Case study: RIEGL LMS Q560/GeoCodeWF (oranges2)

This document shows the usage of the open source CHP toolkit software with an example file provided in .lgc/.lwf format which has 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: 55393445-55393555, and 6169145-616255. 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 (oranges2.pls, oranges2.wvs) used in this example can be found https://github.com/kdf200/CHP.

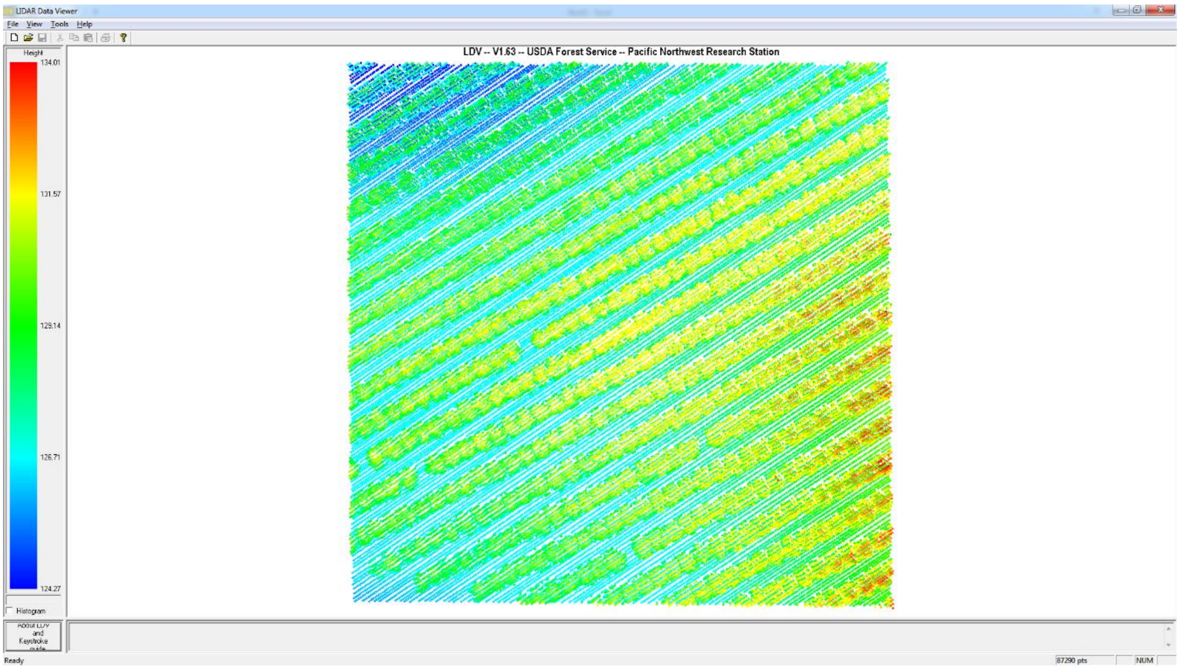
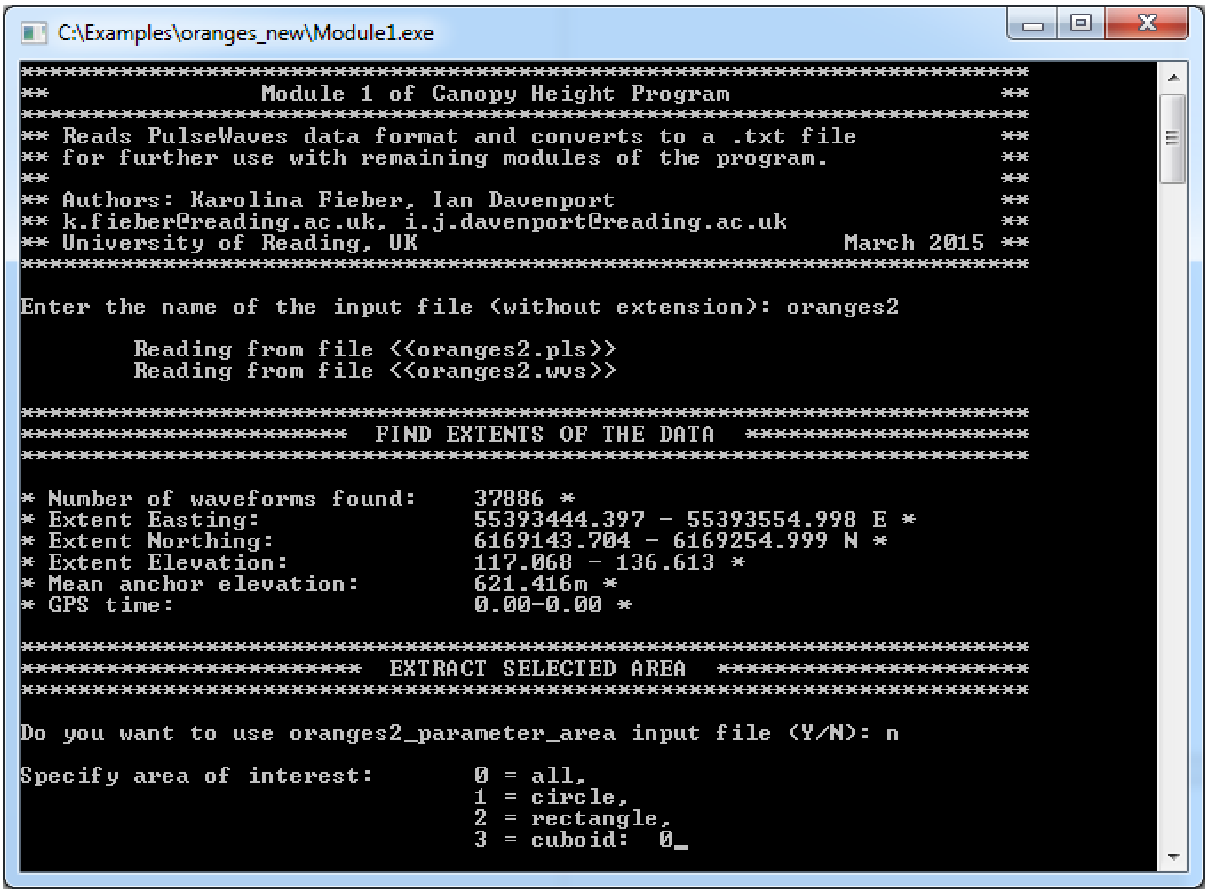


Figure 1. Visualization of the study area in FUSION.

Module 1 – Converts PLS files to ASCII format

Running Module1.exe and typing in “oranges2” 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. If you want to use a parameter file 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.



```
C:\Examples\oranges_new\Module1.exe
****************************************************************************
**               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 **
****************************************************************************

Enter the name of the input file (without extension): oranges2

        Reading from file <<oranges2.pls>>
        Reading from file <<oranges2.wvs>>

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

* Number of waveforms found:    37886 *
* Extent Easting:               55393444.397 - 55393554.998 E *
* Extent Northing:              6169143.704 - 6169254.999 N *
* Extent Elevation:             117.068 - 136.613 *
* Mean anchor elevation:        621.416m *
* GPS time:                     0.00-0.00 *

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

Do you want to use oranges2_parameter_area input file (Y/N): n

Specify area of interest:       0 = all,
                                1 = circle,
                                2 = rectangle,
                                3 = cuboid:  0_
```

