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Urban tree damage estimation using airborne laser scanner data and geographic information systems: An example from 2007 Oklahoma ice storm

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ABSTRACT

This study has applied an integrated airborne laser scanning (ALS) and geographic information systems (GIS) technique to estimate urban tree damages caused by an ice storm that affected the City of Norman, Oklahoma between 8 and 11th of December, 2007. Pre- and post-storm ALS data were collected and processed using GIS. The pre-storm ALS data was used to create a digital elevation model (DEM) and the pre-storm digital surface model (DSM) while the post-storm DSM was created from post-storm ALS data. The DEM were subtracted from the two DSMs to create the pre- and post-storm canopy height models (CHMs). Individual and grouped trees were then separated using a combination of Koukoulas and Blackburn and local maxima tree extraction algorithms. Finally, differences in height and canopy diameter between the pre- and post-storm CHMs within the extracted trees were calculated to measure the damage. Results showed that approximately 9% of the urban trees were completely damaged while almost 6% did not sustain any damage. It also showed that tree damage from ice storms varied with species and that *Acer saccarinum, Acer saccharum Marsh, Ulmus americana*, and *Ulmus pumila* were most vulnerable while *Platanus occidentalis* and *Quercus palustris* were the most resilient tree species to the ice storm. When compared with the ground reference data, it was found that the proposed methodology can detect tree height/stem damage with >81% accuracy compared to >42% accuracy in canopy damage assessment. Once ALS data is collected after a disaster, the methodology can provide a quick estimate of urban tree damage and hence be useful for city planners. It can also be used to create detailed inventories of tree heights of urban forests and monitor their growth and changes to improve their long-term sustainability.

Introduction

Natural disasters such as hurricanes and ice storms cause massive destructions of trees and forests (Irland, 2000; Lugo, 2008; Zimmerman et al., 1994). Bio-geographers, foresters, and city planners have been developing techniques to measure tree damages due to natural disasters (Bishop et al., 2014; Honkavaara et al., 2013; Vastaranta et al., 2012; Boutet and Weishampel, 2003). Space-borne passive remote sensors have allowed variable level of accuracy in detection and mapping of damaged or changes in single trees and forest stands by capturing and comparing the vegetation reflectance in land use pixels of pre- and post-hazard periods (Franklin et al., 2000; Leckie et al., 1992; Nyström et al., 2013; Olthof et al., 2004; Roberts et al., 1997; Rogan et al., 2002; Wulder et al., 2009). Data from active remote sensors such as Light Detection and Ranging (LiDAR) in general and Airborne Laser Scanners (ALS) in particular are widely used in mapping 3-D changes in the forest structures and estimating individual tree parameters such as their locations, canopy diameter, height, above-ground biomass, leaf area index, basal area, stem density, and timber volume (Clark et al., 2004; Falkowski et al., 2006; Gleason and Im, 2012; Holmgren and Persson, 2004; Holopainen et al., 2013; Jensen et al., 2008; Korhonen et al., 2011; Maltamo et al., 2004; Popescu, 2007; Tonolli et al., 2011; Yao et al., 2012). Numerous studies have used LiDAR and ALS data to estimate hurricane, snowfall, and wildfire damages of trees of open fields and standing plots (Dolan et al., 2011; Wulder et al., 2009; Vastaranta et al., 2012; Yu et al., 2004). However, none of the existing studies have focused on estimating tree damages in urban forest environment where trees are mixed with buildings.

The objective of this study is to quantify and estimate the nature and degree of tree damage in an urban area by using ALS data collected before and after an ice storm. Specifically, the study has

