CFRF CLIMATE FINANCIAL RISK FORUM

CLIMATE FINANCIAL RISK FORUM 2022

SCENARIO ANALYSIS: PHYSICAL RISK

This chapter represents the output from the cross-industry Scenario Analysis Working Group of the Prudential Regulation Authority and Financial Conduct Authority's Climate Financial Risk Forum. The document aims to promote understanding, consistency, and comparability by providing guidance on how to use scenario analysis to assess financial impact and inform strategy/business decisions.

Contents

Acknowledgements

This document has been produced in order to help to guide the thinking of insurers and related stakeholders as they continue to develop their approaches to managing and mitigating climate risk.

This guide has been compiled by the following members of the CFRF: **AIG**, namely Paul Barrett and Matthew Wilmot; **Aviva**; **BUPA**, **Direct Line Group**; **RSA** and **Rothesay Life**.

The following organisations have also partnered with the aforementioned group and played an integral role in producing this guide: **EY**, namely Diego Jimenez-Huerta, Stefan Startzel, Dana-Marie Dick and Nitesh Aidasani; **Risk Management Solutions**, namely Corina Sutter, Joss Matthewman, Gloria Jimenez and Edwina Lister; and **Verisk**, namely Shane Latchman.

While all members were involved in the development of this narrative guide, this document does not necessarily represent the views of all firms involved.

Foreword

Physical risk modelling – especially for weather-related perils, is typically a dedicated, well-established function for many general insurers, and benefits from an aggregation monitoring and risk management process honed over decades. These processes help insurers to comprehend their exposure to today's climate-based risks. Insurers now also want to understand how physical risks might have already been impacted by climate change, and how these risks could change in the future.

There is urgency from insurers as questions need answering around a recent uptick in climate-related losses – has climate change exacerbated current events, and will it lead to losses growing in the future? And as an industry so pivotal to climate risk resilience within society, insurers also recognize their growing role in helping to understand, communicate, mitigate, and ultimately reduce the potential impact of climate change. To do this, risk management processes need to adapt to accommodate future climate change paradigms.

Initially driven to accommodate evolving regulatory requirements, insurers are looking for a more developed, embedded view of climate change risk – and to build on their existing risk management processes. So, as well as satisfying their regulators, insurers want to assess climate change risk in order to improve their decision-making and drive business sustainability and resilience. By operationalizing projections of future physical risk, especially over medium-term time horizons within the next 10-15 years, insurers will have the necessary insight to improve profitability and minimize disruption to insurance practices and strategy.

But there are significant challenges in developing future climate views, from understanding the underlying science to using climate model data to adjust and adapt existing physical risk tools. In order to fully understand the physical risk to a portfolio, it is also critical to understand the nature of the underlying asset in question, both in terms of its physical location and how an asset will respond to a natural disaster.

This guide sets out to consolidate the reference material for the modelling of physical climate-related risks across each area, together with an outline syllabus of the key questions that insurers should ask when assessing physical risks over a longer time horizon. This consolidation is vital given the significant volume of published literature on physical risk modelling and climate change.

We are conscious that some users may have less experience around this topic than others, and our guide helps ensure users can quickly obtain a summary of the most material physical perils today that are likely to be influenced by climate change. The guide includes a broad range of use cases and best practices across finance, investments, actuarial, underwriting, and risk management functions, and supports the nascent practice area of modelling climate change impacts on life and health insurance liabilities and long-term savings providers.

This guide has been positioned to help insurers and reinsurers on their climate change journey, and the authors hope it will provide valuable insights for overcoming these challenges.

Joss Matthewman, Senior Director | Risk Management Solutions

Paul Barrett, Chief Risk Officer & Climate Risk Senior Manager, AIG UK

1. Executive Summary

Climate change has already had diverse adverse impacts on human systems, including on water security and food production, health and well-being, and cities, settlements and infrastructure. The Intergovernmental Panel on Climate Change (IPCC) published its 6th Assessment Report (AR6) in 2021/22, finding with high confidence that in the last 10 years, the impacts of climate change and extreme weather events such as wildfires, extreme heat, cyclones, storms and floods have adversely affected or caused loss and damage to human health, shelter, displacement, incomes and livelihoods, security and inequality[1].

Climate-relate risks have been traditionally split into separate, but highly-related, areas:

- Physical risks, including both the acute impacts felt following individual climate-related events such as hurricanes and severe thunderstorms, as well as chronic climate change impacts, such as the gradual increase of global temperatures.

- Transition risks, including the economic impacts that are incurred from the movement towards a low-carbon economy, such as stranded assets due to governmental policy change.

Climate-related risks affect both sides of the balance sheet, and have different materiality when considering the shorter-term liabilities underwritten within general insurance, versus the longer term life and health insurance liabilities. This guide seeks to consolidate a reference material for the modelling of physical climate-related risks across each, and outlines the key questions that insurers should ask when assessing physical risks over a longer time horizon. The guide has three main intended audiences: underwriting, actuarial and risk management professionals working in General Insurance, Life & Health and Investments disciplines.

General Insurance

The modelling of physical risks within General Insurance (particularly for weather-related perils) benefits from a decades-established aggregation monitoring and risk management process within dedicated functions of a general insurer. Climate models are increasingly becoming an embedded part of this process as firms address the evolving regulatory expectations in relation to managing climate-related risks, set by the PRA, EIOPA and others. However, exercises such as the PRA's 2021 CBES involve multi-disciplinary teams and encourage a broader familiarity with climate-related risk management outside of traditional concentrations of experience.

This section of the guide serves to enable less experienced users to quickly obtain a summary of the most material physical perils today that are likely to be influenced by climate change and provides a syllabus of questions that insurers should ask when assessing risks over a longer time horizon. In

[1] Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2022

doing so, we bring out the views of leading experts in the catastrophe modelling community on the most material peril regions today, and the models and approaches/methodologies are being used commercially in the insurance industry to arrive at a view of risk that looks forward to 2050 and beyond.

We also show that climate scenario analysis has a broad range of use cases across Finance, Investments, Actuarial, Underwriting and Risk Management functions, and share best practise use cases from industry practitioners using this analysis to inform reinsurance structuring and accumulation risk management.

<u>Life & Health insurance</u>

Given the longer term time horizon of the risks underwritten by Life (re)insurers, the impact of climate-related risks is significantly more uncertain. The modelling of the physical risks on the liabilities for life and health insurers and long term savings providers is a nascent area of activity given the focus on transition risks to date. A review of the literature given in Section 5 identifies how longevity may be affected by climate change, and we suggest a framework for assessing the climate change impacts on insurance liabilities for life and health insurance companies. This is underpinned by a worked example illustrating each of the steps within the framework provided, in order to help insurers in making concrete next steps in this area.

<u>Investments</u>

To fully understand the physical risk to an insurer, it is critical to understand how both sides of the balance sheet may be affected. Assets backing an insurers liabilities and economic capital may be impacted both in terms of their physical location and how that asset will respond to a natural disaster. We introduce a clear and consistent framework for assessment of climate change across both sides of the balance sheet to facilitate accurate internal reporting, as well as meeting evolving regulatory expectations.

2. Introduction

The Climate Financial Risk Forum ("**CFRF**") was conceived in 2019 as a joint initiative by the Prudential Regulatory Authority (**"PRA"**) and the Financial Conduct Authority ("**FCA**"), in order to build capacity for the management of climate-related risk and share best practice across industry and financial regulators to advance our sector's responses to the financial risks from climate change. One key objective for the CFRF is to consolidate the insights and market practices that are emerging, in order to strategically respond to climate change, and share this knowledge to support other members of the financial services sector to develop their own tools and business strategies.

The CFRF produces thought leadership pieces, or 'guides', to develop the narrative on various climate-related topics on an annual basis, with each iteration focusing on a different core theme. Previous guides address topics including scenario analysis and the impact of climate-related governmental policies.

This guide focusses on the impacts of the physical risks resulting from climate change faced by the insurance industry. Physical risks resulting from climate change are defined as the potential negative direct financial impacts from damage to assets and indirect impacts from supply chain disruption, due to the increasing severity and frequency of extreme weather events (acute risks) or longer-term shifts in climate patterns (chronic risks) caused by climate change[2]. These risks affect general insurance, life and health liabilities, as well as property, equity and fixed income assets held by financial institutions. This guide seeks to consolidate industry approaches to managing each of these areas of risk over the following sections:

Assessment ManualAssessment Manual introduces the weather-related perils influenced by climate change. This section is written in a "Q&A" style to support a podcast discussion by industry experts on how climate change is affecting the assessment of different peril regions and approaches used within the market to develop a view of risk that incorporates the effects of climate change.

> The discussion with Jo Paisley, Paul Barrett, Joss Matthewman and Shane Latchman can be found in a podcast prepared by the Global Association of Risk Professionals ("**GARP**").

Use Cases highlights the range of applications of a climate-conditioned view of risk, and provides practical examples of the decision-relevant use of climate scenario analysis within the insurance industry.

Physical Risk Modelling of Life Insurance Liabilities provides a review of the existing literature on the impact of physical climate-related risk on the

[2] Recommendations of the Task Force on Climate-related Financial Disclosures, 2017

liabilities for life and health insurers, and suggest a framework that can be used to model this emerging area of risk.

Physical Risk Modelling of GI Assets & Liabilities focuses on how the insurance liability modelling framework can be expanded to the asset side of the balance sheet, to assess how the risk from climate change could impact the valuation of an asset.

3. Assessment Manual

Climate risk has traditionally been split into distinct yet highly interrelated risks: physical risk and transition risk. Physical risks refer to the impacts felt following individual climate-related events, such as hurricanes and severe thunderstorms, as well as impacts attributed to chronic climate change impacts, such as volatile weather patterns and the gradual increase of global temperatures[3]. Meanwhile, transition risks refer to the economic impacts that are incurred from the movement towards a low-carbon economy, such as stranded assets due to governmental policy change (e.g. certain high polluting transport types no longer allowed).

3.1. Introduction to physical risks

It is unequivocal that the combined impact of all types of human activity is having a significant impact on the Earth’s climate, primarily through the emission of greenhouse gases, and one key manifestation of this is higher temperatures. In 2022 alone, record breaking weather extremes were seen across the globe:

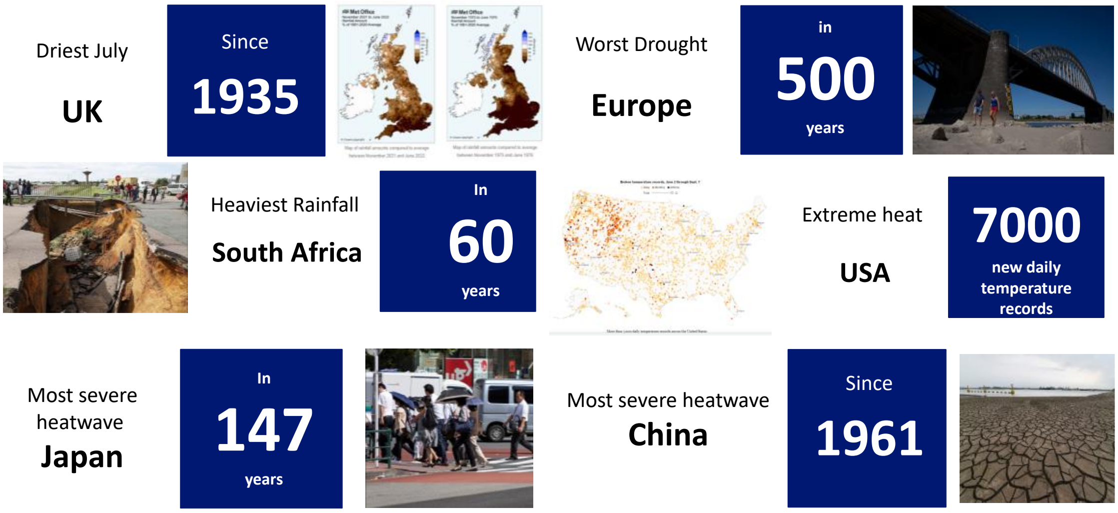


Figure 1: Weather extremes in 2022

Climate change will alter the way many natural catastrophe perils behave over the course of this century:

1. Regions that weren’t exposed to natural catastrophes before may become exposed in the future
2. The hazards underlying natural catastrophe perils may change. For example, changes in sea levels due to climate change will affect the storm surge hazard of tropical cyclones.
3. These changes in turn are likely to increase the expected losses that may arise from natural catastrophe perils.

---

[3] NGFS. 2021. *Climate-related litigation: Raising awareness about a growing source of risk.*

The section provides an overview of the acute weather-related perils that may be influenced by climate change. Firstly, we provide an overview of the perils that are currently material when considering a typical general insurance portfolio, and which account for the majority of insured catastrophe losses to date. Separately, we provide examples of physical perils which, while not currently as material for general insurers, may become more prominent over a longer time horizon, and may be more material for the assessment of Life and Health liabilities.

Material physical risks – based on current view of risk

Tropical Cyclone

$90bn: Largest insured loss to date (2021 USD): Hurricane Katrina[4]

$685bn: Total insured losses since 1950 (2021 USD)[2]

What is it?

