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Silvilaser 2019
Iguazu Falls - Brazil
8-10 | october| 2019

Proceedings

Luiz Carlos Estraviz Rodriguez, *Ed.*

To access video-playlists of the presentations, click:

Day 1 | Day 2 | Day 3

Instituto de Pesquisas e Estudos Florestais – IPEF
Piracicaba, SP – Brasil

Iguazu Falls – Brazil

October | 8-10 | 2019

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Summary

Welcome to Silvilaser 2019

Welcome to SilviLaser 2019, hosted for the first time in Latin America, and close to one of the most spectacular wonders of nature, the Iguazu Falls, in Brazil. This is the 16th international conference in a series focusing on LiDAR applications for assessing and managing forest ecosystems. The conference brings together scientists, students and LiDAR users from around the world to share their experience in the development and application of laser scanning techniques to improve our understanding of forest ecosystem functioning and facilitate their sustainable management through improved forest assessment and inventory. It also aims to strengthen and develop new linkages between researchers, data providers, and product users.

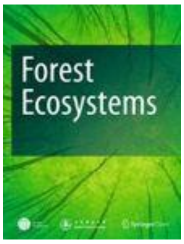
History of SilviLaser

SilviLaser 2019 is the 16th conference in a series focused on the applications of LiDAR and related technologies for assessing and managing forest ecosystems. The conference has allowed scientists and practitioners from around the world to share their experience in the development and application of LiDAR to improve our understanding of forest ecosystem structure and function and to facilitate sustainable forest management through (a) improved forest assessment and inventory and (b) enhanced silviculture decision making. From 2002 to 2017, many countries in four different continents have hosted Silvilaser conferences. Brazil has the privilege to become one of the twelve countries in the list. The chronological sequence of conferences has unfolded as follows:

2002	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*
Brisbane **Australia**	Victoria **Canada**	Umea **Sweden**	Freiburg **Germany**	Blacksburg **USA**	Matsuyama **Japan**	Espoo **Finland**	Edinburgh **UK**

2009	*2010*	*2011*	*2012*	*2013*	*2015*	*2017*	*2019*
College Station **USA**	Freiburg **Germany**	Hobart **Australia**	Vancouver **Canada**	Beijing **China**	Grande-Motte **France**	Blacksburg **USA**	Iguazu Falls **Brazil**

Call for Papers



Forest Ecosystems

Springer, ISSN: 2197-5620
https://forestecosyst.springeropen.com/

Special call for Thematic Series

Laser scanning in Forest Ecosystems

Forest Ecosystems is an open access science journal focusing on the structure and dynamics of natural and domesticated forest ecosystems. We welcome original and innovative science, and interesting contributions that highlight the important role of forests in soil and water conservation, economic development, and the global climate. The publication cost for manuscripts that are accepted for publication in Forest Ecosystems are still covered by the Beijing Forestry University.

Submissions: https://www.editorialmanager.com/fecs/default.aspx
Deadline for manuscript submissions:29 February 2020
Guest Editor:

Luiz Carlos E. Rodriguez (lcer@usp.br)
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134180-900 Piracicaba, SP - Brazil

Scientific Data

Macmillan, ISSN: 2052-4463
https://www.nature.com/sdata/

Special call for Datasets

Open access of LiDAR data in Forestry

Scientific Data is a peer-reviewed, open-access journal for descriptions of scientifically valuable datasets, and research that advances the sharing and reuse of scientific data. To publish in *Scientific Data* authors are required to pay an article-processing charge (more info: www.nature.com/sdata/about/oa). All content-types are published under a Creative Commons Attribution 4.0 International License (CC BY). *Scientific Data* primarily publishes Data Descriptors, a new type of publication that focuses on helping others reuse data, and crediting those who share. Before submission, authors are asked to deposit their data to a trusted data repository and to release their data to the public under open terms of use at the time of publication.

Submissions: https://www.nature.com/sdata/publish
Deadline for manuscript submissions: 29 February 2020
Special Issue Editor:

Jingjing Liang (jjliang@purdue.edu)
Department of Forestry and Natural Resources, Purdue University
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West Lafayette, IN 47906, USA

Field Trip

Attendees of Silvilaser 2019, separated in two different visiting groups, choose to participate in field activities not mutually exclusive.

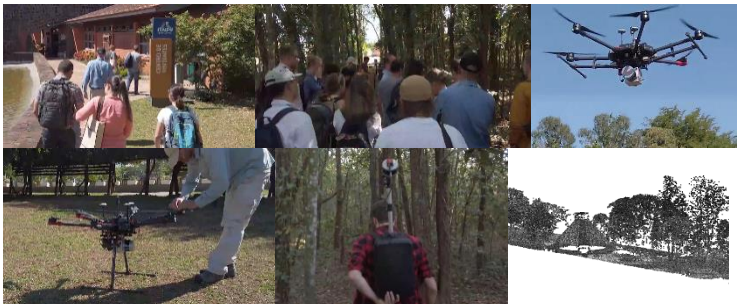
Visit to the Itaipu Hydroelectric Power Plant

This group visits the Itaipu Hydroelectric Power Plant, one of the largest operating hydroelectric projects in the world in terms of annual energy generation (14 GW), second only to Three Gorges in China (22.5 GW). The visit to the hydroelectric plant is limited to a group of 80 participants, and takes approximately two hours.

Source: Itaipu Binacional (https://www.itaipu.gov.br/energia/vertedouro, Oct 26 2019)

Visit to the Bela Vista Itaipu Biological Refuge

This group joined LiDAR laser scanning demonstrations on riparian native forests close to the Itaipu water reservoir. Developed in partnership with a team of researchers from the Bela Vista Itaipu Biological Refuge, the field trip involved the use of terrestrial mobile and UAV platforms to produce point clouds and create 3D maps of the vegetation at the Biological Refuge.



Dual visit to the Power Plant and Biological Refuge

Attendees can register for both activities. Participants that have chosen to do both visits will join the second group after the visit to the dam.

Program Overview

<table>
<tr><th rowspan="2">Day</th><th colspan="25">Sessions</th></tr>
<tr><th>0800</th><th>0830</th><th>0900</th><th>0930</th><th>1000</th><th>1030</th><th>1100</th><th>1130</th><th>1200</th><th>1230</th><th>1300</th><th>1330</th><th>1400</th><th>1430</th><th>1500</th><th>1530</th><th>1600</th><th>1630</th><th>1700</th><th>1730</th><th>1800</th><th>1830</th><th>1900</th><th>1930</th><th>2000</th></tr>
<tr><td>Oct 08</td><td colspan="3">Registration
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Opening</td><td colspan="3">Keynotes
KN1</td><td>Break</td><td colspan="2">Parallel Sessions
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D1B1R2</td><td colspan="3">Lunch</td><td colspan="4">Parallel Sessions
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B1B3R1
B1B3R2</td><td colspan="4">Icebreaker /
Posters</td></tr>
<tr><td>Oct 09</td><td colspan="6">Keynotes
KN2</td><td colspan="3">Posters</td><td colspan="2">Lunch</td><td colspan="10">Field trip</td><td colspan="2">Posters</td><td colspan="2">Dinner</td></tr>
<tr><td>Oct 10</td><td colspan="4">Keynotes
KN3</td><td>Break</td><td colspan="4">Parallel Sessions
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D3B1R2</td><td colspan="3">Lunch</td><td colspan="4">Parallel Sessions
D3B2R1
D3B2R2</td><td>Break</td><td colspan="4">Parallel Sessions
D3B3R1
D3B3R2</td><td colspan="4">Farewell</td></tr>
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Invited Talks

Michael Keller
US Forest Service

Understanding management, degradation, and regeneration of forests in the Brazilian Amazon using LiDAR remote sensing

Deforestation rates in Brazil have decreased by about 70% since 2004 but forest degradation processes including logging, fire, and fragmentation continue to change forest structure and deplete carbon stocks. Airborne LiDAR remote sensing provides a window on forest changes whether from natural processes such as droughts, deliberate management such as reduced impact logging, or unmanaged human induced destruction through predatory logging and fire. In this talk, I will present examples from a wide range of forest sites collected by the Sustainable Landscapes Brazil program, a partnership operated by the US Forest Service and EMBRAPA. As a sidelight, I will also tell how Sustainable Landscapes Brazil engaged a large community of Brazilians practitioners and researchers in forest studies and management. I highlight how LiDAR helps us to understand the ecological processes in dynamic frontier forests and examine what we can learn from LiDAR to manage the future of tropical forests.

Ralph Dubayah
Univ. of Maryland

The first glimpse at GEDI data that will help us produce the first three-dimensional map of the world's temperate and tropical forests

For over 50 years NASA, along with other international space agencies, has supported important scientific and policy issues related to the present and future states of the Earth's carbon and water cycles, its climate, its habitat suitability, and other ecosystem services using a constellation of Earth-orbiting satellites. The most direct and accurate way of obtaining vegetation three-dimensional structure and its above-ground carbon content is through LiDAR remote sensing. The Global Ecosystem Dynamics was selected as part of NASA's Earth System Science Pathfinder (ESSP) Earth Ventures 2 (EV-2) competition. GEDI was launched from Cape Canaveral, Florida in the Dragon capsule of SpaceX CRS-16 on board of a Falcon 9 rocket and subsequently installed on the Japanese Experiment Module-Exposed Facility (JEM-EF) in December of 2018. Using its three lasers, GEDI provides billions of observations of vegetation vertical structure over the Earth's temperate and tropical forests. GEDI LiDAR observations are the first set of space-borne measurements from an instrument specifically designed to measure vegetation structure. In this talk, I provide the GEDI mission scientific goals and objectives, explain its rationale within a context of carbon balance and biodiversity and next I present the GEDI LiDAR instrument, its measurement capabilities, and some early results.

Svetlana Saarela
SLU

Treating LiDAR-based predictions as pseudo-field data: possibilities and pitfalls

Among the variety of remote sensing (RS) data types, LiDAR data have been shown to be strongly correlated with forest attributes such as volume and biomass. The strong correlation makes it possible to treat LiDAR-based predictions as pseudo-field reference data, which in turn can be used to train models linking forest attributes with other types of remote sensing data. Such a setup allows for forest surveys in remote areas at minimal fieldwork effort. Thus, the use of sample LiDAR data in an intermediate step of model-based large-area forest surveying offers many possibilities. But there are also pitfalls. An obvious one is that all sources of uncertainty are not accounted for when overall uncertainty metrics are computed. For example, if the uncertainty in the LiDAR to field data modeling step is ignored the overall variance of mean biomass estimators may be substantially underestimated; a recent study suggests that the underestimation may amount to 70%. With hierarchical model-based (HMB) inference it is possible to handle all sources of modeling uncertainty in an appropriate way in this type of surveys.

Jean P. Ometto
INPE

LiDAR and broad-scale forest biomass estimates in the Amazon

Estimates of biomass and carbon for the Amazonian biome has been the object of several studies. The studies have used different approaches, methodologies, and data. INPE's Earth Science Center has supported research meant to improve the accuracy of these estimates. With resources from the Amazon Fund, 950 non-overlapping LiDAR airborne strips (300 m wide by 12.5 km long, 375 ha each), and 50 hyperspectral transects were obtained and processed to generate a new set of estimates for biomass and carbon in the Amazon. Some of these transects were targeted to cover areas in which forest inventory sample plots had already been measured. This talk will present the percentage of forest types covered by the assessment and comment about the allometric equations used, the biomass and carbon estimation at the field plot level, the selection of LiDAR metrics and model fitting, and the use of complementary satellite images to extrapolate estimates to the whole Amazonian region.

William Kim
Leica

Optimizing the selection of LiDAR technology for forest data collection

With the availability of multiple LiDAR technologies, it can be challenging to optimize the choice. Each technology must be configure to work at peak performance toward a specific result. In this presentation, I discuss linear and single photon mode for specific applications, including optimal settings for a variety of forest-related missions.

Matheus Nunes
Univ. of Cambridge

Repeat-LiDAR survey reveals the primary tropical forests are most impacted by El Niño drough

Droughts associated with El Niño events can lead to leaf loss, tree mortality and lower productivity in tropical rain forests, but what remains unclear is how and why drought impacts vary across tropical landscapes. We used repeat airborne LiDAR surveys conducted before and after the strong El Niño event of 2015-16 in Malaysian Borneo to produce high-resolution maps of canopy height change across 25,000 ha of a human-modified tropical landscape. Using a combination of LiDAR surveys, topographic models, field measurements of aboveground biomass change and microclimate, we found that tall forest canopies on hilltops shrunk by an average of 0.6 ± 0.3 m following the El Niño whereas regenerating forests in valleys grew 1 ± 0.2 m. Long-term tree census and Leaf Area Index data revealed that canopy loss in canopy height was primarily driven by leaf shedding rather than tree mortality, which is consistent with a short-term physiological response owing to increased water pressure deficit. This study has uncovered environmental controls on forest canopy dynamics over unprecedented scales and demonstrated the power of repeat airborne LiDAR to understand forest responses to extreme climatic events.

Eben N. Broadbent
Univ. of Florida

LiDAR and hyperspectral data fusion for ecological mapping using the GatorEye Unmanned Flying Laboratory

I provide an overview of how unmanned aerial vehicles fit into a framework for ecological mapping in tropical forests, discussing potential synergism among new satellites (e.g., Planet, GEDI), airborne systems, and drone platforms. I will describe the University of Florida’s GatorEye Unmanned Flying Laboratory, a newly developed system integrating simultaneous co-aligned LiDAR, upward and downward facing hyperspectral, radiometric thermal, and visual sensors. Following a discussion of hardware and technical specifications of the sensors, and software post-processing and integration approaches, I will discuss how they contribute to ecological mapping of different key forest parameters and how their combination through fusion algorithms results in significantly greater ecological insights. To provide context and examples, I will describe a variety of projects, associated field campaigns, and processing approaches that use the GatorEye, as well as other platforms. I will conclude with a discussion of future research directions, both in terms of hardware and processing algorithms, but especially questions related to conservation biology, ecology, and archeology.

Tiago de Conto
ForLiDAR

Mobile Laser Scanning - towards a new standard for forest inventory

An overview will be given on the evolution of Terrestrial Laser Scanning, point cloud processing techniques and tools for getting accurate tree-wise information, focusing on how terrestrial laser surveys are now scalable for large operational applications, thanks to the current stage of Mobile Laser Scanning (MLS) systems. MLS has shown its potential for replacing the traditional forest inventory strategies by applying (semi) automated approaches based on cutting edge technology, from fieldwork to data analysis. By mixing portable LiDAR sensors and state of the art cloud co-registration algorithms, fast and accurate MLS surveys are now possible regardless of auxiliary GNSS. The current possibilities of MLS applied to both planted and natural forests monitoring will be discussed in depth, bringing up the main challenges and opportunities that arise from it on the perspective of precision forestry, LiDAR-based technologies, data processing techniques, and software development.

Martin Isenburg
LAStools

Tales of a Rascal (Scientist): What I Did for Love (of Points)

As a sequel to the story told at the 2012 Vancouver Silvilaser conference, the presentation now shifts towards the nomadic on-site development of the LAStools suite for point cloud processing. Subtly rich in human and technical aspects, the saga spans seven years of experiences with users in different parts of the world. The challenge of merging rebel flexibility with lovely perfectionism spices the story. The talk covers some key events that have spurred the development of new tools and features, and how these outcomes have supported and inspired others. The point of view is that of a scientific-minded, nature-loving vagabond who pursues a make-it-up-as-you-go mashup of technical challenges and personal passions in the complex landscapes of a world described by every denser and richer point clouds. The narrative will also paint a picture of where this odyssey might be heading and how forest managers, educators, environmental scientist, and remote sensing researchers may benefit from or can participate in its future.

Oral Presentations

SLS016D1B1R1

The Past, Current and Future Vision for NASA Research on Forest Ecosystem Structure and Function from Space

Margolis, Hank; Falkowski, Michael
(michael.falkowski@nasa.gov / NASA Terrestrial Ecology Program)

The National Academies of Sciences, Engineering, and Medicine decadal survey, Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space (2018) laid out a strategy for defining and attaining NASA's Earth observation priorities for the coming decade. Ecosystem change is a "most important" priority and one of the main science questions that will be addressed is, "What is the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space?". Both lidar and radar technologies will likely play a critical role in addressing this question over the coming decade. This talk will explain the current status of forest structure research at NASA and the decadal survey priorities for the future. We will highlight the portions of the decadal strategy that are relevant to lidar applications. For example, a Surface Topography and Vegetation (STV) Incubator initiative responds to a request to accelerate the readiness of high-priority STV observables not yet feasible for cost-effective flight implementation in the 2017-2027 timeframe. We seek to develop new approaches and architectures for high-resolution global topography including bare surface land topography ice topography, vegetation structure, and shallow water bathymetry from space. *NASA, decadal survey, forest structure, ecosystem change*

SLS145D1B1R1

Adopting GEDI's algorithms for estimating forest aboveground biomass with ICESat-2

Duncanson, Laura; Neuenschwander, Amy; Silva, Carlos A. ; Hancock, Steven; Armston, John; Fatoyinbo, Lola; Simard, Marc; Thomas, Nathan; Kellner, Jim; Hofton, Michelle; Luthcke, Scott; Dubayah, Ralph
(lduncans@umd.edu / University of Maryland)

Two new NASA spaceborne lidar missions, GEDI and ICESat-2, were launched in the fall of 2018. While GEDI is the first spaceborne lidar specifically designed to study Earth's forests, ICESat-2 will collect useful supplementary data, and the fusion of these two datasets will enable the production of a global forest aboveground biomass map representative of 2019-2021 conditions. While GEDI's forest biomass algorithms are based on decades of research using full waveform lidar to estimate forest structure, ICESat-2's green laser photon counting measurement approach has yet to be fully explored for biomass applications. A 2016 NASA Carbon Monitoring System (CMS) project was funded to explore strengths and limitations in these two lidar systems, for fusion with the upcoming L-band SAR NASA/ISRO NISAR mission. This research focuses on three structurally complex forest systems; 1) Sonoma County, California, 2) Gabon, Africa, and 3) La Selva, Costa Rica. These sites represent wide gradients in biomass and canopy cover with high biomass densities. GEDI and ICESat-2 are simulated using existing ALS data in each of these sites, and global biomass algorithms developed for GEDI using a pre-launch calibration strategy are explored for application to ICESat-2. The errors in biomass estimation are explored as a function of canopy height, percent canopy cover, and topography to understand the relative limitations of each lidar mission across the three ecosystems. We also explore several data fusion algorithms for improved and higher resolution biomass mapping than is possible with any one mission dataset. While GEDI has the highest accuracies in tall, dense forests, ICESat-2 has good performance provided the laser and processing algorithms are capable of accurately resolving the ground, which is the case in all but the densest forests. This research demonstrates the potential strengths of ICESat-2 data for forest biomass mapping. ICESat-2 provides complementary forest structure data to GEDI, filling important spatial gaps such as the boreal, and increasing the structural sample of the landscape in tropical and temperate systems. Fusion of these data streams with higher resolution data such as from the upcoming NISAR mission will further improve biomass maps and enable high resolution wall-to-wall mapping at a global scale. *GEDI, ICESat-2, Biomass, Fusion*

SLS148D1B1R1

Global products of slope-adaptive waveform metrics of large footprint LiDAR over forested areas

Ni, Wenjian; Dong, Jiachen; Zhang, Zhiyu; Wang, Yao; Sun, Guoqing
(niwj@radi.ac.cn / Chinese Academy of Sciences)

Large footprint lidar has been widely used in the estimation of forest aboveground biomass and canopy height over relatively flat terrain conditions (Sun et al. 2008). The effect of terrain slope on large footprint lidar waveforms is still a great challenge to the accurate mapping of the forest aboveground biomass (AGB), although previous studies have made significant progress for use of lidar waveform data at slopes lower than 15°. There will be several systems of large footprint lidar, such as the GEDI (Hancock et al. 2019), MOLI, China's Gaofen-7 and terrestrial ecosystem carbon monitoring satellites although the Geoscience Laser Altimeter System (GLAS) has stopped working since 2009. There is still urgent need to conquer the broadening effects of terrain slope on lidar waveforms. It is well known that the typical relative height metrics of waveform metrics takes the ground peak as references. We have proposed a new set of slope-adaptive waveform metrics of large footprint lidar, where the effects of slope on the metrics are significantly reduced by referencing to the calculated waveform of bareground with the terrain slope of the lidar footprint (Wang et al. 2019). The lidar waveform of bare ground is firstly calculated using the proposed model. The real forest waveform and its corresponding calculated bare ground waveform are then aligned by the signal ending points. Their energy quartiles are extracted separately by taking the signal ending points as references. The height differences between the corresponding energy quartiles are defined as slope-adaptive waveform metrics. The new metrics has been demonstrated to work well, especially over mountainous area or dense forested areas, where the ground peak is too weak to be detected. We will show the effectiveness and weakness of the new waveform metrics over different terrain conditions as well as different forest types. The performance of new waveform metrics from GEDI will also be shown if the waveform data is publicly available before the meeting. The global products of slope-adaptive waveform metrics of GLAS will be announced to release on the meeting.

TLS045D1B1R2

On separating wood from leaves, accounting for leaf angle distribution, and occlusion effects in terrestrial LiDAR scans of dense forests

Beland, Martin; Tremblay, Jean-Francois
(martin.beland@scg.ulaval.ca / U Laval)

Terrestrial laser scanning (TLS) has shown to provide non-destructive and time efficient means of estimating tree-level biomass and map the 3D distribution of foliage. To both ends, distinguishing laser returns generated from leaves and wood is an important processing step. For mapping 3D foliage distribution, using the correct leaf angle distribution function and minimizing the level of occlusion in the data are very important, as the product of the mapping process enables simulations of intercepted and reflected light. Leaf angles significantly affect the radiative transfer, and occlusion effects results in "holes" in a given virtual forest model through which simulated photons can pass even if material is present in those occluded areas of the actual forest. Here we present results from extensive TLS surveys performed at 4 field sites in the USA and Malaysia using a Riegl VZ-400 instrument. The plot size at each site is 60m x 60m, and scans are done using a grid pattern at every 5m, totaling 121 scan positions per site. We compare leaf-wood separation methods based on reflectance alone and deep learning to assess the gain obtained from using a deep learning approach. We also investigate the distribution of occluded areas at each site by using a ray tracing model on a voxel grid. The effect of using leaf angle distributions which do not fit the field measured distributions on leaf area retrievals is discussed. These results inform on appropriate field protocols and data processing methods to adopt for the purpose of mapping leaf area in dense forests from TLS.

Terrestrial LiDAR, leaf area mapping, occlusion, leaf-wood separation, leaf angle

TLS132D1B1R2

Using multispectral terrestrial LiDAR for early detection of tree decline - from leaf water content to fine structural details

Junttila, Samuli; Holopainen, Markus; Vastaranta, Mikko; Linnakoski, Riikka; Lyytikäinen-Saarenmaa, Päivi; Hyyppä, Juha

(samuli.junttila@helsinki.fi / University of Helsinki)

Climate change is causing novel stress to forests that is difficult to predict. Information on forest health has been identified as one of the key information gaps in evaluating the effects of climate change. The mapping of small-scale forest disturbance events is largely based on visual observations which is time-consuming and prone to error especially in the early stages of tree decline. Thus, new methods for objective estimation of tree decline are required. Multispectral LiDAR can provide highly detailed measurements of tree structure and reflectance simultaneously enabling novel approaches for the detection of tree stress. Over the last four years, we have developed a novel remote sensing method for detecting and evaluating tree decline using multispectral terrestrial LiDAR. The developed methods are based on utilizing LiDAR intensity data and the sensitivity of the used wavelengths to varying leaf water content (LWC). Thus, we have also investigated the relationship between LWC and various disturbance symptoms in different environments to determine the optimal LWC metrics for detecting tree stress. We found that multispectral LiDAR can detect and assess tree decline of single trees with high accuracy in our test forest that was infested by Ips typographus (L.) and its fungal symbionts. The developed methods showed potential in discriminating between healthy and stressed trees already in the early stages of tree decline when the foliage did not show visual symptoms. Therefore, the methods could provide new means for objective assessment of early tree decline allowing improved estimation, prediction and mitigation of forest damages.

Tree health, TLS, leaf water content, tree decline, ips typographus

SLS015D1B2R1

GEDI's potential to map structural diversity of plant canopies – a case study in the Sierra Nevada mountains in the Sierra Nevada mountains

Schneider, Fabian; Ferraz, Antonio; Duncanson, Laura; Dubayah, Ralph; Hancock, Steven; Pavlick, Ryan; Schimel, David

(fabian.schneider@jpl.nasa.gov / Jet Propulsion Laboratory)

NASA's Global Ecosystem Dynamics Investigation (GEDI) is currently mounted on the International Space Station acquiring near global data over the Earth's temperate and tropical forests between 50 degree north and south. Besides the main goal to provide the first large-scale contiguous biomass map, GEDI provides a range of structural traits that can be used to describe the diversity of plant canopies structure, a key attribute for mapping and monitoring biodiversity. However, GEDI samples the landscape with 25 m footprints, spaced at 60 m along track and 600 m across track. Therefore, it is not known how well GEDI will capture diversity patterns, for example as compared to wall-to-wall airborne laser scanning (ALS) with several laser pulses per meter squared. In this study, we investigate the potential of GEDI to map structural diversity by comparing structural traits, trait relationships and diversity patterns derived from high resolution ALS data to simulated GEDI data. NASA's Airborne Snow Observatory covered an exceptional 7380 km2 of the Southern Sierra Nevada mountains, California, with ALS during summer 2017, which we used to simulate over half a million GEDI pulses following realistic scan patterns simulated over the course of two years (GEDI's expected

operation time). GEDI's canopy height, foliage height diversity and plant area index related metrics compared reasonably well to ALS traits and trait relationships are generally maintained. This shows the potential of GEDI to capture structural diversity based on traits, and will allow us to compare diversity metrics derived from trait space analysis at landscape scale (≥1km2). We will show whether the sampling of GEDI resolves similar diversity patterns than ALS and how sampling density influences the results.

GEDI, biodiversity, simulation, vegetation structure, functional traits

SLS026D1B2R1

Exploring the potential of GEDI-derived canopy structure for mapping tree species diversity in the tropics

Marselis, Suzanne; Tang, Hao; Armston, John; Hancock, Steven; Minor, David; Duncanson, Laura; Fitzpatrick, Matt; Hansen, Matt; Dubayah, Ralph

(marselis@umd.edu / University of Maryland)

Mapping tree species diversity is of utmost importance to enable effective conservation and biodiversity management and allow for a better understanding of scale-dependent relationships between forest composition and productivity. Large-scale estimates of tree species diversity are traditionally based on environmental variables such as precipitation, temperature and soil type, but only limited information on the vegetation itself has been incorporated. In this study, we explore a structure-diversity hypothesis in the tropics by relating canopy structural information derived from full-waveform LiDAR data to field information on tree species diversity. The exploitation of full-waveform LiDAR data is of particular importance given the recent launch of the Global Ecosystem Dynamics Investigation (GEDI). GEDI is the first spaceborne LiDAR instrument specifically optimized to measure canopy structure and the GEDI data may allow for mapping tree species diversity if a structure-diversity relationship can be established. In this study we make use of GEDI waveforms simulated from airborne LiDAR data, coincident with field plot information on tree species. LiDAR waveforms were processed to provide information on Canopy height (RH99) and on the vertical canopy structure through Plant Area Volume Density (PAVD) profiles. Canopy height is a proxy for forest volume which may indicate the available niche space, while the PAVD profile is a measure of the amount of plant material along the vertical profile (in 5 m bins) and may provide information on the occupation of the available niche space. We calculated two measures of tree species diversity from field plots: the Shannon diversity index and the total number of species per plot. We then explored the relationship between structure and diversity for study sites across the tropics. We then evaluated the applicability of this relationship to GEDI waveforms. Our results suggest the usefulness of forest structure observations from GEDI LiDAR to better understand the distribution and drivers of tree species diversity across the tropics.

GEDI, biodiversity, tropical forest, canopy structure, tree species richness

SLS104D1B2R1

Forest degradation assessment in Tropical Dry Forests: a comparison of IceSat 2, UAV and ground-based observation data

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The degradation of the world's forests has major impacts on the provided ecosystem services and functions. Monitoring of forest degradation is therefore important, but challenging. This is particularly true for the tropical dry forest in the Argentinian Chaco, where several different land use practices (e.g. agricultural expansion, selective logging, charcoal production and overgrazing inside the forest) strongly influence the forest structure. While extensive research has focussed on changes in humid equatorial forests, little attention has been paid to subtropical woodlands and open forests and monitoring these ecosystem is a research priority. In contrast to forest conversion is forest degradation a gradual process through which the forest's biomass declines, its species composition changes and the vertical complexity alters. In the presented work we assess the Dry Chaco forest structure degradation based on three different data layers, such as

A) the newly released data from the ICESat-2 mission, B) UAV-derived point clouds and structure from motion data products (e.g. vegetation height model with a spatial resolution of ~ 10*10cm) and C) ground-based forest monitoring plots. Each monitoring plot includes four sets of concentric circular plots of 1.000 m² (all trees with a trunk diameter >20 cm measured) and 500 m² (all trees with a trunk diameter >10 cm measured). Our preliminary results highlight the fact that in large areas across the Argentinean Dry Chaco forests are highly degraded. ICESat2 photon data and UAV derived canopy elevation estimates correlate mostly well but show above average deviations in more complex forest structures. The comparison to the individual tree sizes, measured on the ground, requires a further spatial aggregation trials of the data in order to carry out the adequate comparison. More broadly, our work represents a step towards better understanding forest degradation in the Dry Chaco and suggests considerable potential of ICESat2 data and UAV derived degradation indices for addressing and monitoring forest degradation in tropical dry forests.

