# TREE SPECIES CLASSIFICATION USING FULL-WAVEFORM AIRBORNE LASER SCANNING DATA BASED ON A TWO-STREAM RADIATIVE TRANSFER MODEL

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## ABSTRACT

In this contribution a method based on a two-stream radiative transfer model (Bohren, 1987) is presented to calculate two physical parameters derived from full-waveform airborne laser scanning (FWF-ALS) data, which have a close relation to the density and the reflectivity of the foliage and consequently to the tree species. Small-footprint FWF-ALS is an effective technology for acquiring 3D information of forested areas i.e. tree height, geometric distribution of leaves and branches. In opposite to tree heights the physical properties derived from FWF-ALS (i.e. amplitude, echo width, cross-section) are widely not used for operational forestry applications until now.

In forest canopies the emitted laser beam interacts with multiple scatterers. It is assumed that the topmost objects (i.e. leaves, branches, needles) backscatter the first part of the laser light/energy (1$^{st}$ echo), whereas the decreased light travels further downwards until it is finally backscattered from underlying objects (2$^{nd}$, 3$^{rd}$, etc. echo). It is assumed that for different tree species a characteristic range of decrease of the light energy occurs. There are some models describing the loss of energy within the laser beam while penetrating the canopy. A theoretically correct method focusing on the geometry is the Monte-Carlo radiative transfer model (e.g. North et al., 2010). These calculations can model any measured echo as a function of a set of geometrical and spectral parameters of the canopy very precise. The disadvantage of this method is the great number of required model parameters whereas many of these parameters are unknown or not well known in advance.

For the current study a more simple two-stream radiative transfer model (Bohren, 1987) is applied, that describes the downward and the upward radiation in a volumetric, scattering media (like a tree crown) that is illuminated from above. According to the two-stream radiative transfer model the upward radiation as a function of the height shows the characteristics of a ‘recovery curve’. The recovery curve is a negative exponential function with two parameters, the ‘mean free path’ and the ‘asymptote’. Both of these parameters have a physical meaning. The mean free path is a distance, where the intensity of the downward radiation decreases to 1/e part. The asymptote is the upward radiation of an infinitely thick media.

To apply this more simple model on FWF-ALS data, all echoes from multiple shots are selected within a vertical cylinder (representing a tree crown or a group of trees of the same species) (Figure 1). Furthermore to be independent of the actual height of trees, the heights are normalized for each tree. To represent the contribution of individual scatterers to the upward radiation, the cross section for each echo is calculated (the cross section describes the backscattering ability of light by an object). The cross section values (Wagner et al., 2008) for each echo are sorted according to the normalized heights and furthermore the cumulative sum of cross sections (CSCS) is calculated top down. For the CSCS versus the normalized heights a minus exponential function is fitted and furthermore two parameters describing the function are deduced (Figure 2). The first parameter 'mean free path' of the simplified model is reciprocal correlated with the density of the forest canopy where a short/small mean free path parameter means dense canopy. The second parameter 'asymptote' is proportional to the effective reflectivity of the forest canopy.

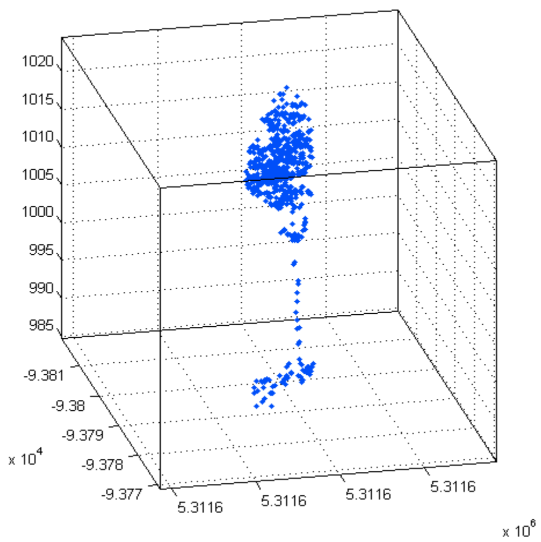


**Figure 1.** Spatial position of echos from a beech tree.

The method was applied for a high density FWF-ALS dataset for an area in Austria, which is covered by coniferous and deciduous trees. For this area also a detailed forest inventory dataset is available. Within this area, for the main tree species (beech, larch and spruce) several trees were selected based on the forest inventory data and furthermore the processing steps described above were applied. The two determined parameters 'mean free path' and 'asymptote' for each tree were plotted in a scatter plot. For each investigated tree species a clear clustering of the derived parameters could be shown (Figure 3). For a final tree species classification for larger areas, the tree species specific parameters were applied on a tree crown level and the derived results were validated with additional forest inventory data.

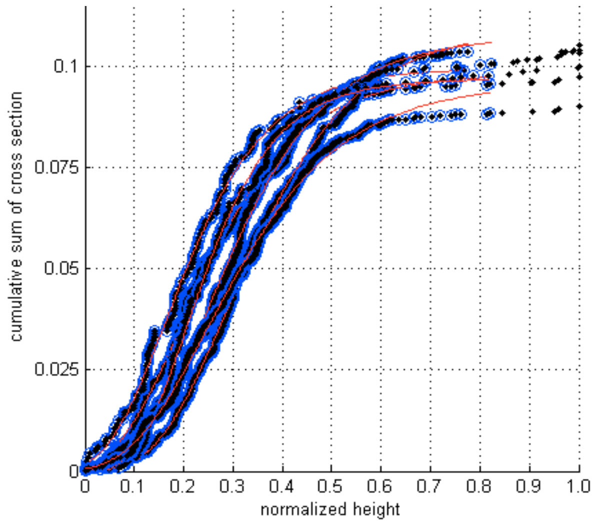


**Figure 2.** Cumulative sum of cross sections as a function of normalized height for 7 spruce samples. Black dots are cumulative sums, only blue circles were involved in the calculations. The red curve shows the fitted minus exponential curves. The the 'mean free path' defined by the slope of a curve relates to the density of the foliage and the asymptotic value of a curve relates to the reflectivity.

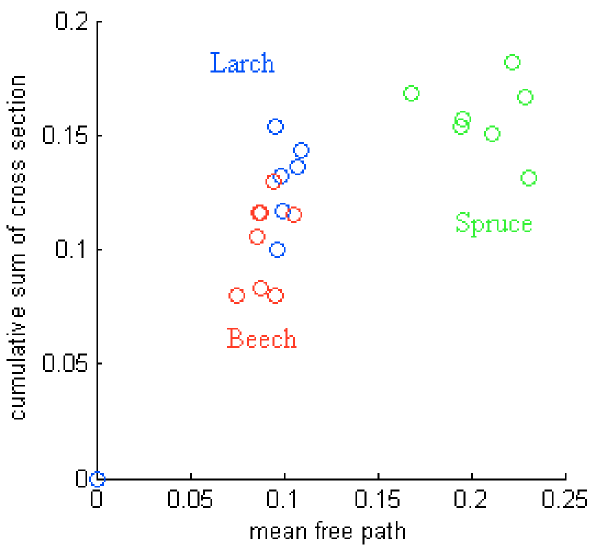


**Figure 3.** The crossplot of 'cumulative sum of cross section' and 'mean free path' values, resulted for sample dataset trees. Spruce can be easily separeted using this crossplot, but for larch and beech only the 'cumulative sum of cross section values' differ.

**Keywords:** LiDAR, Airborne laser scanning, radiation transfer equations, cross-section

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