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Geomorphic change detection in small Alpine basins using LiDAR DTMs

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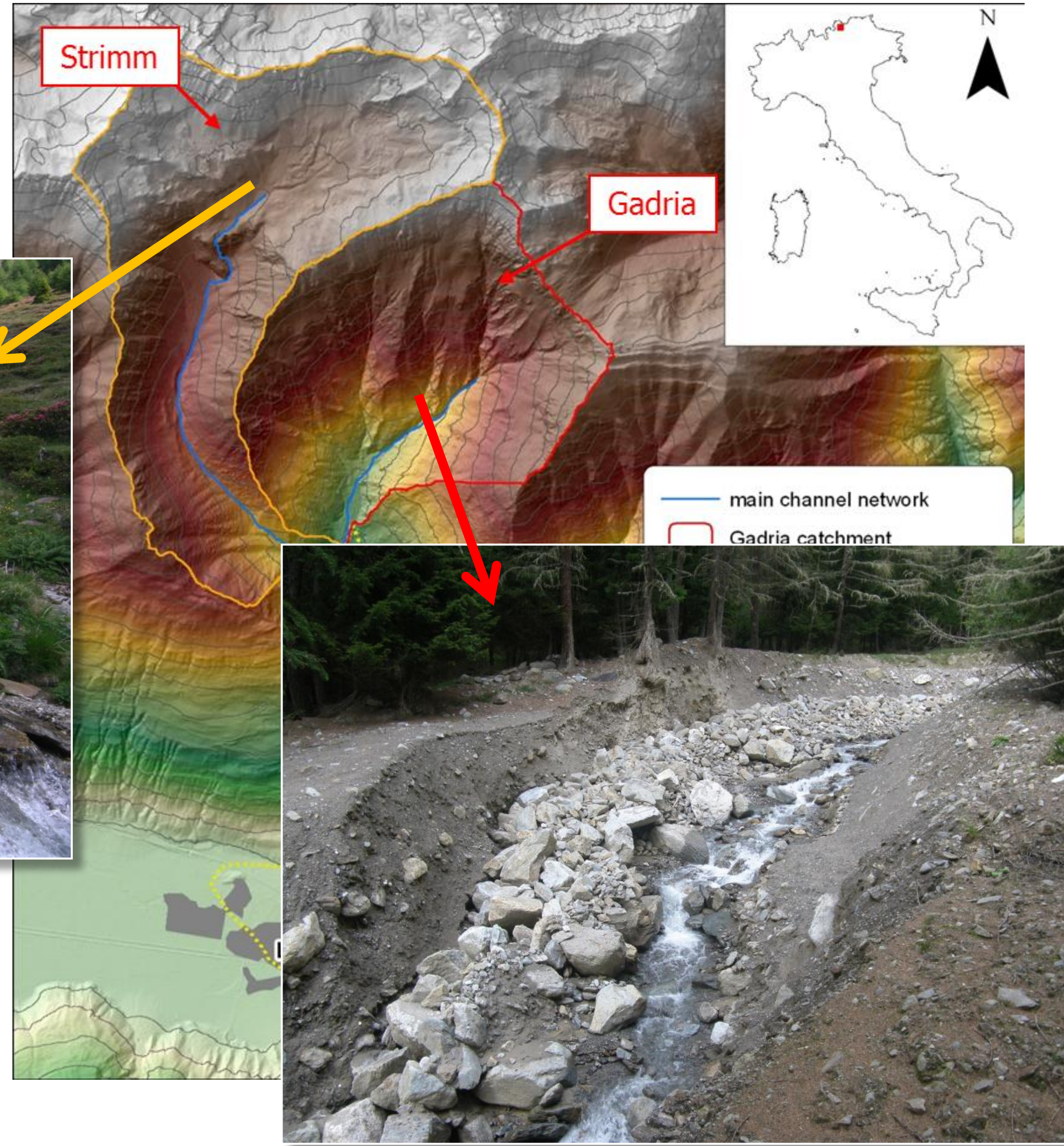
Introduction

- The assessment of geomorphic changes allows to identify unstable areas, to quantify processes intensity, and to estimate volumetric changes through time (i.e. sediment budgets);
- Digital elevation models built from repeated topographic surveys can be used to produce DEM of Difference (DoD) maps;
- LiDAR technology provides Digital Terrain Models at high spatial resolution and over large spatial extents;
- Due to individual DTM quality and uncertainty, geomorphic change detection through DoD is not a straightforward approach.

Study area

Gadria and Strimm catchments

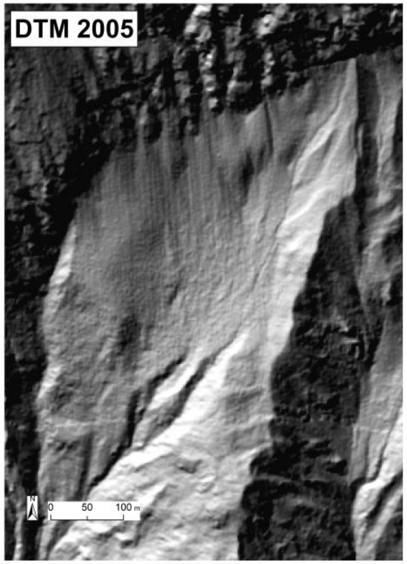
(Eastern Italian Alps)



Strimm: area 8.5 km^2, average slope 61.8%, range in elevation 1394 – 3197 m.

