Forest Research
Extension Note

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Lidar Remote Sensing: Mapping British Columbia's Forests with Lasers

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WHAT IS LIDAR?

Lidar (light detection and ranging system) is a relatively new type of active remote sensing technology that is capable of simultaneously mapping terrain and vegetation heights with sub-metre vertical and horizontal accuracy (Figure 1).

The most common type of lidar sensors operating within British Columbia are small-footprint, discrete return systems that record two to five returns for each emitted laser pulse. The distance between the lidar sensor and a target is estimated by multiplying the speed of light by half the amount of elapsed time between pulse emission and return detection. As the laser signal is reflected back to the sensor, large return peaks are interpreted to represent discrete objects in the path of the beam. The sensor then records these peaks as points in three-dimensional space. Generally, discrete return sensors have a small footprint, i.e., no more than several decimetres in diameter. Lidar is actually a combination of three complimentary technologies (Figure 2):

• A laser mounted on an aircraft in the same fashion as an aerial photography camera.

• An inertial measurement unit that records the pitch, yaw, and roll of the aircraft.

• A global positioning system capable of measuring the aircraft's xyz coordinates within several centimetres.

In a forest, a single laser pulse may receive returns from the overstorey, midstorey, and understorey, and, ideally, a final return from the ground. The number of individual pulses generated is also very high, typically 30 000 to 100 000 per second. (The very latest sensor, produced by Optech Incorporated of Ontario, is capable of emitting up to 167 000 pulses per second.) Thus, a typical four-return system operating at 50 kHz must be capable of receiving up to 200 000 pulse returns each second. As a result, a lidar survey produces a tremendous amount of information about three-dimensional vegetation structure and terrain morphology. The amount of data can be reduced by instead utilizing lidar as a sampling tool; rather than capturing all possible data, a series of transects are flown across the landscape to obtain detailed control information. These estimates are then extended to larger areas using optical remote sensing data such as aerial photographs or satellite imagery (e.g., Wulder and Seeman 2003; Hyde et al. 2006).

FORESTRY AND ECOLOGY APPLICATIONS

Digital Elevation Models

Digital terrain products are key derivatives of a lidar survey. Not only do these products provide high resolution models of terrain, they are also the reference above mean sea level against which the height of vegetation returns above the ground are established. Digital elevation models are created by first separating a lidar point cloud into ground and non-ground (e.g., vegetation) returns. This process usually involves a combination of automated and manual classification, often with the assistance of aerial photographs or video. The ground returns are then interpolated into a continuous raster surface representing the Earth's bare surface. Because ground returns may be extremely dense compared to other forms of

