

An aerial photograph showing a residential area that has been severely flooded. The water is a murky, greenish-brown color, surrounding several houses and a large number of trees. One prominent house in the lower right has a white roof and red walls. Another house in the center has a grey metal roof. The trees are mostly green, but some appear dead or partially submerged. Power lines run diagonally across the scene from the top left towards the bottom center.

**AON**

# 2021 Weather, Climate and Catastrophe Insight



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# Executive Summary

Economic Loss

**\$343 billion**

27% above the 21<sup>st</sup> Century average



**62%**

Global Protection Gap

**50**

billion-dollar economic loss events (4<sup>th</sup> highest on record)

Insured Loss

**\$130 billion**

76% above the 21<sup>st</sup> Century average



**71%**

of global insured losses were recorded in the United States

**20**

billion-dollar insured loss events (4<sup>th</sup> highest on record)



**401**

number of notable disaster events



**\$36 billion**

insured loss from Ida, 4<sup>th</sup> costliest hurricane on record for insurers



**\$17 billion**

insured loss from winter weather; costliest year on record for this peril



**\$13 billion**

insured loss from European floods in July, the costliest disaster on record for the continent

**Germany, Belgium  
Austria, Luxembourg,  
and China**

recorded the costliest insurance industry events on record



**2,248**

number of fatalities from Haiti Earthquake, deadliest event of 2021



**0.84°C (1.51°F)**

Above the 20<sup>th</sup> Century Average (NOAA): World's sixth-warmest year on record for land and ocean temperatures dating to 1880

**54.4°C (130.0°F)**

Temperature on July 9, 2021 in Death Valley, California (USA); unofficially the hottest temperature ever reliably measured on Earth

# Opening Remarks: What Can We Do Today to Plan For Tomorrow?

Over the past year, the world has counted the costs of another round of major, expensive and disruptive natural disasters. These kinds of catastrophes are increasing in frequency and severity — impacting livelihoods, communities, and businesses across the globe. And many of them can be exacerbated by the effects of climate change.

As the world wakes up to the effects of a changing climate, what can organizations do to build for the long-term while tackling the immediate challenges of a volatile world?

## U.S. sees the costliest events

Extreme weather events, some of which were enhanced by climate change, were particularly notable in the United States. Hurricane Ida, which made landfall in August, resulted in one of the highest individual losses ever recorded for public and private insurers (\$36 billion). Ida was one of eight tropical cyclones that made landfall in the U.S. in another above-average Atlantic Hurricane Season.

The country also saw the costliest winter weather event ever recorded following a disruption of Polar Vortex that engulfed much of the country. A high number of severe convective storms, which included a December tornado outbreak and derecho, resulted in the third-costliest year on record for the insurance industry in the United States, record heat and drought conditions set the stage for wildfires which led to a multi-billion-dollar annual loss. This included major fire events in California and Colorado.

## Global records

In other parts of the world, historic rainfall and flooding set records for the costliest individual natural disaster events for the insurance industries in Germany and China. Meanwhile, a typhoon,

equivalent to a Category 5 hurricane, struck the Philippines in December and record-setting heatwaves led to drought and wildfires in North and South America, Europe and Asia. Significant tornadoes and hail affected Australia, Western and Central Europe and Canada while earthquakes struck in Haiti and Japan.

Recovery efforts and the delivery of critical humanitarian aid were further complicated again this year due to the ever-evolving COVID-19 pandemic.

## Unique opportunity

Organizations, governments and communities are beginning to realize that our interconnected world is becoming more directly — and indirectly — affected by the environment around us.

The public and private sector now has a unique opportunity to discover and implement new strategies. One example of this new spirit of cooperation can be seen in the 26<sup>th</sup> United Nations Climate Change Conference (COP26), which demonstrated how national governments, financial institutions, emergency managers and academics can collaborate to advance new plans to cut carbon emissions and put the world on a sustainable path to minimize the effects of climate change.

## The path forward

The impact of climate change has numerous knock-on effects beyond the immediate damage to property and infrastructure. Issues such as the global supply chain, healthcare, transition risk within an evolving regulatory environment, emergency management and climate displacement are all affected by the problems associated with climate change. It is therefore critical that the public and private sectors work together to find a more equitable way to limit future risk.

# How This Report Can Help Build and Promote Resilience

This report highlights 2021 global natural hazards and helps quantify and qualify how topics such as climate change, socioeconomics, and other emerging issues are driving new and emerging types of risk. The data, statistics, and analytics are meant to aid interests in sectors such as insurance, government, academia, real estate, emergency management, and banking.

## Identify Trends



- Explore global and regional catastrophe hazard and loss drivers
- Determine which areas are seeing higher annual or decadal losses
- Detect climate change influence on individual event behavior and impacts

## Promote Risk Mitigation



- Better establish risk mitigation efforts in the public and private sectors — with initial focus in the most vulnerable areas of the world — for enhanced disaster response and business continuity
- Modernize building codes and mandate enforcement
- Improve risk communication and explanation of uncertainty
- Academic collaborations in climate research will aid in the development of new tools and solutions to push forward new ideas to lower risk and promote future mitigation and adaptation practices

## Seize the opportunities



- Explore traditional and alternative insurance to protect people and assets
- Grow the volume of assets dedicated to sustainable investment to accelerate green initiatives that will meet net-zero emissions goals
- Develop strong ESG strategies to reduce risk and strengthen the organizations' access to capital, talent and investors.
- Build and enable an agile and resilient workforce able to respond to climate and other challenges.

## Build resilience through public-private collaborations to close the protection gap, protecting and enriching lives around the world.

### Key learning: Don't forget the non-physical risk

- Costs of climate change extend beyond physical damage
- Larger-scale events can amplify humanitarian aid needs
- Investment in infrastructure or other adaptation methods can reduce long-term costs
- Data and analytics will aid increasingly mandated climate-related regulatory disclosures

Along with this report, we welcome readers to access current and historical natural catastrophe data and event analysis at [catastropheinsight.aon.com](https://catastropheinsight.aon.com)



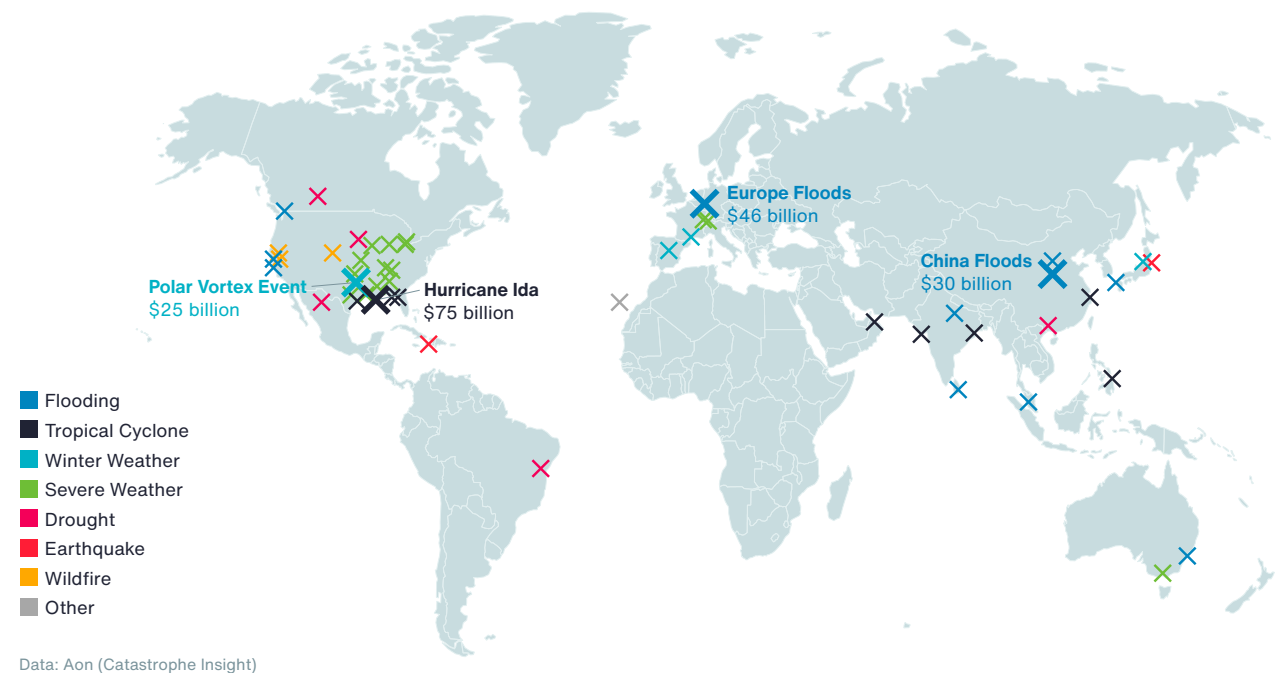
# 2021 Natural Disaster Events & Loss Trends

## Global Economic Losses: Seventh Costliest Year on Record

Exhibit 1: Top 10 Global Economic Loss Events

Date(s)	Event	Location	Deaths	Economic Loss (USD billion)	Insured Loss (USD billion)
08/27 - 09/02	Hurricane Ida	U.S., Caribbean	96	75.3	36.0
07/12 - 07/18	Flooding	Western & Central Europe	227	45.6	13.0
06/01 - 09/30	Seasonal Floods	China	545	30.0	2.1
02/12 - 02/20	Winter Weather (Freeze)	U.S., Mexico	235	25.0	15.0
01/01 - 12/31	Drought	United States	-	9.0	4.3
02/13 - 02/13	Fukushima Earthquake	Japan	1	8.0	2.5
04/05 - 04/08	Winter Weather	Western & Central Europe	-	5.6	0.4
12/10 - 12/12	Severe Weather	United States	93	5.1	4.0
06/17 - 06/25	Severe Weather	Western & Central Europe	7	4.9	3.5
01/01 - 12/31	Drought	Brazil	-	4.3	0.1
	All other events		~9,500	~130 billion	~49 billion
	<b>TOTALS</b>		<b>~10,500</b>	<b>343 billion</b>	<b>130 billion</b>

Exhibit 2: Significant 2021 Economic Loss Events above \$1.0 billion



Direct economic losses and physical damage resulting from natural disasters were estimated at \$343 billion in 2021. This marked the seventh-costliest year on record after adjusting actual incurred damage to today's dollars using the U.S. Consumer Price Index. While not a record-breaking year – far below the peak loss years seen in 2011 (\$615 billion) and 2017 (\$532 billion) – it was above the average (\$271 billion) and median (\$265 billion) of the 21<sup>st</sup> Century. When compared to the last decade (2011-2020), the economic losses were four percent higher than average and 15 percent higher than the median. Note that median analysis helps smooth any potential data bias from anomalous years.

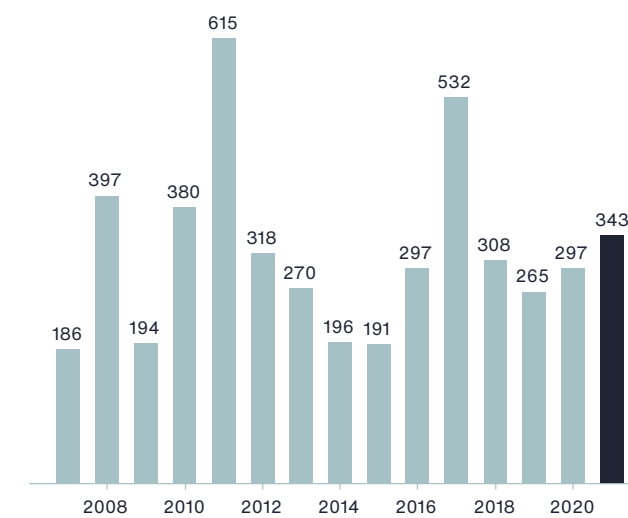
The economic cost solely resulting from weather and climate-related events, which is defined as events caused by atmospheric-driven phenomena, totaled \$329 billion. This was the third-highest loss on record after adjusting for inflation, only behind 2017 and 2005. The total was 45 percent higher than the 21<sup>st</sup> Century average and 52 percent higher than the median. Weather / climate-only analysis serves as a starting point when identifying any emerging trends related to the influence of climate change on natural hazard behavior. The most notable takeaway from the economic costs of natural disasters in 2021 was

the frequency of large-scale and highly impactful events. Four individual events topped the \$20 billion economic loss threshold: Hurricane Ida, July Flooding in Europe (Bernd), Summer Seasonal Flooding in China and the February Polar Vortex in North America (U.S. / Mexico). This was just the second time on record in which four \$20+ billion events had been registered in a calendar year, but the first time that four events were weather / climate related. In 2004, there were two hurricanes (Charley and Ivan) and two earthquakes (October 23 Japan Earthquake and the December 26 Indian Ocean Earthquake and Tsunami).

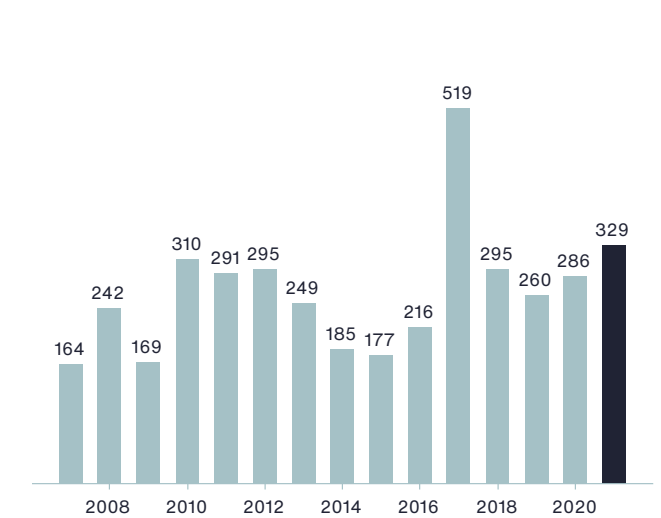
The reasoning behind the increased frequency of large-scale weather events in 2021 is complex. The influence of climate change is notably evident in the case of tropical cyclone and extreme rainfall / temperature behavior, which aligns with scientific research that storms will become more intense, individual events will bring heavier rainfall amounts, and temperatures will reach new heights (lows). How that translates to financial loss is slightly more nuanced since the most vulnerable and urbanized areas incurred the most damage. As climate change influenced hazard behavior grows more volatile and severe, the expansion of population footprints will additionally grow the risk of costlier disasters.

Exhibit 3: Global Economic Losses

All natural disasters (2021 USD billion)



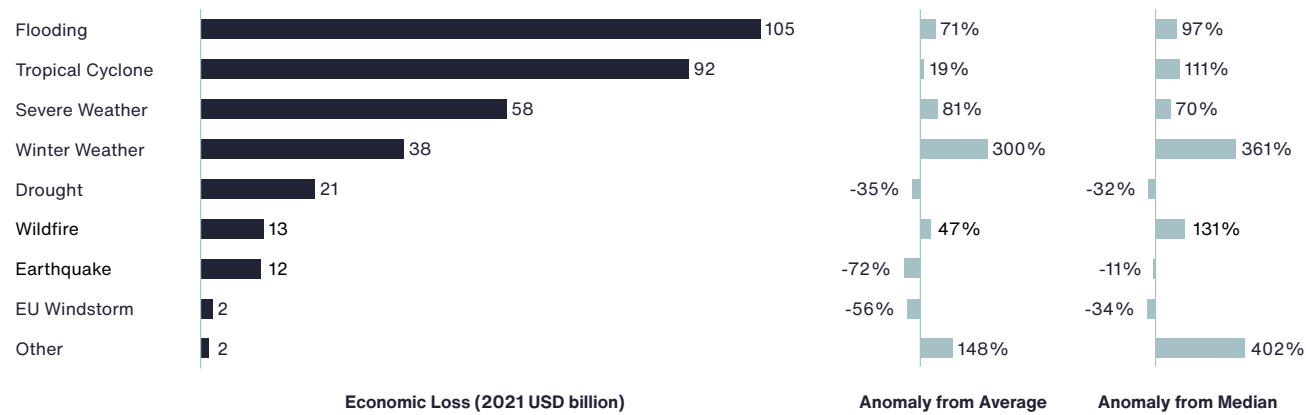
Weather-related disasters (2021 USD billion)



Data: Aon (Catastrophe Insight)

At \$105 billion, flooding was the costliest peril of 2021 on an economic loss basis. This was largely driven by the flooding events in Europe and China. These two events alone accounted for more than \$75 billion in economic losses. The Tropical Cyclone peril came second, despite Hurricane Ida incurring at least \$75 billion in damage and becoming the sixth costliest global tropical cyclone ever recorded. Other perils with above-median losses included Severe Weather, Winter Weather, Wildfire and Other, the latter driven by notable volcanic eruptions.

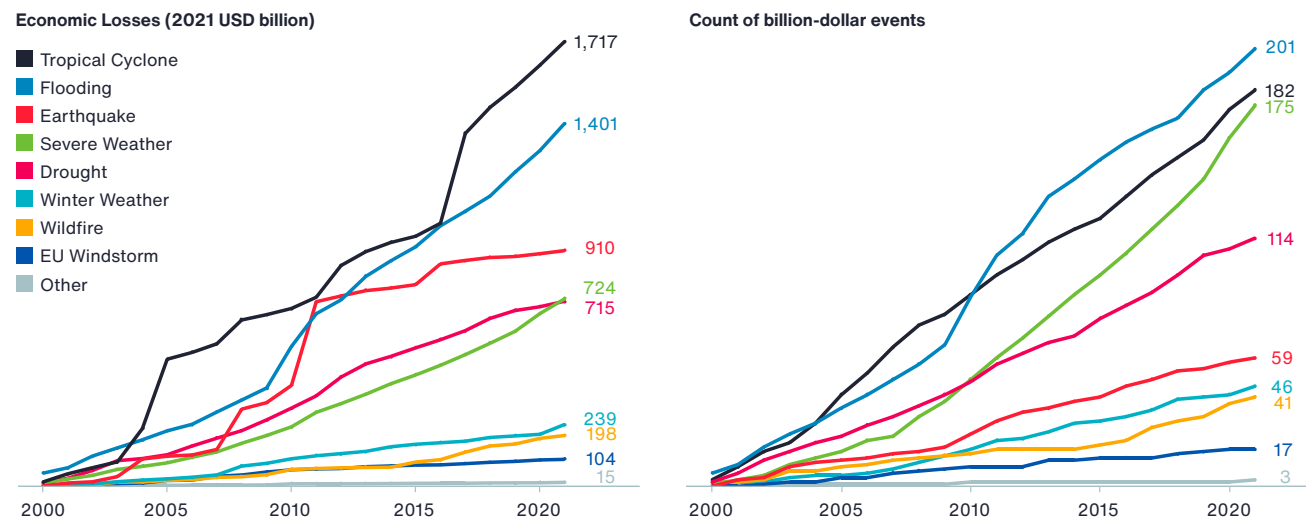
**Exhibit 4: Global Economic Losses by Peril**



Data: Aon (Catastrophe Insight)

When viewing economic losses on an aggregate basis since the start of the 21<sup>st</sup> Century, Tropical Cyclone is the costliest global peril. Like the Earthquake peril, it was largely driven by extreme loss years and single catastrophic events, as opposed to Severe Weather losses, which are driven by an increasing frequency of events. It is worth noting that 41 percent of tropical cyclone losses in this century occurred within the last five years (2017-2021).

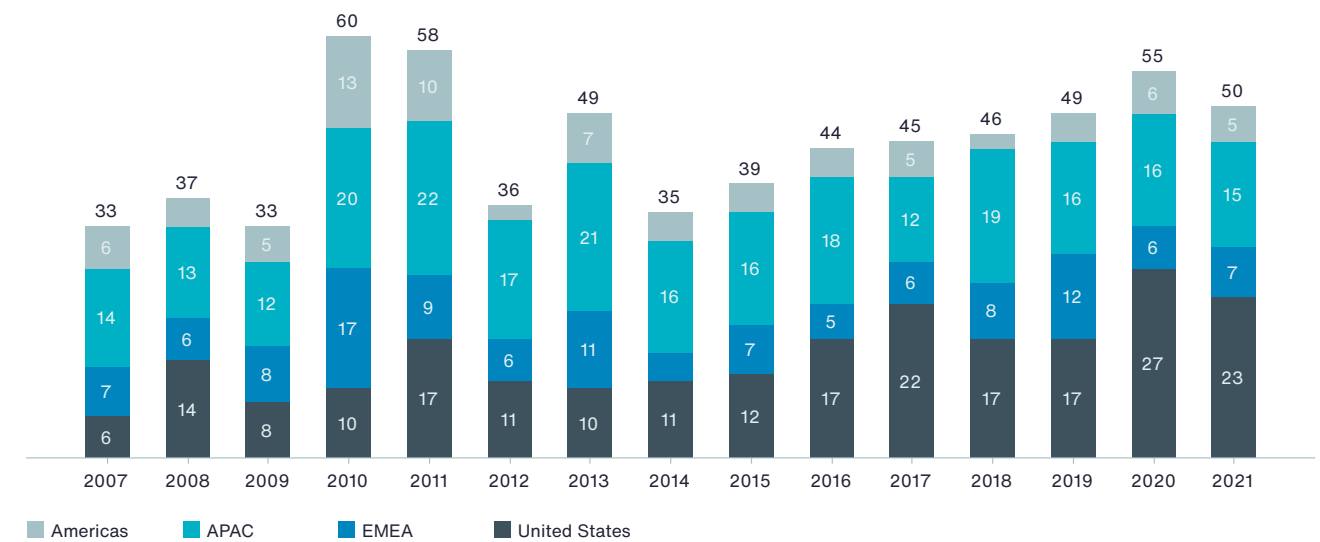
**Exhibit 5: Cumulative Economic Losses by Peril**



Data: Aon (Catastrophe Insight)

There were 50 individual billion-dollar natural disaster events in 2021, which was well above the average of 38 events dating to 2000. All but three were weather or climate-related events. The 50 events were lower than the 55 in 2020, which was the third-highest year on record. Please note that U.S. wildfires are treated as individual events; there were three such events in 2021. The U.S. had a total of 23 billion-dollar events, the second year in a row with at least 20 such occurrences and only the third time on record (2017, 2020, 2021). For some years in the graphic below, tropical cyclone events in the Atlantic Basin resulted in billion-dollar losses in the U.S. and elsewhere in the Americas. Such occurrences are only tabulated once.

**Exhibit 6: Global Billion-Dollar Economic Loss Events**



Data: Aon (Catastrophe Insight)

**Exhibit 7: 2021 Economic Losses Compared to Historical Benchmarks (2021 USD billion)**



Data: Aon (Catastrophe Insight)

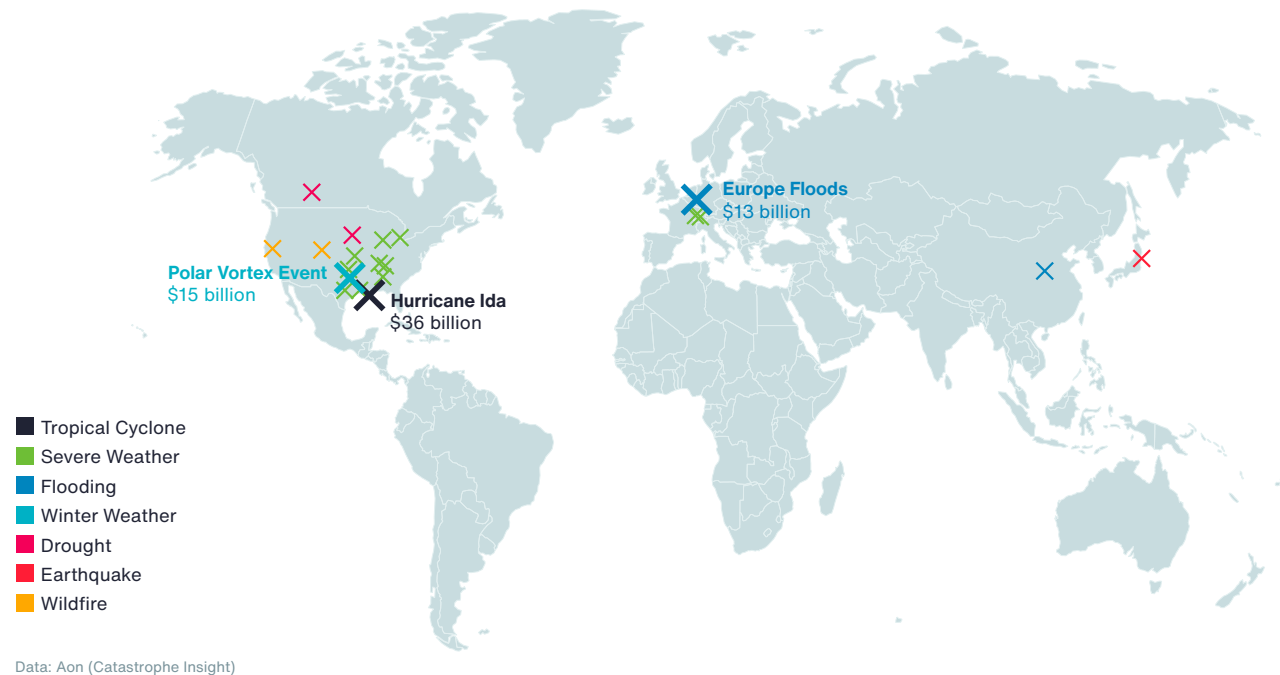


## Global Insured Losses Surpass \$100B for the Fourth Time in Five Years

**Exhibit 8: Top 10 Global Insured Loss Events**

Date(s)	Event	Location	Deaths	Economic Loss (USD billion)	Insured Loss (USD billion)
08/27 – 09/02	Hurricane Ida	U.S., Caribbean	96	75.3	36.0
02/12 – 02/20	Winter Weather (Freeze)	U.S., Mexico	235	25.0	15.0
07/12 – 07/18	Flooding	Western & Central Europe	227	45.6	13.0
01/01 – 12/31	Drought	United States	-	9.0	4.3
12/10 – 12/12	Severe Weather	United States	93	5.1	4.0
06/17 – 06/25	Severe Weather	Western & Central Europe	7	4.9	3.5
04/27 – 05/02	Severe Weather	United States	-	3.4	2.6
02/13 – 02/13	Fukushima Earthquake	Japan	1	8.0	2.5
06/01 – 09/30	Seasonal Floods	China	545	30.0	2.1
12/30-12/31	Marshall Fire	United States	-	3.3	2.0
	All other events		~9,500	133 billion	45 billion
	<b>TOTALS</b>		<b>~10,500</b>	<b>343 billion</b>	<b>130 billion</b>

**Exhibit 9: Significant 2021 Insured Loss Events above \$1.0 billion**



Insured losses from natural disasters reached \$130 billion in 2021. This total was well above the 21<sup>st</sup> Century average (\$74 billion) and median (\$66 billion) and 18 percent higher than in 2020. It was also the fourth-costliest year on record for public and private insurance entities; only behind 2017, 2011, and 2005.

Roughly 38 percent of global economic losses were covered by insurance, which translates to a protection gap of 62 percent, the second lowest on record behind 2005 (60 percent). The global protection gap is the difference between total economic losses and what is covered by insurers. This remains a critical reference point for the insurance industry, financial markets and governments as it highlights the vulnerability of communities and the opportunity for new solutions.

Weather- and climate-related disasters accounted for \$127 billion, or 98 percent of natural disaster losses. It was another largely manageable year for the industry with the earthquake peril.

Global insured losses have steadily increased in recent decades. Much of this growth can be tied to continued improvement in expanding the number of people with active insurance policies, especially in parts of the world where insurance availability has only recently become more widely available. However,

the influence of more substantial catastrophe events – especially by perils not previously identified as expected to have a major impact on an insurance portfolio – has resulted in more claims being filed and processed.

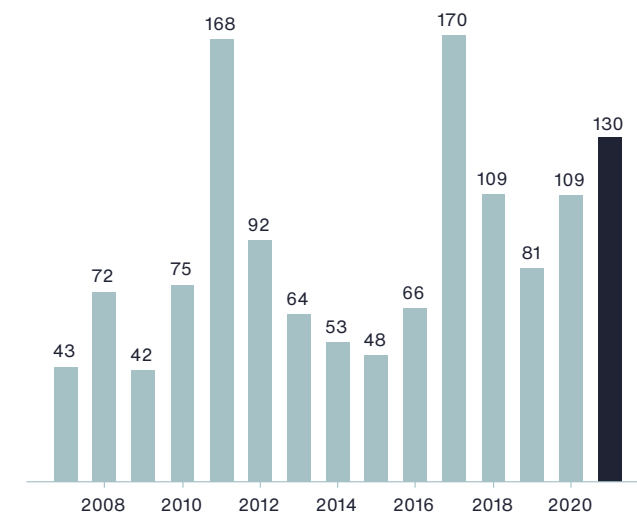
“Secondary” perils, including severe convective storms, wildfires, flooding, winter weather or drought, are more frequently driving annual loss years. Years dominated by “primary” perils (tropical cyclone and earthquake) are occurring with less regularity, though it does not minimize the potential risk. Such a trend suggests that the terms “primary” and “secondary” are increasingly out of step since many of the largest individual “secondary” peril events in the last decade have approached or exceeded \$10 billion for insurers.

The United States, which boasts the most robust insurance industry in the world, accounted for 71 percent of the global insured losses. It was the second year in a row that it topped 70 percent. The combined U.S. insured loss in 2020 and 2021 was \$176 billion; the highest two-year total on record, surpassing 2004/2005 (\$174 billion).

To read more regarding available re/insurance industry capital and the health of the overall market, please refer to [Aon’s Reinsurance Market Outlook](#).

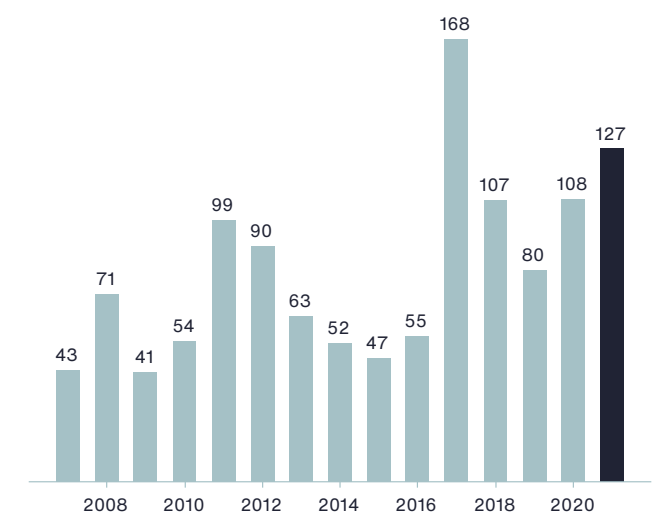
**Exhibit 10: Global Insured Losses**

All natural disasters (2021 USD billion)



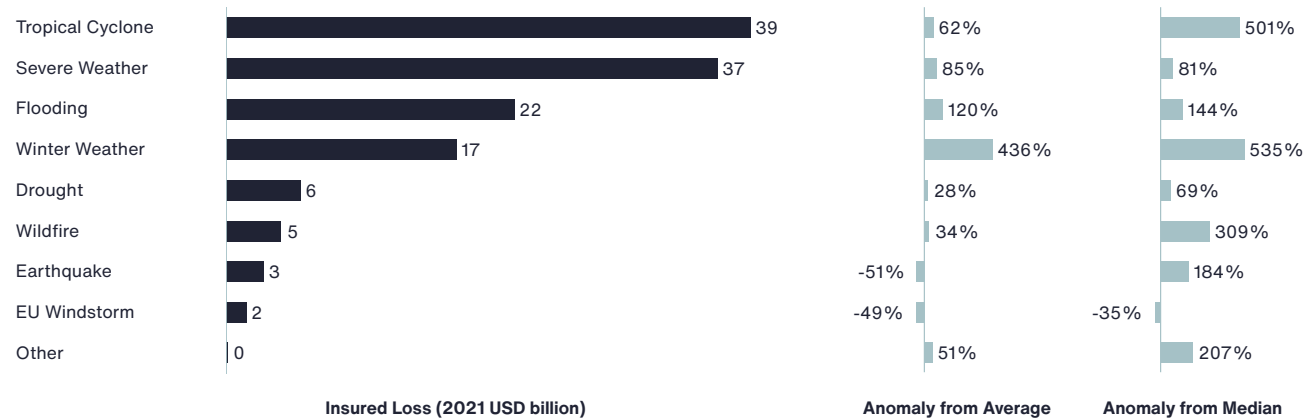
Data: Aon (Catastrophe Insight)

Weather-related disasters (2021 USD billion)



The costliest peril for the insurance industry in 2021 was Tropical Cyclone at \$39 billion. At least \$36 billion of that total came from Hurricane Ida alone. Another very active year for severe weather (severe convective storms) saw insured losses top \$30 billion. Winter Weather was a substantial 436 percent higher than average following a historic U.S. event in February. The only peril that was well below its 21<sup>st</sup>-Century median was European Windstorm.

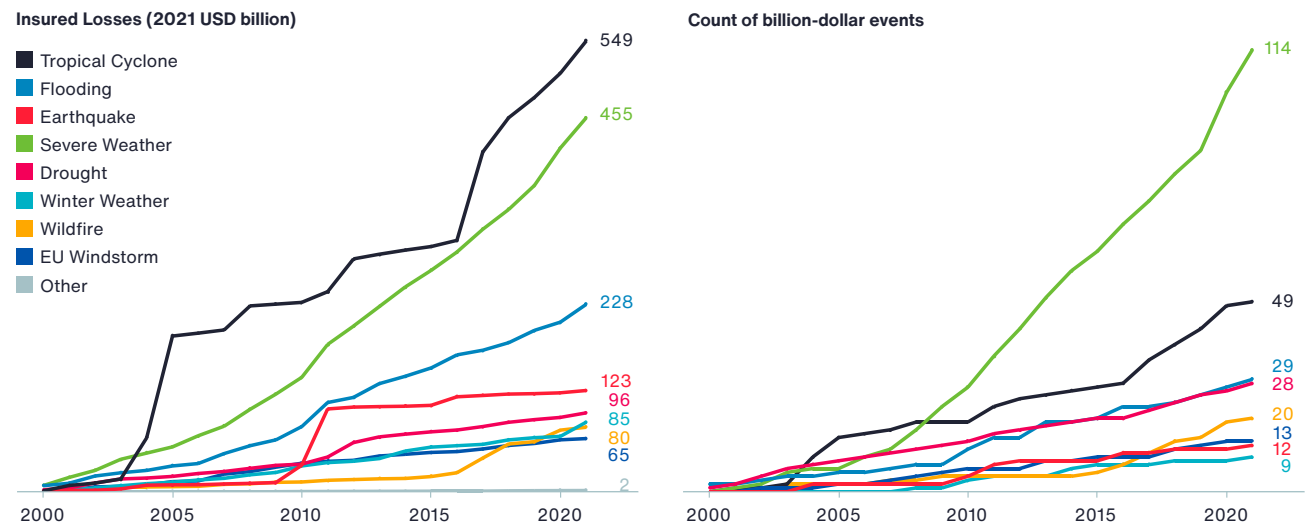
**Exhibit 11: Global Insured Losses by Peril**



Data: Aon (Catastrophe Insight)

Aggregated costs for insurers have been largely dominated by the Tropical Cyclone and Severe Weather perils this century. The two perils combined for more than \$1 trillion, or 60 percent of the total cumulative industry losses, of which roughly 74 percent was incurred in the United States. The Severe Convective Storm peril has also increasingly separated itself as accounting for the highest number of billion-dollar events.

