Case study: RIEGL/GeoCodeWF (rakulaOZ)

This documents shows the usage of the CHP toolkit program with example files provided in .lgc/.lwf format which have been converted to PulseWaves using the pulse2pulse tool (https://github.com/PulseWaves). While converting the data in PulseWaves, a subset area has been chosen within coordinates: 52678560-52678860, and 8540385-8540515. To run the CHP program the tested file needs to be in the same location as the program itself or the path needs to be provided together with the file name. . The test LiDAR file (rakulaOZ.pls, rakulaOZ.wvs) used in this example can be found https://github.com/kdf200/CHP.

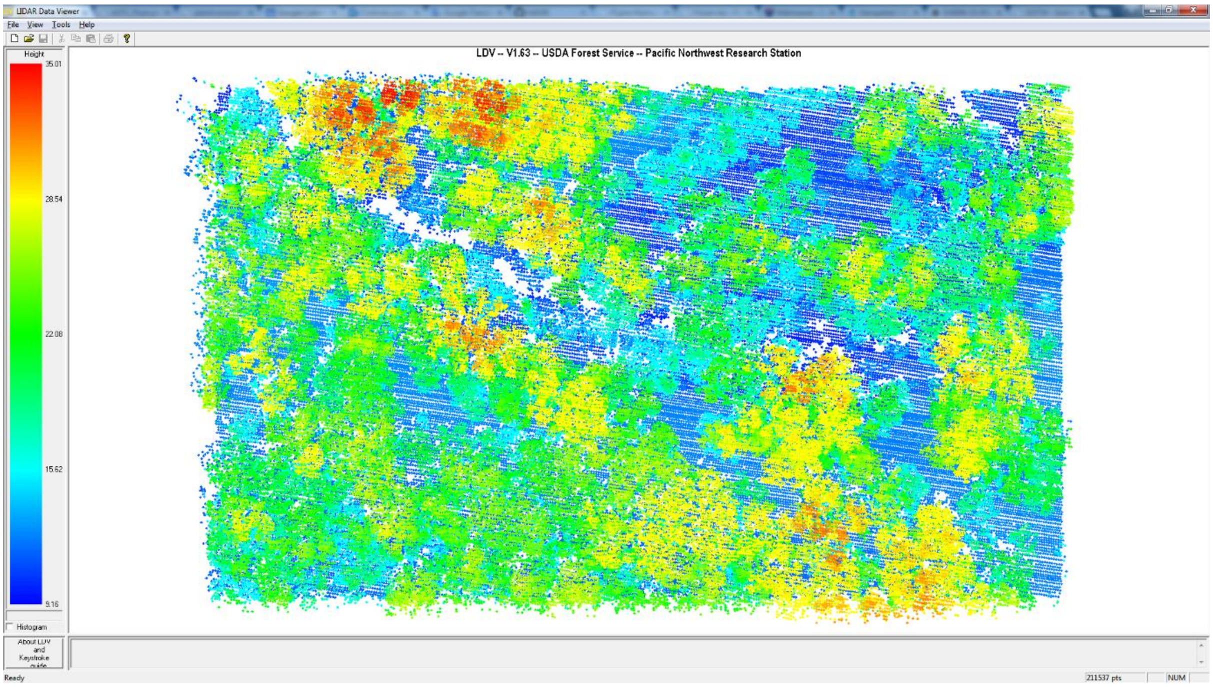


Figure 1. Visualization of the study area in FUSION.

Module 1 – Converts PLS files to ASCII format

Running Module1.exe and typing in "rakulaOZ" followed by hitting <enter> will make the program calculate and display the extents of the data and other parameters. Following that the user will be asked whether they want to use a parameter file to select a specific area to process. This needs to be prepared beforehand and in the data format described in the user manual. In this case we want to process a rectangular subset of the dataset but we do not have a parameter file prepared. By selecting "n" followed by "2" we will be prompted to provide coordinates of the rectangle area. The screen below shows the values used in this example.

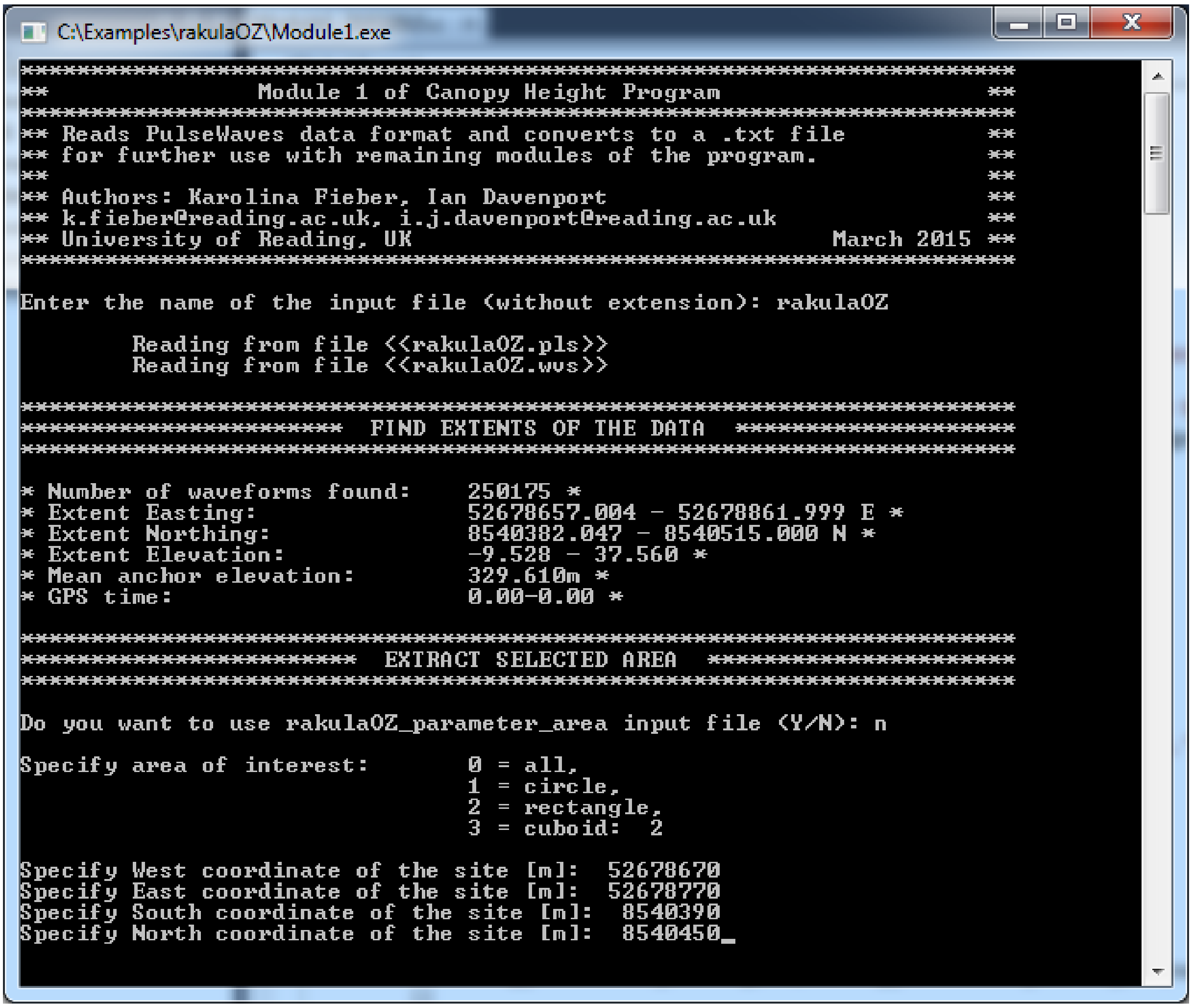


Figure 2. Input parameters in Module 1 of CHP toolkit.

