# Summary Report on the 14 December 2013 Palm Coast, FL Tornado

University of Florida Wind Hazard Damage Assessment Team

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## 1. BACKGROUND

On 14 December 2013, a progressive upper trough of low pressure moved eastwards across the United States, and the strong southerly low-level winds ahead of the front began to transport moisture from the Gulf of Mexico northward into North Florida. The initial convective outlook for December 14 as issued by the National Weather Service did not identify any specific areas as having potential for the development of tornadoes (Figure 1). However, by 11:30AM EST the updated convective outlook identified portions of Florida as having a slight chance for rotating storms in the afternoon and evening (Figure 2).

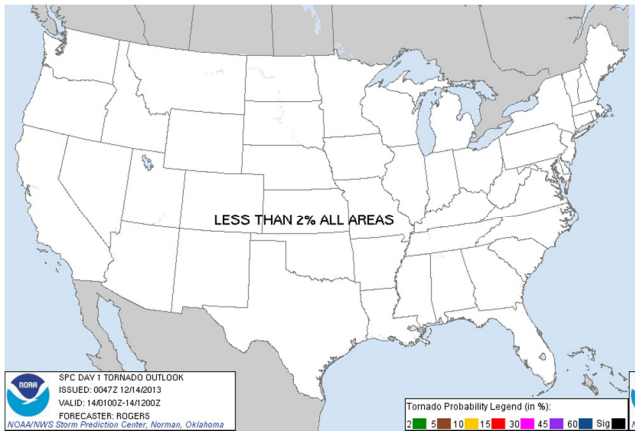



Figure 1: Initial NWS Convective Outlook (13 December 7:00pm EST)

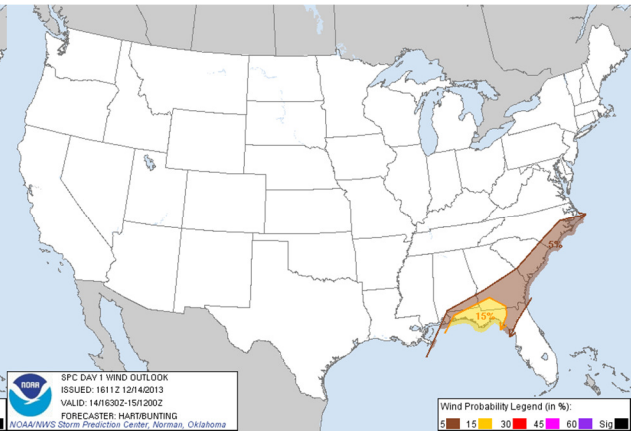



Figure 2: NWS Convective Outlook (11:30am EST)

Between 6:55pm and 7:10pm, a tornado touched down just north of Espanola, FL located in the northern sections of Palm Coast in Flagler County, FL (NWS JAX). From damage observations it appears the tornado touched down intermittently for approximately 9.5 miles, with a nearly 1 mile continuous path in the "B section" of Palm Coast. The National Weather Service survey team (Jacksonville Office) issued the complete tornado track shown in Figure 3. The University of Florida Wind Hazard Damage Assessment Team performed a detailed survey of the area with the heaviest damage, indicated by the callout in Figure 3.

A total of 208 homes were partially damaged, with 25 suffering serious damage and seven deemed destroyed or unlivable (Palm Coast Observer, 1/2/2014). As of 2 January 2014, the damage was estimated at $7.22 million, with all but one or two properties being insured. No fatalities or serious injuries were reported.

## 2. CITY INFORMATION

The city of Palm Coast, FL has a population of 75,180 and a total number of 34,296 housing units with a median value of $172,300 as of the 2010 US Census and 2008-2012 American Community Survey. The city is subdivided into 14 sections, in each of which all streets begin with the same letter. The city is more recently developed, having higher proportion of newer homes than is present in the overall age distribution for the state of Florida (Figure 4). For example, nearly 50% of the Palm Coast homes were built in or after the year 2000, as compared to just 20% for the entire state of Florida. Thus a reasonably high proportion of homes in the city of Palm Coast should be constructed with wind-resistant features that were mandated by the Florida Building Code after 1994, following the devastation caused by Hurricane

Andrew in 1992. In Flagler County, the Standard Building Code was used up to 2001, after which the Florida Building Code was adopted.

