Sustainability Insights | Research

Navigating Uncertainty: U.S. Governments And Physical Climate Risks

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U.S. governments could face worsening physical climate risks. Data and scenario analysis on climate hazards can provide greater visibility about potential long-term risks relevant to our view of creditworthiness.

This research report explores an evolving topic relating to sustainability. It reflects research conducted by and contributions from S&P Global Ratings' sustainability research and sustainable finance teams as well as our credit rating analysts (where listed).

This report does not constitute a rating action.

Authors

US Public Finance Credit Ratings

Randy Layman
Englewood
randy.layman@spglobal.com

Nora Wittstruck
New York
nora.wittstruck@spglobal.com

Sustainability Research

Paul Munday
London
Paul.Munday@spglobal.com

Contributors

Alex Louie
Englewood

Kenneth Biddison
Englewood

Chelsy Shipman
San Francisco

S&P Global
Ratings

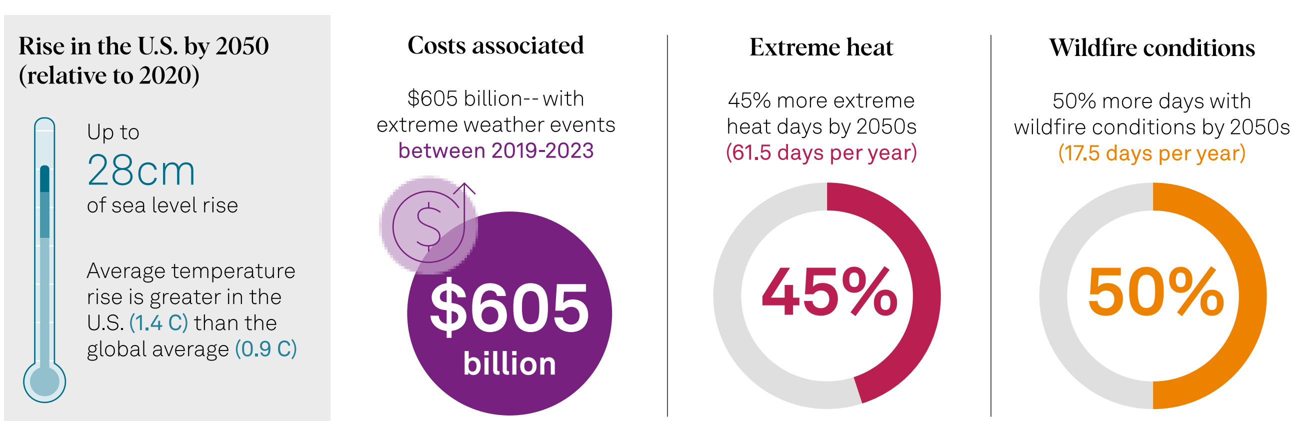
This research focuses on the potential exposures of U.S. states, counties, and municipalities to physical climate risks. To do this, S&P Global Ratings (hereafter, “we” or “our”) uses the U.S. Muni Bond Climate Physical Risk dataset from S&P Global Sustainable1. This dataset includes exposure data for nine climate hazards over various timescales and greenhouse gas emissions scenarios through the Shared Socioeconomic Pathways (SSPs), as defined by the Intergovernmental Panel on Climate Change (IPCC). The dataset shows projected trends and potential insights of how these exposures could evolve. We highlight limitations of the dataset in the appendix.

Consistent with our criteria, our credit ratings incorporate the adverse physical effects of climate change that are sufficiently visible and material--along with all other factors material to our assessment of creditworthiness. We do this when we believe such factors could materially influence the creditworthiness of a rated entity, or issuer, and we have sufficient visibility on how those factors will evolve or manifest. Scenario analysis and climate data can help deepen our understanding of how physical climate risk exposures could evolve over time. Our research aims to provide insights on how the increasing frequency and severity of climate hazards can influence key credit factors for U.S. governments and the methods by which they are preparing for and managing these risks.

Key Findings

- **The global average temperature is projected to continue to rise, leading to more severe and frequent physical climate risks in many regions**. In the U.S., warming is accelerating faster than the global average, according to the U.S. Fifth National Climate Assessment. This is a potential credit risk to U.S. governments, absent adaptation measures.
- **Fixed locations and economic boundaries mean many U.S. local governments could be increasingly exposed to climate hazards.** Data from S&P Global Sustainable1 projects more frequent extreme heat events and coastal flooding from rising sea levels will underpin exposures for U.S. local governments to 2050--that is, if global warming does not remain well below the 2 degrees Celsius ambition of the Paris Agreement.
- **Climate data can help inform our analysis**. The use of climate data--in and of itself--is not expected to lead to credit rating actions. However, climate data and scenario analysis can provide a starting point to help inform our discussions with management, allow for peer comparisons including adaptation measures, and enhance our forward-looking views.

By the numbers: Climate change impacts in the U.S.



Sources: IPCC, NOAA, S&P Global Sustainable 1.

Exposure To Physical Risks Could Lead To Economic and Financial Costs

Rising greenhouse gas emissions mean there is now a 66% likelihood that the global average temperature between 2023 and 2027 will be more than 1.5 C above pre-industrial levels--a key threshold identified by the Paris Agreement--according to the World Meteorological Organization. In addition, the IPCC reports that surpassing 1.5 C could result in increasingly frequent and severe physical climate hazards. In addition, rising temperatures could contribute to worsening chronic events, including changes to precipitation, temperature patterns, and sea levels.

In the U.S., climate hazard related events leading to damage of $1 billion or more nearly doubled between 2010-2019 compared with the previous decade. Between 2010 and 2019, the U.S. recorded 131 disasters costing $1 billion or more (total costs reached $977.9 billion). This was up from 67 events between 2000 and 2009 ($607 billion), according to the National Oceanic and Atmospheric Administration (NOAA). Between 2019 and 2023, the U.S. recorded 102 similar events with total costs exceeding $605 billion. Severe storms are associated with the greatest number of billion-dollar events. However, related damage per such event are the lowest (average $2.4 billion), followed by costs for tropical cyclones and flooding, according to the NOAA. By 2030, if mitigation of greenhouse gas emissions is not stepped up, there could be 40% more disasters than in 2015, with 250 events globally a year, according to a 2022 report by the U.N. Office for Disaster Risk Reduction.

The physical impacts of climate change may play out to a greater extent in the U.S. than some other countries. Due to subsidence, erosion, and other natural and anthropogenic processes, the rate of local sea level rise along the U.S. Southeast and Gulf coasts compared to the global average has accelerated--and NOAA expects it to continue to rise. Rising sea levels at the coast can contribute to increased flood risk, storm damage, and accelerated land loss in unprotected areas. In addition, the rate of warming across the contiguous U.S. has accelerated at a faster rate than the global average. It has risen 2.5 degrees Fahrenheit (1.4 C) since 1970, compared with a global average 1.7 degrees F (0.9 C) over the same period, according to the U.S. Fifth National Climate Assessment, published in 2023. The pace of change could pose a potential risk to local governments, absent adaptation.

Our research shows impacts on economic growth from climate hazards will likely be heterogeneous and we projected they will rise, absent adaptation. Up to 4.4% of the world's GDP could be lost annually without adaptation measures. This would disproportionally affect developing economies (see "Lost GDP: Potential Impacts Of Physical Climate Risks", published Nov. 27, 2023). In the U.S., economic losses could reach 2% of GDP per year by 2050 under Shared Socioeconomic Pathway 3-7.0 (SSP 3-7.0; see box below). Delayed adaptation or no adaptation may increase the costs and the amount of change required to adapt to climate change, according to U.S. Global Change Research Program (USGCRP).

Data And Approach: Assessing U.S. Governments' Physical Risk Exposure

Our analysis and research leverage the S&P Global Sustainable1 U.S. Muni Bond Climate Physical Risk Dataset (hereafter "S1 dataset") on the exposure of U.S. local governments to nine climate hazards. These are: extreme heat, extreme cold, wildfire, drought, water stress, coastal flood (sea level rise), fluvial flood, pluvial flood, and tropical cyclones. The S1 dataset covers the period through to midcentury, under four Shared Socioeconomic Pathways (SSPs).