Accepting (with <enter>) the above parameter will make the program write the waveforms to rakulaOZ_fulwvs.txt file, while all the displayed information and selected parameters will be stored in rakulaOZ_info_Module1.txt. Examining that file we can notice that the length of the waveforms varies across the selected dataset. We can also notice that out of over 250000 waveforms we selected a subset of 65000 waveforms.

rakulaOZ_info_Module1.txt - Notepad

File Edit Format View Help

```
***********************************************************************
**                  Module 1 of Canopy Height Program                **
***********************************************************************
** Reads PulseWaves data format and converts to a .txt file          **
** for further use with remaining modules of the program             **
**                                                                   **
** Authors: Karolina Fieber, Ian Davenport                           **
** k.fieber@reading.ac.uk, i.j.davenport@reading.ac.uk               **
** University of Reading, UK                              March 2015 **
***********************************************************************

        Reading from file <<rakulaOZ.pls>>
        Reading from file <<rakulaOZ.wvs>>

***********************************************************************
***********************   FIND EXTENTS OF THE DATA   ******************
***********************************************************************

DATA INFORMATION:
* Number of waveforms found:     250175 *
* Extent Easting:                52678657.004 - 52678861.999 E *
* Extent Northing:               8540382.047 - 8540515.000 N *
* Extent Elevation:              -9.528 - 37.560
* Mean anchor elevation:         329.610m *
* GPS time:                      0.00-0.00 *

***********************************************************************
************************   EXTRACT SELECTED AREA   ********************
***********************************************************************

Do you want to use rakulaOZ_parameter_area input file (Y/N): n

Specify area of interest (0=all, 1=circle, 2=rectangle, 3=cuboid):  2
Extracting within 52678670.0E and 52678770.0E and 8540390.0N and  8540450.0N

* Waveform processed:                            250175 *
* Number of multisegment waveforms:              0 *
* Waveforms with transmitted pulse only:         0 *
* Waveforms in selected area:                    64924 *

        Number of recorded samples      Number of waveforms
                97                              35
                98                              44742
                99                              246
                103                             1346
                197                             3
                198                             12911
                202                             944
                203                             8
                206                             798
                207                             1
                209                             1
                210                             750
                214                             594
                215                             1
                218                             588
                219                             3
                221                             1
                222                             465
                223                             1
                226                             420
                227                             3
                230                             318
                234                             273
                238                             168
                242                             127
                246                             75
                250                             47
                254                             16
                258                             18
                262                             14
                266                             7

         Writing to file: <<rakulaOZ_fulwvs.txt>>

***********************************************************************

PROCESSING COMPLETED!
```

Figure 3. The info file generated by Module 1 of the CHP toolkit.

Module 2 – Extracts the locations of pulses, and their amplitudes and widths

Running Module 2 will prompt us again to specify the input file name. Once again 'rakulaOZ' needs to be typed in and accepted. The program will then inform us that it starts to process the transmitted waveform. Mean amplitude, width, noise and ringing will then be displayed. Subsequently, the program asks whether the user wants to change the mean noise or ringing estimates. This time we will answer 'y' and change the noise and ringing parameter. Not doing so will result in quite a few ringing echoes that would make selection of ground returns from last returns in Module 3 very difficult.

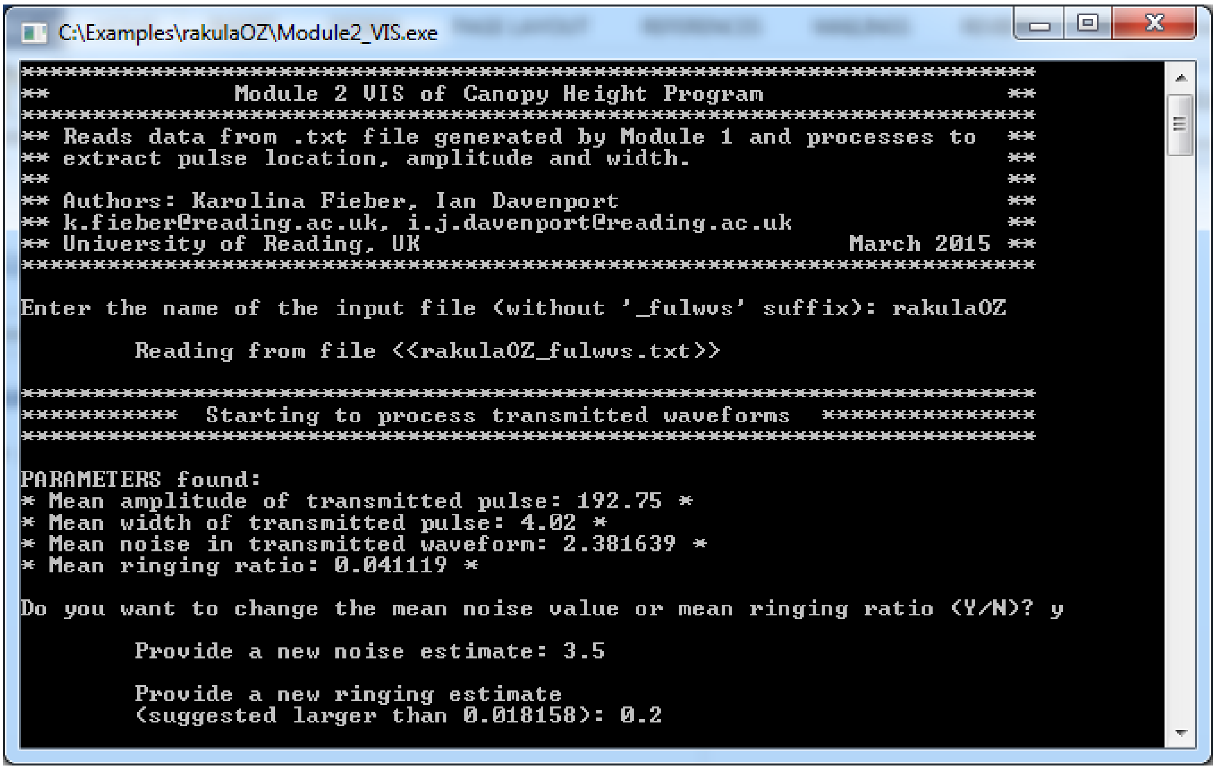


Figure 4. Input parameters in Module 2 of CHP toolkit.

This module will produce four output files for further processing. One needs to remember that the quality of the peak detection result will depend on those parameters so it is worth checking the result by visualizing the output of the program. The basic visualization is provided by **Module 2 VIS** that requires exactly the same input as Module 2 but produces also a simple visualization of all detected points.