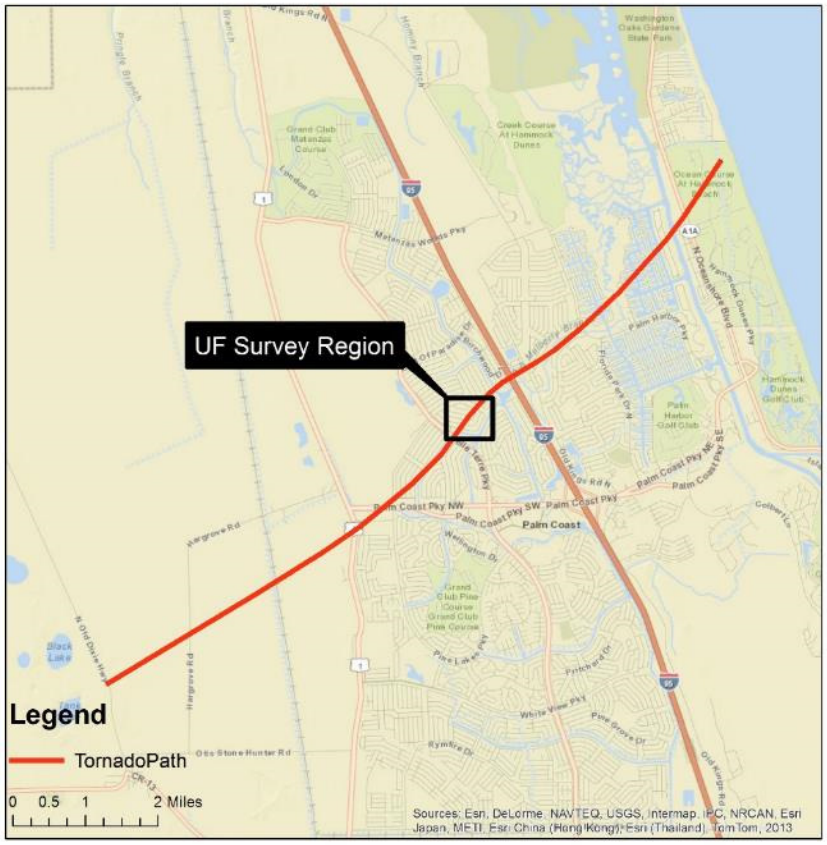



Figure 3: NWS estimate of tornado through Palm Coast in Flagler County, FL

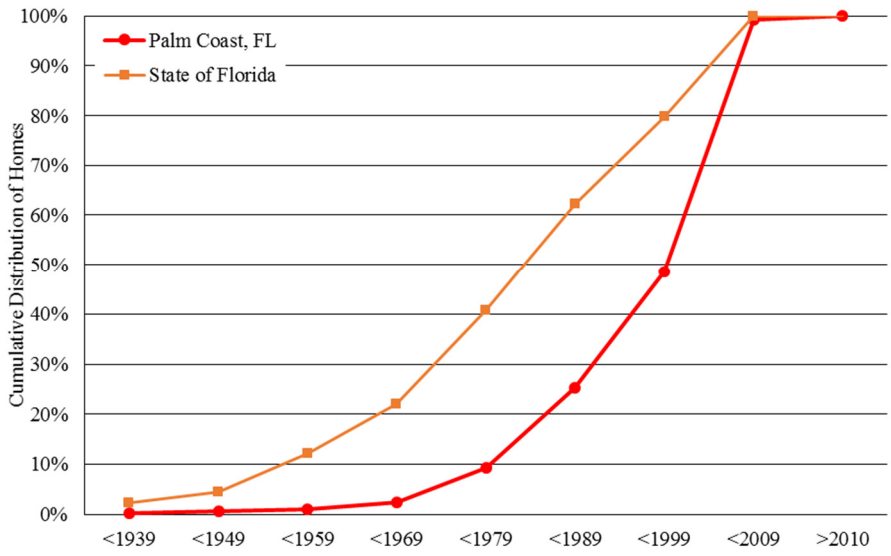



Figure 4: Age of the housing stock in Palm Coast, FL compared to the entire state of Florida

Flagler County has a significant history of tornadoes. The NOAA Storm Prediction Center (SPC) tornado database identified 131 tornadoes that impacted the county between 1950 and 2012, causing a total of three fatalities. The distribution of tornado intensity in Flagler County compared to the state of Florida is provided in Figure 5.

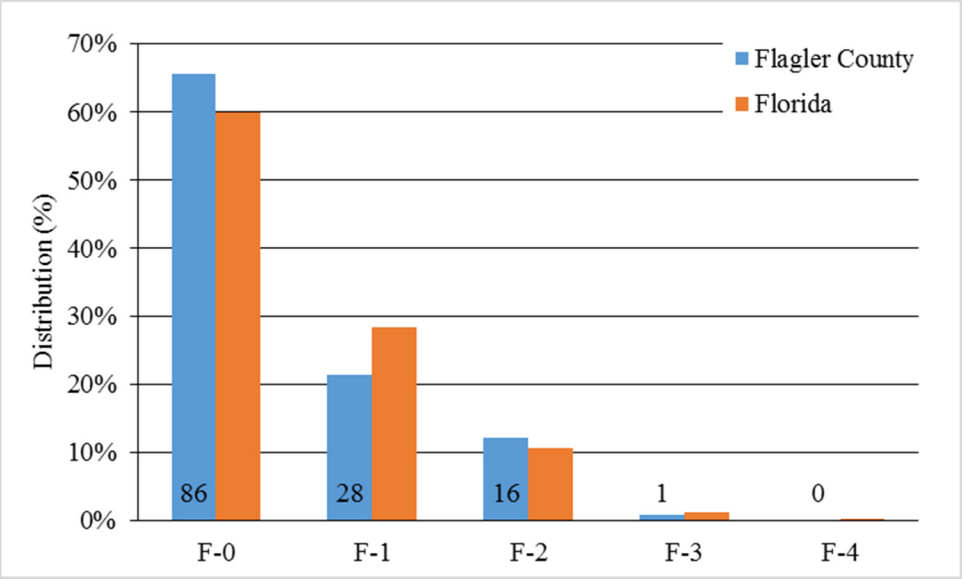



Figure 5: Distribution of tornado intensity in Flagler County (blue) compared to Florida (orange) from 1950 to 2012. Numbers at the base of the Flagler County bars indicate the specific number of tornadoes for each intensity.

## 3. UNIVERSITY OF FLORIDA WIND HAZARD DAMAGE ASSESSMENT TEAM SURVEY

The Wind Hazard Damage Assessment (WHDA) team departed from Gainesville, FL on the morning of 16 December 2013, arriving at approximately noon. Due to time limitations, the team surveyed the damage in the "B" section of Palm Coast only, where the heaviest damage was reported to occur. The team's primary objective was to quantify the damage to residential buildings and determine the effect (if any) of improved building construction practices in Palm County on mitigating tornado damage. Residential damage due to tornadoes is often considered difficult or impractical to mitigate. This assumption has been created and reinforced by the numerous post-tornado damage surveys cataloging decades of catastrophic tornado damage to poorly constructed homes, most of which had significant structural shortcomings and lacking vertical and lateral structural load paths. Florida provides a great opportunity to validate whether this assumption is true, as its propensity for hurricane winds have led to stronger building codes and more wind-resistant structures. By comparing the performance of Florida homes built before and after the stronger building codes, recommendations can be made to other tornado-prone regions for improving the wind-resistance of residential structures.

