MGM 22 & AK Permafrost 22

Nov. 24.-27. 2022

Kaprun

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Organisation

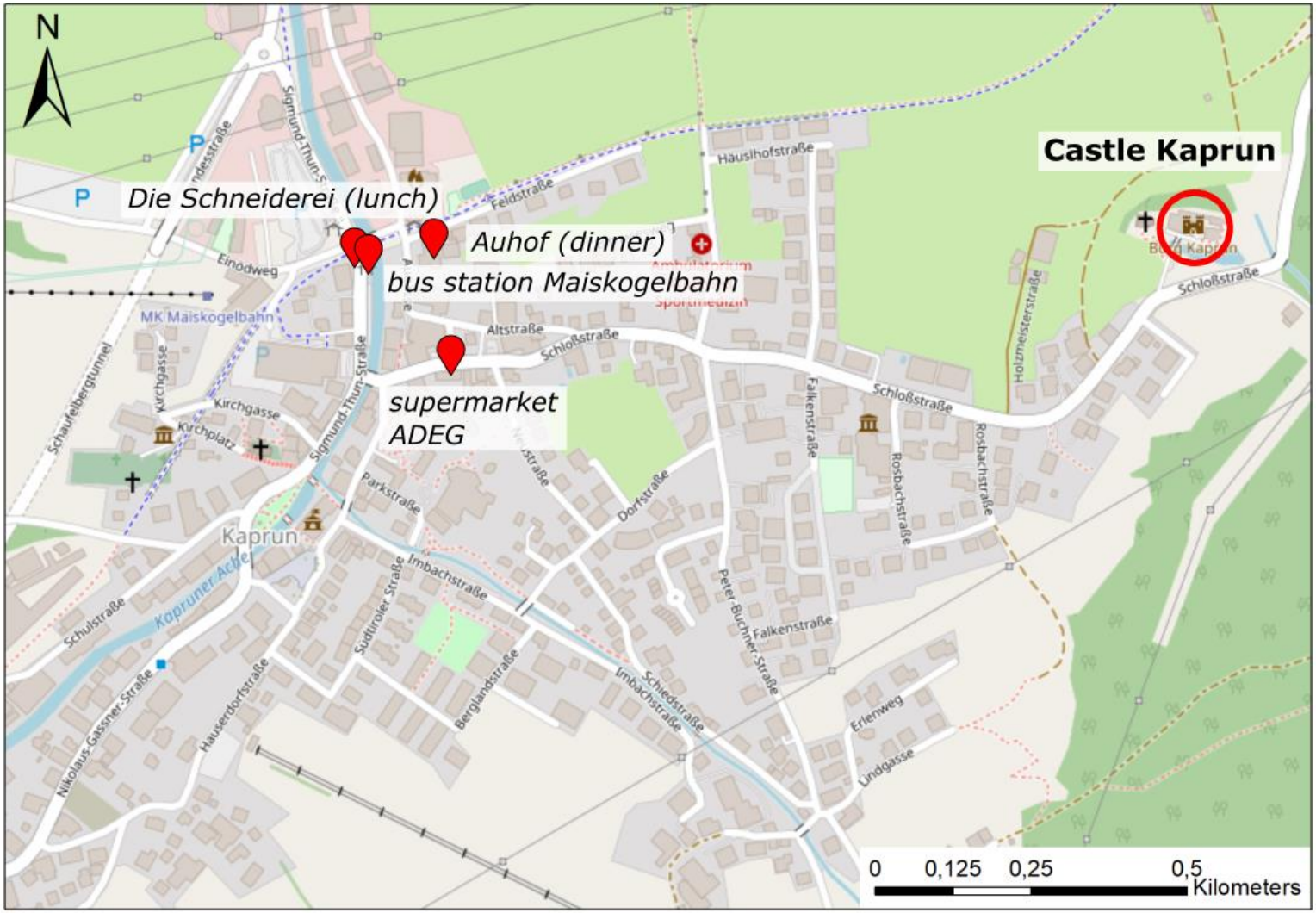
MGM22:

- Jan-Christoph Otto (University of Salzburg)
- Markus Keuschnig (Georesearch)
- Michael Krautblatter (TUM)
- Andreas Lang (University of Salzburg)

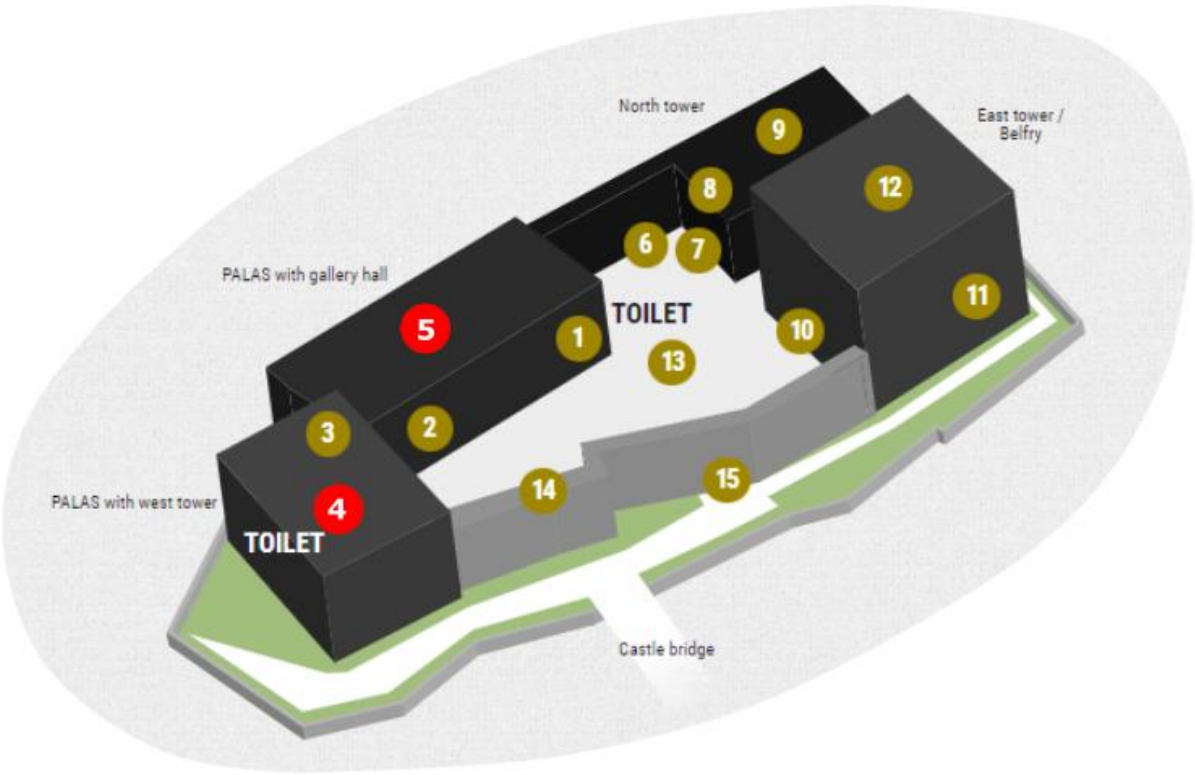
AK PF:

- Ingo Hartmeyer (Georesearch)
- Jens Strauß (AWI)
- Samuel Weber (SLF)

Overview Map Kaprun



Floor Plan Kaprun Castle



1 **Entrance hall**
PALAS - front of the ground floor

2 **Bat cellar / tower parlour**
PALAS - rear ground floor

3 **Castle lord's room / castle room / castle tavern**
PALAS - 1st floor

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PALAS - 2nd floor

6 **Tatzlwurm cellar**
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7 **Castle workshop**
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North tower / REFECTORY - 1st floor

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10 **Dungeons**
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11 **Deteriorated floors**
East tower / Belfry - mezzanine floors

12 **Stairs to the panoramic view**
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13 **Bailey**
Excavation of the old east gate of the castle

14 **South parapet walk**

15 **Castle gate**

Public Transport

The next train station is Zell am See, Station. Trains to Munich leave there.

Busses from Kaprun to Zell am See departure at the Busstation Maiskogelbahn Talstation (marked on the map). The walk from the Castle to the Bussstation is about 1.2km long and will take approximately 20 minutes.

Busses from Kaprun, Maiskogelbahn to Zell am See, Station

(The departure times are the same on Saturday and Sunday.)

Departure Time	Arrival Time	Transport Type
12:22h	12:39h	Plattform B, Bus 660
13:22h	13:39h	Plattform B, Bus 660
14:22h	14:39h	Plattform B, Bus 660
14:52h	15:09h	Plattform B, Bus 660
15:22h	15:38h	Plattform B, Bus 660
15:52h	16:09h	Plattform B, Bus 660
16:22h	16:39h	Plattform B, Bus 660

Shuttle Service to Zell am See, Station on Sunday, Nov.27 for 15:45h-Train to Munich

To find out connections from Zell am See, please use the trip planner of the train company ÖBB (QR-Code). The starting point (A) is 'Zell am See, Bahnhof'.

https://fahrplan.oebb.at/webapp/#!P|TP!histId|0!histKey|H177612

MGM 22 Kaprun

Programme and time schedule

Nov.24		
17:00 – 19:00	Knight Hall	PYRN-DACH Treffen
19:00 - 22:00	Knight Hall	AK Permafrost Pre-Conference Get-Together

Nov.25		
9:00 - 18:00	Gallery Hall	Forum Geomorphology: Sandpit Novel Research Topics in Geomorphology
9:00 - 18:00	Knight Hall	AK Permafrost
13:00 - 15:00		*Lunch break*
18:00 - 20:00	Gallery Hall	Icebreaker MGM + AK PF

Nov.26		
8:30 - 10:00	Knight Hall	2.1 Alpine Geomorphology + AK PF
10:30 - 12:00	Knight Hall	2.1 Alpine Geomorphology + AK PF
12:00 - 14:00		*Lunch break*
14:00 - 14:40	Knight Hall	2.1 Alpine Geomorphology + AK PF
14:40 - 15:40	Knight Hall	2.2 Fluvial and Dryland Geomorphology
16:00 - 17:30	Gallery Hall	Poster session with cold drinks
17:30 - 19:00	Knight Hall/Gallery Hall	DGGM / Geomorph.at Administrative Meeting with voting
19:30 - 22:00	*Auhof*	*Conference Dinner*

Nov.27		
8:00 - 9:20	Knight Hall	2.3 Quaternary geomorphological systems, biogeomorphology and human-environment interaction
9:20 – 10:00	Knight Hall	2.4 Deciphering and modelling long-term landscape evolution
10:20 - 11:40	Knight Hall	2.5 Engineering geomorphology and geomorphological hazards and risks
12:00 - 13:00		*Lunch break*
13:00 - 14:40	Knight Hall	2.6 New methods in Geomorphology
14:40 - 15:00	Knight Hall	*Closing Ceremony and awards*
15:00		*Shuttles to train station – Trains at 15:45 towards Munich*

Nov.28	
9:00 – 15:00	**Excursion Kitzsteinhorn** Meeting Point: Castle Kaprun (8:00) *Public bus transport to Zell am See, train connection 15:45 will be reached*

Nov.25.
9:00-13:00h, Knight Hall

AK Permafrost – Orals

9:30 – 9:50h
Achievements and challenges of multi-year frequent sampling of Arctic rivers

Anne Morgenstern (1), Benneth Juhls (1), Paul Overduin (1)
(1) Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung

Current warming, shifting hydrological regimes and accelerated permafrost thaw in the catchments of the Arctic rivers will profoundly change their water biogeochemistry. The PARTNERS (Pan-Arctic River Transport of Nutrients, Organic Matter, and Suspended Sediments, since 2002) and ArcticGRO (Arctic Great Rivers Observatory, since 2003) programs have established a baseline of interannual estimates of changing water composition for a set of circumpolar rivers draining into the Arctic Ocean. Access to Arctic rivers is challenging, especially during ice break-up and the critical freshet period and often especially at their mouths. Sampling frequency of existing programs (less than 7 samples per year) risks missing short-term events such as extreme meteorological and abrupt permafrost thaw events, which are becoming more frequent. The Lena River monitoring program at Research Station Samoylov Island, located about 80 km upstream of the river mouth, started sampling at higher frequency (1-7 day intervals) in 2018 to fill this gap. The success of the monitoring program depended on a simplified sampling protocol, dynamic partnership with research station staff and broad support across a number of partners for logistic and analytical support.
A number of publications highlight the strong seasonal variations of all biogeochemical parameters analyzed and streamflow partitioning among different sources. The data were also used as a crucial ground truth to develop a new algorithm for satellite-derived flux estimates of dissolved organic carbon. Some analyses are ongoing and, as the data set becomes publicly available, users find new applications to new research questions.The Lena River water sampling terminated in September 2022 after more than four years. We are now developing plans for transferring our scientific approach and experience with high-frequency river water monitoring to another Arctic river system.

9:50 – 10:10h
Morphology and dynamics of thermokarst lakes in the Tavvavuoma palsa mire, northern Sweden

Fabian Seemann (1, 2), Britta Sannel (1)
(1) Stockholm University
(2) Technische Universität Dresden

Permafrost in sub-Arctic peatlands is vulnerable to thaw due to climatic changes, initiating thermokarst landforms such as lakes which cover about 7 % of the northern circumpolar permafrost region. Thermokarst lakes are significant sources of carbon because previously in permafrost locked carbon becomes available for decomposition upon thaw. Since thermokarst processes contribute to global warming, it is important to study the morphology and temporal dynamics of these lakes as it allows projections of future developments. In the Tavvavuoma palsa mire, located in the sporadic permafrost zone of northern Sweden, lake dynamics have been monitored between 1963 and 2003. However,

subsequent developments remain unknown and detailed morphological descriptions concerning shoreline properties and their relation to erosion are missing. Therefore, this master thesis combined field, GIS and statistical methods to study the morphology of thermokarst lakes which helped to explain long-term trends of lake dynamics. It was found that erosion along shorelines is dependent on the height and slopes of palsas facing lakes while the wind direction revealed no significant influence on erosion. The retreat of shorelines is limited due to terrestrialisation with eroded peat blocks and vegetation growth into the shallow lakes. Between 2003 and 2021 the thermokarst lake area decreased by 10 % and the number of lakes decreased by 48 %. The limnicity (proportion of lakes) in the study area decreased from 12.6 % in 2003 to 11.4 % in 2021, which is a continuation of the trend observed between 1963 and 2003. Permafrost degradation causing an enhanced hydrological connectivity is the driving factor for the limnicity trend, although evaporation effects likely play an important role as well. Due to the current warming trend of ca. 0.4 °C/decade in northern Sweden, the observed trends are likely to continue which has implications on the carbon balance.

10:10 – 10:30h
Large Herbivores and Their Interaction with Arctic Soil Carbon Storage

Torben Windirsch (1,2), Guido Grosse (1,2), Bruce C. Forbes (3), Juliane Wolter (4), Mathias Ulrich (5), Jens Strauss (1)
(1) Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Permafrost Research Section, Potsdam, Germany
(2) University of Potsdam, Institute of Geosciences, Potsdam, Germany
(3) Arctic Centre, University of Lapland, Rovaniemi, Finland
(4) University of Potsdam, Institute of Biochemistry and Biology, Potsdam, Germany
(5) German Environment Agency (UBA), Dessau, Germany

Permafrost degradation and organic matter decomposition in the terrestrial Arctic are strongly depending on soil temperatures. A factor that affects these temperatures is grazing and snow trampling by large herbivorous animals, as well as animal-induced changes in vegetation cover. We analysed samples taken from adjacent areas with different grazing intensities, both in a permafrost environment (Siberia) and seasonally frozen ground (norther Finland) for TOC, C/N ratio, d13C, bulk density and radiocarbon age. While in permafrost there was a strong increase in soil carbon storage with high grazing intensity, this effect is not visible in seasonally frozen ground. However, in both areas we observed massive changes in vegetation composition and structure, following the grazing gradient. We conclude that seasonally frozen ground allows for more intensive carbon relocation and mixing, which outweighs the effects animals have in the permafrost region but state that on permafrost, animals might efficiently be utilized to stabilise permafrost temperatures and reduce organic material decomposition.

11:00 – 11:20h
Permafrost carbon on the Canadian Beaufort Shelf: Distribution and origin of organic matter in marine surface sediments

Katharina Schwarzkopf (1), Michael Fritz (1)
(1) Alfred Wegener Instiut Potsdam,Helmholtz Zentrum für Polar- und Meeresforschung, Sektion Permafrost

The continental shelves of the Arctic Ocean are undergoing profound changes due to unprecedented warming of the Arctic. Large amounts of previously freeze-locked carbon and nutrients are released towards the shelves due to increasing river discharge, deeper permafrost thaw and accelerated coastal erosion. Still, their interactions and their effects on carbon turnover, ocean acidification, and greenhouse

gas fluxes between sediment, ocean, and atmosphere are poorly understood. This study aims to distinguish the sources derived from coastal permafrost erosion, Mackenzie River runoff, and submarine permafrost degradation in the Canadian Beaufort Sea. For this purpose, among others, long and short sediment cores on twenty-five positions along five major across-shelf transects were taken in fall 2021. Here we present preliminary results of the upper two centimeters of the surface sediment. We present concentrations and regional distribution maps of organic carbon, nitrogen, and mercury. Bulk 14C radiocarbon ages and stable carbon isotope ratios (13C) will help to distinguish sources and degradation status of terrigenous organic matter. Preliminary results show that the material is predominantly fine-grained clayey silt, and the surface bulk ages vary between 3500 and 8500 years. We found specific spatial distribution patterns of carbon, nitrogen, and mercury, which highlight the influence of bathymetry and distance to the coast and/or the Mackenzie Delta on transport and degradation mechanisms of organic matter.
The Permafrost Carbon in the Beaufort Shelf (PeCaBeau) project took place on the Research Vessel CCGS Amundsen in September and October 2021 on the Canadian Beaufort Sea Shelf. This project was granted by the EU Horizon 2020 Arctic Research Icebreaker Consortium (ARICE, grant no. 730965).

11:20 – 11:40h
Calcium and amorphous silica in Arctic soils: Estimating Pan-Arctic availabilities and importance for CO2 production

Peter Stimmler (1), Jörg Schaller (1)
(1) Leibniz Center for Agricultural Landscape Research (ZALF), Germany

Future warming of the Arctic not only threatens to destabilize the enormous pool of organic carbon accumulated in permafrost soils, but may also mobilize elements such as calcium (Ca) or silicon (Si). Little is known about the effects of Si and Ca on carbon cycle processes in soils from Siberia, the Canadian Shield or Alaska. We incubated five different soils for six months with different Ca and amorphous Si (ASi) concentrations. Our results show a strong decrease in soil CO2 production for all soils with increasing Ca concentrations. The ASi effect was not clear across the different soils used, with soil CO2 production increasing, decreasing or not being significantly affected depending on the soil type and if the soils were initially drained or waterlogged. Including Ca as a controlling factor for Arctic soil CO2 production rates may therefore reduce uncertainties in modelling future scenarios on how Arctic regions may respond to climate change. To project how biogeochemical cycling in Arctic ecosystems will be affected by climate change, there is a need for data on element availability. For this we analysed ASi, Si, Ca, iron (Fe), phosphorus (P), and aluminium (Al) availability from 574 soil samples from the circumpolar Arctic region. We show large differences in element availability among different lithologies and Arctic regions. We summarized these data in pan-Arctic element maps focussing on the top 100 cm of Arctic soil. Furthermore, we provide values for element availability for the organic and the mineral layer of the seasonally thawing active layer as well as for the uppermost permafrost layer. Our spatially explicit data on differences in the availability of elements between the different lithological classes and regions now and in the future will improve Arctic Earth system models for estimating current and future carbon and nutrient feedbacks under climate change.