One can notice in the visualization figure from Module 2 VIS below that the plan and axonometric views do not match to each other colour-wise. This is due to the drawing order. In plan view, points with lower elevation seem to have been drawn on top of the points with higher elevation, hence bluer colour rather than red. It is worth importing the rakulaOZ_XYZ.txt file into e.g. FUSION software for interactive visualization and verification (file format described in the CHP toolkit manual). Such visualization of the output will help us decide the values of the input parameters (noise and ringing ratio).

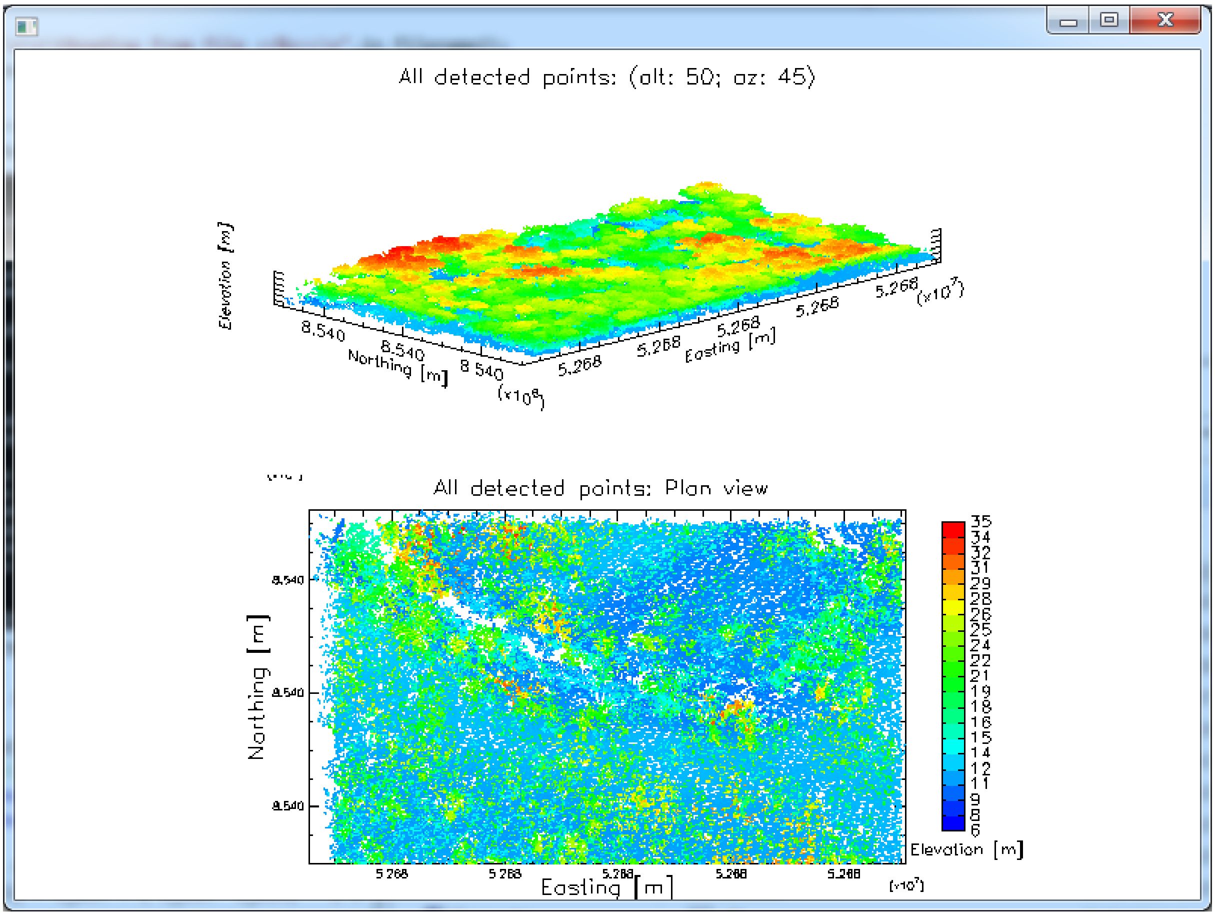


Figure 5. Visualization of all points (waveform peaks) detected by Module 2 VIS.

As in Module 1 all parameters are summarized in the info file rakulaOZ_info_Module2.txt.

rakulaOZ_info_Module2.txt - Notepad

File Edit Format View Help

```
*********************************************************************
**              Module 2 VIS of Canopy Height Program             **
*********************************************************************
** Reads data from .txt file generated by Module 1 and processes to **
** extract pulse location, amplitude and width.                    **
**                                                                 **
** Authors: Karolina Fieber, Ian Davenport                         **
** k.fieber@reading.ac.uk, i.j.davenport@reading.ac.uk             **
** University of Reading, UK                      March 2015 **
*********************************************************************

        Reading from file <<rakulaOZ_fulwvs.txt>>

        Writing to file <<rakulaOZ_received_param.txt>>
        Writing to file <<rakulaOZ_XYZ.txt>>
        Writing to file <<rakulaOZ_XYZ_single.txt>>
        Writing to file <<rakulaOZ_param.txt>>

*********************************************************************
***********  Starting to process transmitted waveforms  ***************
*********************************************************************

PARAMETERS found:
* Mean amplitude of transmitted pulse: 192.75 *
* Mean width of transmitted pulse: 4.02 *
* Mean noise in transmitted waveform: 2.381639 *
* Mean ringing ratio: 0.041119 *

Do you want to change the mean noise value or mean ringing ratio? y
        Provide a new noise estimate: 3.500000
        Provide a new ringing estimate: 0.200000

        Processing of transmitted waveforms is finished

*********************************************************************
**************  Starting to process received waveforms  ***************
*********************************************************************

        Processing of received waveforms is finished

*********************************************************************

* DATA INFORMATION *

* Waveforms processed:  64924 *
* Disregarded waveforms:        0 *

* Waveforms with one peak:      22551 *
* Waveforms with two peaks:     16784 *
* Waveforms with three peaks:   15245 *
* Waveforms with four peaks:    7478 *
* Waveforms with five peaks:    2350 *
* Waveforms with six peaks:     516 *

* Total number of points detected: 146612    *

* Mean ringing effect:                          0.200000 *
* Noise to signal ratio (transmitted):          0.018158 *
* Mean amplitude of the transmitted pulse:      192.754605 *
* Mean width of the transmitted pulse:          4.024979 *
* Mean noise in transmitted waveforms:          3.500000 *

* Sampling unit:                                1 *
* Mean elevation vector:                        -0.148280 *

* Mean amplitude of single returns:             172.342690 *
* Mean width of single returns:                 4.443754 *

        Reading from file <<rakulaOZ_XYZ.txt>>

*********************************************************************

PROCESSING COMPLETED!
```

Figure 6. Info file generated by Module 2 of CHP toolkit.

Module 3 – Extracts single and last returns for ground elevation map (DTM)

Running Module 3 will prompt the user to provide the name of the file to process and, as before, 'rakulaOZ' needs to be typed in. Following that we will need to specify the type of the relief of our data: flat or steep, as well as the search area for mean ground level comparison. Previous visualization in Model 2 VIS and FUSION suggests that the terrain is relatively flat, so option 1 is suitable. Because the terrain is flat we could specify a relatively large area of comparison. This would be especially useful for single-echo ground point selection as these data are usually less dense. Below is the screen grab of the parameters we have used. In this case a search area of +-2m was selected.

