THE END OF NORMAL

HOW CLIMATE CHANGE AFFECTS WEATHER PATTERNS AND WHAT TO DO ABOUT IT

A compendium of essays for the
Allianz Climate Risk Research Award 2019

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Allianz

ABOUT THE COMPENDIUM

The Allianz Climate Risk Research Award supports young scientists whose research improves our understanding of climate change-related risks. The 2019 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 from participants of the 2019 Edition. This compendium is issued online only and is published exclusively for didactic purposes.

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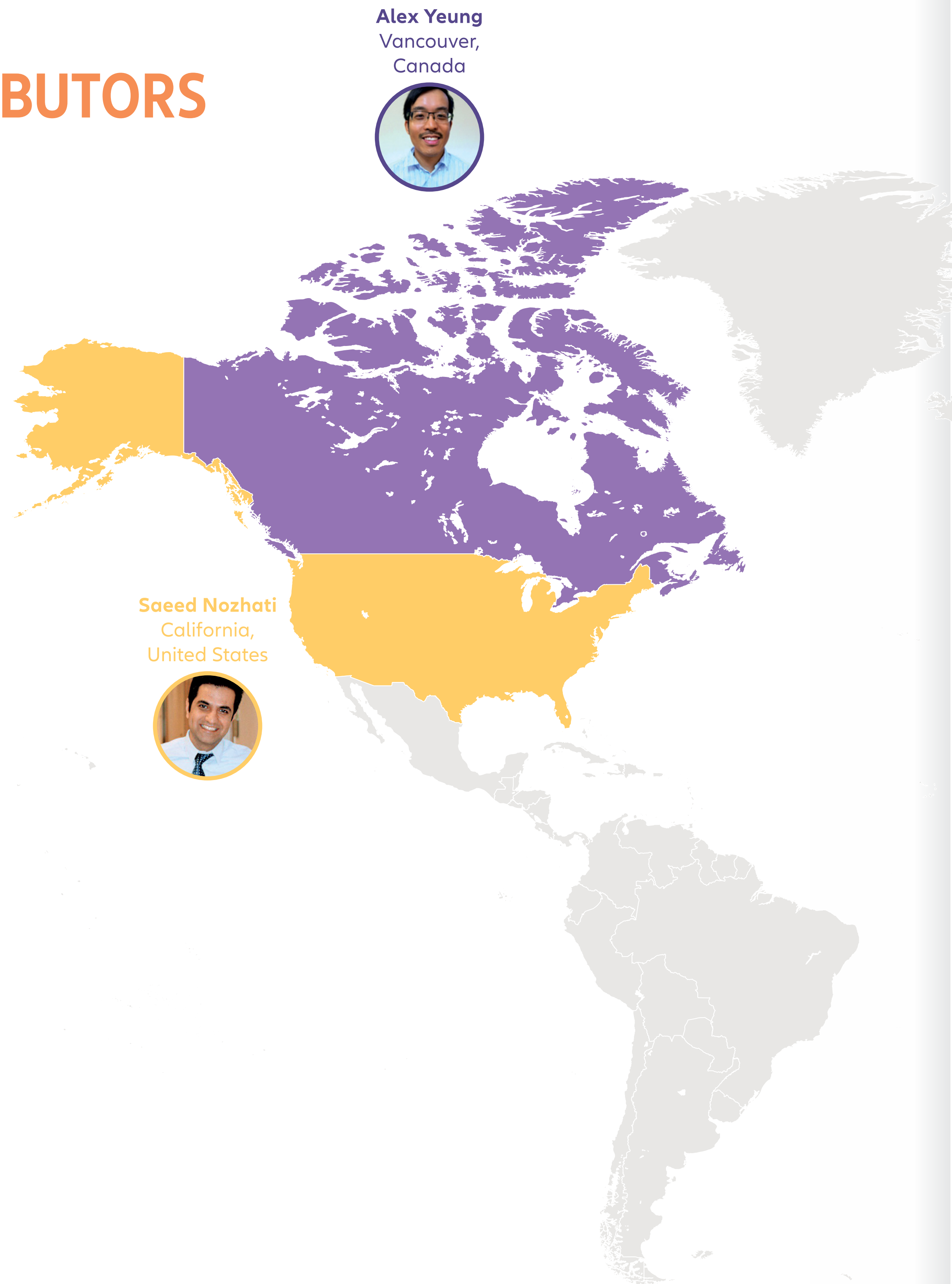

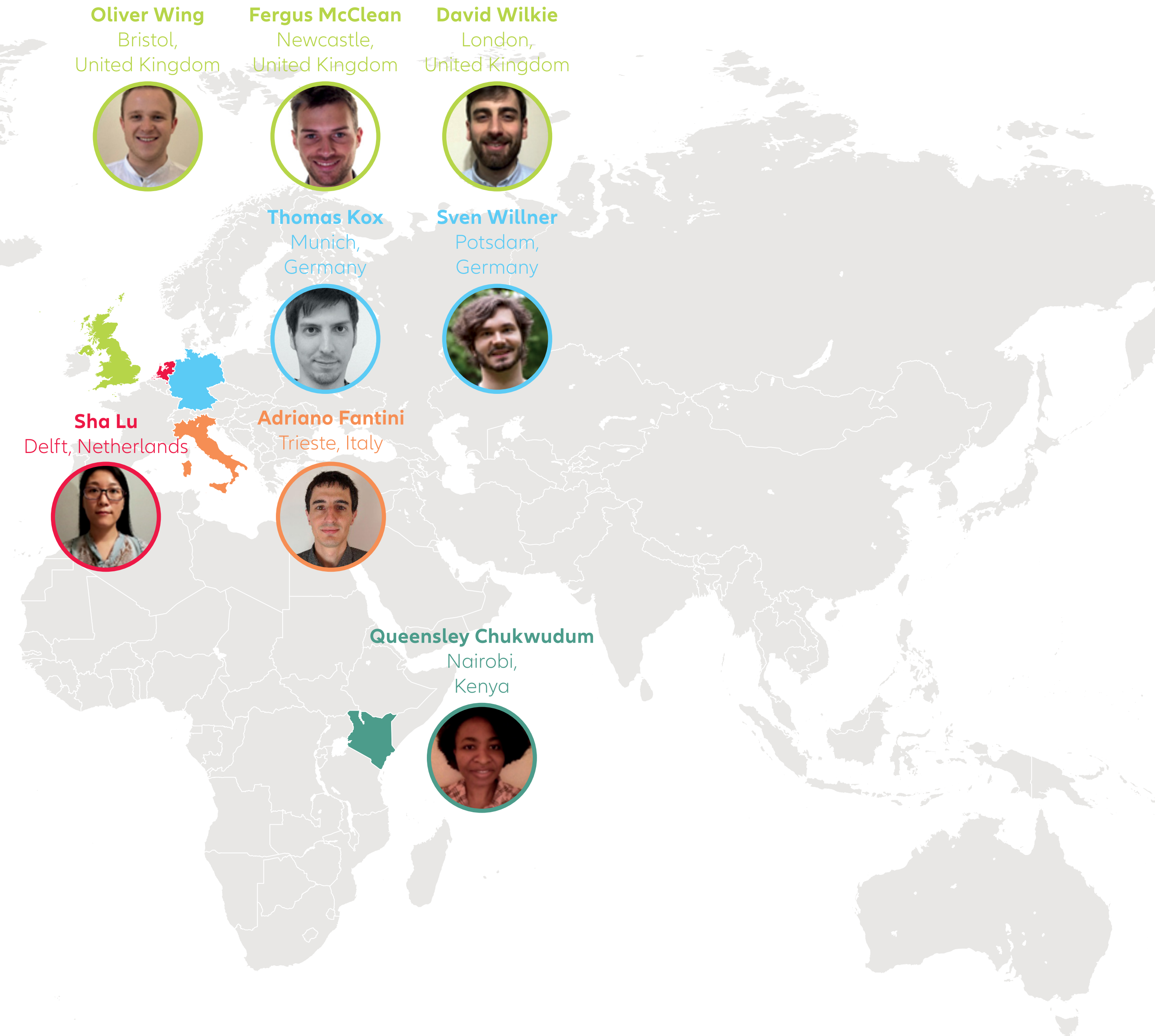
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INTRODUCTION
WE ARE ENGAGING

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Climate change touches everything. It must be tackled urgently, intelligently and concertedly.

Climate change can seem an issue for tomorrow. With global warming paths calculated out to the end of the century, the issue may seem a distant, slow moving and abstract one. But this view is swiftly changing as it becomes clear that this is not only for future generations. Climate change is wreaking havoc right now.

Fires are becoming fiercer, floods are becoming wetter, droughts drier and hurricanes more destructive. Such calamities do not mark a "new normal" in the planet's weather but rather "the end of normal" as weather patterns are pushed to increasing extremes and result in disasters that leave soul-wrenching damage in their wake.

The impact is not only evident in the disasters reflected in dramatic headlines. The stifling weather we endured in Europe in July 2019 is one of several reminders that should awaken us. Belgium, Germany, Luxembourg, the Netherlands and the United Kingdom all experienced all-time high temperatures this year.

