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Opening Up the Sea: A Novel Methodological Approach to Display Mediterranean Shoreline Evolution †

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Abstract: This paper presents a methodological proposal in order to use marine geology data on sea level change through time, to reach an effective display of shoreline evolution in a form easily suitable by archaeologists, taking into account the need of reliable DEMs and hypothetical ancient sea surfaces. The technical aspects and steps of the process are explained, so as to present a possible approach proposal for any area or chronological phase exclusively on the basis of open source software and freely available data.

Keywords: landscape archaeology; GIS; mediterranean sea; prehistory; climate change

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1. Introduction

Would it be useful to dispose of 3D models of ancient landscape situations, including the shoreline and sea level, for coastal areas, while approaching archaeological research? The present work presents an attempt in this direction, developed in the context of the MedAfrica initiative (https://www.medafrica-cam.org/, accessed on 4 March 2024).

It is focused on a proposed methodological approach to be used for displaying existing research data on sea level change through time, in order to make such information effective for archaeological research. The assumption is that the amount of published data on the reconstruction of the sea level in the last millennia, produced by marine geomorphology studies, may be elaborated as to produce, through GIS elaboration, representations of ancient coastal landscapes to be displayed for evaluating archaeology-driven hypothesis.

Summarizing the process, it starts with the analysis of the existing studies on the ancient sea level, normally expressed in terms of time-series plots with curves representing sea level evolution through time. The values for specific moments of the past are derived from such curves for different locations, and used to interpolate pseudo-sea surfaces in specific areas for a given time, which may be plotted against the underwater ground DEM, obtaining models which may be used and displayed in different ways: focusing on specific perspectives, editing time sequences to create videos, etc. The paper is conceived as to expose the GIS methodology for such a purpose, dealing with some study areas from then central Mediterranean Sea, using open source software and freely available data, in order to make the process universally replicable beyond the case study.

2. Materials and Methods

2.1. Aims and Problems: DEM Realization

Unfortunately, dealing with shoreline definition for the past is not a simple task, even with sea level data available. Shoreline is affected both by sea level and surface shape. The latter (conditioned by many factors such as marine underground, sediment deposition, tectonic action, etc.) is very important to determine the emerged and submerged part of the coast. Thus, the Digital Elevation Model to be used should be as detailed as possible.

The study area taken in consideration here, for exposing the approach, was the central Mediterranean region, during the last 10,000 years, from which some specific locations will be considered. Dealing with such a wide area and a regional approach, it is important to have reliable data on the underwater surface. But, as our goal is the effective visualization of landscape, the emerged land DEM is also relevant, although not as crucial.

We decided to use the EMODNET bathymetry data for the underwater surface (3 arcsec resolution. https://emodnet.ec.europa.eu/, accessed on 4 March 2024). and the Shuttle Radar Topography Mission DEM for the overwater lands (30 arcsec resolution. https://lpdaac.usgs.gov/, accessed on 4 March 2024) [1]. Thus we had to deal with two kinds of non-homogeneous data (both sources are freely available). Moreover, the underwater bathymetry DEM ends at the coastal border (0 mt. a.s.l., or slightly above), which is the limit of the SRTM terrestrial DEM in the opposite direction. The two DEMs, thus, overlap each other in many points: an occurrence which has to be managed. However, even if the two DEMs had the same resolution and were perfectly matched in terms of 2d extension, as they have been presumably obtained through different computing operations, the superimposition would result misleading in terms of z-values. It is then crucial to find a way to merge the two elements, limiting the arbitrary areas as much as possible.

The solution followed for the operation may also be an example of methodology for other case studies in which merging two or more DEMs at different resolutions, and overlapping each other, is requested. As the most important data to our goals is the underwater surface, we focused on the EMODNET dataset, setting the resolution to 3 arcsec. and creating a 200 m buffer around its limits (current coastline). The resulting buffer band was then used to "cut" the overwater DEM (SRTM), creating a buffer zone of no data. After merging the two DEMs, such a void band has been filled through a bilinear interpolation algorithm. In this way, the most arbitrary surface is limited to a 200 m coastal band, not affecting underwater surface, which is crucial for determining shorelines in relation to sea level (Figure 1).

