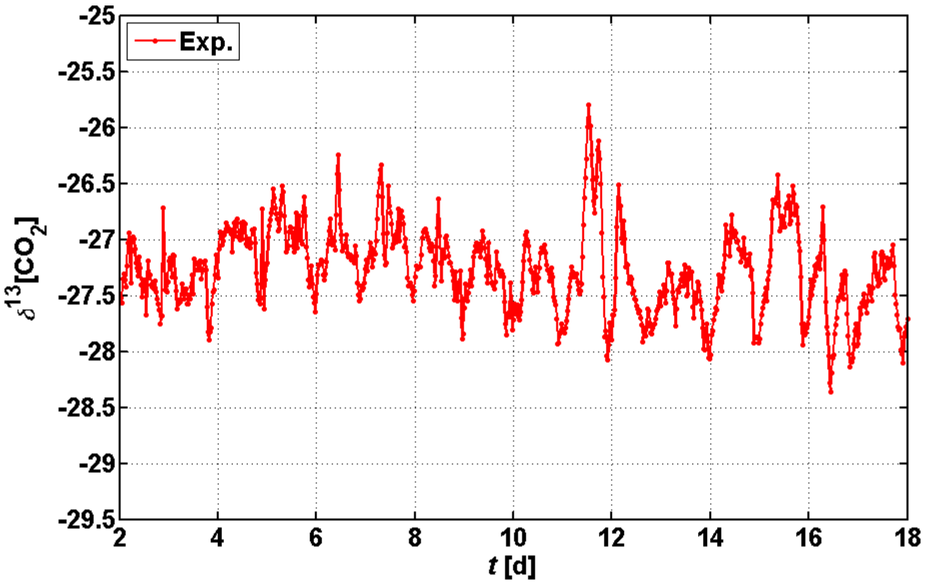
P: additional consumption rate due to photosynthesis, depending on depth, amount of sunshine and temperature, use of classical laws for soils

$$\frac{\partial [^{12}CO_2]}{\partial z} = \frac{\partial [^{13}CO_2]}{\partial z} = 0$$

ULB Results and discussion

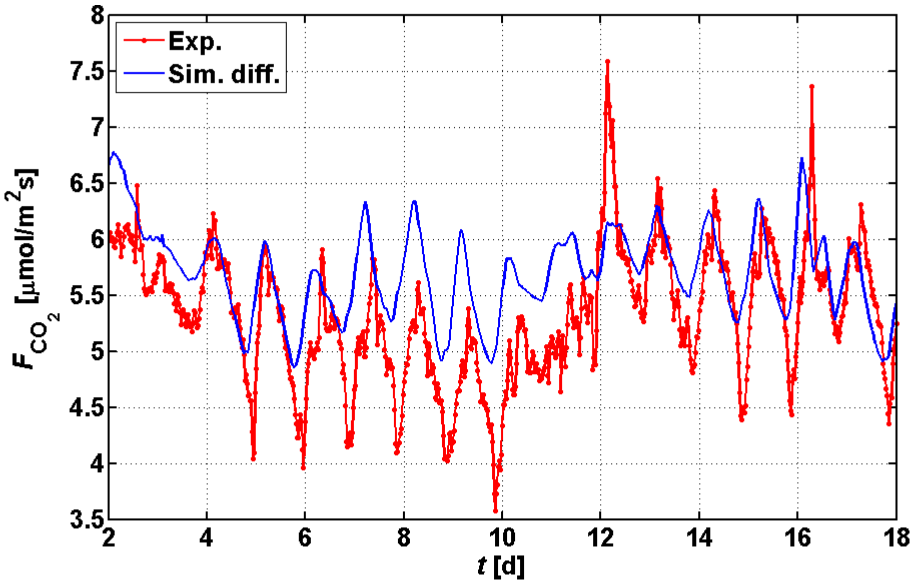
- **Comparison between experimental data and simulations**
  - Experimental measurements

