CFRF provider survey paper

- **Provisional article title:** Evolving Private Climate Risk Services: Insights into Data Gaps, Model Integration, and Financial Sector Needs

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Abstract

Abstract

This study investigates the evolving landscape of private climate risk services and the critical role they play in supporting financial institutions (FIs) in managing physical climate risks. Through a detailed survey of climate data providers, we identify key trends, data gaps, and challenges these providers face in meeting the diverse needs of FIs, including banks, asset managers, and insurers. Our findings highlight that while providers prioritize physical climate risks, there is significant variation in the types of hazards addressed, with a strong focus on long-term projections (10–30 years) and geographic-specific assessments. The study underscores the need for more granular, asset-level data and the integration of complex climate models, such as Global Climate Models (GCMs) and Regional Climate Models (RCMs), to improve the accuracy of climate risk assessments. Providers also face challenges with data standardization, transparency, and addressing uncertainty, particularly in extreme or high-impact, low-likelihood events. This paper offers recommendations for improving climate data services by addressing these gaps and providing targeted, sector-specific solutions for FIs, ultimately contributing to a more resilient financial sector.

Introduction

Financial institutions (FIs), including banks, asset managers, insurers, and pension funds, increasingly rely on precise and actionable climate data to inform investment decisions, manage emerging climate-related risks, and comply with stringent regulatory requirements for climate risk disclosure and resilience (Bank of England, 2024). As climate-related hazards intensify, regulatory pressure on FIs is growing (TCFD, 2023). By aligning investment flows with sustainability goals, the financial sector plays a pivotal role in achieving global climate targets (CFRF, 2023).

In response to this demand, climate services are rapidly developing innovative models and tools that integrate both physical and transitional risks into financial valuation and management frameworks. This integration is critical, as many investors maintain significant exposure to carbon-intensive assets, which risk becoming stranded due to shifts in regulatory environments and market preferences (Battiston et al., 2021). Effective climate services require user-centric approaches that incorporate a wide range of data inputs, including asset-specific economic, social, and environmental metrics, alongside policy and legislative frameworks (Larosa & Mysiak, 2019). As these tasks grow in complexity, private data and service providers are increasingly responsible for downstream activities (e.g., impact modelling and consulting) where they now play a larger role compared to public entities that typically dominate upstream data provision (Cortekar et al., 2020).

However, private data providers face significant challenges in navigating this complex landscape. Client diversity within the financial sector is among the most critical challenges. Financial institutions have widely varying data requirements, necessitating highly customised solutions that address sector-specific risks and geographic considerations. For instance, the agricultural sector in the UK relies heavily on accurate temperature and precipitation data, while the real estate sector focuses on flood risks and sea-level rise. Schroders' case study on climate risks in Vietnam's apparel supply chains underscores the need for tailored, sector-specific metrics, illustrating how different sectors require different types of climate data (Schroders Case Study).

Global supply chains are inherently interconnected, making them particularly vulnerable to climate-induced disruptions. Modelling these risks requires detailed data on the locations and operational dependencies of each component, as well as insights into how climate impacts at one point in the supply chain can propagate throughout the system (UNEP FI, 2024). Furthermore, complexity is compounded by the need to account for both direct physical risks, such as infrastructure damage, and indirect risks, such as shifts in market conditions or regulatory changes (CCC Report).

Selecting and integrating appropriate climate data sources is equally challenging. The choice of climate models is critical, as different models offer varying geographic specificity, temporal resolution, and capacity to capture key climate phenomena, particularly in regions with complex climate dynamics. Global Climate Models (GCMs) from the Coupled Model Intercomparison

Project Phase 6 (CMIP6), coordinated by the IPCC, provide large-scale climate projections essential for understanding long-term trends (CMIP6 data). These models, such as the HadGEM3 from the UK Met Office and NCAR's CESM2, simulate various climate scenarios that reflect different assumptions about physical processes and parameterisations. However, their coarse spatial resolution often limits their utility for detailed regional assessments. In contrast, Regional Climate Models (RCMs) from the Coordinated Regional Climate Downscaling Experiment (CORDEX) offer finer-scale projections tailored to specific regions, making them more suitable for localised impact assessments, though they require careful selection to match the geographic and climatic specifics of the area (CORDEX data). The Coalition for Climate Resilient Investment's (CCRI) Physical Climate Risk Assessment Methodology (PCRAM) highlights the complexity of balancing GCMs' broader insights with RCMs' detailed, region-specific outputs to accurately assess risks to infrastructure assets like hydro power plants and coastal wind farms (CCRI PCRAM Case Study).

The integration of reanalysis datasets further complicates the landscape. Leading reanalysis products such as ERA5 from ECMWF, NASA's MERRA-2, and the NCEP/NCAR Reanalysis combine observational data with model outputs to create continuous climate records, which are essential for understanding past climate conditions and validating model projections (ERA5 data, MERRA-2 data, NCEP/NCAR data). Each dataset offers distinct advantages in terms of spatial resolution, temporal coverage, and variable representation. For example, ERA5 provides high-resolution data suitable for regional analysis, while MERRA-2 focuses on atmospheric dynamics and energy balances. However, biases introduced by the assimilation processes, or differences in how physical processes are represented, can affect the accuracy of climate projections. Integrating reanalysis data into risk assessments requires careful consideration of these potential biases and the challenges of aligning different temporal resolutions, especially when incorporating them into time-step models that demand daily or hourly projections.

Merks et al. (2022) highlight the importance of accessible hydro-climatic data for climate change adaptation, revealing significant discrepancies between different data sources, and underscoring the need for improved quality assurance and model performance.

Methodological rigour is another significant hurdle in climate risk assessments. The integration of diverse data inputs across varying spatial and temporal scales requires robust frameworks capable of managing the inherent variability in models. Ensemble approaches, which combine outputs from multiple GCMs and RCMs, are often employed to address uncertainties in climate projections. This approach adds complexity and computational demands to data processing.

Leveraging advancements in artificial intelligence (AI), blockchain, and satellite data can enhance the accuracy and reliability of climate risk models, but there can be issues with transparency and variability in the depth of risk analysis among existing and novel tools (Bingler & Colesanti Senni, 2022). Additionally, uncertainty and tail risks - including High Impact Low Likelihood (HILL) events - remain a critical component of comprehensive climate risk assessments (UNEPFI 2023).

The recognition of complex, non-linear 'green swan' risks has driven a paradigm shift from traditional, backward-looking metrics to more forward-looking tools and scenario analysis (Bolton et al., 2020). While backward-looking metrics like carbon intensity and historical loss data provide valuable insights based on past exposures, forward-looking metrics, such as Implied Temperature Rise (ITR) and scenario analysis, project future risks by accounting for anticipated climate impacts and decarbonisation efforts. Both approaches remain essential for comprehensive climate risk assessments.

