Natural Hazards and Risks in a Changing World

Second International Conference on Natural Hazards and Risks in a Changing World 2021

5–6 October 2021
University of Potsdam

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Preface

Natural hazards such as floods, earthquakes, landslides, wildfires and multi-hazard events heavily affect human societies and call for better management strategies. Recent events across the globe, including a devastating flood in Western Germany, emphasize the urgency. Due to the severity of such events, it is of utmost importance to understand whether and how they change in response to evolving hydro-climatological, geo-physical and socio-economic conditions. These conditions jointly determine the magnitude, frequency, and impacts of disasters, and are changing in response to climate change and human behavior. Therefore methods are needed for hazard and risk quantification accounting for the transient nature of hazards and risks. The purpose of this conference is to bring together researchers from natural sciences (e.g. hydrology, meteorology, geomorphology, hydraulic engineering, environmental sciences, seismology, geography), risk research, and nonlinear systems dynamics to discuss new insights and developments about changing systems, compound events, and the linkage between hazard and vulnerabilities under unstable environmental conditions. Knowledge transfer, communication and networking will be central for the conference. The conference is organized in a hybrid manner. We invited outstanding experts to give talks and selected further contributions as oral or poster presentations. All oral presentations will be broadcasted online. Online participants will have the opportunity to equally comment and discuss oral and poster presentations and thus, participate in an active way.

We are very pleased to welcome more than 100 participants on-site to Potsdam. We hope you will enjoy your participation at the *Second International Conference on Natural Hazards and Risks in a Changing World* and have an exciting and beneficial experience. Finally, we would like to thank all speakers, participants, supporters, and sponsors for their contributions that for sure will make this event a very remarkable and fruitful meeting. We acknowledge the valuable support of the Deutsche Forschungsgemeinschaft DFG (Research Training Group “Natural Hazards and Risks in a Changing World” (NatRiskChange; GRK 2043/2) and UP Transfer GmbH, as the conference would not have been possible without their help. Without your cooperation, this conference would neither be possible nor successful.

Theresia Petrow, Axel Bronstert and Annegret Thieken

Potsdam, 5th of October 2021

Program Tuesday, 5th October 2021

Time	Program	Room
08:00	**Registration**	**Foyer**
	Welcoming speeches and opening	**H03/04**
09:00	*Prof. Oliver Günther – president of the University of Potsdam, Germany*	
09:10	*Dr. Astrid Evers – Deutsche Forschungsgemeinschaft (DFG), Germany*	
09:20	**Keynote Speech "Disastrous river floods in a changing environment"** *Prof. Bruno Merz – German Research Centre for Geosciences GFZ, Germany*	**H03/04**
10:05	**Coffee break**	**Foyer**

Time	**Session 1** H02 **„Impact of land degradation, drought and wildfires on ecosystem services"** Convener: *PD Dr. Kirsten Thonicke – PIK Potsdam* *Jennifer von Keyserlingk – University of Potsdam*	**Session 2** H03/04 **„Human contributions to climate risks"** Convener: *Dr. Philip Bubeck* *Prof. Annegret Thieken* *Lisa Berghäuser – all University of Potsdam*
10:30	**Restoring ecosystem functions and services in drylands: challenges and chances** *Prof. Britta Tietjen – FU Berlin, Germany*	**An artefact of the future: Globally consistent open-source multi-hazard impact assessment** *Prof. David N. Bresch – ETH Zürich, Switzerland*
11:00	**Climate Change, dietary shift, and traditional norms in the western Himalayan region** *Suraj Das – IIT Rorkee, India*	**Global indirect impacts of extreme flood events** *Samuel Juhel – CIRED, France*
	Short break for ventilation	
11:25	**Do Droughts Drive Deforestation? Evidence from Mozambique** *Prof. Andrew Hobbs – University of San Francisco, USA*	**Monetary loss reduction due to flood early warning** *PD Dr. Heidi Kreibich – German Research Centre for Geosciences GFZ, Germany*
11:45	**Country-wide statistical modelling of flow variability impact on the riverine macroinvertebrates in Poland** *Agata Keller – Warsaw University of Life Sciences, Poland*	**Mapping the characteristics and conditions of path dependency: Re- and deconstructing the 1980–2020 flood risk management in the Aist and Enns river regions in Austria** *Dr. Thomas Thaler – University of Natural Resources and Life Sciences, Vienna, Austria*
12:05	**Easy-to-use diagnostics of mean-term drought vulnerability** *Prof. Gunnar Lischeid – ZALF Müncheberg, Germany*	**Forecast-based operation of blue-green roofs as a new solution to decrease the impact of extreme weather in cities** *Tim Busker – Vrije Universiteit (VU) Amsterdam, the Netherlands*

Time	Program	Room
12:30	**Lunch**	**Mensa**
13:30	**Keynote speech "The Evidentiary Basis for Equitable Risk Reduction in an Era of Increasing Disaster Risk Inequality"** *Prof. Susann Cutter – University of South Carolina, USA*	**H03/04**
14:15	**Short break**	

Program Tuesday, 5th October 2021

Time	Session 3 „Floods and storms" – H03/04 Convener: *Prof. Axel Bronstert – University of Potsdam* *Prof. Ankit Agarwal – IIT Rorkee*	Session 5 „Geomorphological events" – H02 Convener: *Prof. Oliver Korup,* *Lisa Luna,* *Elisabeth Schönfeldt – all University of Potsdam*
14:25	**Accounting for tropical cyclones more than doubles the global population exposed to low-probability coastal flooding** *Job C.M. Dullaart – Vrije Universiteit (VU) Amsterdam, the Netherlands*	**Detection, Observation, and Early Warning of Catastrophic Flow Events Using Regional Seismic Networks** *Dr. Kristen L. Cook – German Research Centre for Geosciences GFZ, Germany*
14:55	**Trends in Seasonality and Flood Timings Over Kenya** *Maureen Anyango Wanzala – University of Reading, UK*	**Insights on rockslide collapse mechanism from pre-event cracking** *Sophie Lagarde – German Research Centre for Geosciences GFZ, Germany*
	Coffee break	
15:45	**Nature-based solutions and global coastal flood risk estimates** *Timothy Tiggeloven – Vrije Universiteit (VU) Amsterdam, the Netherlands*	**Landslide inventories are incomplete. Can we still use them to make forecasts?** *Lisa Victoria Luna – University of Potsdam, Germany*
16:05	**Impacts of extreme wind speeds and other factors on vegetation disturbances in the German railway network** *Henrike Lorenz – FU Berlin, Germany*	**Debris flows induced by Multiple Occurrence Regional Landslides Events in the Colombian Andes** *Prof. Edier Vicente Aristizába – Universidad Nacional de Colombia, Colombia*
16:25	**Detecting changing flood generating mechanisms in long records from reference hydrological sites** *Prof. Paul H. Whitfield – Centre for Hydrology, University of Saskatchewan, Canada*	**Defining criteria for the formation of landslide induced tsunamis in elongated and narrow water bodies** *Katrin Dohmen – TU Berlin, Germany*
16:45	**PICO Presentations of online posters of sessions 1, 2, 3**	

17:00 **Poster sessions 1, 2, 3** .... **Foyer**

19:00 **Conference dinner**

Program Wednesday, 6th October 2021

09:00 **Keynote speech: "The volcanic hazard of distributed volcanic fields - the example of the Eifel, Germany"** **H03/04**
Prof. Torsten Dahm – German Research Centre for Geosciences GFZ, Germany

09:45 **Short break**

	Session 4 **H03/04** **„Causes, impact and mitigations of earthquakes, tsunamis and volcanoes in an urban changing world"** Convener: *Prof. Fabrice Cotton – GFZ Potsdam*	**Session 6** **H02** **„Analysis of complex changing systems "** Convener: *Dr. Tobias Sieg* *Dr. Ugur Öztürk – both University of Potsdam*
09:55	**An Open European Seismic Risk Model (ESRM20)** *Dr. Helen Crowley – Eucentre, Italy*	**A typology of compound weather and climate events** *Dr. Jakob Zscheischler – University of Bern, Switzerland*
10:25	**Testing physics and statics based hybrid ETAS models** *Shubham Sharma – University of Potsdam, Germany*	**Wintertime Compound Climate Extremes in North America and Europe** *Prof. Gabriele Messori – Uppsala University, Sweden*
	Short break for ventilation	
10:50	**A novel physics-based and statistical forecast model for induced seismicity** *Dr. Mauro Cacace – German Research Centre for Geosciences GFZ, Germany*	**Multi-hazard risk and the asynergies of disaster risk reduction measures: the need for an integrated approach** *Dr. Marleen C. de Ruiter – Vrije Universiteit Amsterdam, the Netherlands*
11:10	**The use of high-resolution building exposure models: earthquake damage scenario for the city of Cologne, Germany** *Dr. Cecilia Nievas – German Research Centre for Geosciences GFZ, Germany*	**Integrating network analysis and sequential pattern mining to assess drought compound and cascading impacts** *Dr. Mariana Madruga de Brito – Helmholtz Centre for Environmental Research UFZ, Germany*
11:30	**Scenario-based multi-risk assessment for consecutive earthquakes and tsunamis in Lima, Peru** *Juan Camilo Gomez Zapata – German Research Centre for Geosciences GFZ, Germany*	**Projections of global urban land cover growth** *Manon Glockmann – PIK Potsdam, Germany*
11:50	**PICO Presentations of online posters of sessions 4, 5, and 6**	

12:20 **Lunch** .... **Mensa**

13:30 **Poster session 4, 5, and 6 (incl. coffee)** .... **Foyer**

15:00 **Keynote speech: "Leveraging satellite data to inform multi-scale landslide hazard assessment"** **H03/04**
Dr. Dalia Kirschbaum – NASA, USA

15:45 **Discussion and Goodbye** **H03/04**

Keynote Speeches

Disastrous river floods in a changing environment

Bruno Merz
German Research Centre for Geosciences - GFZ, Germany; University of Potsdam, Germany

The annual average loss of river flooding has been estimated at US$ 100 billion globally. Of particular relevance are disastrous floods defined as those events with devastating consequences to society. They are often caused by fundamentally different mechanisms that distinguish them from regular (non-disastrous) floods, impedes the extrapolation from regular to disastrous floods, and leads to high damage due to an element of surprise of citizens and flood managers. These peculiarities can reside in the atmospheric, land surface and socio-economic processes that are at play during and between flood events. We discuss the causes of disastrous river floods and reflect how changes in flood risk systems affect the magnitude and impact of disastrous floods.

The Evidentiary Basis for Equitable Risk Reduction in an Era of Increasing Disaster Risk Inequality

Susan L. Cutter
University of South Carolina, USA

This keynote highlights the changing nature of disaster risk and its unequal distribution among people and places. Using examples from U.S. disasters experiences, spatial differences in exposure and impact highlight social disparities in who is most affected and where. Geospatial tools such as the Social Vulnerability Index (or SoVI) and bi-variate maps of exposure (or loss) provide an empirically-based and apolitical method for demonstrating the inequality in disaster risk. Such evidentiary-based knowledge provides a rationale for the differentiation of local, state, and federal resources specifically designed to achieve both equitable recovery and risk reduction in the short- and long term. Translation of this geospatial approach to equity for state and federal hazard/disaster policy and practice is also illustrated.

The volcanic hazard of distributed volcanic fields - the example of the Eifel, Germany

Torsten Dahm
German Research Centre for Geosciences - GFZ, Germany; University of Potsdam, Germany

Basaltic volcanic fields are often clusters of volcanic centres that extend over hundreds to thousands of square kilometres. When they occur in populated areas such as the Eifel in western Germany, they represent a poorly understood volcanic hazard and risk. Eruptions in such fields usually involve small batches of basaltic magma originating from the Earth's upper mantle or lower crust. Thus, in the volcanic fields of the East and West Eifel together, about 350 such volcanoes are known.

In the East Eifel, three complex volcanic centres have formed at Rieden, Wehr and the Laacher See Volcano (LSV), which together define a volcanic focal zone with a diameter of ~10 km, where concentrated long-term magma storage in the upper crust is indicated. The most recent LSV phonolitic eruption had a volcanic explosivity index of VEI=6 and released about 20 km^3 of tephra, which could be detected in core lakes as far away as eastern Scandinavia. During this eruption, the pyroclastics dammed up the Rhine and formed a huge lake that extended upstream to the Rhine-Main basin and beyond, causing a huge flash flood after the dam broke.

Even though signs of unrest beneath the LSV have been noted in recent years, the probability of a volcanic eruption in the Eifel is generally considered to be low. Considering that previous eruptions at the LSV were extremely energetic and caused several cascading events with extreme consequences, the reassessment of the volcanic hazard and its potential impact is important. The lecture will present the volcanic systems of the Eifel, show the evidence for current magmatic processes and discuss the problems in estimating the volcanic hazard in such systems.

Leveraging satellite data to inform multi-scale landslide hazard assessment

Dalia Kirschbaum
NASA, USA

The global coverage and temporal frequency that satellites provide offers a unique opportunity to estimate landslide hazard and exposure throughout the disaster lifecycle, from pre-event planning and forecasting to post-event mapping and impact assessment, and finally to recovery and mitigation. The relevance of satellite-derived data and model products is largely contingent on the spatiotemporal sampling, the hazard characteristics, and the needs from the research or applications community. This talk will provide an overview of modeling capabilities to advanced landslide hazard assessment, and present several new ways to map, model, and assess landslide hazard using a range of satellite data.

TALKS

Session 1

Impact of land degradation, drought and wildfires on ecosystem services

Restoring ecosystem functions and services in drylands: challenges and chances

Britta Tietjen
Freie Universität Berlin, Germany

Drylands cover about 41% of the terrestrial land surface and are home to more than two billion people. Worldwide, many drylands are degraded, e.g. because of changes in climate or maladapted land use. Degradation has drastic consequences for species diversity in these areas, but also for their functions and services with strong implications for human well-being. Often, degradation is a result of positive feedback loops: an example is the loss of vegetation during dry spells or as a result of heavy grazing pressure. The resulting lower vegetation cover can lead to high water losses and an increased erosion risk. This will in turn lower soil water availability and soil quality and thus hinder the reestablishment or regrowth of vegetation. Because of these feedback loops, a return to the original, non-degraded state, e.g. to increase the provision of ecosystems and functions, is normally not a matter of time, but requires active restoration measures.

In my talk, I will use two dryland regions as an example to demonstrate causes of degradation, consequences for biodiversity and for the delivery of ecosystem functions and services as well as possibilities to restore these ecosystems towards long-term stable states with a higher value.

For different savanna ecosystems in Namibia we could show how past and still ongoing land use by grazing cattle has degraded various areas throughout the country. Dependent on prevailing climatic conditions, this loss can either lead to large patches of bare ground associated with high erosion risk (in arid areas), or to a massive shrub encroachment with dense shrub thickets (in semi-arid areas) that do not allow for a re-establishment of edible grasses. Using the ecohydrological model EcoHyD that accounts for full feedback loops between water and vegetation at the local scale (Tietjen et al. 2009, 2019; Guo et al. 2016, Lohmann et al. 2012, 2017), we determined how restoring the area towards higher levels of diversity will increase the delivery of ecosystem functions and the resilience of the ecosystem towards changes in climate. In addition, we evaluated how shifting land use to wildlife management rather than cattle farming might offer a long-term sustainable alternative for land use.

In the other example, a Mediterranean-type ecosystem in Western Australia, large areas of the former wheat belt have been abandoned due to secondary soil salinization. One goal of large-scale restoration efforts is to enhance long-term carbon storage in these areas, also under altered climatic conditions. Here, we assessed with a process-based ecosystem model of individual plants (ModEST, Fiedler et al. 2021) the role of plant diversity for the multifunctionality of ecosystems. We could show that the optimal species composition is highly context dependent, and that also the trade-offs between different functions strongly depend on environmental conditions.

Climate Change, dietary shift, and traditional norms in the western Himalayan region

Suraj Das, Aninday J. Mishra
Indian Institute of Technology Roorkee, India

Climate change is the new normal of modern times, complicating the assurance of food security to the vulnerable communities, especially the indigenous communities with deep-rooted customary beliefs system associated with dietary habits of the Himalayan region. But, the local and traditional perspectives are seldom integrated for evidence-based policy formation. Hence, the present study employed the grounded theory approach for thematic analysis with Qualitative Data Analysis (QDA) software and Statistical Package for the Social Sciences (SPSS) to substantiate the observations further. the customary knowledge of indigenous communities is crucial because of its own merits, i.e., component of collective actions that get strengthened at natural calamities. Also, studies related to climate change have focused on what changes are perceived, not on how local communities interpret in terms of associated sociocultural norms, values, and beliefs, and gives meaning within local worldviews. Therefore, it is crucial to have a comprehensive understanding of how local communities amalgamate indigenous knowledge of traditional food habits and scientific knowledge in dealing with changing climate since it serves as a sustainability model. Likewise, for vulnerable communities, even a slight climate variability can have a catastrophic effect on their livelihoods and thus on their food habits. Therefore, the present study intends to fill the gap by examining the impact of climate change on traditional food for the Uttarakhand state of India. The objective of the study is to (1) analyse the perception of people towards climate change, (2) document the perception of local communities toward traditional dietary habits, and (3) examine the changes observed in sociocultural beliefs system due to dietary shift. Thus, based on the finding, the present study concludes that traditional knowledge is significant in addressing the issue of climate change, which further emphasis on the holistic and integrated promotion of both scientific knowledge and indigenous knowledge, especially in developing countries where the customary beliefs play a significant role in food choices.

Do Droughts Drive Deforestation? Evidence from Mozambique

Andrew Hobbs
University of San Francisco, USA

Forests are a critical source of income for the world's rural poor and store a massive amount of carbon. At the same time, forests are an important part of rural livelihoods in many parts of the world, and forest resources can be especially critical in the event of negative agricultural production shocks.

This paper seeks to answer the question: do crop losses resulting from low rainfall increase deforestation? It finds evidence that low rainfall is indeed associated with higher forest loss, and only near human settlements, suggesting that this effect is driven by human actions and not natural responses to drought. I develop a theoretical model to study the dynamic implications of that relationship, showing that more frequent shocks to agricultural production may accelerate deforestation. I find empirical support for a drought-deforestation relationship in Mozambique, where charcoal harvest is a well-documented income diversification strategy: droughts appear to increase the probability of forest loss, especially near population centers.

This paper uses a satellite data from more than 800,000 randomly sampled 35m pixels in Mozambique that were forested as of 2000. I use forest cover and loss data from, rainfall data from CHIRPS, MODIS air temperature data, and data on travel time from cities from from the Malaria Atlas Project. The pixel level loss data is binary, and I use logit regressions to estimate the impact of precipitation shocks on the probability of deforestation at a given pixel. Negative precipitation shocks increase the probability of forest loss near cities with populations of over 50,000, and the relationship steadily weakens as distances increase. This supports the hypothesis that negative precipitation shocks increase the probability of forest loss and that human action (deforestation) is the driver.

To study the dynamic implications of this relationship, I develop a dynamic theoretical model and use numerical simulations to show that rational farmers who are unable to update their yield expectations will deplete forest stocks at an accelerated rate. Intuitively, if farmers base their expectations on historic yield distributions, they will harvest more than the optimal quantity from the forest. This accelerates deforestation relative to what would be socially optimal as well as relative to what would have occurred absent climate change.

This empirical analysis in this study is based wholly on satellite and geospatial data, which means collecting an 18-year panel of data was quick and efficient. This type of approach potentially opens up many research areas that would have been prohibitively expensive to study using survey or other data collection methods, and in particular this type of data provides the statistical power needed to study relatively rare events like deforestation at the pixel level.

Country-wide statistical modelling of flow variability impact on the riverine macroinvertebrates in Poland

Agata Keller
Warsaw University of Life Sciences, Poland

Freshwater biomonitoring programs provide a vast set of valuable information for assessing ecological status of the waters and their potential for ecosystem services. The flow variability, especially extreme events such as droughts or floods, can adversely impact the biota monitored in bioassessments programs. In this presentation, the focus is placed on the populations of riverine macroinvertebrates, as they seem to be more vulnerable and less resilient to the extreme hydrological events. The proposed modelling will collate a large data set of Poland-wide biomonitoring data concerning macroinvertebrates and model it against the flow variability from the neighbouring flowgauges.

The biomonitoring data obtained from the Chief Inspectorate of Environmental Protection in Poland contains results of the macroinvertebrate sampling for the years 2021-2020. Most of the sites were sampled once, however, some of them were sampled twice or even thrice. From over 3,200 sampling points 309 were chosen (with 520 unique sampling instances) through a spatial coupling with the flowgauges database. The coupling was conducted in ArcGIS and resulted in pairing 290 flowgauges with the aforementioned 309 sampling sites based on three criteria: location on the same stream, proximity (<10 km), and difference in the upstream catchment area (<20%).

The river flow data comes from gauged flows provided online by the Polish hydrometeorological service (Instytut Meteorologii i Gospodarki Wodnej) downloaded with “climate” package in R.

As the ecologically relevant flow index, the indicators of hydrologic alteration, previously used in this context in Poland, were computed in R using “IHA” package.

Time series of ecological metrics derived from biomonitoring data on macroinvertebrates will be analysed along with observed streamflow data (expressed in IHA parameters) in order to establish new, empirical flow-ecology (or species-discharge) relationships.

There exists a proliferation of statistical methods applied in the past for the purpose of development of flow-ecology relationships. It will be decided after a thorough investigation of the subject literature which modelling approach to apply, however, the recent study by Kakouei et al. (2017) appears promising in this regard. It applied hierarchical logistic regression model to quantify the flow traits of benthic invertebrates in Germany. This study is of particular interest in the context of the projected modelling as it also deals with national-scale assessment, and also uses biomonitoring and flow gauge data to develop empirical relationships.

It will be the first country-wide modelling of flow-ecology relationships in Poalnd. The results could benefit practitioners and desicion-makers especially in the context of developing environmental flows concept in the country.

Kakouei, K., Kiesel, J., Kail, J., Pusch, M. and Jähnig, S.C. (2017) Quantitative hydrological preferences of benthic stream invertebrates in Germany. Ecological Indicators 79, 163-172

Easy-to-use diagnostics of mean-term drought vulnerability

Gunnar Lischeid
ZALF and University of Potsdam, Germany

Facing a couple of dry and warm years which are consistent with climate change scenarios, there is now increasing need for advanced diagnostic tools for drought risk assessment at the scale of years or decades. Commonly models are used for that purpose. However, they often suffer from a lack of data at sufficient spatial resolution, resulting in substantial uncertainties when applied beyond the bounds of single case studies. On the other hand, recent experience showed that simple extrapolating of trends of observed behaviour would not be adequate due to substantial changes of boundary conditions.

An alternative method has been developed and tested at a regional scale (about 105 km2). It is based on a principal component analysis of a large set of groundwater head and lake water level time series. Most of the variance of groundwater head dynamics at that scale can be ascribed to differing degrees of damping of very similar input signals, that is, groundwater recharge dynamics, depending on the thickness and the texture of the overlying vadose zone. The chosen approach allowed to factor out other effects, e.g., local or direct anthropogenic impacts.

The stronger the damping the more pronounced was the memory. Subsequent analysis focused on wells with pronounced memory in Northeast Germany. They exhibited a consistent substantial decrease of groundwater heads during the last 40 years. Thus the backbone of landscape hydrology has been exhibiting continuous weakening, resulting in increasing drought risk in the mid-term, although intermittent recovery at other sites seems to suggest the opposite.

An artefact of the future: Globally consistent open-source multi-hazard impact assessment

David N. Bresch
ETH Zurich / MeteoSwiss, Switzerland

Using state-of-the-art probabilistic modelling, the CLIMADA platform allows to estimate multi-hazard socio-economic impact and to disentangle the human contribution to climate risk, namely the quantification of risk today, the incremental increase from economic development and the further aggravation due to climate change. The Economics of Climate Adaptation (ECA) methodology as implemented in CLIMADA provides decision makers with a fact base to understand the impact of weather and climate on their economies, including cost/benefit and multi-criteria perspectives on specific risk reduction and resiliency measures as well as risk transfer solutions. The model is well suited to operate on diverse spatio-temporal scales, e.g. from impact-based warning applications (regional to local, timescale of days) to providing an open and independent global (yet still high-resolution, order of kilometer) view on physical risk (including tail risk quantification), in line with e.g. the TCFD (Task Force for Climate-related Financial Disclosure). The CLIMADA platform has been designed to enable risk assessment and options appraisal in a modular form and occasionally bespoke fashion yet with the high reusability of common functionalities to foster interoperable usage in interdisciplinary studies and international collaboration. This approach does not only allow for the quantification of human contributions but also human action to better manage climate risks with the goal to strengthen societal resilience.

Key references: Aznar-Siguan, G., and Bresch, D. N., 2019: CLIMADA v1: a global weather and climate risk assessment platform, Geosci. Model Dev., 12, 3085–3097. https://doi.org/10.5194/gmd-12-3085-2019 and Bresch, D. N. and Aznar-Siguan, G., 2021: CLIMADA v1.4.1: towards a globally consistent adaptation options appraisal tool, Geosci. Model Dev., 14, 351–363, https://doi.org/10.5194/gmd-14-351-2021

Global indirect impacts of extreme flood events

Samuel Juhel, Vincent Viguié
CIRED, France

Recent climate risk analysis expects that economic impacts from extreme events will increase, mainly by exposure increase. While the direct consequences of natural disasters are felt locally, where the natural disasters occur, the consequent functional disruption often spreads through inter-industry flows by creating bottlenecks and delays in the supply chains systems, thus creating indirect economic damages.

Such indirect damages have often proven to make up for a major part of the total social cost of extreme weather events. Quantifying them is therefore crucial to properly account for the consequences of climate-induced disasters.

Research in risk and disaster analysis has studied indirect damages for specific past or simulated events (Hurricane Katrina in Louisiana, possible storm surges in Rotterdam, 2007 summer floods in the UK) and how they add up to total damage assessments. So far, however, there is no clear view on the magnitude, at the global scale, of such “exported” climate damages.

This study aims at assessing the potential indirect impacts of global river floods. Here, we use an input-output model, ARIO, that simulates the indirect impacts of natural disasters through trade networks, and which has already been used and assessed several times for disaster analysis in the literature. We use the EORA26 multi-regional input-output table as a basis for representing the global economy and projections of global river floods according to seven different climate models. For each country, we compare the ‘imported economic impacts’, i.e. the impacts on production related to foreign flood events, with the direct cost of extreme flood events in the country.

