Natural Catastrophe Review: Expert insights, lessons learned and outlook

July — December 2024

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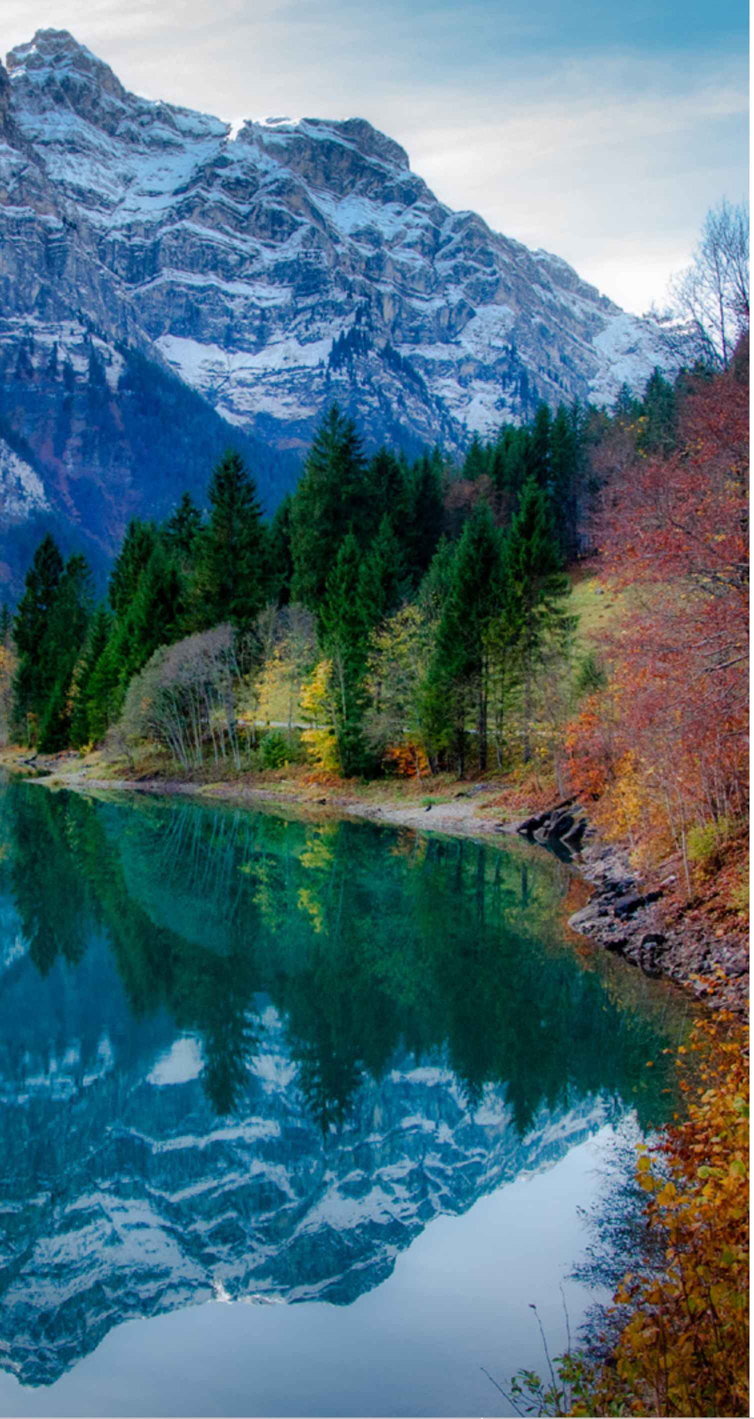

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Foreword

Monsters in the fog: Understanding and preparing for extreme risks

Foreword by Scott St. George

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The most curious thing about rare events is the fact that they happen all the time. A single location that is vulnerable to the 1-in-100-year flood or another equally exceptional hazard has only a 1% chance of being damaged over the coming year. But when that same risk is spread over a longer time frame — say, for example, 30 years (the most common mortgage length in the United States) — the chance of harm rockets up to one in four. And if you have risk exposure at many locations and many places, chances are, next year several of them will be unlucky enough to be hit by that improbable event. Over and over, experience shows that natural catastrophes not only are possible but also ought to be regarded as inevitable.

Even so, too often we disregard the potential danger from floods, wildfires, tropical storms and similar perils. In some situations, we might not have firsthand experience with specific hazards and are obligated to rely on sparse data sets that don't disclose the full range of possibilities. Or we might be aware of a long-ago disaster at the same location but choose to believe something similar won't happen again anytime soon. In other cases, we may be slow to realize that risks have recently gone up, perhaps due to exposure growth, bottlenecks in supply chains or climate change.

We often use models to anticipate the frequency and severity of perils at one or more locations. But when credible models disagree with each other, how can we decide which one is best able to predict the most extreme situations — particularly when those cases have happened only once or twice before in recorded memory or are truly without precedent? Even with the support of such sophisticated tools, it can still be a thorny challenge to judge our exposure to tail risks accurately.

Of course, this problem is not confined to physical perils. In the context of financial markets, the statistician Nassim Taleb has argued that conventional models underestimate the likelihood of fat-tail events — rare events that are much more severe than "everyday" occurrences — and struggle to represent their consequences realistically. Under these circumstances, staying humble is crucial. The more extreme the event (and the larger its potential impact), the more cautious we need to be about the limits of our own understanding.

So, what can we do to prepare better for future catastrophes? One step is to invest in up-to-date models and data, especially for those perils we know are changing rapidly.

In addition, when we use models to inform our decisions about physical risks, we need to be sure they apply to our specific set of conditions and not force them to extrapolate beyond their capabilities. We also can't forget to consider non-modeled risks — things that have happened before and could happen again but are not well represented by even the latest state-of-the-art tools. And finally, because our judgment of the most extreme catastrophes is often hazy, it's smart not to depend on insights from any single model and instead consider as many perspectives as possible.

At WTW, our in-house team of scientists, engineers and financial experts can provide in-depth risk analysis, hazard and catastrophe modeling, and vulnerability/loss assessments for any location or portfolio. And through the WTW Research Network, we are partnered directly with many of the world's top experts on natural hazards, climate change and risk modeling. We shouldn't sit idle, waiting for the next catastrophe to take us by surprise. Instead, let's work together to keep our people, facilities and investments safe when the next monster emerges from the fog to knock at our door.

Executive summary

Executive summary

Welcome to the latest edition of WTW's Natural Catastrophe Review, a biannual publication that brings insights from our experts, including WTW's Research Network, to examine recent natural disasters, lessons learned and emerging trends.

This edition delves into the physical, vulnerability and socioeconomic factors that contributed to the largest natural catastrophes in the second half of 2024 (Figure 1) and examines the overarching themes of the year. Offering a smarter way to risk, this report goes beyond the numbers to provide new perspectives to help with natural catastrophe risk management and resilience across multiple sectors.

The spotlight on climate change intensified in 2024 as the global mean temperature exceeded 1.5°C above pre-industrial levels for the first time (Figure 2). The year saw an array of weather-related catastrophes, many of which were influenced by the effects of a warming planet. Global insured losses exceeded $140 billion, marking the fifth consecutive year above $100 billion. Meanwhile, the protection gap remained substantial, with total economic damages exceeding $350 billion, highlighting the inadequacy in resilience to climate-related risks.

Storms, flooding and drought shape 2024

In the second half of 2024, hurricanes Helene and Milton caused significant destruction, with combined insurance claims of over $40 billion (Section 3.1).

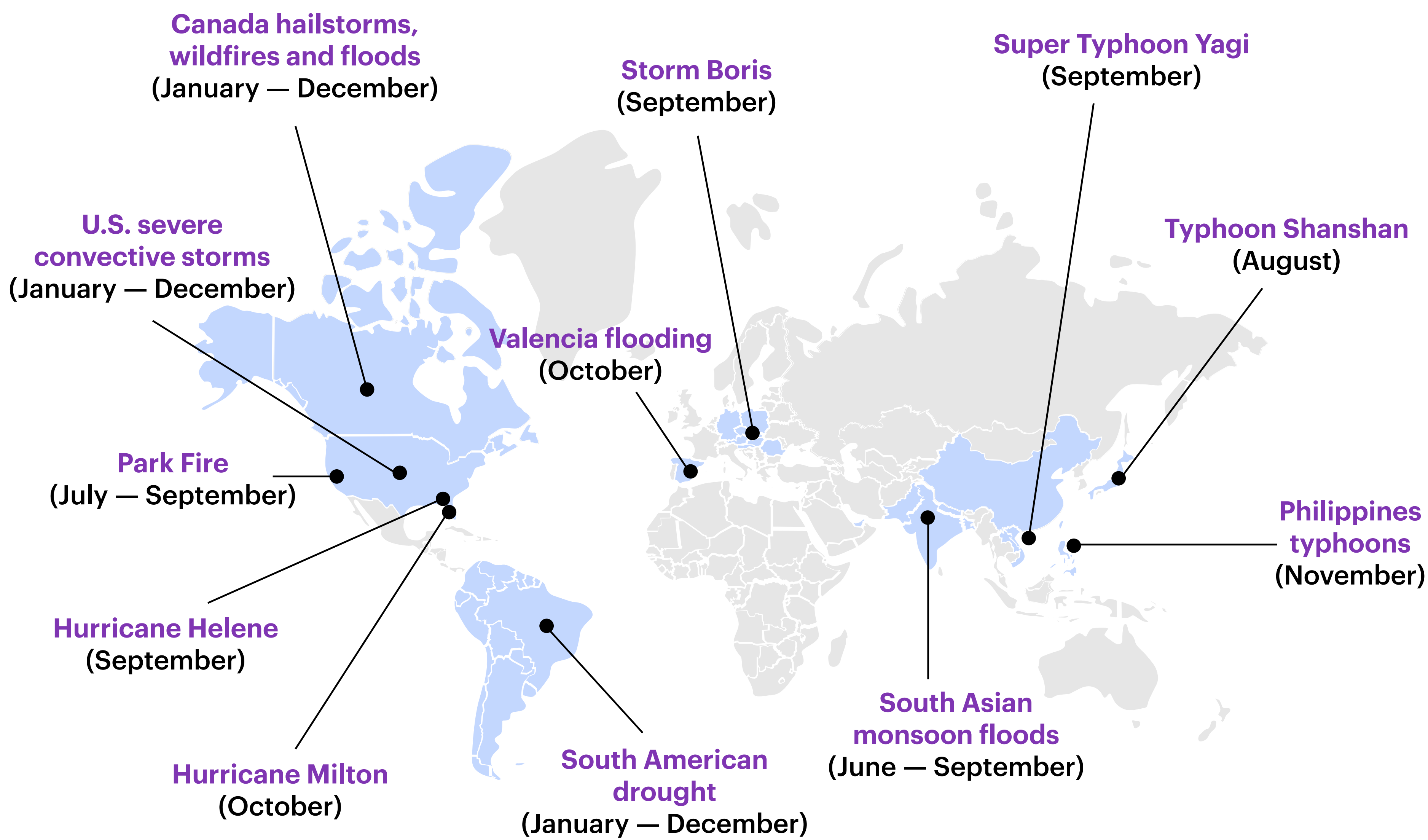
Meanwhile, in the western North Pacific, Super Typhoon Yagi ranked among the 10 costliest storms on record, with economic losses of over $15 billion across Southeast Asia and South China (Section 3.7). U.S. severe convective storms continued their recent trend of elevated damages, with total insured losses exceeding $50 billion for the second year in a row (Section 3.2). And Canada saw its costliest year on record for natural catastrophes as hailstorms, floods and wildfires led to insured damages totaling $5.6 billion (Section 3.6).

Globally, flooding caused significant disruption. Europe endured one of its worst years on record for flood-related damages. In Spain, devastating floods swept through Valencia, resulting in $3.7 billion in insurance claims, marking the country's costliest natural catastrophe on record (Section 3.4). Storm Boris brought extreme rainfall and flooding to Central and Eastern Europe, with claims totaling $2.2 billion (Section 3.3). In South Asia, intense monsoon rains affected millions, disrupting key sectors such as agriculture, energy and manufacturing (Section 3.9). These events followed several severe floods in the first half of 2024, including in the United Arab Emirates, Brazil, China and Germany.[1]

While many regions were overwhelmed by water, large parts of South America faced the opposite extreme — a catastrophic drought that severely impacted key sectors, including agriculture, energy and transportation — highlighting the interconnected nature of climate-related risks (Section 3.8).

[1] WTW. Natural Catastrophe Review January – June 2024 (2024).

Figure 1. **Prominent natural catastrophes July – December 2024 discussed in this Natural Catastrophe Review.**



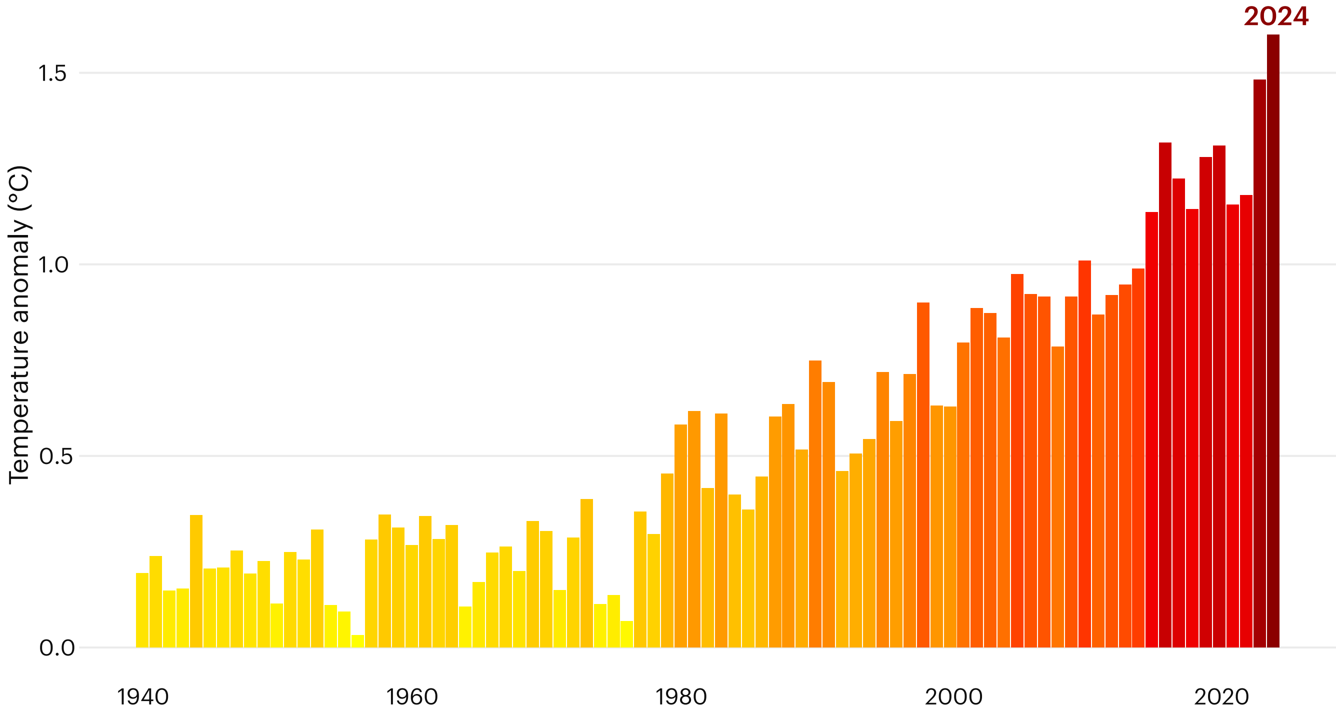
2024 becomes the first year to exceed 1.5°C

In 2024, the annual global mean temperature exceeded 1.5°C above pre-industrial levels for the first time, averaging 1.55°C above the 1850–1900 baseline,[2] according to the World Meteorological Organization. This milestone marks the threshold identified in the 2015 Paris Agreement as critical for avoiding the most severe impacts of climate change. It follows another record-breaking year in 2023, which reached 1.48°C above pre-industrial levels.[1]

However, the Paris Agreement's target refers to long-term average temperatures, meaning a single year exceeding this threshold does not constitute a permanent breach. Nonetheless, the latest temperature data highlight the rapid rate at which the Earth is warming. All of the past 10 years now rank in the top 10 warmest on record.

A key contributor to the record-high temperatures in both 2023 and 2024 was El Niño, which peaked in December 2023 but continued to influence global temperatures during the first half of 2024. By May 2024, neutral El Niño-Southern Oscillation conditions had developed, with sea surface temperatures gradually returning to near-average levels in the Central and Eastern Pacific. Despite this transition, many other regions experienced persistently high sea surface temperatures (SSTs), contributing to the average SST outside the polar regions reaching record levels in 2024 (0.51°C above the 1991 – 2020 average, according to the Copernicus Climate Change Service).

Figure 2. **Annual global surface temperature anomaly relative to a pre-industrial baseline (1850 – 1900).**



Data source: Copernicus Climate Change Service via climatereanalyzer.org.

[2] United Nations. Sustainable Development Goals: WMO confirms 2024 as warmest year on record at about 1.55°C above pre-industrial level. (2025).

A total of 20 heat records were broken across sovereign states and territories in 2024, with Mexico and Egypt experiencing the most extreme temperatures, reaching 52.0°C and 50.9°C, respectively. Research from the WTW Research Network, led by Dr. James Done at the U.S. National Center for Atmospheric Research, reveals that 2024's heat records reflect a broader trend: Extreme heat events in cities have quadrupled in frequency over the past 40 years, with heat waves now lasting twice as long in some regions. These extreme heat events highlight the growing effects of climate change on health, infrastructure and ecosystems, with extreme heat now responsible for approximately 500,000 heat-related deaths annually worldwide.

The growing influence of climate change

The mounting financial impact of natural catastrophes continues to be driven by the expansion in both the number and value of assets at risk. However, climate change is also playing an increasingly prominent role, with several events in 2024 being linked to human-caused warming. Rapid attribution has become a critical tool in understanding these connections. Scientists, including those at the World Weather Attribution project, can quickly assess the extent to which climate change has influenced the likelihood or intensity of specific events.

In 2024, rapid attribution studies provided a number of insights into how climate change influenced the year's weather events. Researchers found that exceptionally warm SSTs in the Gulf of Mexico were 200 to 500 times more likely along Hurricane Helene's path and 400 to 800 times more likely along Hurricane Milton's path due to human-induced climate change.

In Central and Eastern Europe, the rainfall from Storm Boris was determined to be 10% more intense and twice as likely because of climate change. Similarly, the severe drought in South America was found to be 30 times more likely as a result of human-caused warming.

These findings highlight the ongoing need to address climate risks through both mitigation and adaptation measures. This includes investing in protective infrastructure, such as flood defenses, and ensuring adequate insurance coverage to close the protection gap and strengthen financial resilience.

Interconnected and compounding risks

As climate change intensifies, we are also seeing an increase in interconnected and compounding risks across multiple sectors. For instance, the 2024 drought in South America, driven by El Niño and climate change, disrupted energy, transportation, agriculture and businesses simultaneously (Section 3.8). Businesses reliant on electricity, water supplies and transportation — such as those in manufacturing and food processing — faced significant operational challenges, as these interlinked disruptions compounded the economic impact of the drought.

Another example of interconnected risks is the growing threat of dam failures as infrastructure ages and rainfall extremes increase. In 2024, several dam failures occurred across the globe, many triggered by heavy rainfall, leading to flooding that disrupted local populations and economies (Section 3.5).

These examples highlight how climate-related events can lead to multifaceted and often amplified impacts, necessitating integrated, cross-sectoral approaches to resilience and risk management.