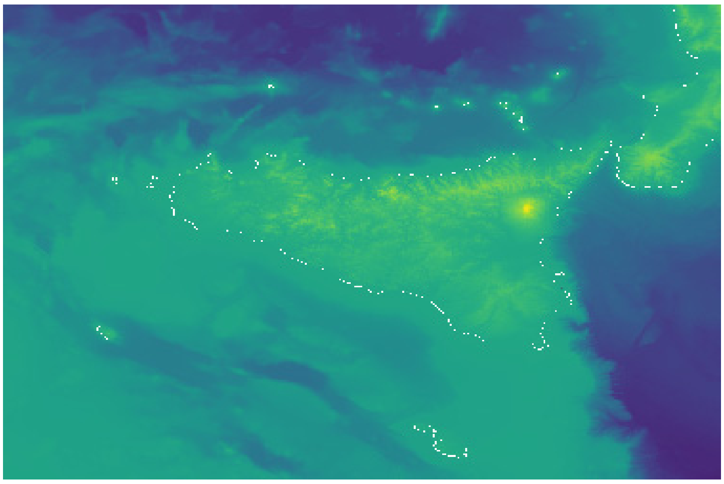

Figure 1. Merging the two DEMs (terrestrial and marine ground) for Sicily area: the 200 mt buffer results in a no-data band (in white, roughly marking the current shoreline) to be interpolated later.

The whole operation was performed thanks to GRASS-GIS software (v.7.8), using the modules r.buffer (creating a 200 m buffer around the underwater DEM), r.mapcalc (cutting out overwater DEM cells which overlap the buffer), r.null (turn to null the cut cells), r.patch (merging the two DEMs), r.fillnull (interpolating the void band between the two merged DEMs [2,3].

2.2. Sea Level Change

As already outlined, the shoreline is influenced both by the coastal ground shape and the sea level, the second factor being no less complex than the first. Normally, it is calculated through a general algorithm, taking into account many factors (global mean temperature, eustatic and isostatic factors, etc.), from which curves are plotted and displayed together with punctual data representing different kind of remains which may be considered referrable to the ancient shoreline zone.

Our work started from the sea level change curves to determine level data from different locations, thus creating a table with values through time. The interpolation of pseudo-sea level surfaces is then a simple GIS operation.

There are many published works on reconstructing sea level changes for the central Mediterranean area, e.g., [4–6]. Here, we refer to a specific one [6], probably the most recent and complete endeavor, based on the SELEN model [7], to perform our examples, but many approaches are possible, even using an average value taking into account different publications.

From the curves, surfaces in different periods were obtained for the area of interest, considering four locations (Figure 2) whose curves were the most consistent for defining the pseudo-sea surfaces. Surfaces were interpolated using vector points obtained from the curves, through GRASS v.surf.rst: a module based on a regularized spline approach, that is to say, calculating the cell values on the basis of regularized spline, with tension and a smoothing factor [2,3]. Basically, the 3D surface is considered as a sort of thin sheet laying on the different-height z points, and the parameters are set to make it softer or stiffer, thus representing terrain in a way closer to a membrane or a sharp-cornered plate. For representing sea surface, mild values were used as settings (tension: 40; smoothing: 0.1).

