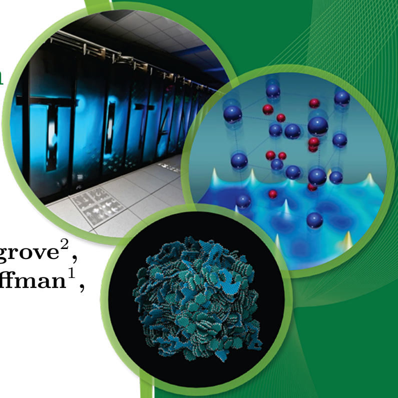
Canopy structure and distribution of vegetation in Great Smoky Mountains National Park



Jitendra Kumar[1], William W. Hargrove[2], Steven P. Norman[2], Forrest M. Hoffman[1], Doug Newcomb[3]

[1]Oak Ridge National Laboratory,
[2]Southern Research Station, US Forest Service,
[3]US Fish and Wildlife Service

Monday August 13, 2018

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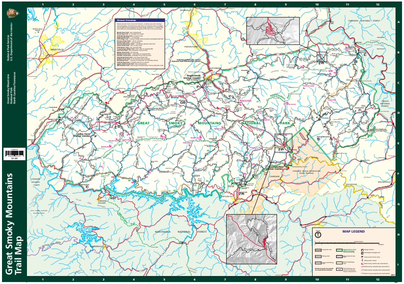
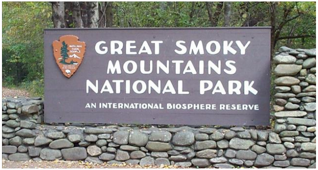
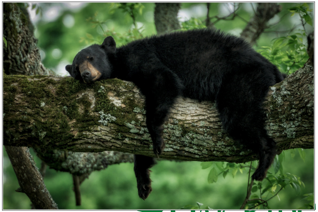
Great Smoky Mountains National Park (GSMNP)

- The GSMNP is the most visited national park in the U.S., and it hosts a rich ecosystem of plants and wildlife.
- The Park encompasses 816 sq. miles in Tennessee and North Carolina and ranges in elevation from 876 to 6,643 feet above mean sea level.
- GSMNP is a biodiversity hotspot. International Biosphere Reserve and a World Heritage Site







Structure and composition of vegetation in GSMNP

Mapping and understanding the vegetation composition and structure is important for:

- forest health management
- maintaining and tracking changes in plant and wildlife habitats and biodiversity in the park
- aid in the forest management planning and decisions

VEGETATION MODELING, ANALYSIS AND VISUALIZATION IN U.S. NATIONAL PARKS

Marguerite Madden

Center for Remote Sensing and Mapping Science (CRMS), Dept. of Geography
The University of Georgia, Athens, Georgia 30602, USA - mmadden@crms.uga.edu

Commission IV, Working Group IV/6

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A new cost-distance model for human accessibility and an evaluation of accessibility bias in permanent vegetation plots in Great Smoky Mountains National Park, USA

Jobe, R. Todd[1]* & White, Peter S.[2]

[1]*Geography Department, CB#3220 Saunders Hall, The University of North Carolina at Chapel Hill, Chapel Hill, NC 27599-3220, USA;* [2]*Department of Biology, CB#3280 Coker Hall, The University of North Carolina at Chapel Hill, Chapel Hill, NC 27599-3280, USA, Email peter.white@unc.edu;*
**Corresponding author; E-mail toddjobe@unc.edu*

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Changing fire regimes and old-growth forest succession along a topographic gradient in the Great Smoky Mountains

William T. Flatley[a,*], Charles W. Lafon[b], Henri D. Grissino-Mayer[c], Lisa B. LaForest[c]

[a] School of Forestry, Northern Arizona University, Flagstaff, AZ 86011, USA
[b] Department of Geography, Texas A&M University, College Station, TX 77843, USA
[c] Department of Geography, University of Tennessee, Knoxville, TN 37996, USA

Journal of the Torrey Botanical Society 129(3), 2002, pp. 194–206

***Cornus florida* L. mortality and understory composition changes in western Great Smoky Mountains National Park[1]**

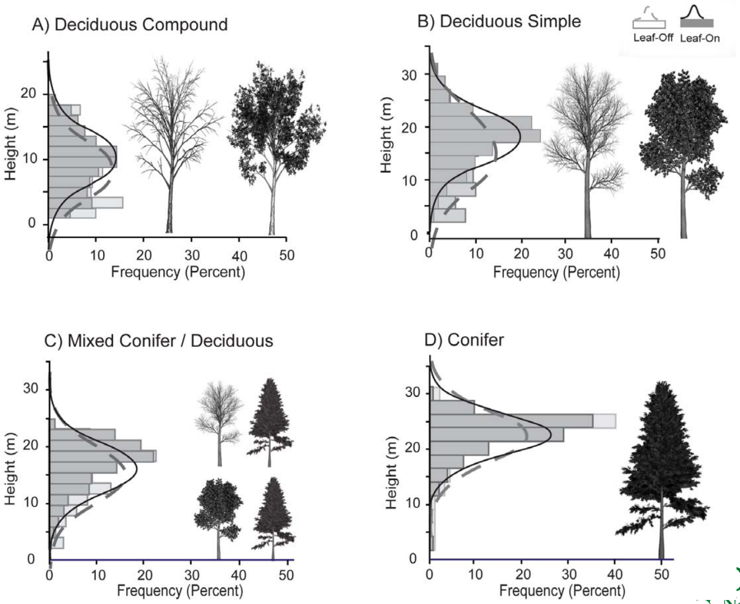
Michael A. Jenkins[2]
National Park Service, Twin Creeks Natural Resources Center, 1314 Cherokee Orchard Road, Great Smoky Mountains National Park, Gatlinburg, TN 37738

