MONITORING TOPOGRAPHIC CHANGE IN HIGHLY ERODIBLE LANDSCAPES BY MEANS OF TERRESTRIAL LASER SCANNING

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1. TERRESTRIAL LASER SCANNING

• Terrestrial Laser Scanners (TLS) have enabled the collection of dense and precise topographic data. TLS are capable of acquiring large volumes of survey-grade observations over ranges 10^{-2} – 10^{3} m at 10^{-3} m accuracy (Figure 1).

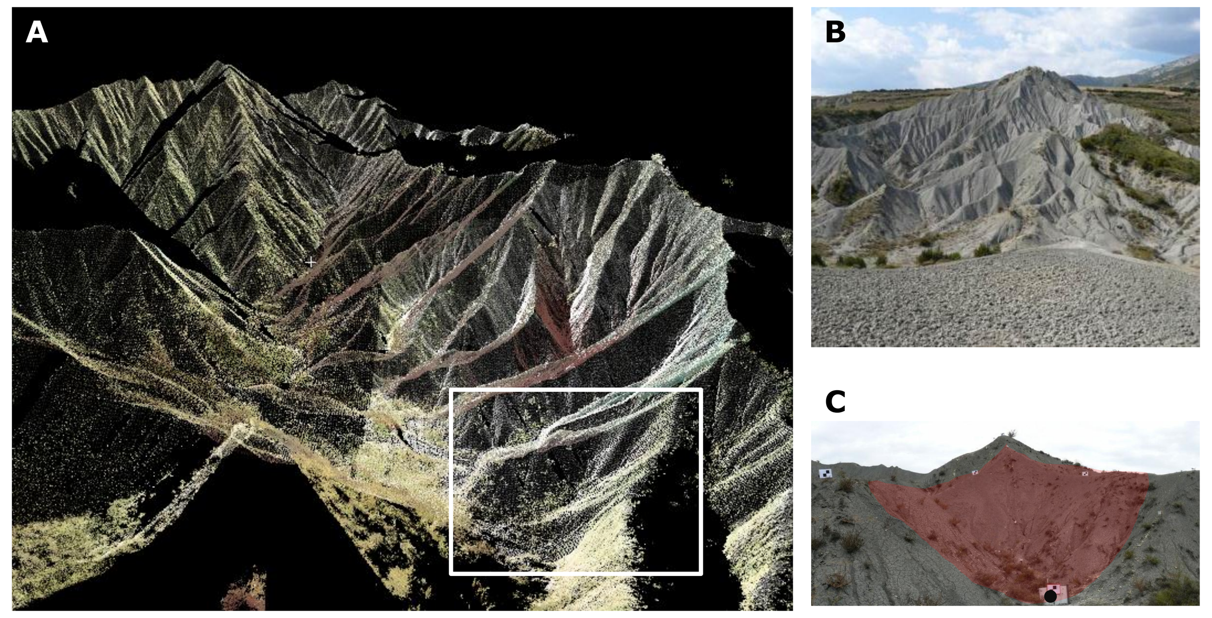
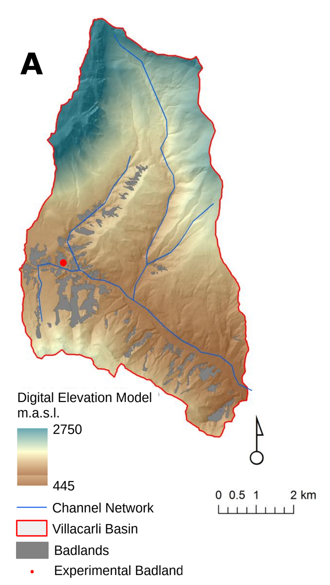


Figure 1. (A) Photo-rendered point cloud of badlands **(B)** in the Villacarli Basin (River Isábena, NE Pyrenees, Spain). **(C)** The experimental badland of this study. The square in A represents its location.

• However, there remain a number of challenges: (a) the limited spatial coverage; (b) the lack of automated protocols to filter uncertain observations; and (c) the post-processing of 3d data structures to simple data-sets while maintaining both topography and statistical information of surface complexity.

