CoMMa Toolbox

Version 1.2

User Guide

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Summary

Multibeam Echosounder Systems (MBES), LiDAR and Satellite-derived Bathymetry (SDB) are increasingly employed to survey the seabed for a multitude of purposes. Consequently, the marine mapping community is accessing a growing collection of bathymetric information suitable for geomorphological mapping. However, manual mapping of seabed features can be extremely time-consuming, it is implicitly subjective, and any analysis of such data is vulnerable to errors by the interpreter. Semi-automated mapping approaches can provide greater consistency and minimise misinterpretation.

The Confined Morphologies Mapping (CoMMa) Toolbox is a new ArcGIS Pro toolbox to semi-automatically map and characterise confined seabed features such as cold-water coral mounds, pockmarks and drumlins. The toolbox includes three toolsets that allow the user to pre-process multibeam data and calculate local topographic parameters, delineate potential features using the delineation tools and describe the morphological characteristics of confined features using the basic, texture and volume descriptors tools. Extracted morphometric data can be used to understand spatial patterns in shape, biodiversity, and environmental conditions (e.g. current speeds and direction) of seabed features such as cold-water coral mounds across the ocean. Although these tools were primarily designed for biologists and geologists working with bathymetric data obtained by MBES, digital elevation terrains (DEMs) obtained with other geophysical and optical instruments (e.g., Lidar, 3D seismic, etc.) can also be used. Additionally, the tools can also be applied to terrestrial or extraterrestrial surfaces.

This user guide offers a general walkthrough of the various tools available within the CoMMa Toolbox, assisting the user from setting up the toolbox to the assessment of the results. In this document, readers will find the following:

- Instructions on how to install the toolbox.
- Detailed list of requirements to run the scripts within the toolbox.
- Description of the individual tools, parameters needed and their outputs.
- Considerations about the threshold values and recommendations about how to assess the quality of the outputs.

These tools were developed to be used with ESRI ArcGIS Pro. However, the method developed could be recreated using another GIS platform or externally using Python or Rust.

1. Introduction

The Confined Morphologies Mapping (CoMMa) Toolbox is an ArcGIS Pro Python toolbox expressly created for semi-automated morphology mapping, which includes a selection of tools for the delineation and description of any type of enclosed features on a DEM, either negative or positive. The delineation procedures consider the features as enclosed topographic relief and combine techniques of DEM filtering, iso-contour definition, or facets assemblage, to provide a flexible and widely applicable solution to feature extraction.

The CoMMa Toolbox comprises several individual Python scripts that use a sequence of pre-existing ArcGIS geoprocessing tools and do not require the installation of any new Python package. These scripts/tools are grouped into three independent blocks:

- Data preparation tools to clean the data or create DEM derivatives (**CoMMa Data Preparation**),
- Landform delineation tools to isolate the features of interest from the data (**CoMMa Delineation**),
- Description tools to characterise each feature by calculating various morphometric attributes (**CoMMa Description**).

***Table 1**: List of Tools Contained in the CoMMa Toolbox.*

CoMMa Data Preparation	**Local Topographic Position (LTP) derivatives**	***Mean LTPs***	Local topographic position index metrics based on the absolute and relative mean of the neighbourhood.
		Median LTPs	Local topographic position index metrics based on the absolute and relative median of the neighbourhood.
	Pre-processing tools	***Fencing***	This tool creates an artificial containing fence at the boundary of the DEM, preventing the Fill algorithm from spilling out and thus permitting the delineation of landforms that are at the boundary. It must be used in conjunction with the Filter and clip tool.
		Filter and clip	This tool removes the flat or featureless areas in the DEM and preserves areas of the seabed where the features are more likely to occur. The application of this tool is particularly useful to remove the effects of broad-scale topography on Boundary-based delineations.
		Smoothing filters	A series of standard filters are used to smooth the DEM and remove noise and artefacts.
CoMMa Delineation	**Boundary-based delineation**		Delineates confined landforms using a Fill algorithm on a DEM or a DEM derivative. Parameters can be modified to adjust for the height and width of the landforms of interest.
	Elements-based delineation		Delineates confined landforms using the Geomorphons algorithm on a DEM or a DEM derivative. Parameters can be modified to adjust for the height and width of the landforms of interest.
CoMMa Description	**Basic descriptors**		Calculates a series of basic geometrical and statistical attributes for each shape contained in the delineation shapefile.
	Texture descriptors		Calculates a few additional metrics, such as zonal vector ruggedness and aspect variability index, and optionally backscatter statistics.
	Volume descriptors		Calculates the volume and more accurately the height for each shape contained in the delineation shapefile.

The CoMMa Toolbox for ArcGIS Pro shares the main goals of the BGS Seabed Mapping Toolbox (Gafeira, 2017) that was developed for ArcMap Desktop after the successful creation of a semi-automatic workflow that would delineate and characterise pockmarks in the seabed (Gafeira et al., 2012).Since then, the approach has been adapted to map both positive and negative confined features in areas of complex seabed morphology with added functionalities. The tools in the CoMMa toolbox allow the delineation and characterisation of vast numbers of confined seabed features in a systematic and consistent way, in a fraction of the time required to perform that task manually.

The outputs and the data extracted with this toolbox can expand our knowledge of the seabed nature and the processes shaping it - including the interaction between the seabed morphology and biological activity. For example, De Clippele *et al.* (2017) used the morphometric characterisation of mounds and an ROV-based high-resolution bathymetric grid to explore the environmental variables that control coral growth on cold-water coral reefs and were used to create a predictive map of the likelihood of the presence of live cold-water coral colonies in the Mingulay Reef Complex.

2. How to load CoMMa Toolbox to a project

The CoMMa Toolbox and additional information can be download from its repository at GitHub and is comprised of three Python toolboxes, which can be loaded to an ArcGIS Pro project as any standard toolbox. To add the three CoMMa python toolboxes to a project:

- In the Catalog pane, right-click on Toolboxes and select "Add Toolbox".
- Navigate to the folder where CoMMa Toolbox was saved and select the following .pyt files: CoMMa Data Preparation.pyt; CoMMa Delineation.pyt and CoMMa Description.pyt

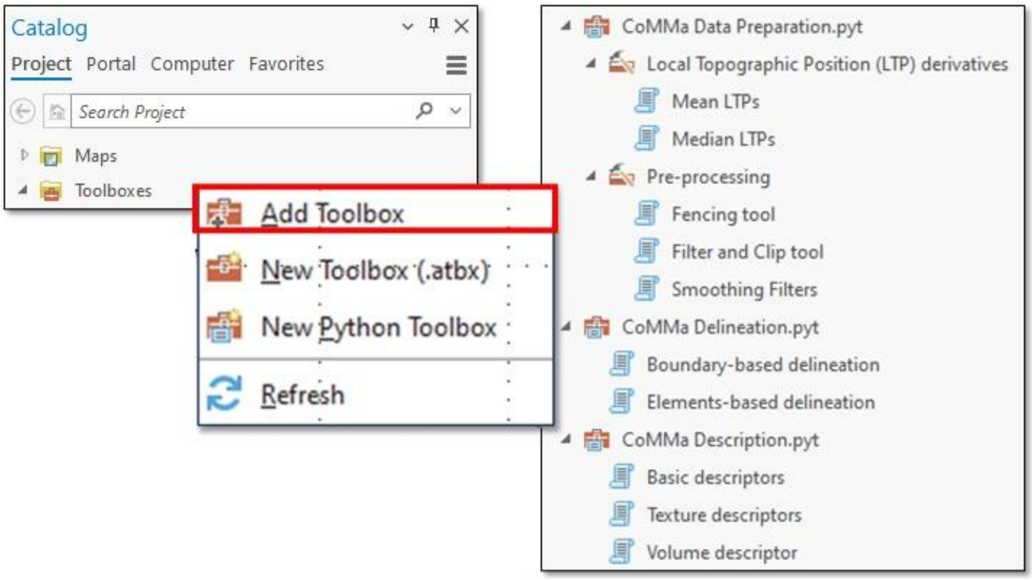


***Figure 1** – Adding the three CoMMa Python toolboxes:*
1) CoMMa Data Preparation; 2) CoMMa Delineation and 3) CoMMa Description.

A reference to the toolsets is saved within the project and they will be in the Toolboxes node of the Catalog pane the next time the project is open.

Requirements

Software requirements

It is recommended to run the CoMMa Toolbox in ArcGIS Pro 3.1, or later – especially if geomorphons landforms will be used. *Geomorphon Landforms* only became available with ArcGIS Pro 3.1 version.

License

The Spatial Analyst extension is required to run some of the CoMMa Toolbox's scripts. Under the Project tab, the list of Esri's extensions available can be found by selecting the Licensing option.

Projection

The Coordinate System of any input raster should be a Projected Coordinate System. Do note that the shapefile outputs will have the same coordinate system that the input raster.

Geodatabase

Geodatabases cannot be used in this version of the CoMMa Toolbox. The input raster files and shapefiles cannot be features classes within a geodatabase.

3. Data Preparation Toolset

The CoMMa Toolbox works on DEMs obtained from multibeam echosounder data or other geophysical and optical instruments (e.g., Lidar, 3D seismic, etc.). These datasets can be affected by artefacts, for example, corrugation in MBES data caused by tidal shifts in line overlap or other vessel motion-related artefacts. These artefacts can hinder the correct delineation of the features of interest. Plus, spurious values may be captured during the morphometric characterization.

A degree of data preparation, such as cleaning the initial data to remove artefacts, could enhance the performance of both the delineation and description tools. Therefore, the CoMMa Toolbox includes five tools devoted to data preparation, which can be found within the sub-toolbox **CoMMa Data Preparation**. These are internally grouped into two toolsets: 1) Local topographic Position (LTP) derivatives and 2) Pre-processing tools.

Additionally, to reduce the tools running time and the likelihood of other features being incorrectly mapped, it is recommended to clip initial DEM just to the areas presenting the seabed features of interest. That can be done by using the ArcGIS *Extract by Mask* tool or the ArcGIS data management tool *Clip*. These tools require a shapefile that defines the area of interest. For example, when mapping pockmarks, areas of outcropping bedrock can be excluded from the initial DEM, as pockmarks will not be present in such substrates. The clipped raster can then be used as the input raster for the delineation tool or any of the other upstream tools.

Local Topographic Position (LTP) Derivatives

The CoMMa Boundary-based delineation relies on a *Fill* algorithm to define areas of confined morphologies. The bathymetric DEM might be sufficient as input to isolate landforms when the general seascape is otherwise flat; however, this is often not the case, and the interference of sloping seabed or other underlying large-scale seabed landforms can distort the signal of the seabed features of interest – the targeted features. To address this issue, mathematical operations can be applied to the bathymetry data to isolate a specific wavelength thought to best represent the feature of interest. De-trending techniques and other Local Topographic Position (LTP) metrics are common approaches in geomorphometric studies.

LTP metrics quantify how elevated or low-lying a site is relative to the local topographic variability, creating a scale-dependent measurement that varies depending on the size of the neighbouring area to which the elevation is being compared (Lindsay et al., 2015). In marine studies, especially applied to habitat mapping, the Bathymetry Position Index (BPI, originally defined by Weiss (2001) as Topographic Position Index, TPI) is arguably the most applied absolute LTP (Harris et al., 2014; Walbridge et al., 2018). However, BPI is not the most robust method, and other derivatives can provide better results (De Reu et al., 2013; Hillier and Smith, 2008; Newman et al., 2018; Wessel, 1998).

The LTPs tools provide the user with a selection of derivatives that can substitute bathymetry raster as input at the delineation stage. The choice includes relative and absolute Median and Mean-derived LTP metrics; the description of each derivative is given in TABLE 2. Other LTPs can be used in CoMMa, like the Elevation Percentile (Newman et al., 2018) and Relative deviation from the mean value (Lecours, 2017), but will have to be calculated with other toolboxes.

