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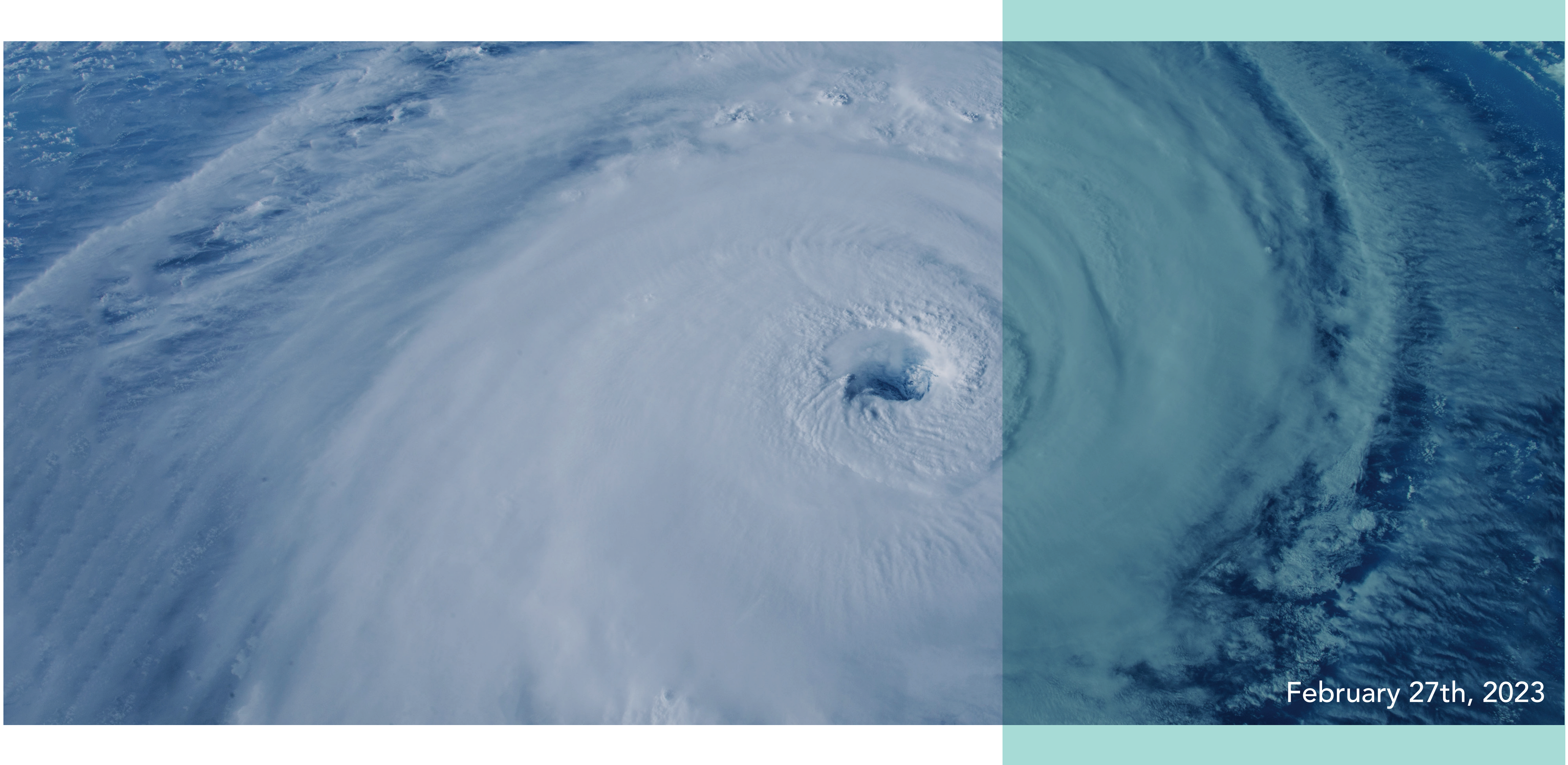

The 7th National Risk Assessment

Worsening Winds

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Disclaimers

First Street Foundation's hurricane wind and climate change risk estimates are based on one or more models designed to approximate risk and are not intended as precise estimates, or to be a comprehensive analysis of all possible hurricane wind-related and climate change risks.

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Without them, our analysis would not be possible.

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To estimate physical building damage and time needed to repair that damage (downtime days), the Foundation collaborated with Arup in order to leverage their expertise as a leader in the risk and resiliency engineering and planning space.

LIGHTBOX

To define building characteristics and property parcel details, the Foundation leveraged data from LightBox, a leading provider of CRE data and workflow solutions.

mapbox

To calculate wind exposure and incurred damage to the building structure, the Foundation leveraged building footprint data supplied by Mapbox. Mapbox also provided geocode lookups and map integrations for the Risk Factor experience.

State, Metropolitan Area, and County boundaries from the U.S. Census TIGER dataset is used on all pages showing maps. This report is not endorsed or certified by the Census Bureau.

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Abstract

Properties in the United States have increasing risk of tropical cyclone winds due to climate change. Driving this increasing risk are severe hurricanes that are more likely to occur when hurricanes form in the future, increasing the estimated damage to buildings and infrastructure. The First Street Foundation Wind Model (FSF-WM) combines open data, open science, and engineering expertise to create a new tropical cyclone wind model that assesses hyper-local climate wind risk across the Nation, and can inform actions to address that risk. The FSF-WM uses high resolution topography, computer modeled hurricane tracks, and property data to create tropical cyclone wind hazard information for the contiguous United States, allowing a detailed evaluation of probable wind speeds by return period, and a comparison of this wind risk between the current year and 30 years in the future. When coupled with archetype-specific damage curves developed with the global engineering firm Arup, property level losses are also estimated. This model reveals extensive risk along the Gulf and Southeast Atlantic Coasts, with significant growing risk in the Mid-Atlantic and Northeast regions of the country. Overall, in the next 30 years, the expected Average Annual Loss (AAL) resulting from this risk increases from $18.5 billion to $19.9 billion, and 13.4 million properties are likely to face tropical cyclone wind risk that do not currently face such risk. Most alarming is the economic risk in the state of Florida, where current levels of expected annual losses are already over 4 times the economic risk of the rest of the Gulf Coast, and account for approximately 73% of all expected damages nationally.

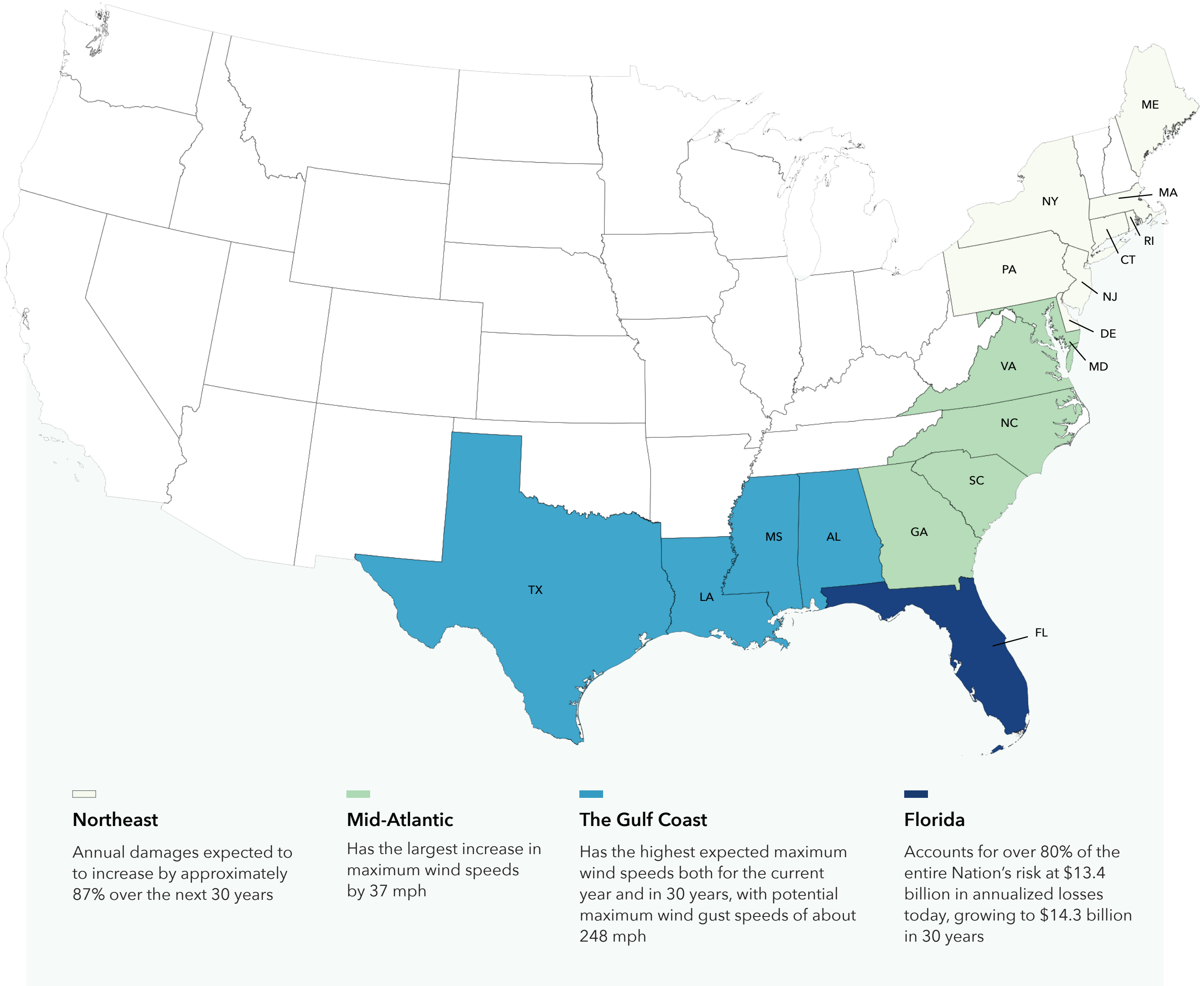

Figure 0. Regional highlights of climate-adjusted U.S. tropical cyclone wind risks from property-specific FSF-WM results.

Introduction

Physical property damage from tropical cyclones has been rising in the United States, and is expected to continue rising in the future (A. Smith et al., 2022). Winds from hurricanes and tropical storms can cause significant damage to property and infrastructure and pose a serious threat to human life. Hurricane winds span large areas, reach high speeds, and are accompanied by heavy rainfall which can cause destructive flooding. In addition, hurricanes can cause widespread power outages and disrupt essential services, such as water and gas supplies.

Notably, hurricanes affect communities within the United States more frequently and severely than other natural disasters (Cutter & Emrich, 2005). As a result, tropical cyclones have caused a total of $1.194 trillion (CPI adjusted) in losses in the United States between 1980 and 2022, with an average cost of approximately $21 billion per event. Additionally, the annual economic costs have increased each of the last four decades (A. Smith et al., 2022). Of the approximately $41-70 billion in losses due to Hurricane Ian in 2022, it is estimated that half of those damages ($23-35 billion) were due to wind damage (Core Logic, 2022).

Tropical storms and hurricanes are types of severe weather systems (tropical cyclones) that form over and gain their energy from warm ocean waters. By definition, tropical storms have sustained wind speeds of 39-73 mph, while hurricanes have wind speeds of 74 mph or higher (NOAA). The wind speed of tropical cyclones is used to classify these storms on the Saffir-Simpson scale, ranging from tropical storms to hurricanes, with Category 1 hurricanes being the weakest and Category 5 storms being the strongest. Tropical storms and hurricanes are both dangerous and destructive, and people in at-risk areas should prepare for potential impacts. While the total number of such storms is not expected to increase in the future due to a changing climate, the frequency of major hurricanes (Category 3-5) relative to the total number of hurricanes that form is expected to increase over time (Knutson et al., 2008).

Figure 1. Billion Dollar tropical cyclones Disasters (CPI Adjusted 2022 USD) services, such as water and gas supplies.

Said another way, the intensity of the hurricanes that develop in the future is expected to increase (see Figure 2). In the North Atlantic, the proportion of major hurricanes (Category 3, 4, and 5) has increased by 4 times since the 1980's, from about 10% of all tropical cyclone events to over 40% of all events today (Kossin et al., 2020). Driving this increase in intensity are rising air temperatures that increase the temperatures and heat content of the upper ocean waters which provide the energy that fuels these storms.

Other environmental changes, including increases of the amount of moisture in the atmosphere and alterations to large-scale wind patterns, also influence the intensity of hurricanes and where they are likely to move. A shift of storms poleward has already been observed in the global historical data and has been confirmed by modeling studies, which means that

Introduction

the probability of storms making landfall further north along the East Coast of the US is expected to increase (Kossin et al., 2014; also see Figure 3).

While tropical cyclone wind events are most common and severe along the Gulf Coast, they pose significant risk in many parts of the United States, particularly along the East Coast. Communities with greater awareness of their risk may take precautions, such as by imposing more stringent building codes which result in structures that better withstand high wind velocities. However, areas unaccustomed to these risks, or unaware of future increases in risk, may be unprepared for wind impacts. As the probability and severity of tropical cyclone activity increase in these areas, more people, property, infrastructure, and economic resources are exposed. Furthermore, since hurricanes that form in the future are more likely to be severe storms, the wind risk resulting from a landfalling hurricane will also extend further into the interior of the US (see Figure 4), as it will take longer for storms' wind speeds to decrease after the source of their energy – warm ocean waters – has been cut off at landfall.

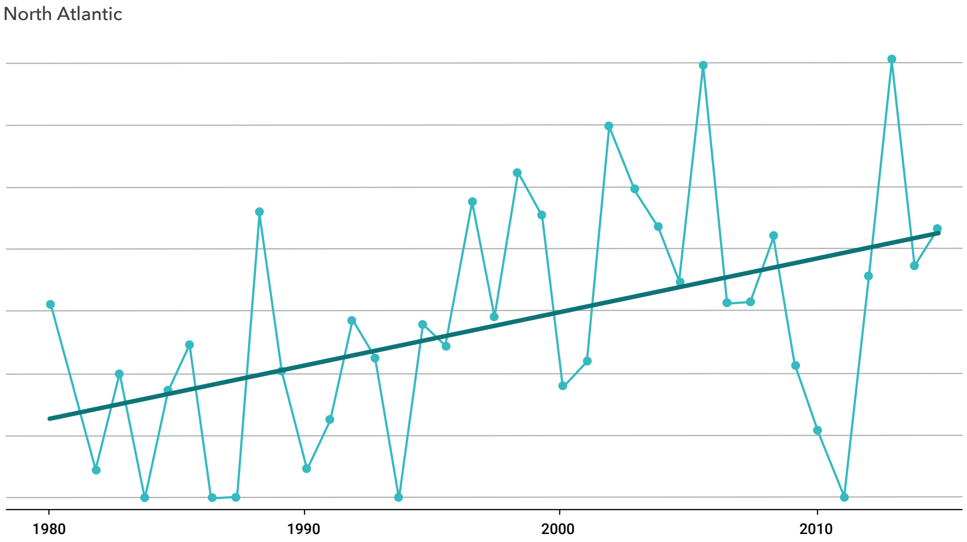

Figure 2. Proportion of Major Hurricane Locations and Intensity

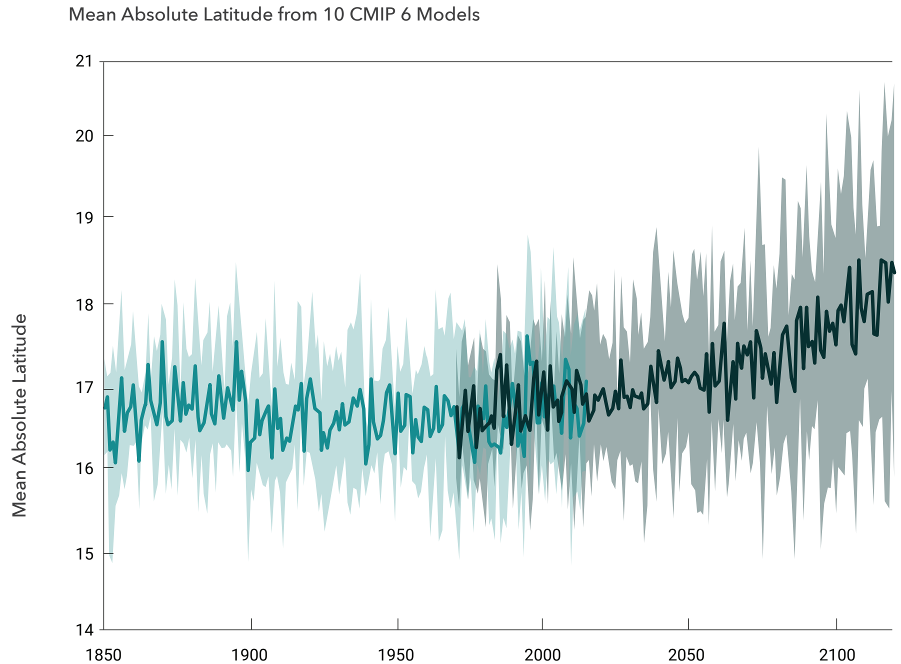

Figure 3. Mean absolute storm latitude from global modeled storms under historical conditions (green line) and future conditions (black line) from Dr. K. Emanuel (pers. comm, 2023)

Introduction

The Intergovernmental Panel on Climate Change (IPCC) presents a framework for understanding risk through the necessary components of hazard, exposure, and vulnerability (Reisinger et al., 2020). Using that framework, current and future exposure to wind from hurricanes and tropical storms is calculated in this report by using modeled tropical cyclone tracks to estimate wind speeds at a 10 km horizontal resolution for the contiguous United States, which are then combined with 30 meter resolution land cover information to apply surface roughness adjustments to those wind speeds to better understand property-level impacts. This approach is consistent with similar methodologies from previous First Street Foundation reports and peer reviewed research, applying parcel-level property information to the high-resolution hazard information provided by the First Street Foundation Wind Model (FSF-WM). The hazard information provided by the FSF-WM relies on information from approximately 50,000 synthetic hurricane tracks, created by computer models and based on historical storms, to enable robust statistical sampling

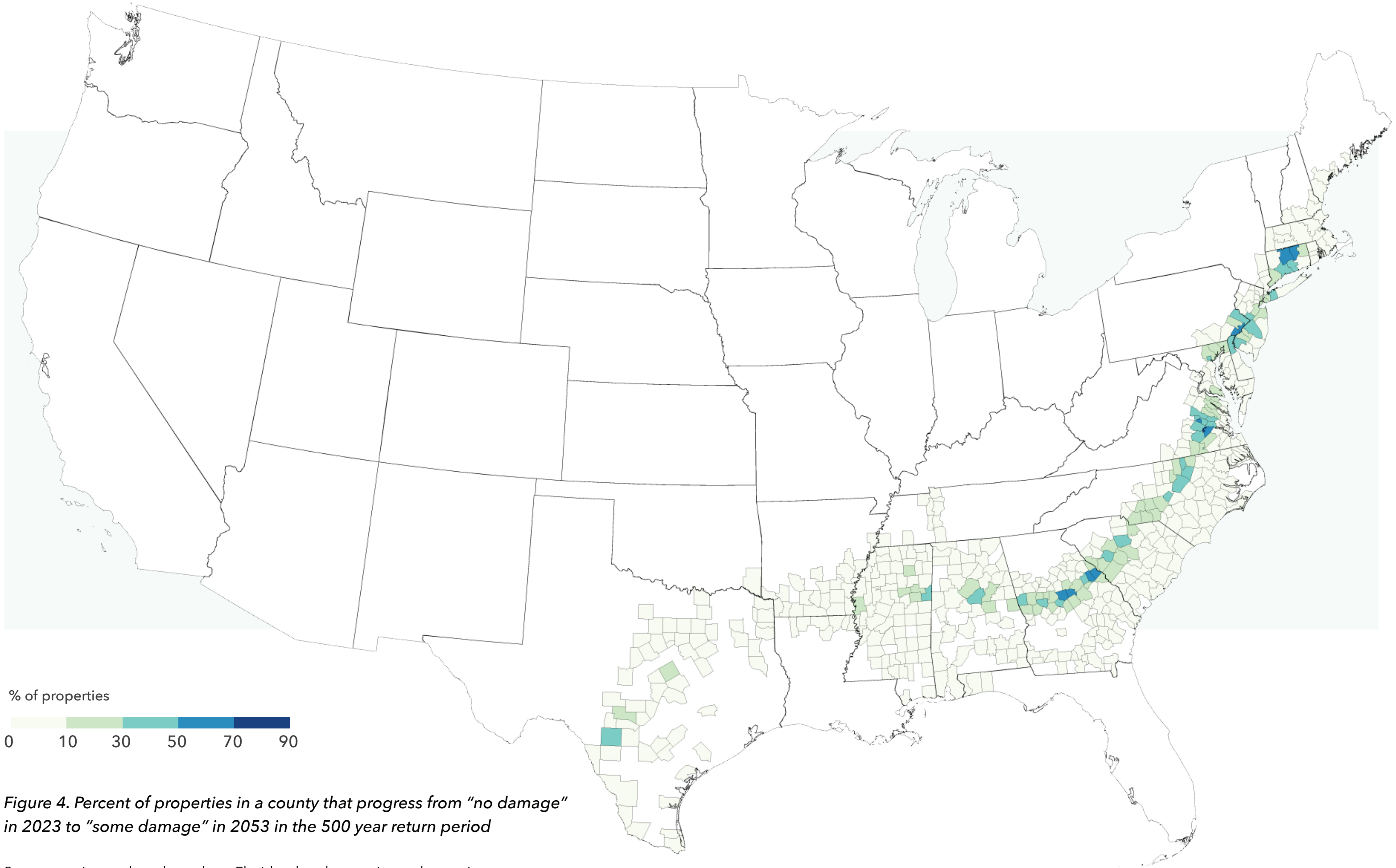

Figure 4. Percent of properties in a county that progress from "no damage" in 2023 to "some damage" in 2053 in the 500 year return period

Some counties, such as throughout Florida, already experience the maximum number of potentially damaged properties in the 500 year return period this year.

o hurricanes' characteristics (Emanuel et al., 2006). The tracks used here in the FSF-WM are consistent with the tracks used in the Foundation's Flood Model. These synthetic tracks These synthetic tracks and their concomitant wind fields are downscaled using surface roughness corrections at the 30 meter resolution, for multiple return periods, and are projected 30 years into the future using the World Climate Research Programme (WCRP) Climate Model Intercomparison Project 6 (CMIP6) climate models (WCRP).

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Much of the research into risks from hurricane wind, especially estimations of physical damage, relies on historical data rather than probabilistic models. However, the FSF-WM modeled hurricanes provide detailed and probabilistic hazard information to estimate how climate change has impacted risk today and into the future. For example, the hurricane risk models currently accepted by the [Florida Commission on Hurricane Loss Projection Methodology]() are based largely on historical patterns of hurricanes and do not explicitly incorporate the effects of climate change on their forecasted impacts for today ([FCHLPM, 2019]()). The difference between the two approaches is most pronounced when reviewing the historical landfall rate of Category 5 hurricanes, which are also the most destructive. When comparing historic Category 5 landfalls in Florida to the current likelihood of a Category 5 landfall from the FSF-WM, there is a 77% increase in the likelihood of this type of severe event taking place (Figure 5). While this difference is most pronounced for Category 5 hurricanes, note that the likelihood of all major hurricanes (Category 3-5) making landfall today in Florida is underpredicted when compared to the historical analysis.

A significant implication of this result is that the typical "catastrophe" risk models used today by Florida to estimate the overall exposure to hurricanes, to set the price of windstorm insurance policies, and to determine an adequate amount of reinsurance for the state windstorm insurance program are unable to resolve a significant portion of the risk, creating a dangerous gap in coverage. While this gap in risk estimation is apparent even for the current year, this gap continues to grow larger in the future with increasing climate change impacts. Without inclusion of climate change impacts explicitly in Florida's catastrophe modeling and risk analyses, the entire state risks significant financial vulnerability to a major hurricane striking any one of its many large metropolitan areas. Through inclusion of climate change in its future hurricane risk projections, Florida's windstorm insurance rates could be set to adequately cover current and emerging wind risk for the state and avoid an inevitable future financial calamity in its windstorm insurance market. The likelihood that a storm such as 2022's Category 4 Hurricane Ian could impact any location in Florida, and the probable damages that would result for any county or city in the state from such a storm, are quantifiable, predictable and are described in detail in this report and suggest that the premiums for households in the state need to increase along with the estimations used to procure reinsurance for the state.

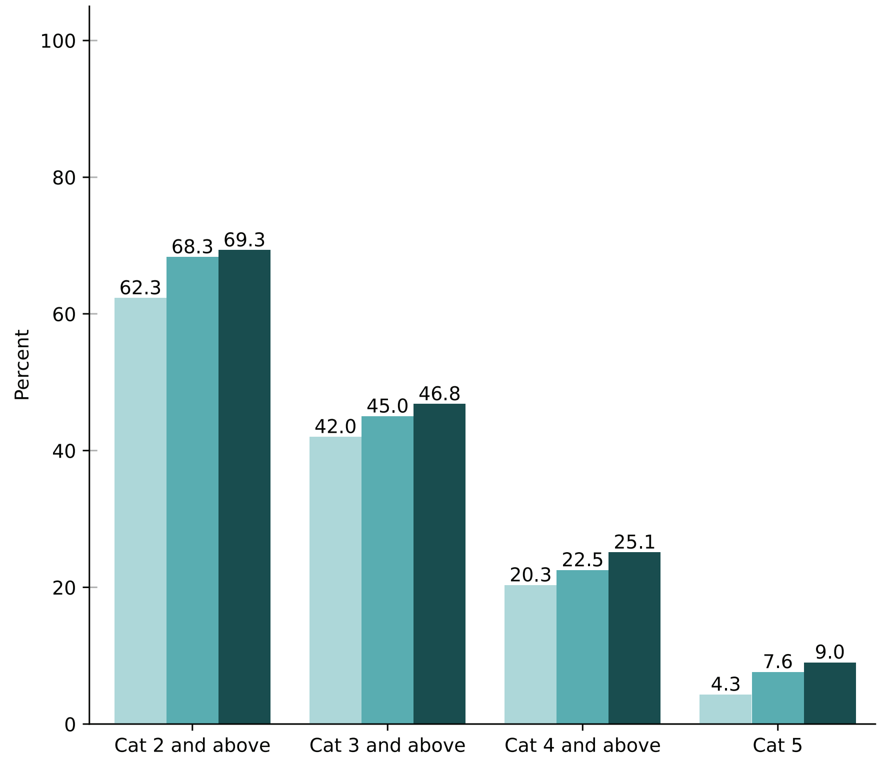


Figure 5. Fractional distribution of hurricanes' intensity at landfall in Florida from historical observations (light teal bars) and estimated from the FSF-WM in 2023 (medium teal) and 2053 (dark teal)

Introduction

The current understanding of the relationship between wind events and associated damage, especially over wide geographical areas, is restricted by data availability issues for property-level information. Some attempts to use satellite imagery have been effective on a large scale, but they are often inadequate in differentiating between building use types. Additionally, government databases are often limited to aggregate damages or to very specific property types such as public infrastructure alone. This lack of information clouds the relationship between tropical cyclones and damage from wind events at the property level, as hurricane wind can cause a wide range of damage to residential and commercial real estate. Since the most common types of wind damage include impacts to roofs, walls, and windows, accurate property-specific data and building use information is critical in assessing risk and likely damage from tropical cyclone winds.

