Moving from Hazard to Risk: The Hurricane Risk Calculator

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NCAR

Direct Hazards from Tropical Cyclones

- Surge
- Inland flooding
  - Landslides
- Wind hazard
  - Building collapse
  - Falling trees
- Waves
  - Rip currents
- Tornadoes

Indirect Hazards

- Cardiovascular failure
  - strenuous exertion during preparations or cleanup
  - heat exhaustion
- Medical device failure due to power outages
- Falls (preparation, power outages)
- Electrocution
- Carbon monoxide poisoning
- Fires
- Hypothermia
- Car accidents (e.g., stoplights out, downed trees, hydroplaning)
- Rip currents
- Disease outbreaks (e.g., cholera, etc.)

Rappaport and Blanchard (2016)

Evacuations also pose risks

The risks of remaining in a storm-affected area must be weighed against the very real, but often under-appreciated risks of evacuation

- Car accidents
- Lack of power
  - Lack of medical services
  - Heat exhaustion
- Stress on the elderly

In Hurricane Rita (2005), there were approximately 80 evacuation-related deaths

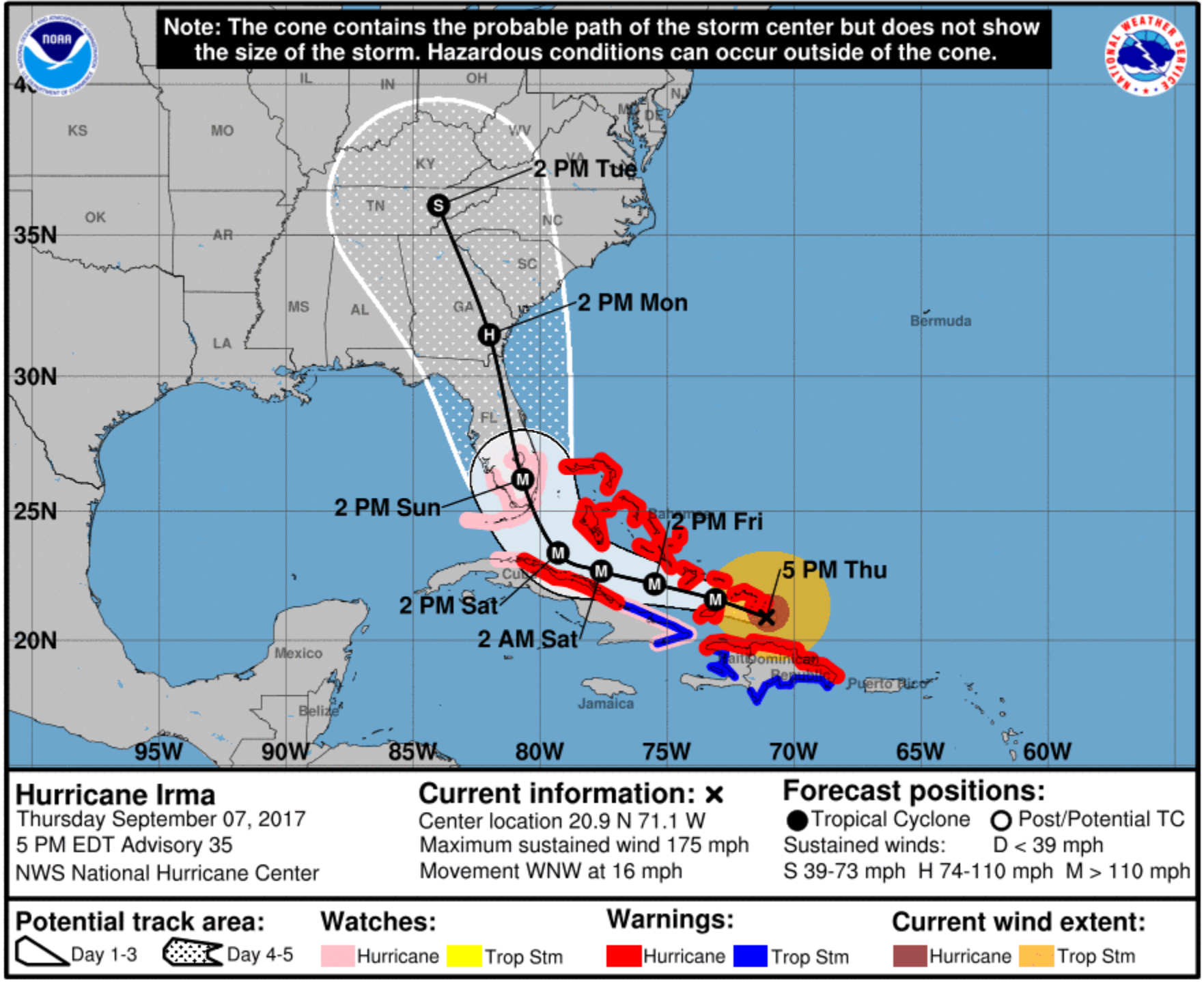
In Hurricane Irma, 6.8 million people are estimated to have evacuated, but 3 million of these were not from evacuation zones!

Current emergency management practice

- Forecast enterprise (observations, modeling -> forecast, products)
- Coordination meetings between forecasters, federal/state/local agencies, emergency managers (EMs)
- Emergency management recommendations made for each local jurisdiction -> communication channels
- Local evacuations (sometimes staged optimally by surge risk zones, sometimes not)
- Response rates of 30 - 80% (FEMA estimated that 10,000 people stayed in Keys during Irma)

Problems with the U.S. system

- Too much emphasis on deterministic scenarios
- People receive info from many different channels, some of questionable quality (e.g., web, social media)
- Since people have trouble interpreting complex information under stress, decision making is often haphazard
- All-or-nothing evacuation scenarios
  - e.g., stay put vs. go out of state
- Those with economic means are able to evacuate; most vulnerable are often still in harm's way
- Timing of evacuations is often not optimal
- "Local leaders know best . . ." (e.g., Harvey local officials contracted state governor, did not recommend evacs)
- Stakeholders (such as homeowners and other residents) find it difficult or impossible to get detailed and trustworthy info needed to optimize their own cost/loss situation


Note: The cone contains the probable path of the storm center but does not show the size of the storm. Hazardous conditions can occur outside of the cone.
2 PM Tue
2 PM Mon
2 PM Sun
2 PM Fri
5 PM Thu
2 PM Sat
2 AM Sat
35N
30N
25N
20N
95W
90W
85W
80W
75W
70W
65W
60W
KS
MO
OK
AR
LA
MS
AL
GA
FL
SC
NC
TN
KY
IL
IN
OH
Bermuda
Mexico
Belize
Jamaica
Puerto Rico
Hurricane Irma
Thursday September 07, 2017
5 PM EDT Advisory 35
NWS National Hurricane Center
Current information:
Center location 20.9 N 71.1 W
Maximum sustained wind 175 mph
Movement WNW at 16 mph
Forecast positions:
Tropical Cyclone
Post/Potential TC
Sustained winds:
D < 39 mph
S 39-73 mph H 74-110 mph M > 110 mph
Potential track area:
Day 1-3
Day 4-5
Watches:
Hurricane
Trop Stm
Warnings:
Hurricane
Trop Stm
Current wind extent:
Hurricane
Trop Stm

