The Era of Resilience
Mitigating Climate Risk

Preventing, preparing and adapting for a secure future

A compendium of essays for the Allianz Climate Risk Award 2022

November, 2022
Munich, Germany

Allianz
Climate Risk Award

About the compendium

Since 2017, the Allianz Climate Risk Award has supported young scientists whose research improves our understanding of climate change-related risks. The 2022 Edition supports researchers whose work focuses on:

- Reducing the risk of extreme weather events that are intensified by climate change
- Fostering resilience by applying technological solutions

The compendium is a compilation of selected essays based on the criteria ofinnovation, research excellence, applicability and impact, from applicants of the 2022 Allianz Climate Risk Award. This compendium is issued online only and is published exclusively for didactic purposes.

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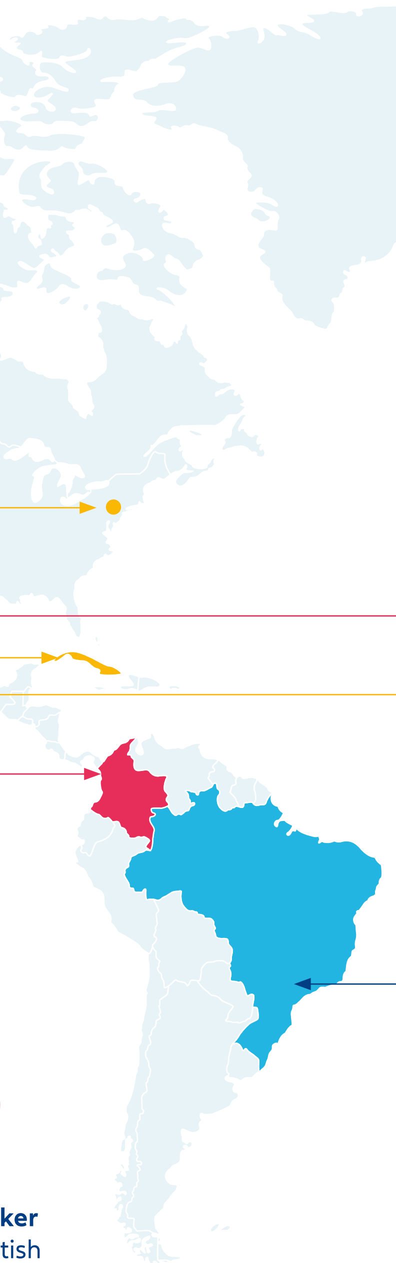
Locations of the contributors

Rapidly spinning storms are known as cyclones, hurricanes or typhoons depending on where they occur. They are among the most destructive forces on the planet as they are associated with strong winds, high storm surges, large waves and associated rains. One of the fundamental questions concerning climate science is whether these storms are getting worse and, if so, what role does global warming play?

Mona Hemmati
Nationality: Iranian
Location: United States

Peter Pfleiderer
Nationality: German
Location: Germany

Emily Vosper
Nationality: British
Location: United Kingdom



Benedikt Mester
Nationality: German
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Location: United States

Laddaporn Ruangpan
Nationality: Thai
Location: Netherlands

Laurence Hawker
Nationality: British
Location: United Kingdom

Since 2008, floods have displaced more than 166mn people, accounting for 54% of all disaster-related displacements. Low-income and fragile states are often hardest hit. But industrialized countries are also at risk of displacement: the 2021 European floods in Germany, the Netherlands, and Belgium destroyed hundreds of homes and left 83,000 people homeless or forced to evacuate. Four candidates this year focused on various aspects of flooding, how to predict and monitor it, and how to mitigate it.

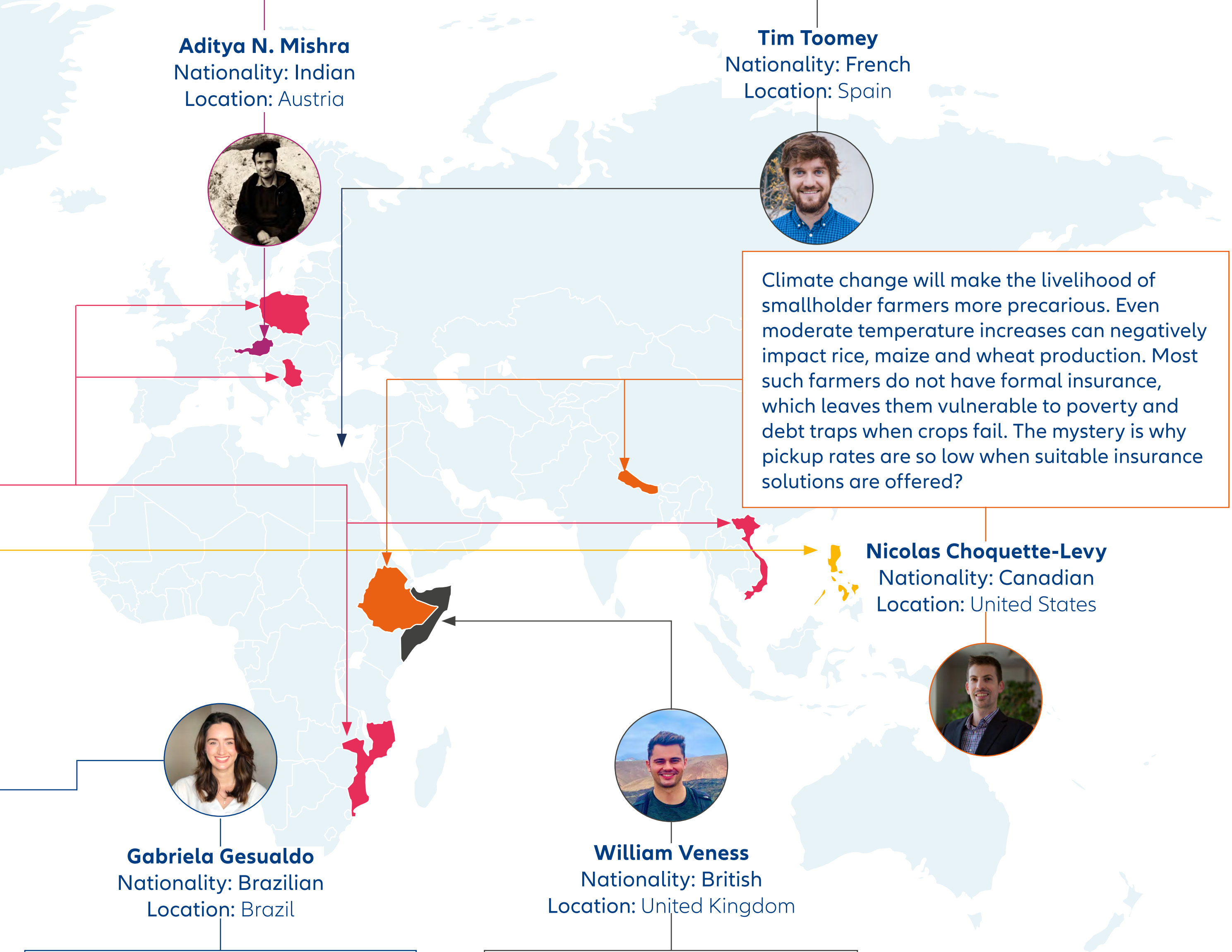
Sources: EPA, EOS, IPCC, NOAA, The Economist, United Nations, USDA

Annually more than 4,000 people die in landslides, and costs run into the billions of Euros. More frequent and intense rainfall could trigger more landslides, debris flows (rapidly descending earth) and rockfalls. The connection between climate change and increased landslides has long been discussed. In the last two decades, much work has been conducted on slope stability to advance the understanding of the threat landslides may pose in decades to come.

Aditya N. Mishra
Nationality: Indian
Location: Austria

The Mediterranean generates tropical-like cyclones, but they are rarely reported because they fail to generate the storm intensity recorded elsewhere. This does not mean they are not dangerous. Such medicanes, as they are known, can cause extreme sea levels causing destruction from storm surges and coastal flooding. However, there have been relatively few studies conducted on the phenomena.

Tim Toomey
Nationality: French
Location: Spain



Climate change will make the livelihood of smallholder farmers more precarious. Even moderate temperature increases can negatively impact rice, maize and wheat production. Most such farmers do not have formal insurance, which leaves them vulnerable to poverty and debt traps when crops fail. The mystery is why pickup rates are so low when suitable insurance solutions are offered?

Nicolas Choquette-Levy
Nationality: Canadian
Location: United States

Gabriela Gesualdo
Nationality: Brazilian
Location: Brazil

Coping with climate chaos requires a clear focus on mitigation and adaptation. Still, risk pooling might make it easier for countries to finance disaster relief programs and reduce the magnitude of overall losses. In an ideal risk pool, the scale of the pool must be such that individuals exposed to different kinds of risks experience them at different times, which is theoretically possible in Brazil in terms of droughts and flooding.

William Veness
Nationality: British
Location: United Kingdom

Climate chaos is altering the natural pattern of droughts, making them more frequent, longer, and more severe. The IPCC believes that areas will increasingly become drier with soil moisture decreasing and an increased likelihood of drought. Better impact indicators need to be developed to respond to the threat of drought, particularly in developing countries that are on the frontline of climate change.

Introduction

Celebrating Science for a Better Future

HOLGER TEWES-KAMPELMANN
(CEO Allianz SE Reinsurance)

Our Allianz Climate Risk Award has been supporting talented researchers who focus on reducing the risk of extreme weather events since 2017. It is important for us to bring together insurance and academia in the work we do here at Allianz Re, and the Award is one way for us to give back to the scientific community. It was also created to strengthen the dialogue with the scientists of tomorrow: We at Allianz know that collaboration is key in combatting climate change, and we must work together to secure the future for the next generations.

As an insurer, we work with the latest insights from climate science to continuously adjust our underwriting and modelling approach in response to a climate-related rise in loss frequency in the property market in particular. A warmer atmosphere will see more frequent and severe natural disasters and extreme weather events, which will also occur outside traditional high-exposure zones. To understand how these changes will shape the natural catastrophes of the future, we rely on the work of scientists like those we are celebrating with our Award.

A future-focused insurance industry also needs to place a greater emphasis on fostering resilience. Building increased climate resilience will be a key element of a sustainable insurance market in future. Here, too, we need insights from science to succeed.

