LiDAR TECHNOLOGY IN FOREST INVENTORY
A comparative overview

Over the past 20 years, LiDAR technology has revolutionized the way we observe and describe forest structure. LiDAR (light detection and ranging) is a precision tool for characterizing the three-dimensional distribution of vegetation. It is an active remote sensing technique that measures distances with a very high accuracy by emitting laser energy and analyzing the backscattered energy as a function of time. In this article, we present the main types of LiDAR systems (ground and airborne) and highlight the opportunities and challenges associated with their use.

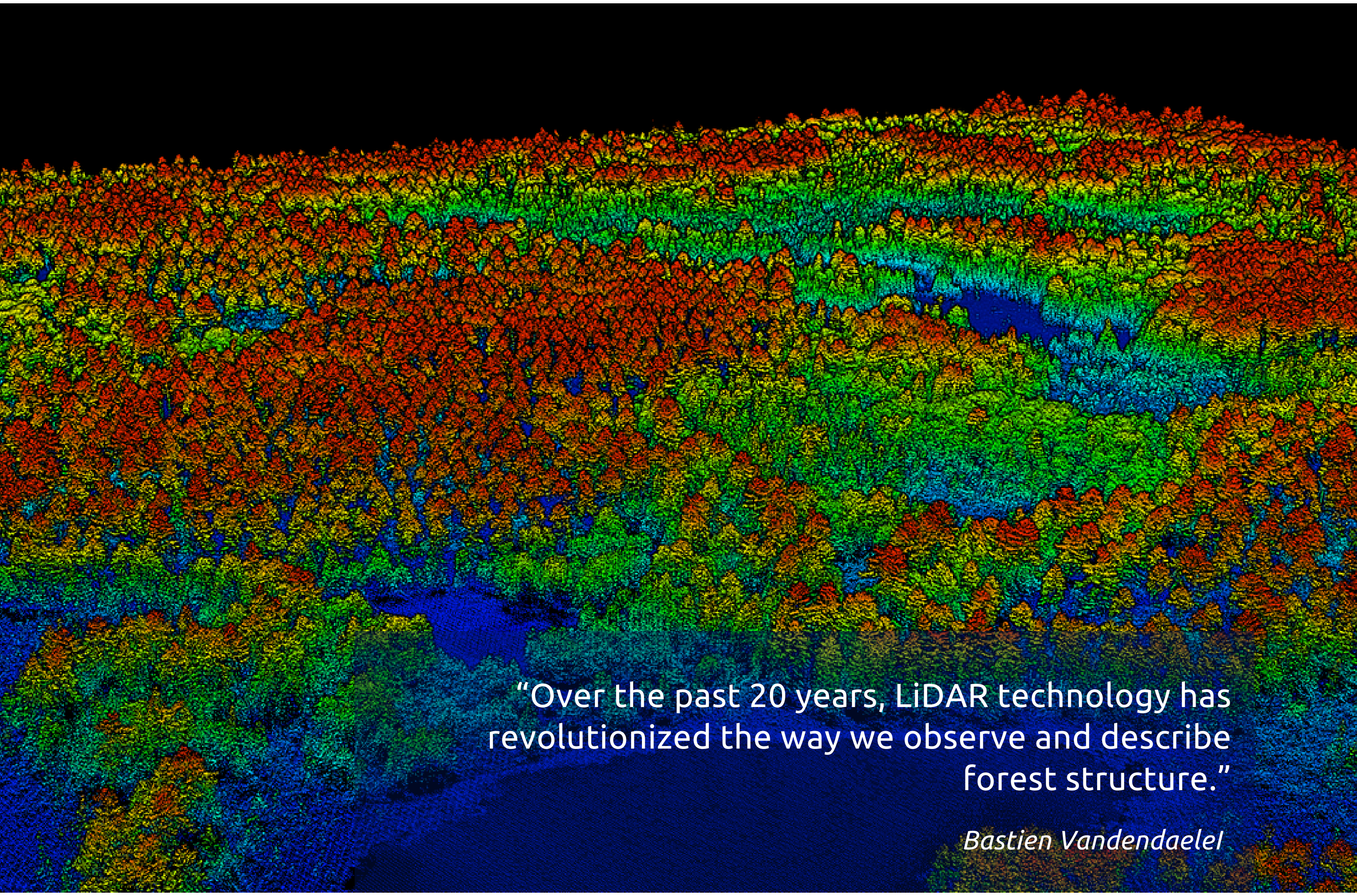

Photo: ALS data - Petawawa Research Forest (ON). Photo credit: Bastien Vandendaele.