A Tropical Cyclone (TC) is a general term for an intense low-pressure weather system that forms over, and is fuelled by, warm ocean waters in the tropics (the regions of the Earth surrounding the equator). These systems get their name from the direction the hurricane winds within them rotate. Cyclonic winds rotate anti-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Cyclones are categorised according to their windspeeds using the Saffir-Simpson Hurricane Wind Scale, which rates cyclones from Category 1 to Category 5. Category 5 is the most destructive, and anything from Category 3 and above is considered a major hurricane due to the potential for life loss and property damage

Main peril regions: North Atlantic, Western North Pacific, Eastern Pacific, Southern Pacific, Indian Ocean

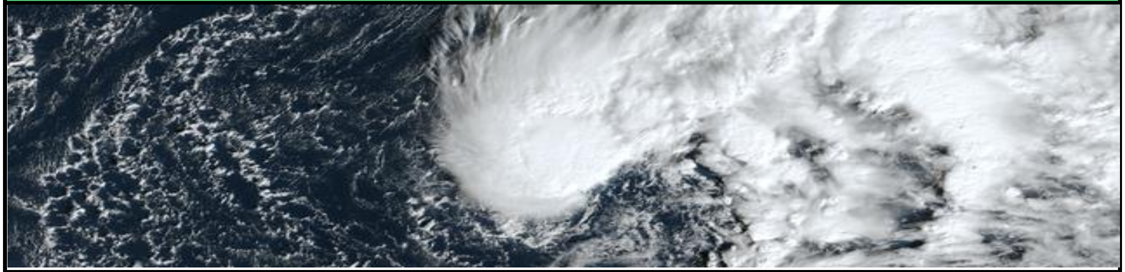
Main hazards: High winds, Storm surge, Rain-driven flood

[4] https://www.aon.com/weather-climate-catastrophe/index.aspx

Extra Tropical Storm

$25bn Economic loss - February 2021 North American winter storm

At least **215 fatalities**



What is it?

Extra Tropical Storms (ETSs) are large scale weather systems (of the order of 1000km wide). In contrast with tropical storms, which are formed by warm, moist air evaporating from the sea, extra tropical storms are formed where a core of cold air interacts with warm air masses over land or sea and can produce rapid changes in temperature across a wide area. They occur over the mid-latitudes of the Earth, between the Tropics and the Poles.

Main peril regions[5]: North America, Northwestern Europe, South Australia, Indian Ocean

Main hazards: Snow, Ice, Freeze, Wind

Severe Convective Storm

$602bn: Total insured losses since 1950 (2021 USD) [6]

9 out of 10 largest insured losses since 2011

What is it?

Severe Convective Storms (SCSs) are localised weather events of intermediate size (10s of km wide) associated with thunder, lightning, heavy rain, hail, strong winds and sudden changes in temperature. These storms generally occur in the summer months but can happen throughout the year. For a thunderstorm to be classed as a severe convective storm, it must also be accompanied by one or more damaging hazards.

Main peril regions: SCSs are a global peril, but are particularly active in North America, Europe, Southeastern Asia, Australia & New Zealand and Argentina

Main hazards: Hail, Straight-line winds, Tornadoes

[5] Ulbrich, U., Leckebusch, G. C., & Pinto, J. G. 2009. Extra-tropical cyclones in the present and future climate: a review. Theoretical and applied climatology, 96(1), 117–131

[6] https://www.aon.com/weather-climate-catastrophe/index.aspx

Inland Flood

$306bn: Total *insured* losses since 1950 (2021 USD) [7]

$2,694bn: Total *economic* losses since 1950 (2021 USD)

What is it?

An overflow of water submerging land that is usually dry. The size and depth of an inland flood event are influenced by the intensity of rainfall (precipitation), the topography of the land, soil characteristics, land use, the shape and depth of nearby rivers, antecedent conditions and the existence and condition of any flood defences (natural or man-made).

Main peril regions:

Flooding is a global peril, and its insurance impacts well known in North America (US), UK, Europe and Asia (China, India & Taiwan)

Main hazards:

Pluvial flood (Surface Water) - when the intensity of rainfall exceeds the capacity of natural and man-made drainage systems

Fluvial flood (River flooding) - when rivers are filled above their capacity by rains or excessive runoff from areas upstream

Wildfire

$10.8bn: Largest insured loss (2021 USD): Camp Fire, USA [8]

>$2bn annual loss (2021 USD) seven years in a row

What is it?

Wildfires are large, destructive fires that spread quickly over woodland or brush, and can occur anywhere around the globe where extended periods of drought can occur (i.e., months to year), where there is also burnable fuel (such as trees and grasslands) and ignition sources (either man-made or natural e.g., lightning strike).

---

[7] https://www.aon.com/weather-climate-catastrophe/index.aspx

[8] https://www.aon.com/weather-climate-catastrophe/index.aspx

Main peril regions: The risk of wildfires is especially high in areas where the above conditions are present and which also have low-humidity environments and high winds.

Main hazards: Fire (size of burned area)

Physical risks – areas of interest when looking over longer time horizons

The following perils do not currently constitute a major share of economic losses and therefore investment in modelling capability lags behind that of other physical perils. However, the examples below are also linked to areas of climate change where there is greatest evidence of man-made influence, such as sea level rise, temperature extremes and extreme precipitation events.

Drought: periods of unusually persistent dry weather that persists long enough to cause one of a number of perils, as well as playing a contributary role in wildfire. Examples of drought include: hydrological drought, where low water supply potentially affects waterway transportation and supply chains; agricultural drought, where crops, grazing and agricultural production become affected; and meteorological drought, where dry weather patterns dominate in a given area – this may have potentially serious human health implication include adverse mental health outcomes and increased mortality rates. The IPCC's provided a high confidence that human-induced climate change is increasing the frequency, severity and/or intensity of droughts, wildfires and land and sea-based heatwaves[9].

Subsidence: the gradual downward movement or sudden sinking of the ground surface, causing damage to physical assets. Subsidence occurs across the globe depending on the prevailing soil type, and is more likely to occur over sand, gravel and clay soils. Subsidence caused by changes in temperature, humidity, groundwater levels and glacial thaw is intrinsically linked to climate change .

Coastal Erosion: refers to the process by which sea level rise and wave action remove rocks, soil and sand along a section of coastline. Global mean sea level rise will continue during the 21st century, very likely at a faster rate than observed from 1971 to 2010[10]. As global sea level rises, the action of waves at higher elevations increases the likelihood for extensive coastal erosion.

---

[9] IPCC, 2021:Cliamte Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

[10] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

3.2. Peril region hazard materiality assessment

How is climate change affecting acute and chronic region perils?

Q: What is the difference between acute and chronic perils?

Acute perils generate single, infrequent, and largely unpredictable natural disasters that cause severe impacts on the built environment and significant subsequent financial loss. The insurance industry has prioritized acute perils because they are typically responsible for the largest losses, especially the traditional "primary" perils of hurricane and earthquake. Insurers also categorized some acute perils that were perceived to be on a lower risk tier as "secondary" perils, whether these perils resulted from primary peril events, such as flooding after a hurricane, or simply were considered to be less loss-producing, such as pluvial floods, wildfires, and severe convective storms. These perils were often more frequent but less severe, causing smaller, attritional losses. However, some "secondary" perils such as wildfires are now under scrutiny because they increasingly causing large losses.

Chronic perils are longer in duration and may include the cumulative effects of many events with overall lower severity. They include droughts, heat waves, and sea level rise. They may overlap somewhat with attritional perils such as severe convective storms, which tend to occur with high frequency but low severity. Without the potential of an immediate physical impact and subsequent large losses, chronic perils have not been a focus of the insurance industry.

Q: Is climate change altering how we think about physical risk, whether from acute or chronic perils?

The insurance industry understands the direct effects of acute perils, and how a specific event is likely to impact property (via damage, business interruption or downtime). The industry generally defines a catastrophe as a single event that produces significant loss. Conceptually, therefore, it is straightforward to incorporate climate change into calculations of future acute physical risk.

What is more difficult is to calculate the loss from a chronic peril such as a multi-year drought, or the gradual changes to acute perils. Questions need to be asked about how we conceptualize loss, what we include in that loss, and on what timescale.

As we think more deeply about climate change's effects on physical risk, the industry is now increasingly grappling with timeframes it is not accustomed to, and knock-on effects it may not have accounted for in the past (such as effects on the asset side of the balance sheet). Similarly, there is increasing recognition that climate change may have profound effects beyond direct physical damage, including on company operations and profitability, supply chain risks, and so forth.

Q: Is climate change shifting some traditionally "chronic" perils into acute ones?

Climate change may increase the frequency and severity of some risks and require perils to be recategorized from chronic to acute. Some examples of chronic perils becoming more acute include heat waves, droughts, and tidal flooding caused by sea level rise.

Focusing on heat waves, whether defined as chronic or acute, they have not been a priority for insurance underwriters as they do not physically impact property or generate losses. However, they can impact human productivity and increase costs such as through higher air-conditioning demand, which can be an issue for the asset management side of the business. As heat waves become more frequent and severe, these non-physical impacts are coming into focus.

Extreme droughts are also beginning to behave more like an acute peril. They impact property through greater subsidence, particularly in areas with clay soils. They can also cause business disruption by leading to reduced power supply (e.g., hydropower or nuclear power) and cause supply chain disruption (e.g., low water levels on the River Rhine in summer 2022).

Finally, sea level rise is contributing to increasing acute hazard in a number of ways, such as tidal flooding and greater storm surge flooding, which can have catastrophic impacts on property.

It's also important to note that these changes in risk are in part due to climate change's effects on the frequency and severity of some perils, and in part due to growth in exposure (the expanding bulls' eye effect[11]).

What are the key peril regions for physical risk globally - both in terms of hazard and exposure (mainly on traditional acute natural catastrophe risks)?

Q: How can we frame climate change's effects on region perils?

We can evaluate climate change's effects on a region peril through two lenses: its impact on the hazard associated with a given peril (e.g., flooding caused by extreme precipitation), and the materiality of that impact to the exposure we care about (where is the flooding happening, what property is in harm's way, and how well can that property withstand damage).

In some cases, climate change is causing a large change in the hazard associated with an acute or chronic peril. Using the example of flooding, as climate change raises global mean surface temperatures, so does the water vapor carrying capacity of the atmosphere, and thus extreme precipitation events increase in both frequency and intensity. These changes may be specific to a given region (e.g., increased extreme precipitation-caused

[11] The Expanding Bull's Eye Effect, Stephen M Strader and Walker S. Ashley, Weatherwise, 2015

flooding in the U.S. Mississippi River Valley) or relatively widespread across various parts of the globe. However, a large increase in precipitation over the oceans, for example, may not have major direct effects on society.

In other cases, climate change may have a more minor effect on a region peril's hazard, but the location of that hazard means that this change will nonetheless materially affect human society and the built environment. An example is climate change's effects on North Atlantic hurricane wind. The general scientific consensus now is that climate change is causing a relatively modest increase in the relative frequency of the most intense storms. However, there is a huge amount of exposure along the U.S. Gulf and East Coast, as well as the Caribbean, some of which is not built to withstand high wind speeds, so the materiality of this impact is high.

Q: In what peril regions is climate change strongly affecting hazard now, or projected to do so in the future?

In general, the clearest effects of climate change are on temperature and precipitation extremes and sea level rise. How these changes propagate through the climate system is complex; however, the chronic and acute perils that are most closely affected by these parameters will also display the clearest signals. These include extreme heat and drought (the Mediterranean Basin, Central and South Asia, northern Australia, western North America), wildfires (western North America, Australia), flooding due to extreme precipitation (the Northeast U.S., China), sea level rise impacts, especially tidal flooding (the U.S. East Coast and the North Sea), and storm surge flooding (the U.S. Gulf).

Q: In what peril regions is climate change strongly affecting materiality, or likely to do so based on future projections?

In general, climate change will affect materiality in areas where some alteration in hazard overlaps with large amounts of exposure (high cost, densely built properties). There is some overlap with the list of peril regions above; for example, the large increase in wildfire hazard in western North America and Australia will also be material.

In other cases, areas with dense exposure will simply be more susceptible to climate change-induced increases in physical risk. The U.S. East Coast and Gulf states will be vulnerable to increases in hurricane risk (from greater storm severity, storm surge flooding, and extreme precipitation), as well as flooding from extreme precipitation.

From a relative materiality perspective, any area where climate change alters hazard so as to affect a major proportion of a country's GDP or population is concerning, such as sea level rise encroaching on small island nations. When establishing the effects of climate change on both hazard and materiality, it is important to note that there is large uncertainty in predicting future impacts. Climate change's effects on complex weather phenomena such as acute or chronic perils are not straightforward and are strongly influenced by the innate natural variability of the climate system.

This could mean, for example, that an area with a high probability of drought or wildfire dodges these perils for some time because stochastic variations in year-to-year weather bring wetting rains. Conversely, low risk does not mean no risk for any given area.

Q: For which perils is there a difference in opinion in the scientific community of its climate signals, are there any that are unmodelled or overlooked?

There is ongoing debate in the scientific community about how climate change will affect many perils. A notable peril is severe convective storm, which is characterized by high natural variability, complicating conclusions about trends and climate change signals. For example, observations show changes in severe convective storm parameters, such as a geographic shift towards the south-eastern U.S., but it is unclear whether this is a trend, a fluctuation influenced by another climate mode, or due to random noise in the system.

Global tropical cyclone frequency is another parameter where vigorous debate in the scientific community still exists. Most studies have suggested an overall decrease in frequency, but some more recent efforts using higher quality models show the opposite.

How comfortable is the community with the ability to assess materiality for chronic hazard?

Q: How will chronic risks—and chronic risks that are becoming more acute—impact insurers and the broader financial system?

Losses are increasingly being driven by simultaneous and interconnected wildfires, heatwaves, and droughts. These chronic perils cause physical damage, as well as having broader impacts that lead to extensive disruption and losses to business operations.

- Agriculture and crop insurance is a particularly vulnerable line of business to drought and water stress, as seen in southern Brazil in 2022. Droughts in 2003 and 2022 also caused significant subsidence property damage across the U.K. and France.
- In some coastal regions such as Florida, flooding from sea-level rise is elevating water tables and increasing water stress in properties distant from the coast.

We are also seeing an increase in "compound" events, such as devastating landslides caused by severe rainfall after a wildfire. In addition to the immediate property damage and business interruption that insurers are accustomed to accounting for, these events can have profound and long-term indirect effects. For example, loss of infrastructure, such as roads and washed-out bridges, can mean that property cannot be repaired and even undamaged businesses are interrupted for months.

Climate change may heighten systemic risk by shifting chronic peril severity and duration, especially in areas unused to such events. Often, these perils may cause greater loss via their impact on business operations than physical damage. For instance, droughts will increasingly affect power generation and costs (hydropower/nuclear power in particular), business operations and supply chains across multiple sectors. The industry has already experienced these effects in river transport disruption in Germany in 2018 and again in 2022, as well as data-centre cooling.