LiDAR data

LiDAR July 2005



- **LiDAR regional survey**
- **Survey sensor:** ALTM 3033 (OPTECH) and Falcon II
  - area < 2000m: 8 pts/25m^2
  - area > 2000m: 3 pts/25m^2
- **Accuracy:** GPS-RTK surveyed ground control points in stable areas

Statistics	2005
Number of points	9
RMSE	0.29

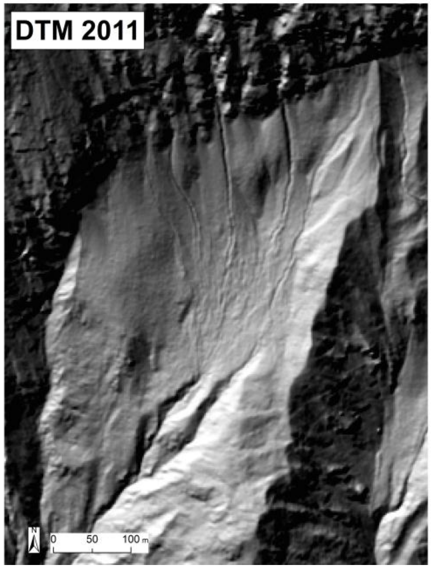
- **Point density**: 0.5 pts/m^2
- **DTM**: 2m

Spatially distributed error in DTMs

- **Survey sensor:** RIEGL LMS Q560. Uniform density acquired: >8 pts/m^2
- **Accuracy:** GPS-RTK surveyed ground control points (in easily accessible areas below 2000 m)

  Point density: 2.32 pts/m^2
- **DTM**: 2m

Statistics	2011
Number of points	22
RMSE	0.16



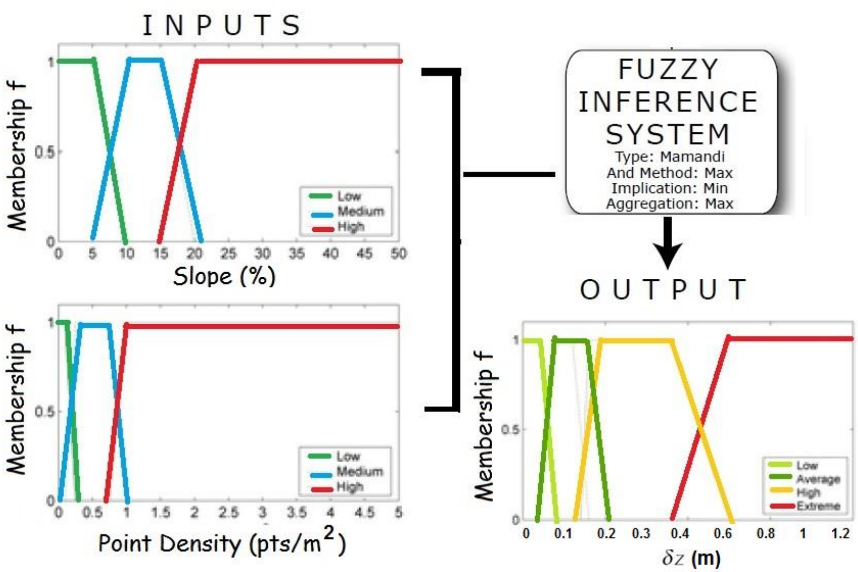
Difference of DTM - 1

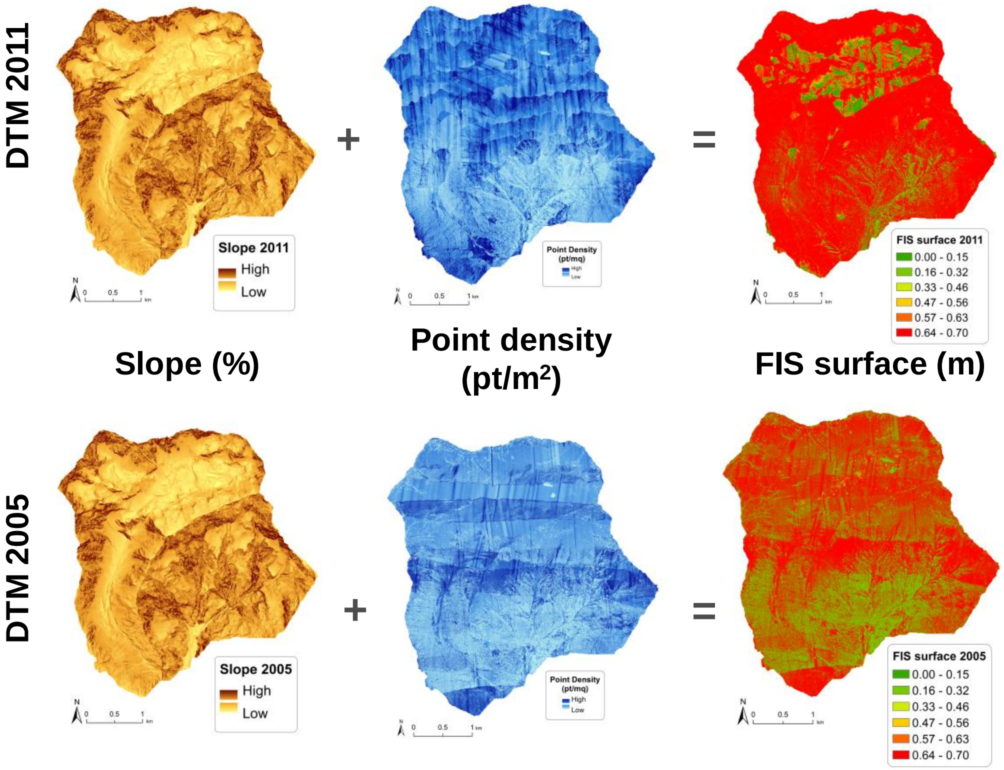
Errors of DTM (survey techniques, surface interpolation methods, morphology representation) are likely to propagate significantly into estimates of sediment budget and confound a clear geomorphic interpretation.