Peter S. White

Objectives:

1. Characterize three dimensional structure of the vegetation (whole vegetation canopy and understory) in GSMNP
2. Analyze the vegetation distribution across the park – across topographic and climate gradient; structural diversity within and across various forest types
3. quantify biomass and productivity of GSMNP vegetation
4. map changes using repeating analysis over time

Vegetation profile using LiDAR



Wasser et. al. (2013), PLOS ONE DOI

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LiDAR data for GSMNP

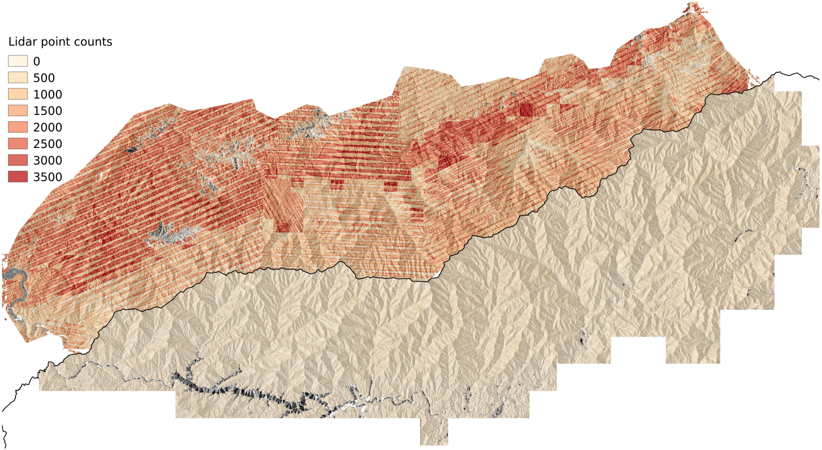
Tennessee

- LiDAR data for 540 sq. miles of the Tennessee portion of the GSMNP and the Foothills Parkway from 1,658 flight miles were collected during February–April 2011 by the U. of Georgia and Photo Science, Inc.
- Four multiple discrete returns per pulse were collected at a rate of 20.2 Hz from a nominal flying height of 1,981 m above ground level.
- Overlapping data were split into 724 non-overlapping 1,500 $\times$ 1,500 m tiles, which we obtained from the National Park Service.
- 724 LiDAR tiles (approx. size 98 GB) projected onto a 3.0 m resolution digital elevation model (DEM) derived from the LiDAR point cloud.
- Projection: UTM Units: meters

North Carolina

- LiDAR data for North Carolina was collected by NC Floodplain Mapping Program in 2005.
- Overlapping data were split into non-overlapping 10,000 $\times$ 10,000 ft tiles, which we obtained from the NC Floodplain Mapping Program.
- 184 LiDAR tiles (approx. size 8.9 GB) projected onto a 3.0 m resolution digital elevation model (DEM) derived from the LiDAR point cloud.
- Projection: NC State Plane Units: ft

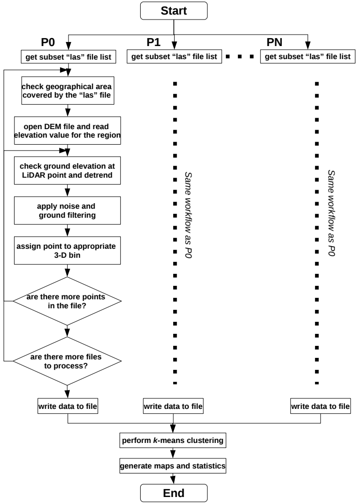
LiDAR quality across GSMNP



Data from NC vs TN side of park have large disparity in the quality, making integrated analysis across the park a challenge.

Computational Workflow and Data Processing

- We employed a process-parallel approach to extract and analyze LiDAR point cloud data using python.
- To estimate vegetation heights above ground level, elevations from the 3.0 m DEM were subtracted from point cloud data.
- The resulting points were grouped into 1 m vertical bins, up to 75 m, at a horizontal resolution of 30×30 m.
- Anomalous high points (aerosols, birds) and low points (steep slopes, surface litter) were filtered out.
- Corrections were made for low height vegetation (shrubs and grasses) and for many returns at the same elevation.



