Allianz

Decoding Climate Risk in an Interconnected World

A compendium of essays for the
Allianz Climate Risk Award 2025

December 2025
Munich, Germany

About the compendium

Launched in 2017, the Allianz Climate Risk Award celebrates scientists at the start of their careers and whose work sheds light on the nexus between climate change and extreme weather events. The award is open to PhD candidates and Post-Doctoral researchers whose research focuses on: Reducing the risk of extreme weather events that are intensified by climate change and fostering resilience by applying technological solutions.

The compendium is a compilation of selected essays based on the criteria of innovation, research excellence, applicability and impact from applicants of the 2025 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 and their research fields

Linked extremes amplify losses

Multi-hazard events – wind, extreme rain, storm surge and high river flows occurring together – dramatically increase flood losses, yet most planning still treats hazards one by one. With warming intensifying heavy rainfall and raising sea levels, linked extremes are becoming more likely, especially in densely populated, low-lying areas. High-level takeaway: risk assessments must model joint probabilities and interdependencies.

Philipp Maximilian Heinrich
Nationality: German
Location: Germany

Alison Peard
Nationality: Irish
Location: United Kingdom

Test tomorrow's crops in tomorrow's climates

Many current European wheat trial sites will no longer represent future heat- and drought-stressed conditions. If trials don't shift, new varieties may be selected for climates that no longer exist, raising yield risk, food-security concerns and insurance uncertainty.

Rogério de Souza Nóia Júnior
Nationality: Brazilian
Location: France

Global Problem

Haokai Zhao
Nationality: Chinese
Location: United States

Soil moisture is the hidden connector

Soil moisture links urban flash-flooding and agricultural drought. A real-time, physics-aware machine learning approach converts subsurface dynamics into short-term forecasts, enabling cities to manage stormwater and farms to optimize irrigation – thereby improving preparedness, pricing and loss forecasting.

Diego Altafini
Nationality: Brazilian
Location: United Kingdom

How floods break a city's circulation

Floods can fracture a city's mobility and lifelines, turning road networks into bottlenecks and isolating neighborhoods beyond the mapped inundation areas. Network analysis identifies critical links, redundancies and 'service corridors,' translating disruption into decision-ready insights so insurers and city leaders can keep people, goods and services moving.

Ali Shiravand
Nationality: Iranian
Location: France

Resilience has a behavioral layer

In climate shocks – such as droughts, heatwaves and storms – the weak link is often human behavior. New work models how community norms, monitoring and learning speed determine whether common-pool resources (such as groundwater, rangelands and coastal fisheries) are sustained or collapse.

Mangroves: coastal shields under pressure

Mangroves reduce storm surge and flood damage by an estimated $65Bn per year but rising seas and intensifying cyclones are pushing many forests toward collapse. Losses would expose millions to coastal flooding, erode fisheries and carbon storage, and raise insured and uninsured losses.

Sarah Hülsen
Nationality: German
Location: Switzerland

Flood risk is everywhere, but impacts concentrate where hazard, exposure and vulnerability meet

Floods are the world's most widespread natural hazard, and risk is intensifying as climate change disrupts the water cycle. Even moderate events can cause outsized losses when people, infrastructure and assets are highly exposed. New satellite- and AI-driven assessments link flood extent to populations and critical services, enabling faster, fairer resource allocation and sharper insurance pricing.

Jeremy Eudaric
Nationality: French
Location: Germany

Making desert floods visible

Desert floods are rising, but standard radar algorithms often miss them because dry sand can resemble open water. New methods bring arid regions into near-real-time flood monitoring, enabling faster response, fairer loss estimates and better adaptation planning.

Shagun Garg
Nationality: India
Location: United Kingdom

Mitchell Anderson
Nationality: New Zealander
Location: New Zealand

When services exist but don't work

Disasters can leave buildings standing but services failing. This 'functional isolation' occurs when floods, storms or other hazards disable power, water, transport or supply chains, so hospitals, schools and supermarkets cannot operate despite being accessible. Direct-damage-only assessments miss these cascading outages and underestimate business interruption.

Guglielmo Zappalà
Nationality: Italian
Location: United States

Allianz Trade Award: Heat shocks move through supply chains

Extreme heat in agriculture triggers losses far beyond farms. Because crops feed global production networks (textiles, food processing, rubber, automotive, etc.), heat shocks propagate via input – output linkages, cutting value added across borders. Models that ignore these effects underestimate climate damages; including them reshapes carbon pricing, adaptation priorities and systemic-risk views.

Foreword

CHRIS TOWNSEND
Member of the Board of Management, Allianz SE

Insurance has always been about forecasting the future, a tradition rooted in 14th-century maritime contracts where underwriters calculated the odds of safe passage. For generations, we relied on the past to predict what lay ahead.

As I welcome you to this collection of essays from our 2025 Allianz Climate Risk Award finalists, we stand at a pivotal moment. Climate change has fundamentally altered the reliability of historical data, forcing our industry to reinvent its risk assessment approach.

Our finalists' research represents the vanguard of that transformation – a bridge between traditional insurance principles and the climate-aware methodologies that will define our industry's future. They remind us that the past can no longer serve as our compass; instead, we must look to science, innovation, and collaboration.

The science behind tomorrow's protection

Understanding the impacts of climate change is essential for assessing tomorrow's risks. As insurers, we need the latest scientific insights to adapt our underwriting and modeling, ensuring we stay resilient. To anticipate how these changes will shape future natural catastrophes, we rely on scientists like those we celebrate through the **Allianz Climate Risk Award**.

Our role as an insurer extends beyond absorbing financial shocks. We are partners in the global response to climate change: supporting the transition to renewable energy, closing protection gaps – especially in emerging markets, promoting climate adaptation and leading the way in sustainability and regulatory compliance. As a global insurer and investor, Allianz is committed to making a difference across all these fronts.

Scientific and practical application

Success in these efforts depends on a continuous dialogue between industry and academia. The challenges of climate risk are complex and ever-changing, and only by working together can we turn scientific breakthroughs into practical solutions. The research shown in the following pages exemplifies the collaborative spirit that will drive progress.

We are grateful to all participants of the 2025 Allianz Climate Risk Award for sharing their ideas and research, and for helping us build a safer, more sustainable tomorrow. Thank you also to the jury for their dedication to assessing the applications, and of course, the organizers for bringing the Allianz Climate Risk Award to life.

Introduction

HOLGER TEWES-KAMPELMANN
CEO Allianz SE Reinsurance

Over the past few years, two developments have significantly changed how we understand natural disasters: we now have far more – and finer – data, and we have AI and machine learning methods capable of transforming that data into valuable insights. Satellites resolve coastlines, river basins and cities in unprecedented detail. Ground sensors, mobile devices and open datasets add the human and operational layers. Machine learning fuses these streams, revealing how hazards interact with exposed assets and vulnerable systems in a warming climate.

This shift moves us beyond counting losses to mapping the mechanics of failure. A flood that never reaches a hospital door can still close wards when power and logistics falter. A desert that looks dry from space can hide a flash flood. A crop that performed in yesterday's trials may stumble under tomorrow's extremes. With better data and models, those second-order effects become visible – and actionable.

The 2025 compendium highlights early-career researchers who use this new toolkit to identify interdependencies and turn them into decisions. AI models detect when river floods and storm surges align in European winters. Generative approaches create realistic 'what-ifs' so portfolios can be stress-tested. Sensor-driven analytics transform soil-moisture readings into real-time foresight, showing when parks absorb rainfall and when they shed it.

Nature risk comes into focus through integrated Earth-observation: mangroves – natural infrastructure that protects lives and assets – are tracked as sea levels rise and cyclone regimes shift. In arid regions, satellite techniques finally make desert floods visible at the scales that matter. In food systems, climate-aware trial design uses data and machine learning to test crops against the conditions farmers will actually face in the decades ahead rather than those of today.

Usefulness is the common thread. Faster, more equitable flood maps speed emergency response and sharpen loss estimation. Clearer views of linked hazards improve accumulation management. Practical simulators make scenario testing accessible beyond specialists. Soil-moisture forecasting helps cities prepare for storms and guides growers through drought. Quantifying nature's protection supports targeted prevention and parametric coverage that pays quickly when ecosystems are impacted.

Crucially, the human layer is made visible. Behavioral models illustrate how community norms and infrastructure dependencies shape recovery. Urban analytics reveal 'functional isolation,' where hospitals, schools or supermarkets survive the event but cannot operate because power, water or supply chains fail – so plans reflect the real burden of recovery.

Allianz Re's role is to turn such insights into action: backing open data and open science, favoring testable and explainable models, and co-developing tools that transition from the lab to the line of business. Protection must work in tandem with prevention, from nature-based solutions to climate-smart agriculture, so today's cover strengthens tomorrow's adaptation.

The work of these talented young scientists collected here helps lift our view from events to systems. By combining richer observations with advanced analytics, it equips underwriters, claims teams and clients with clearer signals, faster decisions and fairer outcomes. Most of all, it shows that resilience is not only measurable – it can be designed, and targeted where it matters most.

Flood risk in the Anthropocene

Author

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Biography

Jeremy is a researcher affiliated with the German Aerospace Center, working at the intersection of climate science, hydrology and remote sensing. His research focuses on the impacts of floods in a warming world, using satellite data, computer vision, and geospatial analysis to understand risks better and strengthen resilience.

He holds a degree in Robotics from Sorbonne University and previously worked as a scientist at the University of Cambridge, where he applied deep learning techniques to tumor imaging. That experience instilled an intense sense of scientific rigor and shaped his approach to complex problems. Motivated by the global climate crisis, he redirected his career toward geosciences.

Title of thesis

Assessing Flood Impacts in the Anthropocene: A Pathway to Achieving Sustainable Development Goals

Contact

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A satellite-driven approach to flood risk assessment combines climate, hydrology and socioeconomic data to strengthen resilience and guide climate justice efforts.

Floods are the most widespread natural hazard worldwide, and their impacts are projected to intensify, particularly across Asia and Africa, as climate change disrupts the water cycle and amplifies existing vulnerabilities (Merz, B., Blöschl, G., Vorogushyn, S. et al.).

We are living in what scientists call the Anthropocene – a proposed new epoch in which human activity has become the dominant force shaping the planet's systems. In this human-made era, the warning signs are stark: researchers increasingly caution that we are edging toward an irreversible climate crisis.

Flood risk is best understood as the interplay of three elements: **hazard** (hydrological extremes, such as riverine and flash floods), **exposure** (people, infrastructure, and assets in flood-prone areas) and **vulnerability** (the socioeconomic conditions and adaptive capacity that shape resilience). International frameworks such as the Paris Agreement and the UN Sustainable Development Goals (SDGs) emphasize these links, and the creation of the Loss and Damage Fund at COP27 marked a significant milestone in mobilizing financial support for low-income and climate-vulnerable countries.

This research advances our understanding of flood risk and human-water feedback, often referred to as socio-hydrology, in the Anthropocene. Guided by the SDG framework, I integrate diverse datasets – climate, hydrological and socioeconomic – and apply methods spanning artificial intelligence, computer vision, geospatial analysis and statistics to assess flood impacts.

