

Alma Mater Studiorum Università di Bologna  
Archivio istituzionale della ricerca

SeeLevelViz: A simple data science tool for dynamic visualization of shoreline displacement caused by sea-level change

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

*Published Version:*

Dean, S., Bursten, S., Spada, G., Pappalardo, M. (2022). SeeLevelViz: A simple data science tool for dynamic visualization of shoreline displacement caused by sea-level change. QUATERNARY INTERNATIONAL, 638-639, 205-211 [10.1016/j.quaint.2022.03.001].

*Availability:*

This version is available at: <https://hdl.handle.net/11585/898306> since: 2023-01-25

*Published:*

DOI: <http://doi.org/10.1016/j.quaint.2022.03.001>

*Terms of use:*

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>).  
When citing, please refer to the published version.

(Article begins on next page)

This is the final peer-reviewed accepted manuscript of:

Silas Dean, Simon Bursten, Giorgio Spada, Marta Pappalardo, *SeeLevelViz: A simple data science tool for dynamic visualization of shoreline displacement caused by sea-level change*, Quaternary International, Volumes 638–639, 2022, Pages 205-211.

The final published version is available online at:  
<https://doi.org/10.1016/j.quaint.2022.03.001>

#### Rights / License:

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>)

**When citing, please refer to the published version.**

# SeeLevelViz: a simple data science tool for dynamic visualization of shoreline displacement caused by sea-level change

Silas Dean<sup>a</sup>, Simon Bursten<sup>b</sup>, Giorgio Spada<sup>c</sup>, Marta Pappalardo<sup>d,\*</sup>

<sup>a</sup> *Department of Earth Sciences, University of Pisa, Italy; current address: Department of Marine Geosciences, University of Haifa, Israel*

<sup>b</sup> *Independent Researcher, Hadar, Haifa, Israel*

<sup>c</sup> *Department of Physics and Astronomy (DIFA) University of Bologna, Italy*

<sup>d</sup> *Department of Earth Sciences, University of Pisa, Italy*

\* Corresponding author.

E-mail address: [marta.pappalardo@unipi.it](mailto:marta.pappalardo@unipi.it) (M. Pappalardo).

## Abstract

We present SeeLevelViz, a free, open-source program written in Python for making interactive visualizations of relative sea-level change in landscapes and shorelines. The accurate reconstruction of shoreline positions is a crucial factor in coastal palaeolandscape studies, particularly in areas where the coast is fronted by islands, since the separation of islands from the mainland drives important ecological and sociocultural outcomes. This program creates accurate time-slice reconstructions of shoreline positions and palaeolandscapes when the user provides two components: 1) a digital elevation model of the target region (including currently submerged areas), and 2) a simple spreadsheet of relative sea-level elevations at different dates derived either from a glacio isostatic adjustment model of relative sea-level change, or from observed past sea-level data points. The tool is presented using the

eastern coast of the Adriatic Sea in the Mediterranean as a test case, since this region has a complex coastline articulation due to combined geological and geomorphological factors. In this area, like in many other Mediterranean coastal areas, the separation of islands from the mainland following the last glacial maximum and throughout the Holocene has occurred in connection with important phases of the development, particularly of Mesolithic and Neolithic cultures, influencing human migrations and the spread of seafaring techniques. Reliable palaeolandscape reconstructions at different time slices are thus crucial for supporting archaeological interpretation. Flexible and user-friendly, SeeLevelViz can compliment reconstructions of coastal landscape changes either based on glacial isostatic adjustment models or on relative palaeo-sea-level evidence, since simple, interactive visualizations are a powerful technique for understanding spatial time-series data, both for the interpretation phase of research, and for presentation to colleagues and the public. The program can be modified or used freely for papers, presentations, etc. by crediting and citing this article.

**Keywords:** Interactive visualization; Python; Coastline; Palaeogeography; Adriatic Sea

## **1. Introduction**

### *1.1 Purpose and goals*

This paper introduces a simple, interactive way for sea-level scientists to view and share palaeo sea-level reconstructions using only a spreadsheet of observed or modelled past relative sea-level (RSL) elevations, and a digital elevation model in TIFF format, either created by the user or retrieved from existing studies or open-source data repositories. It can also be used for sharing future sea-level change predictions if significant morphological changes during the proposed time-slices are not a factor. We suggest this method of presenting results since it is specifically created for the sea-level

community and is simpler and more interactive for the end-user than using GIS or other programs to generate multiple iterations of static visuals. As an example use case, we share a DEM and sea-level reconstruction from an existing study (Dean et al., 2020) concerning the Croatian island of Korčula in the Eastern Adriatic, where dramatic relief above the 100 m isobath resulted in significant palaeolandscape change after deglaciation. This introduction section briefly discusses the general context of Pleistocene- Holocene modern RSL change that creates the need for sea-level visualizations. It also summarizes the use of observational or glacial isostatic adjustment (GIA) model reconstructions, and gives a brief regional context of the example case from Korčula in the Eastern Adriatic.

## *1.2. Pleistocene-Holocene Sea-level Rise*

More than 120 m of sea-level rise has been reported globally in records like Barbados Corals (Fairbanks, 1989; Peltier and Fairbanks, 2006) since the last glacial maximum (LGM) which has resulted in significant palaeolandscape and environmental changes for coastal and shallow-shelf areas. Around the world, the sea-level research community has created reconstructions based on a number of morphological, archaeological, and biological proxies collected into datasets (Gehrels et al., 2011; Khan et al., 2019) which testify to the sometimes dramatic nature of these changes.