Forest degradation, Tropical Dry Forests, ICESat2, UAV, ground-based observation

SLS121D1B2R1

Ground and Top of Canopy Extraction from ICESat-2 Data in the South of China

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Accurate estimation of forest height and biomass is critically important for understanding the regional and global carbon cycle and dynamic changes. Successful mapping of critical forest parameters using NASA's GLAS (the Geoscience Laser Altimeter System) onboard the ICESat (Ice, Cloud and land Elevation Satellite) mission showed its potential in vegetation studies. ICESat-2, which is the next generation of ICESat missions, has been launched in September 2018. In contrast to the previous waveform LiDAR system, ICESat-2 adopted a newly designed LiDAR system named ATLAS (Advanced Topographic Laser Altimeter System), a micro-pulse, multi-beam photon counting LiDAR system working at 532 nm. From the currently released data products from the satellite, the photon counting approach introduced abundant noise appearing in the atmosphere and even below the ground, making it difficult to extract the correct canopy and ground surface in vegetation area. A few studies have been done to detect the noise and separate the signal using pre-validated data, such as a spatial statistical detection algorithm based on discrete mathematical concepts, an ellipse search area based on DBSCAN (Density-Based Spatial Clustering of Applications with Noise) and an automated algorithm using the cumulative density of photons to identify cut off points of canopy top and ground. In this study, an approach which is capable of identifying potential forest signal photons by using local outlier factor (LOF) algorithm modified with an ellipse searching area is proposed for ICESat-2 data. Three datasets from ICESat-2 in Yunnan and Guangxi of China are used to test and evaluate the performance of our algorithm. The classification results for noise and signal photons showed our approach has a good performance not only in lower noise rate with relatively flat terrain surface but also works even for a quite high noise rate environment in relatively rough terrain. The quantitative assessment indicates that the horizontal ellipse searching area gives the best results compared with the circle or vertical ellipse searching area. These results demonstrate our methods would be useful for ICESat-2 vegetation study.

ICESat-2, photon data, filtering, forest parameter, China

SLS143D1B2R1

Synergy of ICESat-2 and Landsat optical imagery data for mapping forest aboveground biomass with deep learning

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Spatially continuous estimates of forest aboveground biomass (AGB) are essential to supporting the sustainable management of forest ecosystems and providing invaluable information for quantifying and monitoring terrestrial carbon stocks. The launch of the Ice, Cloud, and land

Elevation Satellite-2 (ICESat-2) on September 15th, 2018 offers an unparalleled opportunity to assess AGB at large scales using along-track samples that will be provided during its three-year mission. The main goal of this study was to investigate deep learning (DL) neural networks for mapping AGB with ICESat-2, using simulated photon-counting lidar (PCL)-estimated AGB for daytime, nighttime and no noise scenarios, Landsat imagery, canopy cover and land cover maps. The study was carried out in Sam Houston National Forest located in south-east Texas, using simulated PCL-estimated AGB along two years of planned ICESat-2 profiles. Primary tasks were to investigate and determine neural network architecture, examine hyperparameter settings and subsequently generate wall-to-wall AGB maps. A first set of models were developed using vegetation indices calculated from single-date Landsat imagery, canopy cover and land cover, and a second set of models were generated using metrics from one year of Landsat imagery with canopy cover and land cover maps. To compare the effectiveness of final models, comparisons with Random Forests (RF) models were made. Deep neural network (DNN) models achieved R^2 values of 0.42, 0.49 and 0.50 for the daytime, nighttime and no noise scenarios respectively. With the extended dataset containing metrics calculated from Landsat images acquired on different dates, substantial improvements in model performance for all data scenarios were noted. The R^2 values increased to 0.64, 0.66 and 0.67 for the daytime, nighttime and no noise scenarios. Comparisons with Random forest (RF) prediction models highlighted similar results, with the same R^2 and RMSE range (15-16 Mg/ha) for daytime and nighttime scenarios. Findings suggest that there is potential for mapping AGB using a combinatory approach with ICESat-2 and Landsat-derived products with DL. *LiDAR, ICESat-2, AGB mapping, ATL08, Deep Learning*

SLS147D1B2R1

On-orbit evaluation of GEDI waveform biomass estimators

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The NASA Global Ecosystem Dynamics Investigation (GEDI) LiDAR launched to the International Space Station on December 5, 2018, and has been collecting science data since March 25, 2019. Central to the estimation of biomass from GEDI LiDAR waveforms has been the global collation and standardization of field plot inventory datasets coincident with GEDI waveforms simulated from airborne laser scanning (ALS) data. The output of this effort forms the GEDI Forest Structure and Biomass Database (FSBD), which now underpins the calibration and validation of GEDI Level 4A Footprint Aboveground Biomass Data Product (GEDI-L4A). In this talk we present a post-launch evaluation of the GEDI biomass estimators using the FSBD, the first 6 months of on-orbit GEDI science data, and independent data acquired by the NASA Land Validation and Ice Sensor (LVIS). The LVIS acquisitions were undertaken across select tropical and temperate forest sites in the United States and Central America, respectively, in May 2019 as part of the GEDI calibration and validation program. A selection of these LVIS acquisitions were collected coincident with NASA UAVSAR flights undertaken by the NASA/ISRO NISAR mission, in part to enable high spatial resolution (1 ha) wall-to-wall biomass estimation through fusion of spaceborne LiDAR and L-band SAR times-series. First we show validation of the GEDI waveform simulator against on-orbit waveform data and the impact on pre-launch regression estimators developed to generate the GEDI-L4A data product. Next we evaluate the spatial representivity of the FSBD used to train the biomass estimators using GEDI on-orbit waveform-derived height and cover metrics. Finally, we quantify the consistency of GEDI waveform biomass predictions against independent waveform LiDAR estimates from inter-mission (LVIS) and intra-mission (GEDI orbital cross-over) datasets. We discuss the results in the context of the GEDI-L4A data product post-launch calibration and release, the implications for the GEDI Level 4B Gridded Aboveground Biomass Data Product (GEDI-L4B), and next steps in the GEDI calibration and validation program. *GEDI, biomass, spaceborne LiDAR, validation*

TLS002D1B1R2

Accurate geo-referencing of trees with no or inaccurate terrestrial location devices

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Traditionally, trees are numerically described with two attributes, namely diameter at breast height and total height, which are measured with tools in contact with the stem. Alternatively, remote sensing-based technologies can supply fast and precise measurements of the same attributes, and more. However, in many instances the point clouds contain many erroneous values, particularly when created photogrammetrically. The objective of the present study is to develop an automatic procedure for estimation of the diameter along the stem form dense noisy point clouds. The procedure first identifies the axis of the tree, then divide the stem in sections perpendicular on the axis. The most important task is identification of the tree axis, executed by transforming the MLSAC algorithm. For each section, we developed an algorithm that identifies the stem points from which we estimate circumference, diameter, area, and volume. We computed circumference using the convex hull algorithm and a newly developed algorithm that separate each section in at least 30 consecutive arcs covering the cross-section of a section. The new algorithm is more accurate and realistic than current approaches, as discretizes the cross-section of the stem into arcs; therefore, not assuming a shape for the stem, such as circle or ellipse. Furthermore, the algorithm reconstructs the stem by eliminating the noise points. Ground measurements on 14 Douglas firs from Northwestern region of the USA showed that the new circumference algorithm supplies more accurate results than convex hull, with an average 2 mm errors. Using Matlab, the measurements were executed in less than 1 minute/tree. The accuracy is improved significantly for photogrammetric point clouds compared with terrestrial LiDAR, as each point contains coordinates (i.e., x, y, z) and colors.

Unmanned aerial vehicle, structure from motion, photogrammetric point clouds, tree segmentation, point-matching

TLS042D1B2R2

Comparing Terrestrial and UAV LiDAR for Monitoring Forest Structure

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Forest ecosystem functioning is linked to ecosystem structure. In the recent decade, terrestrial laser scanning (TLS) has demonstrated its ability to measure simple structural parameters such as diameter at breast height (DBH) and height, as well as more complex structural parameters like forest aboveground biomass (AGB) or the vertical distribution of plant area volume density. A TLS-driven approach supports the need for accurate, effective and nondestructive methods to assess forest structure at plot scale (typically up to 1 ha). Field inventory plots have been used consistently to extrapolate the understanding of forest structure at plot level to landscape-to-regional scales. However, this is under the explicit assumption that field plots represent their surrounding environment. Recent advancements in the development of unmanned aerial vehicles (UAVs) enables the use of LiDAR sensors from this platform, allowing 3D mapping of larger areas at a fraction of the cost of airborne LiDAR. Combining UAV and terrestrial LiDAR data can potentially be an important tool for the 3D mapping of forest structure at plot to landscape levels. We present a unique and novel high-resolution dataset of co-incident TLS and UAV LiDAR data collected in 2018 in four different tropical sites in Australia (ranging from savanna to rainforest). TLS data were collected with a RIEGL VZ-400 scanner, and UAV LiDAR (UAV-LS) data were collected with the RIEGL VUX-SYS onboard the RiCOPTER platform. Each of the sites had a 1 hectare core-plot that was scanned with TLS. High density UAV-LS (~1000-5000 pts/m2) was collected for an approximate 300 x 300 m area around the core-plot and low density UAV-LS LS (~200-1000 pts/m2) covered an area of approximately 500 x 500 m. At the Savanna site (Litchfield), we also acquired UAV-LS data from two additional commercial sensors onboard

a DJI Matrice 600 platform: Quanergy M8 and Velodyne VLP-16. Here, we will benchmark metrics derived from UAV-LS against those derived from TLS across a range of (tropical) forest ecosystems. Furthermore, we will compare three different commercially available UAV-LS sensors for mapping forest structure. This work will provide some crucial insights into the (processing) challenges of these relatively new UAV-LS datasets. One key question is: can we use and modify existing algorithms developed for terrestrial and airborne LiDAR to exploit UAV-LS data to its full extent, or do these data require their own purposely designed processing tools?

Terrestrial laser scanning, UAV LiDAR, forest structure, tropical forest

TLS057D1B2R2

Estimating fuel consumption at multiple scales from pre- and post-fire TLS and ALS

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Fire behavior, fire effects, and smoke emissions all vary spatially and temporally for a given fire and are directly correlated to spatial and temporal patterns of fuel consumption. Because of this strong correlation, spatially explicit methods are needed to map fuel consumption and inform fire science. Laser scanning data, including three-dimensional point clouds from terrestrial (TLS) and airborne (ALS), provide spatially explicit information on vegetation fuel structure with potential to significantly improve upon traditional techniques to sample fuels and consumption. By empirically relating traditional fuel measures to structural metrics derived from point cloud data, we estimated consumption of understory and overstory canopy fuel components at multiple scales, ranging from 1 m3 microplots in prescribed fire experiments to entire wildfire events. Our first prescribed fire experiment results are from Fort Jackson, South Carolina, USA, where prescribed fire consumption of understory shrub fuels was estimated from pre- and post-fire TLS data co-registered to georeferenced ALS data. To help overcome strong spatial biases in point densities due to occlusion and limited view perspectives at the finer scale of TLS, we tallied occupied voxels to estimate fuel volume, which we converted to fuel density based on destructive 3D fuel samples. At the coarser scale of ALS, where point densities are more spatially consistent, we estimated fuel densities directly using the standard, area-based approach at the 1 m2 microplot scale for ground, surface, herbaceous and shrub fuels and the 400 m2 standard forest inventory plot scale for overstory canopy fuels. At both the TLS and ALS modeling scales, we substantially improved model fit statistics and maps of fuel consumption by combining pre- and post-fire datasets into a generalized model, than by fitting separate pre- and post-fire models and differencing the resulting fuel maps. We attribute this to pooled datasets that provide twice the plot count, and span a broader range of fuel structural characteristics, than independent pre- or post-fire datasets. We conclude that TLS and ALS, and other sources of point cloud data such as photogrammetric points derived from digital aerial photogrammetry (phodar), will play important roles in spatially explicit fuel characterization, although we caution that complementary methodological development is needed to estimate consumption of ground and surface fuels. We are currently inferring total fuel consumption from fire radiative energy flux estimates derived from calibrated thermal imagery, from which ground and surface fuel consumption can be deduced, if not estimated directly from point cloud data.

Fuel consumption, prescribed fire, wildfire, TLS, ALS

TLS064D1B2R2

Optimizing TLS sampling designs for the description of understory vegetation structure

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Quantitative measurements of below-canopy vegetation structure are vital to a range of ecological, fire management and natural resource management disciplines. Estimates of below-canopy vegetation structure, including its horizontal and vertical distribution and connectivity, percentage of live and dead fuel, have been identified as important metrics for carbon accounting, wildlife habitat diversity, precision forestry, precision agriculture, fuel hazard characterization, fire behavior modelling and understory forest competition dynamics. To assess the amount and distribution of forest resources, information is gathered at various scales and for different applications. Over the past years, TLS has proven to be capable of providing precise, and non-destructive estimates of below canopy strata more than any other platform-sensor combination. A crucial consideration when gathering field measurements is determining a suitable sampling design, which ensures the collection of representative measurements. Exhaustive sampling of the forest structure to quantify understory metrics is not feasible, particularly when sampling is destructive or extremely time-consuming and costly. Instead, a sample of the larger area is assumed to be representative, and through inference can reveal something meaningful about that part of the larger area not included in the sample. The validity of this assumption depends on how well the sample captures the spatial and temporal variability of the phenomenon of interest and the level of certainty required for the study. The major issues in sample layout are (1) how to design the sample so that it represents an unbiased view of the true characteristics of the forest structure, and (2) how to draw conclusions about the true population from the results of the sample? In this study, we address these questions by obtaining and evaluating 3D structural measurements of forest across three different sites. These sites vary from open woodland to dense canopy forests. A 50m x 30m plot was located at each site, in which data was collected using TLS. In each plot, 24 scans were captured at a distance of 10 m in a grid pattern. Aim is to investigate and quantify the differences obtained when applying different sampling designs to derive plot scale values of forest structure. A variety of sampling designs such as transects (4 transects with 6 scans in each and 30 transects with 4 scans in each), systematic (15 squares with 4 scans in each, Auscover with 5 scans in each) and random sampling and methods for determining optimal sample spacing will be discussed across the sites. Preliminary results indicate that in an open woodland 7 scans 10 m apart should be enough to characterize vegetation structure. The study suggests that at least in dense canopy forests, different sampling designs will yield similar results. Consequently, the sampling strategy should ultimately be driven according to the desired spatial resolution of the final product. An area of potential research exists to find out how does sampling methods and outcomes can affect the estimation of forest fuel structure over the larger area when using localized terrestrial remote sensing. This aspect of the research represents an area of opportunity for identifying sampling strategy which can be applied to similar forest structure type by using terrestrial point clouds.

Sampling strategies, Terrestrial Laser Scanner, Vegetation structure, Forest

TLS075D1B2R2

Co-registration of ALS and TLS forestry data

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Both airborne laser scanning (ALS) and terrestrial laser scanning (TLS) are well-established acquisition technologies for forest applications. While ALS allows for forest mapping at large scales, TLS provides point clouds at a high level of detail for comparatively small areas. Hence, TLS data covering small parts of the region acquired by an ALS campaign may be useful to “calibrate” the ALS-based estimation of forest inventory parameters. For this purpose, the problem of co-registering both datasets arises. In this contribution, we investigate approaches for automatic co-registration of ALS and TLS data without the need of using signalized targets. We assume that both datasets are consistent in themselves, i.e. we already have a geo-referenced ALS project after strip adjustment and a relatively-registered TLS project (consisting of an ensemble of tens of terrestrial scans). The latter one is supposed to be well covered by the ALS data, approximately leveled, and its position with respect to the ALS data to be known up to some tens of meters in each coordinate. Hence, the task is to determine 6 degrees of freedom (3 rotation angles and 3 translation components) in order to transform the TLS data to the ALS data. The main challenge of co-registration is the different point density characteristics of both data sets (ALS: relatively low, but homogeneous point density; TLS: inhomogeneous point density being very high in the vicinity of the scan positions). This leads to the fact that single trees may be covered in a very detailed way in the TLS data, whereas some tree stems may not even be covered by the ALS data, depending on forest canopy penetration rate and scan angle of incidence. Another challenge is the fact that the tree canopy itself is scanned from opposite sides, i.e. from below (TLS) vs. from above (ALS). For this study, we use parts of flight strips stemming from a flight mission covering Vienna and its extended area acquired by the RIEGL VQ-1560i in September 2018. Within forested parts of the covered area, we use small TLS projects acquired with the RIEGL VZ-2000i in April 2019. First experiments show promising results when applying a voxel-based registration approach that makes use of an FFT (Fast Fourier Transform), of additional transformations in the spatial frequency domain and of phase correlation in order to determine the relative pose of the TLS data with respect to the ALS data.

Registration, LiDAR, ALS, TLS, FFT, voxel, forest inventory

TLS101D1B2R2

Capturing global trends in tree and forest structure with a unified terrestrial laser scanning database

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Terrestrial laser scanning has emerged as the most precise method of non-destructively estimating forest carbon stocks and will be critical in providing accurate calibration and validation datasets for current and future spaceborne missions measuring forest structure. The greatest limitation for terrestrial laser scanning in drawing global conclusions about forest structure is scalability. Here, we present a globally navigable metadata database of current terrestrial laser scanning acquisitions. This unified open data framework enables global-scale scientific inquiry into plot-level trends in forest structure. We focus specifically on the availability of tree and forest structure products, enabling researchers with non-remote sensing background to use terrestrial laser scanning for ecologically-focused questions. Using this global database, we first show the range of products available from these terrestrial laser scanning data, highlighting a specific site in Gabon with the tallest known mangrove trees in the world. Leveraging this database, we show global trends in tree structure that will be essential for the next generation of earth observation satellites.

Global database, carbon, biomass, allometry, calibration, validation, PAVD, foliage, PAI

ALS022D1B3R1

Potential of forest structural types detected directly from airborne LiDAR data in the aboveground biomass estimation

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Airborne laser scanning (ALS) produces accurate canopy information and provides best opportunities to discriminate different forest structural types and estimate the aboveground biomass over a large geographical area. We evaluated the potential of ALS based forest structural types characterization in the aboveground biomass estimation in Boreal forest in Finland. First, two L-moment ratios of ALS height distributions (L-coefficient of variation (Lcv) and L-skewness (Lskew)) were employed to capture different forest structural types directly from ALS data. Lcv=0.5 and Lskew=0 were used to separate even sized (Lcv<0.5) from uneven sized (Lcv>0.5) forest structures and oligophotic zones/closed canopies (Lskew<0) from euphotic zones /open canopies (Lskew>0), respectively. Thereafter, a separate model was developed to estimate the aboveground biomass for each forest structural type as compared to the estimation without a prior classification. A non-parametric modelling method based on the k-nearest neighbour was used to predict the aboveground biomass. And a best subset selection was used to select the ALS-derived metrics involved in the model, including additional restrictions preventing overfitting (inflation in sums of squares) and a hypothesis test on the 1:1 correspondence between observed and predicted values. Several statistical measures (RMSE,

relative RMSE, bias, relative bias, ratio: SSR) were used to evaluate their accuracies. We observed that a reduction of 8.05% in the root mean squared error (RMSE from 37.3 Mg per ha to 34.3 Mg per ha) can be obtained from the identification of areas with open canopies using Lskew>0. For other structural types, we observed no benefit, and difference were only marginal. Further research is trying to reveal relationships between these forest structural types and different, possibly confounding, components of above ground biomass. Forest structural types detected directly from ALS data have the potential to obtain improved aboveground biomass estimation which are crucial in the forest management, planning and global polices to reduce greenhouse gas emissions.

Structural classification, forest structure, aboveground biomass, k-nearest

ALS023D1B3R1

Enhancing sampling design by auxiliary information - potential of airborne laser scanning and satellite image based forest resources maps

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National Forest Inventories (NFIs) provide information on the current state of forest resources. Additionally, a NFI is a monitoring system that enables observing changes occurring in forests. Information from NFIs is used as a base for strategic planning, policy making and international reporting. As NFIs are based on field-measured sample plots, they are costly and enhancement is desired. Recently, utilization of auxiliary remote-sensed data in design-phase has been found to enhance estimation efficiency. Enhancements have been reached with a sampling method called local pivotal method (LPM), which aims at selecting balanced samples in a multi-dimensional auxiliary data space. Auxiliary data may be any data that are available for all units of population and which correlate with the target variables of the inventory. The target inventory variables were compounded productive and poorly productive forest land area, total growing stock volume, and mean growing stock volume for all tree species and tree species groups. The auxiliary data used in this study in the context of the Finnish NFI were derived from two sources: 1) multi-source NFI forest resources maps (MS-NFI), and 2) airborne laser scanning (ALS) data. MS-NFI data are wall-to-wall maps based on the field NFI data in the study region together with satellite images and other spatial data related to the land use containing forest attributes such as growing stock volume, whereas ALS data consist of several features related to height and density of forests. The results showed that both types of auxiliary data enhanced the sampling efficiency. However, the average relative efficiency over all target variables of 1.5 achieved with MS-NFI auxiliary data was higher than the corresponding value of 1.15 with the ALS data. Sample selection was more efficient on average for total growing stock volume and proportion of forested land with using the MS-NFI data than ALS data as auxiliary data whereas for the mean volume of all tree species the situation was the opposite. In addition, the estimation of species-specific volumes was the most challenging with both types of auxiliary data. The challenge in utilizing ALS data is that data acquisition of the nationwide ALS data is not planned for the viewpoint of the NFI resulting with relatively small acquisition areas whereas satellite images used in the MS-NFI enable large spatial coverage with frequent temporal availability annually.

ALS, airborne LiDAR, Local pivotal method, national forest inventory, large area inventory, remote sensing, spatially balanced sampling

ALS055D1B3R1

Influence of vegetation structure on the canopy penetration of single photon LiDAR (SPL)

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The past decades have seen the emergence of light detection and ranging (LiDAR), also known as airborne laser scanning (ALS). While traditional multi-photon LiDAR (MPL) instruments require hundreds to thousands of photons to record a return, recent innovations have led to the development of single photon sensitive detectors. These photon sensitive detector arrays, coupled with high frequency transmitted pulses enable operation of single photon LiDAR (SPL) at high altitude and give the opportunity to cover large areas and produce high-density point clouds at the same time. Despite being a promising technology, some concerns exist mainly because the instrument operates in the green part of the spectrum (532 nm). This results in an inherent lower signal to solar noise ratio and weaker vegetation reflectance compared to traditional MPL LiDAR sensors operating in the near infrared (1064 nm). Moreover, low energy pulses transmitted by SPL instruments could result in reduced canopy penetration abilities and thus fewer ground return detections. The objective of this research is therefore to examine the canopy penetration ability of SPL compared to traditional MPL across a range of forest types and structural conditions. We focus on the Romeo Malette Forest (RMF) in Ontario, Canada, where MPL (Leica ALS40) and SPL (Leica SPL100) data were acquired in 2005 and 2018 respectively. The RMF is an actively managed boreal forest of approximately 630 000 ha. The area is characterized by relatively flat terrain and poorly drained soils with forest stands composed of coniferous and hardwood species. Using the two LiDAR datasets, we investigate the influence of structural variables derived from the point clouds on the canopy penetration using random forest models. Preliminary results indicate that SPL generally has a lower laser penetration index (fraction of ground returns compared to all returns) than MPL, especially in dense canopies. However, due to its much higher pulse frequency, SPL is still able to consistently measure more ground returns per area than MPL. As an emergent and promising technology, SPL characteristics need to be assessed and compared with established MPL. This study will help to characterize this new type of data and understand how it can be used to derive high-value data products useful for many applications. *Single photon LiDAR, ALS, canopy penetration, forest structure*

NLT009D1B3R2

Transferability of ALS-derived Forest Resource Inventory Attributes between Eastern and Western Canadian Boreal Forest Mixedwoods

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Over the last decades, the use of Airborne Laser Scanning (ALS) data to predict a wide range of forest resource inventory (FRI) attributes has become more and more common practice. In most cases, FRI attribute models require locally collected field data to: i) develop the predictive model (i.e., calibration); and ii) assess the model's predictive performance (i.e., validation). The ability to expand the use of these local predictive models to larger regional scales; i.e., to developed a model at one location (the base location) and subsequently apply it at other locations (the target location(s)), may have several advantages. The adoption of a transferred model may reduce the cost and need of field data collection, increase our understanding of how forest structure is related to FRI attributes, and assess which ALS derived metrics are more universally applicable. Predictive FRI models that can be applied regionally, may capture the spatial variation in these FRI attributes at larger spatial and ecological scales, which is crucial for supporting large scale sustainable forest management and conservation efforts. The main objective of this research is therefore to test the transferability of ALS-based FRI attributes for mixedwood forest sites between the eastern and western boreal forest. The boreal mixedwood region is one of the most prevalent and productive forest regions within the boreal forest. However, it is also highly diverse, both structurally and in terms of tree species associations/composition, due to a strong east to west gradient in climate, edaphic conditions and disturbance regimes. We apply two operational approaches, i.e., Ordinary Least Squares (OLS) regressions and Random Forest (RF), to predict four FRI attributes (i.e., Lorey's height (LH), basal area (BA), gross total volume (GTV), and quadratic mean diameter (QMD). We then determine if the inclusion of calibration data from the target location site improves the performance of transferred FRI attribute models. Finally, we assess if the modelling approach and calibration data configuration affect the transferability of the FRI attributes and its accuracy at the forest type level. All modelling results indicate that the inclusion of some target location calibration data improves model performance at the transferred site. However, FRI attribute prediction accuracy varies with modelling approach, FRI attribute, and forest type. This can, in part, be explained by the differences in species associations resulting from climate, edaphic and disturbance regime conditions between the east and west boreal mixedwoods. From an operational forest management perspective, our results highlight the utility of including at least some target calibration data to improve the transferability of FRI attributes between forests. We also identify and discuss various challenges for successfully transferring models of FRI attributes from one forest to another.

Airborne Laser Scanning, Area-based Approach, Forest Resource Inventory Attributes, Model transferability, Random Forest, Ordinary Least Squares, Eastern and Western Boreal woods

NLT019D1B3R2

Terrestrial Photogrammetric Measurements at the Individual Tree and Plot Levels in a Boreal Mixedwood Forest

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Digital terrestrial photogrammetry (DTP) and associated methodologies represent a rapidly developing ground-based tool for deriving forest inventory attributes. Benefits of using DTP include the low cost of cameras and mounts, as well as the ability of resulting point clouds to provide spectral information in addition to structural detail. However, there are current limits to its use in operational capacities. For example, previous studies have relied on either the acquisition of hundreds to thousands of images over a given area, or as many as a few hundred images of single trees, thereby raising issues of acquisition time or data storage requirements. Furthermore, most studies focus on relatively homogeneous stands or a single primary species, and, as a result, an additional analysis of point cloud accuracy across species and environmental gradients is needed to understand the utility of DTP across different stand conditions. In this study, we investigate the utility of DTP using a relatively small number of photographs to estimate forest inventory attributes such as diameter at breast height (DBH), stem taper, and volume for trees across a range of sizes and species. Limited sets of photographs were taken with two spherical cameras mounted on a telescoping pole to acquire images at varying heights and at fixed distances between one another. Sets of 6 images were taken at each of 2 locations (12 images total) for individual tree analysis, and at each of 17 locations for plot-level analysis. These images were then used to automatically generate photogrammetric point clouds for both individual trees and across sample plots in a boreal mixedwood forest in Alberta, Canada. Preliminary results indicate success at the prediction of taper and volume at an individual tree level and position and DBH for trees on sample plots. A variety of postprocessing techniques were tested and the best yielded individual tree volume estimates to within ~16% RMSE, and estimates of taper for the lowest 10 m or approximately 40% of tree height to < 1 cm RMSE. For individual trees, DBH was estimated to an RMSE of 1.28 cm, (5.15%). Although with limitations on the technology such as stem and branch occlusions, results show promise for DTP as an emerging application in deriving ground-level forest inventory attributes at a low acquisition cost.