A central focus is climate justice for low- and lower-middle-income countries, where vulnerabilities are most significant. Using multi-sensor satellite imagery, I generate high-resolution flood maps and combine them with data on buildings, infrastructure and population, alongside climate and socioeconomic indicators. The result is a more comprehensive and robust basis for risk assessment.

Enabling rapid resource allocation

By overlaying flood maps with geospatial datasets on critical infrastructure, population distribution and socioeconomic indicators, we can evaluate both exposure and vulnerability at local and global scales (Figure 1). This integrated approach provides governments and institutions with a powerful tool for informed decision-making. It supports faster disaster assessments, guides resource allocation, public response and insurance-based compensation mechanisms, and strengthens long-term resilience strategies.

The method also enhances the effectiveness of the Loss and Damage Fund by promoting fairness and efficiency in the allocation of resources. This work was recently published in Scientific Reports.

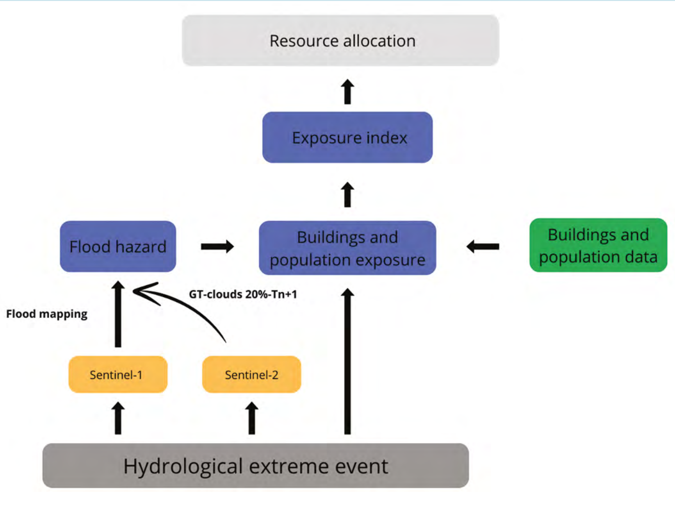

Figure 1: Framework for rapid resource allocation in flood scenarios. *The figure illustrates a global method that uses flood mapping with Sentinel-1 synthetic aperture radar (SAR) images, validated by Sentinel-2 optical imagery. An exposure index is derived from satellite data on flood extent, buildings and population distribution.*

Toward equitable climate resilience

This approach provides a comprehensive view of flood risk at global and local scales. It also enables rapid response and accurate damage evaluation. Although globally applicable, it is especially valuable for countries with limited resources. In such contexts, the availability of open-access satellite data is crucial. Freely available remote sensing empowers even capacity-constrained governments to conduct independent flood assessments and make timely, equitable decisions.

By supporting disaster preparedness, insurance mechanisms and climate resilience planning, this research directly contributes to SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). By strengthening disaster preparedness, insurance mechanisms and climate resilience strategies, this work directly contributes to achieving SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action).

How this connects to insurance

For insurers and public agencies, the results highlight the importance of linking hazard with vulnerability and exposure. High-resolution, data-driven flood assessments not only accelerate claims and resource distribution but also inform pricing, risk transfer mechanisms and underwriting. By integrating climate justice considerations, the approach aligns with insurers focused on resilience, fairness and long-term adaptation.

Floods are expected to intensify in a warming world. By combining satellite data, AI and socioeconomic analysis, this project provides actionable tools that strengthen global resilience – and ensure that vulnerable communities are not left behind.

Flood risk and the global economy

- **Approximately US$9.8Tn** of economic activity is located in flood-prone areas
- With **2°C of warming**, direct economic losses are projected to double
- COP28 established the **Loss and Damage Fund** to aid vulnerable countries
- But funding often moves slowly, hampered by limited data and weak frameworks for distribution

Storm signals: How AI predicts future flood risks

Author

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Biography

Philipp earned his Bachelor of Science in Physics from the Carl von Ossietzky University of Oldenburg, completing his thesis at the Max Planck Institute for Solar System Research in Göttingen. He went on to pursue a Master of Science in Physics, specializing in physical oceanography.

After graduating, he worked for three years as a research assistant at the Zuse Institute Berlin in the Department of Image Analysis in Biology and Materials Science, where he collaborated with the German Federal Institute for Materials Research and Testing on projects in additive manufacturing.

Philipp then completed his PhD at the Helmholtz-Zentrum Hereon in Geesthacht, focusing on compound flood events. The research submitted for this award forms part of his doctoral work, marking his first project involving machine learning. In it, he built on insights from earlier studies on compound flooding, extending his expertise into the application of AI for climate risk assessment.

Title of thesis

Machine learning to analyze frequency changes in compound flooding in Europe under climate change

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As Europe's weather changes, flood protection faces a hidden risk: compound events. When storm surges and raging rivers strike together, the damage can far exceed either hazard alone. A new AI-driven approach reveals why these twin threats are set to rise – and how we must adapt.

Flood protection is often designed for one extreme at a time. But when two flood drivers coincide – such as high river discharge and elevated sea levels – the consequences can be far more severe. These so-called **compound events** have attracted growing attention in recent years, as research shows they can be significantly more damaging than the individual extremes they comprise.

Yet, most flood protection measures still fail to account for them. A recent study for the Netherlands, for instance, found that even coinciding 'above average' events – not necessarily extremes – can cause significant disruption. Given that many of Europe's most important economic centers are located in low-lying coastal areas, underestimating compound risks poses a clear danger to both citizens and infrastructure.

The challenge of analyzing compound flood events

Despite their importance, compound flood risks remain poorly understood in the context of climate change. One reason is the prohibitive cost of analyzing them: robust assessments require downscaled data from multiple global climate models, which demands enormous computational and human resources.

To address this, our research explored a more scalable approach. In earlier work, we found that a weather pattern known as **Cyclonic Westerly** (WZ) – characterized by strong westerly winds and high precipitation – occurs during most compound flood events in northern and central Europe. If the frequency of WZ shifts under climate change, then the risk of compound floods will be reduced.

The difficulty lies in the fact that WZ is part of the **Großwetterlagen** classification, a scheme traditionally defined subjectively. To overcome this limitation, we developed our own deep-learning system: the **Convolutional Neural Meteorology Network (CNMN)**. Trained on mean sea level pressure and geopotential height at the 500 hectopascal (hPa) surface, CNMN automatically classifies circulation types with high consistency, making large-scale and objective analysis possible (see Figure 1).

Stormier winters ahead

We applied CNMN to 31 climate models from the CMIP6 ensemble (see Figure 2). The findings reveal a robust signal:

Winter (16 October – 15 April): Under the high-emission scenario SSP5-8.5, 30 of 31 models project more WZ days by the late 21st century (2071-2100), with an average increase of **8.3 days per season** relative to the historical baseline (196-1990). Even under the low-emission scenario SSP1-2.6, two-thirds of models show an increase, averaging **1.9 additional days.**

Summer (16 April – 15 October): WZ becomes less frequent, consistent with projections of drier summers.

The consistency across models – particularly under high-emission scenarios – suggests a strong climate signal beyond natural variability. The implication is clear: atmospheric conditions conducive to compound flood events are likely to become more common in the future.

Implications for risk assessment and adaptation

Our findings underscore the need to integrate compound flood risks into future protection strategies. For Europe's coastal regions and major economic hubs, the projected increase in WZ during winter means that compound events could become both more frequent and more severe.

By using atmospheric circulation patterns as proxies, our method offers a cost-effective and scalable alternative to high-resolution hydrological or storm surge models. It can be applied to different regions and extended to other extremes, such as droughts. Future research should refine this approach through local studies that consider existing adaptation measures, infrastructure and topography.

Ultimately, the results highlight a critical warning: without updating flood risk assessments to reflect compound events, we risk underestimating future threats in a warming world.

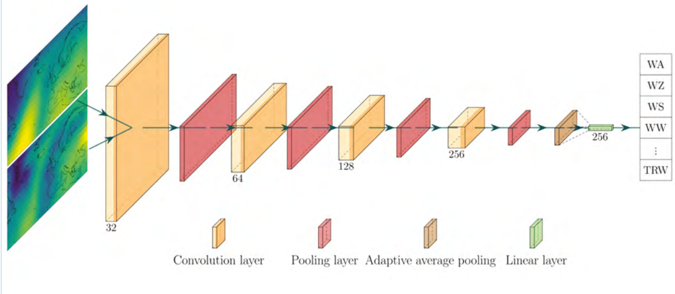

***Figure 1:** Visualization of the neural network architecture*
Numbers under the convolution layers indicate the number of channels.

Acronyms on the right correspond to the 29 Großwetterlagen.

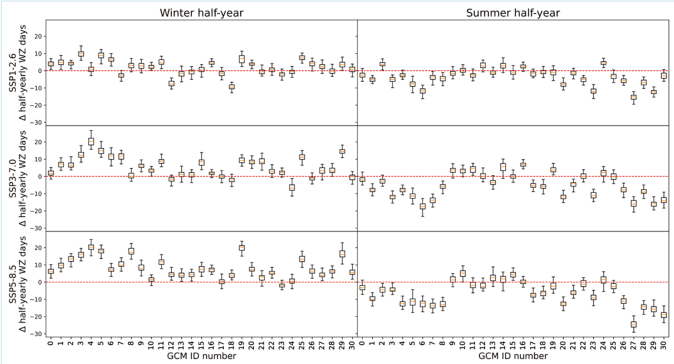

***Figure 2:** Projected changes in semi-annual WZ days across 31 CMIP6 models for three climate scenarios (SSP1-2.6, SSP3-7.0, SSP5-8.5)*
Boxplots illustrate changes from 1961–1990 to 2071–2100, with winter on the left and summer on the right. Outliers are excluded.

Published paper:

Heinrich, P., Hagemann, S., and Weisse, R. (2025). "Automated classification of atmospheric circulation types for compound flood risk assessment: CMIP6 model analysis utilizing a deep learning ensemble." Environmental Research Letters, 20(7), p. 074018.

Heinrich, P. (2025) 'Convolutional Neural Meteorology Network (CNMN)'. Zenodo.

On shifting shores: Modeling climate risk to mangroves and their services

Author

Sarah Hülsen

Institution

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Biography

Sarah Hülsen brings a strong background in land and water management to her research on climate risks to ecosystems. As a consultant in East Africa, she witnessed firsthand how communities depend on natural systems – and how droughts, floods and other climate extremes are disrupting these lifelines.

Her interest in nature-based solutions deepened during an internship with Swiss Re, where she explored innovative ways for the private sector, including insurance, to support ecosystems in reducing disaster risk and tackling climate change.

Sarah has co-authored two scientific publications in collaboration with experts from The Nature Conservancy and WWF, underscoring the vital role of robust global data in conservation and resilience-building. Her current research integrates finance, nature and science to assess spatially explicit risks to ecosystems and their services under future climate scenarios.

Title of thesis

Climate risk to mangroves and their services from changing cyclones and sea level rise by 2100

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Mangroves are coastal powerhouses, protecting people, storing carbon and sustaining biodiversity. But climate change is pushing them to their limits. New modeling reveals how rising seas and stronger cyclones could imperil both these forests and the billions of dollars in protection they provide.