The novel contributions of this report include:

- High Resolution Input Data: A national scale, high-resolution hurricane wind risk model is achieved through the input of high-resolution hazard and property data for the contiguous United States.
- Wind Hazard Information at Multiple Return Periods: A probabilistic approach to cyclone wind prediction allows for the evaluation of speeds and the probabilities of those speeds, allowing for a consistent analysis of wind risks across different locations and over time.
- Structure Archetype-Specific Damage Functions: First Street Foundation partnered with Arup to develop a total of 56 different structural archetypes with separately-developed damage functions, which are used with the high-resolution wind hazard data to understand property-level loss and downtime.
- Future Facing Risk: The FSF-WM allows for the analysis and comparison of risk now and 30 years into the future. The same hazard modeling approach for the current environment is employed in the development of future wind hazard layers, which may be evaluated against current property and vulnerability metrics to isolate the effect of a changing environment.

To understand how properties' exposure to and damage from tropical cyclones will be impacted by climate change, this report introduces the First Street Foundation Wind Model (FSF-WM). The FSF-WM is a probabilistic property-level risk model that estimates likely wind damages by exploring the vulnerability of structures to their exposure to tropical cyclone wind conditions at different return periods, and projecting changes in that exposure over the next 30 years. The First Street Foundation has partnered with Arup, a global consulting and engineering firm, to calculate how this exposure translates to property-specific impacts such as structural damages and downtime days.

The FSF-WM uses open science methodologies, open data provided by the federal government, and additional information and support provided by state and local governments to enable the creation of valuable new information products. This new wind model builds upon synthetic hurricane tracks created by Dr. Kerry Emanuel's Wind Risk Tech LLC, and is used to assess hyper-local climate wind risk across the nation that can inform possible actions to address that risk.

As with all of the climate hazard models developed by the First Street Foundation, these data are publicly available through the Risk Factor™ website to adhere to the Foundation's nonprofit mission of making climate risk accessible, easy to understand, and actionable for citizens, government, and industry. Property-level Wind Factor™ assessments are readily available by address search to help resolve the asymmetry in access to high-quality wind risk information in the United States. Most significantly, this hyper-local resolution allows for an extremely granular understanding of hurricane wind risk, empowering communities, states, and national government actors to take steps to address current and evolving risk.

Hazard Model Development

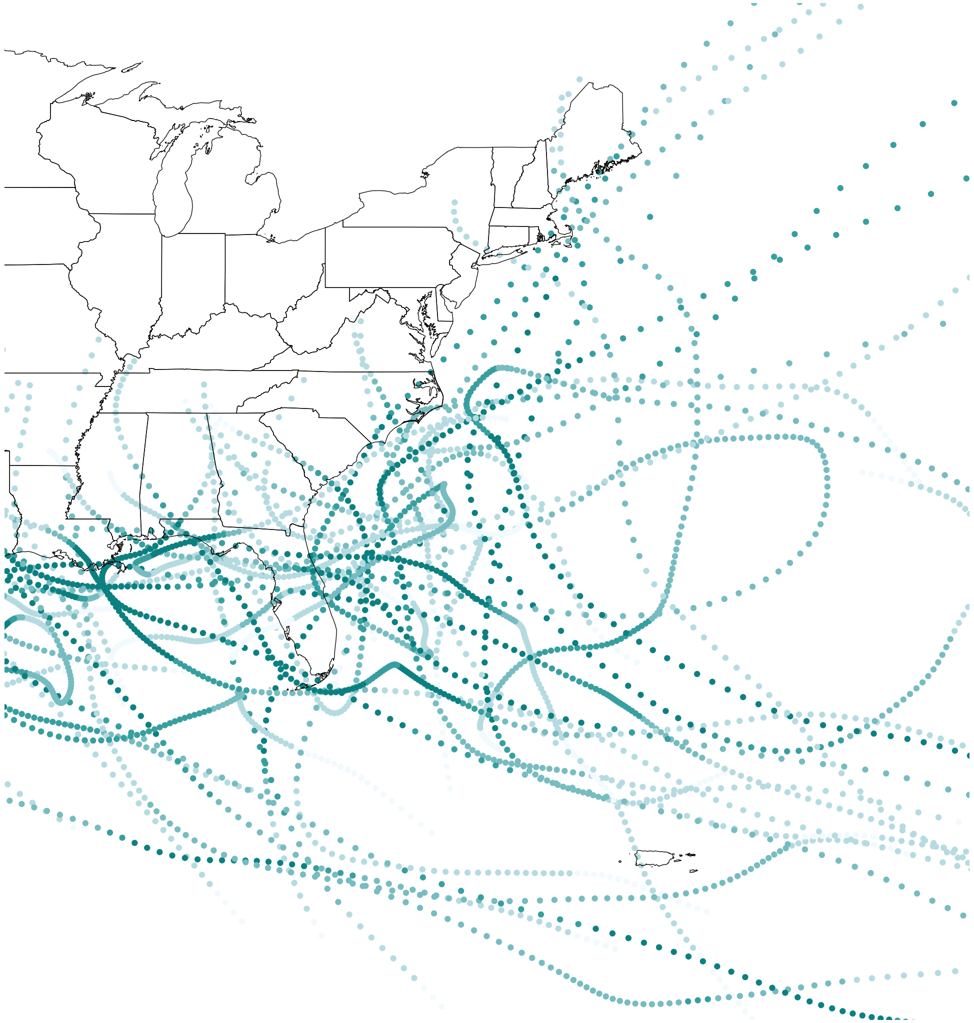


Figure 6. Sample of 50 hurricane tracks from Wind Risk Tech LLC's simulations from the Community Earth System Model 2 (CESM2), using data from SSP2-45, for the current time period (2015-2030).

Synthetic hurricane tracks are provided by Dr. Kerry Emanuel's Wind Risk Tech LLC and the Rhodium Group. The National Land Cover Database provided by the USGS is used in conjunction with Hazus surface roughness coefficients provided by FEMA and informed by American Society for Civil Engineers (ASCE) guidelines to estimate how hurricane winds change over smaller areas to understand property level tropical cyclone wind risk. Property level information is provided by Lightbox® and Mapbox®.

The FSF-WM uses over 50,000 synthetic hurricane tracks derived under current and future WCRP CMIP6 defined climatic conditions. The track generation process starts with a monthly representation of thermodynamic conditions for a given climate state, defined with sea surface temperature and daily winds. Tropical disturbances are then introduced randomly in space and time and are allowed to evolve under the model conditions. The tropical storm intensity is integrated along each track using an ocean-atmosphere model. During this process, most of the disturbances die off and are discarded; the remaining disturbances that amplify to at least tropical storm intensity then define the tropical cyclone climatology of the given model.

Tracks from seven different CMIP6 climate models under the Shared Socioeconomic Pathway 2 (SSP2-45) scenario were used in the FSF-WM. Consistent with other Risk Factor products, this middle-of-the-road future climate scenario aligns well with current environmental observations. For each of the seven climate models, 50 synthetic hurricane tracks per year that made landfall along the Gulf or Atlantic coastlines with at least tropical storm intensity were generated for both the current year and end of century scenarios. To more accurately characterize more intense but less frequent hurricanes, additional tracks were generated using a higher intensity threshold. An example subsample of a trackset is shown in Figure 6.

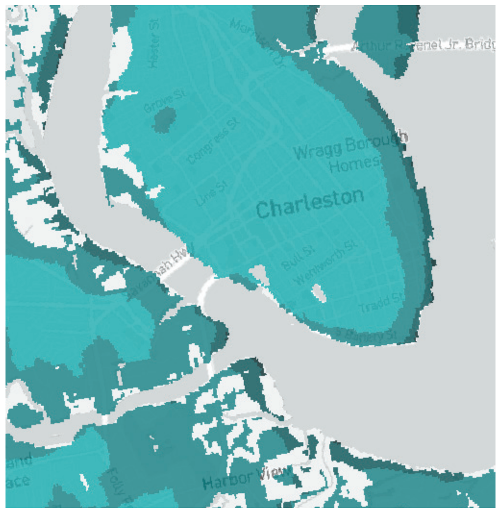
Hazard Model Development

Estimates of sustained 1-minute wind fields were then produced for each synthetic hurricane track on a 0.1 degree grid across their area of influence. These wind fields were derived for each track by fitting a radial profile of gradient wind, modified to account for storm translation and effects of environmental wind shear A boundary layer model, parameterized with surface drag coefficients, was then used to convert gradient wind speeds into estimated surface wind speeds. This process provides detailed information on wind speed and direction, which are then further processed to provide information on the frequencies of their occurrence.

To produce return period and annual exceedance frequency statistics, the FSF-WM used sampling tables from the Rhodium Group that simulate 1,000 synthetic time series for every year, each containing a list of storms that have been randomly selected according to the track frequency. For each synthetic time series, the maximum surface wind speed was extracted corresponding to specific tracks and generated frequency counts in 10 mph bins from 0 mph to 260 mph. These were then converted to annual exceedance probabilities. These 10 mph binned values were interpolated to provide information on the wind speeds corresponding to specific return periods.

The synthetic hurricanes do not account for the hyper-local effects of surface land characteristics on wind speeds. Very rough areas, such as suburban or heavily forested areas, can disrupt and decrease wind speeds, while some types of variations in topography can increase wind speeds. Therefore, a surface roughness correction was implemented for the hurricane wind field model output (1-minute sustained wind speeds and direction) with local terrain data. Surface roughness information is used at a 30 meter resolution, derived from coefficients from the FEMA Hazus toolkit and segmented by USGS land cover classifications. To model the potential effects of surrounding terrain on wind speeds, a circular moving average was calculated to represent the ground surface roughness around any given structure. Moving averages in 45 degree windows were derived to account for how wind speeds may vary depending on the direction of approach. Exposure categories from ASCE guidelines for wind loads on building exposures were used to determine the appropriate averaging radius. Roughness values were extracted at the building level using parcel data from Lightbox® and building footprint information from Mapbox®. Using the wind direction information from the hurricane wind field model, each building was assigned a weighted average of the unique surface roughness coefficients in each of the eight directions using weights equal to the percentage of hurricane force winds from each direction.

The adjusted wind speeds resulting from the model outputs are provided as 1-minute sustained speeds, which are used in determining hurricane storm categories. To provide additional information from the model for damage estimates, these 1-minute sustained winds are converted into a 3-second gust estimate, consistent with the ASCE standard. The gust conversion factor used for converting winds from 60 seconds to 3 seconds is (estimated *gust = 1.28 X sustained wind speed*), derived from curves in Vickery & Skerlj (2005) that describe neutral flow conditions in the lower portion of the hurricane boundary layer. These 3-second gusts are faster speeds that are expected from small-scale effects over a short period of time, which inflict the highest wind stress on properties, and thus are useful for estimating property-level impacts when paired with damage functions. The development and application of these damage functions were done in partnership with Arup, and are described below.

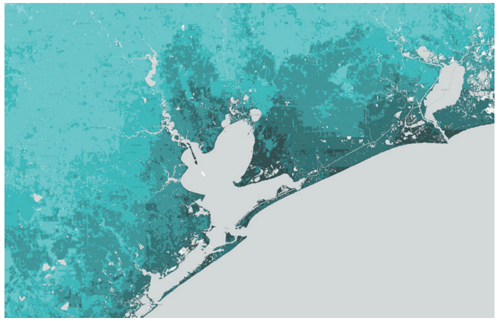


Charleston, South Carolina, 2023 - RP 3000

Damage Model Development

To understand the potential damages from wind for structures on US properties, First Street Foundation partnered with the global engineering firm Arup. Arup simulated the impact of hundreds of different hurricane scenarios using a virtual model of the building to estimate the extent and severity of hurricane damage on individual building components. This physical impact is then translated to economic consequences such as financial loss and downtime. Following this risk modeling approach, a series of curves reflecting downtime and financial loss from wind events were developed for a suite of different building archetypes.

A set of 30 non-residential and 26 residential archetypes were developed and assessed, considering key building characteristics such as: building occupancy (e.g., industrial, commercial, residential), number of stories, roof material (concrete or non-concrete), missile environment (high or low), and design wind speed zone (the area's wind speed standards for building design, which determines the envelope for component wind resistance). These critical building characteristics affect both building performance during damaging wind events as well as the associated financial loss and downtime (FEMA, 2000), and are available through First Street Foundation's building characteristics data.



Houston, Texas, 2023 - RP 500

Damage simulation

The risk modeling approach simulates the impact of wind scenarios using a virtual model of the building (populated with typical building components within the archetype definition) to estimate the extent and severity of wind damage on individual building components. During an actual wind event, how a given building component is impacted depends on several factors including its location, orientation, interaction with other components, and its wind resisting capacity. These complexities were captured by creating a 3D physical based simulation model representative of each building archetype.

3D wind damage simulation model: For each building archetype, and for each wind event simulated, the pressure load on each individual component was calculated based on the wind direction, component geometry, location, and other characteristics. The pressure load on each component was compared with the wind resistance to determine the likelihood of failure of a component. This process was conducted for each component separately for each archetype. For all archetypes other than single family residential buildings, possible exterior components include windows, doors, roller doors, roof cover, roof deck, roof joist, wall panels, rooftop equipment, and ground equipment. For single-family house archetypes, possible building exterior components include windows, doors, garage doors, roof cover, roof sheathing, trusses, and wall panels. Not all components were included in the model for every archetype.

Wind pressure calculation: The wind pressure is calculated based on the wind gust speed, wind direction and the wind pressure coefficients. The external pressure coefficients are a function of the location of the component and the direction of the wind. The corresponding pressure coefficients, derived from past wind tunnel tests, were selected for the calculation.

Wind resisting capacity: The wind resisting capacity for each failure mechanism for each component is explicitly assigned for each archetype. For non-single-family archetypes, it is assumed that the components are designed to fulfill building code requirements based on the design wind speed, and the capacity of each component was calculated accordingly. For single family archetypes, the component capacities are determined based on available literature data (FEMA, 2000; FLPHM, 2015). The capacity is also updated dynamically through the simulation; for example, when a given connection fails, the capacity will be reduced for the adjacent component.

Damage Model Development

Pluvial (rain) intrusion damage: During a hurricane event, pluvial intrusion could occur through damaged exterior components. Using estimations of rainfall amounts related to various hurricane scenarios, the amount of rain entering each floor is explicitly calculated based on the breach area of the roof and side of the building. The interior damage percentage was estimated based on the likely water depth resulting from the breach.

Treatment of uncertainty: To explicitly capture the uncertainty involved in the simulation process, the damage simulation for each wind event was repeated 500 times within a Monte Carlo simulation to create the median and variability of the estimated damages.

Consequence Assessment

Each building archetype was subjected to wind speeds ranging from 30 mph to 200 mph in 10 mph increments and eight different wind directions. The simulated wind speeds are capped at 200 mph as losses at that speed are typically equivalent to complete destruction. For each wind speed and direction, 500 Monte Carlo simulations were run. From the damage estimate results, the likely number of units for each component needing to be repaired or replaced were obtained. This information was used for the financial loss and downtime calculations. Arup also developed consequence functions that link the specific level of damage for components to specific levels of financial loss and lengths of repair times.

Financial loss values, indicating the cost to repair or replace a component, were based on data procured by Arup's cost estimators, and then adjusted for cost by metro area. To get accurate financial loss estimates for other regions, First Street Foundation scales the financial losses using regional price parity data from the Bureau of Economic Analysis. Based on the level of damage, the total building financial loss was calculated for each realization as a sum across all damaged components.

Cape Coral, Florida, 2023 - RP 3000

Damage Model Development

The downtime calculation followed the [REDi methodology], which is adapted for wind by Arup. Downtime estimates consist of repair times for damaged components and impeding factors (such as time for returning from evacuation, building restoration, contractor and engineer mobilization, and equipment supply long lead times) that delay the initiation of building repairs. Following the resolution of the delays, the downtime model allocates crews of workers to make repairs to damaged components based on specific trades. A construction of realistic repair sequences that mimic actual contractor logistics is aggregated to quantify the overall building downtime.

Once the downtime and financial loss had been calculated for each realization for each wind speed and wind direction, a set of loss curves (financial loss in 2022 USD vs. wind speed, downtime in days vs. wind speed) for all archetypes were calculated (see Figure 7 for examples).

Losses are computed for the 3-second gust speeds from the FSF-WM outputs after accounting for local surface roughness and gust conversion in each of the eight compass directions, and then weighted according to the distribution of hurricane-strength wind directions as predicted in the FSF-WM model. The property information in this report is provided by Lightbox®, which provides high-resolution data on property use-types and other building characteristics. Machine learning techniques impute any missing values so that estimated risk may be calculated at the property level.

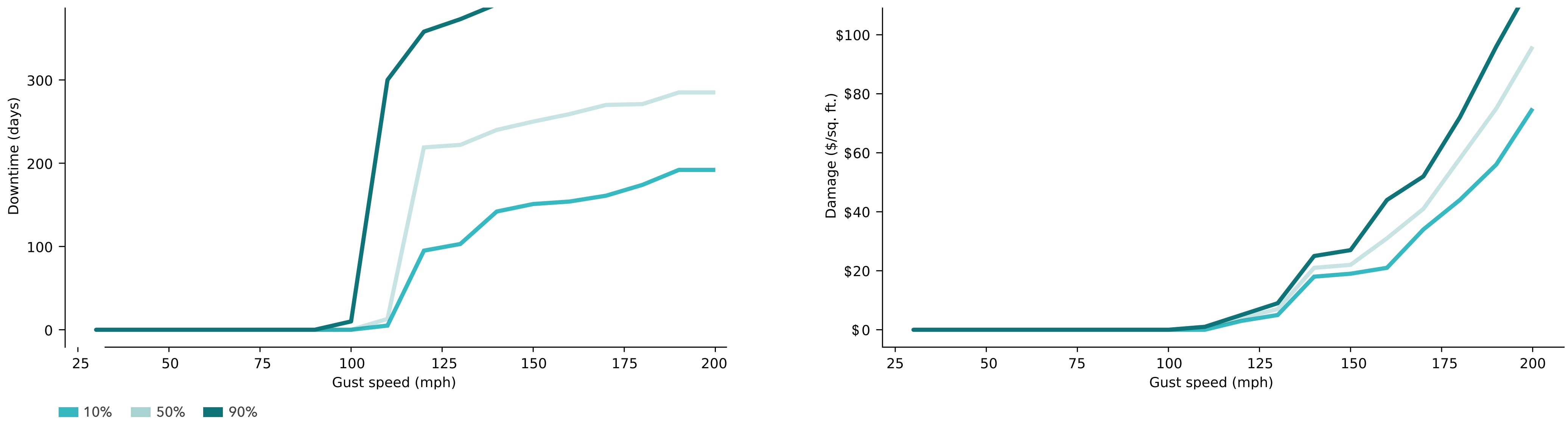
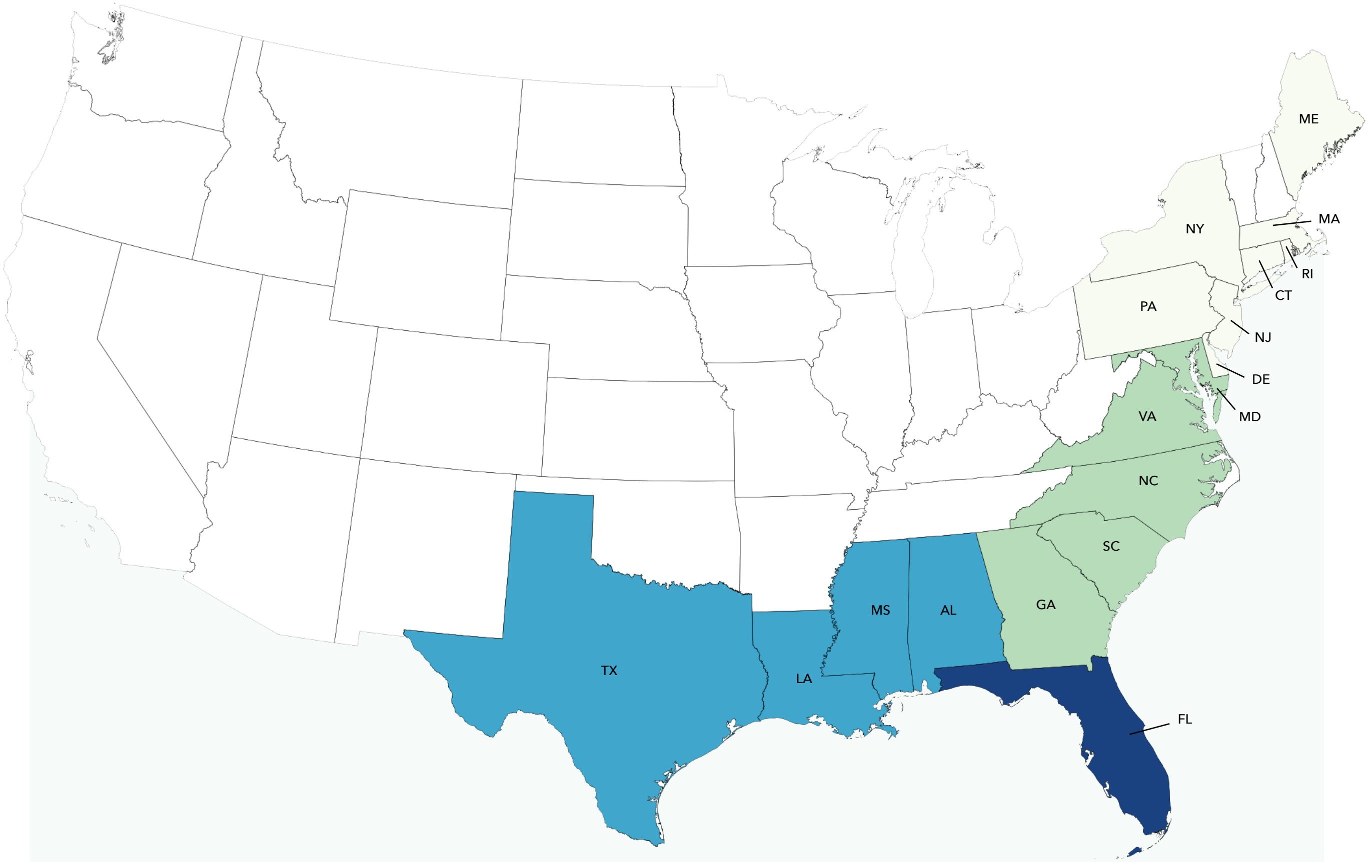


Figure 7. Exemplary loss curves for a 1-story commercial building with a non-concrete roof in a high wind zone, high missile environment for the 10th, 50th, and 90th percentile losses. Loss from rain damage from likely building breaches included. Left: downtime curve in days. Right: financial loss curve in 2022 USD.

Results

Overview of national patterns

In the contiguous United States, the Gulf and East Coasts face the highest probabilities of tropical cyclone winds that can cause significant damage to properties and infrastructure. Over the next 30 years, the tropical cyclones which develop are more likely to become major hurricanes, with greater intensities, and therefore their effects will reach further inland. While wind exposure and damages are most significant along the coast, they are likely to increase inland drastically in many places that have never before been exposed. Additionally, over the next 30 years, tropical cyclones will push further northward before making landfall. Overall, in the next 30 years, Average Annual Loss will increase from $18.5 billion to $19.9 billion, and 13.4 million properties will face tropical cyclone level wind risk that do not currently face such risk. By region, the impacts of these changes in tropical cyclone patterns differ (Figure 8).