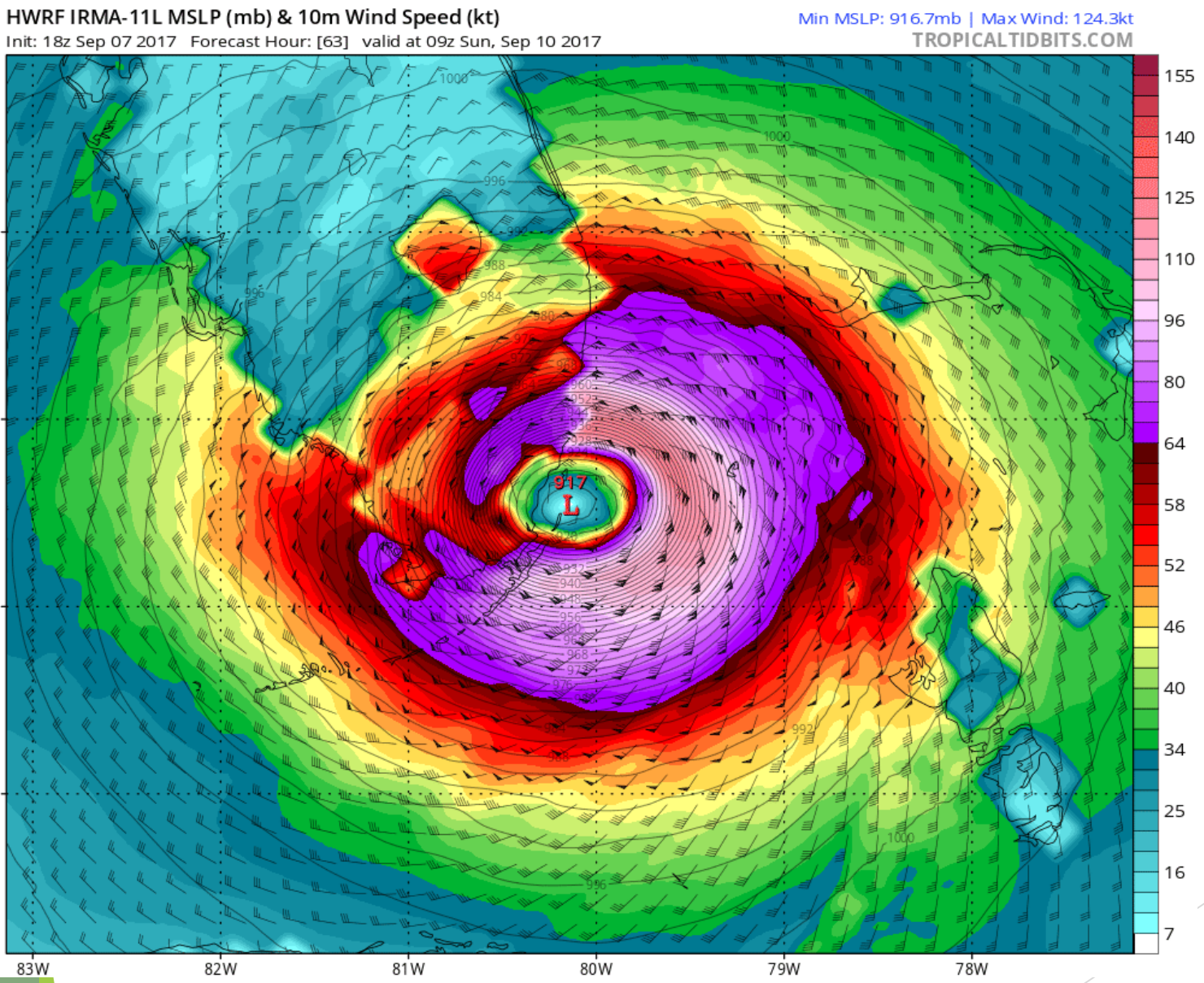
What do people need?

- **They need information specific to their location on the impacts from:**
  - **storm surge**
  - **wind impacts**
  - **inland flooding**

- (It's fairly irrelevant to them where the exact track is, what the size of the cone is, or what the maximum intensity of the storm will be)

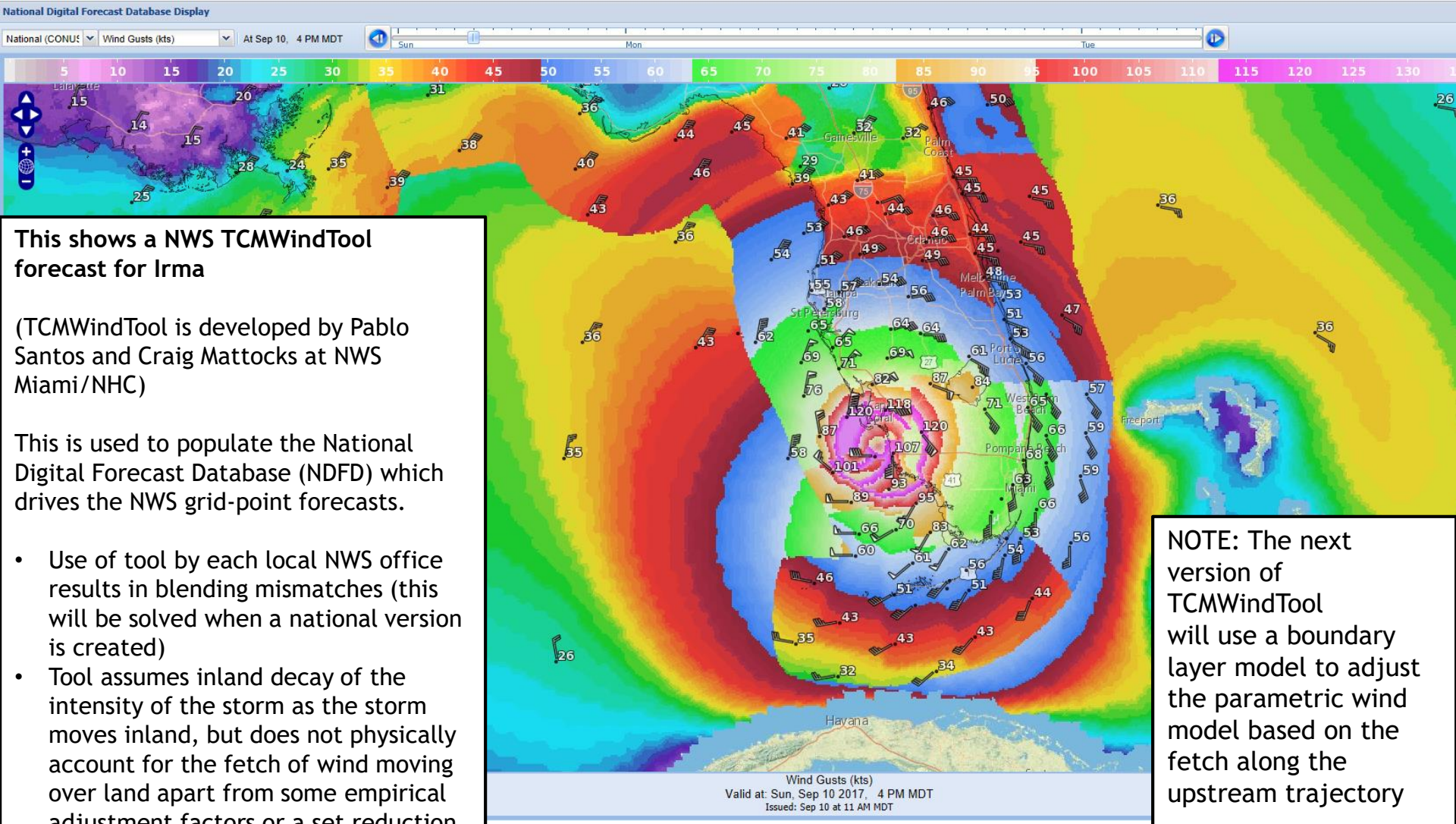
- **More specifically, they really need to know probabilistic information translated into forms that they can understand and which are relevant to their situation**

