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Geointelligence—Geospatial Data Analysis and Decision Support

User Guide: The DEM Breakline and Differencing Analysis Tool

Gridded Elevation Model Analysis with a Convenient Graphical User Interface

S. Bruce Blundell

August 2022

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User Guide: The DEM Breakline and Differencing Analysis Tool

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Abstract

Gridded elevation models of the earth's surface derived from airborne lidar data or other sources can provide qualitative and quantitative information about the terrain and its surface features through analysis of the local spatial variation in elevation. The DEM Breakline and Differencing Analysis Tool was developed to extract and display micro-terrain features and vegetative cover based on the numerical modeling of elevation discontinuities or breaklines (breaks-in-slope), slope, terrain ruggedness, local surface optima, and the local elevation difference between first surface and bare earth input models. Using numerical algorithms developed in-house at the U.S. Army Engineer Research and Development Center, Geospatial Research Laboratory, various parameters are calculated for each cell in the model matrix in an initial processing phase. The results are combined and thresholded by the user in different ways for display and analysis. A graphical user interface provides control of input models, processing, and display as color-mapped overlays. Output displays can be saved as images, and the overlay data can be saved as raster layers for input into geographic information systems for further analysis.

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Preface

This study was conducted for the United States Army Corps of Engineers under PE 633463, Project AU1 // PE 622146, Project AT9, "TGIC/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 Research Division, U.S. Army Engineer Research and Development Center, Geospatial Research Laboratory. At the time of publication, Ms. Jennifer L. Smith was Branch Chief, Mr. Jeffrey Murphy was Division Chief, and Mr. Vijay Acharya was the Technical Director. Ms. Valerie L. Carney was Deputy Director and Acting Director.

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

Acronyms and Abbreviations

Acronym	Meaning
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
GUI	graphical user interface
IDL	Interactive Data Language
TGIC	Tactical Geospatial Information Capabilities
TIFF	Tag Image File Format
TIN	Triangular Irregular Network
USACE	U.S. Army Corps of Engineers

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1 Introduction

1.1 Background

The DEM Breakline and Differencing Analysis Tool (hereafter referred to as the IDL Breakline Tool or simply Breakline Tool) was developed at U.S. Army Engineer Research and Development Center (ERDC), Geospatial Research Laboratory (GRL) in the ENVI/IDL image processing environment developed by the L3Harris Technologies. The Breakline Tool's main function is the analysis of digital elevation models (DEMs) for extraction of fine-scale, subtle breaklines or breaks-in-slope (discontinuities) on a cell-by-cell basis. These terrain model discontinuities are often associated with actual features such as minor escarpments or stream channels.

The IDL Breakline Tool was designed to take advantage of high spatial resolution gridded elevation models, such as those often created from the point clouds collected by airborne lidar scanners. Modern airborne lidar scanning systems generate voluminous patterns of laser pulses of near-infrared light to acquire accurate range measurements. These point clouds can then be converted into high-resolution gridded digital elevation terrain models. The conversion can be performed by special-purpose software, such as the open-source package LAStools (created by rapidlasso GmbH in Germany). In recent years, such models derived from lidar have become more widely available, allowing for more detailed analysis of terrain features, vegetative cover, and artificial structures. These models allow high-fidelity terrain feature mapping at sub-meter resolutions (Carter et al. 2007). Relief patterns in the landscape not only show the locations of individual features but can serve as an indicator of landscape process dynamics, such as erosion and deposition (Hoechstetter et al. 2008).

The IDL Breakline Tool calculates breakline values for each DEM cell location. DEM cell subsets are chosen for output display by selection of upper and lower bounds or thresholds for the breakline values. These cell subsets are shown as color-mapped breakline overlays over a user-selected background, normally a shaded relief or lidar intensity reference image of the underlying terrain. In addition to the breakline overlay, other overlays are available for elevation model differencing, slope, ruggedness, breakline gradient direction, and three types of surface optima: saddle points, peaks, and depressions.

The basic input to the IDL Breakline Tool consists of two coincident DEMs in GeoTIFF format: a digital surface model (DSM), whose elevation values refer to the terrain as well as features above it (e.g., canopy and structures), and a bare earth model, whose elevation values refer only to the underlying terrain. The DSM is also known as a first-surface model. Although any pair of gridded DEMs will suffice, the IDL Breakline Tool is primarily designed to work with gridded DEMs created by systems such as Buckeye, a deployable airborne image and lidar collection capability in use by the US Armed Forces. Such systems provide the horizontal resolution (on the order of 1 m or less) necessary to extract fine-scale terrain features.

1.2 Breakline Tool algorithms

The Breakline Tool incorporates a suite of algorithms that perform initial numerical processing on one or both of the input DEMs, subject to a few user-controlled parameters. This initial processing phase prepares the Breakline Tool for rapid overlay creation controlled by various thresholds chosen by the user.

The basic algorithms dedicated to creating output products perform calculations for (1) breaklines, (2) elevation difference, (3) slope, (4) terrain ruggedness, (5) breakline gradient direction, and (6) three types of surface optima: saddle points, peaks, and depressions. A more thorough treatment of the algorithms is provided in the ERDC/GRL Technical Report *Micro-Terrain and Canopy Feature Extraction by Breakline and Differencing Analysis of Gridded Elevation Models* (Blundell 2021).

Breaklines or slope discontinuities extracted and displayed by the Breakline Tool are often grouped into linear features that may represent micro-terrain. Examples of micro-terrain features include gullies, channels, small scarps, boulder fields, berms, mounds, minor excavations, or any fine-scale terrain irregularity characterized by a sudden change in slope. Such features are found in the DEM by calculating a breakline value with a modified numerical cubic spline interpolation technique applied to elevation values in the neighborhood of each model cell. The interpolation over a neighborhood allows for the calculation of slope and the identification of abrupt changes in slope. This neighborhood is determined by a user-chosen kernel size, providing control over the spatial resolution of breakline features and slope values. The Breakline Tool can display an overlay of color-mapped breakline values over a reference image created from the input DEM. The matrix cells chosen for display are controlled by upper and lower thresholds chosen by the user. By selecting various computation and display parameters, the breakline overlay shows the locations of features associated with elevation discontinuities. The units associated with the breakline value are inverse distance (e.g., 1/m).

In addition to micro-terrain features, vegetated areas may also be extracted with the breakline overlay by taking advantage of the densely packed discontinuities that occur in the DEM representation of canopy. This technique only requires the DSM or first-surface model and is effective in extracting tree canopy, crop canopy, and individual plants.

The elevation model differencing overlay uses an algorithm that subtracts bare-earth model cell elevation values from the corresponding cells in the DSM. The resulting model is normalized for absolute elevation and is often referred to as a “canopy height” model. In addition to tree canopy, buildings and other structures not appearing in the bare-earth model are also represented in like manner in the difference model. If a lidar last return-based DEM is used instead of a bare earth model, buildings and structures will remain in the difference model.

The slope overlay is calculated by a numerical technique similar to that for the breakline values. This overlay provides a slope analysis function for characterizing elevation-dependent features such as hill slopes or roof geometry.

The ruggedness overlay displays values of a ruggedness parameter specially developed for the Breakline Tool called the Breakline Ruggedness Index, or BRI. This parameter, calculated for each matrix cell, incorporates the breakline value, the slope, and a measure of the elevation variance in the cell’s vicinity. This overlay shows the roughness or elevation texture of the terrain surface as well as that of vegetative canopy. The BRI value has no associated units. The algorithm is designed to create a dimensionless value to represent ruggedness in the neighborhood of each cell.

The gradient direction overlay shows the azimuthal direction associated with the maximum breakline value (the maximum spatial rate of change in slope) for all model cells identified in the breakline overlay. These cells are color-mapped by a limited set of defined directions. This overlay is useful in identifying the directional trending of breakline-defined features.

The Breakline Tool can also display overlays for three types of optima on the surface of an input DEM: saddle points, peaks, and depressions. Overlays for peaks and depressions may show mounds and low areas of terrain, such as can occur in disturbed land. Saddle points, which are akin to mountain passes in very rugged terrain, can also occur in gently rolling terrain and may, for example, indicate preferred routes for off-road mobility. The Breakline Tool contains an optimization algorithm that employs a numerical gradient method to find optima on the DEM surface.

1.3 Approach

The Breakline Tool is presented to the user as a graphical user interface (GUI) with a variety of controllable parameters. The GUI is organized as a series of numbered boxes in sequence requiring user input or consideration. There are 12 steps in the sequence in which the user can make selections for input files, initial processing, thresholding of results, and desired types of output overlays for display.

Required input to the Breakline Tool consists of a gridded DSM in GeoTIFF format (normally but not necessarily created from a lidar-derived first-surface model), a bare earth model in GeoTIFF format, and a reference TIFF image coincident with the elevation models and used for background display. If a lidar data collection is the source data for the model—and a bare earth model is not available—a DEM based on the last return data can substitute for the bare earth model. The elevation values of such a DEM will be based on lidar pulse energy reflected from deeper in the canopy and may serve as an acceptable approximation of the under-canopy ground surface.

The ENVI/IDL GUI for this tool is shown in Figure 1. User control of input parameters and desired output display is available directly from the GUI, except for control and display of the optimization overlays. In that case, a separate sub-GUI is available for control and display of saddle points, peaks, and depressions. This sub-GUI is shown in Figure 2.

During processing, various input and output statistics are provided in the IDL console window for input file parameters, breakline and differencing model values, selected histograms, overlay cell counts, and azimuthal breakline direction classes. This information is reflected in a separate text box window that remains open during processing. It is also captured in a text file that is appended with information from all processing runs that take place on any particular date.

Figure 1. DEM Breakline and Differencing Analysis Tool GUI.

