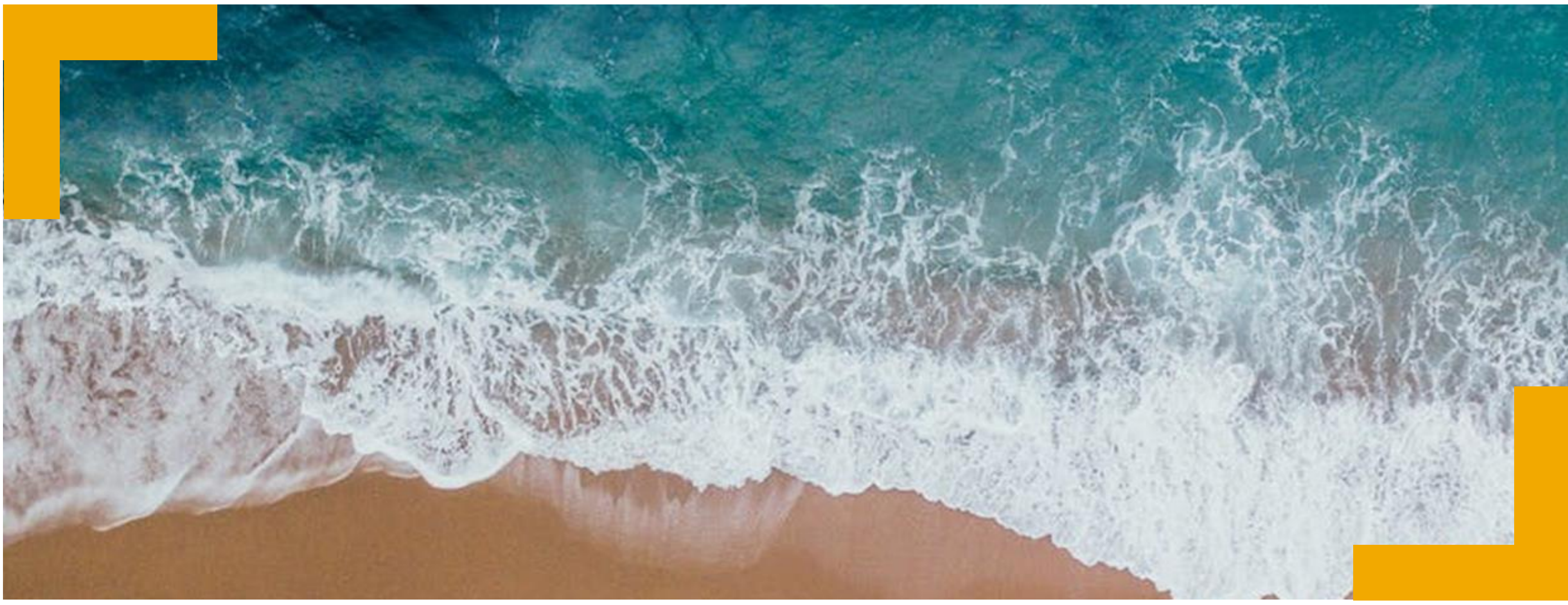


December 2025

DATASETS AND DOCUMENTATION SUPPORTING THE METHODOLOGY AND THE BEST PRACTICES

Deliverable D.2.1.2

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

Deliverable ID

Project acronym	MedSeaRise
Project title	Supporting Adaptation to Mediterranean Sea Level Rise
Project mission	Protecting, restoring and valorising the natural environment and heritage
Project priority	Greener MED
Specific objective	RSO2.4 Promoting climate change adaptation and disaster risk prevention, resilience, taking into account eco-system based approaches
Type of project	Study project (Thematic Project)
Project duration	01/01/2024 – 31/03/2026 (27 months)

Deliverable title	Datasets and documentation supporting the methodology and the best practices
Deliverable number	D.2.1.2
Deliverable type	Report
Work package number	2
Work package title	Information analyses, methodology development and tools generation
Activity name	Data analysis of future sea level rise scenarios and scientific information review
Activity number	2.1
Partner in charge (author)	UM
Partners involved	ARPA FVG , UoM-IBMK, UM

Document history

Versions	Date	Document status	Delivered by
Version 0.1	01/09/2025	Draft	PP2
Version 2.0	29/03/2026	Revised	PP6

Table of contents

Abbreviations

ANATOLIKI	Organisation for Local Development, Anatoliki S.A. – Project Partner - LP1
ARPA FVG	Regional Environmental Agency of Friuli Venezia Giulia Region - Project Partner - PP2
CINCA	Chamber of Commerce and Industry Nice Côte d’Azur - Project Partner - PP3
UoM-IBMK	Public institution University of Montenegro - Institute of Marine Biology - Project Partner - PP4
BCC	Barcelona Chamber of Commerce - Project Partner - PP5
UM	University of Malta - Department of Geosciences - Project Partner - PP6
PP	A Project Partner, in general. Nobody is specifically indicated
PPs	All Project Partners
D.2.1.1	Project deliverable 2.1.1: Assessment of the likelihood for each dataset available for Mediterranean sub basin area.
D.2.4.1	Project deliverable 2.4.1: Methodology and the best practices
Output 2.1	Project output 2.1: Methodology for an effective use of sea level rise scenarios in climate change impact risks assessment
GWL	Global Warming Level
AIS	Antarctic Ice Sheet
GIS	Greenland Ice Sheet
LWS	Land Water Storage

MSL	Mean Sea Level
ESL	Extreme Sea Level
SSP	Shared Socioeconomic Pathway
RCP	Representative Concentration Pathway
ZOS	Sea level above the geoid; used here for the regional sterodynamic component
PRE	Precipitation
TAS	Air temperature at 2 m above ground

Executive summary

This is a deliverable of the MedSeaRise project. The project contributes to the Natural Heritage mission of the Euro-MED Programme and belongs to the Study Project class.

The document summarizes the work done in the frame of the project activity 2.1, describing how the project partners have defined and generated an easy-to-access set of data on future sea level, together with summary datasets and statistical indexes to support the application of the MedSeaRise methodology for an effective use of sea level rise scenarios in climate change impact risk assessment.

In fact, the scientific community shares a large amount of data on future climate scenarios, at highest spatial and time resolution. Furthermore, all those data compose an ensemble of information not accessible from a unique distribution hub.

Through the work done in Activity 1.2 [1.1], the MedSeaRise project has harvested the available scientific data and has organized them according to a logic and a format, letting PPs apply the project methodology easily.

This document starts with a summary presentation of the physical components contributing to total sea level, as an introduction to the datasets. The data and indexes available for each PP focus area are then described in detail, together with the distribution services implemented within the project.

Whenever required, annexes are used to add further details to the text. In addition, references are provided to the other project deliverables, as well as to other relevant public documents and websites.

Fundamentals of Sea Level Variations

The contributions to the total sea level

The sea level measured today, and expected in the future along the Mediterranean coasts, is a highly dynamic environmental feature. Several contributions add to total sea level: some vary at sub-daily frequency, while others are related to long-lasting processes, such as climate conditions.

Thus, within the frame of the MedSeaRise project, the selected sea-level impacts are considered as the consequence of both long-term and short-term contributions. The generated datasets therefore include all sea-level components strictly related to the water. However, vertical land displacement was not taken into account, because its assessment requires detailed investigations of the geomorphological features of the coastal areas where sea-level impacts occur. These investigations are not among the objectives of the MedSeaRise project; however, if available, the local trend in vertical land displacement may be added to the sea-level scenarios to obtain a comprehensive result.

In the following, each component of sea-level variation is described. The sources of scientific information used to generate the summary datasets and indexes are then presented.

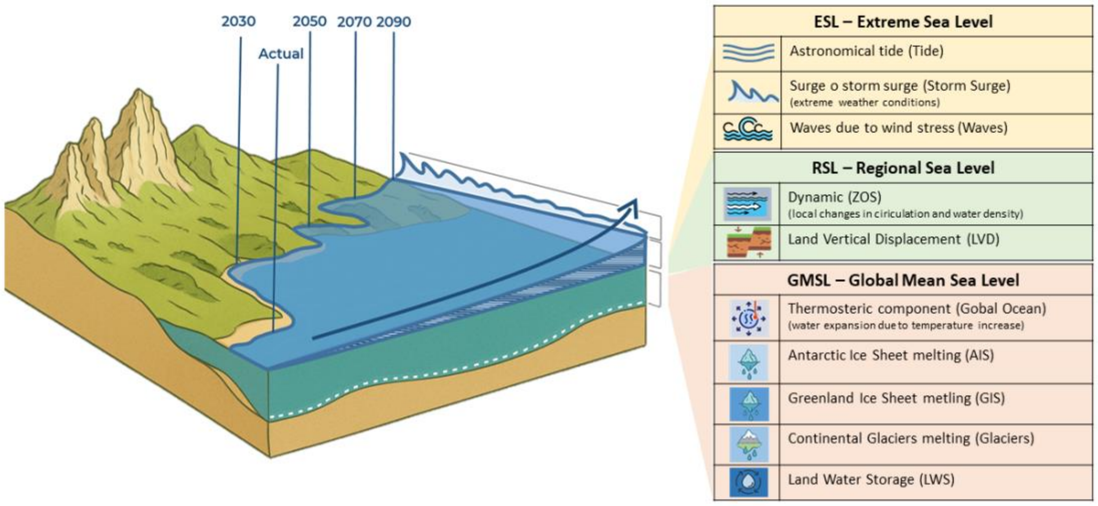


Figure 1.1: Schematic description of the contributions to sea level when measured with reference to a marker fixed to the coast. Contributions are grouped according to their characteristic time of variation. For those related to long-lasting processes, a further distinction is made between contributions with local validity and those belonging to effects that affect all oceans and seas.

Mean sea level

The mean sea level is the average height of the seawater with respect to a marker, which is usually fixed at the ground on land. The average is computed over many days of measures or simulations to filter out the daily and sub-daily variations of the sea level due to tides, surges and wind-driven waves.

The components of sea level that evolve over timescales longer than a few days affect mean sea level. These components are a direct consequence of the state of the climate system, in particular of two of its parts: the hydrosphere, namely the liquid water available on our planet, and the cryosphere, namely the water in solid phase available on Earth.

There are three main processes that contribute to mean sea-level change. These processes alter both the quantity of liquid water available in sea basins and the density of seawater, which in turn affects the volume of water filling oceans and seas.