Mangrove forests are nature's multitaskers. They shield coastlines from storms, sustain fisheries, shelter biodiversity and store vast amounts of carbon. Yet under climate change, these ecosystems face mounting threats from rising seas and intensifying tropical cyclones.

Through their dense root systems, mangroves reduce erosion and blunt storm surges. At the same time, their remarkable adaptive capacity enables them to trap sediments and keep pace with the gradual rise in sea level. This resilience makes them a powerful natural ally in climate adaptation. But their limits are real. With faster sea level rise and more frequent, more destructive cyclones, mangroves risk collapse – taking with them the protection and livelihoods they provide to millions of people.

The insurance industry has begun to recognize this role: Mangroves are estimated to reduce flood damage by more than **US$65Bn annually**. Their degradation, therefore, has critical implications for both insured and uninsured losses, reinforcing the urgent need to assess where these ecosystems and the services they provide are most at risk.

A new global climate risk index

To address this, we developed the first **global, spatially explicit projection of climate risk to mangroves**, integrating changes in both tropical cyclone (TC) activity and sea level rise (Figure 1).

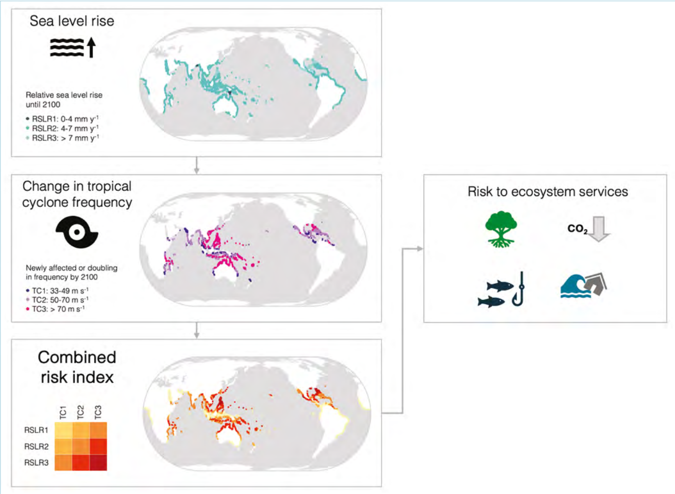

***Figure 1**: Workflow to derive the combined tropical cyclone and sea level rise risk index for mangroves. Colored points indicate local risk rankings, ranging from low to severe*

- **Cyclone risk:** Using storm tracks from a statistical-dynamical downscaling of three climate models, we modeled wind fields under historical and future scenarios (SSP2-4.5, SSP3-7.0, and SSP5-8.5 by 2100). Since mangroves are adapted to historic disturbance regimes, significant departures from these regimes disrupt recovery and are ranked higher in risk.
- **Sea level rise risk:** Mangroves can adjust to moderate rise, but rapid rates can overwhelm sediment-trapping and upward growth, triggering potential collapse. Higher rise rates, therefore, correspond to higher risk.

By pairing cyclone and sea level projections, we produced a **global risk ranking**. Overlaying this with spatial data on services – coastal protection, fisheries, and carbon storage – reveals not just where mangroves are most threatened, but also where the loss of benefits would be most severe (Figure 2).

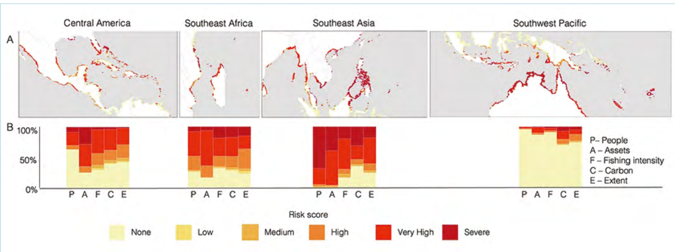

***Figure 2:** Hotspot areas and shares of mangrove services at different risk levels. Panel A shows mangrove locations at risk; Panel B shows the percentage of area (E) and services—coastal protection for people (P) and assets (A), fisheries (F) and carbon storage (C).*

Irreplaceable values at risk

The results are stark. Depending on the scenario, **40-56% of the global mangrove area** faces high to severe risk. Even more concerning, the top regions delivering the most significant benefits are disproportionately exposed, with **60-74% of these service hotspots** falling into the highest risk categories.

In Southeast Asia, for instance, mangroves, which provide up to **98% of coastal protection benefits** for people and assets, are projected to be at high or severe risk by 2100. The socioeconomic stakes are immense: widespread degradation would drive cascading biodiversity loss, erode fisheries, release stored carbon and undermine coastal protection. Millions of people will be impacted.

Implications for insurance and adaptation

Our findings underscore the dual crisis of climate change and biodiversity loss, and the need for insurance to play an active role in promoting resilience. As disturbances intensify, natural recovery pathways may falter. Human-supported interventions such as **mangrove restoration and assisted regeneration** will be essential.

Insurance can accelerate these efforts. **Parametric products** with fast payouts can fund recovery immediately after cyclone damage, maintaining disaster risk reduction benefits for coastal communities. Similarly, insurance can help **mitigate the risks associated with blue carbon projects**, ensuring the long-term viability of carbon credits tied to mangrove conservation.

By highlighting global hotspots, our index provides a tool to prioritize investments, guide adaptation and safeguard the natural infrastructure that protects lives, assets and ecosystems on the world's shifting shores.

Published paper:

Hülsen, S., Dee, L. E., Kropf, C. M., Meiler, S. & Bresch, D. N. (2025). **Mangroves and their services are at risk from tropical cyclones and sea-level rise due to climate change.** Communications Earth & Environment, 6, 1-9.

US$65Bn shield

Every year, mangroves prevent more than $65Bn in flood damage worldwide. Their dense roots stabilize coastlines and buffer storm surges, acting as natural infrastructure that saves lives, assets and ecosystems. Losing them would leave coastal communities vastly more exposed to escalating climate risks.

Hotspots under threat

By 2100, 40-56% of global mangrove area could face high to severe risk. Even more alarming, 60-74% of the most valuable mangrove zones – those providing the greatest protection, fisheries, and carbon storage – are projected to be disproportionately exposed.

Why multi-hazards matter

Author

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Biography

Alison is a doctoral candidate with the Oxford Programme for Sustainable Infrastructure Systems at the Environmental Change Institute, University of Oxford. With a background in mathematics and statistics, she holds a BSc in Mathematical Sciences from University College Cork and an MSc in Mathematical Modelling and Scientific Computing from the University of Oxford. Her research focuses on applying deep learning and statistical methods to improve multi-hazard catastrophe modelling and make climate risk analysis more accessible.

She has contributed to national-scale climate risk assessments for Bangladesh, the Organisation of Eastern Caribbean States, Nigeria and Somalia, in collaboration with partners including the Global Centre on Adaptation and the World Bank Group. In these projects, she assessed the exposure and vulnerability of critical infrastructure to climate hazards and modelled both direct damages and indirect socioeconomic losses.

She is poised to join Oxford Infrastructure Analytics as a Climate Risk Scientist, where she will continue to develop spatially resolved multi-hazard models for use in national climate risk assessments. Her broader research interests span deep learning, emulation, climate and biodiversity, with a focus on advancing open data and open science.

Title of thesis

Simulating spatial multi-hazards with generative deep learning

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A new framework uses deep learning to model the complex interplay of multiple climate hazards occurring together during extreme events.

Be it wildfires kindled in hot, dry summers, tropical cyclones driving winds and rain, or storm surges compounding over high tides, the convergence of multiple hazards can be devastating. Yet existing risk analysis methods often struggle to capture the interdependencies that make multi-hazards so destructive – and sometimes omit them entirely.

This omission forces practitioners to rely on biased or incomplete information when shaping policies for adaptation, emergency response, insurance and urban planning. The challenge grows when spatial interdependencies are considered: across large areas, regional links influence both hazard frequency and co-occurrence. Widespread, simultaneous hazards – capable of overwhelming infrastructure – remain a blind spot in most models.

Our research addresses this limitation by combining deep learning with the statistical theory of extremes. The result is hazGAN, a generative AI framework that produces spatial multi-hazard event footprints at scale. Built on open-source global datasets, hazGAN lowers the barrier to entry for robust multi-hazard modelling and provides a theoretically grounded method for generating new extremes.

AI image generation: from cats to NatCats

The most rigorous approach to climate risk is catastrophe modelling, which calculates impact statistics across thousands of hazard scenarios. Governments and insurers rely on such models for multi-million-dollar decisions. Still, reliable outputs require data from thousands of extreme events. Simulating these events numerically is computationally costly, while traditional statistical approaches struggle to scale to many variables.

Deep learning, however, thrives on high-dimensional problems. Deep generative models (DGMs) – trained on images of cats, dogs, or faces – learn complex relationships across thousands of variables. A coarse 32×32 RGB image is 3072-dimensional. By treating hazard footprints – maps of maximum impacts during extreme events – as images, we can apply similar models to simulate multi-hazard events. Wind, rain and storm surges become data channels much like colours in an image (Fig. 1).

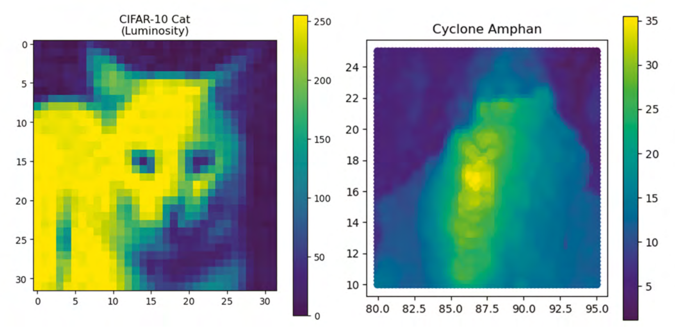

Figure 1: *From cats to cyclones*
Deep generative models developed for image datasets (left: a 32×32 cat image) can also be trained on hazard footprints (right: wind footprint from Tropical Cyclone Amphan in the Bay of Bengal, 2020).

To ensure physical realism, hazGAN integrates extreme value theory. Independent extreme value models are fitted to each variable, controlling the extremes generated by the deep learning model. This ensures all extreme predictions are theoretically justified and standardises the data across different variables, making it easier to model the interdependencies.

Applications: from mangroves to power grids

Figure 2 shows hazGAN-simulated wind footprints compared with historical data for storms in the Bay of Bengal. Additional footprints for precipitation and sea-level pressure are generated simultaneously, enabling the assessment of compound storm impacts.

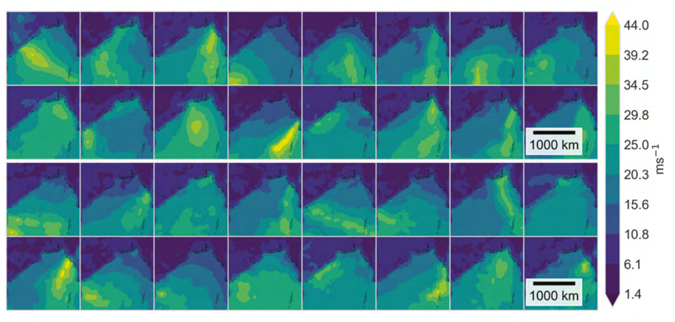

Figure 2: *Simulating storms with hazGAN*
Simulated (top) and real (bottom) 64×64 wind footprints of Bay of Bengal storms. Companion footprints are also produced for precipitation and sea-level pressure.