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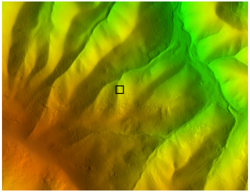
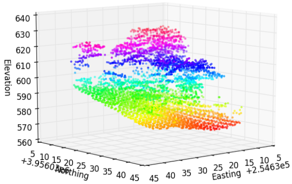
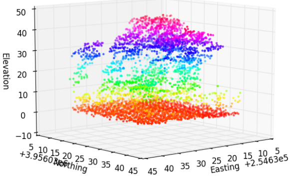
LiDAR Point Cloud Example: 30m pixel



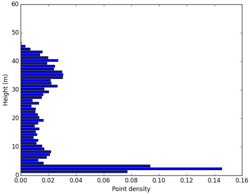
a) 3-D LiDAR point cloud extent at 30×30 m (black square) shown in a typical GSMNP cove forest.



b) Raw LiDAR point cloud (3,985 points), showing imprints of underlying topography.



c) LiDAR point cloud after topographic detrending and filtering (3,936 points).



d) Vertical distribution of LiDAR point density in a cove forest dominated by tall trees and a dense understory.

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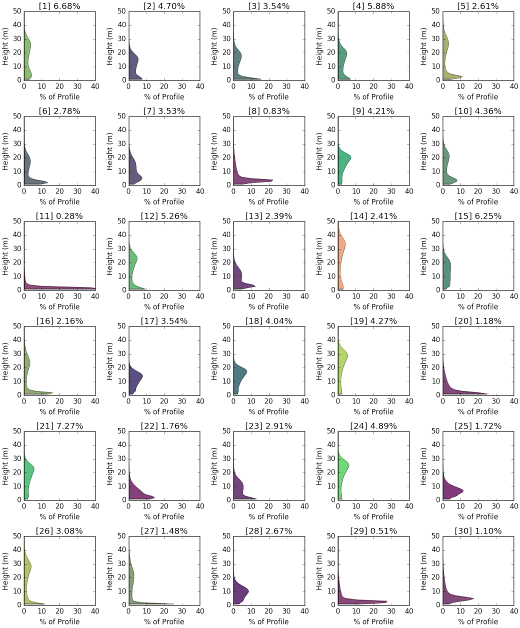
30 vegetation structure classes



We use a similarity color scheme based in Principal Component Analysis: Low (< 20m) canopy (RED); Medium (30 - 36 m) canopy (BLUE); Tall (> 46m) canopy (GREEN)

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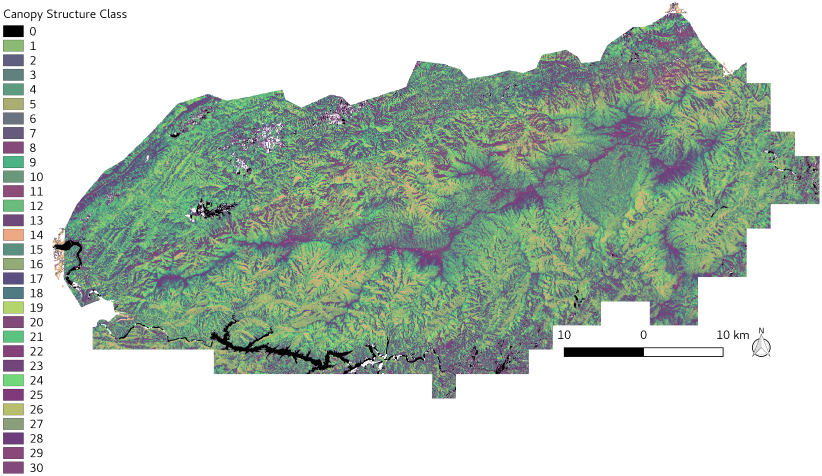
Vegetation of 30 vegetation structure classes across GSMNP



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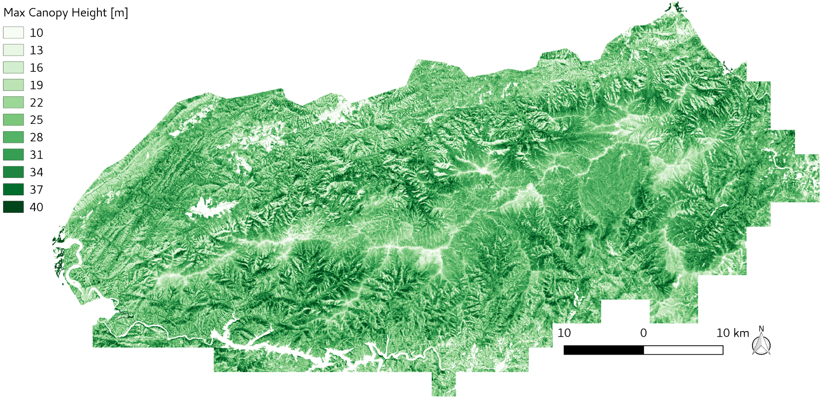
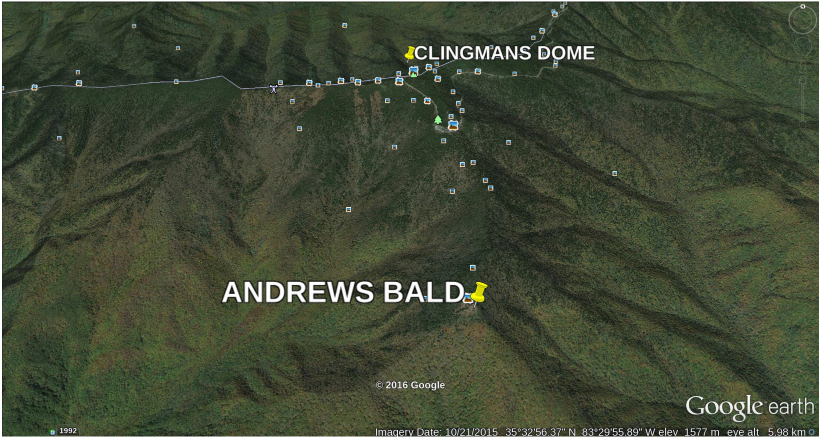
Maximum canopy heights across GSMNP