Since observational sea-level data are not homogenously preserved in all regions, and because RSL itself is different spatially due to the earth's response to changes in water and glacial loading, models of the GIA effect are also a large part of sea-level reconstructions since the last glacial maximum- e.g. (Lambeck and Purcell, 2005; Lambeck et al., 2014; Peltier et al., 2015), realized in computer programs e.g. (Spada and Melini, 2019b) using a variety of parameters, and often visualized against observed data when available e.g. (Vacchi et al., 2018). The large amount of modelled and observed data attest the frequency of palaeolandscape and shoreline changes in the Holocene, which can be discussed in terms of their effects on human and faunal populations (Foglini et al., 2016). As a

72 result, there is a wealth of possible areas where dynamic visualizations of landscape changes can  
73 provide aid to interpretation and dissemination of scientific data to complement the widespread existing  
74 use of static visuals in this field.

### 76 *1.3. Korčula Island and the Eastern Adriatic*

77 As a test case for illustrating the value of dynamic visualizations of sea-level change, a ca.  
78 6,000 km<sup>2</sup> area was selected, located in the Mediterranean Basin, by the eastern coast of the Adriatic  
79 Sea (Figure 1). Geologically the area is part of the Adria Plate (Sani et al., 2016), including the relief of  
80 the westernmost Dinarids (Korbar, 2009) and the facing continental shelf up to the depth of ca. 120 m.  
81 The Dinaric mountain range is mostly shaped in Mesozoic-Triassic limestones and dolomites, with a  
82 minor extent of Eocene flysch terrains. A major thrust front, NE-SW oriented (Vlahović et al., 2005),  
83 controls the morphostructural setting of the eastern Adriatic coast, that is shaped in the form of ridges  
84 and depressions parallel to the thrust orientation. In the northern and central part, the region called  
85 Dalmatia, the relief results in a great number of islands separated from the mainland by the postglacial  
86 sea-level rise. Our study area is located in Central Dalmatia, where the islands are rotated  
87 counterclockwise with reference to the Dinaric strike. In the middle of the study area is the Croatian  
88 island of Korčula, separated by a shallow strait from the seaward protruding Pelješac Peninsula, and  
89 surrounded by other major islands (Figure 1). Korčula is an elongated island, with an area of 279 km<sup>2</sup>  
90 and a hilly relief peaking in the central part at 569 m asl. The Island landscape is dominated by karst  
91 action, resulting in alternating smooth peaks and wide depressions, mainly poljes (Dean et al., 2020a)  
92 with no significant surface drainage. Outstanding prehistoric archaeological heritage is present on the  
93 Island, in the form of hill forts, burial mounds (Radić, 1999) and especially caves preserving  
94 archaeological sequences, among which is Vela Spila, where the stratigraphy ranges from the Late  
95 Upper Palaeolithic up to the Bronze Age (See Branscombe et al. (2020) and references therein). In

96 Korčula changing coastal landscapes and insularity proved to be relevant factors driving human  
97 settlement patterns (Dean et al., 2020); this is an example of how palaeolandscape reconstructions at  
98 different time slices are important for supporting archaeological interpretation in the area. Bathymetry  
99 suggests that in sea-level lowstands the islands around Korčula were connected by a very flat plain  
100 below the present-day isobath of – 70 m (Dean et al., 2020). Dramatic landscape changes have thus  
101 accompanied the inhabitants of this area since the Late Upper Palaeolithic, even at the scale of human  
102 life. Moreover, in this area present-day sea-bottom morphology closely resembles postglacial terrestrial  
103 landforms (Pikelj and Juračić, 2013) owing to the very low sedimentation rate (Giglio et al., 2020)  
104 caused by the poor sediment discharge of the rivers flowing through the few karstic valleys the  
105 estuaries which open in the mainland coastline (Felja and Juračić, 2018).

106

#### 107 *1.4. Interactive Visualizations*

108 Interactive visualizations are a way for scientists to interpret and share scientific data using  
109 computer graphics. The main characteristics of interactive visualization in this program are the ability  
110 for the viewer to change things about the visualization, and for the visual to update quickly in response  
111 to the user's input. However, this principle can be applied to many other types of visualization, for  
112 example 2d plots or graphs, and users may be allowed to change the limits of the y or x axis and see the  
113 graph redrawn in real time, or to change the data series represented by the points. The main purpose of  
114 these capabilities is to help the scientist (initially) and later the audience of the scientific data  
115 (subsequently) view and search for different patterns in the data or derived statistical analyses, and to  
116 suggest additional statistical analyses to be performed (Buja et al., 1996). This represents a very  
117 important part of the scientific process, and though this phase of data exploration can be undertaken  
118 manually with excel or programmatically if using data-science platforms such as R or MATLAB, this is  
119 a time consuming and less responsive process (Sievert, 2019a) than a plot which can be updated simply

by manipulating user interface elements such as buttons or sliders. Moreover, research has also shown that interactivity in graphics can help the audience understand scientific data more easily (Hood et al., 2020). Given this context, and the compelling nature of interactive visualizations, the RSL community should also attempt to make use of these technologies by deploying them in an easy to use program.