Our results highlight the important interrelations of climate impacts between each country, and the potential benefits of international cooperation for adaptation by showing examples of how the local vulnerability translates to global risk.

Monetary loss reduction due to flood early warning

Heidi Kreibich[1], Paul Hudson[2], Bruno Merz[1,2]
[1]German Research Centre for Geosciences - GFZ, Germany; [2]University of Potsdam, Germany

Flood warning systems have a long track record of protecting human lives, but monetary losses continue to increase. Knowledge about the effectiveness of early flood warnings in reducing monetary losses is sparse, especially at the individual level. To gain more knowledge in this area, we analyse a dataset that is unique in terms of detailed information on warning reception and monetary losses at the property level. The dataset contains 4,468 damage cases from six flood events in Germany. We show quantitatively that early flood warnings are only effective in reducing monetary losses if people know what to do when they receive the warning (with at least one hour's notice). The average reduction in contents loss is 4 percentage points, which corresponds to a reduction of EUR 3,800 for the average warning recipient. This is substantial compared to the mean contents loss ratio of 21% and an absolute contents loss of 17,000 EUR. For the building loss ratio, the average reduction is 2 percentage points, which corresponds to a loss reduction of EUR 10,000. This is a remarkable reduction compared to the mean building loss ratio of 11% and a mean absolute building loss of 48,000 EUR. We also show that particularly long-term preparedness is related to people knowing what to do when they receive a warning. Risk communication, training and (financial) support for private preparedness are thus effective in mitigating flood damage in two ways: through precautionary measures and more effective emergency measures.

Mapping the characteristics and conditions of path dependency: Re- and deconstructing the 1980-2020 flood risk management in the Aist and Enns river regions in Austria

Thomas Thaler[1], Sebastian Seebauer[2], Alina Lückl[2]
[1]University of Natural Resources and Life Sciences, Austria; [2]Joanneum Research Forschungsgesellschaft mbH, Austria

Recent extreme flood events clearly show that the challenges posed by climate-related risks demand forward-looking and robust local planning and governance. We analyze the long-term development of decision-making arenas in the Aist and Enns river regions in Austria in order to illustrate how path dependency manifests and evolves in local adaptation policy. The results show that ad-hoc reactions to catastrophic events take precedence over strategic planning for long-term climate risk management. However, flood events are not the sole triggers for action. Paradigm shifts to e.g. riverbank nature conservation or mandatory revision of hazard maps open policy windows for gradual reorientation. Selected individuals from public administration act as policy entrepreneurs by recognizing leverage and loopholes in current funding and legislation. Local mayors voluntarily outsource responsibility to technical experts and regional administration, who then deploy mainly structural risk reduction measures in a top-down approach. Self-reinforcing mechanisms manifest as tight-knit actor coalitions and high institutional density which rely on rigid, pre-defined planning, financing and implementation processes. Adaptive expectations focus on incrementally alleviating the currently most urgent point of concern and on short-term availability of funding schemes, thereby precluding a holistic perspective taking future risks and developments into account. We demonstrate how learning from past pathways highlights particular constellations and situations which influence future flood risk management pathways.

Forecast-based operation of blue-green roofs as a new solution to decrease the impact of extreme weather in cities

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In the coming decades, climate change will increase the intensity and frequency of extreme summer precipitation events as well as heatwaves. Green infrastructure (e.g. parks and green roofs) is generally seen as an effective adaptation measure to address these challenges, especially in the urban setting. Green roofs, however, are often criticized for having a limited water retention capacity during high-intensity rainfall events. In response to this concern, the city of Amsterdam has started a project (RESILIO, https://resilio.amsterdam/en/smart-blue-green-roofs) to investigate a new innovation in this field: smart blue-green roofs. These roofs have an extra water retention layer underneath the green roof, which can be used to buffer extreme rainfall volumes or as a capillary irrigation system for the plant layer on hot and dry summer days. The smart valve on the roof can be opened when extreme precipitation is predicted to create enough capacity to capture and retain the incoming rainfall. It is yet unknown if the accuracy of the forecasts used to trigger drainage is sufficient enough to provide added value. This is because false alarms in the forecast can lead to a reduction of water availability, and therefore a reduction in evaporative cooling and plant health.

To test the magnitude of this trade-off, we evaluate the performance of ensemble precipitation forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF) to trigger drainage from blue-green roofs. We simulate blue-green roofs in a hydrological model on 28 locations over the Netherlands, using hourly meteorological observations over the last 11 years and different quantiles of the ECMWF ensemble precipitation forecasts. They are used to trigger drainage from the roof if an extreme precipitation event is predicted. We show that this forecast-based drainage creates enough buffer capacity to capture 90% of extreme rainfall (>20mm/hr), without major losses in water availability, and therefore evaporative cooling, on hot summer days (>25 degrees Celsius).

We conclude that blue-green roofs are much more effective in reducing pluvial flood risk and heat stress than green roofs, and that relatively low-resolution ECWMF precipitation forecasts can increase the effectiveness of these local-scale nature-based solutions. Initial results of a suitability analysis to upscale this solution in Amsterdam showed that approximately 14km2 of roof surface is potentially suitable for blue-green roof application, which is on average 10% of the area of urban catchments. These results show that blue-green roofs can help to make Amsterdam and perhaps other cities more resilient to the extreme weather events of the future.

Accounting for tropical cyclones more than doubles the global population exposed to low-probability coastal flooding

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Storm surges are driven by low air pressure and strong winds in tropical (TC) and extratropical cyclones (ETC). Coastal flooding is often caused by this type of extreme weather with large socio-economic impacts in densely populated and low-lying coastal areas. Recent examples of coastal disasters include typhoon Hagibis that made landfall in Japan, Hurricane Dorian which devastated the northwestern Bahamas, and extratropical cyclone Xaver that affected northern Europe. Each of these storms generated dangerous storm surges, reaching 6m in some parts of the Bahamas during Hurricane Dorian with approximately 100 fatalities as a result. Economic losses are estimated at 10 billion U.S. Dollars for both typhoon Hagibis and hurricane Dorian.

To inform flood risk management and develop effective adaptation strategies it is important to have accurate information on return periods of extreme sea levels. To date, there exists no global database with return periods of extreme sea levels that fully includes TCs. Global databases of extreme sea levels are typically based on historical climate simulations covering multiple decades. While this is sufficient for ETCs, TCs will be underestimated in such databases. This because TCs have generally low probabilities and affect only a small stretch of coastline, compared to ETCs. A climate reanalysis covering multiple decades includes too few TCs to perform an extreme value analysis. To resolve this, previous studies at local scale have used synthetic TC tracks generated by a statistical model to estimate the probabilities of extreme sea levels.

The aim of this research is to develop a global database of extreme sea levels that include both ETCs and TCs. For ETCs, we force the hydrodynamic Global Tide and Surge Model (GTSM) with ERA5 10-meter wind speed and air pressure data to calculate the return periods of extreme sea levels based on the period 1980–2017. Since ERA5 includes all storms, we filter out extreme sea levels caused by TCs. Results show that GTSM forced with ERA5 atmospheric data performs well for ETCs. For TCs, we force GTSM with synthetic TC tracks that correspond to 3,000 year of TC statistics. The synthetic tracks of TCs are obtained from the STORM model (Bloemendaal et al., 2020) based on the International Best Track Archive for Climate Stewardship (IBTrACS) TC database. With STORM it is possible to statistically extend the ~38-year observed dataset to a 10.000-year synthetic dataset. The synthetic dataset preserves the climatological statistics as found in the original dataset. Finally, we merge the TC and ETC related return periods to create a global extreme sea level database.

Based on the 1-in-1000 year storm tide return period we model coastal inundation globally and compute the number of people exposed to tropical and extratropical cyclone-induced coastal flooding. As a future research direction we would like to explore hydrographs that capture the temporal progression of extreme sea levels. A possible application of these hydrographs is to model inundation more dynamically by taking the time component into account, compared to the static approach that we use here.

Trends in Seasonality and Flood Timings Over Kenya

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The frequency and magnitude of extreme events such as droughts, heatwaves and floods are likely to increase due to the impacts of climate change. Flooding for example, has severe societal, economic, and environmental consequences ranging from loss of lives and livelihoods, displacement of people, major disruption to essential services, and damage to infrastructure especially in developing countries such as Kenya. These impacts are exacerbated by some mesoscale and localized systems that may result in a shift in timing and seasonality of such extreme events. The long-rains wet season of March–May over Kenya is known to be the wettest with exceptionally high monthly rainfall totals in March and April, whereas the short rains occur in October- December resulting to several multi-day heavy rainfall episodes. But, with the changing climate, there has been a shift in the occurrences of extreme rainfall events and rains within the short rains season being more enhanced than usual. However, limited understanding of the observed trends and shifts in flood seasonality and timing results in poorly understood historical flood trends and uncertain predictions of future flood conditions. In this research, we looked at systematic data analyses at catchment scale to explore the changing trends and shifts in timings and seasonality of river floods in Kenya over the past three decades, using a Kenya Water Resources Authority database from 26 observational hydrometric stations and found clear patterns of change in seasonality and flood timing. The wet months have become wetter than usual and the shift in the occurrence of flood peak events is also eminent across the two wet seasons. The results generated here provide a good insight in the disparity in timing and variability between extreme rainfall and flooding and can assist predictions of flooding and flood risk Kenya and in turn save lives and improve livelihoods.

Nature-based solutions and global coastal flood risk estimates

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In the coming century, people in low lying coastal urban areas are projected to face increases in coastal flood risk due to increases in, for example, urban development, sea-level rise, subsidence, and degradation of foreshore vegetation. In order to prevent this increase in coastal flood risk, or even to reduce risk below today's levels, adaptation measures must be implemented. Nature-based adaptation in coastal areas, such as vegetation on the foreshore, is showing potential to mitigate the impacts of climate change. This study aims to provide a global scale assessment of nature-based, structural and hybrid adaptation measures to quantify its potential effectiveness. Although quantifying nature-based adaptation can be challenging, it is critical to document such efforts to better understand the effectiveness of nature-based adaptation at the global scale. In order to address this, we will develop a methodology to include mangrove restoration, conservation of foreshore vegetation and grey infrastructure as adaptation measures in a global coastal flood risk modelling cascade. While foreshore vegetation as nature-based adaptation measure is showing potential for broad scale implementation, no studies have been carried out to assess the potential effectiveness of these adaptation measures on reducing (future) flood risk at the global scale. Furthermore, to date a global assessment of hybrid adaptation strategies is missing. This study aims to bridge this gap and highlight regions where these adaptation measures might benefit for further research at the regional/local scale. We will use this modelling framework to assess the benefits and costs of nature-based, structural and hybrid adaptation measures at the global scale. To address uncertainty of future conditions, we include a range of socioeconomic change projections and sea-level rise projections including uncertainties. The potential results of this study show where it is beneficial from an economic point of view to implement which strategies when assessing at the direct benefits of the adaptation measure through flood risk reduction.

Impacts of extreme wind speeds and other factors on vegetation disturbances in the German railway network

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Winter windstorms are among the most dangerous and costly natural hazards in Central Europe. Their ability to cause tree and branch fall can lead to disruptions and damage along railway systems.

For a more robust railway forest, the Deutche Bahn is continuously developing the vegetation along tracks. About 30.000 trees per year that are diseased or susceptible to storms are removed as a preventative measure. This extended vegetation management has reduced the disturbances caused by trees already by a quarter. Nevertheless, disturbances continue to occur and the consequences of climate change are a challenge for reliable rail transport.

A data set with vegetation disturbance events between 2017 and 2020 along the German railway system has been provided by the Deutsche Bahn. The aim of this study is to use exploratory statistics, mechanistic damage models as well as statistical models, such as regression techniques or decision trees, to explore the relationship between vegetation damage and meteorological parameters like present and antecedent wind gusts, precipitation or temperature. Additionally, tree factors such as height, species and between tree competition, as well as soil conditions like ground frost, soil moisture and soil type will be taken into account. Finally, we plan to derive critical thresholds (e.g. wind speed, tree height) for wind damage and combinations of weather parameters leading to significant damage risk.

Our first results confirm a positive relationship between vegetation disturbance and wind speeds. In particular strong winter storms leave a very clear signal in the disturbance time series. For example, the highest numbers of vegetation disturbance events occurred during the winter storms Sabine (10.02.2020, 515 events) and Friderike (18.01.2018, 360 events). During winter storm days the majority of events occurs in those areas affected by high wind speeds. Tree fall disturbance peaks during the winter storm season between January and March, while branch fall disturbances peaks between June and August. However, a significant number of events occur also during times of low wind speeds. Additionally, high wind speeds do not necessarily lead to vegetation damage. It is clear that other meteorological and tree related factors need to be taken into account. Compound events as well as previous weather and soil conditions are expected to affect wind damage risk and will be explored in our analysis.

Detecting changing flood generating mechanisms in long records from reference hydrological sites

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While every flood in a every river has unique properties and consequences, similar flood generating processes over a basin results in a series of similarly shaped flood event hydrographs. There have been efforts to classify hydrographs building on the concept that a hydrograph represents an integration of hydrological processes over time and space. Others have examined properties of the statistical shape of a flood event hydrograph to group floods into classes. Here, a novel methodology is presented that clusters peak event time-series fragments across multiple river basins. The methodology is based on extracting “peak over threshold” events and grouping with time-series clustering. This clustering allows for time and magnitude alignment and for events of varying length to overcome basin characteristic and precipitation event differences. Synthetic events are used to test the methodology; the method is successful at separating synthetic, even when the event signal is noisy. Classic techniques for determining the optimal number of clusters fail when events are of different lengths, but the technique demonstrates similar events across time and amongst 46 references basins spanning southern Canada and the northern United States. Linking the clustered events to flood generating processes and detecting changes in occurrence over time will contribute to identifying temporal changes in the genesis of floods in response to climate, water management, and land-use change.

An Open European Seismic Risk Model (ESRM20)

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Over the past 30 years the European scientific community has worked together on many aspects of seismic hazard and risk modelling. The SERA project (2017–2020) provided the first opportunity for the scientific community to integrate this research towards the development of a uniform seismic risk model for Europe. This model has been computed with open source software (OpenQuake-engine) and is now being openly released to the wider scientific community through the risk services of EFEHR, the European Facilities for Earthquake Hazard and Risk (www.efehr.org). Open access, without commercial restrictions, ensures that all aspects of the scientific methods and results are understood, available for critique, compliment, or reuse by all relevant stakeholders working on risk mitigation.

The European Seismic Risk Model (ESRM20) combines a model of the frequency of surface ground shaking due to earthquakes (hazard), with a model of the distribution of buildings (and their occupants) classified according to their physical attributes (exposure) with models that describe the propensity of these buildings to be damaged and suffer losses due earthquakes (vulnerability). The model can be used to estimate a number of different quantitative risk metrics, including the average annual economic loss, loss of life (number of fatalities), and number of damaged buildings due to earthquakes in 44 European countries. This invited lecture will describe the hazard, site characterisation and amplification, exposure, and vulnerability models and will provide an insight into the risk results and trends that are emerging from this model.

Testing physics and statics based hybrid ETAS models

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Currently, the Epidemic Type Aftershock Sequence (ETAS) model is state-of-the-art for forecasting aftershocks. However, the under-performance of ETAS in forecasting the spatial distribution of aftershocks following a large earthquake make us adopt alternative approaches for the modelling of the spatial ETAS-kernel. Here we develop a hybrid physics and statics based forecasting model. The model uses stress changes, calculated from inverted slip models of large earthquakes, as the basis of the spatial kernel in the ETAS model in order to get more reliable estimates of spatiotemporal distribution of aftershocks. We evaluate six alternative approaches of stress-based ETAS-kernels and rank their performance against the base ETAS model. In all cases, an expectation maximization (EM) algorithm is used to estimate the ETAS parameters. The model approach has been tested on synthetic data to check if the known parameters can be inverted successfully. We apply the proposed method to forecast aftershocks of mainshocks available in SRCMOD database, which includes 192 mainshocks with magnitudes in the range between 4.1 and 9.2 occurred from 1906 to 2020. The probabilistic earthquake forecasts generated by the hybrid model have been tested using established CSEP test metrics and procedures. We show that the additional stress information, provided to estimate the spatial probability distribution, leads to more reliable spatiotemporal ETAS-forecasts of aftershocks as compared to the base ETAS model.

A novel physics-based and statistical forecast model for induced seismicity

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We present a novel formulation to generalize the classical Seismogenic Index (SI) statistics to arbitrary physics as considered relevant for induced seismicity. We consider induced seismicity to be described by a normalized integral over the spatial reservoir volume of induced variations in Frictional Coulomb Stress and to follow a Gutenberg-Richter frequency magnitude distribution. We demonstrate that the classical log-linear correlation between maximum expected induced magnitude and net injected volume arises as a limiting case from our enriched statistics if the contribution from thermo-poroelastic stress transfer can be neglected. In addition we found that the induced seismic hazard is sensitive to a first order to imposed pressure rates, as also constrained by recent laboratory experiments, and that the non-monotonic character of the injection protocol strongly impacts the induced seismic hazard during both the active stimulation phase and at shut-in, even if the same hydraulic energy is input to the system. By considering non-linear, quasi-static thermo-poroelastic stress transfer results in a systematic increase in the seismic response of the stimulated rock that extends over a larger volume and a longer time scale than traditionally implied if based on pore pressure relaxation dynamics. These results call for caution in assessing the seismic hazard as usually adopted in current traffic light systems, which, neglecting these complex physical interactions, can provide only conservative lower bound hazard estimates. Our approach provides a valuable addition to such traffic light systems, which are usually based on observations of the seismicity before the termination of the injection and helps to project the induced seismicity as a function of the stimulation scheme so to advance forecasting predictability of induced and triggered earthquakes.

The use of high-resolution building exposure models: earthquake damage scenario for the city of Cologne, Germany

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The expanding computational capabilities and increasing availability of open high-resolution volunteered geographic information are opening very interesting new pathways for the modelling of building exposure. Such a task is frequently challenging due to the lack of data on the structural characteristics of the existing building stock. We have built upon these new opportunities and have combined building-by-building data stemming from three open datasets with one another, as well as with census statistics and in-situ vulnerability mapping to generate a building-by-building exposure model for the city of Cologne (Germany). Our procedure for combining these data considered not only their different spatial resolutions but also the fact that available census statistics were already around 20 years old at the time of carrying out this work. As a first step, the more modern building-by-building datasets were combined to define a building-by-building model. However, not all buildings had sufficient information available to characterise their vulnerability to seismic action. The second step thus consisted in using statistical observations from the building-by-building model to adjust the 20-year old census data and to derive meaningful relationships between the two main parameters considered herein to characterise the vulnerability of the buildings as per models proposed by existing studies: the number of storeys and the year of construction. The third step was to carry out a Monte Carlo simulation to enrich the building-by-building model with the census data, which was available at the neighbourhood level. Each realisation of the exposure model allowed us to calculate a complete damage estimate due to a scenario earthquake of moment magnitude 6.5 affecting the whole city, which we defined as part of a seismic risk analysis commissioned by the German Federal Office of Civil Protection and Disaster Assistance (BBK). According to our model, some degree of damage may be expected for around half of these buildings, with several hundred potentially even suffering from the most extreme EMS-98 damage grade 5. The variability across Monte Carlo realisations was negligible when looking at the city as a whole but became relevant when focusing on results for individual buildings. While limitations regarding the reliability, accuracy and completeness of open datasets and challenges in merging these datasets to produce one model always exist, high-resolution building-by-building exposure models open doors for the detailed study and characterisation of a large range of phenomena, including directivity and directionality effects and high-resolution site amplification models, within the realm of seismic risk, as well as those stemming from other hazards.

Scenario-based multi-risk assessment for consecutive earthquakes and tsunamis in Lima, Peru

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Even though multi-hazard risk assessment is still a relatively new field with non-unified terminologies and approaches, there appears to be a consensus on the need of evaluating both multi-hazard and multi-vulnerability interactions. This study is focused on the latter type. In this framework, cumulative damage and losses cannot be simplified as the sum of the effects from each individual hazardous event. Instead, their nonlinear damage accumulation during multi-hazard sequences needs to be carefully addressed. We propose a novel method to assess the differential physical vulnerability of large-scale building portfolios while making use of single-risk fragility/vulnerability models available in the literature for a wide range of natural hazards. We propose the use of probabilistic equivalences between schemes, not only between building classes (due to the diverse supply of specific models) but also between damage states. For the latter purpose, we make use of a Bayesian formulation, a machine learning classification algorithm, and an underlying harmonizing scoring scale describing the likely extent of observable damage to individual building elements. This is accompanied by state-dependent fragility functions for the triggered event. We test this methodology by investigating the cumulative damage that commonly exposed residential buildings in Lima (Peru) may suffer after six scenarios of mega-earthquake (mainshock) and consecutive tsunami (based on flow depth). Lima has been ranked as the capital city exposed to the highest seismic hazard in South America. This city has suffered devastating disasters associated with earthquakes and tsunamis in the past (e.g., 1586, 1724, 1974), and with continued urbanization. After assessing its seismic vulnerability using exhaustive sets of cross-correlated ground motion fields, the resultant distribution of damage states is used as input to evaluate the tsunami vulnerability. Each damage distribution is translated into financial losses to obtain a comparative risk metric and disaggregate each hazard contribution to multi-hazard scenarios. These calculations are performed on variable resolution aggregation units. Our results differ from approaches that rely on the use of empirical tsunami fragility functions and analytical models that assume the equivalence between earthquake and tsunami damage states. This integrative approach also offers the possibility to customize their individual components looking for future improvements while exploring epistemic uncertainties. This study has been conducted within the framework of the RIESGOS project, funded by the German Federal Ministry of Education and Research (BMBF).

Session 5
Geomorphological events

Detection, Observation, and Early Warning of Catastrophic Flow Events Using Regional Seismic Networks

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Geomorphic events such as landslides, debris flows, and flash floods are a major source of hazard in many mountainous areas, and are potentially a growing threat due to both changing climate and increased development in mountain regions. This is of particular concern in the Himalayas, where increases in hydropower development involve placing workers and infrastructure in vulnerable portions of the landscape. The threat was starkly illustrated on 7 Feb. 2021 when a rockslide-mass flow-flood cascade in Uttarakhand India caused a large number of fatalities and severe damage to infrastructure. Such hazardous geomorphic events are often difficult to anticipate and difficult to observe, hampering our ability to mitigate their impacts. Our increasing understanding of the seismic signals generated by geomorphic events offers new opportunities for monitoring geomorphic hazards, with potential for both event early warning and a better understanding of event dynamics. We illustrate this potential using data from the 7 Feb. event, which was recorded by a dense network of 3-component broadband seismic stations set up across Uttarakhand by the National Geophysical Research Institute, under the Council of Scientific and Industrial Research, India (CSIR-NGRI). The seismic data capture the evolution of the event from the detachment of the initial rockslide through to the dissipation of the resulting flood ~55 km downstream, and can be used to track the location of the flow as it propagated downstream. The dense seismic network also allows us to determine the detection limits for each phase of the event. Our results show that such events can be widely detected and located within minutes of initiation, illustrating the potential for geomorphic hazard early warning using regional seismic networks.

Insights on rockslide collapse mechanism from pre-event cracking

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In order to reduce the societal impact of mass-wasting events, high temporal resolution data are required to investigate the controlling and initiating factors just before an event happens. One of these controlling factors is the rupture of small amplitude cracks along the failure plane. Because most of the failure plane is not accessible in-situ, cracks have to be monitored indirectly, for example using the radiated seismic signal. In many cases, the seismic signal-to-noise ratio (SNR) of cracks is too low to be effectively retrieved from seismic waveforms by classical techniques such as STA/LTA or cross-correlation, even if the seismometers are located directly at the failure site.

The use of state-of-the-art machine learning techniques for event identification and classification based on hidden Markov models (HMMs) can help dealing with these situations by generating a time series of crack densities. HMMs are applied in various fields of pattern recognition. Besides the benefit of detecting low SNR crack events, the training technique used here has the advantage to reliably identify rare events and to be almost fully automated, as only one reference event per event class is sufficient for the detection and classification to proceed.

Here, we used this technique to analyse seismic data from an array of six broadband seismometers that registered a series of mass-wasting events, leading to a main event that happened at 03:42 on the 2nd January 2013 in the Illgraben catchment, Switzerland. We obtained the temporal evolution of three types of signals: (1) single crack signal (2) failure and subsequent rockslide (3) rock avalanche activity due to the remobilization of debris along the unstable slope. We located these events, and selected the ones related to the slope where the mass-wasting event happened. The temporal evolution of the crack number is characterized by a linear trend in the weeks prior to the main mass-wasting event and by a sigmoid exponential growth in the hours preceding it. Hence, we propose a mechanistic model to describe the rupture on the failure plane.

Landslide inventories are incomplete. Can we still use them to make forecasts?

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Recent efforts have taken steps toward forecasting landslides at the regional to global scale using probabilistic methods. The statistical models or machine learning algorithms used to make these forecasts are trained using landslide inventories that store the locations, sometimes the occurrence times, and other attributes of mapped slope failures. Landslide inventories arise through a combination of two process groups: 1. physical processes that cause landslides and 2. observation processes that lead to landslides being recorded. Depending on the quality and coverage of the observation process, landslides that have occurred may be missing from inventories. While this incompleteness of landslide inventories has long been recognized, few studies have attempted to explicitly account for this shortcoming in predictive models. In this study, we seek to understand how landslide observation processes impact probabilistic forecasts and propose a method to improve landslide forecasts using incomplete inventories.

We use >120,000 recorded landslides drawn from six published inventories from the Pacific Northwest of the United States to investigate the effect of landslide observation processes on the distribution of recorded landslide points in space and in time. Drawing on these observations, we create a synthetic landslide inventory, modeling landslides as a spatio-temporal inhomogenous Poisson process, in which landslide intensity is driven by relief and seasonality. By removing landslides following specific rules, we then thin the inventory according to five different observation scenarios. In these scenarios, 1. landslides are recorded randomly, 2. landslides are preferentially recorded in urban areas, 3. landslides are recorded only on roads, 4. landslides are recorded only after major landsliding events, and 5. landslide recording improves over time. For each of these scenarios, we fit two types of Bayesian regression models. In the first type, we treat the thinned inventory as if it were complete, allowing us to investigate how each type of observation scenario influences landslide predictions. We demonstrate that models that are trained using thinned landslide inventories can produce misleading results when the observation process is unaccounted for. In the second type, we include the observation process in the model, which allows the model to correctly recover both the parameters governing the underlying landslide process and the observation process. We argue that including landslide observation processes in the statistical models used to predict landslides can improve the accuracy of predictions, while omitting them can produce misleading results.