95th percentile height of vegetation canopy

Clingman's Dome: Google Earth



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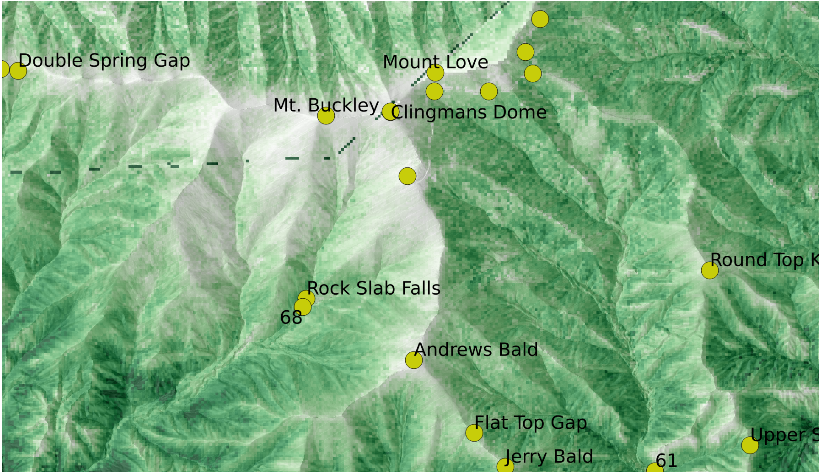
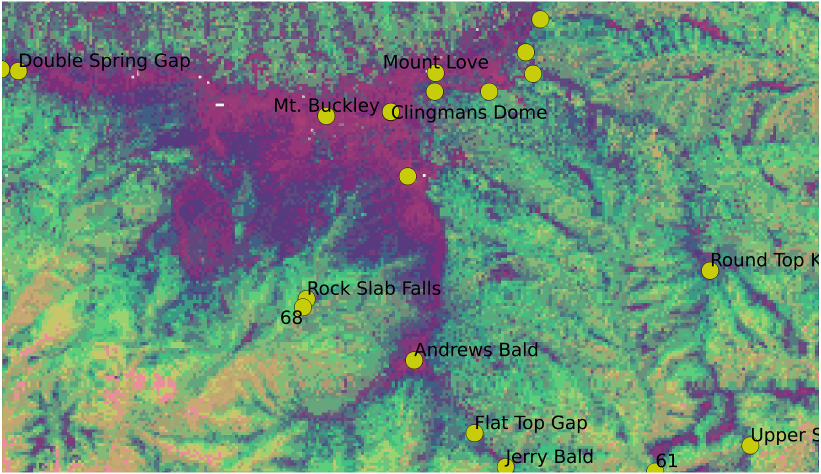
Clingman's Dome: Max. canopy height



