



MedSeaRise

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# DATASETS AND DOCUMENTATION SUPPORTING THE METHODOLOGY AND THE BEST PRACTICES

Deliverable D.2.1.2

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## 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>CINCA</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.2.1.1</b>	Project deliverable 2.1.1: Assessment of the likelihood for each dataset available for Mediterranean sub basin area.
<b>D.2.4.1</b>	Project deliverable 2.4.1: Methodology and the best practices
<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



## Executive summary

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

In this document, a summary presentation of the physical components contributing to the total sea level introduces the datasets. Then the data and indexes, which are available for each PPs focus area, are described in detail together with the distribution services implemented in the frame of the project.

Whenever required, an annex is used to add further details to the text in addition with references to the other project deliverables and public documents and sites.

# Fundamentals of Sea Level variations

## The contributions to the total sea level

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

Since in the frame of the MedSeaRise project, the selected impacts of the sea level are a consequence of both contributions, then the generated datasets include all the sea level components strictly related to the water. Whereas, the vertical displacement of the land was not taken into account because its knowledge requires detailed investigations of the geomorphological features of the coastal areas where the impact of sea level is located. Those investigations are not among the objectives of the MedSeaRise project; anyway, if available, the local trend for the vertical land displacement may be added to the sea level scenarios to get the comprehensive result.

In the following, each component of the sea level variation is described and next the sources of scientific information used for the generation of the summary datasets and indexes too.

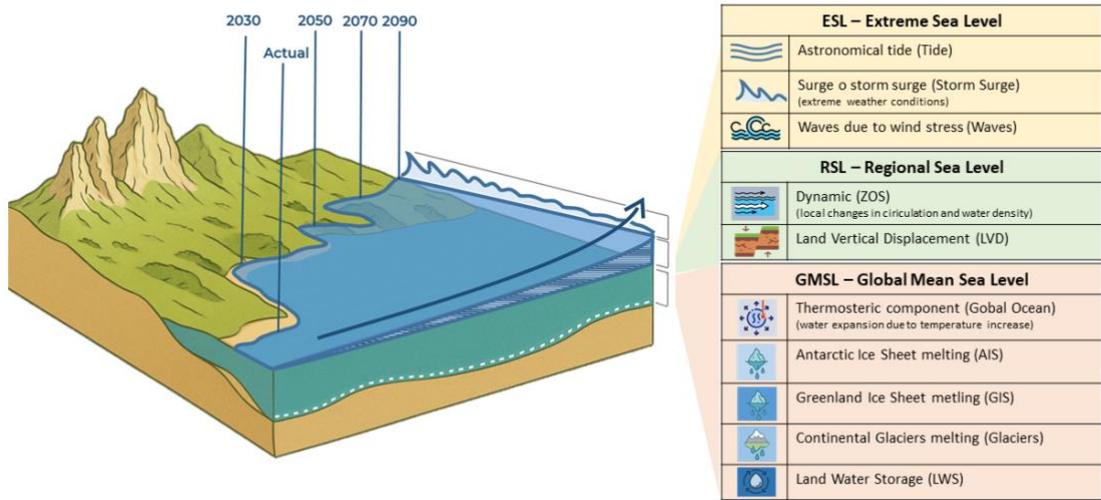


Figure 1.1: schematic description of the contributions of the sea level, when measured with reference to a marker fixed to the coast. Contributions are grouped according to the characteristic variation time. For those related to long-lasting processes, there is a further distinction between those having local validity and those belonging to effects affecting all the 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 the sea level having characteristic evolution times longer than some days are affecting the mean sea level. Those components are a direct consequence of the state of the climate system, in particular of two parts of that system, namely the hydrosphere, which is the liquid water available on our planet, and the cryosphere that is all the water in solid phase available on Earth.

There are three main processes that contribute to the mean sea level change. All these effects change the quantity of the liquid water available in the sea basins and the density of the liquid water, that in turn means the volume of liquid water filling the oceans and the seas.

The first effect is the melting of the ice stored in the continents. In fact, increasing the global temperature of our planet, of both the atmosphere and oceans, ice sheets and mountain glaciers are melting, resulting in the addition of fresh water into the ocean.

The second one is the thermal expansion of the water. Even if the changes in the water density due to the temperature variations are very slight and they are almost imperceptible for small water quantities, the resulting effect from the huge amount of liquid water available in the oceans is evident. Specifically, an increase of the seawater temperature makes the water less dense and then it causes sea levels to rise. Of course a decrease of temperature acts in the opposite way.

Last, it is the variation of the land water storage that is either removed from land and input into the seas or stored on land. Those may be consequences of human activities or changes in the hydrological cycle and they cause a net change in the total water of 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 the component is put in evidence in bold font. That name is found in all the 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 of the ice sheets and on continents (**Glaciers**) [1.5] [1.8] account for a small fraction of the total ice trapped on land. It is about a few percentages of the total ice, anyway the progressive melting of that water storage contributes to the increase in the total

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 relevant too. That is local variations of water salinity, temperature and circulation, which are consequences of climatic processes having spatial scales smaller than global. Freshwater input from rivers, precipitation and evaporation induce a change in water salinity, making water density to change locally. Also changes in sea currents involve the redistribution of water masses. All these effects (**ZOS**) [1.7] [1.8] shall be added to the global ones to describe the overall mean sea level variations.

