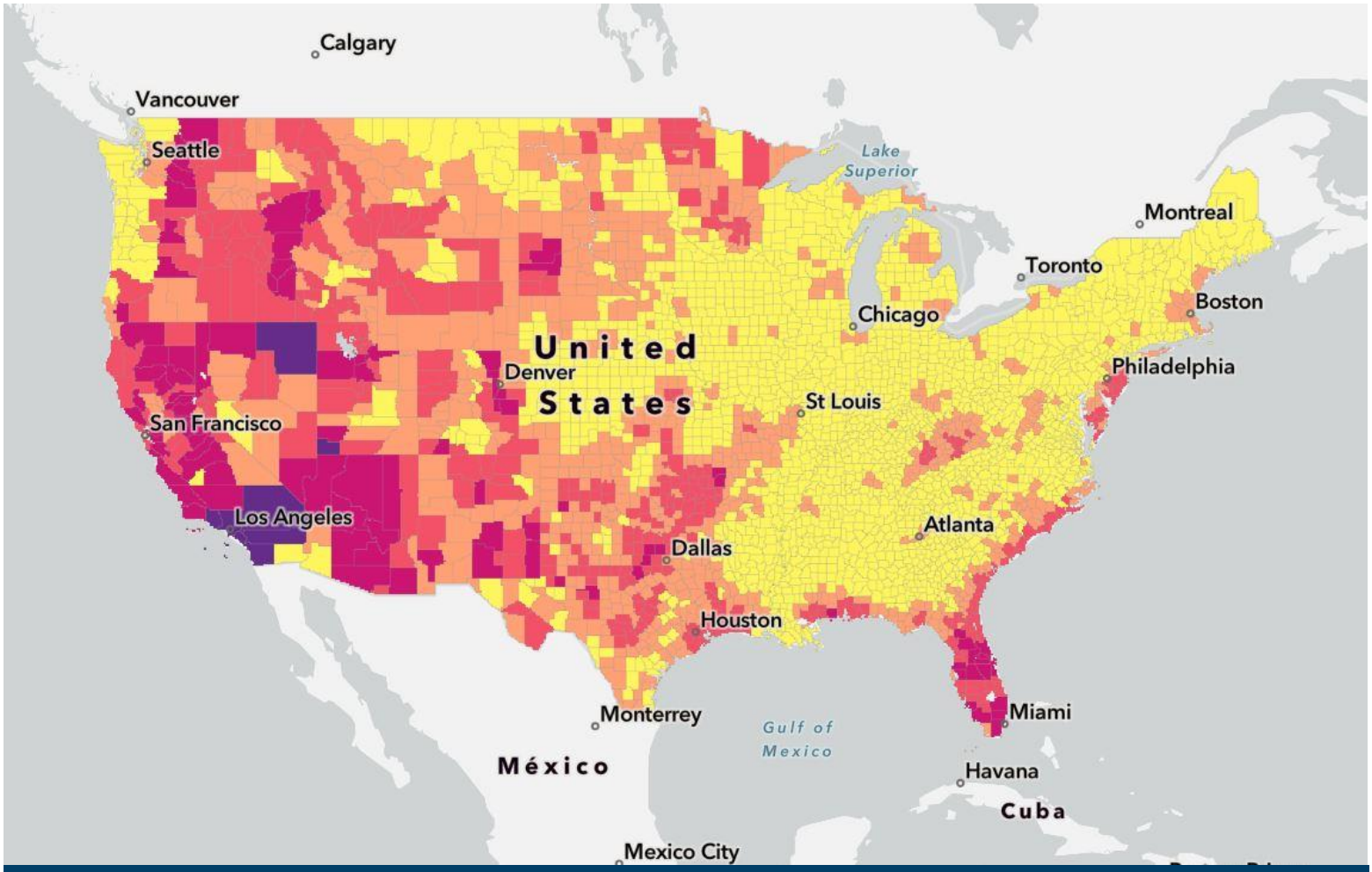

National Risk Index: Future Risk

Technical Documentation

December 2024

FEMA

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Appendix A – Contributors 1

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Acronym List

CFLD	Coastal Flooding
CMIP	Coupled Model Intercomparison Project
DRGT	Drought
EAL	Expected Annual Loss
ESM4	Earth System
EXHT	Extreme Heat
FWI	Fire Weather Index
GCM	General Circulation Model
GFDL-ESM4	Geophysical Fluid Dynamics Laboratory Earth System
HM	Hazard Multiplier
HRCN	Hurricane
HTF	High Tide Flooding
HWAV	Heat Wave
IPCC	Intergovernmental Panel on Climate Change
ITF	Interagency Task Force
LOCA	The Localized Constructed Analogs
MME	Multi-Model Ensemble
NetCDF	Network Common Data Form
NEX	NASA Earth Exchange
PAL	Projected Annual Loss
RCP	Representative Concentration Pathway
SFHA	Special Flood Hazard Area
SLR	Sea Level Rise

SPEI	Standardized Precipitation Evapotranspiration Index
SSP	Shared Socioeconomic Pathway
WFIR	Wildfire

1. Introduction

The Future Risk Index is a prototype risk analysis tool built to act as a supplement to the National Risk Index to estimate future natural hazard risk in the United States. It currently includes five natural hazards and covers the 50 states, the District of Columbia, American Samoa, Commonwealth of the Northern Mariana Islands, Guam, Puerto Rico, and the U.S. Virgin Islands. This prototype is intended to provide estimates of future natural hazard risk under four potential future conditions: lower mean global temperature changes at the middle of the 21st century, lower mean global temperature changes at the end of the 21st century, higher mean global temperature changes at the middle of the 21st century, and higher mean global temperature changes at the end of the 21st century. The purpose of these results is to empower communities to understand possible future natural hazard risk when compared to their current risk as determined by the National Risk Index. Structurally, the Future Risk Index uses the values, scores, and ratings of the National Risk Index as the present-day baseline for natural hazard risk, then applies a Hazard Multiplier (HM) within the context of the four aforementioned scenarios. The Future Risk Index translates the four scenario's conditions into changes of hazard frequency and intensity, then calculates these impacts in terms of monetary losses if applied to today's existing building, population, and agricultural exposures.

The Future Risk Index is designed to highlight the importance of understanding potential climatological scenarios in terms of relative risk. While climate model outputs are computer simulations that identify climatic patterns, they should not be viewed as precise future predictions. The calculations performed within the Future Risk Index therefore contain inherent statistical uncertainty, meaning the results should be viewed as estimates of potential scenarios and not as definitive predictions of future risk.

This documentation provides a detailed overview of the Future Risk Index, including its background, data sources, and hazard-specific descriptions of its methodologies. It assumes the reader has some familiarity with the National Risk Index terms, concepts, and methodologies upon which the Future Risk Index is based. For a detailed overview of the National Risk Index, please see the National Risk Index Technical Documentation which outlines its background, data sources and processing methodologies.

2. Background

The release of the National Risk Index v1.19.0 in March 2023 provided a robust, nationwide, holistic assessment of baseline risk to natural hazards, resulting in a nationally available dataset of existing natural hazard risk at county and Census tract levels. This presented an opportunity to develop a prototype service that built upon these efforts, using the current risk outputs as ingestible data or a comparison point for other risk calculations. The prototype deemed most necessary was a tool that could be used to estimate possible future natural hazard risk on U.S. communities. The National Risk Index team conducted literature reviews, hosted workshops and methodology consultation sessions, and partnered with stakeholders in government, academia, and private industry to develop this prototype Future Risk Index.

2.1. Natural Hazard Selection

The initial release of the NRI: Future Risk includes five hazards: Coastal Flooding, Drought, Extreme Heat (Heat Wave), Hurricane and Wildfire. These were chosen for the initial prototype as they represent significant current natural hazard risk in the U.S., and their future intensity and impacts are more reliably modeled by climate models than the other NRI hazards. The present-day risk was assessed using the expected annual loss values from the National Risk Index and the susceptibility to future climatological conditions was determined through a literature review of climate change data.

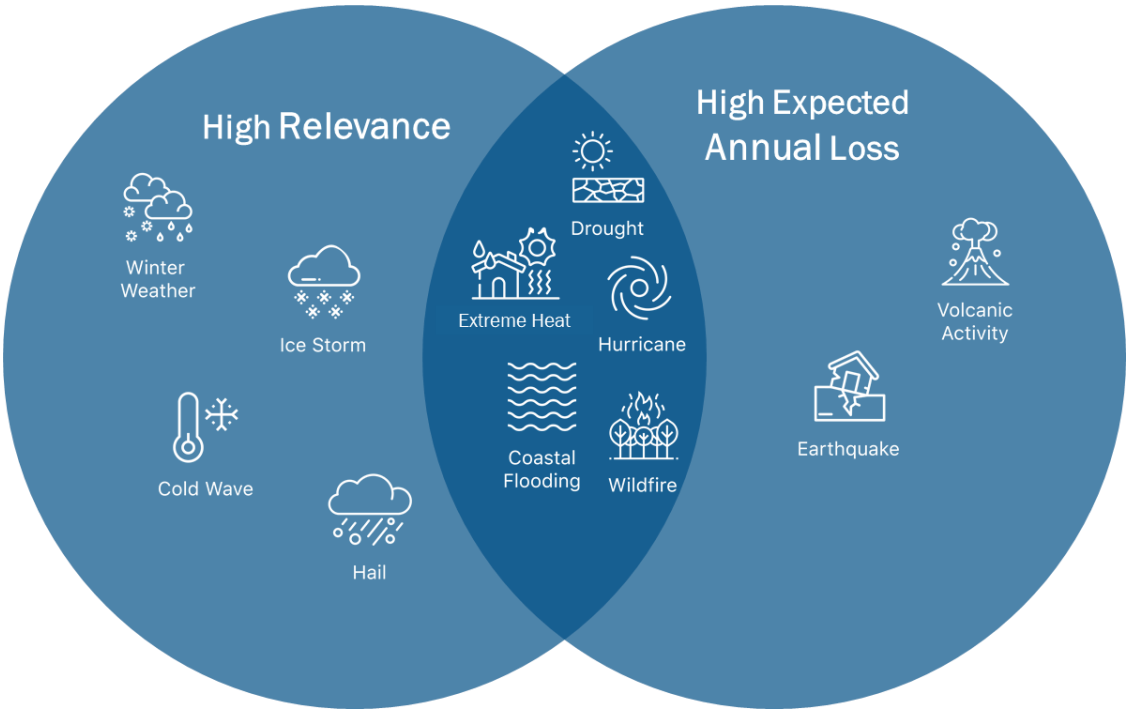

Figure 1: Selection of Initial Hazards for the NRI: Future Risk

The following were the results of the review for the five included hazards:

Coastal Flooding: Current expected annual losses of $1.280 billion. Sea levels are anticipated to rise, resulting in increased frequency and intensity of high-tide and nuisance flooding, including impacts to areas currently not susceptible to coastal flooding.

Drought: Current expected annual losses of $1.668 billion. Future climatological conditions are anticipated to change drought-related factors, including temperature, precipitation and dry period durations. Climatological shifts in these factors would impact the experienced frequency and intensity of drought.

Extreme Heat (Heat Wave): Current expected annual losses of $2.310 billion. Higher projected temperatures and longer durations of extreme heat conditions are expected to increase the extent of impacted areas, and result in increasingly frequent and intense extreme heat events.

Hurricane: Current expected annual losses of $22.441 billion. Future climatological projections show adjustments to sea surface temperatures and atmospheric conditions that likely would affect many of the key contributing factors to hurricane frequency and intensity that would then influence resultant storm surge and wind speeds.

Wildfire: Current expected annual losses of $3.482 billion. Future changes to temperature, relative humidity, precipitation and other factors are anticipated to influence fire weather likelihood and behavior.[1]

Several hazards were investigated in addition to those identified above but were ultimately excluded for one of three reasons:

No Direct Climatological Impact: Insufficient evidence that future climatological conditions would impact the observed frequency or intensity of a given hazard. For example, Earthquake frequencies and intensities may be impacted by glacial melting or sea level rise; however, there is currently no direct correlation between the two.

Insufficient Climatological Data: Insufficient high-fidelity, relevant data or academic research to calculate a frequency or intensity adjustment, despite an established correlation between climatological conditions and hazard frequency or intensity. For example, Riverine Flooding is known to have several key components highly influenced by climatological conditions, including sea level rise, changing weather patterns and increased precipitation; however, data and modeling capacity are not reliable for risk assessment of this hazard within the National Risk Index methodology at this time.

Decrease in Hazard Risk: There are several hazards where a direct negative correlation between climatological change and hazard frequency and intensity can be hypothesized. Using climate modeling data projecting a rise in daily temperatures, it is feasible that winter hazards such as Cold

[1] Touma, D. & National Center for Atmospheric Research Staff. (2023, August). *The Climate Data Guide: Canadian Forest Fire Weather Index (FWI).* https://climatedataguide.ucar.edu/climate-data/canadian-forest-fire-weather-index-fwi

Wave or Winter Weather could decrease in frequency or intensity. These hazards were excluded from this initial release in order to focus on hazards that represent a higher level of risk both currently and in the future.

While the current version of the Future Risk Index is limited to these five hazards, future iterations will improve and expand in scope. These improvements include incorporating additional climate models for the five existing hazards and selecting additional hazards from the National Risk Index for inclusion.

2.2. Scenario Selection

The Future Risk Index uses four climate model scenarios when calculating future natural hazard risk. These are combinations of lower and higher mean global temperature scenarios at mid-century and late-century timepoints, based on the Representative Concentration Pathway (RCP) and the Shared Socioeconomic Pathway (SSP) data formulated by the Intergovernmental Panel on Climate Change (IPCC).

Table 1: Climate Scenario Composition

	Mid-Century	Late-Century
Lower Mean Global Temperature	Scenario 1	Scenario 2
Higher Mean Global Temperature	Scenario 3	Scenario 4

Representative Concentration Pathways (RCPs) were introduced in preparation for the IPCC's Fifth Assessment Report (AR5) to represent potential climate change trajectories based on various socio-economic factors and anthropogenic forcings. Several distinct pathways, labeled as "RCP" and the number of the corresponding radiative forcing value – ex: "RCP 2.6", were determined to describe the anticipated levels of greenhouse gas concentrations and subsequent radiative forcing one could expect from climate change.[2] Of these pathways, RCP 4.5, or the Intermediate Scenario, and RCP 8.5, or the High Emissions Scenario, were selected for the Future Risk Index. RCP 4.5 was chosen as it provided the most realistic scenario wherein emissions peak around 2040 followed by a decline, though RCP 4.5 assumes that climate policies outlined in the Paris Agreement are not met.[3] RCP 8.5 was chosen as a "worst-case" scenario, wherein climate policies outlined in the Paris Agreement are

[2] van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamerque, J.-F, Masui, T., Meinshausen, Nakicenovic, N., Smith, S.J., & Rose, S.K. (2011, August). *The representative concentration pathways: an overview*. National Oceanic and Atmospheric Administration. https://psl.noaa.gov/ipcc/cmip5/rcp.pdf

[3] United Nations Framework Convention on Climate Change. (2015, December). *The Paris Agreement*. United Nations Climate Change. https://unfccc.int/process-and-meetings/the-paris-agreement

unmet and emissions increase throughout the 21st century. Although the scenario is viewed as being unlikely, it represents an upper limit of what is expected as a result of climate change. Figure 2 contextualizes each of these RCPs showing the emissions of main greenhouse gasses that correspond to each, as well as how they compare against one another. It's important to understand the underlying relationship between emissions and potential climate scenarios in order to fully comprehend how these RCPs conceptualize climatological change.

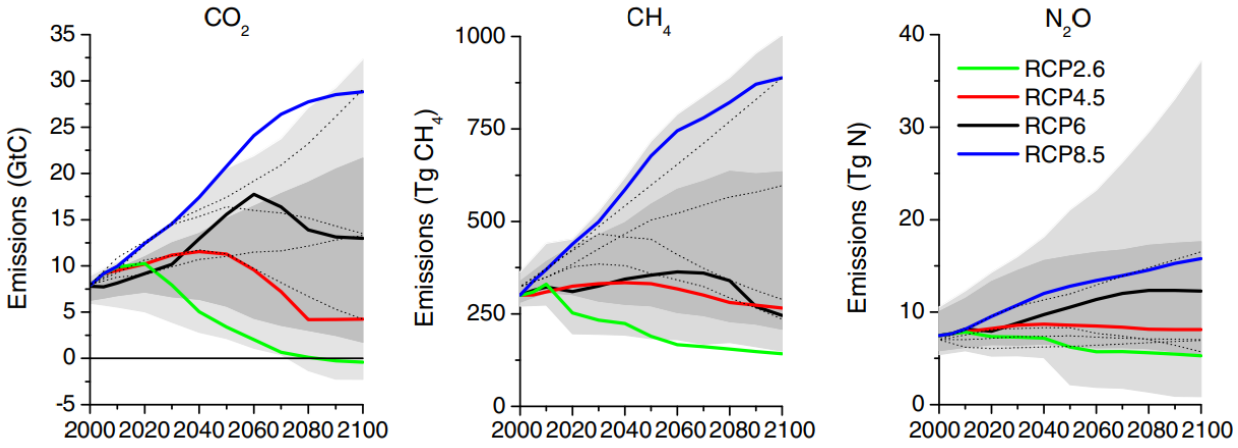

Figure 2: Emissions of Main Greenhouse Gasses across RCPs[4]

The scenarios not included in the Future Risk Index include RCP 2.6, which represents a scenario of active mitigation and anticipates the lowest climatological impact, and RCP 6.0 which assumes radiative forcing is stabilized after 2100. These two scenarios were considered but ultimately not included as RCP 2.6 would not see significant changes when compared against a historical scenario, and the impacts of RCP 6.0 would be well within the window of RCPs 4.5 and 8.5.