This region is home to the world's most extensive mangrove forests, which are vulnerable to the combined forces of wind and rain during storms. Using hazGAN, we simulated 500 years of storms and estimated the aggregate damage to mangroves. The return period-damage curve in Figure 3 shows strong agreement between historical and generated damages, with 100-year losses affecting 28-30% of total mangrove area (9917 km^2).

Two naïve approaches – assuming full dependence between variables or complete independence – both misestimate damages by more than 1000 km^2, highlighting the importance of accurately modelling interdependencies.

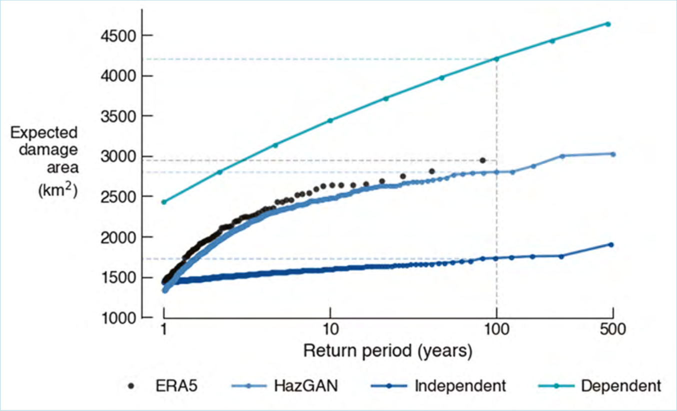

Figure 3: *Modelling mangrove damages*
Return period-damage curve for Bay of Bengal storms. hazGAN simulations (blue) align with historical damages (black), while naïve assumptions (teal/navy) over- or underestimate losses.

Beyond ecosystems, the framework can be applied to critical infrastructure. HazGAN can generate natural hazard footprints to stress-test agricultural supply chains, electricity and transport networks, and emergency response systems. By simulating thousands of events, it can support more realistic risk assessments than previously possible with limited or proprietary models.

Toward accessible catastrophe modelling

Historically, comprehensive catastrophe models have been the preserve of well-funded organisations with access to proprietary datasets. hazGAN can shift that balance. By running on open-source climate data, it enables governments, insurers and researchers worldwide to generate thousands of multi-hazard events and feed them into impact models.

As climate change intensifies natural hazards, this work provides an accessible, evidence-based foundation for climate adaptation, emergency planning and risk transfer.

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Water at risk: Urban floods and agricultural droughts

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Biography

Haokai is a postdoctoral researcher specializing in climate resilience, environmental sensing and machine learning. He holds a PhD and an MSc in Civil and Environmental Engineering from Columbia University, as well as a BEng in Electrical Engineering from Tongji University, combining expertise in hardware development with environmental modelling.

At MIT, his research integrates Bayesian data assimilation and deep learning into a sensor-to-ML framework for real-time estimation and forecasting of soil moisture. He also designs algorithms for anomaly detection and groundwater contamination monitoring, extending sensing approaches to long-term environmental assessment. His work has been published in Sustainable Cities and Society and Scientific Reports, earning recognition, including the Best Short Paper Award at IEEE IE 2022 and the Floyd Hasselriis Educational Support Award from ASME.

Title of thesis

Real-time soil moisture sensing and forecasting for urban floods and agricultural droughts

Contact

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A new sensing-and-modeling framework reveals how soil moisture shapes resilience – from stormwater management in cities to irrigation on farms.

Climate extremes are reshaping how societies live with water. In cities, intense storms overwhelm drainage systems, inundate streets and disrupt daily life. In farmlands and natural landscapes, droughts devastate crops and ecosystems, threatening food production and habitats.

Soil moisture: The hidden connector

The common thread is soil moisture. In urban environments, it determines whether green spaces absorb rainfall or generate runoff. In agriculture, it regulates plant growth, irrigation demand and resilience to prolonged dry spells. Yet, soil moisture is rarely monitored in real-time, leaving both cities and farms vulnerable to unexpected risks.

Traditional approaches often rely on static assumptions, such as fixed runoff coefficients in stormwater guidelines, or on coarse satellite observations that fail to capture subsurface conditions. These methods cannot reflect the dynamic, site-specific behavior of soils that determines whether water becomes a resource or a hazard.

LoRaWAN sensing in the city

To close this gap, we developed a wireless soil moisture sensing network using LoRaWAN technology. Unlike conventional wired instruments, which are costly and complex, or short-range wireless systems such as WiFi and Bluetooth, LoRaWAN supports low-power, long-range communication – up to five kilometers in cities and 15 kilometers in rural areas.

Deployed across seven urban green spaces in New York City, the network monitored soil and atmospheric parameters, proving dependable over a year-long operation (Figure 1).

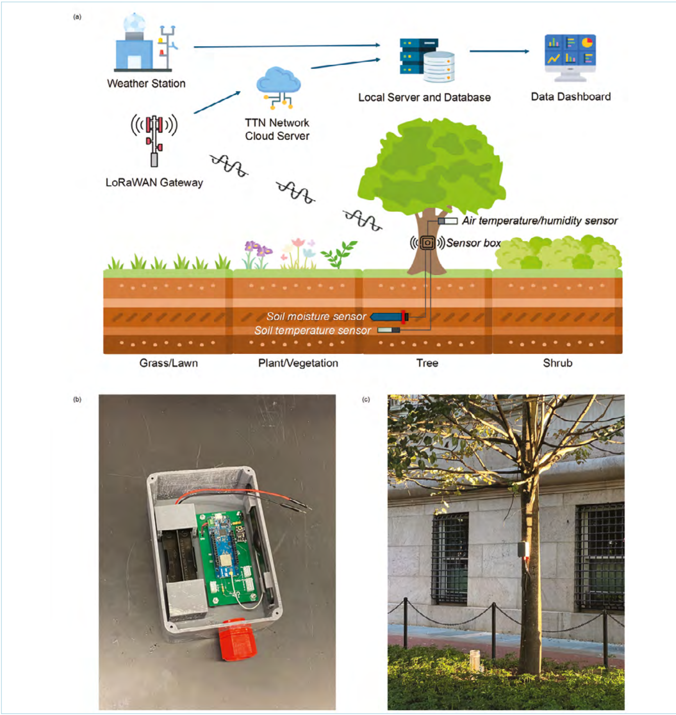

*Figure 1: LoRaWAN sensing network **(a)** System diagram of the LoRaWAN-based environmental sensing network **(b)** Custom-designed sensor board with weather-proof casing. **(c)** Example of a deployed sensor node in the field.*

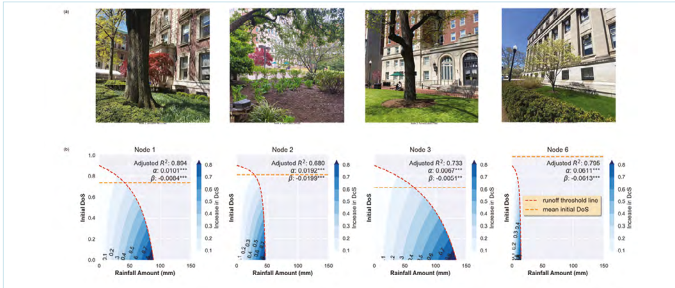

*Figure 2: Mapping stormwater behavior **(a)** Example urban green spaces with deployed sensors **(b)** Models estimating stormwater retention capacity as a function of soil moisture, showing dynamic runoff thresholds compared with static assumptions.*

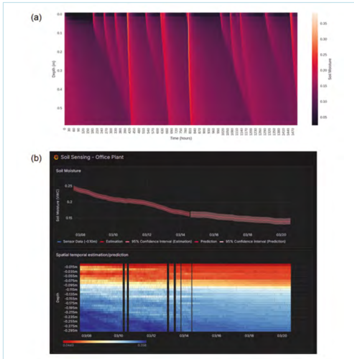

***Figure 3:** From data to decision support **(a)** Soil moisture estimation across the vertical soil column at one sensor node over 1500 hours, showing rainfall infiltration at different depths **(b)** Real-time dashboard combining live sensor data with seven-day forecasts.*

Data showed substantial variation in stormwater behavior across the sites (Figure 2). Grass lawns with shallow soils and subsurface concrete saturated quickly, generating runoff even in moderate storms. In contrast, a tree site with sandy loam soil retained water effectively, reducing flood risk during heavy rainfall. Runoff coefficients ranged from nearly zero to almost one in large storms – far more dynamic than the static values in government guidelines – underscoring the limits of current stormwater design standards.

From sensors to forecasts

Monitoring is only part of the solution. Forecasting soil moisture dynamics is equally critical – helping city managers anticipate which sites will absorb water or generate runoff before storms and assisting farmers in scheduling irrigation or preparing for drought stress.

Many existing machine learning methods are 'black boxes' that ignore physics and rarely integrate real-time sensor data. To address this, we built a sensor-to-ML framework that fuses LoRaWAN measurements with physics-based hydrological models. At its core is the Ensemble Kalman Filter, which assimilates sensor readings into models and estimates soil moisture across the entire vertical soil column.

To reduce computational load, we developed a deep learning emulator that accurately reproduces hydrological simulations at significantly faster speeds. This pipeline delivers forecasts up to seven days ahead and displays them in a real-time dashboard (Figure 3).

Towards risk-aware cities and farms

This combined sensing and modeling system highlights opportunities for resilience planning. Long-term deployments could provide cities with dynamic maps of stormwater resilience, identifying hotspots for investment and high-performing sites as models for design and implementation. Extending the framework to agriculture would enable precision irrigation, reduce water waste and strengthen drought resilience.

For the insurance and reinsurance industry, these advances generate quantifiable, real-time risk indicators. By embedding soil-water dynamics into climate risk models, insurers can improve premium setting, refine loss forecasting and support proactive adaptation measures.

By linking sensors, models and decision-making, this research turns soil moisture from a hidden variable into actionable intelligence. The result: cities better prepared for floods, farms better equipped for drought, and insurers better able to anticipate risk in a climate-challenged world.

A glass of water, two soils

Tip a glass of water onto baked, compacted soil, and it skitters across the surface, pooling and running away. This is how sudden downpours turn into flash floods.

Pour the same glass onto healthy, porous soil, and it soaks in, feeding roots below. Here, water becomes a resource, not a hazard.

That simple contrast explains why soil moisture is at the heart of this research – it determines whether cities drown, fields wither or both thrive under stress.

The fragile pact: Resilience at the edge of scarcity

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Biography

Ali is a PhD candidate in cognitive neuroscience and machine learning at École Normale Supérieure – PSL University in Paris. His research focuses on reinforcement learning and economic decision-making, combining insights from artificial intelligence, behavioral economics and psychology. He also teaches Cognitive Models & Artificial Intelligence, which keeps him engaged with state-of-the-art approaches to modeling human learning and choice.