### *3.1. Methodology*

The focus of the team was on documenting the damage from the tornado to homes around the area with heaviest damage near the intersection of Bannerwood Ln and Bayside Dr. Damage was documented using both hand-drawn notes and sketches and geotagged photographs. Upon completion of the survey, wind speeds were estimated from the damage to homes and trees using the Enhanced Fujita Scale provisions (McDonald et al, 2006). In this process, Degrees of Damage are first assigned based upon the observed

damages to specific damage indicators, including one- and two-story residential homes and trees. Each Degree of Damage for each damage indicator (DI) is correlated to a range of wind speed values to account for variability in strength of construction and other influencing parameters. Upon observing the damage to a given DI, a single wind speed value is then subjectively chosen from each range of values based upon the available details. The UF WHDA survey of the Palm Coast, FL tornado investigated damage to 51 residential structures and 13 instances of observed tree damage.

In addition to the observed damage, county records on the individual homes were also collected so as to relate damage to age of construction, materials or other pertinent features. This aspect of the study enabled important estimates to be made as to the quality of construction and expected performance during a wind event. Of the homes surveyed, 29 (57%) were built in or before 1994 and 22 (47%) were built after 1994, providing near equal sample sets of data from before and after the post-Andrew building codes were implemented.

### *3.2. Observations*

The observed damage in the surveyed region ranged from a DOD of 1 to 6 for residential homes and 1 to 4 for trees. The location of each DOD rating is provided in Figure 7.

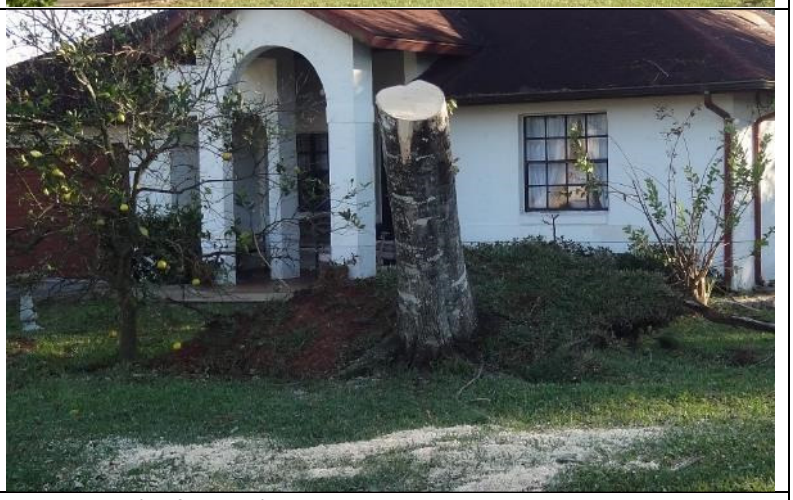

Figure 7: Assigned Degrees of Damage for the homes (solid circles) and tree damage (marked by X) surveyed by the UF WHDA team

Table 1 below provides an example of each observed Degree of Damage for each available damage indicator.

Table 1: Examples of observed Degrees of Damage for each Damage Indicator as specified in Enhanced Fujita Scale.

| One and Two-Family Residences | |
|---|---|
| DOD 1: Threshold of visible damage<br>[53 mph – 80 mph]<br><br>Photograph to the right depicts a home with very minor damage. A single shingle was displaced and evidence of debris impact was present just above the garage door. |  |
| DOD 2: Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding<br>[63 mph – 97 mph]<br><br>This was the most commonly observed DOD and the wind speed was typically chosen from the range of possible values based upon the extent of the shingle loss. |  |

| | |
|---|---|
| DOD 3: Broken glass in doors and windows<br>[79 mph – 114 mph]<br><br>When this DOD was assigned in the current study, wind speed values on the lower end were generally assigned because it did not appear impact-resistant windows were used and because there was typically very little damage to other areas of the home. |  |
| DOD 4: Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward; failure of porch or carport<br>[81 mph – 116 mph]<br><br>This DOD was observed only three times (twice in homes built before 1994 and once to a home built after 1994), all within a relatively small area near Barring Place. |  |
| DOD 6: Large sections of roof structure removed; most walls remain standing<br>[104 mph – 142 mph]<br><br>This DOD was only observed once, and that to a pre-1994 home with significant termite-damage and rotted wood. As a result, the lowest possible wind speed associated with this DOD (104 mph) was used. |  |
| | |

| Trees (Hardwood) | |
|---|---|
| DOD 2: Large branches broken (1”-3” diameter)<br>[61 mph – 88 mph] |  |
| DOD 3: Trees uprooted<br>[76 mph – 118 mph]<br><br>Note: in picture to right, tree was removed after uprooting during cleanup. |  |
| Trees (Softwood) | |
| DOD 4: Trunks snapped<br>[88 mph – 128 mph]<br><br>This DOD was observed multiple times throughout the damage path, while no observations of DOD 3 (trees uprooted) were made for softwoods. The wind speeds assigned in this study were typically much closer to 88mph. A lack of equivalent damage to other nearby indicators limited the wind speed estimates. |  |

### *3.3. Wind Speed Analysis*

After assigning Degrees of Damage, the wind speed determined for each DOD was then determined and used to estimate the EF-rating of the tornado. Additionally, wind speeds that caused specific damage were back-calculated using engineering analysis for a collapsed flag pole (Appendix A) and a buckled garage door (Appendix B). A numerical interpolation technique, called Natural Neighbor Interpolation was employed in the software program ArcMap 10.1, using the nearest four data points to estimate the tornado wind field. The results of this analysis are shown in Figure 8 along with the assigned EF-ratings.

