What has been learned about converting climate hazard data to climate risk information?

Book or Report Section

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CHAPTER 11

What Has Been Learned About Converting Climate Hazard Data to Climate Risk Information?

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Abstract

- Understanding climate risks requires consideration of the hazard, vulnerability and exposure.

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- The understanding and quantification of climate vulnerabilities is central to developing valuable assessments of future risks, with close communication between stakeholders and researchers crucial to achieving this.
- Access to existing exposure and vulnerability data is highly fragmented; a centralised authoritative repository, where such data could be combined with climate data, would widen access and facilitate research.
- There is an ongoing need for multiple risk frameworks and tools to address the breadth of climate resilience issues.
- The analysis of compound, cascading and systemic risks would benefit from more focus in the context of national scale risk assessments.

Keywords Climate · Hazards · Risks · Vulnerability · Exposure

1 INTRODUCTION

The link between human-induced global warming and changing weather and climate is well documented [1]. Changes to UK climate have been observed over recent decades, with implications for both current and future climate hazards [2]. Climate variability and change, including

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changes in the severity, frequency and spatial patterns of extreme weather, can have wide ranging impacts on society, the economy and the environment. Examples of impacts include risks to human health due to increased exposure to heat in buildings, risks to people and the economy from climate-related disruption of power systems and risks to soil health and agriculture from increased flooding and drought [3]. Climate risk is commonly defined as a combination of the climate hazard (see also Chapters 9 and 10), exposure and vulnerability, with response sometimes also considered as a separate determinant (Fig. 1).

Interactions between sectors and systems will also affect risk. Clearly defining, representing and combining elements of these components, which can stretch across social, economic and environmental domains, sometimes in an interrelated fashion, is extremely challenging. In addition, most risk assessments do not consider the potential for compound

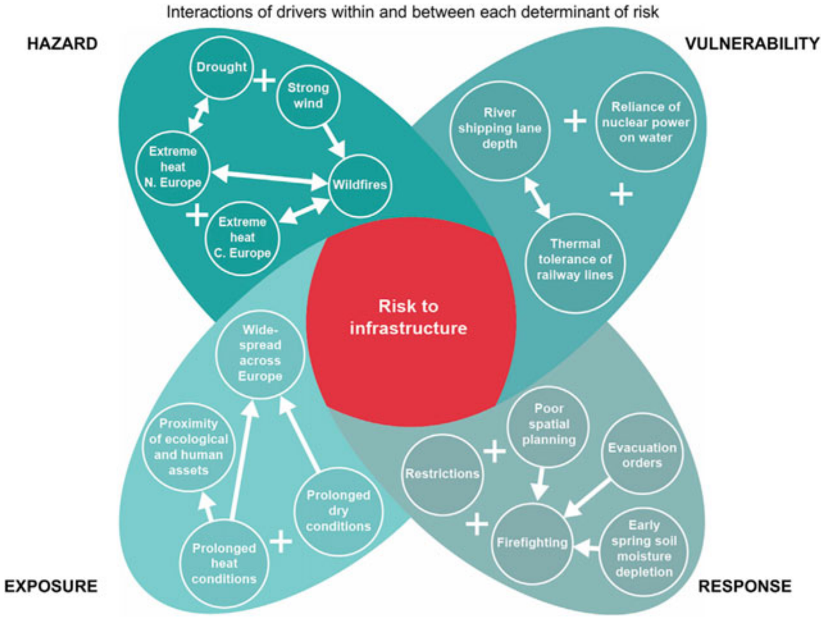

Fig. 1 Risk as a function of hazard, exposure, vulnerability and response. This example illustrates some of the complex interactions that generated risk to infrastructure during the 2018 European heatwave [4]

or cascading consequences [5], which can lead to an underestimate of risk [4]. Different approaches and methodologies to convert climate hazard data to climate risk information have been pursued and applied through the UK Climate Resilience Programme (UKCR).

2 PROGRESS IN CLIMATE RISK QUANTIFICATION—OVERVIEW

Qualitative mapping provides a straightforward approach to draw together pre-existing research and secondary sources to identify hazards and multi-sector risks; for example, to identify multi-sector risks at the city level, as exemplified by the UKCR project 'Manchester Climate Action'. This allows exploration of how risks could evolve in future and a reference point for future research [6], supported by input from key stakeholders and expert-led technical assessments where key risks are identified, or information is incomplete. Similarly, developing a better understanding of historical events (and associated risks) by linking observed reports and datasets with modelled hazard data provides a mechanism to better understand or develop triggers/thresholds that can be used to project the risk of future events occurring—an approach applied by the UKCR project 'Environment Agency Incident Response'. Again, stakeholder engagement or co-production is crucial to support access to novel datasets and exploration of data to support new analyses.