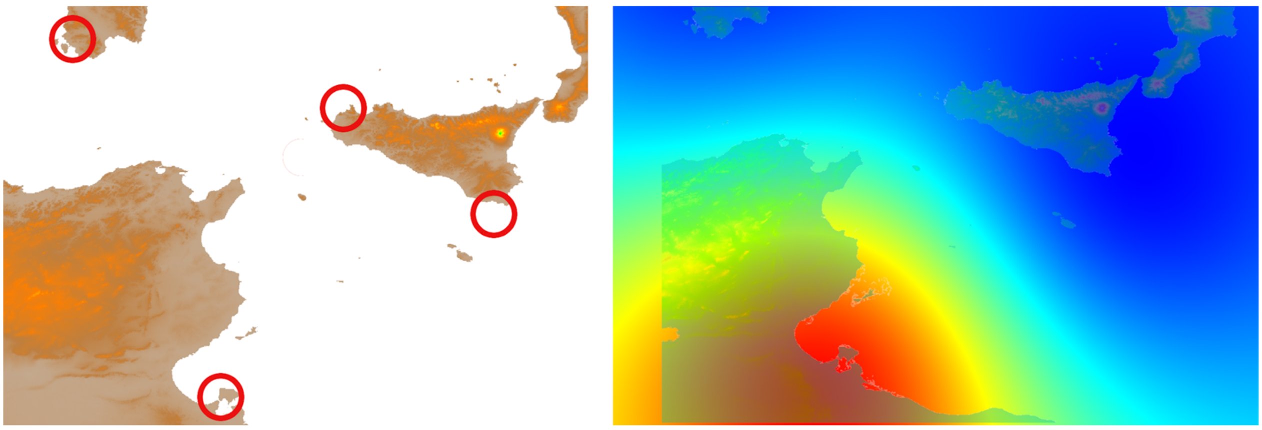

Figure 2. General area chosen for the application (**left**), with the four zones considered for pseudo-sea-surface interpolation (Southern Sardinia, Djerba, Western Sicily and Malta/Eastern Sicily), referring to [6]. An example of pseudo-sea-surface interpolation (10 kyr b.p.) is also shown (**right**), to be used to "cut" the DEM (blue areas are lower sea level in comparison to the present).

The sea level surfaces were then used to cut the total DEM at the z-level of the surface, using the r.mapcalc module. Because of the impossibility of using zero as limit value to cut the cells laying under the ideal water surface (due to the underwater areas, the DEM will also contain below-zero values), the operation is possible by turning all the cells under sea surface to a value out of range (as 10,000, for instance) and then setting them to null value.

The result, according to the different areas to be focused, is a series of maps of the shoreline situation in specific periods of the past, which may be then in various ways to focus different areas from different perspectives, both in 2 and 3d (Figure 3). Simultaneously, a further map may be produced, resulting from cutting out the underwater ground DEM (instead of the total one) through the same sea surface level: it may be useful to mark just the difference between the current terrestrial ground and the ancient one (Figure 3). The r.mapcalc module procedure was obviously the same as described above.

