5.5 **THE HURRICANE RISK CALCULATOR: WORKING TOWARD ENHANCING OUR NATION'S READINESS, RESPONSIVENESS, AND RESILIENCE TO HURRICANES THROUGH PROBABILISTIC RISK FRAMEWORKS FOR EVACUATION DECISION SUPPORT**

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1. INTRODUCTION

Coastal and inland residents often face a barrage of information when a hurricane threatens. These include graphical and textual products from forecast entities such as the National Hurricane Center (NHC) and local National Weather Service (NWS) offices, evacuation orders from local governments, and a wide variety of information from traditional media, blogs, web sites, and social media. Yet, residents still grapple with making effective decisions in the face of uncertainty, products they do not understand, and conflicting information and messages. Worse yet, residents often get hung up on deterministic forecast scenarios which they view as either favorable or unfavorable to their particular situation, sometimes delaying action to see if a more favorable situation develops. Finally, residents struggle to understand how various forecast scenarios will translate into impacts at their specific location. As a result, their decision-making processes are often haphazard and do not properly account for uncertainty, leading to less-than-optimal personal and collective outcomes.

We are focusing initially on the risks posed by hurricane winds. While wind hazard only accounts for 14% of historical direct hurricane deaths in the U.S. (Rappaport 2014), the threats posed by extreme winds can still be a powerful motivating factor in evacuation decisions (whether optimal or not). As an example, 2.5 million people participated in a traffic-choked evacuation in advance of Hurricane Rita (2005). The ensuing chaos resulted in at least 80 deaths, more than the direct deaths from the storm. Many evacuated because they did not know how their houses would perform in the anticipated major hurricane winds.

We aim to develop a framework that intersects real-time probabilistic predictions of hurricane hazards with probabilistic descriptions of vulnerability. This extended abstract describes the development of a “Hurricane Risk Calculator” to provide actionable information about potential hurricane impacts at a user’s specific location and then to contextualize the potential risks and translate these into easily understandable forms to guide effective evacuation decisions and optimize the timing of other protective actions. Through comparison of the risks of various alternatives (e.g., “shelter-in-place” vs. different evacuation scenarios), the personalized probabilistic risk information can be used to guide risk-informed decisions.

This extended abstract is organized as follows. Section 2 briefly describes the probabilistic prediction framework which will be used in the risk calculator. Section 3 describes the approach we will use to assess the vulnerability of a user’s structure. Section 4 describes the risk outputs that will be used in the risk calculator to convey risks in forms that are understandable to lay people. Finally, section 5 provides a summary and the future plans for the calculator.

2. PROBABILISTIC HAZARD INFORMATION

The calculator for wind risk will be driven by a new probabilistic prediction framework, called Forecasts of Hurricanes Using Large-Ensemble Outputs (FHLO, Lin et al. 2020) that accounts for flow-dependent uncertainty by leveraging solutions of global ensemble prediction systems, such as the National Centers for Environmental Prediction (NCEP)’s Global Ensemble Forecast System (GEFS) and the European Centre for Medium Range Weather Forecasting (ECMWF)’s Ensemble Prediction System (EPS). FHLO uses statistical bootstrapping of the global ensemble model tracks to generate a very large ensemble of ~O(1000) synthetic storm tracks that span a wide range of possible scenarios including the possibility and varied timing of landfall or island crossing scenarios and tracks through diverse oceanic and atmospheric conditions. The internal variability present in the global ensemble fields are also used to compute the variance of key parameters that affect the intensity forecast, such as the potential intensity and the ventilation. Then, a 2-dimensional coupled ordinary differential equation system is used to predict the intensity along each track. Finally, a parametric wind model is used to provided gridded fields of the winds. In this manner, the uncertainty inherent in the interrelated predictions of track, intensity, and size can be fully simulated and point-wise probabilities of exceedance can be computed for any wind speed threshold. The risk calculator will use the local probability density function of wind speed exceedance for the full range of wind speeds that can be encountered in a tropical cyclone.