11:40 – 12:00h
Long term behaviour of retrogressive thaw slumps

Saskia Eppinger (1), Michael Krautblatter (1)
(1) Technical University of Munich, Landslide Research Group

Retrogressive thaw slumps (RTS) are a common thermokarst landform along arctic coastlines. They mobilize large amounts of organic carbon rich material. Especially in the western Canadian Arctic their length, width and frequency are particularly great. RTS are strongly characterized by rapidly changing topographical and internal structures and they are highly sensitive to various external factors, e.g. changing climate conditions. We aim for a better understanding of the life cycles of retrogressive thaw slumps. We investigate different phases, their stabilization, regeneration, and reactivation. To monitor their internal structures, we use electrical resistivity tomography (ERT) in combination with geomorphological mapping. Our field campaigns in 2011, 2012, 2019 and 2022 were carried out on Herschel Island – Qikiqtaruk, a highly active and well-studied area in the Yukon, Canada. The two biggest RTS on Herschel Island were investigated to gain a better understanding of the changing system over time. Numerous ERT profiles were carried out crossing the RTS parallel to the coastline as well as horizontally. We calibrated the ERT data by measuring the bulk sediment resistivity under fixed temperature conditions on sediment samples from Herschel Island. Also we conducted active layer probing to detect the frozen-unfrozen transition in the field.
This study leads to an improved comprehension of long-term processes in retrogressive thaw slumps and therefore a better predictability of their future behaviour. We show that ERT can be used to detect thermal and mechanical disturbances in RTS and gain a better understanding of their long term behaviour and different stages.

12:00 – 12:20h
Nitrogen isotopic inventory of the Lena River Delta

T. Sanders (1), C. Fiencke (2,3), B. Juhls (4), O. Ogneva (4,5), J. Strauss (4), R. E. Tuerena (6), K Dähnke (1)
(1) Helmholtz-Zentrum Geesthacht, Institute of Coastal Research, Max-Planck-Straße 1, 21502 Geesthacht, Germany
(2) Universität Hamburg, Institute of Soil Science, Allende-Platz 2, 20146 Hamburg, Germany
(3) Center for Earth System Research and Sustainability, Universität Hamburg, Allende-Platz 2, 20146 Hamburg, Germany
(4) Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Marine Geochemistry Section, Telegrafenberg A 45, Potsdam, Germany
(5) Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Permafrost Research Section, Am Handelshafen 12, Bremerhaven, Germany
(6) Scottish Association for Marine Science, Dunstaffnage, Oban PA37 1QA, UK

Permafrost-affected soils around the Arctic Ocean contain a large reservoir of organic matter including nitrogen, which partly reach the river after thawing, degradation and erosion of permafrost. After mobilization, reactive remineralised nitrogen is either used for primary production, microbial processing or is simply transported to coastal waters.
We have analyzed soil, suspended matter and dissolved inorganic and organic nitrogen for their contents and 15N stable isotope composition to create a baseline for a nitrogen inventory of the Lena River Delta in 2019/2020. We used samples from two transect cruises through the delta in March and August 2019, a monitoring program at Samoylov Island in the central delta (2019/2020), and different soil type samples from Samoylov Island.
Our data shows that the nitrogen transported from the delta to the Laptev Sea were dominated by dissolved organic nitrogen (DON) and nitrate, which occur in similar amounts of approx. 10 µmol/L. DON was available during the whole year. Nitrate showed a clear seasonal pattern: increase from late summer until the spring flood, during summer the nitrate concentration are close to zero. During the spring flood the nitrogen concentration are higher with up to 100 µmol/L.

The nitrogen stable isotope values of the different nitrogen components ranges mainly between 0.5 and 4.5‰, and were subsequently enriched from the soils via suspended particulate matter (SPM)/sediment and DON to nitrate. During the spring flood, the stable isotope signature of nitrate suggested a strong source of atmospheric deposition. The 15N values are depleted with appox. -8‰ and the 18O values are enriched up to 60‰.
Our data provides a baseline for isoscape analysis and can be used as an endmember signal for modeling approaches.

12:20 – 12:40h
Long-term geoelectrical monitoring of bedrock permafrost in the Kammstollen, Zugspitze (Germany/Austria)

Riccardo Scandroglio (1), Maike Offer (1), Till Rehm (2), Michael Krautblatter (1)
(1) Chair of Landslide Research, Technical University of Munich, Germany
(2) Environmental Research Station Schneefernerhaus, Zugspitze, Germany

In the last decades, electrical resistivity tomography (ERT) became the standard technique for permafrost monitoring. Changes in resistivity allow to quantify the response of permafrost to the recent climate change. In high alpine environment, especially in steep bedrock walls, consequences can be critical, putting infrastructures and people at high risk. Numerous locations are monitored along the Alps, mainly installed at the rock surface, and measured once a year. In a few cases, automatic systems have been installed to monitor changes all-year around, but this often implies bad coupling of electrodes, high costs and/or repeated failures. In 2007, we instrumented a former touristic tunnel at about 2800 m asl on the Mount Zugspitze (D/A) in a unique setup for ERT and temperature measurements. (i) The location can be easily reached by cable car and is accessible all year around, independently from weather conditions. (ii) Measures are taken from the inside towards the rock surface. (iii) An ideal compromise between continuous automatic systems and single annual measurements is achieved with monthly repeated measurements: this allows detailed interpretation of bedrock permafrost reactions to seasonal variations as well as of long-term changes, without the burden of fix costs and the complications of automatic setups. (vi) Standard procedures and permanently installed electrodes allowed the collection of a unique dataset of consistent monthly measurements since 2014. (v) Resistivity-temperature calibration from Krautblatter et al. (2010) enable an advanced quantitative interpretation of the results.

Results from 25 rock temperature loggers show an increase of rock temperatures in the last decade, with a gradient decreasing with depth - in good agreement with other locations in the Alps. Inversion results from the ERT fit well to this trend, especially in the summer months where a steady decrease of resistivities is measured. Winter months are strongly influenced by the duration and depth of snow cover, showing therefore more variations.
Krautblatter, M., S. Verleysdonk, A. Flores-Orozco, and A. Kemna (2010), Temperature-calibrated imaging of seasonal changes in permafrost rock walls by quantitative electrical resistivity tomography (Zugspitze, German/Austrian Alps), J. Geophys. Res., 115, F02003, doi:10.1029/2008JF001209.

Nov.25.
16:15-17:45h, Knight Hall/ Gallery Hall

AK Permafrost - Poster

3.1
Postglacial permafrost depositional history of Grøndalen, West Spitsbergen

Schirrmeister, L. (1); Demidov, N. (2); Demidov, V. (2); Wetterich, S. (1); Verkulich, S. (2)
(1) Permafrost Research Section, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI)
(2) Arctic and Antarctic Research Institute (AARI)

To shed light on the postglacial landscape evolution on the western coast of Nordenskiöld Land (West Spitsbergen), drilling and outcrop sampling was performed in the framework of the Russian Scientific Arctic Expedition on Spitsbergen (RAE-S) between 2015 and 2022. The transect near Barentsburg stretches over 20 km and comprises 19 drill locations between 5 and 25 m depths below surface on the marine terraces at Isfjorden, along the Grønfjorden, in the Grøndalen and in the Iradalen. Special emphasis was given to the study of pingos.
Permafrost cores were obtained with a Russian portable gasoline powered rotary drilling rig (UKB 12/25). The core pieces of 79 to 109 mm in diameter were lifted to the surface every 30–50 cm. For each core segment visible features like granulometry, color, organic content, sediment type and ice structures were described. In some of the boreholes ground temperatures were measured. Analyses of gravimetric moisture content, stable water isotope composition, and ion content of water extracts from permafrost deposits have been carried out. Further studies of grain-size distribution, mass-specific magnetic susceptibility, organic components (TOC, TC, TN, δ13C) as well as radiocarbon dating are in progress. First results of this ongoing effort have been published in recent years on pingo properties, formation and distribution (Demidov et al. 2019, 2021, 2022) and on geocryological and hydrogeological conditions (Demidov et al., 2020), while the paleo-environmental and paleo-landscape aspect is only partly studied yet (Verkulich et al., 2018) and subject to further research.
As the area of West Spitsbergen became ice-free about 14 400 years ago, permafrost formation and periglacial landscape evolution covers parts of the Late Glacial and the entire Holocene. The complex interplay of glacial (e.g. retreat), periglacial (e.g. deposition) and marine (e.g. transgression) processes superimposed by climate variability over time define the local permafrost history.
References:
Demidov N, Wetterich S, Verkulich S, Ekaykin A, Meyer H, Anisimov M, Schirrmeister L, Demidov V, Hodson A J (2019). Geochemical signatures of pingo ice and its origin in Grøndalen, West Spitsbergen. The Cryosphere 13: 3155-3169.
Demidov NE, Borisik AL, Verkulich SR, Wetterich S, Gunar AYu, Demidov VE, Zheltenkova NV, Koshurnikov AV, Mikhailova VM, Nikulina AL, Novikov AL, Savatyugin LM, Sirotkin AN, Terekhov AV, Ugrumov YuV, Schirrmeister L (2020). Geocryological and hydrogeological conditions of the western part of Nordenskiold Land (Spitsbergen Archipelago). Izvestiya, Atmospheric and Oceanic Physics 56(11): 1376–1400.
Demidov V, Wetterich S, Demidov N, Schirrmeister L, Verkulich S, Koshurnikov A, Gagarin V, Ekaykin A, Terekchov A, Veres A, Kozachek A (2021). Pingo drilling reveals sodium-chlorine dominated massive ice in Grøndalen, West Spitsbergen. Permafrost and Periglacial Processes 32: 572–586.
Demidov V, Demidov N, Verkulich S, Wetterich S (2022). Distribution of pingos on Svalbard. Geomorphology 412, 108326.

Verkulich S, Zazovskaya E, Pushina Z, Savelieva L, Soloveva D, Demidov N, Shishkov V, Dercon G. (2018). The postglacial environmental changes in vicinity of the Barentsburg settlement (West Spitsbergen). Geophysical Research Abstracts 20: EGU2018-7729.

3.2
Periglacial Landforms in the German Alps – Examples from the Steinernes Meer, Berchtesgaden National Park

Tim Wiegand (1), Julius Kunz (1), Christof Kneisel (1)
(1) Institute of Geography and Geology, University of Wuerzburg

Periglacial environments are well studied in the Central Alps. However, less attention has been paid to the Northern Limestone Alps and especially the German part so far. We used remote sensing data for detection and mapping of landforms along the northern fringe of the Alps. Some of them were investigated in more detail regarding their subsurface structure during fieldwork by means of geophysical soundings.
Here, we present an assemblage of periglacial landforms in the Steinernes Meer, Berchtesgaden National Park (halfway between Salzburg and Kaprun), where special climatic, topographic, and geologic conditions enabled the development of various characteristic landforms such as turf-banked solifluction lobes, karst-related features and pronival ramparts in conjunction with perennial snow patches.
A considerable amount of debris supplied by the mountain ridge between Funtenseetauern and Grieskogel was responsible for the formation of larger lobe and tongue shaped structures. Those typically result from permafrost creep. However, at this site and in the German Alps in general, many relict features are difficult to classify as either of periglacial or of glacial origin as for example lateral margins or ramparts cannot clearly be distinguished from moraines. Such cold-climate landforms should rather be discussed along a continuum related to the debris and ice input into the system.
Nonetheless, some of the landforms we mapped are most likely (relict) rock glaciers. To our knowledge, this is the first documentation of rock glaciers in the German Alps.

3.3
Detection, Distribution, and Internal Structure of Andean Permafrost in Taluses and Block-slopes - Agua Negra basin, Argentina.

Diana A. Ortiz (1), Melanie A. Stammler (1), Tamara Koehler (1), Lothar Schrott (1), Dario Trombotto Liaudat (2)
(1) Department of Geography, University of Bonn, Meckenheimer Allee 166, 53115 Bonn, Germany, E-mail: dianaagostinaortiz@gmail.com
(2) IANIGLA-CONICET, Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales, CCT CONICET Mendoza. Av. Dr. Adrián Ruiz Leal, 5500 Mendoza, Argentina.

Extensive areas in mountain regions are under permafrost conditions (Caine, 2010; Haeberli et al., 2010) with periglacial processes in the arid Andes of Argentina being mostly associated with high mountain permafrost (Schrott, 1994; Trombotto, 2003; Ahumada et al. 2011). Within this Andean periglacial belt, taluses (including protalus ramparts) and block-slopes are widespread above an altitude of 4000 m a.s.l., with a first quantitative assessment revealing a coverage higher than 70 % in the upper part of the Agua Negra (AN) catchment (ca. 30°S and 69°W). We hypothesize that taluses and block-slopes present a high potential for ice content, having great importance as solid water reserves given the current extreme drought in the Andes, which directly affects the availability of water in the lowlands.
This work aims to present the preliminary results of permafrost distribution in taluses and block-slopes

in the Agua Negra basin, San Juan. In the austral summer 2022, a combination of electrical resistivity tomography (ERT), seismic refraction tomography (SRT), hydrochemical data and UAV (and spaceborne remote sensing) analysis was conducted in the study area. Hydrochemical measurements include more than 30 water samples, repetitive discharge measurements and the installation of 6 gauging stations along the course of AN river. A DEM-focused spatial interpretation of surface change is based on Phantom 4 RTK flights and high-resolution tristereoscopic Pléiades data. The systematic two-dimensional geophysical profiles show a clear presence of ice-rich permafrost within taluses, whose distribution is mainly related to the base of these landforms (Lambiel and Pieracci , 2008). The geophysical data acquired will be employed to determine the volume of ice contained applying the Four Phase Modelling approach.
Understanding the spatial distribution of permafrost and its relationship to climatic, topographic and lithological factors will help to identify the regions prone to the occurrence and distribution of Andean permafrost.

3.4
Towards a combined electrical and seismic approach for ice-poor bedrock in mountain permafrost

Maike Offer (1), Riccardo Scandroglio (1), Markus Keuschnig (2), Michael Krautblatter (1)
(1) Chair of Landslide Research, Technical University of Munich, Germany
(2) GEORESEARCH Forschungsgesellschaft mbH, Austria

The ongoing warming process of permafrost regions in the Alps is causing critical changes in water and ice content in bedrock, increasing the likelihood of rock slope destabilization and damages to infrastructures at high altitudes. To provide safe long-lasting constructions and to prevent severe economic consequences, a complete process understanding of these permafrost systems is required. Due to the complementary response of unfrozen and frozen medium, it is common to combine the geophysical monitoring of Electrical Resistivity Tomography (ERT) and Seismic Refraction Tomography (SRT). In the last years, multimethod approaches were developed with main focus on ice-rich permafrost environments. However, high-alpine infrastructures are predominantly founded or anchored in ice-poor bedrock characterized by different, but clearly defined, petrophysical properties.
Here, we present the first results of our quantitative analysis to monitor the frozen areas of low porosity bedrock. The shown electrical resistivity and seismic refraction data sets were recorded at two highly touristic areas with nearby infrastructures affected by degrading permafrost: three parallel transects were located above the Kammhotel on the Zugspitze crestline (Germany, 2.855 m a.s.l.) and one transect below the cable car station at the Kitzsteinhorn (Austria, 3.029 m a.s.l.). A quantitative interpretation of their thermal state is obtained by combining these field measurements with our laboratory calibrations, which provided the relations between temperatures, resistivities, and p-wave velocities.
Results from the ERT and SRT inversions showed reliable information about the occurrence and the thermal states of permafrost in these environments. In the context of global warming, our approach allows to highlight and monitor areas where mechanical destabilizations can be expected. Therefore, it provides a fundamental tool for a non-invasive risk assessment of high-alpine infrastructure which are founded or anchored in degrading permafrost bedrock.

3.5
Three-dimensional subsurface architecture and its influence on the spatiotemporal development of a retrogressive thaw slump in the Richardson Mountains, Northwest Territories, Canada

Julius Kunz (1), Tobias Ullmann (1), Christof Kneisel (1), Roland Baumhauer (1)
(1) University of Wuerzburg, Institute of Geography and Geology

The Peel Plateau Region east of the Richardson Mountains (Western Canadian Arctic) is known for widespread and ice-rich permafrost. Due to high ground ice contents the presence of retrogressive thaw slumps is common in this region, some of which are classified as mega slumps and belong to the largest thaw slumps on earth. The development of retrogressive thaw slumps is affected by relief-related parameters, subsurface properties as well as climatic triggers. The current study investigates the subsurface characteristics in the vicinity of an active slump in the Richardson Mountains to enhance the knowledge about slump development. Using a combined approach of geophysical methods and optical remote sensing data relationships between subsurface structures and the spatiotemporal slump development were investigated. Information on subsurface architecture was obtained using electrical resistivity tomography (ERT) and ground-penetrating radar (GPR). The spatiotemporal development was revealed by high-resolution satellite imagery (Planet Scope, 2014 – 2021), and drone-based digital elevation models (2018, 2019 and 2022). The analysis indicated an acceleration of slump expansion and enabled a detailed balancing of erosion and accumulation based on the drone-derived digital elevation models. The three-dimensional geophysical measurements conducted in 2019 revealed a partly unfrozen layer underlying a heterogeneous permafrost body and a close relation between active layer thickness, morphology and hydrology in the area close to the retreating headwall. Additional measurements conducted in 2022 highlighted the thermal impact below the slump floor of the active thaw slump, but also below a nearby, older and already stable slump scar. The results highlight the complex relationships between slump development, subsurface structure and hydrology, and indicate a distinct research need at other retrogressive thaw slumps in this region.

3.6
Towards mechanical and hydrological controls of rock slope failure in polythermal cryospheric rock slope regimes

Felix Pfluger (1), Michael Krautblatter (1)
(1) Chair of Landslide Research, Technical University of Munich, Germany

Interlinked and simultaneous processes are responsible for the destabilization of rock slopes in cryospheric regions. The contribution of single factors to change remains unknown as subsurface changes are hard to decipher. A coupled model approach can help to gain a better system understanding as it was shown with thermo-mechanical or hydro-thermal analysis. Stability assessment of rock slopes is usually done by mechanical modelling. However shallow movements (<20 m) in cryospheric rock slopes are essentially influenced by alteration of subsurface thermal field and hydrological transient situations including varying phase composition of water and ice and various filling material in clefts. A holistic stability assessment should therefore be defined by an integration of hydrological and thermal information in mechanical calculations. Up to date a single approach towards a temperature dependent rock-ice-mechanical model is known. The existing concept opens a foundation to build on. In a first step we will use a pure modelling approach on simple geometry to create above mentioned holistic mechanical model by using numerical code (UDEC). Sensitivity analysis to parameters as cleft water

pressure and heterogeneous joint infilling will be carried out. The second step is to test the model on a real field example on a geomorphologic active, high alpine study site in Ötztal valley. We will use data from continuous rock temperature monitoring to create a transient thermal model. Moreover thermal images of the rock slope will help to identify water sources and consequently deduce a hydrological model. Geomorphic change and movements of rock slope will be detected by TLS and UAV data. The aim of the study is to demonstrate the sensitivity of rock slope stability to transient situations in cryospheric rock slopes, help identify critical rock slope regimes in different stages prone to failure and contribute to a better understanding of the evolution of high alpine landscapes.

