Development of New Wind Speed Estimation Techniques Following Tornadoes

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INTRODUCTION

- VORTEX-Southeast funding supported work that led to two publications:
  - A new method to estimate EF-scale damage in heavily-forested areas.
  - An analysis of both treefall patterns and wind speed estimates based on the EF scale to derive empirical fragility functions for single-family homes.
- These two completed projects focus on the examination of tornado damage patterns to infer tornado characteristics in situations where traditional ground-based damage assessments are nearly impossible or where there are few traditional damage indicators.
- Historical damage surveys provide the basis for this work due to the scarcity of suitable tornado tracks during the first year of VORTEX-Southeast.

PART 1: ESTIMATING ENHANCED FUJITA SCALE LEVELS BASED ON FOREST DAMAGE SEVERITY

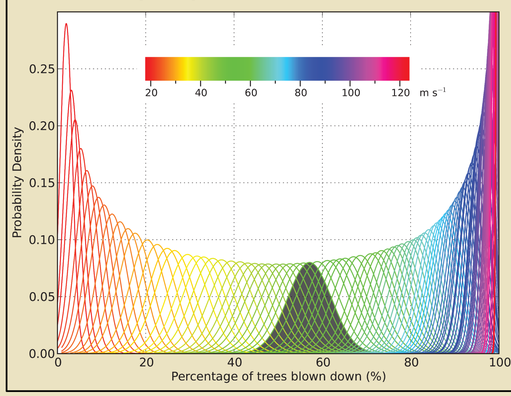
- This work describes a novel method to infer EF-scale categories from forest damage using levels of tree damage and a coupled wind and tree resistance model.
- Based on two tornado tracks from the 27 April 2011 outbreak:
  - Great Smoky Mountains National Park (E. Tennessee)
    - NWS rated EF4 with an 18-mile track
  - Chattahoochee National Forest (N. Georgia)
    - NWS rated EF3 with a 38-mile track

AERIAL PHOTOS & GROUND SURVEYS

- Aerial photos cover the entire length of both tornado tracks, at a ground resolution of 8 inches per pixel.
- Over 448,000 standing and fallen trees were tagged with geographic coordinates, with fall direction recorded for over 130,000 downed trees.
- Ground surveys that sampled more than 2000 individual trees provide details on the composition of tree species and tree diameters within each tornado track.

RESAMPLING PROCESS

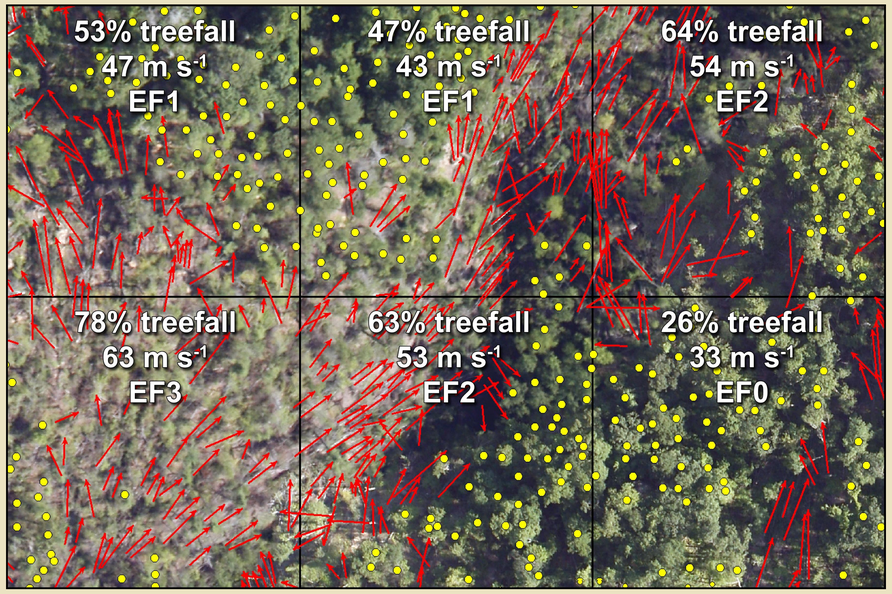
- For each tornado track, a statistical resampling procedure begins by randomly drawing, with replacement, a small sample of 100 trees from the database of observed trees.
- A coupled wind and tree resistance model determines the percentage of trees in that sample that fall for a given wind speed increment.
- By repeating this procedure 10,000 times, each wind speed increment corresponds with a distribution of treefall percentages in the sampled plots.



Left: Probability density functions describing the percentage of trees blown down at various wind speeds in 10,000 fictitious sample plots using trees drawn from a database of observed trees in the Great Smoky Mountains National Park. The shaded region corresponds with a wind speed of 50 m s^{-1}.