Photogrammetry, terrestrial photogrammetry, spherical camera, forest inventory, volume, diameter

NLT032D1B3R2

Using Unmanned Aerial System (UAS) LiDAR to estimate stocking density and basal area for forest hydrology modelling

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Forest growth dynamics within water supply basins dominated by eucalypt forests influence streamflow with changes in actual evapotranspiration (AET) during forest regeneration. We

predict vegetation-induced trends in streamflow with spatiotemporal forest growth estimates that couple Permanent Growth Plots with aerial LiDAR derived stocking density (N), and basal area (BA). Relationships between N, BA and field measured sapwood area (SA) were developed to quantify spatiotemporal SA, a surrogate for annual AET. By subtracting SA derived AET from rainfall estimates, we estimated seasonal streamflow for three large water basins totalling 915 km2 with Nash Sutcliffe efficiencies of 0.85, 0.87, and 0.91. Aerial LiDAR is suitable for estimating N and BA in Ash forest (Eucalyptus regnans) with straight stems and canopy apex above the stems. However, for Mixed Species Eucalypt Forest (MSEF) with leaning stems and highly irregular intertwined canopies, ultra-high resolution Unmanned Aerial Systems (UAS) LiDAR was used to scale plot-level measured SA. Across 43 flight sites, averaging 2 ha each, UAS LiDAR with mean point density of 2525 points m-2 was used to develop a bottom-up individual tree detection (ITD) algorithm for estimating N, and canopy segmentation algorithm for estimating BA and SA. The surveyed MSEF is possibly the most detailed existing measure of forest structure in Australia. The ITD algorithm was evaluated using 60x60 m plots at the centre of each flight, with 2790 field measured stem locations, diameter at breast height for all stems greater than 10 cm, and sapwood thickness for a subset of stems. The novel bottom-up ITD algorithm uses kernel densities of the vegetation profile to remove understorey, and applies a voxel connectivity and Principal Component Analysis (PCA) procedure to generate stem clusters that branch out into canopy clusters. The same ITD parameters were applied across the 43 sites with multi-aged heterogeneous forest types. The Shuffled Complex Evolution (SCE) optimiser was used to calibrate two parameters that differentiate tree clusters of interest from the rest of biomass. For an average flight, tree detection had 88% of field measured stems correctly segmented with a True Positive (TP) (Standard deviation: 5%), negligible bias in aggregated plot-level N predictions, and omitted stems were small stems in high density stands. Visual inspection of segmented canopy in ultra-high resolution UAS LiDAR shows potential for the development of BA and SA estimates using stem and canopy structural features such as cross-sectional dimensions of trunk clusters, and volumetric canopy density estimates.

Unmanned Aerial System, LiDAR, Forest Hydrology,Basal Area, Stocking Density

NLT038D1B3R2

Integration of UAV-based photogrammetric point cloud and hyperspectral data for tree species classification

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The use of remote sensing data for tree species classification in tropical forests is still a challenging task, due to their high floristic and spectral diversity. In this sense, novel sensors on board of unmanned aerial vehicle (UAV) platforms are a rapidly evolving technology that provides new possibilities for tropical tree species mapping. Besides the acquisition of high spatial and spectral resolution images, UAV-hyperspectral cameras operating in frame format enable to produce 3D hyperspectral point clouds. This study investigated the use of UAV-acquired hyperspectral images and UAV-photogrammetric point cloud (PPC) for classification of 14 major tree species in a Mixed Ombrophilous Forest area of Southern Brazil. The flight was conducted in December 2017 by means of a quadcopter UAV (UX4 model) and a frame format hyperspectral camera based on a Fabry-Perot Interferometer (FPI), model 2015 (DT-0011). The study area contains 25 ha and was covered by six image strips (640 m long and 65 m wide) with a forward overlap exceeding 70% and a side overlap greater than 60%, allowing the creation of a high spatial resolution PPC (35 points.m-2). After the pre-processing tasks, four dataset combinations were tested using a support vector machine (SVM) classifier: a) one containing 25 hyperspectral visible/near-infrared (VNIR); b) the second containing the VNIR bands and a canopy height model (CHM); c) the third containing the VNIR bands and six PPC elevation features; and d) the last one containing all features (VNIR, CHM and PPC). Fifty percent of the crown samples of each tree species were used for training the classifier and the other 50% were used as a test set for the evaluation phase. The results showed that the worst accuracy was reached when VNIR hyperspectral bands were used alone, with an overall accuracy (OA) of 65.4% (Kappa index of 0.6). Adding PPC features to the VNIR hyperspectral bands increased the OA by 9%, while the addition of the CHM only increased the OA of about 5%. When both, PPC features and CHM were added to the VNIR dataset, the increase was of 10%, providing the best general result (OA of 75.4% and Kappa index of 0.72). These results showed that the combination of hyperspectral images with PPC features may led to a significant increase in the accuracy classification of the 14 tree species, proving to be a potential and faster way to classify many species of a highly diverse and complex forest.

Tree species mapping, imaging spectroscopy, photogrammetry, support vector machine

NLT088D1B3R2

Using state-of-the-art LiDAR technology for mapping Ecosystem Services of urban trees - a case study from Krakow (Poland)

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The role of urban green infrastructure (urban forests, parks, trees, lawns, meadows etc.) in city inhabitant lives will increase dramatically in next decades. Currently, it is a typically perception that urban greenery (Urban Forest) does not bring any rational benefits, while profits from real estates are obvious. Therefore, the cities green infrastructure is constantly threatened with housing and city infrastructure development. However, urban greenery plays a substantial role in improving quality of urbanites' life, which is particularly significant in terms of predicted 70% urbanization rate by 2050. Healthy and well managed city green infrastructure can improve air quality, remove particulate matters (PM) and CO2, play a role in sequestrate carbon, cool down city temperature and protect against winds. These functions served by vegetation are known as ecosystem services (ES). The study based on integration of the ALS (ISOK project), MLS (VMX-250; Riegl) and TLS (FARO and VZ-400i Riegl) point clouds for the tree inventories and i-Tree Eco (USDA Forest Service) software, which quantifies vegetation structure, environmental effects and values of ES. The implemented model is based on air pollution and local meteorological data along with the field data from inventory of city vegetation. Input parameters (DBH taken from TLS/MLS; H – taken from ALS and MLS, and other biometrical parameters) for i-Tree Eco ES assessment were acquired using LiDAR data sets, through a combination of TLS MLS and ALS point clouds gathered from different projects (2012-2018). Also the newest LiDAR solution like wearable scanning was tested using the Robin GEOSLAM backpack platform. Based on the tree inventory (R3TREES database owned by Urban Greenery Authority of Krakow) of Planty Park (21,55 ha) we found that 2,158 trees (mainly Acer platanoides, Tilia cordata and Aesculus hippocastanum) stored approx. 1,738.5 ton of Carbon, removed 0,83 tons of air pollutants and at the same time contributed to 990,11 m3 of avoided run-off. The total value of ecosystem services served by trees in Planty Park, calculated for year 2015 was in total 21.439,47 EUR (9,93 EUR per single tree). The project confirmed the high precision of the different LiDAR point clouds and the necessity and justification for their use in order to carry out a quick and precise inventory of city trees.

ALS, MLS, TLS, WLS (Wearable Laser Scanning), UF (Urban Forestry)

NLT114D1B3R2

Evaluation of the use of cross flight photo acquisition for improvement of forest structure reconstruction in SFM point clouds

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Structure From Motion (SFM) as a method of point cloud acquisition is becoming increasingly used to derive forest structure and metrics, especially with the proliferation of Unmanned Aerial Vehicles (UAVs) with improved photographic capabilities. With the pace of adoption of this method, and the flexibility these methods demonstrate in comparison to common photogrammetric methods, a wide variety of flight characteristics have been attempted with varying levels of success. There remains a lack of overarching literature on the most effective method for flight planning for deriving point clouds for forest characterisation from UAV photography. Whilst several studies have investigated the effect of varying flying height and sensor quality, the effect of flight direction and camera zenith angle have received minimal attention. This study investigates a number of differing configurations of flight plans for photo capture, including double grid image networks and varying flying directions with respect to sun angles. The resultant point clouds derived from each photo set are compared for accuracy in the retrieval of canopy cover, sub-canopy vegetation density and ground surface reconstruction using dense TLS data as a reference source. Flights were undertaken over a variety of forest types and over a variety of vegetation recovery classes at sites across Queensland, Tasmania and Victoria in Australia. Images were captured using the integrated RGB camera on a DJI Phantom 4 Pro, and image processing was undertaken using Agisoft Metashape. Results suggest that the inclusion of excessive photos in the point cloud derivation process hampers the resultant solution, and efficiencies can be found in existing photo capture techniques to increase potential coverage areas of such surveys.

Landscape monitoring, forest structure, UAV SfM, flight configuration

ALS031D3B1R1

Deep Learning of synchronized Airborne LiDAR and Hyperspectral data to map successional stages on a Tropical Dry Forest

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The synergy of full waveform LiDAR and hyperspectral remote sensing data has the potential to estimate forest canopy structure, biomass as well as the forest successional stage. Here, we use a multilayer deep learning architecture aimed to map the ecological succession path of a Tropical Dry Forest (TDF) of the Santa Rosa National Park Environmental Monitoring Super Site (SRNP-EMSS) in Guanacaste, Costa Rica. The proposed deep learning approach uses both vertical structure metrics from the Laser Vegetation Imaging Sensor (LVIS) and vegetation indices derived from Hyperspectral Mapper (HyMap) data to generate more abstract high-level features useful to identify a forest successional stage. The LVIS and HyMap data were both acquired during the dry season. The LVIS data has a spatial resolution of 20 m, while the HyMap has 125 spectral bands ranging from 0.45 µm to 2.48 µm with a 16 nm sampling and a 15 m spatial resolution. These two datasets were first georeferenced and then resampled to the 20 m spatial resolution of the LVIS data, after which the data were analyzed using the deep learning architecture. Our results demonstrate that when compared against an independent learning approach, the combination of vegetation indices and LVIS metrics enhances the identification of three different types of TDF successional classes: early, intermediate, and late. This case study highlights the potential of combining LiDAR and hyperspectral data to complement each other in mapping the successional stages of TDFs via advanced deep learning approaches. The former contributes to the generation of essential information for estimating the carbon sequestration capacity of secondary tropical dry forests.

LVIS, forest succession, tropical dry forest, deep learning classifier

ALS041D3B1R1

A pan-Canadian characterization of Boreal Forest gap size frequency distributions

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Despite relating predominant ecological and successional processes over forest regions, the characterization of gap-size frequency distributions (GSFD) have been the subject of few broad

scale studies. Remote sensing-based analyses characterizing canopy gaps help to improve our understanding of spatial and structural variations in forest canopies and provide insight into broad scale successional patterns. With the primary goal of characterizing GSFDs across Canadian Boreal Forest ecozones, this study utilized airborne laser scanning (ALS) transects acquired in 2010 to spatially delineate within-stand canopy openings. Originally ~25,000km in length, ALS transects were representatively sampled within eight distinct Canadian Boreal ecozones. Gap detection followed a fixed threshold canopy height model (CHM) approach where CHMs were spatially filtered to remove areas within transects not meeting the Canadian forest definition (stand size ≥ 0.5 ha, canopy coverage ≥ 10% (computed as % of points > 2m), and height ≥ 5m). A gap detection routine was then applied to CHMs meeting these criteria where contiguous areas ≥ 8 m2 and heights ≤ 3 m were delineated. Following gap delineation, forest types were assigned from a Landsat-based, disturbance informed, land cover layer. The GSFD can be characterized by the exponent (λ) of the power-law probability density. The λ coefficient was calculated for ecozones and forest cover types using random sample bootstrapping. Kolmogorov-Smirnov tests confirmed that GSFDs followed power-law distributions in every case. Pairwise comparisons between ecozones, forest types, and their combinations indicated significant differences between bootstrapped λ estimates. Regional differences amongst GSFDs highlighted in this study provide insight into variations in ecological processes in the Canadian Boreal Forest including the manifestation of gap phase dynamics, as well as improving forestry practices predicated on emulating natural disturbance processes and patterns.

Airborne laser scanning, gap-size frequency distributions, gap detection

ALS074D3B1R1

Impact of wildfire regime on forest structural diversity in Northwest Spain

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Wildfire is the main cause of change in Northwest Spain forest ecosystems. Remote sensing constitutes a reliable tool for assessment of landscape structure and dynamics and has become essential for forest managers and planners. Time series of optical moderate spatial resolution data enable characterization of fire regimes over extensive areas and relatively long periods, facilitating the assessment of fire recurrence and intensity effects on forest structure. LiDAR data provide accurate estimates of forest structural characteristics at various scales. Focusing on an area of 10600 km2 in NW Spain our goal is to evaluate the effects of the last decades´ wildfire regime on the structural diversity of forest areas. CORINE Land Cover 2012 and the Spanish Forest Map were the base data for classification of vegetation types, among which the most representative are conifer and broadleaved dense treed forests (44%), and shrubs (48%). A time series of 33 "end of fire season" radiometrically normalized Landsat composites (path/row: 203/031) was input to Composite2Change (C2C) algorithm for development of fire annual cartography (1985-2015), via Normalized Burn Ratio (NBR) time series analysis. More than 14000 fires have burnt twenty seven percent of the area under study at least once. Fire severity, fire recurrence, and time-since-fire were calculated from the Landsat-derived annual fire cartography. Diversity indices characterizing structure at the microscale (e.g. modified Shannon Diversity Index and modified Evenness Diversity Index), and spatial pattern indices characterizing structure at the landscape scale (e.g. canopy cover, height diversity, and height evenness) were calculated from low density LiDAR data (0.5 pulse x m2) acquired in 2009 over the entire study area. All vegetation type patches (10764) were attributed with the Landsat-derived (fire regime) and LiDAR-derived (structural diversity) indices and grouped into hierarchical categories. Statistical analysis of similarity and differences (ANOVA) at various hierarchical levels showed clear differences between burned and no burned patches. These differences are modulated by factors such as the time-since-fire, the fire severity, and the fire size. Fire regime has an important impact on forest structure and diversity. The combination of

remote sensing technologies facilitates forest monitoring, essential for the application of effective forest management policies.

Wildfire, LiDAR, Landsat time series, Spain, structural indices, diversity indices

ALS095D3B1R1

Challenges of multi-temporal and multi-sensor height growth analyses in a highly disturbed Boreal Mixedwood Forest in Canada

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Enhancing forest inventories using airborne laser scanning (ALS) and digital aerial photogrammetry (DAP) is a means of providing prompt and accurate measures of forest stand structure. The increasing availability of contiguous ALS and DAP data provides a means for improving stand dynamic information. While the cost of multi-temporal ALS is occasionally prohibitive to its integration for growth assessment, DAP point cloud data have been proposed as a cost-effective alternative to those from ALS for inventory re-measurement. However, the differences between ALS and DAP point clouds renders their integration to extract stand growth estimates challenging, especially when the point density is low. Further, the stand structure, tree mortality, or growth rate, may introduce another challenge when updating cell-level forest inventories. In relatively slow growing, highly disturbed boreal forests in Canada, this task may be especially difficult. In this study we used low density ALS and DAP point clouds acquired in 2007 and 2015, respectively, to identify and quantify changes in forest structure in a highly disturbed boreal mixedwood forest in Canada. Focusing on Lorey's height, we demonstrate challenges related to data type discrepancies between ALS and DAP, as well as their relation to specific forest stand characteristics. Specifically, we first demonstrate the effect of systematic distortions inherent to DAP datasets on the forest attribute modelling outcomes. Next we applied a customized iterative closest point (ICP) algorithm to co-register the ALS and DAP. We show the importance of stand mortality when estimating growth and analyze how mortality influences prediction error and makes height differences over time hard to quantify. Despite the high error-to-growth ratio on a per-plot basis, the cell-level estimates of height growth were summarized to the stand-level and general landscape-scale patterns in height growth were identified. The results showed that the mean difference between ALS and DAP digital surface models was improved from -3.18 m to -0.59 m, with the standard deviation of differences decreasing from 12.05 to 1.61 m, when the correction was applied. We found the stand mortality was related to growth prediction error, and for stands with mortality of 25% relative RMSE was just below 100%. At landscape level we identified that nutrient regime, moisture regime, species dominance, and the soil classification were the main drivers of height growth. We conclude that forest managers should be cautious when utilizing multi-temporal and multi-sensor analysis of forest growth if growth is slow and level of mortality is high.

LiDAR, digital aerial photogrammetry, growth, airborne laser scanning, forest inventory

ALS122D3B1R1

Fuel Load Mapping in the Brazilian Savanna using LiDAR Data and Multispectral Imagery

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Accurate mapping of fuel loads is critical for planning and implementation of fire management in the Brazilian Savanna (Cerrado). Several remote sensing sensors collect data sensitive to fuel

loads, with different measurements designs. These sensors, such as LiDAR and Sentinel-2, are naturally synergistic, as each presents tradeoffs in terms of coverage and sensitivity to fuel loads. The aim of this study is to develop and test a multi-sensor data fusion approach for improving fuel load estimation and wall-to-wall mapping in the Brazilian Savanna biome. Canopy and surface fuel loads are estimated in the field using field measurements and Terrestrial Laser Scanning (TLS) data. Spaceborne LiDAR (Global Ecosystem Dynamics Investigation LiDAR - GEDI) data are simulated at field plots of 25m in diameter using UAV-LiDAR data. Fuel loads models-derived from the simulation are calibrated at plot level and applied to produce estimates of fuel loads for all the GEDI real observations collected across the Cerrado biome. These estimates are then combined with Sentinel-2A-derived metrics (e.g. mean±sd of the Normalized Difference Vegetation Index NDVI) using machine learning approaches (e.g. Random Forest and Support Vector machine learning algorithms) for wall-to-wall fuel loads mapping at 25m resolution across the entire Cerrado biome. This research demonstrates improvements toward the wall to wall fuel load mapping via data fusion related to individual sensor datasets alone.

Spaceborne LiDAR, Sentinel-2, Cerrado, Modeling

ALS126D3B1R1

Fusing multispectral LiDAR and aerial imagery for tree species classification

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Forest inventory and management requires precise and detailed information about the distribution of tree species. While individual tree-based approaches using single wavelength LiDAR can successfully distinguish broad-leaf and coniferous trees, they cannot conduct more detailed tree species classification due to limited spectral ranges. Recent advances in sensor technology have led to the development of new multispectral LiDAR (MSL) systems that provide up to three different wavelengths. Fusing these MSL data with multispectral aerial imagery significantly increases the radiometric range of the dataset for classifying multiple tree species. Thus far, the status and potential uses of MSL data for classifying tree species have not been fully explored. In this study, different feature sets were extracted from an MSL point cloud and multispectral aerial imagery to classify three tree species (Norway spruce, European beech, Silver fir), and dead spruce trees with crowns (snags) in the Bavarian Forest National Park, Germany. The MSL data were acquired by combining data from three different sensors under leaf-on conditions with an average point density of 37 points/m2. First, the combined 3D point cloud was segmented into 3D clusters using the Normalized Cut segmentation approach. Second, various features from the MSL point cloud and aerial imagery were generated. Third, forward stepwise feature selection was conducted to reduce the number of redundant or irrelevant features. Finally, the classification was conducted using multinomial logistic regression. We tested our classification procedure using 20 sample plots with measured reference single trees. The results for the individual MSL point cloud and aerial imagery datasets showed that cross-validated (15-fold) accuracies of 78% and 66% were achieved, respectively. An improvement of 7-13% over single wavelength approaches were achieved when the MSL data are used. However, there was no considerable improvement in the classification accuracy if the multispectral imagery features were fused with the MSL data features. Overall, the contribution of the MSL point cloud radiometric features to the classification accuracy was higher than that of the geometric features by approximately 10%. Our results show that the features derived from a MSL point cloud have a great potential to improve detailed tree species mapping.

Tree species classification, feature analysis, multispectral LiDAR, Intensity, aerial imagery

ALS151D3B3R1

Forests, fires, and the role of remote sensing science for sustainable solutions in the Amazon

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Illustrated by recent developments, the talk offers some insights on how comprehensively remote sensing has supported the monitoring of 21st century deforestation in the Brazilian Amazon. Specifically in terms of fire detections in the Brazilian Legal Amazon, the definition of different baselines has mattered as they have substantially biased the analysis. Examples are provided when exploring the question "Have baselines been used to either politically, scientifically or arbitrarily come to conclusions?" To avoid unsubstantiated discussions, remote sensing science can contribute with sustainable solutions for the Amazon, mainly when protagonists in the debate are guided by four principles: be prepared; add, don't change; lead with science; and know your audience.

TLS011D3B1R2

JIB-SCAN: How to avoid occlusion in single station TLS assessments

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Terrestrial Laser Scanning (TLS) in forestry has to deal with occlusion unless scanning from multiple stations. A novel patented scanning device can significantly reduce this handicap. A horizontal protruding arm of ~1 meter is mounted on a tripod, slowly rotating at 0.3 rot/min. At the end of this horizontal arm, an (automotive) laser-scanner is rotating vertically at 30 rot/sec. On the opposite end of the arm, CPU and battery help to balance the construction. It can carry different LIDAR sensors like VLP16, Quanergy M8 and additionally two cameras with a stereo-baseline of 200cm. Simulation scans with Riegl VZ2000 on multiple circular positions look extremely promising, showing that this geometrical setup can avoid 90-95% occlusion compared to conventional TLS. The resulting point cloud allows accurate reconstruction of DBH, height, taper functions, crown geometry, tree positions and relief properties within 20-60m radius depending on density of undergrowth. With the slow horizontal rotation and the resulting high angular resolution, diameter extraction will be achieved by edge detection rather than by cylinder fitting. Tests in dense Austrian forests with basal area >50m² show, that, within a radius of 30m, 98% of trees could be detected from one single scanning position. Regarding basal area, even more than 99% of the basal area was detected. In this single station TLS-approach, the Bitterlich angle count method with low basal area factors (1 or below) shows the best results. All datasets can perfectly serve as input for single tree growth simulation based on deep learning algorithms. Especially on NFI sample plots with diameter records from decades, the exact assessment of and tree coordinates, stem properties, crown geometry and micro-relief from DTM offers a high potential for AI-based modelling applications. In combination with digital images, this standardized geo-located snapshot can be certified by watermarks or block-chain technology, thus serving as a proved evidence for carbon trading. While point cloud interpretation and tree feature extraction will surely be further developed, the geo-located TLS point clouds and stereo image snapshots can be stored for future monitoring and modelling purposes. Until the conference we will have a couple of datasets available and present multiple scanning results from mixed mountain forests in Austria as well as from plantations in Brazil. A prototype will be exhibited at the conference. The price of the device will be below 30,000 US$ and the weight below 10 kg. This technology has game-changing potential in forest inventory business, especially regarding NFI as well as standardized carbon monitoring, eg. by calibrating GEDI footprints.

TLS occlusion forest inventory

TLS033D3B1R2

3D Forest 0.5 - new release of the tool for processing high density point cloud data from forest ecosystems

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During the last decade the terrestrial laser scanning technology (TLS) shifted from the initial experiments on measurement of forest structure, towards well established approach providing accurate measurements of trees and forests in 3-dimensional space. Similarly, mobile laser scanning (MLS) and laser scanning using unmanned aerial vehicles (ULS) is nowadays on the rise and both are increasingly applied for studying forests. MLS and ULS can produce point clouds of high density and accuracy, in some ways comparable to TLS data, but with the capability of covering much larger area in much shorter time. General progression does not apply only to laser scanning technology itself but also to development of new algorithms and methods for processing of high density point clouds and automate information extraction. Despite the growing number of algorithms for data processing, its improving efficiency and accuracy, there is still lack of software specialized for processing point cloud data from forest environment and extraction of information useful for forest ecology research and forestry applications. Here we present 3D Forest software version 0.5, which is an open source software designed especially for processing high density Lidar data from forest environment. 3D Forest provides tools for data processing and filtering – terrain extraction, filtering the point cloud by its statistical properties, voxelization of point cloud, automated tree segmentation, automatic crown separation as well as for computation of basic and advanced tree parameters such as: stem base position, stem diameter, tree height and length, planar projection of tree, crown volume or quantification crown to crown intersections. The version 0.5 introduce revised individual tree segmentation which is capable to successfully segment TLS and ULS point clouds. The segmentation is now based on voxel net of given resolution, descriptive value of each voxel (based on PCA, slope or intensity) and spatial relationship between voxels. The version 0.5 further contains functions for tree reconstruction – separation of stem and classification of branching order, computation of tree quantitative structure models (QSM) and also timber assortment by evaluation of stem curvature and taper. The software GUI is easy to use and provide functions needed for data management (import/export) as well as for exporting computed tree parameters and its visualization. *LiDAR, point cloud processing, software, TLS, UAV*

TLS039D3B1R2

Architectural modeling for upscaling tree- and plot-level attributes across forest landscape

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The combination of field and remote sensing data enables large-scale forest assessments. However, our inability to measure and integrate the complexity of the 3D canopy structure contributes largely to the uncertainty in models that use remote sensing to map forest attributes over large areas. As an exact representation of the canopy's complex structure is not feasible through manual practice, architectural models can estimate fine-scale tree structure. The L Architect (Lidar to tree Architecture) model enables the extraction of the tree stem and main branches from terrestrial laser scanner (TLS) data and constructs the fine branching structure with the addition of foliage. We calibrated L-Architect by using structural measurements for two coniferous species found in Newfoundland (Canada), namely, *Abies balsamea* and *Picea mariana*. In this study, we developed a method that uses TLS data and the L Architect model to create a library of trees with associated fine-scale structural attributes. We simulated surrogate plots using these fine-scale structural attributes in conjunction with tree-level input variables from field measurements or alternatively, predicted from airborne lidar data. We first compared several key forest attributes derived from surrogate plots with those derived from a series of reference plots created with L-Architect. The structural attributes included branching structure (e.g. knot surface), crown geometry (e.g. asymmetry), heterogeneity (e.g. lacunarity, fractal

dimension), tree volume and the spatial distribution of material (e.g. LAI). Overall, the surrogate plots reproduced the attributes of the reference plots with normalized RMSE mean value of 17% (R2 = 0.68) using ground measurements and 24% (R2 = 0.51) using inputs estimated with airborne lidar. Attributes such as the crown asymmetry and lacunarity had weak correspondence (R2 < 0.16) while others such as LAI, knot surface and fractal dimension were well predicted (R2 > 0.80). Furthermore, we used the modeled fine-scale structure from the surrogate plots to predict a series of nine wood fiber attributes (WFA) measured from wood cores and summarized at both tree- and plot scales. The fine-scale structural attributes derived from L-Architect explained 27-63% of the variance in WFA at the tree-level, and 39 89% at the plot-level. The results indicated that the fine-scale characterization of forest structure using L-Architect improved significantly WFA estimates when compared with other available models developed with field measurements, TLS data and/or ALS data. The architectural modeling approach thus supports, by integrating detailed structural data, the development of empirical models and the retrieval of biophysical properties with multi-scale remote sensing observations.

Architectural model, TLS, Tree structure, Surrogate forest plots, Wood fibre attributes

TLS053D3B1R2

Estimating forest canopy equivalent water thickness using terrestrial laser scanning and implementing the 3D estimates in radiative transfer modelling

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Forests provide many essential benefits to humanity and the environment, making them a crucial factor in sustaining life on Earth. Terrestrial Laser Scanning (TLS) instruments have been widely adopted in measuring forest structural attributes. However, less attention has been paid to using the TLS intensity data to estimate forest biochemical characteristics, such as the Leaf Equivalent Water Thickness (EWT). EWT is a vegetation water status metric widely used in forest health monitoring and early detection of vegetation stress and risk of wildfire. In this study, EWT was mapped in 3D at canopy level in a mixed species plot in a broadleaf deciduous forest (Wytham Woods, UK) using Terrestrial Laser Scanning (TLS). The intensity data from the commercially-available Leica P20 and P40 TLS instruments (808 nm and 1550 nm respectively) were calibrated to apparent reflectance and combined in a Normalized Difference Index (NDI). The average error in the EWT estimation using NDI was found to be less than 8%. The 3D EWT point clouds revealed a vertical heterogeneity in all scanned trees, with all trees in the plot having an average of 24% higher EWT in canopy top than in canopy bottom. This EWT estimation approach has the potential to provide midday and predawn EWT estimates and to study the drying patterns of vegetation in high spatial and temporal resolutions. Tree 3D models were then created from the TLS data and a virtual forest plot was reconstructed in the radiative transfer model DART. The 3D EWT estimates were implemented in the model by defining the actual EWT in each canopy layer instead of using an average EWT value for the whole canopy. Simulations were conducted to investigate which canopy layers contributed the most to the signal received by satellite sensor. The results revealed that, in this forest plot, the top four to five meters in the canopy dominated the plot reflectance. The satellite sensor was not able to detect severe water stress, caused by disease infection or pest invasion, that started in canopy bottom and spread upward. This may cause misjudgements while monitoring forest health using spaceborne optical sensors. *Forest, water content, vegetation, radiative transfer model, LiDAR*

TLS080D3B1R2

L-Vox: An algorithm to estimate PAD from TLS point clouds acquired in forest environments

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Leaf Area Density (LAD m2.m-3) defines the total one-sided foliage surface area within a given volume. It is one of the most important parameters in characterizing the exchange processes between the atmosphere and the land surface. Plant Area Density (PAD in m2.m 3) refers to the total plant surface areas and makes no distinction between wood and leaf material. Terrestrial laser scanning (TLS) provides unprecedented details of the 3D structure of forest canopies. However, the signal occlusion and the uneven sampling density of the TLS point clouds limit our capacity to characterize the 3D distribution of canopy components. Recently, some studies made use of statistical estimators of LAD/PAD applied on TLS point clouds subdivided into 3D cubes, called voxels. However, a rigorous assessment of the estimated LAD/PAD and the impact of occlusions in forests is still unclear due to laborious, time-consuming, and inaccurate field measurements. We developed an algorithm called L-Vox that computes PAD per voxel for TLS scans acquired in forest by using the bias-corrected method developed by Pimont et al. (2018). We calculated the 3D distribution of PAD for a series of forest scenes. The PAD value in a particular voxel corresponds to the weighted sum of the individual PAD value estimated from each scan. We assessed how L-Vox reduced the impact of occlusion and the uneven sampling to estimate PAD in (1) simulated scenes and (2) scans acquired in hardwood and coniferous plots located in New Brunswick and Newfoundland (Canada). Finally, we evaluated the influence of the voxel size and the number of scans per plot on PAD estimations. Our results showed strong correlations between the estimated PAD from L-Vox and simulated PAD for virtual forest plots with a mean R2 of 97.3%. We demonstrated that in real forest plots, multi scans TLS acquisitions improve the estimation of PAD by reducing significantly the occlusion effect observed when using only one scan. On average, occluded volume resulting in a no-data PAD value ranged from 0 m3 (0.0%) to 3,296 m3 (20.1 %) for 400 m2 plots. The proportion of no-data varies with the number of scans per plot, and the stem and foliage density within the forest plot. The impact of voxel size on PAD estimations highly depended on the relative size of foliar and/or woody elements. The L-Vox algorithm has the potential to improve on the 3D spatial characterization of PAD using TLS in natural forest environments.

