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Climate-Conditioned Catastrophe Models: A Tool for Assessing Acute Physical Risks in the Insurance Industry

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ABSTRACT

The insurance industry plays a key role in mitigating the after-effects of extreme weather events. However, institutions are also uniquely exposed to these acute physical risks via higher mortality and morbidity, as well as property damage due to flooding and coastal erosion. By nature of their business, insurers have more experience with catastrophe risk modelling, and available tools may be leveraged and adapted to support the quantification of potential losses for the industry. This paper seeks to sensitise stakeholders on the acute physical risks facing the insurance industry. Moreover, the influence of future climate scenarios on traditional natural catastrophe models is examined and climate-conditioned modelling approaches are discussed. The usefulness of climate-conditioned models in assessing acute physical risks is hindered by severe data limitations. Greater collaboration among industry stakeholders is required to access identified resources and data sources to close existing gaps.

JEL Classification Numbers: G22, G32, Q54
Keywords: Climate Change, Climate Data, Climate Risk, Physical Risk, Insurance, Financial Stability.

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Climate-Conditioned Catastrophe Models: A Tool for Assessing Acute Physical Risks in the Insurance Industry

Kateri Duke[1]

Introduction

Record-breaking weather over the last few decades is a stark reminder of the climate crisis and its socio-economic implications. Insurance companies play a key role in mitigating the after-effects of natural disasters—such as hurricanes, excess rainfall, and extreme heat—by strengthening the resiliency of policyholders through financial support. However, they are also uniquely exposed to the risks associated with these acute physical hazards via higher mortality and morbidity, as well as property damage due to flooding and coastal erosion. Simultaneous impacts on balance sheet assets and liabilities may follow. The dilemma is magnified in the Caribbean, where the cross-jurisdictional exposure of significant insurers increases the systemic risk of an extreme event, which may impact more than one island within a short period.

By nature of their business, insurers rely on natural catastrophe risk models to estimate potential losses due to extreme weather events. Loss estimates are produced in response to a number of hypothetical hazards of varying intensities, to aid in risk pricing for insured exposures. Output also supports and guides risk selection and underwriting, development of mitigation strategies and risk transfer mechanisms, reinsurance decision-making, and capital setting (Toumi and Restell 2014). Many insurers have successfully underwritten weather-related risks in the past. However, models are often based on historical data, and the increasing severity and frequency of extreme events show that the past may not be the best predictor of the future.

Traditional catastrophe models require adaptation to capture the long-term and evolving nature of climate change, and the subsequent impact on insurers' balance sheets.[2] While some commercial providers have moved in this direction, including major reinsurance companies, these 'climate-conditioned' models are often proprietary. Access to the underlying assumptions and historical datasets may be restricted, thus limiting external validation (Bank for International Settlements 2019). To circumvent this challenge, an increasing number of institutions have begun to develop and offer open-source catastrophe models as a public good. Most notably, the Network (of Central Banks and Supervisors) for Greening the Financial System (NGFS)[3] has leveraged open-source models and databases to help users estimate the impact of acute physical risks under future climate scenarios.

Globally, several insurers and regulatory authorities have incorporated bespoke climate-conditioned tools into traditional risk assessment frameworks. This has facilitated the quantification of the financial impact of climate risks, including through stress testing and scenario analysis. They have, however, been challenged by the short supply of weather and climate experts with experience in risk assessment and modelling. Such experts are desired by the insurance and banking sectors, which face similar challenges concerning data requirements, due to the unique characteristics of climate-related risks (Financial Stability Board 2021, Duke 2022). Indeed, the catastrophe modelling

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[1] The author wishes to express gratitude to Jenia Hamilton of the Central Bank of Trinidad and Tobago for her support in completing this study.

[2] Financial institutions may also consider incorporating climate change as an endogenous variable, to assess macroprudential risks, where the institution measures the implications of their investment or lending decisions on climate change itself (Stiroh 2022).

[3] The NGFS (launched in 2017) is a coalition of central banks and supervisors who, on a voluntary basis, contribute to the development of best practices for climate and environmental risk management in the financial sector, and are willing to mobilise mainstream finance to support the transition towards a sustainable economy. The Central Bank of Trinidad and Tobago became a member of the NGFS in 2021.

process is data-intensive and high-quality data is a necessary precursor to credible and robust results. As such, resources should be geared towards closing data gaps domestically.

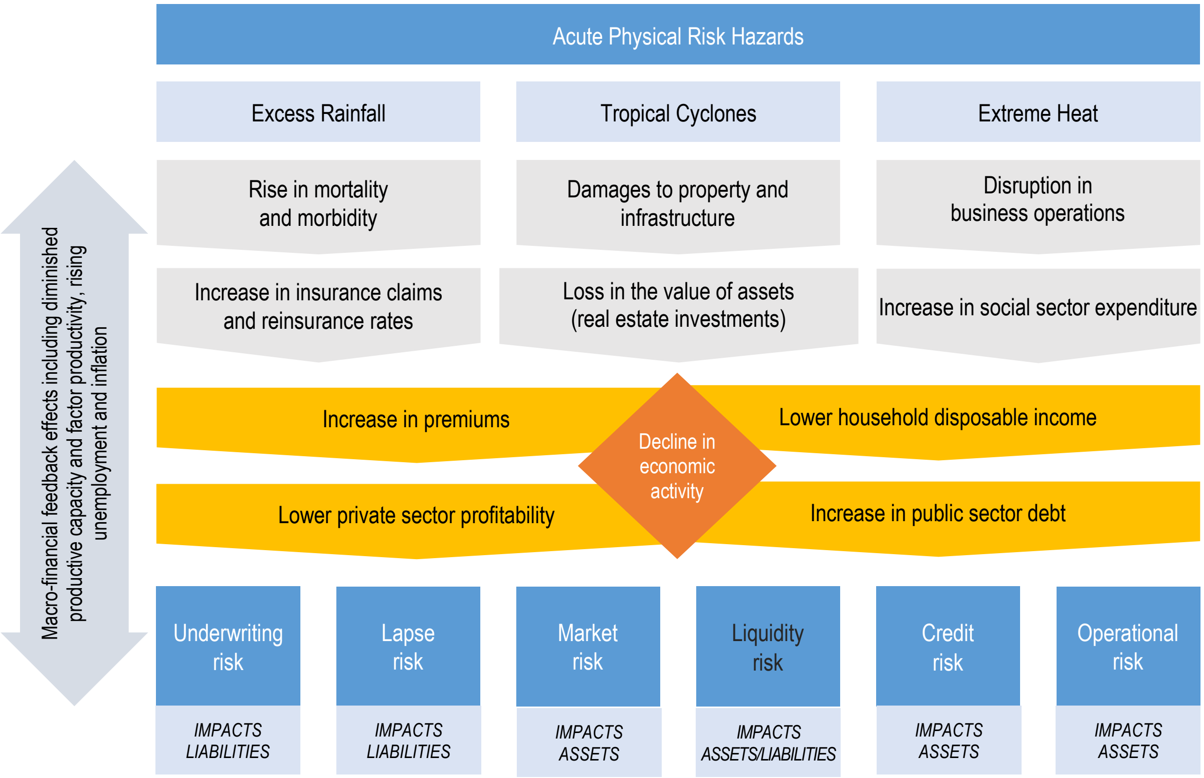
Utilising climate-conditioned catastrophe models to improve the assessment of acute physical risks can lead to better-informed decision-making by risk managers. This paper seeks to sensitise stakeholders on insurers' vulnerability to acute physical risks (**Section 2**), the features of natural catastrophe modelling (**Section 3**), and the influence of future climate scenarios on existing approaches (**Section 4**). Additionally, the paper outlines the data needs to facilitate a comprehensive risk assessment in the domestic industry (**Section 5**). The paper concludes with an action plan for the way forward (**Section 6**).

Acute Physical Risks to the Insurance Sector

Physical climate risks can be described as either acute or chronic. Chronic physical risks are associated with longer-term changes in climate, such as higher average temperatures or changes in precipitation patterns. In contrast, acute physical risks are those that are event-driven and have immediate impact. In Trinidad and Tobago, this includes hazards such as heat waves, or tropical cyclones and excess rainfall events that are accompanied by severe flooding. It should be noted that, although a singular excess rainfall event is expected to intensify due to climate change, total annual rainfall in Trinidad and Tobago is projected to decrease to the year 2100 (GORTT 2019). This may lead to a greater incidence of droughts, the effects of which may be worsened by heat waves.

Acute physical risk hazards can trigger a chain reaction in the macro-financial system, which may manifest as traditional prudential risks to the insurance sector. This includes underwriting, lapse, market, liquidity, credit, and operational risks. The remainder of this section describes the transmission channels of a shock to the domestic economy and the impact on an insurer's balance sheet (**Figure 1**).

Figure 1: Transmission Channels of Acute Physical Shocks in the Trinidad and Tobago Insurance Sector



Source: Author, Duke and Persad (2021), and EIOPA (2022).

Transmission Channels

When a shock is triggered, the following may materialise in the first instance:

- **Rise in mortality and morbidity** – Natural disasters or heat waves in high humidity could result in death. Moreover, compromised air quality due to bush fires, water-borne diseases in flooded areas, or an increase in vector-borne diseases (due to rising temperatures in humid conditions) increases the risk of illness. Economic distress due to decreased food production as a result of floods, and unavailability of power and water could also have a deteriorating effect on public health in the longer term.

- **Damages to property and infrastructure** – Hydrological events may lead to property damage and loss of agricultural products through flooding and (coastal) erosion. Uncontained bushfires as a result of extreme heat may also impact physical assets in close proximity.

- **Disruption in business operations** – Damages to property, including information and communications technology infrastructure, or a disruption in power and water supply may impact firms' ability to operate at full capacity (operational risk). This may impact critical operations such as claims management, if business continuity plans are weak. Generally, a disruption in business operations could lead to reduced private sector income and revenue for both insurers and insured firms, which could impact firms' equity values. Households may also face an income shock if employees are unable to work, leading to greater recourse to the state for income support.