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

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

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

## Daily and sub-daily variations

Short-term causes are responsible for significant displacement of the sea level with respect to the mean sea level. In fact, the forces acting on the whole mass of oceans and those stressing the water surface, that is the interface between the atmosphere and the water, change with time scales that are 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 the sea level displacement reaches values having a very low frequency of occurrence, according to the statistics computed on the past time series of measures, we define that situation as an Extreme Sea Level (**ESL**). Certainly, the extreme deviations of the sea level with respect the mean are both positive, that is above the mean sea level, and negative, that is a sea level lower in comparison to the mean.

Since MedSeaRise deals with the impacts of the mean sea level increase on human activities and ecosystems, the project considers ESL the positive extremes only. The negative ones may produce impacts too, but in a warming planet the progressive increase of the mean sea level moderates the hazards tied to the negative extremes and emphasizes



the positive ones.

Thus the total sea level variation that is possible to record with continuous monitoring at high time resolution, that is having a sub daily frequency of sampling, results from all the sea level contributions:

$$\text{ESL} = \text{MSL variation} + \text{Tide} + \text{Storm Surge} + \text{Wave height}$$

Here below each of the causes of the short term variations are presented in summary.

### **Astronomical tide**

We define astronomical tide (**Tide**) the rise and fall of sea levels, at location with respect to the mean sea level, which are due to the combined effects of the gravitational forces exerted by the Moon and the Sun, on the liquid water present in Earth oceans and seas. It is a large-scale water motion deriving from the rotation of the Earth and the variation of the gravitational force exerted by those 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, the sea water is hold on Earth surface because of the Earth's force of gravitational attraction acts in a direction inward toward the planet centre of mass. The gravitational forces of the Moon and Sun also act externally upon the ocean waters too.

At the Earth's surface, an imbalance between these forces results a net force acting on the hemisphere of the Earth turned toward the Moon, which attracts toward the centre of the Moon. On the side of the Earth directly opposite the Moon, the net force is in the direction away from the moon. Similar forces exist as the result of the revolution of the Earth around the Sun.

The Moon and the Sun gravitational contribution to tide are always present, but they can act in synergy or to reduce the overall effect on water. This depends on the relative positions of these celestial bodies. Thus the tide amplitude has a periodicity resulting from different cycles.

### **Atmospheric driven anomalies**

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

In fact, tide measurements are not matching the tide amplitudes as they computed, keeping in account the Moon and the Sun gravity action together with the Earth 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 them there is the not uniform pressure of the atmosphere over the sea surface. Low pressure tends to raise sea level and high pressure tends to depress it. The water level does not adjust itself immediately to a change of pressure, it responds to the average change in pressure over a considerable area. A difference from the average atmospheric pressure of 1 hPa can cause a difference in height of about 1 cm.



Also, the effect of wind stress on the sea surface induces variations in sea level and therefore in tidal departures from the astronomical perspective only.

The effects of wind on local sea level depend on the geographical features of the area together with the intensity and persistence of the winds action. In general, wind raises sea level in the direction towards which it is blowing. Strong wind blowing straight onshore piles up the water and causes high tides to be higher than predicted considering astronomical forces only, while winds blowing off the land have the reverse effect.

Those effects are defined as "storm surges" and they are a rise above (positive surge) or 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.

The amplitude of the waves is not a common measure as for the tide measures; furthermore, it can assume a wide spectrum of values, from close to zero centimeters in case of lack of significant wind up to meters in case of strong winds and positive feedback of the wave propagation with the 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.

Anyway, to describe the impacts due to waves along the shores in a future climate scenario, a logical assumption is the wave height, which is computed from wave models of resulting from measurements, is quite independent from all the other causes that affect the sea level. So the amplitude of the wave can be added to the total sea level coming from all the other components.



## Datasets on mean sea level evolution

In this section, the sources of data on the components of the sea level variations are described. Those data have been used for the generation of the MedSeaRise dataset and related indexes on sea level that have been used to apply the MedSeaRise methodology for an effective use of sea level rise scenarios in climate change impact risks assess

### Global component variations

Future climate scenarios on the global component variations, namely **Global Ocean, AIS, GIS, Glaciers, LSW**, are coming from the huge work done by the pool of scientist that have prepared and issued the IPCC 6th Assessment Report (AR6) [2.1] [1.8]. The NASA [2.2] has collected all the global components of the sea level variations according to the available future climate scenarios in an interactive tool [2.3] to provide easy access and visualization to the projections available from AR6. The sources of information on scenarios available from that tool are detailed in a specific 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:** contribute to the sea level rise due to the melting of the Antarctic Ice Sheet;
- **GIS:** contribute to the sea level rise due to the melting of the Greenland Ice Sheet
- **Glaciers:** contribute to the sea level rise due to the melting of the continental glaciers;
- **LWS:** contribute to the sea level rise due to changes in inland water stocks.
- **Ocean dynamics:** contribute to the sea level rise due to the thermal expansion of the seawater and dynamic anomalies, usually referred as Sterodynamic Sea Level.

The above describe components are contributions to the sea level variation, relative to the period 1995–2014, for five Shared Socioeconomic Pathway (SSP) scenarios and five different future Global Mean Surface Temperatures (from 2080–2100). The reference period **1995–2014** is the same adopted for all the other contributions included in the MedSeaRise datasets.