The next few slides will examine some of the state-of-the-art sources of hurricane wind hazard information and highlight some deficiencies



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)

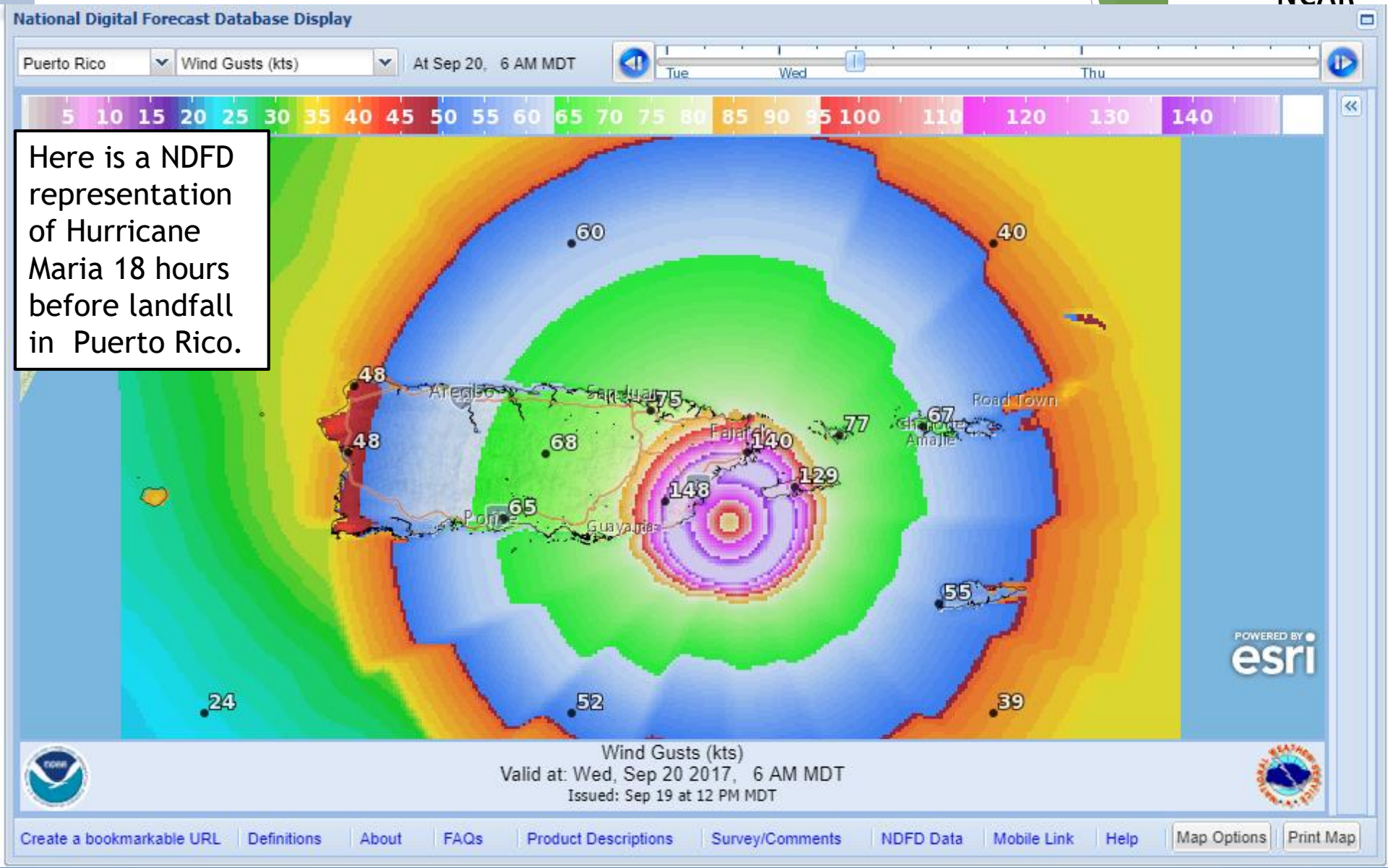
This is used to populate the National Digital Forecast Database (NDFD) which drives the NWS grid-point forecasts.

