AMAPVox
LIDAR data voxelization software

User's Manual

Release date : October 12, 2015

Author : AMAP

Summary

SYSTEM REQUIREMENTS

OS
64 bits
Windows 7 – 8 -10
Linux (Ubuntu)

RAM :
Minimum : 4go
Recommanded : 8go

Processor :
A multi-core CPU is advised, to take advantage of multi-threading for TLS data

Java :
JRE 8 Oracle is needed

OpenGL :
Version 3 (for visualization)

STARTING UP

-Launch script click_me.bat or click_me.sh

-Or from command line, set current directory where file « AMAPVoxGUI-1.0-rxxxxxxxx.jar» is located and enter :

java -jar –Xmx8g AMAPVoxGUI-1.0-rxxxxxxxx.jar

Replace xxxxxxxx by the actual program revision.

Java known issues

Parameter -Xmx followed by 8g value indicate set the maximum heap size value of the JVM to 8 giga-bytes. This amount can be edited and it is advised to do so.
It must be modified in the following cases :

->XmX value need to be increased if you get following exception : java.lang.OutOfMemoryError: Java heap space

→if you don't specify the Xmx parameter then the JVM is going to use as much memory as is available. To avoid crashing or reduced performance you should to set this parameter so that 2go are reserved for the system

If multiple versions of Java are installed on the system, you might have program launching issues. To see which version is currently active you can open a terminal and execute the following command :

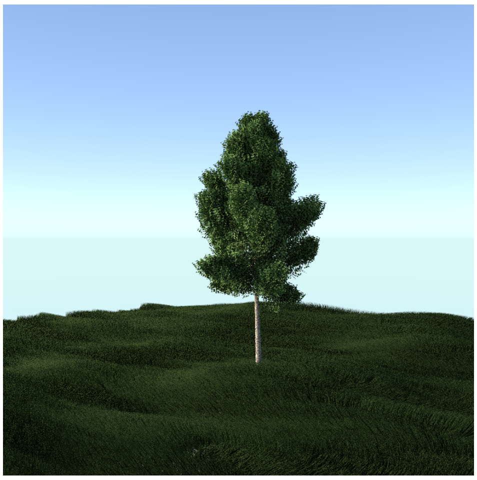
java –version

If the Java version appears to anterior to version 8 even though you have installed Java 8 you can find help with online at https://www.java.com/fr/download/help/path.xml

You need to install JRE/JDK provided by Oracle.
Download link : http://www.oracle.com/technetwork/java/javase/downloads/jre8-downloads-2133155.html

Get 64 bits version (x64).

1 – VOXELIZATION



llustration 1: Isolated tree

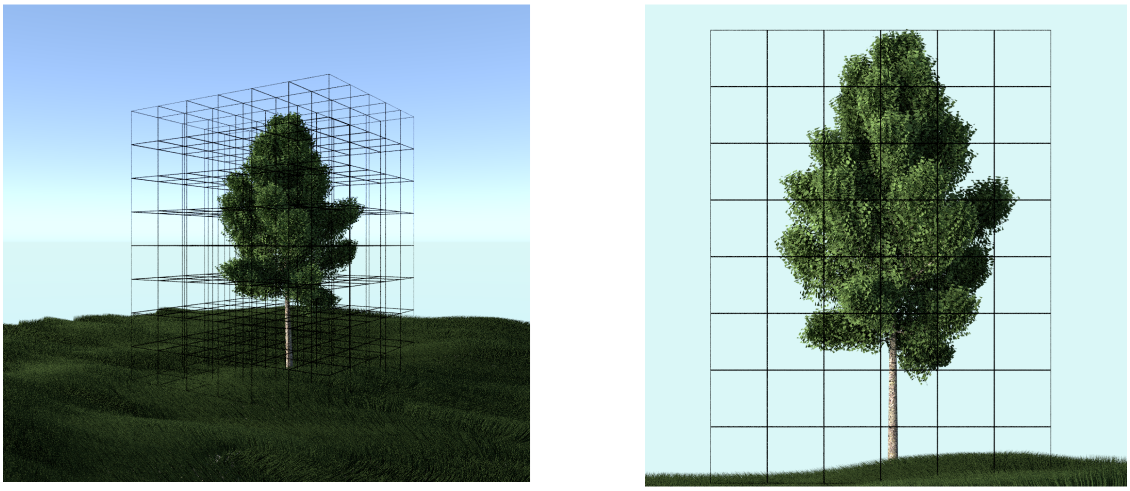


Illustration 2: Space clustering

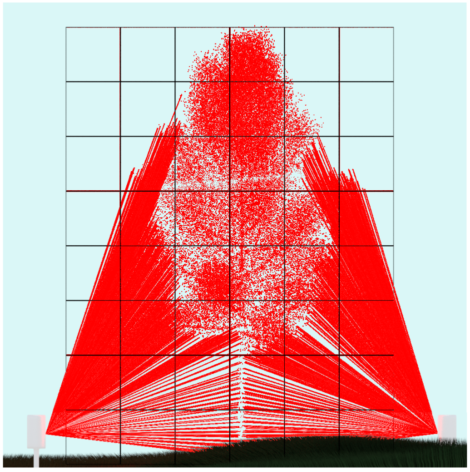


Illustration 3: Shots, space sampling

1.1 - Parameters

Voxelization requires a certain number of parameter values to be set, some of which are mandatory and the others are optional.

1.1.1 - Bounding-box

Voxel number by axes is automatically calculated from minimum and maximum points and resolution. Those values are expressed in unit meters (m).

