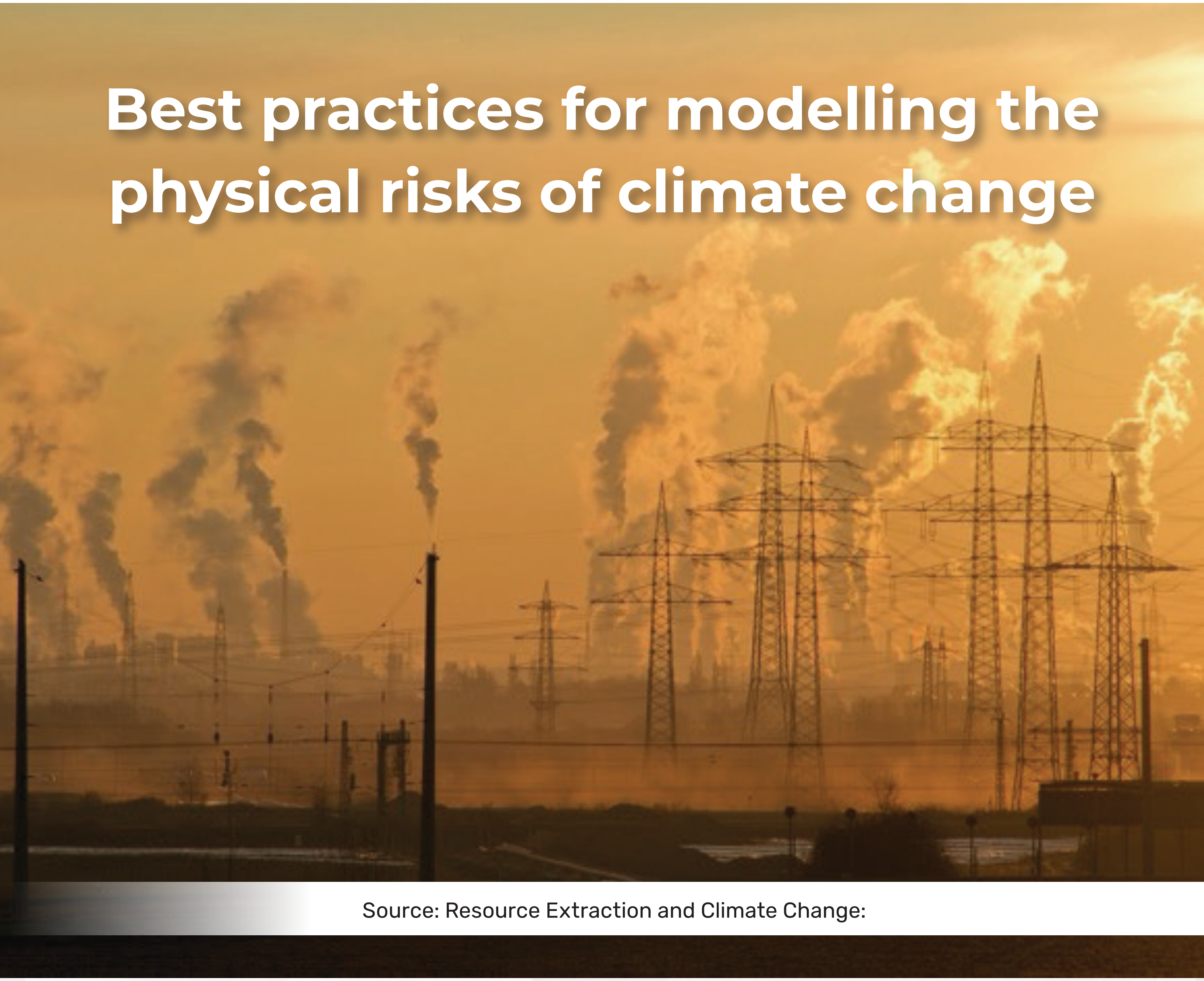
THE LIGHTHILL RISK NETWORK

Catastrophe Resiliency Council

Affiliated with THE INSTITUTES

Best practices for modelling the physical risks of climate change



Source: Resource Extraction and Climate Change:

"Prediction is very difficult, especially if it's about the future."

– Nils Bohr, Danish physicist

Table of Contents

List of Figures

List of Boxes

List of Tables

Authors and Acknowledgements

This report was conceived by the Lighthill Risk Network to not only provide a means for collaboration between industry stakeholders in order to make the best use of available science and limited resources but also to better understand the risks and opportunities for (re)insurers from climate change, with a focus on how best to model weather hazards over future time horizons.

The Lighthill Risk Network is an all-encompassing and inclusive organisation which specifically aims to facilitate and enhance knowledge transfer into business from the academic, government and commercial experts at the forefront of risk-related research. Its members are Aon, Guy Carpenter, Hiscox, Liberty Syndicates, Lloyd's of London and MS Amlin. .

This report is the product of multiple individual and group web-based meetings, desktop research and guidance from the Lighthill Risk Network Steering Group members. The author would like to thank the generous contributions of all Lighthill Risk Network members, as well as other insurers and reinsurers, catastrophe model vendors and industry experts who have patiently listened to his feedback, provided guidance on the topic and assisted with structuring and editing.

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Executive Summary

From extreme summer floods in Europe to tropical cyclones (Hurricane Ida[1]) and exceptional winter weather losses in Texas, 2021 provided further evidence[2] of the role insurers played in bringing financial relief to victims of disasters. It also provided a further grim reminder of the impacts that catastrophes can have on communities, vividly depicted[3] in **Figure 1**.

Figure 1 - German Floods July 2021

Photo: Boris Roeseler/dpa

In July 2021, in Western Germany, the astonishing damage wrought by Storm Bernd to homes and businesses and the destruction of infrastructure, which hampered rescue efforts and contributed to loss of life raised questions about how accurate short-term weather forecasts are when disseminated and what this might portend for public safety in the future. **The reality is that weather events, such as Storm Bernd, will continue to severely impact communities, before scientists are able to establish the extent to which these events are a normal for our new climate.** Hurricane Ian, in September 2022, provided further evidence[4] of the ability of tropical cyclones to carry ever more moisture within a warmer world, bringing hugely intensified rainfall.

(Re)insurers have long voiced their concerns about climate-related catastrophes and use their risk expertise to ensure that catastrophe models provide as accurate, complete and appropriate a view of current risk as possible. They, together with catastrophe model vendors, are constantly learning from these destructive events and incorporating this knowledge into their views of risk. Ensuring that these weather catastrophes are accurately captured allows portfolios to be managed prudently, insurance pricing to appropriately reflect the risk and (re)insurers to be adequately capitalised.

At the same time, a combination of top-down and bottom-up approaches[5] are employed in the supervision of the whole financial services industry in order to understand how longer timescale climate change shocks might batter the balance sheets of banks, insurers and investment funds. This landscape is evolving rapidly, leading to disparate methods and new reporting disclosures. These are being trialled by global regulators and supervisors, eager to raise awareness about the future potential of climate change and to evaluate the systemic risks that would face the global financial system and to ensure their resilience.

While supervisory goals might be different, and not always apparent in the questions asked of (re)insurers, **there is a danger that shifting the onus of determining the level of catastrophe hazard risk away from the risk takers themselves could lead to unnecessary distractions, increased bureaucracy and additional compliance costs. Although serious, the inability itself to meet intended objectives could be a least damaging outcome; the collateral challenge this would pose to the very principles of prudent corporate governance could increase the potential for declarations of insolvency.**

This report describes a framework that addresses both business decision-useful outcomes, as well as providing supervisory bodies with robust outputs that will enable all stakeholders to achieve their respective goals without disrupting existing processes. Depending on the objective, a different set of questions may need to be asked: different tools or methodologies may be required to find the most appropriate solution. **The key to this is to determine the scope of the question. The time horizon should then dictate which tools and methodologies will provide the most suitable answer.** The questions can be tailored to the risk duration of the assets and liabilities being held. There is no one size fits all.

[1] NOAA: NHC Tropical Cyclone Report [2] Munich Re NatCatSERVICE [3] Berliner Morgenpost 4 Climate Signals (2022): Climate change increased rainfall by 10%
[5] NGFS (2021): Progress Report on Scenario Exercises, October 2021, pp6-7

Why is a common approach necessary? Because the increasing demands of shareholders of public companies, as well as **the current lack of alignment in disclosure requests are leading to the wrong questions being asked, using the wrong tools in the wrong way to answer them, ultimately leads to worthless results** that deflect resources away from analysing the potential risks and opportunities faced by (re)insurers.

Financial institutions **<u>are</u>** willing actors in the commitment[6] for increased disclosure, recognising that **"only in creating a market-wide, evidence-backed, comparable and standardised approach on physical climate risk [can] the financial sector be able to price climate risk".** This in turn will lead to greater financial resilience and will enable insurers to provide innovative products to assist with a "just transition"[7] to a green economy.

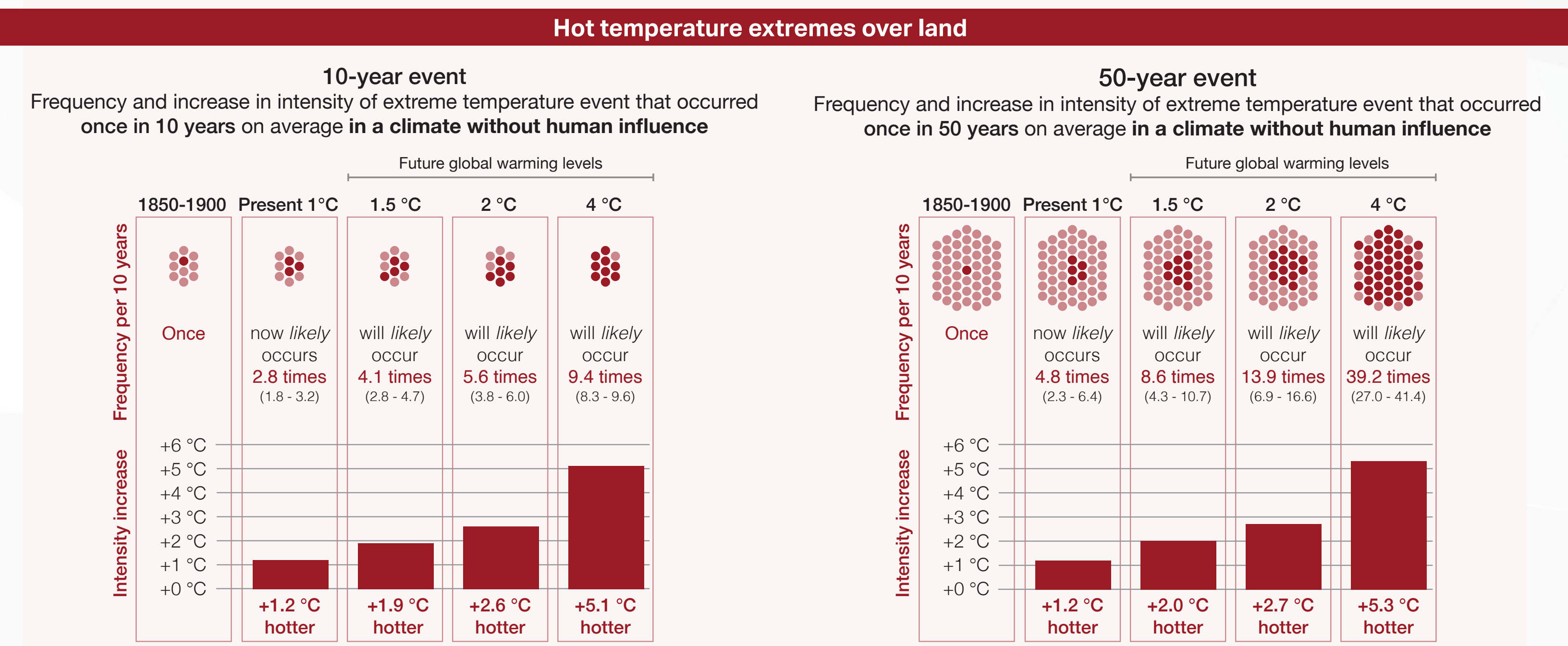
With multiple supervisory methods being employed and driven by this collective desire for mandatory climate risk disclosure, understanding the role of **catastrophe models** in assisting with scenario analysis becomes vital. This report questions whether these tools are fit for the purpose of addressing the interwoven risks of escalating weather losses, population growth, increased coastal and flood plain exposure, urbanisation and efforts to mitigate the impacts of climate change.

In an uncertain world, knowing the boundaries of which inputs can be used without compounding the known uncertainty in model output is key to the evaluation of the financial stability of the insurance sector. Establishing more commonality of approach is an increasingly crucial requirement.

Adding to this urgency, the recent IPCC Sixth Assessment Report[8], highlighted how projected changes in extremes are larger in frequency and intensity with every additional increment in global warming. **Historical return periods for most weather-related events will change. Figure 2**, from the IPCC Summary for Policymakers (SPM.6), illustrates how climate warming changes the return periods of historical heatwaves. In a 2°C warmer world, the 1-in-10-year loss (in this instance a heat extreme) would now occur every 5.6 years; the historical 1-in-50-year event will now likely occur every 13.9 years. Adding to the list of potential attribution events, **the intense record-smashing[9] heat and persistent drought experienced in Europe during summer 2022 has brought increased wildfire losses.**

This report examines what a warmer world implies for the extreme weather perils that concern insurers, and how catastrophe models can be used to estimate these impacts across different time horizons.

Figure 2 - Changes in extreme temperatures



Source: IPCC AR6 - Figure SPM.6

[6] The Physical Risk and Resilience Statement for the Climate Adaptation Summit, January 2021. [7] United Nations (2015): The Paris Agreement
[8] IPCC Climate Change (2021): The Physical Science Basis [9] UK Met Office (2022): Record breaking temperatures for the UK

Catastrophe models are typically designed to estimate the likelihood of insured losses over a 12-months' timeframe. In contrast, climate change projections cover much longer timescales (decades or centuries into the future). As a result, there is a point in time, though, where the value of catastrophe models rapidly diminishes and different approaches are required. One key reason for this is that small changes in hazard can have big impacts on the footprints of future losses, particularly for rainfall-induced events. Adjusting hazard models to reflect changing views of frequency and severity may be essential to ensure that catastrophe models reflect current climate, but they will not be sufficient to capture these fundamental changes in outcomes for longer time horizons.

Actively encouraging changes to catastrophe model inputs to reflect projections of changes in the frequency and severity of weather losses beyond the business planning and strategy cycles (circa 5-10 years) can only increase the uncertainty of model outputs. **Worse than this, providing climate guidance that could underestimate this uncertainty or is simply difficult to adapt into catastrophe models or established modelling processes, might lead to false precision of outcomes[10].**

While insurers are potentially exposed to liability risk (through changes in judicial and litigation environments) and cascading financial risks caused or affected by environmental degradation, as well as transition risks impacting both sides of their balance sheets, **this report focusses only on best practices for modelling the hazards that contribute to the physical risks of climate change in an insurance context.**

The report aims to establish best practices in the use of data, methodologies and tools for the modelling of climate change risk assessment, which can be adopted by all stakeholders to address the risks posed by climate change adaptation. Alignment by industry practitioners, regulators, supervisors, industry associations and rating agencies in these best practices will allow for a more robust and streamlined approach, consistency in qualitative and quantitative analyses. This will enable climate scientists, data providers, industry support services and catastrophe modelling firms to provide standardised inputs that will capture the risks and opportunities for (re)insurers and provide decision-useful outputs.

