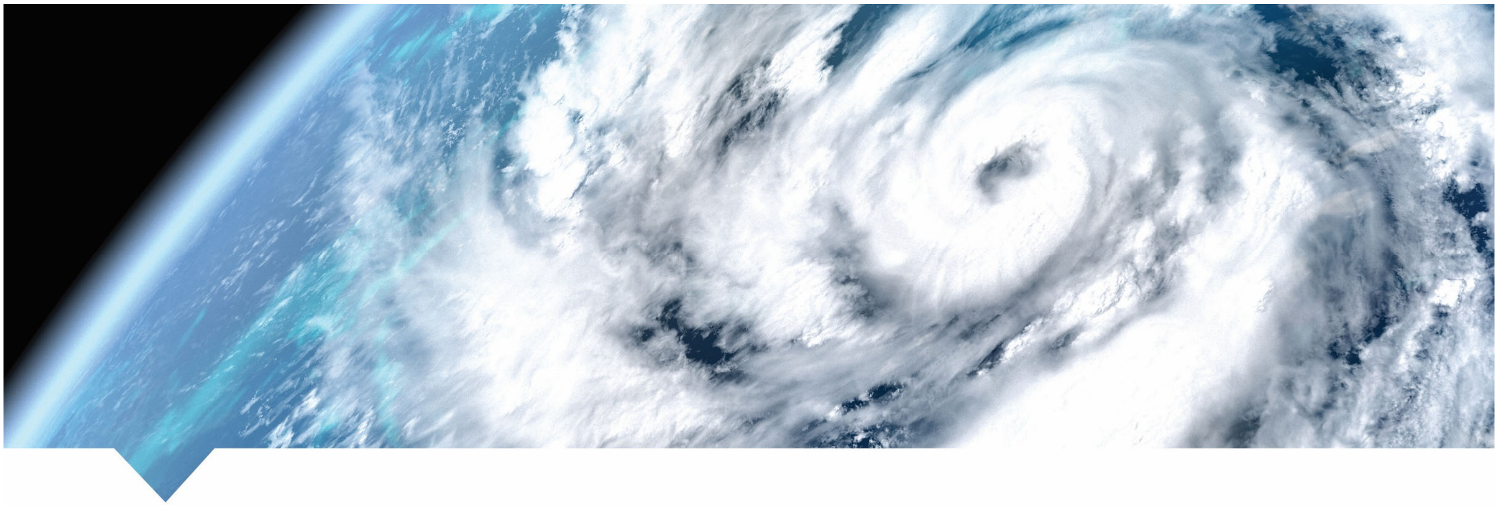

Incorporating Climate Change into a Hurricane Model

The insurance industry has relied on catastrophe modeling to help manage enterprise risk since the inception of these models over 30 years ago. A more recent acknowledged peril is climate change. Climate change affects a range of natural catastrophe risks, including hurricane. There is growing demand for incorporating this heretofore "unmodeled peril" into catastrophe modeling by insurers, their stakeholders, and regulators. But where traditional catastrophe modeling relies on past climatological events and claims history, incorporating climate change scenarios is more of a future cast act, leading to new approaches: using Global Circulation Models (GCM), Representative Concentration Pathways (RCP), multiple environmental parameters and machine learning.

The Intergovernmental Panel on Climate Change (IPCC) reports with high confidence in their Sixth Assessment Report that both the proportion of intense hurricanes (category 3-5) and the peak wind speeds of the most intense events will increase on the global scale with increasing global warming.

This paper examines the effect of a future climate scenario on the US hurricane hazard by seeding ARA's North Atlantic hurricane hazard model with environmental output from the IPCC RCP 8.5 scenario. Perhaps not surprisingly, the largest increase in wind speed is expected to occur in Florida and along the south US Atlantic coastline, ranging from 3-5% in the year 2021 and 5-7% in the year 2050. Windspeeds along the northern coastline see less change.