***Table 2**: List of LTPs calculated by the CoMMa toolbox.*

Mean LTPs			
Bathymetry Position Index (BPI)	BPI measures the vertical position of a pixel relative to the mean elevation (µ) of a user-defined neighbourhood.	$Z_0 - \mu$	*Lundblad et al. (2006)*
Deviation from mean elevation (DEV)	DEV measures the vertical position relative to the neighbourhood mean elevation (µ), but also normalizes by the standard deviation (σ) of the neighbourhood elevation distribution, effectively expressing local topographic position as a z-score.	$\frac{(Z_0 - \mu)}{\sigma}$	*De Reu et al. (2013)*
Median LTPs			
Median Bathymetry Position Index (M-BPI)	M-BPI measures the vertical position of a pixel relative to the median elevation (M) of a user-defined neighbourhood.	$Z_0 - M$	
Minimum Median Bathymetry Position Index (minM-BPI)	minM-BPI first calculates a minimum value surface running a convolution for a window defined as 1/4 of a user-defined neighbourhood. Subsequently, it measures the M-BPI of the minimised surface.	$Z_0 - Z_m - M$	*Adam et al. (2005)*
Maximum Median Bathymetry Position Index (maxM-BPI)	maxM-BPI first calculates a maximum value surface running a convolution for a window defined as 1/4 of a user-defined neighbourhood. Subsequently, it measures the M-BPI of the maximised surface.	$Z_0 + Z_m - M$	*modified after Adam et al. (2005)*
Directional Median Bathymetry Position Index (dirM-BPI)	dirM-BPI divides a given filter circle into N "bow tie" sectors, allocates data points inside the filter circle to each sector based on their relative position within the circle, estimates a median for each sector, and returns the lowest of these N medians.	$Z_0 - Mdir$	*modified after Kim and Wessel (2008)*

Running any of the LTPs tools requires setting a neighbouring area. The neighbouring area defines which cells surrounding a processing cell will be used in the statistic calculation. There are multiple predefined neighbourhood types that can be used (from wedge-shaped to circle-shaped neighbourhoods). The LTPs tools within the CoMMa Toolbox use *a)* a donut-shaped (annulus) neighbourhood defined by an inner radius and an outer radius or *b)* circle-shaped neighbourhood. The default annulus neighbourhood is an inner radius of three cells and an outer radius of five cells, whereas the default outer radius value for the circle-shaped neighbourhood is five cells. However, the user can change the ***Inner radius*** and ***Outer radius*** tool parameters depending on various aspects, such as the input raster cell size, artefact type and dimensions of the targeted morphological features.

FIGURE 2 illustrates the differences between the six different types of Local Topographic Position (LTP) derivatives that can be calculated using the CoMMa Toolbox, regardless of having been calculated with same or similar neighbourhoods.

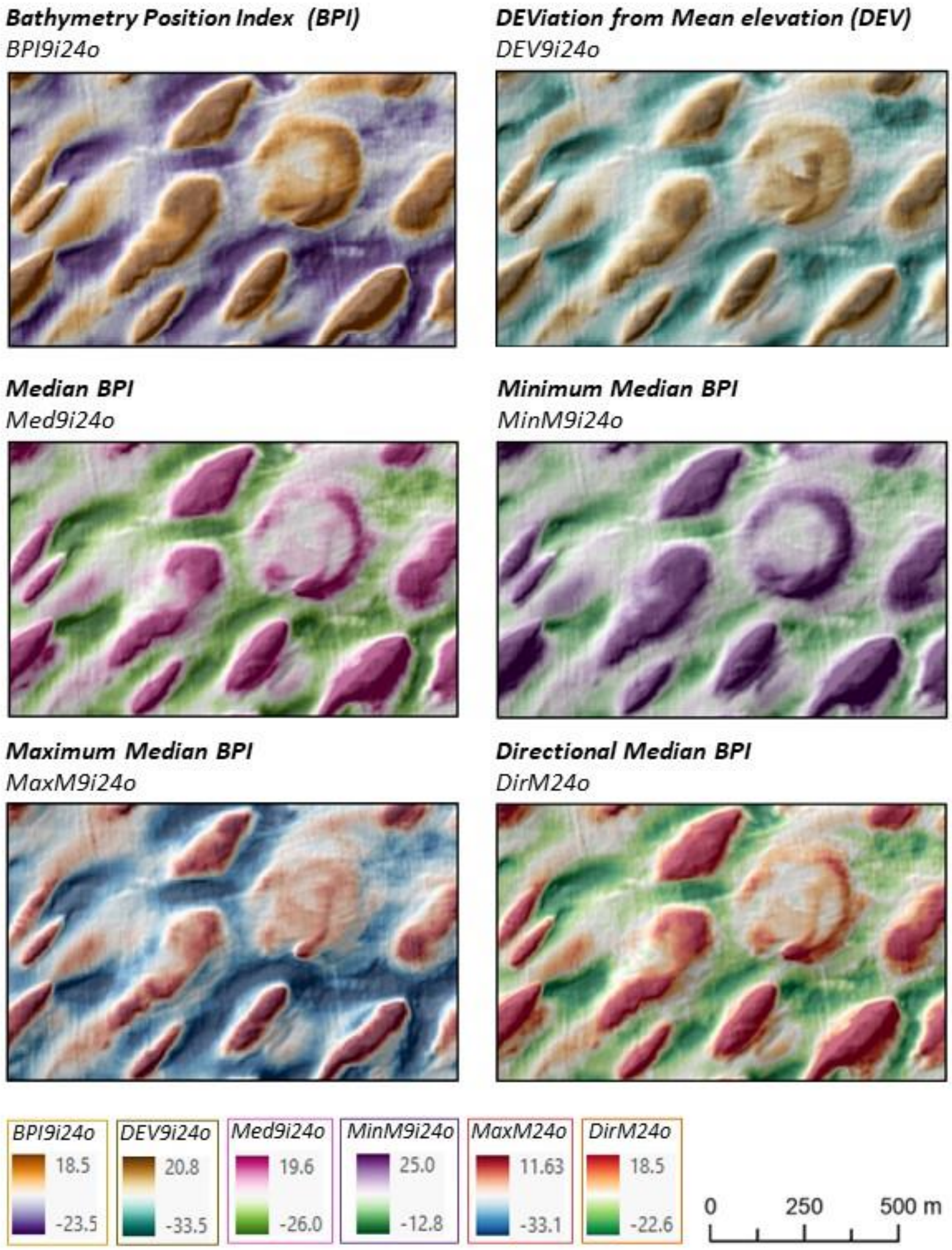


Figure 2 *- Example of the six Local Topographic Position (LTP) derivatives calculated using the CoMMa Toolbox, to highlight the drumlins present at seabed. Do note the differences between them, regardless of having been calculated with same or similar neighbourhoods.*

Pre-processing

Fencing Tool

This tool allows the delineation of landforms only partially captured within the dataset, by creating an artificial containing "fence" around the perimeter of the input DEM. Fencing is recommended when using the **"Boundary-based Delineation"** tool based purely on the DEM (and not a derivative), as unconfined morphological features will not be filled and hence not mapped.

This script assists the feature delineation tools by creating a buffer around the Input Raster. For targeted features with positive relief, the minimum value of the input DEM will be used for the artificial fence set by the buffer, whereas for negative targeted features, it will use the maximum value (**FIGURE 3**).

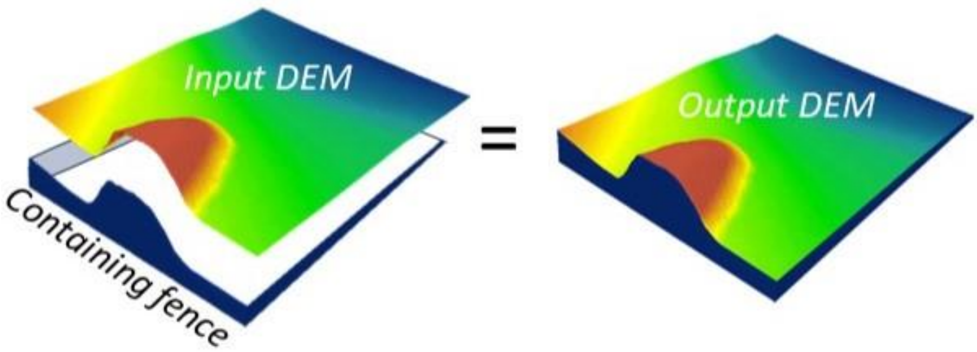


***Figure 3** – Illustration of the Fencing Tool. By running this tool, the Input DEM will be surrounded by a "containing fence" (i.e. a swath of pixels) that confines any feature at the edge of the dataset.*

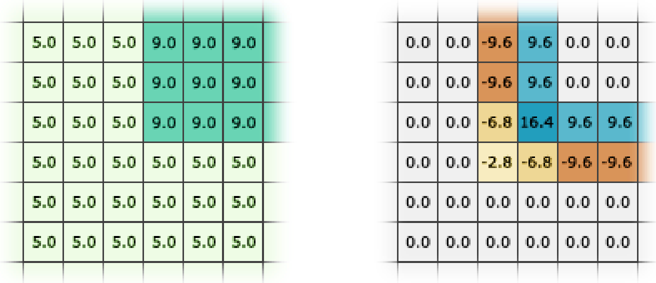
This tool must be followed by the **"Filter and Clip"** tool. The **"Filter and Clip"** tool will introduce NoData pixels (i.e. holes) within the dataset that will prevent the entire dataset to be treated as a single sink by the *Fill* algorithm (used by the delineation tool based on DEM) – which would result as the full dataset delineated as one single confined feature.

The output DEM of this tool (*i.e.* the DEM with the confining fence) may not be appropriated as input to neighbourhood analysis tools, such as LTP tools. The extreme values at around the perimeter of the DEM will affect the derivative values near the boundaries of the raster layer. The impact of the extreme value will depend on the value range of the initial DEM and the size of the window of analysis defined. Therefore, it is recommended to use the original DEM when running the **CoMMa Description** tools after delineation

Filter and Clip

In some cases, the regional morphology or the presence of overlapping features may affect the **"Boundary-based Delineation"** (when used only with DEM) tools' ability to map the smaller-scale features. These issues can be addressed by using the ***"Filter and Clip"*** Tool. This tool will clip the initial dataset, removing the flat or featureless areas in the DEM and preserving bathymetric information only for areas of the seabed where the targeted features are more likely to occur. The areas of higher vertical variability is defined by using: the *Filter tool* (both Low and High) and then the *Reclassify tool* applying an user-defined threshold value.

The *Filter tool* can be used to either highlight features in the data or remove abnormal values. The filters output values are generated by scanning through the input raster with a moving, overlapping 3x3 cell neighbourhood window. As the filter passes over each input cell, the value of that cell and its eight immediate neighbours are used to calculate the output value. Within this tool, there are two types of filters: *High Pass Filter* and *Low Pass Filter*. The *High Pass Filter* will accentuate the comparative difference between a cell's values and its neighbours (**FIGURE 4**), whereas the Low Pass Filter will serve to smooth data to reduce noise.



Input raster
with an edge where cell values change from 5.0 to 9.0

Output raster
The HIGH filter detects the edge. Note that the output values have no relation to the input values.

Figure 4 *- Illustration of the impact of running High Pass Filter to a raster. In this example the input raster has a sharp edge along the region where the values change from 5.0 to 9.0. The edge enhancement characteristic of the High option has detected the edge.*

The **"Filter and Clip"** Tool uses both High Pass Filter and Low Pass Filter to define the areas of higher vertical variability. The user-defined ***Filter threshold*** sets the reclassify range. The threshold value does not have a direct relation to the elevation values of the input DEM and should be positive even when the targeted features are negative. The *Clip Raster* tool is then used to preserve areas of the original DEM with filtered values higher than the threshold set and to exclude areas of the DEM with gentle local variations. The user can also set a ***Buffer distance***, to be sure that the totality of the targeted features is capture and not only the areas of higher vertical variations within the features. Half of the width of the targeted features tend to be a safe buffer distance. It is important to make sure that the *Buffer distance* used for clipping the original dataset is broad enough to include the full feature to be mapped. Otherwise, in the output shapefiles, the features' relief may be underestimated.

FIGURE 5 illustrates how useful **Filter and Clip Tool** can be for preparing the dataset before running the **Boundary-based Delineation Tool** (only on DEM) in areas with complex seabed morphology or where features are connected by regional morphology (e.g. pockmarks within a basin). Moreover, clipping the initial DEM, using the **Filter and Clip Tool***,* can be useful even in area low complexity to reduce the running time of both delineation and characterization tools.

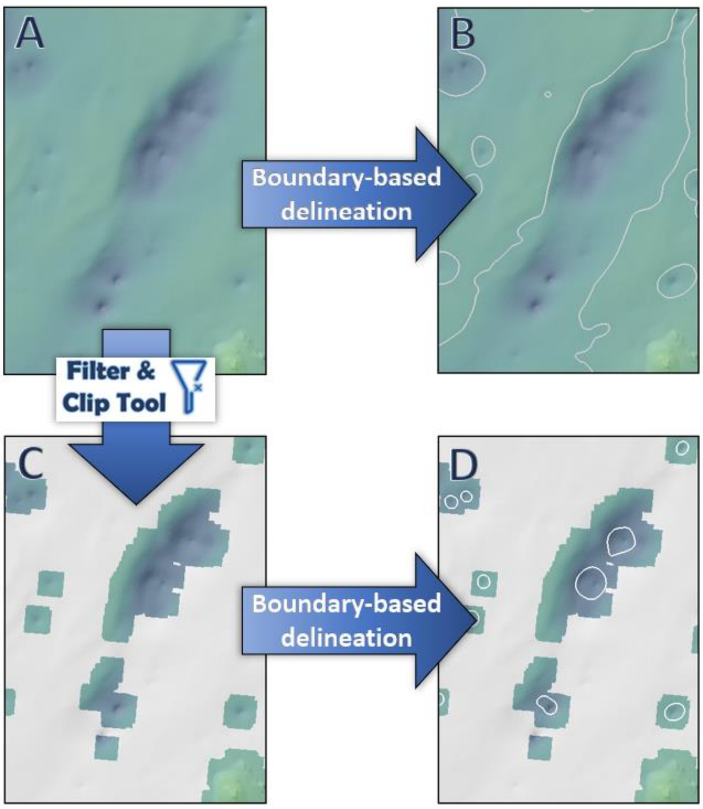


Figure 5 *– Result of running the Delineation Tool with a clipped bathymetry.*

A) *Example of an area where multiple pockmarks are found within a broader seabed depression.* ***B)*** *Example of an inadequate delineation obtained using the original DEM as input to the Boundary-based Delineation Tool.* ***C)*** *The clipped DEM obtained by using the "Filter and Clip Tool", with a threshold value equal to 1 and a 100 m buffer distance.* ***D)*** *The resulting delineation obtain using the clipped DEM and the same delineation thresholds used in B.*

Smoothing Filters

The ***Smoothing filters*** tool provides a selection of standard filtering algorithms that can be used smooth the DEM and remove, at least partially, noise and artefacts. Although they will also subdue the real signal proportionally to their respective aggressiveness. These filters are:

MEAN — Calculates the mean (average value) of the cells in the neighbourhood set by the user.