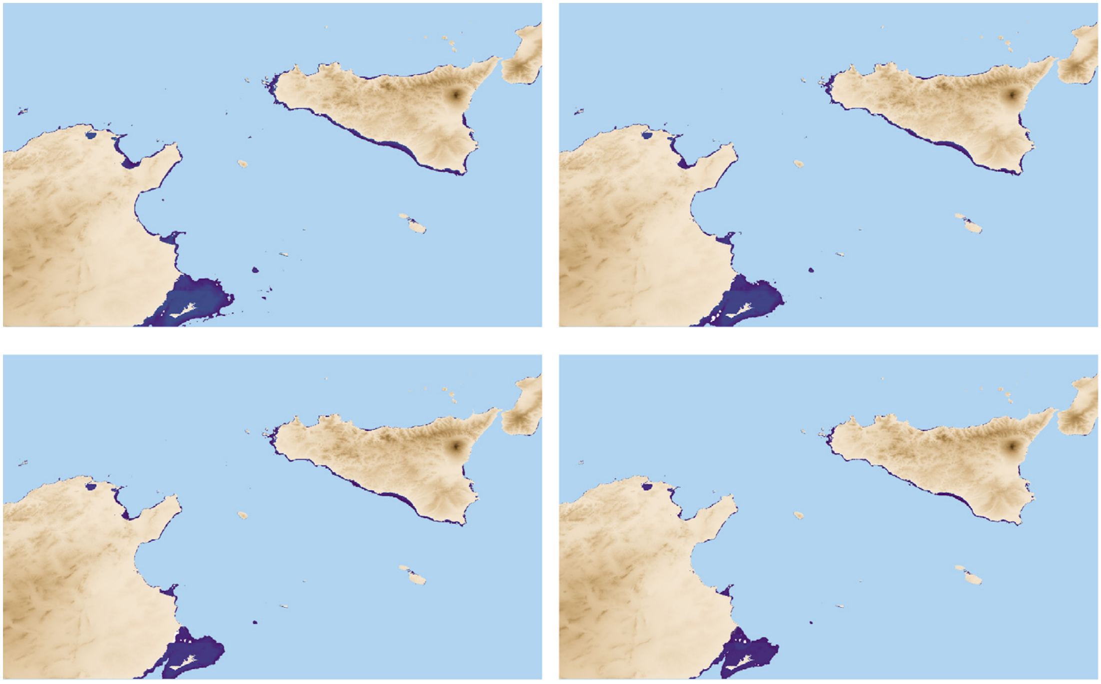

Figure 3. Examples of possible use of raster results: as single images or frame series to create diachronic sequences and videos. Here, frames of the Sicily Channel at 10, 9.5, 9, 8.5 kyrs B.P. showing (blue) the emerging lands currently underwater.

3. Results

3.1. Visualization

The simulated landscape, obtained by superimposing the total DEM and the pseudo-sea surfaces, consists of snapshots of specific landscapes in specific times, which may be used in many ways: as standalone images or as frames of video sequences to show the evolution through time. Many free video editing software packages are available for this purpose, and on different platforms: OpenShot (v.3.1 https://www.openshot.org/, accessed on 4 March 2024) and Shotcut (v.22.10 https://shotcut.org/, accessed on 4 March 2024) are just a few examples. Images may be rendered both in 2 or 3d, or used as input for further elaboration in different software as landscape generation engines or raster visualization tools. In Figure 4, some examples in this sense are provided.

The range of the potential operations is absolutely wide as it is possible to apply all the existing tools for terrain analysis, if GIS data are available. For instance, in Figure 5, a profile contour of the South Sardinia coast, with the indications of hypothetical past sea level, shows a large area of shallow seabed (some 2 km from the current coast at less than 30 m). Even considering the approximation of this kind of data, it seems relevant information to deal with in the study of this area during the early Holocene.

3.2. A Qgis-Three.js Display Option

Among the possible visualization options, for the aim of the project a before/after demonstration video was created, in which the current coastline of the study areas along with the snapshots on how they must have looked 10,000 years ago is here presented. The Sicilian, Maltese and Tunisian coasts were used as samples to create a video sequence. Again, only open data were collected and processed through a completely open workflow.