The S1 dataset covers all 50 U.S. states, the District of Columbia, and more than 3,100 counties or county equivalents. In addition, to better understand the potential sensitivity of U.S. governments to different climate hazards, the S1 dataset is augmented with information on GDP and population, which provides--in S&P Global Ratings' view-- a reasonable approximation for climate exposures that could affect the credit profile of U.S. governments and revenue securing debt service. The thresholds (see Table A1 in the Appendix) are used to define areas of high exposure to each climate hazard.

The S1 dataset helps identify:

- Climate hazards that could present material challenges to each geographic entity in each decade;
- Counties that could face compound physical climate risks (climate hazards occurring at the same time or consecutively); and
- Counties that could face the greatest exposure to physical risks in the near- and medium-term.

Here, we describe the dataset, including the available climate scenarios and climate hazards.

Scenarios allow comparison of multiple potential exposures

To better understand the potential credit impacts of physical climate risks, the S1 dataset applies four SSPs (see below). Given the lock-in effect of historical emissions, many physical risks of climate change will materialize regardless of today's policy choices--this is particularly the case for timepoints before midcentury (see IPCC Sixth Assessment Report: Summary For Policymakers). Countries' current commitments, if met, align with a global temperature increase of between 2.4 C and 2.6 C by 2100, according to UNEP. This is similar to SSP2-4.5. Using a range of scenarios helps us understand the likely transmission channels of credit risk and the potential impact on credit quality. It helps to enhance our forward-looking credit analysis when testing potential future exposures against U.S. governments' resilience and risk management strategies, while also considering the potential range of costs and benefits identified by them.

Shared Socioeconomic Pathways Defined

The IPCC's SSPs are a set of scenarios for projected greenhouse gas emissions and temperature changes. They incorporate broad changes in socioeconomic systems, including population growth, economic growth, resource availability, and technological developments.

- **SSP1-2.6 is a low emissions scenario.** Under this, the world shifts gradually, but consistently, toward a more sustainable path. **This SSP aligns with the Paris Agreement's target** to limit the average increase in global temperature to well below 2 degrees Celsius (2 C) by the end of the century. The scenario projects a global temperature increase of 1.7 C (a likely range of 1.3 C-2.2 C) by 2050 or by 1.8 C (1.3 C-2.4 C) by the end of the century.
- **SSP2-4.5 is a moderate emissions scenario.** This is consistent with a future with relatively ambitious emissions reductions but where social, economic, and technological trends don't deviate significantly from historical patterns. **This scenario is close to countries' current pledges** but falls short of the Paris Agreement's aim of limiting the global temperature rise to well below 2 C. It projects an increase of 2.0 C (1.6 C-2.5 C) by 2050 or 2.7 C (2.1 C-3.5 C) by the end of the century.
- **SSP3-7.0 is a moderate-to-high emissions (a slow transition) scenario.** Under it, countries increasingly focus on domestic or regional issues, with slower economic development and lower population growth. A low international priority for addressing environmental concerns leads to rapid environmental degradation in some regions. This SSP projects a global temperature increase of 2.1 C (1.7 C-2.6 C) by 2050 or 3.6 C (2.8 C-4.6 C) by the end of the century.
- **SSP5-8.5 is a high emissions (limited mitigation) scenario**. This SSP sees the world place increasing faith in competitive markets, innovation, and participatory societies to produce rapid technological progress and development of human capital as a path to sustainable development. It projects the global temperature increase at 2.4 C (1.9 C-3.0 C) by 2050 or 4.4 C (3.3 C-5.7 C) by the end of the century.

In the research presented here, we consider U.S. governments' exposures to climate hazards using SSP3-7.0 through to midcentury and use the other scenarios to describe a range of possible outcomes, where appropriate. We primarily present findings to 2050 using SSP3-7.0--a slow transition scenario--due to the lock-in effect of historical greenhouse gas emissions (as previously described) and uncertainty regarding the precise trajectory. We select midcentury due to uncertainty associated with long-term projections of climate, but also as this timeframe corresponds with the weighted average time to maturity of the $4.1 trillion U.S. municipal bonds outstanding (as of Dec. 31, 2023) that is 12 to 14 years and because many new municipal bonds issues are structured with 30-to-40-year final maturity dates given the useful lives of the assets financed.

How analysis metrics capture change in climate hazards over time

A number of different analysis metrics capture change in climate hazards over time through decadal values (see table 1).

- For the **extreme heat** climate hazard, the S1 dataset defines extreme conditions as temperatures exceeding the local daily maximum temperature for 5% of all days between 1950-1999. The analysis assumes that each locality is currently adapted to their respective historical frequencies of extreme heat events, and that any future increase exceeds what would be expected due to natural variability.
- Flood-related hazards--such as **sea level rise/coastal flooding**, and **fluvial** and **pluvial flooding**--are expressed as the annual frequency of days in excess of the historical 100-year flood level. The metric uses the annual probability of flooding, based on the decadal average.

- The **water stress** metric is based on the projected ratio of demand to basin-specific water supply (from both groundwater and surface water sources), expressed in absolute terms. The metric is reported using a 0-1 range, and it describes the state of water availability (calculated based on a decadal average) for the local water basin. A value of 0.4 and above is defined as high water stress (see table A1 in the appendix).
- Other climate hazards--such as **wildfires** and **droughts**--are based on indices that express, respectively, general fire intensity potential and climatic conditions favorable to drought. For wildfire, the index is further enhanced by incorporating land cover containing or adjacent to burnable vegetation, urban areas, or bodies of water. Both climate hazards are expressed as the absolute frequencies of extreme conditions on an annual basis.

The analysis metrics can help explain the potential change in exposure U.S. governments face to the different climate hazards. However, other variables can contribute to increased (or decreased) vulnerability. For example, a locale's demographic, economic, and fiscal vulnerabilities to specific hazards; prior adaptation; how quickly a climate hazard escalates in a given timeframe and scenario; and whether a locale faces multiple hazards can contribute.

Table 1

Climate change hazard coverage, metrics, and spatial resolution

Climate hazard	Analysis metric	Indicator definition	Spatial resolution
Extreme heat	Projected maximum temperature warmer than the 95th percentile local baseline daily maximum temperature	Annual percentage of days with maximum temperature warmer than the 95th percentile local baseline daily maximum temperature	~25x25km
Extreme cold	Projected minimum temperature colder than the fifth percentile local baseline daily maximum temperature	Annual percentage of days with minimum temperature colder than the 5th percentile local baseline daily minimum temperature	~25x25km
Coastal flooding (sea level rise)	Frequency of 100-year coastal flood	Projected frequency of the historical baseline 100-year coastal flood depth	30x30 meters (USA)
Fluvial (river) flooding	Frequency of 100-year fluvial flood	Projected frequency and extent of the historical baseline 100-yr flood depth	~1x1km
Pluvial (rainfall) flooding	Frequency of 100-year rainfall event	Projected frequency of the historical baseline 100-yr daily precipitation rate	~25x25km
Tropical cyclones	Frequency of category 3 and higher storms	Projected annual frequency of category 3 and higher tropical cyclones	~25x25km
Wildfires	Fire Weather Index (FWI)	Projected frequency of days classified as high, very high or extreme based on the FWI. Adjusted for land cover/presence of burnable vegetation	~25x25km
Water stress	Water Stress Index	Projected future ratio of water withdrawals to total renewable water supply in a given area	River basin
Drought	Standardized Precipitation-Evapotranspiration Index (SPEI)	Projected frequency of months classified as moderate drought, severe drought or extreme drought based on the SPEI	~25x25km

km--kilometer. Source: S&P Global Sustainable1.