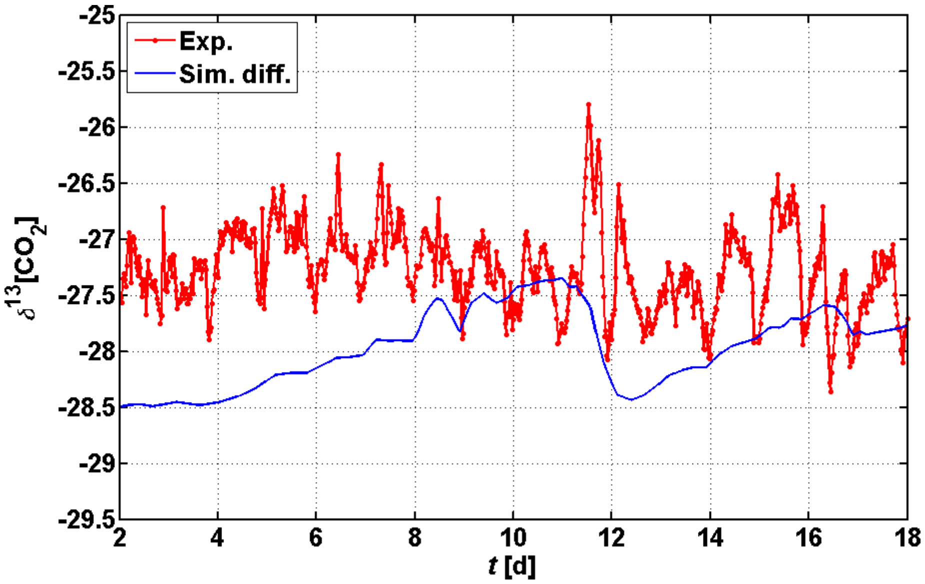




Results and discussion

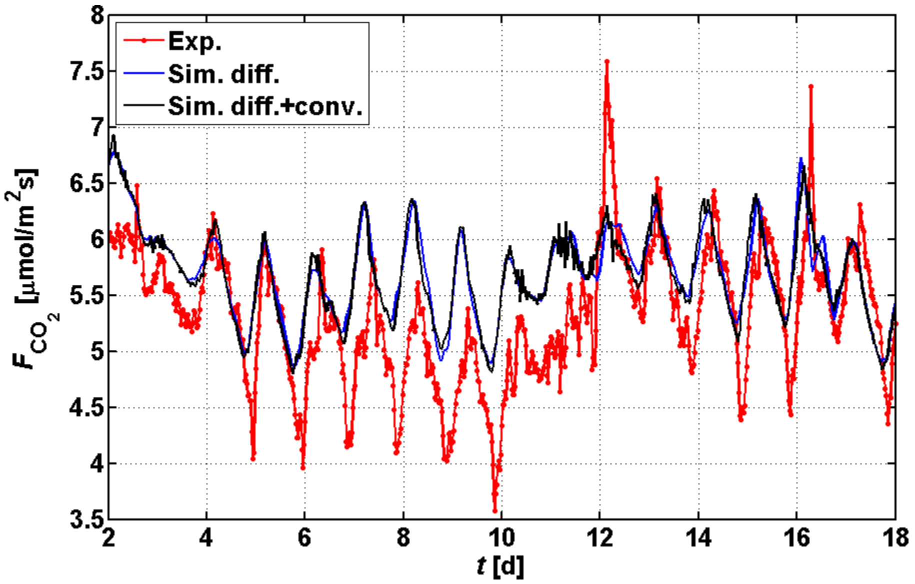
- **Comparison between experimental data and simulations**
  - Experimental measurements
  - Simulation with diffusion model