### *1.5. Python as a data science platform*

Python is a programming language which can be used for data-science and creating graphical user interfaces (Python Team, 2020). It is also developed in an open-source context, meaning it is free and the underlying code is transparent and may be viewed by anyone (Python Team, 2020). Python has become very popular with scientists in recent years, thanks in part to configurations such as Anaconda (Anaconda Team, 2021) which make installation of the core functionality and additional modules easier. For science and engineering alone, more than 10,000 of these additional code modules (known as packages) written by other scientists and programmers are freely available online through package management programs like Pip (Pip Team, 2021) or through Anaconda for very specific scientific purposes and sub-fields. A Scopus search of abstract texts in the earth and planetary sciences fields using the search terms “ABS ( python ) SUBJAREA ( earth )” yields more than 1,300 documents in the last ten years, with an exponential increase over time (see Figure 2). Given the widespread use of this platform, the sea-level community may also benefit from using and modifying a visualization program using this technology.

## **2. Methods**

### *2.1. Program Dependencies*



142 SeeLevelViz has been designed using Python. Qt (The Qt Company, 2020), which is a set of  
143 cross-platform software tools, is used to create cross-platform programs and graphical user interface  
144 elements such as those used to control the visualization. MayaVi (MayaVi Team, 2021), a scientific  
145 data visualizer for Python, is used for the 3D effects. The command `pip freeze` is used to freeze  
146 updating of all required packages to avoid incompatibilities due to version upgrades. The main external  
147 dependencies needed are python3 & pip3, pyqt5 & qt5, VTK, gdal. A number of other dependencies are  
148 also required; a full list can be viewed in the requirements.txt at the GitHub repository  
149 <https://github.com/dsilas/SeeLevelViz>. The other dependencies can then be installed using the  
150 following command:

```
151 pip3 install -r requirements.txt
```

152

## 153 2.2. Standalone usability

154 Normally, getting the SeeLevelViz program to run would require considerable technical  
155 expertise to install python and also install/manage of all the dependencies on the part of the end user,  
156 which is particularly complex on Windows computers. To make this step unnecessary, we package the  
157 program and all the dependencies as a standalone executable (.exe on windows, .app on Mac) using  
158 PyInstaller (PyInstaller Team, 2021), a bundling package for Python that is capable of loading an  
159 external spreadsheet and DEM. For the initial release we provide standalone Windows executable. We  
160 recommend that any future forks or contributions of the project attempt to create these standalone  
161 executable since providing these removes a serious obstacle to using the program. One unfortunate  
162 byproduct of this approach is that the stand-alone files are quite large (hundreds of megabytes) since  
163 they have to include all the software dependencies necessary to make the python program run.  
164 However, most universities now have high-bandwidth connections now, which mitigates this  
165 somewhat. Currently, binary builds are available for Linux and Windows. It is hoped that a Mac OS

166 release will be created later. Any interested researcher with access to a late-model Mac computer and  
167 development tools is invited to assist with this process.

168 More information about running and building from source is available on the GitHub  
169 <https://github.com/dsilas/SeeLevelViz>.

170

## 171 **3. Results**

### 172 *3.1 Initial release features*

173 The initial release of the SeeLevelViz program focuses on a core set of basic features essential  
174 to achieve interactive RSL change visualizations. Presently, this consists of a graphical interface to  
175 prompt the user to select a DEM and a simple 2 column spreadsheet of RSL reconstructions: dates and  
176 elevations. The program renders the DEM, and draws a plane for the sea level. The interface allow the  
177 user to switch between sequential RSL data points and view the reconstruction. The user may alter the  
178 perspective of the 3D view by dragging the scene with their mouse, and a button to reset the view to the  
179 default is present in case of disorientation. An interface element exists which also allows the user to  
180 exaggerate the Z elevation of the rendering, since DEMS that cover a large area may not be informative  
181 without considerable z-axis exaggeration. From a button in the top of the window, the program can also  
182 export a static image of the current 3d visualization in standard formats for use in print journals or  
183 conference presentations.

184

### 185 *3.2 Installing and using SeeLevelViz*

186 We recommend for researchers on computers with Windows or Linux distributions who wish to  
187 use the program as-is to simply download the stand-alone implementation from the GitHub repository

188 in the “releases” section or the Mendeley data repository supplement linked to this paper, then follow  
189 the steps in 3.3 below to use the program with their own data. This should be all that is required.

190 For advanced users who wish to recreate or modify the SeeLevelViz program themselves, the  
191 code repository of the program can be found at <https://github.com/dsilas/SeeLevelViz> where it can be  
192 forked, issues can be posted, etc. The GitHub repository contains a list of all required software at  
193 SeeLevelViz/requirements.txt, but the main requirements are python3, pip3, qt5, VTK, and gdal as  
194 stated above.

195

### 196 *3.3 Data preparation*

197 To use the program with their own data, the researcher must prepare two files: A digital  
198 elevation map of the area of study, and a two-column csv spreadsheet. Details for preparing these files  
199 are given below.