The Allianz Research Fellowship

We created the Allianz Climate Research Award to support science as well as to understand and learn from the current state of the art across research institutes. In some cases, the Award has led to collaborations with our inhouse team of Cat specialists to translate science into business, and I hope that we will see more collaborations like this in the future.

To complement the Allianz Climate Research Award and to support climate risk-related research more proactively, we intend to run an Allianz Research Fellowship as of next year. This Fellowship is tailored to support innovative research projects on topics aligned with our climate strategy.

Our Fellowship is open to researchers from all universities and research institutes worldwide, including NGOs, and targets Post Docs in particular. We will fully fund a one year research project and will offer a close partnership with us to provide further support and insights to the research project.

Climate change and its effect on natural perils is one of the main challenges we and future generations have to face. Our promise is to continue to strengthen the ties between the scientific community and the insurance industry so we find better solutions to make our world more resilient.

Foreword

Managing Risk in a More Complex World:

The state of research on understanding and financing risk and resilience

NICOLA RANGER
UK Centre for Greening Finance and Investment
University of Oxford

The nature of risk is evolving; climate change, biodiversity loss and our more interconnected economies mean that our economies face new risks that are more severe and complex and have longer-lasting impacts on our societies. Our approaches to understanding risk need to evolve in line with this, but so must our approaches to managing risk. There is no one silver bullet solution but finance must play a crucial role. The financial decisions taken today can shape the structures of our economies over decades. While action is advancing to align financial flows with our ambition to limit global temperature rise to 1.5C, we are a long way from aligning our financial system with our resilience goals. I argue firstly that insurance and risk financing can play a critical role in helping to ensure that finance works for societal resilience rather than against it; and secondly, that to align finance with resilience we need a common language of risk as a foundation for action.

We need to aim for 1.5C but plan for 3C. Even if we take the most optimistic view of current government pledges, global temperatures are expected to rise by around 1.8C this century. If we look only at real-world action based on current policies, this would increase to 2.7C (2.2 – 3.4C with uncertainties). This level of warming will lead to structural shifts in our economies and major changes to the global risk landscape, putting people at growing risk.

Financial decisions today impact on societal risks for decades; yet do not account for these climate-related physical risks. For example, around 2.7 trillion per year is invested globally in infrastructure yet much of this without meeting basic resilience standards. Nearly half of the FTSE 100 index companies rely upon supply chains that are exposed to droughts, floods and water scarcity. Yet, the 2022 progress report of the Task Force for Climate-related Financial Disclosures (TCFD) showed that physical climate risks are still underpriced across the financial system. Article 2.1c of the Paris Agreement called for finance to be aligned with climate resilient development; but the evidence clearly shows that this is not happening in practice. Even looking at government expenditure, recent research by the University of Oxford shows as much as 30% may be in areas that could be maladaptive.

Insurance and risk financing can play a crucial role in helping finance and investment – public and private - to align with societal resilience goals. Firstly, through its traditional risk transfer role, insurance is essential to protect people and economies. But importantly, it can also help to unlock the investment needed in adaptation through providing an important risk signal across the wider economy and financial system that can act as an economic incentive for action. The industry can play a key role in catalyzing resilient investment directly through its own investment portfolios and through its relationships with its clients and governments. For emerging and developing economies, insurance also plays a crucial role in mobilizing investment for mitigation and adaptation through de-risking.

To empower insurance as such a resilience catalyst, and support the wider alignment of finance with resilience, the world needs a common language of risk. At the University of Oxford, in partnership with the Insurance Development Forum and international partners, we have been working toward the development of the world's first fully open and globally consistent risk dataset, the Global Resilience Index Initiative. This open climate risk data architecture – launched at COP27 – aims to help level the playing field in risk understanding and enable new financial solutions for resilience. We draw upon the best science from around the world and aim to put this to work to support global resilience. Our partnership with the insurance industry is key to the success of GRII, enabling us to draw upon the world-leading risk knowledge of the industry. For this reason, we applaud the work of Allianz Reinsurance to advance risk knowledge through the Allianz Climate Risk Award.

When the earth slips beneath our feet

Author

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Biography

Aditya N. Mishra is a Ph.D. candidate at the Wegener Centre of the University of Graz. He is part of an interdisciplinary doctoral program on climate change. Aditya is climate modeler working on extreme rainfall events in central Europe and its impact on local communities. Besides modelling, he investigates the changes in extreme rainfall trends in Europe and the large-scale drivers behind such events.

Title of thesis

Understanding and attributing extreme rainfall events

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Heavy rain lashed Central Europe in June 2009, triggering a series of natural disasters. In Austria, the results were flooding and devastating landslides as the moist soil tore away from hillsides. This investigation focuses on the landslides, finding that climate change magnified the event. A similar event in the future would be even more potent, but climate-resilient land use and land cover change could provide protection.

The 2021 IPCC report emphasizes the contribution of human-induced warming to the growing intensity of extreme rainfall events worldwide. Central Europe, as well, will become wetter with an increase in extreme rainfall events, especially in summer. The most recent impact of an extreme rainfall event was the European floods in June 2021, where at least 177 deaths were recorded in Germany alone.

As we brace for more extreme rainfall events in the future, we will need more than improved rainfall prediction skill to prevent irreversible damage to life and property. Enhanced information concerning the risks and hazards in vulnerable regions could boost preparedness, disaster management and adaptability.

Developing landslide storylines

In this study, we primarily focus on an extreme rainfall event in June 2009 that triggered around 3000 individual landslides in the south-eastern state of Styria in Austria. We developed and applied an event storyline approach to exploit a well-dated landslide data set.

A well-dated landslide data set is essential to link actual landslides to individual hydrometeorological events. Previous climate change studies on landslide hazards have often suffered from the limited availability of precisely dated landslide data.

We developed four storylines (see Figures 1 & 2 for storyline names) based on the boundary conditions from four CMIP5 General Circulation Models (GCMs). These were fed into a high-resolution climate model to simulate a counterfactual past that is 1°C cooler compared to the actual world of 2009.

For future storylines, we modeled the event for three warming scenarios: 0.5°C compared to 2009 (Paris Agreement), 3°C and 4°C. After that, the impact was assessed using a statistical landslide model. This is completed discretely, as one cannot translate the change in risks of extreme rainfall to the change in risks of the associated impact due to a complex response function.

Changes in the landslide event

This study finds that landslide risk in a cooler world is as much as 16% lower compared to the 2009 event, with a drop of 14% in high-intensity, short-duration rainfall (Figure 1). In the worst-case future scenario of 4°C warming, landslide occurrence risk rises by up to 66%, and the landslide risk area could increase by 45%. However, if humankind can achieve the Paris Agreement goal, it could help contain this increase to about 10% (Figure 2).

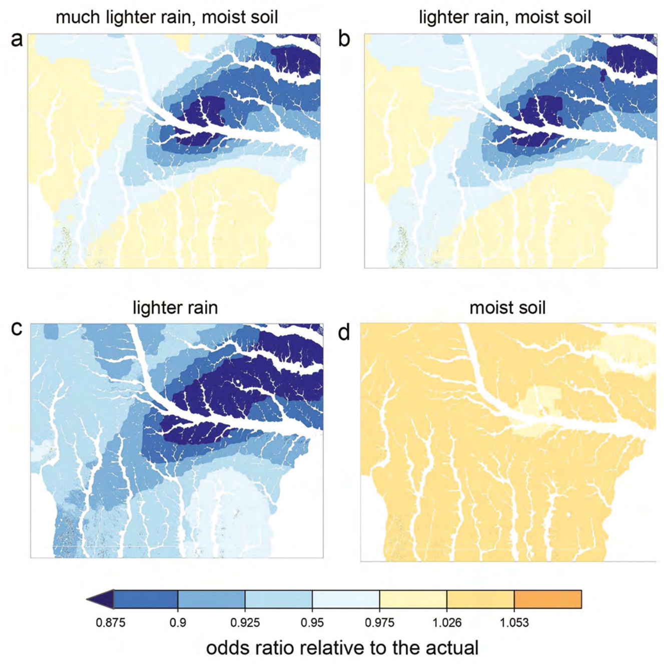

Figure 1: *(a-d) storylines of past landslide odds ratios in the affected region. (c) up to a 16% reduction in odds ratio.*

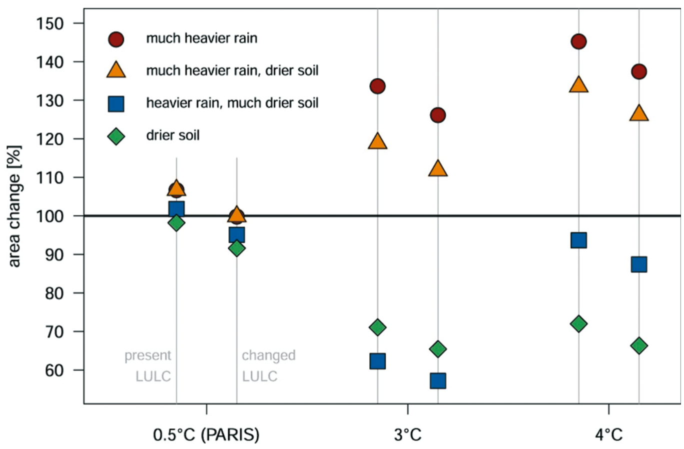

Figure 2: *Future storylines of the affected area. Note parallel vertical lines for LULC changes.*

Climate-resilient land use

We also develop a future land use & land cover (LULC) scenario in collaboration with local authorities towards a climate-resilient mixed-leaf forest. These anticipated LULC changes would help reduce the landslide risk compared to storylines with unchanged LULC conditions.

With a climate-resilient LULC change, the risk can be lowered from 45% to 37% in the worst-case scenario of 4°C warming, while it could be completely neutralized if the Paris Agreement is achieved (Figure 2).

Losing your home in a changing climate

Author

Benedikt Mester

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Biography

Benedikt Mester is a Ph.D. researcher at the Potsdam Institute for Climate Impact Research and the University of Potsdam, Germany. His research focuses on disaster-induced displacement risk in the context of climate and socio-economic change using numerical models, remote sensing, and machine learning techniques. An environmental engineer by training, Benedikt gained experience in flash flood warning systems and local flood protection modeling, which motivated him to investigate the role of climate change and societal vulnerability from a global perspective.