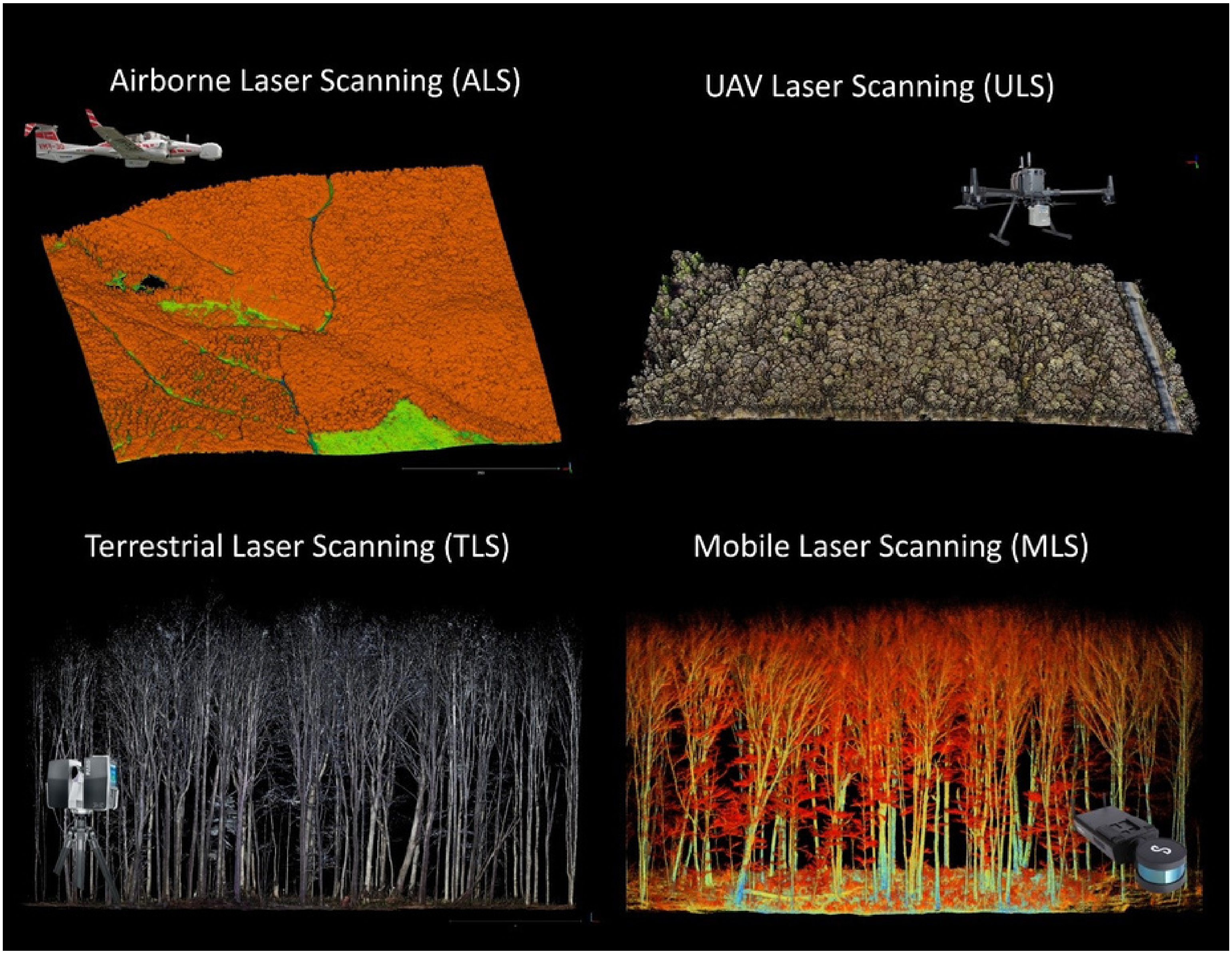

Figure 1. Illustration of the four LiDAR systems (ground and airborne) most commonly used in the forest environment and the corresponding 3D point clouds.

