Multidecadal changes of structural sediment connectivity in alpine catchments

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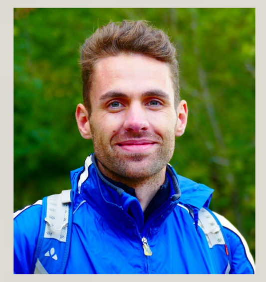

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SEHAG – Sensitivity of high Alpine geosystems to climate change since 1850

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AUTONOME PROVINZ BOZEN SÜDTIROL – PROVINCIA AUTONOMA DI BOLZANO ALTO ADIGE

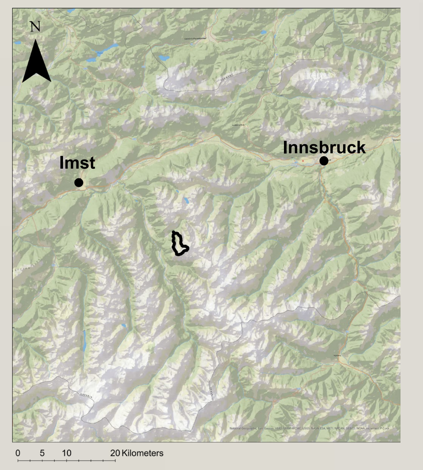
Katholische Universität Eichstätt-Ingolstadt

1. Introduction

- In the SEHAG project we investigate the sensitivity of high-alpine geosystems against climate change.
- Structural sediment connectivity focuses on the spatial arrangement and interconnectivity of landscape elements that facilitate or impede sediment transfer. Connectivity is hence an important factor regulating the propagation of change.
- In this study, we (1) show how digital elevation models (DEMs) and geomorphological maps can be used to create network representations of sediment cascades, generating information on structural connectivity. (2) use historical DEMs and multitemporal geomorphological maps to investigate changes of structural connectivity on the temporal scale of decades.

2. Study area

- Our study area, the Grastal (7.2 km²) is a subcatchment of the Horlachtal (55 km²) and located in the Stubaier Alps, Tyrol.
- Elevation ranges from 1772 m to 3339 m a.s.l.
- Mean annual measured precipitation: 807 mm (Horlachalm).
- Glaciation: 0.7 km² / 9.8 % (1953) to 0.47 km² / 6.5 % (2022)
- The catchment shows a high debris flow activity.
- A major hydrogeomorphic event occurred in july 2022 (prior to our ALS survey).



Location of the study area in the Stubaier Alps.

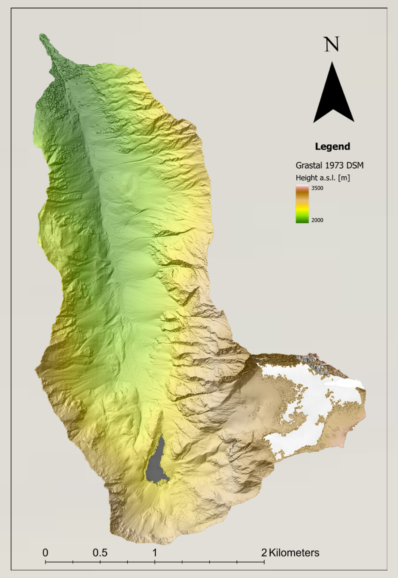
3. Input data

Multi-temporal digital elevation models and orthomosaics (1953 – 2022)

Orthomosaic of the Grastal from 1953.

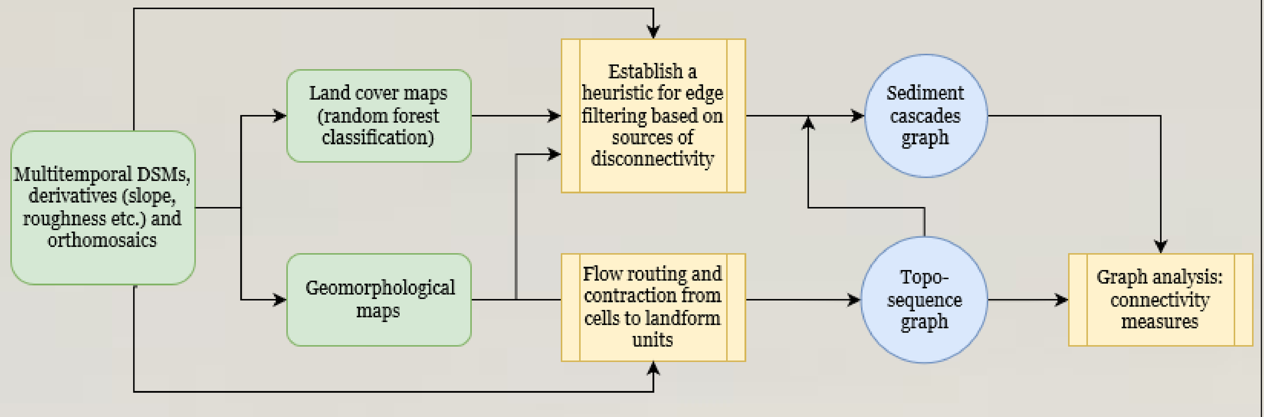
Year	DEM	Orthomosaic
1953	SfM	SfM
1973	SfM	SfM
2022	ALS	UAV + Helicopter Photographs/ Ortho 2020