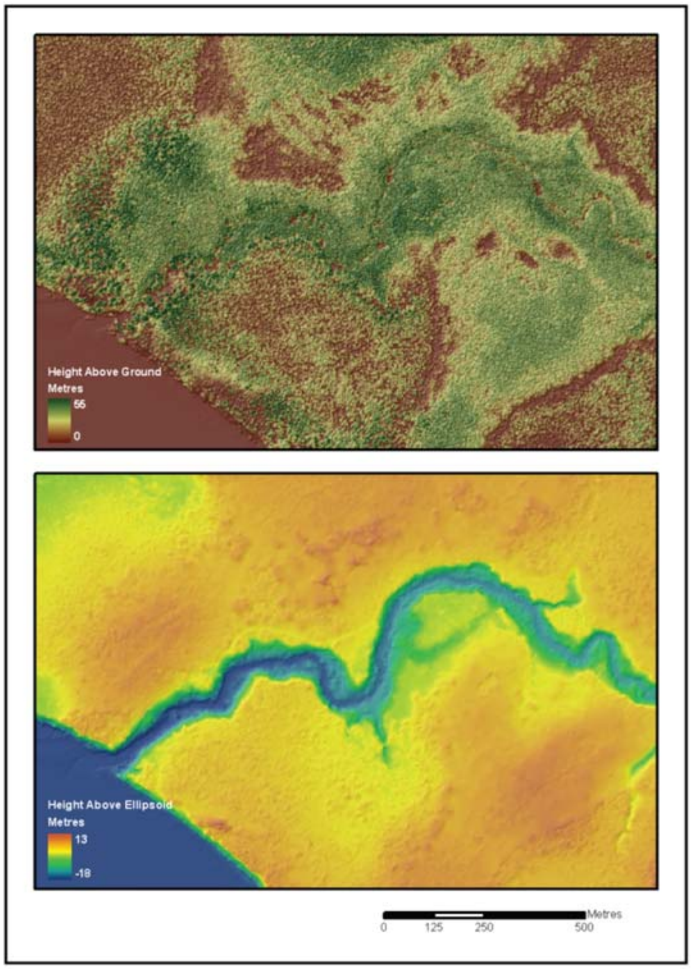

Figure 1. Top: digital surface model incorporating both vegetation and ground returns. Bottom: bare-Earth digital elevation model derived from ground returns only.

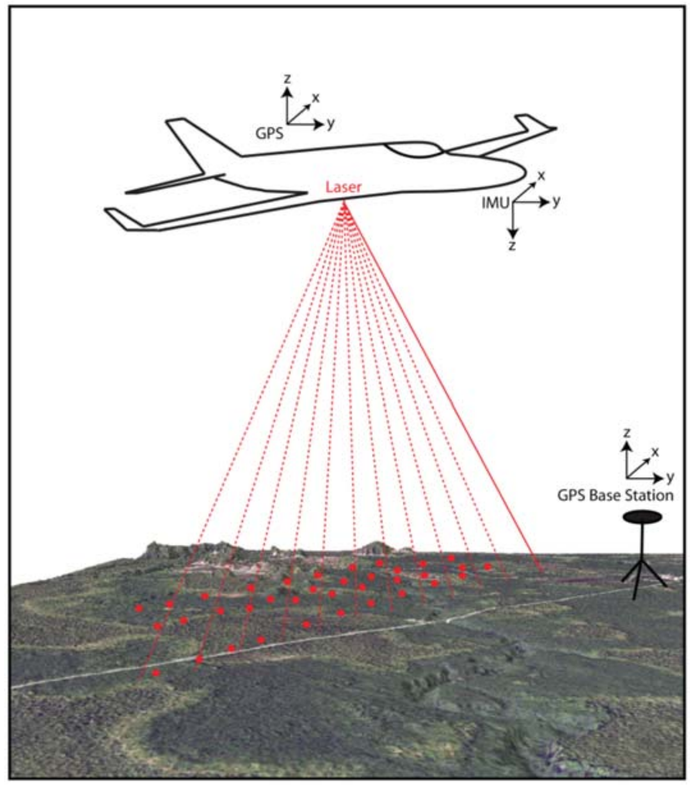

Figure 2. An airborne lidar system includes a laser, an inertial measuring unit (IMU), and a global positioning system (GPS) with a ground base station.

elevation data (typical posting distances of one to several metres are common, depending on survey parameterization and vegetation cover), the resulting digital elevation models represent terrain models of extremely high resolution (Figure 3).

There are many ways to apply lidar-derived digital elevation models in forestry. Just a few examples include fine-scale geomorphic analyses, forest engineering and road development, water flow modelling, flood risk analysis, and shoreline and beach volume changes over time. Figure 4 shows an example of a lidar-derived digital elevation model with landslides delineated. By using a geographic information system to analyze the surface, it was possible to not only identify the landsides and their transport zones, but also estimate the volume of material removed. In addition, forest roads and gullies are easily discernable along slopes.

