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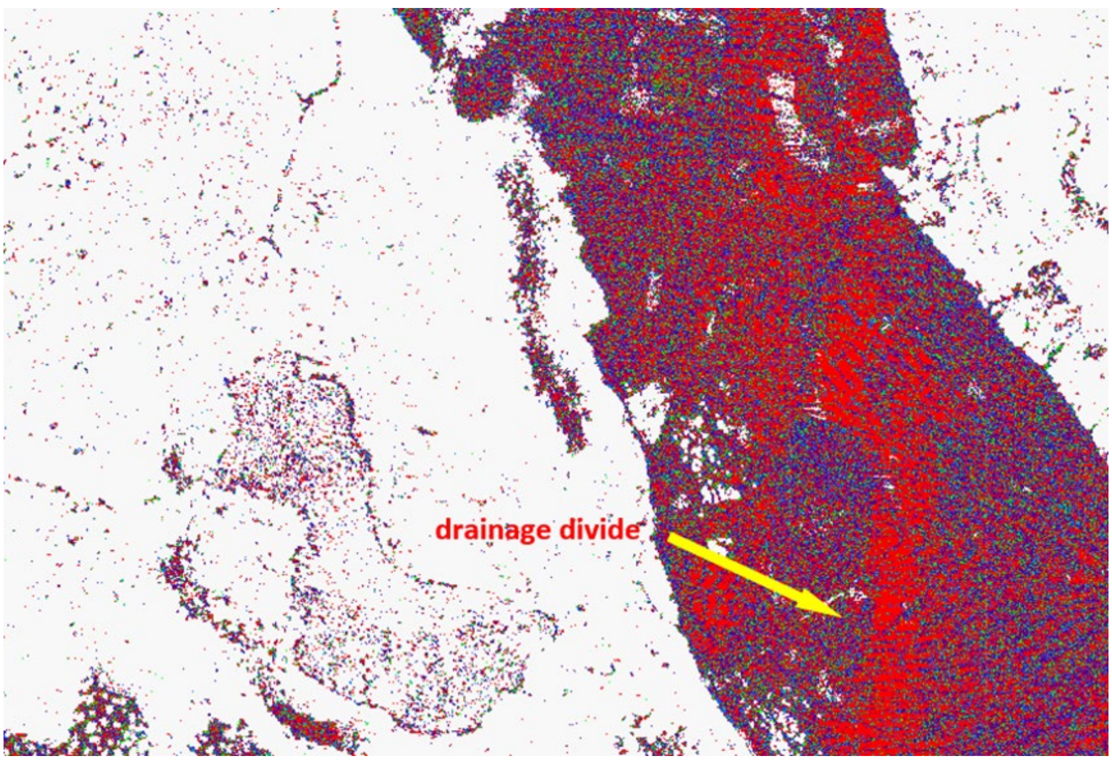
Tactical Geospatial Information Capabilities

Tutorial: The DEM Breakline and Differencing Analysis Tool

Step-by-Step Workflows and Procedures for Effective Gridded DEM Analysis

S. Bruce Blundell

November 2022



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Tutorial: The DEM Breakline and Differencing Analysis Tool

Step-by-Step Workflows and Procedures for Effective Gridded DEM Analysis

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Abstract

The DEM Breakline and Differencing Analysis Tool is the result of a multi-year research effort in the analysis of digital elevation models (DEMs) and the extraction of features associated with breaklines identified on the DEM by numerical analysis. Developed in the ENVI/IDL image processing application, the tool is designed to serve as an aid to research in the investigation of DEMs by taking advantage of local variation in the height. A set of specific workflow exercises is described as applied to a diverse set of four sample DEMs. These workflows instruct the user in applying the tool to extract and analyze features associated with terrain, vegetative canopy, and built structures. Optimal processing parameter choices, subject to user modification, are provided along with sufficient explanation to train the user in elevation model analysis through the creation of customized output overlays.

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Preface

This study was conducted for the US Army Corps of Engineers under PE 633463, Project AU1, "Tactical Geospatial Information Capabilities" (TGIC), "Enhanced Terrain Processing" (ETP). The project manager was Dr. Jean Nelson, and the technical monitor was Ms. Nicole Wayant.

The work was performed by the Data and Signature Analysis Branch of the Topography, Imagery, and Geospatial (TIG) Research Division, U.S. Army Engineer Research and Development Center, Geospatial Research Laboratory (ERDC-GRL). At the time of publication, Ms. Jennifer Smith was Chief, Data Signature and Analysis Branch; Mr. Jeffrey Murphy was Chief, TIG Research Division; and Mr. Austin Davis was Technical Director of the Geospatial Research Laboratory. The Director of ERDC-GRL was Mr. David R. Hibner.

COL Christian Patterson was Commander of ERDC, and Dr. David W. Pittman was Director.

Acronyms and Abbreviations

Acronym	Meaning
BARC	Beltsville Agricultural Research Center
BE	Bare Earth
BRI	Breakline Ruggedness Index
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
ENVI	Environment for Visualizing Images
ERDC	Engineer Research and Development Center
ETP	Enhanced Terrain Processing
GIS	Geographic Information System
GPS	Geospatial Positioning System
GRL	Geospatial Research Laboratory
GSD	Ground Sample Distance
GUI	Graphical User Interface
IDL	Interactive Data Language
MCMWTC	Marine Corps Mountain Warfare Training Center
TGIC	Tactical Geospatial Information Capabilities
TIFF	Tagged Image File Format

1 Introduction

1.1 Background

This tutorial is presented as a step-by-step introduction to terrain and vegetative canopy analysis for new users of the DEM Breakline and Differencing Analysis Tool. This tool, herein referred to as the IDL Breakline Tool or simply Breakline Tool, was developed at the U.S. Army Engineer Research and Development Center (ERDC), Geospatial Research Laboratory (GRL) under a long-term research effort to provide a convenient platform for the analysis of gridded digital elevation models (DEMs).

1.2 Objectives

The IDL Breakline Tool enables analysis of gridded DEMs for extraction of fine-scale, subtle breaks-in-slope, or breaklines, that may represent microterrain features or vegetative canopy. The Breakline Tool is designed to take advantage of high-resolution gridded elevation models that can be created from point clouds collected by airborne laser scanners. A “first-surface” gridded model captures not only the vertical dimension of ground features, but also the top of vegetative canopy as well as artificial structures such as buildings. The first-surface model can be processed with specialized software to produce a coincident “bare earth” (BE) model with buildings and canopy removed. A difference model is created by subtracting the BE model from the first-surface model. Either the first-surface model or the BE model can be chosen by the user for computation and extraction of breakline features.

1.3 Approach

The IDL Breakline Tool was developed in the ENVI/IDL software package, available from L3Harris Technologies. It consists of a large graphical user interface (GUI) offering the user a wide range of control over analysis, extraction, and display of 3D terrain and canopy features and is supported by a suite of IDL algorithms and procedures for elevation model input, DEM processing, and graphical and textual output.

The following is a brief overview of the IDL Breakline Tool output product overlays and supporting algorithms. A more detailed treatment of the underlying computational approach can be found in the ERDC/GRL Technical Report "Micro-Terrain and Canopy Feature Extraction by Breakline and Differencing Analysis of Gridded Elevation Models" (Blundell 2021). A user guide for the Breakline Tool, providing a comprehensive description of GUI operation and functionality, is also available with the title "User Guide: The DEM Breakline and Differencing Analysis Tool" (Blundell 2022) and should be consulted before performing the tutorial exercises given here. The user guide also contains a more complete description of optima extraction theory and methodology.

The breakline overlays, as well as other related masks created by the tool, can be customized and visualized. Breakline values are computed for each model cell by a cubic spline algorithm for numerical interpolation using discrete elevation values in the neighborhood of each cell. Model cells with breakline values in a chosen range are displayed as overlays on a background image. Breaklines are often associated with terrain features such as gullies or escarpments. The Breakline Tool allows breakline overlays to be combined with difference overlays in various ways to enhance the extraction of desired features such as tree or crop canopy.

In addition to breakline and model differencing overlays, the Breakline Tool can create overlays for slope, terrain ruggedness, breakline gradient direction, and surface optima in the form of saddle points, peaks, and depressions. Slope is computed as a precursor to breakline calculations since breakline values are represented by the change in slope in the vicinity of each model cell.

Terrain ruggedness is calculated for each model cell using an algorithm developed at ERDC-GRL that combines three parameters that can influence the perception of the degree of roughness of terrain: slope, sudden changes in slope (the breakline value), and changes in elevation in the immediate vicinity of the model cell. This parameter is known as the Breakline Ruggedness Index (BRI).

Each computed breakline value has an azimuthal direction associated with it, representing the direction in which the change in slope is a maximum. These breakline gradient directions can be represented as a color-coded display that can identify direction trending of features.

The Breakline Tool includes a sub-GUI that allows the user to create overlays for three types of optima on the surface of the model. Each model cell is interrogated locally by a numerical gradient algorithm to determine if it represents a saddle point, peak, or depression in the model. Output displays for each optimum type show the subset of model cells that meet specific criteria for inclusion in the optimum overlay.

The IDL Breakline Tool requires a current working ENVI/IDL license. The Tool consists of a suite of IDL procedures, a set of required graphics files, and an IDL startup file. The Breakline Tool is started by typing `gui_breakline` in the IDL console widow. As detailed in the user guide, there is a specific file structure configuration required for the Breakline Tool to run properly. Changes in the IDL Preferences dialog may also be required. These initialization procedures are fully outlined in the user guide and should be performed before starting the Tool.

1.4 Scope

The Breakline Tool is provided as an in-house resource for general elevation model analysis. The tool can be reconfigured for a user's specific research task or input dataset. The following sections provide a tutorial to demonstrate to the user how to employ the tool. The examples provided in this tutorial come from Fort A. P. Hill, Beltsville Agricultural Research Center (BARC), Marine Corps Mountain Warfare Training Center (MCMWTC), and Philippines.

2 Sample Datasets

Two input DEMs are required to operate the Breakline Tool: a first-surface or digital surface model (DSM) and a coincident BE model, whose elevation values approximate the terrain underlying canopy and artificial structures. Both DEMs must be in GeoTIFF format and have the same gridded dimensions. The final input requirement is an image of either of the input models in TIFF format, also with the same dimensions, to be displayed as background to the output overlays. This reference background is usually a shaded relief or intensity image.

The IDL Breakline Tool installation package includes several sample DEM datasets, which serve as the basis for the tutorial exercises presented in this document. Each dataset consists of a first-surface DEM, a coincident BE DEM, and a shaded relief or intensity image of the elevation model. The datasets included in the installation package are Fort A. P. Hill, Beltsville Agricultural Research Center (BARC), Marine Corps Mountain Warfare Training Center (MCMWTC), and Philippines.

2.1 Fort A. P. Hill, VA

We will use this dataset to explore forest canopy and terrain surface features.

```
Full dataset width × height: 1,920 × 1,293
Ground Sample Distance (GSD): 1.0 meter
Files:
DSM: APHILL_1stReturn_DEM
Bare Earth Model: APHILL_BareEarth_DEM
DSM Shaded Relief Image: APHILL_ShadedRelief_IMG
Bare Earth Shaded Relief Image: APHILL_BE_ShadedRelief_IMG
```

2.2 Beltsville Agricultural Research Center (BARC), Beltsville, MD

We will use this dataset to investigate the canopy for different crop plots in an experimental field.

```
Full dataset width × height: 269 × 193
Ground Sample Distance (GSD): 0.23 meter
Files:
DSM: BARC_Crops_1stReturn_DEM
Bare Earth Model: BARC_Crops_BareEarth_DEM
DSM Shaded Relief Image: BARC_Crops_ShadedRelief_IMG
```

```
Bare Earth Shaded Relief Image: BARC_Crops_BE_ShadedRe-
lief_IMG
```

2.3 Marine Corps Mountain Warfare Training Center (MCMWTC), CA

We will use this dataset to investigate the heights and geometric characteristics of rooftops in the scene.

```
Full dataset width × height: 3,842 × 2,084
Ground Sample Distance (GSD): 0.50 meter
Files:
DSM: MCMWTC_1stReturn_DEM
Bare Earth Model: MCMWTC_BareEarth_DEM
DSM Intensity Image: MCMWTC_Intensity_IMG
```

2.4 Philippines

We will use this dataset to explore canopy in a mixture of natural and managed forest. We will also walk through the optional SADDLE, PEAK and DEPRESSION menu.

```
Full dataset width × height: 5,038 × 5,028
Ground Sample Distance (GSD): 1.0 meter
Files:
DSM: PHILIPPINES_1stReturn_DEM.tif
Bare Earth Model: PHILIPPINES _BareEarth_DEM.tif
DSM Intensity Image: PHILIPPINES_Intensity_IMG.tif
```

3 Sample Dataset Workflows

A tutorial workflow is provided for each of the sample datasets described in Section 2. Each workflow is a step-by-step process involving user-specified parameters controlled by interactive features of the Breakline Tool GUI, such as radio buttons, pull-down menus, and text boxes. Each workflow is designed to show the flexibility and capability of the Breakline Tool to extract particular features from the sample data for analysis. In each workflow, the numbered steps for user interaction correspond to the numbered features in the GUI.

3.1 A. P. Hill tutorial workflow

In this exercise, we will use the Breakline Tool to explore forest canopy and terrain surface features. The user should first open the Breakline Tool in ENVI as instructed in Section 1.3 above.

1. INPUT FILE SELECTION

Browse and select:

```
APHILL_1stReturn_DEM.tif
APHILL_BareEarth_DEM.tif
APHILL_ShadedRelief_IMG.tif
```

2. SELECT DEM FOR BREAKLINE ANALYSIS

Select default menu choice “Digital Surface Model or 1st Return DEM.”

3. SPECIFY DEM SUBSET

Notice that the full size of the file is 1,920 × 1,293 (width × height). The ground sample distance is 1.0 meter.

Change defaults to

horizontal offset: 480
vertical offset: 323
width of subset: 1,440
height of subset: 970

Click on "Display Image Subset." The shaded relief image will appear in the Reference Image Display window.

4. BREAKLINE AND SLOPE ANALYSIS PARAMETERS

Change size of default computation kernel to 5.

Retain size of default median filter kernel as 0. Elevation values in the chosen model for breakline and slope analysis will not be median filtered before processing.

5. ELEVATION DIFFERENCE ANALYSIS PARAMETERS

Retain default "no" for negative difference values. Normally, the number of negative difference values should be very small with a BE model of reasonable quality. When negative difference values do occur, it is often due to local discontinuities in the first-surface model ("micro-terrain" features) that may or may not show up in the regular "breakline" overlay. If you wanted to investigate this possibility, you could select "yes" and input difference thresholds to create a difference overlay showing model cell locations with negative values.

Retain the default "neither input DEM" for the median filter menu.

Retain size of default median filter kernel as 0. Elevation values in both the first-surface and BE models will not be median filtered during difference analysis.

