Step-by-step residual relief modelling GIS workflow for geomorphological characterization of shipwreck sites

Appendix to *Residual relief modelling: digital elevation enhancement for shipwreck site characterisation* paper

1. In ESRI ArcMap v. 10.6.1

Step 1: High-pass filtering

Open ArcMap

Add digital elevation model (DEM) data to *Table of Contents*

Locate *Focal Statistics* tool. Open *ArcToolbox/Spatial Analyst Tools/Neighborhood/Focal Statistics* or use ArcMap search engine (Windows/Search in Menu Bar) and type *Focal Statistics.*

Make sure you have *Spatial Analyst* extension active (Customize/Extensions… in Menu Bar)

Focal Statistics parameter set-up is described in subsection 2.3.1 of the paper and discussed in subsection 4.2. The general rule is that the moving kernel needs to be wide enough to capture more cells from the outside of a scour mark than from the inside. High-pass filtering can be performed using moving mean or median (see section 4.2). When working with floating-point DEM in ArcMap, *statistics type* can be set to mean only. Moving median can be calculated in QGIS with GRASS (see section 2 of this appendix).

Calculate the low-pass filter by executing *Focal Statistics* tool.

Locate *Raster Calculator* tool. Open *ArcToolbox/Spatial Analyst Tools/Map Algebra/Raster Calculator* or use ArcMap search engine. Set-up *Map Algebra expression*: subtract the low-pass layer (result of *Focal Statistics*) from the original DEM; "DEM" – "low_pass_result"

Calculate the high-pass filter by executing *Raster Calculator* tool.

Normalise the high-passed DEM to standard scores for further classification. Open *Raster Calculator*, set-up *Map Algebra expression:* (("high_pass_result")-mean_raster_value))/standard_deviation

mean_raster_value and standard_deviation values can be found by opening the resultant high-pass filtered DEM's (high_pass_result) *properties* and then *source/Statistics/Mean* and *Std dev*.

Calculate the normalised standard score layer by executing *Raster Calculator* tool.

Step 2: Preliminary classification

Open *Raster Calculator* tool. Breakpoint classification is conducted using Con() statements:

$Con("HPstdd"<-0.5,2, Con("HPstdd">5,3, Con("HPstdd">0.5,1,0)))$

Where: $HPstdd$ is the normalised high-passed filtered DEM

Values: below -0.5 are assigned to Class 2 (negative residuals), above 0.5 to Class 1 (positive residuals), between -0.5 and 0.5 to Class 0 and above 5 to Class 3 (wreck separation). Breakpoint values can be adjusted to capture features, accordingly to a target of the classification (see subsection 4.2 of the paper).

Step 3: Wreck marks separation with support of DEM visualization techniques

For the preliminarily classified layer, Class 0 fill color should be set to *No Color* in the layer's *Symbology* tab in *Properties*. In the *Display* tab, *Transparency* should be set to 50%. The layer should be moved up to the top in the *Table Of Contents.*

In Menu Bar, open Windows/Image Analysis. Choose the original, unfiltered DEM raster. In *Processing* tab, choose *Add Function* button, then right click on *Identify Function* and choose *Insert Function/Hillshade function*. Choose *Multidirectional* in *Hillshade Type* dropdown menu. Execute the multidirectional *hillshade* function by clicking Ok. In *Symbology* tab in the new layer's *Properties* choose *Stretch Type: Standard Deviations* and compute statistics for the layer. *Stretch Type* needs to be set to *standard deviations* for each layer derived from *Image Analysis* to improve visualization.

Apply other functions (see subsection 2.3.3 of the paper) and examine the geomorphological setting of the site.

Final separation is supported by clipping out unwanted residuals, using *Extract by Mask* tool from *Spatial Analyst Tools/Extraction* toolbox.

Create a new polygon shapefile – mask for extraction. Set the layer's transparency to 100%. In Menu Bar, open Customize/Toolbars and add *Editor* toolbar. *Start Editing* the mask for extraction. Based on the detailed examination of the residual geomorphological features on the site, delineate a polygon around residuals corresponding to scour features. In the *Editor* toolbar, *Save Edits* and *Stop Editing* the mask layer.

Use *Extract by Mask* tool. *Input raster* is the preliminarily classified layer, *Input raster or feature mask data* is the mask polygon layer created in the Step 3 of the workflow. Execute the tool and examine the resulting layer.

2. In QGIS 3.10.0 with GRASS 7.8.0*

*GRASS plugin is necessary to calculate kernel statistics for the high-pass filtering step 1. QGIS 3.10.0 cannot calculate Sobel edge detection filters used in the paper in the Step 3. Instead, open-sourced ORFEO standalone toolbox can be used to apply Sobel function to a DEM.

Step 1: High-pass filtering

Add DEM data to *Layers*.

In *Processing Toolbox* available in Menu Bar/Processing/Toolbox search for *r.neighbors* tool. Parameter set-up is described in subsection 2.3.1 of the paper and discussed in subsection 4.2. The general rule is that the moving kernel needs to be wide enough to capture more cells from the outside of a scour mark than from the inside. High-pass filtering can be performed using moving mean or median (see section 4.2). Note that in GRASS, neighborhood size unit corresponds to pixels, not to distance units and the input value must be an **odd** number. Execute *r.neighbors* – low-pass filter is calculated. The process may take from several minutes to several hours depending on kernel size, raster resolution and statistics type.

Open *Raster Calculator* tool from *Processing Toolbox.* Subtract the result of *r.neighbors* from the original DEM to calculate high-pass filter.

Normalise the high-passed DEM to standard scores for further classification. In *Layer Properties* check raster's *STATISTICS_MEAN and STATISTICS_STDDEV* values. Expression in *Raster Calculator* should be written accordingly: (("high_pass_result")- *STATISTICS_MEAN* value))/*STATISTICS_STDDEV* value. Execute the *Raster Calculator.*

Step 2: Preliminary classification

For breakpoint classification, *Reclassify by table* tool can be used. See Step 2 of the ArcMap workflow (section 1 of this appendix) and subsection 4.2 of the paper for the details regarding breakpoints choice for the classification. After executing the classification, adjust the symbology of the resultant layer (*Render type Paletted/Unique values* and then *Add values manually*), set opacity of the Class 0 to 0%.

Step 3: Wreck marks separation with support of DEM visualization techniques

Duplicate the original DEM, by right clicking on it in *Layers* window and choosing *Duplicate.* In layer's properties change *Render type* to *Hillshade* and tick *Multidirectional* box. For better visualization, decrease the raster's *Brightness* and increase its *Contrast*.

Slope/*Aspect* functions are available in Raster/Analysis tab in Menu Bar.

Examine the geomorphological setting of the site (see subsection 2.3.3 of the paper) with support of the DEM derivatives and visualization techniques.

Create a new polygon shapefile and delineate area comprising scour marks. Save edits and clip-out unwanted residuals using *Clip Raster by Mask Layer* tool.