Potential knock-on effects include:

- **Increase in insurance claims and reinsurance rates**
  - In the long-term insurance sector, a greater number of claims may stem from increased mortality and morbidity. However, these risks are partially hedged by longevity products and may be minimised by mitigants such as emergency preparedness measures. In the general insurance sector, increased claims may arise due to damage to insured physical assets, such as real estate and motor vehicles. Claims may be higher than expected due to information asymmetries (underwriting risk), which hinder appropriate pricing in exposed regions and sectors. Higher payouts may result in elevated liquidity risk.
  - General insurance policies, as well as the health or disability lines of long-term insurance, are generally repriced frequently (for example, on an annual basis). Insurers may therefore reprice risks post-shock, in response to increased data availability, or as advancements are made in climate projections. Policyholders may face increased premiums, while the company's exposure to underwriting risks may reduce. However, imperfect information still exists and insurers may be challenged by the possible recurrence of extreme climatic events within a particular year.
  - Insurers may also choose to cede increases in claims to reinsurers, particularly in the property line of business. Some reinsurers may be more resilient to acute hazards due to their geographical diversification; those who are less diversified may be susceptible to a credit rating downgrade. To compensate for the additional risk undertaken, reinsurers may choose to raise rates. These increases may be passed on to policyholders in the form of higher premium payments. An increase in the incidence of extreme weather events over time may lead to prohibitive increases in premiums or reinsurance rates, which may impact the availability of (re)insurance in some markets, further widening the insurance protection gap.
- **Loss in the value of assets (real estate investments)** – An extreme weather event may lead to the devaluation of investments in vulnerable sectors such as real estate, for example due to damaged property. This can trigger fire sales resulting in losses and falling asset prices (market risk). A domestic insurer may choose to raise premiums or withdraw coverage in particular geographical locations or business lines that

are deemed more susceptible to climate risk. This may contribute to falling asset values, especially if they are rendered uninsurable, and further weigh on real estate investments.

- **Increase in social sector expenditure** – An increase in social sector expenditure may arise from Government programmes to support recovery efforts, including for personal assets that are uninsured. This may impact Government finances, with implications for public sector debt and credit ratings. Major credit rating agencies have acknowledged the potential impact of climate change on sovereign credit ratings, but have yet to quantify it. However, researchers have suggested that economic damage as a result of climate change—particularly in developing nations with greater susceptibility to the physical effects—could result in sovereign credit rating downgrades up to two notches in the long term (Klusak et al. 2023). Harsher economic conditions could ensue.

Macro-financial feedback effects could exacerbate risks to insurers. Feedback effects include diminished productive capacity and factor productivity, rising unemployment, and inflation. Harsher economic conditions, lower productivity, and significant costs of recovery may weigh on businesses' continuity and profitability, further diminishing available funds to pay premiums. Moreover, impacts on the insurance sector may have implications for other areas of the financial system. Reduction of insurance in affected areas may impact collateral values. An increase in premiums may also weigh on household and corporate balance sheets. These may have knock-on impacts for banking sector asset quality and profitability.

Acute physical risk hazards trigger the risks to the insurance sector, but ultimately, the magnitude and duration of the impact on an institution's balance sheet is a function of several variables: the *hazard* or extreme weather event; the level of *exposure* due to location and asset values; the *vulnerability* of the exposure in the presence of mitigating factors; and the *financial, social, and macro-economic impacts* as a result of feedback effects. Impacts vary across individual institutions due to their core business model, specific risk profile, and risk horizon. Natural catastrophe modelling, a traditional tool in the insurance industry, aids in quantifying acute physical risks.

Natural Catastrophe Modelling

Natural catastrophe modelling plays an essential role in an insurer's understanding and management of risk. Though the approach was introduced in the late 1980s, its popularity grew in the aftermath of Hurricane Andrew in the early 1990s, which highlighted the shortcomings of the prevailing actuarial technique for estimating catastrophe losses. The technique, reliant on historical experience, resulted in the insolvency of 11 insurers.[4]

Catastrophe modelling leverages computer programs to simulate the behaviour and physical impact of disastrous events, bringing together disciplines such as computer science, climatology, meteorology, seismology, engineering, actuarial science, and statistics (American Academy of Actuaries 2001). In doing so, it provides insurers with more comprehensive information on potential losses than historical data on its own.

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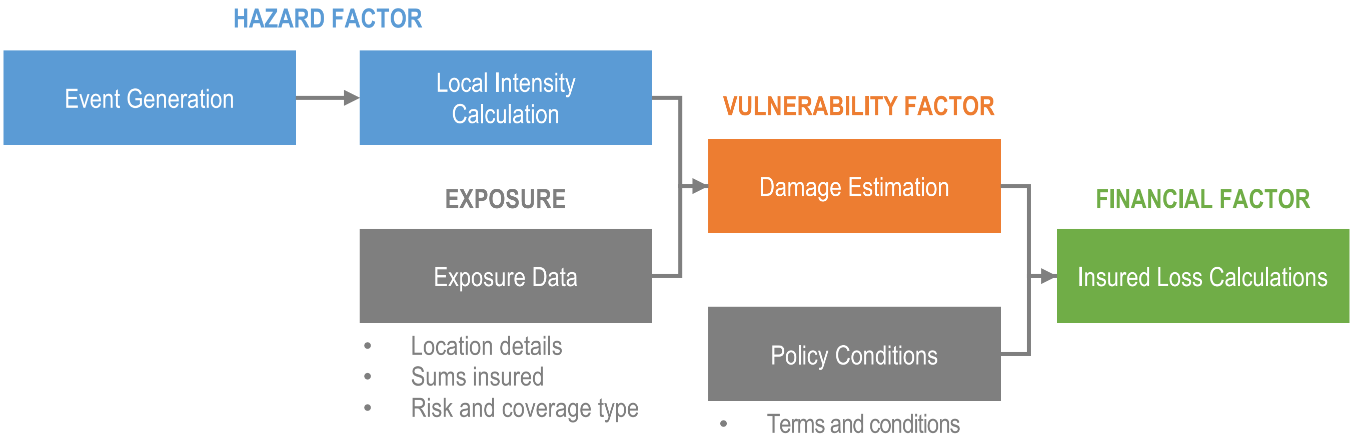
[4] Hurricane Andrew struck the state of Florida (United States) in 1992 as a category 5 hurricane. Economic losses in the United States were approximately US$25 billion, US$15.5 billion of which was insured, making it the costliest hurricane to hit the United States at that time (Churney and Ma 2012).

Traditional catastrophe modelling frameworks generally incorporate four components: event generation, local intensity calculation, damage estimation, and insured loss calculations. These components correspond to the variables required to quantify the financial impact of an acute physical risk, including hazard, exposure, vulnerability, and financial (**Figure 2**).

Figure 2: Catastrophe Modelling Framework



Sources: Adapted from American Academy of Actuaries (2001) and Dlugolecki et al. (2009).

Hazard Factor

Event generation and local intensity calculation are considered under the hazard factor. Using historical data as a starting point, the event generation stage produces thousands of hypothetical stochastic events that could occur over a specific time frame, each with a unique combination of size, strength, location, and probability of occurrence.

Local intensity calculation determines the physical impact of the hazard at a particular geographical location. For tropical cyclones, event characteristics may include landfall point, peak wind speed, or radius of maximum winds; local intensity calculations may be expressed as wind speeds or storm surge height at a particular location.

The hazard component is developed by a multidisciplinary team of scientists including climatologists, meteorologists, and seismologists. These experts continuously refine their methods by analysing the latest scientific research and their own findings to produce more precise results (Verisk 2022).

Vulnerability Factor

Local intensity calculations are combined with insurer exposure data to produce the vulnerability factor. This facilitates the development of damage or vulnerability functions, which assess the average damage to an insured exposure in response to a potential hazard. Actual damages are due to the exposure's physical characteristics, location, and sum insured. In the case of real estate exposures, physical characteristics may include building type, height, age, construction material, population, and usage.

Damage functions provide the ratio of building repair costs to the replacement value of the entire structure (Clark, Manghnani and Chang 2015). They are produced by structural engineering experts using the most recent research in the field, findings from laboratory testing or on-site damage surveys, and claims data provided by insurance companies (Verisk 2022).

Financial Factor

Damage estimates are then considered in the context of specific policy terms and conditions—including limits and values by coverage, deductibles, and reinsurance coverage—to determine the financial impact or estimated insured losses. Other variables such as policyholder preparedness and government assistance may factor into the calculation. Results are produced by experts in the fields of statistics and actuarial science and may be expressed as a distribution of probabilities or the likelihood of various levels of loss, occurring from the hypothetical events generated (Angelina 2014).

Primary metrics produced by a model include the Exceedance Probability (EP) or Probable Maximum Loss (PML), and the Average Annual Loss (AAL). Two types of EP loss distribution curves may be generated: Occurrence EP or OEP (probability of losses from the single largest event in a given year); and Aggregate EP or AEP (probability of losses from all events in a given year). Some firms may also produce the Tail Value at Risk (TVaR). Output may vary by the particular catastrophe model or the needs of the insurance company. **Table 1** describes the characteristics of these metrics.