Debris flows induced by Multiple Occurrence Regional Landslides Events in the Colombian Andes

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Debris flows triggered by Multiple Occurrence Regional Landslide Events (MORLE) are common destructive phenomena in Colombia. In the Colombian Andes, characterized by tropical weather, deep weathering, and steep slopes, MORLE are often triggered by intense and convective rainstorms that are orographically anchored. When such rainstorms take place in steep and small basins, flash floods are triggered, which flow downstream mixing with the hillslope sediments supplied from landslides and erode the streambed sediments. The flow becomes a one-phase viscous surge with high solid concentrations traveling at high speed with great volume and destructive capacity. The final stage of such events is marked on fans or low-land areas that are often populated, turning into disasters.

Historical debris flow occurrence was analyzed from the disaster database provided by the Geohazards Research Group (geohazards.com.co). The database includes 8,248 reports from multiple natural hazards since 1880. 51% of the records correspond to landslides, and 5.7% to debris-flow processes, being rainfall the main trigger for both phenomena. Some of the most deadly debris flow disasters in the record are: San Carlos, Antioquia in September of 1990 that caused 20 deaths, Salgar, Antioquia in May of 2015 that caused 104 deaths, and Mocoa, Puntumayo in March of 2017, that caused 400 deaths.

According to the records, there have been 4,238 landslides that caused 2,221 deceases, and 473 debris flow events that caused 440 deaths. These statistics show how debris flow phenomena are 77% deadlier than landslides, even though they are not so frequent. While not every debris flow in Colombia is related to the occurrence of a MORLE, those reports with a record of landslide clusters have caused a higher number of fatalities and losses. Furthermore, higher landslides count in MORLE are positively correlated with higher human losses and infrastructure damage.

Understanding the drivers of MORLE induced debris flows in Colombia and how these phenomena interact to create a multi-hazard settings is a crucial step towards reducing risks. Hazard and risk assessments are the basic tools for stakeholders to make better land use planning decisions. Such hazard studies are carried out using different modeling methods, which have been traditionally carried out from a single-hazard approach. For debris flows, these approaches include physically-based models to simulate the path of peak clear stream flows, which despise their contrasting rheology. Empirical models have also been used to define potential paths according to the geomorphological features of the terrain.

Nonetheless, new approaches are being developed, which account for the relationships between cluster of landslides and debris flow phenomena. Recent proposals focus on mass-routing mass and momentum conservation software, capable of routing multiphase flows considering the interactions between the flow and sediments. For the application of these methodologies in Colombia and its incorporation into land use planning, it is important to have a clear comprehension of the drivers and interactions of such events, given by the particular conditions of the study area.

Defining criteria for the formation of landslide induced tsunamis in elongated and narrow water bodies

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The city of Palu, Indonesia, was hit by unexpectedly high tsunami waves right after the Mw 7.5 Sulawesi earthquake in 2018. The wave front was with up to 9 m significantly higher than could be expected with regard to the strike slip characteristic of the earthquake, whose epicenter is located about 70 km north of Palu close to the west coast of Sulawesi. Palu Bay is characterized by an elongated and narrow geometry. Simultaneous coastal landslides and wave interferences within the bay are under discussion as an explanation for the phenomena.

Landslide induced tsunamis are a well-known phenomenon and have been reported many times. Especially fjords and reservoir lakes are often comprised of long and narrow water body geometries, similar to the Palu Bay, and the surrounding slopes are usually highly susceptible to landslides due to ongoing deglaciation processes or fluctuating water levels, respectively. Up to now, there is no systematic analysis of the characteristics of landslide tsunamis in narrow water bodies.

The objective of this study is to define criteria for possibly endangered areas based on a statistical analysis of the properties of former landslide tsunamis. The literature on historical landslide induced tsunamis worldwide is investigated regarding the properties of the water body geometry, the triggering earthquake, the tsunami waves, the slope geology, the morphology, and the landslides, in order to find similarities between the individual case studies. Based on those similarities, criteria for coastal areas or other water bodies with a high potential of landslide induced tsunamis are determined. With the help of those criteria, further areas that might be endangered by landslide tsunamis that can be enhanced by the geometrical characteristics of the water body are defined.

The focus of this study is the Indonesian coastline, which was affected by landslide induced tsunamis several times in the past. The findings of this work can be used to take preventive measures regionally, for example to set up monitoring systems on slopes at risk, or to educate the population for this particular form of geohazard.

A typology of compound weather and climate events

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Compound weather and climate events describe combinations of multiple climate drivers and/or hazards that contribute to societal or environmental risk. Although many climate- related disasters are caused by compound events, the understanding, analysis, quantification and prediction of such events is still in its infancy. In this talk will present a typology of compound events including analytical and modelling approaches to aid in their investigation. In particular, the highly diverse compound event types can be organised according to four themes: preconditioned, where a weather-driven or climate- driven precondition aggravates the impacts of a hazard; multivariate, where multiple drivers and/or hazards lead to an impact; temporally compounding, where a succession of hazards leads to an impact; and spatially compounding, where hazards in multiple connected locations cause an aggregated impact. Through structuring compound events and their respective analysis tools, the typology offers an opportunity for deeper insight into their mechanisms and impacts, benefiting the development of effective adaptation strategies.

Wintertime Compound Climate Extremes in North America and Europe

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Recent winters have seen repeated cold spells over North America and stormy (wet and windy) weather over Europe. These climate extremes have typically been discussed separately, but their notable co-occurrence in the same winters raises the question of whether there may be a systematic, physically based link between the two.

In this presentation, I will first provide a statistical analysis of cold spells over North America and stormy (wet and windy) weather over Europe, showing that their co-occurrence is unlikely to be a result of random variability. Next, I will argue that we can identify recurrent large-scale atmospheric anomalies which provide favourable conditions for these spatially compounding extremes. I will specifically focus on the role of the planetary wave-breaking and of the North Atlantic Jet Stream.

Multi-hazard risk and the asynergies of disaster risk reduction measures: the need for an integrated approach

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Many countries face the risk of multiple hazards. Nonetheless, most DRR measures are aimed at one hazard type. However, while positively influencing the risk of one hazard, DRR measures can have adverse effects on the risk of another hazard type.

Most research on hydrological risks focuses either on flood risk or drought risk, whilst floods and droughts are two extremes of the same hydrological cycle. To better design disaster risk reduction (DRR) measures and strategies, it is important to consider interactions between these closely linked phenomena. We show examples of: (a) how flood or drought DRR measures can have (unintended) positive or negative impacts on risk of the opposite hazard; and (b) how flood or drought DRR measures can be negatively impacted by the opposite hazard.

In a case study of Afghanistan, we calculate the asynergies of structural, building-level DRR measures for floods and earthquakes using two scenarios where DRR measured are aimed at either decreasing flood or earthquake risk. These scenarios are used to assess the asynergies and to illustrate to what degree a reduction of one risk may actually be offset by an increase in the other hazard's risk. This is then used to show which type of measure is worthwhile in which part of the country.

Overall, we find that an improved capability of understanding risk and interactions between disaster risk reduction measures more comprehensively would strongly benefit first responders, aid organizations, urban planners and decision makers in designing sustainable DRR measures.

Integrating network analysis and sequential pattern mining to assess drought compound and cascading impacts

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Compound and cascading impacts can no longer be ignored as they interact and overlap both in time and space, often spurring consequences with higher severity than of individual impacts. Here, we propose the use of network analysis and sequential pattern mining to assess compound and cascading drought impacts by using the case of the 2018/19 drought in Germany. A focus is given to the livestock, forestry, industry, and recreation sectors.

The drought impacts were assessed by considering 3,010 newspaper articles published between April 2018 and August 2019. A series of natural language processing (NLP) was used to extract information on the impact type, location, and date. Network graphs were employed to display the compound impacts. Furthermore, sequential pattern mining was used to identify common cascading paths.

A total of 4,839 impacts were identified. Findings show that simultaneous and cascading drought impacts follow a pattern. This has important implications for impact mitigation, suggesting that the understanding of past patterns can help in the prediction of future consequences. Based on this information, efforts can be directed to reduce the initiation of impact interaction networks.

Our approach provides solutions for some of the main issues in the analysis of cascading and compounding impacts, namely: (1) near-real-time drought impact assessment, (2) simplification and synthesis of complex interactions, (3) identification of statistically significant patterns, (4) user-friendly visualization of impact relationships, (5) analysis of spatial trends, and (6) prediction of future cascading impacts. The tools used here can be applied to other hazards and other impact databases. Thus, we expect that this work will encourage a more holistic approach to natural hazards impact research.

Projections of global urban land cover growth

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The global urban growth development is a highly dynamic system, which contributes to the increase of ecological changes through land system changes. Therefore and among other reasons, it is challenging to project the generic urban land cover development. For the base of such a model, we analyse a sample of 100 global locations (tiles of 0.5° x 0.5°) concerning the quantitative development of urban land cover growth between 1995 and 2015. The data base are annual global land cover raster maps from the European Space Agency. Here, we observe different characteristics of urban growth, i.e. infill, expansion, discontinuous as well as leapfrog development. From these urban growth observations we derive a conversion probability, with which land cover is converted from non-urban to urban as a function of the shortest distance to existing urban land cover raster pixels. This is done separately for every tile, which is why there is a separate probability function for each location. As expected, in all cases the conversion probability decreases with distance to urban land cover, which represents infill as well as urban expansion at closer distances and discontinuous development at further distances to urban land cover. However, after reaching a minimum the probabilities interestingly increase. This phenomenon, also referred to as leapfrogging, can be observed in various tiles with a high significance level in several cases. Our quantitative findings are supported by simulations with a simple gravitational urban growth model, which shows similar conversion probabilities but without disturbances from other influences compared to the empirical data. Based on the individual conversion probabilities for different tiles, we develop the base for an urban growth model to project urban land cover. Hereby, human mobility and population growth, which are projected based on six different future scenarios, serve as external driver for the projections of the urban growth model. An advantage of this approach is, that on the one hand it is considering the very local and complex conversion probabilities within each tile separately and on the other hand it is applicable globally by joining tiles to one another. Furthermore, the reverse perspective is the increasing fragmentation of non-urban land cover through urban growth and its ecological consequences due to land system changes. The approach could be further improved by considering the maturity of urban places, which would result in a change of the conversion probability over time.

Poster abstracts

Session 1
Impact of land degradation, drought and wildfires on ecosystem services

Poster 1-1
Impact of climatic changes and anthropogenic activities on ecosystem's net primary productivity in India during 2001–2019

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In recent years, changes in climate and increasing anthropogenic activities such as rapid urbanization have put tremendous pressure on vegetation and ecosystem dynamics. Therefore, it is essential to examine the effect of these factors on the ecosystem's functioning. In this study, we analyzed the impact of anthropogenic activities and climatic change on ecosystem net primary production (NPP) in the Indian region using correlation analysis and Residual Trend analysis (RESTREND). Using different climate variables such as precipitation, temperature, and solar radiation, along with NPP and land use and land cover (LULC) maps, this study has first classified the ecosystems (ES) into two categories: ecosystems affected by climate change alone (ESc) and ecosystems affected by both climate change and anthropogenic activities (ESc+a). Further, the RESTREND analysis is performed on both ESc and ESc+a for the period 2001–2019 to analyze the contribution of climate and human activities to changes in NPP. The results show that the annual mean NPP in the region is about 533 gC/m2; however, there is a large spatial variation [0 - 3258 gC/m2] and inter-annual temporal variability [503 - 585 gC/m2]. The correlation analysis between NPP and climate variables suggested that precipitation plays a key role in NPP change with a positive effect. In contrast, the other climatic variables have a negative effect on NPP in most of the regions, except for northeast and east-coast regions and northern Himalayan regions where solar radiation and temperature, respectively, had positive effects on NPP. The RESTREND analysis indicated a significant increase in the NPP in parts of the country; however, the contribution of climatic change and anthropogenic activities has changed over time. In general, climatic factors have enhanced the NPP, whereas human activities have contributed towards a decline in NPP. The research findings improve our understanding of how India's ecosystems are responding to climatic changes and anthropogenic activities. It will also help predict NPP under external stresses, especially climate change, and identify hotspots for better ecosystem management strategies.

Poster 1-2
Alleviating the Natural Fire Hazard and Sustainability in the Hindu Kush Himalaya Region in India

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The Hindu Kush Himalayan region of India is home to nearly 88 million people and spans ten states, two union territories, and the West Bengal Darjeeling district. The forest area in this region is approximately 0.23 million square kilometers and is divided into two primary forest types: Himalayan subtropical forest and Himalayan tropical forest. This vast forest area is densely forested and home to a diverse range of trees and shrubs, including Indian Pine (Pinus roxburghii), Indian oak (Barringtonia acutangular), Indian Cedar (Cedrus deodara), Beautyberry (Callicarpa macrophylla), which produces millions of tons of forest residues that are more susceptible to igniting the fire during the summer season due to high temperature and low humidity levels. On an average 4000 fires incident per year has been experienced by this region. One of the leading causes for these forest fires in this area is dry pine needles, capable of exacerbating wildfires, massive carbon emissions as well as land degradation. As per the latest estimate, the total black carbon emissions in the Indian Himalayan region are around 431 Mg per year due to natural fire hazards. The Himalayan area will benefit from a systemic collection of fire-prone forest residues by local people, reducing wildfire frequency and creating jobs. These residues can utilize via combustion and thermochemical conversion to produce electricity in rural areas where grid connectivity is inaccessible. Gasification is a promising thermochemical conversion technology that outperforms other pathways in terms of conversion efficiency and capability to handle various biomass and convert residue into fuel and energy. Not only that, it can mitigate environmental degradation but also enhance the livelihood of mountain communities. Biochar is a by-product of the gasification process that can be used as a resource for clean cooking fuel. Thus, in the Himalayan region, a downdraft gasifier combined with an engine and alternator could generate electricity from forest residue. This review can assist in illustrating a feasible and cost-effective solution for reducing fire hazards, creating jobs, reducing pollution, and ensuring clean and sustainable energy.

Poster 1-3
Extreme fires and drought in the Amazon rainforest

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Fires are again increasingly used to clear land in the Amazon rainforest, increasing overall fire activity in addition to fire ignited to renew managed land. Given the small-scale at which these processes occur and the vast area of the study region, high-resolution, remotely sensed data are required to link fire activity to land-cover and land-cover changes. We apply a complex networks approach to identify high-intensity, i.e. extreme, fires occurring in evergreen tropical forest between 2002 and 2019. We analyse the spatial distribution of extreme fires under different observed climate conditions. We find that all identified extreme forest fires occur within a 0.5-km distance from forest edges and up to 56% of them are found within a 1-km distance from roads. Where deforestation is most prevalent, extreme fires occur along major roads.

Poster 1-4
What drives phenological changes in the Mediterranean Basin?

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The Mediterranean Basin is one of the regions with the fastest phenological changes worldwide. This study aims to identify trends in the occurrence of phenological events and determine the effects of meteorological drivers – and in particular their nonlinear interactions – on the timing of phenological phases. We seek to identify how the main climatological drivers of phenological changes differ regionally by species and phenophases.

Phenological data is retrieved from PEP725, AEMET and Perpheclim, encompassing observation sites mainly located in Spain, southern France, northern Italy and the coast of the eastern Adriatic Sea. Meteorological data is obtained from E-OBS for the time span 1950–2020. A predictor set of daily meteorological variables including temperature, solar radiation, precipitation and the number of frost days is used to assess changes in the date of leaf unfolding, flowering, fruit ripening, and leaf falling. Least Absolute Shrinkage and Selection Operator (LASSO) poisson regression analysis is applied, a method that is suitable for variable selection and reduction of multicollinearity.

For many species, significant trends in the timing of phenological events are identified such as advancement of leaf unfolding dates in spring. Nonlinear interactions between temperature and precipitation are more important predictors than precipitation in isolation, highlighting that it is crucial to account for such compound effects. The incorporation of both concurrent, as well as lagged meteorological predictors is vital for the determination of the timing of phenological events.

Poster 1-5
Towards a comprehensive land degradation risk assessment – building on the concept of ecological resilience

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Nowadays, the immense damage caused by land degradation globally is well recognized. The IPCC recently described land degradation as one of the most urgent challenges for humanity, and in 2005, the Millennium Ecosystem Assessment revealed that approximately 60% of examined ecosystem services are being degraded. However, studies on the economic impacts of land degradation are scarce and the existing estimates of the global annual costs vary greatly, ranging between US$ 17.58 billion and US$ 9.4 trillion. Coherent approaches for assessing and quantifying the extent of land degradation and associated damage over large areas, as well as for quantifying future risks, are still lacking.
This talk discusses the particulars of land degradation making it an atypical hazard compared to acute natural hazards of short duration such as floods or earthquakes. These particulars have hindered that land degradation was perceived as a stand-alone natural hazard for a long time. In consequence, methods for assessing land degradation risk are trailing far behind those that have been developed for acute hazards of short duration within natural disaster risk research. Based on a systematic literature review, a number of discrepancies could be identified, preventing a stringent and coherent risk assessment of land degradation up to today. Among those are that the term 'risk' has frequently been used with colloquial meaning, and that risk terminology was not consistent among and within studies. Further, risk assessment and vulnerability assessment were often confused, which hinders a clear differentiation between present degradation status and future risk. Finally, there appears to be no consensus about what the hazard of land degradation contains.
In a last step, ideas towards a comprehensive framework for a land degradation risk assessment building on the concept of ecological resilience are presented. Addressing land degradation risk within the established framework of natural disaster risk research would strongly advance the transferability of research results to decision making and hence promote our ability to efficiently address the risk of land degradation in practice.

Session 2
Human contributions to climate risks

Poster 2-1
An analysis of the problems with electoral politics in an age of climate change

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This poster summarises the conclusions drawn from my essay entitled "An analysis of the problems with electoral politics in an age of climate change". The essay addresses the extent to which the system of electoral politics acts as a limiting factor to the adoption of effective climate action. The basis of the piece is the argument that the sphere of electoral politics where the majority of climate action is considered, is a contributing factor to the continued failure of our planet to reduce greenhouse gas emissions. Term limits cause world leaders to too often adopt a short-term outlook whereby the implementation of mitigation measures against climate change are overlooked and a focus on calls for immediate economic development take precedence over environmental issues. Through analysis of historic and modern case examples, both the complexity that underlies climate policymaking is highlighted, alongside how electoral politics acts as a barrier to effective climate action.

Poster 2-2
Using panel data to understand the mental health effects of severe flooding in Thua Thien Hue province in Central Vietnam

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Every year, millions of people are affected by flooding, particularly in Asia. Also Thua Thien Hue province in Central Vietnam is frequently affected by flooding from rivers, heavy rainfall, and the sea. Without improved risk management, the impacts of flood hazards on the population are projected to increase considerably due to the effects of global warming and ongoing socio-economic development in risk-prone areas. In addition to physical destruction of economic assets, current research suggests that floods can also have considerable effects on the mental health of those affected. However, the literature in this research domain is still scarce, focuses on developed countries, and mostly employs cross-sectional research designs (i.e. surveys taken at one point in time, only). Consequently, insights into the dynamics and heterogeneity of individual response trajectories and risk and protective factors from a region in the Global South are largely lacking. A better understanding of the psychological impacts of flood hazards is needed, though, in order to build more climate-resilient societies. To improve our understanding of the psychological impacts of flooding over time, we started to implement a panel survey among 400 residents in Thua Thien Hue province in the aftermath of a severe flood event that occurred in October 2020. The panel study consists of six survey waves across a time span of at least three years. Data are collected using face-to-face surveys in four different locations in the province. Every respondent will be surveyed twice per year, which is before and after the flood season. Mental health of the respondents is assessed using the Kessler psychological distress scale (K6), which is a widely used measure of psychological distress in general populations. In the poster, we will discuss survey and research design and present results from the first survey wave that was implemented in April 2021 on psychological distress and associated risk factors of flood-affected citizens. Insights of the study can help to inform disaster risk management to pro-actively address mental health issues following flood hazards.

Poster 2-3
Impacts of climate change on Cryosphere and hydrological Regimes of Upper Jhelum River Basin of North-western Himalayas

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The climate of the Himalayas is vulnerable and interlinked with global-scale climate changes, and the hydrology of the region mainly depends on snow and glaciers. This study using observational data, detailed characteristics of long- and short-term, and localized variations in temperature, precipitation, and discharge are analyzed in Upper Jhelum River Basin (UJRB). Further, the Snow cover area (SCA) changes and glacier changes were studied to correlate the impact of glacier recession on streamflow dynamics under changing climate between 1980–2016. Statistical tests were used to examine annual and seasonal changes in temperature precipitation and discharge. The average annual temperature has been rising more rapidly (average rate of 0.04 ˚C/yr or 0.37 ˚C/decade), than the average global increasing rate (0.37 ˚C or 0.12 ˚C/decade 1951–2012), with an alarming rate of decrease of precipitation of about -5.9 mm/yr. A more significant increase of temperature over UJRB was observed during winter (0.05 ˚C/yr) and spring season (0.05 ˚C/yr). This seasonal variation with winter and spring temperatures increasing more significantly as compared to the autumn and summer temperatures (0.04 ˚C/yr) is consistent with other Himalayan regions. The Mann Kendall test and linear regression show SCA's are showing a significant ($p<0.01$) decreasing trend. The annual rate of decrease ranges from -0.03%/yr to -0.78%/yr in different sub-basins. Glaciers in the UJRB have been reported to be retreating at higher rates as compared to other parts of the Himalayan region. The study indicated that the rate of retreat of the Kolahoi glacier (biggest glacier in UJRB) is -0.50%/yr from 1980–2016. The rate of retreat increased as -0.33 %/yr between 1980 to 1992 to -0.54%/yr between 1992 to 2000 which in the later one and half decade increased at an alarming rate of -0.68%/y between 2000 to 2016. The present study revealed that the total area of the Kolahoi glacier remained around 11.1 Km^2 in 2016. In terms of total area, it has lost 2.45 Km^2 from the past 36 years, which is equal to 18% of total glacier loss from1980–2016. Sheshram glacier second biggest glacier in UJRB with a total rate of retreat of -0.33%/y, lost 0.7 Km^2 (11.86 %) from 1980–2016. Hoksar and Sonsar have lost 51.46% and 28.38% of the total area from 1980–2016. The Thajwas group of glaciers has lost an average glacier cover of 3.97 km^2 from 1980–2016. The Nehnar and Machoi group had deglaciated a total area of 2.5 Km^2 and 8.68 Km^2 respectively from 1980 to 2016. Climate change often results in the corresponding shift of discharge in glaciated and snow-fed terrains. The stream flows measured at different sites showed statistically significant depleting trends. The results are contrary to climate models that are predicting peak discharge of Himalayan catchments, especially Indus River Water Basin (IRWB) in the mid-century but observed datasets like proposed in the present study are suggesting that peak discharge of local glaciated regions in IRWB have already peaked its discharge. It is expected that further glacier melting and SCA depletion in the future would threaten streamflow regimes, hydropower generation, and agriculture production in the region.

Poster 2-4
Towards a probabilistic and globally consistent city-level heat mortality risk assessment

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The risk of extreme heat mortality is ever increasing with the rapidly changing climate. With the collision of several mega-trends – aging societies, urbanization, inequality – the need for a comprehensive heat mortality risk analysis is growing rapidly. Here, we present first results of a globally consistent probabilistic analysis of the impact of extreme heat on city-scale mortality, demonstrated for Zurich (Switzerland).

Building on the open-source natural catastrophe risk platform CLIMADA (CLIMate ADAptation), we produce a probabilistic risk assessment for heat mortality on a city level. We combine state-of-the-art epidemiological time series analysis methods with *single model initial condition large ensemble* (SMILE) climate model output. The epidemiological analysis is a based on a well-established approach which relies on quasi-Poisson regression time series analyses and requires daily city-level mortality data. This analysis results in relative risk of exceedance mortality as a function of temperature. The SMILE approach takes one single climate model (in our case the *Community Earth System Model* (CESM)) and runs it 82 times with perturbed initial conditions but using the same climate scenario. It thus indicates 82 physically plausible pathways of the climate which can be used for a probabilistic risk assessment. This allows estimation of tail-risks and quantification of return-period-based mortality impacts. Communicating risk using (shifts in) return periods is helpful to start dialogues with government authorities, city planners and decision makers, as such metrics are commonly used to prepare for natural catastrophes.

Poster 2-5
Evaluation of a global modeling chain for flood-induced displacement risk

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River flooding has displaced more than 100 million people worldwide, just during the last decade. It is important to understand the spatiotemporal patterns of displacement risk and the determinants of vulnerability to flood displacement, and to anticipate future changes in risk, for instance, due to global climate change. Here we investigate a global modeling chain built around this objective. As a first step, we evaluate estimates of flood hazard produced by a global flood model (GFM), driven with runoff simulated by an ensemble of global hydrological models (GHMs) under three different climate reanalysis products. We compare simulated flood extent to satellite observations for eight major recent floods across different continents, and find that depending on the region, the choice of input data and models can have a large effect on the realism of simulated flooding. Our systematic comparison allows us to identify a best-choice modeling setup. As a next step, we evaluate estimates of the number of people affected by flooding. Finally, by relating this to the corresponding number of displaced people, for a large number of events, we derive a geographically explicit pattern of vulnerability, which we then correlate with socio-economic indicators in order to identify major drivers of vulnerability. Thus anchoring process-based model estimates in past observations, our research forms the basis for projections of displacement risk under scenarios of both environmental and socio-economic change.

Poster 2-6
A global natural hazard risk analysis of critical infrastructure

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Critical infrastructure (CI) is fundamental for the functioning of a society and forms the backbone for socio-economic development. Accordingly, worldwide investments in transportation, power, water, and telecom assets are estimated at approximately $2.5 trillion/yr. Natural hazards, however, pose a major threat to CI. They can cause direct physical damages to CI in a region struck by an event, which may lead to disruption of essential services provided by them. Due to interdependencies in the infrastructure network, and the dependence of society to CI, such disruptions can lead to wide-spread impacts. Moreover, the overall risk for CI is expected to rise. This is due to climate change (i.e. intensification and more frequent hazards), and socio-economic development (i.e. increase in the amount and value of CI). This calls for risk assessments to support policy decisions, and to effectively prioritize areas where investments are needed.

