FACULTAD DE CIENCIAS DEL MAR
UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

Preliminary view of the effects of sea level rise in Fuerteventura island

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Academic year 2019/2020

Trabajo Fin de Título para la obtención del título de Graduada en Ciencias del Mar

FINAL DEGREE PROJECT – SIGNATURES SHEET

Title:

Preliminary view of the effects

sea-level rise in Fuerteventura

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ABSTRACT

This document provides a preliminary insight into sea level rise in Fuerteventura. The purpose is to know the affected areas early enough to develop adaptive strategies. Knowing the estimated number of meters for the global increase and the local effects of each area, a balance is made that indicates the sea level for the year 2100. Using a GIS tool, visual information is obtained on the most exposed places. By classifying each study area according to its characteristics, the most appropriate method for its adaptation is decided. Constant monitoring is recommended to minimize uncertainty.

KEY WORDS: sea-level rise, Fuerteventura, coastal impact, coastal planning, adaptative responses.

1. INTRODUCTION

This document summarizes the work carried out to produce the so called Final Degree Project required to obtain the Grade in Marine Sciences at the University of Las Palmas de Gran Canaria (taught in the Faculty of Marine Science).

At the end of university education, the lack of the necessary knowledge and the insecurity in students makes the possibility of being a self-employed worker unthinkable. The main interest of this document is to create the ability in students to become independent in employment, so that they can carry out technical work coordinated with public administration on coastal areas planning, assessment and monitoring. Nowadays, a very important effect in coastal environment planning is climate change and sea level rise.

Climate change is considered a highly relevant process on a global scale but its magnitude is not really known in society, even less outside the scientific field. Currently, the Intergovernmental Panel of Climate Change (IPCC) is the United Nations body for assessing the science related to climate change, providing regular assessment of the scientific basis of climate change, its impacts, future risks and options for mitigation and adaption. The scientific community has incorporated a political summary since is essential that world politicians get to know the problem of climate change. Within all this process of climate change and global warming, sea level rise appears as a very important factor in coastal management as a consequence of various processes that must be understood individually and together to prevent its effects on the coast.

This document consists of a general chapter that explains the relevant processes that make up the existing theoretical foundations, antecedents, projections and response options. The second chapter allows us to know the effects of sea level rise in the study areas selected in this work, specifically, the Island of Fuerteventura (Canary Islands, Spain), using a powerful management tool such as the Geographic Information System (GIS) in a simple manner. Such information is important for public administrations, who can use this to develop adequate responses to sea level rise risks on time.

2. AIMS

It is intended to know which locations on the Island of Fuerteventura (Canary Islands, Spain) can be greatly affected due to sea level rise, such as highly populated tourist locations, crowded beaches, or companies that are an important employment source for local population. Depending on this classification, management measures can be adapted to each location.

3. CHAPTER I: THEORERICAL BACKGROUND

Understanding sea level rise, its origin and repercussions for human beings is related to the importance of coastal areas for Humanity. The current population is concentrated in those regions due to the many options offered by the marine environment, creating pressure in the coastal proximity (Kummu et al., 2016) and causing an impact. Social conflicts may appear, so interest in coastal planning and coastal environment uses should increase (Barragán, 2014). From 1950 to the present, the urbanization rate has experienced unprecedented growth, reaching 2.6% annually (ONU-Habitat, 2009). About 40% of the world population lives in coastal areas (Intergovernmental Oceanographic Commission of UNESCO, 2011). Because of this, a sea level rise can greatly affect coastal populations and their way of life, so assessment and response are essential to reduce risks on time.

3.1 The Representative Concentration Pathways (RCP)

Scenarios help us to understand the changes that would occur on the planet depending on the amount of greenhouse gases emitted, comparing different effects. The set of scenarios was created as a tool to improve knowledge of impact, climate change and to assess risks and vulnerabilities. These are scenarios that cover time series of emissions and concentrations of the full range of greenhouse gases, aerosols and chemically active gases, taking into account the use of land cover (Moss et al., 2010). The scenarios are called Representative Concentration Pathways (RCP). Representative means each RCP is just one of several possible scenarios that would result in such radiative forcing. Pathways emphasizes the importance of the path taken to reach the resulting concentration level. Radiative forcing is the change in net radiative flux in the tropopause due to the change of an external factor to the climate system. It is expressed in watts per square meter (W/m^2). If the radiative forcing is positive, there will be a warming and if it is negative, there will be a cooling of the climate system (AEMET, 2018). These scenarios help identify the range of different technological, socio-economic and political futures that could lead to a particular path of concentration and the magnitude of climate change. The projections of the concentrations up to the year 2100 have been modeled (Fig. 1), identified by the approximate radiative forcing (RF) for the year 2100 with respect to 1750, which is considered to be comprised in a range between 2.6 and 8.5 W/m^2 (these are merely indicative values). For the RCP 2.6, it reaches a maximum and then decreases as the effects of emission reduction policies that limit the global warming to 2ºC are interacted. If RCP is 4.5 then it stabilizes towards 2100. In the case of the RCP it would be 6.0 or 8.5, they are referring to an RF of 8.5 W/m^2 for 2100, but that implies an increasing RF beyond that year (Moss et al., 2010).

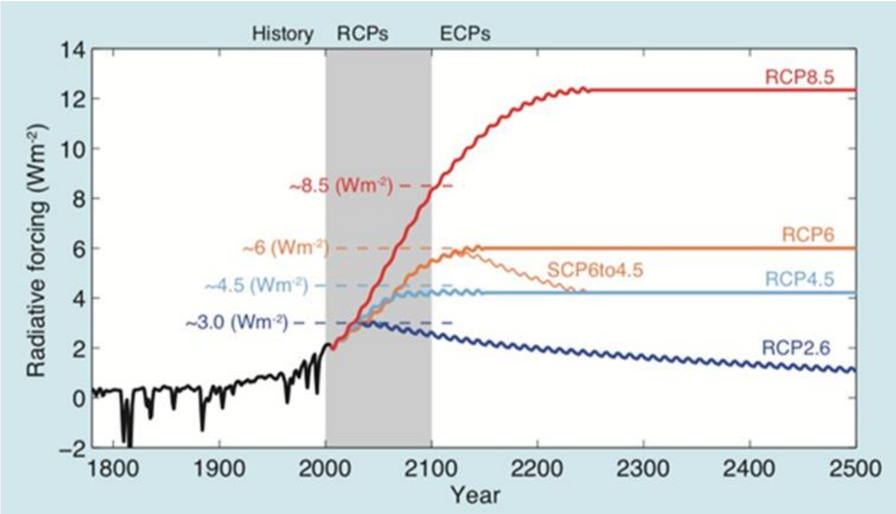


Figure 1 *Total RF (anthropogenic plus natural) for RCPs and extended concentration pathways (ECP) as well as a supplementary extension RCP6 to 4.5 with an adjustment of emissions after 2100 to reach RCP4.5 concentration levels in 2250 and thereafter. Short-term variations in RF are due to both volcanic forcings in the past (1800–2000) and cyclical solar forcing assuming a constant 11-year solar cycle, except at times of stabilization. (Source: Intergovernmental Panel on Climate Change (IPCC), 2013; Reproduced from Meinshausen et al., 2011).*

These scenarios are directly related to sea level rise (Fig. 2) since the different pathways cause changes in the temperature of the water bodies.

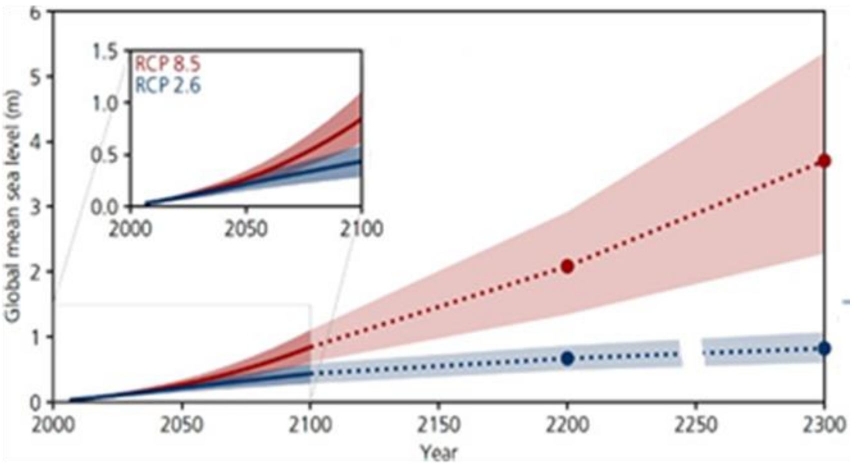


Figure 2 *Projected sea level rise up to 2300. The inset shows an assessment of the likely range of the projections for RCOP 2.6 and RCP 8.5 up to 2100. Projections for longer time scales are highly uncertain. (Source: modified from of Oppenhaeimer et al., 2019).*

3.2 Processes of Sea Level Change

To understand the sea level rise (SLR) induced by climate change, two important aspects of sea level must be taken into account (Fig. 3):

I. The Global Mean Sea Level (GMSL) is caused by an increase in ocean water mass due to the decrease in land ice masses and to thermal expansion produced by the increase in temperature. However, the SRL effects are very important and they are based on the Relative Sea Level (RSL) in a specific location. The SRL undergoes variations due to climate and local factors such as anthropogenic sinking.

II. This gradual change in sea level can be combined with Extreme Sea Level (ESL) events such as tides, surges and waves causing coastal impacts. ESLs on the coast that are rare today will be common in the future and should therefore be considered for coastal planning and decision making.

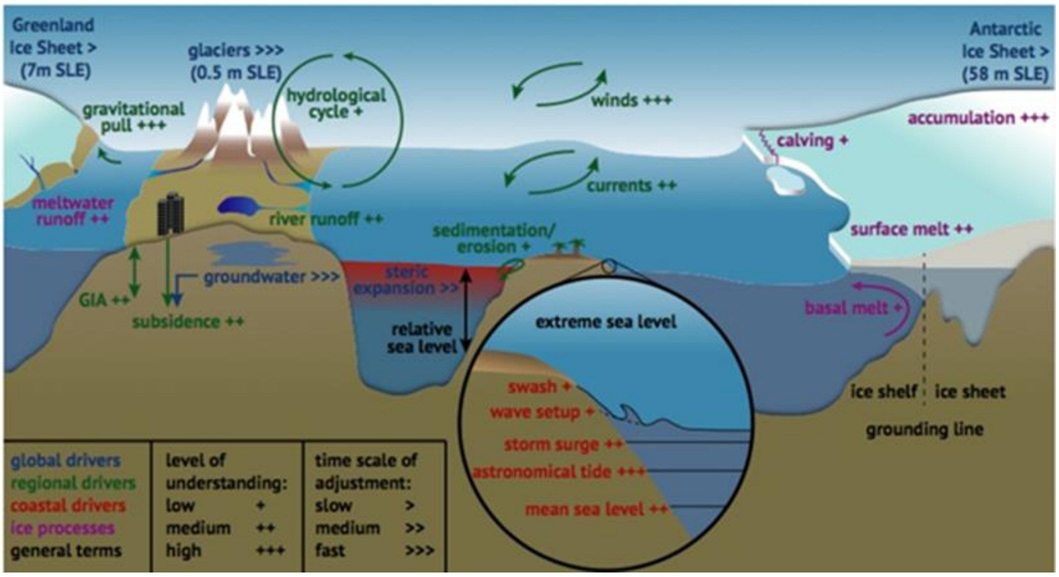


Figure 3 *A schematic illustration of the climate and non-climate driven processes. that can influence global, regional (green colours), relative and extreme sea level events (red colors) along coasts. Major ice processes are shown in purple and general terms in black. SLE stands for Sea Level Equivalent and reflects the increase in GMSL if the mentioned icemass is melted completely and added to the ocean. (Source: Oppenheimer et al., 2019).*

3.3 Sea Level Rise impacts

The impacts of mean and extreme sea level rise include:

i. Permanent submergence of land by higher mean sea levels or higher mean high waters.
ii. Greater frequency and intensity of coastal floods.
iii. Greater coastal erosion.
iv. Loss and change of coastal ecosystems.
v. Salinization of soils, underground and surface waters.
vi. Drainage impeded.

The impacts of sea level rise come from the interaction between both climatic and non-climatic drivers since various biogeophysical effects (Table 1) are involved (Nicholls & Klein, 2005)

Table I *Most significant bio-geophysycal effects of sea level rise including relevant interacting climate and non climate stresses (source: European Environment Agency,2019. modificated of Nicholls y Klein, 2005)*

Bio-geophysical effect		Other relevant factors	
		Climate	Non-climate
Permanent inundation		Sea level rise	Vertical land movement (uplift and subsidence), land use and land planning
Flooding and storm damage	Surge (open coast)	Wave and storm climate, morphological change, sediment supply	Sediment supply, flood management, morphological change, land claim
	Backwater effect (river)	Run-off	Catchment management and land use
Wetland loss (and change)		CO_2 fertilisation, sediment supply	Sediment supply, migration space, direct destruction
Erosion	Direct effect (open coast)	Sediment supply, wave and storm climate	Sediment supply
	Indirect effect (near inlets)		
Saltwater Intrusion	Surface waters	Run-off	Catchment management and land use
	Groundwater	Rainfall	Land use, aquifer use
Rising water tables/impeded drainage		Rainfall	Land use, aquifer use

3.4 Historical trends

Sea level variation can be measured using tide gauges and tide gauge measurements or from space using satellite altimeters. The tide gauge results can be influenced by local and regional effects, such as the vertical movements of plate tectonics. There are time series of decades in some cases exceeding 100 years. Satellite data makes it possible to measure an absolute sea level but the duration of the existing record is only 25 years (Fig. 4.) The GMSL reconstructions carried out based on tide gauge data indicate an increase of 16 ± 4 cm between 1902 and 2015 but its speed does not remain constant on a time scale.