To understand whether global components of the sea level rise in future climate scenarios are highly sensible to geographical position, the global components were retrieved from Nasa Sea Level Projection Tool [2.3], for 10 location across the oceans, of which four of them located within the Mediterranean Sea. See figure 2.1 and table 2.1.

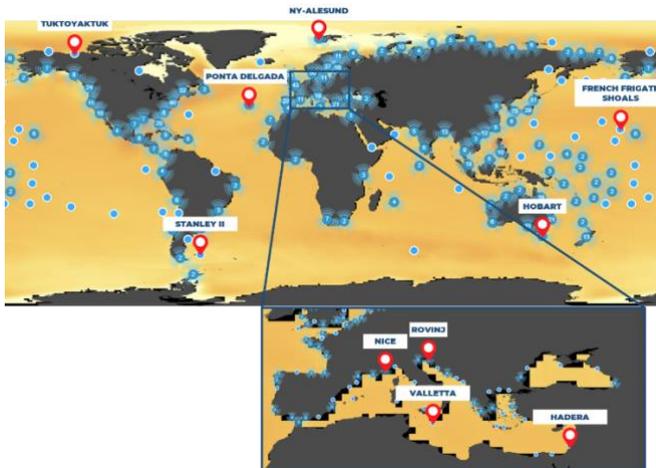


Figure 2.1 Map of the location considered for the sensitivity analysis of the global components of the mean sea level climate scenarios

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

Table 2.1 Table of the location considered for the sensitivity analysis of the global components of the mean sea level climate scenarios

For each of the global components, a comparison was made pairwise for all the couples that can be created using the selected points. The number of couples is:  $C(n, k) = \frac{n!}{(k! \cdot (n-k)!)}$  where n in the number of points and k=2, meaning the pair.

The results were analyzed according to the Global Warming Level perspective and the most relevant percentiles (50% and 95%) of the statistics available from the source of data. The analysis was reproduced for the set of points that are closest to the coastal areas where Project Partners have focused their attention in the methodology application. See figure 2.2 and table 2.2.



Figure 2.2 Map of the Mediterranean location, which have been considered for the sensitivity analysis of the global components of the mean sea level climate scenarios, namely: Global Ocean, AIS, GIS, Glaciers, LSW components of the future climate scenarios for Mean Sea Level variation.

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 2.1 Table of the location considered for the sensitivity analysis in the Mediterranean basin.

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 those analyses are collected in the Annex 4 Together with plots describing the minimum, maximum, mean and median differences and their evolution in time for each Global warming Level. Figure 2.3 gives an example

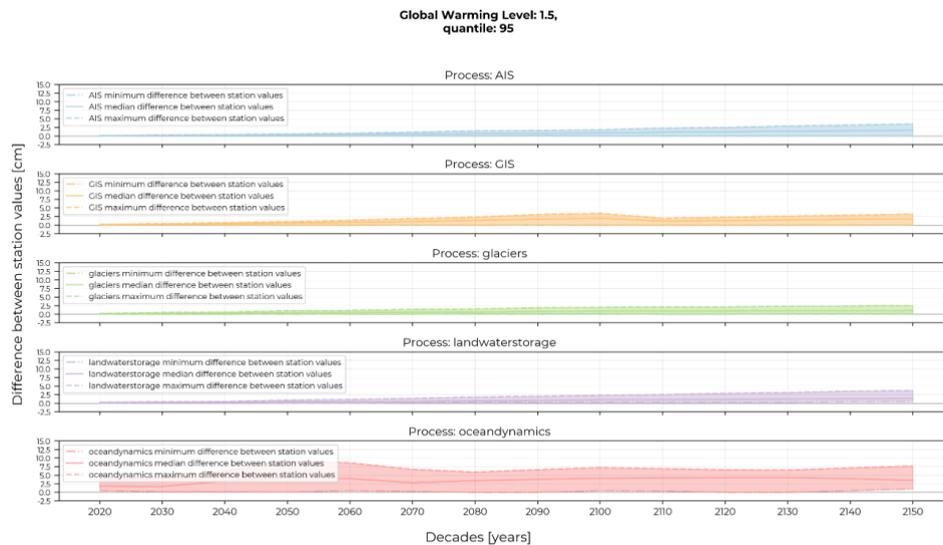


Figure 2.3 Time evolution of the statistics, min, max, median and means, differences across the Mediterranean areas, for all the components of the global effects affecting the means sea level rise. This is an example of the complete analysis available in Annex 4 and it reports differences computed involving the 95% percentile of each component, for the Global Warming Level 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 50<sup>th</sup> and 95<sup>th</sup> percentile values of **GIS**, **AIS**, **Glaciers**, and **LWS** were downloaded from the NASA data dissemination service [2.3] as they are for each of the six MedSeaRise coastal areas; see table 2.2. These two percentiles have been considered only, with the aim to describe a conservative (50<sup>th</sup>) description of the future scenario and an extreme one (95<sup>th</sup>). It is considered realistic to add all the contributions related to the same percentile to get the comprehensive sea level rise, which is representing the sea level rise referring to the same Global Warming Level. In fact, the evolution of the global contributions is driven by the increase of the Earth temperature, then an increase of the planet temperature results in the occurrence of phenomena acting on all the global components, with an uncertainty that we decided to express as the range delimited by the median and the 95<sup>th</sup> percentile of the available data.

