THE SEDIMENT YIELD OF HIGH MOUNTAIN ENVIRONMENT WATERSHEDS

DO HIGH FREQUENCY CLIMATE SIGNALS PROPAGATE THROUGH THE SEDIMENT CASCADE?

Natan Micheletti (natan.micheletti@unil.ch), Christophe Lambiel & Stuart N. Lane
Institut of Earth Surface Dynamics, University of Lausanne, Switzerland

UNIL | Université de Lausanne
Faculté des géosciences et de l'environnement
SGmG SSGm Schweizerische Geomorphologische Gesellschaft / Société Suisse de Géomorphologie
AGU FALL MEETING
San Francisco | 14–18 December 2015

1. Motivation: investigate the sensitivity of Alpine landscapes

Possible sensitivity of Alpine landscape to climate change at the decadal scale:

- Vulnerability of permafrost, glacial and nival processes to temperature and precipitation changes.
- Legacy of large amounts of potentially mobile sediment.
- Steep slopes that may sustain sediment mobilization.

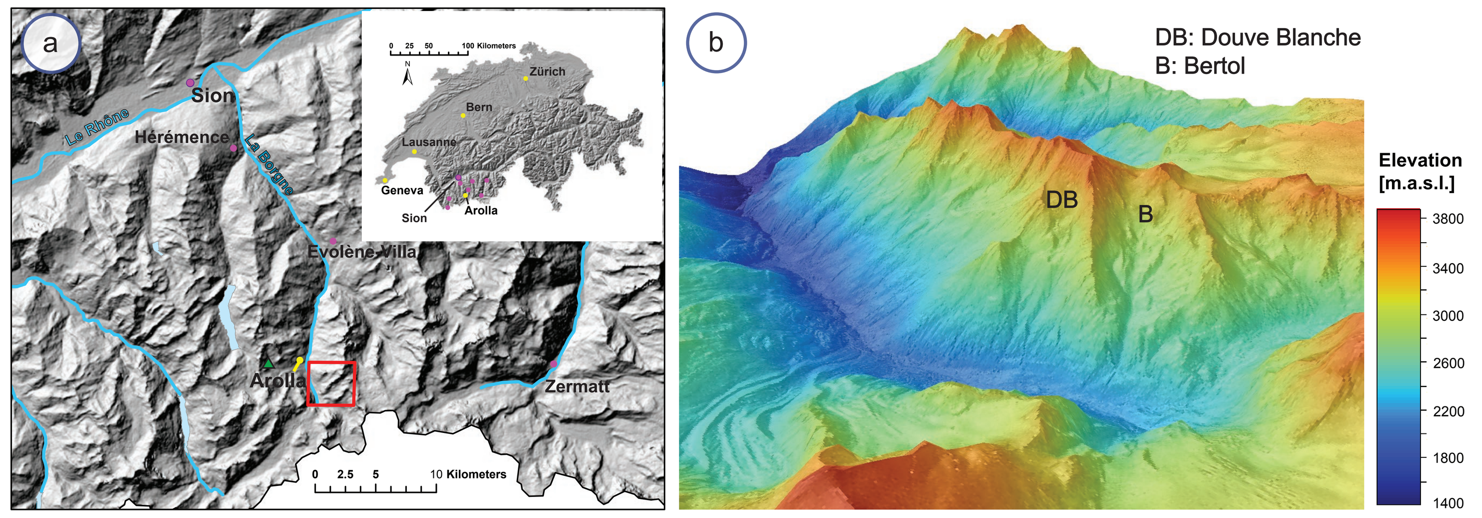
Research goal: examine and evaluate

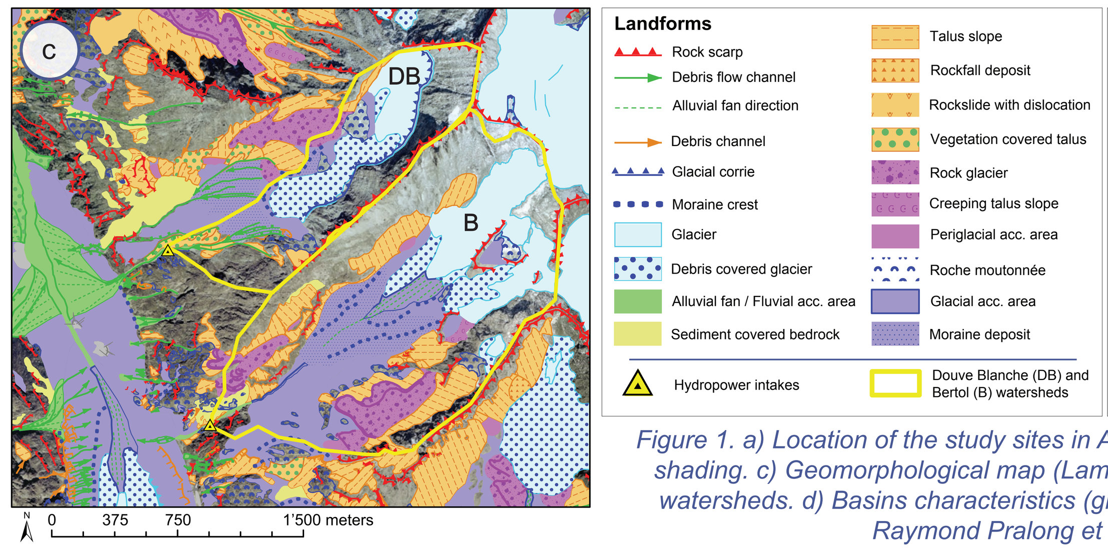
- climate change impacts upon high mountain areas
- their consequences in terms of mass wasting at the landscape scale

However:

1. Climate forcing is manifest over timescales of decades to centuries
