Additional thesis

Paleo data analysis

By

D.H. van der Heide

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Supervisor: dr. R.E.M. Riva

TU Delft

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Abstract

As models are becoming more dominant for the prediction of sea level rise, a review of how this method type is operating is needed. Hence, for this thesis the research objective was to what degree of accurateness is the VM6_C model estimating the relative sea-level during the late Holocene of Sardinia and Crete? To support this question, the following three sub-questions were formulated:

1. What is the influence of components of the simplified sea-level equation in Sardinia and Crete?
2. What are the current tectonic trends for these locations?
3. To what extend can the archaeological sites at these locations be used for validating the model?

The analysis for answering these questions, were divided into two case studies with three different acquisition methods: paleo data (1), GPS stations (2) and the VM6_C current rate of change (3). The accurateness was reviewed by comparing the computed trends and relative sea level heights of both these methods and case studies. This resulted in a rate of change of RSL by paleo data by Crete of 0.6173 mm/yr, whilst Sardinia had 1.297 [mm/yr]. In comparison the difference between the paleo and model data was respectively 0.45 [mm/yr] for Crete and for Sardinia is 1.03 [mm/yr]. The tectonic movement of both islands was concluded to be both subsiding at a millimetre magnitude. Therefore, the conclusion was drawn that the sea level was rising relative to the structures, yet the island was subsiding over time. Finally, the accurateness was reviewed by comparing the average difference between the historic sea level of the paleo data and the VM6_C model. Henceforth the variation was respectively -0.4302 [m] for Sardinia and -1.550 [m]. Thus, according to the results, the model has a higher accurateness relative to the paleo data when measuring at tectonic stable locations, however the trend can be better estimated at tectonic active locations. Which can be caused by the temporal resolution of paleo sites.

1 Introduction

1.1 Definition of the problem

Models are becoming more and more important for predicting the relative sea level in future situations. As the knowledge to the sea level for countries like the Netherlands are vitally important. Therefore, the accurateness of these models can make a difference for the construction of dikes and other sea protecting structures. However validating models could prove difficult, as there is no sea level height data present for 2100 or other long-term analysis years. However, regions like the Mediterranean Sea contain historical sites which date back to the Roman and Minoan time periods. As these sites remain strongly connected to the ocean, the historic level can be determined by surveying the elevation between the functional height and the current sea level. This difference represents the relative sea level, which in turn could be utilised for creating a long-term analysis of how the ocean have responded. Take for instance, the island of Crete which has a rich maritime history in the ancient and classical time area. As the Minoan civilization and Roman Empire ruled Crete 6000 before present (BP) to 2000 BP which left a lot of tidal and sea structures which are still in relatively good shape. When computing the trend of these different structures at specific locations like islands, the historic sea level can be determined up to a certain level. Therefore, when using the model parameters made to predict the future, the user could also reverse these and predict the sea level when the Romans build the fish tanks on the island of Crete. This will be the main goal of this thesis, using different methods available at the pre-selected islands.

1.2 Objective

For this thesis the research objective is: **to what degree of accurateness is the VM6_C model estimating the relative sea-level during the late Holocene of Sardine and Crete?**

To support this question, the following three sub-questions were formulated:

1. What is the influence of components of the simplified sea-level equation in Sardinia and Crete?
2. What are the current tectonic trends for these locations?
3. To what extend can the archaeological sites at these locations be used for validating the model?

1.3 Scope of work

As the sub chapter 1.1 stated the case studies will focus on the islands of Crete (Greece) and Sardine (Italy). These islands were selected for the location on the Eurasian plate. Therefore, the other locations in the Mediterranean area will not be covered. For the comparison between different analysis methods, the VM6_C model (Peltier) will be utilised.

1.4 Thesis structure

This thesis is structed as follows: the first chapter will discuss the theoretical background of the paleo data analysis, the GPS stations on the islands and the results from the literature study regarding the VM6_C model. Whilst the second chapter goes more in depth about the different case studies, followed by the discussion of the results and conclusion. Finally, future research recommendations will be made in the last chapter about the Paleo data analysis.

2 Theoretical study

In this chapter the theoretical background behind the model is explained, by means of components of the simplified ocean equation (2.1). Also, the difference between the variety of the Paleo data (2.2) and how the GPS data can play a role in the understanding how the current islands are moving in vertical direction (2.3).

2.1 Theoretical background of the model

When examining the research question, an understanding of how the model(s) are estimating the different sea levels would be needed. Since several factors are of key influence in how the relative sea level (RSL) is computed. Since the shoreline in relation with the sea is the essence of the RSL, the literature summarised this in the following simplified equation (Pirazzoli, 2005).

$$ps = eu + te + gi + hi \quad (1)$$

Here the **ps** is the elevation of the shoreline over time, which can be seen as how much the island i.e. rose relative to the sea level. The **eu** component represents the eustatic position of the shoreline (see ch. 2.1.1), the **te** is the tectonic plate component (see ch. 2.1.2), **gi** the glacio-isostatic component and **hi** represents the hydro-static component (see ch. 2.1.3). Since the case studies comprises of the Sardinia and Crete, different approaches of the equation can be applied (Pirazzoli, 2005). Due to the fact that locations are experiencing vertical movement relative to the different tectonic plates. For instance, Crete is located on the Hellenic plate (a breach between the Eurasian- and Arabic-plate), whilst Sardine is fixed on the Eurasian plate. Henceforth Sardine would therefore be relative stabler in comparison with Crete. The literature stated that therefore the **eu** and **te** components would arguably not be needed, due to the long-term effeteness of these components. To see if this indeed could be discarded, the eustatic, tectonic and glacio-isostatic/ hydro-static is further explained.

2.1.1 Eustatic component

The eustatic component, represents the sea level change driven by the volume/mass change of the oceans which results in a globally uniform mean sea level variation (Rovere et al., 2016). These variations in mass are caused by the melting or the accumulation process off the continental ice sheet of i.e. Greenland and/or Antarctica. However, the water redistribution of hydrological reservoirs and ground water storage are also having an impact on the eustatic sea level. Whilst the volume changes are influenced by different factors, including the density and/or salinity variations in the ocean (Rovere et al., 2016).
Respectively the tectonic seafloor spreading, and sedimentation also influences the eustatic sea level, which can be classified as geological forces (Rovere et al., 2016). Each of the force (climate and geological) is having different time scales, on which the sea level is being influenced. Which is for the islands of the case studies a timescale of 10-100 million years. Therefore, the Pirazzoli (2005) proposed that this term in the simplified sea level equation can be discarded for the analysis.

2.1.2 Tectonic component

When looking at influence the tectonic component only Crete could be considered. As this relates to the uplifting and down lifting effect caused by the tectonic plate motion. The island is located at the Hellenic arc or subduction zone between the Eurasian, Arabian and African plate. This is depicted in Figure 1 are the tectonic positions of Crete (red circle) and Sardinia (blue circle).

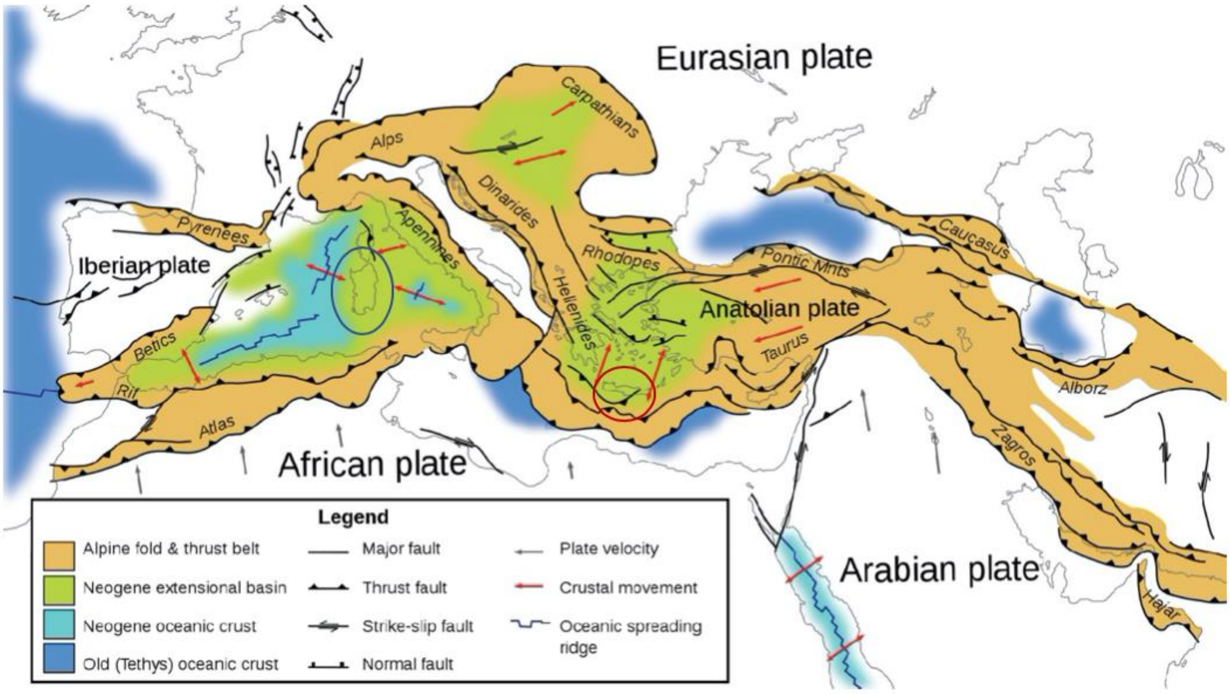

Figure 1 Location of Crete (red circle) and Sardinia (blue circle) relative to the tectonic plates (picture taken from Woudlopen, 2012)

The historical aspect of this component is the event that occurred in AD 365 (Tiberti et al., 2014). Since numerous historical earthquakes occurred in the East of the Mediterranean. Evidence of these historical displacements can be found at the western part of the Crete, where the later continuity of the South West boundary of island is a direct evidence of the influence of this component (Pirazzoli, 2005). The literature stated that after research several sites, the altitude would have increased here about 9m. Unfortunately, any documented evidences of the magnitude of the tectonic components (i.e. number of earthquakes) is not available at the moment of writing. Since the areas of interest did not have major towns present during the Ancient time period (3000 BC – AD 500) and the data regarding tectonic movement is mostly document when there was i.e. damage to structures (Pirazzoli, 2005). Yet when looking at historical data surveyed at the fixed structures (Ch. 2.2), the tectonic plate movement becomes a dominant factor. As this influences the current elevation, position and relation to the sea level by movements in horizontal- and importantly vertical direction.