This report addresses the following themes:

1. Defining the scope to allow for the right questions to be answered which will then show what time horizons and climate scenarios make most sense for (re)insurers to model
2. Reviewing how regulators and supervisors are looking at climate-related financial disclosures
3. Depicting a framework based on future temperature changes that meets the needs of users and regulators
4. Providing examples of best practice for modelling the hazard component of Physical Risk for all stakeholders to follow

Key Findings

- The regulatory environment is evolving rapidly, with new climate-related financial disclosure and reporting obligations being established, which put increasing demands on (re)insurers, especially for those with a global remit.
    - While there is coordination through the International Association of Insurance Supervisors (IAIS) and the Sustainable Insurance Forum (SIF), unless there is harmonisation of approach, the cost of complying with multiple approaches will ultimately spiral and impact the effectiveness of regulated entities.
    - The proposed U.S. Securities and Exchange Commission (SEC) enhancement and standardisation of climate-related disclosure is a significant change and the threshold for financial disclosure reporting could be very onerous on listed companies.

[10] Fiedler *et al.* (2021): Business Risk and the Emergence of Climate Analytics

- The extended time horizons chosen by regulators for climate change scenario analyses have little value to the non-life insurance industry for pricing, solvency or risk assumption. Different approaches are required to measure shorter and longer time horizon impacts of climate change.
- Small changes in hazard can have big impacts in the footprints of future losses, particularly for rainfall-induced events. Adjusting frequency and severity of hazard in catastrophe models to reflect future views of risk may not be sufficient to capture these fundamental changes in outcomes for longer time horizons. However, it is still to be tested whether potential changes like this will outweigh changes in exposure itself.
- Adjusting for "sub-peril" or "secondary peril" losses and uncertainty creates additional complexity; these are amplified beyond useful bounds the longer the time horizon.
- Differences should be understood between Climate Conditioned Event Sets (CCES) and Climate Conditioned Catastrophe Models (CCCM). They are not the same. The former equates to the resampling of existing event sets and would include [usually company specific] changes to frequency and severity. The latter require new events and/or catalogues including new event footprints. However, to fully understand and model climate change, a holistic view of all risks must be taken. It is not just about climate, exposure or policy planning / mitigation should not be viewed independently: it is all three and in equal measure. These "future" Climate Conditioned Catastrophe Models must capture all dimensions, in addition to new events/hazard footprints, alongside how these impact vulnerability to loss, and then they must show how uncertainty is being captured for each component. Climate Conditioned Event Sets should only be used in the analysis of shorter time horizon scenarios.
- Despite the existence of Open Exposure Data (OED) standards[11], there is no industry-wide standardisation of exposure data across assets and liabilities. Opportunities to leverage a standardised reporting format that could feed both asset and liability reporting requirements do exist (e.g. Greenhouse Gas (GHG) Protocol).

Recommendations

- Common approaches in evaluating the impacts of climate change for (re)insurers across supervisory bodies are needed. This would allow more time for resources to be dedicated to evaluating changing hazards and applying them to existing tools and processes. The costs of additional compliance could then be minimised.
- While there does need to be a framework for climate-related financial risk disclosures, there is a danger that being too prescriptive in how to address the hazard component of catastrophe models can allow experts in risk selection and modelling to miss the opportunity to think laterally and fully "own" the risk.
  - Probabilistic modelling works well within existing risk management processes, and aligns with the timescales for solvency and strategic planning.
  - Simplified deterministic approaches for physical risk hazard reporting will provide sufficient insights for longer time horizons, given that the effects of the different Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs) are not distinguishable above natural variability until around 2040.
- In practice, time horizons should be driven by their business relevance as follows:
  - Solvency and budgeting: present-day risk management, which reflects current climate hazards (including natural annual to multi-decadal fluctuations); time horizon 1-3 years, maximum 5 years
  - Business planning / strategy; time horizon 3-5 years, maximum 10 years
  - Medium-term stress testing; time horizon 10-30 years
  - Everything else; horizon scanning into the future: 30-50+ years

[11] Open Data Standards (OED)

- Many feel it would be helpful for climate change impacts to be based on future temperature changes (i.e., 1.5 C, 2.0 C, 3.0 C), which can then be mapped to any SSP-RCP scenario / time horizon
  - Regulators could then interrogate the data to look at whatever RCP scenario they need
  - (Re)insurers could provide just one set of data and at the same time use it for their own in-house view of risk
- There needs to be a better understanding of how catastrophe models can (and cannot) be adjusted, so that all stakeholders are able to get the most out of them.
  - Care should be taken when adjusting for both frequency and severity so as not to overestimate the risk.
  - Some parameters cannot be adjusted in cat models (e.g. precipitation changes for flood models)
  - There are limitations to using models designed to simulate global climate at a local scale. Future scenario analysis should be limited to a few key regions, where there are known significant (re)insurance exposure concentrations, rather than attempting model all areas where (re)insurers are at risk.
  - There is too much uncertainty at the level of granularity required for modelling insurance risk in the future, particularly for sub-peril losses. Regulatory reporting should focus initially on tropical and extratropical cyclone as significant drivers of weather losses, where the peculiarities of site location are less crucial to comprehend future loss potential.
  - Sub-peril or secondary peril losses (explored in more detail in Section 1.5) should be captured within current views of risk; their impact on medium-term and longer-term time horizons should only be catered for in a deterministic and simplified way.
  - Uncertainty needs to be better described by model vendors so that its increasing impact over time can be tested to validate model outputs.
- Metrics should be the same as those used in existing business processes and reporting:
  - Annual Average Loss (AAL) and Occurrence / Aggregate Exceedance Probabilities (OEP/AEP) could be used for short / medium term stress testing
  - Deterministic / plausible disaster scenarios should be used to address longer-term outcomes
  - Reporting timelines should feature two (e.g. 2030 and 2050) or a maximum of three periods ("beyond 2050"); interpolation between them can be inferred without the need to report changes for intermediate years / periods.
- The use of Open Data standards for climate-related reporting on Physical Risks (along the lines of those developed for Transition Risks) should be encouraged
  - Stakeholders should continue to support the adoption of OED and promote the use of the same data for asset and liability exposure reporting.
  - The development of a tool, similar to The Paris Agreement Capital Transition Assessment (PACTA[12]) tool, which provides portfolio-level analysis of Transition Risk in public equities and corporate bonds, and uses asset-level data, should be encouraged for Physical Risk assets.
    - Tools exist (e.g. BREEAM[13] / CRREM[14]) and could be adapted to report fixed assets and liabilities of insurers

[12] PACTA: Paris Agreement Transition Assessment tool [13] BREEAM Sustainability Tool [14] CRREM Carbon Risk Real Estate Monitor

1. Introduction

1.1 Report structure

This report is designed to show how the use of catastrophe models has evolved over the years; how science inputs have framed the discussion on what to expect in the future from climate-related hazards; the accelerating desire for financial disclosure; how the supervisory network is exploring scenario testing and educating stakeholders; and finally, suggest some best practices in applying climate science in catastrophe risk modelling.

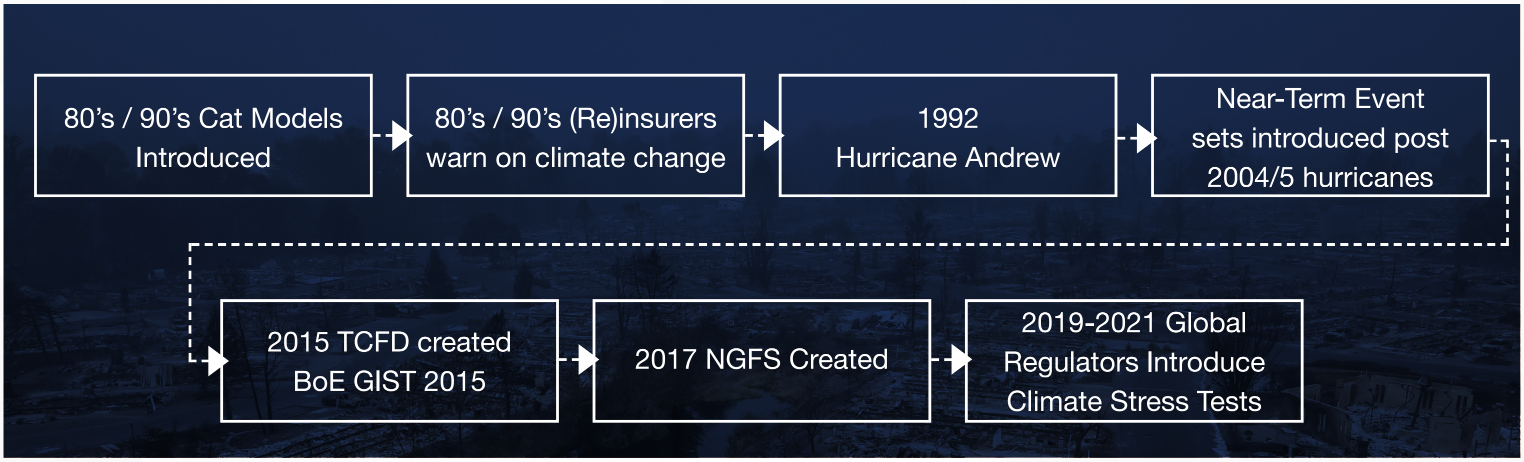
The document is organised in the following manner:

- **Chapter 1. Introduction:** The evolution of catastrophe models, how these changed from focusing on historical data to become tools to help predict future loss activity; the development of financial disclosure framework and insurer actions; an overview of acute and chronic climate-risk hazards; how climate scenarios are being used, often based on future climate pathways, with a focus on the learnings from the latest IPCC Assessment Reports.
- **Chapter 2. Financial Disclosures & Supervision:** A comparison of the evolving nature of climate-related financial disclosure supervision against examples of how some Regulators are beginning to examine Physical Risk exposures of insurers in the future. An exploration of the challenge of understanding the interplay between Transition and Physical Risk, which may lead to large future step-change jolts.
- **Chapter 3. Best Practices in Modelling Climate Change:** Which models are needed to address the time horizons in question, which scenarios to model; deterministic and stochastic solutions are explored; scenarios vs. stress tests are explained and finally, a normative risks-based approach is compared to using exploratory scenarios.

1.2 Evolution and use of catastrophe models

The timeline in **Figure 3** shows the evolution of notable events in the journey from catastrophe model introduction, how events have influenced their application, how climate-related financial disclosures are becoming established and finally, to how some regulators are today attempting to leverage catastrophe models inputs for climate change stress testing analysis.

Figure 3 - From Catastrophe Models to Climate Stress Tests



For many years, the insurance industry has been monitoring and warning of the effects of climate change and what this might mean for policy holders, investors and society at large. A spate of European windstorm losses, from the UK Great Storm of 1987, and clusters of storms in 1990, forced a rethink in terms of pricing and coverage for insurers and reinsurers.

The drive to better comprehend how geographic location and portfolio composition, as well as key components such as construction, occupancy and age all had differing impacts on insurance loss, and provided the momentum for the rapid adoption of catastrophe models. Pricing, aided by the increased transparency and differentiation that the models provided, quickly moved to exposure-driven rather than the "burning cost" approach of yesteryear.

Hurricane Andrew, which slammed into Dade County, Florida on 24th August 1992 as one of only four Category 5 tropical cyclones to ever make landfall in the United States, was one of the defining losses in the history of insurance. Its legacy, which included better understanding of where property exposures were located, the adoption of catastrophe models, the reestablishment of the Bermuda property catastrophe market and ultimately the birth of alternative reinsurance capital, continues today[15].

Following Hurricane Andrew, there was a lull in major insurance loss activity until the late 1990's, when winter storms Anatol, Lothar and Martin decimated large swaths of western Europe, rekindling discussions on the potential for the clustering of storms. However, it was only following the active hurricane years of 2004/5 that **the industry recognised that a new era of increased cyclone frequency required a fundamental reset in exposure management and industry pricing.** The catastrophe models vendors responded by providing users in 2006 with the option of using a "near-term" event set for the forthcoming five years, based on the known increase in sea surface temperatures (SSTs) and how these are a major driver of hurricane intensification.

This became the seminal change in thinking: rather than relying on historical data and looking backwards to derive price, now the intent was about the prediction[16] of future loss activity. While some actors continued to suggest this change in frequency was the consequence of climate change, others saw this as part of multi-decadal and/or other natural seasonal variations in weather, such as El Niño-Southern Oscillation[17] (ENSO).

Understanding and evaluating the risks and opportunities from climate change and how to model them is still in its infancy though and presents new challenges, not least as the time horizons are way beyond the usual business or strategic planning cycles used by general insurers. All the while, the protection gap between economic and insured losses has been increasing. For example, Swiss Re estimated[18] the economic losses from all natural catastrophes in 2021 totalled USD 270 billion, while only 40% of this (USD 111 billion) was insured.

Supervisory efforts have been keen to ensure that (re)insurers really understand how catastrophe models work, and, if they licence them from third-party providers, there is a documentation trail showing that they "own" it by describing the design and operation of the model. The Association of British Insurers assisted with the publication of a guide[19] to managing catastrophe models as part of an Internal Model under Solvency II.

Catastrophe modelling vendors have made enormous strides over the last 30 years to address gaps between actual losses experienced and the losses being modelled. It is challenging though, and expensive, to build and release new catastrophe models that capture enough of current-day climate risks.

And herein lies the problem. If the trend in climate change began in the mid-70's and models have been built on data from around that time, that would infer that, with the time to build, test and release a new model, **even the latest version of a model is based on data that cannot reflect current climate.** Harder still, and a trap that model vendors and regulators could fall into, is to understand whether the changes in catastrophe models adequately capture the changes in extremes. **Adjusting for known changes in the mean (e.g. winter rainfall) is easier than focusing specifically on the extremes, but it will not capture those events that will result in catastrophic losses.**

[15] Hurricane Andrew and Insurance: The Enduring Impact of an Historic Storm [16] Clark, K (2009): A review of the Performance of Near-Term Hurricane Models [17] What is the El Niño-Southern Oscillation (ENSO)? [18] Swiss Re sigma No1/22 [19] ABI 2011: Industry Good Practice for Catastrophe Modelling

1.3 Regulation and Financial Disclosures

Meanwhile, from a regulatory perspective the Financial Stability Board (FSB)[20], established in 2009 by the G20 countries as a successor to the Financial Stability Forum (FSF), created the Task Force on Climate-related Financial Disclosures[21] (TCFD) in 2015 to "promote more informed investment, credit and insurance underwriting decisions" that in turn "would enable stakeholders to better understand the concentrations of carbon-related assets in the financial sector and the financial system's exposures to climate-related risks".

