The Hurricane Risk Calculator: Translating Potential Wind Impacts for Coastal and Inland Residents

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Combining risk assessment methods with real-time wind data to provide actionable information for homeowners to inform evacuate vs. shelter-in-place decisions and other appropriate mitigative actions.

1. Motivation

Current emergency management practice

- Forecast enterprise (observations, modeling -> forecast, products)
- Coordination meetings between forecasters, federal/state/local agencies, emergency managers (EMs)
- EM recommendations made for each local jurisdiction
- Local evacuations ordered
- Response rates of 30 - 80%

Problems with this approach

- Too much emphasis on deterministic scenarios
- People receive info from many different channels, some of questionable quality (e.g., web, social media)
- People have trouble interpreting complex information under stress; decision making is often haphazard
- All-or-nothing evac scenarios (e.g., stay-put vs. go out-of-state) when focus should be on getting those in vulnerable situations into shelters
- Timing of evacuations is often not optimal

Bottom line

Stakeholders find it difficult or impossible to get detailed and trustworthy info needed to optimize their own cost/loss situation

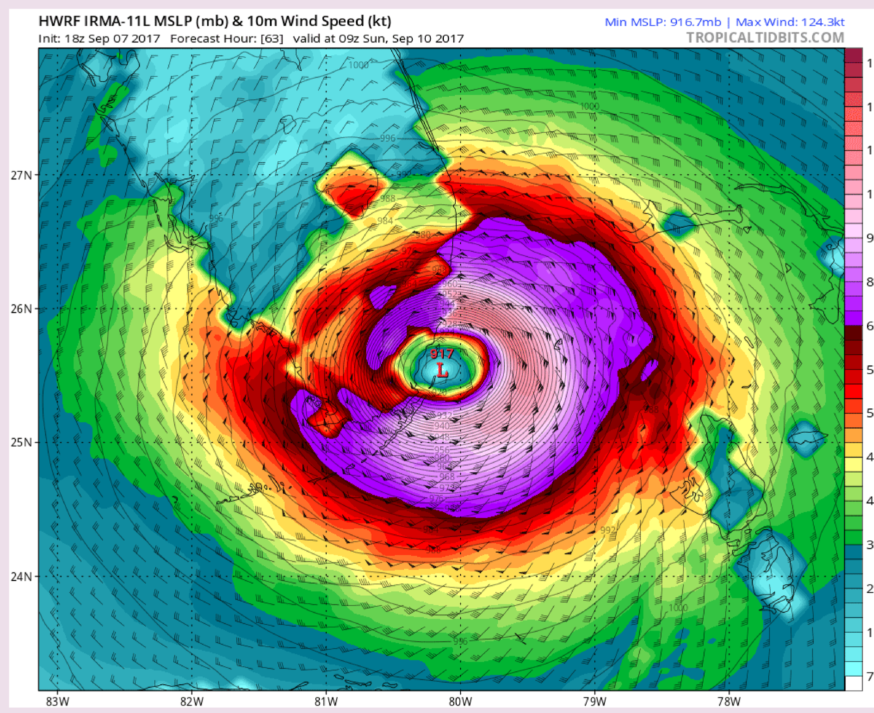
2. What People Really Need

Due to the way in which hurricane forecasts and hazards have been conveyed in the past, people are very tuned to the track forecast and the intensity forecast (or expected Category), however these parameters say little about what the local impacts will be at a given location. Although of scientific importance, it's fairly irrelevant to the average person as to where the exact track will be, whether they will be inside the cone of uncertainty, or what the maximum intensity of the storm will be if this information is not convolved with the size of the storm and the distribution of the wind field!