When looking at blue circle in Figure 1, the location of Sardinia in relation to tectonic plates is relatively stable. Being that the island is located on the Eurasian plate and far from any boundaries. Whilst the mainland of Italy is experiencing the collision between the African plate and the Eurasian/European plate. Which would strengthen the proposition made by Pirazzoli et al (2005), that the **te** component for Sardinia could be neglectable.

2.1.3 Glacio-isostatic & hydro-static component

This final components of the simplified ocean equation in relation with the relative sea level is the Glacio-isostatic and hydro static component. The first one is defined as 'viscoelastic response of the Earth to the redistribution of ice and ocean loads' (Rovere et al., 2016). Since this is a relative important aspect of the sea level equation, as this viscoelastic response caused by the melting of the Feno Scandinavian ice mass, influences the Mediterranean ocean and landmasses. In principle the disappearance of the ice load caused the ocean basins in the "far field" to undergo a relative subsidence.

Whilst the hydro-static component focuses more on the load being induced by the ocean and the influence of the increase of the melt water. Since this would also be a factor that causes the sea level to change over time, when the load varies.

2.2 Paleo-data analysis

The paleo data for the two case studies were acquired by the literature study of the different papers. In this sub chapter the survey methods and different site types are explained. As the paleo-data consists of using the elevation relative to the past shoreline and the functional height with respect to the current sea level. These parameters were defined by Antonioli et al. (2007) as: the height of these sites relative to the mean sea level (MSL) during time of construction. The paper also proposed that the archaeological sites were depending on the construction, since the function can vary over time. For instance, a Roman construction can be in contrast with the Minoan architecture of the same building type. This sets these sites in a time perspective and therefore can be used for finding the RSL during this period. Likewise, the local tide amplitude plays a role in the determination of the functional height parameter, as these are different at each new location. Henceforth, the relation between the minimal height of the construction and the local highest tide can be seen as the functional height (Antonioli et al., 2007).

In the next subchapters the different kinds paleo sites, characterised into two groups (geological and archaeological) are defined.

2.2.1 Geological paleo sites

The first category, geological tidal sites, exists of areas that have been affected by the ocean and can therefore be related back to their original position (i.e. during the late Holocene). These tidal notches can be found at cliffs, that are close to the sea level and have experienced with undercutting and/or indentations, showing an indication of where the sea level was at specific times in history (Mourtzas et al., 2016).

An example is given from the research of Antonioli et al (2007) in Figure 2, where such a site is shown at the coast of Sardinia.

Figure 2 Tidal notch at a cliff (Sardinia) taken from (taken from (Antonioli et al., 2007))

The red arrow indicates the mark, of which the elevation is being measured. The difference between the top of the cutting and the current sea level can be interpreted as the change with the historical RSL.
The second geological indicator are the beach rocks, which can consist of lithified coastal deposits. Here the preservation of the original cement in combination with the other sedimentary knowledge is the driving feature for the determination of the RSL (Vacchi et al., 2016). Important is that intertidal zone in combination with the amplitude of which the structure is exposed to the waves and local geomorphological setting (Vacchi et al., 2016). The literature classifies these indicators into four (time) phases relative between the structure and the different sea levels at the locations of Crete and Sardinia (Mourtzas et al., 2016).

2.2.2 Archaeological paleo data

The second group consists of the archaeological data which can be sub-divided into four categories, characterised by the different accuracy levels. Along the coast of Sardinia and Crete are a variety of different types of historic indicators. Therefore, Mourtzas proposed that there are four main levels of sites that are depending on the accuracy where category 1 having a low precision, whilst the 3th group has a high. The last group consists of quantitative indications of sea level (rise).
The first group consist of coastal structures found above the sea level, however without the necessary knowledge about the relative position to the shoreline in the desired time period (Mourtzas et al., 2016). Therefore, this group was considered not usable for testing the accuracy of the model, yet only as a quantitative indicator which can support the elevations of other categories located in a close vicinity.
The second category has a relative higher precision and includes sites that have been found partly submerged in the sea. Important for this particular group is that the historic information is present and thus having a relatively higher accurate of the elevation to the (historic) sea level. These sites can, among others, include harbours, piers and quays.
The third category consists of the maritime structures that were constructed in relation with the former sea level and considered having the highest relative accuracy level. Due to the fact that the historic information is well documented for this location type. For instance, the Roman fish tanks found on Crete, given in Figure 3.

Figure 3 Roman Fish tank at the coast of Crete[1]

These tanks are typically being surveyed at the bottom by use of metal bars, similar to land measurement rods. Here the subdivision where in centimetre, supported with a spirit-level to keep the bar water level. Therefore, the elevation between the surface and the sea-level can be measured during periods of low wave energy (Mourtzas et al., 2016). To improve these measurements, the survey is being repeated.
Note that the location of the tank is surveyed whilst using GPS devices to measure the vertical and horizontal position of the tank.

[1] https://www.cretanbeaches.com/en/history-of-crete/archaeological-sites-in-crete/classical-and-greco-roman-era

The last group includes the coastal water tables in combination with the response of the variating sea level. An example for such a site can land structures like the Minoan coastal settlement on Kato Zakros (Crete), which was partly flooded (Mourtzas et al., 2016). Here the rise in sea level, caused the supply system to overflood. In doing so setting a section of the palace of the village under water, indicating that the sea rose over time. Also implying that use of this group is more like category 1, since the data collected here are only a quantitative indication and can support the findings of cat. 2 and 3.

2.2.3 Biological paleo data

Besides the geological and archaeological data, there is also the biological features. Fixed biological points are containing the reef-like bioconstructions (including coralline rhodophyte lithopyllum byssoise (Sechi et al., 2020)) that can be found along the shoreline. The functional height of these indicators was defined as the lower limit, which can be the transition between the midlittoral and the infralittoral zone (Vacchi et al., 2016). The accuracy of these points was estimated by Pirazzoli (2005) to be <=0.1 m in environments where the tides are almost not occurring like the Mediterranean Sea.

2.3 GPS station data analysis

The last data analysis method to compare the VM6_C model and to get an understanding of the current vertical movement of the islands is by the use of GPS data. Note that the stations have available data starting from AD 2002 up to the moment of writing (AD 2020), however there are numerus amount of stations available for a long-term trend. For this thesis the linear trend found in present long-term data, was extrapolated back to the late Holocene period. Therefore, accepting several errors that can be induced by these methods. These errors are mainly caused by the linear approach, as short-term events (e.g. the earthquake of Crete in AD 365 (Tiberti et al., 2014) are neglected. Yet one could argue that the analysed model, using the (simplified) terms are utilising a some short of similar approach. Since these small occurrences over time are still poor documented and only be found by circumstantial sources and the paleo data analysis. The individual stations utilised for setting up this linear trend are stationery. Therefore, the Precise Point Positioning strategy is applied on the data for achieving a higher point resolution in vertical and horizontal direction. Which make them ideal for processing of tectonic movements, since the precision of the respective location is accurately known. For this thesis the data will be provided by the Nevada Geodetic Laboratory and can be found on the website of MAGNET network[2].

2.4 Literature study comparison results

Before analysing the archaeological sites with the Paleo-, GPS-data and the VM6_C model, several other studies researched the same areas with respect to different models whilst including the geological data of the Paleo sets. The studies showed that the model (regardless of the used paleo data) is relatively higher for the set regions. In Figure 4 are the results of the study by Roy & Peltier (2018) given, where the green line represents the RSL generated by the new model VM6_C, whilst the black line is the ICE-7G_NA model. The green plusses are the paleo data the is found along the coast of Sardinia.

[2] http://geodesy.unr.edu/NGLStationPages/gpsnetmap/GPSNetMap.html

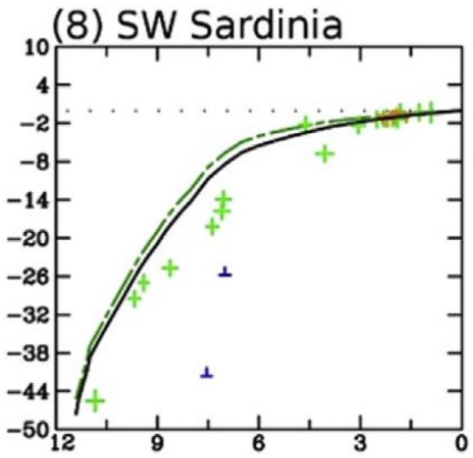

Figure 4 Comparison between the VM6_C (green) & ICE-7G_NA (black) models and the paleo data for Sardinia (taken from Roy & Peltier (2018))

Here the feature of interest is that the paleo data seems to be lower than the model between 9000 BP and 5000 BP, yet during the Minoan and Roman time period the models seems to match the historic RSL. Nonetheless, as the data was not supplied by Peltier of the VM6_C model, a literature study conducted by the same author made an image of the RSL between the Roman time and the current time. This depiction is given in Figure 5, where the colour scale is in meters.