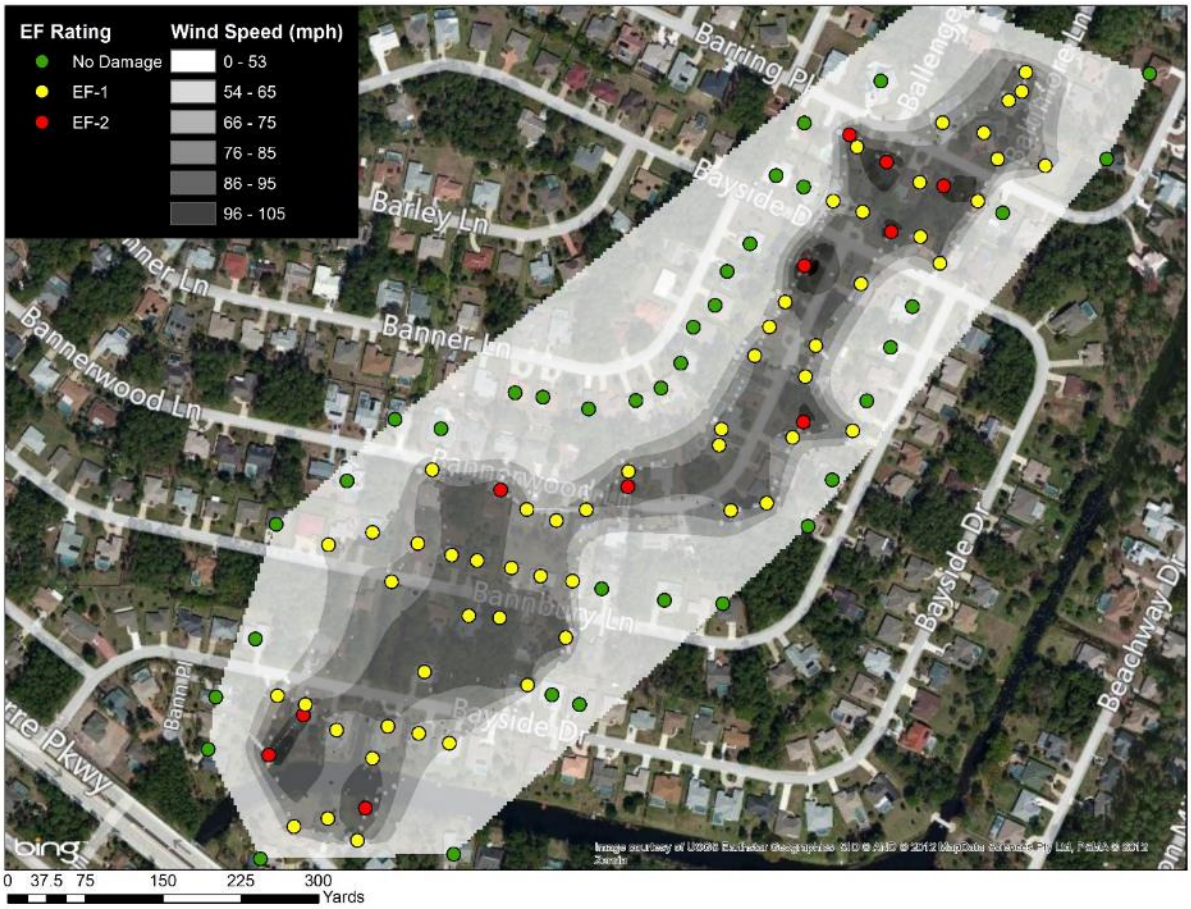



Figure 8: Estimated wind speeds (grey fill) interpolated from rated indicators (green, yellow and red circles)

The estimated wind speed map provides a reasonable portrayal of the tornado path based upon the collected data. Within the surveyed region, the tornado reached its widest point as it crossed Bannbury Ln, but narrowed and possibly increased in intensity as it reached and then followed along Bannerwood Ln, reaching Bayside Dr and Barring Pl. The accuracy of the wind field could be improved by a wider and more complete survey region, which will be considered for future events.

### *3.4. Tree Damage*

While tree damage was not a primary focus of the survey, it was documented as another means of estimating the wind speed at various points along the tornado path. The majority of the trees in the survey region were loblolly pines, a species known for having somewhat poor wind resistance (Duryea, 2011) due to their height and slenderness. A number of live oaks were also observed, which also can have poor wind resistance if the root system is not able to fully extend or if the soil is saturated. Several instances of

the failures of each type were observed, and in a few cases the trees fell on homes, causing extensive damage when the home would have been able to survive the wind alone with little damage (Figure 9).

Figure 9: Tree collapsed onto home which was otherwise undamaged (Photo courtesy of FlaglerLive)

Section 5.01.04(3) of the Flagler County Land Development Code requires that each single-family lot have a minimum number of trees per lot area, and that newly planted trees (including replacement trees for those damaged in storms) be shade trees such as oaks or cedars. While the shade trees listed in the code typically have better wind resistance than most of the local pines, they are still susceptible to being uprooted, particularly during wind events that include heavy rains as the soil becomes saturated and significantly reduces the strength of the root system. Existing pine trees nearby homes also pose a risk as they can cause significant damage when they fall, regardless of how wind resistant the home is on which they fall. Proper landscaping, including spacing of trees and pruning, are important to minimize these risks.

### *3.5. Age of construction Analysis*

One of the primary objectives of this study was to determine whether there was a difference in performance between homes built before and after 1994. The simplest method to ascertain whether any differences exist is to simply compare the average DOD of homes built before to those built after 1994. This will strictly compare differences in the observed physical damage, removing the effects of any interpretive biases. However, spatial biases in the locations of these homes relative to the tornado path may still exist and thus multiple methods of analysis will be beneficial. The results of this comparison, including a Student's t-test for statistical significance, are shown in Table 2.

Table 2: Comparison of Observed Degrees of Damage for Homes Built Before and After 1994

| | Before1994 | Before 1994 |
|---|---|---|
| **Observations** | 27 | 23 |
| **Mean** | 2.185 | 2.087 |
| **Standard Deviation** | 1.311 | 0.538 |
| **Coefficient of Variance** | 52% | 35% |
| **p-value (two-tail assuming equal variance)** | 0.725 | |

Homes built before 1994 had an average DOD that was 5% higher than that for homes built after 1994. However the results of the Student's t-test indicate that there is no statistical difference between these average Degrees of Damage, as there is a 72.5% probability that the two sample sets are from the same population. These results by themselves however are not conclusive since the tornado wind speed and impinging wind direction likely vary throughout the path and so there is no guarantee that both sample sets experienced the same wind speed conditions. Further, the Degrees of Damage are not refined enough to easily differentiate between levels of damage with a specific Degree of Damage.

