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Technical Note: Erosion processes in black-marls at the millimetre scale, the input of an analogical model

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Abstract

An analogical model of badland soil has been created in the aim to study the erosion process at the millimetric scale when exposed to rainfall. The analogical model is composed of a sample of black-marls soil, coming from a badlands area of southern of France. It is holding in a 0.5 m^2 metal case. For the experiment the model has been exposed to a natural rainfall with an angle of 45°. It was monitored by a terrestrial laser scanner (TLS). This experiment allowed identifying several processes as micro-landslides, swelling of the clay content in the black-marls, the compression and creeping of the ground. All these processes have been studied and identified at the millimetre scale.

1 Introduction

The small black-marls watersheds have strong responses to the climate forcing (Malet et al., 2007). This study aims to a better understanding of their behaviour and micro-morphological evolution, as responses to rainfall events. The idea of this experiment was to extract a sample of black marls, then to expose it to a natural rainfall in order to monitor its evolution with a laser scanner.

In the past several studies of artificial-rain simulations have been performed on the site of the Draix Observatory (ORE Draix), which is an observatory, dedicated to the research of mountain hydrological and erosion processes. Previous works were focusing on the measurement of sediment transport (Oostwood and Ergenzinger, 1998) and runoff (Mathys et al., 2005). The badland surface ground evolution has already been monitored during rainfall simulations by using a pin-type micro relief-meter and photographies (Torri et al., 1999), but these tools could not reach the same precision has a laser scanner. Recent studies showed the potentiality of observing and characterizing erosion processes at the level of micro-topography using laser scanner (Schmid et al., 2004; Barneveld et al., 2013).

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The used soil sample comes from the protected study field of Draix (ORE Draix, CEMAGREF). This experiment site is located in the south of France, in a badlands area near the city of Digne les Bains. The experiment has been performed in Lausanne (Switzerland). For the monitoring of this analogical model a LiDAR Leica ScanStation II has been used, in order to:

1. identify erosion processes at the millimetre scale;
2. quantify the swelling of the clay content in the marls during rainfall events;
3. map all the possible modifications of the ground.

2 Geological settings

The sample of soil used for this experiment was extracted from marl outcrop. It is 0.15 m thick. It is 1 m long and for 0.5 m wide. To extract this sample of soil a metal case has been developed (Fig. 1) to keep the soil structure intact (Fig. 2, left panel). The sample has been extract from a 45° slope and has been dried during 3 month in the laboratory.

On the 31 May 2011 the soil sample was exposed to a natural rainfall from 11:01 to 17:47 (GMT + 1). During the experiment the soil sample was in its extracting metal casing, which had the same inclination than the ground in the field in France (45°).

The soil sample was scanned every 30 min by a LiDAR Leica ScanStation II (Germany). Ground-based LiDAR is a remote sensing tool, that produces point-clouds (x, y, z data) in a 3-dimensionnal space. The laser pulses line of sight and time of flight determine the position of the measured points. The rainfall has been measured by the weather station of the University of Lausanne (PluvioMADD2 from MADD Technology) located at 500 m from the experiment place.

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Data acquisition and processing

The first scan (11:01 GMT + 1) and the last scan (17:47 GMT + 1) have a 0.001 m point spacing. All the others scans have a 0.002 m point spacing. From 0 to 50 m 50 % of the laser beam intensity (FWHH-based) is in a spot size of 4 mm diameter (Leica Geosystems AG, 2007). The scan distance is 2 m. Finally twelve scans of the sample were acquired. The scan origin position is identical for all scans as the LiDAR was not moved throughout the experiment. As a consequence, no scan alignment is necessary in order to compare them. The first processing operation was to manually clean the scans of the unnecessary points. Only the surface of the sample is kept. Every scan has a very high point density, more than 400 000 points (after manual cleaning) for 11:01 and 17:47 (GMT + 1) acquisitions. For the others scans they are composed of a minimum of 110 000 points.