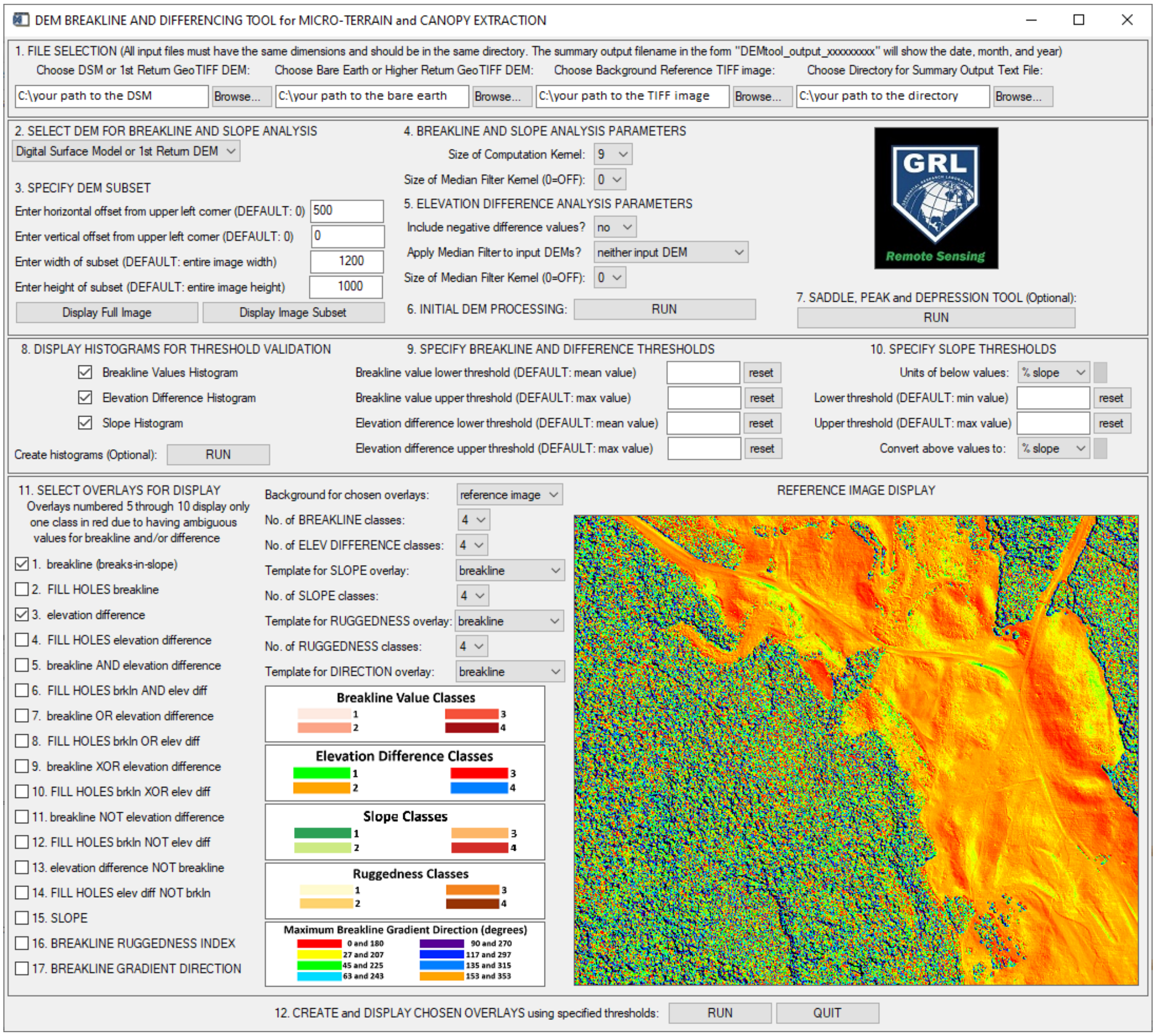
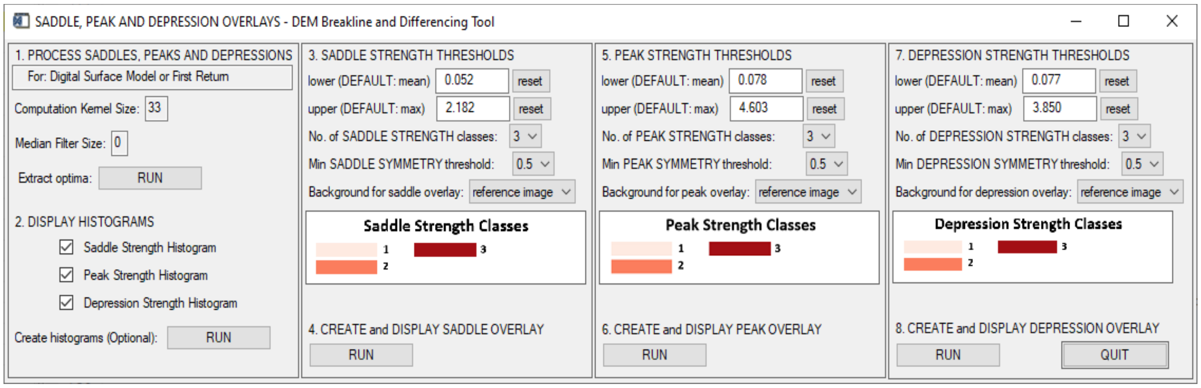


Figure 2. Optima Extraction Tool sub-GUI.



1.4 Objectives

This user guide was prepared in direct support of the Tactical Geospatial Information Capabilities Project, through the Enhanced Terrain Processing (ETP) Task conducted at ERDC GRL. The goal of ETP is to improve the processing of tactical geospatial data in order to generate feature data more quickly and with higher accuracy. The Army requires up-to-date tactical geospatial data and associated terrain products and relies on disparate community databases and software tools with limited processing ability. ETP was created to provide accurate, timely, and actionable geospatial data and products for Army operations.

This report was prepared under direction of the ETP breakline analysis team. This report's purpose is to provide users of the Breakline Tool a complete description of the configuration and functional components of the Breakline Tool's GUI and available options for processing and display creation. Step-by-step workflow procedures are presented for DEM analysis using the Breakline Tool's algorithms and output capabilities. Familiarity with the Breakline Tool's basic design and purpose will foster its continued application to gridded terrain models for ground feature and vegetation analysis. The Breakline Tool and its algorithms were developed over time. Under ETP, they were improved and enhanced, and many of the Breakline Tool's basic capabilities were transitioned to other data processing environments.

1.5 Scope

The complete Breakline Tool in the ENVI/IDL environment is offered as an in-house resource for general elevation model analysis and can be reconfigured for more specific research applications or input datasets. The following sections provide a detailed description of its use, organized around the themes of initialization (Section 2), pre-processing (Section 3), histogram creation and threshold selection (Section 4), overlay creation (Section 5), and optima extraction (Section 6).

2 Initialization

Smooth operation of the Breakline Tool requires initial configuration of the local file structure and of the ENVI/IDL runtime environment. These procedures are described below.

2.1 Breakline Tool setup

The Breakline Tool runs in the ENVI/IDL environment and requires a current license. In addition, certain file structure requirements must be met with respect to the IDL procedures, DEM data files, and required graphics files.

The Breakline Tool consists of 23 separate IDL procedures, a collection of required graphics files in a folder called "GUI_GRAPHICS," and a helpful startup file called "my_startup_gui_breakline.pro." To initialize the ENVI/IDL runtime environment and set up the Breakline Tool on a local computer:

1. Copy the IDL procedures from the Breakline Tool source file location to a folder called "ROUTINES" located somewhere in the file structure. It may be helpful to create a top-level folder called "BREAKLINE TOOL" or something similar that holds "ROUTINES."
2. Copy the folder "GUI_GRAPHICS" to the top-level folder.
3. Place a copy of "my_startup_gui_breakline.pro" in the IDL Workspace location that was created during ENVI/IDL installation (e.g., C:\Users\your ID\IDLWorkspace\my_startup_gui_breakline.pro).
4. Create a folder called "Summary Output Files" or something similar in a convenient location (e.g., C:\Users\your ID\Documents\BREAKLINE TOOL\SUMMARY OUTPUT FILES).
5. The input model data files (first-surface DEM and bare earth DEM) and a required reference TIFF background image should all be located at the same level in the file structure.
6. Start ENVI+IDL.
7. In IDL, go to the Preferences dialog under "Window." For "Startup File" under the IDL menu option, add the full path to the startup file in your IDL Workspace.
8. For "Initial Working Directory," add the full path to the "ROUTINES" folder. When the Breakline Tool is run, the "current working directory" is changed to that location.

9. For "Paths," under "IDL Path," insert the path to the directory that holds the "ROUTINES" folder (e.g., C:\Users\your ID\Documents\BREAKLINE TOOL\). Then check the box next to it; this will force it to include subdirectories. Apply the changes and close the dialog.

2.2 Breakline Tool startup

To start the Breakline Tool:

1. In IDL, select "File" and "Open." You should see the routines in your IDL initial working directory. If not, navigate to the folder containing the routines.
2. Open procedure "gui_breakline.pro" from the File menu or the Toolbar. Compile this procedure.
3. In the IDL console window, type "gui_breakline <RTN>" to bring up the Breakline Tool GUI.

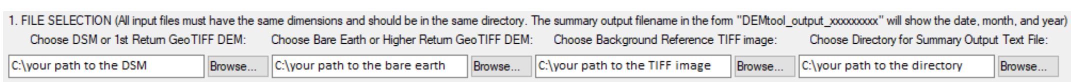
3 Pre-Processing

The steps required for the elevation model analysis functions of the Breakline Tool are organized in a more or less sequential manner. The user should address these steps in the sequence presented in the GUI in order to fully understand the Breakline Tool's capabilities and limitations in creating overlay output for further analysis. Although there are several user-selectable parameters required for controlling the output displays, defaults are provided to allow for rapid initial output that can then be adjusted by fine-tuning the parameters.

3.1 Initial file selection

The first step in breakline processing is initial file selection. Three input files and one output file are required for pre-processing. At the top of the GUI, go to "1. FILE SELECTION" (Figure 3) and use the browse buttons to navigate to a first-surface GeoTIFF DEM, a bare earth GeoTIFF DEM, and a reference TIFF image that will be used as background for generated overlays. The final browse button requires the selection of a directory where a summary output text file for the current session will be located. If a folder was created during setup procedures to hold these files as described above, its location should be specified here.

Figure 3. File selection.



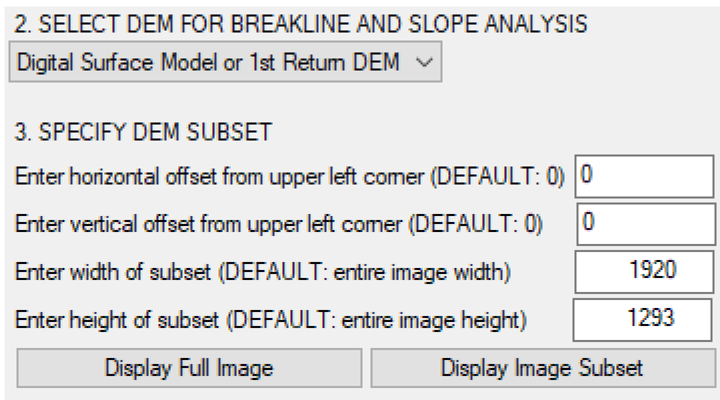
3.2 Selection of DEM subset

After initial file selection, the next step is to select a DEM and a particular subset of it for processing. Under "2. SELECT DEM FOR BREAKLINE AND SLOPE ANALYSIS" (Figure 4), the pull-down menu is used to choose either "Digital Surface Model or 1st Return DEM" or "Bare Earth or Higher Return DEM." The default is the 1st return DEM, which would capture more of the vegetative canopy structure for breakline analysis and potential extraction.

A subset of the DEM selected above may now be chosen under "3. SPECIFY DEM SUBSET" (Figure 4). The text boxes may be edited to provide desired offsets from the upper left corner as well as the subset size in pixels. The default is to allow processing for the entire chosen DEM. The full size of the DEM initially appears here during file selection.

Two buttons are available below the DEM subset text boxes. After specifying subset parameters, the correct portion of the reference TIFF image will appear in the "REFERENCE IMAGE" portion of the GUI in the lower right quadrant upon depressing the "Display Image Subset" button. If you depress "Display Full Image," the entire DEM will appear, and if the default text box values have been changed, they will change back to the values that represent the entire DEM.

Figure 4. Selection of input DEM and subset for processing.



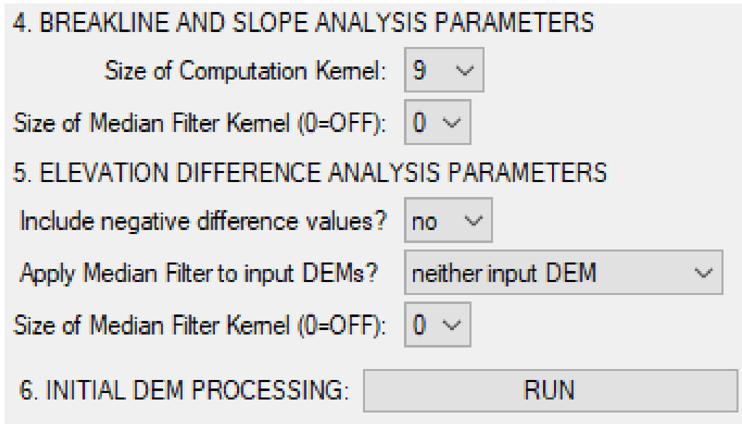
3.3 Selection of analysis parameters and initial DEM processing

After specifying the DEM subset for processing, computation kernel sizes are chosen. The breakline computation kernel determines the geometry of matrix cell sampling for the cubic spline interpolation technique used to compute breakline and slope values for each cell. A median filter option allows for the replacement of each cell's elevation value with the median of values in a surrounding neighborhood determined by the size of the median filter kernel.

Under "4. BREAKLINE AND SLOPE ANALYSIS PARAMETERS" (Figure 5), there are pulldown menus for the size of the breakline computation kernel and the median filter kernel. Available breakline kernel sizes are 5 × 5, 9 × 9, 17 × 17, and 33 × 33, represented by the menu choices 5, 9, 17, and 33. These particular sizes are determined by the kernel geometry and the algorithm's interpolation scheme. The default value is 9 × 9. Smaller kernel sizes allow for detection of more fine-scale detail in discontinuities and slope values for terrain or vegetative canopy. In most cases, the user will probably want to choose either 5 × 5 or 9 × 9. If fine detail is not desired for a particular application, kernel sizes above 9 × 9 may be selected.