Some Risks Are National, Others Are Regional

The S1 dataset shows that expected frequencies for eight of the nine hazards (other than extreme cold waves) increase or remain static through the 2050s under a slow transition scenario (SSP3-7.0). The extent of climate hazard exposures can vary significantly based on region, given the expansiveness and geographic diversity of the U.S. However, we observe a number of national-scale trends from the S1 dataset:

- **Extreme heat conditions are rising in nearly every county and could have a national impact**. The median annual number of days where temperatures exceed the historical 95th percentile daily maximum temperature is estimated under SSP3-7.0 to rise from 42.5 days in the 2020s to 61.5 by the 2050s. An increase--to 58 days per year--is also projected under a moderate transition scenario (SSP2-4.5). Under a limited mitigation scenario (SSP5-8.5), projected annual extreme heat days grow to 70 per year by the 2050s.
- **Exposure to drought conditions is estimated to rise nationally**. The median frequency of months experiencing at least moderate drought conditions rising from 14.9% in the 2020s to 21.8% by the 2050s.
- **National wildfire risk remains largely regional and increases under all modeled emissions scenarios.** This includes a low emissions scenario. Population growth and economic development expanding the wildland-urban interface area and density contributes to the increase in this risk. Under SSP3-7.0, the median annual likelihood of conditions conducive to wildfires increases from 11.6 days in the 2020s to 17.5 days by the 2050s.
- **Exposure to extreme flooding events is shown to increase gradually through the 2050s under all emissions scenarios.** Rising temperatures are predicted to contribute to increasing weather variability. These effects are particularly acute for entities exposed to rising sea levels.

Extreme heat and drought exposure: Acute in the west and southwest

Many of the localities most exposed to extreme heat are projected to remain so by the 2050s. Research projections show temperatures nationally will rise gradually through the end of the century. Entities with the highest levels of extreme heat exposure will face increasingly oppressive conditions, potentially impacting economic factors such as productivity and energy demand and electric grid reliability, according to 2016 research led by Xindu Ke.

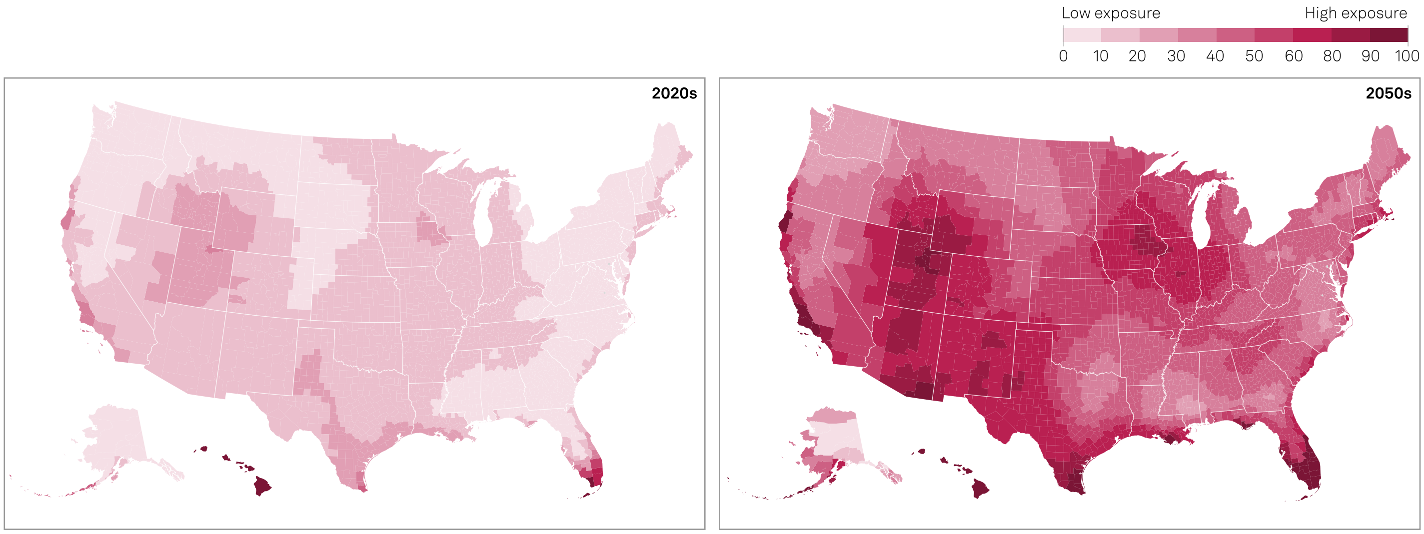
Hawaii, localities in the west and southwest, and the southeast are most exposed to extreme heat conditions. Chart 1 represents the projected change in extreme heat for U.S. counties from the 2020s to the 2050s under SSP3-7.0. The S1 dataset projects that Hawaii will spend nearly half the year under extreme heat conditions by the 2050s compared to the historical baseline, which is around 25% in the 2020s. Furthermore, this scenario projects 12 states experience a 50% or greater increase in exposure to extreme heat conditions by the 2050s. The state with the lowest expected percentage increase in temperatures, Arkansas, is still estimated to realize a 38% increase in extreme heat exposure compared to historical baseline temperatures.

Many of the most exposed localities to drought hazards include areas with high agricultural output. These include Iowa, Indiana, Illinois, and Nebraska. Without compensatory changes to farming practices and technology, rising temperatures and greenhouse gas emissions could negatively affect economic activity in these areas.

Chart 1

Rising temperatures and extreme heat days could have a national impact

Extreme heat exposure under a slow transition scenario (SSP3-7.0)



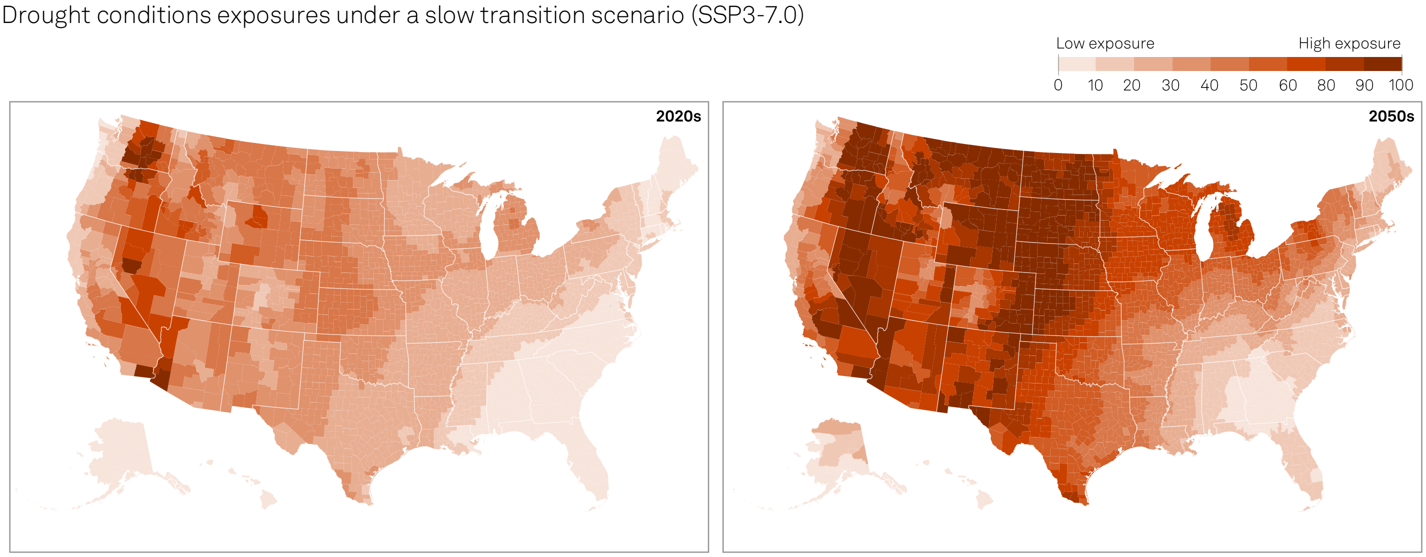
Sources: *S&P Global Sustainable1 and S&P Global Ratings.*

Climate change can lead to compounding effects as climate hazards increase in frequency and severity at the same time. Across much of the Western U.S. and major agricultural belts, county exposures to extreme heat, drought, and water stress trend together. These compound events may contribute to depleted water resources, increased energy demand, disruption to agricultural production, and greater incidences of wildfires. Chart 2 represents the projected change in moderate to extreme drought conditions for U.S. counties from the 2020s to the 2050s under a slow transition scenario (SSP3-7.0). Chart 3 depicts water stress and extreme heat exposures by state for the 2050s, with an emphasis on states that are water stress outliers.