True, hot weather is not new. However, given that nine of the 10 warmest Julys have occurred since 2005 suggests the summers of our youth are long gone. As the World Meteorological Organization (WMO) concluded, the July 2019 "heat waves carry the signature of man-made climate change," adding that climate change effects made the record-breaking temperatures 30 times more likely.

Increasing public discourse with a focus on a "climate crisis" or "climate emergency" is emphasizing the toll our society is already paying. It also reflects the increasing urgency large sections of the population have with a business-as-usual approach and the desire to undertake meaningful action.

THE ROLE OF INSURERS

As risk-carriers, we have skin in the game. The climate crisis is already impacting our business. More frequent, intense and costly disasters will affect our industry. However, there is a window of opportunity. We can still contain global warming to below 2°C with swift action, allowing for preventive measures to keep the overall risk at a manageable level for most perils in developed insurance markets.

In regions with already high exposure to natural disasters, it might be necessary for policyholders to participate more in the risk, either by investing in higher protection standards or by retaining more risk. In the more extreme warming scenarios, insurability challenges will arise and could burden the sector. Some types of climate risks may become effectively uninsurable in highly exposed regions towards end of the century.

At the same time, society looks to our industry to play a key role in making our world more financially resilient to unavoidable climate change impacts as the Paris Agreement of 2015 explicitly includes insurance solutions. Society expects us to incentivize investments in preventive measures while providing prompt financial relief to insured victims of inevitable disasters.

Allianz takes the climate emergency seriously and has been crafting a strategy over several years. We have processes in place to ensure our business model is compatible with the climate agenda. For example:

- We will not insure single coal-fired power plants or coal mines in future and we no longer invest in companies that derive more than 30% of revenue from coal mining or generate over 30% of their energy from coal
- We have committed to source 100% of our global electricity needs from renewable sources by 2023
- We lead a coalition of asset owners to invest more than EUR 2 trillion in climate-neutral investments by 2050
- We have also joined our peers and public-sector partners to develop insurance solutions to help climate-vulnerable societies to better deal with the unavoidable climate change impacts

These actions are science informed. We will continue to engage with the scientific community to shape our actions as we can only incentivize investments in precautionary measures with lower premiums if we are well-informed about the risks we carry.

We therefore see the need to encourage further research on climate change impacts. This underpins the organization of the Allianz Climate Risk Research Award. Already in its third year, the award acknowledges and rewards young scientists whose works shed light on the nexus between climate change and the extreme weather events that threaten millions of livelihoods and present ways these populations could be better protected.

I am happy that the entries we received from these bright young scientists contribute in that direction. A big thank you to all the authors for your dedication, your focus and your incredibly valuable efforts.

FOREWORD

THE "NEW NORMAL" OF EXTREME WEATHER

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Over the last three and a half decades, economic losses stemming from extreme weather-related events have had profound impacts on businesses, communities, governments and people.

About 18,200 disaster loss events occurred across the world between 1980 and 2018.[1] Of those, 91.3% were weather-related (droughts, floods, severe storms and wildfires), and these events accounted for 80.3% of the estimated $4.8 trillion in total economic losses and 91.6% of insured losses (inflation-adjusted).

Climate change is exacerbating such losses. As I write this, the latest blazes are burning through large segments of California. Fierce wildfires seem now an annual occurrence in that region and the most recent fires saw more than 200,000 people ordered to leave their homes and "red flag" warnings raised in 43 of the state's 58 counties.

Such events underline that we have reached a period of "new abnormality" when it comes to extreme weather. From ferocious wildfires to unprecedented hurricanes, global warming is reshaping the lives of millions with increasingly tragic consequences. The 2018 Special Report on Global Warming from the Intergovernmental Panel on Climate Change warns about the costs if the world cannot contain climate change to 1.5° to 2° Celsius over the next 10 years.

Mark Carney[2] during a historic speech in September 2015, identified climate change as the largest potential systemic risk facing the global financial system. He stressed that the "Risks to financial stability will be minimized if the transition begins early and follows a predictable path, thereby helping the market anticipate the transition to a 2-degree world."

For the insurance industry, any temperature increases beyond this limit poses an existential risk. Therefore, the insurance industry, as investors, risk experts and risk managers, must play a critical role in enabling economic resilience and entrepreneurial pathways for addressing climate change goals and targets.

This is where such initiatives as the Allianz Climate Risk Research Award play an important function. By providing a forum for ideas, the award identifies and highlights avenues of research that advance our knowledge and abilities to mitigate and adapt to climate change. For individual academics, who have spent years laboring on their research – often on shoestring budgets, the recognition also provides public acknowledgement of their effort, not to mention a much needed fillip to their research budgets.

In return, public and private sector stakeholders benefit from the outcomes of climate change modelling and research for enhancing climate risk analytics and the development of solutions that are vital for the globe to transition to a resilient low-carbon economy.

Beyond such awards, the insurance industry can help this transition through its underwriting business, by working with customers to help them understand their risks and by developing new business models, investment strategies and innovating new products that incentivize behavioral change toward active reductions in carbon footprints.

Over the last decade, the world has mobilized to proactively prevent and reduce the physical risks of climate change. However, the rising frequency and severity of weather-related hazards could be prohibitively costly if we do not transition to a low carbon economy.

In the last four years, there is notable progress in raising awareness about climate change and in inspiring fundamental actions. Recommendations of the Financial Stability Board Task Force on Climate-Related Financial Disclosure (TCFD), and emergence of sustainable finance framework aim to enable long-term investments for a planned transitioning. Coalitions of investors with commitments to support this are forming to enable investing at scale.

At the 2019 UN Climate Summit in New York in September, for example, an alliance of the world's largest pension funds and insurers – responsible for more than US$ 2.4 trillion in investments – committed to transitioning their portfolios to net-zero carbon emissions by 2050, consistent with a maximum temperature rise of 1.5°C above pre-industrial levels. However, beyond these, there is need for action by governments to establish climate and sectoral policy frameworks to provide clarity and incentivize economic sectors and the society for the implementation of a well-planned low-carbon transitioning.

THE GENEVA ASSOCIATION

The Geneva Association (GA) is the leading international think tank of the insurance industry and the only global association of insurance companies; its members are insurance and reinsurance CEOs. Established in 1973, the GA conducts research to identify key trends and risk areas likely to shape or impact the industry. Among other activities, the Association publishes

Thematic research reports as well as the academic journal, The Geneva Papers on Risk and Insurance. Papers are now being accepted for a special October 2021 issue of The Geneva Papers on 'Climate Finance, Resilience and Insurance.' More details are available on the GA's website.

[1] Munich Re NatCatSERVICE
[2] Former chairman of the Financial Stability Board, and governor of the Bank of England

IMPROVING UNDERSTANDING OF FLOOD RISK

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Oliver is a finalist for the Allianz Climate Risk Research Award 2019. After completing his Ph.D. at Bristol University (UK) this year, he currently works at the same University as a Research Associate in the School of Geographical Sciences. His current research focuses on testing, improving and applying large-scale hydrodynamic models. Oliver has published several scientific papers in this field.

THESIS TITLE

Understanding flood risk at large spatial scales

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Computers and big data now enable large scale flood modelling, which was previously developed locally and painstakingly. However, until recently it was not known how accurately these new maps portrayed the risks of flooding.

To calculate floods, hydraulicians used to build bespoke models of individual local river reaches. Although skilled in fluid mechanics, their task was still taxing, painstaking and the results small in scale.

The last decade has seen a revolution in the field of flood inundation modelling. Enhanced computational ability and the advent of big data have expanded the size of the models that hydraulicians can tackle to now embrace entire regions, continents and even the globe.

This has enabled flood hazard to be understood in previously un-modelled areas. Yet, before this research, it was not known how reliable such models were in terms of the risks they portrayed. The research paper (Wing, et al., 2017) sought to quantify this.

MODEL COMPARISONS

In the research, a continental-scale inundation model (Fathom-US) was compared to a combination of hundreds of thousands of localized hazard assessments conducted by the US Federal Emergency Management Agency (FEMA). The result is that the performance of large- and local-scale modelling strategies is beginning to converge. The large-scale model captured 82% of the FEMA-delineated floodplain, increasing to 86% where a map is designated as high quality.

Compared to events of different magnitude in high-quality engineering assessments with a defined domain (to faithfully constrain model over prediction), the overall similarity averaged to about 75%. These test scores are approaching a performance ceiling; lying within the inherent scale-agnostic uncertainties in hydraulic modelling (for example, quantification of extreme flows). Further scenario-based analyses uncovered greater (lower) correspondence with the large-scale and FEMA models for large (small) rivers, in temperate (arid) climatologies and in rural (urban) areas.

With a validated hazard model, my next paper (Wing, et al., 2018) quantified what this tells us about flood risk in the US. The problem with the FEMA maps is they do not offer total coverage of every US river: only 60% of the US is modelled and, even within this, headwater streams are often ignored and flood maps may be outdated or approximate. This is because local assessments are laborious and expensive to conduct, so financial constraints inhibit this from being a reliable method to understand flood hazard at large spatial scales.