The TCFD recommendations were released[22] in 2017. Subsequent to this, various government-sponsored initiatives were spawned that span the US Financial Stability Oversight Council[23] (FSOC), the Network of Central Banks and Supervisors for Greening the Financial System[24] (NGFS) and the Sustainable Insurance Forum[25] (SIF), amongst others. These networks have encouraged their respective Regulators (who set the rules and guidelines) and Supervisors (who examine and evaluate them), to explore the assets held by banks and insurers, not least as the threat from Transition Risks was seen as more urgent and, to an extent, easier to define.

Impetus for climate-related financial disclosures is accelerating, driven by threats to the global financial system from Physical and Transition Risks **(Box 1)** that are the consequences of a changing climate. The definitions of these climate-related risks have formed the basis for their disclosure across the financial services industry. This report will concentrate on the Physical Risks and how these can be modelled.

Box 1 – Climate-Related Risks

Physical Risks
- Acute – Event Driven
  - Changes in frequency and severity of weather events, such as cyclones, floods and wildfires
- Chronic – Longer-term
  - Shifts in climate patterns

Heat / Cold waves
Sea level rise
- Changes in geographic areas impacted

Transition Risks
- Policy & Legal
  - Limitations to / Increased pricing of GHG emissions
- Technology & Innovation
  - Products no longer used
  - Costs of transitioning
- Reputation
  - Change in customer behaviour
  - Investor action
- Market
  - Increased cost of raw materials
  - Change in interest rates or market price of invested assets

From a supervision perspective, the focus has shifted from examining just the asset risk from Transition Risk to examining the Physical Risk liabilities of (re)insurers as well, beginning with a dialogue of qualitative assessments. The Bank of England (BoE) has been a leader in raising awareness, not least in the 2015 "Tragedy of the Horizon" speech[26], where the then Governor, Mr Carney, explained how climate change was beyond traditional horizons of business, politics and supervisory bodies and the window of opportunity to act was finite and shrinking.

This engagement has evolved into more quantitative scrutiny involving scenario analyses, initially with a limited number of industry participants, on an exploratory basis, to inform stakeholders of potential outcomes and is explored in more details in the next chapter.

To respond to these latter requests, (re)insurers have been required to adapt their existing procedures to interpret these demands and the more specific benchmark variables provided and integrate them into the catastrophe modelling process. Some of these have meant This has sometimes resulted in attempts to adjust hazard model components in a way for which they have not been designed.

Given the challenges faced with trying to adapt the selected variables and consume them in the hazard component of catastrophe models, the purpose of this report is to highlight some recommendations as to how to solve for modelling climate change across future time horizons.

1.4 Insurers and Climate Disclosures

By 2019 the United Nations Environmental Programme's Finance Initiative[27] (UNEP-FI) and the Global Commission on Adaptation (GCA) had come together with banks and investment firms to formally commit to disclosing their risks from the physical risks of climate change. However, it was not until 2021 that insurers joined with them for a call to action to improve this disclosure.

[20] FSB: https://www.fsb.org [21] TCFD: https://www.fsb-tcfd.org [22] TCFD: Recommendations 2017 [23] FSOC: About the FSOC [24] NGFS: https://www.ngfs.net/en
[25] SIF: https://www.sustainableinsuranceforum.org [26] Carney, M. (2015) Breaking the Tragedy of the Horizon – climate change and financial stability
[27] UNEP-FI 2019: Physical Risks and Resilience Statement

Concurrently, shareholders, along with Regulators were seeking greater disclosure from companies as to what exposure existed to both Physical and Transition Risks from their diverse financial and real estate asset portfolios, including their nature and locations. Today, shareholders are actively questioning insurers' underwriting stance on the liability side too, with pressure increasing to withhold new insurance cover for fossil-fuel extraction, which a number of organisations have already done[28]. Many (re)insurers are disclosing how their underwriting actions are evolving, for instance, support of renewables versus fossil fuel extraction.

It cannot be forgotten that insurers play an enormous role in the support of the global economy, without which businesses could not operate nor raise the finance to commence the transition away from fossil fuels. Insurers also play a crucial role both investing in and insuring the new technology and product innovation required to green the economy, as well as ensuring an orderly transition for legacy risks.

Insurers are uniquely positioned for these risks and the opportunities ahead, not least as both sides of their balance sheets are significantly exposed to climate shocks.

In their January 2021 update on adaptation commitments the [now] ten leading financial institutions attributed[29] the delay in the process of adopting financial disclosure to the lack of risk data and standards. They went further, calling for Regulators to:

1. Specify the use of standards for climate-related reporting on physical risks
2. Develop and specify scenario analysis standards
3. Ensure the availability of robust datasets
4. Develop the strategy and roadmap for mandatory climate-related financial risk disclosures

The obvious impacts caused by weather hazards are not the only problem stemming from lack of collective action on the threats faced by climate-related risks. Banks and investment firms have hit the same roadblocks familiar to insurers in assessing their exposures as part of their underwriting process. Capturing information on Greenhouse Gas (GHG) Protocol[30] emissions, particularly those from Scope 3[31], which are derived from indirect emissions through the value chain, is similar to the challenge in capturing risk and location information on business interruption and supply chain risks.

1.5 Climate-Risk Hazards

Climate change will lead to an increase in weather shocks, like those seen in western Germany in 2021. These event driven catastrophes have been referred to as the acute impacts of climate change. Longer term, or chronic impacts, are the irreversible impacts of sea-level rise caused by melting of ice caps, together with the likelihood of cold / heat waves caused by a change in global circulation patterns, also a consequence of Arctic / Antarctic ice extent reductions. These acute and chronic climate-risks can be broadly categorised into water, wind and temperature-related hazards as shown in **Box 2**. The challenge is how to accurately model them for current climate. Even harder then is to determine how best to represent potential outcomes for the future.

Box 2 - Acute and Chronic Climate-Risk Hazards

	Water-related	Wind-related	Temperature-related
Acute	Increased or reduced precipitations: Flood or Drought	Frequency/Severity changes for tropical & extratropical cyclone	Heat or Cold waves: wildfires/freeze
Chronic	Sea level rise Changes in Precipitation patterns	Changes in weather patterns	Biodiversity loss Heat stress

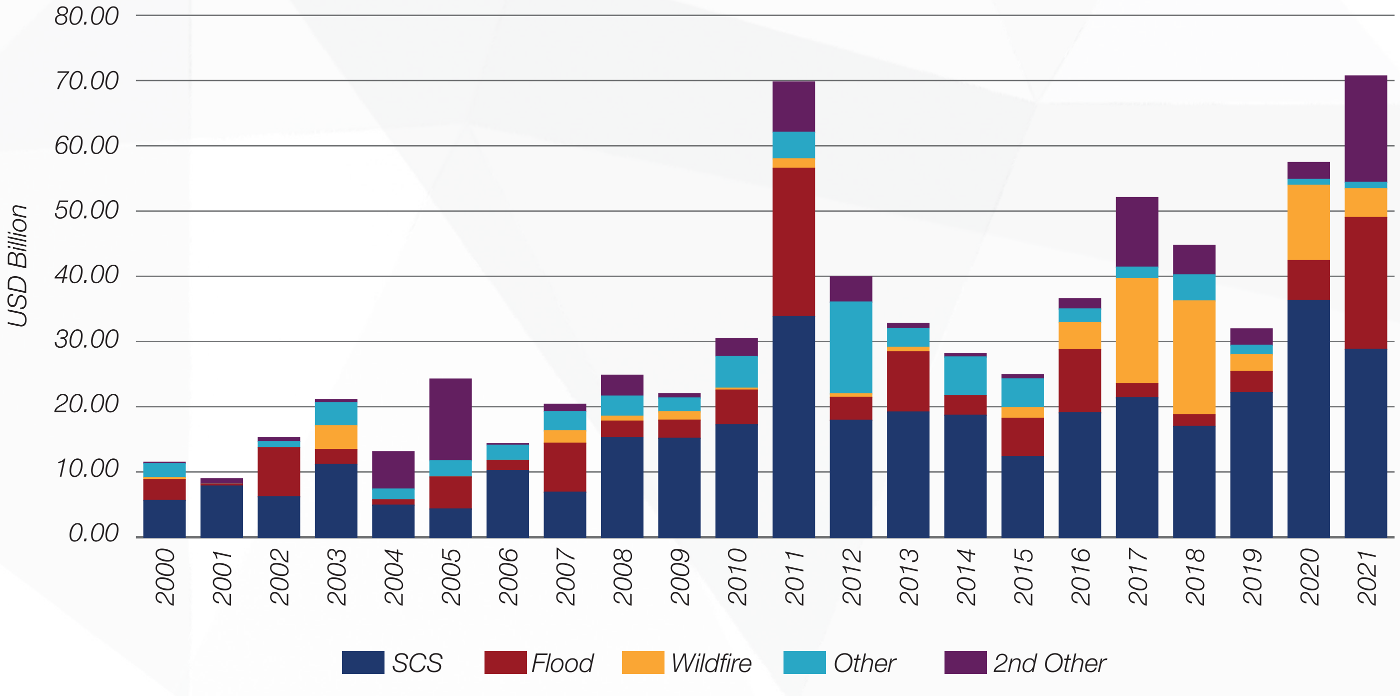
[28] Lloyd's takes action to transition to sustainable economy [29] UNEP FI: Disclosure Update [30] Greenhouse Gas Protocol [31] Carbon Trust: What are Scope 3 emissions?

Over the last thirty years, insurance catastrophe losses have been dominated by tropical cyclones, (interspersed with a few large earthquakes impacting USA, Japan and New Zealand). We know that the characteristics of weather events today is different compared to the past. We have seen an **increase in frequency of sub-peril or secondary peril losses across the spectrum:** from wildfires[32] to flooding to severe convective storms and extratropical cyclones causing unspeakable destruction[33]. Major or "primary peril" events such as tropical cyclones have also seen an associated increased precipitation and consequent flooding.

The physics is simple[34] to explain: a warmer atmosphere is able to hold more moisture due to the relationship between surface temperature and water vapour. For each 1ºC of surface warming, **atmospheric moisture content can increase by 6% -7%; the consequence is more intense and frequent rainfall.**

Providing some evidence for this shift to water-related hazards being on the increase, the chart in **Figure 4**, taken from Swiss Re's *sigma 01/22*[35] . It shows how global insured losses from secondary peril losses (as well as secondary losses from primary perils) has evolved. While there is no clear trend, overall **these secondary perils have represented over 70% of total insured losses for both of the last two years** with fluctuations over the period (when tropical cyclones have been more prevalent). Severe convective storm, flood and wildfire present huge challenges in modelling due to their unique spatial characteristics – for example, the granularity of the area impacted for flood. If it continues to be the case that they represent such a high percentage of overall global losses, it underlines the massive uncertainty that arises when trying to model future climate change scenarios and also underlines why different approaches may be more suitable the longer time horizon in focus.

Figure 4 - Global Insured Losses from Sub-Perils



Hazard uncertainty for tropical cyclone (TC) has been well documented (see Knutson *et al.* (2020) below). We know that the consequence of the increased heat that is forcing sea surface temperatures to rise is creating the potential for tropical cyclones to rapidly intensify. Sometimes, this dramatic intensification comes right up to the point of landfall, without giving time for adequate warnings to be made. This was the case for Super Typhoon Noru, which slammed into the Philippines in September 2022, with peak winds increasing by 100mph in less than 24 hours[36]. In addition, more rainfall, so-called Tropical Cyclone Induced Precipitation (TCIP), is produced.

[32]S&P 2021: As US Wildfire threat grows, capacity shrinks [33]Science.org 2021: Europe's deadly floods leave scientists stunned [34]JBA Risk (2020): The physics of precipitation in a warming climate [35]Swiss Re sigma 01/22 [36] Philippines on high alert as "explosive" Super Typhoon Noru makes landfall

Reed *et al.* (2022), attributed[37] a 10% increase in 3-hourly storm rainfall rates during the 2020 hurricane season to human-induced climate change. Meanwhile, research[38] from Knutson *et al.* (2020) gives a median projected rain-rate increase of 14% for a 2°C warming. This research also described higher storm surges due to sea level rise and increased TC intensity, with a higher proportion of storms reaching category 4-5. By contrast, while confirming this overall increase in global TC rain rate, Tu *et al.* (2021) showed that the inner-core rain rate has actually decreased[39] by ~29% for category 3-5 TCs. While total precipitation and inner-core rain rates are not directly comparable, they illustrate the complexity of providing stakeholders with guidance on what to expect in the future. **(Re)insurers do not have the luxury of waiting for science to concur on the precise impacts of climate change**.

More research is required to understand the likely impact of current secondary perils, but it seems probable that flood (in concert with sea level rise) will become a primary peril, if not the dominant driver of future insured losses. Indeed, Kahraman *et al* (2021) suggest[40] that **slow-moving storms, similar to that which caused the extreme losses in Germany in 2021, may be 14 times more frequent across land by the end of the century.**

Being able to model flood requires far higher precision than, say, extratropical cyclone, where the damage ratio is less likely to fluctuate across a larger spatial area. Flood impacts are binary: neighbouring properties can experience zero to complete inundation. Flood modelling therefore requires the highest level of granularity available and the intensity of any given event is dependent on a variety of factors including topography, flow rates, surface roughness and water depth. Distance to coast / water courses, antecedent events and height above mean sea level can also contribute to dramatically different outcomes as will mitigation strategies, for example, flood defences, how these are likely to change and how their build return period is impacted by ongoing factors such as sea level change.

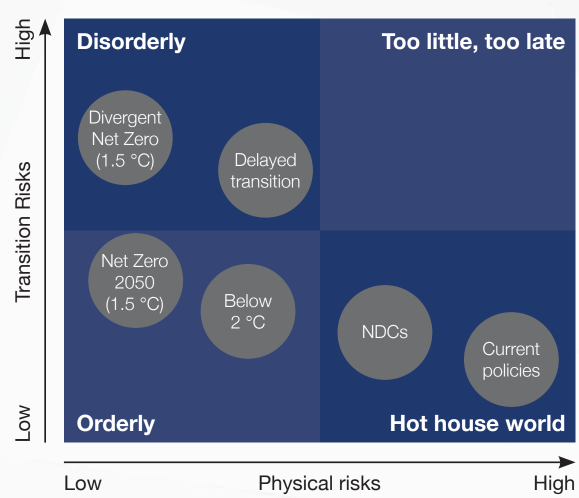
We know there are knowledge gaps in being able to model the impacts of drought leading to increased wildfire risk or flash flood. **The capture of policy changes around infrastructure and flood defences or the vertical uncertainty in digital terrain models or event clustering of intense rainfall on already saturated ground is not yet integrated in models.**

1.6 NGFS Climate Scenarios

Launched at the Paris One Planet Summit in December 2017, the NGFS now has 116 members and was created to provide a common platform for Supervisors to share best practice. Their Climate Scenarios[41], are the starting point for supervisory scenario analysis and provide a common framework to understand not only the impacts of climate policy on CO2 emissions but also what this then means for global temperatures and how this impacts Transition and Physical risks of climate change. The NGFS framework describes increasing levels of Transition and Physical Risk over time. There are six scenarios, with two outcomes for each scenario of **Orderly, Disorderly and Hot House World,** as shown in **Figure 5**.