3.7
Hydrogeology of Rock Glacier Lazaun (South Tyrol, Northern Italy)

Giulia Bertolotti (1, 2, 3), Karl Krainer (2), Gerfried Winkler (3)
(1) Österreichische Akademie der Wissenschaften (ÖAW) - Institut für Interdisziplinäre Gebirgsforschung
(2) Universität Innsbruck - Institut für Geologie und Paläontologie
(3) Universität Graz - Institut für Erdwissenschaften

The present study aims at hydrogeologically characterizing the runoff pattern of active rock glacier Lazaun, its seasonal and weather-related variations and its relationship to permafrost ice in the rock glacier. For this purpose, discharge survey, supported by stable isotope and electrical conductivity analyses, were carried out. The discharge analysis is based on a 2-year dataset. It showed a typical discharge pattern for active rock glaciers, with maximum discharge during the snowmelt period (June-July) and a gradual decrease towards the fall season. Pronounced diurnal variations of discharge, in the order of 20 to 50 l/s, are also recorded, especially during early summer. Discharge is not zero during winter, supporting the theory of a groundwater-fed base flow. Water temperature data measured at the rock glacier spring also show a constant temperature (1.2-1.4 °C) during winter and a sudden drop at the beginning of the snowmelt season. Isotope data seem to confirm this theory. They show at least 3 components: a low-conductivity, low δ18O component (melt water of the winter snow cover), a baseflow, high-EC and high δ18O component (possibly groundwater) and an event water component with lower conductivity and slightly higher δ18O values (rainwater of summer precipitation). A fourth component (melt water of the permafrost ice) might also be assumed. In general, an increase in electrical conductivity and in δ18O is evident from the beginning of the melt season until autumn/winter. Recession analysis also shows 2 to 3 components (“quick flow” and “baseflow”, plus an intermediate flow component), characterized by different recession coefficients. These indicate also at least two different storage units. The baseflow storage unit might be ascribed to the unfrozen lodgment till layer detected at the base of the frozen core of the Lazaun rock glacier. Thickness and storage capacity of this layer are, however, still unknown.

3.8
The footprint of permafrost carbon on the Canadian Beaufort Sea Shelf

Michael Fritz (1), Lisa Bröder (2,3), B. Juhls (1), Julie Lattaud (2), Antje Eulenburg (1), Taylor Priest (4), Atsushi Matsuoka (5), André Pellerin (6), Thomas Bossé-Demers (7), Daniel Rudbäck (8), Matt O’Regan (8), Dustin Whalen (9), Paul Overduin (1), Katharina Schwarzkopf (1), Jorien Vonk (3)
(1) Alfred Wegener Institute, Potsdam, Germany
(2) ETH Zürich, Switzerland
(3) Vrije Universiteit Amsterdam, The Netherlands
(4) MPI for Marine Microbiology, Bremen, Germany
(5) University of New Hampshire, USA
(6) Université du Québec à Rimouski, Canada

(7) Université Laval, Canada
(8) Stockholm University, Sweden
(9) Natural Resources Canada

Arctic continental shelves are strongly impacted by rising air temperatures and declining summer sea-ice extent. Permafrost coasts erode rapidly, subsea permafrost thaws, and river runoff is increasing. This together affects associated particulate and dissolved matter fluxes, with direct consequences for the marine environment. The multi-disciplinary PeCaBeau project ("Permafrost Carbon on the Beaufort Shelf") aims to track the fluxes, transport and degradation of organic material from originating permafrost landscapes along the land-to-ocean continuum. Sampling operations took place in the southern Beaufort Sea in September 2021 onboard the Canadian Coast Guard Ship Amundsen. Water-column profiling and sediment sampling were conducted along five major across-shelf transects in order to quantify the fluxes, burial rates, composition and fate of organic matter to ultimately improve assessments of the Beaufort shelf as a carbon source or sink, and to place these outcomes in the context of the Holocene paleoenvironment and transgressed permafrost. We analysed surface and bottom water particulate organic carbon (POC) radiocarbon content across the Beaufort Shelf to differentiate between recent primary production OC and old permafrost-derived OC. Lower values were present for the shallow shelf stations within the Mackenzie River plume (west of the Mackenzie Delta). Using water temperature and salinity data from Conductivity-Temperature-Depth (CTD) profiles, samples were attributed to different water masses. Surface sediments (0-2 cm sampled from shallow multicores) had significantly lower F14C values than particulate OC in the overlying waters. Low values were found for the shelf break in the east and for the western part of the Beaufort shelf that is generally affected by the Mackenzie River plume. Dual-isotope plots using stable (δ13C) and radiocarbon (14C) data from surface sediments and published measurements serves to assess contributions from potential OC sources.

3.9
Carbon dynamics following permafrost thaw gradient in high latitude peatland environment

Jakob Reif (1,2), Melissa Laurent (2,3), Mackenzie Baysinger (2,3), Katharina Jentzsch (2,3), Timo Kumpula (4), Pasi Korpelainen (4), Mariana Verdonen (4), Jens Strauss (2), Claire Treat (2)
(1) University of Tübingen
(2) Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
(3) University of Potsdam
(4) University of Eastern Finland

Recent studies estimate approximately 1700 Pg of organic carbon in perennially frozen soil areas in Arctic and Sub-Arctic regions. Recent warming causes permafrost areas to thaw and expose formerly frozen carbon-rich soil to potential accelerated microbial decomposition. The goal of this study is to quantify carbon dynamics along a thaw gradient by comparing carbon stocks of a) intact permafrost site, b) partly thawed intermediate site and c) thawed area. One long core until mineral soil for each selected site was taken in a rapidly thawing palsa area in Northern Finland (coordinates). Additionally, bulk density (g cm−3) probes were taken for each location to measure carbon content. For a better understanding of the history of the sites, samples for macrofossil were collected, as well as samples for C:N ratio, radiocarbon measurements and peat properties analysis. Recent similar studies have drawn partly conflicting results, while some measured a rapid carbon loss after thaw, others showed that collapsing permafrost did neither lead to larger carbon loss nor to carbon uptake. Suggested explanations mainly focus on the influence of permafrost type and site history. This study of carbon dynamics in a thawing palsa site aims to contribute to the discussion.

3.10

Improvement of Marine ERT Data Inversion to Quantify Ongoing Subsea Permafrost Degradation at Tuktoyaktuk Island (Beaufort Sea)

E. Erkens (1), M. Angelopoulos (1), **P. Overduin** (1), J. Boike (1)
(1) Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany

The continuous degradation of subsea permafrost and the resulting release of greenhouse gases might contribute to global warming as a positive feedback mechanism. In addition, thawing of permafrost can accelerate coastal erosion with significant infrastructural and socioeconomic consequences as it is currently the case at Tuktoyaktuk Island (NWT, Beaufort Sea). To determine the current degradation rate, the current ice-bearing permafrost table around the island will be inferred based on marine ERT surveys (vertical sounding profiles collected in 2021) and subsequently compared to historical coastline data. The collected data contains more than 30 profiles, consisting of numerous adjacent vertical soundings in a (quasi-symmetric) reciprocal Wenner-Schlumberger array, using a floating cable towed behind a boat. For the first time, GPS records along the electrode streamer were taken, allowing to improve pre-processing by excluding measurements for which the cable was curved and electrode positions deviated too widely. Furthermore, the inversion of floating electrode resistivity survey data can be improved by optimizing the inversion method, including considerations of the roll-along 1-D sounding nature of the measurements and of electrode position uncertainty. Several local search algorithms and different kinds of parametrization will be compared in order to obtain the most precise image of the current subsea permafrost table. The study of the presented data will give insights on the current state of subsea permafrost at the specific location and its degradation over the last decades, as well as the most suitable inversion technique for the applied method of marine ERT survey collection.

3.11

Carbon degradation and potential greenhouse gas production in a changing Arctic thermokarst landscape

Verena Bischoff (1,2,3), Juliane Wolter (2,3)
(1) RWTH Aachen, Faculty of Georesources and Materials Engineering, Aachen, Germany
(2) University of Potsdam, Institute of Biochemistry and Biology, Potsdam, Germany
(3) Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Permafrost Research Section, Potsdam, Germany

Permafrost carbon pools are a major storage component of the terrestrial carbon cycle and are vulnerable in a warming climate. During historic and anticipated anthropogenic climate change, additional thaw will lead to degradation of organic matter stored in permafrost in Arctic lowlands. Within such lowlands, large areas are occupied by and drained lake basins, in which wetlands formed. These wetlands have the potential to store carbon in peat, but they might also turn into sources of additional greenhouse gases.
This presentation will show a master project plan to assess the organic carbon storage and degradation state, as well as potential greenhouse gas production in drained lake basins of the western Canadian Arctic. Therefore, sediment cores from five drained lake basins will be analyzed geochemically and sedimentologically, including an incubation experiment. The study region is located in northwest Canada. All core material on which this master project's topic will be working with was retrieved during the expedition Yukon Coast 2019.

Nov.26
08:30 – 14:40h Knight Hall

2.1 Alpine Geomorphology and AK Permafrost - Orals

8:40 – 09:20h

Towards quantifying long-term fire-vegetation feedbacks in Eastern Siberia: what we learn from sediment

Elisabeth Dietze (1, 2, 3), Vivien Reichel (1, 2, 4), Andrei Andreev (1, 2), Kai Mangelsdorf (3), Simeon Lisovski (2), Ulrike Herzschuh (2, 5, 6)
(1) University of Göttingen, Institute of Geography, Landscape Geoscience, Göttingen, Germany
(2) Alfred-Wegener-Institut for Polar and Marine Science, Polar Terrestrial Environmental Systems, Potsdam, Germany
(3) German Research Center for Geoscience (GFZ), Organic Geochemistry, Potsdam, Germany
(4) University of Leipzig, Institute of Geography, Physical Geography, Leipzig, Germany
(5) University Potsdam, Institute of Environmental Sciences and Geography, Potsdam-Golm, Germany
(6) University of Potsdam, Institute of Biochemistry and Biology, Potsdam-Golm, Germany

The ongoing intensification of forest fires in the Arctic raises concerns if fires might lead to biome shifts from tundra to boreal forest – with consequences for biophysical land properties and biogeochemical cycles. Given short instrumental observations, it is unknown if fire can initiate or support biome shifts under amplified warming or if climate drives fire regime and biome changes independently. Lake El'gygytgyn, NE Siberia, is surrounded by tundra on permafrost, but during "superinterglacial" MIS 11, c. 375-440 kyrs ago, pollen data suggests that biome composition changed several times, from a glacial steppe to various interglacial boreal forest types. The overall question is if and which type of fire regime shifts accompanied these biome shifts and if we can quantify the impact of fire on biome shifts.
In this talk, I reflect on what we can learn from the principles of sediment transport, unraveled by grain size end-member modelling, for quantitative reconstructions of past fire regimes. We analyzed multiple fire proxies in interglacial El'gygytgyn sediments, but also in modern lake surface sediments from three lakes in Eastern Siberia, as a space-for-time analogue, to link fire proxy amounts and composition with fire regime properties. Then, we assessed modern charcoal source areas by simulating charcoal transport using data from modern fires and wind fields.
We find clear differences in fire proxy composition depending on source area of charcoals and anhydrosugars. Modern relationships between fire regime parameters, fire proxy composition and pollen-based vegetation are comparable to past interglacial relationships indicating that fire regime change did play a role during some, but not all interglacial biome shifts. Overall, we provide new understanding of sedimentary fire proxies, crucial for a quantitative reconstruction of long-term fire regime change, that allows to assess the role of fire regime intensification in biome changes during periods of stark warming.

09:20 – 09:40h

More than carbon: Frozen element inventories in ice-rich Yedoma permafrost

Jens Strauss (1), Arthur Monhonval (2), Clara Rutkowski (1,3), Matthias Fuchs (1), Tina Sanders (4), Christina Biasi (5), Sophie Opfergelt (2), Lutz Schirrmeister (1), Guido Grosse (1,6)
(1) Permafrost Research Section, Alfred Wegener Institute Helmholtz-Centre for Polar and Marine Research, Potsdam, Germany
(2) Earth and Life Institute, Université Catholique de Louvain, Louvain-la-Neuve, Belgium
(3) formerly at Department of Geography and Geology, Paris Lodron University Salzburg, Salzburg, Austria
(4) Institute for Carbon Cycles, Helmholtz-Zentrum Hereon, Geesthacht, Germany
(5) Department of Environmental and Biological Sciences, University of Eastern Finland, Kuopio, Finland
(6) Institute of Geosciences, University of Potsdam, Potsdam, Germany

Soils of the permafrost zone store globally relevant reservoirs of frozen matter, such as organic matter, mineral elements as well as other biogeochemical relevant compounds like contaminants. Besides well-studied organic carbon (OC), other compounds can become available in active biological and hydrological element cycling as global climate change is warming northern permafrost regions nearly four times faster than the global average. Current heating in Siberia is unprecedented during the past seven millennia, triggering widespread permafrost degradation and collapse.
This is especially relevant for our study region, the Yedoma domain. In this region, a large amount of belowground ice is present and the ground can become unstable with warming, allowing the mobilisation of previously frozen sediments with their geochemical element contents. With this presentation, we want to synthesise recent studies, which have improved the understanding of various frozen stocks. Here, we estimated that the Yedoma domain contains 41.2 Gt of nitrogen, which increases the previous estimate for the circumpolar permafrost zone by ~46%. The highest element stock within the Yedoma domain is estimated for r Si (2739 Gt), followed by Al, Fe, K, Ca, Ti, Mn, Zr, Sr, and Zn. The stocks of Al and Fe (598 and 288 Gt) are in the same order of magnitude as OC (327–466 Gt). Concerning contaminants, we focused on mercury. Using the ratio of mercury to OC (RHgC, our found value: 2.57 µg Hg g C−1) and the OC levels from various studies for a first rough estimation of the Hg reservoir, we estimate the Yedoma mercury pool to be ~542000 tons.
In conclusion, we find that deep thaw of the Yedoma permafrost domain and its degradation will bear the potential to change the availability of various elements in active biogeochemical and hydrological cycles, which will have the potential to change crucial ecosystem variables and services.

09:40 – 10:00h
Temperature and Microcracks control Frost Cracking in Alpine Rockwalls

Till Mayer (1, 2), Martha-Cary Eppes (3), Daniel Draebing (1, 4)
(1) Chair of Geomorphology, University of Bayreuth, Germany
(2) Chair of Landslide Research, Technical University of Munich, Germany
(3) Department of Geography & Earth Sciences, UNC Charlotte, USA
(4) Department of Physical Geography, Utrecht University, Netherlands

The dominant process of rockwall erosion in high alpine environment is frost weathering. Low-porosity alpine rockwalls are characterized by cracks instead of pores and higher rock strength than high-porosity sedimentary rocks. Frost weathering is controlled by permeability and water distribution inside the cracks. In this study, we use comparable Wetterstein limestone rock samples with different cracking historicity to (1) test the influence of initial crack patterns in combination with different saturation levels. We (2) quantify temperature dependent cracking efficacy and evaluate driving processes by measuring acoustic emissions. Our results show that saturation levels in low porous alpine rocks have a minor impact on ice segregation as sufficient water supply is enabled through cracks (capillary rise) and pores (absorption). Ice segregation shows for alpine rocks a higher efficacy at colder temperatures between -10 °C to -8 °C independent from the sample cracking historicity. At north- or south-facing rockwalls water distribution and temperatures are varying. Our results suggest that frost weathering is mainly prone to cold.

10:30 – 10:50h

Repeating historical ERT campaigns reveals alpine permafrost degradation

Johannes Buckel (1), Rainer Gardeweg (2), Jan Mudler (1), Sebastian Buchelt (3), Christian Hauck (2), Christin Hilbich (2)
(1) Institute for Geophysics and extraterrestrial Physics, Technische University of Braunschweig, Braunschweig, 38106, Germany
(2) Department of Geosciences, University of Fribourg, 1700 Fribourg, Switzerland
(3) Department of Physical Geography, Institute of Geography and Geology, University of Würzburg, 97074 Würzburg, Germany

Ongoing global warming affects the degradation of mountainous permafrost. Permafrost thawing impacts landform evolution, reduces fresh water resources, enhances the potential of natural hazards, and thus has significant socio-economic impact. Electrical resistivity tomography (ERT) has been widely used to map the ice-containing permafrost by its resistivity contrast compared to the surrounding non-frozen medium. We analyse the temporal changes in the resistivity distribution by comparing historical with recently measured ERT profiles. Three periglacial landforms (two rock glaciers and one talus slope) are surveyed in the Swiss and Austrian Alps by repeating historical field campaigns after periods of 10, 12, and 16 years, respectively. The resistivity values have been significantly reduced concerning ice-poor permafrost at all study sites. Interestingly, resistivity values related to ice-rich permafrost in the studied active rock glacier partly increased during the studied time period. To explain this apparent contradictory (in view of observed increase) observation, geomorphological circumstances, such as the relief and creeping behaviour of the active rock glacier, are discussed. Additional remote sensing data indicates an increased velocity in and around the active part with increased resistivity. The present study highlights alpine permafrost degradation resulting from ever-accelerating global warming.

10:50 – 11:10h

The unusual warm summer 2022 and its impact on frost and permafrost conditions at a historic high-mountain pass landscape in central Austria

Andreas Kellerer-Pirklbauer (1), Julia Eulenstein (1)
(1) Cascade – The mountain processes and mountain hazards group, Institute of Geography and Regional Science, University of Graz, Graz, Austria

Surface air temperatures in Europe in 2022 had been the highest on record for both the month of August and the meteorological summer season (June-August) as a whole. Average European air temperatures in summer 2022 were 1.3°C higher than normal. High summer temperatures had a major impact on the cryosphere causing enhanced glacier ablation and permafrost warming or even degradation. We studied the effects of the warm summer 2022 on a high mountain pass landscape in central Austria. The study area is the Hochtor mountain pass (2576 m asl, 47.08°N, 12.84°E) in the Hohe Tauern Range. The pass is located at the main Alpine drainage. It divides and links two subunits of the Hohe Tauern Range (Glockner Mountains/west; Goldberg Mountains/east) as well as two federal provinces (Salzburg/north; Carinthia/south) of Austria. Bronze findings along the former travel route over the Hochtor suggest that this mountain crossing of the Alps was already used for trading and travelling before antiquity in prehistoric times. Solifluction as well as permafrost at this site influenced presumably the dislocation of human remains. As material for this study we used long-term ground temperature data (2010-2022) from three different depths (max. 60 cm) and repeated electrical resistivity tomography (ERT) data from two years (2019 and 2022) to discuss ground temperature and permafrost conditions and trends during the period 2010-2022 and to decipher the impact of the summer-heat wave 2022 on the ground thermal

conditions at the Hochtor site. Results show trends of decreasing freeze-thaw cycles (annual basis) and higher temperatures in June, July and the meteorological summer at all three depths with a clear maximum peak in 2022. ERT data along three profiles measured identically in 2019 and 2022 show distinct permafrost lenses in all three profiles and for both years. However, at all three profiles a general decrease in the resistivity values suggest permafrost warming and degradation on the one hand, but also possibly an increase in the extent of air-filled cavities. Both effects potentially impact the surface topography at the mountain pass site.

