# NEW APPROACH FOR DISTRIBUTION OF SHOOTS IN NORWAY SPRUCE 3D MODEL TO IMPROVE RADIATIVE TRANSFER MODELLING OF CANOPY REFLECTANCE


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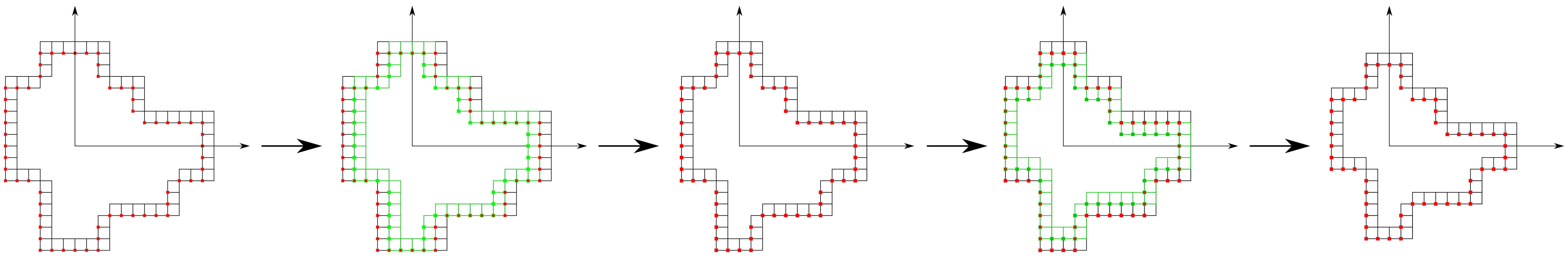


Figure 1 Illustration of enlarging the tree foliage envelope towards to the tree trunk. The process is executed in two steps, one per each axis. a) the original envelope border; b) extension towards the tree trunk in the first axis resulting in c), and d) extension in the second axis producing the final result (e).

## Introduction

Optical canopy radiative transfer models (RTM) simulate interactions between canopy elements and sun radiation. Discrete Anisotropic Radiative Transfer (DART) model is probably the most comprehensive RTM. It works with facet and turbid representations of trees. Using classical turbid tree 3D models (e.g., ellipsoidal turbid tree crown), we noted that DART simulated canopy reflectance does not compare well with reflectance values in remote sensing images. Our hypothesis is that this tree representation (i.e., schematic tree crown geometry filled with turbid medium) is not well adapted to coniferous forest: a more realistic facet-based 3D tree model should be used. However, simulating coniferous forests with realistic facet-based 3D tree models is computationally challenging, because the complex canopy and shoot architecture require a tremendous number of facets. Here, we present a method that creates a realistic facet-based 3D tree model, using terrestrial light (laser) detection and ranging (LiDAR) measurements of a single spruce tree.

## Methods

The process of 3D spruce model building was based on ground laser scanning (LiDAR) data and was divided into two phases:

1/ Creation of basic tree wooden structures (i.e., stem and main branches). We used an automatic algorithm for reconstruction (Figure 2) (Sloup 2013).

2/ Distribution of green biomass (i.e., 3D shoot models) within a tree crown. We designed a new algorithm, that combines LiDAR based spatial distribution, leaf angle distribution (Figure 3) and separates the youngest needles from the older ones (Figure 4). The separation is done in three steps:

1/ Voxelization of the tree,
2/ Calculation of the tree foliage envelope,
3/ Finding the given percent of youngest tree needles per horizontal layer by extending the tree envelope towards the tree trunk (Figure 1).