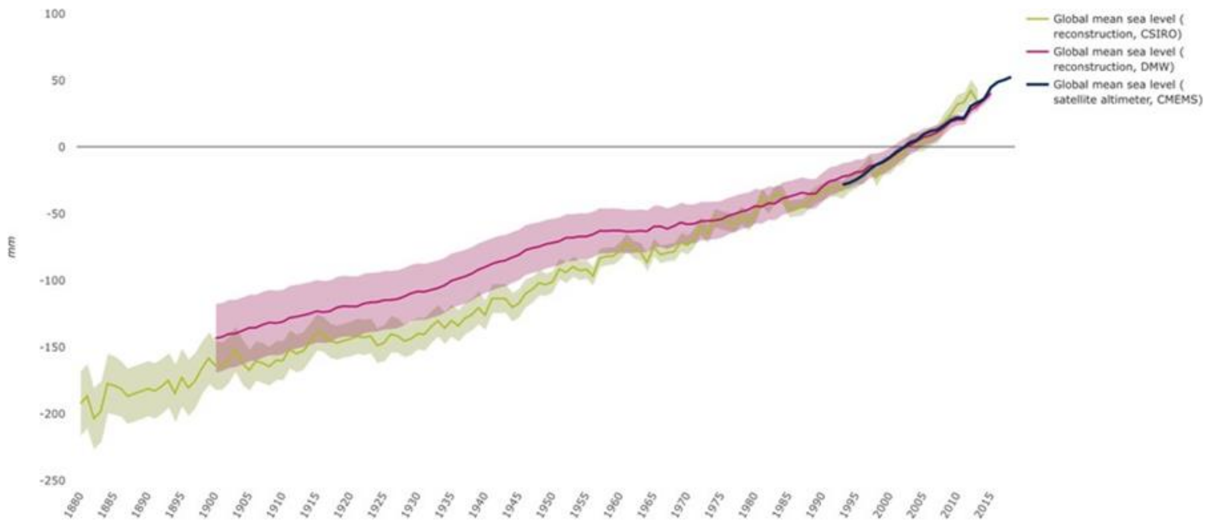


Figure 4 *. The figure depicts the rise in global mean sea level from 1880 to 2018. based on three sources. The green line (CSIRO) shows a reconstruction for 1880 to 2013 from coastal and island tide gauge data (updated from Church and White, 2011). The red line (DMW) shows a more recent reconstruction for 1900 to 2015 (Dangendorf et al., 2019). The uncertainty intervals around these lines are shaded. The dark blue line (CMEMS) shows a time series between 1993 and 2018 based on satellite altimetry data (Source: European Environment Agency, 2019)*

The average trend of the rate of increase of GMSL during the period 1901-1990 was 1.4 ± 0.6 mm / year. During the period 1993-2018 it has been around 3.3 mm / year, which indicates twice the rate of increase than the previous period. In the current period, 2014 - 2019, recorded by satellite altimeters, it has been observed that the rate of GMSL has increased to 5 mm / year (WMO, 2019)

3.5 Future Sea Level Rise trends

Sea level rise will not be uniform in all regions and will depend on the route of carbon dioxide emissions and not only on the accumulated total.

During the last century, a sea level rise of 1-2 mm / year was observed in most regions, while rates of 3-4 mm / year are now observed. According to RCP 2.6 they will continue to increase to up to 4-9 mm / year. If we take into account the RCP 8.5, the increase would be 10-20 mm / year by the end of this century (Oppenheimer et al., 2019). However, until 2050, future sea level uncertainty driven by climate change is relatively small, providing a solid basis for short-term planning (30-year) adaptations. The global mean sea level will increase about 0.24 m (0.17-0.32 m, biing the most probable range) under the RCP 8.5 scenario (Table II).

***Table II** The magnitude of climate change is affected depending on the emission scenarios. (Source: IPCC, 2014)*

		2046–2065		2081–2100	
	Scenario	Mean	*Likely* range [c]	Mean	*Likely* range [c]
Global Mean Surface Temperature Change (°C) [a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	Mean	*Likely* range [d]	Mean	*Likely* range [d]
Global Mean Sea Level Rise (m) [b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

In the case of Antarctic layer collapse, the GMSL would greatly exceed the range projected for the 21st century, so it is suggested not to rule out an increase in the GMSL of two or more meters (Bamber et al., 2019). Sea levels will continue to rise well beyond 2100 due to the loss of ice in Antarctica and Greenland. For a RCP 8.5 scenario, a GSML increase of 2.3-5.4 m is forecast for 2300. These forecasts would increase sea level due to the contribution of Antarctic ice in the coming centuries (Oppenheimer et al., 2019).

Every five years that global greenhouse gas emissions are not reduced, mean estimates of sea level a rise of 0.2-1 m for the year 2300 is considered (Mengel et al., 2018).

3.6 Relative Sea-Level Change (RSCL)

The SRL varies depending on the location and scale, so in addition to the increase in GMSL, it must be taken into account that variations in sea levels at the local scale (of the order of 10 km) are influenced by various factors that can be regional scale (of the order of 100 km) or global. Examples would be changes in ocean circulation, postglacial rebound after decay of land ice, uneven changes in ocean density or local factors such as vertical movement of tectonic plates (Konrad et al., 2013) However, an average local change in sea level is expected to be around 20% of the value of the change in the GMSL, which is projected for 70% of the world coasts (Church et al., 2013).

3.7 Extreme Sea Level events (ESL)

Extreme events such as storm surges, along with high SLR, are worrisome as they can contribute significantly to flood risks (Little et al., 2015). To understand the impact of these processes it requires a detailed knowledge of bathymetry, erosion, sedimentation and all the factors involved in hydrodynamic models. Due to the Global Mean Sea-Level RISE (GMSLR), ESLs that are historically rare (such as Historic Centennial Events, HCEs) will become common by 2100 in all RCPs (IPCC, 2019) (Fig. 5). Many low-lying cities and flat islands will experience such events in 2050. The height of an HCE varies widely and depending on the level of exposure can cause severe impacts that will continue to increase with a higher frequency of HCEs.

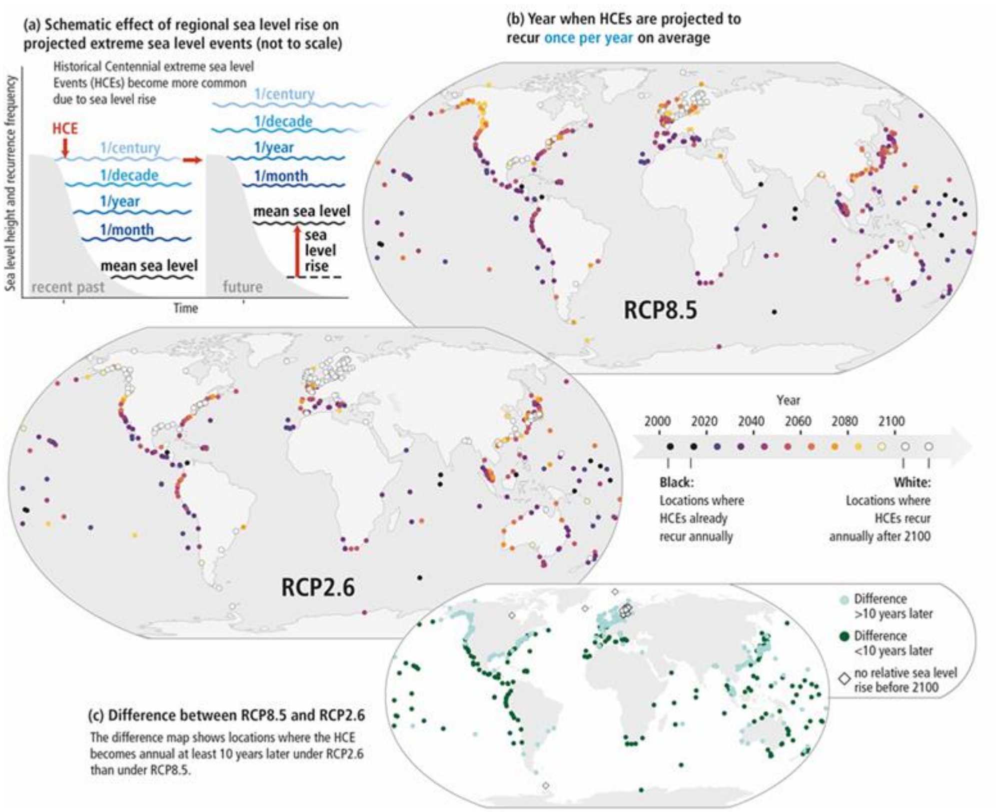


Figure 5 *The effect of regional sea level rise on extreme sea level events at coastal locations. (a) Schematic illustration of extreme sea level events and their average recurrence in the recent past (1986–2005) and the future. Because of mean sea level rise, HCEs are projected to recur more frequently in the future. (b) The year in which HCEs are expected to recur once per year on average under RCP8.5 and RCP2.6. The darker the circle, the earlier this transition is expected. (c) An indication at which locations this transition of HCEs to annual events is projected to occur more than 10 years later under RCP2.6 compared to RCP8.5. (Source: IPCC, 2019)*

3.8 Estimated damages due to sea level rise floods

It must be taken into account that coastal and river floods follow different hydrological mechanisms, in addition to the uncertainty generated by the projection of certain climatic and socioeconomic conditions.

Combining different information on urban areas, Gross Domestic Product (GDP) and population density, the damage caused by the floods has been assessed. In 2010 it has been estimated that the European population living in the 100-year flood area is almost 6%. Without defenses, the economic loss would be € 236 billion. If flood protection is used, damage would be reduced by 67 to 99% and the number of people flooded is reduced by 37 to 99% (Mokrech et al., 2014)

As for the exploration of scenarios on sea level rise of 0.25, 0.5, 1.00, 1.50 and 2.00 m, an increase in the number of people within the flood zones is expected, reaching even 22.9 million people and € 318 billion in economic damage in scenarios of 2m sea level rise. Flood protection at the minimum and maximum levels provides similar benefits.

3.9 Possible responses

You can react to sea level rise in various ways depending on the conditions of the area and the estimated projection. Most islands, coasts, and low-lying communities face considerable risk if adaptation strategies are not developed. This is independent of their level of development, whether continental or insular, at any latitude, on a time scale of a century. At the same time, coastal protection is very effective and profitable for cities, but not for less densely populated rural areas.

In response to rising sea levels, exposure, vulnerability and risks in low-lying coastal areas should be reduced. They are mainly addressed in five different ways.

1) Protection: It consists of reducing the impact and the coastal risk by blocking the spread inland, including:

i. Tough protection such as levees, barriers, breakwaters, and dams to protect against saltwater intrusion, flooding, and erosion (Nicholls, 2018)
ii. Protection with soft structures, based on feeding beaches and coasts with sediments.
iii. Ecosystem-based adaptation.

These three subcategories combine to form hybrid measures. Examples are a green swamp belt in front of a boardwalk, or a boardwalk specially designed to include niches for habitat formation (Coombes et al., 2015).

2) Advance: It is about gaining ground in the sea, reducing coastal risks. This includes: pumping backfill material, planting vegetation that supports natural soil accumulation, protecting surrounding low-lying areas with levees, polderization requires drainage and often pumping systems (Wang et al., 2014).

3) Ecosystem adaptation: (EBa) combination of protection and progress. It is a combination of benefits combining protection and advancement; and based on sustainable management, conservation and restoration of ecosystems (Van Wesenbeeck et al., 2017).

Coastal ecosystems such as wetlands and reefs are conserved or restored. The protection of the coast would be:

i. wave attenuation and, in the case of storm surge, acting as obstacles and providing retention space (Zhang et al., 2012; Vuik et al., 2015; Rupprecht et al., 2017).
ii. Features and solutions based on nature, ecological engineering, ecosystem-based disaster risk reduction or green infrastructure are included (Bridges, 2015) by increasing elevation, reducing erosion by capturing and stabilizing coastal sediments, and promoting the accumulation of organic matter and debris (Spalding et al., 2014).

4) Accommodate: set of biophysical responses, lifting buildings, cultivating salt tolerant species, early warning systems for ESL.

It consists of lifting valuable objects such as houses and floating gardens (Trang, 2016). Land uses would vary by cultivating salinity tolerant species in the intrusion zones. Institutional management would involve early warning systems, emergency planning, insurance schemes, and setback zones (Wong et al., 2014).

5) Retreat: Human activity is removed from the coastal area, thus reducing the risk. There are three possibilities

i. Migration, when the movement is voluntary and permanent or semi-permanent (Adger et al., 2014).

ii. Displacement is about unforeseen and involuntary movement caused by environmental factors or political or military disturbances (Islam and Khan, 2018).

iii. Relocation, or resettlement, is initiated, supervised, and implemented by governments at the national to local levels and generally involves small sites and / or communities (Wong et al., 2014; Hino et al., 2017).

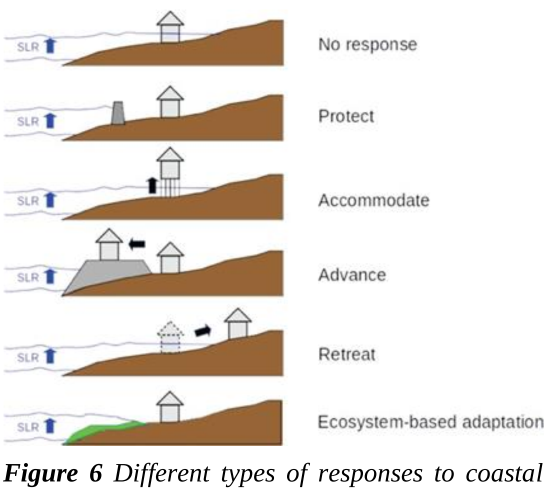


Figure 6 *Different types of responses to coastal risk and SLR. (Source: Oppenheimer et al., 2019)*

The need for these response measures can be reduced by avoiding development in areas prone to serious risks of SLR

Each answer carries specific characteristics with both advantages and disadvantages. Synergy achieves an integrated and sequenced response to SLR.