The same procedure was applied to the ‘Ocean dynamics’ component, that in the NASA dataset [2.3] includes information both on the evolution of ocean circulation and composition, such as currents and density, and on the steric expansion of seawater. In addition, MedSeaRise project has collected a large set of high resolution numerical



simulations for the stereodynamic contribution to the future climate scenarios, specifically focused on the Mediterranean basin. This is the already described **ZOS** contribution. To allow the generation and use of **ZOS** ensemble of scenarios, then exploit the richness of the two sources of available information, namely the global and the regional, it is necessary to separate the global steric expansion by subtracting the corresponding **ZOS** value representing the dynamic component, which is already available in the MedSeaRise high spatial resolution datasets, from the 'Ocean dynamics' component.

This subtraction has produced a variable, named **Global Ocean Mean**, who is bringing the global effects of the stereodynamic only, leaving the ensemble of **ZOS** data to describe the local stereodynamic affects in each location on which MedSeaRise has applied the methodology.

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

## Regional component variations

The sources of information on the regional stereodynamic component of future scenarios of Mean Sea Level (MSL), which has been considered in the frame of MedSeaRise project, is a set of monthly averages of the MSL field covering the time period ranging from year 1850 to year 2100 and the whole Mediterranean Sea area. These data are shortly referred to as **ZOS**.

Data files were downloaded for as many simulations as possible, related to the four main SSP-RCPs scenarios, namely SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5, together with their historical part. Those files are in netCDF format and are selected from Coupled Model Intercomparison Project Phase 6 (CMIP6) [3.1] data sets with 25 km of (horizontal) spatial resolution. Files are accessible from one of the nodes [3.2] of the Earth System Grid Federation (ESGF) [3.3], which is an international collaboration supporting most 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 are extracted (nearest neighbor interpolation) for specific geographic locations of interest by 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: the locations that the MedSeaRise project has identified to conduct the project activities. Each  
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location ID is associated to the latitude e longitude of the location and the notes report information on the location name and the environmental fields available; namely: sea level (ZOS).

Data are stored in a folder for each Project Partner (PP) and therein other subfolders storing time series files of ZOS. There is one netCDF file for each simulation, geographic location and scenario; the time series are composed by monthly average values extending from an historical part (1850 ÷ 2014) to a future RCP scenario (2015 ÷ 2100).

There is only one location, where ZOS has been considered for each PP. Whereas, It is worth noting that for LP1 two locations have been considered, since for a specific scenario (GFDL-CM4\_r1i1p1f1) no data close enough to the area of interest are available. The number of simulations of ZOS for each considered scenario (historical + SSP-RCP) is listed below:

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 the dedicated 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 that the MedSeaRise project has identified to conduct the project activities. Besides the computational experiment (Project) that has generated the dataset, the institution (Institution ID) and the applied model (Model ID) are reported. The Scenario (SSP-RCP) is identified with a string of the type sspXY, that means the SSP X and the RCP Y. The model configuration used to run it is available too (Configuration run).

In CMIP6 [3.1] numerical simulation, the models are required to be initialized and prepared choosing a specific configuration of physical and chemical processes parametrization, besides the climate forcing. That is referred to as the configuration run (see table 3.2). So



the same numerical model has produced more than one climatic simulation, then a corresponding data set.

The specific configuration run is described by an ID. It is called variant-ID and it distinguishes among closely related simulations by a single model. The variant-ID is composed by four pairs of characters **rNiNpNfN** (e.g. r1i1p1f2) and each pair specifies the following:

- **rN** denotes the realization, that is the ensemble member (N). An example is **r1i1p1f2** indicating that it is the 1st (N=1) realization;
- **iN** denotes the initialization method, that is the method (N). An example is r1**i1**p1f2 indicating that it is the 1st (N=1) method;
- **pN** 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;
- **fN** 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 particular set of results. This is crucial for comparing and analyzing model outputs. Further details on the variant-ID and related issues are available through the CMIP Model and Experiment Documentation [\[3.4\]](#).

The scientific literature collected and analysed according to the project Activity 1.1 (see deliverable D.1.1.1 Knowledge and data availability on sea level rise projections [\[3.7\]](#)) highlighted differences among the numerical model that have contributed in creating the datasets used in the frame of the MedSeaRise project.

Even if all numerical models include the fundamental physical processes driving the evolution of the Earth climate, for example the large-scale dynamics and thermodynamics of the atmosphere, the mass and energy conservation, specific interactions and feedback vary from model to model. Furthermore, the possible future climate scenarios have not been simulated by all the models together with the extension far in the future may be different.

Those, not standardized, model features are considered a richness instead of a disadvantage because each model contributes in the realization of an exploration of the possible future Mean Sea Level status.

## Integration into the MedSeaRise dataset

Such regional stereodynamic (**ZOS**) component of the future scenarios of sea level rise were integrated into the MedSeaRise sea level dataset.

From the downloaded files, time series are extracted (nearest neighbor interpolation) for specific geographic locations of interest by each Project Partner (see table 3.1). Those files are accessible from the MedSeaRise data distribution hub [\[4.2\]](#). In the root folder



“**climate\_models**” there is a subfolder for each Project Partner (PP) and therein other subfolders storing time series files of ZOS. There is one netCDF file for each simulation, geographic location and scenario; the time series are composed by monthly average values extending from an historical part (1850 ÷ 2014) to a future RCP scenario (2015 ÷ 2100).