Northeast

Annual damages expected to to increase by approximately 87% over the next 30 years

Mid-Atlantic

Has the largest increase in maximum wind speeds by 37 mph

The Gulf Coast

Has the highest expected maximum wind speeds both for the current year and in 30 years, with potential maximum wind gust speeds of about 248 mph

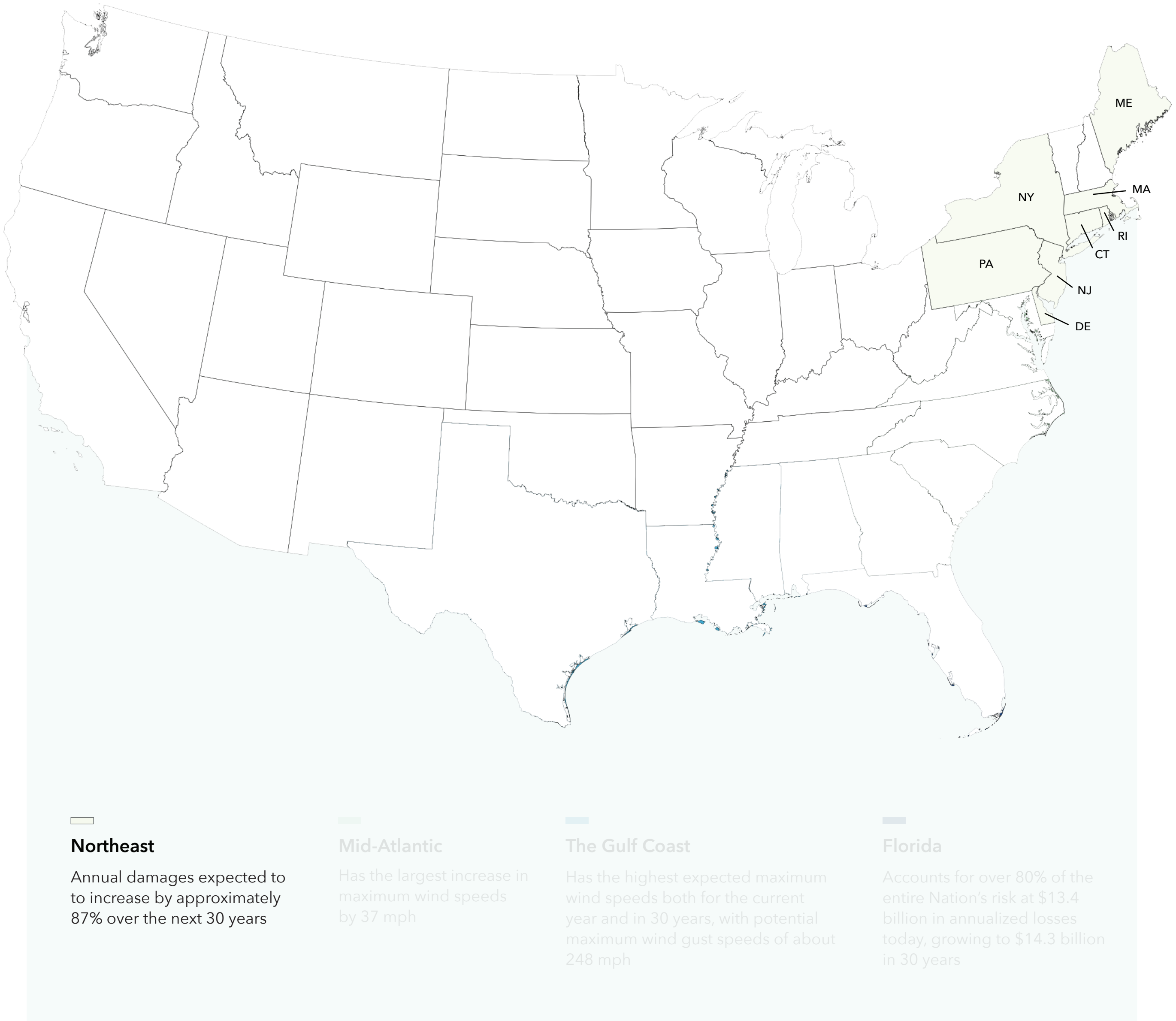
Florida

Accounts for over 80% of the entire Nation's risk at $13.4 billion in annualized losses today, growing to $14.3 billion in 30 years

Figure 8. Estimated regional changes in tropical cyclone wind risk between 2023 and 2053 from the application of the FSF-WM. Tropical cyclones are both growing stronger and moving northward due to a changing climate.

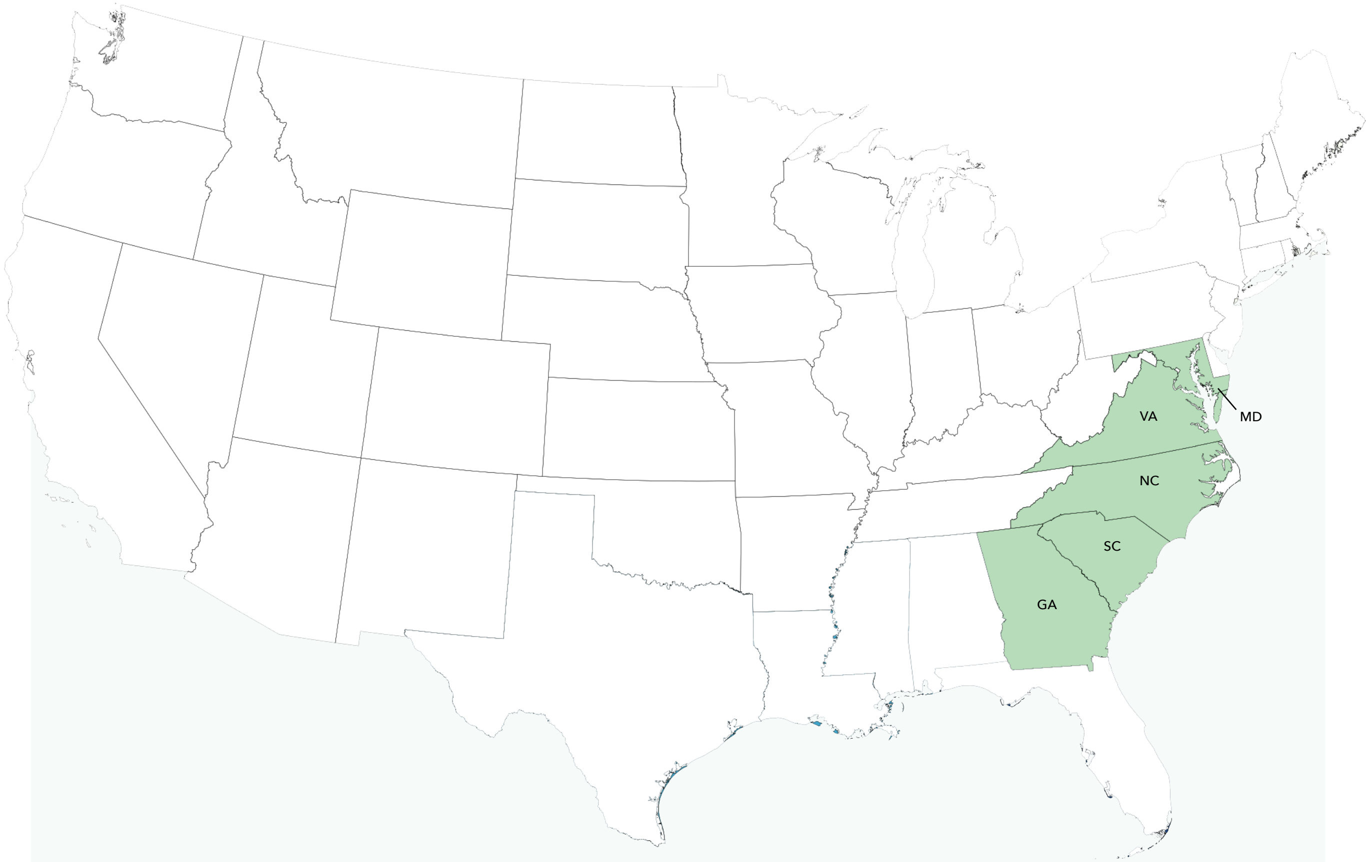
Results

1. Hurricanes are tracking further northward. In the Northeast, there is a concentration of properties that will be newly exposed to some probability of tropical storm level winds or higher in 30 years. The northward increase in hurricane activity may have a significant impact on buildings that have not been built to a code that considers the wind speeds they will likely face over the next 30 years. Annual damages are expected to increase by approximately 87% over the next 30 years. Additionally, the count of properties with any AAL from wind will increase by about 55%, with about 2.2 million newly-impacted properties by 2053.



Results

2. The largest increase in maximum wind speeds will impact states in the Mid-Atlantic. The Mid-Atlantic will see the largest increase in maximum wind speeds in CONUS over the next 30 years, with some areas increasing in maximum wind gust speeds by 37 mph. Additionally, some areas within this region can anticipate relatively large increases in the probability of experiencing a Category 1 hurricane or higher over the next 30 years when compared to today, with many areas expected to see an additional 1% annual probability. With this increase in exposure, the annualized damages are expected to increase by 50.3%.



Northeast
Annual damages expected to to increase by approximately 87% over the next 30 years

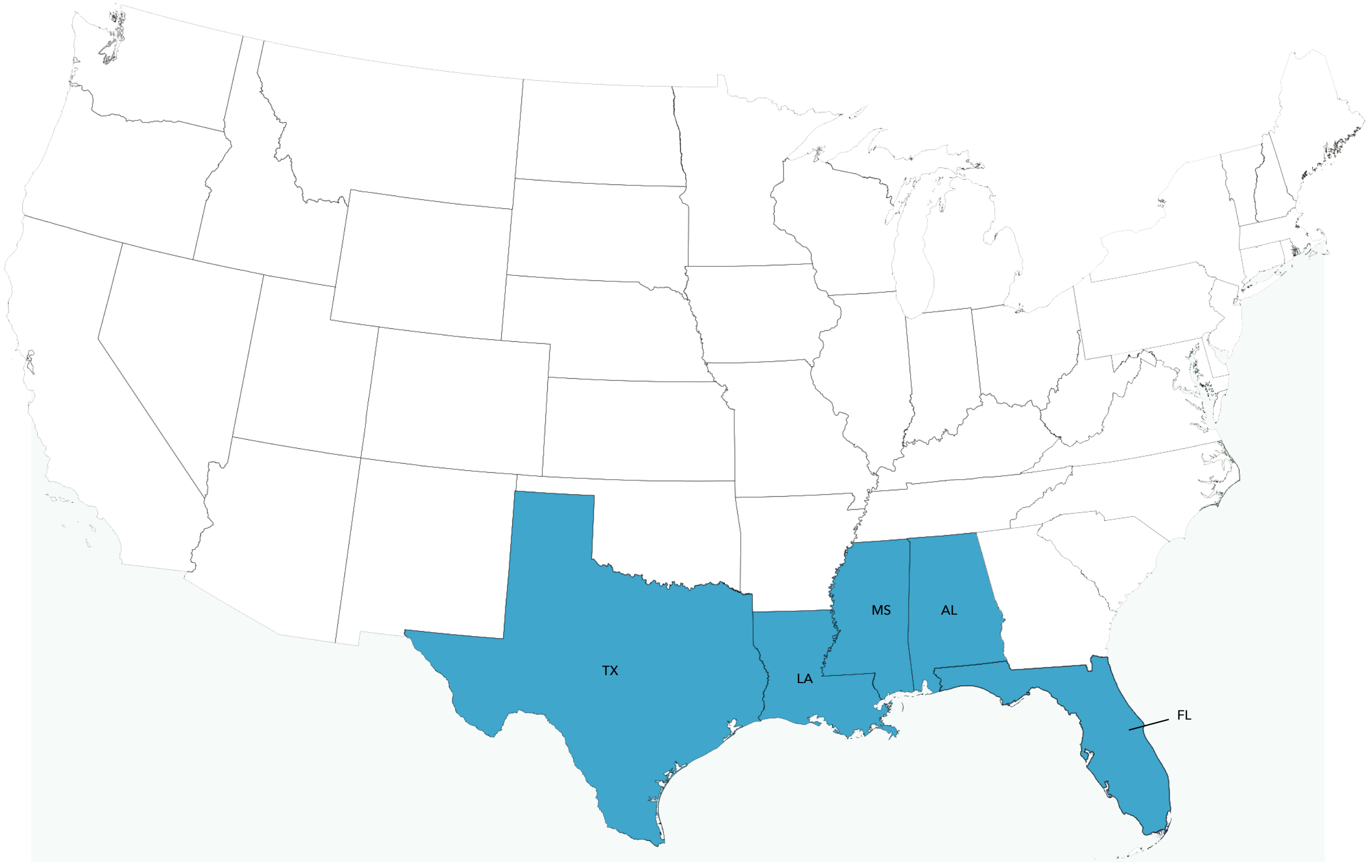
Mid-Atlantic
Has the largest increase in maximum wind speeds by 37 mph

The Gulf Coast
Has the highest expected maximum wind speeds both for the current year and in 30 years, with potential maximum wind gust speeds of about 248 mph

Florida
Accounts for over 80% of the entire Nation's risk at $13.4 billion in annualized losses today, growing to $14.3 billion in 30 years

Results

3. Increased wind speeds put billions of dollars at risk annually in the South. The Gulf Coast has the highest expected maximum wind speeds both for the current year and in 30 years, with potential maximum wind gust speeds of about 248 mph. It also has the highest absolute probabilities of experiencing a hurricane this year and in 30 years, with Monroe County, FL leading the way with a 26.7% chance this year. The western Gulf region (without Florida) sees an increase from approximately $4.4 billion in AAL in the current year to approximately $4.6 billion in 30 years. Including Florida, the AAL expected for this year in the Gulf is $17.8 billion, increasing to $18.8 billion in 30 years.



Northeast
Annual damages expected to to increase by approximately 87% over the next 30 years

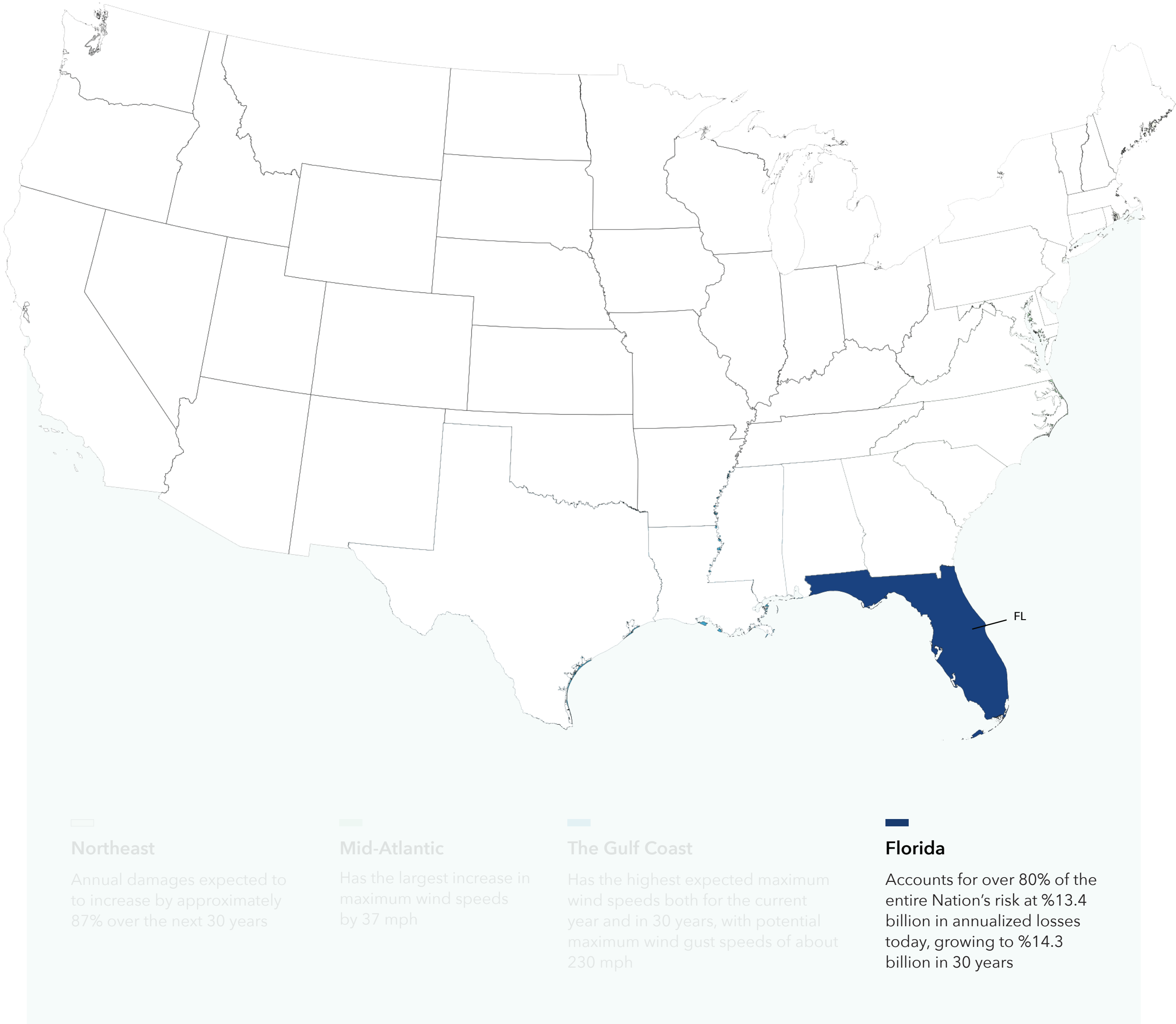
Mid-Atlantic
Has the largest increase in maximum wind speeds by 37 mph

The Gulf Coast
Has the highest expected maximum wind speeds both for the current year and in 30 years, with potential maximum wind gust speeds of about 230 mph

Florida
Accounts for over 80% of the entire Nation's risk at $13.4 billion in annualized losses today, growing to $14.3 billion in 30 years

Results

4. Florida accounts for over 70% of the entire Nation's risk. The country's expected AAL this year and in 30 years is driven almost entirely by Florida, which accounts for $7 out of every $10 in losses for both periods. Uniquely, Florida sees some areas like Miami-Dade decrease slightly in future risk due to the northward shift in tropical cyclones, but areas like Brevard County increase in risk, resulting in an overall increase from $13.4 billion to $14.3 billion over the next 30 years.



Results

To identify the areas with the most severe risk from tropical cyclone wind events, the maximum wind speed that each area is likely to experience in the current year is displayed in Figure 9a. While these wind speeds will not necessarily occur in any given year, this probabilistic approach allows an calculation of what maximum speeds are expected in the worst case scenario, up to the ASCE guidance for building code thresholds at the extreme 1-in-3000 year return period (equivalent to a 0.03% annual chance of occurring, or 1% over a 30 year mortgage). An examination of how wind risk exposure is changing over the next 30 years allows for information on the conditions for which these areas will need to prepare as the environment changes. Areas that may be newly exposed to severe tropical cyclone winds, or those which have an increased likelihood of experiencing severe wind events, may be at particular risk if building standards are reliant on past or current day exposure levels. Although Louisiana has a concentration of the highest maximum gust speeds (approximately 248 mph), South Carolina is expected to face the largest increase in maximum wind speeds over the next 30 years (+37 mph; see Figure 9c).

Cheat Sheet

Terminology	Definition
Moderate wind event	Tropical storm (39-73 mph sustained winds), Category 1 (74-95 mph sustained winds), Category 2 (96-110 mph sustained winds), or higher wind conditions
Major hurricane event	Category 3 (111-129 mph sustained winds), Category 4 (130-156 mph sustained winds), and Category 5 (≥157 mph sustained winds) hurricane wind conditions
Sustained winds	1-minute sustained winds resulting from the circulation within a tropical cyclone, which are used to classify hurricane categories by intensity
Wind gusts	3-second wind gusts, resulting from small-scale variations within a storm, which typically are the cause of maximum wind damage to properties estimated gust = 1.28 X sustained wind speed

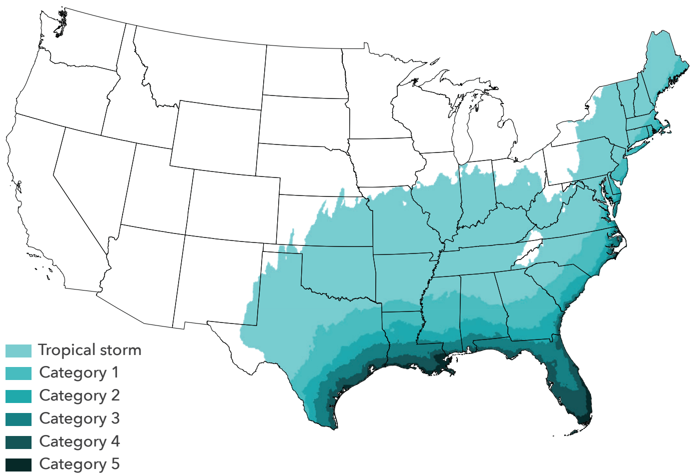


Figure 9a. Maximum wind speeds 2023

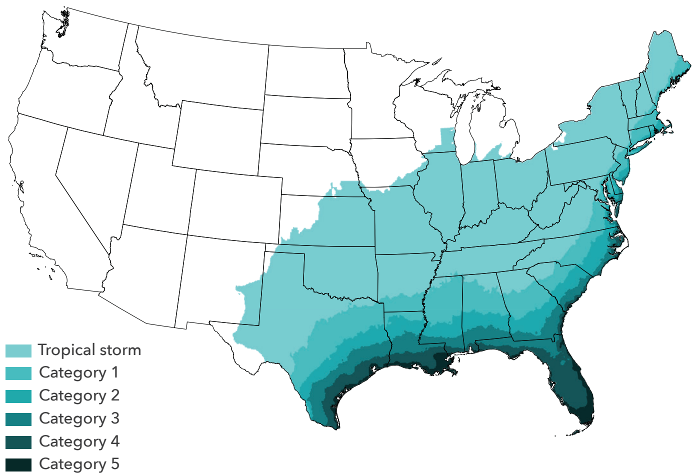


Figure 9b. Maximum wind speeds 2053

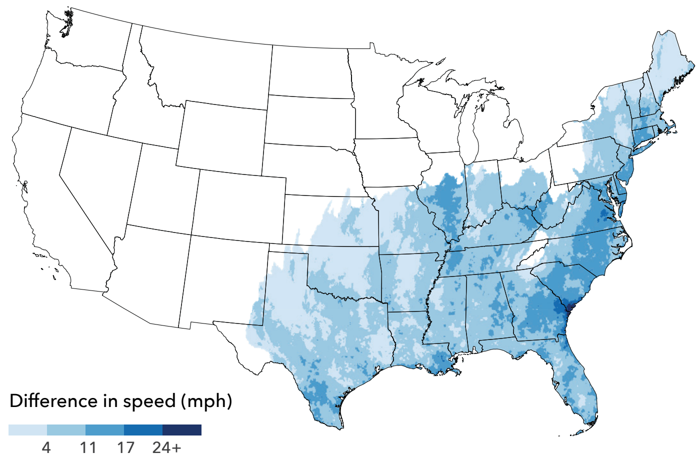


Figure 9c. Increase in maximum wind speed

Results

Additionally, much of the Mid-Atlantic sees relatively large increases in the probability of exposure to hurricane wind speeds, increasing by an additional 1% annual likelihood. Interestingly, inland states like Illinois, Kentucky, and Tennessee will also experience significant increases relative to their current levels, with gust speeds in Tennessee increasing from 87 mph to 97 mph. Even though these inland areas will likely experience lower wind speeds than coastal regions, this exposure is significant given that these inland states may not be fully aware of future expected wind speed increases, which could ultimately result in increased damage during hurricane wind conditions events.

The maximum speed information is calculated by considering the maximum speeds expected for all of the return periods considered by the FSF-WM. Return periods reflect the probabilities associated with possible wind events, where an event which has a 5% probability of occurring in a given year is referred to as a 1-in-20 year event ("20 year return period"), an event which has a 1% probability of occurring in a given year, for any specific location, is referred to as a 1-in-100 year event ("100 year return period"), and so on. The FSF-WM estimates what these events will look like for this year and in 30 years, for return periods 2, 5, 20, 100, 300, 500, 700, 1700, and 3000. Low likelihood return periods, such as the 1700 and 3000 year return periods, are important to characterize as these are the most severe events and thus are considered for engineering design standards. For example, the ASCE considers the 300, 700, 1700, and 3000 year return periods in their standards (ASCE, 2018). While the number of exposed properties stays relatively constant below the 300 year return period, the impact of climate change is evident in the higher return periods. For instance, in the 3000 return period there are 13.4 million additional properties exposed in 30 years which are not today, which represents a 15.6% percent increase. A breakdown of how many properties in the contiguous United States may be exposed to tropical cyclone winds in each of these return periods, for the current year and for 30 years in the future, is shown in Figure 10. The overall number of properties exposed in the lower return periods (the 2 and 5 year return period) is expected to decrease somewhat as storms shift northwards and risk decreases in some areas around the Gulf.

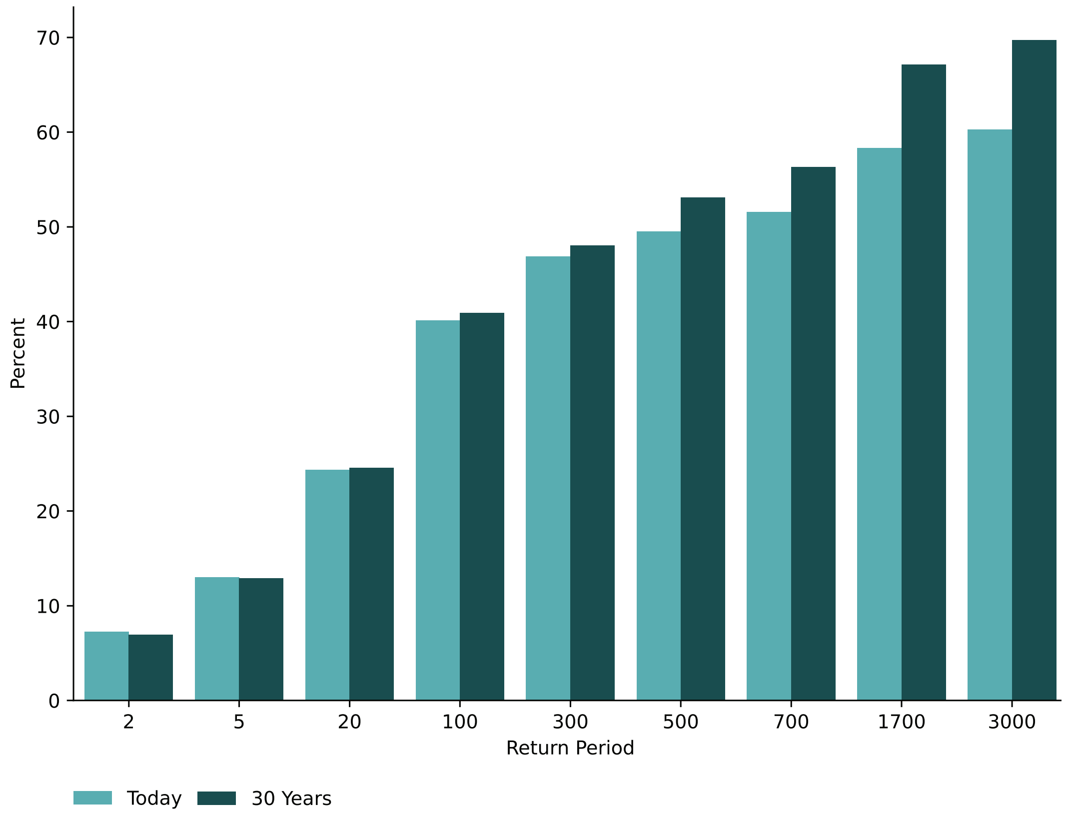


Figure 10. Percent of properties exposed to tropical cyclones by return period

Results

It is equally, if not more important, to understand what areas will see the largest increase in exposed properties in the next 30 years due to a changing climate (Figure 11). FSF-WM results indicate a band stretching from the Northeast through Texas where there are few properties exposed to tropical cyclone strength wind gusts today, but, in 30 years, many more properties in this band will be exposed and will be at risk. For example, in the 500 year return period, some inland parts of the Northeast can anticipate very large increases in the number of properties exposed to tropical storm strength winds or higher, with risk reaching about 249,000 newly-exposed properties. In the 3000 year return period, the number of newly-exposed properties in the Northeast region reaches approximately 3.1 million. Overall, in the next 30 years, 13.4 million properties in CONUS will be exposed to a level of tropical storm or higher wind risk that do not currently face such risk today.