To distinguish real changes from noise in DoDs, a threshold derived from a global measure of surface quality is needed → **fuzzy logic** (Wheaton et al., 2010):

1) **Quantifying uncertainty**: calculation of a spatially variable δz_i in each input DTM using a Fuzzy Inference System (**FIS**) based on:

- Definition of Membership Functions for inputs/outputs;
- Definition of rules relating input to output (es. high point density + low slope = Low Elevation Uncertainty)





Difference of DTM - 2

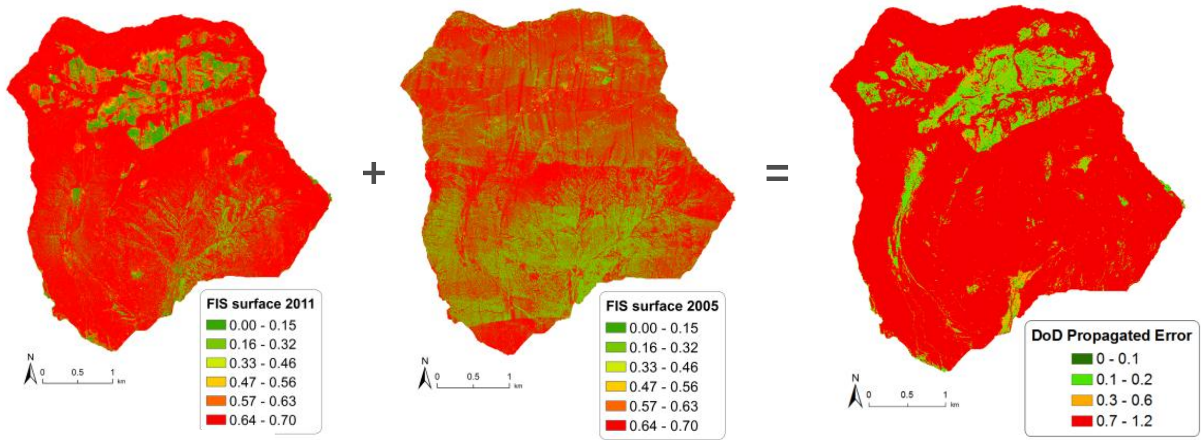
(2) Propagating uncertainty into DoD: propagation of FIS-predicted δz from each DTM into DoD δ(DoD)

$$\delta u_{DoD} = \sqrt{(\delta z_{new})^2 + (\delta z_{old})^2}$$

δz_{old} = Individual error old DTM

δz_{new} = Individual error new DTM

δu_{DoD} = Propagated error into the DoD



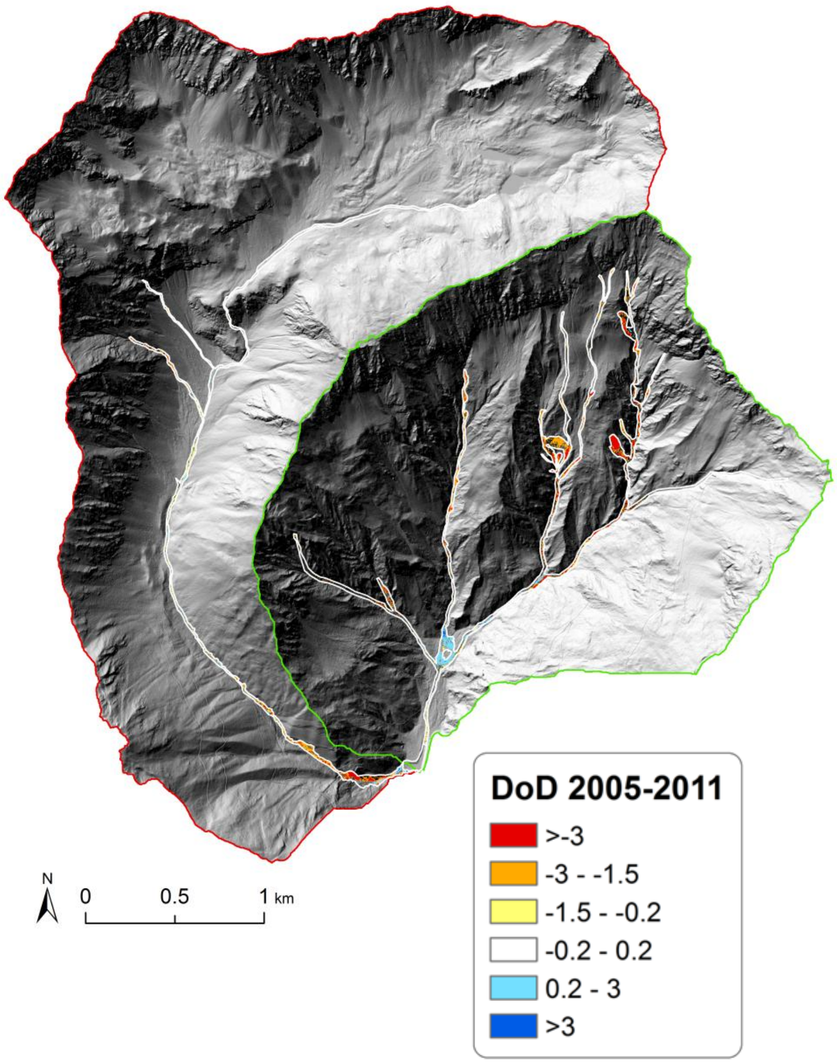
(3) Conversion of $\delta(DoD)$ to a DoD probability raster using a T-test

$$t = \frac{|z_{DEM_{new}} - z_{DEM_{old}}|}{\delta u_{DoD}}$$

Probability of DoD predicted elevation changes is calculated relating t-statistic to its cumulative distribution function

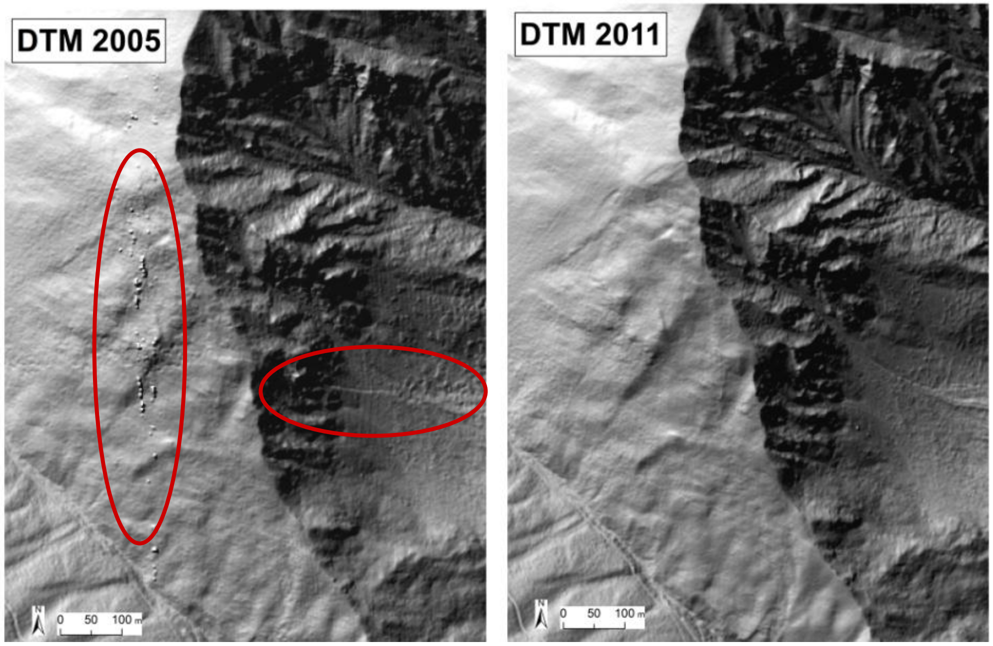
(4) Assessing the significance of DoD uncertainty: applying a confidence interval threshold LoD to DoD (90%)