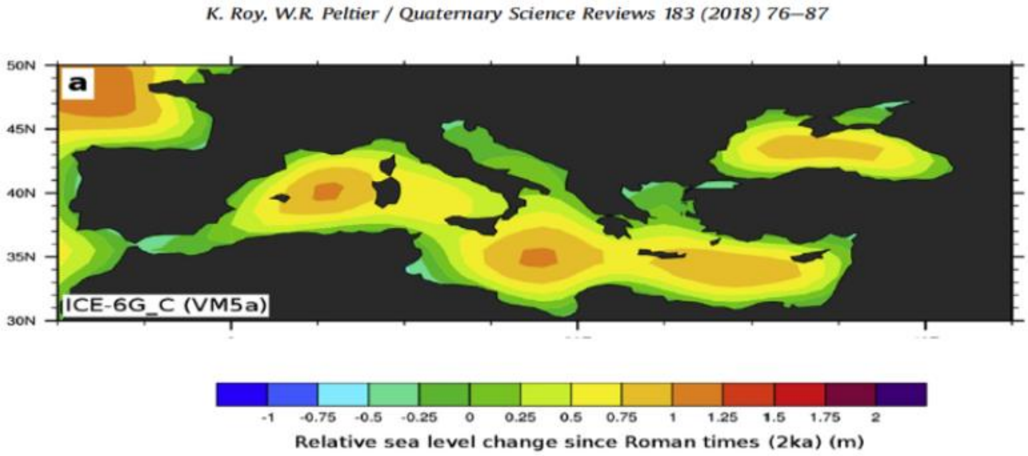

Figure 5 Relative sea level change since the Roman times (2ka) in meters (taken from Roy & Peltier (2018))

The figure shows some interesting features. Crete is by the colour gradient divided into two parts; the western region had a smaller increase over time relative to the eastern part. When analysing the figure, the relative sea level in the two areas have decreased between 0.5 and 0.75 [m] for Sardinia, whilst Crete showed an increase in the sea level with a magnitude of 1 and 1.25 [m] over time.

3 Case Studies analysis

Here the maritime landscape of the case studies will be examined prior to the analysis (ch. 3.1). Followed by the analysis of the paleo data (ch. 3.2), the data analysis of the GPS stations (ch. 3.3) and model (ch. 3.4). This chapter finishes with the comparison of the trends and RSL of the three methods (ch. 3.4).

3.1 Maritime Landscape

For the case studies the islands of Crete and Sardinia were selected to be analysed, for comparing the model against paleo data. To see how the sites of the island are connected an analysis was made to sketch the maritime landscape according to Westerdahl (1992). These zones can help in understanding the origin of how the area was being constructed and what kind of possible structures can be found in these regions.

3.1.1 The Maritime Landscape of Crete

Crete has been an important island during the Ancient time period (3000 BC – AD 500). The island experienced several occupations and was mainly ruled by sea going nations. The Minoan civilization (c. 3000 BC – c. 1100 BC) is seen as the first nation to rule over the island of Crete (1). This civilization constructed impressive structures over the island, which can still be found. Yet the Thera volcanic eruption (c. 1600 BC) followed by another possible earthquake in c. 1450 BC caused the civilization to decline. Until c. 1425 BC, when the Mycenaean Greeks finally invaded the island and made an end to the Minoan rule. However, after several power struggles, in 88 BC Crete was taken over by the Roman empire. This brought the Roman building techniques to the island, which caused for several maritime structures to be constructed like the earlier discussed fish tanks. Figure 6 is the island depicted, where the important maritime zones are highlighted. [3] Note that the yellow bar represents the breach in tectonic movement of the earthquake of AD 365.

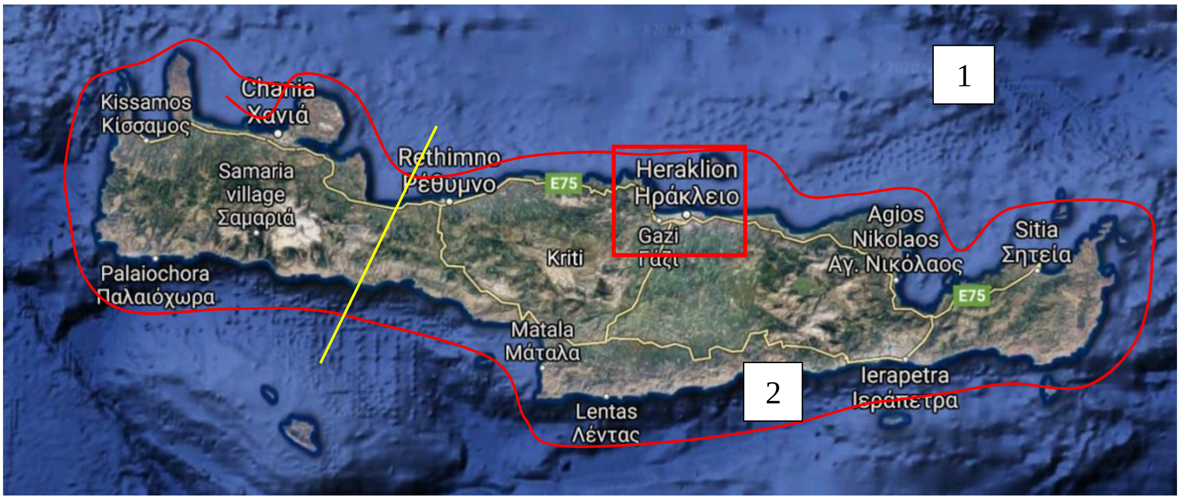

Figure 6 Maritime landscape of Crete

Since the Minoan rule over the island, the centre of commerce is focused around and at the Heraklion city (which is the current capital of Crete). First the Minoans settled in Knossos, which is south of the city, whilst using Heraklion as a harbour for trading with the Greece mainland and the villages along the coast of Crete (Dimopoulou et al. (2007)). Therefore, the transport zones proposed by Westerdahl, have been marked on the figure accordingly. (1) represents the open sea transport zones of the islands. Indicating that the heritage found in these zones (or on the beaches) can be related to the vessels or harbour structures harbouring

[3] https://www.unrv.com/provinces/crete.php

vessels that were seaworthy. (2) represents zones of coastal transport, which can include smaller vessels like fisherman ships. This also results in structures related to this zone, like for instance roman (or Minoan) fish tanks. Overtime the Byzantium -, Ottoman- empire, the kingdom of Greece and was occupied during the second world war by Nazi Germany. These government changes brought peaceful times, but also wartimes during harsh occupations. Which can have damaged or changed the sites related to the maritime landscape of Crete. Yet studies showed that the Minoan and Roman aged structures have remained intact and can therefore be utilised for the analysis of the case studies.

3.1.2 The Maritime Landscape of Sardinia

Sardinia has a rich history, were the first civilization visited and colonised the island around the 9th century BC. The Phoenicians used the island as a safe place to anchorage during severe weather conditions. Since the Sardinia was located along the important trade routes of this civilization. This already showed the maritime connection of the island and the importance of the structures which were built during this time period. During the 6th century the Carthaginian Empire, occupied the island, followed by the Romans who annex the region in 238 BC. This brought the same maritime building techniques seen on Crete, like the fish tanks, peers and harbour structures. At the end of this thesis time period the island was conquered in AD 456 by the Vandals during the migration period. To better understand the use of the maritime structures the zones of Westerdahl are given in Figure 7 for Sardinia.

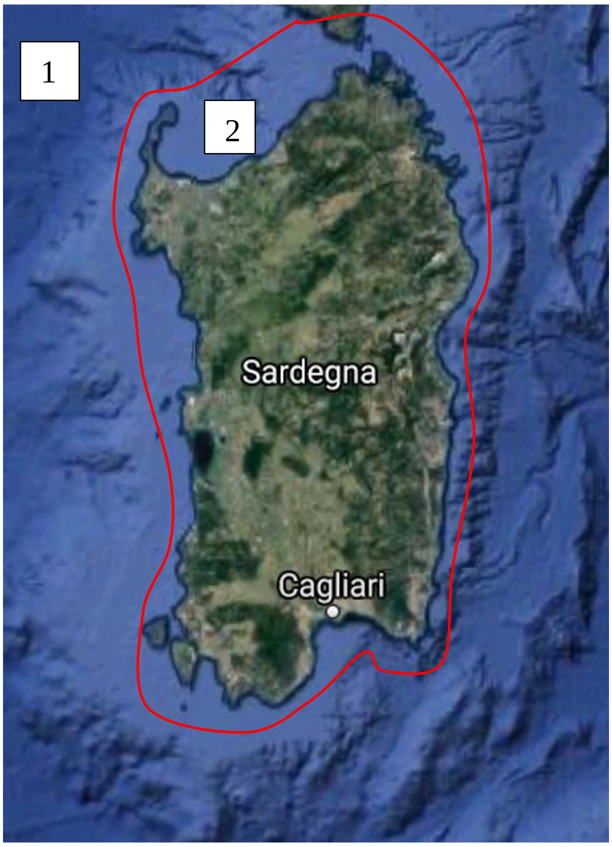

Figure 7 Maritime landscape of Sardinia

Much like Crete the zones of Sardinia have the same layout as the latter case study. Since (1) represents the transport zones of open sea. Which showed that the island would have contain structures to support this type of transportation to and from the island. Also, the influence of Carthaginian, and Roman empires close by, would made the settlements depending on the mainland. Which would therefore need a main port for the island, which was the capital of the Sardinia: city of Cagliari. Like Crete the island was also harbouring transportation zones (2), which over the island structures can be found that represent these zones.