Outlook

The Outlook section of this edition explores several key themes shaping the future of risk management and resilience. The first theme focuses on how predictive science and models support decision making amid uncertainty. In 2024, questions about the accuracy of North Atlantic hurricane forecasts emerged during a mid-season lull in storminess. In response, WTW Research Network partner Dr. Erica Thomson examines the utility and limitations of pre-season hurricane forecasts for decision making (Section 4.1). Section 4.2 then turns to earthquakes, exploring the potential of foreshocks to predict impending large seismic events in the context of Japan's first "megaquake" warning. On the topic of resilience in climate mitigation, Section 4.3 considers the role of insurance in safeguarding carbon markets after the 2024 California Park Fire. Finally, Section 4.4 delves into the evolving landscape of climate litigation, highlighting how increasing accountability and reporting requirements are driving legal risks for organizations.

Natural peril review

3.1 Helene and Milton continue the recent run of major hurricanes hitting the US Gulf Coast

Pre-season forecasts for an active 2024 North Atlantic hurricane season proved accurate, as a mid-season lull gave way to a late burst of storms, with Helene and Milton inflicting significant damage.

The 2024 North Atlantic hurricane season lived up to pre-season forecasts for an extremely active year. By its conclusion at the end of November, the season had delivered 18 named storms, with 11 intensifying into hurricanes and five into major hurricanes (Table 1). These numbers far exceeded the 1991 — 2020 averages of 14 named storms, seven hurricanes and three major hurricanes. The Accumulated Cyclone Energy (ACE) index reached 162, 31% above the 1991 — 2020 average, a clear sign of how busy 2024 turned out to be.

Early in the season, Category 5 Hurricane Beryl set a record as the strongest storm ever recorded before August 1.[1] But then the tropics fell quiet. Just three hurricanes developed during the traditional August to September peak — a stretch of calm that left forecasters questioning the accuracy of their predictions (Section 4.1).

This unexpected pause was caused by several atmospheric factors. Easterly atmospheric waves from Africa, typically a reliable source of storm activity, began emerging farther north than usual. In addition, high vertical wind shear in the eastern Atlantic, very warm temperatures in the upper atmosphere and an unfavorable Madden-Julian Oscillation phase created a hostile environment that suppressed storm formation for several weeks.[2]

However, activity picked up in late September in dramatic fashion, with seven hurricanes forming after the third week — a new record for late-season storm development.

High Gulf temperatures fuel strong storms

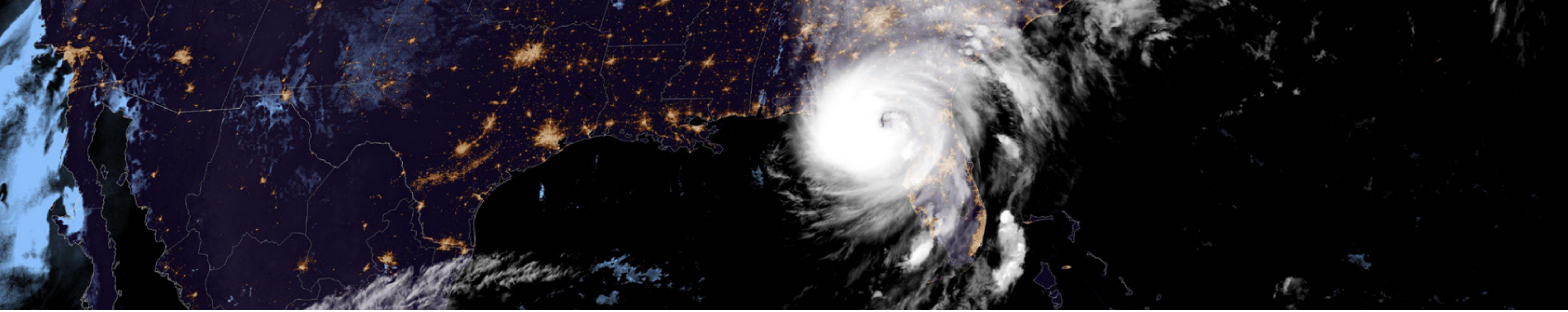
Florida's Gulf Coast saw a historic year, with hurricanes Debby, Helene and Milton equaling the record for the most hurricanes to strike the state in a single season. Helene and Milton represented a substantial share of global insured losses for 2024, with insured damages estimated at $15 billion to $20 billion for Helene and $25 billion for Milton.

The U.S. Gulf Coast faced additional impacts: Hurricane Beryl made landfall in Texas as a Category 1 storm, while Category 2 Francine struck Louisiana. With five Gulf Coast landfalls, 2024 now ranks as the joint second-highest on record, matching 2005 and 2020 and surpassed only by 1886, which saw six.

These storms were driven by extremely high Gulf of Mexico sea surface temperatures (SSTs), which were nearly 1°C degree above the 1991 – 2020 average for the period June to November (Figure 1) — the second warmest on record, after 2023.

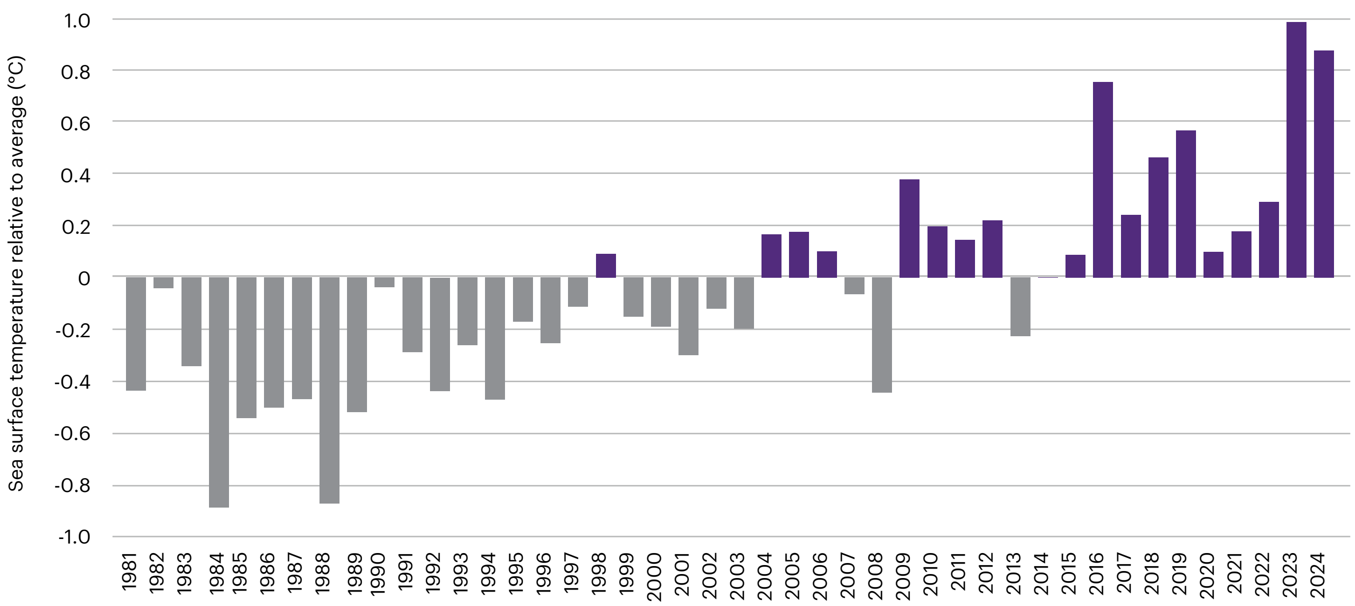
Scientists found that the exceptionally warm Gulf SSTs were 200 to 500 times more likely along Helene's path[3] and 400 to 800 times more likely along Milton's path due to climate change.[4] These findings highlight how human-induced warming has made such extreme conditions more common.

[1] WTW. Record-breaking Hurricane Beryl in three figures. Natural catastrophe review January — June 2024. (2024).
[2] Klotzback, P. J. et al. Summary of the 2024 Atlantic Tropical Cyclone Activity and Verification of Authors' Seasonal and Two-Week Forecasts. (2024).
[3] World Weather Attribution. Climate change key driver of catastrophic impacts of Hurricane Helene that devastated both coastal and inland communities. (2024).
[4] Climate Central. Analysis: Ocean temperatures warmed by climate change provided fuel for Hurricane Milton's extreme rapid intensification. (2024).



The 2024 season exemplified a recent trend of strong storms impacting the U.S. Gulf Coast. Since 2017, eight Category 4+ hurricanes — Harvey, Irma, Maria, Michael, Laura, Ida, Ian and now Milton — have made Gulf landfalls. By contrast, the previous eight Category 4+ landfalls spanned 57 years (1960 – 2016). The Intergovernmental Panel on Climate Change projects that a warming climate will increase the frequency of Category 4+ storms. As a result, risk managers are closely watching this trend, adjusting catastrophe models and refining strategies to better align with the evolving risk landscape.

Figure 1. **Gulf of Mexico sea surface temperature anomalies relative to the 1991 – 2020 average for the period June – October.**



Data source: NOAA.

Hurricane Helene: Third Big Bend landfall in 13 months brings severe flooding to the southeast

On September 26, Hurricane Helene made landfall as a Category 4 storm with sustained winds of 140 miles per hour near Perry on Florida's Big Bend — the curve of the Gulf Coast where the Florida Panhandle meets the Peninsula. In less than three days, Helene rapidly intensified from a weak tropical storm to a major hurricane, bringing up to 15 feet of storm surge to a stretch of coast that had not seen such extreme conditions in decades.

But what really stood out was Helene's size. With tropical-force winds extending 350 miles from its center, the cyclone was one of the largest on record in the Gulf. This resulted in widespread wind and flood damage across multiple states, including Florida, Georgia, South Carolina, North Carolina, Tennessee and Virginia.

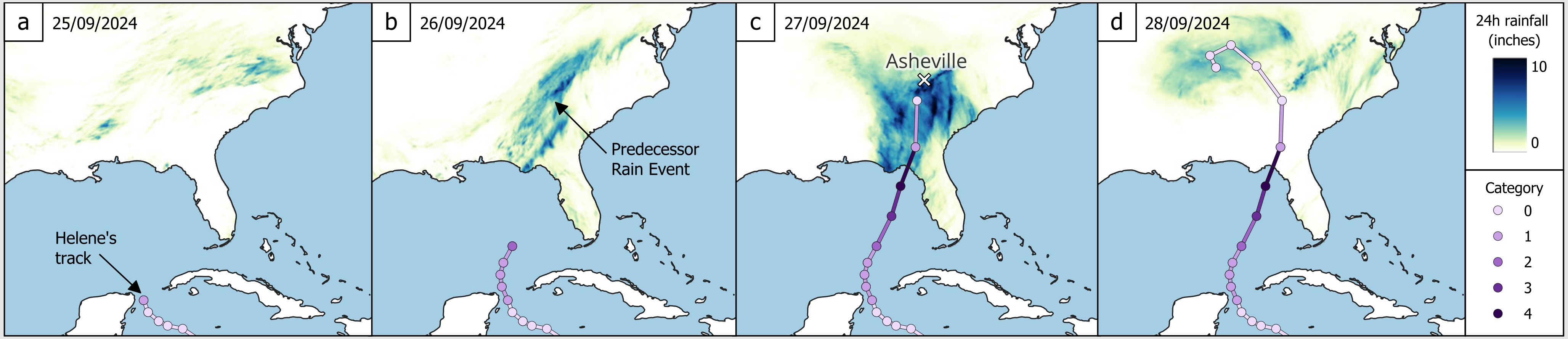
The hurricane's vast size drew in significant moisture and maintained hurricane-force winds as it moved inland, leading to intense rainfall across a wide area (Figure 2). In western North Carolina, Asheville and surrounding areas received over 700 millimeters of rain over three days, resulting in catastrophic flooding. This included precipitation from a predecessor rainfall event (Figure 2b), exacerbating the scale of the disaster.

In the U.S., flood insurance is mandatory for homes in high-risk flood zones as designated by the federal government. But much of the flood damage wrought by Helene occurred in places where flood insurance is not mandatory. As a result, only 1% to 2% of homeowners in the hardest-hit areas are estimated to have flood insurance, revealing a major protection gap.

The flooding accounted for most of the 234 reported deaths, marking the highest fatality count from a mainland U.S. hurricane since Katrina in 2005. The flooding also highlighted the vulnerability of global supply chains to natural catastrophes, as key quartz mining operations critical to the semiconductor industry were temporarily halted in North Carolina.[5]

Helene was the third hurricane in just over a year to hit Florida's Big Bend, following Debby in 2024 and Idalia in 2023. Before this, the region had not seen a landfall since Hurricane Alma in 1966. Catastrophe models had long warned of the Big Bend's vulnerability, and recent storms confirmed that a quiet history does not erase underlying risk. However, preparedness still lagged. Many of the damaged properties predated modern building codes, exposing vulnerabilities that lay dormant in areas untested by recent storms.

Figure 2. **Hurricane Helene's track and the accumulated 24-hour precipitation for 12:00–12:00 UTC in the four-day period prior to and post landfall.**



Data source: NOAA.

[5] Forbes. Quartz Mining Resumes In North Carolina After Hurricane Helene—Here's How The Storm Impacted The World's Semiconductor Industry. (2024).

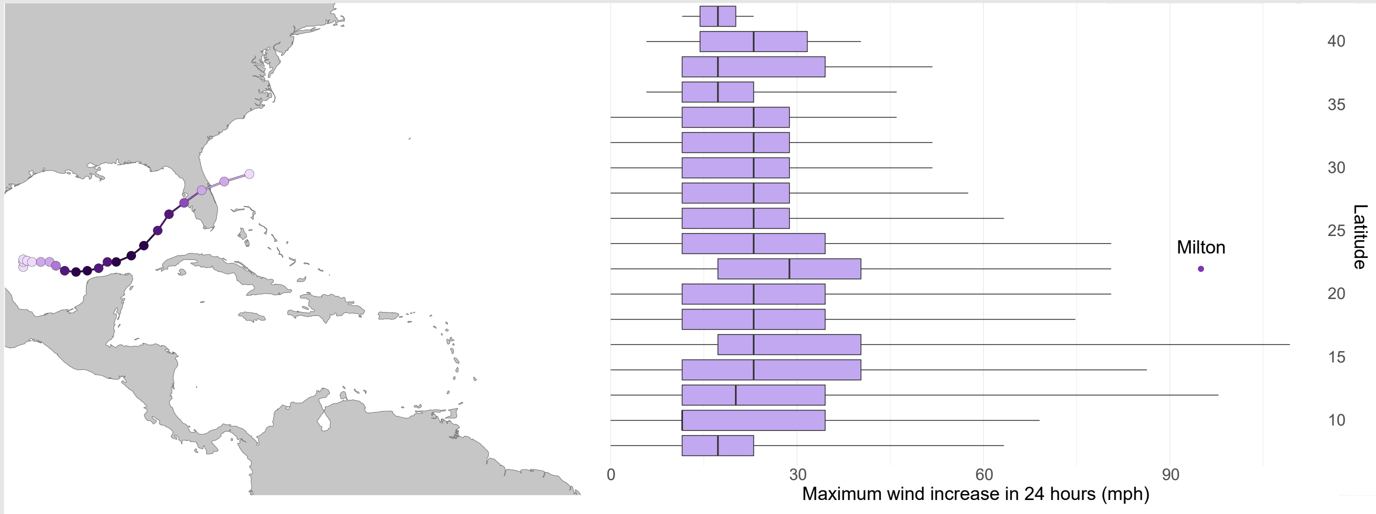
Hurricane Milton: The fastest-intensifying Gulf storm on record maintains pressure on insurers

Just two weeks after Helene, Hurricane Milton headed toward Florida's Gulf Coast, making landfall near Siesta Key on October 9 as a Category 3 storm. Milton's extraordinary intensification of 95 miles per hour within 24 hours prior to landfall set a record for the Gulf of Mexico (Figure 3). The storm caused widespread wind damage across central and southern Florida. Milton also generated a storm surge of five to 10 feet along the coast and brought record precipitation, which flooded inland areas such as St. Petersburg, which saw over 18 inches within 24 hours.

Milton spawned an unusually high number of strong tornadoes, including rare EF3 tornadoes in Palm Beach Gardens and Fort Pierce. The National Weather Service issued 126 tornado warnings on October 9, doubling Florida's previous single-day record.

Demand surge will likely play a role in the financial impact of Milton, as insurance claims are driven up due to limited labor and material supplies following back-to-back storms. With global insured losses exceeding $140 billion and Helene and Milton contributing significantly to these damages, any possible softening in property catastrophe (re)insurance rates for 2025 will likely be muted. Instead, (re)insurers are expected to maintain a disciplined approach to underwriting, a stance shaped by the ongoing pressure of high-cost catastrophe losses.

Figure 3. **Boxplot of the maximum recorded 24-hour intensification rate for all Atlantic tropical cyclones since 1900 and the latitude at which the maximum intensification period began. Hurricane Milton's maximum 24-hour intensification rate is shown with a point.**



Data source: HURDAT2 and NOAA.

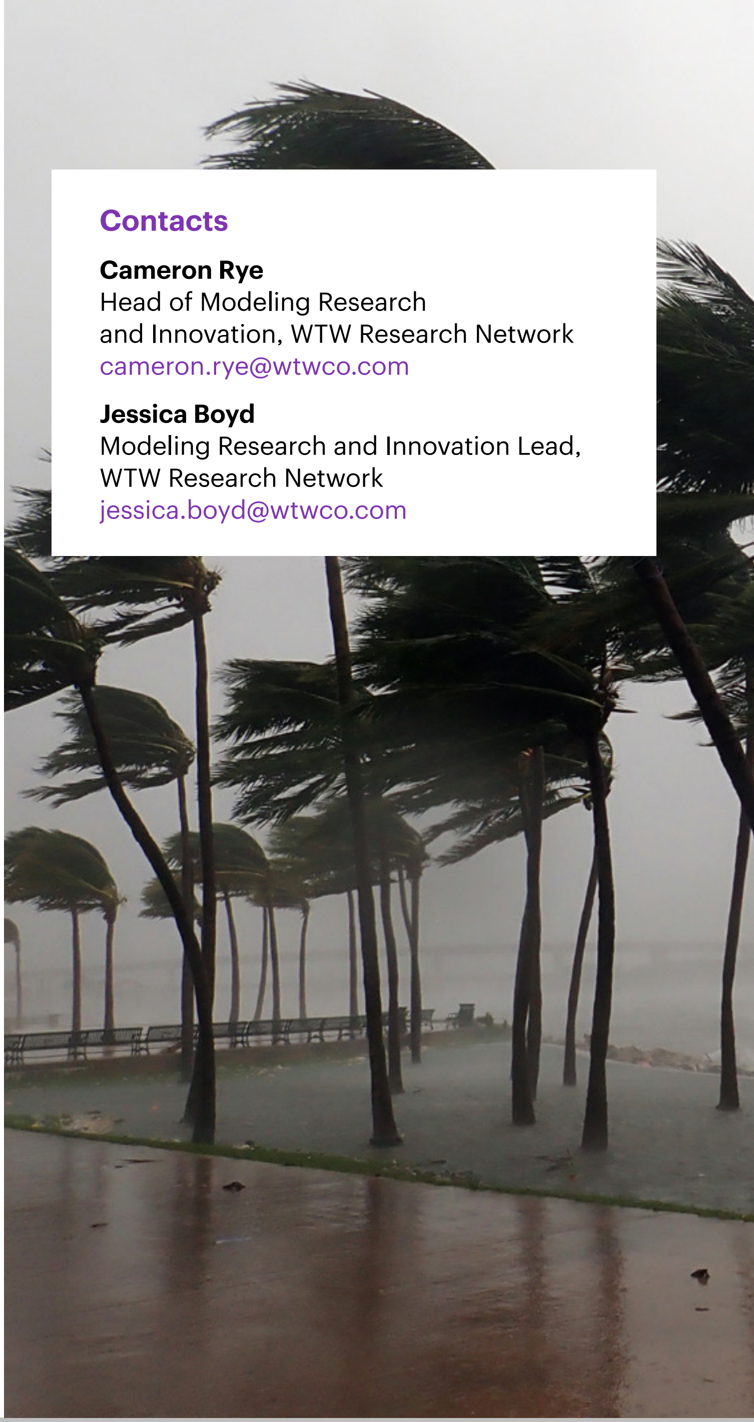
The toll, though, could have been far worse. A slight shift in Milton's landfall northward might have mirrored the 1921 Tampa Bay hurricane, which drove a 10-12 foot surge into the bay's shallow waters. In a more extreme scenario, such as the Tampa Bay Regional Planning Council's "Hurricane Phoenix" (a hypothetical Category 5 storm hitting just north of the bay), insured losses could easily top $100 billion.

