Gorkha earthquake observatory, Nepal

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Strong earthquakes cause transient perturbations of the near Earth's surface system. These include the widespread landsliding and subsequent mass movement and the loading of rivers with sediments. In addition, rock mass is shattered during the event, forming cracks that affect rock strength and hydrological conductivity. Often overlooked in the immediate aftermath of an earthquake, these perturbations can represent a major part of the overall disaster with an impact that can last for years before restoring to background conditions. Thus, the relaxation phase is part of the seismically induced change by an earthquake and need to be monitored in order to understand the full impact of earthquakes on the Earth system. Here, we present first results from the rapid respond earth surface processes monitoring program put in place by several European groups after the Mw7.9 Gorkha earthquake.
To monitor the transient effects of the earthquake on the Earth surface system, we have installed a comprehensive network of 13 river sampling locations for daily water and sediment sampling, covering all major rivers draining the earthquake-affected areas immediately after the event. Nested within this regional network, we have installed an array of 16 seismometers and geophones and 6 weather stations in the upper Bhotekoshi catchment, covering an area of 50 km2. Our field monitoring covered 4 entire monsoon seasons from 2015 to 2018. The field measurements are accompanied by repeated mapping of landslide activities and volumes over subsequent seasons using high resolution optical (RapidEye) and radar imagery (TanDEM TerraSAR-X). The combination of all of these data will help when interpreting our field observation in the regional context of catastrophic failure of hillslopes and their link with sediment transport in the rivers. First river gauging observation show a pronounced increase in river discharge in the order of >20% for the respective pre-monsoon season. We interpreted this as a direct impact of the shaking on the valley-ridge scale sub-subsurface permeability, stressing the large potential effects of strong earthquakes on near-surface processes.

Geologic archives of disturbances: Reconstructing event catalogues of natural hazards using lake sediments

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Instrumental and historic records cover only insufficiently the time span to provide critical information on maximum intensity and recurrence rates of natural hazards. Therefore, geologic archives are needed to expand the temporal coverage of disturbances to prehistoric time scales. Lake sediments, in particular, provide the high-resolution and continuous archives that may identify prehistoric disturbances. Due to their sensitivity to record hazards such as earthquakes, rock falls, floods and tsunamis, lacustrine systems allow long, detailed and quasi-complete catalogues providing critical data for deterministic or probabilistic hazard assessments

Legacy of extreme events: are all landscapes born free and equal?

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Observations of landscapes following extreme floods demonstrate that not all river systems respond similarly to an event of a given magnitude. In this presentation, I will focus on two main questions: - What determines the sensitivity of river systems to large floods? - What determines the recovery of the systems after an extreme event? Using examples from a variety of landscapes, including Nepal and Iceland, I will illustrate the interplay between sediment supply, grain size distribution (in sources and in the rivers) and flood magnitude. Low sediment supply is typically associated with the development of an armoured layer, which will increase the magnitude of the flood required for significant morphological change. Conversely, high sediment supply may increase the vulnerability of river systems to floods through limited armouring, but will also facilitate recovery post-floods. However, in systems where sediment supply is highly episodic, the frequency of major supply events (e.g., widespread landsliding following earthquakes and/or typhoons) will affect the magnitude of the flood capable of morphological change, as increasing the time between supply events will facilitate the development and strengthening of an armoured layer. These considerations are important for assessing landscapes' propensity to change in response to a flood of a given magnitude, as well as for identifying evidence of extreme events in the landscape (preservation of geomorphic markers).

Response of chemical weathering and hillslope hydrology along an exhumation gradient in central Nepal: new insights from groundwater transit times and geochemistry

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The relationships between erosion, water transit times, and chemical weathering are still poorly understood yet fundamental to understanding hydrological function and evolution of the critical zone, as well as global biogeochemical cycles and slope stability. In this study, we use the Melamchi Valley in central Nepal, ~50 km north of Kathmandu, to gain new empirical insight into these relationships. Recent work has revealed a strong gradient in bedrock apatite and zircon U-Th/He thermochronologic age in this valley, suggesting the north has experienced more recent rapid exhumed than the south. In parallel, topographic steepness and landslide activity increase markedly from south to north, while field observations suggest high degrees of weathering in the south and much lower weathering intensity in the north. With limited lithologic variability, this valley offers a compelling natural experiment to explore erosional controls on critical zone hydrology. Here we take advantage of this experiment by measuring proxies for water transit times and chemical weathering. We collected samples from 24 groundwater springs during a field expedition in October 2018, in the immediate post-monsoon season. To constrain transit time distributions, we are measuring SF6 and CFCs on all samples, as well as 3He/3H and 226Ra/223Ra on a subset. Preliminary results from SF6 measurements show spring water transit times range between ~2-35 years, with longer transit times generally in the southern end of the valley where erosion rates are lower. Additional analyses are ongoing to provide additional

constraints across the groundwater age distribution. We have also measured major ion concentrations to provide information about weathering. Concentrations of Si, Ca and Na were significantly higher (3-8x) in the southern end of the valley and systematically decrease to the north, though there does not appear to be a simple relationship between transit times and major ion concentrations. Overall the data suggest a significant change from south to north in hydrological flow paths and associated weathering, corresponding with exhumation and landsliding gradients, but based on preliminary data gathered to date, we do not immediately observe a first order control of water transit time on weathering.

Century-Scale Flood Response in the Rarh Region of Lower Gangetic Plains, India: towards understanding of Climate and Humans' Interaction

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Over recent years, the Rarh region of lower Gangetic plains (LGP) has witnessed severe flooding with immense social impact, including loss of human life and major damage to property and infrastructure. It is constituted of five major tributary systems of the Bhagirathi Hooghly River (a distributary of the Ganges system) in the western part viz. the Kopai-Mayurakshi-Babla System, the Ajay, the Damodar, the Dwarakeswar-Silabati-Rupanarayan System and the Kangsabati-Keleghai-Haldi System. On account of limited geographical area, majority of rivers in this region are short and have small catchments. Only four rivers (the Mayurakshi, Ajay, Damodar and Kangsabati) have basin area more than $5x10^3$ km^2 and only three rivers (the Ajay, Damodar and Kangsabati) have river length exceeding 300 km. This has often resulted in significantly high flooding in terms of unit peak discharges, even significantly higher than world standards, Indian Peninsular Rivers and North Bihar Rivers. A major portion of these discharges is contributed by run-off from the southwest Indian Monsoon, making the system sensitive to any major changes in monsoonal precipitation over time. For combating flood, one of the greatest modifications of the fluvial landscape in the recent decades is the construction of dams, barrages, and embankments. These constructions led to a dramatic effect on river form and function. The floodplain undergoes great changes as a result of the confinement of river flow due to construction of embankment. Confinement increases specific stream power that facilitates sediment entrainment and transport within the system which leads to devastating breaching of embankment. The breaching of embankments results in floods of tremendous areal extent with simultaneous sand incursion on the fertile and densely populated floodplain.

So, it is high time to deeply understand the interaction between humans and climate drivers to know and comprehend the past and recent flood dynamics in the settled landscapes for effective flood management. The present work has three defined objectives: (i) firstly, to analyze the century-scale hydrological variability throughout the monsoon season; (ii) secondly, to quantify the power of extraordinary floods after the confinement of flow; and (iii) thirdly, to assess the future flood risk for this region. The climate and/or anthropogenic controls on flood dynamics of this study will be presented.

Modeling channel responses to change in rainfall frequency and intensity using nondimensional equations

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Geomorphology of a channel is closely tuned to the watershed basin that feeds the channel. While the physical variables of these watershed basins, such as drainage area and elevation do not generally change in a matter of decades or centuries, the input to these watershed basins such as in rainfall can change. Change in rainfall amount, frequency and distribution is a key factor affecting watershed equilibrium in the face of climate changes. Increased rainfall or rainfall intensity due to climate change is particularly consequential for a drainage basin otherwise in equilibrium with low rainfall. Such change can result in channel responses accompanied by flood and damage to life and property. We investigate the role of rainfall frequency and intensity on the channel geometry. A large dataset of over 500 stream reaches of varying physiography from US and Canada is used to predict the bankfull geometry of channel based on basic watershed variables such as area, valley slope, and rainfall distribution. Here we employ non-dimensional equation to represent channel geometry using multiple regression. We approach the effect of changing rainfall patterns as an important factor resulting in disruption in established geomorphological equilibrium in channels. By establishing the channel geometry relations to watershed variables and rainfall pattern over wide climatic regions, we can use the model to predict the channel geometry changes in a given watershed basin with new input variables reflecting the new climatic conditions.

Coarse wood inhibits debris flow runout in forested southeast Alaska, United States

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Landslides that mobilize into debris flows are often triggered by extreme storms in mountainous regions where they transport sediment and carbon through the landscape, carve steep mountain channels that set topographic relief, and are a hazard to humans. Many debris flows occur in humid, forested environments and incorporate large volumes of coarse woody debris (CWD), including entire trees and root wads. However, how CWD affects runout mechanics of individual debris flows or how the integrated effects of multiple debris flows over time affects the spatial distribution of biomass is rarely quantified. To isolate the effects of CWD on runout, we analyzed recent debris flows in southeast Alaska that occurred mainly in mature temperate rainforests with minimal human alteration. We first measured volumes, inundation areas, and runout lengths of debris flows that occurred on 18 August 2015 near Sitka. Compared to a global compilation of debris flow data, the Sitka debris flows inundated channel cross sections that were 59% larger, deposited over areas that were 61% smaller, and ran out distances that were 65% shorter. Similar reductions in runout occurred in discrete element model simulations of a coarse-grained debris flow front that included at least 30% CWD by volume. We therefore interpret that CWD in the Sitka debris flows provided additional frictional resistance at the flow front, causing thicker, less extensive deposits and shorter runout lengths. To further elucidate the role of CWD in controlling runout, we analyzed 1,061 historical debris flows in the surrounding Tongass National Forest with respect to spatial variations in forest characteristics. Runout decreased significantly with average forest age, and debris flows that occurred in the subset of forests with the largest

average diameter trees were significantly less mobile than those in all other forests and nonforested areas. These results demonstrate that large trees inhibit debris flow runout, thereby buffering the effects of extreme storms on long-term sediment and carbon budgets by restricting the export of sediment and carbon from steep mountain channels.