Data providers must also stay current with scenario updates to ensure their climate risk assessments remain relevant and aligned with the latest research. The IPCC's transition from Representative Concentration Pathways (RCPs) to Shared Socioeconomic Pathways (SSPs) exemplifies the need for providers to continually update their models to reflect the most recent climate scenarios (IPCC reports). The climate risk market for the financial sector is dominated by four major quantitative macro scenarios produced by the International Energy Agency (IEA), the IPCC, the Network for Greening the Financial System (NGFS), and the Principles for Responsible Investment (PRI) (International Energy Agency, 2023, IPCC, 2021, NGFS, 2023, PRI, 2021). Each of these scenarios is constructed using different underlying assumptions about future economic, social, and technological developments, as well as varying baselines (e.g., different starting points for emissions or economic conditions) and inputs (e.g., different data sources, model frameworks, and sectoral focus), creating variability in their applications and interpretations (Baer et al., 2023). Medium-sized companies, in particular, face significant challenges in implementing their own quantitative scenarios due to the complexity and resource requirements of these processes (Huiskamp, ten Brinke & Kramer, 2022).

For both physical and transitional risks, FIs often require granular, asset-level data. Neglecting asset-level data can lead to significant underestimation of climate-related losses; one study has shown that excluding such data can result in underestimations of climate-related losses by up to 70% and financial losses by up to 82% when acute risks are not considered (Bressan et al., 2024).

The primary aim of this paper is to provide an overview of the current practices, challenges, and methodologies employed by private data providers in delivering physical climate risk information to financial institutions.

Specific Objectives:

- Explore the diversity of requirements among different types of financial institutions, and how these needs influence the customisation of climate risk data services. This includes investigating to what extent providers adapt their products to sector-specific risks and geographical considerations.
- Investigate the approaches used by companies to select and integrate climate data sources, such as Global Climate Models (GCMs), Regional Climate Models (RCMs) and reanalysis datasets.
- Provide an overview of the methodologies employed by providers to process and analyse climate data, focusing on how they handle varying spatial and temporal scales. The paper will also touch on the use of ensemble approaches and the integration of newer technologies, though with an understanding of the practical limitations companies face.
- Identify the main challenges providers encounter in providing climate risk information, particularly in addressing uncertainty, tail risks, and the integration of asset-level data.
- Offer insights based on survey responses that can inform future guidance for private data providers and improve the quality and consistency of climate risk data delivered to financial institutions.

This paper draws on the findings from the Climate Financial Risk Forum's (CFRF) survey of private-sector providers to provide a realistic snapshot of the current state of climate risk data provision. By synthesising these insights, the study aims to contribute to the ongoing conversation about how best to support financial institutions in managing climate risks.

To begin this process/dialogue, we surveyed a wide range of UK and Europe-based global climate risk data providers to better understand:

- How they prioritise physical climate risks data against other types of risks.
- The specific weather/climate hazards they focus on for financial institutions.
- The time horizons for climate risk assessments commonly provided to financial institutions.
- The types of climate information they generate and provide.
- The methods they employ to source and process climate data.
- The purposes for which their clients (financial institutions) use this information.
- The challenges and factors considered when providing and delivering climate information.
- The additional information or support they believe would be useful for their clients.

This study addresses several key gaps in the current understanding of climate risk data provision:

1. Understanding how providers prioritise physical climate risks relative to other types of risks, and how this prioritisation impacts the services offered to FIs
2. Identifying the specific climate and weather hazards that providers consider most relevant for financial institutions, which may differ from the hazards that institutions themselves are most concerned about.
3. Exploring the time horizons for which climate risk assessments are commonly provided, and how these align with the decision-making needs of financial institutions.

4. Evaluating the types of climate data used and provided, including observations, reanalysis, projections, and the extent to which these align with the needs of financial institutions.
5. Investigating the methods providers use to source and process climate data, including the scientific and technical challenges they face.
6. Understanding the various purposes for which financial institutions use the provided climate information, and identifying gaps between what is provided and what is needed.
7. Identifying the challenges providers face in delivering climate information, including data quality, granularity, and standardisation issues.
8. Highlighting the additional information or support that providers believe would enhance the utility of their services for financial institutions.

Journals: climate services, plos climate, climate resilience and sustainability (wiley)

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Method

The survey was conducted using Qualtrics, an online platform for survey design and implementation. The questions were crafted to gather detailed insights into respondents' organisational backgrounds, their perspectives on risk and adaptation, and their use of information for adapting to physical climate risks. The full protocol is detailed in **Appendix 1**. The design process was informed by insights drawn from previous surveys targeting users of climate information (**REF**).

21 responses were recorded. 20 were fully completed (indicated by "Finished: True"), and 1 was incomplete (Finished: False).

Responses were recorded from various global locations, as seen from the latitude and longitude data, including Europe, North America, and Asia. Specific locations include:

- Europe: UK, Germany, Italy, France, Croatia.
- North America: United States, Canada.
- Asia: India, Japan.

All responses were recorded through an "anonymous" distribution channel.

Survey design and implementation

The survey was conducted using Qualtrics, an online platform for survey design and implementation. The questions were crafted to gather detailed insights into respondents' organisational backgrounds and the physical climate risk services they provide. Unlike the user survey, most questions were optional, and respondents could navigate back and forth through the survey. This was to enhance the user experience and increase completion rates. The full protocol is detailed in **Appendix 1**. The design process was informed by insights drawn from previous surveys (REF).

Sample description

Survey respondents were recruited, and the questionnaire was distributed via the Institutional Investors Group on Climate Change (IIGCC).

Survey responses were completed during spring-summer 2024. We discounted earlier, less complete responses when more than one response was received from the same IP address. Additionally, responses that gave consent but didn't answer any questions were excluded from our analysis.

The respondents to this survey represent a difficult-to-reach expert group, so even sections with only a few respondents provide valuable insights. We estimate that we are sampling X% of the population, underscoring the importance of these insights despite the small sample size. However, caution is needed when making inferences from limited data. As with the user survey, variability in response rates across different sections is important to consider, as we report the findings.

Results

Types of Clients and Services

Respondents (n=20) were asked to specify the types of organizations to which they provide weather and climate services, with multiple selections allowed. The most frequently cited sectors include Insurance (90%, n=18), Asset Owners (80%, n=16), Asset Management - Public Markets (80%, n=16), and Investment Banking (80%, n=16). Corporate Banking (75%, n=15) and Asset Management - Private Equity (70%, n=14) were also prominent.

Fewer respondents provide services to Asset Management - Infrastructure (60%, n=12) and Pension Funds (55%, n=11). The "Other" category, selected by 25% (n=5), includes a diverse range of organizations such as ESG managers, infrastructure companies, real estate firms, corporations, consulting firms, governments, NGOs, and stock exchanges.