Vegetation Mapping

A considerable amount of literature exists about the forestry and ecology applications for lidar data (see for example Dubayah and Drake 2000; Lefsky et al. 2002; Lim et al. 2003; Vierling et al. 2008). While lidar is excellent for mapping terrain, it is also capable of measuring vegetation heights with a high degree of accuracy. In fact, the accuracy of height estimates may approach or even exceed those obtained by field crews using traditional means such as hypsometers. Depending on survey parameters such as flying height and speed, pulse repetition frequency, scan angle, and sidelap, vegetation return densities may be high enough to allow individual tree crowns to be isolated. When point densities are lower, analyses are typically performed at the plot level.

From a forest inventory perspective, tree and stand heights are obvious candidates for measurement by lidar. Analysis techniques have increased in sophistication such that canopy structural characteristics, leaf area index, diameter, basal area, stem volume, biomass, stocking density, and fuel load and arrangement have also been estimated with varying degrees of success. These additional variables are usually estimated by developing statistical relationships between lidar height metrics and data collected in the field (Figure 5).

Beyond the realm of traditional forest mensuration variables, lidar is also a powerful tool for characterizing wildlife habitat. By mapping the three-dimensional structure of vegetation across the landscape, lidar data can be used as a predictive tool to determine species distributions based on the natural history of that species, or it could be employed as an exploratory tool to improve the understanding of resource selection by species of known distributions (Vierling et al. 2008). In either case, lidar offers the fine grain required to map species habitat over the large areas with which resource managers are concerned.

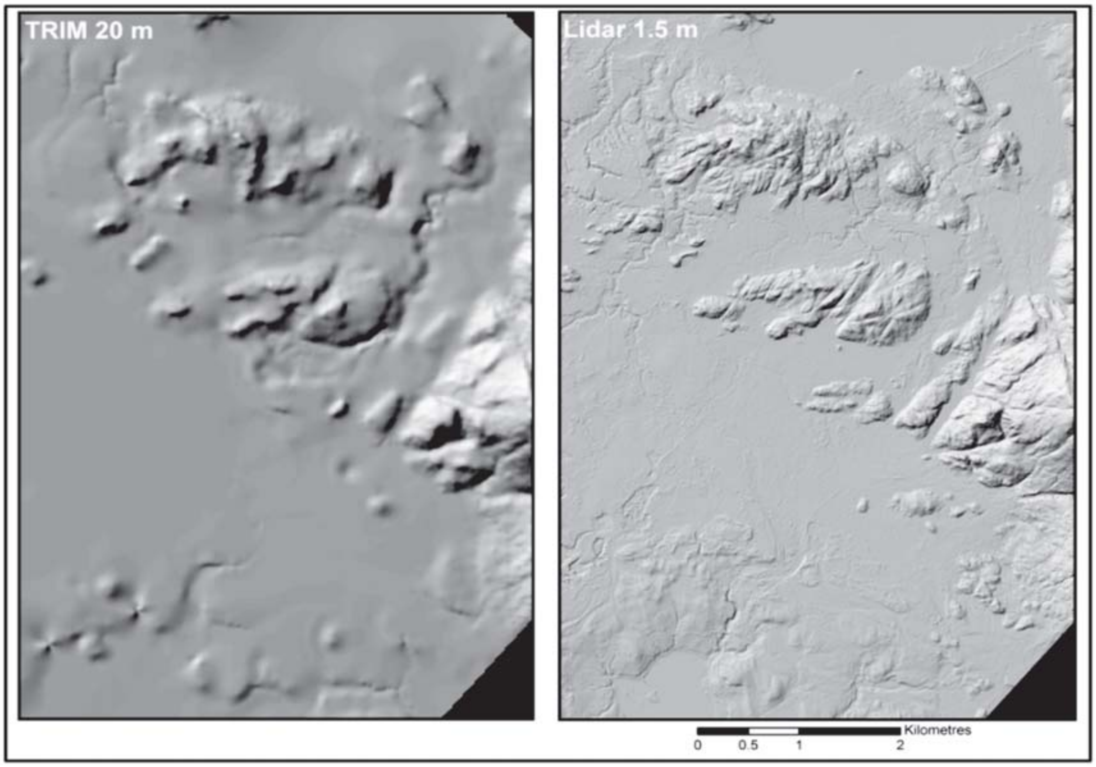

Figure 3. Two bare-Earth digital elevation models. Left: derived from Terrain Resource Information Management (TRIM) with a spatial resolution of 20 m. Right: derived from lidar ground returns with a spatial resolution 1.5 m. Note the fine detail apparent in the lidar-derived model.