To date, however, scientific evidence on the direct impact of natural hazards to CI has remained limited. In this study, we will assess the direct impact of natural hazards to CI at the global scale. Infrastructure types that will be assessed are categorized under seven overarching CI systems: energy, transportation, water, waste, telecommunication, health, and education. This study will: (1) provide insights into the spatial patterns of hazard risk to CI (e.g. where can we find high-risk areas?); and (2) quantify the direct damages to CI (e.g. are there infrastructure types more at risk compared to others?). We will use the risk methodology that is commonly used in risk assessments, whereby exposure, vulnerability, and hazard data is combined to derive risk estimates.

It is crucial to make our cities robust and resilient, so that they are able to cope with current and future natural hazards. Therefore, risk information should systematically be included for infrastructure planning, and the protection of the most vulnerable and critical assets needs to be improved. Limiting the direct impact of natural hazards on exposed assets, will result in economic and social benefits that go beyond direct infrastructure damage.

Poster 2-7
Beyond population exposure – accounting for vulnerability dynamics in global-scale climate risk assessments

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According to the IPCC's risk framework, climate change risks result from the interaction of climatic hazards, exposure to these hazards, and vulnerability of the exposed elements. Thus far, global-scale risk assessments have focused on assessing exposure to climatic hazards, and have largely neglected vulnerability. If accounted for in such assessments, vulnerability is often characterized by applying depth-damage functions to land use types or assets, which are unsuitable for characterizing social vulnerability of potentially exposed population groups. Further, social vulnerability is highly dynamic, and changes in time and space with evolving socioeconomic development. Therefore, socioeconomic scenarios are needed to explore the uncertainty related to these dynamics.

To address these issues, we use state-of-the-art socioeconomic scenarios (Shared Socioeconomic Pathways, SSPs), to produce spatially explicit projections of key variables for characterizing social vulnerability (i.e. age structure (five-year age groups), gender, and education levels). Our projections are grounded in recently published spatial datasets at the global scale and are publicly available at a spatial resolution of 30 arc seconds (~1km at the equator) and at a temporal resolution of five years for each SSP until 2100.

We demonstrate the use of our novel projections in a first-order assessment of vulnerability to sea-level rise (SLR), using the Low Elevation Coastal Zone (LECZ, i.e. elevation <= 10 m) as a proxy for SLR-related impacts in coastal areas. Results show that our projections allow for establishing global vulnerability hotspots in regions where vulnerable population groups (e.g. elderly, children, low education levels) are concentrated, as well as for exploring how these hotspots change over time, depending on the respective SSP. The results of such an assessment can provide more refined insights for decision-making, for instance in the context of adaptation planning, as strategies can be steered towards vulnerability hotspots.

Poster 2-8
Fire Occurrence on the Pantanal Biome in Brazil Between 1998–2020

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This paper presents a statistical perspective of fire occurrence on the Brazilian Pantanal biome, located in the south-central region of the country. The objective is to analyse the fire occurrence. The method focus on compare the fire hazard occurrence by quantitative data, in a monthly resolution between 1998 and 2020 obtained at the National Institute for Space Research of Brazil.

The fire occurrence involves socioeconomic aspects and has a great influence on climate. On the one hand, it may have its origin in natural aspects, facilitated by the increase in temperature and drought. However, most cases result from some type of human activity. The analysis of the recent numbers of total fire in 2020 with 21,893 fires get attention, as the fires in this year are the recorded registered in the history, and changed significantly compared with the total numbers for the last ten years: 9,788 (2019), 1,528 (2018), 5,754 (2017), 5,059 (2016), 3,964 (2015), 1,530 (2014), 3,220 (2013), 7,325 (2012) and 2,889 (2011).

All these record cases of fire suggest has been related to the recent drought period that changed the vulnerability condition to fire occurrence. Other aspects can be related to areas of difficult access, the strong winds and environmental education. Besides the reducing number of inspection operations and smaller combat teams in the field may be related to the pandemic demonstrate the importance of policies for managing the multiple dimensions of risk. Finally, the significant increase of fire occurrence in 2020 represents the record of number of fire registered.

Poster 2-9
A Sociohydrological Flood Risk Model for Companies

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Flood risk is determined by three components - hazard, exposure, and vulnerability - each of which varies over time. Sociohydrology provides insights on the co-evolution of these risk components and can uncover emerging dynamics such as the adaptation effect (i.e., declining vulnerability of a society after consecutive flooding). While the first sociohydrological flood risk models investigated hypothetical human-flood systems, current attempts aim at employing empirical data for the implementation in specific case studies. Yet, these models commonly feature a highly reduced representation of the flooding and damage processes, and mostly concern the residential sector. The flood risk dynamics of companies remain largely unstudied, albeit they contribute considerably to overall losses.

In this study, we present a sociohydrological flood risk model for companies that focuses on changes in vulnerability. In order to integrate more knowledge on damage processes into the sociohydrological modeling framework, we augment a previously developed sociohydrological model by including a process-oriented loss model. The resulting model (i) resolves the inundation and damage process more realistically and (ii) considers the heterogeneity across different economic sectors. In a case study for the river Elbe at Dresden, Germany, we simulate the dynamics of the flood risk system over the course of 120 years for companies that are situated in the floodplain. We estimate the model parameters through Bayesian inference from a collection of heterogeneous data such as historical land use and wealth maps, inundation maps, survey data, and economic data. A comparative experiment with model versions of incremental complexity shows that the model augmentation improves the accuracy of the flood loss estimates and reduces their uncertainty. Furthermore, the incorporation of additional process-detail and object-level loss data enhances the robustness of the loss predictions.

The gained reliability in the flood loss estimates strengthens the validity of the entire simulated evolution of the sociohydrological system and could advance the projection of flood risk dynamics into the future.

Poster 2-10
Future flood risk changes in the Danube basin

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Efficient flood risk reduction and adaptation planning need consistent and reliable information about future risks and associated uncertainties, as well as appropriate tools and services to support comprehensive flood risk assessment and management.

The Future Danube Model (FDM) is a new multi-hazard and risk model suite for the Danube region. FDM provides spatially consistent information on current and future extreme events and can be used to quantify climate risks. The FDM consists of a modular chain of modelling tools including a stochastic weather generator, a hydrological and a hydrodynamic model to produce discharge and water level time-series, inundation depth and inundation duration maps, as well as a vulnerability model which translates flood intensity in combination with information about exposed assets into economic loss estimates. The weather generator stochastically samples from observed or projected climate variables to produce a large event set of spatio-temporal weather. Based on a 25m digital elevation model FDM consistently simulates fluvial flooding for the entire Danube basin. Flood event footprints are provided for the past (reference period) and two future time horizons as well as two climate change scenarios (RCP4.5 and RCP8.5) and four EURO-CORDEX climate model combinations. Impact and risk estimates are presented as exceedance probability curves for current and future climate on different spatial aggregation levels enabling an analysis of risk hotspots.

Results indicate a marked increase in flood recurrence in most parts of the Danube basin already in the near future (2020–2049) compared to the reference period (1970–1999) with further increases at the end of the century. In large parts of the basin, the historical 100-year peak discharge is projected to increase by approx. 10–20%, while the historical peak is projected to be equalled or exceeded every 50–10 years. Residential and commercial areas with a 100-year flood risk are projected to increase by 15–26% (depending on flood protection and climate scenario). Fluvial flood losses to residential buildings in the reference period are estimated to amount to some €12 billion for a 100-year flood event and are projected to increase by 25–40% for the near and far future under RCP8.5. While these numbers are subject to large uncertainty, this assessment demonstrates the value of integrated, high-resolution modelling approaches, co-designed with potential end-users, to inform public and private risk management.

Poster 2-11
Changes in flood risk due to the presence of dams in the German part of the Rhine catchment.

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Dams play an important role in the management of water resources and are a significant flood control measure in Germany. The Rhein catchment is one of the most regulated rivers in Germany, where changes in annual maximum discharges were attributed to river training measures. However, a quantification of the impact of dams on flood risk has not been done so far. Our objective is to investigate the changes in flood risk in the Rhein catchment over the last decades by comparing different scenarios regarding the use of dams for flood attenuation. To accomplish that, we have developed the Simple Basin Model (SBM) which is composed of a catchment model and a routing scheme. The catchment model is the HBV model, and the routing component is based on the Streamflow Synthesis & Reservoir Regulation (SSARR). A module controls the activation of the dams at the basin using simple operating rules. The model was designed to require low computational effort. Streamflow data, meteorological data and technical information about dams were compiled to drive the model. We consider the period of most intensive construction and implementation of dams in Germany (1950–2010), so that we will be able to provide valuable information regarding the impact of dams on flood risk.

Poster 2-12
COASTMOVE ABM

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Sea-level rise (SLR) and socioeconomic trends are increasing the population and assets exposed to extreme coastal flood events in the coming decades. People residing in communities experiencing this increase in coastal flood risk may choose to stay, to stay and adapt, or to migrate towards safer areas. However, these migration decisions are influenced by many socio- economic and environmental factors. For example, current assessments of SLR adaptation and migration do often not address risk perceptions of residents related to different environmental risks, such as flooding and erosion. These factors influence adaptation decisions, and thus exposure and vulnerability. In this study, we aim to improve the representation of the dynamics of adaptive behavior of coastal communities in flood risk assessment by including human behavior and its effect on adaptation decisions, in face of SLR. Therefore, we develop an agent-based model grounded in subjective expected utility theory and simulate adaptation- and migration decisions of households facing coastal flood risk in France between 19xx and 2020. The model is empirically calibrated using survey data on flood risk perception and people's willingness to implement adaptation measures. Then, we use socio-demographic projections to estimate future changes (2020–20xx) in demographic composition, and apply the model to simulate coastal adaptation. The agent-based model presented in this study functions as a platform for further development of 1) more realistic decision models and 2) global modelling approaches of both coastal adaptation and migration under projections of future development.

Poster 2-13
The impact of natural disasters on internal migration in the US

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Over the past decades the yearly number of natural hazards with over a billion dollar in damages has been increasing in the US, in large part due to rising exposure and climate change. Well-known disasters include Hurricane Katrina in 2005, the 2008 California Wildfires or the 2008 Midwest Floods, which have led to billions of US dollars in damages, numerous fatalities, and large-scale population displacements. Using Internal Revenue Service (IRS) tax records we analyze county-to-county migration before and after a natural disaster in the US. Several migration trends are extracted. For example, we find that disasters often lead to outmigration in the year of the disaster. However, more than 50% of the outmigration is temporary as the migration flow is reversed in the following years as people are moving back. Moreover, based on FEMA disaster data, we find that disasters with a relatively small damage per capita do not lead to a significant migration response. Therefore, we estimate a disaster damage threshold for migration. We specifically consider demographic and socio-economic differences between counties, because we hypothesize that these differences explain the heterogeneous response of individuals to extreme events. Finally, the characteristics of counties attracting migrants are analyzed, including the county's disaster risk and economic conditions.

Poster 2-14
Reanalysis and observational precipitation products over the upper ganga basin, India

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This paper is intended to serve as the preliminary reference to the contribution of two precipitation products (P-1 and P-2) which are found to perform better in aspects of (a) spatial resolution, (b) temporal resolution, (c) spatial distribution of precipitation, and (d) accuracy over some or all of the 14 satellite based precipitation datasets examined in this study. The developed datasets are available over the upper ganga basin (UGB), India, covering an area of approximately 60,000 sq. km. and have resolution of 5 km x 5 km at daily time scale. The temporal coverage of P-1 is approximately 50 years, and incorporates contemporary ground station data. The pattern of error amplification during monsoon months, existent in most of the studied datasets is also considerably subdued in P-1. It is formed from a machine learning setup after testing more than 55 regression schemes, and about 200 hyper-parameter sets. Based on P-1 and GPM_3IMERGDF (a daily precipitation product from Global Precipitation Measurement mission), P-2 is a dynamic reanalysis daily precipitation product and provides about 20 years of data with continuous up-gradation capacity. This up-gradation is in terms of temporal coverage and data quality. This dataset bypasses the constraints of P-1 as it is independent of station input data. P-2 has high correlation with P-1 (>95 %), and can potentially serve as a proxy of the latter during its absence.

Poster 3-1
Re-learning observed flood extents can improve remote sensing products

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Flood extent data is critical for both response action and subsequent impact modelling. Satellite-based emergency mapping products are often unreliable in vegetated and urban areas, though, which are of major interest for consequence estimation. As the information content of spaceborne sensor data is limited in these areas, e.g. due to shadow and overlay effects, advances in processing can primarily reduce overdetection, but hardly avoid underdetection. This results in products that have high specificity (detected flood is reliable) but low sensitivity (areas classified as non-flooded are unreliable). We present a novel procedure of re-learning the observed flood extent from different features (i.e. not derived from sensor data) using a one-class classifier (OCC). As opposed to regular supervised machine learning algorithms, which require labeled samples for all classes expected in the classification problem, an OCC can operate with only the class of interest being labeled. This allows us to treat the entire flood mask as training region, and extrapolate into unobservable areas. The approach was tested for hurricane Harvey in Houston, where three satellite-based flood masks of varying quality were available to us, as well as a 50 cm resolution aerial image for validation within the urban area. The flood event occurred 2017 and ranks among the most severe natural disasters that hit the USA in recent decades. An assessment of the initial satellite-based masks showed that the standard emergency mapping product effectively detected only open water, while the high quality products detected about 40% flooded urban areas. All of these products could be improved by our presented modelling approach, with the best models raising the k score by 0.2 (high quality product) to 0.7 (standard product). The most relevant features can already be derived from a digital elevation model and stream location data. Additional rainfall measurements and distance to building footprints did not consistently improve the models in our case study.

Poster 3-2
Spatio-temporal rainfall variability in Tehri catchment of Himalayan Region, India

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Spatio-temporal analysis for rainfall variability plays a decisive role in water resource management. The spatio-temporal variability of rainfall remains more, in general, as compared to plain areas but in contrast, the density of hydro-meteorological stations in mountainous catchments remain very sparse as compared to plain areas. This fact particularly stands true in the Himalayan region. To address water resources-related issues, the gridded rainfall datasets are generally used. These grided data sets are available in different spatial resolution from different agencies, including India Meteorological Department. The present study pertains to the Bhagirathi catchment, up to Tehri dam. For this catchment, the accuracy of these grided data sets with actual observed data has not been compared in the past mainly because of the non-availability of observed data. Recently a network of 11 automatic weather stations has been developed in the Tehri catchment and the data of these stations are available since June 1, 2016. In the present study, five years of highly accurate rainfall dataset acquired from automatic weather stations (AWS), is used to check the consistency and accuracy of the India Meteorological Department (IMD) gridded dataset and other available satellite-based precipitation products (SSPs). Observed mean rainfall of 5 years is correlated with SSPs and IMD datasets to check the accuracy and validity of used datasets with the help of using Pearson correlation coefficient (R). The best dataset out of the IMD dataset and SSPs is selected to carry out further study. Various statistical tests are used in the study to check randomness and to test the presence of short term and long-term dependence in rainfall time series. Rainfall time series is also tested for detecting the change in mean (shifts and jumps). The statistical parameters like five years mean rainfall, standard deviation (SD), mean annual Rainfall (MAR) coefficient of variation (CV) and standardized anomaly (SA) are used to display the catchment's orographic effects over rainfall. The probability distribution for the given rainfall time series included in the study is one of the findings. Annual and monthly time scale rainfall records derived from the daily rainfall dataset are used to study spatial variability of long-term rainfall trends. For temporal variability, 5-yearly average rainfall departure from long term mean rainfall is calculated. Mann Kendall test based long term trends are used to show a decrease or increase in rainfall at various stations. The 5-yearly averaged departure from long term mean gives important result related to temporal variation in rainfall magnitude, which allow evaluating current water management actions. Analysis of trends and 5-year departure from the long-term mean at monthly scale provide additional understanding of rainfall variability, not necessarily shown in the annually scaled results. As this could be possible that, some stations have a significant variation in monthly scale but averaged out in annual scale. The findings are efficient in identifying the catchment level rainfall variability and statistical parameters of the rainfall dataset. These results will be highly advantageous to make sustainable water resource management and planning actions in the water crisis.

Poster 3-3
Clustering of compound flood hazard in deltas and estuaries at the global scale

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Compound flooding in deltas and estuaries can be defined as the combination of vari ous flood drivers leading to a significant flood impact (Zscheischler et al., 2018). For example, as observed during tropical cyclone Idai, elevated sea-levels can impede flood drainage and create backwater effects that worsen flood damages. The influence of riverine and coastal flood drivers on the water level varies along the estuary. At the river mouth, the water level is dependent on sea-levels but this influence reduces moving upstream in the river system. The region where both riverine and coastal flood drivers significantly contribute to the water level is referred to as the transition zone (Bilskie and Hagen, 2018).

In this study, we investigate how the transition zone in estuaries is influenced by their various geophysical characteristics and the nature of their upstream river basins. We set up a global model experiment to compare maximum water levels across estuary types and flood hazard drivers. We use the newly developed rapid flood solver SFINCS to simulate water level time series for average and anomalous compound flood events. For each estuary type, resulting water level time series are analyzed to quantify the contribution of each flood driver to the maximum water level along the complete coastal river profile and to the extent of the transition zone. We find that the interaction between the extreme sea level and extreme discharge is highly nonlinear and that this effect strongly varies depending on the estuary shape and length. Based on these results, we identified clusters of similar compound flood hazard behavior.

This overview of estuarine compound flood behavior allows us to globally identify areas particularly vulnerable for interactions between extreme discharge and sea levels and where in depth modelling efforts are needed.

Poster 3-4
Property-level risk management against pluvial flooding: what do experts say, what do people do?

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Heavy rainfall events cause enormous damage to private households, e.g., insured losses of ~€75 million in Münster in 2014 and ~€60 million in Potsdam and Berlin in 2017. Similar to fluvial flooding, integrated risk management approaches are increasingly being developed that require the participation of all stakeholders to reduce flood risk. One avenue for this is the implementation of risk-reducing measures at the property level as a complement to wider risk management activities. Property-level risk reduction measures can cost-effectively reduce losses, but must be implemented and at least partially funded by households themselves. Therefore, how to increase their implementation is a current research topic. Risk communication is assumed to play an important role, but has not been shown to be very effective if it is not tailored to the recipient. Focusing on coping opportunities would likely help, as high coping appraisal has been identified in studies as a strong positive driver of adaptive behaviour, and therefore represents a new avenue to explore in efforts to improve risk communication. Coping options are presented and communicated in Germany by experts with different affiliations (e.g. the cities of Bremen, Cologne and Remscheid as well as the German Insurance Association (GDV)).

Therefore, we ask (a) which property level risk reduction measures are suggested by experts; (b) which property level risk reduction measures or combinations of these measures have been implemented by households; and (c) what do the differences teach us about risk communication and adaptive behaviour?

To answer these questions, we will first conduct a review of the scientific literature and expert evidence on which and how coping opportunities are presented. Second, we will conduct descriptive and cluster analysis using a survey of households recently affected by heavy rain. This will allow us to identify, among other things, combinations of property level risk reduction measures that are commonly undertaken or whether we can identify groups of people with similar adaptive behaviours. We expect that our results will provide insights into the status quo regarding adaptive behaviour towards heavy rainfall in Germany and contribute to future risk communication strategies regarding heavy rainfall.

Poster 3-5

Towards globally applicable and locally relevant compound flood risk simulations

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Many delta areas in the world are densely populated and have large exposure. These areas are prone to fluvial, pluvial and coastal flood drivers. Cyclone Idai in March 2019 is an example where the combination of these drivers (i.e. compound flooding) led to extensive flooding and large impacts: over $1 billion worth of damage to infrastructure, more than 100,000 houses damaged and over 1000 people killed in Mozambique, Zimbabwe and Malawi combined.

Capturing the spatial and temporal dynamics of compound floods requires a detailed description of floodplains and relevant flood processes for each driver and their interactions. Furthermore, the models need to be computationally efficient to simulate the many plausible combinations of drivers. While global compound flood models have proven useful for large-scale assessments, these lack detail to be locally relevant. On the other hand, many local models exist which provide great detail, but often take many person hours to setup and are therefore not very scalable and hard to reproduce.

We are therefore developing the open-source globally-applicable framework hydroMT to rapidly build nested hydrodynamic models from a command line interface (https://deltares.github.io/hydromt/latest/). The hydrodynamic models are built for floodplains and nested in a hydrological model for riverine boundary conditions and, if at the coast, a global tide and surge model for downstream sea level boundary conditions. The framework uses global datasets as a starting point to setup model schematizations and can incorporate detailed local data if available. The model boundary conditions can be setup for a specific historical event or for combinations of synthetic boundary conditions to simulate compound flood risk. The model setup is configured in a single file which makes it easy to operate and reproduce. We will highlight some key components of the framework and present a case study for Cyclone Idai for which we validated the model framework with good results.

Poster 3-6

Parameter Optimization of fully distributed Hydrological Model (SPHY) using Remote Sensing and Inventory data – A Case Study of a store River Basin Northern Area of Pakistan

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The high vulnerability of Pakistan to climate change has put the water resources to risk and it is expected that the melting of glaciers in the HKH region will increase hazards like floods that will influence water availability for the future generation. This study shows the model calibration and validation of the water resources in the snow-fed and glacier-fed contributor of Indus Basin (IB), Astore catchment, Gilgit, Pakistan. A fully distributed Hydrological model SPHY has been utilized for the calibration and validation that neatly recreates the catchment's reaction. The SPHY model was successfully set up for calibration from 2002–2004, and validation from 2004–2009, respectively.

Relationships among both observed and simulated values describe a high correlation which means good model performance with the R2 of 0.71 for the calibration, and 0.6 for the validation, respectively. The findings suggest a strong concordance between simulated and actual stream flows. The sensitive analysis has been carried out for all the parameters to optimize the runoff results based on the Nash-Sutcliffe model efficiency (NSE) and (R2). In the said analysis, Glacier melt runoff factor (GlacF), snowfall (SnowSC), and recession coefficient (Kc) values were found highly sensitive as the catchment is snow and glacier fed. Comparisons made between observed and simulated streamflows point out that the patterns of flow in the catchment can be symbolized to determine the impacts of climate change under various scenarios of climate change. The modeling results can be propagated among the public and the policy-makers which may have impacts on water asset management and water supply forecasts for natural hazards like floods.

Poster 3-7
Spatial modeling of extreme rainfall events in Berlin Brandenburg with a max-stable process

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When modeling extreme rainfall events in a spatial setting, accounting for the dependence that exists between neighboring rain gauges allows the model to use the information more efficiently, by "borrowing strength across locations". A commonly used strategy involves a mixture of trend surface models (a linear model using spatial covariates) for the overall estimation of GEV parameters for each station and a Max-Stable process for capturing the residual spatial dependence that was not captured by the linear model. This residual spatial dependence arises from the fact that individual extreme events can affect multiple rain gauges simultaneously, inducing a local spatial dependence for nearby stations. This spatial effect is, in turn, heavily dependent on the physical properties of the data-generating process (e.g., local convective storms in Summer are spatially very different from frontal precipitation in Winter). In this study, we aim to better understand how modeling the spatial residual dependence impacts the skill of an extreme rainfall model that predicts return levels for rare events (e.g., the 100-year return level). We do this by using monthly block maxima to model extreme rainfall for two different seasons in Germany with differing storm-generating mechanisms: Winter and Summer. We compare the predictive performance of different residual spatial dependence models for each season using the cross-validated Quantile Score, a measure of out-of-sample accuracy. All the models use Brown-Resnick Max-Stable Processes, using response surfaces with spatial covariates. Furthermore, we compare the skill of our residual dependence model with a trend surface model that assumes conditional independence between sites, to assess how much skill is gained when accounting for the residual spatial dependence.

Poster 3-8
United States Flood Trends and Their Drivers

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Climate change has already altered the magnitude and frequency of river floods around the world and if these trends persist in the future, our flood risk management will have to adapt to the changing conditions. However, to predict future changes, we must first understand how floods have changed in the past. Here we present a study of more than 4000 river gauges across the USA with time series of annual maximum streamflow between 1960–2010. We use a novel clustering approach to find 12 hydro-meteorologically and spatially distinct clusters of catchments with similar flood behavior. Based on re-analysis data we calculate more than 30 hydro-climatological and land-use variables to use them as predictors for 12 separate Random Forest models, one for each cluster. With these we search for the drivers of past trends in flood magnitudes, differences between common and rare floods as well as in the synchrony of floods in different catchments. We use Accumulated Local Effect plots to understand how each of the predictors affected the different trends. We find that in many regions changes in precipitation (e.g. annual precipitation sum, flood generating precipitation) translated to similar changes in flood magnitudes. Furthermore, we show that static land use conditions were of unexpected importance for flood trends, especially in the form of canopy cover, reservoirs, and impervious surfaces. We show that forests and reservoirs have mitigated some of the effects of a changing climate on floods, while urbanization has amplified them. We find varying importance and occasionally opposing effects of the same predictors in different clusters, showing that flood trends are highly dependent on the hydro-climatological circumstances of the catchments. Our results highlight the importance of a holistic approach to the analysis of flood trends and their drivers, considering a wide and consistent range of variables while taking into account the regional variability in flood generation.

Poster 3-9
Controls of heavy tail behaviour of floods in Germany and Austria

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In catchments, where the distribution of flood flows shows heavy tail behaviour, the occurrence of extreme events has a higher probability than if the distribution was bounded or light-tailed. Neglecting heavy tail behaviour can therefore lead to an underestimation of the likelihood of extreme floods and the associated risk. Regarding the controls of such behaviour, partly contradictory results exist in literature and the knowledge is still very limited. To better understand the controls, a wide range of event and catchment characteristics and their association with an indicator of the tail heaviness of flood distributions, namely the shape parameter of the GEV distribution, were analysed for 480 catchments in Germany and Austria. The univariate analyses were enhanced by multiple linear regression and random forests. Across all approaches, indicators of the catchment response were found to dominate the heavy tail behaviour, followed by event precipitation and event seasonality. The moisture state of a catchment prior to a flood event has no relevant impact on the tail heaviness even though it does influence flood magnitudes.