   → challenging to observe.
2. The geomorphic response can be complex
   → spatially differential sensitivity, effects of landscape legacy.

Need to couple data from different sources and to unlock the information held in archival aerial photographs and long term flow and sediment records of hydropower intakes.





d	DB	B
Catchment area [km^2]	1.01	2.51
Elevation at intake [m.a.s.l.]	2421	2426
Highest elevation [m.a.s.l.]	3648	3617
Elevation range [m]	1227	1191
Mean annual water yield 1967-2014 [mio of m^3]	1.15	3.04
River slope	0.633	0.302
Median estimated grain size [m]	0.092	0.075
Q.84 estimated grain size [m]	0.319	0.243

Figure 1. a) Location of the study sites in Arolla, Hérens Valley. b) 3D hill shading. c) Geomorphological map (Lambiel et al. 2015), intakes and watersheds. d) Basins characteristics (grain size estimated following Raymond Pralong et al. 2015)

2. Climatic Context

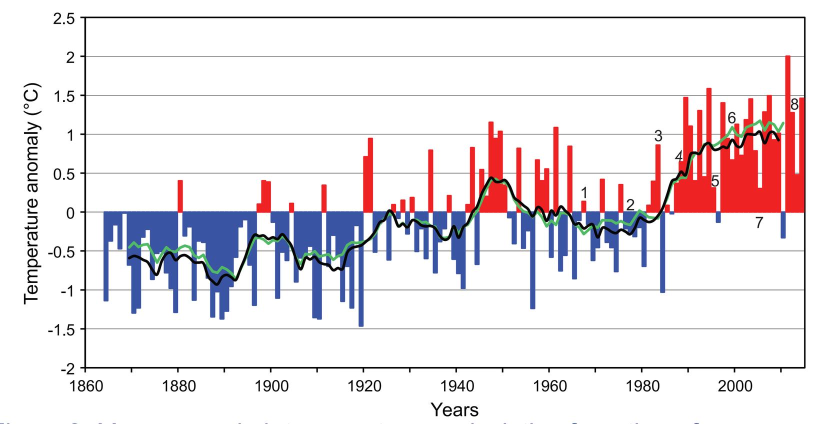


Figure 2. Mean annual air temperature as deviation from the reference mean (1961-1990). Trend lines: 5 year moving average for a site near Arolla and Swiss mean (green). Numbers: dates of available aerial imagery.