The effect of the median filter is to suppress the sharpness and appearance of discontinuities in the selected DEM before calculations are performed. The choices for median filter are 0 (median filter is turned off), 3, 5, and 7. These last three values refer to filter sizes of 3 × 3, 5 × 5, and 7 × 7. The default is 0.

Figure 5. Analysis parameters and initial processing.



Under “5. ELEVATION DIFFERENCE ANALYSIS PARAMETERS” (Figure 5), there are three pulldown menus controlling calculations for the creation of the canopy height model or normalized DEM by elevation difference processing. The first menu allows for the inclusion of negative difference values resulting from the subtraction of the bare earth model from the DSM. Normally, a good bare earth model that conforms well to the actual ground surface will result in very few cells with negative difference. They may sometimes occur due to local micro-terrain discontinuities or depressions in the DSM that are not well-represented in the bare earth model due to the smoothing process during bare-earth model generation. The default is not to include negative difference values, resulting in a more straightforward interpretation of the difference model.

The next menu for elevation difference allows for application of a median filter prior to processing. There are four choices: apply it to neither input DEM (the default), to the DSM or first return, to the bare earth or higher return, or to both input DEMs. As with the breakline and slope median filter, the final menu controls the size of the filter. If any choice other than “apply to neither input DEM” is chosen, the size of the median filter defaults to 3 × 3.

Now that the analysis parameters have been chosen, processing of the input DEMs may proceed. This happens when the user simply depresses the “RUN” button at “6. INITIAL DEM PROCESSING” (Figure 5). Breakline, slope, elevation difference, ruggedness, and breakline direction values will be computed and saved in memory for the creation and display of output overlays. During processing, progress is shown as a percentage of completion in the IDL console window. Processing times vary primarily according to the size of the DEM. A DEM with dimensions of 300 × 400 may take approximately 10 seconds, while a DEM of size 1500 × 2000 may require over 4 minutes.

Upon completion of basic DEM processing, a separate text window appears showing summary output for the run, including file information and elevation, slope, breakline, and elevation difference statistics. This information is also copied into the summary output text file identified in the initial file selection process.

An example of summary text output from basic DEM processing in provided in Appendix A.

At this point in the sequence of Breakline Tool GUI processing steps, under "7. SADDLE, PEAK and DEPRESSION TOOL (Optional)," there is an option to bring up the sub-GUI (Figure 2) for analyzing the surface of the DEM selected under step 2 for optima in the form of saddle points, peaks, and depressions. This option presents the same processing strategy used in the main GUI in terms of histogram creation, selection of particular thresholds, and display of overlays. A full treatment of this sub-GUI will appear in Section 5. To maintain continuity, this processing strategy will first be discussed for the main GUI in the following sections.

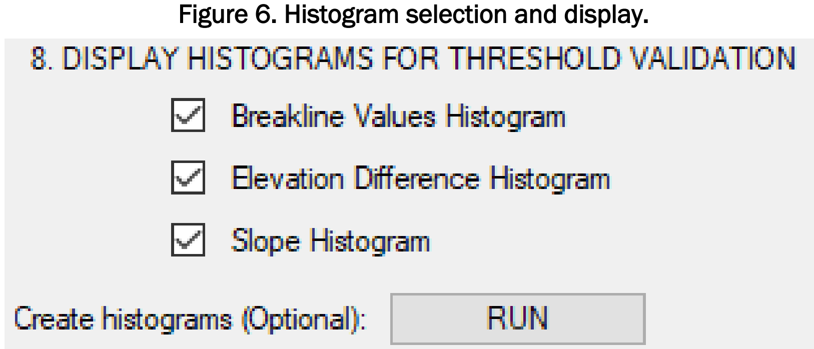
4 Histograms and Thresholds

Now that initial processing of the input DEMs has been completed, the user is ready to specify thresholds for breakline values, elevation difference, and slope, which will be used to control the creation and display of various output overlays. Although defaults are provided for these thresholds, the utility of the Breakline Tool is greatly enhanced by careful selection of relevant thresholds that will result in more useful or desired output. Because all the required parameters are calculated upfront in the initial processing, creation and display of overlays occurs very rapidly, and a trial-and-error process for threshold selection can be very effective. To aid the trial-and-error approach, histogram displays are available to show the user the distribution of parameters before setting their thresholds.

4.1 Optional histograms for threshold validation

The Breakline Tool can display optional histograms for breakline values, elevation difference, and slope. Appropriate upper and lower thresholds for these parameters can sometimes be found by examination of breakpoints in the histogram. For example, there is often a breakpoint at the extreme left of the histogram immediately following an initial spike of very low values (see Appendix B). These voluminous matrix cells are often superfluous to useful overlays for breaklines, elevation difference, and slope and can be excluded by setting the lower threshold to the parameter value at the breakpoint. Under "8. DISPLAY HISTOGRAMS FOR THRESHOLD VALIDATION" (Figure 6), the user can check one or more of the boxes next to the histogram choices, followed by depressing the "RUN" button. The default is to display all three.

Figure 6. Histogram selection and display.



Normally, the user will want to display histograms, if desired, directly after initial processing of the chosen DEM or DEM subset. They will not need to be re-displayed unless changes are made to the selections in steps 1 to 5 above, requiring a re-run of initial DEM processing in step 6.

Examples of generated histograms for breakline values, elevation difference, and slope are provided in Appendix B.

4.2 Threshold selection

The next step in the process is to select upper and lower thresholds for breaklines, elevation difference, and slope. This is done by editing the text boxes in “9. SPECIFY BREAKLINE AND DIFFERENCE THRESHOLDS” (Figure 7) and “10. SPECIFY SLOPE THRESHOLDS” (Figure 8). These parameter limits will define the appearance of overlays to be generated. Default values are provided for an initial attempt at overlay display. For the lower threshold for both breakline and difference, the default value is the mean for all DEM cells in the chosen model. The default lower threshold for slope is the minimum for all chosen model DEM cells. For the upper threshold, the default value is the maximum for all DEM cells for each of the three parameters. The slope threshold units can be specified as percent slope, rise over run (the tangent of the slope angle), or in degrees. These units can be converted one to another using the available pull-down menu. The default is percent slope.

Figure 7. Breakline and difference threshold selection.

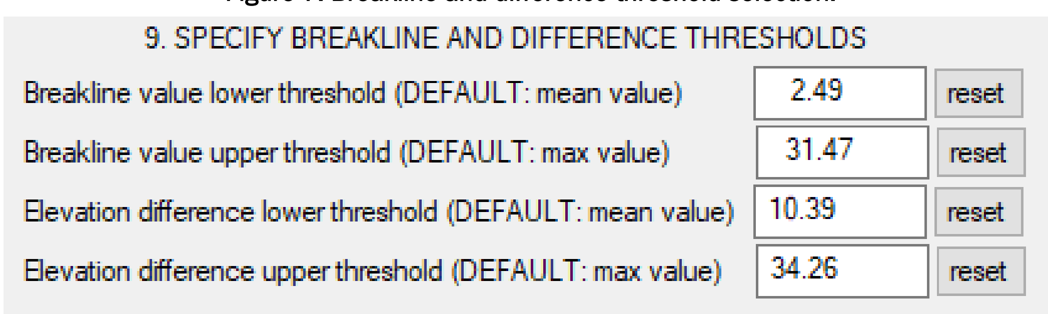
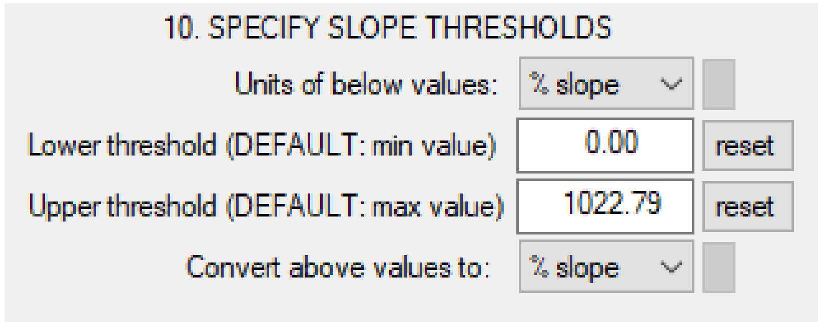


Figure 8. Slope threshold selection and conversion of units.



Using the default threshold values for overlay display provides a quick first look at the breakline, elevation difference, and slope character of the chosen DEM. As mentioned, all the default values can be adjusted after examination of potential breakpoints in the appropriate histogram as described in the preceding section. Alternatively, a trial-and-error fine-tuning process can be employed until an optimal overlay output is found showing a desired level of detail and distribution of the overlay data. For any threshold, the user can return to the default value by depressing the adjoining “reset” button.

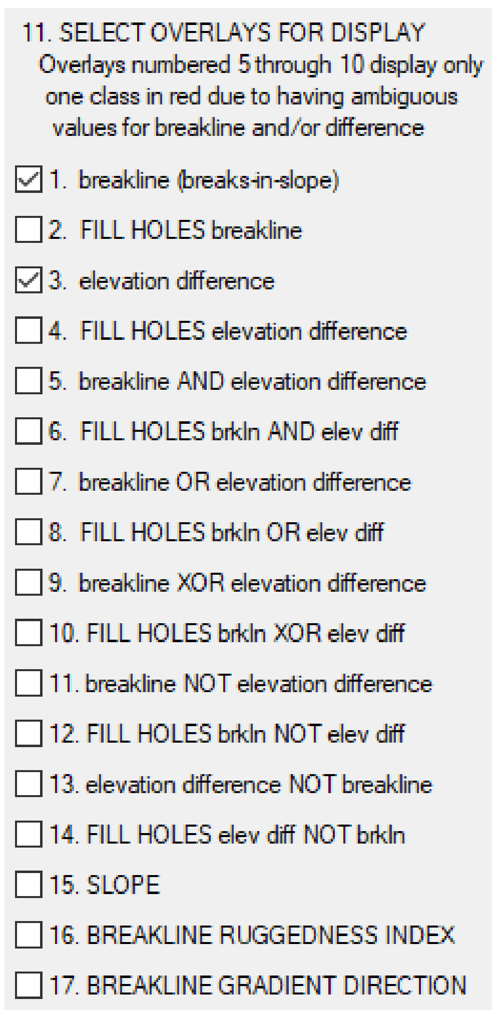
5 Overlay Creation

The final step in the main GUI Breakline Tool workflow is the generation of selected overlays. The appearance of each overlay is based on chosen thresholds, selection of the number of desired color-mapped classes, and selection of a reference background over which the color-mapped matrix cells are displayed.

5.1 Overlay selection

There are 17 overlay types available under "11. SELECT OVERLAYS FOR DISPLAY" (Figure 9).

Figure 9. Overlay selection.



Overlays numbered 1-14 will display thresholded breakline values, elevation difference, or some Boolean combination of the DEM cell locations of the data. There are seven possibilities: breakline value, elevation difference, the intersection (AND) of the two sets of cell locations, the union (OR) of the two sets, the complement of the intersection (XOR) of the two sets, and the subtraction of one set of cell locations from the other (breakline NOT elevation difference and elevation difference NOT breakline). Each of these options is accompanied by a "FILL HOLES" version of the same overlay in which algorithms are applied to the overlay data to fill in small holes and irregularities in the pattern of overlay cells to give the overlay data a more graphic appearance at a slight cost in accuracy with respect to adherence to chosen thresholds.