What tools are needed to help insurers understand their risk from chronic hazard and these new types of climate-driven cat risks?

Q: How have catastrophe models been adapted to incorporate chronic perils and other emerging climate change-driven risks?

Some chronic risks are relatively straightforward to incorporate in catastrophe models. For some years now, the impact of sea level rise so far has been included within the coastal flood and storm surge components of tropical cyclone models. Many catastrophe models also account for the impacts of vertical land movement on coastal flood risk, such as the subsidence of river delta cities such as New Orleans and Shanghai, or conversely, upward rebound following ice age glacial retreat in places such as Norway.

The principles of catastrophe modelling are also now being applied to a greater range of chronic risks, for example in the development of global models for wildfire, drought, and heat stress, with multiple future climate change scenarios and time horizons. Droughts and heat-wave events are now being defined and modelled in terms of both duration and severity. A major effort in applying catastrophe modelling to chronic perils is characterizing their long-term effects on the vulnerability of different property types and business sectors, the loss to physical property, business operations and interruption, and their broader economic impacts.

Q: What opportunities exist for insurers around chronic risks and what challenges remain to be solved?

The impacts of these various chronic risks will create opportunities for new products, including contingent business interruption, parametric heat indexes, or insurance against low water levels for new hydropower plants. Insuring the transition means that new risks will need to be underwritten, such as to support the growth of renewable energy, but the risk will need to be known. In the case of increasing business interruption, the challenge lies as much with data as with modelling. While progress is being made with the ability to rapidly analyse large and emerging sources of data, understanding the interconnectedness of global supply chains remains problematic.

3.3. Assessing materiality by LoB and Insurance Products to understand insured exposure

What are the key drivers of materiality on an exposure basis for insurers?

Q: Where should you start?

The starting point in managing exposure to physical risk is the company's risk appetite – identifying a Probable Maximum Loss (PML) that, within a given timeframe, the company can absorb without an unacceptable business impact. Every company's appetite will be different depending on, for example, their business strategy, level of regulation, cost of capital and the other lines of business underwritten.

Q: What drives an insurer's physical risk?

Physical risk is driven by the geographical location underwritten and the prevailing meteorological conditions. Globally, the perils influenced by climate change (severe storm / cyclone, flooding and wildfire) make up the majority contribution to long-term insured average natural catastrophe losses (Global Modelled Catastrophe Losses, Verisk, 2022).

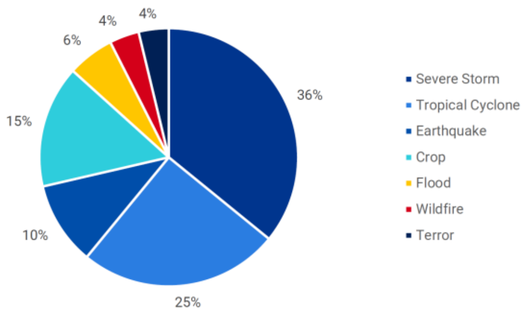


Figure 2: Contribution to global insured AAL by peril for all regions. Source: Verisk.

For individual peril regions, the management of exposure to major insured perils benefit from well-established catastrophe models. Where models aren't available, simple measures, such as the number and sum of limits on insured structures, can still be used as measures of risk that are easily available[12]. Section 1.5 provides further information on the approach to risk assessment in the absence of commercially available models.

Features of the individual underlying risks will also play a part, e.g.:

1. Contract term –the majority of affected property insurance cover is offered on an annual basis, affording (re)insurers the opportunity to monitor gradual changes to the climate risk landscape and consider adjustments to pricing and/or terms. Longer duration risks such as Construction lines mean greater exposure to acute weather perils.

---

12 https://www.actuary.org/sites/default/files/files/catmonograph_june01.4.pdf/catmonograph_june01.4.pdf

2. Value at one location – e.g., for onshore energy, wind farms are typically spread out over a large area whereas individual hydro-electric plants concentrate risk in one place
3. Construction materials used, age of structure and resilience / climate adaptation measures – materials used to adapt to one set of perils may increase exposure to secondary hazards
4. Supply chain – exposure to business interruption will depend on the strength and adaptability of a firm's supply chain e.g., clients could be storing more items on-site to avoid unnecessary transit.

What are the key Lines of Business and Insurance Products that are affected, and how might this change under increased climate risk?

Q: Which lines currently are most affected by physical climate change?

In terms of current climate, attributing the role of climate change in extreme events is a difficult, ongoing subject of scientific study. The effects of climate change may already be present when thinking about lines of business most commonly exposed to weather-related catastrophe perils:

Property – both direct loss to buildings and contents (both personal and commercial), and contingent business interruption (BI)

Energy (Onshore / Offshore) - property damage, BI and delay in start-up, plus specialist machine and equipment covers

Marine – property damage, cargo, hull and liability lines with significant accumulation potential in port facilities

Q: How might this change under increased climate risk?

The level of confidence in scientific results to explicitly attribute man-made climate change to *specific* changes in frequency and severity of weather-related extreme events remains low for many of perils currently most material to insurance portfolios, with stronger evidence that climate change is influencing perils that are currently less material (Bank of England: A framework for assessing financial impacts of physical climate change 2019).

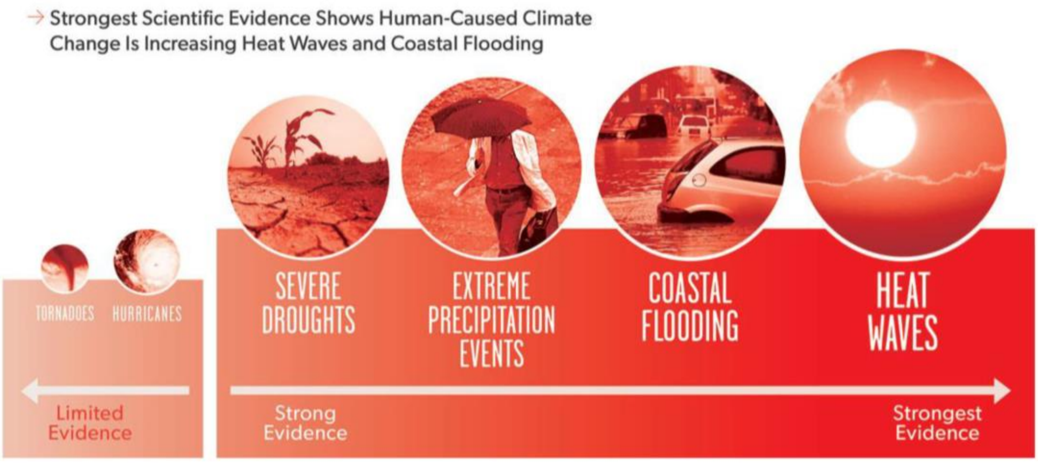


Figure 3: The most material perils in a typical insurance portfolio might not necessarily have the strongest available evidence to support the peril/territory materiality assessment. Source: Union of Concerned Scientists (2012) based on Intergovernmental Panel on Climate Change (IPCC) 2012 report.

Importantly, exposure and vulnerability factors, such as population growth, urbanisation, development choices and supply-chain disruptions (caused by extreme events) distort and could mask any embedded climate change signal[13]. However, when looking out to a 2050 time horizon and beyond:

The severity and frequency of perils will likely change. Insured losses in many areas of the world are likely to increase. For example, the IPCC has shown that across the world, a 20-year rainfall event in the late 20th century is projected to be between 5 to 15 years by the end of the 21st century[14].

"Secondary" perils may become more material – events such as the 2021 flooding from Storm Bernd (*8.2bn EUR market loss*[15]), which brought heavy localised rainfall causing extensive flooding away from the main modelled rivers, may become more prevalent.

The mix of perils in a given region may change – e.g. studies of the effect of climate change on US wildfire show that the biggest increases in risk do not coincide with areas that currently have the highest exposure, with losses potentially tripling in some areas by 2050[16]. The Intergovernmental Panel on Climate provide an authoritative source for discussion of the agreement and evidence of climate change (Technical Summary of the Fifth Assessment Report (AR5) of IPCC 2013 Technical paper (Box TS.1, Figure 1)). Further information on assessing the potential financial impact of these perils is provided in the Bank of England's framework for assessing financial impacts of physical climate change[17].

Insurers' business models will need to adapt to balance the funding of changes in frequency through rate increases with promotion of adaptation measures to control severity. Insurers have a strong partnership role in enabling policyholders to adapt to climate change, for example through industry resilient repair initiatives.

A different approach may be required for "uninsurable" risks – alternatives to indemnity-based cover may need to be explored for risks with near-certain likelihoods of loss due to climate change e.g., providing cover for the downside of a risk relative to an expected outcome only, rather than insuring total loss.

---

[13] Climate Change Risk Assessment for the Insurance Industry, The Geneva Association

[14] Changes in climate extremes and their impacts on the natural physical environment. IPCC, 2012

[15] https://www.ajg.com/gallagherre/news-and-insights/2022/february/gallagher-re-natural-catastrophe/

[16] Potential Impacts of Climate Change on U.S. Wildfire Risk by Mid Century, SOA Research Institute

[17] https://www.bankofengland.co.uk/prudential-regulation/publication/2019/a-framework-for-assessing-financial-impacts-of-physical-climate-change

3.4 What type of models and approaches/methodologies are being used commercially in the insurance industry to arrive at more forward-looking methodologies for climate-conditioning?

Q: How does the industry use global circulation models (GCMs) to understand climate change's effects on physical risk? What should an informed user of GCM data be aware of?

Global circulation models (GCMs) are the basic currency for understanding how climate change will alter the physical variables underlying acute and chronic perils. Most climate risk assessment approaches use GCM data as a first-order input, including the creation of higher resolution "downscaled" versions of GCMs and GCM-based academic studies. Broadly speaking, this data is used to understand how a given hazard variable, for example, seasonal extreme rainfall, can vary.

GCM output and academic studies around it are a useful tool for physical risk assessment for several reasons:

- State-of-the-science: GCM model conclusions represent our best understanding of climate change impacts and are therefore widely used to understand the effects of climate change on acute and chronic weather perils, such as conclusions from the IPCC assessment reports.
- Transparency: GCM data are often widely available and used across the scientific community.
- Ensemble results: GCMs usually come in ensembles, so their conclusions are based on results from multiple models, which is more reliable than any specific single model.

However, GCMs have some important limitations:

- Low climate change signal-to-climate-noise ratio: A low signal-to-noise ratio is a general issue with climate change projections because the climate system is noisy and it can be challenging to distinguish a climate change signal. This is especially true when examining impacts at a human scale, such as a city or an individual structure. Risk managers must often balance trying to arrive at practical conclusions with a realistic assessment of the level of precision that GCM data can bear.
- Low-resolution results: Often, GCM results are at a relatively low resolution, for example hundreds of kilometres, which is problematic given that most decision-useful information requires a higher resolution. Therefore, using GCM output usually requires additional processing to create higher resolution data (such as downscaling), which often gives rise to the signal-to-noise issues discussed above.
- Biases: GCMs are well known to exhibit biases, for example, predicting windspeeds or temperatures that are systematically high or low. The direct use of hazard data from GCMs requires correction of these biases, which can introduce inconsistencies and cause problems with other model outputs. Some GCMs are also known to represent certain climate phenomena badly and would therefore lead

to poor impact estimates, so a GCM with a poor representation of the jet stream which be inappropriate for informing a view of European windstorms. Therefore, it is important to assess a GCM before using its results to ensure that it is suitable for representing the peril and hazard of interest.

Q: Describe the spectrum of tools available to the industry to understand climate change's effects on physical risk.

All of the methods that are widely used in the insurance industry build on GCM results to understand changes in risk. Some entrants to the market have sidestepped the traditional catastrophe model framework, and look at hazard-only climate change scores, while some vendors have built on the traditional catastrophe modelling framework that the insurance industry is accustomed to.

Hazard scores
The most prevalent climate risk assessment tools in the market today are based on hazard scores, which are relatively simple to use and create. They are often derived relatively directly from GCM data and therefore usually have a Zip code or lower resolution. These scores examine how climate change will alter the hazard in an area, with all other things (exposure and vulnerability) being equal. Thus, a portfolio of assets in one geographic area would all have the same hazard score. Examples of this approach include Moody's Climate on Demand, and NOAA CMRA.
Pros:
- Usually have a global extent
- Low cost
- Good for screening: Hazard scores can be a useful way to look at large areas or a first step in understanding how climate change will affect a region.

Cons:
- False positives: Hazard scores may be useful for a high-level analysis but will struggle to differentiate physical risk between components of a portfolio for numerous reasons.
- Hazard ≠ physical risk: Because hazard scores do not account for exposure (the specific location and type of asset) or vulnerability (how an asset will react to hazard), these scores cannot properly differentiate the damage experienced by various assets within a portfolio. Neighbouring properties might experience the same change in hazard but exhibit a very different change in physical risk. For example, an elevated versus a ground-level property could have a similar change in flood hazard due to climate change but very different changes in physical damage. This problem is especially troubling for perils that naturally exhibit large variations in behaviour over relatively small distances, such as flood or wildfire.
- Aggregation: It is difficult to meaningfully aggregate hazard across a portfolio, or between perils (in contrast to financial damage or loss metrics). It is also hard to capture correlations between assets in a portfolio.
- Granularity and biases: Because hazard scoring approaches often use GCM data directly, they suffer from the problems described previously regarding GCM resolution, and may produce spurious results because of a low climate change signal to climate noise ratio. They also may reproduce GCM biases, especially if problematic GCMs have not been

filtered and removed (although this issue can be alleviated by using large ensembles).

Catastrophe modelling

The catastrophe modelling framework has been developed and used within the insurance industry for years and is generally considered to be the gold standard for understanding physical risk by translating hazard into impact. Hazard-only scores take the first step in transforming GCM output into meaningful physical hazard, but the catastrophe modelling process goes much further, progressively layering additional components atop this baseline: precise exposure location, vulnerability, and financial consequences.