6. INITIAL DEM PROCESSING

Select "RUN" to perform breakline and elevation difference calculations. Upon completion, various statistics will be displayed in a separate summary output window. This initial text output should appear as follows:

```
DEM BREAKLINE, SLOPE, AND DIFFERENCE PROCESSING FOR MICRO-TERRAIN
AND CANOPY ANALYSIS
 Run executed Thu Nov 18 12:27:30 2021

CHECK INPUT FILES AND PARAMETERS
Original DSM or first surface file:
```

```
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\AP HILL SAMPLE
DATA\APHILL_1stReturn_DEM.tif
Bare Earth or Higher Return file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\AP HILL SAMPLE
DATA\APHILL_BareEarth_DEM.tif
Hillshade or Intensity image file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\AP HILL SAMPLE
DATA\APHILL_ShadedRelief_IMG.tif

Total width × height of original files:  1920 × 1293

Processing DSM or FIRST RETURN model for breakline and slope analysis...

Horizontal offset from upper left corner:      480
Vertical offset from upper left corner:      323
Width of subset:     1440
Height of subset:      970
Kernel size for breakline computations:        5
Kernel size for breakline median filter:       0
Negative difference values included? no
Apply elevation difference median filter to input DEMs? neither
Kernel size for elevation difference median filter:       0

Ground sample distance =       1.0000000
Units are METERS

Processing started at Thu Nov 18 12:27:31 2021

 Calculating SLOPE, BREAK-IN-SLOPE, and DIRECTION for the FIRST RETURN DEM
 NO Breakline Median Filter

Processing ended at Thu Nov 18 12:28:32 2021
Elapsed time in seconds      61

 ELEVATION, SLOPE, AND BREAKLINE STATISTICS (no breakline median filter)

 DSM or FIRST RETURN Elevation Statistics

minimum elevation =    23.63 meter
maximum elevation =    67.00 meter
   mean elevation =    42.84 meter
   std dev for the set of elevation values =     9.28 meter

 BARE EARTH or HIGHER RETURN Elevation Statistics
```

```
minimum elevation =    23.68 meter
maximum elevation =    41.37 meter
  mean elevation =    32.42 meter
  std dev for the set of elevation values=     3.15 meter

 DSM or First Return parameters for SLOPE and BREAKLINE Vector Magnitudes
are derived from absolute values.
 Slope is given as the tangent of the angle from the horizontal (rise/run).
 Breakline value units are inverse distance.

 DSM OR FIRST RETURN Slope and Breakline Statistics
minimum slope =   0.00
maximum slope =  18.98
  mean slope =   1.70
  std dev for the set of slope values =   2.12

minimum breakline =     0.00 /meter
maximum breakline =   116.83 /meter
  mean breakline =     5.47 /meter
  std dev for the set of breakline values =     8.29 /meter

 Calculating ELEVATION DIFFERENCE MODEL

 NO Elevation Difference Median Filter

 Negative difference cells will be converted to 0.0 (canopy height model will al-
ways be above the BE model)

 CANOPY HEIGHT MODEL STATISTICS

minimum elevation difference =     0.00 meter
maximum elevation difference =    34.26 meter
  mean elevation difference =    10.42 meter
  std dev for the set of elevation difference values =     8.72 meter

 DIFFERENCE CELL COUNTS

 INITIAL POSITIVE DIFFERENCE CELLS
  Count =  1376792 98.57 % subimage cells;  98.57 % difference cells
 INITIAL NEGATIVE DIFFERENCE CELLS
  Count =    20008  1.43 % subimage cells;   1.43 % difference cells
 TOTAL DIFFERENCE CELLS (POS + NEG)
  Count =  1396800 100.00 % subimage cells
```

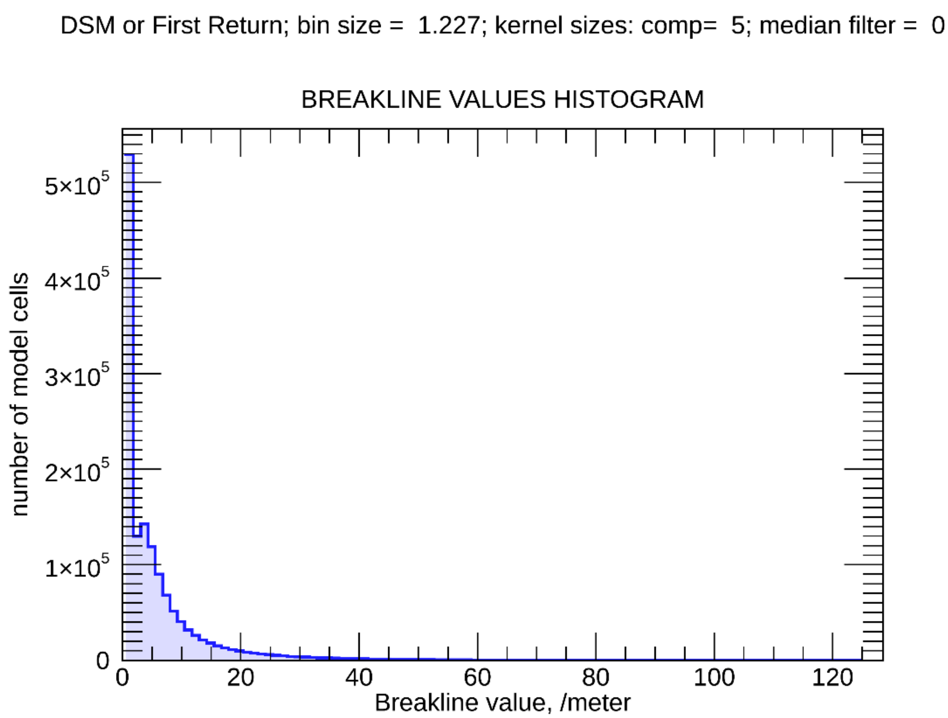
7. SADDLE, PEAK and DEPRESSION TOOL (Optional)

This "RUN" button brings up the optima extraction sub-GUI. We will bypass this feature for this exercise. Continue to step 8.

8. DISPLAY HISTOGRAMS FOR THRESHOLD VALIDATION

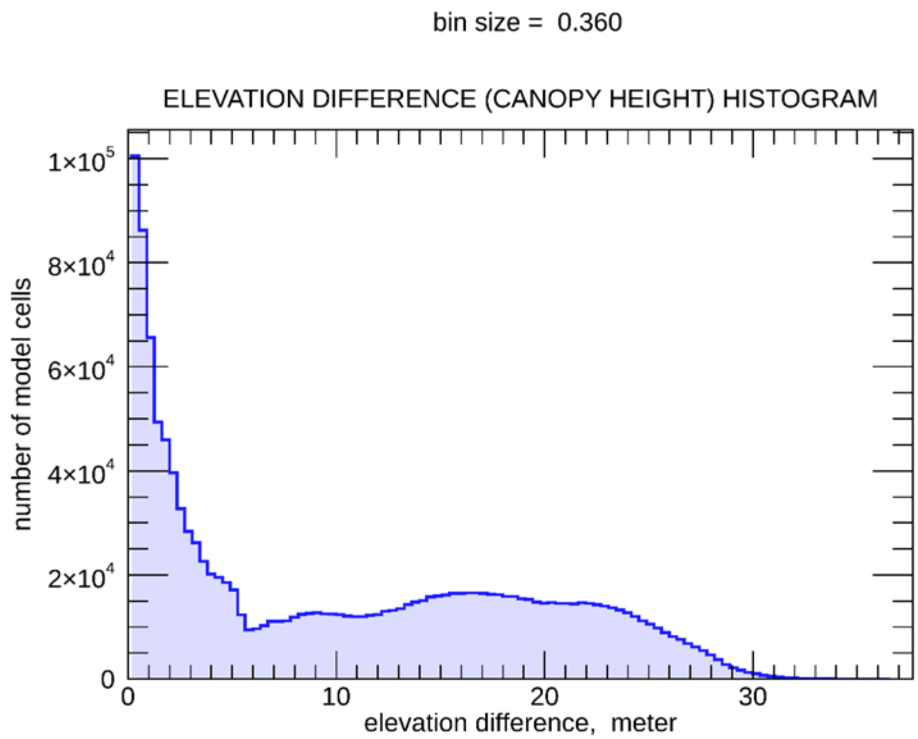
Retain default selections for "Breakline Values Histogram" and "Elevation Difference Histogram." De-select the default "Slope Histogram."

Figure 1. Breakline values histogram for the A. P. Hill dataset.



Select "RUN" to create histograms for threshold validation. Both histograms will appear in separate windows (Figures 1 and 2). Aside from depicting the relative frequencies of data values, the histograms are provided so that one can investigate portions of the breakline and difference data shown in the histograms by making different threshold choices. For example, one can try using breakpoints in the histogram as thresholds to see if a particular section of the histogram spatially correlates to some feature on the ground. There is no need to re-run histogram creation unless you make changes to GUI selections in steps 1 through 5 above.

Figure 2. Elevation difference histogram for the A. P. Hill dataset.



9. SPECIFY BREAKLINE AND DIFFERENCE THRESHOLDS

We will choose different breakline and difference thresholds to best capture tree canopy, other vegetation, and open area ground features.

Initial threshold selection:

Breakline lower threshold: change from 5.47 to 1.

Breakline upper threshold: retain default value of 116.83.

Examine the elevation difference histogram in Figure 2. There appears to be a breakpoint in the distribution at about 6 m. To investigate whether this breakpoint can be used to effectively segment canopy features, change the elevation difference lower threshold from 10.42 to 6.

Elevation difference upper threshold: retain default value of 34.26.

10. SPECIFY SLOPE THRESHOLDS

Retain the lower slope threshold of 0.0 and the upper threshold of 1,897.55 (% slope). We will not require the slope overlay for this exercise.

11. SELECT OVERLAYS FOR DISPLAY

To fully investigate the A. P. Hill data, five different “RUN” passes for overlay creation are described below. In each pass, different thresholds and overlay parameters are explored.

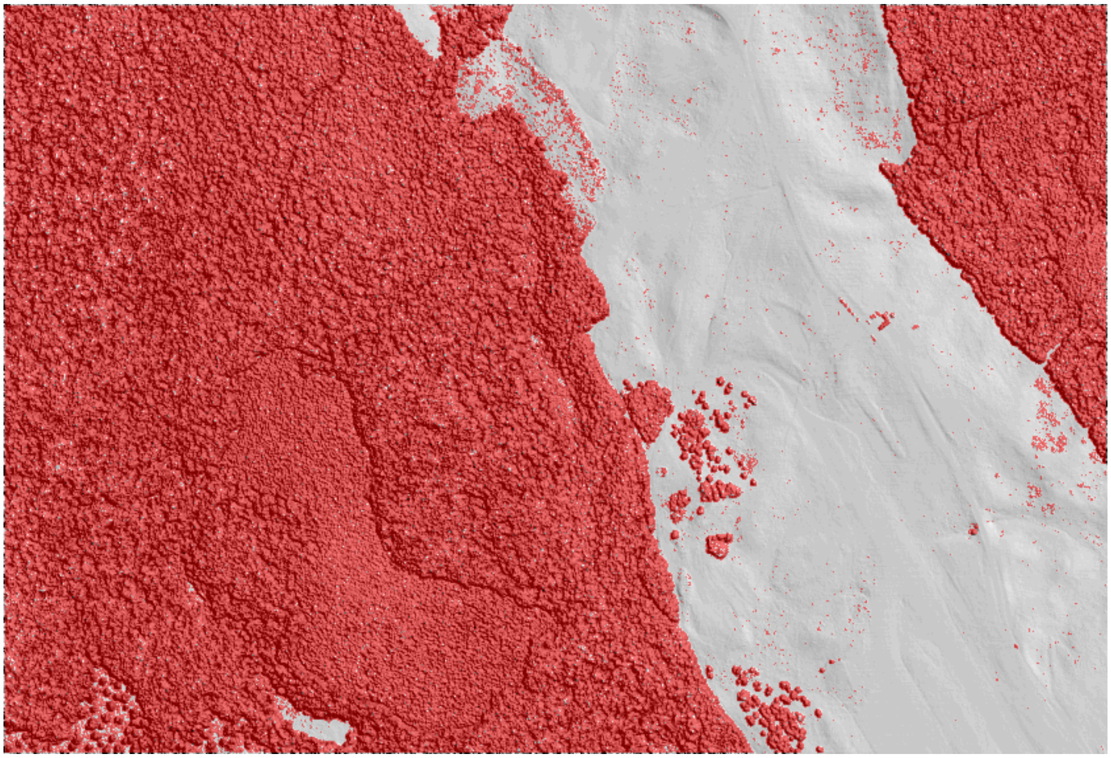
3.1.1 Pass 1

Make sure the default boxes are checked for “breakline (breaks-in-slope)” and “elevation difference.” Retain defaults for the pull-downs “No. of BREAKLINE classes” (1), “No. of ELEV DIFFERENCE classes” (4), and “background for chosen overlays” (reference image). We will use the thresholds selected above for this pass.

Select “RUN” for overlay creation and display.

The breakline overlay, in red (Figure 3), was created using thresholds that show only tree canopy, individual trees, and scattered scrub vegetation in the open treeless area. It is very effective at displaying vegetative canopy but does not provide an indication of heights above ground.

Figure 3. Pass 1 breakline overlay for the A. P. Hill dataset.

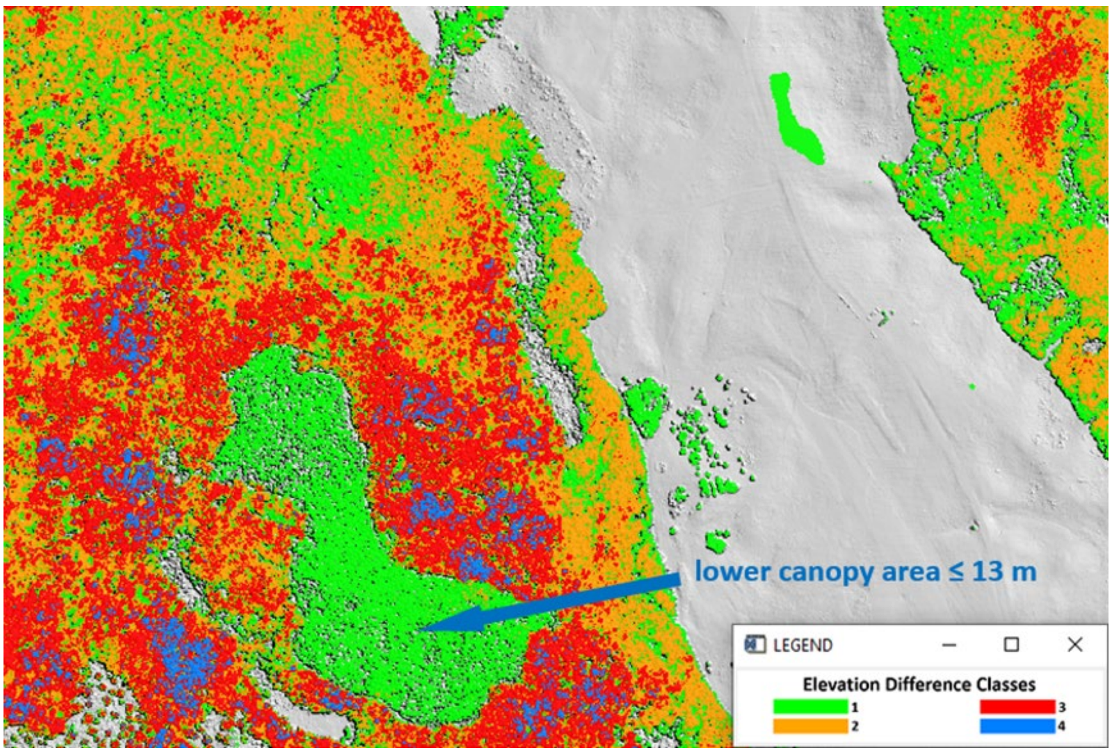


The difference overlay (Figure 4) shows four color-coded classes of canopy height above the BE model surface according to the color legend that appears in the GUI. This legend can be reproduced separately by going to the "Display Options" pull-down menu in the overlay widow and selecting "Show Color Legend." The legend appears in its own small window and can be dragged to any convenient location. The lower and upper bounds of the four difference classes appear in the separate summary text window:

```
Creating the ELEVATION DIFFERENCE Overlay for 4 classes. Class colors range
from green to blue.
Number of elevation difference cells between thresholds =   797149 57.07 % of
subimage cells

 Equal class width solution: width = (high threshold - low threshold) / 4 =    7.065

 DIFFERENCE CLASS LIMITS:
 Class 1 lower:    6.000   upper:   13.065 meter
 Class 2 lower:   13.065   upper:   20.130 meter
 Class 3 lower:   20.130   upper:   27.195 meter
 Class 4 lower:   27.195   upper:   34.260 meter

 DIFFERENCE CLASS COUNTS:
```

Number of Class 1 cells = 235386 29.53 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 2 cells = 305530 38.33 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 3 cells = 230018 28.86 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 4 cells = 26215 3.29 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS

Figure 4. Pass 1 elevation difference overlay for the A. P. Hill Dataset (four classes).



In the display, a crescent-shaped area of canopy is seen on the left side in a uniform green color. This is the lowest elevation class, from 6 m to 13.1 m, and 13 m seems to be a good working value for the maximum tree height in this area. Some trees in the crescent-shaped area are not overlaid in green; they must be below 6 m in height.

3.1.2 Pass 2

In this pass, we will seek a better estimate for the lower limit of the canopy height in the crescent-shaped area.

Go to the Breakline Tool GUI and adjust the following thresholds.

Elevation difference lower limit: change from 6 to 3.

Elevation difference upper limit: change from 34.26 to 13.

Go to the overlay selection list in the Breakline Tool GUI and de-select the button for “breakline.” Change “No. of ELEV DIFFERENCE classes” from 4 to 3.