The first process is the melting of ice stored on land. Due to the increasing temperature of our planet, both the atmosphere and the oceans are warming, and ice sheets and mountain glaciers are melting, resulting in the addition of freshwater to the ocean.

The second process is the thermal expansion of water. Even though changes in water density due to temperature variations are very small and almost imperceptible for limited quantities of water, the effect becomes evident when considering the huge amount of liquid water available in the oceans. Specifically, an increase in seawater temperature makes water less dense and therefore causes sea level to rise. A decrease in temperature acts in the opposite way.

The third process is the variation in land-water storage, with water either transferred from land to the seas or stored on land. These changes may result from human activities or changes in the hydrological cycle, and they cause a net change in the total amount of water in the oceans.

Since the measures of the mean sea level variation are made with a comparison of the water level with a reference marker fixed at ground, it is worth noting that vertical land motion also has to be considered to understand the risks induced by the water level in coastal areas.

The movement up and down of land is affected by natural phenomena and anthropic activities. Natural factors include the movement of tectonic plates, sediment settling, and isostatic rebound. Human factors include groundwater usage and fossil fuel extraction from the ground. In MedSeaRise project the land vertical displacement is not taken into account, so it was not considered to generate the datasets used to achieve the project objectives.

Starting from these processes, a brief description of the mean sea-level components considered in the MedSeaRise datasets is provided. The short name associated with each component is highlighted in bold. This name is used throughout all MedSeaRise datasets and summary indexes.

The thermosteric component (**Global Ocean**) [1.2] [1.8] encompasses the combined effects of steric changes, those referring to water density, and global scale dynamic changes, related to oceans climatic circulation.

The Antarctic Ice Sheet melting (**AIS**) [1.3] [1.8] leads to the increase of the liquid mass present in the oceans. That melting has been observed for decades and it is expected to proceed, even accelerate, as a consequence of the increase of average Earth temperature. Together with the Greenland Ice Sheet (**GIS**) [1.4] [1.8], the ice available on Antarctica and Greenland is stored mainly on land, so its melting brings more water in the liquid state into the oceans.

Glaciers outside the major ice sheets and located on continents (Glaciers) [1.5] [1.8] account for a relatively small fraction of the total ice trapped on land. However, the progressive melting of this water storage still contributes to the increase in total sea level.

Furthermore, the water stored on lands (**LWS**) [1.6] [1.8] represents the exchange of water between land and seas. Its variability depends on the global water cycle, groundwater withdrawal, and water stored inland.

Last but not least, regional climate effects are also relevant. These include local variations in water salinity, temperature and circulation, which are consequences of climatic processes acting at spatial scales smaller than the global one. Freshwater input from rivers, precipitation and evaporation induce local changes in water salinity and therefore in water density. Changes in sea currents also redistribute water masses. These dynamic effects (ZOS) [1.7] [1.8] shall be added to the global ones to describe the overall mean sea-level variation.

Thus, mean sea-level variation can be represented as the sum of the contributions described above:

$$\text{MSL variation} = \text{Global Ocean} + \text{AIS} + \text{GIS} + \text{Glaciers} + \text{LWS} + \text{ZOS}$$

In the following sections of this deliverable, the sources of information for each of these addends, considered to achieve the MedSeaRise objectives, are specified.

Daily and sub-daily variations

Short-term causes are responsible for significant sea-level displacements with respect to mean sea level. The forces acting on the whole mass of the oceans, together with those stressing the water surface, change on timescales of about one day or less.

Some forces are periodic, such as those determining the tides, whereas others are not because they are related to chaotic systems like the weather. Certainly the total effect of these forcing actions may result in a compensation of the sea level displacement or in an amplification of the level.

When sea-level displacement reaches values with a very low frequency of occurrence, according to statistics computed from past time series of measurements, we define that situation as an Extreme Sea Level (ESL). Extreme deviations with respect to mean sea level can be both positive, when the sea level is above the mean sea level, and negative, when the sea level is below the mean sea level.

Since MedSeaRise deals with the impacts of mean sea-level increase on human activities and ecosystems, the project considers as ESL only the positive extremes. Negative extremes may also produce impacts, but in a warming climate the progressive increase of mean sea level tends to moderate the hazards linked to negative extremes and to emphasise the positive ones.

Thus, the positive extreme sea level (ESL) that can be recorded through continuous monitoring at high temporal resolution can be represented as:

ESL = MSL variation + **Tide** + **Storm Surge** + **Wave height**

The main causes of short-term sea-level variations are briefly summarised below.

Astronomical tide

Astronomical tide (Tide) is defined as the rise and fall of sea level at a specific location, with respect to mean sea level, due to the combined gravitational effects of the Moon and the Sun acting on the liquid water present in Earth's oceans and seas. It is a large-scale water motion resulting from Earth's rotation and from the variation of the gravitational force exerted by these two celestial bodies.

The amplitude of astronomical tide varies on timescales ranging from hours to years due to a number of astronomical factors, which determine the periodicity of the comprehensive gravitational action. Tide gauges measure water level over time at fixed stations and they ignore variations caused by waves with periods shorter than minutes, which are consequence of the atmosphere action on the sea surface.

Specifically, seawater is held on Earth's surface because Earth's gravitational attraction acts inward toward the planet's centre of mass. The gravitational forces of the Moon and the Sun also act externally upon ocean waters.

At Earth's surface, an imbalance between these forces results in a net force acting on the hemisphere of Earth facing the Moon, pulling water toward the Moon's centre. On the side of Earth directly opposite the Moon, the net force acts away from the Moon. Similar effects arise from Earth's revolution around the Sun.

The gravitational contribution of the Moon and Sun to the tide is always present, but the two bodies can act synergistically or reduce the overall effect on the water, depending on their relative positions. For this reason, tidal amplitude results from the combination of different periodic cycles.

Atmospheric driven anomalies

While tides are usually the largest source of short-term sea-level fluctuations, sea level is also subject to change due to strong winds and abrupt barometric pressure changes, resulting in storm surges (Storm Surge), especially in shallow seas and near the coast.

In fact, tide measurements do not match the amplitudes predicted by considering only the gravitational action of the Moon and the Sun together with Earth's rotation. There are changes in tidal characteristics that are attributed to a wide range of non-astronomical drivers, affecting tides over a large range of temporal and spatial scales.

Among these drivers there is the uneven atmospheric pressure over the sea surface. Low pressure tends to raise sea level, while high pressure tends to depress it. The water level does not adjust immediately to a pressure change; instead, it responds to the average pressure change over a considerable area. A difference of 1 hPa from the average atmospheric pressure can cause a sea-level difference of about 1 cm.

In addition, wind stress on the sea surface causes fluctuations in sea level and therefore deviations from the astronomical tide alone.

The effects of wind on local sea level depend on the geographical features of the area, together with the intensity and persistence of the wind action. In general, wind raises sea level in the direction towards which it is blowing. Strong onshore winds pile up water and cause sea levels to be higher than those predicted by astronomical calculations only, while offshore winds have the opposite effect.

These effects are considered as a storm surge: a rise above (positive surge), or a fall below (negative surge), the normal predicted tidal level on the open coast, caused by both static pressure and dynamic wind effects.

In addition, the gravitational forces acting on the sea surface restore the sea level when the atmospheric stress is over. This produces oscillations of the sea surface that add to the tide amplitude too.

Waves

On the surface of the sea, there are always waves. Those are wind-generated water waves, which are surface waves that occur on the free surface of water as a result of the wind blowing over the water's surface. The amplitude of such waves (**Wave height**) add to all the other components of the sea level and they can increase the hazard coming from the sea height along the shoreline. Winds blowing along a coast tend to set up long waves which travel along the coast, raising sea level where the crest of the wave appears and lowering sea level in the trough.

Wave amplitude is not commonly measured in the same way as the tide; moreover, it can assume a wide spectrum of values, from values close to zero in the absence of significant wind to several metres in the case of strong winds and positive feedback with coastal characteristics.

In generating the MedSeaRise dataset of sea level, waves have not been considered due to their high dependence on non-climatic coastal features.

However, to describe wave-related impacts along the shore in future climate scenarios, a logical assumption is that wave height, whether computed from wave models or derived from measurements, is largely independent of the other causes affecting sea level. Therefore, wave amplitude can be added to the total sea level resulting from the other components.

Datasets on mean sea level evolution

In this section, the sources of data on the components of sea-level variation are described. These data were used to generate the MedSeaRise dataset and the related sea-level indexes used to apply the MedSeaRise methodology for assessing the risks of climate-change impacts.

Global component variations

Future climate scenarios for the global components of sea-level variation, namely Global Ocean, AIS, GIS, Glaciers and LWS, originate from the extensive work carried out by the scientific community for the IPCC Sixth Assessment Report (AR6) [2.1] [1.8]. NASA [2.2] has collected these global sea-level components for the available future climate scenarios in an interactive tool [2.3], providing easy access to and visualisation of the AR6 projections. The data sources underlying that tool are detailed in the dedicated online documentation [2.4].

For MedSeaRise purposes it was important to identify the global components of the sea level rise to be added to the detailed set of simulations retrieved for the ensemble of regional effects (**ZOS**) and the daily and sub-daily variations (**Tide** and Storm **Surge**).

From the NASA data distribution service [2.3], the following processes have been considered and the corresponding data downloaded:

- • AIS: contribution to sea-level rise due to the melting of the Antarctic Ice Sheet;
- • GIS: contribution to sea-level rise due to the melting of the Greenland Ice Sheet;
- • Glaciers: contribution to sea-level rise due to the melting of continental glaciers;
- • LWS: contribution to sea-level rise due to changes in inland water storage;
- • Ocean dynamics: contribution to sea-level rise due to the thermal expansion of seawater and dynamic anomalies, usually referred to as sterodynamic sea level.

These components are expressed as contributions to sea-level variation relative to the period 1995-2014, for five Shared Socioeconomic Pathway (SSP) scenarios and five future Global Mean Surface Temperature levels (from 2080-2100). The reference period 1995-2014 is the same as that adopted for all the other contributions included in the MedSeaRise datasets.

To understand whether the global components of sea-level rise in future climate scenarios are highly sensitive to geographical position, the global components were retrieved from the NASA Sea Level Projection Tool [2.3] for 10 locations across the oceans, four of which are located within the Mediterranean Sea. See Figure 2.1 and Table 2.1.