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

Accepting (with <enter>) the above parameter will make the program write the waveforms to oranges2_fulwvs.txt file, while all the displayed information and selected parameters will be stored in oranges2_info_Module1.txt. Opening that file we should see the following:

```
oranges2_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 <<oranges2.pls>>
        Reading from file <<oranges2.wvs>>

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

DATA INFORMATION:
* Number of waveforms found:      37886 *
* Extent Easting:                 55393444.397 - 55393554.998 E *
* Extent Northing:                6169143.704 - 6169254.999 N *
* Extent Elevation:               117.068 - 136.613
* Mean anchor elevation:          621.416m *
* GPS time:                       0.00-0.00 *

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

Do you want to use oranges2_parameter_area input file (Y/N): n

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

* Waveform processed:                             37886 *
* Number of multisegment waveforms:               0 *
* Waveforms with transmitted pulse only:          0 *
* Waveforms in selected area:                     37886 *

        Number of recorded samples      Number of waveforms
                58                              37796
                63                              89
                118                             1

         Writing to file: <<oranges2_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 'oranges2' needs to be typed in and accepted. The program will then inform us that it starts to process 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. Selecting 'n' and hitting <enter> will make the program go on to find the peaks in returned waveforms.

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.

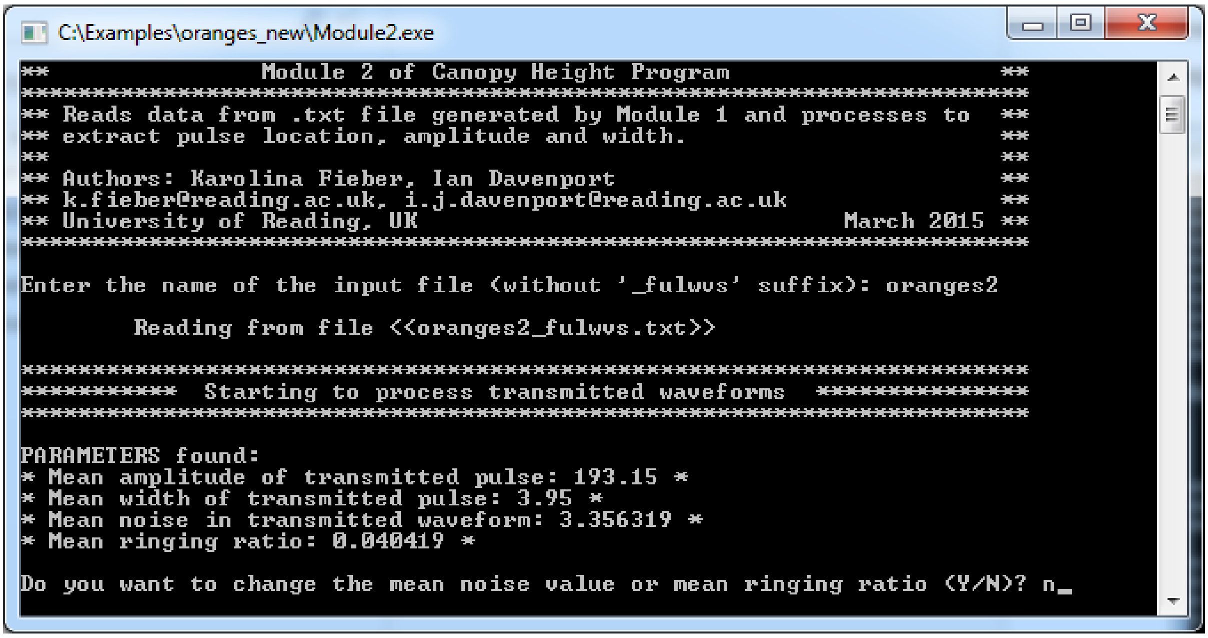


Figure 4. Input parameters in Module 2 of CHP toolkit.

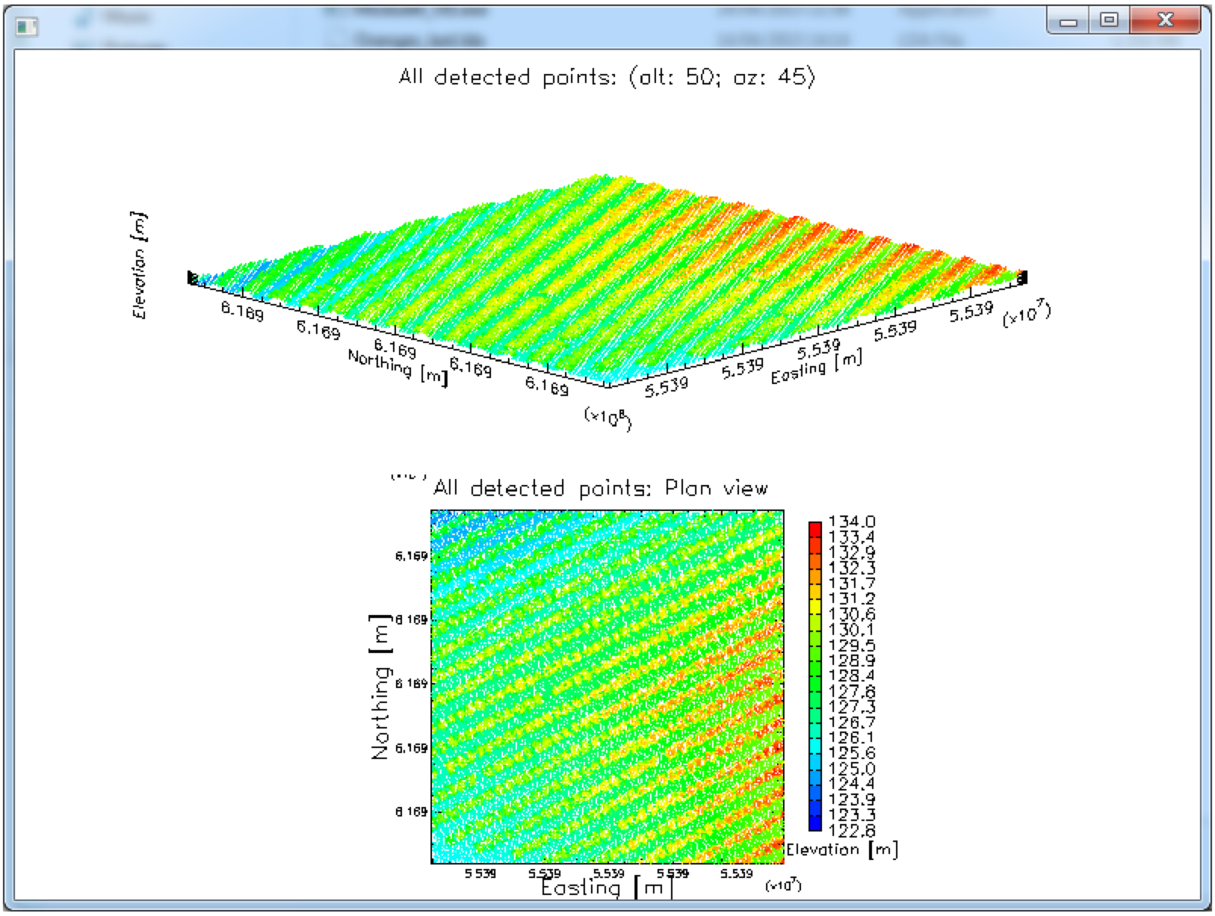


Figure 5. Visualization of all points (waveform peaks) detected by Module 2 VIS.

oranges2_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 <<oranges2_fulwvs.txt>>

        Writing to file <<oranges2_received_param.txt>>
        Writing to file <<oranges2_XYZ.txt>>
        Writing to file <<oranges2_XYZ_single.txt>>
        Writing to file <<oranges2_param.txt>>

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

PARAMETERS found:
* Mean amplitude of transmitted pulse: 193.15 *
* Mean width of transmitted pulse: 3.95 *
* Mean noise in transmitted waveform: 3.356319 *
* Mean ringing ratio: 0.040419 *

Do you want to change the mean noise value or mean ringing ratio? n

        Processing of transmitted waveforms is finished

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

        Processing of received waveforms is finished

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

* DATA INFORMATION *

* Waveforms processed:  37886 *
* Disregarded waveforms:        0 *

* Waveforms with one peak:      28786 *
* Waveforms with two peaks:     6925 *
* Waveforms with three peaks:   1941 *
* Waveforms with four peaks:    226 *
* Waveforms with five peaks:    8 *
* Waveforms with six peaks:     0 *

* Total number of points detected: 49403   *

* Mean ringing effect:                          0.040419 *
* Noise to signal ratio (transmitted):          0.017377 *
* Mean amplitude of the transmitted pulse:      193.148868 *
* Mean width of the transmitted pulse:          3.952765 *
* Mean noise in transmitted waveforms:          3.356319 *

* Sampling unit:                                1 *
* Mean elevation vector:                        -0.146951 *

* Mean amplitude of single returns:             173.022164 *
* Mean width of single returns:                 4.346735 *


        Reading from file <<oranges2_XYZ.txt>>

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

PROCESSING COMPLETED!
```

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

It is however advisable to import oranges2_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 changing the ringing ratio may result in producing more or less spurious returns.