Each TLS scans were interpolated using Surfer software (GoldenSoftware 8) inverse distance interpolation with power of 1 (Shepard, 1968) into a high resolution digital elevation model (DEM). The search radius size was 1.5 mm for scans with a point spacing of 1 and 3 mm for the scans with a point spacing of 2 mm (Fig. 3). The DEM used, is a horizontal regular squared grid of altitude z. DEMs were compared to quantify and map erosion/deposit processes. More recent DEM is subtracted from earlier one (DeRose et al., 1998). The resulting difference image has negative value pixels for the erosion and positive value pixels for the deposit/elevation. To limit the “noise” of the measurements, differences inferior to 0.0015 m were ignored.

3 Results and discussion

The precipitations began at 13:30 (GMT + 1) and were not over at the end of the experiment. The rainfall intensity maximum was reached at 16:30 (GMT + 1) with a measurement of 5.2 mm h^{-1}. At the end of the experiment, a cumulated precipitation of 5.5 mm has been recorded. Three processes of topographic changes could be identified:

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micro-landslides (Fig. 4, I), compression and creeping of the soil surface (Fig. 4, II) and swelling of the ground (Fig. 4, III). The rising of the surface (deposits and/or swelling) appears in blue colors and the erosion appears in red colours (Fig. 4).

As it is possible to observe at a larger scale in a natural environment, here a "mini-landslide" has occurred at the millimetre scale (Fig. 4, I). The small particles in red slid to the bottom of a desiccation crack. The "mini-landslide" deposit appears in blue. This micro-landslide occurred right after the highest intensity rain moment, between 17:00 and 17:30 (GMT + 1) (Fig. 5).

The second observed process is the compression and creeping of the soil surface (Fig. 4, II and III). This process has been observed through the closing of the desiccation cracks, which were present at the surface of the sample. Moreover the metallic case's back offers a good failure plan. The rain drop impacts play also an important role in these processes. Indeed, the top of the model was protected from the rain and no changes have occurred (Fig. 4). The top of the sample appears in grey as the side of the metal case. The compression and the creeping of the soil are two different processes. They are combined and affect the micro-topography together. Thus we were not able to distinguish them separately.

The last identified process is the swelling of the soil (Fig. 4, II and IV). The entire ground surface is affected by a rising of the topography (appearing as a pale blue layer on Fig. 4). This general topographic rising is attributed to the swelling of the clay content of the ground sample. The clay swelling is caused by the water infiltration in the ground. This swelling has been measured as 1.5 to 3 mm on the entire surface, for a cumulated 5.5 mm of rain (Fig. 5). Swelling starts slowly after the first rain. During the rainfall peak intensity (16:30 GMT + 1) the surface has packed down and the process of swelling is momentarily slowed down. After that, the processes re-accelerated following the decrease in rain intensity (Fig. 5).

Another process has also been observed: the stripping of soil particles by the kinetic energy of the raindrops (also known as the "splash effect"). But unfortunately it has

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not been monitored by the LiDAR, but it has been observed by the authors during the experiment.

4 Conclusions

The approach using the high resolution LiDAR data enable to identify different erosion processes at the millimetre scale. The ground based laser's (LiDAR) quick acquisition allows monitoring sequences close to each other.

The rain intensity was not high enough (not enough kinetic energy) to measure some runoff or the creation of rills at the surface of the ground sample. But it has allowed identifying and monitoring different small deformations and processes, which are not observable when rilling occurs.

The processes work at a millimetre scale for this experiment, but they have a global impact at a bigger scale on the topographic changes and the creation of mobilized sediments. Future studies could realize the same experiment under a stronger rain event, in the aim to monitor the creation of rills or micro debris flow (MDFs) and to quantify the erosion by runoff at the millimetre scale.

