TerraceM is a Matlab® GUI to analyze wave-cut marine terraces

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www.terracem.com

1. TerraceM functions

TerraceM was designed by Julius Jara-Muñoz, Daniel Melnick, and Manfred Strecker at the University of Potsdam, Germany, as a tool for teaching and training purposes. TerraceM is programmed in Matlab® GUIDE and contains several functions and interfaces stored in the same folder. The main code (TerraceM_gui.m or .p depending of the version) consists of grouped nested functions (Fig. 1):

a) **Interface functions:** are associated with the behavior of TerraceM GUI and graphic settings. (e.g. Opening function, plots settings, help buttons, parameters boxes, Information display, directories management, UTM zone and visualization options)

b) **Processing and analysis functions:** extracting and analyzing swath profiles, visualizing, post-processing, and exporting the results. (Extract Swaths, Staircase analysis, Cliff analysis, Stack analysis, Scarp diffusion, Table and swath viewers, Project and Filter shorelines, Display statistics, and Export)

c) **Utility functions:** Open source Matlab® functions available at www.mathworks.com used in TerraceM (Table 1).

Function	Author	Release	Version	Copyright
LatLon.m	Rafael Palacios	2006	1	Free
vline.m	Brandon Kuczenski	2001	1	Free
plot_google_map.m	Zohar Bar-Yehuda	2013	1.3	Free
acii2xyz.m	Andrew Stevens	2008	1	Free
dlmcell.m	Roland Pfister	2010	1	© Roland Pfister
errorbar_tick.m	Arnaud Laurent	2009	1	Free
peakdet.m	Eli Billauer	2005	1	Free
dem.m	François Beauducel	2014	10	© François Beauducel
ginputc.m	Jiro Doke	2012	1	© Jiro Doke
moving.m	Aslak Grinsted	2007	2	Free

Table 1: Open source functions nested in TerraceM.

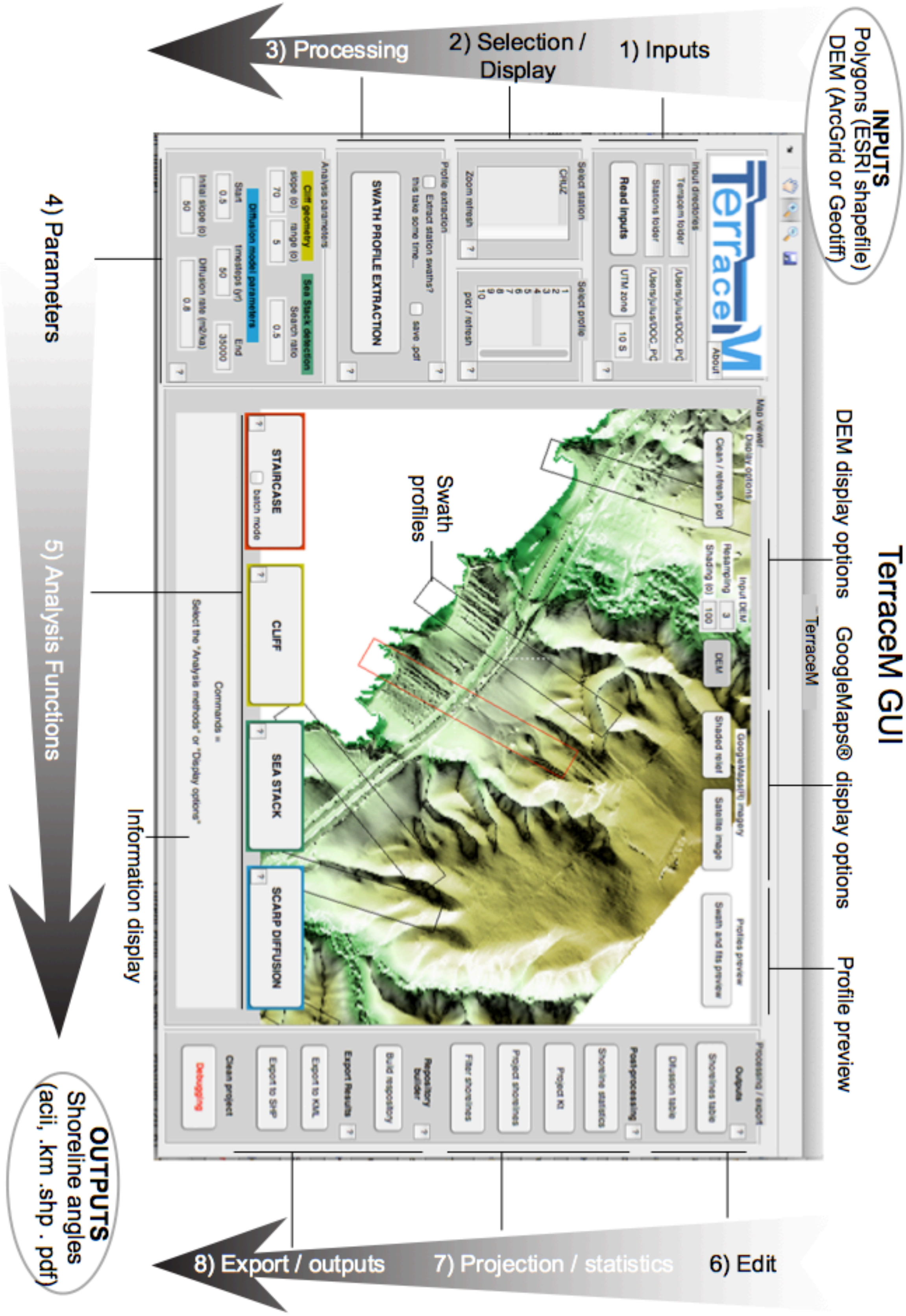


Figure 1: The TerraceM interface

2. Structure and workflow

TerraceM is designed to process and analyze a bulk of profiles in a systematic manner, organized in a tree structure of subfolders (Fig. 2A). Stations (or sites) are arranged in independent folders that contain the inputs and outputs of TerraceM. We recommend defining a four-letter station code for each site (e.g. AAAA), which will be also the name of the station folder. Each input file must be named according to the corresponding station, for instance the DEM for station AAAA should be named 'AAAA_dem.tif' and the associated Shapefile with polygons for swath profiles 'AAAA_clip.shp'. This Shapefile should have all the desired polygons, and should be in the standard 2D format.