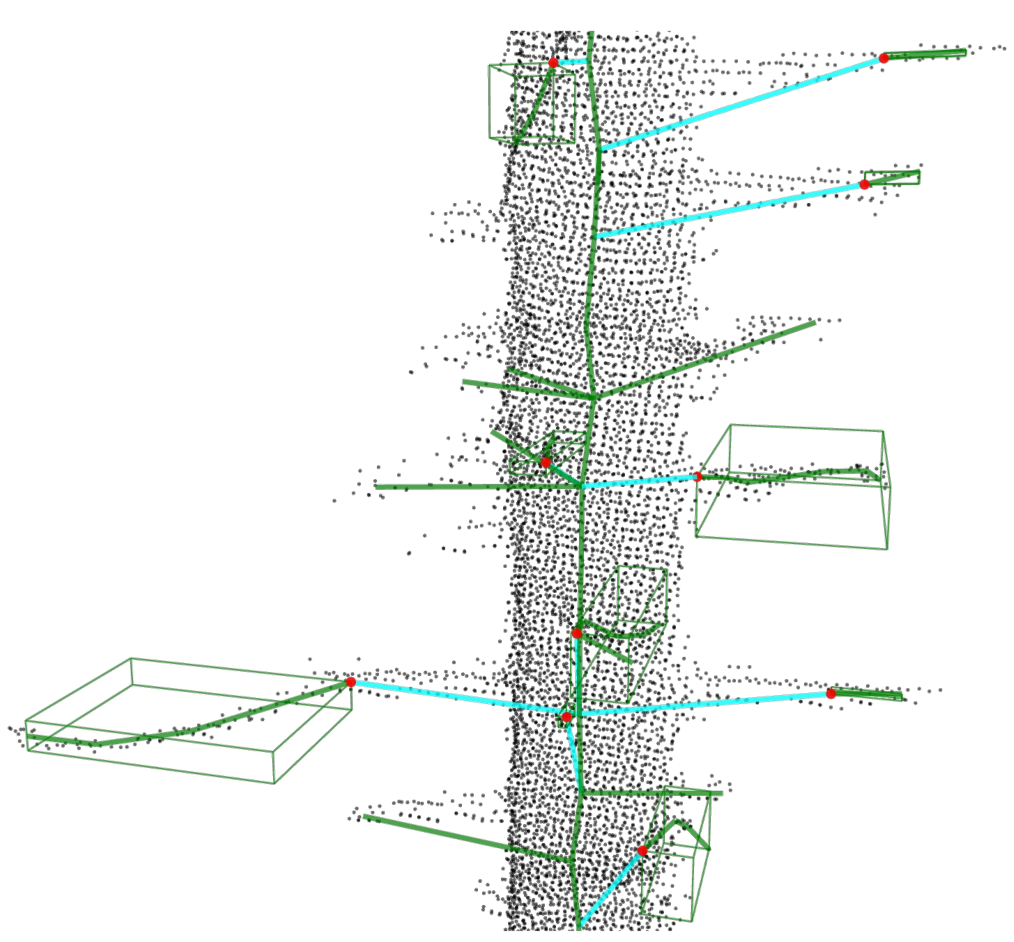

Figure 2 The algorithm for reconstruction of the wooden skeleton uses a LiDAR point cloud as input. It searches parts of branches, interconnects them and attaches them to the trunk (Sloup 2013).

