Case study: ALS50-II data (CropsGB3)

This documents shows the usage of the CHP program with example files.This dataset has been provided in .LAS format which have been converted to PulseWaves format using pulse2pulse tool (https://github.com/PulseWaves). While converting the data in PulseWaves, a subset area has been chosen within coordinates: 447200-447400, and 210350-210550. 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.

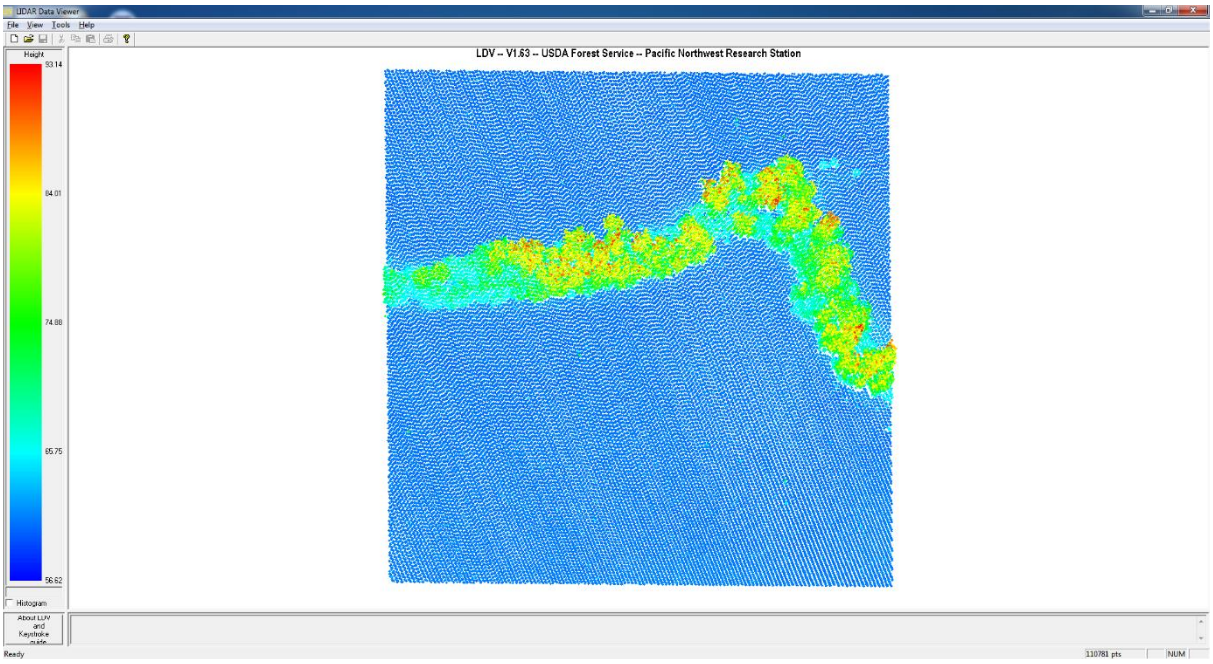


Figure 1. Visualization of the study area in FUSION.

Module 1 – Converts PLS files to ASCII format

Running Module1.exe and typing in "cropsGB3" followed by hitting <enter> will make the program calculate and display the extents of the data and other parameters. Following that we will be asked whether we want to use a parameter file to select 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 all the dataset so "n" is typed in followed by "0". The screen below shows the input example.

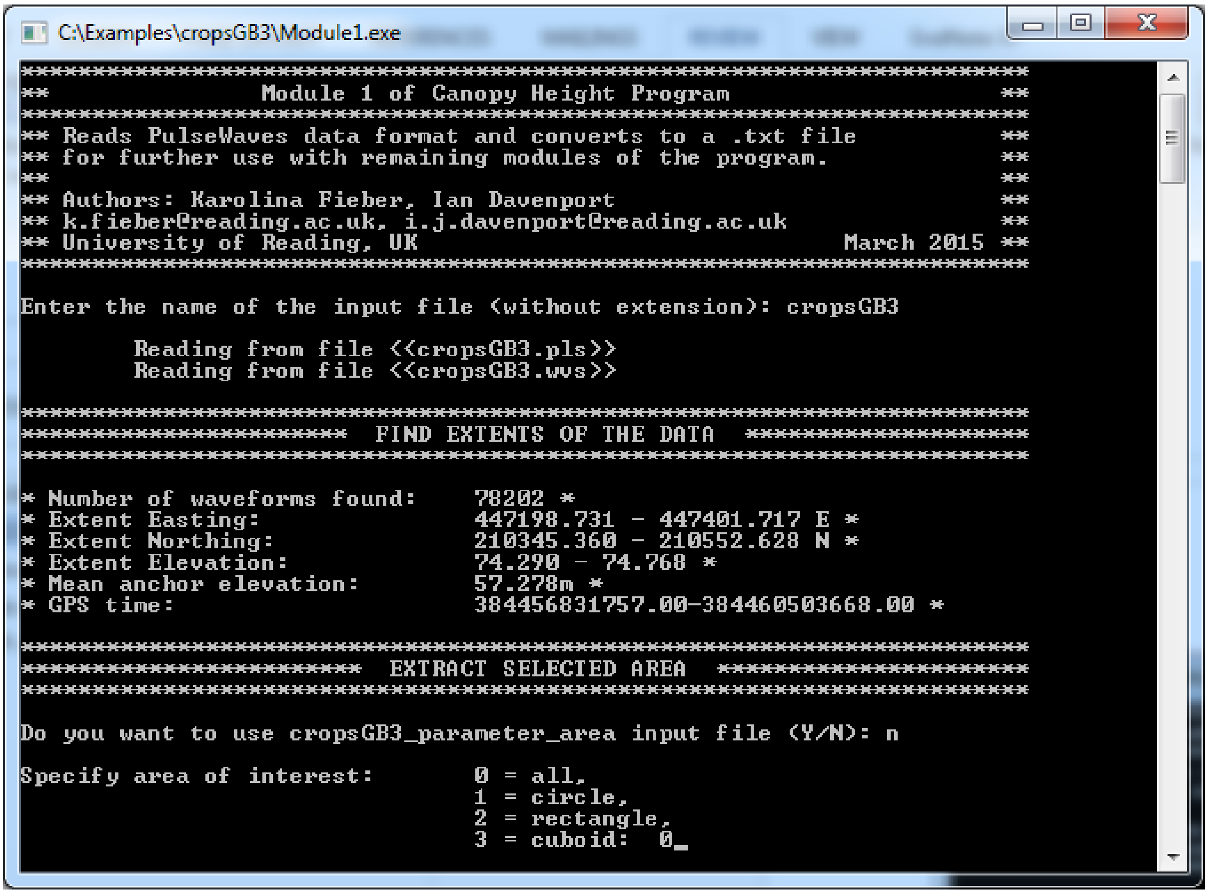
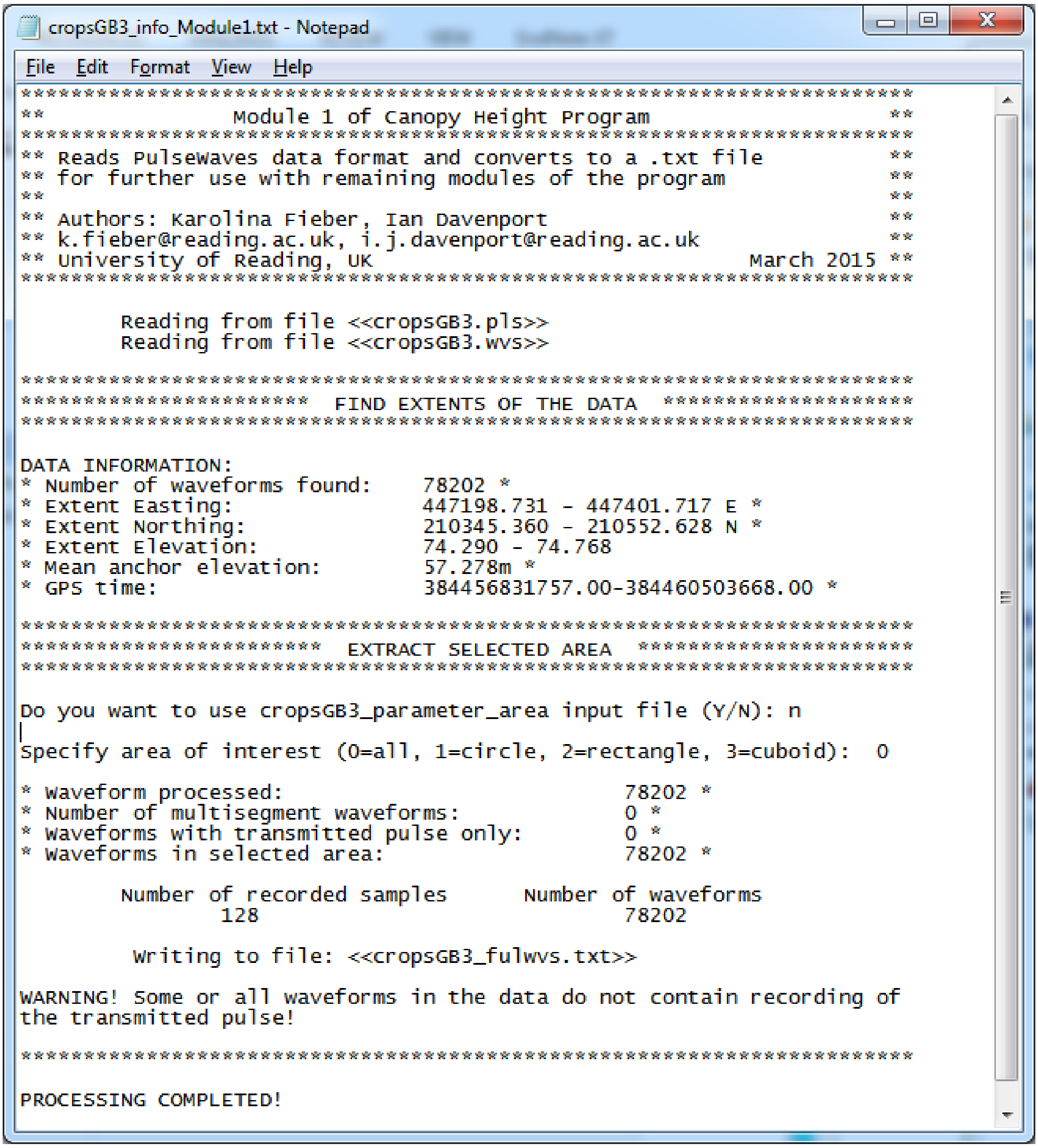