30 MILLION MORE EXPOSED TO FLOODS

The 2018 paper quantified the implication of the failure to have a complete nationwide view of flood hazard. Using Fathom-US, the total number of people exposed to a 100-year flood came to about 41 million. With the FEMA maps, it was 13 million. This is a critical gap in understanding US flood risk that a total-coverage, large-scale flood model can address. Moreover, insurers relying on FEMA maps for their view of US floods may be significantly underestimating the risks they are carrying.

The model also found applicability in a flood forecasting framework for my third paper (Wing, et al., 2019). With few exceptions, traditional flood forecasts generally lack an inundation component: they may predict rainfall or river flow at a point, but often give little indication how this translates to depths of water on the floodplain.

While historically this has been a computationally intractable task, rapid yet accurate (for the purpose of flood inundation) two-dimensional hydrodynamics can now play a role in providing extra value to hydrological forecasts by simulating potential inundation without significantly compromising the speed with which warnings can be issued. When assessed for Hurricane Harvey, the new forecast cascade could identify impacted areas and outperformed simpler approaches. Such a model can aid emergency responders in targeting resources or insurers in rapidly assessing their exposure.

DETECTING LEVEES

The validation conducted in 2017 also highlighted where large-scale models began to break down (that is, deviate from benchmarks). One such place is in areas protected by levees. While information on the location and standard of levees from the US Army Corps of Engineers is incorporated into the model, this information is thought to be only 30% complete.

This means many areas that have some degree of structural flood protection are incorrectly inundated in the model. In a paper currently under review, I have devised a novel solution by sampling the geomorphometric characteristics (for example, elevation, slope and curvature) of known levees and searching for other features in high-resolution elevation data that share these characteristics.

While the model is run with 30-meters resolution elevation data to be computationally tractable, this is derived from data available at 10-meter resolution and even 1 meter or 3 meters for large areas of the US. The necessary coarsening of the model grid scale means that information on small-yet-tall, hydraulically relevant features (for example, levees) is lost. Identifying these features in the finer grid data before coarsening permits their elevations to be preserved. Further tests found that incorporating this method into the model increased its performance on engineered floodplains.

The crux of all this research is that (semi-)automated methods for building flood models at large spatial scales can offer a reliable view of flood hazard amid data-scarcity, with only a marginal sacrifice to local point precision. This can help to build much needed resilience to present and future floods.

FLOOD RISK UNDER CLIMATE CHANGE

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BIOGRAPHY

Sven is a postdoctoral researcher at the Potsdam Institute for Climate Impact Research, Germany, and a finalist for the Allianz Climate Risk Research Award 2019. He investigates the higher-order economic losses and damages due to extreme weather events along the global supply network. Sven obtained his Ph.D. in climate physics from the University of Potsdam in 2018 and has several publications to his name.

THESIS TITLE

Flood risk under climate change – economic losses and their propagation along global supply chains

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Floods not only affect the local community. Their economic impact can be felt "downstream" and cause havoc all along the supply chain. With climate change increasing the frequency and severity of floods, it is important to begin to understand the impact of such extreme weather events.

Some blame God's wrath. Others blame poor disaster-mitigation infrastructure. The results are the same. Floods are among the most common and most deadly natural disasters societies around the globe face.

Under climate change these will increase in frequency and intensity. Indeed, data show that climate change is already influencing the size of flood events. As the planet heats up, sea levels are rising and causing damage to coastal cities, while heavy rainstorms are also becoming more frequent and tropical cyclones more intense.

LOCAL DISASTERS HAVE GLOBAL CONSEQUENCES

Such local disasters can have significant consequences in a world where supply chains are increasingly globalized. The shock that a flood causes to the local economy can result in direct losses in production. This leads to further price effects and potential supply shortages "down-stream" along the supply and trade chains to other regions and economic sectors. These indirect losses then spread through the network.

This was seen vividly during the 2011 Thailand floods when heavy rains caused severe flooding lasting from July until, in some areas, mid-January 2012. The region was the epicenter of essential electronic components for the global market, so the loss of production lead to year-long spike in the prices of hard drives.

Such indirect losses can become even more serious when they affect essentials such as food and medicines. Dependence on a few production facilities and highly specialized suppliers, for instance, make the pharmaceutical sector especially vulnerable.

FROM DIRECT TO INDIRECT LOSSES

My research investigates the economic response to local river flood events on a global level with a focus on direct and indirect production losses. It aims to give insights into changes in flood and supply risk under near-future climate change, as well as to identify risk hotspot.

Historic emissions of greenhouse gases and the inertia of the climate system means that warming is already locked in for the next 20 years. Adapting to the consequences, besides mitigation efforts, will be a major challenge. Such risk assessments, as undertaken in this study, provide a guide to this process.

Using an ensemble of climate change projections that stretch until the middle of this century, the study employs flood models and statistical analyses to calculate changing flood risk. A novel economic loss-propagation model then allows the direct as well as indirect losses to be assessed. With a micro-economic decision rationale, the model describes the short-term reaction of firms and consumers to shocks in the global supply network in a dynamic manner.

This study identifies strong local pressure to adapt to the changing risk of large floods in regions across the globe. While many developing countries, especially in Asia, face increasing flood risk, developed countries will also have to increase their protection if they want to maintain the comparably low flood risk experienced in the past.

Direct losses caused by floods are projected to increase substantially in coming decades with heterogeneous distributions across regions. Though some of these can be mitigated due to flexibilities in the market system (storage, reaction to fast price signals, transport changes, etc.), additional indirect losses can occur with the same order of magnitude.

For example, China is projected to suffer an 80% increase in flood losses in the next two decades. The Unites States, on the other hand, is comparably safe locally but suffers from “imported” indirect losses. The European Union is in a much better position as it is able to mitigate imported losses almost completely. A deeper analysis can derive this result back to the balance in trade between China and the EU in contrast to a very unbalanced import-export relationship between China and the United States.

ADAPTATION ACROSS SCALES

Overall, my research shows that, as with mitigation, climate change adaptation has to be thought across scales; from local protection to reduce vulnerability to improvements in the supply structure that render the overall supply network more resilient. As a top-down modelling approach, this research complements trade policy and supply chain management on a regional and local scale.

Though river floods have been the prime example of extreme weather events investigated in this research, comparable results are expected for other impact categories such as droughts, heat waves or storms. In particular, concurrent events can amplify the consequences when their repercussions combine.

This research also aims to identify bottlenecks as vulnerable points in global supply chains as well as to assess particular network structures regarding their resilience to local weather shocks. Ideally this will be complemented by data on local supply chains to enable validation and eventually result in a forecast system for indirect losses. However, research on the impacts of extreme weather events on the global supply network is still at its very beginning.

WHEN COMES THE RAIN?

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BIOGRAPHY

A finalist for the Allianz Climate Risk Research Award 2019, Sha completed her Ph.D. in 2017 at the Department of applied mathematics, TU Delft, in the Netherlands. She has since then worked as a post doctorate at the Water Management Department of TU Delft. Her research focuses on statistical modelling, rainfall estimation and data assimilation. Sha has published extensively in her field.

THESIS TITLE

Extreme rainfall indices at local scale to support crop insurance for small-holder farmers in Africa

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Reliable local rainfall data are urgently needed to support micro-insurance schemes for small-holder farmers in vulnerable regions of Africa. They are crucial for crop yield models to lower the risk of losses for both crop insurers and farmers.

The farms of Africa are dependent on rain-fed agriculture and African economies in turn are heavily dependent on agriculture. The industry employs 65% of Africa's labor force and accounts for 32% of the continent's overall gross domestic product.

Africa's farms are highly vulnerable to variations in rainfall. Increases in temperature and rainfall reduction linked to climate change will sink agricultural production and increase demand for more land and water to compensate for climate stresses.

The consequences will also be felt on its people. The continent has the largest number of malnourished people, the fewest resources to adapt and the fastest growing population to deal with. The impact of climate change on food security will be greatest in African nations.

INSURING CROPS

Accurate weather data, high-quality crop yield models and knowledge of uncertainties are needed to assess risks and provide advice on seeding and planting. Insurance companies also need such data to design rainfall indices and price micro insurance products.

These low-cost insurance products protect low-income smallholder farmers against weather shocks by paying for crop losses caused by adverse weather conditions. The same data are also essential for insurers to verify crop-loss claims and make strategies to pay-out for crop losses. Among all weather elements, rainfall is one of the most important but also the most variable and unpredictable input for crop yield models. There already exists a variety of high quality satellite-based or reanalysis rainfall products with global coverage, yet they performance varies widely in different regions and for particular features such as drought or rainfall extremes.

To select the rainfall product that will most effectively assess harvest risk in a region, it is essential to quantitatively evaluate all aspects of a rainfall product, and especially its performance in terms of extreme weather estimation.

It is a challenge to conduct such an evaluation over Africa, which has the lowest rain-gauge density and lacks gauge data as a reference for satellite-based rainfall estimation. My research developed a methodology for multi-objective evaluation of precipitation products for extreme weather services in a data scarce environment, which is easy to adapt for other rainfall-related applications.