- 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

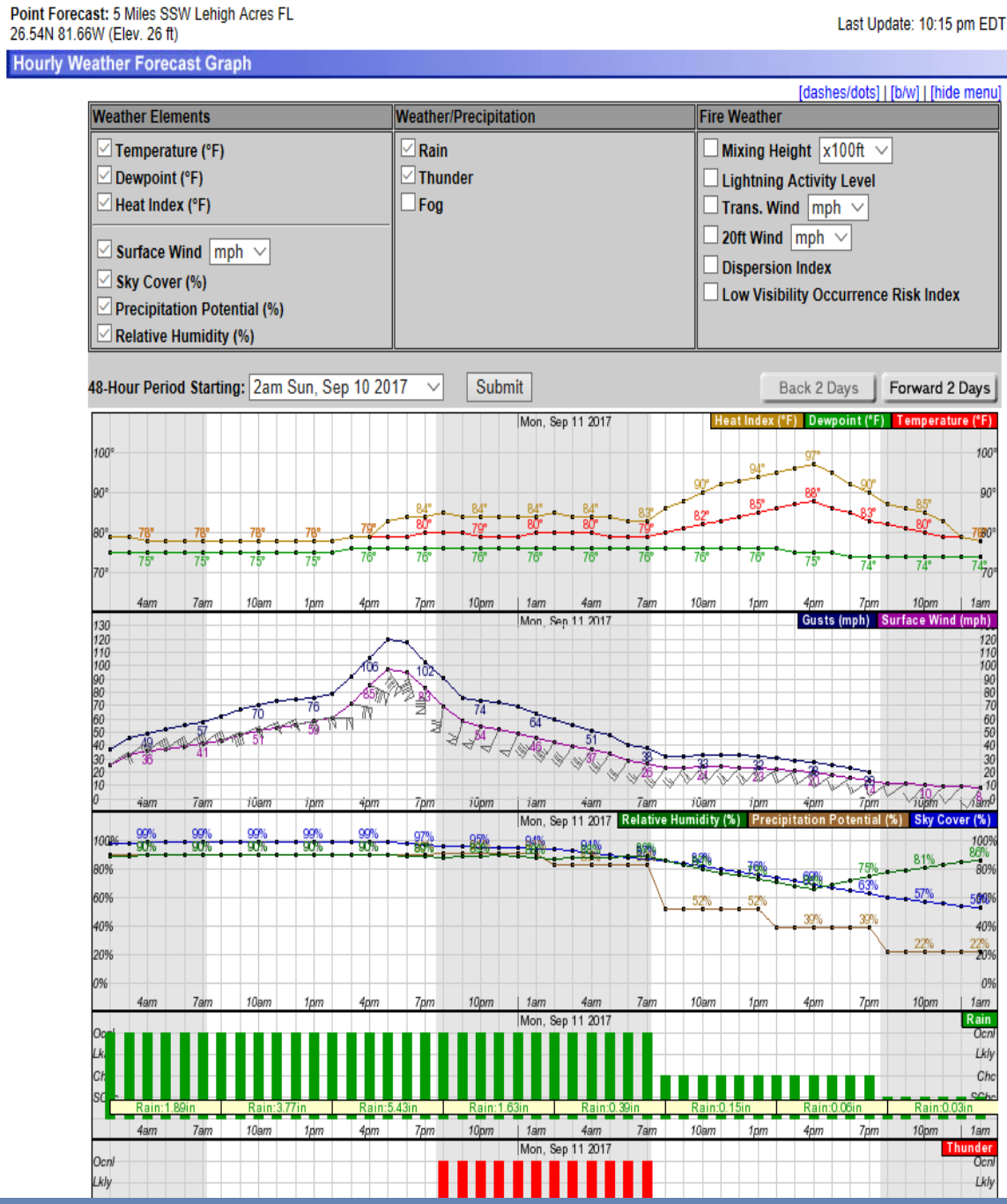
Does not yet include topographic speed-up

Personal communication, Mark DeMaria


National Digital Forecast Database Display
Puerto Rico
Wind Gusts (kts)
At Sep 20, 6 AM MDT
Tue
Wed
Thu
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 110 120 130 140
Here is a NDFD representation of Hurricane Maria 18 hours before landfall in Puerto Rico.
60
40
48
48
68
75
77
67
140
129
148
65
55
24
52
39
Road Town
Wind Gusts (kts)
Valid at: Wed, Sep 20 2017, 6 AM MDT
Issued: Sep 19 at 12 PM MDT
Create a bookmarkable URL
Definitions
About
FAQs
Product Descriptions
Survey/Comments
NDFD Data
Mobile Link
Help
Map Options
Print Map

Other problems with TCMWindTool (and similar approaches)

- Using sustained winds to define storm intensity is problematic because these are typically considerably lower over land than over the ocean, yet the gust factor over land is typically much higher than over the ocean. For land impacts, the gusts are what are most important. Use of an improper wind metric results in sub-optimal results over land.
- Additionally, the analyzed storm intensity is set based on whatever the maximum winds are. Typically, when a storm is on land, these still occur over the water (especially later on when the storm has weakened considerably).
- When the storm center is well on-shore, the winds well away from the center that are over the ocean sometimes are the highest sustained winds, so this may lead to a designation of the storm intensity that is actually not appropriate for modeling the winds over land (if terrain/friction is not appropriately accounted for).



NWS grid-point forecast for Lehigh Acres, an eastern suburb of Fort Myers, FL.

This forecast was made approximately 18 hours before the core of the storm moved through.

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

Point Forecast: 5 Miles SSW Lehigh Acres FL
26.54N 81.66W (Elev. 26 ft)