Another method to compare the performance of pre- and post-1994 homes is through case studies of specific homes where circumstances or location indicate that they should have received the same wind speeds. One location this is possible is along the streets of Bayside Dr. and Barring Pl, which run parallel to one another and both transect the likely path of the tornado. Bayside Dr. at this location consists of post-1994 construction while Barring Pl in this area contains mostly pre-1994 construction albeit with one home built in 2002. The region of interest is shown in Figure 10 with the EF-rating and year built indicated for each damaged home.

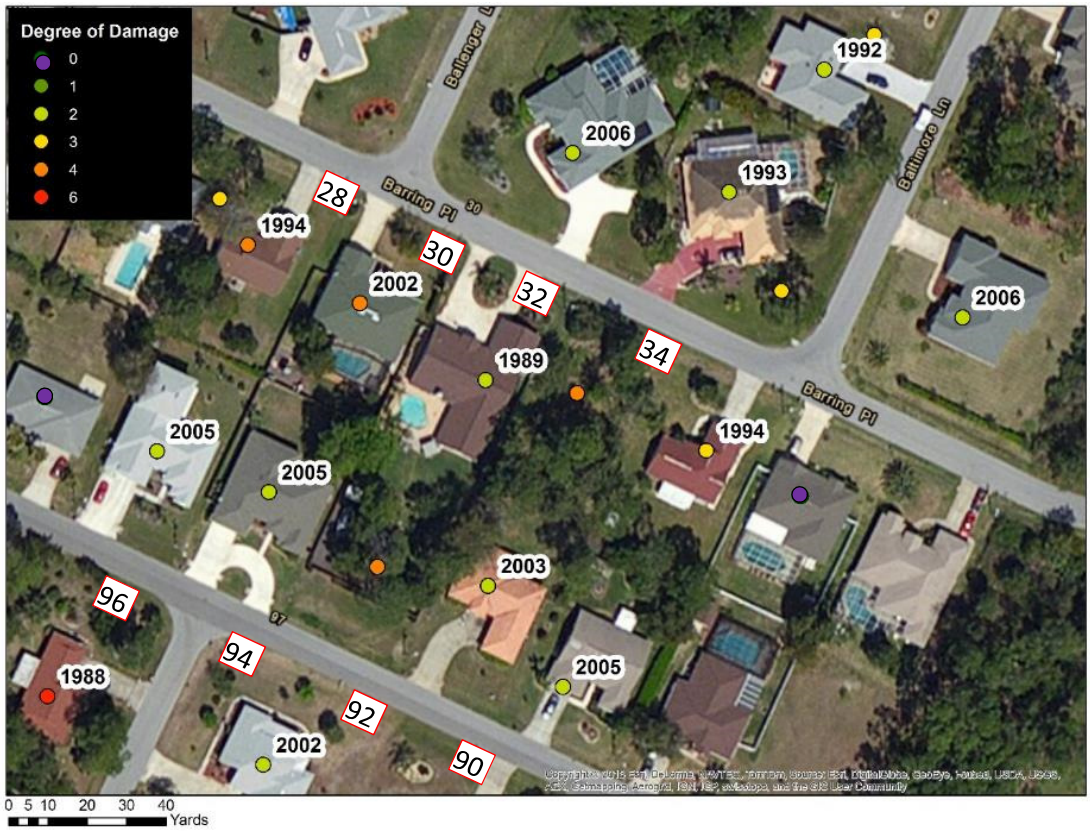



Figure 10: Enhanced view of homes along Barring PL and Bayside DR transecting the tornado path.

Observed DOD is shown using colored dots and labeled with the year built of each damaged home. Street numbers of select homes referred to in Table 3 are shown in the text boxes outlined in red.

Table 3 compares the known characteristics and observed damages of four homes from each street where the lot of the home on one street backs up to the lot of the home on the other street.

More damage was observed to homes along Barring PL than to homes along Bayside Dr., despite the fact that the homes were less than 50 yards apart along the path of the tornado. Age of construction alone however does not appear to be the determining factor, because the heavily damaged home at 30 Barring PL was built in 2002, while an almost equally damaged home next to it at 28 Barring PL was built in 1994. Both of these homes were CMU block construction, and roof-to-wall straps were used in both as well.

Table 3: Comparison of observed damages to lots experiencing approximately similar wind speeds

| Barring PLACE | | | | |
|---|---|---|---|---|
| Street Number | 28 | 30 | 32 | 34 |
| Year Built | 1994 | 2002 | 1989 | Vacant |
| Roof Shape | Gable | Hip/Gable | Gable | N/A |
| DI/DOD | Res/4 | Res/4 | Res/2 | Tree/4 |
| Observed Damage | • Garage buckled inward<br>• ~20% damaged shingles<br>• Sheathing panel uplift | • Garage buckled outward<br>• ~25 damaged shingles<br>• (2) Sheathing panels uplifted at gable over garage<br>• Screened-in porch destroyed at back of house<br>• (3) Broken windows | • Shingle damage to back gable of house (fully tarped)<br>• Back sliding glass door broken<br>• Gutter knocked off house | • (4) Pines snapped at trunks<br>• Several trees uprooted<br>• Multiple trees still standing as well |
| Bayside DRIVE | | | | |
| Street Number | 96 | 94 | 92 | 90 |
| Year Built | 2005 | 2005 | Vacant | 2003 |
| Roof Shape | Hip | Hip | N/A | Hip |
| DI/DOD | Res/2 | Res/2 | Tree/4 | Res/2 |
| Observed Damage | • Small portion of roof tarped on front slope only<br>• No other evidence of damage | • Portions of front of roof tarped only<br>• Garage door impacted but not buckled<br>• Soffit missing along front edge | • Palm tree and (3) pine trunks snapped<br>• Wood privacy fence knocked down | • Small portion of roof tarped on front slope<br>• No other evidence of damage |

Staples were used as the sheathing fastener in the 1994 home, an indication that the home was built to a weaker building code, however damage to these two homes was similar. All of the homes on Barring PL were gable roofs, whereas all the homes on Bayside DR were hip, which may have contributed to the heavier roof damage (specifically sheathing uplift) since hip roofs have a more aerodynamic shape that reduces the uplift loads. But this does not explain the greater damage that occurred to the walls and garage doors. Another possible explanation for the differences in damage between Bayside and Barring is that with the tornado being narrow, it may have moved sporadically such that when crossing Bayside DR it passed through the vacant lot at 92 Bayside DR, but when exiting onto Barring PL, it passed over or between 28 and 30 Barring PL. Such a path does not appear to be consistent with the overall path of the tornado beyond this point however.