SELECTING RAINFALL DATA FOR EXTREME WEATHER SERVICES

To make full use of reference gauge data, the region of study is divided into different rainfall regimes. According to the insurance purpose, the division can be based on climatological rainfall patterns or self-defined by crop types and farmlands. The definitions of agriculture-related extreme weather conditions, such as dry or wet spell, or heavy rainfall, can be flexibly selected and specified depending on the local rainfall regime. Instead of giving overall performance, the evaluation can be targeted to certain weather conditions, crop types and crop growing stages.

Then the frequencies, timing and severities of extreme events for given rainfall products are compared to those from the gauge data. Biases and uncertainties of the products are quantified per weather type. This information can then be included in the harvest estimation, claim verification and risk assessment processes.

As part of the project, new evaluation statistics were developed to cover aspects that are not often addressed by other methodologies but are essential for the use of rainfall data. For instance, some of the statistics identify the minimum usable temporal scale of a dataset in any crop model without the need to run actual models.

WORKING IN THE FIELD

Oasis Horizon2020 Insurance is a European Union funded, cross sector project to operationalize a loss modelling framework that combines climate services with damage and loss information. In my research, I cooperated with both crop modelers and representatives of the insurance industry as part of Oasis H2020.

By consulting on the needs of end users, the method has been developed and assessed in a practice-oriented way. This readily enables rainfall products with strong performances in drought and in heavy rainfall to be identified. Being fed into a crop yield model, it allows poor harvests due to adverse weather to be readily distinguished from those caused by improper agronomy.

A toolbox has been developed from the method and is publicly available. The method is also highly adaptive to other rainfall-related applications by end users. The definitions of extreme weather can be easily changed to match the trigger of a disaster and can be adjusted by the severity of the disaster, such as a pluvial flood. The choice of a rainfall product is then directly targeted to selected extreme weather services of interest to the user.

A comprehensive database on rainfalls, while essential, is not the only resource insurers need. Existing rainfall products commonly have a spatial resolution of 50 km or higher, while stakeholders typically have far smaller scales of less than 1 kilometer.

Due to the high variability of rainfall, localized rainfall data of high accuracy is required to supply reliable information to targeted farms. A flexible model was developed that enables the selected dataset to be quickly downscaled to the local scale without losing the accuracy. The model has been successfully tested over Tanzania.

REVEALING THE FLOOD OF UNCERTAINTY

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Fergus is a finalist for the Allianz Climate Risk Research Award 2019. Fergus completed his Ph.D. in Civil Engineering from Newcastle University, UK, in July 2019 and currently works as a research associate at the same University. His research interests include 2D flood model validation and sensitivity, computational methods in hydrology, workflow development and model automation/visualization.

THESIS TITLE

Broad-scale flood model validation and sensitivity analysis using cloud computing

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With floods becoming more frequent, broad-scale flood model validation and sensitivity analysis will play a vital role in preparing for and recovering from catastrophes. This new methodology seeks to effectively validate flood models to help prepare infrastructure for such events.

Floods are among Earth's most common – and destructive – natural hazards. Globally, floods and extreme rainfall events have surged by more than 50% this decade and are now occurring at a rate four times higher than in 1980, according to a 2018 report by the European Academies' Science Advisory Council (EASAC). "Man-made climate change has proven to have increased recent extreme rainfall and associated floods," the report concluded.

In response to such events, large scale flood modelling has become a growing research area with relevance to fields such as insurance, infrastructure adaptation and emergency response. This interest has in turn been driven by the increasing availability of continental and global scale gridded datasets that provide inputs to a mounting array of models. However, outputs often differ and validation is challenging.

A NEW METHODOLOGY

This research developed a novel and consistent methodology for assigning multiple performance scores to flood model input datasets with continental-global coverage. The approach allows better understanding of the uncertainties involved when assessing large-scale flood risk in areas where high quality local data is not available. It uses a state-of-the-art 2D hydrodynamic model developed at Newcastle University and driven with spatially distributed rainfall. During development of the methodology, both observed flood extents and river discharge data were used from Storm Desmond, an extratropical cyclone that brought major floods to Northern England in 2015. The sensitivity of flood impacts to model inputs was assessed using infrastructure data from OpenStreetMap. The global applicability of the approach has been demonstrated across Europe and in Indonesia.

The methodology combined automatic model setup in the cloud with integrated interactive visualization to allow rapid development, validation and sensitivity analysis of the methodology to input data and parameters.

The project involved designing a parallel cloud computing framework and implementing it on Microsoft Azure to meet the computational demands of running repeated physics-based hydrodynamic simulations across large areas using a wide range of parameters. The distributed framework makes use of a PostgreSQL spatial database to store inputs, outputs and parameters. Visualization and initial interpretation of results was made possible using a web interface designed as part of the research.

The system is still operational and has been demonstrated in the UK, Europe and Indonesia. It can be readily adapted for future applications in regions around the world. The scalable nature of the framework allows parallel simulation of the large event sets required for robust insurance risk analysis. This makes it readily usable for modelling climate change scenarios to assess future flood risk from both extreme rainfall and river discharge.

HIGH WATER FINDINGS

The key findings reveal the dominant effect of rainfall and elevation data on model accuracy and their importance depending on what metrics are used for validation. More variability in river discharge peak error was found between models with different rainfall inputs than models with different elevation inputs. However, the accuracy of the flood extent was more sensitive to elevation data than rainfall. A difference in variability was also seen in the impacts analysis. The number of buildings and distance of roads inundated was more varied between elevation inputs than rainfall. This may mean that elevation data is more important for producing accurate estimates of flood impacts, even though rainfall has more effect on peak discharge.

Elevation data selection had a strong influence on infrastructure inundation with a range of 3,000-8,000 buildings flooded in the Tyne basin across the datasets considered (Figure 1). Rainfall data from global products was found to underestimate river discharge peaks more than rainfall data from the UK Met Office. This means that estimates of discharge based on global precipitation products are likely to be too low. Meanwhile, estimates of infrastructure inundation based on global elevation products may be too high or too low and are likely to be inaccurate. There is clearly substantial variability when using global products to estimate flood risk.

Better agreement was seen with Environment Agency flood maps that use a return period to derive boundary conditions than with remotely sensed observations recorded during Storm Desmond (Figure 2). This may show that both modelled extents are inaccurate but comparable. This highlights model inter-comparison for validation, in isolation, as a concern because it may present misleading representations of performance if observations are not included.

WHERE THE RESEARCH FITS IN

The research illustrates a growing need for more robust validation for broad scale flood modelling. The combination of extent and discharge validation during an observed flood has been a major innovation of this research. This was only possible by using a fully hydrodynamic 2D flood model that also allowed a novel, comprehensive analysis of timing error.

The importance of effective validation has been clearly demonstrated as flood model inputs were shown to strongly effect the magnitude of infrastructure inundation. This uncertainty has consequences for insurance premiums, development planning and adaptation to climate change risks.

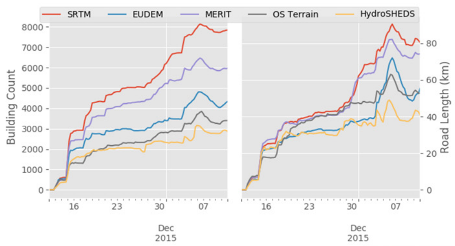

Figure 1: Sensitivity of building and road inundation to elevation data selection

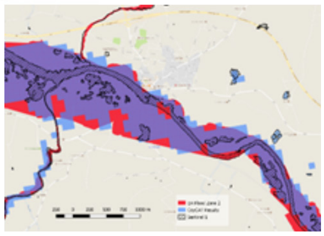

Figure 2: Comparing validation using local models to remotely sensed extents

INSURING AGAINST DROUGHT

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THESIS TITLE

Drought frequency, re(insurance) and extreme climatic dependence in the East African region

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Drought, always a specter haunting East Africa, is set to worsen as the effects of climate change take hold. Having a better understanding of the interdependence of drought conditions across the region is critical for governments and reinsurers to prepare for worse case situations.

In East Africa, already-long dry seasons are growing longer and drier, withering crops. As climate change continues to make its effects felt, the regions can expect lower rainfalls, hotter and more lethal heatwaves and longer dry periods.

The 2011-2012 drought, said to be "the worst in 60 years," gave a foretaste of how severe and widespread the problem could become. Weather conditions over the Pacific, including an unusually strong La Niña, interrupted rains for two consecutive seasons. The rains failed in 2011 in Kenya and Ethiopia and continued a two-year trend in Somalia.

The drought threatened the livelihoods of 9.5 million people across Somalia, Djibouti, Ethiopia and Kenya and caused widespread famine. Refugees from southern Somalia flooded to neighboring Kenya and Ethiopia, where crowded, unsanitary conditions together led to large numbers of deaths. A spike in food prices, including in Sudan, Southern Sudan and Uganda, resulted in acute malnutrition and affected 35-40% under the age of five in many places – twice the threshold for emergency response. In Kenya alone, the 2012 Post Disaster Needs Assessment estimates the overall adverse effect of the 2008-2011 drought events at over $12.1 billion.