There are two ways that catastrophe models are generally adapted to assess forward-looking climate change risk. The first and simpler approach is to use climate change conditioned catastrophe models to create a score. Climate conditioning is performed within the hazard calculation component of the models and then run through the rest of the model framework (exposure, vulnerability, financial modelling). At the end of this process, a climate-conditioned physical damage score is generated, rather than just a climate-conditioned hazard score.

The second approach involves the direct use of climate-conditioned and baseline catastrophe models. Models are run for baseline and future climate scenarios, producing estimates of property loss, business interruption, and downtime for an asset or portfolio. The resulting physical impact metrics might be average annual loss (e.g., to a treaty or portfolio) or the loss associated with a given return period and could be at the portfolio, county, or location level.

Pros:

- Granular: Catastrophe models result in a highly detailed assessment of all elements of catastrophe risk.
- Full impact assessment: Catastrophe models evaluate the entire spectrum of physical risk rather than just hazard, including differentiation down to neighbouring properties.
- Correlation: There is a full treatment of correlation between assets in a portfolio, and full aggregation to portfolio-level metrics. For example, if two locations have similar risk but are unlikely to be impacted by the same weather event, then the risk to a portfolio that includes both should be lower due to diversification. By design, catastrophe models capture these effects.
- Alignment with existing risk management: Many in the insurance industry are already using catastrophe models, so it is easy to incorporate climate-conditioned results that use the same metrics and structure. For example, if an insurer is accustomed to making business decisions based on 1-in-200-year portfolio loss metrics derived from catastrophe models, it is straightforward to evaluate alternate climate change conditioned versions of that same model (such as RCP8.5 in 2030).

Cons:

- Time-consuming
- Costly and specialised
- Limited geographic and peril scope (this applies to derivative scoring products, not just direct use of catastrophe models)
- Limited scope of outputs: Outputs are generally aimed at insurance liability use cases only. Those interested in non-insurance liability use cases, such as an insurer's asset valuation for credit risk, will have to take additional steps to translate physical damage metrics into physical risk measures appropriate for the desired investment type (e.g., climate-conditioned credit default metrics, impairment to net operating incomes, or house price indices). While not directly a drawback for understanding climate change risk to insurers' liabilities, this limitation needs to be overcome if an insurer wants to use these models to understand physical risk to other investments and assets on their balance sheet. It is also important to ensure that a consistent view of risk is applied on both the asset and liability sides.

3.4. What are the classes of climate-conditioned models - and are there principles that are recognized by the market?

Q: What specific approaches exist in the market for climate-conditioned catastrophe modelling?

Do It Yourself

Over the last several years, there has been increasing recognition within the industry that climate change is an important issue, but few formal models or options were available for assessing climate change risk. Lacking external support or guidance, many risk professionals made ad-hoc adjustments to their existing catastrophe models. Sometimes these adjustments were aimed to match results from GCMs or academic studies (e.g., a decrease in all building elevations to represent greater storm surge extents), while other adjustments were arbitrarily defined for exercises such as stress tests (e.g., a 25% increase in the frequency of all U.S. landfalling major hurricanes).

There are significant challenges with this approach, including limitations on how well the appropriate model components can be accessed and adjusted in a way that is consistent with the published climate change literature. This issue can be material, in some cases producing directionally incorrect loss change results. One example of a possible pitfall arises when conditioning the change in U.S. hurricane wind risk, where users might want to adjust a model to match projected changes in maximum lifetime intensity (a metric commonly used in the scientific literature). Given that this metric is often unavailable for a user to adjust in a catastrophe model, the user might instead modify landfall intensity, but the discrepancy can result in a projected decrease in loss across the Northeastern U.S. rather than an increase. This type of apples-to-oranges consistency error is a crucial difficulty with the do-it-yourself method of climate conditioning catastrophe models.

In general, do-it-yourself climate conditioning places an onus on the user to interpret the published literature in an appropriate way, and to correctly generate all the different future climate views that might be necessary. These requirements can be time-consuming and cumbersome.

Climate-conditioned single events

This approach takes a close look at how a well-known event might look if it were to occur in a climate change-altered future. This analysis can make sense for some perils; for example, it can be conceptually useful to model the impact of a past hurricane under heightened sea level rise assumptions, as this would represent how the same event would play out in a world with higher sea levels. For other sub-perils, the interrelationships between physical components can be complex, such as hurricane wind intensity and the radius of maximum winds. It is just as critical to capture these interrelationships in a climate-conditioned model as it is in the baseline model.

Essentially, the climate-conditioned single event approach is analogous to stress testing a single event. It can provide a compelling or intuitive snapshot view of catastrophe risk in a climate change future, especially for non-specialists. However, businesses do not typically make decisions or build their view of risk based on single event outcomes in today’s climate unless there is probabilistic information attached, such as identifying the event as a 1-in-100-year loss, given the full distribution of events that could feasibly impact a portfolio. Therefore, it is difficult for a business to use information based on single-event outcomes for a future climate scenario. Climate conditioning single events is probably best applied as a narrative tool and is less useful as a standalone approach.

Climate-conditioned event sets

In this approach, risk professionals take an existing event set and adjust the frequency assumptions to match a future climate state. Most often, GCM projections are used to derive targets for the components of the climate system that are relevant for a particular peril (e.g., extreme rainfall, frequency of major hurricanes, or maximum windspeeds at a location).

This approach assumes that event types that would occur in a future climate state are similar to those that occur in the present day. This assumption is generally reasonable, since most climate change literature does not suggest that basic event behaviour will change beyond the realm of what could occur today. For example, attribution studies suggest that climate change influenced events such as Hurricane Harvey, could have plausibly occurred in the pre-industrial era when the climate was cooler and unaffected by human activities, albeit with a lower probability. In summary, in the near- to medium-term we think that climate change will affect the likelihood of such extreme events, rather than giving rise to completely new event types.

In some cases, however, the assumption that a climate change-altered future will not hold entirely new event types may be incorrect. Some examples are the poleward migration of tropical cyclones such that storms could be sustained at higher latitudes than current models account for, or if sea level rise raises the maximum extent of storm surge to levels where there is an entirely novel risk to some previously safe location. If this issue becomes material, the climate-conditioned event set approach would have to be augmented to account for novel event types, as described below.

Creating new event sets to represent the future climate
If climate change gives rise to entirely new event behaviour, for example in a more extreme climate scenario, it may be desirable to generate an entirely new event set that is more representative of the expected peril behaviour. This approach is well-suited for analysing highly complex phenomena such as coastal flood under changing sea levels.

Custom-building a novel event set in this manner is highly resource intensive. It is time-consuming for both the creator and the user, because a new event set will require users to rerun losses.

The novel event set approach generally gives users the freedom to customize how they adjust events (for example, dialling up hurricane windspeeds). The downside to this capability is the possibility of adjustments that are unrealistic, internally conflicting given physical relationships between hazard parameters (e.g., hurricane intensity and size), or that are not reflective of the scientific consensus. Because of these pitfalls, many users appreciate vendors doing this work for them, or at least providing pre-defined event sets that reflect a validated interpretation and model realization of the relevant scientific literature.

A major problem that arises in the novel event set approach involves calibration. Climate-conditioned models that build on an existing event set have a baseline calibrated to current losses, which the industry considers a vital step for ensuring models are fit-for-use. Because new event sets are specific to a future climate, it is difficult to calibrate them against historic claims. It is unclear how to appropriately compare a baseline view calibrated to today’s climate with an uncalibrated future climate view. In particular, any observed changes in loss could be due to climate change—or to differences arising from calibration. For this reason, having a common baseline event set for both baseline and future climate change views can desirable.

Hybrid approaches
Approaches can also be a hybrid of the above. For example, a climate change conditioned hurricane model could adjust frequencies in an existing event set to represent changes in wind and track characteristics of storms, but also generate new storm surge footprints for these events to capture the effects of sea level rise.

Q: What are the key principles that underlie all these approaches to cat modelling? What should risk professionals think about when choosing a climate-conditioned catastrophe model?

Use robust, consensus-based climate change projections
Appropriate projections will generally come from groups such as the IPCC or from major literature reviews. Many groups are interested in how climate change will affect extreme weather events, and there are many areas of active debate. When trying to draw real-world conclusions, with lives, property, and money on the line, it is especially important to be careful of “hot topics” where conclusions are not yet settled.

Decide whether prescription or flexibility is more important
There is an inherent trade-off between baking predetermined assumptions and views into a climate-conditioned model and giving a user flexibility to make their own adjustments. A model that prescribes a particular view, such as an assumption about how much hurricane frequency will change, means that the modelers have ensured that all the dials are adjusted consistently and accurately, for example accounting for correlations between variables. However, if a user disagrees with that assumption, they may not be able to adjust the model.

Offering risk professionals the flexibility to make their own adjustments may appeal to more sophisticated users. However, this flexibility can cause confusion or create problems if a user does not understand the implications of a particular change. Increasing regulatory requirements may also add pressure for models to include prescribed views that cannot be adjusted.

Transparency
Models should not be "black boxes." Any built-in adjustments and assumptions should be clearly stated. If there is flexibility to adjust variables, the implications of doing so should be made obvious.

Range of future climates
Allowing risk professionals the flexibility to examine a range of time horizons and future climate scenarios is useful, especially to help them comply with various standards in the industry such as NGFS or TCFD. Accommodating these standards is likely to become a standard requirement.

3.5. Approaches to risk assessment in the absence of commercially available catastrophe model?

In the absence of full climate conditioning, a suitable approach has been developed, which is reflected in Lloyds Thematic Review into Catastrophe Modelling and Climate Change and is considered standard practice in the absence of a suitable catastrophe model, this approach is outlined below.

When modelling the impacts of climate change on future losses, the typical approach is to utilise a climate-conditioned catastrophe model, in which the event set used by the model is tuned or re-simulated to reflect the conditions of a future climate scenario, as reflected in section 1.5. By applying climate conditioning in this way, a catastrophe model can produce loss values for a given year and future climate scenario. However as previously indicated above, climate conditioning is a difficult, time-consuming process, as the development of new event sets requires the running and calibration of complex physical models, alongside the extensive validation of results. In addition, models may have to be adjusted to handle new, considerably large events in a realistic manner, which is a complicated process, governed by a multitude of local and regional conditions. As a result, climate conditioning is not always readily available for a given peril or region.

In the event that full climate conditioning is unavailable, the typical approach used is to adjust or uplift loss and risk values using established scientific literature, as highlighted by the 'Do It Yourself' approach in section 1.5. Using this method, the final output from a catastrophe model (Event Loss Tables, Average Annual Loss etc.) is scaled/uplifted by a set value(s) determined via scientific research. This is achieved either by applying adjustments uniformly to all events regardless of severity, or via a scale, in which only the largest loss events receive the largest adjustments, and less severe events receive a progressively smaller adjustment. However, as reflected above, this approach only allows for the adjustment of existing, present-day events, rather than allowing for new events unobserved under present-day conditions, while failing to consider that some events will scale uniquely in severity under future conditions. Despite this, until full climate conditioning is available for multiple perils globally, and under a variety of climate scenarios, simple adjustments and uplifts represent a useful tool for determining approximate variations in future risk and loss.

https://www.lloyds.com/news-and-insights/risk-reports/library/catastrophe-modelling-and-climate-change-report

4. Use Cases

Typically, the board of an insurance company would approve a climate risk model for use in a particular context, which could include e.g. disclosures, regulatory stress testing or internal decision making. The table in Section 4.1 sets out a non-exhaustive list of use cases relevant to the insurance industry, alongside high-level guidance on how climate scenario analysis of both transition and physical risk might inform these.

In order to have a well defined set of use cases that provide meaningful insights it will be important for companies to clearly define the objectives of each use case, along with the required metrics, scenarios, time horizons and granularity for each. Section 4.2 sets out some practical considerations around the scoping and implementation of use cases.

Finally, in Sections 4.3 and 4.4 we present two case studies of use cases where physical risk scenario analysis and modelling play a leading role.

4.1 Indicative use cases for insurers

Table 1: Indicative use cases for insurers

Typical business owner	Use Case Description
Finance, Risk, Sustainability	**1. External disclosures** – to enable companies to meet regulatory disclosure obligations, including TCFD, climate value-at-risk and portfolio alignment metrics, such as implied temperature rise (ITR).
Strategy, Investments, Underwriting, Sustainability	**2. Climate ambition setting and external commitments** – to help inform the setting of climate ambition targets and performance against these, including the analysis of required management actions.
	3. Sectoral analysis – to inform investment strategy, asset allocation and exclusion policies and sector statements, as well as risk appetite.
	4. Credit analysis – to inform credit assessments, ensuring that proposals adequately consider outcomes of climate scenario analysis where relevant, including at location level for physical risk impacts.

Life Underwriting, Actuarial	**5. Life and health insurance underwriting assumptions** – to understand and quantify the relationship between climate risk drivers and base assumptions.
Non-life Underwriting, Actuarial	**6. Underwriting, pricing and risk appetite framework development** – to understand the impact of physical risk scenarios (the "climate-conditioned" view) on general insurance liabilities and whether further granularity in the risk appetite framework might be required (e.g. through limits/exclusions).
	7. Uninsurable physical risk assessment – this is a specific case of use case 6 above, where companies could use physical risk models and scenario analysis to understand the potential future patterns of perils such as flooding, and their impact on a company's longer term underwriting footprint and strategy.
	8. Reinsurance structuring – to help inform (through the longer-term climate conditioned view) the level and structure of reinsurance needed based on the systemic manifestation of climate risk (e.g., severe physical risk scenarios coupled with severe market stresses). .
Risk Management	**9. Stress testing in corporate and financial planning –** to understand the impact of climate risk drivers on existing business planning risk drivers, but importantly to help shape a house climate scenario and assess its impact on the business plan.
	10. Single name and portfolio level risk appetite – to ensure climate risks are adequately considered when setting single risk exposure caps and portfolio level risk appetite metrics.
	11. Own Risk and Solvency Assessment (ORSA) - to understand the potential impact of climate risk drivers on a firm's solvency position.