Automatic button allow the automatic calculation of the extremums given a set of points (ALS). Fast option read the extremums in header file (als, laz), in the case where an additional transformation is set (VOP matrix = Voxel Orientation and Position), the option behaviour will be the same as the « Deep search» option.
« Deep search » option read all points from the file, apply a VOP matrix if there is any and does filtering by classification as defined in the tab « Filter » → « Other ».

1.1.2 - Transformation matrices

POP matrix

Project Orientation and Position, TLS only
Projection matrix of a Riscan Pro project, this is defined in the project file (*.rsp).
That matrix is automatically filled when a Riscan Pro project file is open, being read in the file. Using single scan (*.rxp) voxelization, it is possible to defined POP matrix, either by opening a matrix file (see file formats in annexe), or by choosing a Riscan Pro project file.

SOP matrix

System Orientation and Position, TLS only.
Each scan from Riscan Project has its own SOP matrix which is included in Riscan Pro project file. If a single scan (*.rxp) is selected, by clicking on the « Open file » button next to POP matrix you can choose the Riscan Pro project file and it will automatically configure the POP matrix and the SOP matrix of that scan.

VOP matrix

Voxel Orientation and Position.
Optional transformation matrix to convert World coordinates into Local coordinates.

1.1.3 - Filtering

From the « Filters » tab you have the possibility to add a filter on the echos (points) and shots (source point and direction vector).

Shot filtering:

-Shot inclination (elevation)
« Shots » panel.

Echos filtering :

-From a Digital Terrain Model : this filtering removes all points above a certain height above ground (those points will therefore be ignored in the vegetation density analysis).
« DTM » panel.

-From one point cloud or more (TLS only):
With this filter, you can keep a point cloud subset from a TLS project in order to sample the voxel space with those points only.
Basically it allows you to extract a tree from a forest or remove the wood of a tree.

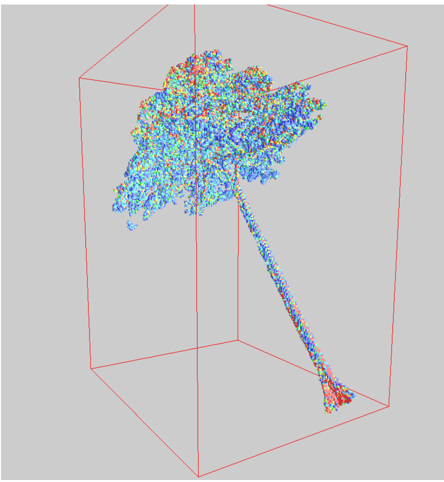


Illustration 4: Voxelization of an isolated tree

In order to do that, you have to go to the « Point cloud » panel.
You can add one ore more point file(s) with two possible actions, « Keep » or «Discard ».
For example, you can add a point cloud of a tree (wood and leaves) with the « Keep » action and add the wood point cloud of this tree with the action « Discard ».
This will only keeps the foliage.

Point cloud file has to be a text file with three columns, x (west), y (north) , z (altitude) splitted by space character and no header.
To deal with rounding issues for echos matching research, you can specify the error's margin. A value of 0.0025 is advised, but it depends of the exporting options.

The algorithm uses an octree to perform the matching research, the margin's error is the diameter of the sphere intersecting octree nodes.

-From echo classification (ALS only), see format specification for information about the classifications : http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html

« Other » panel.

1.1.4 - Echo weighting

Energy attenuation can be simulated by giving a weight associated to the echo rank.
Echos weighting can be activated in « Weighting » tab, assuming you are in « Voxelization » tab.
The only weighting mode available for the moment is the « by rank » weighting, this is going to weight the echoes according to number of echoes in shot and echo actual rank.

A weighting table is applied, column index corresponding to echo rank and row index corresponding to echo number in the shot.

The default ALS weighting table is the following :

1.00	/	/	/	/	/	/
0.62	0.38	/	/	/	/	/
0.40	0.35	0.25	/	/	/	/
0.28	0.29	0.24	0.19	/	/	/
0.21	0.24	0.21	0.19	0.15	/	/
0.16	0.21	0.19	0.18	0.14	0.12	/
0.15	0.17	0.15	0.16	0.12	0.19	0.06

The default TLS weighting table is the following :

1.00	/	/	/	/	/	/
0.50	0.50	/	/	/	/	/
1/3	1/3	1/3	/	/	/	/
0.25	0.25	0.25	0.25	/	/	/
0.20	0.20	0.20	0.20	0.20	/	/
1/6	1/6	1/6	1/6	1/6	1/6	/
1/7	1/7	1/7	1/7	1/7	1/7	1/7

1.1.5 - Limits

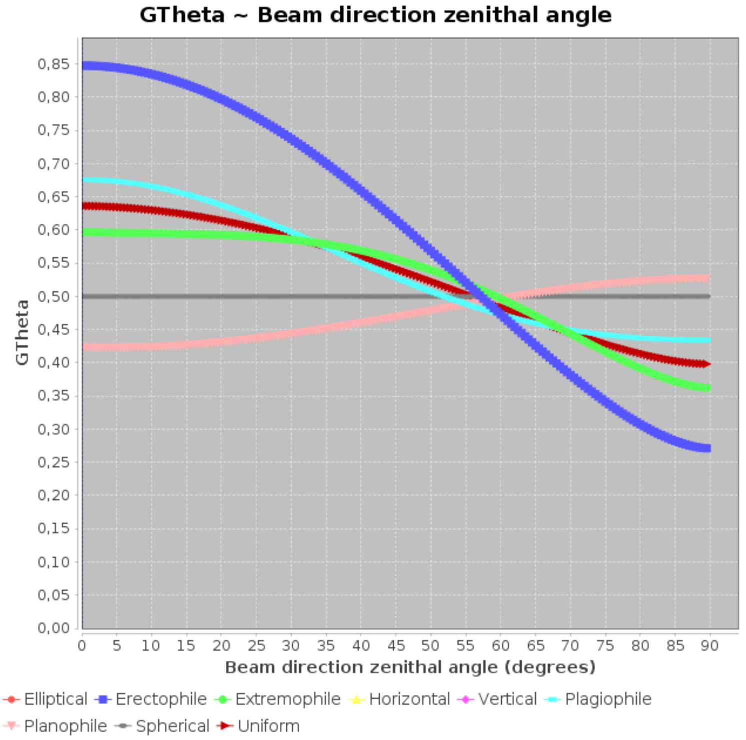
Inside the « Limits » tab you can set the maximum value of PAD (Plant Area Density).
A limit is set to trim unlikely high values which may occur notably in ALS mode under locally low sampling intensity.
The default limit is set to 5 for 1 m^3 voxel size. It is advisable to adjust this parameter based on the voxelization resolution.