Results - DoD



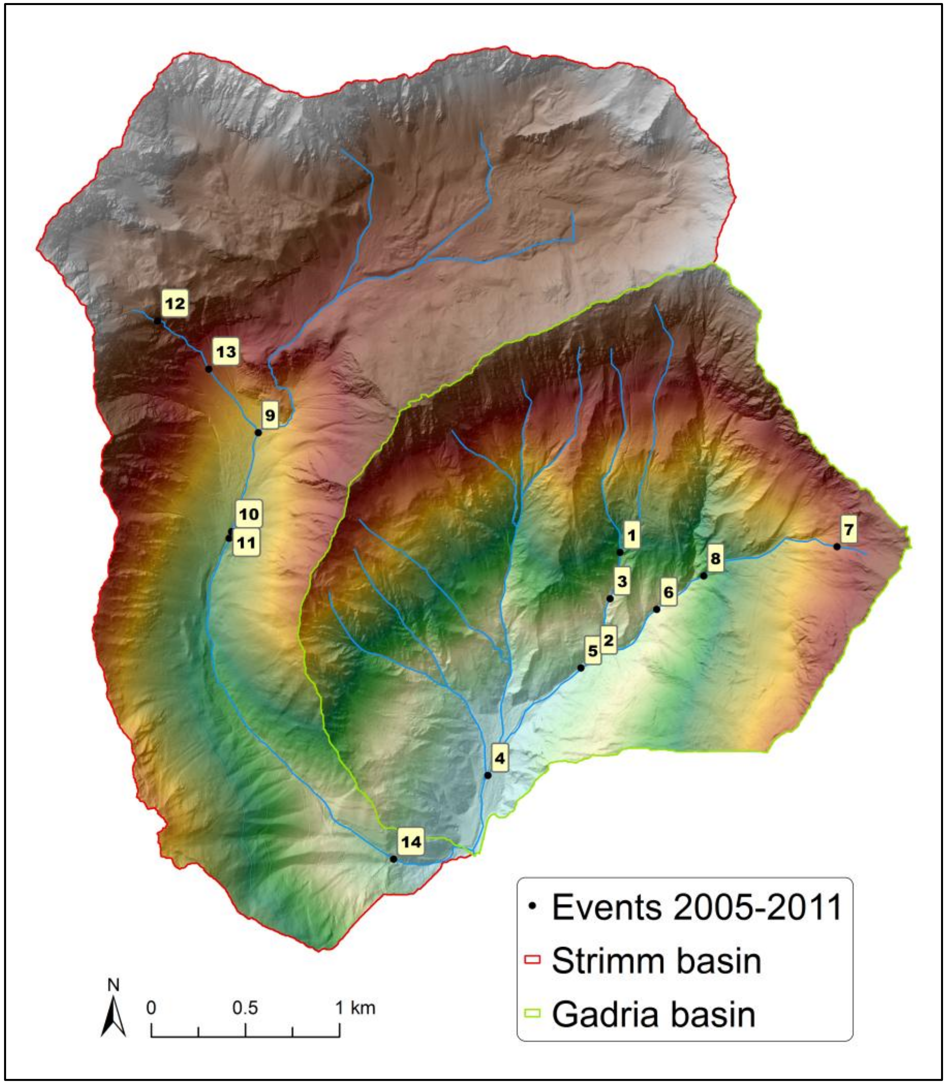
Although based on surface quality, DoD needs a supervised control because of:

1. Different DTM filtering;
2. Co-registration of the different flightlines;
3. Horizontal error moreover in high slope areas.



Starting from the DoD, areas with real variations were selected using hillshade and orthophoto and a spatial mask was created to make zonal statistics on volume distributions.

Historical events (ED30 Data Base)



(ED 30 Autonomous Province of Bolzano)

Gadria

n	Type of event	Date	Volume (m³)
1	Debris flow *	2006	700
2	Debris flow	18/05/2006	10000
3	Debris flow	25/07/2006	35000
4	Debris flow *	10/08/2007	7000
5	Debris flow *	06/08/2008	39000
6	Debris flow	24/07/2009	38200
7	Debris flow **	12/07/2010	21000
8	Debris flow	05/08/2011	3500