As in Module 1 all parameters are summarized in the info file oranges2_info_Module2.txt.

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 'oranges2' needs to be typed in. Following that we will need to specify the type of elevation comparison we want to use: either using mean or weighted mean of the points in the proximity of the considered point. Previous visualization in FUSION suggests the terrain is relatively flat in this study area therefore option 1 should be sufficient. Because the terrain is flat we can also specify a relatively 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.

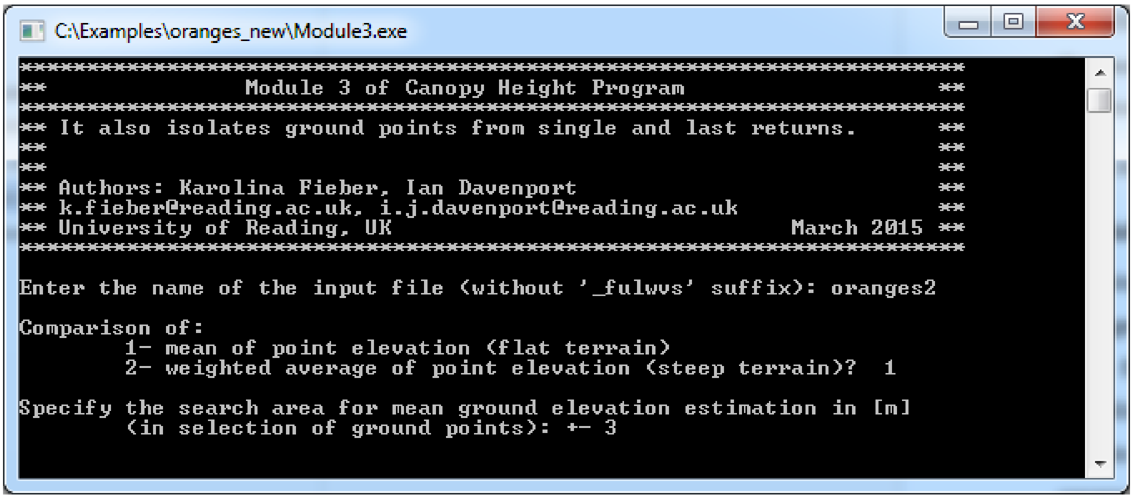


Figure 7. Input parameters in Module 3 of CHP toolkit.

After accepting those parameters the program will go on to process single (located in oranges2_XYZ_single.txt) and last (oranges2_XYZ.txt) returns in an attempt to select ground points. The user should then view both of the files with ground returns (oranges2_ground_single.txt, oranges2_ground_last.txt) and verify them against point cloud from oranges2_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.

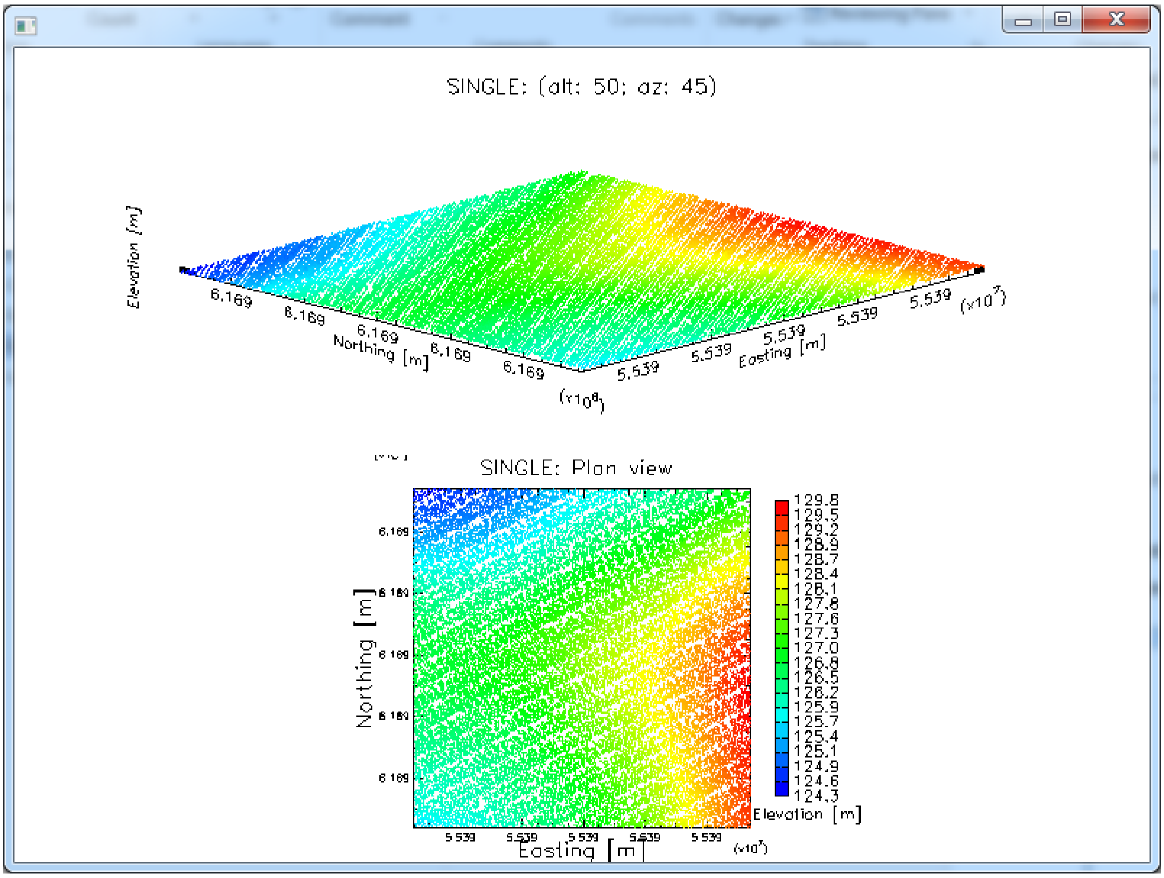


Figure 8. Visualization of single-return-based points separated and visualised by Module 3 VIS.