Title of thesis

Disaster-induced displacement under global change

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Flood-induced displacement is a global challenge of our time. Extreme flooding, which is projected to increase in magnitude and frequency due to global warming, already displaces 12mn people yearly. This calls for innovative approaches to understand the role of climate change in displacement disasters and the underlying complexity of vulnerability.

Since 2008, floods have displaced more than 166mn people, accounting for 54% of all disaster-related displacements. Low-income and fragile states are often hardest hit; for example, hundreds of thousands of people fled their homes after the 2022 Pakistan floods.

But industrialized countries are also at risk of displacement: the 2021 European floods in Germany, the Netherlands, and Belgium destroyed hundreds of homes and left 83,000 people homeless or forced to evacuate. For years, the number of reported displacements has been increasing and is three times higher than conflict-related displacements.

Our work seeks to understand two things: First, why are some countries less vulnerable, as defined by the ratio of flood-related displacement to the number of people affected by floods? Our intuition suggests that financially prosperous countries are less vulnerable to displacement – the richer the country, the higher the dams. Indeed, differences in vulnerability can be partially explained by economic levels, but only to a limited extent (Kakinuma et al., 2020).

Our second research question aims to understand the role of climate change, specifically, did the observed changes in sea level and storm wind speeds exacerbate extreme coastal flooding by Cyclone Idai, leading to more displacements? And how would this historic flood event have looked under different future greenhouse gas emission scenarios?

Assessing vulnerability – beyond economic indicators

First, we matched a recently released inventory of 913 historic flood footprints (Tellman et al., 2021) derived from satellite imagery with a displacement database to create a new dataset of impact and exposure to displacement (Mester et al., 2022).

We then investigated differences in vulnerability within and across countries by linking event-specific exposures with socio-economic data. Our findings show that at the national level, the extent of critical infrastructure affected is one of the main determinants of vulnerability to displacement. This potentially represents a lack of development that weakens a society's resilience and is not defined by pure economic indicators.

We also demonstrate that subnational indicators vary across countries, with the degree of urbanization and forest area being critical factors. This information is valuable for humanitarian organizations to identify vulnerability 'hotspots' and serves as the basis for a general vulnerability function for flood risk analysis.

Cyclone Idai and the role of climate change

We chose Cyclone Idai as a case study to attribute the impacts of climate change on flood-induced displacement. Idai is one of the southern hemisphere's most devastating storms on record and displaced more than 470,000 people in Mozambique in 2019.

Sea level rise off the coast of Mozambique is similar to the global trend of 23cm, and the annual means of maximum wind speeds show an increase of 10 kn (5.1 m s^{-1}) over the last decades. Both variables, the underlying sea level and storm wind speed, are the main drivers of coastal flooding, and intensification is anticipated to exacerbate the societal impacts.

We simulated a counterfactual coastal flood by removing the effects of global warming and compared the results with a factual model driven by present-day climatic conditions (Mester et al., 2022). We find that climate change has already substantially increased the displacement risk by approximately 3.4%, corresponding to 16,000 - 17,000 additional displacements.

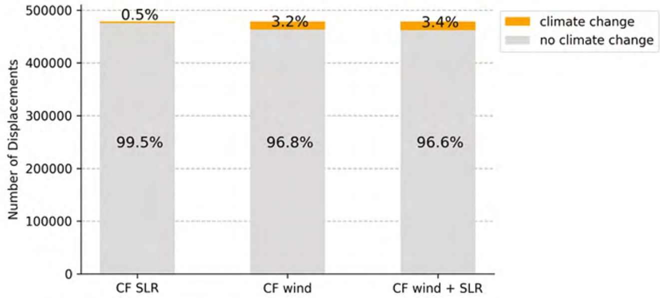

Figure 1: *Simulations of a counterfactual Cyclone Idai indicate the estimated number of displacements attributable to the effects of climate change (orange). Investigated cyclone drivers are sea level rise (CF SLR, left), wind speed intensification (CF wind, middle), and a combination of both (CF wind + SLR, right).*

Using the projections of the IPCC's latest assessment report AR6 for sea level rise and temperature increase associated with storm intensity (Chen et al., 2021), our results for Cyclone Idai under future conditions show a great spread regarding estimated displacements, which depend strongly on the greenhouse gas emission pathway.

A counterfactual event in a world with global temperatures below 2° results in a maximum 2% increase in displacements for projected conditions in 2050 and 11% in 2100, neglecting changes in population size. However, under a very high emissions scenario, the number of estimated displacements would increase by nearly 25% (2050) and 35% (2100).

The direct and indirect impacts of flood-induced displacement are felt in all parts of the world. Our results are a first step in developing a vulnerability function, which can be used for future displacement projections.

Understanding the role of climate change is another factor necessary for assessing displacement risk. Our approach concerning the impact of Cyclone Idai in Mozambique is the first of its kind on displacement, with low-income countries often being under-represented among attribution studies.

We demonstrate that climate change has already contributed to the displacement risk. Depending on the degree of atmospheric warming, the flood event would have been even more disastrous under future conditions. With this work, we aim to raise awareness about the complexity of flood-induced displacement and call for more climate action to mitigate the societal impacts of future extreme flood events.

Growing flood risks: how can we deliver equity?

Author

Daniel Kahl

Institution

University of California, Irvine

Biography

Daniel Kahl is a Ph.D. student in the Flood Lab at the University of California, Irvine (UCI). Daniel received his Bachelor's in Marine Biology from the University of California, San Diego and worked as an environmental consultant studying natural resources. After four years in industry, he transitioned to a M.S./Ph.D. program at UCI to study hydrodynamic modeling and coastal sediment dynamics. Daniel's research involves improving large-scale flood simulations using publicly available information on infrastructure and population demographics to understand community vulnerability. NASA recently funded a proposal spearheaded by Daniel to develop satellite technology to improve coastal flood hazard predictions and inform sediment management strategies along the California coast.

Title of thesis

Integrating Infrastructure and Population Demographics to Inform Regional Flood Risks

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Flooding is the costliest natural disaster globally, but the risks are unevenly distributed across social and demographic groups. By applying a framework intersecting fine-resolution flood models with population information, we can identify who is at greatest risk and promote equity by measuring how proposed solutions re-distribute risks across the population.

Flooding from extreme weather events, including tropical storms, coastal surges, and prolonged rainfalls, poses significant risks to human populations and structures. Losses from flooding have been on the rise for decades globally and are increasingly concentrated in areas of high population densities and high physical and social vulnerabilities.

In 2021, flooding cost the global economy over USD 82 bn affecting nearly a third of the world's population. It is predicted that in 30 years, these flood disaster risks will increase tenfold. Additionally, the recent 2021 IPCC Assessment Report supports uncertainty in future conditions due to irreversible anthropogenic climate change.

As with most disasters, flood damages are not evenly distributed, with poor and non-white populations being disproportionately affected and offered less protection by infrastructure. It is essential to identify such inequalities, especially considering recovery from floods is often prolonged and incomplete among socially marginalized and vulnerable communities.

The compounding uncertainty in future hazards, with unquantified populations and assets exposed, demands new tools to address the inequality of such disasters. In response to this global need, an innovative framework was designed to reveal the magnitude and inequity of flood exposure at the regional level.

Fine-resolution regional flood modeling

The framework's foundation lies upon the Parallel Raster Inundation Model (PRIMo). PRIMo is a dual-grid flood model incorporating fine-scale topographic data with a coarse computational grid. With this innovative dual-grid and parallelized approach, PRIMo addresses the computational bottleneck of large-scale models without overtly sacrificing predictive accuracy.

A weakness of large-scale modeling is that flood hazards in urban areas, where population density and vulnerabilities are greatest, are somewhat crudely estimated. This is caused mainly by the loss of intricate flow pathways and blockage features, such as individual streets, alleys, drainage networks, and protective infrastructure, such as flood walls and levees. Representing this fine-scale information while capturing flood dynamics over regional-scales is a trade-off modelers are often forced to make.

To address this, we developed a semi-automated method to ingest spatial information of flood infrastructure, such as levees and flood walls, which allows large-scale flood models to match the results of fine-resolution models more closely. Our results show that applying our levee method yields improved performance of large-scale models at 300x the compute speeds of a similar fine-resolution model. Our research results in a flood model capable of capturing patterns of street-level flooding at regional scales from precipitation, streamflow and coastal surges.

Novel population disadvantage index

While flood maps are a valuable tool for visualizing flood prone areas, additional layers of data are needed for a detailed risk assessment of affected populations and assets. Understanding flood impacts requires quantifying the number of people at risk, the amount of property exposed, the population's capacity to recover and the socioeconomic and racial inequalities within affected areas.

Information on property parcel levels, or finer, is publicly available for most developed and developing countries. Estimates of income, race and ethnicity can also be gathered from publicly available datasets. Unfortunately, combining all these vulnerability indicators into an evaluation of population risks isn't necessarily straightforward.

To address this, we developed a novel, high-resolution assessment of neighborhood disadvantage, coined the Neighborhood Disadvantage Index (NDI), which represents the capacity of communities to cope with flooding at the neighborhood scale. NDI was developed to incorporate 25 different indicators into one scale, accounting for neighborhood disadvantage, urban and concentrated poverty, neighborhood effects and residential segregation.

Framework for assessing inequitable flood hazards

By combining an innovative regional model and a novel vulnerability index, our framework offers a quantitative approach to assess compound flood risks. This approach intersects flood hazards from rainfall, streamflow and storm surge with measures of exposure and vulnerability based on ethnicity, race and socioeconomic disadvantage.

When applied to the Los Angeles Basin (U.S.), with a population of over 18mn and a USD 880B/yr economy, we found between 197 and 874 thousand people and between USD 36 and USD 108bn in property fall within the 100-year flood zone. These risks are disproportionately higher for non-Hispanic Black and disadvantaged populations that may have more significant challenges recovering from a flood disaster.

This framework can be used to assess the risk reduction from proposed investments into flood infrastructure and evaluate which populations benefit. By intersecting scientific disciplines that have been traditionally separated, our methodology creates opportunities for greater environmental justice when addressing urban flood risks.