The TerraceM workflow (Fig. 2B) consists of several steps that should be executed sequentially in order to analyze a set of profiles. Inputs, Display, Processing and Analysis tools allow obtaining raw shoreline angles, which can be filtered, exported and projected along profiles in the following steps (Editing, Projecting and Export). While TerraceM is running, information messages are prompted inside the command bar, guiding the users through the steps to calculate shoreline angles.

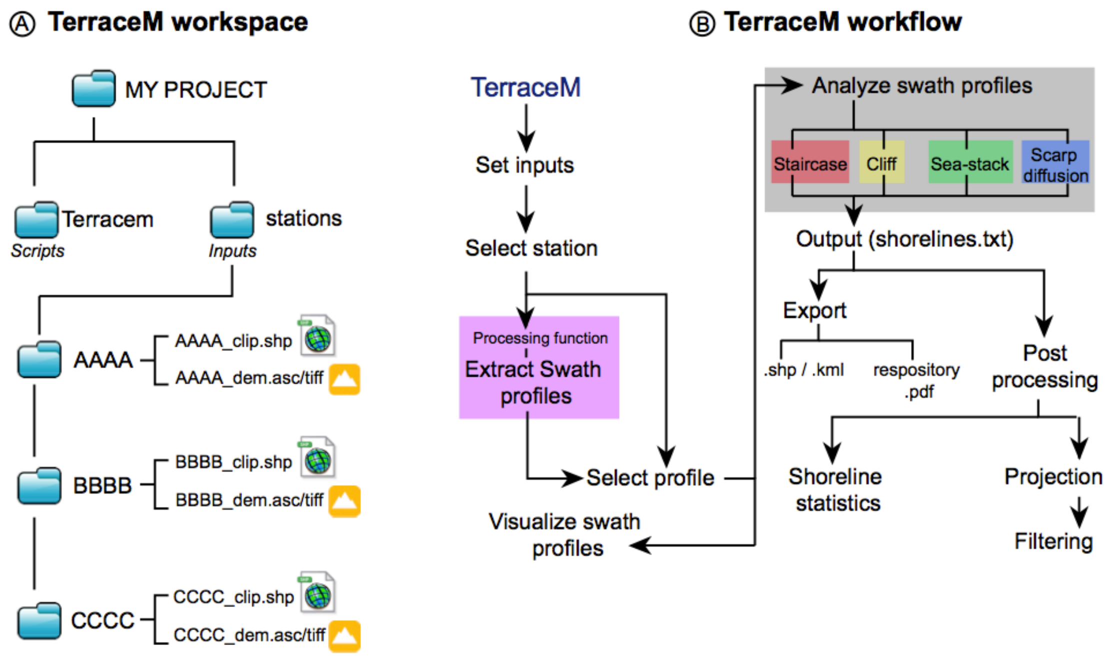


Figure 2: TerraceM workspace and workflow A: Folder directories, the icons denote type of input data (shapefile and raster). B: Stepwise routines to load/process and analyze swath profiles.

3. Tutorial

TerraceM uses two inputs: a) a gridded DEM in Arc Asciigrid or Geotiff formats and b) polygons in ESRI shapefile format. The topography, in UTM projection, should be interpolated in order to fill small gaps in data; non-data values used (-32.767 or -99999) are the typical for most of GIS platforms such as Global Mapper® or ArcGIS®. The polygons must be regular 2D shapefiles that may be created in ArcGIS® using the rectangle tool.

To start TerraceM the user set the “Current Folder” path to the project folder or the TerraceM folder. Then type “TerraceM_gui” in the command window (Fig. 3).

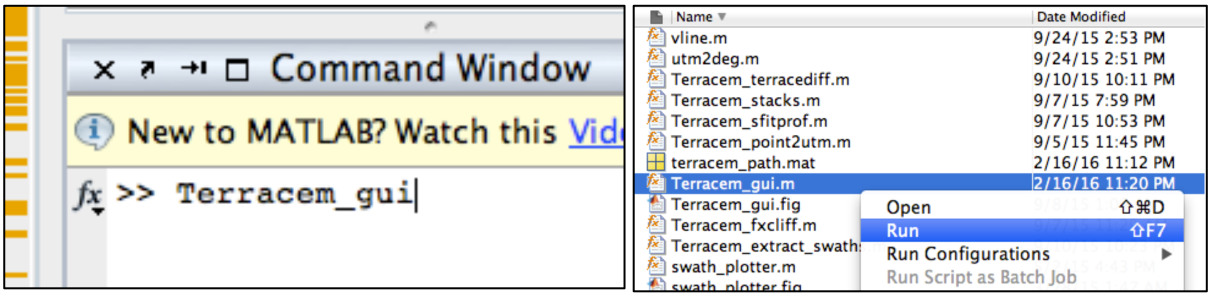


Figure 3: Call to TerraceM in Matlab®

3.1 Inputs interface

The next step is to set the directories. Inputs interface contains two pairs of buttons and text boxes used to explore the directories and a third UTM button to locate the UTM zone of the datasets (Fig. 4). Directories include: a) TerraceM folder, where the TerraceM scripts are stored, and b) the stations folder where your inputs (DEM and polygon shapefile) are stored. (Fig. 2A). Once the inputs are set, push the “Read inputs” to load the data.

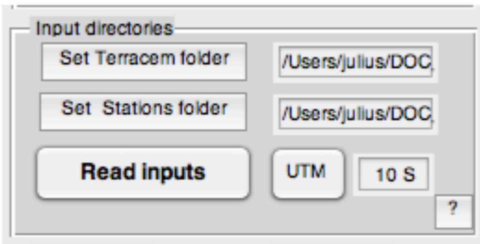


Figure 4: Directories interface

This step populates the list of available stations. If swath profiles were extracted before, the profile list will be also populated (Fig. 6).