Clingman's Dome: Vegetation structure



Cades Cove: Google Earth

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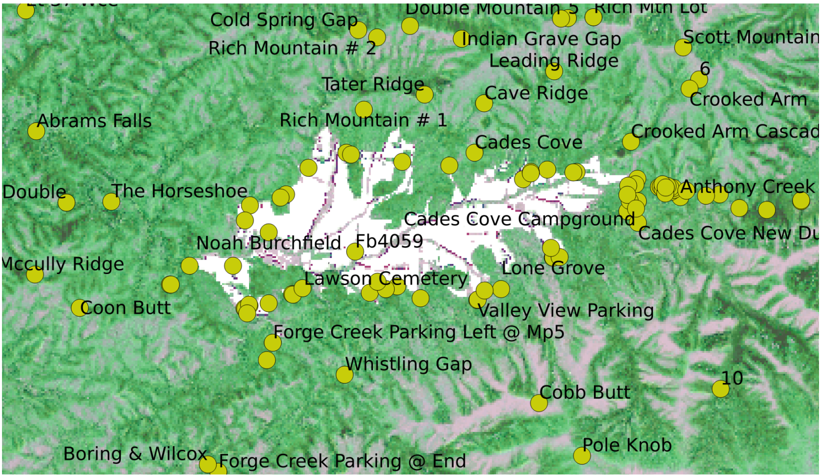
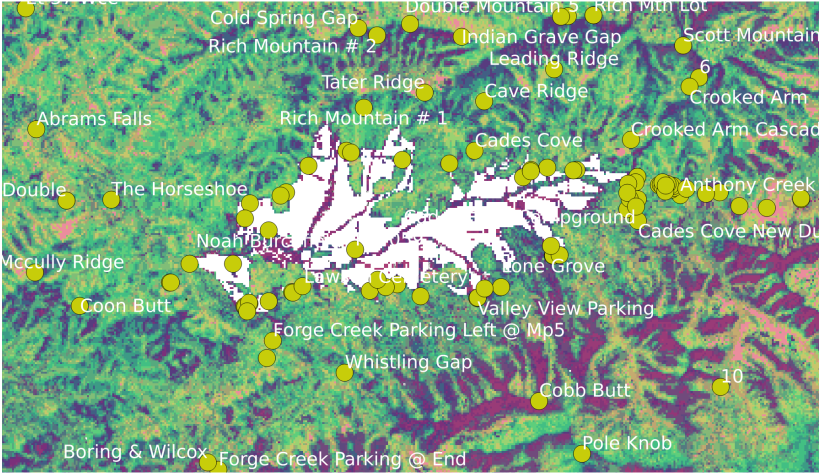
Cades Cove: Max. canopy height



Cades Coves: Vegetation structure



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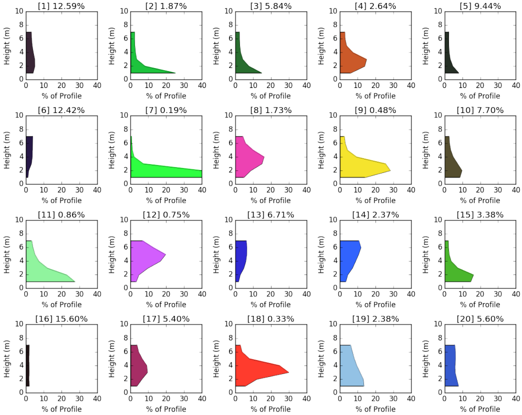
What does the understory vegetation look like?

- Vegetation structure is however fairly dominated by the taller forest canopies.
- To better characterize and map the understory vegetation we performed a second set of analysis by using the LiDAR point cloud data set only up to $8m$ height from the ground.



We use a similarity color scheme based in Principal Component Analysis: Low (< 3m) canopy (GREEN); Medium (3 - 5 m) canopy (RED); Tall (5 – 8m) canopy (BLUE)

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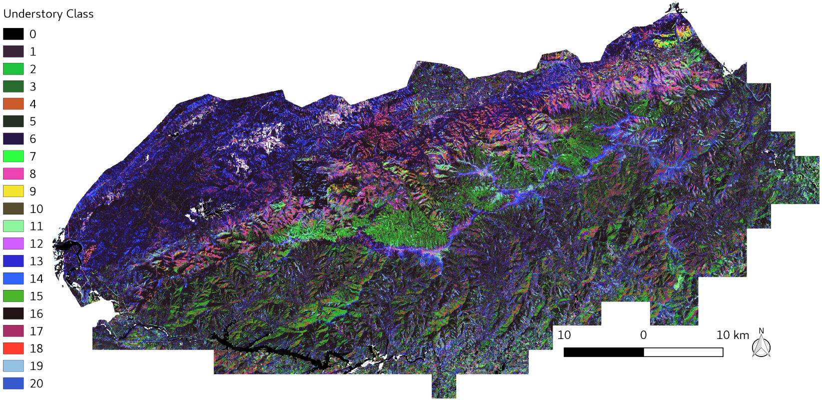
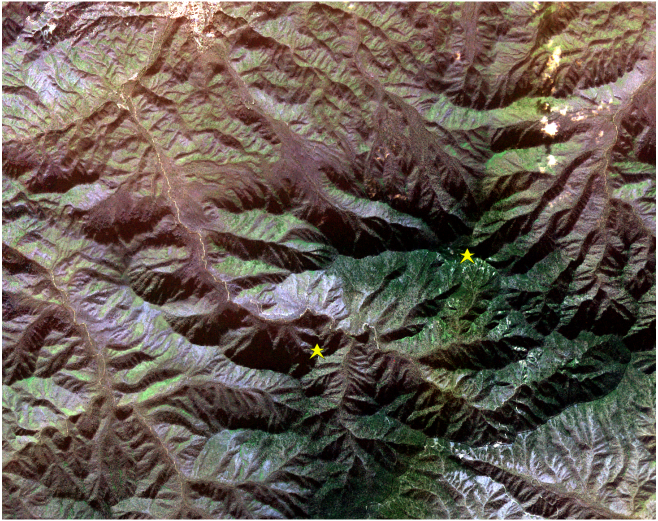
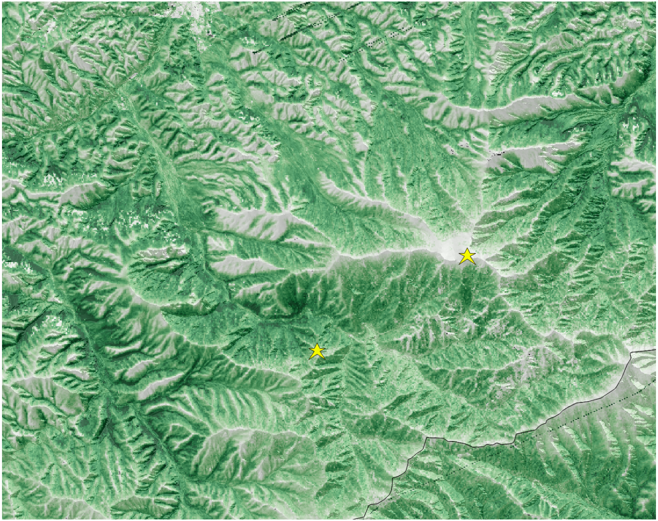
Understory vegetation map



