

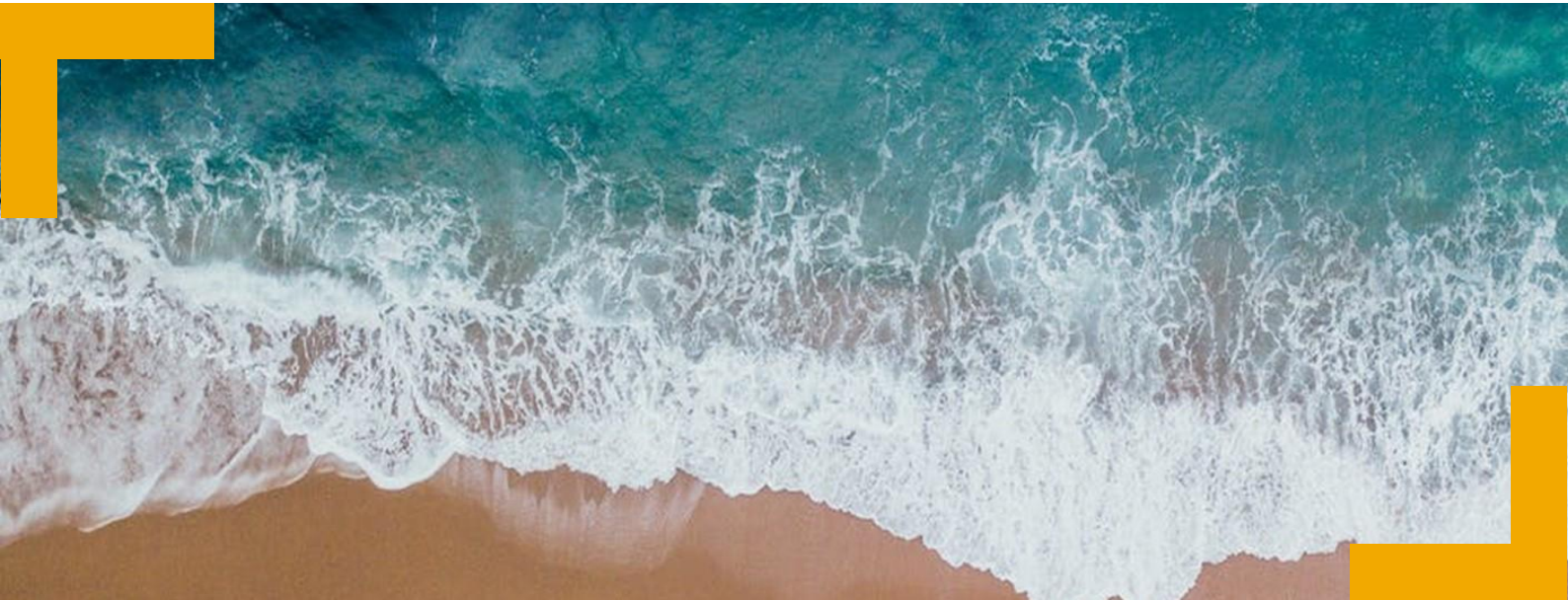


MedSeaRise

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## WHITE PAPER

On the uncertainties affecting the current knowledge and the data on future sea level trend in the Mediterranean.