Table 1: Catastrophe Model Output – Metrics

METRIC	FEATURES	TERMINOLOGY/INTERPRETATION
Exceedance Probability (EP) or Probable Maximum Loss (PML) DESCRIPTION *The likelihood that a loss exceeding a certain threshold will occur in a particular time period*	Most common analysis type used. Loss distribution curve shows the probability of exceeding various loss levels. Equal to the inverse of the return period. Used for portfolio management and reinsurance buying decisions.	If the EP curve shows that the 250-year return period loss is $204m, this implies that there is a 0.4 per cent chance of having losses exceeding $204m or greater in a given year (EP = 1/return period = 1/250 = 0.004 = 0.4 per cent).
Average Annual Loss (AAL) DESCRIPTION *The loss that can be expected to occur per year, on average, over a period of many years*	Mean value of a loss EP distribution Estimate of the amount of premium required to balance catastrophe risk over time. Used for pricing and ratemaking	If the AAL for 10,000 years of simulated activity is $100m, this implies that the mean loss or expected value that occurs in any given year is $100m. It is calculated as the average of each simulation year's losses over 10,000 simulations.
Tail Value at Risk (TVaR) DESCRIPTION *The average expected value of loss beyond a specific exceedance probability*	Also known as Tail Conditional Expectation (TCE) Measures the average severity of losses in the tail of the distribution.	If the 250-year return period loss is $204m and the TVaR is $352m, this implies that there is a 0.4 per cent annual probability of a loss exceeding $204m. Given that at least a $204m loss occurs, the average severity will be $352 million.

Sources: Angelina (2014) and Verisk Analytics (2017).

Model metrics inform routine insurance or actuarial functions. For example, AAL estimates factor into premium pricing[5], alongside the expense load and risk load[6]. Metrics may also aid in underwriting decisions and portfolio

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[5] Pricing is not determined solely by model output, but by a combination of model output, risk from non-catastrophic events, operational expenses, targeted profit margins, and external factors, such as the cost of reinsurance (Verisk 2022).

[6] The risk load is the capital required beyond the expected annual loss to cover potential losses. It is often a multiple of the AAL estimate.

optimisation by highlighting the impact of adding new business to the insurer's portfolio. For example, an individual property exposure may have a relatively high AAL, but if there is low concentration in the insurer's book, then the impact on the overall PML (and reinsurance costs) is minimal. As a result, the new risk may be deemed acceptable. The insurer may also review the portfolio TVaR to determine the effect on the distribution tail (extreme risk) at various return periods (American Academy of Actuaries 2018).

An insurer must maintain sufficient capital to cover unexpected losses due to natural catastrophes and meet its obligations on an ongoing basis, that is, remain solvent. Loss distribution curves and associated metrics may, therefore, impact solvency capital requirements (SCR) such as those outlined under the Solvency II framework introduced by the European Insurance and Occupational Pensions Authority (EIOPA). Companies may use standard or internal models to determine their SCRs. Natural catastrophe models are often embedded into the internal modelling process, which is subject to regulatory approval. Model use and results are also required to complete an Own Risk and Solvency Assessment (ORSA)[7], a key feature of Solvency II.

Catastrophe Modelling and Climate Risk

Catastrophe models are aptly suited to measure climate risk as they are able to translate acute physical risk hazards to potential losses. Moreover, they help overcome limitations of using historical records[8] by simulating a large number of plausible events that are consistent with the scientific view of their likelihood (American Academy of Actuaries 2018). Models are continually reviewed, updated, and validated by providers using actual data and the latest science. That said, if they are not adjusted for long-term trends, events generated for current climate conditions would reflect only the average climate over the period of data inputted (Bank of England 2019). **Table 2** presents further opportunities and limitations of using catastrophe models to measure climate risk and future climate scenarios.

Table 2: Opportunities and Limitations of Using Catastrophe Models for Climate Risk Assessment

OPPORTUNITIES	LIMITATIONS
Catastrophe models simulate significantly more realistically plausible events than are contained in the historical record.	Catastrophe modelling is complex and requires a large number of assumptions; results contain considerable uncertainty.
A large number of simulated years provides comprehensive distribution of potential events.	Some core model assumptions are considered proprietary and are not readily accessible to users. Model changes with software updates can cause stability concerns.
There are several catastrophe models available to the insurance industry.	Requires either reliance on a company's reinsurer or other third party, or significant investment in training, software, and hardware to develop and maintain internal expertise.
Catastrophe models are updated regularly and often, using the latest science.	Collecting crucial building characteristics is not an easy task for an insurance company and may incur a substantial cost.
Catastrophe models are aligned with current risk management used in insurance companies and climate-adjusted results may be presented in familiar metrics.	There are potentially large ranges of output values among different models for the same region.

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[7] The ORSA represents a forward-looking view of risk and helps an insurer understand the impact of its material risks on capital needs. As of August 2024, an ORSA guideline was being developed for domestic insurers (Central Bank of Trinidad and Tobago 2024).

[8] Historical experience is not reflective of potential due to limited records, infrequent events, and potentially changing conditions (including data such as population, building codes, and replacement values) (Angelina 2014).

Catastrophe models capture correlation between assets in a portfolio, and provide full aggregation to portfolio-level metrics.	Outputs are generally aimed at insurance liability use cases only. Requires additional steps to assess impact on assets.
Catastrophe models encourage sensitivity testing, which leads to more frequent and thorough testing.	Climate science is considered over the long-term, while insurance risk management may be considered over shorter horizons.
	Climate change research and models focus on a wider geographical grid than is required by insurers to assess exposures to a particular area.

Sources: Dlugolecki et al. (2009), Angelina (2014), American Academy of Actuaries (2018), Climate Risk Financial Forum (2022), and Aon (2023).

Through a collection of case studies, Lloyd's (2014) analysed the extent to which climate change was incorporated in prevailing catastrophe models and the impact of future climate scenarios. Several model providers concluded that recent trends in climate would be implicitly included in catastrophe models via data, rather than through an explicit adjustment. Long-term data leveraged in model construction captured historical climate variability. In particular, data from the recent past may signal trends in climate change. The uncertainty surrounding the path of greenhouse gas (GHG) emissions and its impact on physical hazards deterred most providers from explicitly modelling future climate change at the time.

For example, future climate scenarios were not incorporated into EQECAT's standard catastrophe model (as of 2014), which assessed the impact on European windstorms. However, when their model was studied alongside an external climate model, EQECAT found that future climate scenarios were expected to increase the frequency of severe storms and shift the storm path further north. The Climate-Knowledge Information Centre concurred that intensification of European windstorms was likely, as suggested by various climate models, but the storm path varied by model and region. In its assessment of UK flood, the JBA Group indicated that climate projections—such as increased precipitation, higher peak river flows, and rising sea levels—were gradually being incorporated into national flood risk models.

The impact of future climate scenarios on tropical cyclones was also analysed. RMS considered the influence of projected sea-surface temperatures on modelled losses in the North Atlantic region. The contribution to existing medium-term activity forecasts was small. In contrast, the impact of changes in sea level on storm surge losses was more significant. Similarly, AIR Worldwide found that there was little increase in modelled losses for tropical cyclones in the South Pacific, when combining existing models with external climate model output. Meanwhile, Climatek found that sea-surface temperatures were a factor in hurricane strength, especially in the North Atlantic region, and the relationship between wind speed and loss was exponential.

Climate-Conditioned Modelling

The catastrophe modelling industry has evolved since its introduction, in response to improved technologies, an increase in data availability and granularity, and the changing risk landscape. Recognising the opportunities presented and cognisant of the limitations, a growing number of institutions have begun to adapt their standard catastrophe models to explicitly account for future climate scenarios. These climate-conditioned approaches leverage the output of external climate models called general circulation models (GCMs) or global climate models, which reflect the latest and best understanding of climate change impacts within the global scientific community (**Box 1**).

Future climate scenarios influence different stages of the traditional catastrophe modelling framework, with potential impacts on model output. The long-term and forward-looking nature of climate change magnifies uncertainties related to the frequency and severity of extreme events. While frequency and severity adjustments are necessary, models should also reflect the possibility of multi-hazard events, macro-financial feedback loops, and tipping points. These factors contribute to increased tail risks (Rye 2023). Further uncertainty is presented due to political issues, which may influence the speed of the climate transition pathway and the impact on GHG emissions. Indirect effects, such as supply chain disruptions, contribute to the systemic impact.

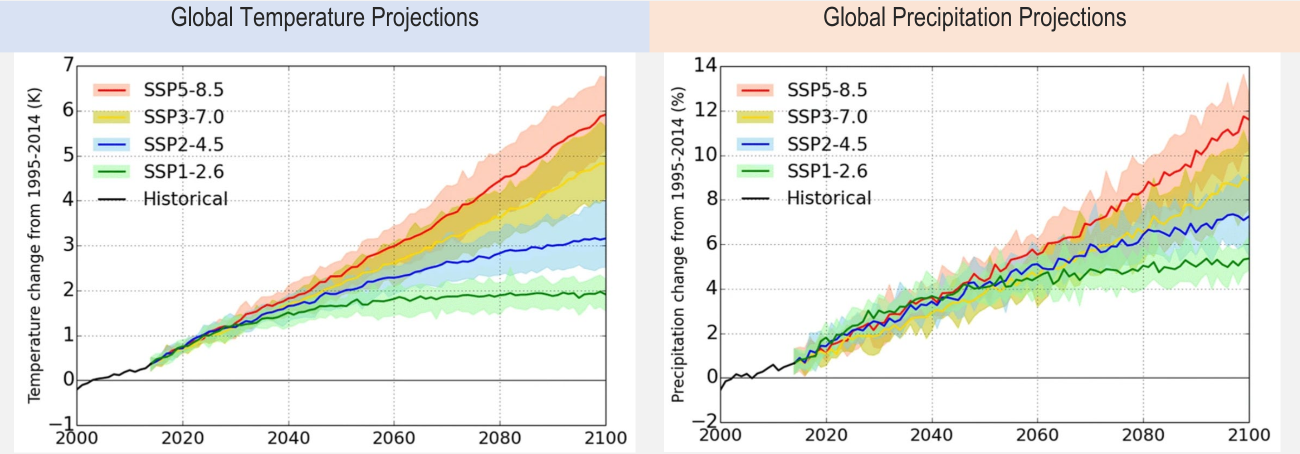
It is important to acknowledge the inherent uncertainties in climate-conditioned models and the limitations of model output over the short- and long-term horizons. In addition to data quality issues, a common challenge is the absence of mitigation and adaptation measures, which require assumptions on public and private actions to improve the resiliency of assets and infrastructure. Limitations should be well understood by users, especially when models are provided by third-party companies, so that results are interpreted soundly. This helps minimise the danger of false certainty and the neglect of potentially extreme adverse outcomes (Turner 2023).