APPROACH

One method of quantifying the effects of climate change on hurricane risk is to allow for a hurricane model to ingest predictions of future global temperatures and wind shear from leading GCMs and providing event occurrence rates for any given time frame and carbon emissions scenario that has been modeled with a GCM. Using this method, multiple environmental parameters can be incorporated, as opposed to only a single parameter such as surface sea temperature.

The hurricane hazard model used here is the same as that used to produce the US design wind speeds in ASCE 7-98 through ASCE 7-22. The simulation approach consists of two components, a

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hurricane wind field model and a hurricane track model. Given key hurricane parameters at any point in time from the track model, the wind field model is used to develop estimates of wind speed and direction at any arbitrary position. Inputs to the wind field model include the central pressure difference, radius to maximum winds, the Holland pressure profile parameter, storm position, translation speed and heading.

The hurricane track methodology, developed using historical hurricanes and environmental reanalysis data, reproduces the frequency and geometric characteristics of historical hurricane tracks as well as the variation of storm size and intensity along the tracks. Environmental parameters used directly in the hurricane track simulation include sea surface temperature, tropopause temperature, and vertical wind shear.

Replacing the historical climate data used in the hurricane track model with environmental output associated with the IPCC RCP 8.5 scenario, we characterize the hurricane hazard under the scenario for a current (2021) and future (2050) climatology. This methodology allows for the consideration of changes in, and interactions of, multiple environmental parameters as opposed to only a single parameter (e.g., sea surface temperature). The same methodology can be implemented with other climate scenarios and time periods of interest to develop a complete picture of possible future climate effects on the hurricane hazard for varying levels of action and future warming.

ENVIRONMENTAL DATA

Four RCP scenarios were developed for the IPCC Fifth Assessment Report to serve as input for climate and atmospheric modeling. In this study, output from RCP 8.5 was used to seed the hurricane track simulation. RCP 8.5 is representative of a scenario in which no technology or policies have been implemented to reduce greenhouse gas emissions. The global mean surface temperature under this scenario is projected to increase approximately 2°C in the near term (2031-2050) and 4.3°C by the end of century (2081-2100) relative to the pre-industrial period (1850-1900). Comparatively, a recent analysis of emissions policies from 39 countries and the EU estimates warming is on pace for roughly a 2.9°C increase by the end of the century (Boehm et al., 2021).

The RCP 8.5 environmental output used herein was generated using the Community Earth System Model (CESM) at the National Center for Atmospheric Research in phase 5 of the IPCC's Coupled Model Intercomparison Experiment (CMIP5). Of all global climate models that participated in CMIP5, the ability of the CESM to replicate observed global patterns of temperature and rainfall ranks first.

A large ensemble of CESM simulations was performed to characterize model uncertainty for the RCP 8.5 scenario, though only a single ensemble member was used to construct the environmental dataset. The interannual variability in the global mean surface temperature anomaly across the ensemble was 0.4°C which bounds the historical observations from 1920 to 2005 (Kay et al., 2015). To account for annual variability using environmental output from a single ensemble member, we use a sample of ± 5 years from the year of interest. For example, to develop tracks representative of the climate state in the year 2050, we use CESM output from the years 2045 to 2055.

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HURRICANE WIND SPEED HAZARD

Long-term Climatology

To define the hurricane wind speed hazard for the long-term climatology (e.g., the reference model), a 500,000-year simulation of tropical cyclones occurring in the North Atlantic basin was performed using the National Centers for Environmental Prediction and Atmospheric Research (NCEP/NCAR) Reanalysis 1 historical environment data. Wind speeds were computed for every simulated event that passes within 250 km of a location.

Since weaker storms contribute very little to extreme wind speed probabilities, a reduced set of weighted storms was selected from the full simulation to maximize the computational efficiency of the final model. Note that all of the most intense events from the 500,000-year event set are retained in the reduced event set. In all other bins, the reduced events are retained from the full event set in the order simulated until the limit for each bin is reached.