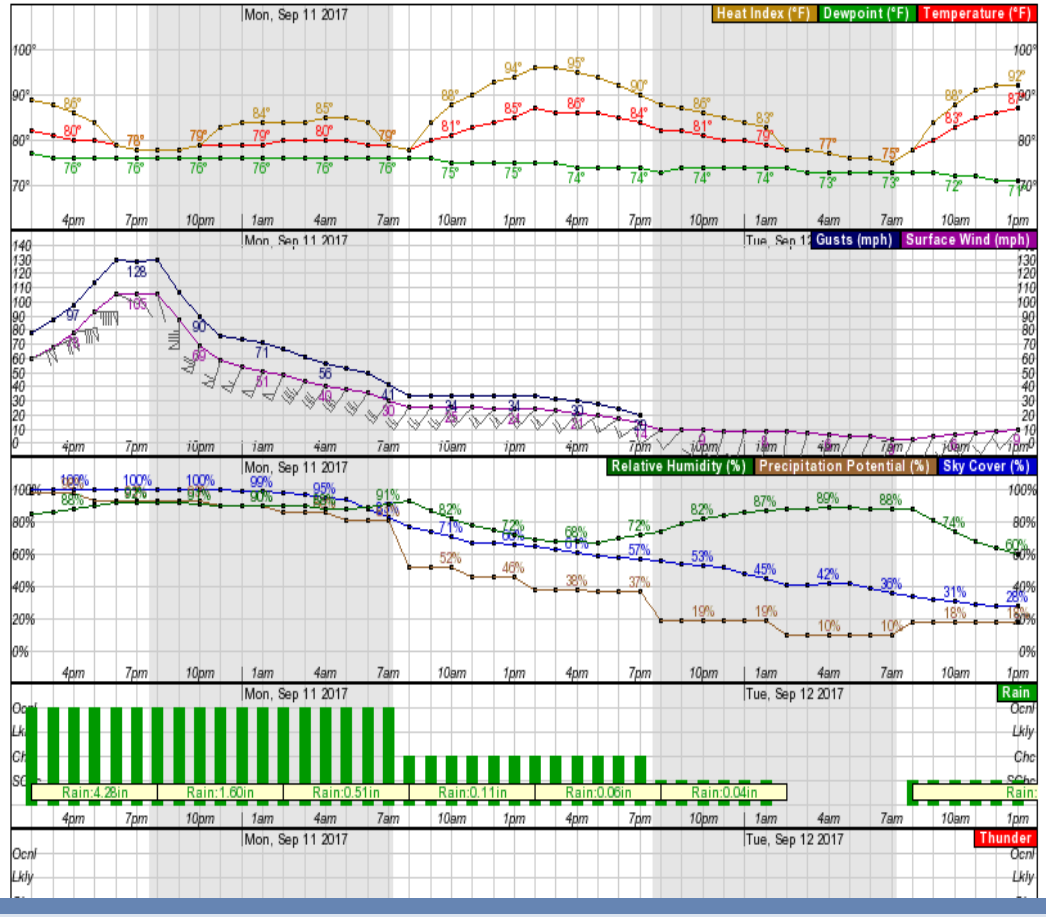
Last Update: 12:09 pm EDT Sep 10, 2017

Hourly Weather Forecast Graph

[dashes/dots] | [b/w] | [hide menu]

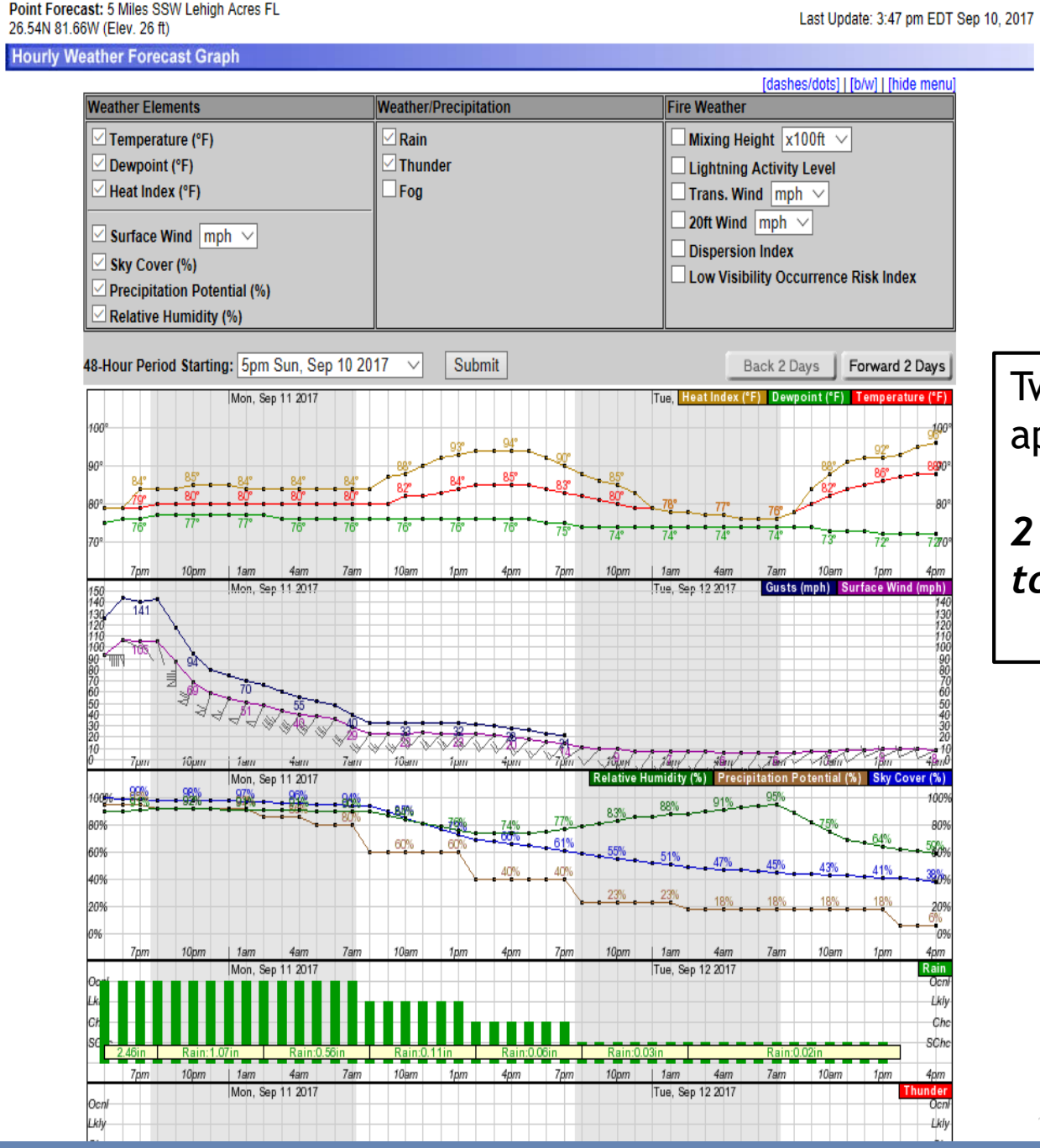
Weather Elements	Weather/Precipitation	Fire Weather
☑ Temperature (°F)	☑ Rain	☐ Mixing Height x100ft
☑ Dewpoint (°F)	☑ Thunder	☐ Lightning Activity Level
☑ Heat Index (°F)	☐ Fog	☐ Trans. Wind mph
☑ Surface Wind mph		☐ 20ft Wind mph
☑ Sky Cover (%)		☐ Dispersion Index
☑ Precipitation Potential (%)		☐ Low Visibility Occurrence Risk Index
☑ Relative Humidity (%)		

48-Hour Period Starting: 2pm Sun, Sep 10 2017 Submit Back 2 Days Forward 2 Days



Five hours prior to impact:

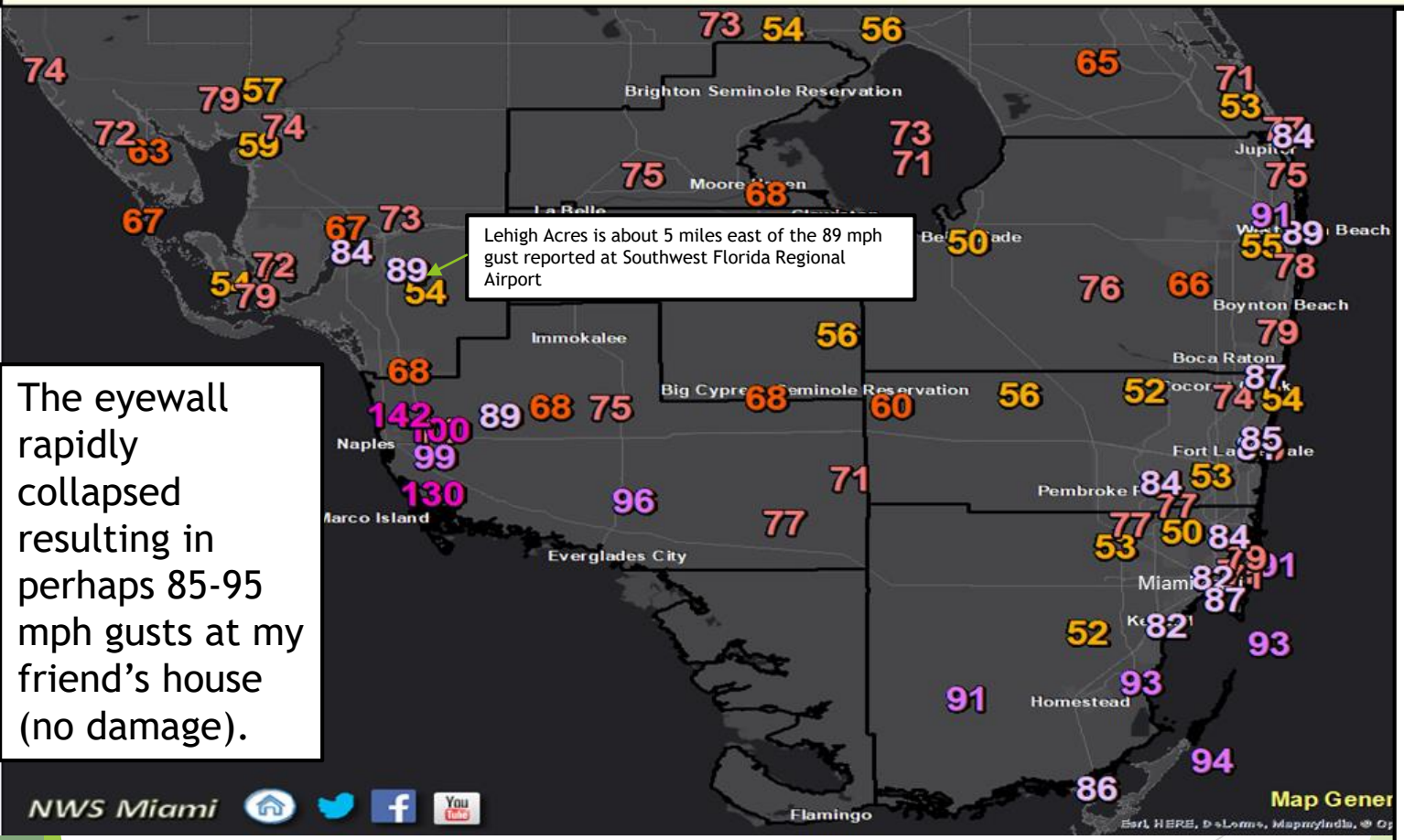
5 h before: 105 mph, gusts to 128 mph (mid Cat 2)



Two hours prior to closest approach:

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

HURRICANE IRMA'S OBSERVED TOP WIND GUSTS (50+ MPH)

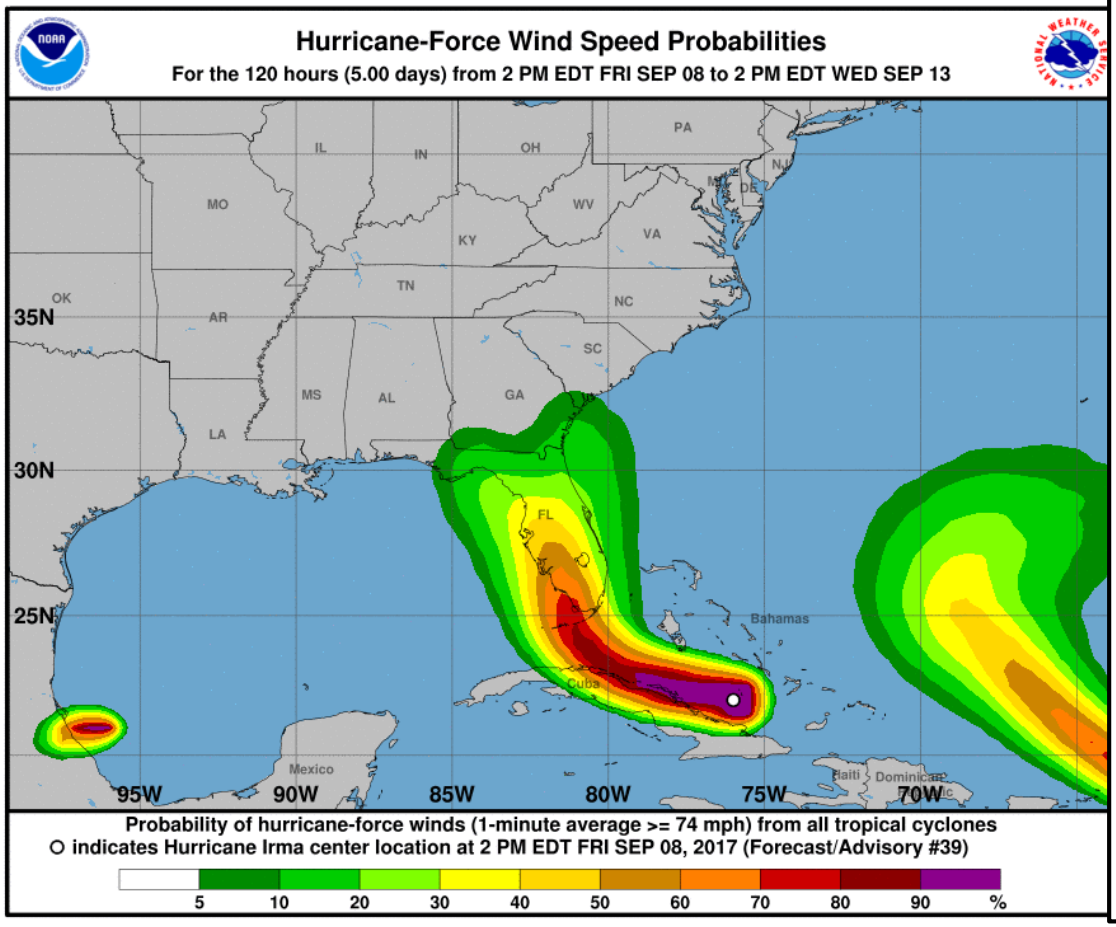


The eyewall rapidly collapsed resulting in perhaps 85-95 mph gusts at my friend's house (no damage).