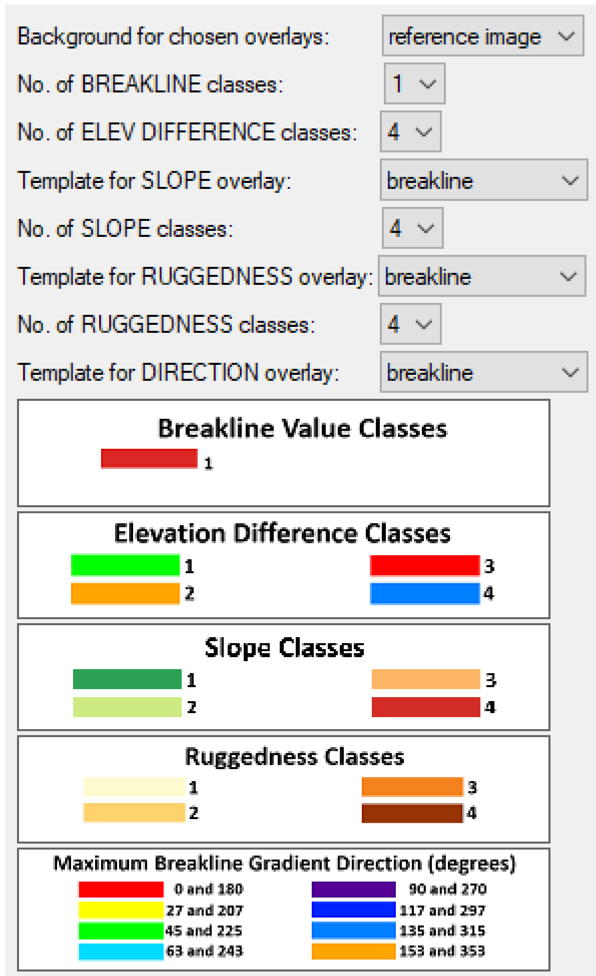
The last three overlay choices, numbered 15–17, are slope, breakline ruggedness index, and breakline gradient direction, respectively. These overlays do not have the same Boolean combination or hole-filling options that are available for the breakline and elevation difference overlays. However, as discussed below, they can use any of the displays 1–14 as a template through which the matrix locations for their computed values are passed, displaying values only for those matrix locations that would appear in the display for the chosen template.

Any combination of overlay choices shown in Figure 9 can be selected at the same time by checking the associated boxes. As a default, selections for the basic breakline and elevation difference overlays are first presented to the user on GUI startup. The selected overlays will be calculated and displayed as a group when processing is started. Each overlay will appear in its own separate window. The appearance of each overlay will depend on chosen thresholds and choices involving the reference background, number of color-mapped classes, and templates selected for overlays 15–17. The selection process for these additional constraints, required before overlays can be generated, is discussed in the next section.

5.2 Overlay display constraints

The user has control over certain features of the final overlay displays before they are generated. This section of the Breakline Tool GUI is shown in Figure 10 as a series of eight pull-down menus above a series of graphics showing a color legend for each basic type of overlay data. The first menu allows for the selection of the display window background for the set of chosen overlays. There are three options: the background reference image identified in the initial file selection procedure, an all-white background, and an all-black background. The default is the background reference image. The latter two options are provided if the user feels the reference image is a distraction during interpretation of the overlay data.

Figure 10. Selection of overlay display constraints



There are four pull-down menus that control the number of color-mapped discrete classes for the various overlay data types. These classes are available for the basic breakline and difference overlays (numbered 1–4), the overlays involving the Boolean NOT operation (numbered 11–14), and the slope, ruggedness, and gradient direction overlays (numbered 15–17). Overlays numbered 5–10 involve the Boolean AND, OR, and XOR operations. As a result, each matrix cell for overlays 5–10 has potentially more than one parameter value assigned to its location. Since these locations may have ambiguous values for breakline and/or difference, overlays 5–10 will only display one class in a single color (red).

For overlays 1–4 and 11–17, the user may select multiple classes if desired. When the number of classes is increased, fewer overlay cells are assigned to each class, increasing the color-mapped representation of the distribution of overlay parameters. Whenever the user changes the number of desired classes, the corresponding color legend graphic is immediately updated.

The second and third pull-down menus in Figure 10 control the number of classes for the breakline and elevation difference overlays, respectively. The default values are 1 class for breaklines and 4 classes for elevation difference. The user may select from 1 to 6 classes.

The fourth and sixth pull-down menus in Figure 10 allow the user to select a template for the slope and ruggedness overlays, if desired. Templates are separate overlays that are intersected with the desired overlay (slope or ruggedness). The templates are chosen from one of the overlays numbered 1–14 in Figure 9. The default is the basic breakline overlay. The user can avoid using a template by selecting “NONE.” If a template is selected, a matrix location for either the slope or ruggedness overlays will only be displayed as a member of a color class if the location is common to the overlay chosen as a template.

The fifth and seventh pull-down menus control the number of color-mapped classes for the slope and ruggedness overlays. The default value for both overlays is 4. For the slope overlay, the user may select from 1 to 6 classes. For the ruggedness overlay, the choice is from 3 to 6 classes. There are fewer choices for ruggedness because this overlay was designed to show the variation in ruggedness over an area, as opposed to identifying particular features. To be of use, the overlay must consist of at least a few color-coded classes. However, the use of a chosen template allows the user some control over the extent of the displayed values. For example, the user might want to show the variation in ruggedness for a particular feature, such as a boulder field, that would otherwise appear in the template overlay display.

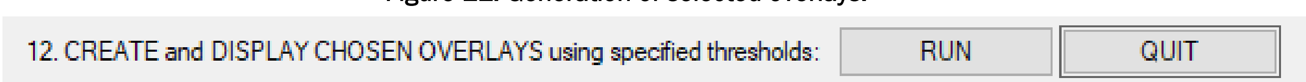
The last pull-down menu in Figure 10 allows the choice of a template for the breakline gradient direction overlay. This overlay shows a color-mapped display of the direction associated with each matrix cell’s breakline value, or direction of maximum slope change. As with slope and ruggedness, a template may be chosen from overlays 1–14, with the default template set to the basic breakline overlay. No template will be applied if “NONE” is selected.

There is no option for the user to choose the number of gradient direction classes. These are limited to either four or eight bilateral directions due to the particular geometry of the cell sampling procedure. The choice of either four or eight directions is set automatically according to the size of the breakline computation kernel. If breakline values were computed for the DEM with a computation kernel size of 5 × 5, there would be four bilateral directions available for color-coded mapping. A chosen computation kernel size larger than this (i.e., 9 × 9, 17 × 17, or 33 × 33) will allow for eight color-coded bilateral gradient directions, as can be seen in Figure 10. The appropriate gradient direction color graphic will change in the GUI in accordance with the user’s choice of breakline kernel size during pre-processing. Because the default breakline computation kernel is 9 × 9, the default number of gradient directions is eight.

5.3 Overlay processing and display

The user is now ready to generate the selected overlays in accordance with chosen thresholds and display constraints. This is done by simply depressing the “RUN” button under “12. CREATE and DISPLAY CHOSEN OVERLAYS using specified thresholds” (Figure 11). The adjoining “QUIT” button can be selected at any time to end the processing session and terminate the main GUI.

Figure 11. Generation of selected overlays.



A separate display window will now appear for each selected overlay type. Since the matrix values for each overlay parameter were already calculated during initial DEM processing, the selected overlays appear rapidly when “RUN” is selected.

Each display window is equipped with a slider at the bottom to adjust the transparency of the color-mapped data over the chosen background. Each window has two pull-down menus: “File” and “Display Options.” Under the “Display Options” menu, there are three options for showing a color legend and two versions of a zoom tool. The color legend comes up as a separate small window showing the colors assigned to the chosen number of classes. Each zoom tool appears in its own window, allowing closer examination of selected portions of the display. The first zoom tool applies to a window snapshot at screen resolution of the visible display, and the second tool applies only to the background image at full resolution. This second zoom tool is only useful when the reference image was chosen as the display background.

Under the "File" menu, both the visible display and the overlay data alone can be saved. The visible display may be saved as an image at screen resolution in four formats: PNG, GIF, JPEG, and TIFF. The overlay data can be saved as a TIFF file for input into another environment such as a geographic information system (GIS). There are two choices for the overlay data format: as color-mapped 8-bit byte integers and as original 32-bit floating point values. However, the floating point option is not available for overlays numbered 5 through 10, which involve AND, OR, and XOR Boolean operations for breakline and elevation difference. As mentioned above, for these overlays, the overlay data DEM cells may have ambiguous floating point values, resulting in confusion.

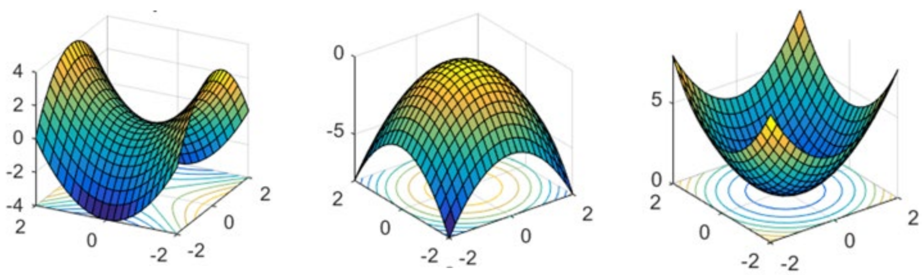
The overlay display window is terminated by pressing 'Quit' under the 'File' menu.

Appendix C provides several examples of overlay output displays for breaklines, elevation difference, slope, ruggedness and breakline gradient direction. Appendix D shows the accompanying textual output for each of the example displays.

6 Optima Extraction

To complement the extraction and display of the parameters described above, the IDL Breakline Tool can also do the same for another class of terrain model features: optima in the form of saddle points, peaks, and depressions (Figure 12). The generation and display of these three related feature types is controlled by a separate sub-GUI, shown in Figure 2, which can be spawned from the main GUI after initial DEM processing. The display of optima is a separate processing thread and is not required to exercise the functions of the main GUI.

Figure 12. Types of optima. At left, saddle; middle, peak; and at right, depression.



6.1 Optimization algorithm

Saddle points, peaks, and depressions can be found on a constantly varying surface such as a terrain model by employing an optimization algorithm in a regular fashion across the surface. Gradient methods are a class of optimization strategies that require the evaluation of derivatives. In the case of a DEM, numerical methods can be used to efficiently evaluate these derivatives of the elevation function represented by the varying elevation values throughout the matrix.

The IDL Breakline Tool employs a gradient method involving the estimation of the elements of a 2 × 2 matrix known as the Hessian matrix (H). The Hessian provides a way to determine whether a multidimensional function has reached an optimum (Chapra and Canale 2002). The elements of this matrix are second-order partial derivatives of the elevation function $E(x,y)$, where x and y are the varying ground distances in a set of orthogonal directions:

$$\begin{bmatrix} \partial^2 E/\partial x^2 & \partial^2 E/\partial x \partial y \\ \partial^2 E/\partial y \partial x & \partial^2 E/\partial y^2 \end{bmatrix}$$

Evaluation of these derivatives can show whether there is a maximum at any DEM cell location (a peak), a minimum (a depression), or neither a maximum nor a minimum, in which case the shape of the terrain surface in the vicinity of the cell can form a saddle point. The derivatives are evaluated numerically by a finite divided-difference approximation method (not shown here). Then, for each cell in the DEM, the determinant of the Hessian matrix (|H|) is calculated:

$$[(\partial^2 E/\partial x^2)\,(\partial^2 E/\partial y^2) - (\partial^2 E/\partial x \partial y)\,(\partial^2 E/\partial y \partial x)]$$

At this point, certain inequalities are evaluated involving Hessian elements and the determinant to determine if there is an optimum at each cell location for the function $f = E(x,y)$. If there is an optimum, there are three possibilities:

If $|H| > 0$ and $\partial^2 E/\partial x^2 < 0$, there is a peak at location x,y.

If $|H| > 0$ and $\partial^2 E/\partial x^2 > 0$, there is a depression at location x,y.

If $|H| < 0$, there is a saddle point at location x,y.

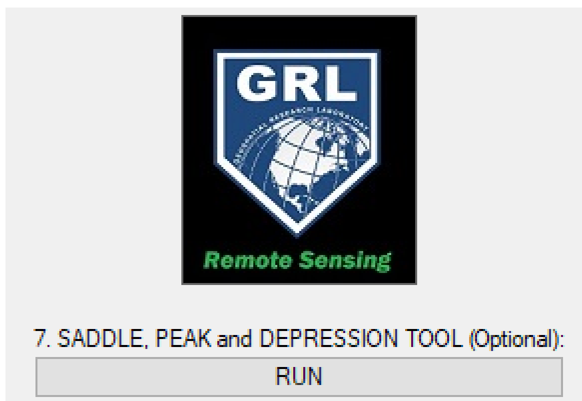
Evaluation of the Hessian matrix in this way for a DEM results in three sets of optima that are mutually exclusive.