3.2 Paleo data results

The data for the paleo analysis was provided by the literature, who did archaeological studies on Crete and Sardinia. The sites experienced several events that can have induced the current state of the structures (as mentioned in Ch. 3.1). In Table 1 are the different sites given, sub categorised by case study, type and amount present at this location. Note that the site naming is as follows: CRE-XX stands for Crete, whilst SAR-XX is Sardinia. The complete data set of each individual site is given in Appendix 1, with the corresponding references.

Site-name	Type	Amount
CRE-01	Submerged structure	33
CRE-02	Uplifted closed harbour	1
CRE-03	Slipway	1
CRE-04	Roman breakwater	1
CRE-05	Fishpond	1
SAR-01	Neolithic burial	1
SAR-02	Harbour structure	3
SAR-03	Quarry	3
SAR-04	Tomb	1
SAR-05	Church pavement	1
SAR-06	Supratidal beach rock	1
SAR-07	Wreck in harbour	1
SAR-08	Breakwater	1

Table 1: Paleo data site types

For CRE-01 the submerged structures included:

- Breakwater (natural) and/or constructed by accumulated rubble blocks
- Harbour morphology
- Fish (carved) tanks (and traps) (Roman)
- Relics of walls of a Minoan villa
- Coastal Minoan quarry
- Roman Quay
- Ruins of a (coastal) Minoan settlement
- Ruins of a roman building
- Rock-cut salt pan
- Concrete masonry (Roman)
- Quarry floor (Roman)
- Foundation and parts of columns from a temple of the Samoio Athena (Minoan)

Striking for Crete are the many submerged structures, that are in relatively good condition, even with the location being close to the Hellenic arc (see Figure 1a). Also, this high amount of structures could really asses the tectonic displacement during this time period and therefore help in answering the research question. Likewise, the amount of archaeological structures of Sardinia is relatively lower (in comparison with Crete). However, as this island had experienced less tectonic movement over the centuries, the assumption was made that 12 sites would show sufficient results. When taking into account that these structures are evenly spread (see 3.3.2) over the island and (except for the Neolithic burial site) focuses on the Roman and Carthaginian rule over the Island.

3.2.1 Paleo data analysis: Crete

How this looks for the different case studies spatial distribution is given for Crete given in Figure 8. Here the island is shown in WGS84 (degrees) with the locations in black dots.

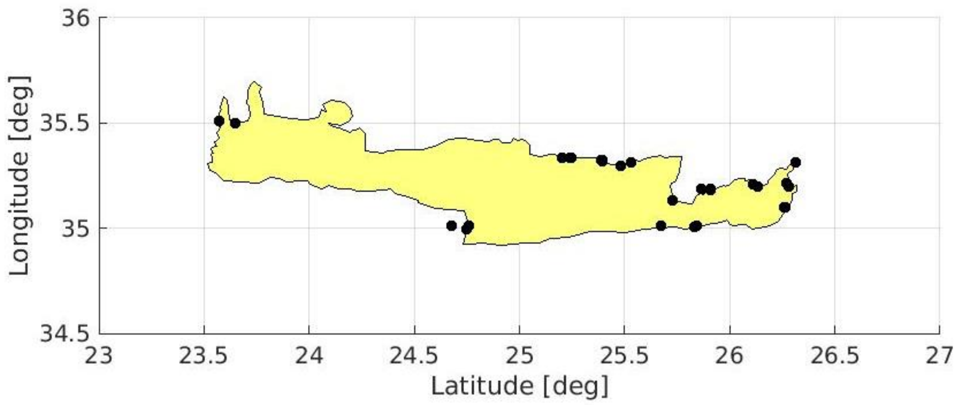

Figure 8 Locations of the Paleo data of Crete

Striking of this distribution, is the fact that these are mostly concentrated to the eastern part. Which can be explained by the maritime landscape of the Crete (see Ch. 2.2), since the civilizations maritime history was focused around the capital. So, researching the effect of the event of AD 365 would not be possible, whilst only using the archaeological data. Therefore, paleo study focuses on the whole Island, instead of local difference in comparison with the VM6_C model. For the analysis the functional height was utilised relative to the current sea level. This would in turn provide the historic sea level, given in Figure 9. Here at the time series is depicted of the evolution of the sea level with relative to the current state. Where the temporal and height errors are given respectively with the horizontal and vertical bars. Note that the reference year for the before present time scale is AD 1950 (1st of January).

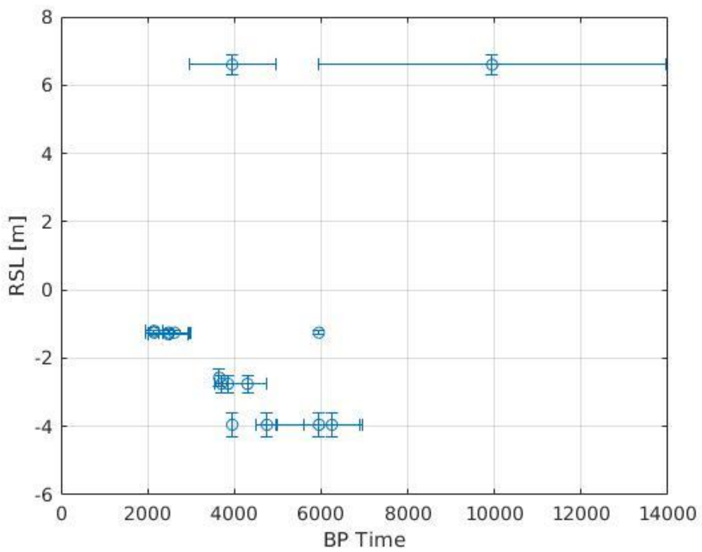

Figure 9 Paleo data of Crete

The first noticeable feature is the rising trend from the Minoan time (6000 BP to 4000 BP) to the Hellenic - Roman period (4000 BP to 1500 BP). With a rise of 2.75 [m] resulting in a linear trend of 0.6173 [mm/yr] (without the two outliners). However, when looking more densely populated samples of the Roman period (< 4000 BP), a weighted average was computed of -1.297 [m] relative the current sea level. Likewise, the next feature is the variation in error influencing this average, as the structures build by the Minoans are rather difficult in estimating an accurate elevation to the sea level. Since these are caused by the fact, that the structures are relatively older and therefore experienced more natural and/or human events. The main sites that have a relative higher error are the submerged Minoan village structures and/or walls, with an error of ±0.35 [m]. Whilst the utilised Roman maritime structures in Crete are mostly fish tanks, which were built of concrete and direct related to the ocean (having an error of ±0.05 [m]). The magnitude of the error remains debatable when researching trend levels and historic RSL's, since the actual level is even for models hard to accurately "predict". The last mentionable feature are the two possible outliers. These are the CRE-02 and CRE-05 sites, dating back to the Minoan and roman age. The information provided by the literature showed that these sites rose during the AD 365 event by 6.6 [m]. Therefore, these structures are only provided as an indication of the implication of the event and that historic knowledge of paleo data is key for the comparison with models.

3.2.2 Paleo data analysis: Sardinia

For seeing if the second case study shows the similar results, the same procedure was utilised. Whilst using the RSL of the different sites, given in Table 1. Here the spatial distribution of the different sites is given in Figure 10, where the Island is depicted in WGS 84 (degrees) and the paleo data sites with black dots.

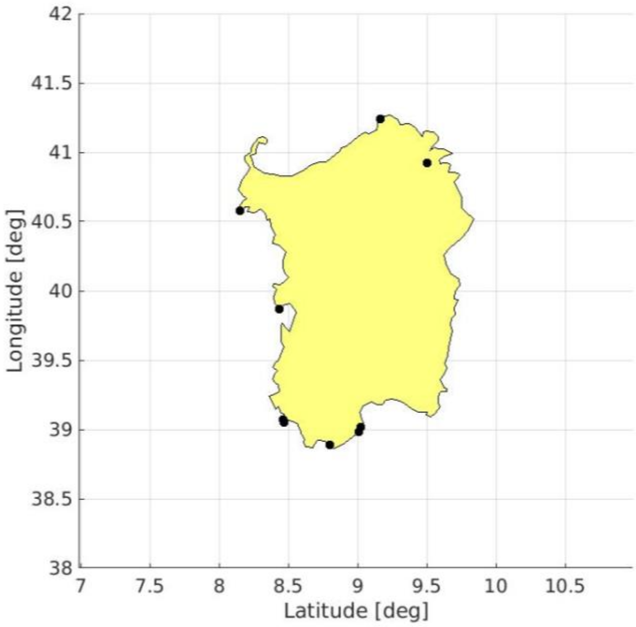

Figure 10Paleo sites of Sardinia

Sardinia has a an equally spread distribution of the sites over island, with a relative higher concentration of archaeological indicators in at the south. Like Crete the analysis will be focused here on the complete island, rather than focusing at different features of Sardinia. However, like Ch.1.2 stated, the island is relatively stable tectonic position. Therefore, regardless of the spatial distribution of given in Figure 9, the sites located at possible other location of the same time period should give the similar results with respect to the sea level. Following in Figure 11 is the paleo time evolution portrayed, where the SL relative to the current state[m] is given as a function of time [years].