1.1.6 - LAD

At the moment, we consider an homogenous Leaf Angle Distribution (LAD).
You can change the LAD type in « Voxelization » section in « LAD » tab.

The available types of LAD are as follows: Uniform, Sperical, Erectophile, Planophile, Extremophile, Plagiophile, Horizontal, Vertical, Ellipsoidal, Elliptical, Two-parameter beta distribution

The leaf phase function G(θ) is the projection of foliage area and is characterized by the Leaf Angle Distribution (LAD).



G(θ) is function of the beam direction zenithal angle which is the lidar shot direction.

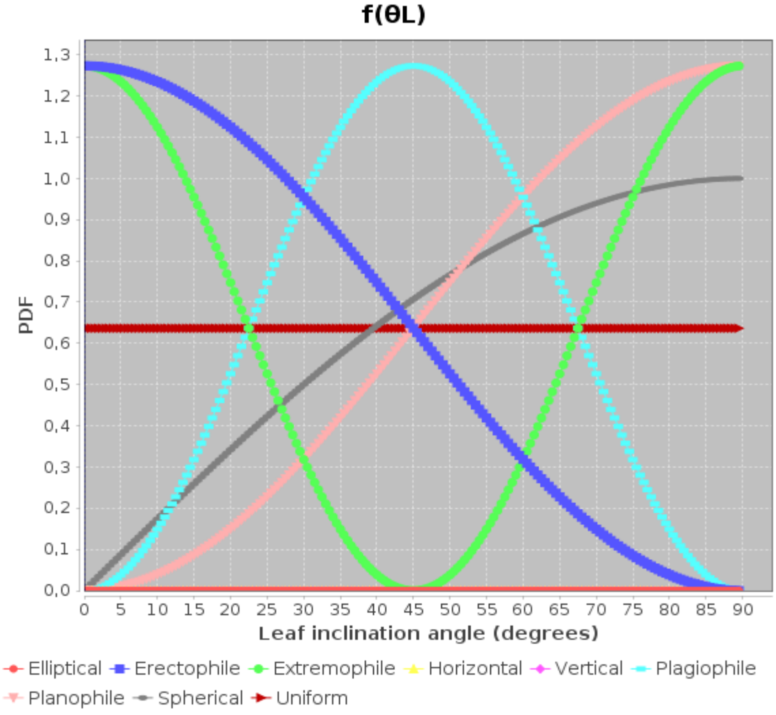
$$G(\theta) = \sum_{j}^{N} \left(\int_{\theta_{j-1}}^{\theta_j} A(\theta, \theta_L) \; d(\theta_L) \cdot f_j \right)$$

From : *Comparison of leaf angle distribution functions: Effects on extinction coefficient and fraction of sunlit foliage W.-M. Wang*

$$A(\theta, \theta_L) = \begin{cases} cos\theta \cos\theta_L, & |\cot\theta \cot\theta_L| > 1 \\ cos\theta \cdot \cos\theta_L \cdot \left(1 + \left(\frac{2}{\pi}\right) \cdot (\tan\psi - \psi)\right), & otherwise \end{cases}$$

$\psi = \cos^{-1}(\cot\theta \cot\theta_L)$
N is the total number of leaf angle intervals
f_j is the leaf area fraction of interval centered at θ_j

$f(\theta_L)$is the probability density function (PDF) , $\theta_L$the leaf inclination angle in radian.
Leaf inclination (zenithal angle) is relative to the surface normal of the leaf.



1.2 - ALS

Supported formats :
Public formats *.las and *.laz only
Process :
To voxelize ALS data you need to specify an input file (*.las or *.laz), a trajectory file (see file formats in appendix) and ouput file path and name.
Transformation matrices are not mandatory but you should at least configure the bounding-box.
You can automatically generate a bounding-box from « Automatic » button.

Special : Correct NaNs
The « Correct NaN's » checkbox can be selected in order to fill all not informed voxels (transmittance and PAD equals to NaN, meaning the value could not be processed).
This happens when voxel sampling is insufficient or null .