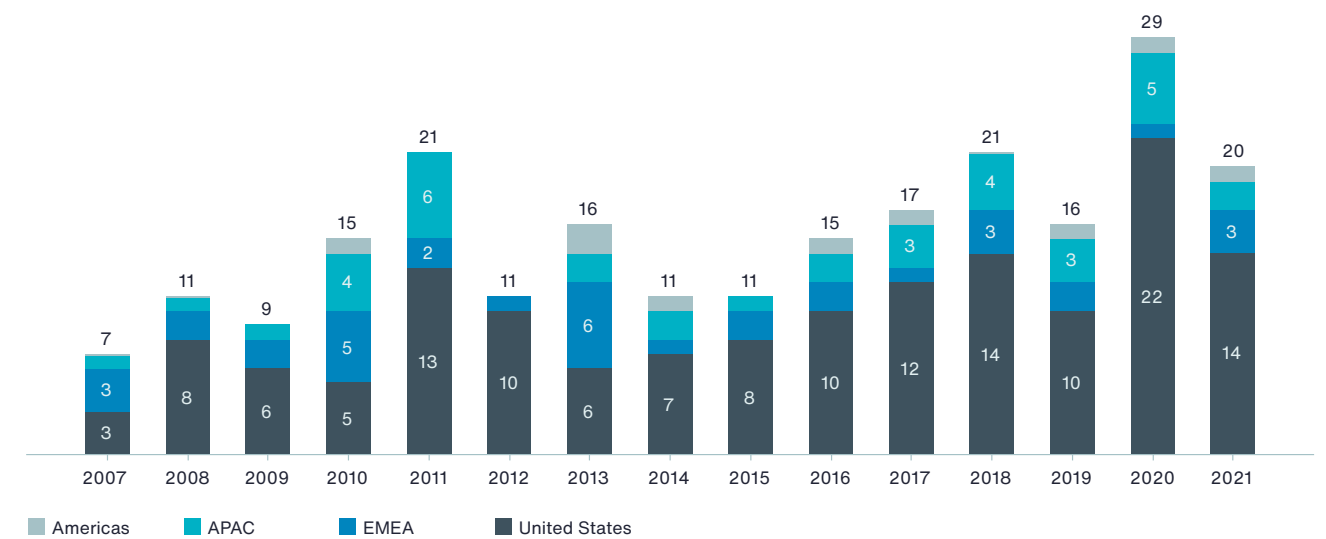
**Exhibit 12: Cumulative Insured Losses by Peril**



Data: Aon (Catastrophe Insight)

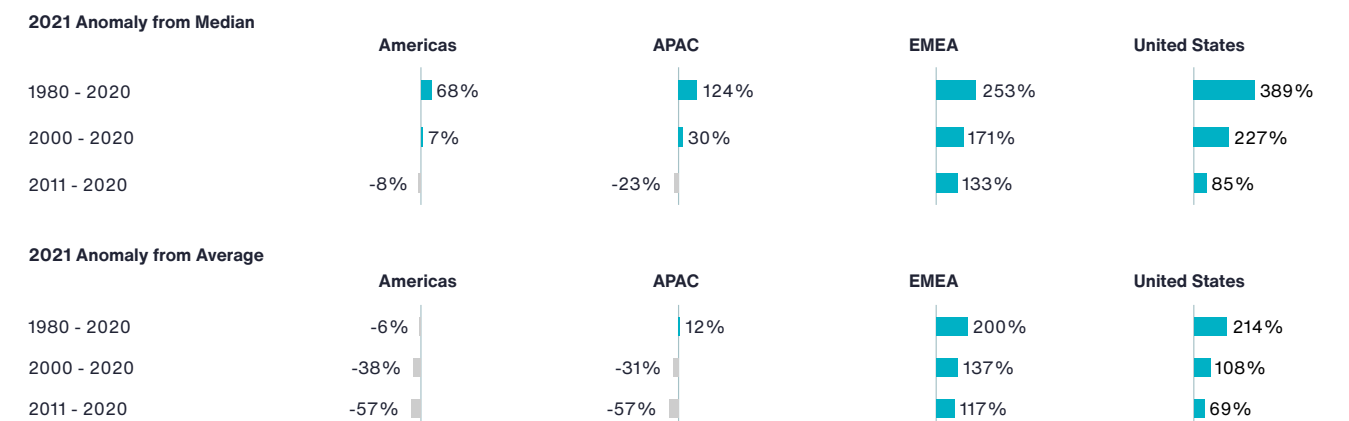
There were at least 20 individual billion-dollar events for the insurance industry in 2021, well above the 21<sup>st</sup> Century average of 12 and the fourth-highest total on record behind 2020, 2018, and 2011. The U.S. accounted for 14 of the 20 events. Of the 14 U.S. events, nine were related to severe convective storms. Please note that U.S. wildfires are treated as individual events. In the case of a tropical cyclone event resulting in billion-dollar payouts in both the United States and the rest of the Americas, the event is bucketed in the region with the higher insurance loss in the graphic below.

**Exhibit 13: Global Billion-Dollar Insured Loss Events**



Data: Aon (Catastrophe Insight)

**Exhibit 14: 2021 Insured Losses Compared to Historical Benchmarks (2021 USD billion)**



Data: Aon (Catastrophe Insight)



## Better Forecasting and Preparation Leads to Continued Decline in Fatalities

**Exhibit 15: Top 10 Human Fatality Events**

Date(s)	Event	Location	Deaths	Economic Loss (USD billion)
08/14	Earthquake	Haiti	2,248	1.6
06/01 – 10/31	Seasonal Floods	India	1,282	3.1
06/26 – 06/30	Heatwave	Western North America	1,029	-
06/01 – 09/30	Seasonal Floods	China	545	30.0
12/16 – 12/18	Typhoon Rai	Philippines, Vietnam	410	1.0
04/03 – 04/12	Cyclone Seroja	Indonesia, Timor-Leste, Australia	276	0.9
02/12 – 02/20	Polar Vortex Event	United States	235	25.0
07/12 – 07/18	Flooding	Western & Central Europe	227	45.6
10/25 – 11/30	Flooding	India, Sri Lanka	217	2.5
02/07 – 02/08	Flooding	India	205	0.2
	All other events		~4,000	~231 billion
	<b>TOTALS</b>		<b>~10,500</b>	<b>343 billion</b>

Approximately 10,500 people lost their lives due to global natural catastrophe events in 2021. More than 80 percent of the fatalities occurred in Asia-Pacific (48 percent) and the Americas (34 percent) as a significant earthquake in Haiti (2,248 deaths), seasonal flooding in India (1,282 deaths) and a prolonged heatwave in North America (1,029 deaths) all topped the 1,000 mark. Flooding throughout Asia was the primary driver of disaster-related fatalities during the year. Super Typhoon Rai marked the deadliest tropic cyclone of the year. Its landfall in late

December left 409 people dead in the Philippines and another casualty in Vietnam.

The number of annual human casualties has shown a notable decline in recent decades. The improvements in forecasting, evacuation planning / strategies, increased public awareness and better building practices have all played a key role. Asia, Africa, and South America show the greatest improvements with reduced fatalities. Please note that confirmed fatalities and missing people presumed dead are included in the above totals.

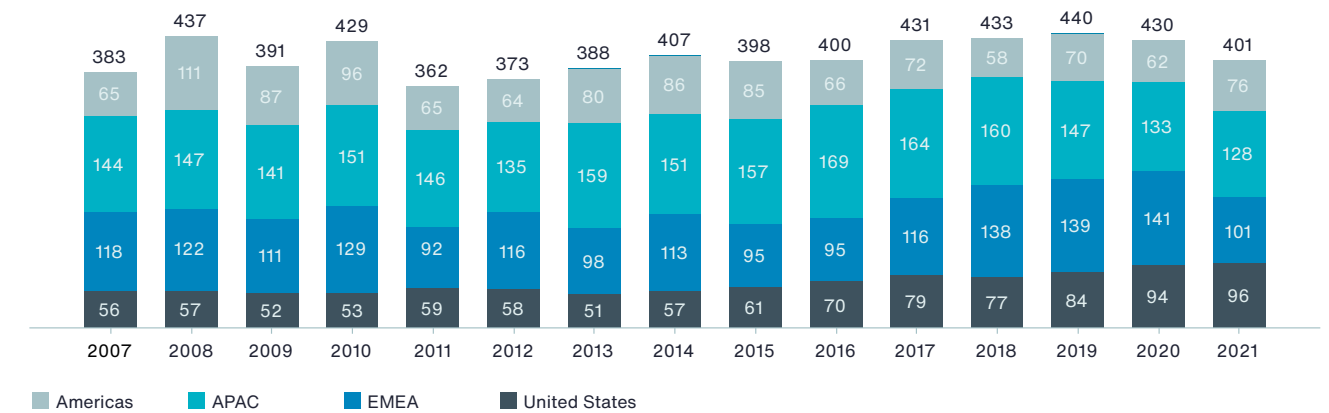
## Natural Disasters Defined: Stable Number of Events as Costs Rise

An event must meet at least one of the following criteria to be classified as a natural disaster in the Aon's Catastrophe Insight Database:

- Economic Loss: \$50 million
- Insured Loss: \$25 million
- Fatalities: 10
- Injured: 50
- Homes and Structures Damaged or Filed Claims: 2,000

Based on the noted criteria above, there were at least 401 individual natural disasters in 2021, which was near both the average (393) and median (396) since 2000. Please note that further 2021 events might be added later due to further research and data updates. As typically anticipated given the highest frequency of SCS, flood and tropical cyclones, the highest number of disaster events occurred during the second (101) and third (134) quarters. The United States recorded 96 disaster events, as per this report's criteria, which tied with the record set in 2020.

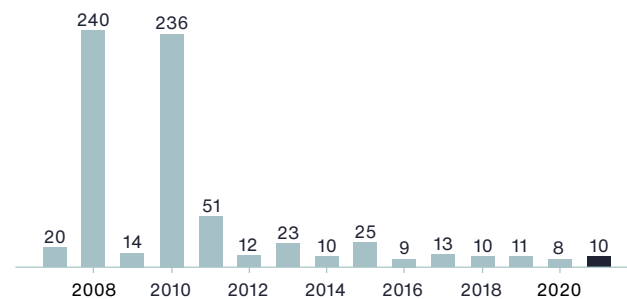
**Exhibit 17: Total Natural Disaster Events**



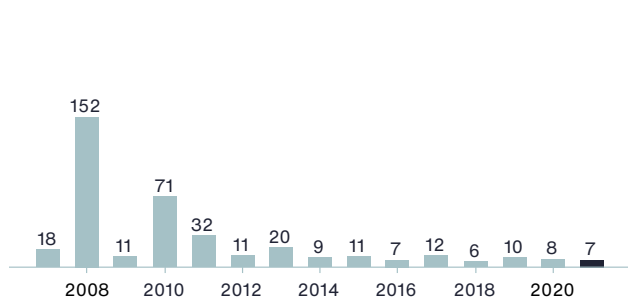
Data: Aon (Catastrophe Insight)

**Exhibit 16: Global Human Fatalities (thousands)**

All natural disasters



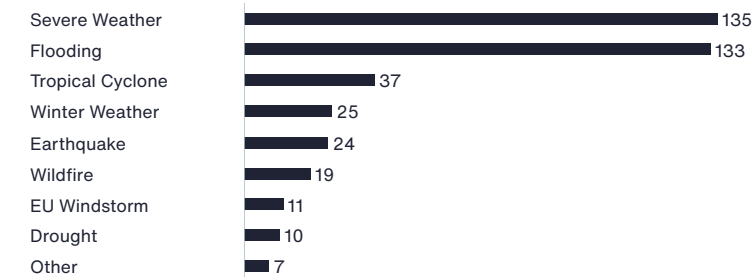
Weather-related disasters



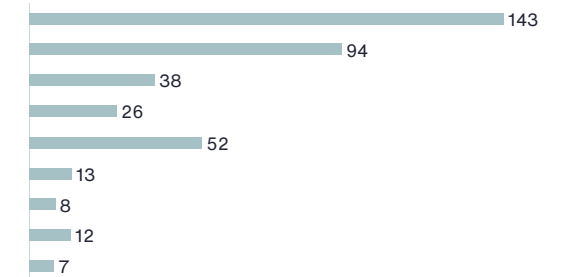
Data: Aon (Catastrophe Insight)

**Exhibit 18: Total Natural Disaster Events by Peril**

2021 Events



Average (2000-2020)



Data: Aon (Catastrophe Insight)

## Behind the Scenes of Weather and Climate Forecasting

**Greg Carbin** is Branch Chief of Forecast Operations at NOAA's Weather Prediction Center. For more than 50 years, the National Oceanic and Atmospheric Administration (NOAA) has leveraged diverse authorities for climate, weather, fisheries, coasts, and the ocean to create huge stores of environmental data and observations.

On the front line of daily weather forecasting, National Oceanic and Atmospheric Administration's (NOAA) National Weather Service Forecast Offices, and National Centers for Environmental Prediction, evaluate the latest observational and numerical data to disseminate outlooks, watches and warnings

for impending weather hazards. From extreme rainfall and tornadoes, to high winds and extreme temperatures, meteorologists remain alert to these hazards 7-days a week, 24-hours a day, and 365 days a year. This information is critical to resilience-building, national security, economic vitality, and the protection of life and property.

### Challenges in Weather Forecasting

One of the greatest challenges faced by NOAA is the need to improve precipitation forecasts across timescales. As we shift from 'day-to-day' weather to longer-term climate patterns, there is a critical need for improved projections of how the climate will change on more granular, regional scales and over the next several decades. More accurate climate projections will work to better inform regional and local adaptation and resiliency planning for infrastructure, natural resource management, food production, finance, national security and other sectors.

### Looking Ahead

In 2022, NOAA is focused on improving fire weather forecasting as wildfires are influenced by the weather and climate, and equally the weather and climate are influenced by wildfires. NOAA will work to improve short-term forecasts to better predict fire behavior and the longer-term modeling of interactions between climate variability, climate change, and the likelihood of hazardous wildfire conditions.

The ultimate goal? To provide science and service in the form of actionable data and information needed to help solve the climate crisis.





# Seasons of Change

**How “normal” continues to evolve with climatological averages, and the real-world implications of these climate change-influenced shifts on various business practice topics**

## Climatological Normals

An important method of identifying changes in global, regional, or local weather / climate patterns are found in what are known as “climatological normals”. Put simply, “normals” are an average that is computed based on 30 years of daily weather readings. They serve as a point of reference to the climatology of a specific location and are used as a benchmark against present day weather. The World Meteorological Organization (WMO) defines the climatological standard normal as the most recent 30-year period that is updated with the conclusion of every decade.

The most recent WMO 30-year baseline – 1991 to 2020 – was enacted in 2021. Governmental agencies are requested by the WMO to implement and use the current baseline to affirm consistent points of comparison around the world. Note that for modern historical reference periods, the WMO retains the 1961-1990 period as a standard reference for modern

era climate change assessments. The one challenge using the 1961-1990 baseline for climate change is that it does not account for changes to temperature and precipitation since the start of the Industrial Revolution (1850 to 1900). Using the 1850-1900 baseline provides a more robust view of how the global climate has accelerated rates of change since carbon dioxide emissions from human activity have dramatically increased.

Looking at changes between the two most recent baselines (1981-2010 and 1991-2020) provides useful guidance of how quickly the climate is evolving. It helps identify areas showing climate change effects at a faster or slower pace. In many locations, the rates of change are notably increasing with each passing decade. This highlights the urgency of passing meaningful legislation and developing investment strategic planning to slow down climate change and improve mitigation / adaptation practices.

Decadal changes to climate normals vary by geographical region, season, and timeframe. Though as already mentioned, some of the more recent trends in normals indicate an accelerated rate of change in the warming of average temperatures. [A NOAA study of the global climate in 2020](#) found that combined land and ocean temperatures have increased at an average rate of 0.08°C (0.13°F) per decade since 1880. However, this rate of increase has more than doubled to 0.18°C (0.32°F) since 1981.

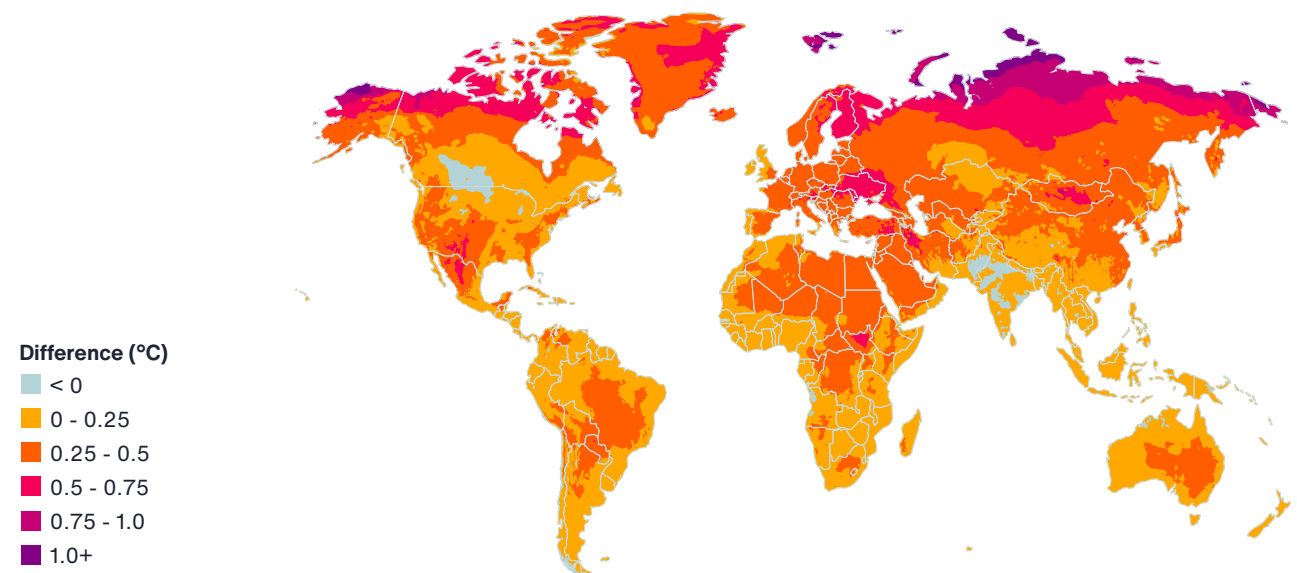
While extreme heat continues to set new maximum temperature records in recent years, it may come as a surprise to realize that the biggest driver in global warming has resulted from a significant shift in minimum temperatures. This means temperatures are not cooling as much overnight as they did in the past. This is particularly concerning during the warm season, as it inhibits the ability of people and “stuff” to cool down overnight: putting vulnerable populations at a greater risk for heat-related stress and illness.

The changes in precipitation normals are less obvious and require more discussion. Pattern adjustments

in how the jet stream behaves can and has led to instances of more extreme precipitation events. However, this has also led to more rapid shifts from extreme rain / flooding to extreme drought. There are increasing examples of areas recording excessive precipitation in short duration, but that rainfall accounts for most of the monthly or annual total. This pattern often means that extreme drought conditions are quick to follow. Regardless, more frequent extreme rain events are occurring, and this is linked to a warmer and moister atmosphere. As a reminder, precipitation trends vary geographically and seasonally.

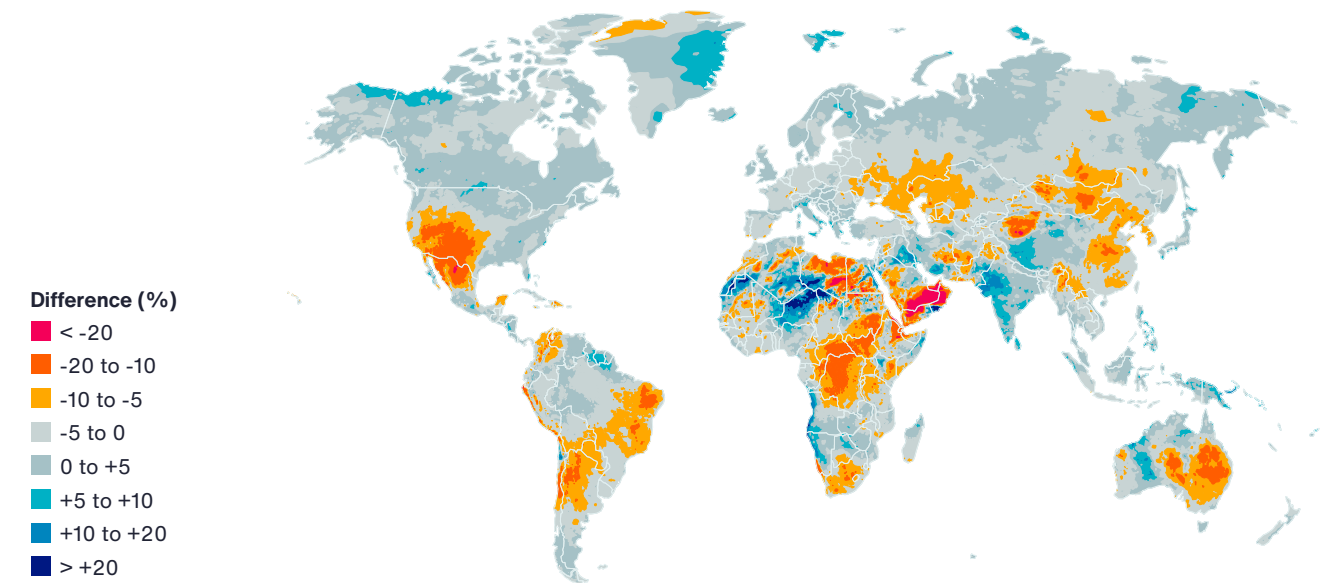
Please note that relatively small absolute changes appear as large percentage changes in regions with dry baseline conditions. The Sahara region and the Arabian Peninsula are two areas with the highest observed relative change between climate normals. Exhibits 19 and 20 both show climate change impacts that are in relatively good agreement with the long-term climate projections released in the IPCC’s Sixth Assessment Report (AR6).

**Exhibit 19: Difference between the 1991-2020 and 1981-2010 normals of average annual temperature**



Data: ERA5 / Copernicus / ECMWF. Graphic: Aon (Catastrophe Insight)

**Exhibit 20: Difference between the 1991-2020 and 1981-2010 normals of average annual precipitation**



Data: ERA5 / Copernicus / ECMWF. Graphic: Aon (Catastrophe Insight)

# Real-Time Impact of Climate Change





## Physical Risk: Building for an Evolving Climate

The behavioral changes seen in individual weather events become more evident in individual events (acute) and longer-term trends (chronic). The subsequent impacts to property in both developed and emerging countries is a point of focus across academia, governmental bodies, international aid organizations and the private sector. It is well chronicled within peer reviewed science that these more intense events are directly tied to greater physical risk to such assets as residential and commercial properties or infrastructure. However, when discussing physical risk within the context of climate change, it is essential to not overlook non-weather natural disaster perils (earthquake, tsunami, volcano, etc.) that also require robust planning and focus.

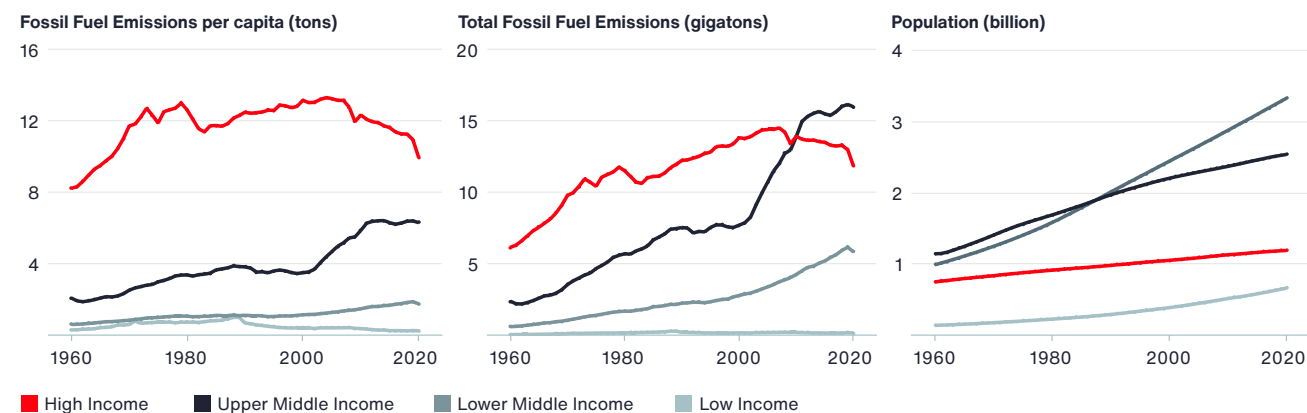
How we adapt to these growing physical risks is essential to limiting damage potential and protecting assets in the future. Even in the most developed parts of the world there remains a critical need to retrofit properties that reside in known high-risk locations. Wealthier nations provide significant opportunities to create, enforce and mandate stringent building code requirements in addition to further growing insurance take-up where gaps exist. While most focus tends to be on world's wealthiest nations, the greatest

challenge is addressing vulnerabilities in regions with the least financial means. Such locations – including parts of Africa, Latin America, Asia, and the South Pacific Islands – account for the lowest insurance take-up and highest dependencies on international aid in the world while among the highest at-risk for future climate change effects.

The need for collaboration between public and private entities has never been greater than today. To limit physical risk in both developed and emerging markets, a strategic investment is needed in identifying best practice and cost-efficient ways to improve how and where we build in the face of growing climate-related impacts. The insurance industry has already taken initial steps by investing in the testing of material building performance. Some examples of companies conducting this research include the Insurance Institute for Home and Business Safety (IBHS) in the United States or the Institute for Catastrophic Loss Reduction (ICLR) in Canada.

**Bottom Line:** Most of the world's homes, businesses, and infrastructure were built to meet the needs for a 20<sup>th</sup> Century climate. As the effects of climate change accelerate, the need to prepare for the more intense events of tomorrow becomes more urgent with each passing day.

**Exhibit 21: Fossil fuel emissions and population by income group**



Data: World Bank / Global Carbon Project / Aon. Graphic: Aon (Catastrophe Insight)

## Beyond Physical: Recognizing Transition Risk and Regulatory Requirements

The effects of climate change are much bigger than a singular tunnel-visioned view on physical assets. The financial sector has seen some of the fastest growing focus on climate change in recent years driven by an evolving global regulatory environment. As the financial markets are increasingly required to conduct various stress tests to ensure solvency given the expectation of accelerating climate change-related losses, the goal is to achieve stability in a highly volatile fiscal environment – especially in the face of the ongoing challenges posed by COVID-19. These climate disclosures are an important step in an organization's journey in transitioning towards a greener investment portfolio.

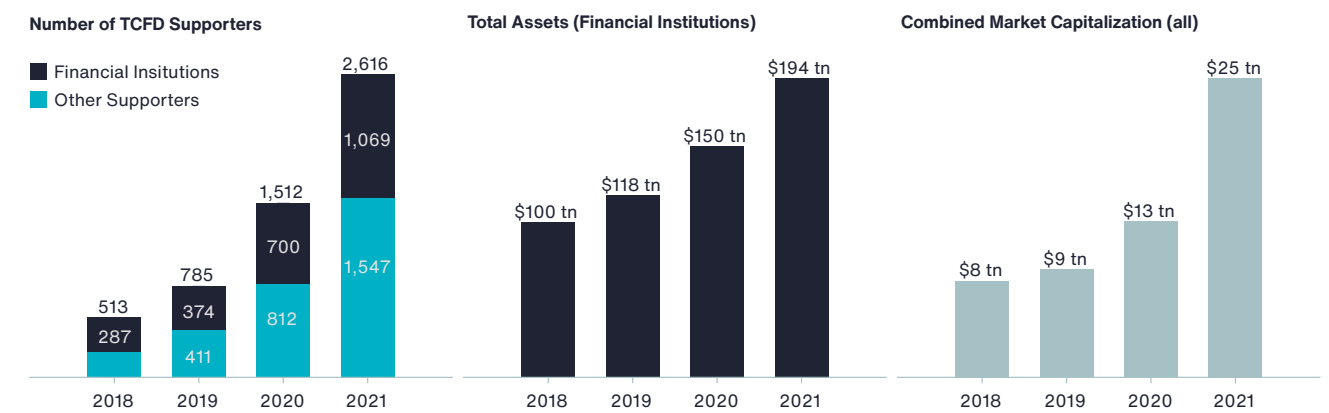
Transition risk is a growing opportunity (or concern) for companies as they account for the evolving regulatory environment. A seismic change during an investment portfolio transition can lead to notable shifts in the value of assets and/or lead to higher day-to-day operational costs. As companies develop their own framework to account for these regulatory requirements or prepare for rating agencies beginning to “score” how well an institution is handling climate or environmental, social, and governance (ESG) topics, there are groups dedicated to developing a forward-looking map.

The most prominent of these organizations is the [Task Force on Climate-Related Disclosures \(TCFD\)](#). The group helps companies gain a clearer sense of what shifts in regulatory requirements, technological advances, and consumer behavior patterns are likely to come as financial markets accelerate the need to quantify the costs of a more climate-focused economy. TCFD has seen a significant increase in the number of organizations adapting to their framework. In 2018, there were 513 “supporters” of the group (287 were financial institutions). By 2021, that number had grown 410 percent to 2,616, including 1,069 financial institutions. These companies totaled a combined market capitalization of more than \$25 trillion and asset representation of \$194 trillion. That represented a 99 percent increase from 2020 alone.

The geographic distribution of TCFD “supporters” is truly global with representation from every continent (excluding Antarctica). This explosive growth in acceptance of the TCFD framework highlights the momentum felt within the financial markets as companies seek to be forward-thinking and not suffer from a reputational hit due to climate inaction.

**Bottom Line:** Regulatory requirements mandating climate-related disclosures are growing. European markets have long been dominant for such filings, but the United States and Asia are increasingly bringing such mandates to the table. The trend is here to stay.

**Exhibit 22: Continued Growth in Support for the TCFD**



Data: Task Force on Climate-related Financial Disclosures: 2021 Status Report. Graphic: Aon (Catastrophe Insight)

## Climate Impact on Health

The effects of climate change pose a significant threat to personal health, health care and subsequent worker productivity than can have downstream effects on global supply chains. While these impacts may seem less obvious than the physical damage seen in the aftermath of an individual disaster event, the effects are growing and are often felt most by populations that face the greatest vulnerabilities. [Peer reviewed academic research](#) shows that the people whose health is being harmed the most (and first) are those who [contribute the least](#) to carbon emissions and subsequent atmospheric and oceanic warming. This means people in low-income countries – especially in Africa, Latin America, Asia, and the Middle East - are more likely to be affected in the future.

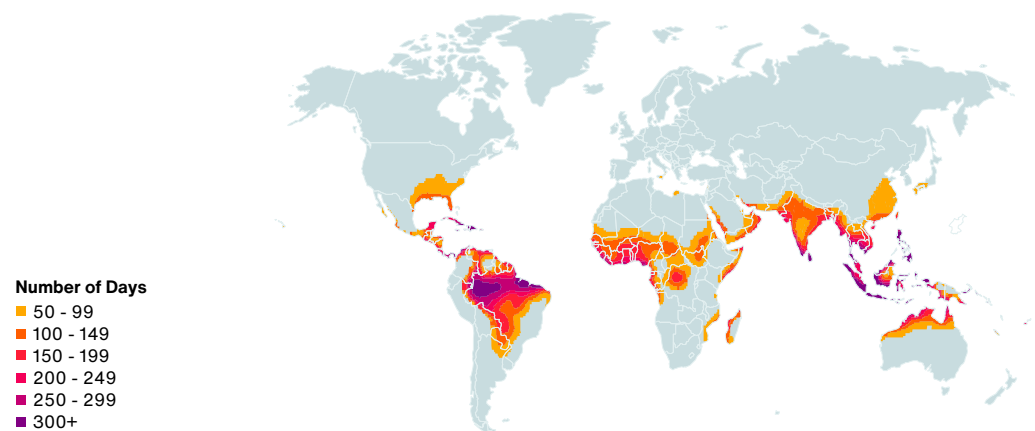
Quantifying the direct consequences of climate change on human health is challenging, and there are new signs of how the broader implications of climate change can be attributed to many diseases, even death. The disruption of food systems, the spread of food, vector, and water-borne diseases, the degradation of social conditions, effects on mental health, and influence from air pollution are all risks with legitimate health repercussions. A 2021 [World Health Organization analysis](#) cited that 12.7 percent of the world’s population (940 million people) spends at least 10 percent of their household budget on healthcare. These costs are projected to grow.

A clearer implication to health risk surrounds the direct and indirect impacts from individual events. Examples include heat stress (cardiovascular stress to humans with prolonged outdoor exposure) and wildfires (smoke can notably decrease air quality thousands of miles (kilometers) away from the fire location). The impact to mental health following a large-scale disaster is the most underappreciated and long-lasting concern.

Organizations can address these concerns by instituting leader and manager training on ways to support employees in the wake of such large-scale disasters. Providing resources to help employees and their families who are suffering from stress, anxiety and depression - such as an Employee Assistance Plan - can help address a variety of challenges exacerbated by climate change.

**Bottom Line:** The most vulnerable populations from climate change are typically in areas with the least means to prepare or protect against the growing effects posed to human health. The good news is that fatalities from individual weather disasters has declined in recent years. But there remains a moral obligation to ensure a more equitable way of investing and limiting risk by the wealthiest and highest emitting nations of the world.

Exhibit 23: Projected Number of days per year with deadly climatic conditions in 2091-2100 under RCP4.5 Scenario



Data: Mora et al. Global risk of deadly heat. Nature Climate Change 7, 501-507 (2017); ESRI's Applications Prototype Lab. Graphic: Aon (Catastrophe Insight)

## Supply Chain: Managing Connected Extremes

An emerging topic in the discussion of climate change is the concept of compounded or connected extremes. Much has been written on the concerns around multiple large-scale disasters happening concurrently that puts major strain on governmental agencies, emergency managers, and the insurance industry in responding to these events in real-time. What has become more prevalent are the secondary or tertiary effects seen across the commercial sector.

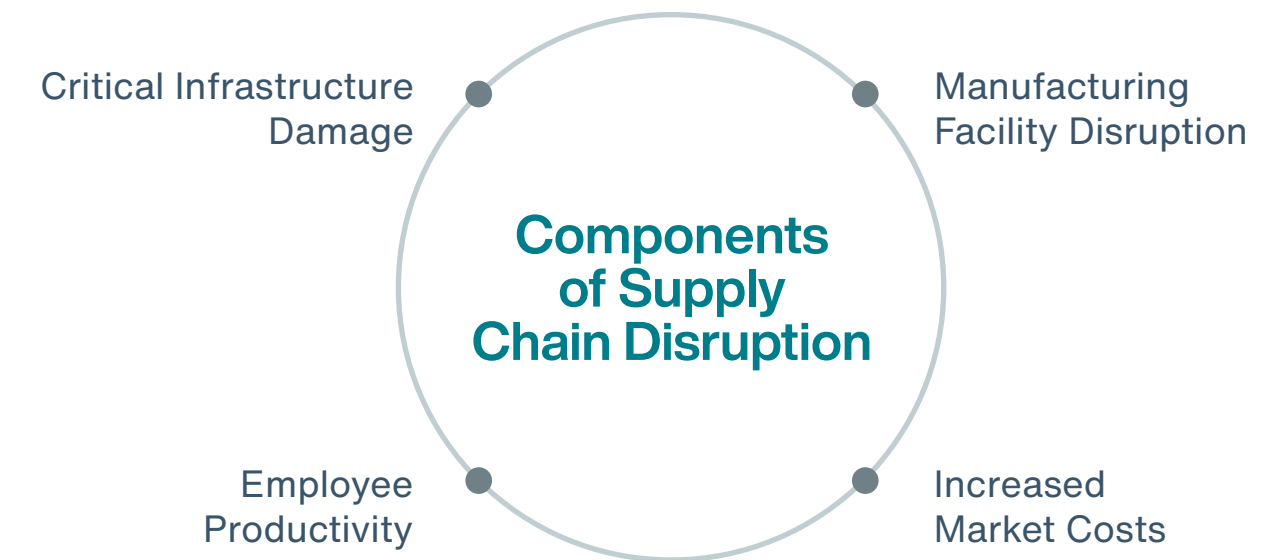
The most obvious effects to the commercial sector due to climate change come via the global supply chain. Many of these effects have already been observed and are likely to occur with increased frequency if strategic planning is not done to limit disruptions in the future. There are multiple components to how supply chain can be disrupted by climate change:

1. More intense events damage critical infrastructure to minimize shipping avenues;
2. Direct damage to manufacturing facilities or equipment;
3. Reduction in employee productivity;
4. Increased market prices for labor, energy, and logistics (such as transport).