Figure 2. Input parameters in Module 1 of CHP toolkit.

One can notice that 'Mean anchor elevation' seems to be below the 'Elevation extent' of the data. The way data is recorded depends on the instrument and format it is stored. In this particular case, the dataset has been provided with 'bottom up' recording so the anchor point is below ground level and the waveform samples recorded from the ground towards the sky, rather than from the aircraft towards the ground. Accepting (with <enter>) the above parameter will make the program write the waveforms to cropsGB3_fulwvs.txt file, while all the displayed information and selected parameters will be stored in cropsGB3_info_Module1.txt. Opening that file we should see the following:



```
cropsGB3_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 <<cropsGB3.pls>>
        Reading from file <<cropsGB3.wvs>>

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

DATA INFORMATION:
* Number of waveforms found:    78202 *
* Extent Easting:               447198.731 - 447401.717 E *
* Extent Northing:              210345.360 - 210552.628 N *
* Extent Elevation:             74.290 - 74.768
* Mean anchor elevation:        57.278m *
* GPS time:                     384456831757.00-384460503668.00 *

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

Do you want to use cropsGB3_parameter_area input file (Y/N): n

Specify area of interest (0=all, 1=circle, 2=rectangle, 3=cuboid):  0

* Waveform processed:                           78202 *
* Number of multisegment waveforms:             0 *
* Waveforms with transmitted pulse only:        0 *
* Waveforms in selected area:                   78202 *

        Number of recorded samples      Number of waveforms
                128                             78202

         Writing to file: <<cropsGB3_fulwvs.txt>>

WARNING! Some or all waveforms in the data do not contain recording of
the transmitted pulse!

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

PROCESSING COMPLETED!
```

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

One more thing apart those already seen on the screen display is the Warning given at the bottom of the info file, that our data do not contain the information on the transmitted pulse.

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 'cropsGB3' needs to be typed in and accepted. The program will then inform us that it starts to process transmitted waveform. However, as the Module1 info file has already informed us, this dataset does not contain information on transmitted pulse. Therefore, in order o proceed, we will need to provide some guess estimates of certain parameters. The program will prompt some suggested values but one can also get an idea what values to put in by looking at the cropGB3_fulwvs.txt file (e.g. import it to Excel).