Furthermore, the ZOS data have been post processed generating the decadal statistics of the sea level anomalies with respect the 20 years reference period **1995-2014**, for the set of 11 years across 2030, 2050, 2070, 2090 years. The statistics considers all the months in a year, this means that it is a yearly view, the summer season and the winter season. Each 11 years statistics is linked to Global Warming Level (GWL) [2.1].

The statistics for all the PPs locations is available from the MedSeaRise data distribution hub [4.2] downloading the file MedSeaRise\_ZOS\_climate\_statistics.csv, which is stored in the subfolder “**climate\_statistics**”. Finally, the same statistics is included in the file MedSeaRise\_SLR\_all\_components\_climate\_statistics.csv, present in the same subfolder, together with all the other components of the future sea level anomalies with respect to the reference period **1995-2014**.

## Daily and sub-daily component variations

To support the project partners in applying the MedSeaRise Methodology also for impacts that require the knowledge of hazards coming from daily and sub-daily sea level variations, such as, **Tide**, **Storm Surge** and **Wave height**, for each Project Partner specific coastal location an hourly time series, 10 years long, of astronomical tide was generated.

That was considered the minimal information to be used in including the short term sea level variations on the mean sea level. Furthermore, all PPs were invited to retrieve, whenever possible, measured time series of sea level for the specific coastal location where the methodology is applied. Surely, that real time series, includes also the effects of the atmosphere on the observed real tide, besides the astronomical contribution only. Of course this is not a possibility shared by all PPs, so the astronomical tide allowed PPs to have at least a set of daily and sub-daily set of data 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 measure are available, tidal fluctuations used in the frame of the project are based on the Oregon State University (OSU) TPXO Tide Models. TPXO is a series of fully global models of ocean barotropic tides 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 1 and Figure 1, respectively. The data were extracted at an hourly temporal frequency 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, while figure 3.1 shows the geographical position of the stations. In figure 3.2 there is an example of 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: the geographical positions of the station considered for the computed tidal time series.



Tide_LP1_00.txt		
1	01/01/2020 00:00	-0.0414
2	01/01/2020 01:00	-0.0176
3	01/01/2020 02:00	0.0173
4	01/01/2020 03:00	0.0535
5	01/01/2020 04:00	0.0813
6	01/01/2020 05:00	0.0928
7	01/01/2020 06:00	0.0844
8	01/01/2020 07:00	0.0571
9	01/01/2020 08:00	0.0164
10	01/01/2020 09:00	-0.0290
11	01/01/2020 10:00	-0.0690
12	01/01/2020 11:00	-0.0946
13	01/01/2020 12:00	-0.1001
14	01/01/2020 13:00	-0.0850
15	01/01/2020 14:00	-0.0534
16	01/01/2020 15:00	-0.0135
17	01/01/2020 16:00	0.0254
18	01/01/2020 17:00	0.0548
19	01/01/2020 18:00	0.0692
20	01/01/2020 19:00	0.0668

Figure 3.2: example of tidal time series.

Apart from the time series, additional files containing basic statistics derived from the ten-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.

	A	B
1	<b>Station</b>	<b>LP1_01</b>
2	Latitude (deg)	40.41616
3	Longitude (deg)	22.75137
4	Start Date	01/01/2020 00:00
5	End Date	31/12/2030 00:00
6	No of Points	96409
7	Mean (m)	0.0046
8	Median (m)	0.0059
9	Standard Deviation (m)	0.0831
10	Minimum (m)	-0.2282
11	Maximum (m)	0.2190
12	1st Percentile (m)	-0.1728
13	5th Percentile (m)	-0.1369
14	95th Percentile (m)	0.1409
15	99th Percentile (m)	0.1727

Figure 3.3: example of statistics computed on a tidal time series for the specific location LP1\_01.

For each station, two additional files were generated to show plots of the entire ten-year time series and 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 1.

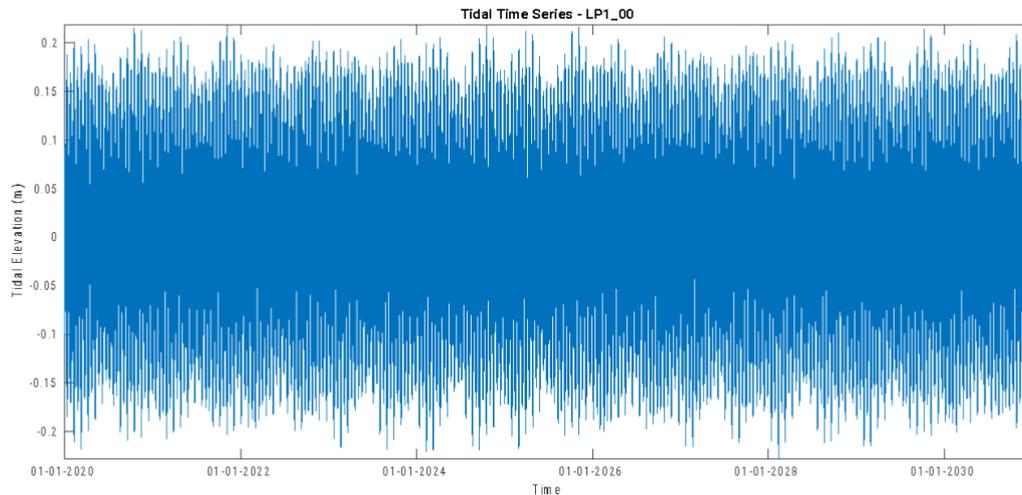


Figure 3.4: ten-year time series plot for LP1\_00 saved in file Tide\_LP1\_00.pdf

