Report of post doc project

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Project title: AdvanCing the Hydrodynamic characterization of hILLslopES (ACHILLES).

1-Introduction

The important variability of intrinsic soil properties along a hillslope will subsequently be translated in a strong differentiation of soil hydrological and biogeochemical functioning. In terms of soil hydrological functioning, for instance, it is well known that the hillslope topography largely controls the soil moisture distribution and associated soil moisture fluxes. In addition, the systematic variation (organized patterns) of soil properties along the hillslope transect (or similarity between some characteristics) may allow predicting and modeling the soil functions with limited experimental data. The current project is embedded in an ARC project that aims to understand the controls of carbon dioxide fluxes in soils of a hillslope. (UCL-ARC: The hillslope as elementary unit for regional scale modeling of soil organic carbon emission (2010-2014)). The specific objective of the SSTC post-doc project is to understand the link between CO2 fluxes and hydraulic controls at the hillslope scale. The study is carried out in the Belgian loam belt along a cultivated hillslope of 150 meters length (50.6669°N, 4.6331° W) in the Marbaix experimental site in Louvain-la-Neuve, Belgium. The experimental hillslope has been equipped for monitoring hydrological and carbon turnover fluxes with an unprecedented high spatial resolution within the framework of the SSTC projects HYDRASENS (HYDRASENS: Integrating radar remote sensing, hydrologic and hydraulic modelling for surface water management, SSTC, 2007-2012) and the UCL-ARC project.

In summary this post-doc project aims to reduce the uncertainty in modeling hydrodynamic processes and biogeochemical cycling at the hillslope scale, by reducing the uncertainty in the assessment of spatially distributed field of hydraulic properties (moisture retention and hydraulic conductivity) within the hillslope.

2- Research methodology

2-1 The experimental hillslope

2-1-1) Measurement stations. Detailed background data (soil map, geological map, land use and land use history map) are available for the site. In addition, 4 measurement stations were selected at different slope positions along the transect: the summit, the shoulder, the backslope and the footslope (fig 1). At each of the 4 stations, the following hydrogeophysical monitoring program is operational for the experimental hillslope from spring 2012 onwards: time lapse electrical resistivity measurements using a 164 surface electrode surface array; time lapse electrical resistivity measurements at 4 local stations using borehole and surface electrical resistivity measurements; and at 3 local stations, fully automated time lapse (hourly) TDR measurements using a 24 channel TDR device.
In addition, at each of the 4 stations, soil surface CO_2 fluxes have been measured by means of a portable infra-red gas analyzer with an automated closed dynamic chamber (LI-8100A system, LI-COR, United-States), and also soil CO_2 concentrations have been measured by means of specific designed soil CO2probes.

2-1-2) Sampling locations. The sampling locations are shown in figure 1. At each of the 4 stations and also at the midway between two units, totally 9 positions were selected to take disturbed and undisturbed soil samples and to conduct soil physical experiments.