3. STRUCTURAL VULNERABILITY

The next step involves intersecting the predicted probabilistic winds with the structure-specific vulnerability to compute the risks of various consequences, such as degrees of structural damage. This requires an assessment of the vulnerability of a given structure to hurricane wind impacts. In particular, we would like to determine the critical wind thresholds at which: (1) structural damage begins to occur, and at which (2) complete structural failure may occur. To a zeroth order, these critical wind thresholds can be estimated by considering the class and age of the structure and the design wind speed to which it was built to. However, variations in construction quality, adherence to code, and other epistemological issues present challenges to identifying the key wind thresholds at which a structure may being to experience damage or failure. A better approach would be to describe the building’s vulnerability through probabilistic fragility curves or a component failure analysis. In that case, probabilistic risk can be obtained, allowing estimation of the likelihood that the structure will lose its ability to protect the life and safety of its occupants. This also allows calculation of the range of damage that may be expected. While fragility modeling approaches are under development, they are not yet ready for use for all classes of structures.

In the interim, this tool will use an intermediate complexity approach based on expert engineering judgement. In partnership with ResilentResidence (ResRe), we will have each homeowner answer a ~20 question survey that includes questions about the characteristics of the house (number of stories, roof shape, roofing material, wall type, method of roof-to-wall connection, type of protection for openings, whether the garage door is reinforced, etc.). The survey also includes several behavioral questions to ascertain their prior hurricane experience and attitudes toward preparedness and mitigation. From this information, ResRe generates a resilience score that estimates how resilient the residence is expected to be against hurricane winds. We will calibrate this score to damage states in a retrospective study (described later).

4. RISK OUTPUTS

We are developing a user-friendly, public-facing version of the risk calculator, in which a user will be able to enter their street address into a web page or mobile app and then view a dashboard-like interface with graphical and textual products that translate the potential wind impacts for the specific structure at that address.

The first type of risk output is called “Risk of Damage” and will convey information about the potential safety of the structure <u>during the storm</u>, as well as the habitability of the structure <u>after the storm</u>.

Communicating risk is challenging because each person may have a different perception of risk. For instance, if someone is told that the risk is “low”, ”medium”, or ”high”, they may have drastically different perceptions of the risk compared to another individual. Risk tolerance, life experience, and social and cultural conditioning may all influence one’s risk perceptions. The middle category (“medium risk”) is also problematic, because some might think that protective action is only warranted at the highest risk level. To keep the tool’s risk outputs simple and understandable, yet fine-grained enough to be useful, we have developed a color-coded scale that includes explicit descriptions of several types of consequences. These include the: a) damage to outbuildings or fences, b) minor structural damage to the home (including potential for water damage), and c) major structural damage, up to a total loss. We also include a qualitative description of the associated likelihood for the relevant consequence (e.g. “possible”, “likely”, “expected”). Finally, a “bottom-line” message is given, summarizing the overall risk message.

We have intentionally selected five key risk categories: “minimal”, “low”, “elevated”, “severe”, and “extreme”. Figure 1 presents simulated views of the proposed example outputs for the “Risk of Damage” screen.

The “minimal” risk of damage category is meant to be used when the risk of damage is really so low as to be comparable to the normal background risk when a hurricane is not present (e.g., a wind gust from a stray thunderstorm). It signals to the user that their location is outside of the zone of any expected damaging impacts. For technical clarity, we explicitly convey that the risk of damaging winds is less than 0.1% and the risk of wind gusts exceeding 50 mph is less than 10%. The bottom-line message is “No damage *expected*”.

The “low” risk of damage category is at a higher risk level than “minimal” but conveys that the risk is still quite small. This category states that damage to fences or outbuildings is *possible* and that the home is still expected to be habitable following the storm. The bottom-line message is “Little to no significant structural damage *expected*”.