Tot erosion	139300
Tot deposition within the catchment	15100

Strimm

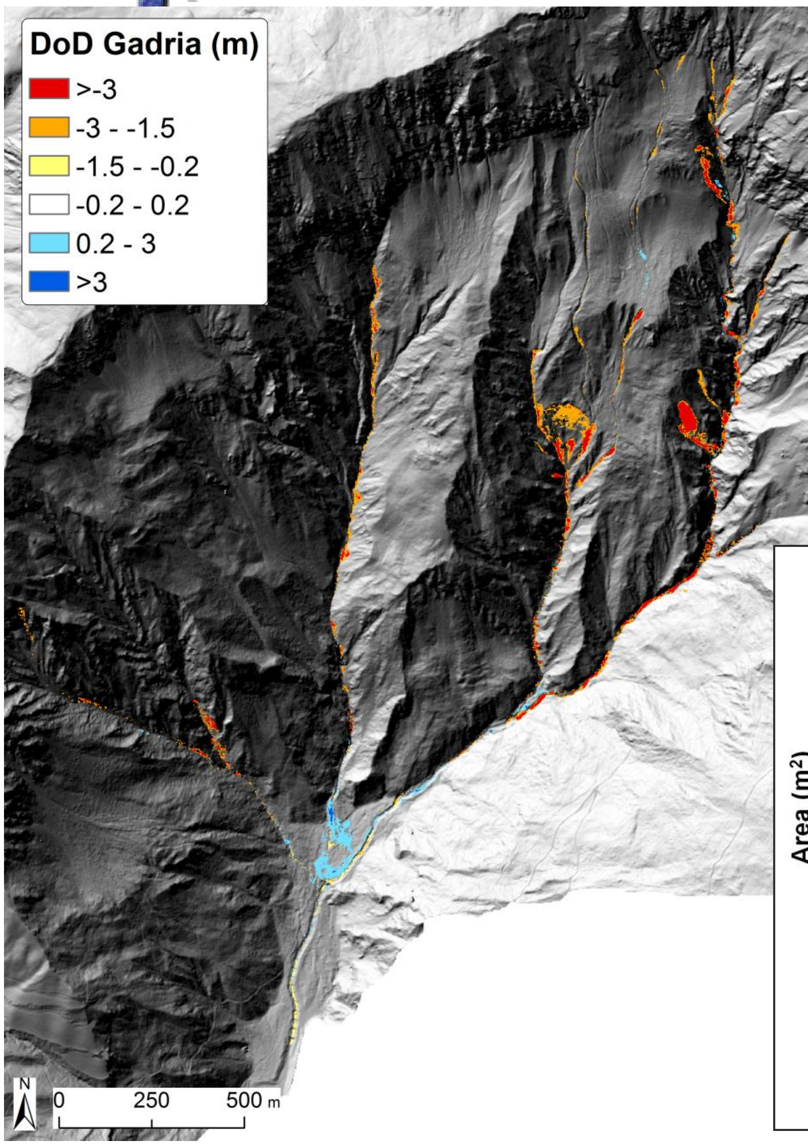
n	Type of event	Date	Volume (m³)
9	Debris flow	06/08/2008	1000
10	Debris flow	24/07/2009	3000
11	Debris flood	13/06/2010	700
12	Debris flow **	12/07/2010	15000
13	Debris flow *	01/10/2010	3500
14	Flood	27/05/2011	2500

Tot erosion	24000
Tot deposition within the catchment	1700

* Uncertain date

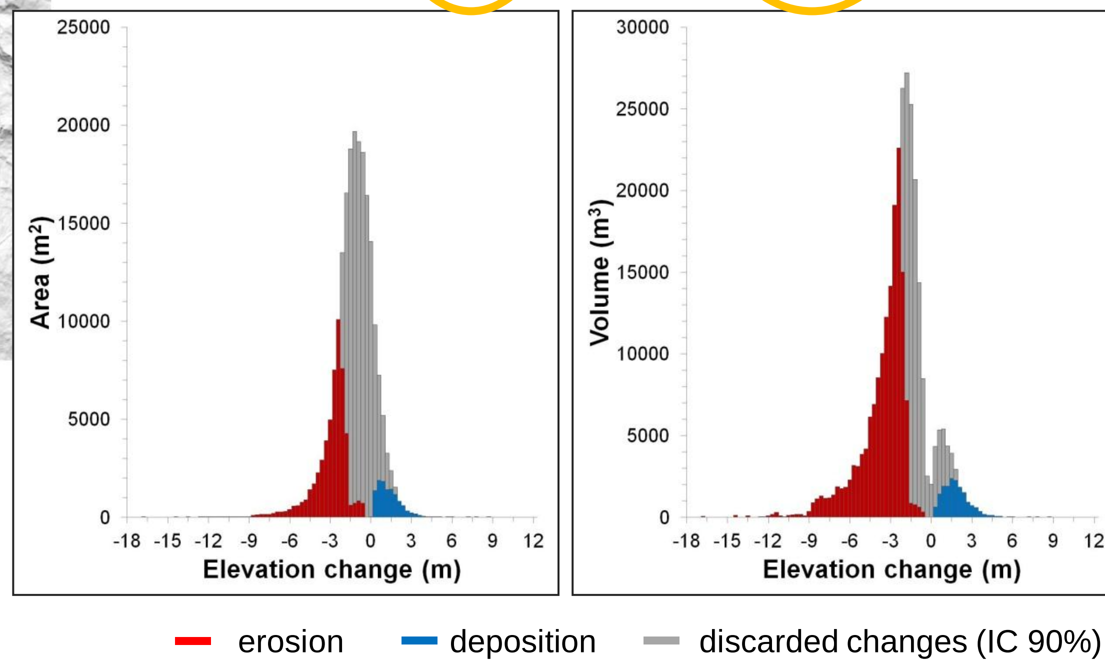
**Difficult estimation of the contributions of two contemporary events (Rio Gadria and Rio Strimm).