One important variable previously mentioned for supply chain and/or commercial risk is on the individual worker. This is especially true for industries heavily based on agriculture or construction. These professions heavily rely on a workforce that works outdoors. A [2019 study by the International Labor Office](#) noted that further global warming will lead to a 2 percent global reduction in total working hours by 2030 because of lost work or reduced rate of work. In parts of Southern Asia or Western Africa, that productivity reduction could reach 5 percent. Heat stress will be a major challenge in less affluent countries where more vulnerable populations handle more dangerous jobs. The UN cites that accumulated direct and indirect losses due to heat stress could reach \$2.4 trillion by 2030 if nothing is done to mitigate climate change risk.

**Bottom Line:** As large-scale disasters happen with more regularity, the downstream effects on the commercial sector is only going to become more noticeable. Recent years in 2021, 2020, 2017, and 2011 highlighted the types of prolonged supply chain and economic disruptions that can occur. As more expensive and impactful disaster events occur in quick succession, this type of complex risk on commercial business has the potential to become the new normal.

Exhibit 24: Components of Supply Chain Disruption





## Building a resilient and sustainable supply chain in the face of climate change

Richard Waterer, Aon's Global Risk Consulting Leader

Interruptions to supply chains are regular and costly occurrences – demonstrated with the blocking of the Suez Canal, the Texas cold snap and a drought in Taiwan. Against the backdrop of a pandemic, such events are estimated to have created supply chain challenges, costs and losses for over two thirds of the global business community.

Coupled with the risk of disruption caused by catastrophes and the evolving climate, it has never been harder to balance the need for flexible, cost-effective supply chains.

Aon's Chief Broking Officer community rated Supply Chain Risk and Climate Change as the two biggest challenges from a risk transfer perspective.

Source: Aon's Global Risk Management Survey (GRMS)

As climate change makes extreme weather more frequent and severe, it raises the probability of events that are more intense than manufacturing facilities are constructed to withstand. Companies and consumers alike are already seeing the impact of climate change on production costs, reduced delivery times and the quality of goods delivered to the end user.

Expected losses from supply chain disruptions equal 42 percent of one year's EBITDA (earnings before interest, taxes, depreciation and amortization) on average over the course of a decade.

Source: S&P and Capital IQ; McKinsey Global Institute analysis

### The need for innovation

Supply chains were already fragile as companies sought to drive efficiencies and margins through sourcing of materials, ingredients and components as well as the distribution of their end products. Liquidity strategies based on the use of reduced inventories and 'just-in-time' (JIT) fulfilment processes have increased exposure to disruption. Though effective at reducing flow times and costs within production and distribution systems, these inventory and manufacturing workflows are susceptible to supply and demand shocks. When global supply chains are disrupted – as we've seen with the pandemic, the Suez blockage and unpredictable weather events as recent examples – JIT production can fail. Leaving companies to pay fines for missing deadlines, empty shelves for consumers and extensive delays for components of larger products (chips for electronic goods, as another recent example) – all of which can have serious repercussions on a retailer's reputation, cash flow and revenue.

Simultaneously, climate change is evolving so quickly that quantifying risk is increasingly important and insuring risk is increasingly more difficult. Companies are hard-pressed to remain agile in today's increasingly volatile landscape but need to understand both the current and possible future risk exposure, including the influence of our changing climate. Beyond limiting loss and disruption, visibility into risk exposures has far-reaching implications on a company's growth. Board Members must be seen as aware of risk exposures and how they're being handling in answering to shareholders and conducting due diligence around M&A deals. With a data-driven approach to understanding its position, a company is better equipped to proactively mitigate risk and optimize its risk financing strategy.

As companies deal with physical changes and a transition to a more sustainable business, they need to align the impacts of climate change to balance sheet solutions that can reduce volatility. Climate change requires a forward-looking approach and the assessment of the 'more intangible' transition risks.

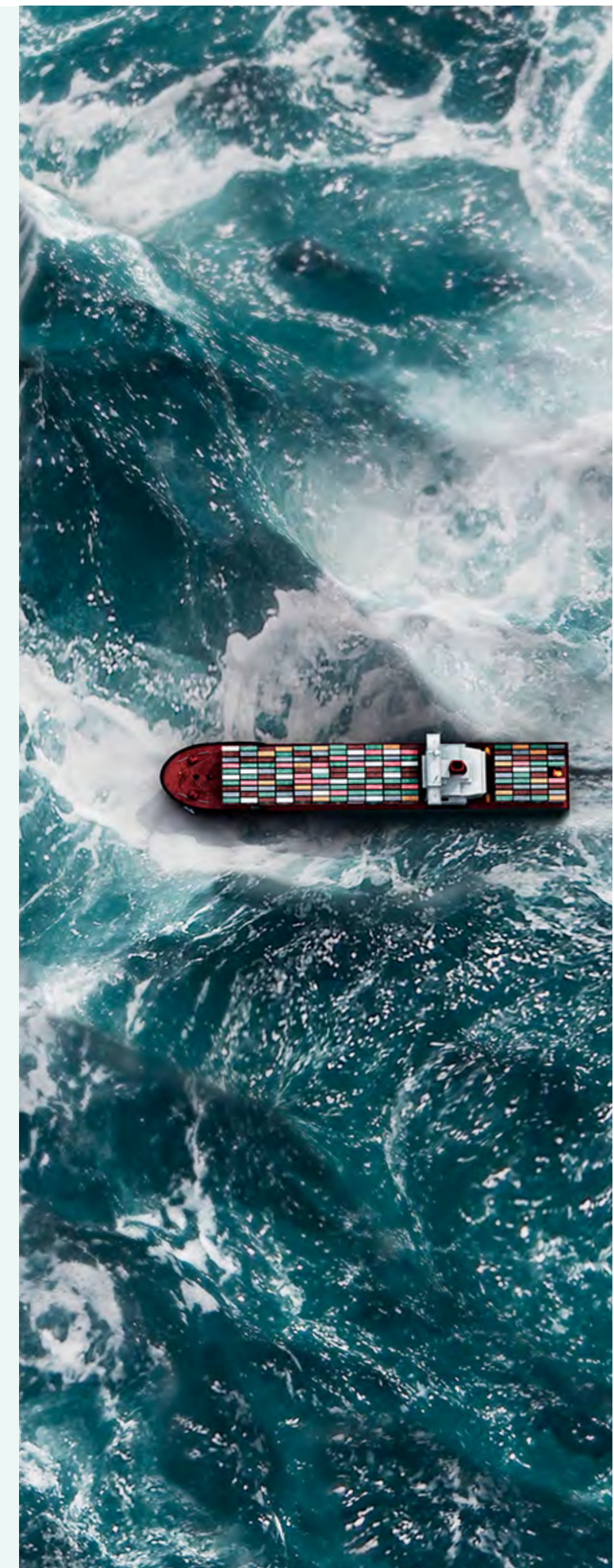


Organizations should think about climate change on two fronts, one is managing the balance sheet impacts. The other is developing the organization's stance on climate change and deciding how to report that to stakeholders. Though even with the same fundamentals, climate risk approaches will differ depending on company and industry dynamics.

**Corey Green**, Head of Strategy & Execution, Global Risk Consulting

### 5 ways to strengthen your supply chain resilience

- Assess and align your macro exposures to specific industry sector events including extreme weather conditions, environmental and climate forecasting as well as political unrest to protect the assets from sea-level rises, wildfires, earthquakes etc.
- Identify and mitigate a range of reputational issues culminating from supply chains including diversity and inclusion, modern slavery, child or forced labour and human trafficking.
- Where there is a concentration of exposure, consider de-risking the supply chain by re-engineering where possible, managing risk and assessing the role of contracts and agreements, as a tool for risk management.
- Explore how you can improve existing supply chain processes and procurement operations with insurance, risk management and finance teams
- Discover how you can match insurer capital to current and emerging exposures through improved risk insights across key suppliers and third-parties. This could include captive insurance companies or index-linked, parametric solutions.





## Elevating Risk Management to Enhance Disaster Responses

Among the most important aspects of climate change is how to effectively prepare and/or respond to the societal challenges posed by the various physical and non-physical risks. Such challenges require comprehensive assessments via risk management, including disaster relief and emergency management, to respond to the more impactful events of tomorrow. Complicating preparation efforts is that the likely effects of climate change will be different for every peril and region. This reality means there will be a greater need for more detailed planning will down to a localized level.

Before discussing what can be done to lower climate change-related risks, we must define the differences between disaster relief and emergency management. Emergency Management involves the identification of a smaller-scale event and determining which specific group(s) will handle various short-term aspects of shelter, clean-up, or any request for local or state-level financial assistance. Disaster Relief involves a much larger-scale incident that requires substantial coordination between various federal agencies and humanitarian groups for short and long-term assistance around housing, food, medical, and financial aid.

As risk managers grapple with the complexities of future climate risk and how to prepare for future response, there are some basic categories to follow:

1. **Mitigation:** Identify best practice ways to reduce the volume of carbon emissions and stabilize greenhouse gases which trap heat in the atmosphere.
2. **Adaptation:** Plan for future life in a changing climate environment by investing to minimize human and physical vulnerabilities, such as investing in infrastructure projects, building more storm-resistant structures, improving risk communication, or shifting human lifestyle behaviors.
3. **Education:** Expand the basic knowledge of the climate system and recognize that there is still time to make a meaningful impact to reverse anthropogenic-driven damage to the earth's environment.

**Bottom Line:** The underlying challenge is that there needs to be a fundamental change in how risk management professionals prepare for the disasters of today and tomorrow. The need for increased funding and planning from the federal level down to the local level is obvious, but how these agencies work together to address the problem and ensure a level playing field for all communities, rich and poor, is the most urgent first step. It can and will literally save lives.

## Climate Displacement

The humanitarian risks posed by climate change are consequential and require a detailed view through a moral and/or ethical lens. One of the areas of growing concern surrounds climate displacement. This represents people who are forced from their homes due to an individual weather or climate-related disaster, or the compounded effects of climate change that can enhance issues such as food insecurity.

Food insecurity is a real and growing challenge, especially in countries or regions most vulnerable to the effects of climate change. Poor agricultural practices or changing land use has accelerated food scarcity in many parts of the underdeveloped world. A 2020 United Nations study indicated that one-third of the world's cropland had been abandoned in the past 40 years due to erosion. The agency further cited that another 20 million hectares (49 million acres) of agricultural land every year becomes too poor for crop production or lost due to urban sprawl. A separate 2020 UN study noted that more than 50 percent of the world's population was likely to be living in a "water-stressed region" by 2050. These issues can quickly compound and lead to serious instances of acute malnutrition – especially in children.

Places facing the highest risk of food insecurity are also the ones dealing with the greatest wealth inequalities and threats of regional conflict. As people move due to a lack of food availability, this can often result in rising conflict as farmers or other agricultural

practices are forced to share diminishing resources and enflame tensions in areas that have a dearth of strong governance. The lack of structured and well-functioning governance increases the difficulty to adapt or make the critical social, structural, or economic changes needed to improve humanitarian sustainability. When combined with accelerated temperature warmth and intensifying droughts, this can amplify environmental degradation. While there is no direct correlation between climate change and regional conflict, there is little doubt that the indirect effects are leading to increasing geopolitical concerns.

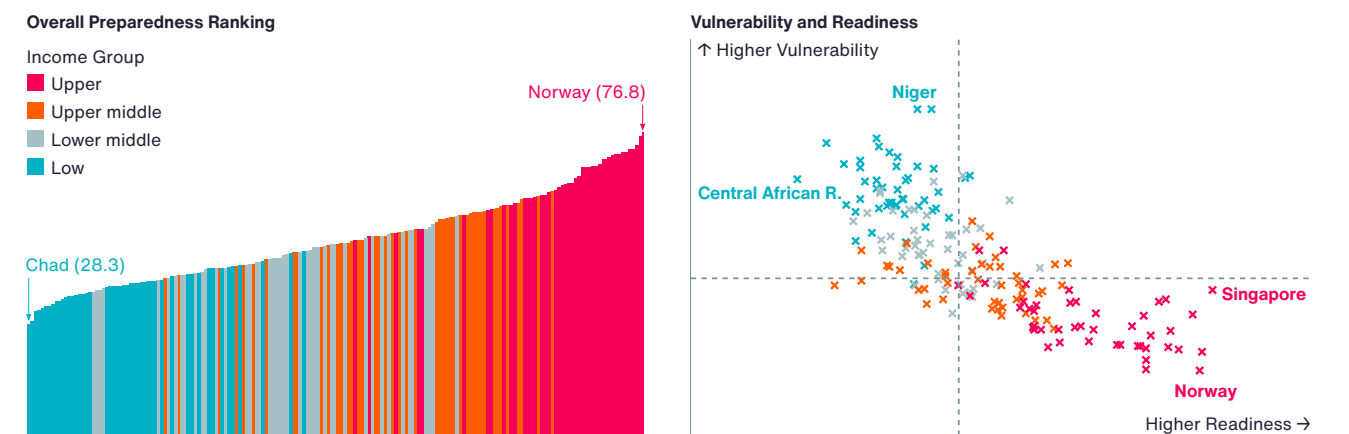
[A 2019 study by the University of Notre Dame's Global Adaptation Index \(ND-GAIN\) project](#) found that 60 percent of the top 20 countries most at-risk to climate change were in countries at high risk of armed conflict. The factors used to measure climate risk include: Food, Water Access, Health, Ecosystem Services, Human Habitat, Infrastructure, Economic Readiness, Governance Readiness, and Social Readiness.

**Bottom Line:** As increasingly vulnerable populations in lower income countries are faced with food insecurity or a limited number of employment opportunities, this will lead to these residents leaving their homes to find a new place to live. Ensuring safe access to food, medical aid, and shelter is essential in underdeveloped nations.

Exhibit 25: Emergency Management and Disaster Relief



Exhibit 26: Notre Dame Global Adaptation Index



Data: University of Notre Dame (ND-GAIN). Graphic: Aon (Catastrophe Insight)

## 8 Ways to Assess the ESG Risks You Can and Can't See

On the morning of December 11, 2021 I awoke at 3:00 am to a series of alerts from the National Weather Service and the sound of Nashville's tornado sirens wailing to life. I hurried downstairs and turned on the local weather coverage. Almost immediately, it became clear that we were facing an incredibly serious tornado threat.

In total, 24 tornadoes touched down in Tennessee during a 24-hour period on December 10-11. This more than doubled the state's previous combined December total of 9 from 1950-2020. We were lucky, however, when you consider the death toll from Kentucky just to the north.

As weather events become more severe due to influences from climate change, the Environmental, Social and Governance (ESG) risks to businesses rise as well.

Following the latest tornado outbreak, a Kentucky candle factory is already facing a class-action lawsuit and an Indiana logistics facility made the international news as, in total, sadly 16 workers lost their lives. A class-action lawsuit is already in motion for one of the firms, while the other has received intense scrutiny over policies and workforce safety protocols as well.

### Act today to prepare for tomorrow

These instances highlight just four of the myriad ESG risks (workforce safety, physical risks, liability, social license to operate) facing companies as climate change increasingly threatens people and our planet.

As firms evaluate their exposure to climate risks, in addition to broader ESG risks, they should assess and disclose the following:

### 1 Access to capital:

Funds directed to ESG investing reached \$8 trillion in 2021 and could hit \$30 trillion by 2030<sup>1</sup>. As investors look to manage long-term risk and volatility by factoring in material ESG issues, capital sources from banks to bonds to equity will be impacted. Companies who aren't up to ESG standards could face reduced access to capital, or higher costs of capital.

### 2 Liability risk:

The risk of litigation related to climate change cannot be understated. Legal exposure is increasing, and proceedings based on everything from mitigation and adaptation, greenwashing, disclosure, negligence, human rights, and administrative claims are on the rise, to name a few.

### 3 Regulatory risk:

As governments look to avert a climate disaster and ensure long-term resilience, laws and policies that impact how a company operate will grow. According to the Principles for Responsible Investing (PRI), there were more than 159 new or revised ESG policies before September 2021, more than the entire calendar year prior<sup>2</sup>.

### 4 Physical risk:

The actual physical peril to property, employees, supply chains and distribution routes

### 5 Access to insurance:

As insurers navigate their own material ESG risks on both the asset and liability side, it will create a knock-on effect on what coverage is available and at what cost.

### 6 Social license to operate:

A bit broader than just PR, social license to operate refers to the ongoing acceptance of business practices and operating procedures by a variety of stakeholders, including investors, employees and the general public.

### 7 Transition risk:

Includes all the prior risks plus non-regulatory factors that impact a company's ability to conduct business the world moves to a green economy. For example, companies may face increased costs of raw materials or have to make more investment in new technologies.

### 8 Governance:

Catastrophic events like the December tornado outbreak highlight environmental and social risks, but governance remains critical in this discussion. It is virtually impossible to successfully manage environmental and social risks without strong and senior (think board level) oversight. Robust disclosure about ESG and climate change, which also stems from good governance practices, will also be required to help manage legal, regulatory and social license to operate relationships.

#### How else can I stay ahead of the game?

Frameworks such as the Task Force for Climate-Related Financial Disclosure (TCFD) are key when it comes to thinking through and disclosing exposure to the risks created by climate change. As companies, investors and insurers work through TCFD, they should consider:

1. Governance – how does the firm oversee and report on climate change risk?
2. Strategy – how does the firm structure their risk management strategy to mitigate the physical and operational/transitional impacts of climate change, while also identifying business opportunities created in the transition?
3. Risk management - how does the firm assess and manage climate change risks?

4. Metrics and targets – what methodologies and data are behind disclosed statistics and metrics, and how does the organization plan to manage into a new climate-resilient paradigm?

It is important to note that climate change is just one piece of a bigger ESG puzzle. Even with TCFD disclosure, companies should ensure they are taking all material ESG risks in hand by evaluating their business against evolving International Sustainability Standards Board (ISSB) criteria, as well as staying abreast of emerging regulatory requirements and investment and industry norms.

While these actions cannot prevent devastating natural disasters, they can minimize risks to business, people and planet and help create a more resilient world.

**Meredith Jones** is the Head of Environmental, Social and Governance (ESG) at Aon

<sup>1</sup> <https://www.barrons.com/articles/esg-investing-outlook-2030-51638493803?tesla=y>  
<sup>2</sup> <https://www.unpri.org/policy/regulation-database>

# Historical Database Reanalysis & Loss Development

Since the release of the 2018 Weather, Climate & Catastrophe Insight Report, Aon's Catastrophe Insight team has utilized a new historical natural disaster dataset. The highly detailed and ongoing research process – more commonly referred to as “Reanalysis” – has helped fill in data gaps in many regions around the world. Some countries, like the United States and various other developed nations, have much more detailed and prolonged data records available. Most countries, however, do not – resulting in incomplete views of historical events beyond a few decades.

It is generally understood that most natural disaster databases show a significant decline in the number of annual global events prior to 1980. While the biggest events are typically captured, most small and medium-sized events have been missed. While Aon's data reanalysis process has not completely removed the data gap, it has made major progress in identifying a large portion of events not previously

catalogued. The dataset primarily comprises events since 1950 but has a long record of events dating into the 19<sup>th</sup> Century. The multi-year research has included the local translation of decades' worth of government datasets, newspaper accounts, and journal publications.

Along with the addition of events not previously included in the database, a significant effort has been made to ensure a full country-level breakout of event losses. In many instances, the loss breakout helps identify trends beyond the peril aggregate and down to a more regional or localized level. The United States has the most events in our database. Research since 2017 resulted in database entries for the period of 1900-2016 growing from 3,370 to 7,335 in early 2021. This eliminated recency bias for the country, a persistent challenge for other regions beyond the early 21<sup>st</sup> Century.

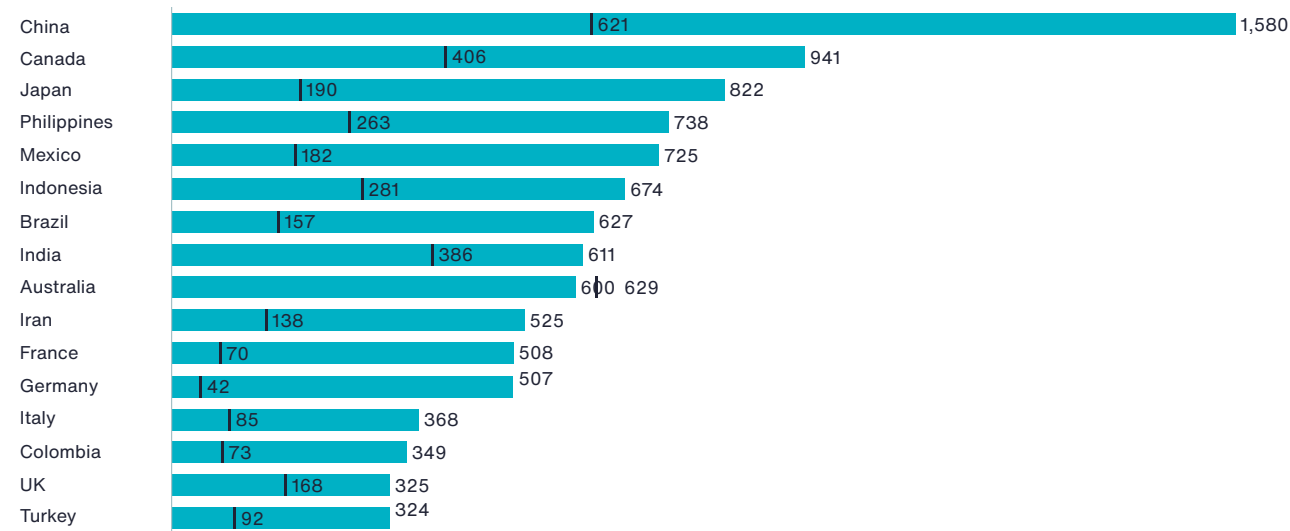
The Catastrophe Insight team heavily emphasizes updating existing event records as new data is identified. The “final” event loss total can dramatically change from its initial estimation extended over a multi-year period. The combination of topics like loss creep, claims litigation, Assignment of Benefits (AOB), higher replacement costs or demand surge, delayed releases of official damage estimates or agency releases on a quarterly / annual basis can all explain why losses may update years after event occurrence.

For example, in the last 12 months, the nominal insured loss for 2020 increased from \$97 to \$104 billion. Some of the most notable revisions include

increase of the insured loss related to Hurricane Laura in the United States from \$10 to \$12 billion, or for the U.S. severe weather outbreak in August (incl. the Midwest Derecho) from \$8.3 billion to \$9.2 billion. At the same time, insured losses from the 2020 seasonal flood in China were originally estimated at \$2.0 billion but were later revised downward.

**Bottom Line:** Aon's Catastrophe Insight team takes a proactive stance in updating its historical loss database to identify actual trends. No database will ever be perfect and completely capture every global event going back many decades, but this is one of the most robust natural disaster datasets ever compiled.

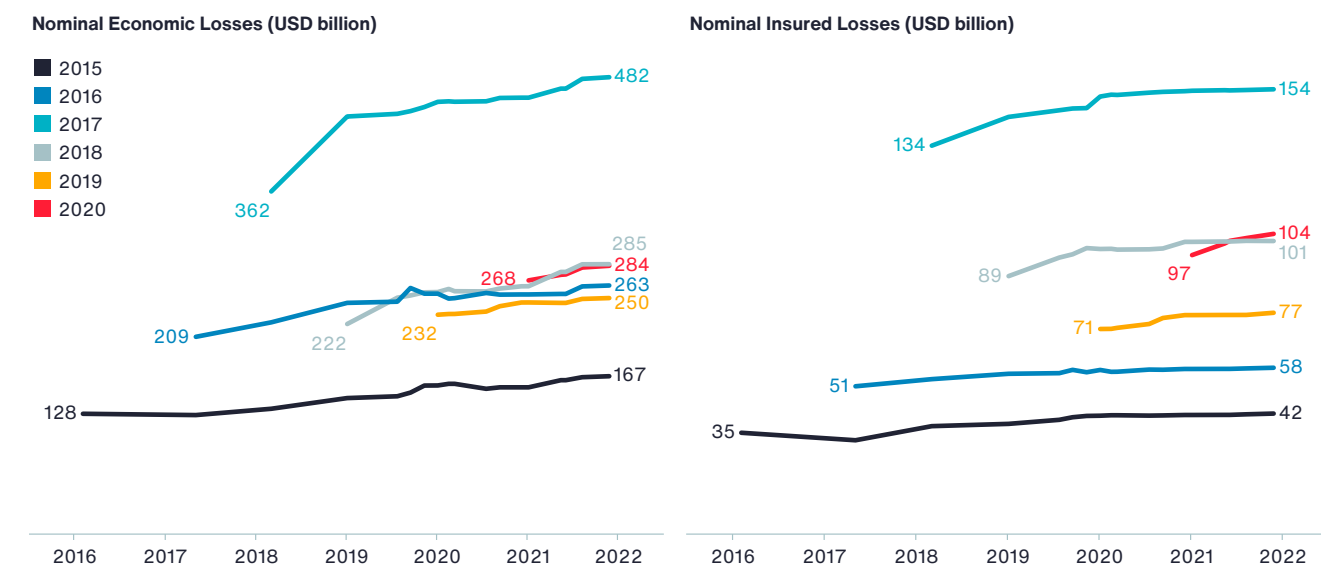
**Exhibit 27: Increase in Number of Non-U.S. Database Entries by Country between 2017 and 2022**



■ 2017 version of the database ■ 2022

Data: Aon (Catastrophe Insight)

**Exhibit 28: Revisions of global annual nominal losses since first publication**



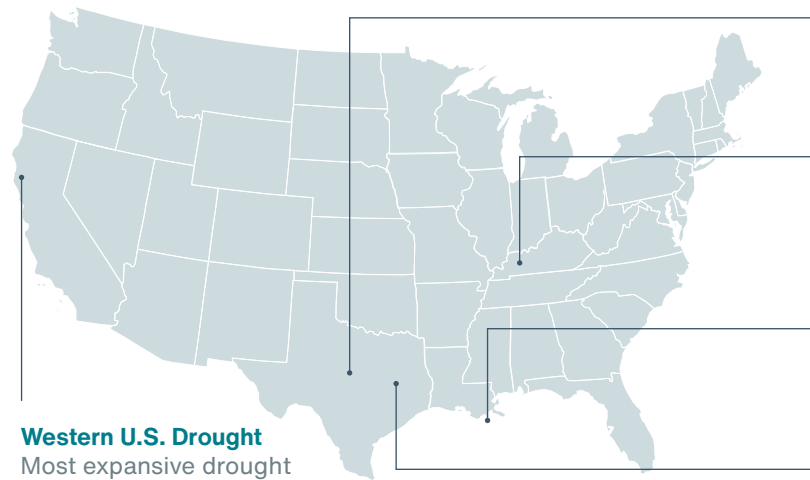
Data: Aon (Catastrophe Insight)



2021 Global  
Catastrophe Review



## United States



**Western U.S. Drought**  
Most expansive drought since 2000  
Economic Loss: \$9 billion

**February Polar Vortex**  
Costliest winter weather event on record for insurers  
Insured loss: \$15 billion

**December 10-11 Tornado Outbreak**  
Two long track EF4 tornadoes surveyed  
Economic Loss: \$5.1 billion  
93+ fatalities reported

**Hurricane Ida**  
Strongest U.S. landfall of 2021  
150 mph sustained winds  
Economic Loss: \$75 billion

**April Texas and Oklahoma Hail**  
Record 6.4-in hail stone fell in Texas  
Insured Loss: \$2.6 billion



**1,329+**

Structures destroyed in Dixie Fire;  
Largest individual wildfire in California dating to 1932



**74°F (23.3°C)**

Warmest average summer temperature (June-August) for continuous U.S.  
Tied with the dust-bowl summer of 1936



**20.73 in / 527 mm**

Tennessee record 24-hour rainfall measured in McEwen on August 21



**73.2%**

Record snowfall cover across the contiguous U.S. on February 16

**\$169 billion**

economic loss, 93 percent above average since 2000

**\$92 billion**

insured loss, 105 percent above average since 2000



**49%**

of global economic losses



**71%**

of global insured losses



**54%**

of losses covered by insurance

### Exhibit 29: Top 5 Most Significant Events in the United States

Timeframe	Event	Location	Deaths	Economic Loss (USD billion)	Insured Loss (USD billion)
08/27 - 09/02	Hurricane Ida	Southeast, Northeast	96	75.0	36.0
02/12 - 02/20	February Polar Vortex	Rockies, Plains, Midwest	215	23.7	15.0
01/01 - 12/31	Drought	Nationwide	-	9.0	4.3
12/10 - 12/12	Mid-December Tornado Outbreak	Plains, Southeast	93	5.1	4.0
04/27 - 05/02	Texas and Oklahoma Hail	Plains	-	3.4	2.6
	All other events		~365	~53 billion	~30 billion
	<b>TOTALS</b>		<b>~770</b>	<b>169 billion</b>	<b>92 billion</b>

Economic and insured losses derived from natural catastrophes in the U.S. were substantially above the long-term average in 2021. The overall economic total was estimated at \$169 billion. Public and private insurers covered nearly \$92 billion. When compared to annual data from the 21<sup>st</sup> Century, economic losses in 2021 were 95 percent above the average (\$86 billion), and 230 percent higher than the median (\$51 billion). At least 23 individual events exceeded the \$1 billion loss threshold in 2021. Insured losses were 108 percent higher than average (\$44 billion) and 227 percent higher than the median (\$28 billion).

The U.S. endured eight tropical cyclone landfalls during the Atlantic Hurricane Season: Claudette, Danny, Elsa, Fred, Henri, Ida, Mindy, and Nicholas. The most significant was Hurricane Ida, which tied the record for the strongest Louisiana landfalling hurricane at 150 mph (240 kph). Louisiana became the first U.S. state to record back-to-back years with a 150 mph (240 kph) hurricane landfall. The remnants of Ida later aided in record-breaking flooding in the Northeast. Total insured losses from Ida reached \$36 billion; the fourth-costliest tropical cyclone on record for insurers.

SCS generated nearly \$27 billion in insured losses and became the third-costliest year for the peril; only behind 2020 and 2011. Losses were initially driven by spring hail events, which included notable late April hailstorms that impacted the greater metro areas of San Antonio and Fort Worth (Texas) and Oklahoma City and Norman (Oklahoma). Rapidly expanding urban centers in hail-prone areas in the U.S. have resulted in continually rising thunderstorm-related

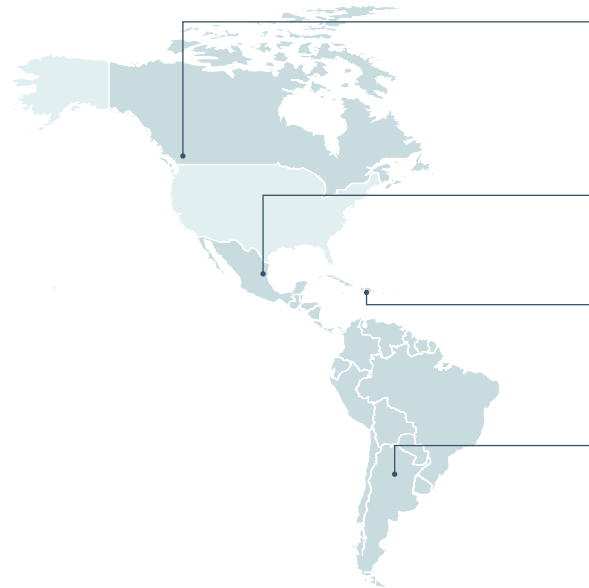
damage costs in recent years. However, December proved the costliest month for the SCS peril. Two separate events within a week's time saw a major tornado outbreak (70+ tornadoes) spawn a pair of long-track EF4 tornadoes (December 10-11) and a historic derecho on December 15 cause widespread wind damage and initiate 117 tornadoes. It ended as the most active December on record for U.S. tornadoes.

The February Polar Vortex was the costliest winter weather event on record for insurers, with losses to property and agriculture reaching \$15 billion. As many as 10 million customer power outages were cited at the peak of the event which resulted in hundreds of deaths in the Plains: mostly in Texas. In contrast, the June Western North America Heat Wave set a considerable number of daily, monthly, and all-time warm temperature records across the Pacific Northwest. The heat resulted in hundreds of fatalities and hospitalizations.

Wildfires burned at least 7.1 million acres (2.9 million hectares) in 2021, which was marginally below the 10-year average. The Dixie Fire was the second largest fire event in California in the modern record dating to 1932, but it was the largest single fire (2020's August Complex Fire merged multiple fires together). In 2021, wildfires in California destroyed 3,629 structures. A late December major grassland fire, named the Marshall Fire, became the costliest and most destructive fire ever recorded in Colorado. The Western U.S. experienced one of the worst droughts in decades, with drought affecting 95 percent of the region by August.



## Americas (Non-U.S.)



### June Western North American Heatwave

Canadian national heat record set on June 29; 121°F (49.6°C); world record for hottest temperature at 45 degree or higher latitude  
800+ deaths reported in Canada (1,029+ total)

### Hurricane Grace

Strongest landfalling hurricane in Mexico's Veracruz State, 125 mph sustained winds

### Haiti Earthquake

M7.2 earthquake struck Haiti on August 14  
2,248 deaths reported  
Economic Loss: \$1.6 billion

### La Plata Basin Drought

Paraná River reached 77-year low, drought emergencies declared in Argentina, Brazil, and Paraguay



**75%**

Area of Mexico affected by drought conditions in 2021 (largest since 2011)



**35.8°C / 96.4°F**

Highest national temperature ever recorded on the island of Dominica; record set on August 12



**10 km / 32,000 ft**

Maximum height of ash plume from La Soufrière eruption on St. Vincent on April 9



**541 mm / 21.3 in**

Wettest November on record for Abbotsford, British Columbia

**\$22 billion**

economic loss, 32 percent below average since 2000

**\$3.4 billion**

insured loss, 38 percent below average since 2000



**6%**

of global economic losses



**3%**

of global insured losses



**16%**

of losses covered by insurance

Exhibit 30: Top 5 Most Significant Events in the Americas

Date	Event	Location	Deaths	Economic Loss (USD billion)	Insured Loss (USD billion)
01/01-12/31	La Plata Basin Drought*	South America	N/A	4.7	0.1
06/26-06/30	Heat Wave	Canada	800+	-	-
11/13-11/15	BC Atmospheric River	Canada	4	2.4	0.4
08/14	Haiti Earthquake	Haiti	2,248	1.6	Millions
08/16-08/21	Hurricane Grace	Mexico	13	0.5	0.1
	All other events		~425	~13 billion	~2.8 billion
	<b>TOTALS</b>		<b>~3,500</b>	<b>22 billion</b>	<b>3.4 billion</b>

\*Combines annual drought loss data from Brazil, Argentina, Paraguay, and Bolivia

The overall economic loss total for the Americas (Non-U.S.) was roughly \$22 billion, of which public and private insurance entities covered \$3.4 billion. This highlights the importance of continuing to narrow the protection gap in this region. Economic losses in 2021 were 32 percent lower than this century's average (\$32 billion), and 4 percent lower compared to the 21<sup>st</sup> Century median (\$23 billion). Insured losses were 38 percent below the average (\$5.5 billion) but above the median (\$3.2 billion).