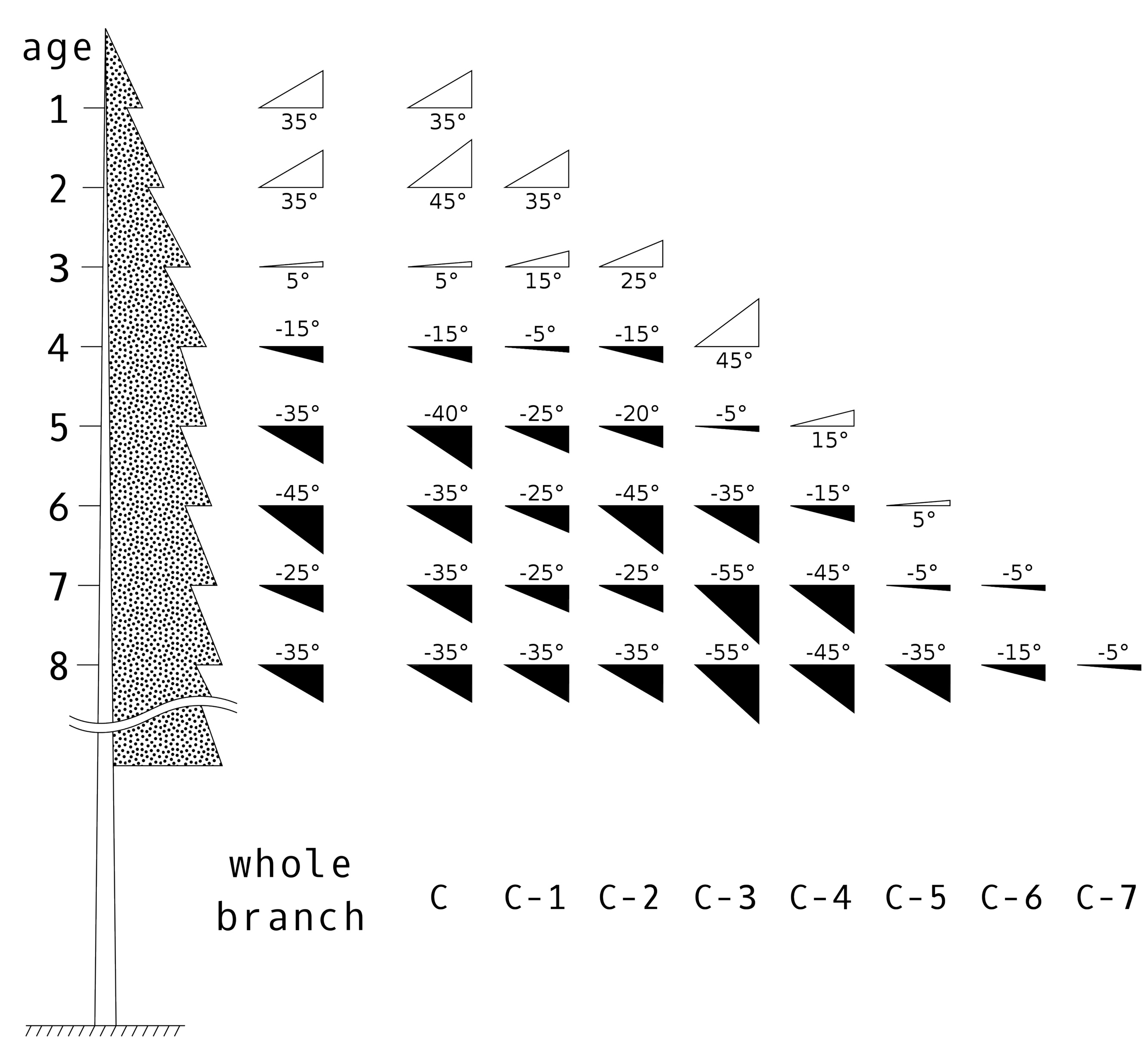


Figure 3 Vertical and horizontal angular distribution of N. spruce needle shoots. The horizontal distribution is separated by age of the shoots. C ~ current year, C-1 ~ previous year, etc. (adapted from Barták, 1992).

## Results

The designed 3D model of the spruce tree contains about $22 \cdot 10^6$ triangles, which is very computation demanding for DART modelling. Hence, it is our reference 3D model for further simplification of this spruce model for operational use in DART model. We will evaluate the following 2 to possible simplifications. (1) We simplify the shoot structure, which implies also to modify foliage optical properties in order to consider in-between-needle scattering. Second, we transform the 3D facet tree model into turbid cells with appropriate dimensions and characteristics (e.g. foliage density, turbid optical properties) of each cell. This approaches should be particularly efficient with next DART version where cells can have different dimensions within the same forest simulation.