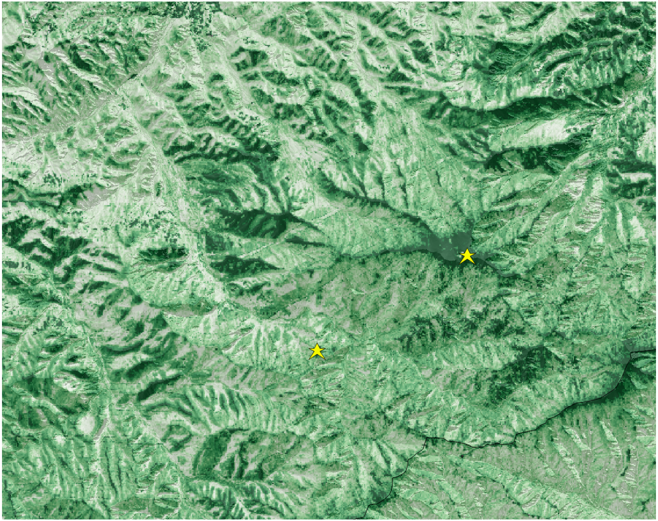
Mt. Leconte / Chimney Tops: Rapideye 12/29/2015



Mt. Leconte / Chimney Tops: Max. canopy height



Mt. Leconte / Chimney Tops: Amount of understory vegetation



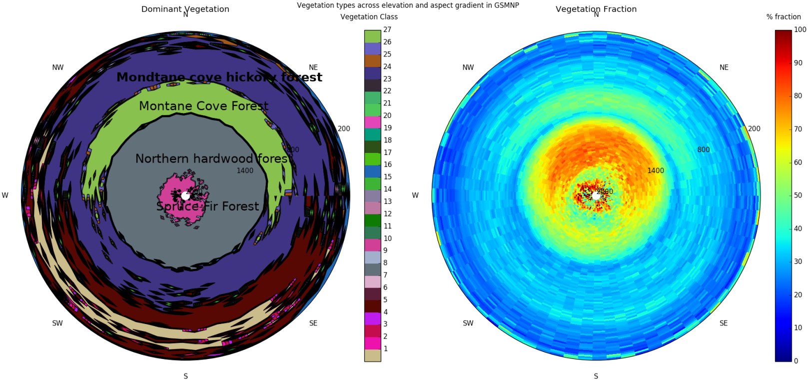
Map shows the fraction of total tree canopy in the understory. High elevation areas in the park have low height trees with a dense understory vegetation (dominated by Rhododendron and Mountain Laurel).

Understanding the patterns across the park

Putting things in landscape scale perspective to understand the vegetation across the park.

Virtual Mountain: We represent the variability across the topography using a Virtual Mountain plot that captures the distribution of data across elevation and aspect gradient for the entire park. Radial direction represents elevation with highest elevation at the center to lower elvations in radially outward direction. Azimuth direction represent the topographic aspect on the landscape.

Vegetation across complex topography within GSMNP



Climate and topographic gradients across the park supports diverse forest types, which show preferential distribution and dominance along these gradients.