Shared Socioeconomic Pathways (SSPs) were defined in the IPCC's Sixth Assessment Report (AR6).[5] SSPs are similar to the Representative Concentration Pathways of the IPCC's Fifth Assessment Report in that they represent a level of adherence to climate policies. While RCPs are based on greenhouse gas emissions and radiative forcing levels, SSPs have a more narrative focus with each Pathway representing the impact of mitigation and adaptation.[6] The carbon dioxide emission projections for each SSP are provided in Figure 3.

[4] van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamerque, J.-F, Masui, T., Meinshausen, Nakicenovic, N., Smith, S.J., & Rose, S.K. (2011, August). *The representative concentration pathways: an overview*. National Oceanic and Atmospheric Administration. https://psl.noaa.gov/ipcc/cmip5/rcp.pdf

[5] Intergovernmental Panel on Climate Change. (2023). *Climate Change 2023: Synthesis Report*. https://www.ipcc.ch/report/sixth-assessment-report-cycle/

[6] Riahi, K., van Vuuren, D.P, Kriegler, E., Edmonds, J., O'Neill, B.C, Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., ... & Tavoni, M. (2017).

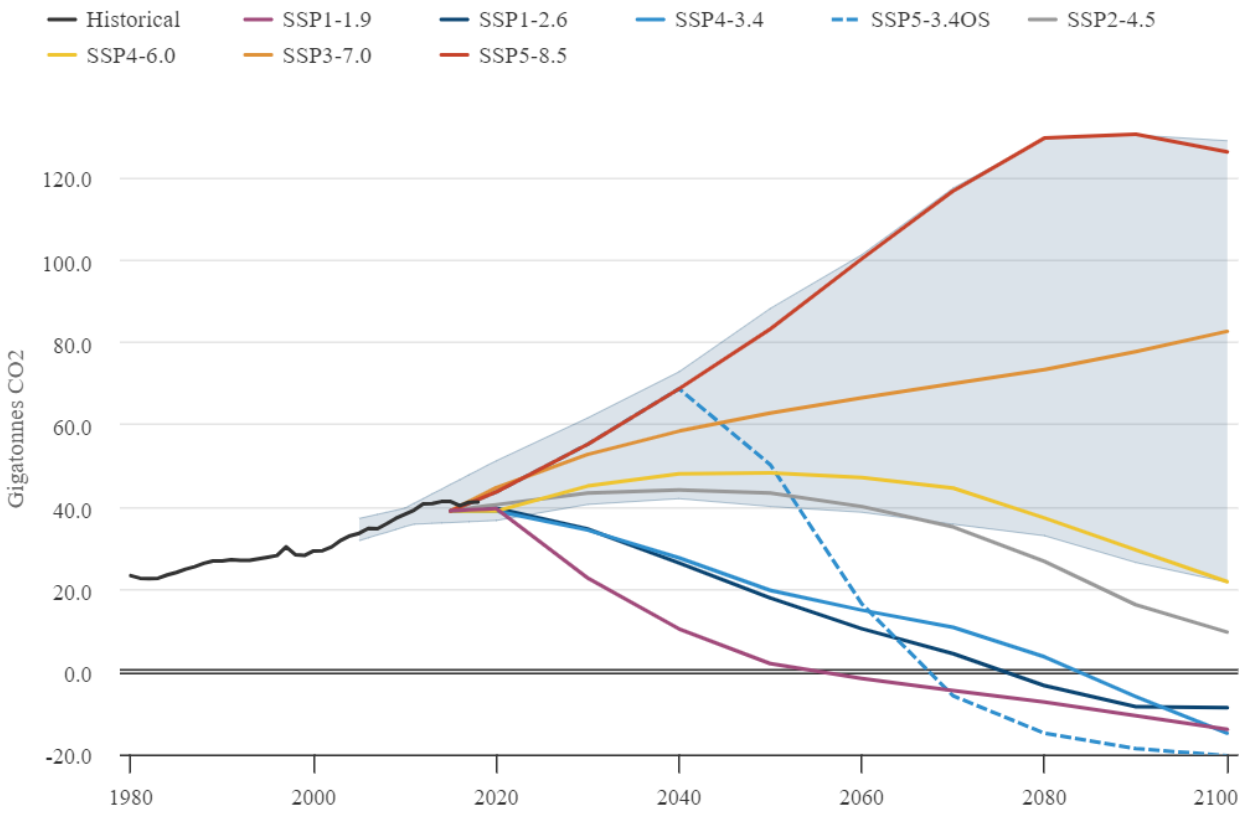

Figure 3: Emissions of CO2 across SSPs[7]

To ensure that results produced using RCPs were comparable to those produced with SSPs, the selected scenarios are equivalent to RCP 4.5 and RCP 8.5. Figure 4 provides a visual comparison of the RCPs and SSPs. The selected SSPs are SSP 2-4.5, which represents a scenario that does not stray from historical emissions, and SSP 5-8.5, which represents an increased use and dependence on fossil fuels.

The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change*, *42*, 153-168, https://doi.org/10.1016/j.gloenvcha.2016.05.009

[7] Hasufather, Z. (2019, December) *CMIP6: the next generation of climate models explained*. CarbonBrief. https://www.carbonbrief.org/cmip6-the-next-generation-of-climate-models-explained/

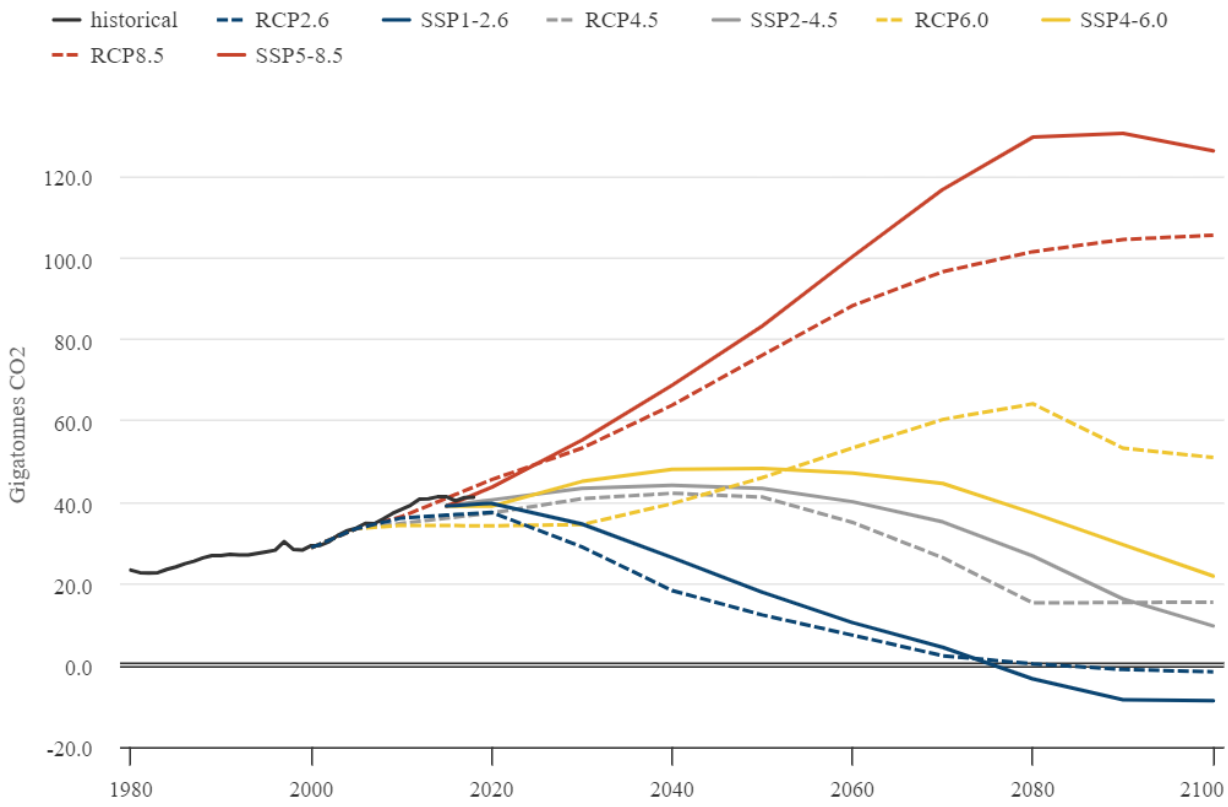

Figure 4: Comparison of Emissions between RCPs (dotted) and SSPs (solid)[8]

With the RCPs and SSPs chosen for emission levels, the Future Risk Index established mid-century and late-century timeframes for the temporal element of climate modeling. Mid-century is defined as the aggregation of impacts between the years 2036 and 2065 and Late-century is defined as the aggregation of impacts between 2070 and 2099. Producing results at these two timescales provides a reasonable summary of both the near- and late-term impacts of global temperature changes. For more information about the scenarios used for a given hazard, see Data Sources Considered.

2.3. Data Sources Considered

The Future Risk Index used two criteria when initially considering potential data sources: they must be publicly accessible and they must provide data on a nationwide scale.[9] Datasets that met these thresholds were further refined to those that used the Coupled Model Intercomparison Project (CMIP) as this would bolster validity by ensuring results were easily replicable and directly comparable to each other within the IPCC scenario framework referenced in the previous section. A final requirement was that the Future Risk Index would only use bias-corrected climate models and

[9] "Nationwide scale" for the purposes of the Climate-Informed Risk Index indicates the contiguous US.

data to ensure that all calculations are reasonable and actionable. This section provides a brief overview of the data that were selected.

Many localized climate projections exist for the hazards selected for the Future Risk Index; however, these usually include variables or assumptions that cannot be reproduced at a nationwide scale, such as shifts in population or planning and mitigation efforts. One example of a projection that was considered was the implication of climate change, population dynamics, and urban mitigation for future heat extremes,[10] which was ultimately not included as the results could not be scaled to the national level with confidence. These types of locally-sourced projections are highly useful for considering local risk, but lose efficacy when applied to larger regions where comparable quality data are not present. Therefore, the Future Risk Index selected the best of the available, nation-wide, relatable data for its calculations on future natural hazard risk. The following paragraphs describe the data used for the five hazards of the Future Risk Index.

Currently, the Future Risk Index leverages statistically downscaled data provided by the Localized Constructed Analogs version 2, or LOCA2,[11] and NASA Earth Exchange (NEX).[12] Both LOCA2 and NEX provide climatological downscalings utilizing CMIP6 projections,[13] and have released several climatological downscalings including Minimum Temperature, Maximum Temperature, Precipitation, and Fire Weather Index. The climate adjustments for the Drought and Wildfire hazards are calculated using NEX data, while Extreme Heat uses both NEX and LOCA2 data.

Table 2: LOCA2 Fact Sheet

Localized Constructed Analogs (Version 2)	
Hazards Impacted	Extreme Heat
Climate Scenarios Used	Shared Socioeconomic Pathways (2-4.5, 5-8.5)
GCM Used	CMIP6
Resolution	6-kilometer
Variables Used	Minimum Daily Temperature

[10]Vahmani, P., Jones, A.D., & Patricola, C.M. (2019, August). *Interacting implications of climate change, population dynamics, and urban heat mitigation for future exposure to heat extremes*. https://iopscience.iop.org/article/10.1088/1748-9326/ab28b0/meta

[11] Pierce, D.W. (2023, January). *LOCA version 2 for North America (ca. Jan 2023)*. https://loca.ucsd.edu/loca-version-2-for-north-america-ca-jan-2023/

[12] National Aeronautics and Space Administration. (2024). *NEX downscaled climate projection Data Portal*. https://data.nas.nasa.gov/index.php?portal=nex-dcp30-cmip6

[13] World Climate Research Programme. (n.d). *CMIP Phase 6 (CMIP6)*. https://wcrp-cmip.org/cmip6/

Table 3: NASA Earth Exchange (NEX) Fact Sheet

NASA Earth Exchange	
Hazards Impacted	Drought, Extreme Heat, Wildfire
Climate Scenarios Used	Shared Socioeconomic Pathways (2-4.5, 5-8.5)
GCM Used	CMIP6
Resolution	30 arcsecond
Variables Used	Fire Weather Index, Maximum Daily Temperature, Minimum Daily Temperature, Precipitation, Evapotranspiration

Coastal Flooding adjustments are produced using data provided from the Interagency Taskforce on Sea Level Change 2022.[14] The methodology used in producing these results closely aligns with that used in the current National Risk Index providing Minor, Moderate and Major High Tide Flooding frequencies under a variety of Sea Level Rise Scenarios. These data are also available for the entire United States and Territories' Coastlines utilizing NOAA Tidal Gauges.

[14] Sweet, W.V., Hamlington, B.D., Kopp, R.E., Weaver, C.P., Barnard, P.L., Bekaert, D., Brooks, W., Craghan, M., Dusek, G., Frederikse, T. , Garner, G., Genz, A.S., Krasting, J.P., Larour, E., Marcy, D., Marra, J.J., Obeysekera, J., Osler, M., Pendleton, M., ... & Zuzak, C. (2022, February). *Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastline*. National Oceanic and Atmospheric Administration. https://cdn.oceanservice.noaa.gov/oceanserviceprod/hazards/sealevelrise/noaa-nos-techrpt01-global-regional-SLR-scenarios-US.pdf

Table 4: Interagency Task Force on Sea Level Change Fact Sheet

Interagency Task Force on Sea Level Change 2022	
Hazards Impacted	Coastal Flooding
Climate Scenarios Used	Representative Concentration Pathways (4.5, 8.5)
GCM Used	CMIP5
Resolution	Data provided for each of NOAA's 187 Tidal Gauges
Variables Used	High Tide Flooding Probabilities

Hurricane adjustments are produced using the Climate Conditioned Landfall Rates data provided by Applied Research Associates, which project the frequency of hurricane category winds under a series of climatological scenarios. These data are produced using the Hazus hurricane wind model simulations,[15] which estimate damage to buildings due to hurricane wind and windborne debris. The model is run using variables from future climatological scenarios in order to project the impact and intensity of future hurricane events.

[15] Federal Emergency Management Agency. (2021, June). *FEMA Hazus Factsheet: Hazus for Hurricane Modeling*. https://www.fema.gov/sites/default/files/documents/fema_hazus-hurricane-modeling-factsheet_102021.pdf

Table 5: Climate Conditioned Landfall Rates Fact Sheet

Applied Research Associates' Hazus Wind Model	
Hazards Impacted	Hurricane
Climate Scenarios Used	Representative Concentration Pathways (4.5, 8.5)
GCM Used	CMIP5
Resolution	Data provided in the form of a wind map
Variables Used	Hurricane Category Wind Frequencies

2.4. Subject Matter Expert Review

To ensure the reliability and integrity of the Future Risk Index's data, methods, and results during its development, multiple subject matter expert (SME) reviews were conducted. The first occurred in September 2023 during the initial methodology development and conceptual exploration; and the second in July 2024 to verify initial results and further refine data and methodologies. In addition to the two formalized review periods, ad hoc SME reviews were hosted for individual hazard components. Audiences for these meetings included source data experts as well as specific hazard experts from state and federal agencies and academia. Table 6 provides a full list of SME organizations consulted for each hazard.

Table 6: List of Hazard Contributors

Hazard	*Contributor*
Coastal Flooding	National Oceanic and Atmospheric Administration (NOAA)
Drought	National Integrated Drought Information System (NIDIS) United States Department of Agriculture (USDA) Southern Climate Impacts Planning Program (SCIPP)

Hazard	*Contributor*
Extreme Heat	Centers for Disease Control and Prevention NASA Jet Propulsion Laboratory (JPL) National Integrated Heat Health Information System (NIHHIS) National Oceanic and Atmospheric Administration (NOAA) University of California, Davis (UC Davis)
Hurricane	Applied Research Associates (ARA)
Wildfire	Argonne National Laboratory (ANL) NASA Jet Propulsion Laboratory (JPL) United States Department of Agriculture (USDA) United States Fire Administration (USFA)

These SME reviews yielded the following methodological and data improvements to the Future Risk Index:

- **Wildfire.** The initial Wildfire model only incorporated the Fire Weather Index when producing the HM. Following SME recommendation, the Wildfire methodology was updated to incorporate land cover and available fuel types when calculating the HM.
- **Extreme Heat.** The initial approach to Extreme Heat only utilized the variable, 'Annual Number of Days with Minimum Temperature Greater than the 99th percentile.' Following SME recommendation, the Extreme Heat methodology was expanded, now including days over 95th percentile as an additional variable. Additionally, recommendations were made to incorporate a Heat Index threshold when determining whether an Extreme Heat event should be included.
- **Drought.** The initial Drought model only utilized the variable 'Consecutive Dry Days' from the Localized Constructed Analogs when producing the HM. Following SME recommendations, the Standardized Precipitation Evapotranspiration Index (SPEI) was investigated and subsequently incorporated as the primary drought HM variable.
- **Hurricane.** Hurricane SMEs were very influential in the development of the intensity variable used to merge hurricane subcategory frequencies and in producing the Hurricane HM.

In addition to the formal SME Review periods, continuous communication channels were maintained to encourage an open dialogue pertaining to the improvement of data and methodologies. For more

information about individual contributors to the SME Reviews and the Future Risk Index see Appendix A.

2.5. Data and Methodologies

As an extension of the National Risk Index, the Future Risk Index leverages the data and methodologies of the National Risk Index as the baseline inputs for its own calculations. An in-depth discussion of the Future Risk Index's overall risk analysis methodology is presented in Section 3 Risk Analysis Overview, but the National Risk Index component discussions are not included and should instead be accessed via the National Risk Index Technical Documentation.

Details of the data and methodologies used for each of the give included hazards are provided in Sections 4 through 8. Each of these sections provide a definition of the hazard, the data sets used by the Future Risk Index for that hazard, the methods for how those data were processed, and an explanation of the type of available results.

3. Risk Analysis Overview

The philosophical and general approach to risk analysis in the Future Risk Index is the same as the one used in the National Risk Index. Natural hazard risk, as defined in the National Risk Index, is the likelihood (or probability) of a natural hazard event happening multiplied by the expected consequence if that natural hazard event occurs. The generalized form of a risk equation is given in Equation 1.