People really need to know probabilistic information about the potential wind, surge, and inland flooding hazards that are translated into forms:

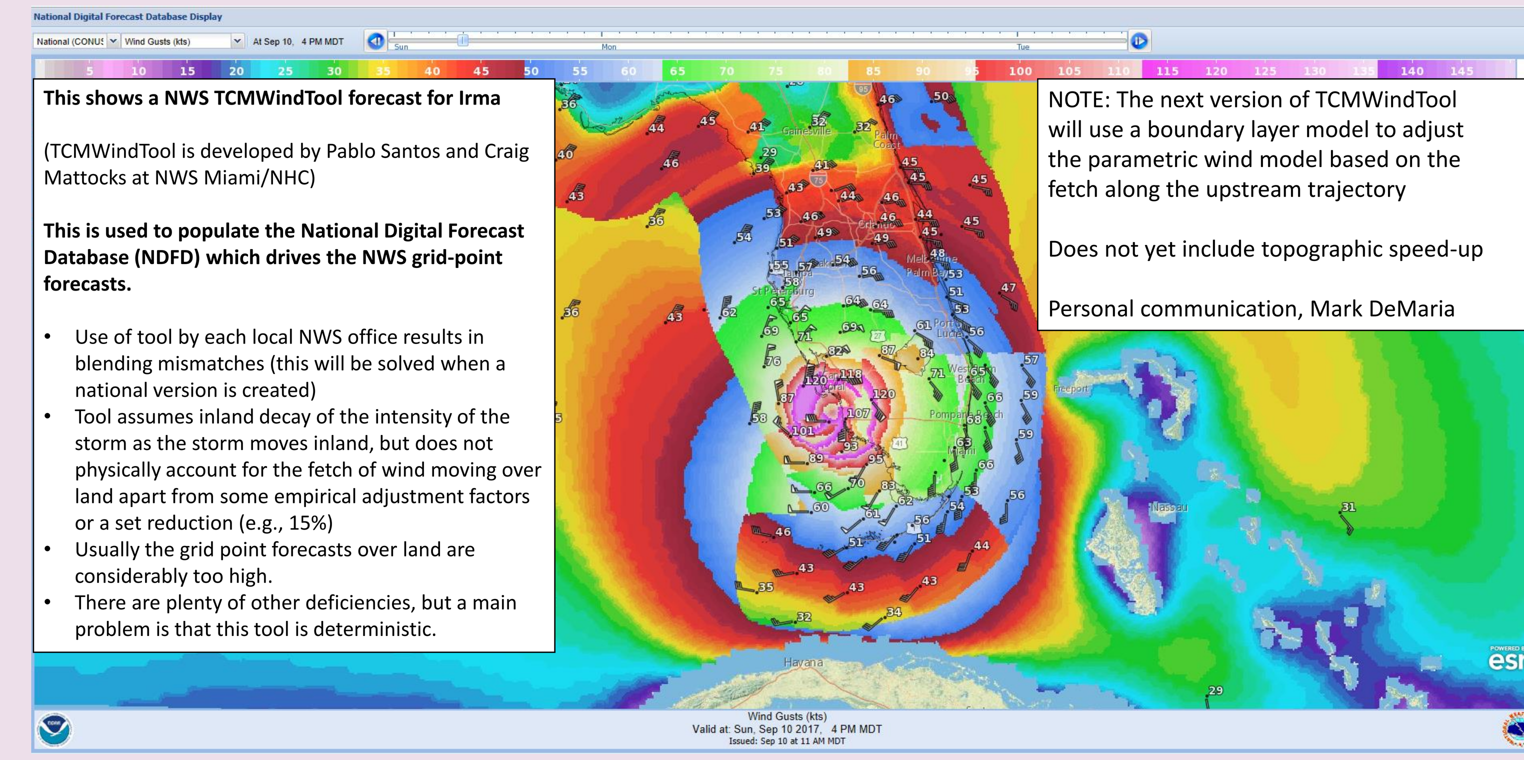
- **that they can easily understand,**
- **are relevant to their situation,**
- **are localized and adapted to their specific residence,**
- **are made available within actionable timescales**

3. Examples of Currently Available Data Sources



Example of current state-of-the-art NWP: the Hurricane WRF model (HWRF)