200

#### 201 *3.3.1. Digital elevation map*

202 The digital elevation map should be a geoTIFF of the area of interest. Z values can be either in  
203 meters or feet, but you must use the same system of measurement in the spreadsheet. The projection of  
204 the geoTIFF is not relevant as the 3d visualization is not georeferenced. You can use a GIS program  
205 like the free QGIS, or ArcGIS to create a geoTIFF. The source or sources of the elevations in the DEM  
206 are of course up to the user – bathymetric soundings, LIDAR, interpolation from contour lines, etc. The  
207 example DEM of the Korčula island from Dean et al. (2020) area is an interpolation combining  
208 bathymetric soundings and satellite datasets. Dean et al. (2020) also describes one method to create a  
209 DEM by merging free datasets in QGIS.

210

### 211 3.3.2. *Spreadsheet of RSL reconstructions*

212 The simple spreadsheet must be saved as a csv (comma separated value) file, not an excel  
213 spreadsheet. This can be done in excel by choosing “Save as” and choosing “Comma Separated  
214 Values” for the format. The spreadsheet must consist of only two columns with the text values in the  
215 first rows of dateBP and elevation. dateBP contains years before present (BP). elevation contains the  
216 reconstructed RSL for that year, relative to present sea level. Researchers in countries where data  
217 products are released using imperial units, take note: The distance/elevation units of your DEM must be  
218 the same as the elevation units in your RSL spreadsheet – the SeeLevelViz program does not perform  
219 any check for this. The example spreadsheet is available at the GitHub repository  
220 SeeLevelViz/data/input.csv

221

## 222 4. Discussion

### 223 4.1 *Value of interactive visualizations for RSL studies*

224 The field of sea-level studies can benefit significantly from a simple, interactive, and open-  
225 source visualization tool for reconstructions of RSL. The typical interpretive work flow of a sea-level  
226 scientist doing landscape reconstructions in the past or future might consist of something like the below  
227 list. The below process is not dissimilar from that used by scientists in many other fields as discussed  
228 by Sievert (2019b).

- 229 1. Obtain observational or modelled data points that reconstruct relative-sea level in the future or  
230 past. See section 1.2)
- 231 2. Obtain a digital elevation map from public or private repositories of global sub-sea and emerged  
232 elevation data e.g. (GEBCO, 2014; Tozer et al., 2019) or new local remote sensing data e.g. (Foglini et  
233 al., 2016). In order to get a reliable result it is necessary to correct the topographic/bathimetric DEM

234 taking into account as accurately as possible all changes in the topography of the area since the time-  
235 slice in question, such as sediment deposition and erosion processes. It may also be necessary to correct  
236 the DEM elevations in order to account for the overburden due to sediments accumulation which,  
237 especially on the inner shelf, can be relevant. For an example approach to this see Lo Presti et al.  
238 (2019).

239 3. Collation between the DEM obtained in step 2 and elevations obtained in step 1 to recreate  
240 landscapes, coastlines etc at relevant time slices by repeated and iterative comparison between  
241 spreadsheets, GIS layers, model outputs, etc.

242 4. Interpret the effects of palaeolandscape change with results obtained in step 3 in terms of likely  
243 impact on subject of research- such as geomorphological processes, environmental change, human  
244 societies, faunal dispersion, etc.

245 5. Share results in the form of static graphics in publications or presentations e.g. Figure 3.

246 The interactive visualization program SeeLevelViz introduced in this research aims to make  
247 steps three & four easier. Usually these steps require time consuming and slow interactions. For  
248 example, a GIS program can be used to create a cover at an arbitrary sea-level specified by the user, but  
249 this requires several steps of user interaction, in addition to fluency with GIS programs, and the need to  
250 continually cross reference the spreadsheet of sea-level reconstruction data points, or use advanced  
251 scripting to automate the process. Likewise, a program like SELEN4 (Spada and Melini, 2019b) can be  
252 used to re-run the model at different time slices; however this requires a higher level of technological  
253 skills, and in both cases the process is not immediately responsive or interactive. The higher technical  
254 expertise required for the above solutions also decreases the access to it among geoscientists. The  
255 program developed here is an excellent tool for viewing sea-level data in terms of palaeolandscape  
256 changes during the data interpretation phase because it responds immediately to the input of the user  
257 for changing the time slice, and can be rotated in real time in three dimensions to aid the scientist in

258 visualization as a supplement to other tools such as sophisticated an GIS analyses and GIA models. It  
259 also provides a simple way for the researcher to interact with GIA modelled or observational RSL data.

260 In addition, the SeeLevelViz program has value for step 5 – sharing the palaeolandscape  
261 implications of RSL change with other members of the community. Typically this is done with static  
262 visuals that show only the reconstruction at a very limited number of time slices (e.g. Figure 3), those  
263 deemed most relevant to the research question, and shared in the context of journal articles or  
264 conference presentation slides. The dynamic visualization of this program promotes the sharing of  
265 open, reproducible data in the form of digital elevation maps and spreadsheets of RSL reconstruction  
266 needed to make the program work, and it allows colleagues to easily view reconstructions in three  
267 dimensions at whatever time slice available data permits in order to assess and expand interpretations.

268

#### 269 *4.2. Best practices for use*

270 The SeeLevelViz program works best with a sequence of data points that indicate a clear trend  
271 to sea-level change, rather than data points which contradict each other. The latter situation is often the  
272 reality in many localities when actual observational data is relied upon. For example, the dataset of  
273 Israeli sea-level indicators (Dean et al., 2019) in Figure 4 would present a confusing and non-linear  
274 reconstruction if fed directly into the program as a two column spreadsheet, because there are multiple  
275 datapoints on the same date, or datapoints which reverse the trend of those most temporally proximal. A  
276 more suitable dataset for use with this program would be a spreadsheet-based output of a regression  
277 analysis, for example the error-in-variables IGP regression shown in the same figure, which reduces  
278 “noise” to an overall trend.