Verification:

Irma was already experiencing vertical wind shear and dry air. By the time it made landfall on Marco Island, it had weakened to a Category 3 hurricane (100 kt) and had an asymmetric structure.

Probabilistic Information



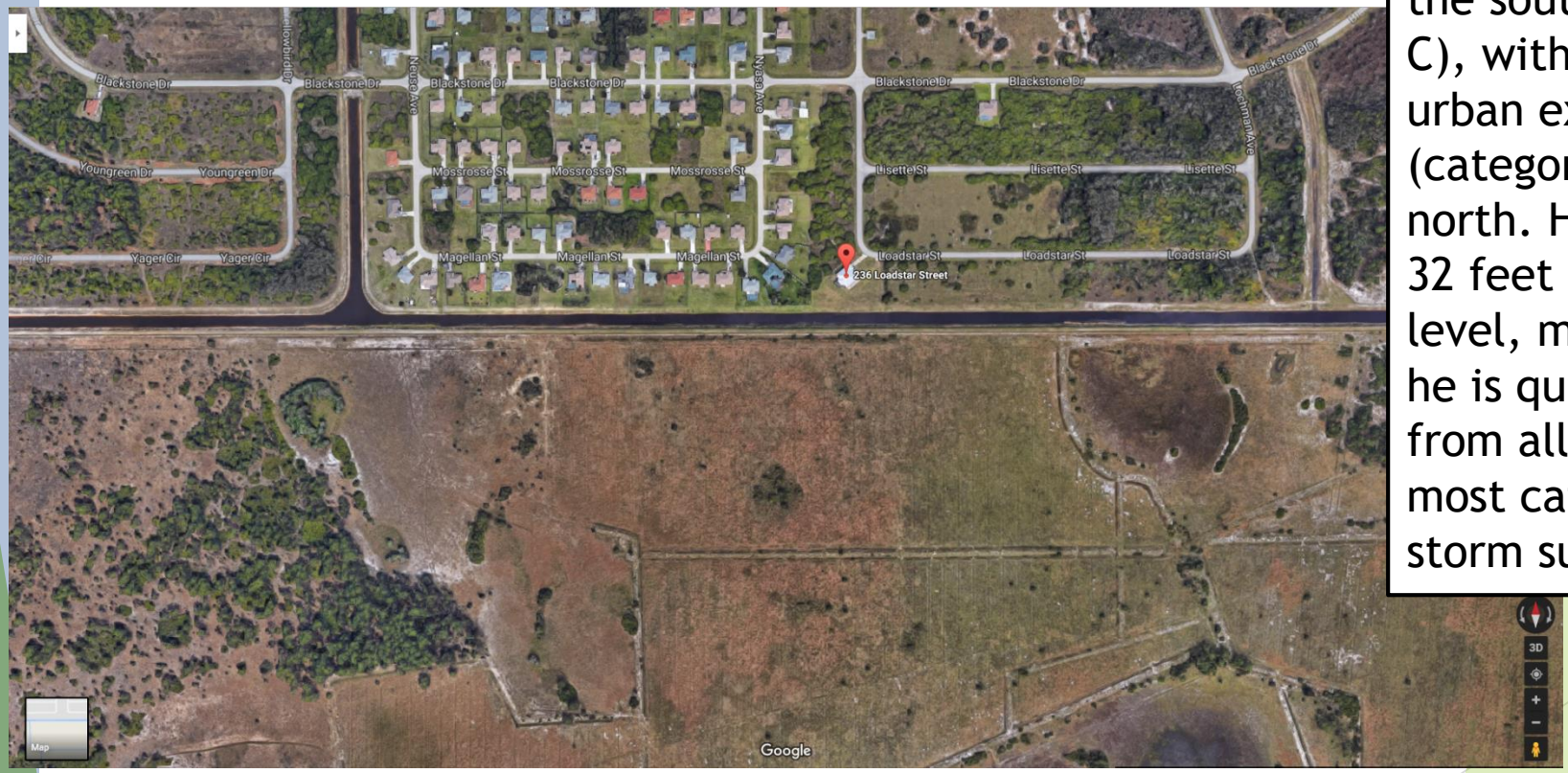
Probabilistic approaches offer a much better way to incorporate all of the various sources of uncertainty (track uncertainty, intensity uncertainty, size uncertainty, etc.).

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

Problems:

- uses inland decay rather than an explicitly physical modeling of the changes in wind over land
- does not account for terrain
- does not provide info for > 64 kt

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



The place marker shows the location of my friend's house. He has an open exposure to the south (category C), with trees and urban exposure (category B) to the north. His house is 32 feet above sea level, meaning that he 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.

The problem of topographic speedup

- Hurricane wind fields impacting terrain (even low hills of just 50 m) can experience a significant speedup due to the Bernoulli effect.
- A modeling study of Hurricane Fabian over Bermuda found that topographic speedup on ridgetops in Bermuda resulted in more than a category increase in winds (from upper Cat 2 to Cat 4 winds). Damage surveys and observations have borne this out.
- Topographic speedup is especially dangerous in islands such as St. Thomas (USVI) where residents have described “horizontal tornadoes” causing severe damage in past hurricane events.
- For certain regions of the storm, the higher wind risk posed by topographic speedup will depend critically on the exact track. Tracks which result in a hillside locations getting exposed to the upslope wind may experience a 30-50% speedup in the winds, while a track shift may result in the same location being sheltered and getting a 20-30% decrease in the expected winds.
- The only rationale way to take all of this into account is in a fully probabilistic framework which accounts for the many possible track scenarios and upwind vs. downwind fetches. It’s possible an eddy-resolving boundary layer may be required to fully capture this effect.

Importance of translation

- Even if the wind information is accurate, users will not know how to interpret this without context (e.g., “120 mph sounds bad, but will my house hold up?”)
- Translation includes assessing the forecasted wind hazard in relation to the thresholds at which damage is expected to occur for their structure
- Needs to account for additional risks such as falling trees, wind-borne debris from neighboring structures, etc.
- Can also include estimates of how long it will take for power and other services to be restored
- Needs to stress uncertainty and get users to incorporate high-end scenarios rather than just the most-likely scenario

Translating Wind Hazard to Impacts

- In the absence of actual information about a given structure, the design wind speeds 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.
- The "acceptable stress design wind speed" (v_{asd}) is 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.
- New standards, such as the ASCE 7-16, now use what is called the "ultimate design wind speed" ($v_{ultimate}$) which is set by structure category. For residential construction (Risk Category II), $v_{ultimate}$ is determined by the 700-year return level wind speed.
- 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).
- 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.