The "Net Zero by 2050" Orderly scenario translates to limiting global warming to +1.5°C, which matches the goals of the Paris Agreement[42], but requires a combination of stringent climate policies and innovation to be achieved. Delaying, or divergent policy action could still achieve Net Zero by 2050, but this leads to increased Transition Risks, partly caused by a quicker phasing out of oil. **Physical risks increase the most where there is no change in current policies.**

Figure 5 - NGFS Scenarios Framework



Positioning of scenarios is approximate, based on an assessment of physical and transition risks out to 2100.

[37] Reed et al. (2022): Attribution of 2020 hurricane season extreme rainfall to human-induced climate change [38] Knutson *et al.* (2020): Tropical Cyclone and Climate Change Assessment [39] Tu, S. *et al.* (2021): Recent global decrease in the inner-core rain rate of tropical cyclones [40] Kahraman *et al.* (2021): Quasi-stationary Intense Rainstorms Spread Across Europe Under Climate Change [41] NGFS Scenarios Portal [42] COP 21: Paris Agreement

Each NGFS scenario explores a different set of assumptions about how climate policy, emissions and temperature evolve. The scenarios, shown by Risk Type and organised by category, are shown in **Figure 6**. Those with a higher risk are coded in pink.

To assist in understanding what these scenarios mean in terms of impacts by hazard and region Climate Analytics developed the **Climate Impact Explorer**[43] in collaboration with the NGFS. This tool enables users to overlay scenarios used by NGFS, the IPCC and others and see hazard impacts (for example, precipitation, windspeed, river flood depth), down to the province level in all countries and at different levels of temperature increases. Incidentally, this tool was the source of data used by the Prudential Regulation Authority (PRA[44]) for the 2021 CBES exercise, (with the exception of the UK, where a combination including UK Met Office[45] and Oasis Hub[46], as well as NGFS data was used).

Figure 6 - NGFS Scenarios by Risk Type

Scenarios are characterised by their overall level of physical and transition risk. This is driven by the level of policy ambition, policy timing, coordination and technology levers.

		Physical Risk	Transition Risk			
Category	**Scenario**	**Policy Ambition**	**Policy Reaction**	**Technology change**	**Carbon dioxide removal**	**Regional policy variation***
Orderly	Net Zero 2050	1.5 °C	Immediate and smooth	Fast change	Medium use	Medium variation
	Below 2 °C	1.7 °C	Immediate and smooth	Moderate change	Medium use	Low variation
Disorderly	Divergent Net Zero	1.5 °C	Immediate and divergent	Fast change	Low use	Medium variation
	Delayed transition	1.8 °C	Delayed	Slow/ Fast change	Low use	High variation
Hot House World	Nationally Determined Contributions (NDCs)	~2.5 °C	NDCs	Slow change	Low use	Low variation
	Current Policies	3 °C+	None - current policies	Slow change	Low use	Low variation

Colour coding indicates whether the characteristic makes the scenario more or less severe from a macro-financial risk perspective^ — Lower risk / Moderate risk / Higher risk

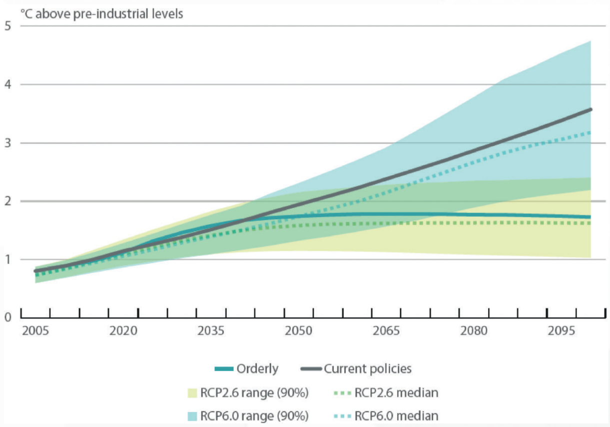
1.7 RCPs and SSPs

To understand how Regulators are using the latest science to guide their supervisory work on the insurance impacts for given scenarios it is important to step back and look at how future climate pathways have been developed and how these could be used to frame best-case and worst-case outcomes. This in turn will allow for a more informed view of potential Best Practices that could be adopted by all stakeholders and create alignment for decision useful outputs.

[43] Climate Analytics: Climate Impact Explorer [44] Prudential Regulation Authority [45] UK Met Office [46] Oasis Hub

Representative Concentration Pathways[47] (RCPs), introduced for the IPCC Fifth Assessment Report in 2014, show the likely GHG concentration levels since pre-industrial times, measured as radiative climate forcing values of increased watts per square metre (W/m2). The four RCPs that were revealed described low to high emissions scenarios (RCP 2.6, 4.5, 6 and 8.5) and included projections of global temperature increases to 2100. RCP 2.6 limits warming to the Paris Agreement's target of well below 2ºC, whereas RCP 8.5 assumes no policy changes to reduce emissions resulting in global temperatures rising by +4ºC - +5ºC. RCPs describe equally likely pathways of future emission and concentrations of GHGs and have no socioeconomic or policy projections included.

Figure 7 - NGFS Climate Scenarios Mapped to RCPs



The NGFS Climate Scenarios can be mapped[48] to RCPs in the following way: the orderly and disorderly 1.5C and 2.ºC are in the range of RCP 2.6, whereas the Current Policies scenarios is close to RCP 6.0. These are shown **in Figure 7.**

NGFS noted that the RCP scenarios were somewhat dated and do not match well with recent emissions trends. Also, neither RCPs or NGFS scenarios incorporated economic damage from physical risks, so ignore feedbacks from emissions and temperature change onto infrastructure systems and the economy.

The March 2022 IPCC Assessment Report[49] (AR6) included a summary from Working Group II on **impacts, adaptation and vulnerability to climate change.** Some of the key messages included:

1. All regions will be affected, with **irreversible impacts more far-reaching than previously thought**, beyond the limits of adaptation
2. Understanding future climate risks requires **modelling not just climate hazards, but also exposure and vulnerability to these hazards;** disclosure of these risks enables a better understanding of them.
3 **Climate change is creating complex, compound and cascading risks;** this "increases the complexity of modelling them, (they) are rarely integrated into climate risk assessments, potentially underestimating the possible financial impacts of medium- to long-term climate change."
4. The **economic costs of climate change will rise exponentially with temperature rise;** mid- to long-term impacts may be multiple times higher than those witnessed today.

AR6 reconfirmed previous projections of anthropogenic induced climate change, noting how the impacts on climate become increasingly large with greater rises in mean global temperatures. This includes increased frequency and intensity of extreme heat events, as shown in **Figure 2** above, precipitation (see **Figure 8** below), as well as droughts and more intense tropical cyclones.

AR6 also introduced new Shared Socioeconomic Pathways[50] (SSPs) that attempt to capture changes in economic growth, population, urbanisation and the rate of technological development. The SSPs themselves have been developed by Integrated Assessment Models (IAMs)[51] that capture these population changes, land and energy-use choices and technology changes as well as economic GDP projections.

[47] IPCC Data Distribution Centre [48] NGFS (2020): Climate Scenario Technical Documentation [49] IPCC's Sixth Assessment Report (AR6) [50] Carbon Brief: Explainer on SSPs
[51] Riahi, K. *et al*. (2017) The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview

The RCP emissions and GHG pathways can be combined with the socioeconomic assumptions of the SSPs to test the response of climate policies. The integration of SSPs and RCPs is shown in **Box 3,** where "SSP2-4.5" shows the middle of the road outcome (SSP2) with a likely pathway RCP4.5. SSP3-7.0 is a combination of a "Regional Rivalry" or un-coordinated socioeconomic pathway approach and the new RCP 7.0, which is seen as a more likely scenario for CO2 concentrations than RCP 8.5.

The projections showing the global surface temperature change relative to the period 1850-1900, taken from AR6 WGII[52] (Figure SPM.8a), for different SSP-RCP scenarios, are displayed in **Figure 9**. The ranges of uncertainty are shaded for SSP1-2.6 and SSP3-7.0 representing the "very likely" range.

Being able to combine policy and socioeconomic conditions with pathways of future emission and concentrations of GHGs provides a significantly more robust baseline against which to measure future climate change. It should enable a more quantifiable low and high scenario against which to measure the range of outcomes. It would also more neatly frame a +/-2ºC warmer world for supervisory efforts to test against, creating a commonality of standards for regulators and insurers to use. It would also provide an opportunity for catastrophe model vendors and the users of their tools to develop more constructive ranges of outcomes.

Figure 8 - Change in Precipitation

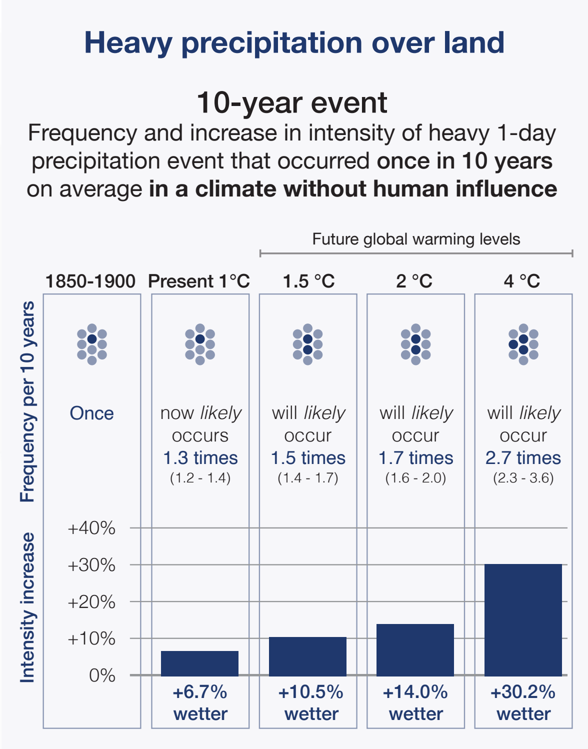
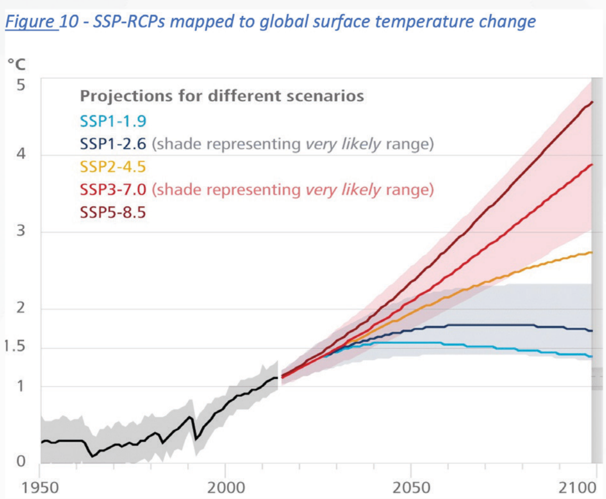


Figure 9 - SSP-RCPs mapped to global surface temperature change



Box 3 - Shared Socioeconomic Pathways

	Near term, 2021-2040		Near term, 2041-2060		Long term, 2081-2100	
Scenario	**Best Est (°C)**	**Very Likely range (°C)**	**Best Est (°C)**	**Very Likely range (°C)**	**Best Est (°C)**	**Very Likely range (°C)**
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP1-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP1-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP1-8.5	1.5	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

[52] IPCC (2022) WGII – Impacts, Adaptation and Vulnerability; Summary for Policymakers

2. Financial Disclosures and Supervision

2.1 Background

Supervision of financial institutions is based on a framework of rules established by global regulators. For (re)insurers, this involves solvency tests and was formulated as part of Solvency II[53] (SII) (or an equivalent requirement for non-European supervisors) with a forward-looking own risk and solvency assessment (ORSA[54]) (or similar regime) and this framework allows for market aggregation and corporate differentiation.

The rationale behind these frameworks is to allow for individual (re)insurers to assess their own risk profile and to ensure that they have sufficient capital commensurate with their business planning time horizon. By its nature, it allows for the development of a robust risk culture and appropriate capital management. The lack of detailed regulatory requirements or written prescription contained within the Level I or 2 Directives "facilitates forward-looking discussion of the firm's risk profile and the capital consequences of potential changes to the business[55]".

Supporting these regulatory requirements are well-established "stress tests"[56] measured against the current and following year balance sheet projections. These have been developed over many years of consultation and stakeholder cooperation and are enshrined in business-as-usual (BAU) workflow patterns established as part of Solvency II[57] and are increasingly being digitalised to streamline these processes.

Stress tests are designed to ensure that insurers keep an appropriate level of capital, with detailed requirements for this to be maintained or for remedial action to be taken should specified hurdle rates not be met. At the same time and as part of the regulatory framework, (re)insurers will have rigorously tested, calibrated, adjusted and documented their catastrophe modelling frameworks.

(Re)insurers need not just to be seen to be owning but also practising their own view of current climate risk in pricing, risk selection and aggregation reporting, right through to the Executive Board. For example, many (re)insurers adjust frequency and/or severity of weather perils to reflect their current view of risk, approved and documented in their Enterprise Risk Management (ERM) process.

Ideally, (re)insurers should produce their own view of what future risks look like too. Performing new stress tests outside of the constraints of the ORSA is counter-intuitive though, as many of the risks fall way beyond the one-year time horizon, which cannot be fully captured in Solvency II capital requirements (and ultimately through their ORSA process). For this reason, many Regulators, including Lloyd's of London, now include longer-term climate stress tests in ORSAs. EIOPA updated their Opinion[58] and "expects insurers to integrate climate change risks in their systems of governance, risk-management and ORSA". This was enacted[59] by the European Commission, **introducing the new Article 45a, where insurers now have to assess the impact of long-term climate change scenarios on their business. Those with material exposure will need to specify in their ORSA scenarios in which "the global temperature increase remains below, or is equal to or higher than two degrees Celsius".**

In order to cement how climate change-related risks can be incorporated into a stress testing framework, **EIOPA updated their guidance[60], explaining that these should be more explorative compared to traditional financial stress testing.**

This approach would seem to align well with the spirit of the ORSA: each insurer should produce their own view of what they perceive the risk to be. This allows for a continuation of self-learning, guided by a principles-based oversight.

[53] EIOPA (2016): Solvency II [54] NAIC (2021): Own Risk and Solvency Assessment Example [55] LMA (2017): Keeping the "O" in ORSA [56] EIOPA (2019): EIOPA-BoS-19/568 Methodological Principles of Insurance Stress Testing [57] Bank of England: Solvency II Regulations [58] EIOPA (2021): EIOPA-BoS-21-217 Opinion on the supervision of climate change risk scenarios in ORSA [59] European Commission Directive September 2021 [60] EIOPA (2022): EIOPA-BOS-21/579 Climate Change Component

2.2 How do Regulators & Supervisors Compare?

Supervisory bodies are beginning to work collectively, leveraging networks such as the International Association of Insurance Supervisors[61] (IAIS), for example, to comprehend how **Transition Risk could affect insurers' assets**, as economies transition away from fossil fuel and carbon-intensive production. The impacts of climate change on **Physical Risks (acute and chronic) and how future balance sheet liabilities** might be impaired over different time horizons for given climate change scenarios has seen an increased focus by supervisory bodies. Not only are they raising awareness of the potential impacts of climate change, but they are also wanting to understand the potential systemic risks to the financial sector as a whole.