Equation 1: Generalized Risk Equation

$$Risk = Likelihood \times Consequence$$

In the National Risk Index, risk is presented using three different metrics: monetary **values**, unitless **scores**, and qualitative **ratings**, which are discussed in Section 3.2. The risk equation behind the National Risk Index includes three components: a natural hazards risk component, a consequence-enhancing component, and a consequence-reduction component. Expected Annual Loss, or EAL, is the natural hazards risk component measuring the expected loss of building value, population, and/or agriculture value each year due to natural hazards. Social Vulnerability is the consequence-enhancing component and analyzes demographic characteristics to measure the susceptibility of social groups to the adverse impacts of natural hazards. Community Resilience is the consequence-reduction component and uses demographic characteristics to measure a community's ability to prepare for, adapt to, withstand and recover from the effects of natural hazards. The Social Vulnerability and Community Resilience components are combined into one Community Risk Factor (CRF) which is multiplied by the EAL component to calculate risk using Error! Reference source not found..

Equation 2: Generalized Risk Equation for National Risk Index

$$Risk = Expected\ Annual\ Loss \times Community\ Risk\ Factor$$

$$where\ Community\ Risk\ Factor = f\left(\frac{Social\ Vulnerability}{Community\ Resilience}\right)$$

$$and\ Expected\ Annual\ Loss = Annualized\ Frequency \times Exposure \times Historic\ Loss\ Ratio$$

Where:

Social Vulnerability	is the susceptibility of social groups to the adverse impacts of hazards, including disproportionate death, injury, loss, or disruption of livelihood
Community Resilience	is the ability of a community to prepare for anticipated natural hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions

Annualized Frequency	is the expected frequency or probability of a hazard occurrence per year
Exposure	is the representative value of buildings, population, or agriculture potentially exposed to a natural hazard occurrence
Historic Loss Ratio	is the representative percentage of a location's hazard type exposure that experiences loss due to a hazard occurrence or the average loss associated with the hazard occurrence

For more information on how Risk and its components are calculated please see the National Risk Index Technical Documentation.

3.1. Future Risk Calculation

Future risk is incorporated into the EAL calculation as a modifier to Annualized Frequency, or the expected frequency for a given hazard type. This is called a Hazard Multiplier (HM) and represents how the experienced intensity or frequency of a given hazard is anticipated to change into the future. Figure 5 depicts how the EAL calculation from the National Risk Index is modified by the HM in the Future Risk Index.

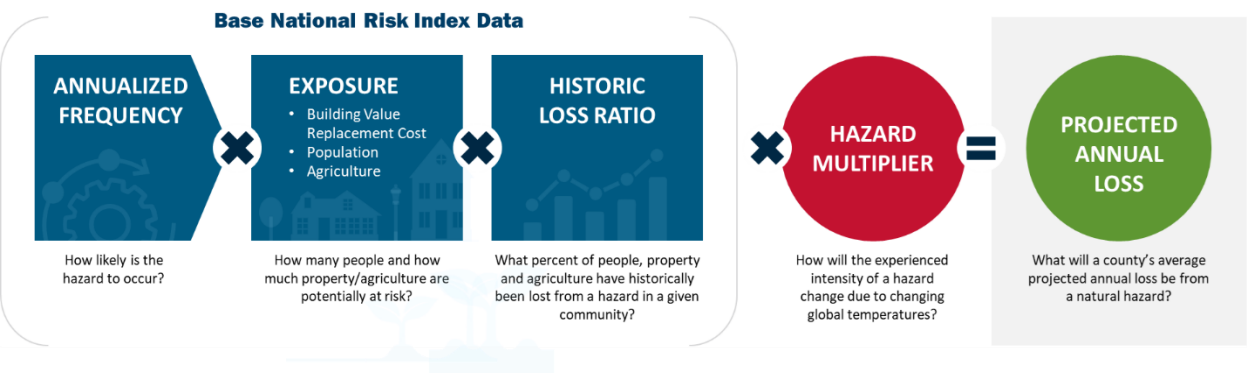

Figure 5: Projected Annual Loss Calculation

The HM is dependent on the hazard and location and is currently only available at the county level. It is important to note that as a frequency adjustment the HM does not account for any changes to hazard exposure or historic loss ratio. Further, no adjustments are made when calculating the Community Risk Factor (CRF), meaning the equation does not account for potential future changes to a community's vulnerability or resilience. In other words, the Future Risk Index analyzes how the increased frequency or intensity of hazards due to climate change would affect a community today, assuming all else was held constant to create the Projected Annual Loss (PAL). This is demonstrated in Equation 3.

Equation 3: Generalized HM Equation

$$Projected\ Annual\ Loss = Hazard\ Multiplier \times Expected\ Annual\ Loss$$

$$where\ Hazard\ Multiplier = MAX(1, \frac{Anticipated\ Increase}{Historical\ Benchmark})$$

Where:

Anticipated Increase	is how the climatological factors influencing a given hazard are anticipated to change
Historical Benchmark	is the currently observed historical benchmark of the climatological factor which is anticipate to change

It should be noted that the HM assumes that hazard risk due to climatological shifts can only increase from the observed historical baseline. It is possible that the anticipated shift in frequency is less than the observed historical benchmark, leading to a HM of less than one, for this reason a HM floor has been implemented for all hazards. This means that the PAL for any county cannot be less than the currently observed EAL in the National Risk Index.

3.2. Values, Scores and Ratings

The National Risk Index has three ways in which it provides results: Values, Scores and Ratings.

- **Values**. Values for Risk and EAL are in units of dollars, representing the community's average economic loss from natural hazards each year. For Social Vulnerability and Community Resilience, values are the index values for the community provided by the source data sets.
- **Scores**. Scores represent the national percentile ranking of the community's component value compared to all other communities at the same level (county or Census tract).
- **Ratings**. Ratings are provided in one of five qualitative categories describing the community's component value in comparison to all other communities at the same level. Rating categories range from "Very Low" to "Very High."

To acknowledge and accurately account for the inherent uncertainty of future climate modeling, the Future Risk Index communicates its results in terms of Ratings. However, the data for the underlying National Risk Index EAL values and the Hazard Multipliers are available for download for users who wish to perform additional analyses.

Ratings are determined using fixed-bin thresholds defined using the National Risk Index, where the threshold between each Rating is determined by each hazard's maximum observed EAL or Risk Value. All Community PAL and Projected Risk Values are then sorted into these bins to determine their new Rating. In this way, communities can better observe how their anticipated risk would

change between future risk scenarios, but in terms of current Ratings. Figure 6 provides an example visual of how ratings in the Future Risk Index use the National Risk Index-calculated Ratings and allows users to quickly make an at-a-glance comparison between current and possible future natural hazard risk. It should also be noted that communities currently rated as being either "Not Applicable" or "No Rating" will maintain that rating throughout all Future Risk Index scenarios.

Note: National Risk Index EAL and Risk Ratings are defined using a machine learning technique referred to as k-means clustering. This process is illustrated in **Section 3.2. Values, Scores and Ratings** in the National Risk Index Technical Documentation.

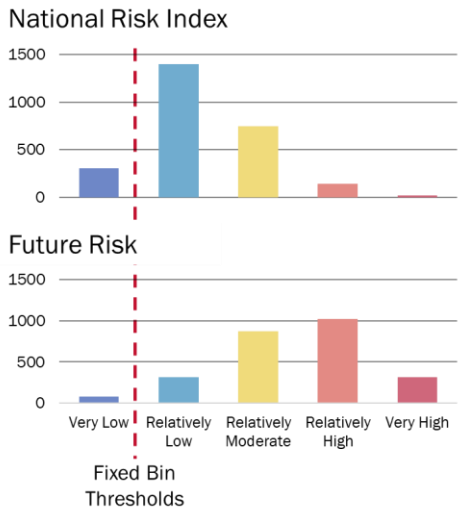

Figure 6: Projected Risk Rating Fixed-Bin Threshold Determination

Table 7 represents the fixed-bin thresholds of a hypothetical hazard. These thresholds equal the highest observed Risk or EAL value within that Rating. For example, the threshold for "Very Low" equals $50,000 meaning the highest observed value amongst communities ranked as "Very Low" was $50,000.

Table 7: Hypothetical Fixed-Bin Thresholds

Ratings	*Fixed-Bin Threshold*
Very Low	$50,000
Relatively Low	$150,000
Relatively Moderate	$450,000
Relatively High	$750,000
Very High	$1,000,000

To illustrate how a community's rating may change as a result of its HM adjustment, assume there exists a community with an EAL Value of $100,000. This community is rated as having a "Relatively Low" level of losses in the National Risk Index. Under the Lower Mean Global Temperature Mid-Century Scenario, the Future Risk Index calculates a 2-times increase in associated PAL for a value of $200,000. Using the fixed-bin thresholds above, this community's PAL now exceeds the maximum observed value for the "Relatively Low" Rating but not that of "Relatively Moderate", meaning that under Lower Mean Global Temperature Mid-Century this community's hazard risk Rating would be "Relatively Moderate".

Table 8: Hypothetical Community Risk

Scenario	*Hazard Multiplier*	*Projected Risk Value*	*Projected Risk Rating*
Current	NA	$100,000	Relatively Low
Lower Mean Global Temperature Mid-Century	x2	$200,000	Relatively Moderate
Higher Mean Global Temperature Late-Century	x8	$800,000	Very High

The HM Rating is an additional rating unique to the Future Risk Index. This HM Rating is based on percentiles, which ranks communities relative to all other communities. For example, communities whose HM Value rank in the bottom 20th percentile for a given hazard receive a HM Rating of "Very Low" for that hazard, while communities who rank between the 20th and 40th percentiles receive a rating of "Relatively Low". All communities with either no recorded HM or a HM of zero will receive a rating of either "Not Applicable" or "No Rating" respectively. For all HM Rating definitions please refer to Table 9.

Table 9: Hypothetical Fixed-Bin Thresholds

HM Rating	*Percentile*
Not Applicable	No Recorded CIF
No Rating	HM = 0
Very Low	< 20th
Relatively Low	20-40th
Relatively Moderate	40-60th
Relatively High	60-80th
Very High	>= 80th

To illustrate how counties can interpret and use the HM Rating, please refer to the hypothetical counties outlined in Table 10. There are many cases where absolute risk alone is not an indicator of how a county may be impacted by a scenario. Many counties, like County B, may currently experience low levels of annual losses when compared to those of County A. However, County B has a greater HM under all future risk scenarios. While the absolute impact may be greater for County A, the relative impact experienced by County B is greater than that of County A.

Table 10: HM Ratings for two Hypothetical Counties

	Scenario	*Hazard Multiplier*	*Future Risk Value*	*HM Rating*
County A	**Current**	NA	$100,000	No Rating
	Lower Mean Global Temperature Mid-Century	x2	$200,000	Very Low
	Higher Mean Global Temperature Late-Century	x8	$800,000	Relatively Moderate

	Scenario	Hazard Multiplier	Future Risk Value	HM Rating
County B	Current	NA	$20,000	No Rating
	Lower Mean Global Temperature Mid-Century	X6	$120,000	Relatively Low
	Higher Mean Global Temperature Late-Century	X12	$240,000	Relatively High

3.3. Assumptions and Limitations

The Future Risk Index and its associated data are meant for planning purposes only. This tool was created for broad, nationwide comparisons and is not a substitute for localized risk assessment analysis. Nationwide datasets used as inputs for the National Risk Index are, in many cases, not as accurate as available local data. Users with access to local data for each National Risk Index risk factor should consider substituting the provided data with local data to recalculate a more accurate risk index. If downloading the Future Risk Index data and substituting it with local data, the user assumes responsibility for the accuracy of the data and any resulting data index. Please visit the Contact Us page to discuss this process further.

The methodology used by the Future Risk Index has been reviewed by subject matter experts in the fields of natural hazard risk research, risk analysis, mitigation planning, and emergency management. The Future Risk Index continually seeks opportunities for improvement, whether that be through the incorporation of new and additional variables or hazards, data, or revisions to methodologies. All recommendations can be emailed to FEMA-NRI@fema.dhs.gov.

The Future Risk Index does not consider the intricate economic and physical interdependencies that exist across geographic regions. Users should be mindful that hazard impacts in surrounding counties or Census tracts can cause indirect losses in a location regardless of the location's risk profile. Furthermore, the Future Risk Index does not account for human adaptation in response to climatological changes. Exposure and Historical Loss Ratios are held constant between scenarios.

A significant limitation in the current methodology is the absence of adaptation measures. It is understood that as conditions change, communities and people may need to find new ways to adapt to their new surroundings. Unfortunately, there are no currently widely available data sources that could support this proposed hazard exposure adjustment, despite human adaptation being recognized as an integral part in determining future natural hazard risk. This will continue to be investigated as a potential methodological improvement to the Future Risk Index.

All Future Risk Index hazard types except Hurricane use an annualized frequency model to determine PAL. It is difficult to accurately estimate PAL for high consequence, low frequency events unless these kinds of events are represented in historic period of record. Hurricane utilizes a probabilistic model which estimates the likelihood of a hazard occurrence over an extended period of time. For more details on how the probabilistic model impacts Hurricane EAL Calculation, see Section 13.6. Annualized Frequency of the National Risk Index Technical Documentation.

The Future Risk Index's processing database is a complex system, and localized inaccuracies in any source data can exist. The Future Risk Index should be considered a baseline measurement and a guideline for determining potential natural hazard risk but should not be used as an absolute measurement of future risk. This is due to the level of uncertainty involved when projecting future risk, as these projections cannot fully account for natural variability, human intervention and uncertainty surrounding model-based climate simulations. It is for these reasons that the Future Risk Index does not provide specific PAL or risk values by county, rather presenting a categorical rating along with a range of values one could reasonably see occurring within that rating. Similarly, the calculation of risk under four distinct future risk scenarios, rather than a single scenario, is meant to reinforce that there are several possible, reasonable climatological projections that should be considered for a robust estimate of potential future natural hazard risk. Even within the climatological data there is inherent uncertainty: aggregating data at the county level potentially results in diluting extreme records and an underestimation of future risk assessments.

Assumption of Risk

With the identified limitations of the Future Risk Index associated data, by using the data users acknowledge and agree that FEMA makes no representations or warranties about the accuracy, completeness, or fitness for any particular purpose of the data; that the data are provided "as is" without warranty of any kind; that the user assumes full responsibility for any consequences that may arise, including financial losses, legal disputes, or other adverse outcomes; and that the user releases FEMA and the federal government from any liability that may arise to the extent allowable by law.

4. Coastal Flooding

Coastal Flooding is when water inundates or covers normally dry coastal land as a result of high or rising tides or storm surges.

4.1. Spatial Source Data

Interagency Task Force on Sea Level Change 2022: Global and Regional Sea Level Rise Scenarios for the United States (noaa.gov)

The Interagency Task Force (ITF)[16] leveraged NOAA's High Tide Flooding Probability set[17] to determine the frequency of Minor, Moderate and Major Flooding events under a variety of climatological scenarios. High Tide Flooding (HTF) event frequencies for each of the climatological scenarios were produced using United States Global Change Research Program (USGCRP) projections of sea level rise.

These data were provided for each of 187 NOAA Tidal Gauges along the United States and Territories' coastlines.

4.1.1. AGGREGATION OF FUTURE RISK SCENARIOS

Interagency Task Force on Sea Level Change 2022:

The Interagency Task Force (ITF) provided high tide flooding probabilities based upon sea level rise (SLR) scenarios for the mid-century (2050) and late-century (2100). These data were categorized by flooding severity level, including;

- Minor Flooding Events – 1 to 2 Year Floods (50-100% Annual Chance)
- Moderate Flooding Events – 10 to 50 Year Floods (2-10% Annual Chance)
- Major Flooding Events – 100 Year Floods (1% Annual Chance)

Sea level rise scenarios were defined by the ITF as Low, Intermediate Low, Intermediate, Intermediate High and High based upon the anticipated rate of sea level rise. These scenarios are based on set exceedances above mean higher high water (MHHW) levels, shown in Table 11.

[16] National Aeronautics and Space Administration. (n.d). *What are the scenarios from the Sea Level Rise Interagency Task Force and how do they compare to the projections from the IPCC AR6?*. https://sealevel.nasa.gov/faq/16/what-are-the-scenarios-from-the-sea-level-rise-interagency-task-force-and-how-do-they-compare-to-the/#:~:text=The%20Sea%20Level%20Rise%20and%20Coastal%20Flood%20Hazard,Technology%20%28SOST%29%2C%20and%20the%20National%20Ocean%20Council%20%28NOC%29.

[17] National Oceanic and Atmospheric Administration. (n.d). *Annual High Tide Flooding Outlook*. https://tidesandcurrents.noaa.gov/high-tide-flooding/annual-outlook.html

Table 11: Sea Level Rise Scenario Definitions (by 2100)

Scenario	*Meters above MHHW*
Low	0.3 m
Intermediate Low	0.5 m
Intermediate	1.0 m
Intermediate High	2.0 m
High	2.5 m

The Future Risk Index currently presents results for the Intermediate and High SLR scenarios, which anticipate 1.0 meters and 2.5 meters in sea level rise respectively. While mid and late-century data are available for all 5 scenarios, only the intermediate and high SLR scenarios were chosen as a representative window for the initial release of the Future Risk Index, which is similar to that seen for other hazard types.

More information on how the Interagency Task Force produced its results can be found here.

4.2. Spatial Processing

Projected high tide flooding event frequencies provided for each of 187 NOAA tidal gauges (Figure 7) are spatially joined to the nearest National Risk Index counties. The merge is run with the criteria that a county would inherit the information of the closest tidal gauge, based purely on geographic distance between the two. This framework does not account for the impact of coastal inlets, as a more distant tidal gauge might better reflect a county due to nearby inlets.