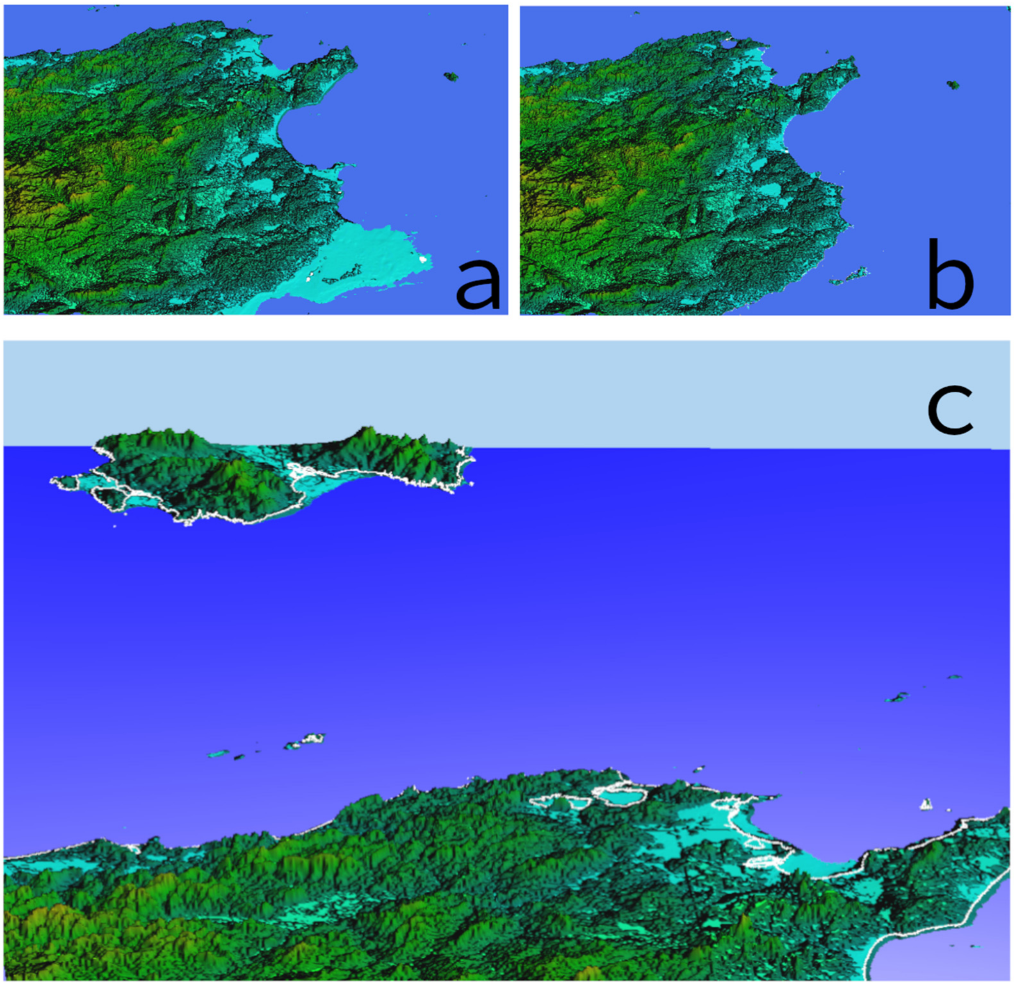

Figure 4. Some examples of possible elaboration and 3D rendering of reconstructed landscapes: an ideal overlook of the Tunisian peninsula at 10 kyrs B.P. (**a**) and today (**b**), comparison of Southern Sardinia (**c**), from the south at 10 kyrs B.P., with the current coastline (white), evidencing a large part of the Cagliari gulf being overwater and the western islands (Carloforte and St. Antioco) completely connected to the current coastal area. (GRASS-nviz rendering).

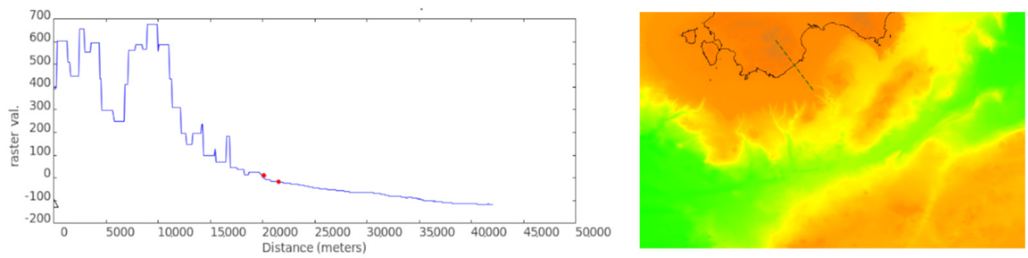

Figure 5. Profile contour (**left**) of the South Sardinia coast, along the transect shown by the green dotted line (**right**), with sea level indication today and (hypothetically) at 10 kyrs B.P. (red dots on the **left**). A large area of shallow seabed (some 2 km from the current coast at less than 30 mt.).

Once created the total model as described above, this was imported as in QGIS and from this step all processing has been performed in QGIS software (v.3.16): such data, together with the national boundaries of the regions and countries, was assembled with satellite images using Google Satellite Dataset, in order to make the landscape as realistic and comprehensible as possible and to clearly mark a difference upon the reconstruction. The difference between the current terrestrial lands and the model for each time interval (that is to say: the relative past coastal area now underwater) was represented through a generic, fictional raster image (sand, in this case, but it is possible to choose whichever fitting material: gravel, grass, etc.).

The main tool used to reconstruct the ancient landscape is Qgis2Threejs v.2.6 (https://plugins.qgis.org/plugins/Qgis2threejs/, accessed on 4 March 2024). It is an openly licensed and QGIS compatible plugin, developed by Minoru Akagi (https://github.com/minorua/Qgis2threejs, accessed on 4 March 2024).