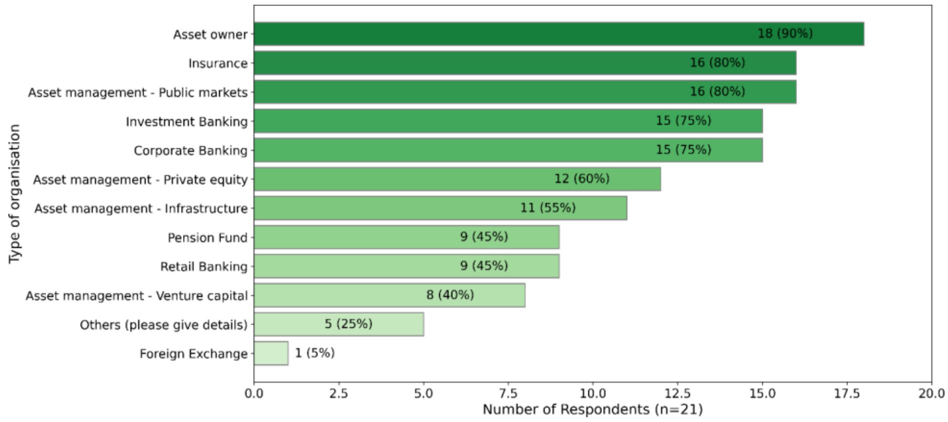

Figure 1 The bar chart represents the responses to the question "What types of organisations do you provide weather/climate services to?" (multiple selections were allowed). The most common recipients of these services are Asset Owners (90% of respondents), followed by Insurance companies and Asset Management (Public Markets) organisations (both at 80%). Other significant recipients include Investment Banking and Corporate Banking (75% each). Additionally, smaller proportions of respondents provide services to Foreign Exchange (5%) and various other types of organisations (25%). The total number of respondents was 21.

Client Size

Respondents (n=19) indicated the sizes of clients they serve, with multiple selections allowed. The largest proportion (47%, n=9) serve smaller organizations with fewer than 20 employees, while larger organizations with more than 500 employees are also a significant focus, served by 42% (n=8) of respondents. Medium-sized organizations, specifically those with 100 to 500 employees, are served by 32% (n=6) of respondents, and those with 20 to 100 employees by 26% (n=5). These findings indicate that weather and climate services are reaching organizations of all sizes, with strong engagement across both small and large companies. The lower engagement with medium-sized organizations might point to a market gap or perhaps some confusion in how respondents interpreted the question. In larger organizations, service providers may be interacting primarily with specialized teams or sub-teams, which could result in an underreporting of services provided to the organization**.**

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(80%, n=16), and Investment Banking (80%, n=16). These were closely followed by Corporate Banking (75%, n=15) and Asset Management - Private Equity (70%, n=14).

In contrast, fewer respondents provide services to Asset Management - Infrastructure (60%, n=12) and Pension Funds (55%, n=11). Notably, services to Foreign Exchange were mentioned by only 5% (n=1) of respondents. The "Other" category, encompassing specialized or less common sectors, was selected by 25% (n=5) of respondents. This section includes a diverse range of organizations such as ESG managers and tools, infrastructure companies, real estate firms, corporations, consulting firms, governments, NGOs, and stock exchanges.

Billing Models

Respondents (n=18) were surveyed on the billing models employed for weather and climate services, with the option to select multiple models. The recurring license fee model emerged as the most prevalent choice, used by 72% (n=13) of respondents. This model emphasises the need for predictable revenue streams while fostering long-term client relationships. Recurring fees are particularly well-suited to the continuous updates and sustained access that characterize Software as a Service (SaaS) platforms, thereby enhancing their value proposition.

In contrast, 33% (n=6) of respondents prefer customized or negotiable pricing structures, which offer greater flexibility and the ability to tailor services to specific client needs. Notably, no respondents reported using a flat rate model, suggesting that fixed pricing may be less appropriate for the complex and variable nature of weather and climate services.

Among the "Other" billing models, selected by 22% (n=4) of respondents, innovative approaches were highlighted. For instance, volume-based pricing aligns costs with actual usage, encouraging efficient service utilization, especially for clients with fluctuating needs. Another notable model is the open-source community approach, which fosters collective problem-solving, contributing to a broader data ecosystem.

Geographical Coverage

Respondents (n=18) were asked to specify the geographical regions covered by their climate information services. The most frequently covered region is North America, with 94% (n=17) of respondents providing services there. The United Kingdom and multiple European countries closely follow, each covered by 89% (n=16) of respondents. Other regions, including Asia and Australasia/Oceania, are served by 78% (n=14) of respondents, while Africa and South America are each covered by 72% (n=13).

The extensive coverage in North America suggests significant demand for climate services, driven by the presence of major financial markets, diverse climatic conditions, and stringent regulatory requirements. Similarly, the substantial coverage in the United Kingdom and Europe reflects the importance of robust climate regulations and a strong focus on sustainability within these regions.

The presence of services in Asia, Africa, South America, and Australasia/Oceania indicates a growing demand for climate services across both developed and emerging markets. The relatively low coverage in Antarctica highlights its specialized interest, likely centered around the use of global climate models and the observation of climate fluctuations in polar regions.

Types of Risks Covered

Respondents (n=18) were asked to identify the types of risks their products address, with the option to select multiple categories. The findings reveal that Physical Climate Risks - encompassing extreme weather events and changes in agricultural seasons - are universally prioritized by all respondents (100%, n=18).

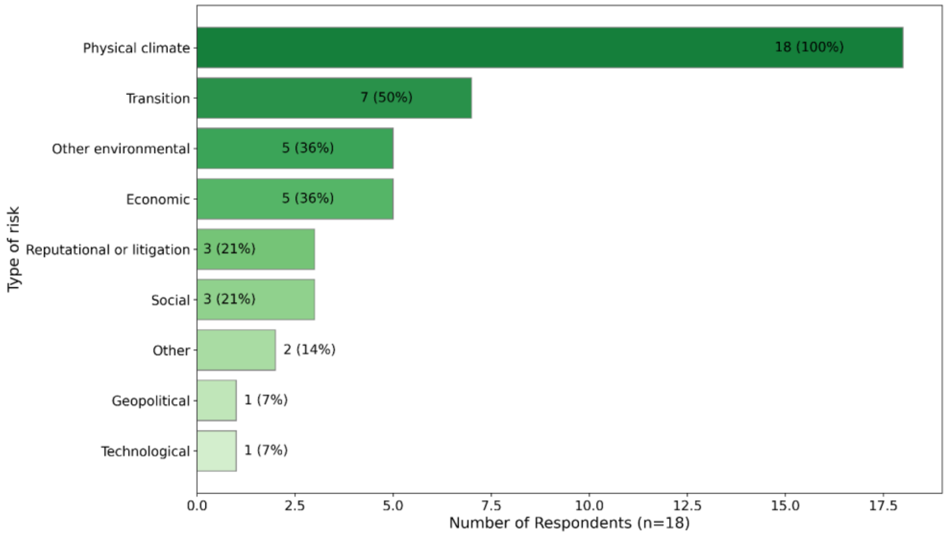
Transition Risks related to achieving Net Zero targets were identified by 39% of respondents (n=7), underscoring the increasing significance of these risks as companies navigate the complexities of transitioning to a low-carbon economy.

Economic Risks were selected by 33% of respondents (n=6), reflecting notable concerns around factors such as economic growth, inflation, and supply chain disruptions. Other Environmental Risks, including ecosystem collapse and resource scarcity, were chosen by 28% of respondents (n=5), highlighting the wider environmental/nature challenges that are becoming increasingly pertinent to financial outcomes.