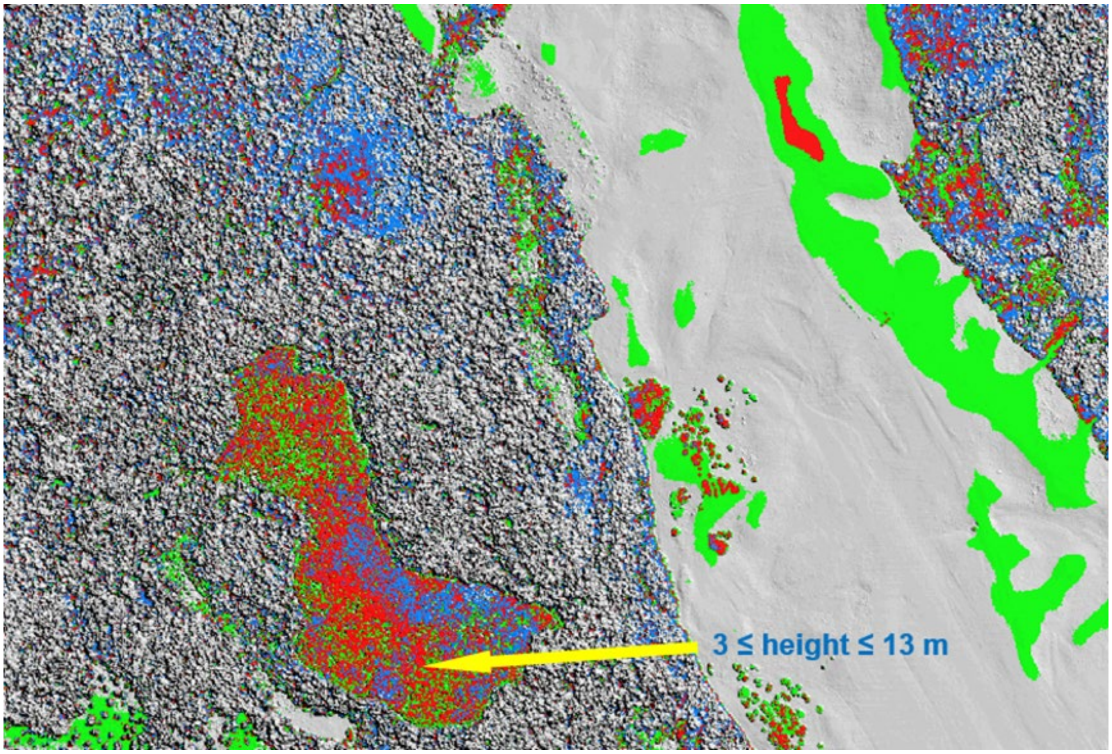
Select “RUN” for overlay creation and display.

This difference overlay (Figure 5), in three color-coded classes of increasing height (green, red, and blue, respectively), shows the canopy height distribution between 3 and 13 m. The crescent-shaped region is now almost completely filled in with color. The summary text output provides the color class lower and upper bounds:

```
DIFFERENCE CLASS LIMITS:
 Class 1 lower:   3.000   upper:    6.333 meter
 Class 2 lower:   6.333   upper:    9.667 meter
 Class 3 lower:   9.667   upper:   13.000 meter
```

The upper bound of the lowest class, in green, is about the same as the lower bound of the lowest class from Pass 1 (6 m). Examination of the Pass 2 difference overlay in Figure 5 shows that the trees in green closely match the scattered open areas in the crescent-shaped region from the Pass 1 display (Figure 4). Although there may be a few trees below about 3 m in height, 3 m appears to be a good working lower bound for the canopy in the crescent-shaped region.

Figure 5. Pass 2 elevation difference overlay for the A. P. Hill dataset (three classes).



3.1.3 Pass 3

Go to the Breakline Tool GUI and adjust the following thresholds.

Breakline lower limit: change from 1 to 0.

Breakline upper limit: change from 116.83 to 0.3.

Elevation difference lower limit: change from 5.5 to 0.

Elevation difference upper limit: change from 12 to 6.

Go back to the overlay selection list and select the button for “breakline.” Retain selection of “elevation difference.”

Select “RUN” for overlay creation and display.

Both the breakline (Figure 6) and elevation difference (Figure 7) overlays now show the open treeless area. The breakline overlay may be displaying some subtle micro-terrain structure. This might become more apparent later with the “breakline gradient direction” overlay.

The difference overlay also shows open areas within the canopy and a sinuous feature of vegetation under about 6 m height adjoining the treeless area. The crescent-shaped region of lower trees shows an increased amount of green color in the upper and lower portions, due to more lidar energy reaching, or almost reaching, the ground. This area appears to have less crown closure than in the central portion.

Figure 6. Pass 3 breakline overlay for the A. P. Hill dataset.

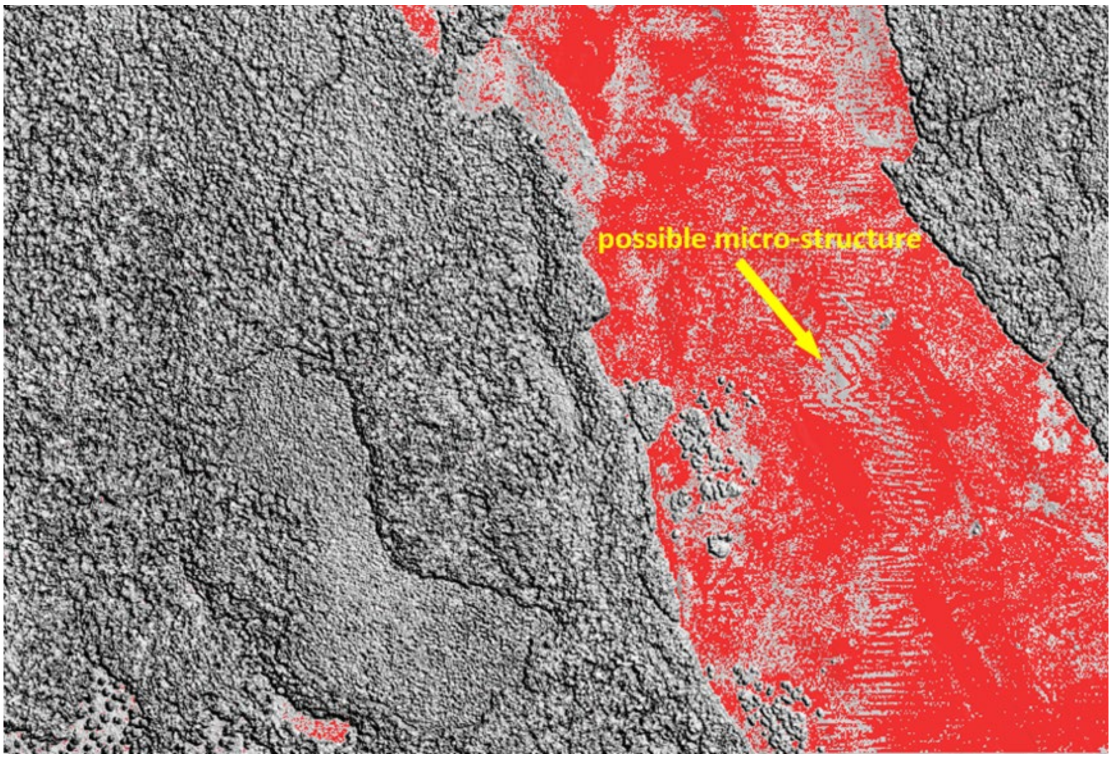
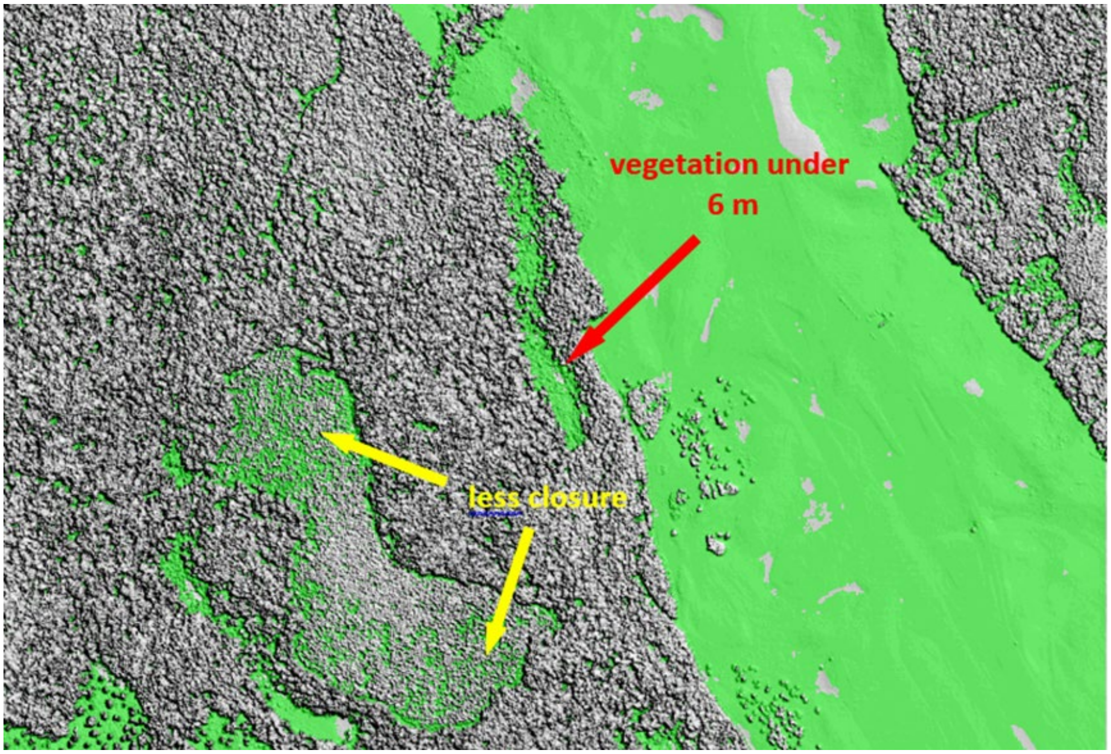


Figure 7. Pass 3 elevation difference overlay for the A. P. Hill dataset.



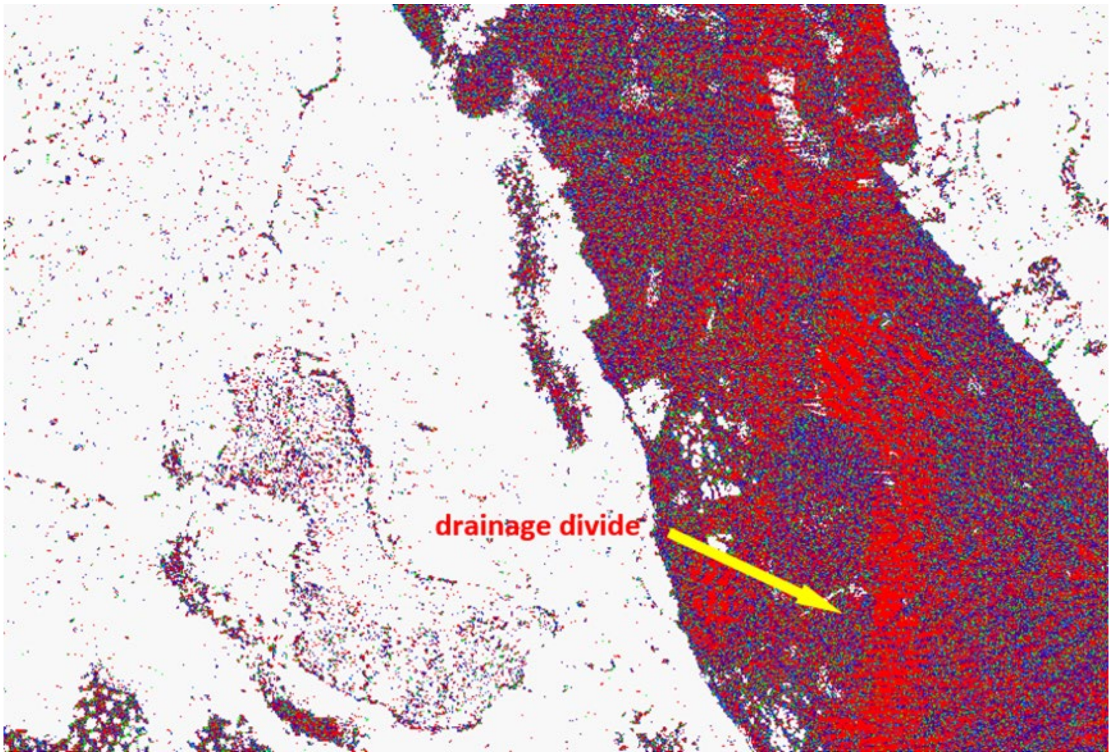
3.1.4 Pass 4

Retain the chosen thresholds from Pass 3.

De-select overlays for “breakline” and “FILL HOLES elevation difference.” Select overlay for “BREAKLINE GRADIENT DIRECTION.” Go to the pull-down for “Background for chosen overlays” and select “white.” This will help you better see the fine-grained variation in direction colors. Go to the pull-down for “Template for DIRECTION overlay” and select “brk OR dif.”

Select “RUN” for overlay creation and display. This will bring up the breakline gradient direction overlay (Figure 8).

Figure 8. Pass 4 breakline gradient direction overlay for A. P. Hill dataset.



The breakline gradient direction, or maximum spatial rate of change in slope, is shown in Figure 8 according to the direction bin colors shown on the Breakline Tool GUI. Note that because we selected a computation kernel size of 5, as explained in the *User Guide*, only four of the eight possible directions can be displayed due to characteristics of the kernel geometry.

The DEM cells displayed for this breakline direction overlay are those included in the Boolean union of the “breakline” and “elevation difference” overlays due to the selection of the “brk OR dif” template. Looking closely, we can see some periodic horizontal wavy lines in purple. If not due to some artifact in the data, these lines may represent a series of very subtle terraces or breaks-in-slope on the ground.

Also notice the amorphous linear feature in red trending generally north-south. The drainage divide between the Rappahannock River basin to the north and the York River basin to the south runs right through this high, open area of Fort A. P. Hill. The DEM cells forming this linear feature in red have similar breakline gradient directions. The breakline gradient algorithm and subsequent display may have found the gentle divide between these two drainage basins that empty into the Chesapeake Bay.

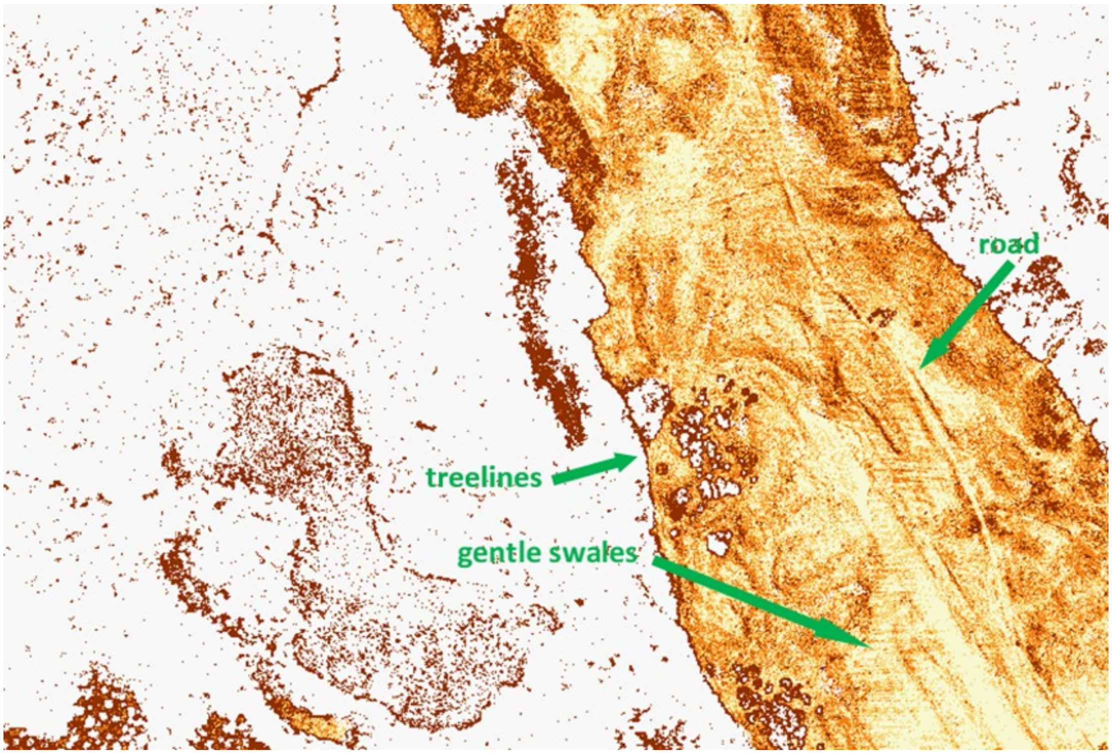
3.1.5 Pass 5

Retain the chosen thresholds from Pass 3.