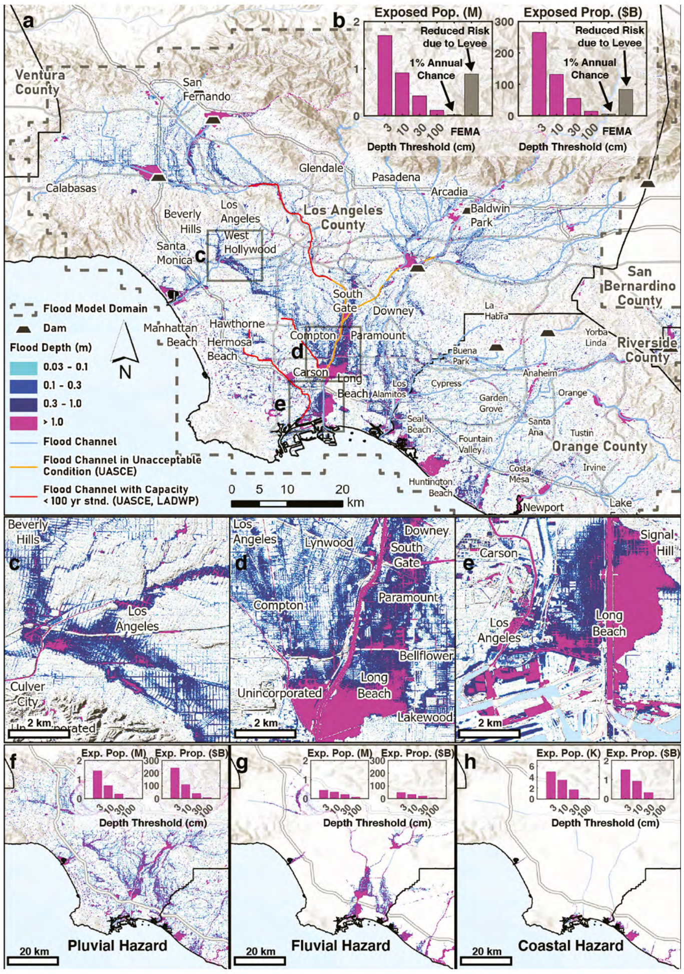

__Figure 1:__ Compound flood hazards impacting populations in millions and property values in ($) billions in Los Angeles, U.S. (1a-b). A closer view of flood extents in downtown Los Angeles, south Los Angeles, and Long Beach is shown in 1c-e. Exposed population and property is shown as for each hazard drivers 1f-h.

Through the AI of the storm

Author

Emily Vosper

Institution

University of Bristol, United Kingdom

Biography

Emily is a multidisciplinary PhD candidate at the Schools of Geographical Sciences and Computer Science at the University of Bristol. Her research combines Artificial Intelligence with Climate Science to assess the impacts of extreme events, such as tropical cyclones, on society. Emily is developing a downscaling model for tropical cyclone rainfall risk quantification by using techniques from the field of Computer Vision.

Title of thesis

Machine Learning for explainable tropical cyclone downscaling and future climate change risk management

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Tropical cyclones are one the world's most colossal natural disasters with the potential to impact entire countries. Though synonymous with severe winds, the flooding from tropical cyclones often causes the most damage and highest mortality.

The past two decades have seen significant advances in our understanding of the effects of global warming conditions on tropical cyclones. It is now widely agreed that climate change will lead to a greater proportion of intense tropical cyclones, and with a hotter atmosphere, tropical cyclones can hold more water.

To reduce the impact of tropical cyclones on society, it is not only vital to understand how they are affected by global warming but also how their flood risks are expected to change. With decision-making guided by thorough scientific insight, we can improve adaptation and resilience efforts in a targeted way.

Current predictions are computationally expensive

Traditionally, climate risk is quantified using output from general circulation models (GCMs), physics-based climate models that simulate the global atmospheric system under various greenhouse gas concentrations. Since these models simulate data for the entire globe, they struggle to accurately resolve tropical cyclones (typically between 200-500 km in diameter) at their standard resolution of 100 km.

While model resolution can be increased to improve tropical cyclone precipitation estimates, these simulations are extremely computationally expensive and can take months to run.

Given that tropical cyclones are high-impact, low-probability events, generating sufficient high-resolution data is critical to accurately evaluate regional flood risks. The well-established solution to this is to employ a 'downscaling' technique. In short, downscaling models use the outputs from GCMs to simulate tropical cyclones over a specific region and offer a computationally cheaper alternative while conserving – or even improving – performance.

Looking to machine learning techniques for inspiration

Increasingly, rainfall downscaling studies have adopted machine learning techniques from a field of Computer Vision called image super-resolution, which specializes in enhancing low-resolution images. Following their success in classical image super-resolution problems, machine learning models called conditional Generative Adversarial Networks (cGANs) have been increasingly used in rainfall downscaling.

cGANs work by employing a 'generator' network that acts as an artist forging famous paintings, and a 'critic' network which assigns a realness score to each painting it sees. The two networks compete against each other until the generator, the art forger, can create realistic images that are hard to tell apart from the original.

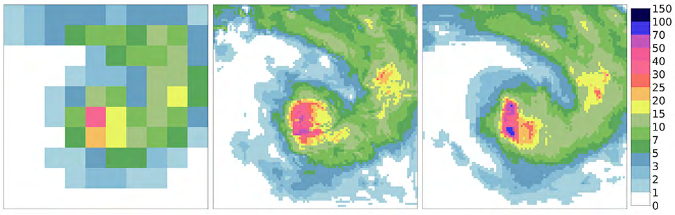

Figure 1. *Using only precipitation data at 100km resolution (left), the cGAN predicts (center) the corresponding high-resolution rainfall field (right), which increases resolution by a factor of 10.*

I adapted a cGAN to – for the first time – downscale tropical cyclone rainfall from 100km resolution to 10km. Generative approaches have the potential to reproduce the fine spatial detail and variable nature of rain to achieve comparable results to traditional downscaling at a fraction of the computational cost, as shown in figure 1.

As the cGAN is a stochastic model, meaning it can produce a variety of predictions given a single input, I can generate an ensemble of predictions for each tropical cyclone. Ensemble predictions are useful because they allow for representations of uncertainty that can be used to identify the scenarios most likely to occur.

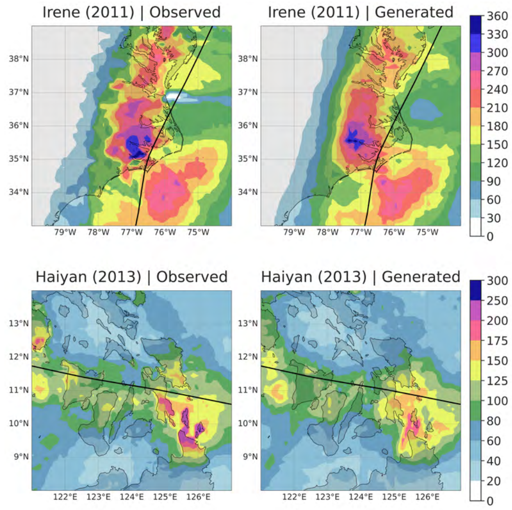

Figure 2. *Original observations of accumulated rainfall from two tropical cyclones: Hurricane Irene (2011) and Typhoon Haiyan (2013) are shown on the left. The predictions from the cGANs are shown on the right.*

Figure 2 shows accumulated rainfall predictions from the cGAN compared to observations of two tropical cyclones: Hurricane Irene (2011) and Typhoon Haiyan (2013). Overall, the cGAN can accurately reproduce accumulated rainfall estimates and generate large ensemble members of thousands of tropical cyclones in minutes.

This allows me to generate enough storms to look at the extreme cases: storms that severely impact the areas they hit but rarely occur in the observed data. The versatility of the cGAN will enable me to generate storms under different global warming conditions and thus evaluate how flooding risks may change in the future.

Preparing for future risk

The efficiency of the cGAN enables its application toward global tropical cyclone risk, generating larger ensembles at lower computational costs than conventional climate models allow. This will help us analyze sufficient extreme events for risk quantification and generate regional hazard maps for any region worldwide.

Overall, this will improve climate change attribution and global tropical cyclone risk quantification, allowing for targeted funding distribution to the most at-risk areas. It will also increase resilience to climate change by providing decision-makers with the best available climate science.

When disaster comes, it comes in pairs

Author

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Biography

Gabriela Gesualdo is a Ph.D. candidate at the University of São Paulo in Brazil. Her research focuses on understanding the spatial connectiveness of extreme events to support adaptation plans. She believes that before applying practical strategies, there is a need to understand and simulate system behavior, which motivated her to investigate spatially compound events to propose risk-transfer mechanisms during her Ph.D.

Gabriela is an expert in water security. She has a master's degree in water resources and is an environmental engineer by training with experience in hydrological modeling and climate change. She has published several scientific papers in this field.

Title of thesis

Spatially compounding events to multi-hazard risk adaptation in Brazil

Contact

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Can a large country like Brazil be divided into risk pool regions that provide ideal risk transfer mechanisms that ensure individuals exposed to risks experience them at different times?

When Paulistanos, as the residents of São Paulo are known, took to the streets in 2014 to celebrate Carnival, some of the costumes had a more serious theme than usual. Among the pirates, Vikings and dancing queens were many outfits referencing the water crisis gripping Latin America's biggest metropolis (pop. 12 million).

A significant drought had hit southeastern Brazil, compromising water, food, and energy security. São Paulo, long known as 'drizzle city' because of its frequent downpours, was suffering severe water shortages. The governor of the region had to ask for emergency powers to deal with the drought.

In Brazil, such disasters tend to come in pairs. At the same time São Paulo lay parched, the northeast of the country was also experiencing the worst drought in the last 50 years.

This pattern is often repeated for different hazards. For example, Goiania, in the central west of Brazil, and Petropolis, in the southeast, suffered substation inland rain and flooding in February 2022.

Spatially compounding events

Such extreme events, affected by the same or different hazards, co-occur within limited time windows. They are known as spatially compounding events. Despite the cascading impacts and challenges compound events impose on society, we still lack an in-depth understanding of spatially connected drought and flood occurrences.

In Brazil, extreme events are complex and costly. For example, between 1995 and 2014, direct losses relating to drought and flood events are estimated at BRL USD 9bn (USD 1.6 bn) per year. Identifying regions likely to co-experience droughts and flood events is essential for developing adaptation and mitigation measures, as it is expected that the frequency and intensity of such events will increase under a changing climate.