Reputational or Litigation Risks and Social Risks were each selected by 17% of respondents (n=3). Although these risks are acknowledged, they may not yet be perceived as critical or as directly tied to financial outcomes as physical and transition risks. Nonetheless, these categories indicate an awareness of the broader societal and legal implications of climate change.

The least selected categories were Geopolitical Risks and Technological Risks, each mentioned by only 6% of respondents (n=1). This suggests that while these risks are recognized, they are perceived as either less immediate or less directly linked to climate change compared to other risks.

In the "Other" category, selected by 11% of respondents (n=2), responses varied, including risks such as Value at Risk in commercial and residential real estate and Biodiversity. This reflects a tailored approach to risk assessment that extends beyond conventional categories.



Timescales

Respondents (n=18) were surveyed on the timescales for which financial institutions request climate risk assessments, with multiple selections permitted. The findings reveal a strong preference for longer-term assessments, with 78% (n=14) of respondents indicating demand for timescales ranging from 10 to 30 years. Similarly, 72% (n=13) highlighted the need for assessments spanning 2 to 5 years, as well as those exceeding 30 years. This reflects the financial sector's dual focus on medium- to long-term planning horizons.

Interestingly, short-term assessments of less than a month were not requested by any respondents. However, there is moderate demand for shorter-term insights, with 17% (n=3) selecting timescales between 1 to 6 months and 56% (n=10) favouring periods between 6 months to 2 years. This illustrates the need for actionable insights that can inform immediate to near-term decisions while maintaining a focus on longer-term strategic risks.

One respondent noted that “Banks and asset managers strive to obtain as much historical data as possible” and “seek time-granular data,” while another emphasized the importance of long-term perspectives, stating, “Asset owners with long-dated obligations tend to be more interested in a long-term view on risk.”

The varied demand across different timescales reflects the diverse needs of financial institutions, which must balance immediate, medium-term, and long-term climate risks in their decision-making processes. The absence of demand for assessments of less than a month underscores a lesser focus on transient weather fluctuations.

Physical Climate Risk Services

Respondents (n=15) shared a variety of strategies for assessing climate risks, with a strong emphasis on evaluating hazards (e.g., severe wind, wildfires, coastal flooding, and drought). As one respondent noted, "*The platform assesses hazards such as severe wind, wildfire, hail, heavy precipitation, coastal flood, heatwave, river flood, late frost, tropical cyclone, and drought, providing precise risk calculations for all geolocations with a resolution up to 10 meters*."

A common theme among data providers is the focus on granular asset analysis. Several providers offer detailed risk assessments on individual assets, such as manufacturing sites and energy plants. One respondent highlighted, "*We look at the physical locations of nearly 50,000 companies - covering over 1 million manufacturing sites, energy plants, mining operations, office buildings, and retail sites."*

Some providers also deliver highly localized data and risk assessments, down to the census block, zip code, and parcel levels. The emphasis on user-friendly design is aimed at making complex data more accessible and actionable for a broad audience.

The integration of machine learning (ML) and artificial intelligence (AI) is a notable trend, significantly enhancing the efficiency of risk assessments by combining historical, satellite, and unconventional datasets with future climate model predictions. One organization noted: "*The algorithm uniquely combines historical data, satellite data, and unconventional datasets with future climate model predictions."*

Companies emphasize the reliance on well-established open-source data portals, including the Copernicus Climate Data Store and NASA Earth Exchange. Regular updates (e.g., the shift from CMIP5 to CMIP6), are essential for staying aligned with the latest scientific advancements.

Biodiversity risks are increasingly gaining attention, with some organizations specifically focusing on assessing the biodiversity risk exposure of financial actors. As one respondent noted, "*Our databases CRIS and BIA focus on physical risks and biodiversity risks. BIA-GBS highlights the biodiversity risk exposure of financial actors by identifying the most at-risk companies, entities, and sectors."*

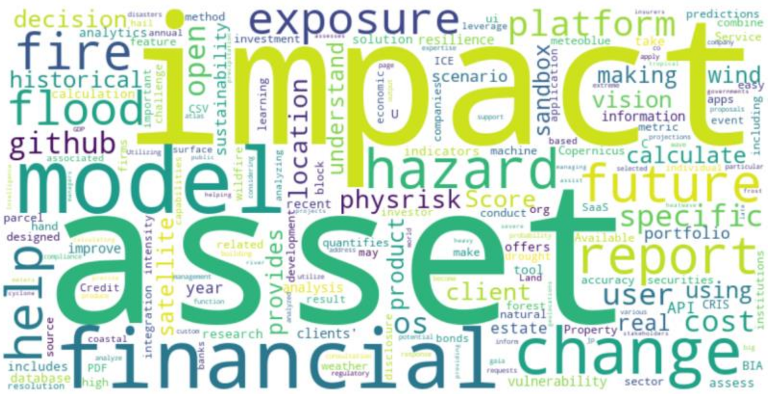
A key offering across several companies is the translation of physical climate risks into financial metrics like Property Value-at-Risk (VaR) and GDP impairment.

One responded noted: “*We provide detailed economic projections for each analysed asset, offering users insights into future cost changes due to climate impacts."*

Additionally, the use of standardized risk scores is increasingly prevalent in decision-making for various securities, portfolios, and asset classes.

Transparency in data sourcing is also emphasized, particularly through the use of self-reported data from companies, which helps build large, reliable databases of physical risks.

Some organisations are focusing on providing open-source building blocks and plug-and-play architectures: "*We provide the basic open-source building blocks for firms to connect assets to hazard models and apply any available vulnerability models."*

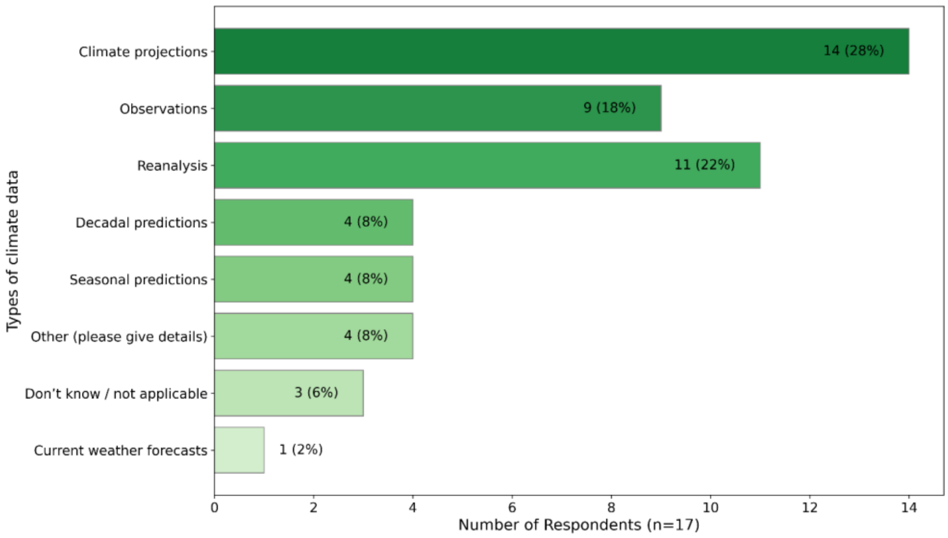


Climate data used in tools

Respondents (n=17) were asked to identify the types of climate data used in their tools. The responses show a pronounced preference for climate projections, with 82% (n=14) of respondents incorporating these into their tools. Reanalysis data also features prominently, used by 65% (n=11) of respondents, highlighting its importance in refining and validating climate models. Observational data is utilized by 53% (n=9), reflecting its role in grounding projections in empirical evidence.