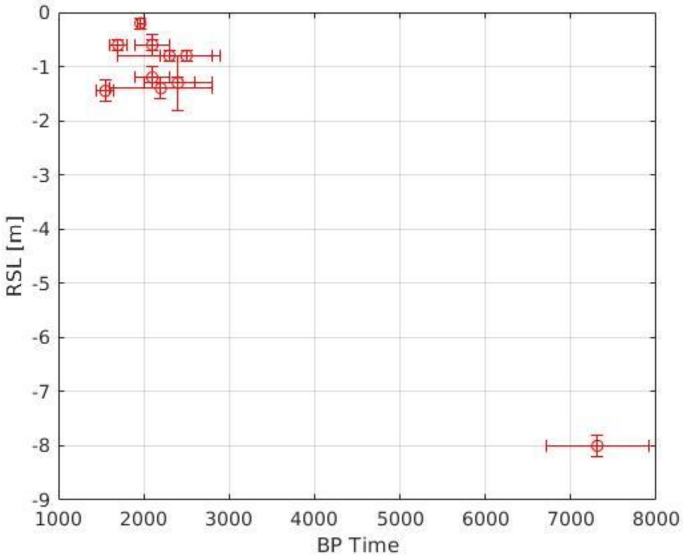

Figure 11Paleo data of Sardinia

The first feature that can be noticed of this depiction, is the difference between the maritime site SAR-01 and the others. This site showed that Sardinia see level would be -8m respectively and therefore have a linear increase of 1.321 [mm/yr]. Yet when analysing the sea level during the roman time period (1000 BP and 3000 BP), the weighted historical sea level is -0.840 [m]. Again, the height error was selected for the weighting. When looking at the figure published by Peltier (Figure 4), a similar trend can be noticed. Since this rising movement seems to be ending around 3000 BP, with the Neolithic burial site is the presumed last remainder that gives this low RSL. Following that the second feature is the stable trend that the paleo sites are portraying over the course of 1000 years. This would strengthen the deduction of the stability the island experienced with respect to the tectonic movement. The RSL variability between the maximum and minimum was 1.25 [m], which is lower than of case study 1.

3.3 GPS station data analysis

The data provided by Blewitt (2018) gave a high density of GPS stations located at both islands. To get a better understatement of how these islands are currently been moving relative to the IGS14, this sub chapter is divided into the two case studies.

3.3.1 GPS Stations analysis: Crete

To see how the spatial distribution of the stations are for the island of Crete, the following figure was made. Here the locations of the used GPS stations are given indicated by the blue squares.


Figure 12GPS stations of Crete

Like the Paleo data, the distribution is similar to the paleo data of Figure 8. Where there are more stations concentred at the western area of the island and only three usable at the opposite parts. Nonetheless this would still create complete overview of how Crete is currently experiencing the tectonic movement over the past 18 years. Hence, when analysing the data, the up motion was selected, as this would portray the elevation of the island with respect to the sea level. So, the resulting movement is given in Figure 13, where the elevation is given in meters and the time in years. Note that the vertical movement is relative to the IGS14.

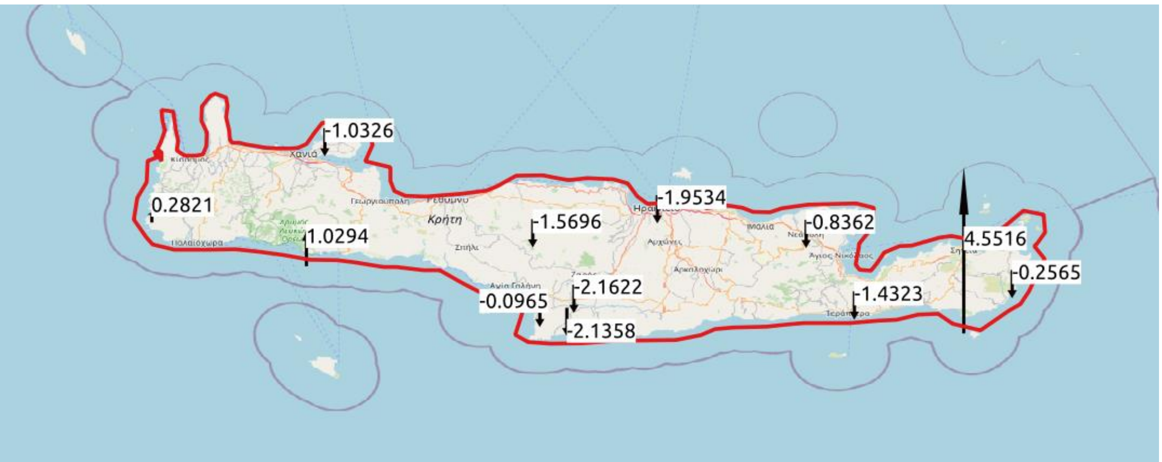

Figure 13Vertical movement[m] of the stations of Crete relative to time [yr]

Interesting is the fact that the stations are experiencing different amounts of vertical motion on the island. Almost every station in the western part of the island shows a subsidence motion, except for the SITI station (see Table 2). However, the eastern part shows interesting phenomenon. Although there is less GPS station with usable data present (long time series), the three stations all have a different vertical motion rate relative to IGS14. Implying that the Island of Crete is experiencing different movements over the island, potentially influencing the paleo data (see Figure 9) and the model outcome.

Therefore, the trend of each station was computed, which was then utilised for estimating the average trend of the whole island. The results are given in Table 2, where the id-name, trend [mm/yr], average error [mm] and location on the island relative to the AD 365 breach (see Figure 6) is given.

GPS-Station id	Trend [mm/yr]	Mean error up [mm]	Location
AKYR	-2.134	2.9427	West
ANOP	1.029	3.0743	East
HERA	-1.953	3.0766	West
IDI0	-1.570	3.2727	West
IERA	-1.432	3.9025	West
MOIR	-2.162	2.8694	West
NEA1	-0.836	3.6875	West
PA01	0.390	2.8707	East
SIT1	4.552	2.6827	West
SIVA	-0.0965	5.7924	West
TUC2	-1.033	3.4059	West
XRSO	0.282	2.9823	East
ZKRO	-0.257	6.5033	West

Table 2: Paleo data site types

This table shows the contrast between the locations relative to the AD 365 breach, as the east stations portrays a lower trend than the west stations. Likewise, the weighted mean was computed for all the stations at the individual locations. Resulting the average weighted trend of the island is therefore -1.207 [mm/yr] relative to the IGS14 reference frame, with an average error ± 3.620 [mm]. Using this trend, the elevation relative to the current situation for the time period of the analysis period was linear computed, given in Figure 14. Here the tectonic height with respect to the IGS14 is depicted in meters and time in years.

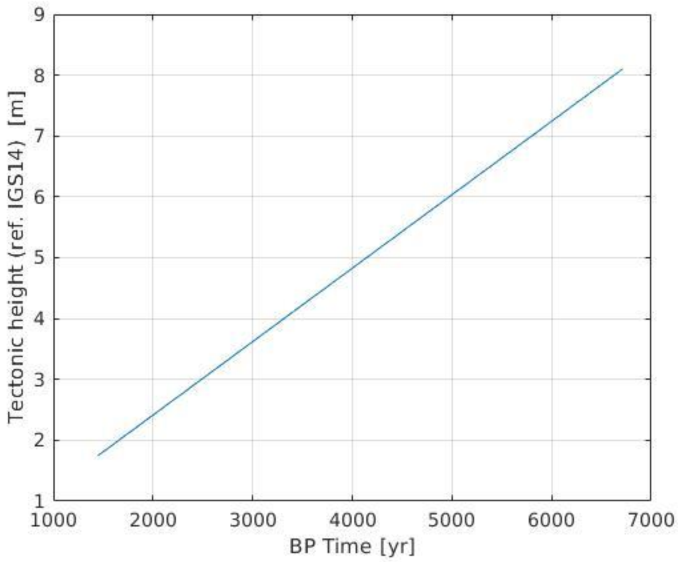

Figure 14Resulting historic elevation [m] over time [yr] for Crete

When analysing the resulting elevation differences that Crete would have experienced whilst linear extrapolating the GPS data. The result depicts that the island would have been subsiding from roughly 6.5 m to 1.7 m relative to the IGS14 frame. This decrease is difficult to connect to the rising sea relative to the functional height seen in the paleo analysis. Since the island seems to subside on a millimetre scale, whilst the sea has been rising according to the paleo data and Figure 5.

To see how the breach (shown in Figure 6) was influencing the average weighted trend, the rate of change for the eastern and western part (indicated by table 2) were computed. When comparing both results, the variation was for the eastern part of the island a rising effect relative to the west with 0.48721 [mm/yr]. Portraying that this type of difference did influence how the tectonic movement of the island and respectively the location of the function height of the paleo structures.

3.3.2 GPS Stations analysis: Sardinia

Likewise, for Sardinia the same procedure has been utilised, where the following stations (black dots) were picked given in Figure 15.