With Milton's impact still fresh, this is an opportune time for insurers to run downward counterfactual scenarios[6] to assess how much larger their losses could have been.

[6] Rye, C.J., and Boyd, J.A. Downward Counterfactual Analysis in Insurance Tropical Cyclone Models: A Miami Case Study. In: Collins, J.M., Done, J.M. (eds). Hurricane Risk in a Changing Climate. Hurricane Risk, vol 2. Springer, Cham. (2022).

Table 1. **List of 2024 North Atlantic hurricanes (Category 1+).**

Hurricane	Dates active	Maximum category	Direct landfalls
Beryl	June 28 – July 9	5	Grenada, Saint Vincent and the Grenadines, Yucatán Peninsula, Texas
Debby	Aug. 3 – 9	1	Florida, South Carolina
Ernesto	Aug. 12 – 20	2	Bermuda
Francine	Sept. 9 – 12	2	Louisiana
Helene	Sept. 24 – 27	4	Florida
Isaac	Sept. 26 – 30	2	None
Kirk	Sept. 29 – Oct. 7	4	None
Leslie	Oct. 2 – 12	2	None
Milton	Oct. 5 – 10	5	Florida
Oscar	Oct. 19 – 22	1	Bahamas, Cuba
Rafael	Nov. 4 – 10	3	Cuba



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3.2 Rising US severe convective storm risks in the solar energy sector

Severe convective storms are driving record insured losses in the United States and posing growing risks to solar farms. Innovative mitigation strategies and advanced risk assessments are vital for resilience.

In 2024, insured losses from U.S. severe convective storms (SCSs) exceeded the $50 billion mark for the second consecutive year. This category of peril — which includes tornadoes, hail and straight-line winds — has grown increasingly prominent in recent years, posing significant challenges for risk managers across multiple sectors, including energy, agriculture, insurance, construction and transportation.

As detailed in WTW's H1 Natural Catastrophe Review,[1] the 2024 season began at a rapid pace, with 1,264 preliminary tornado reports from January to June — the second highest total for this period since 2010. This momentum carried into the second half of the year, culminating in 1,855 preliminary reports for 2024 (Table 1), surpassed only by the 2,240 reports in 2011.

Additionally, the year experienced above-average large hail activity — historically the leading cause of SCS-related property damage in the U.S. — with 829 preliminary reports. Straight-line wind activity also exceeded historical norms, with 16,701 reports, making 2024 the third most active year since 2010.

Table 1. **Preliminary tornado, large hail and straight-line wind reports for 2024 and the 2010 – 2024 average.**

	Tornadoes	Large hail (more than 2 inches)	Straight-line wind
2024	1,855	829	16,701
2010 – 2024 average	1,355	775	14,959

Data source: U.S. storm prediction center.

[1] WTW. An unwelcome fast start to the U.S. severe weather season. Natural Catastrophe Review January — June 2024. (2024).

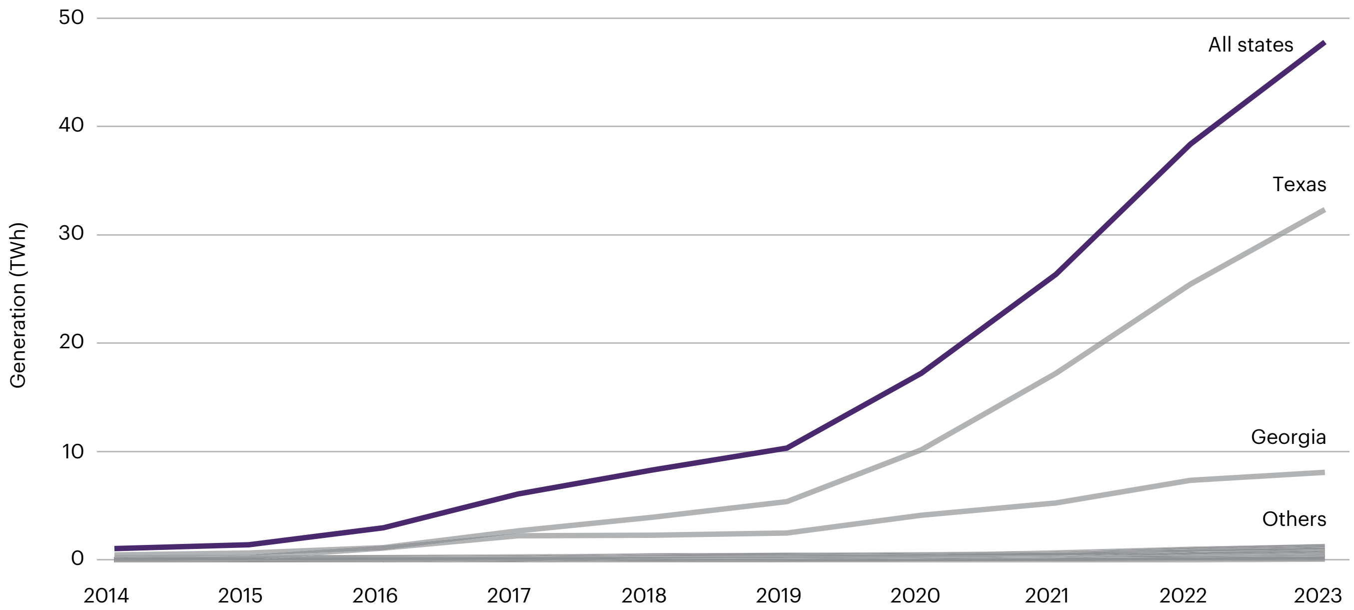
Storm clouds over solar farms

One sector facing increasing risk from SCS events is utility scale solar energy — large solar installations that generate electricity for the power grid. This industry has seen rapid growth in recent years, particularly in Texas (Figure 1). Since 2014, solar energy generation in Tornado Alley and Dixie Alley states has increased by almost a factor of 50, from 1 terawatt hour to 48 terawatt hours. Most of this growth comes from Texas due to its high solar irradiance levels and streamlined process for approving and building new solar energy projects.

However, as more solar farms are built in storm-prone states, the risk of large losses for farm owners and insurers is increasing. The risk is heightened by a recent trend toward larger, thinner solar panels, which are more vulnerable to damage. In March 2024, for example, a hailstorm damaged thousands of solar panels at the Fighting Jays Solar Farm in Fort Bend County, Texas. This event resulted in costly panel replacements and reduced energy output.[2] Insurers anticipated paying out a total loss of $50 million, reaching the farm's hail coverage sublimit.

The risk is not just restricted to the Central U.S. In October 2024, an EF2 tornado that spawned from Hurricane Milton tore through a solar farm in central Florida, also damaging 30 homes in the area.[3]

Figure 1. **Solar energy generation from both photovoltaic and solar thermal sources in Tornado Alley and Dixie Alley states between 2014 and 2023. Data represent both utility-scale and small-scale sources. States included are Texas, Oklahoma, Kansas, Nebraska, South Dakota, Iowa, Missouri, Alabama, Arkansas, Mississippi, Louisiana, Tennessee, Georgia and Kentucky.[4]**



The property insurance market for utility-scale solar has struggled with high premiums and limited coverage availability. These challenges stem from significant losses in recent years and the unique vulnerability of solar panels, which complicates risk assessment. As a result, utility-scale developers have turned toward improving resiliency through engineering design and innovations in tracking technology.

Harnessing resilience in a changing climate

The most significant natural peril loss drivers for solar projects are hail and named windstorms. The solar panel modules are the primary components that have high vulnerability to windborne debris and hail-related damage, which is dependent on the module glass thickness. While the exposure value of solar modules is project dependent, they typically account for a significant proportion of the insurable risk.

[2] PVTech. 'Golf ball-sized' hailstorms damage Fighting Jays solar project; Array launches hail tracking software. (2024).
[3] PV Magazine. Tornado rips through solar farm in Florida. (2024).
[4] U.S. Energy Information Administration. Electricity Data Browser. (2024).

As a result of the recent increase in SCS loss activity, risk managers for solar projects are increasingly considering a range of mitigation strategies, such as:

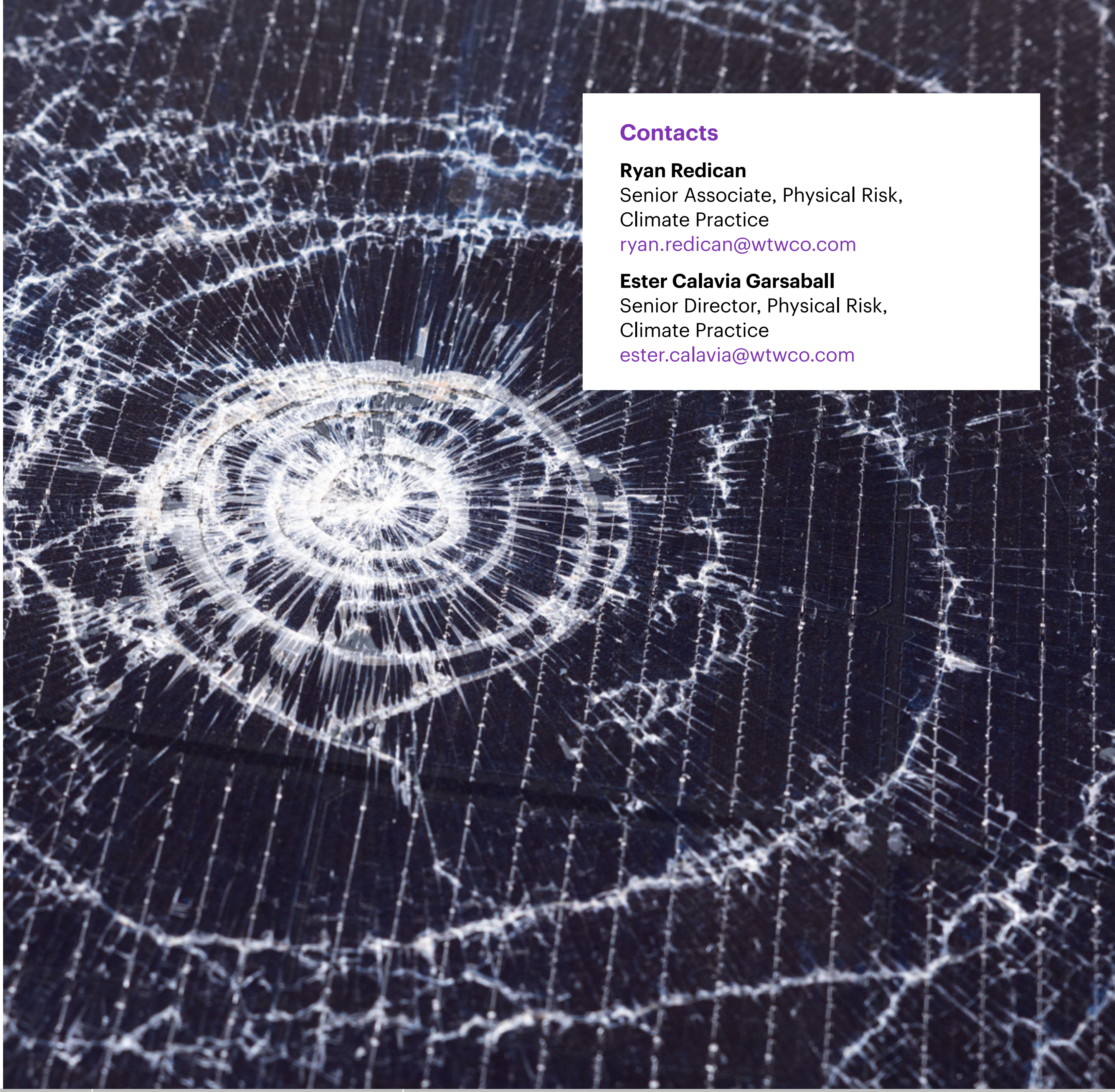
- Stowing solar panel modules at specific tilt angles, decreasing the angle of impact for hailstones and reducing the likelihood of wind-related damage
- Implementing real-time weather monitoring and automation, automatically initiating protective measures, such as tilting, as storms approach

New and existing solar projects can also benefit from a comprehensive risk assessment, including geographic and historical analyses of hail, tornado and straight-line wind events. WTW works with utility-scale solar developers and operators to evaluate and quantify probable maximum losses, considering site-specific engineering design, risk mitigation and tracking system stow strategies for both wind and hail to quantify natural catastrophe risk precisely.

Additionally, understanding how the risk is evolving over time is vital for effective risk management. This is something that WTW Research Network partner Columbia University has been exploring. In a recent research paper, Columbia scientists found a two-to-threefold increase in tornado outbreaks across the southeastern U.S., particularly during winter and spring, over the past four decades.[5]

By combining these risk assessment and mitigation methods into a comprehensive, proactive approach, the solar industry can better prepare for severe weather events and navigate an evolving risk landscape.

[5] WTW. Uncovering trends in U.S. tornado outbreaks. (2024).



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3.3 Storm Boris flooding affects 2 million people across Central and Eastern Europe

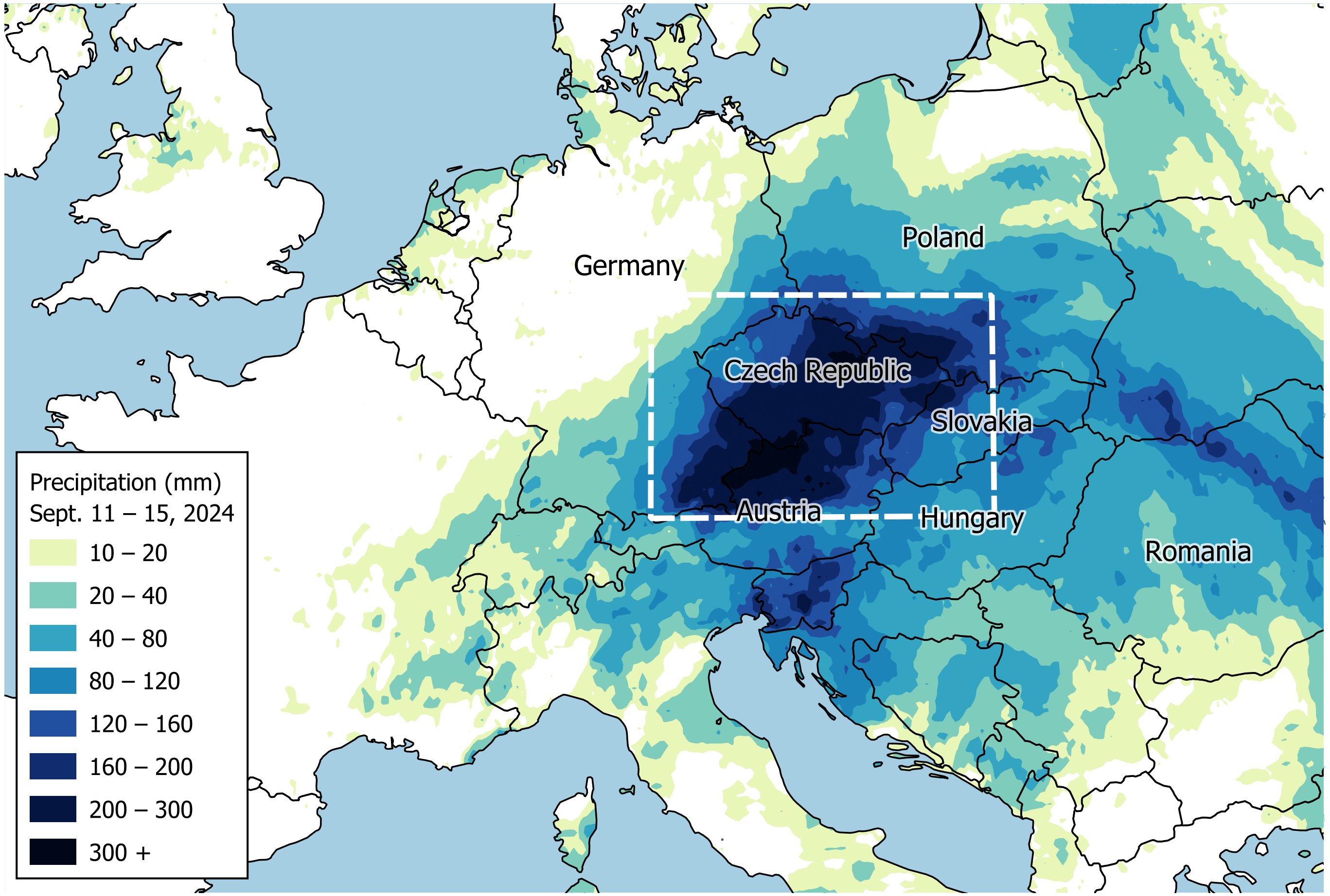
In September 2024, Storm Boris caused record rainfall, severe flooding and €2 billion in insured losses across Central and Eastern Europe. New flood defenses helped reduce impacts, but more investment and proactive risk management is required in a warming world.

Between September 12 and 15, 2024, Central and Eastern Europe experienced exceptionally heavy rainfall over a wide area. The storm, named Boris (also known as Anett), was a Vb cyclone — an extratropical low-pressure system that follows a characteristic path from the Mediterranean toward Central Europe. Boris formed when cold Arctic air from the north collided with warm, moist air from the Mediterranean and Black seas. This convergence of air masses created a sharp temperature gradient, triggering cyclogenesis.

A prolonged storm over a wide area

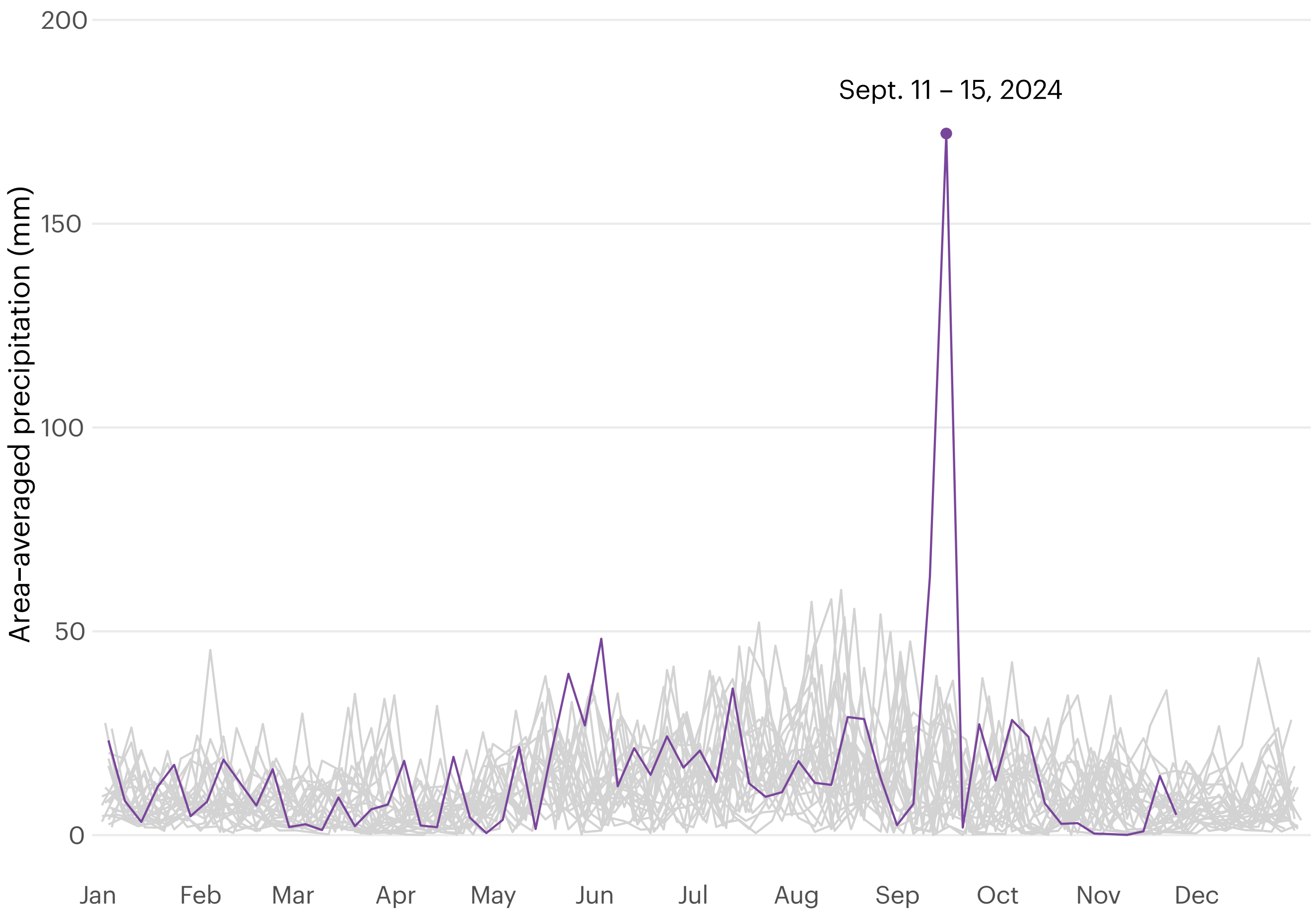
The storm became trapped between two areas of high pressure, effectively stalling over the continent. This slow movement brought sustained heavy rainfall over a large part of Central and Eastern Europe (Figure 1), resulting in a five-day precipitation total that was 12 times greater than average for September (Figure 2). Poland received four times its monthly average in just four days, while the Czech Republic experienced five times its monthly average in five days.