When do the plants matter? Improving our understanding of landslides and ecology via interdisciplinary research.

Buma, Brian

University of Colorado, USA

The biosphere plays a major role in regulating the occurrence, magnitude, and impact of natural hazards, including geomorphic disturbances like landslides. Forests clearly enhances slope stabilization in some areas, but it also serves as a complex interface between drivers of slide characteristics – some quite relevant to human hazard concerns. As forests are something that is commonly managed for a variety of reasons, this coupled human-natural system deserves attention. For example, taller vegetation may play an important role in promoting landslides by transferring wind energy to the soil; they also influence runout distances when long tree boles jam against the intact edges of narrow debris flows. Understanding the complex interplay between the biotic realm and disturbance processes requires a holistic look at those processes and the emergent ways in which they interact. Here we will present work that presents an updated version of landslide runout modeling that dynamically incorporates tree size while also incorporating wind disturbance as a driver of landslide initiation (as well as a disturbance agent on its own). Results for the area around Sitka, Alaska, will be shown – an area where this probabilistic, exposure modeling framework is being used to better understand cumulative spatial distribution of human risk as well as fundamental ecosystem properties such as carbon storage potential and stocks.

Glacial lake outburst floods and fluvial erosion in the Himalaya – insights from the 2016 Bhote Koshi GLOF

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The Himalaya is a region of rapid erosion where fluvial processes are assumed to be driven by precipitation delivered during the annual Indian Summer Monsoon. However, the rivers in this region are also subject to catastrophic floods caused by the failure of glacial lake and landslide dams. In July 2016, the Bhotekoshi/Sunkoshi River in central Nepal was hit by a glacial lake outburst flood (GLOF) that caused substantial changes to the channel bed, banks, and adjacent hillslopes, causing at least 26 landslides and an average of 11 m of channel widening. The flood passed through a seismic and hydrological observatory installed along the river in June 2015, and we have used the resulting data to constrain the timing, duration, and bedload transport properties of the outburst flood. The impact of the flood on the river can be further observed with hourly time-lapse photographs, daily measurements of suspended sediment load, repeat lidar surveys, and satellite imagery. The outburst flood

affected the river on several timescales. In the short term, it transported large amounts of coarse sediment and restructured the river bed during the hours of the flood pulse itself. Over intermediate timescales it resulted in elevated bedload and suspended load transport for several weeks following the flood. Over longer timescales the flood undercut and destabilized the river banks and hillslopes in a number of locations, leading to bank collapses, slumps, and landslides. Our data indicate that impacts of the GLOF far exceed those driven by the annual summer monsoon, likely due to extremely coarse sediment that armors much of the channel. The relatively frequent occurrence of GLOFs and the extremely high discharges relative to monsoon floods suggest that GLOFs may dominate the dynamics of fluvial systems and channel-hillslope coupling within a zone that can extend many tens of kilometres downstream of glaciated areas. Fluvial erosion in these regions may therefore be driven not by precipitation, but rather by GLOF frequency and magnitude, which may increase in response to climate change.

Post-seismic export of organic carbon – a reduced-complexity approach

Croissant, Thomas
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In mountain ranges, the widespread landsliding triggered by earthquakes mobilise large amounts of organic carbon by stripping soil and vegetation from hillslope. During the postseismic period, the organic carbon is either transported out of river catchment by physical sediment transport and/or degraded by heterotrophic respiration when it is not directly available for transport. However, the relative importance of these two processes on the postseismic organic carbon evolution has never been explored. Here, we propose a statistic analysis to quantify the post-seismic redistribution of organic carbon in atmospheric and offshore reservoirs. The underlying idea of this approach is to combine predictions based on empirical observations of co-seismic sediment mobilisation with the description of the physical processes involved during the post-seismic phase. Earthquakes-triggered landslide populations are generated by randomly sampling landslide area distribution, a proportion of which is initially connected to the fluvial network. The remaining part of the population connects to the rivers at a velocity controlled by the distance of the landslide to the streams. The landslide connectivity status controls the organic carbon export process. Disconnected landslides lose organic carbon by oxidation while connected ones see their organic carbon content synchronously decreasing by physical export and oxidation. This approach is fast enough to explore systematically a range of parameters that exert a control on organic carbon redistribution. Amongst them, the influence of climatic context (mean annual runoff and runoff variability), tectonic context and river transport capacity on the residence time of organic carbon is investigated.

The new normal? A major decline in the Mekong's fluvial sediment load is driven by shifting tropical storms and extreme anthropogenic pressure

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As one of the Asian ‘mega-rivers’ that drain the Himalayas and Tibetan Plateau, the Mekong has, in the recent past, contributed a large supply (~160 Mt/yr) of fluvial sediment to the coastal zone. In this paper I review recent work undertaken by my colleagues and I that has shown that a large component of the Mekong’s natural sediment load is driven by extreme events, notably tropical storms that track across the Indo-China peninsula. However, even as tropical cyclones in the Western Pacific increase in their frequency and intensity as a result of anthropgenic climate change, our work has also shown that a commensurate shift in the geographic location of cyclone tracks has in recent decades been driving a steady decline in the Mekong’s sediment loads. That is, the spectrum of extreme events perturbing the Mekong’s natural sediment supply has been steadily changing, with a commensurate impact on the Mekong’s sediment load. However, our new work shows that in the last decade major anthropogenic pressures, such as dam construction and excessive sand mining, are now driving much larger declines in the Mekong’s sediment load. In this paper I argue that these anthropogenic pressures represent an extreme perturbation to the Mekong’s natural sediment transfer system that have caused the Mekong’s sediment system to operate in a way that is completely distinct from its natural state. I will also show that other major river systems, where the ‘pulse’ of sediment transfer to the coast can also be expected to be significantly affected by tropical storms, are also being significantly disrupted by these same anthropogenic pressures. I argue that many of the world’s major storm-affected rivers are now functioning in a new way whereby the relative effects of extreme storms on fluvial sediment supply to the oceans have been significantly dampened by terra-forming human activities.

M9 Earthquakes and Landscapes of the Cascadia Subduction Zone

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The last decade has provided unexpected lessons in the enormous risks from great subduction earthquakes: Sumatra 2004, Chile 2010, and Japan 2011 were each devastating, resulting in surprising impacts distinct from shallow seismic events. Similar large-magnitude earthquakes are known to occur on the Cascadia subduction zone (CSZ), with the potential of rupturing the entire 1100 km length of the Pacific Northwest plate boundary. Coseismic landslides represent one of the greatest risks to the millions of people living along the Cascadia Subduction Zone, from northern California to southern British Columbia. Empirically derived relationships between earthquake magnitude and landsliding are well studied, and suggest a magnitude 9 earthquake is likely to trigger thousands of landslides. Because a magnitude 9 subduction earthquake is well known to have occurred just over 300 years ago, evidence of coseismic landslides triggered by this event should still be present in the landscapes of the Washington and Oregon Coasts. We are systematically hunting for these landslides through field and LiDAR mapping and are using a combination of radiocarbon dating and surface roughness analysis, a method first developed to study landslides near to the Oso 2014 disaster site, to develop more robust regional landslide chronologies. In addition, we compare our results to new probabilistic quantification of ground motions from a M9 earthquake, including uncertainties, which is a novel approach to delivering synthetic seismograms for engineering and other purposes. With these new data, we hope to better characterize how the landscape will respond to the next large subduction zone earthquake in the Pacific Northwest.

Analyzing Post-Flood Recover After an Extreme Flood: North St. Vrain Creek, CO

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Assessing the ongoing sediment remobilization and deposition following an extreme flood is important for understanding disturbance response and recovery, and for addressing the challenges to water resource management. From September 9-15, 2013, a tropical storm generated over 350 mm of precipitation across the Colorado Front Range. The resulting 200-year flood triggered landslides and extreme channel erosion along North St. Vrain Creek, which feeds Ralph Price Reservoir, water supply for the Cities of Lyons and Longmont, CO. The flood resulted in 10 m of aggradation upstream of the reservoir. 4 years after the flood, transport of this flood sediment and deposition in the reservoir continues. This research tracks the fate of flood-derived sediment to understand delta evolution, quanitfy sediment remobilization, and assess post-flood response processes and controls. Bathymetric DEM differencing from 2014 and 2016 (years 1 and 3 post-flood) indicates a minimum sediment accumulation of 68,000 m^3 on the delta plain, and progradation of 170 m of the delta front since the 2013 flood. Between fall 2016 and spring 2017, the reservoir level was dropped approximately 10 m during construction at the spillway, creating a base level drop, delta incision, and causing over 15,000 m^3 of sediment to be transported further into the reservoir. Based on bathymetry and reservoir core analyses, a total of 74,000 m^3 of sediment was deposited in the delta from 2014 through 2017, producing an estimated loss of 0.4% in reservoir storage capacity. Approximately 184,000 m^3 (equivalent to another ~1% of reservoir storage capacity) is estimated to remain in storage upstream of the reservoir. Although the approach channel upstream of the reservoir appears to be adjusted to a typical snowmelt runoff, the remaining large volume of sediment still in storage upstream highlights the potential for future disturbances to trigger additional sediment inputs.