Deliverable D.3.4.1

<https://medsearise.interreg-euro-med.eu/>





## Deliverable ID

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## Abbreviations

<b>ANATOLIKI</b>	Organisation for Local Development, Anatoliki S.A. – Project Partner - LP1
<b>ARPA FVG</b>	Regional Environmental Agency of Friuli Venezia Giulia Region- Project Partner - PP2
<b>CCINCA</b>	Chamber of Commerce and Industry Nice Côte d’Azur - Project Partner - PP3
<b>UoM-IMBK</b>	Public institution University of Montenegro - Institute of Marine Biology - Project Partner - PP4
<b>BCC</b>	Barcelona Chamber of Commerce - Project Partner - PP5
<b>UM</b>	University of Malta - Department of Geosciences - Project Partner - PP6
<b>PP</b>	A Project Partner, in general. Nobody specifically indicated
<b>PPs</b>	All Project Partners
<b>D.2.4.1</b>	Project deliverable 2.4.1: Methodology and the best practices
<b>D.3.4.1</b>	Project deliverable 3.4.1: White paper: on the uncertainties affecting the current knowledge and the data on future sea level trend in the Mediterranean.
<b>Output 2.1</b>	Project output 2.1: Methodology for an effective use of sea level rise scenarios in climate change impact risks assessment
<b>GWL</b>	Global Warming Level
<b>GrP</b>	The MedSeaRise Green Paper. Project deliverable 3.4.2
<b>WhP</b>	The MedSeaRise White Paper. Project deliverable 3.4.1
<b>SLR</b>	Sea level Rise



## Executive summary

This is the MedSeaRise White Paper, which is highlighting issues related to the uncertainties affecting the current knowledge and the data on future sea level trends in the Mediterranean basin, as well as the difficulties in information interpretation, data accessibility, post elaboration and usability in the context of risk assessment.

The information and the ideas exposed in this document have been collected thanks to the results of the MedSeaRise methodology application and the experience gained by project partners during the project implementation.

The paper is aimed at stimulating further insights into the topics related to the reported items.

The structure of the document is single issue oriented; that means the issues are presented as self-contained paragraphs. Each paragraph deals with a specific issue in which the core of the issue is presented reporting evidence of the situation or the problem that is considered an issue. Then the elements of the hypothetical causes of the issue are described in summary, in addition there are the consequences deriving from the issue, for example the limits in knowledge, the applications reliability, the retrieval and the usage of data, besides the robustness of concepts, just to give some examples.

When feasible, proposals on how to face the issue with the aim to reduce the consequences are included too, such as new measure campaigns, sets of simulations, development of tools and applications, innovative approaches, besides required and hoped collaborations and explorations, just to mention some of them.

The paper does not require a background in any topic related to the issues.



# Purpose of this document

## Introduction

This document presents the knowledge and the experience achieved working with data describing scenarios of the future state of the sea level in the Mediterranean. These results have been gained thanks to the activities carried out in the frame of the MedSeaRise Project.

As the project approaches its end, all the MedSeaRise PPs have become aware of the added value created in collecting, analysing, post-processing and using the wide variety of data produced by the scientific community to explore the future climate change scenarios.

According to the mission of the Euro-MED Programme, this know-how has to be shared within the cooperation area community and beyond.

Through this white paper, MedSeaRise aims to provide experts and decision-makers with useful knowledge to make informed decisions on the impacts deriving from the progressive increase in sea level.

The document analyses strengths and weaknesses of the available information on how the mean sea level is likely to affect the coast of the Mediterranean basin.

Furthermore, it is expected to provide science operators with stimulating perspectives for research that could contribute to pushing further ahead the limits affecting knowledge on the effects of a progressively warming planet on mean sea level.

The document is organized into sections in which specific issues are presented and explored, highlighting their relevance, the causes of the related problems, and proposing solutions or actions to respond to the needs deriving from (or stimulated by) each issue.



## Issues and Proposals

### **Sea-level rise scenario information is fragmented and uncertainty is not communicated in a consistent way.**

Sea-level rise scenario information is fragmented and uncertainty is not communicated in a consistent way. This makes it hard for stakeholders to choose the right data and apply it reliably for coastal risk and adaptation decisions.

The core of the issue: There is a lot of sea-level rise information available, but it is not always easy to use in practice. Different datasets and studies can give different results because they use different assumptions, baselines, components, time periods, and levels of detail.

The causes: Sea level is influenced by several processes, and different models and methods handle these in different ways. Some datasets are global, and some are regional, and they may not match well at the local scale. Metadata and documentation are sometimes incomplete or not presented in a user-friendly way.