Sea level rise is a very complex process, which is made up of numerous variables (Fig. 7). Designing a suitable combination of responses is a political choice in addition to technical work; where the set of values, goals and interests must be taken into account, and it is acted on the local scale since each region offers different peculiarities.

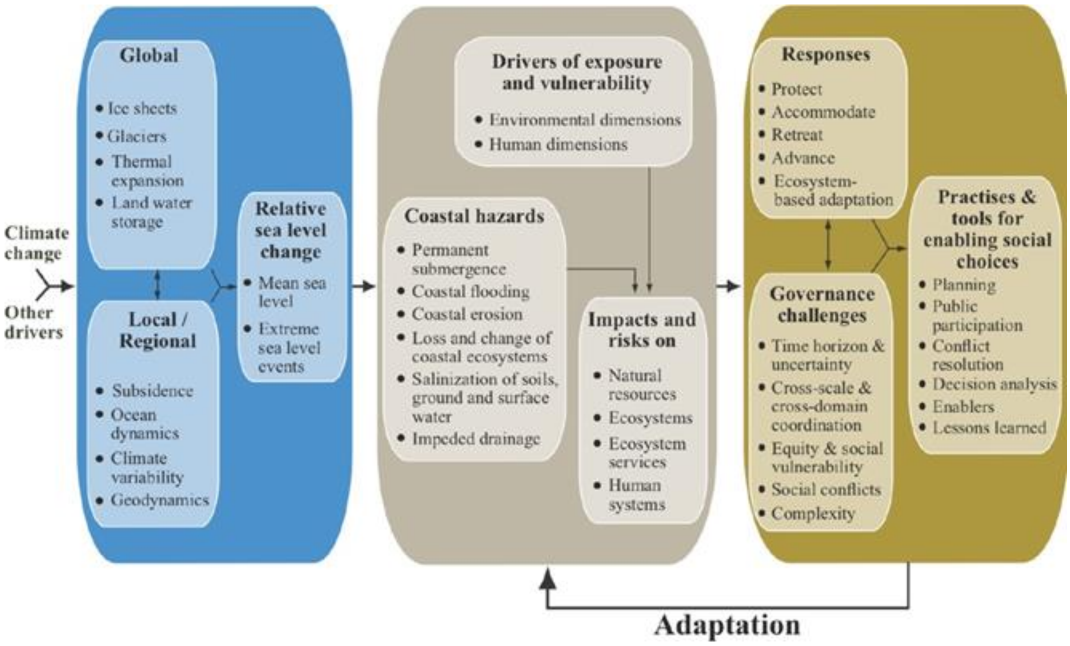


Figure 7 *Diagram of the interconnectedness of SLR-related issues, including sea level drivers and hazards (extremes), exposure, vulnerability, impacts and risks related to sea level rise, associated government responses and challenges.   (Source: Oppenheimer et al., 2019)*

4. CHAPTER II. INTERVENTION AT STUDY LOCATIONS.

The methodology used focuses on creating an estimate that can be simply applied to various areas of Fuerteventura, generating an image that will inform the future reach of sea level in the analyzed area. The purpose of these images is to show the land-sea contact areas where a response measure must be used to avoid damage.

4.1 Study locations

The island of Fuerteventura belongs to the Canary Islands archipelago, specifically to the province of Las Palmas. Located in the Atlantic Ocean and approximately 100 km from the northwest coast of Africa. Since 2009 it has been declared in its entirety as a Biosphere Reserve by UNESCO. The number of inhabitants registered in 2019 is 116,886 (ISTAC, 2019).

The areas studied throughout the island (Fig. 8) have been selected for various reasons:

Corralejo Viejo, Punta Elena, Puerto Lajas and Gran Tarajal have homes close to the sea and busy beaches

Hotels are a source of income for a large number of workers.

El Jablito, has houses located on the beach and there is controversy between the population and a corporate promoter.

El Cotillo (La Concha beach) is an example of a place with high tourist interest.

UNELCO is the energy source of the entire island.

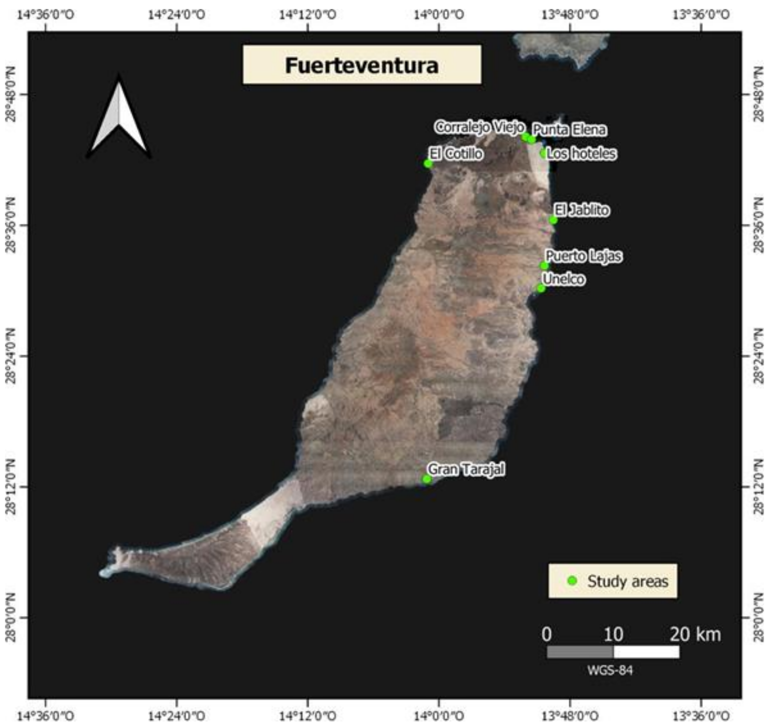


Figure 8 *Location of study areas in Fuerteventura*

4.2 Methodology

The SLR is made up of a set of contributions of diverse origin (Fig. 9), (1) that are grouped into global and relative as they depend on the characteristics of a specific location. The GMSL has followed trends and different projections called RCP (2) that have been made to differ from each other according to the amount of gases emitted into the atmosphere. As for the global increase, its main sources are thermal expansion and the various contributions caused by thawing. The relative increase is mainly influenced by the vertical movements of the Earth's crust and extreme events. Adding the data of the global increase plus the regional (3), the estimated amount of SLR for the specific area is obtained. By adding this data to the current sea level, maps can be produced that provide a preliminary idea of the future situation. Through the images, the affected areas are detected in the future and, according to their type of use, a response type is selected to manage the coastline.

In short, the aim is to apply the data and estimates obtained to a DTM on the island of Fuerteventura, in order to visually know the scope and effects of sea level rise caused by climate change. To carry out this process, first the data to be used to project the increase is selected, and then it is applied using a Digital Terrain Model.

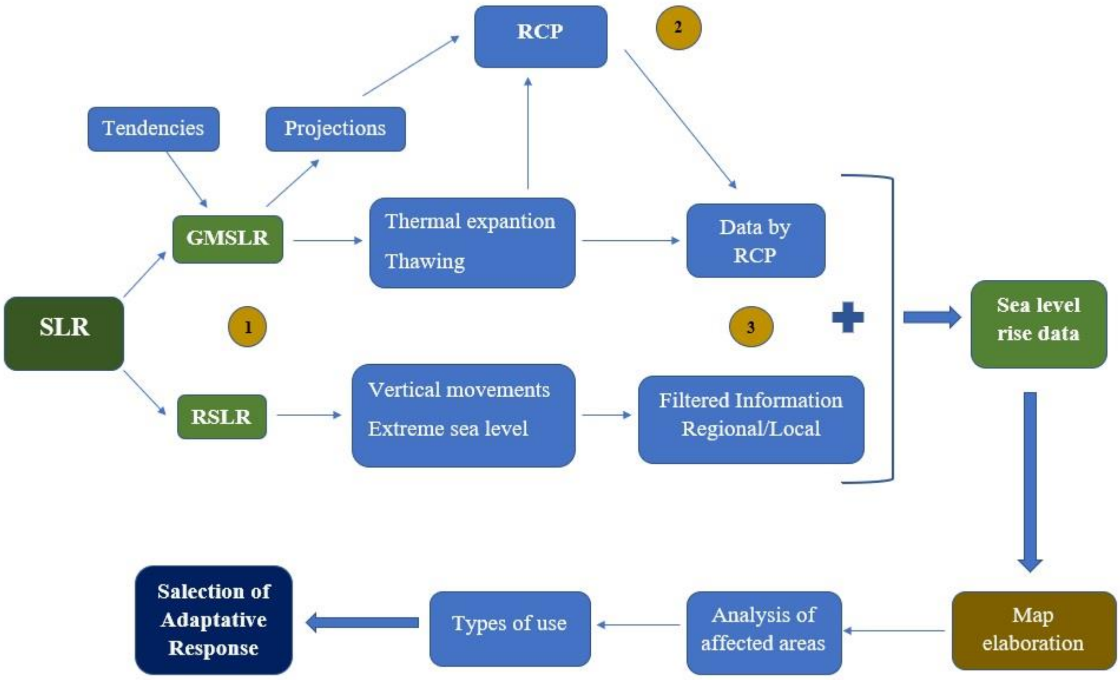


Figure 9 *Diagram of the developed methodology*

4.2.1 Data selection

1. Regarding GMSL: Since it is about preventing damage, the worst-case scenario data (RCP8.5) is used, the probable range is 0.61-1.10 m for the year 2100.

2. About RSLR: Vertical movements are neglected since the island of Fuerteventura remains stable (Zazo et al., 2012). Regarding extreme events, Puertos del Estado provides information about the highest high water and waves that it has recorded (Puertos, 2010). It should be taken into account according to Figure 5, that in the Canary archipelago it is estimated that extreme ESL events that are historically rare (HCE) will have an annual frequency around the year 2030.

3. It must be taken into account that the sea level zero given by the DTM and the data provided by state ports are different, so a conversion is necessary to use said data or take it directly from the tide gauge file.

4. Regarding the waves, they are not represented by the GIS because it would extend the flooded area in its depth, slightly increasing its area. As sea level rise is a prolonged process in time, the effect of erosion will change the coastline and its bathymetry, therefore also its waves. Knowing the contact area where the flood will start, the direction of the predominant waves and the highest wave height registered, the defense can be adapted to the wave height from which it is desired to protect (Sekimoto, 2013)

4.2.1.1Tide gauge data

According to the tide gauge information (Annex II) provided by Puertos del Estado, the relationship between the mean sea level in Fuerteventura (NMMF) and the REDMAR zero referred to the port is -1.49 m. This means that the data and figures provided by the tide gauge must be adapted to the NMMF average level by subtracting that amount. (Puertos, 2020)

Figure A of Annex III shows that approximately 94% of cases sea level does not exceed 1 m, and when it does it reaches 1.31 m in 5% of cases, with which this reference can be taken as a current level.

Regarding figure B, it is observed that the maximum recorded sea level was 1.7 m and it occurred in September 2006, due to astronomical tides.

Regarding the waves (Fig. C, Annex III), the direction of provenance is mostly NE with some variation of provenance E in its majority. The significant wave height (Hs) does not exceed 1.5 m in more than 90% of cases, nor 2 m in 98% according to figure D of Annex III.

4.2.2 Air maps elaboration

From the QGIS software, data on terrain elevations are processed, and focusing on some affected areas of the island,

Given that the time horizon is uncertain, an increase of one meter above sea level is used to minimize the error, since it is estimated that around the year 2100 this amount could rise.

A DTM with a 2-meter mesh pass is used given the scale of the maps to be represented. It has been obtained on the website of the Centro de Descargas del centro Nacional de Información Geográfica (CNIG, 2020). The DTM provides terrain information in three dimensions, so the height of any point can be known. Carrying out an extraction of the contour lines of the terrain, it is possible to know the location of a specific height, therefore to know the areas where height is 1m, simply follow its contour line. The contour lines are created 1m apart. In order not to confuse the values of the curves, the label is placed with the height value of each line.

The next step is to create a linear file in which the lines referring to sea level are drawn:

- The 1 m elevation is taken as the current level given the tide gauge data (Fig. A, Annex III) as discussed in the previous section.
- The 2 m elevation is taken as an increase of 1 m above sea level.
- The 3 m elevation is taken as a 2 m rise in sea level

To correctly create the lines taking into account the characteristics of the terrain, an orthophoto from the Canary Islands, generated in the services of the Canary Islands Spatial Data Infrastructure website, is used as support.

The physical elements that would protrude from the water with rising sea levels have been outlined, as have the localized rocks.

4.3 Results from the study locations

4.3.1Corralejo Viejo

• Increase of 1 m: part of the E coast of the town of Corralejo is affected by the loss of a beach of great tourist interest since they are located very close to the urban nucleus. Some homes and accommodations are affected by their proximity to the sea by contacting the water at high tide. (Fig. 10)

• 2 m increase: several houses are seriously affected by contact with water, and in some parts immersed. The beach area is reduced to a minimum and is practically non-existent.