Chart 2

Rising exposure to drought conditions is likely to occur nationally

Drought conditions exposures under a slow transition scenario (SSP3-7.0)

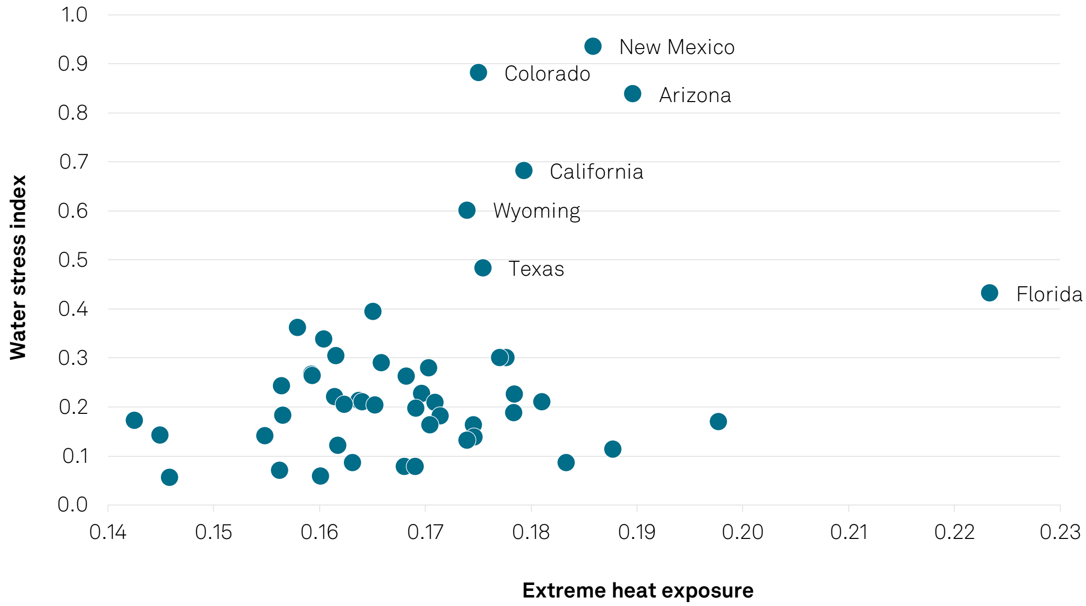


Sources: *S&P Global Sustainable1 and S&P Global Ratings.*

Chart 3

Several states face outsize exposure to compound effects of extreme heat and water stress

Water stress versus extreme heat by state under a slow transition scenario; 2050s



Sources: *S&P Global Sustainable1 and S&P Global Ratings.*

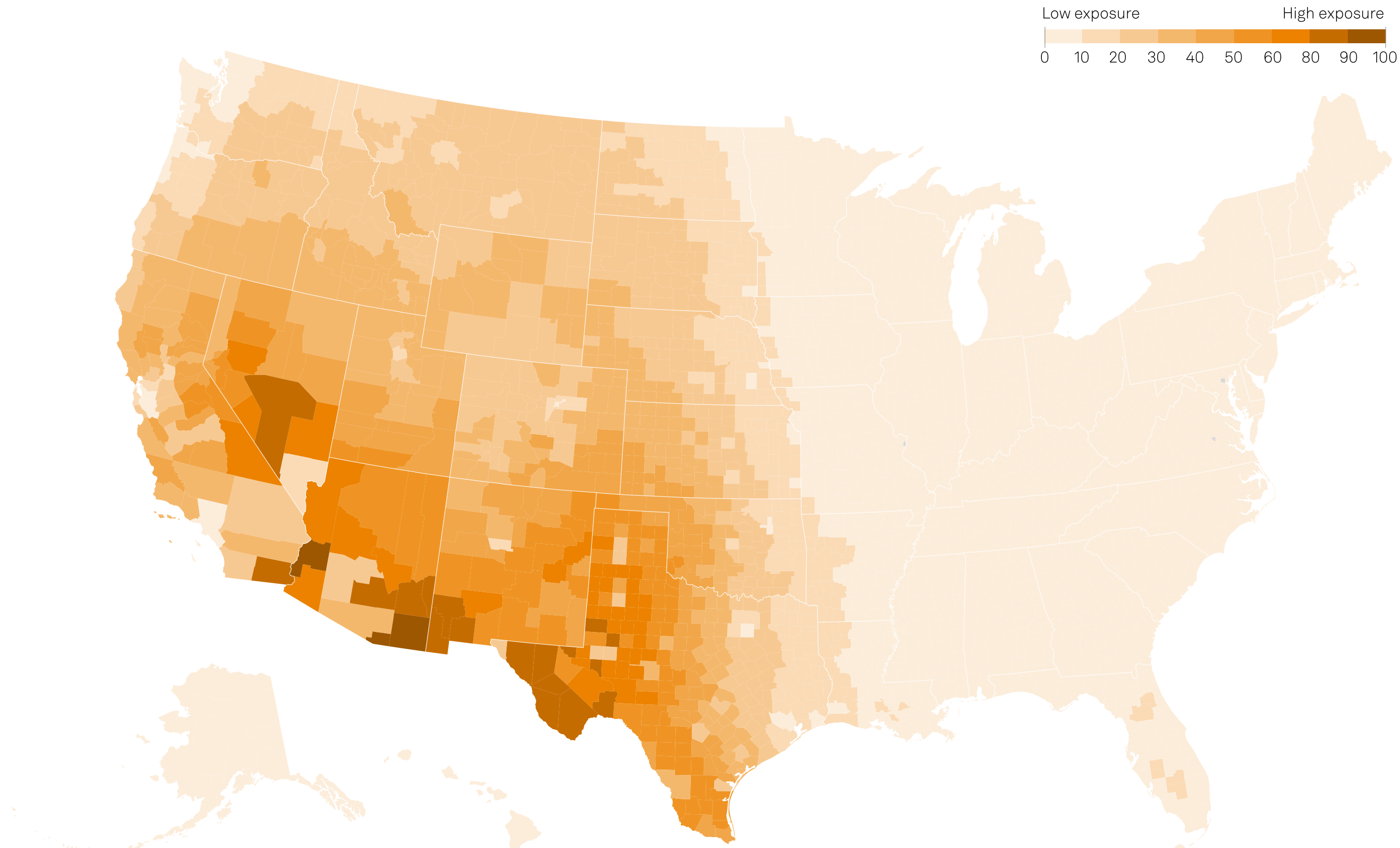
Exposure to wildfire conditions expands east, stays high in the west

The slow transition scenario projects exposure to heightened wildfire conditions will further increase in areas where it is already elevated (see chart 4). For instance, the S1 dataset highlights in the 2020s that 44 of California's 58 counties are exposed to high-to-extreme wildfire conditions at least three months of the year. For 22 counties, heighted wildfire conditions are estimated to be present for at least five months annually in the 2020s. For these counties, and other localities with high exposure in states such as Arizona, Oregon, and Texas, exposure to wildfire conditions is already comparatively high. Although the dataset projects these states will experience greater exposure over time, changes are more gradual compared to areas where baseline exposure is lower. However, when higher average and extreme temperature exposures are present during wildfires, weather conditions conducive to them may be sustained for longer periods, owing to low soil moisture content and humidity.

Chart 4

Wildfire risks projected to remain high across much of the western U.S.