The consequences: Coastal risk studies can be hard to compare between places and hard to reproduce, because stakeholders choose different datasets or interpret them differently. Uncertainty may be ignored, simplified too much, or misunderstood, which can reduce trust in the results. This makes it harder to justify decisions and can slow down adaptation, or lead to choices that are not well matched to the level of risk.

The proposal: Provide clearer, more usable sea-level rise information. This includes a set of recommended datasets for the Mediterranean, with clear descriptions of what they include, how they were made, and how uncertainty should be interpreted. Prepare standard ways to show uncertainty. Promote a minimum set of impact-ready layers and templates for filling key data gaps, so scenario information can be linked more easily to real-world assets and sectors and used consistently across different sites.

### **Limited integration of high-resolution infrastructure data in sea-level rise impact assessments for critical coastal systems.**

There is a limited integration of high-resolution infrastructure data in sea-level rise impact assessments for critical coastal systems.

The core of the issue: Assessing the impacts of sea-level rise (SLR) on highly engineered coastal areas, such as port systems and highly urbanised coastal settlement, requires combining climate projections with detailed information on infrastructure elevation,



layout, and operational characteristics. The Barcelona case study in the Llobregat Delta illustrates that, even where robust sea-level projections and high-resolution digital elevation models are available, translating these scenarios into reliable estimates of exposure and economic impacts remains challenging when infrastructure-level information is difficult to integrate into spatial analyses.

**The causes:** Several factors contribute to this limitation. Infrastructure data are often fragmented across institutions, with varying levels of detail and accessibility. Some elements of coastal infrastructure (e.g. breakwaters, quay walls, or protective structures) may not be fully represented in publicly available elevation datasets. In addition, methodologies linking physical exposure to economic indicators require information about asset values, operational disruptions, and future development plans, which may sometimes not be available, requiring assumptions that may not always be standardised across case studies.

**The consequences:** These constraints can introduce uncertainty into estimates of potential impacts and may lead to partial assessments of exposure in complex infrastructure systems such as ports. As a result, risk assessments may underestimate vulnerabilities or overlook interactions between infrastructure components and surrounding coastal dynamics. This can reduce the reliability of impact indicators and complicate the integration of SLR considerations into infrastructure design, long-term investment planning, and coastal adaptation strategies.

**The proposal:** Improving the integration of infrastructure data into SLR impact assessments would significantly strengthen the usability of climate risk analyses. This could involve developing shared protocols for combining climate projections, elevation models, and infrastructure datasets, as well as promoting greater data exchange between infrastructure operators, public authorities, and research institutions. In addition, creating standard approaches for linking exposure analysis with economic indicators could help produce more consistent and comparable assessments across Mediterranean coastal infrastructures.

## **Difficulty in linking physical sea-level rise exposure with systemic economic impacts.**

It is difficult to link physical sea-level rise exposure with systemic economic impacts across interconnected coastal infrastructures and regional markets.

**The core of the issue:** SLR assessments often focus on the direct physical exposure of specific assets, such as port terminals, coastal infrastructure, or transport nodes. However, complex coastal systems such as ports operate within wider networks that include logistics



chains, transport corridors, and regional markets. The Barcelona case study in the Llobregat Delta illustrates that while it is possible to estimate the potential exposure of individual port infrastructures, translating this exposure into broader economic and systemic impacts remains significantly more complex.

**The causes:** Several factors contribute to this challenge. Economic and operational data describing logistics flows, supply chains, and infrastructure interdependencies are often confidential, fragmented, or unavailable at the level required for modelling. In addition, existing methodologies typically focus on asset-level exposure rather than on cascading effects across transport networks, regional trade systems, and economic activities. Modelling these interactions would require integrating climate scenarios with transport modelling, economic analysis, and sector-specific operational data.