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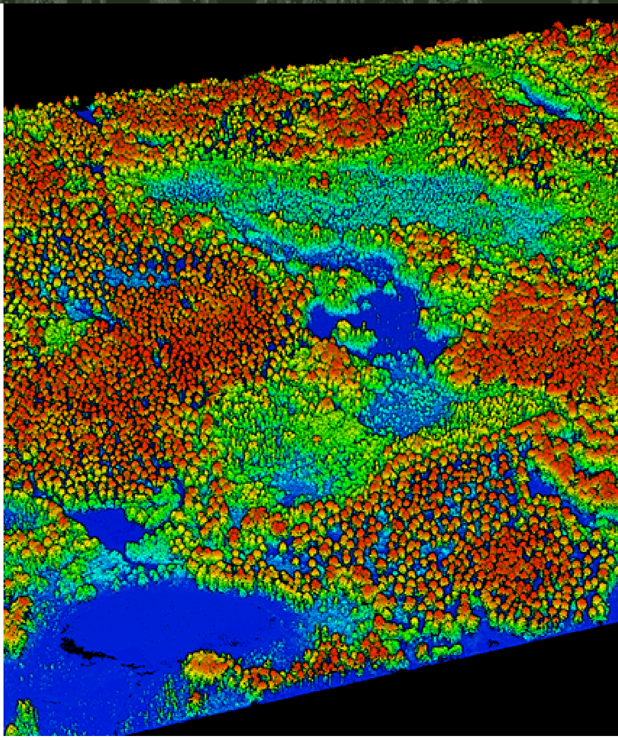
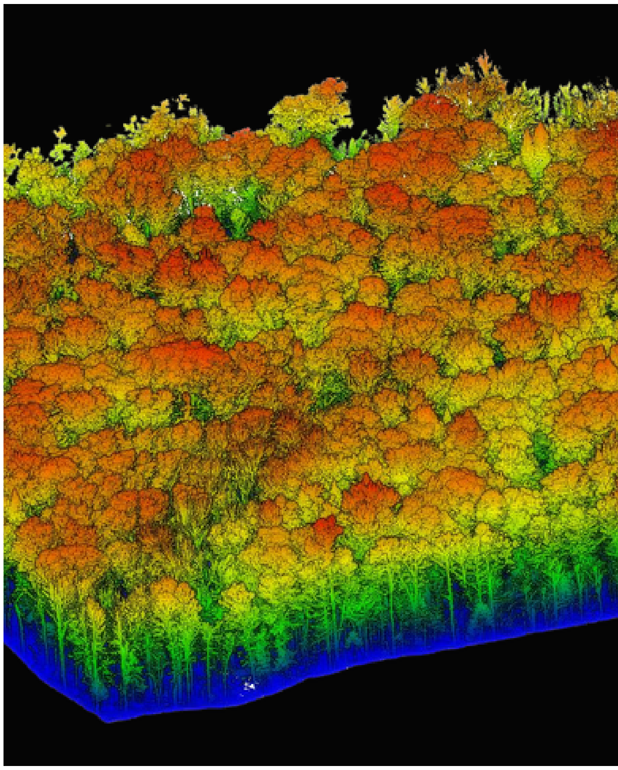


AIRBORNE LASER SCANNING (ALS)

ALS systems are deployed on aircraft at altitudes between 500 and 3000 meters. They scan forests over very large areas (10 - 1000 km²) with a point density generally between 5 and 20 points/m². They are used to support the strategic and tactical level of inventory and allow the generation of forest metrics (e.g. height, root mean square diameter, volume, etc.) in pixels of about 20 m × 20 m. Operational in many forest ecosystems, ALS is a key management tool for forest inventory. Its main limitation is the complex logistics associated with acquisition as well as the cost. Most of the time, foresters use service providers, which limits the temporal resolution of the overflights.



UAV LASER SCANNING (ULS)

AULS systems are similar to ALS in terms of components but are miniaturized and installed on fixed-wing or rotor UAVs and scan the forest at altitudes of 50 to 300 m above ground level. The democratization of these miniature systems has caused a great boom in ULS technology over the past decade. We are witnessing a strong growth of ULS users in the forestry industry. Unlike ALS, ULS is capable of capturing very fine details of the structure of individual trees. We are talking about a point density of 50 to 5000 points/m². Its ease of use makes it a very versatile tool for the study of forest stands. There is currently a wide range of LiDAR sensors on the market with very variable properties and accuracy levels. The main attributes that can be extracted from high-density ULS data are: tree height, crown dimensions, canopy gaps, number of stems per hectare, and in some cases direct diameter measurements at breast height. However, occlusion of the laser beam in the canopy limits accurate extraction of stem and branch attributes.