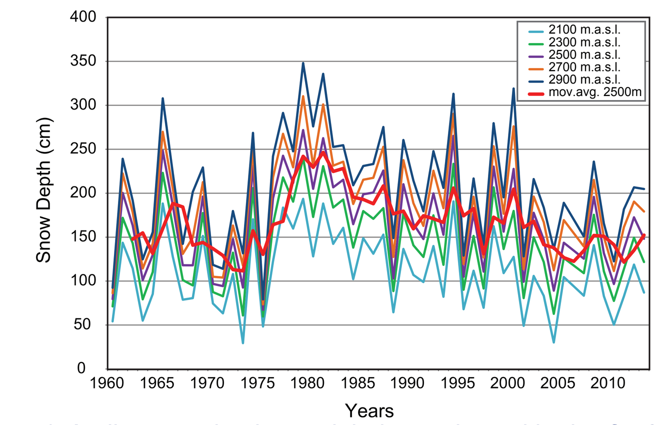


Figure 4. Arolla snow depths modeled at various altitudes for 31th of March using the GSM-SOCONT modeling approach (Schaefli et al. 2005).

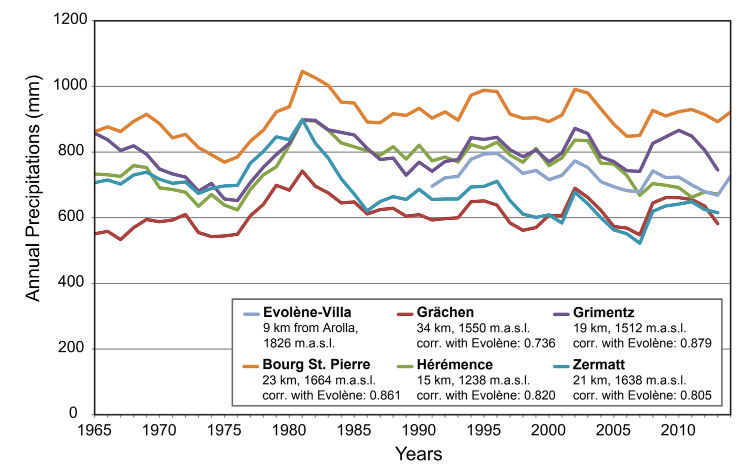


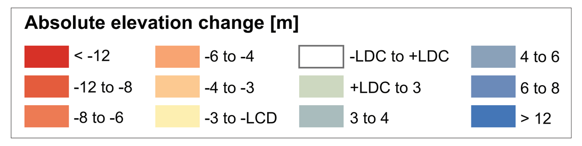
Figure 3. Annual precipitation for meteorological stations located near Arolla (purple dots in Figure 1a, 5 years moving average).

- **Temperature**: distinct cold/stable and warming periods.
- **Precipitation**: considerable increase since the mid-1970s, then relative stability.
- **Snow cover**: higher between the mid-1970s and the mid-1980s
  → coincides with widespread glacial advance in the region (WAV 2013).

Data: Swiss Federal Office of Meteorology and Climatology MeteoSwiss (2014).