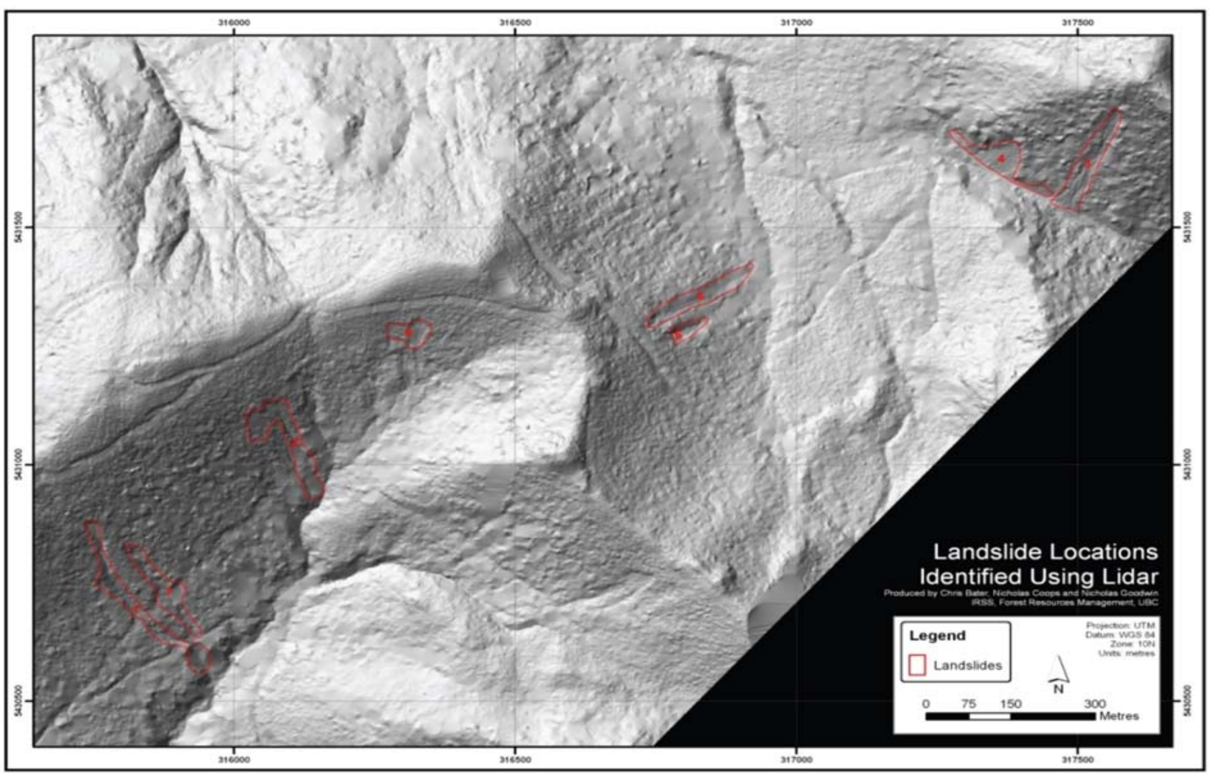

Figure 4. One-metre spatial resolution hillshade displaying landslide locations in part of Clayoquot Sound, Vancouver Island. The landslides are delineated by red polygons. Note the roads and gullies evident on some of the hill slopes.

