Tornado Wind Speed Estimation Methods in Rural Forested Regions: The Alonsa, MB Tornado

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ABSTRACT:
Wind speed estimation of a tornado is exceptionally difficult in forested regions where minimal structural damage is observed. Instead, tornadoes inflict extensive tree damage. This tree damage can be used to estimate the near-surface wind field by analyzing the fall patterns (i.e., tree-fall analysis). Aerial imagery was collected following the EF-4 rated Alonsa, MB by the Northern Tornadoes Project (NTP). The necessary tree characteristics were extracted from aerial photographs using image processing tools, and other tornado properties such as the damage path and width were acquired by the NTP. The tree-fall analysis showed the evolution of tornado growing in both intensity and size with an overall maximum wind speed of 88 m/s (195 mph). Debris flight analysis and detailed structural analysis were also carried out and compared as independent wind speed estimates.

Keywords: Tornado, Near-surface Wind Speed, Tree-fall Pattern, Debris Flight

1. INTRODUCTION

According to Sills et al. (2020), more tornadoes are believed to occur than currently reported, especially in the northern part of Canada where majority of the land is heavily forested and uninhabited. However, near-surface wind speed estimation of a tornado is often difficult in these regions using conventional methods (i.e., structural damage). Tree-fall analysis is a tool that utilizes the fall pattern of trees to estimate the near-surface wind field of a tornado (Lombardo et al., 2015; Rhee and Lombardo, 2018) and is particularly useful in forested regions.

In August 2018, a violent tornado developed near Alonsa, MB, which caused significant tree (and forest) damage. The tree-fall pattern was acquired by Rhee et al. (2021) using computer vision and image processing tools and the near-surface wind field was estimated by tree-fall analysis based on the acquired tree-fall pattern and the estimated critical wind speed of tree-fall V_c. Independent wind speed estimations were also made by the NTP using structural damage and debris flight analysis and compared to the wind field estimation from the tree-fall analysis.

2. WIND FIELD ESTIMATION BASED ON TREE-FALL PATTERNS

2.1. Critical Wind Speed of Tree-fall

Through the use of computer vision and image processing tools, the dimensions of tree can be estimated from an aerial photo with a known resolution and estimated tree pixels. An example sampled from the Alonsa, MB tornado aerial photograph with a resolution of 5-cm is shown in Figure 1. First, an RGB color-filter that depicts the tree pixels is applied and converted into a

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binary image (Figure 1(b)). Second, the object detection algorithm is applied to remove noise (Figure 1(c)) and separate the tree pixels (Figure 1(d)). Multiplying the resolution scale to the number of pixels (5-cm/pix for length and 25-cm^2/pix for area), the actual dimensions of tree can be estimated. In the HWIND model (Peltola et al., 1999), a wind-induced force is exerted on the tree, which is governed by the frontal area. Herein, the area of tree estimated from the aerial photo using image processing tool is used. A total of 41 trees are sampled and their mean V_c was estimated to be 47.5 m/s (106 mph).

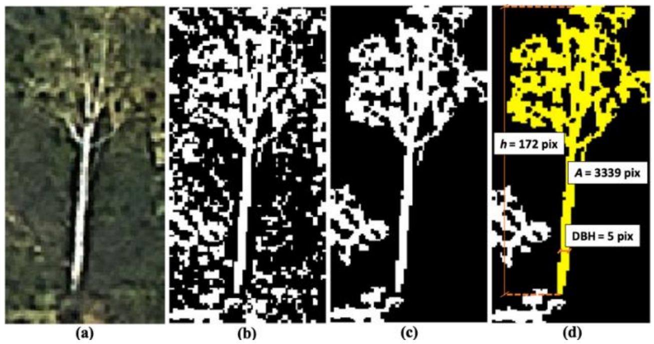

Figure 1. Extraction of tree pixels using image processing tools

2.2. Near-surface Wind Field Estimation

Tree-fall patterns acquired by a semi-automated tree-fall identification technique (Rhee et al., 2021) were used to estimate Rankine vortex (RV) parameters and recreate the near-surface wind field of the Alonsa tornado. A total of six transects at different locations along the tornado track were selected and analyzed to capture the evolution of the tornado. With an assumed translational speed (V_T) of 18 m/s (COD, 2018) and the average V_c (48 m/s) estimated in section 2.1, tree-fall analysis was carried out for each transect, in which the wind speed contour lines are shown in Figure 2. The overall maximum wind speed from the "best-match" RV parameters was estimated at 88 m/s (195 mph) with an uncertainty range of 71-97 m/s (160-215 mph).

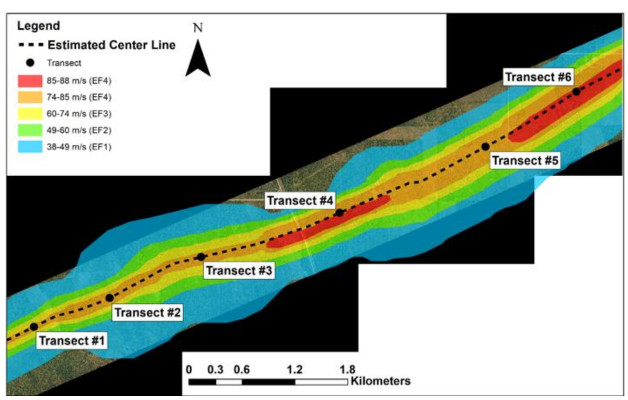

Figure 2. Estimated near-surface wind field of the Alonsa tornado

3. WIND SPEED ESTIMATION BASED ON OTHER DAMAGE INDICATORS

3.1. Structural Analysis

A ground-based damage survey was also conducted by the NTP. Two members of the NTP assessed the site and determined an EF4 damage (DOD 9) for One- and Two-Family Residences (FR12) and several EF2 and EF3 damages of FR12 and Small Barns and Farm Outbuildings. A more detailed structural analysis can provide more accurate wind speed estimates by inspecting the weak links between structural components. In the Alonsa tornado, wall baseplate failures due to nail withdrawal from the plywood floor were observed in the EF4 and one of the EF3 damaged FR12. The strength required to cause the wall baseplate failure was estimated by Stevenson et al. (2020). The 3-s gust wind speed to cause the same failure for the damaged FR12 was estimated at 67 m/s (150 mph), confirming an at least EF3 wind speed.

3.2. Debris Flight Analysis

Ground observations also showed evidence of debris flight where large haybales and vehicles were lofted from the ground and traveled mid-air. The threshold wind speed to loft an industrial haybale was estimated at 75 m/s (170 mph) using a debris flight model (Wills et al., 2002). However, the lofted haybales were found near the shore of Lake Manitoba, traveling at least 1.5 km and indicating that the wind speed may have been significantly higher than the debris threshold wind speed. Although debris flight analysis was carried out for the lofted vehicles, wind tunnel and tornado simulator experiments performed by Haan et al. (2017) suggest that debris threshold wind speed for lofting of vehicles tends to occur in wind speed of high-end EF3 to low-end EF4 range.

4. COMPARISON

The preliminary analysis suggests that the independent wind speed estimates using different damage indicators show reasonable agreement with one another. The tree-fall analysis estimated the maximum wind speed in the high-end EF4 range (195 mph), and the other damage indicators estimated the wind speed to be at least high-end EF3 (150-165 mph), and possibly EF4 wind speed (170 mph or higher). A more detailed spatial comparison is yet to be performed.

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