Box 1: General Circulation Models (GCMs)

GCMs are complex mathematical models that provide a thorough representation of physical processes in the climate system, including the atmosphere, ocean, cryosphere, or land surface. Multiple GCMs representing the different components of the climate system are "coupled" to form global climate models. They give insight into the changes in the climate system, over different time periods and geographic grid locations, due to natural changes or an increase in greenhouse gas (GHG) emissions (World Bank 2016).

More than one global climate model is used as the basis for climate projections provided by the Intergovernmental Panel on Climate Change (IPCC)[1], under different GHG emissions scenarios (Lee et al. 2021). Multi-model ensembles provide output related to hazard data such as temperature, precipitation, sea levels, and wind speeds (**Figure 1**). When jointly considered, model output characterise a climate scenario. As such, GCM data is typically the first input into quantitative climate risk assessments.

Figure 1: Climate Change Projections Simulated by CMIP6 Model based on GHG Concentration Pathways



Global Temperature Projections

Global Precipitation Projections

Source: Sung (2021).
Note: CMIP6 consists of the "runs" from around 100 distinct climate models being produced across 49 different modelling groups. Charts depict the time series for the historical simulation (black) from 1995 to 2014, and future simulations for four climate scenarios (SSP-RCPs) from 2015 to 2100, respectively. The shaded area indicates the ensemble spread of multiple models.

According to the IPCC, GCMs may facilitate geographically and physically consistent estimates of climate change, which are required in impact analysis. However, there is significant uncertainty and variability in their output due to the number of assumptions applied. Moreover, GCM estimates may not be at the required granularity due to coarse spatial and temporal resolution. Additional processing is therefore required to "downscale" output to a regional or local resolution (Climate Risk Financial Forum 2022). These are referred to as regional climate models (RCMs). The Network for Greening the Financial System (NGFS) recommends that GCMs be selected based on data availability for a particular region (NGFS 2020).

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[1] The IPCC is the leading authority on assessing the science related to climate change. The assessments produced by the international body are used as a basis for governments to develop climate related policies as they underlie negotiations at the United Nations Framework Convention on Climate Change (IPCC 2021).

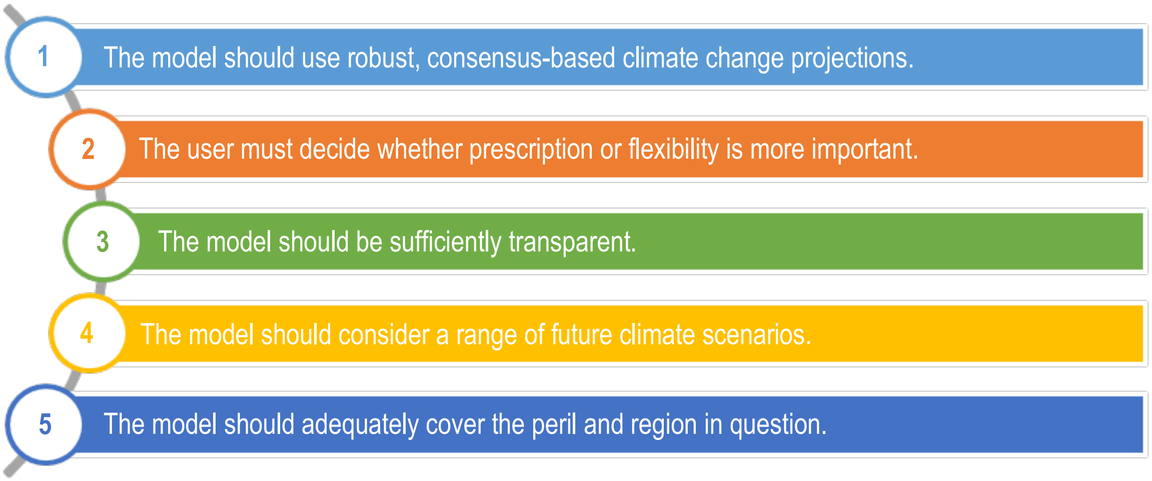
Model Adaptation and Selection

A traditional catastrophe model may be adjusted to account for future climate scenarios in three ways (Zurich Insurance Group 2019, Bank of England 2019):

1. **Scenario mock-up**: model output may be adjusted in a scenario mock-up, that is, existing events are modified to reflect average climate change effects. Expert judgement may be required to determine the necessary adjustments.
2. **Partial rebuild** (coupling climate models with existing natural catastrophe models): a partial rebuild adjusts the frequency and severity of events in the stochastic data set (new events are created), for example, changing the frequency of events in the event loss table. Through the use of GCMs, input variables and parameters are modified for a range of future climate scenarios, corresponding to different GHG emissions. While this approach is more scientifically robust than a scenario mock-up, it is resource intensive.
3. **Complete rebuild** (developing an in-house solution): a complete rebuild involves the construction of a proprietary natural catastrophe model, which reflects all relevant climate data. It is the most sophisticated and costly approach.

When selecting a climate-conditioned catastrophe model, users should consider the business decisions (and associated time horizons) and whether there are sufficient internal resources available for more complex analysis (Bank of England 2019). **Figure 3** suggests guiding principles for model selection.

Figure 3: Principles for Selecting a Climate-Conditioned Catastrophe Model



Sources: Climate Risk Financial Forum (2022) and Bank of England (2019).

Climate-Conditioned Approaches in Practice

Many climate-conditioned models, databases, and methods are proprietary and not freely or openly available to the public. Commercial providers, such as reinsurance companies with a domestic presence, have been introducing climate-specific services, including climate advisory and modelling[9][10][11]. While open-source catastrophe modelling tools are beneficial to insurance companies and supervisors, they may require additional validation. Moreover, training or technical expertise is required to adapt such tools for specific country applications (NGFS 2022b). The remainder of this section highlights two open-source modelling platforms, the Oasis Loss Modelling Framework and CLIMADA. Further, the climate-adjusted model for the CCRIF risk-pooling facility is reviewed, followed by a commercial model.

Open-Source Climate-Conditioned Modelling Platforms

Oasis Loss Modelling Framework[12]

The Oasis Loss Modelling Framework is an open-source catastrophe modelling platform[13] with global coverage for a range of natural and man-made disasters. The platform, which uses a web-based user interface, was launched in 2012. Development is largely driven and funded by the global reinsurance industry. Users may freely access over 90 models, from more than 18 providers, that utilise a consistent set of standards for hazard and vulnerability data. As such, model output is reported in a consistent format. Output may reflect full uncertainty, event loss tables, or year loss tables. The platform also includes a toolkit for developing, testing, and deploying catastrophe models (**Figure 4**).

A unique advantage of the modelling platform is its range of deployment options. Users may:

1. Deploy the entire platform as an in-house or hosted solution.
2. Deploy the Application Programming Interface (API) and model execution framework externally, and integrate with internal exposure management systems.
3. Deploy the model execution framework to the cloud, providing scalability and the ability to add capacity during periods of peak usage.
4. Deploy specific modelling components in other applications, for example the platform has a financial module, which could be used for exposure reporting.

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[9] Guy Carpenter. 2021. *Guy Carpenter launches suite of climate advisory and modeling services.* July. Accessed April 2023. https://www.guycarp.com/insights/2021/07/guy-carpenter-launches-suite-of-climate-advisory-and-modeling-services.html.

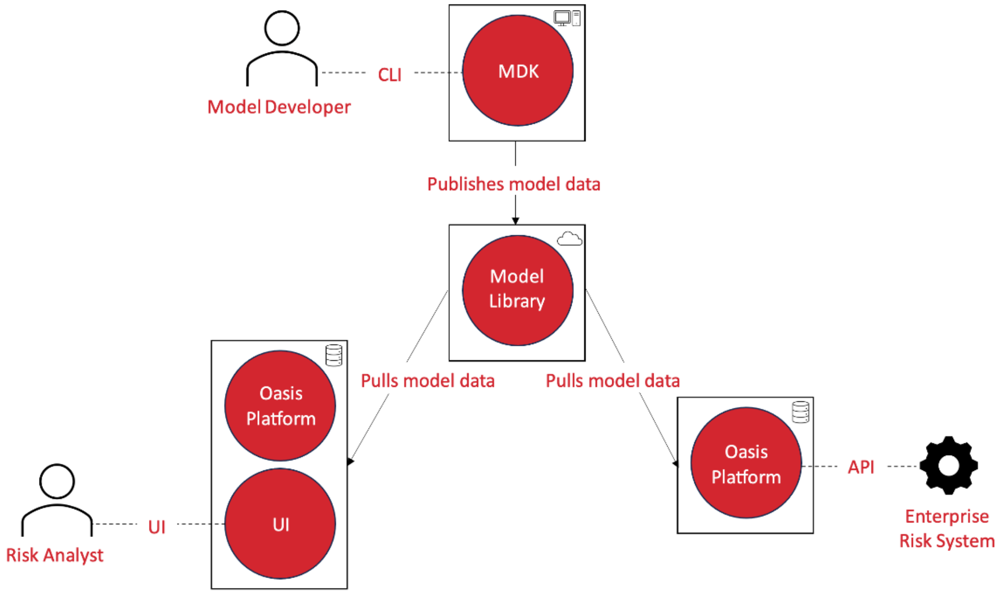
[10] Aon. 2022. *Aon Expands Catastrophe Modeling and Consultancy Capabilities with Acquisition of ERN in Latin America.* November. Accessed April 2023. https://aon.mediaroom.com/2022-11-10-Aon-Expands-Catastrophe-Modeling-and-Consultancy-Capabilities-with-Acquisition-of-ERN-in-Latin-America.

[11] Swiss Re. 2021. *Swiss Re Corporate Solutions launches Climate Risk Solutions for Corporates in Asia Pacific.* April. Accessed April 2023. https://corporatesolutions.swissre.com/insights/news/climate-risk-solutions-for-corporates-in-asia-pacific.html.