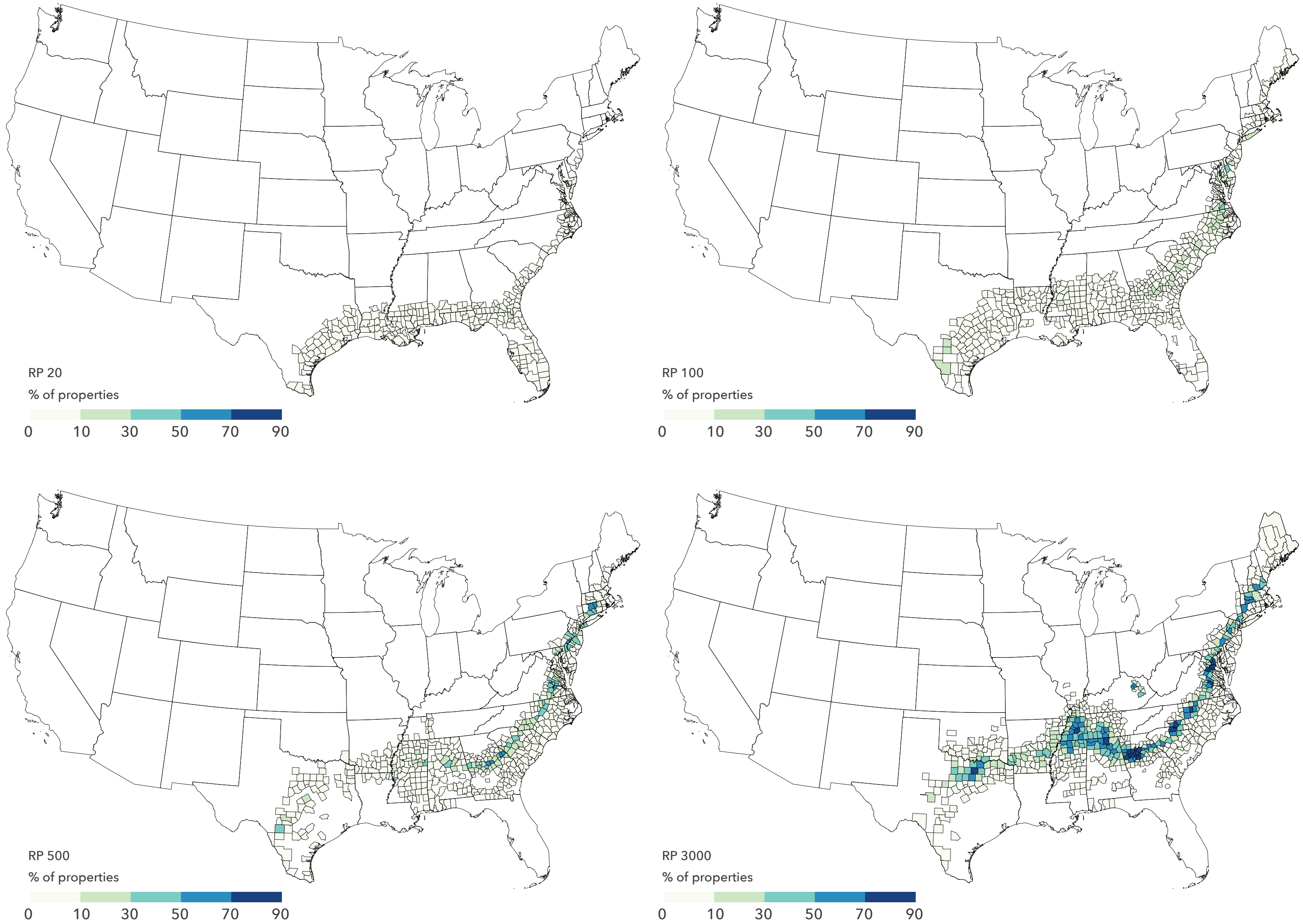


Figure 11. Percent of properties estimated to change from a level of risk of "no damage" in 2023 to "some damage" in 2053, by return period (RP)

Results

The number of properties exposed to different hurricane categories will also change over the next 30 years. Knowing which areas will be the most exposed to severe storms allows for community planning and informed decision-making on investment and risk mitigation opportunities. While a high intensity event may be rare in specific locations, the probability of it occurring somewhere in the U.S. is much higher." In the current year, there are about 3.5 million properties within the contiguous United States with a chance of experiencing Category 5 hurricane winds, but in 30 years this number increases to over 5.6 million properties (Figure 12). Additionally, there are about 10.3 million properties with a chance of experiencing Category 4 hurricane wind conditions this year, increasing to approximately 14.9 million properties that could be exposed to those wind conditions in 30 years. This illustrates the impact of the previously mentioned results that hurricanes that form in the future in a changing climate are expected to increase proportionally in severity.

These wind speed and probability results may be translated into estimated property damages for current and future conditions. For a given hurricane wind event, information on probable wind direction and speed are combined with data on property location and building characteristics to calculate the likely damage to an individual property. Based on the calculated damage for properties when exposed to different wind speeds, the count of properties with damage may be summed for the different return periods (Figure 13).

Through the aggregation and weighting by probability of all possible wind scenarios, and the associated damage that may be experienced at a property for each, an estimate of these expected damages may be calculated as an AAL. The total estimated AAL due to tropical cyclone wind damage across the country in 2023 is approximately $18.5 billion, and it is expected to increase to $19.9 billion in 30 years. Florida makes up approximately 72% of these estimated annualized losses, with about $13.4 billion in AAL this year and over $14.3 billion in 30 years. Note that these numbers are calculated by holding the built environment and all else constant from 2023-2053 except for climate change and its impacts on hurricane wind, so if further property development were to occur in these at-risk areas, the expected damage numbers in 2053 are likely to be much higher.

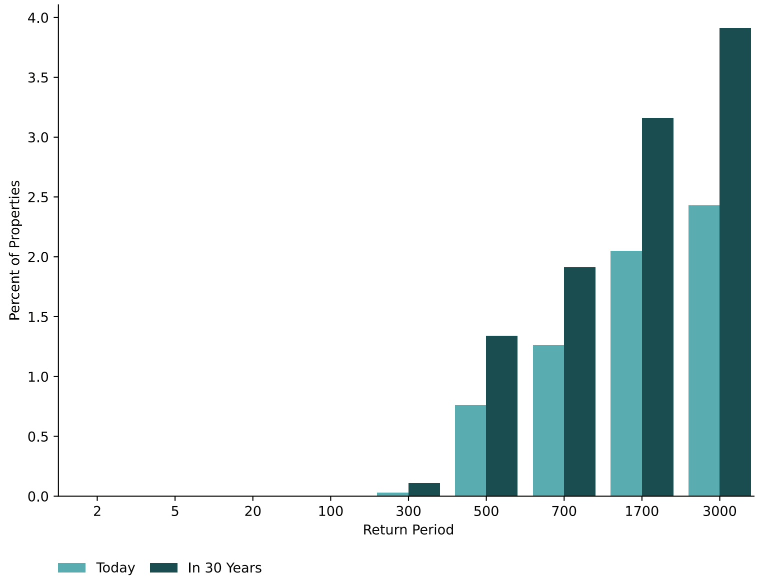


Figure 12. Percent of properties exposed to Category 5 hurricane winds by return period today and in 30 years

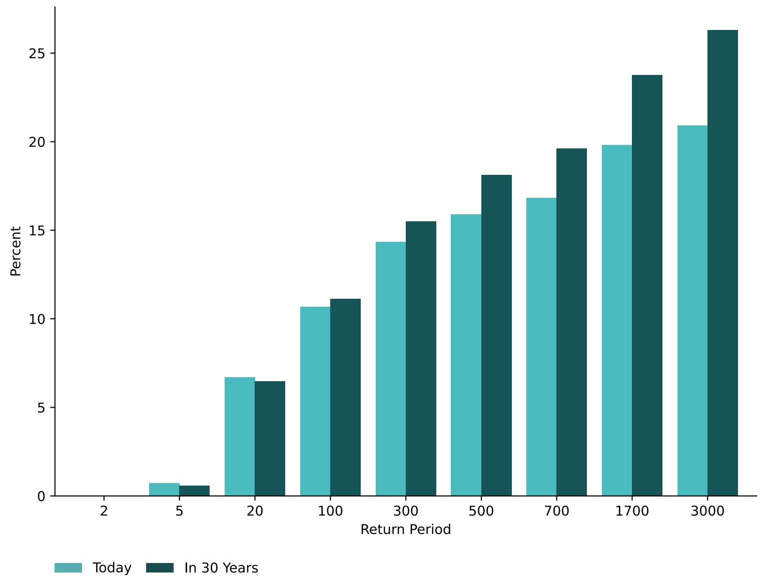


Figure 13. Percent of damaged properties by return period today and in 30 years

Results

Along the Gulf Coast, excluding Florida, about $4.4 billion is expected in AAL in the current year, increasing to $4.6 billion in 30 years. Throughout the Northeast, the AAL is expected to increase by $97 million over the next 30 years, an alarming 87.3% increase from approximately $111 million in 2023 to $208 million in 2053 (Figure 14).

The northward shift of hurricane risk with climate change results in an associated decrease of risk in some of the areas with the most exposure currently, such as along the Gulf Coast. Notably, expected changes in Florida's AAL (Figure 15) over the next 30 years illustrate how even as some areas decrease (Monroe, Miami-Dade, and Broward Counties), areas just northwards, such as Palm Beach County, increase resulting in an overall increase in AAL for the state.

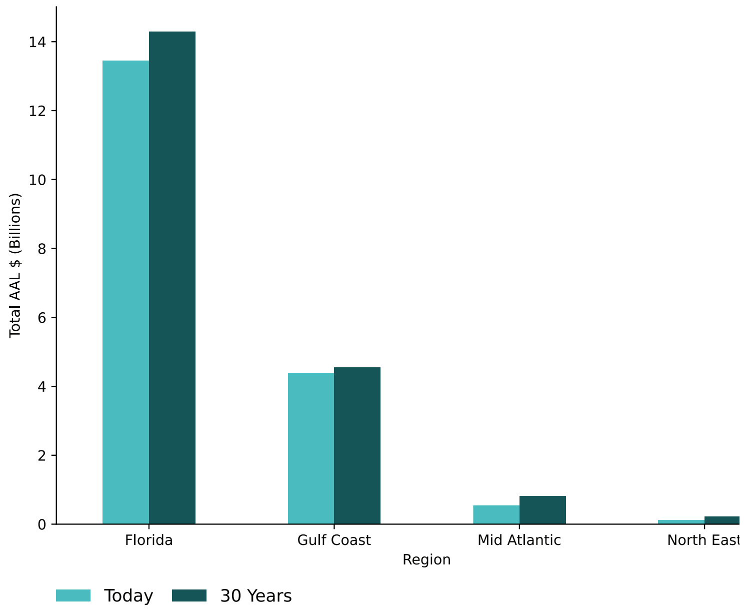


Figure 14. Estimated tropical cyclone wind AAL by region today and in 30 years

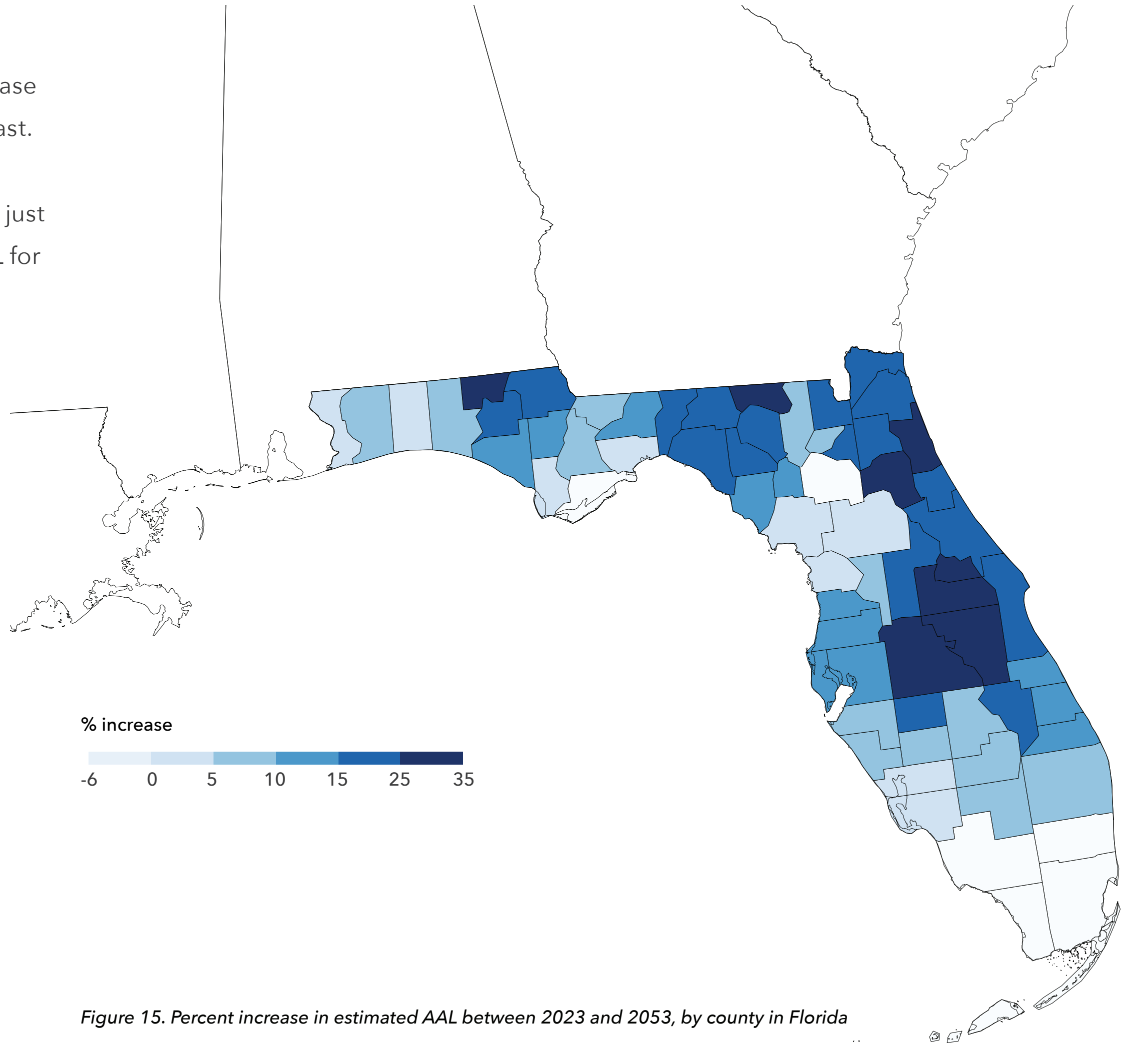


Figure 15. Percent increase in estimated AAL between 2023 and 2053, by county in Florida

Results

Exposure to tropical cyclone wind speeds

The counties exposed to the highest maximum wind speeds in the 500 year return period for the current year are listed in descending order in Table 1. The list is topped by counties in Louisiana, Texas, and Florida. The highest maximum speeds are expected in St. Bernard, LA (wind gusts up to 218 mph); Plaquemines, LA (wind gusts up to 215 mph); Monroe, FL (wind gusts up to 212 mph); Galveston, TX (wind gusts up to 211 mph); and Terrebonne, LA (wind gusts up to 209 mph). The top ten county list is rounded out by Iberia, LA; Lafourche, LA; Chambers, TX; Vermilion, LA; and Miami-Dade, FL, respectively.

Table 1. Top counties by expected wind gust speeds (mph)

	Wind gust speeds (mph) by return period and year									
County	RP5 2023	RP5 2053	RP20 2023	RP20 2053	RP100 2023	RP100 2053	RP500 2023	RP500 2053	RP3000 2023	RP3000 2053
St. Bernard, LA	92	90	133	131	182	179	218	218	230	242
Plaquemines, LA	99	95	141	138	183	182	215	218	232	244
Monroe, FL	102	99	141	138	183	180	212	215	230	244
Galveston, TX	90	87	131	128	175	174	211	214	232	244
Terrebonne, LA	96	93	137	136	179	180	209	215	228	244
Iberia, LA	91	88	133	133	179	182	209	216	228	247
Lafourche, LA	96	92	138	136	179	179	207	211	221	239
Chambers, TX	87	84	128	125	172	173	207	211	227	241
Vermilion, LA	88	87	131	132	175	179	207	214	227	243
Miami-Dade, FL	101	97	138	137	180	180	207	212	229	242
Jefferson, TX	88	86	127	127	172	173	207	210	228	237
Orleans, LA	87	84	127	124	173	170	207	210	225	239
St. Mary, LA	90	87	129	129	174	177	206	211	227	242
Cameron, LA	88	86	127	128	172	173	206	211	225	238
Collier, FL	100	97	138	137	177	174	206	212	224	238
Jefferson, LA	95	92	138	134	179	178	206	211	221	239
Broward, FL	100	97	137	134	175	174	206	211	227	239
Palm Beach, FL	100	96	136	133	172	173	205	209	227	238
St. Tammany, LA	87	83	125	123	172	166	205	207	223	238
Harrison, MS	87	83	127	124	173	169	204	205	219	230

Results

The cities expected to experience the highest maximum wind gust speeds in the current environment for the 500 year return period (Table 2) are Marathon, FL; Key West, FL; Galveston, TX; Hitchcock, TX; and Cudjoe Key, FL, with speeds of 212, 211, 211, 210, and 210 mph, respectively. Other cities which make up the top 10 cities by wind gust speeds in the 500 year return period include Big Pine Key, FL; Big Coppitt Key, FL; Bolivar Peninsula, TX; New Orleans, LA; and Miami, FL. In 30 years, the top cities expected to see the highest wind speeds in the 500 year return period include (1) Galveston, TX (speeds of 214 mph); (2) Miami, FL (212 mph); (3) Miami Beach, FL (212 mph); (4) Marco Island, FL (212 mph); and (5) Miami Shores, FL (212 mph).

Table 2. Top cities by expected wind gust speeds (mph)

	Wind gust speeds (mph) by return period and year									
City	**RP5 2023**	**RP5 2053**	**RP20 2023**	**RP20 2053**	**RP100 2023**	**RP100 2053**	**RP500 2023**	**RP500 2053**	**RP3000 2023**	**RP3000 2053**
Marathon, FL	101	97	138	136	179	178	212	210	230	242
Key West, FL	101	97	140	137	182	179	211	210	228	244
Galveston, TX	90	87	131	128	175	174	211	214	232	242
Hitchcock, TX	88	86	131	127	173	173	210	211	228	238
Cudjoe Key, FL	102	99	141	138	182	178	210	210	229	243
Big Pine Key, FL	101	99	140	138	182	178	210	210	228	241
Big Coppitt Key, FL	101	97	140	137	182	179	209	209	225	244
Bolivar Peninsula, TX	88	86	131	128	173	174	209	212	228	244
New Orleans, LA	87	84	127	124	173	170	207	210	225	239
Miami, FL	100	97	138	136	177	174	207	212	223	239
Meraux, LA	87	84	127	124	172	170	207	209	223	237
Miami Beach, FL	100	97	138	136	177	174	207	212	223	239
North Key Largo, FL	101	97	138	137	180	179	207	210	224	239
Key Largo, FL	101	97	138	137	180	179	207	210	227	241
Violet, LA	87	84	128	125	172	170	207	209	221	236
Miramar, FL	100	97	136	134	175	173	206	211	224	236
Gladeview, FL	100	97	137	134	177	174	206	211	221	238
Pembroke Pines, FL	100	97	136	133	174	173	206	211	224	236
Miami Shores, FL	100	97	138	134	177	174	206	212	223	239
Lauderhill, FL	99	96	134	133	173	173	206	210	225	237

Results

Areas that face the largest increases in maximum wind speeds over the next 30 years may not be prepared for damaging wind events, as building codes are typically defined by historic events and not future predicted probabilities of maximum wind speeds. This is especially true for areas that may face relatively low maximum wind speeds in the current year, as they will cross over damaging wind speed thresholds sometime over the next 30 years. The impact of such changes in wind gust speeds on properties could be drastic, as the expected damage increases. The counties expected to see the largest increase in maximum wind gust speeds in the 500 year return period (Table 3) are primarily in Virginia, with some counties in South Carolina, Georgia, and North Carolina making the top 20 county list. Jasper, SC will see the largest increase in wind gust speeds in the 500 year return period, increasing by approximately 15 mph. Rounding out the top five include Amelia, VA; Goochland, VA; Chesterfield, VA; and Culpeper, GA, respectively.

Table 3. Top counties by increase in max wind gust speeds (mph)

	Wind gust speeds (mph) by return period and year					
County	**RP 500 2023**	**RP 500 2053**	**Change in RP 500**	**RP 3000 2023**	**RP 3000 2025**	**Change in RP 3000**
Jasper, SC	155	170	15	170	207	37
Amelia, VA	73	87	14	84	108	23
Goochland, VA	72	86	14	81	102	22
Chesterfield, VA	83	97	14	95	115	20
Culpeper, VA	63	77	14	73	90	17
Fauquier, VA	63	77	14	73	91	18
Colonial Heights, VA	82	96	14	92	114	22
Screven, GA	108	122	14	119	145	26
Hopewell, VA	83	97	14	95	115	20
Powhatan, VA	70	84	14	81	101	20
Accomack, VA	138	152	14	155	177	22
Hampton, SC	127	140	13	138	166	28
King and Queen, VA	106	119	13	119	141	22
King William, VA	90	102	13	100	123	23
Somerset, MD	125	138	13	141	163	22
Orange, VA	59	72	13	68	86	18
Richmond, VA	79	92	13	88	111	23
Burke, GA	97	110	13	113	133	20
Petersburg, VA	83	96	13	93	114	20
Alamance, NC	70	83	13	83	100	17

Results

The cities that are expected to see the largest increases in maximum wind gust speeds in the 500 year return period (Table 4) are primarily in Virginia, South Carolina, and Georgia. Daufuskie Island, SC is expected to see the largest increase in wind gust speeds in the 500 year return period, increasing by approximately 15 mph. Rounding out the top five also include Tybee Island, GA (increases of 15 mph); Midlothian, VA (increases of 15 mph); Woodlake, VA (increases of 15 mph); and Brandermill, VA (increases of 15 mph).

Table 4. Top cities by increase in max wind gust speeds (mph)

	Wind gust speeds (mph) by return period and year					
City	RP 500 2023	RP 500 2053	Change in RP 500	RP 3000 2023	RP 3000 2025	Change in RP 3000
Tybee Island, GA	160	175	15	174	214	40
Daufuskie Island, SC	155	170	15	170	209	38
Captains Cove, VA	131	146	15	147	173	26
Rockwood, VA	74	90	15	86	105	19
Brandermill, VA	73	88	15	83	104	20
Midlothian, VA	73	88	15	84	104	19
Woodlake, VA	72	87	15	82	102	20
Port Royal, SC	164	178	14	177	212	36
Beaufort, SC	163	177	14	175	211	36
Burton, SC	159	173	14	173	207	35
Wilmington Island, GA	156	170	14	173	209	36
Whitemarsh Island, GA	154	168	14	168	206	38
Bluffton, SC	150	164	14	164	200	36
Horntown, VA	132	146	14	150	173	23
Port Wentworth, GA	125	140	14	138	172	33
Rincon, GA	116	131	14	129	159	29
Hopewell, VA	83	97	14	95	115	20
Colonial Heights, VA	82	96	14	92	114	22
Meadowbrook, VA	78	92	14	90	110	20
Manchester, VA	77	91	14	87	108	20

Results

The different return periods and their respective speeds are used the calculate the probability of different storm categories each year. For example, one area may experience Category 3 winds during a 1-in-100 year event, while another area may experience only Category 1 winds during a 1-in-100 year event. The FSF-WM facilitates the exploration of all of these different types of information, allowing for communities, property-owners, and all other stakeholders to more fully understand what their risk is due to hurricane wind events.

The breakdown of properties exposed to different tropical cyclone categories, within each return period, is shown in Figure 16, for this year and in 30 years.