Poster 3-10
What controls step changes in flood frequency curves? Insights from a physically-based stochastic model (PHEV!)

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Accurate estimations of high floods quantiles is key for the design of engineering structures, risk assessment and mitigation, urban planning and many others applications. Observed flood frequency curves sometimes show a discontinuity -which will be here referred to as “step change”- after which the steepness of the flood frequency curve increases. As step changes might affect the estimation of non-yet observed rare events, it is important to understand if they are a statistical artefact only, i.e. occurring for example due to the limited size of the time series, or if they are instead linked to catchment dynamics, geomorphology or climatic characteristics.

Here, we analyze daily seasonal streamflow time series for 73 basins (101 catchment-season combinations) in the USA and Germany and developed a dedicated robust methodology to identify step changes on the observed flood frequency curves. We then leverage a parsimonious mechanistic-stochastic expression of flood frequency curves (PHEV!), which stems from an accurate mathematical description of catchment-scale daily soil moisture and runoff dynamics in river basins, in order to 1) check if PHEV! is able to correctly detect step changes and 2) understand what controls their emergence.

PHEV! accuracy in step changes detection is fairly high, especially in case studies characterized by low persistency indices (typical of erratic regimes), while it tends to detect a step change more often than in the observations when the regime is persistent, likely due lower probability of observing relatively high flow values in these basins. By means of dimensional analysis, namely the Pi theorem, we theoretically identify the exponent of the recession curves and the persistency index as main controls of the position (in terms of normalized streamflow maximum) of the step change. A correlation analysis on data confirms the theoretical results, showing a strong negative correlation between the streamflow values at which step changes occur and the recession exponent, modulated by the persistency features of the catchment. Our results give a significant contribution to appraising high floods hazard, especially in areas where the collection of streamflow data has started in very recent times only: having unveiled the controls on the emergence of the step change, we are able to provide valuable information on whether such a feature should be expected in any basin.

Poster 3-11
Extreme precipitation return levels in gauged and ungauged locations using the simplified MEV distribution: lessons learned from Germany

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Extreme precipitation represents a severe risk for population and structures. Estimation of extreme precipitation amounts corresponding to low yearly exceedance probabilities, termed return levels, is crucial for managing these risks, especially in ungauged locations. Recent advances in the estimation of extremes proved higher accuracy than traditional methods and, thanks to their reduced uncertainty, could be promising for estimating return levels in ungauged areas. This study focuses on the estimation of high daily precipitation return levels over Germany at-site and in ungauged locations. To this purpose, we used the simplified version of the Metastatistical Extreme Value distribution (SMEV), showing how to effectively employ it when only a portion of the "ordinary" events can be described using a two-parameter distribution. We further examined its ability in estimating return levels in ungauged locations using different interpolation methods.

SMEV has a tendency to underestimate the probability of the largest annual maxima, but a comparison with the official design precipitation values shows that SMEV-estimates lie within their uncertainty range when 50-years return levels are considered, whereas they slightly over-estimate the 100-years return levels. The estimated Weibull parameters spatial patterns resemble the German orography, highlighting a positive correlation between the scale and shape parameters and elevation, stronger for the former. When estimating extreme return levels at ungauged locations, inverse distance weighting outperforms both nearest neighbor and ordinary kriging, even if tends to under-estimation in some areas (mainly in the Alpine region and eastern Germany).

Our results show that the proposed approach is suitable for estimating heavy rainfall in ungauged locations, and despite the error variability not being significantly explained by the elevation (<10%), uncertainty might be reduced including altitude in the interpolation method. Moreover, as the SMEV framework allows a more accurate description of precipitation phenomena, a deeper analysis on precipitation types would improve the estimation of high rainfall quantiles, for example in areas affected by "Vb" cyclones, which generate heavy rainfall notwithstanding their low frequency of occurrence.

Poster 3-12
Incorporation of multiple disaster risk reduction strategies into a global coastal flood risk assessment framework

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Coastal flood risk is a major global challenge facing current and future generations. Indeed, this risk is expected to increase over the next several decades due to the changing climate, increased urbanization within flood-prone areas, loss of natural coastal defenses, and resource extraction, among other global factors. A number of disaster risk reduction strategies have been posited as methods of mitigating the deleterious impacts of coastal flooding. These include structural measures, nature-based solutions, flood proofing of existing assets, spatial planning, etc. The aforementioned strategies have been examined thoroughly in several small-scale applications around the world. On the global scale, however, efforts to model such disaster risk reduction strategies are rather limited. Most modeling efforts that have been undertaken typically examine the potential risk reductions of structural measures (e.g. dykes and levees), and none have ever determined the reductions to be expected from employing multiple strategies at once. In reality, the ideal solution for several locations throughout the world may be a different type of strategy, or a combination of strategies. This paper looks to examine this potential by 1) modeling several different types of disaster risk reduction strategies within the same global flood risk modeling framework and 2) determining what risk reductions are possible via (combinations of) these disaster risk reduction strategies. By using a disaster risk framework (i.e., risk defined as a product of hazard, exposure, and vulnerability) and a benefit-cost analysis that measures financial and human impacts of each strategy, we determine expected levels of risk reduction for different regions of the globe. These results are available for various points in the future (specifically 2030, 2050, and 2080) under various representative concentration pathway and shared socioeconomic pathway combinations. Further, we demonstrate which (combinations of) strategies may be able to achieve similar levels of overall risk reduction that would be anticipated with solely structural measures, thus expanding the envelope of potential options for regional and international decision makers addressing coastal flood risk around the world.

Poster 3-13
Tail characteristics control the choice of the ordinary distribution in the Metastatistical Extreme Value approach.

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Standard flood frequency analyses hinge on unrealistic asymptotic assumptions, discard a large portion of the available data (using annual maxima or a few values above a high threshold only), and are ill-suited for short time series. Lately, advances in the estimation of extremes, i.e. the Metastatistical Extreme Value framework (MEV) have been proposed. This approach, relaxes the assumptions on which traditional methods are based and makes a more effective use of the information at hand. Moreover, being more flexible in the choice of the distribution of the ordinary events (i.e., events belonging to the bulk of the distribution, in contrast to annual maxima), it gives room for accurately analyzing which is the statistical model that better describes the data.

In this work, we leverage this property of the MEVD and develop an approach to a priori select the distribution of ordinary peaks according to the tail index, which we define as the ratio between their empirical 99th and 95th percentiles, and evaluate its performance on 182 daily mean streamflow time series in Germany. Based on the value of the tail index, we choose either the Gamma or the Log-Normal distributions to describe ordinary peaks that show lighter or heavier tails respectively. This distinction allows us to correctly identify the distribution of ordinary peaks in 76% of basins in the dataset and improves the estimation of the magnitude of floods associated with high return periods, when compared to a MEVD application in which the ordinary distribution is chosen without investigating the tail features of the underlying data. In particular, this approach allows us to limit the under-estimation issues that arise by applying to the whole set of catchment the MEV-Gamma, and reduce the bias of the MEV-Log Normal. Also in the comparison with the standard Generalized Extreme Value distribution, our method proves advantageous, as it allows to reduce the estimation uncertainty, especially for return periods much higher than the calibration sample size, which are crucial for most practical applications.

Poster 3-14
Changes in European windstorm characteristics

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Windstorms are among the most common and devastating natural hazards in Europe. Their occurrence can cause damage to the infrastructure, industry, or insured property worth up to several billion euros. It is therefore not surprising, that most studies about windstorms focus on the impact, occurrence, or overall severity of these extreme events. A comparably less studied topic, on the other hand, is windstorm characteristics such as intensity, size, or duration. However, these characteristics are determinant for the severity of the event itself. In this study, we, therefore, focus on the identification and understanding of important windstorm characteristics, and how they influence the severity of the event. In the center of the study stands Quasi-Supervised k-Means, a novel clustering method that we have developed specifically to cluster windstorms based on their characteristics. Quasi-Supervised k-Means is used for the production of a cluster that is representative for historically documented windstorms, while also identifying key characteristics of those events in the process. The resulting cluster is further used to study trends in windstorm characteristics and how their changes influence windstorm severity.

Poster 3-15
Fluvial and pluvial flood hazard assessment in Lagos, Nigeria, using a hydrological-hydrodynamic model cascade

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The megacity of Lagos, Nigeria, is subject to recurrent severe floods. Different parts of Lagos are thereby affected by different kinds of hazards, including pluvial floods induced by heavy rainfall in many parts of the city, fluvial floods by high water stages of the Ogun river in the north, and coastal floods from storm surges in the south. Climate change may exacerbate all three flood types, however, it is yet largely unknown how future flood hazard will change. The objective of this study is to analyse pluvial and fluvial flood hazard in the northern parts of the city along the Ogun river and quantify the impacts of climate change.

The eco-hydrological model SWIM is used for the simulation of water stages and to study the impact of water management which is mainly influence by two major upstream reservoirs. SWIM is coupled with the floodplain model CaMa-Flood to achieve the routing of water through the network of river channels at the floodplain where the Ogun river discharges into the Lagos Lagoon. The river stages provide the boundary conditions for the hydrodynamic model TELEMAC that is used to simulate the inundation of urban areas.

To quantify flood hazard different design storms are constructed and fed into the model cascade. It is analysed how water stages and rainfall events, i.e. pluvial and fluvial floods, influence each other. Finally, we quantify climate change impacts on water resources and design storm events and, consequently, how pluvial and fluvial flood hazard is affected in the area.

Poster 3-16
Quantifying climate and catchment control on seasonal flood across multiple timescales in Europe

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Seasonal flood forecasting is usually performed in order to derive streamflow or other related hydrological (e.g. precipitation) values for the season ahead. This is particularly interesting for water management and community preparedness. It is essential to understand the contributions of climate and catchment information on flood. However, the impacts of these information on flood at inter-annual and inter-decadal scales have rarely been assessed quantitatively. To achieve this goal, this study develops a nonlinear hybrid model, which integrates ensemble empirical mode decomposition (EEMD), back propagation artificial neural networks (BPANN) and weights connection method, to forecast extreme seasonal streamflow from around 650 stations in Europe by considering climate and catchment state before the target streamflow season. In total 14 indices with different time lags from the target streamflow season are used as covariates for the analysis. Results reveal that drivers and flood have similar periods at each time scales. Precipitation and antecedent streamflow are the best covariates identified. Their influence is strong for 0–2 months between the covariate and streamflow season. The nonlinear hybrid model substantially outperforms MLR in all performance measures. We highlight the different impacts of drivers on flood at multiple timescales, which cannot be represented by MLR or many other, more traditional methods.

Poster 3-17
Accounting magnitude, spatial extent and duration for ranking of extreme precipitation events in Indian Western Himalayan

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Extreme weather and climate events rarely occur at a single location (station) rather over a wider impacted area. In fact, the magnitude, spatial extent and duration, in general, have potential to indicate whether the particular event is local, regional or global. In this study, we rank the extreme precipitations events in the Indian Western Himalayan by accounting the precipitation magnitude, spatial extent and duration. The results reveal that multi day ranking scheme helps in better understanding the different air circulation patterns/precipitation bands causing precipitation over an area at different times. The single day event happening for four days was insignificant, if studied independently, but turns out be hazardous if studied through multi day ranking scheme. We observe that the ranking method apart from identifying such long temporal scales extremes also gives an idea that at what time scale it will be of high impact. Our result reveal that even in many cases, socioeconomic impacts are not just a result of short and intense events but also accumulated moderate events for a longer period which then become significant.

Poster 3-18
The effects of climate change upon tipping points of tropical extreme events such as MJO

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More than half of the globe is occupied by the tropical zones, thus a proper understanding of the tropical atmosphere and it extreme events are crucial for the projections of the global climate change. The tropical atmosphere is traditionally considered dominated by moist cumulus convection associated with strongly divergent horizontal flows. The Madden-Julian Oscillation (MJO) is the dominant slowly eastward propagating mode of intra-seasonal planetary scale variability in the tropical atmosphere that is known as one of global extreme events that not only affects Maritime continent, but also has influences on mid-latitude atmospheric jets. Previous theoretical studies, modeling, and field observations have contributed positively to our understanding of MJO; nevertheless, there is no robust theory for a few aspects of the dynamics of MJO such as its initiation, role of moist-convection on propagation speed, role of global warming upon its genesis and evolution, the barrier effect of the Maritime Continent on MJO propagation, and its slowly eastward propagation mechanism, which are poorly understood. Understanding response of the MJO to climate change is vital for estimating the natural hazards.

By using a hierarchy of models and theoretical studies, we have raised this theory that MJO-like skeleton can be generated in a self-sustained manner from a large-scale localized heating in the lower troposphere, over the warm pool, as a “hybrid structure”. The latter is constituted by combination of an “equatorial modon” that is convectively coupled by detaching baroclinic Kelvin wave. The hybrid structure can last for an interseasonal scale. Indeed, augmentation of temperature and humidity could intensify the genesis and consequently the precipitation pattern of the MJO. The presentation includes a summary recently findings in relevant to MJO genesis and its evolution. Some of the preliminary results have already been published in some ISI journals by the authors (see references). Firstly, we show the construction of new improved moist-convective Thermal Rotating Shallow Water (mcTRSW) model with pseudo-spectral based method on spin-weighted coordinate and previous version of the model so called mcRSW [1, 2], which is well-balanced, shock capturing, front resolving, with finite volume scheme. Secondly, we explain one of the main observations of the authors that was discovery of a nonlinear dynamical regime in the Rotating Shallow Water (RSW) model which arises in the limit of small pressure variations and gives a slow propagating coherent dipolar structure so called “Equatorial Modon” [3]. Thirdly, we demonstrate that in the pioneering work by authors [4] the Equatorial Modon’s structure can also be emerged from the process of geostrophic adjustment of localized large-scale depression-type disturbance in the mcRSW model on the equatorial beta-plane. Other dynamical features of equatorial modons, such as loss of coherency, eastward propagating phase speed, role of bottom topography, etc have been investigated too [5]. Finally, after reproducing “generation” of MJO-like structure from geostrophic adjustment of baroclinic disturbances in tropical atmosphere, we propose the aforementioned theory as the backbone structure of the MJO [6] and present the effect of climate change upon its genesis and tipping point by recently improved mcTRSW conceptual model.

Poster 3-19
Changes in Rhine River flood characteristics at 1.5, 2.0 and 3.0 °C global warming

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Climatic change alters the frequency and intensity of natural hazards. In order to assess potential future changes in flood characteristics in the Rhine River Basin, we analyze changes in streamflow, snowmelt, precipitation, and evapotranspiration at 1.5, 2.0 and 3.0 °C global warming. The mesoscale Hydrological Model (mHM) forced with a group of climate projection scenarios is used to simulate the present and future climate conditions of both pluvial and nival hydrological regimes. Our results indicate that future changes in flood characteristics in the Rhine River Basin are controlled by increases in antecedent precipitation and diminishing snow packs. In the pluvial-type sub-basin of the Moselle River, an increasing flood potential due to increased antecedent precipitation is accompanied by declining snowpacks during winter. The decrease in snowmelt seems to counterbalance increasing precipitation resulting in only small and transient changes in streamflow maxima. For the Rhine Basin at Basel, rising temperatures evoke changes from solid to liquid precipitation, which enhance the overall increase in precipitation sums, particularly in the cold season. At gauge Basel, the strongest increases in streamflow maxima show up during winter, when strong increases in liquid precipitation encounter almost unchanged snowmelt-driven runoff. To refine obtained results, next steps need to be the representation of glaciers and lakes in the model set-up, the coupling of simulations to a streamflow component model and an independent validation of the snow routine using satellite-based snow cover maps.

Poster 3-20
A Convolutional neural network approach for urban pluvial flood susceptibility mapping: A case study in Berlin, Germany.

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Pluvial flash floods are one of the major natural hazards in urban areas that threaten both human life and property. Intensive and short duration rainfall storms cause pluvial flash floods. They are considered a ubiquitous hazard and could occur anywhere subject to the existence of the minimal area for surface runoff generation and concentration. Therefore, pluvial flood susceptibility mapping is vital to flood mitigation and urban planning. The current study evaluated pluvial flood susceptibility mapping based on the convolutional neural network (CNN) in Berlin. We examined several network architectures to assess flood susceptibility mapping in an urban watershed. A gathered flood inventory between 2005 and 2017 for Berlin was randomly split into training, validation and testing datasets with a ratio of 60/20/20. Eleven flood triggering factors related to historic flood events in Berlin were selected from literature to generate a spatial flood database. The triggering factors include elevation, slope, topographic wetness index, plan curvature, profile curvature, aspect, distance to roads, distance to rivers, distance to the storm drainage system, curve number and precipitation. We compared the CNN performance to benchmarks, Deep Learning Neural Network (DLNN) and Support Vector Machine (SVM) for different spatial resolutions (30m, 10m, 5m, and 2m) using several objective criteria. Flood susceptibility maps were produced using CNN, DLN, and SVM for each spatial resolution. Experiments results showed that the CNN-based methods produce more reliable flood susceptibility maps. Finer spatial resolutions showed better identification to risk areas than the coarser spatial resolution. Finally, the models were validated with the help of statistical measures, Receiver Operating Characteristic Curve (ROC), Area Under the Curve (AUC). We concluded that the proposed model is able to predict reliable urban pluvial flood susceptibility maps and can be used as a tool to assist the authorities in urban pluvial flood mitigation and urban planning.

Poster 3-21
Glacial Lake Bathymetry Derived from ICESAT-2 and Multispectral Satellite Images: A Case Study on Tso Lhamo Lake, Sikkim Himalaya

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Global and regional warming enhance melt from every cryosphere element (e.g., glacier, snow, permafrost, etc.) worldwide. Meltwater from glaciers and snow cover in high-mountain Asia, including the Himalayas, feed many glacial lakes. Previous studies have reported that the glacial lakes in the Himalayas are increasing both in numbers and sizes, threatening the communities living in the mountainous regions. One such threat is because of glacial lake outburst floods (GLOF) that can be very catastrophic, as happened in the Kedarnath valley of India in 2013. Glacial lake depth and volume estimations are very essential parameters in order to predict a GLOF event and model its impact on a valley's infrastructures. The consistent and continuous observations of lake bathymetry using in-situ techniques in the Himalayas are limited due to harsh weather conditions, remote locations, and lack of trained manpower. A few studies have been attempted but the bathymetry of most lakes in the Himalayas is largely unknown.

In this study, we use laser altimetry data from the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) and multi-spectral satellite images from Sentinel-2 and Landsat- 8 in order to estimate the depth of Tso Lhamo lake, Sikkim Himalaya. The lake is located in Northern Sikkim (28.0°N 88.7°E), India, at an elevation of about 5330 m above mean sea level (amsl). Green photons of the ICESat-2 mission can penetrate into water bodies up to several meters, as noticed by recent studies in the polar regions e.g., Datta & Wouters, 2021. We use ICESat-2 ATL03 point cloud data of June 23, 2019, to capture lake surface and bottom and measure lake depth at several locations of the lake. Afterward, we use near-time geometrically and atmospherically corrected Sentinel-2 and Landsat images and establish a mathematical relationship between reflectance in visible bands (e.g., red, green and blue) and ICEsat-2 based lake depth estimates at those locations. This mathematical relationship finally used to resolve lake depth of Tso Lhamo and neighboring lakes with spatial details. This study tests the feasibility of fusing these two independent remote sensing datasets to estimate glacial lake bathymetry in the Indian Himalayas region.

Poster 3-22
Development of Inflow Forecast based Warning System for Downstream Reach of Tehri Dam, Uttarakhand, India

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Hydrologic forecasting is the estimation of the future states of hydrologic systems. There is a growing concern among the research community in providing accurate and reliable hydrological forecasts in space and time. Streamflow forecasting is vital for flood forecasting and a range of applications related to design operation and water resources management. Streamflow forecasts with sufficient lead time are essential for issuing warnings and enacting preventive measures, including evacuation. Increasing lead time also provides significant economic benefits as it facilitates cost-effective water management and provides protection from water shortages. The Early Inflow Warning System is a system to minimize and prevent the risk of flooding. The most crucial input in a flood early warning system is real-time Hydrometeorological observations provided by weather radar satellites and automatic Hydrometeorological station network. The usefulness of an early warning system may be estimated by calculating the amount of flood damage to private and public assets that might be avoided by taking action in response to the warning The benefits of inflow forecasting systems derive from savings on flood damage. This paper discusses the methodology of Medium range streamflow forecasting using statistical-dynamical approach. For statistical modelling system, the Local Polynomial regression model is adopted due to its ability to capture nonlinear relationships between the dependent and independent variables. The HEC-HMS hydrologic model is selected as the dynamical model. An inflow forecast based warning system is also developed for the downstream reach of Tehri Dam. To take advantage of the better performing approach, methods were developed to objectively merge statistical and dynamic forecasts into a single forecast. The HEC-RAS hydraulic model is also used to analyze the effect of release from Tehri dam and the effect of Alakhnanda river in the downstream area.

Poster 3-23
Changing flood generation processes across European catchments

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River floods can be generated by numerous processes that might change their frequency and intensity under a changing climate. Causative classification of river flood events allows to combine this multitude of processes efficiently into a manageable amount of event types. Analyzing temporal changes of event types can be an effective and insightful tool to detect changes and anomalies in flood series.

Here we investigated flood generation processes across a recently compiled European flood database. Maximum annual floods observed in 1960–2010 in 1415 catchments were classified according to the nature of their inducing precipitation events, space-time organization of these events and their interaction with the antecedent catchment conditions. For the classification of flood events we used observed precipitation and temperature data, whereas snowmelt and soil moisture states were obtained with the aid of a hydrological model.

Our results showed that the variety and composition of flood generation processes were systematically changing in the past decades across European catchments.

Specifically, we have identified several regions revealing opposite changes in the flood generation processes. In the Atlantic, Pyrenees and South Scandinavian regions the variety of flood generation processes decreases, and the dominant processes do not change. In Central Europe a decrease in the variety of flood generation processes was observed till the mid-1970s and it is increasing ever since. Instead, in the Eastern Europe, North Scandinavia and West Mediterranean the variety of flood generation processes increased greatly from the 1960s and even led to changes in the dominant flood generation processes in the majority of these catchments.

We are further investigating which implications these changes in the variety and composition of generation processes might have for European floods.

Poster 3-24
Evaluation of the joint impacts of fluvial floods and storm surges on the risk of flooding in an ungauged coastal river basin

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In this study, an integrated river flood and storm surge modelling system was employed and developed to simulate inundation in the Tra Bong River where observed data is limited and scarce. The approach used for this analysis is based on the integration of the rainfall-runoff model, the one-dimensional, and two-dimensional models for the rivers and the sea to compute flooding in the low-lying areas and storm surges or storm tides at the river mouth. The study revealed that the risk of flooding in the study basin is closely related to the high water levels and discharges in the rivers as well as heavy rainfall in the floodplain, while storm surges enhance the risk by increasing the flood extent and depths. Analyzing one of the extreme typhoons landing on the basin (Ketsana-2009) shows that the total inundated area and maximum water depth were increased from 5 to 10% due to the joint effect. The potential hazard maps were then produced based on a hypothesis of the occurrence of a super typhoon that might occur in the future in the South China Sea. We found that about 71.2 km^2 (nearly 25% of the delta area) would be flooded and at high and very high risk, in which 80% of the area would be inundated from 12 to 48 hours with water depths above 0.5 m. The methodology and approach employed in this study can be applied to other ungauged coastal river basins and the applicability of hydrodynamic models is required for such basins.

Poster 3-25
Modeling seasonal variations of extreme rainfall on different time scales in Germany

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To estimate the properties of extreme precipitation events on different time scales, intensity-duration-frequency (IDF) curves are a well-known tool in hydrology.

It has been shown that within the block maxima approach monthly block sizes can be sufficient to model extreme precipitation in the mid-latitudes. In addition, information on the occurrence probabilities in different months may well be needed by stakeholders in, for example, agriculture or water storage.

However, monthly block sizes have not yet been considered for modeling the IDF relationship. Still, particularly for this application, the use of monthly maxima may be relevant, because extreme precipitation events related to different time scales typically occur in different seasons due to different mechanisms causing them. In Germany, convective extreme events with a duration of minutes to a few hours occur almost exclusively in the summer months, while long-lasting extreme events are scattered throughout the year or even occur more frequently in autumn and winter months, depending on the location.

In this study, we model monthly precipitation maxima at different stations in Germany for a wide range of durations from one minute to 5 days using a duration dependent GEV with seasonally varying parameters. On the one hand, this allows us to compare the characteristics of the IDF curves of different months. On the other hand, we can also investigate the influence of intra-annual variations on the distribution of annual maxima of different durations.

Poster 3-26
Identifying drivers of hydrological hazards of river basins in spatial heterogeneities of rainfall and catchment attributes

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Hydrological hazards with extreme magnitude are associated with changing variability of sources in river basins. Streamflow probability distributions at the outlet with heavy-tailed behavior imply sizable chances of the occurrence of extreme events and are therefore a marking of enhanced hydrological hazard in river basins. However, due to the complexity of the processes affecting the hydrological response of catchments, identifying specific mechanisms which promote the emergence of heavy-tailed flow distributions has proved challenging.

In this study we combine a continuous hydrological model grounded on the geomorphological theory of the hydrologic response with archetypical descriptions of the spatial and temporal distributions of rainfall inputs and catchment attributes to investigate physical mechanisms and stochastic features leading to the emergence of heavy tails. The framework enables a parsimonious distributed description of hydrological processes, suitably considered with their stochastic character, and is thus fit for the goal of investigating manifold mechanisms promoting heavy-tailed streamflow distributions.

Observed rainfall and streamflow data are used to calibrate a lumped version of the model. Spatially heterogeneous rainfall intensity and catchment attributes are then distributed on the catchment by means of either stochastic or physically-based considerations and their impacts on the tail behavior of flow distributions are synthetically analyzed. Our results show that the intra-event variability of rainfall in space has no significant effects on the tail behavior. Instead the cross-event spatial variability of rainfall is strongly correlated to the emergence of heavy-tailed behavior. This highlights the importance of the degree of variability of spatial rainfall patterns (rather than the patterns themselves) for enhanced hydrological hazards. The study of impacts from catchment attributes is on-going and is anticipated to be presented.