Figure 15GPS stations of Sardinia (blue), where green indicates the used locations

Unlike Crete, the islands stations experienced high amount of missing data or stations that had just started logging. Which is the cause of the lower amount of stations utilised in for the Sardinia case study. Still the different up motion of the island over time (yr), relative to IGS14 is given in Figure 16.

Figure 16Vertical movement [m] of the stations of Sardinia relative to time [year]

The resulting data, like Crete, is portraying different kinds a uniform vertical motion over the island. Yet one station at the east showed a lifting motion over an 8 years span. Nonetheless the motion is relatively small, which therefore would likely not influence the average weighted mean of the trends. These trends are computed similar to the Crete case study and given in Table 3. Where the station ID is portrayed with the trend in mm/yr.

GPS-Station id	Trend [mm/yr]	Mean Error up [mm]
ARBU	-2.803	3.377
CAO2	-1.211	3.491
CAEF	-0.892	3.101
GALG	-0.562	2.801
GCAR	-3.927	3.530
GSTG	-1.522	3.443
MURA	-5.528	3.193
OLB2	-1.089	3.024
SIN2	0.0115	3.401
VISI	-0.753	3.041

Table 3: Paleo data site types

Like the Figure 16 showed, the SIN2 movement is in the order of 10^{-5} [m]. Which is neglectable when averaging the average weighted trend. The average weighted subsiding is therefore –1.792 [mm/yr], with an average error of ± 3.237 [mm]. Whilst using this result, the linear elevation of the island is given in Figure 17 with respect to the current height of Sardinia.

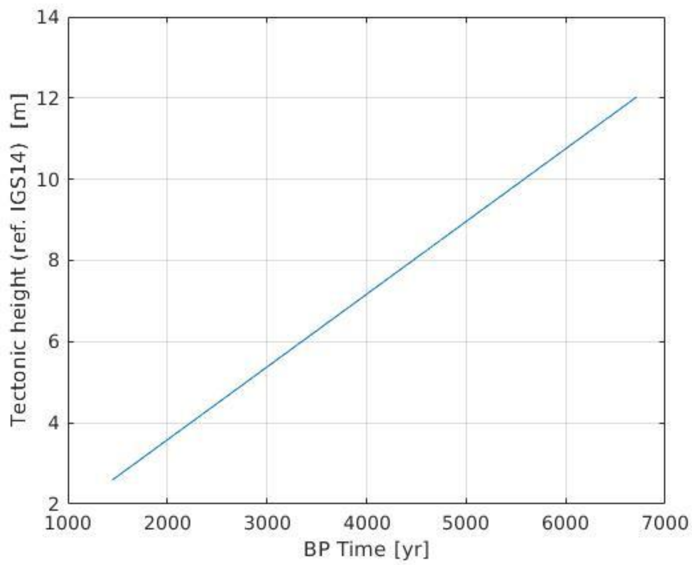

Figure 17Resulting historic elevation [m] over time [yr] for Sardinia

The graph depicts that the island of Sardinia is subsiding over the course of 5206 years from 12.2m to 2.6m, relative to the current position. This steep increase was also shown in the paleo data, which indicates that the island is behaving similar to the previous case study. Where the island is moving at the relative same pace relative to the sea level. However, determining if the sea level has risen over time or the if the island has just subsided is difficult to conclude according to these results.

3.4 VM6_C model results

The last method utilised for estimating the historic RSL and trend at the islands of Crete and Sardinia, is the VM6_C model. As there are several outputs provided, the data whilst using an updated PSML station file from Augustes 13, 2012. When looking at the first results supplied by the model, Figure 18 depicts the RSL rate at time=now, which is an average between the -250yr and the +250yr result. Here the rate of change is depicted in mm/yr.

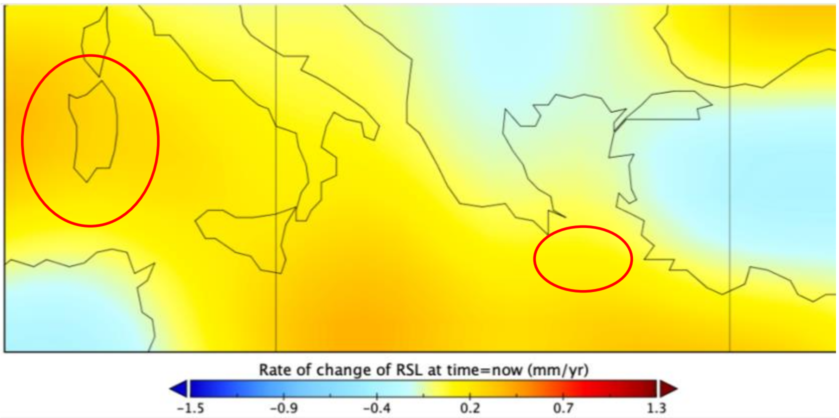

Figure 18Rate of change in RSL at the time = now [mm/yr]

Striking is the fact that the rate is relatively low compared to regions closer to the melting ice masses i.e. Greenland or Antarctica, in the order of 0 and 0.3 [mm/yr]. Where Sardinia seemingly experiences a slightly higher increase than in the Crete region (both indicated by red circles). To see if this trend is continuing with the historical data, the rates of change where computed of the supplied data of Crete and Sardinia. Respectively the trend for case study 1 was -0.1641 [mm/yr] and for case study 2 was -0.2709 [mm/yr]. Since Figure 4 and the Paleo data, showed that the change was behaving linear, the trend was computed and extrapolated when presuming that the current sea level represents the starting position. The results have been given in Figure 19a, where the results from the model is depicted with the paleo data. Whilst in Figure 19b, the comparison of the RSL is given in meters. Note that the two structures, that were indicated as outliners, have been removed from this analysis.

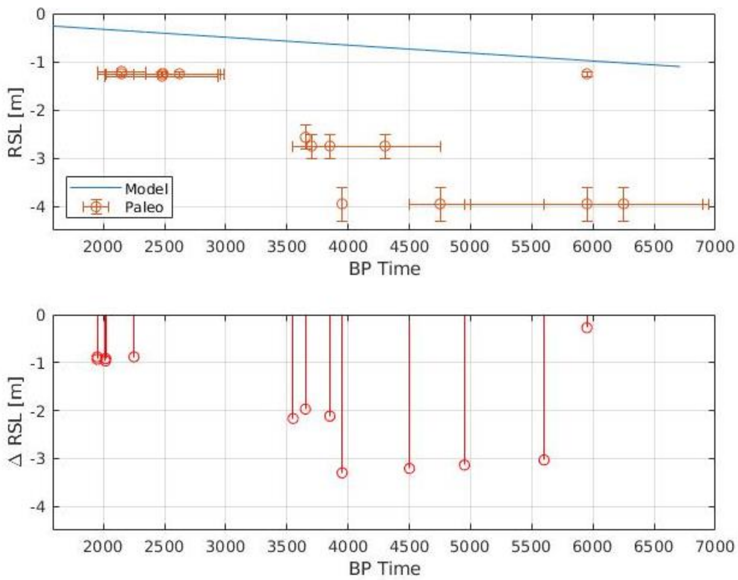

Figure 19Timeseries comparison between Paleo and Model(a), Variation in RSL between paleo and the model (b) for Crete

Figure 19a shows that the model results are higher than what the paleo indicates, even with the error bars included. Nonetheless the trend seems to match the paleo (and also the GPS movement), indicating that the model would provide "safe" data that could be representative for the historic sea level. Note that here safe is referred to as that the sea level would be estimated higher than the original sate. This would therefore be safer due to the fact that measures could be taken to account for these rising trends. Yet the analysing Figure 19b, two features are noticeable. The difference between model and the roman period (2000 BP) is that the difference between the model and the paleo data is not higher than 1m. Yet when looking at the Minoan the model starts to deviate from the paleo data, in total the average variation the model has with the paleo data over the course of 4000 years is -1.5540 [m].
The next analysis between the paleo data and the model is from the Sardinia (case study 2), where the historic data is depicted in red and the model is represented by the blue linear line in Figure 20a. Likewise, the difference between each individual site is portrayed in Figure 20b.

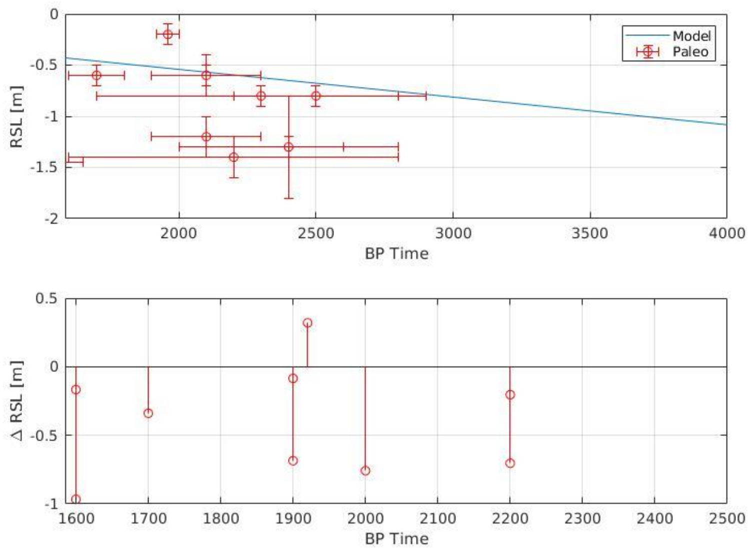

Figure 20Timeseries comparison between Paleo and Model(a), Variation in RSL between paleo and the model (b) for Sardinia

Figure 20a shows that the model seems to match the paleo sites in the time period of the Roman occupation. In comparison with the latter case study, this is already a big improvement. Showing the local dependency of the model, that the results can therefore deviated per region. Even if the Figure 18 showed little difference in the RSL trends over the Mediterranean area. When analysing Figure 20b, the variation is in the order -1 [m] to 0.5 [m] difference. With the smallest difference of 8.54 [mm] and a mean variation of -0.4302 [m]. Showing that even that when the island is located at a tectonic stable region, the model seems to match the data more evenly.
In Table 4 is a summary given of the average results of the Paleo data analysis and the GPS, with the results from the VM6_C model. With the trends of the paleo data, model and GPS in [mm/yr]. Also, the average difference between the paleo data and the model is given in meters. Keep in mind the time period for Crete is longer than Sardinia, due to the higher temporal resolution of case study 1.