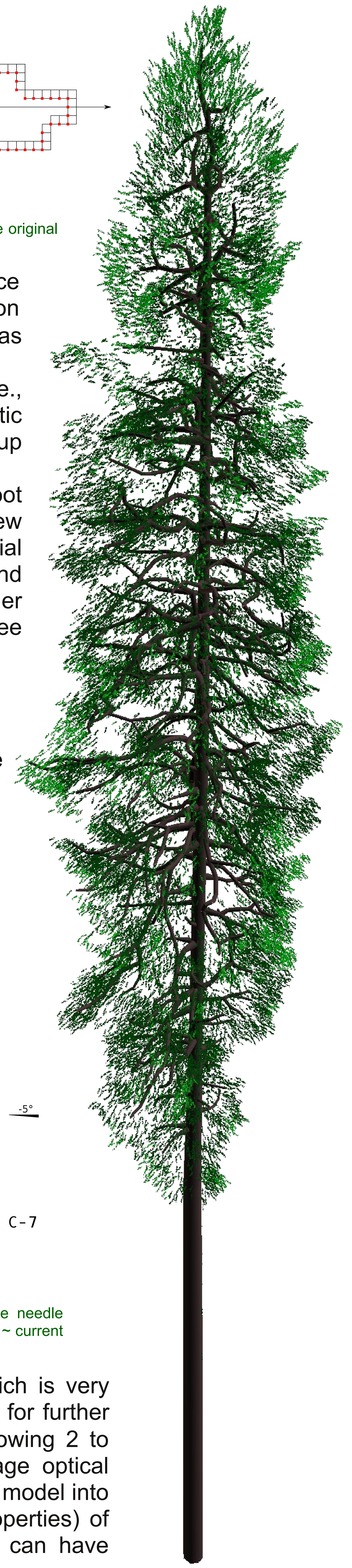

Figure 4 The final 3D model of a spruce tree with LAI = 6. The light green foliage represents the youngest needle shoots, while the dark green illustrates the older ones.

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## Introduction

Optical canopy radiative transfer models (RTM) simulate interactions between canopy elements and sun radiation. Discrete Anisotropic Radiative Transfer (DART) model (Figure 5) is probably the most comprehensive RTM. It works with facet and turbid representations of trees. Using classical turbid tree 3D models (e.g., ellipsoidal turbid tree crown) (Figure 7), we noted that DART simulated coniferous canopy reflectance does not compare well with reflectance values in remote sensing images (Figure 6). Modelling light scattering within a turbid cell tree model uses the so-called leaf angle distribution that describes angularity of shoots, but not the actual angular distribution of needles. In addition, in turbid cells that represent shoots, the foliar surface density is locally very large and spatially heterogeneous, which strongly affects scattered radiation, and consequently the simulated canopy reflectance.

