THE UTILITY OF LiDAR FOR LARGE AREA FOREST INVENTORY APPLICATIONS

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Abstract.—Multi-resource inventory data are used in conjunction with Light Detection and Ranging (LiDAR) data from the Pennsylvania Department of Natural Resource's PAMAP Program to assess the utility of extensive LiDAR acquisitions for large area forest assessments. Background, justification, and initial study designs are presented. The proposed study will involve three phases: 1) characterization of relationships between LiDAR cloud metrics and statistical summaries of tree information on forest inventory plots, 2) use of the inventory data to calibrate LiDAR-based forest biomass models, and 3) use of subsets of the LiDAR dataset as part of a ground-based forest inventory. Initial results of the first phase indicate moderate relationships between various combinations of ground inventory and LiDAR data.

INTRODUCTION

Large area forest assessments have been of interest for many years. Traditionally, these assessments have been conducted by ground-based inventories like those conducted by the U.S. Forest Service's Forest Inventory and Analysis (FIA) Program (Gillespie 1999). Since the early 1900s, FIA has conducted inventories of the nation's forest resource through a combination of periodic and annual field data collection campaigns. Data on tree and site factors in forested areas are collected, processed, and converted into summary information that is used by resource planners, land managers, scientists, and other interested parties.

The use of air- and space-borne sensors in forest assessments has increased over the last 40 years. In the last decade, the use of LiDAR (Light Detection and Ranging) technology in particular has increased dramatically. Cost considerations previously limited the use of LiDAR to relatively small—generally sub-state—areas. Now, entities such as state governments can afford to acquire LiDAR over large areas. For example, Pennsylvania's PAMAP Program funded state-level acquisition of LiDAR between 2006 and 2008 (PA DCNR 2012). The existence of co-occurring, large area LiDAR and forest inventory datasets creates opportunities for studies assessing the costs and benefits of using LiDAR in various ways for forest assessments.

The most common use of LiDAR in forest assessments involves the generation of pixel-based estimates of forest parameters such as volume, biomass, or tree abundance in relatively small study areas (e.g., Asner et al. 2011, Lefsky et al. 2003). However, recent interest in large area assessments of forest carbon stocks as part of United Nations climate change agreements, such as those contained in the United Nations Framework Convention on Climate Change's program for Reducing Deforestation and Degradation (REDD) (Gullison et al. 2007), has led to a need for investigations of cost-effective

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strategies for measuring and monitoring forest carbon in areas that do not have established, ground-based forest inventories. LiDAR is a particularly appealing option due to the nature of the information obtained, reflectance information generally shows strong relationships with forest canopy height and density, two attributes closely related to forest biomass and thus carbon content. LiDAR has the added benefit of targeted acquisitions that can be less susceptible to cloud cover which affects space-borne sensors like Landsat.

An option that is not often explored, however, is the practical use of LiDAR to aid in large area, ground plot-based forest inventories. Due to the immense data volumes and processing requirements, it can be impractical to collect and process LiDAR over large areas on a regular basis. However, advances in computing technology make this an option worth exploring. A promising approach is the use of subsets of the LiDAR information for stratification or, in another supporting role with ground plots, as the basis for the estimate generation.

The goal of the current study is to address the need for methods that use LiDAR to generate estimates of forest attributes, particularly tree carbon stocks, over large areas in an efficient way. Specific objectives of the study are to 1) characterize relationships between LiDAR cloud metrics and FIA data from various ecosystems around Pennsylvania, 2) assess the usefulness of FIA data for calibrating LiDAR-based forest biomass models, and 3) compare the costs and benefits of using LiDAR-based maps of forest attributes with estimates generated from several combinations of LiDAR and ground data in a design-based forest inventory framework. Results of these three analyses will not only improve our understanding of how FIA data can serve as training data for LiDAR-based biomass modeling, but also to help inform decisions about carbon inventory and monitoring strategies both in the United States and in other countries considering using LiDAR for this purpose.