Historical aerial photographs were processed using SfM-MVS to create DSMs and orthomosaics. More recent datasets were gathered using ALS and UAV-surveys.



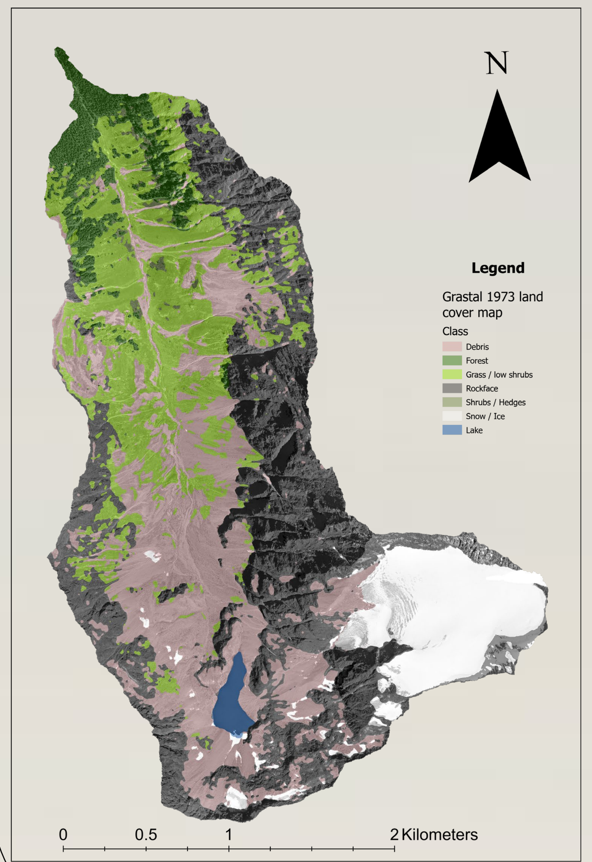
Digital surface model with hillshading of the Grastal 1973.

4. General Workflow



- To derive the initial toposequence graph, an edge list was created using a multiple flow direction algorithm on the basis of raster cells[1].
- In a subsequent step, the cell vertices are contracted to landform unit vertices.
- Additional attributes like predominant land cover can be attached to the vertices or edges.