Forest structure, Leaf Area Density, Terrestrial laser scanning, signal occlusion

TLS094D3B1R2

Estimation of the tree and stand volume on point clouds derived from Terrestrial Laser Scanning using fractal methods

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The fractal dimension is a spatial metric that describes the geometry and complexity of natural objects such as rivers or trees. Specifically, this metric has been widely used to describe the architecture and the biomass allocation of trees. However, few studies have been conducted to describe the fractal dimension of trees or forest stands using Terrestrial Laser Scanning (TLS). Here we first analyze the relationship between tree volume and the fractal dimension of trees, and then we explore the potential of this relationship to predict the volume of artificial forest stands. Point clouds of 189 trees around the world with (n = 76) and without (n = 113) leaves were used. At the tree level, the tree volume was estimated per each point cloud using Quantitative Structure Models. The fractal dimension of each point cloud was estimated using a voxel-counting approach; creating voxels of different size while measuring the frequency of voxels necessary to occupy the cloud space. From this, the scaling component and the intercept of the fractal dimension in point clouds with and without leaves were estimated. Our results suggest that the variation of the intercept is strongly associated with the tree volume in point clouds with (R2 = 0.92) and without leaves (R2 = 0.83). However, the scaling component of the fractal dimension does not seem to predict the tree volume (with leaves: R2 = 0.13; without leaves: R2 = 0.13), but it can describe the presence or absence of leaves in a given point cloud. At the stands level, artificial stands were created using tree point clouds with known tree volume. This was created using different scenarios of plot areas and densities. The voxel-counting approach was then applied to the artificial stands, and the intercept and scaling component were also extracted. Overall, the intercept seems to predict the forest stand volume at different scenarios (R2 > 0.85), while the scaling component seems to describe the aggregation of trees in a given plot. Due to the close relationship of the volume and the biomass allocation of a given tree or stand, the method and relationship presented here may help future studies to improve current allometric algorithms, and therefore, the prediction of the carbon storage in tropical ecosystems. *Tree volume, stand volume, fractal dimension*

ALS024D3B2R1

Using airborne LiDAR and Landsat imagery to map forest aboveground biomass in the Brazilian Amazon

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The spatial distribution of aboveground biomass of Amazonian forests is extremely important for understanding the global carbon cycle and implementation of Reduce Deforestation and Forest Degradation (REDD+). Extensive and high-quality forest structure information is extremely difficult and expensive to obtain in Amazonian forests. Light detection and ranging (LiDAR) systems provide an ability to penetrate the canopy through small leaf gaps for detecting horizontal and vertical vegetation structure simultaneously. Thus LiDAR can significantly reduce the need for very large forest inventory measurements. The height metrics derived from LiDAR is strongly related to aboveground biomass. However, the expansive nature of the Brazilian Amazon makes wall-to-wall collections of airborne LiDAR data unrealistic. The combination of airborne LiDAR and Landsat imagery has the potential to be the most promising strategy for overcoming the obstacle in mapping aboveground biomass since it integrates vertical structure information derived from LiDAR data and horizontally continuous spectral reflectance derived from Landsat imagery. Deforestation and degradation in the Brazilian Amazon have changed significantly from large-scale patterns to fine-scale patterns since the early 2000s. However, existing forest biomass maps for tropical forest based on the combination of coarse resolution satellite data and LiDAR are with limited sensitivity to fine-scale variations in forest structure. Therefore, we attempt to combine airborne LiDAR and Landsat imagery to generate aboveground biomass map with fine spatial resolution in the Brazilian Amazon. As the first step to this goal, in this study we used the extensive field measurements and airborne LiDAR to explore the best model form and LiDAR metrics for estimating aboveground biomass in the Brazilian Amazon. A total of 22 field and airborne LiDAR inventory sites across 5 Brazilian states were used to develop a multiplicative power model and evaluate performances of Random Forest and AdaBoost. We found that the multiplicative power model is the optimal approach to estimate aboveground biomass from airborne Lidar with the highest accuracy (Pseudo-R2 value of 0.6911and root mean square errors of 469.6 g/m2). Besides, this study highlights the success of three-phase upscaling strategy (ground inventory plots –airborne LiDAR – Landsat) in mapping aboveground biomass of the Brazilian Amazon.

Airborne LiDAR, aboveground biomass, Brazilian Amazon, Landsat, statistical models

ALS106D3B2R1

Changes in site productivity in the dynamic southeastern United States

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In the southeastern US, southern pine forests have changed dramatically in the past century, with a significant increase in planted pine and an increase in productivity that has been attributed in large part to intensive forest management and silvicultural practices in the region. This anthropogenic influence on regional productivity has important implications for our understanding of human-environment interactions, and the impacts of policy and regional socioeconomic factors over time. There is a need to develop repeatable methods to quantify these changes in productivity. In our preliminary work, we examined disparate airborne laser scanning (ALS) acquisitions to estimate an ALS-derived canopy height model that was applicable over a large area of the southeastern US (R2 = 0.84, RMSE = 1.85 m). These heights were combined with estimates of age derived from 'time since stand clearing disturbance' calculated

from Landsat-based forest change products to generate spatial maps of site index in pine areas as an indication of expressed site productivity. Results showed a median site index of 19.4 m (base age 25 years), and a 95th percentile site index of 23.3 m. A preliminary comparison of ALS-derived site index with historical site index (i.e., from the 1960s and 70s) for loblolly pine obtained from the USDA Natural Resource Conservation Service's Soil Survey Geographic Database showed a median increase in site index of 3.2 m over the past 50 years for a smaller subset of the data. Our findings of increased site index are consistent with other authors, and with our understanding of the impact of intensive forest management in the region. Other possible contributing factors include carbon dioxide in the atmosphere, temperature, and nitrogen deposition. We expand this work to areas in the southeastern US which had 2018 state-wide acquisitions of image point clouds derived using photogrammetric techniques as part of an initiative with the National Agriculture Imagery Program (NAIP) (Tennessee, Virginia, and North Carolina). Our study area is drawn from within these states, where ALS data had also been collected post-2014. Building on our preliminary ALS work, we follow the same general approach, but substitute ALS-derived heights with height estimated from NAIP point clouds subtracted by the ALS-derived DEM. Assuming the NAIP image point cloud efforts continue, this will enable the monitoring of growth and productivity of pine stands across very large regions over time (every three years) at a substantially reduced cost.

Site index, heights, age, image point clouds, ALS

ALS127D3B2R1

Resolution Dependence in Airborne Laser Scanning Based Forest inventory

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Differences in resolution between field measurement plots and grid cells can have effects on predictions and estimates from forest inventory with the area based approach (ABA). These resolution effects may include bias and increased prediction errors, but the nature of the consequences is poorly documented in peer-reviewed literature. The aim of this study was to identify causal factors, which contribute to a resolution dependence in forest inventory with ABA, and quantify the effects in a real world use case. The problem was found to be surmountable, and we present conditions under which ABA forest inventory is resolution invariant (robust to resolution effects). To quantify the magnitude of effects from different factors, we conducted our investigation using large stem-mapped field plots, and subsets of trees on the plots to match target spatial resolutions. Factors contributing to resolution dependence were found to include 1) variation in LiDAR point density, 2) the type of response variable, 3) how the predictor variables are computed, and 4) the properties of the prediction model. Many of these factors are not be controlled for in a standard ABA: LiDAR echoes are not regularly spaced in the horizontal domain, some response variables are not additive, and there are several commonly used LiDAR metrics such as height percentiles that cause resolution effects. The varying point density can be taken into account by several means but the benefit may be questionable. The error rate of above ground biomass increased when the prediction plots were larger than the fitting plots, and vice versa. The maximum BIAS was 1.50 % and the maximum change of RMSE compared to its value in native resolution was 0.97 % when there was a 4-fold difference in resolution. This indicates that the resolution effect is small in most real-world use cases, however, resolution effect should be carefully considered in LiDAR-assisted large area inventories that target unbiased estimates of forest parameters. *Resolution scale*

ALS130D3B2R1

Extending LiDAR-based forested inventories through space and time

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A patchwork of spatially and temporally disjoint LiDAR collections is rapidly developing across the USA. Often times these LiDAR datasets are acquired with different project goals and thus

different LiDAR acquisition parameters. Additionally, depending on the purpose of this LiDAR survey, forest inventory measurements are not always collected in conjunction with LiDAR data collection. As this trend continues, forestry researchers and practitioners are faced with questions regarding the most efficient means to leverage these spatially and temporally disjoint LiDAR collections, with sometimes limited field data, to estimate forest structural variables across large spatiotemporal domains. This study is focused on addressing two separate but related questions: i) can combining field measurements across time improve estimates of forest structural variables from LiDAR data, and ii) can existing LiDAR and coincident inventory datasets be used to estimate forest structural variables in areas where LiDAR data exist, but coincident field data do not? Our results indicate that pooling LiDAR and associated field datasets across space and time was effective for estimating several forest structural variables across large spatiotemporal domains. *LiDAR, Inventory, forest, space, time*

ALS017D3B2R2

UAS LiDAR data: very high density 3D data for accurate automatic assessment of individual tree parameters

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Three-dimensional (3D) LiDAR point clouds acquired from unmanned aerial systems (UAS) represent a new type of remotely sensed data for forestry and environmental applications. Multi-return lightweight laser scanners designated for UAS carriers can reach measurement rate up to 1 million measurements per second with survey grade accuracy 10 mm. Due to the low flying altitude varying around 100 m above ground level and arbitrarily low speed of multicopter-type UAS carriers, the density of resulting point clouds can reach the level of thousands of points per square meter. Such point clouds constitute a high-quality representation of 3D structure of forest stands and individual trees. Moreover, a relatively large range of scanning angles ensures a good coverage of ground, forest canopies and even individual tree stems. With the use of Riegl RiCOPTER UAS equipped with VUX-1 UAV LiDAR sensor we acquired 3D data of a set of forest stand with different species and structure characteristics. Using the highest measurement frequency 550 kHz and the flight ground speed of 6 ms-1, the forest stand were covered with the average density of 2,000 points per square meter with a good coverage of points on all tree crowns and stems from all directions. For Norway spruce and Scotch pine, the two most important economic species of central European forests, the average tree in a typical mature forest stand (400 - 500 trees per hectare) was covered with 100,000-150,000 points, in dependence on forest density and tree size. From this amount, 1,000 – 2,000 points represent the surface of the tree stem, which corresponds approximately to 20 – 60 points per meter of the stem length. Number of algorithms have been published for individual tree detection from aerial laser scanner (ALS) data (e.g. Ayrey et al. 2017) and for individual stem recognition and diameter estimation from terrestrial laser scanner (TLS) data (e.g. Olofsson, Holmgren, and Olsson 2014). However, UAS-borne LiDAR data have markedly lower densities than TLS and require different approaches. In a few so far published works regarding tree parameter estimation from UAS-borne LiDAR data, the processing workflow comprised a large share of manual work (e.g. Brede et al. 2017). We modified previously published automatic workflows for individual tree detection in ALS and TLS data. For tree segmentation, we applied modified Layer stacking algorithm for ALS and Stem probability algorithm (Olofsson, Holmgren, and Olsson 2014) designated for TLS data. Diameters were automatically derived using Hough transform, random sample consensus (RANSAC) and robust least trimmed squares (RLTS) (Nurunnabi, Sadahiro, and Lindenbergh 2017) with context-based constraints for cylinder and circle fitting. The automatic workflows correctly detected all trees in the plots. Hough transform algorithm correctly detected stem cross-sections only if the points formed a perfect circle, i.e. in stem sections with no branches and perfect coverage of laser hits. However, with RANSAC and RLTS we were able to segment stem points and crown points automatically. The stem was detected and its diameters estimated with centimeter level accuracy even in the crown section.

In this contribution, we describe best practices for data acquisition, referencing and processing, we provide a detailed description of the data and we bring an overview of techniques for automatic stem detection, tree segmentation and diameter estimation from UAS-borne LiDAR data. *UAS, LiDAR, point cloud, forestry, tree detection, segmentation, diameter*

ALS037D3B2R2

Impact of acquisition characteristics of unmanned aerial vehicle LiDAR missions on the quality of derived forest metrics

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Laser scanning sensors mounted on unmanned aerial vehicles, so-called ULS-systems, provide high resolution point clouds on local to regional scales. For forested areas, the high level of detail of such ULS data allows for the 3D modelling of individual trees up to branch level and to retrieve physical information directly from the point cloud. Such parameters comprise the stem position, the tree height, the diameter at breast height (DBH) or the taper function. ULS therefore contains the potential to complement traditional field measurements, what offers new possibilities in context of forest inventories (FI). In addition, ULS enables to cover larger areas with reduced working effort compared to field campaigns. However, for their incorporation into existing FIs, the tree metrics derived from ULS require a rigorous quality assessment in order to prove them accurate and robust. The quality of the derived products thereby relies on the completeness with which the forest scene was acquired by the ULS-campaign. The completeness of the scene coverage, again, depends on the flight altitude, the flight path, the strip overlap, the sampling rate and, due to differing canopy transmittances, the deployed sensor system. In our study, we investigate the impact of these acquisition parameters on the derived FI-metrics. Within predefined plots, we reconstructed stems from point clouds within variances in the acquisition characteristics. We used cylinder and cone models, respectively, to model the stems. For the derivation of the DBH, the z-ranges, within which the points were selected for the model fitting, varied between 0.8-1.8 m and 0.4-3.0 m. We found the stem detection rate to vary between 79-95% for acquisitions using a Riegl VUX-1 and miniVUX-DL system, respectively. DBH retrieval using cylinder models revealed a higher fraction of stems, which could be successfully modelled, compared to the cone model. Failures for DBH modelling occurred predominantly for trees with DBHs < 0.2 m. The cone model, on the other hand, slightly outperformed the cylinder model in terms of the mean difference of the modelled DBH to the reference from the field inventory. However, mean errors were small in general (0.3-0.1 cm). We further found the number of successfully modelled DBHs to increase if the z-range was increased from range 0.8-1.8 m to range 0.4-3.0 m. From our findings, we can deduce the required acquisition parameters for ULS missions which enable the derivation of the sought tree metrics directly from the point clouds. *UAV-LiDAR, single tree parameters, DBH, taper function, forest inventory*

ALS059D3B2R2

How can variation in growth characteristics between genetic level and spacing of Douglas-fir realized-gains trials be characterized by ALS derived attributes?

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Tree breeding programs for Douglas-fir have been carried out in British Columbia since the 1950's; these programs aim to develop genetically improved trees to increase the economic value of a planted forest. Programs use the natural genetic variation within Douglas-fir to produce trees with greater volumes at rotation age, while maintaining wood density at the population level. To evaluate individual tree performance, periodic field measurements are taken to determine whether specific target gains are being met. Currently, variables collected focus on yield estimates and are not informative about how physical traits are expressed in a plantation setting. High density Airborne Laser Scanning (ALS) has the potential to provide additional insights into individual tree attributes, as well as identify variables that could improve the selection process. In addition, we can observe what effect genetic level (Top Cross, Mid Gain, and Wild Stand) and stand spacing (2.3 m, 2.9 m, and 4.0 m) might have on tree structure. ALS derived metrics were used to test hypotheses such as: genetically superior trees will have taller crowns, as well as greater crown length. For this study, we first used a conditional random forest to identify important candidate metrics. In order to take interaction effects into account, a two-way analysis of variance was conducted for each metric, followed by a post-hoc test to investigate whether significant differences between genetic levels and spacing existed. The scale and shape parameters of Weibull cumulative density functions were found to be important metrics for our hypothesis; scale as a proxy for crown height and shape as a proxy for crown length. Results show that both scale and shape experienced significant interaction effects, indicating that there is not a straight forward relationship between structural attribute and genetic level. While genetic level appears to be the dominant control for the scale parameter, the shape parameter is related to spacing. At 2.3 m, the mean shape parameter for Top Cross trees is significantly higher than Mid Gain and Wild Stand, indicating that crown length is actually shorter for these trees. This indicates that while Top Cross trees typically have taller crowns, crown length is only significant at tight spacing, where earliest crown closure occurs. This may be representative of greater phenotypic plasticity in Top Cross trees, as they possess the ability to respond to tighter stand spacing and allocate resources differently within the crown.

Airborne Laser Scanning, Genetic Improvement, Douglas-fir

ALS060D3B2R2

Characterizing phenotypes and modeling realized genetic gain in tree breeding trials using super-dense UAV laser scanning

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Selective tree breeding programs play an integral role in sustainable second-growth forest management by providing genetically improved stock for reforestation. While airborne laser scanning (ALS) has been a valuable tool in forest inventory for decades, tree improvement trials require fine-scale data to describe phenotypes and have been limited to ground-based methods due to the high cost of acquisition and limited spatial resolution of ALS. Unmanned aerial vehicles (UAV) are rapidly developing as a phenotyping platform; UAV-mounted laser scanning (UAV-LS) has great potential for assessing genetic gain and generating proxies for desirable phenotypic characteristics such as tree height, self-thinning, crown closure, and stand evenness. We undertook this study (1) to test the utility of UAV-LS metrics for modelling realized genetic gain at the stand level, and (2) to present a novel approach for characterizing forest phenotypes using point cloud metrics to categorically describe stand architecture. We produced extremely dense UAV-LS point clouds (>500 points per m2) from 24-year-old realized-gains trials of coast Douglas-fir (*Pseudotsuga menziesii var. menziesii*) at three distinct sites in coastal British Columbia, Canada. We produced area-based point cloud metrics across trials of different levels of genetic gain and selected metrics which characterized stand architecture in terms of four structural categories: canopy height, density, volume, and heterogeneity. The magnitude of realized genetic gain differed greatly among the three sites; yet the selected metrics revealed consistent trends across sites when normalized to percent gain over the mean performances of control plantations. Stand height, density, and volume metrics were highly correlated with realized gain, while heterogeneity metrics did not show consistent relationships. We accurately predicted genetic gain in wood volume at the three sites using a simple modelling approach which paired complementary metrics of mean canopy height and canopy density (adjusted R^2 ranged from 0.86 to 0.94). Our modelling results show the utility of UAV-LS for assessing realized genetic gain in tree improvements programs at the stand level. Additionally, we present a novel

phenotyping platform for selective tree breeding which employs descriptive categories of point cloud metrics to assess differences in stand structure.

Tree breeding, area-based metrics, UAV, LiDAR, phenotyping platform

ALS065D3B3R1

Lasers, cyclones, and the dry rainforest: explorations in mapping and disturbance quantification

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While the plight of ever-wet rainforest is well documented, comparatively little attention has been paid to tropical dry forests — high-biomass, species-rich biomes that thrive in comparatively marginal conditions and hold international significance for both biodiversity conservation and carbon sequestration. These ecosystems are poorly represented in the conservation estate, and are subject to a variety of threatening processes, the interplay of which are not well understood. Within Australia, tropical dry forests reach an apex of biodiversity and extent in the Iron Range region of Cape York Peninsula, where they form complex mosaics with surrounding vegetation that have formerly precluded accurate mapping. We present here an airborne LiDAR based approach to fine-scale tropical forest classification using Convolutional Neural Network techniques developed for medical image analysis. Vegetation types were validated against a terrestrial plot network, while classification accuracy was assessed on-ground and with high-resolution RGB imagery and complementary LiDAR product spot surveys. The combination of machine learning and small footprint aerial LiDAR proved effective in distinguishing between complex vegetation types in closed-forest mosaics. In March 2019, five months after the initial LiDAR survey, the Iron Range forests were heavily impacted by Tropical Cyclone Trevor. Cyclones are large infrequent disturbance events with decadal-scale influences on forest structure and composition, and substantial impacts on carbon storage and sequestration. Despite these long-term changes, short-term recovery of forest ecological function can be relatively rapid in the absence of further disturbances. In the Iron Range area, annual wildfires are a key threatening process. In the months following the cyclone, information derived from the initial LiDAR surveys was used to plan and implement a protective fire regime across multiple land tenures. Overall, the combination of products derived from Airborne Laser Scanning, machine learning, and plot level data has generated new insights into the complex interplay between topography, biomass, diversity, and disturbance events within this region. Results demonstrate the utility of ALS for complex vegetation mapping and provide a workflow for pointcloud analysis. Subsequent use of LiDAR derived products demonstrate their potential as a management tool, and in particular their use in stakeholder engagement, threat assessment, and damage mitigation.

Tropical dry forest, ALS, Riegl Q680-iS, forest classification, mapping, carbon

ALS070D3B3R1

Assimilating laser scanning and Landsat data following classical calibration

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Remotely sensed (RS) data, especially laser scanning data, can be used for accurate predictions of several forest characteristics at the level of stands and plots, as well as for larger regions. A normal procedure is to estimate prediction models from training units (plots or stands) where both field truth and RS data are simultaneously available. The predictive accuracy of such models vary. While they may be very accurate when laser scanning data are applied, they are typically less accurate when optical satellite data are used. Further, such models typically tend to provide predictions that are shrunk towards the mean, i.e. small true values are overestimated and large true values are underestimated. This is a complication that must be tackled when data assimilation routines are applied for making use of the wealth of RS data that is continuously

supplied at low cost though different remote sensing missions. Our work with developing data assimilation methods, at the level of plots and stands, from RS-data based estimates begun in 2012. Although very promising theoretical results were obtained, the results from practical studies have been less promising. One reason might be that we have not yet applied satisfactory methods for reducing the bias that may vary across the range of predicted values for the variable being addressed. In this paper we (i) summarize the initial Swedish experiences from developing data assimilation routines based on RS data, (ii) propose a potential solution to the calibration problem by characterizing the structure of errors in the RS-based predictions and applying classical calibration as an integral step of the assimilation procedures, and (iii) evaluate the proposed framework in a case study where predictions based on optical Landsat and laser scanning data are combined. *Airborne laser scanning, Landsat, data assimilation*

ALS072D3B3R1

Spatial analysis of ultrahigh density LiDAR data for species classification

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Remotely sensed data with LiDAR (Light Detection and Ranging) mounted on low altitude flying platforms UAVs (Unmanned Aerial Vehicles), provide one of the best possibilities and opportunities for forest stand level inventory. In this work, we studied two types of forest stands two broadleaf and two coniferous for evaluation of structural characteristics of point cloud acquired by UAV based LiDAR. Autonomous flights over these stands were performed using perpendicular zig zag pattern with flight speed 6 ms-1 in constant fight altitude of 90 meters above ground with the use of VUX-SYS UAS (Unmanned Aerial System) comprising of octocopter RiCOPTER, VUX-1SYS LiDAR multi return laser scanner with 550 kHz frequency and AP20 multipurpose IMU (Inertial Measurement Unit). The average density of point clouds was 2,000 points per square meter, what allowed for a good point representation of the tree along the whole stem profile. These point clouds consisted mainly from the first return, but also multiple returns were observed up to seven returns of one laser beam in the forest conditions. The individual trees were delineated in ArcGIS (Esri) environment directly from the point clouds using toolbox 3DSample originally created for ALS (Aerial Laser Scanning) data. The delineation used CHM (Canopy Height Model) derived from whole stand digital point cloud and from CHM were delineated horizontal crown projections of single individual trees. For these individual tree point clouds were calculated various metrics based on descriptive statistics methods with regard to point density on Y and Z axis. The final result of this study is a Generalized Linear Model that was derived from the calculated metrics with using Stepwise Regression by combining forward and backward selection. The most significant metrics were found to be Q (quantiles), RMS (Root Mean Square) and especially Clark-Evans index, which is used for describing level of aggregation in horizontal level, where extreme values of this index signify either a systematic horizontal structure, either an aggregated (clustered) points, with a random (Poisson) structure between the two extremes. The Clark Evans-Index explained the difference between the broadleaf and coniferous form of growth, where in different point layers were points aggregated mainly around branches. The other metrics differed mainly due to different sizes and tree crowns bases.
UAS, LiDAR, forestry, species classification, point cloud

ALS087D3B3R1

Impact of simplifying assumptions on plant area density estimation with UAV-based Laser Scanning

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Explicit information on the 3D distribution of canopy elements is important for the study of light distribution and utilisation within forest canopies. However, its characterisation in forests is

hampered by complicated and labours field methods. Active proximal and remote sensing in the form of laser scanning has proven a useful substitute in order to assess 3D canopy structure over large areas in case of Airborne Laser Scanning (ALS) or in great detail in case of Terrestrial Laser Scanning (TLS). Structure is then expressed as 3D distribution of Plant Area Volume Density (PAVD). Nonetheless, retrievals typically need to apply simplifying assumptions, most prominently on the Leaf Angle Distribution (LAD). Principal reason for this is the lack of sufficient number of viewing angles on all locations within the canopy in order to simultaneously invert the gap fraction model for plant area index and leaf angle distribution. Recent specific Unmanned Aerial Vehicle Laser Scanning (UAV-LS) sensors allow the fast collection of point clouds with widely varying viewing angles across plot scales thanks to the moving platform. In this study, we will assess the impact of simplifying assumptions on the retrieval of PAVD by comparing simplified retrievals with retrievals that fully invert the gap fraction model. For this purpose, we collected UAV-LS data with the RIEGL RiCopter with VUX-1UAV system with a field of view up to 330°, maximising the range of viewing zenith angles and surpassing that of typical ALS systems. Data collection took place over a small, mixed forest (200 x 180 m) dominated by oak and birch. The site was visited four times during the leaf flushing period (May to July) to capture different stages of leaf development. For each flight, ≥32 flight lines were acquired in multiple directions in order to maximise viewing angles on the canopy and utilise canopy gaps to observe lower canopy elements. The resulting point clouds will be utilised together with the flight trajectories in order to conduct ray tracing, and count hits and passes of laser pulses for individual volume units (voxels). Subsequently, the gap fraction model will be inverted to retrieve LAD and PAVD per voxel. This will be compared to simplified PAVD retrievals assuming the plant area projection coefficient to be 0.5. The resulting differences will give an indication of the errors to be expected when using simplified retrievals versus full inversions.

