Reconstruction of Near-Surface Tornado Wind Fields from Forest Damage Patterns in Complex Terrain

Christopher M. Godfrey[1] and Chris J. Peterson[2]

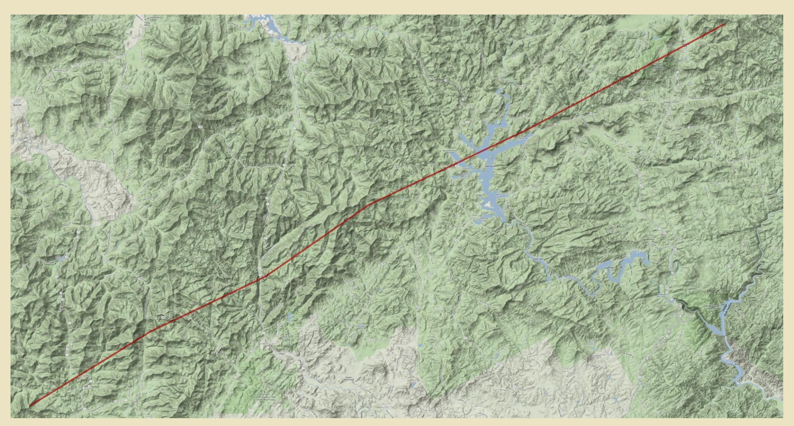
[1]University of North Carolina at Asheville, [2]University of Georgia

INTRODUCTION

- Obtaining direct or remotely-sensed observations of tornadoes in steep topography remains a challenge
- Two tornadoes in the 27–28 April 2011 outbreak provided an opportunity to study the near-surface wind field in rugged terrain

Great Smoky Mountains National Park (Eastern Tennessee)
- EF-4
- 18-mile track

Chattahoochee National Forest (Northern Georgia)
- EF-3
- 38-mile track



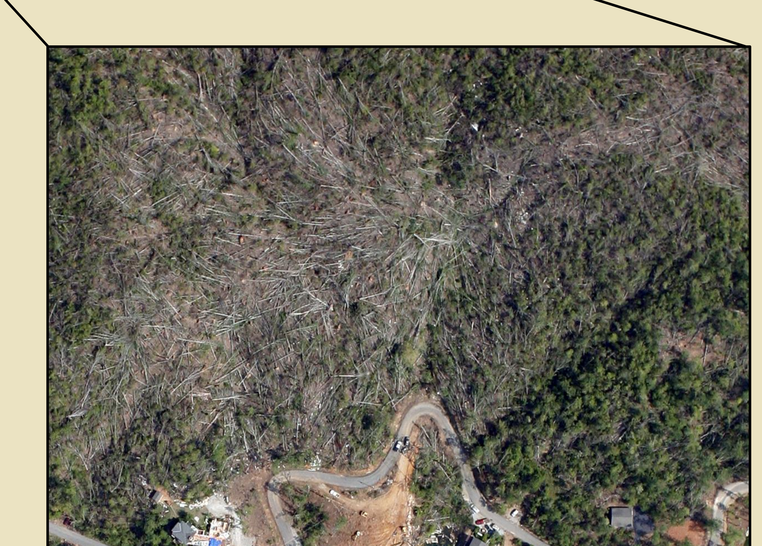
PROJECT GOALS

- Reconstruct the near-surface wind field in heavily-forested and mountainous landscapes based on forest damage
  - Simulate a vortex moving through the forest
  - Couple the wind model with a tree model
  - Wind impacts modeled trees at locations of real trees
  - Match simulations with observed fall directions
- Examine how complex terrain influences the low-level tornadic wind field