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TERRESTRIAL LASER SCANNING (TLS)

TLS systems scan the forest below the canopy at the tree and forest plot scale. They are static and mounted on a tripod. Therefore, it is usually necessary to perform multiple scans from different vantage points to increase coverage and minimize laser signal occlusion. TLS allows for the extraction of fine attributes such as diameter at breast height, height, stem taper, merchantable wood volume, or aboveground biomass. It is the most accurate tool for characterizing the 3D structure of vegetation as it is able to scan a scene with a point density of approximately 50,000 points/m². The main limitation of the use of TLS in forestry is its lack of operability. Complex to set up, it generally takes 45 minutes of scanning per plot to obtain a 3D point cloud and about the same time to process the data.

MOBILE LASER SCANNING (MLS)

MLS systems can be placed on a vehicle, in a backpack or simply carried at arm's length to obtain 3D data while moving through the woods. Most of the newer generations use a technique called simultaneous location and mapping (SLAM) to collect data in real time without the use of targets or landmarks in the field. The use of SLAMs in forestry is relatively new. Research is underway to evaluate their potential and limitations in different forest types. Current results are more than promising and many foresters see great potential to support field data collection and forestry operations. MLS can extract the same types of structural attributes as TLS but with less accuracy because the LiDAR beam footprint is wider and the data is noisier. However, it only takes about 5 minutes to scan a forest inventory plot and 10 minutes (automatic processing) to process the data. Although the technology is less accurate than TLS, it is much faster and much better suited for field data collection.

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Table 1. Main advantages and disadvantages of LiDAR systems for forest environment mapping. Source: modified from Béland et al (2019).

LiDAR System	ADVANTAGES	DISADVANTAGES
ALS	• Covers relatively large areas in a spatially contiguous manner. • Provides direct estimates of canopy roughness, cover fraction. • tree height terrain elevation, slope and aspect • GIS-ready raster maps of vegetation height, crown • extents, stem locations, LAI and biomass can be generated. • Can be used to monitor disturbance using repeat measurements. • Allows scaling from plot to satellite data.	• Limited description of within-canopy structure. • Due to high cost to acquire instrument data collection is typically conducted by airborne lidar service providers. • Requires the coordination of optimal weather conditions, airborne logistics and a ground support crew.
ULS	• Matches most advantages of ALS systems except for reduced coverage. • Significant increase in detail level within the canopy structure compared with ALS. • Higher pulse density compared to ALS. • Potentially less expensive than ALS acquisitions (depending on area size). • Can be acquired together with high resolution multispectral or hyperspectral data.	• Coverage of surveys is significantly lower than for ALS. • Line of sight government regulation can limit the use of this system in some environments, especially in dense forests. • Existing processing methods for ALS data may not all be directly transportable to ULS because of higher resolution and larger off-nadir angles; some methods development may be required. • Data collection needs to be contracted out and the currently limited number of service providers results in service not being available in all areas.
TLS	• Tree to plot level coverage. • Provides detailed information within canopy structure (lower and middle parts of the canopy). • Possible to separate wood from leaf material within data. • Can provide accurate LAI and full 3D foliage distribution within plots. • Can be used to generate accurate above-ground biomass allometric equations. • Provides stem maps, DBH, taper and basal area.	• Limited spatial coverage, unless extensive field campaign efforts are deployed. • Potential gaps in data, particularly higher up in the canopy and in areas of dense understory/canopy foliage. • Field methods are complex, particularly logistics and multiple scans alignment to a common positioning reference system. • 3D raw and derived data can be challenging to work with and are not always GIS compatible.
MLS	• Can cover relatively large plot areas • Inexpensive compared to other systems, highly portable • Simple to use and process data • Provides vertical profiles of LAI and within canopy structure • along transects. • Provides canopy roughness and cover fraction, tree height, DBH, stem taper, basal area and stem density.	• Limited spatial coverage. • Noisier and less accurate data than those from TLS technology. • Potential data alignment errors when simultaneous localization and mapping (SLAM) technology is used. • Accuracy in various forest types still relatively unknown.