UAV-Laser Scanning, Plant Area Volume Density, Leaf Angle Distribution, Forest

ALS100D3B1R1

LiDAR monitoring of canopy clearings after sustainable logging operations in forest concessions in the Amazon

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Sustainable Forest Management has emerged as the best alternative to ensure the continued production of natural resources in tropical forests, but little is known about the level of impact of this activity and the resilience of managed forests. Monitoring of areas affected by selective logging and damage assessment in the remaining stand depends on field surveys. In this study shows how airborne LiDAR technology was used for monitoring the Brazilian Jamari National Forest in the Amazonian state of Rondonia. LiDAR was flown before and after logging, in conjunction with field measurements in ten permanent plots, following the standards set by the Amazon Forest Dynamics Monitoring Network (REDEFLOR). Damage on the remaining stand, as a result of the selective logging operations, was counted as clearances larger than 10 square meters in diameter and less than 10 meters as indicated by metrics extracted from the LiDAR Canopy Height Model (CHM). Before forest logging, natural clearances covered 4.36% ± 1.36% (mean and standard error of the mean) of the area. After logging, clearances represented 12.56% ± 3.15%. However, the clearance effectively due to logging was estimated as 10.40% ± 3.44%. The F test from the analysis of variance detected a significant difference for clearances among assessed areas ($P < 0.05$). The higher clearance observer in the logged forest was confirmed by the Tukey test at 5% probability, indicating that the logging increased significantly clearances due to selective logging, the opening of roads, trails, and patios. The mapping of clearings based on LiDAR showed a good correlation with field observations, as the areas with the highest number of clearings were also the ones with the highest level of field-assessed damage. Area #10, in which logging extracted the largest number of individuals, was the one with the highest percentage of LiDAR detected clearings. Data from area #10 shows that 62

ind.ha-1 were harvested (13% reduction in the number of individuals), 69.8% reduction in biomass (146.56 Mg.ha-1), 64.03% reduction in volume (87m³.ha-1), 58.2 reduction in basal area (8.4m².ha-1) and highest canopy cover reduction (35%). LiDAR technology has shown to be effective for monitoring the impacts of selective logging on Sustainable Forest Management operations in the Amazon, as it has supported the quantification of clearings in post logging operations. Due to the high cost and challenges of effectively monitoring concessionaires in remote areas, it is reasonable to consider the use of LiDAR as a viable forest management-monitoring tool. *Tropical forests, sustainable forest management, damage mapping*

ALS058D3B3R2

Comparison of multispectral airborne laser scanning and stereo matching of aerial images as a single sensor solution to forest inventories by tree species

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Airborne Light Detection and Ranging (LiDAR) data alone is insufficient for species-specific prediction of forest stand attributes. As a result, optical image features (OIF) are commonly used to decrease the prediction errors of species-specific tree attributes. However, such approach requires the acquisition and merging of two data sources, LiDAR and OIF, which increases the costs of the inventory and introduces undesirable complications. Multispectral airborne LiDAR (M-ALS) provides a potential single-sensor solution for obtaining species-specific information, as its multispectral intensity values can be considered to resemble optical image data. Image point clouds (IPC) derived from aerial images via stereo matching are another single-sensor alternative that provides both geometric and optical information. Here, we compared the two new single-sensor alternatives, M-ALS and IPC, with two conventional single wavelength LiDAR datasets (leaf-on and leaf-off) combined with auxiliary OIF, for the prediction of volumes by tree species using the area-based approach. The study was in conducted in a managed boreal forest area in Finland. K nearest neighbor imputation was used to produce the predictions. Predictions were validated in a separate validation data consisting of large (30 m x 30 m) sample plots mimicking stand level inventory. With respect to average root-mean-square error (RMSE) of all response variables (total volume and tree species-specific volumes of Picea abies, Pinus sylvestris and broadleaved tree species, namely Betula pendula and Betula pubescens), the single wavelength LiDAR+OIF combinations performed best (leaf-on RMSE: 33.3%; leaf-off RMSE 34.3%), followed by M-ALS+OIF (RMSE = 35.2%) and IPC+OIF (RMSE = 42.4%). The mean RMSE value associated with M-ALS increased to the same level (44.7%) as the IPC+OIF combination when optical image features were not included. Based on the results, both IPC and M-ALS have potential as single sensor solutions for forest inventories by tree species. IPC data performed better than M-ALS in predicting the tree species-specific volumes, while M-ALS data performed better in predicting the total volume. Neither M-ALS nor IPC, however, performed as well as the combination of LiDAR and optical image features. *Multispectral airborne LiDAR, stereo matching, tree species*

ALS063D3B3R2

Forest canopy cover analysis using UAV-based LiDAR and photogrammetry

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Forest canopy cover was used to describe the vegetation coverage over underneath ground, which could be expressed as the ratio between crown projection area and ground area. It was one of the most important features of stand structure that affected the distribution of environmental factors such as light, water, etc. The Unmanned Aerial Vehicle (UAV) based Light Detecting and Ranging (LiDAR) and photogrammetry had been used to describe the three dimensional spatial structure of vegetation. Laser pulses could penetrate forest canopy and obtain more accurate terrain elevation than that from stereo photogrammetry. The Digital

Terrain Model (DTM) with LiDAR was used to generate height Normalized Point Clouds (NPCs) and canopy height models (CHMs) based on the point cloud of LiDAR and reconstructed dense point cloud of photogrammetry. This study is aim to compare the forest canopy cover estimated by LiDAR and photogrammetry. The results showed that the forest canopy cover using LiDAR-based CHM was highly correlated with that using photogrammetry-based CHM. It indicated that photogrammetry-based CHM had similar effect on forest canopy cover as LiDAR-based CHM. The forest canopy cover using photogrammetry-based CHM was highly correlated with that using photogrammetry-based NPC. This meant that reconstructed point cloud of photogrammetry were mainly distributed on the upper canopy of forest. It was difficult to detect low vegetation and forest floor using photogrammetry. The mean value of forest canopy cover using LiDAR-based CHM was slightly lower than that using LiDAR-based NPC with single and first returns. This might be due to that larger scan angle of LiDAR has higher effect than the interpolation of CHM using point cloud. Meanwhile, the mean value of forest canopy cover using photogrammetry-based CHM was a bit higher than that using photogrammetry-based NPC. This meant that interpolation of CHM using reconstructed point cloud of photogrammetry had slightly overestimated forest canopy cover. The correlation between forest canopy cover values using photogrammetry-based CHM and photogrammetry-based NPC was very high. This discovered that photogrammetry-based NPC had very similar characteristics with photogrammetry-based CHM. The CHMs based on LiDAR and photogrammetry were tend to overestimate forest canopy cover because the interpolation of CHM that might fill the gaps within crowns or between crowns. Larger scan angle would easily obtain more returns from crowns than from within crown gaps and between crown gaps, and introduce significant error on forest canopy cover estimation.

UAV, LiDAR, photogrammetry, canopy height model, point cloud

ALS071D3B3R2

Understanding the forest structure by utilizing full waveform LiDAR data

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In order to understand the spatial forest structure in more detail, visualizing the three-dimensional structure, including gap within the forest which refers to the space where there are no branches, leaves, trunks, etc., is believed to be effective. This study focused on utilizing low reflection data obtained from full waveform LiDAR to visualize the spatial distribution of gap within the forest. The Full waveform LiDAR data records the distribution of features on the path of the irradiated laser pulse as the time series of the reflection intensity. Of the series of waveform data, high reflection data is considered to be due to reflection from a canopy or ground surface. On the other hand, low reflection data is considered to be the weak reflection by branches and leaves or noise, which indicates that reflection from features is almost nonexistent. This low reflection data can be divided into two types. The first type is when existing features cannot be distinguished since the laser pulses are all reflected from the canopy, and it seems that there is no reflection. Therefore, high reflection data and low reflection data were extracted from the waveform data and classified into "FEATURE", "GAP" and "UNKNOWN" based on the above principle, and then the hierarchical structure diagram was created. As a result, it became clear that the spatial distribution of the gap within the forest can be visualized by utilizing low reflection data obtained from full waveform LiDAR. In addition, the result suggests that the structure of the forest could be understood more clearly by visualizing the gap within the forest.

Full waveform LiDAR, Hierarchical tree structure, Voxel

ALS073D3B3R2

Exploring very high resolution UAV-Laser scanning for above-ground biomass estimators

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Aboveground biomass (AGB) estimations are becoming crucial, because they indicate forest functioning and play an important role in mitigating climate change as trees sequester vast amounts of carbon. Traditional forest inventories, in combination with allometric scaling equations, estimate AGB based on tree biophysical parameters such as tree height and diameter at breast height (DBH). These methods tend to be biased for large trees. Laser scanner methods have a tremendous potential to accurately estimate AGB from 3D forest structure, but there is a trade-off between scalability and level of detail. While spaceborne laser scanning covers large areas with a large footprint, terrestrial laser scanning (TLS) operates at plot scale with very high detail. On the other hand, Unmanned Aerial Vehicle laser scanning (UAV-LS) has the capacity to bridge the gap between scalability and level of detail, because UAV-LS can cover large areas with high return pulse densities. This study explores UAV-LS -based estimators for AGB. This study uses high detail UAS-derived data (pulse density > 200 p/mÂ²) that covers a 26 ha plot in a sub-tropical forest in Australia. Forest inventory data is used as validation. Well established airborne laser scanning (ALS)-based AGB estimators, such as height of median energy (HOME), and new UAV-LS derived estimators will be compared to proxies for AGB, such as DBH. Furthermore, this study assesses to what extent tree segmentation methods are convenient for UAV-LS in tall and dense canopies. This study will derive alternative UAV-LS -derived metrics in (dense) sub-tropical forests that will enable AGB estimation at scales relevant to satellite footprints, which ultimately has implications for understanding forest functioning and increases accuracies for national biomass-inventories.

UAV laser scanning, LiDAR, biomass, above-ground biomass, forest inventory

ALS077D3B3R2

Assessing the role of vegetation structure and foliage characteristics as drivers of avian diversity

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Avian diversity has long been used as a surrogate for overall diversity of an ecosystem. This study examines how structure metrics from LiDAR data and narrowband indices from hyperspectral data relate with avian diversity. The aims are to compare the capabilities of both data sets in identifying the drivers of diversity, and to gain insight on which features of vegetation structure, condition, and potentially composition are most important for determining avian diversity. This was assessed in four deciduous-dominated woods with differing age and structure set in an agricultural matrix in eastern England (52°25’13.5" N, 0°12’34.0" W). The four woods were: Riddy Wood (9.4 ha), Lady’s Wood (8.4 ha), Raveley Wood (7.2 ha), and Gamsey Wood (4.9 ha), and they were visited four times from late March to early July 2014 for bird survey. The woods were delineated into 333 cells of size 30 x 30 m within which metrics of avian diversity and remote sensing based predictors were calculated. The selected avian diversity measures were the Simpson index, Shannon index, and species richness (i.e. species number). Hyperspectral and LiDAR data were both collected on June 1st, 2014 (leaf-on conditions) during a single flight using a fixed-wing aircraft flown at an altitude of 1600 masl. The LiDAR sensor on board the aircraft was a Leica ALS50-II that scanned the area with a field of view of 20°, a pulse repetition frequency of 143.7 MHz, and a pulse footprint on the ground of ca. 35 cm. Hyperspectral data were collected with Specim’s Aisa Fenix sensor, which collected data from 620 spectral bands across wavelengths between 380 and 2500 nm at a spatial resolution of 2 m. In total 16 LiDAR metrics and 17 hyperspectral indices were used in best subset regression to obtain the optimum LiDAR-only models, hyperspectral-only models, and combined models. The amount of understorey vegetation was the best single predictor, followed by foliage height diversity, reflectance at 830 nm, anthocyanin reflectance index 1, and Vogelmann red edge index 2. This showed the significance of the full vertical profile of vegetation, the condition of the upper canopy, and potentially tree species composition. The results thus agree with the role that vegetation structure, condition, and floristics are assumed to have for diversity. However, the inclusion of hyperspectral data resulted in such minor improvements to models that its collection for these purposes should be assessed critically. *LiDAR, hyperspectral, biodiversity, ecology, habitat*

ALS131D3B3R2

Retrieving the stand volume of Scots pine stands using an allometric model applied on ALS-derived auxiliary metrics

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Reliable information concerning stand volume (V) is fundamental to making strategic decisions in sustainable forest management. Airborne laser scanning (ALS) point clouds are widely used for the estimation of stand volume (V) and forest biomass using an area-based approach (ABA) framework. The proposed method relies on the reference measurements of field plots with the prerequisite of a precise co-registration between a ground reference and the ALS samples. In this research, the allometric area-based approach (AABA) is proposed in the context of the V estimation of Scots pine stands. The proposed method does not require information about the coordinates of training set field plots. The Polish National Forest Inventory (NFI) data from 8 190 circular field plots (400 m2) were used for the development of a plot level allometric model for V using independent variables, obtainable by using ALS point cloud metrics: top height (TH) and relative spacing index (RSI). The hypothesis was that, in case of Scots pine stands, the field measurements of TH and RSI could be replaced with their ALS-derived proxies. Performance of the developed AABA model was compared to the semi-empirical ABASE (with two predictors: TH and RSI) and empirical ABAE (number of point cloud metrics as predictors). The models were validated at the plot level using 315 forest management inventory (FMI) plots (400 m2) and at the stand level using the complete field measurements from 42 Scots pine dominated forest stands in the Milicz forest district (Poland). The AABA model showed a comparable accuracy to the traditional ABA models. The proposed approach is novel and, in comparison with the classic ABA method, reduces time- and cost-consuming fieldwork without a significant reduction in the accuracy of V estimations. *Allometric area-based approach (AABA), airborne laser*

Poster Presentations

ALS006TV1

Fine-scale prediction of yield in sugarcane: A comparison of UAV-derived LiDAR scans and multispectral imagery

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Unmanned Aerial Vehicle (UAV) platforms and associated sensing technologies is a rapidly developing field being extensively used in precision agriculture and farming. Using 3D LiDAR and imaging sensors mounted on small rotorcraft UAVs we can observe fine-scale variations in crops that can help improve the efficiency of fertilizer inputs and maximize yields. In this study we use a combination of LiDAR and multispectral imaging sensors mounted on a DJI M600 Pro quadcopter to map multiple sugarcane nitrogen (N) fertilizer rates field trials in the Wet Tropics region of Australia throughout the 2017-2018 growing season. The LiDAR scans were collected using Velodyne's VLP-16 sensor and processed using Simultaneous Localization and Mapping (SLAM) algorithm, while multispectral imagery was collected using Micasence RedEdge sensor and processed using Pix4D software. From UAV surveys performed every 42 days we generated a time-series of structural and spectral characteristics of the sugarcane crops allowing us to monitor crop growth in terms of height, density and vegetation indices (e.g. normalized difference vegetation index (NDVI)). Furthermore, we created predictive models of sugarcane yields, allowing us to infer the stage at which it is possible to derive reliable at-harvest yield predictions from UAV-derived data at fine scale. The field data for informing UAV-derived data using multiple regression analysis was collected in 2 m transects across crop rows, where sugarcane was cut and weighed for total, leaf and stalk (i.e. yield) biomass. Our preliminary results suggest that LiDAR and multispectral imagery have similar performance in predicting at-harvest yield throughout the growing season, while their combined use increased R2 and decreased RMSE values by 0.08 and 0.5 kg, respectively. The combined use of LiDAR and multispectral imagery resulted in most accurate sugarcane yield prediction models with R2 of 0.63 and RMSE of 4.5 kg at both 100 and 142 days from planting (DFP), which gradually decreased to 0.35 and 6 kg at pre-harvest (i.e. 268 DFP). Interestingly, our predictive models based on N application rate, soil type and NDVI information alone performed about as well as the models based on the combination of LiDAR and multispectral imagery throughout the growing season with highest R2 of 0.6 and RMSE of 4.7 kg at 100 DFP. However, the main advantage of using LiDAR and multispectral imagery in combination is the ability to predict yield in the absence of site-specific information. Our results are of particular interest to nutrient-management programs aiming to deliver soil- and site-specific N fertiliser guidelines for sustainable sugarcane production, as fine-scale yield predictions are feasible when management interventions are still possible (i.e. as soon as at 100 DFP).

Sugarcane, UAV, LiDAR, multispectral imaging, biomass, yield, nitrogen, fertiliser

ALS028TV1

ALS-derived indicators for monitoring sustainable forest management

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Monitoring sustainable forest management (SFM) is an important step to verify the recovery of the forest ecosystem after a logging intervention. To overcome limitations associated with multispectral images to SFM monitoring, applications based on airborne laser scanning (ALS) technology are becoming more popular in the forest sector. The laser beam is capable to record information from different layers of the canopy, generating a geo-referenced point cloud. This study verified the capability of four indicators to differentiate the production unity logging stage. Seven annual production units (PU) locate in the western Amazon (Paragominas, PA, Brazil) were

classified into 3 groups based on logging stage: non-logged, 2 years after logging and 5 years after logging. The indicators evaluated were the number of emergent trees (TOP), average above-ground biomass per square meter (AGB), the proportion of clearings per hectare (GAP), and the proportion of low relative density area per hectare (LRD). The indicators were calculated individually for each PU. Higher differences between stages were observed for GAP and LRD. In another hand, AGB and TOP were less sensible to the logging stage. In unlogged PUs, the TOP indicator was in average 5.33 individuals per hectare. Two years after logging the value decrease by 9%, and 5 years later the TOP returned to the same level of unlogged sites. The AGB for unlogged areas was 36.2 Kg/m². Two years after logging the AGB decrease by 11.41% and by 13% after 5 years, reaching 31 kg/m². LRD increased 113.3% two years after logging, moving from 1.7% to 3.6%. Five years after logging, LRD returned to a similar level of the unlogged sites (~ 2%). GAP increased two years after logging by 104% and five years after logging by 200%. Unlogged units showed on average 2.5% of clearings, increasing its value five years after logging to 7%. GAP and LDR were the most sensitive indicators to monitor recently logging stages. Both indicators are clearly associated with logging activities such as the opening of trails, roads, and tree falling. The indicators were able to differentiate the logging stage, however, they differed regard to sensitivity. *LiDAR, remote sensing, tropical forest*

ALS040TV1

Detection of Sub-Canopy Forest Structure Using Airborne LiDAR.

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Knowledge on forest structural is vital for making sound forest management decisions. Currently, airborne LiDAR data has been well established as a tool to delineate and analyze the structure of forest canopies worldwide. However, what remains less well known is information on the forest sub-canopy. Sub-canopy structure consists of regenerating saplings, shrubs, herbs, snags and coarse-woody-debris. With the increasing density of LiDAR footprints, new opportunities exist to describe these sub-canopy structural components in forests that were previously overlooked by other remote sensing technologies. In this research we use discrete return airborne LiDAR acquired at a density of 22/ppm to estimate sub-canopy forest structure for 50,000 hectares of forest area in northern British Columbia, Canada. In order to do this we first segmented the forest into canopy and sub-canopy based on Lorey's mean height. Lorey's height is a weighted average based on basal area and provides a more stable representation of stand height compared to an unweighted mean height as it is less affected by large numbers of smaller trees. Once Lorey's height was established we defined the threshold between canopy and sub-canopy as 10% less than Lorey's height. Both ground truth forest inventory data and the LiDAR point cloud were then segmented into canopy and sub-canopy components. A mixture of standard height based and density based LiDAR metrics were then computed to develop models to predict sub-canopy component of the stands. Models were cross-validated through a forward stepwise regression with the strongest predictors being P95, leaf area density and vertical rumple. The vertical rumple in particular describes the complexity of the vertical structure of the stand. Using the selected metrics, linear regression models were developed that predicted the basal volume and basal area of sub-canopy trees with R-squared = 0.72 and 0.63 respectively. We then applied these models over the entire study area by generating 20m wall-to-wall metrics to estimate stand-level sub-canopy basal volume and area. These results can be used by forest managers to determine future timber supply and candidate locations for selective logging. Additionally, theses attributes can be used to identify fuel loads and potential presence of ladder fuels for fire susceptibility assessments. *LiDAR, ALS, Forest Structure, Under-story, Sub-canopy*

ALS043TV1

Studying tree growth based on multi-temporal ALS data

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Tree height is one of the most important parameter describing a tree. In traditional forest inventories (FI), the heights of the sample trees are measured with e.g. a vertex. Due to the increasing availability of airborne laser scanning (ALS) data, the estimation of tree heights is no longer limited to the sample plot level only but possible on area-wide level. Based on multi-temporal ALS data, the growth of individual trees can be studied on a wall-to-wall level, which allows new insights into tree growth in relation to sea level, slope, aspect, crown cover and tree height. To extract the growth of individual trees, several processing steps are required such as detecting tree positions, finding identical trees, and extracting the tree heights from each ALS data set of different acquisition times. Based on georeferenced ALS points, digital surface models (DSMs) are calculated based on a land cover dependent approach combining the strength of different algorithms (i.e. highest laser echo within a raster cell or moving least squares interpolation with a tilted plane as functional model). As the accuracy of the height differences is strongly related to georeferencing accuracies of the individual ALS data sets, a quality check is done by calculating the DEM-of-Difference (DoD) models of individual DSMs epochs for stable and smooth surfaces (e.g. open land, street, roofs). Do minimize the height differences to few centimeters, least square matching (LSM) of the DSMs is performed on a tile-base. The derived 3D-shifts are applied to the older ALS data sets whereas the newest ALS data is used as master DSM and will not be changed. The detection of trees is based on local maxima search on the DSM and is performed for each ALS data set separately. In a following processing step, corresponding trees are selected that are present in each ALS data set. Finally, the tree heights, the growth and several topographic features (i.e. sea level, slope and morton aspect) derived from the digital terrain model, and the crown cover derived from the canopy height model are extracted for each tree. Additionally, the top height is calculated by averaging the heights of the 100 highest trees in a one hectare circular surrounding. The described approach was applied for the entire area of the federal district of Vorarlberg in Austria. For this 2600 km² region, multi-temporal district-wide ALS data are available from 2005, 2011, and 2017. The derived results were quantitatively validated against the available FI data by comparing the estimated tree growth for the individual FI plots. Based on machine learning techniques, the relation between tree growth, tree height, topographic features, and crown cover were studied. The outcomes demonstrate that multi-temporal ALS data sets are an excellent data source for studying tree growth and consequently for assessing the site index in an operational context.

Tree growth, ALS, top height, forest inventory, modelling, tree height

ALS044TV1

Method Comparison for the Assessment of Vertical Structure from ALS Data in Natural Forests

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In the light of climate change and the related risks to forests, today more and more foresters tend to re-structure their forests “back” to a more natural state, which gives the forests higher resilience against wind-throw, drought and insect infestations. In addition, national park managers have legal obligation to prove, that their forests remain in their supposed natural state by repeated monitoring over time. In order to assess the success of forest management measures that intend to work in this direction objective and effective tools should be at hand. Forest status assessment is currently done by point-wise field assessments, which are time-consuming and thus costly and error-prone and subjective, all at the same time. ALS can provide the needed information area-wide and in an objective manner. This paper provides basic investigations on methods to monitor the vertical structure as one important indicator of the “naturalness” of the forest for a larger area. We have investigated a mixed forest in the Kalkalpen National Park in Austria by means of airborne LiDAR data. We evaluated three different sets of spatial reference units to calculate vertical structure: simple raster, automatically generated image segments and overlapping circles. Further, we compare, if the height distribution of the LAS returns or the height distribution of detected tree tops perform better in the assessment of the vertical structure. Finally, different classification methods including thresholding procedures, expert-based classification, regression analysis and random forest classifiers were compared for the purpose of classifying vertical stand structure. The individual results were evaluated against independently gathered reference field data. The results showed that simple, non-overlapping raster is an insufficient basic unit. Non-overlapping, automatically generated segments and overlapping circles showed similar results depending on the classifier. As for the use of LAS returns versus tree tops, the results are ambiguous: while forests with lower density and thus a low crown base height, methods based on LAS returns tend to confuse low branches with small trees. In contrast, when using detected tree tops, understory trees are often omitted. Therefore, future work should be dedicated to the combination of both approaches. The overall best result was achieved using the segments and the LAS returns with an overall accuracy of 89% after plausibility check. However, this evaluation was done in an area with very few one-layered stands (= stands with low vertical structure). When expanding the reference data set to include more one-layer stands, the same method still achieved 73% overall accuracy, third to the same classification method, but using tree tops yielding 77%. In our analysis, the expert-based classification method performed best, followed by thresholding procedures. The regression-based method and the random forest classifier achieved comparably lower accuracies. One reason could be the amount of training data, which was limited due to limited field work available. More tests with extended reference data should be performed to unleash the potential, which might be inherent in machine learning and other AI classification approaches. Our results form the basis for an area-wide assessment of vertical structure as one main indicator in the monitoring of the naturalness of forest ecosystems both in managed as well as in protected forests. *Vertical structure, naturalness of forest, ALS*

ALS046TV1

Define northern interior old-growth forests with airborne LiDAR

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Forests in their later stages of development attain attributes that support biodiversity and provide a variety of benefits to human populations. Despite their irreplaceable values, old-growth forests are declining worldwide due to anthropogenic pressures. Conservation approaches to maintain old-growth forests do exist, such as Old-growth management areas (OGMAs) in British Columbia, CA. Currently, OGMAs are mainly defined by estimates of forest age. However, it is uncertain if this selection strategy suitably identifies forests with characteristics/attributes expected in old-growth forests. In this work, we developed a range of old-growth indexes that capture multiple forest attributes associated with old-growth forests. We then developed LiDAR-derived metrics that we utilized with a random forest (RF) modelling framework to model old-growth forest attributes across the landscape. We designed three RF models in classification mode using field estimated classes as response variables: (1) age classes (54% accuracy), unsupervised classification of old-growth attributes (2) with age (69% accuracy) and (3) without age (68% accuracy). In addition, we designed three other RF models in regression mode with field estimated (4) stand age (R2: 35%), an old-growth index (5) with age (R2: 71%) and (6) without (R2: 71%). We found that for both classification and regression models, age was not a crucial attribute, as age alone were not well predicted in neither classification nor regression models. As well, we found that excluding age did not significantly reduce the overall model's performances. Based on a combination of model performance and simplicity of the models themselves, we selected a LiDAR-derived model (model 6) to scale up the old-growth index from plot to landscape level. Using this model we found that 14.7% of the study area is covered by forests with high old-growth values. Inside the currently designated OGMAs' areas, the "old-growth" cover is 24.9%, indicating that OGMAs are retaining forests with some high old-growth value. However, only 2.5% of the OGMAs have more than 50% of its area covered by forests with high old-growth value. This research brings light to old-growth and OGMAs' definition and their assessment through the use of fine scale remotely sensed data, LiDAR. More importantly, the identification of the amount and location of old-growth forests over the landscape can aid to the conservation of this rare resource and its services. *Community forest, conservation, old-growth forests, airborne LiDAR*

ALS082TV1

Forest growth monitoring using bitemporal areal LiDAR data: case study of national park Czech Switzerland

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Growth from remote sensing can be assessed based on repeated measurements (separated by an interval of time) of the same tree or the same stand. The temporal differences in the remotely sensed data usually directly or in some other manner indicate the growth. Such studies make sense particularly in protected areas, i.e. areas where there is no human intervention or management and temporal changes are driven only by natural development of the forest. Growth dynamics assessment from remotely sensed data has been addressed by many authors (Maltamo et al. 2007; Næsset and Gobakken 2005; Tompalski et al. 2016; Yu et al. 2008), who evaluated the use of remote sensing data to estimate changes in stand characteristics such as: height, diameter, basal area, but also the volume or site index. The aim of the research is to evaluate the growth dynamics from bitemporal three-dimensional data obtained with repeated laser scanning and photogrammetric methods from aerial images. In the research are used historical data from the National Park Czech Switzerland with area approximately 80 km2, which was acquired in April 2005 by the Technical University of Dresden, Germany. The data were acquired using aerial laser system Falcon II. The average flight altitude was 1200 m above ground with 50% overlap. The final data represent the first and the last reflection of each pulse. The average density of the last reflection points was 8.5 points / m2 (Trommler & Csaplovics, 2006). The repeated data collection was carried in April 2019. LiDAR Leica ALS70-CM and multispectral camera Leica RCD30 Series was used in our data acquisitions. Flying height was from 579 to 1069 m above ground level (AGL) and laser pulse rate was used 231 kHz. The point density of the laser scan was 5 points / m2, FOV angle is no more than 50 degrees. The flights were made with longitudinal overlap of at least 80%, transverse overlap of at least 50% and average image resolution of 12.5 cm. As large-scale verification data covering the whole area, we used forest management plan, which includes the repeated stand inventory. Moreover, detailed ground verification data are collected in the field, including the cores for diameter growth estimation. This study presents the methodology for growth dynamics assessment and describes the advantage and disadvantage of each type of the data. Resulting increment maps and overall summary estimation for dominant species are presented. *LiDAR, point cloud, forestry, segmentation, diameter*

ALS096TV1

Qualification of emergent trees extracted from LiDAR point cloud in the Amazon forest

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Before any logging operation in Brazilian native forests, managers are required to provide location and volume for all commercial trees above 50 cm of DBH. A census and a map geolocating all these trees is also required. The forest census is time consuming and expensive. This research aimed to qualify how many commercial trees are able to be detected by airborne laser scanning (ALS). To validate the trees extracted from LiDAR point cloud, we used an inventory dataset from 22 one-hectare plots. The study area is located in Paragominas, state of ParÃ¡, Brazil. Every tree within the plots with DBH larger or equal to 35 cm had its diameter, height and canopy radius measured and its geographic coordinate recorded. Additionally, the stem quality and canopy position were also determined. We used in our analysis a subset of the collection of measurements, as we only considered trees with DBH â‰¥ 50 cm. An ALS assessment flown in 2012 coincided with the inventory. We applied the maximum local (ML) algorithm to individualize the emergent trees, extracting also height and canopy radius. Key points indicated the presence of a tree if located by the ML algorithm and validated by the uncertainty index threshold. The uncertainty index was a function of (i) the horizontal distance to neighbor trees, (ii) the difference between canopy size estimated by LiDAR and measured in the field, and (iii) difference between LiDAR and field recorded height. From the 504 trees (DBH â‰¥ 50 cm) coming from 96 different species found in field plots, LiDAR was capable to locate 217 individuals coming from 69 species (considering an uncertainty index threshold of 9). From the 69 species, 25 were considered as commercial species. According to the structural analysis, 12 species listed as highest importance values (IV) from LiDAR plots were included between the 15 highest IV species from field plots. LiDAR sampling missed 57% of total trees (DBH â‰¥ 50 cm), however, maintaining a similar forest structure. Our results demonstrated that the total emergent trees located by LiDAR are enough to plan the logging, and could be an alternative to the forest census.