11:10 – 11:30h

Sediment transport after rockslide-induced lake outburst flood and dam failure (Flims, CH)

Sibylle Knapp (1), Michael Schwenk (2), Michael Krautblatter (1)
(1) Landslide Research Group, Technical University of Munich, Munich, Germany
(2) Institute of Geological Sciences, University of Bern, Bern, Switzerland

With atmospheric warming, permafrost degradation and glacier retreat enhance a drastic change of alpine geomorphology and hazard conditions. Destabilized slopes and resulting mass movements become the main "producers" of sediments, with new lakes in the close vicinity. The chance of large rock-slope failures and their impact on a lake increase. Amongst the tremendous effects are high impact waves, lake outburst floods, and dam failures. Highly-fluidized rock material may overcome shorelines and travel much further down a valley. We investigated the sediment transport after the Holocene Flims rockslide-induced lake outburst flood in the Swiss Alps. Several km of geophysical profiles (ERT) accomplish up to 120 m deep insights into the sediments, which have been affected by the event. Large-scale bulldozing, water-rich entrainment and hyperconcentrated flow are revealed in the sediments of the Bonaduz plain. The results improve our understanding of the formation of the famous Bonaduz Formation and Toma hills, and allow to review stratigraphical relationships in the Tamins and Flims rockslide area.

11:30 – 11:50h

Reconstruction and quantification of the massive sediment transport after a cliff fall in a highly-active alpine basin

Natalie Barbosa (1), Juilson Jubanski (2), Johannes Leinauer (4), Ulrich Münzer (3), Florian Siegert (1,2), Michael Krautblatter (4)
(1) Department of Earth and Environmental Sciences, Faculty of Earth Sciences, GeoBio Center, Ludwig-Maximilians-University, Munich.
(2) 3D RealityMaps GmbH
(3) Department of Earth and Environmental Sciences, Section Geology, Ludwig-Maximilians-University, Munich.
(4) Chair of Landslide Research, Technical University of Munich, Munich, 80333, Germany

This study focused on the Hochvogel mountain, a prominent pyramid shape summit in the Northern Calcareous Alps and a popular destination for hikers. The Hochvogel massif consists of Hauptdolomit, highly fractured, tectonically stressed and highly weathered. A meter-size fracture at the summit poses a catastrophic rock failure scenario (Leinauer 2020, Leinauer 2021) directly impacting the south-western Weittal valley with long-term possible consequences to the Hinterhornbach town due to cascading debris flows. Between Saturday 9 and Monday 11 of July 2016, noises and a dust cloud alerted the local authorities due to a rockfall event.

We characterize the 130,000 m3 slope failure that occurred in 2016 by using seismic information and aerial imagery. The analysis of 6 intervals over the last 10 years elucidate the massive cascade redistribution of the event's sediment in the Weittal channel. The majority of the failed material takes 5-6 years to reach the channel outlet. For the first time, we reveal the morphodynamics of an alpine basin at a high temporal and spatial resolution over one decade using wide-extent digital aerial imagery. These findings advance future hazard prevention and mitigation in highly active alpine basins.

14:00 – 14:20h

The elevated low relief landforms of the Eastern Alps: Distribution and age constraints from cosmogenic nuclide dating

Kurt Stüwe (1), Jörg Robl (2), Lukas Plan (3), Derek Fabel (4), Gerit Gradwohl (1), Moritz Liebl (2), Fin Stuart (4)
(1) Department of Earth Sciences , Graz University
(2) Department of Environment and Biodiversity, Division of Geology and Physical Geography, University of Salzburg, 5020 Salzburg, Austria
(3) Naturhistorisches Museum Wien
(4) Isotope Geoscience Unit, Scottish Universities Environmental Research Centre, East Kilbride G75 0QF, United Kingdom

The Eastern Alps hold an abundance of landscapes with noticeably low topographic gradients at higher elevations above much steeper slopes. Many of these low-relief landscapes are organized in distinct surface levels and cave-system elevations often correlate with these levels. Because of an active discussion on the nature of these low-relief surfaces (i.e. are they glacially formed or are they relicts of pre-Pleistocene landforms) we have mapped these surfaces across the Eastern Alps in both, formerly glaciated and non-glaciated regions. Here, we present results from this mapping and show that the distribution and elevation of these landforms is independent of their position with respect to the Pleistocene alpine ice cap. We therefore interpret that they are mostly relicts of Pre-Pleistocene landforms that only experienced local lowering and overprinting in the glaciated regions.
Because of their low relief and because of the apparently simultaneous formation of cave systems at the same elevation we infer that many of these low-relief surfaces were formed at ground water level at much lower elevations than their present day position. As such, dating their formation allows to constrain the surface uplift rates with which they were raised to their present elevation, often at 2500 m asl. In order to date the low relief surfaces we employ cosmogenic nuclide dating (10Be, 21Ne, 26Al) of allogenic sediments from caves and low-relief surfaces. We present some 40 new data and show that they suggest mean surface uplift rates of some 0.2 - 0.4 mm/year for much of the Eastern Alps since the Pliocene.

14:20 – 14:40h

Changing thermal conditions and freeze-thaw cycles and implications for suspended sediment fluxes: The case of Ötztal, Austria

Amalie Skålevåg (1), Oliver Korup (1), Axel Bronstert (1)
(1) Institute of Environmental Science and Geography, University of Potsdam, Germany

In recent decades, the European Alps, along with other high mountain areas, have been warming faster than the global average. As thermal conditions change, temperature dependent phenomena like freeze-thaw cycles of the land surface are likely to be affected. Freeze-thaw cycles are linked with various mass-wasting processes occurring in alpine areas. Therefore, changes in their frequency and characteristics may alter the amount of sediment available for transport downstream.
In this study, we characterise freeze-thaw cycles of air and ground temperature, and their relevance for

sediment dynamics and export in a high alpine catchment within the Ötztal Alps, Austria. Taking advantage of the catchment's long monitoring history, we use air and ground temperature stations along with gridded air temperature data to analyse changes in freeze-thaw on various spatiotemporal scales. Additionally, in order to look at smaller scale variability, we supplement the sparse ground surface temperature stations with our own measurements in one of the glaciated sub-catchments of the Upper Ötztal. Finally, we connect detected patterns in freeze-thaw cycles to measured suspended sediment fluxes.

Preliminary results show that Ötztal is warming at a rate of approximately 0.4 °C per decade since 1961. Increasing (decreasing) annual air thawing (freezing) indices indicate warming permafrost and decreasing seasonal frost penetration. However, no significant trends in annual frequency of diurnal freeze-thaw cycles were found throughout the catchment. Continued investigations of the characteristics of freeze-thaw cycles and the inclusion of data on ground surface temperature and snow cover are required to get to the bottom of the 'story'.

Nov.26
14:40 – 15:40h Knight Hall

2.2 Fluvial and Dryland geomorphology - Orals

14:40 – 15:00h

Capturing complex mega dunes – New insights on self-sustained formation and aeolian processes

Manuel Herzog (1), Katharina Anders (1), Bernhard Höfle (1,2,3), Olaf Bubenzer(1,3)
(1) Institute of Geography, Heidelberg University, Im Neuenheimer Feld 348, 69120 Heidelberg, Germany
(2) Interdisciplinary Center for Scientific Computing (IWR), Heidelberg University, Germany
(3) Heidelberg Center for the Environment (HCE), Heidelberg University, Germany

Morphologies of highly complex dunes are the result of aeolian dynamics in past and present times. These dynamics reflect climatic conditions and associated forces like sediment availability and vegetation cover as well as feedbacks with adjacent environments. However, an understanding of aeolian dynamics on specific star dune morphometries is still lacking sufficient detail and their influence for formation and evolution remain unclear. We therefore investigate dynamics of a complex star dune (Erg Chebbi, Morocco), by analyzing morphometric changes derived from multitemporal high-accuracy 3D observations compared to wind measurements during two surveys (October 2018 and February 2020). Using Terrestrial Laser Scanning (TLS) and Real-Time Kinematic Global Navigation Satellite System (RTK-GNSS) measurements, the reaction of a complete star dune surface and the horizontal movement of its corresponding crests lines to an observed constant unimodal sand-moving wind were recorded. TLS point clouds are then used for morphometric analysis as well as direct surface change analysis, which relates to sand transport. Observed cumulated reaction of the dune between the different epochs of point clouds lead to the identification of an overall shielding effect, resulting in sand accumulation mainly on luv-sided slopes. Our data point to a self-sustained dune growth, which has not yet been described in such spatial detail. Furthermore, our results indicate a, to our knowledge, hitherto undescribed mechanism for dune growth on star dune forms. Steep to steepening slopes, therein, under the observed wind conditions, seem to hinder up-slope sand transport and lead to sand accumulation and, probably, under bimodal wind conditions to the formation of isosceles dune slopes. Though a comparatively short observation period, we therefore hypothesize that, besides wind intensity alone, slope angles are more decisive for sand transport than previously assumed. Particularly, dune slopes reaching maximum inclinations of 34° seem to act as sediment traps if a certain relative height of the dune arm is reached. However, evaluation of the magnitude and boundary conditions of this mechanism require long-term monitoring including 3D observation.
Overall the methodological approach of combining meteorological data, relevant for sand transport, and high-resolution multitemporal surface models can be applied for all dune forms at varying scales (barchan to star dunes) in order to understand dune dynamics and evolution. In the future, UAV-based laser scanning should be deployed to obtain similarly accurate and more frequent surface models of large dune forms, with strongly reduced effort compared to TLS acquisitions.

15:00 – 15:20h

Aeolian sediments in western Mongolia: Distribution, geomorphology and paleoclimatic implications of dunefields in the basins and sandy silt in the mountains

Frank Lehmkuhl (1), Dennis Wolf (1), Bruno Boemke (1), Michael Klinge (2), Ochirbat Batkhishig (3), Jörg Grunert (4)
(1) RWTH Aachen University, Department of Geography, Wüllnerstr. 5b, 52062 Aachen, Germany
(2) University of Göttingen, Department of Geography, Goldschmidtstr. 5, 37077 Göttingen, Germany
(3) Institute Geography-Geoecology, Mongolian Academy of Science, Erkhuu str. 11r horoolol. Sukhbaatar duureg, Ulaanbaatar-14192. Mongolia
(4) University of Mainz, Department of Geography, Johann-Joachim-Becher-Weg 21, 55099 Mainz, Germany

Aeolian sediments in Mongolia shows two main regions of aeolian sedimentation: (1) the accumulation of major sand fields especially neighbouring the eastern bank of rivers and lakes in western Mongolia. (2) The distribution of aeolian mantles of loess-like sediments in the mountains. Three large dunefields in the Valley of Great Lakes resulting from strong westerly winds, being more strength especially during the glacial periods. During glacial times lower lake levels provide additional sand sources. The dunefields stretching from 800-1400 m asl from the basins for about 200 to 300 km into the mountains up to about 2100 m asl. The basins are from North to South: (A) Uvs Nuur with Borog Deliin Els (~5000 km²), (B) Khyargas Nuur with Bor Khay Els (~2500 km²), (C) Khar Nuur with Mongol Els (~5000 km²). Different dune types were maps and in addition three major dune generations could be distinguished (1) The oldest one is mostly represented by longitudinal and by giant transversal dunes, respectively. They are covered by dense steppe vegetation and a well-developed Castanozem covering the old dunes which began to develop after the younger Dryas arid phase. (2) The next dune generation is predominantly represented by parabolic dunes of an age probably younger than 3,000 ka. The dunes are covered by an initial grey soil and sparse steppe vegetation. Parabolic dunes cover more than 50 % of the whole dune area. They have developed from old dunes due to an aridification of the climate during the younger Holocene and they also represent the earliest influence of human induced desertification. (3) The youngest dune generation is represented by active barchans. The sand and silt accumulation and transport pathways can be explained by a model of basin wide transport during the Late Quaternary as an interplay of fluvial and aeolian processes.

15:20 – 15:40h

Aeolian substrate relocation processes related to land use and land cover highlighted by wind tunnel tests in the Souss Basin, Morocco

Miriam Marzen (1), Mario Kirchhoff (1), Ali Aït Hssaine (2), Johannes B. Ries (1)
(1) Department of Physical Geography, Trier University, DE-54286 Trier, Germany
(2) Department of Geography, Université Ibn Zohr, MA-80060 Agadir, Morocco

The Souss Basin features soil-, surface- and climatic conditions potentially enhancing processes of wind erosion and mineral and organic dust emissions while subject to frequent grazing, tillage and driving. The fine-grained compacted surfaces are characterized by physical and biological crust, rock and litter cover and sparsely vegetated by patchily distributed bushes and open argan woodland. Wind-tunnel experiments and soil sampling were conducted on the deeply incised alluvial fans originating from High Atlas and Anti-Atlas mountains to test different surfaces for information on wind-erodible substrate and dust emission potential.
The results indicate dynamic aeolian substrate relocation processes on a local to regional scale. The

moderate wind velocity applied in the tests is sufficient to move considerable quantities of mineral and organic material. Differences in mean collected material are related to surface types (rock fragments, soil crust, cohesionless sand) and landscape units (wasteland, agropastoral argan woodland, wadi).
While the tested moderate-wind erosion processes are key to understand on-site sediment and nutrient dynamics between dryland fertile islands, the results also imply a considerable dust emission potential under high wind pressure.

Nov.26
16:00 – 17:30h Gallery Hall

Poster Session

2.1 Alpine Geomorphology

2.1.1
Changes in sediment connectivity due to a major precipitation event in lower Grastal, Austria

Toni Himmelstoß (1), Sarah Betz (1), Jakob Rom (1), Moritz Altmann (1), Fabian Fleischer (1), Florian Haas (1), Michael Becht (1), Tobias Heckmann (1)
(1) Chair of Physical Geography, Cath. University of Eichstätt-Ingolstadt

Sediment connectivity is an important factor regulating the propagation of change in alpine geomorphic systems. Connectivity is not a static property – but is subject to continuous and sometimes rapid change, especially in catchments with high process dynamics. Major hydrogeomorphic events affect functional connectivity and have the capacity to change structural connectivity.
In this study we investigate the changes in functional and structural sediment connectivity due to a major precipitation event in Grastal (Austria) in July 2022. With regard to sediment transfer, the investigated lower Grastalbach is longitudinally decoupled from the glacier forefield by a lake. Due to high debris flow activity in the catchment, a lateral coupling to adjacent talus slopes exists at some points. During the event, several debris flows delivered sediment into or deposited it nearby the channel. While this represents a temporary change of functional connectivity, a relocation of the main channel took place and the fluvial corridor was restructured in some parts.
To assess these changes, two surveys were conducted in the weeks after the event: One UAV survey covering the fluvial corridor and one helicopter-based ALS survey with additional image capturing, covering the whole catchment. Those data have been used to generate post-event orthomosaics and digital elevation models (DEM). Similar surveys have been carried out in the years before, hence pre-2022 DEMs and orthomosaics already exist. On this basis, two geomorphological maps are created, one reflecting the pre-event and one the post-event system structure. These maps are used to derive toposequences and sediment cascades. In addition, a DEM of difference was calculated, which is used to detect sediment fluxes and hence to validate the coupling between landforms. Our research also highlights the merits of rapid post-event surveys to document and quantify changes (attributable to a single event), and to understand their implications for system structure.

2.1.2
Growing size and impacts of outbursts from ice-dammed Desolation Lake, Alaska

Georg Veh (1), Natalie Lützow (1, 2), Bretwood Higman (3), Mark Zimmermann (4), Bodo Bookhagen (2), Anja Dufresne (5), Marten Geertsema (6), John J. Clague (7), and Oliver Korup (1,2)
(1) Institute of Environmental Science and Geography, University of Potsdam, Potsdam-Golm, Germany.
(2) Institute of Geosciences, University of Potsdam, Potsdam-Golm, Germany.
(3) Ground Truth Trekking, Seldovia, AK, USA.
(4) National Marine Fisheries Service, NOAA, Alaska Fisheries Science Center, Seattle, WA, USA.
(5) Engineering Geology and Hydrogeology, RWTH-Aachen University, Aachen, Germany.

(6) British Columbia Ministry of Forests, Prince George, BC, Canada.
(7) Department of Earth Sciences, Simon Fraser University, Burnaby, BC, Canada.

Glaciers in SE Alaska have been receding rapidly in past decades, trapping meltwater at their margins. Such ice-dammed lakes usually exist only for a few years and gradually decrease in size as the damming glaciers thin and lose water storage capacity. In Lituya Bay, Alaska, we show a contrasting case to this usual life cycle of ice-dammed lakes. There, ice-dammed Desolation Lake has been eroding the adjacent Lituya Glacier and has grown to an area of more than 12 km² during the past five decades. This lake growth is interrupted by at least 48 outburst floods, which increased their volumes between 1972 and 2022. In the past 15 years, most floods exceeded volumes of 100 mil m³, ranking among the largest reported meltwater floods in human history. Field work, airborne LiDAR, and satellite images indicate that lake outbursts cut cavities and canyons into bedrock. Individual floods leave deposits of differing lithologies in the river delta that enters Lituya Bay, suggesting that erosion during the flood is focused at different sites beneath the glacier. These sediments have formed a delta with an area of ~3 km² since the 1970s. Bathymetric surveys from 1959 revealed an average water depth of ~100 m in the delta area, such that the visible onshore part of the delta alone has accumulated more than 0.3 km³ of sediments in the past six decades. Our study reports one of the highest rates of sediment mobilisation and deposition in proglacial areas and coastal marine environments driven by glacier-related outburst floods worldwide. The rapid accumulation of loose material raises concerns about the stability of the delta. Delta-front failure could be triggered by either large earthquakes or undrained loading from landslide impact. The delta sits atop the Fairweather Fault, which is amongst the most active crustal faults in the world, in an area historically swept by large subaerial landslides. These potential instabilities contribute to the hazard posed by Desolation Lake to tourism, fisheries, and marine habitats, and call for timely monitoring and adaptation to glacier-related hazards in this and similar landscapes.

2.1.3
Explaining and anticipating extreme vertical accumulation rates in high-alpine catchments with rockfalls and debris-laden flows

Matthias Hofner (1), Felix Pfluger (1), Michael Krautblatter (1)
(1) Technical University of Munich

Sedimentation rates of fluvial dominated catchments usually reach magnitudes in the order of up to few millimetres per year. This is due to these systems either being in a sedimentary equilibrium or only having a low sediment supply to the stream. In contrast to these non-alpine systems, alpine systems provide a multitude of processes like debris flows and rockfalls which can disturb the sedimentary equilibrium. This can provide large sediment yields to the stream and create storages. The influence of those processes on the sedimentation rate must be analysed to better understand the vertical sediment accumulation in high-alpine catchments. To achieve this, we used a combined approach of geophysical methods, utilising electrical resistivity tomography (ERT), and mapping of depositional structures. As research area we chose the Reintal and Höllental valley in the Wetterstein Mountains. Here we show that, the sedimentation rates reach up to approximately 50 cm/a with an average of 2 to 5 cm/a. Processes having the highest impact on the sedimentation rate seem to be rockfall, landslide and bergsturz events by which the equilibrium of the fluvial system is massively disturbed due to the formation of dams or the breaching of these. We further assessed that debris-laden flows also contribute significantly to the high sedimentation rates. This shows that alpine catchments are highly dynamic systems, with sedimentation rates exceeding those of non-alpine catchments. It is important to be aware of this because in a rapidly

changing climate such extreme vertical accumulation rates can have an unexpectedly strong impact on infrastructure in alpine regions.