He holds an MSc in Artificial Intelligence and Robotics, graduating top of his class, and a BSc in Computer Engineering. Beyond academia, he has applied behavioral analytics in data-science roles spanning urban mobility, product development and people analytics. His research includes peer-reviewed contributions to international conferences such as RLDM, CogSci and CCNeuro, alongside advanced training in modeling social and collective behavior.

Title of thesis

Cognition, Commons & Climate Shocks: Turning Behavior into Resilience

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A machine learning framework shows how community behavior shapes resilience in times of droughts, heatwaves and storms.

When droughts, heatwaves or storms arrive, they not only strain resources, they also stress the rules communities use to share them. In common-pool resources (CPRs), such as coastal fisheries, groundwater, rangelands and rivers, access is hard to exclude, and one person's use reduces what remains for others. This is the **tragedy of the commons**: individually reasonable choices can collectively lead to damaging outcomes. When scarcity rises or monitoring weakens, people overuse the shared stock, and both the resource and community welfare erode (Hardin, G., 1968).

The late Elinor Ostrom, a Nobel Prize-winning political economist, showed that this slide is not inevitable. With local monitoring, shared rules and graduated sanctions, communities can and do govern CPRs sustainably.

Most freshwater is a commons in practice. Agriculture accounts for roughly 70% of global withdrawals. Groundwater supplies approximately one-half of domestic water and one-quarter of irrigation water. The UN Food and Agriculture Organization reports that only 62.3% of assessed marine fish stocks are within biologically sustainable levels, while the World Bank estimates that weak fisheries management leaves $83Bn in benefits unrealized each year. These figures underscore why CPR failures are not only ecological, but also political, economic and cultural.

What this project adds

Classic climate-risk research is strong on flows, stocks and hazards, but it often underplays collective behavior under stress. Recent work in Nature Communications has demonstrated that deep reinforcement learning can foster sustainable human behavior in common-pool settings. At the same time, reviews in Environmental Modelling & Software have examined how agent-based models capture the interactions between groundwater and society.

Our project introduces NORMARL, a Norm-Oriented Multi-Agent Reinforcement Learning framework that makes the behavioral layer explicit. We focus on two practical questions that any water users' association or fishers' cooperative will recognize.

The first is how strongly people feel about the shared rule – do they internalize a fair-share norm even without monitoring? The second is how fast they learn from feedback – do they adjust promptly when the reservoir is low, the monsoon is late, or others start to conserve water.

We simulate a community that repeatedly harvests from a shared stock, observes consequences and adapts. By varying the mix of internalizers versus free riders (non-internalizers) and fast versus slow learners, we diagnose when rules hold, when they fray, and how quickly the system recovers after a shock.

What we find and why it matters

Composition matters as much as averages. Communities with a healthy core of rule followers sustain both resources and welfare (Figure 1). When the share of non-internalizers approaches roughly one-fifth, even otherwise cooperative communities struggle to avoid over-extraction. If too many members adapt slowly, small shortages can turn into significant crises.

Resilience is behavioral, not only hydrological. We shock the system with an abrupt stock drop after it has stabilized, mimicking a failed monsoon or a heat-driven demand spike (Figure 2). Groups that both care about the norm and learn quickly rebound faster and avoid the familiar post-shock rush to over-use. The result is a practical metric that planners already use: **time to recovery**.

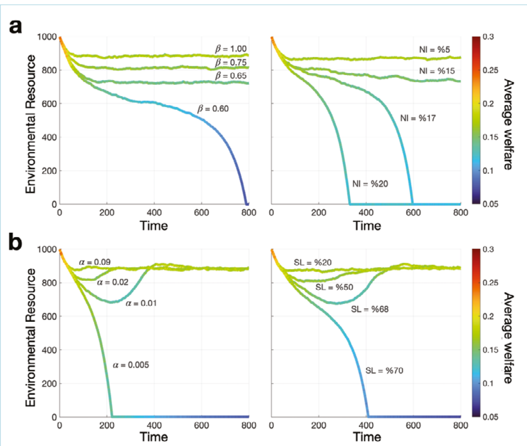

***Figure 1:** Composition and stability*
*Different mixes of **(a)** norm internalizers versus non-internalizers (NI), and **(b)** fast versus slow learners (SL), map onto stable versus collapsing outcomes.*
Source: Project simulation.

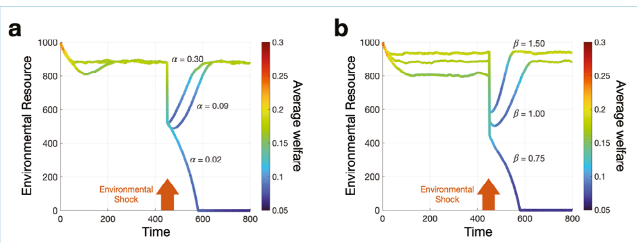

***Figure 2:** Shock and recovery*
*Recovery paths after an abrupt stock drop, highlighting the role of **(a)** norm-keeping and **(b)** feedback uptake in reducing time to recovery.*
Source: Project simulation

Design innovations

- **Norm salience rises with scarcity.** As the resource becomes scarce, social pressure to adhere to a fair share increases.
- **People consider not only payoffs, but also the norm.** Agents update a belief about what 'people like us do here' and act accordingly, aligning the model with Ostrom's emphasis on shared rules and local monitoring.
- **Population mix is the risk driver.** We analyze the share of non-internalizers and slow learners rather than a single average person, revealing tipping shares that explain why identical droughts can yield different outcomes across neighboring basins.
- **Embedded shock experiments.** Outputs are decision-ready under realistic climate scenarios, including collapse probability, welfare loss and time to recovery.

How this connects to insurance

Our results provide two informative signals that matter for prevention and adaptation programs.

Tipping shares help identify communities where shock-driven overextraction is likely, allowing behavioral support to be targeted before losses escalate.

Time to recovery is a clear resilience KPI for monitoring and for selecting partner projects.

Both signals translate social dynamics into decision-ready risk intelligence that complements hydrology and engineering in the places where Allianz and public agencies already collaborate.

Climate extremes will continue to test the commons. By making the human layer of risk visible and tractable, this project helps communities, public agencies, and insurers ensure that when the next shock hits, the commons can bend but not break.

> Resilience is not only hydrological – It is behavioral.

> When the next shock hits, the commons can bend but not break.

When the lights go out but the doors stay open: Functional isolation in a climate-challenged world

Author

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Biography

Mitchell is a researcher and entrepreneur whose work focuses on cascading climate risks and community resilience. He holds a PhD in Civil Systems Engineering from the University of Canterbury in Christchurch, New Zealand, where he also earned a BE with First Class Honours in Civil Engineering and a Diploma in Global Humanitarian Engineering. Growing up in a suburb that frequently flooded shaped his perspective on how risks unfold in practice, highlighting the gap between academic risk models and the lived realities of communities.

Alongside his doctoral research, Mitchell founded and leads Urban Intelligence, a company that develops the Resilience Explorer platform. Based in Christchurch, a city deeply familiar with earthquakes, floods and cascading disruptions, his work operationalizes innovative methods in spatial risk assessment, infrastructure network analysis and distributional justice. These tools support local authorities, iwi (Māori tribal groups) and international organizations in climate adaptation planning. Driven by a commitment to equity, his research addresses the cascading impacts of climate hazards – from power outages to supply chain disruptions and transportation breakdowns – that often harm the most vulnerable communities.

Title of thesis

Risk-informed spatial analysis for climate adaptation and distributional justice

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Disasters do more than damage buildings. They can strip away the ability of essential services to function, leaving communities stranded even when roads and structures appear intact.

When disasters strike, loss is measured not only in collapsed bridges or flooded streets. Communities can remain physically connected to hospitals, schools and supermarkets – yet those services may not be functioning. A supermarket surrounded by floodwaters but without power, a hospital intact but without clean water, a school accessible but without staff: these are the failures that quietly dismantle resilience.

Traditional risk assessments tend to focus on direct damage – how many homes are inundated and how many roads are washed away. What they often miss are the compounding burdens created when supporting infrastructure fails. Ignoring this hidden dimension grossly underestimates the consequences of disasters. It obscures where adaptation strategies, emergency planning and insurance coverage will fall short.

Innovation: mapping hidden failures

To expose this blind spot, I developed a framework that links infrastructure networks with accessibility analysis. Using high-resolution geospatial data for Christchurch, New Zealand, I modelled how flooding not only damages assets directly but cascades through electricity, transport, wastewater and water systems. The analysis then tested the operability of hospitals, schools and supermarkets under these cascading conditions, factoring in disrupted supply chains.

The goal was to translate technical failure cascades into everyday outcomes. Can families still buy food? Will schools reopen quickly? Are hospitals online when most needed? By reframing resilience in terms of lived experience, functional isolation becomes tangible and actionable.

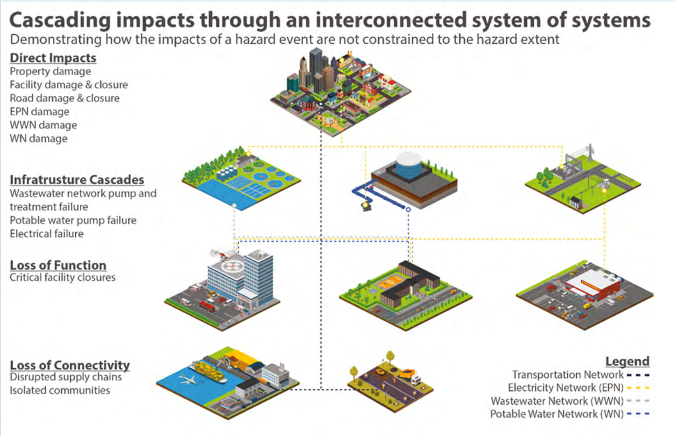

Figure 1

Key findings: a hidden multiplier of risk

When functional isolation is considered, the scale of disruption multiplies:

- Isolated residential buildings increased by 198% compared to direct impacts alone.
- Non-functional hospitals rose by 178%, supermarkets by 114% and schools by 142%.
- Average travel distances to services lengthened by 0.5-1 km, with some families forced to travel up to 27 km for basic needs.

The result: communities that appear connected on maps may, in reality, be cut off. Entire suburbs become 'service islands,' where critical amenities exist only in name.

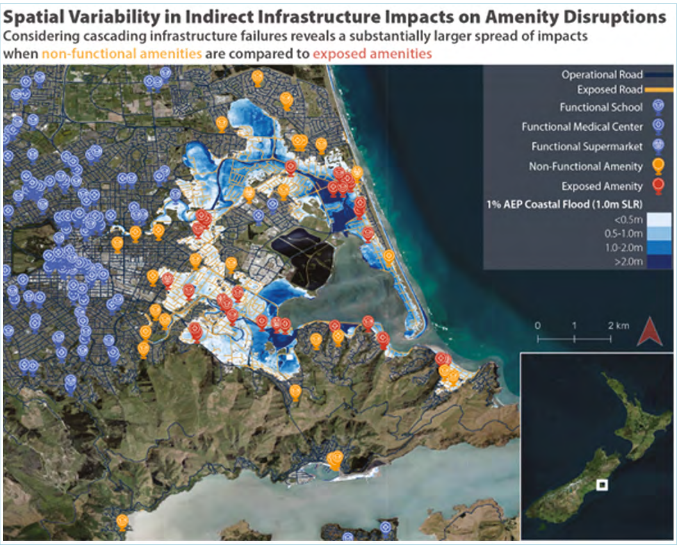

Figure 2

Impact: from insurance practice to societal resilience

For insurers, these findings redefine the concept of risk. Business interruption models that only account for direct flood damage miss systemic losses emerging from functional isolation. A supermarket may be undamaged yet unusable, triggering claims through disrupted supply chains. Hospitals unable to operate magnify mortality risks and liability exposures. Schools that remain closed prolong socioeconomic costs, eroding productivity and community stability.