De-select overlay for "BREAKLINE GRADIENT DIRECTION." Select overlay for "BREAKLINE RUGGEDNESS INDEX." Retain selection "white" for the "Background for chosen overlays" pull-down. Go to the pull-down for "Template for RUGGEDNESS overlay" and select "brk OR dif." Retain the default of 4 for "No. of BREAKLINE RUGGEDNESS classes."

Select "RUN" for overlay creation and display.

Figure 9. Pass 5 breakline ruggedness index overlay for A. P. Hill dataset.



BRI values, grouped into 4 classes, are now shown according to the reddish-brown shades displayed in the color legend on the Breakline Tool GUI. Darker shades depict higher BRI values. The DEM cells displayed (Figure 9) are those included in the Boolean union of the breakline and elevation difference overlays, for which BRI values are computed. The BRI values represent the degree of discontinuity at each cell's location, the local slope value, as well as an elevation variance-derived ruggedness parameter in the cell's immediate neighborhood.

Looking closely at this ruggedness overlay and comparing it to the preceding gradient direction overlay, we see that the periodic purple lines in the direction overlay are not well represented in the ruggedness overlay with a similar spatial pattern. This suggests that the purple lines may only be an artifact in the data, perhaps created at the limit of the precision involved in assigning breakline values to a particular direction class. On the other hand, the periodic pattern in the broad red linear feature in the direction overlay does seem to appear in the ruggedness overlay as a periodic pattern of BRI values. This suggests that that these variations may result from actual changes in the land surface as a region of very gentle parallel swales along the Rappahannock-York drainage divide.

You can see that the treelines at the edges of the open area are shown as sharp lines with the highest ruggedness class. An additional feature that is not readily apparent elsewhere appears in the ruggedness overlay: a generally north-south linear feature, a narrow road, just to the right of the drainage divide. This road is difficult to discern in the shaded relief reference image alone. The gentle breaks-in-slope at the edges of the road show up in the higher ruggedness classes, while the center of the track is generally assigned to the lowest class. This suggests that the breakline ruggedness index may be effective in extracting such subtle indicators of roads and off-road tracks and trails.

This concludes the tutorial exercises for the A. P. Hill sample dataset.

3.2 BARC tutorial workflow

In this exercise, we will investigate the canopy for different crop plots in an experimental field.

1. INPUT FILE SELECTION

Browse and select:

```
BARC_Crops_1stReturn_DEM.tif
BARC_Crops_BareEarth_DEM.tif
BARC_Crops_ShadedRelief_IMG.tif
```

2. SELECT DEM FOR BREAKLINE ANALYSIS

Select default menu choice “Digital Surface Model or 1st Return DEM.”

3. SPECIFY DEM SUBSET

Notice that the full size of the file is 269 × 193 (width × height). Retain the offset defaults of 0. We will process the entire DEM.

Click on “Display Full Image.” The shaded relief image will appear in the Reference Image Display window.

4. BREAKLINE AND SLOPE ANALYSIS PARAMETERS

Select the default breakline computation kernel size of 9.

Change the default median filter kernel size from 0 to 3. This turns on the 3 × 3 median filter.

5. ELEVATION DIFFERENCE ANALYSIS PARAMETERS

Retain default “no” for negative difference values. Normally, the number of negative difference values should be very small with a BE model of reasonable quality. When negative difference values do occur, they are often due to local discontinuities in the first-surface model (“micro-terrain” features) that may or may not show up in the regular breakline overlay. If you wanted to investigate this possibility, you could select “yes” and input difference thresholds to create a difference overlay showing model cell locations with negative values.

Select “DSM or 1st return” for the DEM choice median filter menu.

The size of the median filter kernel now defaults to 3. Retain this choice. Elevation values in the first-surface model will be median filtered during difference analysis.

6. INITIAL DEM PROCESSING

Select "RUN" to perform breakline and elevation difference calculations. Upon completion, various statistics will be displayed in a separate summary output window. This initial text output should appear as follows:

```
DEM BREAKLINE, SLOPE, AND DIFFERENCE PROCESSING FOR MICRO-TERRAIN
AND CANOPY ANALYSIS
 Run executed Mon Nov 29 15:15:25 2021

CHECK INPUT FILES AND PARAMETERS
Original DSM or first surface file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\BARC CROP SAMPLE
DATA\BARC_Crops_1stReturn_DEM.tif
Bare Earth or Higher Return file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\BARC CROP SAMPLE
DATA\BARC_Crops_BareEarth_DEM.tif
Hillshade or Intensity image file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\BARC CROP SAMPLE
DATA\BARC_Crops_ShadedRelief_IMG.tif

Total width × height of original files:   269 ×   193

Processing DSM or FIRST RETURN model for breakline and slope analysis...

Horizontal offset from upper left corner:       0
Vertical offset from upper left corner:       0
Width of subset:      269
Height of subset:      193
Kernel size for breakline computations:       9
Kernel size for breakline median filter:       3
Negative difference values included? no
Apply elevation difference median filter to input DEMs? 1st return
Kernel size for elevation difference median filter:       3

Ground sample distance =      0.23320000
Units are METERS

Processing started at Mon Nov 29 15:15:25 2021

 Calculating SLOPE, BREAK-IN-SLOPE, and DIRECTION for the FIRST RETURN DEM
BREAKLINE MEDIAN FILTER KERNEL SIZE =  3
```

```
Processing ended at Mon Nov 29 15:15:27 2021
Elapsed time in seconds       2

 ELEVATION, SLOPE, AND BREAKLINE STATISTICS with breakline median filter ap-
plied, size =  3

 DSM or FIRST RETURN Elevation Statistics

minimum elevation =    25.44 meter
maximum elevation =    28.85 meter
   mean elevation =    26.40 meter
   std dev for the set of elevation values =     0.62 meter

 BARE EARTH or HIGHER RETURN Elevation Statistics

minimum elevation =    25.40 meter
maximum elevation =    26.80 meter
   mean elevation =    26.06 meter
   std dev for the set of elevation values=     0.28 meter

 DSM or First Return parameters for SLOPE and BREAKLINE Vector Magnitudes
are derived from absolute values.
 Slope is given as the tangent of the angle from the horizontal (rise/run).
 Breakline value units are inverse distance.

 DSM OR FIRST RETURN Slope and Breakline Statistics
minimum slope =   0.00
maximum slope =   3.30
   mean slope =   0.41
   std dev for the set of slope values =   0.59

minimum breakline =     0.00 /meter
maximum breakline =    33.36 /meter
   mean breakline =     2.55 /meter
   std dev for the set of breakline values =     3.78 /meter

 Calculating ELEVATION DIFFERENCE MODEL

DIFFERENCE MEDIAN FILTER KERNEL SIZE =  3
 Applied to DSM or 1st Return Model

 Negative difference cells will be converted to 0.0 (canopy height model will al-
ways be above the BE model)
```

```
CANOPY HEIGHT MODEL STATISTICS

minimum elevation difference =     0.00 meter
maximum elevation difference =     2.71 meter
   mean elevation difference =     0.35 meter
   std dev for the set of elevation difference values =     0.53 meter

 DIFFERENCE CELL COUNTS

 INITIAL POSITIVE DIFFERENCE CELLS
  Count =    51545 99.28 % subimage cells;  99.31 % difference cells
 INITIAL NEGATIVE DIFFERENCE CELLS
  Count =      356  0.69 % subimage cells;   0.69 % difference cells
 TOTAL DIFFERENCE CELLS (POS + NEG)
  Count =    51901  99.97 % subimage cells
```

7. SADDLE, PEAK and DEPRESSION TOOL (Optional)

This “RUN” button brings up the optima extraction sub-GUI. We will bypass this feature for this exercise. Continue to step 8.

8. DISPLAY HISTOGRAMS FOR THRESHOLD VALIDATION

Select “Breakline Values Histogram” and “Elevation Difference Histogram.”

Select “RUN” to create histograms. Both histograms will appear in separate windows (Figures 10 and 11). We will examine them for possible breakpoints to aid in threshold selection.

Figure 10. Breakline values histogram for the BARC dataset.

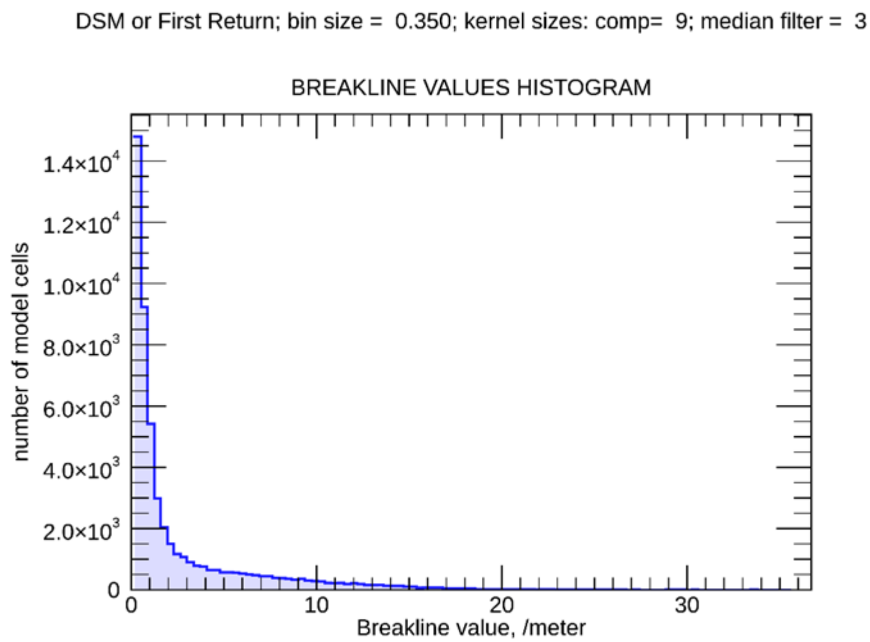
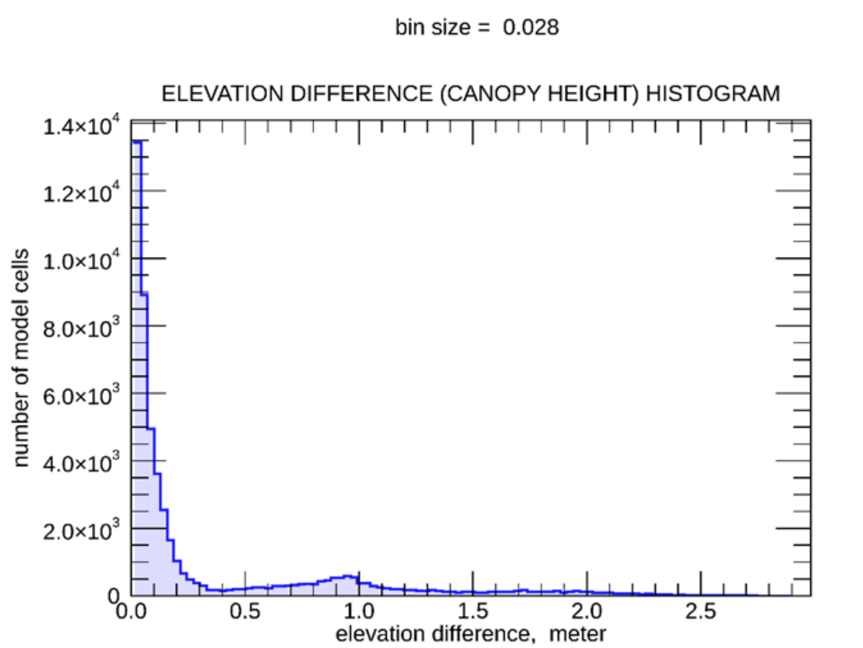


Figure 11. Elevation difference histogram for the BARC dataset.



9. SPECIFY BREAKLINE AND DIFFERENCE THRESHOLDS

In this exercise, we will choose different breakline and difference thresholds to best capture a variety of crop types in the BARC data.

Initial threshold selection:

The breakline values histogram shows a fairly smooth descending curve with a large number of very small values and a breakpoint at a value of about 2 to 3. We will retain the default lower threshold (the mean value) of 2.55.

Breakline upper limit: retain default value (33.36).

The elevation differences histogram shows a breakpoint at about 0.3 or 0.4 m. We will retain the default lower threshold value (0.35).

Elevation difference upper limit: retain default value (2.71).

10. SPECIFY SLOPE THRESHOLDS

Retain the lower slope threshold of 0.0 and the upper threshold of 329.93 (% slope). We will not need the slope overlay for this exercise.

11. SELECT OVERLAYS FOR DISPLAY

We will do three "RUN" passes in this section to investigate the BARC data.

3.2.1 Pass 1

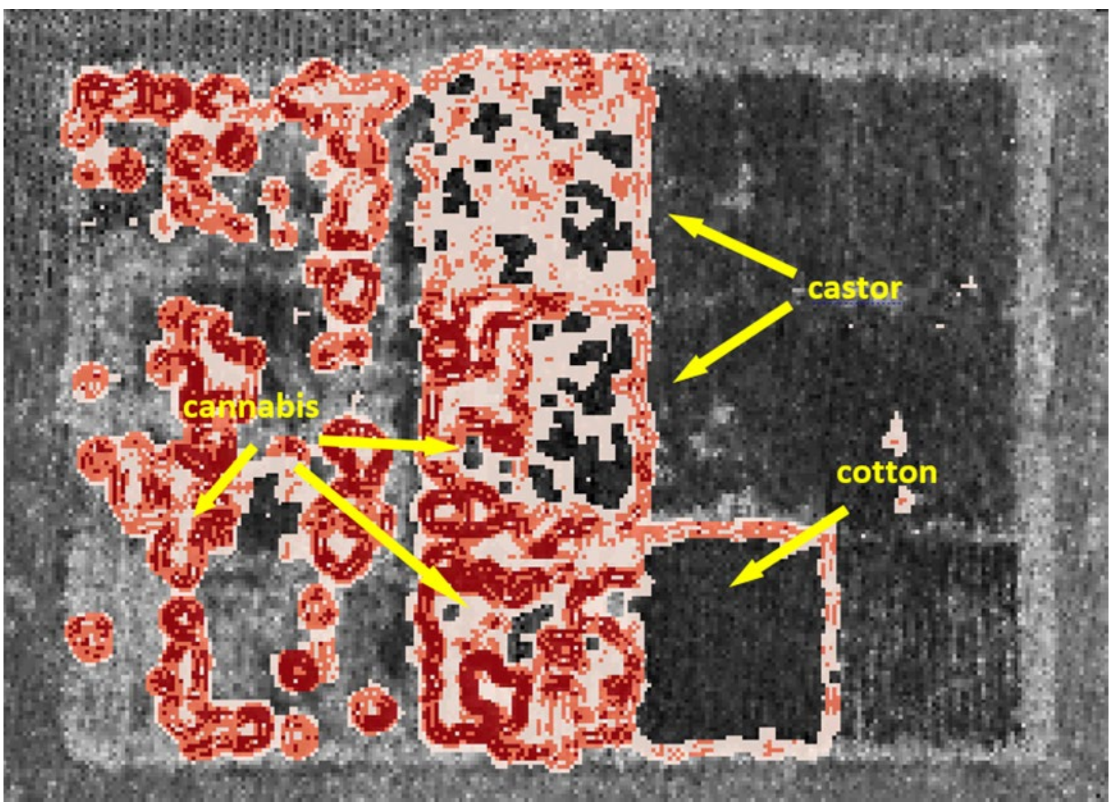
Check the boxes for "FILL HOLES breakline" and "FILL HOLES elevation difference" and de-select any others. Small holes will be filled in and irregularities will be smoothed in the pattern of overlay DEM cells.

Select "reference image" as the overlay background. Choose 3 for "No. of BREAKLINE classes" and "No. of ELEV DIFFERENCE classes."

Select "RUN" for overlay creation and display.

The breakline overlay, in shades of red (Figure 12), shows a portion of the crop canopy in this experimental field of cannabis, castor, cotton, and other crops as defined by sudden changes in slope. Darker shades depict the stronger breaklines surrounding individual plants. There are individual cannabis volunteers on the left side of the DEM; these are well represented. Castor plants occupy the plot at top center and on the right side of the plot just below that, in the center of the model. These plants are only partially represented in the breakline overlay using the default thresholds. There is a cotton crop on the bottom just left of the crop plot in the lower right-hand corner. The cotton has a canopy surface that is too smooth and/or too fine-grained to show up for the chosen breakline thresholds. However, the edges of the crop are shown, as the canopy falls away to the surrounding ground.

Figure 12. Pass 1 filled breakline overlay for the BARC dataset.