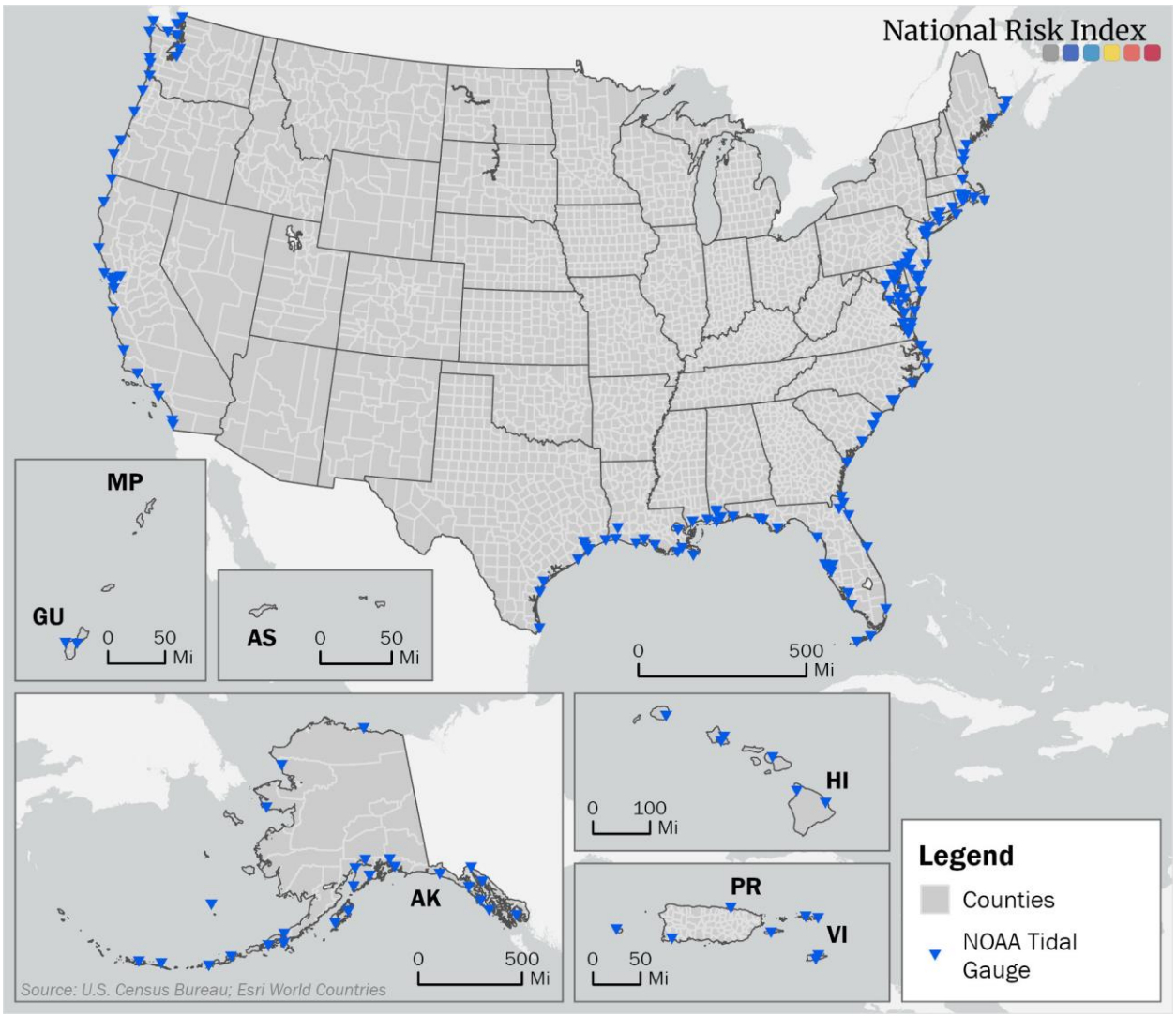

Figure 7: NOAA Tidal Gauges along the United States Coastline

4.3. Projected Annual Loss

The Future Risk Index uses the newly calculated hazard data to develop future risk measurements by calculating new PALs and determining their risk Ratings. Coastal Flooding utilizes Minor, Moderate and Major high-tide flooding events to determine Coastal Flooding frequency, enabling the scaling of this frequency at these sub-types. This approach provides a more accurate assessment of how changes in sub-type event frequencies impact the overall PAL.

The amount of the National Risk Index's EAL attributed to a given sub-type is determined by its sub-type proportion calculated at the county level, and represents the percentage of EAL attributed to each of the Minor, Moderate and Major flooding categories. The increase in sub-type event frequency is determined by comparing observed historical event frequencies against those anticipated under

several SLR scenarios. This frequency adjustment factor, per Equation 4, is calculated for each of the 187 NOAA Tidal Gauges.

Equation 4: Frequency Adjustment Factor and Sub-type Proportion

$$Sub_{FAF} = \frac{Projected\ CFLD_{SubHazard_{Frequency}}}{Current\ CFLD_{SubHazard_{Frequency}}}$$

$$Sub_{Proportion} = \frac{CFLD_{SubHazard_{EALT}}}{CFLD_{Total_{EALT}}}$$

Where:

$CFLD$	stands for Coastal Flooding
Sub_{FAF}	is the Frequency Adjustment Factor for a given sub-type
$Projected\ CFLD_{Sub_{Frequency}}$	is the sub-type frequency attributed to a given climate scenario
$Current\ CFLD_{Sub_{Frequency}}$	is the current sub-type frequency
$Sub_{Proportion}$	is the proportion of EAL attributed to a given sub-type
$CFLD_{Sub_{EALT}}$	is the total EAL attributed to a given sub-type
$CFLD_{Total_{Frequency}}$	is the total EAL across all sub-types

Note: To adjust frequencies for areas protected by levees, these areas are clipped out prior to sub-type frequency computation.

The PAL is then calculated at the county level for each future risk scenario using Equation 5. The change in sub-type proportion from Equation 4 is multiplied by its corresponding frequency adjustment factor to create the HM. This function relates the change in sub-type event frequency to the observed sub-type EAL attribution at the county level. Then the HM is used as a multiplier on the EAL sourced from the National Risk Index to calculate the PAL.

Equation 5: Coastal Flooding Climate-Informed EAL Calculation

$$PAL_{CFLD} = EAL_{CFLD} \times HM_{CFLD}$$

$$where\ HM_{CFLD} = \sum SubHazard_{FAF} \times SubHazard_{Proportion}$$

Where:

PAL_{CFLD}	is the Projected Annual Loss of a given county
EAL_{CFLD}	is the Coastal Flooding EAL from the National Risk Index
HM_{CFLD}	is the Hazard Multiplier calculated for a given county
$SubHazard_{FAF}$	is the Frequency Adjustment Factor for a given sub-type
$SubHazard_{Proportion}$	is the proportion of EAL attributed to a given sub-type

Figure 8 provides a visualization of the resulting PAL Ratings resulting from these calculations.

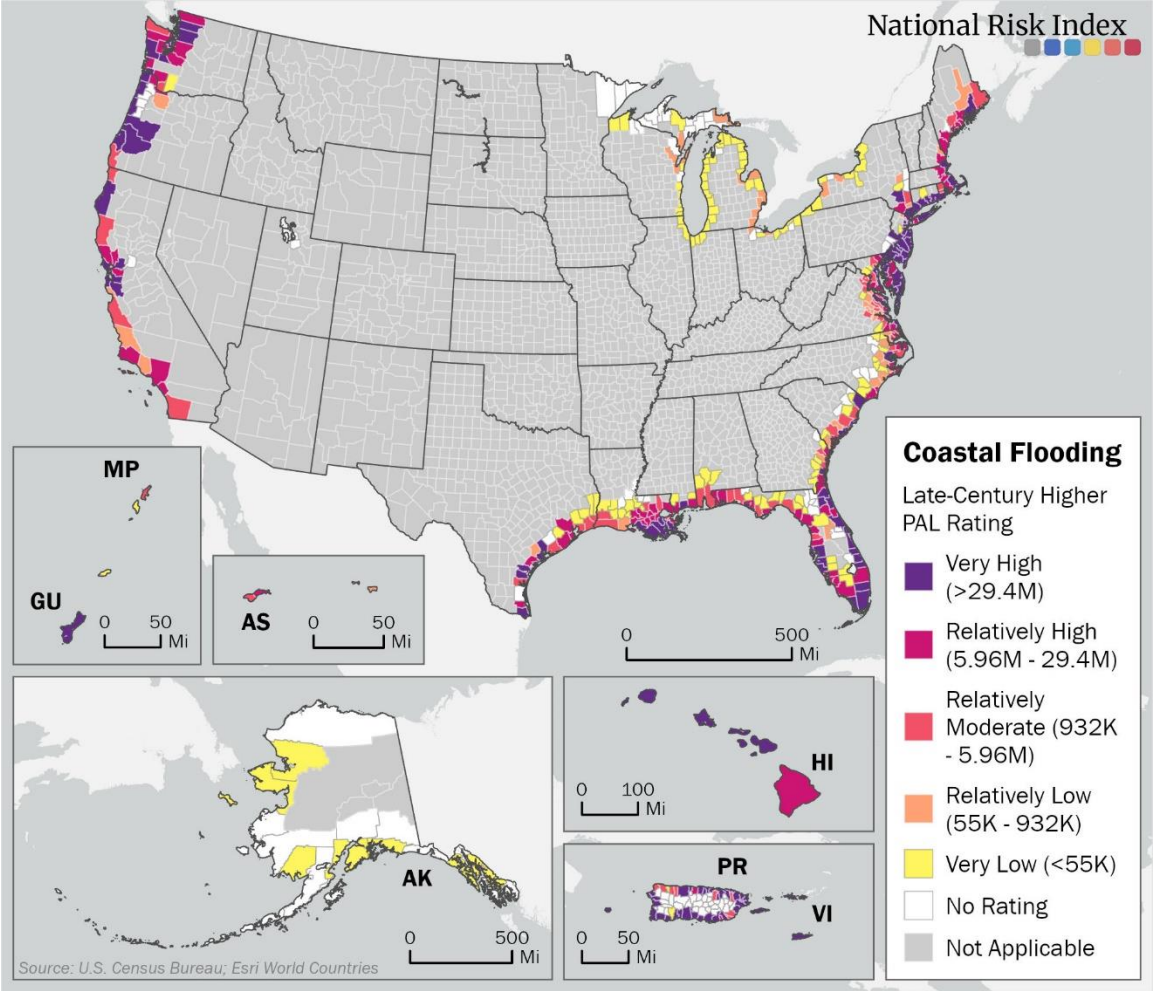

Figure 8: Late-Century Higher Mean Global Temperature PAL

The PAL values are then used to calculate the Projected Risk values for the Coastal Flooding hazard type. These are also calculated at the county level for each scenario using Equation 6. The PAL value is multiplied by the Community Risk Factor as a consequence modifier to determine the overall risk values.

Equation 6: Coastal Flooding Projected Risk Calculation

$$Projected\ Risk_{CFLD} = PAL_{CFLD} \times Community\ Risk\ Factor$$

Where:

$Projected\ Risk_{CFLD}$	is the Projected Risk value of a given county
PAL_{CFLD}	is the Projected Annual Loss of a given county

Community Risk Factor is the function of Social Vulnerability and Community Resilience calculated in the National Risk Index

Note: No adjustments are made to Community Risk Factors.

Figure 9 provides a visualization of the resulting Projected Risk Ratings resulting from these calculations.

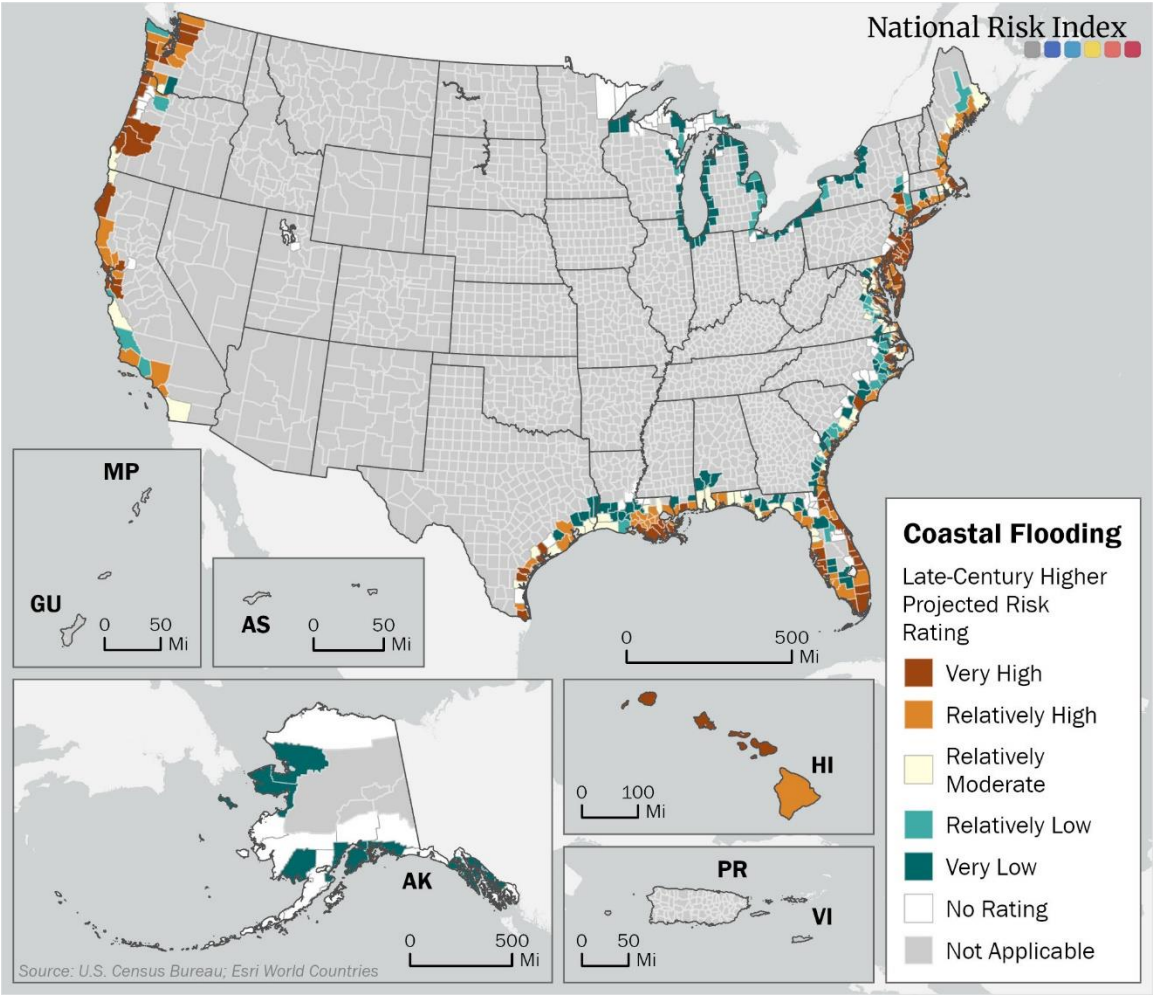

Figure 9: Late-Century Higher Mean Global Temperature Projected Risk

5. Drought

A Drought is a deficiency of precipitation over an extended period of time resulting in a water shortage. The Future Risk Index methodology measures drought on an event-day basis. The increase or decrease in drought-event days for a particular location is measured across climate scenarios using a daily Standardized Precipitation and Evapotransporation Index (SPEI).

5.1. Spatial Source Data

NASA Earth Exchange: NEX-GDDP-CMIP6 | Data Browse

NASA Earth Exchange (NEX) provides a repository of statistically downscaled CMIP6 projections reflecting a wide array of variables projected out under different climate scenarios. Using daily precipitation and average temperature data , an (SPEI) capable of identifying and characterizing meteorological drought under these different climate scenarios can be produced.

These data were provided as Network Common Data Form (NetCDF) files which were converted into flat data tables and processed using the 'SPEI' R Package.

5.1.1. AGGREGATION OF FUTURE RISK SCENARIOS

NEX presents 30 distinct CMIP6 models spanning the period of 1950-2100. The MPI-ESM1-HR model was specifically selected as it most closely simulates the Equilibrium Climate Sensitivity (ECS) produced by the IPCC's Sixth Assessment Report.[18] The ECS is currently understood to be the most likely warming scenario and is often used when validating CMIP6 model projections.

These data were provided at a 30 arcsecond resolution under both SSPs 2-4.5 and 5-8.5. These data were aggregated using daily projections over 30-year periods across three timeframes, including;

- Historical – aggregated over the years 1985-2014
- Mid-Century – aggregated over the years 2036-2065
- Late-Century – aggregated over the years 2070-2099

For more information about how NEX produced its result please see NEX-GDDP | NASA Center for Climate Simulation

5.2. Spatial Processing

Daily precipitation and temperature raster data were used to calculate the SPEI for each month and year at a given location. SPEI builds upon the Standardized Precipitation Index (SPI) by including the

[18] Bayesian weighting of climate models based on climate sensitivity | Communications Earth & Environment (nature.com)

impacts of temperature variability in its drought detection and characterization. SPEI has become one of the most widely-used drought metrics due to its flexibility of use and water balance approach to drought characterization.[19] [20] Notably, SPEI is used to categorize drought events as shown in the US Drought Monitor, a joint effort of National Drought Mitigation Center, National Oceanic and Atmospheric Administration and the U.S. Department of Agriculture.[21]

Monthly SPEI values are obtained by using the 'SPEI' R package with a scale factor of 3 months. The Thornthwaite method is used to calculate daily potential evapotranspiration (PET) values using monthly mean temperature projections and computing a daily average within each month.[22] SPEI values are then computed using 'SPEI' package in R using a log-logarithmic distribution function with a 60-year reference period. Following methods used by the Consejo Superior de Investigaciones Científicas on computations of SPEI, a reference period from January 1950 to December 2010 was used to calibrate the parameters of the model.