Identification of key predictors for the susceptibility of Himalayan glacial lakes to sudden outburst floods

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Although glacial lake outburst floods (GLOFs) have a low frequency of 1.3 events per year across the Hindu-Kush-Himalaya (HKH) mountains, their high water and sediment load presents a significant hazard to downstream communities. Peak discharge rates of up to 30,000 m^3/s and flood volumes of > 50 million m^3 provide GLOFs with strong erosion and accumulation dynamics. Their landscape-forming potential is also seen in the Quaternary sediment record of a number of HKH valleys. Recent studies, based on few selected glacial lakes and even fewer reported GLOFs, focus on a small set of variables (e.g. lake freeboard and moraine dam width) and use subjectively set thresholds to produce GLOF hazard classification matrices. The aim of our study is an unbiased, statistically robust and reproducible assessment of GLOF susceptibility in the HKH mountains. It builds on the currently most complete inventory of HKH GLOFs comprising 38 events over the past three decades. In order to identify key predictors for GLOF susceptibility, a total of 22 potential geomorphic, geologic, and climatic GLOF predictors are tested in multivariate logistic

regression models. We are assessing, for instance, whether spatially distinct climatic conditions along the HKH, such as the seasonal precipitation patterns influenced by the Indian summer monsoon (ISM) in its south-eastern ranges, are driving GLOF susceptibility.

Geomorphic impacts of the intense monsoon 2018 in Kali Gandaki Valley, Nepal Himalaya

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Geomorphic activity in the central Nepalese Himalaya is largely driven by monsoonal precipitation. Recent climate trends indicate shifting monsoon intensities and patterns, what might go along with enhanced geomorphic response. However, a better understanding of related geomorphic processes is of high relevance, especially in populated regions. In this study, we evaluate the dramatic impact of the intense monsoon 2018 in the Kali Gandaki Valley known as the deepest valley on earth with elevation differences of > 5500 m between the valley bottom and the peaks of Dhaulagiri and Annapurna (> 8000 m). The study ranges along a climate gradient from Dana (1400 m) in the wet South (precipitation: ~ 1500 mm/a) to Muktinath (3800 m) in the dry North (~ 400 mm/a). However, besides monsoon dynamics, numerous infrastructure projects in the area (e.g. Kali Gandaki road and power line construction) cause changes in geomorphic activity as well. Geomorphic impacts were assessed based on comparative interpretations of high-resolution Pleiades satellite images of March and October 2018 and field visits in April, September and November 2018 and March 2019. In addition, newspaper reports were analyzed. Results show that a severe rainstorm event in August was followed by a secondary one in September 2018. Whereas the highest August rainfall total since 1978 was measured in Muktinath, no exceptional monthly values are recorded further south. The entire study area shows increased geomorphic activity, including floods, hyperconcentrated and debris flows and multiple landslides. Most dramatic impacts occurred south of Chhoya Deurali, where severe flooding caused a huge collapse (min. 2.5 million m^3) of parts of the prehistoric Dhampu rock avalanche deposit. This slope failure caused an enormous sediment input impacting on the 12 km downstream stretch (Chhoya Deurali to Dana) and increasing the average active floodplain width from 36 to 63 m. Furthermore, many landslides were triggered along this stretch (e.g. in Bandarjung, Pahiro Thapla and Kopchepani). However, upstream of the slope failure (Kalopani, Lete), dust storms originating from the collapsed flank lead to enhanced aeolian sedimentation for several weeks. Especially north of Ghasa almost all tributaries show significant channel erosion (and partly deposition) due to hyper-concentrated flows e.g. in the Thapa Khola (Tukuche) and the Lupra Valley. Parts of the highly active landslide complex in the Muktinath Valley including the Jharkot/Khingar earthflow were significantly boosted as well, increasing the probability of future landslide dams and potential outburst floods in the Jhong River.

A remarkable contrast in stable isotopic composition of Nepalese rivers before and after Gorkha Earthquake (Mw 7.9)

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Stable isotopic compositions (H and O) monitored from the major Himalayan rivers (Kosi and Narayani) together with their small tributaries since the pre-Gorkha Earthquake (Mw 7.8) of 25 April 2015 shows a remarkable contrast in data set before and just after the earthquake. Strong seasonality in oxygen isotopic composition of river water (4-5‰) in the catchment of Narayani River in the Himalaya in 2010 is recorded, while the composition remains much more stable with a slight evolving tendency in the same ruptured area by the Gorkha Earthquake during the monsoon in 2015. However, the Kosi data set of 2015 shows a variation of 4‰ in δ18Osmow and 30‰ in δDsmow. Ghalegaon precipitation data illustrates the variation ranging from -20‰ to -3‰ in oxygen isotopic composition for excursion of seasonality in 2013. The precipitation gradient in our data set reveals around 1.7‰ per kilometer in the Himalaya. For the precipitation at a given location, data are marked by strong seasonal contrast (e.g. Zhang et al. 2001, Gajurel et al. 2006) probably related to source of moisture and amount effect. The seasonal trend in δ 18O generates an offset particularly between June-July and August that influence on river isotopic composition. The river isotopic compositions are progressively depleted in heavy isotopes during the monsoon reflecting the seasonal evolution of precipitation, however, it is buffered by the ground water reservoir. At the beginning and end of the monsoon, the contrast between precipitation and ground water is large and precipitation events generate scattered river variations depending on direct runoff to ground water supply, however, such trend did not found in the Narayani River at Narayanghat, particularly, immediately after the 2015 Gorkha earthquake.

Rapid alluvial fan and terrace development in response to a large, high-magnitude rockfall in the Klados Gorge, Crete, Greece.

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The impact of high-magnitude, stochastic events, such are large landslides, on drainage basin-scale earth surface dynamics is poorly understood. Here, we present results from one such natural experiment, where we show that a geologically-recent catastrophic rockfall altered catchment-scale dynamics and generated a spectacular set of alluvial terraces and fans in southwestern Crete, Greece. We present results from a detailed field investigation of the ~11.5 km^2 Klados River drainage basin, the smallest of five river gorges carved into carbonate bedrock of the Levka Ori Mountains along a ~30 km stretch of coastline. The alluvial fans and terraces in Klados stand out among neighboring gorges for their great thinkness and extent. Our mapping reveals two large inset alluvial fans, a lower unit (~25 m thick) and an upper unit (~50m thick), at the river mouth that transition to river terraces upstream and vertically separate exposing bedrock straths before terminating near the catchment headwaters. Both fan-terrace units blocked bedrock tributary valleys, generating ponds preserved as laminated fine-grained deposits. Both allostratigraphic units are similar,

with poorly sorted and coarse-grained basal debris flow deposits overlain by a crude fining upward sequence of angular-to-subangular clasts with weak bedding. Importantly, the lower fan forms a buttress unconformity with a prominent bio-erosional notch that was coseismically uplifted in an earthquake in 365 AD, constraining its age to late Holocene. The slope of the lower and upper fans is similar, indicating consistent base level at the time of emplacement, suggesting that the upper fan is also mid-to-late Holocene in age. Radiocarbon geochronology on bulk sediment from fine grained deposits in both units supports the interpretation of Holocene deposition. Mapping also reveals an older patchy matrix-supported unit with sedimentology consistent with a large debris flow that is locally >100 m thick and fills a paleo-bedrock topography. The source of this deposit is attributed to a large rockfall along an ~900 m relief cliff in the catchment headwaters that pulverized upon impact with the valley floor. This interpretation is supported with numerical modeling of landslide runout based on reconstructed deposit volume and rockfall detachment zone that shows that such a scenario would backfill the valley by ~100 m. Our study suggests that this catastrophic rockfall altered the dynamics of the Klados drainage basin. Prior to this rockfall event the catchment was a small bedrock river gorge. Post-event the catchment became ultra-sensitive to external perturbations (extreme rainfall and seismic activity) that episodically liberated weak landslide deposit material allowing for alternating episodes of deposition and bedrock incision that rapidly built the impressive fan and terrace sequences. These results emphasize the role of stochastic events in changing catchment-scale earth surface dynamics and the development of landforms traditionally linked with longer-term external drivers such as climate and tectonics.

Relict debris flows and modern slushflows as agents of severe landscape transformation in the low Subarctic Mountains of NW Russia: magnitudes, affects and age

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Medium magnitude debris flow phenomena are widespread in the Kola Peninsula Mountains, NW Russia. Most frequently observed types are snowmelt period slushflows and rainfallinduced debris flows. Similar sets of hazardous events are reported for mountainous areas of Scandinavia, Japan and Northern America. Investigation of such events in the Khibiny Mountains over the last 50 years produced a unique dataset of >200 slushflow-affected catchments. However, those surveys concentrated largely on monitoring the consequences of presently observed events while reconstructions of their magnitude and frequency in the past remained beyond the scope of investigations. Large-scale bottom features and piedmont fans found in the majority of small valleys indicate periods of much higher debris flow activity in the past. Reconstructing debris flow activity through the Holocene involved detailed description of associated landforms and deposits using field inspections, satellite and UAV imagery in several mountain valleys of Khibiny and Lovozerskiye Tundry. Grain size analysis and radionuclide fingerprinting of 232Th content in the finer-grained sediments were applied. Limited geochronological framework was established by 14C dating of buried humic and peat layers between superimposed slushflow deposits and was compared to the previously published chronology of slope processes. Available results for >10 studied mountain valleys suggest slushflows and, for some valleys, typical debris flows with lower frequency as a leading mechanism of downstream sediment delivery and valley floor topography formation. Fluvial topography is extremely suppressed

or nonexistent under such conditions, as stream channels are unable to rework slushflow deposits and forced to passively adjust. Much lower frequency of extreme events can be estimated as at least twice per millennia. In general, debris flow magnitude has significantly reduced since the recession of the last continental ice cover.

Outburst floods from overtopping lakes and the long-term evolution of landscape. From Lake Bonneville to the Zanclean flood.