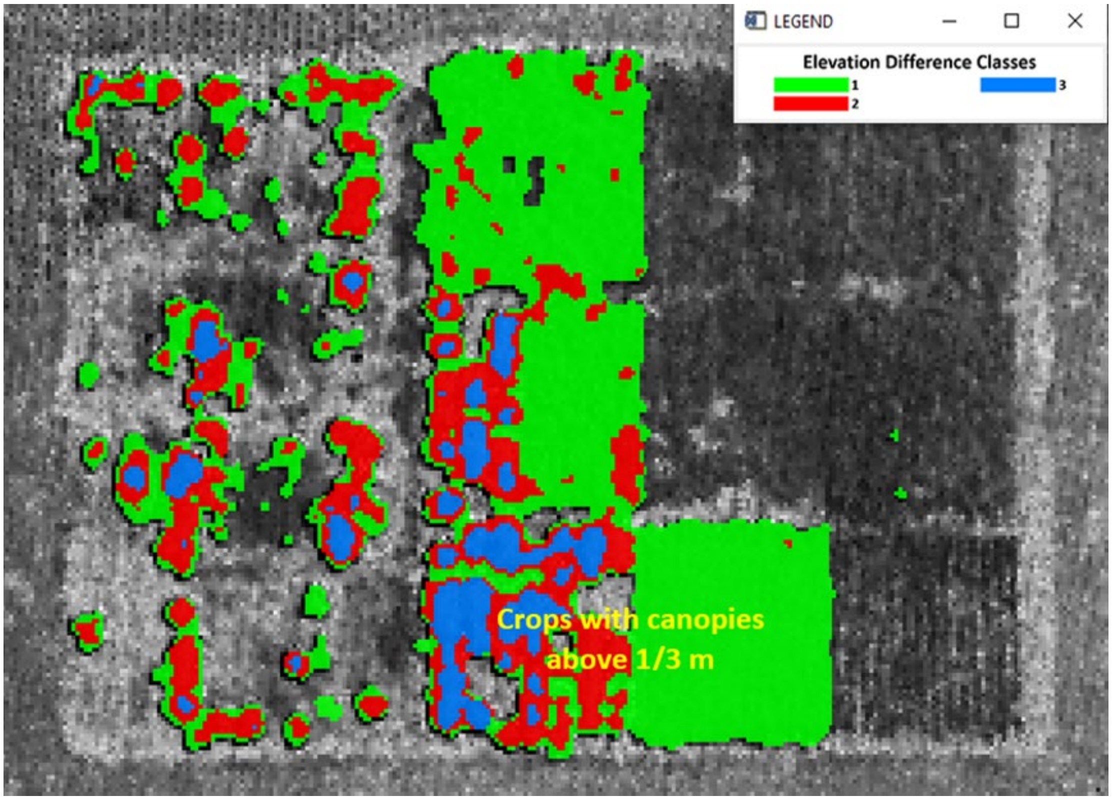


The text output for the filled difference overlay shows the height above ground for the three classes:

```
Creating the FILLED ELEVATION DIFFERENCE Overlay for 3 classes. Class colors
range from green to blue.
Number of filled elevation difference cells between thresholds =    14111 27.18 %
of subimage cells

 Equal class width solution: width = (high threshold - low threshold) / 3 =    0.787

 FILLED DIFFERENCE CLASS LIMITS:
 Class 1 lower:    0.350   upper:    1.137 meter
 Class 2 lower:    1.137   upper:    1.923 meter
 Class 3 lower:    1.923   upper:    2.710 meter

 FILLED DIFFERENCE CLASS COUNTS:
 Number of Class 1 cells =     8729  61.86 percent of FILLED DIFFERENCE OVERLAY
cells within CURRENT THRESHOLDS
 Number of Class 2 cells =     3687  26.13 percent of FILLED DIFFERENCE OVERLAY
cells within CURRENT THRESHOLDS
 Number of Class 3 cells =     1324   9.38 percent of FILLED DIFFERENCE OVERLAY
cells within CURRENT THRESHOLDS
```

Since the lower threshold for the first class is reported as 0.35 meters, the filled difference overlay (Figure 13) shows canopies with heights more than about 0.33 m above the ground, which includes the cotton plot, cannabis, and castor plants. Some of the taller cannabis plants may reach a height of greater than 2.5 m.

Figure 13. Pass 1 elevation difference overlay for the BARC dataset.



3.2.2 Pass 2

Retain the lower and upper limits (2.55, 33.36) for breakline value.

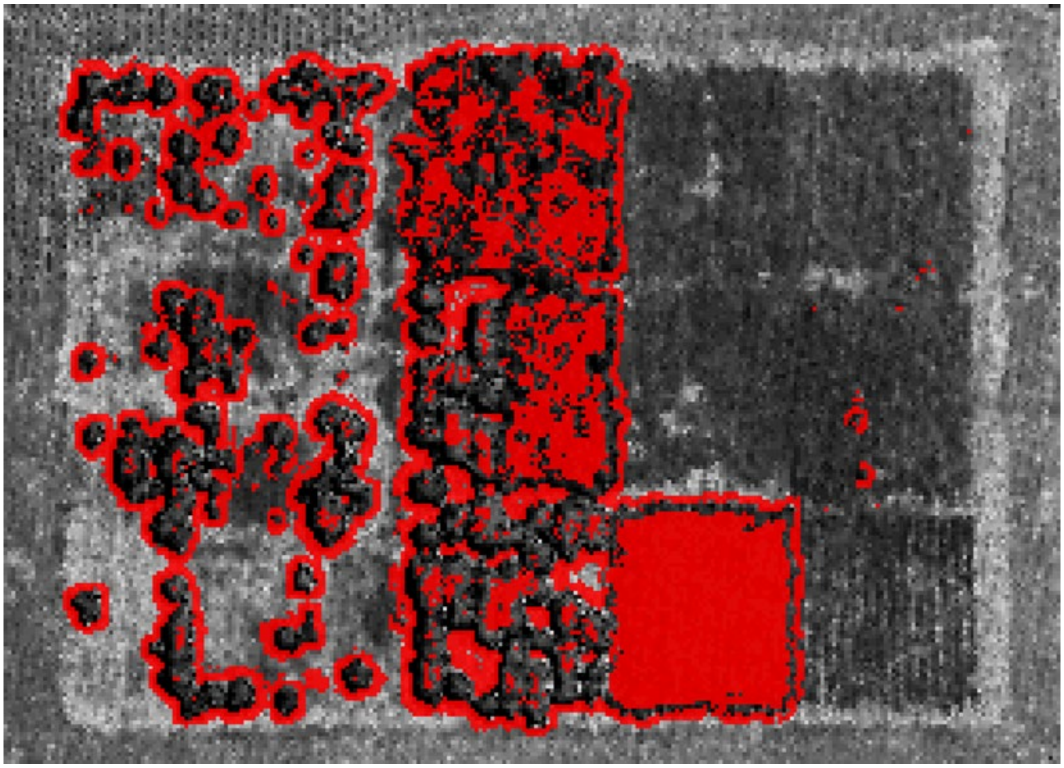
Retain the lower and upper limits (0.35, 2.71) for elevation difference.

Return to 11 and check the box for “FILL HOLES breakline XOR elevation difference.” De-select all others. The exclusive OR (XOR) operation is also called “exclusive disjunction” and is a display showing the union of the breakline and difference overlays with the DEM cells representing their intersection removed. There is no need to select the number of classes; this overlay will always appear as one color (red).

Select “RUN” for overlay creation and display.

The XOR overlay (Figure 14) shows the crops on the right side, including the cotton. The cotton shows up because although it does not appear in the breakline overlay, it appears in the difference overlay. However, the DEM cells shared by the two original overlays are now excluded. This results in an outline in red for the canopy of many individual plants of cannabis and for crop plot borders.

Figure 14. Pass 2 breakline XOR difference overlay for the BARC dataset.



3.2.3 Pass 3

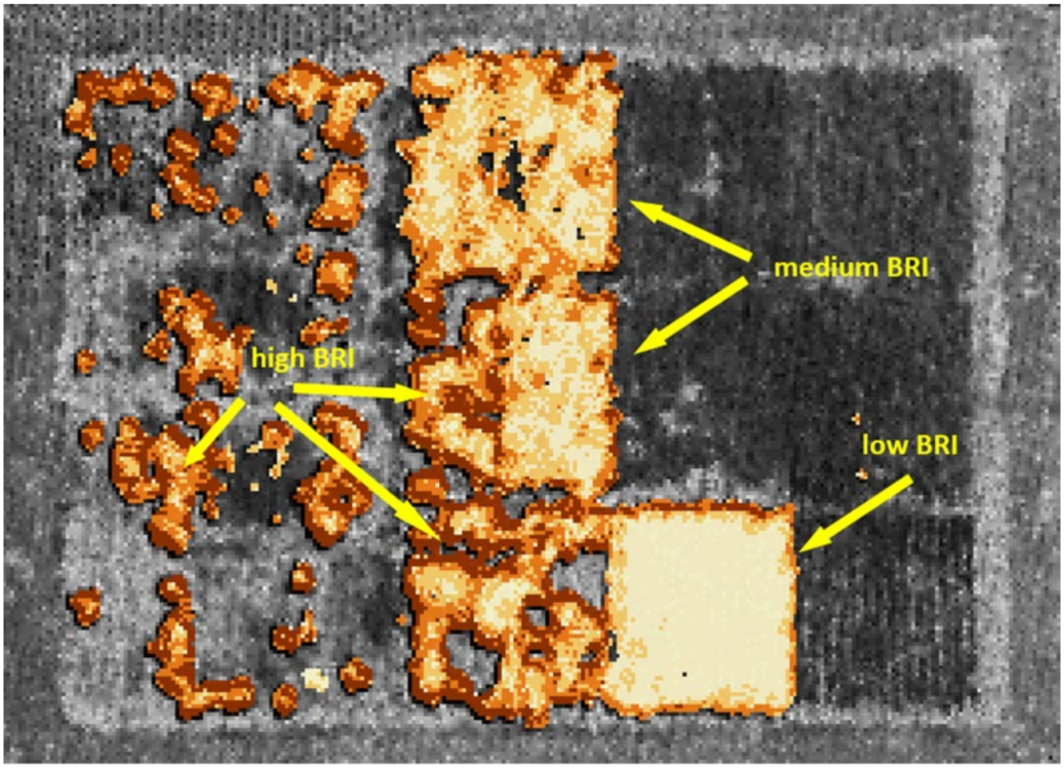
Retain all lower and upper threshold limits from Pass #=2.

Return to 11 and check the box for “BREAKLINE RUGGEDNESS INDEX.” De-select all others. Keep “reference image” as the overlay background. Choose 4 for “No. of RUGGEDNESS classes.” Choose “difference” as the template for the ruggedness overlay.

Select “RUN” for overlay creation and display.

BRI values are shown for the crops in four classes (Figure 15). You can see in general terms high ruggedness for the cannabis (dark reddish-brown), medium ruggedness for the castor plants (medium reddish-brown), and low ruggedness for the cotton crop (light reddish-brown). The BRI provides more detail about the elevation variance for a particular subset of model cells (the chosen difference template), and may serve as a tool to differentiate crop or other types of canopies. This concludes the tutorial exercises for the BARC CROP sample dataset.

Figure 15. Pass 3 breakline ruggedness index overlay for the BARC dataset (four classes).



3.3 MCMWTC tutorial workflow

In this exercise, we will investigate the heights and geometric characteristics of rooftops in the scene.

1. INPUT FILE SELECTION

Browse and select:

```
MCMWTC_1stReturn_DEM
MCMWTC_BareEarth_DEM
MCMWTC_Intensity_IMG
```

Notice that the reference image for this dataset is in the form of lidar intensity data rather than as shaded relief. The intensity image is derived from a highly monochromatic reflective response in the near-infrared for each lidar pulse.

2. SELECT DEM FOR BREAKLINE ANALYSIS

Select default menu choice “Digital Surface Model or 1st Return DEM.”

3. SPECIFY DEM SUBSET

Notice that the full size of the file is 3,842 × 2,084 (width × height).

The ground sample distance is 0.5 m.

Change defaults to

horizontal offset: 450

vertical offset: 250

width of subset: 2250

height of subset: 1550

Click on “Display Image Subset.” The intensity image will appear in the Reference Image Display window.

4. BREAKLINE AND SLOPE ANALYSIS PARAMETERS

Select the size of the computation kernel as 5.

Retain size of default median filter kernel as 0. Elevation values in the chosen model for breakline and slope analysis will not be median filtered before processing.

5. ELEVATION DIFFERENCE ANALYSIS PARAMETERS

Retain default “no” for negative difference values. Normally, the number of negative difference values should be very small with a BE model of reasonable quality. When they do occur, it is often due to local discontinuities in the first-surface model (“micro-terrain” features) that may or may not show up in the regular breakline overlay. If you wanted to investigate this possibility, you could select “yes” and input difference thresholds to create a difference overlay showing model cell locations with negative values.

Retain the default “neither input DEM” for the median filter menu.

Retain size of default median filter kernel as 0. Elevation values in both the first-surface and BE models will not be median filtered during difference analysis.

6. INITIAL DEM PROCESSING

Select “RUN” to perform breakline and elevation difference calculations. Upon completion, various statistics will be displayed in a separate summary output window. This initial text output should appear as follows:

```
DEM BREAKLINE, SLOPE, AND DIFFERENCE PROCESSING FOR MICRO-TERRAIN
AND CANOPY ANALYSIS
 Run executed Wed Dec 08 10:59:30 2021

CHECK INPUT FILES AND PARAMETERS
Original DSM or first surface file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\MCMWTC SAMPLE
DATA\MCMWTC_1stReturn_DEM.tif
Bare Earth or Higher Return file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\MCMWTC SAMPLE
DATA\MCMWTC_BareEarth_DEM.tif
Hillshade or Intensity image file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\MCMWTC SAMPLE
DATA\MCMWTC_Intensity_IMG.tif

Total width × height of original files:  3842 ×  2084

Processing DSM or FIRST RETURN model for breakline and slope analysis...

Horizontal offset from upper left corner:      450
Vertical offset from upper left corner:      250
Width of subset:     2250
Height of subset:     1550
Kernel size for breakline computations:       5
Kernel size for breakline median filter:       0
Negative difference values included? no
Apply elevation difference median filter to input DEMs? neither
Kernel size for elevation difference median filter:       0

Ground sample distance =      0.50000000
Units are METERS
```

```
Processing started at Wed Dec 08 10:59:30 2021

 Calculating SLOPE, BREAK-IN-SLOPE, and DIRECTION for the FIRST RETURN DEM
 NO Breakline Median Filter

Processing ended at Wed Dec 08 11:02:05 2021
Elapsed time in seconds      155

 ELEVATION, SLOPE, AND BREAKLINE STATISTICS (no breakline median filter)

 DSM or FIRST RETURN Elevation Statistics

minimum elevation =  2022.60 meter
maximum elevation =  2194.51 meter
   mean elevation =  2060.00 meter
   std dev for the set of elevation values =    33.73 meter

 BARE EARTH or HIGHER RETURN Elevation Statistics

minimum elevation =  2022.51 meter
maximum elevation =  2183.03 meter
   mean elevation =  2059.45 meter
   std dev for the set of elevation values=    33.58 meter

 DSM or First Return parameters for SLOPE and BREAKLINE Vector Magnitudes
are derived from absolute values.
 Slope is given as the tangent of the angle from the horizontal (rise/run).
 Breakline value units are inverse distance.

 DSM OR FIRST RETURN Slope and Breakline Statistics
minimum slope =   0.00
maximum slope =  26.44
   mean slope =   0.49
   std dev for the set of slope values =   1.08

minimum breakline =     0.00 /meter
maximum breakline =   323.92 /meter
   mean breakline =     2.43 /meter
   std dev for the set of breakline values =     7.09 /meter

 Calculating ELEVATION DIFFERENCE MODEL

 NO Elevation Difference Median Filter
```

```
 Negative difference cells will be converted to 0.0 (canopy height model will always be above the BE model)

 CANOPY HEIGHT MODEL STATISTICS

minimum elevation difference =     0.00 meter
maximum elevation difference =    26.46 meter
   mean elevation difference =     0.55 meter
   std dev for the set of elevation difference values =     1.88 meter

 DIFFERENCE CELL COUNTS

 INITIAL POSITIVE DIFFERENCE CELLS
  Count =  2323259 66.62 % subimage cells;  97.78 % difference cells
 INITIAL NEGATIVE DIFFERENCE CELLS
  Count =    52823  1.51 % subimage cells;   2.22 % difference cells
 TOTAL DIFFERENCE CELLS (POS + NEG)
  Count =  2376082  68.13 % subimage cells
```

7. SADDLE, PEAK and DEPRESSION TOOL (Optional)

This "RUN" button brings up the optima extraction sub-GUI. We will bypass this feature for this exercise. Continue to step 8.