Forest structure, Uncertainty index, Airborne laser scanning, Forest management

ALS083TV2

Deep Learning based single tree species classification using ALS data

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In recent years, Deep Learning (DL) has become the core technology in machine learning (ML) and has gained popularity in a variety of applications. Due to the great success in other fields of application (computer vision, robotics etc.), DL approaches have also got much attention of the remote sensing community. Adopting and combining DL and LiDAR (Light Detection And Ranging) technologies opens up new possibilities, especially for solving more complex problems like the individual tree species classification based on ALS (Airborne Laser Scanning) data. Our approach uses various strategies (for pre-processing) and DL approaches to perform the tree species classification based solely on the geometric properties of the individual trees that exist in the ALS data. The process starts with the automatic detection of single trees from the ALS data. This makes the basis for the subsequent pre-processing and the tree species classification. The pre-processing step involves the extraction of individual tree point clouds (of tree crowns) from the ALS data. The data (point clouds - x, y, z) extracted in this way can be used directly as input for the deep learning process. Depending on which DL approach has been selected, an additional transformation into raster could be necessary. Based on the type of input from pre-processing (2D raster or 3D point cloud) two different DL based approaches were developed for further processing. In case of 2D rasters, several existing network architectures (Inception V3, VGG16) were re-trained to perform the classification by transfer learning. Furthermore a proprietary network architecture was developed. For 3D point cloud data, two different network architectures (PointNet ++, PointCNN) were used and trained from scratch for the new task. The ALS data used covers a mixed forest area (2 x 9 km) in Burgau, Austria, with different tree species, the most common being spruce and pine as well as some deciduous tree species (beech, oak, birch, ash and alder). The classification is successfully performed for these three different tree species. The classification accuracy ranges from 70 % to 90 % depending on data type, network architecture and tree species. Our results also show that using the point clouds directly (without the transformation to raster) gives better accuracies, especially in the case of PointCNN network architecture.

Machine learning, deep learning, Forestry, tree species classification, ALS

ALS089TV2

Altimetric evaluation of ground models of ground models from ALS over loblolly pine stands

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Filtering ground points is an important step for Airborne Laser Scanner (ALS) datasets. The accuracy of the DTM generated influences the precision of information extraction and is strongly linked to the filtering method used. This work aimed to compare different filtering methods in relation to a parametric model obtained with a total station, in 16 years old loblolly pine plantation with density of 1,275 trees.ha-1, in order to check the accuracy of the generated models. A total of 200 points were collected with total station for generating the parametric model by means of the open polygonal supported by two control points method. We selected three ground filtering methods were evaluated over the ALS dataset (Kraus & Pfeifer, Adaptive Triangular Irregular Network (ATIN) and Chen's Morphological). The terrain points were modeled as a continuous surface through the Inverse Distance Weighted (IDW) interpolator and the evaluation was performed by visual analysis contour lines of 0.50 m equidistant and statistical analysis of error. Our results showed that all selected filters underestimated the ground height values. values of the heights. The differences of maximum and minimum height in the parametric model reached 14.96 m. The ATIN and Kraus & Pfeifer filters had a similar performance as the minimum and maximum heights with a difference of 14,02 m and the Morphological filter had a difference of 13,31 m. By analyzing the contour lines, the Kraus & Pfeifer and Morphological filter presented many noises, meaning presence of remaining vegetation in the DTM, in which the ATIN filter was the most efficient, with less noise of remaining objects. All the filtering methods homogenized areas with lowest elevations which were not detected during the filtering process. The errors for the highest height were 0.19% for the Kraus & Pfeifer and ATIN filter and 0.25% for Morphological filter. The lowest height was 0.09% for all tested methods. Based on the evaluation methods of this study, the ATIN filter obtained the best performance, mainly by providing the smaller noises. The existence of sub-forest as well the lack of silvicultural treatments hampered the penetration of many laser pulses into the ground, increasing the errors when compared to the parametric model. This study was sponsored by CAPES, CNPq and FAPESC. The ALS data were provided by the Sustainable Landscape Project. *LiDAR, forest plantations, topography, total station*

ALS092TV2

A comparative assessment of the area-based approach and individual tree detection for volume estimation in mixed temperate forests using Airborne Laser Scanning data

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The study presents the steps taken so far to develop a method for assessing the stand volume based on Airborne Laser Scanning (ALS) data for mixed forest stands in the temperate climate of southwest Romania. For this purpose, several dendrometric parameters (i.e. height, dbh) were extracted or predicted from ALS data by the use of two methods, individual tree detection (ITD) and area-based approach (ABA), respectively. A computer-assisted field inventory system (Field Map) together with a high accuracy GNSS receiver and a Vertex inclinometer were used to collect the reference ground data from four one-hectare (100 x 100 m) mixed tree species plots. The main tree species within each plot are Norway spruce (*Picea abies*) and Beech (Fagus sylvatica). For the ITD approach ALS data were used to extract the digital terrain model (DTM), digital surface model (DSM) and the normalized canopy height model (CHM). A local filtering algorithm with a canopy-height based variable window size was applied to identify the position, height and crown diameter of the individual tree within each plot. The dbh was predicted by a linear regression model that relates field dbh for each tree with their corresponding ALS-derived tree height and crown diameter. The ALS-predicted dbh and the derived tree height were used for tree volume

computation, and the stand volume is calculated as the sum of the individual trees' volumes inside each plot. The overall root mean square error (RMSE) calculated for all the plots between field measured tree volume and their corresponding tree volume identified using the ITD method was 0.48m3. The ABA method consists of using regression models for the estimation of stand volume directly from the ALS point cloud metrics. In this study the predictor ALS variables were height percentiles (hp20, hp60, hp80) and canopy relief ratio. The total wood volume of the identified trees based on ITD method represented 52-71% from the total volume calculated by field measurements and specific methods. In the case of ABA, the total wood volume predicted based on represented, for one plot, 91% from the total volume calculated by field measurements. The results of the ABA methodology applied in the mixed temperate forests of Southwest Romania indicate a better estimation of the total wood volume than the one obtained by use of ITD method. *ALS, area based approach, individual tree detection, forest parameters*

ALS093TV2

The use of very dense ULS and ALS point clouds in monitoring the effects of protective treatments carried out in Scots pine (Pinus sylvestris L.) stands in the National Park Bory Tucholskie, Poland

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Detection of changes taking place in stands and on individual trees in their 3D space has become possible with the appearance of very dense clouds of LiDAR points that can be achieved through the use of ULS (Unmanned Laser Scanning) platforms. The aim of the presented project was to compare parameters (solar energy reaching the ground under the canopy) and selected taxation features (number of trees, tree height, canopy cover and other) stands after applying active protection activities in the protected area in the Bory Tucholskie National Park. The research experiment consisted in thinning in pine stands (Pinus sylvestris L.) to ensure protection of lichens that require direct access to solar light. In 2018, a gyrocopter was used with a RIEGL VQ-580 scanner, thanks to which it was possible to obtain about 90 pts/m2 in the research area of about 13 ha. The flight was performed at 250 AGL with speed 28m/s and overlap 30% of 8 strips.The classified point clouds were used for generating altitude models and determining the number of trees and shortening stands. In 2019, after thinning, flights were made using the RICOPTER platform and the RIEGL VUX-1 scanner, reaching the average density of points at 300 pp / m2. Comparison of both sets of LiDAR data (Gyrocopter / ULS) allowed to calculate the change in the canopy cover parameter and the insolation reaching the ground. The results confirmed the performance of thinning works in stands (a canopy cover by about 30%). At the same time, for individual pines, the height increase reached an average of 27cm in the period from 08.2018-09.2019. Attempts have also been made to compare the number of tree trunk detection results based on ULS point clouds compared to TLS reference data. The experiment confirmed the right choice of the ULS platform, which with high precision (RMSE XYZ approx. 1-2 cm) achieved the acquisition of LiDAR point clouds with a density of approximately 300 pt / m2.

ALS097TV2

Multiscale 3D-windows for detecting dead standing Eucalyptus from voxelised full-waveform LiDAR data

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Dead Eucalyptus camaldulensis are an important for preserving biodiversity in native Australian forests. Nevertheless, detecting Eucalypt trees from LiDAR data acquired from native Australian forest is a challenge due to its big spatial resolution, the variance density of trees and the high standard deviation between tree heights. Most studies first perfom tree crown delineation and afterwards classify trees as dead or alive. Tree crown delineation is usually performed by detecting local maxima from the canopy height model (CHM) and then segmenting trees using the watershed algorithm, but Eucalypt trees has multiple trunk splits making tree delineation difficult.

Shendryk et al, 2016, published an interesting Eucalyptus delineation algorithm that performs segmentation from bottom to top, but pulse density was 36 points/m2 around forested areas (expensive to acquire for big spatial resolution). This study improves the approach presented at Miltiadou et al, 2018, where it was showed that detection of dead standing Eucalypt trees without tree delineation is possible. Miltiadou et al, 2018, uses 3D windows to extract composite information characterising dead trees and then performs machine learning approaches (weighted-distance KNN with Random Forest) for 3D object detection (dead trees). This study introduces detection of dead standing Eucalypt trees using multi-scale 3D-windows for extracting composite information and consequently tackling height variations. By cross validating the algorithm implemented, it is shown that the multi-scale 3D-windows approach improved the precision (TP/(TP+FP)) and recall (TP/(TP+FN)) of predication.

Full-waveform LiDAR, forestry, biodiversity

ALS099TV2

LiDAR assessment of biomass changes in sustainably managed timber harvesting areas in the Amazon

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Estimates of biomass and carbon stocks associated with Reducing Emissions from Deforestation and Forest Degradation (REDD) require reliability and accuracy of information. Since obtaining field variables consumes time and resources, the study of alternative methods has made it possible to extract information from forest areas reliably. The LiDAR (Light Detection and Ranging) airborne laser system provides three-dimensional information about the earth's surface. The aim of this study was to test the use of LiDAR data to estimate changes in above ground biomass (AGB) associated with logging management in Jamari National Forest, Rondonia, Brazil. Overflights occurred before and after logging, together with field collections in ten permanent plots, according to the methodology of the Amazon Forest Dynamics Monitoring Network (REDEFLOR). Changes in AGB and canopy cover were observed after exploration and correlated to fit a regression model. Predictor variables of the model were evaluated for correlation and normality assumptions, by Pearson and Lilliefors tests, respectively, and by graphical analysis of the residuals. Then, the model was evaluated by the performance of the regression statistical parameters and significance of the coefficients by the F test. A linear equation was generated from the field-collected AGB (dependent variable “Y”) and the estimated canopy coverage with LiDAR data (independent variable “X”). The average forest canopy AGB reduction was 21.36 Mg.ha-1 (8.9%) and the canopy cover reduction was 0.08 ha (8.2%), showing a high correlation (0.88; p-value> 0.05) with normal distribution among the variables. The model was considered satisfactory, as it presented good statistical results such as: R2 of 0.77, Raj2 of 0.74, RMSE of 21.10 Mg.ha-1 and F test of 27.21. Based on the graphical analysis of the residues it was not possible to identify over or underestimation. This work demonstrates LiDAR's potential for quantifying changes in AGB stocks in logged forests, indicating that the method can be a valuable tool for REDD-related AGB and carbon monitoring systems. Due to the difficulties associated with fieldwork in remote areas and the high costs, it is permissible for remedies to be obtained with LiDAR data. In future studies, we recommend that overflights and field measurements remain constant. This will provide a higher level of confidence in the predictions of AGB changes.

Monitoring, tropical forests, canopy cover, carbon, airborne laser scanning

ALS109TV2

The Impact of Point Density for the generation of LiDAR derived Terrain Models

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The aim of this study is to evaluate the impact of point density in the retrieval of ground points for further generation of digital terrain models (DTM). Multiple Airborne LiDAR (Light Detection

and Ranging) datasets acquired over the Amazon under the Sustainable Landscape project were selected. Two study areas were selected inside the Tapajós National Forest (TNF) where a mosaic of different successional forest stages can be found due to shifting agriculture and land abandonment. Land cover types were generated based on available RapidEye and/or PlanetDove images acquired close to the LiDAR acquisitions. The performance of different freeware and commercial software such as BCAL, MCC, FUSION and TIFFS were also evaluated. Results show that BCAL, MCC and FUSION software responded better for the retrieving of ground points according to the increasing of point density. The quality of the ground generated models also improved with the increasing of point density. TIFFS performed similarly for the datasets regardless of the point density of the input data. However, residuals were always noticed over selected land cover types identified by both RapidEye and PlanetDove images. This study was sponsored by FAPESC and CNPq. The Satellite images were provided by PlanetScope. ALS datasets were provided by the Sustainable Landscape Project.

Ground Filtering, DTM, Ground points, Terrain modeling

ALS116TV3

Tree detection and height measurement from aerial laser scanning point cloud

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Forest stand variables such as number of trees, height and diameter are important for forest management. Traditionally, these variables are estimated by forest inventory plots which can be time consuming and costly. LiDAR aerial data have been an efficient technique to measurement tree heights and detect individual trees. The most of conventional methods convert LiDAR data point to Digital Elevation Model (DEM) and Digital Surface Model (DSM) to obtain the Canopy Height Model (CHM). In this work, normalize point cloud was applied to detect the individual trees and measuring their heights. The experimental area is a Eucalyptus urograndis plantation located in Telêmaco Borba, Paraná State, Brazil. The stand age is five years old and the initial stand density was 1.111 trees ha-1. Four plots (512 m2 each) were selected to measurement of trees height and obtaining the numbers of trees. The LiDAR data were collected with a Trimble® Harrier 68i sensor mounted in a Cessna 206, flying height of 666.17 meters above sea level and density of five points per square meters. The FUSION 3.70 software was used to generate a normalized point cloud and the tree_detection function in the package lidR (2.0.3 version) in R software was used to detect trees and heights. This function implements an algorithm based on a local maximum filter. The arguments of the function were: the window size (numeric or a function), the minimum height of a tree and the shape of window (square or circular). In this study the window size was coincident with the average crown area (empirical) and the tree heights minimum was based on forest inventory data. The accuracy of number of trees was evaluated in terms of recall, precision and F-score. The statistical significance of the mean differences between the tree height observed in ground (plots) and the LiDAR height was evaluated by t-test. The algorithm detected correctly 91% of trees (recall), the value of precision was 97% and the F-score was 94%. The t-test (p-value = 0.37) indicated there was no statistical difference between the tree heights. The bias of height tree was overestimated in 0.34 m (RMSE = 3.5%, R2 = 0.85). The method proposed can be used to support the forest inventory planning with high accuracy.

LiDAR, individual tree, forest inventory, Eucalyptus

ALS117TV3

Estimating Burned Ecosystem Properties with NEONs Airborne Observation Platform

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Wildfires represent a critical component of the global carbon budget and generate atmospheric pollutants that have negative short and long-term human and environmental consequences. Characterizing the full impact of a wildfire requires observation of the fire emissions as well as the

affected ecosystem. In the summer of 2018, the BB-FLUX wildfire emission observation campaign was supported by the National Ecological Observatory Network (NEON) Airborne Observation Platform (AOP) to collect aerial waveform LiDAR and hyperspectral data over the burn scars of four wildfires in the Western United States. The flights also encompassed some unburned forested area surrounding the burn scars, which were used as a proxy for the pre-burned conditions. The remote sensing observations were used to estimate burned ecosystem parameters of area burned and above ground biomass in order to better constrain the amount of available fuel. We present an algorithm for predicting live biomass using a random forest supervised machine-learning model incorporating LiDAR and hyperspectral data, and ground-based measurements at nearby NEON sites for training data. Since NEON has collected coincident remote sensing data and ground-based measurements over a number of eco-climactic domains throughout North America, it provides a rich dataset for assessing biomass model performance across variable ecological regimes. We conducted exploratory analysis to determine optimal model parameters for predicting biomass in differing ecosystems. Results of this analysis are shown, along with lessons learned on developing a model that works across large spatial scales and in dissimilar forest types. *LiDAR, Hyperspectral, Biomass, Wildfire*

ALS120TV3

Airborne LiDAR technology in support of forest management

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As a renewable resource, forest quantity and quality can be improved through management activities, especially for plantations. Good management operation need reliable forest stand information and dynamic monitoring. During the past two decades, the LiDAR-derived fine-resolution forest parameter information, which usually shown as gridded cells with attributes like height and density, has been used operationally for forest stand maps. The forest stand map provide is the fundamental information at operational forest management planning unit. Meanwhile, high resolution aerial photos are used successfully to segment into the forest stand polygons. The hyperspectral spectrum data provide species composition information for these forest polygons. These provide the fundamental information for forest management planning. After the management activities have been operated, the ALS technologies can be used to evaluate the implementation and effects together with other imagery sensed data. We used the CAF's LiCHy (LiDAR, CCD and Hyperspectral Integrated Airborne Observation System) to estimate several typical forest parameters in the North and South of China, including species composition, dominate height, crown base height mean height, volume density, biomass, and canopy closure. The operations including pruning and thinning were also monitored and evaluated. After the stratification with species group information from hyperspectral image, the overall accuracies are over 90% for mean height and volume density. The management operations also showed clear patterns vertically or horizontally. *Airborne LiDAR, hyperspectral, forest management, inventory*

ALS129TV3

Choosing filtering parameters in LiDAR clouds collected over Amazon rainforest

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With the advent of Airborne Laser Scanning (ALS), the possibility of obtaining a large number of geo-referenced points from the Earth's surface coverage has arisen. This technology has opened up new horizons in the field of forest measurement, especially in the quantification studies of forest biomass and structure. However, during the path traveled by the laser beam, some returns that must be considered as noise can be recorded by the sensor. Such noise may be caused by equipment interference, error in the interpretation of the return signal and physical obstacles between the forest and the aerial platform, such as birds and water vapor. These noises can be easily visualized, but manual removal becomes impractical, as the cloud of points can reach the magnitude of terabytes of data. In this way, the need to use automated algorithms to filter out the noises is perceived. The objective of this work was to optimize the cloud filtration parameters obtained by means of an airborne laser survey of the Amazon rainforest. Overflight was conducted between 2015 and 2016, with a minimum density of four returns per square meter (average of six returns per square meter) and a footprint of approximately 0.3 m. The study area is located in the northern channel of the Amazon River, in the state of Pará, in the Jari river basin. The processing was performed using the free software FUSION (v.3.8) and R (v.3.5.1), using the package lidR (v.2.0.1). The returns from the terrain were classified by means of the cloth simulation filter (CSF) algorithm and then the digital terrain model (MDT) was generated, with a resolution of 1 m. The cloud was normalized and then subjected to a local noise filter, testing standard deviation ranging from 1 to 7, with a 1-deviation interval. The standard deviation was computed locally considering a 10-meter window. The number of points removed by the filter decreased as the standard deviation increased. Up to 3 deviations, all the noises were removed, but points referring to the tree canopies were also filtered. Using 4 detours, it was possible to remove all visible outliers without compromising the forest canopy structure view. From 5 deviations up it was noticed that the filter was not efficient to remove the noises. *LiDAR, tropical forest, standard deviation*

ALS134TV3

Predicting species-specific diameter distributions in boreal forests using bi-temporal ALS, multispectral ALS, and aerial images

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A diameter distribution describes the size distributions of trees in a forest and is a vital output from a forest inventory. Diameter distributions are predicted using remotely sensed data in modern forest inventories. Unispectral airborne laser scanning (ALS) data are the most commonly used remotely sensed data from which to derive features for the prediction of diameter distributions. Typically, the spectral features derived from aerial images are also used when predictions are carried out by tree species. Nowadays, remotely sensed data are increasingly available, and datasets, such as multispectral and bi-temporal ALS data, are also accessible. It is evident that studies are needed to efficiently utilize different data sources in the modern ALS-based forest inventories. Species-specific diameter distributions are needed in Finland. Because of the low number of commercial tree species, the prediction by tree species is possible. A nearest neighbor (NN) approach enables to predict forest attributes and diameter distributions simultaneously. We applied the NN approach to predict diameter distributions by tree species in a study area that is located in eastern Finland. The study area represents typical managed boreal forests where Scots pine and Norway spruce dominate. We used a separate training (n = 424) and validation dataset (n = 420). The predictor variables for NN approach were selected using an optimization-based feature selection. Our objective was to examine how the different combinations of remotely sensed data affect to the predictive performance associated with the predicted diameter distributions. We used the following remotely sensed datasets: unispectral ALS data (leaf-off and leaf-on), multispectral ALS data (leaf-on), old unispectral ALS data (leaf-off), and aerial images. The predictive performance was evaluated by means of RMSE% and BIAS% values associated with the predicted timber assortment volumes (logwood and pulpwood). The combination of ALS data and aerial images was selected as a reference combination since it is operationally used in Finland. The results showed that the reference combination of features outperforms the multispectral ALS features in the prediction of diameter distributions. Instead, the findings showed that the features derived from bi-temporal ALS data (old leaf-off and recent leaf-on) achieved the lower mean of RMSE% values than the reference. The findings promote the knowledge how to apply remotely sensed datasets in the future forest inventories.

Diameter distribution, k nearest neighbor, bi-temporal ALS, multispectral ALS

SLS048TV4

Overview of MOLI Mission to Estimate Forest Biomass

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It is important to have precise information about forest volume and area to evaluate forest biomass contribution as a carbon dioxide sink in the global carbon cycle. However, IPCC AR5 reports mentioned that the error in such estimates is still large. Spaceborne L-band SAR derives forest biomass empirically based on the relationship between the biomass and observed data, but the L-band signal saturates for dense tropical forests (i.e., over 100 t/ha). Forest canopy height is a significant factor in evaluating its biomass and can be observed by LiDAR using remote sensing techniques without signal saturation, so measuring canopy height from space will lead to a better understanding of the global carbon cycle. Japan Aerospace Exploration Agency (JAXA) has begun a study using space-based LiDAR to measure forest canopy height and biomass called Multi-footprint Observation LiDAR and Imager (MOLI). MOLI uses dual beams with footprints small and close enough to determine ground slope, called “Multi-footprint” method. Previous studies to estimate canopy height and above ground biomass using ICESat/GLAS data reported that terrain relief in GLAS footprints affects accuracy of canopy height data considerably. MOLI’s “Multi-footprint” is useful for correcting estimation errors of canopy height and above ground biomass. Another feature of MOLI is that a three-band imager (green, red, and near-infrared) can determine where LiDAR is pointing and to measure the vegetation index at the same time. The MOLI mission provides product data about canopy height and above ground biomass density for each footprint. Improving MOLI’s data accuracies will require a better waveform analysis algorithm. On the other hand, it is difficult to obtain ground information from LiDAR waveforms observed for forests with high canopy cover ratio using conventional peak-fitting techniques. So, we try to solve this problem using novel algorithm such as machine leaning. This presentation will introduce the MOLI mission and an algorithm for converting observation raw data into product data. The authors have also conducted airborne-LiDAR experiments for preliminary testing of the validity of multi-footprint LiDAR and the imager to be used in MOLI’s observations and analyze the results of the experiment.

Spaceborne LiDAR, canopy height

SLS144TV4

Estimation of forest AGB from ICESat-2 and Landsat

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The Ice, Cloud and land Elevation Satellite-2 (ICESat-2) launched on September 15th, 2018, offers a phenomenal opportunity to obtain large-scale coverage about vegetation, through data collected along transects on the earth’s surface. This study served to examine the utility of ICESat-2 for estimating AGB using a combinatory approach with Landsat. Specifically, the objectives of this study were to: (1) Estimate AGB using ICESat-2 photon-counting LiDAR (PCL) data over vegetation in south-east Texas, (2) Upscale estimates to generate a wall-to-wall map of AGB using spectral metrics derived from Landsat imagery and land cover and canopy cover data from the National Land Cover Database (NLCD), (3) Validate map estimates using airborne-LiDAR derived AGB. Predictions equations were previously developed by relating simulated PCL metrics for 100 m segments along planned ICESat-2 tracks to reference airborne LiDAR-estimated AGB over Sam Houston National Forest (SHNF) in south-east Texas using linear regression analysis and then relating predicted AGB estimates to spectral metrics derived from Landsat TM imagery and land cover and canopy cover data from NLCD, with Random Forests (RF).These prediction equations are applied to actual ICESat-2 data along a 13-mile track over similar vegetation conditions in Texas to estimate and map AGB, and then validate estimates for the extent of the SHNF site. Findings from this study demonstrate how ICESat-2 can be used with Landsat data, to estimate and characterize the spatial distribution of AGB.

LiDAR, ICESat-2, aboveground biomass, Landsat, PCL

SLS146TV4

Preliminary validation of the ICESAT-2 land water vegetation elevation product (ATL08)

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The new Ice, Cloud and Land Elevation Satellite-2 (ICESat-2) mission provides various data product for land ice, sea ice, the atmosphere, vegetation and land, oceans and inland water. Of interest to the vegetation community are the Geolocated Photon Data (ATL03) that contain precise latitude, longitude and elevation for every received photon and the Land Water Vegetation Elevation product (ATL08), which comprises terrain and canopy height information. Given the novelty of photon counting data to the vegetation community and its susceptibility to solar background noise, there is a great need to develop methods for analyzing and validating ICESAT-2 datasets. In this study, we present preliminary assessment results on deriving terrain elevation and vegetation canopy height from ICESAT-2 global geolocated photon data (ATL03) data granules. Our methodology, which has already proved effective on simulated ICESAT-2 data, applies a multi-level noise filtering approach to minimize noise photons and subsequently classifies the remaining photons into ground and top of canopy using an overlapping moving window method and cubic spline interpolation. We assessed our methodology on ATL03 data granules across selected sites in California and Oregon by comparing derived ground and canopy estimates with existing airborne LiDAR data, we also used to validate ATL08 ground estimates. Overall, the multi-level filtering process shows great promise in identifying background noise and preserving signal photons in the raw data but continued testing will be needed to adequately document its strengths and weaknesses with respect to estimating vegetation biophysical parameters.

Photon Counting, ICESAT-2, ATL03, ATL08, Canopy Height

SLS149TV4

Modeling the growth of forest height using ICESat-2 photon counting data over tropical forested areas

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The growth of forest heights represents the forest dynamics as well as the increase of forest above-ground biomass. Precise growth model of forest height is required for the verification of dynamic models such as 3PG (Tickle et al. 2001), ZELIG (Urban 1990) and others. Typically, the age-height model is based on the repeated measure of tree height on permanent sample plots. However, it is difficult to obtain such kind of measurements, especially over long-term periods. Multi-temporal small footprint LiDAR data has been used to model the forest growth (Song et al. 2016; Vepakomma et al. 2011; Zhao et al. 2018). However, the length of observation period is mostly less than 10 years due to the limited history of small footprint LiDAR system. In addition, such kind of data is also limited. The synergy LiDAR with other data is necessary to extend the length of observation (Vega and St-Onge 2008). The photon counting data of ICEsat-2 has just been released. Some results demonstrated its good performance on measuring the forest height (Popescu et al. 2018). Though the ICESat-2 data is not able to model the growth of natural forests, it should be possible to model the growth of secondary forest, especially those grew up over bare ground caused by logging or heavy wild fire. The forest age can be estimated from SAR or multispectral historical images, while the ICEsat-2 provides the current height of forest stand. The detailed results will be presented on the meeting.

TLS029TV5

Tropical tree biomass equations from terrestrial LiDAR

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Large uncertainties in tree and forest carbon estimates undermine countries' efforts to accurately estimate aboveground biomass (AGB) for national monitoring, measurement, reporting and

verification of emission reductions in forested landscapes. Biomass estimates, although much improved, still rely on destructive sampling; large trees are under-represented in datasets; crown dimensions are typically not considered, and allometric models are often inaccurate when transferred between regions – which all leads to uncertainties and systematic errors in biomass estimations. We earlier used terrestrial laser scanning (TLS) to test the accuracy of existing models (Calders et al., 2015; Gonzalez et al., 2018), and now we propose the use of TLS to develop local allometric models without felling trees. Here we (1) assessed the accuracy of TLS-derived tree metrics (diameter at breast height - DBH, height, crown width, and AGB) and (2) developed local allometric models to estimate tree AGB in Guyana based on tree parameters obtained from TLS point clouds from 72 tropical trees and wood density. We validated our methods and models with data from 26 destructively harvested trees. We found that TLS-derived DBH was slightly lower, total tree height was higher, and crown width and AGB were not different from field-measured values, even with the presence of hollow and irregularly shaped trees. The assessed pantropical models underestimated AGB by 5 to 13 %. An older pantropical model —Chave et al. (2005) without height— consistently performed best among the pantropical models tested (R2 = 0.89). Our best TLS-derived allometric models included crown diameter, and provided more accurate AGB estimates (R2 = 0.92–0.93) than traditional pantropical models (R2 = 0.85–0.89). Our methods also demonstrate that tree height is difficult to measure, and the inclusion of height in allometric models consistently worsened AGB estimates. Our study has advanced the use of TLS methods to estimate tree metrics and explored the accuracy of field and TLS-derived methods to develop local allometric models. Interestingly, our study shows that locally developed models are not always better than pantropical models, but this could not be known without destructive or TLS-derived validation data on true AGB. Our findings support our goal of improving tropical forest biomass estimates and can be applied to upcoming remote sensing missions such as GEDI and BIOMASS.