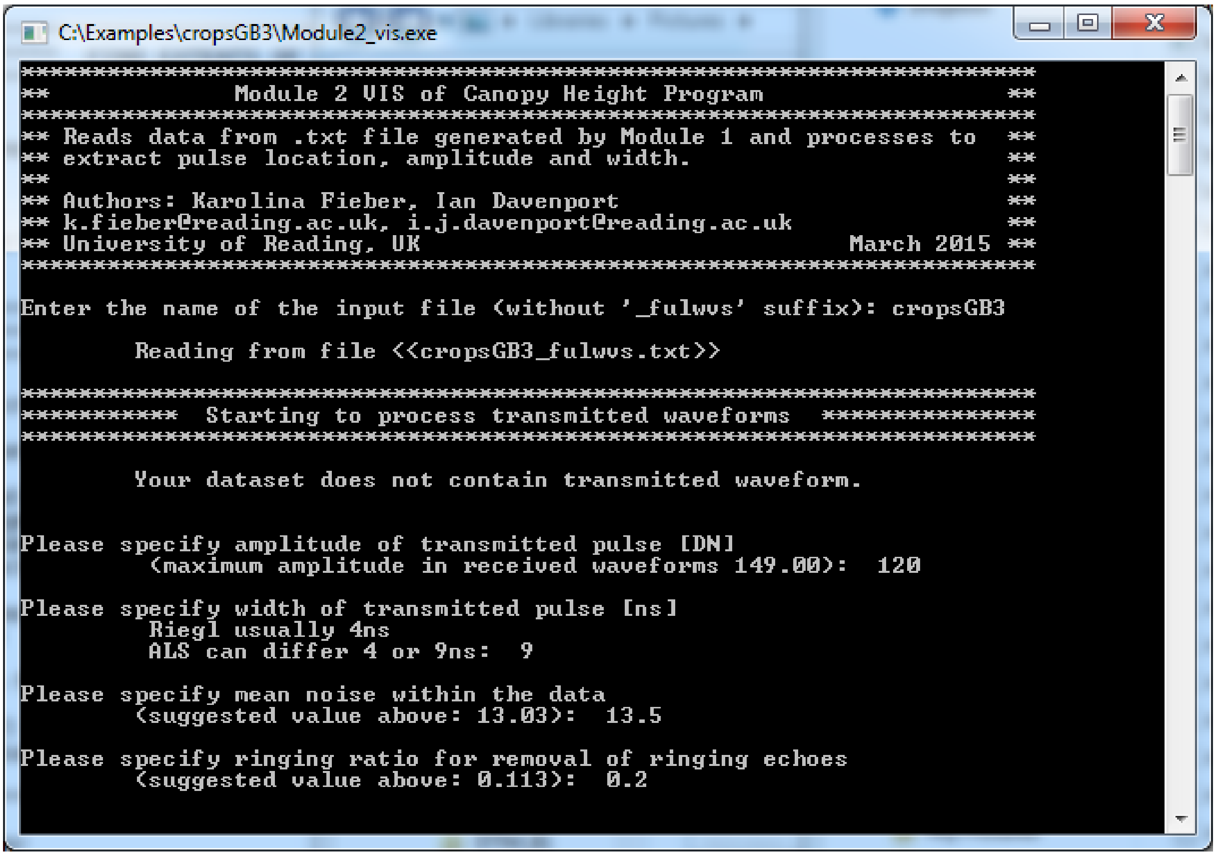


Figure 4. Input parameters in Module 2 of CHP toolkit.

Looking at waveform train we can notice that noise within the data is on the order of 12-15DN and peak amplitude values are about 100DN. The peak amplitude is however not that of a single return so a value higher than 100 would be advisable. The width of the transmitted pulse can be sought in the instrument specification and should be around 9ns for this dataset. A screen grab above shows the suggested values of the required parameters. Finally, we will be asked to specify the ringing echo removal parameter. Ringing echo is an artificial low-amplitude pseudo-peak occurring after strong echoes due to receiver electronics. Ringing removal parameter is a ratio between the amplitude of ringing echo to amplitude to genuine echo. If the ratio between two peaks is smaller than the specified ratio, the low-amplitude peak will be treated as ringing echo and removed. The program will suggest to the user the minimum value that should be used, which is based on the noise to amplitude ratio, which we specified beforehand.

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.

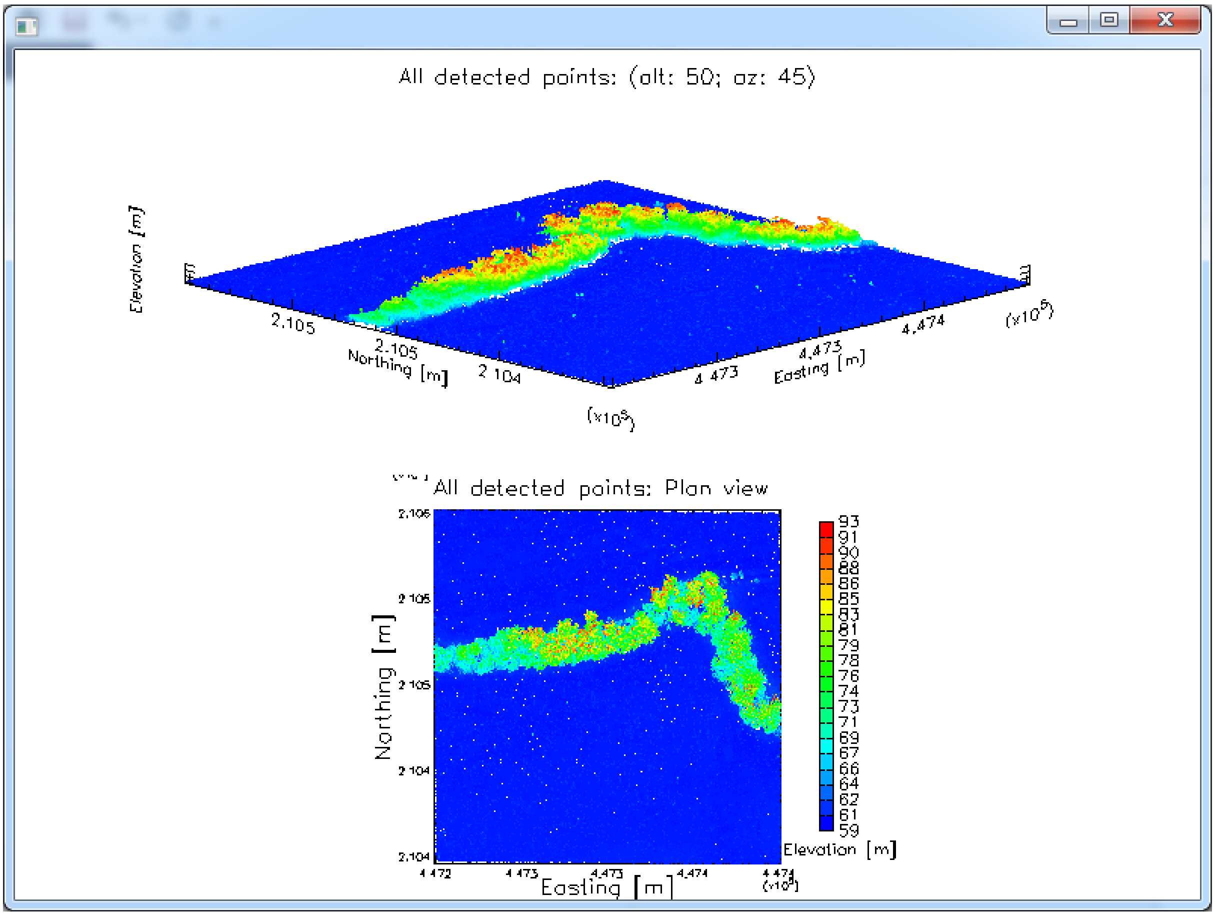


Figure 5. Visualization of all points (waveform peaks) detected by Module 2 VIS.

It is however advisable to import cropsGB3_XYZ.txt into an interactive visualization program such as FUSION (http://forsys.cfr.washington.edu/fusion/fusionlatest.html)) to verify the quality of the peak detection. The structure of the file (for import) is described in the program specification. For example using amplitude of 110 rather than 120 as shown above will give much noisier result. Decreasing the ringing ratio to 0.11 will also produce more returns, which are not necessarily correct.

As in Module 1 all parameters are summarized in the info file cropsGB3_info_Module2.txt.