Results – DoD vs Historical data Gadria

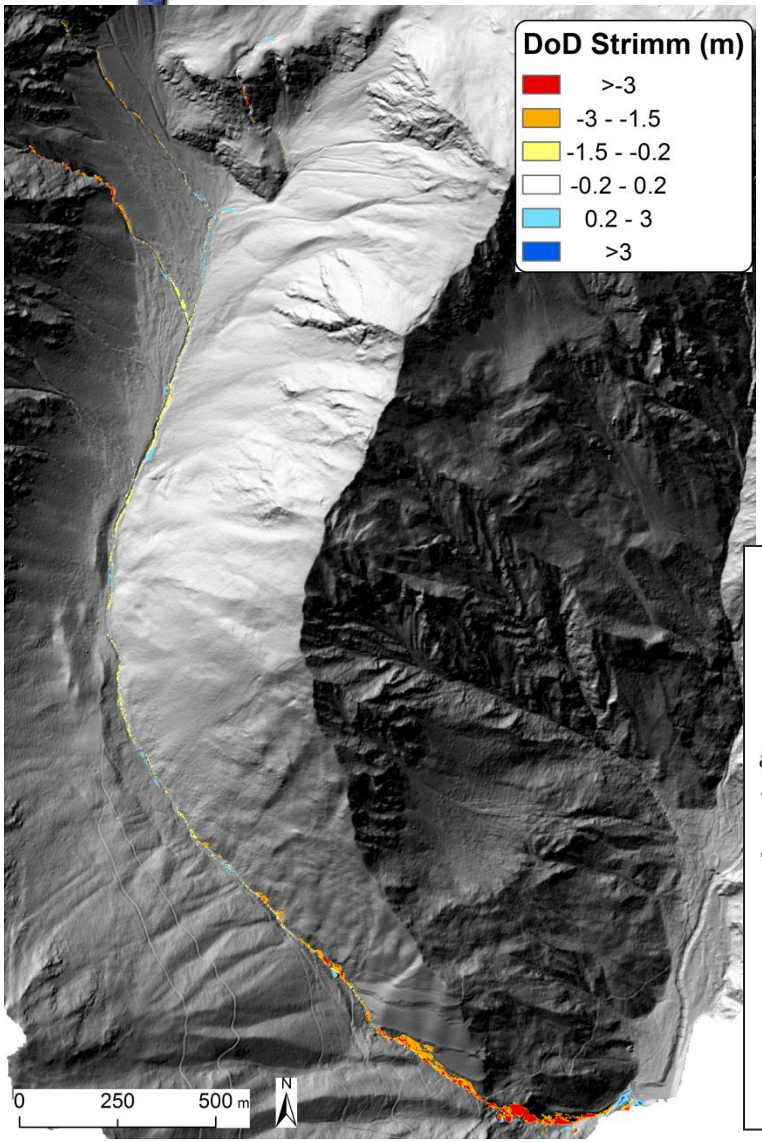


AREA (m²)	Raw DoD	DoD thresholded
Total Area of Erosion	162,768	54,832
Total Area of Deposition	45,932	11,540

VOLUMES (m³)	Events ED30	Raw DoD	DoD thresholded	Error Volume
Total Volume of Erosion	139,300	256,003	155,930	± 58,152
Total Volume of Deposition	15,100	35,037	17,160	± 5,015
Total Net Volume Difference	**-132,100**	**-220,967**	**-138,770**	**± 58,368**

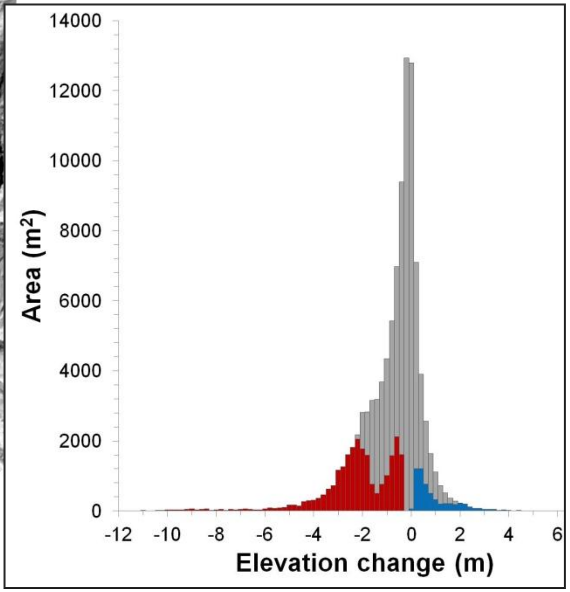


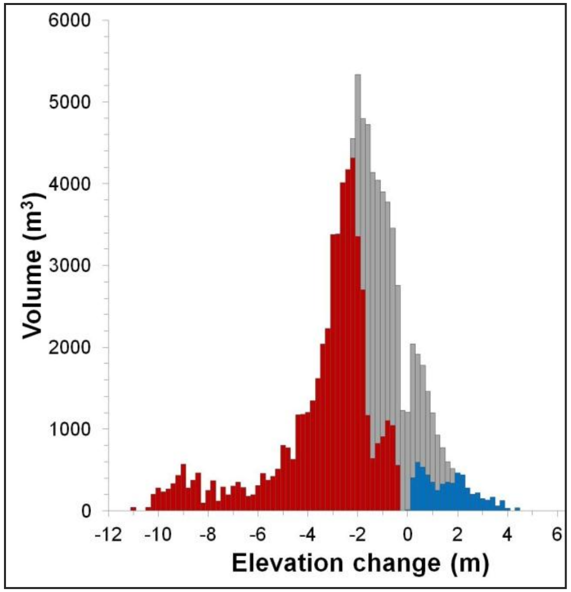
Results – DoD vs Historical data Strimm



AREA (m²)	Raw DoD	DoD thresholded
Total Area of Erosion	67,368	24,240
Total Area of Deposition	31,848	5,752