County exposure to wildfire conditions under a slow transition scenario (SSP3-7.0) in the 2050s



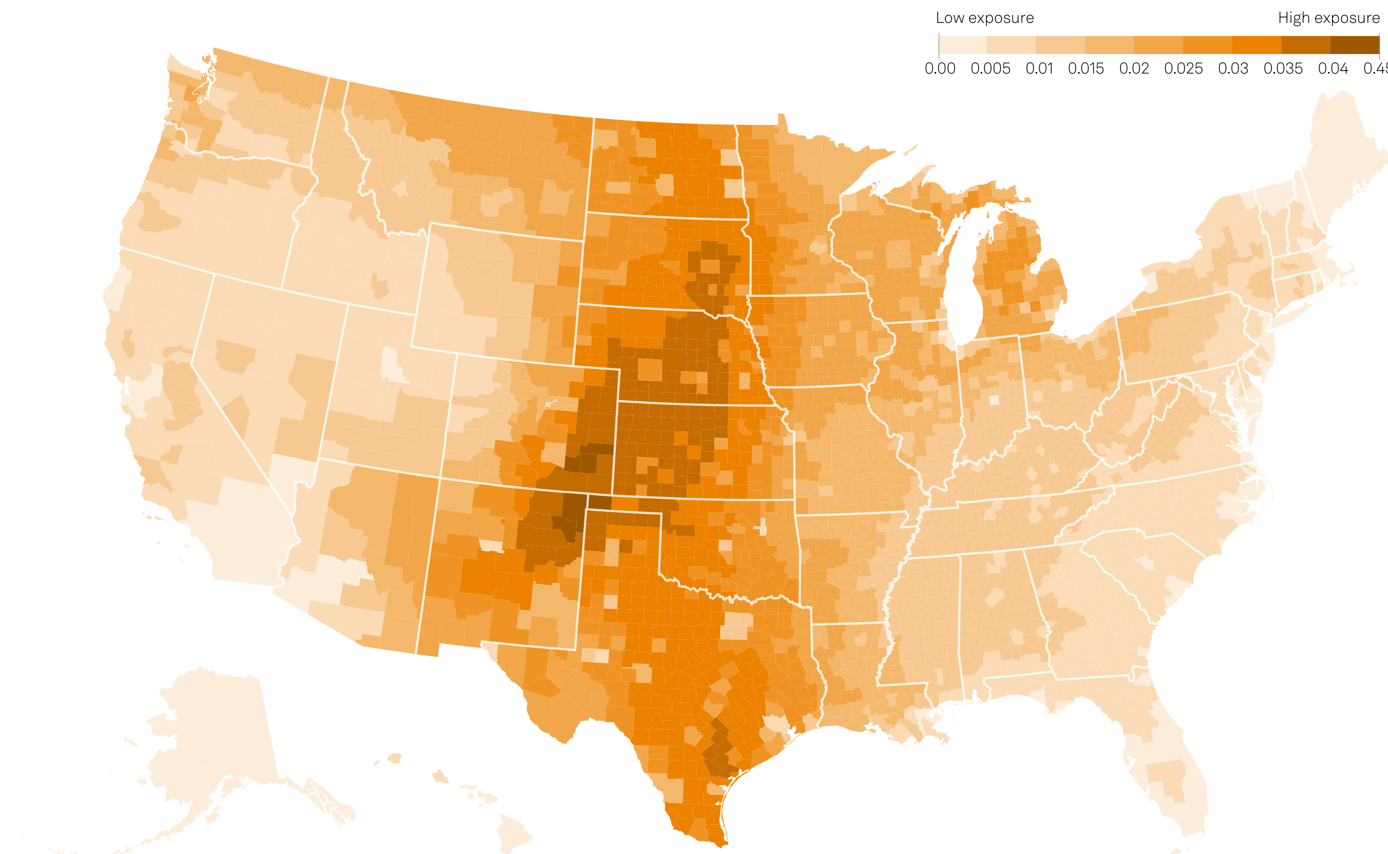
Sources: *S&P Global Sustainable1 and S&P Global Ratings.*

As temperatures increase and climate hazards generally become more extreme, the S1 dataset shows the greatest changes in exposure to wildfire conditions occurring in areas with historically low wildfire incidence, such as the Great Plains (see chart 5). Similar, but slightly less change is anticipated under a moderate transition scenario (SSP2-4.5), while wildfire conditions are expected to further intensify under a limited mitigation scenario (SSP5-8.5).

Chart 5

Wildfire risks are expected to spread eastward as drought conditions intensify

Projected percentage point changes to wildfire conditions under a slow transition scenario (SSP3-7.0), 2020s to 2050s



Sources: *S&P Global Sustainable1 and S&P Global Ratings.*

Rising sea levels could lead to flood-related risk, absent adaptation

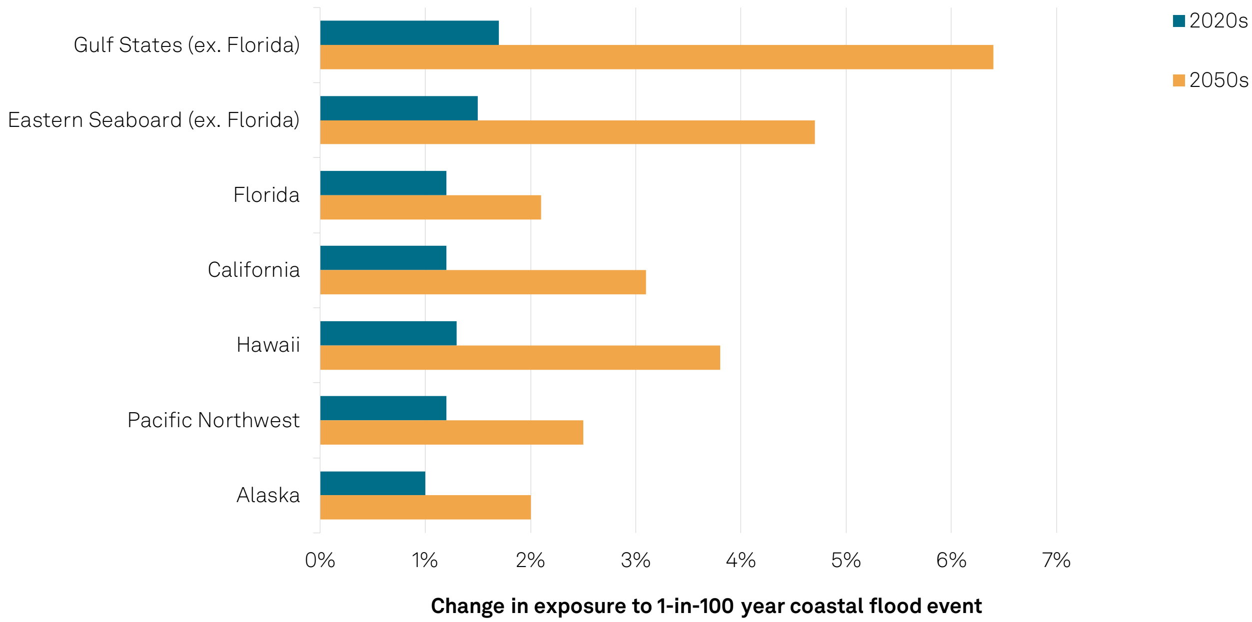
Under a slow transition scenario (SSP3-7.0), U.S governments' exposures to rising sea levels increases dramatically through the 2050s. Chart 6 depicts the change in exposure of different U.S regions to a one in 100-year coastal flood event; this is a flood event that would be expected to occur once a century and is a proxy for rising sea levels. The coastal flood hazard includes projections of storm surge heights and changes in local elevations owing to land movements between the 2020s and 2050s.

The S1 dataset suggests that, by mid-century, the frequency of a one in 100-year coastal flood event could at least double for many coastal U.S. counties. For counties in states on the Gulf of Mexico, the average increase is nearly fourfold, and for counties on the East Coast the increase is over threefold. For Gulf States, flood events with a presumed historical annual frequency of around 1%--or once every 100 years--are projected to have an annual frequency of about 6%--or once every 15 years or less--by the 2050s. Counties in Florida could see an average 1.7x increase in historical 100-year flood frequencies. Chart 7 depicts predicted coastal flood frequencies for counties along the Gulf of Mexico and the Eastern U.S, under a slow transition scenario.