[19] S.M. Vicente-Serrano, S. Beguería, J.I. López-Moreno. 2010. A Multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index – SPEI. Journal of Climate 23: 1696, DOI: 10.1175/2009JCLI2909.1

[20] Peng, L., Sheffield, J., Wei, Z., Ek, M., and Wood, E. F.: An enhanced Standardized Precipitation–Evapotranspiration Index (SPEI) drought-monitoring method integrating land surface characteristics, Earth Syst. Dynam., 15, 1277–1300, https://doi.org/10.5194/esd-15-1277-2024, 2024.

[21] U.S. Drought Monitor. (n.d). *Drought Classification*. Drought Classification | U.S. Drought Monitor (unl.edu)

[22] To obtain daily water balance values, monthly PET values were divided by the number of days in each month, respectively, to obtain daily average PET values. These daily averages were used to compute daily water balance. See Thornthwaite (usgs.gov)

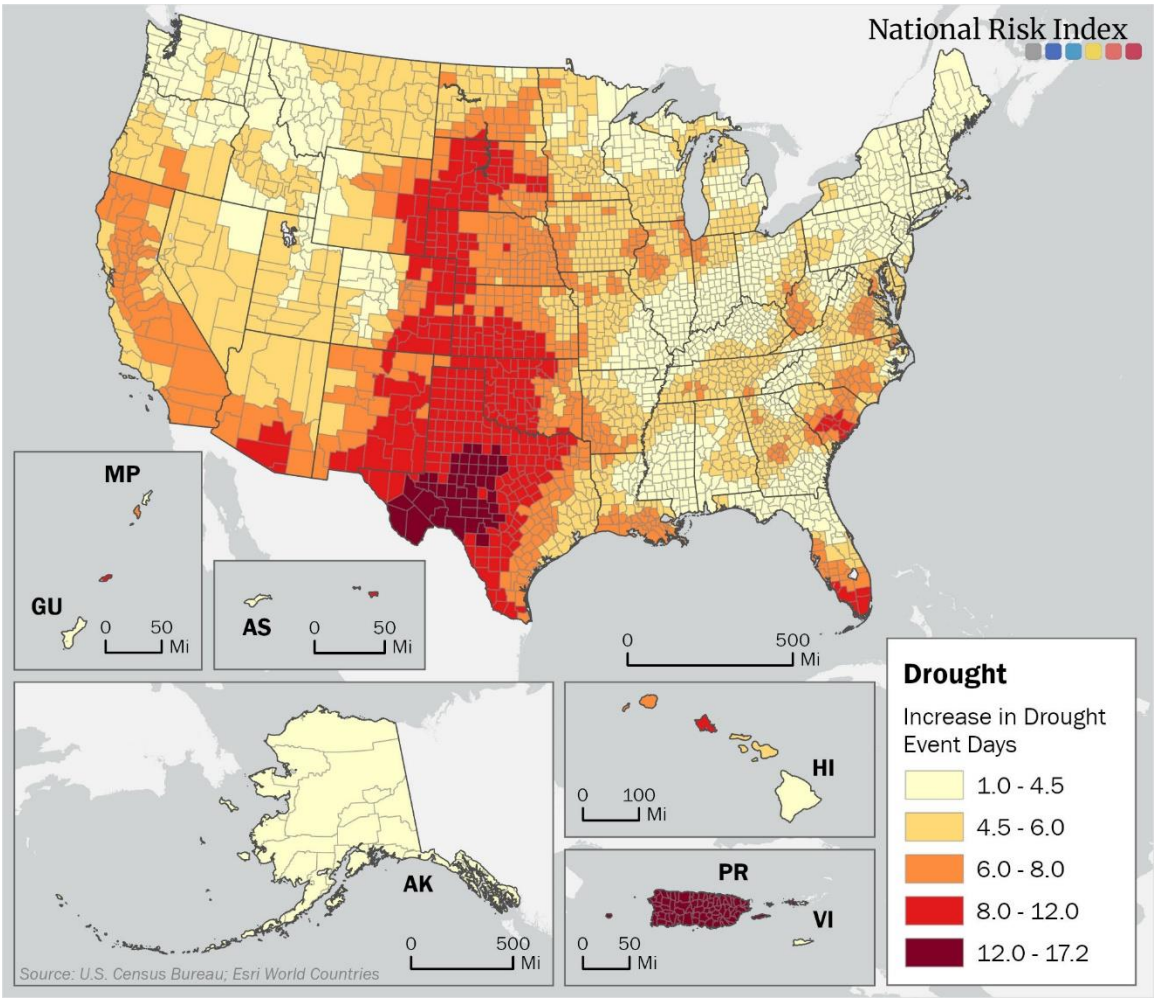

Figure 10: Increase in Drought Event Days by U.S. County

5.3. Projected Annual Loss

The Drought HM is defined as the projected increase in drought event-days under a given scenario as compared to what is observed historically. This is accomplished using SPEI values to determine whether the meteorological conditions for a point in time are considered a drought event. SPEI values closer to zero represent normal conditions, while values above or below zero indicate above- or below-normal precipitation-evapotranspiration amounts. A threshold of SPEI ≤-1.6 (Extreme Drought per the US Drought Monitor) was selected to indicate a drought occurrence to align with the drought methodology used in the National Risk Index. If an SPEI value for a given month were to fall below this threshold, each day within the month was considered a drought event-day. Total drought event-days for each climate scenario are computed as the sum of days within months with an SPEI value below the threshold of -1.6. Then a drought event rate for each location is computed for each future risk scenario by dividing total drought event days by the number of days in each 30-year scenario.

To obtain HM values at a given location, the drought event rate values for each future climate scenario are divided by the historical drought event rate value per Equation 7. Using latitude and longitude values provided in the source data, a table with HM values for each future climate scenario is converted into 0.25x0.25-degree polygon grid. For each future scenario, county level HM values are calculated using an area weighted average by intersecting the 0.25x0.25-degree polygon grid with county boundaries. The PAL is then calculated at the county level for each climate scenario by multiplying this HM against the EAL sourced from the National Risk Index.

Equation 7: Drought PAL Calculations

$$PAL_{DRGT} = EAL_{DRGT} \times HM_{DRGT}$$

$$HM_{DRGT} = \frac{Increase\ in\ Average\ \#\ of\ Drought\ Events}{Historical\ Average\ \#\ of\ Drought\ Events}$$

Where:

$DRGT$	stands for Drought
PAL_{DRGT}	is the Projected Annual Losses of a given county
EAL_{DRGT}	is the Drought EAL from the National Risk Index
HM_{DRGT}	is the Hazard Multiplier calculated for a given county

Note: All calculations are performed at the Census tract level and aggregated up to allow for a more detailed and accurate estimation of PAL at higher levels.

Figure 11 provides a visualization of the resulting PAL Ratings resulting from these calculations.

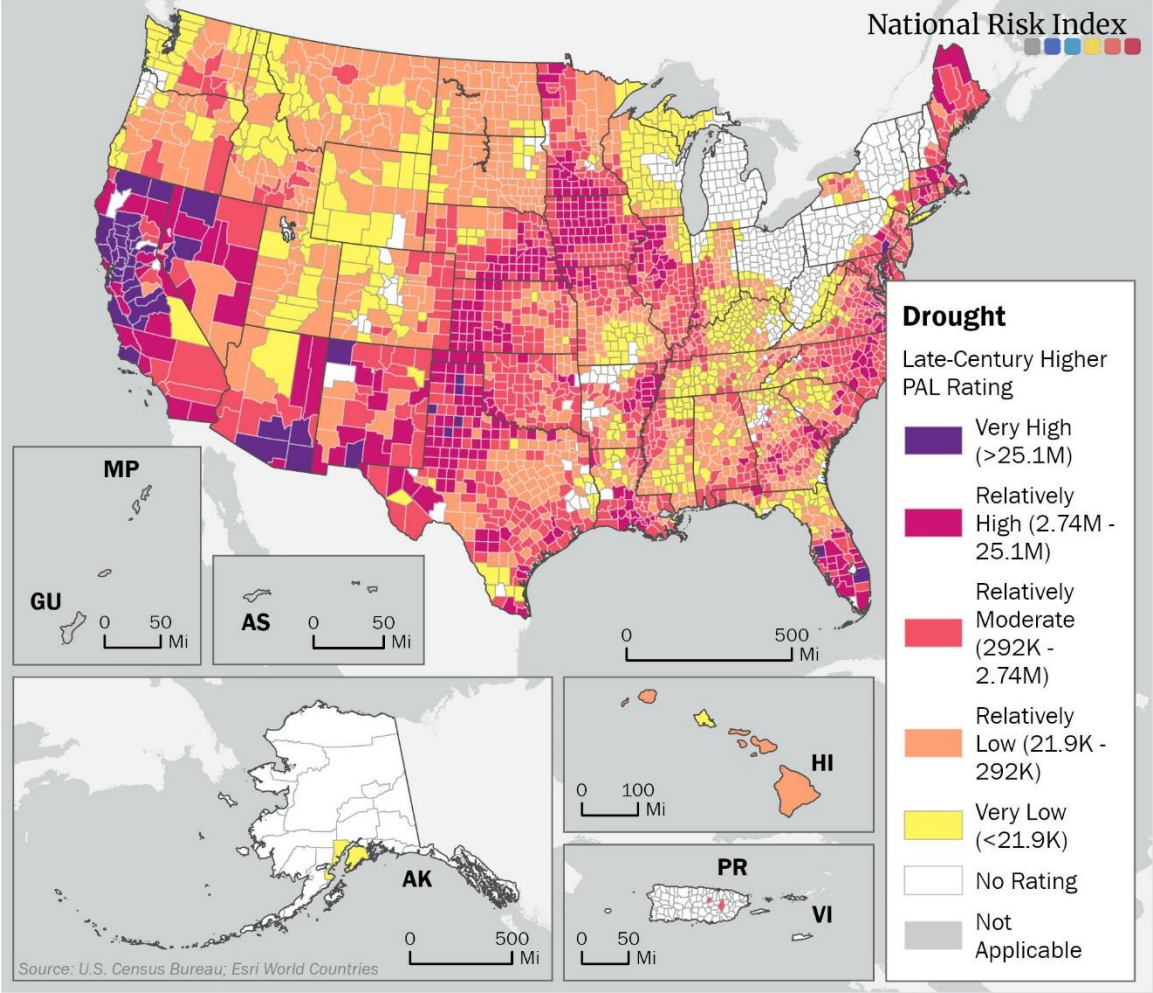

Figure 11: Late-Century Higher Mean Global Temperature PAL

The PAL values are then used to calculate the Projected Risk values for the Drought hazard type. These are also calculated at the county level for each scenario using Equation 8Equation 6. The PAL value is multiplied by the Community Risk Factor as a consequence modifier to determine the overall risk values.

Equation 8: Drought Projected Risk Calculations

$$Projected\ Risk_{DRGT} = PAL_{DRGT} \times Community\ Risk\ Factor$$

Where:

$Projected\ Risk_{DRGT}$	is the Projected Risk of a given county
PAL_{DRGT}	is the Projected Annual Loss of a given county

Community Risk Factor is the function of Social Vulnerability and Community resilience calculated in the National Risk Index

Note: No adjustments are made to Community Risk Factors.

Figure 12 provides a visualization of the resulting Projected Risk Ratings resulting from these calculations.

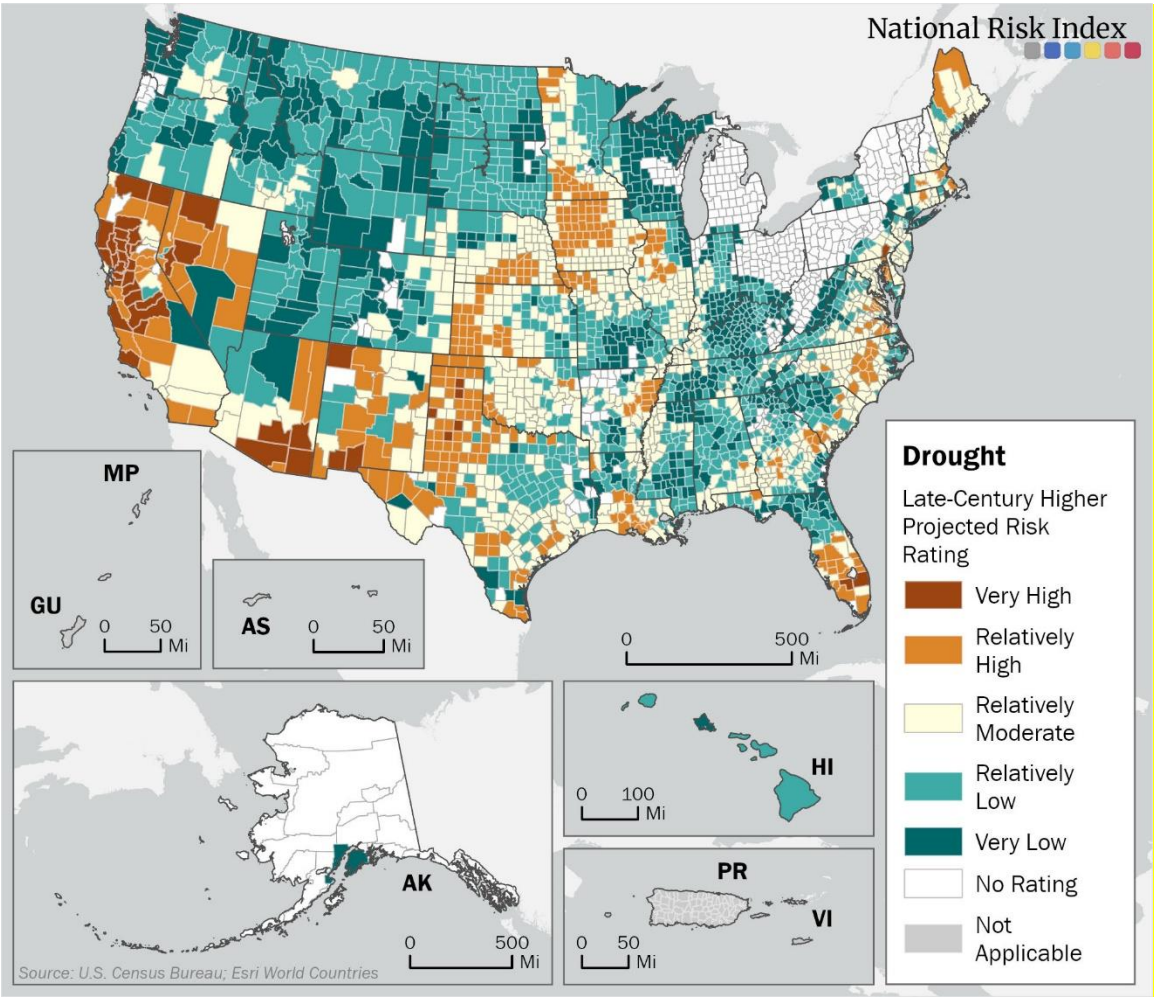

Figure 12: Late-Century Higher Mean Global Temperature Projected Risk

6. Extreme Heat (Heat Wave)

Extreme Heat is a climatological occurrence of abnormally high temperatures usually accompanied with higher-than-normal levels of humidity. The conditions necessary for an Extreme Heat event are dependent on the location.

6.1. Spatial Source Data

Results for Extreme Heat were developed using two different data sources, the Localized Constructed Analogs version 2 (LOCA2) and NASA Earth Exchange (NEX), both of which are based on CMIP6 projections.

Localized Constructed Analogs version 2: LOCA version 2 for North America (ca. Jan 2023) - LOCA Statistical Downscaling (Localized Constructed Analogs) (ucsd.edu)

LOCA2 provides statistically downscaled CMIP6 projections as they relate to temperature and precipitation. Among these is daily temperature data projected out under different climate scenarios provided both in terms of daily maximum recorded temperature and daily minimum recorded temperature. Utilizing the daily minimum recorded temperatures, or tasmins, historical 95th and 99th percentiles are produced.

These data were provided in the form of a NetCDF file which was converted to a raster in ArcGIS.

NASA Earth Exchange: NEX downscaled climate projection Data Portal (nasa.gov)

NEX provides a repository of statistically downscaled CMIP6 projections reflecting a wide array of variables. Among these is daily temperature data projected out under different climate scenarios, provided both in terms of daily maximum recorded temperature and daily minimum recorded temperature. Utilizing the daily minimum recorded temperatures, or tasmins, historical 95th and 99th percentiles are produced.

Additionally, daily average temperature projections and daily average relative humidity projections can be used to produce projected Heat Index Values.

These data were provided in the form of a NetCDF file which was converted to a raster in ArcGIS.

6.1.1. AGGREGATION OF FUTURE RISK SCENARIOS

Localized Constructed Analogs version 2:

LOCA2 presents 27 distinct CMIP6 models spanning the period of 1950-2100. Because no multi-model ensemble (MME) was provided, the MPI-ESM1-HR model was selected as providing more moderate projections similar to what one would see from a MME. These data are provided at a 6-kilometer resolution for both SSPs 2-4.5 and 5-8.5 and were aggregated using daily projections over 30-year periods across three timeframes, including;

- Historical – aggregated over the years 1976-2005
- Mid-Century – aggregated over the years 2036-2065
- Late-Century – aggregated over the years 2070-2099

For more information on how LOCA2 produced its results please see LOCA Bibliography - LOCA Statistical Downscaling (Localized Constructed Analogs) (ucsd.edu)

NASA Earth Exchange:

NEX presents 30 distinct CMIP6 models spanning the period of 1950-2100. The MPI-ESM1-HR model was specifically selected as it most closely simulates the Equilibrium Climate Sensitivity (ECS) produced by the IPCC's Sixth Assessment Report.[23] The ECS is currently understood to be the most likely warming scenario and is often used when validating CMIP6 model projections.