Threshold-based methodologies assess climate-related risks by linking hazard data to the exceedance of a given operational or warning threshold (see also Chapter 10). UKCR projects 'Climate Risk Indicators', 'Meeting Urban User Needs' and 'Hazard to Risk' [7, 8] applied this approach to a wide range of risk-related indicators, including: health and well-being; energy use; transport; agriculture; wildfire; heat stress and hydrological indicators. The UKCR project 'Multiple Hazards' also used this method in its study of compound events [9]. The use of impact-specific thresholds, where discernible, can ensure risk indicators are meaningful to end-users and provide information in relevant and understandable terms at a variety of scales. While thresholds are often based on historical/observed data and are assumed to remain static in future, most analyses could be repeated relatively easily with alternative thresholds if required.

Simulation models can capture more complex relationships between hazard, vulnerability and exposure. For example, implications of heat on care settings, given the vulnerability of specific building characteristics and locations to temperatures, were identified in the UKCR project 'ClimaCare' [10]. Detailed modelling such as this provides new insights into how different components of vulnerability and their relative sensitivity, such as building construction, will affect risk at more localised levels.

Catastrophe (CAT) modelling frameworks, typically used by insurance and financial sectors, model the risks of extreme weather, combining hazard, exposure and vulnerability data. Extensions have allowed future climate risks to be estimated in several UKCR projects; 'AquaCAT' achieved this by enabling the changing spatial structure of flood events to be reflected in national flood risk assessments, whereas the 'Multiple Hazards' project created spatially coherent assessments of heat-related risk and 'Risk Assessment Frameworks' examined heat impacts on physical outdoor work capacity, with risks quantified in terms of cost and days affected.

Systems-based approaches move away from considering individual risks in isolation, aiming to capture the interconnections and interdependencies of risks within a single framework. Bringing together diverse models and methodologies allows multiple sectors to be analysed in a comprehensive and consistent manner. Under 'OpenCLIM', progress has been made in how we design integrated frameworks, develop linkages between models and incorporate adaptation into assessments. However, coupling models also increases the complexity of data requirements, outputs and uncertainties, particularly where multiple dynamics exist.

2.1 Risks and Indicators

Moving from hazard to risk has many challenges, and while the term 'risk' is used universally, often it is sometimes used as shorthand for 'risk-related indicators of exposure or vulnerability only to a climate hazard'. The 'Climate Risk Indicators' project did not explicitly include exposure and vulnerability, although certain indicators were weighted (e.g. based on population) to reflect the hazard and current levels of exposure, and many of the indicators are based on thresholds representing current interpretations of levels of vulnerability. Other studies have mapped overlapping factors that contribute to risk, including data on socioeconomic vulnerability and exposure at the national scale [11]. The UKCR project 'Meeting Urban User Needs' incorporated more localised conditions, drawing together data on vulnerable people, the built environment, green space and council assets. Embedding components such as these will be especially important for decision-makers wanting to understand risk in detail, particularly at smaller scales.

Communicating risk can also be challenging (see also Chapter 12), particularly because the most suitable scale for calculating risk rarely aligns with how risk is best communicated and used. Indeed it is common that the spatial resolution which it is possible to calculate risk at is misaligned with what is needed to inform decisions at different spatial scales [6]. However, the above UKCR projects have demonstrated the benefits of working with stakeholders to maximise utility and uptake—for example, 'Climate Risk Indicators' provided risk indicators based on policy relevant thresholds and critical values, 'Multiple Hazards' provided additional risk-density metrics that allowed a national comparison of results [9], and 'Meeting Urban User Needs' used risk frameworks that align with existing stakeholder frameworks.

3 AREAS OF PROGRESS IN METHODOLOGICAL DEVELOPMENT

3.1 *Spatially Coherent Event Set Generation Versus Local Return Periods*

The spatial characteristics of extreme events are important in assessing the return frequency of a geographically aggregated impact. For example, extreme events may affect multiple assets in a national portfolio, but if return frequencies of events are calculated locally, they do not capture the spatial relationship between impacts on these assets. The risk assessment for a portfolio should be calculated incorporating those spatial relationships to capture the total impacts. This has long been recognised in the insurance sector but should also be considered in assessing systemic or cascading impacts.