By quantifying these cascading impacts, functional isolation provides insurers with a sharper tool for advising clients on resilience investments, designing business interruption coverage, and pricing risk. It also equips governments and utilities with evidence to prioritize adaptation – such as diversifying supply chains, reinforcing substations or pre-positioning mobile facilities.

A generalizable framework

While demonstrated in Christchurch with coastal flooding, the framework is hazard-agnostic and globally applicable. It can assess earthquake-triggered utility failures in Turkey, wildfire-driven power outages in California or typhoon-induced supply chain disruptions in Southeast Asia. Wherever interdependent infrastructure exists – which is nearly everywhere – functional isolation is a hidden amplifier of disaster burden.

Looking ahead: planning for cascading futures

As climate change drives more extreme floods, storms and wildfires, ignoring functional isolation will leave millions exposed. Communities may not collapse because a road is impassable, but because the hospital it leads to has no power or the supermarket it connects to is empty.

By revealing these hidden risks, this research offers a pathway for insurers and policymakers to anticipate and mitigate cascading burdens before disasters strike. Resilience is not only about stronger walls. It is about safeguarding the invisible systems that allow societies to function, from eating to learning and living, when the lights go out.

When services exist but don't work

- **The hospital:** The building stands and the road is clear, but the power is out and water pumps have failed. Patients cannot be treated.
- **The supermarket:** The shelves are stocked and doors are open, but supply chains have stalled and refrigerators are off. Food spoils, and families go hungry.
- **The school:** The classrooms are intact and accessible, but the staff cannot return, and the sanitation systems are offline. Children stay home.

This is functional isolation – communities appear connected on maps, yet critical services fail in practice. It is a hidden amplifier of disaster risk that insurers, planners and governments must confront.

The syntax of vulnerability: Decoding flood impacts in urban networks for decision-support and climate adaptation

Author

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Cardiff University, Welsh School of Architecture

Biography

Diego is an urban analytics researcher specializing in decision-support systems, socio-spatial and network analysis and climate adaptation. He began his academic path in Brazil, earning degrees in Economics and Urban & Regional Planning, the latter funded by the National Council for Scientific and Technological Development (CNPq). He subsequently earned a European PhD in Energy, Systems, Territory, and Construction Engineering from the University of Pisa. His doctoral research pioneered a method that combined network analysis with economic modelling to evaluate territorial imbalances.

Since completing his PhD in 2022, Diego has authored more than 45 peer-reviewed publications and contributed to secure major European grants, including a Marie Skłodowska-Curie Actions Postdoctoral Fellowship (funded by UKRI) and a Driving Urban Transitions grant (DUT-EMC2). Now a UKRI/MSCA Fellow at Cardiff University, he leads the DECIDE project. This project reimagines decision-support systems as inclusive, outcome-driven platforms that translate complex analytics into actionable insights.

Diego's work was tested in real-world conditions during the devastating 2024 floods in Rio Grande do Sul, Brazil, where he led Cardiff University's efforts to provide local authorities with a critical analysis of road network accessibility and redundancy. His experience across academia, teaching, and the public sector – including work in housing finance and risk assessment – underscores his commitment to turning research into tangible solutions that build resilience for cities and communities.

Title of thesis

The syntax of vulnerability: Decoding flood impacts in urban networks for decision-support and climate adaptation

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When Brazil's worst floods in 80 years struck Porto Alegre, roads turned into rivers and the city's lifelines snapped. New research shows how network analysis can decode such collapses, transforming raw data into decision-support tools that help insurers and city leaders to anticipate, rather than just react.

A city's pulse is its movement – the flow of people, services, and goods. In May 2024, that pulse in Porto Alegre, capital of Rio Grande do Sul in southern Brazil, flatlined.

From late April through May, an atmospheric block over central Brazil unleashed record rainfall across the state. In some areas, precipitation reached **333 millimeters**, three times the average of the past two decades. The result was Brazil's worst flooding in 80 years, affecting **91% of the state's municipalities.**

The human toll was devastating. Approximately 1Mn people were affected, with over **560,000 displaced in the metropolitan region of Porto Alegre alone**. The city's urban fabric unraveled overnight. Neighborhoods once linked by roads became islands in an archipelago of half-submerged houses, cut-off families and shuttered businesses. Rebuilding costs may exceed **€3Bn**, but the more profound loss lay in the collapse of everyday life.

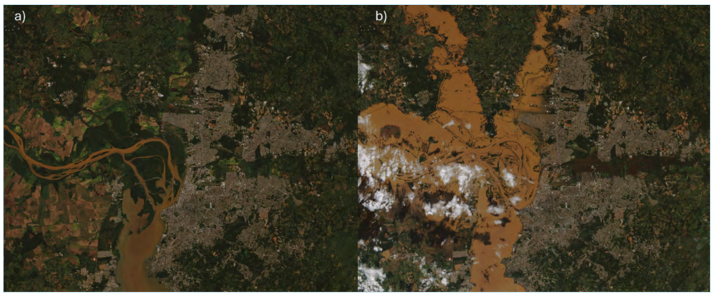

***Figure 1:** Sentinel-2 satellite images of the Porto Alegre Metropolitan Area before and after the flood, Copernicus Earth Observation Program.*

Beyond the waterline: How urban networks collapse in a flood

The Porto Alegre floods revealed how natural disasters expose – and are amplified by – urban fragilities. Severing five of the seven main highways into the state capital, the disaster fragmented the metropolitan region into disconnected enclaves.

This collapse in accessibility was not random. It followed **hidden properties of the road network**, patterns that can be decoded through network analysis. Using three key metrics, we modeled and visualized these disruptions:

- **Normalized Angular Integration (NAIN):** measures relative accessibility – how reachable a road is within the network.
- **Normalized Angular Choice (NACH):** Indicates the frequency at which a road segment is utilized as part of the shortest paths.
- **Kemeny-Based Centrality (KBC):** Estimates redundancy – roads whose failure would critically impair accessibility have high values.

Simulating four scenarios, from pre-flood stability to disrupted highways, complete redundancy collapse and the establishment of humanitarian corridors (Figure 2), we mapped how accessibility fractured and partially recovered. This **syntax of vulnerability** turned abstract metrics into spatial storytelling, making fragility visible and decision-making tangible.

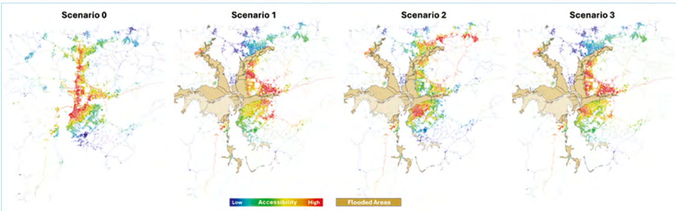

Figure 2: ***Accessibility patterns across four flood scenarios, including validation of emergency humanitarian corridor interventions.***
Scenario 0 – stable system before floodings – no interruptions/business as usual; scenario 1 – 6th-8th May 2024 flood impact on accessibility; interruption of the main highways that gave access across the metropolitan region; scenario 2 – hypothetical accessibility reduction upon collapse of all redundant connection roads; scenario 3 – validation of the emergency humanitarian corridor actions and their effect in partially reestablishing the accessibility in the region – 10 May 2024

From reaction to prediction: Designing decision-support systems

The experience of responding to this crisis marked a turning point in how we believed decision-support systems (DSS) should be conceived – not only as technical dashboards for experts, but as inclusive platforms for informed actions. Many DSS tools fail to communicate actionable insights to diverse users. Our project, DECIDE, reimagines DSS as outcome-driven platforms, universally accessible for different kinds of stakeholders.

Instead of burdening users with complex metrics, DECIDE focuses on what the numbers mean in practice – how a flood would affect accessibility, risk, or the delivery of essential services. By embedding analysis into everyday workflows, the system is designed to support both immediate crisis response and long-term planning. Decision-support, in this view, is not just about presenting data – it is about building trust and enabling informed action.

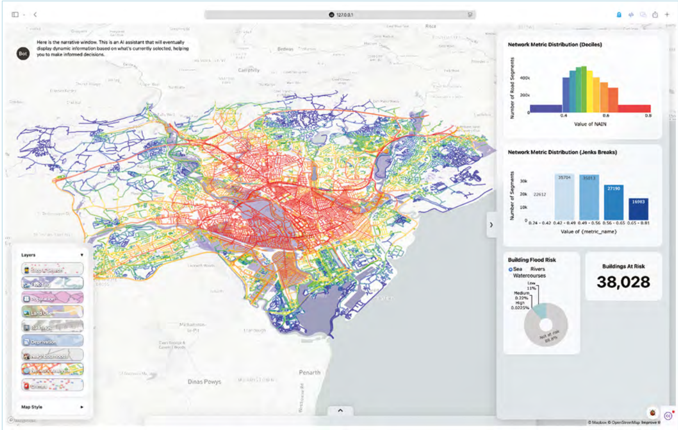

Figure 3: *DECIDE DSS Prototype*
A Python-based tool that combines road accessibility and flood vulnerability analysis for Cardiff, UK. The system integrates diverse spatial data and offers two modes: a simple interface for non-experts and an advanced version for technical users

Implications for insurers and urban governance

Floods and storms account for more than **70% of climate-related disasters worldwide**. Porto Alegre's experience demonstrates why risk assessment must extend beyond hazard maps to encompass systemic vulnerabilities in urban networks.

For insurers, this means identifying not just where hazards strike, but how failures propagate through infrastructure – compounding losses by disrupting emergency response, supply chains and economic continuity. For city leaders, it means embedding systems thinking into governance, linking rigorous analytics with clear communication that diverse stakeholders can act upon.

By decoding the syntax of vulnerability, we can transition from reaction to anticipation, enabling insurers to model risks more accurately and helping cities design adaptive strategies that withstand the floods of tomorrow.

DECIDE: Smarter Decision Support

The **DECIDE-DSS** prototype is a Python-based system that blends network analysis and urban analytics to guide disaster-risk management, liveability and urban planning. It can integrate diverse spatial data – from movement patterns to infrastructure and land use – and will be available in two versions: a simple interface for non-experts, and an advanced version for technical users to build knowledge and embed analysis.

Why can't we 'see' floods in deserts?