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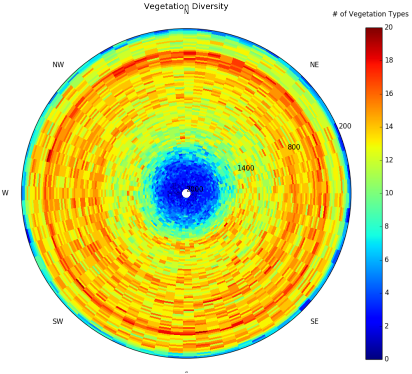
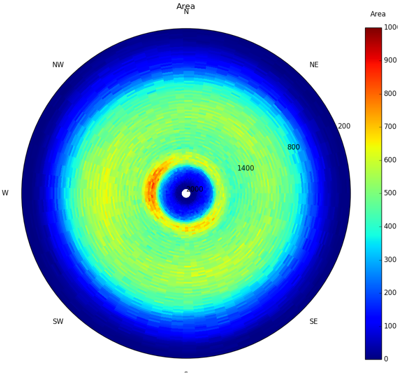
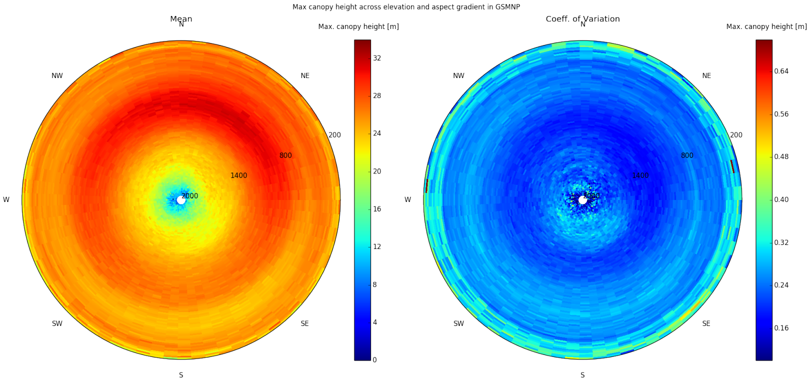
Vegetation diversity within the park





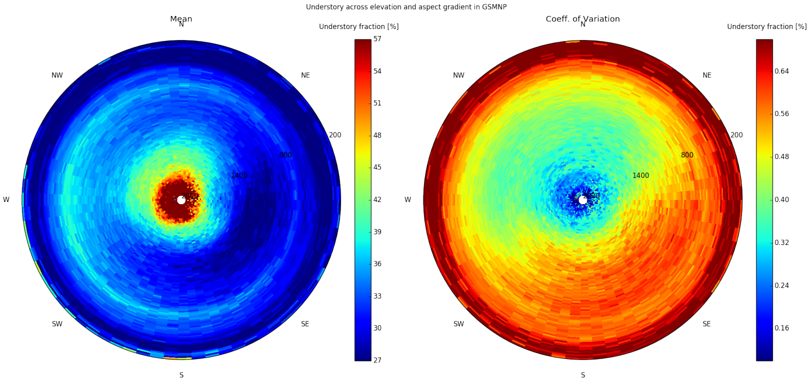
Higher vegetation diversity at low to mid elevations, while lower diversity at high elevations

Patterns of tree heights



Forest canopies are taller at low to mid elevations, and shorter vegetation at higher elevations

Pattern of understory vegetation



Dense understory and low height vegetations are dominant at higher elevations in the park

Summary and Conclusions

- We developed an approach, parallel software tools, and workflow for analyzing large volumes of LiDAR point cloud data in a scalable fashion.
- Multivariate Spatiotemporal Clustering (MSTC) provides a valuable quantitative framework for stratifying vegetation canopy structure data derived from LiDAR point clouds.
- We applied these tools to LiDAR data from the GSMNP to identify vegetation classes based on overstory/understory distributions.
- Early validation efforts for various areas in the park are promising. We are also comparing with the available plot observations from the park.
- These tools and the resulting maps will inform resource management and conservation planning by forest and wildlife managers, who were not previously able to use large, complex LiDAR data sets.

Free and Open Source Software for Open Science

Data Source:

USGS, National Park Service, US Forest Service

LiDAR Data Processing:

Custom developed `Python` software using `laspy` module for processing `las` files. `multiprocessing` module was used to implement shared memory parallelism.
Unsupervised classification software was developed in `C` using `MPI` for distributed memory parallelism.

Geospatial analysis and visualization

All geospatial analysis and visualization was done using `GDAL`, `GRASS GIS`, `QGIS`, and `Python`

Computational resources

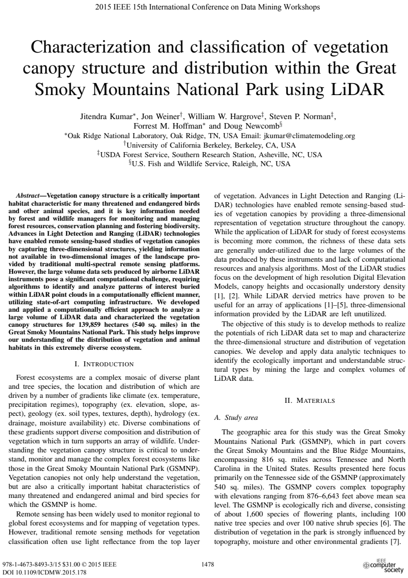
All data analysis were conducted on compute clusters at ORNL running Fedora/CentOS Linux.

Document preparation

All documents/presentations/posters were prepared using LaTeX and `beamer`.

Publications, data and software products

All publications, data and software from this research are available publicly.