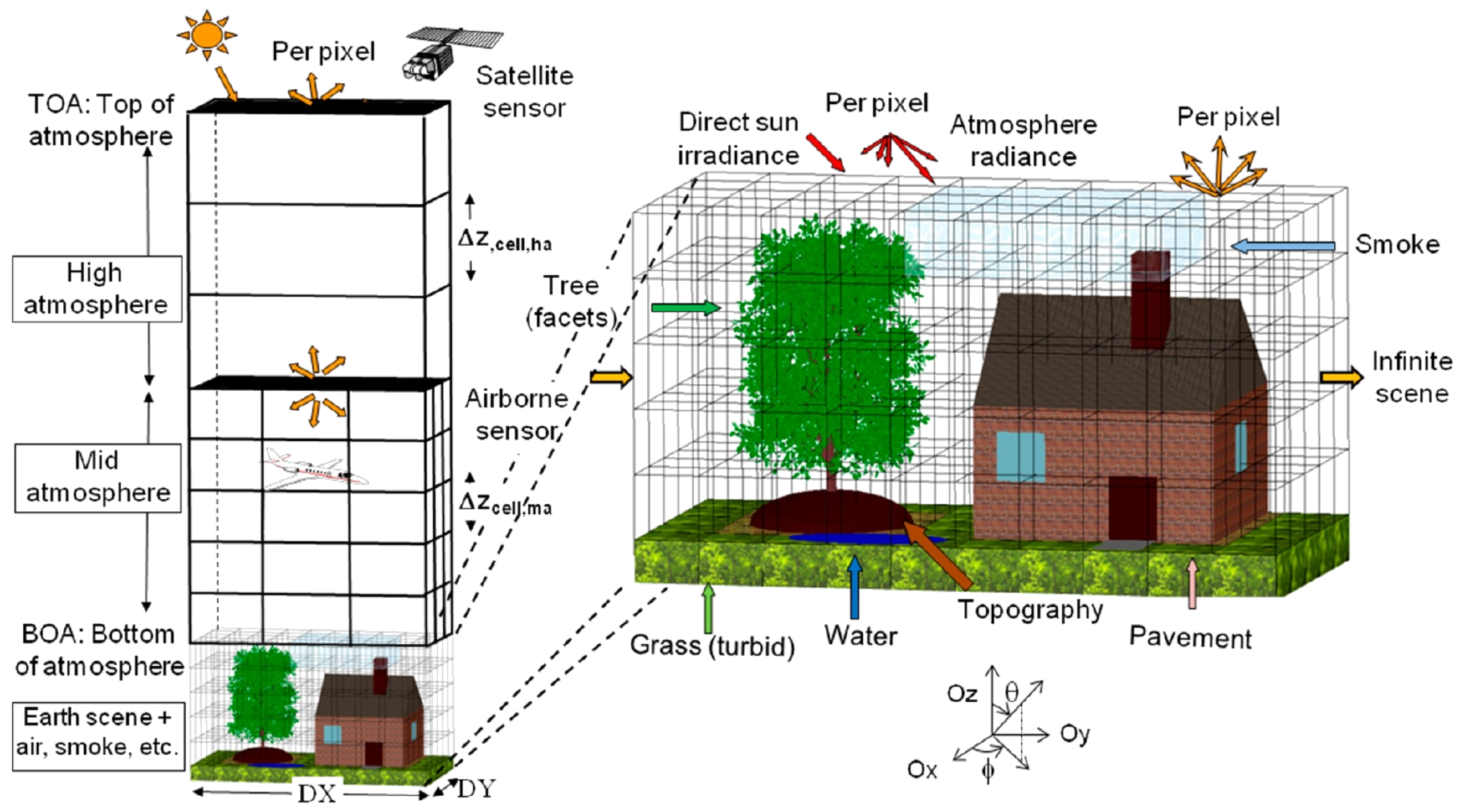


Figure 5 DART cell matrix of the Earth/Atmosphere system (Gastellu-Etchegorry et al., 2015).

Our hypothesis is that this tree representation (i.e., schematic tree crown geometry filled with turbid medium) is not well adapted to coniferous forest: a more realistic facet-based 3D tree model should be used. However, simulating coniferous forests with realistic facet-based 3D tree models is computationally challenging, because the complex canopy and shoot architecture require a tremendous number of facets. Here, we present a method that creates a realistic facet-based 3D tree model, using terrestrial light (laser) detection and ranging (LiDAR) measurements of a single spruce tree.