- Due to the use of the parent domain for the coastal-land mask and land surface, wind speeds over land are not well represented
- Furthermore, use of the metric of 1-min sustained winds also accentuates the marine vs. land differences in model products
- This 62-h forecast for Irma shows that Cat 3-4 winds would suddenly diminish to Category 1 winds within a couple miles of the coast – unrealistic!
- What really matters for damage are the gusts. These do not differ as much from sea to land as sustained winds.
- **Use of 1-min sustained wind in products can send the wrong message to users**



This shows a NWS TCMWindTool forecast for Irma

(TCMWindTool is developed by Pablo Santos and Craig Mattocks at NWS Miami/NHC)

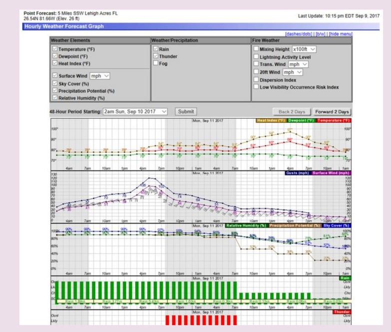
This is used to populate the National Digital Forecast Database (NDFD) which drives the NWS grid-point forecasts.

- Use of tool by each local NWS office results in blending mismatches (this will be solved when a national version is created)
- Tool assumes inland decay of the intensity of the storm as the storm moves inland, but does not physically account for the fetch of wind moving over land apart from some empirical adjustment factors or a set reduction (e.g., 15%)
- Usually the grid point forecasts over land are considerably too high.
- There are plenty of other deficiencies, but a main problem is that this tool is deterministic.

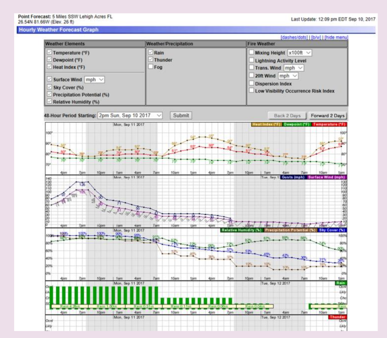
NOTE: The next version of TCMWindTool will use a boundary layer model to adjust the parametric wind model based on the fetch along the upstream trajectory

Does not yet include topographic speed-up

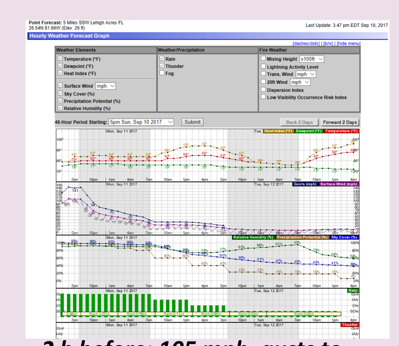
Personal communication, Mark DeMaria



18 h before: 98 mph, gusts to 120 mph (low Cat 2)



5 h before: 105 mph, gusts to 128 mph (mid Cat 2)



2 h before: 105 mph, gusts to 141 mph (upper Cat 2)

4. Need for Fully Probabilistic Wind Modeling

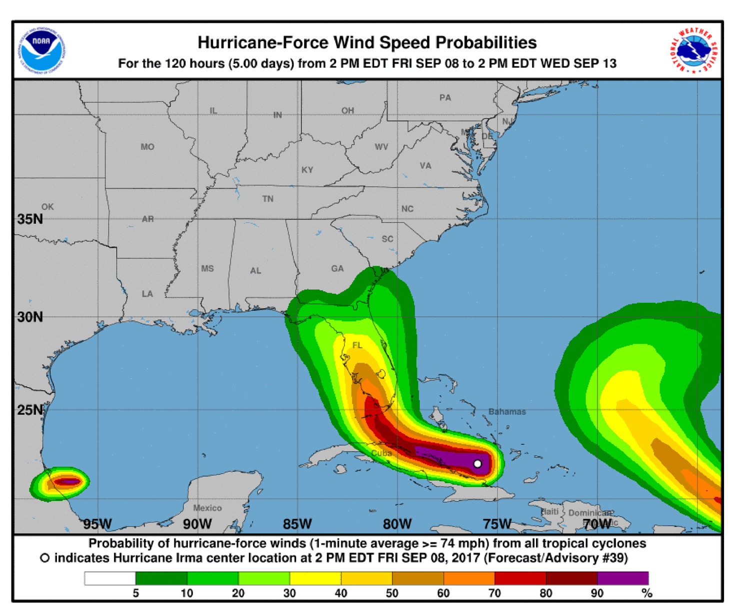
Probabilistic approaches offer a much better way to incorporate all of the various sources of uncertainty (track uncertainty, intensity uncertainty, size uncertainty, etc.).