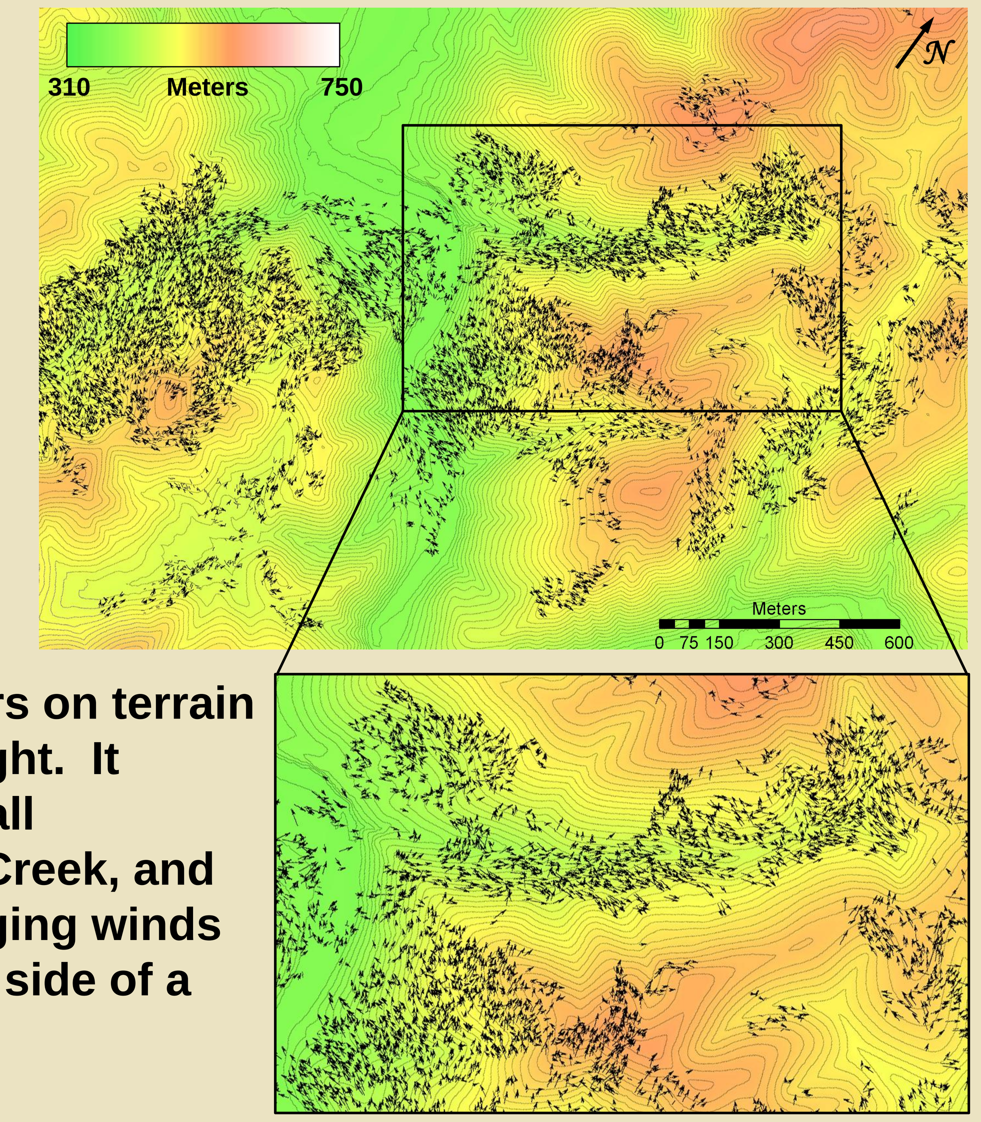
AERIAL PHOTOGRAPHS

- Entire length of both tornado tracks
- Width: 5000 feet (~1500 meters)
- High-resolution: 8 inches per pixel