Algorithm is as follows :

```
For each  (« voxel » from voxel space):

        current_nbSampling = voxel.nbSampling
        current_transmittance = voxel.transmittance

        While (current_nbSampling ≤ threshold or current_transmittance == 0 ):


                -Get list of « neighbour » according to Moore neighborhood, which also verify the following
criteria : neighbour voxel is above the ground and below the top of canopy

                For each («neighbour» in neighbours list ):

                        sum_BVEntering += neighbour.bvEntering
                        ssum_BVIntercepted += neighbour.bvIntercepted
                        sum_lgTotal += voisin.lgTotal
                        mean_nbSampling += neighbour.nbSampling


                current_transmittance = (see formula below)
                current_nbSampling =  mean_nbSampling / size (neighbours)


        If (size(neighbours list) > 0) :

                count = 0
                For each («neighbour» in neighbours list ):

                        If (neighbour.transmittance != 0 et neighbour.transmittance!= NaN)
                                PAD_mean += neighbour.PadBVTotal
                                count++


                voxel.PadBVTotal =  PAD_ mean  /   count
                voxel.nbSampling =  current_nbSampling
                voxel.transmittance =  current_transmittance
```

$$current\_transmittance = \frac{\sum BVEntering - \sum BVIntercepted^{\frac{\sum BVEntering}{\sum lgTotal}}}{\sum BVEntering}$$

1.3 - TLS

Supported formats:

*.rxp (scan) and *.rsp (Riscan Project) files only

Process :

To voxelize in TLS you need to specify an input file (*.rxp or *.rsp) and an output file.
In case of voxelization of all scans in Riscan project, you need to filter on scan names because a Riscan project contains « mon » file for each scan.
A « mon » file is a decimated file of the original (~0.5%)
In order to check parameters, it is advised to begin a voxelization on those files before launching voxelization process on the original much larger files.

Warning : Only registered scans will be processed

The transformation process :

The transformation applied to a shot origin is the result of the following matrix product :
SOP %*% POP %*% VOP

The rotation part of this matrix is applied to the direction vector of the shot.

Execution time on 8 cores CPU :

Parameters: Voxel space splitting : 24x144x70
Scan number : 98
Average points by scan : 22 millions

Decimated scans : 1 minute
Full points scans : 35 minutes

Merging

In TLS, we can merge generated voxel files of each scan.

There are two options :

1-First is to merge after generation of voxel files, you just need to check the check-box « merge after » in « TLS » tab and give the output file name.

2-Second option is a separate mode and you need to select voxel files to merge.
You have to go in « Voxels files » panel, select the « merging » tab, drop your files in the list and choose an output file directory and name.
Next thing to do is generating a configuration file. Click on the button « Save and add to task list », which create a configuration file and add it to « Tasks » panel on the bottom left.
Finally click on the «Execute » button.

You can see in appendix the merging algorithm.

1.4 - Dart export

⚠ Dart formats are going to be changed by constructor soon.

Dart is a software developped by Cesbio (http://www.cesbio.ups-tlse.fr/). « It models radiative transfer in the system « Earth - Atmosphere », from visible to thermal infrared».

Dart can create model files as an input from its graphical user interface.
By creating/editing a model from the interface a « plots.xml » file is created/edited in the input folder of the Dart project simulation.

By running the module « Maket » in Dart it will use the file « plots.xml » from the input folder to generate the file « maket.txt ». This file will be written in the output folder of the Dart project simulation.

AMAPVox can convert voxel file to Dart file (« maket.txt » or « plots.xml ») so it can be used as an intermediary.
By analogy, a voxel from voxel file is a cell in the Dart file.
Cell of vegetation type contains LAI (Leaf Area Index) information, which is the surface density (m^2 leaf / m^2 of ground per plot) .
Voxel file contains PAD (Plant Area Density), it is converted into LAI by the formula :

$$LAI(cell) = cell's\ PAD * (cell\ size\ x) * (cell\ size\ y) * (cell\ size\ z)$$

To export a voxel file in Dart format :
You need to open a voxel file from « Voxels files » list in bottom right corner and click on « Export » button then « Dart » choice.
There are two output formats :

-A « plots.xml » file
-A « maket.txt » file + in option a « triangles.txt » file.

The first describes voxelized space in xml format, this file need to be moved inside the « input » folder of the Dart simulation.
The second represents voxelized space in maket Dart format, a text file.

1.4.1 – plots.xml

There are 5 types of plots/cells in Dart « plots.xml » file:
- -ground (type = 0)
- -vegetation (type = 1)
- -ground + vegetation (type = 2)
- -Fluid (type = 3)
- -Water (type = 4)

AMAPVox exports only the vegetation type, ground exports is not available yet.

Leaf Phase Function

You can assign a leaf phase function to each vegetation cell by editing the « plots.xml » file generated by AMAPVox.
The « VegetationOpticalPropertyLink » tag of each plot contains the index and identifiant of the phase function.
Phase functions can be created from Dart in the « Optical and temperature properties » section.
When you create a vegetation phase function the index value is 0 for the first created, 1 for the second, etc.

Leaf phase function is characterized by the Leaf Angle Distribution (LAD).
See LAD section (1.1.6) for further information.

Process :

Replace « plots.xml » (located in the input folder) of Dart simulation project by the generated one.

For dealing with the inability to exports ground plot, you can import a DEM from Dart interface inside the earth scene section.
The DEM needs to have the same size as the scene dimensions, and the supported format is the Tiff format with the tfw aside.

1.4.2 – maket.txt / triangles.txt

From Dart documentation : « Maket.txt file stores the 3D cell marix of the Dart scene. »
It contains the simulated scene generated from « plots.xml » and various parameters.

The plot/cell types are many, so a short list below :

- -Empty cell (type = 0)

- -Opaque :
    - -Air (type = 1)
    - -Ground (type = 2)
    - -Water (type = 3)

- -Opaque DEM :
    - -Ground_DEM (type = 7)
    - -Plot_DEM (type = 14)
- -Turbid :
    - -Crown (type = 6)

Opaque DEM category is like the Opaque one but we specify here that the plot contains DEM.
It has no effects on the results.

AMAPVox exports ground and crown types.
The ground type is exported if one of the following conditions is satisfied :

-DTM filter has been configured for voxelization process.
All voxels below or over the ground will be exported as a cell with opaque ground type.