MEDIAN — Calculates the median of the cells in the neighbourhood set by the user.

LOW-PASS 3x3 — It calculates the average value for each 3 x 3 neighbourhood.

LOW-PASS 5x5 — It calculates the average value for each 5 x 5 neighbourhood.

4. Delineation toolset

There are two available delineation tools in CoMMa, the "**Boundary-based delineation**" and the "**Elements-based delineation**" tools. The "**Boundary-based delineation**" tool can be applied directly to bathymetric DEM and, when the general seascape is otherwise flat, it might be sufficient to isolate and correctly delineate the targeted features. However, this is often not the case, and the interference of sloping topography or other underlying large-scale landforms can distort the signal of the targets. In this case, the "**Boundary-based delineation**" tool can also use a LTP derivative to isolate a specific wavelength thought to best delineate the feature of interest. The "**Elements-based delineation**" relies on land surface units created by the geomorphons tool (Jasiewicz and Stepinski, 2013), which are grouped and mapped depending on whether the user is mapping positive or negative features.

Boundary-based Delineation

The "**Boundary-based Delineation**" tool, when using exclusively the DEM as delineation input, takes advantage of the hydrological **"Fill"** tool. "Fill" defines where the rim of an enclosed sink would be based on the distribution of pouring points. Within the "**Boundary-based Delineation**" tool, the hydrological algorithm will fill up positive or negative enclosed relief, according to the type of the targeted features. The resulting surface is subtracted from the original DEM, creating a mostly flat surface preserving only the geometry of the confined, sink-like features. A user-defined threshold, the Vertical Cutoff, defines the contour line used to delineate the confined features in the otherwise featureless surface.

Once all the areas of confined morphologies are delineated on the basis of the Vertical Cutoff threshold, features that do not satisfy a set of criteria defined by the user will be excluded. The criteria cover aspects related to the minimum vertical relief (calculated using the position of the rim of the filled features), dimensions (Minimum Width) and aspect ratio (Minimum W/L Ratio) (FIGURE 6) desired for the targeted features. Only features with dimensions above the specified thresholds for Minimum Vertical Relief, Minimum Width and Minimum W/L Ratio will be mapped.

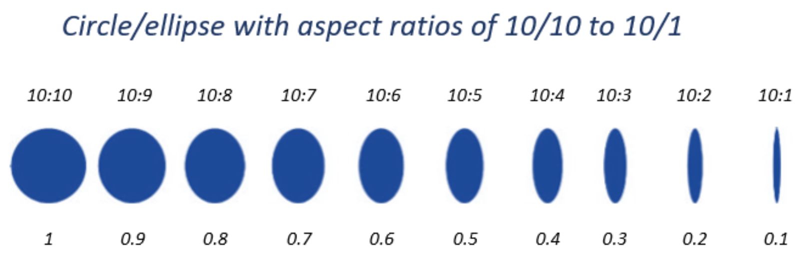


Figure 6 *– Circle/ellipse with aspect ratios of 10/10 to 10/1. The Minimum W/L Ratio can be used as a proxy to the feature aspect ratio and the values.*

Optionally, the user can filter the features delineated using a geomorphons layer. The area of each delineated polygon feature is compared to the area of geomorphons classes that correspond with the relief type mapped contained within that specific polygon (e.g. a positive landform, like a mound, will be compared to positive geomorphons classes, i.e. peak, ridge, shoulder and spur). If the ratio of the areas is below a threshold set by the user, then the polygon will be discarded. For example, if a polygon mound contains less than 50% positive geomorphons classes (the user will set a threshold = 0.5) it is deleted. The geomorphons layer has to be created in advance by the user (Geomorphon Landforms).

The Buffer Distance compensates for the fact that the delineation process is based on the internal contour line correspondent to the Vertical Cut-off threshold. This value should reflect approximately the distance, in plan view, from the contour line outlined based on the Vertical Cut-off to the actual rim of the feature. Therefore, the greater the value of the Vertical Cut-off the greater should be the Buffer Distance. The Buffer Distance is meant to compensate for the Vertical Cut-off being greater than zero, which often means that the periphery of features is not completely included (see Gafeira et al. (2018) for more information).

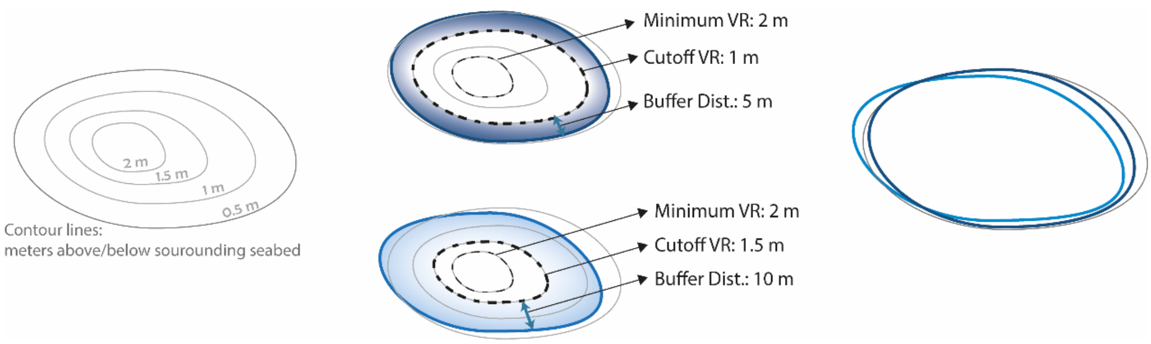


***Figure 7** - Example of distinct outlines obtained by using different threshold values.*

In summary, the Minimum Vertical Threshold (i.e. height of a feature), Minimum Width, Minimum Width/Length Ratio, and optionally the Geomorphons comparison permit the user to define basic geometrical properties expected in the features, eliminating any delineation that does not possess the defined characteristics.

Elements-based Delineation

The second delineation tool, **"Elements-based Delineation**" defines the limits of the targeted features based on the spatial arrangement of homogeneous surfaces and relies on surface units created by the geomorphons algorithm (Jasiewicz and Stepinski, 2013). The Geomorphon Landforms algorithm combines elevation differences and visibility concepts to classify terrain into landform types, classifying each cell into 10 common landform facets (FIGURE 8).

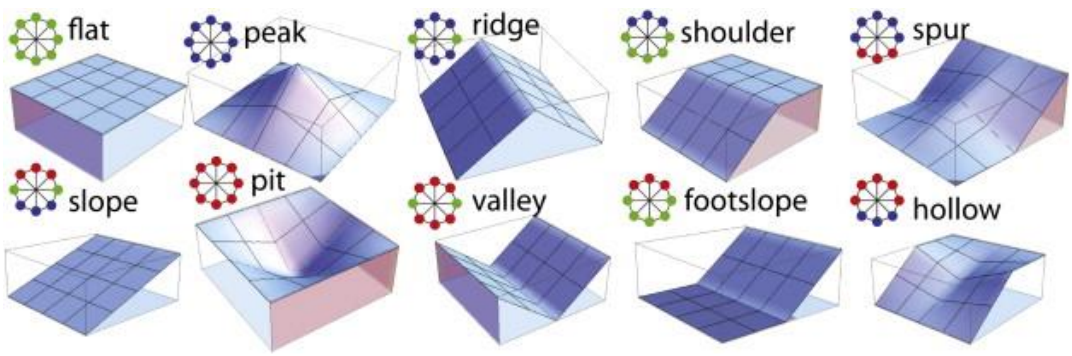


***Figure 8** – Symbolic 3D morphologies and their corresponding geomorphons for the 10 most common landform elements.*

"**Elements-based Delineation**" tool will merge and reclassify certain landform facets, selected by the user, and then convert them into polygons. User will be able to define "core" and "subordinate" landform facets. A grouping comprised of only subordinate facets, without core facets, will not be delineated. The same geometrical criteria as in the "**Boundary-based Delineation**" tool (apart from the geomorphons/polygon areas ratio) are then applied to sift out undesired delinations.

Assessing the results of the Delineation

The output shapefiles of both delineation tools should be visually assessed. The visual assessment of the polygons can be done by overlaying the generated shapefile on to either the original bathymetric data or derived surfaces, such as a slope map or multidirectional hillshade. This can help to establish if the acquired mapping results are satisfactory and assess if sporadic manual edits required or if any features were missed by the automated method. With the appropriate threshold values, the number of polygons that require manual editing should never exceed 10% of a total number of targeted features delineated. If the percentage of output polygons requiring manual editing is higher, then it may be convenient to redefine the threshold values or derivative initially chosen and to re-run the delineation tool.

Manual editing is usually required for the following two reasons: the location of the targeted **feature relative to the study area edges** and the **spatial proximity of several features**. Features at the periphery of the dataset may not be considered as enclosed depressions by the DEM-based delineation tool, and therefore they may a) not be delineated or b) be delineated but having underestimated areas and depths. The use of the "***Fencing tool"*** should prevent this problem. Adjacent or very proximal features may be delineated as a single feature; in these situations, it will be necessary to use the editing tools within ArcGIS Pro to manually correct or split delineated polygons.

Additionally, the visual assessment should be complemented by a quick analysis of the attributes compiled in the table of attributes. For instance, plotting:

- **Area vs Relief (*Relief*)**:
  For some target seabed features, the Area vs Relief plot can provide an effective way to detect erroneous results. That is particularly the case when there are artefacts in the data that could be incorrectly mapped as a targeted feature. The artefacts can present higher relief than seabed features with similar areas. Artefacts can also be detected by examining the Area vs Mean Slope, as artefacts tend to present higher slope values.
- **Area vs Perimeter:**
  Two polygons with similar areas but very distinct perimeters will necessarily present very different shapes, which can be indicative of a delineation error. Most geomorphological features tend to present similar geometries within the same region. In these cases, the anomalous shape of a polygon, detected by plotting the Area vs Perimeter, could indicate that the feature outline was incorrectly mapped.

5. Characterisation Toolset

CoMMa provides the user with three landform description tools that can be run independently from one another and in any order:

- **Basic Descriptors:** Calculates a series of geometrical and statistical attributes for each shape contained in the delineation shapefile.
- **Texture Descriptors:** Calculates a few additional textural metrics, such as zonal vector ruggedness and aspect variability index, and optionally backscatter statistics.
- **Volume Descriptor:** Calculates the volume and more accurately the height for each shape contained in the delineation shapefile.

The "**Basic Descriptor"** tool calculates a series of geomorphometric parameters for each polygon feature, ranging from shape metrics to zonal statistics of slope, depth and relative elevation compared to global median (TABLE 3). Optionally, this tool allows the user also to compare the delineation with landform elements calculated by geomorphons, measuring the percentage area of each land surface unit, and counting the number of peaks (if positive morphologies) or pits (if negative morphologies) contained within each polygon feature. These measurements can give useful indication of the complexity of the mapped landforms.

The **"Texture descriptors"** tool adds a few additional metrics that describe the quality of the surface, including zonal vector ruggedness measurement, aspect variability index and optionally backscatter statistics (TABLE 3).

Finally, the **"Volume descriptor"** tool calculates the best approximation of the relief and the volume of the feature (TABLE 3). These calculations are based on the Cookie-Cutter method proposed by Smith *et al.* (2009) and are performed on a feature-by-feature basis, slowing down considerably the processing time.

These tools can be applied to characterise any morphological features, regardless of the approach adopted to delineate them. Both, automated and manually mapped features can described by these tools.