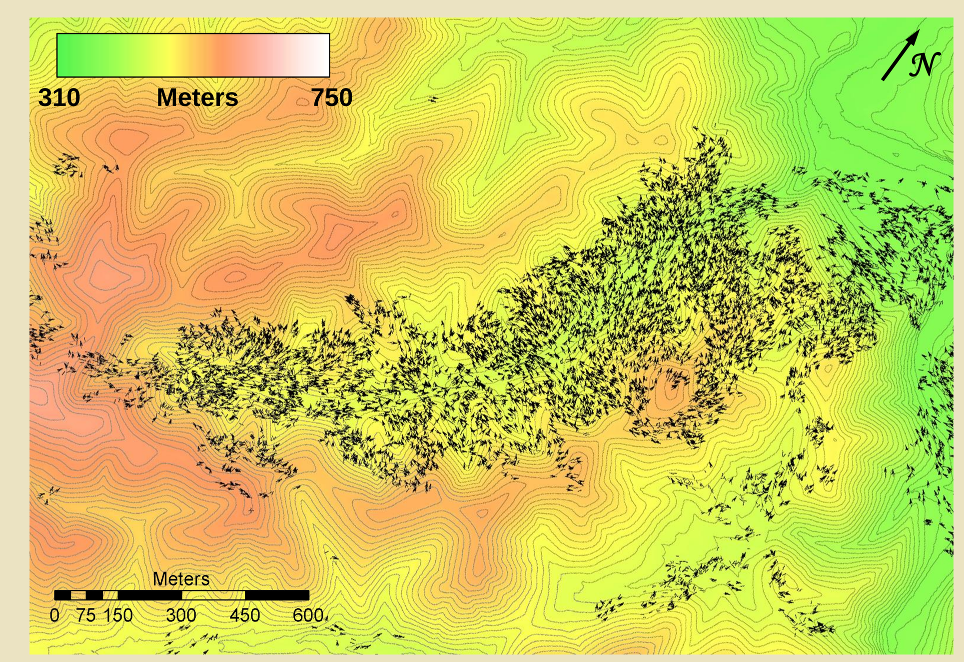
- Recorded fall direction of over 130,000 downed trees
- Over 448,000 standing and fallen trees tagged with geographic coordinates



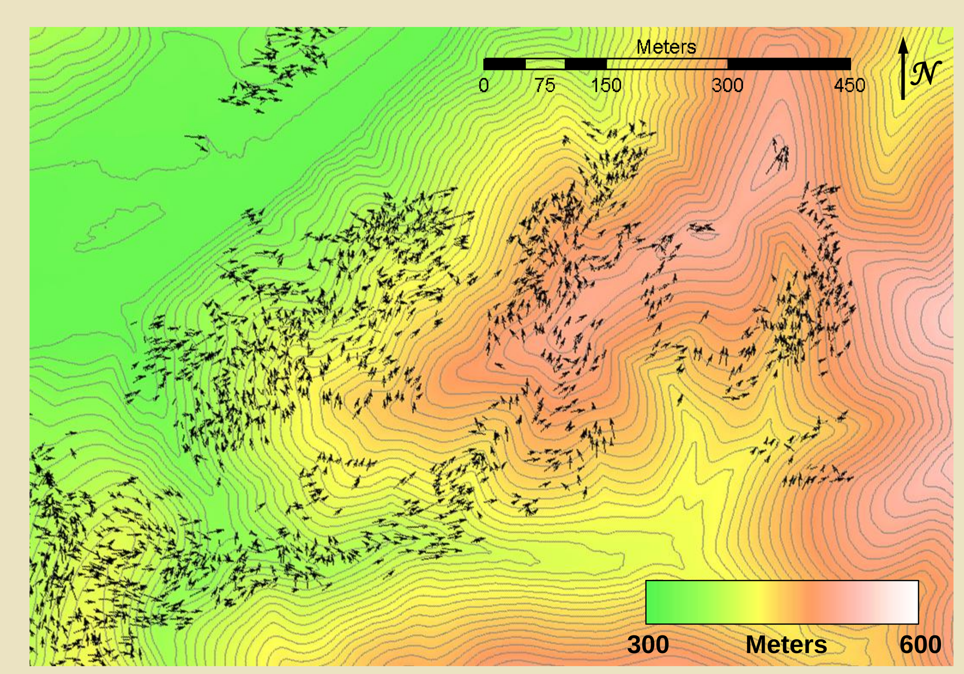
TERRAIN INFLUENCES THE TORNADIC FLOW FIELD