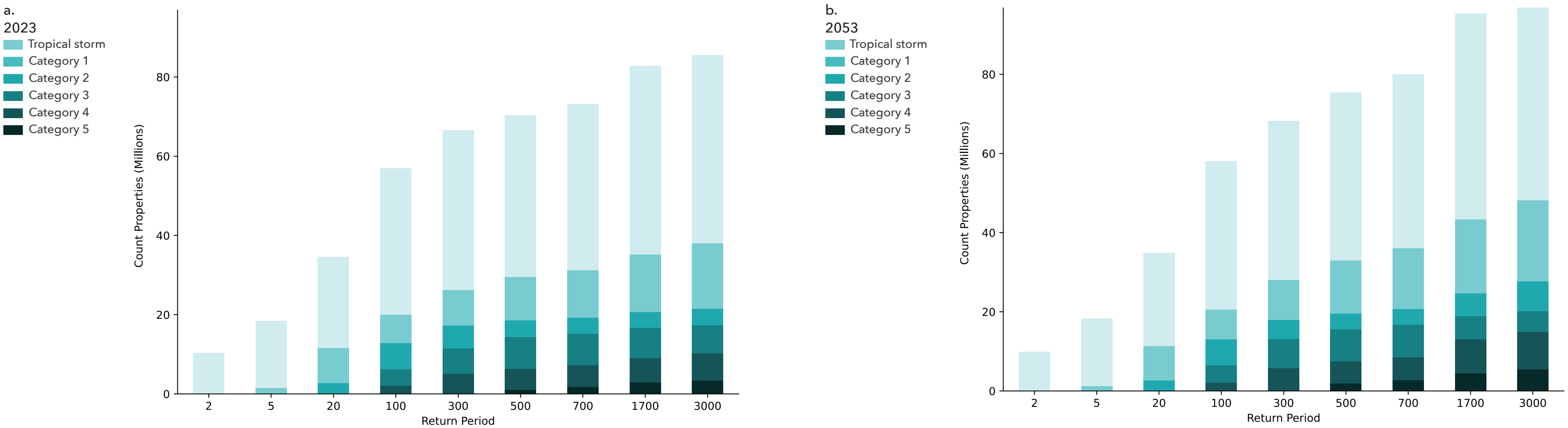


Figure 16. Number of properties exposed to storm categories within different return periods for 2023 (a) and 2053 (b)

Results

Under current environmental conditions, about 11.6 million properties are exposed to the chance of a Category 1 hurricane or higher in the 20 year return period. For approximately 11.6 million properties in the contiguous United States, there is a cumulative probability of about 79% of being exposed to at least one Category 1 hurricane over the span of a 30 year mortgage. All probabilities of various tropical cyclone winds (for example, “the probability of exposure to Category 1 winds”) refer to the likelihood of reaching at least that speed. An area beginning in the Gulf Coast and stretching northward along the East Coast towards the Northeast has a significant chance of a Category 1 storm or higher reaching it. The highest probabilities of exposure to a Category 1 storm this year are focused along the Gulf Coast, with some areas exceeding a 27% likelihood this year (Figure 17a). In 30 years, while the spatial patterns remain fairly similar, some areas around the Gulf may see a slight decrease in their annual probabilities of experiencing a hurricane (Figure 17b), which illustrates the northward shift of hurricanes over the next 30 years due to a changing climate.

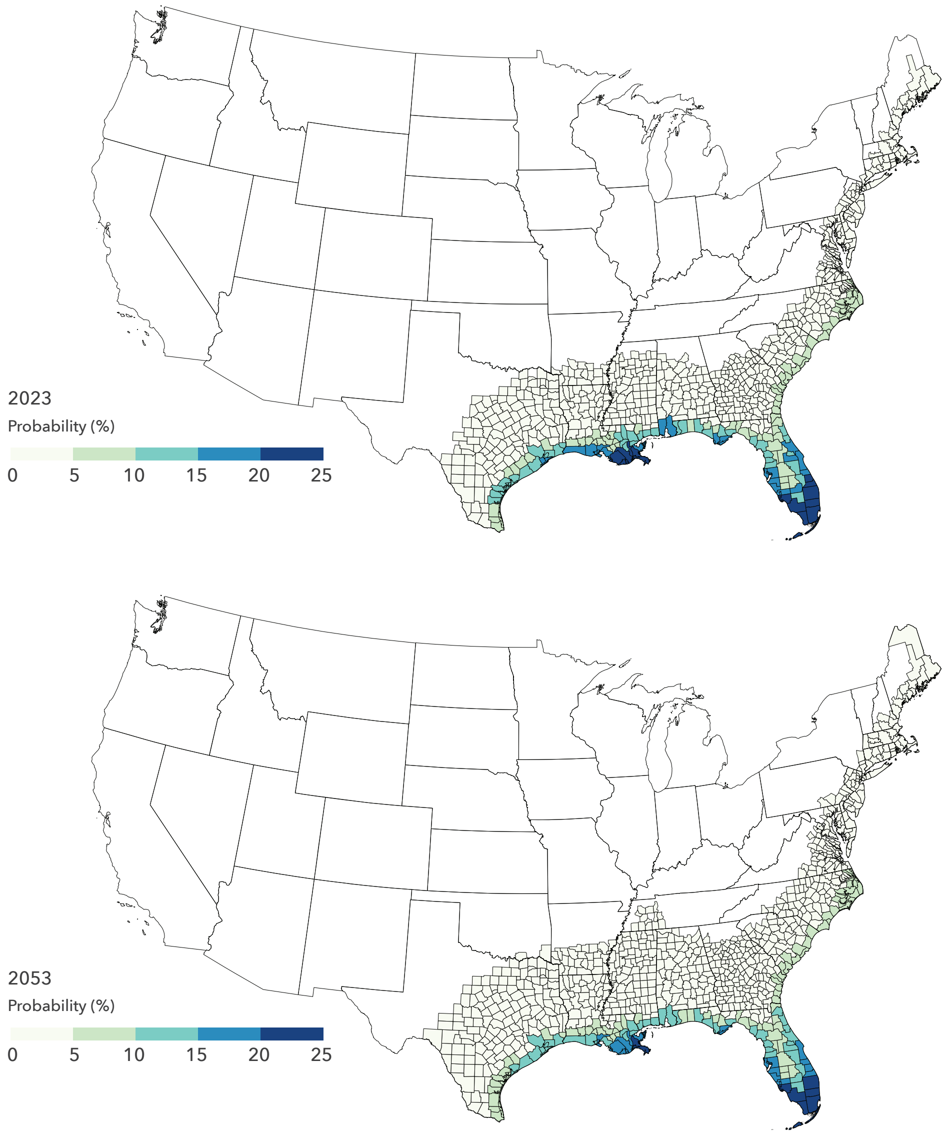


Figure 17. Probability of exposure to Category 1 hurricane wind speeds or higher.

Results

The counties with the highest probabilities of experiencing a Category 1 hurricane or higher this year (Table 5) are primarily located in Florida and Louisiana. Monroe, FL tops the list with a 26.7% probability of experiencing a Category 1 hurricane this year. Over the next 5 years, there is a cumulative probability of approximately 78.5% that Monroe, FL will experience at least one Category 1 hurricane or higher; over the next 10 years, this probability increased to 95.5%. Monroe, FL is followed by Miami-Dade, FL (25.8%); Broward, FL (24.6%); Palm Beach, FL (24.4%); and Collier, FL (24.3%) in Category 1 wind exposure likelihood in 2023.

Table 5. Top counties by probability of hurricane winds (2023)

	Probabilities of various tropical cyclone winds*											
County	**Tropical Storm 2023**	**Tropical Storm 2053**	**Cat 1 2023**	**Cat 1 2053**	**Cat 2 2023**	**Cat 2 2053**	**Cat 3 2023**	**Cat 3 2053**	**Cat 4 2023**	**Cat 4 2053**	**Cat 5 2023**	**Cat 5 2053**
Monroe, FL	82.6%	77.0%	26.7%	23.5%	9.4%	8.2%	4.9%	4.5%	2.1%	1.9%	0.5%	0.4%
Miami-Dade, FL	82.4%	77.4%	25.8%	22.6%	8.9%	7.8%	4.5%	4.3%	1.8%	1.8%	0.4%	0.4%
Broward, FL	84.0%	78.6%	24.6%	21.9%	8.1%	7.5%	4.3%	3.9%	1.6%	1.4%	0.3%	0.3%
Palm Beach, FL	84.0%	79.4%	24.4%	21.5%	7.8%	7.2%	4.0%	3.8%	1.3%	1.4%	0.3%	0.3%
Collier, FL	79.1%	76.3%	24.3%	22.1%	8.3%	7.7%	4.4%	4.2%	1.7%	1.5%	0.3%	0.3%
Plaquemines, LA	77.1%	71.4%	23.1%	20.2%	8.3%	7.6%	4.9%	4.6%	2.2%	2.1%	0.5%	0.5%
Lee, FL	81.5%	77.4%	22.3%	20.5%	7.4%	7.0%	4.3%	3.9%	1.7%	1.5%	0.2%	0.3%
Martin, FL	83.0%	79.4%	21.9%	19.8%	6.8%	6.6%	3.2%	3.5%	1.0%	1.2%	0.2%	0.2%
Terrebonne, LA	71.8%	69.2%	20.9%	18.6%	7.7%	7.1%	4.4%	4.4%	1.9%	2.0%	0.4%	0.4%
Lafourche, LA	73.1%	69.7%	20.8%	18.5%	7.6%	7.0%	4.6%	4.3%	1.9%	1.8%	0.3%	0.4%
Jefferson, LA	72.5%	69.5%	20.4%	18.1%	7.5%	6.8%	4.5%	4.1%	1.9%	1.8%	0.3%	0.4%
St. Lucie, FL	81.5%	79.4%	20.3%	18.4%	6.1%	6.1%	2.8%	3.2%	1.0%	1.1%	0.2%	0.2%
Charlotte, FL	80.4%	76.4%	19.5%	18.0%	6.4%	6.2%	3.5%	3.4%	1.2%	1.1%	0.1%	0.2%
Indian River, FL	81.5%	79.4%	19.3%	17.5%	5.8%	5.7%	2.6%	3.0%	0.9%	1.1%	0.1%	0.2%
Manatee, FL	79.8%	76.6%	19.1%	18.3%	6.1%	6.3%	3.1%	3.5%	1.1%	1.2%	0.2%	0.2%
Pinellas, FL	79.9%	76.5%	18.6%	17.9%	6.0%	6.2%	3.2%	3.4%	1.1%	1.2%	0.2%	0.2%
Hillsborough, FL	79.7%	76.5%	18.6%	17.9%	6.0%	6.2%	3.2%	3.4%	1.1%	1.2%	0.2%	0.2%
Sarasota, FL	78.6%	75.8%	18.2%	16.8%	6.0%	5.9%	3.2%	3.3%	1.1%	1.0%	0.1%	0.2%
St. Bernard, LA	72.1%	67.9%	18.1%	15.7%	6.6%	6.1%	4.0%	3.8%	1.9%	1.7%	0.5%	0.4%
Brevard, FL	80.2%	78.4%	17.8%	16.3%	5.5%	5.5%	2.5%	2.8%	0.7%	0.9%	0.1%	0.2%

** Probabilities of all tropical cyclone wind categories (such as tropical storm, Category 1, etc.) refer to the likelihood of reaching at least those wind speeds.*

Results

The cities with the highest probabilities of experiencing a Category 1 hurricane or higher this year (Table 6) are all located in Florida. Cudjoe Key, FL tops the list with a 26.5% probability of experiencing a Category 1 hurricane this year. Rounding out the top 5 cities by the highest probabilities of exposure to Category 1 hurricane winds include Marathon, FL (26.4%); Islamorada, Village of Islands, FL (26.3%); Big Pine Key, FL (26.3%); and Big Coppitt Key, FL (26.1%).

Table 6. Top cities by probability of hurricane winds (2023)

	Probabilities of various tropical cyclone winds*											
City	**Tropical Storm 2023**	**Tropical Storm 2053**	**Cat 1 2023**	**Cat 1 2053**	**Cat 2 2023**	**Cat 2 2053**	**Cat 3 2023**	**Cat 3 2053**	**Cat 4 2023**	**Cat 4 2053**	**Cat 5 2023**	**Cat 5 2053**
Cudjoe Key, FL	81.0%	75.9%	26.5%	23.0%	9.2%	8.1%	4.7%	4.4%	2.0%	1.8%	0.4%	0.3%
Marathon, FL	80.9%	76.3%	26.4%	22.4%	8.9%	7.8%	4.3%	4.2%	1.7%	1.7%	0.3%	0.4%
Islamorada, Village of Islands, FL	82.6%	77.0%	26.3%	22.4%	8.9%	7.8%	4.5%	4.4%	1.8%	1.8%	0.3%	0.4%
Big Pine Key, FL	80.9%	76.0%	26.3%	22.9%	9.0%	8.1%	4.7%	4.4%	2.0%	1.8%	0.4%	0.4%
Big Coppitt Key, FL	80.3%	75.8%	26.1%	22.6%	9.0%	8.0%	4.7%	4.4%	2.0%	1.8%	0.4%	0.3%
Key West, FL	80.4%	75.9%	26.1%	22.7%	9.0%	8.0%	4.7%	4.4%	2.0%	1.8%	0.4%	0.4%
North Key Largo, FL	80.1%	75.9%	25.8%	22.4%	8.8%	7.8%	4.3%	4.2%	1.8%	1.8%	0.3%	0.4%
Key Largo, FL	82.2%	76.6%	25.8%	22.3%	8.7%	7.8%	4.4%	4.3%	1.9%	1.8%	0.3%	0.4%
Tavernier, FL	82.6%	76.8%	25.4%	22.1%	8.4%	7.7%	4.5%	4.4%	1.9%	1.8%	0.3%	0.4%
Homestead, FL	79.9%	75.5%	25.2%	22.3%	8.5%	7.7%	4.2%	3.9%	1.7%	1.6%	0.3%	0.3%
Cutler Bay, FL	78.7%	75.4%	25.1%	21.9%	8.5%	7.6%	4.1%	3.9%	1.6%	1.5%	0.3%	0.3%
Florida City, FL	80.0%	75.6%	25.1%	22.4%	8.4%	7.7%	4.2%	3.9%	1.7%	1.6%	0.3%	0.3%
Miami Beach, FL	82.1%	77.4%	25.1%	22.0%	8.4%	7.6%	4.4%	4.1%	1.7%	1.5%	0.3%	0.4%
Miami, FL	82.1%	77.3%	25.1%	22.0%	8.4%	7.6%	4.4%	4.0%	1.7%	1.5%	0.3%	0.4%
Coral Gables, FL	80.3%	76.4%	24.9%	21.7%	8.4%	7.5%	4.2%	4.0%	1.7%	1.5%	0.3%	0.3%
Gladeview, FL	81.5%	77.1%	24.8%	21.9%	8.2%	7.5%	4.3%	3.9%	1.6%	1.5%	0.3%	0.4%
Miami Shores, FL	82.1%	77.3%	24.8%	22.0%	8.2%	7.5%	4.4%	4.0%	1.6%	1.5%	0.3%	0.4%
West Little River, FL	81.5%	77.1%	24.8%	21.9%	8.2%	7.5%	4.3%	3.9%	1.6%	1.5%	0.3%	0.4%
Pinewood, FL	82.0%	77.2%	24.8%	22.0%	8.2%	7.5%	4.3%	3.9%	1.6%	1.5%	0.3%	0.4%
Leisure City, FL	79.1%	75.2%	24.8%	21.9%	8.3%	7.5%	4.0%	3.8%	1.6%	1.5%	0.3%	0.3%

** Probabilities of all tropical cyclone wind categories (such as tropical storm, Category 1, etc.) refer to the likelihood of reaching at least those wind speeds.*

Results

Understanding how the probabilities of exposure to hurricane winds change between this year and 30 years in the future allows adequate planning for resilient communities. A holistic understanding of wind risk over the next 30 years allows for communities to plan investment opportunities, risk mitigation, and building-hardening strategies. In 30 years, the counties with the highest probabilities of experiencing hurricane winds are again topped by Monroe, FL; Miami-Dade, FL; Collier, FL; Broward, FL; and Palm Beach, FL. The rest of the top 20 list for county probabilities of hurricane winds are similar to those of the current year, and are made up primarily by counties in Florida and Louisiana.

The counties which will likely face the greatest absolute increase in their annual likelihood of experiencing Category 1 hurricane wind conditions (Table 7) include Gloucester, VA; Isle of Wight, VA; York, VA; Mathews, VA; and Poquoson, VA, respectively. The cities expected to see the greatest absolute increase in the probability of experiencing at least Category 1 hurricane wind conditions (Table 8) include Yorktown, VA; Gloucester Point, VA; Gloucester Courthouse, VA; Carrollton, VA; and Bethel Manor, VA. Other cities on the top 20 list also include cities in North Carolina and Georgia.

Table 7. Top counties by absolute increase in probability of hurricane winds

City	Probability of at least Cat 1 (2023)	Probability of at least Cat 1 (2053)	Absolute increase in probability of Cat 1	% increase in probability of Cat 1
Gloucester, VA	1.8%	2.8%	1.0%	58.5%
Isle of Wight, VA	1.5%	2.5%	1.0%	69.0%
York, VA	1.8%	2.8%	1.0%	55.0%
Mathews, VA	2.0%	3.0%	1.0%	47.8%
Poquoson, VA	2.1%	3.1%	0.9%	45.0%
Newport News, VA	1.9%	2.9%	0.9%	47.9%
Hampton, VA	2.3%	3.2%	0.9%	40.9%
Martin, NC	2.3%	3.2%	0.9%	38.2%
James City, VA	0.8%	1.6%	0.9%	110.3%
Middlesex, VA	1.6%	2.4%	0.8%	53.5%
Norfolk, VA	2.6%	3.4%	0.8%	32.2%
Suffolk, VA	1.8%	2.7%	0.8%	44.6%
Glynn, GA	6.8%	7.6%	0.8%	12.1%
Bertie, NC	3.0%	3.8%	0.8%	27.1%
Portsmouth, VA	2.0%	2.8%	0.8%	40.1%
Lancaster, VA	1.5%	2.3%	0.8%	52.0%
Clay, FL	8.9%	9.7%	0.8%	8.5%
Effingham, GA	1.5%	2.3%	0.7%	48.7%
Monmouth, NJ	1.2%	1.8%	0.7%	60.0%
Chowan, NC	3.5%	4.2%	0.7%	19.3%

Table 8. Top cities by absolute increase in probability of hurricane winds

City	Probability of at least Cat 1 (2023)	Probability of at least Cat 1 (2053)	Absolute increase in probability of Cat 1	% increase in probability of Cat 1
Gloucester Point, VA	1.4%	2.6%	1.2%	83.5%
Carrollton, VA	1.5%	2.5%	1.0%	69.0%
Poquoson, VA	2.1%	3.1%	0.9%	45.0%
Newport News, VA	1.9%	2.9%	0.9%	47.9%
Hampton, VA	2.3%	3.2%	0.9%	40.9%
Smithfield, VA	0.9%	1.7%	0.9%	101.2%
Deltaville, VA	1.6%	2.4%	0.8%	53.5%
Plymouth, NC	2.7%	3.5%	0.8%	30.9%
Norfolk, VA	2.6%	3.4%	0.8%	32.2%
Suffolk, VA	1.8%	2.7%	0.8%	44.6%
Portsmouth, VA	2.0%	2.8%	0.8%	40.1%
Rincon, GA	1.3%	2.1%	0.8%	59.0%
Green Cove Springs, FL	8.8%	9.6%	0.8%	8.9%
Rehoboth Beach, DE	2.6%	3.4%	0.8%	30.2%
Orange Park, FL	8.8%	9.5%	0.8%	8.8%
Edenton, NC	3.3%	4.1%	0.8%	23.4%
Lakeside, FL	8.8%	9.5%	0.8%	8.8%
Bellair-Meadowbrook Terrace, FL	8.8%	9.5%	0.8%	8.8%
Fruit Cove, FL	8.6%	9.3%	0.8%	9.0%
Asbury Lake, FL	8.9%	9.7%	0.8%	8.5%

** Probabilities of all tropical cyclone wind categories (such as tropical storm, Category 1, etc.) refer to the likelihood of reaching at least those wind speeds.*

Results

There is a high increase in the probability of lower category storms impacting the East Coast in 2053 (Figure 18a). The probability of a moderate hurricane event (tropical storm, Category 1, or Category 2 wind conditions) increases in the next 30 years over inland areas and along the Atlantic coast, with some areas expected to see an additional 5% annual likelihood (Figure 18b). The Northeast is expected to see the largest increases in the annual probability of at least tropical storm wind conditions or higher, as hurricanes are expected to move further up the Atlantic coast in the future. The probability of major hurricane winds (Category 3 winds or higher) impacting the Gulf Coast (Figure 18c) in 2053 is relatively high, and this probability increases the most (relative to the probability in the current year) along the Atlantic side of Florida and along the mid-Atlantic (Figure 18d). Key West, FL and Galveston, TX have the highest probabilities of any city (defined as a city with more than 2,000 properties) to experience severe Category 5 hurricane wind conditions, with a 0.4% probability in the current year. Following these two cities, the top five list is rounded out by Cudjoe Key, FL; Big Pine Key, FL; and Big Coppitt Key, FL, respectively. The rest of the top 20 list of cities with the highest probabilities of Category 5 hurricane winds are mostly located in Florida, and include Marathon, Miami Beach, and Key Largo.

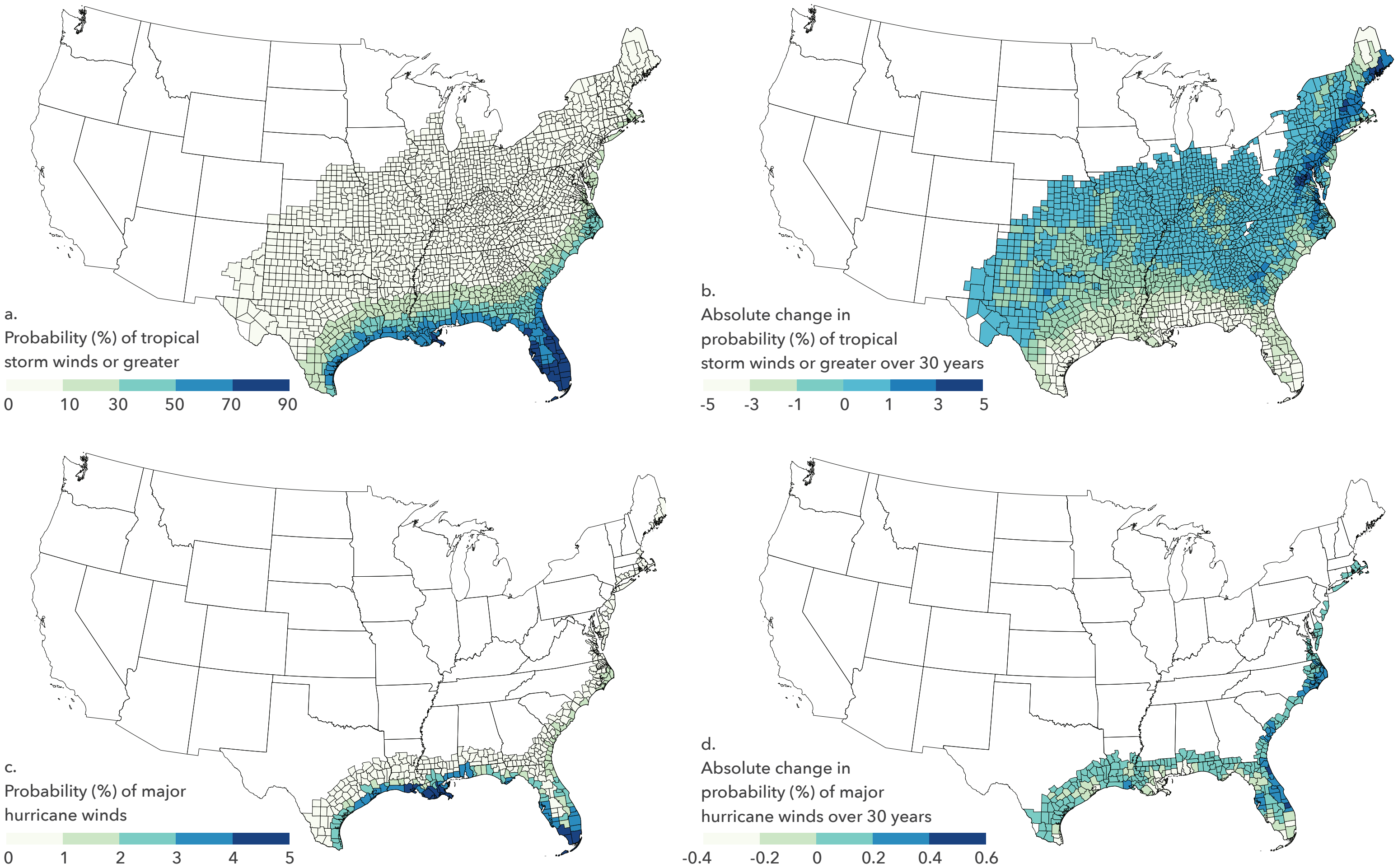


Figure 18. Probabilities of different storm categories exposure in 2023 (left panels) and their increases over the next 30 years (right).

Results

Damages

The FSF-WM was used to estimate the wind gust speeds expected at the property level, which then were used in conjunction with property-level building characteristic data to calculate the damages that may be expected for various speeds and return periods. Building characteristics can include factors such as the direction of a building's most vulnerable face (the long side of the building), building age, roof material, and the surrounding environment (density of structures surrounding the building that contributes to a greater missile environment). Differences in building standards, wind directions, and other preparedness factors can cause discrepancies when comparing between the number of properties exposed and the number of properties that may be damaged. Simple exposure in a given return period does not translate directly to damage, but damage is driven primarily by other factors such as wind speeds, counts of properties, and building standards. Changes in the 500 year return period wind speeds result in an increase of the number of additional properties which may be damaged in 30 years (Figure 19). This increase occurs primarily inland from the coast, and is especially concentrated in the Northeast, illustrating the impacts of tropical cyclones increasing in severity, penetrating further inland, and shifting tracks northwards.