Disaster financing schemes are vital for sharing the financial burden of widespread floods and drought. In particular, risk transfer is an important means of reducing the magnitude of overall losses. The most common risk transfer mechanism is insurance. However, large-scale insurance with multiple drivers and hazards can be extremely costly.

In this context, risk pooling, a social-insurance system that involves sharing all risks among a group of individuals or communities, can be an effective approach to risk management. In addition, risk pools offer a cost-effective insurance solution that benefits from reduced operating costs and can cover a wide range of types of risk.

In an ideal risk pool, the scale of the pool must be such that individuals exposed to different kinds of risks experience them at different times. Thus, scaling up a risk pooling system may be the answer to reducing the synchronicity of events. But, the critical question with such an approach in the Brazilian context is how to group a continental-scale country with a diversity of environmental and social systems into risk-sharing regions?

Identifying how droughts and floods are spatially connected

This research tackles this issue by analyzing how hydrological droughts and floods are spatially connected across Brazil and group catchments according to their co-occurrence risk.

The assessment was performed across 511 catchments in Brazil in three steps:

- First, 39 years of data concerning drought and flood events at each site was extracted.
- Second, the spatial connectedness of events was assessed by counting the number of co-occurrences between pairs of catchments.
- Third, a hierarchical clustering algorithm was applied to define similar regions using drought and flood characteristics – deficit, intensity, duration, the number of events and spatial connectedness.

The results show that Brazil can be divided into five regions with similar regional drought and flood characteristics. The regions show distinct patterns in terms of drought and flood characteristics and catchment attributes such as the aridity index, catchment area and mean elevation.

The need to consider interactions of spatially compounding hydrological events in developing multi-hazard management is emphasized in the study. In addition, these newly identified regions can be used as risk management regions, and in the development of pre-agreed disaster response plans. Nevertheless, if such an approach to risk pooling were to be applied successfully, it would require a strong political commitment.

The assessment presented in this research supports the development of future adaptation plans with risk-transfer mechanisms to hydrological extreme multi-hazards at the catchment and regional scale.

Working with natural protection

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Biography

Laddaporn Ruangpan is a final year Ph.D. candidate at IHE Delft Institute for Water Education and Delft University of Technology, the Netherlands. She has a master's degree in Hydroinformatics – Modelling and Information Systems for Water Management from IHE Delft Institute for water education.

Her research interests include hydro-meteorological risk reduction, Nature-Based solutions, climate change adaptation, and modelling. Laddaporn is developing a framework for selecting and evaluating NBS for hydro-meteorological risk reduction and co-benefits enhancement. Her work has been applied in many countries within the EC-funded HORIZON 2020 RECONECT project. Laddaporn is also a founder of a consultancy company (Climate Adapt) that works on climate change adaptation and nature-based solutions.

Title of thesis

A Framework for evaluating Nature-Based Solutions to reduce flood risk and enhance co-benefits

Contact

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Nature-Based Solutions are increasingly seen as an important alternative to 'grey infrastructure,' like dams and dikes, to protect communities against the impacts of climate chaos. This study sets out to create methodologies for decision-makers to use when assessing the value and returns of NBS designed to reduce flood risk and evaluating their performance before and after their implementation.

The risks of extreme hydro-meteorological hazards, such as floods, droughts or storm surges, will increase and become more extreme due to climate change, population growth, land use change and other pressures. These risks impact societies, the environment and the global economy.

Effective risk reduction methods are required to reduce or mitigate the impact of these hazards. While traditional 'grey infrastructure' approaches, such as dikes, pipes and dams, are often used, they are generally not flexible enough to deal with future uncertainty. They can even contribute to increasing risk factors, such as climate change.

Nature-Based Solutions (NBS) have recently gained increased attention as flexible hazard mitigation options. According to the Federal Emergency Management Agency (FEMA) in the United States, NBS are sustainable planning, design, environmental management and engineering practices that weave natural features or processes into the built environment to promote adaptation and resilience.

These solutions use natural features and processes, like river, dune and wetland restoration, that can combat climate change, reduce flood risk and increase resilience.

NBS measures also have the potential to generate co-benefits such as biodiversity enhancement, recreational opportunities and temperature reduction. These contribute to many of the Sustainable Development Goals (SDGs), including SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 11 (sustainable cities and communities), SDG 13 (climate action), and SDG 15 (life on land). The risk reduction benefits and co-benefits of NBS are the subject of this research.

Identifying the knowledge gap

A systematic review of existing literature was performed to understand the state-of-the-art scientific publications on hydro-meteorological risk reduction through NBS (Ruangpan et al., 2020). The review indicates directions for future research based on current knowledge gaps. It also shows that there is still a need for methodologies that can help the decision-making process in selecting NBS and evaluating their performance both before and after the implementation of NBS.

Based on this knowledge gap, the present research aims to develop a framework for selecting and evaluating NBS for hydro-meteorological risk reduction and co-benefits enhancement. The work is developed and implemented within the EC-funded HORIZON 2020 RECONECT project (Regenerating Ecosystems with Nature-based solutions for hydro-meteorological risk rEduCTion) (see http://www.reconect.eu/). The objective of this framework is to select potential NBS measures for an area of interest and identify and estimate their potential value to support decision-making before the implementation of a project.

Where to start in selecting potential NBS Measures

An important step is to identify and quantify 'indicators' of the benefits and co-benefits relevant to the specific location. This set of indicators should be able to reflect a variety of local contexts and situations. In this research, an indicator selector tool was developed to help decision-makers select indicators suited to their specific situation. The indicator tool is in an easy-to-use excel format.

Next, decision-makers need to decide what NBS satisfy local stakeholders' specific objectives and needs. Therefore, we developed an innovative methodology to select potential measures for reducing hydro-meteorological risk and simultaneously offering co-benefits (Ruangpan et al., 2021). The methodology comprises a preliminary selection of feasible measures (screening) and a multi-criteria analysis (MCA) framework that incorporates stakeholders' preferences.

1. The preliminary selection

The process can define applicable measures to the case study based on local characteristics. The process has been incorporated into a web-based decision-making tool called the 'measure selector tool' and includes an extensive database of hydro-meteorological risk reduction measures. The tool provides users with a user-friendly interface (see Figure 1).

Figure 1: *The measure selector tool on a web-based interface*

2. MCA framework

The MCA framework helps prioritize the top five to ten most suitable NBS measures for the specific situation. The advantage of this framework is that it allows stakeholders to give their preferences on the benefits from an NBS measure and the specific measures themselves. This methodology has been applied to 11 case studies within the RECONECT project, including Colombia, Poland, Serbia, Taiwan and Thailand.

The trade-off and economic outcome

Ongoing research focuses on the economic assessment of these prioritized measures, expanding on traditional economic risk assessment by including the co-benefits of NBS. The economic assessment in this study is based on a life-cycle cost-benefit analysis (CBA), including net present value (NPV) and benefit/cost ratio (B/C). CBA is useful when selecting or evaluating measures as it can help decision-makers identify the trade-off and economic outcome of implementing NBS.

Future research

The monitoring and evaluation process can significantly help determine whether the implemented NBS are working, will adapt to expected climate change or can perform better. Future research will focus on exiting NBS in two aspects of existing NBS: 1) monitoring and evaluating their performance, and 2) improving that performance through Real-Time Control (RTC).

To conclude, this research will improve NBS evaluation and decision-making, pre- and post-implementation.

Modeling risk with ever finer detail

Author

Laurence Hawker

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University of Bristol

Biography

Laurence Hawker is a post-doctoral researcher at the School of Geographical Sciences at the University of Bristol. His research broadly aims to improve understanding of global flood risk and developing datasets to contribute to climate risk analysis. Recently Laurence has developed a fine-resolution global map of terrain elevations that help to improve the modelling of a number of perils. Laurence is currently assessing the sensitivity of global flood risk to changing climate, geomorphology and population change and has published research into flood hazard assessment and flood forecasting.

Title of thesis

A 30m global terrain map to support natural catastrophe modelling

Contact

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Risk modeling has advanced dramatically in recent years, allowing for models of ever-finer resolution produced on a global scale. A new 30-meter global terrain map creates a unique global terrain map that can support hazard modelling in regions that have been poorly served until now.

Risk from natural catastrophes is modeled at ever-increasing complexity, aided by the proliferation of computing power and availability of 'big data.' We have gone from modeling at a local level to being able to model at the global scale at an ever-finer resolution. Knowledge of the Earth's landscape is crucial for many of these models, where precise terrain heights are needed to characterize the physical hazard accurately.

For example, for riverine flooding, it is critical to have accurate terrain information to delineate riverbank heights and floodplain features so we can accurately determine at what point a flood will spill onto the floodplain and where it will go. Similarly, knowledge of terrain height is needed along the coastal boundary for coastal flooding. For landslides, accurate knowledge of the slope is crucial.

Limitations in current global elevation datasets

Substandard elevation data is the key limiting factor in the quality of many natural catastrophe models. In 2018, I estimated that just 0.005% of the Earth's land area was covered by high-quality LiDAR elevation data (Hawker et al., 2018). Although this percentage has slightly increased in recent years, the amount of high-quality LiDAR elevation data available is tiny and almost exclusively focused on developed nations.

The result of the lack of high-quality elevation data is that, for most of the world, modelers must use global elevation datasets. Although global elevation datasets have achieved significant advancements in the last two decades, there remains one fundamental issue – they contain building and forest artifacts, or in other words, they depict the Earth's surface.

As a result, existing global elevation datasets have errors in the region of meters compared to high-quality terrain elevation reference data (Hawker et al., 2019). The presence of such artifacts can have significant impacts on modelling catastrophes. For example, these artifacts can create unrealistic blockages of the floodplain for flood models, thus leading to misinformed risk estimates.

A new approach to datasets

To fill the need for a high-resolution global terrain elevation map, this research developed FABDEM (Forest and Buildings removed Copernicus DEM) (Hawker et al., 2022). This new dataset uses advanced machine learning techniques to remove buildings and trees from an existing global elevation dataset to create a unique global terrain map with a 30-meter resolution. FABDEM is the first dataset to remove both building and tree artifacts. Compared to other global elevation datasets, FABDEM was found to be the most accurate, with median errors close to zero and absolute errors reduced by up to half.