cropsGB3_info_Module2.txt - Notepad

File Edit Format View Help

```
***********************************************************************
**                 Module 2 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 <<cropsGB3_fulwvs.txt>>

        Writing to file <<cropsGB3_received_param.txt>>
        Writing to file <<cropsGB3_XYZ.txt>>
        Writing to file <<cropsGB3_XYZ_single.txt>>
        Writing to file <<cropsGB3_param.txt>>

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

        Your dataset does not contain transmitted waveform.

Please specify amplitude of transmitted pulse [DN]
         (maximum amplitude in received waveforms 149.00): 120.000000
Please specify width of transmitted pulse [ns]: 9.000000
Please specify mean noise within the data: 13.500000
Please specify ringing ratio for removal of ringing echoes: 0.200000

        Processing of transmitted waveforms is finished

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

        Processing of received waveforms is finished

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

* DATA INFORMATION *

* Waveforms processed:  78202 *
* Disregarded waveforms:        0 *

* Waveforms with one peak:      65008 *
* Waveforms with two peaks:     5290 *
* Waveforms with three peaks:   2152 *
* Waveforms with four peaks:    1710 *
* Waveforms with five peaks:    2356 *
* Waveforms with six peaks:     1686 *

* Total number of points detected: 110780    *

* Mean ringing effect:                          0.200000 *
* Noise to signal ratio (transmitted):          0.112500 *
* Mean amplitude of the transmitted pulse:      120.000000 *
* Mean width of the transmitted pulse:          9.000000 *
* Mean noise in transmitted waveforms:          13.500000 *

* Sampling unit:                                1 *
* Mean elevation vector:                        0.148805 *

* Mean amplitude of single returns:             98.905642 *
* Mean width of single returns:                 11.073285 *

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

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 'cropsGB3' 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 FUSION, suggests the terrain is flat so option 1 is the most suitable. Because the terrain is flat we can specify a large area of comparison. This will be useful for areas covered by trees where vegetation is so dense that it did not allow for pulse penetration to the ground, therefore ground level needs to be approximated from the neighbourhood. Below is the screen grab of the parameters we have used.

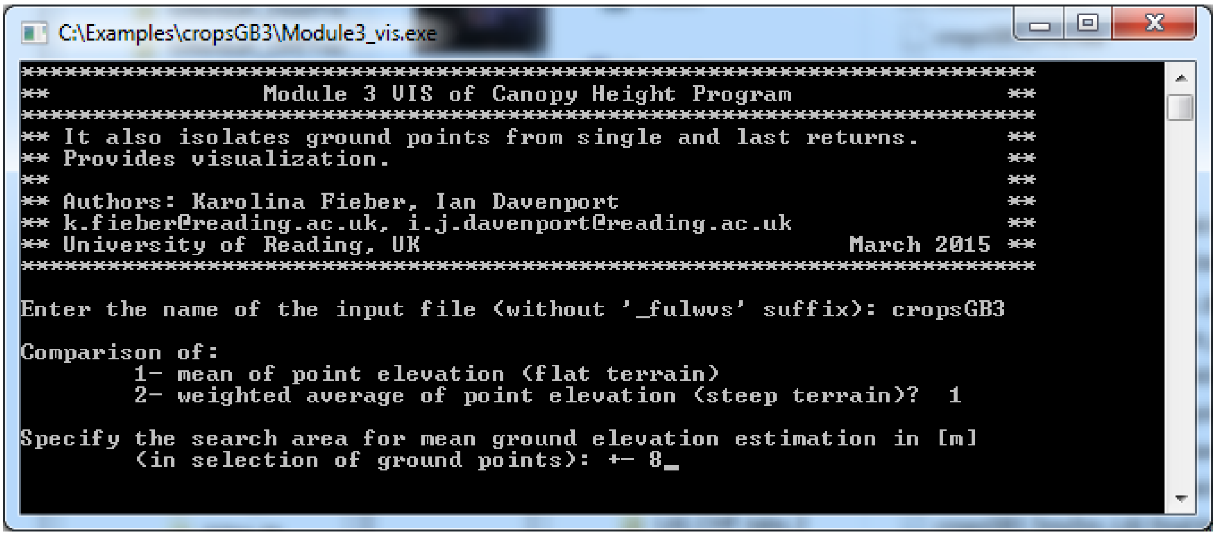


Figure 7. Input parameters in Module 3 of CHP toolkit.

After accepting those parameters the program will go on to process single (located in cropsGB3_XYZ_single.txt) and last (cropsGB3_XYZ.txt) returns in an attempt to select ground points. The user should then view both of the files and verify them against point cloud from cropsGB3_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.

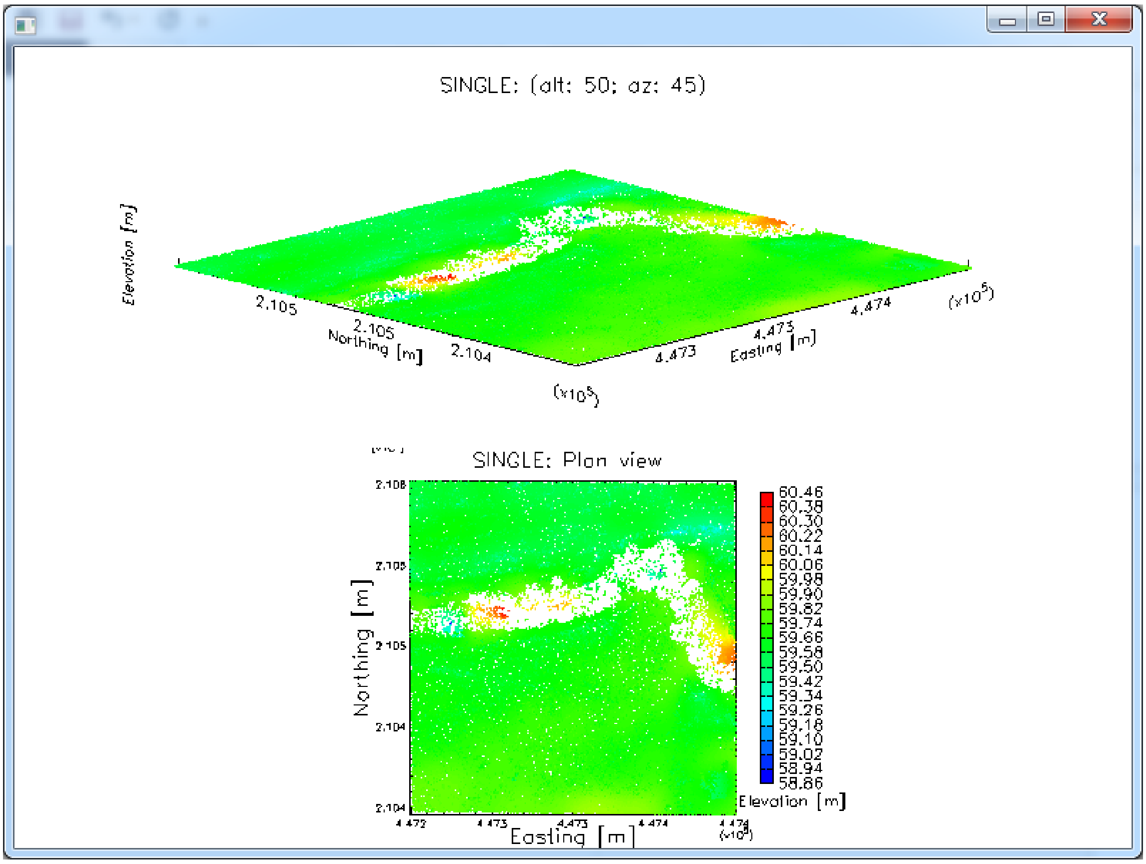


Figure 8. Visualization of single-return-based points separated and visualised by Module 3 VIS.

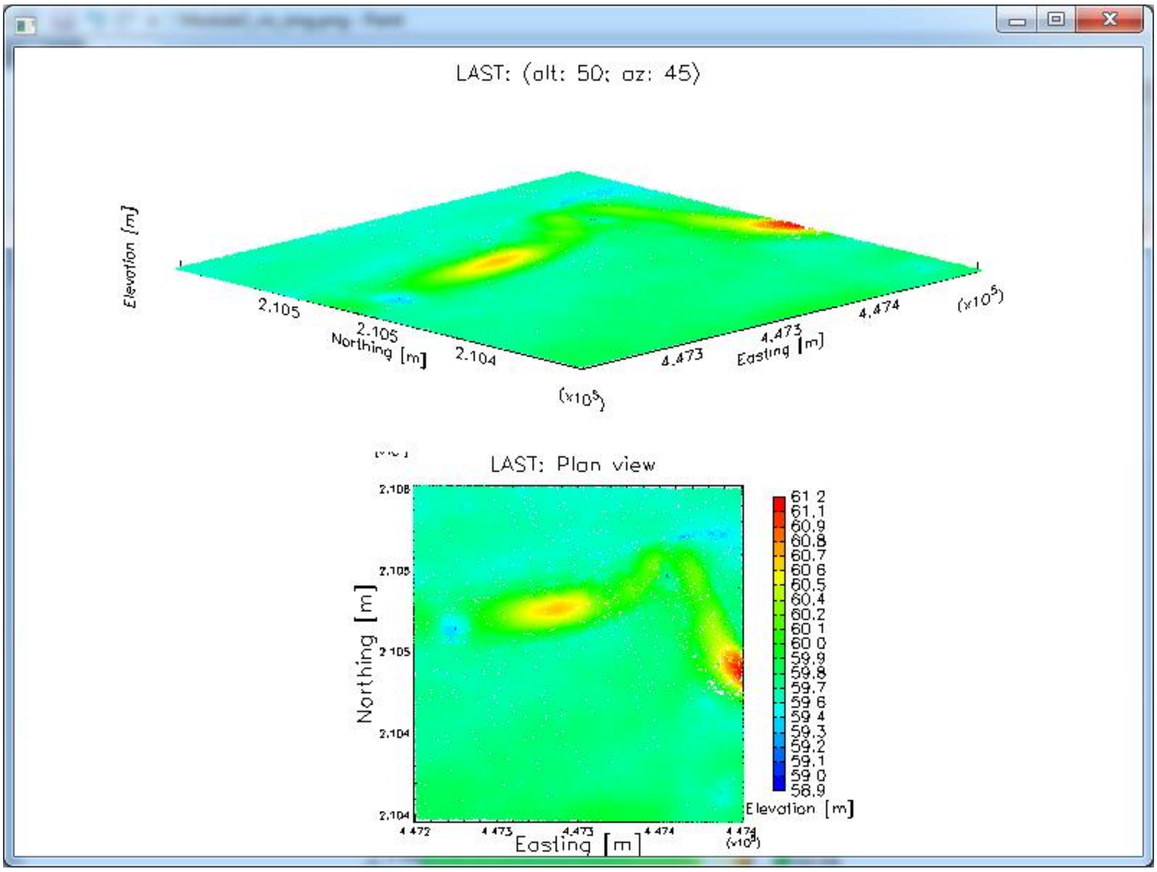


Figure 9. Visualization of last-return-based points separated and visualised by Module 3 VIS.

As before it is advisable to import cropsGB3_ground_single.txt and cropsGB3_ground_last.txt into interactive visualization program such as FUSION to determine which ground representation is better. The ground point files should also be compared with cropsGB3_XYZ.txt. One can debate which file is better to use – ground point file from single peak waveforms misses the data over tree covered area but should be more accurate, whereas the last return file seem to provide slightly too high values in those areas. Therefore, if one wants to compute LAI and CHP in tree covered areas depending on the size of the gaps, using single-return ground data may not allow it. Using last-return ground file will allow it but the results should be considered with caution. The alternative is to generate your own ground file based on single-returns (cropsGB3_XYZ_single.txt) in different software and interpolate the gaps. This version of the CHP program does not perform interpolation.

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