The need for considering spatial coherence, and the potential for change in the spatial characteristics, has been examined in UKCR projects 'AquaCAT' [12–14], 'OpenCLIM' [11, 15], and 'Multiple Hazards' [16]. For flooding, 'AquaCAT' predicts an increase in widespread events with very extreme river flows, as well as more widespread events that are formed by much more frequent high levels of river flow. Results from using the tool CLIMADA (https://wcr.ethz.ch/research/climada.html) ('Risk Assessment Frameworks' project), show large increases in the impact of heat on outdoor productivity across the UK, but with potential for regionally differentiated optimal adaptation approaches. Projects such as ‘AquaCAT’ have advanced novel statistical methods to generate stochastic event sets for both hazard and risk, generating values for the underlying climate simulations.

3.2 Exposure and Vulnerability Data

Vulnerability and exposure can be the key source of uncertainty in risk calculations. It is difficult to fully encompass the range of complex, intersecting factors that these components are contingent upon. For example, data may not exist at the required spatial level, or detailed spatial data may exist but not be available or spatially coherent across different regions of the UK, or projected data may not be available for the desired future time periods.

An important methodological advance is that local, regional and global data underpinning the latest UK Climate Projections (UKCP18) used to model and project hazards, can now be linked to the recently released UK Shared Socioeconomic Pathways (UK-SSPs). The UK-specific SSPs are consistent with the global SSPs, qualitatively and quantitatively describing a set of internally consistent, alternative plausible trajectories of societal development which can be used to support risk assessment. A benefit of this is that climate scenarios can be temporally aligned with projections of socioeconomic change. Certain risks to different sectors, and feedbacks of socioeconomic change, can also be evaluated consistently across a range of socioeconomic futures, as illustrated in ‘OpenCLIM’, although there are some challenges to using the time-varying UK-SSPs in the context of hazard expressed on global warming levels.

3.3 New Datasets for Hazard, Risk, Vulnerability and Exposure

Throughout the UKCR programme, there have been several developments which have allowed the production and sharing of datasets to better inform assessment of changing climate risk. The availability and use of these by the community will support the evidence base underpinning the next UK Climate Change Risk Assessment. A selection is listed in Table 1.

Table 1 A selection of the new datasets for hazard, vulnerability, exposure and risk developed through the UKCR programme

Class	*Project*	*Dataset*
Hazard	Coastal Climate Services	Future storm surges, waves and extreme water levels around the UK coast
Hazard	Risk Assessment Frameworks	Events set of outdoor heat stress
Hazard	EuroCORDEX-UK	Regional climate model (RCM) projections over the UK reformatted to complement the UKCP18 ensemble
Hazard	AquaCAT	AquaCAT flooding event sets
Hazard	Climate Risk Indicators	Risk-informed indicators of climate-related hazards for different UK sectors
Exposure & vulnerability	UK-SSPs	UK-specific socioeconomic pathways (SSPs), down-scaled from the Global/European SSPs
Risk	Meeting Urban User Needs	Heat Vulnerability Index to assess heat risk within the city of Belfast
Risk	Risk Assessment Frameworks	Future of outdoor productivity loss (in person hours) under different socioeconomic and climate futures
Risk	OpenCLIM	Risk-related metrics covering heat stress; inland flooding; risks to water supply; drought; biodiversity and agriculture under different socioeconomic and climate futures
Risk	Multiple Hazards	Maps of future climate risks for cattle heat stress and potato blight occurrence

3.4 Treatment of Uncertainties

There are many sources of uncertainty in the calculation of risk, from the physical characterisation of hazards, the exposure of assets or systems to these hazards and the amount of impact a given hazard will have. These are compounded by the uncertainties around methodological choices in how hazard information is combined with exposure and vulnerability to estimate risk.

Physical uncertainties in climate projections arise from many overlapping factors. Different weather and climate products have been developed over the years which, depending on the intended use, prioritise different types and sources when sampling uncertainty. These uncertainties broadly split between ‘aleatoric uncertainty’ (the inherent randomness in chaotic systems) and ‘epistemic uncertainties’, which arise from our incomplete understanding of the physical system and ability to simulate it, including scenario uncertainty arising from the forcing of the system by uncertain human actions [17]. All these sources are considered across different climate products used within UKCR, with some notable advances in the treatment of uncertainty.

The 'EuroCORDEX-UK' project expanded the UKCP18 regional model ensemble with a range of model simulations from EURO-CORDEX [18] to better sample structural uncertainties (from use of different regional and global climate models) as well as the parametric uncertainty (from uncertain physical parameters in a single model) from the original UKCP18 simulations.

An alternative approach was taken by the project 'Coastal Climate Services' which, instead of carrying out new surge and wave simulations, adapted an operational technique for medium- to long-range forecasts to look at the influence of climate change on future coastal risk [19]. Historical wave and storm surge events were linked with North Atlantic pressure patterns and used to quantify the distributions of wave and surge for each pressure pattern. Combining these with projections of future local sea levels and accounting for frequency changes in atmospheric circulation patterns allowed them to assess the changes in coastal risks from extreme water levels.