Case Study	Paleo trend [mm/yr]	Model trend [mm/yr]	GPS trend [mm/yr]	mean ΔRSL [m]
Crete	0.6173	0.1641	-1.0469	-1.5540
Sardinia	1.297	0.2709	–1.792	-0.4302

Table 4: Comparison between the results of the three methods including the trend of the Paleo, model and GPS, and the mean difference in RSL

The table showed that the difference in trend between the model is 0.4532 [mm/yr] for [mm/yr] for Crete and 1.0261 [mm/yr] for Sardinia, where the model is estimating the rate of change at a lower level than the historic sites. This would be still be beneficial for the climate protection measures, yet these results depict that there is still an error relative to the paleo sites. Furthermore, the GPS trend of the islands are matching the magnitude of the paleo data. Still both islands are seemingly subsiding relative to the respective reference frame. This could be in correspondents with the rising difference between the functional height of the paleo sites and the current sea level. Still this is hard to say, when having only measured the sites at for a brief period in time. Finally, the mean difference in RSL of the model and the paleo data showed that Crete has a higher variation. Whilst the tectonic stable Island of Sardinia had a difference within the meter magnitude. Thus, concluding from these findings, the model presumably is estimating the RSL at a higher level for an island type like Sardinia. Whilst Crete, experienced relative more tectonic movements (i.e. earthquakes), the accurateness is respectively 1.1 m lower than case study 2. Implying that the model estimates the RSL at a higher accurateness at tectonic stable locations, yet the trend at active regions.

4 Discussion

In this analysis one component seemed to have the highest unknown factor, which was the influence of the tectonic parameter on the increasing RSL around the coasts of Crete and Sardinia. As this GPS results showed that both islands are currently subsiding, yet the temporal resolution was relatively low for most of the locations. Therefore, only a small window in time was analysed, rather than on a long-term scale. Especially for the island of Crete, since the tectonic movement was likely not to be linear at this location concluded from the data of Table 2 and Figure 13. The variety of the trends showed that the island spatially is experiencing different rates of vertical motion. Yet when taking this data, an unknown error was accepted in the analysis, as tectonic movement can have a higher impact than the linear trend would suggest. Therefore, small change in the trend can have a big impact on the outcome for this type of movement.

The VM6_C model is in fact the predecessor of the latest ICE-7G_NA, where the parameters have not been updated. Therefore, the outputted RSL data at the different PSML stations, can have included uncertainties that were accounted for in the ICE model. Further the trend was estimated on the current rate of change of the sea level. Which do include the new climate change factors, which could have caused the trend to be higher than the actual rate. Therefore, the assumption that the change was linear could have been wrong. As a small change in the trend can have a major impact on a longer time scale, like the scale used for this analysis.

Also, the model data was not self-generated, hence the influence of different parameters applied in this model remains unknown. Therefore, the strength of the model could not be fully tested including a deduction of the how VM6_C parameters would have responded to the different case studies. Likewise, determining errors that are included with the model were not disclosed for the RSL. Yet the quality of the resulting data was validated with the GRACE satellite missions (Peltier, 2009).

Since the historic sites have been surveyed by other researchers, therefore making a valid assumption of the error budget difficult. As the literature stated the individual error for each site, this cannot be fully accepted when validating the model of Peltier. Since measuring these sites would have being depending on several factors like the weather, number of measurements, state of the individual sites and/or the moment of the tide. Since these sites are being survey relative to the current sea level, which could be alternating for the current tide-level. With the fact that the time of measurements Is not being published by the different studies, making the validation with the functional height and the tide not possible. Also, the amount is relatively low in the temporal spectrum. Since only a minor number of the used sites were in the Roman time period and even less in the Minoan. Only when looking at the whole Mediterranean Sea, numbers could become higher in the temporal spectrum. Yet when analysing the local difference with the model, the thesis had to accept this low distribution, since the spatial would still give a good representation of the island (however on a longer time scale). Also, the sites could have been measured more frequently, instead of the one moment in time. Henceforth the analysis of how the tectonic movement of the paleo site relative to the corresponding GPS data could therefore not be estimated.

5 Conclusion

The research objective for this thesis is to what degree of accurateness is the VM6_C model estimating the relative sea-level during the late Holocene of Sardine and Crete? To support this question, the following three sub-questions were formulated:

What is the influence of the four components of the sea-level equation in Sardinia and Crete?
Evaluating the individual components of the simplified sea level equation was difficult, whilst only using the results from the model and the Paleo data. Especially the Eustatic component and the Glacio/ hydro-static which was not represented by the results. This can also be explained due to the fact that the effect of this component is more or less the same over a small-time span. Likewise, the tectonic component, which was more variable over the periods, showed a significant influence in both islands by the GPS stations and the indirectly by Paleo data. The indirectness of the paleo data is due to historic information that was supplied with the sites in the literature. For instance, Minoan structures have been found relative lower to the current sea level than the functional height of the Roman structures. Indicating the tectonic movement in the Crete are have played a significant role during the time period. Yet, linking both the tectonic movement and the paleo data proved difficult, since the historic information was lacking for accurate knowledge of the functional height relative to the sea level.

What are the current tectonic trends for these locations?
The current tectonic trends were localised by the use of the GPS-stations distributed over the islands. Here the long-term trends were analysed for each individual station and then the average was determined between the maximum and minimum time period. This resulted in a 1.207 [mm/yr] subsidence for Crete, whilst Sardinia experienced a subsidence of 1.792 [mm/yr]. Interestingly showing that Sardinia is subsiding at a higher rate than Crete, even when there is minor tectonic movement at this region. This shows that both islands have the vertical motion direction, however Crete was a factor 2 higher than Sardinia.

To what extend can the archaeological sites at these locations be used for validating the model?
The Archaeological sites can be used for validating the model, still taking into account the error of which this data type is experiencing. Since there are many factors of which the elevation between functional height and the current sea level. Also, there is a subjective part of that can intervenes with the final results. Since the sea level is not a stable height, this influence the final results. Also, determining the functional height can be very different for each surveyor. This can be seen in the Paleo data for both case studies, where some sites had a higher error than i.e. the roman fish tanks on Crete.

Thus, when analysing to what level of accurateness the model can estimate the historic relative sea level, the comparison between the archaeological sites and VM6_C was important. As the variety is depending on the location relative to the tectonic plates and time period of where the paleo sites were built. Since the Roman structures are closer to the model, whilst the Minoan sites on Crete showed a higher difference. The difference between the rate of change is 0.45 [mm/yr] for Crete and for Sardinia is 1.03 [mm/yr]. Yet this contrast between rates, is not shown in the when computing the average difference. Since the Sardinia has an -0.4302 [m] average difference between the model and the paleo data and Crete has -1.550 [mm/yr]. These high variety of differences can be explained by the fact that the sites in Sardinia are more concentrated around the Roman period and had a range of 1.25 [m]. Concluding that the model could estimate the sea level with a higher accuracy in the Sardinia region, whilst the trend is estimated better in the Crete region.

6 Recommendations

For future research using the paleo data, the following recommendations are advised to be taken:

- *Amount of paleo data (spatial and temporal)*
  To get a better understanding of the spatial distribution of the data relative to the current sea level, more sites could be used in future research. Since looking locally at the locations could limited the analysis, knowing that there are more islands/landmass present that can add valuable information about the historic RSL. Likewise, only looking at the Roman (and Minoan) ages of both case studies limited the comparison capability with the model. Yet for instance for Crete the venetian and ottoman structures could also have been utilised for validating the model. Further, when measuring paleo sites, a higher frequency could be beneficial for an understanding of the relation between the tectonic movement and the rate of sea level change. Research studies also showed that the model is not only validated in the Mediterranean area but tested worldwide. Like the coast of Japan of Indonesia has a rich maritime history, having potentially paleo sites usable for this analysis. This would give a better understanding in the validation between the data and the model.

- *Looking at different estimation models*
  For this research only the results of the VM6_C were utilised, yet this a relative older model. The news ICE-7G_NA model is the newest available. The literature already showed promising results from this set, which could indicate that the paleo could be matching relatively better when using different models. This process could show which model is preforming conform to the paleo data and in which order. Even an error analysis of the models can then be made, as comparison can be made to how precise the results are compared to the paleo sites.

- *Generating model data*
  Instead of using data that is already being created by the model (having pre-set parameters) the data could also be self-generated. Then a better understanding of how the model is operating could be determined and also an error deduction could be made. As several parameters can be tested for different outcomes, possibly fitting the paleo data differently. Which can give an intensity in the usefulness of the historic results and even which parameter would be important for the Mediterranean region.