Western Canada was notably impacted by natural disasters in 2021. The historic Western North American Heat Wave in late-June claimed at least 800 lives in Canada – a majority reported in British Columbia. The most remarkable heat was observed in the Village of Lytton that set a national heat record of 49.6°C (121°F) on June 29. A devastating wildfire on June 30 (Lytton Creek Fire) subsequently largely destroyed the village. The heatwave generated non-negligible impacts to regional agriculture and infrastructure. Prolonged hot and dry conditions aided above average wildfire activity in British Columbia. The BC Wildfire Service indicated 868,000 hectares (2.1 million acres) were affected between April and September - prompting a province-wide state of emergency. An exceptional atmospheric river brought catastrophic flooding to the lower mainland in November and generated economic losses of at least \$2.4 billion – a majority of which went uninsured. This event exacerbated ongoing supply chain issues as highway and rail transportation between the

Fraser River Valley and the Port of Vancouver were significantly disrupted. Abbotsford recorded its wettest November on record.

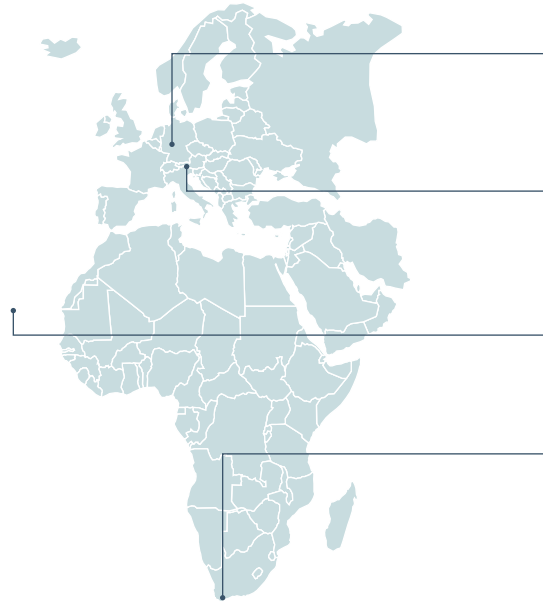
In the Caribbean, a strong magnitude-7.2 earthquake struck Haiti on August 14 claiming 2,248 lives and marked the deadliest global natural disaster in 2021. The earthquake struck further west and resulted in less significant ground shaking compared to the magnitude-7.0 event that struck in January 2010. The eruption of La Soufrière volcano on St. Vincent in April generated economic losses into the hundreds of millions (USD).

In Mexico, four landfalling Pacific hurricanes (Nora, Pamela, Olaf and Rick) each resulted in non-negligible damages. In the Atlantic, Hurricane Grace struck the nation twice, with landfalls in the Yucatan Peninsula and Veracruz, becoming the costliest tropical cyclone to impact Mexico in 2021.

In South America, the ongoing La Plata basin drought generated a multi-billion-dollar (USD) economic loss in 2021 – particularly in Brazil, Argentina, Paraguay, Uruguay and Bolivia. The drought significantly impacted natural ecosystems, agriculture, transportation and power generation. Imports and exports at the Argentinian ports of Greater Rosario along the Paraná River were particularly impacted. In December, incessant rainfall in northern and central Brazil, enhanced by La Niña conditions, generated an economic toll reaching into the hundreds of millions (USD).



## EMEA (Europe, Middle East & Africa)



### July Western and Central Europe Flooding

Costliest insured loss event on record for Europe (in 2021 USD)  
Insured Loss: \$13 billion

### June European Severe Weather Outbreaks

June 17-25 outbreak was the costliest global SCS event of 2021 for insurers  
Insured Loss: \$3.5 billion

### Cumbre Vieja Volcano Eruption

Left nearly 3,000 properties destroyed in September  
Economic Loss: \$1 billion

### April Table Mountain Wildfire

Notable damages to historic buildings in South Africa



**48.8°C (119.8°F)**

Preliminary European heat record; set on August 11 in Sicily, Italy



**153.5 mm / 6.04 in**

24-hour precipitation in Cologne, Germany on July 14, nearly twice the average monthly July rainfall



**51.8°C (125.2°F)**

New national temperature record set in the United Arab Emirates on June 6



**380 kph / 235 mph**

Rough approximation of maximum winds of the June 24 F4 tornado in South Moravia, Czechia; strongest in country's modern record

**\$74 billion**

economic loss, 92 percent above average since 2000

**\$25 billion**

insured loss, 137 percent above average since 2000



**22%**

of global economic losses



**19%**

of global insured losses



**34%**

of losses covered by insurance

Exhibit 31: Top 5 Most Significant Events in EMEA

Date	Event	Location	Deaths	Economic Loss (USD billion)	Insured Loss (USD billion)
07/12 - 07/18	Flooding	Western & Central Europe	227	45.6	13.0
06/17 - 06/25	Severe Weather	Western & Central Europe	7	4.9	3.5
04/05 - 04/08	Winter Weather	Western & Central Europe	N/A	5.6	0.4
07/28 - 08/09	Wildfire	Mediterranean Region	12	0.8	< 0.1
08/11	Flooding	Turkey	82	0.3	< 0.1
All other events			~750	~17 billion	~8.0 billion
TOTALS			~1,075	74 billion	25 billion

Total economic losses caused by natural disasters in Europe, the Middle East and Africa (EMEA) were substantially higher when compared to the 21<sup>st</sup> Century average. The aggregate direct economic toll exceeded \$74 billion, which was 92 percent above the average annual loss (2000-2020) and 109 percent above the median. Insured losses surpassed \$25 billion, which was 137 percent above the 21<sup>st</sup> Century average, and 171 percent above the median. 2021 was the second-costliest year on record for insurers (USD 2021); only behind 1990, but above 1999.

Torrential rainfall caused by an area of low pressure – named “Bernd” by the Free University of Berlin – caused catastrophic flooding and an economic cost of more than \$45 billion across Western and Central Europe in mid-July. The flood damages resulted in record-breaking losses for insurance industries in Germany, Belgium and Luxembourg. With insured losses of \$13 billion, it became the costliest event on record in Europe on an inflation-adjusted basis.

The July floods were a continuation of one of the most expensive six-week periods in Europe for the insurance industry in the modern era. The floods followed a series of SCS outbreaks in late June which prompted a multi-billion dollar (USD) insured loss. After an unusually quiet year for the peril in 2020, both the June 17-25 and 28-30 SCS outbreaks generated billion-dollar (USD) economic losses. This included a long track F4 tornado that impacted the

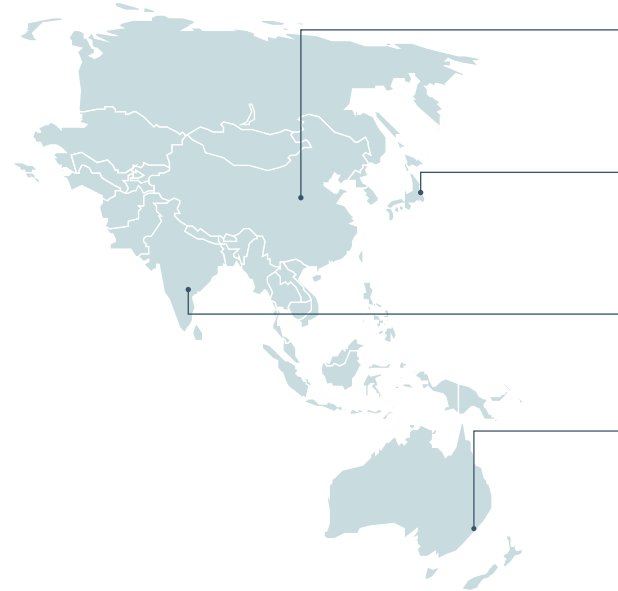
Czech Republic on June 24, which became the most destructive and deadliest in the country's modern history. During the same period, extensive hail damage aided in the costliest natural disaster event on record for the local insurance industry in Austria, and the costliest SCS event on record in Switzerland.

A prolonged period of abnormally hot and dry conditions engulfed regions of the Mediterranean in damaging wildfires in July and August, including notable events in Greece, Turkey and Algeria. A weather station on the island of Sicily in Italy recorded a temperature of 48.8°C (119.8°F) in August, preliminarily setting a new European heat record. In contrast, an unusual spring frost event in April generated significant agricultural losses in Western and Central Europe, particularly in viticulture and fruit production. France incurred most of the losses.

The eruption of Cumbre Vieja Volcano on the Canary Islands' La Palma island in September left nearly 3,000 properties destroyed and resulted in a \$1 billion economic loss.

In the Middle East, Cyclone Shaheen made a historic landfall in Oman and generated an economic toll which minimally reached into the hundreds of millions (USD). In Africa, Cyclone Eloise produced non-negligible damages in Southern Africa in January. A particularly difficult humanitarian situation unfolded in South Sudan, where one of the country's worst flooding episodes in decades displaced thousands.

## APAC (Asia & Pacific)



### China Seasonal Floods

Included record breaking rainfall in the Henan Province in July  
Economic Loss: \$30 billion

### Fukushima Earthquake

M7.1 struck offshore Japan's Fukushima Prefecture on February 13  
Economic Loss: \$8.0 billion

### India Seasonal Floods

1,282 fatalities  
Economic Loss: \$3.1 billion

### March East Coast Low

Costliest Australian event in 2021  
Economic Loss: \$2.1 billion

**40.6°C**  
**(105.1°F)**

New maximum temperature heat record in Taiwan on August 11

**201.9 mm /**  
**7.95 in**

Max hourly rainfall rate in Zhengzhou, China on July 20

**16 cm /**  
**6.3 in**

Record hailstone which fell in Queensland, Australia on October 19

**260 kph / 160 mph**

Maximum sustained winds at landfall of Category 5 Super Typhoon Rai in the Philippines on December 16

**10.1M ha /**  
**24.9M acres**

Area burned by wildfire in Russia in 2021

**\$78 billion**

economic loss, 31 percent below average since 2000

**\$9.4 billion**

insured loss, 31 percent below average since 2000



**23%**

of global economic



**7%**

of global insured



**12%**

of losses covered by insurance

Exhibit 32: Top 5 Most Significant Events in APAC

Timeframe	Event	Location	Deaths	Economic Loss (USD billion)	Insured Loss (USD billion)
06/01 - 09/30	Flooding	China	545	30.0	2.1
02/13	Earthquake	Japan	1	8.0	2.5
06/01 - 10/31	Flooding	India	1,282	3.1	0.1
05/25 - 05/29	Cyclone Yaas	India	19	3.0	0.1
03/13 - 03/25	Flooding	Australia	2	2.1	0.7
	All other events		~3,300	~31 billion	~3.9 billion
	<b>TOTALS</b>		<b>~5,000</b>	<b>78 billion</b>	<b>9.4 billion</b>

After three consecutive years (2018-2020) of economic losses topping \$100 billion, the toll in Asia-Pacific (APAC) dipped to \$78 billion in 2021. This was 31 percent below the 2000-2020 average (\$113 billion) on an inflation-adjusted basis. The below average losses were mainly due to the relatively quiet tropical cyclone season in the western Pacific Ocean and slightly lower flood-related costs. The absence of El Niño conditions helped suppress losses from wildfire and drought. Insurers in APAC recorded aggregated losses of \$9.4 billion, which was 31 percent below the 21<sup>st</sup> Century average and 57 percent below the decadal average. The protection gap remained a challenging issue in APAC as insurance covered just 12 percent of the economic losses in the region.

Flood events account for more than 55 percent of the economic losses in 2021. For the second consecutive year, seasonal flood losses in China topped \$30 billion, as Henan experienced record-breaking rainfall caused by the confluence of the “Meiyu” frontal boundary and a moisture belt from Typhoon In-fa in the summer monsoon. Coincidentally, the “Plum Rain” season was also the cause of the severe flooding in central and southern China (Hunan, Chongqing, Guizhou etc.) last year. The percentage of damage covered by Chinese floods was slightly higher than normal, primarily attributed to the July floods in Zhengzhou, China where the urbanized area has a higher volume of active commercial and automobile policies in place. The Zhengzhou floods became China’s costliest individual weather event for the Chinese insurance industry on record.

In India, annual seasonal flooding killed more than 1,600 people. A “double-dip” La Niña brought amplified rainfall to Australia, with record rainfall observed across eastern Australia in March and November. Malaysia encountered its costliest and most extensive flood event on record in December. Aggregated losses for both the Australia and Malaysia floods topped \$2.2 billion and \$2 billion respectively, but the insured portion was significantly higher for Australia.

In Japan, the most damaging catastrophes were attributed to the earthquake peril. The combined economic loss was nearly \$9 billion, mainly from the Fukushima (February) and Miyagi (March) events. The Fukushima event in particular was significant, as the magnitude-7.1 tremor caused insured losses approaching \$2.5 billion.

Despite elevated tropical cyclone losses in the last few years, they were significantly lower in 2021 as the number of West Pacific typhoons were below normal. The costliest APAC tropical cyclone was India’s Cyclone Yaas at \$3 billion. The deadliest and strongest was December’s Super Typhoon Rai. It struck the Philippines and left more than 400 people dead. Rai became the third-costliest typhoon on record in the Philippines.

Extensive wildfires in Russia’s Siberia caused significant environmental impacts, with smoke from the Yakutia region traveling at least 4,800 kilometers (3,000 miles) toward the North Pole. Damage was limited.

2021 Natural  
Peril Review





## Focus Topic: Tropical Cyclone

### Atlantic Basin

The 2021 Atlantic Hurricane season generated an above normal number of named storms (21), becoming the sixth-consecutive above normal season, and the third-most active season dating to 1851. It followed the record-breaking season in 2020 which featured 30 named storms and 2005 with 28 named storms. For the second year in a row storms exhausted the conventional alphabetical list of 21 names (letters Q, U, X, Y and Z are excluded). Nine of the storms formed in September, marking the second highest September formation total on record; only behind 2020 (10). The season was fueled by warmer than average sea-surface temperatures in the Tropical Atlantic and Caribbean and below average wind shear early in the season. A transition from ENSO neutral conditions to La Niña further aided a favorable environment.

Seven hurricanes formed in 2021. Four reached major hurricane status (Category 3+): Grace, Ida, Larry, Sam. The season resulted in Accumulated Cyclone Energy (ACE) reaching 145; 118 percent of the 1991-2020 average. ACE is a metric that accounts for storm and/or seasonal intensity and longevity.

The United States recorded eight named storm landfalls. Six occurred along the Gulf Coast. The most consequential was Hurricane Ida, which struck Louisiana as a high-end Category 4 storm before its remnants later spawned catastrophic inland flooding in the Northeast. Total economic losses were minimally estimated at \$75 billion, and Ida thus became one of the costliest U.S. hurricanes on record. Hurricane Nicholas struck Texas as a Category 1 storm and resulted in a billion-dollar economic loss. Other notable landfalls included tropical storms Elsa, Fred and Mindy striking Florida, and Tropical Storm Henri coming ashore in the Northeast. It marked Rhode Island's first named storm landfall since Hurricane Bob (1991). Outside the United States, Hurricane Grace made multiple landfalls in Mexico, including a Category 3 strike in the state of Veracruz.

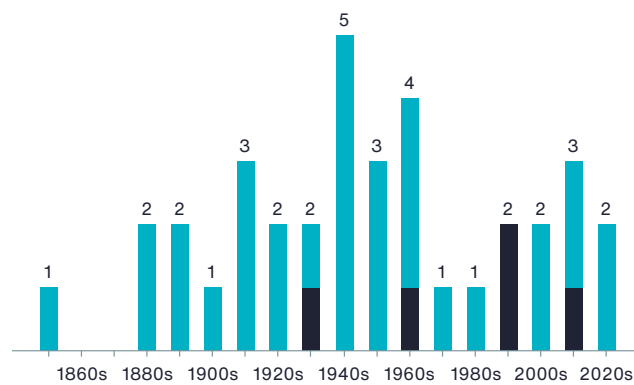
Please note that the United States mainland is in its most active stretch for Category 4/5 landfalls in the official record. When conducting a five-year rolling sum, the five Category 4/5 landfalls from 2017-2021 is the highest such total dating to 1851.

### Exhibit 33: United States Mainland Category 4/5 Landfalls

U.S. Mainland Category 4 & 5 Landfalls



By Decade



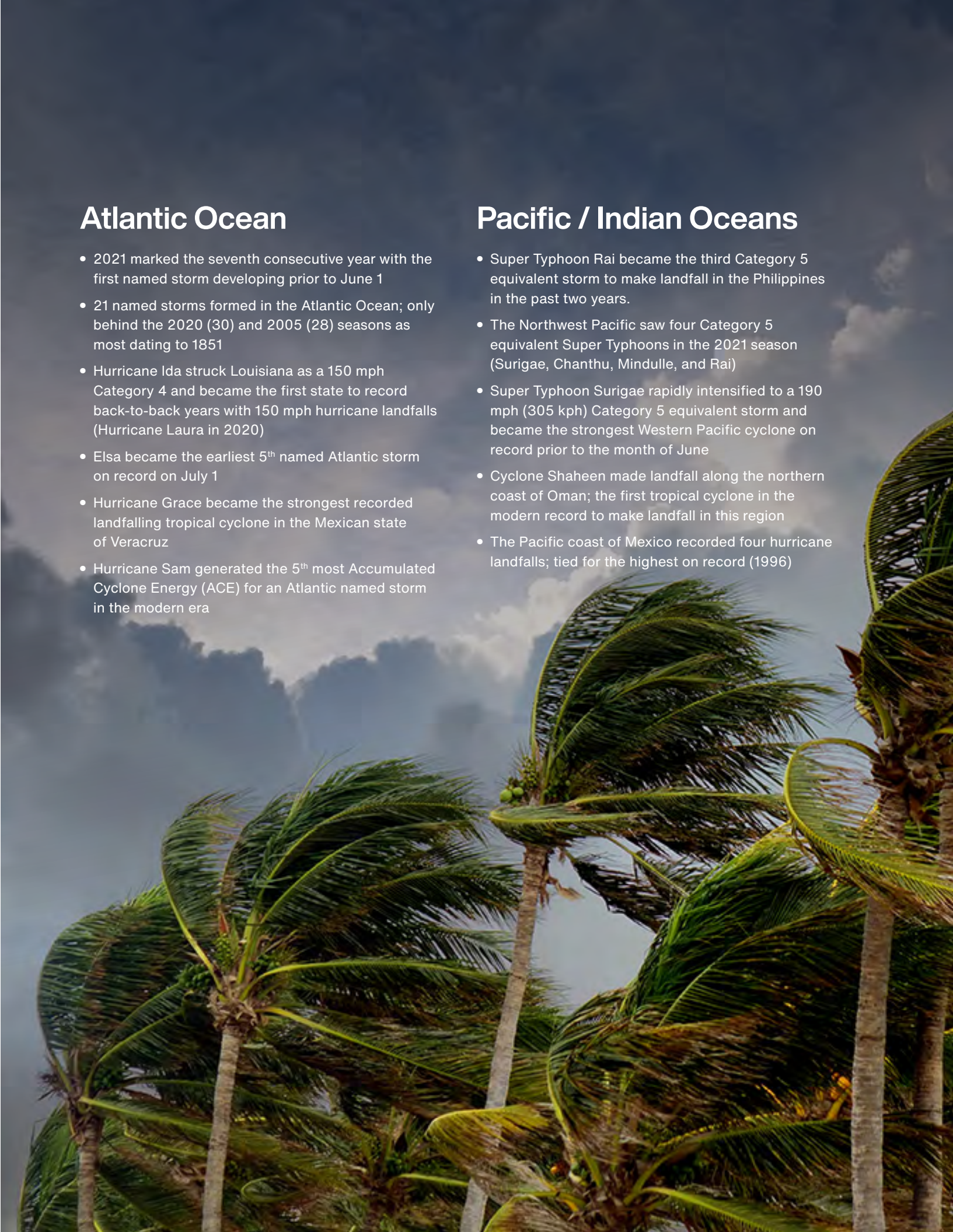
Data: NOAA. Graphic: Aon (Catastrophe Insight)

## Atlantic Ocean

- 2021 marked the seventh consecutive year with the first named storm developing prior to June 1
- 21 named storms formed in the Atlantic Ocean; only behind the 2020 (30) and 2005 (28) seasons as most dating to 1851
- Hurricane Ida struck Louisiana as a 150 mph Category 4 and became the first state to record back-to-back years with 150 mph hurricane landfalls (Hurricane Laura in 2020)
- Elsa became the earliest 5<sup>th</sup> named Atlantic storm on record on July 1
- Hurricane Grace became the strongest recorded landfalling tropical cyclone in the Mexican state of Veracruz
- Hurricane Sam generated the 5<sup>th</sup> most Accumulated Cyclone Energy (ACE) for an Atlantic named storm in the modern era

## Pacific / Indian Oceans

- Super Typhoon Rai became the third Category 5 equivalent storm to make landfall in the Philippines in the past two years.
- The Northwest Pacific saw four Category 5 equivalent Super Typhoons in the 2021 season (Surigae, Chanthu, Mindulle, and Rai)
- Super Typhoon Surigae rapidly intensified to a 190 mph (305 kph) Category 5 equivalent storm and became the strongest Western Pacific cyclone on record prior to the month of June
- Cyclone Shaheen made landfall along the northern coast of Oman; the first tropical cyclone in the modern record to make landfall in this region
- The Pacific coast of Mexico recorded four hurricane landfalls; tied for the highest on record (1996)





### Eastern Pacific

The 2021 Eastern Pacific Hurricane season recorded an above normal number of named storms (19), featuring eight hurricanes, and two major hurricanes. However, ACE was 30 percent below the long-term average. With two named storms forming in November, the 2021 season marked the fourth consecutive year with a named November tropical system.

On May 9, the formation of Tropical Storm Andres marked the earliest forming tropical storm in the eastern Pacific in the modern era. The Pacific coast of Mexico endured four landfalling hurricanes (Nora, Olaf, Pamela and Rick), tying for the record with the 1996 season. Most storms in the Eastern Pacific did not track near land.

### Northwest Pacific

The prevalence of La Niña conditions resulted in another year of below normal activity in the Northwest Pacific. Based on preliminary best track data from the Joint Typhoon Warning Center (JTWC), there were a total of 23 named storms; ten which became typhoons. This was lower than the basin's climatology from 1991-2020 with 25 named storms and 16 typhoons. As a reminder, La Niña tends to suppress the number of tropical cyclones in the Northwest Pacific. The aggregate ACE value for the season was 209.6, or 30 percent lower than the 30-year average of 299.

Super Typhoon Rai and Typhoon In-fa were the costliest typhoons in the basin after causing catastrophic damage across the Philippines and China respectively. April's Super Typhoon Surigae packed the highest ACE at 42.9, lasting eight days as a typhoon.

### North Indian Ocean

The 2021 North Indian Ocean cyclone season was near normal, with five named storms and three attaining hurricane equivalent status. Two of those hurricane-equivalent storms made landfall in the basin; both of which were in India. The two events, Cyclone Tauktae and Cyclone Yaas, occurred in May with a combined economic cost of \$4.5 billion. Cyclone Gulab first came ashore in India as a tropical storm, but its remnants later formed to become Cyclone Shaheen. That storm would become the first known hurricane-equivalent system to track into the Gulf of Oman from the east and strike the north coast of Oman (though it weakened to a strong tropical storm just prior to coming ashore). Heavy rains from Shaheen caused substantial damage in Oman. Seasonal ACE approached 20; slightly below the climatological norm of 24. Cyclone activity was weaker in the second half of the season, based on ACE scores.

### Southern Hemisphere

During the calendar year 2021, there were two notable cyclones that affected Australia: Cyclone Seroja and Cyclone Niran. Seroja struck the west coast of Australia in April and caused notable damage in areas of Western Australia after first prompting catastrophic damage and fatalities in parts of Indonesia and Timor-Leste. Niran grazed the coast of Queensland, Australia and left extensive crop damage and later caused widespread property damage in New Caledonia. Elsewhere, Cyclone Eloise rapidly intensified to a Category 2 equivalent hurricane prior to making landfall in Mozambique. Damage was much less than initially feared.

### Climate Change and Tropical Cyclones

The influence of climate change on tropical cyclones is becoming more evident on an annual basis. However, what remains less obvious is a simple explanation of what these influences mean on tropical cyclone behavior on a global and regional level.

The Sixth Assessment Report (AR6) from the IPCC provided some clarity on the subject but continued to reiterate the uncertainties that exist. Here is a list of known impacts of climate change on tropical cyclones as identified by peer reviewed literature in AR6:



Higher percentage of hurricane-equivalent storms reaching the highest intensity ratings: Category 4/5



Warmer and wetter atmosphere translating to heavier precipitation on a per-storm basis



Slowing forward motion and reduced rates of inland decay following landfall



Warmer sea surface temperatures aiding more occurrences of rapid intensification



Storms tracking at a higher latitude due to warmer waters from ocean circulation pattern changes

While there is relative confidence in the five points listed above, there is less confidence in what climate change means in the context of the overall number of storms each year and subsequent landfalls. Based on historical and official global data records, there is not yet any obvious signs of an increasing trend of more storms and/or landfalls. Interannual seasonal variability remains a highly important piece of context as large-scale environment influences – such as the El Niño Southern Oscillation (ENSO) – can cause some basins to have enhanced activity and others less activity. Since 1995, the Atlantic Ocean had a higher number of storm frequency given more La Niña-like conditions in the Pacific Ocean. This has conversely led to a major reduction in Northwest Pacific Ocean storm frequency during the same timeframe. This “yo-yo” type of tropical cyclone genesis behavior across basins is one of the difficulties in fully acknowledging any climate change influence on the overall frequency of events.

**Note:** Advances in technology will continue to aid in the detection of weaker and shorter-lived storms. Such observational improvements are why the most

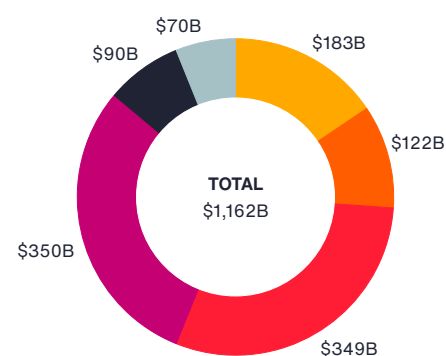
accurate assessments for climate change attribution typically begin in the Satellite era (mid-1960s) in the Atlantic Ocean and from 1980-onward in the rest of the world’s basins. It signifies the highest quality data.

For the insurance industry and beyond, the most important aspect of climate change research is on how it may affect tropical cyclone landfall behavior. Like research focusing on overall frequency, there is not yet an obvious trend in global landfalls. However, as the behavior of storms further evolves and a higher percentage of storms reach Category 3/4/5 intensity, this increases the probability of such landfalls. In the Atlantic Ocean, this is particularly important. Within the full historical record, storms making landfall on the U.S. mainland with at least Category 1 intensity caused nearly \$1 trillion in economic damage. More than three-quarters of those losses are tied to storms coming ashore as a Category 3/4/5.

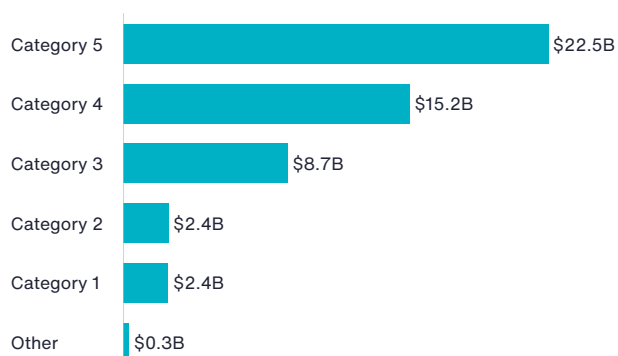
**Aon’s Impact Forecasting is partnering with Columbia University to implement new climate change tropical cyclone research into its catastrophe model suite.**

**Exhibit 34: U.S. Economic Losses from Tropical Cyclones since 1900 by Landfall Category**

Cumulative Economic Losses by Landfall Category (2021 USD billion)



Average Economic Loss by Landfall Category (2021 USD billion)



Category 1 Category 2 Category 3 Category 4 Category 5 Other

Data: Aon (Catastrophe Insight)

**2021 Global Tropical Cyclone Review**

**Exhibit 35: 2021 Global Tropical Cyclone Activity by Basin compared to climatology\***

Basin	Named Storms		Hurricanes		Major Hurricanes		ACE	
	2021	Climo	2021	Climo	2021	Climo	2021	Climo
Atlantic	21	14	7	7	4	3	145.7	122.5
East Pacific	19	17	8	9	2	5	94.0	132.7
West Pacific	23	25	10	16	5	9	209.6	299.6
North Indian	5	5	3	2	1	1	20.5	24.3
Northern Hemisphere	68	61	28	34	12	18	469.7	579.1
South Pacific	10	10	4	5	1	2	31.6	69.4
South Indian	17	16	5	9	3	4	119.7	138.4
Southern Hemisphere	27	26	9	14	4	6	151.3	207.8
GLOBAL	95	88	37	48	16	25	621.0	787

\*Compared to the 1991-2020 climatological average. Southern Hemisphere statistics include full calendar year 2021 events. Source: National Hurricane Center; Joint Typhoon Warning Center; Colorado State University

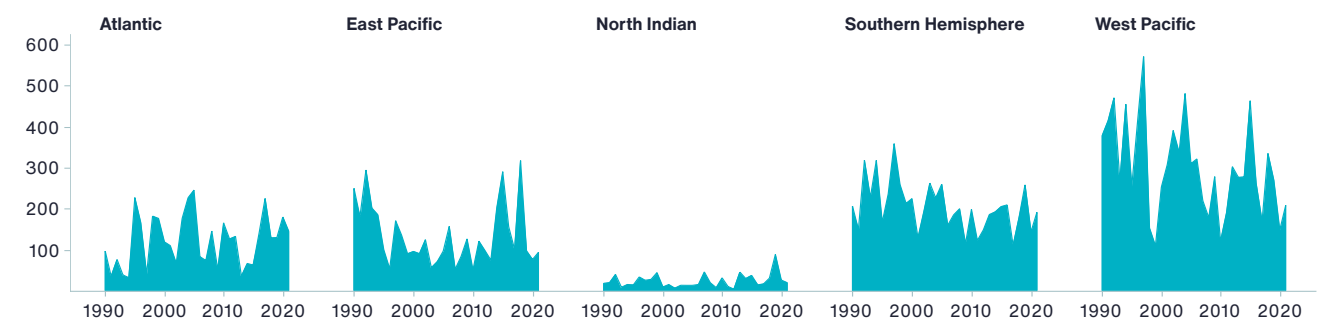
A different type and meaningful measurement of how active or significant tropical cyclone activity is for an individual storm or basin is Accumulated Cyclone Energy (ACE). Total ACE in 2021 was preliminarily tallied at 621. This was well below the climatological average of 787. Despite being below its own regional average, the West Pacific Basin had the highest ACE at nearly 210. The Atlantic was the only basin above its climatology.

The general trend of ACE dating to 1990 has not shown any appreciable change. The annual rate of growth is flat at -0.80 percent. Such a return suggests that complex global variables, including the influence of ENSO, results in different seasonal behavior across basins. History has shown that when the Atlantic

Ocean has an above average year, the opposite is true in the Pacific Ocean – and vice versa. It further confirms that the total number of storms has not appreciably changed on an annual basis over time.

Changes to storm behavior are more evident regarding intensity. As noted earlier, this is where climate change influence is more obvious. Warmer atmosphere and oceans allow more opportunity for rapid intensification and maintaining storm intensity for a longer period. Storm data shows that a higher percentage of tropical cyclones reaching hurricane-equivalent intensities are now becoming Category 4 or 5 events. This enhances the potential for greater risk and loss potential to coastal and inland assets.

**Exhibit 36: Global Accumulated Cyclone Energy (ACE) by Basin**



Data: Colorado State University. Graphic: Aon (Catastrophe Insight)



## Focus Topic: Severe Convective Storms

### Increased Losses Change Focus for Re/Insurers

The risks associated with severe convective storms are well documented. While tornadoes drive most external media coverage, the reality is hail and non-tornadic straight-line winds are an increasing portion of annual losses for the peril on a global scale. SCS has accounted for higher annual insured losses than tropical cyclones in more than two-thirds of years dating to 1990. As losses continue to go up, it is causing a reevaluation of how insurers and reinsurers view the risk. A December 2021 AM Best report noted that increasing losses “will lead to insurers re-examining their reinsurance protection and to reinsurers becoming more cautious as they look at demand and risk, which may be reflected through pricing, limits, deductibles, and other underwriting tools.”

### United States

The United States is the SCS loss capital of the world, and 2021 reaffirmed its unofficial title. Public and private insured losses totaled nearly \$27 billion and topped \$20 billion for the third consecutive year, and the fourth time in five years. It was the third-costliest year on record for U.S. insurers with the peril, only

behind 2020 (\$38 billion) and 2011 (\$33 billion). Aggregate loss totals at this level continue to suggest this is an increasingly expensive peril for the industry. It may require a shift in the “new normal” being a minimal \$10 billion annual industry loss to instead at least \$15 to \$20 billion.

There is no question that the U.S. dominates annual SCS insured losses. The number of insured loss events that top \$500 million has increased globally in recent decades, but the increase is most pronounced in the U.S. The country has accounted for 79 percent of all SCS events beyond \$500 million dating to 1990. After a record 19 events in 2020, another 14 were recorded in 2021. The rest of the world had three such events.

Identifying risk and attempting to limit damage via improved building code practices and enforcement is a pervasive challenge. However, population and exposure patterns across the U.S. continue to shift into warmer and more southern climates that have increasingly become larger annual loss drivers. With the most favorable SCS environments shifting a bit further east from the traditional “Tornado Alley” across the Plains, this is also causing the insurance industry to reassess the risk from a hazard and property perspective.

The costliest U.S. SCS event from an economic and insured loss perspective resulted from an unprecedented tornado outbreak and associated hail and non-tornadic damaging winds on December 10-11. It spawned at least 70 tornadoes across the Mississippi and Ohio River Valley, including two EF4 tornadoes. The most notable EF4 tornado tracked nearly 166 miles (267 kilometers) across western Kentucky – becoming the longest surveyed December tornado in the modern era (since 1950). The tornadoes alone claimed 90 lives, plus three additional non-tornadic fatalities. This outbreak was followed by an extraordinary mid-December derecho that left tremendous damage from the Rockies across the Plains and into the Upper Midwest. Beyond the straight-line wind damage included 117 tornado touchdowns during an 8-hour span. This was the largest single-day December outbreak on record and one of the highest single-day tallies for any month. December ended up being one of the costliest SCS months of the year. In total, there were 12 individual billion-dollar SCS economic loss events.

The Storm Prediction Center (SPC) preliminarily tallied 1,376 tornadoes in 2021. This is subject to change. This was above the Doppler radar era (1990-Present) average of roughly 1,200. While April featured the lowest number of U.S. tornadoes since 1993, the start of the ‘second-season’ in October saw exceptional tornadic activity, followed by the previously noted record activity in December. At least 24 tornadoes were rated EF3 (21) or EF4 (3). The U.S. has not recorded an EF5 tornado since May 2013; the longest such streak since NOAA began keeping tornado statistics in 1950. Thirteen individual tornadoes combined to kill at least 101 people; the highest tornado-related death total since 2011 (553).