3. Archival Photogrammetry

- Archival aerial imagery available from the 1960s (Swisstopo, Flotron AG).
- Photogrammetric restitution as in Micheletti *et al.* (2015a, 2015b)
  → Digital Elevation Models (DEMs) and ortho-photographs
    → Elevation and surface changes, volumetric estimations



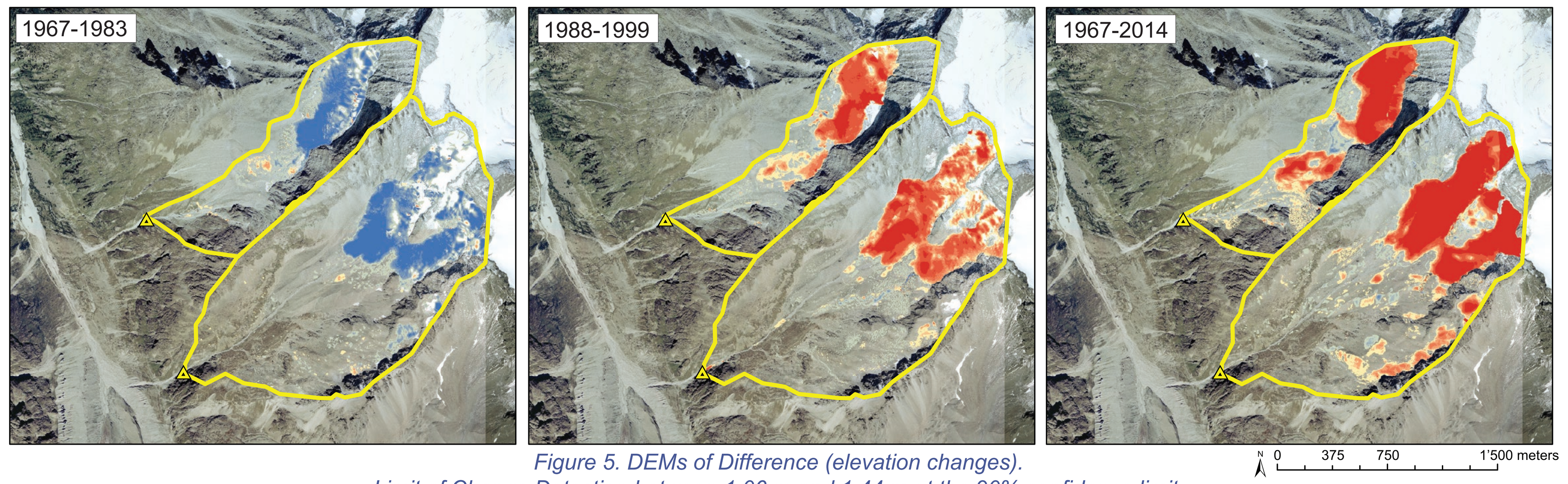


Figure 5. DEMs of Difference (elevation changes). Limit of Change Detection between 1.06 m and 1.44 m at the 90% confidence limit.

- Distinct response to temperature forcing: the periods 1967-1983 and 1983 to 2014 represent climatic conditions either side of a critical threshold for glaciers in the region (see also WAV 2013).

4. Yield at water intakes, climate forcing and geomorphic control

- Water yield record from 15 minutes resolution hydrographs → Typical nivo-glacial regime: peaks in early June (snowmelt) and mid/late July (ice melt).
- Sediment export from intake flushing: purges → $\overline{V}$ of material exported per purge: Douve Blanche: 20 m^3 , Bertol Supérieur: 15 m^3 , with packing uncertainty (Bezinge *et al.* 1989).

