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Using vegetation management and LiDAR-derived tree height data to improve outage predictions for electric utilities

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ABSTRACT

The interaction of severe weather, overhead electric infrastructure and surrounding vegetation contributes to power outages. Given that 90% of storm outages in Connecticut are tree-related, accurate modeling of power outages before a storm arrives could result in improved pre-staging of crews and equipment resulting in improved electric reliability. The authors have generated a light detection and ranging (LiDAR) data product that provides a 1-m resolution measurement of vegetation that is tall enough to strike overhead distribution powerlines, called "ProxPix". These data, along with other vegetation management (e.g. tree trimming) and infrastructure data were evaluated for their improvement an outage prediction model over eastern Connecticut during Hurricane Sandy. A random forest model utilizing a repeated balanced sampling (RBS) approach with 10,000 iterations was used to evaluate which model forcing data accurately predicted the occurrence of a power outage in a 0.5 km grid cell. The authors found that models inputted with infrastructure, vegetation management, ProxPix, performed up to 5–13% better than simpler models depending on model evaluation criteria and input data; and that the model forced with utility infrastructure and ProxPix had the best overall performance. The ProxPix data created for this study have application to other research topics such as prioritizing areas for vegetation management near utilities and providing data on potential tree threats to roads, railways, or other infrastructure networks.

1. Introduction

1.1. Motivation

Connecticut has been subjected to prolonged power outages due to damage caused primarily by the interaction of trees and overhead power lines during extraordinary storms (i.e. Storm Irene and the October nor'easter in 2011, and Hurricane Sandy in 2012). Hurricane Sandy was especially impactful to Eversource Energy (formerly Connecticut Light & Power), with >500,000 customers without power and >15,000 outages (defined as individual locations requiring the manual intervention of a utility restoration crew for repair) caused mostly by branches or entire trees falling onto the overhead lines [1]. Contributing to these high storm-related outages, Connecticut has the highest wildland-urban interface in the United States [2] with a majority of residents living under a rural or urban tree canopy.

Trees provide a host of benefits including: habitat for wildlife [3], shade that moderates temperatures [4], and aesthetic benefits [5]. Electric utility companies are tasked [6] with managing these trees surrounding overhead lines to maintain acceptable reliability for customers (e.g. limiting the number of interruptions and duration of outages). The management of trees and other flora around overhead lines is known as vegetation management (VM); a multi-faceted program of managing trees by trimming above, below and on the side of overhead lines; and the management of vines and shrubs.

1.2. Literature survey

There are many research papers that try to predict the impact of weather on overhead distribution lines using a variety of methods, including multiple linear regression [7], artificial neural networks [8], tree-based models [9,10], and hybrid models where combinations of binary and count data models are used in combination

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[11]. Among these studies, [12] showed that increasing trimming on distribution circuits could lead to decreased outages on the Duke Power system in the Carolinas. Other researchers [13] have investigated including VM data and other weather and geographic data into outage prediction models and found that the data could help the accuracy of these models. Further, although multiple VM trimming strategies exist (e.g. trim overhead lines every 2–7 years), [14] showed that an optimized vegetation management program as a function of utility cost and customer cost could yield an improvement in reliability (4–6%) and a reduction in total cost (9%).

Understanding the vegetation risk of an infrastructure network can lead to better management of the vegetation. Utilities typically track where VM has occurred on the overhead lines in a geographic information system. Airborne Light Detection And Ranging (LiDAR) data complement VM data by making it possible to develop accurate models of tree heights and locations over large areas. Airborne LiDAR data have been used for more than a decade to model the heights of forest canopies [15]. Canopy height models (CHM) estimate forest canopy height at any given location and make it possible to identify trees that are within striking distance of power lines. The identification of these risk trees provides a direct physical basis for outage prediction models to better incorporate the environmental conditions surrounding overhead power lines.