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Ever since the early landscape evolution numerical models in the 90's, their application to the understanding of specific geological scenarios has been limited by the poor knowledge of the ancient hydrological conditions and the controls on key rock parameters such as their erodability. As a consequence, when applied to a geological setting, LEMs need to be calibrated with local erosion data to make sure that the model's surface processes and sediment transport are working at the proper speed. I will show that outburst paleofloods caused by overtopping lakes are phenomena that often record both the hydrological regime and the resulting erosion, providing an ideal test for water-driven erosion models. 82 megafloods have been compiled in an overtopping-flood database, including the Bonneville flood, the Zanclean flood of the Mediterranean and some lab experiments. Our erosion model mathematically links the erodability to observables, namely the flood's peak discharge and the lake size. The erodabilities thus estimated from the 82 settings are qualitatively consistent with the outlet's lithology and with erodability values previously obtained from river incision studies, suggesting that the method is capable of a first-order estimation of rock strength and erosion rates. These results are promising for developing future predictive models of landscape evolution.

Does the seismic cycle slip towards randomness?

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Seismic hazard estimates are based on time-interval distributions between earthquakes with a reference magnitude (i.e., periodic to random). In the Himalaya, recurrence times are currently described by a cyclic model. We report by statistical analyses on a 6000-year lakesediment seismic record implies that time intervals between large (M 6.5) earthquakes are robustly described by a Poisson distribution, i.e. a random occurrence. Second-order fluctuations evidence event clustering. These patterns are calibrated against an instrumental catalogue for the entire Himalaya and are inconsistent with periodic or quasi-periodic models. Our results imply that the occurrence of major seismic events is as uncertain as smaller events on any time scale, increasing drastically previous estimate of the seismic hazard. Throughout this presentation we will compare the Himalayan results with global paleoseismic data.

Downstream mobilization of very large boulders during riverbed liquefaction: Insights from grain-scale simulations

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Steep mountainous bedrock channels often host large boulders with a diameter of up to tens of meters. These boulders are believed to be derived from nearby hillslopes or proximal debris flow channels, and observations show that they can move downstream the river during extreme events. However, shear stress-based calculations indicate that the threshold for motion is not surpassed for very large boulders even during severe floods, posing a mechanistic problem. Here, we propose a new mechanism for the mobilization of very large boulders that rely on seismically induced liquefaction of thick riverbed sediments that underlie the boulders. Earthquake-induced liquefaction of saturated loose sediment layers, such as soils, is a catastrophic phenomenon that causes a phase transition from stress-bearing solid layers to fluid-like slurries that flow in response to small shear stresses. It is commonly believed that effectively undrained conditions are a necessary criterion for liquefaction. However, recent numerical, experimental, and theoretical advances demonstrate that well-drained, saturated grain layers could also undergo liquefaction due to the coupling between grain compaction and the outward flow of the interstitial pressurized fluid. Riverbed sediments are therefore a prime candidate for seismic induced drained liquefaction because they are saturated, well-drained and loosely packed. We develop a two-phase model that solves the coupled dynamics between deforming, cohesionless grains and flow and pressurization of the interstitial fluid. We use the model to study the behavior of a saturated granular layer with a large overlying grain in response to horizontal shaking. This setting represents a seismically excited layer of riverbed sediments with a very large boulder residing on top. Model results show that for natural parameters, the riverbed liquefies and moves downstream carrying with it the large grain that simultaneously moves downstream and sinks into the sediment layer.

Source to sink: the journey of landslide sediment following the 2015 Gorkha earthquake

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Rivers draining the Himalaya and feeding the Indo-Gangetic plain support around 10% of the world's population. However, these rivers are also prone to frequent and often devastating floods such as the 2008 Kosi floods which displaced more than 2.5 million people. Changes in sediment supply from the Himalaya affect the magnitude and frequency of floods. For example, an increase in sediment flux from widespread landsliding associated with large earthquakes is expected to result in channel bed aggradation and increased rates of channel migration, and therefore higher flood risk at the Himalayan mountain front in future years. This study aims to constrain the timescales and modes of migration of coarse sediment following widespread landsliding in mountains using the example of the 2015 Gorkha

(Nepal) earthquake. Through several field campaigns, we have collected gravel size and lithology as well as channel geometry data, and constructed a unique record of high-resolution channel cross-sections along the Kosi River (East Nepal) using an Acoustic Doppler Current Profiler (ADCP) in the years following the Gorkha earthquake. This dataset is used to estimate the river's sediment transport capacity, sediment mobility and cross-sectional channel geometry change through time. We test whether the changes are consistent with the location of sediment sources (landslides) and magnitude of the monsoon floods by mapping zones of sediment input from optical satellite imagery and using flow data from gauging stations. Preliminary results show little evidence for largescale downstream transport of coarse sediment, suggesting the Gorkha landslides will have less of a direct impact on flood and sediment dynamics on the Indo-Gangetic plains than expected from comparison with similar events.

Fluvial recovery following volcanic eruptions

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Mount Pinatubo, Philippines, erupted in June 1991, in the second biggest eruption of the 20th century. River valleys filled with pyroclastic flow deposits that were not hot enough to weld, leading to massive redistribution of sediment by lahars following the eruption. We studied channel recovery and evolution for two decades following the eruption, tracking sediment-laden channels as lahars ceased and normal fluvial processes were finally able to process and rework the channel bed. Results were compared with the North Fork Toutle River at Mount St. Helens to further evaluate long-term river recovery following a major volcanic eruption. These eruptions offered a unique look into how rivers process high volumes of sand-rich sediment providing insight into river recovery following landslides, dam removals, or other extreme sediment-producing events. This talk will cover the different kinds of impacts associated with major explosive eruptions, from immediate impacts to the surrounding landscape to the longer-term impacts to the fluvial system, drawing upon examples primarily from Pinatubo and Mount St. Helens. At both volcanos, sediment loads fell exponentially in the years following the eruption, but in watersheds with the greatest impact, sediment loads leveled off much higher than pre-eruption yields. Continued instability within the braidplain may continue for decades, as sediment availability within the valley bottom remains abundant and high channel mobility limits growth of stabilizing vegetation. Ultimately, the complex interactions between hydrology, geomorphology, sediment supply, and vegetation regrowth following volcanic disturbances govern the recovery pathway and dictate the timescales associated with fluvial recovery following a major eruptive event.

Ferruginous nodules as a novel medium to evaluate the mineralogical and geochemical impact of palaeowildfires

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Wildfires are a prevalent phenomenon on the Earth’s surface and they have a significant influence on atmospheric composition, elemental cycling, plant life and soil composition. With reported surface temperatures of close to 850°C, wildfires have a strong potential to significantly impact surficial geochemistry and mineralogy usually dominated by low temperature weathering processes. Despite this, little is known about the contribution of wildfires to surficial mineralogy and geochemistry throughout Earth's history. Previous work on the subject has identified thermally altered ferruginous nodules as novel medium to determine the effects of wildfires on surficial geochemistry and mineralogy. Thermal experiments on artificial and natural Fe-nodules have been used to characterise the mineralogical, geochemical and textural changes that occur as a result of heating. X-ray diffraction confirms maghemite and γ-alumina, two phases commonly observed in Fenodules, are formed at temperatures greater than 500°C and 800°C respectively. Preliminary LA-ICP-MS data indicates fractionation of some trace elements and alkali metals within nodules exposed to high temperatures. Textural observations suggest fracturing and loss of the nodule cortex is common upon heating, potentially increasing weathering of nodules post wildfires and allowing leaching of any water-soluble elements from the ferruginous matrix. This will be examined in future leaching experiments.

Looking for Past and Future Landslides triggered by the Seattle Fault

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Coseismic landslides are a major secondary hazard of earthquakes, as they can be more destructive to both the built and natural environment than the triggering earthquake. Western Washington state is a dynamic landscape with a history of both earthquakes and landslides. Steep topography, high precipitation, and weak glacial deposits make this an ideal site to study the impacts of coseismic landslides. Though the nearby Cascadia subduction zone has the potential to cause large M9 earthquakes, recent work suggests that a smaller earthquake on the Seattle Fault may cause more landsliding in the Seattle area. To better understand the coseismic landslide hazards associated with the Seattle Fault, this study is looking at both the past and future of landslides caused by earthquakes on this fault. First, we are using the record of landslide deposits in the Seattle Fault Zone to observe the volume, style, and distribution of landslides possibly caused by the Seattle Fault. Specifically, we used LIDAR to perform a survey of landslides near the surface trace of the Seattle fault. We then will date some of these landslides using a roughness-based metric and C14 wood dating. Using these dates, we can estimate whether each slide may have been triggered by the well-known Seattle Fault earthquake 1000 ybp. To find the areas that are susceptible to future coseismic landslides we will model the expected ground motions for a Seattle Fault earthquake using the finite difference code SW4. This model used a recently updated crustal velocity model and a topography dataset for the Puget Lowlands. This ensured that basin and topographic seismic amplification effects were considered. These ground motions will then be used to create a landslide susceptibility map of the area. Combining the results from this modelling with the dated landslides will provide a more complete picture of the coseismic landslides that are caused by the Seattle Fault.

Earthquake-induced landsliding enhances carbon export and burial in the deep ocean over millennial timescales.

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Erosion of biospheric particulate organic carbon (POC), export by rivers and subsequent burial in ocean depocentres affects the atmospheric carbon reservoir over geological timescales. Attempts to quantify terrestrial POC fluxes at the global scale have largely neglected the role of extreme events, such as earthquakes. Quantifying POC fluxes from extreme events has proved challenging because responses to them often persist beyond the duration of instrumental data series. We overcome this challenge by using sedimentary archives of earthquake-induced erosion from lakes adjacent to the Southern Alps, New Zealand. Landslides triggered by four Mw>7.9 ruptures of the range bounding Alpine Fault produce pulses of earthquake-mobilized carbon that represent 23 ± 5% of the record length, but account for 43 ± 5% of the biospheric carbon in the sediment cores. Landslide simulations suggest that 14 ± 5 million tonnes of carbon (MtC) could be eroded in each earthquake. Turning to the earthquake-induced burial of terrestrial POC in the deep ocean, we have gained insights by studying the marine geomorphic and sedimentary responses of the Hikurangi Margin to the 2016 Mw7.8 Kaikōura earthquake. Sediment gravity flows triggered by this earthquake flushed sediment from submarine canyons transporting over 7 MtC to the deep ocean. Such flows dominate the transfer of sediment and carbon to the deep ocean on this margin. Hence, large earthquakes can significantly contribute to both carbon export from mountain forests and burial in the deep ocean over millennia timescales providing a direct link between active tectonics and the surface carbon cycle.