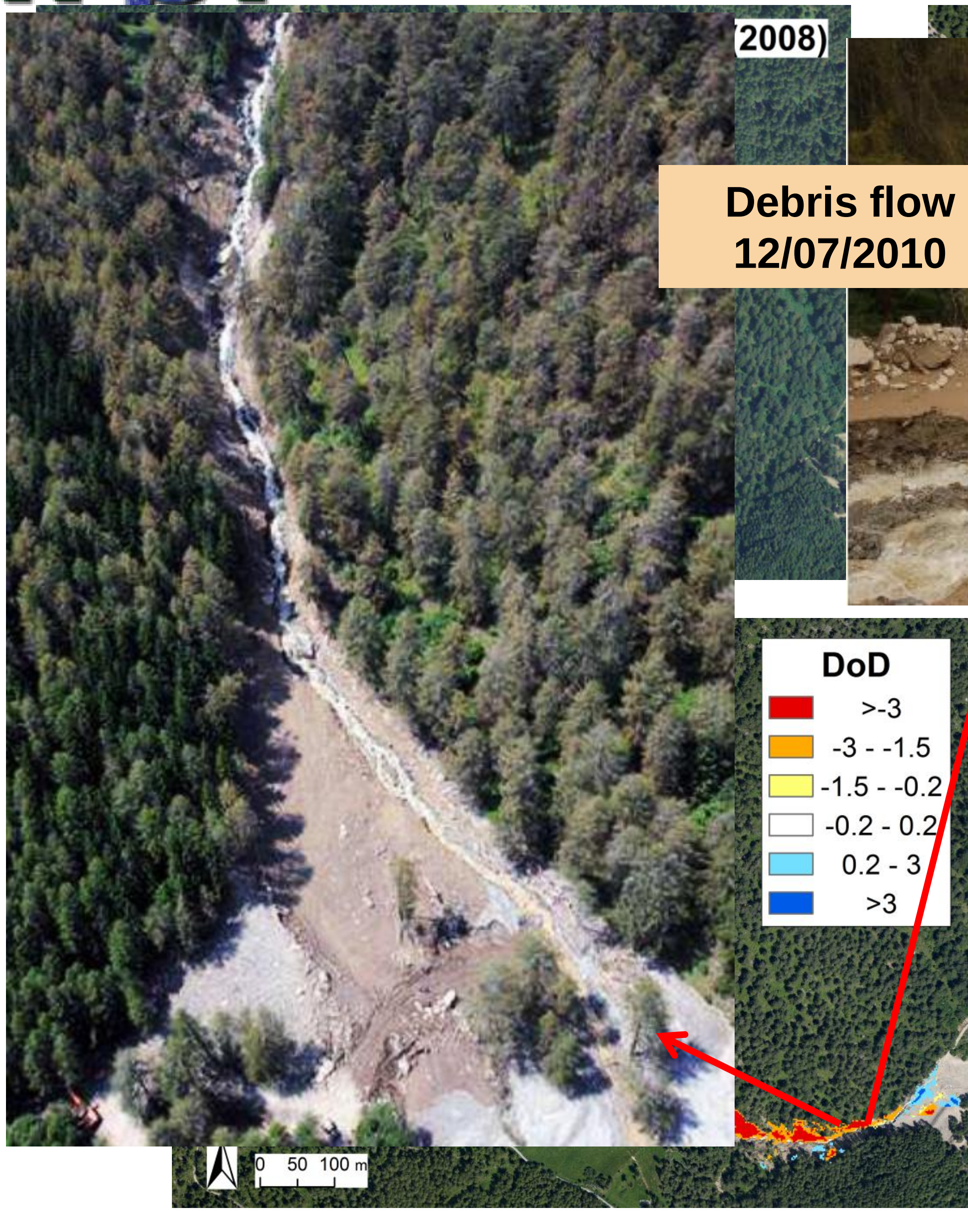
VOLUMES (m³)	Events ED30	Raw DoD	DoD thresholded		Error Volume
Total Volume of Erosion	24,000	78,884	52,805	±	18,589
Total Volume of Deposition	1,700	14,725	5,915	±	2,101
Total Net Volume Difference	**-22,300**	**-64,160**	**-46,890**	±	**18,708**





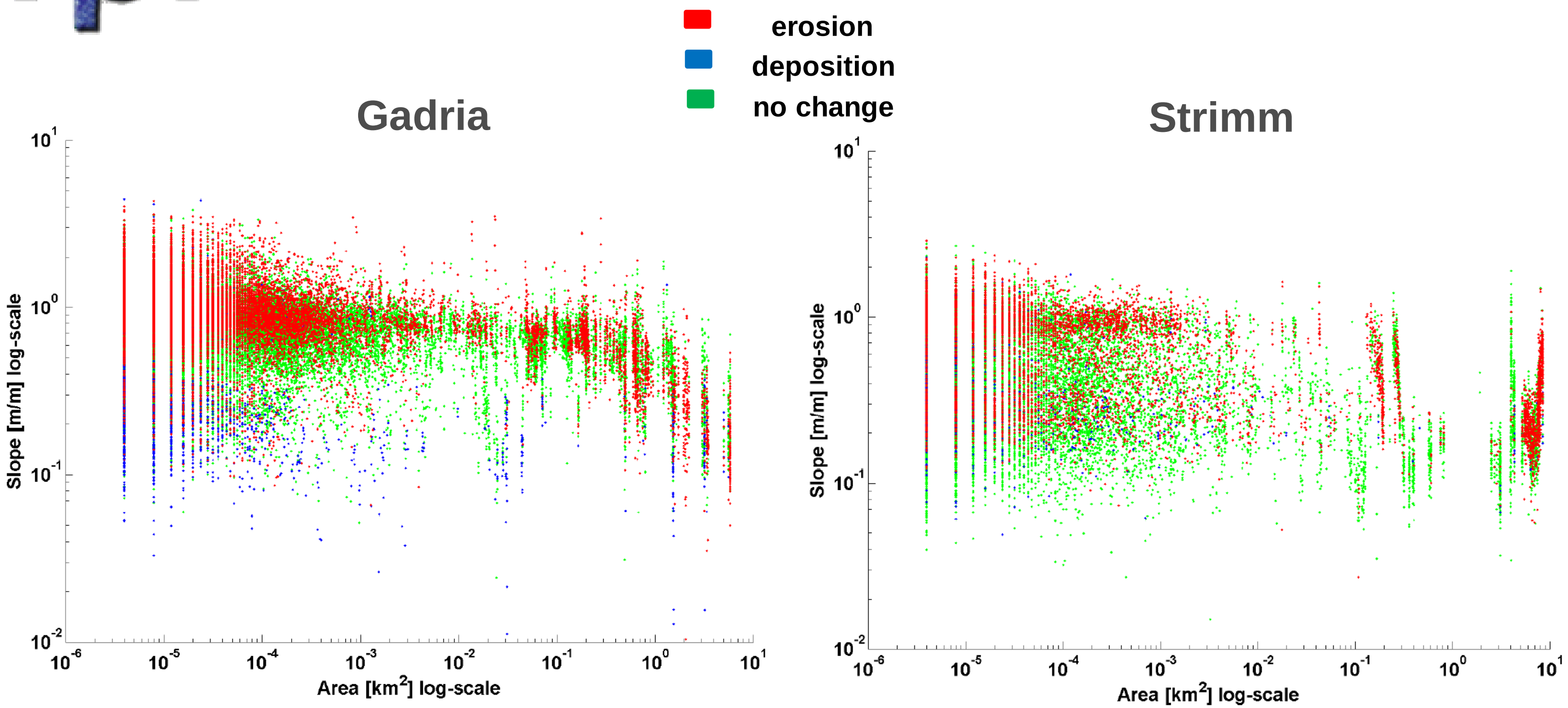
erosion deposition discarded changes (IC 90%)