Figure 1. **Total precipitation above 10 millimeters for the five-day period September 11 to 15, 2024. Dashed box shows the area referenced in Figure 2.**



Data source: NASA GPM.

Figure 2. **Five-day precipitation (in millimeters) for all years since 2000 (gray lines) averaged over the dashed bounding box shown in Figure 1. The precipitation for 2024 is shown in purple.**



Data source: NASA GPM.

The extensive footprint of the precipitation caused flooding across Germany, Hungary and Romania, with particularly severe impacts in Slovakia, the Czech Republic, Austria and Poland. This led to extremely high river flows, including an estimated 1-in-140-year event on the Danube River in Vienna.[1] Boris then shifted southward, bringing additional flooding to Italy's Emilia-Romagna region, still recovering from 2023's devasting floods.[2]

In Austria, 12 dams failed, and parts of Vienna's metro system were inundated. According to the European Commission, over 2 million people were affected in total, while separate reports from individual nations confirmed a total of 27 fatalities. The flooding also disrupted transportation across the affected region, while power outages closed schools, hospitals and factories. The European Commission responded by mobilizing €10 billion in aid through the European Solidarity Fund.

Storm Boris was well forecast, providing emergency managers with around a week to prepare. They pre-positioned resources, supervised evacuations and lowered reservoir levels to increase storage capacity. These measures, along with new flood defenses and reservoirs built after major floods in 1997 and 2002, mitigated the damage. For example, Poland's new Raciborz Dolny flood control reservoir reduced downstream flows by smoothing the flood peak, and new defenses in Prague protected areas affected by the 2002 flooding.

[1] JBA. Storm Boris triggers havoc across Europe. (2024).
[2] WTW. Natural Catastrophe Review January — June 2023. Emilia-Romagna floods: a product of urbanization and climate change. (2023).

Insured losses and the challenges ahead

As of November 2024, PERILS estimated the insured loss from Boris to be around €2 billion, with 95% coming from Austria, the Czech Republic and Poland. Other notable flood losses in Europe in 2024 include:

- Germany (July 2024): Insured losses estimated at €1.7 billion
- Valencia, Spain (October 2024): Estimated insured losses of €3.5 billion (Section 3.4)

Combined, these events will add to a bruising few years for European insurers, who also experienced significant claims from Storm Bernd flooding in 2021 (€13.5 billion) and hailstorms in 2023 (€7 billion). While European insurers remain well capitalized to pay extreme weather claims, the recent flood events are part of a broader pattern of costly natural disasters in recent years, especially from so-called secondary perils, the cumulative effect of which is adding pressure to the global availability and affordability of (re)insurance.

The effects of climate change

The event brought the heaviest rainfall ever recorded in Central Europe, with scientists estimating that climate change made the precipitation 10% more intense and twice as likely.[3] Researchers also found that the storm affected an area 18% larger than it would have in a cooler climate.[4]

Storm Boris demonstrated the benefits of investing in flood defenses and early warning systems; however, more investment is still needed to reduce the risks of future flooding. The European Union's Joint Research Centre estimates that 160,000 Europeans are currently exposed to flooding each year, resulting in average annual economic damages of €7.6 billion. But under a 2°C warming scenario, these figures are expected to rise to 365,000 people and €31 billion annually in 2050.[5]

Proactive risk management

The flooding seen across Europe this year, which also includes Valencia (Section 3.4) and Germany,[6] will add to concerns among risk managers about the availability of affordable property insurance in a warming world. As a result, businesses are increasingly adopting a proactive, forward-looking approach to flood risk management to better protect their assets, infrastructure and supply chains. This requires knowledge of current asset or portfolio flood risks and an awareness of how the risk profile could change in the future under different climate scenarios. However, this can be challenging due to data limitations, modeling uncertainties and the sensitivity of floods to site-specific conditions.

Risk managers can address these challenges by using reliable information sources, such as frequently updated national flood maps and bespoke flood models. To ensure a robust risk assessment, careful consideration should be given to factors such as the spatial resolution of maps and models as well as the representation of flood defenses.

Businesses can also partner with natural catastrophe risk engineers — such as those at WTW — to undertake site-specific assessments and better understand modeling results and uncertainties.

Comprehensive risk assessments, combined with mitigation measures — such as protecting key equipment and developing comprehensive emergency plans — can reduce potential losses, demonstrate well-managed risks to insurers, and help secure more favorable premiums and coverage.

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[3] World Weather Attribution. Climate change and high exposure increased costs and disruption to lives and livelihoods from flooding associated with exceptionally heavy rainfall in Central Europe. (2024).
[4] Athanase M. et al. How climate change intensified storm Boris' extreme rainfall, revealed by near-real-time storylines. Nature Communications Earth and Environment. 5(676). (2024).
[5] Joint Research Centre. Facing increasing river flood risk in Europe: adaptation measures can save lives and billions of euro. (2023).
[6] WTW. Natural Catastrophe Review January — June 2024. Introduction. (2024).

3.4 Spain's costliest natural catastrophe: Valencia floods

In October 2024, extreme rainfall devastated Valencia, affecting 200,000 people and highlighting the need for urban areas to be prepared for the increased frequency of severe flooding amid a changing climate.

On October 29, 2024, Spain saw its costliest natural catastrophe on record as extreme rainfall led to severe flooding that swept through Valencia. Spain's General Council of Economists estimated that economic losses in the hardest-hit areas of Valencia amounted to €16.6 billion, representing 1.3% of the country's GDP.[1] As of November 19, around €3.5 billion in insurance claims had been made to the government-backed insurance entity, the Consorcio de Compensación de Seguros (CCS). Beyond Valencia, other regions — including Palma, Málaga and Barcelona — were also affected by heavy rainfall and flooding.

Understanding the cause: What is a DANA event?

The flooding was caused by a *Depresión Aislada en Niveles Altos* (DANA), often referred to in English as a "cut-off low" or "cold drop." This phenomenon occurs when a pocket of cold air in the upper atmosphere becomes detached from the jet stream.

[1] Cadena SER. Economistas cifran en 16.600 millones las pérdidas ocasionadas en Valencia, el 1,3% del PIB de España. (2024).

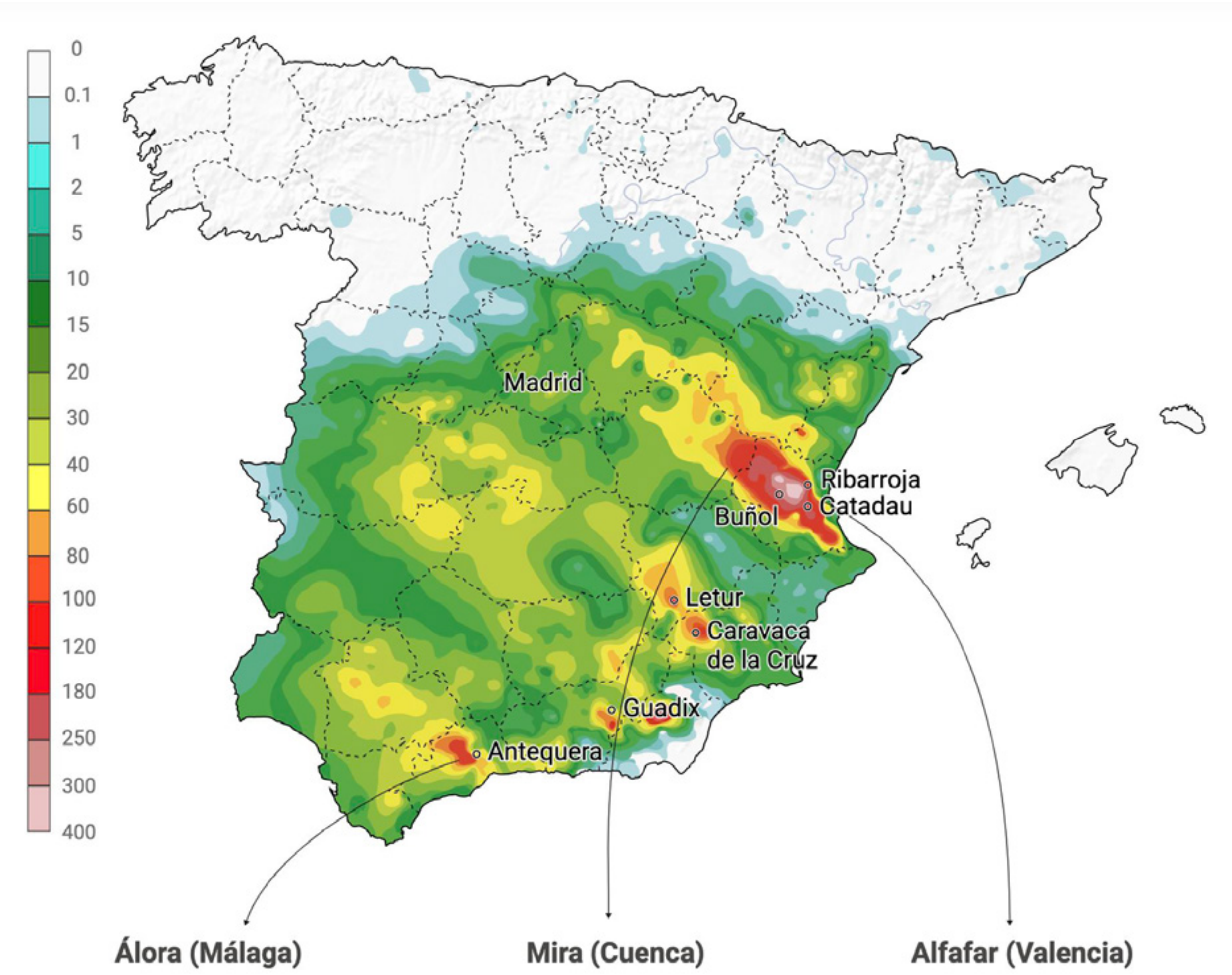
As this cold air interacts with warm, moisture-rich air near the surface, it can trigger intense convection, leading to torrential rain and severe flooding, known locally as *riadas*. While DANA events are relatively common in the Mediterranean basin, the 2024 Valencia event was among the most intense ever recorded in the region.

Impacts of the 2024 extreme rainfall

The DANA event brought extreme rainfall, with 100 to 300 millimeters falling across a wide area in just a few hours (Figure 1). Remarkably, some locations, including Chiva, experienced nearly 500 millimeters in just eight hours, equivalent to the region's average annual total. The town of Turís, 15 kilometers upstream from the city of Valencia, saw 184.6 millimeters of rain in a single hour — a new national record for Spain. Overall, the precipitation totals were approximately double those recorded during Valencia's previous largest flood event in 1957, which was also the result of a DANA storm.

The intense rainfall followed a period of drought, which likely exacerbated the flooding due to the firm ground leading to higher runoff. Rivers, including the Turia and Júcar, overtopped, and the urban drainage system was unable to handle the huge volume of water, causing extensive property and infrastructure damage. The event claimed over 220 lives, the largest toll from floods in Spain since 1973. The European Space Agency measured a total flooded area of 15,633 hectares in Valencia province, affecting nearly 200,000 people.[2]

Figure 1. **24-hour accumulated rainfall on October 29, 2024 (millimeters).**



Source: AEMET

[2] European Space Agency. Devastating floods in Spain witnessed by satellites. (2024).

Hail, strong winds and flooding also damaged crops in several provinces, including Valencia, Murcia, Albacete and Almería. Initial estimates from Agroseguro, the entity overseeing Spain's agricultural insurance system, indicated at least 20,000 hectares of agricultural land were affected by these perils in Valencia alone.

The Valencia Chamber of Commerce estimated that 1,800 businesses were destroyed, with a further 4,500 suffering damage and many thousands more facing operational disruption. Additionally, over 100,000 vehicles were damaged, many of them being picked up by flood waters that swept along the city's narrow streets.

According to the Intergovernmental Panel on Climate Change, the confidence is high that the occurrence of heavy precipitation events has increased globally since the 1950s.[3] In Spain, research indicates that September to December daily rainfall extremes in central and southeastern regions have become 12% more intense and twice as likely over the past 75 years due to climate change.[4]

However, for DANA events specifically, the evidence is inconclusive. While we should expect warmer seas and land temperatures to increase the frequency and intensity of such events, scientists have yet to see a clear trend in the observational record.

The Consorcio de Compensación de Seguros

Spain benefits from the Consorcio de Compensación de Seguros, a government-backed entity that serves as a guarantee and compensation scheme for extraordinary risks, including large natural catastrophes. The CCS was formally established in 1954, with all private insurance policyholders in the country paying an annual surcharge that funds the entity.

The CCS is well capitalized, with reserves of just over €10 billion at the end of 2023, and is therefore well placed to pay the 190,000 claims from the Valencia flooding that were submitted as of November 19, 2024.

As the claims from this event will likely exceed one-third of the reserves, the CCS may decide to review the appropriateness of surcharge rates. But this is not certain, as any decision will likely take into account other factors, including government policies.

Preparing for future flooding

The Valencia floods highlight the need for cities and businesses to adapt to the realities of climate change and to prepare for extreme weather events by taking proactive steps:

- **Prediction and modeling:** Advanced hydrological modeling is essential for exploring flood scenarios — under both present-day conditions and future climate projections — to inform risk mitigation strategies. Tools such as CityCat, used by WTW and developed by WTW Research Network partner Newcastle University, can be used to simulate urban flood dynamics, including water flow and velocities, to support decision making and enhance flood risk management.
- **Adaptation:** Flood resilience requires strategic urban planning and adaptation measures. New developments should be built with flood risks in mind, such as elevating buildings and using permeable materials, including more green spaces, to serve as natural buffers that absorb excess rainwater. Retrofitting buildings, improving existing drainage systems and enhancing flood defenses are equally crucial.
- **Preparedness:** The preparedness of authorities, businesses and communities is vital for reducing damages and saving lives. To this end, authorities and businesses can work closely with communities to increase awareness, invest in early warning systems and develop emergency response plans to ensure readiness.

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[3] Intergovernmental Panel on Climate Change. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Masson-Delmotte, V. et al.) 8.3.2.3, 1145–1150 (Cambridge Univ. Press, 2021).
[4] World Weather Attribution. Extreme downpours increasing in southeastern Spain as fossil fuel emissions heat the climate. (2024).

3.5 Dam failure risks in the age of climate change

Dams are critical yet increasingly vulnerable infrastructure. Aging assets, the increasing frequency of weather extremes and growing downstream risks from advancing urbanization demand proactive management to prevent failures and protect communities and economies.

The global hydrological cycle supports and influences economies at every level, yet it is easy to forget that water is a finite resource. Over 200,000 large dams — those taller than 15 meters or holding in excess of 3 million cubic meters — exist globally and are essential for such industries as global food systems, energy production, industrial processes and urban water supply. However, as dams age, their reliability diminishes, posing significant risks to communities and economies that depend on them. It is essential for all sectors to understand and address these growing risks.

In 2024, several notable dam failures occurred, most triggered by extreme rainfall (Table 1). Managing aging dam infrastructure is increasingly challenging in a warming climate due to the rising frequency of extreme weather events (see sidebar). Additionally, significant urban development has occurred downstream of many dams since construction, increasing the population and economic value at risk should failure occur.

A proactive approach to risk management is required among dam operators, insurers, local communities and governments to identify vulnerabilities, enhance preparedness and implement strategies to reduce risks.

The challenge of aging assets

While engineered assets typically last 50 to 100 years, dams often last longer due to conservative design, maintenance and strict regulations. After World War II, dam and reservoir building surged globally, peaking in the early 1970s, to manage floods, mitigate droughts and provide hydropower.

High-hazard dams, which would cause substantial loss of life or economic damages if they failed, are often designed to withstand 1-in-10,000-year events or the Probable Maximum Flood (PMF).[1] Meanwhile, lower-hazard dams are usually designed to withstand the 1-in-100-year or 1-in-500-year event.

Many mid-20th-century dams are now aging and require attention.[2] The American Society of Civil Engineers reports that the U.S. alone has nearly 16,000 high-hazard dams. The estimated cost to repair and upgrade non-federal high-hazard dams ($34 billion) and all non-federal dams ($157.5 billion) highlights the scale of the task facing dam operators, governments and other stakeholders.

Not taking action puts people, assets and communities at risk — an issue highlighted by the 2017 Oroville Dam crisis in California. Spillway[3] damage led to the evacuation of nearly 200,000 people and an estimated emergency response and recovery cost of over $1 billion.

[1] The PMF, as defined by the American Society of Civil Engineers, is the flood resulting from the most severe combination of meteorological and hydrological conditions reasonably possible in a region.
[2] D Perera. Ageing Water Storage Infrastructure: An Emerging Global Risk. United Nations University Institute for Water, Environment and Health. (2021).
[3] A spillway is a structure built into a dam to safely release excess water. It acts like an overflow valve, preventing the water from rising too high and damaging or overtopping the dam.
[4] Intergovernmental Panel on Climate Change. Sixth Assessment Report: The Physical Science Basis (eds. Masson-Delmotte, V. et al.) Ch. 11, 11-3–11-6 (2021).

The effects of climate change: Intensification and amplification

According to the Intergovernmental Panel on Climate Change, there is high confidence that precipitation extremes have increased globally since the 1950s.[4] This changing hazard increases the likelihood of extreme floods, which, when combined with the risks posed by aging dams, can lead to overtopping and structural failure, with catastrophic consequences.

Furthermore, unusual weather patterns such as atmospheric rivers are becoming more common. These narrow bands of moisture-laden air bring extended clusters of wet weather, which have been associated with the hydrologic exceedance or failure of 554 dams in the U.S. since 2000.[5] For example, in South Carolina in 2015, one storm cluster led to 40 dam failures.[6]

Traditionally, engineers would use historical records of past rainfall, river flow and flood events to predict the magnitude of future extreme events. However, climate change means historical data may not adequately reflect future risks. For this reason, forward-looking information, such as from climate models, is increasingly being used in dam design and upgrading decisions.