Chart 6

Sea level rise impacts could increase exponentially without adaptation

Projected 100-year coastal flood frequencies under a slow transition scenario (SSP3-7.0), county average by region and specific states



Sources*: S&P Global Sustainable1 and S&P Global Ratings.*

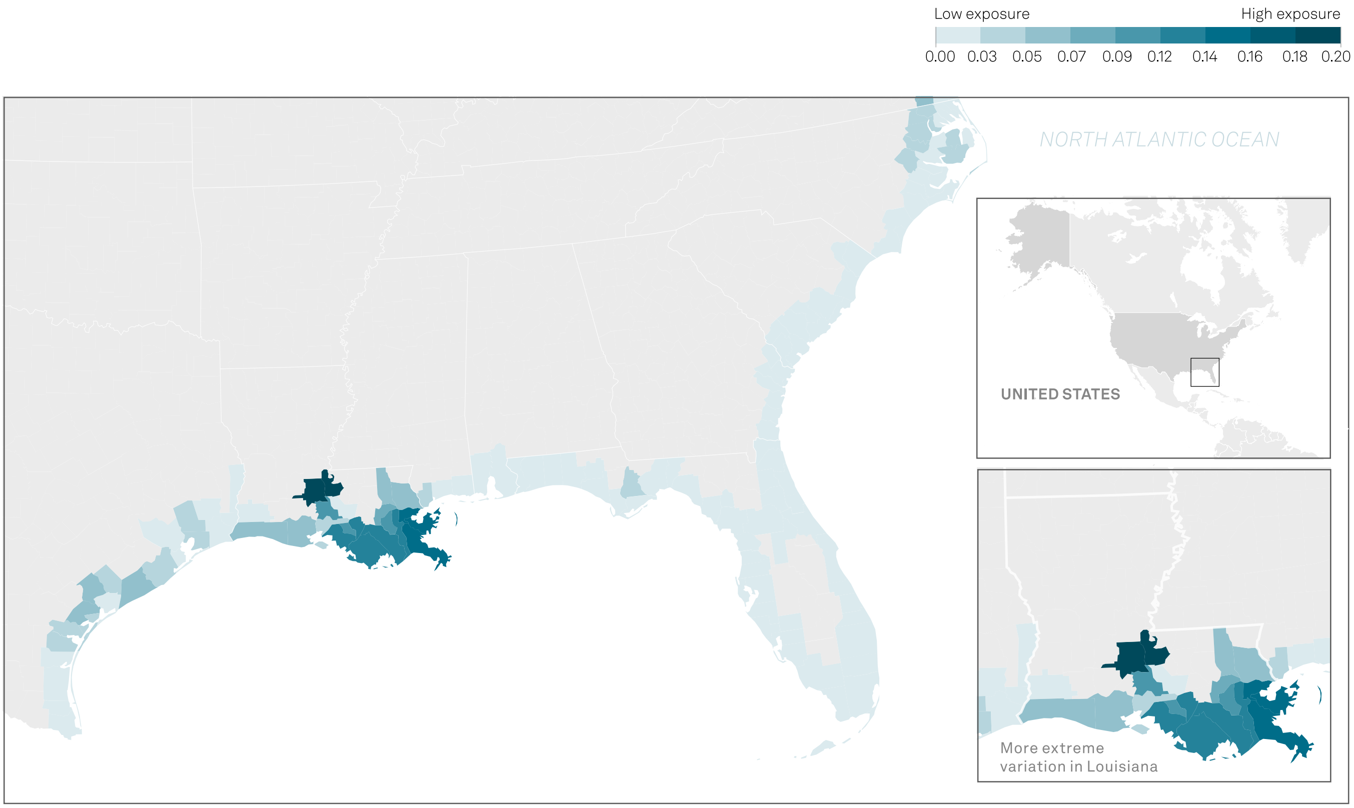
For all types of flooding covered, the S1 dataset provides insights into the projected frequencies at which a one-in-100-year flood event could occur, under a given climate scenario. A one-in-100-year flood event is defined relative to local conditions based upon the flood depth reached during similar historical events. Therefore, the extent of flooding captured in the data varies by location. Furthermore, coastal flood exposure captures events such as storm surges and tidal flooding. Consequently, when assessing coastal flood exposure, it is important to view this alongside tropical cyclone exposure. For instance, one in 100-year coastal flood depths in Florida are generally higher than many other locations nationally, given the prevalence of tropical storms and tidal flooding, but the return period frequency may appear smaller compared to locales with relatively lower 100-year flood depths. However, localities in Florida have, by far, the highest tropical cyclone exposure nationally.

Given the lock-in effect of historical emissions, many of the physical risks of climate change will materialize irrespective of today's policy choices. Coastal U.S. counties could face an accelerated rise in sea levels after 2050 if global warming does not remain well below 2 C. Under a moderate emissions scenario (SSP2-4.5) to midcentury, U.S. coastal counties' exposure to coastal flooding and rising sea levels are only slightly less severe compared those under a slow transition scenario (SSP3-7.0). However, projected coastal flood exposure sharply intensifies from the 2020s under the limited mitigation scenario (SSP5-8.5), increasing 4.2 times for Gulf states, 3.6 times for the Eastern Seaboard, and 3.4 times for Hawaii. Absent long-term planning and adaptation, exposed entities could face rising risks from infrastructure damage, property value loss, and changes to economic activity, among other impacts.

Chart 7

Sea level rise is projected to increase coastal flooding in the Eastern U.S. (%)

County exposure to 100-year coastal flood events under a slow transition (SSP3-7.0) in the 2050s



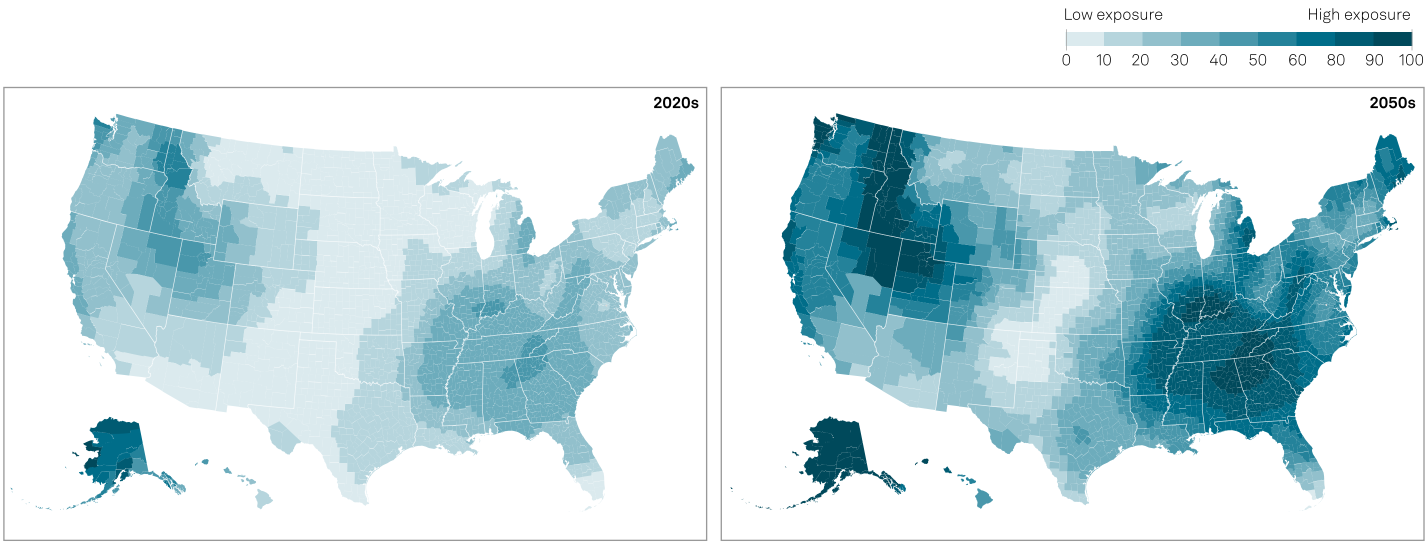
Sources: *S&P Global Sustainable1 and S&P Global Ratings.*

Warming temperatures are projected to increase extreme inland flooding events across much of the U.S. Portions of the Northwest, Midwest, and Southeast face the highest relative exposures (see chart 8). Both fluvial (river-basin-related) and pluvial (heavy rainfall-related) flooding periodically impact communities in much of the U.S. Our recent report "Flooding Events For California Cities And Counties Are Unlikely To Abate And May Result in Long-Term Credit Risks," published March 5, 2024, highlights longer-term credit considerations posed by these flood events. Under a slow transition scenario (SSP3-7.0), one-in-100-year fluvial flooding events are projected to increase 31%, on average, nationally by the 2050s. Pluvial flooding events with the same return frequency are projected to increase by 24%, on average.