2015 IEEE 15th International Conference on Data Mining Workshops

Characterization and classification of vegetation canopy structure and distribution within the Great Smoky Mountains National Park using LiDAR

Jitendra Kumar*, Jon Weiner†, William W. Hargrove‡, Steven P. Norman‡,
Forrest M. Hoffman* and Doug Newcomb§
*Oak Ridge National Laboratory, Oak Ridge, TN, USA Email: jkumar@climatemodeling.org
†University of California Berkeley, Berkeley, CA, USA
‡USDA Forest Service, Southern Research Station, Asheville, NC, USA
§U.S. Fish and Wildlife Service, Raleigh, NC, USA

Abstract—**Vegetation canopy structure is a critically important habitat characteristic for many threatened and endangered birds and other animal species, and it is key information needed by forest and wildlife managers for monitoring and managing forest resources, conservation planning and fostering biodiversity. Advances in Light Detection and Ranging (LiDAR) technologies have enabled remote sensing-based studies of vegetation canopies by capturing three-dimensional structures, yielding information not available in two-dimensional images of the landscape provided by traditional multi-spectral remote sensing platforms. However, the large volume data sets produced by airborne LiDAR instruments pose a significant computational challenge, requiring algorithms to identify and analyze patterns of interest buried within LiDAR point clouds in a computationally efficient manner, utilizing state-of-art computing infrastructure. We developed and applied a computationally efficient approach to analyze a large volume of LiDAR data and characterized the vegetation canopy structures for 139,859 hectares (540 sq. miles) in the Great Smoky Mountains National Park. This study helps improve our understanding of the distribution of vegetation and animal habitats in this extremely diverse ecosystem.**

I. Introduction

Forest ecosystems are a complex mosaic of diverse plant and tree species, the location and characteristics of which are driven by a number of gradients like climate (ex. temperature, precipitation regimes), topography (ex. elevation, slope, aspect), geology (ex. soil types, textures, depth), hydrology (ex. drainage, moisture availability) etc. Diverse combinations of these gradients support diverse composition and distribution of vegetation which in turn supports an array of wildlife. Understanding the vegetation canopy structure is critical to understand, monitor and manage the complex forest ecosystems like those in the Great Smoky Mountain National Park (GSMNP). Vegetation canopies not only help understand the vegetation, but are also a critically important habitat characteristics of many threatened and endangered animal and bird species for which the GSMNP is home.

Remote sensing has been widely used to monitor regional to global forest ecosystems and for mapping of vegetation types. However, traditional remote sensing methods for vegetation classification often use light reflectance from the top layer of vegetation. Advances in Light Detection and Ranging (LiDAR) technologies have enabled remote sensing-based studies of vegetation canopies by providing a three-dimensional representation of vegetation structure throughout the canopy. While the application of LiDAR for study of forest ecosystems is becoming more common, the richness of these data sets are generally under-utilized due to the large volumes of the data produced by these instruments and lack of computational resources and analysis algorithms. Most of the LiDAR studies focus on the development of high resolution Digital Elevation Models, canopy heights and occasionally understory density [1], [2]. While LiDAR dervied metrics have proven to be useful for an array of applications [1]–[5], three-dimensional information provided by the LiDAR are left unutilized.

The objective of this study is to develop methods to realize the potentials of rich LiDAR data set to map and characterize the three-dimensional structure and distribution of vegetation canopies. We develop and apply data analytic techniques to identify the ecologically important and understandable structural types by mining the large and complex volumes of LiDAR data.

II. Materials

A. Study area

The geographic area for this study was the Great Smoky Mountains National Park (GSMNP), which in part covers the Great Smoky Mountains and the Blue Ridge Mountains, encompassing 816 sq. miles across Tennessee and North Carolina in the United States. Results presented here focus primarily on the Tennessee side of the GSMNP (approximately 540 sq. miles). The GSMNP covers complex topography with elevations ranging from 876–6,643 feet above mean sea level. The GSMNP is ecologically rich and diverse, consisting of about 1,600 species of flowering plants, including 100 native tree species and over 100 native shrub species [6]. The distribution of vegetation in the park is strongly influenced by topography, moisture and other environmental gradients [7].

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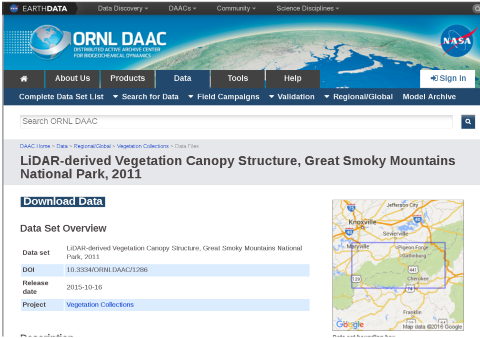

Kumar, J., J. Weiner, W.W. Hargrove, S.P. Norman, F.M. Hoffman, and D. Newcomb. 2015 LiDAR-derived Vegetation Canopy Structure, Great Smoky Mountains National Park, 2011. ORNL DAAC, Oak Ridge, Tennessee, USA. http://dx.doi.org/10.3334/ORNLDAAC/1286

http://dx.doi.org/10.1109/ICDMW.2015.178

Jitendra (Jitu) Kumar, jkumar@climatemodeling.org