Aerial photograph (left) and treefall vectors on terrain (right). The tornado moved from left to right. It descended a mountain by following a small streambed (see below), crossed Abrams Creek, and ascended another ridge. The most damaging winds accelerated both up a draw and along the side of a steep slope facing the tornado (inset).



Aerial photograph (left) and treefall vectors on terrain (right) for the same tornado, but just southwest of the example above. The tornado moved from left to right and followed a streambed as it descended roughly 400 m down a mountain.

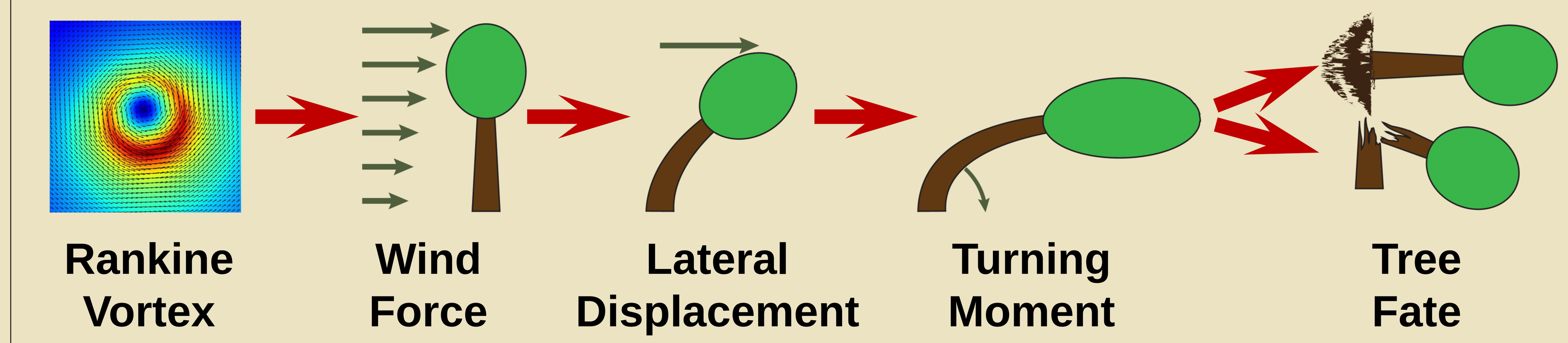


Aerial photograph (left) and treefall vectors on terrain (right). The tornado moved from the bottom left to the top right, traveling parallel to a creek, but it ascended roughly 250 m up and over a ridge rather than following the creek bed.