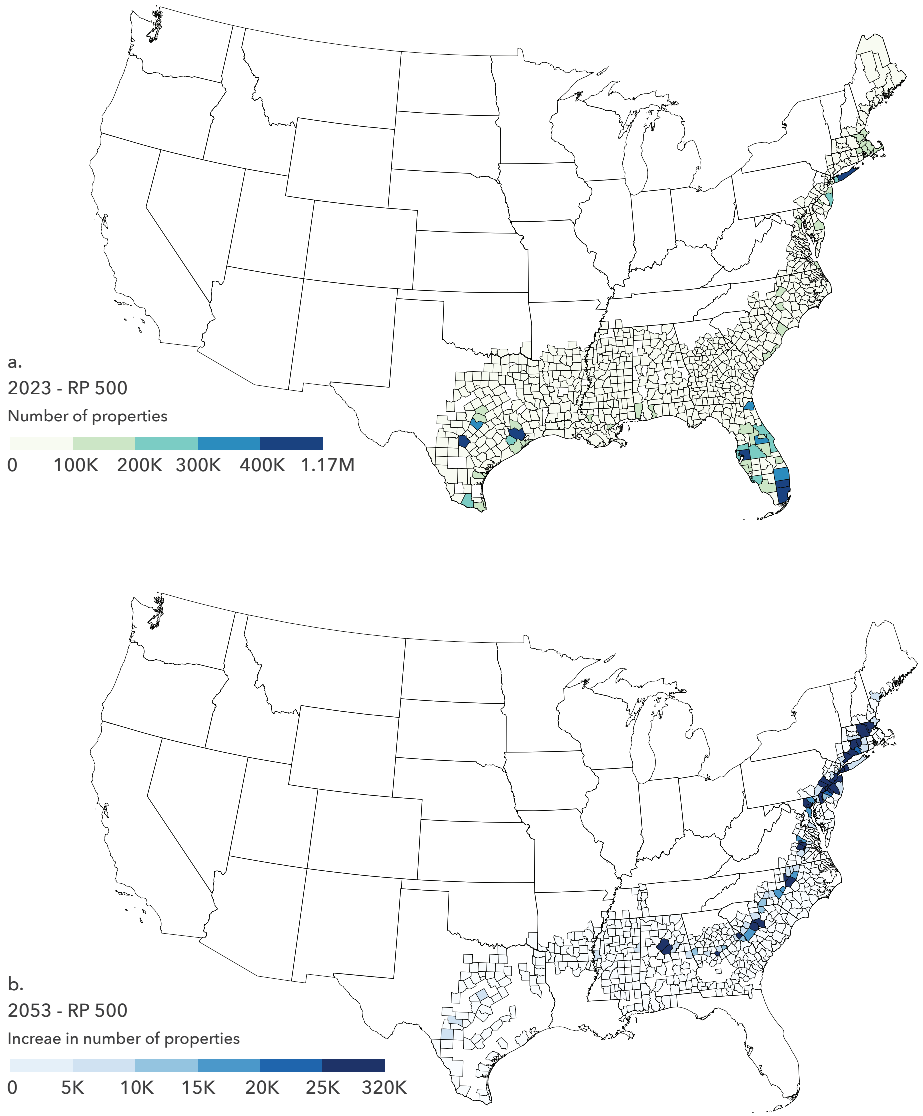
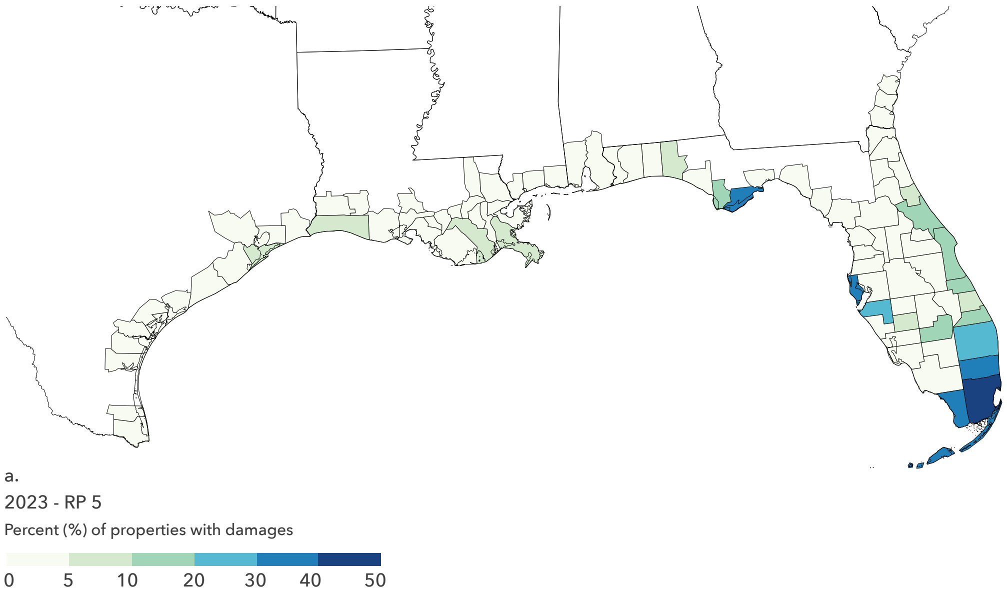


Figure 19. Number of properties with damages for RP 500 in 2023 (a) and the increase in the number of properties with damages for RP500 in 2053 (b)

Results

Beyond the number of properties with damage, the percentage of properties in an area that might experience damage is useful to estimate the level of vulnerability for communities. When higher percentages of properties in an area are expected to experience damage at one time, there may be significant consequences for community recovery. Areas throughout Florida are expected to have high percentages of properties (up to 45% in Miami-Dade) with some level of damage in even the 5 year return period scenario. In a span of five years, nearly half of all properties within some of these counties are likely to be damaged by tropical cyclone winds. For the higher return periods, such as the 500 year or 3000 year RPs, higher percentages of properties along the mid-Atlantic coast and throughout the Northeast may be damaged (Figure 20). These numbers increase over 30 years when accounting for climate change.



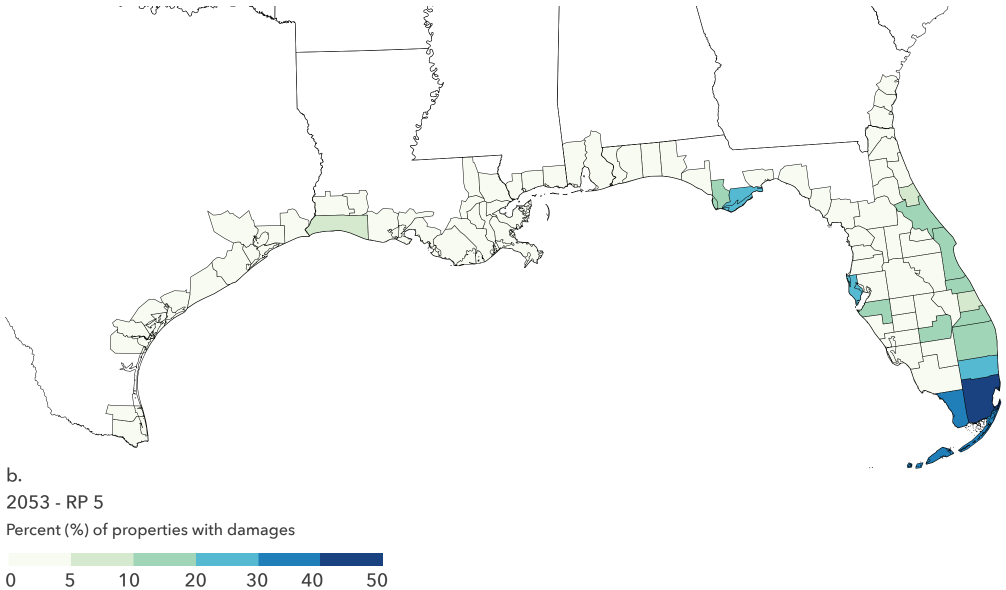


Figure 20. Percentages of properties with damages for different return periods, for 2023 (a) and 2053 (b).
Some counties, such as throughout Florida, already experience the maximum number of potentially damaged properties in the high return periods this year.
Additionally, some counties may have low percentages of properties that may be damaged as not all properties have buildings or building characteristics.

Results

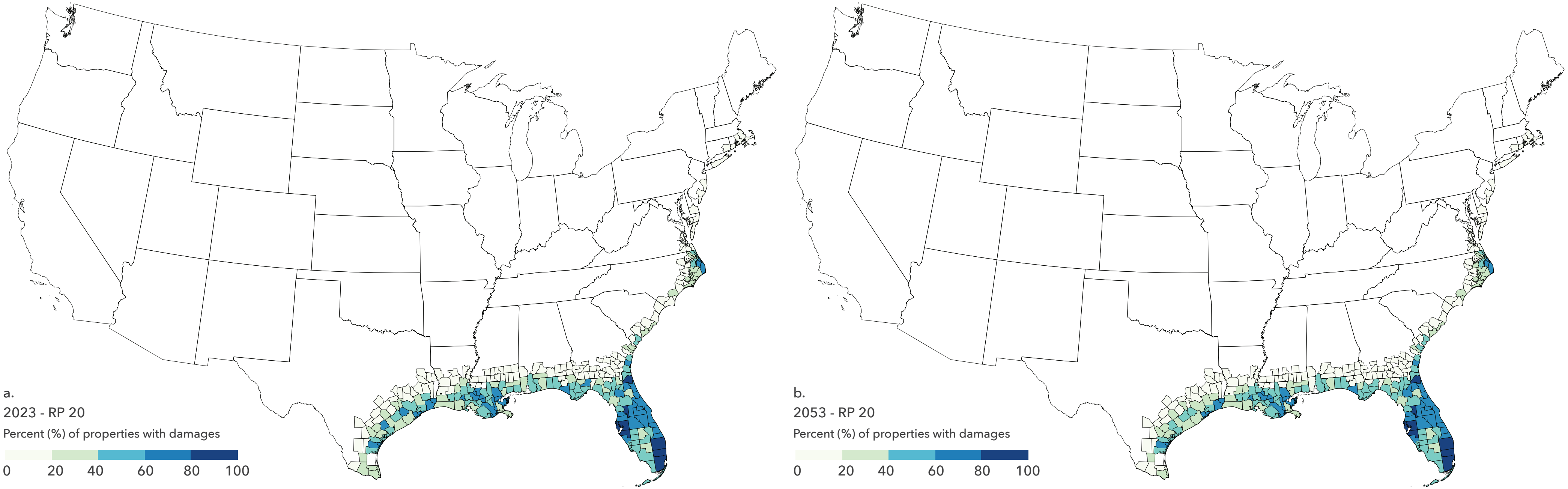


Figure 20. Percentages of properties with damages for different return periods, for 2023 (a) and 2053 (b).
Some counties, such as throughout Florida, already experience the maximum number of potentially damaged properties in the high return periods this year.
Additionally, some counties may have low percentages of properties that may be damaged as not all properties have buildings or building characteristics.

Results

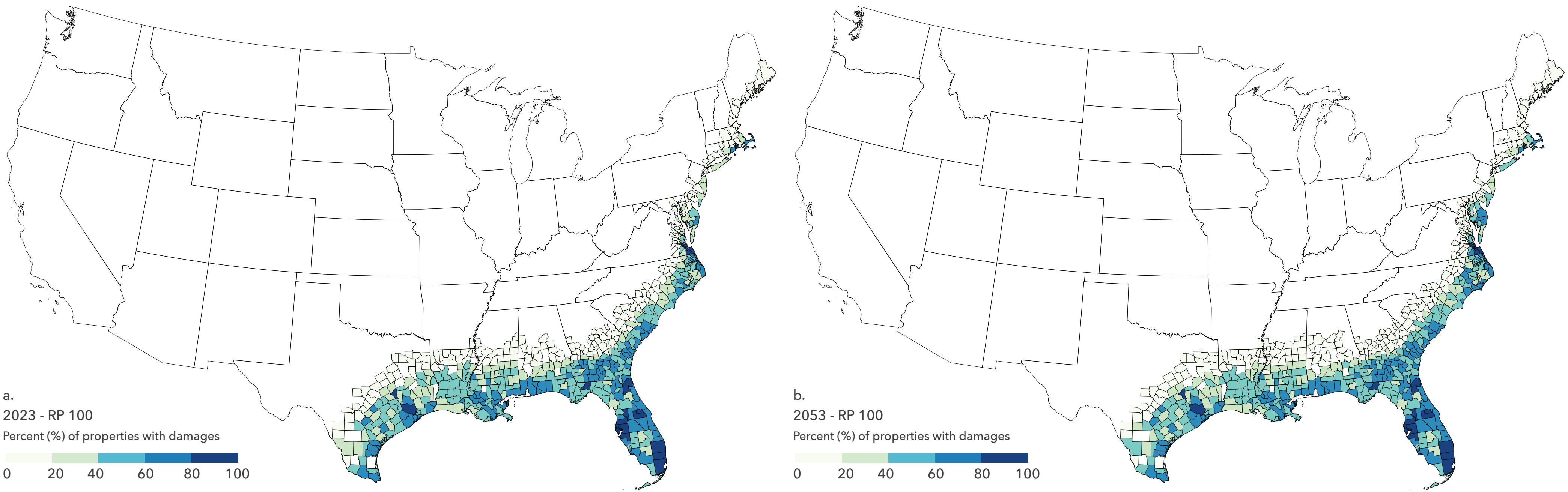


Figure 20. Percentages of properties with damages for different return periods, for 2023 (a) and 2053 (b).
Some counties, such as throughout Florida, already experience the maximum number of potentially damaged properties in the high return periods this year.
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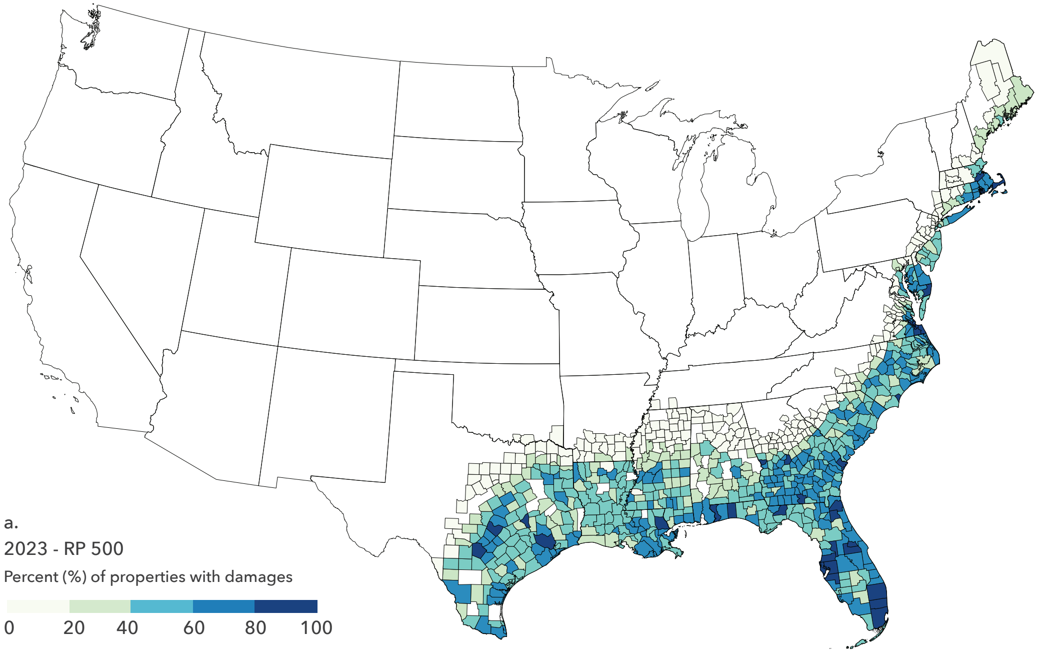
Results



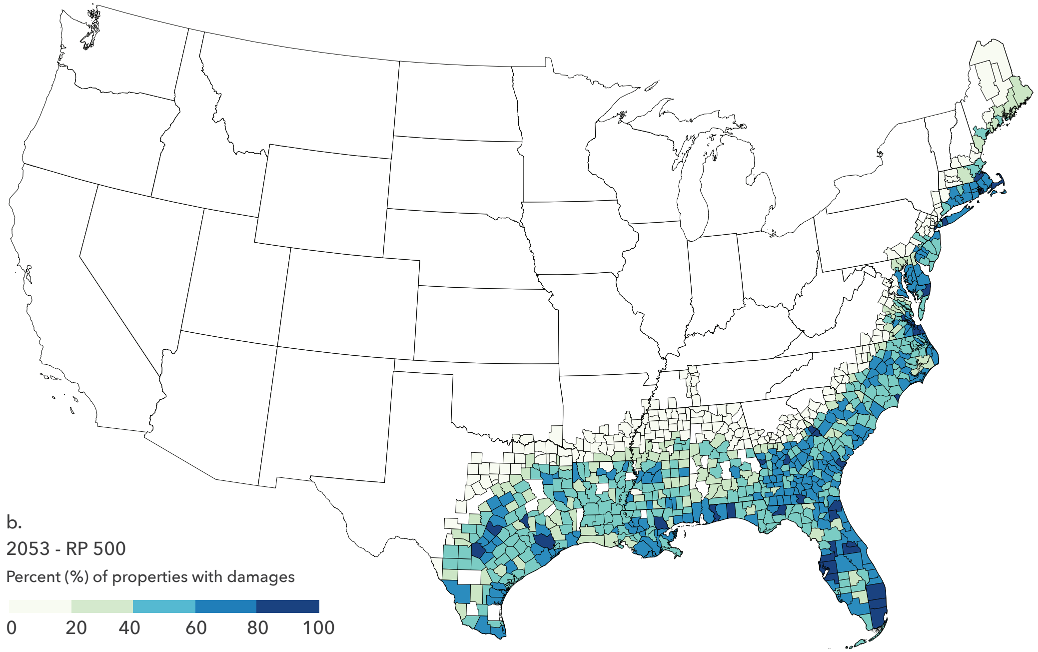


Figure 20. Percentages of properties with damages for different return periods, for 2023 (a) and 2053 (b).
Some counties, such as throughout Florida, already experience the maximum number of potentially damaged properties in the high return periods this year.
Additionally, some counties may have low percentages of properties that may be damaged as not all properties have buildings or building characteristics.

Results

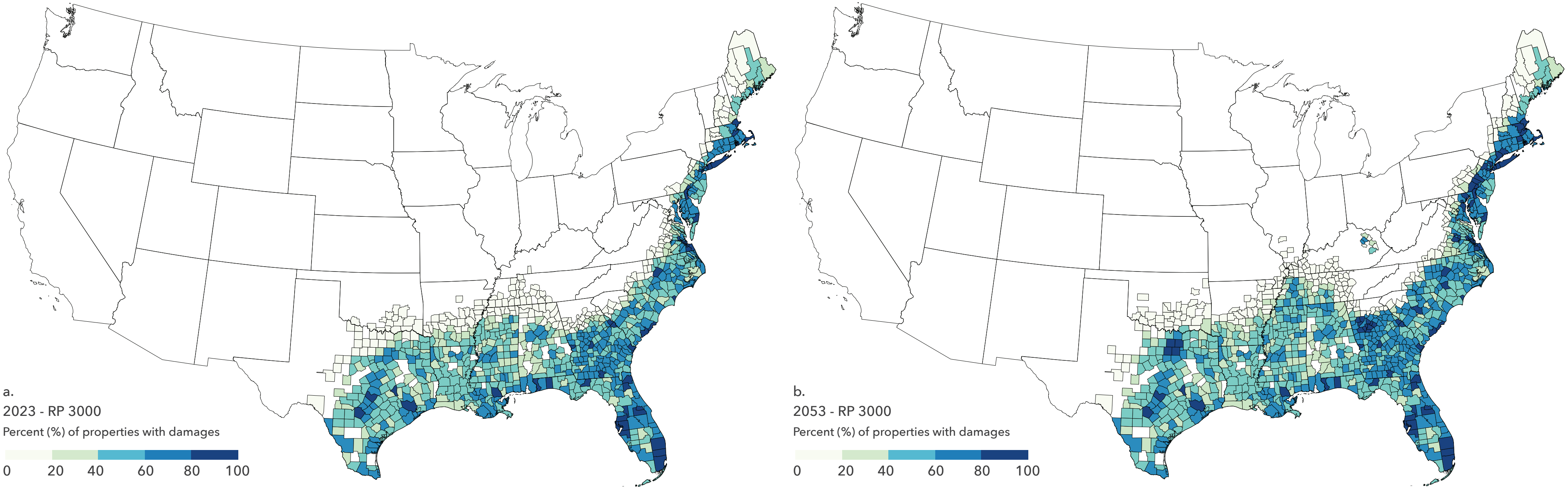


Figure 20. Percentages of properties with damages for different return periods, for 2023 (a) and 2053 (b).
Some counties, such as throughout Florida, already experience the maximum number of potentially damaged properties in the high return periods this year.
Additionally, some counties may have low percentages of properties that may be damaged as not all properties have buildings or building characteristics.

Results

Recognizing how average annual losses are increasing, in both absolute terms and relative to overall property values, due to increased hurricane wind risk from climate change is useful to:

1. Identify areas and sectors that are particularly vulnerable to changes in hurricane wind risk, allowing for targeted adaptation measures. Areas that have high proportions of AAL to property values may see large losses over shorter time periods. Additionally, areas that increase significantly from low proportions of AAL to overall property values, to higher proportions in the next 30 years, should understand how much their overall risk is changing.
2. Inform risk management and insurance decisions, allowing for better protection against potential losses. AAL estimates are informative for property owners, insurers, and reinsurance entities to understand how much funding should be made available for recovery from damaging hurricane wind events.
3. Inform investment decisions, allowing for more informed choices about which projects and assets are likely to be more resilient in the face of a changing climate.
4. Guide policy decisions at the local, national, and international level, allowing for more effective action to reduce the exposure of important assets and build resilience to the impacts of changing hurricane wind patterns.

While some areas may have similar counts of properties likely to be damaged, the building standards, values of buildings, and wind speeds, the total likely cost of damage may vary considerably depending on the types of buildings in those areas. Areas which differ in the make-up of types of buildings (such as cost, or use-type), may also see significant differences between their total costs, even when the count of buildings with damage is similar (Figure 21).

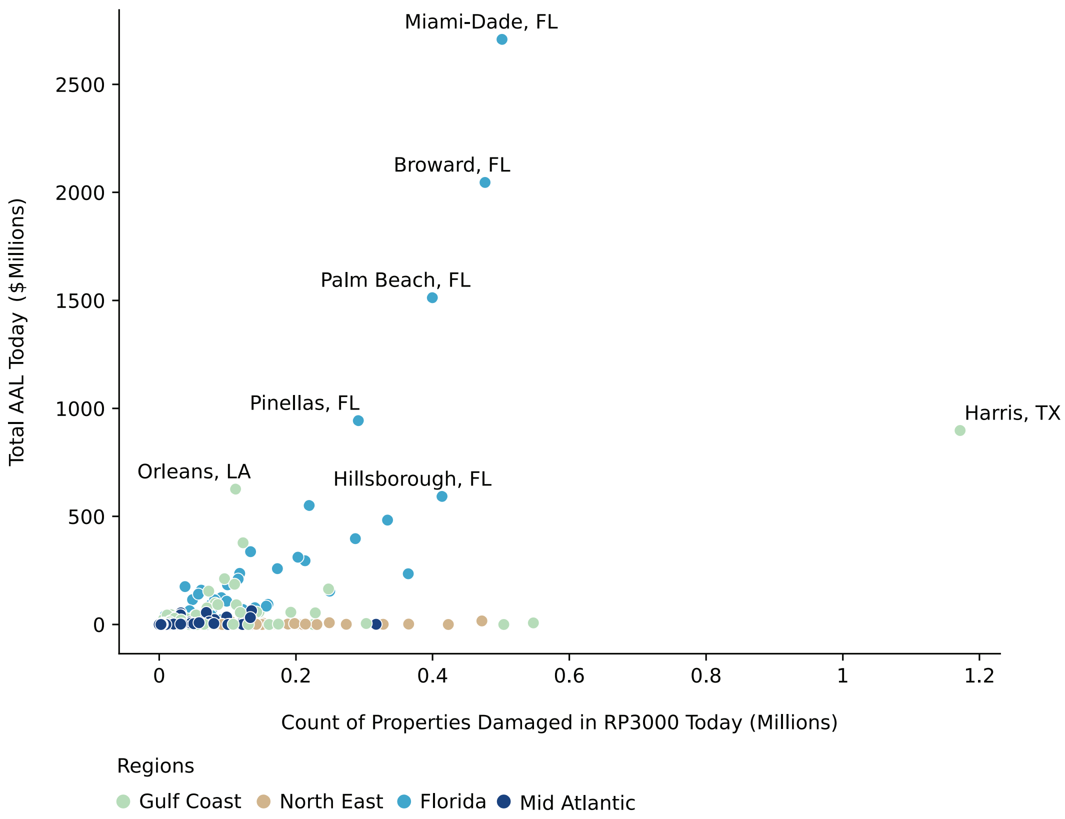


Figure 21. Count of properties with damage in 2023 for RP3000, versus total AAL ($MM), by county.

Results

Estimates of the AAL associated with a property are an important indicator. AAL contains information on the magnitude of wind speeds, the probabilities of those wind speeds occurring, and how much damage a property might sustain on an annualized basis due to varying wind speeds. By calculating the average losses that are likely to occur in a given area per year, the potential cost of premiums for insuring properties in that area may be better estimated. Additionally, AAL estimates can help citizens, governments, and industries identify areas that are particularly vulnerable to wind losses. This information can help governments, property owners, and communities develop targeted policies to protect property assets and risk management strategies to reduce the potential losses.

The counties expected to have the greatest estimated AAL in current environmental conditions due to hurricane wind risk are Miami-Dade, FL; Broward, FL; Palm Beach, FL; Pinellas, FL; and Harris, TX, with approximately $2.71 billion, $2.05 billion, $1.51 billion, $943 million, and $897 million in AAL, respectively (Table 9). The list of cities with the greatest AAL under current environmental conditions are topped by New Orleans, LA; Miami, FL; Jacksonville, FL; Fort Lauderdale, FL; and Houston, TX, respectively (Table 10).