**The consequences:** As a result, many SLR assessments capture only the direct exposure of individual infrastructures while overlooking the broader systemic impacts that disruptions may generate across interconnected systems. This can lead to partial estimates of risk and may underestimate the potential economic implications of climate-related disruptions for critical infrastructure and the regional markets that depend on them.

**The proposal:** Advancing the understanding of cascading climate risks requires the development of interdisciplinary approaches that combine physical exposure analysis with transport system modelling and economic impact assessment. Strengthening collaboration between climate scientists, infrastructure operators, and economic analysts could help develop methods capable of capturing systemic impacts across interconnected critical coastal systems. Pilot applications integrating these approaches in major Mediterranean infrastructure hubs could provide valuable insights to support more comprehensive climate risk assessments and adaptation planning.

## **Limits affecting our current knowledge on sea level rise causes.**

Despite a large amount of work done to explore the causes of contemporary climate change and the effects it brings along, there are still important limits in the knowledge of the manifold effects deriving from a progressive global warming.

**The core of the issue:** Future sea level is determined by changes in several contributions. Current scientific knowledge on this specific consequence of contemporary climate change identifies six elements. The global thermosteric component, affecting water density, whereas Antarctic and the Greenland ice sheets melting, plus the melting of continental glaciers outside of the ice sheets, and the variations of water exchange between land and seas, all these increase the total water mass. Last but not least, the local variations of water salinity, temperature and circulation, generating regional effects in the conditions of seawater stationary vertical equilibrium. For each of these contributions there



is a different degree of knowledge and insight into the likelihood of evolution scenarios in the future climate.

**The causes:** The dependence of each of those elements on the possible scenarios of global warming is investigated by adopting approaches and tools suitable for the analysis and the exploration of the specific element. Furthermore, the physical and environmental processes involved in the evolution of each element, which is contributing to sea level variations, present a wide spectrum of complexity. In some cases the relation between global warming and the resulting evolution of the contribution is straightforward, whereas for others the network of forcing and feedbacks is hard to understand and to model. Uncertainties affecting each of those sources of information have quite different magnitudes too.

**The consequences:** The comprehensive future mean sea level results from the sum of all those contributions, thus there is a clear limit in the knowledge on the expected increase of sea level, both at the global scale and especially at the regional scale, that is sea basins and sub-basins. Furthermore, the uncertainty affecting the knowledge of each element of the compound, that is the mean sea level, propagates along the logical and computational flow, which is applied to assess the future sea level variation, but that propagation is understood partially only. So, despite the undoubted positive correlation between global warming and the mean sea level and the large likelihood of the mean sea level increase trend for the future decades, the range of possible values for that trend needs a careful evaluation before to apply it in the assessment of the risk related to the sea level rise due to climate change.

**The proposal:** The removal of limits in knowledge requires the persistence of research and investigation on the topics that are affected by limits. In addition to stimulating and supporting the research focused on the sensitivity of each of the elements contributing to the total sea level to global warming, it is important to investigate the degree of correlation between those sensitivities. In a warming planet, all the contributions to the increase of the mean sea level are not independent, they are linked. Anyway, the degree of connection between the magnitude and the uncertainty of each of them may be affected by significant deviations and potential turning points, which are marking the prevailing of some of them with respect to the others at specific stages of the global warming evolution. These are aspects worth considering in future research on the consequences of climate change on mean sea level.

## **How to deal with uncertainty of the data on future sea level trends.**

How to deal with uncertainty of the data on future sea level trends at the global and Mediterranean scales is essential to quantify the uncertainty affecting the assessment of the risks related to future sea level rise.



The core of the issue: Future sea level scenarios are known with a degree of uncertainty that is not negligible in comparison to the other factors involved in the risk assessment of impacts caused by the increase of the mean sea level. Thus, it is mandatory to handle that source of uncertainty and include a proper procedure in the comprehensive logic that is adopted to generate information suitable for the risk management.