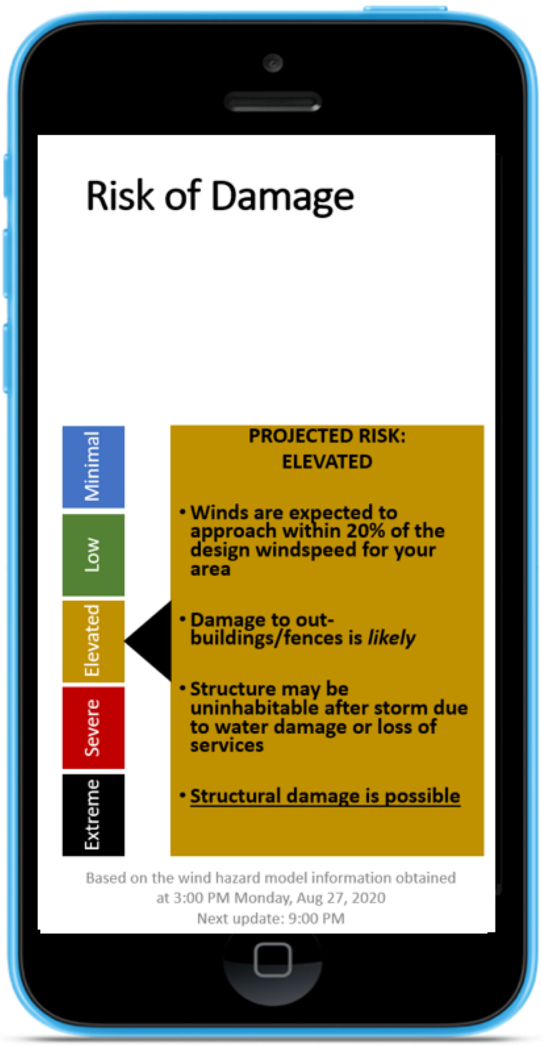
The “elevated” risk of damage conveys that there is a distinct chance of damaging wind impacts (even if the risk may be relatively modest at the lower bound of this category). The output mentions that damage to fences and outbuildings is *likely*, and that the structure may not be habitable following the storm due to water damage or loss of services. The bottom-line message is that “Structural damage is *possible*”.

The “severe” risk of damage category conveys that significant damage is *expected*. Physical reasoning for this is conveyed by the fact that the wind speeds are expected to exceed the design wind speed for the home. It states that fences and outbuildings are *likely* to be destroyed and that the structure *may* be uninhabitable due to extensive damage or loss of services. The bottom-line message is “Structural damage is *likely*”.

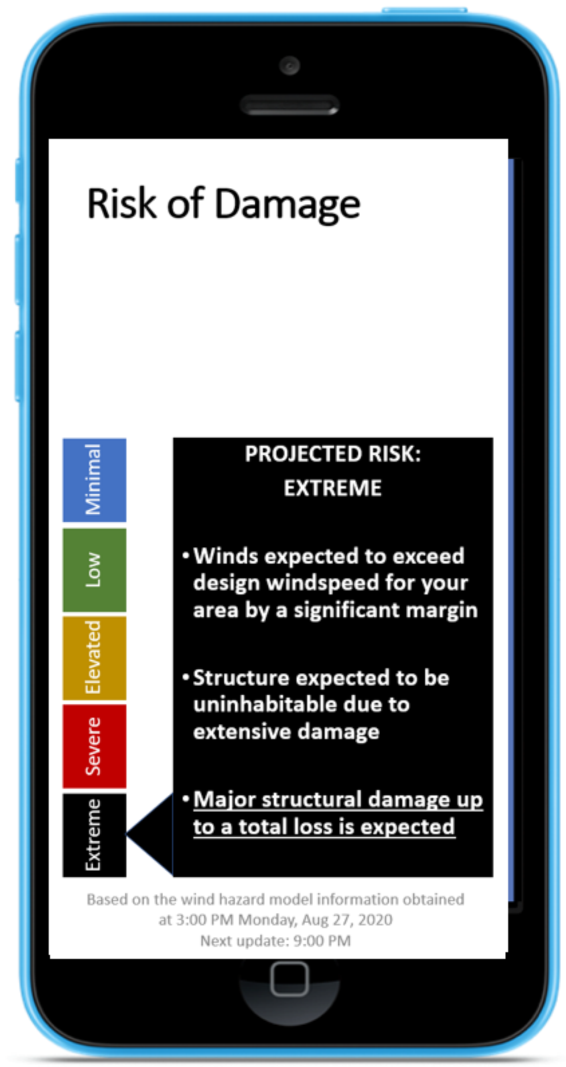
The “extreme” risk of damage category is reserved for the most extreme cases when the winds are projected to exceed the building’s design wind speed by a significant margin. The structure is *expected* to be uninhabitable due to extensive damage. The bottom-line message is that “Major structural damage up to a total loss is *expected*”.

Because the risk of power outage is another key factor that drives evacuation decision-making for many people (especially those who are heat-sensitive or have underlying medical conditions), the risk calculator will also provide a second type of risk output called “Risk of Power Outage”. For these outputs, the relevant consequences are “short-term interruptions” (less than an hour), “significant power outage” (a few hours to a few days), and “extended power outage” (days to weeks or more). Explicit probabilities for the key consequences are given (expressed as % chance). The bottom-line messages range from “minimal risk of significant power outage” to “long-term power outage expected”.