5. Land cover maps

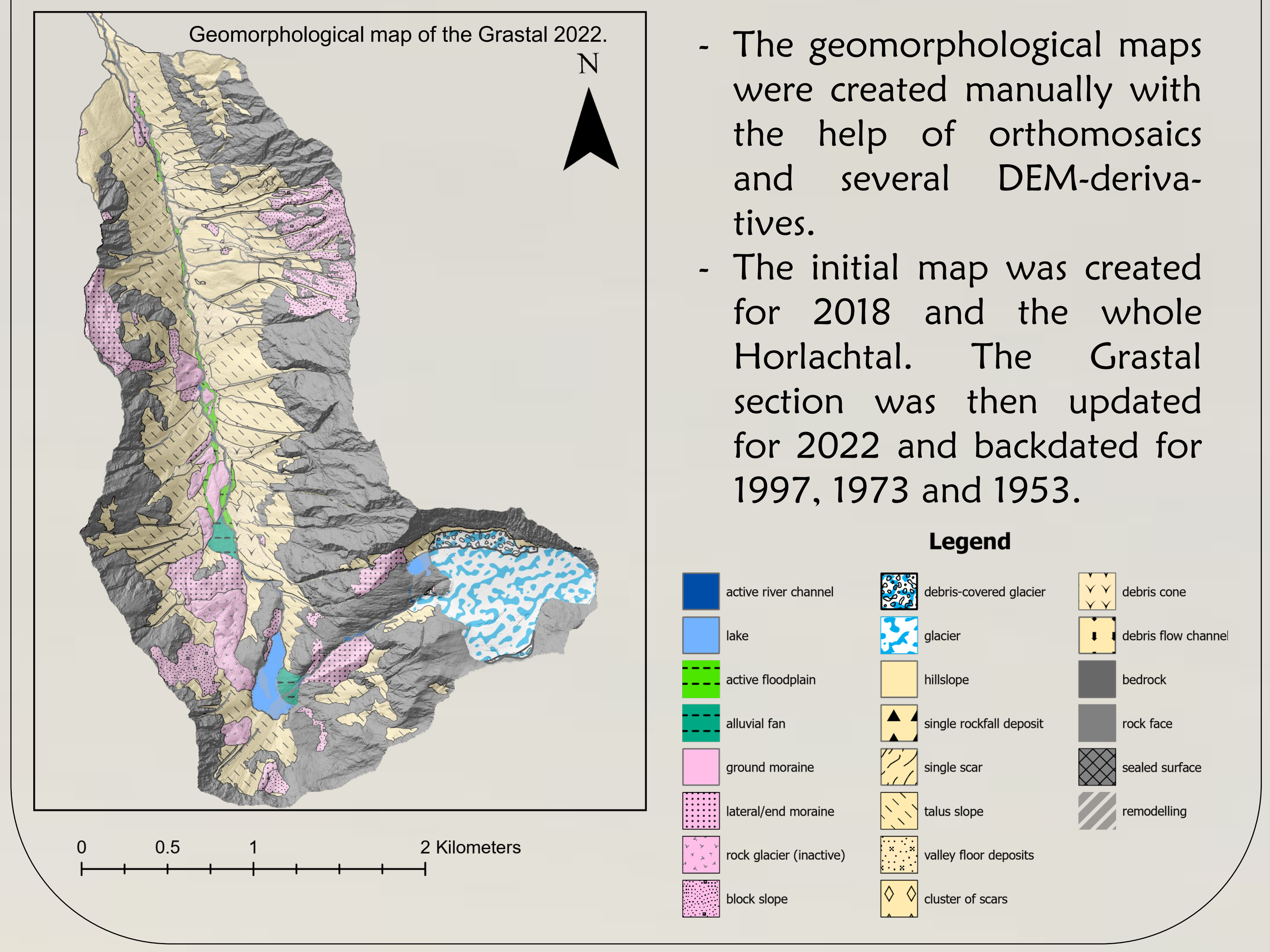


- We created land cover classification maps for all time steps using a random forest algorithm in R.
- For the older datasets only greyscale images were available.
- Eight different variables were tested, the best combination was RGB + DSM + Slope + TRI.

Confusion Matrix (GT 1973):

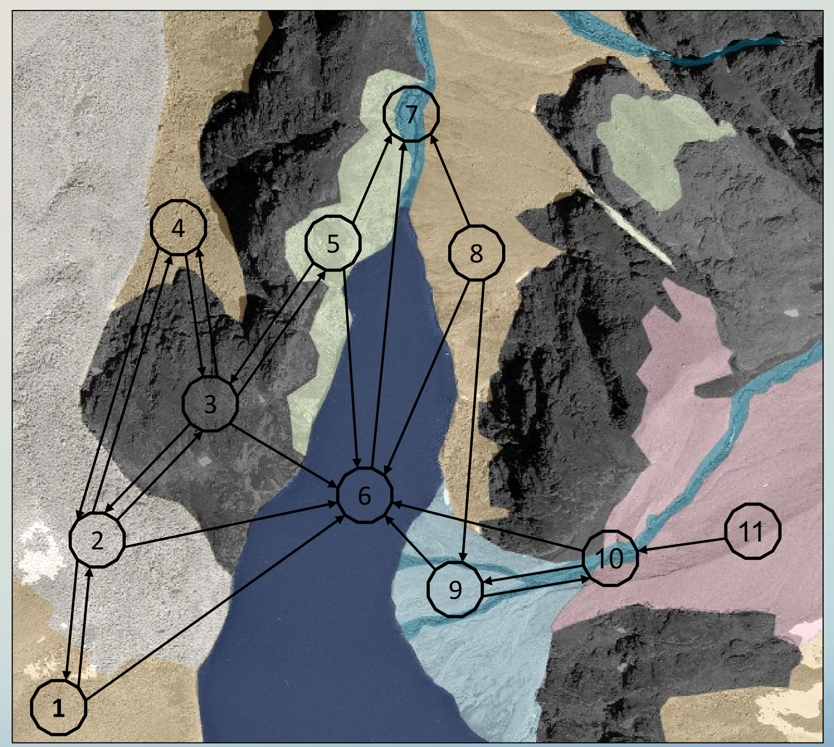
Class	Debris	Forest	Grass	Rockface	Shrubs	Snow/Ice	Lake
Debris	4017	3	461	235	0	30	1
Forest	2	1049	3	0	3	0	0
Grass	301	1	2549	54	36	0	0
Rockface	237	0	81	5037	0	26	4
Shrubs	5	4	18	0	89	0	0
Snow/Ice	18	0	0	16	0	1448	0
Lake	0	0	0	0	0	0	44

6. Geomorphological maps



- The geomorphological maps were created manually with the help of orthomosaics and several DEM-derivatives.
- The initial map was created for 2018 and the whole Horlachtal. The Grastal section was then updated for 2022 and backdated for 1997, 1973 and 1953.