The proposed framework provides a way to disentangle physical attributes and mechanisms of hydroclimatic variables and catchment heterogeneities in space which control the emergence of heavy-tailed streamflow distributions. By understanding these linkages, our work contributes to identify the hydrological hazards remarked of enhanced extreme streamflow magnitude in river basins.

Poster 4-1
Multi-Hazard Risk Assessment of Schools of Dehradun District

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Indian Himalayan Region being prone to various disasters due to its neo-tectonic mountain-building process, like earthquakes, landslides, and floods, suffers a significant loss of life and properties every year. The last few decades have been witnessed the impact of multi-hazard frequency. Due to the geographical features of the Himalayas, Uttarakhand has been the center of disasters such as earthquakes, landslides, floods, Cloudbursts, forest fires. Dehradun is the capital of Uttarakhand state and comes under seismic zone IV, which is highly prone to earthquakes, with a population of 578,000 in 2011 and 895,000 in 2020.

In the event of a disaster, educational institutions like schools serve as lifeline buildings. Hence it is very crucial to safeguard these buildings for the communities that may depend on the school as a disaster shelter and aid center. When designing the schools, it is essential to identify the gaps in the existing construction practices and aware of or train the people for future construction to minimize the hazard risk and decrease the impact of disasters.

With the same aim, Multi-hazard risk assessment surveys have been conducted manually through a mobile app at 50 schools (with a total of 246 building blocks) at various locations in the Dehradun district of Uttarakhand India. Assessment of the hazard is divided into two surveys. The first survey consists of a school campus survey with Rapid Visual screening of existing buildings, Non-Structural Risk Assessment within a school, and Fire Safety Audits. And the second survey has the school's location survey that includes a Flood vulnerability survey, an Industrial Hazard vulnerability survey, Landslide vulnerability survey, and a Wind Vulnerability survey.

This study will list several gaps and unrecognized practices going on in the region that are contributing to increase the multi-hazard risk in the schools. The outcome of the study can help to prioritize the planning of Disaster awareness, retrofitting execution, and other measures to be taken to minimize the risk and prepare the school for the upcoming disasters.

Poster 4-2
When science meets standardization: the case of the national seismic hazard assessment for Germany

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Probabilistic seismic hazard assessments (PSHA) represent the most well established means to calculate seismic load parameters for seismic building codes or other anti-seismic design provisions. This talk will present the lessons learned from the development of the seismic load parameters for the upcoming German national design regulation (DIN EN 1998-1/NA) and related interactions with the engineering community. This PSHA project was developed for about seven years on behalf of the Deutsches Institut für Bautechnik (DIBt; German Institute for Civil Engineering) and was launched by the respective national committee on standardization of the DIN. We will describe this new version of the national seismic hazard assessment (Grünthal et al., 2018) and present the key questions which have emerged from the use of this new model by stakeholders. We will first discuss the key issue of uncertainties evaluation, visualisation and communication, which highlight how modern methods used to capture epistemic uncertainties (e.g. logic trees) are generating probability distributions which are difficult to handle for many practical applications. We show how to visualize these uncertainties and identify their controlling factors. We will also discuss the critical issue of the choice of the mean or fractiles (e.g. median) of the resulting probability distribution to represent the seismic action, and its potential implications for seismic safety. In a second step, we will show that new methods are needed to evaluate the consistencies of this new generation of models with other logic-tree based PSHA studies obtained in neighbouring countries (France, Switzerland) or at the European level (ESHM20). Finally, recent developments (e.g. testing strategies) that have been initiated and influence the way the model is updated to take into new needs (e.g. seismic criteria for the site research for nuclear waste disposal) will be presented.

Poster 4-3
Temporal Variations, recovery and in-situ stress-strain behavior of shallow materials during the Kumamoto earthquake sequence

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We analyze the variations of subsurface seismic properties associated to the successive shaking of the 2016 Mw 7.3 Kumamoto foreshocks, mainshock and aftershocks. We use autocorrelation functions and interferometery methods as suggested recently by Bonilla et al. (2019). The used data was recorded by surface and borehole sensors at the KiK-net stations over a period of 8 years. The seismic velocity of subsurface exhibits clear changes during the earthquake followed by a recovery phase. We observe a decrease of about 30% of seismic velocity during the mainshock, showing average changes of shallow material properties between borehole and surface stations by using the interferometry method. Using autocorrelation technique, we detect about 60% decrease of seismic velocity during the mainshock ground motion, showing the velocity changes of material properties just below the surface sensor. In a further analysis, we analyze the memory properties of material by using the velocity changes during the peak ground acceleration. It shows a gradual decrease in velocity changes after the mainshock. In addition, we analyze the variation of shear modules based on shear strain and also Vs30, which show degradation of shear modulus in the mainshock and healing process of shear modulus. Such observation can be used to improve estimate of seismic shaking hazard, site effect, and healing process of material.

Poster 4-4
Rabotnik – An asyncronous and flexible data and task management ecosystem

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A series of tools and applications developed within the Global Dynamic Exposure model group leverage a multitude of different data sources such as the OpenBuildingMap database, satellite imagery and cadastral information for the generation of an exposure model to be used for the assessment of risk due to natural hazards. Each updated, added or removed datum needs to be reflected within the different analyses which all together constitute the Global Dynamic Exposure model and dataset. The highly complex dependencies between individually developed and maintained data-analysis stages requires a flexible and extensible task queuing, processing and messaging system that is scalable across computational nodes to enable a real-time processing of the ever changing datasets.

To tackle the challenges of Big Data computing in an online operating production system with continuously changing heterogeneous data sources, we designed Rabotnik. Rabotnik uses the Message Queuing Telemetry Transport protocol (MQTT) to pass information, triggers and messages accross client instances that are hooked into the Rabotnik ecosystem.

The current implementation leverages RabbitMQ as the message broker which also provides basic monitoring of task execution. The broker, however, can easily be exchanged. The decentralized architecture allows any participant to subscribe to broadcasting channels and to trigger computations, e.g., if a certain datum such as an attribute of a building within the OpenBuildingMap database is updated. The receiving instance can in turn issue a message for other subscribed entities to react upon.

Computations can be abstracted in atomic rules which can be dynamically added to the analysis flows. This level of abstraction will in the future allow to store rules with a time history of changes which can be recorded in the analysis results to provide transparent and reproducible analyses.

The asyncronous client allows non-blocking code execution flow which is currently being benchmarked by means of several computation rules acting on the OpenBuildingMap data to provide a realistic testing scenario.

The current work in progress is hosted under AGPLv3+ license at https://git.gfz-potsdam.de/dynamicexposure/rabotnik/rabotnik

Poster 4-5
Tile- and building-by-building-based damage calculations

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The Global Dynamic Exposure (GDE) model continuously integrates building-level data from OpenStreetMap (OSM, processed within the sibling product OpenBuildingMap, OBM) with aggregated exposure models and other open data sources to generate a high-resolution building exposure model (see Schorlemmer et al. 2021, Nievas & Schorlemmer 2021). This integrative nature, and the fact that the input building data from OpenStreetMap is not complete everywhere, results in the GDE model employing both a tile- and building-by-building-based approach. For every level-18 Quadtree tile (approx. 100m wide in Europe), both individual building footprints and an aggregated exposure model are provided, in terms of structural types, their reconstruction value and number of expected occupants. At the tile level, the number of buildings refer to numbers per structural type, while at the building level the number of buildings actually refer to the probability of the building belonging to that particular type.

This type of exposure data requires a new type of loss calculator and new types of visualizations of damage or loss computations. We have developed a new loss calculator using the GDE-type of exposure data that can work both via a direct connection to the GDE database or input files (CSV and GeoPackage). This calculator delivers the damage/loss assessments in a similar way: either aggregated per tile or separated between the damage/loss of individual buildings and the damage/loss of the remaining aggregated buildings of the respective tile. The former result type allows for easy comparison to classical damage/loss assessments per tile (or any other type of grid) while the latter provides the building-by-building details augmenting the aggregated damage/loss assessments. The likelihood of buildings suffering from pre-defined levels of damage and the consequences of such damage are input into the calculator in the form of fragility and vulnerability models. We present the calculator and ways of visualizing the new types of damage/loss assessments, combining building-by-building information with tile-based information. Additionally, we present results of our case study in Athens using a scenario earthquake.

Poster 4-6
OBMGapAnalysis – Automatic building completeness assessment with open settlement datasets

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OpenStreetMap (OSM), especially its content regarding building footprints has proven to be an excellent resource in the production of risk maps and models and the assessment of human exposure to different hazards. Such products play an important role in life-loss prevention as well as disaster management. Because OSM is a community effort project, it has different levels of development around the world: poor coverage in some cities as well as many rural areas and, in contrast, highly detailed maps in others. With this in mind, additional sources and methods come in handy to help mappers to identify gaps in the OSM building coverage, i.e. locations where buildings have not yet been mapped. These methods are also useful as well in providing input for the making of rough estimations of built-up areas for further risk and exposure assessments.

A tool named OBMGapAnalysis has been developed as part of OpenBuildingMap, a system that continuously retrieves and processes building data from OSM, and may also be implemented in other similar projects. It is a processing chain for settlement layers designed to evaluate the completeness state of OSM buildings on a level-18 QuadTree tile resolution (ca. 100–150 m depending on the latitude). The input data for this tool is any set of raster files that contain the spatial distribution of human settlements, such as the Global Human Settlement (GHS) built-up area (30 m grid) from the Joint Research Centre (JRC) of the European Commission, the World Settlement Footprint (10 m resolution) from the Deutsche Zentrum für Luft- und Raumfahrt (DLR) or any self-produced land cover classification from remote sensing approaches. The processing of these raster files results in gridded values of built-up areas that are directly compared with the built-up areas in OSM as defined by the building footprints. By comparing these values, a completeness state can be assigned. Since there is a considerable difference between the spatial resolutions of OSM and the settlement layers, the tool can optionally take as input the streets from OSM to refine the built-up model under the assumption that streets are not buildings but are often included in raster files as built-up area. The results of this processing chain are stored in a database for public access and may serve as an input for further analyses such as the Global Dynamic Exposure (GDE) model or other applications. This poster explains in detail the results of the first case study (Greece) as well as how it scales up to a global gap analysis.

Poster 4-7
Liquefaction of stratified soil under initial static shear stresses

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After the occurrences of several earthquakes, tremendous research works have been carried out to understand free-field liquefaction. Moreover, the liquefaction phenomenon is not only limited to the free field conditions but also it prevails in slopes, foundations and other engineering structures having significant initial stresses over the soil mass. In order to understand such field situations, the initial shear stress ratio (α) was used by Yang and Sze (2011), along with its threshold value. The ignorance of this parameter (α) can cause liquefaction failures, resulting in unsafe design practices. The initial static shear stress (qs), present before the occurrence of an earthquake, is responsible to enhance liquefaction resistance in loose sands. Although, it is arguable at higher relative densities where confining stresses play their role. After considering the initial static shear stresses in seismic designs, several unexpected lateral deformations and flow liquefaction failures in earthen dams, embankments and foundations could be avoided. The authors of this research work have performed cyclic triaxial tests under an anisotropically consolidated state (soil mass with initial static shear stress) on the stratified soil. In this research work, soil stratification has been replicated using the triaxial specimen of diameter 70 mm and 140 mm height prepared by air pluviation technique. The stress-controlled cyclic triaxial tests were performed at a frequency of 1 Hz. Silt (ML) had been used as the intervening layer to create the stratification effect. The static shear stress of 20 kPa was imparted on the test specimen before the application of cyclic deviatory stress (qcyc). Results of the stratified soil specimens were compared with the similar tests conducted on homogeneous soil specimen through which it was noted that pore pressure movement was decreased due to the presence of silt seam and thereby changes in deformation patterns of the stratified specimen were also noted. The presence of silt seam caused the early failures in the stratified specimen where the placement depth was H/2 from the top where H is the height of the specimen. The liquefaction failures in the anisotropically consolidated specimens were considered when the single strain amplitude reaches a value of 2.5 % strain. In most of the specimens, the flow deformations caused the sudden failure of the specimen at larger strains. To observe the relative density effect, similar tests were also performed on the medium dense specimens (relative density between 35% to 65%). The outcome of this work has suggested the vulnerability of stratified soil mass present near seashore, landfills, tailing dams, alluvial or marine deposits under initial static shear stresses.

Poster 4-8
Quadtree based multi-resolution grids for global earthquake forecast experiment

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The Collaboratory for the Study of Earthquake Predictability (CSEP) is an international effort to independently evaluate earthquake forecasting models. CSEP provides the necessary cyber-infrastructure along with a suite of testing methods for earthquake forecasts. CSEP defines a grid-based format for expressing earthquake forecasts: the expected rate of earthquake occurrence within 0.1° x 0.1° spatial cells. This uniform gridding approach leads to 6.48 million spatial cells. The distribution of earthquakes around the globe is non-homogenous, resulting in 99% of spatial cells containing no earthquake. This leads to an unjustifiably high-resolution grid in low-seismicity regions with an unnecessary computational burden.

In this study, we propose a quadtree-based gridding approach that is capable of providing a multi-resolution spatial grid. The quadtree is a hierarchical tiling strategy for storing and indexing geospatial data. It follows the Mercator projection in which the whole globe is divided into 4 squared tiles and then each tile can be divided into four children tiles, until a final desired grid is acquired. Each tile refers to a unique region on Earth and is identified by a unique identifier called quadkey. To create a multi-resolution grid, subdivision of a tile is driven by a criterion, e.g. maximum number of earthquakes allowed per cell (Nmax). Thus, instead of dividing the whole globe into 0.1° x 0.1° cells, the quadtree approach generates high-resolution (smaller) grid cells in seismically active regions and low-resolution (bigger) grid cells in seismically quiet regions. The proposed multi-resolution gridding approach reduces the total number of cells in the grid from the order of millions to a few thousand cells, thereby reducing the quantity of cells without earthquakes and limiting the computational cost associated with model generation and evaluation. Most importantly, the quadtree offers ease of handling gridding process and compatibility with web mapping services for rendering the data.

Poster 4-9
Increasing computational efficiency of seismic risk analysis for infrastructure networks

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Seismic risk assessment of spatially distributed infrastructure networks requires an enormous amount of simulations of earthquake scenarios, ground motion fields, damage states of infrastructure components and subsequent cascading failures. In fact, if the uncertainties in all steps were to be assessed accurately, the number of required simulations would pose a completely intractable load for existing computational frameworks. The simulation of ground motion fields and cascading failures in the network are the most demanding steps in the described workflow. Therefore, developing novel, computationally efficient methodologies for these tasks and applying them to a reasonable number of simulations is the most promising strategy on the way towards reliable evaluation of infrastructure network performance in the aftermath of an earthquake.

In our study, we assess the applicability of two machine learning approaches to the tasks at hand: On the one hand, Gaussian Process Regression (GPR) provides not only a value prediction of the network performance, but also the uncertainty associated to such a prediction. It poses a shortcut in terms of modeling the network performance directly as a function of earthquake source parameters, skipping the task of ground motion simulation and infrastructure damage estimation. However, it requires the inversion of the covariance matrix during the learning process, which becomes a bottleneck in computational efficiency if the training set is large and inefficiently sampled. As an alternative, we evaluate the applicability of the graph neural network architecture (GNN) to model cascading failures in a damaged infrastructure network. Compared to GPR, neural network approaches are expected to be computationally more efficient and potentially also provide intermediate results such as the final damage state of the infrastructure network including all cascading failures, whereas the GPR only provides a scalar performance measure for the entire network. However, uncertainty quantification is less comprehensible compared to the GPR approach and ground motion simulations are necessary to estimate the initial damage state of the infrastructure network. All experiments are conducted with synthetic data generated from graph-based modeling approaches, where we aim to represent the Peruvian electrical power supply network.

Successful replacement of graph-based or even physics based infrastructure modeling approaches with efficient machine learning methodologies would be a game changer for the seismic risk modelling community, since it poses a step towards fully probabilistic risk assessment of infrastructure networks as well as rapid assessment of network performance in the direct aftermath of earthquakes.

Poster 4-10
Effects of large aftershocks in spatial distribution of 2017–2019 western Iran sequence

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Large earthquakes are always followed by aftershocks sequence that last for months to years. Sometimes, these aftershocks are as destructive as the mainshocks. Hence, accurate and immediate prediction of spatial and temporal distribution of aftershocks has a great importance for planning search and rescue activities. Based on the correlation between Coulomb failure stress changes (ΔCFS) and spatial distribution of aftershocks, the CFS criterion is the most commonly used method for predicting spatial distributions of aftershocks. However, there are large uncertainties associated with the calculation of Coulomb stress changes.

Recent studies have questioned the use of classic ΔCFS with predefined receiver mechanism. Results from receiver operating characteristic (ROC) binary test revealed that alternative stress metrics such as Coulomb stress changes on optimally oriented planes (OOP) and on variable mechanism (VM) and stress scalars such as maximum shear (MS) and von-Mises stress (VMS) as well as deep neural network (DNN) approaches are more accurate and reliable than CFS. On the other hand ROC results of simpler distance-based approach showed that this method is superior to DNN approach and all stress metrics and scalars. Previous studies show that larger aftershocks are in better agreement with the calculated stress maps and triggering of small events usually are under effect of secondary static stress changes due to larger aftershocks. So, the role of aftershocks especially large aftershocks in spatial forecasting of aftershocks following a large mainshock are negligible.

In order to examine the effects of large events in spatial forecasting of aftershocks during a sequence, we use the 2017–2019 seismic sequence in western Iran. This sequence started by Azgeleh M7.3 mainshock (12 November 2017) and followed by Tazehabad M5.9 (August 2018) and Sarpol-e Zahab M6.3 (November 2018) events. Furthermore, 15 aftershocks with magnitude > 5.0 and more than 8000 aftershocks with magnitude > 0.4 were recorded by Iranian seismological center (IRSC) during this sequence until the end of 2019.

In this study we analyze the effect of the magnitude cut-off, grid size variation, aftershock duration, and role of large aftershocks in forecasting spatial distribution of aftershocks by using ROC analysis. Our results for this case study show that by increasing magnitude cut-off and decreasing grid size the area under curve (AUC) for classic Coulomb stress on the predefined planes does not change significantly but for all other metrics (OOP, VM, MS, VMS) increase significantly. In this case the OOP (0.808) and VM (0.795) stress metrics are more sensitive to magnitude cut-off (reducing effects of secondary triggering) and MS (0.796) and VMS (0.794) scalars are also sensitive to grid size decreasing. When we add the large aftershocks $M > 5.0$ as a secondary source of stress, the AUC of ROC analysis for OOP, VM, MS, and VMS increase significantly and MS (0.920) and VMS (0.921) become the highests. So, we could say that by considering effects of large aftershocks, stress metrics can outperform to classical CFS and distance-slip probabilistic models.

Poster 4-11
Robust, an Earthquake Early Warning System in the Lower Rhine Embayment, Germany

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The Lower Rhine Embayment in western Germany is one of the most important areas of earthquake recurrence north of the Alps, facing a moderate level of seismic hazard in the European context but a significant level of risk due to a large number of important industrial infrastructures. In this context, the project ROBUST aims at designing a user-oriented hybrid earthquake early warning and rapid response system where regional seismic monitoring is combined with smart, on-site sensors, resulting in the implementation of decentralized early warning procedures.

One of the research areas of this project deals with finding an optimal regional seismic network arrangement. With the optimally compacted network, strong ground movements can be detected quickly and reliably. In this work simulated scenario earthquakes in the area are used with an optimization approach in order to densify the existing sparse network through the installation of additional decentralized measuring stations. Genetic algorithms are used to design efficient EEW networks, computing optimal station locations and trigger thresholds in recorded ground acceleration. By minimizing the cost function, a comparison of the best earthquake early warning system designs is performed as will be presented in the meeting.

Poster 4-12

Inside the Global Dynamic Exposure model: bringing together aggregated models and crowd-sourced building-level data

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The assessment of risk due to natural hazards requires knowledge on the location, value and vulnerability of susceptible assets and populations. As information on these is usually scarce and/or restricted, much effort is usually required to define exposure models that are suitable for such assessments, in terms of the level of detail offered and their connection with vulnerability models that exist or can be derived. In addition to the classical challenges associated with the gathering and processing of relevant data, a key aspect is that exposure is not static and changes in time: new structures are built, old structures are retrofitted or demolished, structures in general can be damaged and their future behaviour altered as a consequence. At GFZ, we are currently developing a Global Dynamic Exposure (GDE) model that continuously retrieves data about individual buildings that are voluntarily mapped by contributors to the OpenStreetMap (OSM) initiative. This is combined with transparent engineering judgement and openly available building exposure models that are defined in terms of administrative units to produce a high-resolution building exposure model to be used for risk assessment (Schorlemmer et al. 2021, Evaz Zadeh et al. 2021). While currently focused on seismic action, our work has been conceived from the very beginning with a multi-hazard (or hazard-agnostic) perspective in mind. The development of the GDE model comprises components of various kinds, whose details are presented in a series of posters in this conference. Here we focus on our strategy for combining the valuable information contained in aggregated exposure models defined by administrative units (e.g. Shinde et al. 2021) with building data that is continuously added to OSM and can thus reflect changes to the building stock in a rapid fashion (Delattre et al. 2021). The buildings mapped in OSM are processed to determine their occupancy type and retrieve relevant characteristics as part of our sibling product OpenBuildingMap (OBM). Aggregated exposure models are distributed onto high-resolution level 18 Quadtree tiles (approximately 100 m wide at the Equator) using ancillary datasets, both in terms of numbers of buildings and proportions of structures of different classes. The number of buildings per tile is determined by combining both sources, taking into account the completeness of the tile in OSM, that is, considering whether all existing buildings are mapped in OSM or not, which is defined by means of our completeness module (Prehn & Schorlemmer 2021, Garcia Ospina & Schorlemmer 2021). When mapped, individual buildings are characterised by their OSM footprints, while any expected buildings of an incomplete tile that are not mapped in OSM are represented as a lumped sum in the centre of the tile. Individual buildings get assigned probabilities of belonging to different building classes as per the aggregated model, with the range of possibilities narrowed down whenever possible as a function of properties retrieved from OSM, such as the number of storeys. This poster describes the full procedure in detail and illustrates it by focusing on the test case of the city of Athens, Greece.

Poster 4-13
Clickpleteness – How to assess the degree of completeness of building stock data in OpenStreetMap

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While image-based raster data has its advantages in continuous spatial representation of single phenomena, it is vector data that allows for the accurate modeling of real-world objects and their interconnection with topology and other objects. One such object class of particular interest are buildings, as they not only give people shelter and a home, but also pose a significant risk when exposed to natural hazards. Among the available sources for building data the OpenStreetMap (OSM) project stands out as an open, crowd-sourced and, through voluntary contributions, growing and improving source of geo-referenced vector data with global coverage. While the bottom-up nature of OSM facilitates a comprehensive source with a plethora of features, in reality the coverage strongly varies from region to region, leading to a high variability in terms of completeness. To determine the quality of processed information stemming from such ever-changing datasets as is OSM, it is crucial to gauge the completeness of the underlying data first, as the former is heavily influenced by the latter. That is, when working on the building level it is paramount to assess, for a given region, whether the whole of the local building stock is represented, and to what degree it is lacking. We present the concept and specification of completeness, as well as a proof-of-concept application programming interface (API) and the “Clickpleteness” web-application to help determine the completeness level of OSM building data, either via manual assessment on a grid cell-by-cell basis, or through the importing of data from third party sources. We define completeness as a qualitative measure on a grid, expressing to what degree all real-world buildings in a given grid cell are mapped in OSM. Therefore, we introduce a set of completeness classes to specify whether a cell is unknown, complete, incomplete, whether it is undecidable or water. We show that comparing a layer of up-to-date OSM building data against buildings in a high-resolution raster satellite imagery layer representing the real-world ground-truth building stock allows for the deriving of a grid layer of completeness statements. We furthermore show that assessing completeness in well-defined classes on a quadtree grid provides efficient data storage. It also allows for seamless integration with other applications built on a quadtree, especially data acquisition, while garnering support from the OSM mapping community and yielding a tile-based completeness map that is naturally compatible with most web-map rendering solutions. This in turn allows for completeness statements at multiple scales, ranging from a single ~5 arc-seconds wide tile over any level of administrative boundary to the whole world. As a practical application completeness is an important precursor in the Global Dynamic Exposure (GDE) model, serving as a guide to deciding where building-by-building exposure applies. With our completeness tools we invite interested people to partake in completeness assessment, to help us to acquire more detailed knowledge about products derived from OSM data, while also helping to fill in the gaps in and to ultimately increase the quality of such products.

Poster 4-14
Developing methods to resolve the computational challenges in probabilistic tsunami hazard and risk assessment

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Tsunami as a peril occur infrequently but have devastating consequences, the 2004 Indian ocean and 2011 Tohoku events are examples of their potential to cause damage. Probabilistic tsunami hazard and risk assessment are vital tools to understand the risk of tsunami and mitigate its impact by guiding the risk reduction and transfer activities.

Regional or large-scale probabilistic tsunami hazard and risk assessment require many numerically-intensive simulations of the seismically induced tsunami events, involving tsunami phases of generation, wave propagation and inundation on the coast which are not always feasible unless large computational resources are at disposable like HPCs.

In order to undertake a regional PTHA for a larger proportion of the coast we need to develop concepts and algorithms for reducing the number of events simulated, or more rapidly approximate the simulations needed. This work involves investigating some potential methods for doing this (a) Geo-statistical method clustering the source parameters and the inundation caused on coastal segments (b) Machine learning methods (c) Simpler flood inundation schemes, etc.

Such methodology can further be extended to the application in other probabilistic coastal hazard and risk assessments where similar computational challenges exist like storm surge.

Poster 4-15
Global Dynamic Exposure and the OpenBuildingMap – A Crowd-Sourced Approach to Disaster Risk Assessment and Reduction

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The substantial reduction of disaster risk and loss of lives is a major goal of the Sendai Framework of the United Nations Office for Disaster Risk Reduction (UNISDR). Such a goal requires a clear understanding of the dynamics of the built environment and how it affects societies, as represented by local governments and individuals, when natural disasters occur. These dynamics are best understood and captured by local communities, following two of the guiding principles the UNISDR has formulated: “empowerment of local authorities and communities” and “engagement from all of society”. Moreover, the active engagement of the general public in risk assessments contributes to increasing their understanding of efficient risk mitigation measures. Our Global Dynamic Exposure model and its technical infrastructure therefore builds on the involvement of communities in a citizen-science approach.