In contrast, shorter-term data types (e.g., current weather forecasts) are the least utilized, with only 6% (n=1) of respondents indicating their use. There is a clear focus on long-term risk assessment over immediate weather conditions. Seasonal and decadal predictions are each used by 24% (n=4) of respondents, showing that while there is interest in these mid-range timescales, they are not as widely adopted as long-term projections.

The "Other" category, selected by 24% (n=4) of respondents, includes a variety of additional data sources such as satellite data, reforecasts, research on asset vulnerabilities, and financial data. Finally, 18% (n=3) of respondents indicated uncertainty or non-applicability regarding the types of climate data used, which could point to gaps in data integration strategies or the evolving nature of climate data usage within the industry.



Datasets

Among the 14 organizations surveyed, 4 reported leveraging observational datasets such as the Global Historical Climatology Network (GHCN) and SYNOP (Surface Synoptic Observations) /ESWD (European Severe Weather Database).

Nine out of 14 participants reported using reanalysis datasets and numerical weather prediction models. Key sources include established global datasets such as ERA5 (ECMWF Reanalysis 5th Generation), CERRA (Copernicus European Regional ReAnalysis), the CESM-LENS (Community Earth System Model Large Ensemble) and ICON (a global numerical weather prediction model developed by the German Weather Service) were also mentioned. These datasets are employed primarily for bias correction and model training, ensuring that climate models are adjusted to reflect historical climatology accurately and are suitable for predicting future conditions. One respondent highlighted the importance of these datasets, stating, "*Reanalysis is used for bias-correction and model training. When aggregated over multiple years, reanalysis datasets give the best available estimate of the historical climatology*."

In climate projections, 9 companies indicated a wide application of Global Climate Models (GCMs), emphasizing downscaling and bias correction. The reliance on CMIP5 and CMIP6, along with the integration of sector-specific projections from IEA and IPCC, highlights a focus on broad applicability with sector-specific relevance. For example, one company noted, "*CMIP6 as 'data basis,' but downscaling is performed because standard resolution is not sufficient for EU taxonomy and general site-specific climate risk analyses*."

Specific datasets (e.g., runoff estimates) are used in global climate projections with different spatial and temporal resolutions. As mentioned by one respondent, "Runoff: global, 0.1 arcdeg, daily," while another provided further details on utilizing "Surface temperature, Precipitation, Surface wind speed, Total runoff: 0.25deg, daily, global, 5 ensembles." Companies are trying to apply tailor-made approaches to climate projections on different geographical scales and variables.

For current weather forecasts, seasonal predictions, and decadal predictions, the organizations did not specify datasets, with some indicating a gap in the detailed information available.

Three participants also reported the use of advanced satellite data, such as those from ESA and NASA, to ensure high-resolution and large-scale data processing capabilities. This approach emphasizes the integration of modern satellite technologies with traditional climate models to enhance the accuracy and applicability of climate risk assessments.

Plot - Climate projections

Category	Quotations
Observations	- "We use historical events (severe wind, hail, flood...) by lat/lon and SYNOP data for verification." - "We draw data from a range of high-quality sources including commercial third-party providers; industry; and academic research." - "The primary observation dataset used is the Global Historical Climatology Network (GHCN)." - "We use ESWD, SYNOP."
Reanalysis	- "Reanalysis is used for bias-correction and model training. When aggregated over multiple years, reanalysis datasets give the best available estimate of the historical climatology." - "Global climate models have systematic errors (biases) in their output. We therefore apply bias correction using reanalysis and observational data." - "Copernicus (ERA5, CERRA)" - "We draw data from a range of high-quality sources including commercial third-party providers; industry; and academic research."

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Climate Projections	-"Near-surface air temperature (tas, at 2-meter height), maximum near-surface air temperature (tasmax, at 2-meter height), minimum near-surface air temperature (tasmin, at 2-meter height), mean near-surface wind speed (sfcWind), U-component and V-component of wind (at 10-meter height), cumulative precipitation (pr), near-surface specific humidity (huss), mean near-surface relative humidity (hurs, at 2-meter height), mean sea level (msl), mean surface pressure (p), orography (orog), temporal scale: 1 day, spatial scale: 0.11°, post-processing: YES." "uses a variety of climate variables for different hazards. These include temperature, precipitation, wind speed, and tornado data, among others. For example: Heat: Maximum daily temperatures, extreme heat thresholds. Precipitation: Daily precipitation totals, intensity-duration-frequency (IDF) curves. Wind: Daily wind speeds, tornado counts, and magnitudes. Wildfire: Fire Weather Index (FWI) considering temperature, precipitation, humidity, and wind speed."
	-"Projections typically extend to 2065 or 2100, using 30-year windows centered around specific years (e.g., 2021-2050). The ensemble size refers to the number of models or simulations used to create the projections: Wind and Heat: Utilizes data from up to 32 CMIP5 Global Climate Models (GCMs). Precipitation: Uses 27 to 32 CMIP5 GCMs depending on the region (LOCA and BCCAQv2 methods for downscaling). Wildfire: Involves 20 CMIP5 GCMs downscaled by the Multivariate Adaptive Constructed Analogs (MACA) method."
	-"Plenty of open data sources such as WRI aqueduct, Nasa downscaled CMIP sets for chronic heat and drought, TUDelft European flood models, Imperial College IRIS wind model, public mid to low-resolution datasets from Jupiter Intelligence for most core hazards."
	-"IAE & IPCC & sector specific projections (ex: IAE)."
	-"Forward-looking projections from Global Circulation Models."
	-"Global climate models (GCMs), state-of-the-art computational tools for climate modeling developed by the environmental science community, are evaluated across multiple climate scenarios looking forward to the year 2100. GCM output data are a suite of numerical values for environmental variables (e.g., surface wind speed, temperature, humidity, etc.) for discrete locations on a global grid with a horizontal resolution of approximately 1–1.5° (110–160 km)."
Other	"ESA and NASA satellite data constellations."" we use the best resolution available from the open data which can range from 300 meters to 30 kilometers sq. Typically we optimise the datasets into chunks to enable rapid processing on millions of assets."

Information Sources

Out of 14 respondents, 5 reported using observational data, primarily sourced from globally recognized datasets such as the Global Historical Climatology Network (GHCN), the Japanese Automated Meteorological Data Acquisition System (AMeDAS), and the Integrated Surface Dataset (ISD). Reanalysis datasets, particularly the fifth generation of the European Reanalysis (ERA5), the Community Earth System Model Large Ensemble (CESM-LENS), and Copernicus datasets (e.g., the Copernicus European Regional Reanalysis (CERRA)), are utilized by 8 out of

14 respondents for bias correction and model training. Specific datasets were not mentioned for current weather forecasts, seasonal predictions, and decadal predictions.