Assessing provenance, exposure timing and emplacement processes of large exotic boulders in central Himalayan river valleys

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In central Himalayan river valleys, numerous large boulders (>10 m in diameter) lie on or are incorporated within Quaternary river terraces, active floodplains or the modern river bed. Their lithology frequently differs from the surrounding bedrock and reveals that they are derived from rock units outcropping >10 km of kilometres upstream. The large boulders are located 2000 m lower in elevation than the terminal moraines associated with the last glacial maximum (LGM) (e.g. Owen & Benn, 2005). The exact transport mechanisms of such exceptionally large grain sizes remain unknown and may be linked to reoccurring catastrophic mass-wasting events. (1) The boulder size of 16 boulders was used to estimate paleo-discharges in two valleys of central Nepal (Trishuli and Sunkoshi) based on different literature fluid flow approaches (e.g. Alexander & Cooker, 2016). These estimates indicate discharges in the order of 104 to 105 m3 /s are necessary to mobilize the surveyed boulders. (2) 10Be exposure ages of these boulders show ages up to 10.2 - 14.2 ka BP for two boulders in the Sunkoshi but also show clustering of emplacement at ca. 4.5 - 5.5 ka BP in both valleys. Exposure dating implies a reoccurrence interval >103 yrs for such large magnitude

events. The ages documented in this study were compared to dated glacial landforms, alluvial deposits and earthquake occurrence in central Himalaya (e.g. Abramowski et al., 2003; Pratt-Sitaula et al., 2004; Bollinger et al., 2014) as well as terrestrial climate records of the Indian monsoon influenced region (e.g. Sarkar et al., 2015). Correlation between boulder exposure ages, shift on monsoon governed climate regime, and glacial retreat suggests linkage of emplacement to mid Holocene climate transition after an Early Holocene climate optimum (EHCO). We reason that the mid-Holocene weak monsoon induced wide-spread glacier retreat and may have led to high magnitude Glacial Lake Outburst floods (GLOFs) responsible for large scale boulder emplacement in central Himalayan river valleys.

Impact of Coseismic Landslides on Himalayan Chemical Weathering

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Chemical weathering of silicate rocks is a key regulatory process of atmospheric CO2, over geological time, with atmospheric derived carbonic acid being neutralised by the hydrolysis of silicate rocks and eventually being converted to carbonate. The rate of silicate chemical weathering is dependent on temperature, rainfall and erosion rates, that is supply of reactants. The 2015, Nepal earthquakes, magnitude 7.3 and 7.5, triggered thousands of coseismic landslides, affecting delivery of rock material to rivers.

Our research is examining whether this increase in landslides perturbed sediment and chemical weathering fluxes, a connection which is difficult to establish owing to the infrequent nature of such events. We seek to identify the provenance of the sediment, changes in sediment fluxes, and to determine the chemical evolution of the sediment as it is transported down river.

Depth profiles of suspended load samples were collected from the Sun Kosi and Sapta Kosi Rivers, immediately after the 2015 earthquakes and annually for each of the 4 following years. The chemistry, grainsize and flux of the sediments Kosi Basin will be presented. The sediment chemistry was partitioned into carbonate, silicate and Fe-oxide fractions by sequential extraction.

Mineralogical control, source effects and degree of sediment weathering were investigated by plotting silicate mobile/immobile (molar) elemental ratios for K, Na, CaSil, CaCarb, building on pioneering work from [1&2]. The complexity of the mineralogical controls on elemental concentrations and how this impacts estimates of chemical weathering will be discussed.

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Understanding Seismic Velocity variations after the 2015 Gorkha Earthquake, Nepal.

Illien, Luc

In the last decade, we saw the emergence of a new field called Environmental Seismology. In using the ambient noise recorded by seismometers, one can infer relative changes of seismic velocity in the subsurface. A successful growing body of work has been focused to relate these changes to hydrological changes such as variation of ground water level using simple models of reduced complexity. However, very few studies have attempted to process ambient noise and push these models in extreme environments where the amplitude of the precipitation forcing exceed the global continental norm.

In this study, we address this gap in presenting results from single station cross correlations performed on a seismic network of 10 seismic stations deployed after the 2015 Mw 7.8 Gorkha Earthquake, Nepal. Our data spans a period of four years and covers four monsoon seasons in the epicentral area of the Bothe Koshi basin.

We observed that the hydrological cycle induces variation in velocities up to 8% magnitude in the high frequency band of 4 to 8 Hz. These variations of velocity give insights into the threshold in the antecedent precipitation rate needed to start decreasing the velocities and therefore generates groundwater. We show that this threshold corresponds to the time needed for the soil to reach saturation.

We model these observations with an existing model of ground water level evolution and introduce new variables to incorporate the effect of soil for the input and output flux of the groundwater reservoir. Limits concerning these models in these environments are also discussed and comparison between the 2015 Monsoon and the following monsoons are made to isolate the effect of Gorkha Earthquake on the properties of subsurface.

We believe that our dataset provides a unique opportunity to disentangle the key controls on the hydrological cycle in presence of extreme precipitations and steep topography in terrains that are classically challenging for performing hydrological measurements.

Quantifying earthquake preconditioning of monsoon-triggered landslides in Nepal: implications for landslide susceptibility modelling.

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Landslide susceptibility models are a vital resource that facilitate improved management of future landslide hazard. Existing landslide susceptibility models are implicitly time-independent, assuming that landscape susceptibility to a given landslide trigger is static. However, the validity of this assumption is challenged by observations which suggest that earthquakes can cause transient, time-dependent, changes in climate-triggered landslide rates, a concept commonly referred to as earthquake preconditioning. Here, we quantify earthquake preconditioning in central-eastern Nepal by using satellite-based landslide mapping methods and the PERSIANN-CDR precipitation product to develop a climate normalised monsoon-triggered landslide rate from 1988 to 2018. We find that between 1988 and 2014 the precipitation-normalised rate of landsliding remained broadly static, seemingly not impacted by the Mw 6.9 earthquake which struck east-Sikkim in 2011. However, in 2015 the precipitation-normalised rate of landsliding increased by a factor of 10 before decreasing linearly back to the pre-2015 background rate over the next 3-4 years. This suggests that the Mw 7.9 Gorkha earthquake significantly moderated the landscape response to the post-earthquake monsoons, and that time-independent landslide susceptibility models would have under-predicted post-earthquake monsoon-triggered landslide occurrence. We suggest that new time-dependent landslide susceptibility models, which can account for the transient impacts of earthquakes on the landscape, should be developed in order to increase the accuracy of post-earthquake climate-triggered landslide modelling.

Learning Latent Patterns of Himalayan Hazards

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The ongoing loss of Himalayan glaciers has been creating new unstable terrain and setting the stage for glacier lake outburst floods (GLOFs), ice and rock avalanches. Predicting these sudden and potentially destructive releases of ice, water, and debris has made some advances, and we can now estimate average return periods of rare events. Yet these estimates hinge on peak-over-threshold data and thus rely on how well we can pin down the size distributions and mean intensities of these processes. Extreme-value models show that the contemporary 100-year GLOF from moraine-dammed lakes in the greater Himalayan region has a peak discharge of 15,000-25,000 m^3/s. This range encapsulates different lake inventories and newly detected outbursts, but relies on a few dozen peak-over-threshold samples thought to represent the varying causes and triggers across the mountain range. This uncertainty is part of a larger question that asks whether and how frequency-magnitude curves can change. We use a Bayesian approach to learn how credibly the size distribution of Himalayan GLOF sources and landslides varies as a latent function of geographic location, topography, seismicity, precipitation, and other candidate predictors of unstable terrain. We find that heavy tails in landslide data stretch most systematically with increasing topographic relief, whereas the central tendency of landslide size remains unchanged. Our method also shows that distributions of meltwater-lake size appear to be more robust across temperature and precipitation regimes than previously assumed. These results offer an alternative to relying on bulk statistics of magnitude and frequency, and more flexibly meet the need for locally adapted extreme-value models in modern hazard appraisals.

Bedrock landslides induced landscape evolution in the Upper Ganga catchment of the Himalaya

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Bedrock landslides are the primary agent of hillslope erosion, mass wasting and an important source of sediment to the fluvial network in the mountains, especially, in the tectonically active Himalayan mountain belt. To explore and understand the spatial interrelationship of the geological and geomorphological controls on landslide susceptible zones in catchments, we have attempted landscape characterization using morphometric analysis and field verifications in the landslides induced Birahi Ganga, Madhyamaheshwar Ganga and Kanaudia Gad catchments of the upper Ganga terrain in the Garhwal Himalaya. The river profile and their derivatives including knickzones were identified and modelled to compare the inferred high erosion zones with the landslide occurrences and growth of transient signals in the landscape. The results of morphometry analysis show a positive correlation with the landslide zone localization and the same can be used as a marker to explore other regions.