The use cases highlighted in Table 1 above are illustrative and do not constitute an exhaustive list. Use cases 1, 2, 6, 8 and 9 are examples of high priority uses given the requirement to comply with regulatory and external disclosure requirements (including SS3/19, PS21/24) , whereas #2, #4 and #11 could be seen as medium priority with a medium term time horizon for development and #5 would be low priority and with a medium to long term time horizon. Prioritisation of use case development according to criteria agreed by the multiple stakeholders across the business will be important to focus development efforts and the required investment.

4.2 Considerations for scoping and implementation

Once the use cases have been identified, the next step is to scope the requirements for each use case which will then inform the desired outputs from the climate model. These requirements include the specific metrics, scenarios, time horizon and granularity.

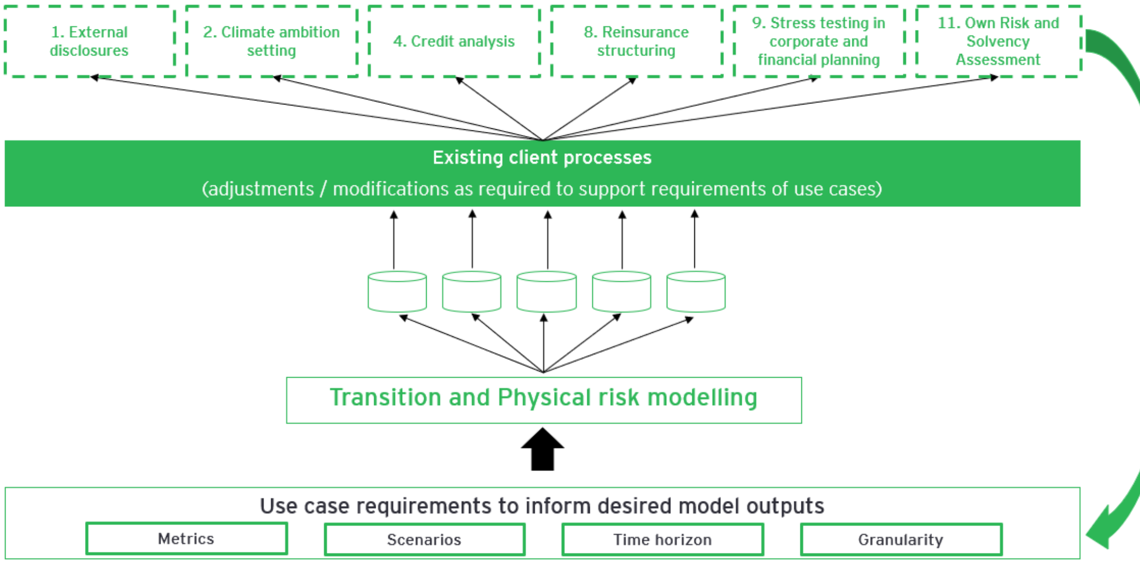


Figure 4: Use case design

For example, for the climate ambition setting use case, the metric needed might be a carbon reduction percentage under a net zero scenario, with a time horizon of 30 years, at a granularity of global region/country. Whereas, for stress testing in corporate and financial planning, the metric could be climate-adjusted asset values over a shorter, say 4-year time horizon, under a house climate scenario.

Once the use case requirements have been established, they will serve as inputs into the modelling process to ensure the model outputs are fit for purpose for the specified use cases.

The next step would be to adjust the raw climate model outputs such that they can be integrated into the company's existing processes. It is likely that some modifications will be needed to support the requirements of the particular use case being implemented. For example, if a company’s existing climate model produces projected CO_2 emissions tonnage as the output and the use case needs an annual carbon reduction percentage, there would need to be some transformation of the current output.

The process is cyclical as shown in Figure 4 above.

Scoping process example

Use Case #9: Stress Testing in Corporate and Financial Planning

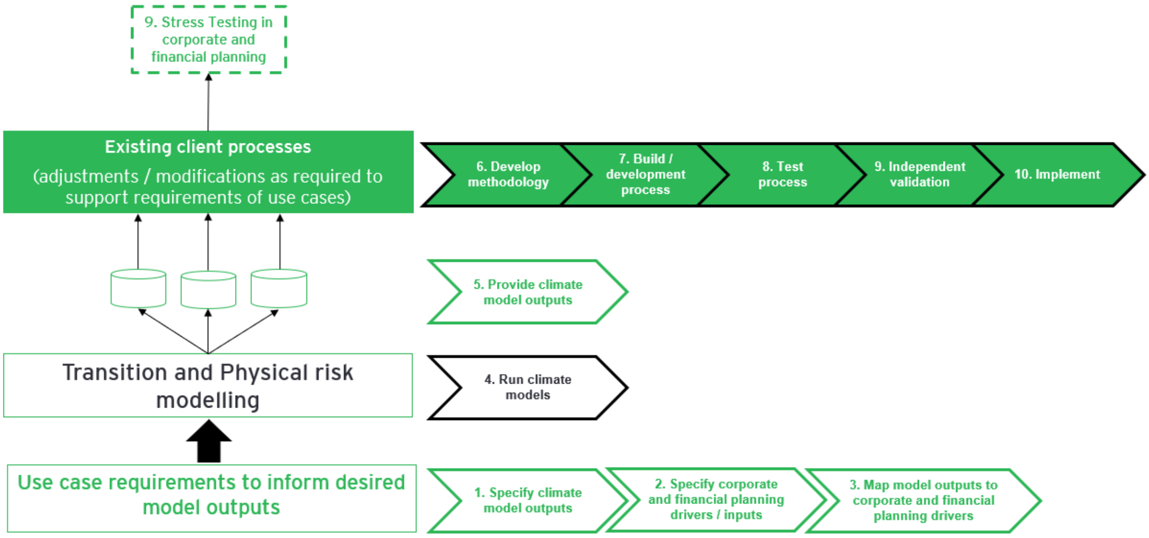


Figure 5: Use case scoping – Stress testing in corporate and financial planning

The diagram above provides an example of the steps to be taken when scoping a particular use case. The main steps (from the bottom up) are:

- Use the use case requirements to inform model outputs
- Run the transition and physical risk climate models
- Produce climate model outputs
- Modify existing client processes to support the requirements of the use case

Expanding on the first step listed above - to establish the use case requirements and model outputs, it is necessary to:

1. Specify the outputs required from the climate risk model (both transition and physical risk components) e.g. carbon taxes, GDP, unemployment, real wages, inflation under the specified climate scenarios.

2. Specify the drivers or inputs that would impact corporate and financial planning. This would include working alongside the company's chief economist to understand the macroeconomic variables such as interest rates and inflation that feed into the business plan. Similarly, it would be useful to engage the demographics team to identify assumptions such as lapses and mortality that might be required to stress the liabilities side of the balance sheet.

3. Map the model outputs to the corporate and financial plan drivers to identify which model outputs are needed for this use case.

   For some it will be quite clear e.g. yield curves are an input into the business plan and climate-adjusted yield curves are produced by the climate model.

For others the link is less obvious e.g. how does climate impact lapse rates in the life underwriting context?

a. determine a relationship between lapse and climate-adjusted macroeconomic variables such as GDP, unemployment and wages

b. Once this correlation is established and validated, the client's existing assumptions setting process would need to be enhanced, tested, and potentially independently validated before being implemented into the wider business plan stress testing process

It is critical to clearly define the specific use case requirements and one shouldn't underestimate the effort it takes to integrate the climate models and outputs into existing client processes.

4.3 Use case example – Reinsurance arrangement structuring (RSA)

We can use scenario analysis to consider stressed events in a number of ways, and by varying the gross loss from our exposure to understand the most appropriate way to structure reinsurance.

Flood catastrophe modelling can be complex, but using historic events as a basis for analysis and then stressing the outcomes can give insight that is valuable but also easy to communicate to stakeholders. Similar analysis can be used to assess storm losses, where climate change is expected to increase severity or frequency of landfall for events.

The example below considers flood losses generated from the Desmond, Eva and Frank storms of 2015. The chart below shows daily rainfall over the three month period and peaks of claim activity that relate to the storms.

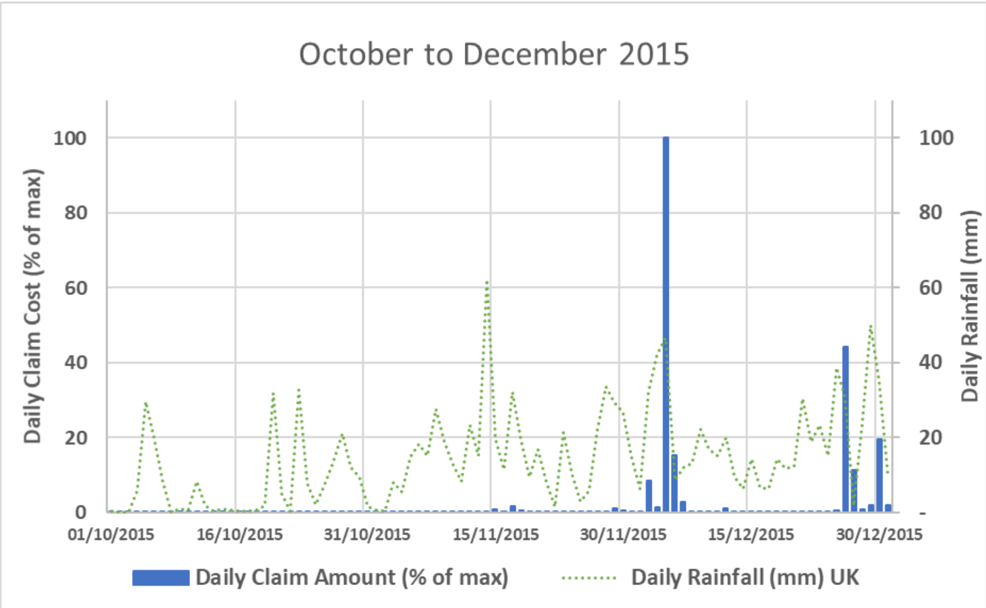


Figure 6: Flood losses generated from the Desmond, Eva and Frank storms of 2015

There is a build up period of rainfall that led to river swelling and increased ground saturation. The month of December included three events, with one substantial peak of losses.

To consider the impact of climate change, the risks are that flood events become more extended, become more severe or both, as storms become slower moving and carry more moisture. Using past experience as a basis is one approach to considering the impact of these more severe events.

The graphic below demonstrates one example of an extended duration flood event based on that real experience. The second and third month are duplicated, based on December 2015, to create both an extended pattern of rainfall and additional claim peaks. Claims experience has also been increased by 20%.

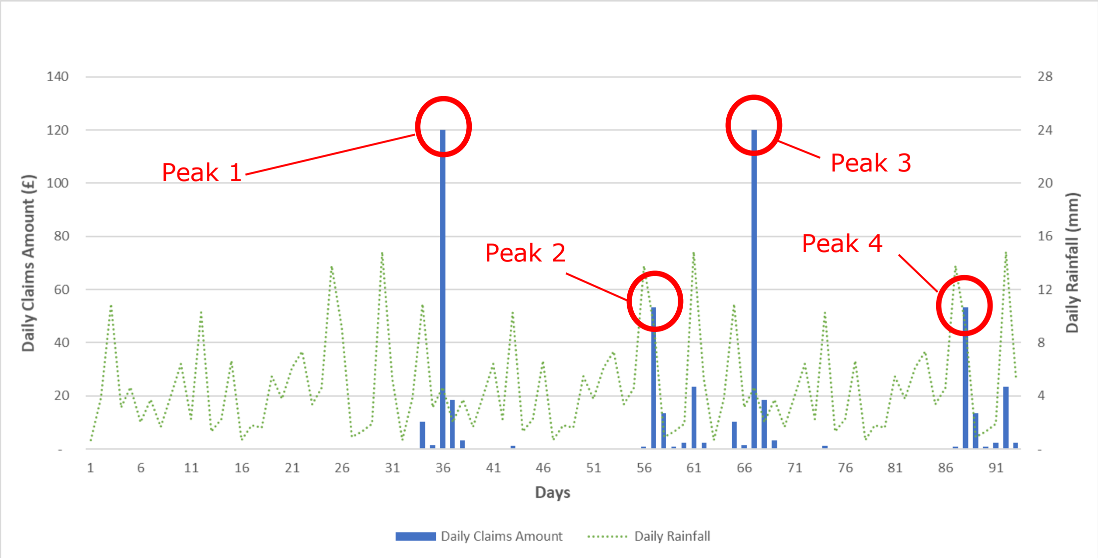


Figure 7: Example of an extended duration flood event

We have highlighted four peaks under the new scenario for simplicity in the explanation.

Given the initial peak, (Peak 1), we might expect an excess of loss programme to provide a response. The understanding of programme cost when purchasing lower layers of cover is important, but also appetite for absorbing profit volatility.

The second largest peak (Peak 3) is now part of a more extended period of losses. There are two considerations here. The first is the hours clause that defines the event, how this is triggered by the first occurrence of loss and the duration of the hours clause. Is it possible under the current wording to collate losses from Peak 2 through to Peak 3 to be considered as one event? Does the hours clause restrict the definition of this event, and how would this impact on recoveries?

Assuming that another event is defined as at least as large as that associated with Peak 1, the second consideration is reinstatement provision. A cost-benefit of pre-agreed reinstatements needs to allow for sensitivity to increasing likelihood of multiple events. The options include pre-paid reinstatements, which mitigates the risk of exposure, but with an upfront cost attached. Pre-agreed terms with the treaty provider which result in additional but known costs at the time of an event remove the potential impact of market conditions at the time of purchase.