DROUGHT FREQUENCY

The African Union responded in 2012 by creating the African Risk Capacity (ARC) to provide insurance to African countries devastated by such natural disasters. Countries like Kenya and Mauritania have taken out drought insurance from the ARC and the premiums they pay vary. Drought frequency and the loss severity caused by such disasters significantly affect the price of drought insurance policies and the allocation of reserves needed to cover such events. Accurately estimating and predicting the expected drought frequency is important to both the insurer and the insured.

The drought historical annual count data from 1960 to 2012 is used to model the frequency of drought in six African countries and to predict the occurrence of drought up to the year 2030. Three models – the constant, linear and exponential models – are used to achieve this. These models cater for varying (which reflects reality better) and non-varying drought intensity assumptions. Under the exponential model, Kenya showed the highest drought mean frequency, followed closely by Ethiopia. Niger, Somalia and Sudan have similar estimates. The lowest was Mauritania.

IMPACT ON REINSURANCE

The impact of the drought frequency on reinsurance was investigated using the losses incurred in Kenya in 2008-2011. Simulations and univariate extreme value analyses were implemented to estimate the loss severity. By combining the frequency of drought and the severity of drought losses, the expected excess-of-loss reinsurance pure premium was estimated for the predicted years based on different retention levels.

It proved that the constant drought frequency model has no effect on the pure premium for all the predicted years within a given retention level, but the same cannot be said for the non-constant frequency models. These models significantly increase the pure premium that the insured will have to pay. The increases not only depends on the specific retention level but also on the specified predicted year.

The result indicated that the constant drought frequency model has no effect on the pure premium for all the predicted years within a given retention level. In other words, for each year, the premium that the insured is expected to pay remains the same if the drought frequency does not change. However, drought frequency is predicted to increase and its impact is reflected by the non-constant frequency models – the linear and exponential methods. These models significantly increase the pure premium that the insured will have to pay. This increase depends on both the retention level and the specified predicted year.

UNRAVELLING THE NETWORK OF EXTREME CLIMATE DEPENDENCE

Knowing that Kenya exhibits the highest drought frequency, which is mainly driven by extreme temperatures and low rainfalls, and noting how this affects insurance premiums, there is a possibility that a drought in Kenya could spread to the neighboring countries of Ethiopia, Somalia and Sudan.

If this occurs, the number of claims will be significant and could challenge re(insurance) companies that cover drought insurance policies within this region leading to severe solvency issues and possibly ruin. There is, therefore, a compelling need for insurance companies to understand the tail dependence structure of the climatic conditions in different African regions. This type of study is lacking in literature and the existing studies that model temperature and precipitation extremes are limited to a given country.

In order to study the dependence structure, the annual maximum temperatures and minimum rainfall levels for the selected East African countries were extracted (1901-2015). These extreme climatic factors were then used to investigate if a tail dependence exists between Kenya and its surrounding countries.

Bivariate extreme value theory was applied to analyze the joint extremes for temperature (rainfall) at the 80% (20%) thresholds. The key results show that, except for the Kenya-Sudan rainfall pair, extremal dependence exists, and it varies between weak to moderate tail dependence. The weakest temperature/strongest rainfall dependence is the Kenya-Somalia pair, while the Kenya-Sudan temperature pair is the strongest.

The reflection of the existence of extremal temperature dependence in each pair's probability ratio was significant. That is, the probability that both exceed their maximum temperatures at the same time is greater under the dependent assumption than when compared to the independent case.

LOOKING FORWARD

Daily data can be used to assess monthly extremes along with higher temperature (lower rainfall) thresholds to produce better results. Nevertheless, this study has shown that the interdependence of drought conditions across East Africa extends to the extremes of their climatic variables. This should be accounted for in drought-related insurance policies. Additionally, based on this knowledge, governments and stakeholders in the region can, this, create resilient strategies that will reduce losses that may be incurred in the event of widespread droughts.

ESTIMATING FLOOD HAZARD IN TIMES OF DANGEROUS CLIMATE CHANGE

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BIOGRAPHY

In March 2019, Adriano obtained his Ph.D. in Earth Science and Fluid Mechanics from the University of Trieste, Italy. Adriano is a physicist specialized in climatology and hydrology with experienced in programming and data analysis, numerical simulation on High Performance Computing infrastructures and administration of Linux systems. He has several publications in this field.

THESIS TITLE

Climate change impact on flood hazard in Italy, using a novel approach

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Using Italy as a test case, a new flexible and reliable interdisciplinary method delivers large-scale, high-resolution product for flood estimation and projection. This is a major step forward in the protection of the general population from future devastating flood events.

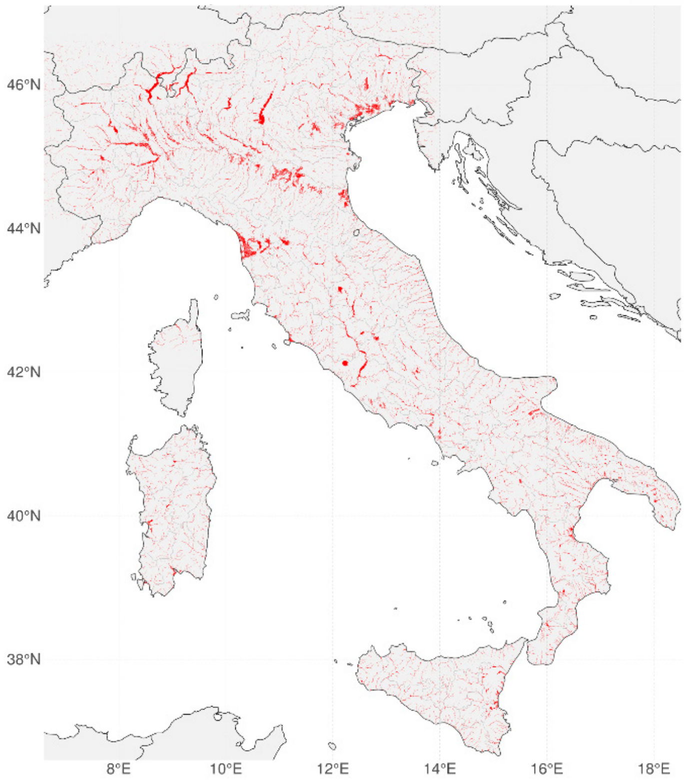

Figure 1: Simulated flood extent in CHyM (GRIPHO)

Return period: 100 years

The impact of climate change on temperature and precipitation is by now well understood by scientists. What is less clear is how these changes spread to other complex systems that directly influence societies.

In Europe, extreme precipitation events are projected to increase in both frequency and intensity under a business-as-usual future scenario. However, uncertainty remains as to how this will affect the hydrological cycle and the frequency of floods. Some of the most devastating natural disasters, floods cause approximately €5 billion in damages in Europe every year.

While present-day flood hazards can be estimated from historical records, these are often not available and are unreliable. Moreover, this approach assumes a stationary climate. Under changing climatic conditions, insurance entities, policy makers and practitioners require higher confidence in hazard estimations, as well as a solid understanding of the long-term prospects for the second half of the century.

We are now capable of answering this by exploiting a chain of computational models spanning climate, hydraulics and hydrology. This interdisciplinary approach allows physically based estimations of flood proxies and flood inundation both for the present day and for possible future scenarios, in any part of the world and with limited input data requirements.

ITALY: A PILOT PROJECT

Due to the complex topography of Italy and frequent strong rainfalls, 15.7% of the population and 19.4% of the cultural heritage of the country is exposed to significant flood hazard. In the last 50 years, floods have caused more than 600 casualties and 160,000 evacuees, with the large alluvial plains of Northern Italy being most affected. Estimating and projecting flood hazard for such a region is challenging, a task not previously accomplished. As such, Italy is a perfect testing ground for our method and was selected for a pilot study aimed at assessing its performance.

Starting from observed precipitation datasets, our model chain reproduced the present flood hazard as calculated by the regional environmental agencies, while being more flexible and extensible. In particular, if using projected climate data from climate models, we can estimate the changes in flood hazard under different climatic conditions.

At the same time, thanks to a number of computational enhancements, the analysis is performed at a much higher spatial resolution (90 meters) compared to earlier European studies (~5 km). This allows for the inclusion of smaller river catchments, which are often affected by flash floods that, while small in scale, can cause devastating damage.

Under a business-as-usual scenario, our findings show that several flood proxy indicators increase strongly by the end of the century. The spatial distribution of these changes generally mirrors that of changes in extreme precipitation, but with some notable exceptions: this indicates that the multi-model procedure adds useful information that would not otherwise be available if using only precipitation extremes as proxies for flood hazard.

Decision makers and insurance entities can benefit from these improved projections, which will allow them to plan and define adaptation and mitigation strategies based on more dependable, physically simulated data.