We are employing a crowd-sourced capturing of exposure using OpenStreetMap (OSM), an ideal foundation with already more than 475 million building footprints (growing by more than 100’000 per day), and a plethora of information about schools, hospitals, and other critical facilities. With our OpenBuildingMap system, we are harvesting this dataset by processing every building in near real-time. We are collecting exposure and vulnerability indicators from explicitly provided data (e.g. hospital locations), implicitly provided data (e.g. building shapes and positions), and semantically derived data, i.e. interpretation based on the application of expert knowledge and aggregated exposure models. The expert knowledge is needed to translate the simple building properties as captured by OpenStreetMap users into vulnerability and exposure indicators and subsequently into building classifications, as defined in the Global Earthquake Model (GEM) Building Taxonomy 2.0 and the European Macroseismic Scale (EMS98). With this approach, we increase the resolution of existing exposure models that we use as input (such as the European Seismic Risk Model, ESRM20) from their original aggregated resolution to the building-by-building level. Additionally, we include available open datasets to further improve our indicator assessment. The joint processing of all these data sources results in the Global Dynamic Exposure (GDE) model, which is defined as a combination of individual building footprints and a high-resolution grid (approx. 100m x 100m tile size).

With our tools, interested communities can capture their exposure and analyze how natural disasters may affect them. This helps to communicate risks down to the community level and provides the means to directly involve interested actors to mitigate the risks they might be subject to.

Poster 4-16
A census-derived aggregated exposure model (AEM) for Japan

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Exposure, that is, the characterization of buildings, population, infrastructure, etc. of a given area, is one of the primary components when determining risk due to a hazard or group of hazards. Exposure is a dynamic factor, arising from evolving built environments (new buildings, new infrastructure, demolitions, renovations and retrofitting, etc.) and changing populations. Such factors substantially increase the complexity in disaster risk assessment and raise the need for the development of exposure models that continuously integrate up-to-date information, as is being done in the Global Dynamic Exposure (GDE) model (see abstract by Schorlemmer et al., 2021). However, open dynamic datasets do not contain all the information required for this purpose and the need may arise to first develop so-called aggregated exposure models (AEM), that lead to the creation of a detailed dynamic exposure model when combined with the former (see abstract by Nievas et al., 2021). AEMs can be defined as a distribution of buildings and dwellings, their replacement cost and number of people that occupy them, at some administrative level. They represent a static snapshot, representative of a given country or geographical region at a particular point in time.

We have developed an aggregated exposure model for Japan at the municipality level. This model is entirely derived from open building data (e.g., census) and resulting in an open inventory of uniformly defined building parameters available for risk assessments. The Japanese ESTAT website (https://www.e-stat.go.jp/en) provided information about building type (apartments, detached houses, tenements) and their number, dwelling type (used exclusively for living, and those also used for commercial or other purposes), their number and size, tenure type (owned houses, issued houses, and rented houses), construction material type (wooden and non-wooden), year of construction, number of stories, persons per dwelling and size of dwelling (area in square meters). After interpreting this information, different combinations of building type, construction material, year of construction, and number of stories were mapped to the GEM taxonomy-based building classes. Furthermore, building parameters required for loss assessments (e.g., average floor area of a dwelling, replacement cost per unit area of a dwelling, number of people per dwelling) were assigned to the identified building class at the municipality level and stored in a database open for public access. This model thus represents an open catalogue of rules for mapping Japanese building attributes to a GEM taxonomy-based building class and, in doing so, creates an opportunity for the scientific and non-scientific community to collaborate on the assessment, correction, and expansion of individual aspects of the aggregated exposure model and hopefully encourages the development of such open aggregated exposure models for other countries.

Poster 4-17
Application of Permutation Entropy for characterizing the precursory phase of the 2014/2015 Holuhraun eruption, Iceland

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Permutation Entropy (PE) has been recently suggested to be a promising tool for the prediction of volcanic eruptions. It is a robust yet simple tool to quantify the complexity of time series. However, how PE should be used in the field of volcano-seismology and what the limitation of this method are, is not well-defined yet. Our final aim is to quantify what features in the PE can be interpreted as eruption precursors and whether this is applicable to different eruptions from the same or different volcanoes. Before applying PE on the real seismic data from a volcano, we need to understand how to determine the length of the signal and the value of the embedding dimension and delay time. Therefore, we performed several synthetic tests using synthetic monochromatic signals with different frequencies and signal to noise ratios (SNRs). Our synthetic tests show that for the monochromatic signals with frequency lower than 1 Hz, the length should be longer than 2 times the period. For the monochromatic signals with frequency above 1 Hz, the length should be at least 10 times the period. Our tests also show that PE depends strongly on the delay time and embedding dimension. When the delay time is too small or equal to the period of the signal, the value of PE will be strongly influenced by the noise. Thus, the delay time in between should be chosen. The embedding dimension should not be smaller than 5 to be able to identify the characteristics of the underlying signal. We decided to test PE on the Holuhraun eruption, Iceland in 2014–2015. In Iceland, excellent datasets from a seismic network and several weather stations are available, providing ideal data for the PE test. Here, we present the temporal variation of PE prior and during the dyke propagation and the effusive eruption of Holuhraun 2014–2015.

Session 5
Geomorphological events

Poster 5-1
Tracing alluvial sediments using geophysical surveying, Braunsbach, Germany

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Sedimentary deposits in alluvial fans and terraces preserve valuable information about morphodynamics processes including possible evidence of catastrophic floods. The study of such archives is key to understanding whether the sediments were deposited gradually during multiple minor events (e.g., during frequent rainstorms) or whether these sediments originate from catastrophic events (e.g., debris flows). Minor hydro-meteorological events rarely perturb the sedimentary record. In contrast, processes such as flash-floods might potentially leave long-lived sedimentary layers. Alluvial fans and terraces in humid areas may offer few outcrops, making it challenging to map their sedimentary composition. However, with non-invasive 2D and 3D geophysical surveying, we are able to map the general stratigraphic and geometric characteristics in such environments. To exemplify this approach, we consider the Grimmbach alluvial fan (~150 m^2) located near Braunsbach, south of Germany. This fan and its catchment were highly impacted during a flash flood in May 2016 that caused massive erosion and sedimentation. To understand up to which extend this event was exceptional and learn more about past hydro-meteorological events in this catchment, we use the few available outcrops in the alluvial fan area, and extend our inquiry using different geophysical data sets (collected in November 2019 and September 2020) including electromagnetic induction (EMI), electrical resistivity tomography (ERT), and ground penetration radar (GPR). The EMI method showed high potential to characterize 3D near-surface structures for depths < 3 m. With ERT, we mapped 2D structures up to depths of 15 m, and with GPR, we mapped 2D structures up to a depth of 2 m for conductive soils and up to 4 m for more resistive soils. A joint interpretation of the inversion results of these geophysical data sets reveals the presence of at least two near-surface disconnected paleo-channels at depths < 3 m. From this, we hypothesize that the relatively recent history of this alluvial fan (which shows a total thickness of 9–13 m) has probably experienced past catastrophic events that have caused a sudden lateral change in the channel (avulsion). This hypothesis is also supported by one outcrop (~15 m long and ~2.5 m in height), where we distinguished sharp contacts between silty-clayey sediments and coarse materials (six layers in total). The sharp nature of these contacts indicates that the river in this area is shifting laterally abruptly during major floods instead of gradual lateral migration as expected in meandering rivers mainly transporting fine sediments. This case study demonstrates that linking field observation and geophysical models in small alluvial fans can provide valuable information to inform or improve hazard models of extreme sediment transport.

Poster 5-2
Landslide and torrential flow susceptibility conditions regarding landscape evolution in the northern Colombian Andes

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Colombia is an equatorial country characterized by a complex mountainous topography and strong hydroclimatic variability, located in a tectonically active region, as a result of an interaction of three tectonic plates and crustal blocks in subduction and collision settings. As a consequence, it is configured as a multi-hazard setting, where earthquakes, volcanoes, landslides, flooding, torrential flows and concatenated processes are very common, and the origin of huge destructive disasters such as Armero (1985) where a lahar claimed the lives of more than 22,000 people; and recently, Salgar (2015) with 104 fatalities and Mocoa (2017) where 333 people died.

In order to evaluate current hazard conditions it is needed to understand that landscape configuration is not a static process, it corresponds to a continuous evolution and transformation process control by tectonic and climatic settings. In this study, we aim to gain a better understanding of landscape evolution in the northern Colombian Andes by using quantitative geomorphology analysis derived from 30m and 12.5m Digital Elevation Models (DEM) to unravel landslide and torrential flow susceptibility current conditions.

Several morphometric indexes (Stream Lenght-Gradient Index, the χ-z coordinate plot, indexes related to drainage network, basin geometry, drainage texture, relief characteristics) were implemented for 168 basins, ranging in areas from 10 km^2 to 5000 km^2. Furthermore, morphometric index patterns were compared with regional fault systems, landslide inventories, and torrential fans location to correlate landscape evolution with hazard conditions. The results indicate the existence of several basins in a transitory state. The imbalance in the drainage networks evidences an increase in the basin morphodynamics and is correlated with the most critical areas showing historical records of landslide and torrential events. Another important result corresponds to the association of mega-landslides location along steady-state basins.

Poster 5-3
Definition of Rainfall Thresholds for Shallow Landslides in Colombian Tropical Mountainous Terrains

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Landslides generate economical losses and human fatalities worldwide, and especially in mountains and tropical countries, such as Colombia. According to Geohazards database (www.geohazards.com.co), 10.438 landslides have been registered in the Colombian Andean between 1921–2020, with almost 7.313 fatalities. Colombian Andean region exhibits a complex tropical hydrometeorological dynamic affected by different temporal and spatial scale climate processes. It is composed of a diverse geological and geomorphological setting characterized by high steep slopes and morphogenic conditions that are predisposed to gravitational hillslope processes. Most of the Colombian population are established in the Andean region occupying large hilly areas without an adequate planning control representing a risk condition that in recent years has encouraged the development of forecast models and Early Warning Systems (EWS).

EWS based on rainfall thresholds can be defined by empirical-statistical and physically-based methods. Empirical-statistics is based on historical data on rainfall and mass movements; and physically-based models take into account the effects of rainfall coupling distributed hydrological and geotechnical models providing landslide spatial distribution by calculating the distributed safety factor.

This study shows the importance of defining rainfall thresholds by empirical-statistical and physically-based models in the Colombian Andean region on a basin scale. We are proposing an approach where the definition of the rainfall thresholds integrates IDF gauge-based rainfall data and the physically-based model (TRIGRS) to calculate the cumulative density function from the histogram of the distributed safety factor within a basin, providing a better comprehension of the response to heavy rainfall events in a basin scale in tropical mountainous terrains.

Rainfall thresholds is a powerful tool for early warning systems (EWS) that would help local governments in the development of planning risk and hazard assessment benefitting people who are in vulnerable conditions and exposed to shallow landslide events.

Poster 5-4
Seismic constraints on rock damaging and stick-slip motion at the Hochvogel, Alps

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Large rock slope failures play a pivotal role in long-term landscape evolution and are a major concern in land use planning and hazard aspects. While the failure phase is increasingly well studied, the nature of the preparation phase remains enigmatic. This knowledge gap is to a large degree related to challenges in collecting appropriate data in such high mountain terrain. Classic monitoring techniques provide detailed data but mostly of point character and only reflecting the surface expression of processes within the rock mass. Thus, the integral behaviour of a peak, at the surface and at depth remains elusive.

We present results from a continuous multi-sensor seismic analysis of the Hochvogel summit, a 2592 m high Alpine peak, which is deemed to fail in the near future. The seismic network consisted of up to seven sensors, installed during July–October 2018. Modal analysis and HVSR data reveal diurnal cycles of increasing and decreasing coupling stiffness of the fragmented rock volume, due to thermal forcing. Relative seismic wave velocity changes mimic this pattern but also reveal the release of stress within the rock mass. At longer time scales, there is a superimposed pattern of stress evolution, which increases for five to seven days and suddenly drops within a few days, also expressed in an increased emission of short seismic pulses indicative of rock cracking. Our data provide essential first order information on an early stage of a large-scale slope instability, which evolves towards a catastrophic failure.

Poster 5-5
Outburst flood risk assessment for the Pokhara Valley, Nepal

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Pokhara (c. 850 m asl) is Nepal's second largest city and lies on a large (ca. 120 km^2) alluvial fan at a topographically distinct transition between the Greater and Lesser Himalayas. In the past decades, the city has seen rapid socio-economical changes including a tripling of its urban population as well as substantial expansion of its tourism sector. This development is accompanied by a significant change in land use, most prominently reflected by an increase in urban areas by c. 45% from 1977 to 2010 and a concurrent decrease in areas classified as cultivated land. Ongoing migration dynamics also result in increased urbanisation pressure, which in turn led to a rise in informal settlements. These settlements – predominantly consisting of corrugated-iron structures - are often built in close proximity to the Pokhara Valley's main river system, the Seti Khola. The Seti Khola runs along one of the steepest topographic gradients in the Himalayas and is fed by the debris-covered Sabche glacier below the flanks of Annapurna III (c. 7500 m asl). Concerns about future landslide- or glacier-surge-related outburst floods along this river rekindled after the May 2012 Seti Khola Flood Disaster, which caused 72 fatalities and destructed livelihoods as well as vital infrastructure in the upper valley. We seek to objectively substantiate these concerns by exploring a number of inundation scenarios using hydrodynamic outburst flood modelling with HEC-RAS and ANUGA. These numerical models provide us with spatially resolved estimates of flow dynamics and inundation depths for potential future outburst flood scenarios involving 5,000 to 600,000 m^3/s peak discharge, i.e. scenarios that are informed by recent and Medieval geomorphic evidence. We also use a combination of medium to high-resolution satellite imagery (Sentinel-2, RapidEye, PlanetScope, Maxar, GoogleEarth) to identify land-use changes along the Seti Khola, including settlement and infrastructure dynamics as well as sites of gravel mining in the past decades. We combine these remotely-sensed data with our inundation maps to provide a comprehensive outburst risk assessment for the city of Pokhara and its surrounding regions. We offer insights from a case study focussing on the squatter settlement of Kaseri, which is located on the Seti Khola's lowermost river terrace in an area prone to potential hydraulic ponding during floods. Our results highlight the benefit of using different numerical models to identify those regions prone to highly dynamic risks from catastrophic outburst floods.

Poster 5-6
Monitoring and modelling the aftermath of landslide events

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Landslides are a major source of sediment in steep active mountain ranges. A landslide event, composed of either a single large or hundreds of small landslides, can alter a mountainous catchment by depositing large volumes of sediment into the channel network. The deposited sediment can change the course of the flow creating epigenetic gorges, braided channels or lakes. In other cases, the landslides fail to systematically deposit sediment into the channels and there is no apparent short-term effect on the river. The rate at which this sediment moves through the river network can have significant impacts on the evolution of the mountain range by altering the incision rates or the discharge of water downstream. The increase in sediment can also increase the likelihood of natural hazards such as debris flows and dam outburst floods. Geomorphic and natural hazard processes act on significantly different time scales but likely influence each other through feedback cycles of erosion and deposition.

On short time scales, it has been shown with numerical models and sediment discharge records that rivers can react rapidly to landslides, but this response decays to a background level before the majority of the sediment is mobilised from the catchment. This period of rapid erosion is strongly linked to the increase in the frequency of natural hazards. Monitoring and modelling these natural hazard processes is crucial to linking short term observations with long term landscape evolution and sedimentary records. To investigate the aftermath of landslides in mountainous landscapes and the controlling factors of their impact on the landscape we have conducted in-depth studies of two locations with differing reactions to landslide events. The first site is in the Himalaya, where the 2015 Gorkha earthquake has generated thousands of landslides, but there is no significant impact on the river network. Our second site in Taiwan is a catchment that has been dramatically altered by the sediment produced by a series of large landslides over a period of several decades. By using remote sensing observations of these two sites, we propose possible explanations for their differences in response to landslides. We also identify the key processes in the sediment transport and use these observations to build a modelling framework to consider the role of landslides in mountain ranges over multiple timescales.

Poster 5-7
Exploiting high-resolution InSAR Rate Maps to the Fullest: Landslides, Fault Slip and Groundwater Changes in Northeastern Afghanistan

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Northeastern Afghanistan is located at the Asia-India continental collision zone and is frequently affected by destructive earthquakes that pose a large threat to the local communities. Over 80% of the territory is mountainous, with peaks rising well above 5,000 meters. Cultivable land is mostly confined to the river valleys with wheat cropping dominating the slopes. The resulting overgrazing and almost complete deforestation leads to slope instabilities and. In consequence, frequent landslides, like the 2015 Ab-Barik landslide that caused 52 casualties and destroyed hundreds of houses, pose major social and economic problems to the poor communities. At large cities the constantly growing population, poor governance and climate effects impede fresh water access, which, in turn, is mostly supplied by groundwater. As consequence, significant groundwater-level drop, local subsidence and infrastructure damages are reported. Nevertheless, the mitigation of omnipresent geohazards is impossible, as the region lacks ground-based instrumentation to observe and assess these.

We present open-access, high-resolution satellite interferometric radar (InSAR) data of NE-Afghanistan acquired by the European Sentinel-1 radar satellite mission over the last four years. We use pre-processed radar imagery and open-source time-series analysis software to resolve surface displacement with mm-accuracy in line-of-sight (LOS) in high temporal (2–3 weeks) and spatial (400 m) resolution. The resulting rate maps exhibit landslide activity in NE-Afghanistan, coseismic displacement, interseismic fault slip and subsidence due to groundwater level changes. Our preliminary results identify tens of active landslides in the Badakhshan province near the town of Fayzabad. In Kabul, the largest city of Afghanistan, we observe subsidence of an area of 45 km^2 with up to 13 cm of total range increase due to ground water extraction. Across the ENE-trending Herat fault and its NE-continuation, the Panjsheer fault, we observe sharp E-W rate changes of 3–7 mm/yr, caused by dextral slip, and local slope movement, probably caused by soil dynamics.

Poster 5-8
Sensitivity of landslide susceptibility or hindcast models: role of baseline landslide inventory and grid rainfall precision

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Exploring various landslide causes—covariates—in mapped landslides multivariate logistic regression models estimate landslide susceptibility, or hindcast landslides by also including rainfall. Sensitivity of these models to the input data are frequently tested given the dependence of any statistical model to covariates. However, the influence of data quality is rarely discussed, for example, whether grid rainfall estimates accurately represent spatial variability of rainfall beyond the temporal accuracy of those estimates. Model sensitivity to the sample size, location, or time of the mapped landslides is not well studied. Using an inventory that covers predominantly smaller landslides would hinder a model to sufficiently capture the diversity of the factors that lead to slope instability. Whereas larger landslides tend to represent more broadly the range of values in the covariate space likely decreasing the model performance. Another aspect is whether more landslide data over time would improve the overall accuracy of the final susceptibility estimates.

Surprisingly the model performance marginally varied after progressively adding more landslide data over time in a pilot study. Results further highlight that using only part of the individual landslides may already suffice to make accurate estimates, while using a landslide inventory that involves rather smaller landslides might outperform a model that relies on larger landslides. Lastly the accurate representation of spatial rainfall distribution has major influence on a hindcast model, and the global grid rainfall products are far from securing this.

Poster 5-9
Landslide Geometry Reveals its Trigger

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Landslide inventories rarely include the triggering mechanisms that make these inventories unusable for landslide hazard modeling. We developed a method for classifying the triggering mechanisms of landslides based on the geometric properties of the landslide's polygon. Employing a combination of feature selection methods, we choose seven geometric properties of landslide polygon that best classify the landslide into two categories: earthquakes and rainfall. We used these geometric properties of landslide polygon as a feature space for the machine-learning-based classifier random forest. Random forest is a decision tree-based ensemble learning method that is highly robust to classification and regression problems.

In this work, we use seven landslide inventories spread over the Japanese archipelago. Out of seven inventories, six inventories include the triggering information, while the rest one inventory has missing triggering information. We used various training and testing sets to achieve around 85% earthquake and rainfall classification accuracy using a known triggered inventories dataset. Moreover, In another approach, we trained the algorithm on five inventories and tested it on sixth inventories. Using this approach, We achieved mean classification accuracy ranging from 67% to 92%. We use the unknown ground truth as testing inventory for a real-world usage scenario of the developed method.

Apart from classification, we did an in-depth analysis of probability distributions of geometric attributes of earthquake and rainfall polygons. We found dissimilarities between the probability distributions of geometric attributes of earthquake and rainfall polygons. The probability distributions of geometric attributes also support classification results for the trigger of unknown ground truth inventory.

The classification results show that the developed method is robust and provides high landslide triggers classification accuracy. Furthermore, our feature importance analysis indicates that landslides having identical trigger mechanisms exhibit similar geometric properties. A long-suspected fact that we anticipate landslide modelers will find helpful.

Poster 5-10
Suspended sediment and discharge dynamics across multiple spatial and temporal scales in a glaciated alpine environment: the case of the upper Ötztal, Austria

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The mobilization and transfer of suspended sediment from alpine areas to a river system can have various hazardous effects. For example, it may alter the flood hazard in downstream riverine ecosystems, as e.g. river profiles change due to deposition of sediments or infrastructure such as reservoirs may be affected in their ability to buffer discharge peaks. As the sediment delivery from high mountain areas is particularly high, it is very important to understand the changes in discharge and suspended sediment dynamics in such areas as these areas are affected disproportionately by global warming. One of the clear consequences is accelerating glacial retreat, which can for example lead to changes in runoff volumes and hydrograph timing as well as increasing sediment source areas and the associated magnitude and timing of transport capacities.

Yet in order to assess trends and set future changes into perspective, we must understand the behavior and variability of discharge and suspended sediment transport in the recent past and present. For this purpose, we used the excellent data situation of discharge and suspended sediment concentrations in our study area in the upper Ötztal in Tyrol, Austria, to make such an assessment at three gauges and for a minimum of seven years in the case of the most recent gauge. The resulting nested catchment setup covers an elevation range between 931 and 3772 m.a.s.l., with catchment sizes ranging between almost 100 km^2 and 785 km^2. It allows us to learn about discharge and sediment fluxes and their spatial distribution, thus enabling us to quantify the relative importance of the glaciated areas as compared to the lower-lying catchment areas. It also allows us to study the temporal dynamics, such as the seasonal timing of the peaks and their inter-annual differences. In turn, the nested catchments allow us to investigate the spatial variability of these temporal dynamics.

The results confirm the high specific sediment yields for alpine catchments in the order of 10^3 t/km^2 per year and stress the importance of the glaciated areas for both discharge and sediment transport. As about 80% of the annual suspended sediment yields are transported in only 10% of the time, few events such as flooding in the mountain torrents following intense precipitation or debris flows are responsible for the majority of the annual sediment export. The areas above 2500 m, which are above the treeline and include glacier forefields, seem to be especially important for sediment export, as sediment transport at all gauges starts around the time of the year when these areas start to be snow-free.

Poster 5-11

Flash-flood induced Erosion-Prone Area Prioritization and Potential Soil Loss Estimation using RUSLE for Alaknanda River Basin

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Flash-flood-induced soil erosion is the primary cause of soil loss in the Alaknanda river basin, Uttarakhand. Extreme rainfall in the form of cloudburst, undulating topography, and inadequate soil and water conservation practices further exacerbates this problem. In the last 30 years, the region has experienced numerous incidents of flash floods, resulting in a great loss of the upper part of the soil and further leading to flooding, water siltation, and pollution. Hence, in this study, an attempt has been made to estimate and establish a sub-watershed priority list based on average soil erosion rate and vulnerability over a 30-year period (1991–2020). The long-term soil loss of the watershed was estimated by incorporating a revised universal soil-loss equation (RUSLE) in the GIS environment. The parameters of RUSLE include Rainfall Erosivity- R, Soil Erodibility-K, Topographic-LS, Crop Management-C, and Conservation Practice- P are estimated for each of the 12 sub-basins. The result showed that sub-basin number 7, lying in the central part of the watershed, is worst affected with soil loss of about 890 t/ha/yr. (17%), followed by sub-basin number 5,11 and 4 with soil loss of 689 (13%), 577 (11%) and 498 (10%) t/ha/yr respectively. Together, these four sub-basins constitute 51% soil loss, which needs prior intervention for the planning and implementation of soil conservation measures. Consequently, for the entire Alaknanda basin, the average R, K, LS, C & P factors are estimated to be 450.69 MJ mm /ha /yr., 0.071-ton h /MJ /mm, 40.63, 0.63, and 0.61, respectively. The annual soil loss ranged up to 5210 t/ha/yr. with a mean soil loss of 400 t/ha/yr. in the Alaknanda Basin. Overall, the combined use of RUSLE, GIS, and remote sensing was determined to be indispensable, less expensive, and effective for estimating soil erosion and prioritizing vulnerable sub-watersheds.

Poster 5-12

Bed non-uniformity effects on the flow resistance equations in high-gradient streams

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Flow velocity estimation in high-gradient rivers is extremely challenging due to uneven channel characteristics and complex flow physics. The accurate assessment of flow resistance in such complex situations might improve the knowledge of other related hydraulic phenomena, including the sediment transport of coarse grains (bedload). A dataset consisting of 2184 field measurements reported in the literature was used to test the predictive capability of eight conventional flow resistance equations in their original form for the prediction of mean flow velocity in high-gradient gravel-bed rivers. The results indicate considerable disagreement with the observed flow velocities for the highly non-uniform bed material ($\sigma g > 7.5$) for all the equations. However, the predictions made using the Smart and Jäggi (1983), Ferguson (2007), and Rickenmann and Recking (2011) equations were closer to the observed values of flow velocity. Furthermore, bedload sediment transport also reduces the predictive capability of the equations considered in this study except for the Recking et al. (2008) equation, which was developed considering the increased flow resistance in the case of bed-load transport. The flow resistance seems underestimated in the case of highly non-uniform bed material, and during the bedload transport, that can be corrected by considering the statistics of the bed microtopography in the form of geometric standard deviation. Here we present a semi-empirical approach using the whole dataset and its subsets for accounting for the additional energy losses occurring due to the wake vortices, spill losses, and free surface instabilities occurring due to the protrusions from the bed. The results obtained using the validation dataset shows the importance and usefulness of this approach to account for the additional energy losses. During bedload transport, statistical indices of modified Ferguson (2007) equation for validation dataset (R2 =0.86, RMSE=0.43, SI=46.57, IA=0.94) shows the betterment of this approach. The improvement in the best performing equations of Smart and Jäggi (1983) and Ferguson (2007) shows that the new approach can account for the dissipative processes that conventional equations fail to consider. The Akaike information criterion and Bayesian (Schwarz) information criterion supports the improvements in the modified equations.