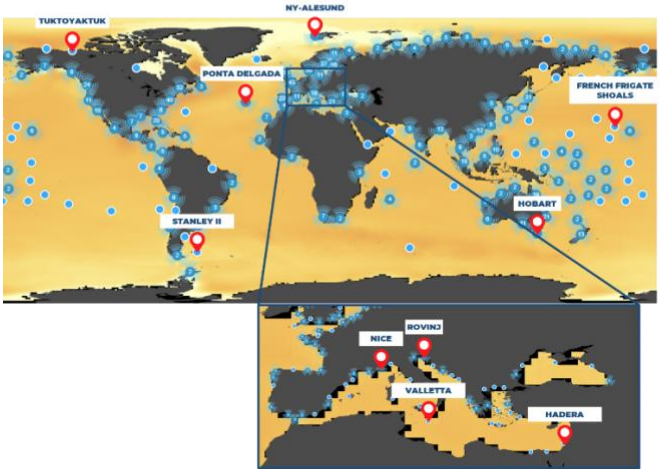


Figure 2.1: Map of the locations considered for the sensitivity analysis of the global components of mean sea-level climate scenarios.

Station name	Station code
Ponta Delgada	258
Hobart	838
Tuktoyaktuk	1000
French Frigade Shoals	1372
NY-Alesund	1421
Nice	1468
Stanley II	1796
Hadera	1797
Valletta	1735
Rovinj	761

Table 2.1: Locations considered for the sensitivity analysis of the global components of mean sea-level climate scenarios.

For each global component, a pairwise comparison was performed for all possible pairs that can be created using the selected points. The number of pairs is given by C(n, k) = n! / (k! · (n-k)!), where n is the number of points and k = 2.

The results were analysed according to the Global Warming Level perspective and the most relevant percentiles (50% and 95%) available from the source data. The analysis was then reproduced for the set of locations closest to the coastal areas on which the Project Partners focused the methodology application. See Figure 2.2 and Table 2.2.

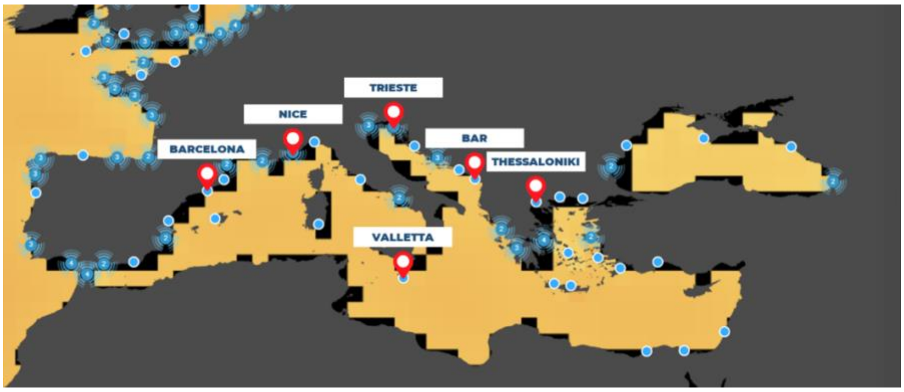


Figure 2.2: Map of the Mediterranean locations considered for the sensitivity analysis of the global components of mean sea-level climate scenarios, namely Global Ocean, AIS, GIS, Glaciers and LWS.

Station name (Project Partner)	Station code
Thessaloniki (LP1)	373
Trieste (PP2)	154
Nice (PP3)	1468
Bar (PP4)	1075
Barcelona (PP5)	1811
Valletta (PP6)	1735

Table 2.2: Mediterranean locations considered for the sensitivity analysis.

In both analyses, it was found that for each global component of the future sea level variation, the differences among data related to distinct geographical areas, especially in the Mediterranean basin, are of about a few centimeters, for the whole XXI century.

The details of these analyses are collected in Annex 4, together with plots describing the minimum, maximum, mean and median differences and their evolution over time for each Global Warming Level. Figure 2.3 provides an example.

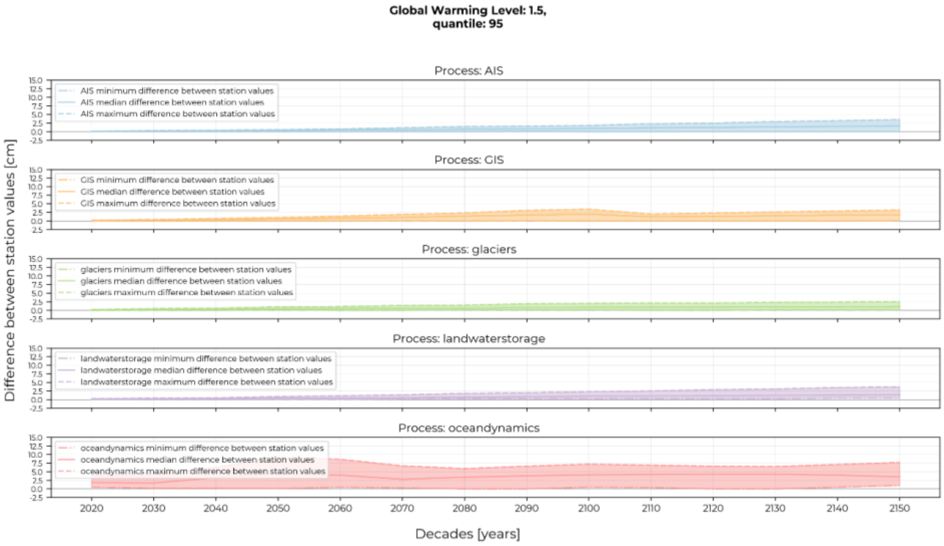


Figure 2.3: Time evolution of the statistics describing the minimum, maximum, mean and median differences across the Mediterranean areas for all components of the global effects affecting mean sea-level rise. This example, taken from the complete analysis available in Annex 4, reports differences computed using the 95th percentile of each component for the Global Warming Level of 1.5 °C.

Integration into the MedSeaRise dataset

Such global components of the future scenarios of sea level rise were integrated into the MedSeaRise sea level dataset.

The 50th and 95th percentile values of GIS, AIS, Glaciers and LWS were downloaded from the NASA data dissemination service [2.3] for each of the six MedSeaRise coastal locations; see Table 2.2. Only these two percentiles were considered, with the aim of describing a conservative scenario (50th percentile) and an extreme scenario (95th percentile). It is realistic to add together the contributions associated with the same percentile to obtain a comprehensive sea-level rise signal corresponding to the same Global Warming Level. The uncertainty was expressed as the range delimited by the median and the 95th percentile of the available data.

The same procedure was applied to the “Ocean dynamics” component, which in the NASA dataset [2.3] includes information on ocean circulation and composition, such as currents and density, as well as on the steric expansion of seawater. In addition, the MedSeaRise project collected a large set of high-resolution numerical simulations for the sterodynamic contribution to future climate scenarios focused on the Mediterranean basin. This is the already described ZOS contribution. To exploit both sources of information, namely the global and the regional one, it was necessary to separate the global steric expansion from the “Ocean dynamics” component by subtracting the corresponding ZOS value representing the dynamic component already available in the MedSeaRise high-spatial-resolution datasets.

This subtraction produced a variable named Global Ocean Mean, which represents only the global sterodynamic effects, while the ensemble of ZOS data describes the local sterodynamic effects at each location where MedSeaRise applied the methodology.

To make Global Ocean Mean representative of a unique and robust value for the whole Mediterranean basin, the mean across the six aforementioned Mediterranean locations was computed and considered in the MedSeaRise datasets.

Regional component variations

The sources of information on the regional sterodynamic component of future Mean Sea Level (MSL) scenarios considered within the MedSeaRise project are a set of monthly averages of the MSL field covering the period from 1850 to 2100 over the whole Mediterranean Sea area. These data are referred to here as ZOS.

Data files were downloaded for as many simulations as possible for the four main SSP-RCP scenarios, namely SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5, together with their historical part. Here, the historical part refers to the modelled period preceding the scenario runs and used to connect past and future simulations consistently. These files are in netCDF format and were selected from Coupled Model Intercomparison Project Phase 6 (CMIP6) [3.1] datasets with a horizontal spatial resolution of 25 km. Files are accessible from one of the nodes [3.2] of the Earth System Grid Federation (ESGF) [3.3], an international collaboration supporting global climate-change research [3.4], including the climate assessments of the Intergovernmental Panel on Climate Change (IPCC) [3.5]. From the downloaded files [3.6], time series were extracted by nearest-neighbour interpolation for specific geographic locations of interest for each Project Partner (see Table 3.1).

location ID	latitude [°N]	longitude [°E]	notes
LP1_01	40.41616	22.75137	Point offshore in the Thermaic Gulf; ZOS
LP1_02	40.26243	22.83822	Point offshore in the Aegean Sea; ZOS
PP2_01	45.49458	13.15274	Point offshore in the North Adriatic Sea; ZOS
PP3_01	42.56954	7.34774	Point offshore the Cote d'Azur; ZOS
PP4_01	42.16527	18.40141	Point offshore in the South Adriatic Sea; ZOS
PP5_01	41.22654	2.472953	Point offshore in the Balearic Sea; ZOS
PP6_01	36.12255	14.73559	Point offshore the coastline of Malta; ZOS

Table 3.1: Locations identified by the MedSeaRise project for the implementation of project activities. Each location ID is associated with latitude and longitude, and the notes report the location name together with the environmental field available, namely sea level (ZOS).

Data are stored in a folder for each Project Partner (PP), with subfolders containing ZOS time-series files. There is one netCDF file for each simulation, geographic location and scenario; the time series consist of monthly average values extending from a historical part (1850-2014) to a future SSP-RCP scenario (2015-2100).

There is one location where ZOS has been considered for each PP. It is worth noting, however, that for LP1 two locations were considered because, for one specific simulation (GFDL-CM4_r1i1p1f1), no data close enough to the main area of interest were available.

SSP1-2.6, number of available datasets: 3
SSP2-4.5, number of available datasets: 2
SSP3-7.0, number of available datasets: 6
SSP5-8.5, number of available datasets: 7

The main features of the simulations mentioned above are listed in Table 3.2.