2.1.4
Lab results on rock moisture movement during freezing cycles

Andrew Mitchell (1), Oliver Sass (1)
(1) University Bayreuth, DFG

As a key part of landscape evolution and a hazard to people in Alpine terrain, rock weathering leads to the breakdown and weakening of rock, causing rock fall and ultimately slope failure. Rock moisture availability is a major factor in these processes. It is understudied, partly due to a lack of reliable measurement techniques. Understanding weathering regimes in a changing climate are key to mitigating Alpine hazards and to understand long-term landscape evolution.
As part of the CLIMROCK project, Wettersteinkalk blocks were used in a series of laboratory based experiments in a climate chamber to look at rock moisture movement and it's weathering effect in alpine rock walls. Experiments: (1) slow frostcracking cycles on 40x40x20cm blocks with a water reservoir and equipped with 4 time domain reflectometry (TDR) and 2 acoustic emission (AE) sensors attached to measure cracking events as a proxy for weathering; (2) Diurnal freeze-thaw experiments on blocks of the same size, this time equipped with 9 Electrical Resistance (ER) sensors and 4 AE sensors; (3) small blocks (10x10x10cm) with AE sensors at different saturations (0, 25, 50, 75 & 100%) and temperature cycles.

In experiment (1), probable evidence of rock moisture movement to the freezing front and refreezing events occurred. Due to accuracy achievable with (1), only a qualitative link between moisture movement and acoustic events triggered by subcritical cracking was possible. Experiment (2) enabled more accurate locating of cracking events and moisture movement through the block.
Converse to initial hypothesis, it appears the samples with a lower volumetric water content (VWC) show increased cracking events during freezing cycles. This was seen in both experiments (1) and (3). Findings from these laboratory experiments will be applied to the interpretation of field rock moisture movement observations in the Bavarian and Austrian Alps.

2.1.5
Detecting interannual and seasonal variability in rock glacier movement using a feature tracking approach

Lisa Rehn (1), Carla Tapia Baldis (2), Jan Blöthe (1)
(1) Universität Freiburg, Institut für Umweltsozialwissenschaften und Geographie, Schreiberstraße 20, 79098 Freiburg
(2) Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales, CCT CONICET, 5500 Mendoza, Argentina

Permafrost degradation induces changes in water availability and runoff as well as slope instabilities in alpine regions. A thorough quantification of the degradational processes is therefore important for society in the immediate region and beyond, as it helps deepening our understanding and ultimately allows anticipating future trajectories of the alpine cryosphere. However, permafrost being an underground phenomenon makes quantification and temporal differentiation of the degradation processes inherently difficult. Active rock glaciers have become a prime research object as internal permafrost degradation induces changes in their kinematic behaviour.
In our study, we investigate the surface kinematics of the Kaiserberg rock glacier in the Austrian Kaunertal

on different timescales. To derive interannual surface displacement rates, we rely on UAV-derived digital topography from 2019-2022. In addition, we installed a time-lapse camera that records daily images of the rock glacier in July 2022 to resolve rock glacier movement at a higher temporal resolution. For both data sets, we use a feature-tracking approach as implemented in the environmental motion tracking software EMT. Preliminary results show differentiated velocity fields on the rock glacier surface with the southern lobe moving significantly faster than the larger northern lobe. Mean movement rates (2019-2022) are around 0.58 m yr-1 for the southern lobe where maximum movement rates range up to 1.80 m yr-1. In contrast, mean movement rates for the northern lobe are only 0.1 m yr-1 with maximum rates of 0.36 m yr-1. Similar to earlier studies, we find a general increase in surface velocities over the past years that points to ongoing permafrost degradation. The pending analysis of the daily time lapse photos will provide an insight into how much of the annual movement occurs in summer and how the kinematics vary within a single season. As the timing of data acquisition varied each year, this knowledge can then also be used to refine the interpretation of interannual movement rates.

2.1.6
Glaciological Investigation of the Stubacher Sonnblickkees in the Upper Stubach Valley, Salzburg, Austria

Andreas Gschwentner (1), Karl Krainer (2), Andrea Fischer (1)
(1) Österreichische Akademie der Wissenschaften (ÖAW) - Institut für Interdisziplinäre Gebirgsforschung (IGF)
(2) Innsbruck University- Institue of Geology and Paleontology

The present study aims at investigating and describing diverse quaternary phenomena of the upper Stubach valley (High Tauern range, Salzburg, Austria). In particular, glacier mass balance measurements on Stubacher Sonnblickkees (SSK) and the investigation of a suspected rock glacier, located northeast of the Medelzscharte, are presented here. BTS and electrical conductivity measurements at the rock glacier have shown that this morphological feature is built up of permafrost-saturated debris, originated after the retreat of a former glacier. However, whether an embryonic rock glacier will develop from it remains debatable, as this depends strongly on future climate evolution. Between 2016 and 2021 glacier mass balance measurements on SSK have shown that in the year 2016/17 the glacier suffered a mass loss of 751·103 m3 water equivalent (w.e.) and a specific mass balance of -829 mm w.e. In the period of 2017/18, the mass loss was 1764·103 m3 w.e. with a specific mass balance of -1946 mm w.e., and was thus more than twice as high as in the previous measurement period. During the following years, the mass balance tended to more positive values. In 2019/20, SSK achieved the best annual balance since measurements began in 2017. The SSK is an east-facing glacier in the eastern Granatspitz Group. It extends from an altitude of about 3.050 m (accumulation zone), in the summit region of Granatspitze (3.086 m) and Stubacher Sonnblick (3.088 m), to 2.650 m a.s.l. (altitude of terminus). The glacier has been retreating since 1850, with only brief advance periods around 1920 and 1980. Since H. Slupetzky began annual measurements of length changes in 1960, an average 160 m retreat has been recorded. Due to ongoing climate warming and the low elevation of the glacier, it is only a matter of time before the glacier will completely retreat and disappear.

2.1.7
Paraglacial landform dynamics at the forefield of the Obersulzbach glacier (Austria)

Sabine Dietel (1), Jan-Christoph Otto (1)
(1) Department of Environment and Biodiversity, University of Salzburg, Salzburg, Austria

Glacier retreat in high mountain areas leads to the exposure of landscapes with unstable landforms (e.g. slopes, moraines). These highly dynamic systems provide potential for failure which poses threat to humans. In 2001, three hikers were killed by a rock avalanche at the foot of a moraine slope of the Obersulzbach glacier. Recently deglaciated hillslopes in the glacier forefield experience paraglacial transformation in order to adjust to the changing environmental conditions and recover from the geomorphological disequilibrium. This study aims to gain knowledge about the hillslope dynamics, the underlying paraglacial adjustment processes and the driving mechanisms for sediment release. Investigations on a spatio-temporal scale seek to contribute to a better understanding of the previous developments and enable prospects for the future of these paraglacial land systems in the context of climate change.
Field mapping was carried out to gain knowledge about the recent geomorphological situation. The field observations were compared with historical orthophotos to identify changes in landforms, surface structures and process chains. Past surfaces were reconstructed and compared through the analysis of multi-temporal point cloud data from terrestrial laser scans (2009, 2011, 2014, 2016, 2019, 2022). The M3C2 algorithm (Multiscale Model-to-Model Cloud Comparison) was applied for the detection of topographic surface changes over time. Based on DEM of Difference (DoD), volumetric changes were estimated.
The results of the study reveal hotspots of erosion and accumulation along the studied hillslopes for the investigated time period. Due to the geological and sedimentological properties of the study area, precipitation has a major influence on the observed non-linear sediment release. Sediment availability is the limiting factor for the gravitational, fluvial and fluvio-glacial reworking processes resulting in relatively small transport volumes. General stability is assumed for the studied hillslopes after almost 25 years of deglaciation.

2.2 Fluvial and Dryland geomorphology

2.2.1
Terracettes in the hyperarid Atacama Desert – a fog-driven landform of Holocene age?

Simon Matthias May (1), Dirk Hoffmeister (1), Dominik Brill (1), Olaf Bubenzer (2)
(1) University of Cologne, Institute of Geography, 50923 Cologne, Germany
(2) Heidelberg University, Institute of Geography and Heidelberg Center for the Environment, 69120 Heidelberg, Germany

Terracettes are quasi-contour parallel step-like microtopographic features consisting of repetitious platform-type benches and slope-type risers and are documented from hillslopes in a range of climates. While a number of studies emphasize their formation by trampling of livestock and grazing animals (cat steps or stock trails), it has been shown that terracette formation may be explained by a number of natural processes, including solifluction or freeze-thaw processes, slumping, soil creep, or vegetation control. Despite this variability and the controversy about their origin, these micro-terraces may alter hillslope soil moisture and vegetation patterns, infiltration and surface hydrology, as well as downslope sediment flux, potentially disconnecting downslope conveyance processes of surface runoff. Given the process mechanisms discussed in these previous studies, the extremely hyperarid climate of the central Atacama Desert in northern Chile may be regarded as unfavourable for terracette formation; here, livestock and grazing animals are virtually absent, moisture availability is extremely limited, and frost processes in elevations below ~1000 m asl are rare. Nevertheless, here we report on terracette-covered slopes in the central Atacama Desert located close to the Rio Loa canyon in the Coastal Cordillera that

represents an important inland pathway for coastal fog in the Atacama Desert. Based on sedimentological and geomorphological investigations, UAV-derived aerial photos and soil moisture monitoring, we present geomorphological, stratigraphical and soil hydrological characteristics of the terracettes and discuss potential drivers of terracette formation. Our observations suggest a combination of wind and fog-related moisture supply, particularly during several day-long periods of sustained high relative humidity and fog occurrence, as the key driver for terracette formation, adding to the various processes discussed in previous studies. Finally, OSL dating of terracette platform sediments suggests a Holocene activity of terracette formation, thereby illustrating the importance and activity of fog-driven hillslope dynamics under present hyperaridity.

2.2.2
Assessing the Connectivity of the River Network in the Aral Sea Basin based on Connectivity Indices

Florian Betz (1), Rafael Schmitt (2), Magdalena Lauermann (1), Tobias Heckmann (3)
(1) Catholic University Eichstätt-Ingolstadt, Applied Physical Geography
(2) Stanford University, The Natural Capital Project and Stanford Woods Institute for the Environment
(3) Catholic University Eichstätt-Ingolstadt, Chair of Physical Geography

Connectivity is crucial for the functioning of the ecosystems within river corridors and thus for the provision of ecosystem services. Today, the connectivity of most (large) rivers is affected by anthropogenic infrastructure such as hydropower dams. This is also true for the Aral Sea Basin in Central Asia. The importance of rivers as freshwater resource led to an intensive exploitation of water resources and to the construction of a large number of dams and reservoirs and thus to a fragmentation of the river network. Despite its relevance for the functioning of the river corridors, connectivity remains unexplored for the Aral Sea Basin.
In this study, we present a first assessment of the connectivity of the river network in the Aral Sea Basin. Basis is a channel network delineated from the 30 m Copernicus DEM. Additional input are the barriers in the Aral Sea Basin. We use the dam data from Global Dam Watch as basis and complement it by mapping from high resolution Google Earth imagery. The river network and the barrier locations are used to create a graph representation of the river network where river reaches are treated as edges and confluences as well as dam locations as nodes. This river graph is used to compute connectivity metrics.

With this study, we deliver a first analysis of the connectivity of the river network in the Aral Sea Basin. However, the static analysis of structural connectivity gives a first indicator only and further analysis is required to understand the dynamic processes shaping the river corridors in the Aral Sea Basin. Thus, rather than a final result, we see our study on river network connectivity as important basis for assessing sediment dynamics across the network, natural flow regime and its impairment as well as river and floodplain habitat integrity.

2.3 Quaternary geomorphological systems, biogeomorphology and human-environment interaction

2.3.1
Holocene landscape reconstruction in the surroundings of the Temple of Pepi at ancient Bubastis, southeastern Nile Delta (Egypt)

Philipp Garbe (1), Amr Abd El-Raouf (2), Ashraf Es-Senussi (3), Eva Lange-Athinodorou (4), Julia Meister (1)
(1) Physical Geography, Institute of Geography and Geology, University of Würzburg, Würzburg, Germany
(2) Geology Department, Faculty of Science, Zagazig University, Zagazig, Egypt
(3) Ministry of Tourism and Antiquities of Egypt, Cairo, Egypt
(4) Egyptology, Institute for Ancient Studies, University of Würzburg, Würzburg, Germany

For temples in ancient Egypt, sacred water canals or lakes that provided water for many types of religious rites and other activities were very specific and important features. In recent years, two of these sacred water canals have been demonstrated for the Temple of Bastet in ancient Bubastis. It has now been investigated whether sacred water channels also flowed around the Temple of Pepi (2300–2250 BCE), located approximately 100m to the northwest, and whether there is a direct connection to those at the Bastet Temple. Exploring the Holocene landscape genesis of the Temple of Pepi, 15 drillings and 7 ERT measurements were carried out in the surroundings of the Temple in spring 2022. The results show loamy to clayey sediments in deeper sections of all drillings with a maximum thickness of 1.70m, indicating a marshy or swampy depositional environment. Based on the ceramic fragments found in these deposits, which can be roughly dated to the Old Kingdom (2700-2200 BCE), the area around the Temple of Pepi was most likely characterized by a marshy, swampy landscape. However, the time frame still needs to be explored in detail. In the course of time, this areal fell dry or was deliberately drained for its subsequent use for occupation. Regarding to the original research question, there is no evidence for a direct connection to the canals of the Temple of Bastet yet. This poster presents preliminary results of the ongoing research.

2.3.2
Preliminary geomorphological activity analysis and their implications for the Landscape development of Bajestan Playa, Iran

Christian Büdel (1), Zakieh Rashidi (1)
(1) Institute for Geography and Geology, Julius-Maximilians-University Wuerzburg

The central Iranian highlands nowadays encompass hotspots of both meteorological extreme events and of severe landscape change due to climate change. The record of recent catastrophic events in the Middle East draws a picture of alternating periods of drought and periods of intense flooding. Holocene pronounced lake level retreats as derived for phases at Younger Dryas (~12.8-10.5 ka), ~8,2 ka, ~5,2-4,2 ka, and the Medieval Climate Anomaly (MCA) usually come with a subsequential increase of prograding fluvial channels, where periodical water supply was secured, and of aeolian activity.
This study aims to the identification of geomorphological activity areas within the Bajestan Playa in Northeast Iran, in order to understand youngest landscape development and process rates. Here previous investigations by Calzolari et al (2016) revealed three phases of alluvial fan and river terrace formation at ~53, ~25, and ~6 ka (OSL ages). They were controlled by base level changes related to both drainage network changes and fault-activity.
Remote sensing time series analyses and initial field data now suggest a complex interplay of aeolian

and fluvial erosional and depositional processes alternating along the narrow transitions from pediment and alluvial fan toe to playa and alluvial plain. Dust accumulation due to prevailing easterly winds as well as extensive deflation thus take place at the site in close proximity to each other.

2.3.3
Geomorphology of the Laguna Caracota catchment, Altiplano northern Chile – linking landscape evolution, wetland formation and early human occupation

Jan-Christoph Otto (1), Luca Sitzia (2), Matias Gallardo (2)
(1) Department of Environment and Biodiversity, University of Salzburg, Salzburg, Austria
(2) Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile

The landscape evolution of the central Altiplano in northern Chile has received relatively little attention so far. Early human occupation in this high-mountain, semi-arid environment is relatively well known, based on individual sites. However, a landscape scale perspective on the human occupation and distribution of the archeological record is lacking. Particularly relevant to resolve the archeological questions are the formation of wetlands and temporary lakes by geomorphological processes and climatic conditions. As part of a geoarcheological research project focusing on Pleistocene/Early Holocene hunter-gatherers groups, we present a detailed geomorphological map of the Laguna Caracota catchment (18°49'S 69°11'W, 4200 – 4600 m) in the Altiplano of Northern Chile (Arica y Parinacota Province). From a geomorphological perspective the research aims at explaining the past and present landscape dynamics and the evolution and distribution of wetlands. Furthermore, geomorphological mapping is used to discuss the distribution of lithic artefacts with respect to the potential age of the land surface.
Preliminary results show that the Laguna Caracota catchment is a wide glacially shaped valley with smooth topography and two shallow depressions, where temporarily dry lakes persist. The current landscape is mainly modified by wind erosion and locally by sheet and gully erosion that onset in the humid phases from December to March. Past processes of glacial activity as well as lake level changes could be reconstructed in the field. Considering the locus of archeological artefacts concentration and their relative chronology on the current surface we propose that landscape changes since the time of early human occupation have been limited to small scale changes with little impact on the spatial distribution of the archeological material.

2.3.4
Catchment-scale distribution of biogeomorphic succession stages and potential ecosystem engineering

Stefan Haselberger (1), Ulrich Zangerl (1), Simon Scheper (2, 3) , Jan-Christoph Otto (4), Lisa-Maria Ohler (4), Robert R. Junker (4, 5), Sabine Kraushaar (1)
(1) University of Vienna, Department of Geography and Regional Research, 1010, Vienna, Austria
(2) Dr. Simon Scheper – Research | Consulting | Teaching, 29413 Dähre, Germany
(3) Environmental Geosciences, University of Basel, 4056 Basel, Switzerland
(4) University of Salzburg, Department of Environment and Biodiversity, 5020, Salzburg, Austria
(5) Philipps-University Marburg, Evolutionary Ecology of Plants, Department of Biology, 35043, Marburg, Germany

The frequency and magnitude of geomorphic processes and the presence of vegetation shapes the interaction between abiotic and biotic factors glacier forelands as shown in plot-scale studies. Geomorphic processes may disturb vegetation succes-sion and plants have the potential to stabilize terrain, as described in the biogeomorphic succession model.
Capturing this interplay between disturbance and stability remains challenging as abiotic and biotic processes happen on different temporal and spatial scales. As proxy for potential disturbance, we combined the revised universal soil loss equation model (RUSLE), adapted to high mountain areas to calculate potential soil loss and mapping of geomorphic processes domains. Vegetation cover is

considered as proxy for stability and has been automatically assessed using high-resolution imagery collected via an unmanned aerial vehicle (UAV). Field-based plot sampling along a chronosequence provides insight into the distribution of species along the biogeomorphic succession.
Potential disturbance is closely related to steep slopes for gravitational and denudational processes as shown by RUSLE results and process domain mapping. The disturbing potential of fluvial processes is covered by process domain mapping. First bigger patches (~100 m²) of very high stability (vegetation cover > 75%) occur about 50-80 years after glacier retreat, increasing in size (~5000 m²) in areas older than 100 years. Outside the LIA moraine 30% of the area shows very high stability. The combination of methods allowed us to differentiate three stages of biogeomorphic succession and to locate initial, current and past stages of potential ecosystem engineering of plants. The catchment-wide analyses of stability showed how important it is to consider geomorphic disturbance, as geomorphic processes locally distort the general trend of primary succession.