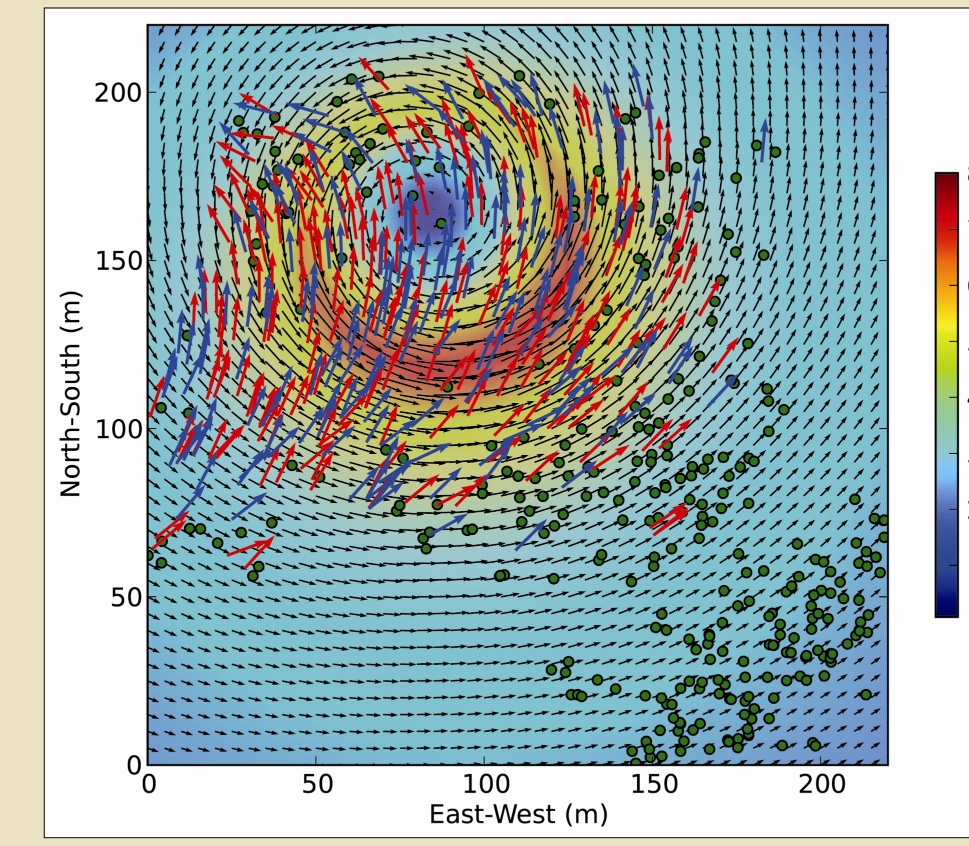
FUTURE PLANS

- Couple the wind model with topography
- Determine new tree stability data for local species via winching studies
- Create a detailed map of EF-scale intensity along the length of both tornado tracks

COUPLED WIND AND TREE MODEL



- As a simple Rankine vortex passes through the forest, a tree model determines the fate of each tree.
- If a tree falls, it does so in the direction of the instantaneous wind vector.
- **Red**: Uprooted trees
- **Blue**: Broken trees
- **Green**: Standing trees