```
cropsGB3_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.                                          **
**                                                                  **
** Authors: Karolina Fieber, Ian Davenport                          **
** 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]: +- 8.00

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

        Reading from file <<cropsGB3_param.txt>>

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

        Reading from file <<cropsGB3_XYZ_single.txt>>
        Writing to file <<cropsGB3_ground_single.txt>>
        Ground points from single returns: 65008

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

        Reading from file <<cropsGB3_XYZ.txt>>
        Writing to file <<cropsGB3_ground_last.txt>>
        Ground points from last returns: 78202

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

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 'cropsGB3'. 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, the grid cell size and the site dimensions. Having inspected the data in FUSION we can suspect the tree height of about 30-35m. According to https://arsf-dan.nerc.ac.uk/trac/wiki/Sensors/LeicaLIDAR the ALS50-II instrument should have 1064nm wavelength therefore reflectance ratio should be set to 2. Ground vegetation separation should not be smaller than half the pulse width so should be at least 5 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 50m by 50m subset of the data with 10m resolution. Separation of ground/vegetation was left to the program to find.

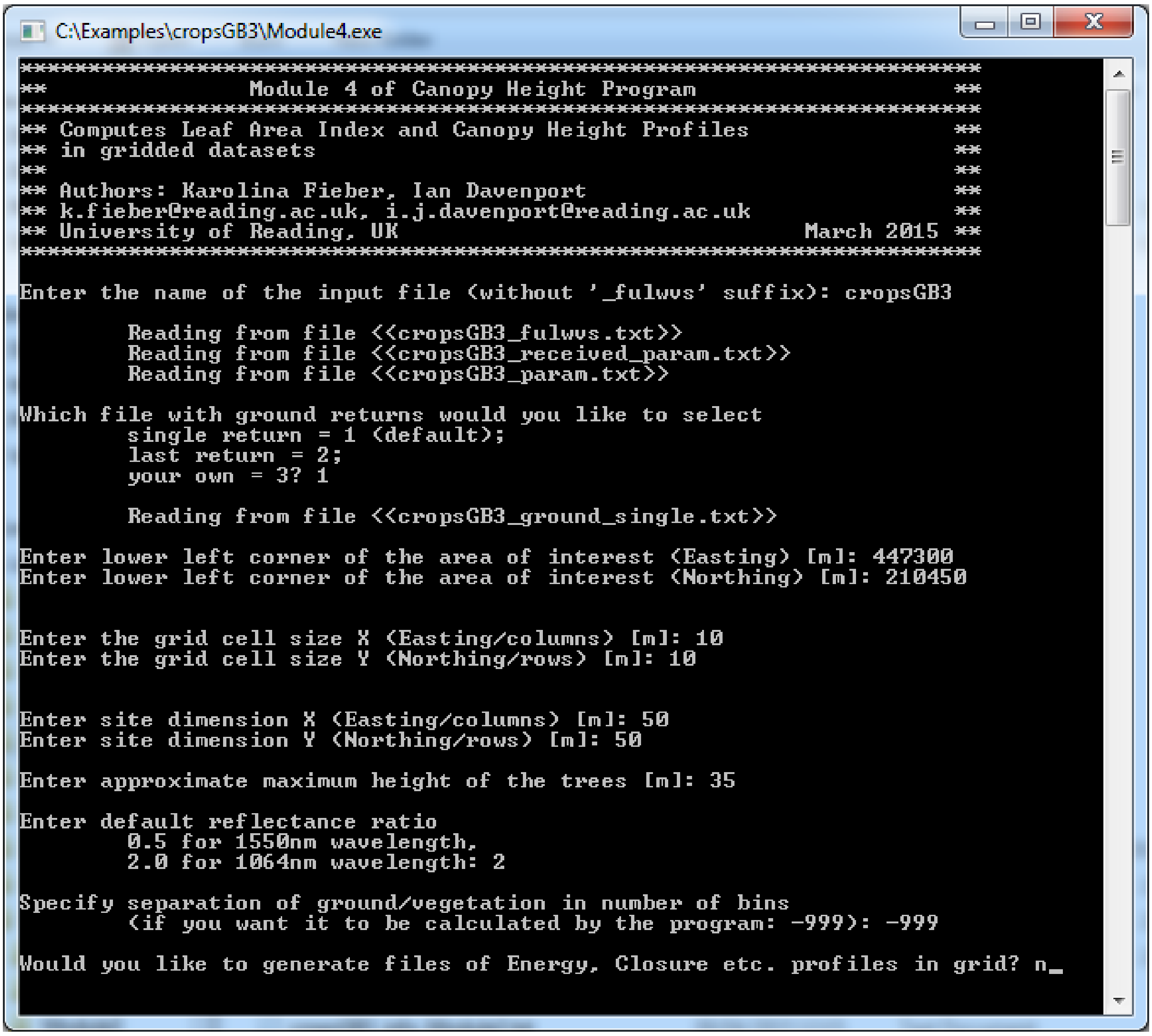


Figure 11. Input parameters in Module 4 of CHP toolkit.