The causes: There are many sources of information, namely data, on the same physical process contributing to the sea level change. Those sources are coming from the variety of studies and research conducted by different teams at different times, that is with specific and not common methods and tools. None of the sources generated data free of uncertainty. Furthermore, among the adopted methods to explore future scenarios of climate, then of sea level, there are numerical simulations. Those simulations attempt to reproduce the complexity of the climate evolution, according to a deterministic approach, and it is well known that the large variability of the complex systems' evolution is often affected by poor predictability.

The consequences: In the assessment of the climate change impacts, due to the large availability of scenarios on the future climate, it is common practice to choose only one of those available, which is considered the most suitable for the purpose. This is true for the risks related to the future mean sea level too. In this case, the frequent practice is to look for the worst scenario or to use an average scenario computed on the considered data. This represents a weak point in the risk assessment process, because nobody knows which is the best simulation of a scenario and the statistical approach to future climate scenario data, which are generated by different methods and simulations, is not supported by the hypothesis of the probabilistic nature of the differences and fluctuations found in the data. Furthermore, using only one source of data does not allow the uncertainty of the information to be transferred through the risk assessment process. In addition, the use of statistical estimators for the dispersion of the information, namely the variance, around a central value of the datasets, namely the mean, may give a quite poor representation of the future evolution of the hazard.

The proposal: According to the idea that a simulation of a future climate scenario is an attempt to explore the huge space of the possible states of the scenario, it follows the idea to use ensembles of data on the scenario. An ensemble of possible evolutions of climate, under the same scenario, represents a set of explorations of the evolution of the future climate. None of those explorations has to be considered better than the others, but the ensemble delimits the ranges of the expected evolution, according to the capability to simulate that reality. Many decisions can be taken using the range of the system evolution, instead of using what is assumed to be the best.



## Accessibility of data on sea level scenarios may limit the use of that information.

Accessibility of data is a key aspect of information usability. For scenarios of future climate, which include the trends on sea level, the data format, size and the availability of software to post-process and to explore them may limit the use of that information, reducing the efficacy of related decision-making and the reliability of the decision taken.

The core of the issue: Data accessibility is not merely a technical issue. This also includes users' ability to identify the relevant datasets, to retrieve the needed data and to use them to answer questions through the results of their elaboration. Data accessibility may become a barrier for non-specialists.

The causes: Data on future climate scenarios are generated by means of numerical models that are characterized by a three dimensional description of the environment. Those models simulate the evolution of the climate according to time steps that are strictly tied to the spatial resolution of the three dimensional domain. Thus, the higher the spatial resolution the shorter the time step. The resulting output is a huge amount of data that requires TeraBytes of storage. To keep the data size at minimum and to include metadata in the data files, it is common practice to use file formats that are specifically designed for the purpose.

The consequences: Accessibility of data directly determines the ability to use all the available information. Applications of methods may be inhibited by the incompleteness of data because the methods are based on information that is hard to retrieve. Furthermore, post elaboration and summary indicators of climate evolution require the knowledge of the existence and the skill to use software developed and distributed specifically to handle climate data.

The proposal: It is necessary to provide operational guidance on usable data and their access points and to document the "hardest steps" that prevent smooth use. In addition, the data accessibility barriers can be removed through online services that generate queries to data and the computation on demand or simply the retrieval of climate indexes or summary indicators, besides slices or subsets of data from a whole simulation ensemble dataset.

## Weaknesses of the methods and tools applied to assess the impacts

In evaluating the magnitude of the impacts deriving from the progressive increase of the mean sea level, each approach presents a degree of weakness. Some weaknesses are conceptual, others refer to more practical problems.



The core of the issue: The methods and tools used to “calculate” impacts (on both human systems and ecosystems) deriving from the increase of the mean sea level face internal limitations linked to their level of technical demands, the implementation burden, and the difficulty of properly translating uncertainty and causal chains (sea-level rise → hazards → damage/effects) into information that is directly actionable. In practice, scientific robustness can coexist with difficulties in use, interpretation and generalization of results.