2. BADLANDSCAN: AIM AND TASKS

• Here we present an integrated methodology to study the topographic changes of an experimental badland (soft marls) in the highly dynamic River Villacarli (NE Pyrenees, Spain, Figure 1B-C and 2A) through 6 rainfall events during the period 2009-2010.



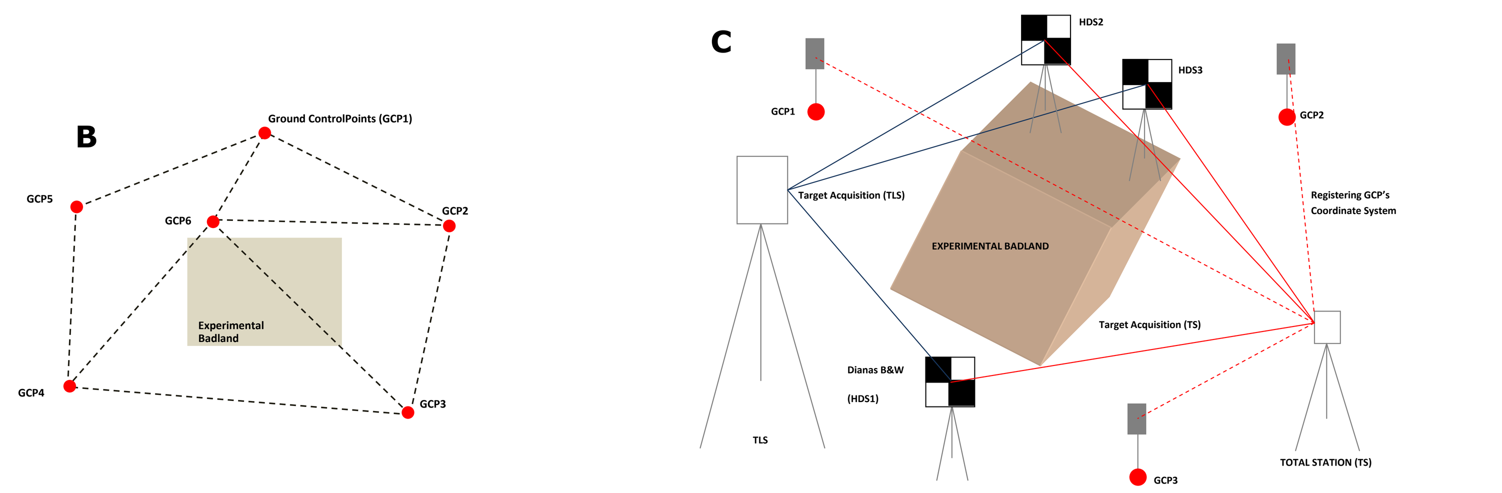


Figure 2. (A) The Villacarli Basin and the location of the experimental badland. **(B)** *Conceptual* distribution of the first order survey network control (GCP). **(C)** Point cloud registering and quality control.

• **DATA COLLECTION**: The experimental badland (90 m^2, Figure 1C) was surveyed 7 times during 2009 and 2010. The first context scan was obtained in summer 2009 (using a Leica ScanStation from multiple locations). The remaining six scans were surveyed regularly after rainfall events occurred between September and December 2010 (using a HDS2500 from a single location, fix window). Rainfall between each survey was measured by a network of 12 tipping bucket rain gauges. Sediment export was monitored using a pit trap installed at the outlet (V-noch station). Water samples were obtained when runoff was generated using a multiple stage sediment sampler, while air temperature was monitored continuously (Figure 3).

• **DATA PROCESSING:** Point clouds were registered to the same coordinate system (Figure 2B and 2C). Registration errors range between 5 and 10 mm. Data were filtered by intensity to remove vegetation (Figure 4A and 4B). A sub-section (36 m^2) with high data density and fully coverage (*no shading*) was selected for further analysis (Figure 4C).