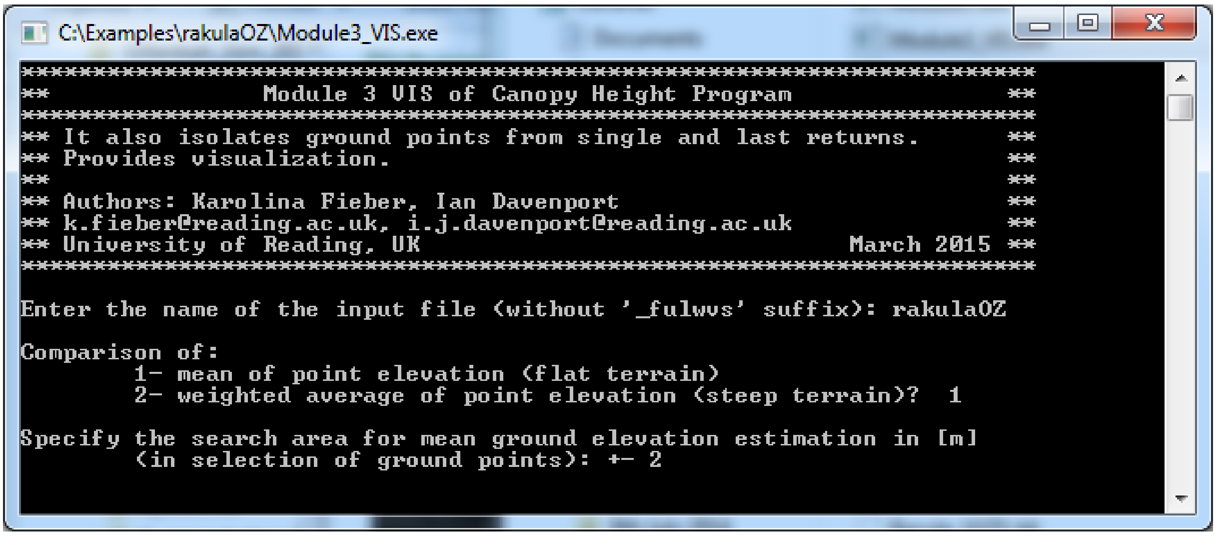


Figure 7. Input parameters in Module 3 of CHP toolkit.

After accepting those parameters, the program will go on to process single (located in rakulaOZ_XYZ_single.txt) and last (rakulaOZ_XYZ.txt) returns in an attempt to select ground points. The user should then view both of the files with ground returns (rakulaOZ _ground_single.txt, rakulaOZ_ground_last.txt) and verify them against point cloud from rakulaOZ_XYZ.txt. This should help decide which file produced the better representation of the terrain. As in the case of Module 2, Module 3 also comes with the visualization variant. All the input parameters in **Module 3 VIS** are the same as in Module 3. The program will first visualize the result of ground point selection from single returns. After pressing "Enter" ground point selection from last returns will be displayed.

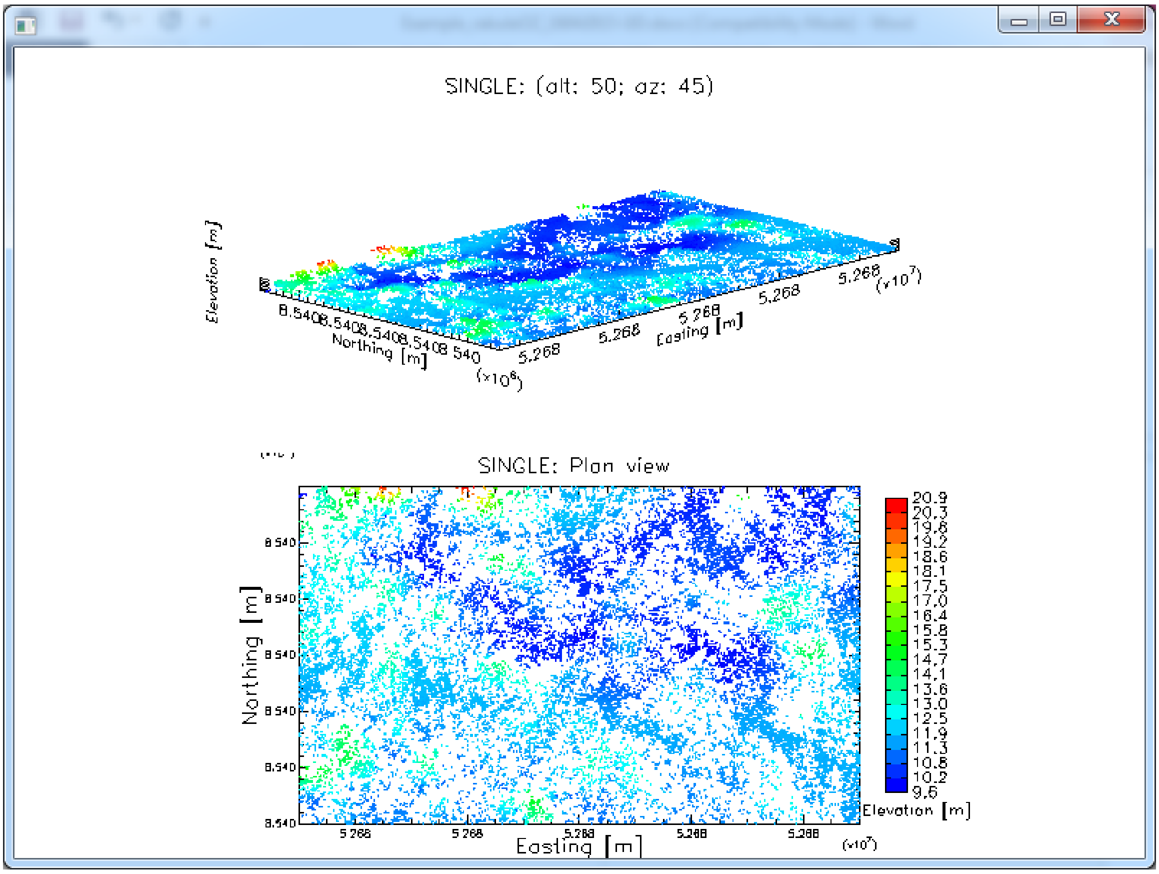


Figure 8. Visualization of single-return-based points separated and visualised by Module 3 VIS.