[12] Oasis LMF (2024).

[13] https://github.com/OasisLmf

Figure 4: Overview of the Oasis Loss Modelling Framework



Source: Oasis LMF (2024).
Notes: UI – Oasis User Interface; MDK – Oasis Model Development.

CLIMADA[14]

CLIMADA (CLIMate ADAptation) is a global, open-source natural catastrophe platform[15] that provides users with the tools to understand the impact of weather and climate on their economies, including a cost/benefit analysis of risk management options (**Figure 5**). The framework was developed in 2017 and has been maintained by the Weather and Climate Risk Group at ETH Zürich (a public research university). CLIMADA is an event-based, probabilistic approach that is underpinned by Python programming. It simulates the impact of thousands of hypothetical hazard events on infrastructure, environmental assets, and people, taking into account their exposures and vulnerabilities. In particular, it provides global coverage of tropical cyclones, river floods, agricultural droughts, and wildfires at high resolution, via a data API. The framework may also be used to assess averted damages due to adaptation measures[16], and to quantify socioeconomic impacts under varying scenarios.

Most notably, the model considers future climate scenarios and has been leveraged to derive the economic damages reported in the NGFS's Climate Impact Explorer. Risk measurement units are selected based on relevance. For example, risk may be quantified by the size of the land exposed to the hazard, the number of persons affected, or the cost of repairs. While CLIMADA provides open access to globally consistent hazard and exposure datasets, the model may be customised with national data to improve the quality of the output.

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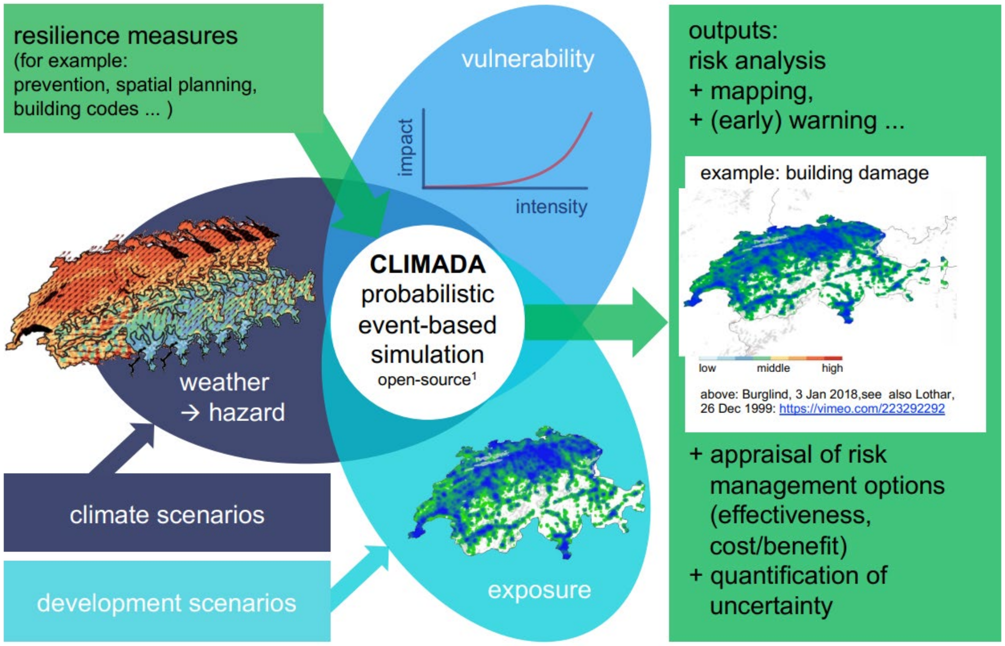
[14] Global Programme on Risk Assessment and Management for Adaptation to Climate Change (Loss & Damage) & Climate Analytics (2021) and ETH Zürich (2017).

[15] https://github.com/CLIMADA-project/climada_python

[16] Measures include eco-system-based approaches, strengthening of building codes, retrofitting of infrastructure, rainwater harvesting, building of sea walls and other structures, ridge-to-reef and whole-island approaches, and risk transfer against more extreme weather events.

Figure 5: Visualisation of the CLIMADA Framework



Source: Global Programme on Risk Assessment and Management for Adaptation to Climate Change (Loss & Damage) & Climate Analytics (2021).

As an example, CLIMADA was used to quantify the risk arising from tropical cyclones in Antigua and Barbuda, and the ensuing economic impact on Small Island Developing States (Global Programme on Risk Assessment and Management for Adaptation to Climate Change (Loss & Damage) & Climate Analytics 2021). CLIMADA engaged the use of hazard, exposure, and vulnerability data from open-access sources such as 'IBTracs' (International Best Track Archive for Climate Stewardship). This data was inputted into the model to calculate climate risk for two specified time horizons (2030 and 2100) and two climate change scenarios (1.5°C and 3°C of global warming by the end of the century).

Subsequently, the annual expected damages (AED)[17] in 2020, 2030, and 2100, and the aggregated damages for 2020–2030 and 2020–2100, were calculated for each scenario. From this, benefit/cost ratios for each measure were then determined from external sources and were estimated based on regional studies or global assessments. Benefits were computed as the averted damages resulting from the hazard reduction factor of each adaptation measure. For risk transfer, benefits were calculated as the covered or insured losses. Lastly, the reduction in damages through adaptation measures was calculated for each scenario.

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[17] Similar to AAL, the AED is the cost that would be incurred in any given year the financial losses from all hazard probabilities and magnitudes were distributed evenly over time.

Other Climate-Conditioned Modelling Approaches

SPHERA[18]

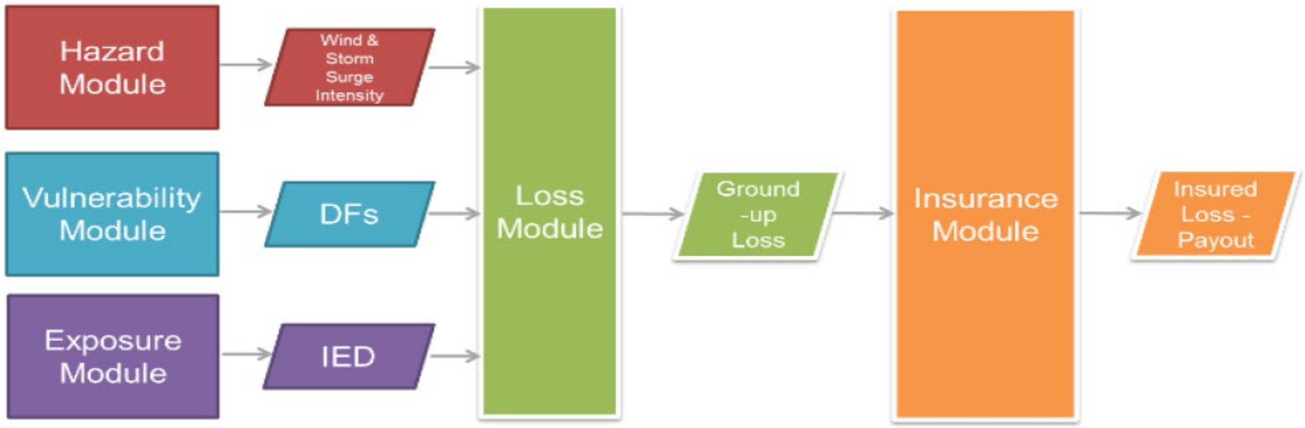
In the 2016/2017 policy year, CCRIF SPC (the Caribbean Catastrophe Risk Insurance Facility) began the development of tropical cyclone and earthquake loss assessment models—System for Probabilistic Hazard Evaluation and Risk Assessment (SPHERA)—to incorporate the impacts of climate change into their existing model. The SPHERA model utilises current datasets and techniques, enabling it to produce a probabilistic assessment of tropical cyclone risk; estimate the damages to buildings and infrastructure in near real-time; and compute payouts to countries insured under CCRIF in the event of a tropical cyclone.

The SPHERA model is composed of three elements of risk analysis: hazard, vulnerability, and exposure (**Figure 6**). The hazard module computes the probability of the occurrence of an event. The intensity of each event has two components, maximum wind speed and maximum storm surge, which are calculated in this module. The vulnerability module calculates how the country's asset levels will respond to different levels of event intensity. The exposure module quantifies the value or replacement cost of the country's assets.

The datasets used in the exposure module include national building census surveys; land use/land cover maps; night-time lights imagery; population censuses; Digital Elevation Models; and satellite imagery. These facilitate the identification of the most prevalent forms of construction in the country under observation. Peer-reviewed literature and reports from the World Housing Encyclopedia are used to define the building classes. Information regarding the residential building stock is collected from the most recently available national census survey data.

A loss computation module is used to combine these three components to estimate the damages caused by an event or a set of events. Finally, the insurance module determines if the country in question has triggered its insurance policy, and, if so, calculates the related payout.

Figure 6: Conceptual Flow of the SPHERA Tropical Cyclone Model



Source: CCRIF SPC (2019).
Notes: DF – Damage Function; IED – Infrastructure Exposure Database.

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[18] CCRIF SPC (2019).

RMS/EQECAT

UK climate projections have been incorporated into catastrophe modelling programs, such as Risk Management Solutions (RMS) and EQECAT, to assist insurance companies in assessing their likely losses due to flooding in the UK. Their methodology begins with validating the climate-conditioned catastrophe flood model for the UK. Using the UK Climate Projections 2018 (UKCP18) climate simulations, hazard layers are generated for various return times and climate scenarios throughout the entire region.

With regards to datasets, information pertaining to UK flood hazard and risk at national and subnational scales can be categorised into five broad classes: UK flood hazard maps; UK flood risk maps; current and future flood risk estimates produced as part of the UK's Climate Change Risk Assessment process; flood hazard and risk data produced by commercial modelling firms; and flood losses recorded by the Association of British Insurers. Flood events are then characterised accordingly.