### ‘Late Season’ U.S. Tornadoes

The bulk of U.S. tornadoes have historically occurred during the peak tornado season months of April, May, and June. This, unsurprisingly, holds true for the most intense tornadoes (F/EF3+), though the month of March recorded a notable volume of such incidents. The months of October, November and December are typically quieter, though strong tornadoes can occur

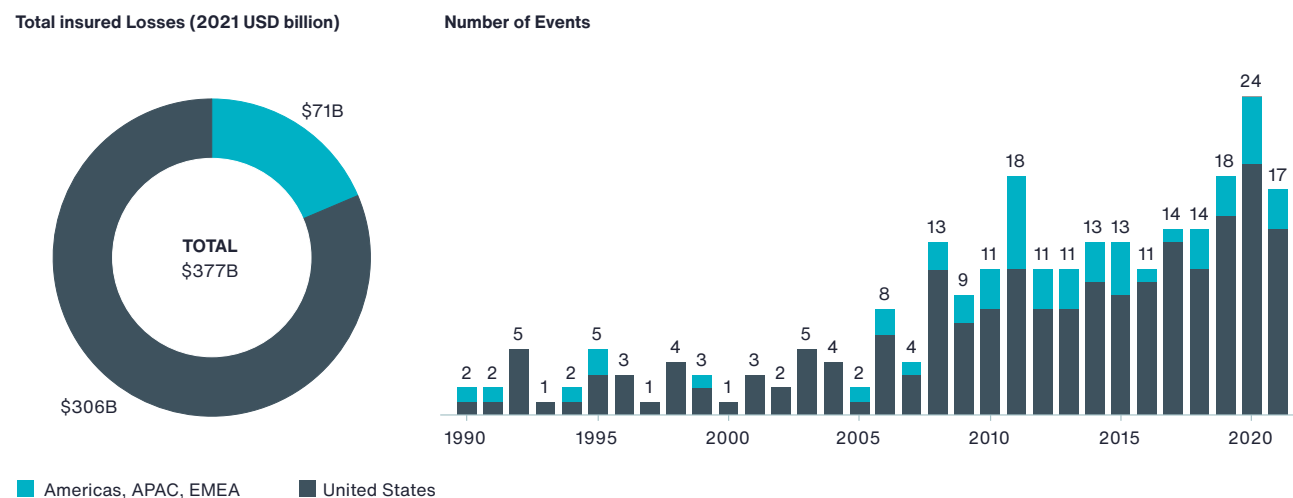
at any time of year if the atmospheric conditions are right, as was observed in 2021. While no change in the overall annual frequency of tornadoes has been observed in the United States, recent trends and climate-model projections indicate an increasingly greater occurrence of future severe weather outbreaks extending into the late season. This is particularly true in a climate change environment, as favorable moisture and heat are available later into the year than what was historically observed.

### Europe

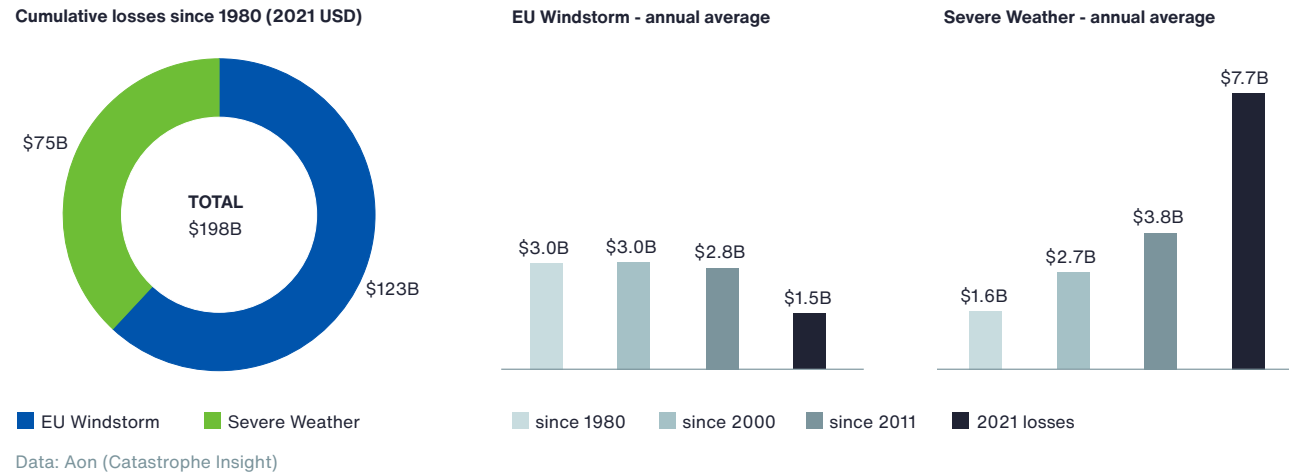
While the United States accounted for most of the SCS headlines in 2021, it was a very active and expensive year for the peril in Europe. The nearly \$7.7 billion in insured SCS losses marked the second-highest year for the continent on record, only trailing the \$8 billion incurred in 2013. Most of the losses came from two extended periods of severe weather in mid/late June that left extensive damage across western and central portions of Europe.

The main outbreak from June 17-25 was initially fueled by record temperatures and a pattern that caused intense thunderstorms forming along a stalled trough / frontal boundary as multiple areas of low pressure formed. Convective storms throughout the second half of June spawned significant hail, wind, and tornado activity in 14 European countries. Germany was the hardest hit as large hail accounted for the bulk of the country’s €1.7 billion (\$2.0 billion) in insurance payouts. Insurers in Switzerland reported losses in excess of CHF1.35 billion (\$1.5 billion) in the costliest stretch of severe convective storms on record by far. Austria endured its costliest natural disaster event on record for the local insurance industry following extensive hail damage that affected homes, automobiles, and the agricultural sector. The strongest confirmed tornado ever recorded in the Czech Republic, an F4, left catastrophic damage in several municipalities in the South Moravia region (Hrušky, Moravská Nová Ves, Mikulčice, Lužice and Hodonín). The June 17-25 outbreak alone cost European insurers \$3.5 billion in payouts; making it one of the costliest global SCS events of 2021.

Exhibit 37: Total Insured losses from SCS events that caused at least USD500 million insured loss



**Exhibit 38: European insured losses from winter and summer storms – historical comparison**



**Climate Change and Severe Convective Storms**

The significant increase in SCS losses accelerated the debate as to what is the main driver. While it is well chronicled that the United States dominates most SCS losses, many other parts of the world – including Canada, Europe, Asia, South Africa, and Australia – are also facing the reality of greater risk from the peril. Are there more reports of tornadoes, hail, and straight-line winds? Are there more people now living in harm’s way? Is it climate change? The answer to all three questions is “yes”, though it is a complex answer that requires an understanding of how much uncertainty exists and that uncertainty does not mean change is not occurring.

Climate research vastly improved in the last decade with advances in technology and computational power enabling the handling of highly complex equations and scenarios required to simulate future conditions. It has allowed for greater clarity in identifying where the science has the highest level of confidence of where climate change is influencing individual events and more broadly on overall peril behavior.

The least understood peril with the least amount of confidence on event attribution is SCS. Why? Global climate models (GCMs) are meant to identify future atmospheric and oceanic conditions at a decadal or centennial scale. The models can provide a useful overview of what global or regionally downscaled

conditions may look like, but they are not meant to specifically identify how that may translate to storm event frequency or individual event behavior. GCMs are not meant to be interpreted as a daily weather forecast projection. For simplicity, this means GCMs:

**CAN** provide an overview of how the large-scale environmental “ingredients” may be changing that may increase the potential of more widespread or intense SCS outbreaks.

**CANNOT** provide specific forecast guidance or attribution to whether the total number of tornadoes, hail or straight-line wind occurrences will increase.

A recent study on climate change and SCS in the United States noted that for every 1°C (1.8°F) increase in atmospheric warming, it would cause a 14 to 25 percent increase in the number of favorable environments in the spring, fall and winter months. This is due to more available energy from higher surface temperatures. Note that more favorable ingredients do not always translate to more events. It is also important to remind that climate change influence on SCS environments is not globally uniform and will show regional differences.

*Aon’s Impact Forecasting will soon be announcing a new partnership that will work to implement new climate change research into its United States SCS catastrophe model.*

**Focus Topic: Flooding**

**July: Record-Breaking Industry Events**

The month of July is often marked by peak monsoon-influenced flooding in parts of Asia and Africa. The combination of summertime warmth, advances in seasonal frontal boundaries, and ample low-level moisture can initiate significant overflows of rivers, flash floods and other fluvial / pluvial-triggered inundation. However, as July 2021 proved, historic rainfall and subsequent flooding can occur in any month and in any region.

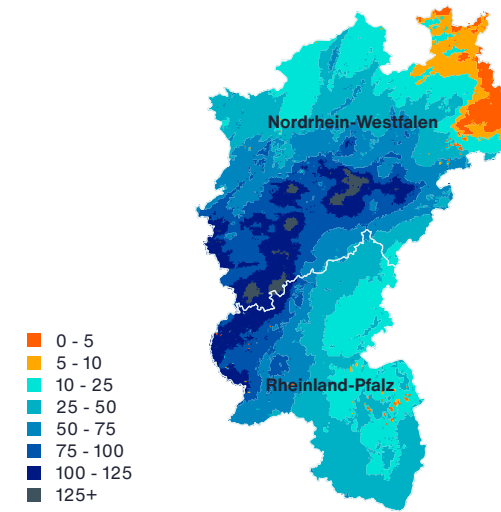
**Europe**

Portions of Western and Central Europe were affected by extreme 72-hour precipitation totals in mid-July, affecting parts of Western Germany, Belgium, the Netherlands, and Luxembourg. The most prolific impacts were felt in Germany, where some areas saw rainfall totals nearing 200 percent of its monthly average. The floods, initiated by an area of low pressure named “Bernd” by Free University of Berlin, were most impactful within the central reaches of the Rhine River basin.

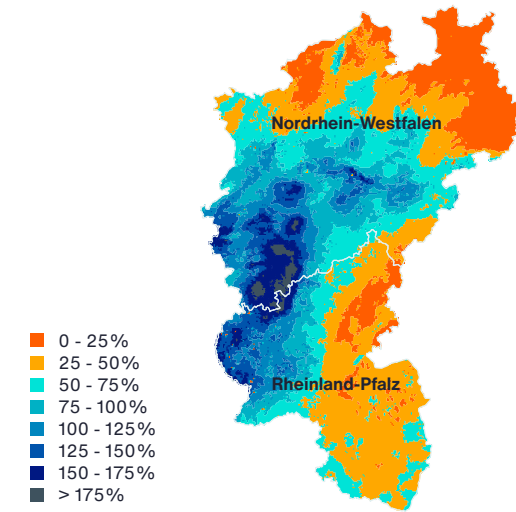
Based on various national and individual industry loss estimates, the July floods became the costliest natural disaster event for insurers ever recorded in Europe on an inflation-adjusted basis. Robust loss development occurred in the months after the event. This was most pronounced in Germany, where the German Insurance Association (GDV) originally estimated an insured loss of €4 to €5 billion (\$4.5 to \$5.7 billion) in the weeks after the event. That total steadily increased, with the most current estimate listed at €8.2 billion (\$9.3 billion). The overall European insured loss total is listed at €11.5 billion (\$13 billion). This surpassed 1990’s Windstorm Daria, which resulted in insured losses of \$5.9 billion at the time, or \$12.4 billion in today’s dollars. This event additionally became the costliest individual insurance industry event on record in Germany, Belgium, and Luxembourg. It became the industry’s second costliest flooding event on record globally, only behind the Thailand Floods of 2011 (\$18.5 billion; 2021 USD).

**Exhibit 39: Radar Estimate of Rainfall in Western Germany on July 12-15, 2021**

**Total Rainfall Estimate for July 12-15 2021 (mm)**



**July 12-15 2021 rainfall relative to July monthly Average**



Data: DWD. Graphic: Aon (Catastrophe Insight)

**China**

Summer monsoonal rains in China are a regular feature that have long caused flooding issues throughout the Yangtze and Yellow River Basins. However, the traditional “Meiyu front” – known as the seasonal “Plum Rain” in China – was amplified by additional moisture indirectly fed into the Meiyu frontal boundary via Typhoon In-fa. This tremendous push of moisture centered on Henan Province, particularly in Zhengzhou City (population: 12.6 million) in mid/late July.

A historic volume of rainfall during a 72-hour period created catastrophic flooding and subsequent damage throughout Zhengzhou and neighboring communities. For one 24-hour period alone ending

during the morning of July 21, a remarkable 612.9 millimeters (24.13 inches) of rain fell. This compared to total annual average rainfall of 640.8 millimeters (25.23 inches). Between 4 and 5 PM local time on July 20, Zhengzhou registered 201.9 millimeters (7.95 inches) of rain. The graphic below highlights hourly rainfall from July 19 to July 21.

The flooding led to more than 552,000 filed insurance claims, with the local Henan insurance industry citing total losses of \$1.9 billion. This marked the costliest weather event ever recorded for Chinese insurers. The overall economic cost in Henan was listed at ¥120 billion (\$19 billion), with a sizeable portion occurring in Zhengzhou.

**The Role of Insurance in Major Flood Events**

The July 2021 floods in Germany revealed stark regional differences in insurance take-up rates between federal states. This difference further underscored the challenges of trying to lower the protection gap in a world where climate change impacts are becoming more apparent. The German Insurance Association (GDV) noted that only 37 percent of buildings in Rheinland-Pfalz, the most affected state, were comprehensively insured against flood damage. This compared to 47 percent in Nordrhein-Westfalen, which was close to the national average.

Despite the high insurance cost in Germany of €8.2 billion (\$9.3 billion), the overall economic cost was a much higher €31 billion (\$35 billion). This included extensive impacts to property, infrastructure, agriculture, and other sectors. Only 26 percent of the total was covered by insurance, a ratio comparable to those seen in historical floods in the country in 2013 (26 percent) and 2002 (19 percent). It reveals that much more work is needed to limit the protection gap and ensure more residential and commercial assets are properly covered ahead of the inevitable next event.

On the other side of the world in Henan Province, China, it was previously mentioned that provincial authorities estimated total economic losses at \$19 billion. Even though the event primarily impacted the highly urbanized region of the Zhengzhou metro, only around 10 percent of the overall economic cost was covered by insurers. While this represents an improvement based on other major historic Chinese flood events, it shows that a significant growth opportunity for the insurance market on the residential and commercial sides of the business.

It is worth reminding that loss development – also known as “loss creep” – is standard practice in the aftermath of major disaster events. The complexity of conducting damage assessments in the immediate aftermath, plus accounting for challenging issues such as prolonged business interruption, increased supply chain costs, claims litigation, third-party interference, etc. can all lead to higher claims payouts or delayed data reporting. As the global economy becomes increasingly interconnected, these types of events require more time to take full stock of not only the physical damage, but the additional direct costs.

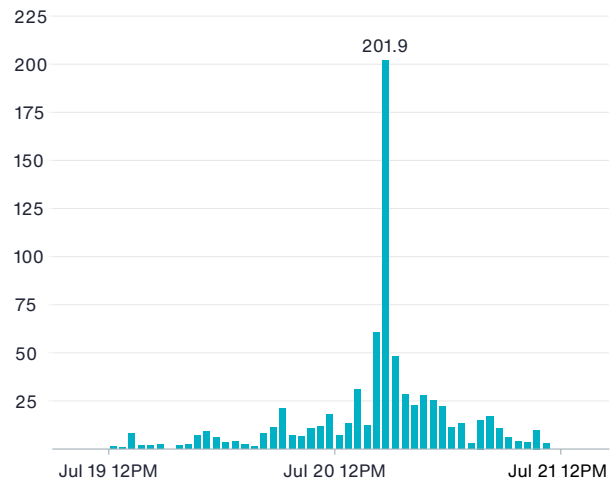
**Climate Change and Extreme Precipitation**

The question of climate change attribution in the aftermath of extreme precipitation / flooding events always garners excessive attention in academic and media circles. While there is much higher confidence in the role of climate change on extreme rainfall than other perils, it remains quite difficult to precisely quantify what percentage of rainfall or damage is attributable to the phenomena. Scientific research shows that as the oceans and atmosphere warm, this accelerates the evaporation process over the oceans or other large bodies of water and puts more water / moisture into the atmosphere. A basic law of thermodynamics – the Clausius-Clapeyron equation – notes that for each 1°C (1.8°F) of atmospheric warming the air can hold up to 7 percent more moisture. Simply put: Warmer air can hold more water vapor than cooler air. This increases the probability of heavier rain events.

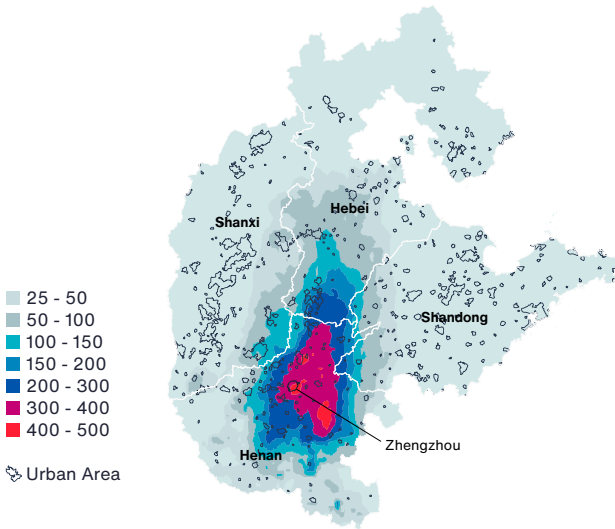
***Aon’s Impact Forecasting is partnering with scientists from the Karlsruhe Institute of Technology (KIT) to implement new climate change research into its European flood catastrophe model.***

**Exhibit 40: Record-breaking rainfall in Henan in July 2021**

Hourly observed rainfall in Zhengzhou on July 19-21, 2021 (mm)



Satellite rainfall estimate for July 19-21, 2021 (mm)



Data: CMA, NASA / GPM. Graphic: Aon (Catastrophe Insight)



## Focus Topic: Wildfire

### Shifting Perspective on Wildfire Losses

The rising costs of wildfires in the United States, Australia, Canada, and Portugal in the last decade resulted in a notable shift in how we view the peril. The combination of more extreme hazard behavior, shifting preventative suppression tactics and accelerating population / exposure into known fire locations is leading to more risk, and subsequently, greater losses.

Prior to 2015, the globe recorded just four years in which aggregated wildfire-related insured losses had topped \$2 billion (2021 USD). The year 2021 marked the seventh consecutive year that insured wildfire losses surpassed that threshold. There have been 21 individual billion-dollar insured fires globally. Sixteen have occurred since 2015, and all but two of those events were in the United States. During the peak industry loss years of 2017 (\$18 billion), 2018 (\$17 billion), and 2020 (\$14 billion), the billion-dollar damage costs from these fires prompted important conversations on the rising costs of the peril. However, prior to 2015, the thought of a \$500 million or \$1 billion industry loss from a wildfire – or at least 1,000 properties destroyed – would generate

significant attention. As larger and more destructive fires have become more commonplace within the past five years, there has become a general acceptance of fire events surpassing \$1 billion. In similarity with the SCS peril, individual wildfires now seem to require a multi-billion-dollar damage bill to truly earn the full interest of the market. This acceptance of a “new normal” highlights the rapid shift in how the peril is viewed.

In 2021, the most notable fires were found in the U.S., where the Dixie and Caldor fires in California combined to top \$2 billion in insured losses. The Marshall Fire ignited in late December near Boulder, Colorado and became the state’s most destructive fire on record. The fire resulted in \$2 billion in insured losses and became the first fire event to reach that threshold in the United States outside of California. Extreme heat in Canada’s British Columbia helped ignite numerous blazes, including the Lytton Creek and White Rock Lake fires. Elsewhere, high temperatures and drought aided major wildfires in parts of the Mediterranean, Russia’s Siberian region, and Australia.

### Climate Change & Wildfires

Wildfires increased in prominence from a financial loss and humanitarian perspective around the world in recent years. The United States, Australia, Portugal, Greece, Spain, Brazil, and Russia – among many others – reported significant and historic fire activity in the past decade alone. These impacts are enhanced by the combination of severe drought, prolonged above-average temperatures, poor land management and illegal agricultural practices. While human activity is a major factor in the ignition of wildfire events, the ground conditions in place have also increasingly become more conducive for rapid fire spread and more unusual fire behavior.

No region of the world has seen more dramatic impacts of worsening fire conditions and resultant damage than the state of California in the United States. While large fires have been recorded in California for more than 100 years, there is a noticeable shift in the seasonality of fire events, the intensity of the fires themselves, and surface conditions fueling the more unusual activity.

A key climate change factor influencing wildfire risk is the notable shift in the timing of the rainy season in California and the U.S. West. [Peer reviewed research](#) concludes that rainy seasons are shortening but can induce more intense precipitation events. This means that fire seasons and summer-like conditions now extend longer into the calendar year. California’s wet season now begins 27 days later than it did in the 1960s.

As a result, the California Department of Forestry and Fire Protection (Cal Fire) recently declared the term “fire season” outdated as wildfire risk is now prevalent during the full calendar year. This year-round wildfire potential means a greater likelihood of more extreme fire behavior that can translate to hotter, larger, and faster spreading fires and more damaging impacts. [A 2018 study](#) sponsored by the California Natural Resources Agency estimated that the average acres burned annually in the California Sierra Foothills could significantly increase in the coming decades. Such increased acreage burned could increase the number of postal codes “at risk” by mid-century.

The structure-to-risk index reflects the percentage of structures affected by wildfire and considers the combined effect of projected acres burned and future population growth. This helps tie climate change risk with the insurance market.

### Wildfires and Climate Change: What’s Next?

While there are obvious signs of climate change influence on the wildfire peril across California and elsewhere around the world, there are additional key factors which are resulting in increased loss costs. Most include the significant growth of population and exposure into known fire locations – also known as the Wildland Urban Interface (WUI) or Intermix. These are areas where fire risk is highest.

More exposure and worsening wildfire behavior contributed to a near complete re-write of the modern California record book from an acre burned, destroyed structures and fatality standpoint in the past five years alone. This has consequently led to combined losses totaling beyond \$40 billion for the insurance industry alone since 2017.

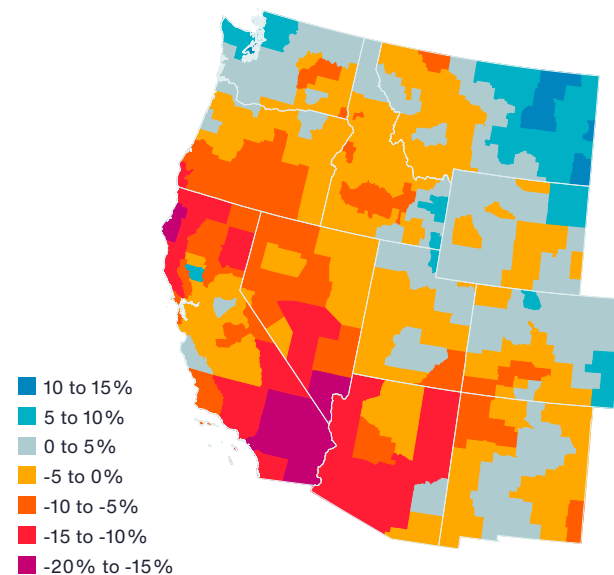
As climate change makes wildfire activity more challenging in the future, it is essential for strategic planning to include mitigation measures for homes and businesses which insist on living in these high-risk areas. This could include:

- Enforcing or mandating defensible space between vegetation and a structure
- Installing fire resistant or less flammable material for roofing, siding, and/or decking
- Maximizing distance between properties
- Vastly improved wildfire risk mapping
- Enhancing infrastructure to improve evacuation and firefighting efforts

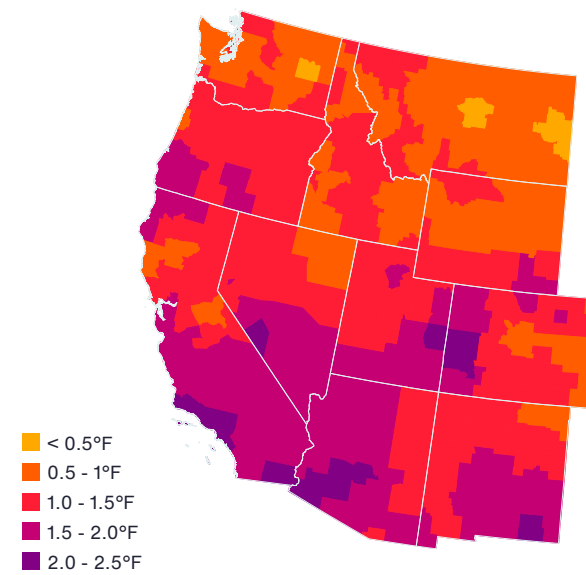
*Aon’s Impact Forecasting will soon be announcing a new partnership that will work to implement new climate change research into its United States wildfire catastrophe model.*

Exhibit 41: Western U.S. Fire Season Climatology (1991-2020) Compared to 20<sup>th</sup> Century Average

May - November Precipitation Difference



May - November Average Temperature Difference



Data: NOAA. Graphic: Aon (Catastrophe Insight)

## Focus Topic: Drought and Extreme Heat

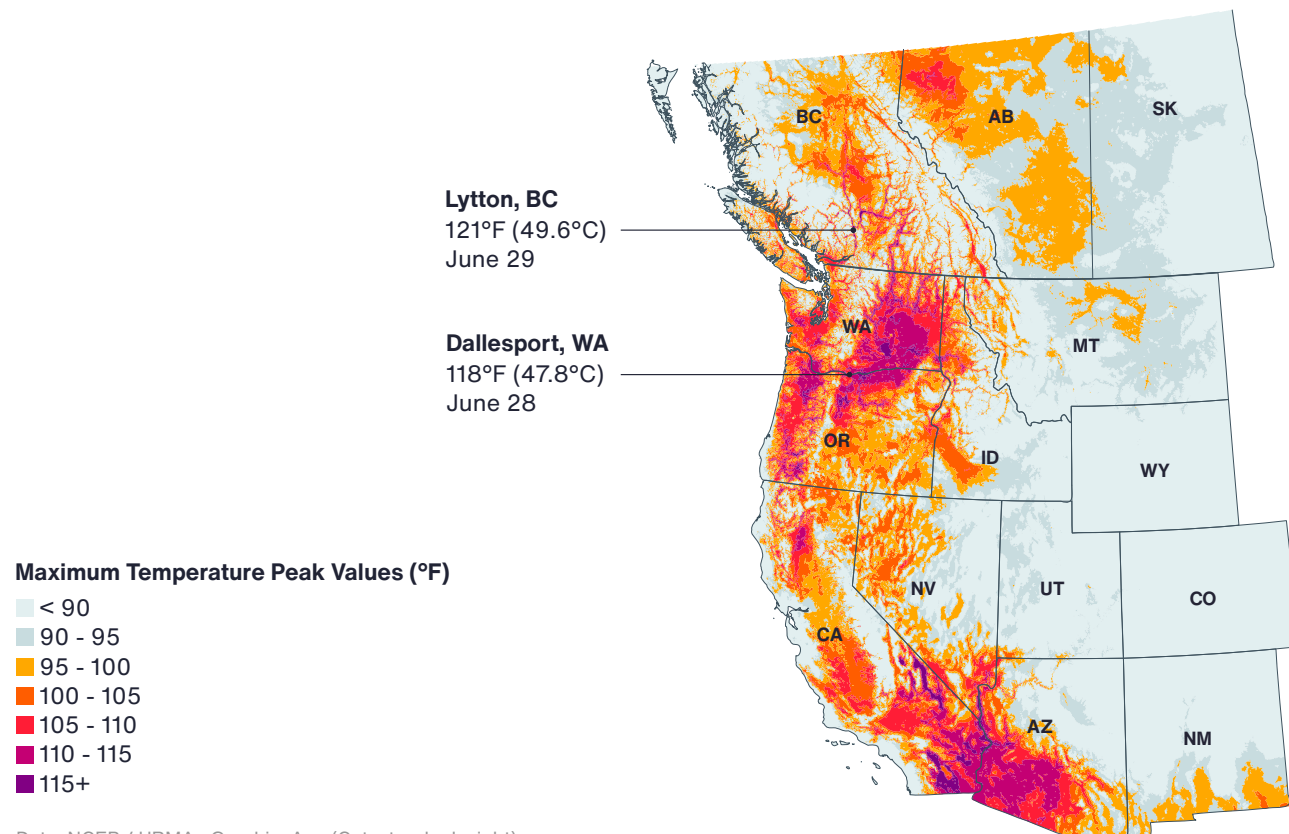
### 2021: Historic Heat Waves

Numerous all-time or monthly extreme heat records were broken in many areas of the world in 2021, though perhaps the most notable event occurred in Western North America in late June. An anomalous rise in the jet stream allowed for a “heat dome” to form and settle for several days in the United States (Pacific Northwest) and Canada (British Columbia). The unprecedented warmth was [noted by NOAA](#) as a 1-in-1,000-year occurrence; or having a 0.1 percent chance of happening in any given year. A weather station in Lytton, British Columbia set a new Canadian national heat record on three consecutive days: peaking at 121°F (49.6°C) on June 29. This also set a new world record for the most extreme high temperature observed north of 45 degrees latitude. The next day, 90 percent of the Village of Lytton was destroyed by a major wildfire. Across the border in the

state of Washington at Dallesport, an all-time state record-tying 118°F (47.8°C) was registered on June 28. Oregon also broke its all-time state maximum temperature record on June 29 at 118°F (47.8°C). Record-breaking warm overnight temperatures and a disproportionate number of households in the Pacific Northwest without air-conditioning enhanced the health impacts of the heatwave. While it remains difficult to know the exact total of direct heat-related fatalities during the event, it was estimated that more than 1,000 casualties occurred. Most of those were in British Columbia.

Extreme summer heat was also seen in Europe. A new European record of 119.8°F (48.8°C) was registered in Sicily, Italy on August 11 – though the record still needed to be verified by the World Meteorological Organization (WMO).

**Exhibit 42: Peak Hourly Temperatures during Western North America Heatwave of June 2021**



Data: NCEP / URMA. Graphic: Aon (Catastrophe Insight)

### North and South America: Major Drought Impacts

Historic drought conditions affected large portions of North and South America in 2021, peaking in the spring and summer months. In Mexico, one of the worst droughts in decades affected 75 percent of the country by April. Nearly one-fifth of the country experienced extreme or exceptional drought conditions by May. Dozens of large reservoirs in central and northern Mexico saw water level drop below 25 percent of capacity as major impacts to agriculture were incurred. In Canada, prolonged drought conditions across the Prairies had a significant and multi-billion-dollar (USD) impact on agricultural and livestock production. Extensive droughts also impacted the United States and South America.

#### United States

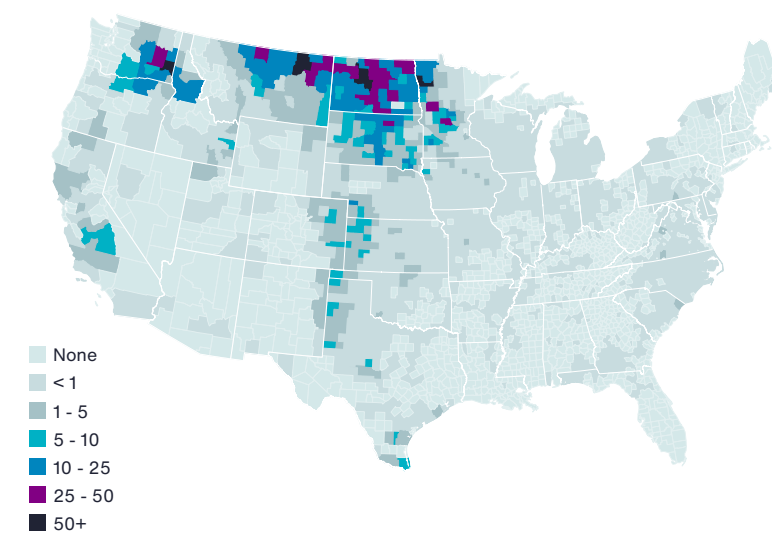
The physical and financial toll due to prolonged drought and above-average temperatures left a major strain on the agricultural and agribusiness sectors as direct economic losses were anticipated to exceed \$9 billion. The severe and ongoing drought conditions

were a continuation of what had originally developed in 2020 across parts of the U.S. West, Southwest, and Northern Tier. Data from the United States Drought Monitor (USDM) indicated that 27 percent of the contiguous United States (CONUS) was impacted by extreme or exceptional drought conditions by August; the highest percentage of CONUS since reliable records began being kept in 2000. Drought conditions were particularly severe in California, where 89 percent of the state endured extreme or exceptional drought by early August. At the peak, more than 95 percent of the state experienced severe drought conditions before an active and early start to the 2021/22 water year saw multiple atmospheric river events begin to ease the drought.

The drought conditions resulted in considerable payouts via the United States Department of Agriculture’s (USDA’s) Risk Management Agency (RMA) crop insurance program. More than \$4 billion in indemnity payouts were made; the highest since 2013. The peak year resulting from drought, heat and excess sun related payouts occurred during the historic drought of 2012 (\$17 billion).

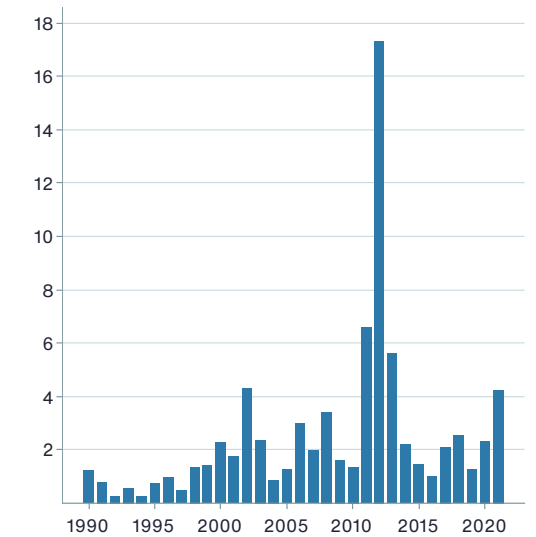
**Exhibit 43: U.S. Crop Insurance Payments from Drought, Heat, Excess Sun**

2021 Payments by County (USD million)



Data: USDA. Graphic: Aon (Catastrophe Insight)

Total Annual Payments (2021 USD billion)



**South America**

A recent study published by the [European Commission](#) highlighted the severity and impacts of extreme drought in the South American La Plata Basin since 2019. The La Plata Basin is the second-largest river basin in South America, accounting for 17 percent of the continent’s land area. The multiple episodes of La Niña (often linked to markedly lower median rainfall across the basin) is a contributing factor of the region’s drought. In 2021, Argentina, Brazil and Paraguay each individually declared formal drought emergencies. The Paraná River, the second-longest in South America, saw water levels recede to their lowest since 1944. This resulted in significant

impacts to the transport of goods and the volume of available drinking water across the region. The longevity and intensity of the drought additionally caused a major reduction in energy production. The Itaipú Dam, one of the most important hydroelectric facilities in the region, saw its energy output in 2021 fall by nearly 40 percent from its record high of 103,000 gigawatt hours in 2016. This prompted energy shortages in many communities in both countries. The drought and its connected impacts to agriculture, agribusiness and other residential and commercial property across South America was a multi-billion-dollar impact.