Or - « triangles.txt » export option is enable, and a valid ascii grid file (.asc) has been set up.

A cell can have multiple LAI values and to each one a leaf phase function is bounded.
AMAPVox exports a single LAI value.
Phase functions are created from Dart interface.

The leaf phase function is represented by an index.
Phase functions can be created from Dart in the « Optical and temperature properties » section.
When you create a vegetation phase function the index value is 0 for the first created, 1 for the second, etc...

At the moment, the leaf phase function index exported by AMAPVox is 0, assuming an homogeneous canopy.

1 - VISUALIZATION

1.1 - Load a file

In Voxels files panel :

Open a file by clicking on « + » button.
Click on the « Load » button.
In « Vizualisation » panel, choose an attribut.
Click on « Open display window » button.

1.2 - Visualize a raster

You can in « Vizualisation » tab choose a raster file, typically a DTM (Digital Terrain Model), in esri ascii grid format (.asc).
The « Transformation » option allows you to apply a transformation to the raster object.

1.3 - Toolbox

1.3.1 - Voxel viewing parameters:

Attribute to show : Voxel attribut to represent (in a colouring way)

Gradient : Color gradient

Stretched : Stretch colors in order to use the entire color scale available.
It may enhance readability but color scale is no longer valid.

Size : voxel size, default value is the half of the voxel edge actual size.

Min value/ Max value : Define color scale from a value scale, restrict true value interval.

Filtering (Don't display values / Display only those values) : Display or not voxels according to their values.

Usage :
Values filtered from 4 included to 5 excluded : [4->5[
Filtering unknown values: NaN
Filtering value 1 and 2 : 1, 2

1.3.2 - Scene

World :
Background color : the background color

View : Project view

Camera :
Perspective : perspective view
Orthographic : orthographic view
Near/Far : Minimal/maximal drawing distance of the camera. Too low or too high values can create visual artefacts.

1.3.3 - Tools

Sectional view : Cross section view of the voxel space.

+ and – buttons move forward and backward inside voxel space according to camera position.

3 - CONFIGURATION FILES

Before executing a task, it is necessary to generate a configuration file.

3.1 - Save a configuration file

Button « Save and add to task list » is the way to go to create a configuration file, this button is present in every task panel that needs a configuration file to works.

3.2 - Task list

« Tasks » panel in the bottom left corner of the window may contain a list of configuration files. If you click on the « Execute » button the program is going to execute all tasks one after another.

Warning: All unsaved parameters will not be taken into account to the execution of the task. That's why it is necessary to save any modification before executing.

3.3 - Editing a configuration file

To edit a configuration file previously saved you need :

If the file is not in the « Tasks » panel you have to click on the « + » button and open the file.
Next, select the file and click on the « Load » button, file parameters will fill in the relevant fields in the window.
You can now edit fields in the different panels and erase the old file/create a new one by clicking on the « Save and add to task list » button.

4 - Annexe

4.1 - File formats

4.1.1 - Point files (.las)

Public binary file format for the exchange of 3-dimensional point cloud data.

Format specifications : http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html

4.1.2 - Compressed point files (.laz)

Compressed format of *.las file, the tool to generate those files has been developed by Martin Isenburg and is integrated in the LASTools software.
This can be downloaded here:
http://www.laszip.org/ or http://www.cs.unc.edu/~isenburg/lastools/

4.1.3 - Trajectory file

Contains GPS position at a given time.
Existing format are *.pof (binary, not supported) and custom text format.
Text file needs to have 4 columns and one header line, ordered this way : x (easting), y (northing), z (elevation), time (s). The time is like an index.

```
Easting[m],Northing[m],Elevation[m],Time[s]
349104.142,533198.318,6.660,305247.002716
349104.143,533198.303,6.660,305247.007717
349102.636,533202.338,9.682,305247.012716
349102.636,533202.323,9.682,305247.017715
```

Example: extract of a trajectory file

4.1.4 - Riscan scan file (.rxp)

Binary and proprietary file format owned by Riegl.
Those files contain point cloud and other data and can be read with the RivLib library provided by Riegl or with Riscan Pro software.

4.1.5 - Riscan Project (.rsp)

XML file format containing project information.
Containing in particular scans file paths, POP (Project Orientation and Position) matrix and SOP (System Orientation and Position) matrices for each scan.

4.1.6 - DTM (Digital Terrain Model)

A DTM file represents height information of the ground.

At the moment, the only supported format is the ascii grid or esri grid (*.asc).
This file can be generated by LASTools which can classify points as belonging to the ground and generate a raster from this classification.

4.1.7 - Voxel file

« Voxel » file contains a signature row, four meta-date lines and a header line.

```
VOXEL SPACE
#min_corner: -24.55 -19.08 9.21
#max_corner: 21.12 267.67 68.98
#split: 45 286 59
#type: ALS #resolution: 1.0
i j k Pad angleMean bvEntering bvIntercepted ground_distance lMeanTotal lgTotal nbEchos nbSampling transmittance
```

« min_corner » and « max_corner » parameters are the extremums of the bounding box.
The « split » parameter indicates voxel number along the 3D axis, it is directly related to resolution and extremums.
The parameter « type » can be either ALS or TLS.