The NHC Wind Probability Product (developed by NESDIS/RAMMB at CSU/CIRA) three days prior to landfall appropriately showed that this location had a high (60-70%) chance of hurricane force winds.

This product is really good in that it does account for the track/intensity/size uncertainty using a Monte Carlo method (1000 realizations) with a parametric wind model.

Problems are that it still uses inland decay rather than an explicitly physical modeling of the changes in wind over land. It does not account for terrain (no topographic speed-up is included, which can be substantial in mountainous areas). Also, it does not provide info for winds > 64 kt.

While development of a fully probabilistic wind modeling system is beyond the scope of the current project, this is a long-term need.



NHC hurricane-force wind speed probabilities for Irma Approximately 60 h prior to landfall

5. Design Wind Speeds

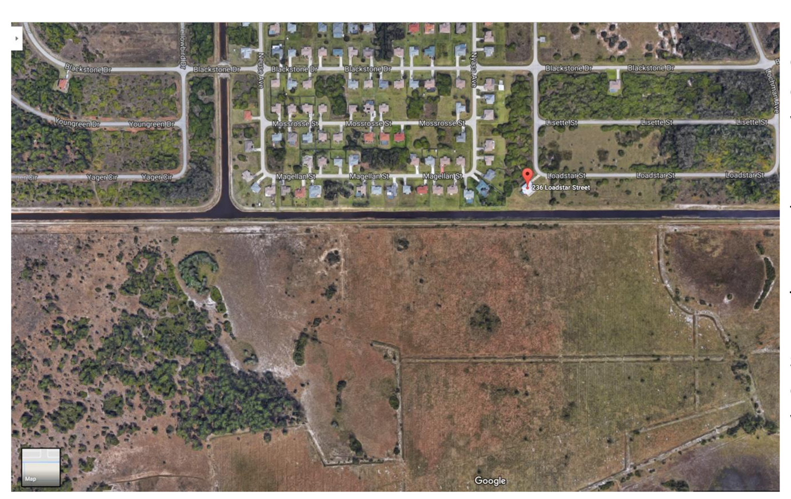
Historically, the design wind speed used to set building codes, called the v_{basic} or v_{design} was the 3-sec gust wind speed that has a 50 year return period (2% probability of occurring in a given year), measured in an open exposure (Category C) at 10 m height. Various importance and wind loading factors were applied based on region and building category.

New standards, such as the ASCE 7-10, now use what is called the "ultimate design wind speed", or $v_{ultimate}$, which is set by structure category. For residential construction (Risk Category II), $v_{ultimate}$ is determined by the 700-year return level wind speed. In the 2012 International Building Code (2012 IBC), a building code used by many communities, the older design wind speed was based on the philosophy of acceptable stress design (v_{asd}). This wind speed is related to the ultimate design wind speed by:

$$v_{asd} = v_{ultimate}\sqrt{0.6}$$

For design of specific structures, the exposure category, terrain factor, building height, and other factors must all be taken into account.