Again the results are summarized in the info file.

cropsGB3_info_Module4.txt - Notepad

File Edit Format View Help

```
************************************************************************
**                 Module 4 of Canopy Height Program                  **
************************************************************************
** Computes Leaf Area Index and Canopy Height Profiles                 **
** in gridded datasets                                                **
**                                                                    **
** 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 <<cropsGB3_fulwvs.txt>>
        Reading from file <<cropsGB3_received_param.txt>>
        Reading from file <<cropsGB3_param.txt>>
        Reading from file <<cropsGB3_ground_single.txt>>

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

USER INPUT VALUES

The lower left corner coordinates are:  447300.00m, 210450.00m
The grid cell size is:                  10.00m by 10.00m
The site dimensions are:                50.00m by 50.00m (2500.00m2)
        making total number of cells    25 (5 by 5)

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

Transmitted pulse width is:     9
Default reflectance ratio is:   2.00

Tree height specified by user is        35.00m
Profile height length is:               37.05m
        eqating to 247 bins of 0.15cm

No default location where the canopy ends specified by user (-999).

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

        Writing to file <<cropsGB3_10mx10m_LAI_final.txt>>
        Writing to file <<cropsGB3_10mx10m_CHP_final.txt>>

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

PROGRAM OUTPUT VALUES


Total site LAI (LAI1):
        saturated cells replaced with
        the maximum dataset LAI value:  1.138931

Total site LAI (LAI2):
        saturated cells replaced with
        the mean total site LAI1 value: 1.138931

Total site LAI (LAI3):
        with saturated cells removed:   1.138931

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 2.000000

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

PROCESSING COMPLETED!
```

Figure 12. Info file generated by Module 4 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 Canopy Height Profile is drawn, one needs to press "Enter" to move to LAI map. Alternatively, once the processing has been completed using Module 4, the LAI map can be produced directly from cropsGB3_10mx10m_LAI_final.txt file and the CHP profile from cropsGB3_10mx10m_CHP_final.txt file using LAI_plot.exe and CHP_plot.exe by providing file names without their extension.

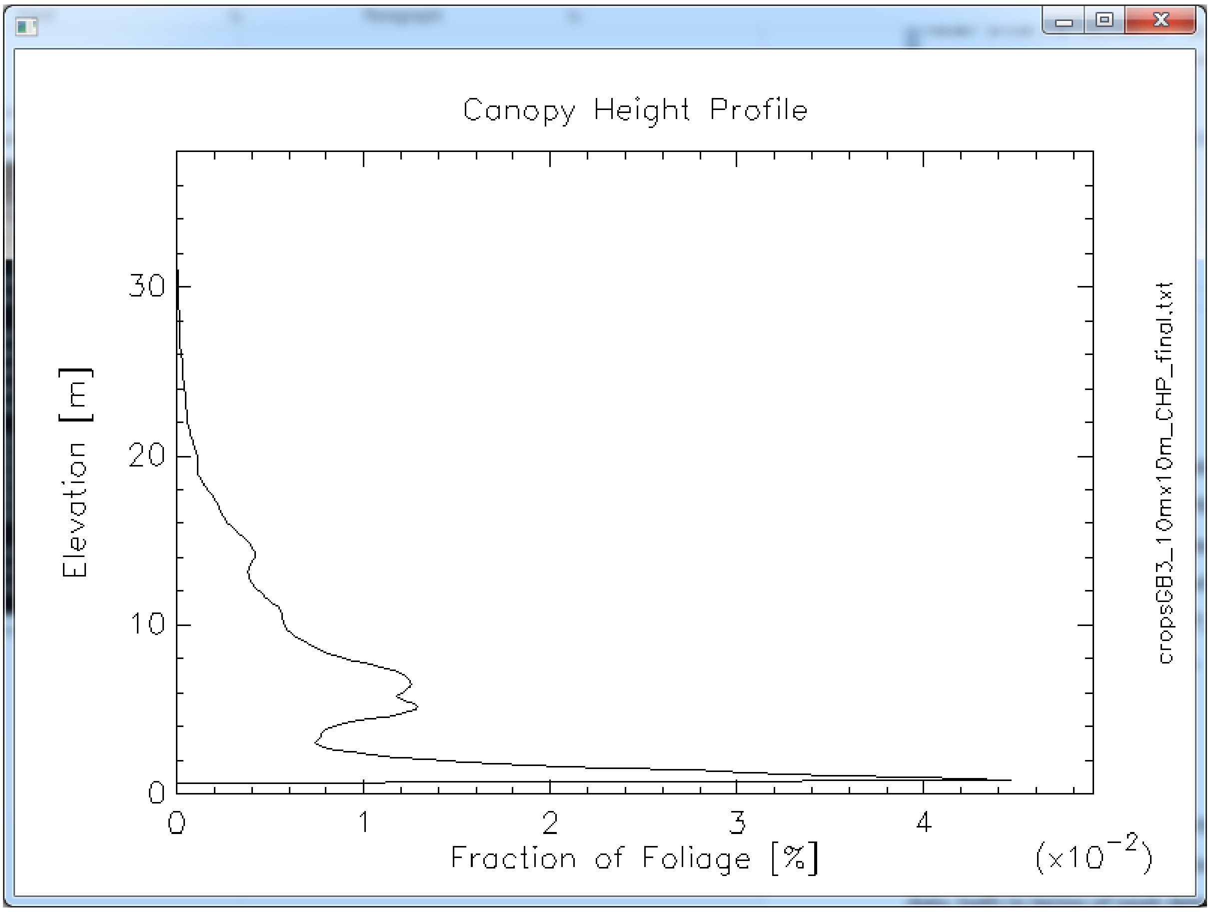


Figure 13. Canopy Height Profile of the study area generated by Module 4 VIS of CHP toolkit (10m cells).