3.2 Profile extraction interface

The profile extraction interface contains one big button and two checkboxes, the first checkbox confirms the execution of the swath profiles after pressing “Swath Profile Extraction” (Fig. 5). The efficiency of this routine depends of the size and number of swath profiles and the resolution of the topography, and can take a long time. We strongly recommend reducing overall memory consumption by closing other programs while the Profile extraction routine is executed. The second checkbox enables creation of a file with a plot of the swath profile in Adobe pdf format.

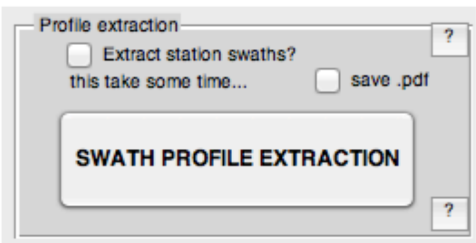


Figure 5: Swath profile extraction interface

Each time the profiles are edited inside a GIS platform (e.g. ArcGIS®) this function needs to be used to update the swath profiles. After running swath profile extraction, the profile list will be displayed (Fig. 6).

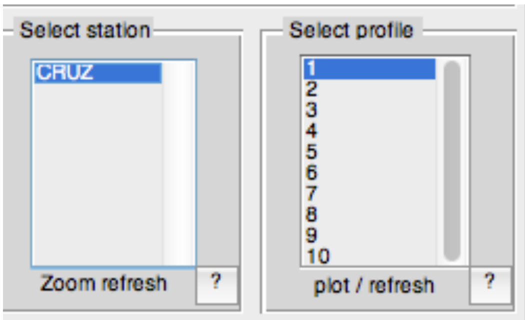


Figure 6: Station and profile selection interface

Click on any profile of the list to identify its location in the main plot. The selected profile box will change to red.

3.3 Display Interface

The display is controlled from an upper rectangular panel (Fig. 7). The DEM button displays the gridded DEM used for the analysis, the text boxes are used to control the shaded direction and resolution, the Clean /Refresh button must be used to update the view each time the display options are modified. It is recommended to resample the DEM when using large datasets with a high resolution to speed the visualization. The display includes a direct link to shaded relief maps and satellite imagery from the online GoogleMaps® portal. In a first view the DEM may look pixelated, but this may be solved by changing the resampling (to e.g. 5). Use the Clean button each time to change between display options and to show a white screen.

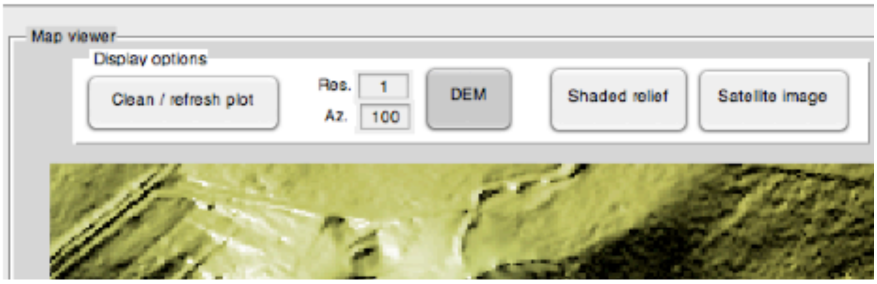


Figure 7: Display options

3.4 Swath profile plotter

The swath profiles may be visualized with the "Swath profile plotter" (Fig. 8). This function plots a selected profile with either a grey area bounded by the maximum and minimum elevations or as a color-coded grid formed by stacked probability distribution functions. Shorelines-angles, if already calculated, can be displayed together with their corresponding linear regressions.

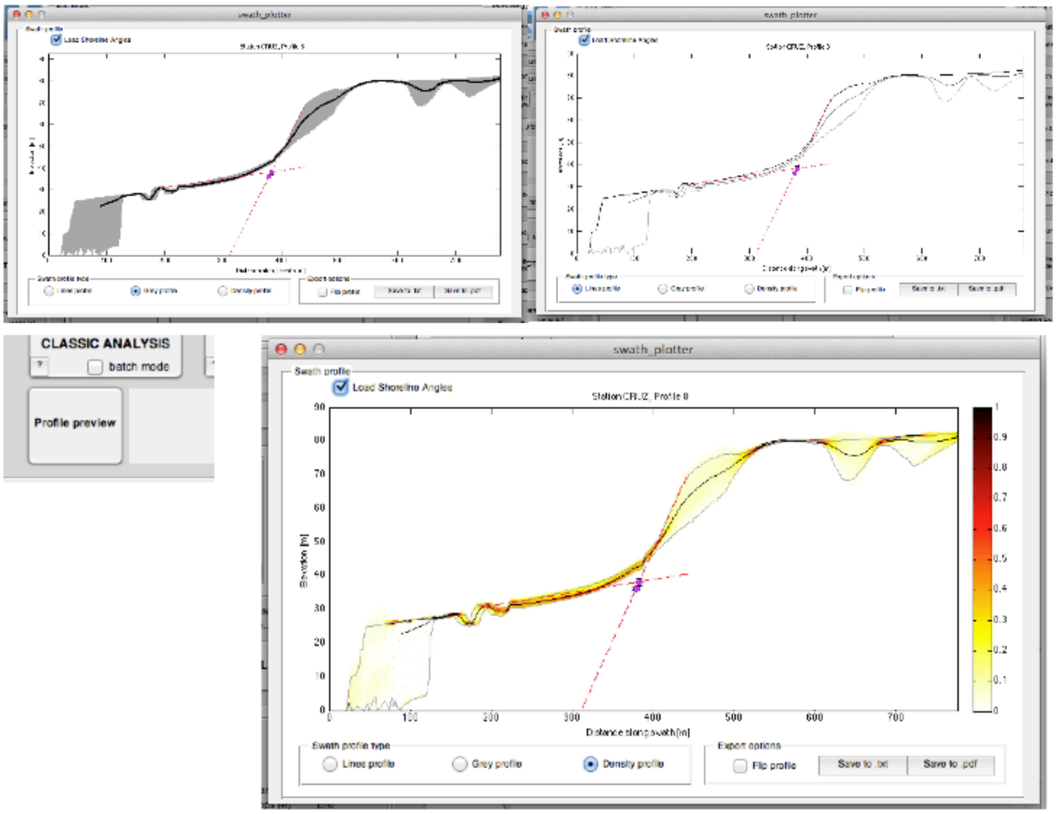


Figure 8: Swath profile viewer

To change between different profiles the display must be closed.