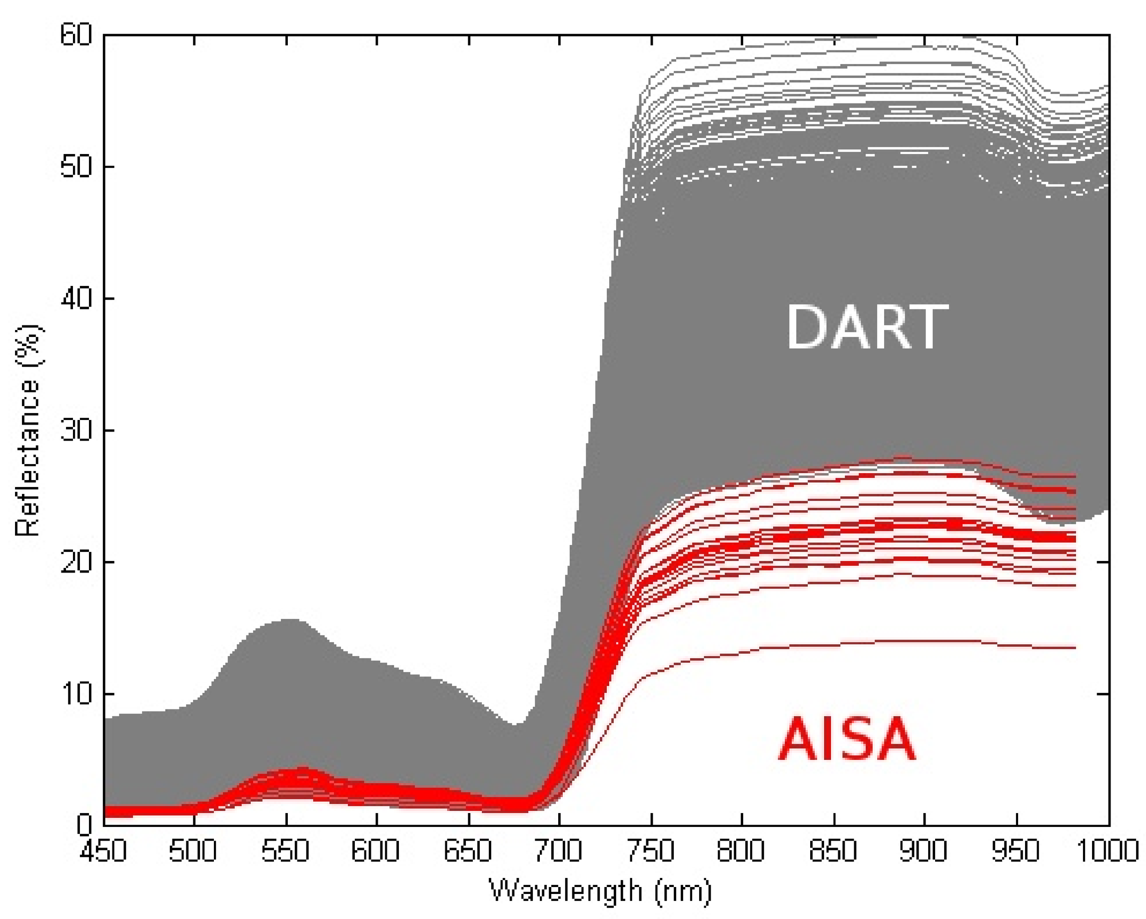


Figure 6 Spruce top-of-the-canopy reflectance simulated by the DART model (grey) and acquired for the same site by an AISA Eagle airborne hyperspectral sensor (red).