The x and y directions need only be orthogonal to each other, and the simplest scenario for ease of calculations is to assume that they represent the column and row directions in the DEM. However, the Breakline Tool optimization strategy is to take the x direction as the direction of the breakline gradient, or direction θ, and the y direction as orthogonal to it, or direction φ. In this way, the optimum-finding process for each matrix cell is tuned to the direction of maximum steepness for each potential optimum, increasing its sensitivity. The directions θ, φ change from cell to cell, and become the directions for sampling the cells needed for numerical evaluation of the Hessian matrix elements. To enable cell sampling in the breakline gradient direction, the algorithm contains a look-up table to translate sampling locations in the θ, φ coordinate system to the corresponding locations in the column*, row* coordinate system of the DEM in the ENVI/IDL environment.

6.2 Optima processing and histogram display

In order to process and display optima from the DEM selected for breakline analysis, the optima extraction tool sub-GUI (Figure 2) must be initiated from the main GUI. This is done by selecting the "RUN" button under "7. SADDLE, PEAK and DEPRESSION TOOL (Optional)" (Figure 13). This tool will not be active until initial DEM processing has been completed.

Figure 13. Optima extraction tool startup.

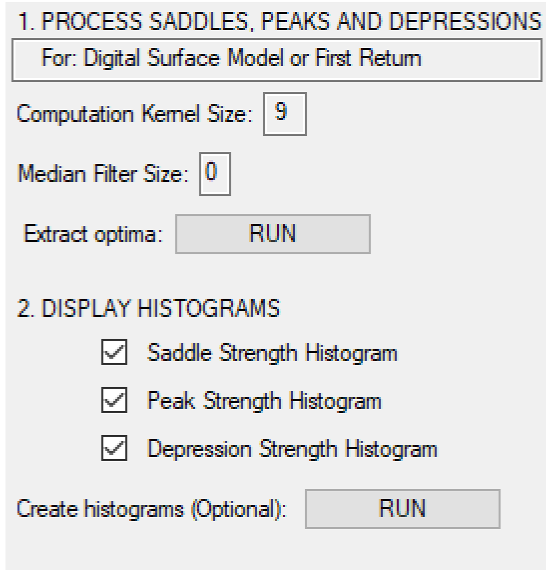


The optima extraction tool for saddles, peaks, and depressions will now appear. To process and extract optima, the user simply selects the "RUN" button in the tool sub-GUI under "1. PROCESS SADDLES, PEAKS, AND DEPRESSIONS" (Figure 14). A text box will then identify the DEM from which optima can be extracted and displayed. This will be the same DEM that was chosen for initial processing, either the "Digital Surface Model or 1st Return" or the "Bare Earth or Higher Return."

The optima processing will take place using the same breakline computation kernel size and median filter already selected. These will appear in separate text boxes for information purposes when calculations are complete. If a different computation kernel size and/or median filter is desired, basic DEM processing must be re-run using the main GUI.

An example of summary text output from optima processing is provided in Appendix E.

Figure 14. Optima processing and histogram completion.



As was the case for displays for breaklines, elevation difference, and slope, the user may display optional histograms to assist in selecting thresholds for controlling the overlays for saddles, peaks, and depressions. This is done by depressing "RUN" in the optima extraction tool under "2. DISPLAY HISTOGRAMS" (Figure 14). In each case, the histogram will show the distribution of the "strength" of each optimum type. For the purposes of the optima extraction tool, "strength" is defined for each extracted optimum as the sum of the absolute values of the elements in the principal diagonal of the Hessian matrix. It expresses the steepness or sharpness of curvature for saddles, peaks, and depressions. The strength of any optimum is always positive and can be thresholded by the user before display. Examples of histograms generated for extracted optima are shown in Appendix F.

6.3 Threshold selection and optima display

The remainder of the optima extraction sub-GUI is given over to the creation and display of optima overlays after setting certain thresholds and display constraints. There are three sections for saddles, peaks, and depressions organized in identical fashion (Figure 15, Figure 16, and Figure 17). The last section for depressions also contains a "QUIT" button to end optima processing while allowing the main GUI to remain active.

Figure 15. Saddle point overlay creation and display.

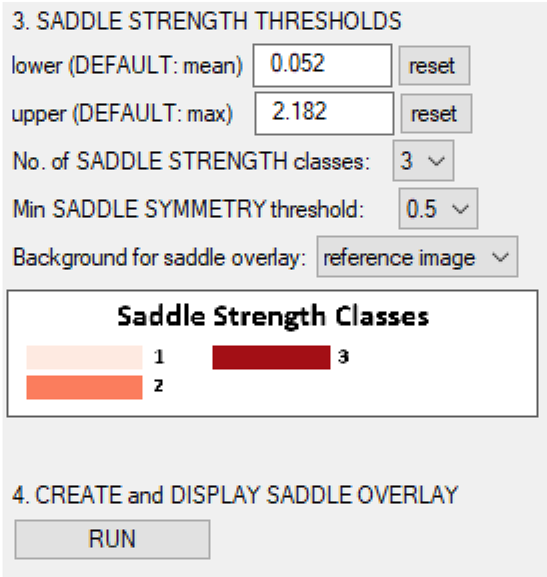
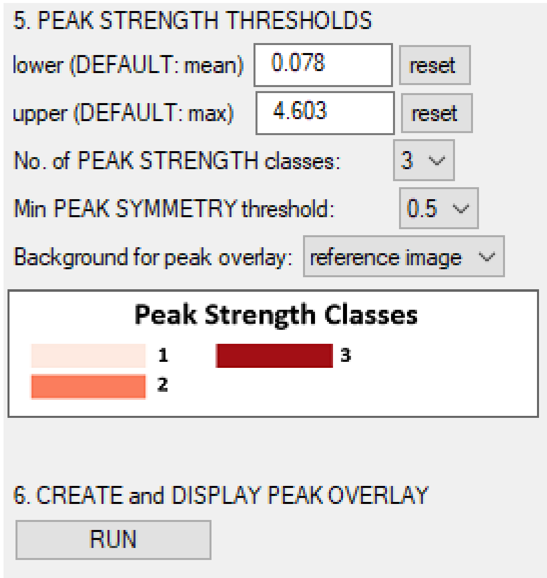
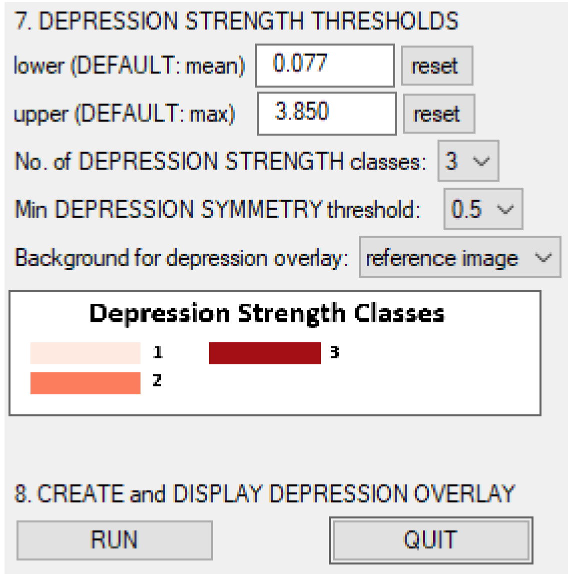


Figure 16. Peak overlay creation and display.



For each optimum type, the user is first asked to select thresholds for the strength parameter, shown in two text boxes. The default for the lower threshold is the mean for all cells found to be an optimum, and for the upper threshold, the default is the maximum. The full range of strength values are provided in the associated histogram.

Figure 17. Depression overlay creation and display.



Below the threshold text boxes are three pull-down menus. The first menu controls the number of discrete classes for the optimum strength parameter. The user may select from 1 to 6 classes; the default is 3. Increasing the number of classes will increase the color-mapped representation of the distribution of the strength parameter. Whenever the user changes the number of desired classes, the corresponding color legend graphic is immediately updated.

The next menu controls another kind of threshold: optima symmetry. This parameter evaluates the curvature of an optimum in orthogonal directions about the optimum's DEM cell location. For the purposes of the optima extraction tool, "symmetry" is defined for each extracted optimum as a ratio of the absolute values of the elements in the principal diagonal of the Hessian matrix. Symmetry is constrained to be between 0 and 1. Therefore, if a ratio is greater than 1, it is inverted according to the following rule:

$$\text{IF} \quad \left|\frac{\partial^2 E}{\partial x^2}\right| > \left|\frac{\partial^2 E}{\partial y^2}\right| \text{ THEN sym} = \left|\frac{\partial^2 E}{\partial y^2} / \frac{\partial^2 E}{\partial x^2}\right| \text{ ELSE sym} = \left|\frac{\partial^2 E}{\partial x^2} / \frac{\partial^2 E}{\partial y^2}\right|$$

The user is asked to select a minimum symmetry threshold for each optima type, above which the optima are saved for display. The choices are from 0 to 0.9 in steps of 0.1. The higher this number is for an optimum, the closer it is to perfect symmetry. The default threshold value is 0.5. The symmetry threshold allows the optima cells that fall between the lower and upper strength thresholds to be further winnowed before display.

The default threshold values for strength and symmetry provide a quick first look at the locations of saddle points, peaks, and depressions in the chosen DEM. As with the breakline, elevation difference, and slope thresholds, these default values can be adjusted to get the best overlay after examination of the appropriate histogram for potential breakpoints. Alternatively, a trial-and-error fine-tuning process can be employed until an optimal overlay output is found showing a desired level of detail and distribution of the overlay data. For any threshold, the user can return to the default value by selecting the adjoining "reset" button.

The last pull-down menu allows the user to select the display background for the overlay data. As before, the choices are the reference image and a black or white background. The default is the reference image.

The overlay display for each optimum type is generated upon selecting the appropriate "RUN" button under the color legend graphic.

Appendix G provides examples of overlay output displays for saddles, peaks, and depressions. Appendix H shows the accompanying textual output for each of the example displays.

Appendix A

Example summary text output from basic DEM processing

DEM BREAKLINE, SLOPE, AND DIFFERENCE PROCESSING FOR MICRO-TERRAIN AND CANOPY ANALYSIS
Run executed Tue Sep 14 11:36:47 2021

CHECK INPUT FILES AND PARAMETERS
Original DSM or first surface file:
C:\your path\Documents\BREAKLINE TOOL\AP HILL SAMPLE DATA\APHILL_1stReturn_DEM.tif
Bare Earth or Higher Return file:
C:\your path\Documents\BREAKLINE TOOL\AP HILL SAMPLE DATA\APHILL_BareEarth_DEM.tif
Hillshade or Intensity image file:
C:\your path\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...

Horizontal offset from upper left corner: 480
Vertical offset from upper left corner: 300
Width of subset: 1440
Height of subset: 980
Kernel size for breakline computations: 9
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 m

Processing started at Tue Sep 14 11:36:47 2021

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

Processing ended at Tue Sep 14 11:39:47 2021
Elapsed time in seconds 179

ELEVATION, SLOPE, AND BREAKLINE STATISTICS, no median filter

DSM or FIRST RETURN

minimum elevation = 23.71
maximum elevation = 67.00
mean elevation = 42.87

std dev elevation = 9.29

BARE EARTH or HIGHER RETURN

minimum elevation = 23.72
maximum elevation = 41.37
mean elevation = 32.48
std dev elevation = 3.15

Parameters for SLOPE and BREAKLINE Vector Magnitudes are derived from absolute values:

minimum slope = 0.00
maximum slope = 10.23
mean slope = 1.38
std dev slope = 1.46

minimum breakline = 0.00
maximum breakline = 31.47
mean breakline = 2.49
std dev breakline = 2.89

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
maximum elevation difference = 34.26
mean elevation difference = 10.39
std dev elevation difference = 8.69

DIFFERENCE CELL COUNTS

INITIAL POSITIVE DIFFERENCE CELLS
Count = 1390643 98.54 % subimage cells; 98.54 % difference cells
INITIAL NEGATIVE DIFFERENCE CELLS
Count = 20557 1.46 % subimage cells; 1.46 % difference cells
TOTAL DIFFERENCE CELLS (POS + NEG)
Count = 1411200 100.00 % subimage cells

Appendix B

Example histograms from basic DEM processing

Figure B-1. Elevation difference (canopy height) histogram.