3.5 Analytical functions

The analysis functions consist of four buttons defined by different colors (Fig. 9).

Figure 9: Analysis buttons

Each function uses the same mapping display (Fig. 10) but with different terrace elements (Fig. 11). The mapping interface displays the swath profiles, the slope, and two buttons in the lower part for selecting either the minimum or maximum topography for the fitting. By default the display is set to use the maximum values.

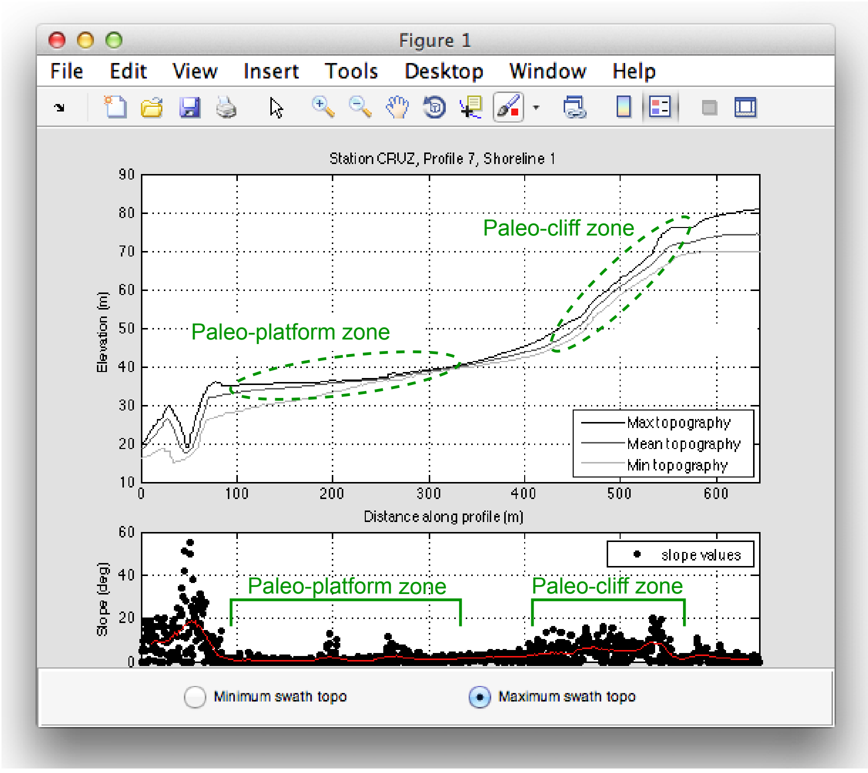


Figure 10: Mapping interface.

These functions use points clicked on the profile by the user that define the extent of the paleo-cliff and paleo-platform, entered in order always from right to left. The type and number of points vary between functions as described below (Fig. 11):

Staircase: these marine terraces are analyzed based on the concept of shoreline angle defined by Lajoie (1986). This function is useful when working with well-preserved paleo-platform and paleo-cliff morphologies. The identification of the shoreline angle can be performed using the maximum or minimum topographic distribution obtained from swath profiles. The maximum distribution of elevation in swath profiles allows observing the pre-incision topography; however, the maximum topography may be biased locally by climbing dunes. In this particular case the minimum elevations can be used to isolate the base of the dune field that should represent a maximum estimate of the original paleo-platform surface.

This function allows analyzing swath profiles interactively by clicking two points along the steepest part of the profile that defines the paleo-cliff, and two further points that delineate the extent of the paleo-platform (Fig. 11). Lineal regressions are then calculated upon the enclosed segments on the profile and extrapolated to find the intersection that marks the position of the shoreline angle. Vertical errors of shoreline angles are based on the extrapolation of the 2σ ranges of the linear regressions.

Free-face Cliff: The Free-face analysis function is similar to the Staircase function but uses a single value and its uncertainty as input for the slope of the paleo-cliff. These values may be estimated for example from the mean and standard deviation of the slope of modern cliffs. The concept of free-face refers to the exposed part of fault scarps above the colluvium (e.g. McCalpin, 2009), here extended to a wave-cut scarp. This analysis is recommended for terraces with well-defined colluvial wedges below exposed cliffs with restricted heights but formed on resistant bedrock, or for smoothed paleo-cliffs with marked transitions at the top of the colluvium. This method is also recommended for terraces covered by calcrete or beach-rock, where low diffusion rates are favourable for preserving the free-face morphology over longer periods of time. The slope of the cliff is defined by graphically selecting a single point on the topographic profile. This point should be defined at the lower limit of the free-face or at the contact between the colluvium and exposed bedrock. Two further points enclosing the paleo-platform are defined beyond the wash slope to find the shoreline angle and its associated 2σ error (Fig. 11).

Sea Stack: The Stack Analysis function allows estimating shoreline-angle elevations in rough coasts. Sea stacks and stumps form where portions of a retreating coast become isolated through erosion and dissection of the cliff base; these features are detached from the cliff forming isolated promontories, columns, stack-arcs and caves, which represent fragments of partly eroded terrace levels.

The maximum elevation of swath profiles highlights stack morphology and the location of peaks that delineate the dismantled terrace platform. By using a peak-detection algorithm, individual stack positions and their maximum elevations are extracted along the profile. Peaks are grouped in classes and linearly interpolated to reconstruct the paleo-topography of the platform.