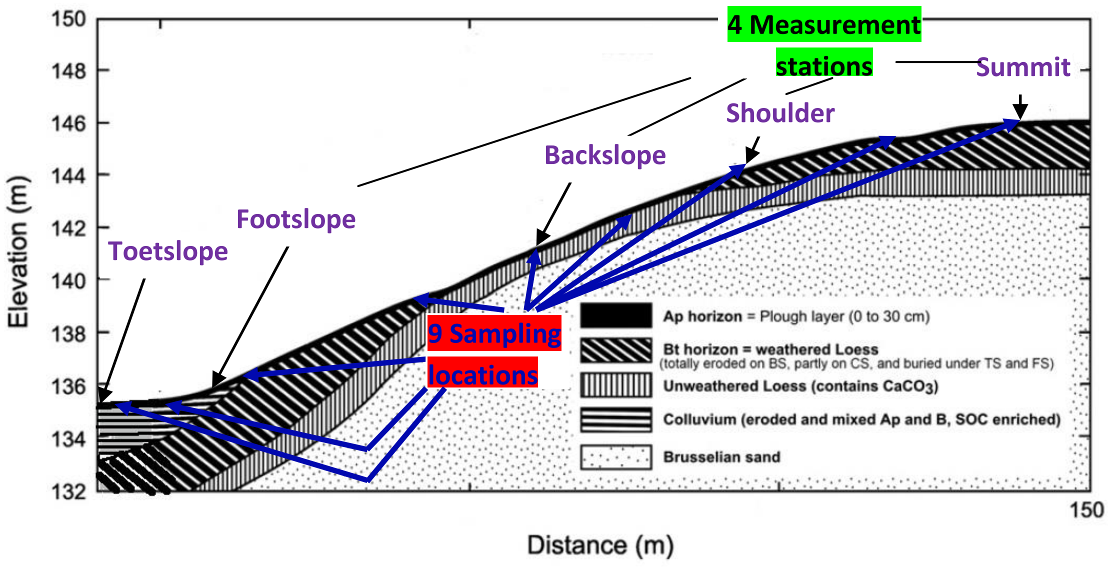

Fig. 1. Hillslope and schematic representation of the study site (profile view) and, 4 measurement stations and 9 soil sampling locations along the hillslope (plan view).

Samples:

1- Small samples (5cm id * 5cm h): 3 small undisturbed soil samples were taken from each position and each pedogenic horizon. Total number is 45.
2- Large samples (4.5cm id * 100cm h). Undisturbed soil samples were taken along the transect. Total number is 36.
3- Disturbed samples: From each sampling position and pedogenic horizon, a ~2 Kg soil sample was taken.

2-2-Experiments

2-2-1-In-situ experiments

Gas conductivity experiment. A hand-made instrument was designed and constructed based on the "Marriot device" steady out flow. One-dimensional advective air flux in soils was measured for the top soil at each sampling position (with 5 replicates) according to the method of Iversen et al (2001). This experiment was repeated for different soil moisture contents (at least 5 moisture contents) to achieve the relationships between the soil moisture content and the gas conductivity.

Double ring infiltration rate. Infiltration was measured using a double ring infiltrometer, with 32 cm inner diameter and 53 cm outer diameter rings (four replicates) installed in the each sampling position. Grass was carefully cut at the soil surface with shears in the inner and outer rings. A constant water head of approximately 2 cm was kept in both rings and amount of the water drop and the depth of added water were recorded.

Single ring infiltration rate. The infiltration rate was also measured in field with a single ring infiltrometer which is merely a thin ring that is pushed partly into the soil and then ponded with water (Reynolds et al 2002). For each sampling position, different size of rings (including; 5, 8.1, 11.2, 16.4, 32, 53 cm) were used to estimate the macroscopic length scale, saturated hydraulic conductivity and the eventual effect of preferential flow.

Dye tracer experiments. At the end of in-situ experiments, a dye tracer experiment was conducted with 2 g/L Rhodamine B (CI 45170) and a soil vertical profile(width=1.2m) was diged up to depth of 150 cm for the each hillslope unit (five experiments). Image analysis was subsequently conducted on the vertical view for the each hillslope unit.

2-2-2-Laboratory experiments

Soil moisture characteristic curve (SMC). The SMCs were obtained using a hanging water column (0.1-15 kPa), pressure plate (30-100 kPa), and pressure membrane apparatus (100-1500 kPa) (Dane and Hopmans, 2002). The soil bulk density and porosity were also measured during the measurement of the SMC.

Soil particle size distribution (PSD). The PSD was determined using a hydrometer and the sieving method according to Gee and Or (2002).Totally 20 size fractions were measured. The pipette method was also used to determine the soil texture and to verify the hydrometer method.

Aggregate size distributions .Wet sieving was performed on soil aggregates smaller than 8 mm (Yoder 1936). An undisturbed sample was placed on the nest of sieves consisting of eight aperture sizes,8, 4.75, 2, 1, 0.5, 0.25, 0.15 and 0.053 mm, and then gently submerged in the standard water . The samples were shaken for 10 min with a vertical stroke (~30 mm distance and speed of ~35 cycles min^{-1}).

Gas conductivity experiment. The field gas conductivity instrument was adopted to measure air flux in small soil samples (5cm id * 5cm h). This experiment was conducted for different soil moisture contents (at least 8 moisture contents) to achieve the relationships between the soil moisture content and the gas conductivity (Iversen et al., 2001).