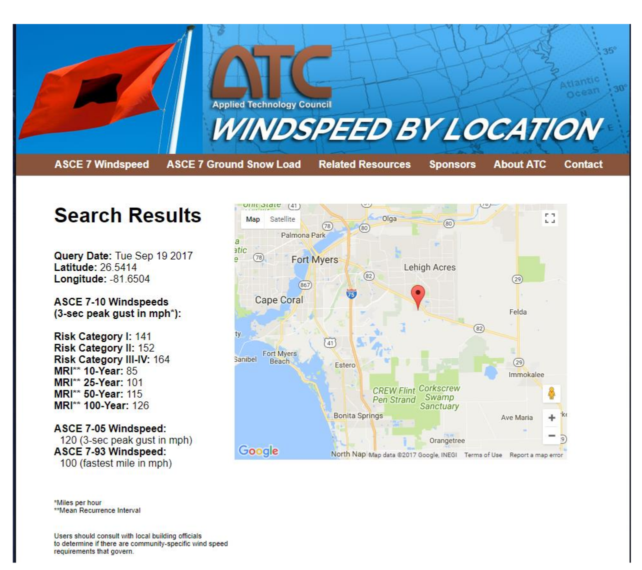
Another key aspect is to account for the fetch of the wind as it travels over varying terrain and orography. We will use the Kepert-Wang boundary layer model as a first step, later bringing in capabilities of the Australia Geoscience Tropical Cyclone Risk Model.



Place marker shows location of an example house. There is open exposure to the south (category C), with trees and urban exposure (category B) to the north. The house is 32 feet above sea level, meaning that it is quite safe from all but the most catastrophic storm surges.

The local exposure (within a few miles) is very important to the strength of the gusts that can be experienced for a given strength of winds in the boundary layer.

Importance of adjustment for local terrain, fetch, and drag characteristics



ASCE 7-10 3-sec gust return levels for that specific location

6. Translating Wind Impacts

In the absence of actual information about a given structure, the design wind speeds v_{asd} and $v_{ultimate}$ that the structure was built to can be used as a rough guide to formulate an expectation on how a residential structure may perform during a hurricane. For purposes of estimating damage to the structure itself, and losses of the contents therein, the relevant structural performance characteristic is the breach of the building envelope (Li and Ellingwood 2009). Building components are typically rated such that they will not experience inelastic deformation or other types of failure so long as $v < v_{asd}$. For wind speeds above v_{asd} but still below $v_{ultimate}$, inelastic deformations may occur (i.e., damage to the building envelope), sometimes leading to significant damage to the contents within (e.g., water damage) which could compromise the ability of occupants to remain in the home after the storm (e.g., mold). In general, however, the structure should still generally maintain significant ability to protect life and safety of its occupants. As the wind speed approaches and exceeds $v_{ultimate}$, significant damage becomes likely with an increasing possibility of total structural collapse.

Another approach to estimating the wind impact is a fragility analysis on the individual building components (e.g., roofing system, method by which roof is attached to walls, large windows, patio doors, garage doors). Generally, the weakest component in the building envelope represents the most significant risk to experiencing a breach of the envelope, although this depends significantly on the wind direction. If such information is available, a more accurate picture of the potential damage can be provided. Gathering the requisite information however, would likely require a structural inspection.

To keep things as simple as possible, the initial version of the Hurricane Risk Calculator will probably display potential damage in a 3-point color categorical scale that relates to the potential safety of the structure during the storm and the habitability after the storm:

- **Green tag condition likely** ($v \leq v_{asd}$): no significant structural damage is expected (non-structural damage possible, e.g. fences, out-buildings, etc.)
- **Yellow tag condition is likely** ($v_{asd} < v \leq v_{ultimate}$): some structural damage possible; some loss to contents is likely; structure may not be habitable following the storm due to water damage, mold, and/or loss of utility services
- **Red tag condition is likely** ($v > v_{ultimate}$): significant damage is possible up to a total loss of the structure and its contents. Structure could lose its ability to protect life and safety of occupants, the real-time predicted wind information can be convolved with vulnerability curves for that particular class of structures to estimate a dollar figure for the probable damage.

The presence of large trees, wind-borne debris, and other factors must also be considered.

The calculator will ask some basic questions of users to screen for these risks.