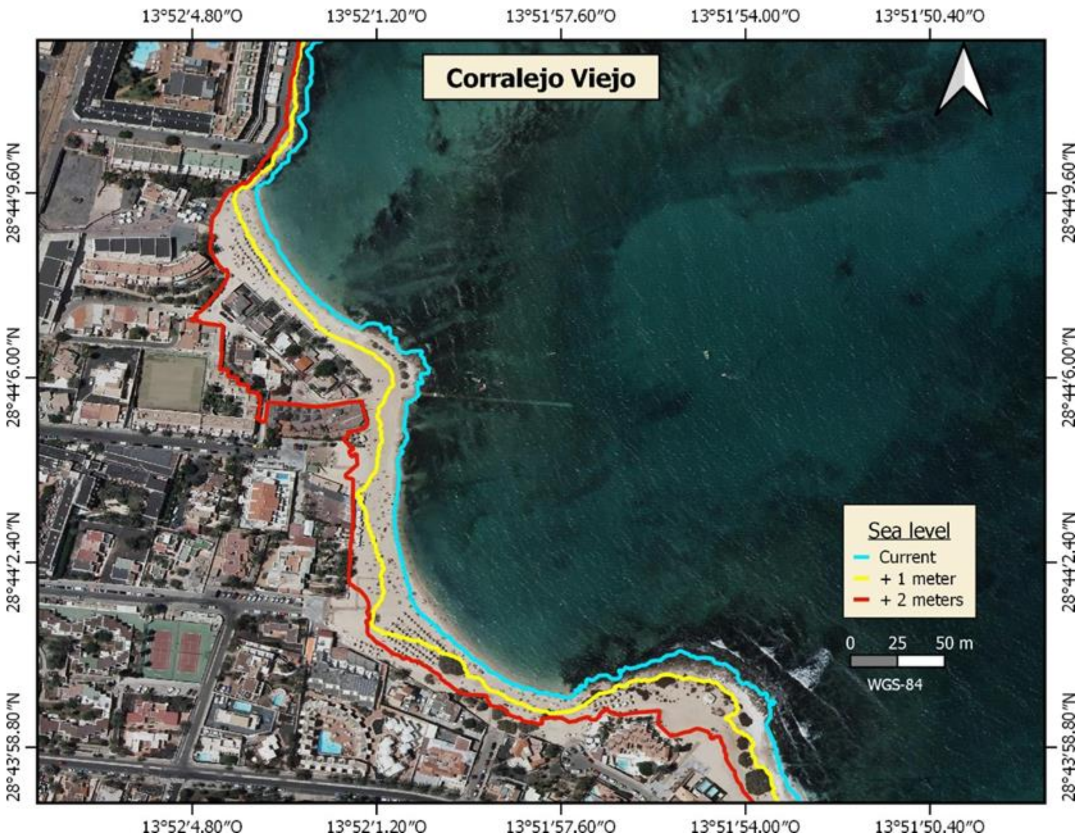


Figure 10 *Sea level projection in Corralejo Viejo*

4.3.2 La Concha (El Cotillo)

Currently on this beach there is already an area immersed in high tide that is popularly called "El Charquito" (Fig. 11)

• Increase of 1 m: the sea level extends to reach part of the car parks, approaching two groups of houses and the beach bar. "The puddle" is lost in its entirety, leaving some higher areas forming emerged mounds.

• 2 m rise: Several houses and the bar are in direct contact with the water, and a puddle is even formed that directly contacts another group of houses. The parking area is submerged, leaving the water right next to the road that leads to the other beaches.

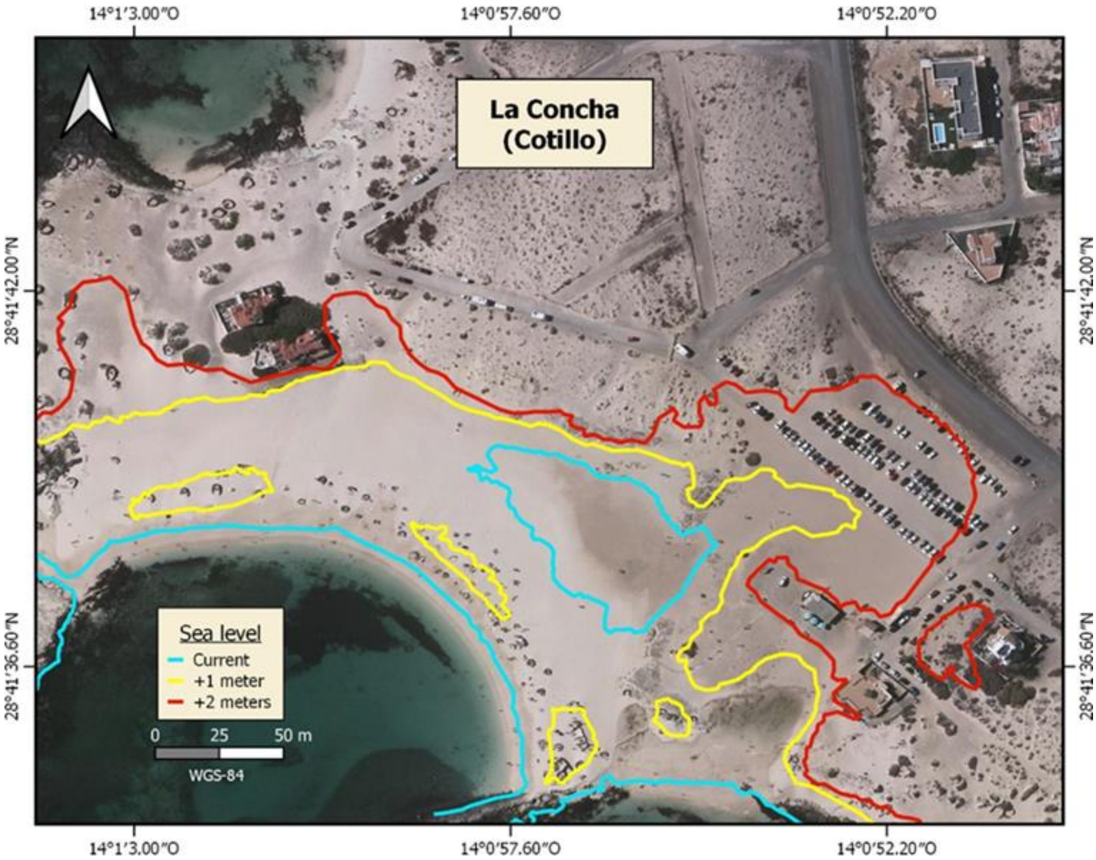


Figure 11 *Sea level projection in La Concha beach*

4.3.3 El Jablito

It is a small population built mostly illegally, except for a few cases, prior to the Coastal Law. The use of the houses is mainly as a second residence, vacation or weekend use only, although there is also a small stable population (Fig. 12)

There is controversy in this area since a marina has been planned for several years, but its construction could not be carried out due to the population's refusal. Such has been the altercation, that house demolishing has been caused by the developer in order to reduce the town, which are being rebuilt by the inhabitants.

• Increase of 1 meter: The water has contact with several houses located on the first line of the coast, and surrounds the small site created by the neighbors as a cultural center.

• Increase of 2 meters: the extension of land that protects the beach is almost completely immersed, more than half of the houses are affected by contact with water, several of them being completely surrounded.

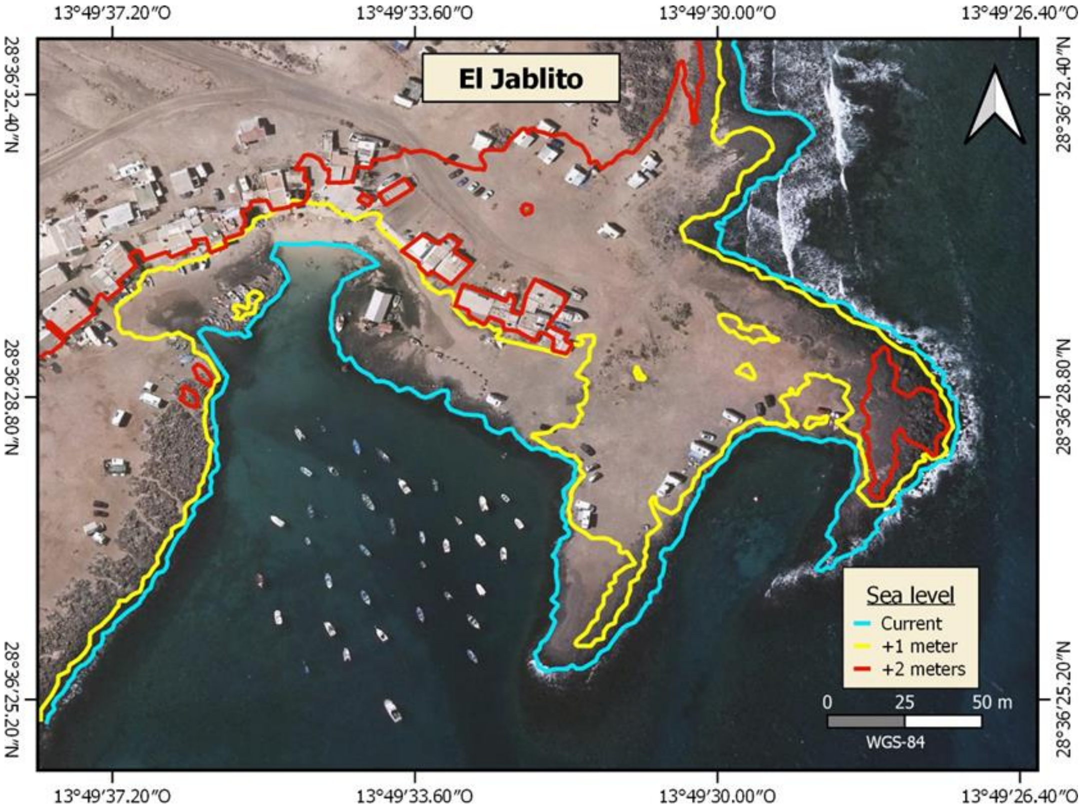


Figure 12 *Sea level projection in El Jablito*

4.3.4 Gran Tarajal

Currently the Barranco de Gran Tarajal has an exit on this beach (Fig. 13), the course of which has been modified as the town has developed. In the area there is an aquifer that floods the basements of the buildings.

• Increase of 1 m: The sea directly contacts the wall of the promenade, the beach area disappearing in its entirety and the old facilities of a Pub that are currently closed are affected.

• Increase of 2 m: many homes and facilities are affected, some are located far from the coastline, but when they are on low-grade terrain, they are affected. The ravine is also affected.

It would be necessary to take into account the sediments contributed by the ravine, which could act as a protective barrier against the rise of the sea.

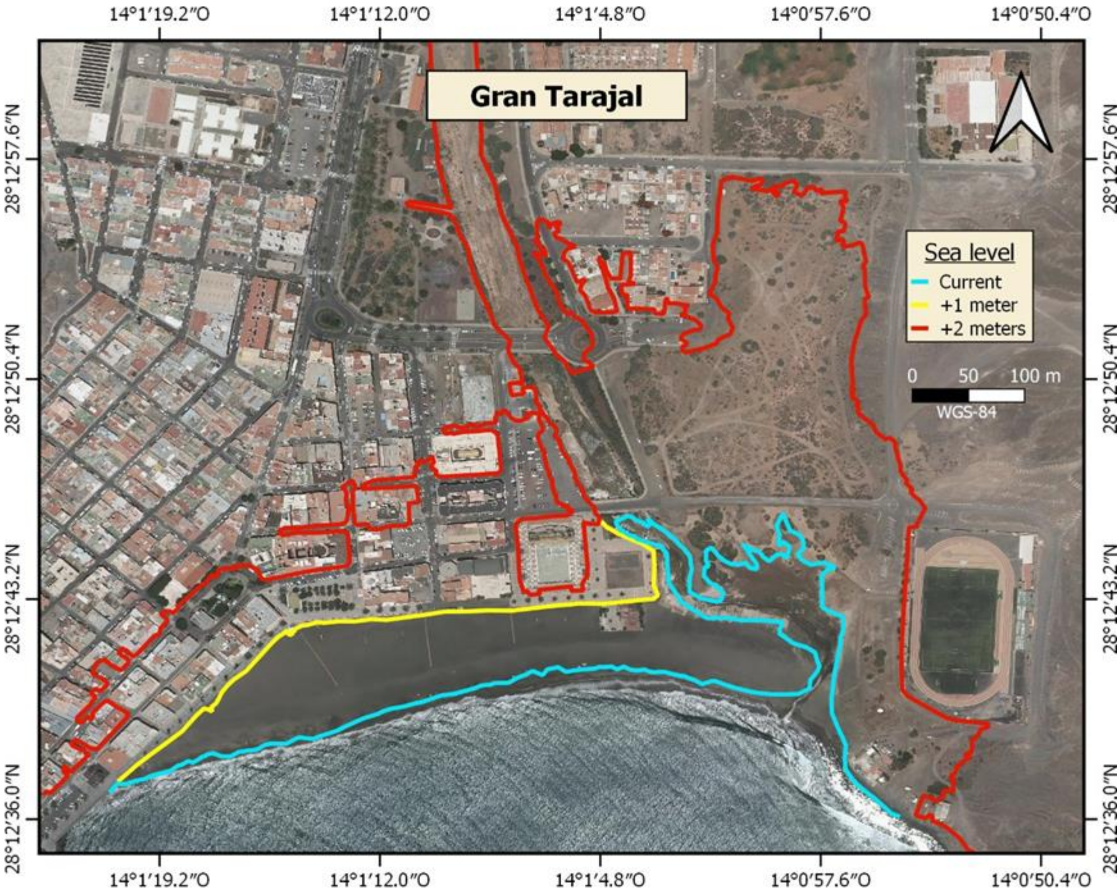


Figure 13 *Seal level projection in Gran Tarajal*

4.3.5 Puerto Lajas

• Increase of 1 m: It has few effects, (Fig. 14) mainly the contact with some houses that were originally created next to the sea to carry out the loading of merchandise on boats since historically this town was dedicated to the agriculture and the export of lime.

• Increase of 2 m: The beach area is lost in its entirety and the facilities closest to the sea, various premises dedicated to hotels, several homes and the yacht club are affected.