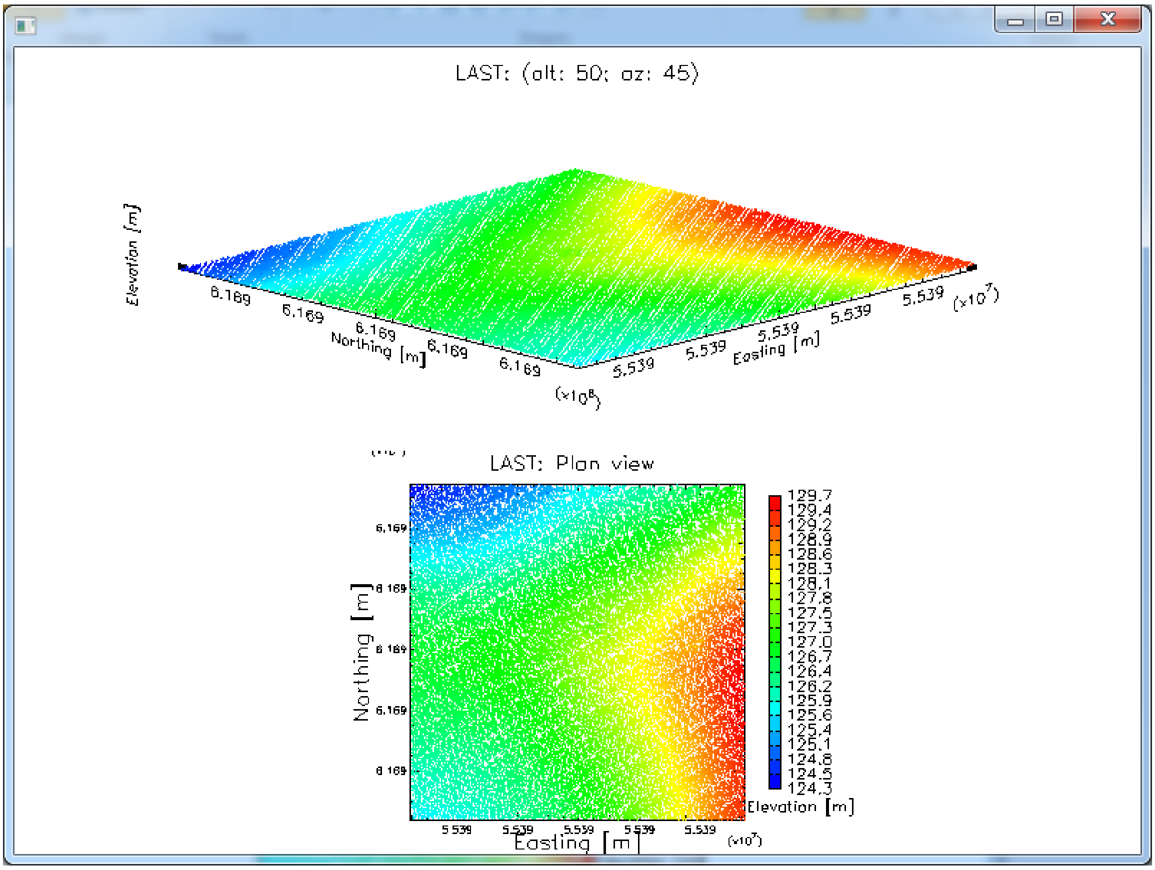
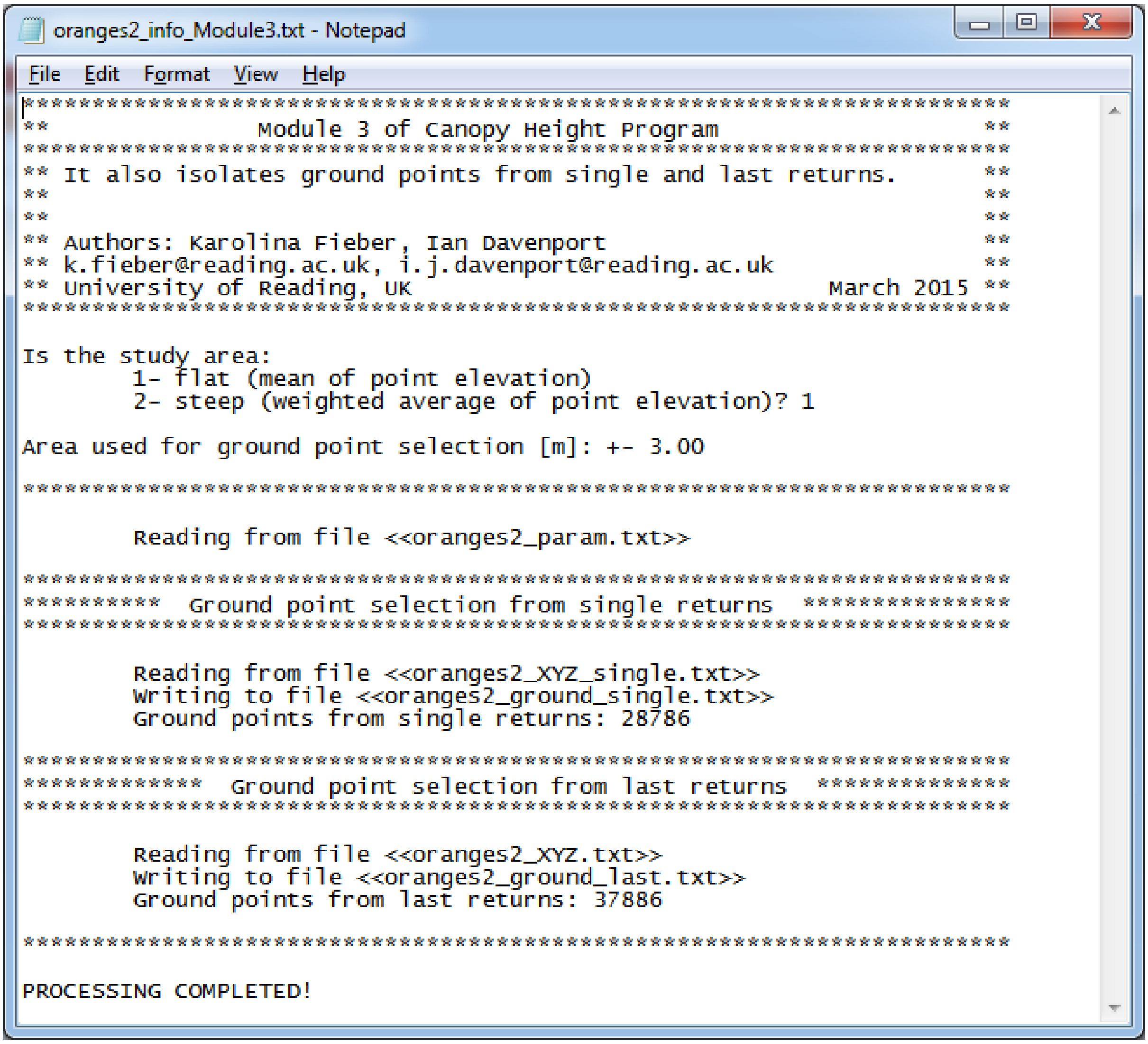


Figure 9. Visualization of last-return-based points separated and visualised by Module 3 VIS.

Comparison in FUSION of oranges2_ground_single.txt and oranges2_ground_last.txt files to oranges2_XYZ.txt shows that both of the ground point files are good quality and match the XYZ point cloud of all detected points. Using the last-return ground file will therefore be advantageous due to higher density of points.

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



```
oranges2_info_Module3.txt - Notepad
File  Edit  Format  View  Help
***********************************************************************
**                Module 3 of Canopy Height Program                  **
***********************************************************************
** It also isolates ground points from single and last returns.      **
**                                                                   **
**                                                                   **
** Authors: Karolina Fieber, Ian Davenport                           **
** k.fieber@reading.ac.uk, i.j.davenport@reading.ac.uk               **
** University of Reading, UK                              March 2015 **
***********************************************************************

Is the study area:
        1- flat (mean of point elevation)
        2- steep (weighted average of point elevation)? 1

Area used for ground point selection [m]: +- 3.00

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

        Reading from file <<oranges2_param.txt>>

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

        Reading from file <<oranges2_XYZ_single.txt>>
        Writing to file <<oranges2_ground_single.txt>>
        Ground points from single returns: 28786

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

        Reading from file <<oranges2_XYZ.txt>>
        Writing to file <<oranges2_ground_last.txt>>
        Ground points from last returns: 37886

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

PROCESSING COMPLETED!
```

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

Module 4 – LAI and CHP calculation

As in the case of the previous modules, the first thing to run Module 4 is to provide it with the input file name 'oranges2'. 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. Having inspected the data in FUSION we can suspect the tree height as being about 6m. Pulse width of Riegl LM Q560 scanner is 4ns and the laser wavelength 1550ns. Ground vegetation separation should not be smaller than half the pulse width, so 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 100m subset of the data with 10m resolution. Separation of ground/vegetation was left to the program to find.