8. DISPLAY HISTOGRAMS FOR THRESHOLD VALIDATION

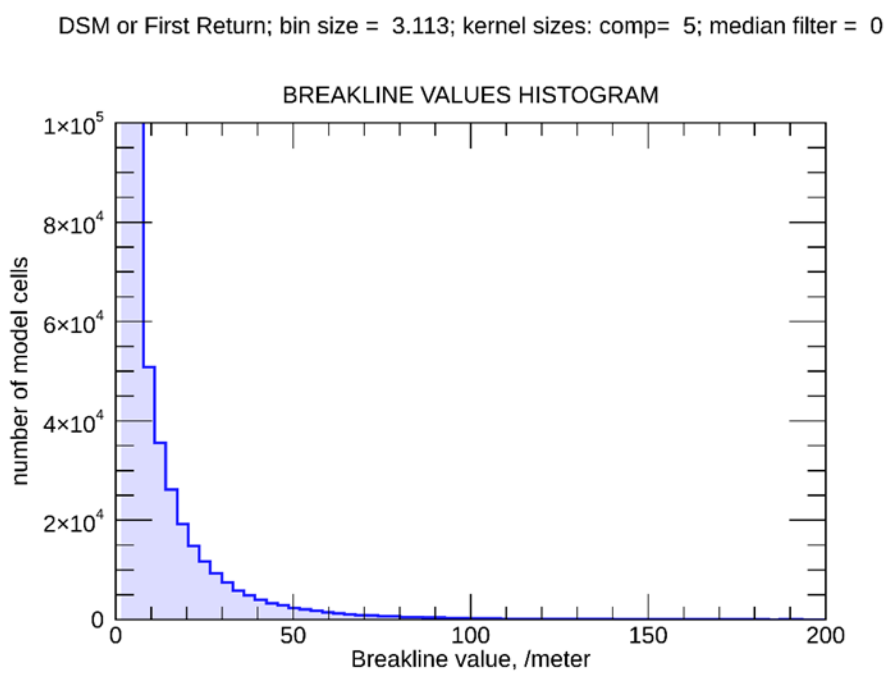
Retain default selections for "Breakline Values Histogram" and "Elevation Difference Histogram." De-select the default "Slope Histogram."

Select "RUN" to create histograms for threshold validation. The default breakline and difference histograms for this DEM both show a high narrow spike at the extreme left of the graphic, with very low model cell numbers to the right. If there is any useful breakpoint information in either histogram, it will be captured in the lower left portion of the graphic. The histogram window provides an interactive capability to manipulate the display. We will now set limits for the axes to further explore the distribution.

In the breakline values histogram, go to the pull-down menu on the toolbar labeled "Window" and select "Visualization Browser." In this new window, double-click on "View 1." Now double-click on "Visualization

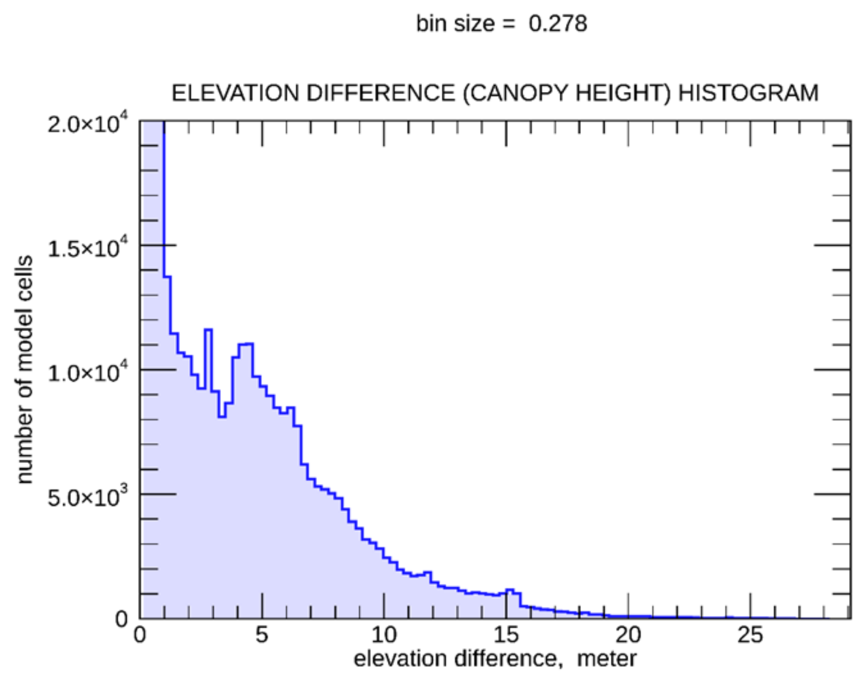
Layer." Finally, double-click on "Data Space." A list of editable parameters will appear. Change "X maximum" to "200." Change "Y maximum" to "100000." Finally, hit the "enter" key. The breakline values histogram now appears as in Figure 16.

Figure 16. Breakline values histogram for the MCMWTC dataset.



In the elevation difference histogram, go to the same "Data Space" parameter list. Change "Y maximum" to "20000" and hit the "enter" key. The elevation difference histogram now appears as in Figure 17.

Figure 17. Elevation difference histogram for the MCMWTC dataset.



9. SPECIFY BREAKLINE AND DIFFERENCE THRESHOLDS

We will choose various breakline, difference, and slope thresholds to create overlays that best represent building rooftops.

Initial threshold selection:

The adjusted breakline values histogram shows a smooth descending curve with no obvious breakpoints to try as thresholds. A trial-and-error process is called for to extract desired features. In this case we are hoping to extract tree canopy, to be excluded from the final roof overlay.

Breakline lower limit: retain default value (2.43).

Breakline upper limit: retain default value (323.92).

The elevation differences histogram shows a breakpoint at about 3 or 4 m. Change the default lower difference threshold value to 3.5.

Elevation difference upper limit: change the default value to 16. This upper threshold will capture all the roofs in the DEM. Any DEM cells higher than this above ground, such as for tree canopy, are not needed.

10. SPECIFY SLOPE THRESHOLDS

Retain the lower slope threshold of 0.0, but change the upper threshold to 48 (% slope).

11. SELECT OVERLAYS FOR DISPLAY

We will do three “RUN” passes in this section to investigate the MCMWTC data.

3.3.1 Pass 1

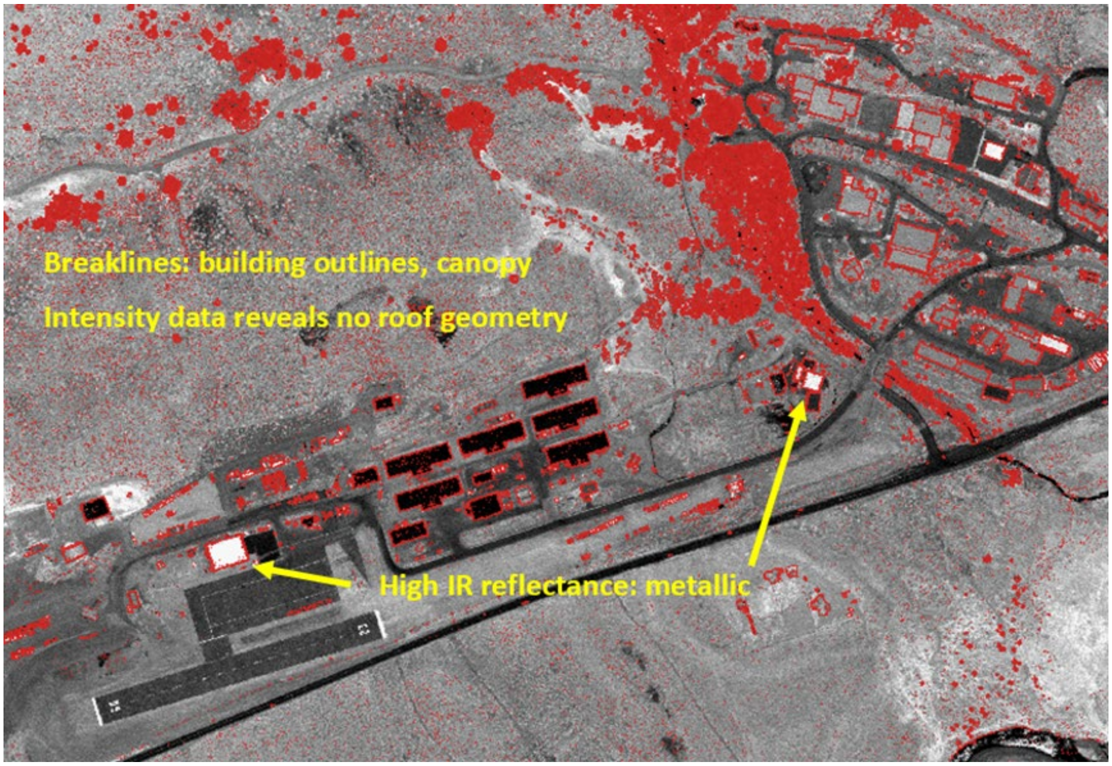
Check the boxes for “breakline” and “elevation difference,” and de-select any others.

Select “reference image” as the overlay background. Choose 1 for “No. of BREAKLINE classes” and “No. of ELEV DIFFERENCE classes.”

Select “RUN” for overlay creation and display.

In the breakline overlay (Figure 18), tree canopy and other scrub vegetation are well represented. Buildings are outlined in red due to the high breakline values at building edges. The intensity image provides no detail for the roofs themselves, most of which appear a uniform black or gray. At least two roofs, however, are white in color with a high reflectance in the near-infrared, and are probably metallic.

Figure 18. Pass 1 breakline overlay for the MCMWTC dataset.



In the elevation difference overlay (Figure 19), tree canopy appears without the scrub vegetation due to the lower threshold of 3.5 m. Buildings are also evident, but now the roof interiors appear in the overlay. Next, we will perform a Boolean operation to remove the canopy from the difference overlay.

Figure 19. Pass 1 difference overlay for the MCMWTC dataset.

3.3.2 Pass 2

Check the box for “FILL HOLES elev diff NOT brkln” and de-select any others.

Keep “reference image” as the overlay background. Choose 6 for “No. of ELEV DIFFERENCE classes.”

Select “RUN” for overlay creation and display.

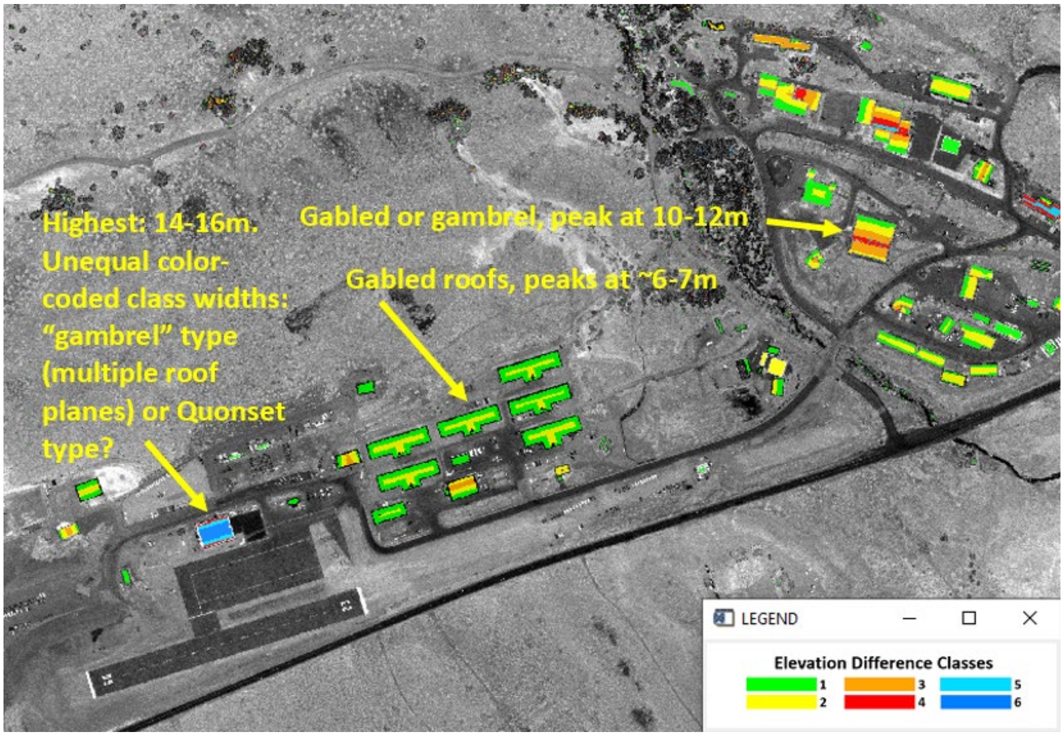
This overlay (Figure 20) shows the elevation difference overlay after removing any model cells that the difference overlay has in common with the breakline overlay, effectively removing the canopy. The “FILL HOLES” option fills in the few breakline overlay cells that appear in the roof interiors, resulting in a smooth appearance. The text output shows the lower and upper limits and cell counts for the elevation difference color-coded classes:

```
Creating the FILLED ELEVATION DIFFERENCE NOT BREAKLINE Overlay for 6 classes. Class colors range from green to blue.
Number of filled elevation cells NOT breakline between thresholds =    89254
2.56 % of subimage cells
```

```
Equal class width solution: width = (high threshold - low threshold) / 6 =    2.083

FILLED DIFFERENCE NOT BREAKLINE CLASS LIMITS:
Class 1 lower:    3.500   upper:    5.583 meter
Class 2 lower:    5.583   upper:    7.667 meter
Class 3 lower:    7.667   upper:    9.750 meter
Class 4 lower:    9.750   upper:   11.833 meter
Class 5 lower:   11.833   upper:   13.917 meter
Class 6 lower:   13.917   upper:   16.000 meter

FILLED DIFFERENCE NOT BREAKLINE CLASS COUNTS:
Number of Class 1 cells =    43048  48.23 percent of FILLED DIFFERENCE NOT
BREAKLINE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 2 cells =    29340  32.87 percent of FILLED DIFFERENCE NOT
BREAKLINE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 3 cells =     9004  10.09 percent of FILLED DIFFERENCE NOT
BREAKLINE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 4 cells =     3742   4.19 percent of FILLED DIFFERENCE NOT
BREAKLINE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 5 cells =     2194   2.46 percent of FILLED DIFFERENCE NOT
BREAKLINE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 6 cells =     1874   2.10 percent of FILLED DIFFERENCE NOT
BREAKLINE OVERLAY cells within CURRENT THRESHOLDS
```

Several gabled roofs (roofs with a simple ridgeline) are visible, as well as a few that could be gabled or of the gambrel type (multiple roof planes). Many gabled roofs in the scene have ridgelines (in yellow) that reach about 6 to 7 m above the ground. The gable or gambrel roofs have upper ridgelines in class 4 (red) that reach to about 10 to 12 m. One roof that reaches the highest class, 14 to 16 m (in blue), shows three color bands with unequal widths. This roof may be of Quonset-type, with a semi-circular cross-section, resulting in gradually decreasing height from the ridgeline to the roof edges. We will investigate this further in the next pass.

Figure 20. Pass 2 difference *not* breakline overlay for the MCMWTC dataset.



3.3.3 Pass 3

Ensure that the slope thresholds are 0% (lower) and 48% (upper).

Check the box for "SLOPE" and de-select any others.

Keep "reference image" as the overlay background. Choose "FILL dif NOT brk" for the template for the slope overlay. Choose 4 for "No. of SLOPE classes."

Select "RUN" for overlay creation and display.