SIMULATIONS FOR THE COMPLETE EUROPEAN DOMAIN

The method defined in this project proved sufficiently solid and dependable in our case study, and, most importantly, it can be extended to any domain with any chosen spatial scale, thanks to its inherent flexibility. Additionally, thanks to the wide availability of a large number of regional climate simulations, ensemble projections of future hydrology and flood hazard are also possible. Currently, simulations at a resolution of 1 km are being produced for the complete European domain using an ensemble approach, which will increase the robustness and reliability of the results.

The creation of a new large-scale, high-resolution product for flood estimation and projection in time of dangerous climate change is a major step forward in the protection of the general population from flooding events. It will assist in adaptation to the challenges arising from a more extreme future climate and an increase in the frequency of such events.

ANTICIPATING CLIMATE CHANGE

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BIOGRAPHY

Alex obtained his Ph.D. in Forestry from the University of British Columbia (Canada) in 2019, and worked on stream ecosystem responses to natural and human disturbances in watersheds. Alex's main research interests are freshwater ecology and conservation, and natural resources management under climate change. He has published several peer-reviewed articles in these areas.

THESIS TITLE

Atmospheric change in the Canadian boreal zone: knowing the past and present to guide future actions.

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A horizon scan of climate change impacts in Canada's boreal zone revealed risk-prone areas and called for anticipatory actions.

With fires becoming increasingly frequent in the forests of Canada's boreal zone (the boreal), the region is becoming a net carbon source – instead of a sink – to the atmosphere. Northern infrastructure and roads are also becoming unstable, as permafrost degradation and melting ice cause foundations to shift. Several large-bodied freshwater fish are also less safe to consume in the boreal because of rising mercury concentrations.

These few examples highlight the diverse risks of hazards under intensifying climate change.

The boreal is home to 10% of the Canadian population and a rich biodiversity that provides enormous ecosystem services to communities and resource-dependent industries within and outside of the region. Boreal sustainability is at risk owing to the cumulative effects of climate change and natural resource extraction activities.

Climate change impacts on ecosystems also affect socioeconomic well-being in vast regions such as the boreal, and these impacts are variable and multifaceted. Therefore, assessing and managing boreal climate risks often involve a high level of complexity. This is not only due to the many drivers of contextual change and their interactions, but also because a large amount of literature exists reporting on different spatial and temporal scales.

A horizon scan was conducted to offer a big-picture look at climate change impacts in the boreal and to investigate how major components of terrestrial and freshwater ecosystems have responded, and will respond to drivers of atmospheric change (including the atmospheric deposition of pollutants, precipitation, and temperature) and natural disturbance regimes (including fires and permafrost thawing).

The selected ecosystem components include biological diversity, carbon budget, ecosystem condition and productivity, soil quality and water quantity and quality, which are all important indicators of sustainable resource management. Guided by a literature review, current and emerging climate risks on natural resources and socioeconomic conditions of boreal ecozones were proposed. Projections of natural hazards and ecosystem components (to 2050) under contrasting climate change trajectories in the literature were summarized in a scenario analysis of boreal futures (see Yeung et al. (2019) Environmental Reviews, 27, 346-376).

This research identifies current and near-future climate-vulnerable regions that will require management attention from communities, governments, and industries (for example, forestry, insurance, oil and gas, and renewable energy) for risk reduction. Moreover, projected changes in natural hazard patterns and ecosystem components across diverse climate scenarios will enable different sectors of society to plan adaptive measures to enhance climate resilience.

IDENTIFYING CLIMATE-VULNERABLE REGIONS

The horizon scan shows differences in ecosystem components across boreal ecozones that face increasing climate risks, which will have negative consequences on resource-dependent economic sectors and communities. Examples include elevated tree mortality due to diseases, droughts, and fires in the western boreal, greater concentrations of atmospherically deposited pollutants in waterbodies in the Athabasca Oil Sands in the northeast Alberta region, and increased frequency and duration of cyanobacterial blooms in southern boreal lakes.

The north-western boreal, including the Taiga Plains and Taiga Cordillera, will be vulnerable to increases in burn rates due to drier conditions, as well as warming-driven permafrost degradation and ice melting that destabilize homes, and community and industrial infrastructure. Precipitation extremes, and hence floods, are projected to occur more often in some parts of the eastern boreal.

This research suggests that government and business decision-making should consider the broad-scale disparities of climate risks driven by ecozone characteristics, in addition to administrative boundaries. Rural and indigenous communities particularly in the north-western boreal may be more vulnerable to multiple hazards. Regional financial and infrastructural support mechanisms by government agencies and insurance companies should be established to safeguard and restore these communities.

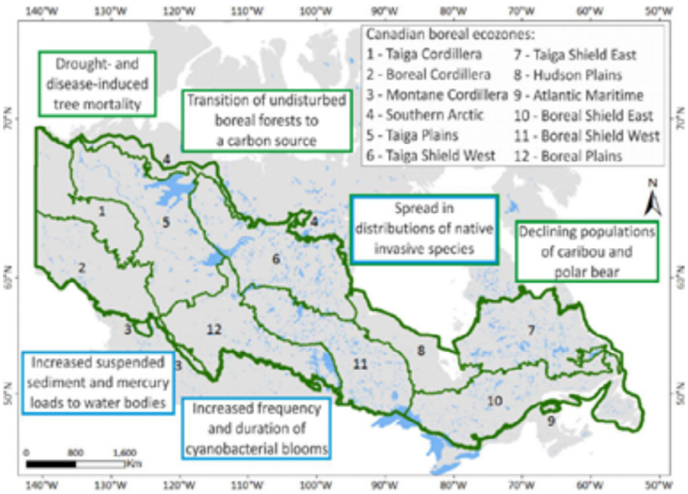

Figure 1: Selected undesirable trends of ecosystem components under ongoing climate change in the Canadian boreal zone. Green (blue boxes denote trends occurring in the terrestrial (freshwater) ecosystem

MANAGING FOR FUTURE SCENARIOS

Multiple undesirable changes in boreal ecosystem components and natural hazard patterns are projected to occur in the business-as-usual climate scenario. Despite considerable uncertainty in these projections, adaptive technological and management solutions are clearly and urgently needed to reduce climate risks.

All sectors of society should begin to assess the efficiency of these measures in reducing the risks of natural hazards, such as fires (by adaptive forest management) and permafrost thawing (by building all-weather roads and developing community-scale renewable-energy facilities; see Yeung, A.C.Y. (2018) Nature, 557, 166), in order to prepare for their large-scale applications.

This horizon scan illustrates a framework for scoping and summarizing climate risks facing socioecological systems on a broad spatial scale. It could be further adopted to analyze climate risks in other parts of the circumpolar zone and large geographic regions. It is hoped that this research output can serve as one of the "go-to guides" for decision-makers in Canadian businesses, communities, and governments to recommend actions in anticipation of climate change.

FORECASTING UNCERTAINTY

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BIOGRAPHY

Thomas is scientist and lecturer at the Department of Geography at Ludwig -Maximilian University of Munich, Germany. He has received a Diploma in Geography from Bonn University and a doctorate in Geography from Potsdam University. Before coming to Munich he has worked as researcher at the Free University of Berlin and at the Hans Ertel Centre for Weather Research of the German Meteorological Service (Deutscher Wetterdienst). His interdisciplinary work is on perception and use of uncertainty and risk in weather information and warnings, and on practices of emergency management and civil protection

THESIS TITLE

Coping with future weather risks by communication of forecast uncertainty and impacts

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Every weather forecast contains a degree of uncertainty. This is inevitable. The question for meteorologists is: how do you quantify and then explain that uncertainty?

Extreme weather events cause major losses of life and properties. More accurate forecasts about the likelihood of a potential event can enhance the preparation of mitigation and response measures to such an event and help reduce or even avoid losses.

Such forecasts play a growing and influential part in the development of long-term plans by businesses and governments around the world. These forecasts stem from highly complex computer-based models of the earth system backed by satellite data and observations on land and ocean. These complex models are largely based on mathematical representations of the laws of physics, applied to the Earth's fluids (ocean, atmosphere) plus references to the science of chemistry.

Scientists know that these models have a degree of uncertainty. Due to their complexity, the chaotic character of the atmosphere and unavoidable inadequacies in weather observations and models, uncertainty is inherent.

Scientists strive to quantify the uncertainty by creating mathematical equations that represent that uncertainty. It is a continual process, with innovative approaches developing new types of mathematical equations that better represent the randomness that exists in weather patterns. Enormous scientific and technological progress has been made in the field of numerical weather prediction. Information technology, in particular, has led to an improvement in the spatial and temporal accuracy of weather forecasts.

However, less has been achieved in communicating the uncertainty in forecasts and enabling adequate responses. A notable exception is the of rain forecasts featured on most weather websites. But a wider communication of forecast uncertainty is not common and not well-known in many countries. Most weather forecasts are still deterministic.

COMMUNICATING FORECAST UNCERTAINTY

Uncertainty is an expression that can be confusing for users of weather forecasts. To include it in forecasts was long viewed as a weakness instead of a useful and scientific fact. However, there are theoretical and operational arguments for the benefits of communicating probabilistic information.