This plugin is a very useful and versatile tool, as it allows 2D maps organized in GIS with DEM raster surfaces to be transformed into 3D views to be exported to the web. In standard conditions, Qgis2threejs allows 3D views of portions of the territory, fast project design and quick and easy visualizations. The scene assembled can be shared on web pages or local project presentations [8].

Actually, the tool is far more powerful, allowing OBJ to be imported and landscapes created in Three.js to be used to reach complex web 2.0 compatible scenarios from a georeferenced base map. Alternatively, the plugin allows to export in gLTF format as to allow the 3D printing of the model. A further, recent function of the tool is the capability to make videos of the 3D model. Using this option, a camera is set up by pointing at the desired area and deciding frame by frame the chosen view. Some results of the operation are presented in Figures 6 and 7, as the complete video is visible at: https://youtu.be/lpjd2HUVZlA, accessed on 4 March 2024.

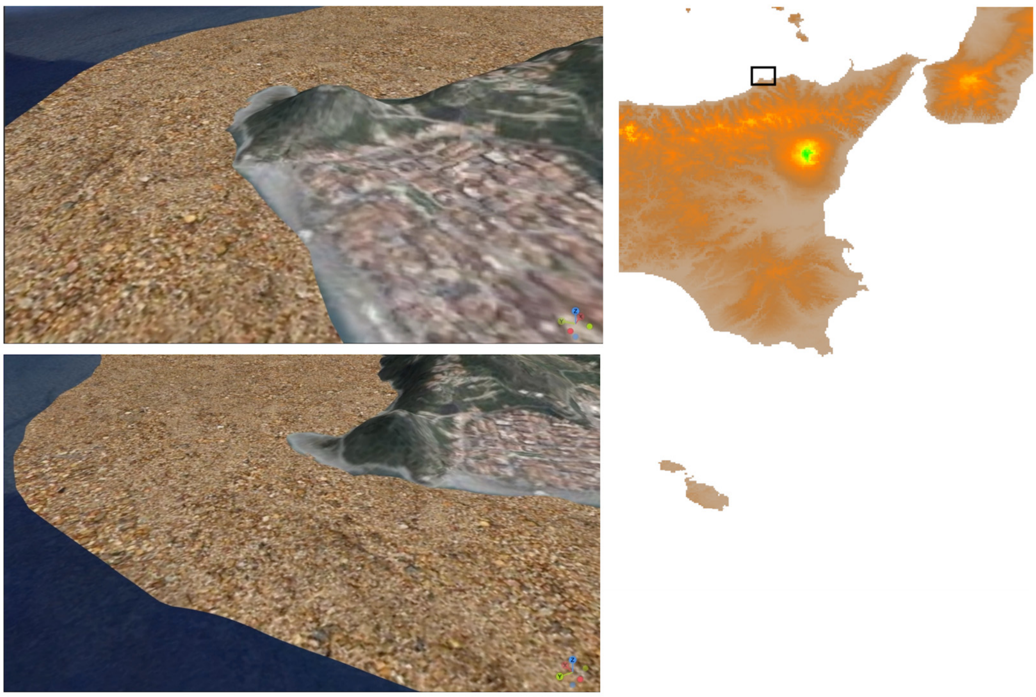

Figure 6. Reconstruction in a Qgis2threejs environment of Capo d'Orlando coast in Sicily, 10,000 years BP.

The resulting demo is an example of the results reachable, for the system, in terms of readable views for archaeological research. A detailed 3D map increases the impact of targeted explorations of the seabed around the most important islands and coastlines, changed over the last 10,000 years. One of these is a flat island with a possible lagoon near the shore north of Malta (Figure 7).

The correct data visualization can improve both the scientific impact and the emotional dissemination power of the project's outputs. In this case, QGIS seems to be the most suitable toolkit for the purpose.