### 3.6. *Summary of Results*

In summary, while damage occurring to both older and newer homes from the tornado provided an opportunity to compare structural performance, no significant trends were observed. The average Degree of Damage for both pre- and post-1994 homes were not statistically different, and a more direct comparison between post-1994 and pre-1994 homes in close proximity to each other did not reveal any differences in performance as both a 2002 and a 1994 home received nearly the same damage.

Maintenance of a home is very important however, particularly for wood-frame construction, as the 1988 home with a Degree of Damage of 6 (Figure 11, Figure 12), had obvious termite damage in the structural garage door header which likely caused premature failure of the garage door, then failure and removal of large portions of the roof due to the buildup of internal pressures, and finally collapse of the garage walls. Due to the observed condition of the wood, it is possible that the minimum wind speed value for a DOD of 6 (104 mph) may still be an overestimate of the true wind speed here as none of the surrounding trees or structures had damage that indicated wind speeds close to this value.

Figure 11: Removal of large portions of roof and collapse of walls to 1988 home with significant termite damage

Figure 12: Termite damage to structural wood header over garage door opening.

## 4. CONCLUSIONS AND RECOMMENDATIONS

A small tornado struck the city of Palm Coast, FL on December 14, 2013, damaging 208 homes and causing an estimated $7 million in economic losses. The University of Florida Wind Hazard Damage Assessment Team surveyed the damage in the B-region of Palm Coast, where the heaviest damage occurred, with the objective of establishing any relationships between the age of the structure and its performance in a tornado. A total of 64 residential structures or other damage indicators were surveyed and used to estimate the wind speeds throughout the damage path. The maximum wind speed was estimated to be 104 mph. The conclusions and recommendation from the survey include the following:

(1) The analysis of the performance of post-1994 homes compared to pre-1994 homes performed in this study did not reveal any significant differences for this tornado. For the most part, the surveyed homes of all ages performed reasonably well, in part because wind-resistant features such as hurricane clips or straps were installed in each of the homes that were observed in detail, but also because the wind speed was likely not strong enough to expose any further weaknesses in the load paths. The winds were strong enough to destroy a home (albeit a wood-frame home with maintenance issues that significantly weakened its wind resistance) and snap tree trunks, but for the most part caused little damage to surrounding homes.

(2) Maintenance of a home is very important for maintaining its wind resistance. If termite damage is noted in a home, care should be taken to not only eradicate them, but to replace or secure any damaged structural components.
(3) The most common failure observed was that of roof covering systems (asphalt shingles or clay tiles). Recent studies have identified unsealed shingles as the primary cause of premature shingle failure during a wind event (Dixon et al, 2013). Regular inspection of the roofing system to identify these problems is important as roof covering failures quickly escalate into significant economic losses due to the ensuing water ingress.
(4) Trees with poor wind resistance, such as pines, increase the risk of damage to nearby homes regardless of the home's wind resistance. When located close to homes, they should be removed and replaced with local species that are more wind resistant. General guidelines concerning the proper selection and placement of trees to reduce wind hazard potential are available through the University of Florida IFAS Extension or a local Palm Coast building official.

The better construction practices used in the majority of homes within the surveyed region impacted by the tornado limited the catastrophic damage. It is likely that if this same tornado had impacted an older community elsewhere in Florida that was less wind resistant, the damage would have been more severe. However, this should not be taken to imply that these Palm Coast homes (particularly those built before more stringent building codes were adopted) are adequately prepared to resist a significant wind event, as the wind speeds encountered here were significantly below design level (130 mph vs 104 mph). It is important that communities in Florida understand that their homes can be made much more resilient to wind hazards, but it must be the community's choice to retrofit and strengthen their homes, particularly in older, less wind-resistant communities.

## 5. FURTHER RESEARCH

The above summary provides a basic overview of the tornado and the observed damage it caused in the B-region of Palm Coast, FL. Further research that could be conducted using this dataset include the following:

(1) Quantify shingle losses to each home using the available photographs. Then compare amount of shingle loss to the age of each roof (assuming age of roof is equal to year built, or checking Flagler County property assessors website to see if permits pulled for new roof). This could further establish the relationship between shingle loss and age of roof noted by Gurley and Masters (2011) and may also reveal more subtle differences between pre- and post-1994 construction.
(2) Estimate tornado flow field from shingle loss. Shingle loss primarily occurs due to approaching wind flow, not uplift pressures. As a result, loss of shingles on one or more slopes of the roof can be used to estimate the direction of wind flow at the damaged homes. This would help establish the location of the vortex along the path and better answer the questions raised in Section 3.4.

## 6. ACKNOWLEDGEMENTS

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## 7. REFERENCES

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**About the Wind Hazard Damage Assessment Team**

*This report was prepared using information from a damage survey performed by University of Florida civil engineering students in Prof. David O. Prevatt's Research Group. The study is done in parallel to our experimental research seeking to understand and quantify the strength of tornadoes and their impact on vulnerable wood-framed residential structures.*

*Please visit our website, http://windhazard.davidoprevatt.com, for additional information, and to download previous damage reports, and filed survey results conducted by our group. Dr. Prevatt and his colleagues have published several papers on recent violent tornadoes that stuck Tuscaloosa, AL, Joplin, MO, and Moore, OK. His group has also inspected damaged structures and compiled reports on tornadoes that occur in Florida. Information is also available on the research at www.davidoprevatt.com. Your questions and comments on any aspects of our work are most welcome. Please direct your enquiries to NSF Graduate Research Fellow and PhD Graduate Student, Mr. David B. Roueche, who can be reached at david.roueche@ufl.edu. Mr. Jeandona (JD) Doreste, is a civil engineering undergraduate student at UF and Webmaster of the Wind Hazard Damage Assessment Team site. JD is actively recruiting other UF students to join the team, and he can be reached at jdoreste1@ufl.edu.*