Communicating forecast uncertainty allows for a provision of information on potential future events at an earlier time. The desired benefit is to enable forecast users, like emergency services and the public, to start earlier with preparatory protective actions based on their own risk assessment and decision threshold. It is yet unclear how exactly forecast users understand probabilistic information and how they make use of the added lead time.

PERCEPTION AND USE OF UNCERTAINTY

This research was conducted within the WEXICOM project (Wetterwarnungen: Von der Extremereignis-Information zu Kommunikation und Handlung) and builds upon a mixed methods design using questionnaire surveys addressing the German public, and questionnaire surveys and semi-structured interviews with German emergency services. Results show a high potential for misunderstanding graphical, numerical and verbal statements of forecast uncertainty as they are ambiguous and context dependent, and consequently a source of further uncertainty.

For example, a single probability threshold that motivates forecast users to start with mitigation measures was not found. Whereas it became clear that risk-averse users tend to avoid forecasts based on low probabilities for their decision-making, overall forecast users generally have a good conception of the skill of a forecast of both different weather phenomena and different time scales. The studies revealed that participants do not refer the probability statement to the likelihood of a weather event, but to a risk. That means that the severity of possible impacts is assessed, too.

IMPACT-BASED WEATHER FORECASTS

The significance of impacts for weather related decision-making is recognized by the current development of impact-based forecasts that represent a shift from those focused on weather phenomena to ones that incorporate information about impacts. Impact-based forecasts provide information closer to the users' reality and their decision-making. The studies with the German public and emergency services showed that such information, for example, about traffic obstructions due to a flooded road, can be helpful support for action as they are practically relevant for the users.

Several challenges must be addressed before introducing impact-based forecasts. First, users must know their risk tolerances to define decision thresholds. Discussions between forecasters and users might reveal specific risk-based decision-making. While this helps professional user groups, such as emergency services, it might be difficult if it concerns the public.

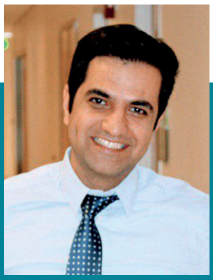
Second, the consequences of weather can mean many things to different people. Impacts are therefore difficult to quantify. Forecasters should be aware of this and formulate forecasts and warnings with this in mind. Third, real impacts may differ from predicted impacts. As any estimate adds a further source of uncertainty to the forecast, this must be communicated openly and transparently. Fourth, it is impossible to make valid estimates about the public's response to a warning, and it must be accepted that this will not change in the near future.

Finally, technology, transport and people's behavior means other local factors may change over time. While this can influence the impact of weather, this change cannot necessarily be attributed to the impact-based forecast.

Implementing impact-based warnings demands awareness for and acceptance of the limits of knowledge, as well as the capabilities of forecasts and of the users' ability to make sense of this information. It is recommended to enhance weather communication not only by improving computer models and observation tools, but also by fostering communication and cooperation between forecasters and forecast users.

While such research may appear abstract, it has a deeply practical impact; weather forecasts are important for many economic sectors and the simulation of uncertainty in weather forecasts is critical.

OPTIMAL DISASTER PREPARATION



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BIOGRAPHY

Saeed is currently a postdoctoral Scholar at the Garrick Institute for Risk Sciences, University of California at Los Angeles (UCLA). He earned his Ph.D. in Civil Engineering from Colorado State University. He has an M.S. degree in Computational Sciences from Marquette University, Wisconsin and an M.S. in Civil Engineering from Sharif University of Technology, Iran. During his Ph.D., Saeed developed a decision-making framework based on Approximate Dynamic Programming techniques to support policymakers to manage community recovery under disasters. He specializes in resilience/risk and loss analysis, natural hazards, dynamic optimization, and machine/reinforcement learning.

THESIS TITLE

Stochastic optimal control methodologies in risk-informed community resilience planning

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Artificial intelligence can assist with decision-making in times of catastrophes to help ensure efficient and effective recovery.

The well-being of households around the world relies on essential items like water, food, energy and transportation. These necessities are delivered by what is referred to as interdependent critical infrastructure systems (ICISs).

While ICISs shape the ability of communities to meet household needs, the level to which these needs are met vary significantly across households and through time and space. Natural hazards and man-made events pose significant challenges to civil infrastructure systems and can result in acute periods of disruption.

For example, the physical impacts of natural disasters include casualties and property damages. The World Bank (2010) estimated that natural disasters have caused 3.3 million deaths since 1970, or about 82,5000 year and that the total damage caused by all hazards between 1970 and 2008 is around $2,300 billion (in 2008 dollars). In addition, disaster also affect 255 million people annually (Narsey, Lal, et al., 2009).

DECISION-MAKING AT THE COMMUNITY LEVEL

Initiatives such as proactive mitigation planning can lessen catastrophes, but efficient and effective recovery scheduling can provide significant post-event benefits. Particularly, if it can restore the functionality of critical systems to a level of normalcy in a prompt fashion, thereby minimizing the waste of limited resources and disaster-related societal disorders.

The lack of a comprehensive decision-making approach at the community level is an important problem that deserves attention. Artificial intelligence (AI), specifically network-level decision-making algorithms, can assist, but to be useful needs to solve large-scale optimization problems that pose computational challenges.

The complexity of the optimization problems increases when various sources of uncertainty are considered. During the recovery process, the decision maker (also called the "agent") must select recovery actions sequentially to optimize the aims of the community. A comprehensive decision-making framework must consider indirect and delayed consequences of decisions (also called the post-effect property of decisions), which requires foresight or planning. Such a comprehensive decision-making system must also be able to manage large-scale scheduling problems that encompass vast combinatorial decision spaces to make the most rational plans at the community level.

A RATIONAL ARTIFICIAL AGENT

My research is to develop a rational artificial agent with the following Comprehensive Risk-informed Decision-making Framework Features. The agent must:

- Balance the desire for low present cost with the undesirability of high future costs (in the sequel, this is referred to as "non-myopic agent" or look-ahead property).
- Consider various sources of uncertainties.
- Make decisions periodically to not only take advantage of information that becomes available when recovery actions are in progress, but also to adapt to disturbances during the recovery process. Periodic decisions need not be taken at fixed intervals; rather, they may occur at arbitrary decision epochs, as required in the recovery process.
- Manage a vast decision-making space, which is typical for the problems at the community level. This decision-making space can cause an agent to suffer from decision fatigue. Decision fatigue refers to the diminished quality of decisions made by a human decision maker after a prolonged spell of decision making. Thus, no matter how rational and high-minded an agent tries to be, one cannot make decision after decision without paying a cost.
- Assess diverse types of dependencies and interdependencies among networks, because a single decision can trigger cascading effects in multiple networks at the community level.
- Undertake multi-objective tasks, which are common in real-world domains. The interconnectedness among networks and probable conflicts among competing aims complicate the decision-making procedure.
- Consider different constraints, such as time, limited budget and repair crew, and current regional entities' policies.
- Factor in external factors, like available resources, the type of community and the hazard, to shape the risk attitude of the agent. Different risk behaviors must be considered.

With a proposed aid methodology based on AI and Approximate Dynamic Programming (ADP), insurance companies and any public and private entity can compute optimal strategies owing to their available limited resources. In fact, the developed artificial smart agents can support human policymakers to minimize the cost of restoring the community as well as do so in a timely fashion.

FEASIBILITY TESTING

The feasibility of the proposed method was tested through a case study at Gilroy in California in the United States. The city in Santa Clara County, known as the Garlic Capital of the World, is an area prone to earthquakes. In the past 365 days (as of 6 November 2019) the surrounding region had experienced several earthquakes with the largest recording a magnitude of 7.1.

The study was mainly conducted in 2016-2019 when it was funded by the National Science Foundation. In this study, collaborative researchers from Colorado State University, the University of Illinois at Urbana-Champaign, and Texas A&M University were involved. The feasibility study involved this community with respect to different goals that are popular for policymakers in the community resilience problems. Different popular goals like the restoration of critical networks in the minimum amount of time and providing safe structure and functional food retailers to the people are considered. Furthermore, the performance of the method for policymakers with different risk attitudes was also considered.

The resulting policies rollout appear to be near-optimal and is substantially better than the performance of their underlying base policies. The base policies are the current restoration strategies of the regional companies, mostly computed with the importance analyses in the system reliability context. As an example, while the current base policies provide utilities (i.e., electricity and potable water) in 28 days following the earthquake, the computed optimal policy completes this task in 18 days (~36% improvement). Furthermore, the proposed approach has the all the above characteristics of a comprehensive framework. We also believe that the method can be adaptable to other infrastructure systems and hazards.

SIMULATING DESTRUCTION

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BIOGRAPHY

David is a Ph.D. candidate within the Earthquake and People Interaction Centre (EPICentre) at University College London. His research focuses on developing risk-based assessment methods for offshore wind turbines, aiming to reduce the levelized cost of wind energy. The ultimate goal is to contribute towards making wind energy an affordable source of renewable energy for the future.