Table 9. Top counties by AAL in 2023

County	AAL 2023
Miami-Dade, FL	$2,708,500,000
Broward, FL	$2,046,200,000
Palm Beach, FL	$1,512,900,000
Pinellas, FL	$943,600,000
Harris, TX	$897,400,000
Orleans, LA	$626,400,000
Hillsborough, FL	$592,300,000
Brevard, FL	$551,000,000
Duval, FL	$483,100,000
Lee, FL	$396,700,000
Galveston, TX	$377,800,000
Manatee, FL	$336,400,000
Volusia, FL	$311,300,000
Pasco, FL	$295,000,000
Sarasota, FL	$257,900,000
Collier, FL	$236,500,000
Orange, FL	$234,200,000
Jefferson, LA	$211,400,000
St. Lucie, FL	$209,700,000
Nueces, TX	$186,100,000

Table 10. Top cities by AAL in 2023

City	AAL 2023
New Orleans, LA	$626,400,000
Miami, FL	$539,000,000
Jacksonville, FL	$440,600,000
Fort Lauderdale, FL	$320,200,000
Houston, TX	$306,500,000
St. Petersburg, FL	$277,900,000
Hollywood, FL	$199,500,000
Tampa, FL	$187,000,000
Corpus Christi, TX	$167,500,000
Miami Beach, FL	$152,100,000
Pembroke Pines, FL	$147,400,000
Boca Raton, FL	$147,000,000
Hialeah, FL	$136,600,000
Miramar, FL	$136,200,000
Coral Gables, FL	$131,200,000
Cape Coral, FL	$130,600,000
West Palm Beach, FL	$124,600,000
Plantation, FL	$123,800,000
Port St. Lucie, FL	$122,800,000
Coral Springs, FL	$120,300,000

Results

The counties that are expected to have the greatest absolute increases in AAL over the next 30 years are Duval, FL; Palm Beach, FL; Pinellas, FL; Brevard, FL; and Hillsborough, FL, with increases of approximately $119 million, $113 million, $104 million, $102 million, and $87 million, respectively (Figure 22 and Table 11). Other counties on the top 20 list are spread through Florida, Texas, South Carolina, North Carolina, Virginia, and Georgia. Increases in AAL appear to be primarily driven by potential future hurricane exposure moving up the Atlantic coast of Florida.

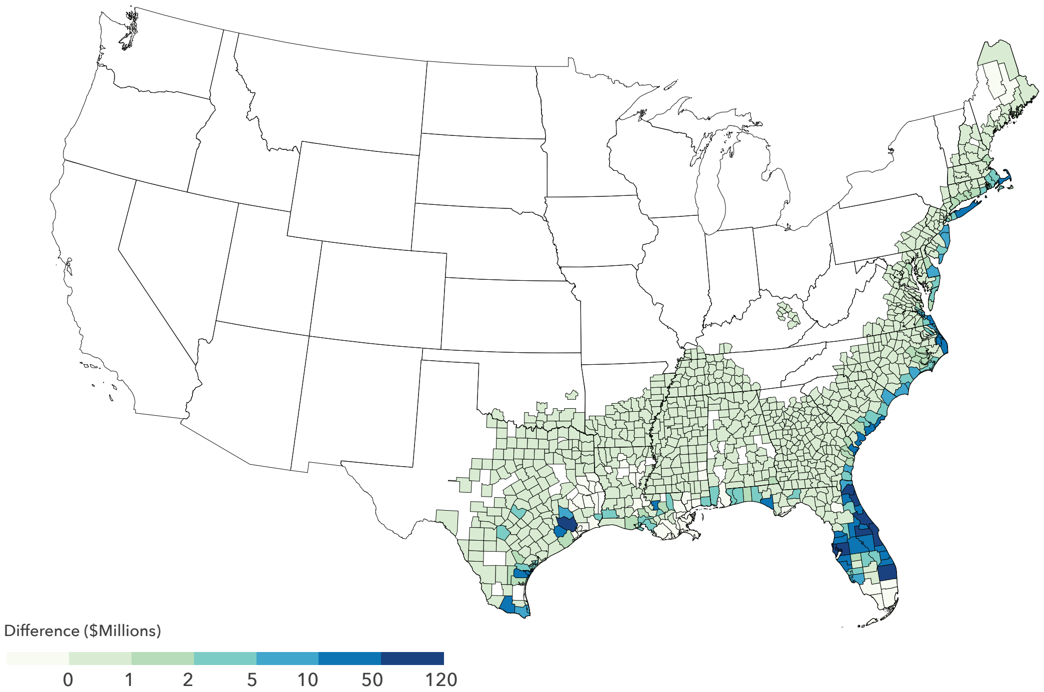


Figure 22. The estimated absolute increase in AAL over 30 years by county, in $Millions.

Table 11. Top counties by absolute increase in AAL over 30 years

County	AAL 2023	AAL 2053	Increase in AAL
Duval, FL	$483,100,000	$602,500,000	$119,400,000
Palm Beach, FL	$1,512,900,000	$1,625,900,000	$113,000,000
Pinellas, FL	$943,600,000	$1,047,200,000	$103,600,000
Brevard, FL	$551,000,000	$652,600,000	$101,600,000
Hillsborough, FL	$592,300,000	$679,300,000	$87,100,000
Orange, FL	$234,200,000	$307,500,000	$73,300,000
Harris, TX	$897,400,000	$957,800,000	$60,500,000
Volusia, FL	$311,300,000	$366,600,000	$55,300,000
St. Johns, FL	$183,300,000	$237,900,000	$54,600,000
Polk, FL	$154,200,000	$201,600,000	$47,400,000
Pasco, FL	$295,000,000	$337,000,000	$42,000,000
Beaufort, SC	$55,900,000	$90,600,000	$34,700,000
Manatee, FL	$336,400,000	$367,400,000	$30,900,000
Nueces, TX	$186,100,000	$216,300,000	$30,200,000
Seminole, FL	$84,900,000	$112,100,000	$27,200,000
Flagler, FL	$115,000,000	$140,600,000	$25,600,000
Chatham, GA	$34,700,000	$59,700,000	$25,000,000
St. Lucie, FL	$209,700,000	$233,800,000	$24,100,000
Clay, FL	$91,100,000	$113,800,000	$22,700,000
Charleston, SC	$63,600,000	$85,600,000	$22,000,000

Results

The cities that are expected to have the greatest absolute increase in AAL over the next 30 years are Jacksonville, FL; Houston, TX; Corpus Christi, TX; Tampa, FL; and St. Petersburg, FL, with increases of approximately $108.5 million, $29.5 million, $26.7 million, $23.5 million, and $23.4 million, respectively. Other cities on the top 20 list of greatest absolute increases in AAL over the next 30 years are spread through Florida, Texas, Georgia, South Carolina, and Virginia (Table 12).

Examining the percentage increase in AAL provides another view of the impact of climate change. Among counties with at least $1 million in AAL this year, Kings County, NY tops the list with a 296% increase in AAL. Rounding out the top five counties by largest percentage increase in AAL over the next 30 years, Nassau, NY will see a 219% increase; Monmouth, NJ will experience a 172% increase; Newport News, VA will have an increase of 157%; and York, VA will experience a 148% increase (Table 13).

Table 12. Top cities by absolute increase in AAL over 30 years

City	AAL 2023	AAL 2053	Increase in AAL
Jacksonville, FL	$440,600,000	$549,100,000	$108,500,000
Houston, TX	$306,500,000	$336,000,000	$29,500,000
Corpus Christi, TX	$167,500,000	$194,200,000	$26,700,000
Tampa, FL	$187,000,000	$210,500,000	$23,500,000
St. Petersburg, FL	$277,900,000	$301,300,000	$23,400,000
Palm Bay, FL	$89,300,000	$110,300,000	$21,000,000
Virginia Beach, VA	$31,500,000	$52,100,000	$20,500,000
Palm Coast, FL	$85,700,000	$105,300,000	$19,600,000
Port St. Lucie, FL	$122,800,000	$139,300,000	$16,500,000
Orlando, FL	$36,300,000	$51,500,000	$15,100,000
Clearwater, FL	$97,400,000	$112,300,000	$14,900,000
Melbourne, FL	$71,800,000	$85,500,000	$13,700,000
Hilton Head Island, SC	$25,100,000	$38,100,000	$13,000,000
West Palm Beach, FL	$124,600,000	$135,300,000	$10,600,000
Savannah, GA	$11,000,000	$21,700,000	$10,600,000
Palm Beach Gardens, FL	$81,700,000	$92,200,000	$10,500,000
Charleston, SC	$25,200,000	$34,600,000	$9,400,000
Daytona Beach, FL	$44,800,000	$53,800,000	$9,000,000
Largo, FL	$56,400,000	$65,100,000	$8,700,000
Spring Hill, FL	$70,400,000	$78,700,000	$8,300,000

Table 13. Top counties by percentage increase in AAL over 30 years

County	AAL 2023	AAL 2053	% Increase in AAL
Kings, NY	$1,300,000	$5,200,000	296%
Nassau, NY	$1,500,000	$4,800,000	219%
Monmouth, NJ	$4,100,000	$11,300,000	172%
Newport News, VA	$3,300,000	$8,400,000	157%
York, VA	$1,600,000	$3,900,000	148%
Suffolk, VA	$1,300,000	$3,000,000	124%
Hampton, VA	$5,600,000	$12,200,000	117%
Suffolk, NY	$16,400,000	$34,700,000	112%
Portsmouth, VA	$2,400,000	$4,900,000	105%
Chesapeake, VA	$4,200,000	$8,600,000	105%
New London, CT	$1,800,000	$3,500,000	95%
Ocean, NJ	$7,900,000	$15,300,000	94%
Atlantic, NJ	$4,900,000	$9,100,000	86%
Norfolk, VA	$8,200,000	$15,300,000	85%
Accomack, VA	$3,500,000	$6,500,000	83%
Montgomery, AL	$1,100,000	$1,900,000	78%
Essex, MA	$1,900,000	$3,400,000	77%
Northampton, VA	$1,700,000	$3,000,000	73%
Chatham, GA	$34,700,000	$59,700,000	72%
Plymouth, MA	$5,200,000	$8,800,000	69%

**Filtered to counties with at least $1 million in AAL in the current year*

Results

The cities that will experience the largest percentage increase in AAL over 30 years (filtered by those with at least $1 million in AAL this year) are primarily located along the Mid-Atlantic and Northeast coasts (Table 14). The top 5 cities by percentage increase in AAL include New York, NY (increasing by 302%); Newport News, VA (157%); Suffolk, VA (124%); Hampton, VA (117%); and Bluffton, SC (109%). Rounding out the top ten include Portsmouth, VA; Chesapeake, VA; Savannah, GA; Norfolk, VA; and Port Royal, SC.

While the estimated AAL due to tropical cyclone wind exposure is concentrated in Florida, it is important for citizens, governments, and industry to also have information on how AAL per property varies, rather than only total AAL by a larger area. The total estimated AAL within a region may be more influenced by the number of buildings damaged rather than the damage incurred by each building. In Florida, the average AAL per property with annualized losses is approximately $2,063, while it is $1,265 in Louisiana, and is only $460 in Texas. This can be a helpful proxy to estimate the average cost for a wind insurance product per home in each state, and allows an understanding of the magnitude of the difference in risk.

Table 14. Top cities by percentage increase in AAL over 30 years

City	AAL 2023	AAL 2053	% Increase in AAL
New York, NY	$2,100,000	$8,400,000	302%
Newport News, VA	$3,300,000	$8,400,000	157%
Suffolk, VA	$1,300,000	$3,000,000	124%
Hampton, VA	$5,600,000	$12,200,000	117%
Bluffton, SC	$2,400,000	$5,000,000	109%
Portsmouth, VA	$2,400,000	$4,900,000	105%
Chesapeake, VA	$4,200,000	$8,600,000	105%
Savannah, GA	$11,000,000	$21,700,000	96%
Norfolk, VA	$8,200,000	$15,300,000	85%
Port Royal, SC	$1,900,000	$3,300,000	75%
Beaufort, SC	$4,300,000	$7,300,000	70%
Barnstable Town, MA	$4,300,000	$7,300,000	70%
Whitemarsh Island, GA	$1,700,000	$2,900,000	68%
Ocean City, NJ	$3,200,000	$5,400,000	67%
Elizabeth City, NC	$1,500,000	$2,600,000	66%
Virginia Beach, VA	$31,500,000	$52,100,000	65%
Alice, TX	$1,400,000	$2,300,000	62%
Wilmington Island, GA	$4,500,000	$7,200,000	60%
Newport, RI	$1,500,000	$2,300,000	58%
Ocean Pines, MD	$1,400,000	$2,200,000	57%

**Filtered to counties with at least $1 million in AAL in the current year*

Results

The proportion of total AAL to the total property values for an area may help decision-makers discern how much of the property stock in an area is expected to be damaged over time. When considering which counties have the highest proportion of AAL to total residential property values, the top 20 list is dominated by counties in Texas, Louisiana, and Florida (Figure 23 and Table 15). The top five counties with the highest AAL to property value ratio are Calhoun, TX (with a ratio of 2.7%); Orleans, LA (2.4%); St. Bernard, LA (2.4%); Galveston, TX (1.9%); and St. Mary, LA (1.8%). Rounding out the top ten include Gulf, FL (1.7%); Jackson, TX (1.5%); Refugio, TX (1.4%); Miami-Dade, FL (1.4%); and Nueces, TX (1.4%). On average, the most exposed county of Calhoun, TX can expect to write off the equivalent amount of 2.7 of every 100 properties every year.

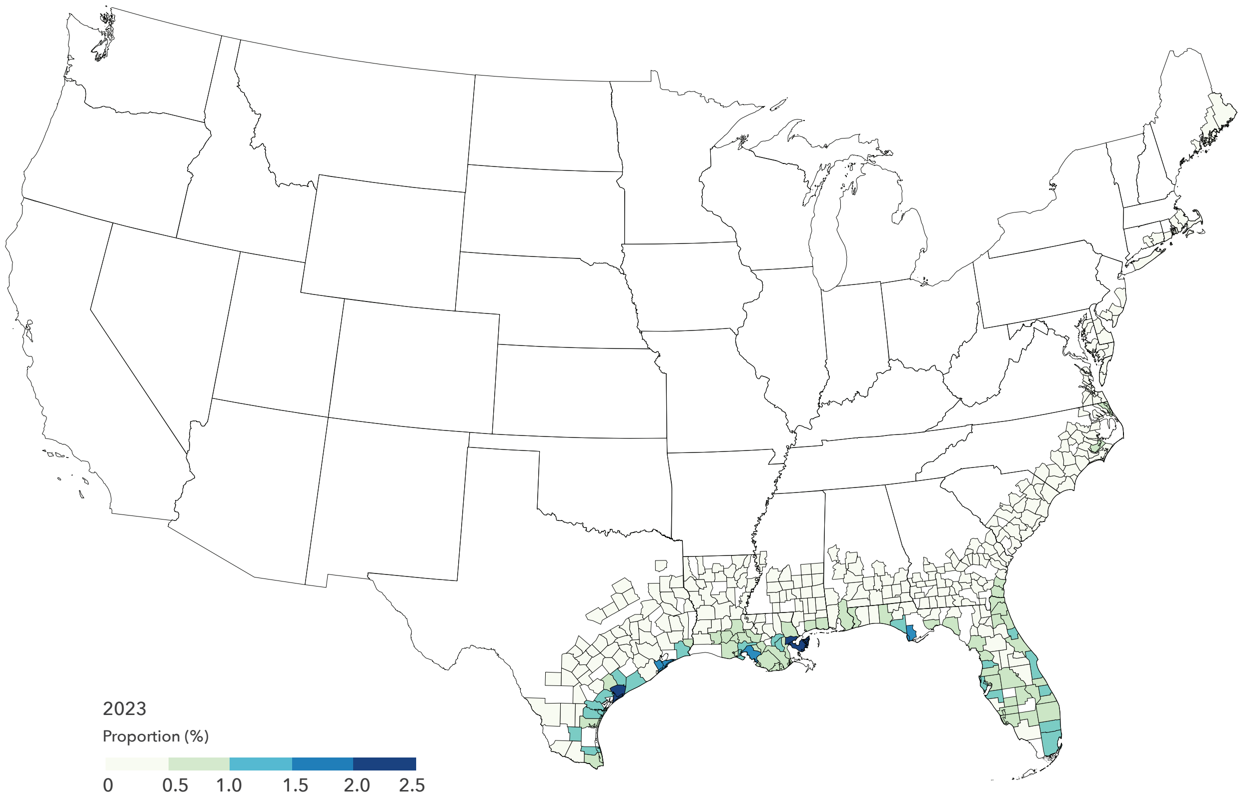


Figure 23. Proportion of AAL to total property value (2023)

Results

When considering the top counties with the highest proportion of AAL to property value in 30 years, holding current property values constant to isolate the impact of changing hurricane wind patterns, the top 20 list is dominated by a similar makeup of counties across Texas, Florida, and Louisiana. Calhoun, TX; Orleans, LA; and St. Bernard, TX respectively remain in the top three county spots, with AAL to property value ratios of 2.8%, 2.3%, and 2.3%, respectively. The top five are rounded out by St. Mary, LA (2.0%) and Galveston, TX (1.8%). These are followed by Jackson, TX; Brevard, FL; San Patricio, TX; Miami-Dade, FL; and Broward, FL.

Table 15. Top counties by AAL to total property value ratio

County	AAL 2023 ($MM)	AAL 2053 ($MM)	Total Property Value ($MM)	AAL to Value Ratio 2023	AAL to Value Ratio 2053	Difference in Ratio
Calhoun, TX	$22.3	$22.8	$828,000,000	2.7%	2.8%	0.1%
Orleans, LA	$626.4	$599.2	$25,582,000,000	2.4%	2.3%	-0.1%
St. Bernard, LA	$42.4	$40.4	$1,778,000,000	2.4%	2.3%	-0.1%
Galveston, TX	$377.8	$365.9	$20,124,000,000	1.9%	1.8%	-0.1%
St. Mary, LA	$29.6	$32.5	$1,631,000,000	1.8%	2.0%	0.2%
Gulf, FL	$18.8	$19.2	$1,135,000,000	1.7%	1.7%	0.0%
Jackson, TX	$7.1	$7.5	$488,000,000	1.5%	1.5%	0.1%
Refugio, TX	$3.5	$3.9	$242,000,000	1.4%	1.6%	0.2%
Miami-Dade, FL	$2,708.5	$2,541.8	$191,504,000,000	1.4%	1.3%	-0.1%
Nueces, TX	$186.1	$216.3	$150,582,000,000	1.4%	1.6%	0.0%
Broward, FL	$2,046.2	$1,985.1	$13,645,000,000	1.4%	1.3%	0.2%
Iberia, LA	$36.2	$38.6	$2,694,000,000	1.3%	1.4%	0.1%
St. Charles, LA	$45.8	$45.9	$3,599,000,000	1.3%	1.3%	0.0%
Flagler, FL	$115.0	$140.6	$9,135,000,000	1.3%	1.5%	0.3%
St. John the Baptist, LA	$26.7	$27.2	$2,180,000,000	1.2%	1.2%	0.0%
San Patricio, TX	$28.0	$32.8	$45,453,000,000	1.2%	1.4%	0.2%
Brevard, FL	$551.0	$652.6	$2,309,000,000	1.2%	1.4%	0.2%
Pinellas, FL	$943.6	$1,047.2	$79,300,000,000	1.2%	1.3%	0.1%
Matagorda, TX	$16.5	$16.6	$1,406,000,000	1.2%	1.2%	0.0%
Bay, FL	$124.0	$137.0	$10,826,000,000	1.1%	1.3%	0.1%

Results

The counties with the greatest change in the ratio of AAL to total property values over the next 30 years under changing environmental conditions include counties across Florida, Texas, Virginia, Louisiana, North Carolina, and Georgia. Note that even though some areas throughout the Gulf Coast are expected to see decreases in risk over the next 30 years, the increase in risk further inland still results in the Gulf region representing some of the largest growth in this metric. The top five counties by increase in this ratio are Flagler, FL (with an additional 0.3%), and then Currituck, NC; Brooks, TX; Brevard, FL; and Duval, FL, all with increases of 0.2% of total property value (Table 16).

Table 16. Top counties by change in ratio of AAL to total property value over 30 years

County	AAL 2023	AAL 2053	Total Property Value	AAL to Value Ratio 2023	AAL to Value Ratio 2053	Difference in Ratio
Flagler, FL	$114,995,000	$140,591,000	$9,135,000,000	1.3%	1.5%	0.3%
Currituck, NC	$13,116,000	$18,989,000	$2,435,000,000	0.5%	0.8%	0.2%
Brooks, TX	$1,098,000	$1,342,000	$107,000,000	1.0%	1.3%	0.2%
Brevard, FL	$551,020,000	$652,592,000	$45,453,000,000	1.2%	1.4%	0.2%
Duval, FL	$483,080,000	$602,495,000	$53,544,000,000	0.9%	1.1%	0.2%
Nueces, TX	$186,110,000	$216,344,000	$13,645,000,000	1.4%	1.6%	0.2%
San Patricio, TX	$28,020,000	$32,806,000	$2,309,000,000	1.2%	1.4%	0.2%
St. Johns, FL	$183,252,000	$237,871,000	$29,332,000,000	0.6%	0.8%	0.2%
Clay, FL	$91,097,000	$113,758,000	$12,393,000,000	0.7%	0.9%	0.2%
Refugio, TX	$3,460,000	$3,882,000	$242,000,000	1.4%	1.6%	0.2%
Jim Wells, TX	$4,016,000	$5,959,000	$1,113,000,000	0.4%	0.5%	0.2%
St. Mary, LA	$29,608,000	$32,453,000	$1,631,000,000	1.8%	2.0%	0.2%
Pamlico, NC	$4,464,000	$5,915,000	$832,000,000	0.5%	0.7%	0.2%
Duval, TX	$637,000	$957,000	$199,000,000	0.3%	0.5%	0.2%
Live Oak, TX	$1,478,000	$2,161,000	$433,000,000	0.3%	0.5%	0.2%
Polk, FL	$154,183,000	$201,617,000	$30,467,000,000	0.5%	0.7%	0.2%
Volusia, FL	$311,266,000	$366,585,000	$35,685,000,000	0.9%	1.0%	0.2%
Washington, NC	$862,000	$1,479,000	$402,000,000	0.2%	0.4%	0.2%
Kleberg, TX	$5,058,000	$6,167,000	$730,000,000	0.7%	0.8%	0.2%
Beaufort, SC	$55,928,000	$90,634,000	$23,594,000,000	0.2%	0.4%	0.1%

Results

Florida Tropical Cyclone Wind Results

Much of the research into hurricane wind risk in Florida relies on historical data rather than probabilistic models. When comparing the historical landfall rate of Category 5 hurricanes in Florida to the likelihoods from the FSF-WM, this difference is especially visible (a 77% increase). Therefore, the typical "catastrophe" risk models used today in Florida by the [Florida Commission on Hurricane Loss Projection Methodology] are unable to capture a significant portion of the overall risk. Additionally, this gap (Figure 24) will continue to grow in the future with climate change. Without explicitly including the impacts of climate change in Florida's catastrophe modeling and risk analyses, the state faces significant financial vulnerability in the event of a major hurricane. The likelihood that a storm such as 2022's Category 4 Hurricane Ian could impact any location in Florida, and the probable damages that would result from such a storm, are quantifiable and predictable, and described in detail in this report.

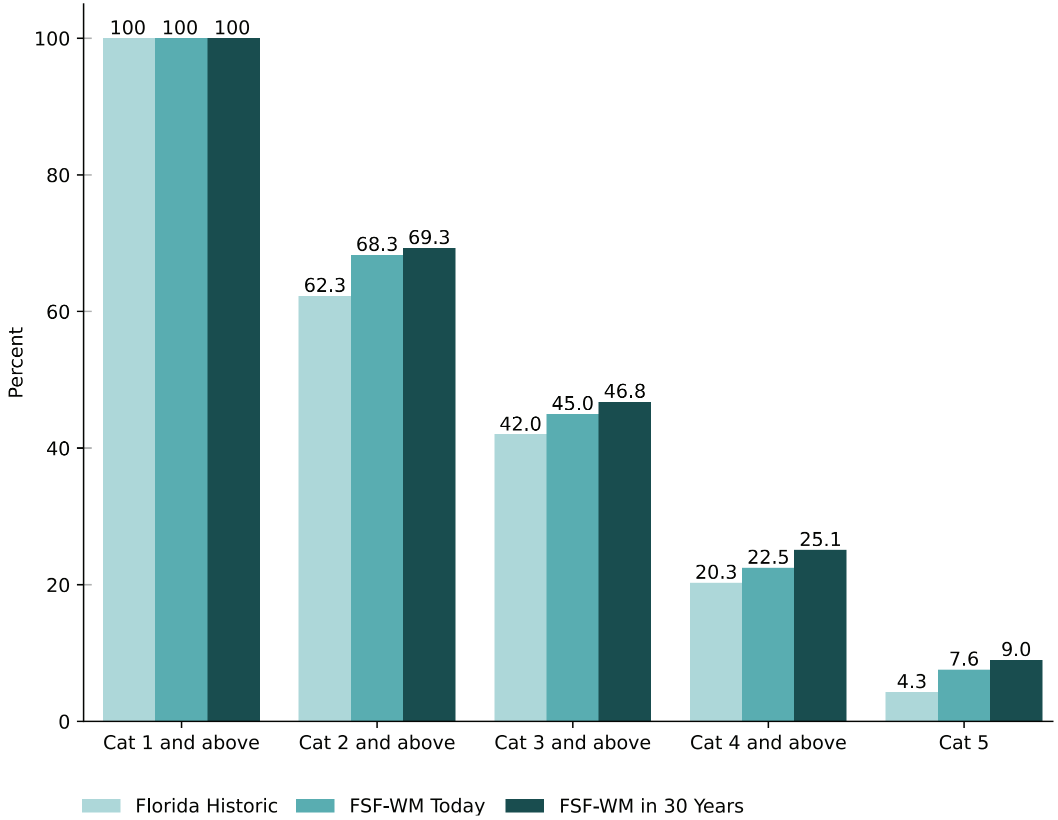
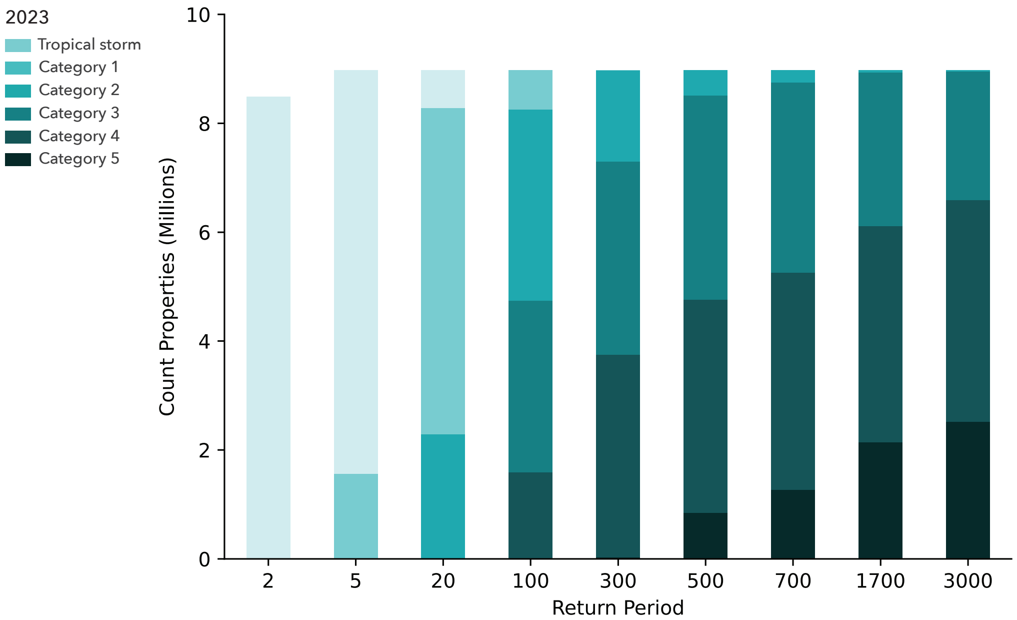


Figure 24: Fractional distribution of hurricanes' intensity at landfall in Florida from historical observations (light teal bars) and estimated from the FSF-WM in 2023 (medium teal) and 2053 (dark teal).