A proactive approach

A proactive path to dam safety, which focuses on mitigating risks and preventing failures before they arise, is essential for ensuring long-term resilience of aging infrastructure in a changing climate. Bespoke risk modeling that considers evolving climate conditions and structural vulnerabilities can help address this challenge. Collaboration between insurers, asset owners and regulators is also essential to enhancing risk assessment and implementing resilience strategies.

The approach should be risk-based and bring stakeholders together across the value chain:

- **Comprehensive risk assessment:** Analyze possible failure modes and understand their likelihood and impact using bespoke modeling. Take account of the potential for human factors such as mis-operation, which might drive failure. Where appropriate, integrate forward-looking climate information and scenarios.
- **Continuous monitoring and maintenance:** Program routine inspections and audit the findings; keep a record to monitor change in condition to spot developing problems early. Ensure appropriate funds are in place to keep on top of maintenance. Periodically review downstream risks and make sure new development funds safety improvements when required.
- **Emergency preparedness and stakeholder engagement:** Operators and communities can enhance preparedness by sharing risk information, planning effectively, and undertaking regular testing and training.
- **Climate-resilient upgrades and innovation:** Review the adequacy of safety systems considering current and future drivers of risk. Take an adaptive approach to risk management and consider novel techniques as long as they don't introduce unforeseen problems.
- **Risk transfer and financial preparedness:** Work with risk transfer specialists to develop appropriate insurance solutions for addressing both first-party and third-party losses.

Implications for insurers

While insurers frequently model natural catastrophes, dam failures — despite their potential for property damage and loss of life — are often excluded. This omission stems from the complexity of modeling dam-specific risks and the limited historical data available. To address this gap, asset owners and insurers can collaborate with engineering and hydrological experts — such as those at WTW — to better quantify the risk, facilitating risk transfer and financial resilience.

[5] Hwang, J.C. & Lall, U. Increasing dam failure risk in the USA due to compound rainfall clusters as climate changes. npj Nat. Hazards 1, 27 (2024).
[6] Sasanakul, I., et al. Dam failures from a 1000-year rainfall event in South Carolina. Geotechnical Frontiers (2017).

Table 1. **Notable dam failures in 2024 following extreme weather events.**

Date	Name/Location	Cause of failure
April 2024	Panguitch Lake Dam, Utah, U.S.	Insufficient maintenance, heavy rainfall
May 2024	14 de Julho Dam, Rio Grande dol Sul, Brazil	Heavy rainfall
June 2024	Rapidan Dam, Minnesota, U.S.	Insufficient maintenance, heavy rainfall
June 2024	Augsburg Dam, Germany	Heavy rainfall
June 2024	Dongting Lake, Hunan, China	Heavy rainfall
July 2024	Braskereidfoss Dam, Norway	Operational challenges, heavy rainfall
August 2024	River Bends, Cape Town, South Africa	Design limitations exacerbated by heavy rain
August 2024	Georgia, 3 unnamed dams	Heavy rainfall exceeded design capacity
August 2024	Arbaat Dam, Sudan	Heavy rainfall
September 2024	Stronie Śląskie, Poland	Heavy rainfall exceeded design capacity
September 2024	Topola, Poland	Heavy rainfall exceeded design capacity
September 2024	Austria, 12 unnamed dams	Heavy rainfall
September 2024	Alau Dam, Nigeria	Insufficient maintenance, heavy rainfall

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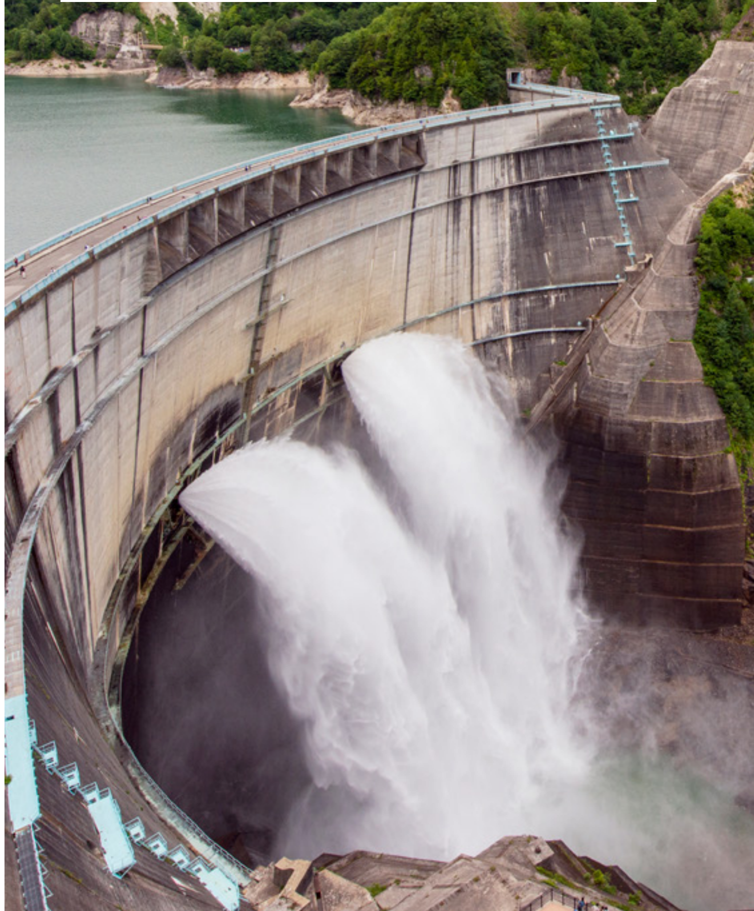


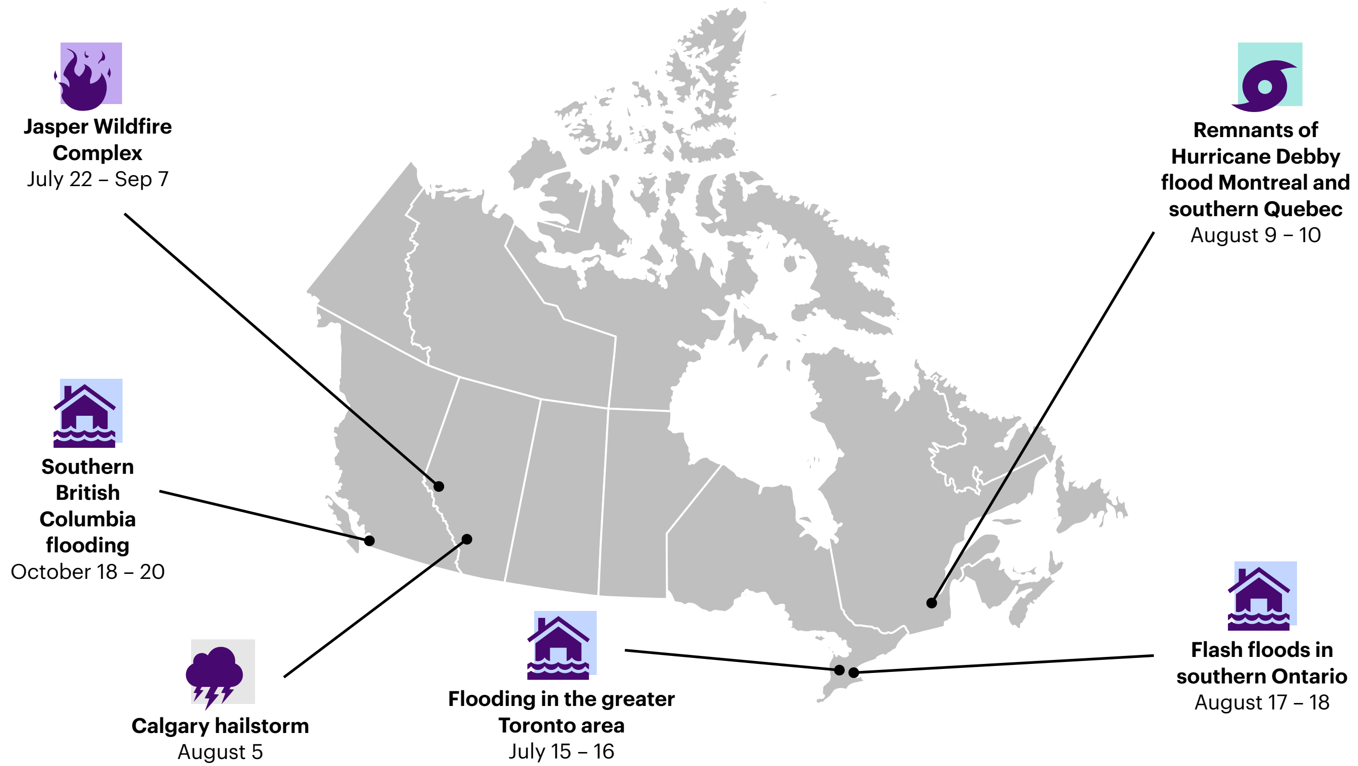
3.6 Wildfires, floods and hailstorms: How 2024 became Canada's costliest year for insurers

In 2024, Canada was battered by wildfire, flood and hail as insured losses shattered the previous record. Is this sudden spike the product of hard luck or a sign of things to come?

For Canadian insurers, an unlucky sequence of severe weather made 2024 the most bruising year in the industry's history. The previous record for insured catastrophe losses was set in 2016, when the Fort McMurray wildfire and other events led to CAD $6.2 billion in claims (all figures adjusted to 2024 Canadian dollars). By mid-November, with year-to-date losses approaching CAD $8 billion,[1] 2024 had already well surpassed that benchmark. Once all outstanding claims are settled, the Institute for Catastrophic Loss Reduction expects insured losses from natural catastrophes will be CAD $9 billion in 2024[2] — 50% higher than the previous record.

None of the catastrophes that happened in 2024 were as ruinous as the Fort McMurray wildfire. Instead, this new record was the result of several separate events hitting the country in the same year (Figure 1). In mid-July, two days of torrential rain across the Greater Toronto Area (GTA) caused flash flooding, power outages and over $940 million in insured

Figure 1. **Map of notable catastrophic events that affected Canadian communities in 2024.**



damages. In early August, the remnants of Hurricane Debby caused widespread disruption to southern Quebec and Atlantic Canada. Nearly half a million people lost power, Montreal set a new single-day record for rainfall, and floods and landslides were reported across the region. Southern Ontario was hit hard by flooding again in mid-August, as intense thunderstorms brought heavy rains and at least one tornado to Mississauga, Etobicoke and other parts of the GTA. But just like in 2016, again this year natural catastrophes exacted their heaviest toll from the western province of Alberta.

[1] Insurance Bureau of Canada. Insured damage from October storms in Southern BC surpass $110 million. (2024).
[2] Canadian Underwriter. 2024 insured NatCat losses could top out at $9 billion. (2024).

One in five Calgary homes hit by hail

During the afternoon and evening of August 5, a sequence of severe thunderstorms spun up over the foothills of the Canadian Rockies and headed east across southern Alberta. According to Western University's Northern Hail Project, the storms cast down a swath of hail more than 120 kilometers long and 12 kilometers wide.[3] The impact was most severe in Calgary, where the golf ball-sized hail shredded siding, smashed windows, battered rooftops and dented vehicles. According to the Insurance Bureau of Canada, almost one in five homes in Calgary was damaged.[4] The end result was nearly $2.8 billion in insured losses, making it the second-costliest event in Canada's history (exceeded only by the Fort McMurray fire).

The Calgary area has been hit hard by catastrophic hailstorms in recent years, and research sponsored by WTW predicts that global warming will cause thunderstorms to become more frequent and more severe in this part of Canada.[5] It is known that hail risks near Calgary are among the highest in Canada, but the most recent scientific survey of hail trends in Alberta is now out of date by almost 20 years.[6] Until a more up-to-date survey is available, it may be prudent to assume that Calgarians — and Canadians — have not yet seen the worst case possible for insured losses due to hail from a single event.

A fiery monster devastates Canada's 'crown jewel'

In 2023, Canadian forests burned like never before. Sparked by record-high temperatures and widespread drought, wildfires consumed 15 million hectares of land across the country[7] (roughly the same size as the U.S. state of Georgia). Scientists were shocked by the extent of the 2023 wildfires — more than twice the previous record — and heavy smoke blanketed several large Canadian and U.S. cities throughout the summer. Alberta also set an all-time record for area burned in 2023, but because wildfires did not spread into larger communities, overall insured losses in the province were relatively modest.

That good luck did not hold for a second year. During the late afternoon of July 22, 2024, three wildfires were reported south of the town of Jasper.[8] An hour later, strong winds merged the three wildfires into a single 6,000-hectare monster, with enormous columns of smoke and flames 30 to 50 meters tall. The fire reached the townsite two days later. Firefighters were able to save critical infrastructure such as the hospital, schools and wastewater treatment plant, but one out of every three structures were damaged or destroyed. The devastating wildfire resulted in $880 million in insured damages[9] and, because Jasper is the central hub for the national park of the same name, is expected to suppress tourism for some time.

In Alberta, like much of North America, wildfires have become larger and more common in recent decades, a trend scientists expect will continue because of climate change.[10] As their exposure to risk keeps rising, communities like Jasper urgently need to adopt measures to make their buildings and infrastructure more resilient to future fires.

Beware the long tail

Like many other countries, Canada has seen a steady rise in insured losses due to a combination of factors, including higher population, greater wealth, and some perils increasing in frequency and severity. And we should be mindful of long-tail risks. The country has two regions — the West Coast and the Charlevoix Seismic Zone — that have been jolted by major or extreme earthquakes in historical memory. Should either place suffer a repeat event, the expected losses would be higher than the country has ever experienced.

Contacts

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[5] Lepore and colleagues. Future global convective environments in CMIP6 models. Earth's Future. (2021).
[6] Etkin. Hail Climatology for Canada: An Update. Institute for Catastrophic Loss Reduction. (2018).
[7] Natural Resources Canada (n.d.), Canada's record-breaking wildfires in 2023: A fiery wake-up call. (2024).
[8] Jasper National Park. Timeline of the Jasper Wildfire. (2024).
[9] Insurance Bureau of Canada. Insured losses from Jasper wildfire surpass $880 million. (2024).
[10] Jain and colleagues. Drivers and impacts of the record-breaking 2023 wildfire season in Canada. Nature Communications (2024).

3.7 Key elements of the 2024 Pacific typhoon season: Shanshan, Yagi and the Philippine storm cluster

Despite fewer storms than usual, the 2024 Western North Pacific typhoon season became the deadliest since 2013. It was marked by Typhoon Shanshan's record-breaking rainfall in Japan, Super Typhoon Yagi's catastrophic impact across Southeast Asia and South China, and an intense clustering of storms in the Philippines, highlighting the growing influence of climate change on tropical cyclone behavior.

The Western North Pacific saw a slightly below-average typhoon season with 23 named storms, 15 typhoons and nine intense typhoons (equivalent to Category 3+ hurricanes), compared with the 1991 – 2020 average of 25, 16 and nine, respectively.[1] Total basin activity, measured by the Accumulated Cyclone Energy (ACE) Index, was 204 — almost one-third lower than the 1991— 2020 average. The reduced activity was in part due to the late start of the season, with the first cyclone not developing until May 23, the fifth latest start on record.

Despite lower-than-average storm counts, 18 made landfall, with nine at typhoon strength. The season was the deadliest since 2013, with approximately 1,200 fatalities, primarily due to Typhoon Yagi. Economic losses for the year were over $20 billion, while insured losses were significantly lower at $2 billion to $3 billion, reflecting a significant projection gap.

Western North Pacific sea surface temperatures (SSTs) were above average in 2024, but cyclone development was close to average, likely due to the transition from El Niño to ENSO-neutral conditions, which increased both atmospheric stability and vertical wind shear. However, those storms that did form were fueled by the above average SSTs, and some were extremely damaging.

Three particularly notable aspects of the season stood out: Typhoon Shanshan, Typhoon Yagi and six consecutive storms that hit the Philippines within one month.

[1] National Oceanic and Atmospheric Administration (NOAA). Monthly Report. (2024).

Shanshan strikes Japan

Typhoon Shanshan struck Japan in August 2024 as one of the strongest typhoons to make landfall in the country in recent decades. Sustained winds exceeded 130 miles per hour (equivalent to a Category 4 hurricane). Exceptionally high rainfall totals were reported due to its slow translational speed, with some areas receiving over 800 millimeters in a five-day period, resulting in severe flooding and landslides.

The storm underwent rapid intensification near Japan's Amami Islands due to favorable conditions: low vertical wind shear, unusually warm sea surface temperatures and high ocean heat content. Climate change has been linked to the increased intensity of such storms, with typhoons as strong as Shanshan now around 36% more likely compared with pre-industrial times.[2]

Economic and insured losses were relatively small, both at less than $1 billion in part because the storm affected areas with lower exposures. Other storms of comparable intensity that have impacted Japan in recent years have resulted in far higher insured losses. For example, Typhoon Jebi in 2018, which impacted the cities of Kobe, Osaka and Kyoto, resulted in insurance claims totaling up to $14 billion — an order of magnitude higher than from Shanshan.

Yagi: A costly and deadly Typhoon

Yagi (also named Enteng), the first super typhoon of the 2024 Western Pacific season, struck Southeast Asia and South China in early September (Figure 1). After making landfall as a tropical storm in Luzon, the largest island of the Philippines, Yagi rapidly intensified over the South China Sea due to unusually warm waters, reaching wind speeds of 160 miles per hour (a Category 5-equivalent hurricane). This sudden change left little time for preparation before the storm impacted Hainan, Guangdong and Northern Vietnam. Unusually strong winds and heavy rainfall extended as far inland as Myanmar, Laos and Thailand.

With sustained wind speeds exceeding 150 miles per hour at landfall — equivalent to a Category 4 hurricane — Yagi was the strongest autumn typhoon to affect the Hainan province of China and the strongest ever to hit Vietnam, with wind speeds around 135 miles per hour. The storm led to 800 fatalities and caused economic damages of over $15 billion, ranking it among the top 10 costliest inflation-adjusted Western North Pacific typhoons on record. Insured losses were limited to around $1 billion due to low insurance penetration in South China and Vietnam.[3]

Historically, the South China Sea has served as a "natural buffer," weakening tropical cyclones passing through the Luzon Strait due to atmospheric and oceanic environments unfavorable for typhoon intensification. However, climate change has reduced this effect by increasing both sea levels and sea surface temperatures, raising the risk of strong typhoons reaching southern China and Vietnam.[4]

Figure 1. **The track of Typhoon Yagi as it moved east to west from September 1 to September 7, affecting the Philippines, China and Vietnam.**

Data source: IBTrACS

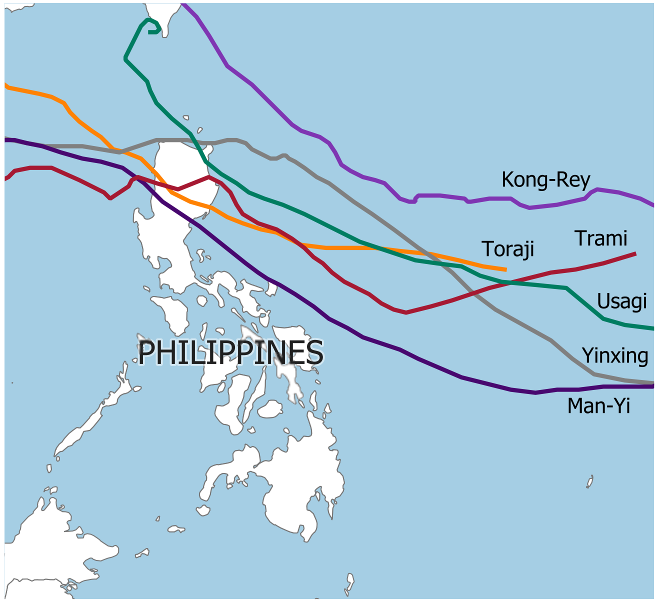
[2] Grantham Institute – Climate Change and the Environment. Typhoon Shanshan. (2024).
[3] Insurance Asia News. Yagi third costliest typhoon in Asia with $1Bn insured loss. (2024)
[4] Sun, J.et al. Sea level rise, surface warming, and the weakened buffering ability of South China Sea to strong typhoons in recent decades. Sci Rep 7, 7418 (2017).