2.3.5
Sensing destruction, timely and from safe distance: real time insights to fast propagating catastrophic flood events

Michael Dietze (1,2), Rainer Bell (3), Thomas Hoffmann (3), Lothar Schrott (3), Niels Hovius (2)
(1) Georg-August-University, Faculty of Geosciences and Geography, Goldschmidtstr. 3, D-37077 Göttingen
(2) GFZ Potsdam, Section 4.6 Geomorphology, Telegrafenberg F427, D-14473 Potsdam
(3) University of Bonn, Department of Geography, Meckenheimer Allee 166, D-53115 Bonn

Landscapes under transient forcing conditions are exposed to episodic yet stochastic phases of extreme activity. The unpredictability and severity of process activity bring established sensing approaches to and beyond their limits: stream gauges get washed away, optical systems may miss timing or location of the activity, and dedicated sensors miss the emerging target variable of relevance. These exemplary shortcomings illustrate the need for a different, complementary method that allows for continuous and spatially distributed sensing of a multitude of key metrics that characterise extreme events as they happen.
Here, we explore the July 2021 Ahr valley flood event as well as subsequent, focused and distributed landscape activity in the catchment using geophysical sensor networks. We introduce a new approach to real time extraction of key flood kinetic parameters such as water level, discharge, debris flux and propagation velocity. We present the legacy of the 2021 flood as expressed by triggered hillslope activity and increased sediment transport effectiveness during subsequent (smaller) floods. While the Ahr valley flood serves as a drastic example of rain driven geomorphic activity, there are numerous further landscapes of similar configuration in Central Europe that are inevitably similarly subject to future stochastic events. Hence, we discuss to which extent generic sensor systems could improve our preparedness and early warning capabilities.

2.4 Deciphering and modelling long-term landscape evolution

2.4.1
Controls of Andean valley-floor widths

Stefanie Tofelde (1), Fiona J. Clubb (2)
(1) University of Potsdam, Institute of Geosciences, Potsdam, Germany
(2) Durham University, Department of Geography, Durham, UK

River-valley geometries range from deeply incised valleys with narrow or no floodplains to cross sections of kilometer wide, densely populated plains. The diversity of valley shapes is the product of the interplay

between tectonic uplift and erosion by rivers. Rivers deepen valleys through vertical incision into underlying bedrock and widen valleys by lateral erosion of enclosing valley walls. While the rate of incision is thought to mainly compensate tectonic uplift, comparably little is known about processes and controls of valley widening and valley-floor width. Due to this knowledge gap, we are currently unable to reproduce the wide range of valley shapes that we observe in nature and fail to predict floodplain evolution under changing environmental conditions.
Field measurements of valley floors are sparse, but generally indicate that valleys are narrower at sites of enhanced uplift and grow wider with greater river discharge and in softer lithologies. However, order of magnitude scatter in those datasets suggest further, so far unknown controls on valley-floor width. Here, we systematically quantify valley-floor widths of 163 river valleys draining the Western Andes between 5°S and 38°S. At each site, we estimate potential control parameters on valley-floor width including river discharge, rock erodibility, uplift rates, total sediment discharge, and lateral sediment supply. The respective influence of each of these parameters on valley-floor widths is investigated using a random-forest approach. A better understanding of controls on valley-floor evolution will both enhance future prediction of floodplain response to climate change and enable past climate and tectonic reconstructions from valley topography.

2.4.2
The influence of continental rifting on the development of drainage networks

Fabian Dremel (1), Jörg Robl (1), Christoph von Hagke (1), Moritz Liebl (1)
(1) University of Salzburg, Department of Environment and Biodiversity, 5020, Salzburg, Austria

In many regions of Europe and North America, rocks of the Variscan orogeny occur in so called "Mittelgebirgs"-landscapes with peak heights exceeding 1500 m. As the topography of the Variscian orogen was levelled already in the Permian due to post-orogenic erosion and thermal subsidence, processes other than mountain building at a convergent plate boundary must be accountable for the observed high topography. In the context of Cenozoic topography formation in the Massif Central, the Black Forest and the Vosges Mountains, as well as the Bohemian Massif, mantle plume activity, continental rifting, slab break-off or tearing, and lithospheric buckling are discussed.
In this study, we focus on the Black Forest and the Vosges Mountains to investigate the link between continental rifting, relief formation, and the response of the drainage system to spatial and temporal changes in uplift rate. Using a simple landscape evolution model (LEM) for fluvial erosion and flexural isostasy, we describe the principal patterns in the topography that evolve in such a geodynamic setting over time. We compare characteristic landscape metrics (e.g., normalised steepness index) from the study area with those from different time steps of a LEM. To constrain timing and rates of the topographic adjustment we complement existing low-temperature thermochronology datasets with new measurements at key sites.
Early results show that our simple numerical model reproduces the observed first order features in plan view and profile geometry of the drainage network. A drainage divide close to the escarpment edge of each graben shoulder separates short, steep rivers that drain directly into the rift valley, from long, low gradient rivers that first drain away from the rift to eventually confluence with the receiving stream several tens of kilometres downstream of the source area. The numerical model predicts across divide differences in river steepness and consequently in erosion rate. Over time this leads to drainage divide migration away from the rift centre, unloading of the lithosphere on the current rift flanks, and isostatic uplift with wavelength and amplitude as a function of lithospheric strength. New apatite U-Th/He data are not yet available but results from morphometry and time-dependent numerical models support targeted sampling.

2.4.3
Conceptual Approach: Modelling Plume Mode Erosion in a Multilayer Landscape Model Using TopoToolbox

Max Rau (1)
(1) Chair of Landslide Research, Technical University of Munich, Germany

Landscape evolution models (LEMs) usually provide a better understanding of the processes and phenomena that contribute to the formation and evolution of landscape forms.
The formation of a landscape in uplift due to a plume in the subsurface has hardly been studied so far. Therefore, in a first approach, the modeling of the valley development in a plume mode influenced area is planned using the example of the southern German stratigraphic plain. For the modeling the LEM named TTLEM, which is part of the Matlab based program TopoToolbox, will first be adapted to be able to create a multilayer model. However, it remains to be seen to what extent the stream power law integrated in TTLEM is suitable for reproducing the geomorphological landscape of the stratified plain with its characteristic strata and wide valleys.
Furthermore, TTLEM is to be adapted in such a way that it no longer describes the inflow of the slopes as implicit linear or non-linear diffusion with a treshold slope. Instead, the parallel slope weathering observed in nature in solid rocks shall be implemented.
Since fractures can have a large effect on the spatial distribution of rivers and valleys, as well as their incision rates, attempts are being made to integrate fracture systems into TTLEM.
Currently there are many ideas, but implementation is just being worked on and no concrete results are available yet. I am therefore looking forward to a stimulating technical exchange and discussions on possible solutions.

2.5 Engineering geomorphology and geomorphological hazards and risks

2.5.1
Are Large Landslides Getting Larger?

Joaquin Vicente Ferrer (1), Oliver Korup (1)
(1) Institute of Environmental Science and Geography, University of Potsdam

The influence of changing climate conditions on the frequency and magnitude of landslides in mountainous areas. There is a common notion that warming temperatures and changing rainfall patterns affect hillslope processes that enhance slope instability. While shallow landslides are controlled by peak rainfall intensity at short durations, large deep-seated landslides (ALS > 100,000 m2 or VLS > 1 x 106 m3) are affected by variations in the groundwater regimes that result from changes in temperature and rainfall patterns. Large landslides are exceptionally damaging and fatal catastrophic events with the mobility to runout over kilometers at high velocities and potential to dam rivers.
Changes in the hydrological cycle driven by warming air temperatures indirectly impacts large deep-seated landslides but extent of this relationship remains an open question. An upsurge in accessible digital landslide inventories in recent years provides a contemporary characterization of distribution of landslides triggered by rainfall and earthquake events. The increased volume of detailed spatial information also reveals an increased number of large landslide events that result from such extreme triggering-events.
In this study we investigate whether catastrophic large landslides from 1970-2020 are increasing in area.

We present a global catalog of large landslides collated from openly accessible modern landslide inventories containing geometric and temporal information. The objective of this study is to provide meaningful probabilistic insight on the occurrence of these events. We explore the temporal changes in the General Pareto Distribution model parameters based on triggers, known lithology, and elevation. The results are poised towards making headway in establishing a relationship between the impact of air temperatures and the magnitude of failure areas of large landslides.

2.5.2
What three years of TLS- based monitoring tells us about rockfall hazards in touristically developed alpine gorges Höllentalklamm, Bavarian Alps).

Benjamin Jacobs (1), Paul Emil Schmid (1), Michael Krautblatter (1)
(1) TUM, Chair of Landslide Research

The Höllentalklamm (Höllental Gorge) in Grainau is part of the main mountaineering route to the Zugspitze and with up to 2000 daily visitors a major tourist attraction in the Bavarian Alps. Following several recent rock fall events (up to 300 m³) the TU Munich collaborates with the local Alpine Club (DAV-GAP) to detect, assess and monitor rock fall hazards in the Höllentalklamm. We combine multi-temporal terrestrial laser scanning, field mapping and the use of wireless sensor networks and evaluate the applicability of these methods for deeply incised alpine gorges.
In this study, we investigate a deeply incised and tectonically shaped alpine gorge in a well-researched mountain range (Wetterstein). In visibly accessible areas, multi-temporal terrestrial laser scanning is applied to (a) detect active rock fall areas, (b) identify hazardous objects pre-failure and (c) monitor potentially unstable parts of the rock face. Additionally, larger objects, such as a 600 m³ rock tower located directly above the track, are equipped with a redundant crackmeter system implemented in a wireless sensor network. After three years of biannual TLS epochs we can draw conclusions from our rockfall monitoring approach. TLS in alpine gorges is well-suited for the detection and quantification of rockfalls of several orders of magnitudes. The data also show that rockfall activity is linked stronger to structural geological features than only relief and that events above certain magnitudes have a good chance of being detected pre-failure. However, the extreme terrain and geometry of alpine gorges are a challenge for LiDAR coverage.
Here we show a benchmark rock fall hazard assessment and safety concept for Alpine gorges with high safety demands providing several years of data. This work helps to evaluate the applicability of well-established monitoring techniques in confined and inaccessible terrain (deeply incised gorges).

2.5.3
Probability of rockfall occurrence under climate change conditions in Central Europe – results from the ClimXtreme project working group

Martina Wilde (1,2), Katrin M. Nissen (3), Thomas M. Kreuzer (1,2), Annika Wohlers (1), Uwe Ulbrich (3), Bodo Damm (1)
(1) Institute for Applied Physical Geography, University of Vechta, Vechta, Germany
(2) Institute for Geography and Geology, University of Würzburg, Würzburg, Germany
(3) Institute for Meteorology, Freie Universität Berlin, Berlin, Germany

The impact of climate change on mass movements remains difficult to assess and in this context, it is important to investigate the dynamics and influence of changing meteorological conditions. The analysis of these impacts on mass movement processes in Central Europe is the focal point of the project “Landslides in a changing climate (LASLI)“, which is a subproject within the ClimXtreme project (Module

C: Impacts of extreme weather and climate events on natural and socio-economic systems) funded by the German Federal Ministry of Education and Research (BMBF).
The current activities of the project include studies on the influence of antecedent precipitation on the occurrence of landslides and investigations on the Eifel floods of 2021. Furthermore, a statistical model was develop based on a rockfall dataset for Germany to analyse the meteorological triggers and to quantify rockfall probability due to changing meteorological- and hydrological factors. The data set includes data from a rockfall database for Germany for the period between 1838 and 2018 and data provided by the German railway company (Deutsche Bahn) covering the period from 2015 to 2020.
The goal of this project is to determine controlling factors and triggers of rockfall events and changes in rockfall probability during the last decades in the German lower mountain ranges. Furthermore, it comprises the integration of climate change scenario simulations to analyse possible changes of rockfall probability in the future under climate change conditions.
Results of the rockfall analysis show a decrease in rockfall probability in the lower mountain ranges of Germany. Here, decrease in freeze-thaw cycles is determined as the dominant factor for this trend. These findings emphasize the importance of differentiating process types and regional characteristics when investigating the impact of climate change on mass movements.

2.5.4
Anthropogenic landslides at transportation infrastructure – examples from Lower Saxony, Central Germany

Annika Wohlers (1), Bodo Damm (1)
(1) University of Vechta

With growing urbanization, an increasing number of landslides worldwide are linked to anthropogenic influences, especially along transportation routes. In southern Lower Saxony at least 30% of occurring landslides are linked to anthropogenic interactions. Based on the analysis of historical landslide data, different approaches have been utilized to evaluate the consequences of anthropogenic influences considering landslides at transportation infrastructure in Lower Saxony.
The anthropogenically affected predisposing and triggering factors of landslides are evaluated by statistical means. From construction and mitigation practices linked to landslide occurrence, case histories have been developed to analyze the complex interactions between human interactions in land use practices, landslide activity, risk perception as well as repair and mitigation measures are illustrated. In addition, the road network vulnerability is assessed and modeled using vulnerability indicators. These illustrate a close link between existence and state of existing mitigation measures and landslide activity.

2.5.5
Global trends and patterns of Glacier Lake Outburst Floods since 1900 monitoring

Natalie Lützow (1), Georg Veh (1), Oliver Korup (1)
(1) Institute of Environmental Science and Geography, Potsdam

Ongoing climate change has led to significant glacier mass loss in many mountain regions across the globe. Retreating glaciers have provided new space for glacier lakes to form and grow in past decades, posing hazards to mountain communities when they empty catastrophically. Such Glacier Lake Outburst Foods (GLOFs) are often accompanied by heavy channel erosion and deposition in the downstream areas, leading to millions of dollars of damages and fatalities in mountain regions worldwide. However, it remains unclear, if the observed increase in number and size of glacier lakes has changed the flood

volumes or peak discharges of GLOFs. Here, we scanned information from 773 different literature and web resources and compiled the largest available database of GLOFs, comprising 3102 cases in High Mountain Asia (HMA), Scandinavia, Greenland, Iceland, the European Alps, the Andes, the Pacific NW, New Zealand and Russia. We find limited evidence that the reported global increase of glacier lake size has led to a commensurate increase in the magnitudes of GLOFs since the beginning of the 20th century. Trends in flood volumes depend strongly of the type of dam that impounds glacial meltwater. Temporal trends for moraine-dammed lakes vary strongly between the study regions, indicating increases and decreases in flood volume since 1900. In contrast, ice-dammed lakes, water pockets and lakes influenced by geothermal activity have produced smaller floods in the majority of the study regions. Time series of satellite images show that ice-dammed lakes with repeat outbursts decreased in area with time, fostering smaller flood volumes. On regional scale, these trends correlate only weakly with rates of glacier thinning. We infer that outbursts causing substantial impacts may occur in a future degrading cryosphere, which calls for close monitoring of this climate-driven natural hazard.

2.5.6
Complex, deep-seated landslide dynamics in the Italian Alps: understanding the temporal evolution by integrating the results of multi-technical monitoring

Edoardo Carraro (1), Lorenzo Brezzi (2), Lorenzo Nava (3), Filippo Catani (3)
(1) ENGAGE - Geomorphological Systems and Risk Research, Department of Geography and Regional Research, University of Vienna, Vienna, Austria
(2) Department of Civil, Environmental and Architectural Engineering, University of Padova, Padova, Italy
(3) Department of Geosciences, University of Padova, Padova, Italy

The wide range of landslides that commonly occur in the hilly and mountainous areas makes it essential to properly define the geomorphological characteristics of each specific site. In fact, these can be interpreted as the combination of predisposing factors and hydro-meteorological conditions, which result instead to be triggering factors. Furthermore, analyzing the slope conditions is important in order to assess the resulting landslide risk, particularly in relation to the consequences that might negatively affect people and infrastructure.
In this regard, this study presents the results of multi-technical monitoring of the Sant'Andrea landslide, a complex and deep-seated active landslide located in the municipality of Perarolo di Cadore (Belluno, Italy). In recent years, the mass movement has shown a progressive worsening of stability, with sudden increases in displacement rates. Numerous investigations have been carried out to characterize the geomorphological and geotechnical properties of the site. The kinematics has indicated an alternation of slow displacements, such as long-term creep, and episodic or seasonal accelerations, strongly related to rainfall events.
To better understand the dependence of the landslide accelerations on hydro-meteorological factors, the surface displacements have been monitored over time by means of several monitoring approaches (both with continuous and discontinuous surveys). The methodologies included the use of Terrestrial Laser Scanning (TLS) and Robotic Total Station (RTS), as well as real-time monitoring by ground-based radar interferometry (GB-InSAR) and time-lapse image analysis (DIC).
The monitoring results confirmed the complexity of the kinematics underlying the landslide dynamics. By interpreting the velocity fields derived from the multi-technical monitoring, it is possible to identify the evolution of the displacements over time, to forecast accelerating trends as a marker of potential failures, as well as determine the different sensitivity of the landslide sectors to rainfall events of varying duration and intensity.

2.5.7
Towards a conceptual model for lahar triggers in periglacial environments of Ecuadorian volcanoes

Theresa Frimberger (1), Michael Krautblatter (1)
(1) Technical University of Munich, Chair of Landslide Research

Volcanic debris flows pose a major threat to surrounding areas and commonly occur during volcanic eruptions or heavy precipitation in post-eruptive periods. However, the unprecedented occurrence of secondary lahars that originate in periglacial areas of the glacier-capped volcanoes Chimborazo and Cotopaxi, is challenging the current understanding of secondary lahar triggering. Due to the remote location and a lack of measurement recordings, the trigger mechanism remains unknown.
Here, we systematically assess possible triggers of periglacial secondary lahars under consideration of site-specific geological and geomorphological conditions and the glaciological history. By using evidences from geophysical field surveys conducted in previous years and by analysing multiannual satellite images, we can identify seven different trigger mechanisms that can likely release secondary lahars in the forefield of tropical Ecuadorian glaciers. Considering the significant deglaciation and loss of permafrost and buried glacier ice, our results can help to anticipate future lahar risks in a changing periglacial environment.

2.5.8
Preparation of rock slope failure towards a high-sensitivity close-to-failure system

Johannes Leinauer (1), Michael Dietze (2), Sibylle Knapp (1), Maximilian Jokel (1,3), Natalie Barbosa (4), Michael Krautblatter (1)
(1) Technical University of Munich, Chair of Landslide Research
(2) Georg-August-University, Faculty of Geosciences and Geography, Göttingen
(3) Technical University of Munich, Faculty of Informatics, München
(4) Ludwig-Maximilians-University Munich, GeoBio Center, München

Rock slope failures are an important geomorphologic process and cause significant risk in populated alpine areas. To anticipate the final failure, a detailed understanding of the preparatory process dynamics and potential triggering factors is needed. Although standard causes and triggers are known, measured evidence of external and internal drivers of a rock slope instability towards a highly sensitive system is often lacking. The Hochvogel summit failure (200,000–400,000 m³) is preparing since many decades. Here, we use historical earthquake and seismic information and analyse high-resolution seismic and crackmeter data of the last 4 years to determine and quantify the relevant promoting and triggering factors. We prove that the Hochvogel instability is now a close-to-failure system. This will improve the understanding of rock failure dynamics and so the anticipation ability for instable rock slopes.