Their challenge is how to provide enough of the right sort of guidance to capture their supervisory needs, without narrowing the focus (re)insurers already employ to adjust catastrophe models for non-modelled or not-enough modelled risks. This presents a conundrum of whether a rules-based regime can provide the depth of answers and understanding required. Guidance that does not capture the key inputs required for adjusting catastrophe models could create outcomes that impact the results and which miss the opportunity of providing the insights both regulators and regulated entities need i.e. information that is useful for making business decisions on growth, profitability and solvency.

Research for this report has revealed an increasing global effort by central banks and supervisory bodies, which is summarised in **Table 4** in the Appendix. This summary captures the types of risk being addressed and the different time horizons, methodology and engagement paths for each of the main insurance centres around the world. While broadly consistent in their approach to understand the impacts of climate change on Transition Risks, there are some differences in supervisory requests for details on Physical Risk exposures.

These supervision requests are becoming increasingly complex. Some are more exploratory in nature and therefore open to interpretation, while others are more prescriptive (due to the number of benchmark variables that are provided). Both are resource intensive to complete. Both approaches need to be understood, validated and actioned by (re)insurers, requiring existing tools, processes and reporting to be adapted to be able to respond. This involves the entire Enterprise Risk Management (ERM) process, as well as involving climate science, actuarial and finance roles.

While the precise intent of individual supervisory exercises is not always apparent, these complementary strategies are designed to better comprehend the systemic market aggregation as well as being able to compare and contrast insurers' maturity of approach. Nonetheless, by being too prescriptive, there is a risk of compounding the systemic risk itself, through restricting insurers' ability to comprehend all the potential impacts and the time to "own" the future risks, as they do for current risks. Equally, estimates with large error bars may lead to indecision. North Atlantic hurricane risk, for example, may go up or down, leaving Boards with the easier option of doing nothing, because the uncertainty is too opaque. The drivers of uncertainty need to be clearly understood in order to be able to make informed decisions. This may not always be the case, particularly where catastrophe risk is not a core driver of capital and catastrophe model use may not be such a familiar skill at board level. **A balance needs to be found between accounting for uncertainty and enabling a business to make decisions.**

To achieve their respective goals, there needs to be a better understanding, by all stakeholders, of the sensitivity of changing the parameterisation of general circulation models, of how to consume scientific data and model outputs, with alignment on the future time horizons to consider along with how many and which climate scenarios to model. Catastrophe models are complex tools, with limited options available to (re)insurers to adjust without increasing the uncertainty of outputs. They are calibrated on long-term historical records, so may therefore not fully represent current climate; introducing alternative views of risk across different time dimensions could lead to even greater uncertainty in model outputs. This is without the further uncertainties that human influences introduce such as increasing exposure or local and/or regional law changes.

[61] IAIS: https://www.iaisweb.org

Understanding and evaluating the risks and opportunities from climate change and how to model them is still in its infancy and presents new challenges, not least as the time horizons are way beyond the usual business or strategic plan cycles used by general insurers. Catastrophe modelling vendors have made enormous strides over the last thirty years to address gaps between actual losses experienced and the losses being modelled.

2.2.1 Who's driving the change?

The ambition for climate-related financial disclosures has been driven by government coordination, led by the FSB. The FSB released their roadmap[62] prior to COP26, which covers Disclosure, Data, Vulnerability Analysis and finally Regulatory and Supervisory practices. Further recommendations followed[63] that included encouraging the framework established by the TCFD, promoting the sharing of experiences, increasing coordination across jurisdictions and, where appropriate, increasing third-party verification on disclosures.

Supported by the IAIS, the Sustainable Insurance Forum is a global network of 33 insurance regulators and supervisors hosted by the United Nations that is supporting the adoption of TCFD-aligned disclosures. Their November 2021 report[64] on their implementation highlighted a number of case studies including Japan, Singapore and United Kingdom that illustrated the reach and desire for international cooperation.

In order to understand the complementary and different approaches, the next section provides an overview of some of the actions Regulators are taking in their respective markets.

2.3 Selected Regional Regulators

2.3.1 Australian Prudential Regulation Authority (APRA)

APRA take the view that climate risks and opportunities "can and should be managed within an institution's overall business strategy and risk appetite", so their Prudential Practice Guide[65] (CPG229) did not impose any new requirements to manage climate risks. The onus is on Boards to evidence ongoing oversight and adjust risk appetite accordingly. Suggested scenario analyses should include a short-term assessment following current business planning cycles as well as a longer-term assessment. They suggest using **one scenario of well below 2.0ºC by 2100 and alternatively one where there are no mitigating actions and policies and global warming of 3.0ºC or more is the consequence.**

Their suggestions for best practice include:

- The importance of seasonal data for some risks (compared to annual / decadal data for others)
- Impacts of concurrent and multiple extreme events
- Detail to capture geographic specificity
- Broad range of emissions pathways

APRA has released an information paper on the **Climate Vulnerability Assessment** (CVA) based on work with Australia's five largest banks. Whilst not a prudential capital stress test (there are no capital adequacy components), it is designed to test resilience to climate-related financial risks. The CVA is based on the NGFS Disorderly Transition (RCP2.6 / SSP2) and Hot House World scenarios (RCP8.5 / SSP5), though used different pathways for Physical and Transition Risks. As the initial CVA is for banks, the quantitative outputs are mainly based on credit risk exposure, split between agriculture and non-agriculture lending.

[62] FSB (2021): Roadmap for Addressing Climate-Related Financial Risks [63] FSB (2021): Report on Promoting Climate-Related Disclosures
[64] SIF (2021): Implementation of TCFD Recommendations [65]APRA (2021): Climate Change Financial Risks

Meanwhile, the **Climate Measurement Standards Initiative**[66] (CMSI), which brought banks, insurers, scientists and others together to support the TCFD in Australia, has developed scientific scenario specifications and disclosure guidelines for climate-related physical damage to buildings and infrastructure. Their report made seven recommendations for Australian banks, general insurers and asset-owners covering scenarios, time periods for these and various assumptions on the parametrisation.

They suggested the following data points should be used to assess physical risks:

- Two scenarios (RCP2.6 for 2°C or lower and RCP 8.5 for higher)
- Two time periods: 2030 and 2050
- Static portfolio assumptions; no changes in vulnerability to reflect adaptation or resilience measures
- Sectoral splits:
    - Portfolio commercial/residential
    - By hazard
    - By geographic region
- Annual Average Loss, 1 in 100 Aggregate Exceedance Probabilities (AEP) and Gross/Net 1 in 200 Occurrence Exceedance Probabilities (OEP)

While the focus is purely on Australia, their goal of "**developing open-source technical business and scientific standards for climate physical risk projections of future repair and replacement costs of residential and commercial buildings and infrastructure**" merits further global support. Their recommendations may not be optimum for all stakeholders, but their recommendations warrant further discussion by other regional insurance bodies.

2.3.2 Bank of England / PRA

Initially, the PRA took a similar approach, expecting firms to conduct scenario analysis to inform strategic planning. The PRA issued their Supervisory Statement[67] SS3/19 in April 2019, requesting firms to conduct scenario analyses on both short-term business horizons and longer-term assessments, potentially over decades, with global temperatures consistent with or in excess of 2ºC, with an orderly or disorderly transition to a low carbon economy.

Following the creation of working groups to establish a good practice framework, they published a guide[68] to this framework, including tools and case studies to assist with the understanding of the impacts of climate change. Using expert judgement, hazard maps, footprints and catastrophe models, the report demonstrated how a combination of these could be tailored depending on the data available, what was required as outputs and the needs of users.

The PRA hoped that the measure of success of the report would be to see a movement from awareness to action. However, it accepts (p7) that as non-life liabilities are short-term, **it may be difficult to distinguish the impact of climate change related hazards from natural variability.** Indeed**, the impacts may be dwarfed by other factors, such as interest rate movements, or changes in exposure.**

As part of the process of understanding and communicating the risks of climate change, the PRA along with the Financial Conduct Authority (FCA), established the Climate Financial Risk Forum[69] (CFRF). The CFRF has core membership from banks, insurers, asset-manager and other interested groups. A series of guides (Session 1 and 2) have been produced that capture Risk Management, Scenario Analysis, Disclosure and Innovation as well as a guide to Climate Data and Metrics.

[66] CMSI (2020): Scenario Analysis of Climate-Related Physical Risk for Buildings and Infrastructure [67] PRA (2019): SS3/19
[68] PRA (2019): A framework for assessing financial impacts of physical climate change [69] BoE (2019): Climate Financial Risk Forum (CFRF)

The PRA then moved on from encouraging awareness to more determined action. They launched perhaps the largest and most onerous exercise by global regulators to date: the **Climate Biennial Exploratory Scenario** (CBES[70]), which involved the largest UK banks, life and general insurers as well as Lloyd's of London.

The CBES exercise was prescriptive, but provided the freedom to choose how the three scenarios were implemented. These involved Early Action and Late Action policy scenarios and were primarily designed to explore Transition Risks from climate change. A third "No Additional [policy] Action" scenario was designed to explore Physical Risk impacts, over a 30-year time horizon. To ensure this scenario captured severe physical risks without lengthening the modelling period, the Bank calibrated the 30-year scenario assuming that the more material risks anticipated in the period from 2050 to 2080 occurred by 2050.

The PRA's CBES Early Action scenario maps to the NGFS "Net Zero by 2050" scenario. Late Action maps to Disorderly, while No Additional Action maps to "Current Policies" in a Hot House World, with warming at +3°C.

Table 1 - PRA CBES: Global Mean Warming Outcomes

Reporting Period	Year 0 (2020)	Year 10	Year 30	2100
Early / Late Action	1.1 °C	1.4 °C	1.8 °C	1.6 °C
No Additional Action	1.1 °C	2.5 °C	3.3 °C	4.1 °C

The global mean warming projections, shown in **Table 1**, are based on the 50% percentile NGFS climate scenarios for Early/Late Action and 90% for No Additional Action. What was remarkable was the detail provided in the provision of projected changes in physical variables[71] for a selected number of perils/regions shown in **Table 2**. These referenced scientific journals, links to UK Met Office, NGFS and Oasis Hub open data. Projections[72] were given in terms of **percentage changes for maximum daily and annual average wind speeds, precipitation rates, soil moisture and land area exposed to wildfire or crop failure** for a representative list of countries. The physical risk **scenarios were based on two global mean warming outcomes for 2020, 2030, 2050 and 2100 for each scenario.**

Table 2 - PRA CBES: Global Mean Warming Outcomes

Variable	Peril	Historical	Early Action	No Additional Action	Early Action	No Additional Action
		2020	2030		2050	
Air Temp Annual Avg. change °C	Drought	0.80	1.00	2.60	1.30	2.30
Wind Speed Annual Avg. % change	Wind	(5.10)	2.80	(16.60)	(2.40)	(18.50)
Precipitation Annual Avg. % change	Flood	1.00	0.90	10.60	0.30	11.00
Soil Moisture % change	Drought	(0.60)	(0.90)	(1.10)	(0.80)	(2.20)
Wildfire % change	Wildfire	0.02	0.02	0.04	0.06	0.06
Sea level rise M	Flood	0.08	0.10	0.31	0.16	0.39

[70] PRA (2021): CBES [71] Variables were also provided for macroeconomic, financial and transition risks. [72] PRA (2021): Guidance for participants

(Re)insurers were presented with a conundrum: how to interpret this level of precision about future assessments of risk, especially where there could be differences from internally established viewpoints that were documented in their ORSA? Some of the benchmark variables chosen by the PRA were different or contradictory to individual companies' existing views of risk. How best to manage both internal and external responses? In addition, (re)insurers would likely need to integrate these new change factors into the proprietary models on which their existing ORSA was based. Some of the parameters used might not have been those seen to be the key drivers of tail-risk, which ultimately should have been the purpose of the exercise. It should be acknowledged that some (re)insurers find it difficult to make these adjustments to third-party vendor models that they license as they are not designed to be adjusted in this way in many cases.

Examples of parameters that caused consternation included:

- Changing annual average precipitation rates does not capture the potential for a reduction in mean losses while, at the same time, producing an increase in the tail losses, which science suggests may be more likely to occur.
- Decreasing the overall frequency of tropical cyclones in certain regions may ignore the likely increases in the severity and frequency of larger tail events in these same regions.

For UK insurers there is a further complication: how will risks, currently ceded to Flood Re[73] be managed? The scheme, which receives funds from insurers to ensure coverage in known flood risk areas, is legally in place until 2039. Absent an extension, many risks that are currently insured in these flood prone areas will likely be uninsurable.

Consequently, should CBES become the de facto norm with minor tweaks to benchmark variables? What confidence can be placed in the outputs if there is low confidence in the parameterisation of the model inputs? The results are not going to be trustworthy and cannot be relied upon for pricing or business strategy. Further, there might be other (and simpler) factors to use, such as the impact of inflation on loss costs and change in insurance exposure that will have a far bigger impact than the annualised cost of climate change when viewed over a 30-year time horizon. These key components were not included in the CBES Physical Risk scenarios.

2.3.3 Banque de France / ACPR

The *Autorité de Contrôle Prudentiel et de Résolution* (ACPR) conducted a pilot climate exercise[74] in 2020 involving banks and insurers, with a 30-year horizon (2020-50). While the Transition Risk was viewed as "moderate", **the Physical Risks (based on RCP 8.5) would likely see insurance premiums rise by 130% to 200% over 30 years through a combination of increased drought and flood claims.** This would outpace Gross Domestic Product growth by 170 percentage points.

As the brunt of claims are covered by the *Catastrophes Naturelles*[75] (CATNAT) scheme, a 50% increase in the contribution rate (from 12% to 18% of property premiums) is envisioned. This ignores how consumers might respond to price increases and the potential for a larger protection gap.

There were some methodological lessons learned, including the challenge for insurers more used to dealing with sudden weather shocks to inform pricing and underwriting decisions, rather than the longer-term impacts, assumed to be more gradual as a result of chronic physical risk. Modelling this, together with not being able to capture detailed geographic coordinates of future climate events and overlay these on current exposures, proved challenging. **Incompatibility of data available at a global scale and how to apply this with internal models and assumptions was highlighted.**

[73] UK Flood Re [74] ACPR (2021): Analyses et synthèses no.122 [75] CATNAT Compensation Scheme

2.3.4 Bermuda Monetary Authority (BMA)

The Bermuda Monetary Authority[76] (BMA) recently performed a mini-CBES exercise on an equivalence basis, working in conjunction with the PRA. The goal was to analyse three climate physical risk scenarios over 5-, 10- and 25- year time horizons. (Re)insurers were given the option of either using a vendor model that included RCP 4.5 event sets or a set of defined parameters that they provided.

The focus included changes to tropical cyclone frequency, impacts from storm surge, inland flood losses as well as increases in losses from wildfire. The approach is similar to the current Bermuda Solvency Capital Requirement[77] (BSCR).