Current and Future Climatology

To define the hurricane wind speed hazard under the RCP 8.5 scenario, 500,000-year simulations of tropical cyclones occurring in the North Atlantic basin were performed using the RCP 8.5 environmental output data from NCAR's CESM for both the years 2021 and 2050. From each set of tracks (e.g., reference model, RCP 8.5 2021, RCP8.5 2050), climate conditioned landfall rates were calculated by region and storm intensity. The ratio of landfalls by category and region in the RCP 8.5 scenarios to those of the reference model were used to scale the weights applied to the events in the reduced event set developed from the reference model. Expanding the reduced event set using the weights defined as the ratio of the number of events retained in each wind speed bin to the total number of events in the wind speed bin from the full simulation, the wind probability distribution is defined.

This weighting approach makes the evaluation of the effects of a given climate scenario on the US hurricane hazard more robust by utilizing a single reduced event set with modified weights, eliminating the need to run the full numerical wind field model for every climate scenario or time period. Under this approach, weights can be readily generated for any climate scenario or time frame of interest.

RESULTS

The climate conditioned landfall rates calculated by region and storm intensity for the reference model and the RCP 8.5 scenario in the years 2021 and 2050 are shown in Figure 1. For all regions, the frequency of intense events (i.e., category 3 – 5) increased under RCP 8.5 in the year 2021 compared to the reference model developed from historical data over the period 1900 – 2018. Under RCP 8.5 in the year 2050, the frequency of intense events increased further for all regions except the northeast coast from Virginia to Maine. In Florida, the frequency of landfalling category 5 events in the RCP 8.5 scenario in the years 2021 and 2050 is found to be approximately 60 and 100 percent higher, respectively, than the reference model.

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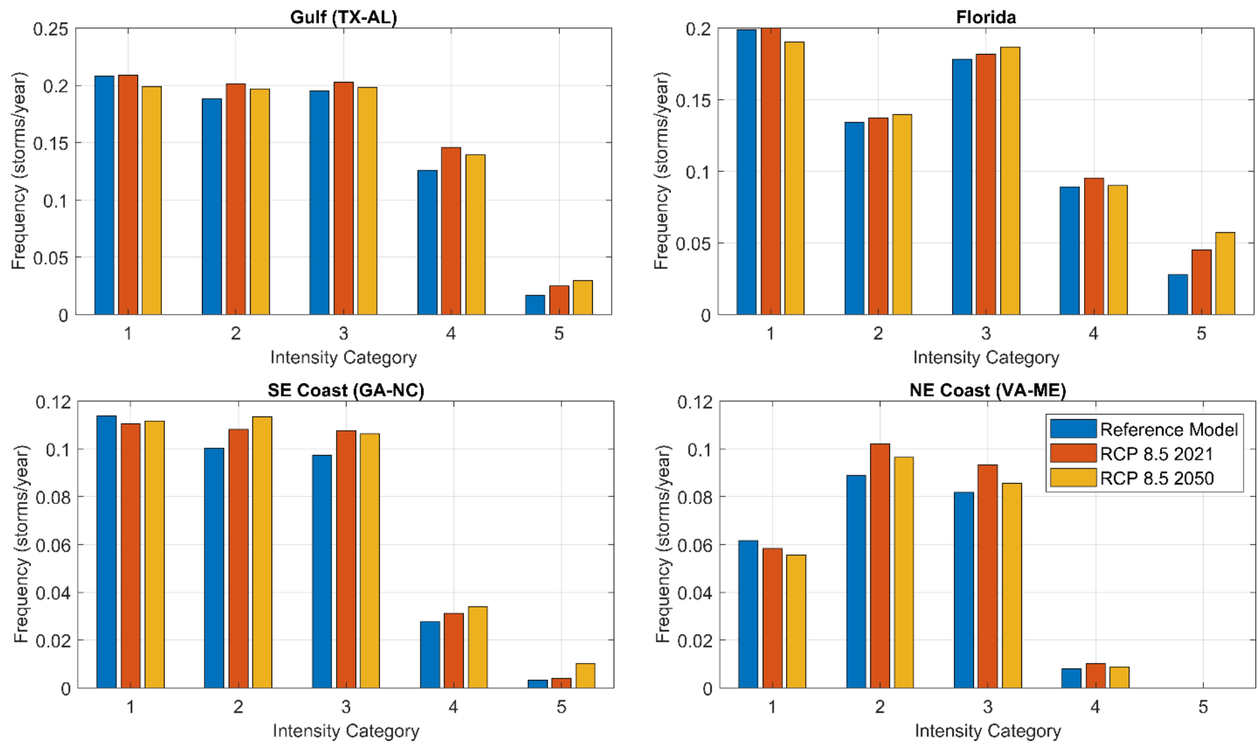