Project	Institution ID	Model ID	SSP-RCP	Configuration run
CMIP6	AWI	AWI-CM-1-1-MR	ssp126	r1i1p1f1
CMIP6	MOHC	HadGEM3-GC31-MM	ssp126	r1i1p1f3
CMIP6	CNRM-CERFACS	CNRM-CM6-1-HR	ssp126	r1i1p1f2
CMIP6	AWI	AWI-CM-1-1-MR	ssp245	r1i1p1f1
CMIP6	CNRM-CERFACS	CNRM-CM6-1-HR	ssp245	r1i1p1f2
CMIP6	AWI	AWI-CM-1-1-MR	ssp370	r5i1p1f1
CMIP6	AWI	AWI-CM-1-1-MR	ssp370	r4i1p1f1
CMIP6	AWI	AWI-CM-1-1-MR	ssp370	r3i1p1f1
CMIP6	AWI	AWI-CM-1-1-MR	ssp370	r2i1p1f1
CMIP6	AWI	AWI-CM-1-1-MR	ssp370	r1i1p1f1
CMIP6	CNRM-CERFACS	CNRM-CM6-1-HR	ssp370	r1i1p1f2
CMIP6	NOAA-GFDL	GFDL-CM4	ssp585	r1i1p1f1
CMIP6	AWI	AWI-CM-1-1-MR	ssp585	r1i1p1f1
CMIP6	MOHC	HadGEM3-GC31-MM	ssp585	r4i1p1f3
CMIP6	MOHC	HadGEM3-GC31-MM	ssp585	r1i1p1f3
CMIP6	MOHC	HadGEM3-GC31-MM	ssp585	r2i1p1f3
CMIP6	MOHC	HadGEM3-GC31-MM	ssp585	r3i1p1f3
CMIP6	CNRM-CERFACS	CNRM-CM6-1-HR	ssp585	r1i1p1f2

Table 3.2: List of the available datasets for each location identified by the MedSeaRise project to conduct project activities. Beside the project and institution IDs, the table reports the model ID, the SSP-RCP scenario and the configuration run.

In CMIP6 [3.1] numerical simulations, models are initialised and configured by selecting specific physical and technical settings. As a result, not all possible future climate scenarios were simulated by all models, and the extension of simulations into the distant future may differ among model outputs.

The specific configuration run is described by an ID called variant-ID. This identifier distinguishes closely related simulations through a single formula composed of four terms.

- **r**N denotes the realization, that is the ensemble member (N). An example is **r1**i1p1f2 indicating that it is the 1st (N=1) realization;
- **i**N denotes the initialization method, that is the method (N). An example is r1**i1**p1f2 indicating that it is the 1st (N=1) method;
- **p**N denotes the physics parameterizations, that is the physical parametrizations (N). An example is r1i1**p1**f2 indicating that it is the 1st (N=1) set of physical parametrizations;
- **f**N denotes the forcing adopted or scenario, that is the scenario (N). An example is r1i1p1**f2** indicating that it is the 2nd (N=2) scenario.

The variant-ID helps researchers distinguish between different model runs, ensuring that they can track which specific simulation produced a given dataset.

The scientific literature collected and analysed according to project Activity 1.1 (see Deliverable D.1.1.1 “Knowledge and data availability on sea level rise projections”) and Activity 1.2 (see Deliverable D.1.1.2 “Data collection on sea level rise scenarios”) highlights the importance of using an ensemble of climate simulations when investigating the future status of mean sea level.

Even though all numerical models include the fundamental physical processes driving the evolution of Earth’s climate, for example the large-scale dynamics of the atmosphere and ocean, each model also contains specific formulations, parameterisations and numerical choices.

These model features, which are not standardised, are considered a strength rather than a disadvantage, because each model contributes to the investigation with its own representation of the Earth system.

Integration into the MedSeaRise dataset

The regional sterodynamic (ZOS) component of the future sea-level scenarios was integrated into the MedSeaRise sea-level dataset.

From the downloaded files, time series were extracted by nearest-neighbour interpolation for specific geographic locations of interest for each Project Partner (see Table 3.1).

Furthermore, the ZOS data were post-processed to generate decadal statistics of sea-level anomalies with respect to the 20-year reference period 1995-2014, for each scenario, location and month or season considered.

Statistics for all PP locations are available from the MedSeaRise data distribution hub [4.2] by downloading the file MedSeaRise_ZOS_climate_statistics.csv from the subfolder climate_statistics.

Daily and sub-daily component variations

To support the Project Partners in applying the MedSeaRise methodology also to impacts that require knowledge of hazards arising from daily and sub-daily sea-level variations, such as Tide, Storm Surge and Wave Height, an hourly astronomical-tide time series, 10 years long, was generated for each Project Partner's specific coastal location.

This was considered the minimum information required to include short-term sea-level variations together with mean sea level. Furthermore, all PPs were invited, whenever possible, to retrieve measured multiyear sea-level time series for the coastal locations where the methodology is applied. Such real time series also include the effects of the atmosphere on the observed sea level, beyond the astronomical contribution alone. Because this possibility was not available to all PPs, the astronomical tide provided a common daily and sub-daily dataset on which to test the MedSeaRise methodology.

So, one of the MedSeaRise objectives was to generate tidal fluctuations representative of Mediterranean conditions. Although the Mediterranean is a relatively enclosed sea, it still experiences tidal variations driven largely by water exchanges through the Strait of Gibraltar and local resonance effects. Whilst these tides are smaller in magnitude than those found in the open ocean, they can be accurately modelled and predicted through hydrodynamic and spectral methods.

When no tidal measurements are available, the tidal fluctuations used within the project are based on the Oregon State University (OSU) TPXO Tide Models. TPXO is a series of fully global barotropic tide models that best fit, in a least-squares sense, the Laplace Tidal Equations and assimilated data. The models apply the methods detailed by Egbert, Bennett and Foreman [5.1] and further refined by Egbert and Erofeeva [5.2].

All global TPXO models include gridded harmonic constants of mean sea level (MSL)-relative sea-surface elevations and transports/currents for eight primary (M2, S2, N2, K2, K1, O1, P1, Q1), two long-period (Mf, Mm), and three non-linear (M4, MS4, MN4) tidal constituents. TPXO9 and TPXO10 also include nine and eleven minor tides, respectively. These models are provided at a resolution of 1/6 degree [5.3].

TPXO10 predicts tides by assimilating satellite altimeter data (TOPEX/Poseidon, Jason series) and in situ tide gauge measurements, thereby enhancing tidal predictions through observational data correction. This entails an inverse modelling approach that integrates observational data with hydrodynamic simulations to produce accurate barotropic ocean tide models. The main objective is to refine tidal predictions by dynamically adjusting the model based on real-world measurements, such as satellite altimetry and in situ data. This ensures that the model not only adheres to theoretical formulations but also aligns with observed tidal variations across diverse oceanic settings.

At the core of this methodology lies the representer technique, which decomposes the inverse problem into smaller, computationally tractable components. This approach accommodates large datasets and addresses spatial and temporal tidal variability. The representer method enables the assimilation of elevation and current data, allowing the model to account for disparities between simulated and observed tidal dynamics. This is particularly significant for barotropic tides, where the entire water column moves in unison.

A key instrument in this process is the Oregon State University Tidal Inversion Software (OTIS). OTIS implements the generalised inverse (GI) scheme, which minimises discrepancies between modelled and observed tidal fields by iteratively adjusting solutions of the shallow water equations (SWEs). It supports grid generation, boundary condition specification, and data assimilation by leveraging efficient matrix factorisation techniques. This facilitates rapid representer calculations, thereby reducing the computational cost of solving large-scale inverse problems.

Egbert and Erofeeva [5.2] address complexities such as inaccurate bathymetry, open boundary conditions, and dissipation parametrisation by incorporating dynamical error covariances into the model. OTIS makes it possible to develop high-resolution regional and global tidal models by efficiently handling grids with up to 100,000 nodes. By retaining the first-order SWE system in the GI penalty functional, the model ensures mass conservation while allowing for relaxed momentum balance constraints, thereby achieving both flexibility and precision.

This inverse modelling framework greatly improves tidal predictions, particularly in coastal regions with intricate bathymetry and irregular coastlines. The iterative refinement process, driven by data assimilation, results in tidal models of high accuracy, making them invaluable for coastal management, navigation, and oceanographic research. By merging observational data with hydrodynamic modelling, this approach provides a robust and adaptable platform for comprehending and forecasting tidal systems worldwide.

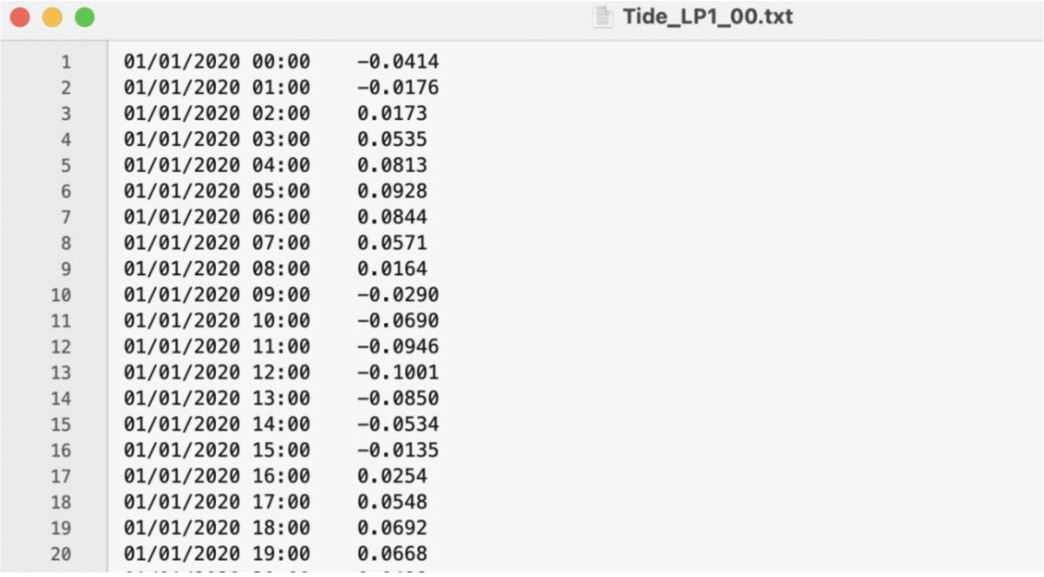
More information on the Oregon State University (OSU) TPXO Tide Models can be found from the official web site [5.4].