1.3. Contributions

The objective of this paper is to evaluate the available data on trees and infrastructure for their effect on improving hurricane outage model predictions. Specifically, the authors compare models incorporating these datasets to more traditional models that incorporate only limited environmental data. The authors introduce a newly created 1 m proximal tree pixel dataset that encapsulates the risk of an overhead line to potential vegetation failures, provide detailed information on physical architecture of the distribution network (covered vs. bare wire, backbone and lateral circuit) and evaluate the benefit to a model predicting the occurrence of an outage in a 0.5 km grid cell. The gridded spatial resolution is believed to be the highest of other outage modeling papers in the literature, which the authors hope will provide more detailed results on the processes that contribute to power outages. In addition, the authors present partial dependence and variable importance plots to demonstrate how each variable influences the model predictions. Given the temporal and spatial constraints of the data, the authors focus the paper exclusively on outages occurring during Hurricane Sandy [2012] in eastern Connecticut.

1.4. Paper structure

This paper is divided into six additional sections: Section 2 describes the study area; Section 3 describes the data used in more detail; Section 4 describes the methodology and error metrics; Section 5 presents the results; Section 6 discusses the results; and Section 7 presents the conclusion and future areas of research.

2. Study area

The study area is focused on eastern Connecticut (Fig. 1) due to the availability of LiDAR data over the region. Eastern Connecticut has a diverse landscape with a lowland coastal southern region and a hilly northern region encompassing the Thames River valley. Population is most heavily concentrated along the shoreline and along the Thames River valley. Eversource Energy-Connecticut delivers power to nearly every town in eastern Connecticut except for three which are served by municipal utilities.

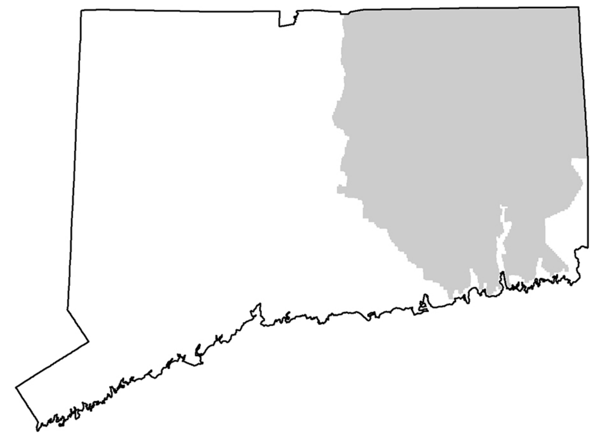

Fig. 1. Distribution of the 4600 km^2 LiDAR data in eastern CT over the study area.

3. Data

The data used in this study (described below) were aggregated using a grid with 0.5 × 0.5 km cell sizes; representing a total of 9000 grid cells covering the study area. All datasets were averaged within each grid cell. Weather simulation data were processed at 2 km spatial resolution using the Weather Research and Forecasting (WRF) model [16], while all other explanatory data were processed at the 0.5 km grid resolution. For this study, the authors used the weather simulation and land cover data [17] for Hurricane Sandy as described in Ref. [9]—see this article for a full description of the weather simulation methodology and validation of winds. Examples of variables from the weather simulation include the maximum gust and wind at 10 m, the total accumulated precipitation, and the duration of wind at 10 m above specific thresholds (i.e. 9, 13, and 18 m/s). To join the 2 km weather data to the 0.5 km aggregated data, the centroid of each 0.5 km grid cell was joined to the nearest 2 km centroid and assigned the corresponding data. See Table 1 for a description of all variables included in the model.

3.1. Utility infrastructure

The authors considered attributes of the conductors related to their circuit material (e.g. bare or covered) and designation (e.g. backbone or lateral) to make the model more physically-meaningful. Conductor material was deemed important because the overhead lines suffer from different types of outages (i.e. incidental touching of trees for bare conductors, destruction of conductors for bare and covered conductors). Circuit designation was included because backbone circuits typically serve many more businesses and essential town functions (e.g. police, fire, ambulance) than lateral circuits, and are expected to be more resilient due to enhanced VM activities from 1994 to 2007 (Personal Communication, Sean Redding, Eversource Energy).

3.2. Vegetation management

Using vegetation management annual planning data for years 2009 through 2012, the authors calculated the percentages of overhead lines that received Standard Maintenance Trimming (SMT) and Enhanced Tree Trimming (ETT) treatment as a function of conductor material and circuit designation for a given year in each 0.5 × 0.5 km grid cell. A linear decay function (Eq. (1)) was applied to the SMT to express the diminishing benefit of such treatment as time passes due to regrowth. A cumulative function (Eq. (2)) was applied to ETT because the benefit of such trimming activities are