279 GIA model outputs such as those generated by SELEN4 (Spada and Melini, 2019b) are also an  
280 excellent dataset to use with this program for the same reason. It is important to note, however, that the

281 RSL variations induced by GIA are not spatially uniform and characterised by a marked regional  
282 imprint caused by the interactions within the solid earth-oceans-cryosphere system (Spada and Melini,  
283 2019a). For this reason, if the researcher intends to visualize large areas (hundreds of kilometres or  
284 more of latitude/longitude) using this program, it is highly recommended to first use SELEN4 (Spada  
285 and Melini, 2019b) or another GIA modelling solution across the study area before SeeLevelViz is  
286 used, to ensure that RSL over the visualized areas was actually uniform during the selected time slices.

287 In addition, it bears noting researchers must use the program only for visualizations of past sea  
288 levels in study areas where sedimentation, erosion, and other geomorphological processes have not  
289 significantly changed the nature.

290

#### 291 *4.3. Additional features for further development*

292 A number of possible additional features were not added to the initial release. However due to  
293 the open source nature of the SeeLevelViz program, other RSL researchers with the necessary technical  
294 capacities with Python and GitHub can either create a fork of the repository, or submit code to this  
295 repository for approval according to the normal GitHub procedures.

296 One such possible feature is smooth interpolation of sea levels between data points, via an  
297 interface element. We currently have avoided implementing this because it can create the impression of  
298 data points which do not in fact exist, and because the interpolation itself can be a complex statistical  
299 process. However, such a feature may be desirable to some users for cosmetic reasons for presentation  
300 purposes

301 Another area that the program does not currently treat with are the  $2\sigma$  uncertainties typically  
302 associated with sea-level data – either chronological (for example 14C date  $2\sigma$ ) or in the elevation  
303 levels of observed data points using concepts such as indicative range, or modelled reconstructions

304 with 2  $\sigma$  or other uncertainty envelopes. This possibly could perhaps be added by the use of transparent  
305 additional sea-level cover layers at the levels of the uncertainties.

306 The ability to easily switch between alternative datasets (such as different GIA models) for the  
307 same site is also a potentially desirable feature, which could use either an interface button to fluidly  
308 switch between models, or transparent layers as described above.

309 The ability to host the interactive visualization on a website so that any internet-connected  
310 individual can access the visualization using a web browser is also an extremely desirable feature.  
311 Currently this has not been pursued due to the cost and complexity of reliable web hosting and  
312 technical challenges in getting the required libraries to perform well.

313 Additional cosmetic features suggest themselves as well. For example a contour line marking  
314 the present day sea-level “0” is also advisable for future implementation, as are other potential  
315 graphical options like contour lines at set isobaths, and additional texturing options for the 3D DEM.

316

## 317 **5. Conclusion**

318 The SeeLevelViz program is a simple, free, and open-source tool to visualize and “play with”  
319 the palaeolandscape implications of sea-level changes from observational datapoints or GIA models.  
320 This allows the researcher to consider the changes in their study area over time in a flexible way that  
321 can help guide the interpretation phase and suggest additional, more formal terrain analyses to produce  
322 conclusions about a range of topics such as coastal morphology and dynamics, palaeolandscape  
323 change, faunal dispersion over time, and impacts on ancient (or future) human societies.

324 In addition, the tool can be an eye-catching and memorable way to present results to other  
325 researchers, either in-person at conferences, or by distributing the app with your own map and  
326 spreadsheet of sea-level reconstructions.



327

328 **Author contributions**

329 All authors contributed to the general discussion of the topics addressed, In particular SD and MP have  
330 been in charge of the article design and writing, GS provided the GIA models realizations and checked  
331 the consistency of the program outputs, SB designed the program using Python.

332

333 **Data availability**

334 The program can be downloaded from the Mendeley data repository associated with this article in a  
335 version made at the initial release of the paper. The latest release can be downloaded from the GitHub  
336 page <https://github.com/dsilas/SeeLevelViz> in the releases section. For advanced users wishing to build  
337 and modify the program, the code is also available at the GitHub.

338

339 **Declaration of competing interest**

340 The authors declare no conflicts of interest.

341

342 **Acknowledgements**

343 Members of the EU project no. 692249 “Smart Integration of Genetics with Sciences of the Past in  
344 Croatia: Minding and Mending the Gap” (<http://mendthegap.agr.hr/>) are kindly acknowledged for  
345 inspiring the idea of building the program and for inspiring its application to the case-study of Korčula.

346

347 **Funding**

348 The research was supported by Scuola di Dottorato in Scienze della Terra, University of Pisa  
349 (Beneficiary S. Dean).

350

351 **References**

352 Anaconda Team, 2021. Anaconda | Individual Edition [WWW Document]. Anaconda. URL  
353 <https://www.anaconda.com/products/individual> (accessed 2.4.21).

354 Branscombe, T.L., Bosch, M.D., Miracle, P.T., 2020. Seasonal Shellfishing across the East Adriatic  
355 Mesolithic-Neolithic Transition: Oxygen Isotope Analysis of *Phorcus turbinatus* from Vela Spila  
356 (Croatia). *Environmental Archaeology* 1–14.