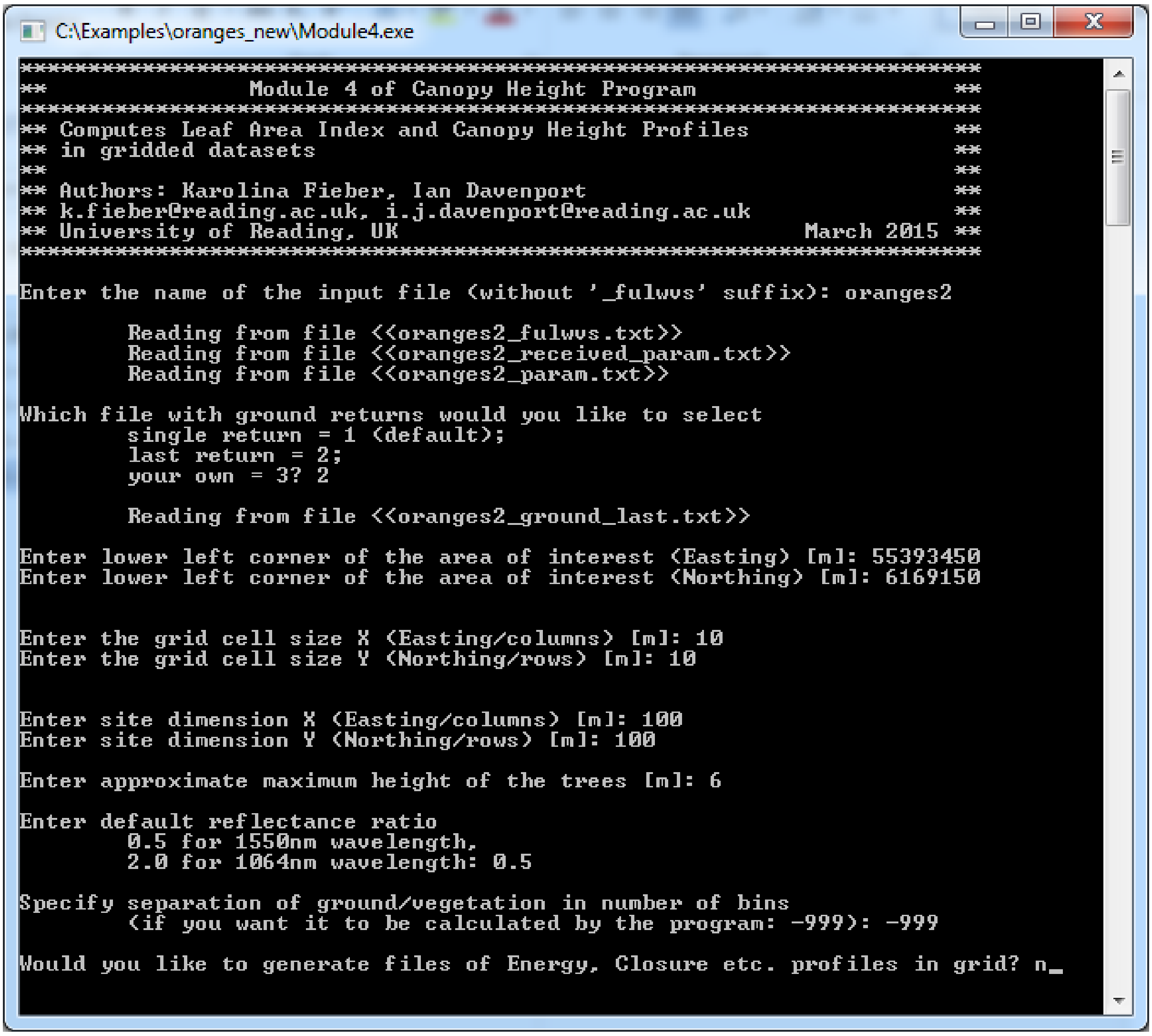
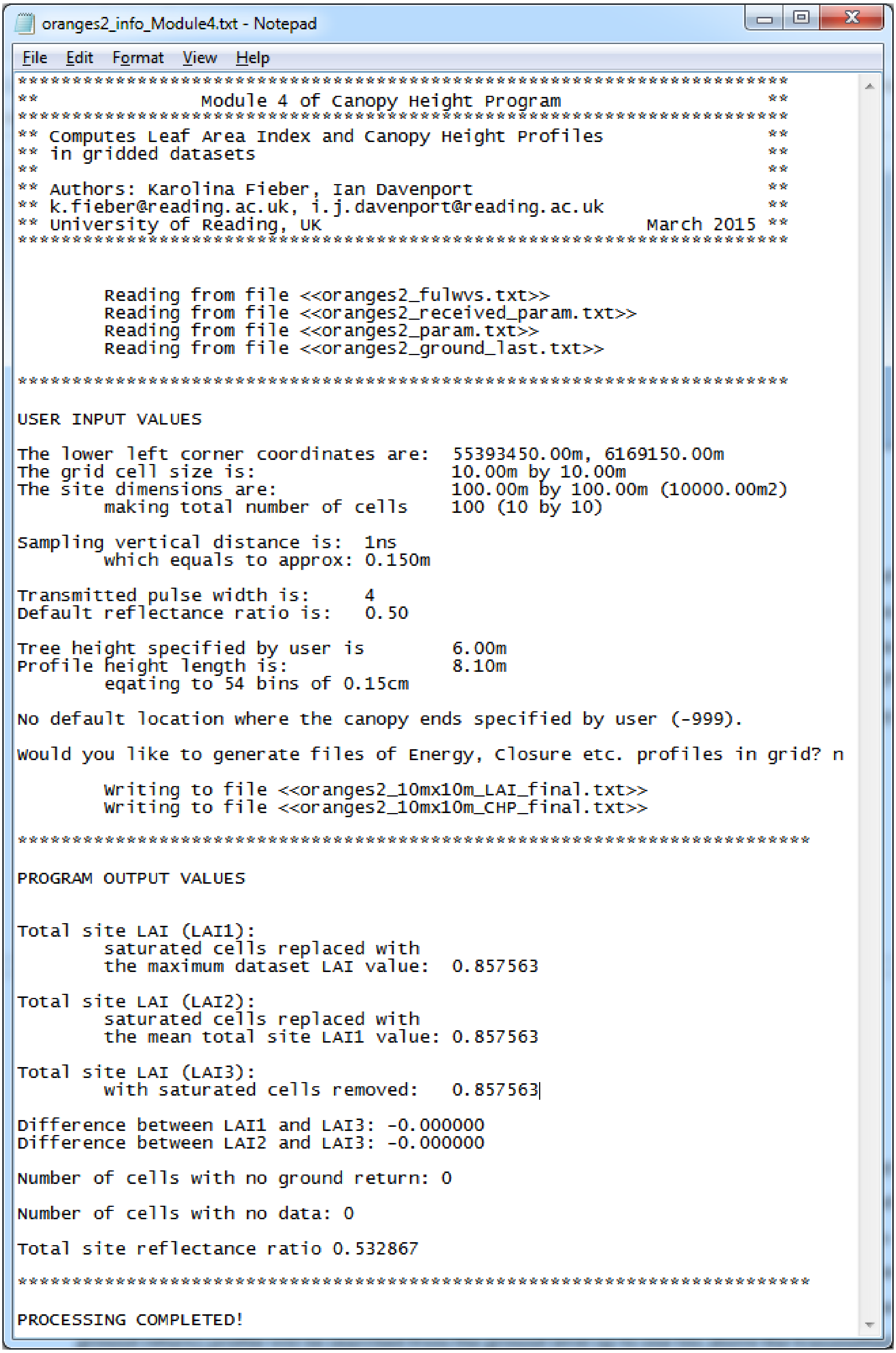


Figure 11. Input parameters in Module 4 of CHP toolkit.

Again the results are summarized in the info file.



oranges2_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 <<oranges2_fulwvs.txt>>
        Reading from file <<oranges2_received_param.txt>>
        Reading from file <<oranges2_param.txt>>
        Reading from file <<oranges2_ground_last.txt>>

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

USER INPUT VALUES

The lower left corner coordinates are:  55393450.00m, 6169150.00m
The grid cell size is:                  10.00m by 10.00m
The site dimensions are:                100.00m by 100.00m (10000.00m2)
        making total number of cells    100 (10 by 10)

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

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

Tree height specified by user is        6.00m
Profile height length is:               8.10m
        eqating to 54 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 <<oranges2_10mx10m_LAI_final.txt>>
        Writing to file <<oranges2_10mx10m_CHP_final.txt>>

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

PROGRAM OUTPUT VALUES


Total site LAI (LAI1):
        saturated cells replaced with
        the maximum dataset LAI value:  0.857563

Total site LAI (LAI2):
        saturated cells replaced with
        the mean total site LAI1 value: 0.857563

Total site LAI (LAI3):
        with saturated cells removed:   0.857563

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 0.532867

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

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 the 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 oranges2_10mx10m_LAI_final.txt file and the CHP profile from oranges2_10mx10m_CHP_final.txt file using LAI_plot.exe and CHP_plot.exe by providing file names without their extension.