Point clouds were filtered using TopCat, an open source algorithm designed to analyse large 3D point clouds (Brasington et al., 2012; Rychkov et al., 2012). This unifies point densities to create multi-resolution gridded terrain products and facilitates sub-grid scale statistical analysis. A 50x50 mm DEM (minimum elevation) and the sub-grid roughness (detrended elevation) were calculated.

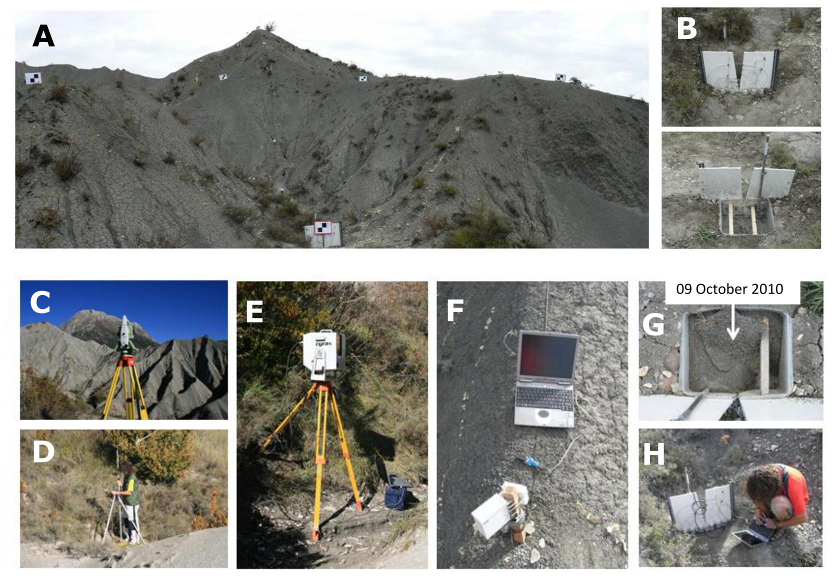


Figure 3. (A) The experimental basin where the location of the rain gauges and the V-noch station **(B)**, where the pit trap and the Trutraclk are installed, can be observed. Data collection: **(C)** the Total Station (TS) set up to survey the control network **(D)** and the B&W targets (between 8-6 targets in each scan); **(E)** the HDS2500 TLS in operation; **(F)** downloading data from one of the rain gauges; **(G)** the pit trap near-full of sediment after a rainfall event; and **(H)** downloading data from the Trutrack to obtain air temperature.

Topographic models between surveys were compared (DEMs of Difference; DoD). To remove uncertain data (i.e. potential errors; not real changes) the open source algorithm DoD3 (Wheaton et al., 2009) was implemented. Uncertainty analyses were based on: (i) point density, (ii) slope and (iii) roughness. These provide a threshold level of detection (LoD) at a 0.95 confidence interval for each DoD; values below the LoD were removed.

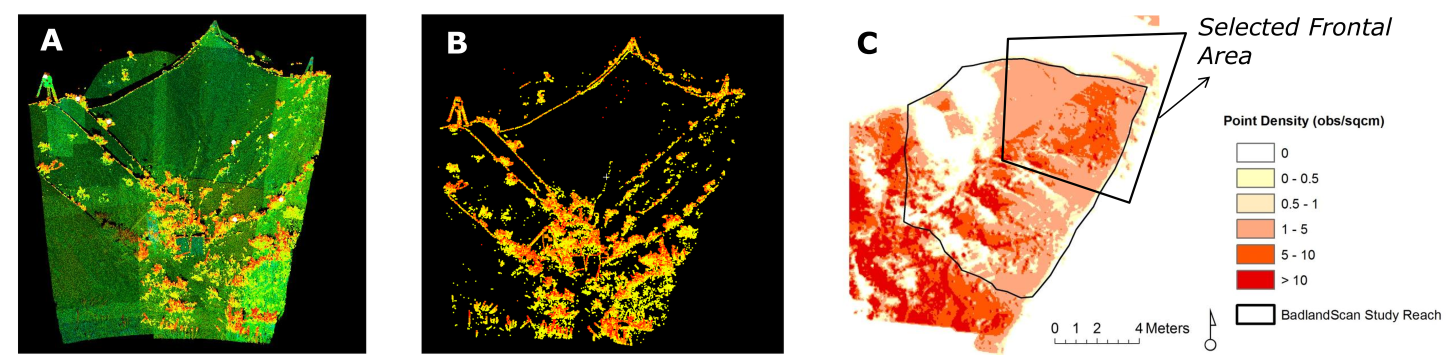


Figure 4. (A) Intensity-rendered point cloud. **(B)** Cloud fragmentation by intensity: removing vegetation and other non-ground elements (e.g. tripods). **(C)** Example of a survey density map (08 October 2009) used to select and area maximizing point density for all surveys and minimizing surface shading in order to perform data analysis.