- *Use the GRACE data and tidal stations as an alternative of GPS data*
  Previous research showed that the model was being validated with data acquired by the GRACE satellite mission. This could also be using as an extra data set in the estimating the accurateness of the model in combination with the paleo data. As this would give a better understating of the current gravity anomalies in the regions and can used for estimating a trend. Likewise, the lack of information of tide stations can also be used in estimating the RSL sea level relative to tectonic movement of the locations.

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Appendix 1 Paleo Data Crete

Case study	Location	Latitude	Longitude	Time [BP]	Type	RSL [m]	Error [± m]
Crete_1	Katelli Kissamou	35°30'4.49"	23°38'45.83"	2700 – 1555	Uplifted breakwater constructed by accumulated rubble blocks	2.5 to 4.3	0.3
Crete_2	Kommos	35°00'47.74"	24°45'29.87"	3950	Submerged harbour morphology	-3.95	0.35
Crete_3	Matala bay	34°59'35.55"	24°44'49.81"	1949 – 1750	Eleven submerged carved fish ranks (and traps)	-1.25	0.05
Crete_4	Amnissos	35°19'57.17"	25°12'15.37'	3650	submerged relics of walls of a Minoan villa	-2.57	0.25
Crete_5	Nirou Chani	35°19'58.93"	25°14'38.22"	3650	submerged ruins of Minoan buildings	-2.57	0.25
Crete_6	Nirou Chani	35°20'01.40"	25°14'36.00"	3650	Submerged coastal Minoan quarry	-2.57	0.25
Crete_7	Chersonisos	35°19'11.33"	25°23'31.41"	2017 - 1555	Submerged roman quay	-1.3	0
Crete_8	Chersonisos	35°19'24.09"	25°23'36.23"	1949 – 1750	Submerged fish tank	-1.2	0
Crete_9	Chersonisos	35°19'23.16"	25°23'24.30"	2017 - 1555	submerged relic of walls and a natural breakwater	-1.3	0
Crete_10	Malia	35°17'48.01"	25°29'01.60	3850 - 3400	submerged coastal Minoan quarries	-2.75	0.25
Crete_11	Spiliada	35°18'46.29"	25°31'48.29'	4500 - 4250	Submerged walls of a coastal Minoan settlement	-3.95	0.35
Crete_12	Ierapetra	35°00'44.91"	25°40'29.22"	2017 - 1555	Submerged roman building	-1.25	0.05
Crete_13	Istron	35°07'49.79"	25°43'35.12"	4950 - 3950	submerged ruins of a Minoan settlement	-3.95	0.35
Crete_14	Koutsounari	35°00'30.91"	25°50'03.18"	1949 – 1750	Submerged rock-cut salt pan	-1.25	0.05
Crete_15	Ferma	35°00'40.80"	25°50'30.82"	1949 – 1750	Submerged fish tank	-1.25	0.05
Crete_16	Psira Island	35°11'07.29"	25°51'48.71"	2017 - 1555	Submerged concrete masonry	-1.25	0.05
Crete_17	Mochlos	35°11'09.63"	25°54'20.63"	5600 – 4950	Submerged Minoan settlement	-3.95	0.35
Crete_18	Mochlos	35°11'00.77"	25°54'22.02"	1949 – 1750	Submerged fish tank	-1.25	0.05
Crete_19	Sitia	35°12'37.54"	26°06'31.74"	2017 – 1555	Submerged quarry floor	-1.25	0.05
Crete_20	Sitia	35°11'54.79"	26°07'50.91"	2250 – 1881	Slipway	-1.25	0.05
Crete_21	Farmakokefalo	35°05'57.04'	26°15'52.53"	3550 – 3400	submerged harbour morphology	-2.75	0.25
Crete_22	Farmakokefalo	35°05'52.26"	26°15'40.45"	1949 - 1750	Submerged fish trap	-1.25	0.05
Crete_23	Palaikastro	35°11'48.86"	26°16'43.80"	3850	Submerged ruins of late Minoan walls and structures	-2.75	0.25
Crete_24	Kouremenos	35°12'55.84"	26°16'18.98"	2019 - 1550	Roman breakwater	-1.25	0.05
Crete_25	Agios Isidoros bay	35°18'51.20"	26°18'40.58"	5950	Submerged foundation and parts of columns from temple of the samoio Athena	-1.25	0.05

Appendix 2 Paleo Data Sardinia

Case stduy	Site	Latitude	Longitude	Time [BP]	Type	RSL (m)	Error (± m)
Sardinia_1	S.Antioco	39.07	8.46	2200 - 2400	Functional interpretation of harbour structure	-1.3	0.5
Sardinia _2	Nora	38.98	9.01	1600 - 2200	Functional interpretation of harbour structure	-1.4	0.2
Sardinia _3	Tharros	39.87	8.43	1900 - 2100	Quarry measured at	-0.6	0.1
Sardinia _4	Tharros	39.87	8.43	2200 - 2500	Tomb measured at	-0.8	0.1
Sardinia _5	Capo Malfatano	38.89	8.8	2000 - 2400	Reconstructed top of breakwater	-1.3	0.1
Sardinia _6	Nora	38.98	9.01	1600 - 1700	Church pavement	-0.6	0.1
Sardinia _7	S.Antioco	39.05	8.47	1920 - 1960	Supratidal beach rock	-0.2	0.1
Sardinia _8	Perd'é Sali	39.02	9.02	1700 - 2300	Roman quarry	-0.8	0.1
Sardinia _9	Capo Testa	41.24	9.16	1900 - 2100	Functional interpretation of harbour structure	-1.2	0.2
Sardinia _10	Capo Testa	41.24	9.16	1900 - 2100	Quarry	-0.6	0.2
Sardinia _11	Capo Caccia	40.58	8.15	6710 - 7310	Neolithic burial	-8.0	0.2
Sardinia _12	Olbia	40.92	9.50	1450 - 1550	Wreck in harbour	-1.5	0.2

Appendix 2 Data References

ID case study number	Reference 1	Reference 2
Crete_1	Flemming & Pirazzoli (1981)	
Crete_2	Mourtzas (1988a, 1990)	Shaw (1990, 2006)
Crete_3	Mourtzas (1988a, 1990),	Shaw (1990, 2006)
Crete_4	Blackman and Branigan (1975)	Mourtzas and Marinos (1994), Mourtzas (1990),
Crete_5	Evans (1928), Marinatos (1934), Flemming and Pirazzoli (1981)	Mourtzas (1990) Schafer (1991), present study
Crete_6	Flemming and Pirazzoli (1981)	Mourtzas (1990), Mourtzas (2015)
Crete_7	Flemming and Pirazzoli (1981)	Mourtzas (1990), Mourtzas (2015)
Crete_8	Leatham and Hood (1958), Flemming and Pirazzoli (1981)	Mourtzas (1990, 2012a &b)
Crete_9	Leatham and Hood (1958), Flemming and Pirazzoli (1981)	Mourtzas (1990, 2012a &b)
Crete_10	Leatham and Hood (1958), Flemming and Pirazzoli (1981)	Mourtzas (1990, 2012a &b)
Crete_11		Mourtzas (1990)
Crete_12		Simosi (2003), Mourtzas (2015)
Crete_13	Mourtzas (1988a, 1990)	Mourtzas (2015)
Crete_14		Mourtzas (1990)
Crete_15	Mourtzas (1988a, 1990)	Mourtzas (2015)
Crete_16	Davaras (1975), Flemming and Pirazzoli (1981)	Mourtzas (1990, 2012a, b)
Crete_17	Leatham and Hood (1958/1959)	
Crete_18	Leatham and Hood (1958/1959)	Mourtzas (1990) Soles (2007), Mourtzas (2015)
Crete_19	Leatham and Hood (1958/1959)	Mourtzas (1990, 2012a, b)
Crete_20	Davaras (1974)	Mourtzas (1990, 2012a, b)
Crete_21	Davaras (1974)	Mourtzas (1990, 2012a, b)
Crete_22	Montaggioni et al. (1981), Peters (1985)	Mourtzas (1990)
Crete_23	Nakasis (1987)	Mourtzas (1990, 2012a, b)
Crete_24	Pirazzoli (1980), Flemming and Pirazzoli (1981)	Mourtzas (1990)
Crete_25	Simosi (1988)	Mourtzas (2015)
Crete_26	Spratt (1865), Chalikiopoulos(1903), Papadakis (1989)	Mourtzas (1990)
Sardinia_1	Orrù et al., 2011	Lambeck et al., 2012
Sardinia_2	Antonioli et al., 2007	Lambeck et al., 2012
Sardinia_3	Antonioli et al., 2007	Lambeck et al., 2012
Sardinia_4	Antonioli et al., 2007	Lambeck et al., 2012
Sardinia_5	Antonioli et al., 2007	
Sardinia_6	Antonioli et al., 2007	Lambeck et al., 2012
Sardinia_7	Orrù et al., 2011	Lambeck et al., 2012
Sardinia_8	Antonioli et al., 2007	Lambeck et al., 2012
Sardinia_9	Antonioli et al., 2007	Lambeck et al., 2011

Sardinia_10	Antonioli et al., 2007	Lambeck et al., 2011
Sardinia_11	Antonioli et al., 2012	
Sardinia_12	Porqueddu et al., 2011	