STUDY AREA

The study area is the state of Pennsylvania. It is located between 74° 43′ and 80° 31′ west longitude, and 39° 43′ and 42° north latitude; the state contains approximately 44,819 square miles (116,083 km^2) of land area. Pennsylvania is nearly 60 percent forested and is composed of a variety of ecosystems including highly urbanized in the east, agricultural in the center, and large areas of contiguous forest in the mountainous regions in the north and west.

METHODS

Each FIA plot consists of four circular 48 ft (14.6 m) diameter subplots, with one subplot located in the center and three equidistant subplots distributed symmetrically around and located 120 ft (36.6 m) from the center subplot. The subplots occupy 0.17 acres (0.07 ha), and the subplot array can be subtended by a circle of 1.5 acres (0.6 ha) in area. On each plot, information for several site factors (including ownership, forest type, land use, slope, and others) are collected, as well as data on individual trees, including species, diameter at breast height, total height, and the relative canopy position of each tree (classified as dominant, codominant, overtopped, intermediate, and open grown). Tree data are collected in the field on portions of plots that are classified as "accessible forest," which is defined in part as belonging to a group of trees at least 0.4 ha in extent and at least 37 m wide at its narrowest point, being capable of natural tree regeneration, and having a minimum stem count (stocking), dependent on species and tree size (USDA Forest Service 2011). All data are stored in a relational database.

Using information found in and tools associated with the relational database, total volume, total aboveground carbon, total basal area, average tree height, and average diameter-weighted height were computed for each combination of species, canopy position class, and forest type. About 1500 single condition plots—those that are 100 percent forested land use—were used in the analysis. Some plots were omitted based on LiDAR data quality (outliers were removed with heights three standard deviations above the mean height).

The statewide LiDAR dataset was processed using the Toolbox for LiDAR data Filtering and Forest Studies (TiFFs) (Chen et al. 2007). The .LAS LiDAR files were provided in a preprocessed format with ground and canopy returns identified by the PAMAP vendor. One-foot (0.3-m) resolution Digital Elevation Models (DEMs) were generated using these predefined classifications. The LiDAR point cloud was then spatially intersected with each FIA plot location and clipped to spatial extent of each subplot. Data from each subplot were aggregated to the plot-level and standard LiDAR-derived statistical parameters (mean and quadratic mean, standard deviation, skew, kurtosis, and decile heights) and the LiDAR derived Canopy Height Profile (CHP) parameters (Skowronski et al. 2011) were generated using only first returns for each plot.

PROPOSED ANALYSES

To characterize relationships between LiDAR cloud metrics and FIA data, exploratory data analysis will be performed, including the generation of correlation and scatterplot matrices relating the independent variables (the LiDAR metrics) to various subsets of the FIA data, including subsets of the data by species, species group, forest type, geographic area, and canopy position class. The goal of these analyses will be to gain a better understanding of inter- and intra-variable group relationships, and to inform decisions for and interpret results of the second phase of the project: carbon model development. For this phase, all subsets linear regression will be performed to generate a suite of carbon models and associated fit statistics and error assessments, with the goal of obtaining predictive models that can be applied to large areas of Pennsylvania. Finally, based on results of the first two phases, a sample design study will be performed. FIA generates estimates of forest parameters using a post-stratification statistical design (Bechtold and Patterson 2005) using strata created from classified Landsat images. We plan to generate a stratum map using LiDAR canopy maps instead of Landsat and calculate various estimates of forest parameters. We also plan to subdivide the LiDAR dataset by generating "strips" of LiDAR over the FIA plot locations and over several randomly selected areas with no FIA plots, to generate estimates using a double sampling (two phase sample) design. Finally, we plan to implement the regression estimator using the appropriate model(s) from phase 2 of the study. We will then compare all of the resulting estimates in terms of relative efficiency, or the improvement in sampling error relative to that achieved by a simple random sample. Of particular interest will be an assessment of the relative costs and benefits of acquiring and processing the LiDAR information (versus standard methods using less costly combinations of plots and Landsat imagery) and the development of a decision framework for the use of LiDAR in large area inventory applications (Kohl et al. 2011).

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