These data were provided at a 30 arcsecond resolution under both SSPs 2-4.5 and 5-8.5. These data were aggregated using daily projections over 30-year periods across three timeframes, including;

- Historical – aggregated over the years 1976-2005
- Mid-Century – aggregated over the years 2036-2065
- Late-Century – aggregated over the years 2070-2099

For more information about how NEX produced its result please see NEX-GDDP | NASA Center for Climate Simulation

6.2. Spatial Processing

The aggregated NetCDFs are loaded into ArcGIS and converted into rasters. The raster data are then merged with county geographies using a custom raster-vector intersect tool that allows for the direct intersection of the high-resolution raster layer with each county. The tool use the attributes of the raster cell to directly calculate the proportion of the cell value within each county. Figure 13 shows the observed daily minimum temperature calculated by LOCA and Figure 14 shows the observed daily minimum temperature calculated by NEX.

[23] Bayesian weighting of climate models based on climate sensitivity | Communications Earth & Environment (nature.com)

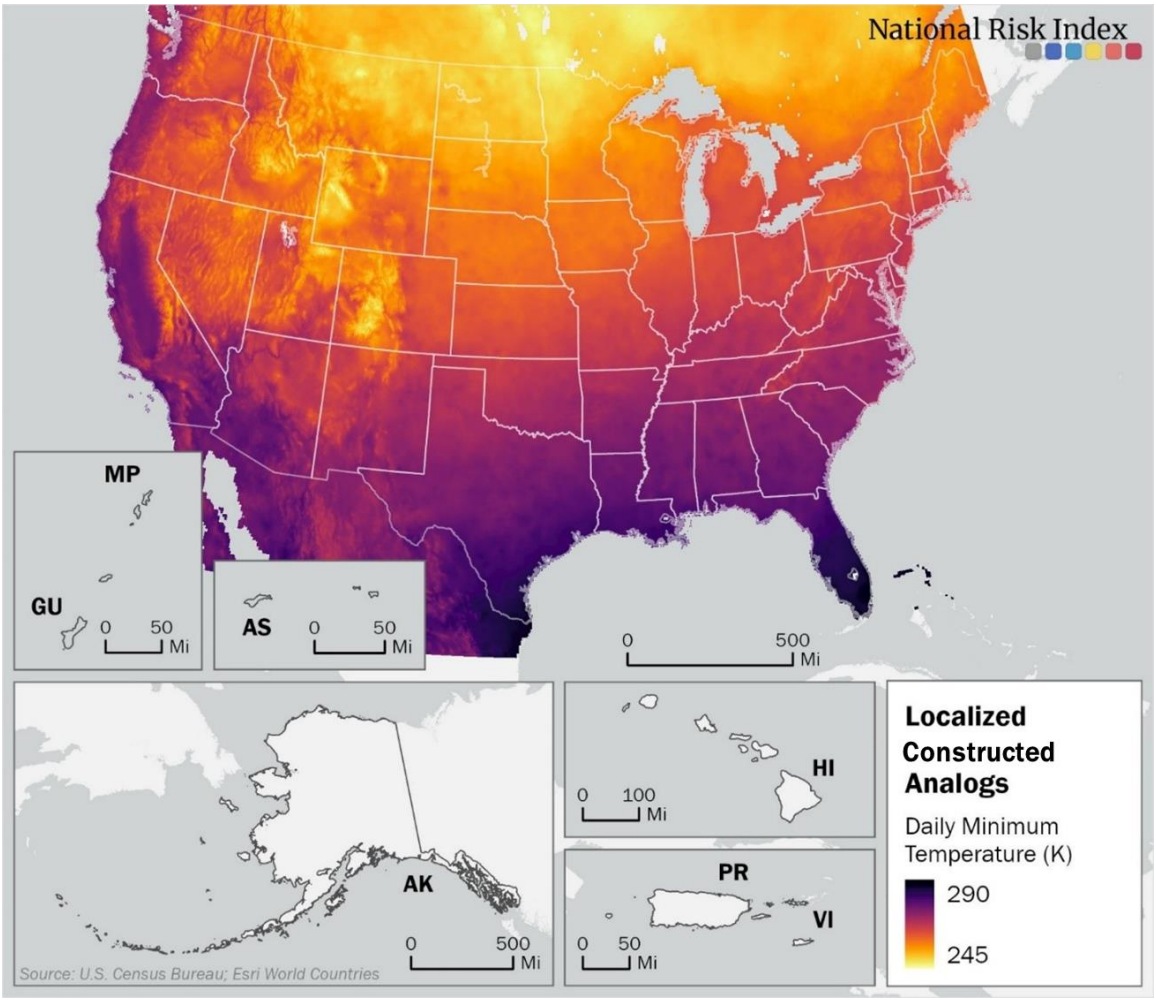

Figure 13: Observed Daily Minimum Temperature as presented by LOCA

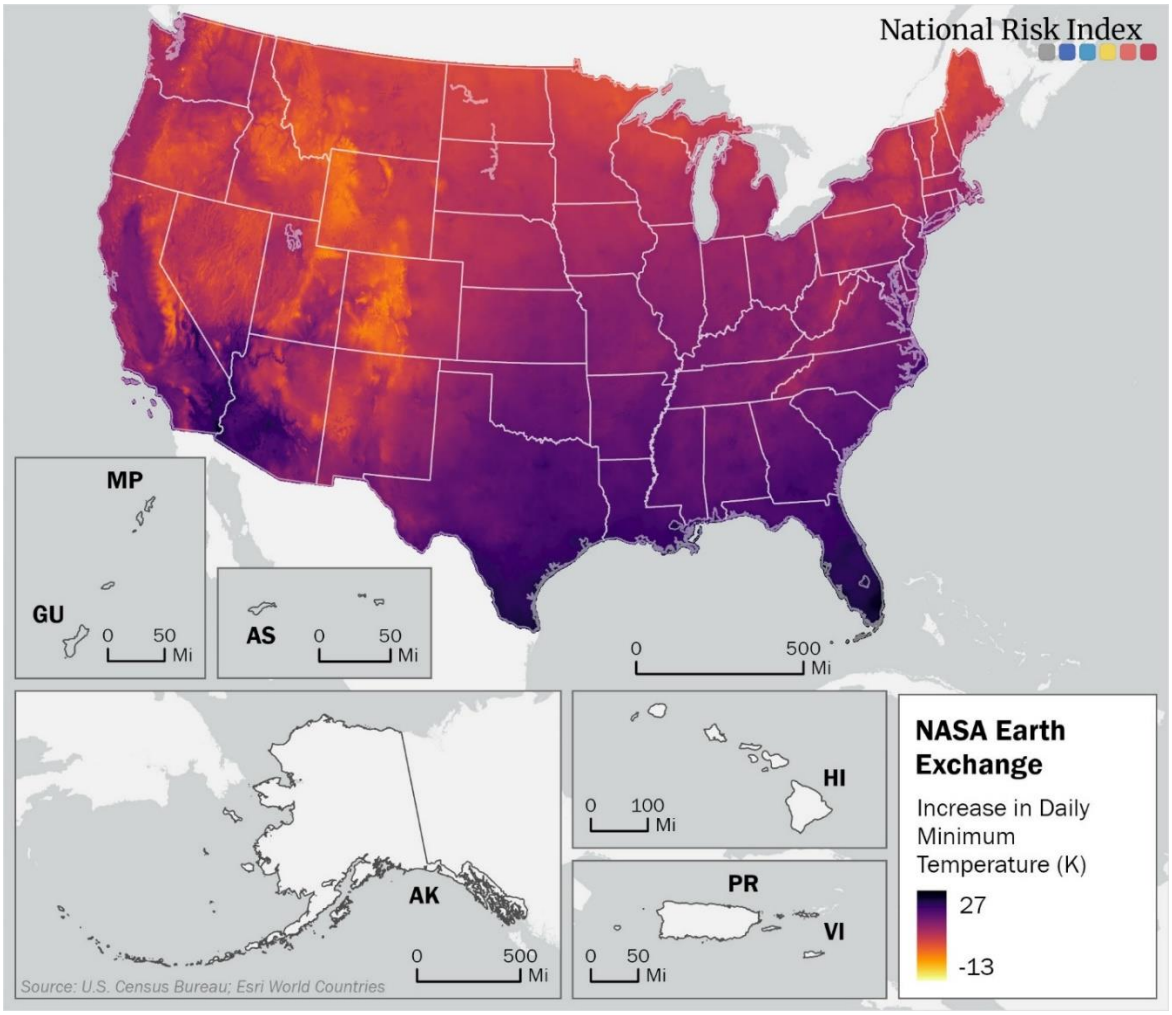

Figure 14: Increase in Observed Daily Minimum Temperature as presented by NEX

6.3. Projected Annual Loss

For both LOCA2 and NEX, the Extreme Heat HM is defined as the projected increase in extreme heat events under a given scenario as compared to what is observed historically. However, due in part to the differences in available climatological variables like relative humidity, the process of calculating the HM differs slightly between the LOCA2 and NEX data.

Currently, there is no agreed upon definition of an extreme heat event, just that it is characterized by unusually hot and/or humid conditions.[24] For this reason, the Future Risk Index leverages percentiles to determine whether an event is considered as an extreme heat event. The 95th and 99th percentile were chosen as the threshold for an extreme heat event, following guidance from the Centers for Disease Control and Prevention. These percentiles are calculated using historically

[24] Centers for Disease Control and Prevention. (n.d). *Climate Change and Extreme Heat Events.* ClimateChangeandExtremeHeatEvents.pdf (cdc.gov)

observed daily minimum temperatures over a 30-year period from 1976-2005 at a 6-km and 30-arcsecond resolution for LOCA2 and NEX, respectively, before being aggregated at the county level.

To account for historically cool regions which could potentially see 95th and 99th percentile temperatures well below what would be considered dangerous, a minimum heat index threshold is applied. Heat index is a commonly-used measure which accounts for the influence of relative humidity on the apparent (often referred to as "feels like") temperature. The applied threshold is based on the minimum heat index that would result in an increased skin blood flow, at which point an individual would experience sweating as the body attempts to cool itself. According to Lu and Romps (2022), this occurs at a heat index of 298K. [25]

Note: While NEX provides the variables necessary to calculate a heat index, The heat index could not be directly calculated from LOCA2 derived variables due to the lack of relative humidity data. For this reason, a temperature value of 296.22 K was chosen as the LOCA2 threshold, as this temperature at 100% relative humidity equates to a heat index of 298 K. Since high relative humidity has a positive correlation with high heat index values, this provides a conservative estimate of the lowest temperature at which the heat index threshold would occur.

Table 12: LOCA2/NEX Extreme Heat Event Thresholds

LOCA2		***NEX***	
95th Percentile	Observed Temperature > 296.22 K	95th Percentile	Observed Heat Index > 298 K
99th Percentile		99th Percentile	

The projected number of extreme heat events is then calculated by summing the number of heat event-days that exceed both the nth percentile and the heat index threshold.

The PAL is then calculated at the county level for each climate scenario using Equation 9. First the HM is produced by dividing the projected number of days by the historically observed number of days exceeding the nth percentile. Then the HM is used as a multiplier on the EAL sourced from the National Risk Index to calculate the PAL.

[25] Lu, Y., Romps, D.M.. (2022, October). *Extending the Heat Index*. https://romps.berkeley.edu/papers/pubdata/2020/heatindex/20heatindex.pdf

Equation 9: Extreme Heat PAL Calculations

$$PAL_{EXHT} = EAL_{EXHT} \times HM_{EXHT}$$

$$HM_{EXHT} = MAX(1, \frac{Projected\ \#\ of\ Days\ with\ Minimum\ Temperature\ over\ n^{th}\ Percentile}{Historical\ \#\ of\ Days\ with\ Minimum\ Temperature\ over\ n^{th}\ Percentile})$$

Where:

$EXHT$	stands for Extreme Heat
PAL_{EXHT}	is the Projected Annual Loss of a given county
EAL_{EXHT}	is the Extreme Heat EAL from the National Risk Index
HM_{EXHT}	is the Hazard Multiplier calculated for a given county

Figure 15 provides a visualization of the resulting PAL Ratings resulting from these calculations.

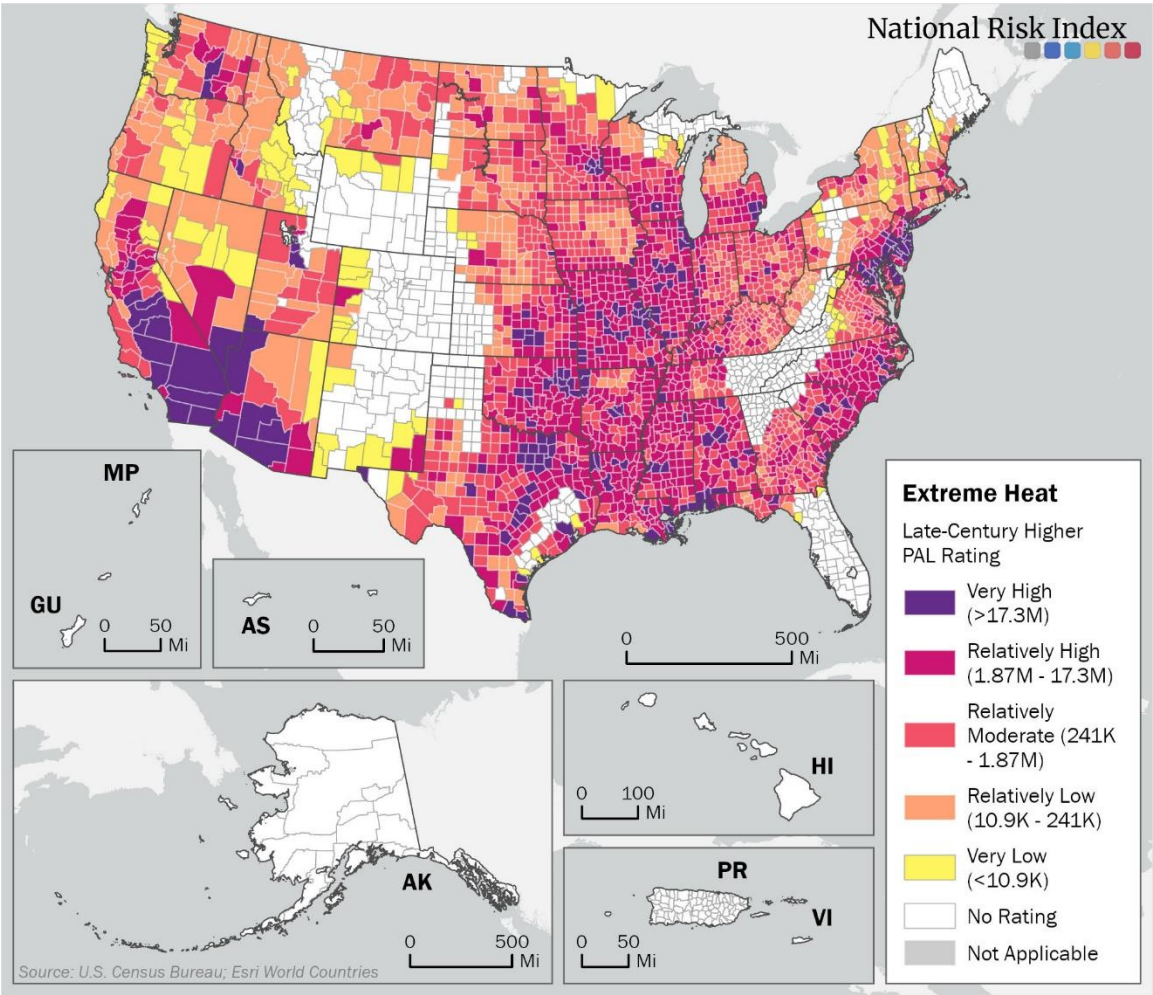

Figure 15: Late-Century Higher Mean Global Temperature PAL (LOCA 99th Percentile)

The PAL values are then used to calculate the Future Risk values for the Extreme Heat hazard type. These are also calculated at the county level for each climate scenario using Equation 10Equation 6. The PAL value is multiplied by the Community Risk Factor as a consequence modifier to determine the overall risk values.

Equation 10: Extreme Heat Projected Risk Calculations

$$Projected\ Risk_{EXHT} = PAL_{EXHT} \times Community\ Risk\ Factor$$

Where:

$Projected\ Risk_{EXHT}$	is the Projected Risk of a given county
PAL_{EXHT}	is the Projected Annual Loss of a given county
$Community\ Risk\ Factor$	is the function of Social Vulnerability and Community Resilience calculated in the National Risk Index

Note: No adjustments are made to Community Risk Factors.

Figure 16 provides a visualization of the resulting Projected Risk Ratings resulting from these calculations.