Study on the relationship between dam and river geomorphologic evolution in the upper Indus river

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The upper Indus river is located at the junction of the Eurasian plate and the Indian plate, which belongs to the western Himalayan syntaxes. The strong uplift of the terrain caused by the squeeze between the plates, which has led to frequent geologic hazards such as large-scale collapses, landslides and debris flows, and the formation of dams blocking rivers, which impact on river geomorphology evolution can not be ignored. Therefore, discuss the geomorphic response of river damming can provide a new perspective and entry point for the interpretation of regional geomorphic evolution mechanism. The paper combine remote sensing and digital terrain analysis to study the relationship between dam and river geomorphologic evolution in the upper Indus river. The research results are as follows:(1) There are 121 dams (with a volume greater than 0.001km^3) were found in the upper Indus river region, which are mainly landslide dams. The dam body is relatively large in scale, which are mainly between 0.01 and 0.1km^3; The dam height is mainly between 100 and 200 meters, which is relatively high. It is mainly located in middle and high altitude areas of 2000-5000m. In the Hunza river valley, the dams are the most densely distributed, which most of them are glacier or moraine dams. (2) The longitudinal profile of the trunk rivers of six major rivers in the upper Indus region was analyzed, and it was found that the longitudinal profile of all the major rivers had obvious convex region, especially that the Indus and Shyok rivers developed significant knickpoint. In addition, we make the spatial superposition comparison of the dam with river kinckpoint, fault and lithology of some rivers. It is found that the dam and the river knickpoint have a good fit, indicating that the dam affects the formation and migration of river knickpoint in this area to some extent. (3) Dams and rivers profile, steep index space comparison found that that the high value of steep index has a good correlation with the dam. The variability of river profile of most rivers are related to the dam in this area, which elevates the local erosion base level in the upstream of the dam body. It indicates that the dam affects the geomorphologic evolution of the river in this region, which form the knickpoint in river channel, delay the river headward erosion, and protecte the integrity of the Tibetan Plateau.

Landslide signatures in fluvial sediments from paired cosmogenic nuclides

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Cosmogenic nuclides, such as 10Be, measured in detrital river sediments are widely used to derive denudation rates and sediment fluxes at the scale of entire catchments. Pairing 10Be with another short-lived nuclide such as in-situ 14C (5700 years half-life) allows erosion and sediment processes occurring on Holocene time-scales to be traced at the Earth's surface [1]. In this contribution we evaluate the use of paired 10Be - in-situ 14C in detrital sediments eroded from the rapidly eroding Himalayan range to better quantify how sediments are produced and transferred from source to sink. 10Be and in-situ 14C data from trans-Himalayan rivers shows that the concentration of in-situ 14C relative to 10Be is lower than what would be expected if sediments were produced by steady-state superficial erosion of the landscape. Since long term storage and transfer over 10's of thousands of years of the sediment along the Himalayan valleys seem incompatible with present very active sediment export [2], such apparent offset between 10Be and 14C concentrations may be explained by the erosion and mobilisation of sediments from large, deep-seated, landslides. In that case, we show that it is possible to use paired 10Be and insitu 14C measurement in detrital sediments to evaluate the average landslide depth and recurrence time at the scale of entire catchments. These data confirm other recent studies showing that landslides are the dominant mode of erosion in the Himalayan range [3]. [1] Hippe, 2017 – Quaternary Science Reviews, vol. 173, p. 1-19. [2] Morin et al., 2018 – JGR-Earth Surface, vol. 267, p.482-494. [3] Gabet et al., 2015 – EPSL, vol. 12, Q07023-36.

Organic and inorganic long-term carbon budget of the Himalayan erosion after the 2015 Gorkha earthquake

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The erosion of mountain ranges plays an important role in the carbon cycle by controlling the magnitude of the main geological carbon sinks namely silicate weathering and organic carbon export. Here, we investigate the impact of extreme and rare events on the carbon budget of continental erosion by quantifying the response of weathering and organic carbon fluxes to the April 2015 Gorkha earthquake (Mw 7.8) in central Nepal. We acquired daily river suspended sediment and water samples during 3 post-earthquake monsoon seasons (2015-2017) from the Narayani River, a large trans-Himalayan tributary of the Ganges. Samples collected in 2010 from the same location provide a pre-earthquake comparison point. Organic carbon sources and fluxes are constrained using suspended sediment load estimates, the total organic carbon content and radiocarbon isotopic compositions of the sediments. Silicate weathering fluxes are calculated using river water dissolved elemental compositions. These two complementary datasets allow us to make a geological carbon budget of Himalayan erosion before and after the earthquake. Our preliminary results confirm that carbon drawdown from the burial of organic carbon of the Central Himalaya is about 3 times more important than the silicate weathering carbon sink. We show that co-seismic landsliding due to the Gorkha earthquake did not significantly influence the carbon budget of erosion. However, the magnitudes of organic carbon export and of silicate weathering fluxes are strongly correlated to the total river discharge of a monsoon season. We therefore suggest that the long-term carbon budget of this Himalayan catchment is mainly controlled by the monsoon intensity rather than by rare but intense coseismic events as has been suggested in other systems.

Streamflow response to earthquakes

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Following earthquakes, it has long been noted that the amount of water discharged at Earth's surface can increase. The magnitude can exceed 1 km3 of excess discharge in streams, and elevated discharge can persist for many months. Even dry streams may begin to flow. The mechanisms responsible for increased stream discharge remain uncertain. Proposed hypotheses include squeezing water out of aquifers from coseismic contraction, breaking subsurface hydraulic barriers, consolidating (near-)surface material, mobilizing soil water, and increasing permeability. One limitation in testing hypotheses is that observations are restricted to documenting how one or more streams respond to a single earthquake. Documenting responses to multiple earthquakes has proven insightful in showing that at least some springs and streams do not respond to coseismic volumetric strains. Instead, dynamic strains from seismic waves must be responsible for changes in discharge. In this presentation I will review observations and provide a global compilation of responses to earthquakes. These observations are used to test models and to show that enhanced vertical permeability is likely responsible for most streamflow observations.

Long-term erosion of the Nepal Himalayas by bedrock landsliding: the role of monsoons, earthquakes and giant landslides

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In active mountain belts with steep terrain, bedrock landsliding is a major erosional agent. In the Himalayas, landsliding is driven by annual hydro-meteorological forcing due to the summer monsoon and by rarer, exceptional events, such as earthquakes. Independent methods yield erosion rate estimates that appear to increase with sampling time, suggesting that rare, high-magnitude erosion events dominate the erosional budget. Nevertheless, until now, neither the contribution of monsoon and earthquakes to landslide erosion nor the proportion of erosion due to rare, giant landslides have been quantified in the Himalayas. We address these challenges by combining and analysing earthquake- and monsoon-induced landslide inventories across different timescales. With time series of 5 m satellite images over four main valleys in central Nepal, we comprehensively mapped landslides caused by the monsoon from 2010 to 2018. We found no clear correlation between monsoon properties and landsliding and a similar mean landsliding rate for all valleys, except in 2015, where the valleys affected by the earthquake featured ∼5–8 times more landsliding than the pre-earthquake mean rate. The long-term size–frequency distribution of monsoon-induced landsliding (MIL) was derived from these inventories and from an inventory of landslides larger than ∼0.1 km^2 that occurred between 1972 and 2014. Using a published landslide inventory for the Gorkha 2015 earthquake, we derive the size–frequency distribution for earthquake-induced landsliding (EQIL). These two distributions are dominated by infrequent, large and giant landslides but under-predict an estimated Holocene frequency of giant landslides (> 1 km^3) which we derived from a literature compilation. This discrepancy can be resolved when modelling the effect of a full distribution of earthquakes of variable magnitude and when considering that a shallower earthquake may cause larger landslides. In this case, EQIL and MIL contribute about equally to a total long-term erosion of ∼2±0.75 mm yr^{-1} in agreement with most thermo-chronological data. Independently of the specific total and relative erosion rates, the heavy-tailed size–frequency distribution from MIL and EQIL and the very large maximal landslide size in the Himalayas indicate that mean landslide erosion rates increase with sampling time, as has been observed for independent erosion estimates. Further, we find that the sampling timescale required to adequately capture the frequency of the largest landslides, which is necessary for deriving long-term mean erosion rates, is often much longer than the averaging time of cosmogenic ^{10}Be methods. This observation presents a strong caveat when interpreting spatial or temporal variability in erosion rates from this method. Thus, in areas where a very large, rare landslide contributes heavily to long-term erosion (as the Himalayas), we recommend ^{10}Be sample in catchments with source areas > 10 000 km^2 to reduce the method mean bias to below ∼20 % of the long-term erosion.

Environmental controls of glacial lake outburst flood duration and magnitude from ice-dammed lakes

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Understanding the time evolution of glacial lake outburst floods (GLOFs), and ultimately predicting peak discharge, is crucial to mitigating the impacts of GLOFs on downstream communities. The dearth of in situ measurements taken during GLOFs from ice-dammed lake has left many GLOF models currently in use untested. Here we present a dataset of 13 GLOFs from Lago Cachet Dos, Aysen Region, Chile with measurements of key environmental variables (total volume drained, lake temperature, and lake inflow rate) and high temporal resolution discharge measurements at the source lake, in addition to well-constrained ice-dam and glacier thickness and bedrock topography. Using this dataset we test two commonly used empirical equations as well as the physically-based model of Spring-Hutter-Clarke. We find that empirical relationships based solely on lake volume drained fail to predict the large variability in observed peak discharges from Lago Cachet Dos. This disagreement is likely because these equations do not consider additional environmental variables that we show also control peak discharge, primarily, lake water temperature and the rate of meltwater inflow to the source lake. We find that the Spring-Hutter-Clarke model can accurately simulate the exponentially rising hydrographs that are characteristic of ice-dammed GLOFs, as well as the order of magnitude variation in peak discharge between events if the hydraulic roughness parameter is allowed to be a free fitting parameter. Although satisfactory model fits are produced, the range in hydraulic roughness required to obtain these fits across all events was large, which suggests that current models do not completely capture the physics of these systems, thus limiting their ability to truly predict peak discharges using only independently constrained parameters. We suggest what some of these missing physics might be.