Chart 8

Inland flooding risk rising across the U.S.

Relative pluvial (heavy rainfall) flooding exposure under a slow transition scenario (SSP3-7.0), 2020s and 2050s



Sources: S&P Global Sustainable1 and S&P Global Ratings.

Physical Climate Risks Could Influence Credit Ratings

Assessing rating impacts from physical risk and climate change for U.S governments is rooted in our methodology (see "ESG Principles in Credit Ratings," Oct. 10, 2021) and our sector-specific criteria that together allow us to analyze the issuer's ability to pay financial obligations on time and in full. The paragraphs that follow discuss why physical climate risks are embedded in our analysis and how they are incorporated into our assessment of creditworthiness when material and relevant.

Local governments particularly exposed to worsening climate hazards

Given the size of the U.S., nearly all counties are exposed to at least one climate hazard. Physical risks can pose a particular threat to the creditworthiness of many public finance issuers where locations are fixed, and the risk cannot be divested or diversified away. For example, extreme climate hazards such as hurricanes and heavy precipitation that lead to flooding are likely the most acute risks. However, we observe possible exposure to extreme heat and drought nationally. Extreme heat can have productivity impacts, and result in more indirect impacts on an entity's economy and population growth. Meanwhile, direct impacts could result in higher costs to accommodate employees who work outside, such as public safety and street maintenance teams.

The way that physical climate risks may influence the creditworthiness of local governments could vary. Impacts can be either direct or indirect and/or emerge over varying timescales.

- **Direct impacts:** These can manifest through infrastructure and asset damage and/or disruption to operations (including unexpected or increased operating costs), and result in higher-than-expected investments to rebuild (and adapt) housing, roads and bridges, and buildings. Chronic changes--such as water or heat stress--may require development of alternate water supply resources or reduce workforce productivity. They may also require building material modifications to withstand higher and longer periods of extreme heat conditions.

- **Indirect impacts:** These may materialize as even greater financial risks--such as higher amounts or greater costs of debt and increased insurance premiums and/or reduced coverage. Furthermore, economic and/or demographic changes could result from extreme heat conditions, higher home purchases, and/or rebuilding costs in exposed areas and could pressure U.S. governments' financial resources (e.g. property, income, or sales tax collections). Planning for infrastructure investments through adaptation may reduce these potential indirect risks, if and when they materialize.

The physical impact from climate hazards can weigh on the credit quality of some entities more than others. Our article "Through The ESG Lens 3.0: The Intersection Of ESG Credit Factors And U.S. Public Finance Credit Factors," published March 2, 2022, discusses physical risks. It explores how they can affect a government's capacity to serve its population, respond to service demands, and prioritize resources to protect its economic base from the acute and chronic effects of climate change. These impacts, in turn, can affect long-term fiscal sustainability, economic development efforts, and the ability or inability to implement revenue enhancements when necessary. Management teams may balance physical risk exposures with addressing the needs and costs associated with adapting to them. Disclosure of these potential effects and risk management actions are an important input into our assessments of management planning. When material and relevant, we incorporate policies and practices into our overall assessment of creditworthiness (see "Credit FAQ: Understanding Climate Change Risk And U.S. Municipal Ratings," published Oct. 17, 2017).

Better data can provide foundations for understanding risk exposure

Climate data can enhance our analytical insights into the specific physical climate exposures local governments in particular face. However, we do not expect that using the S1 dataset to help inform our credit rating analysis will, in and of itself, drive rating actions. Below, we outline our analytical considerations for assessing rating impacts for U.S. local governments.

Assessing underlying credit fundamentals. As noted in our research, "Lost GDP: Potential Impacts Of Physical Climate Risks," published Nov. 27, 2023, economic strength and institutional resources are key factors for sovereigns in responding and adapting to physical climate risk exposure. We believe these principles apply to U.S. local governments as well (see chart 9).

Chart 9

Where physical risk exposures are embedded in our analysis when material and relevant

Financial strength
This includes revenue diversity and available reserves. These factors can help entities withstand the potential credit impact from natural disasters and finance ongoing infrastructure improvements to mitigate the acute impacts of physical risks.

Debt capacity
This helps determine the affordability of financing long-term solutions to growing chronic risks. These include rising sea levels and water stress.

Management and governance
This can be underpinned by long-term planning, including regular monitoring and updates, that reflects economic, financial, and demographic changes. When it does, this typically reflects preparedness to respond to rising risks, including those from the physical impacts of climate change. Furthermore, we observe that local governments that collaborate with other levels of government to drive regional resiliency projects and secure resources, such as grants, could maintain credit quality in the face of physical risks.

Identify current and future exposure to physical risks under a variety of scenarios. Data can help us assess absolute and comparative exposure to headline physical risks. The current trajectory of warming due to the lock-in effect of historic greenhouse gas emissions is likely to contribute to the increasing frequency and/or severity of climate hazards in many geographies. Visibility into how these risks may trend is important. It allows us to formulate questions for management teams about resource and planning priorities allocated to adaptation and resilience efforts. The data can help identify types of physical risk exposure, the materiality of the exposure, how these exposures may trend over time under different emissions scenarios, and how exposures could materialize differently relative to geography and sector. In addition, data may help us evaluate nonlinear exposures to physical risks and whether multiple physical risks could worsen simultaneously.

Understanding current long-term plans and overall adaptation and resiliency efforts. After deepening our understanding of which physical risks may be most relevant to our analysis, we can focus our questions with management on key adaptation and resiliency actions. For example, we may ask local governments about dedicated financial reserves available to cover response costs following an acute event, or whether building codes include construction requirements for buildings to withstand higher wind speeds (if exposed to hurricanes). Finally, we may ask if modifications for employees who work outside in regions experiencing increasing exposure to extreme heat have resulted in productivity changes or costs from adapting work schedules.

Adaptation by U.S. governments is gathering pace which, when material and relevant, we embed in our management and governance analysis. We are beginning to observe how U.S. governments we rate are adapting to the physical impacts from climate change (see chart 10).

Chart 10

U.S. governments planning and adaptation examples

Financial
Bolstering liquidity to cover initial costs associated with an acute event as well as maintain operations and ensure timely payment of debt service costs

Structural
Considering different temperature warming scenarios to help inform infrastructure adequacy, such as sea walls for coastal flooding and stormwater facilities for inland flooding

Institutional
Updating land use policies to limit development in chronic flood-prone areas

Social
Engaging in business continuity planning to prepare for an acute event

Source: S&P Global Ratings.

Weigh physical risks exposures against credit fundamentals and long-term planning efforts. As with many aspects of our analysis, we typically consider an entity's specific risk exposures, including those from physical risks, against peers to help determine the relative influence on aspects of our analysis like the economy, budgetary performance and financial flexibility, liquidity, and debt and long-term liability profile. Our analysis reflects not only the exposure but how each entity's planning and preparation may help the credit rating withstand the immediate impact from an event. Furthermore, given the uncertainties of climate change and resulting physical impacts, our analysis also reflects how an entity is modifying its capital or financial plans to address longer-term impacts and risks.

Looking Ahead

In this research, we show how climate data and scenario analysis can provide greater visibility about long-term risks relevant to our view of creditworthiness. We believe climate data and modeling can provide greater transparency for market participants and facilitate a dialogue with U.S. governments that are potentially exposed to physical climate risks. Increased transparency surrounding these risks also presents an opportunity for issuers to demonstrate the benefits of existing or planned adaptation actions. When assessing these risks, we also consider in our credit analysis the balance between service provision and investment in adaptation projects. This is because of the uncertainty associated with climate science and how the benefits of adaptation projects may manifest over time.