Unprecedented storm clustering affects the Philippines

Typhoon clustering was a particularly striking feature of the 2024 season, with six separate storms affecting the Philippines within 30 days (Figure 2). Four were simultaneously active in the basin in November — the most for that month since reliable records began in 1951. All storms that made landfall did so on the northern island of Luzon, affecting over 13 million people, displacing more than half a million and causing hundreds of fatalities. The series of typhoons strained emergency response systems, leaving communities little time to recover between storms. The National Disaster Risk Reduction and Management Council estimated that economic losses were in the region of $500 million.

Researchers found that climate change played a significant role in this unfortunate, rapid sequence of typhoons. The conditions that allowed this series of storms to develop, including warm seas and high atmospheric humidity, were 1.7 times more likely to occur today than in pre-industrial times. Of the six storms, three — Man-Yi, Usagi and Yinxing — made landfall as major typhoons (wind speeds over 112 miles per hour), a phenomenon estimated to be 25% more likely due to human-induced warming.[5]

Figure 2. **The tracks of the six tropical cyclones that affected the Philippines within 30 days (September 1 to November 2, 2024). The cyclones moved from east to west.**



Data source: IBTrACS

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With thanks to WTW research network partner, the National University of Singapore, for its contributions.

[5] World Weather Attribution. Climate change supercharged late typhoon season in the Philippines, highlighting the need for resilience to consecutive events. (2024).

3.8 Diverse and compounding implications of South America's drought for risk managers

In 2024, South America's drought — driven by El Niño and climate change — affected agriculture, energy, transport and water supplies, highlighting cross-sector challenges for risk managers in a warming world.

South America, known for its vast network of rivers that collectively contribute around 30% of global runoff to the oceans, has faced severe drought conditions since mid-2023. These conditions have been driven by reduced rainfall and above-average temperatures (Figure 1). Brazil's National Center for Monitoring and Early Warning of Natural Disasters (CEMADEN) declared it the country's worst drought since monitoring began in the 1950s. The prolonged dry period also affected neighboring countries, including Argentina, Bolivia, Chile, Colombia, Ecuador and Paraguay. Rivers across the region dropped substantially, including the Rio Negro — one of the main tributaries of the Amazon River — which fell to its lowest level in more than a century (Figure 2).

El Niño was partly to blame. This natural climate pattern, which develops every two to seven years, usually reduces rainfall across the Amazon basin and northeastern South America.

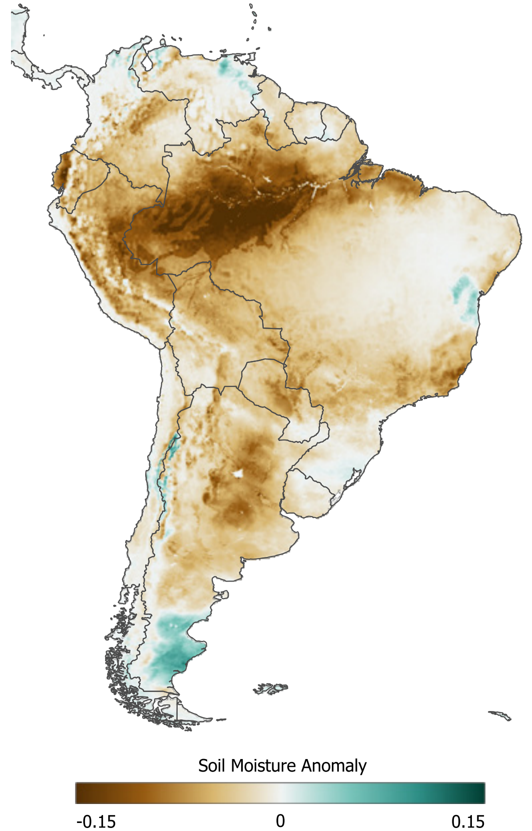
The most recent El Niño began in mid-2023[1] and ended in spring 2024. This event contributed to the onset of the drought; however, the severity of the dry spell was much larger than usual. According to CEMADEN, the magnitude of the 2023 – 2024 drought was double that of the one in 2015 – 2016, the last time a strong El Niño occurred.[2]

So, what explains the severity this time around? Scientists believe it is due to climate change.[3] In the past, agricultural droughts of this scale occurred less than once in a millennium. But under the present climate, the return period is much more frequent at one in 50 years. As a result, researchers estimate that climate change has increased the likelihood by around a factor of 30, which poses significant challenges for a range of industries.

Five cross-sector impacts

The severe and widespread nature of the South American drought caused diverse impacts across multiple sectors, often in interconnected and compounding ways. Here are five major consequences:

Figure 1. **In 2024, severe drought affected large parts of South America, with conditions being most severe across the Amazon basin.**

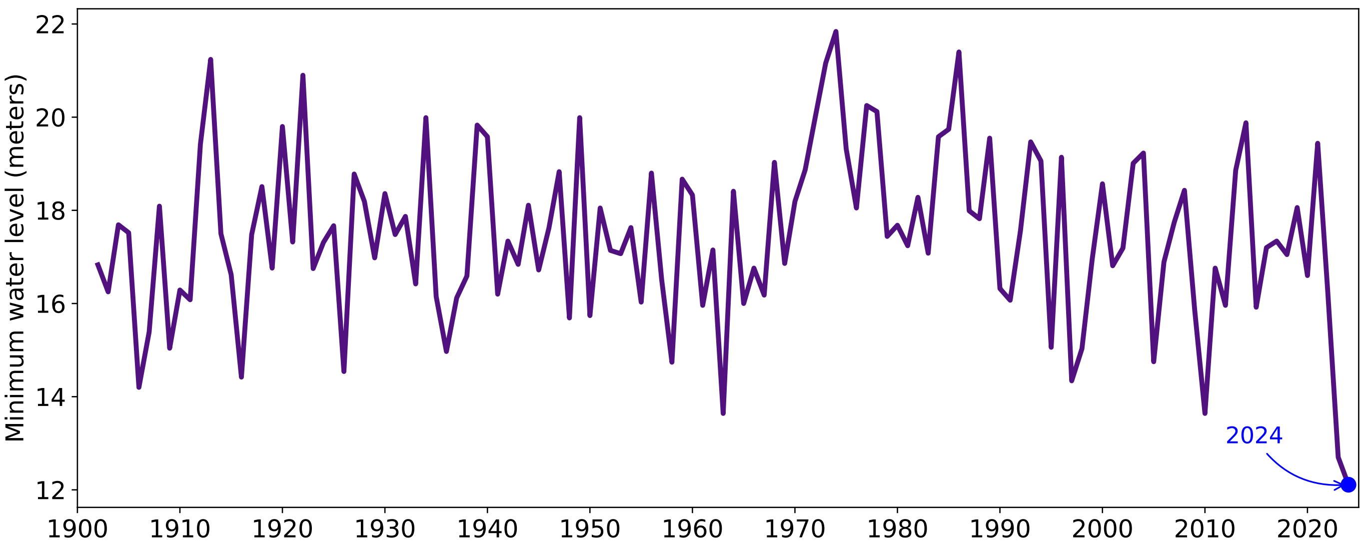


Data source: Muñoz Sabater, J. (2019): ERA5-Land monthly averaged data from 1950 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.68d2bb30.

[1] WTW. Natural Catastrophe Review January — June 2023. From the tropical Pacific, El Niño is in the wind. (2023).
[2] NASA Earth Observatory. Intense, Widespread Drought Grips South America. (2024).
[3] World Weather Attribution, Climate change, not El Niño, main driver of exceptional drought in highly vulnerable Amazon River Basin. (2024).

1. **Agriculture:** The drought reduced yields for key crops such as soybeans, coffee and corn while also driving up farming operational costs. For example, Brazil's National Supply Company estimated that safrinha yields, which represents most of Brazil's corn harvest, would be 12% lower for the 2023 – 2024 season compared with the prior year.[4] Local farmers faced substantial financial losses, some of which were passed on to insurers. Additionally, global supply chains were disrupted, particularly for commodities such as coffee, which were already in short supply.
2. **Transportation:** Critically low water levels extended shipping times and forced reductions in cargo loads. Goods transported along the Paraguay River, for example, fell by 29% compared with 2023.[5] This reduction pushed up shipping costs, compounding the impact on sectors such as agriculture, which were already strained by the drought.
3. **Hydropower:** Reduced water levels in rivers and reservoirs diminished hydropower generation capacity. Ecuador, which gets 70% of its electricity from hydropower, was particularly hard hit. The country had to enforce nighttime blackouts, which left businesses that require continuous power facing significant losses. The Guayaquil Chamber of Commerce reported that power outages resulted in weekly losses of $700 million for Ecuadorian businesses, with the food and beverage sector among the hardest hit.[6]

Figure 2. **Brazil's Rio Negro set a new record for low water in 2024, eclipsing the previous record set in the year prior. The Port of Manaus is an important commercial center for marine transport.**



Data source: Port of Manus.

4. **Wildfires:** According to MapBiomas, from January to September 2024, Brazil saw more than 22 million hectares of land burned — a two-and-a-half-fold increase compared with the same period in 2023.[7] Fires compounded the agricultural impact of the drought by damaging crops and pastures while also increasing air pollution and causing significant biodiversity loss.
5. **Water resource management:** Water shortages affected multiple industries beyond agriculture, including food and beverage production, textiles and pharmaceuticals. The San Rafael reservoir, which provides 70% of water supply for the Colombian city of Bogota, dropped to just 19% of its capacity in early 2024. This led to rationing, with different parts of the city facing 24-hour supply cuts on a rotating basis, impacting both residents and economic productivity.[8]

[4] Valor International. Drought reduces corn yields in Brazil. (2024).
[5] Observatorio Económico Latinoamericano. Latin America's continuing drought. (2024).
[6] Association Press. Power shortages in Ecuador are melting away the future of a small town's ice-cream industry. (2024).
[7] MapBiomas. The area burned in Brazil between January and September was 150% higher than last year. (2024).
[8] The Water Diplomat. Water shortages in Bogota prompt rationing. (2024).

Scenarios for risk managers

According to the Intergovernmental Panel on Climate Change, severe droughts, such as those in 2015 – 2016 and 2023 – 2024, will become more frequent in the future.[9] For local and global risk managers, the challenge is identifying and managing the multifaceted risks that stem from these events. An effective approach involves combining climate projections with traditional risk models (e.g., actuarial models) to explore a variety of future business scenarios. Consideration of multi-sectoral dependencies in these scenarios can add significant value — for example, exploring how drought concurrently affects both agriculture yields and crop transportation costs. This approach helps companies screen their entire portfolio of assets, operations and supply chains to identify exposures now and in the future. A deep dive of the most at-risk exposures can then guide decisions about how best to avoid, reduce and transfer risk.

[9] Intergovernmental Panel on Climate Change. Sixth Assessment Report Regional Fact Sheet Central and South America. (2024).

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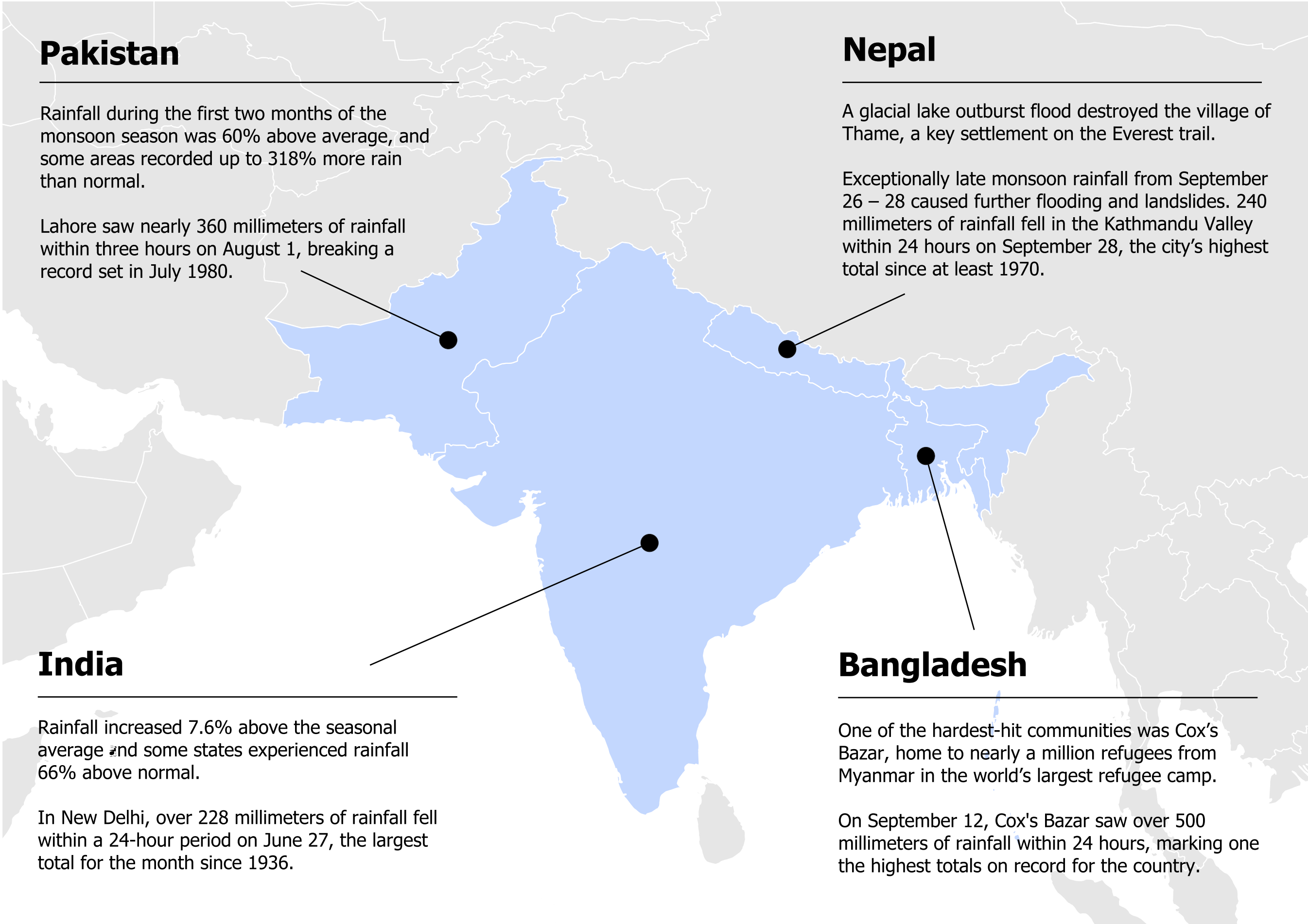
3.9 South Asian flooding highlights risks of an increasingly intense and erratic monsoon

The 2024 southwest monsoon brought severe flooding to South Asia, impacting multiple sectors. Climate change is leading to more intense and erratic monsoon seasons, requiring a proactive approach to manage the evolving risk.

The southwest monsoon is a seasonal wind pattern, which typically lasts from June to September and brings heavy rains to South Asia. These rains — which account for around three-quarters of the region's annual precipitation — are vital for agriculture, water availability and the overall economy. However, in 2024 the monsoon rains were more intense than usual, leading to widespread flooding in India, Bangladesh, Nepal and Pakistan. Rain gauges across South Asia recorded unusually high precipitation totals, including in New Delhi (India), Lahore (Pakistan), Kathmandu (Nepal) and Cox's Bazar (Bangladesh) (Figure 1).

Figure 1. **Flooding occurred across India, Pakistan, Bangladesh and Nepal.**



Flood-induced challenges across sectors

The flooding was extensive, disrupting multiple sectors, including:

Agriculture: 60% of South Asia's land area is used for agriculture,[1] making the sector particularly vulnerable to monsoon flooding. In Bangladesh, for example, the Agricultural Ministry estimated that monsoon flooding in 2024 destroyed crops worth an estimated 45 billion taka ($380 million), including 1.1 million metric tons of rice.

Industrial activity: Flooding affected industrial areas, such as Chennai and Bengaluru in India, disrupting production, services and logistics. Cotton production, which supplies South Asia's textile manufacturers, was also impacted. The Cotton Association of India estimated that 2024 – 2025 cotton production will be 7% lower than the previous year, in part due to flood-damaged crops.

Transportation: Flooding damaged roads, bridges and railways, affecting the movement of goods and people. For example, in Nepal landslides damaged 19 major roads and blocked all highways out of Kathmandu, while in Pakistan floods damaged 500 kilometers of roads and 40 bridges.[2]

Energy: Hydroelectric power plants suffered damage, leading to reduced electricity production. Nepal — which generates more than 95% of its electricity from hydropower — reported damage to 16 hydropower plants, impacting the nation's power supply.

A more intense and erratic monsoon

Severe flooding in South Asia is no surprise in a warming world, with research pointing to an increase in extreme precipitation events during the monsoon season in recent years. Scientists at the Indian Institute of Tropical Meteorology, for instance, have observed a threefold increase in extreme rainfall events over central India since 1950.[3] At the same time, the timing of the monsoon has become less predictable, with both its onset and withdrawal exhibiting greater interannual variability. Climate model projections suggest these trends will continue, with future monsoons producing even heavier rainfall and greater year-to-year variability.[4]

Parametric insurance: Bridging the gap

For risk managers across the region, this evolving reality demands a proactive approach to safeguard communities and economies. Central to this effort is strengthening risk management and financing strategies, including the development of robust risk transfer solutions. In South Asia, around 80% to 90% of natural catastrophe damages are uninsured, highlighting a significant protection gap.

One solution that could help to bridge this financing gap is parametric insurance. Parametric insurance pays out based on a pre-agreed trigger threshold (e.g., amount of rainfall over a 24-hour period, measured at a specified rain gauge). This strategy bypasses the need for a lengthy loss adjustment process, which allows funds to be quickly released to the policyholder.

Additionally, parametric insurance can be used to cover non-damage losses such as those resulting from business interruption. This flexible application means that parametric insurance can be a valuable complement to more traditional indemnity-based insurance coverages.

Parametric insurance has been implemented for decades in certain sectors, for example, to cover agricultural losses where it is more commonly referred to as "weather index insurance." In this case the indices (or "parameters") may relate to extreme rainfall that causes flooding, soil erosion and associated crop losses. Following a qualifying event, payouts could be made to farmers directly, to some form of "aggregator" such as a farming cooperative, or even to a government ministry that has responsibility for overseeing agricultural activities. Implementing parametric insurance at various scales, alongside other risk management and financing instruments, can strengthen the financial and wider climate resilience of key sectors.