In the area of climate projections, 9 out of 14 participants rely on the Coupled Model Intercomparison Project Phase 5 (CMIP5), Phase 6 (CMIP6), and the Coordinated Regional Climate Downscaling Experiment (CORDEX), with a strong emphasis on downscaling methods to improve spatial resolution. These projections are often complemented by sector-specific data from the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA). Additionally, the integration of satellite data from the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) by 2 respondents reflects an effort to incorporate latest technology for better coverage and resolution. Other notable data sources include the World Resources Institute (WRI) Aqueduct for water risk assessments, TUDelft European flood models, and the Imperial College Institute for Risk and Disaster Reduction (IRDR) wind model.

Category	Summary	Quotations
Observations	Core data sources include GHCN, AMeDAS, ISD, and GSOD.	"Global Historical Climatology Network (GHCN), Japanese Automated Meteorological Data Acquisition System (AMeDAS), Integrated Surface Dataset (ISD) and its daily aggregated counterpart (Global Summary of the Day; GSOD)"
Reanalysis	Key sources include ERA5, CESM-LENS, and Copernicus datasets like ERA5 and CERRA.	"The ERA5 dataset is proven to be the reanalysis most accurately reflecting observations."; "The CESM-LENS data also provides a useful historical dataset because it provides a robust sample of internal climate variability."; "ERA5, CESM-LENS data, Copernicus (ERA5, CERRA)"
Climate Projections	Core data sources include CMIP5, CMIP6, CESM Large Ensemble, CORDEX, IBTrACS, Aqueduct Floods Hazard Maps, WRI Aqueduct, TUDelft European flood models, and the Imperial College IRIS wind model. IPCC, IEA	"Global Climate Model (GCM) input and can use both CMIP5 and CMIP6."; "Daily wind speed data from nine North American Coordinated Regional Climate Downscaling Experiment (NA-CORDEX) regional climate simulations with a 24 km resolution."; "CMIP6, IBTrACS..."; "Plenty of open data sources such as WRI aqueduct, Nasa downscaled CMIP sets for chronic heat and drought, TUDelft European flood models, Imperial College IRIS wind model..." 'IEA & IPCC, and soon: internally developed scenarios. We also rely on Sovereign and corporate climate targets'
Other	Data sources include ESA and NASA satellite data constellations.	"ESA and NASA satellite data constellations"; "We use the best resolution available from the open data which can range from 300 meters to 30 kilometers sq."

Commented [AF3]: Supplimentary

Influences on the Choice of Weather or Climate Datasets

Respondents (n=15) were surveyed on the factors influencing their choice of weather or climate datasets. The results indicate a strong preference for data that is peer-reviewed and open, highlighting the importance of credibility and scientific validation in the selection process. As one respondent succinctly noted, "*We prefer data which is peer-reviewed and open*."

A significant number of respondents align their datasets with globally recognized climate scenarios, particularly those endorsed by the Intergovernmental *Panel on Climate Change (IPCC)*. One respondent explained, "The climate data we use are verified and aligned with the UN IPCC RCP scenarios, and are frequently used and recommended within the scientific community." Another emphasized their adherence to IPCC standards, stating, "When simulating hazards, ISS ESG uses the same climate model outputs as the Intergovernmental Panel on Climate Change (IPCC) used in the 5th Assessment Report (AR5)."

Innovation is also a key factor for participants, with one noting: "*We develop our own models with higher accuracy than publicly available ones*," demonstrating a drive towards developing customized tools to meet specific client requirements.

Several respondents rely on the expertise of climate advisers or scientific committees. As one participant stated, "*We have a climate advisor for each hazard in our portfolio. They guide our team by sharing newly published scientific papers*."

Practical considerations such as data availability, coverage, granularity, and ease of integration into existing frameworks also play a significant role in dataset selection. One respondent remarked, "*We aim to model physical risks in ways that are useful for decision makers, and where it is possible to do so robustly*."

In addition, some companies provided detailed criteria for selecting Global Climate Models (GCMs), including factors like the availability of predictors, temporal frequency, accessibility, ensemble membership, and model quality. One explained, "*The GCM must produce the output variables required to categorize a particular peril metric at the appropriate temporal frequency*."

Gaps in the data used

Respondents highlighted significant limitations in spatial and temporal resolution, particularly in underrepresented regions.

Challenges in data accessibility and quality were noted, including issues with incomplete or corrupted datasets, which affect the usability of General Circulation Models (GCMs). Additionally, there gaps in availability of solid matter-related datasets within the EU taxonomy and CSRD.

Uncertainty in climate projections, particularly when using multiple models or pathways, complicates risk interpretation. Difficulties in accurately modeling extreme events, such as tornadoes and hurricanes, were identified, alongside challenges in defining what constitutes an extreme event under changing climate baselines.

General data gaps, especially in sector-specific vulnerability models and the granularity of flood models, were identified as areas needing further development. Open flood models often lack the granularity required for major decision-making, prompting the integration of commercial datasets.

Post-processing techniques and data integration present challenges, as methods to increase data resolution can introduce additional uncertainties. Consistent methodologies are needed to avoid inaccuracies when combining multiple data sources.

General data gaps remain a concern, particularly in sectors that require detailed, sector-specific data for accurate risk assessments. While some gaps are filled with statistical approaches, significant challenges persist, especially in achieving global spatial coverage.

The reliability of risk assessments is affected by concerns over ensemble size and model quality, particularly for extreme value analysis. A more extensive number of climate ensemble members is necessary to improve the accuracy of these assessments.

Category	Representative Quotes
Spatial and Temporal Resolution	*“The major gap... is the lack of detailed wind and convective data, which are still not present in climate models.”*
	“Spatial Gaps: There are regions, especially in Canada, with less dense data coverage...”
	“ERA5 reanalysis at 25km resolution does not meet current needs.”
Data Accessibility and Quality	*“Not all GCM output is easily accessible or available for commercial use...”*
	"Solid matter-related datasets are poorly available within the EU taxonomy and CSRD."
Scenario Uncertainty	*“The use of multiple models... provides a range of possible futures, but there is still inherent uncertainty...”*
	"Scenario Uncertainty: The reliance on specific RCPs introduces uncertainty..."
Modelling Extreme Events	*“Current climate models do not adequately resolve tornado events...”*
	"The methodology for defining extreme events may not fully account for changing baselines and the potential for more severe future extremes."
Data Gaps and Sector-Specific Challenges	*“We find that open flood models are generally not granular enough for major decision making...”*
	“There remain large gaps in vulnerability models describing how vulnerable different assets are to the climate event...”