7. Informing Evacuation vs. Shelter-in-Place Decisions

The risks of remaining in a home (as well as the risks of being in the area after the storm) must be weighed against the very real, but often under-appreciated risks of evacuation. The following table contextualizes the potential mortality risks of evacuation within the larger spectrum of per-event risks for a variety of activities. Ultimately, the resident must make their decision based on their unique situation, vulnerability, and risk tolerance. We propose that optimal outcomes will become more likely when decisions are made in a risk-informed probabilistic framework.

1 in X chance	Probability	Beta	Categorical Risk Description	Example activity with comparable mortality risk, along with the risks of other types of events
1	1.00		Certain death	Sum total of all-cause mortality over a lifetime
2	0.50	0		Participating in a duel
3	0.33	0.430727299	Catastrophic risk	
5	0.20	0.841621234		
10	0.10	1.281551566	Profound risk	Climbing Mount Everest without oxygen (actual risk: 12.4%)
20	0.05	1.644853627		Summitting Mount Everest (actual risk: 4.0%)
50	0.02	2.053748911	Grave risk	Attempting to climb Mount Everest (actual risk: 1.6%)
100	0.01	2.326347874		***Not evacuating New Orleans during Hurricane Katrina (~1100 deaths out of ~100,000 who remained)***
200	0.005	2.575829304	Severe risk	
500	0.002	2.878161739		*(e.g., some major surgeries)*
1,000	0.001	3.090232306		
2,000	0.0005	3.290526731	Very significant risk	Base jumping, 1 jump (1 death every 2317 jumps)
5,000	0.0002	3.540083799		
10,000	0.0001	3.719016485	Significant risk	Summitting Longs Peak (1 death for every ~10,000 successfully summits each year)
20,000	0.00005	3.890591886		***Hurricane Rita evacuation (actual risk: 1 in 23,364, based on 107 deaths out of 2.5 million evacuees)***
50,000	0.00002	4.107479655	Acceptable risk for some necessary activities	***Taking a round-trip trip by car to a destination 500 miles away (actual risk: 1 in 66,000*)***
100,000	0.00001	4.264890794		
200,000	0.000005	4.417173413		Sky diving, 1 jump in 2010 (1 death per 153,000 jumps; based on 21 deaths for 3 million jumps in 2010)
500,000	0.000002	4.611382362	Moderate risk	
1,000,000	0.000001	4.753424309		Skiing at a Colorado ski resort (about 1 death per million skier visits)
2,000,000	0.0000005	4.891638476	Routine daily acceptable risk	***Commuting to work or evacuating to a local shelter (20 miles round-trip, actual risk: 1 in 3,300,000*)***
5,000,000	0.0000002	5.06895775	Minimal risk	Taking a long-haul round-trip flight (10,000 total miles; actual risk: 1 in 7,142,857**)
10,000,000	0.0000001	5.199337582		
20,000,000	0.00000005	5.326723886	Very low risk	
50,000,000	0.00000002	5.490851752		***Taking a short-haul round-trip flight (1000 total miles; actual risk: 1 in 50,000,000**)***
100,000,000	0.00000001	5.612001244	Extremely low risk	
200,000,000	0.000000005	5.730728868		
500,000,000	0.000000002	5.884193355	Astonishingly small risk	Lifetime odds of being killed by hail in the U.S. (actual risk: 1 in 734,000,000)
1,000,000,000	0.000000001	5.997807015		

* From 2000-2005, the risk of car travel in the U.S. is 1.5 deaths per 100 million passenger miles travelled.
+ Between 2000 and 2010, the mortality risk of flying on commercial avaiation in the U.S. is 0.2 deaths per 10 billion passenger miles travelled.
From: https://en.wikipedia.org/wiki/Transportation_safety_in_the_United_States and references therein.

Acknowledgments

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References:

Li, Y. and B. R. Ellingwood (2009), "Framework for multi-hazard risk assessment and mitigation for wood-frame residential construction." J. Struct. Engrg. ASCE 135(2):159-168.

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