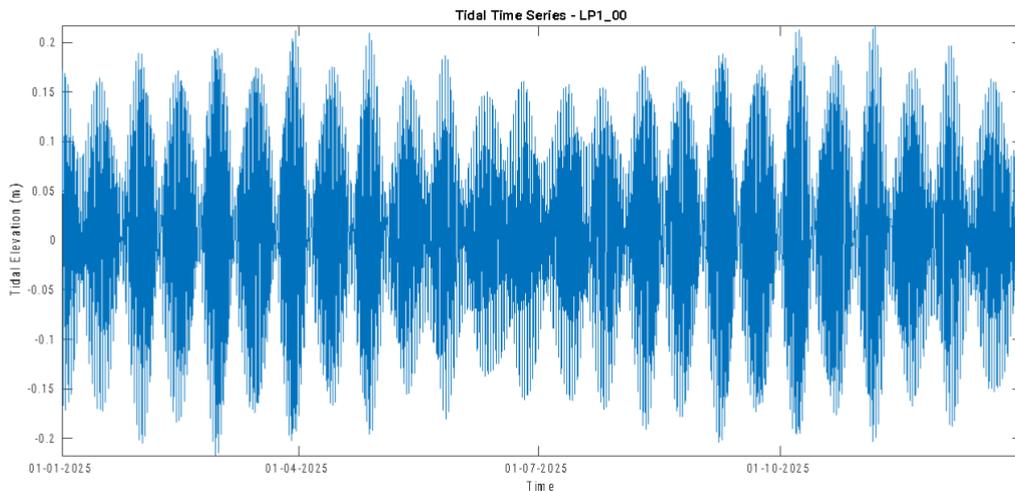


Figure 3.5: zoom of time series plot for 2025 only at LP1\_00 saved in file Tide\_LP1\_00.pdf

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 project MedSeaRise, have been used to generate the extreme sea level whenever it was



necessary to assess the impacts due to daily and sub-daily sea level variations. Since the independence of the high frequency sea level displacements from the mean sea level, also the statistic on tides was used according to the logic:

$$\text{ESL} = \text{MSL variation} + \text{Tide} + \text{Storm Surge}$$

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 the PPs locations is available from the MedSeaRise data distribution hub [\[4.2\]](#) downloading the files available in the subfolder **Tides**, which is present in each of the **PPs** folders of the root "**climate\_models**".



# MedSeaRise datasets

## Mediterranean ensemble scenarios

The original information on the Mean Sea Level climate scenario and those on daily and sub-daily deviation are accessible from the MedSeaRise data distribution hub [4.2].

The structure of the hub composed by three main root folders, namely **climate\_model**, **climate\_statistic** and **Med\_sea\_level**; see figure 4.1.

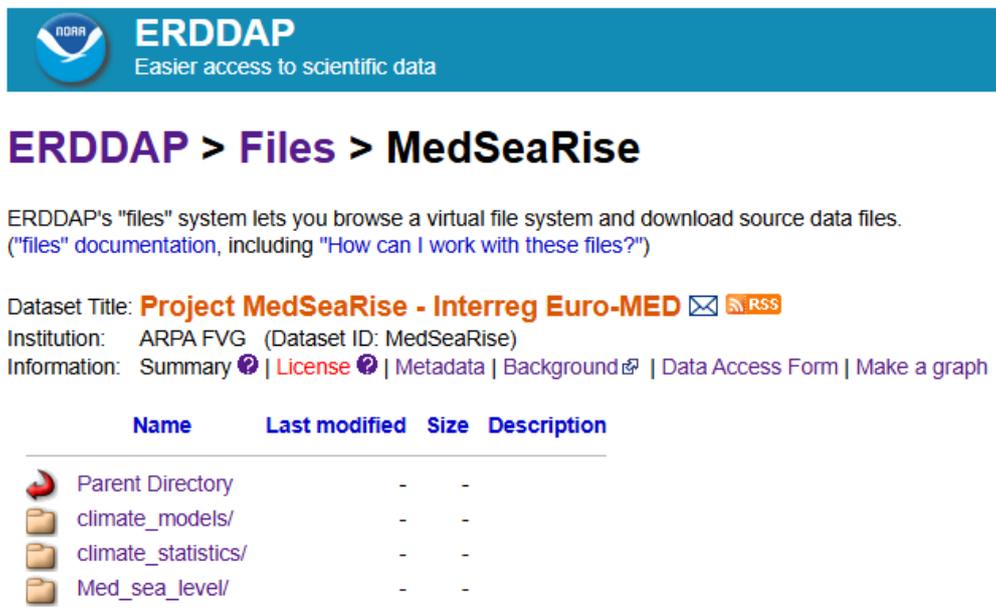


Figure 4.1: the root folders in the first level of the MedSeaRise data distribution hub [4.2].

The folder **climate\_models** stores all the data available for each location where the Project Partner has focused the application of the MedSeaRise Methodology. So, there is one subfolder for each PP that contains the original and high resolution data from all the numerical models that have generated the **ZOS** component of the mean sea level, all the numerical models that have generated the supplemental atmospheric climate scenarios, that if **TAS** and **PRE**, plus the simulated astronomical tides and the related statistics (**Tides**). In figure 4.2 there is an example of exploration of the MedSeaRise data distribution hub [4.2].