Post-Processing and Data Integration	*"Combining multiple sources of data, such as elevation models, soil databases, and land cover data, is crucial for accurate risk assessments."*
	"Post-processing techniques are necessary to increase the resolution but may propagate errors from the original models."
General Data Gaps	*"Some data gaps filled with statistical approach & and for the bottom-up approach, there are some gaps because our precise methodology is time-consuming."*
	"We are not yet global, which creates limitations in spatial coverage for our clients."
Model and Scenario Limitations	*"To obtain realistic risk information, more number of climate ensemble is necessary for extreme value analysis."*
	"Ensemble Size: The use of multiple models helps, but there is still inherent uncertainty..."

Public Availability of Methodologies

Respondents (n=16) were asked whether the methodologies involved in their risk calculations were publicly described. The results revealed a nuanced approach to transparency, with 38% of respondents (n=6) indicating that only certain aspects of their methodologies were made publicly available.

Similarly, 38% of respondents (n=6) reported that their methodologies were not disclosed to the public, highlighting a more cautious approach. This guarded stance likely stems from concerns about safeguarding sensitive business processes and maintaining an edge in the rapidly evolving field of climate risk assessment.

In contrast, 13% of respondents (n=2) confirmed that their methodologies were fully available in the public domain, showing a commitment to maintain transparency. Another 13% (n=2) of respondents were either uncertain or found the question not applicable to their services, which may suggest varying levels of engagement with public disclosure or differing interpretations of what constitutes a publicly described methodology.

It is apparent that private data providers strategically balance the concepts of transparency and protection of intellectual property by selectively disclosing information, thus establishing credibility while also preserving a competitive edge.

Uncertainty estimates

Respondents (n=16) were surveyed on whether their methodologies and product sets include clear estimates of uncertainty. The majority (50%, n=8) indicated they do incorporate clear estimates of uncertainty into their products.

A quarter of respondents (n=4) acknowledged that their methodologies do not include clear estimates of uncertainty, while another quarter (n=4) either did not know or did not consider the question applicable to their services. The gap in uncertainty estimates suggests either a limitation of current models or a deliberate choice to prioritize other aspects of risk assessment.

HILL Events, and Tipping Points

The survey responses from 16 organizations show a strong focus on addressing tail risks, High Impact Low Likelihood (HILL) events, and tipping points in climate risk products. The majority (63%, n=10) of respondents confirmed that their products include estimates for these extreme and low-probability events. Three respondents indicated that their products do not incorporate these estimates, possibly due to specific model focuses or limitations. Another three were either uncertain or found the question inapplicable.

Further exploration of the methodologies used to estimate tail risks, HILL events, and tipping points (n=8) shows diverse approaches. One respondent described a broad approach covering extreme heat, precipitation, wind, flooding, and wildfire risks, using 2-day precipitation totals exceeding the 98th percentile of historical data to identify extreme events. Another emphasized the use of high return periods and full probability distributions, particularly the 95th percentile of risk in each location, to capture severe impacts.

Some companies rely on existing datasets to expose uncertainties without specifically modelling tipping points, maintaining connections to research communities focused on these areas. Others incorporate biodiversity and climate performance data to help clients identify the most at-risk entities, linking environmental factors with financial vulnerabilities.

Finally, one respondent highlighted the role of high-emission scenarios, such as SSP5/RCP 8.5, in considering tipping points through feedback mechanisms in climate models, emphasizing the importance of scenario analysis in anticipating potential shifts in climate systems.

Generally, the approaches and focus areas tend to differ among respondents.

Asset Data

Dependence on Asset Data

Respondents (n=15) were asked whether their climate risk products rely on asset data. A significant majority (67%, n = 10) confirmed this, underscoring the importance of precise asset-level data for accurate risk assessments. This dependence is particularly relevant in industries such as asset management, real estate and insurance. In contrast, 27% of participants (n=4) stated that their products do not utilize asset data, potentially prioritizing broader climate risk evaluations that are not specific to assets. One respondent (7%) was unsure or found the question inapplicable to their services.

Types, Sources, and Spatial Resolution of Asset Data

Among those who use asset data (n=10), respondents identified a broad range of data types and acquisition strategies, highlighting the diversity in how asset data is integrated into climate risk products.

The majority (n=7) emphasized the importance of physical characteristics, such as location coordinates, height, surface area, and asset value. As one respondent noted, "These are the data we request from users: Year of construction, Asset height above ground (m), Asset's surface area (m²), Asset value (€), Yearly income from asset (€), Yearly asset expenses (€)."

A few participants (n=2) incorporate financial and operational data alongside physical characteristics. This includes metrics like revenues, GDP, financial income, debt levels, and production volumes, demonstrating a comprehensive approach to risk assessment.

Some respondents mentioned using partnerships with other companies to enrich their data sets. This often involves integrating specialized data from physical climate risk providers or third-party data sources, allowing organizations to leverage comprehensive databases for more robust assessments.

Spatial Resolution

Respondents (n=9) provided insights into the spatial resolution of the asset data used in their products. There is a clear divide in the precision of this data:

Several respondents (n=4) use highly precise spatial resolutions, with asset locations pinpointed to within a few meters. This allows for detailed, granular analysis crucial for high-stakes decisions.

Some organizations (n=2) use broader, more general data. For example, one respondent mentioned their analysis is "Country-specific and region-specific where more precise," indicating that resolution can vary depending on the source's granularity.

Specific grid resolutions also vary. One respondent uses a 90x90 meter grid cell, while another operates at a 1-degree grid resolution (approximately 100km by 100km), though updates are anticipated.

The significance of context-specific resolution in climate risk assessments is highlighted by a range of different approaches, as some companies choose to prioritize high precision for detailed analysis, while others offer broader spatial data that is suitable for regional or national-scale assessments.

Sources of Asset Data

Respondents (n=9) discussed the sources of asset data they utilize, reflecting a diverse range of acquisition strategies. A few respondents (n=2) rely on user-provided data and satellite imagery, which includes detailed geographic and environmental information such as ground slopes, geomorphology, and proximity to natural features like rivers and the sea.

Some participants (n=2) source asset data from specialized providers or third-party vendors, leveraging various databases to compile comprehensive datasets.

Other respondents (n=3) gather asset data through proprietary methodologies or public sources, such as Environmental Protection Agencies (EPAs), annual reports, or official websites, ensuring the data meets their specific needs.

One company noted that when using open-source code, firms typically rely on their own data or augment it with public datasets, particularly for real estate lending.

Enhancing Climate Risk Services

In response to what would improve their climate risk service offerings, several themes emerged from the survey (n=5). A prominent suggestion was the development of sector-specific modules tailored to industries like banking, insurance, and real estate. Expanding globally was also identified as a key strategy.

Improving risk modelling was another significant focus, with respondents emphasizing the need to incorporate multiple return period losses (e.g., 1 in 100, 1 in 200, 1 in 500 years) to better capture extreme events. Enhancing asset location data with greater detail and integrating indicators for adaptation, resilience, and biodiversity were also seen as valuable additions that could differentiate services.

Collaboration was identified as a crucial element for progress. Respondents expressed a desire to partner with other firms to test and validate early-stage products in new regions. There was also a call for increased collaboration at the foundational level, where companies could work together to develop more effective solutions.