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WINDSPEED BY LOCATION

ASCE 7 Windspeed | ASCE 7 Ground Snow Load | Related Resources | Sponsors | About ATC | Contact

Search Results

Query Date: Tue Sep 19 2017
Latitude: 26.5414
Longitude: -81.6504

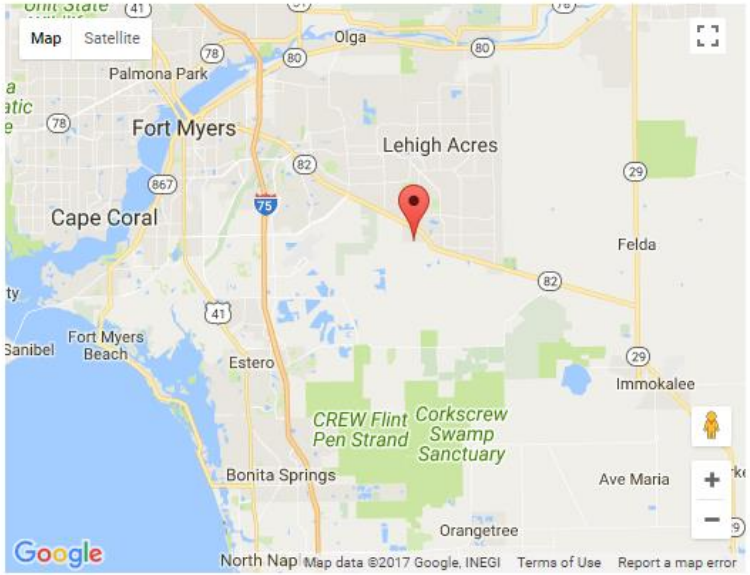
ASCE 7-10 Windspeeds
(3-sec peak gust in mph*):

Risk Category I: 141
Risk Category II: 152
Risk Category III-IV: 164
MRI 10-Year:** 85
MRI 25-Year:** 101
MRI 50-Year:** 115
MRI 100-Year:** 126

ASCE 7-05 Windspeed:
120 (3-sec peak gust in mph)
ASCE 7-93 Windspeed:
100 (fastest mile in mph)

*Miles per hour
**Mean Recurrence Interval

Users should consult with local building officials to determine if there are community-specific wind speed requirements that govern.



The 2012 International Building Code (2012 IBC) and many older building codes used the older design wind speed, V_{asd}. This wind speed is related to $V_{ultimate}$ 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.

Residential buildings use Risk Category II, in which $V_{ultimate}$ corresponds to the 700-year return level wind speed. For his location according to the American Society for Civil Engineers (ASCE 7-16 wind standard), that is a wind gust to 152 mph.

Therefore, the V_{asd} for his location is likely to be around 152 mph x 0.7746 = 118 mph.

Translation: **IF** his house is built to the current code, it should be fine in wind gusts up to ~118 mph. Damage of increasing severity is expected as winds approach 152 mph. Complete building failure becomes likely much above that wind speed.

More sophisticated approaches

- Another approach to estimating the wind impact is a **fragility analysis** on the individual building components:
  - 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.
- When coupled with probabilistic wind information, fragility analysis can provide an estimated range of damage that may occur.
- The likelihood that the structure may lose its ability to provide life and safety protection can also be estimated.

Keeping the message simple

The Hurricane Risk Calculator will likely 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.

The Risk Spectrum

1 in X chance	Probability	Probability	Categorical Risk Description	Example activity or event with comparable mortality risk
1	1.00	10^{-0}	Certain death	Sum total of all-cause mortality over a lifetime
2	0.50		Catastrophic risk	Participating in a duel
5	0.20			
10	0.10	10^{-1}	Profound risk	Climbing Mount Everest without oxygen (actual risk: 12.4%)
20	0.05			Summitting Mount Everest (actual risk: 4.0%)
50	0.02			Attempting to climb Mount Everest (actual risk: 1.6%)
100	0.01	10^{-2}	Grave risk	***Not evacuating New Orleans during Hurricane Katrina (~1100 deaths out of ~100,000 who remained)***
200	0.005			
500	0.002			*(e.g., some major surgeries)*
1,000	0.001	10^{-3}	Severe risk	
2,000	0.0005			Base jumping, 1 jump (1 death every 2317 jumps)
5,000	0.0002			
10,000	0.0001	10^{-4}	Significant risk	Summitting Longs Peak (1 death for every ~10,000 successfully summits each year)
20,000	0.00005			***Hurricane Rita evacuation (actual risk: 1 in 23,364, based on 107 deaths out of 2.5 million evacuees)***
50,000	0.00002			***Taking a round-trip trip by car to a destination 500 miles away (actual risk: 1 in 66,000*)***
100,000	0.00001	10^{-5}	Considerable risk	
200,000	0.000005			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			
1,000,000	0.000001	10^{-6}	Low risk	Skiing at a Colorado ski resort (about 1 death per million skier visits)
2,000,000	0.0000005			***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			Taking a long-haul round-trip flight (10,000 total miles; actual risk: 1 in 7,142,857**)
10,000,000	0.0000001	10^{-7}	Very low risk	So-called *des minimis* risk
50,000,000	0.00000002			***Taking a short-haul round-trip flight (1000 total miles; actual risk: 1 in 50,000,000**)***
100,000,000	0.00000001	10^{-8}	Extremely low risk	
500,000,000	0.000000002			Lifetime odds of being killed by hail in the U.S. (actual risk: 1 in 734,000,000)
1,000,000,000	0.000000001	10^{-9}	Astonishingly small risk	

* 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.

Goals of the Hurricane Risk Calculator

- **Provide wind risk information localized by a user's address**
- Users will enter their address, then get back wind hazard and risk information customized for their specific location, including:
  - Their elevation (if <40 feet, flag the potential storm surge risk which would take precedence over wind risk)
  - NDFD grid-point-forecasted winds
  - Official NHC hurricane wind probabilities for 34-, 50-, and 64-kt winds at their location
  - Additionally, the tool will use the terrain-adjusted Kepert-Wang boundary layer model to provide an estimate of the local wind over land that accounts for terrain
  - Timing of onset of tropical storm-force and hurricane-force winds
  - Provide a "swath" or storm "footprint" showing the maximum expected winds.
  - Provide the ASCE 7-16 wind hazard information for their location to provide context
- Information will then be translated into understandable forms in a dashboard-like interface with graphs and text, with a goal of informing evacuation vs. shelter-in-place decisions.

The initial project is funded by the RAL Opportunity Fund. The tool will be incorporated into the Tropical Cyclone Guidance Project by 2018 hurricane season.