***Table 3**: List of attributes extracted by the delineation tools and the description tools for each of the mapped features.*

<table>
<tr><th>Attribute</th><th>Field name</th><th>Description</th><th colspan="4">Tools</th></tr>
<tr><td>Area</td><td>Area</td><td>The area of the polygon feature.</td><td rowspan="7">Delineation tool</td><td rowspan="20">Basic Descriptors</td><td rowspan="20"></td><td rowspan="20"></td></tr>
<tr><td>Perimeter</td><td>Perimeter</td><td>The perimeter of the polygon feature.</td></tr>
<tr><td>MBG width</td><td>MBG_Width</td><td>Width of the Minimum Bounding Geometry (rectangle) as calculated by the ArcGIS Pro tool.</td></tr>
<tr><td>MBG length</td><td>MBG_Length</td><td>Length of the Minimum Bounding Geometry (rectangle) as calculated by the ArcGIS Pro tool.</td></tr>
<tr><td>MBG width/length ratio</td><td>MBG_W_L</td><td>Ratio of MBG width and MBG length.</td></tr>
<tr><td>MBG main orientation</td><td>MBG_Orient</td><td>Orientation of the Minimum Bounding Geometry (rectangle) as calculated by the ArcGIS Pro tool.</td></tr>
<tr><td>Relief</td><td>relief</td><td>The first calculated polygon feature height, based on the general fill of the bathymetry, it may give spurious numbers as it gets heights from areal fills instead of feature-focussed fills.</td></tr>
<tr><td>Minimum, mean and maximum slope</td><td>Slope_MIN;
Slope_MAX;
Slope_MEAN</td><td>The minimum, mean and maximum slope within the polygon feature.</td><td rowspan="13"></td></tr>
<tr><td>Mean and maximum LDfG</td><td>LDfG_MAX;
LDfG_MEAN</td><td>The mean and maximum local deviation from global median value within the polygon feature.</td></tr>
<tr><td>Minimum, mean and maximum depth</td><td>Depth_MIN;
Depth_MAX;
Depth_MEAN</td><td>The minimum, mean and maximum depth within the polygon feature.</td></tr>
<tr><td>Polsby-Popper test for circularity</td><td>PP_Score</td><td>Calculated as
$4\pi\times Area/Perimeter^2$
(Cox, 1927).</td></tr>
<tr><td>Convex hull area</td><td>Area_CH</td><td>Area of the Minimum Bounding Geometry (convex hull) as calculated by the ArcGIS Pro tool.</td></tr>
<tr><td>Convex hull-object area ratio</td><td>CH_Score</td><td>The ratio between the convex hull area (Area_CH) and the area of the polygon feature (Area).</td></tr>
<tr><td>Dissection index</td><td>Dissect</td><td>The ratio of the maximum relative relief to maximum absolute relief
$(Depth_{MIN}-Depth_{MEAN})/(Depth_{MIN}-Depth_{MAX})$</td></tr>
<tr><td>Depth range</td><td>Depth_RAN</td><td>The difference between the maximum ($Depth_{MAX}$) and minimum ($Depth_{MIN}$) depth.</td></tr>
<tr><td>LDfG variance</td><td>LDfG_VAR</td><td>The variance of local deviation from global median value within the polygon feature.</td></tr>
<tr><td>LDfG percentile rank</td><td>QuLDfG_ran</td><td>Ranked quintiles of LDfG mean (mound belongs to one of the quintiles).</td></tr>
<tr><td>Confined relief</td><td>Conf_R</td><td>The second calculated polygon feature height; this is extracted by first clipping the features, then filling the bathymetry, producing a “confined” relief that can be sometimes an underestimation of the real height.</td></tr>
<tr><td>Geomorphons class percent</td><td>gm_peak;
gm_ridg; gm_shou; gm_spur; gm_slop; gm_holl;
gm_vall;
gm_pit</td><td>Percentage area of different geomorphons land surface units contained within each polygon feature. Positive features will count % area of peaks, ridges, shoulders, spurs and optionally slopes. Negative features will count % areas of pits, valleys and hollows.</td></tr>
<tr><td>Geomorphons peaks or pits number</td><td>peak_no;
pit_no</td><td>The number of distinct peaks (if positive) or pits (if negative) within the polygon feature as calculated by the geomorphons layer. Peaks or pits composed of less than 4 pixels are not counted.</td></tr>
</table>

Minimum, mean and maximum ruggedness	Rugg_MIN; Rugg_MAX; Rugg_MEAN	The minimum, mean and maximum ruggedness within the polygon feature.			Texture Descriptors	
Minimum, mean and maximum AVI	Avi_MIN; Avi_MAX; Avi_MEAN	The minimum, mean and maximum aspect variability index (AVI) within the polygon feature (Nielsen et al., 2004).				
Minimum, mean and maximum backscatter	Bsc_MIN; Bsc_MAX; Bsc_MEAN	The minimum, mean and maximum multibeam echosounder backscatter value within the polygon feature.				
Optimal relief	Optim_R	Last and best approximation of height. This number is calculated on a feature-by-feature basis on the isolated and detrended DEM of the feature.				Volume D
Volume	Volume	Volume of each polygon feature calculated using the Cookie-cutter method (Smith et al., 2009).				

6. Considerations

Use of Local Topographic Position: BPI

When using a Local topographic Position (LTP) derivative as delineation input, the delineation output will depend on how the LTP raster was calculated.

The Bathymetric Positioning Index is the "marine" equivalent of the Topographic Position Index (TPI), originally derived from topographic data to characterising watersheds (Weiss, 2001), and the most applied LTP derivate used with seabed mapping. This use neighbourhood analyses to calculate the relative position of a cell compared to the surrounding cells, identifying topographic/bathymetric features. Positive BPI values represent locations that are shallower than the average of their surroundings, negative BPI values represent locations that are deeper than their surroundings, and BPI values near zero are either flat areas or areas of constant slope (FIGURE 9).

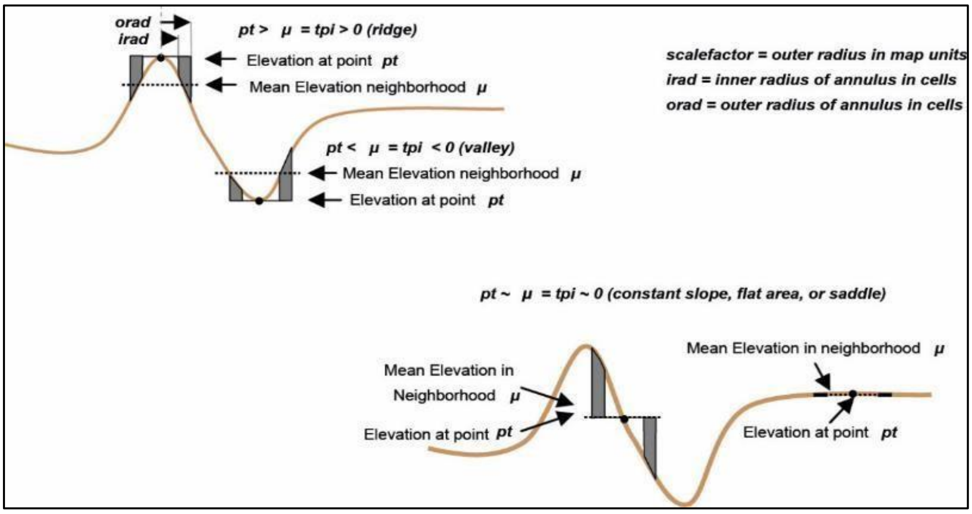


Figure 9 - Topographic Position Index (TPI) illustration taken from Weiss's poster (2001).

The BPI algorithm compares each cell's value to the mean value of the surrounding cells within a user-defined analysis neighbourhood. The analysis neighbourhood may be shaped as a rectangle, an annulus (doughnut shape) or a circle of any size. The BPI value for a given cell will depend on of the geometry and size of the analysis neighbourhood used in its calculation. Smaller analysis neighbourhoods will allow the detection of smaller, localized variations in the terrain.

To illustrate this, bathymetric data from the Mingulay Reef (in the Sea of the Hebrides, Scotland) was used to generate several BPI maps with different analysis neighbourhood using Benthic Terrain Modeller (BTM). **FIGURE 10** shows the four distinct analysis neighbourhood used, with the smallest neighbourhood set to be i6:o9, with an inner radius of 6 cells and outer radius of 9 cells, and the broader neighbourhood set to be i18:o36, with an inner radius of 18 cells and outer radius of 36 cells. **FIGURE 11** shows the resulting BPI maps generated with the different analysis neighbourhood, where is visible the difference in range of BPI values and the number of cells that are classify as topographic highs.

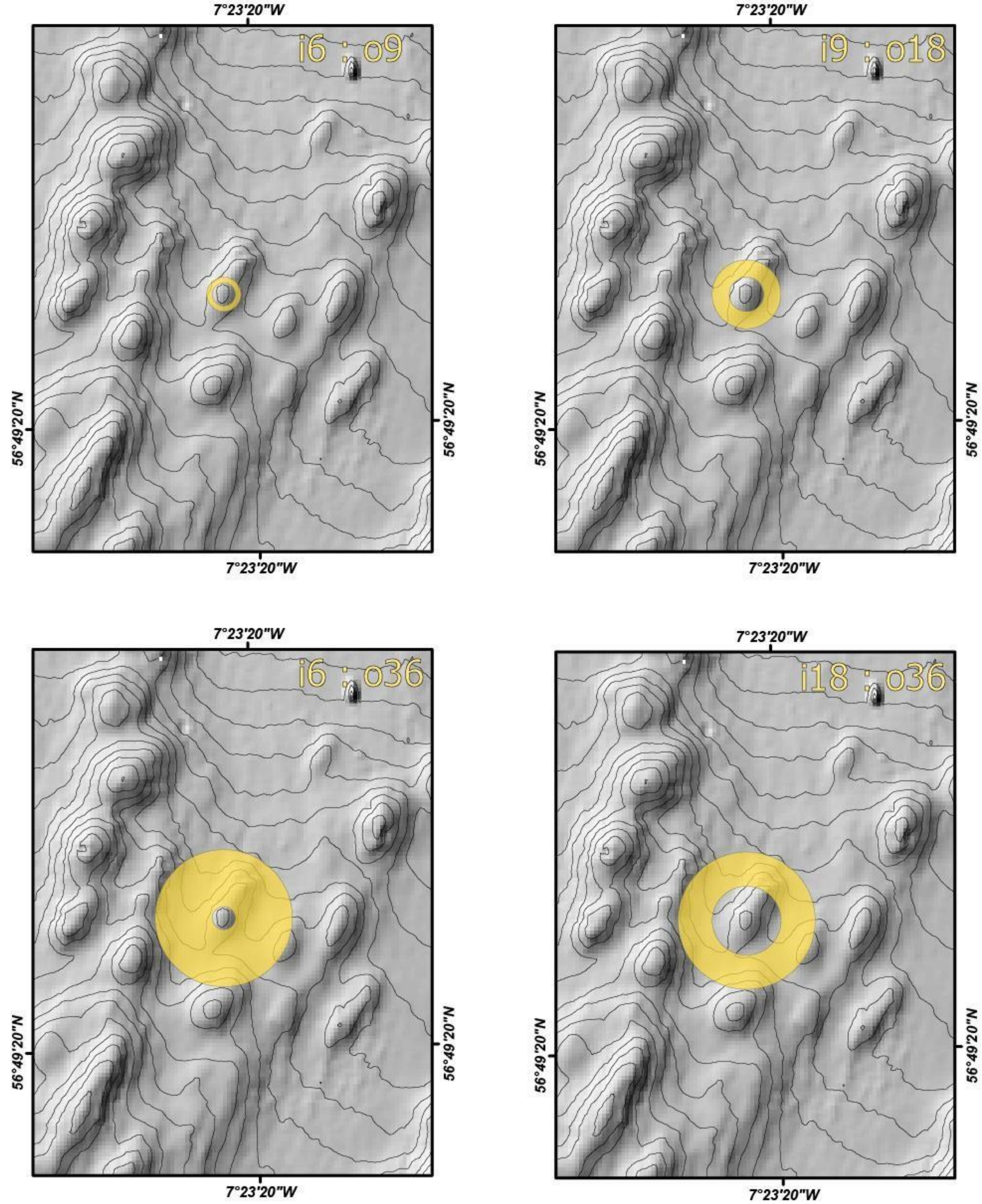


Figure 10 *- Illustration of the analysis neighbourhood used to create the four different BPI maps.*

From with the finest scale map (i6:o9) with an inner radius of 6 cells and outer radius of 9 cells, and the broader scale (i18:o36) with an inner radius of 18 cells and outer radius of 36 cells.