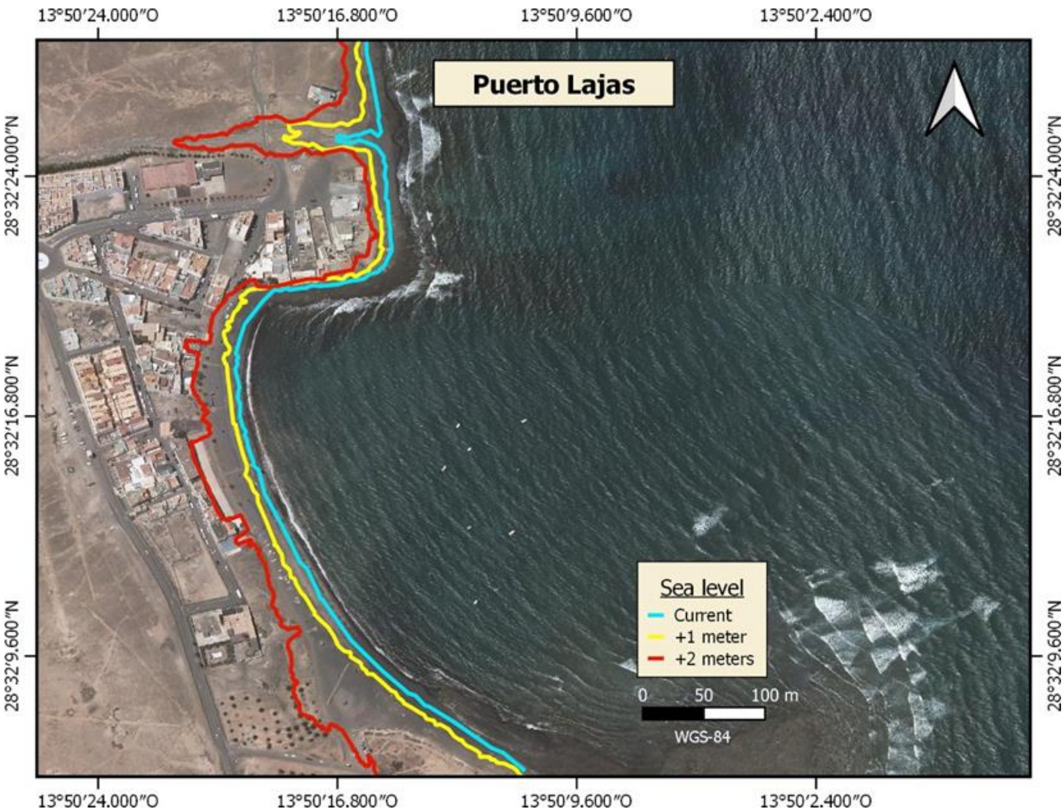


Figure 14 *Sea level projection in Puerto Lajas*

4.3.6 The Hotels

The so-called area and beach of "Los Hoteles" is located in the "Dunas de Corralejo Natural Park" and it is an area of great tourist and environmental interest. Currently a puddle forms at high tide next to the Riu Oliva Beach hotel (Fig.15)

• Increase of 1 m: The coast is hardly affected, the water can reach some of the hammock sector. The puddle produced by infiltration considerably increases its size by contacting the hotel wall and public toilets.

• 2m increase: Loss of the current beach area, the hotel is greatly affected along with the access road and parking. The rescue facilities and the adjoining tennis court are also affected.

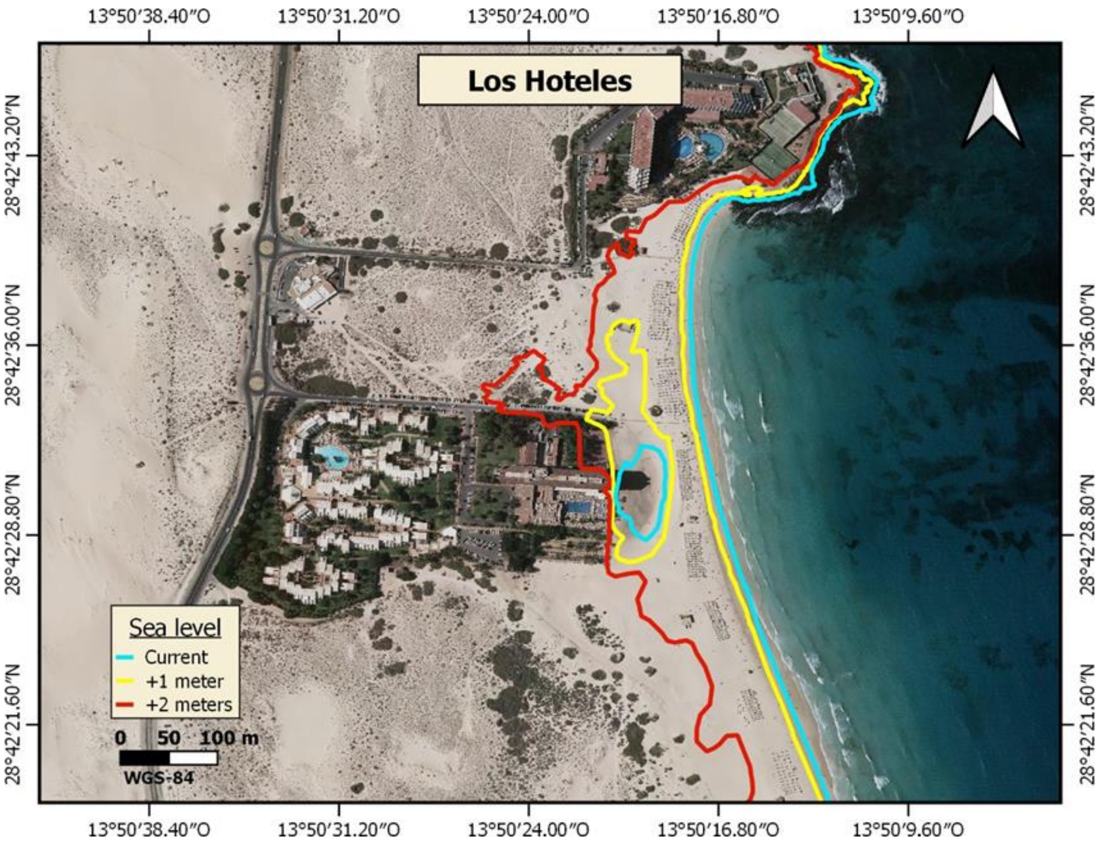


Figure 15 *Sea level projection in Los Hoteles*

4.3.7 Punta Elena (Corralejo)

• Increase of 1 m: The Punta Elena beach area is mostly flooded by contacting the water with some walls that surround houses (Fig 16). The rest of the coastline is hardly affected.

• Increase of 2 m: Numerous houses, shops, tourist accommodations and streets are directly affected, being completely surrounded by water.

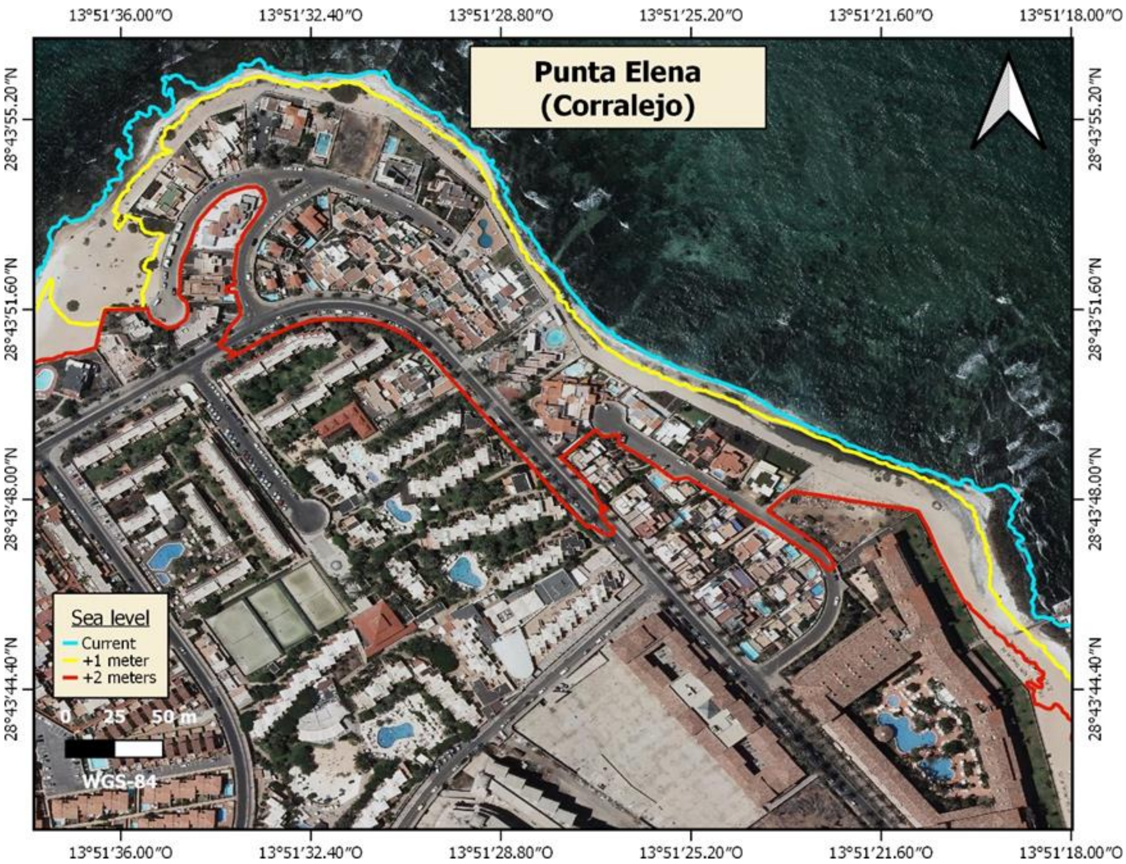


Figure 16 *Sea level projection in Punta Elena*

4.3.8 UNELCO (Puerto del Rosario)

The UNELCO plant currently supplies electricity to the entire island of Fuerteventura and part of Lanzarote. The installation consists of an electrical generation plant with a total of 186.58 MWe of nominal electrical power, which are distributed in several generation groups, being 9 diesel, 2 gas turbine and 1 mobile gas turbine. The diesel groups are located in three engine buildings and all the turbines are outdoors, their use forecast is only at extreme points of demand and in emergency situations. It also has a fuel storage, supply and treatment system, since the fuel used continuously is fuel oil with sulfur (less than 1%) and diesel fuel during the start and stop periods. The turbines operate on diesel. Fuel oil is supplied from the Puerto del Rosario dock and diesel fuel from DISA facilities, both through underground pipelines. The fuel is stored in several tanks with a total volume of 21,349 m3 of fuel oil and 2,489 m3 of diesel fuel (Resolution 387 of 2009).

• Increase of 1 m: The water contacts part of the exterior wall of the installation. (Fig.17)

• 2 m rise: Water maintains direct contact with approximately half of the walled area surrounding the facility. The contiguous land is emerged, being affected also to the urban section and the closest houses.

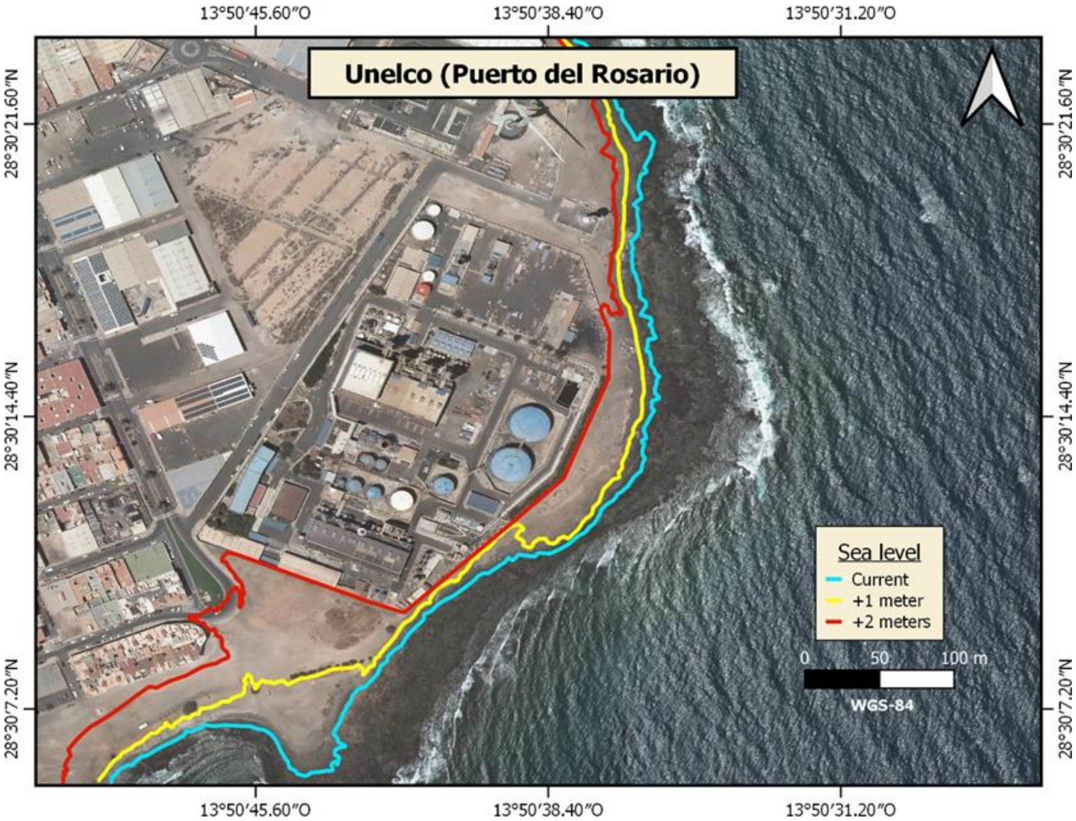


Figure 17 *Sea level projection in UNELCO*

4.4 Elaborated air maps comprobation

In order to recognize the veracity of the images, the areas are visited and the neighbours are asked to corroborate the information. The most conflictive area has been Gran Tarajal, since it is located at the mouth of a ravine and has an aquifer. The veracity of the coastline has been verified, which, at its eastern end, takes on a particular shape. Figure 18 shows the winding shapes that are currently reflected on the map, a view of the area with high accumulated salinity and water. It is due to the position of a mound, that after the rise of the tide does not allow the return of water.