In my current work, I am integrating FABDEM into natural catastrophe modelling applications. For example, significant improvements were found when using FABDEM for flood modeling in Vietnam (Figure 1). In my latest project, EvoFlood, I am incorporating FABDEM into a global flood hazard model to assess the importance of climate, geomorphological and population change drivers on present and future flood risk.

To complement this research, I am developing a global high-resolution gridded future population dataset that maps future populations under various socio-economic scenarios at a resolution one order of magnitude finer than existing products. These developments will better inform us of the critical drivers in future flood risk so that communities can mitigate them appropriately.

Additionally, I am working on mapping flood risk based on forecast data to support humanitarian efforts in southeast Africa, as well as supporting climate attribution studies, such as an analysis of what flooding from a future Super Cyclone Amphan-type event could be for Bangladesh and India.

Amphan was an extremely powerful and catastrophic tropical cyclone that caused widespread damage in Eastern India and Bangladesh in May 2020. It was the strongest tropical cyclone to strike the Ganges Delta and caused over USD 13bn of damage, making it the costliest cyclone ever recorded in the North Indian Ocean.

Improving the understanding of current and future risk

The central point of my research is that significantly improving global elevation data allows for a step-change in our understanding of modelling natural catastrophes. As highlighted by the recent humanitarian crisis in Pakistan as a result of flooding, states in the developing world bear the brunt of the impact of climate change, with modelling efforts limited by the lack of high-quality elevation data. My research can help improve our understanding of current and future risk, building much-needed resilience to a range of natural catastrophes.

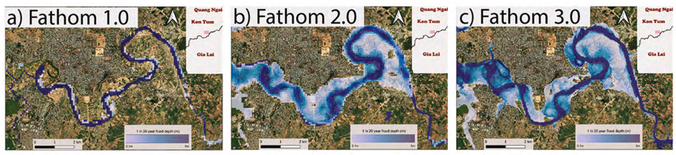

Figure 1: *Flood hazard map of Kon Tum, Vietnam, for the one in 20-year flood event. Three versions of a Global Flood Model (GFM) courtesy of Fathom, each with a different underlying elevation dataset, were compared. Panel a) uses the SRTM elevation dataset, Panel b) uses MERIT DEM, and Panel c) uses FABDEM. Note the improved delineation of floodplain features in panel c).*

Sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Storm chasing on computers for real-world impact

Author

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Biography

Mona Hemmati is a Postdoctoral Research Scientist at Lamont-Doherty Earth Observatory of Columbia University, USA. Her research interests comprise disaster risk reduction, risk modeling of natural hazards and risk communication. Mona is designing a framework to evaluate flood-related risks in tropical cyclones at both global and local scales. Her research aims to connect science to action to assist policymakers and stakeholders in building cities and communities that are sustainable, safe and resilient to natural hazards.

TITLE OF THESIS

Examining tropical cyclone flood-related risks

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Most of the damage from tropical cyclones comes from storm surges that drive the ocean deep inland. The intense computational power requires to simulate hydrodynamical models means our understanding of storm surges is lacking. A new comprehensive tropical cyclone risk model addresses that.

Nearly 50% of the American population (about 164mn people) live or work in coastal counties. The areas generate 58% of the gross domestic product of the United States. These statistics are expected to rise as new economic development and leisure attractions make coastal areas desirable places to live, and more people move to coastal cities in the US and worldwide.[1,2,3]

Tropical cyclones (TCs, locally known as hurricanes or typhoons) are significant threats to coastal communities. Wind, coastal flooding driven by storm surges, and inland floods driven by heavy precipitation are the primary hazards caused by TCs. Although TCs are known for strong wind, most economic damages and fatalities are caused by flooding due to storm surges and heavy precipitation.

Storm surge, in general, is a giant slow wave that drags the ocean inland due to strong winds in TCs. In the past, large death tolls and catastrophic damages have resulted from devastating storm surges from TCs. For instance, Hurricane Ian (2022), which made landfall in Florida, brought a devastating five-meter storm surge leading to catastrophic damages, including more than 100 deaths.

Most of the damages from Hurricane Katrina (2005) were caused by storm surges. Katrina's storm surge resulted in over 1,833 fatalities and USD 108bn in damage. Superstorm Sandy (2012) also brought a 4.5-meter storm surge ashore near Atlantic City, New Jersey, which resulted in devastating coastal flooding in New Jersey and New York City. Sandy caused over USD 60bn in damage, claiming at least 125 lives and knocked out power to more than 7mn customers.

A more hostile world

The academic and insurance industry catastrophe models often focus on assessing damages caused by strong winds in TCs. However, as the climate warms and the sea level rise, the risk for more devastating storm surges is projected to escalate sharply. Therefore, understanding the storm surge risk under the current and future climate conditions is vital in planning for achieving sustainable and resilient coastal communities that are vulnerable to these destructive events.

For risk assessment, significant historical events are required. However, as there is a lack of historical storms that made landfall on the coastline, methodologies in assessing the storm surge risk incorporate synthetic but realistic storms from the TC simulation models.[4, 5] Then, such frameworks combine the storms with a hydrodynamic model to assess the potential flooding associated with each storm track.

There are two challenges in this framework. First, the implemented hydrodynamical models can usually only be applied locally rather than at a global scale as the computational effort associated with modeling storm surges using hydrodynamic models is expensive. Second, they do not incorporate open-source exposure and vulnerability layers to assess the economic loss and social consequences associated with each storm.

As a result of these two factors, these frameworks have not been applied to assess the storm surge risk in terms of expected annual loss as the point of interest in disaster risk management actions, as well as insurance industries.

Simulating thousands of years of storms

This research aims to develop a global open-source compound wind-storm surge risk model under current and future climate conditions. As the wind pushes the ocean into coastlines, wind and storm surge models should be combined to consider the interaction between these two hazards.

This model assesses the probability of these compound hazards along the global coastlines. Furthermore, the model is flexible in that it can easily be adapted to accommodate different exposure and vulnerability datasets. This flexibility supports the analysis of the socioeconomic impacts of different storm scenarios at both global and local levels.

To do so, we adopt the recently developed open-source Columbia Tropical Cyclone Hazard Model (CHAZ) that can simulate thousands of years of TC activity along the global coastlines. Then, the CHAZ storm is coupled with an open-source storm surge model, GeoClaw, to evaluate the characteristics of floods, including flood depth, velocity and duration.

As the required computational efforts for this developed framework are considerably lower than hydrodynamic models, it can be applied globally. Moreover, we have utilized the exposure and vulnerability layers to convert the compound wind-storm surge hazard model into a risk model.

The model can apply various resolutions for exposure and vulnerability datasets which are crucial in developing localized policy implementation strategies for creating sustainable and resilient communities to these disasters.[6] This ongoing research is currently being tested for the Caribbean islands and the United States.[7]

Future work on compound floods

The current framework integrates wind and coastal flood risk models by simulating storm surges generated by strong winds. However, as mentioned previously, inland floods can also result in catastrophic damages, and their coincidence or consecutive occurrence with storm surges may result in compound floods.

Compound floods affect a larger footprint than individual inland and coastal floods, leading to property damage for which homeowners may not have implemented any adaptation measures or do not have any flood insurance coverage.

Future research plans focus on two different thrusts. First, modeling the compound flood hazards that can happen when TCs make landfall in coastal communities. Second, developing an epic first-of-its-kind full TC risk model that can be used to adequately study all different hazards and their compound impacts in TCs. This will provide a comprehensive global TC risk model that provides a thorough understanding of TC risk from wind-coastal flood-inland flood hazards to coastal communities.

Planning for the resilient communities that may be affected by devastating TCs starts with a comprehensive view of the risk that can threaten coastal cities. Therefore, such a framework can be helpful to federal and local authorities, stockholders, and the insurance industry to make risk-informed decision-making in developing the strategies and measures to improve the sustainability of future rapidly urbanizing coastal communities.

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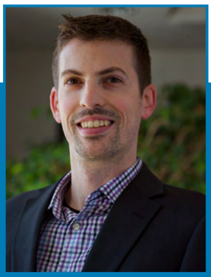
Developing a 'pro-social dividend' for smallholder farmers



Author

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Biography

Nic Choquette-Levy is a Ph.D. candidate at Princeton University's School of Public and International Affairs, studying climate adaptation and rural-urban migration among smallholder farmers in Nepal. Nic's research integrates survey work and computational modelling to understand how climate change and public policy shape farmers' adaptation strategies. A primary objective of his work is to develop decision-making tools that help diverse stakeholders navigate the complexities of environmental change.

Before his Ph.D. Nic obtained Bachelor's degrees in Biomedical Engineering and International Relations from the University of Southern California and a Master's degree in Energy and Environmental Systems from the University of Calgary. Nic has worked in professional sustainability roles with the Canadian Consulate, the Canadian energy industry and the World Bank.

Title of thesis

Navigating a Warming World: Rural-Urban Migration in the Context of Smallholder Farmer Climate Adaptation

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Why do insurance solutions designed to help smallholder farmers have such low pickup rates? Could one solution to more complete risk coverage lay in combining traditional cooperative community arrangements with newer insurance solutions?

Climate-driven risks – including extreme droughts, floods, and heatwaves – are likely to increase in frequency and intensity over the coming century, threatening the livelihoods of many of the world's 2bn smallholder farmers.

Currently, most such farmers do not have access to formal insurance, leaving them especially vulnerable to poverty and debt traps after an income shock. Furthermore, this lack of insurance coverage strains the resources of already cash-strapped governments in their response to natural disasters.

The unfulfilled potential of index-based insurance

Index-based insurance holds great promise in developing scalable insurance solutions at affordable premiums to farmers, partly by reducing the administrative costs of assessing damages in remote communities. Yet, existing index insurance programs for subsistence agriculture have delivered mixed results, with only 10-20% of farmers adopting such policies despite large subsidies.[1]

One reason for this low uptake may be unintended competition between formal insurance and existing community arrangements to manage risk, for example, cooperatives and informal lending. In this project, we explore the potential for insurance programs to be paired with behavioral interventions that help crowd-in, rather than crowd-out, informal risk management in subsistence communities.

Could pairing be the answer?

To test our theories, we first simulated how different risk management strategies will likely impact farmers' economic outcomes over the next 50 years. These strategies include rural-urban migration, a community-based income cooperative and index insurance.