The slope overlay shows color-coded slope classes for the DEM cells identified in the overlay created in pass 2. The text output shows the lower and upper limits and cell counts for the slope classes:

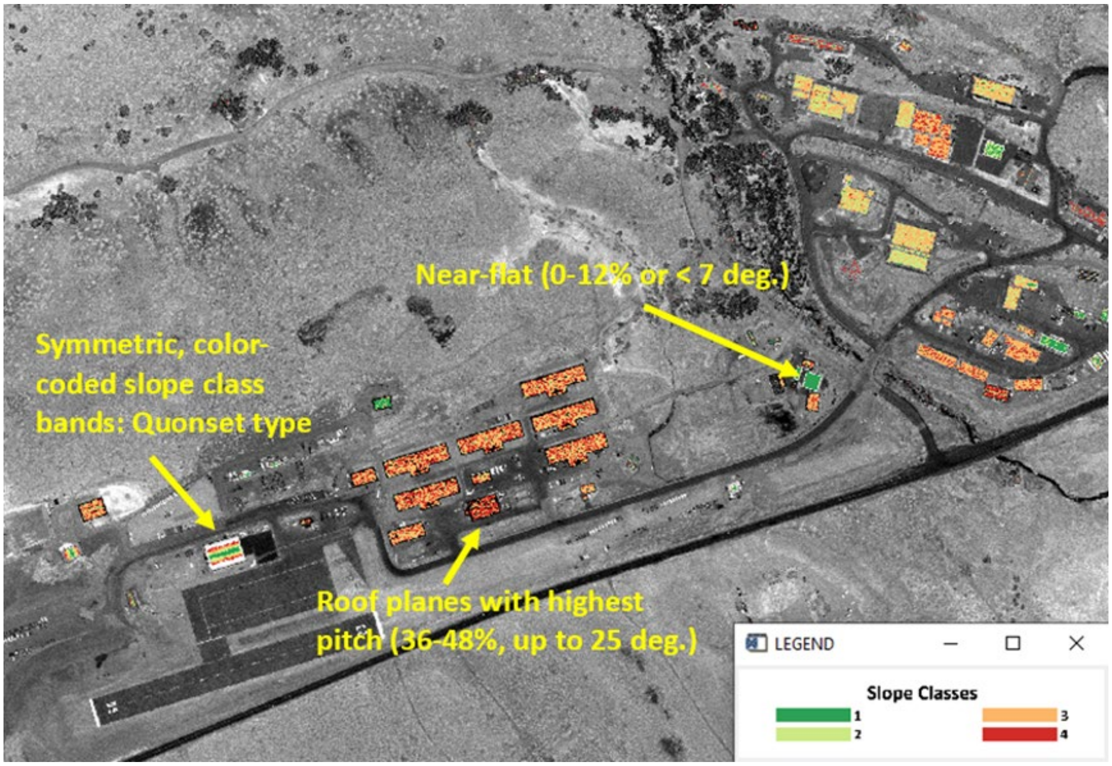
```
Creating the SLOPE Overlay for 4 classes. TEMPLATE will be the FILLED DIFFERENCE NOT BREAKLINE overlay.
 Colors for slope classes range from GREEN (lowest slope) to RED (highest slope)
 TOTAL SLOPE OVERLAY CELLS with template fildifnotbrk:    77392
```

```
Equal class width solution: width = (high threshold - low threshold) / 4 =    0.118
(rise/run)

SLOPE CLASS LIMITS:
Class 1 lower:    0.914   upper:   12.685   % slope
Class 2 lower:   12.685   upper:   24.456   % slope
Class 3 lower:   24.456   upper:   36.227   % slope
Class 4 lower:   36.227   upper:   47.998   % slope

SLOPE CLASS COUNTS:
Number of Class 1 cells =     5033   6.50 percent of SLOPE OVERLAY TEMPLATE
cells within CURRENT THRESHOLDS
Number of Class 2 cells =    15486  20.01 percent of SLOPE OVERLAY TEMPLATE
cells within CURRENT THRESHOLDS
Number of Class 3 cells =    36627  47.33 percent of SLOPE OVERLAY TEMPLATE
cells within CURRENT THRESHOLDS
Number of Class 4 cells =    20246  26.16 percent of SLOPE OVERLAY TEMPLATE
cells within CURRENT THRESHOLDS
```

In this overlay (Figure 21), the upper threshold has been chosen so that almost all of the roof area has been captured with an appreciable number of DEM cells in each class. The roofs near the scene center appear to be mostly in class 3 (24–36% slope, or about 14–20 degrees), except for one in this group with roof planes in class 4 (36–48%, or about 20–26 degrees).

One roof, right of center in the scene, was earlier labeled metallic and appears as a uniform green color. It is apparently near-flat (0–12% slope, or < 7 degrees).

Figure 21. Pass 3 slope overlay for the MCMWTC dataset.



The roof at the lower left, also apparently metallic, shows symmetrical color-coded bands of fairly equal width, with the lowest slope class (green) down the center. To take a closer look at this roof, go to the menu bar on the slope overlay window under “Display Options” and select “ZOOM TOOL: Window Snapshot at Screen Resolution.” A separate interactive window appears showing the entire scene with a zoom subset. Click on the roof in question to bring it up for examination in the zoom subset window (Figure 22).

Figure 22. Pass 3 slope overlay zoom tool for the MCMWTC dataset.

The color banding seen on the right side of Figure 22 represents a roof with a near-flat centerline and gradually increasing slope out toward the roof edges. The edges have no color, suggesting that they have slopes higher than class 4, falling outside the selected threshold range. This is consistent with a Quonset-type roof with a semi-circular cross-section.

This concludes the tutorial exercises for the MCMWTC sample dataset.

3.4 Philippines tutorial workflow

In this exercise, we will use the Breakline Tool to explore canopy in a mixture of natural and managed forest.

1. INPUT FILE SELECTION

Browse and select:

```
PHILIPPINES_1stReturn_DEM.tif
PHILIPPINES _BareEarth_DEM.tif
PHILIPPINES _1stReturnIntensity_IMG.tif
```

2. SELECT DEM FOR BREAKLINE ANALYSIS

Select default menu choice “Digital Surface Model or 1st Return DEM.”

3. SPECIFY DEM SUBSET

Notice that the full size of the file is 5,038 × 5,028 (width × height).

The ground sample distance is 1.0 m.

Change defaults to

horizontal offset: 2000

vertical offset: 1400

width of subset: 504

height of subset: 420

Click on “Display Image Subset.” The shaded relief image will appear in the Reference Image Display window.

4. BREAKLINE AND SLOPE ANALYSIS PARAMETERS

Change size of default computation kernel to 17.

Change the size of the default median filter kernel to 5. A 5 × 5 median filter kernel will be applied to the elevation values in the chosen model for breakline and slope analysis.

5. ELEVATION DIFFERENCE ANALYSIS PARAMETERS

Retain default “no” for negative difference values.

Retain the default “neither input DEM” for the median filter menu.

Retain size of default median filter kernel as 0. Elevation values in both the 1st surface and BE models will not be median filtered during difference analysis.

6. INITIAL DEM PROCESSING

Select “RUN” to perform breakline and elevation difference calculations. Upon completion, various statistics will be displayed in a separate summary output window. This initial text output should appear as follows:

```
DEM BREAKLINE, SLOPE, AND DIFFERENCE PROCESSING FOR MICRO-TERRAIN
AND CANOPY ANALYSIS
 Run executed Tue Dec 14 14:01:15 2021

CHECK INPUT FILES AND PARAMETERS
Original DSM or first surface file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\PHILIPPINES SAMPLE
DATA\PHILIPPINES_1stReturn_DEM.tif
Bare Earth or Higher Return file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\PHILIPPINES SAMPLE
DATA\PHILIPPINES_BareEarth_DEM.tif
Hillshade or Intensity image file:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\PHILIPPINES SAMPLE
DATA\PHILIPPINES_1stReturnIntensity_IMG.tif

Total width × height of original files:  5038 ×  5028

Processing DSM or FIRST RETURN model for breakline and slope analysis...

Horizontal offset from upper left corner:     2000
Vertical offset from upper left corner:     1400
Width of subset:      504
Height of subset:      420
Kernel size for breakline computations:       17
Kernel size for breakline median filter:       5
Negative difference values included? no
Apply elevation difference median filter to input DEMs? neither
Kernel size for elevation difference median filter:       0

Ground sample distance =       1.0000000
Units are METERS

Processing started at Tue Dec 14 14:01:15 2021

 Calculating SLOPE, BREAK-IN-SLOPE, and DIRECTION for the FIRST RETURN DEM
BREAKLINE MEDIAN FILTER KERNEL SIZE =  5
```

```
Processing ended at Tue Dec 14 14:01:25 2021
Elapsed time in seconds       9

 ELEVATION, SLOPE, AND BREAKLINE STATISTICS with breakline median filter ap-
plied, size =  5

 DSM or FIRST RETURN Elevation Statistics

minimum elevation =   385.78 meter
maximum elevation =   450.07 meter
   mean elevation =   412.77 meter
   std dev for the set of elevation values =    12.43 meter

 BARE EARTH or HIGHER RETURN Elevation Statistics

minimum elevation =   385.59 meter
maximum elevation =   426.56 meter
   mean elevation =   402.54 meter
   std dev for the set of elevation values=     9.74 meter

 DSM or First Return parameters for SLOPE and BREAKLINE Vector Magnitudes
are derived from absolute values.
 Slope is given as the tangent of the angle from the horizontal (rise/run).
 Breakline value units are inverse distance.

 DSM OR FIRST RETURN Slope and Breakline Statistics
minimum slope =   0.00
maximum slope =   4.51
   mean slope =   1.25
   std dev for the set of slope values =   0.89

minimum breakline =     0.00 /meter
maximum breakline =     6.20 /meter
   mean breakline =     1.28 /meter
   std dev for the set of breakline values =     1.04 /meter

 Calculating ELEVATION DIFFERENCE MODEL

 NO Elevation Difference Median Filter

 Negative difference cells will be converted to 0.0 (canopy height model will al-
ways be above the BE model)

 CANOPY HEIGHT MODEL STATISTICS
```

```
minimum elevation difference =     0.00 meter
maximum elevation difference =    28.45 meter
   mean elevation difference =    10.12 meter
   std dev for the set of elevation difference values =     7.00 meter

 DIFFERENCE CELL COUNTS

 INITIAL POSITIVE DIFFERENCE CELLS
  Count =   188614 89.10 % subimage cells;  98.65 % difference cells
 INITIAL NEGATIVE DIFFERENCE CELLS
  Count =     2585  1.22 % subimage cells;   1.35 % difference cells
 TOTAL DIFFERENCE CELLS (POS + NEG)
  Count =   191199  90.32 % subimage cells
```

7. SADDLE, PEAK, AND DEPRESSION TOOL

Press the "RUN" button to bring up the optima extraction sub-GUI. In this exercise, we take advantage of the optima-finding algorithm for peaks to find individual tree canopies. We will do two "RUN" passes to investigate the Philippines data, starting with a peak overlay from the sub-GUI and finishing with an elevation difference overlay from the main GUI.

3.4.1 Initial optima processing

On the sub-GUI, under "1. PROCESS SADDLES, PEAKS AND DEPRESSIONS," select the "RUN" button to perform processing for the three types of optima in the DEM. The algorithms use the same kernel and median filter sizes that were selected for breakline and slope processing, and these will appear in adjoining text boxes. The text output for optima processing should appear as follows:

```
Performing SADDLE POINT, PEAK and DEPRESSION processing.

Processing DSM or FIRST RETURN model...
File:
C:\Users\RDTECSBB\Documents\BREAKLINE TOOL\PHILIPPINES SAMPLE
DATA\PHILIPPINES_1stReturn_DEM.tif

Horizontal offset from lower left corner:     2000
Vertical offset from lower left corner:     1400
Width of subset:      504
```

```
Height of subset:      420
Kernel size for saddle, peak, and depression computations:      17
A Median Filter will be applied to the DEM with kernel size =  5

 ABSOLUTE STEEPNESS STATISTICS
 min saddle steepness =     0.000000 /meter
 mean saddle steepness =     0.248077 /meter
 median saddle steepness =     0.000000 /meter
 max saddle steepness =      2.83357 /meter

 min peak steepness =     0.000000 /meter
 mean peak steepness =     0.264741 /meter
 median peak steepness =     0.000000 /meter
 max peak steepness =      4.72430 /meter

 min depression steepness =     0.000000 /meter
 mean depression steepness =     0.259043 /meter
 median depression steepness =     0.000000 /meter
 max depression steepness =      4.16780 /meter

 OPTIMA CELL COUNTS
 Total # cells:      211680
 # of saddle cells above zero steepness:       79903
 # of saddle cells above mean steepness:       59642
 # of saddle cells above median steepness:       79903
 # of peak cells above zero steepness:       57407
 # of peak cells above mean steepness:       47345
 # of peak cells above median steepness:       57407
 # of depression cells above zero steepness:       59842
 # of depression cells above mean steepness:       47139
 # of depression cells above median steepness:       59842
```

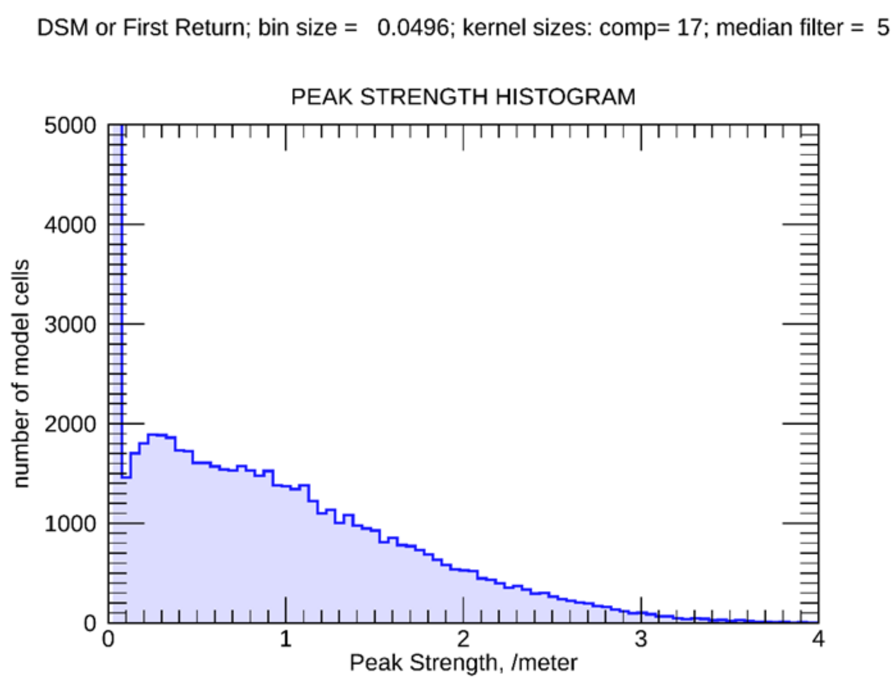
3.4.2 Display peak strength histogram

Under “2. DISPLAY HISTOGRAMS,” de-select the boxes for saddle and depression strength histograms, but retain the selection for peak strength. Select the “RUN” button to bring up the peak strength histogram. The “strength” of optima expresses the steepness or sharpness of curvature for saddles, peaks, and depressions. The strength of any optimum is always positive. After adjusting the X and Y maxima to bring out greater detail, we will examine the peak strength distribution in the histogram to select a lower threshold.

In the peak strength histogram, go to the pull-down menu on the toolbar labeled “Window” and select “Visualization Browser.” In this new window, double-click “View 1.” Now double-click “Visualization Layer.” Finally, double-click “Data Space.” A list of editable parameters will appear. Change “X maximum” to 4. Change “Y maximum” to 5000. Finally, hit the “enter” key. The peak strength histogram now appears as in Figure 23.

The distribution of DEM cells in Figure 23 shows a tall spike at the extreme left near the origin, followed by a breakpoint at about 0.1 peak strength. We will try this value as a lower threshold, removing those cells with very small values from the overlay.

Figure 23. Pass 1 peak strength histogram for the Philippines dataset.



3.4.3 Pass 1

Under “5. PEAK STRENGTH THRESHOLDS,” change the lower threshold to 0.1. Retain the upper threshold of 4.724.