For MedSeaRise purposes, tidal time series were extracted for 13 stations. The coordinates of each station and a corresponding graphical representation are provided in Table 3.3 and Figure 3.1, respectively. The data were extracted at hourly temporal resolution from 01/01/2020 00:00 to 31/12/2030 23:00, resulting in 96,409 rows. Each row follows the format dd/mm/yyyy HH:MM d.dddd and is saved in a text file named Tide_StationName, where StationName corresponds to the station ID in Table 3.3. Figure 3.2 shows an example of a tidal time series.

Station	Latitude (deg N)	Longitude (deg E)
LP1_00'	40.45168	22.73286
'LP1_01'	40.41616	22.75137
'LP1_02'	40.26243	22.83822
'PP2_00'	45.64325	13.7903
'PP2_01'	45.49458	13.15274
'PP3_00'	43.70313	7.26608
'PP3_01'	42.56954	7.34774
'PP4_00'	42.42067	18.76825
'PP4_01'	42.16527	18.40141
'PP5_00'	41.38879	2.15899
'PP5_01'	41.22654	2.472953
'PP6_00'	35.89972	14.51472
'PP6_01'	36.12255	14.73559

Table 3.3: List of the stations for which the tidal time series were computed.

Figure 3.1: Geographical positions of the stations considered for the computed tidal time series.

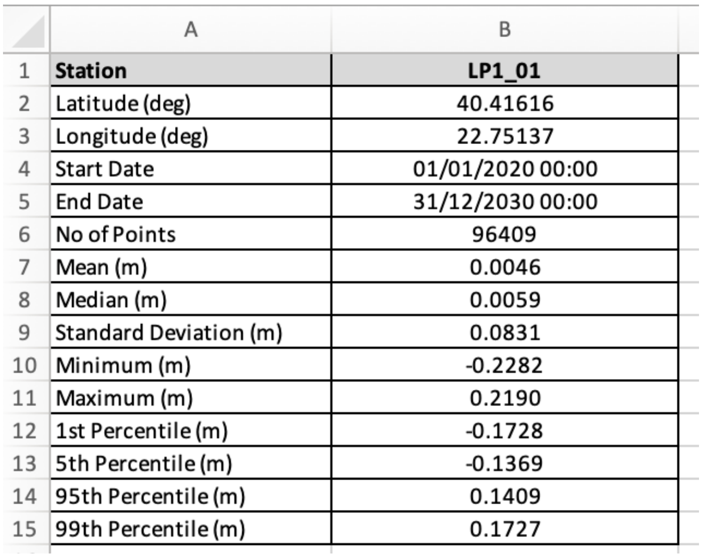


Tide_LP1_00.txt

```
01/01/2020 00:00    -0.0414
01/01/2020 01:00    -0.0176
01/01/2020 02:00    0.0173
01/01/2020 03:00    0.0535
01/01/2020 04:00    0.0813
01/01/2020 05:00    0.0928
01/01/2020 06:00    0.0844
01/01/2020 07:00    0.0571
01/01/2020 08:00    0.0164
01/01/2020 09:00    -0.0290
01/01/2020 10:00    -0.0690
01/01/2020 11:00    -0.0946
01/01/2020 12:00    -0.1001
01/01/2020 13:00    -0.0850
01/01/2020 14:00    -0.0534
01/01/2020 15:00    -0.0135
01/01/2020 16:00    0.0254
01/01/2020 17:00    0.0548
01/01/2020 18:00    0.0692
01/01/2020 19:00    0.0668
```

Figure 3.2: Example of a tidal time series.

Apart from the time series, additional files containing basic statistics derived from the 10-year time series were also generated. These files are named Tide_StationName_STATS.xlsx, where StationName corresponds to the station ID in Table 3.3. Each Excel file includes a table with the following information: Latitude (deg), Longitude (deg), Start Date, End Date, Number of Points, Mean (m), Median (m), Standard Deviation (m), Minimum (m), Maximum (m), 1st Percentile (m), 5th Percentile (m), 95th Percentile (m), and 99th Percentile (m). Figure 3.3 shows the summary for the file Tide_LP1_01_STATS.xlsx.



Station	**LP1_01**
Latitude (deg)	40.41616
Longitude (deg)	22.75137
Start Date	01/01/2020 00:00
End Date	31/12/2030 00:00
No of Points	96409
Mean (m)	0.0046
Median (m)	0.0059
Standard Deviation (m)	0.0831
Minimum (m)	-0.2282
Maximum (m)	0.2190
1st Percentile (m)	-0.1728
5th Percentile (m)	-0.1369
95th Percentile (m)	0.1409
99th Percentile (m)	0.1727

Figure 3.3: Example of statistics computed for the tidal time series at location LP1_01.

For each station, two additional files were generated to show plots of the entire 10-year time series and of the 2025 time series, respectively. These files are named Tide_StationName.pdf, see Figure 3.4, and Tide_StationName_2025.pdf, see Figure 3.5, where StationName corresponds to the station ID in Table 3.3.

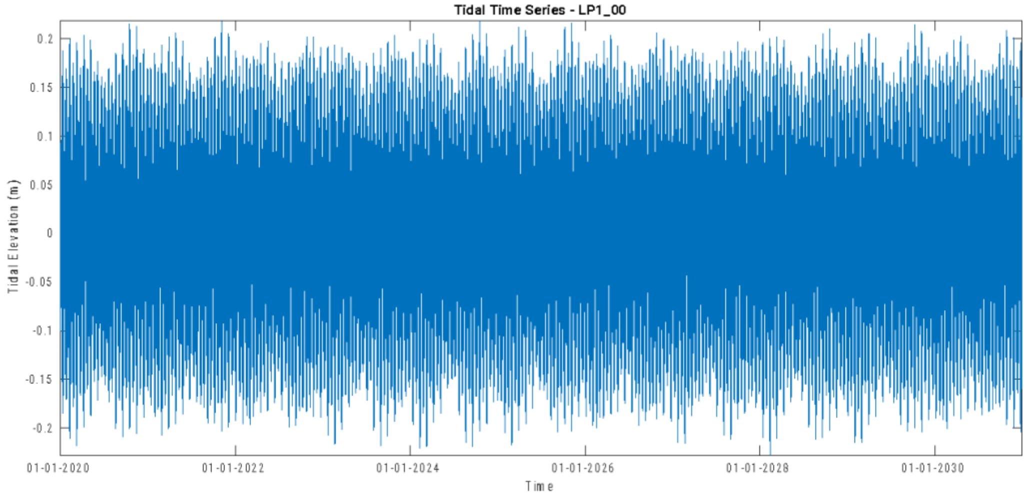


Figure 3.4: Ten-year time-series plot for LP1_00 saved in file Tide_LP1_00.pdf.

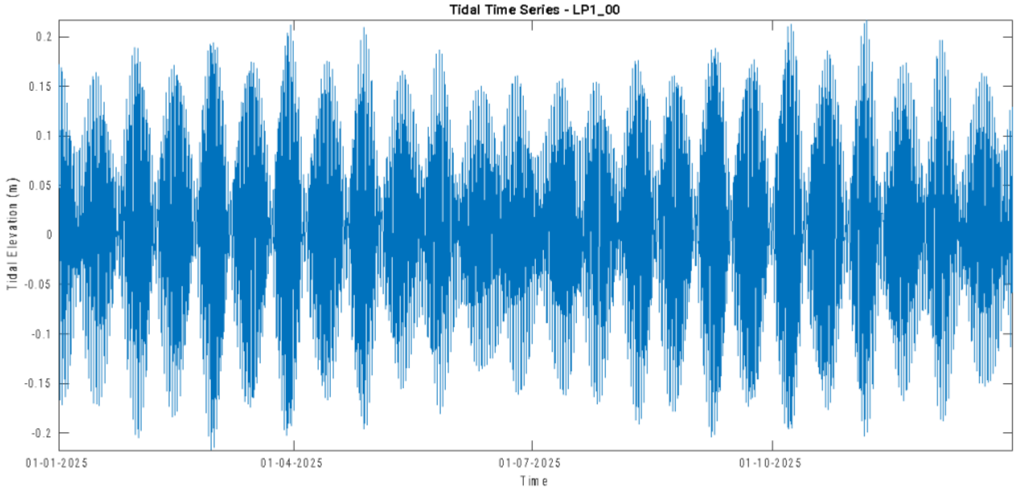


Figure 3.5: Time-series plot zoomed in on 2025 for LP1_00, saved in file Tide_LP1_00_2025.pdf.

The Tide Model Driver (TMD) version 2.5 Toolbox for Matlab [5.3] was used to extract the time series from the model binary files. This toolbox provides a suite of functions for processing and analysing tidal data.

Integration into the MedSeaRise dataset

The tidal time series and the corresponding statistics for each of the stations considered in the MedSeaRise project were used to generate the extreme sea level whenever this was necessary to assess impacts due to daily and sub-daily sea-level variations. Given the independence of high-frequency sea-level displacements from mean sea level, the tide statistics were used according to the following equation:

ESL = MSL variation + **Tide** + **Storm Surge**

For those Project Partners that had the possibility to acquire tidal measures for a multiyear time series, the contribution of atmospheric forcing was included too.

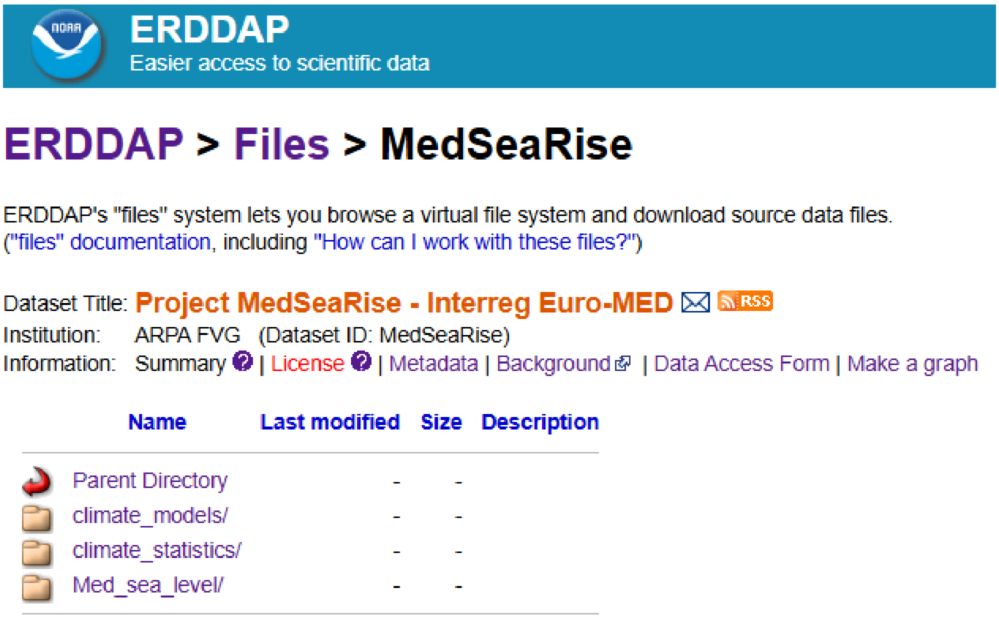
The tidal data and the corresponding statistics for all PP locations are available from the MedSeaRise data distribution hub [4.2] by downloading the files available in the Tides subfolder present in each PP folder within the root folder “climate_models”.