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Table 1. Recapitulative LiDAR scans table of the experiment (TLS campaign 31 May 2010), with for each scan its time, the number of point before and after cleaning, the mean spacing between the points and the density of points.

Time series	LIDAR	Number of points before cleaning	Mean spacing [mm]	Distance from LiDAR [m]	Number of points after cleaning	Density [pts cm^{-2}]	RMS Residual Z (Root Mean Square) [m]
11:01	Leica	601 349	1	2	496 391	84.84	1.44E-03
12:00	Leica	149 951	2	2	123 233	21.06	1.47E-03
14:00	Leica	149 951	2	2	123 477	21.10	1.58E-03
14:30	Leica	149 951	2	2	123 269	21.07	1.66E-03
15:00	Leica	149 951	2	2	123 496	21.11	1.68E-03
15:30	Leica	149 951	2	2	122 857	21.00	1.66E-03
16:00	Leica	149 951	2	2	120 162	20.54	1.91E-03
16:30	Leica	149 951	2	2	118 301	20.22	1.98E-03
17:00	Leica	149 951	2	2	117 290	20.05	2.01E-03
17:30	Leica	149 951	2	2	116 322	19.88	2.08E-03
17:32	Leica	601 349	1	2	467 484	79.90	2.22E-03
17:47	Leica	601 349	1	2	469 906	80.31	2.05E-03

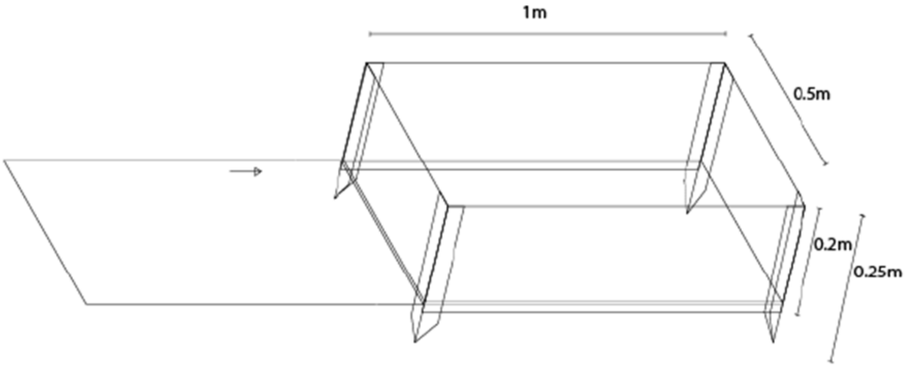

Fig. 1. Schematic plan of the developed metal case used to extract ground sample.

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Fig. 2. Left panel: view of the sampling. Center panel: view of the sample of soil inclined at 45. Right panel: LiDAR installation covers by a tent.

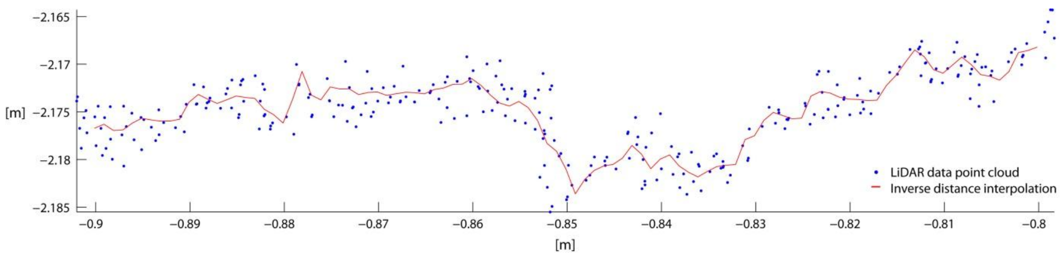

Fig. 3. Original LiDAR data point cloud compared with the 1 mm DEM profile (17:47 GMT + 1 scan data). The profile has been done with an inverse distance interpolation.