The beginning and end of a glacier-dammed lake – insights from Lago Cachet Dos, Chile

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Glacial lake outburst floods (GLOFs) represent one of the most significant, yet poorly understood, glacial hazards, particularly as glaciers retreat globally from Little Ice Age highstands. Lago Cachet Dos (LC2) is a glacier-dammed lake on the eastern edge of the Northern Patagonian Icefield that has produced more than 20 GLOFs since 2008, with peak discharges exceeding 10,000 cubic meters per second. In total, more than 25 x 106 m3 of sediment has been removed from the LC2 basin, resulting in channel rearrangement along the Rio Colonia and substantial delta growth at the Rio Colonia-Rio Baker confluence. The drainage of LC2 and subsequent erosion during this GLOF cycle revealed an upright stand of trees in the LC2 basin, which radiocarbon dating revealed were all likely killed nearly simultaneously around 1750 as the Colonia Glacier thickened during the Little Ice Age, thereby transforming this valley from a fluvial to lacustrine system. Other radiocarbon/OSL dates suggest that this fluvial-lacustrine cycle was not the first during the Neoglacial. The latest chapter of this story began in 2015, as LC2 remained free-draining for longer intervals following GLOFs despite ~90 thick ice dam in the LC2 valley and ~500 m thick ice just downstream in the Colonia valley, and then, beginning in 2017, LC2 has remained empty, suggesting that a significant change to the subglacial hydrologic system or lake damming mechanism has occurred preventing dam formation. Here, we utilize satellite-derived ice elevation change, time-lapse imagery and physically-based modeling to investigate the post 2015 lake behavior and make a prognosis for the future of this ever-evolving glacier-dammed lake.

Ecogeomorphic Processes and Carbon Fluxes in Disturbed Patagonian Rainforests

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The contrast of deeply carved valleys and fjords, steep rock slopes, and flat valley floors make coastal temperate rainforests some of the most spectacular landscapes on Earth. These forests draw from a large pool of terrestrial organic carbon and constitute globally important carbon sinks. Yet, natural disturbances may compromise the efficiency of these sinks. Overall, the ecogeomorphic disturbance regime in Patagonian rainforests is restricted to landslides and wind throw, and thus predictable given their topographically dominated nature. In this concert, volcanic eruptions may enter the stage. First, volcanic eruptions may cause massive forest dieback leading to root strength decay and, thus, promote shallow landsliding. Second, thick volcaniclastic deposits, e.g. from lahars and aforesaid landslides may bury large areas, potentially sequestering huge carbon stocks. We use UAV surveys, remote sensing, geochemical soil analysis, forest surveys to estimate the erosion of sediment, biomass, and organic carbon, and develop a time-varying, physics-based landslide susceptibility model following recent explosive eruptions in Patagonia. We find that post-eruptive erosion rates by shallow landslides in forests smothered by thick tephra layers were at least one order of magnitudes higher than in volcanically undisturbed forests nearby. This distinctly clustered distribution of landslides is in line with conceptual models from forestry that capture opposing trends of root decay after forest dieback and successive regrowth. These competing trends offer a window for maximum hillslope instability some four to six years after the eruptions. We could quantitatively simulate these effects in a physically-based landslide model that explicitly accounts for time-varying root cohesion. Given a recurrence

interval of ~275 years for major explosive eruptions in the Andean Southern Volcanic Zone, we estimate the combined long-term annual carbon release from hillslopes and floodplains into the fjords at 3-13 tC km-2 . This average does not capture the pulsed nature of sediment and biomass flushing observed in the first few years following the eruptions. Yet, this export may be offset by extensive burial of organic carbon rich soils. We conclude that Patagonian temperate rainforests may episodically tip from carbon sinks to carbon sources, if impacted by explosive volcanic eruptions. We argue that explosive volcanic eruptions may be previously overlooked generators of terrestrial organic carbon pulses into the Patagonian fjords, and that the delayed hillslope response to these eruptions adds to the portfolio of protracted geomorphic hazards.

Geological setting and adverse geological structures for extreme events in Nepal Himalaya

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From geological view point, Nepal Himalaya can be divided into five tectonic units: the Terai, the Sub-Himalaya, the Lesser Himalaya, the Higher Himalaya and the Tibetan Tethys Himalaya as separated by well-known thrusts and fault boundaries from south to the north respectively. Each of the tectonic units is characterized by its lithology, age, metamorphism, structures and geological history of evolution. The Himalaya is said to be the most active and fragile mountain range in the world: it is a live mountain with active tectonics. A major factor of such dynamism of the Himalaya is its continual battle between weathering and uplift. The Himalaya is still rising and its rocks are under constant deformation. The active nature of the range is also evidenced by frequent earthquakes in the region. Moreover, the inherently weak geological setting and active faults seem the key causes to make the Himalaya more fragile. Triggering factors such as rainfall, earthquake along with haphazard infrastructural development and quarrying for industrial and construction materials have played the major role to make the mountains highly vulnerable for landslides, rock falls, landslide damming floods and GLOFs. The main factor of landslide in Nepal Himalaya are the inherent geological condition, adverse geological structures like the shear zones, axial regions and overturned limbs of folds, steep slope, highly erosive mountain rivers, deforestation combined with unscientific construction activities, cloudburst and frequent earthquakes. Therefore, infrastructural development in this region is a formidable task with considerable problems caused by washouts and failures from landslides, erosion and gulling. Such problems are, to a significant extent, triggered by faulty planning and designing of mountain infrastructure which also have ramifications on their construction and maintenance. Within five years of period, catastrophic events like Jure landslide in eastern Nepal, Kaligandaki river damming, Armala subsidence and Turture landslide damming floods in western Nepal, Gorkha Earthquake west-central Nepal, and Bharse landslide of western Nepal etc are some of the major extreme events that Nepalese communities faced. The progressive and effective development of mountain communities through an integrated approach is the immediate need of the region.

Linking earthquake-induced mass wasting with increased suspended sediment transport in Himalayan rivers.

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In the active mountain belt of the Himalayas, landsliding is a dominant geomorphic process. Earthquakes are known to cause extensive mass wasting by co-seismic landsliding. Yet, their role in supplying sediment is not well understood. This study aims to investigate the impact of co- and post-earthquake landslides on river sediment transport, by using data of a field observatory campaign from 2015 to 2017, installed shortly after the Mw 7.8 Gorkha Earthquake in April 2015. We exploit data from a nested catchment study along the Bhotekoshi-Sunkoshi-Saptakoshi river system in Nepal. Especially the Bhotekoshi drainage area, as well as other catchments draining into the Sunkoshi-Saptakoshi system, were hit by numerous co-seismic landslides in the Gorkha Earthquake. We analyzed the temporal and spatial variability of the grain size distribution of suspended load samples collected at four hydrologic stations along the main channel. The composition of these can act as a proxy for supply sources and processes. The grain size data were processed with the R Package EMMAgeo, to unmix the multi-modal grain size distributions into four to five statistical distinct and meaningful end-members. Based on the temporal resolution and under the assumption that landslide deposits deliver coarse grains, we identified one end-member that can be directly related to earthquake-induced sediment supply. Overall, we observed an increased coarseness of suspended load and a higher concentration per liter at each station during the post-earthquake monsoon 2015. This is evidence, that landslide debris entered the channels. An earthquake-related end-member can be only identified at the upstream stations, Kahule Khola and Bhotekoshi. This indicates that a clear sediment supply signal is generated for small catchments that were strongly affected by earthquake-induced landsliding. At large drainage areas, the fraction of the area affected by landsliding is much lower, and the signal is consequentially diluted downstream. The signal related to the earthquake is mainly present during the post-earthquake monsoon 2015, which suggests that the majority of landslides have a poor connectivity to the channels, and are principally stored at hillslopes. Material that reached the river in 2015 was effectively washed out in one monsoon season.

Fires, Floods, and Debris Flows: Assessing Sediment Flux, Geomorphic Impacts, and Fluvial System Recovery Following Extreme Events

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Extreme events are predicted to increase in step with climate change, altering Earth surface processes and landscapes. Of particular concern are disturbances that increase sediment delivery to channels because of the effects of increased sedimentation on aquatic ecosystems, channel and floodplain restructuring, and water resource management including water quality and quantity. Within the last seven years, extreme flooding, wildfire, and debris flows have occurred within the Colorado Front Range, resulting in widespread hillslope erosion, morphologic channel change and avulsion, sediment pulse evolution and transport, and extensive deposition. Because damage to communities and infrastructure commonly accompanies extreme events, mitigating the effects of sediment disturbance is of broad societal interest. Analysis of flood effects from a substantial storm (>2000 yr) in September

2013 in two basins, one burned by wildfire in 2012 (260 km^2), and one unburned (100 km^2), indicates that 10s to 100s of years of sediment were eroded during the storm and transported to downstream receiving waters. Field data collection indicates that in-channel sediment fluxes returned to pre-disturbance values by year three after the fire. In the unburned basin, more than 100 debris flows resulted from the same storm, contributing 43% of the total flood eroded volume. Measured debris flow volumes exceeded 23,000 m^3, and the formation and subsequent failure of an in-channel dam resulted in extensive channel erosion. Sediment delivery from the unburned basin to a downstream water supply reservoir has decreased by an order of magnitude, and the fire-flood combination in the burned basin appears to have hastened sediment recovery. Projected increased frequency of intense rainstorms, and increased fire intensity, frequency and extent in the coming decades requires that multiple or overlapping disturbances be addressed during postdisturbance response and in landscape resilience planning.

Using Cosmogenic Nuclides to Evaluate the Role of Coseismic Landsliding on Measured Erosion Rates Following the Mw 7.8 Gorkha Earthquake, Nepal.

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The Mw 7.8 2015 Gorkha earthquake presents a unique opportunity to study the effects of coseismic landsliding on sediment transport and landscape response in the years immediately following a large earthquake. The effects of these infrequent mass wasting events on longerterm erosion rates is still not fully understood and recent studies question whether these large earthquakes build or destroy topography at the orogen-scale. In this study, we repeatedly sample river sediments in earthquake affected valleys of central Nepal for terrestrial cosmogenic nuclides (TCN). Assuming landslides mobilize deeper material with lower TCN concentrations, we expect an “earthquake signal” in the export of these lower concentration sediments. However, preliminary data do not show such a clear response after the Gorkha earthquake in our measurements of 10Be concentrations in sands and pebbles. To better understand the absence of an obvious earthquake signal, we model how concentrations of cosmogenic nuclides respond to coseismic landsliding and longer-term erosion rates. Ongoing measurements and modeling will better resolve this data set and help us further investigate the effects of seismicity on both long- and short-term erosion in an active orogen.