Separately, the BMA conducted a survey on climate change in 2020, the results of which were published[78] in March 2021. The survey, of 170 companies, focused on their understanding of climate change risks, its impact on strategy and governance, stress testing and disclosures. The survey highlighted the increasing awareness of climate change risks and opportunities and how it is seen as a long-term risk, versus mid- to short-term business planning horizons. They noted the challenge of building up knowledge and skillsets and a lack of standardisation.

2.3.5 DeNederlandsche Bank (DNB)

The DeNederlandsche Bank (DNB), following EU Solvency II Regulation, expects (re)insurers to document and evidence in their ORSAs the risks of climate change. Insurance coverage in the Netherlands generally excludes flood, due to the acute risk with much of the country below sea-level. However, there are other perils (hail, extratropical cyclone, drought) that have been subject to research by the Royal Netherlands Meteorological Institute[79] (KNMI).

In their Good Practice[80] guidance notes, DNB provided a review of 2018 ORSA submissions, noting that insurers used different principles for integrating climate-related risks into their ORSAs. Some used the EIOPA Insurance Stress Test 2018 while others referenced the DNB 2017 Non-Life Insurance Stress Test. The former used one single scenario with four severe northwest European storms. The latter used a combination of a single very severe storm or three single storms to test reinsurance purchase adequacy.

DNB set up The Sustainable Finance Platform, which included members of the Banking, Insurance and Finance Associations. While the focus was on how the largest finance institutions measured and managed climate risks, there were some interesting findings: data availability was limited and methodologies were not yet robust, requiring qualitative rather than quantitative analysis. There were four challenges cited[81]:

1. Relevant climate data is not available, incomplete and/or not at the right level of granularity
2. Time horizon discrepancies between how risks are modelled to match regulatory requirements (3-5 years) and the knowledge that actual impacts will occur years later and at a non-linear rate with increasing uncertainty
3. Critical risks are not all known, or their probabilities assessed at the time of investment
4. No single model accounts for all risks, nor are there widely accepted methods

2.3.6 European Insurance and Occupation Pensions Authority (EIOPA)

As described in **2.1 Background** above, EIOPA have provided guidance on the methodological principles of stress testing, with their most recent publication[82] in January 2022, which was designed to assist with developing bottom-up stress tests for climate change risks

[76] Bermuda Monetary Authority (BMA) [77] BMA (2021): BSCR 2021 [78] BMA (2021): Climate Change Survey Report [79] KNMI (2017): Waterproof? An exploration of climate-related risks for the Dutch financial sector [80] DNB (2019): Good Practice – Integrating climate-related risks in the ORSA [81] The Sustainable Finance Platform: Sharing Good Practices [82] EIOPA (2022): Methodological Principles of Insurance Stress Testing – Climate Change Component

EIOPA, through the introduction of Article 45a, require (re)insurers with material exposure to specify in their ORSAs, two business impact scenarios:

1. **where the global temperature increase is limited below 2.0°C**
2. **where the global temperature increase is equal to or higher than 2.0°C**

They also suggest two methods that (re)insurers could use to test the temperature scenarios against:

1. **Prescribing specific Nat-Cat events** linked to climate change evidence as is already in place (EIOPA ST 2018)
2. **Prescribing changes to frequency, severity and correlation of specific (regional) perils** linked to climate change evidence (but not prescribing the specific events)

EIOPA will be looking for support from all stakeholders to help define the approaches, but noted several challenges in these approaches. Some of the key advantages and disadvantages are shown in **Table 3**.

Table 3 - Pros and Cons of Different Scenario Approaches

Scenario	Advantages	Disadvantages
Event-based scenario	Aggregation of industry losses	Which event ID can be linked to climate change? Which ID across different models?
Frequency / Severity / Correlation	Market aggregation. Aligned severity for all, as not tied to specific events	Challenging linking increasing frequency and severity of specific perils to climate change. Requires granular data; no single model used

Like all Regulators, EIOPA are keen to understand the systemic risks across the financial system as a whole, so any scenario-based solution for the physical risks from climate change must address the ability to consolidate individual insurer feedback. The challenge with this is that not all insurers have the same spatial distribution of their portfolio or mix between residential, commercial and industrial business. That means that one specific event will not impact all insurers equally. Further, each insurer may use different internally developed or third-party vendor model(s), making it hard to either specify an event that impacts insurers equally or the ability to combine results. On the positive side, the outcome of an exercise that uses the specific Nat-Cat events method could demonstrate that impacts on different firms are not all additive and cumulative and there is some diversification of risk.

Solutions to the problem of combining results from different models are being developed collaboratively by the industry through the **Open Data Standards**[83] initiative, where vendor model inputs can be standardised using Open Exposure Data. Outputs from different models can then be combined using Open Results Data tools. In the meantime, capturing and then aggregating industry losses is another example of the uncertainty in building an accurate picture of the physical risks from climate change.

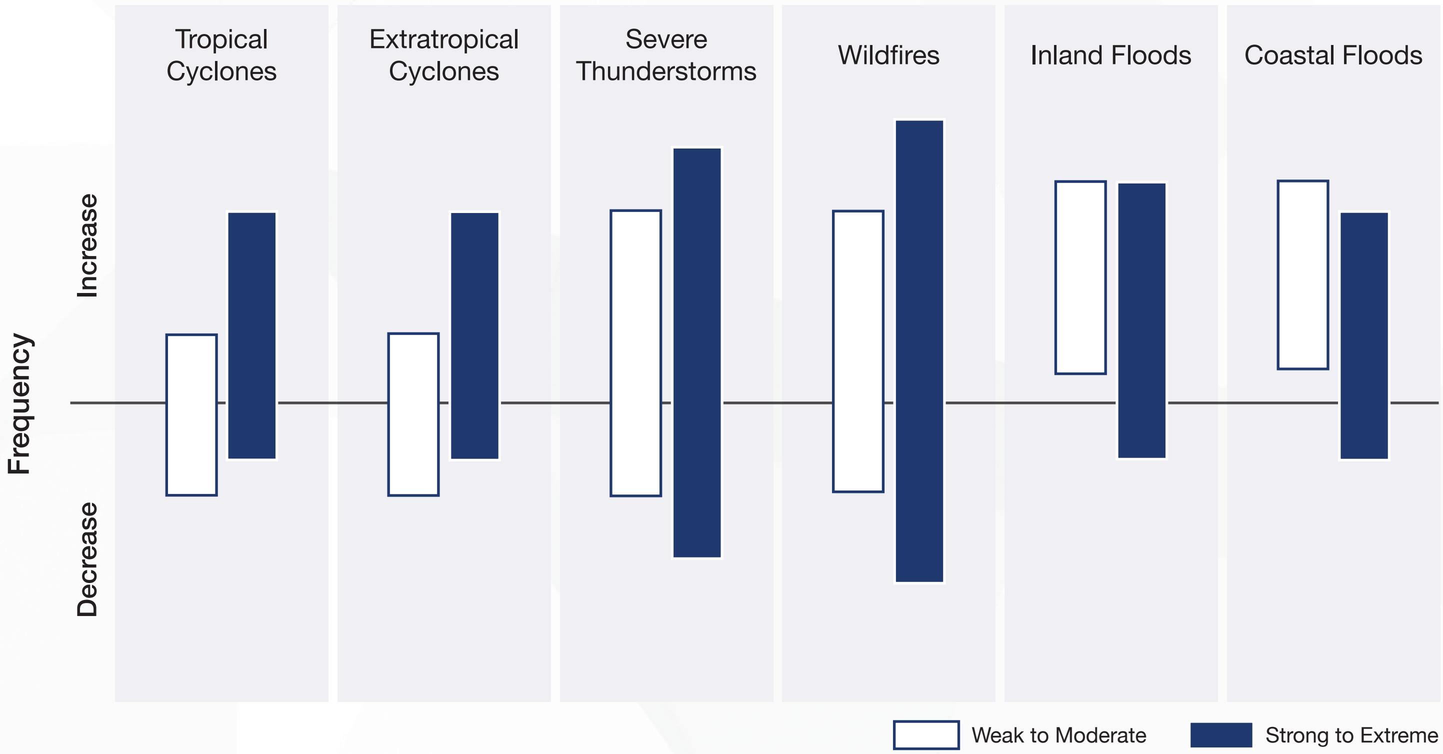
EIOPA suggest linking scenarios to RCPs in order to frame scenario outcomes and using assumptions to adjust hazard. Reference is made to the AIR Worldwide White Paper[84] on extreme weather impacts from climate change, where the range in the change in frequency is shown for short (2- to 10-year) and long (50-250year) return period events. **Figure 10** represents these globally-averaged estimates at the time (2017), noting that significant regional differences may exist.

[83] Open Data Standards [84] AIR Worldwide (2017): Climate change Impacts on Extreme Weather

EIOPA provided some useful guidance in the choice of stress test scenarios, providing some principles[85] (pp11-12) for the design and narrative:

- Principle 1: as they are interlinked, transition and physical risks should be assessed in conjunction.
- Principle 2: a range of climate scenarios and transition pathways provides a way to capture the risks
- Principle 3: to assess resilience, both central and outlier tail events should be considered
- Principle 4: quantitative information on key climate change factors needs to be granular and should identify key variables and assumptions that affect pathways
- Principle 5: scenarios should cover appropriate time horizons

Figure 10 - Global Likely Frequency Increases / Decreases by Peril



In their Opinion[86] on the supervision of the use of climate change risk scenarios, EIOPA set out the background for the change in Solvency II Directive to require supervisors to integrate climate change risks into systems of governance. Based on a sample of 1682 undertakings in the EEA, less than 10% included reference to climate change scenarios in their ORSAs. Various examples of quantitative climate change risk analyses were shown, including increases of loss ratio and scenarios of combinations of specific events, which have been used by specific supervisors within the EEA.

Finally, for those insurers relying on the Standard Formula for the Solvency Capital Requirements (SCR), EIOPA provided insights[87] into how process changes could formalise an approach to re-assess the parameters used every 3-5 years. This could be triggered based on new scientific evidence on climate change, model changes due to the impacts of climate change as well as changes in adaptation, exposure and/or vulnerability.

[85]EIOPA (2022): EIOPA-BOS-21/579 [86]EIOPA (2021): EIOPA-BoS-21-217 [87]EIOPA (2021): EIOPA-BoS-21/253

2.3.7 International Association of Insurance Supervisors (IAIS)

The IAIS continues to drive initiatives to address climate change risk as part of its Global Monitoring Exercise (GME). Setting out its roadmap[88], they plan to take stock of existing practices on climate risk scenario analysis, assessing the need for guidance on effective supervisory exercises. Their Global Insurance Market Report[89] (GIMAR) was focused on insurers' investments and how the asset-side of their balance sheets were exposed to climate risk.

IAIS have issued various papers[90] related to the supervision of insurers in respect to climate-related risks, giving examples of relevant indicators and questions that individual supervisors are using in their respective countries. Commenting on the financial stability of the insurance sector as a whole, IAIS noted[79] that over 35% of insurers' investment assets were exposed to climate risks. Further, they explained that **"climate change scenario analysis is still in its infancy and methodologies are developing and evolving. Furthermore, insufficient standardised and granular data, alongside methodological limitations may hinder scenario analyses that are consistent and comparable."**

2.3.8 Monetary Authority of Singapore

The Monetary Authority of Singapore (MAS) has provided various guidelines[91] on environmental risk management, which closely follow the TCFD's recommendations on financial disclosure, governance, underwriting and risk management. They included a climate variability scenario in their 2018 Industry-Wide Stress Tests (IWST), which required insurers to estimate the impact of severe flooding in specific flood-prone zones in Singapore. Work is ongoing to refine future stress test scenarios, including time horizons.

The MAS seem to go further in referencing the impacts that Environmental Risk can have on all areas in which insurers operate (Market, Operational, Liability and Liquidity).

2.3.9 United States

The United States has a state-based system of insurance regulation and the National Association of Insurance Commissioners (NAIC) provides expertise, data and analysis and is the U.S. standard-setting and regulatory support organisation, governed by the chief insurance regulators. Surprisingly, as the US Financial Oversight Committee (FSOC) notes, there is **currently no nationwide requirement for the disclosure of climate-related financial risks for the entirety of the U.S. insurance industry[92].** Further, "neither existing regulatory requirements nor voluntary frameworks have led to comparable, consistent, and decision-useful climate-related disclosures across U.S. companies and financial institutions." The exception is for those insurers that are public, who must comply with the Securities and Exchange Commission (SEC) rules[93]; these rules have recently been enhanced[94] (March 2022) **to oblige disclosure of climate-related risks in annual filings**, beginning in fiscal year 2023.

In line with other disclosures, **a threshold of 1% of the aggregated line-item financial impacts of severe weather, other natural conditions and transition activities, as well as future climate-related risks has been set.** Positive and negative impacts can be accumulated, but the implications of this proposed rule seem onerous.

The NAIC has been catching up with the creation of a Climate & Resiliency task force[95] in June 2020, which has recently adopted a voluntary risk management tool for state insurance regulators and updated the 2010 Climate Risk Disclosure Survey[96], in which only fifteen states had participated during 2021. This revised survey responds to the FSOC's recommendations and is aligned with the TCFD framework.

[88] IAIS (2022): Roadmap 2022-2023 [89] IAIS (2021): GIMAR [90] IAIS (2021): Application Paper on the Supervision of Climate-related Risks in the Insurance Sector [91] MAS (2020): Guidelines on Environmental Risk Management for Insurers [92] FSOC (2021): Report on Climate-Related Financial Risk [93] SEC (2010): Commission Guidance Regarding Disclosure Related to Climate Change [94] SEC (2022): Enhancement and Standardisation of Climate-Related Disclosures [95] NAIC (2020): Climate & Resiliency Task Force [96] NAIC (2022): Climate Risk Disclosure Survey

3. Best Practices in Modelling Climate Change

Catastrophe models are robust tools that enable (re)insurers to analyse hazard and vulnerability components on their exposures in order to test financial loss impacts under different conditions. Adjusting for climate change, especially far into the future, can amplify the uncertainty that is inherent within model outputs. This **uncertainty** can be split between aleatory (dice throwing statistical probability) and epistemic (incomplete or inaccurate knowledge). We know that aleatory uncertainty cannot be reduced through capturing additional data, whereas a lack of knowledge can, to an extent, be improved.

Uncertainty can be further separated into primary and secondary uncertainty. In the former, we have the uncertainty that the model captures the full range of outcomes for the hazard: for example, is the event catalogue complete, does it include the absolute worst-case scenario, or, is the exposure data complete and accurate and what is the uncertainty in the event rates? Secondary uncertainty concerns the uncertainty in the actual damage that results from an event, given that the event itself has occurred. Translating windspeed, ground motion or flood depth requires parameterisation and assumptions in the form of vulnerability functions. These outcomes then need to be calibrated against actual insured loss experience.

Each new loss event provides model vendors with vital new data points on which to recalibrate damage functions, but there is always uncertainty in translating these into individual building performance at the time of a loss. For example, a lack of standardised claims data inhibits model developers from capturing all the insights gained with each new loss. There is likely then to be a lag between a rapidly evolving climate state, which produces new extremes of losses that in turn provide additional insights to be incorporated into models.