3D tree modelling, aboveground biomass estimation, destructive sampling, Guyana, LiDAR, local tree allometry, model evaluation, quantitative structural model

TLS047TV5

Terrestrial Laser Scanning: an alternative for collecting dendrometric data in Atlantic secondary forests

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Monitoring forest resources requires accurate, consistent and well-defined measurement techniques. This accuracy is a result from both the techniques and the data measuring instruments. In this way, the aim of this study was to compare dendrometric variables estimates achieved by conventional dendrometry (method I) and by terrestrial laser scanning (TLS) (method II) in a Atlantic secondary forests located in Brazil's southeastern. A total of 29 trees belonging to 10 different species were selected, whose diameter at breast height, (DBH) were equal to or greater than 5 cm. Those trees had their DBH, total and commercial heights measured using applied methods. In method II, the TLS data were processed in Riscan Pro and 3D Forest softwares. The Pearson's linear correlation coefficient (ρ) was calculated to compare DBH, commercial and total height estimates obtaining from both methods. Among the dendrometric variables considered, the DBH exhibit very close values for aforesaid methods, followed by the total height. These variables estimated had a very strong positive correlation ($\rho \geq 0.9$). However, it was noted that total height values derived by the method II presented a tendency of overestimation when they were compared to the method I. The commercial height estimates showed moderate positive correlation ($0.5 \leq \rho \leq 0.7$) between methods. The multiple scans approach, which guarantees complete stem circumference coverage, can explain the very strong correlation found among the DBH estimates. Another factor that contributed to the high correlation between DBH estimates, is the height of the LiDAR (close to 1.30 m), which prevents view angle errors and consequently points cloud distortions. On the other hand, factors such as crowns overlapping, high view angle

and/or manual data filtering may explain the total height overestimation by method II. Regarding to the commercial height, the moderate correlation among values can be elucidated simply by the fact that in a native environment there are subjectivities in first branch definition and its detection, which can be different among observers and observations. Ultimately, we concluded that the TLS may be an alternative for dendrometric variables measurement highlighting the opportunity to automatize the process and to measure at the millimeter scale.

TLS, Atlantic Secondary Forests, Dendrometric Data

TLS049TV5

Using terrestrial and airborne laser scanning in the estimation of wood properties in standing timber

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Changes in climate and silviculture are altering forest growth and wood formation globally, including changes in wood properties, such as wood density. These developments may affect the carbon sequestration in forests, as well as limit timber usage in long-term carbon storage in, e.g. construction. Because wood properties result from tree's adaptation to the environment through tree crown, the crown and branching attributes could be used to model the underlying wood formation processes and wood properties. The emergence of three-dimensional terrestrial point clouds, such as those from terrestrial laser scanning (TLS), has made it possible to obtain detailed crown and branching data from standing timber. Moreover, increasingly dense airborne laser scanning (ALS) point clouds enable the delineation of individual tree crowns and the extraction of crown features that are suited for the generalization of detailed branching structures over larger spatial extent. Combining high-resolution remote sensing data sets could thus improve the conditions for forest managers and decision makers to account for the variability of wood formation and wood properties across variable scales. Here, we demonstrated such an approach with Scots pine (Pinus sylvestris L.) stands from various development stages in a landscape of boreal forests in Southern Finland. We recorded a sample of ca. 300 Scots pines across 27 stands with TLS, and obtained dense (~six pulses/m2) ALS data over the entire area of 2000 hectares. We reconstructed the branching structures of the TLS sample trees, and built Random Forest - models of select branching attributes with respect to the geometrical ALS features of respective tree crowns. We then used our data to predict branching structures for each tree over three Scots pine - stands within the area (not included in the other 27). We will evaluate the accuracy of our predictions by comparing the predicted branching variables against X-ray measurements of ca. 2000 trees harvested from the studied stands. By doing so, we aim at assessing the feasibilities of using a combination of TLS and ALS data to model the branching structures in such detail that the variabilities of various crown-dependent wood properties (e.g. wood density) could be estimated tree-specifically over a larger region. We will discuss the benefits, possibilities and challenges of including wood properties in remote sensing-based forest inventory data, from the point-of-view of informing the decisions regarding the management and use of forest resources.

Precision forestry, data fusion, tree modelling, wood density

TLS052TV5

Application of terrestrial laser scanner for the determination of forest inventory parameters using simple scans

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The laser scanner technology (TLS) has been gaining strength as an alternative in acquiring accurate and detailed forest information, bringing improvements to conventional forest inventory techniques. Several studies have been carried out and show that one of the main bottlenecks in the use of simple scans is due to the partial detection of trees due to the shading effect caused by the interposition of other individuals, thus underestimating the number of trees and subsequently interfering with estimates in the plot. In this sense, the objective of the present research was to perform the automatic detection and determination of the diameter at breast height (DBH) of individuals of Pinus taeda L. by the TLS survey using simple scans, in order to verify if there are significant differences between the method TLS and conventional inventory. With densities ranging from 1111 to 2500 arv.ha-1, the population evaluated covers an area of 4.1 hectares with 4 spacings. The total was installed 11 circular sample units of 300 m² and were measured the DBH and total height all individuals. The TLS survey was performed with the Leica BLK 360 equipment, allocating the equipment at the central point of the plot. The laser data processing was performed in the statistical environment RStudio® applying the TreeLS package that uses the algorithm for automatic detection and the algorithm for determination of the DBH. The number of trees detected at settlement level was 88.4%. It was possible to verify that trees dead and next to the equipment caused considerable shading effects, and that most of the undetected trees were located near the edge of the sample unit. The highest percentage of detection was for the 4x2 spacing (94.3%) possibly due to the lower density of trees. The 3x3 spacing showed the lowest detection rate that can be explained by the presence of cloud noise due to expressive sub-forest. Regarding the diameters, there was a tendency of underestimation in all spacings, however, no significant differences were observed at the 5% level even the algorithm did not detect all the trees in the sample units. It was possible to verify that TLS technology can be applied in the automatic detection and determination of diameters, but the sub-forest generates noises in the cloud of points, which must be removed before the processing of the inventory variables.

Forest inventory, relief, point cloud, terrestrial laser scanning

TLS067TV5

Improving ground filter optimization using terrestrial point clouds

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Accurate measurements of vegetation extent and structure are vital for a range of ecological assessments; ecological monitoring, precision forestry, carbon accounting and fuel and fire behavior estimates. Active and passive sensors have been utilized to capture 3D point clouds to be subsequently analyzed describing vegetation health, structure and biomass. Height is a common metric to extract from these 3D representations. As such, the extraction of height requires the use of a ground filter to determine the location of the underlying terrain. Prior research has highlighted that despite point clouds containing large amounts of information describing the ground, the extraction of this information and optimization of filter settings to the required accuracy can be challenging particularly in forested areas with complex vertical structure and undulating terrain. This research presents a new approach for optimizing the ground filtering process in a forested environment. A suite of point clouds were captured using both passive and active sensors over a 50 x 30m plot. Image based point clouds were captured from the ground using a Sony A6000 that was converted to capture reflectance in the Near Infrared (NIR) and a DJI Phantom 4 Pro for airborne capture. A Trimble TX-8 and Velodyne Puck were used to capture LiDAR data. The terrestrial NIR point clouds were captured as a 20m transect with a reflectance threshold applied to characterize the ground surface. This estimate of ground was validated against reference ground measurements in four 0.5mx0.5m quadrats placed along two transects. The NIR image based point cloud was subsequently used as the reference for optimizing settings for the cloth simulation, adaptive TIN and progressive morphological filters for the TLS and airborne point clouds minimizing for rmse. Spot heights were sampled across the plot for ground control. Results indicate that using spot height measurements for filter parameterization often results in significantly different parameters to using the proposed transect approach. Whilst, UAV SfM and UAV LiDAR had sufficient information content in this environment to characterize a ground surface, the variations in filter parameterization are sufficient to cause large differences in metrics describing understory vegetation (height, volume and biomass). With terrestrial and airborne methods of 3D data capture being increasingly used to observe and monitor fine scale change in vegetated landscapes, the method presented may be used to determine a ground surface that allows a more accurately characterization of these forest strata.

Structure from Motion, point clouds, optimisation, ground filters

TLS081TV5

Fusing ALS and TLS point clouds - towards better forest parameters estimation

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Airborne Laser Scanning (ALS) and Terrestrial Laser Scanning (TLS) are both active remote sensing techniques in use on a wide scale in forested areas. The ground-based approach allows precise reconstructions of the below canopy structure, lacking accuracy in heights measurement. Its downfalls are the inability to penetrate dense canopies and cumbersome georeferencing procedures. Contrary, aerial scans, despite being natively georeferenced, offer little information on stems due to low point density and sensitivity to vegetation density. The current research proposes a method of combining the strengths of the two, through a registration approach. Due to differences in point cloud characteristics, previous work avoided geometric similarities approaches and focused on either external reference (e.g. GNSS data), object level registration (e.g. stems) or key point correspondence (e.g. SIFT, SURF). Located in South West Romania in mixed forest strands, the main tree species in the 1ha studied area were Norway spruce (Picea abies) and Beech (Fagus sylvatica). ALS data was collected using a Riegl LMS-Q780 scanner, with a point density of 5-8 points/sqm. For TLS recordings, a FARO Focus3D X130 was used, with a 3x quality factor and ¼ resolution (10,240 points per revolution). In order to combine TLS and ALS based point clouds, ground classification was computed on each (15 individual TLS + 1 ALS) this being the only element of the scene similarly recorded by both. Initial cloud to cloud registration of the TLS scans resulted in a mean point error of 16.7mm and a minimum overlap of 13.2%. In order to reduce the processing requirements and uncertainty, each TLS scan was spatially sampled to ~0.1ha areas and substituted in the coregistered TLS cloud. Resulting data sets followed a rigid transformation to best match their centers (ALS as reference) and a rotation based on a Four Points Congruent Sets (4PCS) algorithm. Difference in spatial resolution only allowed for a general alignment. Refinement was done through an Iterative Closest Point (ICP) algorithm. Transformations repeated until the sum of the squared distance differences decreased below 1.0e-2. Finally, a transition from the 0.1ha subplots to the full scans was performed for TLS scans. Each transformation matrix was then applied on the corresponding unclassified point clouds, leading to the final coregistered ALS and TLS data set. The results (i.e. over 99% less than 0.4m height deviation and over 95% below 0.2m horizontal misplacement) provide confidence towards future improvements in forest parameters estimation.

ALS, TLS, fusion, Iterative Closest Point, forest parameters

TLS085TV5

Carbon sequestration potential and wood quality aspects of southern African trees extended to agroforestry systems - an assessment through 3D data

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Southern Africa is faced with several impacting and interrelated issues such as climate change, degraded landscapes, food insecurity and other severe economic, social and environmental challenges. We selected the southern African region to address these pressing issues by exploiting technological advancements for the accurate estimation of aboveground biomass of trees. Simultaneously, the employment of innovative and integrated land use systems such as agroforestry systems (combining agricultural crops and trees) is expected to be part of the solution by supporting resilience against a changing climate. Through inclusion of trees within farmed landscapes increased carbon sequestration, water retention, soil erosion control and enhancement of rural livelihoods can be achieved. In order to promote trees and agroforestry

systems, the application of terrestrial laser scanning technology is of high interest and importance. A non-destructive methodology to estimate the aboveground carbon sequestration potential of tree species growing in southern African landscapes is applied under the framework of the ASAP project ("Agroforestry in southern Africa – new pathways of innovative land use systems under a changing climate", grant number 01LL1803 funded by the German Federal Ministry of Education and Research). We use 3D data derived from single trees scanned in multiple positions for the assessment of tree volume. In this context, the tree volume data estimated through quantitative structure models (QSMs) is used as basis for calculating the aboveground tree biomass. For this purpose, we combine the tree volume with species specific wood density. The use of QSMs enables a truthful description and examination of the topological (branching structure), geometric and volumetric properties of the woody structure of a tree. The eventual absence of 3D data specific to agroforestry trees is overcome by selecting sample trees growing in more open landscape conditions (open forests, solitary grown trees such as trees outside forests). Standard tree parameters such as height to crown base, crown volume and tree height, help to quantify the tree impact on the neighboring crops. Equally important are TLS-detectable tree attributes that relate to wood quality and efficient wood utilization (e.g. stem volume, sweep, taper, branchiness). Furthermore, we place a special focus on the biomass distribution between different tree components (e.g. between stem and branch fractions) and on distinct tree species occurring in agroforestry systems. *TLS, agroforestry, aboveground carbon, QSM, point clouds*

TLS086TV5

Terrestrial Point Cloud Processing to Estimate Individual Tree Parameters

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In following abstract we will introduce our developed approach for individual tree parameters estimation from terrestrial point clouds but not restricted to. The whole workflow is fully implemented in DendroCloud software which is free and developed at Technical University in Zvolen (Slovakia). The main parameters estimated by DendroCloud are diameters of tree trunk at desired height, position of trunk, height, stem curve, biomass. By-products are digital surface model (DSM) and digital terrain model (DTM). The most important parameter estimated by our approach is a diameter of tree trunk, especially the diameter at breast height. Which is an important attribute in forestry. Multiple circle fitting approaches are used to estimate the trunk diameter. Three simple ones are minimum bounding box, centroid, maximum distance. Furthermore, two robust circle fitting methods are implemented: monte carlo and optimal circle. The performance of the methods was tested at plot with monoculture of European beech with size 50 × 50 m. We have used terrestrial laser scanner FARO 3D 120. The most accurate results were achieved by the robust methods and there was not significant difference between them when multi-scan method was used. In overall the best result was achieved by optimal circle method. The root mean square error of DBH estimation was in this case 0.77 cm [1]. We were also part of "International benchmarking of terrestrial laser scanning approaches for forest inventories" [2] under International society for photogrammetry and remote sensing (ISPRS) where our approach provided similar results as approaches which used more complex workflows. The results from terrestrial photogrammetry are not as accurate as results achieved by terrestrial laser scanning (TLS). In our experiment we have achieved RMSE 4.41 cm [3] on plot with European beech with size 35 × 35 m. This is mainly caused by the data acquisition approach which provided point clouds with higher noise and lower density that the point clouds from TLS. The further research should focus on data acquisition which will provide point clouds with lower noise and higher density. DendroCloud is free and available at http://gis.tuzvo.sk/dendrocloud/

DendroCloud, Terrestrial laser scanning, photogrammetry, diameter at breast height

TLS090TV5

Long time series of ground based laser scanning measurements of single trees and forest stands - 4D LiDAR monitoring

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The precise ground based laser scanning measurements (TLS, MLS, HLS, WLS) conducted regularly allow to describe dynamics of changes happening in horizontal and vertical structure of the single tree and forest stands. The volumetric changes of selected tree parts and whole forest stand (biomass) taking place over time enable conducting the so called 4-D monitoring. In the presented paper case studies are presented: 1- the single tree monitoring; 2- the old-growth forest stand observations; 3-Norway spruce stand in forest decay stage and 4- secondary forest succession on the abandoned land. The aim of the case study no.1 was the monitoring based on multi-temporal comparison of point clouds captured with Terrestrial Laser Scanning (TLS) and Hand-Held systems. First TLS point clouds were collected during the Leaf-OFF (04.2013) and in Leaf-ON period (07.2013) using FARO FOCUS 3D. Additionally the RIEGL VZ-400, Leica C10 and RevScan (HandyScan) were used to collect point clouds. The height (H) of the oak tree differed approx. 0.41 cm using altimeter Vertex (Haglöf; H = 29.31 m) and TLS point cloud (28.49 m). Trunk circumference (L) was 9.80 m much shorter then adjacent along the shape of bark (LT = 13.70 m). The TLS point cloud-based measurements showed 9.97 m and Hand-Held RevScan 13.54 m. The study no. 2 was the old growth forest located in the Niepolomice Primeval Forest on the research area TR2. The first TLS point cloud was collected in 2006 and the last one in 2019 using FARO LS 880 and RIEGL VZ400i respectively. Throughout the 13 year analyzed period different scanners like: FARO, ZEB1, Leica, RevSca, Robin GEOSLAM (Wearable Laser scanning) equipped with RIEGL VUX-1 were used. The case study no. 3 was located in Gorce National Park in total reserve zone where the forest decay of Norway spruce stand is observed since last two decades. The 4-station TLS scanning was performed in years 2012, 2016 and 2018 as well. The high dynamic changes were observed like broken of dead trees, falling of logs and destruction of the wood. In the same time we observed the natural regeneration of the forest resulted as the inflow of a significant amount of sun light. Very high dynamics of secondary forest succession is observed in the last years (2012-2016-2018) in Poland on the on a high-mountain meadow where sheep grazing was stopped. Thanks to the precise TLS point cloud (FARO) you can follow the dynamics of the appearance of spruce individuals and their growth in height and width and closing of the tree cover. Conducted research demonstrates usefulness of TLS technology application in observation of natural processes taking place in natural forests ecosystems.

ALS, MLS, TLS, WLS (Wearable Laser Scanning), UF (Urban Forestry)

TLS091TV5

Comparing the number of trees retrieved with both ALS and TLS point cloud over a loblolly pine stand

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The aim of this work was to isolate 16 years old loblolly pine trees, in a 400-m² circular plot, by means of two different methods of data collection: Airborne Laser Scanner (ALS) and Terrestrial Laser Scanner (TLS) data and compare them/. The ALS data were collected at flight height of 853 m, with a scan angle of 11° and 65% of overlap. The density of point cloud is approximately 22 points.m-2. The TLS data were collect with a Leica ScanStation P40 equipment with a scan resolution of 1 point at each 6.3 mm. We performed 5 scan stations at plot level, one with 360° in the center of the plot and 4 other on the corners with 110°. This configuration was adopted to avoid shading between the plot trees and ensure multiple scan data. Reference targets were distributed at the scan moment to ensure the geometric registration of each single scan in a multiple scan data. The ALS data processing consisted of filtering the point cloud by using Adaptive Triangular Irregular Network (ATIN) filter to separate the terrain and vegetation points. Next,

Digital Terrain Model (DTM) and Digital Surface Model (DSM) were obtained by interpolating the filtered points, and normalizing them to obtain the Canopy Height Model (CHM). The CHM was smoothed with different search windows to emphasize the treetops pixels, and with this, the Thiessen's Polygons segmentation was used to isolate the trees crowns. As TLS data processing, the steps were: (i) point cloud registration and delimitation, (ii) point cloud cut in a cross section with a certain height to obtain only the points relative to the tree stems, (iii) application of Label Connected Components algorithm to eliminate the points that not represent the tree stems, and (iv) segmenting them from octree and minimum number of points parameter. With the segmented tree, the tree detection was performed by assuming a threshold in the segments and the plantation alignment which resulted in vectors that were classified as stem, non-stem and uncertain. The evaluation of the applied methods was performed based on the counting of the trees in the field and calculated the commission and omission errors and accuracy. With the ALS data, the accuracy of detected trees was 60.38%, with an omission error of 30.19% and commission error of 9.43%. In TLS data, the automatic method for tree detection had an accuracy of 96.23% with an on omission error of 3.77%. The lack of paring and silvicultural treatment increased the amount of suppressed trees and many tree brunches, making it harder to identify the treetops in ALS data as well as the trees shading, interfering the stem identification in TLS point cloud. These factors affected negatively the automatic identification mainly in ALS points cloud. This study was sponsored by CAPES, CNPq, FAPESC and MANFRA. The ALS data were provided by the Sustainable Landscape Project.

Tree segmentation, Thiessen's Polygons, Automatic Tree Identification, Connected Components

TLS103TV5

Use of terrestrial laser scanning to assess fuel consumption in amazon rainforests

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Fires are a great disturbance in rainforests. Understanding fire fuels is essential to prevent fire ignition and propagation, thus reducing the fire risk. Terrestrial Laser Scanning (TLS) is presented as a good option for assessing and modelling fuel categories, as it produces high density point clouds taken in the forest understory. In this study we propose a method for assessing fuel consumption in the amazonian rainforest, comparing pre and post-fire TLS scans. The data was collected in a transitional amazon rainforest - state of Mato Grosso, Brazil. The study area has been subjected to controlled fire in 2013. Point cloud data analysis shows that the mean difference between pre and post fire metrics is statistically significant at 95% probability. Pre and post fire data comparison shows that most of matter loss occurs in the first meter above ground and almost nothing is lost above 5 meters. This demonstrates that superficial fires do not reach adult healthy trees. A model was fit to predict relative difference in height returns with a coefficient of determination of 0.71. The proposed methodology can identify which height classes underwent greater fire disturbance, serving as an indicator for the fire's behaviour. Our findings support other research which indicate that fire in rainforests is restricted to superficial matter due to high vegetation moisture. *Fuel, fuel consumption, fire behavior, LiDAR, TLS*

TLS108TV5

Extraction of biophysical parameters using terrestrial laser scanner in a sample of Pinus taeda L.

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Biophysical parameters Retrieval using Terrestrial Laser Scanning Profiling data over a Pinus taeda L. stand. Retrieving biophysical parameters in a Pinus taeda L. stand using Terrestrial Laser Scanning (TLS). This manuscript presents the major results of the retrieval of biophysical parameters derived from a 3D cloud point collected by a Light and Detection and Ranging (LiDAR) terrestrial platform. The study area is a planted forest stand of Pinus taeda L. with 17 years with a regular spacing of 2 by 2m designated for pulp and paper production. Data processing was

performed using the software Scene, CloudCompare, and Python. Both automatic tree detection and diameter at the breast height (DBH) parameters were extracted using voxels with different size dimensions. Additionally, filtering techniques were evaluated to remove both duplicated and redundant points. The results derived by terrestrial LiDAR were compared to those obtained by conventional continuous forest inventory methods. The automatic tree detection was able to detect 100% of the trees of the selected forest stand unit. Voxel with the dimension of 0,43 (m) x 0,43(m) x NH (m) showed the best performance for the DBH retrieval with r^2= 0,78 and r= 0,86. Filtering removing factors of 1.5cm, 2.5 cm and 3.5cm were similar at the significance level of 0.05. Both methodology and results showed promising perspectives for the LiDAR terrestrial measurements for counting trees and retrieving DBH. Future studies should be addressed in height determination and volume retrievals. *Planted forest, Point cloud, forest attributes, LiDAR*

NLT007TV6

Deciduous Broad Leaf Bidirectional Scattering Distribution Function (BSDF): Measurements, Modeling, and Effects on Leaf Area Index (LAI) for Forest Ecological Assessments

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LiDAR remote sensing has shown high accuracy/precision for quantification of forest biophysical parameters needed for ecological management. Although the significant effect of Bidirectional Scattering Distribution Functions (BSDF) on remote sensing of vegetation is well known, current forest metrics derived from LiDAR data seldom take leaf BSDF into account. Despite the importance of BSDF effects, leaf directional scattering measurements are almost nonexistent, particularly for transmission. Previous studies have been limited in spectrum, lacked models to capture all angles beyond measurements, and did not adequately incorporate transmission scattering. Furthermore, many current remote sensing simulations, which are vital to our understanding of LiDAR data, assume leaves with Lambertian reflectance, opaque leaves, or apply purely specular or Lambertian transmission. The accuracy of these assumptions and the effect on simulation results are currently unknown. This study captured deciduous broadleaf BSDFs from the visible through shortwave infrared spectral regions, accurately modeled the BSDF for extension to any illumination angle, viewing zenith or azimuthal angle, and assessed the effect of leaf BSDF on LAI derived from waveform LiDAR. The goniometer of the Rochester Institute of Technology-2 (GRIT-T) was used to make leaf bi-conical directional reflectance and transmittance measurements. Leaves from three species of large trees, Norway Maple (Acer platanoides), American Sweetgum (Liquidambar styraciflua), and Northern Red Oak (Quercus rubra) were measured. Data then were fit through nonlinear regression to physical-based microfacet BSDF models, resulting in normalized root mean square errors less than 15% for reflectance and 30% for transmission, averaged across all wavelengths. Leaf physical parameters, including the index of refraction and a relative physical roughness, were extracted from the microfacet models delineating the three species. The effect on LAI (due to leaf BSDF) and dependence on wavelength, LiDAR footprint, view angle, and leaf angle distribution (LAD) all were explored using the Digital Imaging and Remote Sensing Image Generation (DIRSIG) remote sensing radiative transfer simulation model. The largest effects on LAI were observed at visible wavelengths, small footprints, oblique interrogation angles, and small LADs. These effects were attributed to (i) the BSDF becoming almost purely specular in the visible, (ii) small footprints having fewer leaf angles to integrate over, (iii) oblique angles causing diminished backscatter due to forward scattering, and (iv) larger LADs resulting in diffuse LiDAR signals. Armed with the knowledge from this study, researchers are able to select appropriate sensor configurations to account for or limit BSDF effects in forest LiDAR data.

Bidirectional Scattering Distribution Function, BSDF, Bidirectional Reflection Distribution Function, BRDF, Bidirectional Transmission Distribution Function, BTDF, Leaf Area Index, LAI, LiDAR, waveform, simulation, modeling, microfacet

NLT012TV6

Adjustment of leaf area conversion functions in managed conifer stands in Sweden

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The structure of contemporary managed forests are complex and deviate from experimental forests which are usually even-aged monocultures and single-storied. To apply growth functions developed from experimental forests on managed forests, adjustments are required especially for leaf area index (LAI) which is a key biophysical variable in many process-based growth models. To asses this, the effect of heterogeneity on the performance of canopy LAI in modelling the basal area (BA) of managed boreal forests dominated by Norway spruce (Picea abies (L). Karst) and Scots pine (Pinus sylvestris L.) in Sweden was investigated. The study was based on the assumption that crown leaf area and stem diameter are strongly related and are vital for estimating stand productivity. Managed forests were represented by field data from the Swedish National Forest Inventory (NFI). Species-specific LAI conversion parameters (developed from experimental stands) were applied on general plant area index (PAI) values from hemispheric fish-eye photos which were taken from the sample plots during the 2016 and 2017 NFI campaigns. The heterogeneity was studied in two parts by (a) ground-based stand structural heterogeneity (SSH) described by species composition, coefficient of tree diameter variation, tree social status and height-diameter ratio and (b) spectral heterogeneity (SPH) by vegetation and textural indices developed from Sentinel-2. Species-specific final (with heterogeneity metrics) and base (without heterogeneity metrics) models were fitted for BA-LAI and BA-PAI relationships by nonlinear least squares and generalised additive regression, respectively. For both species, a significant positive nonlinear relationship was found between BA-LAI whereas, the fit between BA-PAI demonstrated a positive linear trend. Generally, BA-LAI final models (FMs) accounting for heterogeneity resulted in larger explained variance (RMSE, m2 ha-1) than the base models (BMs). Relative to the BMs, FMs with SSH reduced the variance by 55% in Norway spruce (RMSE = 3.330, relative-RMSE = 15.398%) and 43% in Scots pine (RMSE = 3.701, relative-RMSE = 17.377%). The fit between BA-LAI with SPH was also significant and showed an improvement in the RMSEs over the BMs for Norway spruce (5.561) and Scots pine (5.659), suggesting the potential use of Sentinel-2 in future growth models. The conclusion from this study indicates that in growth models, when extrapolating functions developed from experimental forests to managed forests, there is a need to take into account the stand structural heterogeneity. This is important for effective growth and yield modelling of managed stands of Norway spruce and Scots pine.