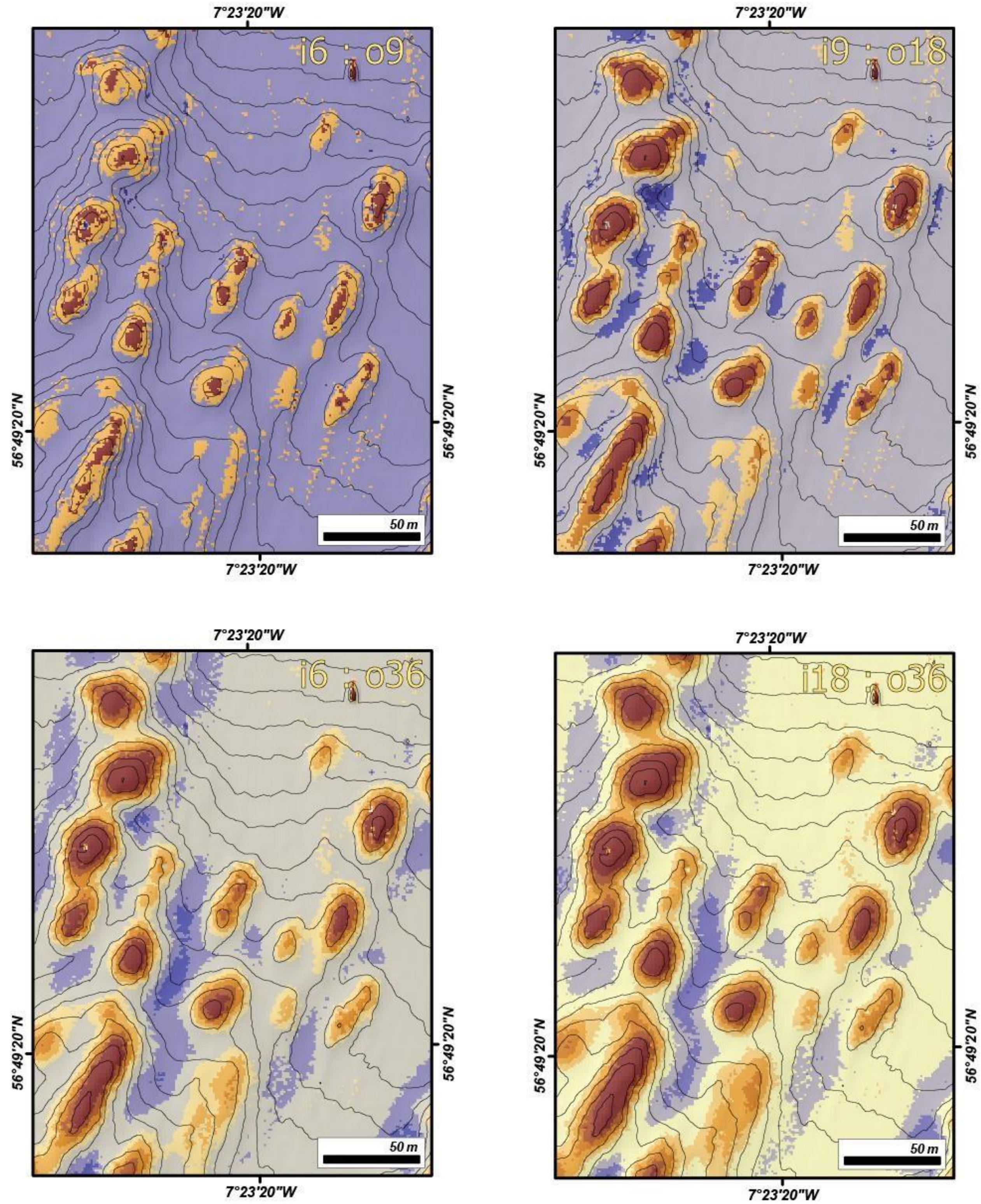


Figure 11 *- Illustration of the four different BPI maps created using different analysis neighbourhood.*

From with the finest scale map (i6:o9) with an inner radius of 6 cells and outer radius of 9 cells, and the broader scale (i18:o36) with an inner radius of 18 cells and outer radius of 36 cells. Note that the areas identified as topographic highs (in brown) change depending on the scale used.

Additionally, to the visual assessment of the BPI maps generated, profiles across some seabed features can be used to assist the selection of the BPI map that should be used as input raster and to define the threshold values for the automated delineation (FIGURE 12).

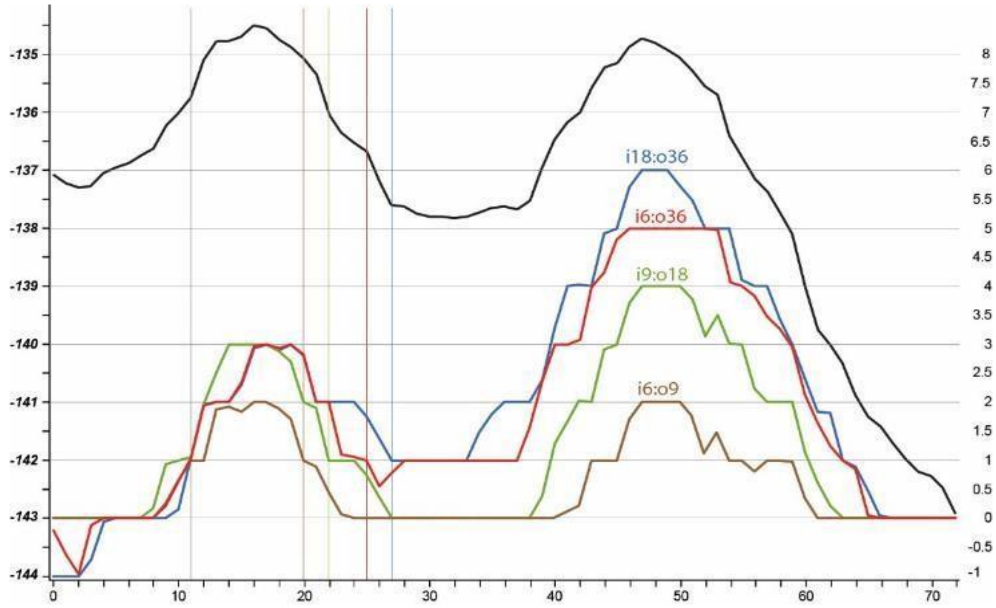


Figure 12 - The bathymetric profile (black) and four corresponding BPI profiles (in brown, green, red and blue).

Use of Local Topographic Position: DEV and median LTPs

CoMMa Toolbox offers a selection of LTPs that go beyond the commonly adopted BPI. While BPI is a good and quick solution to isolate morphologies, median LTPs or DEV can on many occasions provide better results. This depends often on the type of background (large-scale) topography, shape, distribution and abundance of features to be mapped (see FIGURE 13). The same principles of neighbourhood dimension and type apply to these LTPs as in BPI, and each is designed to optimise a specific aspect of topographic position comparison.

- DEV is a normalised BPI, it works similarly to relative deviation from the mean value (RDMV, Lecours, 2017) an enhances local differences reducing clumping. More information can be found in Newman et al. (2018)
- Median BPI is a slower but better BPI measurement, as it partly eliminates the creation of positive or negative values at shoulder or footslope locations.
- Minimum and maximum medians are designed to capture to the fullest respectively positive or negative features. Both are most effective to isolate landforms in relatively flat surroundings. More information can be found in Adams et al. (2005).
- Directional median is the slowest to calculate, however is most effective to isolate features on rough or sloping terrain. More information can be found in Kim and Wessel (2008).

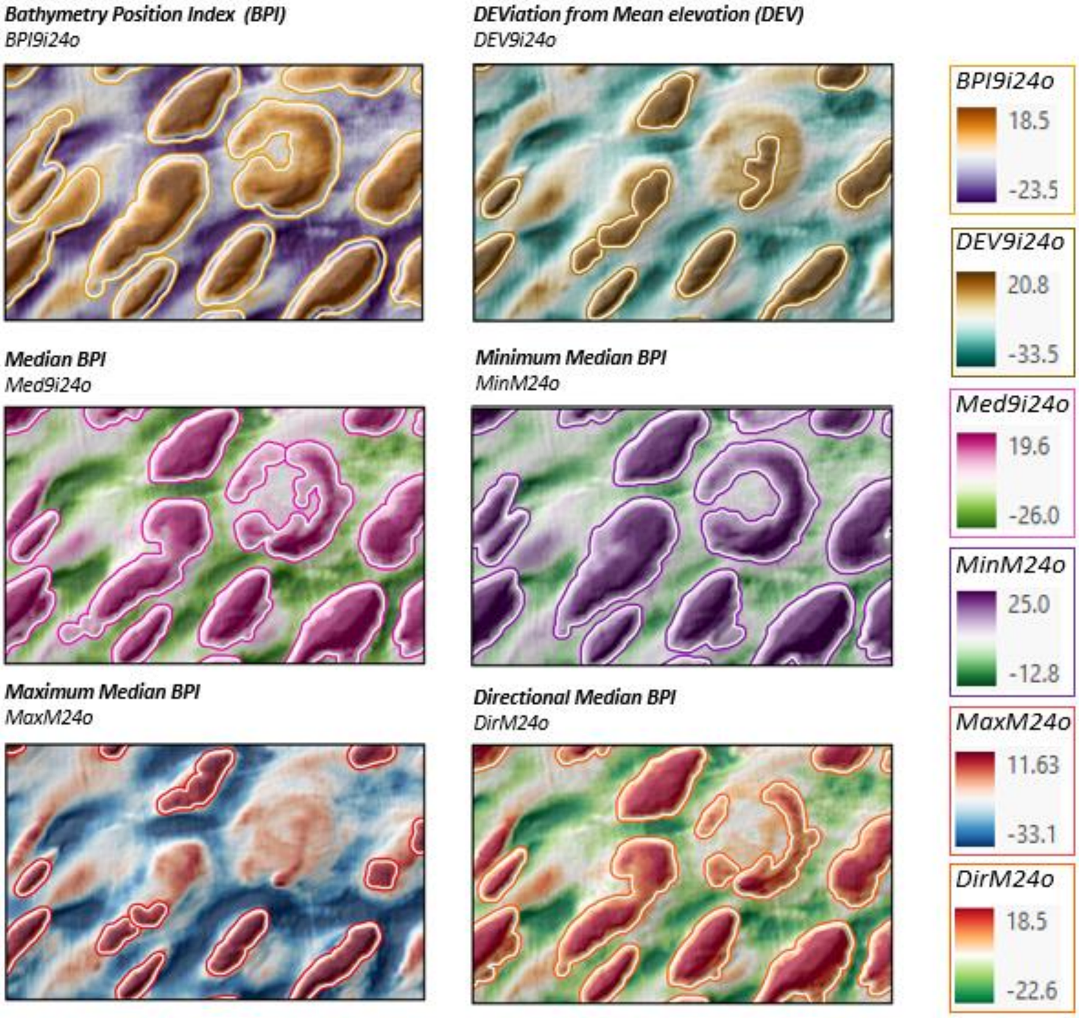


***Figure 13** - Contrasting delineation outputs using the same threshold values by using different LTPs derivatives as input for the Boundary-based delineation tool.*

Use of Geomorphons

Jasiewicz and Stepinkski (2013) presented a method for classification and mapping of landform elements from a DEM based on the principle of pattern recognition. At the core of the method is the concept of a geomorphon (geomorphologic "phenotypes"), that represent the elevation differences within the surrounding area of a target cell.

By using the Geomorphons classes as delineation input, the delineation will depend considerably on how the Geomorphons raster was calculated. Like the LTPs derivatives, the Geomorphon classification will depend on the choice of the size of the analysis's neighbourhood (FIGURE 14). The algorithm is particularly susceptible to the slope threshold introduced, apart from the neighbourhood, and lower slopes will be potentially more affected by artefacts. To solve at least partly this problem Geomorphons can be applied to LTPs instead of directly to the DEM.

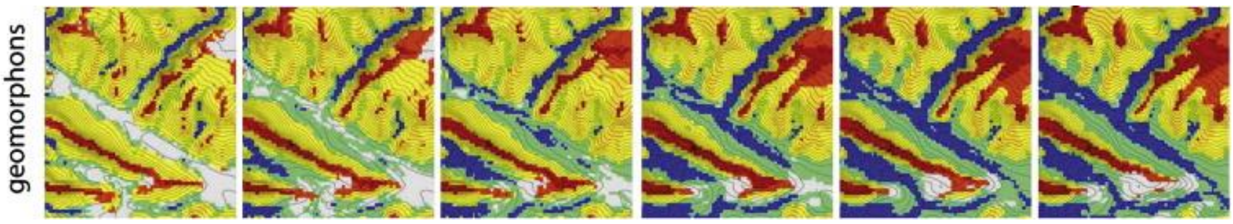


***Figure 14** – Dependence of geomorphometric map on analyses neighbourhood - varying from 5 pixels to 50 pixels. Extracted from Jasiewicz and Stepinkski (2013).*

Use of Minimum Bounding Geometry (MBG)

The "Minimum Bounding Geometry" ArcGIS tool creates a feature class containing polygons which represent a specified minimum bounding geometry enclosing each input feature or each group of input features. The MBG polygons can be of five types (FIGURE 15) and each polygon can be characterised by a set of measurements. For Rectangle by width type of MBG polygons, the measurements are:

MBG_Width: The length of the shorter side of the resulting rectangle.

MBG_Length: The length of the longer side of the resulting rectangle.

MBG_Orientation: The orientation of the longer side of the resulting rectangle.

The width and length measurements are in feature units (normally meter) and the orientation angles are in decimal degrees clockwise from north. If the feature is circular or nearly circular the value of "MBG_Orientation" will be zero.