One needs to remember that when using for example different ground point files, 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 sought 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).

The lower sharp peak in the CHP profile is most likely related to the ground peak that was not entirely subtracted. Changing the ground separation ratio to 4 bins may help eliminate that.

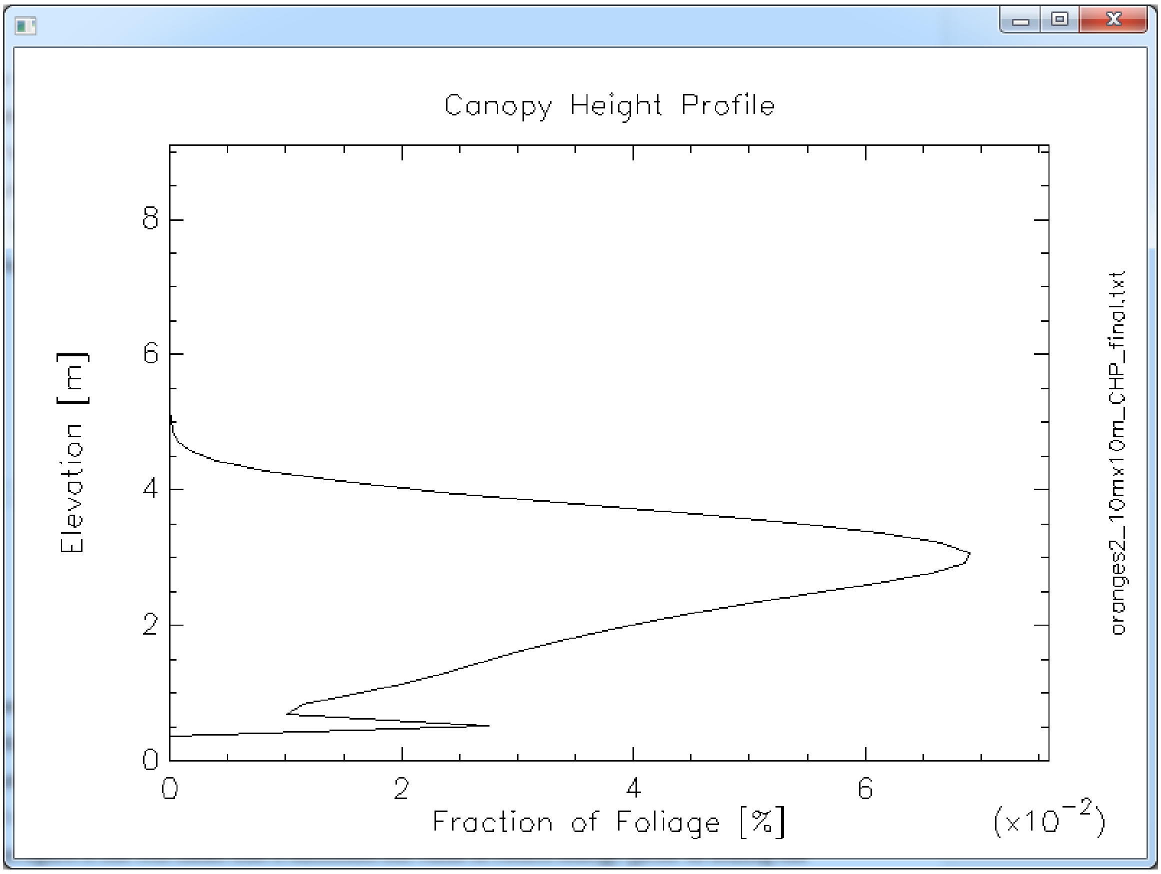


Figure 13. Canopy Height Profile of the study area generated by Module 4 VIS of CHP toolkit (10m cells).

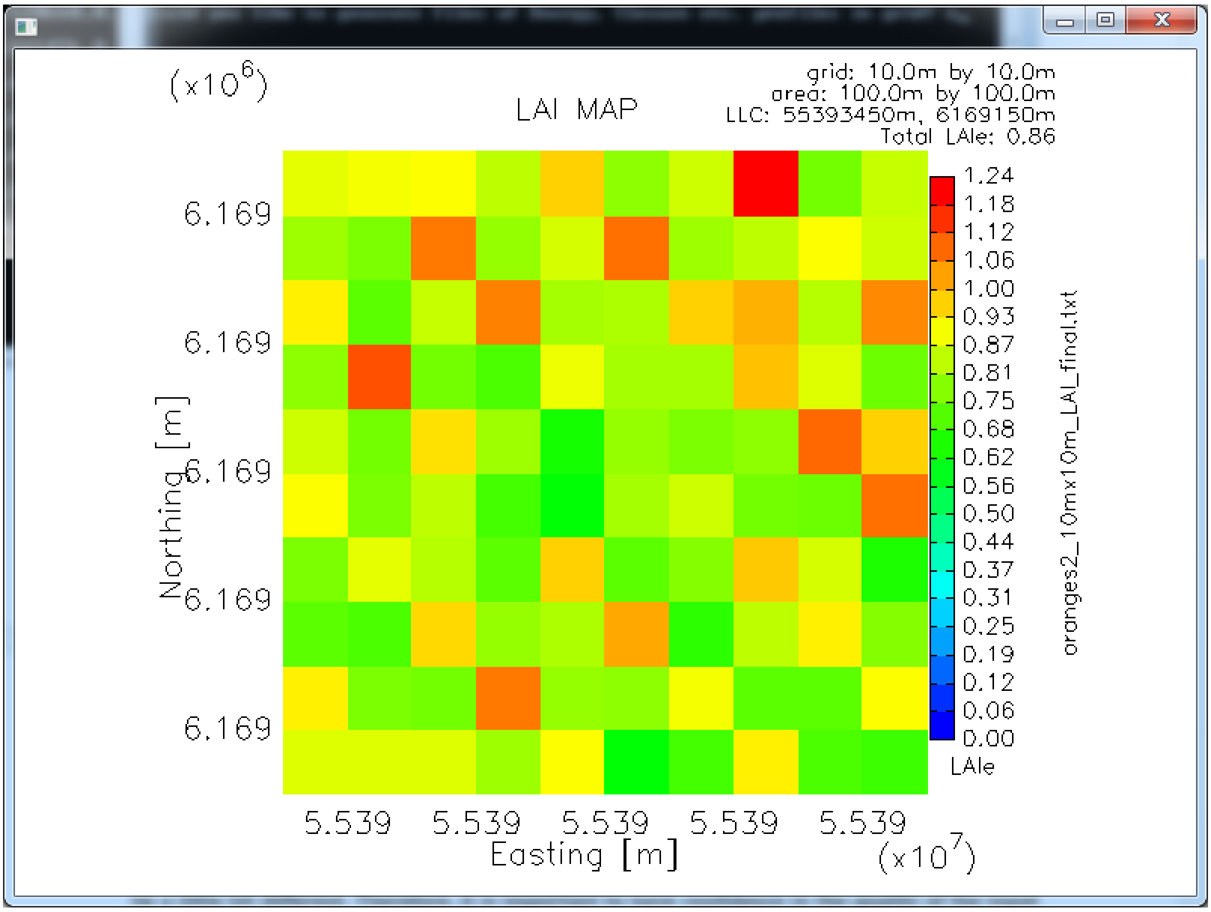


Figure 14. Leaf Area Index Map of the study area generated by Module 4 VIS of CHP toolkit (10m cells).