2.5.9
Reconstruction of the Parraguire 1987s Ice-rock avalanche: Lessons from the Chilean Central Andes

David Farías (1,2), Johannes Fürst (1), Thomas Bruckner (1), Lucía Scaff (3)
(1) Glacier systems and Natural Hazards, Institut für Geographie, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
(2) Department of Geography, University of Concepcion, Chile
(3) Water Research Center for Agriculture and Mining, University of Concepción, Chile

In November of 1987, a massive ice-rock avalanche occurred in a permafrost area in the upper reaches of the Estero Parraguirre, central Andes of Chile. This event is considered one of the most destructive in the last decades. The ice-rock avalanche was initiated at an elevation of 4350 m and developed into a debris flow propagating down the valley, reaching a total run-out distance of ~57 km after 2 hours.
In this study, we use historical aerial photographs, acquired just a few days after the event, historical maps, and satellite imagery to estimate the trigger volume and the affected area. We also apply a physically-based multi-phase mass flow model to reconstruct the dynamics and characteristics of this debris-flow event. Furthermore, we evaluate the meteorological conditions that preclude this unprecedented ice-rock avalanche using atmospheric observations and reanalysis data. Preliminary results suggest that the trigger volume is significantly larger than previously thought, as is the travel speed along the Estero Parraguirre. We further hypothesize that the avalanche was likely triggered by warm temperature anomalies during the spring season and high snow accumulation at high elevations linked due to the strong El Niño event in 1987. The reconstruction of this event allows us to gain a better knowledge of the processes involved and can help to forecast and mitigate future events in the changing mountain regions.

2.5.10
Tree rings as a source of data for mass movements studies – examples from the Western Carpathian Mts

Katarzyna Sitko (1,2), Małgorzata Wistuba (2), Ireneusz Malik (2)
(1) Institute for Ecology of Industrial Areas, Katowice, Poland
(2) Institute of Earth Sciences, Faculty of Natural Sciences, University of Silesia in Katowice, Sosnowiec, Poland

Characteristically deformed tree stems – tilted and bent under the influence of ground movement – may indicate the impact of landslides and soil creep on forested slopes. Each tree growing on the studied area is a separate sensor of the ground motion, which allows to analyse the temporal and spatial variability of the course of mass movements. Trees growing in the area affected by mass movements are subject to mechanical stress, which is recorded in the form of anatomical changes: development of eccentricity growth and reaction wood.
In the present studies, the eccentricity index method was applied, using the difference in width of tree rings between upslope and downslope parts of tilted tree stems to calculate eccentricity, eccentricity index and its annual variation (after Malik and Wistuba 2012, Wistuba et al. 2013). This method allowed to date events of landslides and soil creep with annual resolution. All dendrochronological samples were taken with a standard Pressler borer at chest height, in accordance with the slope of the terrain and the inclination of the stems. Two cores were taken from each tree: one from the upslope side of the stem, the other from the downslope side of the stem. Individuals visually healthy, without mechanical damage, and of sufficiently old age were selected for the study. The sampled cores were then glued into wooden stands and sanded to reveal the wood structure. The reaction wood was analysed visually under a binocular using the criteria proposed by Yumoto et al. (1983). The development of a landslide activity map and landslide hazard map was performed using statistical and GIS analysis of the results of dendrochronological analysis.
The use of dendrochronological methods in the above studies allowed to determine the temporal variability of landslide activity and its spatial variability within landslides and slopes with soil creep. A map of landslide activity and hazard in the studied Sucha Góra massif was also created.
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2.6 New methods in Geomorphology

2.6.1
Application of Infrared Radiofluorescence (IR-RF) dating on the Riedstadt-Erfelden drill core to assess northern Upper Rhine Graben chronology

Anna-Lena Geis (1), Mariana Sontag-González (1), Christian Hoselmann (2), **Markus Fuchs** (1)*
(1) University of Giessen, Department of Geography, Giessen, Germany
(2) Hessisches Landesamt für Naturschutz, Umwelt und Geologie, Wiesbaden, Germany
** Corresponding author: markus.fuchs@geogr.uni-giessen.de*

The Upper Rhine Graben (URG), a rift extending over 300 km from Basel, Switzerland to Frankfurt, Germany, contains one of the thickest and most continuous successions of Pleistocene and Pliocene sediments in central Europe. Therefore, its investigation is of utmost importance in order to understand driving factors behind sedimentation and erosion processes of the Rhine system as well as the geological evolution of the graben system throughout the Quaternary and beyond. In 2020/21, a new drilling project at Riedstadt-Erfelden, Hesse, was conducted by the Hessian Agency for Nature Conservation, Environment and Geology (HLNUG) to obtain further information on the development of the northern part of the URG and its sedimentary fillings, yielding sediment cores down to 323 m depth. The new core supplements previous drilling studies in Viernheim, Heidelberg, Ludwigshafen and Kronau (Gabriel et al., 2013; Preusser et al., 2021). While the first three have been thoroughly analysed (e.g., Lauer et al., 2010; Lauer et al., 2011, Li et al., 2018), several investigations are currently underway on the Riedstadt core, including numerical dating. The present work aims at complementing the litho- and chronostratigraphic information by applying luminescence dating methods on the upper section of the Riedstadt core. We present first results obtained from infrared radiofluorescence (IR-RF) dating of K-feldspar, a technique that reportedly does not suffer from the signal instability common to other luminescence methods on this mineral (e.g., Murari et al., 2021). Further, we give perspectives on the planned application of additional methods that may help in improving the chronological framework for the northern URG.

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2.6.2
GeTiTool - Open-Source Software to analyse Geoelectric timelapse data in Geomorphology

Dominik Herler (1), Christian Bauer (1)
(1) University of Graz - Institute of Geography and Regional Science

Timelapse geoelectrical monitoring provide powerful insight to understand subsurface processes in fields like Karst, Permafrost, Hydrology and landslide monitoring. Currently, a semi-automated, easy-to-use tool for the analysis of large time-lapse data sets is lacking. To close this gap, the Geoelectrical Timelapse Tool (GeTiTool) was developed and presented in this contribution. In addition, the semi-automated workflow for the collection of these data as well as the post-processing are presented. The collection of the test data took place in an Austrian karst area north of Graz. The goal was to investigate the hydrological characteristics of a doline floor and its borders during precipitation events.
With the GeTiTool common geoelectrical file formats can be imported directly, by entering the topography data and inversion parameters, the inversion is started and .vtk files are exported which can be further processed in an open-source postprocessing software like Paraview. From this postprocessing work, integrated data for specific areas of interest can be exported for further analysis. These postprocessed data can be parsed into the GeTiTool for trends shown in different geoelectric parameters also in combination with meteorological data.
Results of the GeTiTool are inverted timelapse data and simple plots of certain areas that one wants to analyse in more detail. The open-source tool is developed for Windows and Linux and is available on Github (https://github.com/dominik504/GeTiTool). To run the inversion a working python environment is necessary, as well as a postprocessing software. So far, the tool was proved to work with the test data generated during the survey, but is expected to work for various geoelectric timelapse data.

2.6.3
High-resolution precision maps for DEM differencing

Florian Strohmaier (1), Jason Goetz (1), Sam T. McColl (2)
(1) Friedrich Schiller University Jena, Institute of Geography, GIScience group, Löbdergraben 32, Jena
(2) GNS Science, 1 Fairway Road, Lower Hutt, New Zealand

In quantitative geomorphology, differencing of topographic models is widely used for sediment budgeting and monitoring landform changes in morphologically active areas. The value and utility of these analyses is partly contingent upon the data quality and uncertainties. Although there is recognition within the geoscience community of the need to account for uncertainties, such uncertainties are often under- or over-conservative, or fail to represent the spatial variability of error.
We suggest this practice arises in part because of a paucity of suitable and simple methods for generating spatially variable error models. Herein we make an argument for the value of precision maps in topographic differencing models, and provide a methodology to generate and integrate precision maps into standard topographic differencing workflows.
We demonstrate the use of precision models in a sediment budgeting case study at the highly active Tarndale and Mangatu badass gully systems, located in New Zealand's East Coast region. We constructed high resolution terrain models from UAV images within a Structure-from-Motion workflow for the period between 2018 and 2020. To estimate the spatial variability of errors in the terrain models, we made multiple synthetic flight simulations from each photoset and used these to statistically estimate cell-wise precision values. The resulting precision maps indicate the spatial variability of terrain model errors,

which we propagated into our maps of erosion and deposition. These statistically-derived precision maps provide smaller – and thus more precise – confidence intervals helping to better quantify “true” gully erosion.
We discuss the implications of our methodology for terrain model differencing in practice, and comment on the challenges of this method for large data sets. Overall, our research enhances the exchange between spatial statistics, geomorphology, and geospatial communities.

2.6.4
Concept for an integrated landslide inventory system: technical foundation and automation methods

Thomas M. Kreuzer (1)
(1) Institute for Geography and Geology, University of Würzburg, Würzburg, Germany

In landslide research, databases (here synonymous with inventories) are of particular importance, as they are used to record and document information necessary for statistical and process-oriented analyses. However, landslide data are currently collected and analysed largely independently of a database system (DBS), although such a system would provide a central location for data analysis and processing. Operators are thus confronted with problems of their operational level without being able to receive support from a DBS. Yet, comprehensive data collection consequently involves a large amount of work, which moreover affects analyses that depend on the availability of up-to-date and numerous data. Therefore, this regularly leads to self-imposed restrictions in problem definitions in order to limit the required scope of data, and hence the associated effort of data collection.
The overall objective of the present work is to counteract the presented problems by minimizing the effort for use of a landslide database. For this purpose, a concept for an ''Integrated Landslide Inventory System'' (IRIS) is developed, which integrates the level of data collection and analysis into a DBS by means of automation. The users of this system are thus relieved to the extent that they only have to monitor automated processes. Automation methods for such a system often focus on remote sensing, however this work focuses on digital texts. This means the utilization of established machine learning and AI-methods, specifically, from the field of information retrieval. Furthermore, a quantitative evaluation of the usefulness of various textual source types was carried out. Thus, knowledge of usefulness of different types of sources enables the efficient control and focus in manual, as well as digital, data acquisition. Consequently, the IRIS is a quasi-closed, extensible, and self-sufficient system controlled by the operator that allows for the management of large and continuously accumulating landslide data.

Nov.27
08:00 – 09:20h Knight Hall

2.3 Quaternary geomorphological systems, biogeomorphology and human-environment interaction - Orals

08:00 – 08:20h

Influence of bioturbation on sediment redistribution along climate gradient in Chile

Paulina Grigusova (1), Annegret Larsen (2), Roland Brandl (1), Nina Farwig (1), Diana Kraus (1), Jörg Bendix (1)
(1) Philipps-University Marburg
(2) Wageningen University and Research

Soil bioturbation activity was shown to affect soil texture, bulk density and soil water content while the redistribution of nutrients impacts vegetation distribution. All of these factors influence surface and subsurface sediment and hydrological processes. However, up until now, bioturbation has never been included into a soil erosion model which would enable to study these effects on several temporal and spatial scales.
In our study, we analysed the impact of bioturbation on sediment redistribution, surface runoff, subsurface runoff and infiltration capacity within several climate zones and identified environmental parameters determining the positive or negative impact of bioturbation on sediment redistribution. Our study area was located along Chilean climate gradient. We measured the needed soil properties and location of burrows created by bioturbating animals in the field. Then we applied machine learning algorithms and used satellite data as predictors to upscale the soil properties and burrow distribution into the catchment. At each of the predicted burrow locations we adjusted the topography, soil properties and vegetation cover accordingly. We validated the model by self-developed sediment fence constructions located at the base of each catchment. Model with integrated bioturbation activity had an R2 of 0.71 while a model without bioturbation activity had an R2 = 0.45. Bioturbation increased sediment redistribution in all but humid climate zone. The surface runoff increased in semi-arid zone while the infiltration capacity and subsurface runoff increased in the mediterranean and humid climate zone. Bioturbation increased sediment erosion at high and middle values of elevation, at high values of slope, sinks and TRI, and at low values of profile curvature. Bioturbation increased sediment accumulation at high values of surface roughness and topographic wetness index and at low values of NDVI.

08:20 – 08:40h

Investigating debris flow activity and fan delta formation in an alpine lake using amphibious methods

Carolin Kiefer (1), Patrick Oswald (2), Jasper Moernaut (2), Stefano Claudio Fabbri (3), Christoph Mayr (4), Michael Strasser (2), Michael Krautblatter (1)
(1) Chair of Landslide Research, Technical University of Munich, Arcisstraße 21, 80333 Munich, Germany
(2) Department of Geology, University of Innsbruck, Innrain 52 f, 6020 Innsbruck, Austria
(3) Institute of Geological Sciences, University of Bern, Baltzerstrasse 1+3, 3012 Bern, Switzerland
(4) Institute of Geography, Friedrich-Alexander University Erlangen-Nuremberg, Glückstraße 5, 91054 Erlangen, Germany

Debris flows occur with varying intensity and recurrence intervals in the same catchments. The increase of debris flow frequencies and magnitudes is frequently postulated yet the basis to evaluate frequency increases is poorly understood. The morphology and spatial extent of debris-flow fans reflect the previous sediment dynamics and therefore past climatic and environmental conditions. Lake Plansee (Tyrol, Austria) shows a continuous sedimentation regime which provides a long-term archive of debris flow activity in a setting of highly connective catchment morphology. We investigated alluvial fan deltas on the south shore of Plansee and the adjacent sediment inventory using LiDAR data, Electrical Resistivity Tomography (ERT) and sediment cores. ERT provides information on the size of debris-flow fans. Sediment cores recovered from the subaquatic fan delta to the depocentre reveal different turbidites related to debris flows and earthquakes. The 4,000 year sediment record covers 138 debris flow events. The event chronology reveals four phases of different debris flow recurrence. A constant background sedimentation with low debris flow rates is interrupted by i) debris flow frequency increases interpreted as post-seismic landscape response and ii) a drastic 7-fold increase in debris flow frequency between the periods ~1520 to 1920 CE and 1920 to 2018 CE. The presented increase in debris-flow frequency since the 20th century coincides with a 2-fold enhanced rainstorm activity in the Northern European Alps. We hypothesize that debris-flow fluctuations in the Holocene provide an analogy for future scenarios with elevated climatological forcing such as periods of enhanced rainstorm magnitudes and help anticipating a likely increase in debris-flow frequencies and magnitudes in the foreseeable future.

08:40 – 09:00

Non-linear dependence of silicate, carbonate and sulfide weathering on erosion and climate

Aaron Bufe (1), Jeremy K.C. Rugenstein (2), Niels Hovius (1)
(1) GFZ German Research Center for Geosciences, Telegrafenberg, 14473 Potsdam, Germany
(2) Department of Geosciences, Colorado State University, Fort Collins, CO 80521 USA

Chemical weathering of silicate, carbonate, and sulfide minerals modulates the global carbon cycle and impacts Earth's climate on geologic timescales. Weathering rates are controlled by erosion that supplies fresh minerals to the weathering zone and by climate that modulates the supply of acidic waters and the kinetics of mineral weathering. Existing approaches that model the carbon cycle over geologic timescales assume that the dependence of weathering on climate and erosion trade off. Thus, at low erosion rates, weathering is thought to be sensitive to mineral supply and insensitive to climate whereas the opposite is hypothesized for rapidly eroding landscapes. However, testing these models on the landscape scale and applying them to carbon cycle models is complex, because existing data do not cover all limits, do not consider all relevant mineral phases, or because co-variation between runoff and erosion obscures the driver for changes in weathering rates.
Here, we compile five datasets of solute concentrations in streams that span well-defined erosion rate gradients in relatively uniform lithologies and with limited or well-constrained variations in runoff. Across 2-3 orders of magnitude of erosion rates, we find that silicate weathering rates are limited by climate and insensitive to erosion rates. In turn, weathering rates of sulfide and carbonate minerals increase with erosion, consistent with a limitation by mineral supply. In contrast to existing models, weathering rates at this apparent supply-limit increase non-linearly with erosion rate and scale as a power-law with an exponent of ~0.57 ± 0.04. A bypass of unweathered minerals through landslide erosion could explain such a non-linearity. Our findings imply that weathering in mountain landscapes is less sensitive to erosion and more sensitive to climate than existing models would imply with important implications for the effect of mountain building on the carbon cycle and on Earth's climate.

09:00 – 09:20h

Geoarchaeological studies in Germany´s largest Bronze Age barrow cemetery in the forest area "Schweinert" (SW Brandenburg) – First results

Alexandra Raab (1), Thomas Raab (1), Sandeep Puthenveedu Mohanadasan (1), Alexander Bonhage (1), Anna, Schneider (1), Robert Martin (2), Franz Schopper (2), Thomas Schenk (3), Albrecht Bauriegel (4), Judith Walter (4)
(1) BTU Cottbus-Senftenberg, Chair of Geopedology and landscape development, Siemens-Halske-Ring 8, 03046 Cottbus
(2) BLDAM, Wünsdorfer Platz 4,15806 Zossen
(3) HTW Berlin, Wilhelminenhofstraße 75A, 12459 Berlin
(4) LBGR, Inselstraße 26, 03046 Cottbus

Within the scope of the DFG-project "Holocene Landscape History in the forest area "Schweinert" – a geoarchaeological study in Germany´s largest Bronze Age barrow cemetery", interdisciplinary investigations are carried out to expand the knowledge about this important necropolis in SW Brandenburg. The study area is situated in the Schwarze Elster river floodplain between Herzberg/Elster and Falkenberg/Elster in the forest area "Schweinert". Here, about 650 well preserved burial mounds spread over a total area of approximately 30 ha. They date from the late Bronze Age to the early Iron Age (1100 to 650 BC) and are assigned to the Lausatian culture. Due to the remote location, the barrow cemetery is only little archaeologically investigated. We assume that there is a causal connection between the location/distribution of the burial mounds and the Holocene floodplain evolution, leading to the key question: Which topographical and soil environmental conditions have prevailed in the "Schweinert" area and its surroundings before, during and after the Bronze Age? To investigate the relationship between the distribution of the burial mounds and the physiogeographical site conditions, a geomorphological-pedological approach with toposequences as core element is used. Along the toposequences, soils and parent materials are described, sampled and genetically classified by means of soil pits and soil drillings. Running parallel to the catenae, geophysical prospection by ERT and GPR are performed. Furthermore, geomagnetic measurements of selected subplots will be carried out. On basis of geophysical prospection results sites will be selected for archaeological excavations. We are presenting preliminary results from our first field campaigns conducted in 2022.

Nov.27
09:20 – 10:00h Knight Hall

2.4 Deciphering and modelling long-term landscape evolution - Orals

09:20 – 09:40h

The Erosion and Lifetime of Impact Craters on Earth

Alexa Pietrek (1), Stefan Hergarten (1)
(1) Albert-Ludwigs-Universität Freiburg

Due to the high geological activity, most of the impact craters on Earth are completely eroded or heavily degraded. As a consequence, not much is known about the general erosion stages in terms of change of shape or lifetime of impact crater units save for a few snap-shots in time that are represented by the 190

preserved impact crater structures. This study uses a geometrical model for fresh impact craters and landscape evolution modelling to investigate the lifetime and erosion patterns of the most important impact crater units in dependence on erosion rate.