The causes: Several structural drivers emerge. On the one hand, the methodology requires specialist know-how: understanding scenarios, managing uncertainty, selecting indicators, setting parameters, and interpreting outputs. On the other hand, an application can be resource-intensive (time, skills, data collection/processing), leading to frequent reliance on external experts rather than autonomy for local teams. Finally, two technical aspects weigh on impact assessment: the difficulty of interpreting uncertainty (and communicating it) and the difficulty of making explicit/quantifying the link between mean sea-level rise and tangible impacts on assets, activities or ecosystems (impact pathways, local factors, non-linearity, compound effects).

The consequences: These weaknesses translate into: (i) a risk of low reproducibility if the process depends too heavily on tacit expertise; (ii) use being limited to a handful of pilot cases rather than scaling up; (iii) divergent interpretations of uncertainty, ranging from paralyzing caution to excessive simplification; and (iv) difficulty comparing results across territories/sectors if assumptions and data vary widely. At the level of public policy and planning, this can reduce the perceived reliability of applications, complicate integration into trade-offs, and limit the acceptability of conclusions for decision-makers who expect clear messages on risks, priorities and options for action.

The proposal: To strengthen the operational robustness of the methods/tools, several actions are proposed: (i) further formalize the “how-to” through step-by-step protocols, calculation templates and rules for selecting assumptions (traceability); (ii) develop tools to support the interpretation of uncertainty (standard visualizations, decision narratives, confidence categories, usage recommendations aligned with the level of uncertainty); (iii) produce sectoral reference frameworks that explicitly link sea-level rise to impact mechanisms (and to measurable indicators), drawing on documented cases; (iv) design a “lightweight” toolkit for rapid diagnostics and an “advanced” toolkit for in-depth studies, so that analytical effort can be matched to available resources; and (v) organize collaborations (scientists–practitioners) and multi-site cross-validation exercises to improve transferability, comparability and confidence in the results.

## **Limits in understanding the content of the data on sea level scenarios.**

Scenarios of future climate are generated assuming a set of hypotheses, which are parameters of the simulations executed to generate the scenarios. Those



parameters require enough knowledge to understand what kind of scenario the user is going to download, explore and include in the risk assessment process.

The core of the issue: A future sea level scenario dataset is only truly usable if its content, underlying assumptions and limitations are understood. Therefore, it is necessary for the final user to understand the meaning of each content brought by scenario data and metadata.

The causes: There are many parameters, besides fundamental concepts that support the generation of a climate scenario through model simulations. Several times it is assumed the user already knows what a socio-economic pathway that leads to a specific degree of warming means, or why the planet warming is expressed with an amount of Celsius degrees, besides understanding what means the anomaly of an environmental variable and why it is presented as the result of the simulation instead of the variable itself. This is just to make a short list of all the possible causes.

The consequences: Misuse of the sea level scenarios is the direct consequence of a partial understanding of the scenario data and metadata content. Furthermore, computing impacts and interpreting the results lead to a biased assessment of the risk, which affects the decisions on how to face the impact, that is the adaptation and resilience solutions to the sea level rise related consequences.

The proposal: It appears necessary for the scenario metadata to present and explain the method that has generated the scenario widely, as it requires specialist know-how which may itself lead to difficulties in understanding. Documentation should be characterized by stratified levels of insight that may be useful, from popular shaped metadata and description to high-level technical information. Glossaries and schemes, together with infographics are worth being considered at all the levels of insight.



# Indicators of deliverable achievement

## Deliverable indicators

The achievement of the objective described in this deliverable is summarized by means of the indicators reported below. For each of them, the expected indicator value and the actual one are presented. In addition, comments are also included, if any.

Indicator	Expected value	Actual value	Comments
Documents	1	1	The White Paper



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