*The Wind Hazard Damage Assessment Team was created through support from the NSF Award #1150975. Its mission is to train university students interested in building construction, engineering and architecture in the forensic engineering and techniques for post-hazard damage surveys and data collection. The team has surveyed damage after several Florida tornadoes and continuously monitors the prevalence of tornadoes worldwide. Ultimately the Damage Assessment Team hopes to inspire upcoming engineers and building professionals in hopes to change the paradigm of widespread catastrophic damage to houses in tornadoes and other extreme wind events.*

Appendix A - Back-Calculate Wind Speed Required to Bend Flag Pole

A flag pole was noted collapsed along the tornado path, located as shown in Figure 1. The buckled state of the flag pole is shown in Figure 2. The flag pole had buckled at the base and when found was pointing opposite the direction the tornado was traveling.

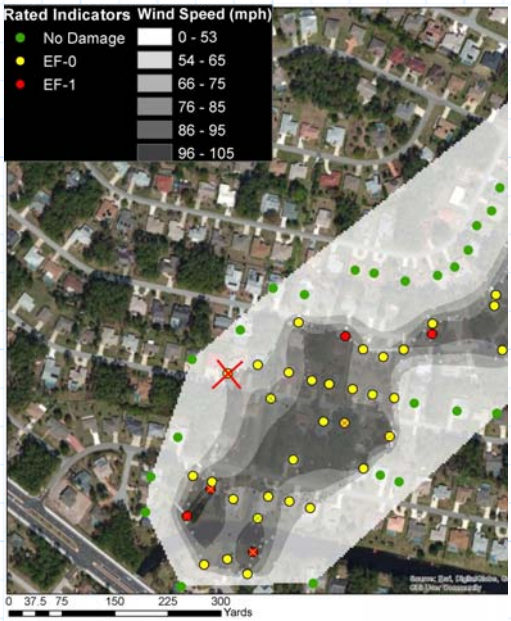



*Figure A-1: Location of flagpole (red "X") in relation to tornado path*

*Figure A-2: Flag pole buckled at base. Note that portion of pole below ground has been pulled out of ground*

| | |
|---|---|
| $H := 20\ ft$ | Height of flag pole above ground |
| $D.o := 2\ in$ | Outer diameter of flag pole |
| $t := 0.0625\ in$ | Thickness of the flag pole |
| $A.p := H \cdot D.o = 3.333\ ft^2$ | Projected area to approaching wind |
| $D.i := D.o - 2 \cdot t = 1.875\ in$ | Inside diameter |
| $I := \frac{\pi}{64} \cdot \left(D.o^4 - D.i^4\right) = 0.179\ in^4$ | Moment of inertia |
| $\sigma.y := 58\ ksi$ | Yield stress of aluminum alloy |
| $M.y := \frac{\sigma.y \cdot I}{D.o \div 2} = 10.364\ kip \cdot in$ | Yield bending moment for aluminum flag pole with given dimensions |



Use ANSI FP 1001-07 "Design of Metal Flagpoles" to determine required wind load to reach bending moment

$V := 60\ mph$ Wind speed iterated until bending moment equal to yield moment

$P(Ch, Cd, G) := 0.00256\ psf \cdot \left(\frac{V}{mph}\right)^2 \cdot Ch \cdot Cd \cdot G$ Equation 1

$Ch := 0.9$ Table 3.2.3A

$Cd := 1.10$ Table 3.2.4

$G := 1.14$

$Wp := P(Ch, Cd, G) \cdot A.p \cdot Cd = 38.138\ lbf$

Assuming polyester flag:

$A.f := 4\ ft \cdot 6\ ft = 24\ ft^2$

$G := 1.14$

$Wf := 0.0014\ \frac{lbf}{ft} \cdot \left(\frac{V}{mph}\right)^2 \cdot \sqrt{A.f} \cdot Ch \cdot G = 25.333\ lbf$

$M1 := Wp \cdot \frac{H}{2} = 0.381\ kip \cdot ft$

$M2 := Wf \cdot (H - 2\ ft) = 0.456\ kip \cdot ft$

$Mb := M1 + M2 = 0.837\ kip \cdot ft$

$M.y = 0.864\ kip \cdot ft$

The estimated wind speed need to bend this flag pole, assuming a 4 ft x 6 ft flag was in use at the time, is approximately 60 mph.

## Appendix B – Wind Speed Analysis from Buckled Garage Door

The garage door buckled at a home at 30 Barring Pl. Upon inspection of the garage door (shown in Figure B-1), it was noted that a sticker was affixed to it providing the garage door wind rating (Figure B-2).