Subsequently, flood event footprints are generated through the process of sampling from existing hazard layers. These are used to calculate monetary losses for specific global warming levels over pre-industrial levels. To determine whether an index has succeeded or failed, the final step involves validating this index against historical national return period flood maps.

Data Needs

The catastrophe modelling process is data-intensive; high quality and sufficiently granular data are necessary to achieve credible output. Moreover, for a complete acute physical risk assessment, a range of quantitative and qualitative tools and approaches should be utilised in tandem, especially in light of the large uncertainty in model outputs (The Geneva Association 2021). The following section identifies data needs under both approaches.

Qualitative Data

In practice, qualitative data is viewed as an important supplement to quantitative exposure data. Where there are known challenges with exposure data, qualitative data may be used as a starting point for risk analysis.[19] This information is typically captured via questionnaires issued to the industry.

The Sustainable Insurance Forum (2020) provides a comprehensive question bank (over 70 questions), developed by its supervisory and regulatory membership, which seeks to capture the impacts on insurers' business as underwriters and investors. Questions vary in complexity and are organised into nine categories: overall familiarity; governance and strategy; underwriting practices; investment practices; liability risks; scenario analysis and stress testing; disclosure and information; skills, capacities, and culture; and the role of the supervisor. Results should point to levels of awareness, understanding, and sophistication of insurers' climate risk management practices. The question bank may have a range of applications for ongoing supervision.

Based on the aforementioned guidance, the International Association of Insurance Supervisors (IAIS) (2021) suggested a number of questions according to physical, transition, and liability risks.[20] **Table 3** extracts general questions, and questions related to catastrophe modelling and physical risk. In conducting its own industry surveys,

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[19] In 2020, the Central Bank of Trinidad and Tobago issued a qualitative survey to domestic insurers to capture information on climate-related risk management (**Appendix A**). However, just over 20 per cent of companies responded.

[20] Recommendations also consider guidance provided by the United States National Association of Insurance Commissioners.

the Sustainable Insurance Forum noted that supervisors or regulators may retain open-ended questions, or to facilitate quantitative analysis, adapt potential responses to multiple choice or the Likert scale.

Table 3: Sample Qualitative Questions for the Assessment of Physical Climate Risk

GENERAL	
1.	What are the environmental, economic, social, political, technological, or reputational risks and opportunities related to climate change that are relevant for your business?
2.	Has your organisation implemented or planned any substantive changes to its business model, strategy and/or risk appetite in response to current and potential future climate-related risks?
3.	Does your organisation have a strategy to address climate change?
4.	Are there governance structures in place in your organisation through which Board Members may have oversight over climate-related risks? Is there a specific Board Member identified to deal with these risks?
RISK MODELLING	
1.	Does your organisation utilise catastrophe modelling (either proprietary models or third-party service providers) in any of your underwriting processes? Describe if and how these models consider climate change factors, and the sources of data used to model climate change impacts.
2.	How does your organisation evaluate whether risk models are providing a robust view of physical climate risk profiles in the jurisdictions in which you operate?
3.	How confident is your organisation in the robustness of projections for physical climate risks in the near term (next 3-5 years)? What about the longer term (5-10 years)?
4.	Beyond catastrophe models, does your organisation use other types of quantitative analytics or data to inform your analysis of climate-related risks?
5.	How are you seeking to explore potential long-term impacts of climate change (i.e. 10-20 years) on your underwriting business?
PHYSICAL RISK	
1.	Does your organisation expect that physical risks will materially affect business performance, in terms of market demand, claims experience, or other factors?
2.	Does your organisation expect that physical risks will materially affect the valuation of financial assets in your investment portfolio, and how do you expect these risks to materialise over the short, medium, and long term?
3.	Does your organisation directly or indirectly incorporate climate-related factors into the pricing and underwriting of insurance products?

Source: Sustainable Insurance Forum (2020) and International Association of Insurance Supervisors (2021).

Domestically, an insurer may incorporate climate risk into its internal risk assessment framework in the context of the Financial Conditions Report (FCR)[21], which provides a qualitative assessment of an insurer's financial conditions. Catastrophic scenarios are described on an institutional basis, together with potential extreme outcomes. However, the FCR neither outlines standard scenarios across all companies, nor provides quantitative data for ease of comparability or compilation. In Trinidad and Tobago, insurers submitted their first FCR in 2022/2023.

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[21] Pursuant to sections 159 and 214 of the Insurance Act, 2018 (Act) and regulation 11(2) of the Insurance (Financial Condition Report) (FCR) Regulations, 2021 (Regulations), the FCR provides a qualitative assessment of insurers' financial conditions.

Quantitative Data

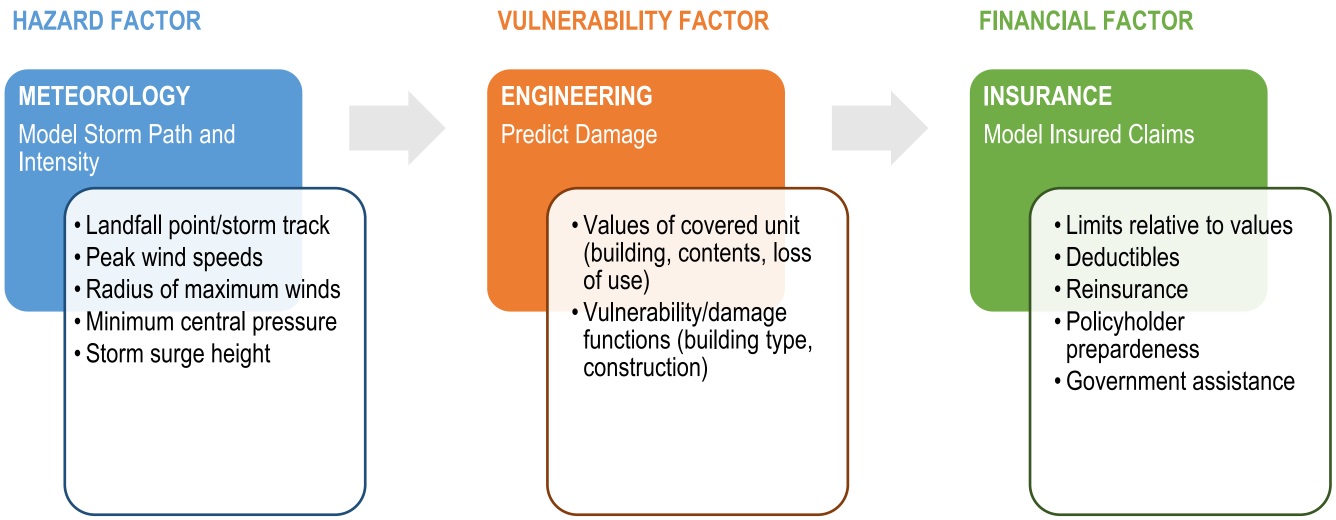
Quantitative data needs can be classed according to two stages of the risk assessment:

1. Measuring the exposure of households, firms, and the government to acute physical risks; and
2. Measuring the exposure of the insurer to the entities considered in (1.).

The first risk assessment stage relates to the first three components of a catastrophe modelling framework, namely event generation, local intensity calculation (hazard factor), and damage estimation (vulnerability factor). The second stage relates to insured losses (financial factor) (**Section 3**).

Along with historical event and loss data, high-resolution environmental and balance sheet data are necessary to produce robust results. This data is challenging to collect and requires coordination with multiple non-financial stakeholders, including government agencies, environmental authorities, meteorologists, structural engineering experts, and other scientific organisations. Technical experts in relevant fields may be required at the different stages of the catastrophe modelling process. **Figure 7** summarises the data outputs required under each factor[22], which are provided by different stakeholders and used as inputs in a catastrophe model. Insurers may leverage models provided by experts, or develop in-house solutions. The selected models should be relevant to an insurer's geographical scope and business lines.

Figure 7: Catastrophe Modelling Process – Sample Data Inputs



Sources: Author and Angelina (2014).

Exposure of Economic Agents

The first stage requires geospatial data on hazards at a highly granular level. The physical impacts of thousands of hypothetical events, at particular geographical locations, are determined. Historical data supports hazard projections.

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[22] Data is described in **Sections 3.1-3.3**.

Historical Data

The **International Disaster Database (EM-DAT)**[23] aggregates data on the occurrence and impact of natural and technological (industrial) disasters since the 1900s. Each event includes the number of fatalities, number of persons affected (including injuries and those requiring shelter), reconstruction costs, insured damages (economic damage covered by insurance companies), and total damages (all economic losses). Data is adjusted for inflation. For some countries, including Trinidad and Tobago, the details of some events are incomplete. Locally, the **Office of Disaster Preparedness and Management (ODPM)** collects data on, inter alia, flooding and landslide events based on reports received.

In particular, tropical cyclone modelling leverages historical track data. The International Best Track Archive for Climate Stewardship (**IBTrACS**) dataset[24], which was developed in collaboration with the World Meteorological Organization, is available from the National Centers for Environmental Information. The dataset captures tropical cyclones from the 1842-2024 and variables include maximum sustained wind speed or minimum central pressure.

Regarding climate data, the **Trinidad and Tobago Meteorological Service (TTMS)** collects and provides primary data for standard weather and climate variables such as temperature, rainfall, wind speed, and wind direction. Daily data for temperature and precipitation (at Piarco and Crown Point) is available for 1981-2022.[25] Short-term outlooks are also produced. As the national meteorological agency, the TTMS supplies global climate databases.

Local sea level rise is monitored by the **Caribbean Community Climate Change Centre (CCCCC)**, though there are concerns with the accuracy of the data due to the large variances provided by measurement stations in close proximity (Chin Sang 2015). Downscaled global data is useful in this instance, for example from the IPCC.

Further, geospatial data is available from the **Trinidad and Tobago (Ministry of Planning) Biodiversity Information System**. Available datasets[26] capture geographic, forest, marine, and socio-economic data.[27] The most recent data was uploaded in 2020, however, most data is dated (2011-2014). A specialised marine data hub is also available from the Institute of Marine Affairs[28].