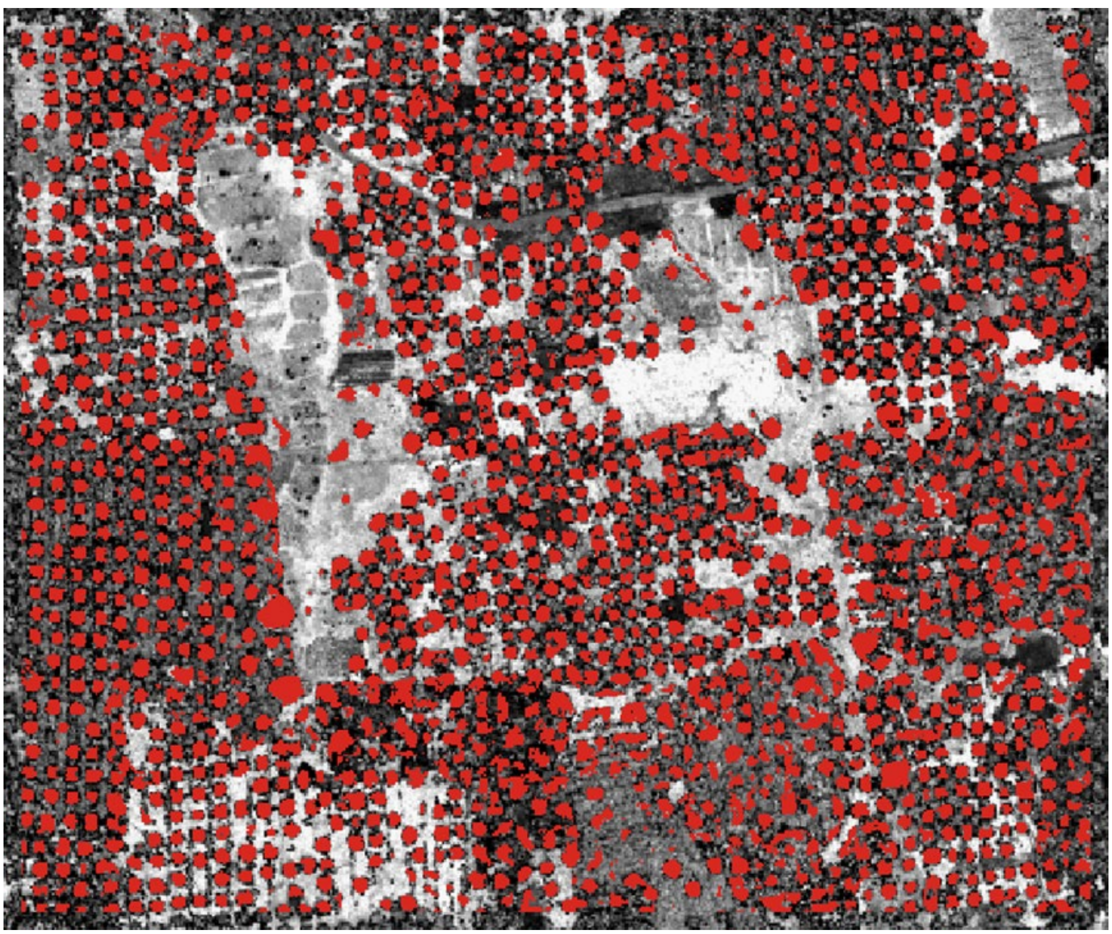
Change the number of peak strength classes from three to one.

Change the minimum peak symmetry threshold from 0.5 to 0. This parameter controls the number of optima included in the overlay by evaluating the curvature in orthogonal directions. The closer this number is to 1 for an optimum, the more perfect the symmetry. By setting the threshold to 0, we are including all defined peaks in the overlay, regardless of their symmetry value.

In the pull-down menu for the background for the peak overlay, retain the selection “reference image.”

Under “6. CREATE and DISPLAY PEAK OVERLAY,” select the “RUN” button. The peak overlay appears in a separate window (Figure 24).

Figure 24. Pass 1 peak overlay for the Philippines dataset.



The overlay shows that the peaks algorithm, with the chosen computation and threshold parameters, is able to extract individual tree canopies in a managed, orchard-like setting given the spatial resolution of the DSM. In fact, these parameters were selected to create an effective graphical display of the canopies. The larger computation kernel of 17 × 17 avoids the detection of unnecessary fine spatial detail in the model. The 5 × 5 median filter reduces the sharpness of the elevation discontinuities detected by the peaks algorithm, enhancing the blocked-up effect of the red color within each canopy. Finally, the lower peak strength threshold was chosen to limit the overlay color to the canopies themselves.

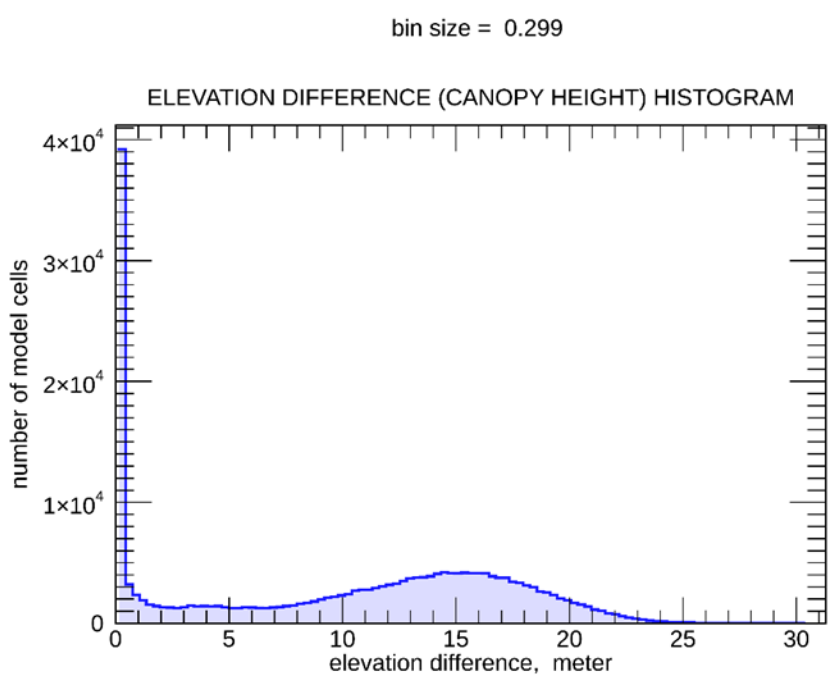
Now return to the main Breakline Tool GUI.

8. DISPLAY HISTOGRAMS FOR THRESHOLD VALIDATION

In the main GUI, de-select the boxes for the breakline values and slope histograms, but retain the selection for elevation difference.

Select "RUN" to create the elevation difference histogram (Figure 25). There is the usual narrow spike at the extreme left, then a flat region with relatively few model cells, followed by a symmetrical hump that may represent tree canopy. Considering only this portion of the histogram, its mode, or most frequent value of elevation difference, is about 15 m.

Figure 25. Elevation difference histogram for the Philippines dataset.



9. SPECIFY BREAKLINE AND DIFFERENCE THRESHOLDS

The default lower threshold for elevation difference is 10.12 m. Change this value to 7 m to capture more of the lower tail of the symmetrical hump in Figure 25. Retain the default upper difference threshold of 28.45 m.

10. SPECIFY SLOPE THRESHOLDS

We will not be creating a slope overlay for this dataset. Continue to the next step.

11. SELECT OVERLAYS FOR DISPLAY

We will create a standard difference overlay to compare to the peaks overlay in terms of canopy segmentation.

3.4.4 Pass 2

Select the box for “elevation difference” and de-select all others.

Retain “reference image” as the overlay background. Choose 3 for “No. of ELEV DIFFERENCE” classes.

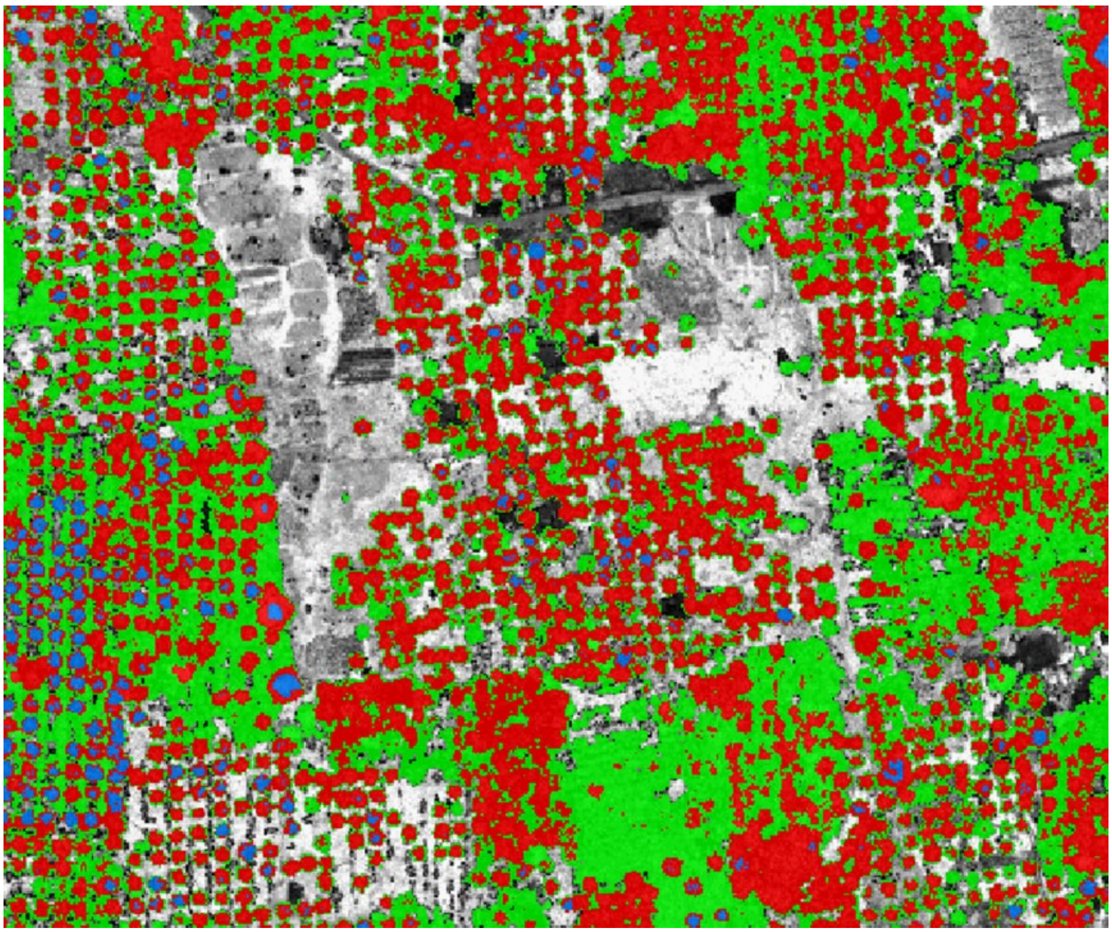
Select “RUN” for overlay creation and display.

The difference overlay (Figure 26) depicts the canopy in three classes for height above ground. The text output shows the boundaries of each class:

```
Creating the ELEVATION DIFFERENCE Overlay for 3 classes. Class colors range
from green to blue.
Number of elevation difference cells between thresholds =   139306 65.81 % of
subimage cells

 Equal class width solution: width = (high threshold - low threshold) / 3 =    7.150

 DIFFERENCE CLASS LIMITS:
 Class 1 lower:    7.000   upper:   14.150 meter
 Class 2 lower:   14.150   upper:   21.300 meter
 Class 3 lower:   21.300   upper:   28.450 meter

 DIFFERENCE CLASS COUNTS:
```

Number of Class 1 cells = 63032 45.25 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 2 cells = 71517 51.34 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 3 cells = 4757 3.41 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS

Figure 26. Pass 2 elevation difference overlay for the Philippines dataset.



The lowest class, in green, shows vegetation from 7 to about 14 m in height interspersed with taller crowns. The middle class (red) and highest class (blue) capture most of the individual tree crowns represented in the peaks overlay that appear to be managed in an orchard-like setting. Figure 26 shows that these trees are mostly above 14 m in height and that the highest trees, above 21 m, are mostly concentrated on the left side of the DEM subset. In this case, the difference overlay complements the peaks overlay in providing addition height information for the tree crowns as well as extracting some surrounding vegetation. This concludes the tutorial exercises for the Philippines sample dataset.

4 Conclusion

The DEM Breakline and Differencing Analysis Tool, developed in the ENVI/IDL image processing application, is designed to serve as an aid to research in the investigation of DEMs representing terrain, vegetation, and the built environment. The Breakline Tool's ability to effectively extract and display breaklines from digital terrain models is a key feature of the tool's algorithmic approach. Output can be customized through user control of various processing parameters. Breakline overlays can be combined with difference models from input first-surface and BE models to extract a range of features associated with open terrain, canopy, and structures. Other output overlays for slope, terrain roughness, and breakline gradient direction are available in the tool to enhance the analysis of extracted features from digital terrain models.

In this tutorial, step-by-step workflows and example data are provided to engage the user in creating and interpreting a variety of output overlays from a diverse set of sample data models. It is hoped that the techniques and parameter choices demonstrated herein will serve as lessons learned for applying the tool to other data models in a research setting or in specific tactical situations.

References

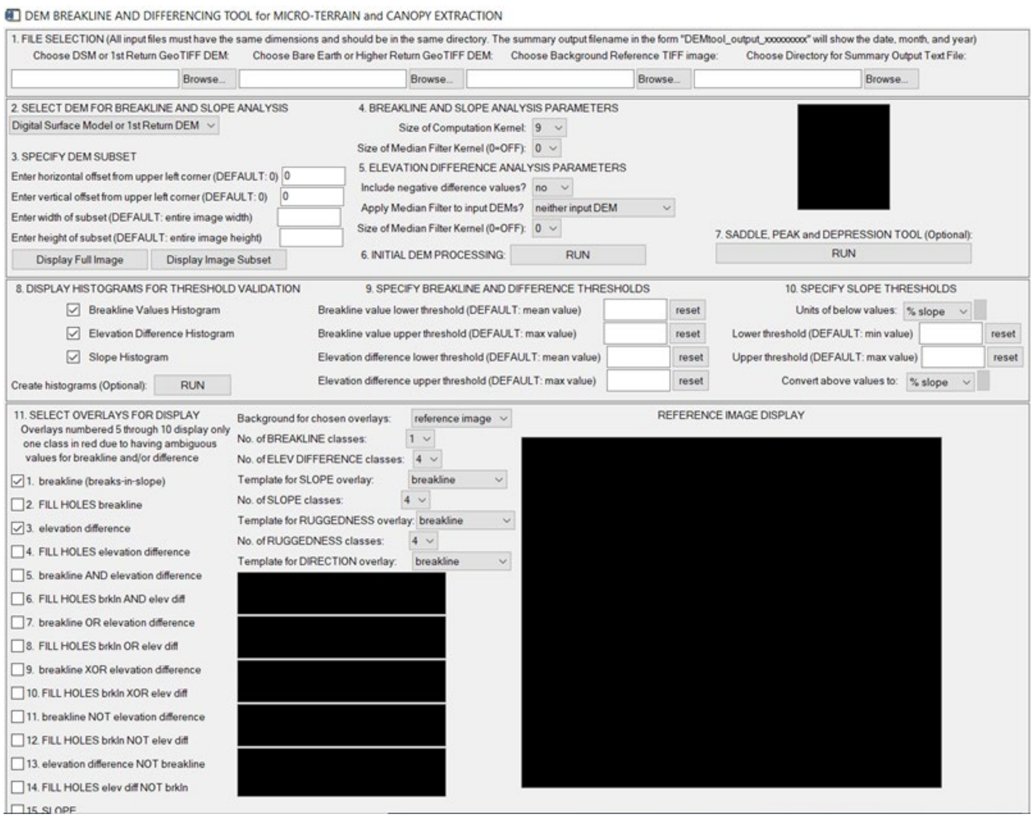
Blundell, S. B. 2021. “Micro-Terrain and Canopy Feature Extraction by Breakline and Differencing Analysis of Gridded Elevation Models: Identifying Terrain Model Discontinuities with Application to Off-Road Mobility Modeling.” ERDC /GRL TR-21-2. Vicksburg, MS: Engineer Research and Development Center, Geospatial Research Laboratory. http://dx.doi.org/10.21079/11681/40185.

Blundell, S. B. 2022. “User Guide: The DEM Breakline and Differencing Analysis Tool: Gridded Elevation Model Analysis with a Convenient Graphical User Interface.” ERDC/GRL TR-22-1. Vicksburg, MS: Engineer Research and Development Center, Geospatial Research Laboratory.

Appendix A: Breakline Tool GUI

The latest version of the breakline tool GUI is shown in Figure A-1. This GUI provides all of the functionality in a single interface.

Figure A-1. Graphical user interface (GUI) in ENVI of the breakline tool.



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14. ABSTRACT
The DEM Breakline and Differencing Analysis Tool is the result of a multi-year research effort in the analysis of digital elevation models (DEMs) and the extraction of features associated with breaklines identified on the DEM by numerical analysis. Developed in the ENVI/IDL image processing application, the tool is designed to serve as an aid to research in the investigation of DEMs by taking advantage of local variation in the height. A set of specific workflow exercises is described as applied to a diverse set of four sample DEMs. These workflows instruct the user in applying the tool to extract and analyze features associated with terrain, vegetative canopy, and built structures. Optimal processing parameter choices, subject to user modification, are provided along with sufficient explanation to train the user in elevation model analysis through the creation of customized output overlays.

15. SUBJECT TERMS
Digital elevation models; Military geography; Remote sensing; Optical radar; Geospatial data; Computer programs; Graphical user interfaces (Computer systems); Workflow

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