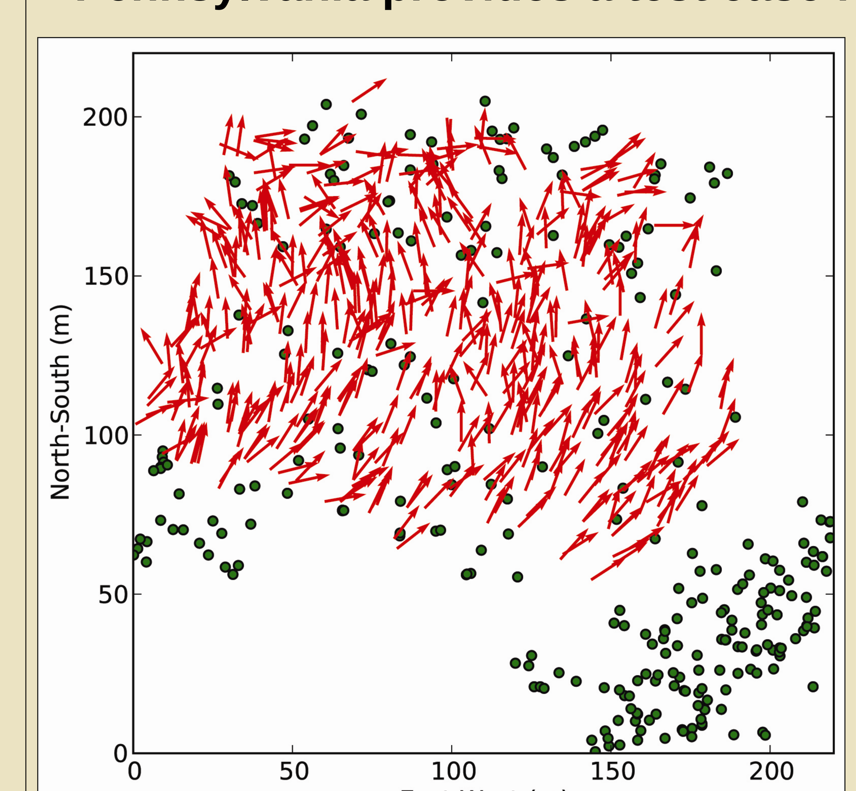


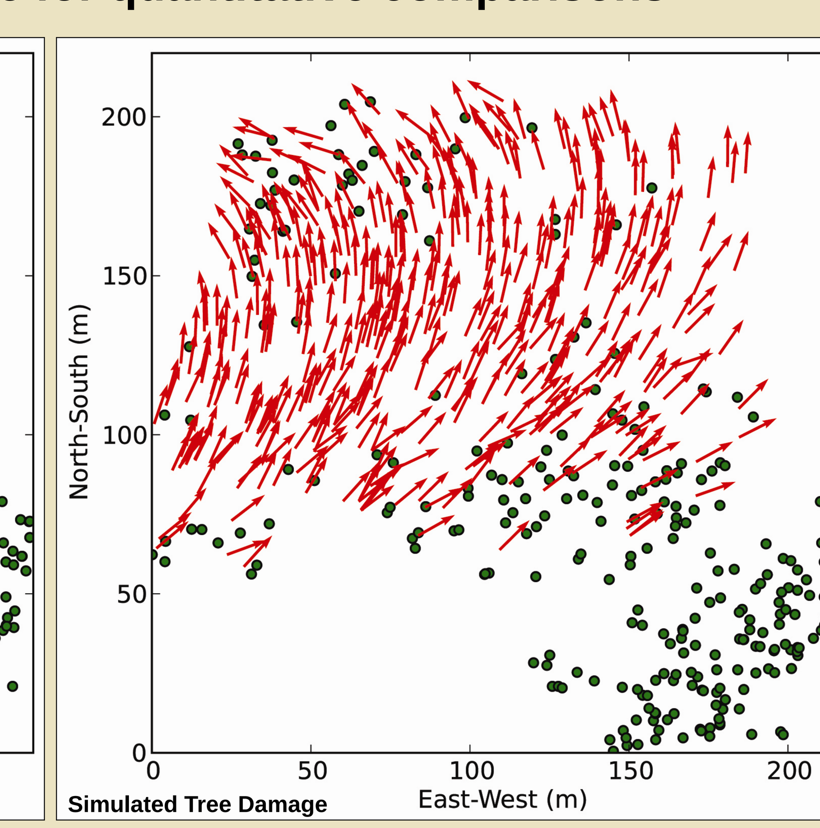
MATCHING OBSERVED DAMAGE

- Find the best match to the observed damage by adjusting the vortex parameters:
  1) Maximum tangential velocity (V_T)
  2) Radial velocity (V_R)
  3) Radius of maximum tangential velocity (R)
- Calculate a skill score for every possible parameter combination
- The skill score ranges from 0 to 2 and is the sum of two terms:
  1) The fraction of all trees correctly knocked down or left standing
  2) A normalized root-mean squared error for treefall direction

A TEST IN FLAT TERRAIN

- An F2 tornado in flat terrain on 31 May 1998 in Northeastern Pennsylvania provides a test case for quantitative comparisons





Observed tree damage (left) and simulated tree damage (right) for the vortex parameters that correspond with the maximum skill score: $V_T = 68$ m s^{-1}, $V_R = -3$ m s^{-1}, and R = 40 m.

ACKNOWLEDGMENTS

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