The final peak, Peak 4, comes after two more significant events and may not reach the attachment point of a conventional excess-of-loss treaty. An aggregate loss or stop loss treaty would provide additional protection against this kind of sustained loss experience, but these can be very expensive and a have a significant impact on long-term profitability of the portfolio. Understanding the value to the business of these protections should allow for stresses as well as historic experience historic experience, and sensitivity to future trends in loss duration and severity.

4.4 Use case example – Accumulation risk management (DLG)

There is an increased underwriting and reinsurance risk arising from climate change. The CBES results showed that insurers' projected UK general insurance losses in the "No Additional Action" (NAA) scenario were highly geographically concentrated. Just 10% of four-digit postcode districts accounted for two thirds of the total increase in annual UK retail insurance losses in the NAA scenario. For the 5% of postcodes most affected, the increase in average annual losses is 548%. There is an undeniable benefit to improving the management of geographic exposure to accumulation risk.

Identifying the sources of accumulation risk

In order to identify the source of accumulation risk, the firm must first identify its key drivers of physical risk. The firm can then use model outputs to identify geographic areas which are driving the firm's reinsurance and capital costs.

Windstorm

Past loss experience / forward looking physical risk modelling can support the production of heat maps e.g., for average annual loss contribution to extreme windstorm risk by UK postcode area. This can be compared to corresponding maps showing annual average reinsurance recoveries to windstorm risk by postcode area. Any patterns should reflect typical damaging storm tracks / footprints. Using these footprints, accumulation zones can be set up e.g., containing areas in one, two or more of the damaging storm footprints. Controlling accumulation in these zones is key to controlling the main source of the firm's catastrophe risk. Then, the capital model can be utilised to understand how exposure growth in these zones impacts standalone catastrophe risk. At this stage the firm should consider underwriting KRIs that relate to Risk Appetite guidance e.g. working through what % increase in exposure would reach limits for Group Risk Appetite guidance. Metrics which consider total exposure in these regions, or a risk weighted exposure measure would be suitable KRIs to monitor.

Flood risk

At a general level, there are certain areas where accumulation risk is more concentrated, however, the risk may be much more localised and becomes less coherent as granularity increases. It is useful to link these regions to known river systems i.e. identify river systems responsible for a reasonable proportion of catastrophe risk and associated floodable postcodes to assist with the creation accumulation zones and suitable KRIs. For example, flood maps could be used to identify which of these postcodes are in the 1000-year flood extent to more accurately identify individual postcodes contributing most to catastrophe risk.

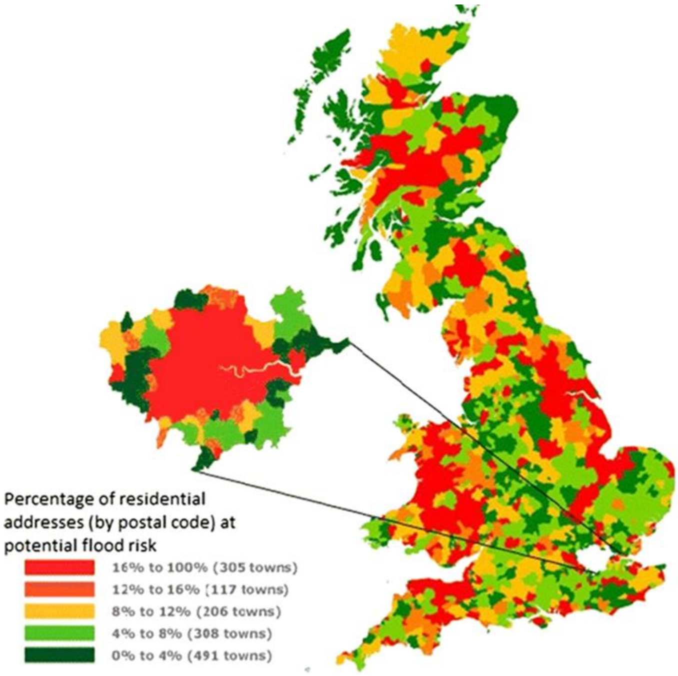


Figure 8: Map of potential flood risk by postcode area[18]

Linking Underwriting Decisions to Catastrophe Risk Appetite Guidance

The capital model can be used to assert how much exposure would need to grow to reach amber and red status for each risk appetite statement. Consideration would need to be given to the weight of the different drivers such as windstorm and flood risk in the contribution to each statement. Suitable KRIs should be created to track exposure (rebuild values) in the accumulation zones which are giving rise to the risk. These KRIs should be split across relevant business areas, taking account of the relative contribution of loss per unit of rebuild value (high rise properties for example have lower risk relative to their rebuild value).

Whilst ensuring that Group Risk Appetite guidance is unlikely to be breached, active accumulation management can also help control any

[18] https://www.researchgate.net/figure/Around-5-million-UK-population-currently-live-in-potential-flood-risk-areas-in-England_fig1_316179962

planned loads for weather events, capital costs and reinsurance costs. By linking exposure growth in the accumulation zones to weather related loads and reinsurance costs, it can be considered at what point the relevant business areas would want to take action if these metrics increased. For example, a business area might become concerned if an increase in exposure resulted in increased costs (weather related load plus reinsurance costs) from either flood or windstorm which moved the loss ratio by more than 0.5% and want to ensure the loss ratio does not increase by more than 1% without additional scrutiny.

Climate Modelling can allow refinement of accumulation zones to better reflect future catastrophe risk, particularly for flood, and targets and limits could be set for each accumulation zone. This could enable a better understanding of the contribution to weather related loads, reinsurance and capital costs of the business a firm writes, and further optimise the written business through this additional lens. In refining the accumulation zones and improving catastrophe risk management, there may be a need to build in specific underwriting controls.

As risk models are refreshed, consideration should be given towards the increased risk from climate change for the relevant models and these changes should be reported through the relevant oversight forum / committee. While current risk appetite needs to be articulated, it should be identified what forward looking indicators can be measured/monitored to help ensure that the firm remains within appetite and/or that the appetite remains appropriate. Climate scenario modelling may identify additional accumulation zones, such as those more at risk from rising sea levels and accompanying storm surge risk, as well as inland and surface water flooding. Reinsurance purchase needs to be reviewed alongside the underwriting controls to optimise the use of capital whilst remaining within appetite.

5. Physical Risk Modelling of Life Insurance Liabilities

In the recent past, most of the focus in relation to climate assessment has been driven by most material risks - focusing on stressing transition and physical risks on Life Insurer's Assets and physical risks on General Insurer's Liabilities. However, it is not the case that other risks are immaterial. For example, climate risk could also have an effect on demographic and underwriting assumptions used by the Life Insurance industry; while these were not covered in the CBES exercise, there is a great deal of emerging research on these topics, and it will still be important to be able to quantify just how material they are for individual insurers.

In this section of the guide, we explore previous literature on physical risk on the liabilities for life and health insurers and suggest a framework that can be used to model this risk.

5.1 Literature Review

Table 2: Literature review summary

Title (with link), Author & Publication Date	**Summary**
Every breath we take: the lifelong impact of air pollution Royal College of Physicians Royal College of Paediatrics and Child Health February 2016	This report sets out the dangerous impact air pollution is currently having on the health of the UK population. It also highlights the impact of poor air quality in homes, workspaces, and schools. A number of major reform proposals are offered setting out what must be done to tackle the problem of air pollution.
Projections of temperature-related excess mortality under climate change scenarios Antonio Gasparrini, PhD et al. November 2017	This study collected global temperature and mortality data over a 32-year period and generated current and future temperature series under four scenarios of climate change. Results indicate, on average, a net increase in temperature-related excess mortality under high-emission scenarios. Furthermore, this study shows the negative health impacts of climate change that, under high-emission scenarios, would disproportionately affect warmer and poorer regions of the world.

The Lancet Countdown on health benefits from the UK Climate Change Act: a modelling study for Great Britain Prof Martin L Williams, PhD et al. May 2018	This study combined various models, inventories and associations between concentrations and health outcomes. Four scenarios were used that focused on the air pollution implications from fine particulate matter, nitrogen dioxide and ozone. The modelling infrastructure created will help future researchers explore a wider range of climate policy scenarios, including local, European, and global scenarios.
Hot and Bothered? How climate change might affect UK longevity Club Vita July 2018	This paper discusses how climate change and resource constraints might impact UK longevity. Three climate change longevity scenarios are introduced that pension schemes can use in stress tests of their funding plans. These scenarios, together with consideration of other risks such as covenant and investment risk, can help pension schemes introduce the issues of climate change and resource constraints into their risk management framework.
A Practical Guide to Climate Change for Life Actuaries David Ford, Bradley Ashton, Kyle Audley, Marjan Qazvini, Yixuan Yuan, Yvonne McLintock November 2019	This paper: 1) describes the linkages between the roles of life actuaries and the implications of climate change for these roles 2) discusses how life actuaries can allow for climate change in their work 3) identifies regulatory and disclosure requirements of climate change and how these may change in future 4) proposes approaches and frameworks to directly link climate change considerations into typical insurance risk frameworks 5) considers approaches that are available for climate change modelling that may be appropriate for life actuaries 6) sets out some specific considerations, and the challenges, specific to linking the implications of climate change to demographic modelling.

Climate Risk Analysis for Life and Health Insurance Companies Didier Serre, FSA, MSc June 2022	This paper: 1) discusses the current challenges with climate risk analysis 2) outlines how to model climate risks in practice for life and health insurance liabilities with a particular focus on physical risks 3) outlines how to communicate and disclose uncertainty in climate risk analysis
Over half of known human pathogenic diseases can be aggravated by climate change Camilo Mora et al. August 2022	This article carries out a systematic search for empirical examples about the impacts of ten climatic hazards sensitive to greenhouse gas emissions on each known human pathogenic disease. The article concluded that 58% of infectious diseases confronted by humanity worldwide have been at some point aggravated by climatic hazards; 16% were at times diminished. Empirical cases revealed 1,006 unique pathways in which climatic hazards, via different transmission types, led to pathogenic diseases.

5.2 Framework for Physical Risk Modelling of Life & Health Insurance Liabilities

We present below a framework for assessing the climate change impacts on insurance liabilities for life and health insurance companies. Recognizing the uncertainty associated with climate risks notably regarding their timing, frequency and severity, this framework leverages qualitative and quantitative approaches and builds on systems thinking to reflect the interconnectedness of climate risks.

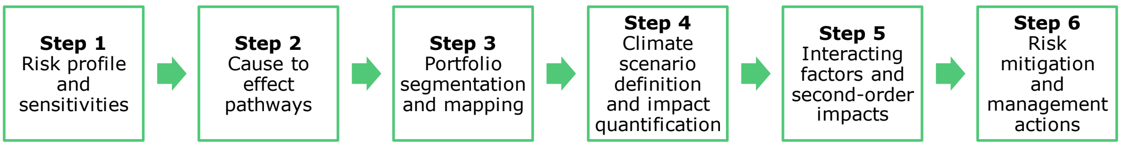


Figure 9: Framework for physical risk modelling of life & health insurance liabilities

Step 1: Risk profile and sensitivities

Understanding the current risk profile and sensitivities will highlight the key financial risks inherent to the nature of the business activities. This can act as a starting point for identifying areas likely to be exacerbated by climate change given the interconnectedness and cascading effects of climate risks onto financial risks and financial drivers. Given that climate risk analysis is forward-looking, it is also advised to consider any changes in the risk profile due to observed trends, upcoming management actions, and/or future strategic planning to work with a more accurate representation of the future risk profile of the business.

Step 2: Cause to effect pathways

With the risk profile in mind, the next step involves researching existing literature on the ways by which climate change can have an impact on your portfolio and increase your financial risks. This is usually referred as cause-to-effect pathways, or transmission channels, which play a pivotal role in developing and later internalizing climate narratives. These essentially consist of linking up climate risk drivers, for example various extreme weather events, to potential financial downstream impacts through a climate risk pathway. While some companies may be familiar with these causal models already, most will require at the very least to revamp prior analyses as new complex pathways emerge and as the predictive power of historical data diminishes. Hence, developing narratives in the context of climate change can be useful in bridging existing gaps, and increasing knowledge of how risks could behave if they materialize. Section 5.1 provides a high-level summary of the existing literature.

Step 3: Portfolio segmentation and mapping

Once knowledge of the cause-to-effect pathways is established, portfolio segmentation can enrich the analysis by linking up climate risk pathways to key portfolio segments. Generally, companies will use segmentation as part of existing business or regulatory reporting practices. For climate risk analysis however, the segmentation might differ as the aim is to select a level of segmentation which can help assess the overall sensitivity of the portfolio to climate change.

Preferably, segments with a higher vulnerability indicator or with larger exposures should be prioritized, for materiality purposes, to guide the assessment of impact in the follow-on step. Each segment should then connect to one or more climate risk drivers and resulting pathways.

Step 4: Climate scenario definition and impact quantification

Defining specific scenarios of interest, focusing on plausible yet disruptive climate scenarios, and agreeing on the selected timeframes provides the foundational overlay for the impact quantification. Again, understanding the narrative behind each scenario is key to ensuring that results are meaningful. Direct impacts should be modelled given available data, which is sometimes provided across the entire impact distribution (at various percentiles). Where data is sparse or not available, semi-quantitative, or qualitative analysis can help to fill in the gaps. The impacts might differ by geography, sector, and should be tailored to each portfolio segment. The prior research on cause to effect pathways will inform the identification and the way in which key model assumptions (e.g., morbidity, mortality, lapse) should be flexed. Because climate risks show up in both chronic (e.g., gradual worsening of climate conditions) and acute (one-off shocks) forms, both impacts should be assessed, alongside the use of potential risk mitigants/offsets. Finally, climate risk analysis should link to key financial and risk indicators.

Step 5: Interacting factors and second-order impacts

Current climate models cannot quantify all potential financial impacts. As such, it is important to research the assumptions and limitations of these models and be familiar with their uncertainties. Where possible, these may be addressed either qualitatively or quantitatively using data adjustments and/or expert judgments. It is key to also consider other (macro)trends and socio-economic, demographic, or migratory changes which can further interact with climate-related drivers, thus compounding their impacts. Given the potential for second-order impacts and knock-on effects, adopting a systems thinking view can enrich the climate risk analysis, especially when dealing with a complex risk with many interdependencies.