We understand that public entities and not-for-profit enterprises have to balance these longer-term pressures with competing priorities and resource constraints. Much like our approach to analyzing the long-term impacts of retirement liabilities, an understanding of management's assumptions, plans, and financial capacity to address chronic and acute physical climate risks may increase over time in terms of their importance to overall credit quality. Climate data and modeling may enable us to gauge managements' proposed, or in-flight, actions to adapt to or mitigate physical climate risks. We can then compare those actions to the potential magnitude, timing, and expected duration of such risks.

Related Research

- White Paper: Assessing How Megatrends May Influence Credit Ratings, April 18, 2024
- North American Wildfire Risks Could Spark Rating Pressure For Governments And Power Utilities, Absent Planning And Preparation, Nov. 29, 2023
- Lost GDP: Potential Impacts Of Physical Climate Risks, Nov. 27, 2023
- Is Climate Change Another Obstacle To Economic Development? Jan. 16, 2023
- Climate Change Will Increase Output Volatility, Jan. 5, 2023
- Western U.S. Drought: Declining Supply, Rising Challenges, Aug. 16, 2022
- Materiality Mapping: Providing Insights Into The Relative Materiality Of ESG Factors, May 18, 2022
- Through The ESG Lens 3.0: The Intersection Of ESG Credit Factors And U.S. Public Finance Credit Factors, March 2, 2022
- ESG Principles in Credit Ratings, Oct. 10, 2021
- Model Behavior: How Enhanced Climate Risk Analytics Can Better Serve Financial Market Participants, June 24, 2021
- Economic Research: Why It May Make Economic Sense To Tackle Global Warming, Dec. 5, 2018
- Credit FAQ: Understanding Climate Change Risk And U.S. Municipal Ratings", Oct. 17, 2017

External Research

- Acceleration of U.S. Southeast and Gulf coast sea-level rise amplified by internal climate variability, Dagendorf, S., Hendricks, N., Sun, Q., Klinck, J., Ezer, T., Frederikse, T., Calafat, F., Wahl, T. and Tornqvist, T.E. (2023), Nature Communications, 14 (1935).
- Assessing the costs and benefits of climate change adaptation, European Environment Agency (EEA), March 3, 2023.
- European climate risk assessment. EEA Report No 1/2024, European Environment Agency (2024), 425pp.
- Sixth Assessment Report: Summary For Policymakers, International Panel On Climate Change (IPCC), Feb. 11, 2022.
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- Extreme heat effects on perennial crops and strategies for sustaining future production, Parker, L., McElrone, A., Ostoja, S., Forrestel, E., Plant Science, Volume 295, 2020.
- Global Assessment Report on Disaster Risk Reduction 2022: Our World at Risk: Transforming Governance for a Resilient Future, UN Office for Disaster Risk Reduction (2022), Geneva

- Fifth National Climate Assessment. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, D.C., USA.
- The Global Climate 2011-2020, World Meteorological Organization (WMO) (2023) 60pp.

Appendix

This section provides an overview of the S&P Global Sustainable1 U.S. Muni Bond Physical Risk Dataset. Limitations are described thereafter.

Exposure thresholds

Table A1 describes the exposure thresholds used to calculate percent GDP and population exposed to each climate hazard.

Table A1

Thresholds for each climate hazard

Climate hazard	Type	Threshold	Rationale
Extreme heat	Annual percentage of days with maximum temperature warmer than the 95th percentile local baseline daily maximum temperature	0.246	Equivalent to three months of extreme heat days
Coastal flooding	Projected frequency of the historical baseline 100-year coastal flood depth	0.01	A 1% annual probability of a 1 in 100-year flood in exposed areas
Drought	Projected frequency of months classified as moderate drought, severe drought, or extreme drought based on the Standardized Precipitation Evapotranspiration Index (SPEI)	0.246	Equivalent to three months of high drought likelihood days
Fluvial (river) flooding	Projected frequency and extent of the historical baseline 100-year flood depth	0.01	A 1% annual probability of a 1 in 100-year flood in exposed areas
Pluvial (rainfall) flooding	Projected frequency of the historical baseline 100-year daily precipitation rate	0.02	A 2% annual probability of a once in a century flood
Tropical cyclones	Projected annual frequency of category 3 and higher tropical cyclones	0	All exposure to category 3 and higher tropical cyclones is considered material
Water stress	Projected future ratio of water withdrawals to total renewable water supply in a given area	0.4	High water stress as defined by the Fire Weather Index (FWI) Aqueduct dataset
Wildfires	Projected frequency of days classified as high, very high or extreme based on the Fire Weather Index (FWI). Adjusted for land cover/presence of burnable vegetation	0.246	Equivalent to three months of high wildfire likelihood days

Limitations

We describe some of the limitations and assumptions of our analysis below. This list is not exhaustive.

The climate hazard metrics capture exposure to physical climate risks only. This is separate from vulnerability, which for a locality can depend on socioeconomic footprint, industry sector spatial distribution, trade linkages, and supply chains, among other factors. This is also distinct from value at risk of associated economic factors, whether GDP, tax base, human capital, property value, or infrastructure or transit systems, for example. Finally, the exposure hazard data is a first step only toward understanding the diverse range of factors that may contribute to (or offset) the climate-related credit impairment of an issuer/instrument--such as adaptation and resilience measures (e.g., levees, green roofs, and managed retreats).

As with any long-term estimation of future events, there are some inherent uncertainties associated with climate science. These include the crystallization and severity of climate risks (see "Model Behavior: How Enhanced Climate Risk Analytics Can Better Serve Financial Market

Participants," published June 24, 2021, which describes some of these uncertainties and potential mitigants). These uncertainties may include (but are not limited to):

- Complexities associated with climate hazards: The causes of wildfires may be natural, for example, lightning or ignition of dry vegetation by the sun; or human, such as unattended campfires. Many other factors contribute to the number of wildfires in an area in any given year, including how high summer temperatures are, how low precipitation is, and wind conditions. Research suggests a strong relationship between temperature and fire extent, particularly in the U.S., with warmer years generally having greater fire extent (principally due to fuel aridity) than relatively cooler ones, since the early 1980s. While the long-term change in climate that may increase the risk of wildfire events is relatively visible, it is not possible to precisely predict where and when specific wildfire events will happen and what damage they may cause. By their nature, wildfires (like heavy summer rainfall events in many parts of the world) are highly localized. Notwithstanding this, the potential increasing exposure over time highlights the importance of dialogue and learning about how U.S. local governments within these areas consider these risks and whether they have measures in place to reduce wildfire risk.
- Modelling highly localized events: Wildfires and other events are challenging to model as local conditions (including topography and wind patterns) are not easily replicated at scale in global climate models. It is currently a challenge to model changing wind patterns (which can fuel wildfire intensity) in wildfire projections with the available science. Model limitations could obscure some of the likely changes in intensity that may happen over the next 30 years.
- Climate hazard thresholds: S&P Global Sustainable1 defines hazard metrics using climate extremes and recognizes hazard thresholds of major magnitude in the measurement of GDP and population exposed, to ensure the capture of significant climate trend developments beyond natural variability. Differences in the vulnerability of specific locales are likely to mean that significant impacts exist at hazard levels beyond the extremes and thresholds defined.
- Focus on productive areas: Regional hazard metrics have been calculated using GDP to weight cell hazard inputs for computing representative regional averages.
- Cascading and/or multi-climate hazards are not considered: All hazards are modeled independently, and correlation or vulnerability associated with the co-occurrence of multiple hazards is not currently specifically modelled. For example, the tropical cyclone hazard metric encompasses the frequency of associated wind risks while the coastal flooding hazard metric independently includes storm surge flooding, likely capturing flooding associated with tropical cyclones.
- The GDP and population datasets are historical and do not capture future changes in economic or population geography: The datasets used to represent the distribution of population and GDP are historical and are held constant in the future scenario projections. We project the distribution of population and the production of GDP will change with time as economies and communities develop, and these changes will not be reflected in the metrics presented in this dataset.

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Editor

Richard Smart

Digital Designer

Victoria Schumacher