Figure 1: Simulated views of the risk outputs on a mobile phone screen for the risk of damage for the following risk categories: a) minimal risk, b) low risk, c) elevated risk, d) severe risk, and e) extreme risk.


Risk of Damage
Minimal
Low
Elevated
Severe
Extreme
PROJECTED RISK: ELEVATED
• Winds are expected to approach within 20% of the design windspeed for your area
• Damage to out-buildings/fences is likely
• Structure may be uninhabitable after storm due to water damage or loss of services
• Structural damage is possible
Based on the wind hazard model information obtained at 3:00 PM Monday, Aug 27, 2020
Next update: 9:00 PM


Risk of Damage
Minimal
Low
Elevated
Severe
Extreme
PROJECTED RISK: SEVERE
• Winds expected to exceed design windspeed for your area
• Out-buildings/fences likely destroyed
• Structure may be uninhabitable due to extensive damage or loss of services
• Structural damage is likely
Based on the wind hazard model information obtained at 3:00 PM Monday, Aug 27, 2020
Next update: 9:00 PM



In each of the risk output screens, a large area exists near the top to provide the user with important limitations about the risk output. For example, for users who reside less than 40 feet above sea level, storm surge is likely to pose a much higher risk than wind. Users will be strongly encouraged to heed any local evacuation orders.

The third type of risk output that the tool will provide is called "Risk of Injury and Death". This output is meant to convey information about potential life and safety of occupants who remain in the structure during the storm and will provide some specific behavior recommendations concerning evacuation. As the name implies, the two chief consequences considered are the risk of injury and the risk of death. While the absolute risk level of either consequence may be quite small in most cases, the risk of sheltering in place can be measured against the risk of undertaking a local evacuation or a long-distance evacuation. Both of these risks can be quantified in an approximate risk by the baseline risk of driving a personal automobile, which is 1.5 deaths per 100 million vehicle miles driven (see https://en.wikipedia.org/wiki/Transportation_safety_in_the_United_States and references therein). Examples of the proposed risk outputs for the "severe" and "extreme" categories are shown in figure 2. In the "severe" example, the risk of sheltering-in-place is compared to the risk of a long-distance evacuation to offer a clear behavioral recommendation ("evacuate to a local shelter"). In the "extreme" example, the risk is so high that multiple behavioral recommendations are offered, ranging from "evacuate to a local shelter", to "evacuate long distance if necessary", to "find safer structure of last resort". This is meant to stress to the user that even a less-than-optimal evacuation option is preferred to sheltering-in-place.

Another type of risk output that could be useful would be projected financial costs. Such a screen could compare the costs to the homeowner based on the expected damage and the type of insurance coverage that the owner carries. The tool could also provide projected financial costs with and without window protection to inform the owner of the potential benefits of installing their window protection. We expect that the current state of knowledge about predicting damage will lead to quite large ranges of projected costs. This might render this type of output unusable for the time being.

A final type of risk output is meant to compare the risks of various evacuation options to the risk of sheltering-in-place in order to guide the user to a risk-informed decision about whether to evacuate or stay. Figure 3 shows an example of this risk output for a hypothetical scenario for a resident in south Florida. The user will be able to input several different evacuation options they are considering, such as evacuating a few miles inland to a friend's house, going to a hotel a couple hundred miles away, or undertaking a long-distance evacuation to stay with family in another state. The risk outputs follow the same categorical schema as the previous screens, but now the risk of each option is portrayed as a rainbow-colored bar. To drive home the risk level, the risk of each potential option is compared to the risk of different activities the user may have familiarity with (e.g., major surgery, sky diving, or commuting to work). In most cases, the safest option will be for the user to shelter-in-place at home (for low-end hurricanes) or to evacuate to a local shelter. A long-distance evacuation would normally only show up as the safest option for the most extreme storms.

Figure 2: Simulated views of the risk outputs on a mobile phone screen for the risk of injury and death for the following risk categories severe risk (left) and extreme risk (right).