Figure B-1: Buckled garage door at 30 Barring Pl

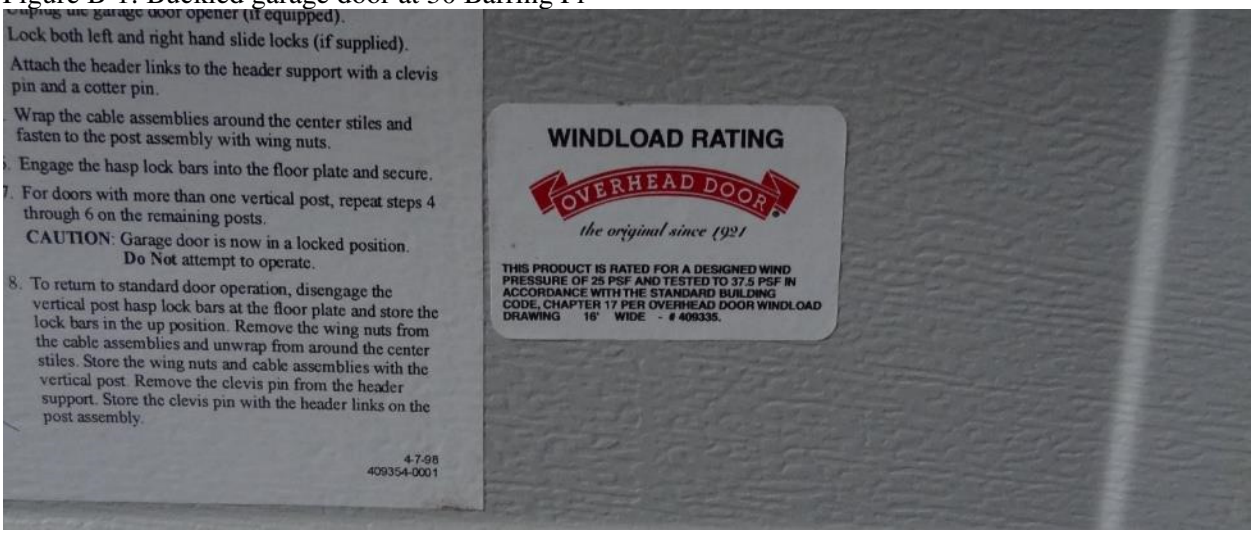
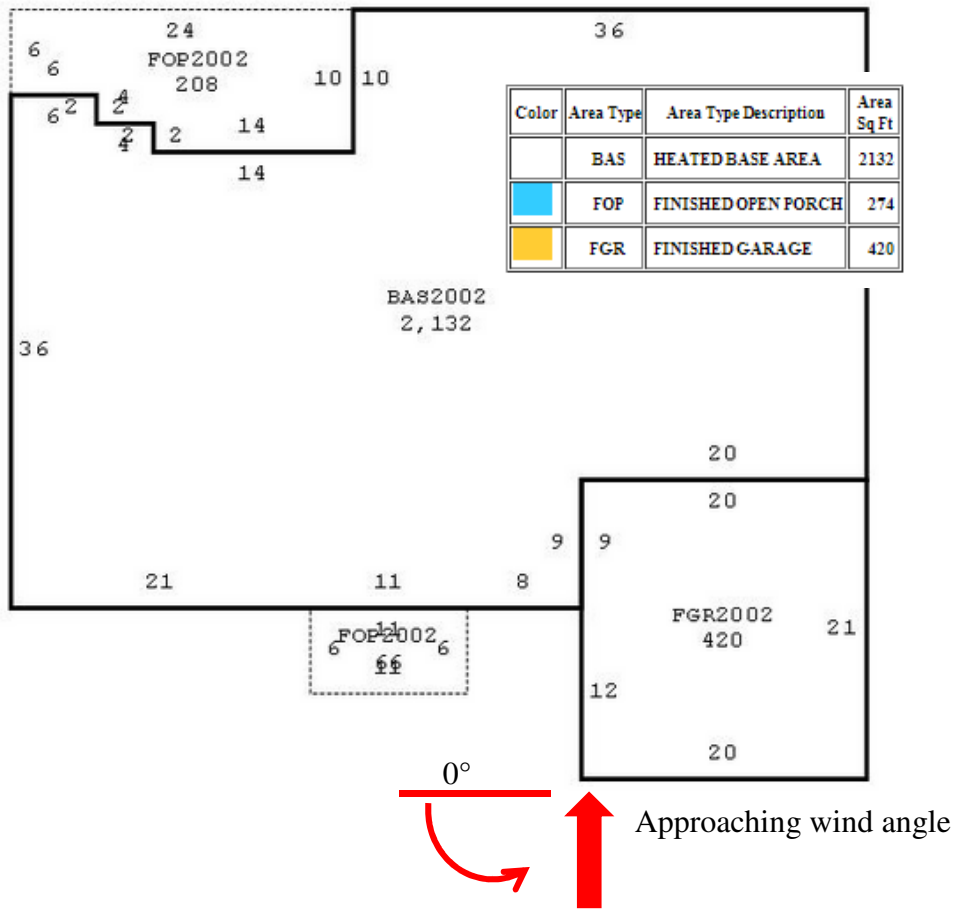



Figure B-2: Wind load rating of 25 psf obtained from the buckled garage door

The outline of the house is provided in Figure A-3 from the county appraiser website.




| Color | Area Type | Area Type Description | Area Sq Ft |
|---|---|---|---|
| | BAS | HEATED BASE AREA | 2132 |
| | FOP | FINISHED OPEN PORCH | 274 |
| | FGR | FINISHED GARAGE | 420 |

Figure B-3: Layout of building with possible wind approach angles

As is common during a tornado, the wind direction may have changed significantly as the tornado passed over and it is unclear at what specific point the garage collapsed. As can be seen from Figure B-4, the middle portion of the garage door is buckled outward, however branches and other debris were lodged in the right edge of the door in a manner that could have only been achieved if the wind direction was positive on the face of the door (> 0° using layout in Figure B-3). Since the main portion of the door appears to have buckled outward however, it will be assumed that a suction pressure was applied to the door that exceeded its capacity. To apply a suction pressure on the garage door, the wind direction will be assumed to be $\leq 0°$. Under this assumption, the wind speed required to generate the necessary suction pressure is calculated below.

Figure B-4: View of buckled garage door from outside

DesignPressure = 25 psf

| | |
|---|---|
| V = 92 mph | Iterate velocity until design pressure (P) is reached |
| $vp = 0.00256*Kz*Kd*Kzt*V^2$ | Velocity pressure from ASCE 7-10 |
| Kz = 1.0 | Height factor not applicable |
| Kd = 1.0 | Directionality factor not applicable |
| Kzt = 1.0 | Topographic factors not applicable |
| $vp = 0.00256*1.0*(92\ mph)^2 = 21.7$ psf | Velocity pressure |
| EWA = span * 1/3 span = 16ft * 16ft/3 = 85 $ft^2$ | Effective Wind Area |
| $GCp_e = -1$ | ASCE 7-10 Figure 30.4-1 |
| $GCp_i = 0.18$ | Internal pressure coefficient for enclosed building |
| $P = vp*(GCp_e - GCp_i) = -25.6$ psf | Local pressure on garage door equals DesignPressure |

Using methodology and pressure coefficient values from ASCE 7-10 Components and Cladding, the wind speed required to buckle the garage door rated for 25 psf is approximately 92 mph.