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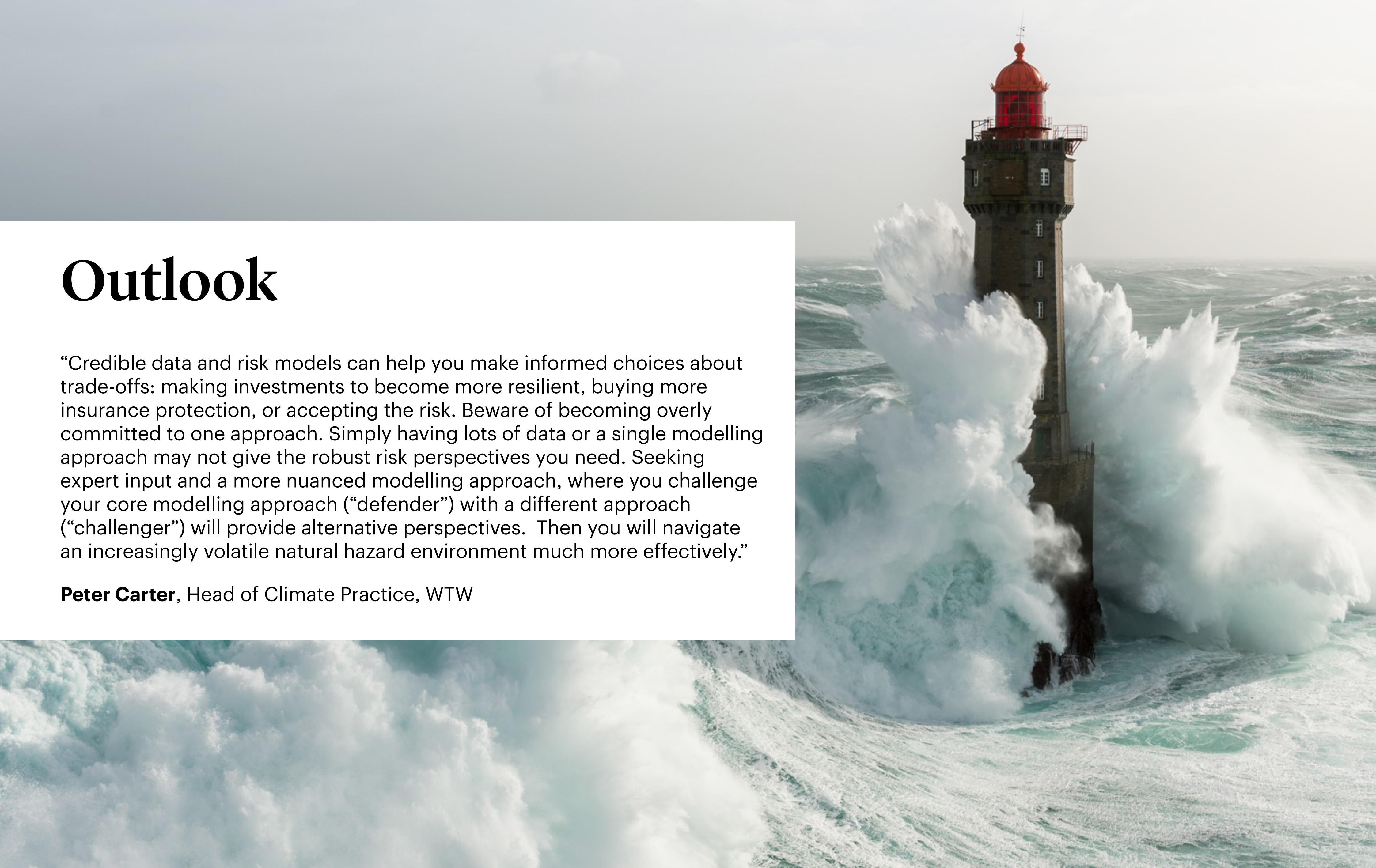
[1] World Bank Group. DataBank. (2024).
[2] Assessment Capacities Project (ACAPS). Pakistan 2024 Monsoon Floods Briefing Note. (2024).
[3] Roxy, M.K et al. A threefold rise in widespread extreme rain events over central India. Nature Communications 8, 708. (2017).
[4] Katzenberger, A. et al. Robust increase of Indian monsoon rainfall and its variability under future warming in CMIP6 models. Earth System Dynamics 12.2 (2021).



Outlook

“Credible data and risk models can help you make informed choices about trade-offs: making investments to become more resilient, buying more insurance protection, or accepting the risk. Beware of becoming overly committed to one approach. Simply having lots of data or a single modelling approach may not give the robust risk perspectives you need. Seeking expert input and a more nuanced modelling approach, where you challenge your core modelling approach (“defender”) with a different approach (“challenger”) will provide alternative perspectives. Then you will navigate an increasingly volatile natural hazard environment much more effectively.”

Peter Carter, Head of Climate Practice, WTW

4.1 Challenging models with observations: The case of the 2024 North Atlantic hurricane seasonal forecasts

Did the seasonal forecasts get it "right"? If most forecasts produce similar errors and we don't fully understand why, then we need greater model diversity and more structured application of expert judgment.

High expectations

Pre-season forecasts of North Atlantic hurricane activity in the 2024 season were particularly high. All major forecasters agreed that the season would be extremely active with a much higher number of storms than average.

So the post-season question is, were the forecasts any good? Have the forecasters been proven right? As discussed in Section 3.1 of this Natural Catastrophe Review, the season was indeed significantly more active than average. But what can we conclude about the forecasts — and the models?

A game of two halves

Despite a fast early start by record-setting Hurricane Beryl and very high sea surface temperatures, at the halfway point 2024 was looking like an unremarkable season overall with little activity in what would typically be the most active months of August and early September.

If that pattern had continued and 2024 had been a normal-to-slow season, it would have suggested that our models aren't able to represent hurricane activity well. Given the context of high sea surface temperatures, this would also indicate limited confidence in the effects of climate change.

In reality, hurricane activity picked up again in late September, and the season ended with storm numbers largely in the high ranges predicted by forecasters. That's certainly good for confidence in our broad understanding of hurricane activity, but what does it mean for model evaluation? And perhaps more important, are the forecasts useful?

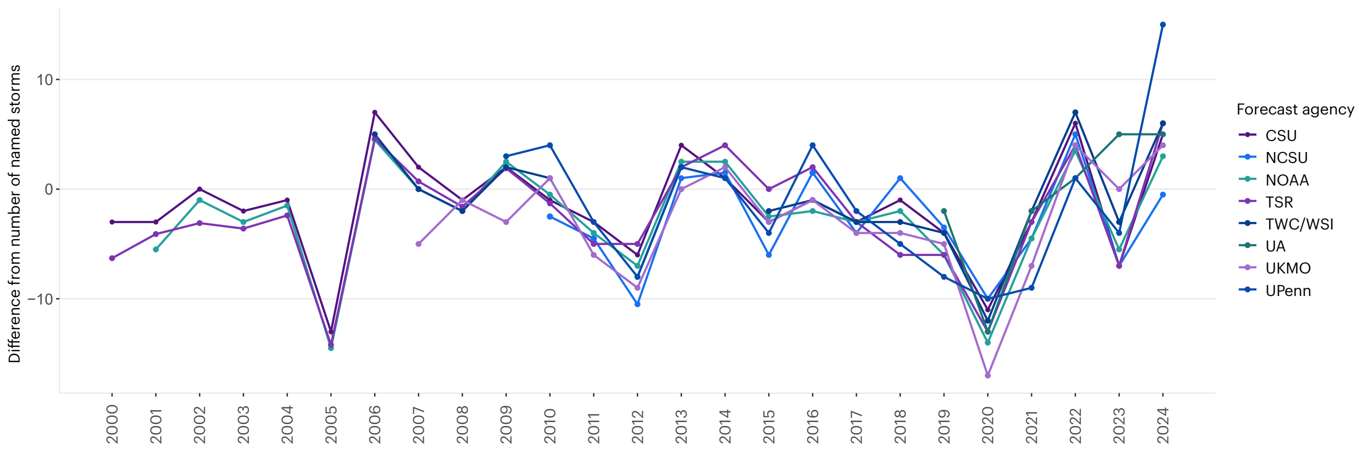
Forecast evaluation and ensemble bias

Probabilistic forecasts (which is effectively what these are, even those that state a single number) cannot be assessed solely on how well they perform in a single year. We need to look at previous years as well to get an overall picture of reliability.

Interestingly, across the past 24 years, the differences between forecast and observations are usually in the same direction for most modeling groups. Figure 1 shows the final differences, or "residuals," for eight modeling groups. If the ensemble was unbiased, then the residuals would be randomly spread around the zero line, but instead they often all fall on the same side of it.

There could be two reasons for this. The first is that some degree of "peer pressure" may be at work in the forecast space; once one forecast is published, others might then cluster around it either because of a confirmation bias or an unwillingness to be an outlier. The other possibility is that the models we have are simply all making similar assumptions that are systematically inadequate in some way; we are either still missing some important secondary driver of activity or even just systematically failing to account for some kind of uncertainty or randomness and ending up overconfident in the final answer.

Figure 1. **Plot showing highly correlated differences between predicted and actual named storms in the North Atlantic. Based on pre-season forecasts for eight major forecasting groups, published in April, May or June of each year.**



In either case, there isn't an a priori way to identify and correct the error from within "Model Land."[1] The only way to deal with systematic biases is by getting out of Model Land using our expert judgment.[2] One person might be able to make an expert judgment about the degree of peer pressure among modeling groups, while someone else might be able to make an expert judgment about the quality of alternate models and the degree to which they share assumptions, limitations or biases. By doing that, perhaps we could prune the ensemble of forecasts down to a smaller number (maybe one), which more accurately reflects the number of truly independent lines of evidence in the overall forecast and its confidence. Just because we have nearly 30 forecasts available[3] doesn't mean they all contribute additional information; what we need is more diverse models, not more copies of essentially the same model. (In fact, since there is clear over-confidence in the ensemble, we might even find that we could make a better probabilistic forecast by including information from a zero-skill benchmark model.)

[1] Thompson, E. Escape from Model Land: How Mathematical Models Can Lead Us Astray and What We Can Do About It. (2022).
[2] WTW. Rethinking catastrophe model evaluation by getting out of Model Land. (2024).
[3] The Barcelona Supercomputing Center, in collaboration with other institutions, manages a platform that compiles forecasts from nearly 30 forecast centers across the world.

Driving more useful seasonal hurricane forecasts

A second issue to consider is whether this informal forecasting competition is actually helpful to decision makers. A general steer toward more or less activity is probably useful for general preparedness or adjustment of (re)insurance coverage, but a major hurricane can happen even in an otherwise inactive season, as was the case in 1992 with Hurricane Andrew; conversely, an active season might happen to contain few damaging events.

If we want to encourage competitive pre-season forecasting activity, perhaps a competition (or even a formal prediction market)[4] with more directly relevant variables would be helpful. One aspect highlighted by Hurricane Helene in 2024 and Harvey in 2017 is the importance of excess rainfall as a major driver of impacts, something that is also likely to increase in a warmer climate. The number of landfalls is harder to forecast but of great interest; a competition on that could spark more work on the location and path of hurricanes, steering influences and the relative numbers in the Gulf of Mexico and the Atlantic.

Encouraging model diversity

Ultimately, despite the useful indicativeness of seasonal hurricane activity forecasts, there appears to be a general tendency toward overconfidence. The most credible forecasts are therefore those with the widest uncertainty ranges. Getting out of Model Land and improving the forecasts will require a concerted push for greater model diversity, followed by a longer-term approach to quantitative evaluation.

[4] Such as those trialed by CRUCIAL.

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Written by WTW Research Network Partner Dr. Erica Thompson.

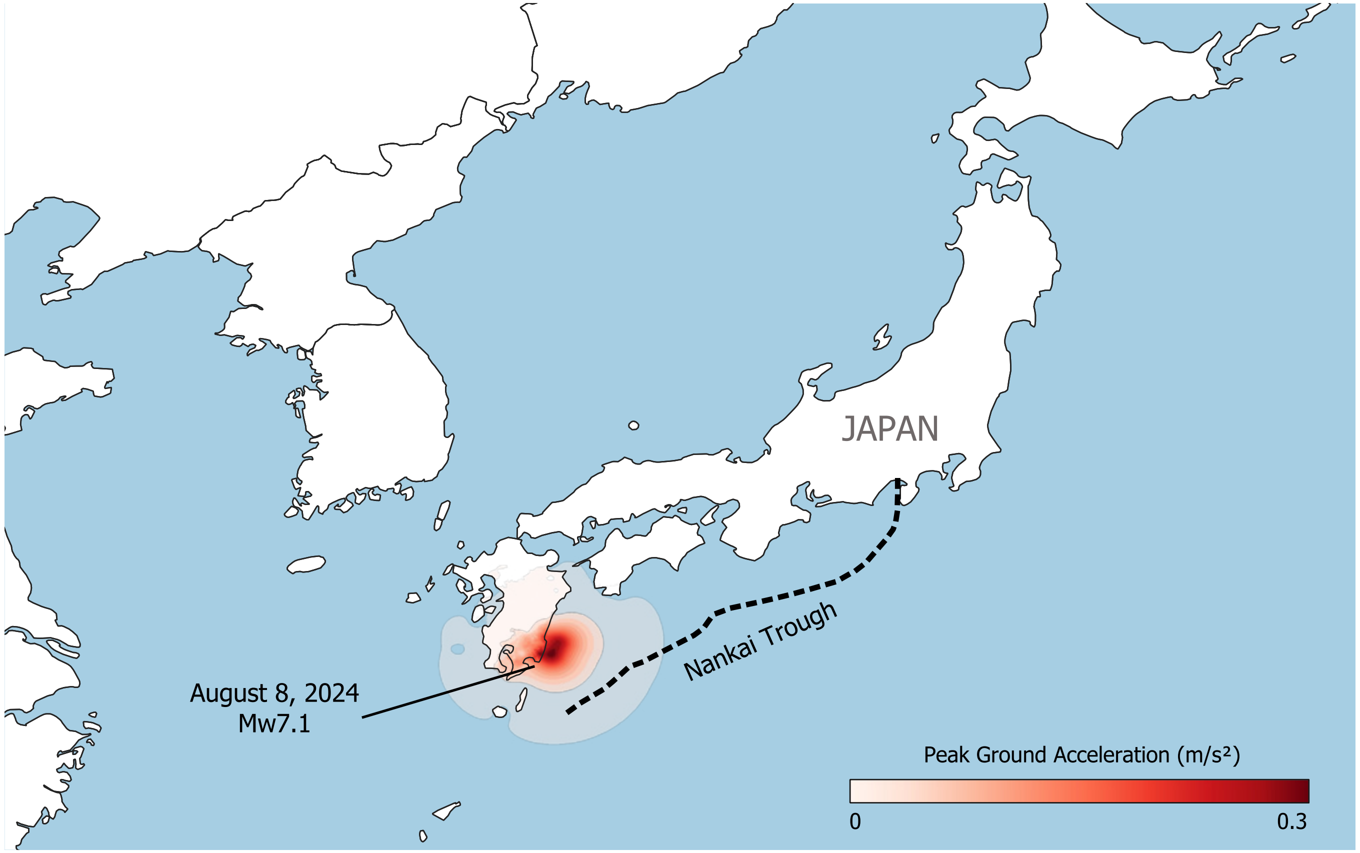
4.2 Japan's megaquake warning: Are foreshocks reliable indicators of major earthquakes?

A moment magnitude (Mw) 7.1 earthquake off the coast of Nichinan, Japan, triggered warnings of a potential "megaquake." While immediate risk was low, long-term threats from the Nankai Trough exist, highlighting the need for preparedness and resilience.

On August 8, 2024, a Mw7.1 earthquake struck 6 kilometers off the coast of Nichinan in southern Japan in the Hyuga-nada Sea (Figure 1). This event was felt by nearly a million people and reached a widely reported Modified Mercalli Index of VII (very strong).[1] It resulted in no deaths, 14 injuries and the destruction of only one building.[2]

Following the event, the Japan Meteorological Agency (JMA) issued its first-ever Nankai Trough Earthquake Extra Information bulletin, warning of an increased risk of a "megaquake." This advisory, which remained in effect for a week, called for authorities and residents to take precautionary measures for a potential large magnitude (Mw8 – 9) event, such as securing furniture and familiarizing themselves with evacuation procedures.

Figure 1. **The location of the Nankai Trough south of Japan (dashed line) and the peak ground acceleration from the August 8, 2024, Mw7.1 earthquake event.**



[1] USGS. Earthquake Hazards Program. (2024).
[2] Reliefweb. Japan - Earthquake ECHO Daily Flash of 9 August 2024. (2024).

Historical precedents

The megaquake advisory was based on historical observations, which suggest that significant megathrust earthquakes along subduction zones, such as those in Japan, can be preceded by smaller tremors. For example, Kato et al. (2012)[3] found that a Mw7.3 foreshock, along with hundreds of smaller seismic events in the preceding days, likely triggered the Mw9.0 Tohoku earthquake in 2011. This catastrophic event resulted in tens of thousands of deaths and over $200 billion in economic losses.

However, despite the foreshock-mainshock link observed in Tohoku, such cases are relatively rare. According to the U.S. Geological Survey, the probability of any given earthquake being followed by a larger one within a week is approximately 5%. This statistic highlights the challenge of determining whether a seismic event is a foreshock or an isolated incident until a larger quake occurs.[4]

The recent Mw7.1 event struck the Hyuga-nada tectonic region, which links the Nankai Trough to the north and Ryukyu Trench to the south. Earthquakes of comparable magnitude have historically occurred every 25 to 30 years in this region without triggering megaquakes.[5] Palaeoseismic records also indicate that no Mw8 – 9 events have previously been recorded within 100 kilometers of the Mw7.1 event, suggesting that the Hyuga-nada "repeater" events primarily release stress locally. If correct, this would likely limit stress transfer to the Nankai Trough, reducing the risk of triggering a megaquake.

While the JMA stated that the immediate risk of a megaquake was low following the August 2024 event, the long-term risk remains significant. The most recent major event on the Nankai Trough was the Mw8.1 earthquake in 1946. With return intervals of 90 to 150 years, Japanese seismologists estimate a 70% to 80% probability of a Mw8 – 9 earthquake occurring in the next 30 years.[6]

Uncertainties in fault interactions

The advancement of stress change and fault mechanism analysis to the point where potential warnings can even be considered is a remarkable achievement in seismology. However, significant gaps in our knowledge remain, which makes prediction challenging and uncertain. For example, there is uncertainty in how adjacent faults interact and the mechanisms by which smaller earthquakes could trigger larger events.

While there is no documented evidence of Hyuga-nada earthquakes triggering megaquakes on the Nankai Trough, this does not mean it is impossible. Hyuga-nada and the Nankai Trough are both part of the same subduction system, so it is logical that a Hyuga-nada event could redistribute stress and trigger an event on the neighboring trough.

As a result, a cautious approach is justified. The JMA's advisory reflects the possibility, however small, of unexpected outcomes in such a complex system. Additionally, the Nankai Trough's closer proximity to coastal communities — compared with the Japan Trench, where the Tohoku earthquake occurred — leaves less time for tsunami warnings, demanding heightened vigilance and likely contributing to the JMA's decision to issue its advisory.

Recent modeling advances

Recent modeling advances are helping researchers improve short-term earthquake forecasts by better distinguishing foreshocks from other seismic events. For example, a recent model developed by researchers at Waseda University and The Institute of Statistical Mathematics, both in Tokyo, uses logistic regression to estimate the likelihood, timing and magnitude of potential mainshocks within 30 days of seismic activity.[7] While such models show promise, they are still under development and often only work in specific scenarios. The researchers highlight their model's potential as an alert system while emphasizing the need for continued development to enhance accuracy and broaden applicability.

[3] Kato, A. et al. Propagation of Slow Slip Leading Up to the 2011 Mw 9.0 Tohoku-Oki Earthquake. Science. 225 606 (2012).
[4] USGS. What is the probability that an earthquake is a foreshock to a larger earthquake? (2024).
[5] Toda, S. et al. Japan's magnitude 7.1 shock triggers megaquake warning. How likely is this scenario? (2024).
[6] Japan News. Nankai Trough Megaquake Tsunami could Hit in 2 Minutes; Japan Authorities Urge Caution after Recent Earthquake. (2024).
[7] Nomura, S. and Ogata, Y. Cluster-based foreshock discrimination model with flexible time horizon and mainshock magnitudes. Progress in Earth and Planetary Science 10, 20 (2023).

Preparedness and resilience

Japan is one of the most well-prepared countries in the world for earthquakes, as demonstrated during the January 2024 Noto Peninsula earthquake, where stringent building codes and rapid emergency response helped mitigate the impact of the Mw7.5 quake.[8] However, despite this preparedness, the Japanese government estimates that a worst-case scenario Mw8 – 9 earthquake on the Nankai Trough could cost up to $1.4 trillion in economic losses and result in over 200,000 fatalities.[9]

The recent megaquake warning therefore highlights the ongoing need for investment in earthquake preparedness and resilience, including the use of natural catastrophe models to evaluate the impacts of various scenarios. Such efforts can guide infrastructure improvements, emergency response planning and risk transfer strategies, ensuring that communities and businesses are better equipped to withstand and recover from future seismic events.