Giant landslides in the Patagonian Andean foreland

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The Patagonian Andean foreland has one of the greatest clusters of low-gradient landslides on earth. Located in a subduction back-arc setting, basaltic eruptions formed prominent tablelands. Quaternary glaciations and successive drops in glacial lake levels left the landscape in an unstable condition causing some of the world´s largest terrestrial landslides (≥ 108 m^3) around the plateaus and in river gorges. This study focuses on the Meseta del Lago Buenos Aires in the eastern piedmont of the Patagonian Ice Sheet, Argentina. We mapped more than 283 large rotational landslides and lateral spreads. Furthermore, over

hundred earthflows developed in the semiarid climate on top of the rotational landslides. Using a high-resolution UAV survey, radiocarbon dating of peat bogs, and topographic analysis we reconstructed the cyclic dynamics of the earthflows and decipher their causes: 1) disintegrations of cap rock during giant slope failures provided material necessary for turning into earthflows; 2) the intercalation of sandstone and ash layers of the cap rock underlying sediment provide aquifers appearing as springs on the margin of the plateau; 3) low-gradient slope and wetter climate during the Late Holocene favor the evolution of peat bogs and supporting the development of peat slides which turn into earthflows along river channels. Therefore, the plateau topography and the interplay of lithology, hydrology, and a wetter climate during the Late Holocene favored the evolution of giant earthflows.

Sediment composition and flux in the Narayani and Koshi Rivers in the Nepal Himalaya following the 2015 Ghorka Earthquakes Abstracts

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The extent to which co-seismic landslides deliver bedrock and alluvium into the critical zone to 1) undergo chemical weathering and 2) supply bed and suspended sediment directly into river channels remain controversial and poorly constrained. The magnitude 7.8 (25/4/15) and 7.3 (12/5/2015) earthquakes in Nepal in 2015 triggered thousands of landslides which were anticipated to cause major perturbations to sediment and chemical loads carried by the local Himalayan rivers. We collected both sediment and water samples following the earthquakes in a transect across Nepal, including depth profiles of suspended sediment in the major Narayani, Koshi and Karnali Rivers and some tributaries with the overall goal of quantifying the impact of this ~100 year event on the export of matter from this part of Himalayas. In the 6 monsoon seasons since the earthquakes we have collected sediment at different depths in the river channel to take into account hydrodynamic sorting, at different places in the river channel to account for heterogeneity within the channel, coupled with depth integrated time-series at critical localities, making our data set a unique archive to refine suspended sediment concentrations using a depth integrated Rouse type method. Reading the chemical fingerprint of the sediment is non-trivial and our work has focused on characterizing the sediment composition and understanding how both sediment transport and chemical weathering control the chemical composition of suspended sediment. Here we summarise our findings on sediment transfer, transport and composition in major Himalayan Rivers.

Balancing the scales: can volcanism tip West Antarctica over the edge?

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The fate of the West Antarctic Ice Sheet is of massive consequence to the entire world – its collapse would lead to more than 5 meters of sea level rise around the entire world. Importantly, there is evidence that this continental scale ice sheet has melted in previous interglacial periods. However, questions remain about the drivers of this collapse: did it slowly retreat due to warming ocean and air temperatures, or was its instability precipitated

by an extreme event? Recent research has focused primarily of the first of these, considering ocean warming and marine ice sheet instability as the drivers of collapse. Here I present the results of our recent research that identified nearly 100 previously unknown volcanoes in West Antarctica, and propose an alternate hypothesis: a burst of increased basal heat flux and subglacial eruptions may flip the ice sheet from a steady to an unsteady state. We find that many volcanoes are in the most sensitive portions of the ice sheet, and that subglacial eruptions could lead to previously stable grounding lines being breached. Additionally, we examine a positive feedback mechanism by which even moderate glacial thinning can greatly increase eruption rate. We conclude that volcanism is unlikely to initiate ice sheet instability, however that in key areas it may be a first order control on the rate and extent of collapse.

Frequency and hazard from Himalayan glacial lake outburst flood

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Outburst floods from glacial lakes in Himalayan headwaters occur rarely, but mostly with fatal and catastrophic consequences for downstream communities and infrastructure. Glacial lakes have grown in number and size with ongoing glacier retreat in the Himalayas. Theory holds that enhanced meltwater production in past decades may increase GLOF frequency, but has remained untested. Because these flood waves can attenuate rapidly, many GLOFs have likely gone unnoticed in past decades. Our knowledge on GLOFs is hence likely biased towards larger, destructive cases, which challenges a detailed quantification of their frequency and their relation to climate change. We developed an algorithm that efficiently detects GLOFs from satellite images to compile the first consistent Himalayan GLOF inventory. We found 22 newly detected GLOFs in the entire Himalayas, and thus more than doubled the existing GLOF count from 16 previously known cases since 1988. This revised inventory shows a cluster of GLOFs in the Central and Eastern Himalayas (Bhutan and Eastern Nepal), compared to the rarer affected ranges in the North (Hindu Kush-Karakoram). Yet, the total of 38 GLOFs showed no change in annual frequency, so that the activity of GLOFs per unit glacial lake area has decreased in the past 30 years. This updated GLOF frequency is a key input for estimating hazard from Himalayan GLOFs. We define hazard as the annual exceedance probability of a given GLOF peak discharge or larger at the breach location. We use an extreme-value model that couples the empirical rate of GLOFs per region to simulations of physically plausible peak discharges from all 5,200 Himalayan glacier lakes. We found that the 100-year GLOF discharge (the flood level that is reached or exceeded on average once in 100 years) is ~15,600 m^3 s -1 , rivaling meteorological river discharges far downstream. Contemporary GLOF hazard is highest in the Eastern Himalayas, and substantially lower in the northern regions of the Hindu Kush-Karakoram. We find that both glacier lake and GLOF abundance are the key determinants of GLOF hazard, which are vital to monitor in the light of melting glaciers and growing meltwater lakes

The Erosive Power of Earthquakes: Quantifying Landscape Response to a Large Magnitude Seismic Event through Joint Detrital Thermochronometry and Cosmogenic Nuclide Analysis in Kaikoura, New Zealand

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Large magnitude earthquakes exert a strong control on surface erosion in tectonically active mountain ranges by rapid transport of material from hillslopes to river channels. Yet the relative importance of erosion during seismic and interseismic periods is poorly constrained. To quantify the magnitude and spatial pattern of coseismic erosion, we perform a joint inversion of zircon (U-Th)/He and cosmogenic 10Be data from river sediment samples collected before and after the 7.8M 2016 Kaikoura earthquake. By utilizing the dilution of detrital 10Be concentrations from landslide exhumed material as a proxy for erosion, and leveraging low-temperature thermochronometry age-elevation relationships as a tracer for sediment source, we directly compare coseismic erosion with pre-earthquake erosional processes.

Development Perturbations on Coastal Tsunami Risk – Examples from New Zealand and Samoa

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Tsunami hazards can cause devastating direct impacts on coastal human environments, with flow-on effects that can influence socioeconomic recovery across multiple development levels many years after a disaster event. In tsunami risk science, it is widely accepted that risk is driven by the choices and decisions a society makes on the development, modification and settlement of coastal locations that are exposed to the impacts of tsunamis. While a specific tsunami exceedance probability hazard for a specific location might not change, the risk to that hazard could increase, decrease, or be minimized over time depending on the types of development choices made. In this paper, we present examples from New Zealand and Samoa to discuss the perturbations in tsunami risk dynamics associated with coastal development systems; expressed in terms of direct exposure and economic cost implications. For the New Zealand case we show how tsunami risk to residential buildings in Omaha Beach has increased since 1992 due to changing land use patterns, demand and expansion of residential development into tsunami exposed areas. In the case of Samoa, we show how tsunami risk to buildings at the village level has undergone variable changes along the south coast of Upolu Island after 10 years of commercial and residential building recovery since the 2009 tsunami disaster. Emphasis in both cases is made on the development drivers and perturbations underpinning the observed changes in tsunami risk. These are also discussed within the broader context of best-practice approaches to monitor spatio-temporal changes in coastal tsunami risk, and how these could be applied to adapt and manage resilience interventions to reduce the risk from tsunami threats.

The propagation of extreme landslide events through the fluvial systems of Taiwan Abstracts

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The island of Taiwan is an excellent natural laboratory for understanding how extreme events impact surface dynamics. The 1999 Chi-Chi earthquake and Typhoon Morakot in 2009 both generated >10^4 individual landslides in relatively small areas. The influx of this material entered the river systems where is continues to be evacuated in many rivers draining these regions influencing flood hazards and erosion potential of these river systems. I present past, on-going, and future work quantifying both the cascade of hazards these events initiated and their impacts on landscape evolution. Both events caused widespread aggradation, however, the tectonic environment in the different regions provided distinct natural laboratories on how tectonic processes condition the landscape for the cascade of geomorphic events. Moreover, the meteorological driven event caused significantly more aggradation, which we interpret to be a result of the rapid connectively between landslide deposits and fluvial systems during the historical rainfall event. Such aggradation has caused continued downstream hazards, illustrated by the continued abandonment of some towns and structures due to increased flooding associated with increased bed elevations. I also compare estimates of evacuation timescales for both events and show that river systems impacted are still adjusting to the influx of landslide sediment even though the finer grained suspended sediment concentrations quickly returned to pre-event levels. The results have implications for both the prediction of cascading hazards and the effects of extreme events on surface processezs and landscape evolution. A major conclusion that I draw from the comparison of these systems is that the fluvial response to extreme landslide events drives a significant proportion of the fluvial relief of the Taiwan orogen.