The "MBG_W_L" values are calculated using the field calculator by dividing the "MBG_Width" by the "MBG_Length" values. This value can be used as a proxy to the feature aspect ratio.

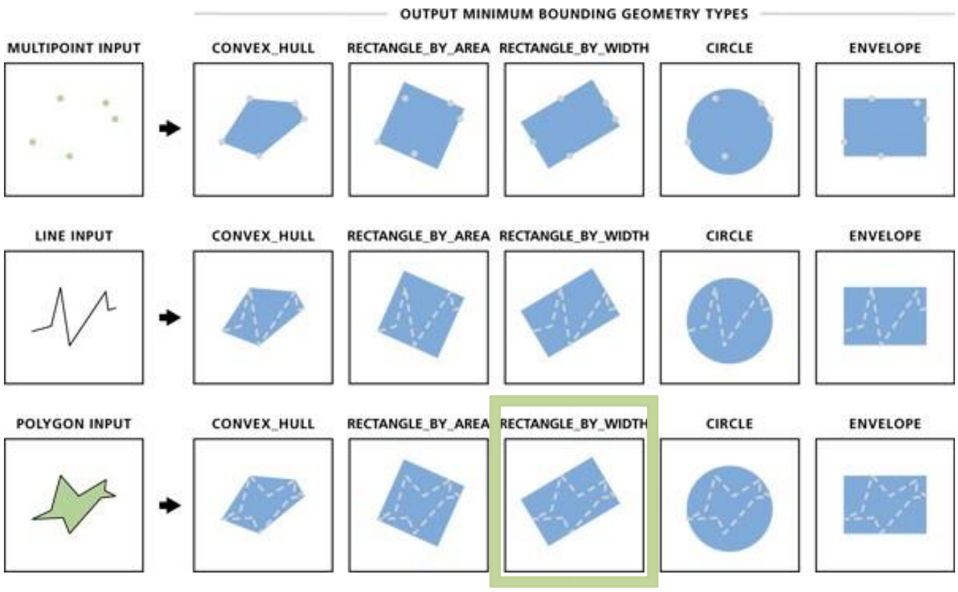


Figure 15 *- Output Minimum Bounding Geometry Types (extracted from the ArcGIS Pro Tool Reference site). The geometry used within the BGS Seabed Mapping Toolbox as proxies for the geometry of the delineated features is rectangle by width.*

Interactions Between Delineation Tool's Parameters

Although the threshold values are set independently, there is a certain degree of "interaction". For example, by increasing the *Minimum Width* threshold value the minimum relief of the features mapped may also increase, without changes in the value of the *Cutoff Vertical Relief* threshold.

Assuming that the width of the polygon delineated for a 70 cm deep pockmark, using *Cutoff Vertical Relief* threshold of 50 cm, would be smaller than the threshold set for the *Minimum Width*. Therefore, this and of most 70 cm deep pockmarks would not actually be mapped whereas pockmarks deeper than 100 cm would probably all be mapped. By reducing the value of the *Minimum Width* threshold, shallower pockmarks would be also mapped. Thereby indirectly reducing the minimum pockmark depth to be mapped without changing the *Cutoff Vertical Relief* threshold.

Other interactions are observed between the different parameters set by the user. Figure 9 illustrates the effect of changes in the *Cutoff Vertical Relief* and *Buffer Distance*. In the example, a feature that initially satisfied the *Minimum Width* and would have been mapped fails to satisfy the Minimum Width threshold if a smaller *Buffer Distance* is provided or if a greater *Cutoff Vertical Relief* is requested.

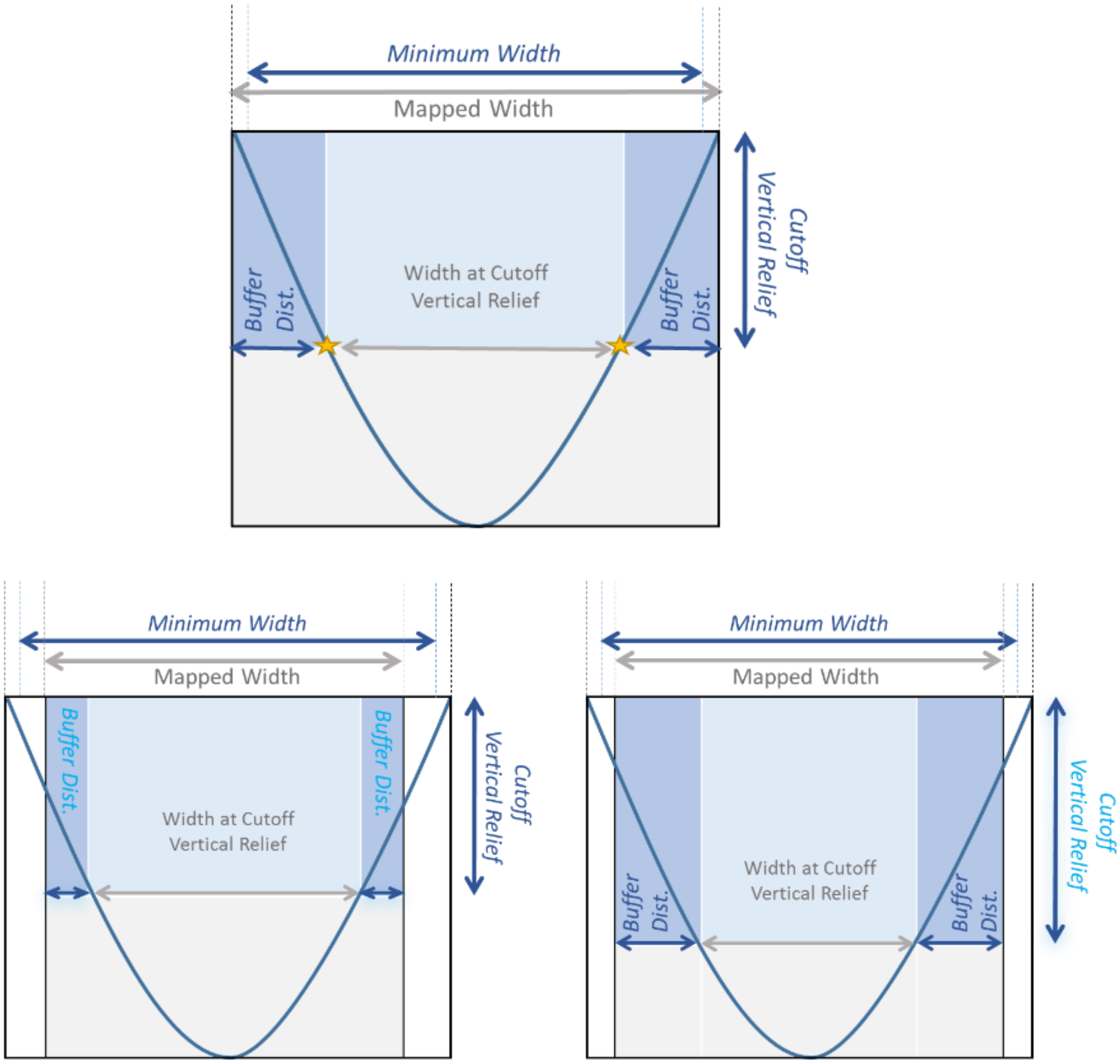


Figure 16 *- The effect of changes in the Cutoff Vertical Relief and Buffer Distance values.*

Top) *Diagram showing the three of the parameters required for the Feature Delineation Bathy tool: Minimum Width, Cutoff Vertical Relief and Buffer Distance.* ***Bottom left)*** *The same feature with the same Minimum Width and Cutoff VR does not satisfy the Minimum Width requirement by having a smaller Buffer Distance.* ***Bottom right)*** *The same feature with the same Min Width and Buffer Distance does not satisfy the Min Width requirement by having a deeper Cutoff VR.*

Difference between Relief, Confined relief and Optimal relief

The vertical dimension of the mapped features can be captured in three different ways: Relief (Relief), Confined Relief (Conf_R) and Optimum Relief (Optim_R).

The Relief (Relief) is the first available measurement and it is calculated during the delineation process. In the boundary-based delineation tool it corresponds to the vertical difference between the deepest/shallowest point of the feature and the pouring point, as defined by the Fill tool. This measurement can give inaccurate or spurious figures (i.e. higher values) as it extrapolates heights from areal fills without accounting for the Vertical Cutoff of the delineation.

In the Elements-based delineation the Relief is defined by subtracting the maximum Water Depth (MaxWD) to the minimum Water Depth (MinWD). Since the MinWD and the MaxWD correspond to, respectively, the shallowest and deepest point within the outlined area, the value captured may be higher if the feature is on a sloping terrain.

The Confined Relief (Conf_R) is the second available measurement of relief and it is calculated using the Basic Descriptors tool. This measurement is extracted by clipping the DEM using the delineated features first, and then filling the DEM using the Fill algorithm. The vertical difference between the deepest/shallowest point of the feature and the pouring point, as defined by the Fill tool, will return a "confined" relief based on the delineations. This number can be an underestimation of the real height.

Finally, the Optimal Relief (Optim_R), is calculated using the Volume Descriptors tool. This is the best approximation of height, as the value is extracted on a feature-by-feature basis on the isolated and detrended DEM of the feature, utilising the Cookie-cutter method (Smith et al., 2009).

7. Acknowledgements and authorship contribution statement

Riccardo Arosio (University College Cork) and Joana Gafeira (British Geological Survey) conceived the original idea of the new ArcGIS Pro based on a previous toolbox created by Joana Gafeira, the BGS Seabed Mapping Toolbox (Gafeira, J., 2017). Riccardo Arosio, Joana Gafeira and Laurence De Clippele ideated the toolbox contents. Riccardo Arosio wrote the Python scripts while Joana Gafeira and Laurence De Clippele performed extensive testing and gave useful feedback.

The tools development was mainly funded by INFOMAR (www.infomar.ie) through the Irish Marine Institute's research grant PDOC 19/08/03 (https://www.ucc.ie/en/marinegeology/projects/seabedmapping/nomanstif/) and the British Geological Survey. iAtlantic has also supported the creation of the toolbox and funded Joana Gafeira to write this User Guide.

How to cite the CoMMa toolbox

We hope you will find this toolbox a useful resource to support the mapping and characterisation of the morphological features you will encounter and that will allow you to advance your research. If you happen to publish data extracted using the CoMMa tools, please cite the tool:

Arosio, R., Gafeira, J. and De Clippele, L. (3 May 2024) CoMMa Toolbox v 1.2 https://zenodo.org/records/8434457

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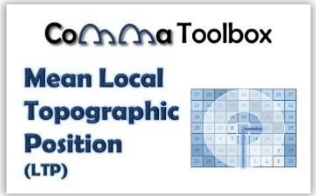
Appendix 1: ArcGIS Pro help description

Mean LTPs

Description

The "**Mean Local Topographic Position (LTP)**" provides access to two different algorithms that compare the elevation of each cell in a DEM to the mean elevation of a specified neighbourhood around that cell.

llustration



Usage

The **"Mean Local Topographic Position (LTP)"** tool allows the calculation of the BPI or DEV of the provided DEM, according to the window of analyses set by the user.

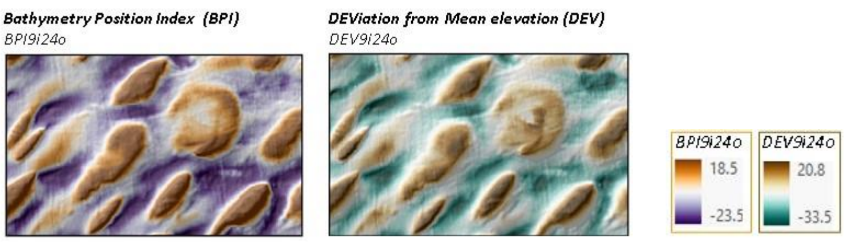
The **Bathymetry Position Index (BPI)**: BPI measures the vertical position of a pixel relative to the mean elevation (μ) of a user-defined neighbourhood.

The **Deviation from mean elevation (DEV)**: DEV measures the vertical position relative to the neighbourhood mean elevation (μ), but also normalizes by the standard deviation (σ) of the neighbourhood elevation distribution, effectively expressing local topographic position as a z-score.

Parameters

Parameter	*Explanation*	*Data Type*
Input DEM	*The DEM that will be used as input.*	*Raster Layer*
Filter Type	*Type of position index to be calculated.* *BPI (Bathymetry Position Index) or* *DEV (Deviation from mean elevation)*	*String*
Inner radius	*The Inner radius of the annulus-shaped neighbourhood, that will be included in the LTP calculation.* *This can also be referred to as skip distance and is the distance in cells to the internal circle, after which the cell values will be included in processing the neighbourhood.* *unit: cells*	*Long*
Outer radius	*The outer radius of the annulus-shaped neighbourhood, that will be included in the LTP calculation.* *This can also be referred to as search distance and is the distance in cells to the external circle, after which the cell values will not be included in the analysis neighbourhood.* *unit: cells*	*Long*
Output position index	*Output raster name.*	*Raster Layer*

Help Image

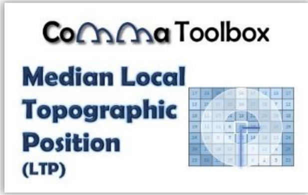


Median LTPs

Description

The "**Median Local Topographic Position**" tool allows the calculation of local topographic position index metrics based on the absolute and relative median of the neighbourhood.