The user defines the area for peak detection with two points clicked from right to left (Fig. 11). Then an interactive window ask for the number of groups of peaks to isolate, which is usually only one, but can be a maximum of three. Finally an interactive window prompts for clicking the remnant of an inner edge or slope inflection at the paleo-cliff, this point must be located below the upper limit of a fringe (dashed line) and at the cliff.

Scarp Diffusion: The geomorphic age of a terrace paleo-cliff (Kt) may be estimated from the linear diffusion equation of Hanks et al. (1984). The first step of the Scarp Diffusion analysis is to define the temporal resolution of the model by specifying the range of iterations and the geometry of the profile. The user enters one point at the upper inflection of paleo-cliff, which represents a change in slope between the paleo-cliff and the extent of the platform above the cliff. Then, two points are entered which define the paleo-platform and a last point to define the center of the profile, which is used to adjust the profile geometry and is usually located at the center of topography distributions marked by a dashed line. The point is located at the intersection of the dashed line with the maximum topography, however in asymmetric profiles the location of center of profile might vary. We recommend to adjust the zoom of the plot and to make several tries with different positions of profile center to minimize the RMS value.

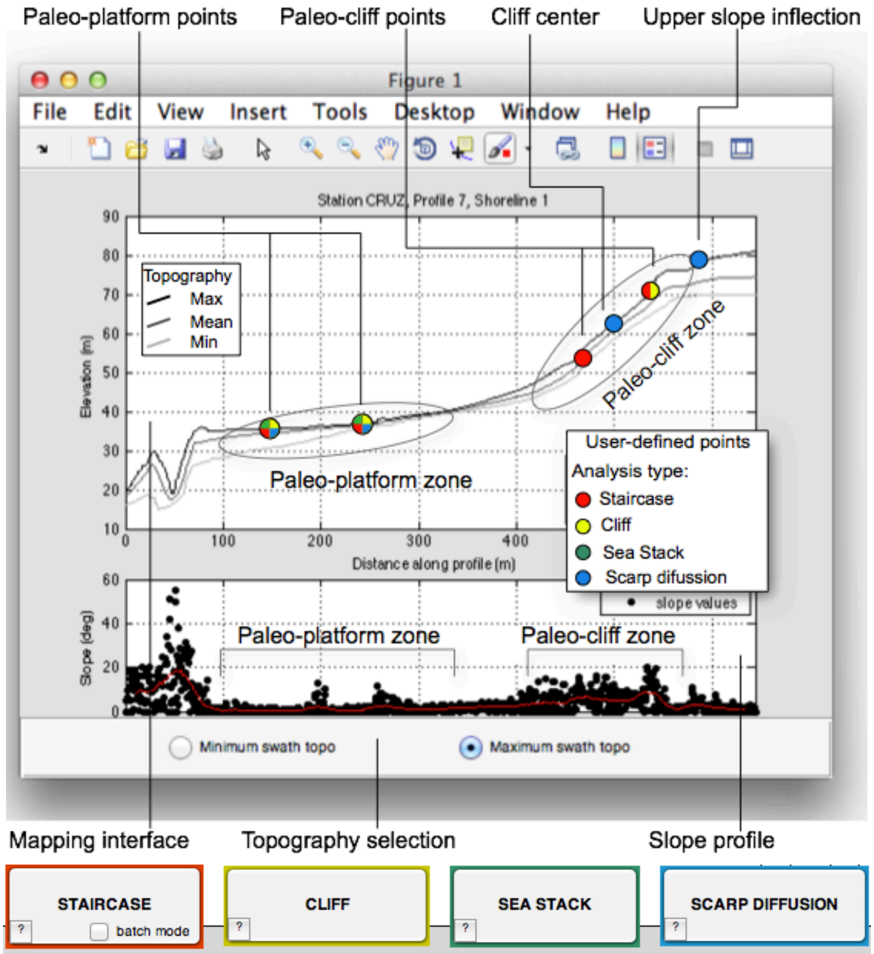


Figure 11: Input points for each function displayed in the mapping interface.

The type of user-defined clicking points for each function is different, and in order to facilitate the understanding of shoreline angle mapping for each function a video tutorial is provided.

3.6 Analysis parameters

The "Analysis Parameters interface" defines the variables for each function following its color (Fig. 12).

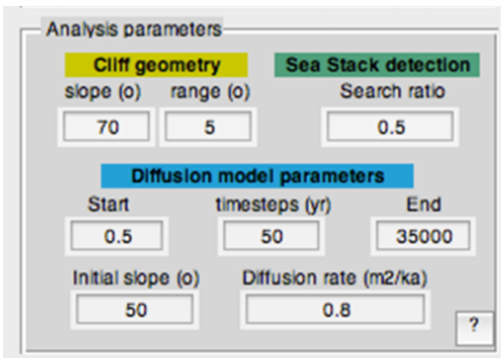


Figure 12: Parameters

3.7 Outputs

Outputs are stored inside the respective station folder, andconsist of graphic files in Adobe pdf format as well as tables in ascii and Matlab® formats, which are updated by TerraceM and can be edited by the user. Station CRUZ (Santa Cruz, California) is used as example to illustrate the structure of data files (Table 2).

Main output tables:	
shorelines.txt	ASCII table containing the shoreline angles and associated spatial data
diffusion.txt	ASCII table containing the KT values for Scarp Diffusion analysis and associated spatial data.
Secondary output tables:	
sh_projected.txt	ASCII table containing the shoreline angles projected along a user-defined line
Outliers_level_1.txt	ASCII table containing the shoreline angles classified as outliers
Interpolation_level_1.txt	ASCII table containing the linear interpolations between shoreline angles
Graphic outputs:	
Data-Repository_CRUZ_1.pdf	Output of Repository builder
CRUZ_1_stack.pdf	Graphic output of stack function
CRUZ_prof_1_shoreline_1_diff.pdf	Graphic output of diffusion function
Swaths_CRUZ_page_1.pdf	Graphic output of swath profiles
Temporal Matlab® outputs	
CRUZ_swaths.mat	Swath profiles
CRUZ_Clicks.mat	History of fits defined by the user
CRUZ_fits.mat	Matlab structure with fit parameters
DEM_CRUZ.mat	Formatted DEM for the visualization function.
CRUZ_diffusion.mat	Scarp diffusion analysis parameters

Table 2: TerraceM output files

3.8 Table viewer interface

The two buttons at the upper right corner of TerraceM interface (Fig. 13) may be used to visualize the main output tables (Table 2).