Step 6: Risk mitigation and management actions

This step consists of identifying and later prioritizing areas where monitoring should be performed, and knowledge improved. The interpretation of the findings and any subsequent mitigation should consider the direction and order of magnitude of the risk, as well as any observed and likely trends. This could also lead to various risk management actions which can support strategic initiatives and may also include external partnerships to promote risk awareness with public and other organizations.

Ultimately, the goal of climate risk analysis is for companies to move along the maturity continuum and feel more confident making decisions under uncertainty. While this framework is applied on insurance liabilities specifically, it is important for companies to look at other parts of the organisation, and other parts of the balance sheet, using a consistent view. Finally, it is important to realise that there might not be any 'right' number coming from any analysis, instead the value is in the process, and on the continuous refinements over time as knowledge and data increases. Certainly, this framework supports the quantification of the impacts of climate change on insurance liabilities, yet it also relies on internalizing the narratives to reap the full benefit.

5.3 Practical example

This section contains a worked example of the discussed framework for physical risk modelling for a monoline life insurer with annuity liabilities. Steps 2 and 4 have been combined for brevity and to suit this particular example.

Step 1: Risk profile and sensitivities

The largest insurance risk facing an annuity provider is longevity risk, i.e. the risk policy holders live significantly longer than assumed. Longevity extension is likely to be related to climate related changes that happen over the medium to long-term, so it is helpful to understand the sensitivity of the annuity portfolio to changes to assumed future mortality projections. For example:

- A 1% increase to all future mortality improvements might lead to a 5% increase in gross annuity liabilities
- A 1% increase to the long-term rate of mortality improvements (as assumed in the CMI Mortality Projections Model) might lead to a 2% increase in gross annuity liabilities

If the annuity portfolio is closed, as the population ages the liabilities will become more sensitive to changes in mortality rates, hence this should be taken into account when considering long term climate related scenarios.

Steps 2 & 4: Cause to effect pathways, climate scenario definition and impact quantification

To help model the impact of climate change on longevity a driver-based cause of death model can be a helpful tool to turn high level scenarios into quantifiable impacts. These models work by:

- choosing a series of quantifiable drivers (for example, air pollution);
- understanding the relationship of that driver with mortality of certain causes of death. For example, there are studies which have looked at the relative risk of death from respiratory disease from the percentage of a given year where particulate matter is above a certain threshold;
- choosing a "best estimate" scenario. For example, central estimate of how particulate matter levels will progress through time;
- choosing "stressed" scenarios. For example, large increase in particulate matter;
- examining the impact for each cause of death and therefore all-cause mortality for the best estimate and stressed scenarios;
- calculating life expectancy or liability impact of the stressed scenarios using the projections of all-cause mortality.

It would be important that the model allows for frailty effects. For example, extreme temperature may only accelerate deaths of the very frail who were close to death anyway. Using robustly calculated relative risks of death (rather than using spikes in death numbers on hot days) will help model this appropriately.

The scenarios considered can be defined and sized relative to the IPCC representative concentration pathways (RCPs) or from a scenario provider such as NGFS. In particular, the following scenarios might be typical of those selected for modelling:

i) An early action world in which warming occurs but is limited to less than 1.5C. It causes milder winters but does not lead to dangerously hot summers. CO2 emissions are drastically reduced and a concomitant benefit of that is an improvement in air quality due to reduced release of particulate matter. Furthermore, there is wide scale adoption of healthier lifestyles that feature plant based diets and exercise associated with cycling or walking to work.
ii) A no action scenario in which warming reaches 4C such that summer heatstroke becomes an important new cause of death. At the same time particulate pollution gets worse causing higher mortality from respiratory disease.

Under these scenarios, we would identify our drivers as:

- Air Pollution (measures of particulate matter or ozone)
- Average temperature (or days above/below threshold temperatures)
- Measures of levels of exercise / healthy eating

Armed with how these drivers impact mortality rates of different causes of death, one can estimate the impact of each scenario on the overall mortality of the portfolio, relative to a suitably chosen baseline.

Step 3: Portfolio segmentation and mapping

Whilst in one sense climate change scenarios are fairy universal in terms of impact on the portfolio (e.g. we all experience heat waves), there are a number of considerations relating to the composition of the portfolio:

- It is well documented that high deprivation urban areas experience higher morbidity and mortality relating to poor air quality, hence scenarios relating to air quality could consider this
- Typically, older populations and those with existing health conditions will be more at risk to extreme temperature changes or changes in air quality

Step 5: Interacting factors and compound effect

It would be important in such a model to consider the compounding effects between drivers qualitatively if not quantitatively due to over complicating the model. For example, improved air quality and positive behavioural changes could have greater impact than the sum of the assumed standalone impacts.

Step 6: Management actions / climate adaptation / strategic initiatives

Key to the robustness of this modelling framework is regular literature reviews in order to ensure the correct list of drivers in the model, refine the relative risks of each driver, and to ensure scenarios considered are suitable and representative of potential outcomes.

6. Physical Risk Modelling of GI Assets & Liabilities

6.1 A consistent approach to climate change assessment for general insurance Assets and Liabilities

What is the risk to my asset portfolio from natural perils today? How is that risk going to change with the impacts of climate change, and how quickly? What is the impact on asset valuation going to be? How might I change my portfolio risk profile over time? These are all questions that portfolio managers today are having to grapple with for internal reporting and the increasing pressures of regulatory reporting. The good news is that the insurance liability side have been modelling natural catastrophe risk for over 30 years and are well equipped to answer these questions.

Consistent methodology across both sides of the balance sheet is critical to enable identification of which assets are driving the risk within the portfolio and how these will change over time. A clear and consistent framework for assessment of climate change across both sides of the balance sheet facilitates accurate internal reporting, as well as meeting the ever increasing regulatory pressures.

For the insurance Liability portfolios, data has been one of the predominant challenges that has steadily improved over that time. The greatest improvement in data has been seen in the US where high insurance coverage combined with high threat from natural perils has driven the need. On the asset side, data is once again the initial challenge to overcome. However commercial data solutions now exist to help enhance or validate data, or create representative portfolios to enable more appropriate modelling. Once the data issue has been tackled, the tried and tested framework for modelling insurance liabilities can be applied to the asset side leading to a consistent modelling approach across the whole balance sheet.

This section focuses on how the insurance liability modelling framework can be expanded to the asset side of the balance sheet, to assess how the risk from climate change could impact the valuation of an asset.

6.2 Creating a consistent framework for assessment and aggregation of physical and transition risk for insurance asset portfolios

The following flow chart depicts a high-level framework for assessment and aggregation of both physical and transition risk to understand the impact of climate change on the value of any given asset. The focus for this discussion paper is physical risk. Transition risk is a core element to this process but is not considered in detail in this guide.

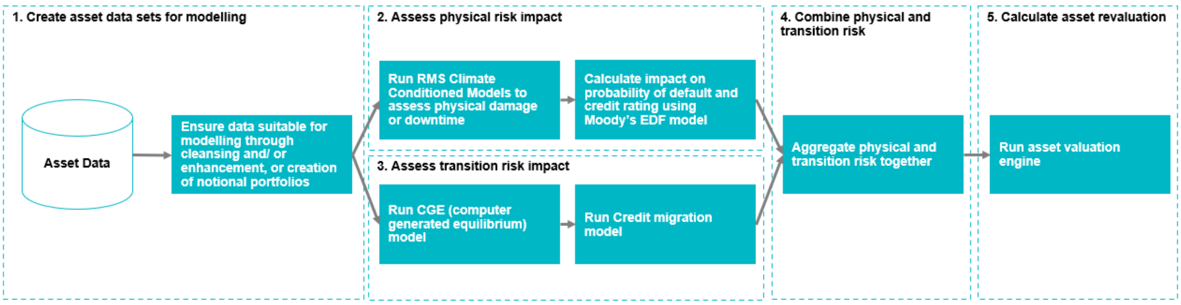


Figure 10: High-level framework for assessment and aggregation of physical and transition risk

6.2.1 Data

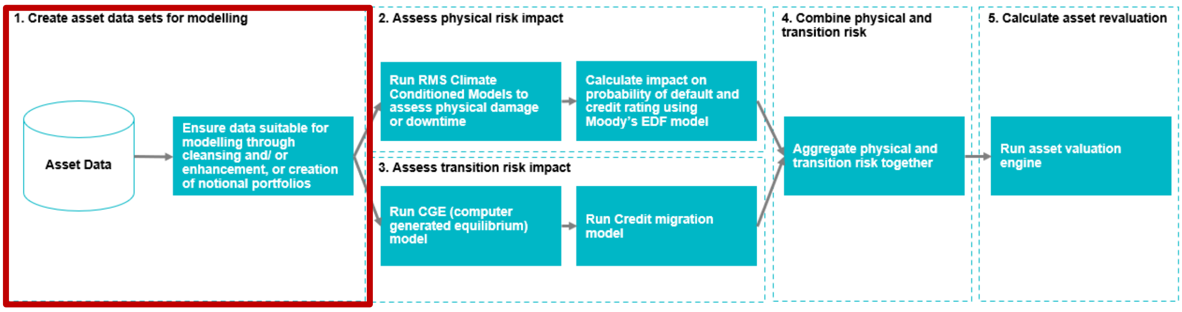


Figure 11: High-level framework for assessment and aggregation of both physical and transition risk – Creating asset data sets for modelling

To fully understand the physical risk to a portfolio, it is critical to understand details of the underlying assets both in terms of their physical location and how that asset will respond to a natural disaster. The impact on valuation of an asset is dependent on the physical damage incurred and/or the length of time of disruption, therefore hazard assessment on its own is not sufficient.

For some asset classes, e.g. investment property, this information may be readily available. However, for most asset classes only some of this information is collected and stored, often in disparate systems, and for others none is available.

Commercially available databases of company information e.g. Moody's CreditEdge database, are designed to populate information for a given corporate if the name or ISIN is listed. For non listed portfolios notional portfolios can be created for modelling. This is discussed below:

A. Physical location of the underlying asset

Location level information is integral to understanding the physical risk to an asset. The more granular the information is, the more accurate risk assessment can be provided. A matter of only a few metres can make the difference between minimal or significant flooding. It is important to ensure that the granularity of the model used is sufficient to define the changing hazard over a given area.

For a corporate, the underlying facilities are often geographically dispersed and therefore subject to a wide range of different natural disasters that are all important to consider when calculating the overall risk. Are your manufacturing plants exposed to increasing flood risk in Europe, or Typhoon risk in Japan? How will the risk for each facility change over time? What are the correlations between each location? What impact does that have on the valuation of the overall corporate?

B. Characteristics of the asset to determine how the asset will react to a peril

Understanding the hazard of a particular location is only the first step to fully comprehending the total physical risk to an asset. The impact on asset valuation will be determined by the damage or downtime incurred, and therefore it is vital to understand how that particular asset will respond to a peril.

Core building characteristics are used to determine how a building will react to a peril. Primary attributes are the building's occupancy, construction, number of stories and year built. Additional details can be populated e.g. first floor height or presence of basements and associated contents, to further refine the building vulnerability to a given peril, in this example flood, although these are less commonly populated.

These attributes are then used to define the level of impact that asset will incur for a given peril. Using hurricane as an example, as the peak wind speed increases, a one-story wood frame single family dwelling will react very differently to a low-rise concrete office building (see12). Each RMS peril model has a comprehensive catalogue of vulnerability curves based on all combinations of primary attributes by region that define the level of damage or downtime incurred by event parameter e.g. for Hurricane by increasing peak wind speed. If attributes are unknown, then an industry inventory is used to define an average value, but with increasing uncertainty as less information is known.

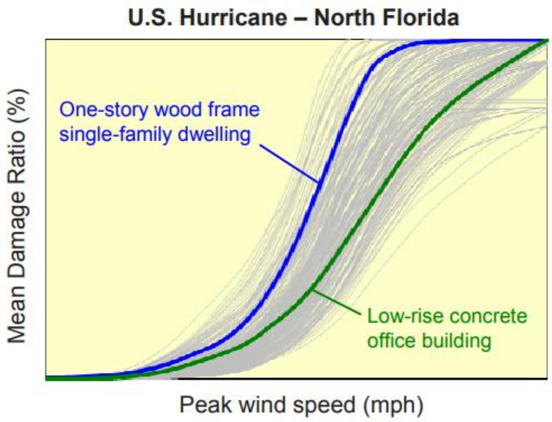


Figure 12: Catalogue of vulnerability curves for North Atlantic Hurricane in North Florida

Building valuation is required if physical damage is to be calculated. Note that models require replacement cost value, rather than new build cost, as this is a representative reflection of the costs incurred and therefore more pertinent when considering the insurance use case. In the insurance industry, there is a big challenge regarding under valuation of properties, leading to larger than expected losses incurred. Building value is very rare when it comes to asset data, but for commercial classes it can be argued that the time taken to come back online is more important that the actual damage in terms of impact on asset valuation. The business interruption can be modelled as number of days per year, without the building value.

C. Assumed insurance cover/ financial structures

In order to understand the exact cost of the physical damage incurred, it is important to understand any financial structures in place to mitigate the impact, and how these might change in the future.

As an asset owner, the concern is the impact net of insurance. Therefore it is important to understand what you are and are not covered for. Some perils, for example flood, are often not insured and therefore damages would not be covered. Under valued properties would potentially lead to losses being incurred that exceed that limit of the insurance terms. When considering the impact on a lifetime mortgages portfolio, the risk of someone defaulting on their mortgage is dependent on the losses they incur vs the amount outstanding on the mortgage. Therefore it is important to understand the underlying insurance structures in place. While assumptions can be made, knowing the exact structures is more accurate.

D. Creating data sets for modelling

Listed companies

For asset classes such as public equity and debt, or collective investment schemes the underlying assets are often identifiable via ISIN. However, more information is often not available and therefore a third-party data source is often required. Multiple third parties can provide this type of data.