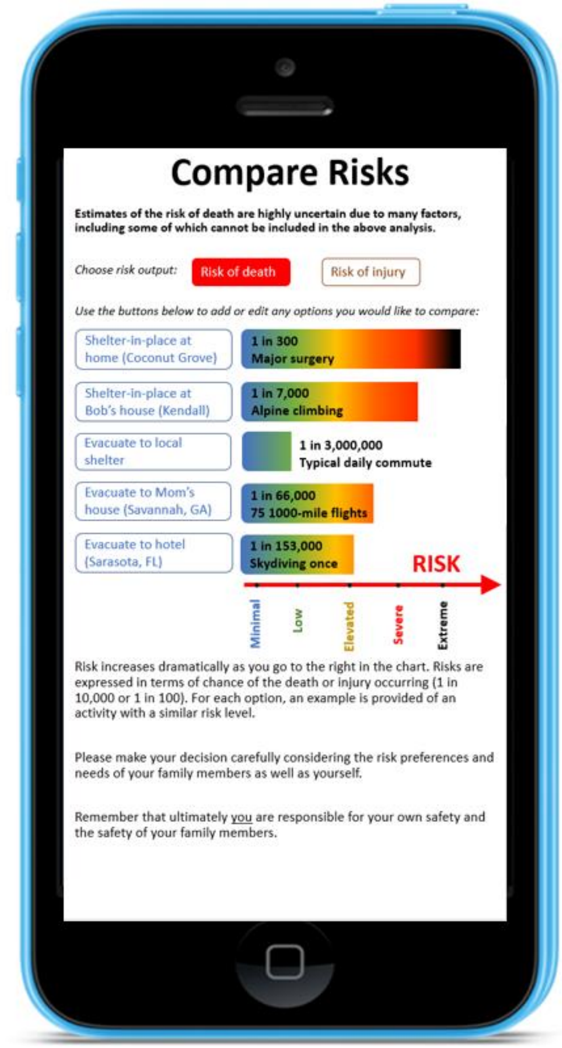


Figure 3: Simulated view of the risk comparison screen for various evacuation options.

5. SUMMARY AND FUTURE PLANS

This extended abstract has outlined a vision to develop a “hurricane risk calculator” which provides detailed and relevant information about potential hurricane wind impacts for a user’s specific location. In the initial version, which is slated to be beta-tested during the 2020 hurricane season, a user will be able to enter in their street address (or geographical coordinates) into a web page and then view a dashboard-like interface with graphical and textual products that detail the expected magnitude and timing of potential wind impacts for the user's location. Care has been taken to design risk outputs which are both understandable and actionable. Each risk category provides information about the likelihood of one or more specific consequences as well as a “bottom-line” message. Risk outputs will be provided for the risk of damage, risk of power outage, and the risk of injury and death. Projected financial costs may also be provided. Finally, a risk comparison screen will guide the user to the safest evacuation option.

As a next step, we will analyze the accuracy of the probabilistic risk framework by comparing retrospectively predicted damage states to actual damage states obtained by on-the-ground assessments from one or more high-impact storms, such as Hurricane Harvey (2017) and Hurricane Michael (2018). Results from this retrospective study will be reported at a poster at the 34th Conference on Hurricanes and Tropical Meteorology in May 2020.

Pending further funding, future work will refine the framework, extend it to additional hazards such as storm surge, and estimate utility restoration times. Social science studies are needed to understand how these new forms of information affect people’s decision-making process for evacuations and other protective actions and to determine the best ways to communicate the risk outputs of the tool. Other work is needed to improve the modeling of wind over land, including fetch-dependent influences of land use, terrain, and the environment, as well as to incorporate the effect of terrain speed-up.

To bring in the relevant expertise needed for an interdisciplinary project like this, we have established a “Researcher Collective” comprised of experts spanning the disciplines of meteorology, numerical and geophysical modeling, verification, structural engineering, cloud computing, user design and user experience, social science, utility modeling, cognitive psychology, emergency management, and human vulnerability. The collective is open to all researchers and practitioners interested in contributing. We especially welcome participation from the emergency management community, the forecaster community, and industry. For more information, please see https://wxrisk.ucar.edu.

We envision that this research will lead to a broad range of tools and applications, which, when coupled with next-generation emergency management practices, will better enable the most at-risk populations to take protective actions that enhance life safety, while allowing those at low risk to remain in place. Achieving these goals will substantially enhance our nation’s readiness, responsiveness, and resilience in the face of hurricane threats.

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