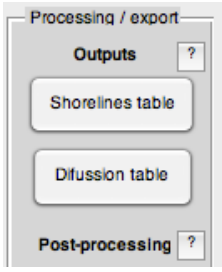
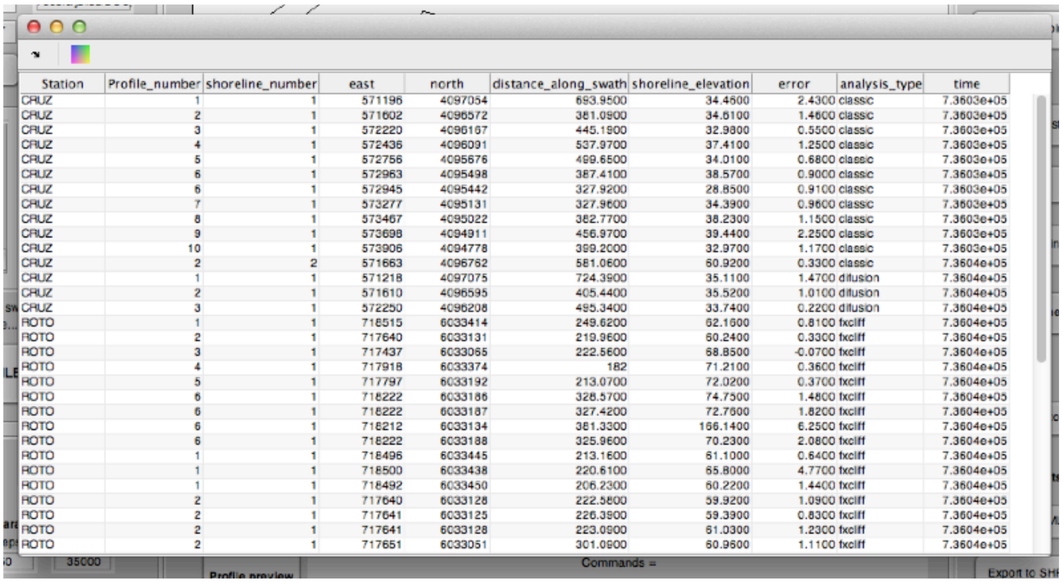


Figure 13: Outputs display

Stations, profiles and spatial data are stored within these tables as well as the time of analysis in the MATLAB® serial date format (Fig. 14).. Table viewer also allows editing by selecting and deleting rows



Station	Profile_number	shoreline_number	east	north	distance_along_swath	shoreline_elevation	error	analysis_type	time
CRUZ	1	1	571196	4097054	693.9500	34.4600	2.4300	classic	7.3603e+05
CRUZ	2	1	571602	4096572	381.0900	34.6100	1.4600	classic	7.3603e+05
CRUZ	3	1	572220	4096167	445.1900	32.9800	0.5500	classic	7.3603e+05
CRUZ	4	1	572436	4096091	537.9700	37.4100	1.2500	classic	7.3603e+05
CRUZ	5	1	572756	4095676	499.6500	34.0100	0.6800	classic	7.3603e+05
CRUZ	6	1	572963	4095498	387.4100	38.5700	0.9000	classic	7.3603e+05
CRUZ	6	1	572945	4095442	327.9200	28.8500	0.9100	classic	7.3603e+05
CRUZ	7	1	573277	4095131	327.9600	34.3900	0.9600	classic	7.3603e+05
CRUZ	8	1	573467	4095022	382.7700	38.2300	1.1500	classic	7.3603e+05
CRUZ	9	1	573698	4094911	456.9700	39.4400	2.2500	classic	7.3603e+05
CRUZ	10	1	573906	4094778	399.2000	32.9700	1.1700	classic	7.3603e+05
CRUZ	2	2	571663	4096762	581.0600	60.9200	0.3300	classic	7.3604e+05
CRUZ	1	1	571218	4097075	724.3900	35.1100	1.4700	difusion	7.3604e+05
CRUZ	2	1	571610	4096595	405.4400	35.5200	1.0100	difusion	7.3604e+05
CRUZ	3	1	572250	4096208	495.3400	33.7400	0.2200	difusion	7.3604e+05
ROTO	1	1	718515	6033414	249.6200	62.1600	0.8100	fxcliff	7.3604e+05
ROTO	2	1	717640	6033131	219.9600	60.2400	0.3300	fxcliff	7.3604e+05
ROTO	3	1	717437	6033065	222.5600	68.8500	-0.0700	fxcliff	7.3604e+05
ROTO	4	1	717918	6033374	182	71.2100	0.3600	fxcliff	7.3604e+05
ROTO	5	1	717797	6033192	213.0700	72.0200	0.3700	fxcliff	7.3604e+05
ROTO	6	1	718222	6033186	328.5700	74.7500	1.4800	fxcliff	7.3604e+05
ROTO	6	1	718222	6033187	327.4200	72.7600	1.8200	fxcliff	7.3604e+05
ROTO	6	1	718212	6033134	381.3300	166.1400	6.2500	fxcliff	7.3604e+05
ROTO	6	1	718222	6033188	325.9600	70.2300	2.0800	fxcliff	7.3604e+05
ROTO	1	1	718496	6033445	213.1600	61.1000	0.6400	fxcliff	7.3604e+05
ROTO	1	1	718500	6033438	220.6100	65.8000	4.7700	fxcliff	7.3604e+05
ROTO	1	1	718492	6033450	206.2300	60.2200	1.4400	fxcliff	7.3604e+05
ROTO	2	1	717640	6033128	222.5800	59.9200	1.0900	fxcliff	7.3604e+05
ROTO	2	1	717641	6033125	226.3900	59.3900	0.8300	fxcliff	7.3604e+05
ROTO	2	1	717641	6033128	223.0900	61.0300	1.2300	fxcliff	7.3604e+05
ROTO	2	1	717651	6033051	301.0900	60.9600	1.1100	fxcliff	7.3604e+05

Figure 14: Table viewer

3.9 Shoreline projection interface

Shoreline angles can be projected interactively through the Project Shorelines button located in the right panel of the TerraceM interface. Before starting the projection or filtering routines, we recommend to revise the main output table (shorelines.txt) and remove repeated shoreline angles and nan values.