Table 2. Current and potential products derived from different LiDAR systems. Colors refer to state of progress of research in deriving each product; red: not available, yellow: experimental, requires more research, green: operational but accuracy is not well defined or controlled, blue: operational and accuracy is characterized and satisfactory for most applications. For those colors requiring significantly more research (yellow and green), + and − signs refer to the suitability of the system for deriving a given product+sign refers to the potential to provide product at a scale and accuracy level which is relevant to research questions, hence research in this direction is considered promising, - sign indicates weak suitability of a system to derive a given product. These represent opinions based on a review of the literature and the experience of the co-authors. Source: Béland et al (2019).

Retreivable product	LiDAR Platform and Measurement Approach						
	Airborne Laser Scanning (ALS)		UAV Laser Scanning (ULS)	Terrestrial Laser Scanning (TLS)	Portable Canopy LiDAR (PCL)	Simultaneous Localization and Mapping (SLAM)	Spaceborne Laser Scanning (SLS)
	Small Footprint (discreet return)	Large Footprint (full waveform)					
Ground slope and aspect	Blue	Blue	Blue	Green −	Red	Blue	Red
Canopy height	Blue	Blue	Green +	Green +	Green +	Red	Green +
Stem map	Green −	Red	Yellow −	Blue	Yellow −	Blue	Red
Crown dimensions	Green −	Red	Yellow +	Blue	Yellow −	Red	Red
Percent cover and gap fraction	Blue	Green −	Yellow +	Green +	Blue	Red	Yellow +
Leaf area distribution (vertical 2D or complete 3D)	Green +	Yellow +	Yellow +	Green +	Blue	Red	Yellow +
Leaf Area Index (LAI, ID)	Green +	Yellow +	Yellow +	Blue	Blue	Red	Yellow +
Above-ground biomass	Green +	Green +	Yellow +	Blue	Green +	Green +	Yellow +
Stem density and basal area	Yellow −	Yellow −	Yellow −	Blue	Green −	Blue	Red
Foliage clumping	Yellow −	Yellow −	Yellow +	Green +	Green −	Red	Red
Gap size distribution and connectivity	Yellow +	Yellow +	Yellow +	Yellow +	Red	Red	Yellow +
Aerodynamics parameters	Green +	Yellow −	Yellow +	Green +	Green +	Red	Red
Competition intensity	Yellow +	Red	Yellow +	Yellow +	Yellow +	Yellow +	Red
Branch architecture	Red	Red	Yellow +	Yellow +	Red	Red	Red

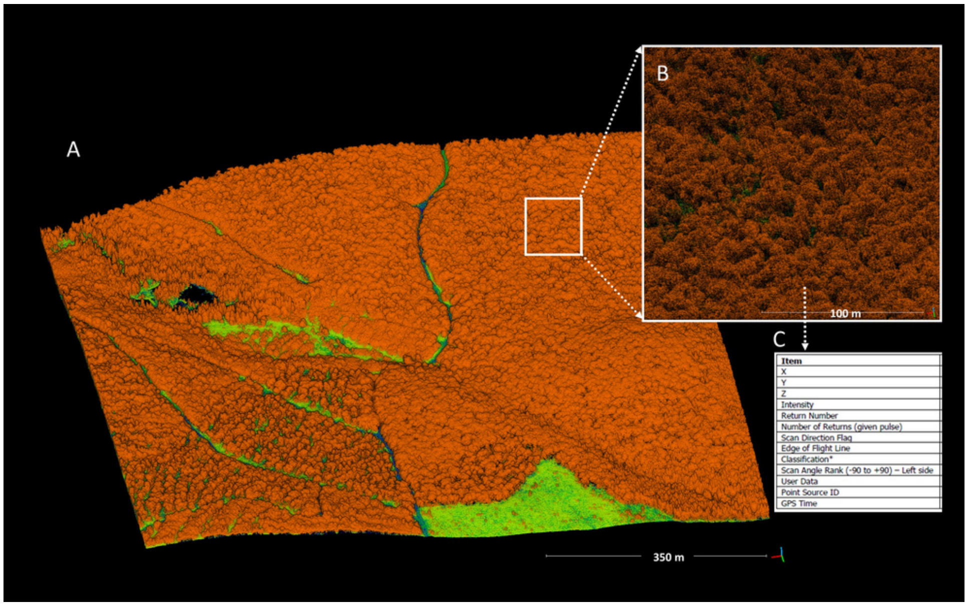

Photo: ALS data (NB). Photo credit: Bastien Vandendaele.

For those who wish to learn more about the potential and limitations of each of these LiDAR technologies, I invite you to consult the thesis (page 19-33) or the article dealing with this subject.

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