357 Buja, A., Cook, D., Scientist, D.F.S.R., 1996. Interactive High-Dimensional Data Visualization. *Journal*  
358 *of Computational and Graphical Statistics* 5, 78–99. doi:10.1080/10618600.1996.10474696

359 Dean, S., Horton, B.P., Evelpidou, N., Cahill, N., Spada, G., Sivan, D., 2019. Can we detect centennial  
360 sea-level variations over the last three thousand years in Israeli archaeological records?  
361 *Quaternary Science Reviews* 210, 125–135. doi:10.1016/j.quascirev.2019.02.021

362 Dean, S., Pappalardo, M., Boschian, G., Spada, G., Forenbaher, S., Juračić, M., Felja, I., Radić, D.,  
363 Miracle, P.T., 2020. Human adaptation to changing coastal landscapes in the Eastern Adriatic:  
364 Evidence from Vela Spila cave, Croatia. *Quaternary Science Reviews* 244, 106503.  
365 doi:10.1016/j.quascirev.2020.106503

366 Fairbanks, R.G., 1989. A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates  
367 on the Younger Dryas event and deep-ocean circulation. *Nature* 342, 637–642.  
368 doi:10.1038/342637a0

369 Felja, I., Juračić, M., 2018. Formation, evolution and characteristics of karstic estuaries - the Adriatic  
370 example. *Revue Paralia* 11, s02.1-s02.7. doi:10.5150/revue-paralia.2018.s02

371 Foglini, F., Prampolini, M., Micallef, A., Angeletti, L., Vandelli, V., Deidun, A., Soldati, M., Taviani,  
 372 M., 2016. Late Quaternary coastal landscape morphology and evolution of the Maltese Islands  
 373 (Mediterranean Sea) reconstructed from high-resolution seafloor data. Geological Society,  
 374 London, Special Publications 411, 77–95.

375 GADM, n.d. Database of Global Administrative Areas.

376 GEBCO, 2014. General Bathymetric Chart of the Oceans (GEBCO) 2014 Grid.

377 Gehrels, W.R., Horton, B.P., Kemp, A.C., Sivan, D., 2011. Two millennia of sea level data: The key to  
 378 predicting change. *Eos, Transactions American Geophysical Union* 92, 289–290.  
 379 doi:10.1029/2011EO350001

380 Giglio, F., Romano, S., Albertazzi, S., Chiarini, F., Ravaioli, M., Ligi, M., Capotondi, L., 2020.  
 381 Sediment Dynamics of the Neretva Channel (Croatia Coast) Inferred by Chemical and Physical  
 382 Proxies. *Applied Sciences* 10, 807. doi:10.3390/app10030807

383 Hood, J.C., Graber, C., Brase, G.L., 2020. Comparing the Efficacy of Static and Dynamic Graph Types  
 384 in Communicating Complex Statistical Relationships. *Frontiers in Psychology* 10.  
 385 doi:10.3389/fpsyg.2019.02986

386 Khan, N.S., Horton, B.P., Engelhart, S., Rovere, A., Vacchi, M., Ashe, E.L., Törnqvist, T.E., Dutton, A.,  
 387 Hijma, M.P., Shennan, I., 2019. Inception of a global atlas of sea levels since the Last Glacial  
 388 Maximum. *Quaternary Science Reviews* 220, 359–371. doi:10.1016/j.quascirev.2019.07.016

389 Korbar, T., 2009. Orogenic evolution of the External Dinarides in the NE Adriatic region: a model  
 390 constrained by tectonostratigraphy of Upper Cretaceous to Paleogene carbonates. *Earth-Science*  
 391 *Reviews* 96, 296–312. doi:10.1016/j.earscirev.2009.07.004

392 Lambeck, K., Purcell, A., 2005. Sea-level change in the Mediterranean Sea since the LGM: model  
 393 predictions for tectonically stable areas. *Quaternary Science Reviews* 24, 1969–1988.  
 394 doi:10.1016/j.quascirev.2004.06.025

395 Lambeck, K., Rouby, H., Purcell, A., Sun, Y., Sambridge, M., 2014. Sea level and global ice volumes  
396 from the Last Glacial Maximum to the Holocene. *Proceedings of the National Academy of*  
397 *Sciences* 111, 15296–15303. doi:10.1073/pnas.1411762111

398 Lo Presti, V., Antonioli, F., Palombo, M.R., Agnesi, V., Biolchi, S., Calcagnile, L., Di Patti, C., Donati,  
399 S., Furlani, S., Merizzi, J., Pepe, F., Quarta, G., Renda, P., Sulli, A., Tusa, S., 2019.  
400 Palaeogeographical evolution of the Egadi Islands (western Sicily, Italy). Implications for late  
401 Pleistocene and early Holocene sea crossings by humans and other mammals in the western  
402 Mediterranean. *Earth-Science Reviews* 194, 160–181. doi:10.1016/j.earscirev.2019.04.027

403 MayaVi Team, 2021. Mayavi: 3D scientific data visualization and plotting in Python — mayavi 4.7.2  
404 documentation.