Illustration



Usage

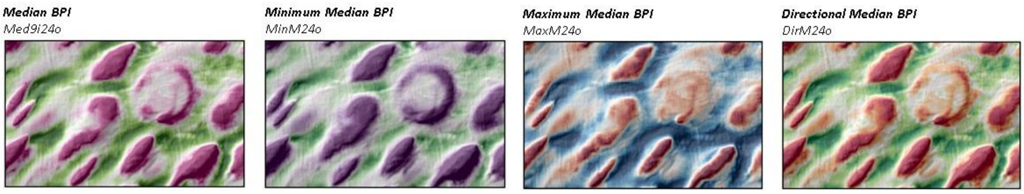
The **"Median Local Topographic Position"** tool allows the calculation of the following local topographic position index metrics:

- **Median Bathymetry Position Index (M-BPI):** measures the vertical position of a pixel relative to the median elevation (M) of a user-defined neighbourhood.
- **Minimum Median Bathymetry Position Index (minM-BPI):** first calculates a minimum value surface running a convolution for a window defined as 1/4 of a user-defined neighbourhood. Subsequently, it measures the M-BPI of the minimised surface.
- **Maximum Median Bathymetry Position Index (maxM-BPI):** first calculates a maximum value surface running a convolution for a window defined as 1/4 of a user-defined neighbourhood. Subsequently, it measures the M-BPI of the maximised surface.
- **Directional Median Bathymetry Position Index (dirM-BPI):** divides a given filter circle into N "bow tie" sectors, allocates data points inside the filter circle to each sector based on their relative position within the circle, estimates a median for each sector, and returns the lowest of these N medians.

Parameters

Parameter	*Explanation*	*Data Type*
Input DEM	*The DEM that will be used as input.*	*Raster Layer*
Filter Type	*Type of position index to be calculated:* *Median Bathymetry Position Index* *Minimum Median Bathymetry Position Index* *Maximum Median Bathymetry Position Index* *Directional Median Bathymetry Position Index*	*String*
Inner radius	*The Inner radius of the annulus-shaped neighbourhood, that will be included in the LTP calculation.* *This can also be referred to as skip distance and is the distance in cells to the internal circle, after which the cell values will be included in processing the neighbourhood.* *unit: cells*	*Long*
Outer radius	*The Outer radius of circle or annulus-shaped neighbourhood, that will be included in the LTP calculation.* *This can also be referred to as search distance and is the distance in cells to the external outline circle, after which the cell values will not be included in the analysis neighbourhood.* *unit: cells*	*Long*
Output position index	*Output raster name.*	*Raster Layer*

Help Image



Fencing Tool

Description

This tool creates an artificial containing "fence" around the perimeter of the input DEM, allowing the delineation of landforms that are at the boundary of the dataset and that otherwise would be considered, by the "**Boundary-based Delineation**" tool, as unconfined.

- ***It must be used in conjunction with the "Filter and Clip" tool.***
- ***The output DEM, i.e. the DEM with the confining fence, may not be appropriated as input to neighbourhood analysis tools (such as LTP tools).***

Illustration

Usage

This script assists the feature delineation tools by creating a buffer around the Input Raster. For targeted features with positive relief, the minimum value of the input DEM will be used for the artificial fence set by the buffer, whereas for negative targeted features, it will use the maximum value. This artificial fence should allow the delineation of landforms only partially captured within the dataset and that otherwise would be considered, by the "**Boundary-based Delineation**" tool, as unconfined.

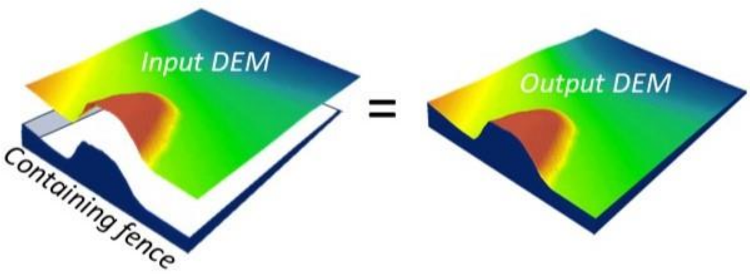
If this tool is used, it must be followed by the "Filter and Clip" tool. Without it, the artificial containing fence will confine the full dataset and the delineation tools will be unable to recognise the targeted features. The "**Filter and Clip**" will introduce NoData pixels within the dataset that will prevent the delineation of the full dataset as one single confined feature.

The output DEM of this tool, *i.e.* the DEM with the confining fence, may not be appropriated as input to neighbourhood analysis tools (such as LTP tools). The extreme values at around the perimeter of the DEM will affect the derivative values near the boundaries of the raster layer. The impact of the extreme value will depend on the value range of the initial DEM and the size of the window of analysis set by the neighbourhood defined.

Parameters

Parameter	*Explanation*	*Data Type*
Input DEM	*The DEM that will be used as input.*	*Raster Layer*
Are you mapping positive or negative features?	*The relief of the targeted features will define the value used for the artificial containing fence. For positive features (e.g., mounds and drumlins), it will be the minimum value of the input DEM, whereas for negative features (e.g., pockmarks, sinkholes) it will be the maximum value of the input DEM.*	*String*
Workspace	*The location where the output raster will be stored.* *Geodatabases cannot be used in this version of the CoMMa Toolbox.*	*Workspace*
Output fenced raster name	*Output raster name.*	*String*

Help Image



Filter and Clip tool

Description

In areas with complex seabed morphology or features connected by regional morphology (e.g. pockmarks in basins), it may be needed to prepare the data to allow the best results when running an automated mapping tool. The **"Filter and Clip Tool"** will clip the initial dataset, removing the flat or featureless areas in the DEM and preserving information only for areas of the seabed where the features are more likely to occur. The application of this tool is particularly useful to remove the effects of broad-scale topography on Fill based delineations, in situation like when mapping coral mounds on top of a reef.

Illustration

Usage

The regional morphology or the presence of overlapping features may affect the delineation tools' ability to map the smaller-scale features. These issues can be addressed by using the **"Filter and Clip Tool"**. This tool will clip the initial dataset, based on a user defined threshold, removing the flat or featureless areas in the DEM, and preserving bathymetric information only for areas of the seabed where the features are more likely to occur.

The **"Filter and Clip Tool"** uses both High Pass Filter and Low Pass Filter to define the areas of higher vertical variation. The High Pass Filter accentuates the comparative difference between a cell's values and its neighbours. The Low Pass smooths the entire input raster and reduces the significance of anomalous cells. The user-defined filter threshold sets the reclassify range. The threshold value will not have a direct relation to the elevation values of the input DEM and should be positive even when the targeted features are negative. The Clip tool is then used to preserve areas of the original DEM with filtered values higher than the threshold set and to exclude areas of the DEM with gentle local variations.

Parameters

Parameter	*Explanation*	*Data Type*
Input DEM	*The DEM that will be used as input.*	*Raster Layer*
Filter threshold for reclassification	*Note that this threshold value does not have a direct relation to the values of the input DEM and that this should be positive even when the targeted features are negative.*	*Double*
Buffer size	*Buffer distance should be wide enough the cover the totality of the targeted features and not only the areas if higher vertical variations. Half of the width of the targeted features tend to be a save buffer distance.*	*Double*
Workspace	*The location where the output raster will be stored.* *Geodatabases cannot be used in this version of the CoMMa Toolbox.*	*Workspace*
Output name	*Output raster name.*	*String*
Do you want to delete the temporary files?	*When checked all the files within the temp folder will be deleted.*	*Boolean*

Smoothing Filters

Description

The “**Smoothing Filters Tool**” provides a selection of standard filtering algorithms that can be used to smooth the DEM and remove, at least partially, noise and artefacts.

Illustration

Usage

The “**Smoothing Filters Tool**” provides direct access to key smoothing filters: MEAN (that calculates the mean value of the cells in the neighbourhood set by the user, MEDIAN (that calculates the median of the cells in the neighbourhood set by the user) and LOW-PASS (that calculates the average value for either a 3 x 3 or 5x5 neighbourhood).
While smoothing filter can be used to remove noise and artefacts, they will also subdue the real signal proportionally to their respective aggressiveness.

Parameters

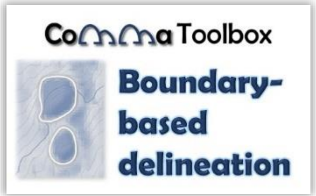
Parameter	*Explanation*	*Data Type*
Input DEM	*The DEM that will be used as input.*	*Raster Layer*
Filter type	*Standard filtering algorithm that will be used smooth the DEM and remove, at least partially, noise and artefacts.* *MEAN — Calculates the mean (average value) of the cells in the neighbourhood set by the user.* *MEDIAN — Calculates the median of the cells in the neighbourhood set by the user.* *LOW-PASS 3x3 — It calculates the average value for each 3 x 3 neighbourhood.* *LOW-PASS 5x5 — It calculates the average value for each 5 x 5 neighbourhood.*	*Long*
Neighbourhood type	*The shape of a neighbourhood can be an annulus (a donut), a circle, a rectangle, or a wedge.* *A circle neighbourhood is created by specifying an outline radius value - distance 1.* *The rectangle neighbourhood is specified by providing a width and a height - distance 1 and 2.* *The annulus shape is composed of two circles, one inside the other to make a donut shape. The smaller circle is defined by the inner radius (distance 1) and the larger circle is defined by the outer radius (distance 2)* *A wedge is a pie-shaped neighbourhood specified by a radius (distance 1), a starting angle (angle 1), and an ending angle (angle 2).*	*String*
Distance 1	*In a CIRCLE neighbourhood, is the outline radius.* *In a RECTANGLE neighbourhood, is the width.* *In an ANNULUS neighbourhood, is the inner radius.* *In a WEDGE neighbourhood, is the wedge radius.*	*Long*
Distance 2	*In a RECTANGLE neighbourhood, is the height.* *In an ANNULUS neighbourhood, is the outer radius.*	*Long*
Angle 1	*In a WEDGE neighbourhood, is the starting angle.*	*Long*
Angle 2	*In a WEDGE neighbourhood, is the ending angle.*	*Long*
Output Filtered	*Output raster that will be a smoother version of the input DEM.*	*Raster Dataset*

Boundary-based delineation

Description

The “Boundary-based delineation” tool can be applied directly to bathymetric DEM and, when the general seascape is otherwise flat, it might be sufficient to isolate and correctly delineate the targeted features. However, this is often not the case, and the interference of sloping topography or other underlying large-scale landforms can distort the signal of the targets. In this case, the “Boundary-based delineation” tool can also use a LTP derivative to isolate a specific wavelength thought to best delineate the feature of interest.

Illustration



Usage

The “Boundary-based Delineation" tool, when using exclusively the DEM as delineation input, takes advantage of the hydrological algorithm “Fill”. This algorithm will fill up positive or negative enclosed relief, according to the relief of the targeted features. Then the filled output will be subtracted from the original DEM, creating a flat surface with only the potential features of interest. Then a user-defined threshold, the Vertical Cutoff, is used to define the contour line that Is going to be the base of the delineation.

When an LTP layer is provided as input, the “Boundary-based Delineation" Tool will reclassify the derived raster according to the user-defined threshold Vertical Cutoff.

Once all the areas of confined morphologies are delineated based on the Vertical Cutoff threshold, a sequence of steps is followed and features that do not satisfy the criteria set by the user-defined thresholds will be excluded. The threshold covers aspects related to the minimum vertical relief and dimensions expected for the targeted feature. Additionally, the user can filter the features delineated using geomorphons classification layer.

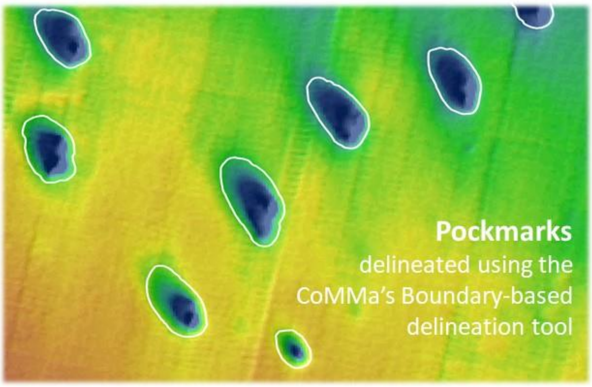
The delineation of some features, especially based on some LTPs layers, may fail to include the top of positive features or the base of the negative features, by focusing on areas of change of relief – creating holes within the delineating polygons. If that occurs, the user can choose to have it automatically removed.