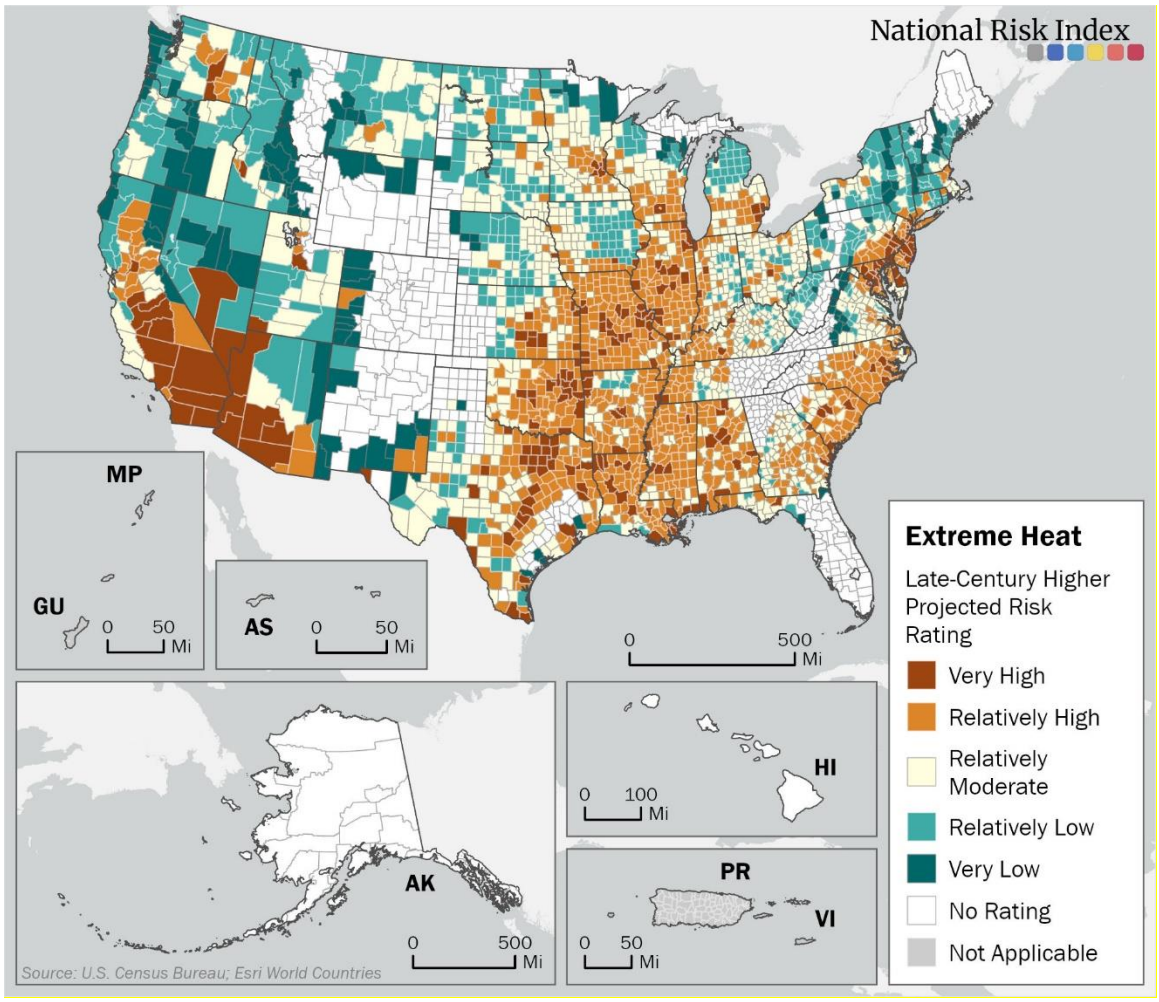

Figure 16: Late-Century Higher Mean Global Temperature Projected Risk (LOCA 99th Percentile)

7. Hurricane

A Hurricane is a tropical cyclone or localized, low-pressure weather system that has organized thunderstorms but no front (a boundary separating two air masses of different densities) and maximum sustained winds of at least 74 miles per hour (mph). The Hurricane hazard also includes data about tropical storms for which wind speeds range from 39 to 74 mph. Only wind-related damages are considered; storm surge is not included.

7.1. Spatial Source Data

Applied Research Associates: Climate Conditioned Landfall Rates

Using the hurricane windfield model in Hazus, Applied Research Associates ran a series of simulations to determine the potential impacts on hurricane tracks and frequencies under a series of climate scenarios. Variations in storm size and intensity can be simulated using variables like sea surface temperature, tropopause temperature and vertical wind shear. These variables were collected from various GCMs and simulated across the RCP 4.5 and 8.5 emissions scenarios for both mid and late centuries.

These data were then provided in the form of a .csv containing the simulated Category 1 through 5 Hurricane wind frequencies as they would appear in a windfield model. To obtain a copy of this report, please email FEMA-NRI@fema.dhs.gov.

7.1.1. AGGREGATION OF FUTURE RISK SCENARIOS

Applied Research Associates:

Several independent GCMs were used when simulating future climatologies. In order to determine their accuracy, ARA evaluated the GCMs against a simulation ran using historical data. Individual runs of the simulations were weighted and aggregated for the years 2050 and 2100 under both RCPs 4.5 and 8.5.

7.2. Spatial Processing

Hurricane sub-type frequencies are provided as coordinate pairs. These points are then overlaid against National Risk Index county polygons in order to merge the point-level records with National Risk Index county data. The merge is run with a 1-km buffer to account for smaller counties that did not intersect any ARA points. All points within this 1-km buffer are then averaged to determine that specific county's hurricane sub-type frequencies.

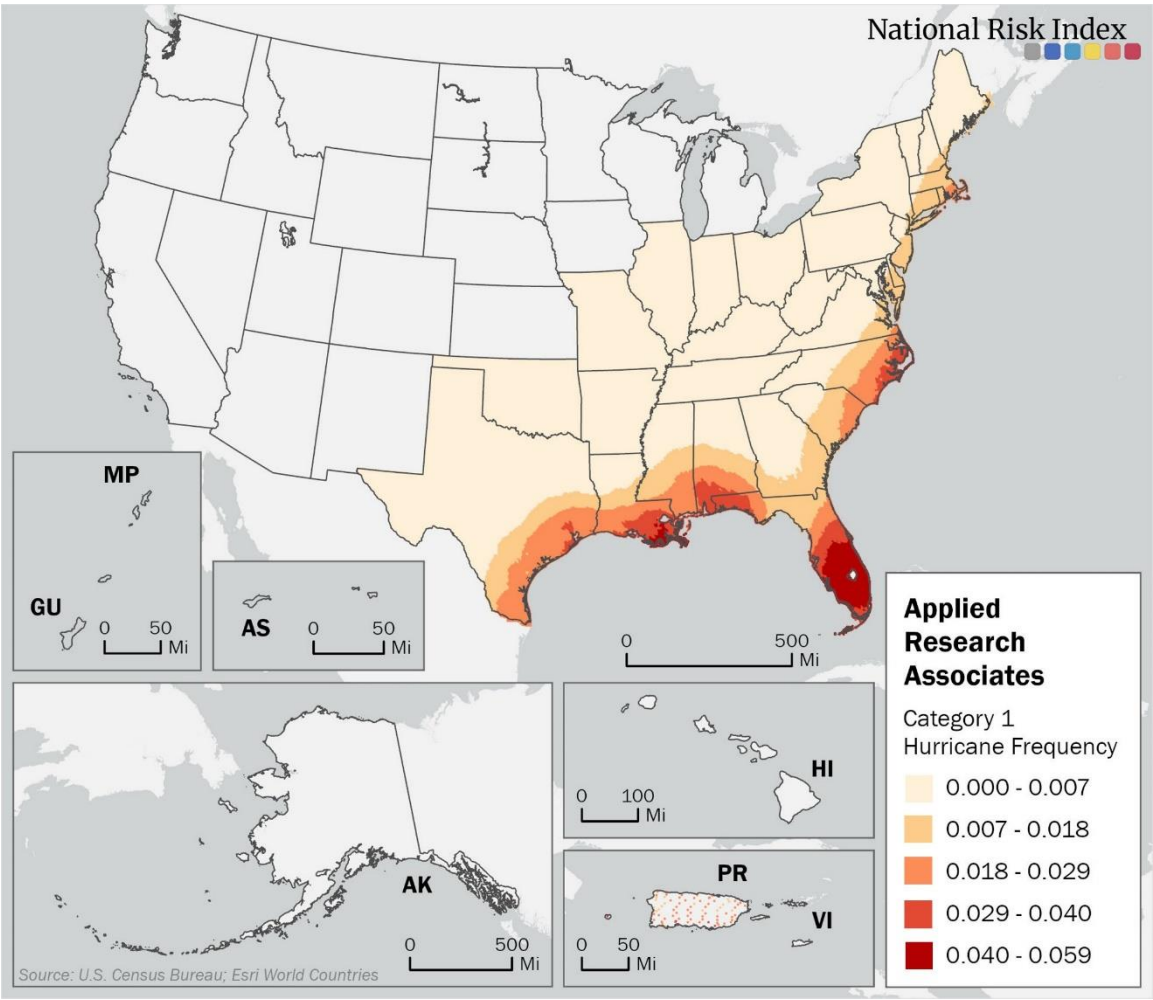

Figure 17: ARA Record Coverage (Category 1 Hurricane Late-Century Higher Mean Global Temperature)

7.3. Projected Annual Loss

Since the National Risk Index does not calculate hurricane event frequency at the sub-type level, sub-type frequencies from ARA needed to be combined to provide a relevant adjustment factor. For this reason, an intensity formula was developed (Equation 11), which weights each hurricane sub-type and combines them into a single value. The intensity formula weighs each sub-type type twice as much as the one before it. This weighting scheme reflects the relative impact hurricane categories have on the level of losses experienced. A Category five hurricane, although rare, would contribute far more to experienced losses than a Category one hurricane. The correlation between county intensity values and National Risk Index loss rates were compared between several different intensity calculations, including a control where all hurricane sub-types were weighted equally, and another where each sub-type type was progressively weighted with for each ascent in Category. Of the various intensity calculation weighting methods, the method that doubled the intensity from one Category to the next outperformed the alternatives with the correlation attributed to the doubling method at .815 with a p-value of $<2.2e^{-16}$.

For more information on National Risk Index Loss Rates see 5.4.4. HLR Methodology of the National Risk Index Technical Documentation.

Equation 11: Hurricane Intensity Calculation

$$Intensity = (Freq_{HRCN_{CAT1}} \times 1) + (Freq_{HRCN_{CAT2}} \times 2) + (Freq_{HRCN_{CAT3}} \times 4) + (Freq_{HRCN_{CAT4}} \times 8) + (Freq_{HRCN_{CAT5}} \times 16)$$

Where:

$HRCN$	stands for Hurricane
$Freq_{HRCN_{CAT1}}$	is the frequency of a Category 1 Hurricane
$Freq_{HRCN_{CAT2}}$	is the frequency of a Category 2 Hurricane
$Freq_{HRCN_{CAT3}}$	is the frequency of a Category 3 Hurricane
$Freq_{HRCN_{CAT4}}$	is the frequency of a Category 4 Hurricane
$Freq_{HRCN_{CAT5}}$	is the frequency of a Category 5 Hurricane

The HM is calculated using historical and projected intensities to determine the climatological impacts on hurricane event frequency and losses.

PAL values for the Hurricane hazard type are calculated at the county level for each climate scenario using Equation 12.

Equation 12: Hurricane PAL Calculations

$$PAL_{HRCN} = EAL_{HRCN} \times HM_{HRCN}$$

$$where\ HM_{HRCN} = MAX(1, \frac{Projected\ Intensity}{Historical\ Intensity})$$

Where:

PAL_{HRCN}	is the Projected Annual Loss of a given county
EAL_{HRCN}	is the Hurricane EAL from the National Risk Index
HM_{HRCN}	is the Hazard Multiplier calculated for a given county

Figure 18 provides a visualization of the resulting PAL Ratings resulting from these calculations.

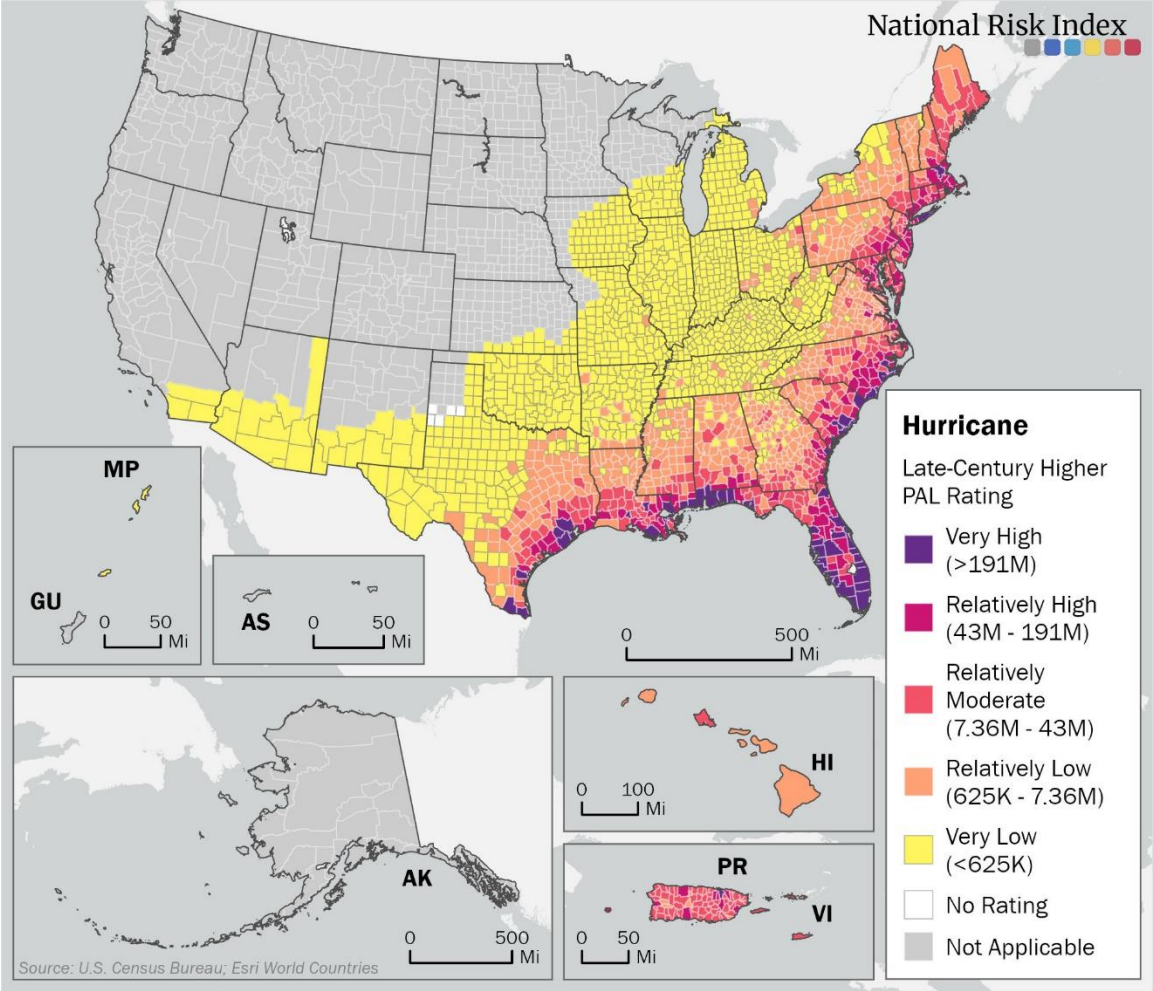

Figure 18: Late-Century Higher Mean Global Temperature PAL

The PAL values are then used to calculate the Projected Risk values for the Hurricane hazard type. These are also calculated at the county level for each climate scenario using Equation 13. The PAL value is multiplied by the Community Risk Factor as a consequence modifier to determine the overall risk values.

Equation 13: Hurricane Projected Risk Calculations

$$Projected\ Risk_{HRCN} = PAL_{HRCN} \times Community\ Risk\ Factor$$

$$where\ Community\ Risk\ Factor = f\left(\frac{Social\ Vulnerability}{Community\ Resilience}\right)$$

Where:

$Projected\ Risk_{HRCN}$ is the Projected Risk of a given county

PAL_{HRCN}	is the Projected Annual Loss of a given county
Community Risk Factor	is the function of Social Vulnerability and Community Resilience calculated in the National Risk Index

Note: No adjustments are made to Community Risk Factors.

Figure 19 provides a visualization of the resulting Projected Risk Ratings resulting from these calculations.

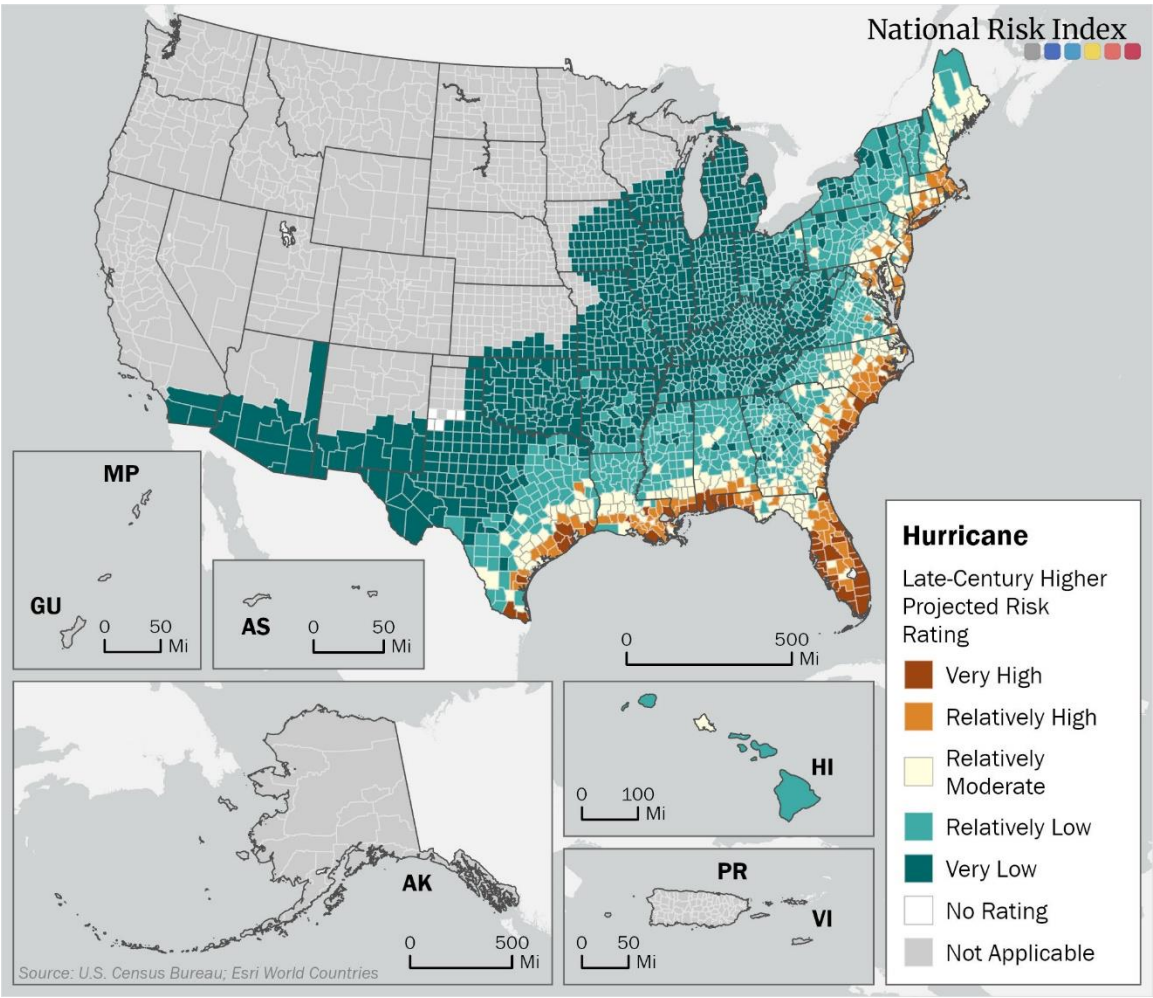

Figure 19: Late-Century Higher Mean Global Temperature Projected Risk

8. Wildfire

A Wildfire is an unplanned fire burning in natural or wildland areas, such as forest, shrub lands, grasslands, or prairies.