Figure 18 *Current sea level in Gran Tarajal*

Since the maximum sea level recorded by the tide gauge corresponds to 1.7 m during astronomical tides, this means that it can be represented on the 1 m rise line, which is corroborated in figure 19, a photograph taken in September 2012.

Figure 19 *Effect of astronomical tides in Gran Tarajal.*
(Source: Herrera R.,4/09/2012)

This representation is also confirmed with the residents of Jablito (Fig. 20), whose scope of astronomical tides is very similar to that represented by the 1m rise line.

Figure 20 *Effect of astronomical tides in El Jablito*
(Source: Rodríguez S.)

4.5 Decision making and selected responses

When deciding and planning an Adaptation System it is important to remember that there is considerable uncertainty regarding a time horizon, and that an increase of up to 6 m is expected due to the collapse of Greenland and Antarctica (Oppenheimer et al .., 2019) in the coming centuries. It should be borne in mind that, if this occurs, the type of response that is taken may be affected over time. Figure 21 shows that the risk can only be reduced in its entirety by linking climate change mitigation with the responses in time, so if there is no mitigation there will always be considerable risk.

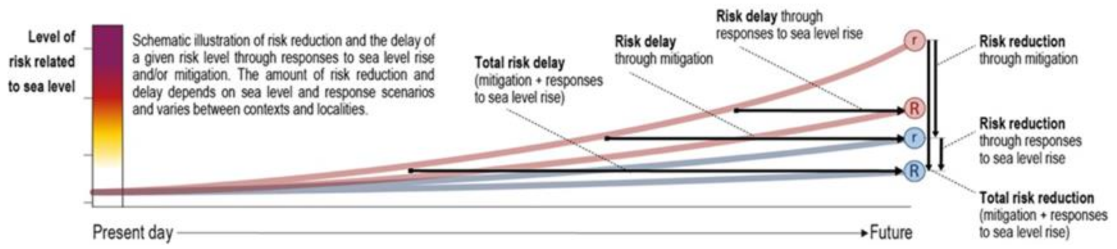


Figure 21 *Benefits of mitigation and responses to sea level rises (Source: IPCC, 2019).*

To plan and implement coastal responses, the risk tolerance of those affected and those who decide must be taken into account. Stakeholders who are risk tolerant and can easily adapt to unexpected conditions can use the probable ranges of RCP2.6 and RCP8.5 to adapt their situation in the long term. When planning for coastal safety in cities, a low risk tolerance must be taken into account and, therefore, a 2m GMSL in the year 2100 cannot be ruled out (Oppenheimer *et al*., 2019). In fact, several national reports have used values in the range of 1.5-2.5 m as superior estimates for the increase of GMSL during the 21st century (KNMI, 2014; NOAA, 2017). Scenarios with high projection values may be somewhat speculative, but for long-term coastal risk management it is important to consider it, especially in densely populated areas (Abadie *et al*., 2019).

Adaptation decision-making is carried out following generic steps (Fig. 22) in which its evaluation and adaptation according to evolution are continuously taken into account.

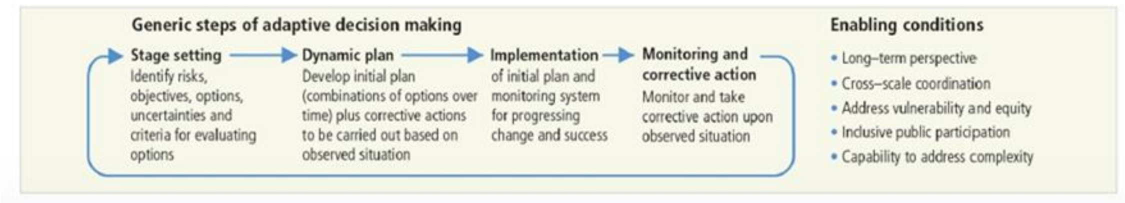


Figure 22 *. Choosing and enabling sea level responses (Source: IPCC, 2019)*

Once the study areas have been located, their current use and risks are observed to weigh the possibilities of adaptation. To analyze the most important factors at a glance, each area is objectively evaluated (Table III). It is valued in comparison with the other areas studied, with "*** the maximum quantity" and "* the minimum", and it is left blank when there is absence. In the case of business, it is valued in ranges of up to 5 units, from 5 to 10 and more than 10. In terms of services, it is valued according to the diversity, that of shops and beach services and the presence of adapted lifeguards and wheelchairs. For anthropization, consideration is given to whether there is urbanization along the coast, promenades, houses and any type of construction or source of contamination. Natural interests depend on the threatened species and whether they are affected by adapting the coastline.

Table III *Objective assessment of the characteristics of the areas studied*

Zone	Anthropization	Beach (influx)	Households	Natural interest	Touristic interest	Sport interest	Business	Services	Direct importance for the whole island
La Concha	**	***	*	***	**		*	*	
Corralejo V	***	**	***	*	***	*	**	***	
Punta Elena	***	*	***	*	**	**	**	***	
Gran Tarajal	***	**	***	*	*		**	**	
Los Hoteles	**	***		**	***	***	**	**	**
Unelco	***		*						***
El Jablito	**	**	**	*		*			
Puerto Lajas	**	*	**	***	*	**	*	**	

Once the area is valued according to the value of its characteristics and depending on the use you want to give (you can keep the same use or change it) the possible options for adaptation are analyzed. The cost and benefit of each possible action should be evaluated.

Since the island of Fuerteventura bases its economy mainly on sun and beach tourism, it would be relevant to preserve these areas. Natural coastal ecosystems can cope and adjust in whole or in part to relative sea level rise, but the natural adaptive capacity is strictly dependent on rates of sea level rise; since if it grows too fast the natural ecosystems will not be able to counteract the negative effects induced by the rise in sea level.

An example of Ecosystem Based Adaptation (EBa) on the island is the Jandía salt marsh. This type of Eba could be integrated into hybrid adaptation systems and spread to other parts of the island, with the consequent biological enrichment.

Following Annex III, the coastal areas with beaches of tourist interest such as La Concha and Las Grandes Playas de Los Hoteles, can be preserved with protection based on the contribution of sediments, this would lead to the destruction of the sediment-producing habitat and the problem of its availability. It is interesting that the areas with natural interest maintain their landscape, avoiding the placement of hard infrastructures to maintain their scenic beauty.

In heavily anthropized areas, risk should be kept as controlled as possible, since many lives depend on it. The most effective is hard protection, but in order to harmonize the landscape and / or services, it could be implemented with an advance system creating sun and bathing areas where it corresponds to the current beach area and some adaptation based on ecosystems that enriches the coastline. A good example is the project “2100 Climate Change Scenarios for the Barcelona Metropolitan Coast” carried out by Landlab (Fig. 23), which rehabilitates a deteriorated area at the mouth of the Besòs River creating a space that integrates nature and leisure in the coastline of the city.

Figure 23 *Landlab company project showing the current state of the Besòs river delta in Barcelona, (left) and future image after adapting the coastline to rise in sea level with a hybrid system that integrates natural and leisure use with the urban landscap (right). (Source: Urbannext, 2020)).*

As for the area of the UNELCO plant that supplies electricity to the entire island and is a source of neighborhood complaints, the most convenient solution would be their eviction, relocating and / or implementing sustainable energy systems, with the dual purpose of not contributing to the increase of climate change and to avoid shortage problems caused by extreme phenomena that are increasingly abundant.

CONCLUSIONS

1. The forecast of the progressive rise in sea level implies a well-anticipated planning for the adaptation of the coastal zones, which must also foresee a continuous increase for several centuries. The responses to be developed pose both a technical and a governance challenge, both temporal and spatial scales imply the need for great coordination and a multidisciplinary team that continually renew their knowledge accordingly.
2. Adaptation is worked on a local scale to be effective since the characteristics of each place will affect the level of increase and its effects; but also influences the use that is given to the area both now and in the future.

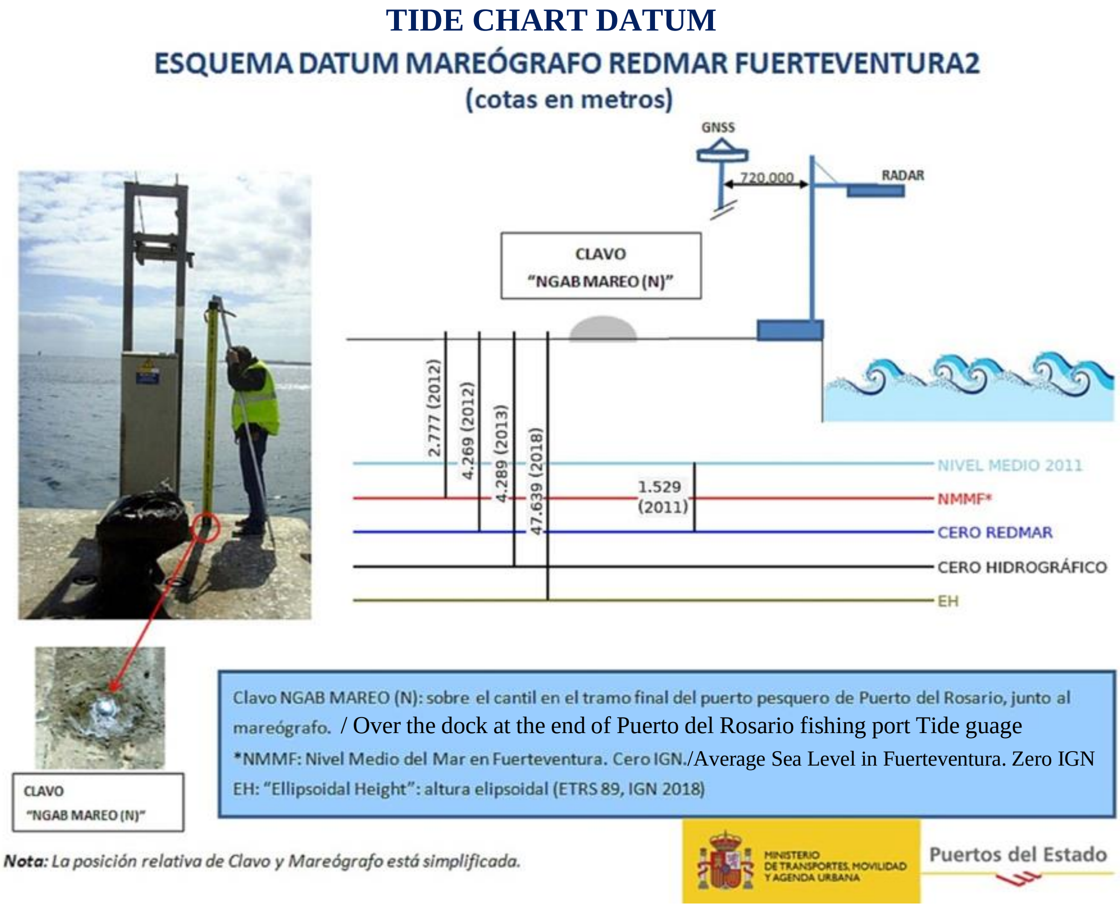
3. A fairly reliable estimate of the sea level projected for the year 2100 (~ 1 m) on the island of Fuerteventura is the current astronomical tides.
4. Depending on the diverse uses of the coast, adaptation systems that are more defensive or based on ecosystems can be implemented to preserve the landscape. An example of the island's own natural ecosystem that can be used as adaptation (EBa) is the Salt Marsh in Jandía.