Heterogeneity, Sentinel-2, National Forest Inventory, Forest Planning, Monitoring, Sweden

NLT018TV6

Estimating charcoal piles volume using an unmanned aerial vehicle

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A common challenge for charcoal production companies is to implement inventory control in the context of Manufacturing Resources Planning (MPR). Large charcoal production is conducted in rectangular ovens with a capacity of around 320 cubic meters of wood. However, the carbonization process is not statistically controlled, and the production is accounted in the MPR considering an average value per cycle. During the charcoal shipment, the trucks are weighted and the volume is gravimetrically computed. The consequence of the difference between the precision of the shipment discount (weighted) and the accreditation of the production (average) in the MPR is a permanent divergence between real and MPR charcoal stock. The objective of this study is to compare the volumetric estimation of charcoal piles based on digital stereoscopy to the estimation based on GNSS/RTK field points. Two charcoal piles were surveyed using GNSS/RTK and their volumes were topographically estimated. In the same day, an aerial image collection was performed with DJI Phantom 3 Standard. The flight planning was performed in the software

Pix4D Capture, using a double grid design, and flight height of 40 meters. The resulted ground sample distance was 1.86 cm/pixel. The images were processed in two ways: low accuracy for photos alignment and for dense cloud creation; and high accuracy for photos alignment and for dense cloud creation. HIgher the accuracy slower the processing time. The piles' polygon were visually created based on the orthomosaic and the volume determined based on the digital elevation model. The volume determined for the first pile was 461 m^3 and 328 m^3, for the higher and lower accuracy respectively. The second pile had 185 m^3 and 135m^3 the higher and lower accuracy respectively. The volume determined by GNSS/RTK survey were 399 m^3 and 175 m^3 for piles one and two respectively. The low accuracy processing resulted in lower volumetric model quality. As a consequence, the analyst had greater difficulties to delineate the piles and less precision in the solid creation. The values found by the high accuracy processing approximate more to the GNSS/RTK values. For piles monitoring using UAVs, we recommend processing considering high accuracy parametrization. *UAV, stereoscopy, forest plantation, eucalyptus*

NLT076TV6

Highly Accurate Estimation of Lower Part Tree Trunk Perimeter by SfM Photogrammetry for Annual Tree increment Estimation

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Our research is focusing on the methodology development of individual tree image acquisition with emphasis to achieve high precision of perimeter estimation using Structure from Motion (SfM) photogrammetry. Furthermore, we are investigating the potential to estimate the annual increment of mature trees. We captured four tree species (Fagus sylvatica, Quercus petraea, Picea abies and Abies alba). Ten trees per species. A perimeter was measured at three heights (0.8 m. 1.3 m and 1.8 m) by conventional methods (measuring tape). We have used the standard approach within Agisoft Photoscan Professional to process images to point clouds. Then we have used DendroCloud software (1) to deliver the cross-sections for further analyses. Cross-sections were processed within ArcGIS for Desktop where the convex hull was used to estimate the perimeters. In the first stage, we have compared two different lenses. Fisheye and non-fisheye (Canon EF 8–15 mm f/4L and Canon EF 35 mm f/2). The best approach was chosen based on the accuracy of perimeter estimation. In overall, the best approach was when the fisheye lens was used. The best accuracy of estimation based on root mean square error was achieved for Fagus sylvatica at 1.3 m height (RMSE of 0.25 cm) (2). Based on the results, we have used in the following stage the fisheye lens which was most accurate and time efficient. In the second stage, we captured images and measured trees before and after the vegetation period. Then we have calculated annual increment and compared the increment for each tree species. We have used a t-test to statistically verify the agreement of used approaches (SfM versus conventional). Only in the case of Quercus petraea was a statistically significant difference between those two. In our opinion, the reason is the rough surface of the bark. On the other hand, the annual increment of mature trees is relatively low and even with conventional methods, the accuracy is questionable. In further research, we would like to take increment cores and used them as the third most accurate approach. *SfM Photogrammetry, tree increment, point cloud, convex hull, fisheye*

NLT078TV6

Advanced earth observation techniques in forest biodiversity assessment

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European aspen (Populus tremula) is a keystone species for boreal forests biodiversity, since hundreds of other species of various life of forms are dependent on it as a source of nutrition or a living environment. Due to a low economic value and sparse and scattered occurrence of aspen species in boreal forests, there is a lack of information on the spatial and temporal distribution from national forest inventories, which hamper efficient planning and implementing sustainable forest management practices and conservation efforts. Nowadays airborne earth observation techniques are commonly used for biodiversity assessment over the large areas, however, operational costs of data acquisition are still relatively high and there is strong dependence on the availability and quality of field data. New unmanned aerial vehicle (UAV) based earth observation technique proved to be very efficient in providing ultra-high spatial and temporal resolution imagery for detailed forest properties assessment at reasonable costs and serve as a supplement or even able to replace part of the currently required field work to support biodiversity assessments. The main objective of this study was to recognize individual European aspen trees in old-growth boreal forests in conservation area and estimate its structural properties based on the combination of spectral bands and structural features extracted from UAV data. The results were compared with the airborne laser scanning and hyperspectral data-based approaches. *Biodiversity, ALS, UAV, hyperspectral*

NLT111TV6

The Importance of GRSS Student Grand Challenge for promoting UAV Application

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The Geoscience and Remote Sensing Society (GRSS) promote on a yearly basis the Student Grand Challenge. It is intended to engage students and young professionals in solving a complex engineering problem within the scope of GRSS and other sister societies (e.g., Aerospace and Electronic Systems, Antennas and Propagation, Ocean Engineering, Computer, Microwave Theory and Techniques). Among five selected projects worldwide, one was selected from Brazil. The Grand Challenge consists on a joint program encompassing several small projects being conducted by students and professionals from UFMS, UCDB and UDESC. All the projects are related with the development of UAVs and innovative machine learning methods applied to both precision forest and farming. The developed UAVs and preliminary results achieved in both precision forest and farming applications will be also presented in this session. Sponsored by GRSS, CNPq, CAPES.

Education initiatives, data contest, student grants, student sponsorship, networking

NLT112TV6

The Science of SAFE, a Smallsat complement to SBG

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The Surface Biology and Geology (SBG) mission recommended by the 2017 Decadal Survey for Earth Science and Applications from Space from the U.S. National Academies will be welcomed by the scientific community for its ability to measure vegetation functional properties such as light use efficiency, plant pigment concentrations, water content, etc. at the time of overpass. However, those measurements are dependent on diurnal effects such as vegetation stress and scene shadows, which we demonstrate using diurnal G-LiHT (Goddard's LiDAR, Hyperspectral & Thermal Imager) data acquired over eddy flux sites in North Carolina, USA. We show that the typical mid-morning crossing times used for imaging satellites in sun-synchronous near-polar orbits (such as that proposed for SBG) do not capture periods of stress that occur later in the day. The photochemical reflectance index (difference in surface reflectances between 531 nm and 570 nm divided by their sum) overestimates light use efficiency if shaded pixels are not identified. The latest National Academies recommendations also call for specific measurements for vegetation structure and function and dynamics of ecosystems. We describe a concept for measuring diurnal Structure and Function of Ecosystems (SAFE) that complements and enhances SBG vegetation science. The SAFE concept utilizes high-resolution pan band and VSWIR multispectral instruments to measure structure and function, respectively, on a smallsat bus. With respect to structure, a panchromatic visible imager will acquire stereo triplet images to achieve 1 m canopy height models. With respect to function, a multispectral radiometer will acquire spectral radiance in prescribed very narrow wavelength bands needed for functional parameters (light use efficiency, pigments, nutrients), clouds and atmospheric effects. Two to three smallsats can be placed in orbits that would enable measurements at the location of the SBG overpass at 1030 local time, but also at later times (i.e., 1330 and 1630). The results could then be used with SBG data to find markers (in the morning overpass) of the diurnal signal for plant stress. In addition the 3D models developed from SAFE could be used to estimate the shadow fraction at the time of the SBG overpass. Overall, SAFE is individually responsive to the Decadal Survey as a standalone competed mission and also as an important precursor mission to SGB, enabling maximization of SGB's science impact. *Canopy height model, canopy structure, ecosystem function, diurnal LiDAR*

NLT128TV6

The challenge to assess the Amazon forest structure

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The identification of forest structure is critical for several lines of investigation, including ecology, ecosystem functioning, micrometeorology, forest dynamic, forest management, among others. Assessing forest structure at a regional level is challenging and, often, expensive. The ALS (airborne laser scanning) technology and associated remote sensing are used to directly retrieve vegetation structure variables such as canopy height, number of individuals, volume, crown diameter, and indirect biophysical measurements over a much larger geographical extent than plot-based forest inventories. The diversity of information that can be extracted from ALS data provide exciting opportunities for improving forest monitoring, especially related to degradation, precision forestry, and carbon-stock estimation across large areas. Besides that, the surveyed extent allows reducing the levels of uncertainty in forest biomass estimation. We launched a large survey, randomly distributing 375 hectares ALS transects within the 3.5 million km2 of the Brasilian Amazon forest, the largest continuous tropical humid forest in the globe. The point cloud obtained from the ALS surveys allowed us to spatially describe the distribution of the emergent trees, to assess the forest structure across the Amazon basin, to produce a forest biomass map (assessing the uncertainty) and to correlate the variation of the environmental factor to the actual field sampling plots. At field plot level (first level), the data are used to validate the forest biomass estimated by LiDAR scanning (second level), based on allometric equations and the third level by extrapolating the forest biomass to the Brazilian Amazon Biome, by the use a suite of satellite information and metrics. Despite the incredible results already published, the ALS data is still offering the opportunity for new investigations. *LiDAR, ALS, forest structure*

Authors

Links to recorded video-presentations

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Michael Keller
US Forest Service

Understanding management, degradation, and regeneration of forests in the Brazilian Amazon using LiDAR remote sensing (part 1) (part 2)

Ralph Dubayah
Univ. of Maryland

The first glimpse at GEDI data that will help us produce the first three-dimensional map of the world's temperate and tropical forests (part 1) (part 2)

Svetlana Saarela
SLU

Treating LiDAR-based predictions as pseudo-field data: possibilities and pitfalls (part 1) (part 2)

Jean P. Ometto
INPE

LiDAR and broad-scale forest biomass estimates in the Amazon (part 1) (part 2)

William Kim
Leica

Optimizing the selection of LiDAR technology for forest data collection (part 1) (part 2)

Matheus Nunes
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Repeat-LiDAR survey reveals the primary tropical forests are most impacted by El Niño drought (part 1) (part 2)

Eben N. Broadbent
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LiDAR and hyperspectral data fusion for ecological mapping using the GatorEye Unmanned Flying Laboratory (part 1) (part 2)

Tiago de Conto
ForLiDAR

Mobile Laser Scanning - towards a new standard for forest inventory (part 1) (part 2)

Martin Isenburg
LAStools

Tales of a Rascal (Scientist): What I Did for Love (of Points) (part 1) (part 2)

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SLS016D1B1R1	*The Past, Current and Future Vision for NASA Research on Forest Ecosystem Structure and Function from Space* *Michael Falkowski (michael.falkowski@nasa.gov / NASA Terrestrial Ecology Program)*
SLS145D1B1R1	*Adopting GEDI's algorithms for estimating forest aboveground biomass with ICESat-2* *Laura Duncanson (lduncans@umd.edu / University of Maryland)*
SLS148D1B1R1	*Global products of slope-adaptive waveform metrics of large footprint LiDAR over forested areas* *Wenjian Ni (niwj@radi.ac.cn / Chinese Academy of Sciences)*
TLS045D1B1R2	*On separating wood from leaves, accounting for leaf angle distribution, and occlusion effects in terrestrial LiDAR scans of dense forests* *Martin Beland (martin.beland@scg.ulaval.ca / U Laval)*
TLS132D1B1R2	*Using multispectral terrestrial LiDAR for early detection of tree decline - from leaf water content to fine structural details* *Samuli Junttila (samuli.junttila@helsinki.fi / University of Helsinki)*
SLS015D1B2R1	*GEDI's potential to map structural diversity of plant canopies – a case study in the Sierra Nevada Mountains* *Fabian Schneider (fabian.schneider@jpl.nasa.gov / Jet Propulsion Laboratory)*
SLS026D1B2R1	*Exploring the potential of GEDI-derived canopy structure for mapping tree species diversity in the tropics* *Suzanne Marselis (marselis@umd.edu / University of Maryland)*
SLS104D1B2R1	*Forest degradation assessment in Tropical Dry Forests: a comparison of IceSat 2, UAV and ground-based observation data* *Philipp Gärtner (gaertner.p@gmail.com / Universidad Nacional de Tucumán, Tucumán)*
SLS121D1B2R1	*Ground and Top of Canopy Extraction from ICESat-2 Data in the South of China* *Yong Pang (pangy@ifrit.ac.cn / Chinese Academy of Forestry)*
SLS143D1B2R1	*Synergy of ICESat-2 and Landsat optical imagery data for mapping forest aboveground biomass with deep learning* *Lana Narine (lln0005@auburn.edu / Texas A&M University)*
SLS147D1B2R1	*On-orbit evaluation of GEDI waveform biomass estimators* *John Armston (armston@umd.edu / University of Maryland)*
TLS002D1B1R2	*Accurate geo-referencing of trees with no or inaccurate terrestrial location devices* *Bogdan Strimbu (bogdan.strimbu@oregonstate.edu / Oregon State University)*
TLS042D1B2R2	*Comparing Terrestrial and UAV LiDAR for Monitoring Forest Structure* *Kim Calders (kim.calders@ugent.be / Ghent University)*
TLS057D1B2R2	*Estimating fuel consumption at multiple scales from pre- and post-fire TLS and ALS* *Andrew Hudak (andrew.hudak@usda.gov / USDA Forest Service Rocky Mountain Res. Sta.)*
TLS064D1B2R2	*Optimizing TLS sampling designs for the description of understory vegetation structure* *Luke Wallace (luke.wallace2@rmit.edu.au / The RMIT University)*
TLS075D1B2R2	*Co-registration of ALS and TLS forestry data* *Bernhard Groiss (bgroiss@riegl.com / RIEGL Laser Measurement Systems GmbH)*
TLS101D1B2R2	*Capturing global trends in tree and forest structure with a unified terrestrial laser scanning database* *Atticus Stovall (atticus.e.stovall@nasa.gov / NASA Goddard Space Flight Center)*

ALS022D1B3R1	*Potential of forest structural types detected directly from airborne LiDAR data in the aboveground biomass estimation* *Syed Adnan (adnan@uef.fi / University of Eastern Finland)*
ALS023D1B3R1	*Enhancing sampling design by auxiliary information - potential of airborne laser scanning and satellite image based forest resources maps* *Minna Räty (minna.raty@luke.fi / Natural Resources Institute Finland)*
ALS055D1B3R1	*Influence of vegetation structure on the canopy penetration of single photon LiDAR (SPL)* *Martin Queinnec (queinnec@mail.ubc.ca / The University of British Columbia)*
ALS079D1B3R1	*Spatial pattern of old large trees in a region of Amazon tropical forest* *Gustavo Henrique de Oliveira Mourão (gustavo-mourao@hotmail.com / UFVJM)*
NLT009D1B3R2	*Transferability of ALS-derived Forest Resource Inventory Attributes between Eastern and Western Canadian Boreal Forest Mixedwoods* *Karin van Ewijk (karin.vanewijk@queensu.ca / Queen's University)*
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NLT114D1B3R2	*Evaluation of the use of cross flight photo acquisition for improvement of forest structure reconstruction in SFM point clouds* *Bryan Hally (bryan.hally@rmit.edu.au / RMIT University)*
ALS031D3B1R1	*Deep Learning of synchronized Airborne LiDAR and Hyperspectral data to map successional stages on a Tropical Dry Forest* *Arturo Sánchez-Azofeifa (arturo.sanchez@ualberta.ca / University of Alberta)*
ALS041D3B1R1	*A pan-Canadian characterization of Boreal Forest gap size frequency distributions* *Tristan Goodbody (goodbody.t@gmail.com / University of British Columbia)*
ALS074D3B1R1	*Impact of wildfire regime on forest structural diversity in Northwest Spain* *Isabel Aulló-Maestro (isabel.aullo@inia.es / INIA-CIFOR)*
ALS095D3B1R1	*Challenges of multi-temporal and multi-sensor height growth analyses in a highly disturbed Boreal Mixedwood Forest in Canada* *Piotr Tompalski (piotr.tompalski@gmail.com / University of British Columbia)*
ALS122D3B1R1	*Fuel Load Mapping in the Brazilian Savanna using LiDAR Data and Multispectral Imagery* *Andrew Hudak (andrew.hudak@usda.gov / USDA Forest Service)*
ALS126D3B1R1	*Fusing multispectral LiDAR and aerial imagery for tree species classification* *Peter Krzystek (krzystek@hm.edu / Munich University of Applied Sciences)*
ALS151D3B1R1	*Forests, fires, and the role of remote sensing science for sustainable solutions in the Amazon* *Douglas Morton (douglas.morton@nasa.gov / NASA's Goddard Space Flight Center)*
TLS011D3B1R2	*JIB-SCAN: How to avoid occlusion in single station TLS assessments* *Günther Bronner (g.bronner@umweltdata.at / Umweltdata Ltd)*

TLS033D3B1R2	*3D Forest 0.5 - new release of the tool for processing high density point cloud data from forest ecosystems* *Martin Krůček (krucek.martin@gmail.com / The Silva Tarouca Research Institute)*
TLS039D3B1R2	*Architectural modeling for upscaling tree- and plot-level attributes across forest landscape* *Jean-François Côté (jean-francois.cote@canada.ca / Canadian Forest Service)*
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ALS037D3B2R2	*Impact of acquisition characteristics of unmanned aerial vehicle LiDAR missions on the quality of derived forest metrics* *Wilfried Karel (wilfried.karel@geo.tuwien.ac.at / TU Wien)*
ALS059D3B2R2	*How can variation in growth characteristics between genetic level and spacing of Douglas-fir realized-gains trials be characterized by ALS derived attributes?* *Francois du Toit (fdutoit2009@gmail.com / University of British Columbia)*
ALS060D3B2R2	*Characterizing phenotypes and modeling realized genetic gain in tree breeding trials using super-dense UAV laser scanning* *Samuel Grubinger (samuel.grubinger@alumni.ubc.ca / University of British Columbia)*
ALS065D3B3R1	*Lasers, cyclones, and the dry rainforest: explorations in mapping and disturbance quantification* *Gabrielle Davidson (gabrielle@iinet.net.au / Iron Range Research Station)*
ALS070D3B3R1	*Assimilating laser scanning and Landsat data following classical calibration* *Göran Ståhl (Goran.Stahl@slu.se / SLU)*
ALS072D3B3R1	*Spatial analysis of ultrahigh density LiDAR data for species classification* *Martin Slavík (mslavik@fld.czu.cz / Czech University of Life Sciences)*
ALS087D3B3R1	*Impact of simplifying assumptions on plant area density estimation with UAV-based Laser Scanning* *Alvaro Lau Sarmiento (alvaro.lausarmiento@wur.nl / Wageningen University & Research)*
ALS100D3B1R1	*LiDAR monitoring of canopy clearings after sustainable logging operations in forest concessions in the Amazon* *Leilson Gomes (leilsonferreiragomes@gmail.com / Universidade de Brasília)*

ALS058D3B3R2	*Comparison of multispectral airborne laser scanning and stereo matching of aerial images as a single sensor solution to forest inventories by tree species* *Mikko Kukkonen (mikko.kukkonen@uef.fi / University of Eastern Finland)*
ALS063D3B3R2	*Forest canopy cover analysis using UAV-based LiDAR and photogrammetry* *Qingwang Liu (liuqw@ifrit.ac.cn / Chinese Academy of Forestry)*
ALS071D3B3R2	*Understanding the forest structure by utilizing full waveform LiDAR data* *Yoshiko Maeda (yoshiko_maeda@kk-grp.jp / Kokusai Kogyo Co.)*
ALS073D3B3R2	*Exploring very high resolution UAV-Laser scanning for above-ground biomass estimators* *Alvaro Lau Sarmiento (alvaro.lausarmiento@wur.nl / Wageningen University & Research)*
ALS077D3B3R2	*Assessing the role of vegetation structure and foliage characteristics as drivers of avian diversity* *Ross Hill (rhill@bournemouth.ac.uk / Bournemouth University)*
ALS131D3B3R2	*Retrieving the stand volume of Scots pine stands using an allometric model applied on ALS-derived auxiliary metrics* *Jaroslaw Socha (jaroslaw.socha@ur.krakow.pl / University of Agriculture in Krakow)*

(click the code to watch a video version of the poster)

ALS006TV1 *Fine-scale prediction of yield in sugarcane: A comparison of UAV-derived LiDAR scans and multispectral imagery*
yuri.shendryk@csiro.au / CSIRO

ALS028TV1 *ALS-derived indicators for monitoring sustainable forest management*
jhonathan.santos@ceca.ufal.br / UFRPE

ALS040TV1 *Detection of Sub-Canopy Forest Structure Using Airborne LiDAR.*
jarronlukas@gmail.com / University of British Columbia - Faculty of Forestry

ALS043TV1 *Studying tree growth based on multi-temporal ALS data*
wilfried.karel@geo.tuwien.ac.at/ Vienna University of Technology

ALS044TV1 *Method Comparison for the Assessment of Vertical Structure from ALS Data in Natural Forests*
manuela.hirschmugl@joanneum.at / Joanneum Research

ALS046TV1 *Define northern interior old-growth forests with airborne LiDAR*
barros@unbc.ca / University of Northern British Columbia

ALS051TV1 *Tree buffer exclusion improves tree detection on airborne laser scanning surveys in even-aged stands*
chamaral@ufv.br / Federal University of Viçosa

ALS082TV1 *Forest growth monitoring using bitemporal areal LiDAR data: case study of national park Czech Switzerland*
melichovaz@fld.czu.cz / Czech University of Life Sciences

ALS096TV1 *Qualification of emergent trees extracted from LiDAR point cloud in the Amazon forest*
cristiano.reis@usp.br / University of Sao Paulo

ALS083TV2 *Deep Learning based single tree species classification using ALS data*
mustafic@tugraz.at / Graz University of Technology, TU Graz

ALS089TV2 *Altimetric evaluation of ground models of ground models from ALS over loblolly pine stands*
rorai.neto@gmail.com / São Paulo State University, FCT/UNESP

ALS092TV2 *A comparative assessment of the area-based approach and individual tree detection for volume estimation in mixed temperate forests using Airborne Laser Scanning data*
bogdan.apostol@icas.ro / "Marin Drăcea" Institute, Transilvania University

ALS093TV2 *The use of very dense ULS and ALS point clouds in monitoring the effects of protective treatments carried out in Scots pine (Pinus sylvestris L.) stands in the National Park Bory Tucholskie, Poland*
p.wezyk@ur.krakow.pl / University of Agriculture in Krakow

ALS097TV2 *Multiscale 3D-windows for detecting dead standing Eucalyptus from voxelised full-waveform LiDAR data*
mapro93@gmail.com / Cyprus University of Technology

ALS099TV2 *LiDAR assessment of biomass changes in sustainably managed timber harvesting areas in the Amazon*
leilsonferreiragomes@gmail.com / Universidade de Brasília

ALS102TV2 *Topographic Wetness Index from LiDAR Terrain Model Helps Forest Roads Maintenance*
bruno.martins@cenibra.com.br / Celulose Nipo-brasileira SA - CENIBRA

ALS107TV2 *Regression and machine learning models for estimating stand volume of eucalypt clonal and tropical highly diverse forests from LiDAR metrics*
chamaral@ufv.br / Federal University of Viçosa

ALS109TV2 *The Impact of Point Density for the generation of LiDAR derived Terrain Models*
veraldo.liesenberg@udesc.br / UDESC

ALS116TV3 *Tree detection and height measurement from aerial laser scanning point cloud* *anacorte@ufpr.br / UFPR*

ALS117TV3 *Estimating Burned Ecosystem Properties with NEONs Airborne Observation Platform*
bhass@battelleecology.org / National Ecological Observatory Network

ALS120TV3 *Airborne LiDAR technology in support of forest management*
pangy@ifrit.ac.cn / Chinese Academy of Forestry

ALS129TV3 *Choosing filtering parameters in LiDAR clouds collected over Amazon rainforest*
jhonathan.santos@ceca.ufal.br / UFAL

ALS134TV3 *Predicting species-specific diameter distributions in boreal forests using bi-temporal ALS, multispectral ALS, and aerial images*
janne.raty@uef.fi / University of Eastern Finland

ALS150TV3 *The Use of Deep Learning and Three-Dimensional Convolutional Neural Networks to Interpret LiDAR Data for Live Standing Carbon Estimation in the Context of Carbon Offsets*
e@pachama.com / Pachama Inc

SLS048TV4 *Overview of MOLI Mission to Estimate Forest Biomass*
mitsuhashi.rei@jaxa.jp / Japan Aerospace Exploration Agency, JAXA

SLS144TV4 *Estimation of forest AGB from ICESat-2 and Landsat*
lln0005@auburn.edu / Texas A&M University

SLS146TV4 *Preliminary validation of the ICESAT-2 land water vegetation elevation product (ATL08)*
mmoonga@tamu.edu / Texas A&M University

SLS149TV4 *Modeling the growth of forest height using ICESat-2 photon counting data over tropical forested areas*
niwj@radi.ac.cn / Chinese Academy of Sicences

TLS029TV5 *Tropical tree biomass equations from terrestrial LiDAR*
alvaro.lausarmiento@wur.nl / Wageningen University & Research

TLS047TV5 *Terrestrial Laser Scanning: an alternative for collecting dendrometric data in Atlantic secondary forests*
chamaral@ufv.br / Federal University of Viçosa

TLS049TV5 *Using terrestrial and airborne laser scanning in the estimation of wood properties in standing timber*
jiri.pyorala@helsinki.fi / University of Helsinki

TLS052TV5 *Application of terrestrial laser scanner for the determination of forest inventory parameters using simple scans*
vapesck@unicentro.br / Universidade Estadual do Centro Oeste – UNICENTRO

TLS067TV5 *Improving ground filter optimization using terrestrial point clouds*
luke.wallace2@rmit.edu.au / RMIT University

TLS081TV5 *Fusing ALS and TLS point clouds - towards better forest parameters estimation*
serban.chivulescu@icas.ro / "Marin Drăcea" Institute, Transilvania University

TLS085TV5 *Carbon sequestration potential and wood quality aspects of southern African trees extended to agroforestry systems - an assessment through 3D data*
Rafael.Bohn.Reckziegel@iww.uni-freiburg.de / University of Freiburg

TLS086TV5 *Terrestrial Point Cloud Processing to Estimate Individual Tree Parameters*
mokros@fld.czu.cz / Czech University of Life Sciences

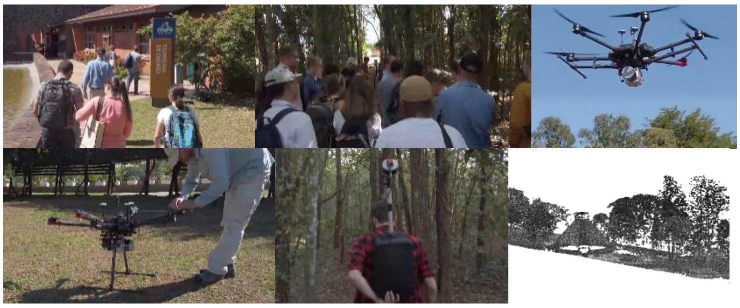
TLS090TV5 *Long time series of ground based laser scanning measurements of single trees and forest stands - 4D LiDAR monitoring*
p.wezyk@ur.krakow.pl / University of Agriculture in Krakow

TLS091TV5 *Comparing the number of trees retrieved with both ALS and TLS point cloud over a loblolly pine stand*
rorai.neto@gmail.com / São Paulo State University, FCT/UNESP

TLS103TV5	*Use of terrestrial laser scanning to assess fuel consumption in amazon rainforests* *gaprata@usp.br / University of São Paulo*
TLS108TV5	*Extraction of biophysical parameters using terrestrial laser scanner in a sample of Pinus taeda L.* *veraldo.liesenberg@udesc.br / UDESC*
NLT007TV6	*Deciduous Broad Leaf Bidirectional Scattering Distribution Function (BSDF): Measurements, Modeling, and Effects on Leaf Area Index (LAI) for Forest Ecological Assessments* *bdr3295@g.rit.edu / Rochester Institute of Technology*
NLT012TV6	*Adjustment of leaf area conversion functions in managed conifer stands in Sweden* *alex.appiah.mensah@slu.se / Swedish University of Agricultural Sciences*
NLT018TV6	*Estimating charcoal piles volume using an unmanned aerial vehicle* *luizacarvalhoflo@gmail.com / UFVJM*
NLT076TV6	*Highly Accurate Estimation of Lower Part Tree Trunk Perimeter by SfM Photogrammetry for Annual Tree increment Estimation* *mokros@fld.czu.cz / Czech University of Life Sciences Prague*
NLT078TV6	*Advanced earth observation techniques in forest biodiversity assessment* *anton.kuzmin@uef.fi / University of Eastern Finland*
NLT111TV6	*The Importance of GRSS Student Grand Challenge for promoting UAV Applications in Brazil* *daviddimartini2303@gmail.com / Universidade Federal do Mato Grosso do Sul*
NLT112TV6	*The Science of SAFE, a Smallsat complement to SBG* *wynne@vt.edu / Virginia Tech*
NLT128TV6	*The challenge to assess the Amazon forest structure* *assismauro@hotmail.com / INPE*

FIELD TRIP

Click **here** to watch a short video with memories from the field trip and LiDAR scanning activities at the Itaipu Biological Refuge.



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