A single rainfall record was established by averaging the 15-minute data from all gauges (Figure 5). Sediment retained in the trap was weighted and the grain size distribution (pipette method) of the eroded sediments calculated.

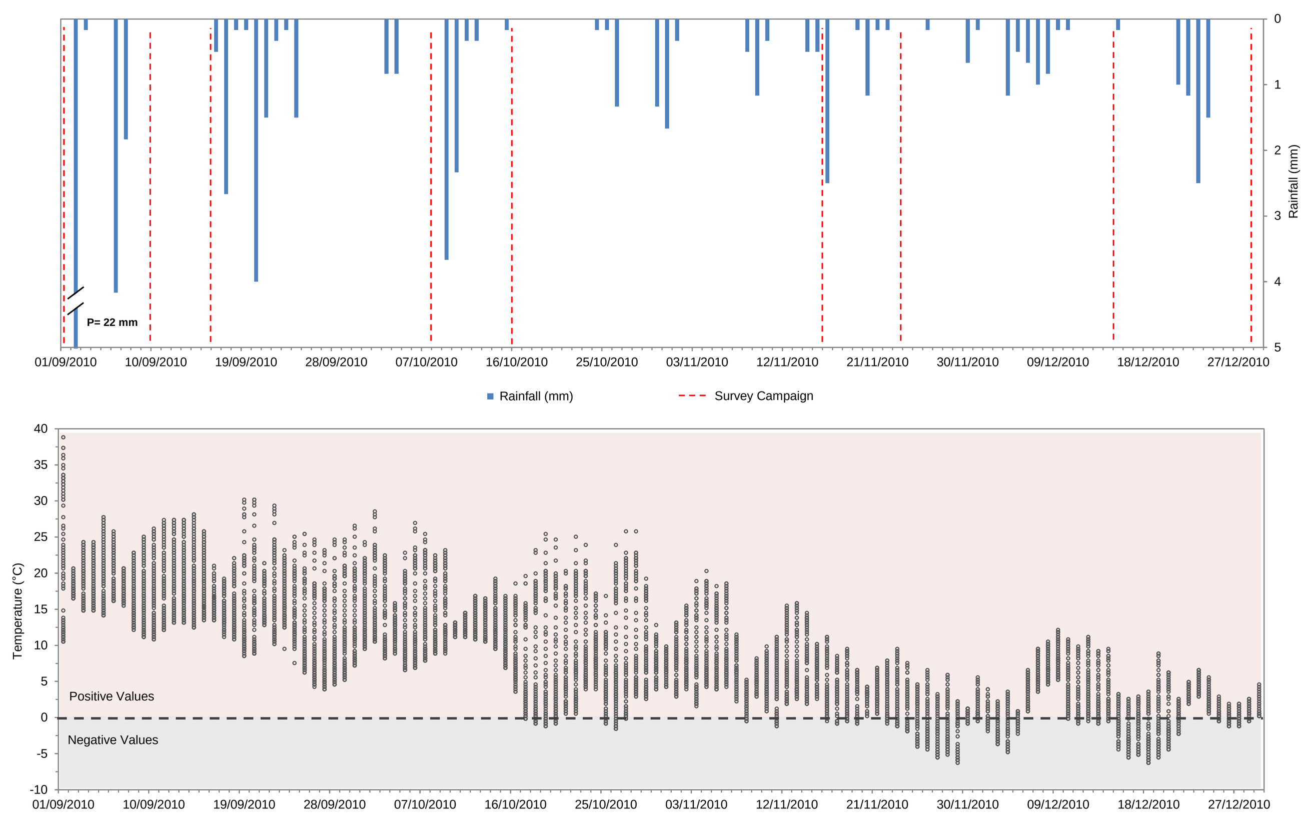


Figure 5. Rainfall and air temperature from September to December 2010 where the event-based data collection was performed. Note that each survey campaign is indicated with the dashed red lines.