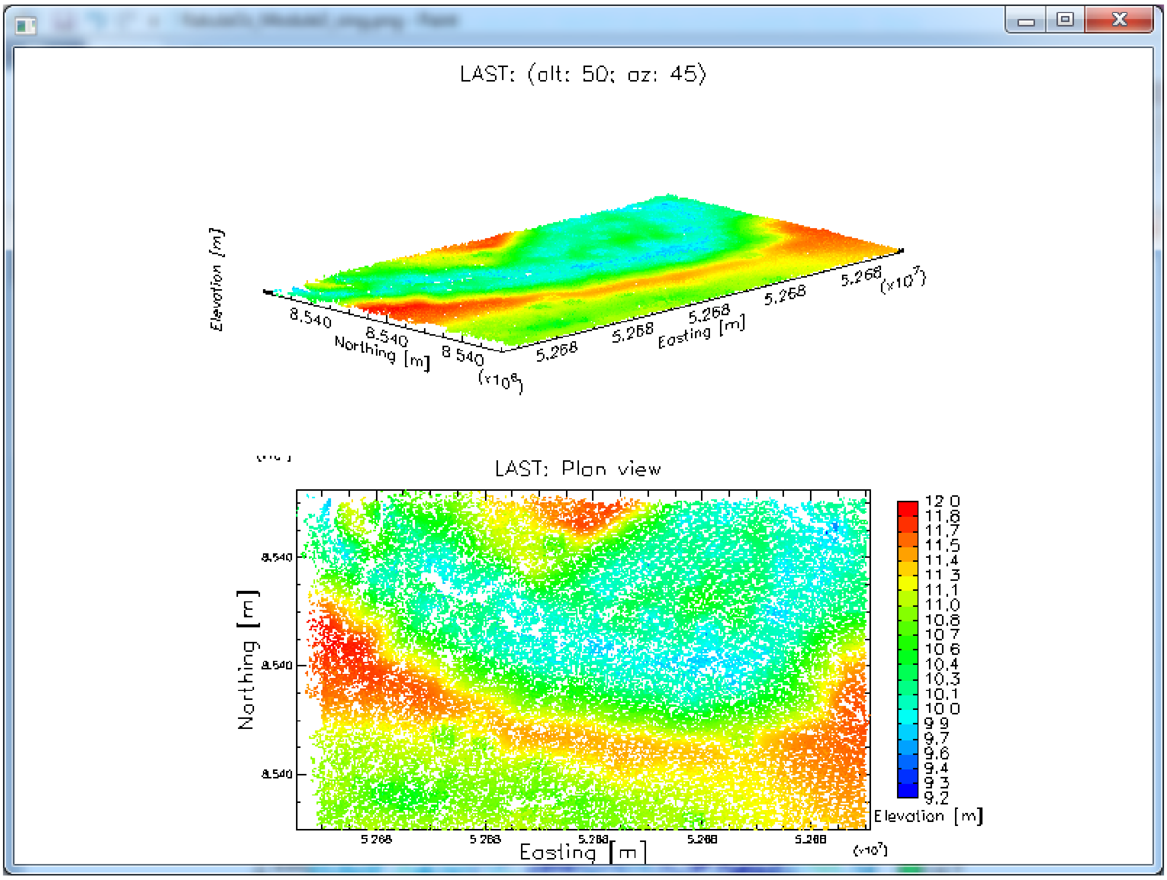
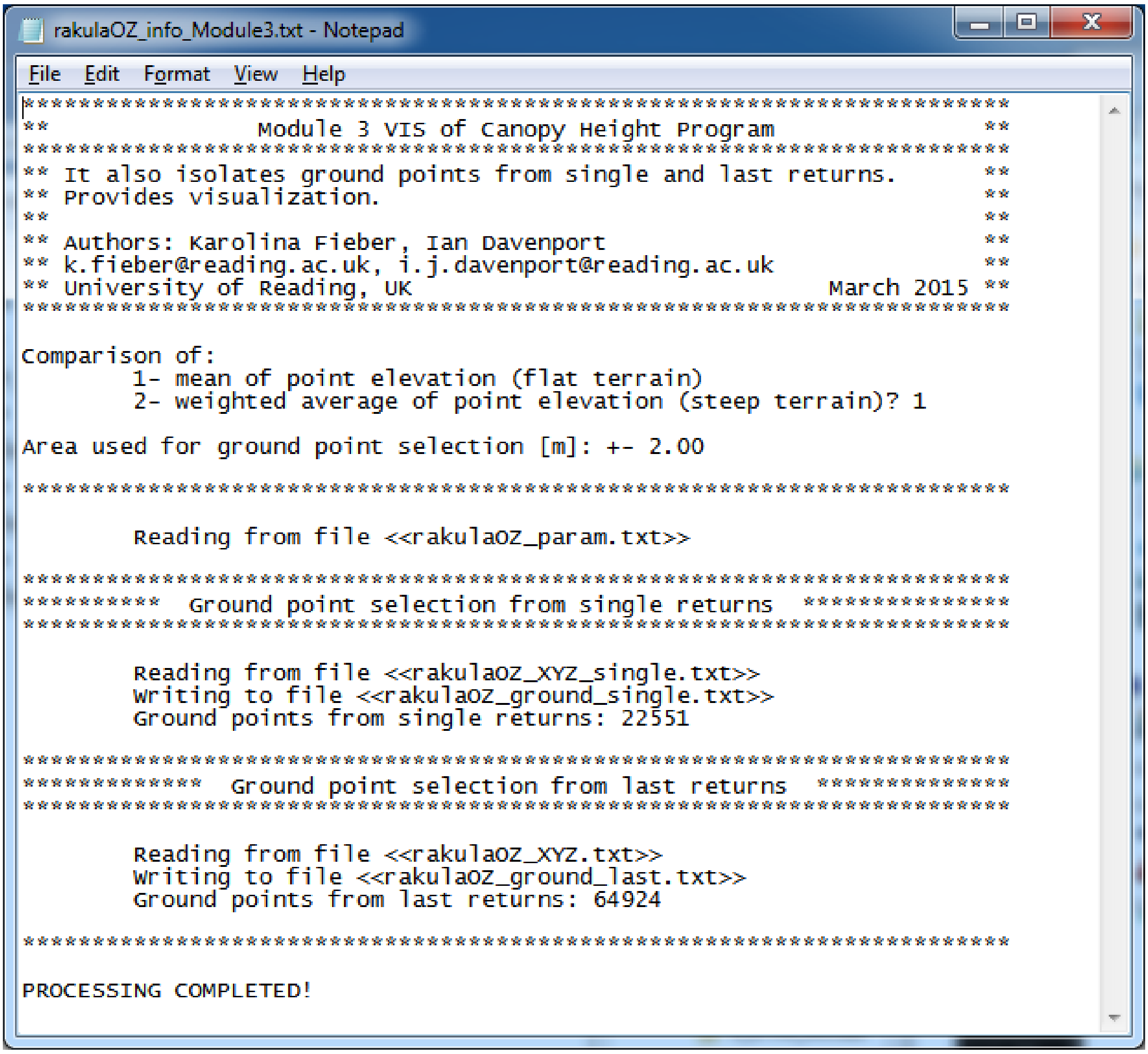


Figure 9. Visualization of last-return-based points separated and visualised by Module 3 VIS.

From simple Module 3 VIZ visualization one can tell that the selection of ground points differs between single and last points. In the single-echo based file there are still a number of points high above ground level that have not been removed due to relatively narrow area of search. Ground point selection from last-echos seems like the better option. Comparison in FUSION of rakulaOZ_ground_single.txt and rakulaOZ_ground_last.txt files to oranges2_XYZ.txt confirms that rakulaOZ_ground_last.txt not only is denser but also provides more realistic results (without outliers) that match the XYZ point cloud of all detected points. One needs to remember that keeping the default parameters of noise and ringing in Module 2 would lead to completely different results in Module 3.