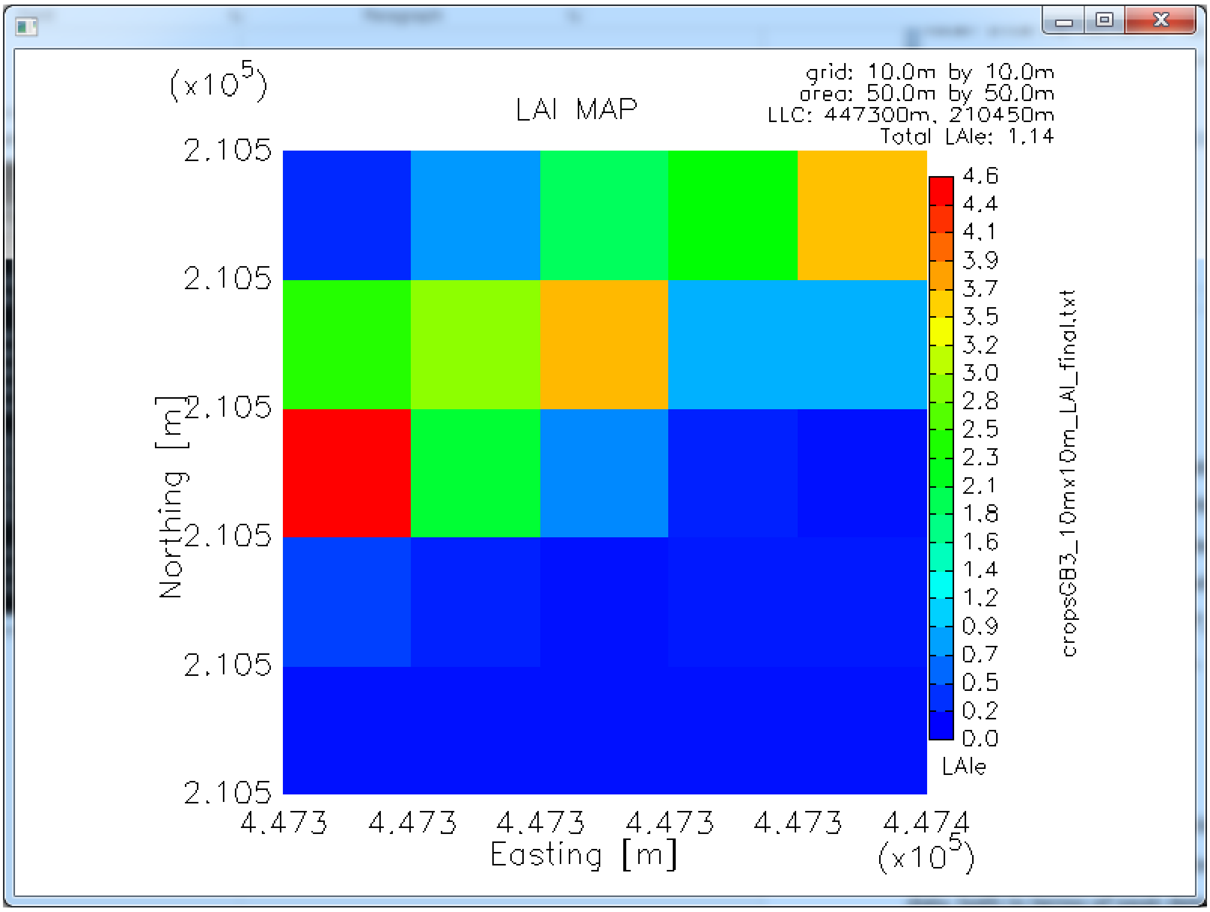


Figure 14. Leaf Area Index Map of the study area generated by Module 4 VIS of CHP toolkit (10m cells).

One needs to remember that when using for example different ground point file, the results may be a little bit 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 9ns, the search area will be 10ns = 1.5m 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 4+2=6 meaning 0.9m, as 4.5 will be rounded down to 4).

The lower sharp peak in the CHP profile is most likely related to the ground peak that was not entirely subtracted. In the case of this dataset the width of transmitted pulse should be 9ns. Module 2 also provided information that the mean width of single-peak received waveforms was around 11ns. This is most likely due to the fact that most of this site was covered by about 30cm crop, which merged with the ground return causing the widening of the pulse width. The height of the crops was nevertheless small in comparison to the nominal pulse width making them (almost) indistinguishable by a simple peak detection method. Tweaking the input parameters like ringing ratio in Module 2 may allow to detect some of those returns, however, their elevation will most likely be incorrect as no optimisation is performed by this program. Therefore due to them being merged with ground return, the correct position of their peak will not be found and will be approximated higher than it should be. Detecting those may however allow for some of those returns to be included in the CHP and LAI calculation process.

This program is designed to provide estimates of LAI and CHP for tree covered areas. It is not meant for small crops especially if they are shorter than half of the transmitted pulse width. In such a case calculation of LAI from discrete returns (after full decomposition with optimisation of Gaussian fit) may be an alternative however may still not provide good results. Using narrower width of transmitted pulse would definitely give some advantage for such short vegetation.

Changing the resolution to 5m and the vegetation-ground separation bin to 10, we will get the following result. 11 out of 100 cells saturated over the tree covered area (as previously discussed the vegetation there is so dense that there are hardly any ground returns). Depending whether we want to include or exclude those cells from LAI calculation our estimate will vary between 1.4 and 0.8. For areas like the one considered here calculation of LAI in homogenous cells is important as LAI does not scale linearly. Therefore, calculation of LAI for the whole considered area will provide much lower value than calculation of LAI in homogenous cells without the mixture or completely no vegetation and trees. Alternatively, one could select in Module 1 only area covered by trees and then process it as uniform site.

There are also visible changes in CHP profile. These are due to exclusion of saturated cells from the profile calculation causing a bias in the profile. The peak just below 2m AGL still remains despite setting a 1.5m vegetation-ground cut off point. This cut-off point should possibly be increased further as it still belongs to the ground return (crops cannot be distinguished from it due to their very small height). All in all, while using homogenous cells even if some of them saturate is advantageous for LAI calculation, using a cell size that does not saturate is advisable for CHP. This is due to the relative character of the CHP.

```
cropsGB3_info_Module4.txt - Notepad
File  Edit  Format  View  Help
**                                                                    **
** 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 <<cropsGB3_fulwvs.txt>>
        Reading from file <<cropsGB3_received_param.txt>>
        Reading from file <<cropsGB3_param.txt>>
        Reading from file <<cropsGB3_ground_single.txt>>

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

USER INPUT VALUES

The lower left corner coordinates are:  447300.00m, 210450.00m
The grid cell size is:                  5.00m by 5.00m
The site dimensions are:                50.00m by 50.00m (2500.00m2)
        making total number of cells    100 (10 by 10)

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

Transmitted pulse width is:     9
Default reflectance ratio is:   2.00

Tree height specified by user is        35.00m
Profile height length is:               37.05m
        eqating to 247 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? y

        Writing to file <<cropsGB3_5mx5m_1_Energy_grid.txt>>
        Writing to file <<cropsGB3_5mx5m_2_Closure_grid.txt>>
        Writing to file <<cropsGB3_5mx5m_3_LAI_grid.txt>>
        Writing to file <<cropsGB3_5mx5m_4_CHP_grid.txt>>
        Writing to file <<cropsGB3_5mx5m_5_Reflectance.txt>>
        Writing to file <<cropsGB3_5mx5m_LAI_final.txt>>
        Writing to file <<cropsGB3_5mx5m_CHP_final.txt>>

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

PROGRAM OUTPUT VALUES

 LAI in [6,1] cell is not possible to calculate (no ground return)
 LAI in [6,2] cell is not possible to calculate (no ground return)
 LAI in [6,3] cell is not possible to calculate (no ground return)
 LAI in [7,1] cell is not possible to calculate (no ground return)
 LAI in [7,3] cell is not possible to calculate (no ground return)
 LAI in [7,4] cell is not possible to calculate (no ground return)
 LAI in [7,5] cell is not possible to calculate (no ground return)
 LAI in [8,5] cell is not possible to calculate (no ground return)
 LAI in [8,9] cell is not possible to calculate (no ground return)
 LAI in [10,7] cell is not possible to calculate (no ground return)
 LAI in [10,9] cell is not possible to calculate (no ground return)

Total site LAI (LAI1):
        saturated cells replaced with
        the maximum dataset LAI value:  1.424367

Total site LAI (LAI2):
        saturated cells replaced with
        the mean total site LAI1 value: 0.821592

Total site LAI (LAI3):
        with saturated cells removed:   0.803531

Difference between LAI1 and LAI3: 0.620836
Difference between LAI2 and LAI3: 0.018061

Number of cells with no ground return: 11

Number of cells with no data: 0

Total site reflectance ratio 2.000000
```

Figure 15. Info file generated by Module 4 of CHP toolkit (5m cells).