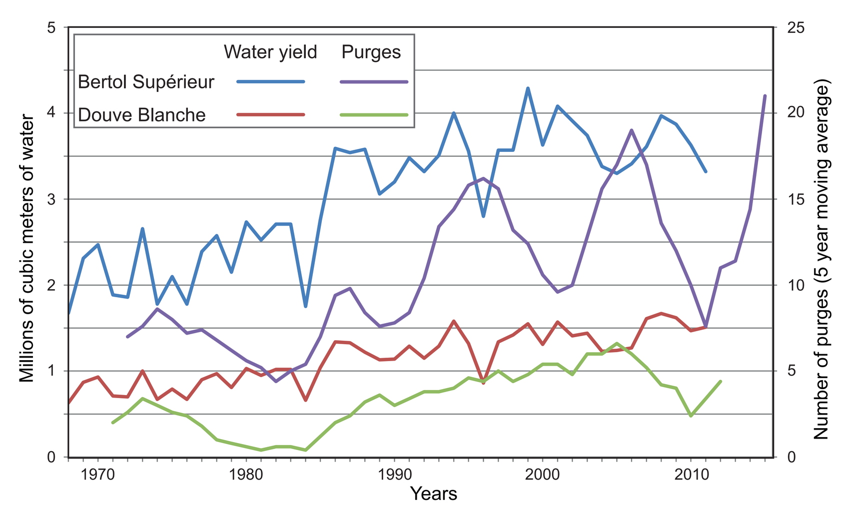


Figure 6. Water yield and number of purges at the Douve Blanche and Bertol intakes

- Water budget: annual water yield ↑
  Cause: temperature ↑ (r = 0.73, r = 0.75)
  → ice melt (DB: 1.10 , B: 1.30 $m^3m^{-2}yr^{-1}$)
  → snow line ↑ , hence snowpack fully melted at the end of hydrological year, so more efficient glacier melt.
- Frequency of purges ↑: assumptions:
  1) Annual water yield ↑ , hence sediment transport capacity ↑
  2) Acceleration of landscape dynamics, hence sediment supply ↑

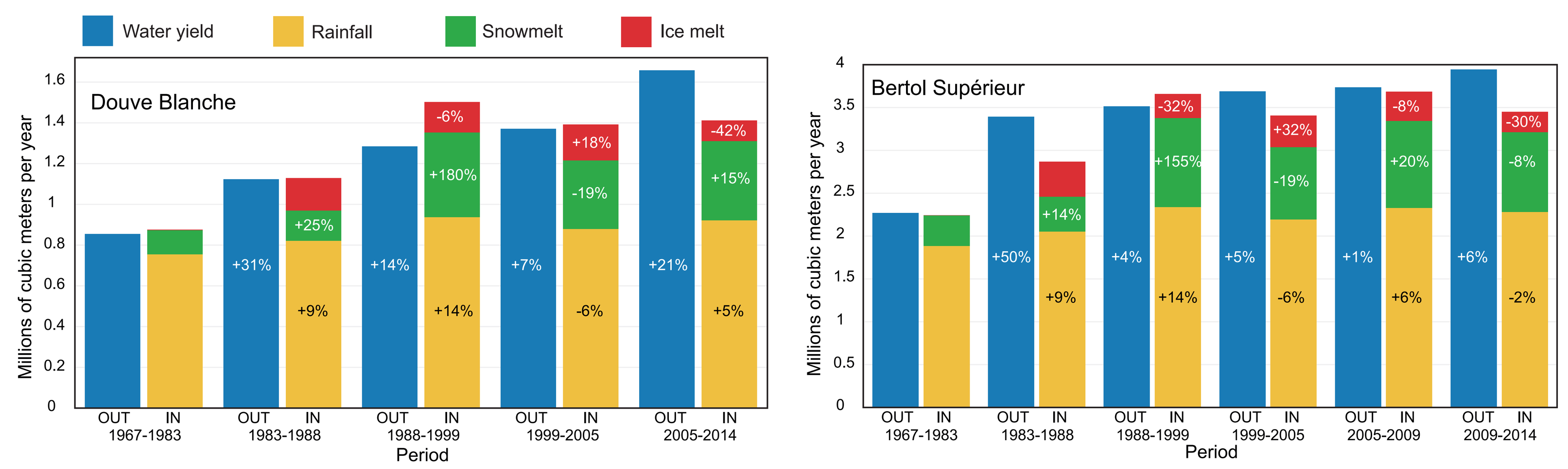


Figure 7. Water budget per period of available archival imagery. The % indicate the change over the previous period. Water equivalent of ice melt and snowmelt is estimated following Huss (2013).

- Modelled sediment transport capacity shows a relation with sediment export in the Douve Blanche basin, but not for Bertol.
- For both, impeded sediment delivery caused by topographic complexity and surface roughness: ineffectiveness of rockwalls-hillslope-channel-outlet connectivity, notably in Bertol.