09:40 – 10:00h

Use the second nuclide: former glaciations affect the validity of 10Be-derived denudation rates in the Vosges Mountains (NE France)

Timothée Jautzy (1), **Gilles Rixhon** (1,2), Régis Braucher (3), Aster Team (3)
(1) Laboratoire Image Ville Environnement (LIVE), UMR 7362, CNRS-Université de Strasbourg, France
(2) Ecole Nationale du Génie de l'Eau et de l'Environnement de Strasbourg (ENGEES), France
(3) CEREGE, Aix-en-Provence, France

Assessing the rates at which mountain ranges erode is fundamental to disentangle interactions between the various factors controlling their denudation. Measurements of in situ-produced cosmogenic nuclides in modern riverborne sediments allow inferring catchment-wide denudation rate averaged over several thousand years. This well-established method allows determining the main factor(s) controlling the denudation in those mountain ranges displaying strong gradient(s) in e.g., lithology, morphometry or climate. However, the validity of this method depends on several assumptions. One of these is the cosmogenic steady-state for which it is assumed that the nuclide production equals the nuclide removal by erosion. Paired-nuclide analysis consisting in measuring the concentrations of two different nuclides from the same sampling material allows testing the validity of this assumption. Although this was commonly undertaken in the early days of the method, the overwhelming majority of cosmogenic-derived denudation rates now only rely on a single nuclide, i.e., 10Be.
Quaternary erosion of the Hercynian low-mountain ranges strewn across the European alpine foreland (where much of the recent work was undertaken) has received little attention so far. Among them, the Vosges Mountains (VM) are particularly suitable for assessing denudation via cosmogenic nuclides since they display a strong N-S gradient for potential factors controlling denudation. A sharp N-S precipitation gradient (>1000mm/yr) is especially recorded, well matching the imprint left by former glaciations: whereas the southern part hosted abundant valley glaciers, the northern part was free of ice. This study thus aims to test the validity of the cosmogenic-based approach by sampling 22 catchments draining the whole VM for a paired-nuclide analysis (26Al-10Be). Lithological, morphometric and climatic characteristics were also quantified for each catchment. Our results show that almost half (10/22) of the samples violate the steady-state assumption. Interestingly, a vast majority of these unsteady catchments are located in the south of the massif which was massively and repeatedly glaciated during cold stages. The impact of former glaciations on the cosmogenic steady-state was confronted with the surface of glacial and fluvio-glacial deposits in each catchment. The negative relation suggests a complex exposure history in the formerly glaciated catchments (i.e., bedrock inheritance and/or sediment reworking). Whilst this unsteadiness most probably prevents the observation of a N-S gradient in denudation rates, it importantly emphasises the importance and need for using a second nuclide to infer reliable denudation rates at the massif-scale when glacial erosion is involved.

Nov.27

10:20 – 12:00h Knight Hall

2.5 Engeneering geomorphology and geomorphological hazards and risks - Orals

10:20 – 10:40h

Estimating the probability of huge rock avalanches in the Alps based on the concept of event-size dependent exhaustion

Stefan Hergarten (1)
(1) Institut für Geo- und Umweltnaturwissenschaften, Albert-Ludwigs-Universität Freiburg

Power-law distributions of landslide sizes have been considered for several decades. The exponents of these distributions apparently differ fundamentally between rockfalls and landslides in unconsolidated materials. Size distributions of rockfalls are characterized by low exponents, so that an extrapolation towards large rock avalanches would predict unrealistically high probabilities of huge events. Consequently, there must be a transition to a different (e.g., exponential) distribution at large event sizes. In this study, a theory of exhaustion is developed in order to explain and quantify this transition in the context of deglaciation. The idea is that the distribution starts from a power law at a given time (e.g., when permafrost retreated at the beginning of the Holocene). From this time on, the topographic potential is successively consumed. As a key point, it is assumed that the probability of an event depends on its size (e.g., rupture area or outcrop length of the rupture area). The theoretical model can be calibrated and validated for the Alps by combining data on prehistoric, historic and recent events. As a main result, the naturally triggered rock avalanches that occurred in the 20th century are by far not the largest possible events. The largest events that might be expected in the future could be about one order of magnitude in volume larger, so some 100 million cubic meters.

10:40 – 11:00h

Study of rockfall activity in the Alpine and pre-alpine environment outside permafrost areas

Mateja Jemec Auflič (1), Ela Šegina (1)
(1) Geological Survey of Slovenia

Recent rockfall research activities are strongly biased towards glaciated or permafrost areas, whereas most rockfall events that threaten infrastructure and structures originate from slopes which are far below the permafrost line. In Slovenia, the morphology of slopes, unfavorable geological and tectonic conditions, and climatic diversity contribute significantly to the large rockfall potential in alpine and pre-alpine environments outside permafrost zones. In this research, we focus on deciphering the sensitivity of geologically diverse rock faces to temperature variations and freeze-thaw cycles in such permafrost-free areas. Multimethod monitoring, which includes measurements of temperature and stress in the rock at three depth levels, has now been in operation for a year and a half at the two study sites in the pre-alpine area that are characterized by different geological and geomechanical properties of the rock and different thermal conductivity of the material. We present the preliminary results of the analysis of

such rock faces and the effects of temperature variations on rock deformation at the surface and below the surface.

11:00 – 11:20h

Advanced photogrammetric methods for automated rockfall monitoring

Xabier Blanch (1), Antonio Abellán (2), Marta Guinau (3), Anette Eltner (1)
(1) Institute of Photogrammetry and Remote Sensing, Technische Universität Dresden, Dresden, Germany
(2) Centre de recherche sur l'environnement alpin (CREALP), Sion, Switzerland
(3) Departament de Dinàmica de la Terra i de l'Oceà, Facultat de Ciències de la Terra, Universitat de Barcelona (UB), Barcelona, Spain

The purpose of this communication is to show the results obtained in a doctoral thesis based on the development of new algorithms and time-lapse photogrammetric systems for automatic rockfall monitoring that were tested on two active slopes in different geographical environments.
On the one hand, a very cost-efficient photogrammetric system using Raspberry Pi Camera (8Mpx) was designed and tested in the study area of Puigcercós (Spain). This system suffered from low-resolution, but the results obtained demonstrated that this system was able to identify active processes such as rockfalls and pre-failure deformation at a very low-cost. On the other hand, a more conventional system using 24Mpx-48Mpx cameras controlled externally by microcomputers. This approach yielded higher quality 3D models both in terms of model accuracy and resolution, allowing for a more accurate monitoring of rockslope processes. The high-resolution system has also been installed in the study area of Puigcercós, and in a real rockfall risk scenario in the Alhambra (Granada, Spain). All systems are highly configurable, transmit the images remotely, and are powered by solar panels.
On the other hand, two workflows were developed in order to obtain 3D change detection with the highest possible accuracy, as follows: The first algorithm was based on Point Cloud Stacking (PCStacking) to maximize the benefits of redundant information (Blanch et al., 2020). The second algorithm is based on "Multi-Epoch and Multi-Imagery" workflow (MEMI) (Blanch et al., 2021). The redundant use of multiple imagery reduced the error to a factor of two when compared to the classical approach. In addition, the latest workflow developed allowed the automation of rockfall detection methods from point clouds using machine learning approaches. The fully automated workflow allows the detection of rockfalls in an unsupervised way by simply receiving the images captured in the field, allowing near real-time and 4D rockfall monitoring.

11:20 – 11:40h

The effects of the extreme 2021 flood event in the Ahr valley (Germany) on an existing landslide in Müsch – a multi-method approach

Till Wenzel (1), Rainer Bell (1), Lothar Schrott (1), Michael Dietze (2, 3), Karin Gernet (4), Jörg Klonowski (4)
(1) Department of Geography, University of Bonn, Bonn. till.e.wenzel@gmail.de
(2) GFZ German Research Centre for Geosciences, Geomorphology Division. D-14473 Potsdam. mdietze@gfz-potsdam.de
(3) Department of Physical Geography, Georg-August-Universität Göttingen,
(4) Department of Geoinformatics and Surveying, University of Applied science Mainz, Mainz. karin.gernet@gmx.de

Exceptional rainfalls in W-Germany, led to severe floodings on 14-15 July 2021 in the Ahr valley, resulting in 134 fatalities and substantial loss of property and infrastructure. Besides damage in the floodplains, numerous shallow landslides were triggered and several old landslide bodies undercut. One such landslide in Devonian Schist bedrock is located at a narrow, bended reach of the Ahr, near the town of Müsch. A complete failure has the potential to fill the entire valley bottom cross section and dam the Ahr river, posing a considerable hazard.
The main objectives of this study are to understand the landslide mechanisms and its transient activity. These objectives are tackled by a multi-method approach including remote sensing and geophysical methods.

The landslide is 100 m wide and 200 m long with an estimated depth of 15-20 m, leading to an overall landslide volume of approximately 430,000 m³. Analysis of remote sensing data shows that so far only the frontal part at the Ahr river banks has been active and about 7000 m³ has been lost due to fluvial erosion and landsliding. Field mapping shows clear signs of retrogressive landsliding. Further movement in the frontal slope was detected with a delay of months after the initial flood in 2021. Most seismic signals recorded with five geophones at the slope can be allocated to daily traffic and road construction in the area. However, a regime shift in summer 2022 is notable, with less seismic noise recorded compared to the winter.
The combination of geophysical and remote sensing methods enables a profound insight into the mechanisms and present processes of the Müsch landslide. Based on this, we will be able to assess the probability for a reactivation of the whole landslide body, which could trigger cascading hazards affecting a much larger region.

11:40 – 12:00h
Gorge formation explained: Massive bedrock channel erosion during a hyperconcentrated flow event

Verena Stammberger (1), Michael Krautblatter (1)
(1) Chair of Landslide Research, Technical University of Munich, Germany

An extreme precipitation event causing a hyperconcentrated flow in a narrow alpine gorge caused massive lateral erosion of the present subvertical limestone walls. With an unprecedented LiDAR campaign, we were able to detect and quantify the massive breakout of particles and areal abrasion along the full 900 m long channel. A M3C2 change detection analysis results in eroded particle volumes between 0.0001 m^3 and 3.5 m^3 with 90 % of the particles being smaller than 0.15 m3. We deduced two main processes responsible for the visible erosion of the bedrock: Shearing of particles that protrude into the flow as well as particles with a predefined failure surface, and areal abrasion of larger surfaces along the whole channel. These findings provide quantitative evidence for erosion processes in alpine bedrock gorges that might also be controlling factors in the formation and evolution of rock gorges over Holocene/Lateglacial time scales.

Nov.27
13:00 – 14:40h Knight Hall

2.6 New methods in Geomorphology - Orals

13:00 – 13:20h

Deciphering small-scale periglacial surface dynamics in alpine environments using DInSAR time series analysis

Sebastian Buchelt (1), Jan Blöthe (2), Claudia Künzer (3,4), Andreas Schmitt (5), Tobias Ullmann (1), Marius Philipp (4), Christof Kneisel (1)
(1) Dep. of Physical Geography, Institute of Geography and Geology, University of Wuerzburg
(2) Institute of Environmental Social Sciences and Geography, University of Freiburg
(3) Deutsches Fernerkundungsdatenzentrum, Deutsches Zentrum für Luft- und Raumfahrt Oberpfaffenhofen
(4) Dep. of Remote Sensing, Institute of Geography and Geology, University of Würzburg
(5) Dep. of Geoinformatics, University of Applied Sciences Munich

Permafrost is identified as an Essential Climate Variable (ECV) by the Global Climate Observing System of the World Meteorological Organisation and is currently undergoing strong changes due to rising temperatures and amplified warming in mountainous regions. Surface movement is one key indicator for the existence of mountain permafrost that results in the formation of characteristic landforms such as rock glaciers. As such, monitoring these landforms and their movements can indicate ongoing changes in permafrost affected mountain environments. Recently, the International Permafrost Association (IPA) started to promote Differential SAR Interferometry (DInSAR) for the detection of permafrost-induced displacements. DInSAR uses the phase difference between two SAR remote sensing acquisitions to detect distance changes of the surface towards the sensor and is capable to detect relative displacements of a few millimetres along the so-called Line of Sight (LOS). Strozzi et al., 2020 indicate the potential of Sentinel-1 interferometry for monitoring rock glacier kinematics, but the applicability of this method especially for smaller areas is still unassessed. Hence, we generate and analyse Sentinel-1 DInSAR time series data over 5 years during snow-free conditions to detect small-scale displacement rates in several high alpine permafrost environments located in the Upper Engadine, Swiss Alps on a weekly basis. Our approach is based on a semi-automated procedure using open source programs such as SNAP (SeNtinel Application Platform) by ESA and PyRate by GeoScience Australia. We compare the aggregated DInSAR displacement with movement derived from Feature Tracking by using high-resolution airborne orthophotos and found good agreement between these two independent approaches. Moreover, the DInSAR time series unveils spatio-temporal variations of surface movement, which contributes to a better understanding of the related process dynamics of permafrost creep. Thereby, DInSAR can help to assess the future evolution of permafrost under changing climatic conditions.

13:20 – 13:40h

Systematic quantification of digital image correlation performance for landslide monitoring

Doris Hermle (1), Markus Keuschnig (2), Michael Krautblatter (1), Valentin Tertius Bickel (3)
(1) TU München
(2) GEORESEARCH
(3) ETH Zürich

Accurate and reliable analyses of high-alpine landslide displacement magnitudes and rates are a key requirement for current and future alpine early warning systems and safety measures. Remote sensing data with high spatial and temporal resolution derived by air- and spaceborne sensors can be combined with digital image correlation (DIC) algorithms to detect and monitor ground displacements.
However, applying DIC codes requires significant knowledge and user input: there exists neither general mathematical description of the type and spatial/temporal resolution of input image data nor DIC input parameters that are required for i) successful landslide detection, ii) accurate characterization of the displacement magnitude and rate, and iii) overall error estimation.
Here, we use the open source code DIC-FFT (https://github.com/bickelmps/DIC_FFT_ETHZ) in combination with data acquired between 2014 and 2020 for the Moosfluh deep-seated gravitational slope deformation (~1'320,000 m²), in Switzerland, to quantitatively show i) which spatial resolution is required to recognise slope displacements in the first place, using a wide range of resolutions from Sentinel-2 (10 m), RapidEye (5 m) and PlanetScope (3.125 m) satellite images, as well as swisstopo aerial orthophotos (0.25 m), and ii) how the spatial resolution of the sensor affects the accuracy of the modelled displacement magnitude and rate.
In addition, we provide a mathematical formulation to estimate the optimal DIC input parameters based on the available spatial and temporal resolutions of a sensor, as well as the expected displacement rate of the landslide body, for a range of landslide sizes.
We verified the ground truth of all our results by manually tracing geomorphic markers in the swisstopo aerial orthophotos.
Our results have direct implications for the improved early detection and monitoring of alpine hazards, and for the planning and design of future remote sensing-based monitoring campaigns.

13:40 – 14:00h

Deriving calibration and validation data for physical based soil erosion models from time-lapse imagery

Anette Eltner (1), Anne Bienert (1), Oliver Grothum (1), Lea Epple (2), Pedro Zamboni (1), Jonas Lenz (2)
(1) Technische Universität Dresden, Institut für Photogrammetrie und Fernerkundung
(2) Universtität Jena, Institut für Geographie

In this study, we introduce approaches to derive various time series of parameters relevant for the calibration and validation of a process-based soil erosion model from time-lapse imagery. We focus on hydrological and geomorphological aspects. We estimate the water coverage from image time series using deep learning methods to segment the areas, which are submerged by water. The parameter is important in regard of spatio-temporally resolved infiltration assessment and to better understand the temporal lag between rainfall onset and discharge. Furthermore, we measure the flow velocities with image particle tracking velocimetry applied to videos and compare it with modelled runoff velocities considering different resolutions of the input soil surface model. This is relevant to assess how well transport capacity and detachment by runoff is described by the models. Point clouds describing the soil surface will be derived with structure from motion photogrammetry to compare modelled soil surface changes, i.e., erosion and accumulation, with observed changes. Thereby, also compaction and thus an indication of soil bulk density change is assessed. In addition, the 3D point clouds can be used to measure the surface roughness changes, which might be a future approximation for the Manning coefficient. Finally, thermal imagery will be analysed in regard of their suitability to give some indications in regard of soil water content changes. Therefore, thermal time-lapse images are orthorectified considering the

3D model of the soil surface derived from the structure from motion photogrammetry. This study combines various established as well as newly developed data recording and processing methods to create a spatio-temporal high resolution data set. This data set can be used to test soil erosion models and to foster the understanding of soil erosion processes.

14:00 – 14:20h
Infrared thermography monitoring of rock faces – potential and pitfalls

Oliver Sass (1), Christian Bauer (2)
(1) University of Bayreuth, Chair of Geomorphology
(2) University of Graz, Department of Geography

Rock surface temperatures are of fundamental importance for studies on weathering, rockfall and permafrost. Single sensors may not reflect the small-scale variabiliy of temperature as a function of micro-topography. To close this gap, IR thermography seems to be a simple and promising approach. However, there are several pitfalls in terms of interpretation, as radiation temperatures depend on emissivity and reflectivity of the rock, which in turn are influenced by rock type, surface roughness, wetness, surrounding weather conditions, and angle to the camera axis.
We performed laboratory and exemplary field experiments in order to estimate the magnitude of possible errors. We used rough and smooth (sawn) specimen of six different stone types in wet and dry condition, and took infrared imaged at different tilt angles between camera axis and rock surface. Furthermore, we applied the approach to a small rock outcrop (approx. 3 x 3 m) and to a rockwall (approx. 100 x 100 m).
The results of the laboratory measurements show that the temperature error increases with increasing tilt angle of the rock surface. Depending on the nature of the reflected surrounding, radiation temperatures can be warmer or cooler than sensor temperatures. In typical settings, the error is low (< 0.5 K) up to a tilt of 40° but it may increase to > 1 K at tilt angles of 50° and more. Smooth and wet surfaces tend to be more prone to deviations.
The field examples confirm the results of the laboratory tests. But they show that spatial differences in temperature can still be detected as the "true" differences are usually larger than the magnitude of error. It is possible to reduce the error of the IR image by correcting temperatures using a high-resolution surface model.

14:20 – 14:40h
Large scale survey of anthropogenic soil landscapes in New England, USA, using state-of-the-art machine learning techniques (Yolov4)

Alexander Bonhage (1), Wouter Verschoof-van der Vaart (2), Thomas Raab (1), Anna Schneider (1), Alexandra Raab (1), William Ouimet (3), Florian Hirsch (1)
(1) BTU-Cottbus-Senftenberg, Germany
(2) Leiden University, Netherlands
(3) University of Connecticut, United States

The use of automated mapping approaches, based on machine learning Convolutional Neural Networks (CNNs), in combination with high resolution airborne LiDAR digital elevation models (DEMs) has led to an interdisciplinary surge in publications in the domains of archaeology, geoarchaeology and geopedology. State-of-the-art object detectors are used to detect geomorphological features on DEMs commonly associated with historic anthropogenic activities e.g., burial mounds and charcoal production sites. In

this study we present the results of a large-scale mapping of Relict Charcoal Hearths (RCHs, sometimes referred to as charcoal kilns) spanning different regions in New England (USA) using a modified YOLOv4 object detector. RCH sites are circular or slightly elliptical shaped micro relief structures with average diameters of about 11 meters. As part of the research, we have optimized the output bounding boxes of YOLOv4 to allow for the determination of the area covered by RCHs. Furthermore, we have included a GIS-based post-processing step to detect the site-specific local slope. This geometrical information enables the calculation of specific RCH site volumes and thereby soil element stocks. In a GIS-based geospatial analysis the RCH site distribution and site densities in relation to topographic landscape units and other potential controlling factors is determined. We present a comprehensive assessment of the often discussed legacy effect of historic charcoal production on today's soil properties on a regional and landscape scale.