**Focus Topic: Winter Weather**

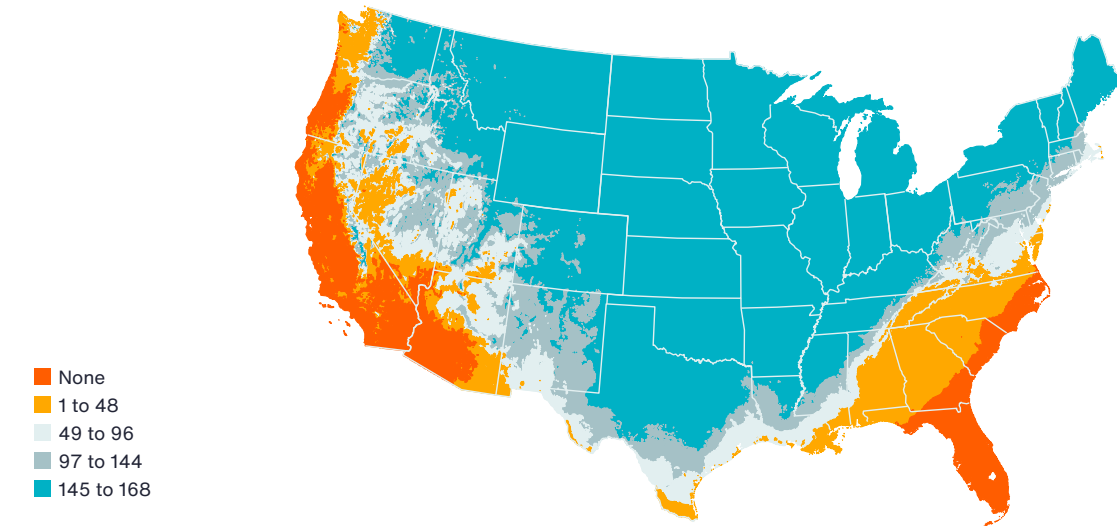
**February Polar Vortex**

The winter weather peril has historically resulted in a one or two billion-dollar economic or insured loss events on an annual basis – mostly due to heavy snowfall or prolonged cold – but it has never been a major annual loss driver even on an aggregate basis. That changed in 2021. Total economic losses from winter weather were \$38 billion, the highest on record. Most of those losses, \$25 billion, were tied to a single event that affected the United States and Mexico in February. That event was associated with a prolonged Polar Vortex that brought nearly a full consecutive week of sub-freezing temperatures to an area that extended as far south as the U.S. and Mexico border. Losses from the event were amplified by an inadequately weatherized electrical grid, limited preparation for a winter weather event at such magnitude and a lack of targeted investment into other infrastructure and maintenance to handle increasingly volatile weather conditions in a climate change environment. The massive disruption to the electrical grid caused extensive indoor flooding due to burst / frozen pipes in residential and commercial

structures. Many businesses also endured extended business interruption. Total insurance claims payouts – including those from residential, commercial, and agribusiness entities – were listed at \$15 billion. This became the costliest event for the peril on record; surpassing the previous record of \$4 billion from the March 1993 U.S. “Storm of the Century”.

The high cost of the February Polar Vortex and winter weather event initiated discussion on whether this is now a peril that needs consideration as a more dominant and regular future loss driver. The answer is complex since this event was substantial but not without precedent in the historical record. The intensity and longevity shone a bright light where vulnerabilities exist within current infrastructure. If these types of prolonged cold events are expected to become more prevalent on a global scale in the years to come, much more needs to be done to prepare and mitigate against future losses. There is an enormous opportunity for proactive steps forward based on the lessons learned from this event. It is imperative we act on those lessons.

**Exhibit 44: Hours At or Below Freezing (32°F / 0°C) Recorded From February 13 to 19 (CST)**



Data: URMA / NOAA. Graphic: Aon (Catastrophe Insight)



**Climate Change: Polar Vortex / Extreme Temperatures**

The February 2021 North America polar vortex event brought renewed focus on what potential role climate change may have on various weather phenomena. Scientific research consistently shows that the most pronounced effects of climate change are most easily observed with extreme temperature behavior. While the extreme maximum highs are expected to become more frequent in their occurrences, the more unusual and pronounced dips in the jet stream also mean that bouts of extreme minimum lows are additionally likely.

As a reminder, the February 2021 event resulted from an intrusion of warm air into the Arctic beginning in January, which subsequently prompted a significant disruption of the polar vortex. Warming in the mid-levels of the atmosphere – known as “Sudden Stratospheric Warming” (SSW) – is known to cause a normally strong (more stable) Polar Vortex to weaken and wavier as pieces (lobes) break off and sink equatorward into North America, Europe, or Asia. When lobes of the Polar Vortex shift southward, this results in a “wavy” jet stream pattern that can sink well into the southern United States – such as seen in February 2021. The southern extent of a particular lobe and its longevity is dependent on the intensity of the cold air dome and air flow patterns at the mid- and upper- levels of the atmosphere.

Further highlighting the intensity of the February polar vortex event, the United States set nearly 3,000 individual daily low temperature records.

This coincided with 2021 ranking as the fourth-most February snow cover dating to 1967 in North America. It included a remarkable 73.2 percent of the contiguous U.S. being covered by snow on February 16, which was the highest daily total since such records began in 2003.

The attribution of climate change to the polar vortex in becoming more unstable during the winter months is an increasingly studied area in [academic research](#). Some initial conclusions suggest that the continued accelerated warming seen in the Arctic is causing more rapid glacial decay and sea ice melt. Such trends appear to be linked in the disruption of larger scale weather patterns across the Northern Hemisphere. This type of pattern disruption can result in more bouts of extreme cold during the winter months and prolonged heat waves during the summer months.

While there are no conclusive emerging trends suggesting that SSW occurrences are happening with more regularity, the expectation of wavier jet streams acting as a conveyor belt of warm air into the Arctic / Antarctic is growing. While the intensity and longevity of the February 2021 cold snap may remain an outlier in the near-term, the probability of occurrence may grow as the atmosphere becomes more unstable in its behavior. Such behavior spawning significant weather extremes can realistically be referred to as “weather weirding”.

**Focus Topic: Additional Perils**

**Earthquake**

There were multiple notable earthquake events in 2021 with consequential impacts. The most significant was the magnitude-7.2 earthquake which struck Haiti’s Tiburon Peninsula on August 14. This tremor left 2,248 people dead and was the deadliest natural peril event of the year. The UN estimated direct damage costs at \$1.62 billion; or nearly 11 percent of Haiti’s Gross Domestic Product (GDP). The most expensive earthquake disaster was an offshore magnitude-7.1 tremor near Fukushima Prefecture, Japan on February 13. The total economic toll was estimated at upwards of \$8 billion. Globally, three earthquakes registered above magnitude-8.0 and 19 at or above magnitude-7.0 in 2021. Nearly all of these did not have a significant impact to life or property.

**Volcanoes**

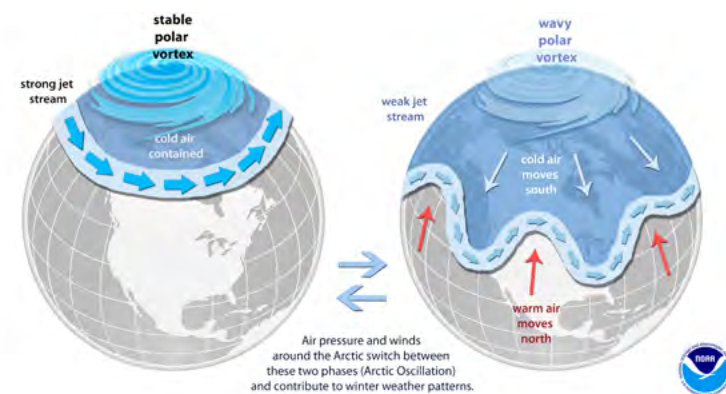
An unexpectedly active year for volcanic activity considerably impacted many parts of the world. It was the costliest year globally for the peril since the eruption of Iceland’s Eyjafjallajökull Volcano in 2010. The most significant was the multi-month eruption of Cumbre Vieja on the Canary Islands’ La Palma island.

The eruption left nearly 3,000 properties destroyed across more than 1,000 hectares (2,471 acres) of land on the western flank of the volcano. It resulted in a \$1 billion economic damage cost. Elsewhere, the La Soufrière volcanic eruption left at least \$554 million in economic loss on the Caribbean island of Saint Vincent. The deadliest eruption of 2021 occurred near Indonesia’s Mount Semeru. At least 57 people were confirmed dead.

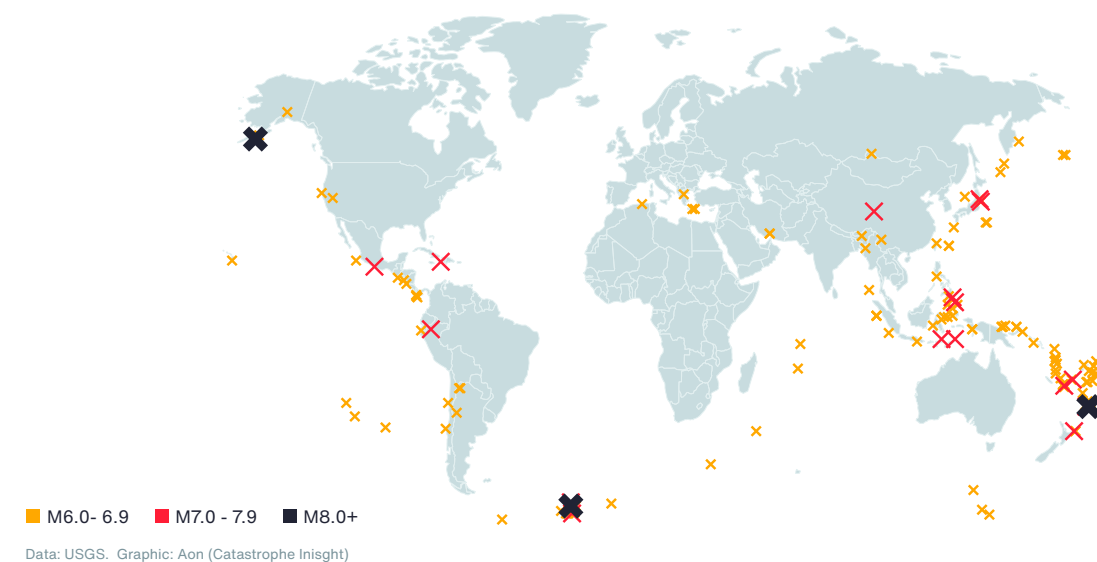
**European Windstorm**

One of the few perils that did not generate a memorable, historic event in 2021 was European Windstorm. Aggregated insured losses for the calendar year only reached \$1.3 billion, which was well below long-term averages and at its lowest since 2016. Windstorm Aurore (also known as Hendrik) was the most significant event of the year. It affected large parts of Western and Central Europe in October. Even though winter storm peril remains the costliest for European insurers (largely because of the peak events in 1990s), its average annual losses have been surpassed by summer storms (severe weather) in recent years.

**Exhibit 45: Explanation of the Polar Vortex Phenomenon**



**Exhibit 46: Global M6.0+ earthquakes in 2021**





# 2021 Climate Review



## IPCC's Sixth Assessment Report Highlights Need for Climate Urgency

The United Nations Intergovernmental Panel on Climate Change (IPCC) released its [Climate Change 2021: The Physical Science Basis](#) from Working Group I, as part of the phased launch of its Sixth Assessment Report (AR6) in August 2021. The report was finalized during the 14<sup>th</sup> Session of Working Group I and the 54<sup>th</sup> Session of the IPCC, and was researched, written and peer-reviewed by 234 scientists from 66 countries. It represents a key document to aid policymakers and the public with an updated scientific assessment on the current and future implications of climate change as well as providing forward-looking options for adaptation and mitigation.

The primary purpose of the IPCC reports, which are released every five to seven years, is to update the current state of the scientific, technical, and socioeconomic knowledge on climate change, and provide suggestions to help reduce the rate at which climate change is taking place. The AR6 Working Group II (Focus: Impacts, Adaptation, and Vulnerability) and AR6 Working Group III (Focus: Mitigation) releases will come in [2022](#).

### Summary Findings from Working Group I's Climate Change 2021: The Physical Science Basis

The report addresses the latest advances in climate science, and combines multiple lines of evidence from paleoclimate, observations, process understanding and global and regional climate simulations. The 26<sup>th</sup> UN Climate Change Conference (COP26) commenced in Glasgow, Scotland in November 2021. In an encouraging sign of positive momentum, nearly 200 countries agreed to the Glasgow Climate Pact which pushed a more urgent set of initiatives and actions to limit emissions and subsequent warming. Primary report takeaways:

- Anthropogenic (human) influence on atmospheric / oceanic climate system warming has accelerated at a rate that is unprecedented during the past 2,000 years and is now considered an indisputable fact

- Greenhouse gas emissions from human activity has accounted for ~1.1°C (1.98°F) of warming since 1850
- Human-influenced climate change is already affecting weather / climate extremes around the world



Climate change effects on weather / climate extremes are unique per peril and will have regional variability

- Further global warming will lead to even greater variability and extremes in the global water cycle
- Compounded extreme events will put further strain on local, regional, and global resources
- Projected changes in extremes will grow with every additional increment of global warming, including increases in the intensity of heat waves, heavy precipitation, agricultural and ecological droughts, proportion of intense tropical cyclones, and reductions in polar sea ice, snow cover, and permafrost
- All five of the projected emission scenarios now assume global temperatures at or above the 1.5°C (2.7°F) threshold set in the 2015 Paris Agreement by 2040. The threshold was based on the preindustrial age temperature average (1850-1900).
- Many changes built into the climate system due to past and future greenhouse gas emissions (such as impacts to the oceans, ice sheets, and sea levels) will be irreversible for centuries or millennia
- **Not Too Late:** Changes in emission output and human behavior can bring meaningful near-term improvements

## 2021 Marks the Sixth-Warmest Year on Record Dating to 1880

2021 marked the continuation of a warming trend of the planet. Preliminary official data from the National Centers for Environmental Information (NCEI), formerly known as the National Climatic Data Center (NCDC), noted that 2021 was 0.84°C (1.51°F) above average global land and sea surface temperatures. This marked the sixth-warmest year on record dating to 1880. Temperature anomalies are compared against NCEI's 20<sup>th</sup> Century average (1901-2000).

The year also marked the latest entry into the Top 10 warmest years on record. All ten of the warmest years dating to 1880 have occurred since 2010. This includes the top five warmest years occurring in the past seven years: 2016, 2020, 2019, 2015, and 2017. Even more striking is that 19 of the 20 warmest years have been registered since 2001; the lone exception being 1998 when the globe encountered one of the strongest El Niño events on record.

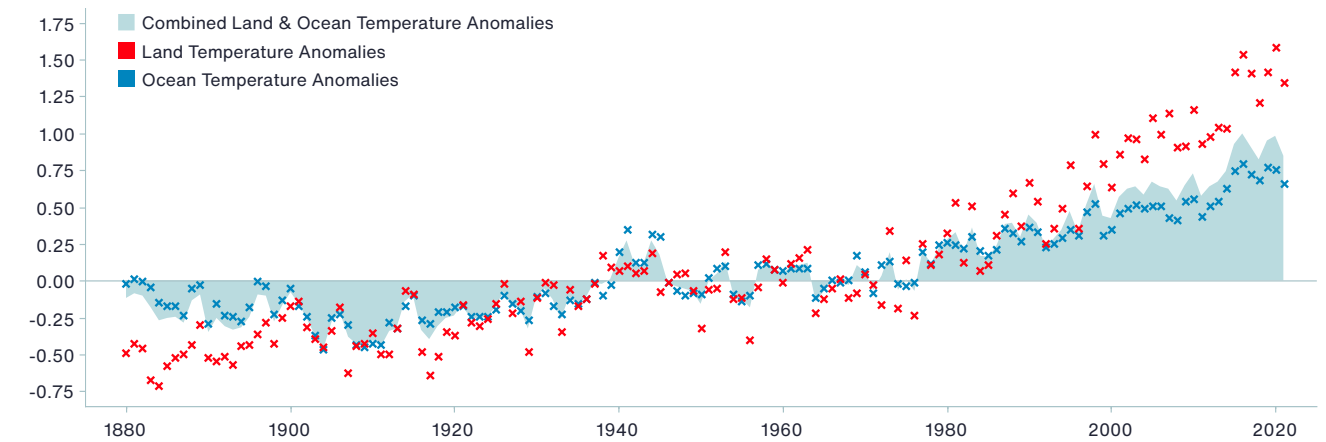
It was previously assumed that El Niño years would comprise most of the warm year lists since it amplifies warming. The opposite was always assumed to be true for La Niña – meaning that historical data typically shows that the globe tends to cool during such phases. Despite enduring two separate La Niña

phases, albeit weak, 2021 was still anomalously warm. This suggests that land and ocean temperatures continue to warm at an accelerated rate regardless of any influence from natural variability, volcanic eruptions, or solar cycles. It is further evidence anthropogenic activity is driving most of the warming. An additional point of perspective is that the warmest year in 2016 at 0.99°C (1.78°F) is more anomalous than the coldest year in 1904 at -0.46°C (-0.83°F).

The last below-average year for the globe occurred in 1976. At that time, global temperatures registered 0.07°C (0.13°F) below the long-term average. The last individual month to be below average was December 1984 at -0.08°C (-0.15°F) lower. December 2021 marked the 444<sup>th</sup> consecutive month with above average global temperatures.

Analyzing land and ocean temperature trends individually, the rates of growth are pronounced since the last below average in 1976. Land temperatures have annually grown by +5.1 percent, while ocean temperatures have grown by +3.2 percent. The combined land and ocean increase is +3.8 percent. The oceans have a larger spatial extent than land and require much more energy to warm or cool.

Exhibit 47: Global Land and Ocean Temperature Anomalies: 1880-2021



Data: NOAA. Graphic: Aon (Catastrophe Insight)



## Greenhouse Gas Emissions Hit New Highs as Accelerated Increase Persists

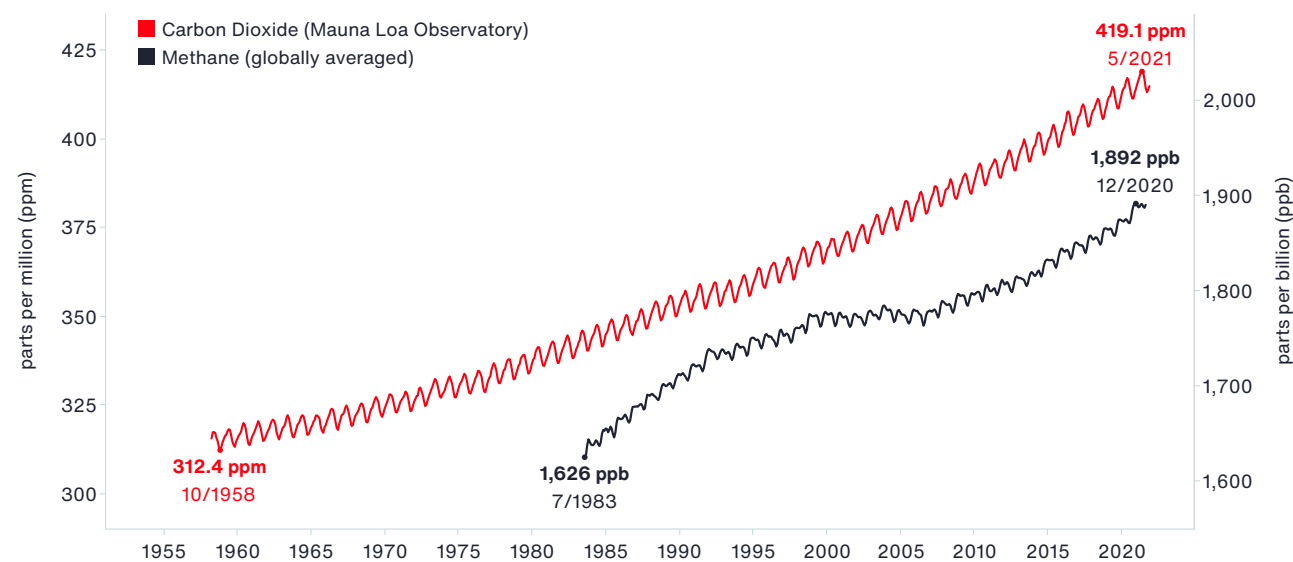
Data from the NOAA Earth System Research Laboratory (ESRL) show global monthly carbon dioxide (CO<sub>2</sub>) levels averaged at least 412 parts per million (ppm) in 2021. Monthly average concentrations at the Mauna Loa Observatory in Hawaii in May peaked at more than 419 ppm. The concentrations did not fall below 413 ppm in any month for the first time in the modern record dating to 1958. On April 8, 2021 the observatory recorded a daily record CO<sub>2</sub> reading of 421.36 ppm. NOAA notes that current CO<sub>2</sub> levels are at the highest in 3.6 million years. This was during the Mid-Pliocene Warm Period when carbon dioxide concentrations ranged from 380 to 450 ppm.

Atmospheric CO<sub>2</sub> levels have a scientifically proven correlation with global temperature, supported by data from ice cores and the geological record. Concentrations annually peak in May as plants begin to grow in the Northern Hemisphere with the arrival of spring. After peaking, a gradual decline occurs through the month of September as the growing season ends. Worth noting is that the annual rate

of growth in CO<sub>2</sub> concentration has increased over the course of multiple decades. The annual mean rate of growth of atmospheric CO<sub>2</sub> in each year is the difference in concentration between the end of December and the start of January of that year. If used as an average for the globe, it would represent the sum of all CO<sub>2</sub> added to, and removed from, the atmosphere during the year by human activities and by natural processes. NOAA also applies a 4-month interpolating technique to account for month-to-month variability.

Methane is the second most important greenhouse gas after carbon dioxide. Despite a lower concentration, it accounts for approximately 20 percent of the total radiative forcing from globally distributed greenhouse gases, as it is more potent at trapping heat in the atmosphere. The ESRL has measured methane globally since 1983 using a distributed network of air sampling sites. Research also suggests that global methane concentrations more than doubled since pre-industrial times.

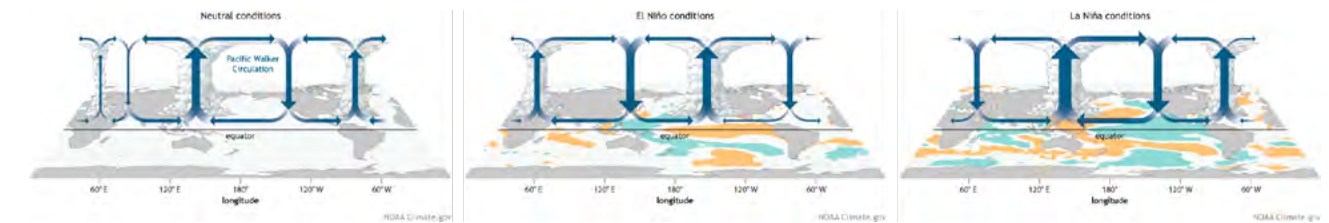
**Exhibit 48: Monthly Carbon Dioxide and Methane Concentrations**



Data: NOAA. Graphic: Aon (Catastrophe Insight)

## Twin Episodes of La Niña Affect Global Weather Patterns in 2021

**Exhibit 49: El Niño/Southern Oscillation (ENSO)**



There are several different types of seasonal oscillations that influence regional weather. The one that has a more robust global influence is the El Niño/Southern Oscillation (ENSO): a warming or cooling cycle of ocean waters across the central and eastern Pacific. This often leads to changes in the orientation of various atmospheric patterns and ocean currents. Warming periods are noted as El Niño cycles, while cooling periods are known as La Niña cycles. The Niño-3.4 Index, which measures the temperature of the ocean waters in the central Pacific, is used to determine ENSO phases/cycles.

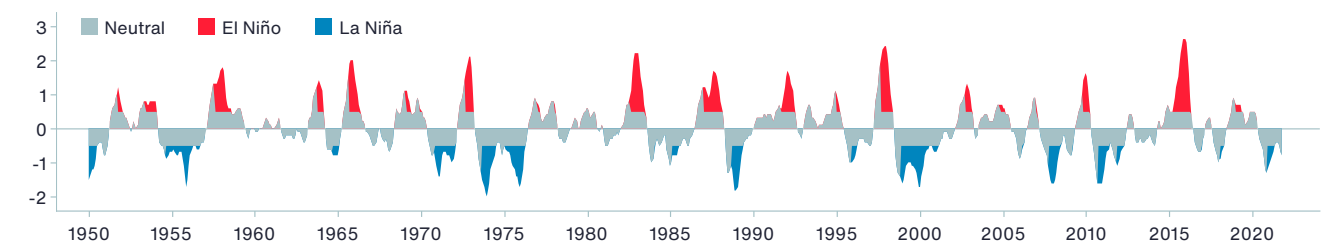
2021 was a unique year which featured two separate occurrences of La Niña: known as a “double-dip” La Niña. The year started with a continuation of moderate La Niña conditions from 2020 before weakening and transitioning to ENSO-neutral conditions by the Northern Hemisphere summer months. However, the central and eastern Pacific Ocean began to cool by the boreal fall and La Niña was again declared. The La Niña was forecast to linger until the boreal spring months of 2022. The recurrence of La Niña conditions with an ENSO

neutral phase in between is not uncommon, and the last such episode occurred in 2016-2018.

While no two La Niña events are the same, most regions are likely to see similar weather conditions extending to 2022. In addition, the associated precipitation variability may become more drastic under a warmer world. A weak La Niña already resulted in widespread flooding across eastern Australia and north-eastern Brazil this year. Australia recorded its wettest November since 1900. It was also a driving component for the above normal Atlantic Hurricane Season in 2021.

Please note that to be considered in an ENSO phase, NOAA requires a five consecutive, three-month running mean of sea surface temperature anomalies in the Niño-3.4 Region to be +0.5°C (El Niño) or -0.5°C (La Niña). The exhibit below highlights individual monthly conditions. In some instances, individual months may meet the ENSO phase criteria, but do not persist for the five-consecutive month requirement.

**Exhibit 50: Oceanic Niño Index and ENSO Phase Conditions by Month**



Data: Climate Prediction Center / NOAA. Graphic: Aon (Catastrophe Insight)

## Arctic & Antarctica: Melting Sea Ice Threatens Ecosystems

The well-documented decline of Arctic sea ice extent and volume in recent years results in changes in essential climatic feedback mechanisms that affect global circulation patterns. Surface air temperatures in the Arctic region increased at a rate twice as fast as the rest of the globe, with far-reaching impacts for the entire Arctic ecosystem. Some of these impacts include a reduction in natural habitats, but also increased accessibility of the Arctic Ocean for shipping since some areas no longer freeze at any point of the year.

Despite an observed trend, this year's minimum extent was one of the highest of the past decade. While a seemingly positive outcome, an even bigger concern is that the amount of multi-year ice stands at a near-record low. An analysis of satellite data from NASA and the National Snow and Ice Data Center (NSIDC) showed that the 2021 minimum extent measured 4.72 million km<sup>2</sup> (1.82 million mi<sup>2</sup>) on September 16. It represents a 1.5 million km<sup>2</sup> (0.58 million mi<sup>2</sup>) reduction from the 1981-2010 September climatology. The 2021 extent was the 12<sup>th</sup>-lowest in

the nearly 43-year satellite record. The last time that Arctic sea ice extent was above climatology was in 2001, and the most recent 15 years are the lowest 15 sea ice extents in the satellite record.

The summer months were generally characterized as relatively cool and stormy with less ice melt, especially in the second half of summer. Loss of Arctic sea ice in June was relatively rapid, tracking just below the 2012 record and very close to record-breaking year 2020 by the beginning of July. The speed of the seasonal decline slowed later in July and in August, due to a persistent low-pressure area in the Beaufort Sea, which resulted in lower temperatures in the Arctic region. An earlier freeze of sea ice, at least compared to recent years, led to logistical complications on the Northern Sea Route towards the end of the year. Despite a non-record-breaking year, the most recent IPCC "[Special Report on the Ocean and Cryosphere in a Changing Climate](#)" showed high confidence that Arctic sea ice cover will continue to shrink during the 21<sup>st</sup> Century.

### Risk of Future Sea Level Rise

As discussed in the previous section, concerns are growing regarding the overall trend of shrinking Arctic sea ice and its decreasing thickness and age. Analyses continually show that the average age of Arctic ice has significantly decreased in the last few decades. As ice grows thinner and younger, it permits more heat to escape into the atmosphere. This in turn aids the warming of Arctic air and sea surface temperatures. As glaciers melt into the ocean and subsequent warming commences it becomes the critical ingredient as to why and how sea level rise continues to accelerate in coastal areas around the world.

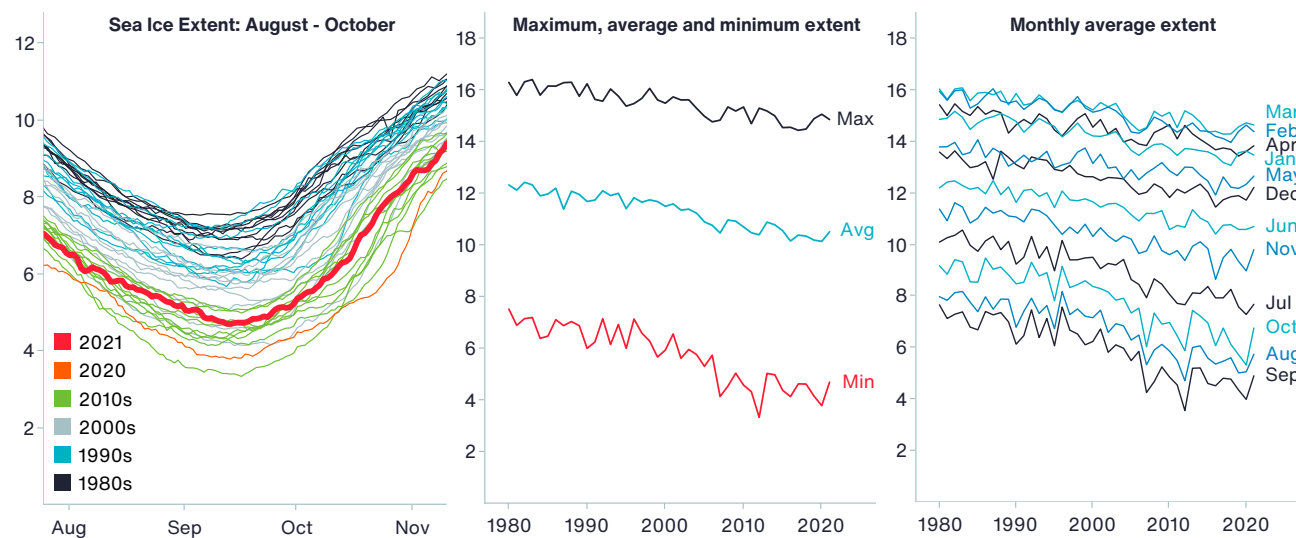
One particularly important place of focus regarding sea level rise is Greenland. [Surface melting of the Greenland Ice Sheet](#) has become increasingly concerning in recent years. The 2021 melting season was above the 1981-2010 average and was quite prolific following two particularly significant summer heatwaves. Both resulted in near-record melt events, extending even to hundreds and thousands of feet in altitude (which is exceedingly rare). The first heatwave was recorded in late July. The second in mid-August was accompanied by unprecedented measured rainfall (instead of snow) at the National Science Foundation's Summit Station. This was the first official record of rainfall at the station since continuous field observations began in 2008. New

climate research and environmental simulations reveal the potential of increased occurrences of liquid precipitation in the Arctic and a reduction in snowfall. [A recent study](#) led by scientists of the University of Manitoba and NSIDC shows that rain may become more common than snow in the Arctic.

On the opposite end of the globe, the Antarctic is responding less rapidly to climate change than the Arctic. Data suggests that the state of sea ice in the Antarctic seems more stable, though large regional differences remain. Despite moderate warming, the amount of sea ice and its volume in the Antarctic have yet to show a substantial decreasing trend. In 2021, the minimum sea ice area was near the long-term average, with about 2.5 million km<sup>2</sup> (0.97 million mi<sup>2</sup>).

Despite greater stability, considerable concern remains on the impact that climate change poses in the region. Most focus was on the Thwaites Glacier Shelf. With a continued moderation in temperatures, a recent study suggested that this shelf could collapse within the next 3 to 5 years. This is a huge concern since it is one of the largest and highest glaciers in Antarctica, and is roughly the size of the U.S. state of Florida. Should the glacier fully collapse into the ocean, scientists fear it could raise levels by 65 centimeters (25.6 inches). Ice loss from the glacier has already accounted for nearly four percent of global sea level rise.

Exhibit 51: Arctic Sea Ice Extent in million km<sup>2</sup>: 1980-2021



Data: Fetterer, F., K. Knowles, W. Meier, M. Savoie, and A. K. Windnagel. 2017, updated daily. Sea Ice Index, Version 3. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. [1/1/2022]. Graphic: Aon (Catastrophe Insight)

## Global Ocean Heat Content Sets Record High in 2021

Our oceans carry the largest heat capacity of the Earth system. Many studies have shown that more than 90 percent of the Earth's energy imbalance goes into increasing ocean heat content. While global mean surface temperature is a useful indicator of global warming, it is also influenced by climate variability in timescales of up to a decade and can lead to the false perception of a warming hiatus. Ocean heat content, on the contrary, is less affected by noisy signals due to smoothing from the subsurface ocean and subsequently warms (or cools) at a slower rate than land.

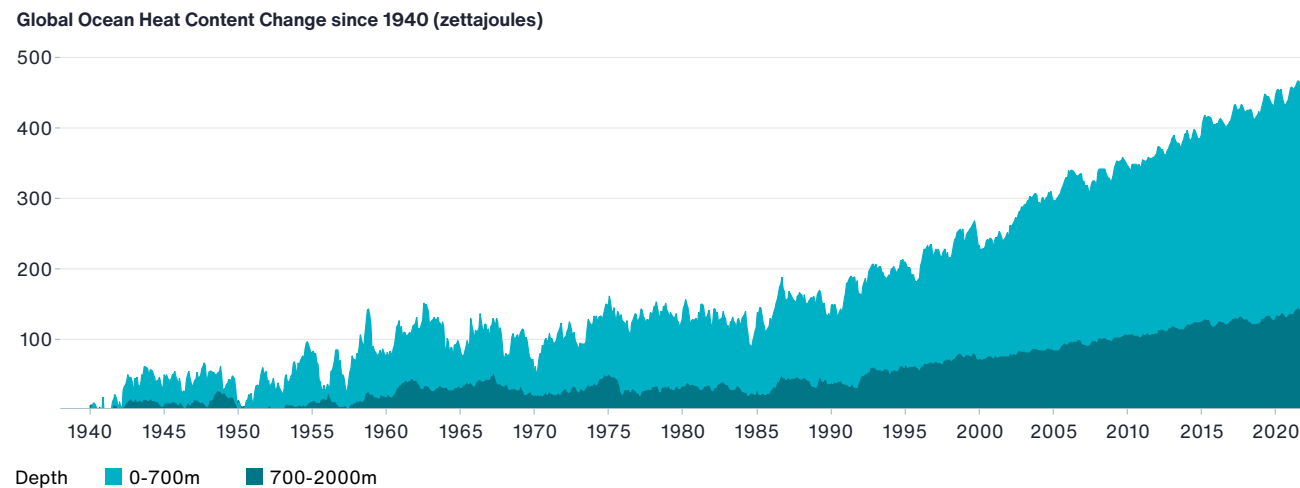
2021 marked another record year for ocean warmth, despite a slowdown of industrial productivity during COVID-19. Ocean heat content has been accelerating at a faster pace since the 1990s. Based on data from separate studies by NOAA and the Institute of Atmospheric Physics at the Chinese Academy of Sciences, ocean heat content in the upper 2,000 meters exceeded the 2020 value by 14 zettajoules. It was also well above the 1981-2010 average by 227 zettajoules. The trend of global warming was especially manifested in the 0-700 meter subsurface layer, with the rate of ocean heat content increasing about two times faster than the 700-2000 meter subsurface layer since 1990. The upper subsurface layer is warming faster due to increasing greenhouse

gases concentrations in the atmosphere. Such warming is also penetrating deeper into the ocean, as evident from the rise in ocean heat content in the 700-2000m subsurface.

Basin-wise, ocean heat content reached record highs in the Mediterranean Sea, North Atlantic, North Pacific and Southern Ocean, with maximum anomaly near 40 degrees in both hemispheres. This can help enhance or initiate more intense weather, such as the December 2021 tornado outbreaks and derecho in the United States, as warmer water fills the atmosphere with abundant moisture. Ocean heat also places ice sheets around Arctic and Antarctica at risk of thinning. Global sea level rise can be affected by both the melting of ice caps and expansion of ocean volume under a higher temperature.