Key point: high frequency climate signals may propagate weakly through the sediment cascade of high mountain valley systems.

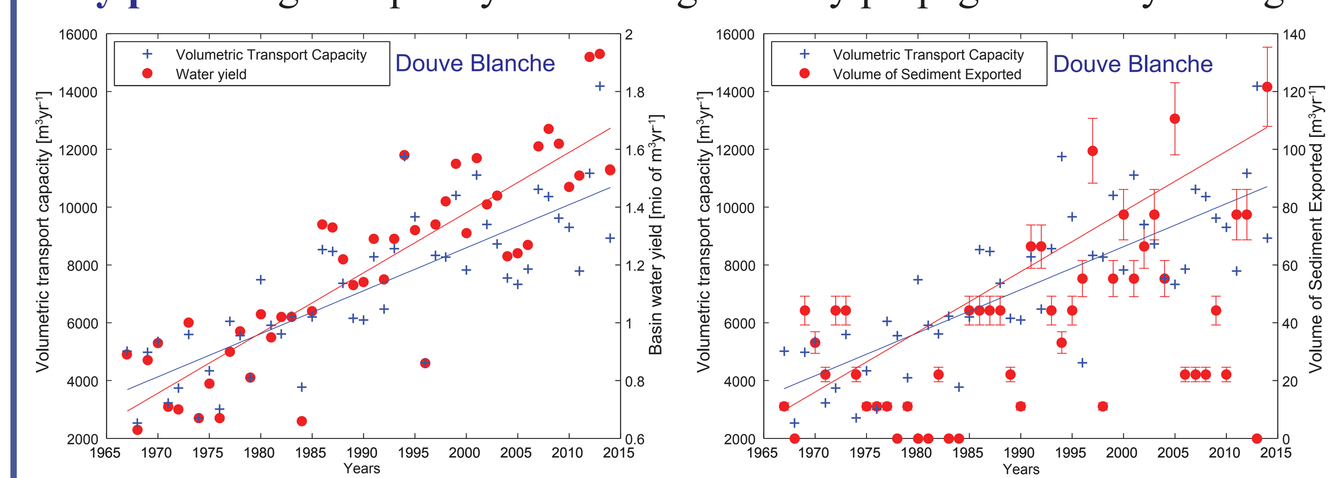


Figure 8. Modelled sediment transport capacity following Nitsche et al. (2011) and its relation with basin water yield (left) and volume of exported sediment (right) for the Douve Blanche watershed