Results – DoD vs Historical data Strimm



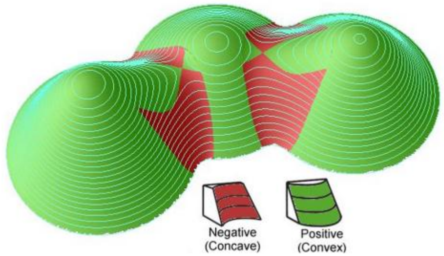
Volumes (m³)	DoD	ED30
Total Volume of Erosion	35,827	-
Total Volume of Deposition	2,778	-
Total Net Volume Difference	-33,048	15,000

Results – DoD vs Slope-Area



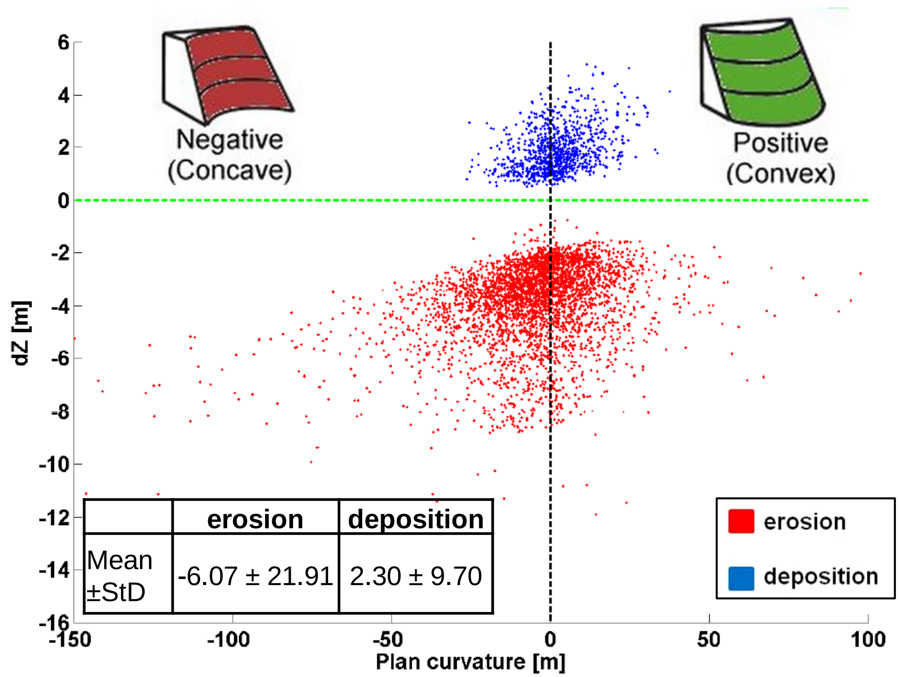
- Different pattern for the basins
- Erosion processes even for higher drainage area values
- In the Strimm, erosion processes at low slope values
- Strong gradient change in the final section of Strimm

Results – DoD vs Plan Curvature



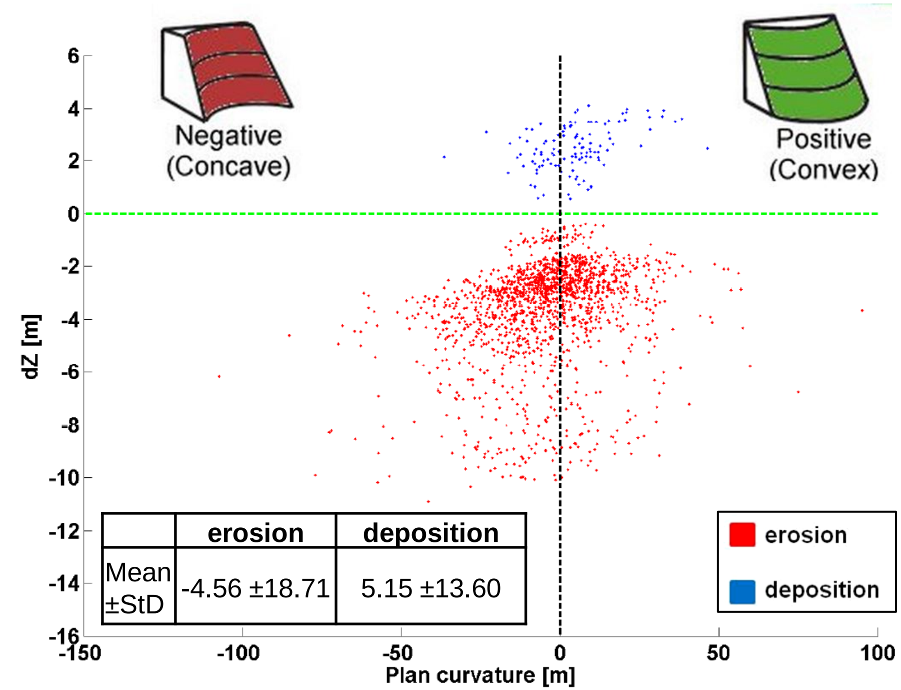
Planform curvature is perpendicular to the direction of the maximum slope.

Gadria



	erosion	deposition
Mean ±StD	-6.07 ± 21.91	2.30 ± 9.70

Strimm



	erosion	deposition
Mean ±StD	-4.56 ±18.71	5.15 ±13.60

- Erosion prevails on negative values (fluvial dominated processes)
- Deposition prevails on positive values (ridges/ hillslope/diffusion processes)
- Erosional processes even in convex area

Concluding remarks

- A spatial distribution error approach is necessary, moreover when using DTMs at different accuracy;
- DoD results are consistent with observed data at basin scale;
- DoD results in higher volumes than field surveys providing useful information on undetected events within the basins and helping in the identification of erosional and depositional processes in uneasily accessible areas;
- Analysis of the relationship between geomorphometric parameters and DoD opens new perspectives for the interpretation of erosional and depositional pattern at the catchment scale.

Questions?

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