Author

Shagun Garg

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Biography

Shagun is a PhD researcher at the University of Cambridge, where he explores how satellite remote sensing can strengthen climate resilience, with a particular focus on nature-based solutions in water and flood management. He previously completed a Master's in Sustainable and Resilient Infrastructure at Cambridge and a Master's in Civil Engineering at IIT Bombay, alongside a DAAD-funded research year at Leibniz University Hannover, assessing the risks of groundwater-related subsidence in Delhi.

His research experience spans IIT Roorkee, IIT Bombay, and GFZ Potsdam (Helmholtz Centre for Geosciences), covering crop monitoring, geohazards, landslides and urban heat projects using Earth observation and AI. Beyond academia, he contributes to international initiatives, such as the UN Space4Water community and the UNU Nexus AID program, helping to make EO data more accessible for disaster resilience. Combining expertise in SAR/optical remote sensing, geophysical processes, and machine learning, he brings an interdisciplinary lens to tackling global flood monitoring challenges.

Title of thesis

Advancing Flood and Water Risk Monitoring in Arid Regions using Satellites and machine learning

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Floods in arid regions are growing more frequent and destructive. New satellite methods are helping reveal them – and the risks they pose to millions.

In February 2020, flash floods swept through Iran's Sistan region, turning dry basins into lakes within hours. Four years later, unprecedented rainfall submerged Dubai's highways and shut down one of the world's busiest airports. These events highlight a paradox: deserts and floods may seem contradictory, yet climate change is making flooding increasingly common – and often more devastating – in arid regions.

When downpours strike deserts, impacts are magnified. Dry sand cannot absorb water quickly, infrastructure is rarely designed for such extremes, and early warning systems are often absent. The result: millions remain highly vulnerable.

Satellites: Our global flood camera

Over the past decade, satellites have become a vital component in flood monitoring. More than 1,000 Earth-observing satellites now provide consistent coverage. Among them, Synthetic Aperture Radar (SAR) is particularly powerful: It can see through clouds and operate day and night. In SAR images, smooth open water appears dark against the brighter land, making floods easier to detect than with optical sensors, which behave like the human eye.

Services such as the Copernicus Global Flood Monitoring (GFM) system, run by the European Commission and the European Space Agency, already use SAR data from Sentinel-1 to produce near-real-time flood maps worldwide. These maps guide relief operations, support insurers and inform climate adaptation.

But deserts are left out. Arid and semi-arid lands cover more than 40% of Earth's surface and are home to 2.3 billion people, yet GFM excludes them because standard algorithms cannot reliably distinguish between sand and water.

The water-sand confusion

The reason is simple but stubborn. Dry sand and open water look almost identical in SAR imagery. Radar waves reflect similarly from smooth water and fine desert sand, so algorithms confuse the two (Figure 1). To avoid false alarms, GFM excludes arid regions altogether. The result: millions of people are invisible to global flood monitoring, just as deserts are expanding under climate change.

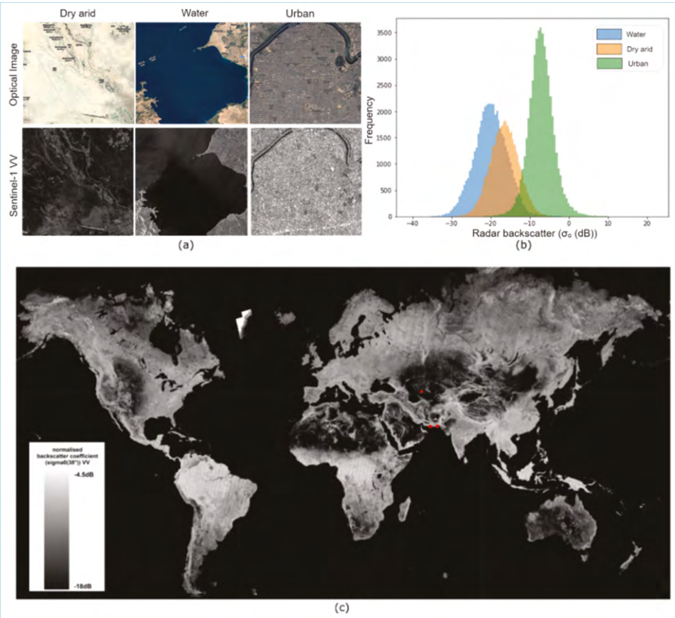

***Figure 1:** The sand–water problem*
Synthetic Aperture Radar struggles to distinguish smooth desert sand (a-b) from open water (c), creating false positives in flood detection.

Making desert floods visible

Our research tackles this problem by combining backscatter (signal strength) with coherence (signal stability) in a machine learning framework. While backscatter alone is prone to sand-water confusion, coherence offers the missing clue: floods disrupt stability between satellite passes, while surrounding dry land remains unchanged.

By fusing these signals, our method separates floodwater from sand with far greater reliability. Tested on three major desert flood events, it achieved approximately 80% accuracy and reduced misclassifications by 85% compared to conventional approaches – while using only one-third of the computing power. Further optimization showed the method could run with two-thirds fewer input layers, making it both efficient and scalable.

Beyond floods: seasonal water cycles

To distinguish true floods from recurring seasonal water bodies, we also map small lakes, ponds and riverbeds that appear and vanish with the seasons. Using both optical and radar satellites, we built a consistent record of these water dynamics. Integrated with flood mapping, this framework enhances near-term disaster response while also monitoring long-term water availability – a critical issue for drylands facing increasing water stress.

Implications for climate risk in arid regions

Floods in Sistan and Dubai are not anomalies, but warnings of a future where extreme weather hits places once considered ‘low risk.’ Excluding deserts from global flood maps means excluding millions from adaptation planning, humanitarian relief and insurance frameworks.

My work lays the foundation for fast, accurate and computationally efficient flood mapping in deserts. The next step is to integrate it into Global Flood Monitoring, unlocking more than 30 years of satellite archives to build historical flood records. With these, AI models can finally ‘learn’ what desert floods look like – enabling automatic detection in future events.

As deserts expand and climate extremes intensify, ignoring desert floods is no longer an option. By improving how we see and map these hidden disasters, this research supports faster humanitarian responses, more accurate insurance models and fairer climate adaptation strategies in regions that have long been overlooked.

Where we test tomorrow's crops matters more than ever

Author

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Biography

Rogério is a crop modeler specializing in climate risk and agricultural resilience. He holds a PhD from the Technical University of Munich and currently works at INRAE Montpellier. His research combines climate projections, crop models and machine learning to understand how extreme weather affects food production. He has collaborated with global institutions such as NASA, the Leibniz Centre for Agricultural Landscape Research (ZALF), and the Joint Research Centre of the European Commission (JRC). His recent work highlights the need to adapt crop breeding trials to future climates, providing tools to strengthen food systems in the face of climate change.

Title of thesis

Wheat breeding trials will lose climate relevance in Europe

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As Europe's climate shifts, wheat breeding trials risk falling out of step with reality. Unless testing sites adapt, tomorrow's crops may be bred for conditions that no longer exist.

Climate change is quietly reshaping how we grow food. For wheat, one of the world's most vital staples, the locations where we test new varieties today may no longer reflect the growing conditions of tomorrow. The hidden risk is clear: if breeding continues in environments that no longer match future climates, we may fail to select resilient varieties, putting food production and farmers' adaptation at stake.

Our research posed a simple yet urgent question: Are we testing future wheat varieties in the right places for a changing climate?

The limits of today's trial networks

Across Europe, wheat varieties are vetted through official trial networks, known as VCU (Value for Cultivation and Use) trials, before being released for commercial use. These networks test performance under 'typical' regional conditions. However, as extremes of drought, heat and erratic rainfall intensify – especially during critical stages of crop development – what constitutes 'typical' is shifting. Unless trial locations evolve with the climate, they risk becoming disconnected from the realities farmers face.

To address this challenge, we developed a method that combines process-based crop models with climate projections extending to the end of the century. We simulated crop growth and exposure to heat and drought stress across thousands of trial and production sites in Europe, then created a continuous 'climate fingerprint' to measure how well each trial site represents projected future conditions in surrounding wheat-growing regions.

Breeding for climates that no longer exist

The results are striking. By 2080-2100, under high-emission scenarios, up to 90% of Europe's current wheat trial locations will no longer reflect the climates expected in key production zones. Even under moderate emissions, many widely used sites – particularly in Austria, France and Germany – will lose their representativeness. In short, we risk breeding for climates that no longer exist.

The study also highlights solutions. Some regions in southern Europe, including parts of the Balkans, Italy and Spain, already experience stress conditions similar to those projected for central and northern wheat areas later this century. These regions could serve as strategic new testing locations, allowing breeders to anticipate tomorrow's climate challenges today.

As shown in Figure 1, our climate similarity analysis demonstrates that most of Europe currently has little in common with the conditions Austria is projected to face by 2100. Continuing to test in today's Austrian trial sites will be insufficient. Instead, the Balkans, central Spain and southern Italy offer more relevant conditions for identifying wheat varieties capable of withstanding heat and water stress.

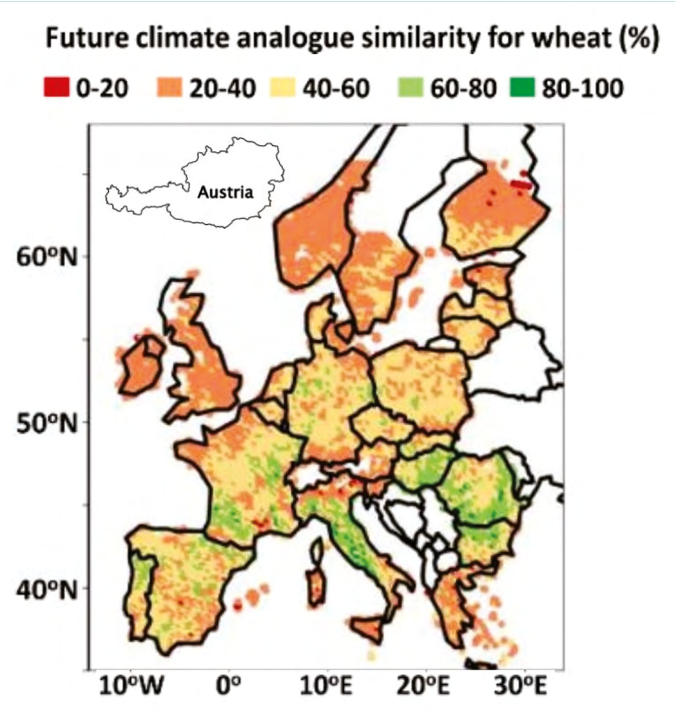

***Figure 1:** Current climate analogues for future Austrian wheat systems*
Map showing the spatial distribution of present-day climates that resemble projected future conditions in Austria. Similarity was calculated by combining independent drought- and heat-stress indices across four phases of crop development. Climate inputs were downscaled to a 25-km grid using an enhanced delta-change method, and crop simulations were run with Sirius Quality under historical conditions. Results reflect the RCP 8.5 high-emission scenario for the end-of-century period (2070–2099).

We also recommend expanding the use of managed-stress platforms – controlled environments where drought or heat can be simulated to test crop responses. Our framework offers a data-driven way to guide their placement and design.