By way of example, Moody's CreditEdge database contains address level information pertaining to 10k companies across the globe, with approximately 3 million underlying facility locations associated with those companies. Where an ISIN can be provided, or some form of corporate identifier such as a stock ticker, the CreditEdge database can be used to populate the underlying facility level information to model.

Modelling from the "bottom up" enables aggregation to any required granularity to align with the portfolio. The specific portfolio can be modelled to provide a view of the risk today, or all corporates could be modelled to create a region/ sector level view.

Non-Listed – loans, property portfolios

For assets that are not listed companies, e.g. loans or investment property portfolios, options are available depending on the level of information captured.

If the data set contains address level information, then for some regions, predominantly US, data sets are available to enhance that data. For example the RMS Exposure Source Database (ESDB) is a US dataset that contains attributes for around 80 million residential and 20 million commercial buildings with a focus in high hazard areas. The data is based off tax records, site visits, areal imaging, construction project reports, ownership records, amongst other sources. This data set is used extensively within the insurance industry to validate and enhance the location level attributes for modelling.

If no data is available, notional portfolios will need to be created. RMS Industry Exposure Databases (IEDs) represent peril specific insured residential, commercial and industrial data for specific geographic resolutions (for example postal code or CRESTA zone), covering major insurance markets of Asia, Europe, North America and the Caribbean. The corresponding industry Loss Curves (ILCs) represent modelled views of industry insured losses, supplied with common loss statistics such as Exceedance Probability (EP) metrics and Average Annual Loss (AAL). The exposure or loss data can then be weighted appropriately to represent the relevant asset portfolio.

Infrastructure is a challenge to model well without specific information as to the nature of the exposure. For known assets, physical risk modelling can be very detailed, as would be required for any risk transfer instrument. For example, RMS modelled the New York Metropolitan Transport Association's (MTA) exposure to storm surge, enabling them to accurately price and transfer risk geared to MTA's risk appetite[19].

6.2.2 Assess physical risk impact

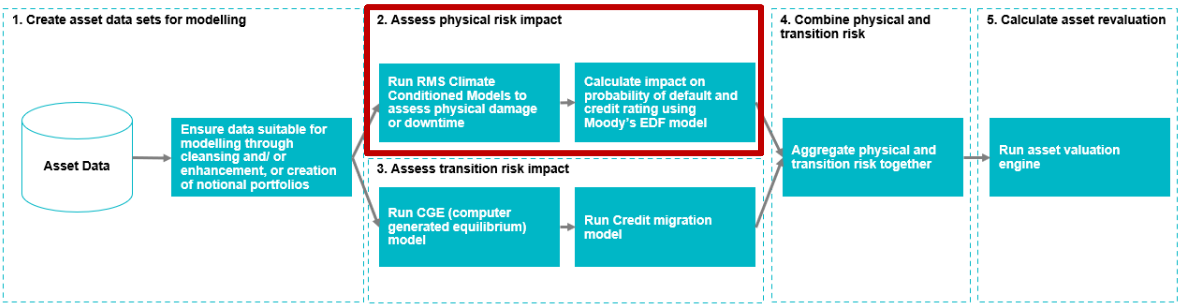


Figure 13: High-level framework for assessment and aggregation of both physical and transition risk – Assessing physical risk impact

When considering the physical risk impact to an asset, there are 2 core steps:

1. Quantify the physical impact to an underlying asset (damage or downtime), and how the impact will change with the impacts of climate change
2. Calculate the change in credit risk arising from physical impacts to the underlying asset and broader systemic physical impacts, e.g. to the supply chain. (This calculation does not consider the credit risk impact arising from transition risk.)

The first step is covered comprehensively in the Assessment Manual section of this discussion document, and therefore is not discussed in detail here. This section will focus on step 2.

A. Listed companies

Multiple vendors provide models for credit risk arising from climate change related physical impacts. A good example of this is the Moody's Analytics climate-adjusted version of its Public Firm EDF (Expected Default Frequency) model. The Public Firm EDF model is a structural model of risk that has been used by global banks, insurers, corporates, and asset

---

[19] https://www.rms.com/blog/2014/02/20/modeling-the-deal-of-the-year

managers for more than 30 years. During that time, continuous updates and validation have shown the model's ability to accurately predict default events in diverse economic environments. The Public Firm EDF model provides a robust framework for understanding the effects of structural climate shocks on corporate credit risk.

To augment the Public EDF framework to account for climate risk, Moody's Analytics has developed a methodology to account for the effect of climate on the underlying drivers of EDF metrics. The climate-adjusted model integrates climate scenarios devised by the Network for Greening the Financial System (NGFS)3 and state-of-the art data and assessment tools from Moody's affiliates RMS, Four Twenty Seven and V.E. (formerly Vigeo Eiris) to forecast the physical and transition risk credit impacts related to global warming.

The Climate-Adjusted EDF models forecast the effect of climate change on firms' financial health as arising from climate-induced shocks on firms' market asset value. These shocks can arise from direct damage to a firm's physical assets or from business disruption that reduces a firm's ability to sell its products. In either case, the current valuation of the firm will be reduced.

The figure below shows an example of the effect of these asset shocks within the EDF model. Consider an acute weather event that occurs with low probability but that causes a large depreciation of a firm's asset value. The weather event shown in the chart occurs in late April during a potential future asset path (from the perspective of January 1) where there happened to be little asset value change during the previous four months.

If the negative shock is big enough to reduce asset value below the default point (it is not in this example), the shock can directly cause firm insolvency. Even if the weather event does not immediately precipitate insolvency, however, the shock reduces the buffer between asset value and the default point. This reduction means that the normal asset volatility the firm experiences over the remainder of the year is more likely to push the firm into default. From the perspective of January 1, therefore, the effect of the additional risk of marginal climate events is to increase the asset volatility of the firm within the year, increasing its probability of default.

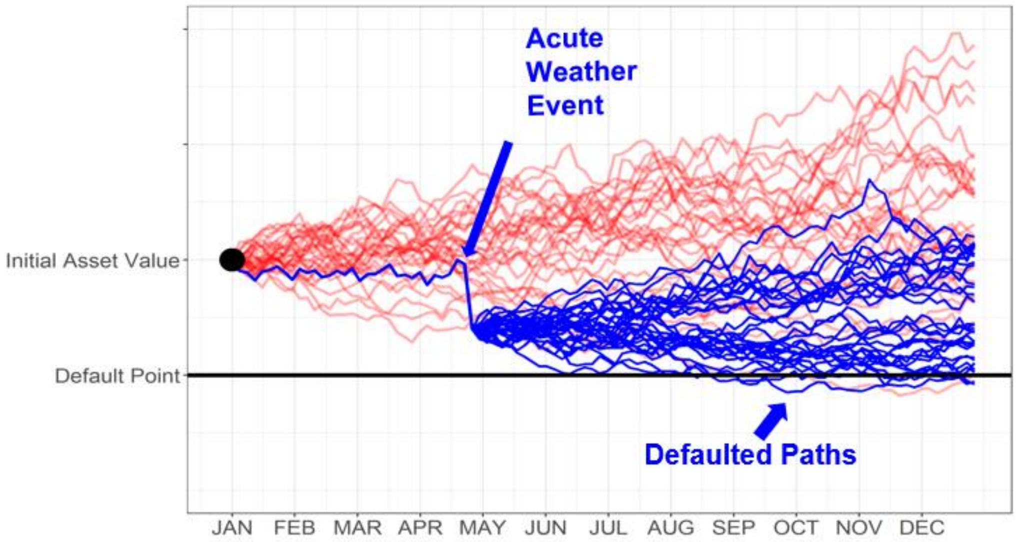


Figure 14: Example of the effect of an asset shock within the EDF model

Once the increased probability of default is known, this can be translated into an expected change in credit rating. Therefore, the output can be consumed in terms of a credit migration or change in probability of default.

B. Non listed companies

The modelling for non-listed companies is dependent on the data available. For these asset classes, the physical risk in terms of the damage or downtime needs to be calculated and somehow turned into the impact on credit risk.

For lifetime mortgages, if detailed data is available about the mortgages, the mortgage data along with the increased physical risk can be run through tools such as Moody's Mortgage Portfolio Analyser (MPA) tool. This will enable quantification of the impact on credit risk from the increased physical risk from climate change.

For investment property, the metric required needs to be determined. Is it the impact on rental income? Or impact to building valuation? Impact on rental income can be directly inferred from the business interruption calculated from the models. For impact to building valuation a house price index will need to be defined to track against.

For different types of loans, again this is heavily data dependent.

6.2.3 Combining physical and transition risk

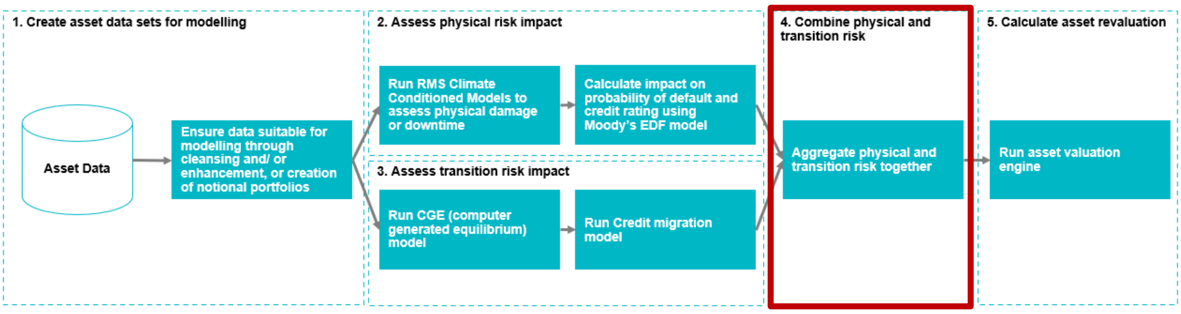


Figure 15: High-level framework for assessment and aggregation of both physical and transition risk – Combining physical and transition risk

The methodology for aggregating physical and transition risk would vary by asset type. For illustration purposes, the below outlines a potential approach for bonds and loans.

For physical risk, the Climate-Adjusted EDF (Expected Default Frequencies) models forecast the effect of climate change on firms' financial health as arising from climate-induced shocks on firms' market asset value.

Whilst the treatment of transition risk is not explicitly explored in this guide, the assumption is there is a transition risk model assessing the impact of climate scenarios on industries and regions.

If the physical risk models and the transition risk models are designed to be orthogonal, this independence will enable firms to better understand the first order impacts of physical risk drivers and transition risk drivers in isolation.

A consequence of model orthogonality is that the resulting dynamics of credit migration (i.e., credit rating state) driven by physical risk and those driven by transition risk are independent random variables.

The importance of this construct is that it enables firms to aggregate the isolated physical risk and transition risk drivers so that they can determine the combined probability of credit rating migration in a tractable way.

Firms can obtain a view of aggregated physical and transition risk by combining individual rating migration matrices through matrix multiplication.

A challenge in this approach is how to address the order in which physical and transition risk occurs. Given these uncertainties, a number of plausible approaches exist, which include:

1. taking the average of the two possible outcomes; or

2. assuming that physical risk and transition risk impacts occur simultaneously.

In any event, it is recognised that as this is an emerging field, all modelling approaches will have certain limitations, which should be considered as firms take steps to improve their modelling.

6.2.4 Asset re-valuation

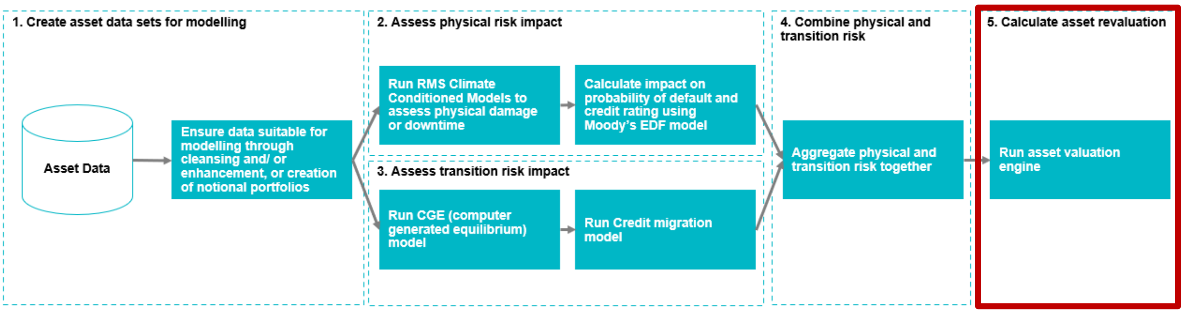


Figure 16: High-level framework for assessment and aggregation of both physical and transition risk – Calculating asset revaluation

The final step in the process would be to arrive at climate-adjusted asset valuations based on e.g. credit migration matrices (in the case of bonds and loans) reflecting the impact of both transition and physical risk as illustrated in Figure 17, above.

We do not go into the detail of this process in this guide as it would follow established methods already explored by firms as part of e.g. their CBES submissions.

7. Conclusions

Given the significant volume of published literature on physical risk modelling and climate change, this guide has set out to consolidate the reference material for the modelling of physical climate-related risks across each area, and outlined the key questions that insurers should ask when assessing physical risks over a longer time horizon. A substantial range of use cases for climate scenario analysis has been made for financial institutions across the market, and this has been supported within the Guide by examples of best practise.

The physical climate-related risks will affect both sides of the balance sheet, and have different materiality when considering the shorter-term liabilities underwritten within general insurance, versus the longer term life and health insurance liabilities. The use of a clear and consistent methodology across both sides of the balance sheet is therefore critical to better understand how these risks interact and change over time, and enable to meet evolving regulatory expectations. We hope the frameworks and practical examples set out within this guide will aid the industry in making tangible next steps in the areas of modelling physical climate risk for life insurance liabilities, and understanding the interaction between asset and liability impacts from physical climate-related risks.

8. Annex

Annex A. Table of Figures

Annex B. Table of Tables