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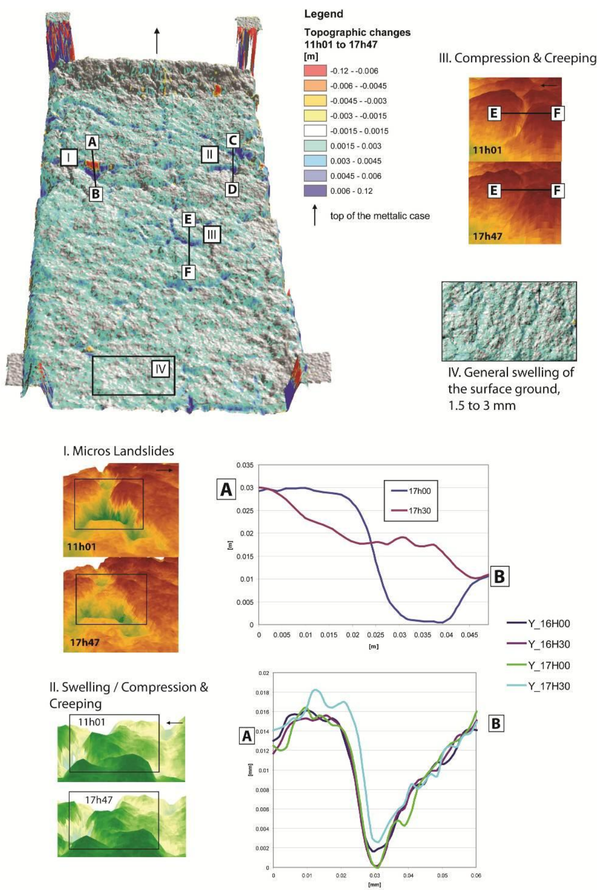

Fig. 4. LiDAR scans comparison; topographic changes from 11:01 (GMT + 1) to 17:47 and surface profiles comparison between 17:00 and 17:30 (GMT + 1). Three processes are also presented on the figure.

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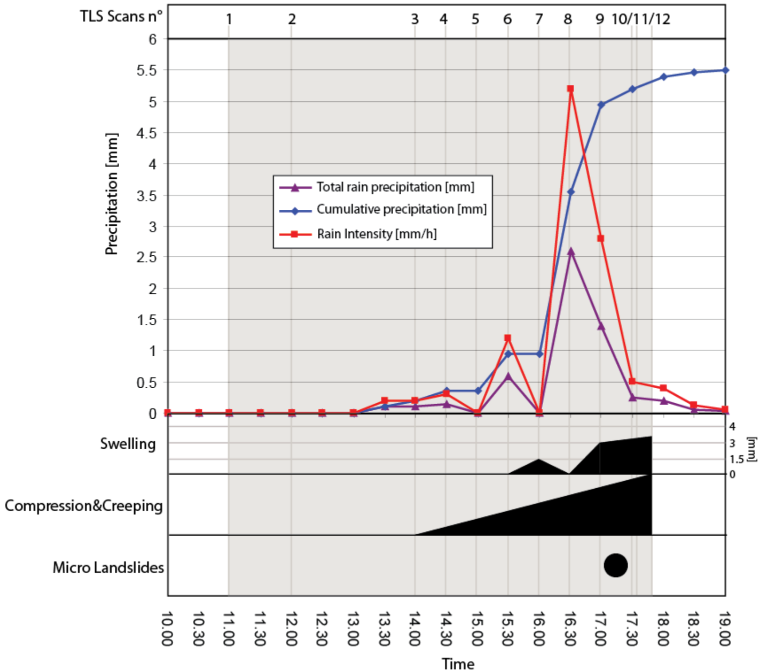

Fig. 5. Observed processes according to the precipitation data. The total rain amount in mm, the cumulative precipitation and the rain intensity are presented. The duration of the swelling in mm, the compression and creeping with its intensity and micro landslides processes are presented in relative scale.

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