The button opens a subroutine (Fig. 15) that imports the projection line in ESRI shapefile format. This shapefile should include a single line with only two nodes. The profile can be also defined manually by graphic input.

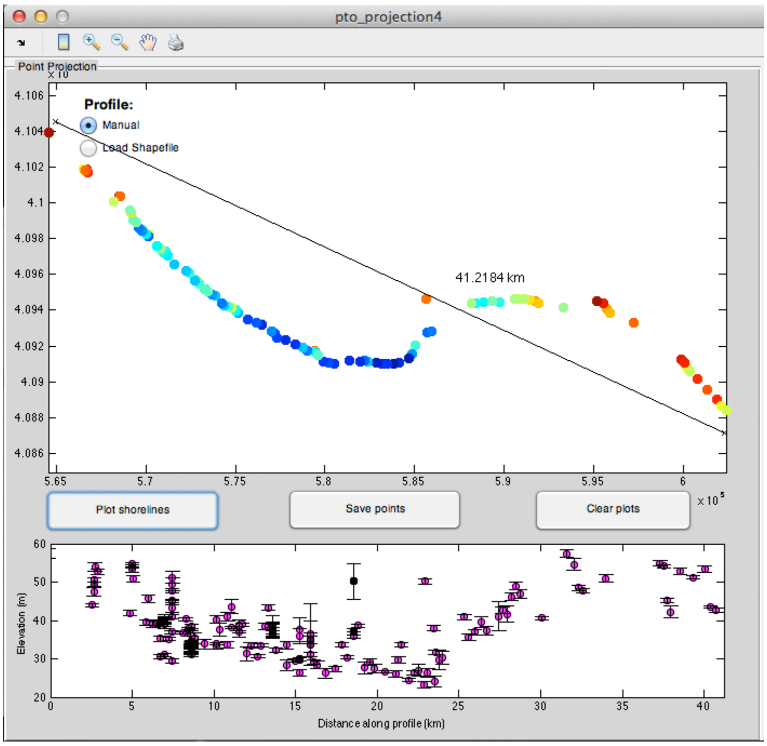


Figure 15: Shoreline projection interface

3.10 Shoreline filtering interface

This interface allows filtering outliers. The X-bin size defines the resolution along the projection line. Y-range is usually defined by the standard deviation of elevations and marks the boundary where shorelines are considered outliers. The proportion of outliers is indicated in the bar plot on the lower right (Fig. 16).

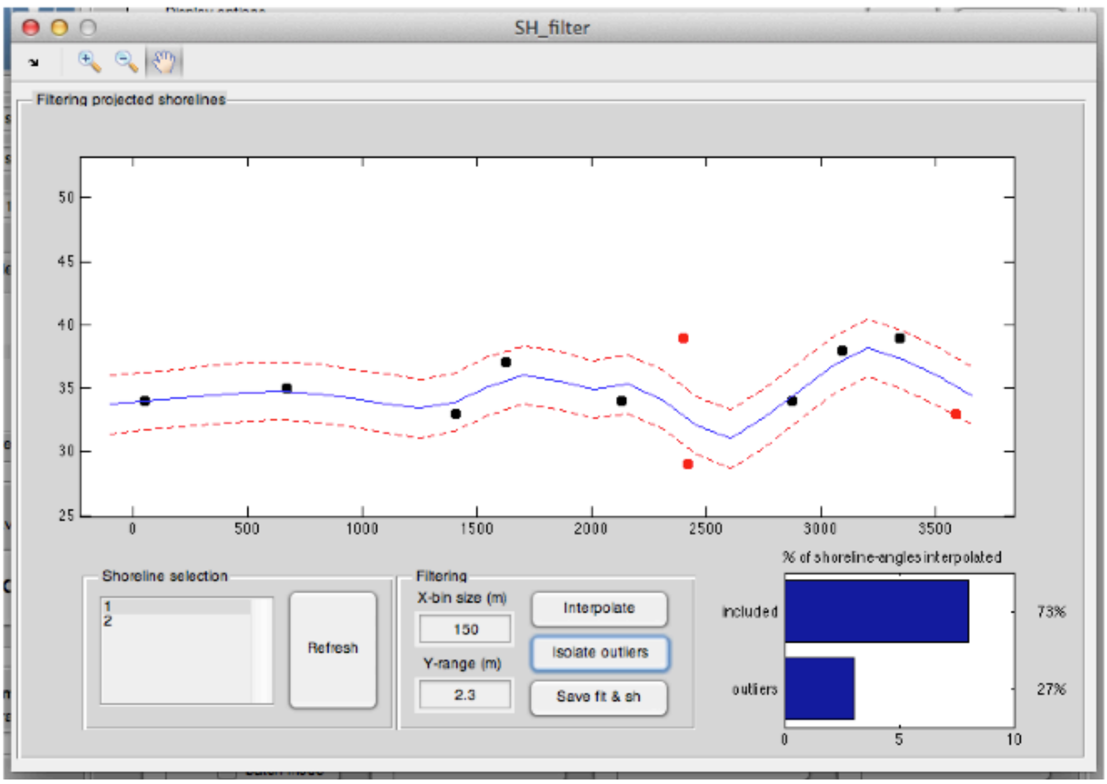


Figure 16: Shorelines filtering interface

3.11 Export functions

The shoreline angles (data in table shorelines.txt) may be exported for rapid visualization in Google Earth® and ArcGIS using ESRI® shapefile formats (Fig. 17), likewise fits can be exported as pdf's, stored in the stations folder.