The info file for Module 3 should provide the following information:



rakulaOZ_info_Module3.txt - Notepad

File Edit Format View Help

```
***********************************************************************
**                Module 3 VIS of Canopy Height Program              **
***********************************************************************
** It also isolates ground points from single and last returns.      **
** Provides visualization.                                           **
**                                                                   **
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** k.fieber@reading.ac.uk, i.j.davenport@reading.ac.uk               **
** University of Reading, UK                              March 2015 **
***********************************************************************

Comparison of:
        1- mean of point elevation (flat terrain)
        2- weighted average of point elevation (steep terrain)? 1

Area used for ground point selection [m]: +- 2.00

***********************************************************************

        Reading from file <<rakulaOZ_param.txt>>

***********************************************************************
**********  Ground point selection from single returns  ***************
***********************************************************************

        Reading from file <<rakulaOZ_XYZ_single.txt>>
        Writing to file <<rakulaOZ_ground_single.txt>>
        Ground points from single returns: 22551

***********************************************************************
*************  Ground point selection from last returns  **************
***********************************************************************

        Reading from file <<rakulaOZ_XYZ.txt>>
        Writing to file <<rakulaOZ_ground_last.txt>>
        Ground points from last returns: 64924

***********************************************************************

PROCESSING COMPLETED!
```

Figure 10. Info file generated by Module 3 of CHP toolkit.

Module 4 – LAI and CHP calculation

As in the case of previous modules the first thing to run Module 4 is to provide it with the input file name ‘rakulaOZ’. Following that we need to specify which ground point file we want to use. Subsequently we need to provide the lower left (south west) coordinates of the area we want the LAI and CHP computed for, the grid cell size and the site dimensions. Since the area is not entirely homogenous in vegetation cover, it is worth processing the site in grid cells. For homogenous areas a grid cell size equal to the site dimensions should be sufficient. Having inspected the data in FUSION we can suspect the tree height of about 25. Pulse width of Riegl LM Q560 scanner is 4n and the laser wavelength 1550ns. Ground vegetation separation should not be smaller than half the pulse width so for 4ns pulse width it should be at least 2 bins, but more would be advisable. Finally the program asks if we want to generate detailed files. Below there is a screen grab of the parameters that have been used to produce a LAI map of a 100m by 60m subset of the data with 10m resolution. Separation of ground/vegetation was set to 10bins (1.5m AGL) to eliminate all shrubs and focus only on trees.

```
C:\Examples\rakulaOZ\Module4_VIS.exe

************************************************************************
**                Module 4 VIS of Canopy Height Program                **
************************************************************************
** Computes Leaf Area Index and Canopy Height Profiles                 **
** in gridded datasets. Provides visualization.                        **
**                                                                     **
** Authors: Karolina Fieber, Ian Davenport                             **
** k.fieber@reading.ac.uk, i.j.davenport@reading.ac.uk                 **
** University of Reading, UK                               March 2015 **
************************************************************************

Enter the name of the input file (without '_fulwvs' suffix): rakulaOZ

        Reading from file <<rakulaOZ_fulwvs.txt>>
        Reading from file <<rakulaOZ_received_param.txt>>
        Reading from file <<rakulaOZ_param.txt>>

Which file with ground returns would you like to select
        single return = 1 (default);
        last return = 2;
        your own = 3? 2

        Reading from file <<rakulaOZ_ground_last.txt>>

Enter lower left corner of the area of interest (Easting) [m]: 52678670
Enter lower left corner of the area of interest (Northing) [m]: 8540390


Enter the grid cell size X (Easting/columns) [m]: 10
Enter the grid cell size Y (Northing/rows) [m]: 10


Enter site dimension X (Easting/columns) [m]: 100
Enter site dimension Y (Northing/rows) [m]: 60

Enter approximate maximum height of the trees [m]: 25

Enter default reflectance ratio
        0.5 for 1550nm wavelength,
        2.0 for 1064nm wavelength: 0.5

Specify separation of ground/vegetation in number of bins
        (if you want it to be calculated by the program: -999): 10

Would you like to generate files of Energy, Closure etc. profiles in grid? n_
```

Figure 11. Input parameters in Module 4 of CHP toolkit.

Again, the results are summarized in the info file. The total site LAI was estimated as 1.33.

```
rakulaOZ_info_Module4.txt - Notepad
File  Edit  Format  View  Help
***********************************************************************
**                Module 4 VIS of Canopy Height Program              **
***********************************************************************
** Computes Leaf Area Index and Canopy Height Profiles               **
** in gridded datasets.Provides visualization.                       **
**                                                                   **
** Authors: Karolina Fieber, Ian Davenport                           **
** k.fieber@reading.ac.uk, i.j.davenport@reading.ac.uk               **
** University of Reading, UK                              March 2015 **
***********************************************************************


        Reading from file <<rakulaOZ_fulwvs.txt>>
        Reading from file <<rakulaOZ_received_param.txt>>
        Reading from file <<rakulaOZ_param.txt>>
        Reading from file <<rakulaOZ_ground_last.txt>>

***********************************************************************

USER INPUT VALUES

The lower left corner coordinates are:  52678670.00m, 8540390.00m
The grid cell size is:                  10.00m by 10.00m
The site dimensions are:                100.00m by 60.00m (6000.00m2)
        making total number of cells    60 (10 by 6)

Sampling vertical distance is:  1ns
        which equals to approx: 0.150m

Transmitted pulse width is:     4
Default reflectance ratio is:   0.50

Tree height specified by user is        25.00m
Profile height length is:               27.00m
        eqating to 180 bins of 0.15cm

Default location where the canopy ends: 10th bin AGL,
        equating to 1.50m AGL

Would you like to generate files of Energy, Closure etc. profiles in grid? n

        Writing to file <<rakulaOZ_10mx10m_LAI_final.txt>>
        Writing to file <<rakulaOZ_10mx10m_CHP_final.txt>>

*************************************************************************

PROGRAM OUTPUT VALUES


Total site LAI (LAI1):
        saturated cells replaced with
        the maximum dataset LAI value:  1.334222

Total site LAI (LAI2):
        saturated cells replaced with
        the mean total site LAI1 value: 1.334222

Total site LAI (LAI3):
        with saturated cells removed:   1.334222

Difference between LAI1 and LAI3: -0.000000
Difference between LAI2 and LAI3: -0.000000

Number of cells with no ground return: 0

Number of cells with no data: 0

Total site reflectance ratio 0.551736

*************************************************************************

PROCESSING COMPLETED!
```

Figure 12. Info file generated by Module 4 of CHP toolkit (10m cells).