3. PRELIMINARY RESULTS AND FUTURE WORK

• The dominant topographic change at large temporal scales (~annual, Figure 6B) is erosion; 70% of the surface experienced erosion (-2.1 m^3). Just a small concave area (2.1 m^2) experienced deposition (0.2 m^3).

• A total of 368 mm of rainfall was recorded between September-December 2010. Suspended sediment concentrations oscillated between 14 and 96 g l^{-1}, while the maximum volume of sediment retained in the trap was of 59 kg (median material D^{50} = 0.0034 mm).

• The distribution of event-based topographic changes move from patchy (Figure 6C) to coherent (Figure 6D, 6E, 6F and 6G). The magnitude of erosion and erosion-dilatation is highly variable (from -0.4 to 0.4 m^3).

• The magnitude of the patchy-distributed topographic changes is higher than that for the coherent distribution. This yields substantially different erosion rates: e.g. the erosion rate in Figure 6C is -4.7 cm, while in 6F is -1.6 cm.

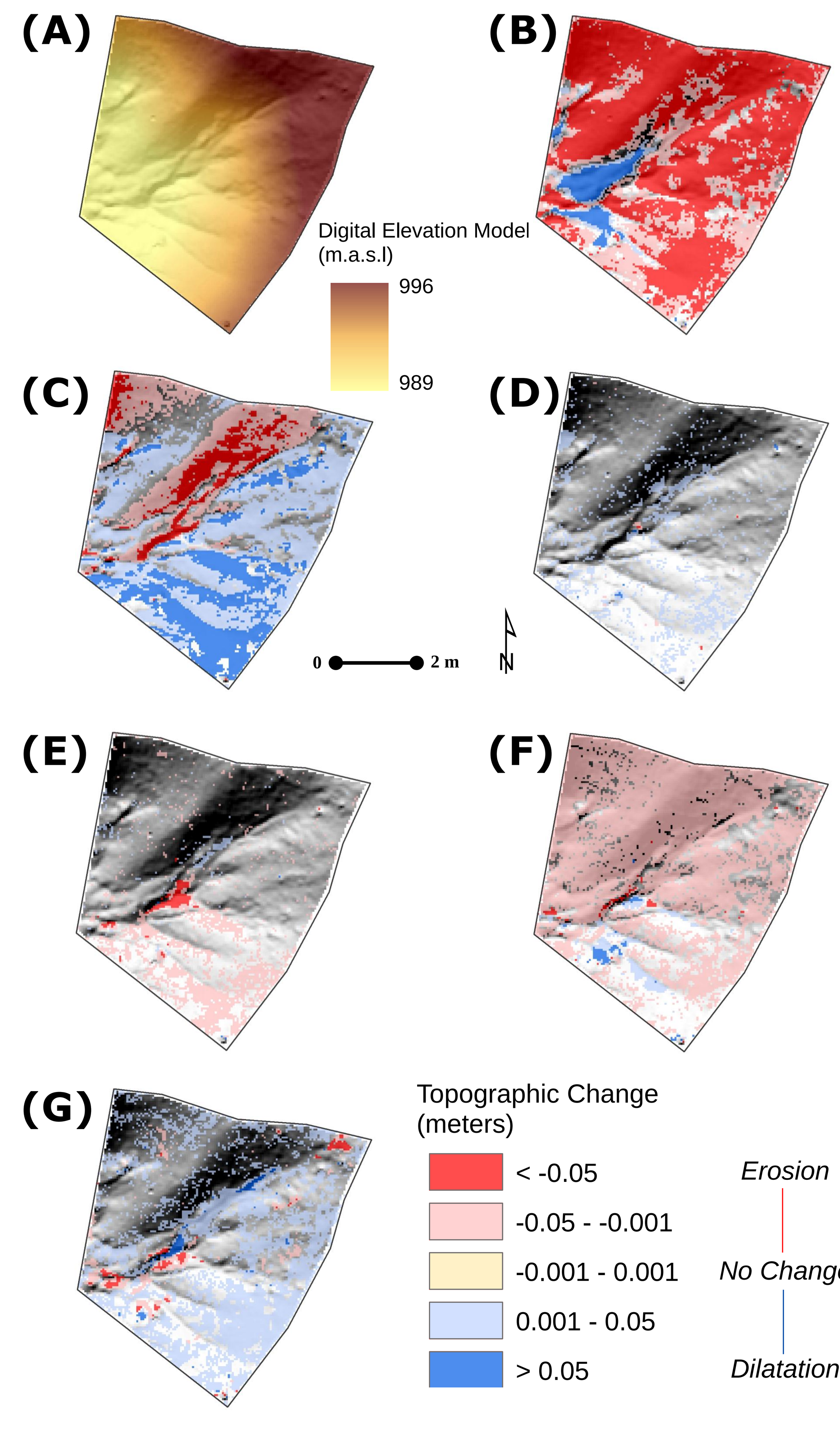


Figure 6. (A) Topographic model of the experimental badland (frontal area selected in Figure 4C). *Thresholded DoDs*: **(B)** 28 August 2009 to 1 September 2010; **(C)** 1 to 16 September 2010; **(D)** 16 September to 8 October 2010; **(E)** 8 to 16 October 2010; **(F)** 16 October to 17 November 2010; and **(G)** 17 November to 29 December 2010.