405 Peltier, W.R., Fairbanks, R.G., 2006. Global glacial ice volume and Last Glacial Maximum duration  
406 from an extended Barbados sea level record. *Quaternary Science Reviews, Critical Quaternary*  
407 *Stratigraphy* 25, 3322–3337. doi:10.1016/j.quascirev.2006.04.010

408 Peltier, W.R., Argus, D.F., Drummond, R., 2015. Space geodesy constrains ice age terminal  
409 deglaciation: The global ICE-6G\_C (VM5a) model. *Journal of Geophysical Research: Solid*  
410 *Earth* 120, 450–487. doi:10.1002/2014JB011176

411 Pikelj, K., Juračić, M., 2013. Eastern Adriatic Coast (EAC): Geomorphology and Coastal Vulnerability  
412 of a Karstic Coast. *Journal of Coastal Research* 289, 944–957. doi:10.2112/JCOASTRES-D-12-  
413 00136.1

414 Pip Team, 2021. Pip [WWW Document]. URL  
415 <https://pypi.org/search/?q=&o=&c=Topic+%3A%3A+Scientific%2FEngineering> (accessed  
416 3.2.21).

417 PyInstaller Team, 2021. PyInstaller.

418 Python Team, 2020. Welcome to Python.org.

419 QGIS Team, 2021. Welcome to the QGIS project! [WWW Document]. URL <https://www.qgis.org/>  
420 (accessed 2.4.21).

421 Sani, F., Vannucci, G., Boccaletti, M., Bonini, M., Corti, G., Serpelloni, E., 2016. Insights into the  
422 fragmentation of the Adria Plate. *Journal of Geodynamics* 102, 121–138.  
423 doi:10.1016/j.jog.2016.09.004

424 Sievert, C., 2019a. Interactive web-based data visualization with R, plotly, and shiny.

425 Sievert, C., 2019b. Preface. In: *Interactive Web-Based Data Visualization with R, Plotly, and Shiny*.

426 Spada, G., Melini, D., 2019a. On Some Properties of the Glacial Isostatic Adjustment Fingerprints.  
427 *Water* 11, 1844. doi:10.3390/w11091844

428 Spada, G., Melini, D., 2019b. SELEN4 (SELEN version 4.0): a Fortran program for solving the  
429 gravitationally and topographically self-consistent Sea Level Equation in Glacial Isostatic  
430 Adjustment modeling. *Geoscientific Model Development Discussions* 1–37.  
431 doi:<https://doi.org/10.5194/gmd-2019-183>

432 Surić, M., Korbar, T., Juračić, M., 2014. Tectonic constraints on the late Pleistocene-Holocene relative  
433 sea-level change along the north-eastern Adriatic coast (Croatia). *Geomorphology* 220, 93–103.  
434 doi:10.1016/j.geomorph.2014.06.001

435 The Qt Company, 2020. Qt | Cross-platform software development for embedded & desktop.

436 Tozer, B., Sandwell, D.T., Smith, W.H.F., Olson, C., Beale, J.R., Wessel, P., 2019. Global Bathymetry  
437 and Topography at 15 Arc Sec: SRTM15+. *Earth and Space Science* 6, 1847–1864.  
438 doi:10.1029/2019EA000658

439 Vacchi, M., Ghilardi, M., Melis, R.T., Spada, G., Giaime, M., Marriner, N., Lorscheid, T., Morhange,  
440 C., Burjachs, F., Rovere, A., 2018. New relative sea-level insights into the isostatic history of  
441 the Western Mediterranean. *Quaternary Science Reviews* 201, 396–408.  
442 doi:10.1016/j.quascirev.2018.10.025

Vlahović, I., Tišljarić, J., Velić, I., Matičec, D., 2005. Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics. *Palaeogeography, Palaeoclimatology, Palaeoecology* 220, 333–360. doi:10.1016/j.palaeo.2005.01.011

## Figure Captions

Figure 1. Regional setting of Korčula Island, taken from (Dean et al., 2020); top: general view of the Adriatic Sea (the red rectangle identifies the area for which the dynamic visualization is provided, the red dot indicates the location of Vela Spila cave); bottom: Korčula and surrounding area. Tectonic information: (Korbar, 2009; Surić et al., 2014). Map and relief data: (GEBCO, 2014; GADM, n.d.).

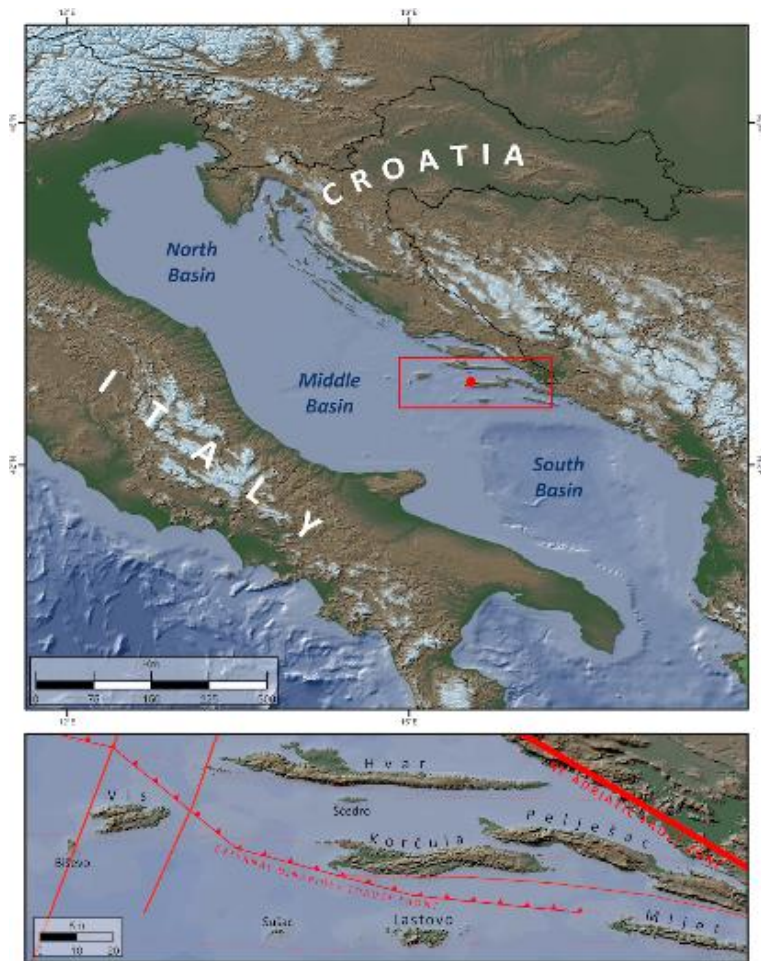
Figure 2. Number of articles in Earth and Planetary science fields with abstracts containing the word python from 2010-2020. Generated by scopus.com