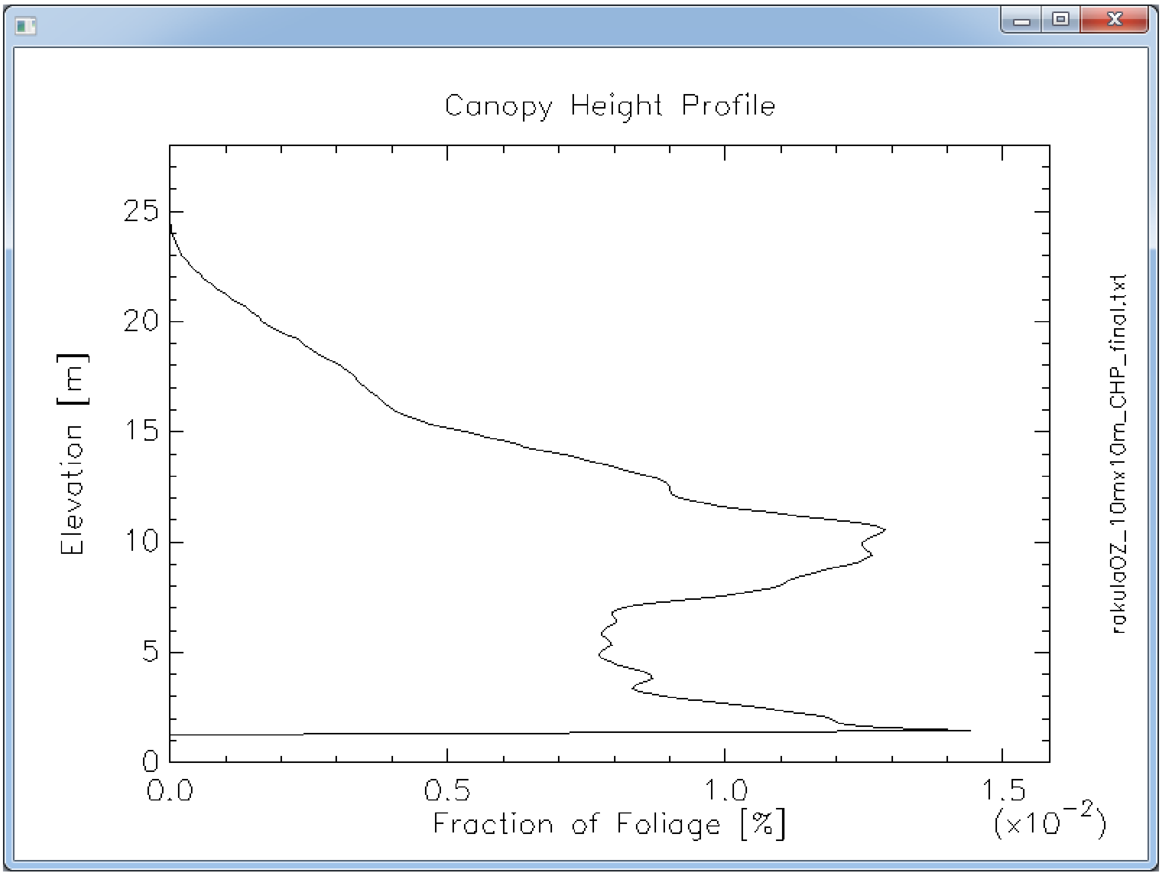

Figure 13. Canopy Height Profile of the study area generated by Module 4 VIS of CHP toolkit (10m cells).

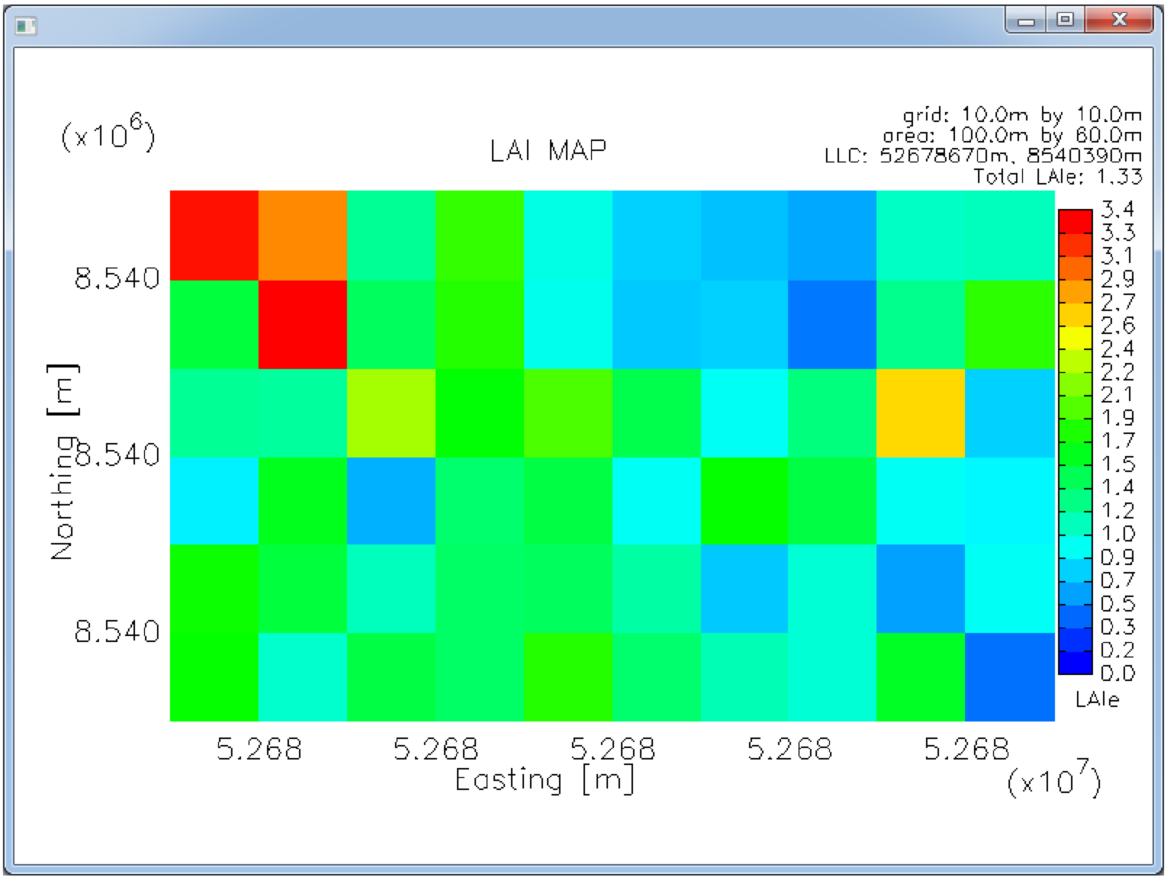

Figure 14. Leaf Area Index Map of the study area generated by Module 4 VIS of CHP toolkit (10m cells).

Module 4 VIS allows visualization of the canopy height profile as well as LAI map. The input parameters are the same as in Module 4. After the Canopy Height Profile is drawn, one needs to press “Enter” to move to the LAI map. Alternatively, once the processing has been completed using Module 4, the LAI map can be produced directly from rakulaOZ_10mx10m_LAI_final.txt file and the CHP profile from rakulaOZ_10mx10m_CHP_final.txt file using LAI_plot.exe and CHP_plot.exe by providing file names without their extension. The figures above show the results of visualization with Module 4 VIS.

One needs to remember that when using for example different ground point file, the results may be different. Therefore, it is important to have confidence in the quality of the input data, both in terms of peak detection and ground points. Moreover, definition of the vegetation-ground cut off point will also have a big impact, especially on the LAI estimates. Letting the program figure it out will mean that a minimum bin value of return energy (prior to scaling the ground return) profile will be searched from the ground level up to one bin above the transmitted pulse width (so if width is 4ns, the search area will be 5ns = 0.75m AGL). If a minimum bin value is not found in that range, a default value of half the pulse width + 2ns is used (in this case it will be 2+2=4 meaning 0.6m).