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, describe the Mediterranean mean sea level daily evolution over the last thirty years period, based on satellite altimeter observations.



Such information was used to check the consistency of climate scenarios historical part with the reality, besides investigating the relative differences of sea level with respect the average sea level trend, for each coastal location considered in the frame of the project.

### ERDDAP > Files > MedSeaRise

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	-	-	
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 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	-	-	
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**  
Institution: ARPA FVG (Dataset ID: MedSeaRise)  
Information: [Summary](#) | [License](#) | [Metadata](#) | [Background](#) | [Data Access Form](#) | [Make a graph](#)

Name	Last modified	Size
Parent Directory	-	-
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp126_r1i1p1f1_gn_MED.nc	08-Apr-2024 13:18	419021
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp245_r1i1p1f1_gn_MED.nc	08-Apr-2024 13:18	419021
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp370_r1i1p1f1_gn_MED.nc	08-Apr-2024 13:18	419021
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp370_r2i1p1f1_gn_MED.nc	08-Apr-2024 13:18	419021
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp370_r3i1p1f1_gn_MED.nc	08-Apr-2024 13:18	419021
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp370_r4i1p1f1_gn_MED.nc	08-Apr-2024 13:18	419021
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp370_r5i1p1f1_gn_MED.nc	08-Apr-2024 13:18	419021
LP1_01_zos_Omon_AWI-CM-1-1-MR_historical-ssp585_r1i1p1f1_gn_MED.nc	08-Apr-2024 13:18	419021
LP1_01_zos_Omon_CNRM-CM6-1-HR_historical-ssp126_r1i1p1f2_gn_MED.nc	08-Apr-2024 13:18	422366
LP1_01_zos_Omon_CNRM-CM6-1-HR_historical-ssp245_r1i1p1f2_gn_MED.nc	08-Apr-2024 13:18	422366
LP1_01_zos_Omon_CNRM-CM6-1-HR_historical-ssp370_r1i1p1f2_gn_MED.nc	08-Apr-2024 13:18	422366
LP1_01_zos_Omon_CNRM-CM6-1-HR_historical-ssp585_r1i1p1f2_gn_MED.nc	08-Apr-2024 13:18	422366
LP1_01_zos_Omon_HadGEM3-GC31-MM_historical-ssp126_r1i1p1f3_gn_MED.nc	08-Apr-2024 13:18	420730
LP1_01_zos_Omon_HadGEM3-GC31-MM_historical-ssp585_r1i1p1f3_gn_MED.nc	08-Apr-2024 13:18	420730
LP1_01_zos_Omon_HadGEM3-GC31-MM_historical-ssp585_r2i1p1f3_gn_MED.nc	08-Apr-2024 13:18	420730
LP1_01_zos_Omon_HadGEM3-GC31-MM_historical-ssp585_r3i1p1f3_gn_MED.nc	08-Apr-2024 13:18	420727
LP1_01_zos_Omon_HadGEM3-GC31-MM_historical-ssp585_r4i1p1f3_gn_MED.nc	08-Apr-2024 13:18	420727
LP1_02_zos_Omon_GFDL-CM4_historical-ssp585_r1i1p1f1_gn_MED.nc	08-Apr-2024 13:18	420434

1 directory, 18 files

Figure 4.2: Example of exploration of climate\_models subfolders which are available accessing the MedSeaRise data distribution hub [4.2].

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

## Summary datasets and indexes

To make easier the work of the Project Partner in applying the MedSeaRise methodology, some statistics was computed starting 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 deriving 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. There are four files and they 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 the type MedSeaRise\_YYY\_climate\_statistics.csv, where YYY stands for PRE, TAS and ZOS: in these files there is the full statistics for all the month of the year for each climate scenario, and geographical position of interest for MedSeaRise Project Partners. The statistics is compute on all the ensembles of retrieve numerical simulations.

The file MedSeaRise\_**SLR\_all\_components**\_climate\_statistics.csv contains the full statistics of ZOS, the fame of that reported in MedSeaRise\_**ZOS**\_climate\_statistics.csv file, together with all the global components of the sea level, From this file, each PP has computed total mean sea level variation with respect to the 1995-2014reference period:

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

Allowing the exploration of the future sea level hazard according to the Global warming perspective of the future time windows and socio-economic pathways. In Annex 3 each of the content of the file is described in detail.

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

The screenshot shows the ERDDAP interface for the MedSeaRise dataset. The breadcrumb path is ERDDAP > Files > MedSeaRise > climate\_statistics/. Below the path, there is a table listing the files in the directory:

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	

Below the table, it says "1 directory, 5 files". At the bottom of the interface, there are links for "ERDDAP, Version 2.23", "Disclaimers", "Privacy Policy", and "Contact".

Figure 4.3: How the folder climate\_statistics presents the summary statistics and indexes files by means of the MedSeaRise data distribution hub [4.2].



## Indicators of deliverable achievement

### Deliverable indicators

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

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 README file on 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 hazard causing the impacts, which have been identified by each Project Partners, with the support of the stakeholders and the experts.

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

That has stimulated the Project Partnership to investigate what all the processes are that can bring the mean sea level to rise in a warmer global climate and how they interact. Furthermore, also the fast-changing sea level anomalies have to be considered relevant for the methodology application. In fact, most of the coastal impacts of sea level changes are related to sporadic and extreme events, resulting from the synergic combination of astronomical tides and atmospheric 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 on future climate scenarios, data were elaborated to generate 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.