Header line indicates columns names.

i	Voxel index along the x axis
j	Voxel index along the y axis
k	Voxel index along the z axis
Pad	Plant Area Density (m^2/m^3)
angleMean	Mean inclination angle of shots which entered the voxel
bvEntering	Sum of weighted fractions (optical path, divergence, attenuation) of entering laser pulses
bvIntercepted	Sum of weighted fractions (optical path, divergence, attenuation) of intercepted laser pulses
ground_distance	Distance from voxel center to the ground (can be negative) If the ground is not set (no DTM filter), this value is the height of the voxel relative to a plane with equation Z = 0
lMeanTotal	Mean length of optical path inside the voxel
lgTotal	Length sum of optical path inside the voxel
nbEchos	Total echoes count inside the voxel
nbSampling	Number of (possibly attenuated) pulses entering the voxel
transmittance	Transmittance (standardized per one meter optical path length)

4.1.8 - Matrix file

Transformation matrix

```
0.95 0.29 0.0 -448120.04
-0.29 0.95 0.0 -470918.39
0.0 0.0 1.0 0.0
0.0 0.0 0.0 1.0
```

Splitting characters can be space or tabulation.
File may contain line returns or not.

Weighting table

```
1.00, NaN, NaN, NaN, NaN, NaN, NaN,
0.62, 0.38, NaN, NaN, NaN, NaN, NaN,
0.40, 0.35, 0.25, NaN, NaN, NaN, NaN,
0.28, 0.29, 0.24, 0.19, NaN, NaN, NaN,
0.21, 0.24, 0.21, 0.19, 0.15, NaN, NaN,
0.16, 0.21, 0.19, 0.18, 0.14, 0.12, NaN,
0.15, 0.17, 0.15, 0.16, 0.12, 0.19, 0.06
```

The weighting table should contain seven rows and seven columns.

NaN means the cell is not used.
The column indicates the echo rank and the row is the echo number of the corresponding shot.

4.1.9 - Configuration file

XML format, its content is function of the task type.
Minimal structure:

```xml
<configuration>
	<process mode = "[mode_value]" type= "[type_value]">
	</process>
</configuration>
```

Possible values for « mode » : voxelization, multi-resolutions, merging
Possible values for « type » : ALS, TLS

Example 1: Configuration file in « voxelisation » mode and « ALS » type

```
<configuration>
        <process mode = "voxelisation" type= "ALS">

                <input_file type = "0" src="/home/Documents/input_file.las"/>
                <trajectory src="/home/Documents/trajectory_file.txt"/>
                <output_file src="/home/Documents/output_file.vox"/>

                <voxelspace xmin="-12 .0" ymin="-2 .0"  zmin="8.0"  xmax="12.0"  ymax="142"
zmax="72"  splitX="24"  splitY="144"  splitZ="64"  resolution="1.0"  />

                <ponderation mode="1"/>
                        <matrix type_id="ponderation">
                                1.0 NaN NaN NaN NaN NaN NaN
                                0.62 0.38 NaN NaN NaN NaN NaN
                                0.4 0.35 0.25 NaN NaN NaN NaN
                                0.28 0.29 0.24 0.19 NaN NaN NaN
                                0.21 0.24 0.21 0.19 0.15 NaN NaN
                                0.16 0.21 0.19 0.18 0.14 0.12 NaN
                                0.15 0.17 0.15 0.16 0.12 0.19 0.06
                        </matrix>
                </ponderation>
                <dtm-filter enabled="true" src="/home/Documents/dtm.asc"  height-min="1.0" />
                <transformation use-pop="false" use-sop="false" use_vop="true" >
                        <matrix type_id="vop">
                                0.95, 0.29, 0.0, -448120
                                -0.29, 0.954, 0.0, -470918
                                0.0, 0.0, 1.0, 0.0
                                0.0, 0.0, 0.0, 1.0
                        </matrix>
                </transformation>
                <limits>
                        <limit name="PAD" min="" max="5.0" />
                </limits>
        </process>
</configuration>
```

<ponderation> tag :
« mode » value is an integer and means weighting type (0 : no weighting ; 1 : echo rank weighting).

<dtm-filter> tag:
This filter removes echoes below the ground , if it is enabled, the DTM path is set in « src » attribute and the height threshold in the « height-min » attribute.
The height threshold expressed in meter (m) is the threshold base from which an echo is considered as ground. If ithat case it will be removed from vegetation analysis.

<transformation> tag :
Apply a transformation to the input file, the value is a 4x4 matrix.

<limits> tag:
Maximum PAD value.

Example: Configuration file for « merge » process and « TLS » type

```
<configuration>
        <process mode = "merging" type= "TLS">
                <output_file src="/home/Documents/merged.vox"/>
                <files>
                        <file src="/home/Documents/tls_scan1.vox"/>
                        <file src="/home/Documents/tls_scan2.vox"/>
                        <file src="/home/Documents/tls_scan3.vox"/>
                        <file src="/home/Documents/tls_scan4.vox"/>
                </files>
        </process>
</configuration>
```

4.2 - Algorithmes

4.2.1 - Merging trajectory and las (ALS)

The trajectory file is in text format. Merging is based on the GPS time and laser time.
Laser positions are determined by linear interpolation between two GPS clock ticks.

4.2.2 - Transmittance processing (ALS+TLS)

The calculation of local transmittance (into a voxel) involves a weighting which aims at taking into account the appropriate contribution of each entering shot in the voxel. This weighting consists of three terms :

- Optical length trajectory in the voxel (always)
- The size of the footprint function of beam divergence and distance from the source (optional)
- The signal extinction because of previous obstacles (optional)

In TLS case, a fundamental indetermination exists because the non intercepted beam fraction is usually unknown.
Weighting

Two options are availables (mimimal and total i.e. with or without weighting).
Total weighting includes signal extinction.
Minimal weighting

$$\left(\frac{\sum_i^n (out_i \cdot l_i)}{\sum_i^n (in_i \cdot l_i)}\right)^{\frac{1}{lMean_i}}$$

with :

out_i =0 if an echo of the shot is inside the voxel, 1 otherwise
in_i =1 if shot penetrate the voxel, 0 otherwise
l_i Light path length of shot i inside the voxel