We develop scenarios based on climate risk and socio-economic data from Ethiopia and Nepal, two countries heavily dependent on subsistence farming, where policymakers are experimenting with index insurance schemes. Under current and plausible future climate risks, cooperatives and index insurance are each effective in reducing poverty rates compared to an absence of either form of risk management.

However, combining these two mechanisms is the most effective option for reducing poverty and minimizing farmers' income volatility over the long term. This is especially relevant for climate risks that are likely to be faced by these two countries in the coming decades (for example, a 1-in-3-year probability of extreme drought).

This is because the co-existence of insurance and income cooperatives offer more complete risk coverage than either mechanism alone. Insurance helps cover covariate shocks, such as those arising from droughts and floods. Cooperatives help to manage uncorrelated idiosyncratic risks like health shocks. Community risk-sharing arrangements are an essential complement to insurance programs when farmers have to pay higher risk premiums, which may combine with idiosyncratic shocks to push some farmers below the poverty line.

The social dilemma of index insurance

We next develop an evolutionary game theory model to evaluate which risk management strategies will likely arise due to repeated interactions between farmers over several years. In many climate scenarios, including the looming risk levels faced by Ethiopia and Nepal, introducing index insurance may unintentionally contribute to a new social dilemma in subsistence communities.

Specifically, participants in an income-sharing arrangement would have an incentive to forego purchasing insurance and free-ride on the insurance purchases of their peers, who are contributing stable income to the cooperative. If enough farmers neglect to buy insurance, the cooperative's reserves may become sufficiently volatile to cause its collapse – just at the risk levels where it becomes especially important to maintain coverage of both covariate and idiosyncratic risks.

One strategy to address this is to pair financial incentives for purchasing index insurance, such as premium subsidies, with behavioral interventions designed to encourage community risk-sharing arrangements.

In particular, we find that farming communities with moderate levels of pro-social values, including altruism and trust, can maintain stable co-existence of formal insurance and informal risk-sharing arrangements over a wide range of future climate risks. Furthermore, for governments seeking to promote insurance uptake through subsidies, cultivating such preferences can reduce the subsidy required to achieve both high insurance adoption and participation in community-based schemes.

For example, in a scenario based on climate risks and typical farmer incomes in Nepal's Chitwan Valley, we found that cultivating moderate pro-social preferences could help governments save approximately 20% on premium subsidies compared to a community without such preferences. This translates to around 9% of a typical community's agricultural income. We call this result a 'pro-social dividend' and develop this concept as a metric for policymakers to evaluate the benefits of potential behavioral interventions promoting such values.

Crowding in effective risk management

Insurance programs will need to crowd in effective risk management arrangements at all levels of society to address increasing climate impacts. Our research demonstrates the importance of expanding the policy toolkit beyond financial incentives to promote the co-existence of formal and informal risk management instruments among vulnerable farmers.

This work provides a framework for future pilot programs that could test the effectiveness of pairing index insurance with specific interventions. For example, informational campaigns could frame insurance as a way to contribute to the well-being of one's community and expand farmers' capacity to coordinate with each other regarding their insurance needs.

1. *See Takahashi, K.; Barrett, C.B.; and M. Ikegami (2018). "Does Index Insurance Crowd In or Crowd Out Informal Risk Sharing? Evidence from Rural Ethiopia," Amer. J. Agr. Econ, **101(3)**: 672-691. (Note – specific reference to this range is on p. 677)*

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Extreme Atlantic hurricane seasons made twice as likely by ocean warming

Author

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Institution

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Biography

Peter Pfleiderer is a postdoctoral researcher at Hamburg University, working on climate impacts in overshoot scenarios. His research focuses on weather extremes in the context of anthropogenic climate change. During his work at Climate Analytics, he developed new methods to study diverse aspects of changes in weather extremes, such as dynamic changes, due to atmospheric circulation changes, compound weather extremes and tropical cyclones. For his research on weather extremes in a changing climate, he obtained a Ph.D. from Humboldt University Berlin.

Title of thesis

Weather extremes in a changing climate

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Every year, hurricanes threaten the Caribbean islands and parts of the east coast of the Americas. In some cases, it takes years for an island state to recover from the impacts of a single hurricane. Therefore, knowing the nature of the upcoming hurricane season is of vital interest. Furthermore, we want to learn to which extent global warming influenced the past hurricane season and how it will affect future seasons.

Tropical cyclones are among the most damaging natural disasters. The 2017 hurricane season alone caused 3000 fatalities and over $200bn in damages. Besides wind damage, tropical cyclones cause flooding through a combination of storm surges and intense precipitation. With anthropogenic climate change, sea levels rise, and extreme precipitation events are expected to intensify. An increase in flooding damage from tropical cyclones can be expected. However, it is still debated to which extent tropical cyclones are becoming more intense and whether their frequency will change.[1]

The challenges in tropical cyclone research are twofold. The number of tropical cyclones in the observational record is insufficient to attribute changes in tropical cyclone characteristics to global warming directly. At the same time, most climate models fail to reproduce the highly complex structure at the storm's center. As a result, new methods are required to study tropical cyclones in a changing climate.

In my thesis, I look at the observational record through the lens of natural variability. If we understand under which atmospheric and oceanic conditions strong tropical cyclones form and how these conditions link to other parts of the climate system, we can explain why there are many intense hurricanes in one year and not another. Finally, this will help to distinguish between natural variations in hurricane activity and changes caused by anthropogenic climate change.

Precursors of active hurricane seasons

Tropical cyclones form over the warm water of subtropical oceans. These storms require similar horizontal wind speeds throughout the atmosphere to develop their vertical structure – low vertical wind shear. I apply **causal effect networks** to identify robust precursors of warm ocean surface temperatures and low vertical wind shear over the tropical Atlantic.

Two months ahead of the main hurricane season, the surface temperature of the tropical Pacific is a robust indicator of both ocean surface temperatures and vertical wind shear over the tropical Atlantic. The identified precursor corresponds to the El Nino Southern Oscillation, which is commonly used in seasonal hurricane forecasts and gives confidence in our methodological approach.

The skill of seasonal forecast models drops considerably four months ahead of the main season. Using the causal effect network approach, I identify novel precursors related to the pressure gradient between the southeastern Pacific and the southern Indian ocean. The seasonal forecast model based on the identified predictors shows competitive skills with operational models in the hindcast, and since 2019, our forecast is publicly available. [2]

Hurricane activity over warming oceans

In the Atlantic basin, the energy produced by hurricanes has increased over the past decades. The warm ocean surface is the primary energy source for tropical cyclones, and we expect more intense storms as ocean surface temperatures rise due to anthropogenic climate change.

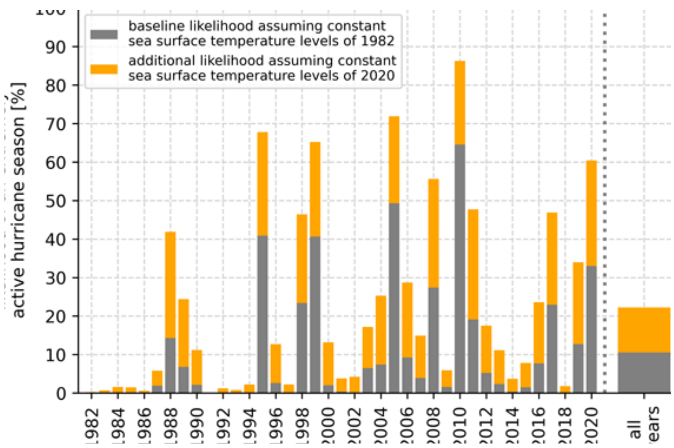
However, the number of hurricanes per year mainly depends on the atmospheric circulation patterns during the hurricane season and parts of the observed increase in hurricane activity could be due to internal climate variability.

To understand to which extent anthropogenic climate change has contributed to the increase in hurricane activity through ocean warming, we first need to know how atmospheric circulation influenced past hurricane seasons. Therefore, I developed a probabilistic model that reproduces hurricane seasons of the past forty years based on the observed sequences of daily atmospheric circulation patterns and ocean surface temperatures.

The model can now be used in counterfactual experiments to compare hurricane activity under pre-industrial [3] and current ocean surface temperatures while the atmospheric circulation component stays untouched. The comparison shows that without the warming of the Atlantic Ocean surface, the most powerful Atlantic hurricane seasons would only be half as likely.

Preparing for future hurricane seasons

The potential for highly damaging hurricane seasons will increase in a warmer world. While the number of hurricanes might decrease or stay unchanged, [1] the predicted intensification of the strongest hurricanes is alarming. Combined with rising sea levels and more extreme precipitation, we can expect hurricane seasons to cause more damage than ever. Although adaptation options are limited, my analysis of the role of ocean surface warming and my seasonal forecast model will help to prepare for future hurricane seasons.



"Likelihood of extremely active hurricane seasons (ACE > 159.6) in two counterfactual scenarios. Both scenarios have the same atmospheric circulation patterns and intra-seasonal and year-to-year variability of SSTs but different SST levels: SST levels for the state of global warming in 1982 (gray) and 2020 (orange).

More details

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Coastal hazards from extreme seas and waves in the Mediterranean

Author

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Biography

Tim is a Ph.D. candidate at the Mediterranean Institute for Advanced Studies (IMEDEA) in Mallorca, Spain. His research focuses on coastal extreme sea levels (ESL) and on improving the current understanding of their temporal and spatial dynamics in the Mediterranean Sea. He has designed and produced an unprecedented regional long-term, high-resolution storm surges and wind-waves database, using a numerical hydrodynamic-wave coupled model, and performing robust statistical analysis for coastal hazards assessment. Tim has further investigated and evidenced the important contribution of waves to ESL at the regional scale, leading to significant quantitative changes in hazard assessments (for example, values of return levels). His work provides essential and free open data for risk-based analysis and cross-disciplinary studies in coastal regions.

Title of thesis

Coastal sea levels and wind-waves in the Mediterranean Sea

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Mediterranean hurricanes do not receive the same attention as those in regions plagued by intense hurricanes, so their potential to cause storm surge and wind-wave damage has been underestimated.

Extreme sea levels (ESLs) are among the most destructive hazards for populated coastal areas, with flooding causing huge damages in assets and casualties. Coastal managers, emergency responders and insurance planners require accurate information on the existing flood risk to develop suitable adaptation measures. Though less publicized because of their lower intensity than hurricane-impacted regions, extreme sea levels occurring in the Mediterranean Sea are a major concern for coastal planners.