MedSeaRise datasets

Mediterranean ensemble scenarios

The original information on mean sea-level climate scenarios and on daily and sub-daily deviations is accessible from the MedSeaRise data distribution hub [4.2].

The structure of the hub is composed of three main root folders, namely climate_models, climate_statistics and Med_sea_level; see Figure 4.1.



ERDDAP
Easier access to scientific data

ERDDAP > Files > MedSeaRise

ERDDAP's "files" system lets you browse a virtual file system and download source data files.
("files" documentation, including "How can I work with these files?")

Dataset Title: Project MedSeaRise - Interreg Euro-MED
Institution: ARPA FVG (Dataset ID: MedSeaRise)
Information: Summary | License | Metadata | Background | Data Access Form | Make a graph

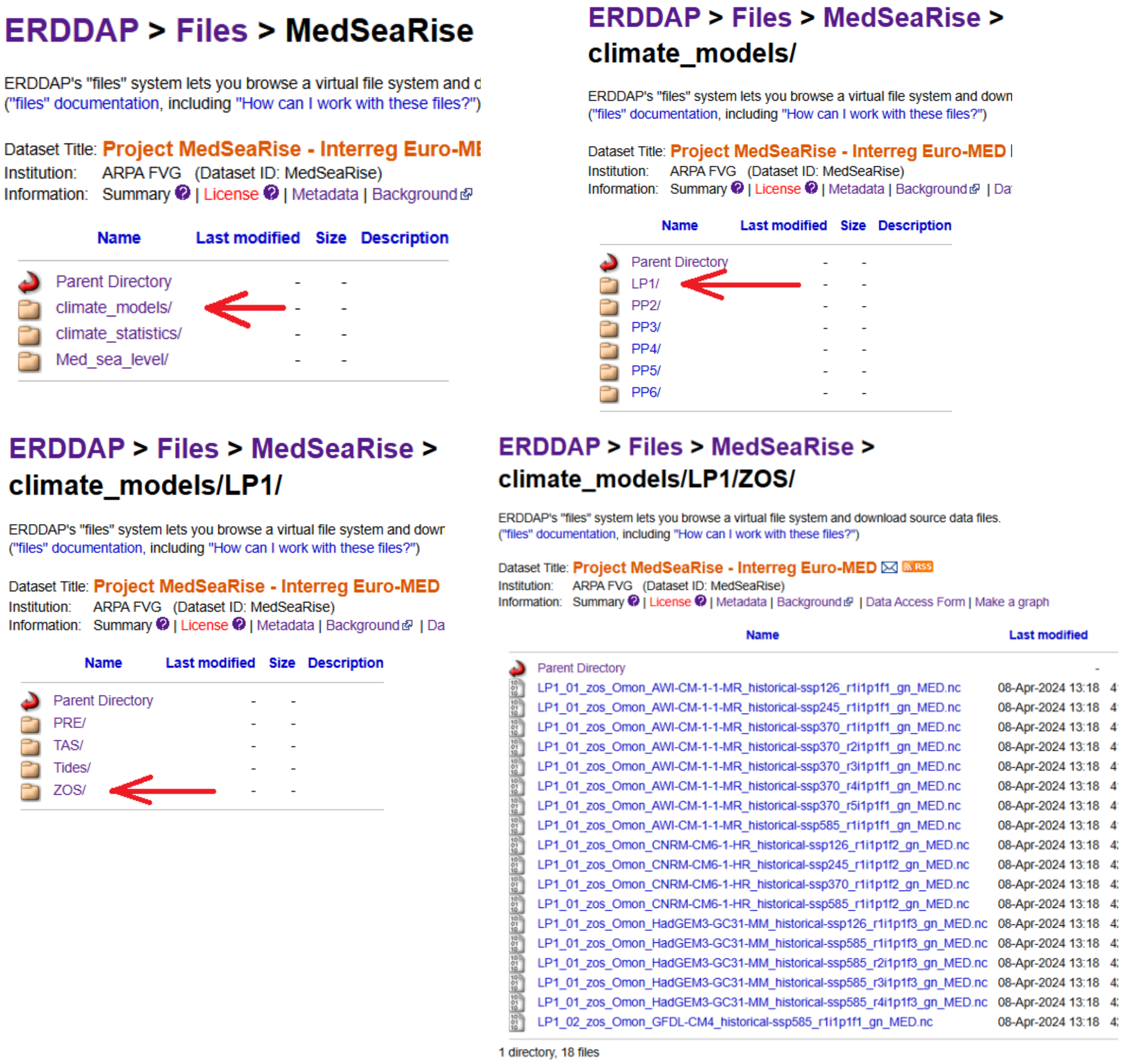
Name	Last modified	Size	Description
Parent Directory	-	-	
climate_models/	-	-	
climate_statistics/	-	-	
Med_sea_level/	-	-	

Figure 4.1: Root folders at the first level of the MedSeaRise data distribution hub [4.2].

The folder climate_models stores all data available for each location where the Project Partners focused the application of the MedSeaRise methodology. There is one subfolder for each PP containing the original high-resolution data from the numerical models that generated the ZOS component of mean sea level, the supplemental atmospheric climate scenarios, namely TAS and PRE, as well as the simulated astronomical tides and the related statistics (Tides). Figure 4.2 provides an example of how the MedSeaRise data distribution hub [4.2] can be explored.

The folder Med_sea_level contains a series of files storing information on sea-level status across the whole Mediterranean for the period 1993-2023, as derived from the Copernicus Marine Service [6.1]. The information therein describes the daily evolution of Mediterranean mean sea level over the last thirty years, based on satellite altimeter observations.

Such information was used to check the consistency of the historical part of the climate scenarios with observations, as well as to investigate the relative differences of sea level with respect to the average sea-level trend for each coastal location considered within the project.



ERDDAP > Files > MedSeaRise

ERDDAP's "files" system lets you browse a virtual file system and c
("files" documentation, including "How can I work with these files?")

Dataset Title: Project MedSeaRise - Interreg Euro-MI
Institution: ARPA FVG (Dataset ID: MedSeaRise)
Information: Summary ❓ | License ❓ | Metadata | Background

Name	Last modified	Size	Description
Parent Directory	-	-	
climate_models/	-	-	
climate_statistics/	-	-	
Med_sea_level/	-	-	

ERDDAP > Files > MedSeaRise > climate_models/

ERDDAP's "files" system lets you browse a virtual file system and down
("files" documentation, including "How can I work with these files?")

Dataset Title: Project MedSeaRise - Interreg Euro-MED
Institution: ARPA FVG (Dataset ID: MedSeaRise)
Information: Summary ❓ | License ❓ | Metadata | Background | Da

Name	Last modified	Size	Description
Parent Directory	-	-	
LP1/	-	-	
PP2/	-	-	
PP3/	-	-	
PP4/	-	-	
PP5/	-	-	
PP6/	-	-	

ERDDAP > Files > MedSeaRise > climate_models/LP1/

ERDDAP's "files" system lets you browse a virtual file system and dowr
("files" documentation, including "How can I work with these files?")

Dataset Title: Project MedSeaRise - Interreg Euro-MED
Institution: ARPA FVG (Dataset ID: MedSeaRise)
Information: Summary ❓ | License ❓ | Metadata | Background | Da

Name	Last modified	Size	Description
Parent Directory	-	-	
PRE/	-	-	
TAS/	-	-	
Tides/	-	-	
ZOS/	-	-	

ERDDAP > Files > MedSeaRise > climate_models/LP1/ZOS/

ERDDAP's "files" system lets you browse a virtual file system and download source data files.
("files" documentation, including "How can I work with these files?")

Dataset Title: Project MedSeaRise - Interreg Euro-MED ✉ RSS
Institution: ARPA FVG (Dataset ID: MedSeaRise)
Information: Summary ❓ | License ❓ | Metadata | Background | Data Access Form | Make a graph

Name	Last modified
Parent Directory	-
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp126_r1i1p1f1_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp245_r1i1p1f1_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp370_r1i1p1f1_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp370_r2i1p1f1_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp370_r3i1p1f1_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp370_r4i1p1f1_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp370_r5i1p1f1_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp585_r1i1p1f1_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_CNRM-CM6-1-HR_historical-ssp126_r1i1p1f2_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_CNRM-CM6-1-HR_historical-ssp245_r1i1p1f2_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_CNRM-CM6-1-HR_historical-ssp370_r1i1p1f2_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_CNRM-CM6-1-HR_historical-ssp585_r1i1p1f2_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_HadGEM3-GC31-MM_historical-ssp126_r1i1p1f3_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_HadGEM3-GC31-MM_historical-ssp585_r1i1p1f3_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_HadGEM3-GC31-MM_historical-ssp585_r2i1p1f3_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_HadGEM3-GC31-MM_historical-ssp585_r3i1p1f3_gn_MED.nc	08-Apr-2024 13:18
LP1_01_zos_Omon_HadGEM3-GC31-MM_historical-ssp585_r4i1p1f3_gn_MED.nc	08-Apr-2024 13:18
LP1_02_zos_Omon_GFDL-CM4_historical-ssp585_r1i1p1f1_gn_MED.nc	08-Apr-2024 13:18

1 directory, 18 files

Figure 4.2: Example of exploration of the climate_models subfolders available through the MedSeaRise data distribution hub [4.2].

See Annex 1, Annex 2 and Annex 5 for further details.

Summary datasets and indexes

To make the work of the Project Partners easier when applying the MedSeaRise methodology, statistics were computed from the original data on sea-level components, both for mean sea level and for daily and sub-daily components. The statistical estimators and the derived indexes are available in the folder climate_statistics; see Figure 4.3.