Figure 1. Frequency of landfalling events by region and intensity.

The hurricane wind speeds under the reference model and under the RCP 8.5 scenario in the years 2021 and 2050 were obtained for return periods ranging from 10 to 3000 years. Figure 2 through Figure 5 display the 700-year return period hurricane wind speed contours along the Gulf coast, Florida, the southeast US Atlantic coast, and the northeast US Atlantic coast. The 700-year return period is the level for which the majority of structures in the United States are designed. In Texas and western Louisiana, the hurricane wind speeds under the RCP 8.5 scenario, in both 2021 and 2050, remain relatively unchanged from the reference model. From eastern Louisiana to Alabama, the hurricane wind speeds are projected to increase 1-2%, with increases up to 3% near the coast in the year 2050. In Florida, typical increases in the 700-year hurricane wind speeds are projected to be 1.5-2% under RCP 8.5 in the year 2021, and 2-3% in the year 2050. The largest increases in Florida are projected along the peninsula, where the most extreme hurricane wind speeds already occur. The largest increases to the hurricane wind speeds are projected to occur along the southeast US Atlantic coast, with increases of 3-4% and 5-7% under the RCP 8.5 scenario in the years 2021 and 2050, respectively. Along the northeast US Atlantic coast, modest increases of up to 2% are projected, with little change between the years 2021 and 2050.