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[8] WTW. Natural Catastrophe Review – H1 2024. (2024).
[9] Mainichi Shimbun. Nankai Trough estimated at 230,000 deaths and 213 trillion yen in economic damage. (2024).

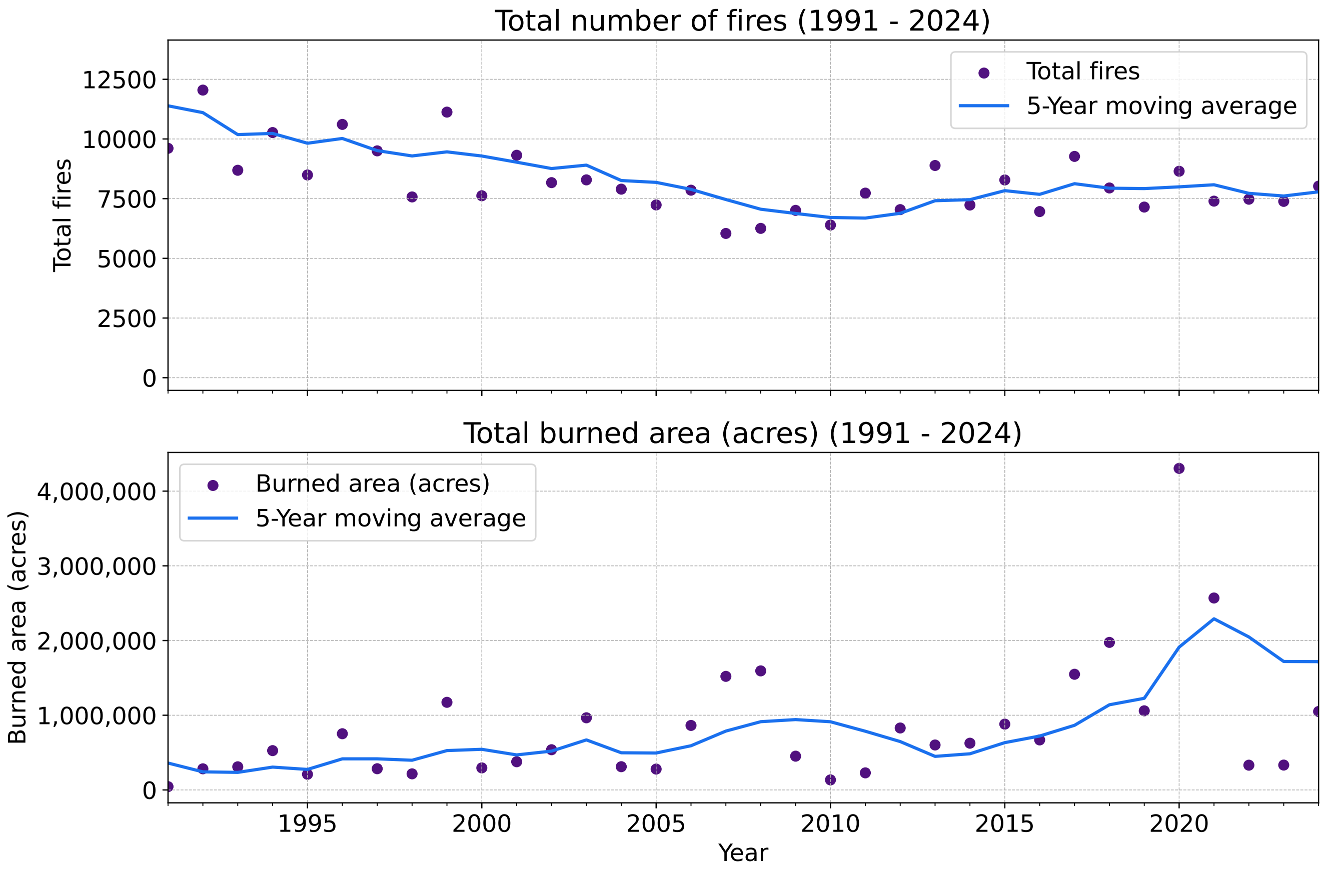
4.3 The role of insurance in protecting carbon markets from wildfire risks

California's 2024 Park Fire highlighted wildfire threats to forestry carbon removal projects, releasing carbon dioxide and reducing future carbon removal. Comprehensive risk management, including insurance solutions, is essential to safeguard these projects.

In 2024, California experienced its hottest summer on record, with temperatures in June to August rising 5°C above the 1895 – 2000 historical average, resulting in several large wildfires. One of the most notable was the Park Fire, which burned 430,000 acres (174,000 hectares) across Butte and Tehama counties in July. Ignited by arson, the fire spread rapidly due to the unusually hot and dry conditions. The Park Fire ranks among California's largest, reflecting a trend in recent years where four of the state's largest wildfires have occurred in the past seven years.

Although improved detection and suppression efforts have helped stabilize the total number of wildfires across California in recent years (Figure 1, top), rising temperatures and prolonged drought continue to drive a steady increase in the total area burned (Figure 1, bottom). With wildfires becoming more intense, the future of forestry projects designed to capture and store carbon dioxide is increasingly at risk.

Figure 1. **Top panel: The total number of wildfires in California (1991 – 2024), showing a plateau in frequency with a five-year moving average. Bottom panel: The annual area burned in California (1991 – 2024), with a five-year moving average indicating an upward trend in burned area, reflecting increasingly severe wildfire seasons, particularly since 2015.**



Data source: CAL FIRE.

The dual threat to carbon removal projects

In 2024, wildfires — including the Park Fire — burned over 52,300 acres of California forests designated for carbon removal projects. The burning of such forests poses a dual challenge: First, wildfires release vast amounts of carbon dioxide into the atmosphere as forests burn, reversing years of carbon storage. Second, they reduce the capacity of forests to absorb future carbon, weakening their role as natural carbon sinks. Compounding this issue, research suggests that land and ocean systems are currently absorbing far less carbon than before, highlighting the importance of understanding and protecting natural capital.[1]

Buffer pools and their limitations

Carbon removal projects such as those in California rely on buffer pools — reserves of unsold credits meant to replace those lost to such disasters as wildfires. However, these safety nets are under significant strain due to the increasing intensity of wildfires. Over the past decade, wildfires have consumed an estimated 11 million buffer pool credits, far exceeding the 6.6 million credits reserved for wildfire losses over the 100-year lifespan of current projects.[2]

This growing pressure on buffer pools has prompted calls for a reassessment of their size and structure. Experts recommend updating buffer pool contributions and halting the approval of new projects in high-risk wildfire regions to ensure the resilience of carbon markets.[3]

However, buffer pools alone are not sufficient to address the growing complexity of these risks nor to protect forests and their vital role as carbon sinks. A comprehensive risk management strategy, including tailored insurance solutions, is required to safeguard carbon removal projects against escalating risks.

Carbon insurance: A growing market

As highlighted by the World Bank, robust risk management strategies are essential for maintaining market integrity and ensuring carbon markets remain effective in delivering both environmental and financial benefits.[4] These markets are essential for accelerating climate action, providing mechanisms for organizations to meet sustainability goals.

Forestry and land-use carbon credits were valued at over $22.5 billion globally in 2023. This includes projects such as reforestation, afforestation and improved forest management, which directly relate to forestry carbon removal efforts. With a projected compound annual growth rate of over 15.1%, the U.S. is expected to be a significant contributor to this growth.[5] As these markets grow, the demand for insurance products tailored to safeguard carbon removal projects is expected to rise, with research estimating that the market for risk transfer related to carbon markets could be worth $10 billion to $30 billion of annual gross written premium by 2050.[6]

Carbon insurance solutions (see sidebar) are vital to ensuring that forestry carbon removal projects remain viable and resilient against escalating risks such as wildfires. By offering protection to buyers and sellers of credits alike, as well as to financial institutions lending capital, these products drive confidence in the market, unlock lending capacity and facilitate the financing of new projects. Without such protections, organizations may hesitate to invest in forestry restoration initiatives, perceiving them as too vulnerable to future disasters.

Collaboration is essential

However, safeguarding the future of carbon removal projects requires more than individual solutions. A collaborative approach — where insurers provide innovative risk transfer solutions, investors and policymakers prioritise resilience, governmental bodies establish supportive frameworks, brokers facilitate tailored coverage, researchers deliver actionable insights, and project developers implement best practices — is essential. By aligning risk strategies with the realities of escalating climate threats, these stakeholders can help protect forestry projects from the dual risks of wildfires: the immediate release of stored carbon and the long-term loss of sequestration capacity. With the carbon dioxide growth rate rising sharply in recent years, protecting forestry carbon removal projects is essential to achieving global climate goals.

[1] Ke, P., et al. Low latency carbon budget analysis reveals a large decline of the land carbon sink in 2023. National Science Review, Volume 11, Issue 12. (2024).
[2] (carbon)plan. California's shrinking buffer pool. (2024).
[3] Financial Times. Californian fires burn trees in company carbon schemes. (2024).
[4] The World Bank. State and Trends of Carbon Pricing: International Carbon Markets 2024. (2024).
[5] Global Market Insights. Forestry & Landuse Carbon Credit Market Size. (2024).
[6] Kita. Are carbon credits the next billion-dollar insurance market? (2024).

Understanding carbon credit insurance for carbon removal projects

Current carbon credit insurance products represent an emerging and growing market, addressing some of the challenges of buffer pools and offering protection against key risks faced by carbon removal projects. As this market evolves, broader adoption of these solutions will be essential to safeguarding these investments and ensuring the resilience of carbon markets.

Pre-issuance risk cover mitigates the risk of a project under-delivering the credits promised before they are issued, protecting buyers and investors of forward purchased credits. For example, when carbon credits are purchased on a forward basis, but the forestry project fails to reach maturity — due to events such as wildfires — insurance can indemnify the policyholder for the financial value of non-delivered credits or replace them with replacement credits.

Post-issuance risk cover offers additional protection, providing financial indemnification or replacement credits, in the event of adverse events impacting credits after issuance. Typically renewed annually, this type of cover safeguards against invalidation and non-permanence risks, providing reassurance to both buyers and sellers of carbon credits.

Credit non-payment risk cover for banks and financial institutions protects against non-repayment of loans from project developers.

Wildfires and natural catastrophes are not the only risks to carbon removal projects, prompting a rapid increase in product development in the carbon credit insurance market. Solutions are now available to protect against political risk relating to carbon credits as well as products specific to compliance regimes such CORSIA and the European Union's Emissions Trading Scheme (EU ETS).[7]

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[7] WTW. EU ETS expansion to shipping spurs demand for carbon and credit insurance in the maritime industry. (2024).

4.4 Climate litigation risk: What next?

Climate litigation risk in the private sector has increased, and we are now entering an era where corporates are required to meet and report on their climate and sustainability commitments, thereby increasing accountability and, with it, litigation risk. Looking forward, WTW expects continued growth in this type of litigation, driven by stronger laws, corporate sustainability reporting requirements and slow progress against the goals of the Paris Agreement.

"Climate litigation" refers to legal disputes that arise from, or are related to, a party's contribution to climate change; the physical consequences of climate change; or laws, regulations and legal duties related to climate change. Within this definition, private sector climate litigation can be sorted into:

- **Mitigation claims** (arising from a defendant's contribution to climate change or a claimant's attempt to limit future greenhouse gas emissions)[1]
- **Adaptation claims** (disputes that arise from a defendant's failure to plan for or adapt to the physical, societal or legal impacts of climate change)[2]
- **Governance and regulatory claims** (disputes arising from breaches of legal duties that raise issues of law or fact related to the science of climate change)[3,4]

This is the definition that WTW uses to frame and consider climate litigation as a risk, but there is no one agreed definition. As a result, the scale of the risk is often underestimated, expanding beyond, for example, cases against high-emitting or high-transition risk companies. What can be agreed, however, is that climate litigation continues to grow, not only by volume of cases but also by the number of jurisdictions in which cases appear.[5] WTW expects such patterns to continue across the private sector as the motivation, strategies and tools to pursue such claims continue to grow. As a result, risk managers face increasing challenges in assessing and mitigating their legal exposure to climate.

[1] An example is an emissions case alleging that a company's activities or products contributed to climate change, as seen in the recent wave of litigation against major oil companies in the U.S.
[2] The Arkema Crosby Facility in the U.S. provides an example of how changing flood maps are often not made known to facility employees and insurers. This can lead to devastating affects as seen at the Arkema facility following Hurricane Harvey.
[3] WTW. Climate Litigation Risk — Is there shelter from the storm? (2023).
[4] MinterEllison, The Carbon Boomerang – Litigation Risk as a Driver and Consequence of the Energy Transition. (2017).
[5] Setzer J. and Higham C. Global Trends in Climate Change Litigation: 2024 Snapshot. London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science. (2024).

All this is set against the backdrop of the risk, as reiterated at the 2024 United Nations Climate Change Conference by the chair of the Intergovernmental Panel on Climate Change (IPCC), that we were "perilously close to 1.5°C warming." Scientists have since confirmed that this threshold was exceeded in 2024, albeit likely temporarily. Exceeding 1.5°C signals the escalation of "moderate" risks to "high" risks, the IPCC chair warned, and if we "carry on as we are global temperatures could reach 3°C within this century, bringing severe impacts, significant irreversibility, and a limited ability to adapt."[6]

Evolving trends

Historically, the majority of climate litigation cases within the private sector focus on changing corporate behavior, known as agenda-setting litigation, rather than seeking large sums by way of damages. The non-governmental organization (NGO) ClientEarth, for example, regularly refers to using "the power of the law to respond to the climate crises,"[7] while others, including Germanwatch and Environmental Justice Australia, advocate for sustainable global development.

An individual, supported by an NGO, filed a civil lawsuit against a German energy company, aiming to set a precedent on whether individual major emitters should pay for protection against climate risks — a judgment still awaited some eight years later.[8] Equally, in Australia a settlement was reached at the 11th hour[9] between an individual (again, supported by an NGO) and an Australian superfund, Retail Employees Superannuation Trust (Rest), the latter agreeing as part of the settlement that "climate change is a material, direct and current financial risk to the superannuation fund," and that "Rest, as a superannuation trustee, considers that it is important to actively identify and manage these issues."[10]

[6] IPCC. IPCC Chair's remarks at the High-Level Ministerial Roundtable on Pre-2030 Ambition. (2024).
[7] ClientEarth. From stocktake to taking action: Using the power of the law to respond to the climate crises. (2024).
[8] The Climate Case. Saúl Luciano Lliuya vs. RWE. (2024).
[9] Rest also agreed to align its portfolio to net zero by 2050, report against the Task Force on Climate-related Financial Disclosures (TCFD), conduct scenario analysis to inform its investment strategy and strategic asset allocation, disclose its entire portfolio holdings and advocate investee companies to comply with the goals of the Paris Agreement.
[10] Equity Generation Lawyers. Mark McVeigh v Retail Employees Superannuation Pty Ltd. (2024).

Greenwashing and greenhushing

"Greenwashing" is a term that has been used since the 1980s and refers to the process of conveying a false impression or misleading information about how a company's products or actions are environmentally sound. Ultimately the aim is to capitalize on growing demand for environmentally sound products. "Greenhushing" on the other hand, is when companies choose not to communicate their sustainability efforts, potentially due to a fear of criticism against sustainability claims.

A marked shift in climate litigation cases has occurred in more recent years. In addition to individuals seeking climate action with NGO support, claimant law firms known for group litigation and often supported by litigation funders are pursuing climate litigation, thereby further increasing the litigation risk.

Greenwashing risk (and greenhushing, see sidebar) is also increasing, with a corresponding growth in legislation to guide and advise companies on "green claims."[11,12] Human rights-based litigation is playing a key role in climate litigation when assessing the adverse effects on human health caused by climate change.[13] Likewise, new and amended legislation aimed at making Europe the first climate-neutral continent by 2050 as part of the European Green Deal[14] has brought with it risks associated with noncompliance. This legislation, which spans topics from deforestation[15] to packaging waste,[16] also includes corporate sustainability reporting under the Corporate Sustainability Reporting Directive (CSRD) and the Corporate Sustainability Due Diligence Directive (CSDDD). Enhanced sustainability disclosure requirements, under the CSRD or other similar global standards, including recent developments in California,[17] require companies to provide more detailed information on their environmental and climate impacts.

[11] See European Commission. Green Claims. (2024).
[12] GOV.UK. Get your green claims right. (2024).
[13] House of Commons Library. A new precedent for climate change in human rights law. (2024).
[14] European Commission. The European Green Deal. (2024).
[15] European Commission. Regulation on Deforestation-free Products. (2024).
[16] European Commission. Packaging Waste. (2024).
[17] Bill SB 219 enacts several amendments to the Climate Corporate Data Accountability Act (SB 253) and the Climate-Related Financial Risk Act (SB 261), known as the Climate Accountability Package. The disclosure of scopes 1, 2 and 3 greenhouse gas emissions and submission of biannual climate-related financial risk reports will now be a legal requirement for certain businesses. Given California is the fifth largest economy in the world by gross domestic product, the impact of this legislation is significant.

While this increased transparency helps stakeholders identify discrepancies between a company's stated sustainability goals and its actual practices, misleading reports leading to financial loss or breaches of fiduciary duties can increase the risk of greenwashing claims, regulatory challenges, enforcement activity, and investor and shareholder action.

Jurisdictional variations

An awareness of jurisdictional variations is also important. As an example, European Union (EU) member states must adhere to legislative requirements around climate not only at the EU level but also at each member-state level. The French Duty of Vigilance Law requires French companies over a certain size to monitor and address human rights abuses and environmental harm throughout their supply chain, while the German Supply Chain Due Diligence Act (LkSG) has a similar focus. The Federal Office for Economic Affairs and Expert Control, responsible for monitoring and enforcing the LkSG, recently published its Accountability Report for 2023,[18] which covers the first year of application. The report analyzes its enforcement activities and lessons learned, providing some reassurance that CSDDD enforcement may not be as onerous as expected, while also noting the larger scale of the European-wide legislation.

Within the U.S., the risk landscape is more nuanced and complex. As well as accounting for the majority of climate litigation cases, we are starting to see what success such cases are having and how the courts are responding to this litigation. The court response extends not only to climate litigation cases but also to policy coverage disputes. By way of example, in recent months the Supreme Court of Hawaii ruled that greenhouse gases are pollutants and therefore excluded from policy cover due to the insured's pollution exclusion in the liability policy.[19] Such developments will be particularly relevant for risk managers to monitor.

Implications for risk managers

For risk managers, the landscape is varied and becoming increasingly challenging given the emergence of new legislation and changing political sentiment.

Following are key areas to focus on in the immediate future:

- Across the business, agreeing on a consistent definition of "climate litigation" to monitor the extent to which certain lines of business are already affected and ensuring good knowledge levels of climate litigation risk and how such risks may aggregate
- Establishing whether climate litigation enforced fines and penalties would be insurable under likely "in scope" policies[20]
- Carrying out stress and scenario analysis of material climate litigation risks to the business to assess such risks, both qualitatively and quantitatively, and using the output to inform decision making.

What is deemed "material" will vary but may include directors' and officers' insurance or environmental liability insurance depending on the makeup of the portfolios. Further information on climate litigation risk across portfolios can be found in the WTW paper "Climate Litigation Risk – Is there shelter from the storm?"[21] WTW has also built a climate litigation heatmap dashboard tool to assist insurers in assessing climate litigation risk across their portfolios.

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[18] Bundesamt für Wirtschaft und Ausfuhrkontrolle. Rechenschaftsbericht 2023. (2023).
[19] Aloha Petroleum Ltd v National Union Fire Insurance Company of Pittsburgh et al SCCQ-23-0000515.
[20] While the litigation risks stemming from European Green Deal legislation are varied, the penalties referenced in the underlying legislation refer to the ability of member states to allow for one or more supervisory authorities to supervise compliance with the legislation. Such supervisory authorities are able to impose financial penalties that are "effective, proportionate and dissuasive.
[21] WTW. Climate Litigation Risk — Is there shelter from the storm? (2023).

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