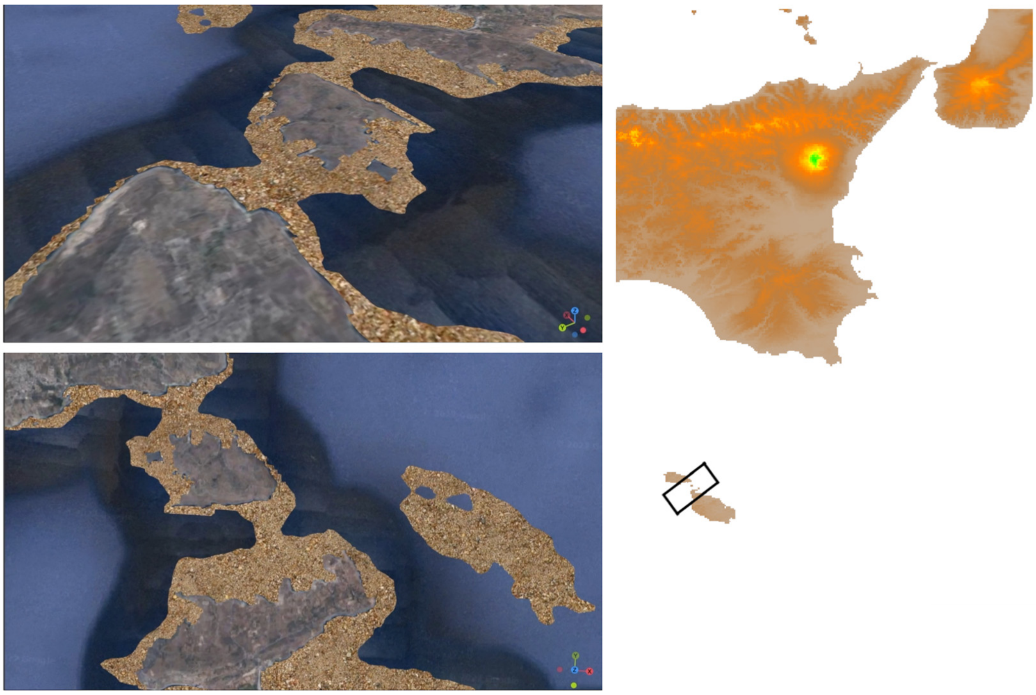

Figure 7. Malta and Gozo Island united by an isthmus, 10,000 year BP, reconstructed in a Qgis2threejs environment. Note in the right side of the image, the ancient island with lagoons nowadays totally covered by the sea.

4. Discussion

Archaeological research, and prehistory domain in particular, would greatly take advantage from a systematic availability of past coastal landscapes and shorelines display. Nevertheless, the environmental chapters of archaeological publications dealing with coastal areas, normally quote sea level change in general terms of trends, instead of focusing on specific landscape situations and their evolution. This is not due to a lack of scientific literature: quite the opposite, there are a huge amount of data on sea level change from the field of marine geology, in particular for some areas as the Mediterranean Sea.

Despite the complexity of shorelines definition (both sea level and coastal shape being conditioned by a various elements), the authors tried to define, in the present job, a working pipeline to create a readable landscape model, in a GIS environment, which may be further elaborated through different media tools, resulting in easily displayable media for archaeological research. One of these possible outputs has been presented here as a QGis Three.js image sequence, but many outputs and analysis may be conceived as well.

Such an approach seems much favorable from different points of view: it is reusable in different contexts and relatively scalable in geographic terms (*relatively*, as the application to very local and small areas stresses the problem of micro-morphological aspects affecting shoreline's shapes and necessarily lower the reliability, but this aspect is strictly related to the ground data resolution); as it seems to be absolutely scalable at chronological level, whereas the growing or lowering of the time span would not change the model's operability. For such reasons, the further steps of our research will be the model widening to the last 20 k year in the Sicily Channel, a crucial period for Mediterranean prehistory.

To sum up, in this work the authors illustrated a possible approach for displaying shoreline evolution data, in order to make them easily manageable for archaeological research. It is a very simple approach to a complex problem (past shoreline identification), which is affected by many factors and, in this sense, it has to be considered as a way to sketch simple overviews and general trends, but representing a potentially relevant benefit to the archaeological research process, dealing with past environment reconstructions.

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