Total weighting

$$\left(\frac{\sum_i^n (BVOutgoing_i \cdot S_i \cdot l_i)}{\sum_i^n (BVEntering_i \cdot S_i \cdot l_i)}\right)^{\frac{1}{lMean_i}}$$

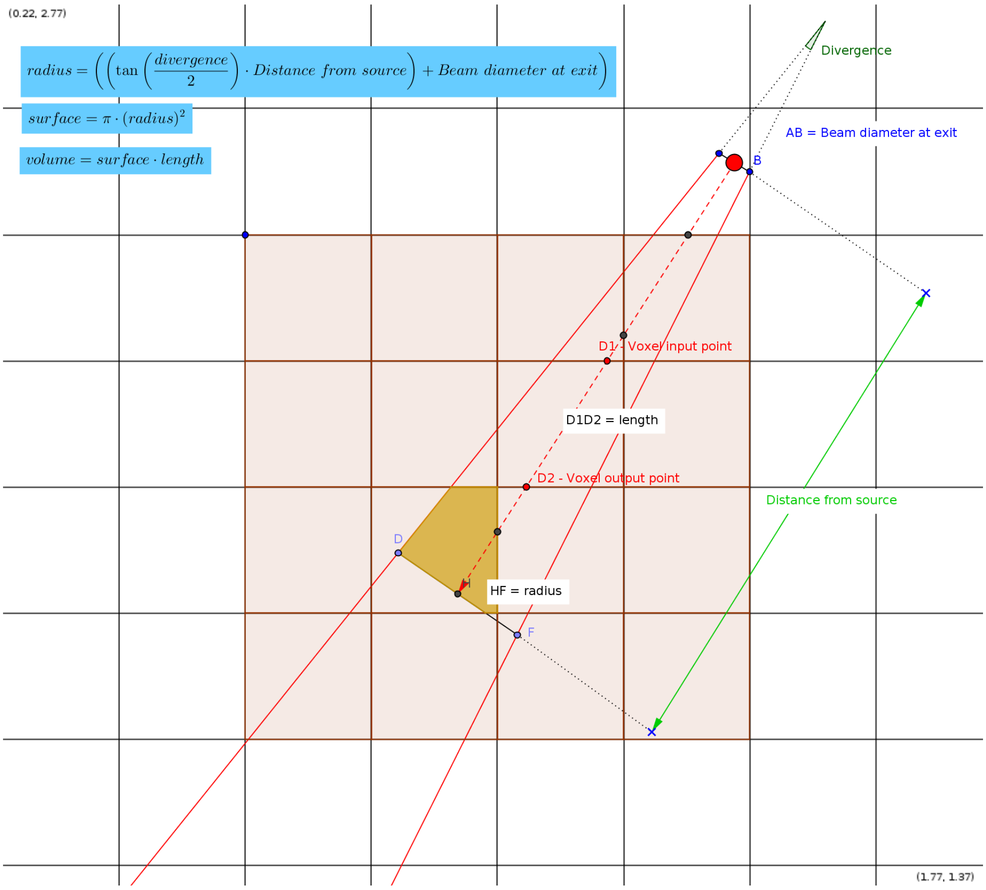
with :

$BVOutgoing_i$, beam energy fraction (between 0 and 1) of voxel outgoing shot i (outgoing of the voxel)

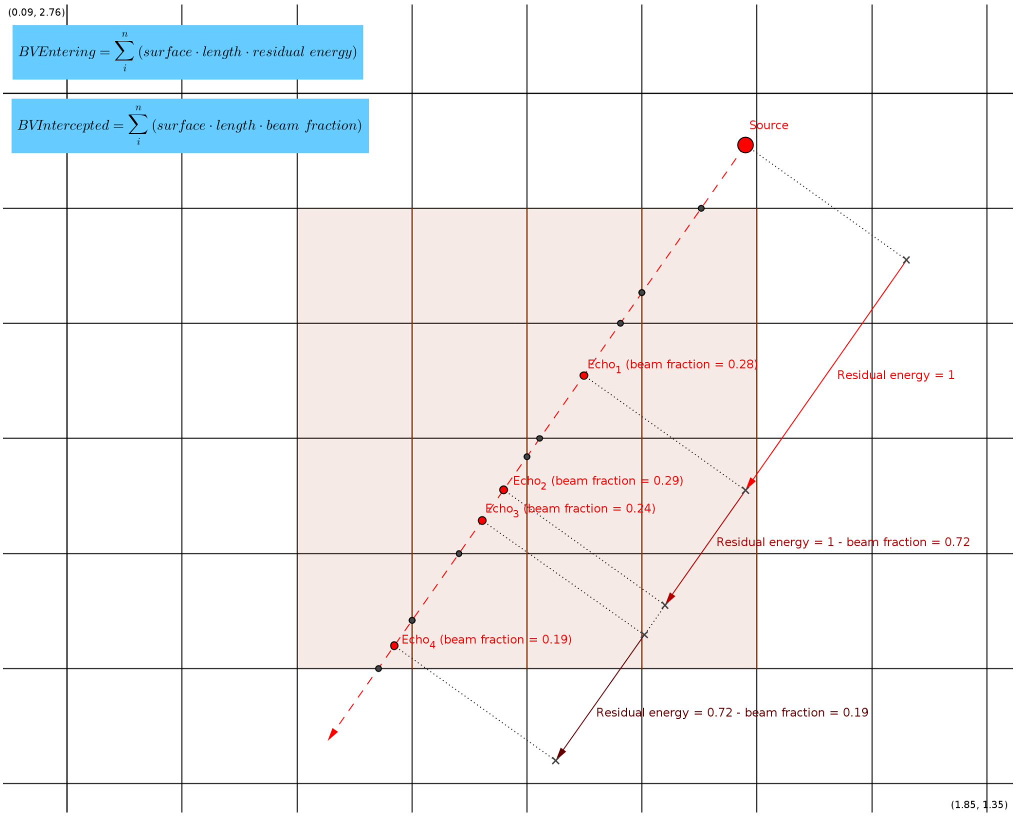
$$BVOutgoing_i = BVEntering_i - BVIntercepted_i$$