Figure 3. Example of a typical static sea-level reconstruction visual, reprinted from (Dean et al., 2020). This visual was created with QGIS (QGIS Team, 2021) using sea-level reconstruction data points obtained by SELEN<sup>4</sup> (Spada and Melini, 2019b). The DEM is a combination of public sources and created for (Dean et al., 2020); see references therein for additional details and sources.

Figure 4. Example of observational RSL dataset reprinted from Dean et al. (2019) figure 5. The observed RSL data points (circles and diamonds) do not always indicate a clear, non-contradictory trend until subjected to an error-in-variables *IGP regression*.

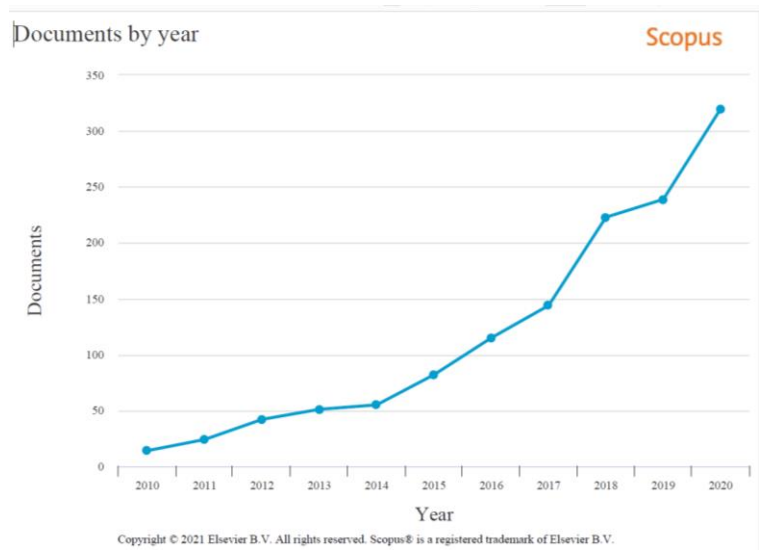
468 Fig. 1

469



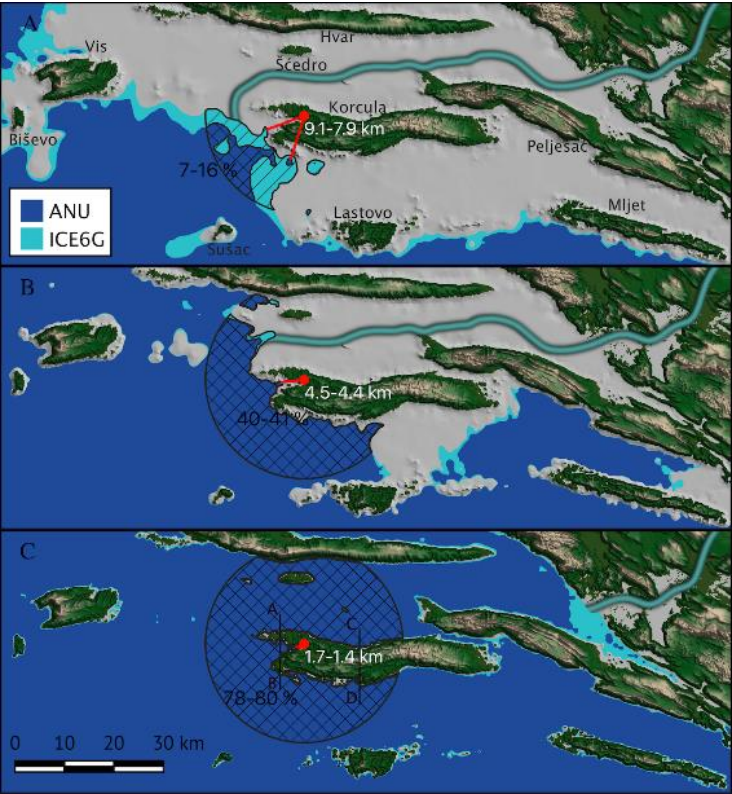
470 Fig. 2

471



472 Fig. 3

473



474 Fig. 4

475