Changing the resolution to 2.5m and the vegetation-ground separation bin to 4, we will get the following result:

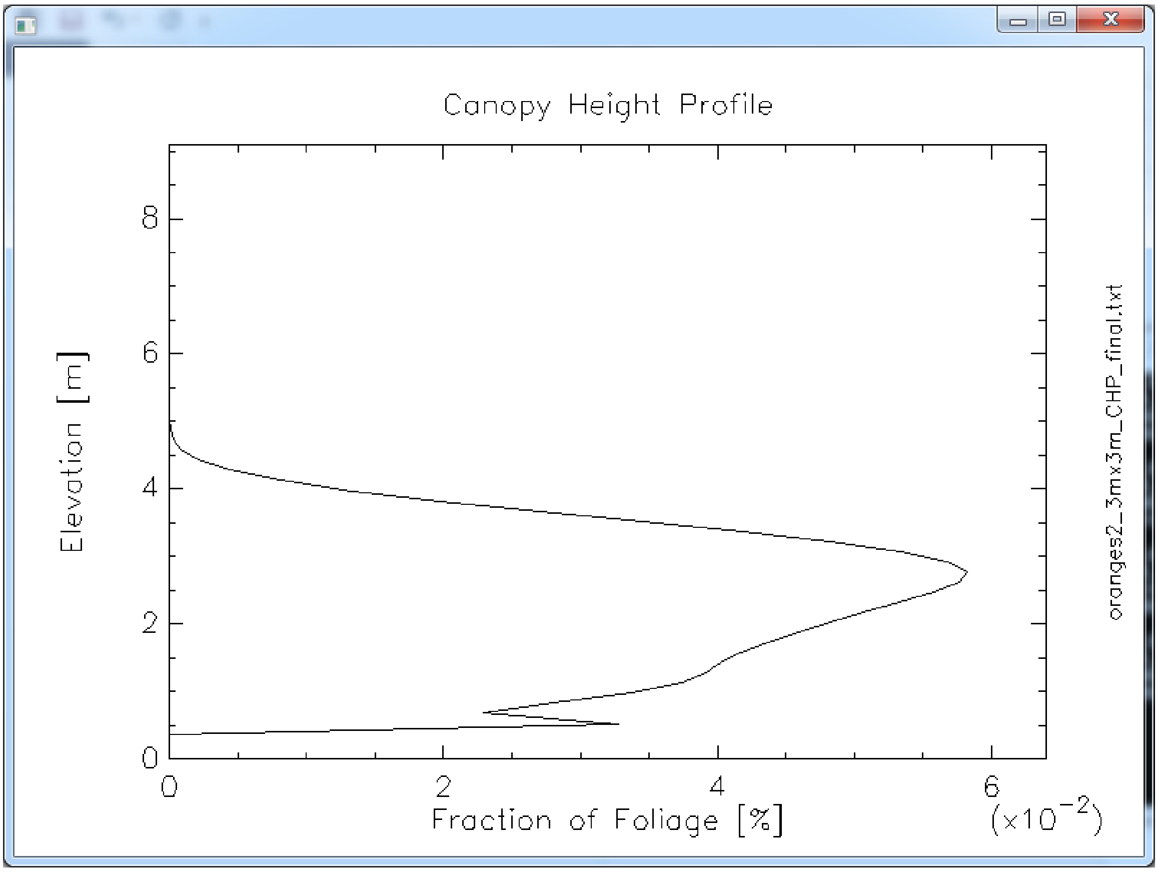


Figure 15. Canopy Height Profile of the study area generated by Module 4 VIS of CHP toolkit (2.5m cells).

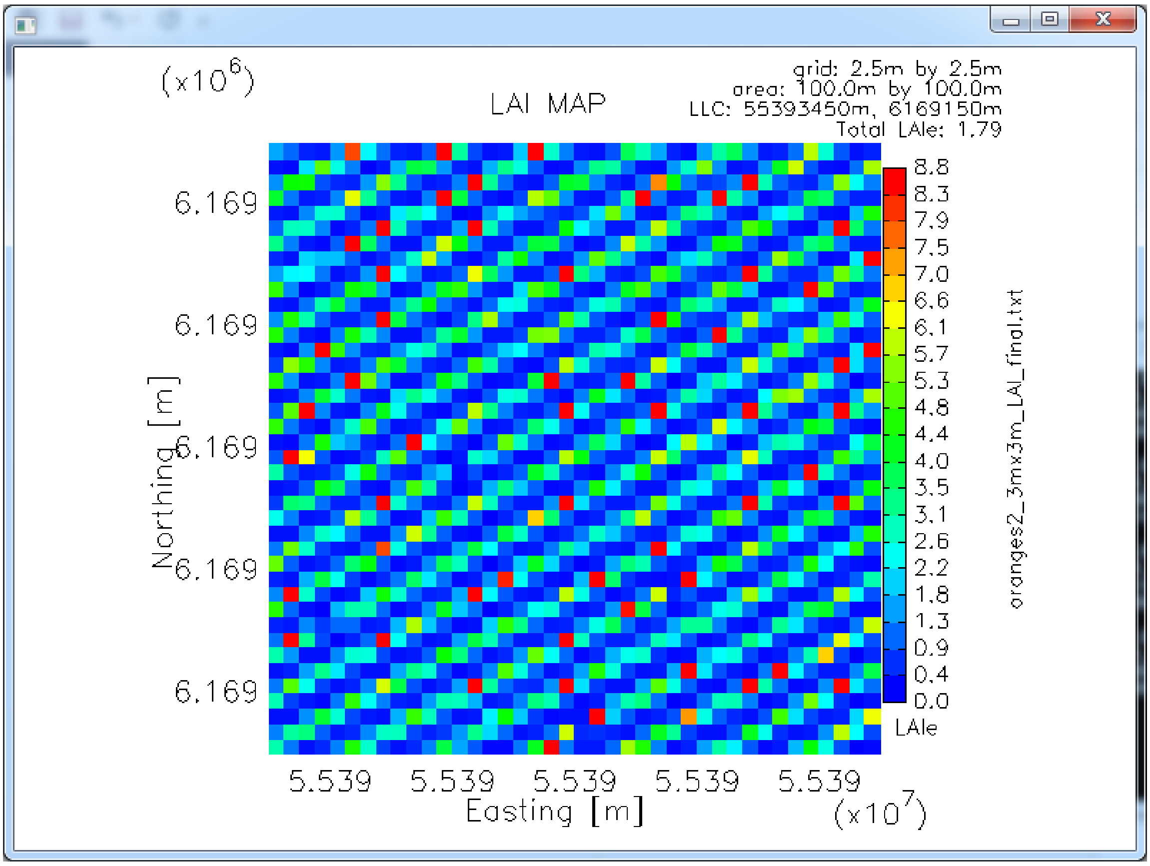
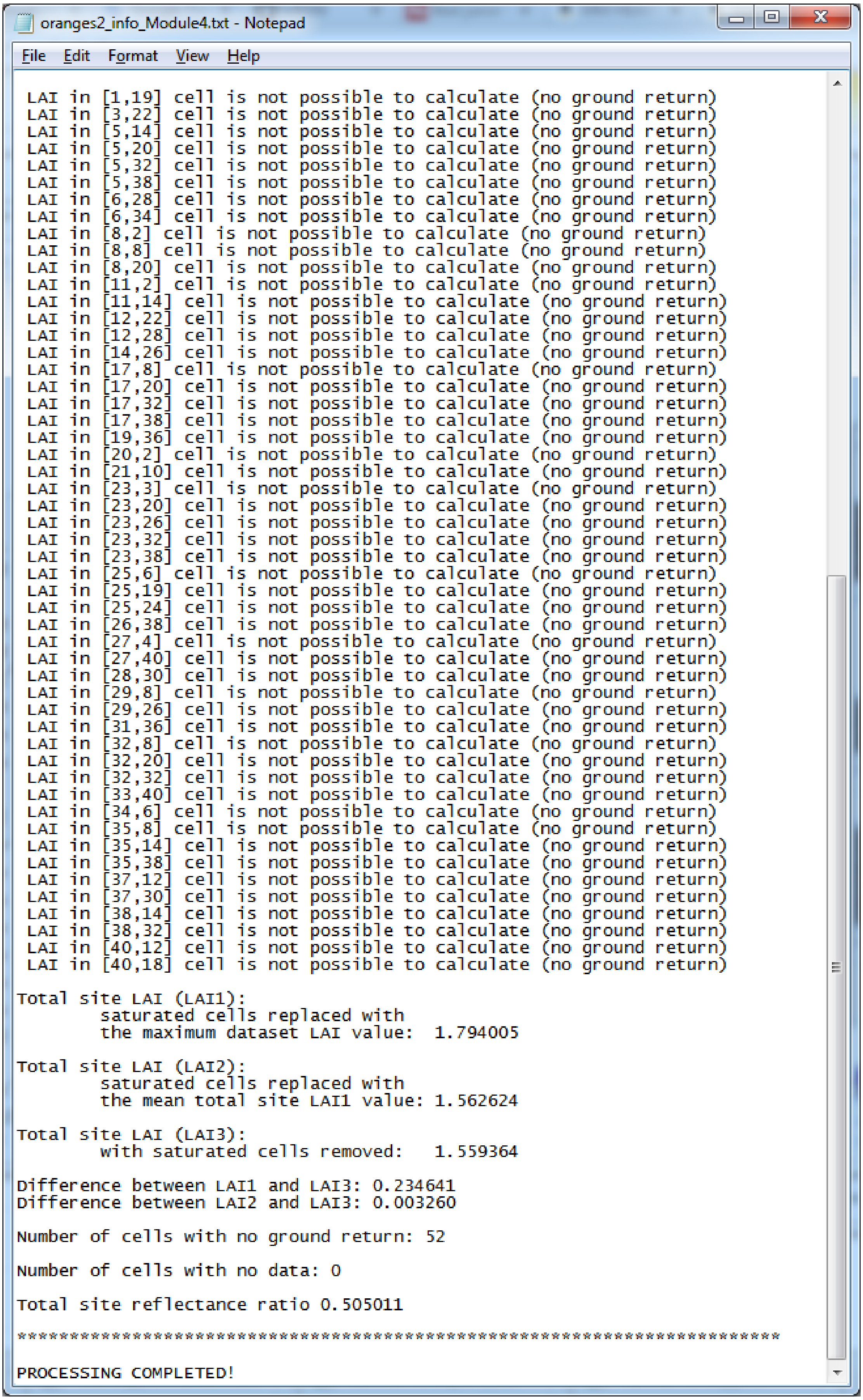