Figure 17: Export to shapefile and GoogleEarth®.

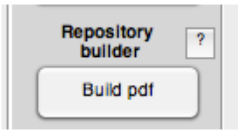


Figure 18: Export fits as .pdf files.

3.12 Debugging

TerraceM creates a path file (path.mat) allowing to quickly access the last edited project, however this file might produce problems when the projects are moved to different directories or computers. Debugging (Fig. 18) deletes these path files from all folders in the project, forcing to redefine the paths the next time TerraceM is run.

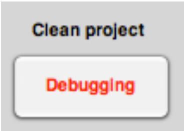


Figure 18: Debugging, delete path files

3.13 Shorelines restoration

If shoreline angles are deleted by accident, the project is corrupt, or if you need to filter repeated values, shoreline angle restoration routine (Fig. 19) rebuild the entire shoreline angle table and figures. Restoration execution takes some time depending of the number of shoreline angles previously mapped, which are re-measured automatically using the stored user-fits, for each station in the project.

Figure 19: Restoration of shoreline angles previously extracted

Other routines such as projection and filtering requires that repeated values must be deleted from the table, Shoreline Restoration delete repeated measurements preserving the earliest one, original values are stored as a backup (in .txt format) in the stations folder. This procedure also fixes problems when building the data repository. Check the output tables and respective back-ups at the station folder, named shorelines.txt and backup_shorelines.txt.

4. Known issues

After testing TerraceM with multiple users we detected some issues that might produce errors or unexpected behavior. The most common issues are:

1) Shape of swath profiles: Non-rectangular or trapezoidal polygons are not recognized and generate errors during swath profile extraction.

2) Size of swath profiles: If the polygon is too narrow or does not enclose enough raster cells, an error will be displayed during the swath profile extraction.

3) Raster datasets containing data voids may produce an error during the swath profile extraction. The topography should be interpolated to fill small gaps in data.

4) Path files may be corrupted when the project is moved to another directory producing unexpected behavior, this can be solved by debugging or by deleting the path.mat files from all folders.

5) Interpolations in the filtering routine cannot be accomplished if repeated values exist in X or Y-axes (Distance along profile or Elevation), or if elevation values are not a number (nan). The problem is fixed by removing these shoreline records from the main output table (shorelines.txt) or by using restore routine.

6) Stations from different UTM zones within the same project might generate conflicts.

7) Google maps displays is reported unstable in Matlab® 2014 or newer versions.

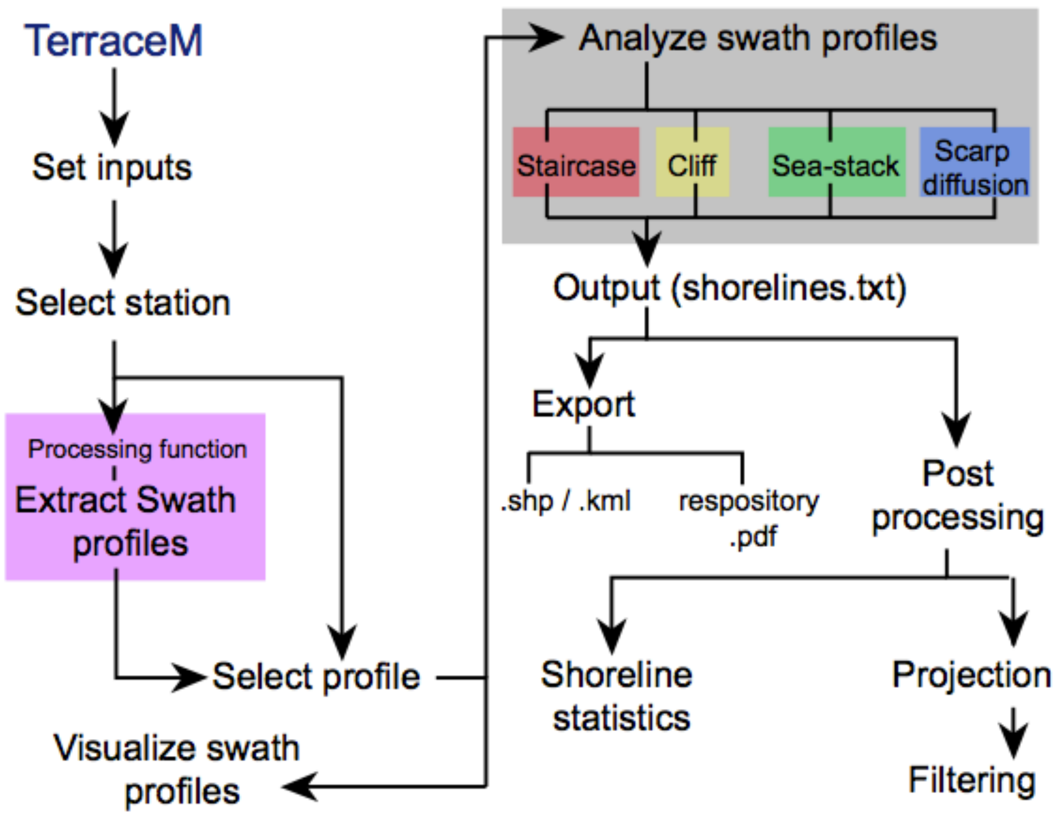
5. References

Hanks, T. C., Bucknam, R. C., Lajoie, K. R., and Wallace, R. E., 1984, Modification of wave-cut and faulting-controlled landforms: Journal of Geophysical Research: Solid Earth (1978-2012), v. 89, no. B7, p. 5771-5790.

Lajoie, K. R., 1986, Coastal tectonics: Active Tectonics, p. 95-124.

McCalpin, J. P., 2009, Paleoseismology, Academic press.

6. Appendix: TerraceM Workflow



The operation of TerraceM in synthetized in this workflow, for any question please contact me at: Julius Jara: jara@geo.uni-potsdam.de