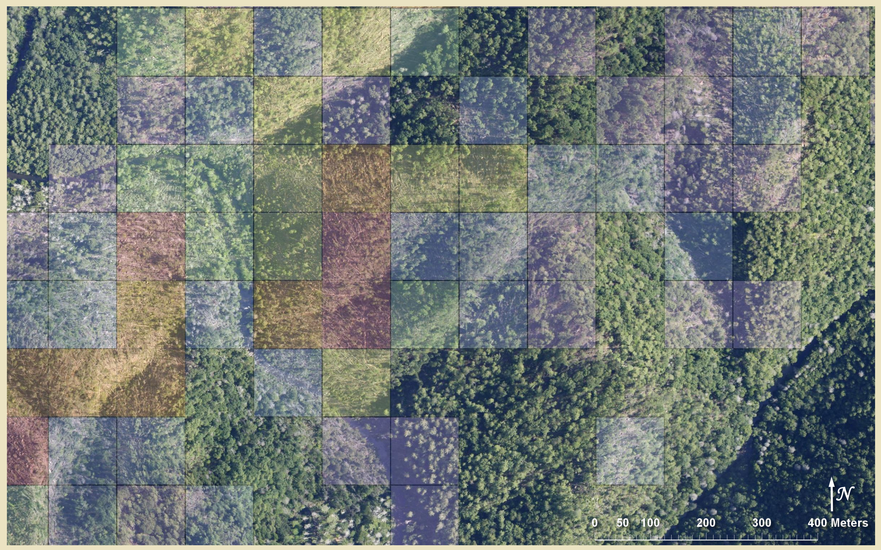
ASSIGN A DAMAGE RATING TO PLOTS ALONG THE TRACK

- The most probable wind speed that produced the damage in 100 m × 100 m subplots is the wind speed corresponding with the Gaussian probability density function with its peak at the observed percentage of downed trees.



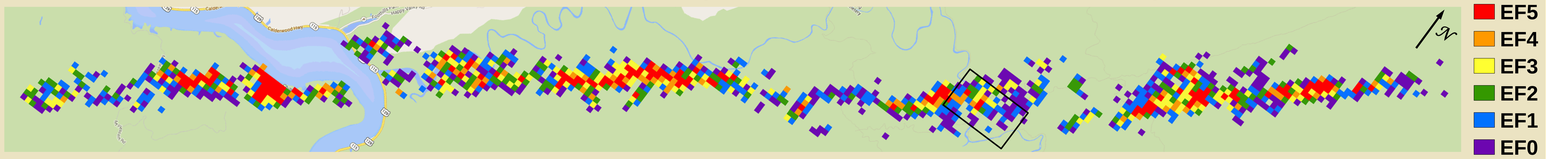
MAPS OF EF-SCALE DAMAGE

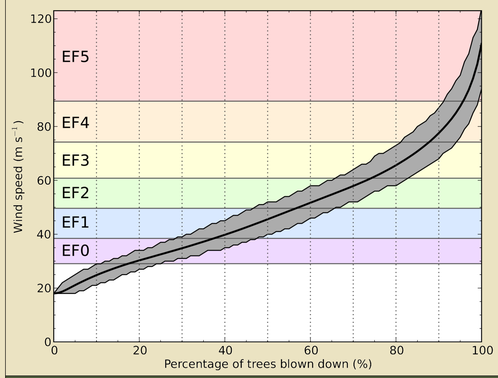
EF0 EF1 EF2 EF3 EF4 EF5



Above: EF-scale estimates near the intersection of the Hatcher Mountain Trail and the Little Bottoms Trail along Abrams Creek in the Great Smoky Mountains National Park (see inset below).

Below: EF-scale ratings assigned to small subplots along the length of the Great Smoky Mountains National Park tornado track. The inset is the region shown above. This tornado track is 18 miles long.





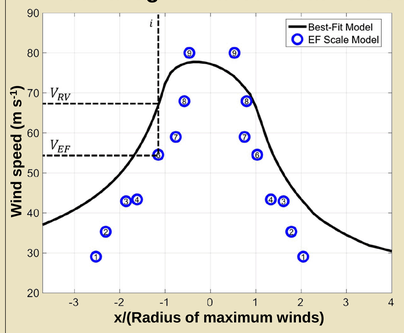
Wind speed estimates (thick line) for the GSMNP forest as a function of the percentage of trees blown down in each fictitious sample plot. The gray-shaded region denotes the 95% confidence interval for each percentage of trees blown down, and the colored regions represent the wind speeds associated with each EF-scale level.

PART 2: EMPIRICAL APPROACH TO EVALUATING THE TORNADO FRAGILITY OF RESIDENTIAL STRUCTURES

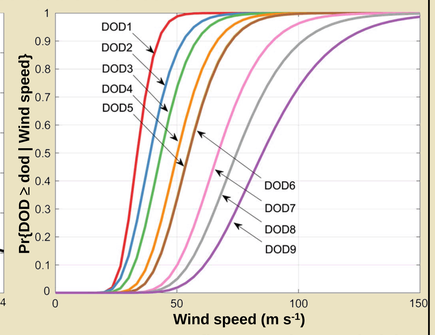
- Goal: Estimate wind speeds by comparing observed and modeled damage
- Modeling damage requires infrastructure fragility curves.
- Infrastructure fragility curves help to assess failure wind speeds under tornadic wind loads.

APPROACH AND RESULTS

- A coupled wind and tree model based on fall direction helps to estimate wind speeds in the 22 May 2011 Joplin, MO tornado.
- Modeled winds are compared with wind speed estimates from EF-scale ratings for single-family homes.
- Refinement of the wind model to match the EF-scale ratings minimizes the weaknesses of either component method and provides a good picture of the wind field.
- Wind speed estimates and the observed degree of damage (DOD) are fit to a lognormal cumulative distribution function.



Comparison of the best-fit Rankine vortex (RV) treefall model (solid line), and mean value of EF scale rating (circles) summarized from 1,241 individual damage observations in Joplin, MO. Numbers inside each circle refer to a specific DOD.



Lognormal CDF fits to the underlying empirical data for damage measures corresponding to the nine degrees of damage for FR12 (one- and two-family residences) of the EF scale.

- The median wind speed estimated for a given damage state progressively increases as the damage state increases, suggesting that these fragilities for residential construction are well calibrated.
- Current efforts use the infrastructure fragility model developed here to simulate debris flight in extreme winds.

ACKNOWLEDGMENTS

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