The approach of using multiple data sources and adapting existing methodologies was taken further in work with CLIMADA, where the uncertainty in future risk was disaggregated with a sensitivity analysis [20]. This served to attribute uncertainty between sources of climate information, methodological choices, assumptions about future socioeconomic trends (from UK-SSP), climate sensitivities[1] and global warming levels. While initially idealised, this combines many of the approaches to dealing with uncertainties that have been used across UKCR.

As well as these specific advances in uncertainty and risk calculation, throughout the UKCR programme different climate products have been used extensively to account for uncertainty. Expert judgement is needed to assess whether a product can credibly represent the hazard of interest and account for uncertainty in the projections, while balancing

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[1] Climate sensitivity is typically defined as the global temperature rise following a doubling of CO_2 concentration in the atmosphere compared to pre-industrial levels. From: https://www.metoffice.gov.uk/research/climate/understanding-climate/climate-sensitivity-explained#:~:text=Climate%20sensitivity%20is%20typically%20defined,be%20at%20roughly%20520%20ppm.

the computational demands of their use or availability over a specific time period. For example, the Urban Heat Service (an outcome of the 'Meeting Urban User Needs' project) used the highest resolution products available, whereas work on compound hazards affecting UK agriculture ('Multiple Hazards' project) used probabilistic and regional UKCP18 products [9].

4 GAPS AND REMAINING CHALLENGES

This section represents the views of the authors in terms of their experiences on the balance of opinions held. It is acknowledged that there may be specific sectors or organisations where the remaining challenges differ to the views expressed here.

4.1 Hazards

Availability of, and access to, climate information needed to calculate future risk has improved over recent years, owing to model advances in complexity, horizontal resolution and sampling of uncertainties driven by both international and UK programmes such as UKCR and UKCP18. The continued development of convective scale climate simulations (~1km horizontal resolution) has driven improved understanding of extreme rainfall events in particular.

However, no 'best' set of climate products exists for all use cases—from the user perspective, deciding which tool to use (with limited resources) is challenging, requiring an understanding of the relevant hazards and the characteristics of the different climate products. This is particularly complex where multiple impacts compound the effects of each other, either directly or indirectly, or over different time scales. Closer communication between climate research and impact sectors would help develop a shared understanding of sector vulnerabilities and climate model capabilities, supporting a more insightful application of climate data to resilience issues and ultimately enabling more valuable advice and services.

There is also often a need for calibration or 'bias-correction' of climate data before calculating impact. As with the choice of climate products, deciding on a methodology requires knowledge and judgement about the nature of the impact and risk of interest. Multivariate methodologies, which are not yet mature, need further development for more hazard cases, including treatment of large-scale biases and local statistical characteristics. As these decisions vary on a case-by-case basis, community calibration toolkits would be a valuable resource, for both efficiency of research and fidelity of outputs.

4.2 Exposure and Vulnerability

A common challenge in the assessment of climate-related risk is the dynamic nature of exposure and vulnerability, either through shifts in policy, explicit adaptation or both. Building on the UK-SSPs through future work, to provide a broader range of indicators, would allow a more informed assessment of future risk.

Additionally, access to exposure and vulnerability data needs to be improved, as it remains a common and substantive challenge. Information is often sensitive with limited accessibility unless direct partnership with data owners exists. Government data sources are useful assets for informing climate risk assessments but often they are in diverse repositories, with varying formats and access requirements. A broader range of historical and projected future data, curated through an authoritative organisation, on an openly accessible platform where climate data could be either hosted or imported would be a valuable community resource.

Finally, nurturing a community of users that understand their vulnerabilities would be beneficial. Getting credible vulnerability information is regularly the hardest component of the data sourcing for risk, as well as identifying exactly what risk metric(s) are most useful for decision-making. Generally, most organisations have yet to develop the maturity in their understanding and data collection to be able to quantify their vulnerabilities, hindering risk calculations.

5 CONCLUSIONS

UKCR has made substantial progress in projections of future exposure and vulnerabilities, and the development of and application of methodologies to combine these with climate projections to quantify future climate risk. Valuable case studies have been produced on agriculture, flooding and overheating, amongst others. However, understanding and quantifying stakeholder vulnerabilities remains a challenge, and access to information needed to estimate exposure and vulnerabilities remains highly fragmented.

The programme has reinforced that different risk frameworks and tools are appropriate for informing different climate resilience and adaptation decisions, and that close communication between stakeholders and climate scientists is crucial to producing valuable analysis and advice.

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