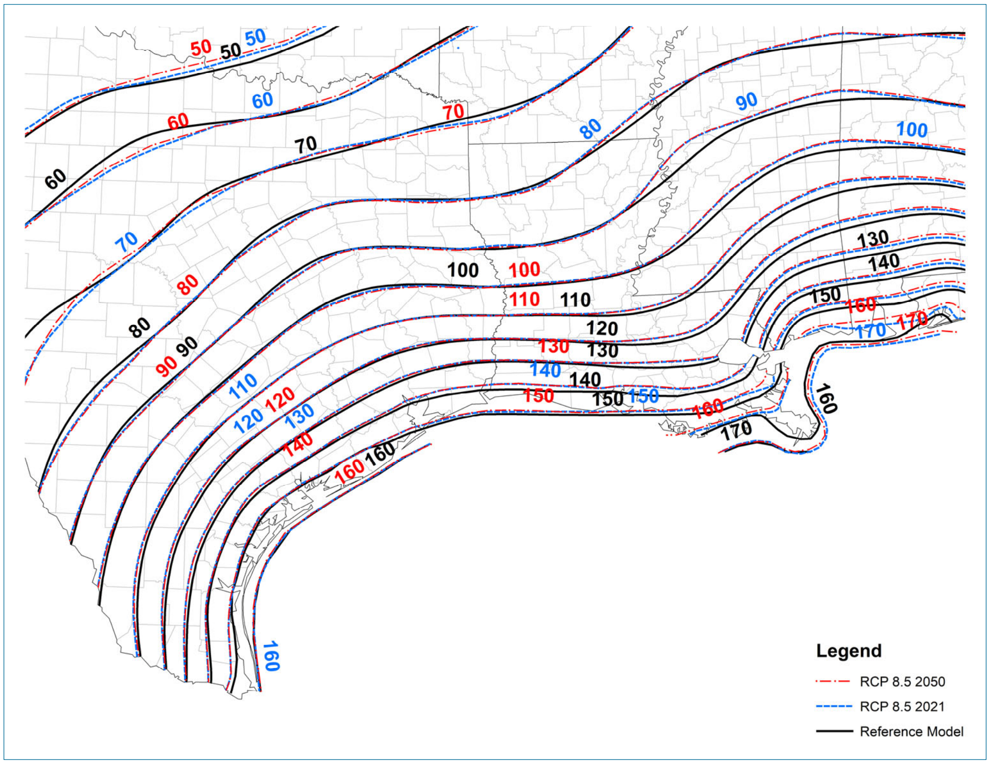

Figure 2. 700-year return period peak gust wind speed contours along the US Gulf coast from the reference model and from RCP 8.5 in the years 2021 and 2050.

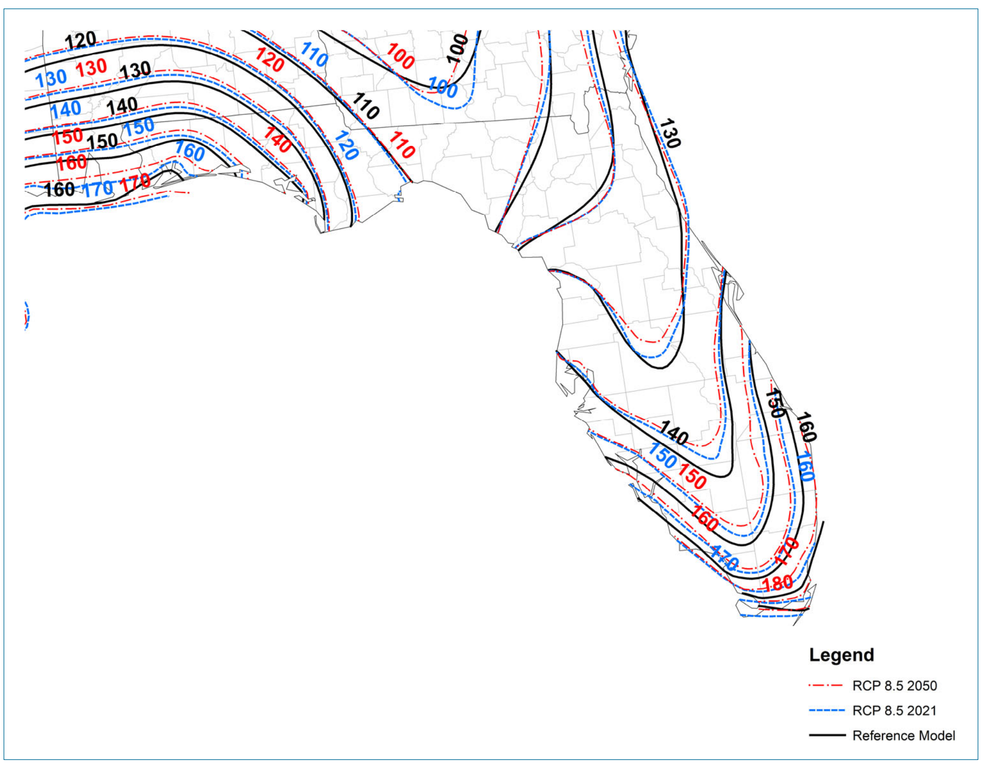

Figure 3. 700-year return period peak gust wind speed contours in Florida from the reference model and from RCP 8.5 in the years 2021 and 2050.