8.1. Spatial Source Data

NASA Earth Exchange: GDDP-IMPACT Data Portal (nasa.gov)

NEX provides a repository of statistically downscaled CMIP6 projections reflecting a wide array of variables. Among these is the Fire Weather Index (FWI)[26] which acts as a predictor of a given county's risk to fire weather events. In particular, this dataset uses the Canadian Forest Fire Weather Index System (CFWIS) framework which considers the effects of fuel moisture and wind on fire behavior and spread. The CFWIS is presented as a numeric rating of fire intensity with higher values representing higher levels of fire weather intensity.[27] The particular model used is a MME which averages several distinct downscaled results.

40 Scott and Burgan Fire Behavior Fuel Models (FBFM40): 40 Scott and Burgan Fire Behavior Fuel Models | LandFire

The FBFM40 is a publicly available dataset provided by LANDFIRE, a jointly managed project by the USDA Forest Service and the US Department of the Interior. This dataset is provided in a raster geospatial data format. Each raster cell within the dataset has a spatial resolution of 30 meters, and the cell values represent the specific fire behavior fuel model that corresponds to that location. These fuel models are numerical codes that indicate the type of fuel, its distribution, and other characteristics essential for modeling fire behavior and facilitating strategic wildfire management and mitigation.

8.1.1. AGGREGATION OF FUTURE RISK SCENARIOS

NASA Earth Exchange:

NEX presents a Multi-Model Ensemble leveraging multiple CMIP6 models spanning the period of 1950-2100. These data were provided at a 30 arcsecond resolution under both SSPs 2-4.5 and 5-8.5. These data were aggregated using yearly projections over 30-year periods across three timeframes, including;

- Historical – aggregated over the years 1976-2005

[26] Touma, D. & National Center for Atmospheric Research Staff. (2023, August). The Climate Data Guide: Canadian Forest Fire Weather Index (FWI). https://climatedataguide.ucar.edu/climate-data/canadian-forest-fire-weather-index-fwi

[27] Natural Resources Canada. (n.d). *Fire Weather Maps*. https://cwfis.cfs.nrcan.gc.ca/maps/fw?type=fwi

- Mid-Century – aggregated over the years 2036-2065
- Late-Century – aggregated over the years 2070-2099

For more information about how NEX produced its result please see NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) | NASA Center for Climate Simulation

8.2. Spatial Processing

Area-weighted average FWI values are calculated for each Census block by intersecting the NEX FWI 25km raster layer with Census block polygon features. FWI values at higher geographic levels (i.e., County and Census tract) are also calculated using an area-weighted average of their underlying Census blocks. To determine the intersections of the NEX FWI raster cells with Census blocks, the raster formatted data are converted to a vector format (i.e., polygons).

The area of a Census block containing the various fuel types reported in the FBFM40 is calculated by intersecting their raster cells with Census block polygon features. To determine the intersections of the raster cells with Census blocks, a custom raster-vector intersect tool was developed that allowed for the direct intersection of the high-resolution FBFM40 raster layer with each Census block. The tool uses the attributes of the raster cell to directly calculate the proportion of each value within each Census block.

8.3. Projected Annual Loss

The HM for Wildfire is calculated across communities for each future climate scenario using Equation 14 below.

Equation 14: Census Block-level Wildfire HM

$$HM_{WFIR_{Scenario}} = \left(\frac{FWI_{Scenario}}{FWI_{Historic}}\right)^{\gamma}$$

Where:

$HM_{WFIR_{Scenario}}$	is the HM for Wildfire associated with a particular future climate scenario of a specific county.
$FWI_{Scenario}$	is the county's FWI value associated with the future climate scenario.
$FWI_{Historic}$	is the county's historic FWI value.
γ	is the FWI elasticity of EAL coefficient.

The ratio in Equation 14 above reports the FWI value associated with a future climate scenario as a proportion of its historic FWI value. The coefficient gamma (γ) is a constant term (greater than 1) that

captures the responsiveness of EAL to a proportional change in FWI. This coefficient is derived from a log-log linear regression of National Risk Index v1.19 County total EAL values from the lower 48 US States on historic FWI values with spatial fixed effects and the proportion of each fuel type present within each census block included as additional control variables. The value for gamma is obtained from the regression coefficient associated with historic FWI values using maximum likelihood estimation.

The PAL is then calculated at the Census block level for each scenario using Equation 15. The HM calculated in the previous equation is used as a multiplier on the EAL sourced from the National Risk Index to calculate the PAL.

Equation 15: Wildfire PAL Calculations

$$PAL_{WFIR} = EAL_{WFIR} \times HM_{WFIR}$$

Where:

$WFIR$	stands for Wildfire
PAL_{WFIR}	is the Projected Annual Loss of a given county
EAL_{WFIR}	is the Wildfire EAL from the National Risk Index
HM_{WFIR}	is the Hazard Multiplier calculated for a given county associated with a particular future climate scenario of the county

Figure 20 provides a visualization of the resulting PAL Ratings resulting from these calculations.

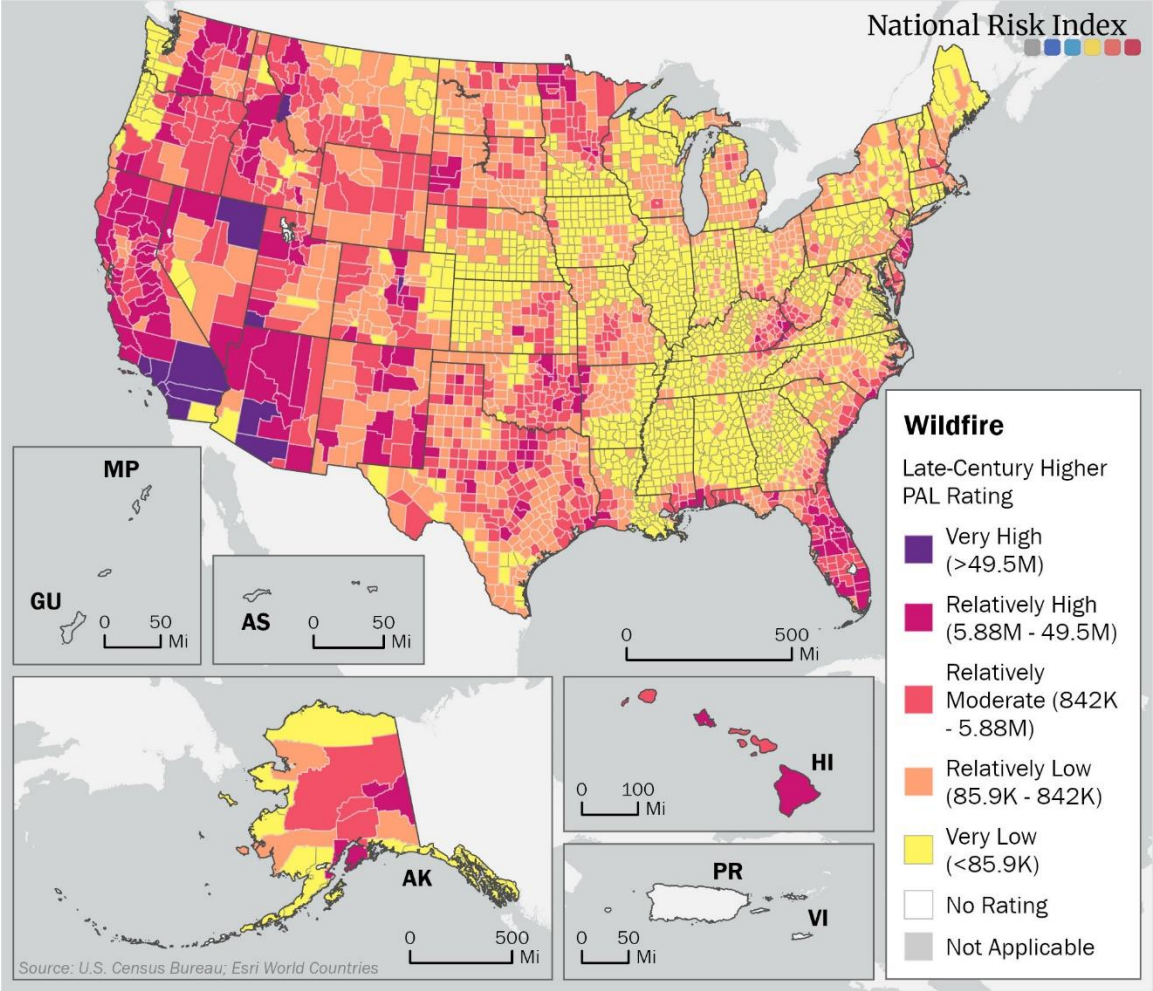

Figure 20: Late-Century Higher Mean Global Temperature PAL

The PAL values are then used to calculate the Projected Risk values for the Wildfire hazard type. These are also calculated at the Census block level for each climate scenario using Equation 16. The PAL value is multiplied by the Community Risk Factor as a consequence modifier to determine the overall risk values.

Equation 16: Wildfire Projected Risk Calculations

$$Projected\ Risk_{WFIR} = PAL_{WFIR} \times Community\ Risk\ Factor$$

$$where\ Community\ Risk\ Factor = f(\frac{Social\ Vulnerability}{Community\ Resilience})$$

Where:

$Projected\ Risk_{WFIR}$ is the Projected Risk of a given county

PAL_{WFIR}	is the Projected Annual Loss of a given county
Community Risk Factor	is the function of Social Vulnerability and Community Resilience calculated in the National Risk Index

Note: No adjustments are made to Community Risk Factors.

Figure 21 provides a visualization of the resulting Projected Risk Ratings resulting from these calculations.

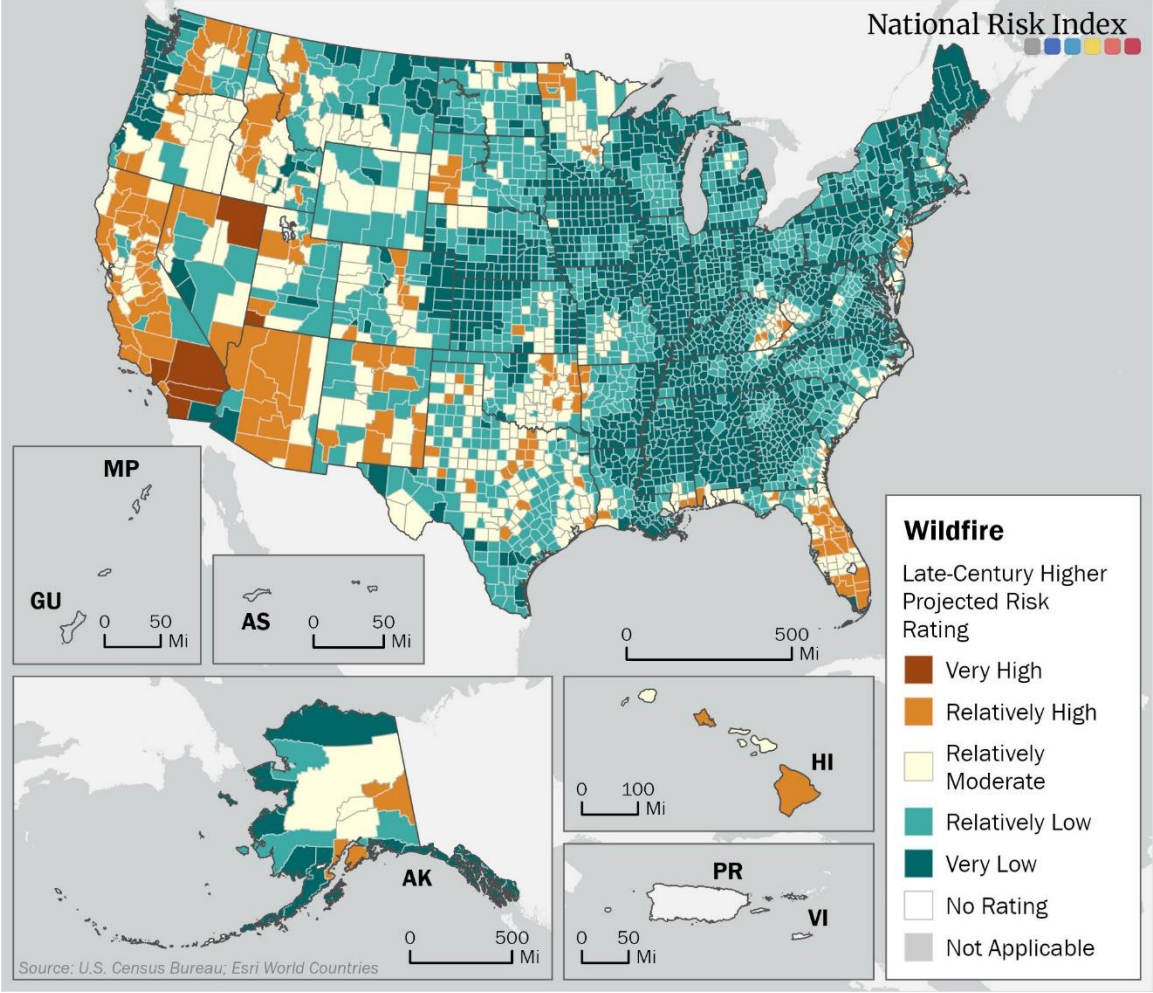

Figure 21: Late-Century Higher Mean Global Temperature Projected Risk

Appendix A – Contributors

Multiple entities contributed to the development of the Climate-Informed Risk Index by providing domain expertise and/or data.

Contributor	*Description*	*Expertise / Source Data*
ARA	Applied Research Associates, Inc. (ARA) is globally recognized for applying technically excellent, in-depth and diversified research, engineering, and technical support services to provide answers to complex and challenging problems in the physical sciences.	Provided Expertise and Data for Hurricane
Compass Identify, Interpret, Integrate	Compass PTS is a joint venture that provides architectural and engineering technical services. It includes ABS Consulting, AECOM, and CDM Smith, Inc., as well as other companies who were not directly involved with the National Risk Index.	Natural Hazards; Determining Risk; Data and Methods; User Experience Research and Design; Software Development Expertise
DEPARTMENT OF DEFENSE · UNITED STATES OF AMERICA	The United States Department of Defense (DoD) is an executive branch department of the federal government of the United States charged with coordinating and supervising all agencies of the U.S. Government directly related to national security and the United States Armed Forces.	Provided Expertise on 2022 Sea Level Rise Technical Report
EPA	The Environmental Protection Agency protects people and the environment from significant health risks, sponsors and conducts research, and develops and enforces environmental regulations.	Provided Expertise on 2022 Sea Level Rise Technical Report
FACTOR	FACTOR, Inc. delivers essential expertise to clients enabling them to better manage the risks inherent in their operations. They apply advanced methodologies, technology, and data analysis to support risk-based decision making and create competitive advantage for their clients.	Data and Methods Expertise
U.S. DEPARTMENT OF HOMELAND SECURITY FEMA	The FEMA is a federal agency responsible for helping people before, during, and after disasters.	Provided Expertise on 2022 Sea Level Rise Technical Report

Contributor	*Description*	*Expertise / Source Data*
JPL Jet Propulsion Laboratory	JPL is a research and development lab federally funded by NASA and managed by Caltech.	NASA Resource Expertise
NASA	NEX is a collaborative supercomputing and data analytics platform that improves the availability of Earth science data from NASA missions and other sources, models, analysis tools and research results through a centralized environment that fosters knowledge sharing, collaboration, and innovation.	Provided Expertise on 2022 Sea Level Rise Technical Report Drought and Wildfire Source Data
National Oceanic and Atmospheric Administration NOAA U.S. Department of Commerce	The mission of the NHC of NOAA is to save lives, mitigate property loss, and improve economic efficiency by issuing the best watches, warning, forecasts, and analyses of hazardous tropical weather and by increasing understanding of these hazards.	Provided Expertise on 2022 Sea Level Rise Technical Report
	The USACE CRREL solves interdisciplinary, strategically important problems for the Corps of Engineers, Army, Department of Defense, and the nation. CRREL discovers, develops, and delivers advanced and applied science and engineering to complex environments, materials, and processes in all seasons and climates.	Provided Expertise on 2022 Sea Level Rise Technical Report
United States® Census Bureau	The U.S. Census Bureau is a principal agency of the U.S. Federal Statistical System, responsible for producing data about the American people and economy.	Data and Methods; Social Vulnerability Expertise
USGS science for a changing world	USGS is a federal agency that provides new scientific methods and tools to enable timely, relevant, and useful information about the Earth and its processes.	Provided Expertise on 2022 Sea Level Rise Technical Report