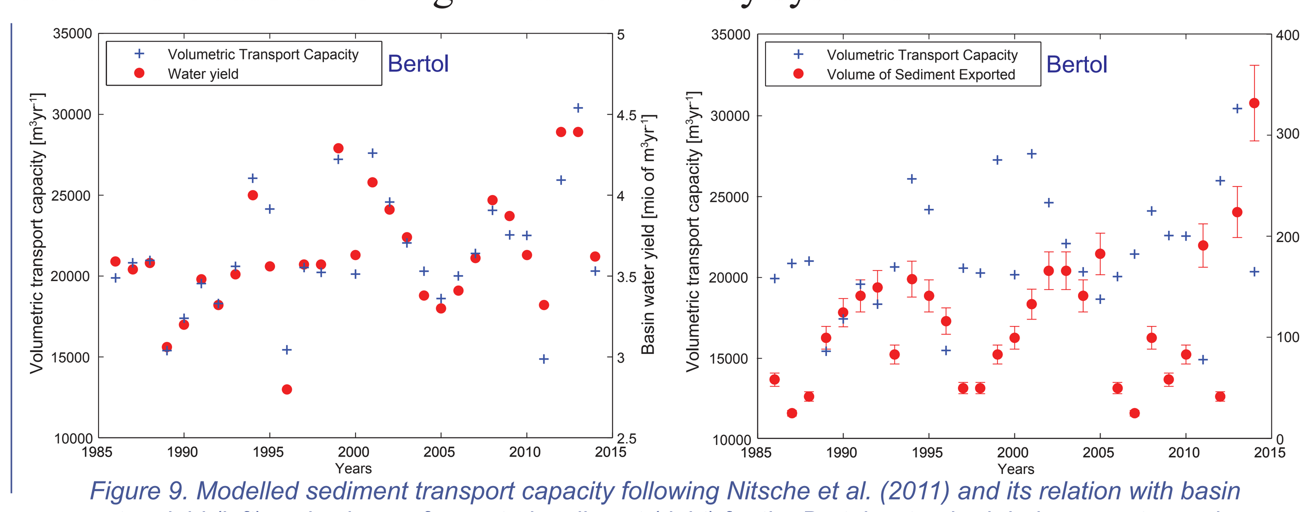


Figure 9. Modelled sediment transport capacity following Nitsche et al. (2011) and its relation with basin water yield (left) and volume of exported sediment (right) for the Bertol watershed during recent warming

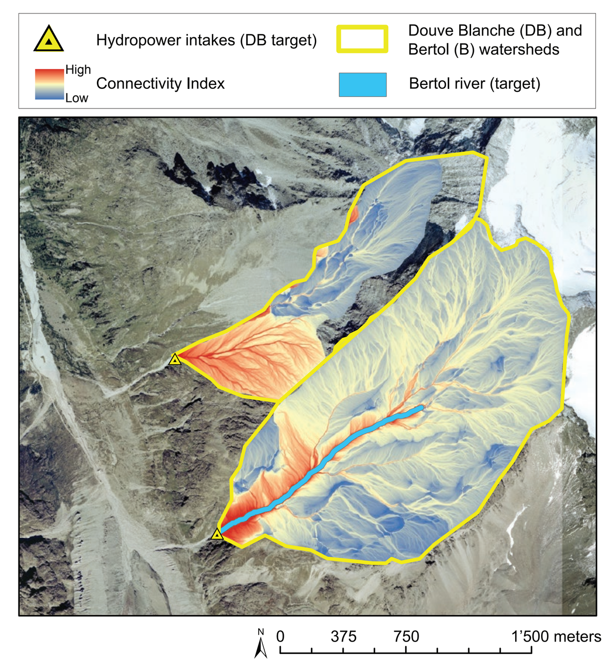


Figure 10. Connectivity Index computed following Cavalli et al. (2013)

5. Summary

Evidence of landscape response to climate forcing → Glacier retreat and snowmelt cause water yield increase

Evidence of landscape response to climate forcing → Enhanced landscape dynamics → Frequency of sediment flushing increase

Glacier retreat and snowmelt cause water yield increase → Enhanced sediment transport capacity → Frequency of sediment flushing increase

but... → Sediment flux is occasionally damped → Key role of connectivity and surface roughness

Climate forcing signal is only partially manifest at outlets

References

- **Micheletti N, Lambiel C, Lane SN (2015b), J. Geophys. Res: Earth Surf.**
- **Micheletti N, Lane SN, Chandler JH (2015a), Photogramm. Rec.**
- Bezinge A et al. (1989), Ann. Glaciol.
- Cavalli M et al. (2013), Geomorphology
- Huss M (2013), Cryosphere
- Lambiel C et al. (2015), J Maps
- Nitsche M et al. (2011), Water Resour. Res.
- Raymond Pralong et al. (2015), Earth Surf. Proc. Landf.
- Schaefli B et al. (2005), Hydrol. Earth Syst. Sci.
- WAV (2013), ETH Zürich
- Background photos: Swisstopo (2005)

Acknowledgements

- **Swiss Geomorphological Society,** for their generous support for the 2015 AGU Fall Meeting participation
- Grand Dixence SA
- Hydroexploitation SA
- Herbette Foundation
- Canton Vaud & Valais
- Jim Chandler
- All collegues that helped us