In addition, a warmer ocean can affect marine life by diminishing the effect of upwelling, a process that rejuvenates nutrients to the surface layer. Reduced fish harvests may affect global food chain supply and prices. There is also increased frequency of marine heat waves, a period characterized by abnormally high ocean temperatures, leading to algae blooms, and the deaths of coral ecosystems. Ocean heat content is projected to increase if greenhouse gas emissions continue.

**Exhibit 52: Global Ocean Heat Content**



Data: NOAA & Cheng, et al (2022). Graphic: Aon (Catastrophe Insight)

## Annual Climate Extremes

### 2021: A Year of Record Extremes

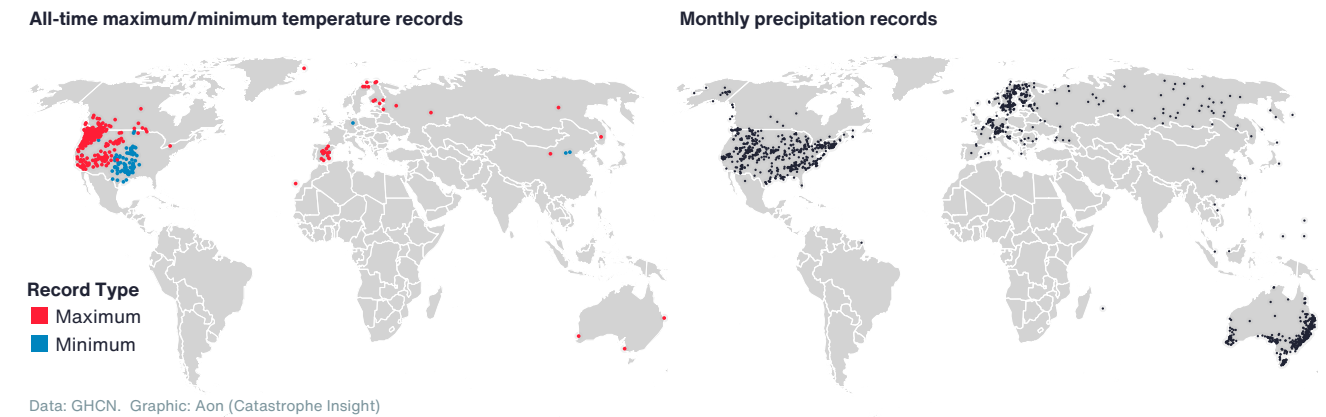
Daily station data from NOAA's GHCN (Global Historical Climatology Network) allows us to visualize anomalous daily, monthly, and all-time global weather and climate events during 2021. Exhibit 53 below indicates stations which tied or broke an all-time record of maximum or minimum temperature and/or monthly record of accumulated precipitation total. The final analysis dataset only included stations which had a total record length of at least 30 years with 90 percent or higher data completeness during the most recent 30-year period.

It is important to note that the GHCN dataset contains weather and climate observations from 180+ countries and is updated daily. However, the spatial and temporal coverage is not uniform and there are notable gaps in data availability in several parts of the world. The highest concentration of stations with the longest and most complete records are primarily located in the United States, western Europe, and Australia with the lowest in Africa and South America. While this is not a perfect dataset, it is helpful in identifying any emerging trends in various parts of the globe.

In 2021, a total of 5,036 stations met the completeness criteria for temperature. For maximum temperature, 1,778 unique stations tied or broke a monthly temperature record during at least one month in 2021, of which 332 stations tied or broke an all-time temperature record. A majority of the all-time maximum temperatures were set during the Western North American Heat wave in late-June. Historic August heat in southern Spain was also evident. For minimum temperature, 400 unique stations tied or broke a monthly temperature record during at least one month in 2021, of which 89 tied or broke an all-time temperature record. A majority of the all-time minimum temperatures were set during the February Polar Vortex event across the Southern Plains in the United States.

A total of 7,782 stations met the completeness criteria for precipitation in 2021. For total accumulated precipitation, 1,323 unique stations tied or broke a monthly precipitation record during 2021. Of these, 262 had a record length greater than 100 years and 109 reported a record in more than one month. The monthly records highlight the significantly wet March and November across eastern Australia. At least 71 stations reported yearly station records.

**Exhibit 53: Temperature and precipitation records broken or tied in 2021**





# Appendix



# Appendix A: 2021 Global Disasters

## United States

Date	Event	Location	Deaths	Economic Loss (USD)
01/01-12/31	Drought	Nationwide	N/A	9.0+ billion
01/11-01/13	Severe Weather	Northwest	2	675+ million
01/17-01/20	Severe Weather	California	0	350+ million
01/24-01/27	Severe Weather	Plains, Midwest, South	1	120+ million
01/24-01/29	Flooding	West	2	1.75+ billion
01/30-02/03	Winter Weather	Midwest, Northeast	4	100+ million
02/08-02/12	Winter Weather	Plains, Southeast, Mid-Atlantic	9	75+ million
02/12-02/20	Winter Weather	Western, Central, Eastern U.S.	215	23.7+ billion
02/25-02/26	Severe Weather	Texas	0	210+ million
02/25-03/01	Flooding	Plains, Southeast, Mid-Atlantic	1	150+ million
03/08-03/10	Flooding	Hawaii	0	50+ million
03/09-03/11	Severe Weather	Plains, Midwest	0	75+ million
03/12-03/15	Winter Weather	Plains, Rockies	0	75+ million
03/16-03/18	Severe Weather	Plains, Southeast	0	500+ million
03/22-03/23	Severe Weather	Plains	0	315+ million
03/24-03/26	Severe Weather	Plains, Southeast, Midwest, Northeast	6	1.7+ billion
03/27-03/29	Severe Weather	Tennessee Valley, Mid-Atlantic	8	1.75+ billion
04/06-04/08	Severe Weather	Plains, Midwest, Southeast	0	880+ million
04/09-04/11	Severe Weather	Plains, Southeast	3	945+ million
04/12-04/14	Severe Weather	Plains, Southeast	13	215+ million
04/15-04/16	Severe Weather	Texas	0	1.55+ billion
04/18-04/18	Severe Weather	Southeast	0	25+ million
04/21-04/22	Severe Weather	Northeast	0	75+ million
04/23-04/25	Severe Weather	Plains, Southeast	1	390+ million
04/27-05/02	Severe Weather	Plains, Southeast, Mid-Atlantic	0	3.4+ billion
05/03-05/05	Severe Weather	Plains, Southeast, Mid-Atlantic	4	1.25+ billion
05/06-05/11	Severe Weather	Plains, Southeast	1	350+ million
05/14-05/19	Severe Weather	Plains, Southeast	5	2.0+ billion
05/22-05/27	Severe Weather	Plains, Midwest	0	535+ million
05/25-05/26	Severe Weather	Mid-Atlantic, Northeast	0	160+ million
05/29-05/31	Severe Weather	Rockies, Plains	1	205+ million
06/02-07/04	Telegraph Fire	Arizona	0	10s of millions
06/03-06/04	Severe Weather	Mid-Atlantic, Northeast	0	50+ million
06/07-06/10	Severe Weather	Plains, Rockies	0	50+ million
06/07-06/10	Flooding	Plains, Southeast	0	950+ million
06/11-06/14	Severe Weather	Plains, Midwest, Mid-Atlantic, Northeast	1	325+ million
06/17-06/21	Severe Weather	Plains, Midwest, Mid-Atlantic, Northeast	1	1.8+ billion

Date	Event	Location	Deaths	Economic Loss (USD)
06/18-06/21	Tropical Storm Claudette	Southeast	14	375+ million
06/24-07/01	Severe Weather	Plains, Midwest, Mid-Atlantic, Northeast	2	1.4+ billion
06/26-06/30	Heatwave	Northwest	229+	Unknown
07/06-07/31	Beckworth Complex Fire	California	0	75+ million
07/01-07/08	Hurricane Elsa	Southeast, Mid-Atlantic, Northeast	1	1.2+ billion
07/06-07/07	Severe Weather	Midwest, Mid-Atlantic, Northeast	0	35+ million
07/06-08/02	Bootleg Fire	Oregon	0	325+ million
07/07-07/08	Flooding	Texas	0	65+ million
07/08-07/10	Severe Weather	Plains, Midwest	1	1.2+ billion
07/09-07/11	Severe Weather	Southwest	0	550+ million
07/12-07/13	Flooding	Mid-Atlantic, Northeast	0	100+ million
07/14-08/31	Dixie Fire	California	0	3.0+ billion
07/16-07/19	Severe Weather	Midwest, Mid-Atlantic, Southeast	0	75+ million
07/16-07/21	Severe Weather	Southwest	8	50+ million
07/22-07/28	Severe Weather	Southwest	9	300+ million
07/24	Severe Weather	Midwest	0	115+ million
07/26-07/27	Severe Weather	Midwest	0	155+ million
07/28-07/29	Severe Weather	Midwest, Mid-Atlantic, Northeast	0	315+ million
07/30-08/02	Severe Weather	Southwest	1	25+ million
08/01	Severe Weather	Texas	0	120+ million
08/07-08/09	Severe Weather	Plains, Midwest	0	135+ million
08/10-08/12	Severe Weather	Midwest, Mid-Atlantic	0	1.1+ billion
08/10-08/17	Tropical Storm Fred	Southeast, Mid-Atlantic, Northeast	7	1.1+ billion
08/10-08/16	Severe Weather	Southwest	3	225+ million
08/13-09/30	Caldor Fire	California	0	1.5+ billion
08/15-08/30	Ford Corkscrew Fire	Washington	0	100+ million
08/17-08/19	Severe Weather	Southwest	0	325+ million
08/20-08/25	Hurricane Henri	Mid-Atlantic, Northeast	0	650+ million
08/21	Flooding	Tennessee	20	150+ million
08/23-08/25	Severe Weather	Plains, Midwest	0	50+ million
08/26-08/30	Severe Weather	Plains, Midwest	0	315+ million
08/27-09/02	Hurricane Ida	Southeast, Mid-Atlantic, Northeast	96	75.2+ billion
09/06-09/07	Severe Weather	Plains, Midwest	0	315+ million
09/12-09/17	Hurricane Nicholas	Plains, Southeast	0	1.0+ billion
09/15-09/17	Severe Weather	Plains, Midwest	1	125+ million
09/22-09/31	Fawn Fire	California	0	75+ million
09/24-09/29	Severe Weather	West, Plains	0	130+ million

Date	Event	Location	Deaths	Economic Loss (USD)
09/30-10/02	Severe Weather	Texas	0	75+ million
10/04-10/05	Severe Weather	West	0	40+ million
10/04-10/07	Flooding	Southeast	4	325+ million
10/10-10/11	Severe Weather	Plains, Midwest	0	300+ million
10/10-10/12	Severe Weather	West	0	105+ million
10/12-10/16	Severe Weather	Plains, Midwest	0	50+ million
10/21	Severe Weather	Midwest, Northeast	0	50+ million
10/24-10/27	Flooding	West, Plains	2	1.3+ billion
10/24-10/25	Severe Weather	Midwest	0	160+ million
10/25-10/27	Severe Weather	Northeast	0	850+ million
10/26-10/28	Severe Weather	Plains, Southeast	0	200+ million
10/29-10/30	Flooding	United States	0	10s of millions
11/10	Severe Weather	Plains	0	100+ million
11/12-11/13	Severe Weather	Northeast	0	90+ million
11/13-11/15	Flooding	Washington	1	200+ million
12/03-12/08	Flooding	Hawaii	0	75+ million
12/05-12/06	Severe Weather	Plains, Southeast	0	10s of millions
12/10-12/12	Severe Weather	Plains, Southeast, Midwest	93	5.1+ billion
12/13-12/16	Severe Weather	West, Plains, Southeast, Midwest	5	1.9+ billion
12/17	Severe Weather	Texas	0	40+ million
12/21	Severe Weather	Florida	0	75+ million
12/23-12/24	Winter Weather	West	2	150+ million
12/29-12/30	Severe Weather	South	0	50+ million
12/30-12/31	Marshall Fire	Colorado	0	3.3+ billion

Date	Event	Location	Deaths	Economic Loss (USD)
06/11	Severe Weather	Canada	0	20+ million
06/18-06/20	Tropical Storm Dolores	Mexico	3	50+ million
06/21-06/22	Severe Weather	Canada	1	20+ million
06/27-06/30	Hurricane Enrique	Mexico	2	50+ million
06/26-06/30	Heatwave	Canada	800+	Unknown
06/28-08/26	Sparks Lake Fire	Canada	0	50+ million
06/29-06/30	Severe Weather	Canada	0	25+ million
06/30-07/02	Lytton Creek Wildfire	Canada	2	178+ million
07/01-07/09	Hurricane Elsa	Caribbean	3	125+ million
07/02-07/03	Severe Weather	Canada	0	567+ million
07/13-08/31	White Rock Lake Fire	Canada	0	120+ million
07/15	Severe Weather	Canada	0	115+ million
07/16-07/17	Flooding	Canada	0	44+ million
07/22-07/23	Severe Weather	Canada	0	77+ million
07/22-07/25	Flooding	Central America	2	Millions
07/22-07/28	Flooding	Mexico	1	Millions
08/10-08/17	Tropical Storm Fred	Caribbean	0	10s of millions
08/14	Earthquake	Haiti	2,248	1.6+ billion
08/16-08/21	Hurricane Grace	Caribbean, Mexico	13	513+ million
08/27-08/30	Hurricane Nora	Mexico	3	125+ million
08/28-09/02	Hurricane Ida	Cuba	0	250+ million
08/31-09/01	Severe Weather	Canada	0	158+ million
09/02-09/07	Flooding	Mexico	23	75+ million
09/07-09/08	Severe Weather	Canada	0	45+ million
09/07	Earthquake	Mexico	9	250+ million
09/09-09/11	Hurricane Olaf	Mexico	1	Millions
09/10-09/11	Hurricane Larry	Canada	0	61+ million
09/12	Severe Weather	Canada	0	25+ million
09/22-09/23	Flooding	Canada	0	185+ million
10/01-10/04	Flooding	Mexico	6	10s of millions
10/12-10/14	Hurricane Pamela	Mexico	0	30+ million
10/24-10/26	Hurricane Rick	Mexico	0	25+ million
11/13-11/15	Flooding	Canada	4	2.4+ billion
11/22-11/25	Flooding	Canada	0	10s of millions
11/24-12/01	Flooding	Canada	0	10s of millions
12/11-12/13	Severe Weather	Canada	0	178+ million
12/15-12/16	Severe Weather	Canada	0	25+ million

Remainder of North America (Non-U.S.)

Date	Event	Location	Deaths	Economic Loss (USD)
01/01-12/31	Drought	Mexico	N/A	2.0+ billion
01/01-12/31	Drought	Canada	N/A	2.5+ billion
01/12-01/14	Severe Weather	Canada	0	130+ million
01/19-01/20	Severe Weather	Canada	0	45+ million
02/12-02/20	Winter Weather	Mexico	20	1.5+ billion
03/26-03/29	Severe Weather	Canada	0	150+ million
04/03-04/12	Flooding	Haiti	7	Unknown
04/09-04/30	Volcano	St. Vincent	0	554+ million
04/21-10/31	Flooding	Guatemala	36	200+ million
05/16-05/18	Severe Weather	Mexico	0	50+ million
06/08	Severe Weather	Canada	0	25+ million



## South America

Date	Event	Location	Deaths	Economic Loss (USD)
01/01-12/31	Drought	Brazil	N/A	3.0+ billion
01/01-12/31	Drought	Paraguay	N/A	200+ million
01/01-12/31	Drought	Argentina	N/A	200+ million
01/01-12/31	Drought	Bolivia	N/A	Millions
01/01-12/31	Drought	Chile	N/A	Millions
01/01-01/03	Severe Weather	Brazil	2	19+ million
01/04	Severe Weather	Bolivia	4	Millions
01/01-01/09	Flooding	Guyana	0	Millions
01/16-01/20	Flooding	Bolivia	5	Millions
01/18	Earthquake	Argentina	0	250+ million
01/21-01/24	Severe Weather	Brazil	2	37+ million
01/26-01/29	Severe Weather	Brazil	0	11+ million
01/29-02/01	Severe Weather	Chile	0	200+ million
01/31-02/01	Flooding	Paraguay	10	Millions
02/10-02/22	Flooding	Brazil	0	36+ million
02/19-02/21	Severe Weather	Brazil	6	26+ million
02/20-02/21	Flooding	Peru	1	25+ million
03/01-06/30	Flooding	Colombia	71	10s of millions
03/08-03/11	Severe Weather	Brazil	0	632+ million
03/15-03/19	Severe Weather	Brazil	0	388+ million
03/20-03/31	Flooding	Peru	1	Millions
03/31	Severe Weather	Brazil	0	49+ million
04/20-06/05	Flooding	Brazil	0	40+ million
05/11-06/30	Flooding	Guyana	0	Millions
05/28/05/30	Severe Weather	Brazil	0	5.8+ million
06/08-06/09	Flooding	Brazil	0	5.0+ million
06/16	Flooding	Brazil	0	82+ million
07/01-11/30	Flooding	Colombia	45	Millions
07/19-07/31	Winter Weather	Brazil	N/A	50+ million
07/26-07/27	Severe Weather	Brazil	0	Millions
08/22-08/24	Flooding	Venezuela	20	Millions
09/06-09/10	Severe Weather	Brazil	0	13+ million
10/23	Severe Weather	Brazil	1	60+ million
11/05-12/31	Flooding	Brazil	32	417+ million
11/28	Earthquake	Peru	2	Millions
12/17-12/20	Flooding	Bolivia	14	Millions

## Europe

Date	Event	Location	Deaths	Economic Loss (USD)
01/06-01/12	Flooding	Southeastern Europe	0	10s of millions
01/08-01/12	Storm Filomena	Spain	5	1.9+ billion
01/13-03/31	Winter Weather	Switzerland, Austria	17	60+ million
01/20-01/21	Windstorm Christoph	Western Europe	1	526+ million
01/21-01/22	Windstorm Hortense	France, Spain	0	90+ million
01/23-01/31	Earthquake	Spain	0	35+ million
02/01-02/10	Flooding	France	0	10s of millions
02/01-02/15	Winter Weather	Western, Central & Northern Europe	N/A	100s of millions
02/15-02/17	Winter Weather	Greece	3	35+ million
03/03	Earthquake	Greece	1	Millions
03/10-03/11	Windstorm Klaus	Western & Central Europe	0	200+ million
03/13	Windstorm Luis	Western & Central Europe	0	185+ million
03/18-03/23	Winter Weather	Spain	0	80+ million
04/05-04/08	Winter Weather	Western & Central Europe	N/A	5.6+ billion
04/13-04/18	Winter Weather	Spain	0	40+ million
05/01-05/02	Windstorm Daniel	Austria	0	15+ million
05/04-05/05	Windstorm Eugen	Western Europe	0	245+ million
05/11-05/17	Flooding	Central Europe	1	40+ million
05/19-05/20	Wildfire	Greece	0	10s of millions
05/29-06/14	Severe Weather	Spain, Portugal	0	150+ million
06/04-06/09	Severe Weather	Western and Central Europe	2	369+ million
06/17-06/18	Flooding	Ukraine	1	170+ million
06/17-06/25	Severe Weather	Western & Central Europe	7	4.9+ billion
06/20	Flooding	Ukraine	0	10+ million
06/28-06/30	Severe Weather	Western & Central Europe	1	2.4+ billion
07/03-07/05	Wildfire	Cyprus	4	47+ million
07/04-07/07	Flooding	Russia, Georgia, Ukraine	11	28+ million
07/08-07/09	Severe Weather	Italy, Central Europe	2	280+ million
07/11	Severe Weather	Hungary	0	15+ million
07/12-07/18	Flooding	Western & Central Europe	227	45.6+ billion
07/17-07/19	Flooding	Central Europe	0	215+ million
07/23-07/28	Severe Weather	Western & Central Europe	3	560+ million
07/23-07/25	Wildfire	Italy	0	59+ million
07/28-08/02	Severe Weather	Western, Central & Eastern Europe	3	157+ million
07/28-08/09	Wildfire	Greece	2	580+ million
08/05-08/07	Severe Weather	Central & Eastern Europe	0	20+ million
08/12-08/16	Severe Weather	Central Europe	3	310+ million

Date	Event	Location	Deaths	Economic Loss (USD)
08/12-08/14	Flooding	Russia	0	Millions
08/16-08/18	Severe Weather	Spain	0	17+ million
08/17-08/18	Flooding	Sweden	0	70+ million
08/24-08/25	Severe Weather	Southern Europe	0	34+ million
08/31-09/02	Flooding	Spain	2	105+ million
09/08-09/09	Severe Weather	Western Europe	0	70+ million
09/13-09/14	Flooding	France	0	23+ million
09/19-09/30	Volcano	Spain	1	1.0+ billion
09/20-09/24	Flooding	Spain	0	152+ million
09/25-09/27	Severe Weather	Western & Southern Europe	1	59+ million
09/27	Earthquake	Greece	1	30+ million
10/03-10/05	Flooding	Italy, France	0	80+ million
10/20-10/21	Windstorm Aurore	Western & Central Europe	6	680+ million
10/23-10/31	Severe Weather	Italy	3	245+ million
11/04-11/05	Flooding	Bosnia and Herzegovina	0	Millions
11/10-11/17	Severe Weather	Italy	2	10s of millions
11/19-11/21	Windstorm Volker	Norway	0	63+ million
11/22-11/30	Flooding	Spain	1	36+ million
11/26-11/27	Windstorm Arwen	United Kingdom, France, Ireland	3	60+ million
11/30-12/01	Windstorm Christian & Daniel	Germany, Denmark	2	89+ million
12/07-12/08	Windstorm Barra	United Kingdom, France, Ireland	2	15+ million
12/10-12/13	Flooding	Spain, France	2	100+ million

## Middle East

Date	Event	Location	Deaths	Economic Loss (USD)
02/01-02/02	Flooding	Turkey	1	76+ million
02/17	Earthquake	Iran	2	10s of millions
04/15-05/05	Flooding	Yemen	13	10+ million
05/01-05/05	Flooding	Iran	11	Millions
05/21	Severe Weather	Turkey, Greece	0	Millions
07/14-07/21	Flooding	Iran	10	Millions
07/15-07/16	Flooding	Oman	7	80+ million
07/16-07/22	Flooding	Yemen	14	Unknown
07/21	Flooding	Turkey	3	23+ million
07/28-07/31	Wildfire	Turkey, Lebanon	10	232+ million
08/11	Flooding	Turkey	82	290+ million
10/02-10/04	Cyclone Shaheen	Oman, Iran	15	1.0+ billion
11/14	Earthquake	Iraq	2	165+ million

Date	Event	Location	Deaths	Economic Loss (USD)
11/29-11/30	Severe Weather	Turkey	6	Millions
12/16-12/17	Flooding	Iran	14	14+ million

## Africa

Date	Event	Location	Deaths	Economic Loss (USD)
01/19-01/21	Cyclone Eloise	Southern Africa	27	90+ million
02/01-02/14	Flooding	South Africa	31	75+ million
02/01-05/31	Flooding	Burundi	0	Unknown
02/06-02/07	Flooding	Morocco	28	Millions
03/06-03/07	Flooding	Algeria	10	Millions
03/15-03/16	Flooding	DRC, Angola	11	Unknown
04/07-05/31	Flooding	Kenya	9	Millions
04/18-04/20	Wildfire	South Africa	0	100+ million
04/19	Flooding	Angola	24	Millions
04/23-04/25	Cyclone Jobo	East Africa	22	Millions
05/01-05/31	Flooding	Somalia	25	Unknown
05/01-05/31	Flooding	Ethiopia	16	Unknown
05/01-09/30	Flooding	South Sudan	7	Unknown
05/22-05/23	Volcano	DRC	32	Millions
06/15-08/31	Flooding	Niger	64	Millions
06/26-08/31	Flooding	Chad	15	Unknown
07/01-09/30	Flooding	Nigeria	11	Unknown
07/02-07/08	Severe Weather	Gambia	10	Unknown
07/20-09/30	Flooding	Sudan	52	Millions
08/09-08/15	Wildfire	Algeria	90	Millions
08/11-08/31	Flooding	Somalia	2	Unknown
08/30-08/31	Flooding	Guinea	5	Millions
09/01-10/31	Flooding	Benin	0	Unknown
09/01-12/15	Flooding	Congo	24	Unknown
11/12	Flooding	Egypt	3	Millions
11/24-11/28	Severe Weather	Malawi	0	Unknown
12/12-12/30	Severe Weather	South Africa	10	Millions

## Asia

Date	Event	Location	Deaths	Economic Loss (USD)
01/01-12/31	Drought	China	N/A	3.1+ billion
01/01-01/04	Severe Weather	Philippines	9	25+ million
01/06-01/08	Winter Weather	China	0	191+ million

Date	Event	Location	Deaths	Economic Loss (USD)
01/07-01/12	Winter Weather	Japan	23	2.0+ billion
01/08-01/12	Winter Weather	Taiwan	18	Millions
01/09-01/15	Flooding	Indonesia	21	78+ million
01/14	Earthquake	Indonesia	108	92+ million
01/14-01/17	Winter Weather	China	0	115+ million
02/07-02/08	Flooding	India	205	210+ million
02/13	Earthquake	Japan	1	8.0+ billion
02/14	Flooding	Indonesia	19	Negligible
02/15-02/19	Winter Weather	Japan	0	9.0+ million
02/19-02/23	Flooding	Indonesia	14	Millions
02/20-02/23	Tropical Storm Djujan	Philippines	5	10+ million
02/22-02/25	Winter Weather	China	1	76+ million
03/12-03/16	Sandstorm	Mongolia, China	21	9.0+ million
03/19	Earthquake	China	0	75+ million
03/20	Earthquake	Japan	0	550+ million
03/24	Earthquake	China	3	125+ million
04/01-12/31	Drought	Afghanistan, Kyrgyzstan, Uzbekistan	N/A	10+ million
04/01-04/30	Winter Weather	China	0	325+ million
04/03-04/05	Cyclone Seroja	Indonesia, Timor-Leste	275	400+ million
04/10	Earthquake	Indonesia	10	Millions
04/17-04/21	Typhoon Surigae	Philippines	9	20+ million
04/23	Other	India	18	Negligible
04/30	Severe Weather	China	28	25+ million
05/01-05/31	Flooding	China	4	750+ million
05/02-05/05	Flooding	Afghanistan	116	Millions
05/11-05/20	Cyclone Tauktae	India, Sri Lanka, Maldives	198	1.5+ billion
05/13-05/15	Severe Weather	China	14	96+ million
05/21	Earthquake	China	3	516+ million
05/22	Earthquake	China	0	637+ million
05/22	Severe Weather	China	21	N/A
05/25-05/29	Cyclone Yaas	India	19	3.0+ billion
05/31	Severe Weather	Pakistan	12	Negligible
06/01-09/30	Flooding	Nepal	132	1.8+ million
06/01-06/03	Tropical Storm Choi-wan	Philippines, Taiwan	11	11+ million
06/01-09/30	Flooding	China	545	30+ billion
06/01-10/31	Flooding	India	1,282	3.1+ billion
06/03-06/08	Flooding	Sri Lanka	22	Millions
06/04-06/07	Severe Weather	Bangladesh	30	Negligible

Date	Event	Location	Deaths	Economic Loss (USD)
06/10-06/12	Earthquake	China	0	5.0+ million
06/10-06/14	Tropical Storm Koguma	Vietnam, Laos	1	13+ million
06/15-06/21	Flooding	Bhutan	10	Negligible
06/24-08/15	Flooding	Russia	0	200+ million
06/25	Severe Weather	China	8	50+ million
07/01-07/05	Flooding	Japan	26	250+ million
07/01-09/30	Flooding	Pakistan	194	10s of million
07/10-07/11	Severe Weather	China	0	50+ million
07/12	Flooding	Kyrgyzstan & Uzbekistan	15	Negligible
07/18-07/21	Typhoon Cempaka	China, Vietnam	3	50+ million
07/19	Flooding	Tajikistan	12	Millions
07/21-07/28	Typhoon In-fa	China, Philippines, Japan, Taiwan	5	2.0+ billion
07/27-07/28	Flooding	Bangladesh	21	Negligible
07/28-07/29	Flooding	Afghanistan	150	Unknown
08/02-08/06	Tropical Storm Lupit	China, Taiwan, Japan	6	220+ million
08/04	Severe Weather	Bangladesh	17	N/A
08/08-08/10	Severe Weather	China	6	150+ million
08/10-08/15	Severe Weather	China	0	75+ million
08/11-08/16	Flooding	Japan	13	1.25+ billion
08/14	Flooding	Indonesia	0	14+ million
08/23-08/24	Tropical Depression Omais	South Korea	0	13+ million
08/24	Flooding	Myanmar	11	Negligible
08/26-09/03	Flooding	Indonesia	5	Millions
09/06-09/12	Typhoon Conson	Philippines, Vietnam	22	45+ million
09/10-09/19	Typhoon Chanthu	East Asia	0	30+ million
09/16	Earthquake	China	3	250+ million
09/23-09/28	Tropical Storm Dianmu	Vietnam	5	Millions
09/23-11/05	Flooding	Thailand	35	591+ million
09/26-09/30	Cyclone Gulab	India	20	269+ million
09/29-10/09	Flooding	Indonesia	12	Millions
10/01	Severe Weather	China	0	169+ million
10/02-10/07	Flooding	China	27	1.8+ billion
10/03-10/10	Tropical Storm Lionrock	East Asia	6	51+ million
10/06	Earthquake	Pakistan	27	Millions
10/07	Earthquake	Japan	0	75+ million
10/10-10/14	Tropical Storm Kompasu	Philippines, Hong Kong, China	44	315+ million
10/16-10/22	Flooding	Nepal	121	Millions
10/16	Earthquake	Indonesia	3	4.5+ million



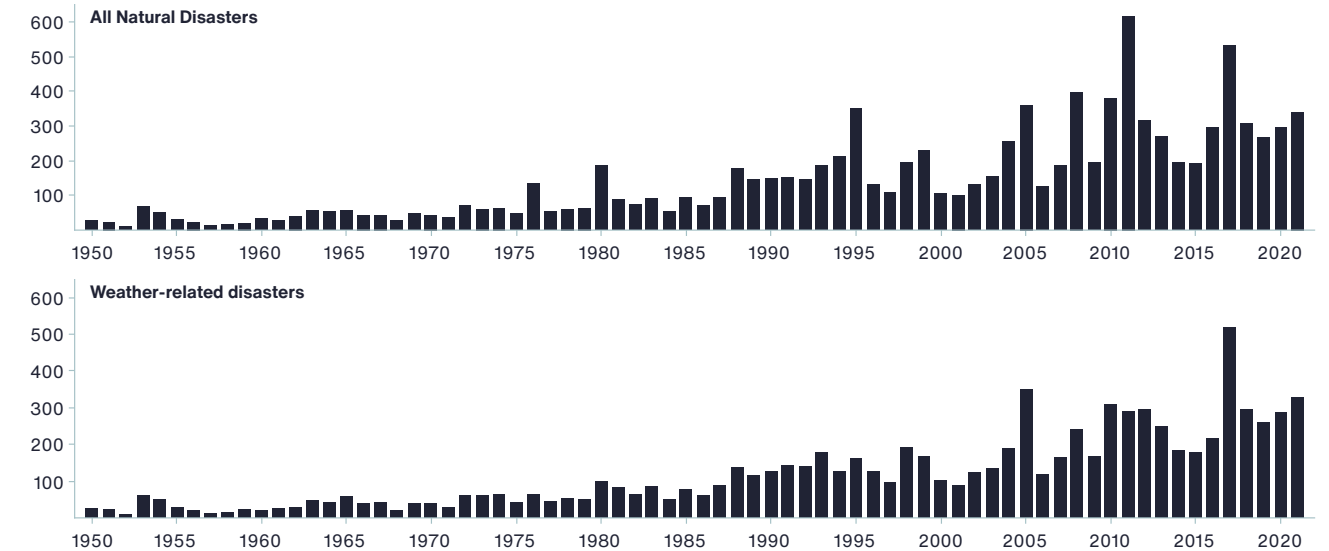
# Appendix B: Long-term Natural Disaster Trends

Date	Event	Location	Deaths	Economic Loss (USD)
10/22-10/28	Flooding	Vietnam	5	7.5+ million
10/23-10/28	Flooding	Indonesia	6	Millions
10/25-11/15	Flooding	India, Sri Lanka	217	2.5+ billion
11/05-11/09	Winter Weather	China	1	935+ million
11/16-11/30	Flooding	India	133	100+ million
11/19-11/30	Flooding	Indonesia	11	Millions
11/21-11/23	Winter Weather	China	0	10s of millions
11/26-11/30	Winter Weather	China	0	78+ million
11/27-11/30	Flooding	Vietnam	18	15+ million
11/29-12/01	Flooding	Thailand	0	Millions
12/04-12/20	Volcano	Indonesia	57	10s of millions
12/16-12/18	Typhon Rai	Philippines, Vietnam	410	1.0+ billion
12/17-12/29	Flooding	Malaysia, Thailand	48	2.0+ billion
12/17-12/28	Winter Weather	Japan	2	10s of millions
12/24	Earthquake	Laos, China	0	70+ million
12/31-01/03	Flooding	Malaysia, Indonesia	5	Millions

## Oceania

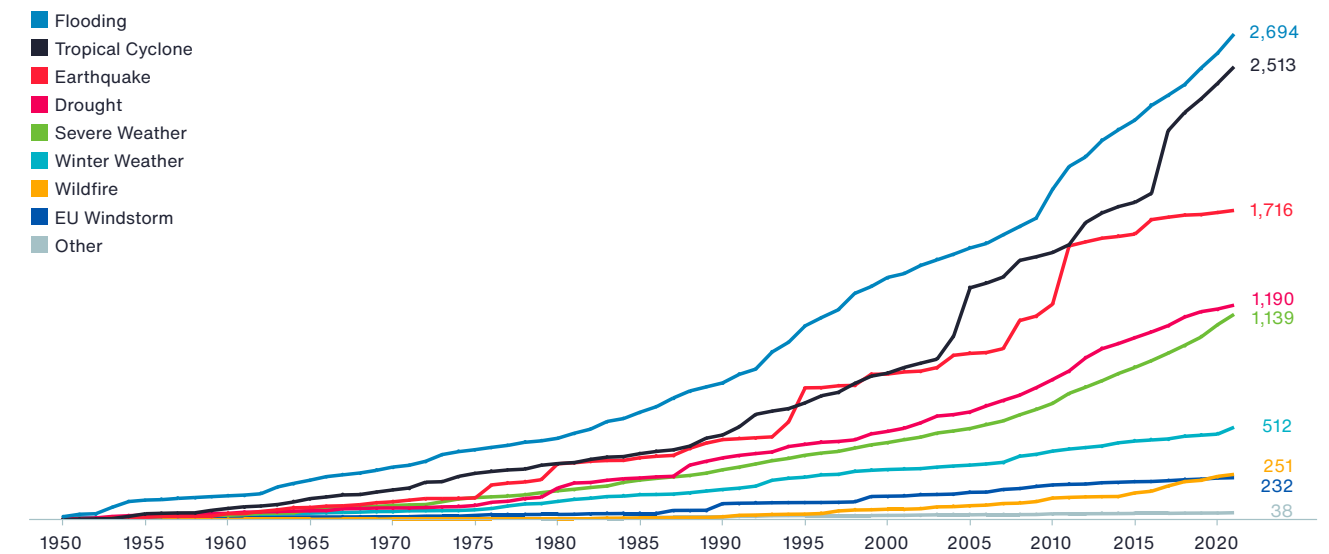
Date	Event	Location	Deaths	Economic Loss (USD)
01/03-01/07	Cyclone Imogen	Australia	0	10s of millions
01/30-01/31	Cyclone Ana	Fiji	6	10s of millions
02/01-02/05	Wildfire	Australia	0	120+ million
02/03-02/08	Flooding	Australia	0	10s of millions
02/25-03/07	Cyclone Niran	Australia, New Caledonia	0	250+ million
03/13-03/25	Flooding	Australia	2	2.1+ billion
04/11-04/12	Cyclone Seroja	Australia	1	530+ million
05/29-06/01	Flooding	New Zealand	0	50+ million
06/09-06/10	Severe Weather	Australia	2	330+ million
06/19	Severe Weather	New Zealand	1	30+ million
07/15-07/19	Flooding	New Zealand	0	140+ million
08/30-08/31	Flooding	New Zealand	0	57+ million
09/09-09/13	Severe Weather	New Zealand	0	17+ million
09/22	Earthquake	Australia	0	36+ million
10/18-10/20	Severe Weather	Australia	0	75+ million
10/27-11/01	Severe Weather	Australia	0	1.1+ billion
11/06-11/12	Severe Weather	Australia	0	10s of millions
11/15-12/01	Flooding	Australia	2	100s of millions

Exhibit 54: Global Economic Losses from natural disasters since 1950 (2021 USD billion)



Data: Aon (Catastrophe Insight)

Exhibit 55: Cumulative Global Economic Losses by peril since 1950 (2021 USD)



Data: Aon (Catastrophe Insight)

# Appendix C: Historical Natural Disaster Events

The following tables provide a look at specific global natural disaster events since 1900. Please note that the adjusted for inflation (2021 USD) totals were converted using the U.S. Consumer Price Index (CPI). Insured losses include those sustained by private industry and government entities such as the U.S. National Flood Insurance Program (NFIP). Inflation-adjusted losses are used since they represent actual incurred costs in today's dollars. Normalized values, while very valuable for analyzing historical scenarios using today's population, exposure, and wealth, are hypothetical. Please note that some of these values have been rounded to the nearest whole number.