Home to one of the highest rates of cyclogenesis (the development or strengthening of an area of low pressure in the atmosphere that results in a cyclone) in the world, the Mediterranean Sea commonly experiences extratropical-like cyclones, and sometimes tropical-like cyclones called Medicanes (Mediterranean hurricanes). These are caused by its complex orography associated with low-level baroclinity and moisture sources.

Occasionally, these extreme events pose severe threats to coastal populations. In November 2017, Medicane Numa resulted in 22 deaths and damage costing USD 100mn (**Global Catastrophe Recap 2017**).

These events are extremely hazardous as they are responsible for heavy rains and intense winds. Over the ocean, the strong winds have two effects. First, they push the water toward land, raising the sea level (the storm surge effect). Second, they originate wind-waves that further increase the sea level on the coast due to the effect of wave setup. The combined effect of these two processes results in intense coastal flooding.

My research focuses on enhancing our understanding of storm surges and wave setup in the Mediterranean Sea to provide a comprehensive and long dataset to estimate more robust ESL probabilities. This can help coastal stakeholders and emergency response managers to be prepared for extreme coastal events.

Mediterranean database for risk-analysis: Numerical modelling tool

Robust statistical analyses to assess ESL-induced risks, such as the computation of return levels, mainly rely on the length of extreme events data available to describe and predict their incidence at mid-to long-term periods, reducing uncertainties.

Yet, current global or Mediterranean model-based databases are limited by their spatial resolution or/and temporal coverage (for example, some only have 40years wave hindcast).[1] Traditionally, ESL analyses have been based only on the surge contribution, neglecting the wave setup effect. Thus, ESLs have potentially been underestimated, impacting the resulting risk calculation for coastal populations.

This research addresses these limitations to improve regional ESL coastal hazards assessment. The resulting datasets and outcomes will enhance our understanding of past, present and future storm surges and wave climate. The numerical hydrodynamic-wave coupled model SCHISM[2] is used for the generation and propagation of storm surges and wind-waves, accounting for the wave setup component.

Mediterranean coastal hazards assessment

The central work of this research focuses on the generation of a storm surge and wave hindcast covering the 1950-ongoing period at an unprecedented 200m coastal spatial resolution in the Mediterranean basin. We perform two simulations at a high temporal resolution (1h), with and without the presence of waves, to assess the relative contribution of waves to the overall coastal sea level.

The hindcast results show an evident ability to capture the wave setup component. Return levels of ESLs and waves (significant wave height, Hs) are computed from 10 to 200 years, showing the most vulnerable Mediterranean coasts. This work was published in **Frontiers in Marine Science**.[3]

As knowledge of ESLs variability is of paramount importance to perform coastal hazards assessments, it is essential to know how these characteristics will change in the future. First, the impact of medicane-induced waves and storm surges has been investigated for the present and future climate (end of 21st century).[4] Because the number of observed medicanes is insufficient to perform robust statistics on coastal risks (either from in-situ data or hindcast), thousands of medicanes synthetically generated from 20 Global Climate Models (GCMs) and two atmospheric reanalyzes were used.[5]

Current and projected return levels for medicane-induced waves and storm surges are quantified, exhibiting only a few areas where significant changes are found (for example, one-meter Hs increase in the southern coasts of Sicily, Italy).

Also, the simulation and investigation of the storm surge and wave climate evolution under different climatic scenarios (from CMIP6) will be performed at regional scale, assessing the overall potential shift with respect to the present coastal hazards assessment.

Wave setup component contribution to extreme sea levels

The ability of our products to capture the wave setup component is further investigated and compared to straightforward methods used at the global or regional scales, such as the extensively used 0.2*Hs approximation.[6]

Findings from the first part of this research show that wave setup is an essential physical process for the computation of return levels.

For instance, using the hydrodynamic simulation, an extreme sea level of 46 cm on a beach near Valencia (Spain) is expected once every 100 years. When accounting for wave setup, the frequency of such an event increases to once every eight years. Therefore, in the Mediterranean, particular attention must be paid to the wave setup contribution to ESL. Drastically different risk assessments can result for coastal planners and insurers depending on whether they consider this mechanism or not.

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Groundwater monitoring for drought early warning

Author

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Biography

William Veness is a Ph.D. candidate in the Faculty of Engineering at Imperial College London. His research investigates the use of low-cost groundwater monitoring systems for better informing drought-mitigating actions by governments, NGOs and communities. William's project in East Africa is supported by Concern Worldwide, UN FAO & Somaliland's Ministry of Water. He has worked on further projects in Uganda with the Red Cross and Ministry of Water to install flood early warning and forecast-based financing systems. He is passionate about developing larger hydrometric monitoring networks to index planning and financing decisions in drought and flood management.

Title of thesis

Groundwater Monitoring for Drought Resilience and Early Warning

Contact

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The delay between rural water shortages and impact indicators means that interventions are often not made until water shortages have significantly impacted livelihoods. Groundwater monitoring of wells and boreholes with sensing technologies can now provide a direct measure of water level for effective interventions.

More than a quarter of a million people died in the Somalia famine of 2011, half of them children. A further drought in 2017 required humanitarian assistance for 6 million people – half of the population – and a severe drought in 2022 has been driven by an unprecedented fourth consecutive failure of seasonal rains.

Countries like Somalia are suffering disproportionally as the risk of drought increases globally. There is an urgent demand for improved Early Warning Systems to enable anticipatory actions that mitigate water shortages. During these droughts, a failure to anticipate and mitigate water shortages leads to community displacement and cascading secondary impacts.

Drought early warning systems

Early Warning Systems (EWSs) display monitoring information with the primary objective of enabling stakeholders to take early, anticipatory actions that mitigate drought impacts.

Existing EWSs display socio-economic impact indicators, such as market prices, migration data and health indices, to trigger drought interventions from governments and international organizations when they exceed thresholds (Figure 1). However, the delay between initial rural water shortages and the associated increases in these impact indicators mean that the earliest interventions are not made until rural water shortages have already significantly impacted livelihoods.

Increasingly, satellite-based climate indicators of physical drought are being incorporated into EWSs to anticipate water and agricultural shortages ahead of their onset. Rainfall anomalies, vegetation indices and soil moisture indices are reviewed alongside seasonal climate forecasts to identify areas most at risk of water shortage. However, these indicators provide a poor proxy of groundwater availability on the local scale during drought. Using these indicators to interpret water availability on the community scale, therefore, risks miscalculating the communities most impacted by drought.

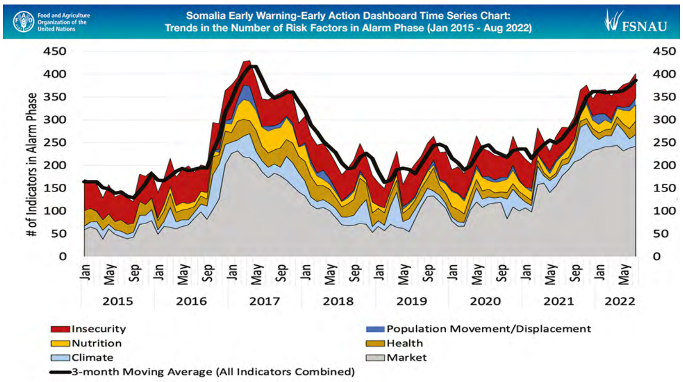

***Figure 1:** The United Nations' Food Security Nutrition Analysis Unit's time series of the number of famine early warning indicators in the alarm phase in Somalia's administrative regions (FSNAU).*

Groundwater monitoring for early warning

Groundwater monitoring of wells and boreholes bypasses the uncertainty of these alternative indicators by providing a direct measure of the water level at abstraction points.

However, despite advice in 2003 from the United Nations Food and Agricultural Organization that data on groundwater level fluctuations are "essential as a basis for management," methods to monitor drought still widely omit groundwater data. Reasons include:

- High economic cost of data collection
- The labor-intensive nature of monitoring
- Complex equipment
- Difficulties with community participation
- Lack of hydrological expertise to process the data into valuable outputs

Advances in sensing technology are reducing the cost and complexity of groundwater monitoring to a level that it can now be implemented on an unprecedented scale.

Modern automatic sensors have lower costs, greater accuracy, higher-frequency measurements, longer battery lives and now require less labor and expertise for installation and data processing. Furthermore, rapid improvements in telecommunications networks mean that data can now be transmitted and accessed remotely in real-time.

Therefore, given the improved technical feasibility of collecting and accessing this data, this research evaluates how groundwater monitoring can now be scaled-up to provide localized early warnings of water shortages.

We are monitoring hand-dug wells in Maroodi Jeex to test experimental, low-cost groundwater sensors using LiDAR technology as a proof-of-concept. Maroodi Jeex is an administrative region in western Somaliland and the most populous district of the self-declared independent region. The data collected has also guided our published recommended methods for processing water level data and simulating well water levels.

Early warning for early action

Semi-structured interviews of expert stakeholders are ongoing to assess how groundwater monitoring can improve decision-making within existing early warning and early action processes. Participants range in role and scale from local water engineers and communities in Maroodi Jeex to the national government and international humanitarian stakeholders in East Africa.

Preliminary findings indicate two primary stakeholder groups that can benefit from access to real-time groundwater data:

1. **For international and national-scale stakeholders:** a groundwater-monitoring system can provide a direct water availability index to supplement existing food & water security indicators in EWSs. It can be used as supporting evidence within organizations for the financing, planning and implementation of anticipatory actions in drought-affected areas to mitigate water and food shortages.
2. **For district water authorities, local NGOs, and private borehole operators:** access to real-time water levels enable early identification of at-risk water points for specific interventions and technical assistance, helping to mitigate water shortages before they occur. Multi-year groundwater data also informs long-term planning of local water supply.

Early, shortage-mitigating actions can reduce dependency on emergency water trucking and improve outcomes for the most vulnerable. These actions include technical advice, borehole construction and rehabilitation, cash transfers, subsidies to private water vendors, water quality assistance and agricultural assistance.

These data-driven actions can be funded by earlier, evidence-based financing informed by groundwater data. Water levels at key water points can index the release of emergency drought financing when water levels fall below thresholds. This data, with appropriate public-private agreements in place, also presents an opportunity to the growing parametric drought and crop insurance industries to index micro- and macro-scale policies with reduced basis risk.

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