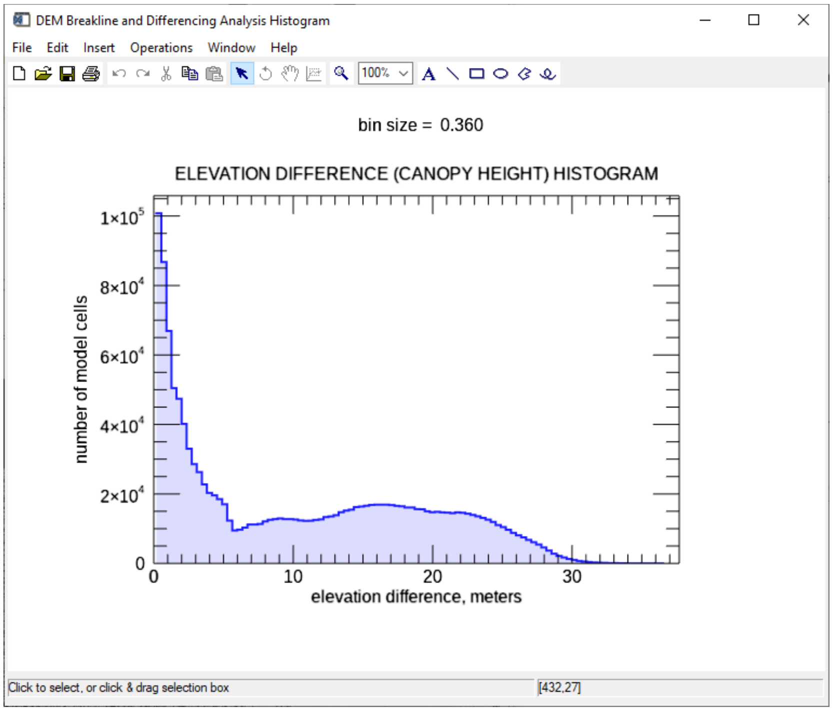


Figure B-2. Breakline values histogram.

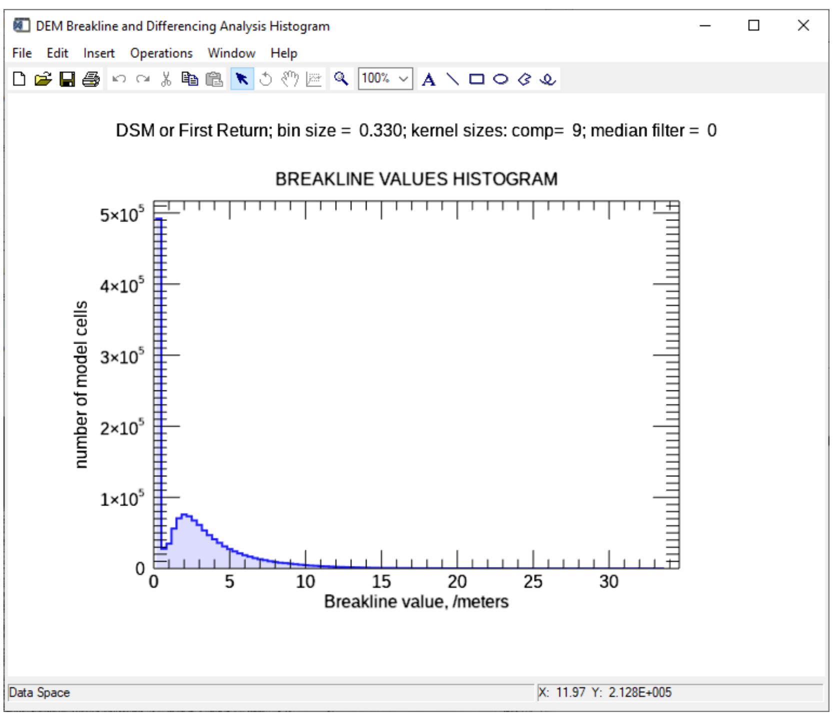
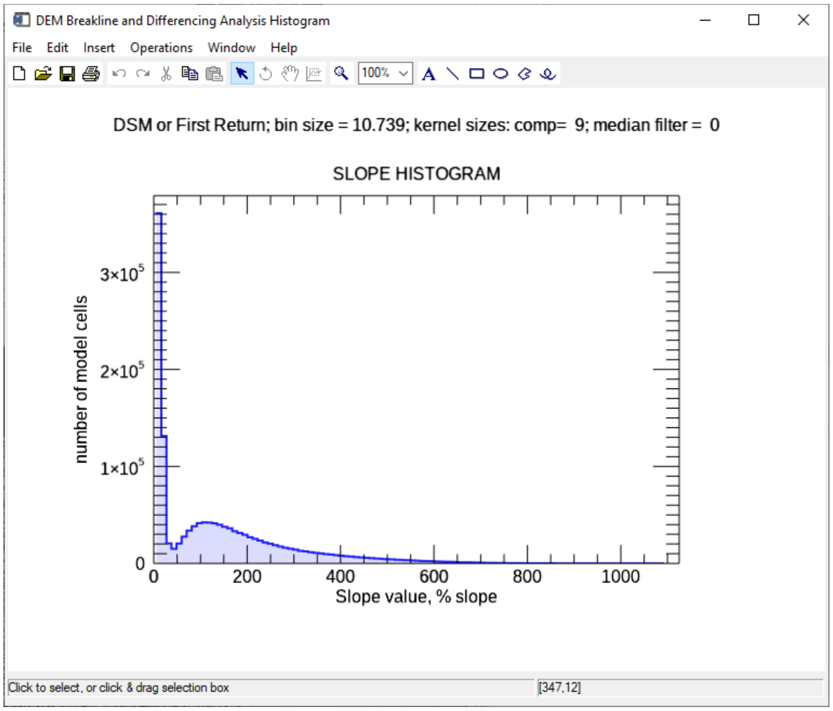


Figure B-3. Slope histogram.



Appendix C

Example overlay displays from basic DEM processing

Figure C-1. Breakline overlay

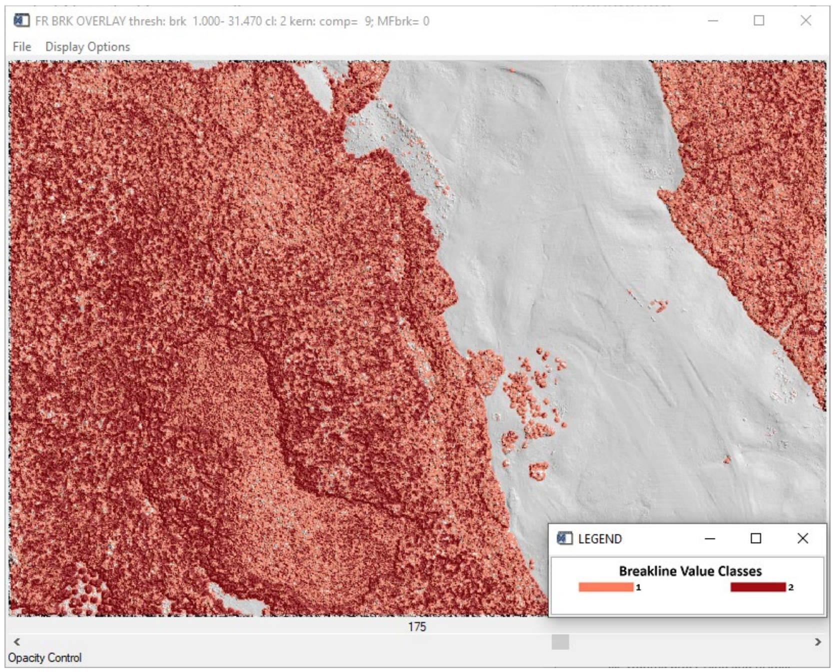


Figure C-2. Elevation difference overlay.

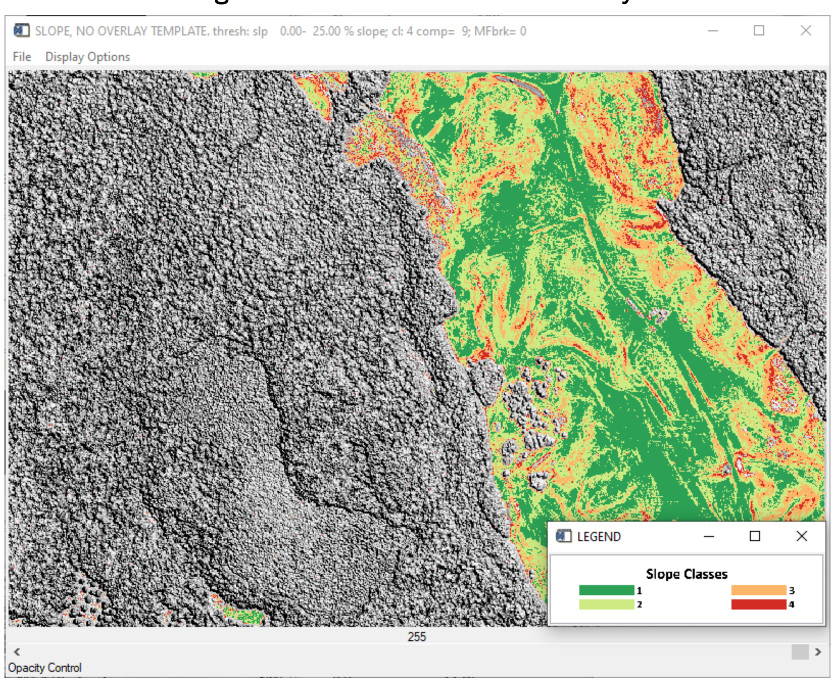


Figure C-3. Slope overlay.

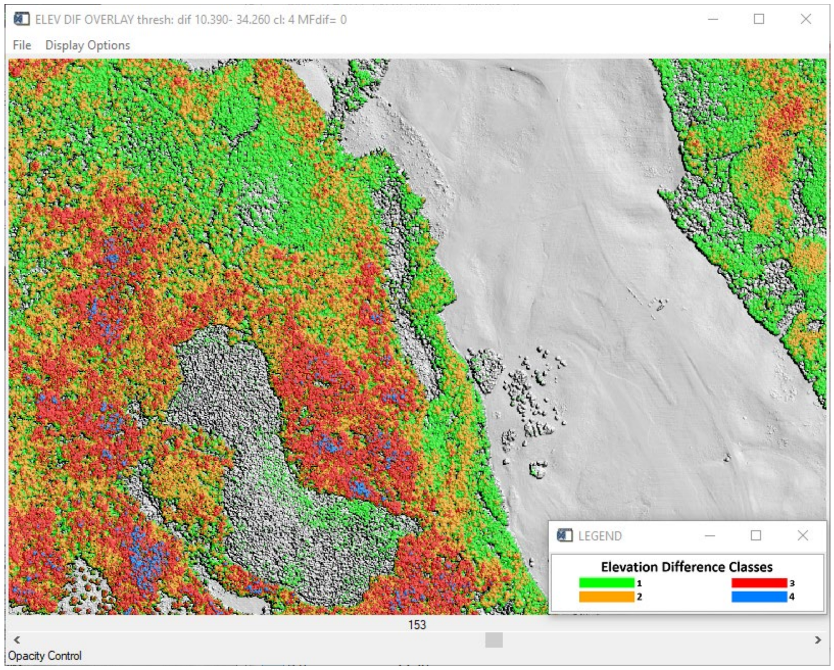


Figure C-4. Ruggedness overlay.