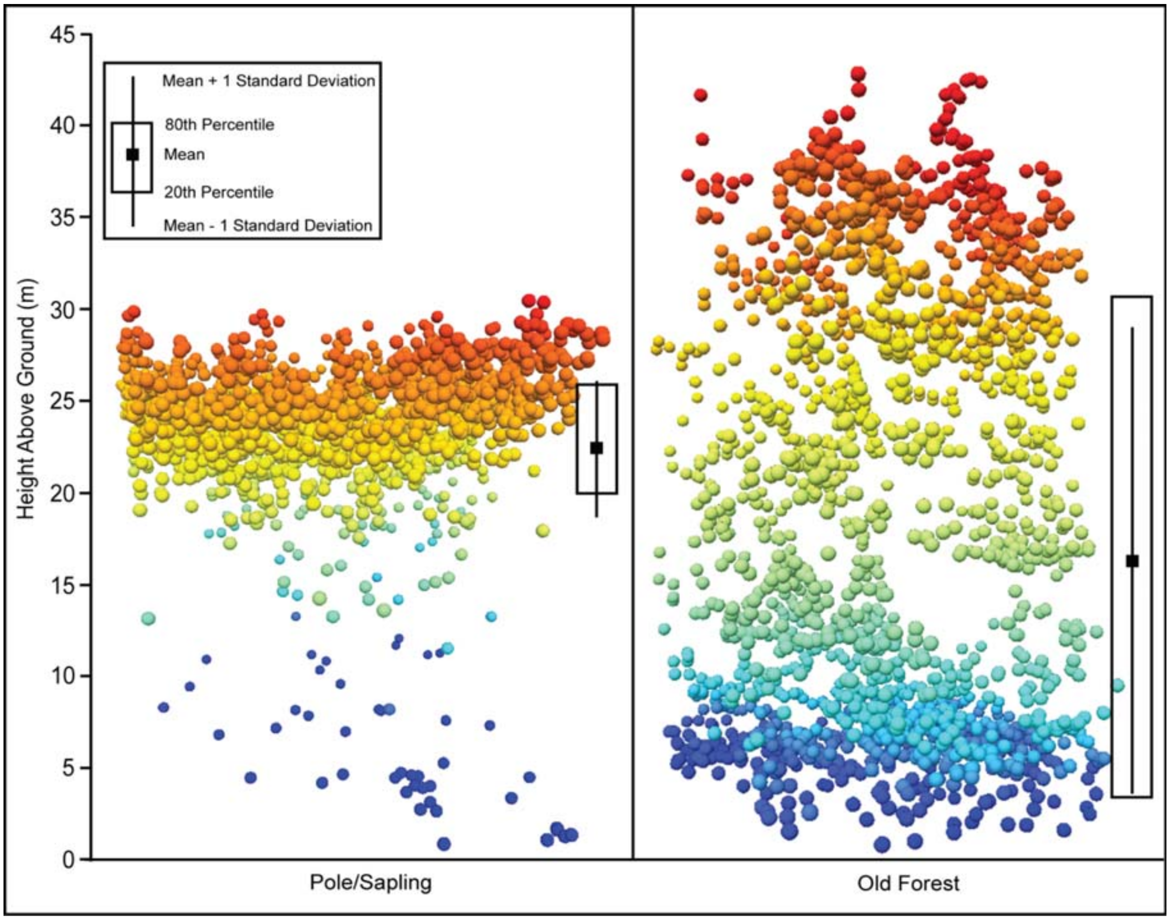

Figure 5. Lidar point clouds from two 625-m^2 forest plots located in Clayoquot Sound, Vancouver Island. The pole/sapling plot (left) has an extremely dense canopy. As a result, the majority of vegetation returns are found in the upper portion of the overstorey. The old forest plot (right) has a very different architecture, with biomass spread more evenly through its vertical profile. As a result, lidar returns are also distributed throughout. The differences are especially apparent when examining lidar-derived height metrics. Though the old forest plot has a maximum height 15 m greater than that of the pole/sapling plot, mean height is almost 10 m less, and the variability is much higher. Lidar-derived statistics such as these can be related to a variety of vegetation characteristics.

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