7. Toposequence Graph



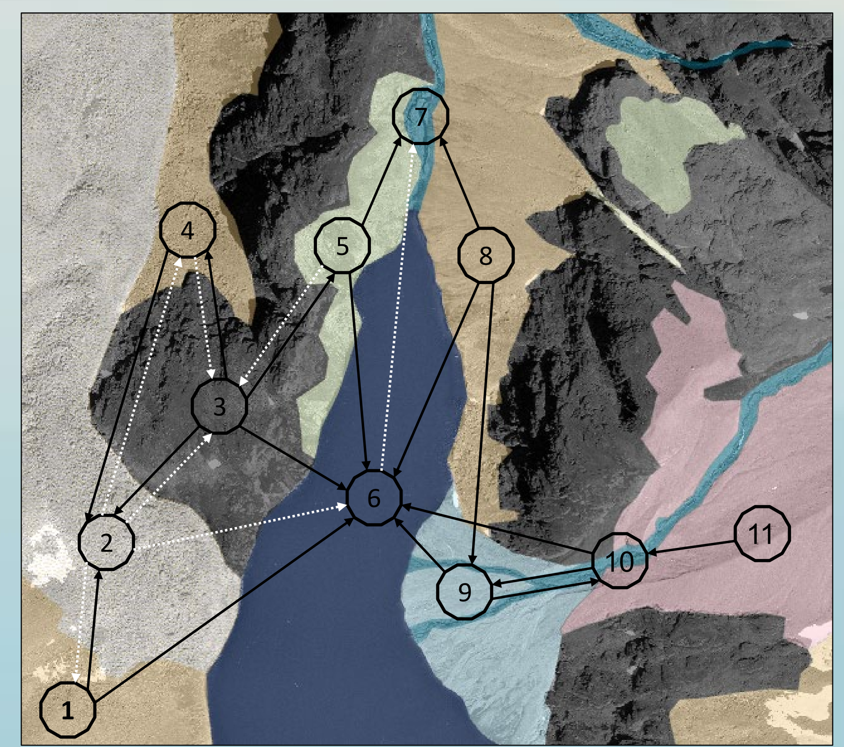
Legend:
1 = Talus slope
2 = Rock glacier (inactive)
3 = Rock face
4 = Talus slope
5 = Block slope
6 = Lake
7 = Active channel
8 = Talus slope
9 = Alluvial fan
10 = Active channel
11 = Lateral moraine

Toposequences are directed sequences of adjacent landforms which are connected along the gradient. The image shows an exemplary section of the GT1973 toposequence graph.

8. Filtering

We filter edges (potential sediment pathways) by a heuristic based on the concept of sources of disconnectivity:
- Landforms are classified as sinks, sources and links
- Predominant vegetation of the landform (e.g. forested units are interpreted as buffers[2])
- Topography (slope thresholding[3])

9. Sediment cascades graph



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The sediment cascades graph was derived by removing edges from the toposequence graph that represent unlikely or insignificant sediment pathways. It is hence a reprasentation of likely sediment fluxes between landforms. Filtered edges are greyed out.

10. Results: Connectivity measures

To analyse changes in structural connectivity, network properties of the actual sediment cascades graph were compared to the graph where toposequences are fully coupled[4].

Metric	Year	Toposequence graph	Sediment cascades graph	Ratio
Edge count	1953	2994	1910	0.64
	1973	3149	1938	0.62
	2022	2773	1566	0.56
In-degree (tc)	1953	93	28	0.30
	1973	103	33	0.32
	2022	82	28	0.34
Average path length	1953	5.3	16.1	3.1
	1973	5.0	13.6	2.7
	2022	5.2	14.2	2.7
Degree assortativity	1953	-0.08	-0.09	1.18
	1973	-0.08	-0.11	1.49
	2022	-0.09	-0.13	1.40

Graph analysis was performed with R and the igraph package[5]. tc = characteristic of the target channel vertex.

11. Discussion and conclusion

- The graph analysis shows only slight changes in connectivity over time, which is consistent with our knowledge of the area.
- Whilst land cover mapping and graph analysis are script-based and hence scalable, manual geomorphological mapping remains very time consuming.
- In contrast to other approaches, our method allows a quantitative analysis of structural sediment connectivity as well as comparisons over space and time.
- The graph representation enables the simulation of various scenarios, e.g. by implementing or removing buffers and barriers.

References

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