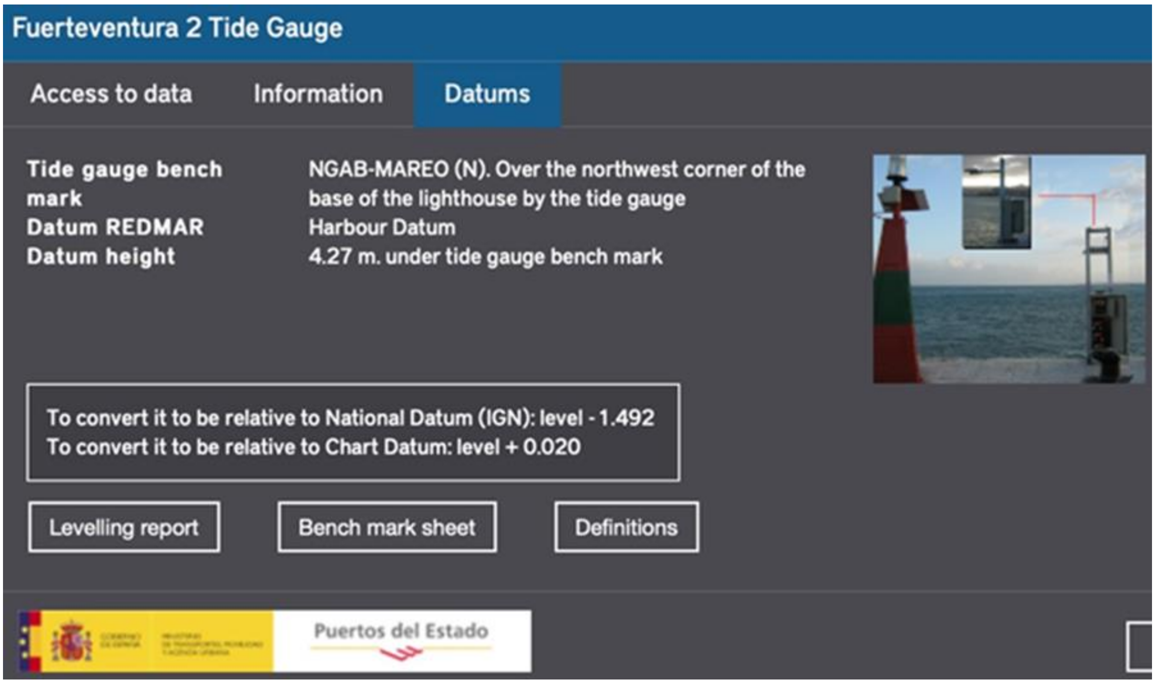
ANNEXES

Annex I List of acronyms

GMSL	Global Mean Sea Level
MSL	Mean Sea Level
RSL	Relative Sea Level
SLR	Sea Level Rise
RSLC	Relative Sea-Level Change:
RSLR	Relative Sea-Level Rise
GMSLR	Global-Mean Sea-Level Rise
GMSLC	Global-Mean Sea-Level Change
VLM	Vertical Land Movement
NMMF	Average Sea Level in Fuerteventura
RCP	Representative Concentration Pathways
ESL	Extrem Sea Level
HCE	Historic Centenial extrem sea level Events
IPCC	The Intergovernmental Panel on Climate Change
GIS	Geographic Information System
DTM	Digital Terrain Model

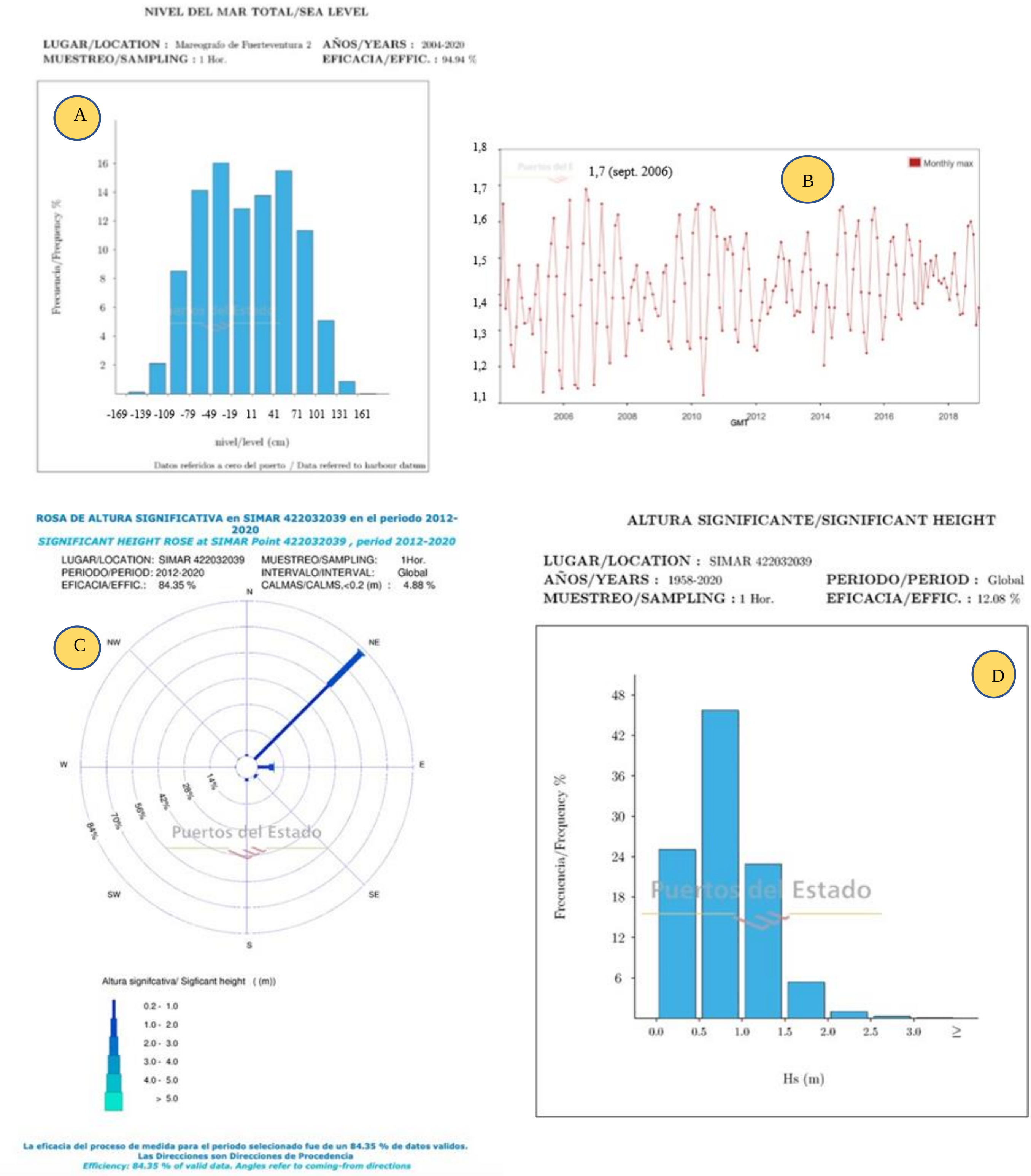
Annex II Tide gauge scheme and datum





Source (Puertos, 2020)

Annex III Tide gauge data



Source (Puertos, 2020)

Annex IV Responses to rising mean and extreme sea levels

The table illustrates responses and their characteristics. It is not exhaustive. Whether a response is applicable depends on geography and context.
Confidence levels (assessed for effectiveness): ●●●● = Very High ●●●= High ●● = Medium ●= Low

Responses		Potential effectiveness in terms of reducing sea level rise (SLR) risks (technical/biophysical limits)	Advantages (beyond risk reduction)	Co–benefits	Drawbacks	Economic efficiency	Governance challenges
Hard protection		Up to multiple metres of SLR {4.4.2.2.4} ●●●	Predictable levels of safety {4.4.2.2.4}	Multifunctional dikes such as for recreation, or other land use {4.4.2.2.5}	Destruction of habitat through coastal squeeze,flooding & erosion downdrift, lock–in, disastrous consequence in case of defence failure {4.3.2.4, 4.4.2.2.5}	High if the value of assets behind protection is high, as found in many urban and densely populated coastal areas {4.4.2.2.7}	Often unaffordable for poorer areas. Conflicts between objectives (e.g., conservation, safety and tourism), conflicts about the distribution of public budgets, lack of finance {4.3.3.2, 4.4.2.2.6}
Sediment–based protection		Effective but depends on sediment availability {4.4.2.2.4} ●●●	High flexibility {4.4.2.2.4}	Preservation of beaches for recreation/ tourism {4.4.2.2.5}	Destruction of habitat, where sediment is sourced {4.4.2.2.5}	High if tourism revenues are high {4.4.2.2.7}	Conflicts about the distribution of public budgets {4.4.2.2.6}
Ecosystem based adaptation	**Coral conservation** / **Coral restoration**	Effective up to 0.5 cm yr⁻¹ SLR. ●● Strongly limited by ocean warming and acidification. Constrained at 1.5°C warming and lost at 2°C at many places. {4.3.3.5.2, 4.4.2.3.2, 5.3.4} ●●●	Opportunity for community involvement, {4.4.2.3.1}	Habitat gain, biodiversity, carbon sequestration, income from tourism, enhanced fishery productivity, improved water quality. Provision of food, medicine, fuel, wood and cultural benefits {4.4.2.3.5}	Long–term effectiveness depends on ocean warming, acidification and emission scenarios {4.3.3.5.2., 4.4.2.3.2}	Limited evidence on benefit–cost ratios; Depends on population density and the availability of land {4.4.2.3.7}	Permits for implementation are difficult to obtain. Lack of finance. Lack of enforcement of conservation policies. EbA options dismissed due to short–term economic interest, availability of land {4.4.2.3.6}
Ecosystem based adaptation	**Wetland conservation** (Marshes, Mangroves)	Effective up to 0.5–1 cm yr⁻¹ SLR, ●● decreased at 2°C {4.3.3.5.1, 4.4.2.3.2, 5.3.7} ●●●			Safety levels less predictable, development benefits not realized {4.4.2.3.5, 4.4.2.3.2}		
Ecosystem based adaptation	**Wetland restoration** (Marshes, Mangroves)				Safety levels less predictable, a lot of land required, barriers for landward expan–sion of ecosystems has to be removed {4.4.2.3.5, 4.4.2.3.2}		
Coastal advance		Up to multiple metres of SLR {4.4.2.2.4} ●●●	Predictable levels of safety {4.4.2.2.4}	Generates land and land sale revenues that can be used to finance adaptation {4.4.2.4.5}	Groundwater salinisa–tion, enhanced erosion and loss of coastal ecosystems and habitat {4.4.2.4.5}	Very high if land prices are high as found in many urban coasts {4.4.2.4.7}	Often unaffordable for poorer areas. Social conflicts with regards to access and distribution of new land {4.4.2.4.6}
Coastal accommodation (Flood–proofing buildings, early warning systems for flood events, etc.)		Very effective for small SLR {4.4.2.5.4} ●●●	Mature technology; sediments deposited during floods can raise elevation {4.4.2.5.5}	Maintains landscape connectivity {4.4.2.5.5}	Does not prevent flooding/impacts {4.4.2.5.5}	Very high for early warning systems and building–scale measures {4.4.2.5.7}	Early warning systems require effective insti–tutional arrangements {4.4.2.6.6}
Retreat	**Planned relocation**	Effective if alternative safe localities are available {4.4.2.6.4} ●●●	Sea level risks at origin can be eliminated {4.4.2.6.4}	Access to improved services (health, education, housing), job opportunities and economic growth {4.4.2.6.5}	Loss of social cohesion, cultural identity and well–being. Depressed services (health, education, housing), job opportunities and economic growth {4.4.2.6.5}	Limited evidence {4.4.2.6.7}	Reconciling the divergent interests arising from relocating people from point of origin and destination {4.4.2.6.6}
Retreat	**Forced displacement**	Addresses only immediate risk at place of origin	Not applicable	Not applicable	Range from loss of life to loss of livelihoods and sovereignty {4.4.2.6.5}	Not applicable	Raises complex humanitarian questions on livelihoods, human rights and equity {4.4.2.6.6}

(Source: Oppenheimer *et al*., 2019)

Annex V Cuestionario

Descripción detallada de las actividades desarrolladas durante la realización del TFT

La búsqueda de información ha sido diversa y muy extensa, desde preguntar a diversos profesores e investigadores sobre fuentes de información, como visitar el archivo histórico de la isla, y visitar las zonas a estudiar.

El volumen de información aportado por el IPCC (Panel Intergubernamental sobre el Cambio Climático) ha sido lento de aprender a gestionar y asimilar. Además se ha obtenido información técnica de diversas fuentes oficiales con la complejidad que ello conlleva.

Una vez aclarado el proceso a desarrollar para su aplicación concreta en la isla de Fuerteventura, se crean los mapas que muestran el aumento del nivel del mar. Para comprobar que no hay errores se visita cada lugar y se habla con los residentes que conocen la zona desde su infancia.

Formación recibida (cursos, programas informáticos, etc.)

La asignatura optativa de cuarto curso “Técnicas de Información Geográfica en el ámbito Geológico” conforma el aprendizaje para el uso de la herramienta con la que se generan los mapas de las zonas afectadas.

El tutor ha realizado una clase sobre el programa utilizado, ya que es diferente del que se ha usado a la largo del curso y es necesario familiarizarse con el interfaz.

Se ha realizado un curso oficial del programa utilizado que compone el inicio del máster certificado de QGIS.

Asistencia al foro Océanos, Canarias y el Cambio Climático

Nivel de integración e implicación dentro del departamento y relaciones con el personal.

El tema de este TFT ha sido totalmente libre, por lo que no está asociado a ningún tipo de departamento ni grupo de investigación, siendo el personal más allegado el propio tutor, que siempre se ha mostrado dispuesto a guiar la labor desarrollada siendo un impulso en los momentos de flaqueza.

La asociación con la Reserva de la Biosfera mediante el cotutor, potencia la sinergia entre universidad y sociedad, aportando importancia a este trabajo con valor para el ciudadano común.

Aspectos positivos y negativos más significativos relacionados con el desarrollo del TFT

Sin duda lo más positivo es la independencia y madurez adquiridas a lo largo del desarrollo del TFT.

El hecho de manejar un gran volumen de información como es el IPCC era impensable antes de esto.

Se desarrollan cualidades como aprender a detectar y corregir los propios errores, buscar criterios externos que aporten un punto de vista diferente, ser autocrítico, buscar información en diversas fuentes y detectar su fiabilidad, conocer los propios límites y sobrepasarlos (o no)

El hecho de no pertenecer a ningún departamento ha sido muy positivo por una parte, pero también negativo por otra, ya que a veces se siente la necesidad de un equipo con el que cuestionar la labor desarrollada. Esta carencia se ha solventado buscando un sinfín de información que ha permitido desarrollar relaciones interpersonales, desde hablar con profesores de diversas ramas y antiguos compañeros dedicados a la investigación, a preguntar a los vecinos o asociaciones de las zonas afectadas, conversar con técnicos de la administración pública e incluso resolver dudas con personal hidrográfico del Malaspina. En el transcurso de este proceso se ha obtenido información de diversa índole sobre diversos problemas de distintas playas, que aunque no se relacionen con el tema de trabajo desarrollado, aportan conocimiento.

El aspecto más negativo ha sido la asimilación, y conexión de un gran volumen de información.

Valoración personal del aprendizaje conseguido a lo largo del TFT.