Why it matters for farmers and insurers

The stakes go beyond plant breeding. If testing networks fail to keep pace with climate change, new varieties released in the coming decades may lack the resilience to withstand extreme years. That increases the risks of yield losses, food insecurity and financial strain for farmers. For insurers, it also raises the likelihood of unexpected claims and undermines current risk models.

By aligning crop testing with projected climate scenarios, our approach supports smarter decision-making for governments, insurers, and seed companies. It provides a transparent, scalable framework that can be applied to other crops, regions, and even sectors.

The message is simple: where we test crops matters. In a rapidly warming world, variety trials must reflect future conditions if we are to ensure resilient, productive food systems for tomorrow.

Allianz Trade Award: Extreme heat in agriculture and its downstream effects through global input-output linkages

Author

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Institution

Harvard University, Environmental Economics

Biography

Guglielmo is an environmental economist and Postdoctoral Fellow at Harvard University's Salata Institute for Climate and Sustainability. He earned his PhD in Economics from the Paris School of Economics, where his dissertation received the Best Doctoral Dissertation Award from both the European Association of Environmental and Resource Economists and the French Economic Association.

Before joining Harvard, he was a postdoctoral researcher at UC Berkeley and worked at the International Monetary Fund. His research explores the socio-economic impacts of climate change and the effectiveness of adaptation, using econometric and climate data to quantify how extreme-heat shocks in agriculture propagate through global production networks. His work has been presented at international organisations including the OECD and IMF and contributes to policy debates on the Social Cost of Carbon and adaptation finance.

Title of thesis

Propagation of extreme heat in agriculture across sectors and space

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Extreme heat in agriculture does not stop at the field. New evidence shows that climate shocks propagate through global production networks, magnifying economic losses and highlighting the need to integrate supply-chain effects into carbon pricing and adaptation strategies.

Understanding the economic consequences of climate change is essential for designing effective climate policies, setting carbon pricing and informing international adaptation strategies. Advances in econometric methods (Hsiang, 2016), combined with increasing availability of high-resolution climate data, have enabled more precise estimates of how rising temperatures affect economic output (Kalkuhl and Wenz, 2020). Despite remaining uncertainties about the magnitude, low- and middle-income countries bear the largest economic costs (Dell et al., 2012), due to both higher exposure to extreme heat and the agriculture-intensive nature of their economies (Nath, 2025).

Traditional approaches typically estimate the impact of local temperatures on economic output, implicitly assuming that shocks remain local. Because agriculture represents a small share of GDP – around 10% worldwide in 2022 according to the World Bank – overall macroeconomic impacts of agricultural losses are assumed to be limited (Costinot et al., 2016). However, agriculture produces many intermediate goods that other sectors rely on, from cotton for textiles to rubber for automotive manufacturing. Local shocks in agriculture can therefore propagate across sectors and borders through input-output linkages, amplifying their impact on the wider economy.

Data-driven estimates accounting for sectoral and spatial linkages

This study quantifies how extreme heat in agriculture propagates through supply chain linkages across sectors and countries. It combines a novel global dataset of country-sector value added with high-resolution daily temperature data and input-output linkages between sectors and countries from 1975 to 2020. Using detailed information on crop locations and crop-specific temperature sensitivities for 118 crops, country-sector heat shocks are constructed to distinguish between the effects of local temperatures and those of domestic and foreign agricultural heat shocks transmitted through supply chain linkages.

The analysis examines how extreme heat in agriculture affects five downstream sectors both domestically and abroad. The methodology leverages variation in crop-specific heat exposure and its transmission through supply chain linkages captured by input-output data. This approach addresses a key limitation of traditional methods, which estimate the impact of local temperatures while holding conditions in other locations fixed. By ignoring trade and sectoral interconnections, previous estimates of damages in the manufacturing sector in Germany, for example, fail to account for simultaneous temperature increases in trading partners such as France or the United States.

The results show that extreme heat in agriculture – both domestic and foreign – has a substantial negative effect on downstream sector value added (Figure 1). These findings highlight a new mechanism in macroeconomic estimates of climate damages, demonstrating the importance of accounting for sectoral and spatial linkages.

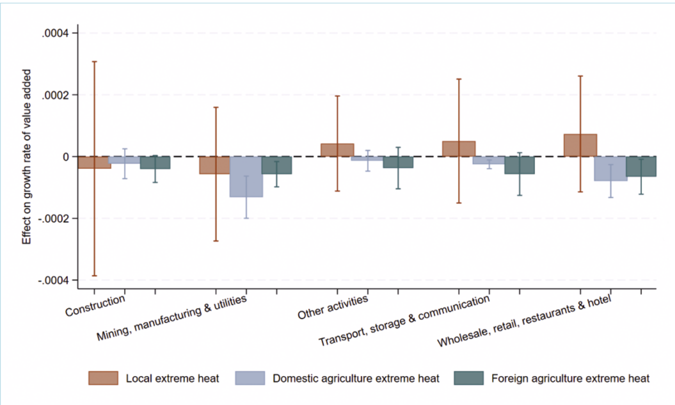

***Figure 1:* Effect of local extreme heat and extreme heat in domestic and foreign agriculture on downstream value added**
Note: Figure from "Propagation of extreme heat in agriculture across sectors and space" (Zappalà, 2025). The figure shows the sector-specific coefficients associated with local extreme heat and with extreme heat in domestic and foreign agriculture in a regression where the sector-specific value-added growth rate is the dependent variable. Vertical lines represent the 95% confidence intervals, with standard errors clustered at the country level.

The economic cost induced by recent warming is substantially underestimated when omitting sectoral interlinkages

Extreme heat in agriculture has effects far beyond directly affected crops. Counterfactual analyses compare losses under two scenarios: one that accounts for shock propagation through supply chains and one that only considers local agricultural losses from 2001 onwards, using 1975-2000 temperatures as a baseline.

Local heat shocks in agriculture alone produce spatially uneven losses, concentrated in regions such as Africa and South Asia. Including propagation through input-output linkages increases aggregate losses by approximately 31% and distributes them more evenly across the globe. Only 29% of aggregate losses are due to direct local agricultural impacts; the remaining 71% stem from downstream effects transmitted through domestic and international supply chains (Figure 2). These results show that trade and production networks – while often viewed as sources of diversification – can amplify the global economic impact of local climate shocks.

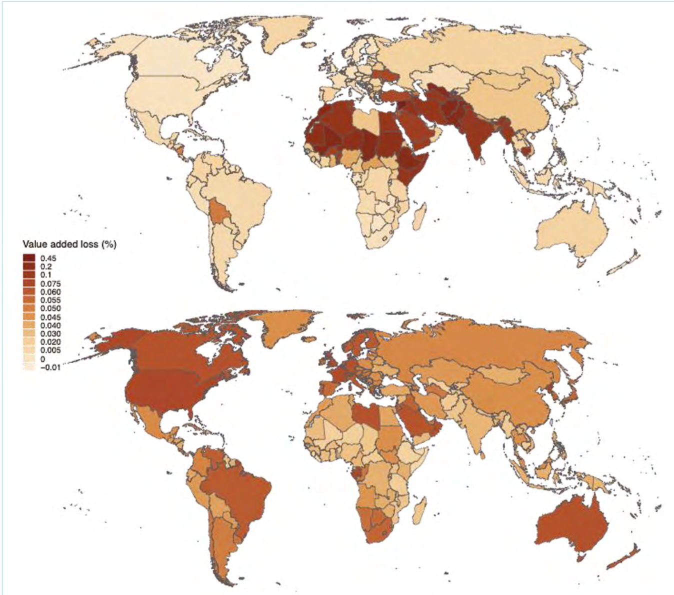

***Figure 2:* Global annual value-added losses (%) in agriculture and downstream sectors induced by recent warming (2001-2020)**
Note: Figure from "Propagation of extreme heat in agriculture across sectors and space" (Zappalà, 2025). The figure shows total annual losses in value added (%) between 2001 and 2020 compared to a counterfactual where extreme heat in agriculture remains at the 1975–2000 average. The top world map displays agricultural value added losses due to local extreme heat conditions (weighted by the average share of agriculture in total value added). The bottom map displays value added losses induced by extreme heat in domestic and foreign agriculture, summed across the five downstream sectors and weighted by the average share of each sector in national value added.

A second counterfactual exercise shows that extreme heat in key agricultural producers generates disproportionately large global losses. Countries with stronger supply chain connections – such as Brazil, China, France, India and the United States – have the greatest impact.

For example, a one standard deviation increase in heat in China's agricultural sector reduces global value added by approximately $235Bn (Figure 3). These five major producers together account for more than 45% of world crop output, with China leading in staples such as cotton, rice, tobacco, ramie and wheat. Aggregating damages across all countries, annual global losses from extreme heat in agriculture amount to approximately $1.6Tn, or 3.5% of global value added.

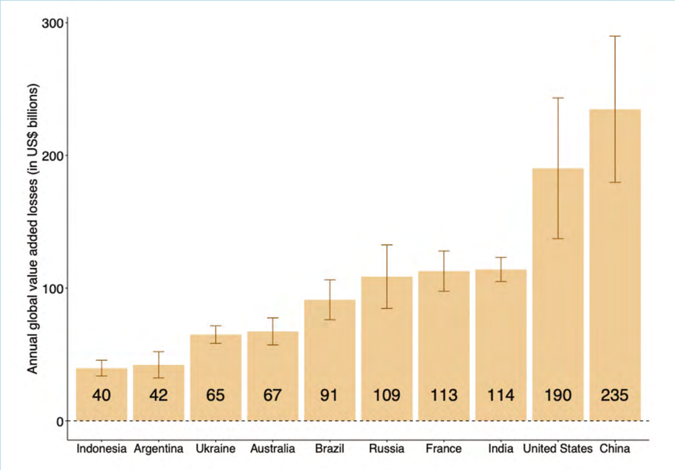

***Figure 3:** Annual global value-added losses for a standard deviation increase in extreme heat in agriculture in a country*

Note: Figure from "Propagation of extreme heat in agriculture across sectors and space" (Zappalà, 2025). The figure shows annual global value-added losses in 2015 USD billions for a one standard deviation increase in extreme heat in agriculture in each country on the x-axis. Brown bins indicate the 95% confidence intervals obtained from 1000 bootstrap replications with replacement.

Policy implications

Input-output sectoral linkages are a key mechanism for propagating and amplifying the impacts of extreme heat in agriculture, significantly increasing the total economic cost of climate change.

There are two main policy implications. First, accurate estimates of climate damages are critical for calculating the Social Cost of Carbon (SCC) and informing international Loss & Damage funds, which compensate countries for climate-related losses. Ignoring supply chain effects could lead to underestimating the SCC, resulting in insufficient carbon pricing, weaker mitigation policies, and underfunded adaptation or compensation mechanisms.

Second, understanding how shocks are transmitted through global production networks can help allocate international adaptation funds more effectively. Targeting resources to countries and sectors with the greatest influence in supply chains may generate larger benefits for global resilience, reducing the worldwide impact of extreme heat.

In 2025, Allianz Trade joined the Allianz Climate Risk Award, expanding its scope with a new category dedicated to research on the links between climate change, extreme weather events and global trade. Guglielmo Zappalà is the inaugural winner.

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