Kaye et al (2020) outlined[97] six principles for improved decision making that could assist with managing uncertainty. Principle 2 discusses **how to deconstruct the problem.** An example of how these are addressed are discussed in **Chapter 3.1** below, explaining how Global Circulation Models (GCMs) and Integrated Assessment Models (IAMs) are used. The biggest challenge for catastrophe model users though is Principle 4: **Models Can Be Helpful, but Also Dangerous.** How can users measure the extent to which each component is quantifiable?

Of the four main components of catastrophe models, uncertainty from both Exposure data and the Financial Model are within the domain of control of (re)insurers. They have the potential to fully "own" Exposure data. **Data capture ratios, data quality controls, replacement value and geocoding accuracy can be measured for completeness and improvements made over time.**

Hazard uncertainty has been explored in **Chapter 1.5.** Another difficult area to model is the Vulnerability component of catastrophe models. Impact Forecasting[98] provided some insights on the main sources of uncertainty including:

- The uncertainty of claims data; are there enough examples and do they represent all possible outcomes?
- The uncertainty of how damage curves are developed and applied in the model

The point is that there are therefore many aspects for all stakeholders to address when making adjustments to model components for climate change. The more assumptions that are introduced into each model component, the more the potential to amplify the uncertainty of outcomes increases.

This chapter summarises the insights gained in this report and suggests some best practices for modelling the physical risks and hazard components of catastrophe models.

[97] Kaye, P. et al. (2020): Managing Uncertainty: Principles for improved decision making [98] Impact Forecasting (2017): Understanding and managing damage uncertainty in catastrophe models

3.1 Climate Conditioning: event sets or models?

As highlighted in **Section 1.2**, even though most catastrophe model vendors have continued to release updates to their models to reflect current scientific views of climate change, it is hard, expensive and time-consuming to capture the latest trends in climate and the science that seeks to explain it. Vendors have begun to release specific "Climate Change Models", principally for "peak zone" perils including European Windstorm, European/UK Flood, North Atlantic Hurricane and Japan Typhoon to allow for some future views to be explored and also to assist with Regulator scenario requests.

If it is accepted that climate change is here already, it could be questioned why these are not already incorporated into current models. Firstly, a key question is therefore to what extent do current models and event sets represent the change in climate that has already occurred and the extent to which they are biased by historical events, which are more reflective of previous climates? Secondly, how are the introduction of climate related datasets / event sets, which are forward looking in nature, addressing other factors that could enhance or mitigate the risk?

Some third-party model vendors have created additional event sets in order to provide probabilistic modelling outputs that allow for the ability to adjust time horizons and map to RCPs. Some updated Industry Exposure Databases (IED) and economic exposure components are also provided, but it is not clear how these can map directly to the SSPs. We are a long way from achieving global coverage and the capture of future adaptation and infrastructure components. These new models also entail additional licence costs. Mitigation in this context is not about the causes of climate change itself; rather, it is how governments, enterprises and individuals adapt to reduce the vulnerability that is the consequence of climate change.

The challenge for model users is then to be able to differentiate between the model vendors that provide solely "Climate Conditioned Event Sets" (CCES), and those that include integrated "Climate Conditioned Catastrophe Model" (CCCM) components. They are not the same. The former equates to the resampling of existing event sets and would include [usually company specific] changes to frequency and severity. The latter require new events and/or catalogues, including new event footprints.

In addition, adjusting hazard is just one element, and while this might be acceptable to assess and report on current climate and short time horizons, it ignores other material changes that will come in the exposure, vulnerability and demographics of the future, limiting its utility.

Both types of models may have value, but the user should be aware that they are different things and will provide answers to different questions. If you a looking for answers to current climate and business applications to manage pricing, solvency and business planning, provided that the CCES has been adjusted to reflect users' own view of risk, then it is suitable to manage those shorter time horizons. CCCM will, all other things being equal, give a better perspective on the impacts of climate change.

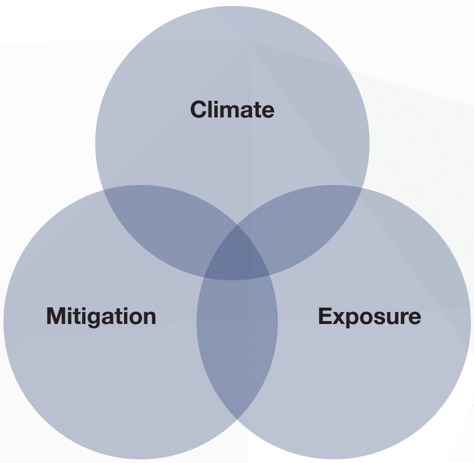
This would indicate that a list of questions should be put to model vendors by users:

1. Have you adjusted for climate change over the last 40 years? If so, how and for which perils?
2. Have you taken into account the uncertainty in that climate change? If so, how?
3. Do the changes you've made focus specifically on the mean, rather than the extremes? If not, why not?
4. What assumptions have you made?

For those (re)insurers who have yet to make adjustments to capture current climate, it may be sensible to start making small adjustments today and over time rather than having to make a larger adjustment later, when it might be too late. Furthermore, changing event sets is more practical for the more established companies; this could impact strategic decisions and allow more time for decision making rather than just completing multiple and different regulator requests. Jewson, S. *et al* (2019) provided examples[99] of how either event loss tables (ELT) calculating losses by simulated event, or *year loss tables* (YLT), where they are calculated by simulated year, could be adjusted by the application of weights to the years. The approach described how "scientific hypotheses relating to the changing frequencies and severities of events could be applied to catastrophe models without having to rebuild the model, which is rarely feasible".

Meanwhile, to capture all sides of the picture, future CCCMs will need to include Climate, Exposure and Mitigation components too. Each component of these future CCCMs overlap with each other (**Figure 11**) and play an equal role, combining to inform a much larger risk altogether.

Figure 11 - Climate Conditioned Cat Model Components



Changes in exposure, the impact of social and other inflation elements on loss costs, as well as elements that could mitigate and reduce vulnerability increase the challenge and add to the uncertainty. Key to understanding how mitigation might reduce vulnerability would be policy decisions on flood defences, for example and how aging infrastructure will cope. This creates a dimension of complexity that is hard to calculate, compounding the uncertainty in model outputs. .

Focusing just on the hazard component, which is the subject of this report, all stakeholders need to be aware of the limitations of using models designed to simulate future climate impacts at a global scale, and the complexities with applying these forecast changes at a local level. The WRCP[100] Coupled Model Intercomparison Project (CMIP6), which allows for ensemble results from Global General Circulation Models (GCMs) to be analysed, was used to inform IPCC assessments, and enabled SSPs and RCPs to be combined for the first time. In turn these GCMs are downscaled in Regional Climate Models (RCMs), and then combined in Integrated Assessment Models (IAMs)[101] that capture population changes, land and energy-use choices, technology changes and economic GDP projections.

According to Fiedler *et al* (2021)[102], the coarseness of GCM resolution (generally 100km^2) is not suitable to represent or capture "weather events" – those that cause insurance losses – where more detailed resolution is required. This is especially true of localised small scale extreme events such as severe convective storms but even remains true of large-scale phenomena such as tropical cyclones. Downscaling them to provide greater resolution may provide additional detail, but the rarity of the extreme events that interest insurers are unlikely to be reliable when used at the scale required to assess hazard on physical assets. Being included in CMIP does not necessary imply that the GCMs have any skill at representing climate phenomenon, when compared to observational data. Further, we know that any **climate modelling comes with uncertainty. This could come from three areas: natural and/or multi-decadal variability; from the climate model itself (how the physics is interpreted) and finally, how they cope with GHG emissions.**

[99] Jewson, S. *et al* (2019): Adjusting catastrophe model ensembles using importance sampling, with application to damage estimation for varying levels of hurricane activity
[100] WRCP Coupled Model Intercomparison Project [101] Riahi *et al*. (2017) The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview [102] Fiedler *et al*. (2021): Business Risk and the Emergence of Climate Analytics

Per Fiedler, **“GCMs are not valid tools for examining how climate will change at these scales, and dynamical and statistical downscaling does not change this assessment.”** In short, an additional layer of complexity and uncertainty is added prior to running catastrophe models.

Uncertainty increases when moving from GCMs to IAMs, where the sensitivity to parameter change is large, through to catastrophe models. The implication is that for longer horizon analyses, a simplified approach should be used.

3.2 Deterministic vs. Probabilistic

Scenario analysis has long been used as a tool by insurance market stakeholders as a means to test hypotheses about potential risks across different classes of business. Scenario typologies and applications are explored in more detail in the Cambridge Centre for Risk Studies (CCRS) report[103], beginning with what scenarios can be used for which purpose. **Scenario analysis is designed to assess the impact of a combination of events, while stress tests are usually designed to analyse the impacts of single but extreme events**.

Key to any approach is creating situations that are likely to occur, within a foreseeable timeframe, where there is sufficient substance to estimate the limits of exposure and what percentage of these limits might be at risk. The advantage of this approach is that loss scenarios can be imagined and impacts calculated without recourse to sophisticated modelling. This “deterministic” approach is simpler to build and execute, but it implies that all the necessary inputs are available to predict the outcome with a degree of certainty. In short, the probability of occurrence is finite.

Probabilistic or stochastic modelling assumes a pre-determined level of randomness that allows for the capture of uncertainty. By its nature, it requires fixed assumptions, for example, a catalogue or an event set for a given peril / region that could be represented by tens of thousands or more hypothetical events, each with an annual rate of occurrence and some implied uncertainty. Uncertainty in these models might be represented as a standard deviation around a mean loss.

Advances in computational speed have allowed for a sampling approach of events to be used by calculating large numbers of “simulation years”. By calculating a random number - or loss quantile - for the loss distribution of an event, each time the event itself appears in the simulation, **these models can capture uncertainty in a different way to prior models.** Uncertainty is only considered once using this quantile approach, which allows for simplification through arithmetic (e.g. summing of columns) rather than using complex computations using mathematics. This also allows for simpler calculations of different financial perspectives (gross to net), increasing transparency of results.

Deterministic scenarios are useful to examine extreme outcomes especially where there is a high degree of uncertainty. Probabilistic scenarios are designed to address the uncertainty by providing a range of outcomes, either in the form of an occurrence (OEP) or aggregate exceedance probability (AEP) distribution. **The challenge with the probabilistic scenario definition is that it requires all potential outcomes to be defined in advance and assumptions made on their parameterisation so that they can be included in the distribution.** This is not always the case or possible.

As the impacts of climate change on key perils and their sub-perils is still evolving, it is challenging to accept outright that probabilistic outcomes can be relied upon in the same way that those for current climate can.

[103] CRS (2020): Developing Scenarios for the Insurance Industry

3.3 Scenarios vs. Stress Tests

The purpose of scenario analysis was defined in the TCFD Technical Supplement[104] as a means of exploring and developing a variety of alternative plausible future states under a given set of assumptions and constraints. **Significantly, the TCFD explained what scenario analysis is not: they are not forecasts, predictions nor are they sensitivity analyses.** A forecast involves looking at trends based on past data or examining physical principles and then predicting likely future trends based on this. Sensitivity tests meanwhile rely on swapping out input parameters and recalculating the results.

TCFD went further to clarify that the goal of scenario analysis is to focus on key drivers of future change, not the full picture. **It follows that they cannot be stress tests of possible future climate states, which would require a more prescriptive description of physical risks to test against.**

This is where CBES differs: these are specific types of stress tests designed to illicit impact of future losses by predicted changes in frequency or severity.

3.4 Normative vs. Exploratory

This report has so far focused on the use of exploratory scenarios such as CBES, which are designed to ask "what if?" questions to identify, and increase awareness of, future risks. However, it can be difficult to make business decisions using exploratory scenarios. This is because they focus on arbitrary time horizons (e.g. 2050) and do not explicitly take into account business objectives such as profitability or solvency.

For this reason, Rye *et al*. (2021) have proposed[105] a complimentary normative approach that focuses on "what for?" questions. Normative scenarios take stakeholder interests into account to help identify desirable or undesirable outcomes. For example, an insurer concerned with the impact of climate change on profitability, may choose to build a scenario around how their average annual loss (AAL) may change in the future. This would typically involve setting an "impact threshold", which if exceeded would lead to a bad outcome for the business. The likelihood of the threshold being breach at different points in time can then be calculated. The advantage of this approach is that it allows a business to make decisions and develop clear strategies against metrics that matter the most to them.

The impact thresholds themselves could still include worst-case disaster scenarios or present-day re-evaluation of historical events, but the real value could come from setting risk appetites as a function of expected loss (AAL) or as a percentage of Regulatory capital, which then sets a future point in time when action must be taken.

Figure 12 - Probability of exceeding an impact threshold

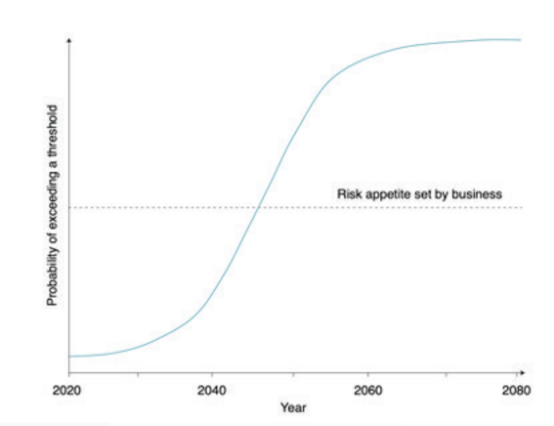


Figure 12 shows how the probability of exceeding an impact threshold (shown as the Risk Appetite set at the 50th percentile) and how this becomes more likely than not over time. The point in time can be deduced, where "unacceptable" levels of climate change risk are reached.

A normative system design is often used in engineering, where a combination of information gathering, diagnosis, dynamic evolution and decision making are combined. Each activity is modelled and evaluated separately but then embedded into an expert system to appropriately balance deterministic and probabilistic analysis. This is a hierarchical process that aims to understand what information inputs are required to inform the action. The diagnosis, to determine the risk at a given time, relies on the quality of information. It is dynamic as the risk changes over time, but this allows for valuable decisions being made given the risk and its change over time.

[104] TCFD 2017: The Use of Scenario Analysis in Disclosure of Climate-Related Risks and Opportunities [105] *Rye, C. et al.* (2021): Normative approach to risk management for insurers

3.5 Best Practice Recommendations

Climate change is a new and unique threat, impacting Environmental, Liability, Transition and Physical Risks in ways we may not yet grasp. (Re)insurance is one of the key pedestals of the financial industry and has frequently demonstrated its worth, enabling individuals and businesses to recover when disaster strikes. The industry will continue to bear the brunt of future losses in a changing world, using its expertise to manage and price risk. This future world, with all of its uncertainty, also provides significant opportunity for innovation in providing new products and incentivisation for reducing the protection gap between economic and insurance loss.

The business of risk is at the foundation of (re)insurance operations; practitioners are well-versed in the skills of managing modelled and non-modelled risks. This has always required the utmost flexibility in approach, adapting to insights gained, both from science and new loss data, to deliver product offerings that are fairly priced and diligently managed.