Figure 16. Leaf Area Index Map of the study area generated by Module 4 VIS of CHP toolkit (2.5m cells).

The info file informs us that 52 out of 1600 cells saturated over the tree covered area and provides the location of those cells [row, column]. Depending on whether we decide to include or exclude those cells from the LAI calculation, our estimate for the whole site will vary between 1.56 and 1.8. 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 a much lower value than calculation of LAI in homogenous cells without a mixture, or having no vegetation or trees. Despite the saturation of 52 2.5m-cells, it is a relatively low percentage (3.3%) of the total site, 100m by 100m (1600 cells in total). Therefore, this cell size could be a good trade-off between capturing the heterogeneity of the site and avoiding saturation in terms of LAI calculation.

There are also visible changes in the CHP profile. These are due to gridding and to exclusion of saturated cells from the profile calculation causing some bias in the profile. The peak at about 0.6m AGL (cut off point) still remains, suggesting the cut-off point should be specified slightly higher (5-6 bins). All in all, while using homogenous cells, even if some of them saturate, is advantageous for LAI calculation in discontinuous canopy site, one needs to be careful when using a cell size that saturates for CHP. In this case, having 3% of cells saturated will not have a high impact on the profile shape, however the higher this number the more biased (and incorrect) the profile. Since CHP represents relative distribution of foliage, using larger cells for CHP generation may be advisable in the case of saturation in smaller cells.



oranges2_info_Module4.txt - Notepad

File Edit Format View Help

```
 LAI in [1,19] cell is not possible to calculate (no ground return)
 LAI in [3,22] cell is not possible to calculate (no ground return)
 LAI in [5,14] cell is not possible to calculate (no ground return)
 LAI in [5,20] cell is not possible to calculate (no ground return)
 LAI in [5,32] cell is not possible to calculate (no ground return)
 LAI in [5,38] cell is not possible to calculate (no ground return)
 LAI in [6,28] cell is not possible to calculate (no ground return)
 LAI in [6,34] cell is not possible to calculate (no ground return)
 LAI in [8,2] cell is not possible to calculate (no ground return)
 LAI in [8,8] cell is not possible to calculate (no ground return)
 LAI in [8,20] cell is not possible to calculate (no ground return)
 LAI in [11,2] cell is not possible to calculate (no ground return)
 LAI in [11,14] cell is not possible to calculate (no ground return)
 LAI in [12,22] cell is not possible to calculate (no ground return)
 LAI in [12,28] cell is not possible to calculate (no ground return)
 LAI in [14,26] cell is not possible to calculate (no ground return)
 LAI in [17,8] cell is not possible to calculate (no ground return)
 LAI in [17,20] cell is not possible to calculate (no ground return)
 LAI in [17,32] cell is not possible to calculate (no ground return)
 LAI in [17,38] cell is not possible to calculate (no ground return)
 LAI in [19,36] cell is not possible to calculate (no ground return)
 LAI in [20,2] cell is not possible to calculate (no ground return)
 LAI in [21,10] cell is not possible to calculate (no ground return)
 LAI in [23,3] cell is not possible to calculate (no ground return)
 LAI in [23,20] cell is not possible to calculate (no ground return)
 LAI in [23,26] cell is not possible to calculate (no ground return)
 LAI in [23,32] cell is not possible to calculate (no ground return)
 LAI in [23,38] cell is not possible to calculate (no ground return)
 LAI in [25,6] cell is not possible to calculate (no ground return)
 LAI in [25,19] cell is not possible to calculate (no ground return)
 LAI in [25,24] cell is not possible to calculate (no ground return)
 LAI in [26,38] cell is not possible to calculate (no ground return)
 LAI in [27,4] cell is not possible to calculate (no ground return)
 LAI in [27,40] cell is not possible to calculate (no ground return)
 LAI in [28,30] cell is not possible to calculate (no ground return)
 LAI in [29,8] cell is not possible to calculate (no ground return)
 LAI in [29,26] cell is not possible to calculate (no ground return)
 LAI in [31,36] cell is not possible to calculate (no ground return)
 LAI in [32,8] cell is not possible to calculate (no ground return)
 LAI in [32,20] cell is not possible to calculate (no ground return)
 LAI in [32,32] cell is not possible to calculate (no ground return)
 LAI in [33,40] cell is not possible to calculate (no ground return)
 LAI in [34,6] cell is not possible to calculate (no ground return)
 LAI in [35,8] cell is not possible to calculate (no ground return)
 LAI in [35,14] cell is not possible to calculate (no ground return)
 LAI in [35,38] cell is not possible to calculate (no ground return)
 LAI in [37,12] cell is not possible to calculate (no ground return)
 LAI in [37,30] cell is not possible to calculate (no ground return)
 LAI in [38,14] cell is not possible to calculate (no ground return)
 LAI in [38,32] cell is not possible to calculate (no ground return)
 LAI in [40,12] cell is not possible to calculate (no ground return)
 LAI in [40,18] cell is not possible to calculate (no ground return)

Total site LAI (LAI1):
        saturated cells replaced with
        the maximum dataset LAI value:  1.794005

Total site LAI (LAI2):
        saturated cells replaced with
        the mean total site LAI1 value: 1.562624

Total site LAI (LAI3):
        with saturated cells removed:   1.559364

Difference between LAI1 and LAI3: 0.234641
Difference between LAI2 and LAI3: 0.003260

Number of cells with no ground return: 52

Number of cells with no data: 0

Total site reflectance ratio 0.505011

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

PROCESSING COMPLETED!
```

Figure 17. Info file generated by Module 4 of CHP toolkit (2.5m cells).