Hazard Projections

While the TTMS is the authority on historical climate data, internal capacities for climate prediction modelling and GIS need strengthening, and climate projection modelling and downscaling need establishing (Kumarsingh et al. 2021). As such, regional climate projections may be leveraged to assess future hazards, particularly where models are downscaled to produce output at a local resolution. Resources with global coverage are also available, though the resolution may be lower than that provided by regional organisations. Future climate projections may, in turn, be used to derive hazard projections (**Section 3.1**), including the frequency and severity of excess rainfall, tropical cyclones, and extreme heat. These projections should also be aligned to one or more future climate scenarios.

At the regional level, a comprehensive dataset of future climate projections is available from the **CCCCC**. Monthly projections are based on three IPCC scenarios[29]—RCP 2.6, RCP 4.5, and RCP 8.5—for the period 2000-2100. Due

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[23] EM-DAT may be accessed with a free account (non-commercial use) at https://www.emdat.be/. Data sources include UN agencies, non-governmental organisations, insurance companies, research institutes, and press agencies.

[24] Data is available freely at https://www.ncei.noaa.gov/products/international-best-track-archive.

[25] Members of the public may access this data with a free account at https://www.metoffice.gov.tt/climate_daily_data.

[26] Most datasets can be downloaded freely, but a few are only available upon request, at https://ttbis.planning.gov.tt/portal/apps/sites/#/geoportal.

[27] Geographic data includes forest type landcover, soils, wetlands, watersheds, reefs, and geological faults; forest data includes conservancies and ranges; marine data includes fish landing sites; and socio-economic data includes census, cadastral, and land use.

[28] https://mdh.ima.gov.tt/portal/apps/sites/#/datahub

[29] See **Appendix B** for more information on climate change scenarios.

to the expected similarity in climate conditions across Trinidad and Tobago, the dataset covers the two islands and a large buffer, at a resolution of 25km^2. This contributes to both event generation and local intensity calculations. **Table 4** outlines the projected variables.

Table 4: CCCCC Climate Projections – Variables

VARIABLE	
1. Max Temperature	6. Relative Humidity at 1.5 Metres
2. Mean Temperature	7. Specific Humidity at 1.5 Metres
3. Min Temperature	8. Total Precipitation Rate
4. Pressure at Mean Sea Level	9. Wind Speed at 10 Metres
5. Evaporation Rate from Soil	

Source: Caribbean Community Climate Change Centre.

A notable global resource is the **Climate Change Knowledge Portal**[30], which provides spatial climate projections for Trinidad and Tobago, depicting seasonal changes over long-term horizons (World Bank 2024). Data is available for a number of time periods and IPCC scenarios (Shared Socieconomic Pathways [SSPs] 1-5)[31], at a resolution of 25km^2. It is generated using multi-model ensembles of the Coupled Model Intercomparison Project (global climate models) in its sixth phase (CMIP6) (**Box 1**). CMIP6 supports the 2021 IPCC Sixth Assessment Report (AR6)—the latest as of June 2024. Temperature variables include, inter alia, average surface air temperature (maximum, minimum, and mean), number of hot days, and warm spell duration index. Precipitation variables include, inter alia, precipitation during wettest days and max number of consecutive wet days.

The **WorldClim** database[32] also provides downscaled future climate projections based on 23 global climate models included in CMIP6. Monthly values, averaged over 20-year periods, are generated for minimum and maximum temperature, and precipitation, under four SSPs. Four spatial resolutions are available. Other databases such as the **KNMI Climate Change Atlas**[33] provide data for the Caribbean, but global climate models are dated (CMIP5).

Climate Analytics, in collaboration with the NGFS, developed the **Climate Impact Explorer**[34] to facilitate time series and map analysis of acute physical risk projections for multiple global scenarios—four from the IPCC (RCPs) and seven from the NGFS. The tool leverages data provided by the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP)[35], available at a resolution of 50km^2. Projections assume constant (2005) socio-economic conditions so that results reflect the impact of climate change only. However, in reality, changes in these variables are expected to impact future pathways.

Vulnerability Assessment

Hazard data is considered in the context of the physical characteristics of insured exposures to determine the vulnerability (for example, via damage functions) (**Section 3.2**). The exposure of economic agents is influenced by the value and location of assets, operational sector, and the application of mitigation or adaptation measures. Existing regulatory data collection instruments do not capture this information in such detail. While data is classified by business

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[30] https://climateknowledgeportal.worldbank.org/country/trinidad-and-tobago/climate-data-projections

[31] See **Appendix B** for more information on climate change scenarios.

[32] https://www.worldclim.org/data/cmip6/cmip6climate.html

[33] https://climexp.knmi.nl/plot_atlas_form.py

[34] https://climate-impact-explorer.climateanalytics.org/

[35] The ISIMIP contains a subset of models in the CMIP6.

line, for example motor vehicle or property, collecting granular data on exposures is onerous for domestic insurance companies, due in part to limited financial and human resources. Alternatively, insurers may determine risk exposures based on historical claims experience in broad geographic areas. Data may also be sourced from reinsurers, who may utilise third-party companies, such as catastrophe modelling firms, to price risk.[36]

Few domestic studies have attempted to quantify the exposure of economic agents to potential hazards. Roopnarine et al. (2018) developed a GIS-based model of areas on the island of Trinidad that are susceptible to flooding. This facilitated the development of a risk model of buildings and populations at risk due to such occurrences. The model was built on the spatial analysis of bio-geophysical factors that contribute to landslides and flooding in Trinidad. GIS data, satellite imagery, and field observations were used to validate the model. While the study considered climate change as an influencing factor in the existing patterns of natural hazards, it did not analyse future impacts.

However, Singh and Obretin (2019) developed a flood risk map to explore the impact of tropical cyclones in Trinidad and Tobago, considering future climate change scenarios. Projections of sea-level rise were based on RCP 8.5 (2030 and 2050). Different levels of storm surges, as generated by a Category 2 and a Category 5 hurricane, were superimposed onto a Digital Terrain Model with a spatial resolution of $10m^2$. Maps of flood zones, by ocean level, during the sea level rise and storm surges were integrated to generate and visualise the results in the form of a vulnerability map (Duke 2022).

Of note, the Climate Impact Explorer incorporates the value and location of assets, operational sector, and the application of mitigation or adaptation measures, alongside hazard projections, to output economic damages from extreme events. The CLIMADA model, a global open-source catastrophe risk modelling framework, is utilised to produce these results (**Section 4.1.2.1**).

Exposure of Insurers

The financial impact on an insurer's balance sheet is a function of estimated damages faced by the insured exposure and the specifics of the insurance policy coverage (**Section 3.3**). An insurer may deduce that a particular region is prone to flooding due to a historically high volume of claims during the rainy season. This may impact limits and values by coverage, deductibles, and possible reinsurance coverage. Some companies restrict business altogether in particular locations, for example, beachfronts and conflagration zones.

Similar to the proposed data request for qualitative information (**Section 5.1**), the Central Bank may explore a request to domestic insurers to gather quantitative data. **Table 5** extracts questions from the Sustainable Insurance Forum bank, pertaining to physical risk.

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[36] AIR Worldwide, a catastrophe modelling and risk assessment firm, approached the Central Bank of Trinidad and Tobago to present and demonstrate the modelling approach utilised by reinsurers for domestic insurance companies, to determine appropriate values for coverage and other factors.

Table 5: Sample Quantitative Questions for the Assessment of Physical Climate Risk

PHYSICAL RISK	
1.	What is the vulnerability to climate change by exposed jurisdiction, for instance, according to the Notre Dame Global Adaptation Initiative (ND-GAIN) Index or Standard & Poor's methodology?
2.	What percentage of power plant locations are exposed to various levels of water stress, flood, and wildfire risks (e.g. from Paris Agreement Capital Transition Assessment (PACTA) model)?
3.	What is the company's exposure to flood risk, or exposure of real estate investments to perils?
4.	Does the company provide agricultural insurance with exposure to drought, variations in weather patterns and other climate change impacts?
5.	What are the outputs from catastrophe models?

Source: Sustainable Insurance Forum (2020) and International Association of Insurance Supervisors (2021).

Conclusion

Insurance companies are, by nature, more vulnerable to weather-related risk than other financial institutions, and climate change may present new levels of loss severity for the sector. The paper identifies the relevant transmission channels of acute physical risks, and discusses the usefulness of existing natural catastrophe models as a starting point in climate risk assessment. Climate-conditioned modelling approaches are gaining traction. Individual supervisors, as well as collaborative groups such as the NGFS, are exploring their application to climate risk assessment, including through climate stress testing and scenario analysis. However, insufficient data granularity may impede the robustness of climate-conditioned model results and limits a complete risk assessment. Qualitative studies have, therefore, been used to supplement quantitative results.

Identifying available data and resources is crucial to close existing gaps, particularly as key variables fall outside the expertise of the financial sector. As such, the paper explores both domestic and international resources that may be leveraged, including open-source models and databases. Data needs must be assessed and met to effectively adapt catastrophe models for use by domestic insurers, in line with idiosyncratic risks. Work must begin simultaneously on several fronts to improve the quality, comparability, and consistency of domestic data (including adequate data infrastructure) so that the risk assessment may be completed in the medium term.

As such, the following should be considered in the short term:

- **Strengthen relationships with stakeholders at the relevant national authorities and public sector agencies.** This would allow the Central Bank to tailor climate scenarios in line with national policy, incorporating the impact of national adaptation efforts. Moreover, this would support consistent application of climate models to project hazards over a long horizon, which may be used as an input into the supervisory assessment. These models would likely utilise more reliable meteorological data than provided in international databases.