La mayor satisfacción ha sido trabajar en un tema que implica un beneficio para la sociedad, la elaboración de mapas crea un impacto visual capaz de llamar la atención tanto a dirigentes políticos como profesionales del sector o personas afectadas.

Este TFT ha sido motivo de crecimiento personal, madurez laboral e independencia, lo cual es motivo de orgullo.

Actualmente se prevé una conferencia sobre este TFT mediante la Reserva de la Biosfera.

REFERENCES

Abadie, L. M., Galarraga, I, Markandya, A., & Sainz de Murieta, E. (2019). Risk Measures and the Distribution of Damage Curves for 600 European Coastal Cities. *Environmental Research Letters, 14 (6),* 1-10. https://doi.org/10.1088/1748-9326/ab185c.

Adger, W. N., Pulhin, J. M., Barnett, J., Dabelko, G. D., Hovelsrud, G. K., Levy, M., Oswald-Spring, Ú., & Vogel, C.H. (2014). Human security. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastandrea, T. E. Bilir, M. Chaterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change* (pp. 755-791). Cambridge: Cambridge University Press.

Bamber, J. L., Oppenheimer, M., Kopp, R. E., Aspinall, W. P., & Cooke, R. M. (2019). Ice sheet contributions to future sea-level rise from structured expert judgment. *Proceedings of the National Academy of Sciences, 116* (23), 11195. https://doi.org/10.1073/pnas.1817205116

Barragán, J.M. (2014). *Política, gestión y litoral. Una nueva visión de la gestión integrada de áreas litorales.* Madrid: Tébar.

Bridges, T., Wagner, P. W., Burks-Copes, K. A., Bates, M. E., Collier, Z. A., Fischenich, C. J., Gailani, J. Z., Leuck, L. D., Piercy, C. D., Rosati, J. D., Russo, E. J., Shafer, D. J., Suedel, B. C., Vuxton, E. A., & Wamsley, T. V.(2015). *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience, North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk.* Vicksburg: Engineer Research and Development Center.

Church, J. A., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, S., Levermann, A., Merrifield, M. A., Milne, G. A., Nerem, R. S., Nunn, P. D., Payne, A. J., Pfeffer, W. T., Stammer, D. & Unnikrishnan, A. S. (2013). Sea Level Change. In T. F., Stocker, D. Qin, G. K. Plattner, M. K. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Climate Change 2013. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

Church, J.A. & White, N.J. (2011). Sea-Level Rise from the Late 19th to the Early 21st Century. *Surveys in Geophysics, 32*, 585-602. https://doi.org/10.1007/s10712-011-9119-1

Coombes, M. A., La Marca, E. C., Naylor, L. A., & Thompson, R. C. (2015). Getting into the groove: opportunities to enhance the ecological value of hard coastal infrastructure using fine-scale surface textures. *Ecological Engineering, 77*, 314-323.

Dangendorf, S., Hay, C., Calafat, F. M., Marcos, M., Piecuch, C. G., Berk. K., & Jensen, J. (2019). Persistent acceleration in global sea-level rise since the 1960s. *Nature Climate Change 9*, 705–710. https://doi.org/10.1038/s41558-019-0531-8

Hino, M., Field C. B., & Mach, K. J. (2017). Managed retreat as a response to natural hazard risk. *Nature Climate Change, 7*, 364–370. DOI: 10.1038/NCLIMATE3252

Intergovernmental Oceanographic Commission of UNESCO. (2011). *A Blueprint for Ocean And Coastal Sustainability: An Inter-Agency Report Towards the Preparation of the UN Conference on Sustainable Development (Rio+20).* University of North Texas Libraries, UNT Digital Library. Available at: https://digital.library.unt.edu/ark:/67531/metadc226586/ (accessed 4 June 2020)

IPCC. (2013). C*limate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovern- mental Panel on Climate Change* [T. F., Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P. M. Midgley (Eds.)]. Cambridge: Cambridge University Press. Available at: presshttp://www.climatechange2013.org/images/report/WG1AR5_Frontmatter_FINAL.pdf

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R. K. Pachauri & L. A. Meyer (Eds.)]. Switzerland: IPCC, Geneva. Available at: pp.https://epic.awi.de/id/eprint/37530/1/IPCC_AR5_SYR_Final.pdf

IPCC. (2018). *Summary for Policymakers. In Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [V. Masson-Delmotte, P. Zhai, H.O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E.

Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (Eds.)]. Geneva: World Meteorological Organization. Available at: https://www.ipcc.ch/sr15/chapter/spm/

IPCC. (2019). Technical Summary [H. O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, E. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. M. Weyer (Eds.)]. In H. O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. M. Weyer (Eds.) *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.* In press.

Islam, M. R., & Khan, N. A. (2018): Threats, vulnerability, resilience and displacement among the climate change and natural disaster-affected people in South-East Asia: an overview. *Journal of the Asia Pacific Economy, 23* (2), 297-323. DOI: 10.1080/13547860.2018.1442153

Konrad, H., Thomas, M., Sasgen, I., Klemann, V., Grosfeld, K., Barbi, D., & Martinec, Z. (2013). The Deformational Response of a Viscoelastic Solid Earth Model Coupled to a Thermomechanical Ice Sheet Model. *Surveys in Geophysics, 35(6)*, 1441-1458. https://doi.org/10.1007/s10712-013-9257-8

KNMI. (2014). *KNMI'14: Climate Change Scenarios for the 21st Century - A Netherlands Perspective, Scientific Report* [P. B. van den Hurk, P. Siegmund, A. K. Tank (Eds.)] . Available at: http://www.klimaatscenarios.nl/brochures/images/KNMI_WR_201401_version26May2014.pdf

Kummu, M., De Moel, H., Salvucci, G., Viviroli, D., Ward, P. J., & Varis, O. (2016). Over the hills and further away from coast: global geospatial patterns of human and environment over the 20th-21st centuries. *Environmental Research Letters, 11*,1-15. doi:10.1088/1748-9326/11/3/034010

Little, C. M., Horton, R. M., Kopp, R. E., Oppenheimer, M., Vecchi, G. A., & Villarini, G. (2015). Joint projections of US East Coast sea level and storm surge. *Nature Climate Change, 5 (12),* 1114-1120, doi:10.1038/nclimate2801.

Meinshausen, M., Smith, S.J., Calvin, K., Daniel, S. J., Kainuma, M., Lamarque, J., Matsumoto, K., Montzka, S., Raper, S., & Riahi, K. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic Change, 109*, 213-241.

Mengel, M., Nauels, A., Rogelj, J. and Schleussner, C. F. (2018): Committed sea-level rise under the Paris Agreement and the legacy of delayed mitigation action. *Nature communications, 9,* 601. https://doi.org/10.1038/s41467-018-02985-8

Mokrech, M., Kebede, A. S., Nicholls, R. J., Wimmer F. and Feyen, L. (2014). An integrated approach for assessing flood impacts due to future climate and socio-economic conditions and the scope of adaptation in Europe. *Climatic Change, 128*, 245–260. https://doi.org/10.1007/s10584-014-1298-6

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., Van Vuuren, D. P., & Meehl, G. A. (2010). The next generation of scenarios for climate change research and assessment. *Nature*, *463(7282)*, 747-756.

Nicholls, R. J. (2018). Adapting to Sea-Level Rise. In Z. Zommers & K. Alverson (Eds.), *Resilience: The Science of Adaptation to Climate Change.* London: Elsevier.

Nicholls R. J. & Klein R. J. T. (2005). Climate change and coastal management on Europe's coast. In J. Vermaat, L. Bouwer, K. Turner,& W. Salomons (Eds.), *Managing European Coasts: Past, Present and Future.* Germany: Spinger.

NOAA. (2017). *Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083* [W. V. Sweet, R. E. Kopp, C. P. Weaver, J. Obeysekera, R. M. Horton, E. R. Thieler, & C. Zervas]. NOAA/NOS Center for Operational Oceanographic Products and Services. Available at: https://pubs.giss.nasa.gov/abs/sw01000b.html

ONU-Hábitat. (2009). Planificación de ciudades sostenibles: orientaciones para políticas. Informe Global sobre Asentamientos Humanos 2009. Resumen ejecutivo. Programa de las Naciones Unidas para los Asentamientos Humanos. http://www.unhabitat.org/grhs/2009

Oppenheimer, M., Glavovic, B.C., Hinkel, J., van de Wal, R., Magnan, A. K., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R. M., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B., & Sebesvari, Z. (2019). Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In H. O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. M. Weyer (Eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.* In press.

Resolución 387 de 2009 [Consejería de Medio Ambiente y Ordenación Territorial. Viceconsejería de Medio Ambiente] Por la que se otorga autorización ambiental integrada al proyecto denominado Central Diesel Salinas. 2 de octubre de 2009.

Rupprecht, F., Möller, I., Paul, M., Kudela, M., Spencer, T., van Weseenbeck, B. K., Wolters, G., Jensen K., Bouma, T. J., Miranda-Lange, M., Schimmels, S. (2017). Vegetation-wave interactions in salt marshes under storm surge conditions. *Ecological Engineering, 100,* 301-315. DOI:10.1016/j.ecoleng.2016.12.030.

Sekimoto, T., Isobe, M., Anno, K., & Nakajima, S. (2013). A new criterion and probabilistic approach to the performance assessment of coastal facilities in relation to their adaptation to global climate change. *Ocean Engineering, 71,* 113-121. http://dx.doi.org/10.1016/j.oceaneng.2013.01.032

Spalding, M., McIvor, A. L., Beck, M. W., Koch, E. W., Möller, I., Reed, D. J., Rubinoff, P., Spencer, T., Tolhurst, T. J., Wamsley, T. V., van Wesenbeeck, B. K., Wolanski, E., & Woodroffe, C. D. (2014). Coastal ecosystems: a critical element of risk reduction. *Conservation Letters, 7* (3), 293-301. https://conbio.onlinelibrary.wiley.com/doi/pdf/10.1111/conl.12074

Trang, N. T. T., (2016). Architectural Approaches to a Sustainable Community with Floating Housing Units Adapting to Climate Change and Sea Level Rise in Vietnam. *World Academy of Science, Engineering and Technology, International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, 10* (2),168-179. https://doi.org/10.5281/zenodo.1111711

Van Wesenbeeck, B. K., Lange, G., Jongman, B., Bosche, L. V., Nieboer, H., Meliane, I., Holm-Nielsen, N.B., Ijff, S., Balog, S. A. B., Kurukulasuriya, P. H., Kaupa, S. M., & Taishi, Y. (2017). *Implementing nature based flood protection: principles and implementation guidance.* Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/739421509427698706/Implementing-nature-based-flood-protection-principles-and-implementation-guidance

Vuik, V., Jonkman, S. N., Borsje, B. W., Suzuki, T., Kratzer, I., & Bouma, T. J. (2015). Nature-based flood protection: the efficiency of vegetated foreshores in reducing wave run-up. In *E-proceedings of the 36th IAHR World Congress.* The Hague, the Netherlands.

Wang, W., Liu, H., Li, Y., & Su, J. (2014). Development and management of land reclamation in China. *Ocean & Coastal Management, 102,* 415-425.

Wong, y P. P., Losada, I. P., Gatusso, J. P., Hinkel, J., Kathabbi, A., McInnes, K. L., Saito, Y., & Sallenger, A. (2014). Coastal systems and low-lying areas. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastandrea, T. E. Bilir, M. Chaterjeee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma., E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastandrea, & L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation and Sectoral Aspects. Contribution of Working group*

II to the Fifth Assessment Report of the IPCC (pp: 361-409). Cambridge: Cambridge University Press.

World Meteorological Organization. (2019). The Global Climate in 2015–2019. https://library.wmo.int/index.php?lvl=notice_display&id=21522#.XeesozJ7lpg.

Zazo, C., Goy, J. L., Hillaire-Marcel, C., Gillot, P. Y., Soler, V., González, J. A., Dabrio, C. & Ghaleb, B. (2012). Raised marine sequences of Lanzarote and Fuerteventura revisited - a reappraisal of relative sea-level changes and vertical movements in the eastern Canary Islands during the Quaternary. *Quaternary Science Reviews, 21*(18-19), 2019–2046. doi:10.1016/s0277-3791(02)00009-4

Zhang, K., Liu, H., Li, Y., Xu, H., Shen, J., Rhome, J., & Smith, T. J. (2012). The role of mangroves in attenuating storm surges. *Estuarine, Coastal and Shelf Science*, (102 -103), 11-23.

WEBLIOGRAPHY

Agencia Estatal de Meteorología (2018). Meteoglosario Visual. Diccionario Ilustrado de Meteorología. Available at https://meteoglosario.aemet.es/es/termino/437_forzamiento-radiativo (accessed 8 July 2020)

Centro Nacional de Información Geográfica (2020). Centro de Descargas. Available at: http://centrodedescargas.cnig.es/CentroDescargas/index.jsp

European Enviromental Agency. (2019). Global and European sea-level rise. Available at https://www.eea.europa.eu/data-and-maps/indicators/sea-level-rise-6/assessment (accessed 5 July 2020)

Herrera, R. (04/09/2012) Veril Majorero. Recovered from: https://verilmajorero.blogspot.com/2012/09/estos-dias-de-septiembre-mareas-del.html (accessed 3 July 2020)

Instituto Canario de Estadística (2020) Explotación Estadística del Padrón Municipal. Available at: http://www.gobiernodecanarias.org/istac/estadisticas/demografia/poblacion/cifraspadronales/E30260A.html (accessed 13 July 2020)

Puertos del Estado (2020) Oceanografía. Available at: http://www.puertos.es/es-es/oceanografia/Paginas/portus.aspx (accessed 11 July 2020)

Urban Next (2020). 2100 Climate Change Scenarios: Barcelona’s Coastline. Available at https://urbannext.net/2100-climate-change-scenarios/ (accessed 3 July 2020)