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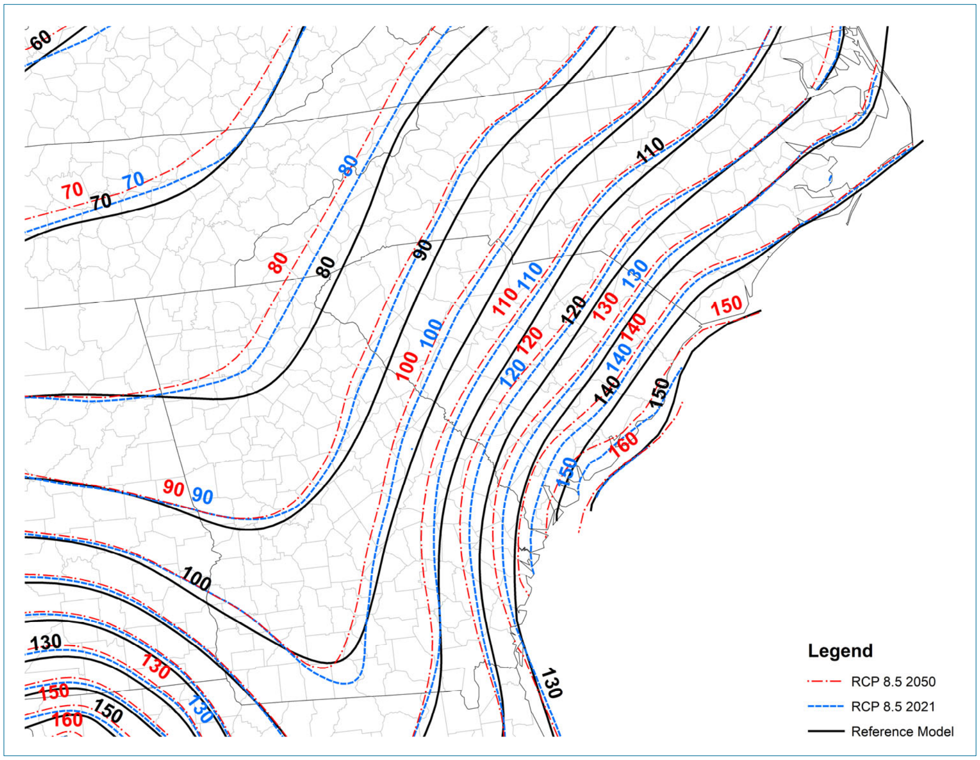

Figure 4. 700-year return period peak gust wind speed contours along the southeast US Atlantic coast from the reference model and from RCP 8.5 in the years 2021 and 2050.