Results

Based on the current climate, rather than historical landfall rates, the current risk to the country may be more accurately calculated. The total estimated AAL due to tropical cyclone wind damage is approximately $18.5 billion, and it is expected to increase to $19.9 billion in 30 years. Florida makes up approximately 72% of these estimated annualized losses, with about $13.4 billion in AAL this year and over $14.3 billion in 30 years. For these reasons, it is critical to understand the risk in Florida distinctly from the rest of the country.

When looking only at the properties exposed and damaged within the state of Florida, the percentage of properties exposed to tropical cyclone winds levels off by the 5 year return period at about 100% (Figure 25). That means, within a span of approximately 5 years, it is likely that every property in Florida will experience tropical storm wind speeds or higher. Additionally, all properties in Florida are exposed to at least Category 1 level winds by the 100 year return period. That means that within a span of about 100 years, every property within Florida would be expected to experience, at least once, a Category 1 level hurricane or higher. Within a span of 20 years, approximately 92% of all properties within Florida are expected to experience Category 1 level or higher hurricane winds. Within a span of the next 5 years, approximately 17% of all properties within Florida are likely to experience at least Category 1 level hurricane winds.



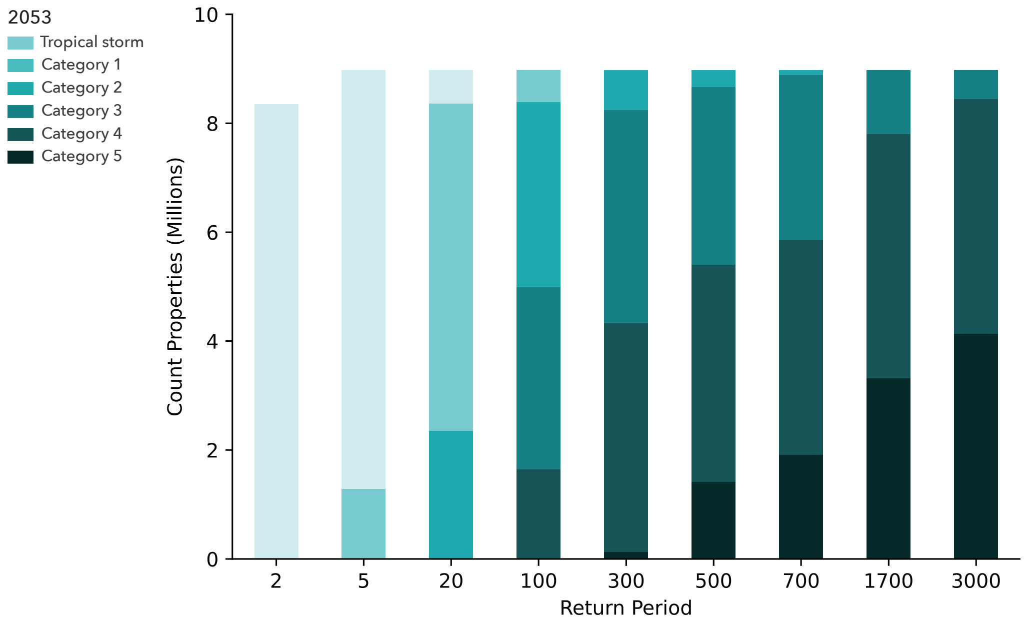


Figure 25. Florida properties exposed to storm categories by return period

Results

Category 5 hurricanes are characterized by extreme wind speeds that impart catastrophic damage to structures. In Florida, there are about 2.5 million properties with some probability of exposure to Category 5 hurricane winds this year. While this probability is relatively low, some counties have as much as a 0.5% likelihood this year of experiencing Category 5 winds. In 30 years, the number of properties with some chance of exposure to Category 5 wind conditions increases to approximately 4.1 million properties (Figure 26).

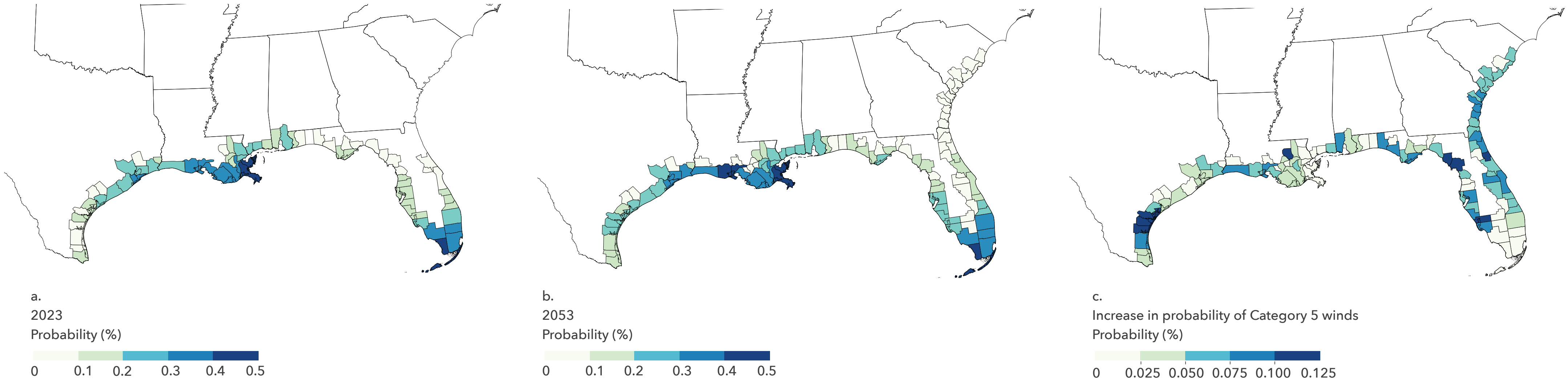


Figure 26. Estimated probability of Category 5 winds today (a), in 2053 (b) and the change in probability over that 30 year period (c).

Results

The severity of hurricane winds, even for low return periods, make it likely that large proportions of properties in areas throughout Florida will experience damage. For example, large percentages of properties in Florida are expected to be damaged even in the 20 year return period, where several counties may experience damage to 80%-90% of all properties. In the 500 year return period scenario, it is estimated that over 93% of all properties in Pinellas County may experience hurricane wind damage. This is followed by Broward (90.2%), Palm Beach (89.7%), Duval (89.1%), and Seminole (88.5%). These patterns are further displayed in Figure 27 and Table 17.

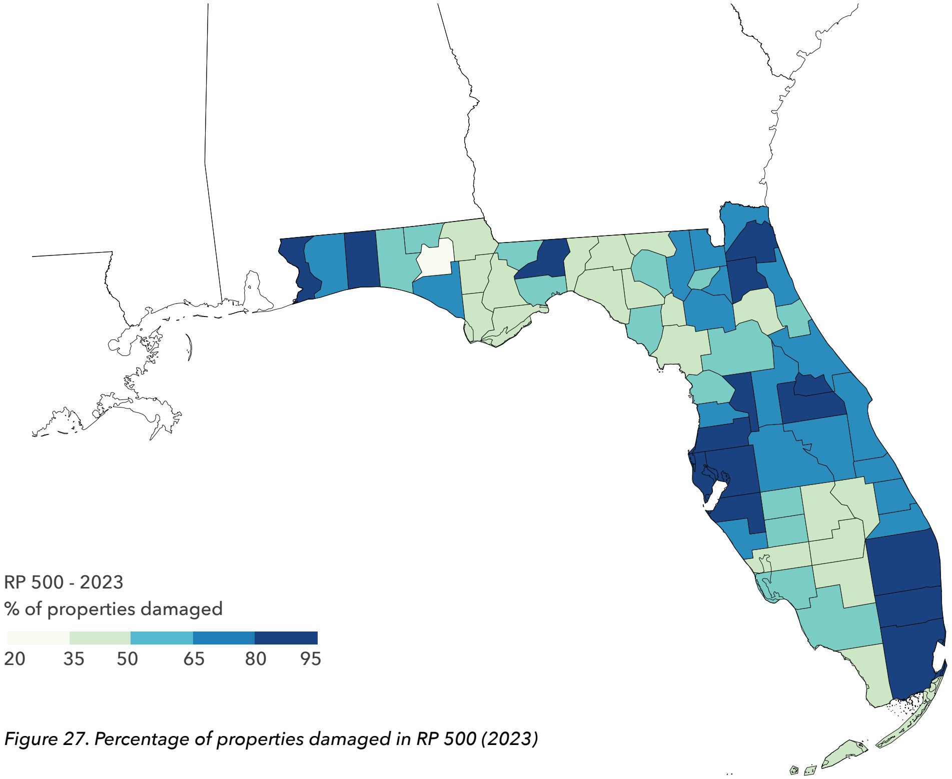


Figure 27. Percentage of properties damaged in RP 500 (2023)

Table 17. Top Florida counties by percentages of properties damaged (2023)

County	Property Count	% in RP 5	% in RP 20	% in RP 100	% in RP 500	% in RP 3000
Pinellas, FL	312,700	38.4%	92.2%	93.1%	93.1%	93.1%
Broward, FL	528,300	31.7%	86.5%	90.2%	90.2%	90.2%
Palm Beach, FL	445,700	23.9%	87.5%	89.6%	89.7%	89.7%
Duval, FL	375,000	2.3%	84.5%	89.1%	89.1%	89.1%
Seminole, FL	177,200	0.9%	74.7%	88.5%	88.5%	88.5%
Hillsborough, FL	470,400	1.2%	83.9%	87.9%	87.9%	87.9%
Miami-Dade, FL	571,000	44.6%	86.0%	87.8%	87.8%	87.8%
Orange, FL	419,2008	1.7%	79.7%	86.9%	86.9%	86.9%
Sumter, FL	82,300	0.2%	81.9%	84.3%	84.3%	84.3%
Leon, FL	107,800	0.0%	61.1%	82.7%	84.2%	84.2%
Manatee, FL	160,200	24.9%	82.2%	83.4%	83.4%	83.4%
Clay, FL	93,100	1.5%	78.4%	81.3%	81.3%	81.3%
Okaloosa, FL	93,700	0.5%	48.0%	78.6%	80.5%	81.3%
Escambia, FL	144,300	1.0%	53.4%	77.9%	80.5%	80.6%
Pasco, FL	265,500	1.4%	77.9%	80.4%	80.4%	80.4%
Alachua, FL	98,600	0.0%	73.6%	79.7%	79.7%	79.7%
St. Johns, FL	126,600	4.7%	76.0%	79.0%	79.0%	79.0%
Indian River, FL	79,400	15.6%	73.6%	77.4%	77.4%	77.4%
Bay, FL	117,700	4.6%	72.2%	77.2%	77.2%	77.2%
Osceola, FL	160,700	0.4%	72.2%	76.2%	76.2%	76.2%

Results

The AAL in Florida for this year is approximately $13.4 billion, and it is estimated to increase to approximately $14.3 billion in 30 years. The magnitude of this annualized risk in Florida contributes to insurance coverage challenges, especially as related to reinsurance. Having large amounts of annualized risk can lead to potentially large payouts in the event of a catastrophic loss, putting insurance and reinsurance companies under significant financial strain if this level of risk has not been anticipated.

In Florida, Miami-Dade County has the highest total AAL, with about $2.7 billion in the current year. This is followed by Broward with approximately $2.0 billion, Palm Beach with $1.5 billion, Pinellas County with $944 million, and Hillsborough with $592 million in AAL in 2023 (Figure 28a).

As hurricanes become proportionally stronger and move farther north up the Atlantic coast, areas within Florida may be less exposed to lower category hurricane wind conditions, even as their probability of exposure to major hurricane events increases. The expected decrease in exposure to hurricane conditions in the lower return periods for some counties, although minor, will cause expected AAL to decrease over the next 30 years. In Miami-Dade, holding property stock constant, the AAL from wind is expected to decrease in 30 years by approximately $37.3 million. Note that this decrease in exposure from the current year to 30 years in the future occurs only in a handful of counties, and is due to hurricane tracks shifting northwards, shifting wind exposure to more northern counties, and contributing to the overall increase for the state. The AAL is expected to increase over 30 years by approximately $119 million for Duval, FL; $113 million for Palm Beach, FL; $104 million for Pinellas, FL; $102 million for Brevard, FL; and $87 million for Hillsborough, FL (Figure 28c).

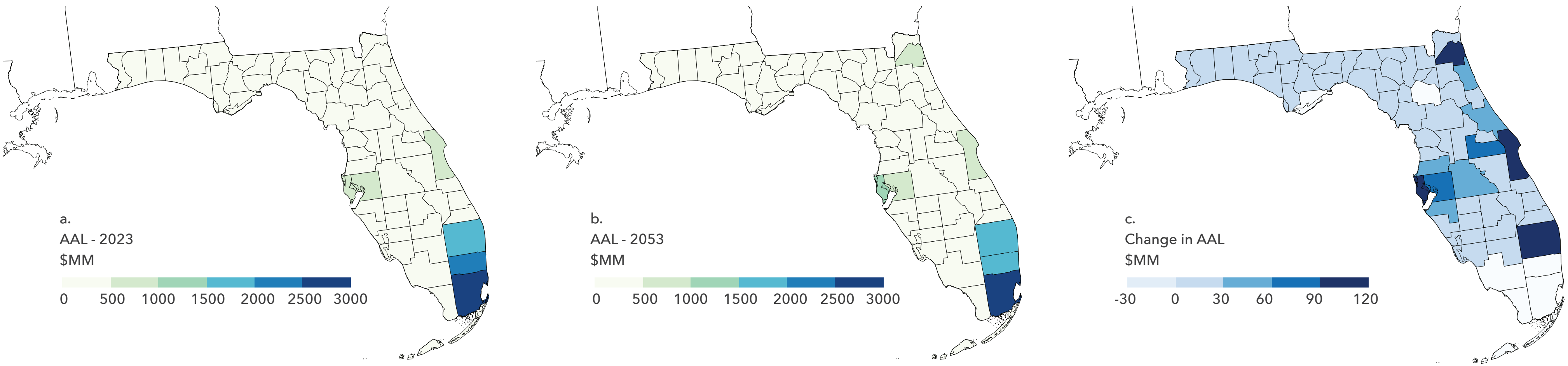


Figure 28. Florida's AAL for 2023 (a), 2053 (b) and change in AAL (c)

Results

By percent change in AAL, Seminole County is expected to see the largest increase in AAL over the next 30 years, by approximately 32%. Orange County is expected to increase by about 31%, Polk County by about 31%, St. Johns County by approximately 30%, and Osceola County by approximately 27%.

The Florida cities with the highest estimated AAL in the current year are Miami (with approximately $539 million in AAL), Jacksonville ($441 million), Fort Lauderdale ($320 million), St. Petersburg ($278 million), and Hollywood ($200 million), respectively. These are followed by Tampa ($187 million), Miami Beach ($152 million), Pembroke Pines ($147 million), Boca Raton ($147 million), and Hialeah ($137 million), rounding out the top 10 cities by AAL this year (Table 18).

Table 18. Top cities in Florida by AAL (2023) ($)

City	AAL 2023	AAL 2053	Change in AAL
Miami, FL	$539,000,000	$501,700,000	-$37,300,000
Jacksonville, FL	$440,600,000	$549,100,000	$108,500,000
Fort Lauderdale, FL	$320,200,000	$309,000,000	-$11,200,000
St. Petersburg, FL	$277,900,000	$301,300,000	$23,400,000
Hollywood, FL	$199,500,000	$187,200,000	-$12,200,000
Tampa, FL	$187,000,000	$210,500,000	$23,500,000
Miami Beach, FL	$152,100,000	$140,000,000	-$12,100,000
Pembroke Pines, FL	$147,400,000	$139,000,000	-$8,400,000
Boca Raton, FL	$147,000,000	$151,900,000	$4,900,000
Hialeah, FL	$136,600,000	$128,900,000	-$7,800,000
Miramar, FL	$136,200,000	$127,500,000	-$8,700,000
Coral Gables, FL	$131,200,000	$124,700,000	-$6,500,000
Cape Coral, FL	$130,600,000	$132,000,000	$1,400,000
West Palm Beach, FL	$124,600,000	$135,300,000	$10,600,000
Plantation, FL	$123,800,000	$120,700,000	-$3,100,000
Port St. Lucie, FL	$122,800,000	$139,300,000	$16,500,000
Coral Springs, FL	$120,300,000	$120,600,000	$300,000
Pompano Beach, FL	$113,900,000	$113,200,000	-$700,000
Miami Gardens, FL	$110,900,000	$102,900,000	-$8,000,000
Davie, FL	$98,400,000	$95,400,000	-$3,000,000

Results

Note that a driving factor of large total AAL numbers is the total count of properties in the area, as well as their property values. To better understand relative risk, AAL may be evaluated with property counts, in terms of its ratio to total property values or average AAL per property. The counties with the highest ratio of AAL to total property value in Florida include Miami-Dade, Broward, Brevard, St. Lucie, Indian River, Palm Beach, Martin, Pinellas, Charlotte, and Lee (respectively). A full figure of these patterns are shown in Figure 29. Miami-Dade County has a ratio of approximately 1.4%, meaning that over the next 20 years, the county could expect to write off about 28% of the total value of the property stock.

Florida currently accounts for approximately 73% of the entire Nation's tropical cyclone wind risk. It also has the highest absolute probabilities of experiencing a hurricane this year and in 30 years, with Monroe County, FL leading the way with a 26.7% chance this year. While the northward shift in tropical cyclone tracks results in a slightly decreased risk for some areas of Florida, other areas like Brevard County increase in risk. This results in an overall increase of the expected AAL over the next 30 years, from $13.4 billion to $14.3 billion.

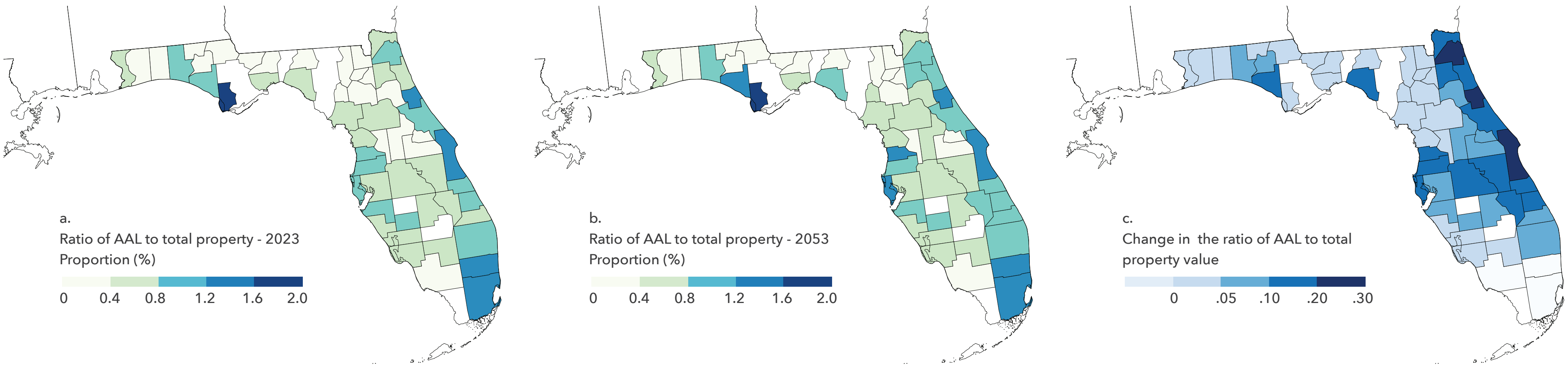


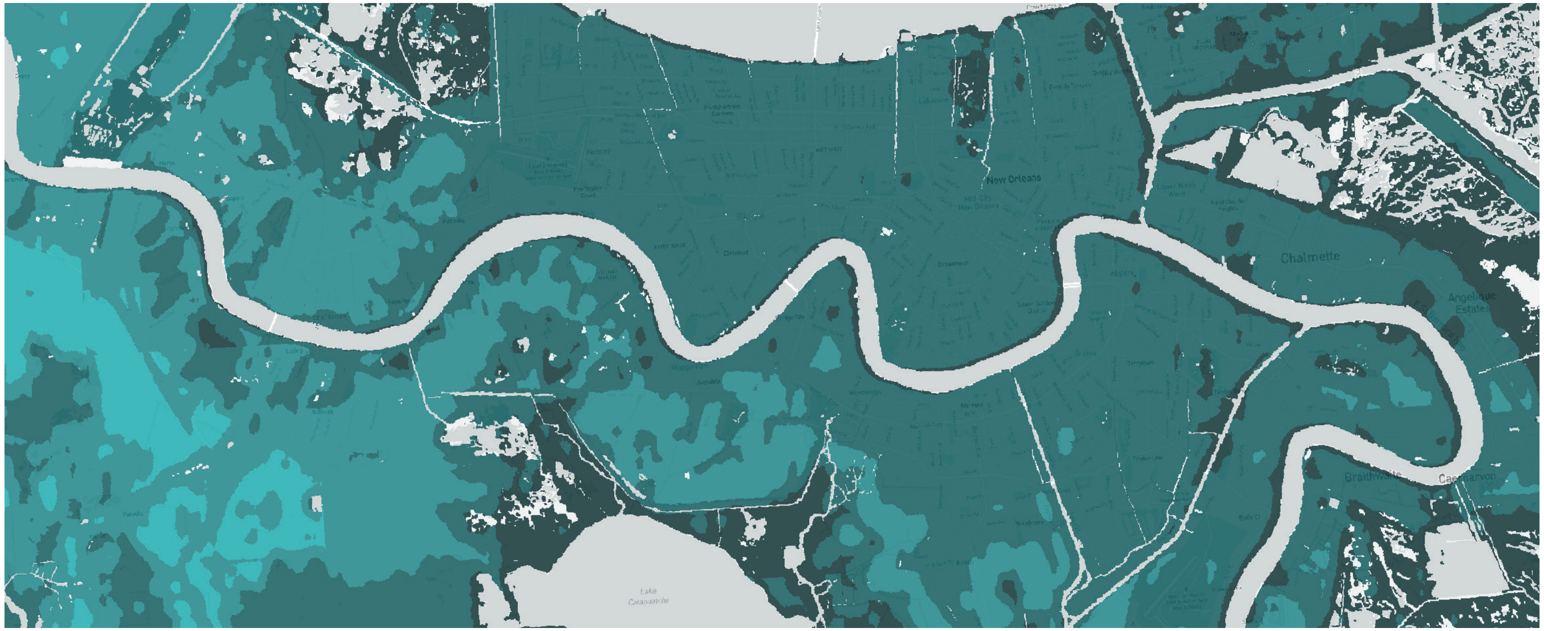
Figure 29. Ratio of AAL to total property value for 2023 (a), 2053 (b) and the change in AAL as a ratio to total property value (c), by county in FL

Concluding Remarks

The First Street Foundation Wind Model (FSF-WM) represents a "first of its kind", climate-adjusted tropical cyclone wind model at the property level. The model gives property owners an objective view of their personal risk to wind damages now and in the future, and can be used to make personal decisions around where to live, adaptation solutions, and property-hardening against that risk. The model incorporates changing climate conditions as a way to predict changes in hurricane risk over the next 30 years. Understanding how wind risks change over time with future environmental conditions at a high spatial resolution is important to know how financial, human, and community resources should be allocated in order to mitigate the risks associated with hurricane winds. First Street Foundation's high-resolution model, which estimates hurricane wind risk now and 30 years into the future under changing environmental conditions, empowers property owners by informing the necessary actions to protect their assets, and for citizens, governments, and industry to fully understand and appropriately price this risk.

Important implications associated with these results center around a community's ability to assess current levels of resilience, plan for future resource allocation around infrastructure and development, and inform individuals of their personal risks. Making this information publicly available allows for a better understanding of risk and provides a common knowledge base, informed by high-quality risk models which are often inaccessible for most communities. This accessibility of climate risk information facilitates collaboration within and across different stakeholder groups, and informs public policy and funding decisions for risk adaptation and mitigation strategies.

More specifically, this product works to quantify and understand the changes that are occurring in the environment, and then translates and communicates those changes at the property level in a personally relevant way, expressed as property and financial risk. The use of these tools to identify relative risk between areas and under different probabilistic scenarios helps to inform decisions around community resilience and future development. Additionally, identifying areas with high relative risk may allow for the appropriate allocation of resources so that capital is used efficiently and development decisions do not necessarily lead to the unintentional location of vulnerable populations and properties in high-risk areas.



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