• Topographic changes observed at the event scale are not just related to rainfall intensity but also to slope, aspect, temperature and antecedent roughness conditions. Clay shrink-swell and thawing may be the processes controlling the dilatation of certain slopes.

• **WHAT'S NEXT?** Numerous questions need to be addressed: (Q1) Can these patterns be the result of gridding the data? (Figure 7). (Q2) Can aspect or the Topographic Wetness Index help in understanding dilatation processes? (Q3) What is the scale dependence of these?

4. FINAL REMARKS

• These results show that TLS data sets provide new opportunities in the study of topographic change in highly erodible landscapes where the use of conventional 'invasive' topographic technologies is limited. TLS-derived morphometric sediment budgets offer distributed estimations of topographic change, permitting evaluation of the main factors controlling erosion processes. This is relevant for predictions of sediment production and, consequently, for landscape evolution modelling.

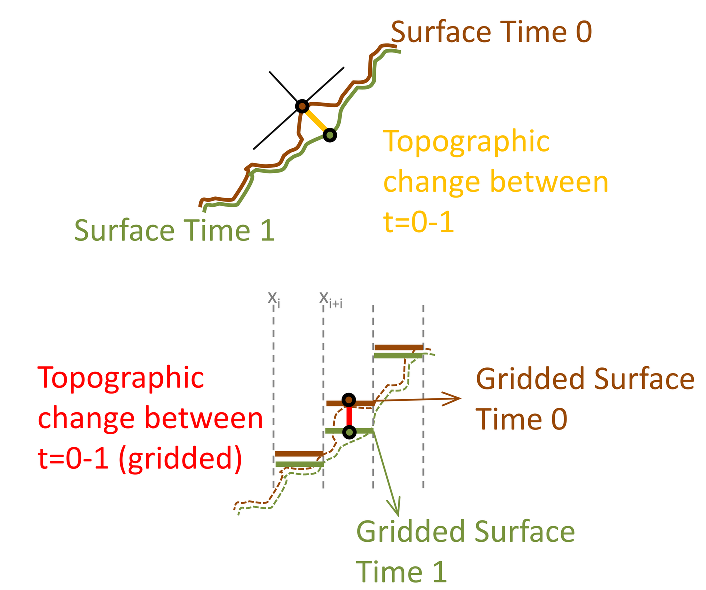


Figure 7. Are gridded changes real in steep slopes? Comparison between a topographic change normal to the ground (top) and a change from two gridded surfaces.

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