When discussing physical climate risks, respondents underscored the need for clearer guidelines on defining these risks and improving methods for verification, such as back-testing. There was a strong emphasis on the necessity for institutions to thoroughly consider how physical climate risks could impact their operations. One respondent pointed out that while risks projected for the next 30-50 years may seem distant, they are likely to begin influencing asset valuations within the next five years. Additionally, a detailed response highlighted the importance of a bottom-up approach to transition risks, stressing the need to include all emissions scopes (Scope 1, 2, and 3) in assessing systemic transition risks.

4. Discussion [ALL]

Fostering closer collaboration between academia and commercial providers?

Clients

Data providers are adapting to a wide range of clients. The demand is currently hight from the asset owners, management firms, insurance companies, and investment banks who are under significant regulatory and market pressure to produce risk disclosures. However, there is an emerging need from venture capital and pension funds. For venture capital, this might relate to the future viability of startups in a climate-impacted world, while for pension funds, it relates to safeguarding retirement investments over decades.

The perception of climate risk time horizons could be the reason why retail banking and foreign exchange tend perceive them as less immediate, highlighting the potential gap in integrating climate risks into their financial models (REF).

Billing

Data providers lean towards recurring licence fees billing model, which allows a more stable, long-term revenue streams and supports sustained client engagement and regular data updates.

However, given the wide diversity of clients (by type/size of their business), to be flexible, some data providers choose negotiable billing models and dynamic pricing strategies. The emergence of innovative billing approaches (e.g., volume-based pricing and open-source models) demonstrates the industry's responsiveness to client preferences and the evolving landscape of climate risk management.

Geography

There is a need for broader engagement in emerging markets, where climate risks are escalating but where there may be fewer resources or less regulatory pressure to drive demand for climate services.

The uneven geographic distribution of services highlights an unspoken challenge for providers: balancing the immediate, revenue-generating opportunities in well-established markets with the strategic necessity of expanding into underrepresented regions. Additionally, the reliance on established markets could expose providers to risks if these markets become saturated or if regulatory frameworks change unexpectedly.

Positively, the strong presence in North America and Europe demonstrates the effectiveness of these regions as proving grounds for climate services, potentially serving as models for expanding offerings in other parts of the world. The existing engagement in diverse regions like Asia, Africa, and South America, albeit lower, suggests that the foundations for growth are already in place, ready to be built upon as awareness and demand for climate risk assessments continue to rise globally.

Data sources

The overly reliance on Global Climate Models (GCMs) and reanalysis datasets such as ERA5 highlights the industry's commitment to regulatory frameworks that govern climate risk disclosures for financial institutions. These frameworks often rely on GCM outputs for scenario analysis, particularly focusing on Representative Concentration Pathways (RCPs) and the newer Shared Socioeconomic Pathways (SSPs). Many GCMs are developed as part of large international collaborations like the Coupled Model Intercomparison Project (CMIP), which means that they adhere to international scientific standards. Additionally, GCMs are frequently used to model long-term climate risks at the global scale, which is essential for meeting the stress-testing requirements (REF).

The inherent limitations of GCMs, including coarse spatial resolution and the need for bias correction, present challenges in delivering precise, actionable insights. While downscaling techniques are employed to address these issues, their adoption appears uneven across organizations, suggesting a potential gap in the integration of regional climate data.

Moreover, the limited specificity in utilising current weather forecasts and decadal predictions indicates a need for further refinement in short- and medium-term climate modelling.

Risk types

Financial institutions are most concerned with managing physical and transition risks, reflecting their significant focus on the impacts of extreme weather, agricultural shifts, and the regulatory dynamics of carbon reduction. Additionally, there is notable attention to economic and environmental factors such as growth, inflation, supply chain disruptions, ecosystem collapse, and resource scarcity. While still less emphasised, the need to address reputational, litigation, geopolitical, and technological risks is likely to increase as these factors become more directly relevant to climate change.

Modelling these factors requires not just climate data but also economic, policy, and technological data, which may be less readily available or more difficult to integrate into traditional climate risk models.

Some explore more specialized and nuanced risk assessments, which could offer competitive advantages in a market where one-size-fits-all solutions are becoming less viable.

Possible blind spot, especially as geopolitical tensions and technological disruptions increasingly intersect with climate change.

Timeframe

The findings show that financial institutions place importance on climate risk assessments for both short (2-5) and long-term planning (10-30).

Tech

Emphasise granular, asset-level analysis, with some providing risk assessments down to the census block or parcel level.

The integration of machine learning (ML) and artificial intelligence (AI) is becoming a key differentiator in enhancing the efficiency and accuracy of climate risk assessments. **Black boxes?**

Data

Open-source data can sometimes have a lag in availability, meaning that the most recent environmental changes may not be reflected in the data used for assessments.

The limited use of current weather forecasts and seasonal predictions reflects a gap in addressing immediate risks.

Challenge of achieving transparency and clarity in data sourcing and integration

AI/ML models are only as good as the data they are trained on.

Some companies emphasise the link between physical risks and financial metrics. However, there may be challenges in ensuring that these links are robust.

Customisation can be resource-intensive, and there is often a trade-off between the depth of customisation and the scalability of solutions.

The increasing digitalisation and integration of various data sources raise cybersecurity concerns. Data providers must ensure that their platforms are secure against cyber threats, especially when providing APIs or integrating third-party data.

The lack of standardisation across different data sources can lead to inconsistencies in assessments.

Services

This variation in services suggests that companies are tailoring their services to specific client needs or market niches indicating a fragmented market where no single company covers all possible climate risks comprehensively.

While the translation of complex scientific findings into actionable tools remains a challenge, there are clear opportunities for improvement that can enhance both the efficacy and reliability of these services.

A critical step toward this goal is fostering closer collaboration between academia and commercial providers. The demand for peer-reviewed data among commercial providers is a promising sign of a commitment to quality. However, the integration of these data into commercial products is often inconsistent.

Other

Businesses often struggle with how much of their methodology and data sources to disclose as revealing too much could undermine their competitive advantage.

Clients often expect high precision and accuracy in climate risk assessments, but there is a gap between these expectations and what current data and models can realistically deliver.

Ensuring that clients trust the data, especially when it involves significant uncertainty or probabilistic outcomes, can be challenging.

There is often a need to fill in gaps with estimates or less reliable data.

Businesses face pressure to innovate and improve their data and models continuously, but it can be difficult to justify the return on investment for these innovations, especially when the market is still maturing.

Adapting to a constantly changing regulatory environment can be costly and time-consuming.

Protecting sensitive asset-level data from breaches or misuse is a critical concern, especially when dealing with high-value clients.

Collaborations with public entities often come with expectations of data sharing or contributing to public knowledge, which may conflict with business goals.

Keeping staff and stakeholders up-to-date with the latest in climate science and risk assessment techniques requires continuous training can be both costly and logistically challenging.

The market for climate risk data is still maturing, and many clients may not fully understand the complexities involved, leading to unrealistic expectations or resistance to adopting new methodologies.

Integrating diverse datasets from multiple sources without compromising accuracy or consistency remains a significant technical challenge.

Businesses may struggle to balance the immediate demands of clients with the need to invest in long-term research and development to improve data quality and modelling techniques.

References