- **Engage commercial model and data providers.** Leveraging international expertise in climate risk modelling would aid in bridging internal knowledge gaps and advancing supervisory risk assessment. Climate-conditioned catastrophe approaches should incorporate the uncertainties in global warming trajectories, and reflect scenarios developed by domestic supervisors in line with national policy. Domestic data sources are preferred, particularly for environmental data. However, many commercial data and model providers are arms of major international reinsurance agencies, which collect exposure data in places of operation such as the Caribbean.
- **Develop a comprehensive dataset to capture location-specific exposures from insurance companies.** This should be developed to incorporate different levels of granularity. Such an exercise will facilitate mapping of exposures to geographic areas prone to weather-related events. Sector-specific sensitivities will also be considered. Financial institutions should be engaged through the supervisor to determine the feasibility of compiling the required datasets and the availability of data in-house.
- (**Re)issue a qualitative survey to assess domestic insurers' awareness and potential exposures to climate risk.** As the Central Bank advances efforts in the area of climate stress testing and scenario development, qualitative data may be used as a starting point for risk analysis. Anecdotal evidence suggests that domestic financial institutions are ramping up their attention to climate-related issues, especially sustainability. It is the opportune time to engage with the sector to understand the extent of climate-related activities, and potential exposures to climate-related risks. The survey could also provide a platform for institutions to make suggestions to the Central Bank regarding priority focus-areas, potential data sources, and existing methodologies that may be relevant for climate risk analysis.

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Appendix A: Central Bank of Trinidad and Tobago Climate Risks Survey for Insurers (2020)

1. Does the institution have a climate change policy with respect to risk management and investment management? Please include:
    a. How is the mandate and mission of your institution related to the topic of climate and broader environmental risks?
    b. Where in the structure of the institution is climate risk addressed?
    c. What is your institution's overall strategy /approach/framework to the topic of climate and environmental risk and natural catastrophes?
    d. Does the institution approach climate change as an Enterprise Risk Management (ERM) issue?
    e. Does the institution have a dedicated point-person or team within the institution that is responsible for managing its climate change strategy?
    f. What is the role of the board of directors in governing climate risk management?
    g. Does the institution consider potentially correlated risks affecting asset management and underwriting?
    h. Has the institution issued a public statement on its climate policy?
    i. Are there any challenges or barriers identified for the further uptake of climate and environmental risk management?

2. Describe your institution's process for identifying climate change-related risks and assessing the degree that they could affect your business, including financial implications. Please include:
    a. How may climate change shift customer demand for products?
    b. What implications may climate change have on liquidity and capital needs?
    c. Is there modelling to take into consideration the impacts of climate hazards and climate change?
    d. How might climate change affect limits, cost and terms of catastrophe reinsurance, including reinstatement provisions?
    e. What type mitigation actions related to climate and environmental risks have been undertaken?
    f. Has the insurer considered creative methods of risk distribution such as contingency plans to reduce financial leverage and resolve any liquidity issues in the event of a sudden loss in surplus and cash outflows as a result of a catastrophic event?
    g. How are these impacts likely to evolve over time?
    h. Does the institution have plans to regularly reassess climate change related risks and its responses to those risks?

3. Summarize the current or anticipated risks that climate change poses to your institution. Explain the ways that these risks could affect your business. Include identification of the geographical areas affected by these risks. Please include:
    a. Which business segments or products are most exposed to climate-related risks?
    b. Has the institution considered its potential exposure to climate liability?
    c. Are there geographic locations, perils or coverages for which the institution has increased rates, limited sales, or limited or eliminated coverages because of catastrophic events? How do those actions relate to assessments of climate change impacts made by the institution?

   d. Has the institution examined the geographic spread of property exposures relative to the expected impacts of climate change, including a review of the controls in place to assure that the insurer is adequately addressing its net exposure to catastrophic risk?

4. Has the institution considered the impact of climate change on its investment portfolio? Has it altered its investment strategy in response to these considerations? If so, please summarize steps you have taken. Please include:
   a. Does the institution consider regulatory, physical, litigation, and competitiveness-related climate risks, among others, when assessing investments?
   b. Has the institution considered the implications of climate change for all of its investment classes, e.g. equities, fixed income, infrastructure, real estate?
   c. Does the insurer use a shadow price for carbon when considering investments in heavy emitting industries in markets where carbon is either currently regulated or is likely to be regulated in the future?
   d. Does the insurer factor the physical risks of climate change (water scarcity, extreme events, weather variability) into security analysis or portfolio construction? If so, for what asset classes and issuers (corporate, sovereign, municipal)?
   e. How does climate change rank compared to other risk drivers, given the insurer's asset liability matching strategy and investment duration?
   f. Does the insurer have a system in place to manage correlated climate risks between its underwriting and investments?

5. Summarize steps the institution has taken to encourage policyholders to reduce the losses caused by climate change-influenced events. Please include:
   a. How has the institution employed price incentives, new products or financial assistance to promote policyholder loss mitigation? In what lines have these efforts been attempted, and can the outcome of such efforts be quantified in terms of properties retrofitted, losses avoided, etc.?
   b. For insurers underwriting professional liability policies, what steps has the institution taken to educate clients on climate liability risks or to screen potential policyholders based on climate liability risk? How does the institution define climate risk for these lines?

6. Discuss steps, if any, the institution has taken to engage key constituencies on the topic of climate change. Please include:
   a. How has the institution supported improved research and/or risk analysis on the impacts of climate change?
   b. What resources has it invested to improve climate awareness among its customers in regulated and unregulated lines?
   c. What steps has it taken to educate shareholders on potential climate change risks the institution faces?

7. Describe actions your institution is taking to manage the risks climate change poses to your business including, in general terms, the use of computer modelling. Please include:

a. For what perils does the institution believe that future trends may deviate substantially from historical trends due to changes in the hazard? Similarly, for what perils, if any, does the institution believe that a catastrophe model extrapolating observed trends would be insufficient to plan for maximum possible loss or yearly average loss? What steps has the institution taken to model or analyze perils associated with non-stationary hazards?
b. Has the institution used catastrophe models to conduct hypothetical "stress tests" to determine the implications of a wide range of plausible climate change scenarios? If so, over what timescale, in what geographies and for what perils?
c. Has the institution conducted, commissioned or participated in scenario modelling for climate trends beyond the 1-5 year timescale? If so, what conclusions did the institution reach on the potential implications for insurability under these scenarios?

Appendix B: Climate Change Scenarios

Intergovernmental Panel on Climate Change (IPCC)

(IPCC 2023)

The IPCC has defined various climate change scenarios to describe the impact of future greenhouse gas concentrations. RCP (Representative Concentration Pathway)-based scenarios are referred to as RCPy, where ‘y’ refers to the level of radiative forcing (in watts per square metre) resulting from the scenario in the year 2100. SSP (Shared Socioeconomic Pathways)-based scenarios are referred to as SSPx-y, where ‘SSPx’ refers to the Shared Socioeconomic Pathway describing the socioeconomic trends underlying the scenarios, and ‘y’ refers to the level of radiative forcing (in watts per square metre) resulting from the scenario in the year 2100.

The SSP scenarios cover a broader range of greenhouse gas and air pollutant futures than the RCPs. They are similar but not identical, with differences in concentration trajectories. The overall effective radiative forcing tends to be higher for the SSPs compared to the RCPs with the same label (medium confidence). SSPs, as outlined in CMIP6, are based on the RCPs from CMIP5.

SSP	ASSOCIATED RCP(S)	DESCRIPTION
SSP1	**RCP 1.9** **RCP 2.6**	**Sustainability**: The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries.
SSP2	**RCP 4.5**	**Middle of the road**: The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns.
SSP3	**RCP 7.0**	**Regional rivalry**: A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues.
SSP4	**RCP 3.4**	**Inequality**: Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries.
SSP5	**RCP 8.5**	**Fossil-fueled development**: This world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated.

Source: US Department of Agriculture (2024)

Network for Greening the Financial System (NGFS)

(Climate Analytics 2023)

As part of a collaboration with the NGFS, a consortium of international research institutes has developed a set of climate scenarios to serve as a common reference framework for central banks and supervisors. They are assessed under the NGFS’s Scenario and Climate Impact Explorers.

The seven NGFS Climate Scenarios include:

1. **Current Policies:** This scenario assumes that only currently implemented climate policies are maintained, with no further strengthening. Global greenhouse gas emissions grow until 2080, leading to about 3°C of

warming and irreversible changes like higher sea level rise. In the NGFS terminology, this is considered a "hot house" scenario, characterised by high physical risks, but low transition risks.

2. **Net-Zero 2050**: This ambitious scenario limits global warming to 1.5°C through immediate introduction of stringent climate policies and innovation, reaching net zero CO_2 emissions globally around 2050. Some jurisdictions such as the US, EU and Japan reach net zero for all greenhouse gases by this point. Carbon Dioxide Removal (CDR) is used to accelerate the decarbonisation but kept to the minimum possible and broadly in line with sustainable levels of bioenergy production. Physical risks are relatively low but transition risks are high.
3. **Fragmented World**: This scenario assumes a delayed and divergent climate policy response among countries globally, leading to high physical and transition risks. Countries without zero targets follow current policies, while other countries achieve them only partially (80 per cent of the target).
4. **Nationally Determined Contributions**: This scenario includes all pledged targets even if not yet backed up by implemented effective policies.
5. **Below 2 degrees**: This scenario gradually increases the stringency of climate policies, giving a 67 per cent chance of limiting global warming to below 2°C.
6. **Low Demand**: This scenario assumes that significant behavioural changes take place that lead to reduced energy demand and mitigate the pressure on the economic system to reach global net zero CO2 emissions round 2050.
7. **Delayed Transition**: This scenario makes the assumption that new climate policies are not introduced until 2030 and the level of action differs across countries and regions based on currently implemented policies, leading to a "fossil recovery" out of the economic crisis brought about by COVID-19. The availability of Carbon Dioxide Removal (CDR) technologies is assumed to be low, therefore global emissions decline very rapidly after 2030 to ensure a 67 per cent chance of limiting global warming to below 2°C in 2100. This leads to both higher transition and physical risks than the Net Zero 2050 scenario, but lower physical risk than the Current Policies scenario.