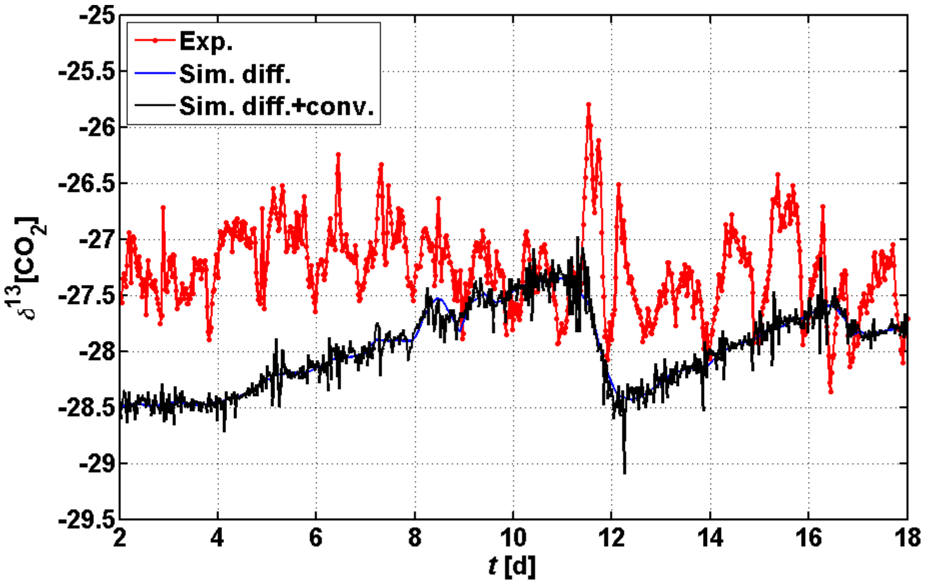




Results and discussion

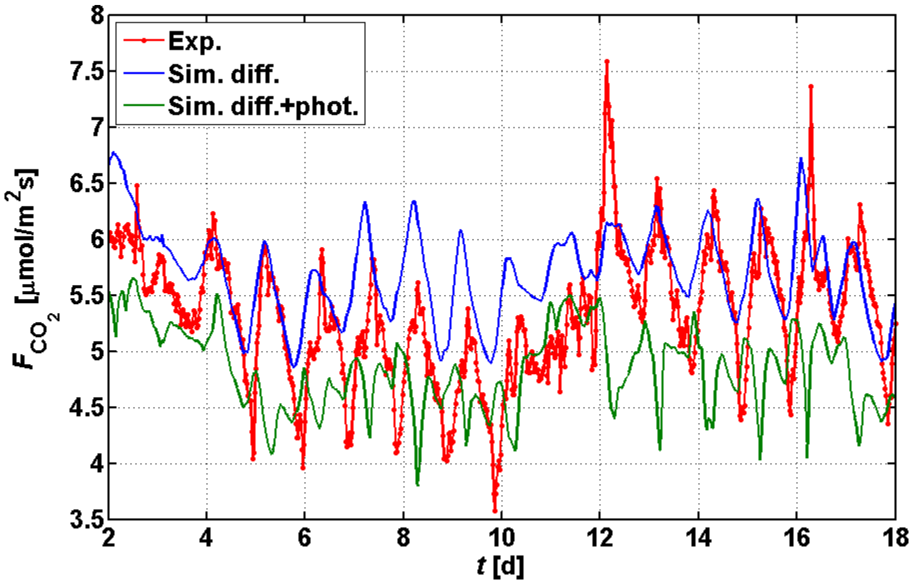
- **Comparison between experimental data and simulations**
  - Experimental measurements
  - Simulation with diffusion model
  - Simulation with diffusion + wind model

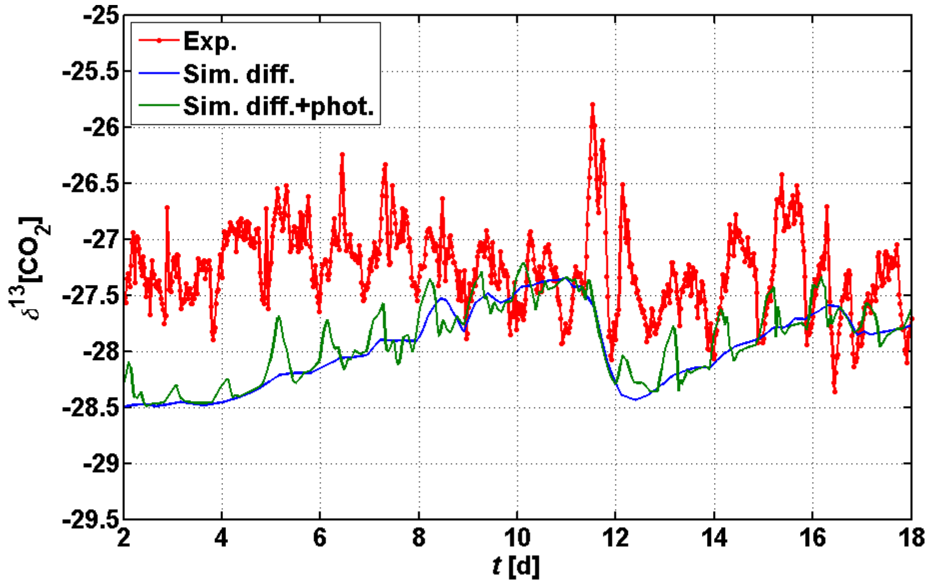




Results and discussion

- **Comparison between experimental data and simulations**
  - Experimental measurements
  - Simulation with diffusion model
  - Simulation with diffusion + photosynthesis model





ULB Conclusion

- **Diffusive model**
  - Rather good estimation of F_{CO2} and $\delta^{13}[CO_2]$ but tending to overestimate F_{CO2} and underestimate $\delta^{13}[CO_2]$
  - Not predicting the intra-hour fluctuations of F_{CO2} and $\delta^{13}[CO_2]$
- **Model with effect of wind**
  - Lead to simulated intra-hour fluctuations of F_{CO2} and $\delta^{13}[CO_2]$!
- **Model with effect of photosynthesis**
  - Significant decrease of F_{CO2} → better agreement with measurements
  - Lead to moderate intra-hours fluctuations
- **COMSOL is a perfect tool for such a study**

Thanks for your kind attention