Session 6

Analysis of complex changing systems

Poster 6-1

Complex network approach to study the impacts of ENSO over the United States

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Complex network analysis is a powerful tool that encodes the intricate relationship between the many components of a complex system. Functional climate network analysis is particularly designed to study the complex interactions between the different components of the Earth's climate system. As the weather changes, the dynamical interaction between the grid points or the nodes should also change. We have used an evolving climate network approach to study this evolution of interaction between the nodes over time. In our work, we study temperature and precipitation patterns in the United States using this framework. El Niño–Southern Oscillation (ENSO) is one of the most important sources of annual global climate variability, associated with characteristic patterns of rainfall and temperature, including extreme events such as floods and droughts. The United States is one of the most susceptible regions to severe weather outbreaks due to the ENSO. We use Pearson correlation and edit-distance methods as similarity measures to construct temperature and extreme precipitation networks respectively.

We study the course of evolution of the link patterns using network measures such as robust links, link density, and transitivity during the different phases of the ENSO. Through our analysis,Zwe are able to distinguish between the different phases of the ENSO, and hence, identify the different large-scale atmospheric circulation patterns associated with them.

Poster 6-2

Integrating evidence-based dynamic flood precautionary behaviour in an agent-based modelling approach

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Among the range of potential natural hazard events, flooding is the most common and regularly devastating. Flooding causes significant adverse impacts that are assumed to increase in the future due to a combination of socio-economic development and a changing climate. Therefore, understanding the processes that generate and limit (potential) flood impacts is an important research topic. Integrated flood risk management approaches that request more efforts and adaptive behaviour from flood-prone residents are on the rise, but not fully understood by now.

Agent-based modeling (ABM) allow us to reproduce complex dynamic systems, with a strength on the interaction of humans and their environment. Flood risk assessments using agent-based approaches already have been presented successfully, showing that they can be a powerful tool to reflect complex decision pathways and individual behaviours. Here, the integration of individual precautionary behaviour has proven to be an important component to estimate risks. This was implemented in different ways but without assessing different types of behaviour or evidence-based individual dynamics due to the lack of data. Recent studies based on longitudinal surveys (panel data) showed different types of dynamic precautionary behaviour among residents. Here, we present an ABM in a multi-disciplinary approach, integrating evidence-based individual precautionary behaviour. We assume that the consideration of a more heterogeneous adaptation in a model facilitates a more detailed insight in complex dynamic risk assessments. Such a model can be further used to study different scenarios, e.g. effect of changing policies.

Session 6
Analysis of complex changing systems

Poster 6-3
Complex Network Analysis of Synchronized Extreme Precipitation during the Australian Summer Monsoon

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The global monsoons have long been recognized as highly multiscale systems, with associated planetary- (e.g., the El Niño Southern Oscillation), synoptic-scale atmospheric and oceanic processes, as well as the embedded mesoscale/storm systems. The prediction of the onsets, strength (amount of precipitation) and the active / inactive phases of monsoons has been one of the most challenging tasks facing the meteorological and forecast community for many decades. Recently, research methodologies for analyzing nonlinear complex systems are increasingly applied on the global monsoons. These methodologies include complex network, which is an ideal tool to analyze the multiscale, mutually interactive processes during the development of the monsoons.

This study is a follow up to Cheung and Öztürk (2020, Chaos), which was the first study to apply complex networks of synchronized extreme precipitation on the Australian summer monsoon (ASM) development. In that study, networks based on sliding time windows before and after the climatological onset time of the ASM were examined. The networks were constructed using the Event Synchronization algorithm applied to satellite-estimated precipitation. Several major characteristic changes in the network during the ASM onset were identified. For example, the degree centrality has a distinct spatial distribution with higher degree over the north Australian continent and the low-latitude tropics, but low over the ocean in between. The link distance distribution has a shift toward a lower mean when the average onset date is approached. The clustering coefficient, a metric to examine the smoothness in the network, also shows a distinct change. The region to the north of Australia shows an abrupt decrease in the clustering coefficient just before monsoon onset, likely related to the development of more organized, synoptic rainfall system. Moreover, the identified communities in the network have interesting features. There is one community (among the seven in total) close to the oceanic region northwest of Australia, which has been used to define the ASM index. Another community to the north of the first one extends to the east substantially during the ASM onset.

This extension study aims to obtain deeper insights of how the above characteristic changes in the metrics of the precipitation networks are related to the atmospheric and oceanic processes responsible for the ASM development. During the construction of the network, the ASM onset time each year is considered to better represent the monsoon development sequence in the networks. The actual links in the network, which determine the degree centrality and link distance distribution, are examined to identify the ‘hotspots’ in the network. In order to explain the changes in the clustering coefficient, the precipitation distributions during the typical ASM onset scenarios are examined especially in regard to the presence of mesoscale and synoptic rainfall systems. For the changes identified in the communities, cross-degree across the major communities relevant to the ASM will be analyzed for potential indicator of remote drivers for the ASM. These analyses would contribute to enhanced understanding of the precipitation pattern during the monsoon development in this region, and possibly new factors for its seasonal prediction.

Poster 6-4
Combining system dynamics modeling with Bayesian Network modeling for assessing water scarcity in Iran

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Water scarcity depends on a multi-faceted and complex social-ecological system that can only be described with a high degree of uncertainty; it is influenced by many climatic and non-climatic drivers. The drivers can be highly correlated, and ignoring these correlations leads to an underestimation of risk. To account for both the inter-relation of dynamic feedbacks and the uncertainty of quantification of risk drivers, System Dynamics Modeling (SDM) and Bayesian Network modeling (BNM) has been coupled to assess water scarcity. To put the multidimensionality and dynamic aspect of water scarcity drivers in perspective, the SDM was built by a chain of interactions of hydrological, agricultural, and socioeconomic components in annual time steps from 2001–2016. This simulation quantifies variables that are used to derive indices that represent hazard, exposure and vulnerability regarding the risk of water scarcity to farmers. The estimation of the probability of the risk, computed from hazard, exposure and vulnerability is done with BNM. This framework integrates the knowledge of the different components in the form of indices, propagated by SDM-BNM, and calculates the risk of the system. We further investigate the impact of climate change by importing an ensemble of climate models in the time period 2025–2054. We implement this integrated framework focusing on the risk of high levels of water scarcity in the Qazvin Plain in Iran. This semi-arid region is facing frequent droughts, a decreasing trend of surface water availability and an extreme pressure on groundwater, leading to ecological degradation, economic losses and social problems. The SDM-BNM allows modelers to assess the sensitivity of the risk due to changes in the factors influencing the risk. In addition, the dynamic nature of risk at different time scales can be analyzed in a probabilistic manner. Such uncertainty information can greatly improve the quality of decisions made by the various actors that drive the risk, providing the decision-makers with a comprehensive view of the system to evaluate the full range of possible outcomes.

Poster 6-5
A general framework for impact assessments of compound dry-hot events on different sectors based on vine copula

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The compound weather and climate extremes have attracted more attention due to their amplified impacts on various sectors under global warming, including water resources, crop yields and ecosystems. Typical compound dry and hot events (CDHEs), such as those during 2003, 2010, 2015, and 2018 in Europe, have caused widespread impacts on human society and ecosystems. However, quantifying the impacts of compound extreme is complicated due to the multiple variables involved in the atmospheric processes and impact variables. In addition, uncertainties generally exist in the assessment of impacts from different compound weather and extremes due to the limited sample size. Thus, a flexible framework is needed in the impact assessments of compound weather and climate events or extremes on different sectors. In this study, a statistical framework is proposed for probabilistic assessments of the impacts of CDHEs based on the vine copula, which is capable of modeling complicated dependence among multiple variables. We apply the conditional distribution to quantify the impact of CDHEs on crop yields, vegetation and water resource, respectively. The study provides a useful tool for impact assessments of CDHEs to aid disaster management and mitigation measures.

Poster 6-6
Multiscale SST streamflow connectivity via wavelet complex network techniques

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Understanding the interactions between oceanic conditions and streamflow can deepen our knowledge on hydrological aspects. Most studies exploring this relationship only focus on seasonal or annual scales. However, various atmospheric and oceanic phenomena occur at different timescales and need to be accounted to attribute connectivity between sea-surface temperature and streamflow to specific oceanic and climate processes. In this study, we have investigated the influence of sea-surface temperature (SST) on German streamflow at timescales ranging from sub-seasonal to decadal. We apply wavelets' concepts to decompose the time series into multiple frequency signals and fed into complex networks to identify spatial connections. We employ degree centrality metric and average link distance concepts to interpret the outcomes of coupled SST-Streamflow networks. Our results indicate that the SST anomaly at North Atlantic Ocean region has a stable connection with German streamflow at shorter timescales up to annual scale. We also noticed scale-specific connections of streamflow in the Pacific, Indian and Southern ocean regions at different timescales ranging from seasonal to decadal scale. We observed that streamflow stations are influenced by short-range local connections at lower timescales and long-range teleconnections at higher time scale. Our preliminary analysis highlight that the low frequent streamflow extremes have long-range connections, usually not captured at the original scale, and geographical proximity plays a role in high-frequency streamflow signals. The results obtained from this study reconfirms reported existing streamflow influences and helped gain insights over other possible large-scale climatic influences.

Poster 6-7
Disentangling increasing compound extremes at regional scale during Indian Summer Monsoon

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Compound extremes exhibit adverse impacts than their univariate counterparts. Several studies reported changes in frequency and the spatial extent of extremes in India; however, investigation of compound extremes is in the infancy state. This study investigates the historical variation of compound dry and hot extremes (CDHE's) and compound wet and cold extremes (CWCE's) based on monthly precipitation and temperature during the Indian summer monsoon period from 1951 to 2019 over India's homogeneous regions. Our results unravelled that CDHE's frequency has increased by 1–3 events per decade while CWCE's are decreasing for the recent period (1977–2019) relative to the base period (1951–1976). This increasing pattern is high across North-central India, Western India, North-eastern India and South-eastern coastlines. Furthermore, a statistically significant increase in the spatial extent exists in the CDHE's across India. While there is a decline in the regions affected by the CWCE's. Our findings highlight that most parts of the country were affected by frequent and widespread CDHE's during the recent period, which is indeed an alarming situation.

Poster 6-8
Accounting for temporal variability for improved precipitation regionalization based on self-organizing map coupled with information theory

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Precipitation regionalization deals with an investigation of the seasonality and its temporal variability and is useful for a wide variety of applications in hydro-meteorology. The d homogeneous regions can be used as a basis for transforming the information from gauged to ungauged sites and can reduce the uncertainty in estimating the seasonal characteristics of precipitation across India. Despite several studies stressing the importance of seasonality and temporal variability to the environment, there is a lack of studies on accounting for temporal variability in regionalization. Precipitation regionalization must account for both the precipitation magnitude and its temporal variability at multiple time-scales to extract the seasonality of a region representing coherent local and inter-annual variability. Therefore, in this study, we propose a framework for precipitation regionalization, considering both precipitation magnitude and its temporal variability. High resolution (0.250 x 0.250) gridded daily precipitation time series over the period 1901–2013 from Indian Meteorological Department (IMD) was used for the evaluation of the framework. First, the historical daily time series was transformed into multiple time scales, i.e., annual, seasonal, and monthly time scales. Entropy-based standardized variability index was used to measure the inter-annual variability of precipitation at each time scale. Regionalization of grid points was performed using self-organizing maps, an artificial neural network. Ten distinct regions were identified that can be tied back to two general categories, such as climate characteristics and physical characteristics. Coupling of the self-organizing map with standardized variability index reveals unique seasonal distribution of precipitation for each region. The temporal evolution of clusters unravels a new emerging pattern across Central India. Consideration of temporal variability plays an insignificant role in the shape, size and stability of south-central India, south-eastern coastlines, and Konkan Coast. Intriguingly, separate Rain-belt and Rain-shadow Western Himalayas are formed due to the difference in topography and seasonal characteristics of precipitation. The temporal evolution of clusters unravels a significant change in the occurrence of the 50th percentile monsoon after the 1940s across the north-western region; a significant increase in the 50th percentile monsoon after the 1940s across western India, and decrease in the 50th percentile monsoon after the 1980s in the north-central Region.

Poster 6-9
Identifying the meteorological drivers of yield variability in Europe

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Understanding the meteorological drivers of year-to-year yield variability is crucial for estimating future changes in the frequency of harvest loss events. Here, we analyse the output of 15 different crop models from the Gridded Global Crop Model Intercomparison (GGCMI) project to identify the meteorological drivers of yield anomalies of maize and wheat in Europe. Working with simulated yield data has the advantage that yield anomalies can, in principle, be entirely explained by the climate input. The disadvantage is that individual models may not incorporate all relevant process that cause yield variability in the field, which is compensated for through use of an ensemble of models covering a range of processes. We define indicators for quantifying the occurrence and severity of four different types of extreme climate events: droughts, heat waves, frost periods, and flooding. Each type is characterized by a combination of indicators quantifying the deviation from the long-term mean (e.g., using SPEI for droughts) as well as the severity of the events (e.g., using aridity index for droughts) to assure that the identified meteorological extremes have an actual effect on yields. We find that about half of the yield-loss years (characterized by a deviation of more than 1.5 standard deviations from the mean) can be linked to at least one of the four extreme types. We aim to further improve the predictive skills of our approach by refining the employed indicators and by developing new indicators that can capture more complex compound or multi-hazard events. Such events are characterized by a sequence or co-occurrence of not necessarily extreme meteorological conditions that result in unusually low yields. The overall aim of this analysis is to derive a set of indicators that can explain a large part of yield variability and which can then be applied to climate simulations to estimate the frequency of yield-loss events in the future. Because such indicators can more easily be applied to a large set of climate simulations than process-based crop models, it provides a means to obtain robust estimates of changes in yield-loss events in the future.

Poster 6-10

Understanding compound events in fragile contexts: Examples from the Horn of Africa

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In recent years, the Horn of Africa has been increasingly exposed to compound events. Frequent extreme wet and dry conditions often compound with its fragile context characterized by internal ethnic conflicts, unstable governments, and high levels of poverty, resulting in impacts usually larger than anticipated. An improved understanding of the drivers and their interactions can help to reduce future risks associated with compound events. In this study, we conducted a retrospective analysis of the 2017–18 humanitarian crises that occurred in Kenya and Ethiopia. In this period, a severe drought lasting around 18/24 months was followed by extensive flooding. The impacts and their related drivers were explored through a quantitative review of the literature, online surveys and semi-structured interviews. The approach resulted in a participatory co-creation of cognitive diagrams used as qualitative mental maps of the perceived drivers and interactions. These were then used for modelling the impacts of immediate and long-term effects of the compound events. In the analysis, we identified the societal and physical factors that led to negative or positive feedbacks and how these mechanisms changed over time and space, highlighting the differences between Ethiopia and Kenya. Moreover, the analysis showed that certain coping mechanisms adopted by the rural communities to withstand the drought resulted in an increase in vulnerability and exposure to floods, further increasing the risk of compound disasters. Our analysis underlines the importance of boosting the positive effects of above-average rainfall on drought impacts.

Poster 6-11

Lifelines, Losses, Livelihoods: An end-to-end risk modelling chain for loss of basic services from cascading infrastructure failures

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Critical infrastructure systems are more exposed than ever to the risks of extreme weather events in a changing climate (Koks et al., 2019[1]). At the same time, the sheer size of those systems may connect seemingly unconnected weather and climate events (cf. the notion of ‘connected events' in Raymond et al. 2020[2]), leading to unexpected impact distributions. Yet, traditional risk assessment methods do not include the specificities of infrastructure dynamics, while infrastructure modelling frequently lacks the thorough treatment of natural hazard risks. Our work therefore bridges knowledge from both fields.

We demonstrate first results from a globally consistent and spatially explicit implementation to critical infrastructure failure cascades and their impacts on basic service losses from natural hazards at national scales. The model is built on globally available infrastructure asset, demand and supply data and embedded within a state-of-the-art open-source natural hazard risk modelling platform (CLIMADA, cf. Bresch and Aznar-Siguan 2020[3]). We represent infrastructure interdependencies by integrating a graph theoretical-functional hybrid model (extending an approach put forward by Thacker, Pant, and Hall 2017[4]). The end-to-end risk calculation chain starts from spatio-temporally explicitly modelled hazard events such as tropical cyclones and floods. The ensuing disruptions are modelled in a way that they respect infrastructure-specific dependencies between the power, transport, telecom and social infrastructure sectors. We hence use this information to provide an estimate of human-centric impacts (loss of power, access to mobility, healthcare and communication).

As the approach relies on generalized and transferrable dependency heuristics, is automated and draws on globally available data, we aim at providing a big-picture analysis of infrastructure risks under ever-increasing threats from extreme weather events.

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Poster 6-12
Heat Waves Occurrence Analysis Between 2017–2020 in São Paulo, Brazil

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The heat waves pose a substantial risk to human health. This paper presents a statistical perspective of heat have occurrence in São Paulo, the most populated city in South America. In 2020, Brazil experience extreme temperatures with a historical national record of 44.5 °C and the second highest temperature in São Paulo with 37.4 °C after the record of 37.8 in 2014.

The goal of this study is to provide an analysis of the heat wave observed in 2020 for São Paulo compared with previous years. The method are based on quantitative data on daily values of maximum temperature between 2007 and 2020 obtained at the National Meteorological Institute of Brazil. A complementary data analysis was made using hour resolution for 2020. Different definitions of a heat wave exist, this study use the World Meteorological Organization definition as a sequence of five or more consecutive hot days during which the daily maximum temperature exceeds the average maximum air temperature by 5 °C.

In general, results indicate 2014 as the record year with 34 days of heat waves and 2015 with the highest temperatures of 36.7 °C. During 2020 a total of 2 heat waves were observed for eleven days, one in September during 5 days with 33.4 °C (maximum hour temperature with 34.1 °C) and the second on November during 6 days with 32.4 °C (maximum hour temperature with 33.6 °C). Even though the national temperature record were registered in 2020, the heat waves observed were not the longest and strongest register in the particular case of São Paulo city. Finally, as a conclusion in 2020 São Paulo did suffer the historical heat waves for the city.

Poster 6-13
Exploratory agent-based model to understand migration in Indian Himalaya Region

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Researchers argue that climate change impacts might manifest in migration patterns due to 1) an increase in the experience of risk due to natural hazards and resulted in socioeconomic disturbances, 2) a change in natural resource conditions through time, and 3) perception of risk due to climate change. Migration due to climate change will follow and reinforce the established channels. Migration is prominent in Indian Himalayan Region in the state of Uttarakhand in India. However, migration studies in this region have not been seen through complex adaptive system (CAS) lenses and analyzed using simulation experiments. This study captures the complexity and dynamic behavior of migration in the Tehri Garhwal district of Uttarakhand using agent-based modeling (ABM). Scenarios considering different starting points were developed to understand variables influencing migration. Exploratory simulation techniques can add to the understanding of migration-related complexity and act as a base to test hypotheses and assumptions about the system.

In this study, the worst-case scenario highlights that without any policy intervention regarding current migration, the villages in the study area might turn into ghost villages. The holistic development scenario emphasizes that the opportunity to enhanced income through alternate livelihoods, along with better education and health facilities, can curtail migration. However, with the exploratory agent-based model, it is evident (scenario 3: livelihood focused) that even if income levels are increased, migrants will continue to migrate in absence of infrastructural facilities. The study shows that enhanced income alone cannot change the agent’s decision to migrate. Thus, migration is an outcome of complex human-environment interaction and not a purely economic or linear phenomenon. Therefore, policymakers must link all the factors that interplay in a system for a clearer picture and to make informed decisions. Presently, most of the health and education infrastructure is either inadequate, ill-equipped, or difficult to reach due to its distance from the village, resulting in migration.

Human-environment interactions are governed and regulated by policymakers through different policy instruments. Therefore, knowledge of the probable range of future outcomes can improve policy decisions. Exploratory ABM facilitates these decisions by utilizing a variety of secondary data that are available through government and institutional documents and websites. Though a simulation of human-environment interaction is inherently complex and intricate, exploratory ABM can capture the essence. The methodology can also be used in other study areas to explore similar migration issues. Migration study through using a CAS perspective has the potential to divulge the intricate linkages that might not be operational at the decision-making level. Research highlights that migration decision is a proactive diversification strategy to cope with a long-term decline in livelihood rather than a reactive response to the onset of a natural disaster. The study reveals that development interventions should not only focus on enhancing livelihood options but also on improving health and education facilities within the area to have any effect on the current migration trend.

Contributions, feedback and ideas are very welcome.

Poster 6-14

Capturing the drivers and dynamics of adaptation strategies in mountain agriculture communities

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The communities inhabiting the fragile mountain regions are disproportionately vulnerable to climate-related changes due to their high dependence on climate-sensitive livelihoods. Negative impacts are being observed in the agriculture sector, one of the primary sources of livelihood. Research highlights that adoption of adaptive strategies is influenced by socio-economic characteristics, risk perception factors, and preferences of individuals. However, these drivers are not standard but vary significantly across different farmer types, social groups, and geographical zones. Identification of factors that determine the choice of farmer's adaptive strategies is essential in maintaining the livelihoods of these vulnerable communities. Estimating the efficacy of these adaptive strategies in future climate scenarios is necessary for these strategies to be successful in long-term scenarios. The proposed research investigates the drivers (rules) for adopting adaptation strategies by different farmer types in the vulnerable hotspots of Uttarakhand state. Agent-based modelling (ABM) will simulate the effect of future climate change scenarios on present-day adaptation strategies. Empirical data has been collected through field-based interviews with the farmers in villages identified as the hotspots of vulnerability. The study results will help in a comprehensive understanding of farmers' adaptation in decision-making processes enabling a more targeted policy.

Poster 6-15

Agent-based socio-hydrological model for analysing human-drought feedbacks in dryland regions

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The Horn of Africa Drylands (HAD) region is one of the most vulnerable regions to climate-related risks, including droughts. The rural livelihoods of countries in the HAD region are highly dependent on rain-fed agriculture and livestock herding (agro-pastoralism), which is extremely sensitive to weather and climate variability. The communities tend to have low socio-economic levels and a low adaptive capacity to climatic shocks, such that recent severe droughts have dramatically increased food insecurity, leading to livestock loss and major water shortages. Adaptation behaviour by agro-pastoralists influence drought hazard, however, only few drought models incorporate these feedbacks in drought analysis. In this research we present a dynamic drought adaptation modelling framework that combines socio-hydrological and agent-based modelling approaches. By coupling the spatially explicit hydrological Dryland Water Partitioning model (DRYP) with a behavioural model capable of simulating different (bounded rational) behavioural theories, the model enables simulating the feedbacks between the environment and agro-pastoralists and agro-pastoralists among each other (both through 'communication structures' and indirectly via their water and land use). Model parameterisation is informed by qualitative data on adaptive decision behaviour of agro-pastoralists, applied to the upper Ewaso N'giro river basin in Kenya. We demonstrate that it is possible to capture adaptive human-drought feedbacks, laying the foundation for in-depth analysis of human-drought feedbacks and future climate and policy scenarios. Through the Horizon 2020 Down2Earth project, this model will contribute to increase drought resilience in the vulnerable HAD region.

Poster 6-16
Synchronicity of heavy rainfall induced by atmospheric rivers over North America

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Atmospheric rivers (ARs) are dynamical features of the low atmosphere, responsible for much of the moisture transport in the midlatitudes, that can produce copious amounts of precipitation as long as an external uplifting mechanism is available. In particular, land-falling ARs are strongly linked to heavy precipitation over the orographically complex western coast of the United States. Recently, complex network approaches have proven to effectively extract spatiotemporal variability patterns from climate data and have contributed to significant advances in the understanding and prediction of extreme weather events. In this study, we investigate the synchrony and interdependency of heavy rainfall occurrences related to ARs along the west coast of North America and the underlying physical mechanisms. We use the SIO R1 catalog of land-falling ARs and the daily rainfall estimates of the ERA5 reanalysis project during the period 1980–2018 to construct complex climate networks by applying the nonlinear Event Synchronization measure to the rainfall events above the 95th percentile. Our results reveal substantially different spatiotemporal rainfall patterns depending on the presence (or absence) of ARs. On the one hand, we find that ARs are linked with highly interconnected regions of synchronous heavy rainfall along the coastline and the adjacent Pacific Ocean. On the other hand, weaker but significant connections are observed over the continental North America in the absence of land-falling ARs. Also, the underlying atmospheric conditions differ visibly and exhibit a robust decadal pattern that is, however, highly variable for seasonal means. Resolving the typical synchrony structures of heavy rainfall related to the land-falling ARs, should lead to improved understanding of hydroclimate variability, likely leading to improved seasonal predictability of extreme precipitation.

Poster 6-17
Towards a multi-risk, multi-sector, systemic approach to risk management

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Most research and policy still addresses risk from a single-hazard, single-sector, perspective. This presents obstacles for addressing real-world challenges. First, multiple hazards can have interrelated effects on risk. How can risk be better managed by considering these interrelated effects? Second, DRM measures may increase risk from another hazard. How can we better account for these dynamic feedbacks between drivers? Third, these interrelated effects have impacts across sectors. How can we account for these trade-offs and synergies across sectors, regions, and hazards? These challenges exist within the context of an increasingly interconnected world, increased pressure for space, and climate change, in which the magnitude and frequency of single and multi-hazards are changing at an unprecedented rate.

MYRIAD-EU is a new project that aims to enable policy-makers, decision-makers, and practitioners to develop forward-looking disaster risk management pathways that assess trade-offs and synergies across sectors, hazards, and scales. We will co-develop a framework for multi-hazard, multi-sector, systemic risk management, and state-of-the-art products and services to operationalise the framework. This will be tested with stakeholders in 5 Pilots: North Sea, Canary Islands, Scandinavia, Danube, Veneto. In this contribution, we present our plans and vision and look for links with existing risk multi-risk projects and activities.