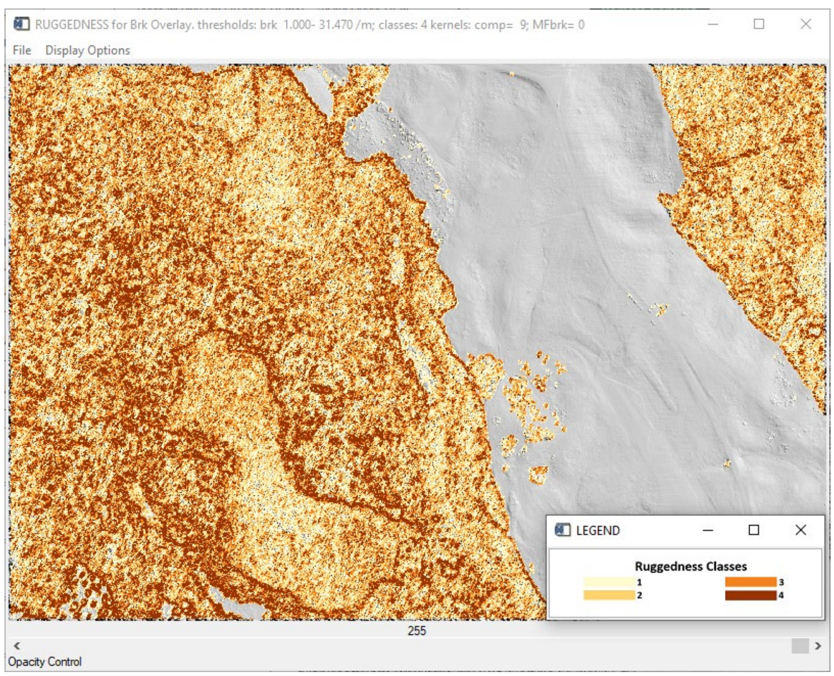
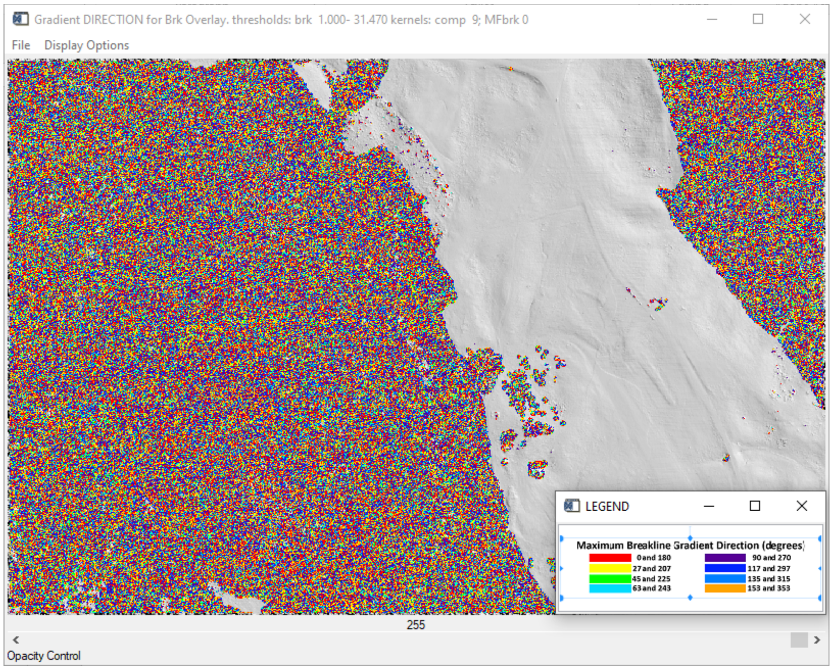


Figure C-5. Breakline gradient direction overlay.



Appendix D

Example summary text output from basic overlay displays

Breakline overlay

Running GUI_OVERLAY...
Generating overlays and summary statistics.

CURRENT USER-DEFINED THRESHOLDS:
Number of model cells in subimage = 1411200
Breakline thresholds: 1.00000 to 31.4700 /m
Difference thresholds: 10.3900 to 34.2600 m
Slope thresholds: 0.000000 to 1022.79 % slope

Creating the BREAKLINE Overlay for 2 classes. Class colors range from light red to dark red.
Number of breakline cells between thresholds = 856534 60.70 % of subimage cells

Equal area solution: class limits adjust to allow the same number of cells in each class.
Target cell count for each of 2 classes = 428267

BREAKLINE CLASS LIMITS:
Class 1 lower: 1.0000 upper: 3.1425 /m
Class 2 lower: 3.1425 upper: 31.4700 /m

BREAKLINE CLASS COUNTS:
Number of Class 1 cells = 428269 50.00 percent of BREAKLINE OVERLAY cells
Number of Class 2 cells = 428269 50.00 percent of BREAKLINE OVERLAY cells

Elevation difference overlay

Running GUI_OVERLAY...
Generating overlays and summary statistics.

CURRENT USER-DEFINED THRESHOLDS:
Number of model cells in subimage = 1411200
Breakline thresholds: 1.00000 to 31.4700 /m
Difference thresholds: 10.3900 to 34.2600 m
Slope thresholds: 0.000000 to 1022.79 % slope

Creating the ELEVATION DIFFERENCE Overlay for 4 classes. Class colors range from green to blue.
Number of elevation difference cells between thresholds = 661272 46.86 % of subimage cells

Equal class width solution: width = (high threshold - low threshold) / 4 = 5.967

DIFFERENCE CLASS LIMITS:

Class 1 lower: 10.390 upper: 16.358 m
Class 2 lower: 16.358 upper: 22.325 m
Class 3 lower: 22.325 upper: 28.292 m
Class 4 lower: 28.292 upper: 34.260 m

DIFFERENCE CLASS COUNTS:
Number of Class 1 cells = 240972 36.44 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 2 cells = 253862 38.39 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 3 cells = 154747 23.40 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS
Number of Class 4 cells = 11691 1.77 percent of DIFFERENCE OVERLAY cells within CURRENT THRESHOLDS

Slope overlay

Running GUI_OVERLAY...
Generating overlays and summary statistics.

CURRENT USER-DEFINED THRESHOLDS:
Number of model cells in subimage = 1411200
Breakline thresholds: 1.00000 to 31.4700 /m
Difference thresholds: 10.3900 to 34.2600 m
Slope thresholds: 0.000000 to 25.0000 % slope

Creating the SLOPE Overlay for 4 classes. NO TEMPLATE CHOSEN
Colors for slope classes range from GREEN (lowest slope) to RED (highest slope)
TOTAL SLOPE OVERLAY CELLS with template NONE: 482143

Equal class width solution: width = (high threshold - low threshold) / 4 = 0.062 (rise/run)

SLOPE CLASS LIMITS:
Class 1 lower: 0.356 upper: 6.517 % slope
Class 2 lower: 6.517 upper: 12.678 % slope
Class 3 lower: 12.678 upper: 18.839 % slope
Class 4 lower: 18.839 upper: 25.000 % slope

SLOPE CLASS COUNTS:
Number of Class 1 cells = 202666 42.03 percent of SLOPE OVERLAY TEMPLATE cells within CURRENT THRESHOLDS
Number of Class 2 cells = 179221 37.17 percent of SLOPE OVERLAY TEMPLATE cells within CURRENT THRESHOLDS
Number of Class 3 cells = 76909 15.95 percent of SLOPE OVERLAY TEMPLATE cells within CURRENT THRESHOLDS
Number of Class 4 cells = 23347 4.84 percent of SLOPE OVERLAY TEMPLATE cells within CURRENT THRESHOLDS

Ruggedness overlay

Running GUI_OVERLAY...

Generating overlays and summary statistics.

CURRENT USER-DEFINED THRESHOLDS:
Number of model cells in subimage = 1411200
Breakline thresholds: 1.00000 to 31.4700 /m
Difference thresholds: 10.3900 to 34.2600 m
Slope thresholds: 0.000000 to 25.0000 % slope

Creating the Breakline RUGGEDNESS OVERLAY. TEMPLATE will be the BREAKLINE overlay
Colors for ruggedness classes range from LIGHT (lowest value) to DARK (highest value)
TOTAL RUGGEDNESS OVERLAY CELLS with chosen template brk: 856533
Target cell count for each of 4 classes = 214133

RUGGEDNESS CLASS LIMITS:
Class 1 lower: 0.004 upper: 0.829
Class 2 lower: 0.829 upper: 1.347
Class 3 lower: 1.347 upper: 2.196
Class 4 lower: 2.196 upper: 12.399

RUGGEDNESS CLASS COUNTS:
Number of Class 1 cells = 214133 25.00 % of RUGGEDNESS OVERLAY cells
Number of Class 2 cells = 214132 25.00 % of RUGGEDNESS OVERLAY cells
Number of Class 3 cells = 214134 25.00 % of RUGGEDNESS OVERLAY cells
Number of Class 4 cells = 214134 25.00 % of RUGGEDNESS OVERLAY cells

Breakline gradient direction overlay

Running GUI_OVERLAY…
Generating overlays and summary statistics.

CURRENT USER-DEFINED THRESHOLDS:
Number of model cells in subimage = 1411200
Breakline thresholds: 1.00000 to 31.4700 /m
Difference thresholds: 10.3900 to 34.2600 m
Slope thresholds: 0.000000 to 25.0000 % slope

Creating the Breakline DIRECTION OVERLAY. TEMPLATE will be the BREAKLINE overlay

TOTAL BREAKLINE GRADIENT DIRECTION OVERLAY CELLS with template brk: 856534

DIRECTION BIN COUNTS OF MAX BREAKLINE VALUES
Number of cells with direction 1 & value 254 (red) = 180393 21.06 % of DIRECTION OVERLAY TEMPLATE cells
Number of cells with direction 2 & value 191 (yellow) = 102384 11.95 % of DIRECTION OVERLAY TEMPLATE cells
Number of cells with direction 3 & value 146 (green) = 33742 3.94 % of DIRECTION OVERLAY TEMPLATE cells

Number of cells with direction 4 & value 111 (aqua) = 107695 12.57 % of DIRECTION OVERLAY TEMPLATE cells
Number of cells with direction 5 & value 31 (purple) = 186580 21.78 % of DIRECTION OVERLAY TEMPLATE cells
Number of cells with direction 6 & value 63 (blue) = 108748 12.70 % of DIRECTION OVERLAY TEMPLATE cells
Number of cells with direction 7 & value 79 (medblue) = 34623 4.04 % of DIRECTION OVERLAY TEMPLATE cells
Number of cells with direction 8 & value 207 (orange) = 102369 11.95 % of DIRECTION OVERLAY TEMPLATE cells

Appendix E

Example summary text output from optima processing

Performing SADDLE POINT, PEAK and DEPRESSION processing.

Processing DSM or FIRST RETURN model...
File:
C:\your path\Documents\BREAKLINE TOOL\MCMWTC SAMPLE DATA\MCMWTC_1stReturn_DEM.tif

Horizontal offset from lower left corner: 1900
Vertical offset from lower left corner: 200
Width of subset: 1000
Height of subset: 800
Kernel size for saddle, peak, and depression computations: 33
NO Median Filter was applied to the chosen DEM for optima computations. Therefore the DEM will not be filtered in optimizing for saddles, peaks, and depressions.

ABSOLUTE STEEPNESS STATISTICS
min saddle steepness = 0.000000
mean saddle steepness = 0.0521367
median saddle steepness = 0.000000
max saddle steepness = 2.18152

min peak steepness = 0.000000
mean peak steepness = 0.0776945
median peak steepness = 0.000000
max peak steepness = 4.60257

min depression steepness = 0.000000
mean depression steepness = 0.0768313
median depression steepness = 0.000000
max depression steepness = 3.84984

OPTIMA CELL COUNTS
Total # cells: 800000
# of saddle cells above zero steepness: 280434
# of saddle cells above mean steepness: 151803
# of saddle cells above median steepness: 280434
# of peak cells above zero steepness: 205659
# of peak cells above mean steepness: 117934
# of peak cells above median steepness: 205659
# of depression cells above zero steepness: 257331
# of depression cells above mean steepness: 151953
# of depression cells above median steepness: 257331

Appendix F

Example histograms from optima extraction

Figure F-1. Saddle strength histogram.