In that folder there is a README file describing in detail the content of each file. The four files are:

- MedSeaRise_**PRE**_climate_statistics.csv
- MedSeaRise_**SLR_all_components**_climate_statistics.csv
- MedSeaRise_**TAS**_climate_statistics.csv
- MedSeaRise_**ZOS**_climate_statistics.csv

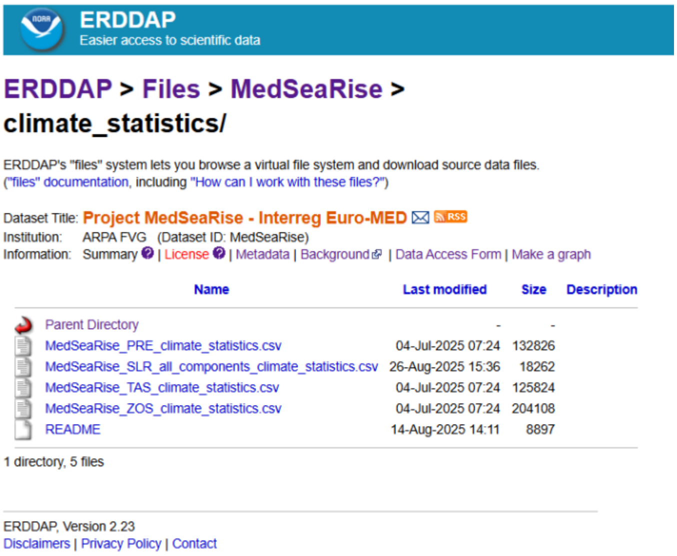
The three files of type MedSeaRise_YYY_climate_statistics.csv, where YYY stands for PRE, TAS and ZOS, contain the full statistics for all months of the year, for each climate scenario and for each geographical position of interest to the MedSeaRise Project Partners. The statistics are computed on all available ensembles of retrieved numerical simulations.

The file MedSeaRise_SLR_all_components_climate_statistics.csv contains the full statistics of ZOS, the same as those reported in the file MedSeaRise_ZOS_climate_statistics.csv, together with all the global components of sea level. From this file, each PP computed the total mean sea-level variation with respect to the 1995-2014 reference period:

MSL variation = **Global Ocean** + **AIS** + **GIS** + **Glaciers** + **LSW** + **ZOS**

This allows the exploration of future sea-level hazard according to the Global Warming Level perspective, future time windows and socio-economic pathways. Annex 3 describes in detail the content of the file.

The indexes and statistics for the astronomical tidal component (Tides) are also available and have already been mentioned in the discussion of the content of the Tides subfolder.



ERDDAP
Easier access to scientific data

ERDDAP > Files > MedSeaRise > climate_statistics/

ERDDAP's "files" system lets you browse a virtual file system and download source data files.
("files" documentation, including "How can I work with these files?")

Dataset Title: Project MedSeaRise - Interreg Euro-MED
Institution: ARPA FVG (Dataset ID: MedSeaRise)
Information: Summary | License | Metadata | Background | Data Access Form | Make a graph

Name	Last modified	Size	Description
Parent Directory	-	-	
MedSeaRise_PRE_climate_statistics.csv	04-Jul-2025 07:24	132826	
MedSeaRise_SLR_all_components_climate_statistics.csv	26-Aug-2025 15:36	18262	
MedSeaRise_TAS_climate_statistics.csv	04-Jul-2025 07:24	125824	
MedSeaRise_ZOS_climate_statistics.csv	04-Jul-2025 07:24	204108	
README	14-Aug-2025 14:11	8897	

1 directory, 5 files

ERDDAP, Version 2.23
Disclaimers | Privacy Policy | Contact

Figure 4.3: How the climate_statistics folder presents the summary statistics and index files through the MedSeaRise data distribution hub [4.2].

Indicators of deliverable achievement

Deliverable indicators

The achievement of the objectives described in this deliverable is summarised by means of the indicators reported below. For each of them, the expected value and the actual value are presented, together with comments where relevant.

Indicator	Expected value	Actual value	Comments
Summary datasets and statistical indexes developed to generate the data and services supporting the MedSeaRise methodology application	6	6	One specific dataset for each PP.
Documentation of datasets	1	2	This deliverable and the README file in the dataset area.

Conclusions

The application of the MedSeaRise methodology for an effective use of sea-level-rise scenarios in climate-change impact risk assessment required quantitative information on the hazards causing the impacts identified by each Project Partner, with the support of stakeholders and experts.

Since the issue addressed by the project is how to use future sea-level climate-scenario data in the risk assessment of impacts on human activities and ecosystems, it was necessary to consider all contributions to sea-level variation with respect to the present sea state.

This stimulated the Project Partnership to investigate all the processes that can raise mean sea level in a warmer global climate and how they interact. In addition, fast-changing sea-level anomalies also had to be considered relevant for the application of the methodology. In fact, most coastal impacts of sea-level change are related to sporadic and extreme events resulting from the synergistic combination of astronomical tides and atmosphere-induced phenomena.

All the widely shared scientific datasets nowadays available for the mean sea level variation have been considered, reviewed and analysed. Data were retrieved and explored in detail to understand spatial dependencies and relevance for the Mediterranean basin.

From the large amount of numerical simulations available for future climate scenarios, data were elaborated to generate an easy-to-access set of information on future sea level, together with summary datasets and statistical indexes to support the application of the MedSeaRise methodology.

Data and indexes available for each PP focus area are accessible through an open-access distribution service implemented within the project.

Annexes

Annex 1 – ERDDAP dataset and services

All files generated in support of the MedSeaRise project, specifically those describing future Mean Sea Level scenarios, the tidal contribution to daily and sub-daily variations, and other atmospheric variables such as air temperature and precipitation, have been collected and are accessible through an ERDDAP service [4.1]. The MedSeaRise dataset is reachable from [4.2] and is available 24/7.

ERDDAP is a data server that provides a simple way to download subsets of scientific datasets in common file formats and to make graphs and maps.

MedSeaRise ERDDAP dataset: https://fenice.arpa.fvg.it/erddap/files/MedSeaRise/

Annex 2 – Original model output data for future climate scenarios

All future climate scenarios generated by the numerical models considered within the activities carried out in the MedSeaRise project are accessible from the MedSeaRise ERDDAP dataset [4.2].

MedSeaRise ERDDAP dataset: https://fenice.arpa.fvg.it/erddap/files/MedSeaRise/

Annex 3 – Statistical indexes for each Mediterranean subarea

A file named MedSeaRise_SLR_all_components_climate_statistics.csv is available for each Project Partner. It reports the main statistics of all contributions to sea-level rise with respect to the reference period (1995-2014). The physical unit is metre [m]. The header of the file summarises the content of each column. The file format is ASCII CSV with semicolon-separated fields. The details of each field are as follows:

Location: ID of the Mediterranean location. It is composed of the Project Partner ID plus the sequential number of the geographical point associated with the reported information. The geographical coordinates of each point are available in Table 3.1.

RCP: climate-change scenario, expressed through the corresponding Shared Socioeconomic Pathway (SSP) / Representative Concentration Pathway (RCP) combination.

Ref period: reference period (twenty years) to which the sea-level anomalies are computed. The reported information has to be added to the mean sea level of the reference period in order to obtain the future sea level.

Period: 10-year period to which the reported information refers.

GWL [°C]: Global Warming Level associated with the reported information and therefore with the period as well. The unit is degrees Celsius.

Decade: the central year of the period.

Months: part of the year described by the reported information. Jan-Dec means the whole year, from January to December.

Sample size: number of elements in the ensemble used to compute the statistics of the Mediterranean dynamical and steric component of sea-level anomaly (an). It is therefore the sample size of an only.

Avg an [m]: average of the Mediterranean dynamical and steric component on sea level anomaly (an), computed over all the monthly values of the period.

Min an [m]: minimum of the Mediterranean dynamical and steric component on sea level anomaly (an), computed over all the monthly values of the period.

1% an [m]: 1st percentile of the Mediterranean dynamical and steric component on sea level anomaly (an), computed over all the monthly values of the period.

5% an [m]: 5th percentile of the Mediterranean dynamical and steric component on sea level anomaly (an), computed over all the monthly values of the period.

25% an [m]: 25th percentile of the Mediterranean dynamical and steric component on sea level anomaly (an), computed over all the monthly values of the period.

50% an [m]: median of the Mediterranean dynamical and steric component on sea level anomaly (an), computed over all the monthly values of the period.

75% an [m]: 75th percentile of the Mediterranean dynamical and steric component on sea level anomaly (an), computed over all the monthly values of the period.

95% an [m]: 95th percentile of the Mediterranean dynamical and steric component on sea level anomaly (an), computed over all the monthly values of the period.

99% an [m]: 99th percentile of the Mediterranean dynamical and steric component on sea level anomaly (an), computed over all the monthly values of the period.

Max an [m]: maximum of the Mediterranean dynamical and steric component on sea level anomaly (an), computed over all the monthly values of the period.

50% GIS [m]: median of the contribution to the sea level due to the Greenland ice sheet melting

95% GIS [m]: 95th percentile of the contribution to the sea level due to the Greenland ice sheet melting

50% AIS [m]: median of the contribution to sea level due to Antarctic Ice Sheet melting.

95% AIS [m]: 95th percentile of the contribution to sea level due to Antarctic Ice Sheet melting.

50% glaciers [m]: median of the contribution to the sea level due to the imbalance between mass gain and mass loss of the continental glaciers.

95% glaciers [m]: 95th percentile of the contribution to the sea level due to the imbalance between mass gain and mass loss of the continental glaciers.

50% landwater storage [m]: median of the contribution to the sea level due to the imbalance of hydrological cycle accounting for surface water, soil moisture, groundwater storage and snow, excluding water stored in glaciers and ice sheets

95% landwater storage [m]: 95th percentile of the contribution to the sea level due to the imbalance of hydrological cycle accounting for surface water, soil moisture, groundwater storage and snow, excluding water stored in glaciers and ice sheets

50% Global Ocean [m]: median of the contribution to the sea level due to the dynamical and steric component at the global scale, which is considered the reference level for the Mediterranean dynamical and steric component on sea level anomaly (an). The total steric component of the Sea Level Rise comes from the sum of the Mediterranean component and the Global component.

95% Global Ocean [m]: 95th percentile of the contribution to the sea level due to the dynamical and steric component at the global scale, which is considered the reference level for the Mediterranean dynamical and steric component on sea level anomaly (an). The total steric component of the Sea Level Rise comes from the sum of the Mediterranean component and the Global component.