Parameters

Parameter	*Explanation*	*Data Type*
Input DEM	*The DEM that will be used as input.*	*Raster Layer*
LPT derivative (Optional)	*The LPT derivative to be used to base the delineation.*	*Raster Layer*
"Select whether you want to map positive or negative features"	*This defines the type of features that will be mapped by identifying the targeted features’ relief. The user can choose between: POSITIVE (e.g., mounds, drumlins) or NEGATIVE (e.g., pockmarks, sinkholes).*	*String*
Vertical Cutoff	*Defines the value that will be used as the confining boundary to delineate the targeted features.* *The value will be in meters if the delineation is fully based on the source DEM, OR on the derivative unit, if the latter is used.* *When the targeted features are well disconnected for other features, this value should be as low was possible, to best capture the geometry of the feature’s boundary. However, the user may want to use a higher value to reduce the likelihood of adjacent features being mapped as a conjoined polygon.*	*Double*
Minimum Vertical Threshold	*Only features with a relief greater to Minimum Vertical Threshold value will be mapped.* *unit: m*	*Double*
Minimum Width	*Minimum Width threshold allows to exclude features based on their size. Only features with width greater the Minimum Width value will be mapped.*	*Double*

	unit: m	
Minimum W/L Ratio	*The Minimum Width/Length Ratio threshold allows to exclude features based on their shape. Width and Length are defined by the features' Minimum Bounding Geometry (MBG).* *It should be noticed that the Minimum Width/Length Ratio value can range from 1 (for a circle-shaped feature) to almost 0 (for a very elongated feature).*	*Double*
Buffer to apply to the delineation	*The Buffer Distance value is applied to the initial polygons created based on the feature's internal contour line correspondent to the Vertical Cutoff. The Buffer Distance should reflect approximately the distance, in plan view, from the reference internal contour line delineated to the actual rim/edge of the features.* *unit: m*	*Double*
Select whether you want to simplify and smooth the delineations	*The user can decide whether to apply smoothing and simplification to the initial (or buffered) polygons. Light, heavy or no simplification and smoothing options are offered. Simplification is calculated using the Retain weighted effective areas (Zhou-Jones) algorithm, with tolerance(T) based on the size of the polygon (light T = width feature / 10; heavy T = width feature / 5). Smoothing is done using the PAEK algorithm with tolerance(T) based on the size of the polygon (light T = width feature / 5; heavy T = width feature / 2).*	*String*
Workspace	*The location where the shapefile with the delineated features will be stored.* *Geodatabases cannot be used in this version of the CoMMa Toolbox.*	*Workspace*
Output Feature name	*The name of the output shapefile with the delineated features.*	*String*
Do you want to apply the geomorphons filter? (Optional)	*When checked, by setting a Minimum Geomorphons ratio threshold, it is possible to exclude features based on the area cover by certain geomorphons classes.*	*Boolean*
Geomorphons File (Optional)	*The input classified landforms raster, generated directly from the DEM or from an LPT-derived raster. Every cell of this raster will have an integer value corresponding to a specific landform type: Flat—cell value 1, Peak—cell value 2, Ridge—cell value 3, Shoulder —cell value 4, Spur—cell value 5, Slope—cell value 6, Hollow—cell value 7, Footslope—cell value 8, Valley—cell value 9, Pit—cell value 10.*	*Raster Layer*
Minimum Geomorphons area over total area ratio (Optional)	*Features with a ratio geomorphons area/total area smaller than Minimum Geomorphons ratio threshold will be excluded from the delineation.*	*Double*
Do you want to delete internal holes in the polygons? (Optional)	*When checked holes inside a delineated feature are removed.* *The delineation of some features, especially based on some LTPs layers, may fail to include the top of positive features or the base of the negative features, by focusing on the main areas of change of relief – creating holes within the delineating polygons.*	*Boolean*
Do you want to delete the temporary files?	*When checked all the files within the temp folder will be deleted.* *It should be noted that some of these "intermediate" files could be useful to understand the reason behind an unexpected output.* *If the tool is run multiple times the temp files will be overwrite, to avoid excessive use of disk space. If is required to compare the temp files created with different parameters, then different workspaces should be selected.*	*Boolean*

Help Image

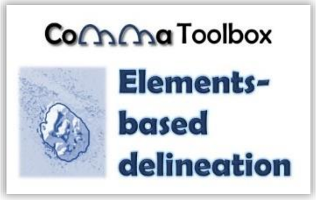

Pockmarks
delineated using the
CoMMa's Boundary-based
delineation tool

Elements-based delineation

Description

The “Elements-based Delineation” defines the limits of the targeted features based on the spatial arrangement of homogeneous surfaces and relies on surface units created by the geomorphons algorithm.

Illustration



Usage

The “Elements-based Delineation” tool allows the delineation of confined features by using the geomorphons classification generated directly from the DEM or from an LPT-derived raster.

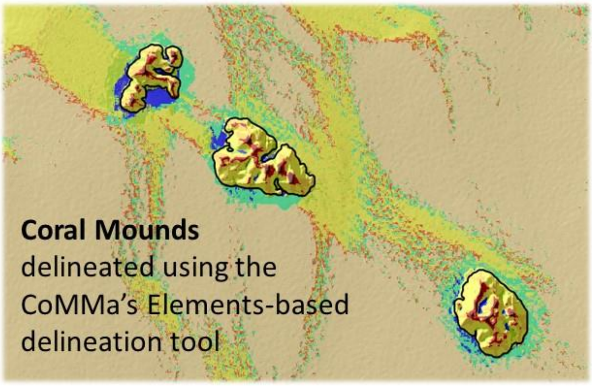
This tool will merge and reclassify the landform type depending on whether the targeted features are POSITIVE (peaks, ridges, shoulders, spurs and possibly slopes) or NEGATIVE (pits, hollows, valleys and possibly footslopes), and then converted into polygons. The tool can be applied to the bathymetry or an LTP.

Parameters

Parameter	*Explanation*	*Data Type*
Input DEM	*The DEM that will be used as input.*	*Raster Layer*
Input Geomorphons raster	*The input classified landforms raster, generated directly from the DEM or from an LPT-derived raster.* *Every cell of this raster will have an integer value corresponding to a specific landform facet: Flat—cell value 1, Peak—cell value 2, Ridge—cell value 3, Shoulder —cell value 4, Spur—cell value 5, Slope—cell value 6, Hollow—cell value 7, Footslope—cell value 8, Valley—cell value 9, Pit—cell value 10.*	*Raster Layer*
"Select the core geomorphons you wish to map"	*This defines the essential landform facets that compose the structure of the landform to be mapped. The user can select any landform facet in a Geomorphons raster.*	*String*
"Select the subordinate geomorphons you wish to map"	*This defines the landform facets that may be part of the structure of the landform but are not essential. A grouping comprised of only subordinate facets, without core facets, will not be delineated. The user can select any landform facet in a Geomorphons raster.*	*String*
Minimum Vertical Threshold	*Minimum Vertical Threshold allows to exclude features based on their relief. Only features with a relief greater to Minimum Vertical Threshold value will be mapped.* *unit: m*	*Double*
Minimum Width	*Minimum Width threshold allows to exclude features based on their size. Only features with width greater the Minimum Width value will be mapped.* *unit: m*	*Double*
Minimum W/L Ratio	*The Minimum Width/Length Ratio threshold allows to exclude features based on their shape. Width and Length are defined by the features' Minimum Bounding Geometry (MBG)* *It should be noticed that the Minimum Width/Length Ratio value can range from 1 (for a circle-shaped feature) to almost 0 (for a very elongated feature).*	*Double*
Buffer to apply to the delineation	*The Buffer Distance value is applied to the initial polygons created based on the feature's internal contour line correspondent to the Vertical Cutoff. The Buffer Distance should reflect approximately the distance, in plan view, from the reference internal contour line delineated to the actual rim/edge of the features.* *unit: m*	*Double*

Select whether you want to simplify and smooth the delineations	*The user can decide whether to apply smoothing and simplification to the initial (or buffered) polygons. Light, heavy or no simplification and smoothing options are offered. Simplification is calculated using the Retain weighted effective areas (Zhou-Jones) algorithm, with tolerance(T) based on the size of the polygon (light T = width feature / 10; heavy T = width feature / 5). Smoothing is done using the PAEK algorithm with tolerance(T) based on the size of the polygon (light T = width feature / 5; heavy T = width feature / 2).*	*String*
Workspace	*The location where the output raster will be stored.* *Geodatabases cannot be used in this version of the CoMMa Toolbox.*	*Workspace*
Output Feature name	*The name of the resulting shapefile with the output delineation of the mapped features.*	*String*
Do you want to delete internal holes in the polygons? (Optional)	*When checked, holes inside a delineated feature are removed.*	*Boolean*
Do you want to delete the temporary files?	*When checked all the files within the temp folder will be deleted.* *It should be noticed that some of these "intermediate" files could be useful to understand the reason behind an unexpected output.* *If the tool is run multiple times the temp files will be overwrite, to avoid excessive use of disk space. If is required to compare the temp files created with different parameters, then different workspaces should be selected.*	*Boolean*

Help Image



Basic descriptors

Description

Calculates a series of geometrical and statistical attributes for each delineated feature contained in the input shapefile.

Illustration

Usage

The “Basic Descriptor tool” calculates a series of geomorphometric parameters for each polygon feature, ranging from shape metrics to zonal statistics of slope, depth and BPI. Optionally, this tool allows the user to also compare the delineation with landform elements calculated by geomorphons, measuring the percentage area of each land surface unit, and counting the number of peaks (if positive morphologies) or pits (if negative morphologies) contained within each polygon feature. These measurements can give a useful indication of the complexity of the mapped landforms. This tool can be used to describe any confined morphological features, regardless of the approach adopted to delineate them. Even manually mapped features can be characterised using this tool.

Parameters

Parameter	*Explanation*	*Data Type*
Input DEM	*The DEM that will be used as input.*	*Raster Layer*
Input delineated morphologies	*Shapefile delineating the features to be described.* *This can be the output of one of CoMMa's delineation tools, manually mapped or obtained by another mapping approach.*	*Feature Layer*
Workspace	*The location where the output raster will be stored.* *Geodatabases cannot be used in this version of the CoMMa Toolbox.*	*Workspace*
Output Feature name	*The name of the shapefile that will contain the additional fields calculated by this tool.*	*String*
Are you mapping positive or negative features?	*This defines the type of features that will be mapped by identifying the targeted features’ relief (POSITIVE or NEGATIVE).*	*String*
Geomorphons raster file	*Geomorphons raster that will be used to describe the features based on their landform elements.*	*Raster Layer*
Do you want to delete the temporary files?	*When checked all the files within the temp folder will be deleted.*	*Boolean*

Texture descriptors

Description

Calculates additional descriptive metrics, such as zonal vector ruggedness and aspect variability index, and optionally backscatter statistics.

Illustration

Usage

The "**Texture descriptors**" tool adds a few additional metrics that describe the quality of the surface, including zonal vector ruggedness measurement, aspect variability index and optionally backscatter statistics.
This tool can be used to describe any confined morphological features, regardless of the approach adopted to delineate them. Even manually mapped features can be characterised using this tool.

Parameters

Parameter	*Explanation*	*Data Type*
Input DEM	*The DEM that will be used as input.*	*Raster Layer*
Input backscatter raster	*Backscatter raster that will be used to describe the features based on their backscatter values.*	*Raster Layer*
Input delineated morphologies	*Shapefile delineating the features to be described.* *This can be the output of one of CoMMa's delineation tools, manually mapped or obtained by another mapping approach.*	*Feature Layer*
Workspace	*The location where the output raster will be stored.* *Geodatabases cannot be used in this version of the CoMMa Toolbox.*	*Workspace*
Output Feature name	*The name of the shapefile that will contain the additional fields calculated by this tool.*	*String*
Do you want to delete the temporary files?	*When checked all the files within the temp folder will be deleted.*	*Boolean*

Volume descriptor

Description

Calculates the volume and more accurately the height for each delineated feature contained in the input shapefile.

Illustration

Usage

The “**Volume descriptor**” calculates the best approximation of the relief and the volume of the feature. These calculations are based on the Cookie-Cutter method and are performed on a feature-by-feature basis, slowing down considerably the processing time.
This tool can be used to describe any confined morphological features, regardless of the approach adopted to delineate them. Even manually mapped features can be characterised using this tool.

Parameters

Parameter	*Explanation*	*Data Type*
Input DEM	*The DEM that will be used as input.*	*Raster Layer*
Input delineated morphologies	*Shapefile delineating the features to be described. This can be the output of one of CoMMa's delineation tools, manually mapped or obtained by another mapping approach.*	*Feature Layer*
Are you mapping positive or negative features?	*The targeted features' relief (POSITIVE or NEGATIVE).*	*String*
Workspace	*The location where the output raster will be stored.* *Geodatabases cannot be used in this version of the CoMMa Toolbox.*	*Workspace*
Output Feature name	*The name of the shapefile that will contain the additional fields calculated by this tool.*	*String*
Do you want to delete the temporary files?	*When checked all the files within the temp folder will be automatically deleted.*	*Boolean*