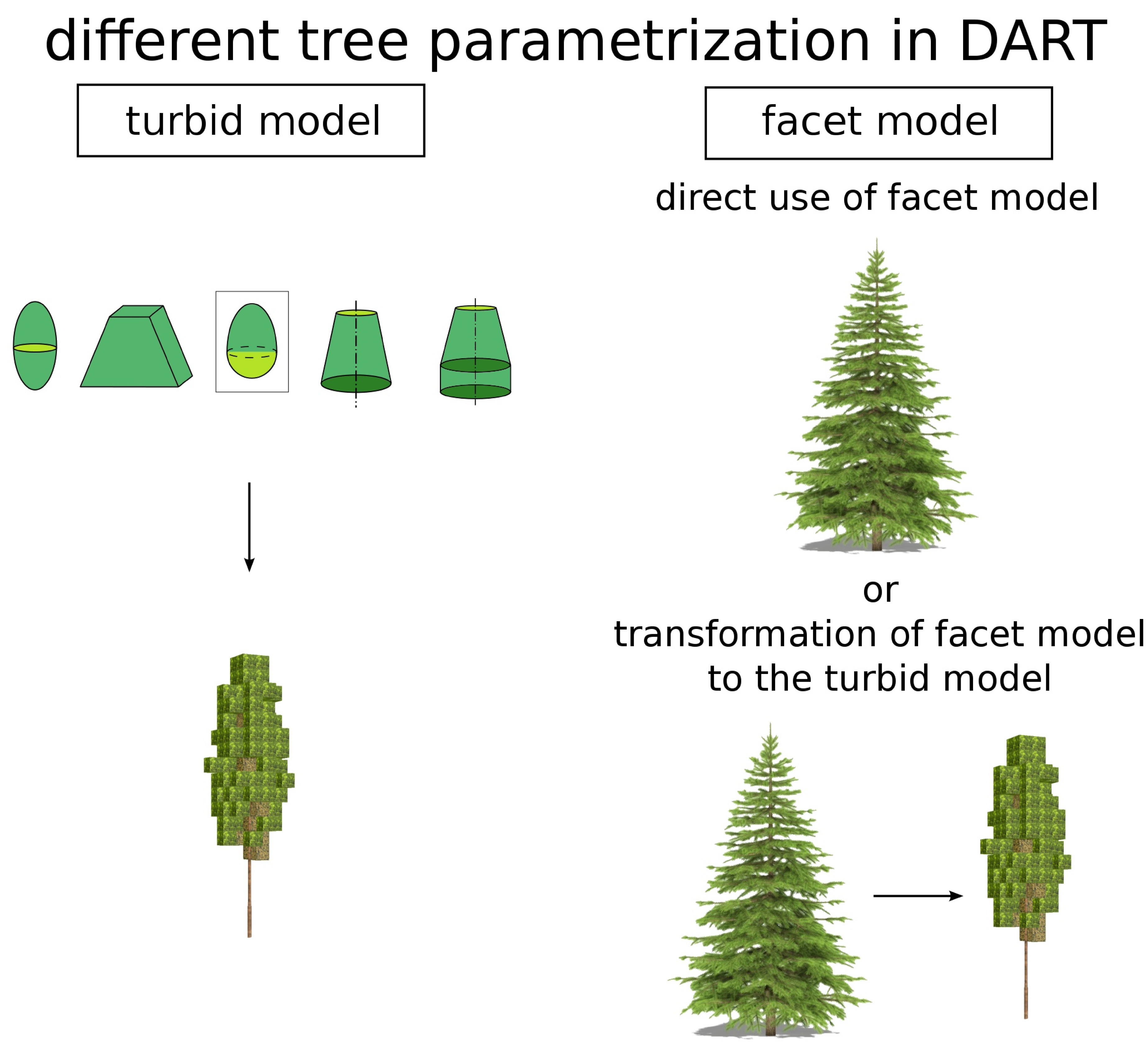


Figure 7 DART tree representation options. The basic option is a tree built from turbid cells according to one of the prepared crown shapes (on the left side). An advanced option is creation of tree as a 3D facet model (on the right-hand side) , which can be used as it is or subsequently transformed in turbid cells.

## Data

LiDAR data were acquired using an OPTECH Ilris-36D terrestrial laser scanner (Figure 8) at locations near the Kvilda village in Šumava Mountains in the Czech Republic in October 2009. The LiDAR emits laser beams (λ = 1500 nm) in slightly varying directions and measures the amount of returned light for up to 2500 points per second. The laser scanning data were acquired for individual standing mature spruce trees that were left standing at the edge of a bark beatle outbrake clearing. Trees were scanned from multiple directions and several observations were joined into a singular common point cloud.

The input data for a shoot angle distribution (Figure 3) were taken from study of Barták et al. (1992, 1993), which describes the crown structure of twenty 35-years old trees of Norway spruce (Picea abies /L./ Karst.) stand at Bílý Kříž (Moravskoslezské Beskydy, 49° 30' 17'' N, 18° 32' 28'' E, altitude 870 m, Czech Republic).

Figure 8 Terrestrial laser scanner OPTECH Ilris-36D.

## Methods

The process of building the 3D spruce model uses ground laser scanning data. It has two phases:

1/ Creation of basic tree wooden skeleton (i.e. stem and main branches): The wooden parts of the tree were separated from foliage by using the intensity threshold of LiDAR signal returns (Figure 9). The separated foliage was used in the follow-up step. We developed an automatic algorithm for reconstruction 3D tree main wood components (i.e. trunks and main branches) from terrestrial LiDAR scans (Figure 2). The algorithm is fully automated and does not require high-resolution LiDAR scans (Sloup 2013).

2/ Distribution of green needle biomass (i.e. 3D shoot models) within a tree skeleton: We proposed a new algorithm based on the LiDAR scan of tree foliage (Figure 9), that combines LiDAR based foliage spatial distribution with the leaf angle distribution (Figure 3) and separates the youngest needles of the latest generation from the older ones (Figure 4). The separation is done in following steps:

1/ Voxelization of the tree,

2/ Calculation of the tree foliage envelope, and

3/ Finding appropriate percentage of youngest tree needles per horizontal layer by extending the tree envelope towards the tree trunk(Figure 1).

The algorithm also controls the tree LAI, which influences the number of shoots within a tree. The whole procedure of the tree reconstruction is illustrated in Figure 9.


Figure 9 Creation of a 3D N. spruce construct from a LiDAR point cloud. a) Original LiDAR scan, b) separate point cloud of wooden parts, c) reconstructed wooden structure, d) reconstructed wooden structure with LiDAR foliage point cloud, and e) the final 3D tree model populated by shoots with needles of two types (age classes: dark and light green colors).

## Results

The designed 3D model of the spruce tree contains about $22{\cdot}10^6$ triangles, which is very computation demanding for DART modelling. Hence, it is our reference 3D model for further simplification of this spruce model for operational use in DART model. We will evaluate the following 2 to possible  simplifications. (1) We simplify the shoot structure, which implies also to modify foliage optical properties in order to consider in-between-needle scattering. Second, we transform the 3D facet tree model into turbid cells with appropriate dimensions and characteristics (e.g. foliage density, turbid optical properties) of each cell. This approaches should be particularly efficient with next DART version where cells can have different dimensions within the same forest simulation.

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