Data and indexes, which are available for each PPs focus area, are available from an open access distribution service implemented in the frame of the project.



# Annexes

## Annex 1 – ERDDAP dataset and services

All the files generated in support to the MedSeaRise project, specifically those describing the scenarios of future Mean Sea Level, the tidal contribution to the daily and sub-daily variations, together with the 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 it is working 24/7.

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

## Annex 2 – Original model output data for future climate scenarios

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

## Annex 3 - Statistical indexes for each Mediterranean subarea

A file **MedSeaRise\_SLR\_all\_components\_climate\_statistics.csv**, is available for each Project Partner. It reports the main statistics of all contributions to the Sea Level Rise, with respect to the reference period (1995-2014). The physical quantity unit is meter [m]. The head of the file summarizes the field content of the corresponding column. The file format is ASCII CSV, semicolon separated fields. The details of each field are the following:

**Location:** ID of the Mediterranean location. The ID of the Project Partner plus the sequential number of the geographical point associated to the reported information, The Geographical coordinates of each point are available in table 3.1.

**RCP:** Shared Socioeconomic Pathway (SSP) and Representative Concentration Pathways (RCP) of climate change scenario.

**Ref period:** the 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 to get the future sea level.

**Period:** the ten years period the reported information refers to

**GWL [C]:** the Global Warming Level associated to the reported information that is to the period too. Units are degrees Celsius.

**Decade:** the central year of the period.

**Months:** the part of the year the reported information describes the future climate. jan-dec



mean the whole year

**Sample size:** the number of element of the ensemble that was used to compute the statistic on the Mediterranean dynamical and steric component on sea level anomaly (an). It is 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]:** 95<sup>th</sup> percentile of the contribution to the sea level due to the Greenland ice sheet melting

**50% AIS [m]:** median of the contribution to the sea level due to the Antarctica ice sheet melting

**95% AIS [m]:** 95<sup>th</sup> percentile of the contribution to the sea level due to the Antarctica 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]:** 95<sup>th</sup> 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]:** 95<sup>th</sup> 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]:** 95<sup>th</sup> 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 project MedSeaRise has conducted a deep analysis of all the components contributing to the mean sea level changes, together with their sources. Sensitivity to the geographical area inside the Mediterranean basin was one of the most detailed. The compressed (zip) archive attached to this deliverable reports all the results. It is file:

**Act\_2.1\_D.2.1.2\_datasets\_and\_docs\_supporting\_methodology\_annex\_04.zip**

## Annex 5 – Supplemental data from climatic scenarios

MedSeaRise project has produced also datasets suitable to complement those of sea level rise. Files of monthly averages, covering part of the XX century and the whole XXI century, have been downloaded for several simulations, related to the three main RCP scenarios, namely RCP2.6, RCP4.5 and RCP8.5, and their historical part. Those files are selected from EURO-CORDEX data sets [3.8] (CORDEX regional climate model data on single levels).

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

For each Project Partner (PP), time series files of air temperature a 2 m above the ground (**TAS**) and precipitation (**PRE**). Are available for each simulation, geographic location and scenario; the time series are composed by monthly average values extending from an



historical part (1951 ÷ 2005 or 1971 ÷ 2005) to a future RCP scenario (2006 ÷ 2100 or 2006 ÷ 2099). The access point for data is the MedSeaRise ERDDAP dataset [4.1].

The number of simulations of 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 location for which the supplemental data (TAS and PRE) are available. To complete the table, the off shore points where ZOS has been included in the dataset 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	r11p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MOHC-HadGEM2-ES	CLMcom-CCLM4-8-17	rcp45	r11p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MOHC-HadGEM2-ES	KNMI-RACMO22E	rcp45	r11p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17	rcp45	r11p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	rcp45	r11p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	SMHI-RCA4	rcp45	r11p1	v1a	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	NCC-NorESM1-M	GERICS-REMO2015	rcp45	r11p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	CNRM-CERFACS-CNRM-CM5	CNRM-ALADIN63	rcp85	r11p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	CNRM-CERFACS-CNRM-CM5	KNMI-RACMO22E	rcp85	r11p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	CLMcom-CCLM4-8-17	rcp85	r12ip1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	KNMI-RACMO22E	rcp85	r12ip1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	ICHEC-EC-EARTH	SMHI-RCA4	rcp85	r12ip1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	IPSL-IPSL-CM5A-MR	SMHI-RCA4	rcp85	r11p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MOHC-HadGEM2-ES	CLMcom-CCLM4-8-17	rcp85	r11p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MOHC-HadGEM2-ES	KNMI-RACMO22E	rcp85	r11p1	v2	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17	rcp85	r11p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	rcp85	r11p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	SMHI-RCA4	rcp85	r11p1	v1a	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	rcp85	r2ip1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	NCC-NorESM1-M	GERICS-REMO2015	rcp85	r11p1	v1	mon	2m air temperature, mean precipitation flux
CORDEX	EUR-11	NCC-NorESM1-M	GERICS-REMO2015	rcp85	r11p1	v1	mon	2m air temperature, mean precipitation flux

Table 5.1: list of the numerical model outputs included in the supplemental data (TAS and PRE) available for MedSeaRise activities.



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