Changing the resolution to 5m and the vegetation-ground separation bin to 11, we will get the result presented below. The 5m LAI map depicts the heterogeneity of vegetation cover in the study site better than the map with 10m resolution. The total site LAI estimated using 5m grid was 1.5. This shows that for heterogeneous canopies one should take into account the gaps between trees, or otherwise the site-level LAI value will be underestimated. The CHP generated with 5m cell does not differ much in comparison to the 10m profile. This is due to the relative character of the CHPs.

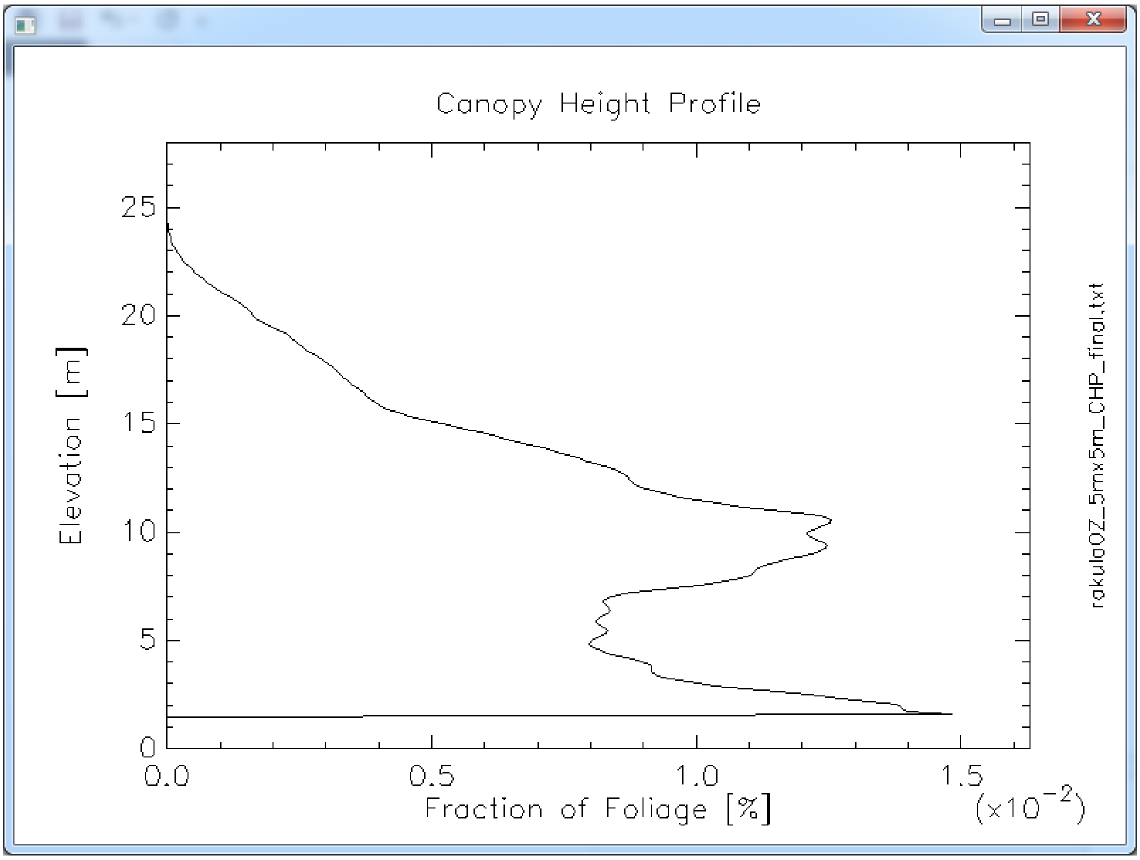

Figure 15. Canopy Height Profile of the study area generated by Module 4 VIS of CHP toolkit (5m cells).

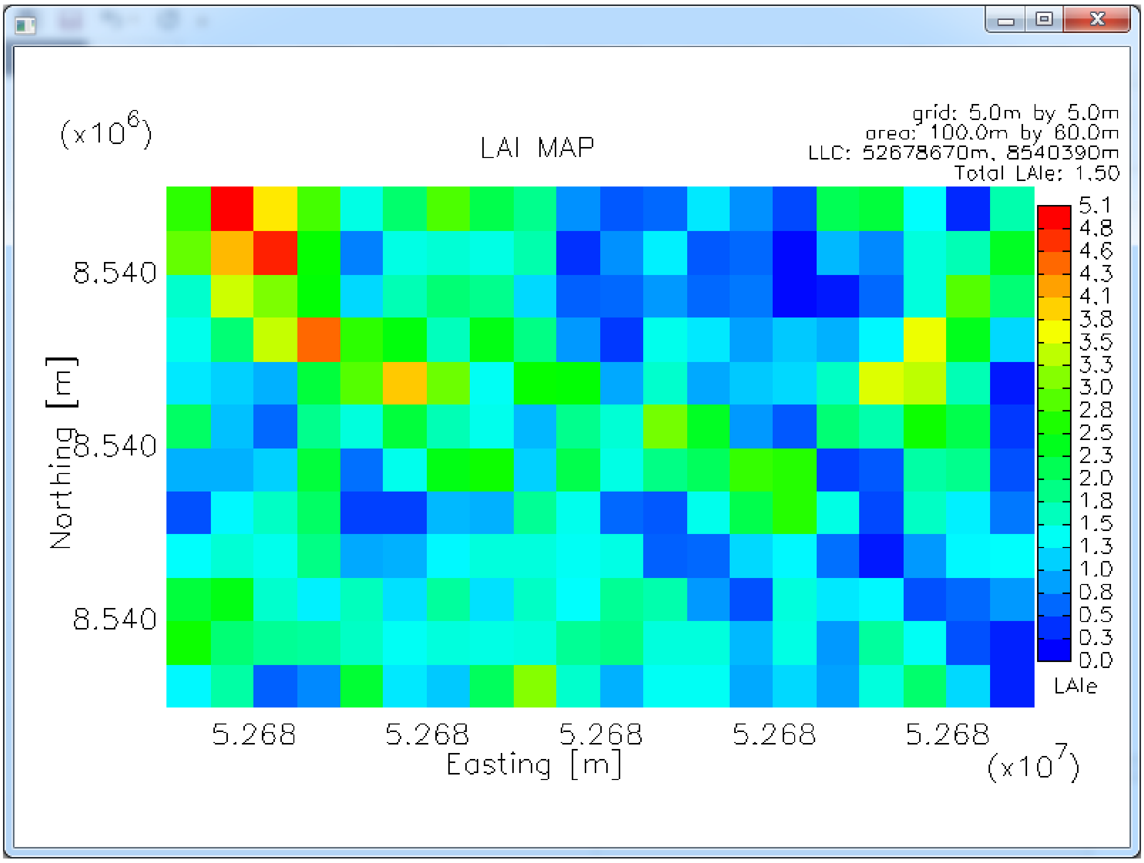

Figure 16. Leaf Area Index Map of the study area generated by Module 4 VIS of CHP toolkit (5m cells).