$BVEntering_i$, beam energy fraction (between 0 and 1) of voxel entering shot i (entering in the voxel)
L_i, Light path length of shot i inside the voxel
S_i, Expected surface of shot i (normal to shot inclination) relative to the distance from the source
$lMean_i$, mean length of the light path in the voxel (total lenght of the light path divided by the total number of entering shots (not weighted, integer value)

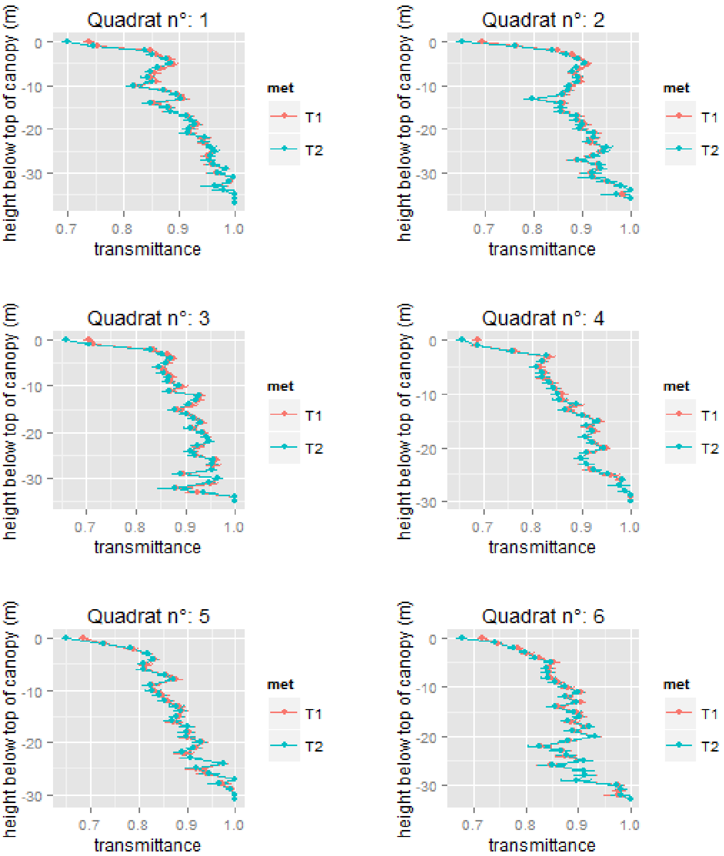
Variables details (divergence angle is exaggerated for a better comprehension):



Residual energy / beam fraction :



Comparison of weighting modes influence on the transmittance of ParacouP15 (ALS) :



4.2.3 - Computation of the optical path (ALS+TLS)

The computation of the optical path into a voxel is always the same. If a pulse is not entirely stopped then the path length is computed from the distance of the entering point to the outgoing point in the voxel. If the last echo from the shot occurs within the voxel then the optical path is computed from the distance of the entering point to the last echo.
Ground echo filtering

A Digital Terrain Model must be provided by the user (esrii grid format *.asc).
All echos having with heights less than or equals to the raster altitude (+threshold) at the corresponding location are considered as non vegetation echoes and are exclude of the vegetation analysis.
Pulse tracing will be extended to the last echo meaning that pulse trajectory before hitting a non vegetation target is taken into account (contributes to transmittance estimate).

When computation transmitted energy to the ground, the information of the « ground type voxel » information is used (cf below).
Computation of transmitted energy to the ground

All ground voxels are derived from ground raster.
We extend the optical path length from the last echo until the first ground voxel.
Then we count for each corresponding raster cell the shot number which could potentially have reached the voxel (in the absence of vegetation) and the effective energy reaching reaching that cell.
The transmitted energy is the ratio of these two sums.

At present, the PAI calculation doesn't distinguish wood from leaves and assume a spherical angular distribution of the vegetation elements.
The formula is :

$$PAD = min\left(\left(\frac{\log(transmittance)}{-0.5}\right), PADmax\right)$$

With : PADmax, maximal eligible value (the default value is 5 for one m³).
This value depends of the resolution.

4.2.4 - Scan merging (TLS)

When data merging of different scans is processed, the following rules are applied :

field	method
BVEntering = $\sum_{i}^{n} BVEntering_i \cdot S_i \cdot l_i$	sum

BVIntercepted = $\sum_{i}^{n} BVEntering_i \cdot S_i \cdot l_i - \sum_{i}^{n} BVOutgoing_i \cdot S_i \cdot l_i$	sum
nbSampling	sum
nbEchos	sum
LgTotal	sum
AngleMean (angle = arcos(z_u))	Weighted mean (weight=occurrence number for a voxel of a scan / total occurrence number for all the scans for this voxel) Occurrences=nbSampling
LMean; PAD ; transmittance => recalculated after merging	Transmittance= $\left(\frac{(BVEntering - BVIntercepted)}{BVEntering}\right)^{\frac{1}{lMean}}$ $PAD = min\left(\left(\frac{\log(transmittance)}{-0.5}\right), PADmax\right)$
Others (i,jk, hag, x,y,z,…)	No changes