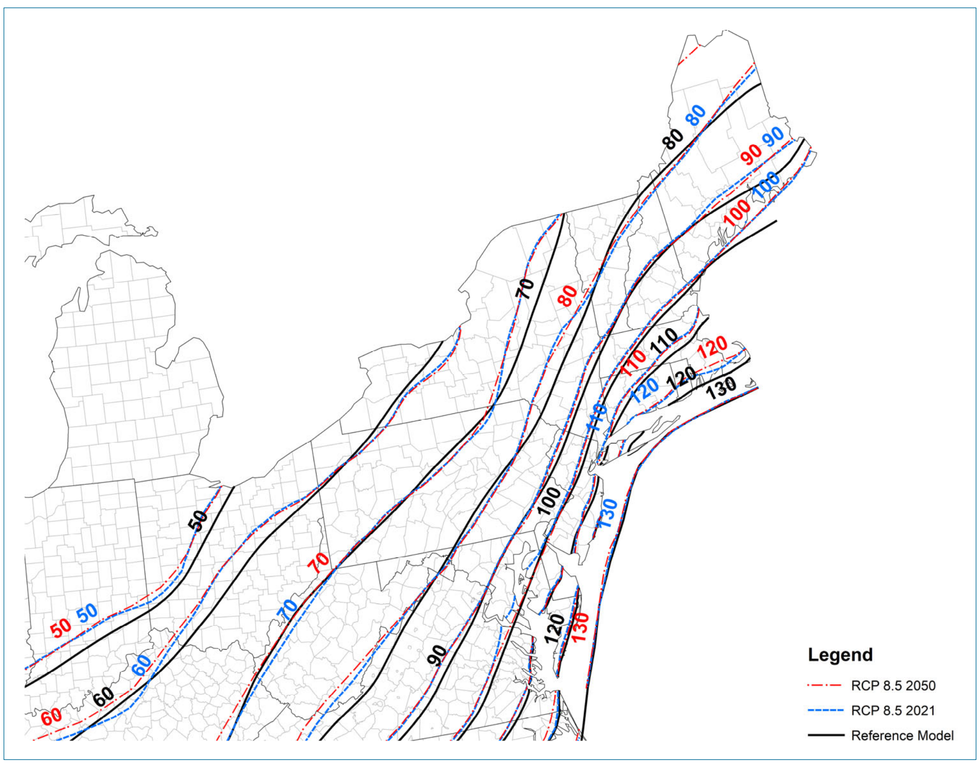

Figure 5. 700-year return period peak gust wind speed contours along the northeast US Atlantic coast from the reference model and from RCP 8.5 in the years 2021 and 2050.

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FUTURE STEPS

The wind hazard is not the only component of the hurricane hazard that is expected to be impacted by climate change. Consensus of recent research indicates there is medium-to-high confidence that hurricane precipitation rates will increase globally, with a projected median increase of about 14% under a 2°C warming scenario (Knutson et al., 2020). Hurricane precipitation is one of the most difficult variables to model due to its dependence on several simultaneous nonlinear processes, though estimates of rainfall rates and their locations can provide vital information for resource planning, flooding, erosion, and structural risk assessment and of course, insurance catastrophe management. To provide such estimates, ARA has developed an empirical hurricane rainfall rate and distribution estimator which is currently implemented in the Hazus Hurricane Model, widely used by FEMA and others. The model relates the sectorial rainfall rate with annular distance from the hurricane center and includes dependencies on intensity, storm translation speed, and frictional convergence during landfall. Implementing this model with the synthetic event set approach allows for the probabilistic characterization of the rainfall hazard now and under various postulated climate scenarios into the future.

As discussed, several components of ARA's hurricane hazard model include direct dependencies on environmental parameters. However, two key components, the hurricane genesis and track steering models, are based upon previous behavior of historical events. In characterizing the full impact of climate change effects on the US hurricane wind hazard, accounting for changes in storm frequency, genesis location, and storm motion is critical. Using machine learning, we aim to supplement our existing physics-based models, as opposed to replacing them. Building upon significant subject matter expertise from many years of research, machine learning can be used to capture complex interactions between environmental parameters and hurricane behavior. This will allow us to obtain a more robust physically-based definition of the hurricane hazard that is linked directly to the climate state and will ultimately lead to the ability to characterize the hurricane hazard more accurately into the future.

SUMMARY

Ingesting data output from future climate scenarios directly into ARA's hurricane hazard model, we have displayed a methodology to account for changes in and interactions of multiple environmental parameters (e.g., sea surface temperature, tropopause temperature, vertical wind shear) and their effect on the US hurricane hazard. This approach further allows for the assessment of a range of postulated future climate scenarios and time periods of interest.

Consistent with findings of the IPCC and other studies, under the RCP 8.5 scenario the frequency of intense US landfalling hurricanes was found to increase in the future compared to a reference model based on the years 1900-2018. Maps of the 700-year return period hurricane wind speeds were compared to those in the US design standard ASCE 7-22. The results indicate increases of up to 7% above US design wind speeds in the year 2050 under the RCP 8.5 scenario.

Insurers are already asking model developers for more insight into climate change upon their portfolios. Industry associations and regulators too are now joining the chorus. In the U.S., the National Association of Insurance Commissioners is encouraging state regulators to obtain insurance company data on resiliency to future climate scenarios; while in the U.K., Lloyds and the

Bank of England are also looking for the insurance industry to go beyond using only historical data to inform their risk assessment of climate change by considering future trends in catastrophe modelling.

The insurance industry, long used to managing enterprise risk with the help of catastrophe models, is facing a new challenge in climate change. Fortunately, a pathway to solution exists with the advent of robust climate change coupled catastrophe models.

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