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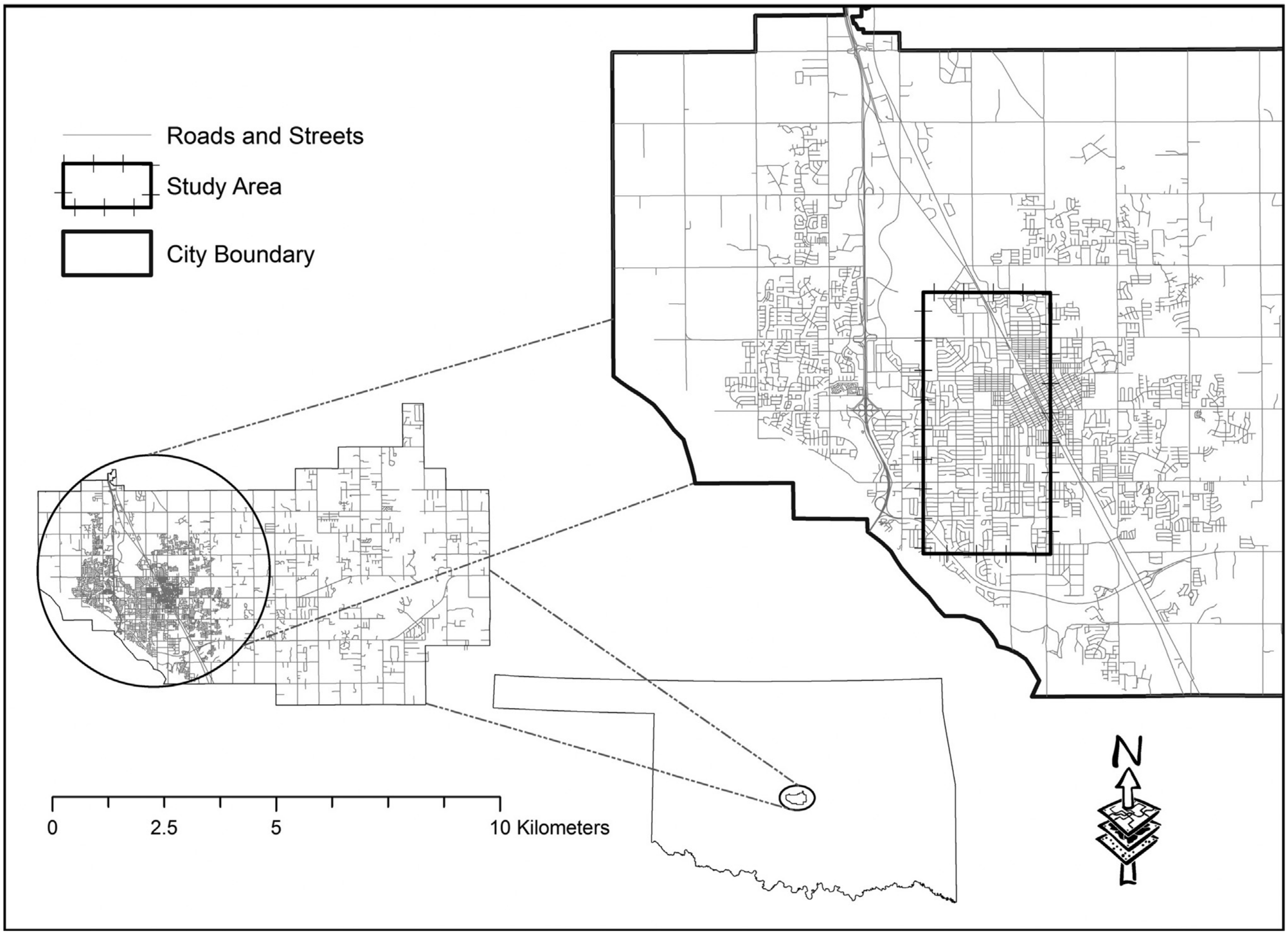

Fig. 1. Study area within the city of Norman, Oklahoma.

developed a replicable and standardized methodology for rapid assessment of damage to individual and grouped tree heights (or stems) and their canopies by processing the ALS data (in a GIS platform) collected before and after an ice-storm that affected the city of Norman, Oklahoma between December 8th and 11th of 2007. In the following section, the nature and duration of ice-storm that struck the State of Oklahoma in December of 2007 and how it affected the city of Norman is described. Data and methods section provides a detailed discussion of the proposed methodology and algorithms. The results are presented in Results section while its discussions and the limitations of using ALS data for tree damage assessments are provided in Discussion section. Finally, Conclusions section contains the conclusion and scope of future research.

Ice storm of December 8–11, 2007 and the study area

A four days long severe ice storm that had hit the State of Oklahoma and its neighboring regions on December 8th, 2007, caused major damages of urban forestry due to an accumulation of 2.54 to 3.81 cm thick ice layer on the tree branches (NOAA, 2014). The City of Norman, located in Central Oklahoma at about 32 km south of the Oklahoma City in Cleveland County, suffered severe tree and property damages from this storm (Fig. 1). About 111,000 people live in the city of 492 km^2 in area (US Census Bureau, 2010). Based on the degree of severity of tree damages from the ice storm, the main urban core of the city (18 km^2 in area) was chosen as the site for this study.

Data and methods

Both pre- and post-storm ALS datasets were collected for this study. The pre-storm data for the study area were collected between February 27th and March 3rd of 2007 while the post storm data were collected on July 10, 2008. Details of these datasets are given in Table 1. The study involved three methodological steps: (1) processing of ALS data collected during pre- and post-ice storm event, (2) isolating tree stems and canopies, and (3) measuring and quantifying the damage that may have occurred to each individual trees.

Table 1
Characteristics of the ALS data sets used in the study.

	Pre-storm data	Post-storm data
Date of data collection	February 27th–March 3rd, 2007	July 10th, 2008
Sensor type used	Leica Geosystems ALS50	Optech (ALTM) 33k LiDAR
Avg. flying altitude (m)	2100 m	1978 m
Scan frequencies	100 Hz	21 Hz
Scan angle	5–75°	18°
GSD	~1 m	~1 m
RMSE	<15 cm	~22 cm
Data supplied by	Merrick & Company	Airborne 1 Corp.