For additional top 10 lists, please visit <http://catastropheinsight.aon.com>.

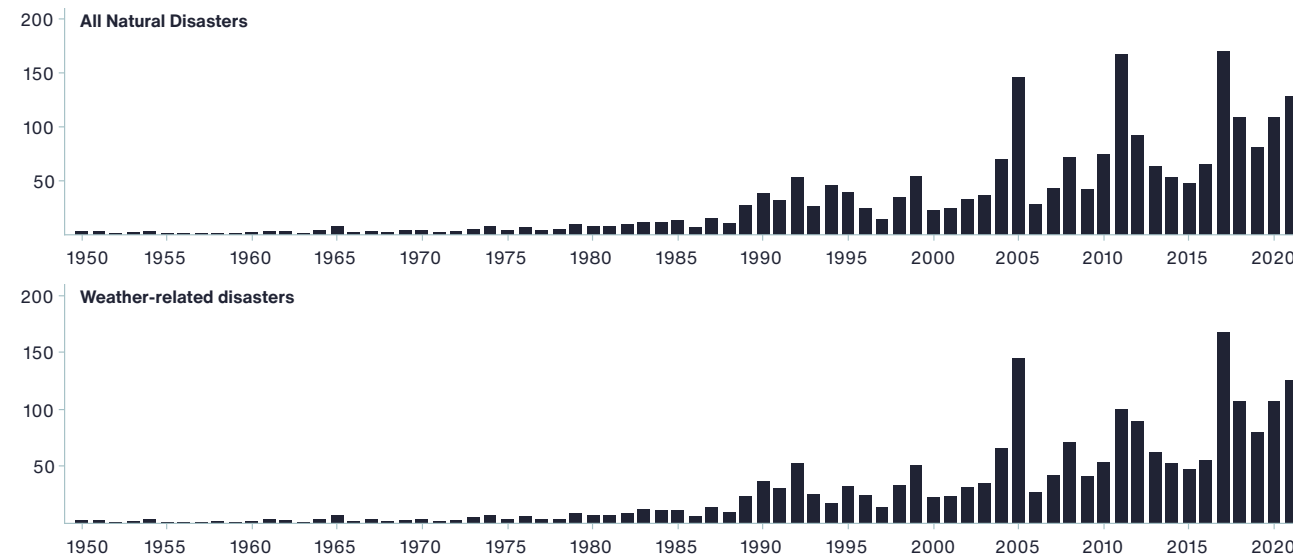
**Exhibit 58: Top 10 Costliest Global Economic Loss Events (1900-2021)**

Date	Event	Location	Economic Loss (Nominal USD billion)	Economic Loss (2021 USD billion)
Mar 11, 2011	Tohoku EQ/Tsunami	Japan	235	285
Jan 16, 1995	Great Hanshin EQ	Japan	103	185
Aug 2005	Hurricane Katrina	United States	125	172
May 12, 2008	Sichuan Earthquake	China	122	152
Aug 2017	Hurricane Harvey	United States	125	138
Sep 2017	Hurricane Maria	Puerto Rico, Caribbean	90	99
Oct 2012	Hurricane Sandy	U.S., Caribbean, Canada	77	90
Sep 2017	Hurricane Irma	U.S., Caribbean	77	85
Jan 17, 1994	Northridge EQ	United States	44	82
Aug - Sep 2021	Hurricane Ida	U.S., Caribbean	75	75

**Exhibit 59: Top 10 Costliest Global Insured Loss Events (1900-2021)**

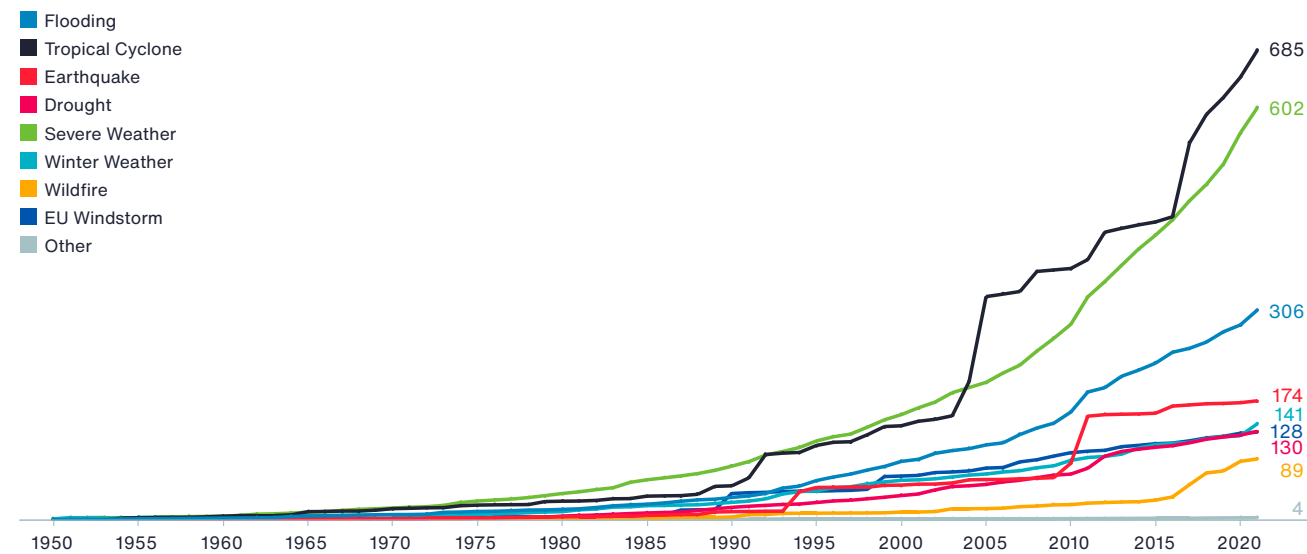
Date	Event	Location	Insured Loss (Nominal USD billion)	Insured Loss (2021 USD billion)
Aug 2005	Hurricane Katrina	United States	65	90
Mar 11, 2011	Tohoku EQ/Tsunami	Japan	35	42
Sep 2017	Hurricane Irma	U.S, Caribbean	33	37
Aug - Sep 2021	Hurricane Ida	U.S., Caribbean	36	36
Oct 2012	Hurricane Sandy	U.S., Caribbean, Canada	30	35
Aug 2017	Hurricane Harvey	United States	30	33
Sep 2017	Hurricane Maria	Puerto Rico, Caribbean	30	33
Aug 1992	Hurricane Andrew	U.S., Bahamas	16	31
Jan 17, 1994	Northridge EQ	United States	15	28
Sep 2008	Hurricane Ike	U.S., Caribbean	18	23

**Exhibit 56: Global Insured Losses from natural disasters since 1950 (2021 USD billion)**



Data: Aon (Catastrophe Insight)

**Exhibit 57: Cumulative Global Insured Losses by peril since 1950 (2021 USD billion)**



Data: Aon (Catastrophe Insight)

**Exhibit 60: Top 10 Costliest Tropical Cyclones: Economic Loss (1900-2021)**

Date	Event	Location	Economic Loss (Nominal USD billion)	Economic Loss (2021 USD billion)
2005	Hurricane Katrina	United States	125	172
2017	Hurricane Harvey	United States	125	138
2017	Hurricane Maria	U.S., Caribbean	90	99
2012	Hurricane Sandy	U.S., Caribbean	77	90
2017	Hurricane Irma	U.S., Caribbean	77	85
2021	Hurricane Ida	U.S., Caribbean	75	75
1992	Hurricane Andrew	U.S., Bahamas	27	52
2008	Hurricane Ike	U.S., Caribbean	38	47
2004	Hurricane Ivan	U.S., Caribbean	27	39
2005	Hurricane Wilma	U.S., Caribbean	27	37

**Exhibit 61: Top 10 Costliest Tropical Cyclones: Insured Loss (1900-2021)**

Date	Event	Location	Insured Loss (Nominal USD billion)	Insured Loss (2021 USD billion)
2005	Hurricane Katrina	United States	65	90
2017	Hurricane Irma	U.S., Caribbean	33	37
2021	Hurricane Ida	U.S., Caribbean	36	36
2012	Hurricane Sandy	U.S., Caribbean, Canada	30	35
2017	Hurricane Harvey	United States	30	33
2017	Hurricane Maria	U.S., Caribbean	30	33
1992	Hurricane Andrew	U.S., Caribbean	16	31
2008	Hurricane Ike	U.S., Caribbean	18	23
2005	Hurricane Wilma	U.S., Caribbean	13	17
2004	Hurricane Ivan	U.S., Caribbean	11	15

**Exhibit 62: Top 10 Costliest Severe Convective Storms: Economic Loss (1900-2021)**

Date	Event	Location	Economic Loss (Nominal USD billion)	Economic Loss (2021 USD billion)
Aug 2020	Midwest Derecho	United States	13.6	14.1
Apr 2011	2011 Super Outbreak	United States	10.2	12.2
May 2011	Joplin Tornado/SCS	United States	9.1	10.9
Apr 1965	Palm Sunday Outbreak	United States	1.2	10.3
Oct-Nov 2018	Storm Vaia	Europe	8.3	8.9
Apr 1974	Super Outbreak 1974	United States	1.5	8.6
Mar 1973	United States SCS	United States	1.3	7.9
May 2003	United States SCS	United States	4.5	6.6
July 2013	Storm Andreas	Europe	5.3	6.1
Apr 1979	Texas Tornadoes & Flooding	United States	1.5	5.8

**Exhibit 63: Top 10 Costliest Severe Convective Storms: Insured Loss (1900-2021)**

Date	Event	Location	Insured Loss (Nominal USD billion)	Insured Loss (2021 USD billion)
Aug 2020	Midwest Derecho	United States	9.2	9.6
Apr 2011	2011 Super Outbreak	United States	7.3	8.8
May 2011	Joplin Tornado/SCS	United States	6.9	8.3
May 2003	United States SCS	United States	3.2	4.7
July 2013	Storm Andreas	Europe	3.8	4.4
Dec 2021	United States	United States	4.0	4.0
May 2019	United States SCS	United States	3.7	3.9
Apr 2016	San Antonio Hailstorm	United States	3.2	3.6
Jun 2014	Storm Ela	Europe	3.1	3.6
Jun 2021	June 17-25 Outbreak	Europe	3.5	3.5

**Exhibit 64: Top 10 Costliest Floods: Economic Loss (1900-2021)**

Date	Event	Location	Economic Loss (Nominal USD billion)	Economic Loss (2021 USD billion)
Jul-Dec 2011	Thailand Floods	Thailand	45	54
Jun-Sep 1998	Yangtze River Floods	China	31	52
Jul-Aug 2010	Yangtze River Floods	China	39	48
Jul 2021	Storm Bernd	Europe	46	46
Jun-Aug 1993	Mississippi Floods	United States	21	39
Jun-Sep 2020	China Seasonal Floods	China	35	37
Jul-Aug 1931	Yangtze River Floods	China	2.0	36
Jun-Aug 1953	Japan Floods	Japan	3.2	32
May-Aug 2016	Yangtze River Floods	China	28	32
Jun - Sep 2021	China Seasonal Floods	China	30	30

**Exhibit 65: Top 10 Costliest Earthquakes: Economic Loss (1900-2021)**

Date	Event	Location	Economic Loss (Nominal USD billion)	Economic Loss (2021 USD billion)
Mar 11, 2011	Tohoku EQ/Tsunami	Japan	235	285
Jan 16, 1995	Great Hanshin EQ	Japan	103	185
May 12, 2008	Sichuan Earthquake	China	122	152
Jan 17, 1994	Northridge EQ	United States	44	82
Nov 23, 1980	Irpinia EQ	Italy	20	63
Apr 14, 2016	Kumamoto EQ	Japan	38	43
Oct 23, 2004	Chuetsu EQ	Japan	28	40
Feb 27, 2010	Chile EQ	Chile	30	38
Dec 7, 1988	Armenian EQ	Armenia (Present Day)	16	36
July 27, 1976	Tangshan EQ	China	6.8	32



**Exhibit 66: Top 10 Costliest Individual Wildfires: Insured Loss (1900-2021)**

Date	Event	Location	Insured Loss (Nominal USD billion)	Insured Loss (2021 USD billion)
Nov 2018	Camp Fire	United States	10.0	10.8
Oct 2017	Tubbs Fire	United States	8.7	9.6
Nov 2018	Woolsey Fire	United States	4.2	4.5
Oct 1991	Oakland (Tunnel) Fire	United States	1.7	3.4
Oct 2017	Atlas Fire	United States	3.0	3.3
May 2016	Horse Creek Fire	Canada	2.9	3.2
Sep-Oct 2020	Glass Fire	United States	3.0	3.1
Aug-Sep 2020	CZU Complex Fire	United States	2.5	2.6
Dec 2017	Thomas Fire	United States	2.2	2.5
Aug-Sep 2020	LNU Complex Fire	United States	2.2	2.3

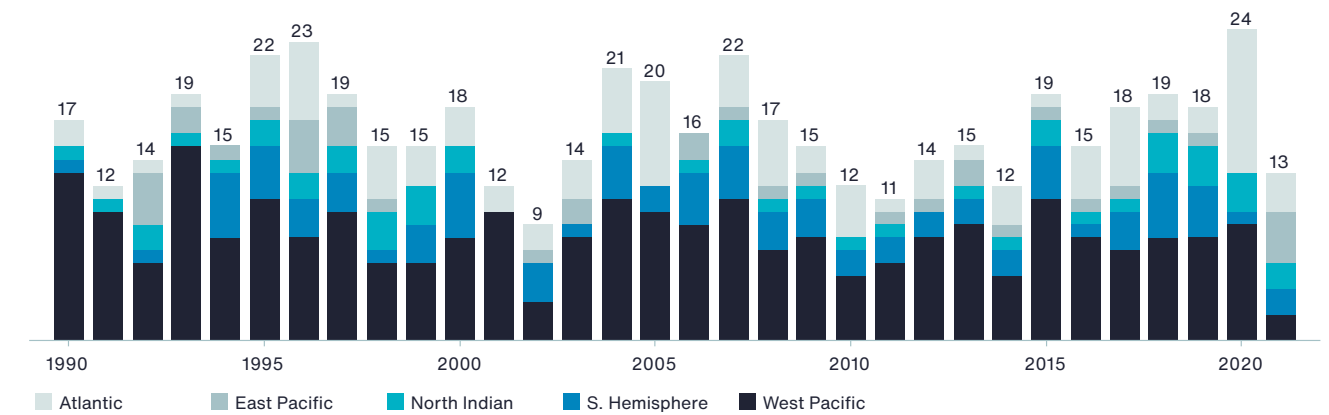
**Exhibit 67: Top 10 Global Human Fatality Events in the Modern Era (1950-2021)**

Date	Event	Location	Economic Loss (2021 USD billion)	Deaths
Nov 12, 1970	Cyclone Bhola	Bangladesh	0.5	300,000
Jul 27, 1976	Tangshan EQ	China	32	242,769
Jul 30, 1975	Super Typhoon Nina	Taiwan, China	6.0	230,000
Dec 26, 2004	Indian Ocean EQ/Tsunami	Indian Ocean Basin	26	227,898
Jan 12, 2010	Port-au-Prince EQ	Haiti	10	160,000
Apr 1991	Cyclone Gorky	Bangladesh	3.6	139,000
May 2008	Cyclone Nargis	Myanmar	16.1	138,366
Aug 1971	Vietnam Floods	Vietnam	N/A	100,000
Oct 8, 2005	Kashmir EQ	Pakistan	9.1	88,000
May 12, 2008	Sichuan EQ	China	152	87,652

# Appendix D: Global Tropical Cyclone Activity

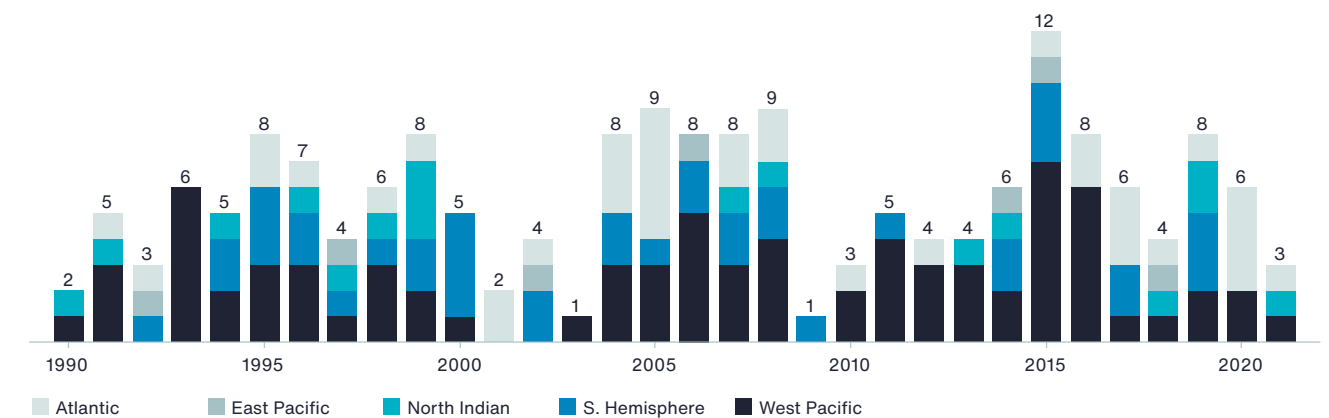
Please note that 1990 is generally considered the first year when global tropical cyclone data are best verified in every basin. Data from the Southern Hemisphere prior to 1990 is still subject to future reanalysis by official tropical cyclone agencies. While there continues to be increasing instances of costlier and more impactful landfalling tropical cyclones, there has yet to be any obvious shift in landfall trends across the globe. This suggests that losses are largely being driven by the increased levels of population and exposure along vulnerable coastal locations. However, as thoroughly referenced elsewhere in this report, emerging trends indicate that tropical cyclones are intensifying at a faster rate and reaching the highest intensity levels for longer periods and near the point of landfall. This is a concerning trend and one that portends to greater future losses for the peril.

**Exhibit 68: Global Tropical Cyclone Landfalls (Category 1+)**



Data: NOAA. Graphic: Aon (Catastrophe Insight)

**Exhibit 69: Global Tropical Cyclone Landfalls (Category 3+)**

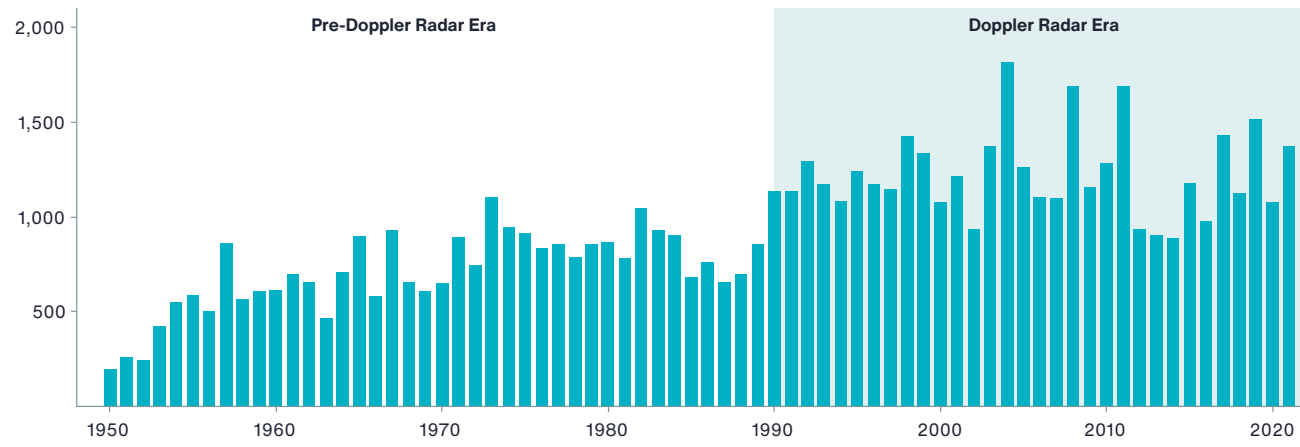


Data: NOAA. Graphic: Aon (Catastrophe Insight)

# Appendix E: United States Severe Weather Data

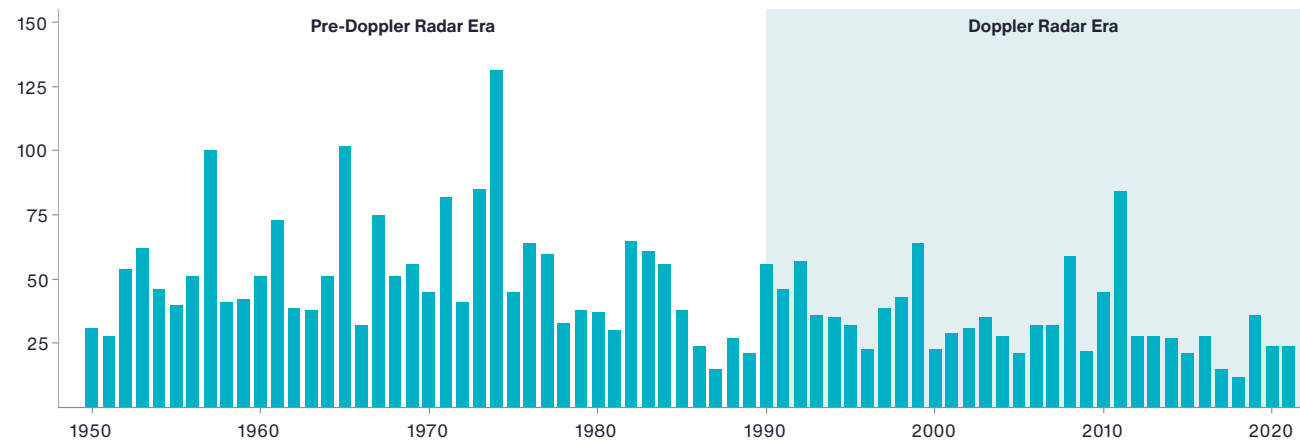
Given the increased cost of severe weather-related damage in the United States during the past decade for insurers, the following is a breakout of reported tornadoes and large hail (2.0 in or larger). The data comes via NOAA's Storm Prediction Center. Please note that data prior to 1990 are often considered incomplete given a lack of reporting. The implementation of Doppler radar, greater social awareness and increased reporting has led to more accurate datasets in the last 30 years. Data from 2021 is to be considered preliminary.

**Exhibit 70: U.S. Tornadoes (F0/EF0+)**



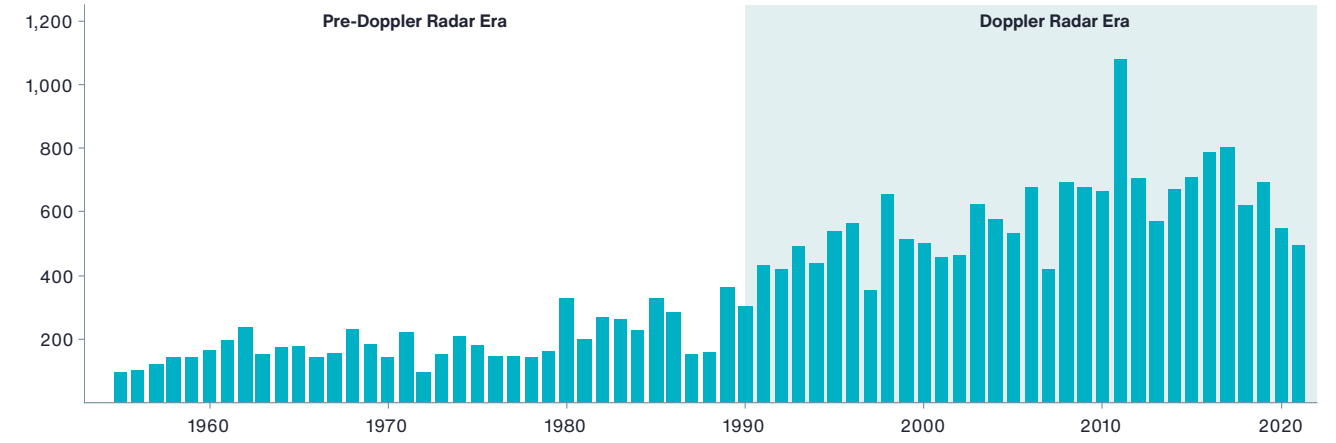
Data: NOAA. Graphic: Aon (Catastrophe Insight)

**Exhibit 71: U.S. Tornadoes (F3/EF3+)**



Data: NOAA. Graphic: Aon (Catastrophe Insight)

**Exhibit 72: U.S. Large Hail Reports (2.0" or Larger)**

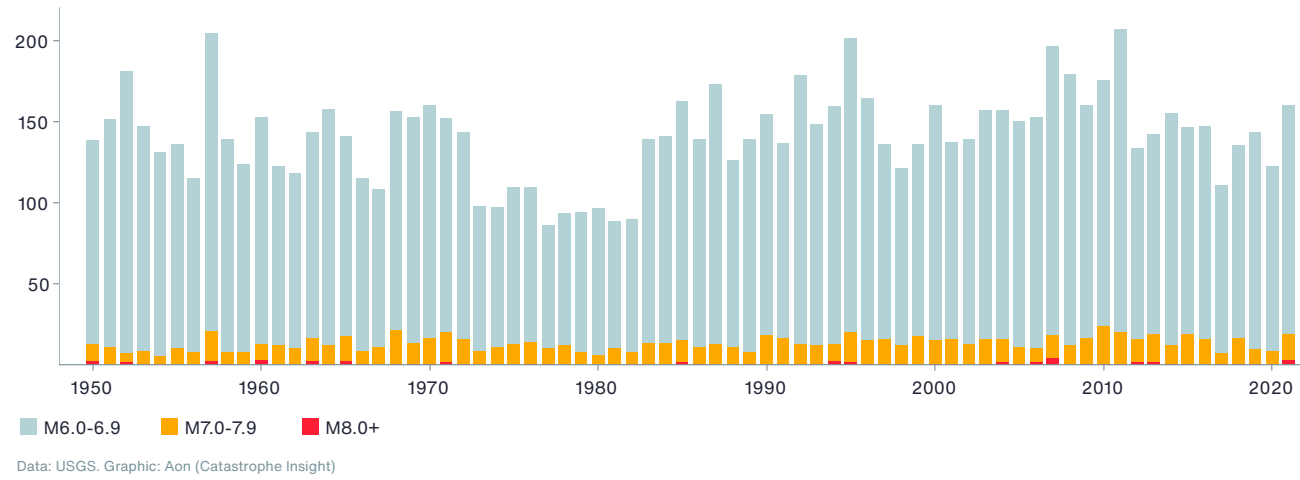


Data: NOAA. Graphic: Aon (Catastrophe Insight)

# Appendix F: Global Earthquakes

Based on historical data from the United States Geological Survey, 2021 saw at least 161 earthquakes with magnitudes of 6.0 or greater. Overall earthquake activity does not often show large fluctuations on an annual basis. This is especially true given the extensive network of global seismograph stations that has led to an improved and more robust dataset in recent decades.

**Exhibit 73: Global Earthquakes (M6.0+)**



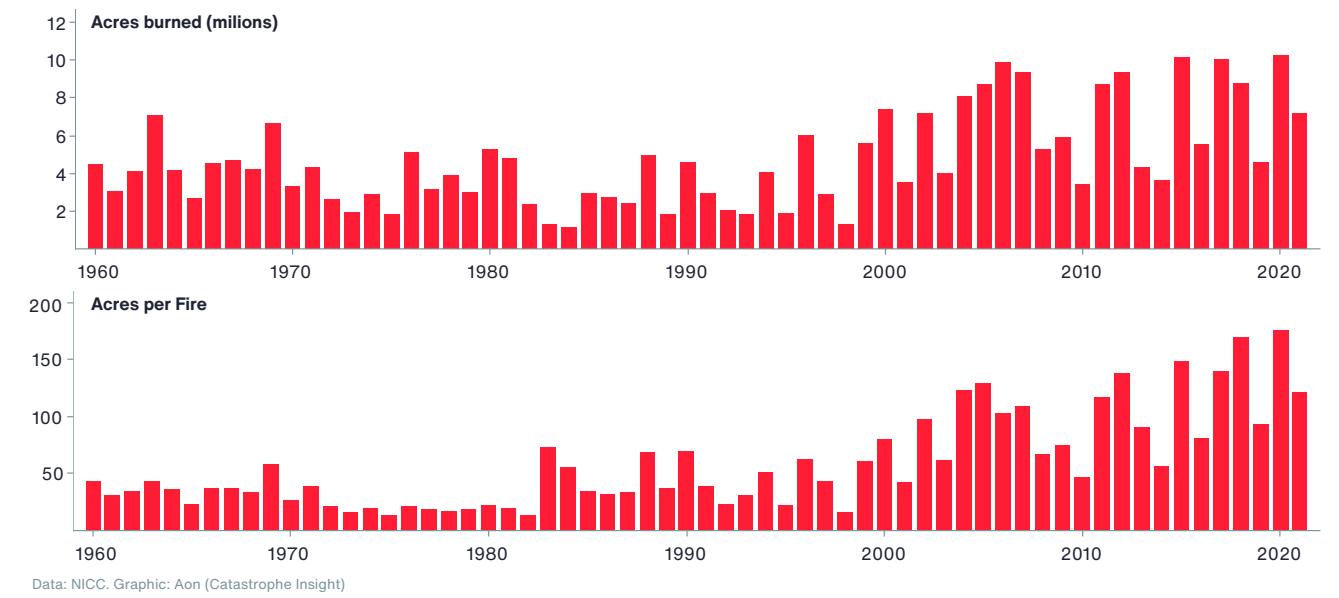
**Exhibit 74: Global M7.0+ Earthquakes (1950-2021)**



# Appendix G: United States Wildfire Data

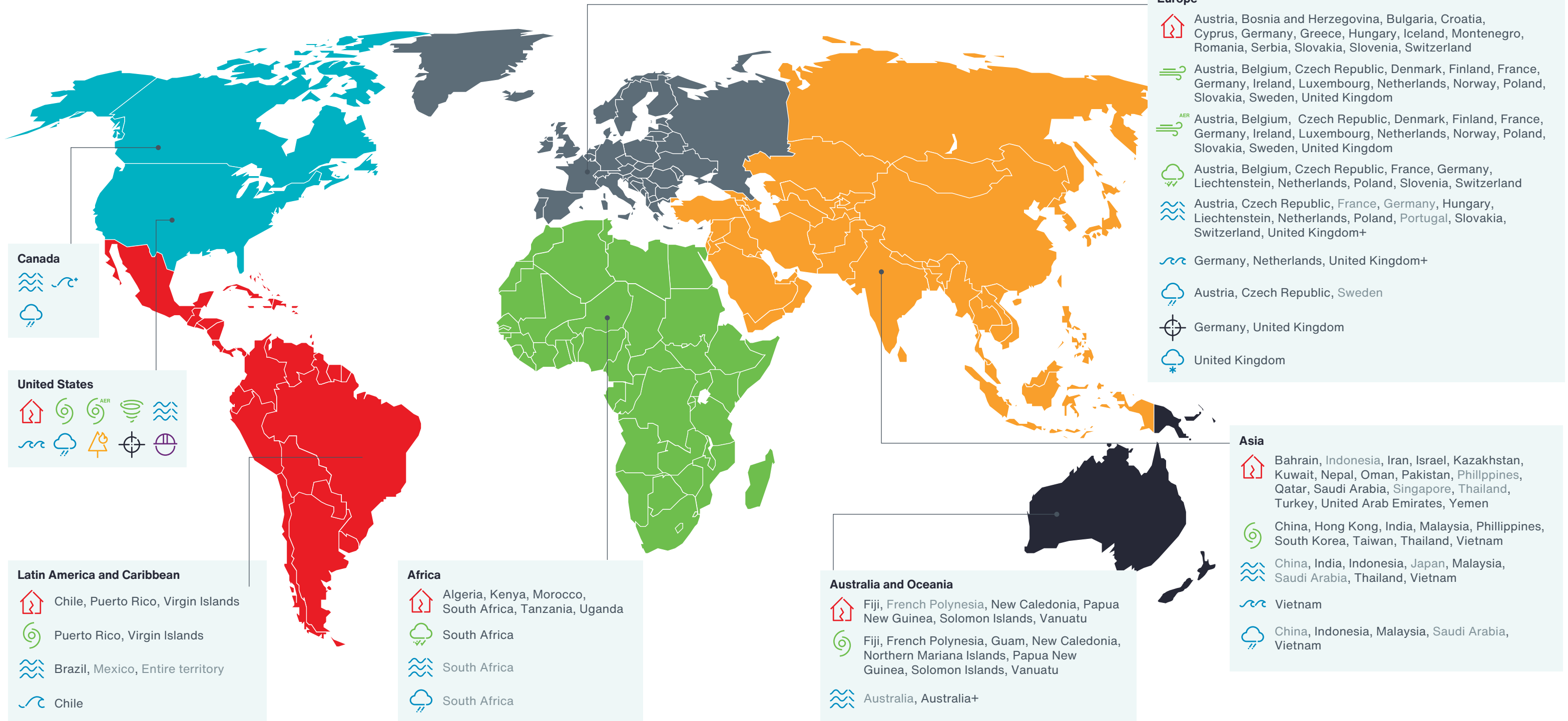
The following wildfire data in the United States is provided from the National Interagency Fire Center (NIFC), which began compiling statistics under their current methodology in 1983. Previous data was collected by the National Interagency Coordination Center (NICC) from 1960 to 1982 but used a different methodology. It is not advised to compare pre-1983 data to post-1983 data given these different data collection methods.

**Exhibit 75: United States Wildfire Acres Burned & Acres Burned per Fire**





# Impact Forecasting Model Coverage Map



## Map Icons

- earthquake
- tropical cyclone
- severe convective storm
- windstorm
- hail
- fluvial flood
- storm surge
- freeze
- tsunami
- pluvial flood/ cloud burst
- bushfire
- terrorism
- workers' compensation
- AER Country
- Automated Event Response scenario model only
- third party models



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