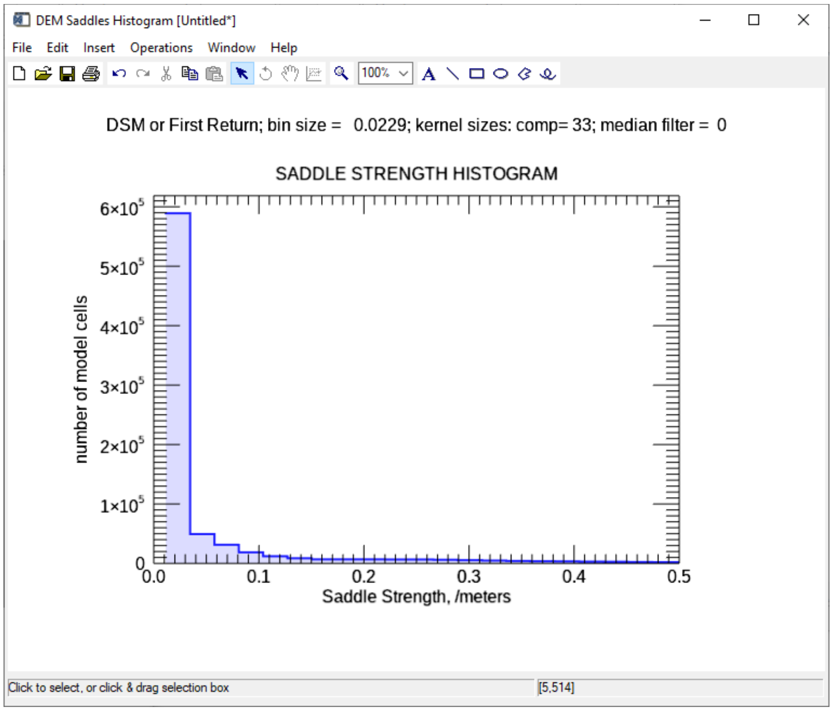


Figure F-2. Peak strength histogram.

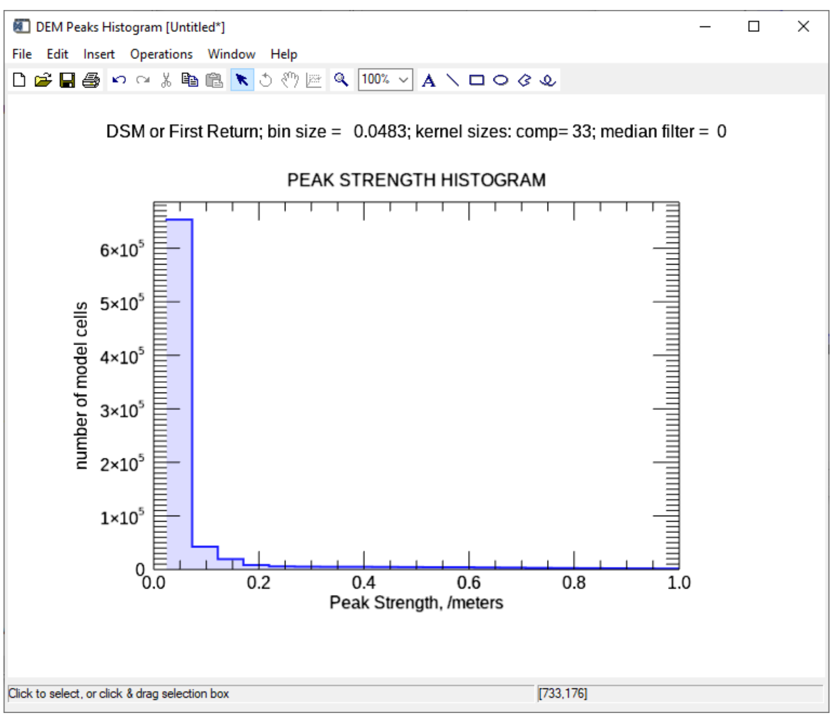
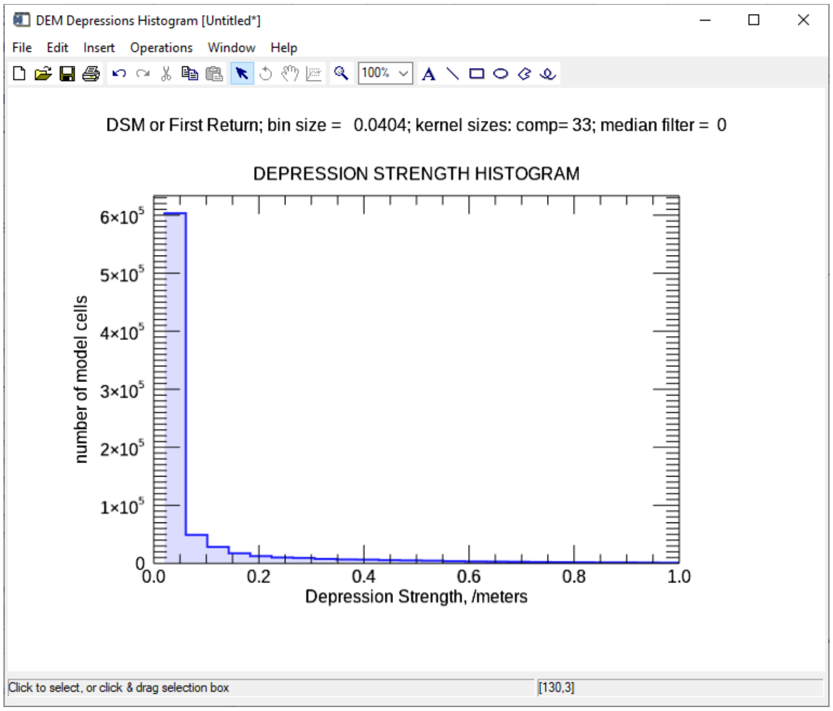


Figure F-3. Depression strength histogram.



Appendix G

Example overlay displays from optima extraction

Figure G-1. Saddle overlay.

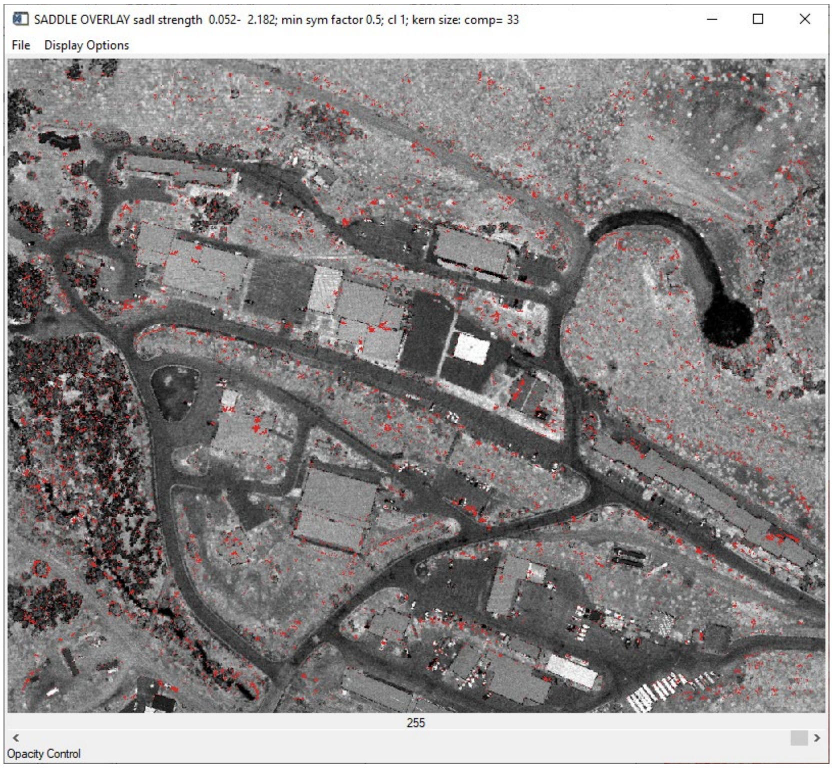
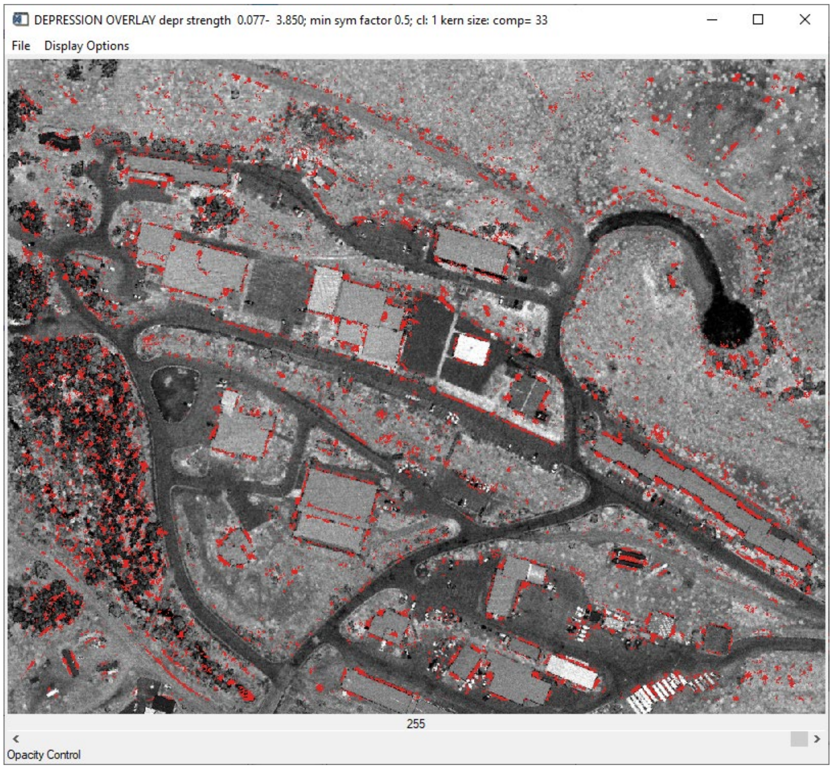


Figure G-2. Peak overlay.

Figure G-3. Depression overlay.



Appendix H

Example text output from optima overlay displays

Running SADLPK_OVERLAY...
Generating optimum SADDLE overlay and summary statistics.

CURRENT USER-DEFINED SADDLE THRESHOLDS:
Number of cells in model subset = 800000
Saddle strength thresholds: 0.0520000 to 2.18200 /m
Saddle symmetry threshold (min): 0.5

Creating the Saddle Overlay for 1 class.
Number of saddle cells between thresholds = 20017 2.50 % of subimage cells

Running SADLPK_OVERLAY...
Generating optimum PEAK overlay and summary statistics.

CURRENT USER-DEFINED THRESHOLDS:
Number of cells in model subset = 800000
Peak strength thresholds: 0.0780000 to 4.60300 /m
Peak symmetry threshold (min): 0.5

Creating the Peak Overlay for 1 class.
Number of peak cells between thresholds = 60816 7.60 % of subimage cells

Running SADLPK_OVERLAY...
Generating optimum DEPRESSION overlay and summary statistics.

CURRENT USER-DEFINED THRESHOLDS:
Number of cells in model subset = 800000
Depression strength thresholds: 0.0770000 to 3.85000 /m
Depression symmetry threshold (min): 0.5

Creating the Depression Overlay for 1 class.
Number of depression cells between thresholds = 44562 5.57 % of subimage cells

References

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14. ABSTRACT

Gridded elevation models of the earth's surface derived from airborne lidar data or other sources can provide qualitative and quantitative information about the terrain and its surface features through analysis of the local spatial variation in elevation. The DEM Breakline and Differencing Analysis Tool was developed to extract and display micro-terrain features and vegetative cover based on the numerical modeling of elevation discontinuities or breaklines (breaks-in-slope), slope, terrain ruggedness, local surface optima, and the local elevation difference between first surface and bare earth input models. Using numerical algorithms developed in-house at the U.S. Army Engineer Research and Development Center, Geospatial Research Laboratory, various parameters are calculated for each cell in the model matrix in an initial processing phase. The results are combined and thresholded by the user in different ways for display and analysis. A graphical user interface provides control of input models, processing, and display as color-mapped overlays. Output displays can be saved as images, and the overlay data can be saved as raster layers for input into geographic information systems for further analysis.

15. SUBJECT TERMS

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

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