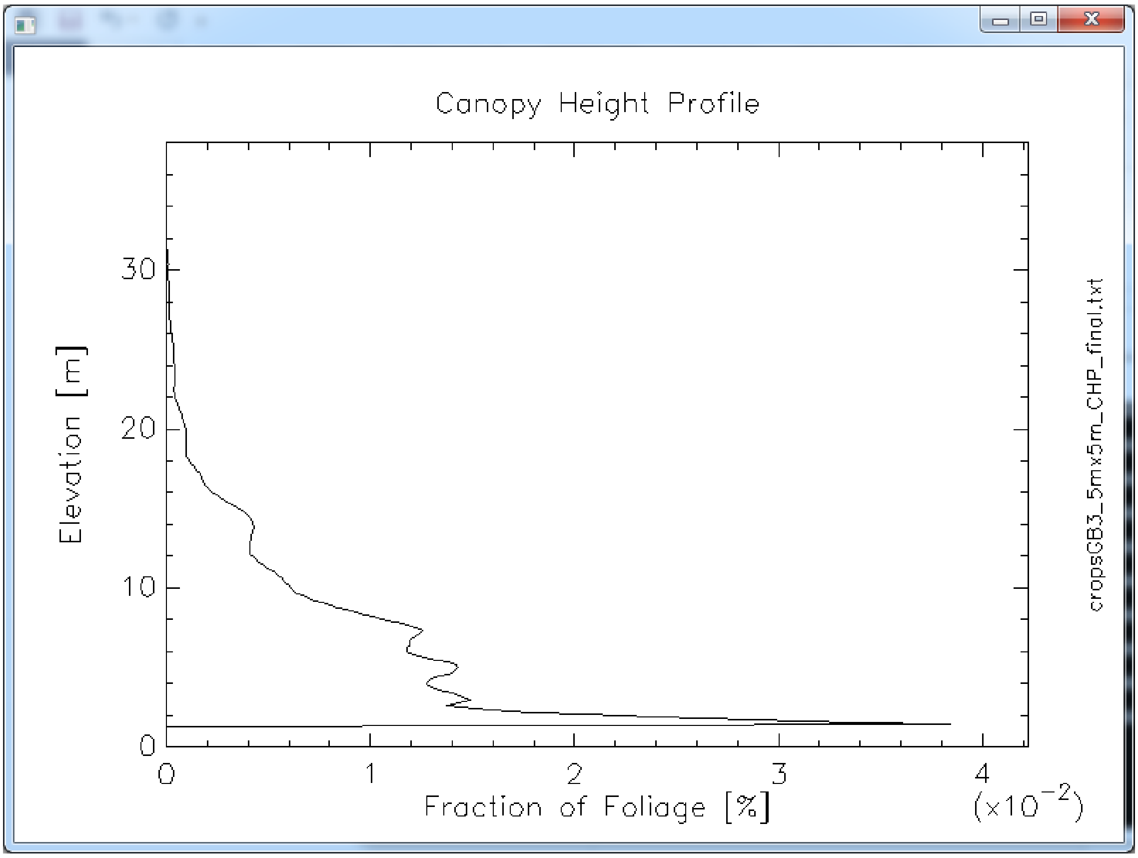


Figure 16. Canopy Height Profile of the study area generated by Module 4 VIS of CHP toolkit (5m cells).

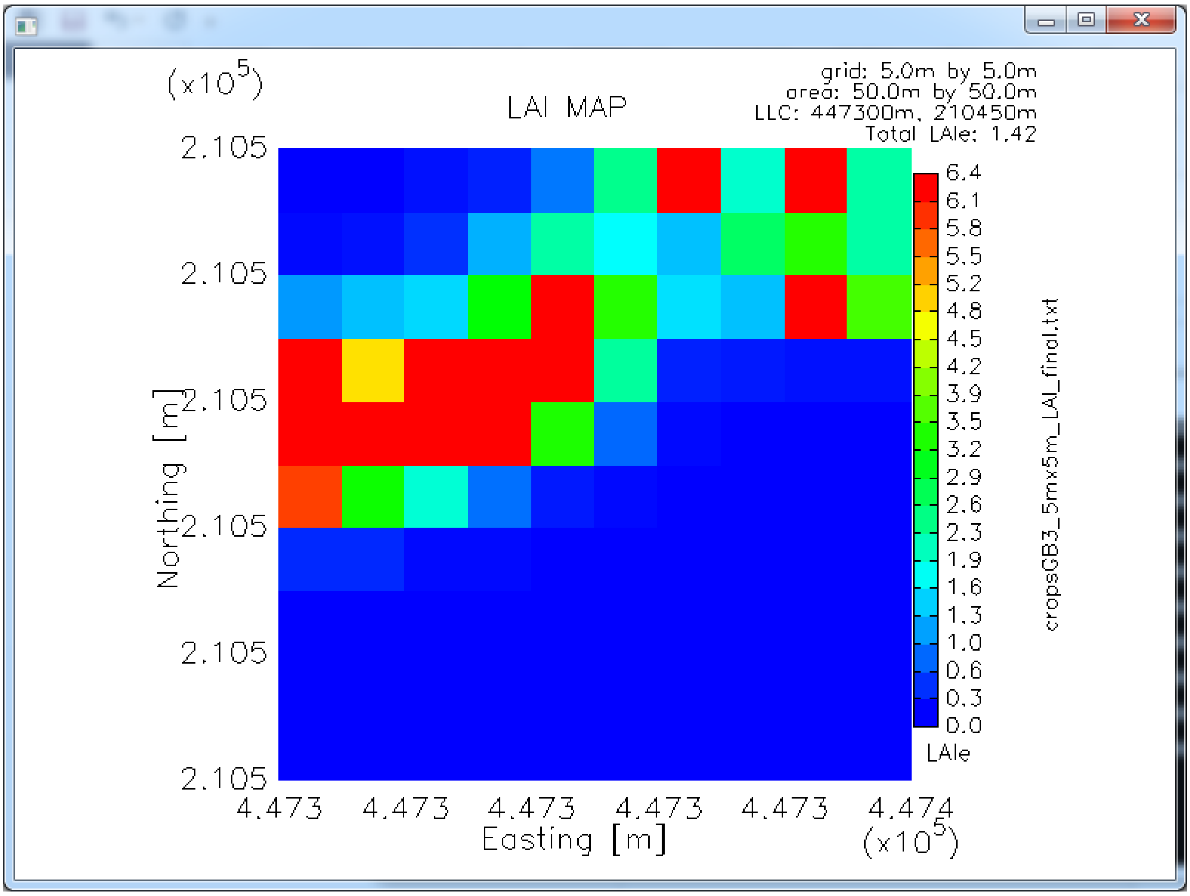


Figure 17. Leaf Area Index Map of the study area generated by Module 4 VIS of CHP toolkit (5m cells).