THESIS TITLE

A probabilistic framework for offshore wind turbine loss assessment

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The German expression "Nordsee Mordsee" (North Sea, murder sea) is well justified, as the stretch of ocean in northern Europe is an extreme environment that regularly experiences severe storms. However, the high wind speeds generated there also make it the perfect location for an large offshore wind energy production

Currently 85% of the world's offshore wind energy is generated in the Nordsee, according to the Comparative Analysis of International Offshore Wind Energy Development Rewind Offshore 2017 report. The North Sea's booming role in alternative energy production will only increase with the development of the North Sea Wind Power Hub, a proposed energy island complex to be built on the Dogger Bank, a relatively shallow area in the middle of the North Sea. This industrial wind hub will connect all the countries with a North Sea border (Belgium, Denmark, France, Germany, Ireland, Norway, the Netherlands and Sweden, as well as Luxemburg) into a single electricity network as part of a European system for sustainable electricity.

The offshore wind turbines (OWTs) central to this plan must be sufficiently robust and resilient to withstand storms over an operational life of 20-25 years in an aggressive marine environment. Extreme storms, such as Typhoon Usagi that hit Asia in 2013 with wind speeds of up to 250 km/h and Rammasun (a Category 5 super typhoon with winds of up to 259 km/h) in 2014, have caused failure of the structural components in onshore wind turbines. However, similar empirical observations do not yet exist for OWTs. In addition, OWTs are rapidly increasing in size: the 9MW OWT introduced last year by Vestas has a rotor diameter of 154 meters (538 ft), more than twice the diameter of the earliest OWTs. This means that observed failure rates from previous generations of OWTs would not be suitable for the current, much larger, generation.

ASSESSING OFFSHORE WIND TURBINE LOSS

Current risk assessment procedures for OWTs often neglect structural failure and focus on equipment failure only, which can be assessed using existing empirical databases. However, this is not enough: an OWT is a complex integrated system where failure of the structure may cause loss of all equipment with consequences of structural damage/failure being both in terms of repair/ replacement cost and business interruption, compounded by the difficulty in arranging offshore maintenance.

Simulation-based (engineering) approaches must be developed to assess the risks associated with offshore wind infrastructure exposed to extreme wind and wave conditions, to ensure safe designs and to price insurance policies. This should also consider the impact of climate change, which will make storms both more frequent and severe.

OWTs differ from other types of engineered assets exposed to natural hazards, such as buildings exposed to earthquakes, because they are operating machines that suffer from structural degradation throughout their service life. This degradation takes the form of small cracks that grow from weak points in the structure over many years of energy production and eventually threaten the integrity of the machine. This type of damage, referred to as fatigue, needs to be assessed in combination with extreme loading from severe storms.

A NOVEL PROBABILISTIC RISK ASSESSMENT FRAMEWORK

This research developed novel practical tools (including computer codes) to quantify financial losses associated with OWTs exposed to extreme wind and waves as well as to fatigue. An overview of the proposed approach is shown on Figure 1. It uses a catastrophe risk modelling framework as a first step toward evaluating offshore wind farm resilience and includes a number of novel elements:

- The development of site-specific numerical fragility relationships, defining the likelihood of various levels of damage experienced by an OWT over a range of wind and wave hazard intensities, accounting for uncertainties in both structural capacity and acting loads;
- The implementation of a closed-form technique, based on a combinatorial system reliability approach, to assess the combined financial loss from both structural and non-structural components;
- A coherent treatment of epistemic uncertainties across the framework (for example, sampling variability in fragility estimation), providing loss results accounting for uncertainty of estimation.

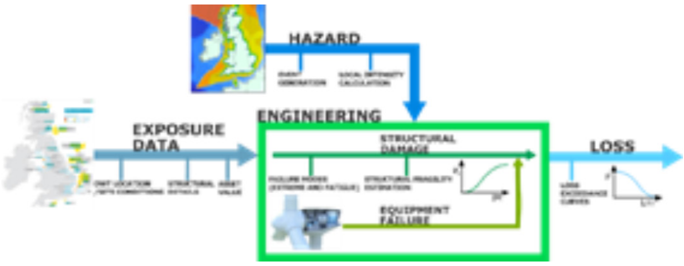


Figure 1: Proposed probabilistic risk modelling framework for offshore wind turbines

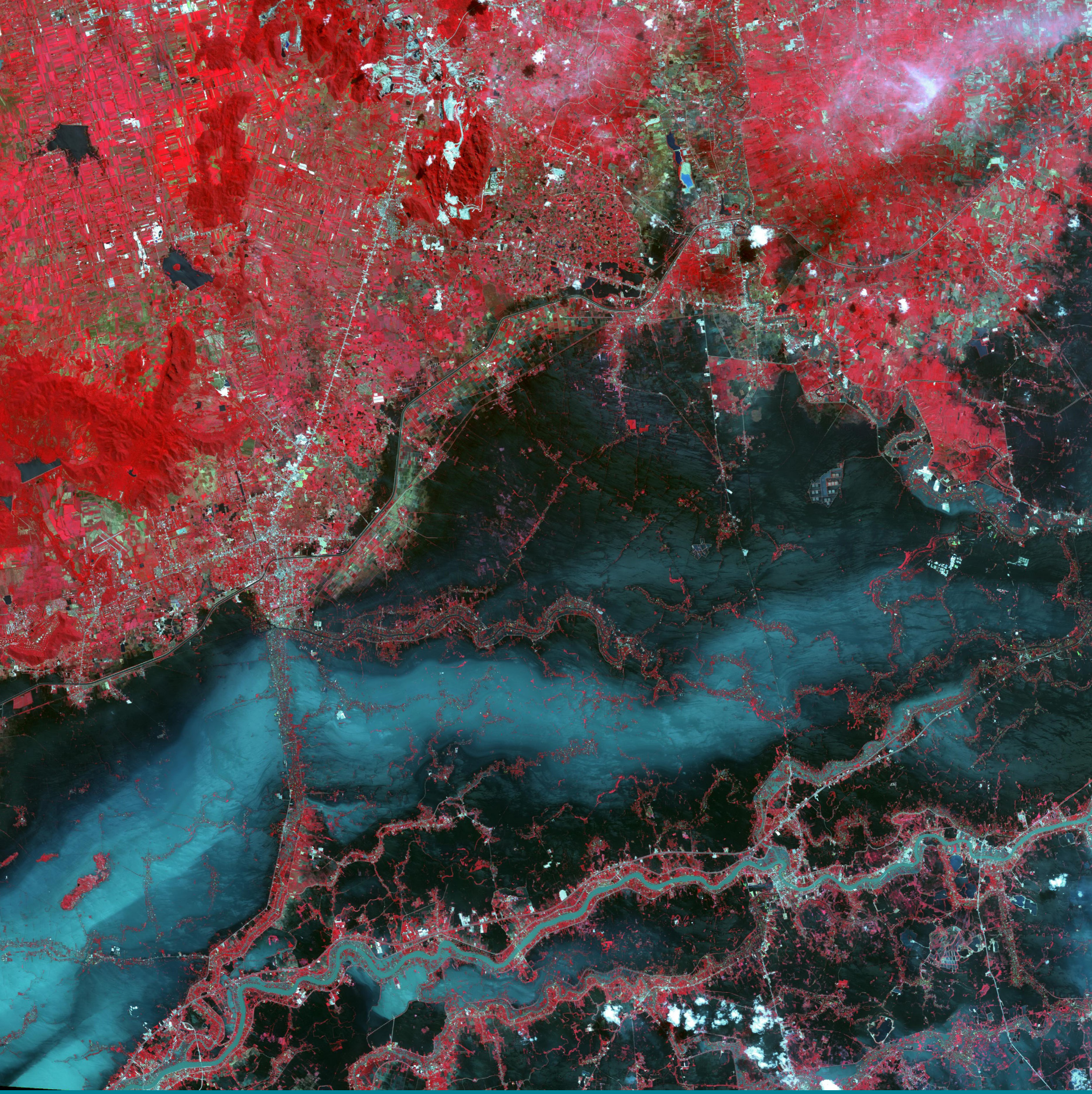
In addition, a novel numerical procedure based on machine learning was proposed to predict failure of the structure due to the growth of fatigue cracks. This is essential because it is computationally challenging to run detailed structural simulations spanning all the combinations of wind and wave conditions that an OWT is exposed to. The proposed machine learning tool, based on Gaussian process regression, allows the detailed simulation to be run at a small training sample of wind and wave conditions and emulates the response at combinations where the structure was not explicitly assessed.

These aspects taken together allow for an integrated probabilistic risk assessment of OWTs exposed to operational and extreme loads, considering both structural and non-structural (equipment) components.

FUTURE WIND FARM ASSESSMENT

The framework has been applied to several case study sites across Europe, showing its ability to predict financial losses for an OWT in practice. It can be used to test optimal design/asset management strategies as well as to improve decision making before decommissioning with the aim to reduce the Levelized Cost of Energy, the total capital and operating cost of each unit of electricity produced, for offshore wind projects.

The framework will be expanded to investigate the relationship between the risk of individual OWTs and the risk profile across an entire offshore wind farm. This will allow loss estimation at the farm level by accounting for the spatial correlation in both hazard and exposure/ vulnerability across the large footprint of a wind-farm site.



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