All laboratory experiments were conducted on the soil samples taken from each position and each pedogenic horizon with at least 3 replicates. Note that during the post-doc stay, the monitoring of hydraulic behavior was ensured by other members of the project team. This monitoring encompassed the measurement of soil moisture related attributes by means of TDR, GPR, and ERT probes. Soil thermal behavior was monitored through the use of CTN probes. Soil respiration was assessed by the infrared technique.

3-Results

3-1) Linking soil hydraulic characteristics to soil basic properties

A priori-estimates of the hydraulic propertes of the macrostructural units of the hillslope can be obtained from pedo-transfer functions (PTFs) (e.g. Weynants et al., 2009; Mohammadi and Vanclooster, 2011). We studied the organized patterns of soil basic properties and eventual correlations with the soil carbon flux and hydraulic characteristics. We aim finding the control depth of infiltration processes and studying the eventual relation with the pedogenics horizons along the transect. To this end, we first improved the theoretical concepts aiming to link basic physical attributes to hydraulic behavior of the soil. These improvement are currently in the process of publication (Meskini-Vishkaee et al,2014; Mohammadi et al., 2014).

3-2) Study the effect of the macropores and the sample size and scale on hydraulic properties and CO2 diffusion. Much progress has recently been made with the hydraulic characterization of the local flow properties using simple fast in-situ flow and tracer experiments (e.g. Lassabatère et al., 2006). The objective of this task is to carry out a set of fast in-situ flow and transport experiment and to use these in combination with existing conceptual models to assess flow parameters and associated uncertainty from in-situ experiments, and their link with CO2 respiration. The experiments supporting this research task have been performed, but time is needed to improve the analysis and writing the research papers related to this topic.

4-Output (joint publications)

During the first stay a conference paper was published, and two A1 research papers were submitted for publication (one has been accepted for publication, the other one is in review).

Mohammadi, M.H., F. Wiaux, K. Van Oost, S. Lambot, M. Vanclooster, 2014. Linking the soil $C0_2$ emission to soil hydraulic properties at the hillslope scale. SOMpatic 2013 (Rauischholzhausen, Germany, du 20/11/2013 au 22/11/2013). In: Book of abstracts, Justus-Liebig Universität Giessen: Germany, 2013. http://hdl.handle.net/2078.1/135266

F. Meskini-Vishkaee, M. H. Mohammadi and M. Vanclooster, 2014. A Scaling Approach, Predicting the Continuous Form of Soil Moisture Characteristics Curve, from Soil Particle Size Distribution and Bulk Density Data. Hydrology and Earth Sciences Systems. In review.

Mohammadi, M.H., M. Khattar and M. Vanclooster, 2014. Combining a single hydraulic conductivity measurement data with soil particle size distribution data for estimating the full range partially saturated hydraulic conductivity curve. Soil Science Society of America Journal. In press.

Two research papers are also in preparation as follows:

1- The effect of sample size and scale in prediction of soil hydraulic properties with using the BEST method.
2- The effect of the soil structure and macropores on CO2 emission at hilslope scale.

5) Perspectives for the second research stay

5-1) The quality and quantity of the organic carbon (OC) may affect the pore shape and size distribution (PSSD). Both the SMC and the air diffusivity are affected by PSSD.

However, PSSD variation due to OC will only be visible at the microscopic scale. Insights in the soil microstructure can improve the interpretation between soil gas diffusion in partially saturated soils.
We will detect the PSSD data with using image analysis technique. This technique allows us to measure soil hydraulic properties at small scales. The OC can be measured at small scale, so it would be possible to investigate the eventual relationships between PSSD and OC along the soil horizons. Since we have prepared 28 large undisturbed soil sample, we analysis the OC micro-structure and variability and, we prepare thin section for eventual the X ray tomography or the micro morphology experiments (which is available) during the second stay.

5-2) Data fusion and hydrodynamic modeling. In this last workpackage, results from the previous experiments will be integrated to constrain the hydrodynamic inversion of the soil moisture maps for inferring the hydraulic parameters. The time lapse ERT and GPR-EMI data will be fused to obtain time lapse soil moisture fields of the hillslope using Bayesian approaches. These soil moisture time series will subsequently be inverted using an inverse hydrodynamic model (HYDRUS 2D) constrained by the a-priori estimates as assessed from PTFs and local scale fast in-situ flow experiments, using global parameter research strategies (e.g. Vrugt et al., 2008).

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