Annex 4 – Analyses of the global components of mean sea level

To generate a reliable dataset of future sea-level climate scenarios, the MedSeaRise project conducted a detailed analysis of all the components contributing to mean sea-level change, together with their data sources. Sensitivity to geographical position within the Mediterranean basin was one of the aspects investigated in greatest detail. The compressed (zip) archive attached to this deliverable reports all the results. It is entitled:

Act_2.1_D.2.1.2_datasets_and_docs_supporting_methodology_annex_04.zip

Annex 5 – Supplemental data from climatic scenarios

The MedSeaRise project also produced datasets suitable for complementing the sea-level-rise information. Files of monthly averages, covering part of the 20th century and the whole 21st century, were downloaded for several simulations related to the three main RCP scenarios, namely RCP2.6, RCP4.5 and RCP8.5, together with their historical part. These files were selected from EURO-CORDEX datasets [3.8], that is, CORDEX regional climate-model data on single levels.

From the downloaded files, time series were extracted by bilinear interpolation for specific geographic locations of interest for each Project Partner. These locations are inland and close to those reported in Table 3.1. See Table 5.1 below.

For each Project Partner (PP), time-series files of air temperature at 2 m above the ground (TAS) and precipitation (PRE) are also available for each simulation, geographic location and scenario. The time series are composed of monthly average values extending from a historical part (1951-2005 or 1971-2005) to a future RCP scenario (2006-2100 or 2006-2099). The access point for the data is the MedSeaRise ERDDAP dataset [4.1].

The number of simulations for each considered scenario (historical + RCP) is listed below:

- RCP2.6, **11**
- RCP4.5, **14**
- RCP8.5, **13**

The list of simulations used to generate the dataset is detailed in Table 5.2.

Location ID	latitude [°N]	longitude [°E]	notes
LP1_00	40.63666	22.94216	Thessaloniki (EL); PRE, TAS
LP1_01	40.41616	22.75137	Point offshore in the Thermaic Gulf; ZOS
LP1_02	40.26243	22.83822	Point offshore in the Aegean Sea; ZOS
PP2_00	45.64325	13.7903	Trieste (IT); PRE, TAS
PP2_01	45.49458	13.15274	Point offshore in the North Adriatic Sea; ZOS
PP3_00	43.70313	7.26608	Nice (FR); PRE, TAS
PP3_01	42.56954	7.34774	Point offshore the Cote d'Azur; ZOS
PP4_00	42.42067	18.76825	Kotor (ME); PRE, TAS
PP4_01	42.16527	18.40141	Point offshore in the South Adriatic Sea; ZOS
PP5_00	41.38879	2.15899	Barcelona (ES); PRE, TAS
PP5_01	41.22654	2.472953	Point offshore in the Balearic Sea; ZOS
PP6_00	35.89972	14.51472	Valletta (MT); PRE, TAS
PP6_01	36.12255	14.73559	Point offshore the coastline of Malta; ZOS

Table 5.1: List of the geographical locations for which the supplemental data (TAS and PRE) are available. To complete the table, the offshore points where ZOS is also available are reported too.

Project	Domain	GCM	RCM	Experiment	Ensemble member	Version	Temporal resolution	Variable
CORDEX	EUR-11	CNRM-CERFACS-CNRM-CM5	CNRM-ALADIN63	rcp26	r1i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	CNRM-CERFACS-CNRM-CM5	KNMI-RACMO22E	rcp26	r1i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	CLMcom-CCLM4-8-17	rcp26	r12i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	KNMI-RACMO22E	rcp26	r12i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	SMHI-RCA4	rcp26	r12i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	DMI-HIRHAM5	rcp26	r3i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MOHC-HadGEM2-ES	KNMI-RACMO22E	rcp26	r1i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	rcp26	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	SMHI-RCA4	rcp26	r1i1p1	v1a	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	rcp26	r2i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	NCC-NorESM1-M	GERICS-REMO2015	rcp26	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	CNRM-CERFACS-CNRM-CM5	CNRM-ALADIN63	rcp45	r1i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	CNRM-CERFACS-CNRM-CM5	KNMI-RACMO22E	rcp45	r1i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	CLMcom-CCLM4-8-17	rcp45	r12i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	KNMI-RACMO22E	rcp45	r12i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	SMHI-RCA4	rcp45	r12i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	DMI-HIRHAM5	rcp45	r3i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	IPSL-IPSL-CM5A-MR	SMHI-RCA4	rcp45	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MOHC-HadGEM2-ES	CLMcom-CCLM4-8-17	rcp45	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MOHC-HadGEM2-ES	KNMI-RACMO22E	rcp45	r1i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17	rcp45	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	rcp45	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	SMHI-RCA4	rcp45	r1i1p1	v1a	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	NCC-NorESM1-M	GERICS-REMO2015	rcp45	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	CNRM-CERFACS-CNRM-CM5	CNRM-ALADIN63	rcp85	r1i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	CNRM-CERFACS-CNRM-CM5	KNMI-RACMO22E	rcp85	r1i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	CLMcom-CCLM4-8-17	rcp85	r12i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	KNMI-RACMO22E	rcp85	r12i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	SMHI-RCA4	rcp85	r12i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	IPSL-IPSL-CM5A-MR	SMHI-RCA4	rcp85	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MOHC-HadGEM2-ES	CLMcom-CCLM4-8-17	rcp85	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MOHC-HadGEM2-ES	KNMI-RACMO22E	rcp85	r1i1p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17	rcp85	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	rcp85	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	SMHI-RCA4	rcp85	r1i1p1	v1a	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	rcp85	r2i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	NCC-NorESM1-M	GERICS-REMO2015	rcp85	r1i1p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	NCC-NorESM1-M	GERICS-REMO2015	rcp85	r1i1p1	v1	mon	2m air temperature, mean precipitation flux

Table 5.2: List of the numerical model outputs included in the supplemental data (TAS and PRE) available for MedSeaRise activities.

References

Bibliography and Sitography

[1.1] MedSeaRise Deliverable D.2.1.1, Assessment of the likelihood for each dataset available for Mediterranean sub-basin areas. Link to be updated once uploaded to the project website.

[1.2] Thermosteric sea level rise, 1955–2003, Antonov, J. I., S. Levitus, and T. P. Boyer (2005), Geophys. Res. Lett., 32, L12602, doi:10.1029/2005GL023112. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2012GL051106

[1.3] Antarctic Ice Sheet, Wikipedia, https://en.wikipedia.org/wiki/Antarctic_ice_sheet

[1.4] Greenland Ice Sheet, Wikipedia, https://en.wikipedia.org/wiki/Greenland_ice_sheet

[1.5] Retreat of glaciers since 1850, Wikipedia, https://en.wikipedia.org/wiki/Retreat_of_glaciers_since_1850

[1.6] Sea Level Change, Observation from Space, Land Water Storage, NASA, https://sealevel.nasa.gov/understanding-sea-level/global-sea-level/land-water-storage/

[1.7] Constraining local ocean dynamic sea-level projections using observations, Le Bars, D., Keizer, I., and Drijfhout, S.: Ocean Sci., 21, 1303–1314, https://doi.org/10.5194/os-21-1303-2025, 2025. https://os.copernicus.org/articles/21/1303/2025/

[1.8] IPCC Sixth Assessment Report Chapter 9: Ocean, Cryosphere and Sea Level Change https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-9/

[2.1] IPCC Sixth Assessment Report (2023) https://www.ipcc.ch/assessment-report/ar6/

[2.2] NASA Earth Data https://www.earthdata.nasa.gov/

[2.3] NASA IPCC AR6 Sea Level Projection Tool https://sealevel.nasa.gov/data_tools/17

[2.4] NASA sources of data for the Sea Level Projection Tool https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?more_overlay_open=true

[3.1] CMIP6 - Coupled Model Intercomparison Project Phase 6 https://wcrp-cmip.org/cmip-phases/cmip6/

[3.2] Earth System Grid Federation (ESGF) data search node https://aims2.llnl.gov/search

[3.3] Earth System Grid Federation (ESGF) https://esgf.github.io/mission.html

[3.4] CMIP Model and Experiment Documentation https://wcrp-cmip.org/cmip-model-and-experiment-documentation/

[3.5] The Intergovernmental Panel on Climate Change (IPCC) https://www.ipcc.ch/

[3.6] MedSeaRise Deliverable D.1.1.2, “Data collection on sea level rise scenarios”. Link to be updated once uploaded to the project website.

[3.7] MedSeaRise Deliverable D.1.1.1, “Knowledge and data availability on sea level rise projections”. Link to be updated once uploaded to the project website.

[3.8] EURO-CORDEX - Coordinated Downscaling Experiment - European Domain https://www.euro-cordex.net/

[4.1] ERDDAP Software https://fenice.arpa.fvg.it/erddap/index.html

[4.2] MedSeaRise ERDDAP dataset https://fenice.arpa.fvg.it/erddap/files/MedSeaRise/

[5.1] TOPEX/POSEIDON tides estimated using a global inverse model. Egbert, G. D., Bennett, A. F., & Foreman, M. G. G. (1994). Journal of Geophysical Research: Oceans, 99(C12), 24,821–24,852.

[5.2] Efficient inverse modeling of barotropic ocean tides." Egbert, Gary D., and Svetlana Y. Erofeeva., Journal of Atmospheric and Oceanic Technology 19.2 (2002): 183-204.

[5.3] Tide Model Driver (TMD) version 2.5, Toolbox for Matlab S. Erofeeva, L. Padman, and S. L. Howard (2020). https://www.github.com/EarthAndSpaceResearch/TMD_Matlab_Toolbox_v2.5), GitHub. Retrieved 4th January 2025.

[5.4] Oregon State University (OSU) TPXO Tide Models https://www.tpxo.net.

[6.1] Mediterranean Sea Mean Sea Level time series and trend from Observations Reprocessing https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/mediterranean-sea-mean-sea-level-time-series-and-trend

MedSeaRise
Interreg
Euro-MED
Co-funded by
the European Union

ANATOLIKI
S.A.
ORGANIZATION FOR LOCAL DEVELOPMENT
arpa FVG
CCI NICE CÔTE D'AZUR
UCG
INSTITUT ZA BIOLOGIJU MORA
Cambra
de Comerç de Barcelona
L-Università
ta' Malta