From a supervisory perspective, gaining an understanding of all aspects of how climate change will impact all financial services is an urgent and ongoing process. Many supervisory bodies, including Lloyd's of London[106], are insisting that explicit reference to climate change must be made in validation of climate-related perils.

The challenge for supervisors and industry practitioners is that, much as it would be interesting to crystal-ball gaze and theorise the outcomes at the end of the 21st century, none of these have much business relevance today for the (re)insurers who provide cover for the Physical Risks of climate change. Remember that most policies are annually renewable. The time horizons used for future climate change analysis should therefore be driven by their business relevance and their operational complexity.

Feedback on this report suggested three or four routine business tasks, each with their own existing internal framework and functions defined: the depth of analysis should be inverse to the length of the time horizon chosen. For example, present day risk management, reflecting current climate hazards, including those from natural annual to multi-decadal fluctuations, focusses on the immediate future time horizon. Normal solvency and budgeting tasks routinely model 1-3 years ahead.

Future horizons could then include the existing business planning or strategy process (3-5 years, with a maximum of 10) and medium-term stress testing could focus on 10-30 years ahead. Beyond that is pure horizon scanning and could be 30-50+ years, but with a very light modelling touch due to the compounding nature of uncertainty.

This report strongly supports the use of probabilistic modelling, but only for the timescales used for solvency measurement and business or strategic planning, as used for existing risk management processes. Simplified deterministic approaches for Physical Risk hazard reporting will provide sufficient insights for longer time horizons, such as medium-term stress testing and horizon scanning.

It is urgent and important that common approaches are adopted by supervisory bodies that align as close as possible to the manner in which (re)insurers run their day-to-day businesses, without disrupting tried and tested processes and controls. This will allow more time for those leaders in the risk space to dedicate sufficient resources to evaluating the changing hazards and applying them to their existing tools and processes.

Indeed, given that the effects of the different Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs) are not distinguishable above natural variability before around 2040 anyway, a far easier and adaptable solution would be to dispense with trying to capture all of the components required to align with the SSP-RCP future scenarios altogether. Simplified deterministic approaches could use climate change impacts based solely on future temperature changes, such as those proposed by EIOPA (where the global temperature increase is limited to below or above a 2.0°C increase), which provide enough of a best-case/worst-case outcome for scenario analyses.

[106] Lloyd's of London: Thematic Review: Catastrophe Modelling & Climate Change

If it must be required to have additional ranges of future global warming, then an additional scenario of 1.5°C (currently highly unlikely), 2.0°C and 3.0°C might be considered. All of these can then be mapped by regulators themselves by interrogating the data to cross-check against whatever RCP scenario they wanted to use. (Re)insurers could provide just one set of data and at the same time use it for their own in-house view of risk.

The metrics used by Regulators should be exactly the same as those used in the normal course of business processes and reporting.

- Annual Average Loss (AAL) and Occurrence / Aggregate Exceedance Probabilities (OEP/AEP) could be used for short /medium term stress testing
- Deterministic / plausible future loss scenarios should be used to address longer-term outcomes
- Reporting timelines should feature two (e.g. 2030 and 2050) or a maximum of three periods ("beyond 2050"); interpolation between them can be inferred without the need to report changes for intermediate years / periods

There needs to be a better understanding of how catastrophe models can (and cannot) be adjusted, so that all stakeholders are able to get the most out the results.

- Adjustments for both frequency and severity should be carefully considered. Sometimes there are good reasons to adjust both frequency and severity (e.g frequency for wind and severity for flood on tropical cyclone events). However, compounding adjustments can sometimes overestimate the risk.
- Some parameters cannot be adjusted in cat models (e.g. precipitation changes for flood models)
- Adjusting for sub-peril or secondary peril losses and uncertainty should be captured within current views of risk. Their impact on medium-term and longer-term time horizons should be catered for in a deterministic and simplified way
- Future scenario analysis should be limited to a few key peril / regions where there are known significant insurance exposure concentrations.
- It should be acknowledged that there are limitations to using models designed to simulate global climate at a local scale; there is too much uncertainty at the level of granularity required for modelling insurance risk.
- Uncertainties should be acknowledged and adequately explained so that decision makers /regulatory oversight appropriately understand the limitations of analyses that may have been carried out.

Finally, there is a huge opportunity to encourage the use of Open Data Standards (ODS) for climate-related reporting on Physical Risks (along the lines of those developed for Transition Risks).

- Stakeholders should continue to support the adoption of Open Exposure Data (OED) and encourage the use of the same data for asset and liability exposure reporting. Indeed, there is potential for ODS to be used to support corporate actions and reporting on net zero capabilities. It could be argued that those with a higher net zero ambition are better managed risks and should be priced accordingly
- The development of a tool, similar to The Paris Agreement Capital Transition Assessment (PACTA[107]) tool, which provides portfolio-level analysis of Transition Risk in public equities and corporate bonds and uses asset-level data, should be encouraged for Physical Risk assets
    - Tools exist (e.g. BREEAM[108] / CRREM[109]) and could be adapted to report fixed assets and liabilities of insurers

[107]PACTA: Paris Agreement Transition Assessment tool [108]BREEAM Sustainability Tool [109]CRREM Carbon Risk Real Estate Monitor

3.6 Taskforce on Nature-related Financial Disclosures

This is beyond the scope of this report, but it is worth referencing the work of the Taskforce on Nature-related Financial Disclosures[110] (TNFD), which is covering the environmental risk posed by climate change. Their focus is on natural capital (Land, Ocean, Freshwater and Atmosphere) and how biodiversity changes will impact people and organisations in the future. Insurers should be aware that as TCFD becomes embedded into supervisory requests, so too will TNFD and the requirement for a coordinated approach to model the impacts on Physical and other risks.

TNFD may ultimately be the mechanism to see meaningful change happen within the financial services industry as the real cost of investment, including, for example, the impacts on biodiversity, can be measured. Better comparisons can be made between alternative investment strategies and the net returns between investing in, say, fossil fuels vs. renewables can be calculated.

3.7 Interplay between Transition Risk and Physical Risk

All stakeholders want to understand potential climate change impacts across the financial services sector, irrespective of whether these come from Physical or Transition Risks. However, there is an interplay between both. The longer it takes for policy action to force a change in regulations, which could include emissions trading schemes, increased fossil fuel or new carbon taxes, combined with technological advances that increase the Transition Risk, the greater the potential shock for Physical Risks in the future.

No economic sector is immune from these shocks. Even domestic and commercial real estate, with tightening energy efficiency standards, could lead to stranded assets, should it become no longer economic to retrofit to be compliant. For example, the UK Clean Growth Strategy[111] aims to upgrade domestic properties to Energy Performance Certificate (EPC) Band C by 2035, with similar targets for commercial property. S&P Global found[112] that more than 40% of companies in the S&P Global 1200 (market capitalisation ~$30 trillion) hold assets at high risk of physical climate change impacts and that this exposure does not conform to clear sectoral patterns.

On the one hand, improved EPC ratings could imply better risk quality (better risk management) and lower future exposure; on the other, risks where the economics of retrofitting make no sense or where Transition Risk itself (e.g. technological progress) could cause assets to be stranded. **Both paths lead to increased uncertainty in the ability to accurately model exposure in any future time horizons. Both paths also occur independently of whether the asset is located in a high exposure location to physical risks.**

As Transition Risks increase, (Re)insurers will need to focus even more clearly on capturing the Secondary Modifiers (such as construction quality and flood protection) that will differentiate those risks with lower loss potential from legacy building stock.

The University of Cambridge Sustainability Leadership (CISL) proposed[113] an integrated assessment of climate risk in their *Climate Tango* report. They suggested five principles for the required systemic approach to understand the interconnections of climate-related risks. These include:

1. Conducting Transition and Physical Risk analysis simultaneously
2. Being sector- AND location-specific
3. Capturing climate risk impacts via forward-looking metrics
4. Accounting for feedback loops between Physical and Transition Risk
5. Alignment to the TCFD pillars on governance, strategy, risk management as well as metrics and targets

[110] TNFD (2022): Risk & Opportunity Management and Disclosure Framework [111] HM Government (2019): Green Growth Strategy [112] S&P Global / Trucost (2019): The Interplay of Transition and Physical Risks [113] CISL (2022): Climate Tango: Principles for integrating physical and transition climate-risk assessment with sectoral examples.

Ultimately, the likelihood is the path to lower carbon emissions will not be a smooth downwards trajectory. Climate shocks will come in phases that force dramatic policy action. Unfortunately, **the danger is that a combination of Nature-based and Physical Risk catastrophes will impact those regions most exposed to heat and drought, causing a lack of water and food that lead to consequent political risk turmoil**. The interplay between all of these is where urgent research and potential scenario analysis is required.

4. Conclusion

The objective of this report has been to highlight the rapidly evolving nature of the regulatory environment, with new climate-related financial disclosures putting increasing demands on (re)insurers, combined with the uncertainty of modelling the Physical Risks of climate change.

Insurers face a paradox. Pricing tends to reflect historical performance, yet each new major catastrophe reinforces what science is telling us: the future will bring more extremes, but it may take decades to verify that these are not just within the realms of natural variability. Meanwhile, the growth of the Insurance Linked Securities market and easy access to and the oversupply of fresh capital make it difficult for incumbents to price future risk to a level at which it perhaps needs to be.

We know that the rate and spatial characteristics of climate change are uncertain and that this change is non-linear. The impacts will be felt across both sides of insurers' balance sheets, although the risk to their assets may be felt sooner than the continued hits to their liabilities. While this report is aimed at reviewing stakeholders' actions on Physical Risks, there is no question that Transition Risk as well as potential impacts from Liability and Environment Risks must be managed concurrently. The greater the delay and the more disorderly its nature, the more Transition Risk will enhance the vulnerability component of Physical Risk.

As the IAIS GIMAR 2021 report[114] stated: "We lack a globally consistent framework for measuring climate risk-related financial information". Accurate and standardised data on exposure information has eluded the insurance market for decades, even before the evolution of catastrophe models. Perhaps the focus by Regulators, and now shareholders, on climate-related financial disclosures will provide a new urgency for this to be addressed. Ultimately, insurers, who are themselves the major investors in real estate and who will be increasingly required to report carbon emissions on the assets they own, should seize the opportunity to unify the reporting across assets and liability that will pay dividends in reducing the uncertainty of the Hazard module within catastrophe models.

There are many new actors in the business of climate analytics. With increasing acceptance of the role that Open Standards has in creating opportunity for product development, for example in Banking, it is urgent that Regulators specify and push for the use of standards for climate-related reporting on Physical Risks. This should extend to ensuring the availability of robust datasets.

We know that the impacts of exposure change and the related consequences of higher consumer price inflation, along with the compounding impacts of post-loss amplification should frequency of loss increase will all become major drivers of future loss. Covid-19 was a stark reminder of how interconnected global business is and how economic disruption and business interruption is perhaps a far greater risk to be considered.

Model vendors are continuing to adapt their arsenal of tools to reflect the latest science. The (re)insurance market has continued to enhance its skills in adjusting models to reflect their views of frequency and severity. This report has explored how increased heat contributes to more intense rainfall in tropical and extratropical cyclones, which leads to increased flood risk. Drought, whilst mostly uninsured, leads to increased wildfire risk, which has proved significantly more costly in the last five years. These harder to model perils are likely to be bigger drivers of insured losses in the future.

[114] IAIS (2021): GIMAR

Calculating the vulnerability of exposed assets is perhaps the hardest model component for (re)insurers to assess and then adjust. It requires deep knowledge of not just the insured asset, but anything that may contribute to enhancing or lessening to the risk from an infrastructure perspective too. Claims data are a vital component, firstly to understand the types of damage and secondly, to be used for back-testing of vulnerability calculations. Accurate and precise claims data, in conjunction with exposure data, is also key to understanding changing characteristics of hazards and thus perhaps contributing to defining the impact of climate change on how the peril has changed over time.

Most models have a broad range of construction and occupancy types that capture details of insurance values. Establishing industry standards for Open Exposure Data and encouraging the use of this, combined with matching claims data, would provide much-needed alignment and also the ability to test the increasing focus from secondary peril claims.

These multiple factors demonstrate that modelling the Physical Risks of climate change requires significant expert judgement; tinkering with model parameterisation may not provide the robust answers that stakeholders desperately need.

Appendix

Table 4 - Selected Regulatory Approaches to Climate Risk Assessment

Organisation	Type of Risk	Time Horizon	Methodology / Approach	Engagement Path
Bank of England (BoE)	• Physical • Transition	30-year modelling horizon (2020-2050 with five-year intervals)	Quantitative and qualitative • Qualitative: impact on business models and how these would change • Quantitative: change in value of assets and liabilities for each scenario Reporting frequency: five-year projections in the time horizon	Seeking feedback to papers/reports/plans Working groups and task forces **Climate Financial Risk Forum** https://www.bankofengland.co.uk/climate-change/climate-financial-risk-forum
Banque de France	• Physical • Transition	30-year modelling horizon (2020-2050 with five-year intervals)	Quantitative Pilot Exercise	Seeking feedback to papers/reports/plans
Sustainable Insurance Forum (SIF)	• Physical • Transition • Liability		Scoping Study – Nature-related risks in the global insurance sector	Seeking feedback to papers/reports/plans
Network for Greening the Financial System (NGFS)	• Physical • Transition	2050 and beyond	Focus on quantitative analysis Climate Scenarios for central banks and supervisors Orderly, Disorderly and Hot House World	Engagement through publication of reports Collaboration on scenarios
Autorité de Contrôle Prudentiel et de Résolution (ACPR)		30-year modelling horizon (2020-2050 with five-year intervals)		https://acpr.banque-france.fr/sites/default/files/medias/documents/20200717_main_assumptions_and_scenarios_of_the_acpr_climate_pilot_exercise.pdf
European Insurance and Occupational Pensions Authority (EIOPA)	• Transition (Introduction of carbon tax, technological breakthrough, market transition to low-carbon economy) • Physical (changes in frequency, severity, distribution of extreme events)	Longer than ORSA (an order of magnitude of decades) Short term: a higher level of precision is expected in order to help determine whether overall solvency needs improvement	Qualitative approach: insight in the relevance of the main drivers of climate change risks in terms of prudential risks Quantitative approach: assess exposure of assets and underwriting portfolios to physical and transition risk, forward looking. Explain why not deemed material	Seeking feedback to papers/reports/plans
Federal Financial Supervisory Authority (BaFin)	• Physical • Transition	Long term horizon (but no specification)	Quantitative	Seeking feedback to papers/reports/plans
International Association of Insurance Supervisors (IAIS)	• Physical • Transition • Liability	No specification other than “extended time horizon”	No prescriptive approaches	Seeking feedback to papers/reports/plans
Monetary Authority of Singapore (MAS)	• Physical	Short term	Quantitative	Seeking feedback to papers/reports/plans
	• Physical • Transition	Short term Long term	Stress testing and scenario analysis, both using quantitative and qualitative methods	Seeking feedback to papers/reports/plans

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