LAYMAN'S REPORT

Agreement Number: ECHO/SUB/2016/742473/PREV16

SEA LEVEL RISE SCENARIOS ALONG THE MEDITERRANEAN COASTS

ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA

Funded by
European Union
Humanitarian Aid
and Civil Protection

SAVEMEDCOASTS

sea level rise scenarios along the mediterranean coasts

SEA LEVEL RISE IS A GLOBAL THREAT FOR COASTAL POPULATIONS

**When I was a child I remember the sea was far from my house even during storms but now the coastline has retreated so much that the waves are flooding roads and fields.
I am aware I am now living too close to the sea, sometimes in dangerous situations, but I want to live here.
This is my land. This is my house**

You may often hear these stories while speaking with old people living along the indented coasts of the Mediterranean. However, you can also hear similar stories elsewhere outside this enclosed basin, where the Oceans meet the continents. Rising sea level is a global threat affecting coastal areas all over the world. Specifically the flat lands facing the sea and the low-lying islands are the more prone to flooding. According to the scientific community could be submerged in the next decades.

Why is sea level rising?

To answer this disturbing question we need to look at the instrumental records and recent scientific papers. Sea level data from the global networks of tide gauge, observations from space by radar altimeters and ground observations, are in agreement with a sea level that started to rise in the mid-19th century and increased by about 14 to 17 cm during the 20th century. Today, sea level is rising at a rate of about 30 cm per century, thus representing a factor of hazard for many coastal populations.
Global warming is the most responsible cause of this rise, triggering the ice melting and the thermal expansion of the oceans. If greenhouse gas emissions will continue in the next years without any mitigation, global sea levels could rise by about one meter throughout the 21st century, several meters by 2300 and beyond. In addition, local sea level rise can be accelerated by natural or human-induced land subsidence that can locally exceed climatically-driven mean sea level rise. Land subsidence is a major problem in historical and modern coastal cities, like for Venice in Italy and New York in USA. The sum of the above natural and anthropogenic factors is causing sea levels to rise and swamp coastal areas, with social and economic consequences. Billions of people living along the coasts of every continent are exposed to this threat. They will become increasingly vulnerable to flooding while higher sea levels would force them to abandon their homes and relocate to inner areas, like in Bangladesh.
The expected sea-level rise projections for the next decades, combined with information on land subsidence, seismicity, tsunami occurrence and extreme waves from storm surges, need to be assessed to prepare people for the ongoing changes. The development of flooding scenarios is therefore crucial for raising the awareness of stakeholders on coastal hazard and fostering a cognizant coastal management to mitigate the economic and social impacts of sea level rise. These are the goals of the SAVEMEDCOASTS project for the Mediterranean Sea in respect of the Prevention Priority plans of the European Union Humanitarian Aid and Civil Protection.

SAVEMEDCOASTS
FACTSHEET

SAVEMEDCOASTS is co-funded by the European Union – Humanitarian Aid and Civil Protection

AGREEMENT NUMBER
ECHO/SUB/2016/742473/PREV16

PROJECT FULL TITLE
Sea Level Rise Scenarios Along the Mediterranean Coasts

DURATION
25 months (18/01/2016 - 31/01/2019)

BUDGET
672.385 euro

GOAL
to produce the first assessment of relative sea level rise projections and flooding scenarios for 2100 along the coasts of the Mediterranean, with particular reference to the pilot sites of Lipari, Monterosso and Lefkada. The contribution of land subsidence, storm surges and tsunamis in the analisys, was considered as well. Raising stakeholder awareness on coastal hazard and communication are also main tasks of the project

PARTNERS
Istituto Nazionale di Geofisica e Vulcanologia (coordinator) | ITALY
Laboratory of Photogrammetry and Remote Sensing Aristotle University of Thessaloniki | GREECE
Centro di Geomorfologia Integrata per l'area del Mediterraneo | ITALY
Centro Euro-Mediterraneo sui Cambiamenti Climatici | ITALY
Environmental Reserach And Consultancy Isotech | CYPRUS
Regional Union of Municipalities of Ionian Islands | GREECE

PROJECT WEBSITE
www.savemedcoasts.eu

DISSEMINATION
Facebook, Twitter, YouTube and Flickr social networks

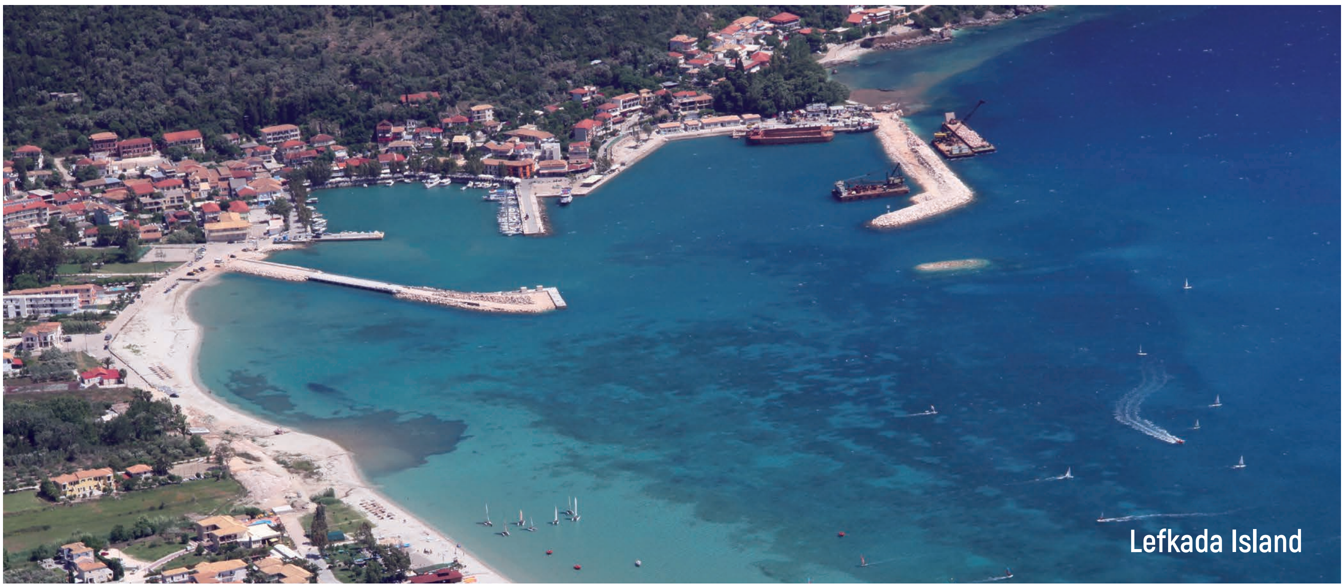
Monterosso | Cinque Terre

THE SAVEMEDCOASTS PROJECT AT A GLANCE

SAVEMEDCOASTS focuses on the Prevention Priority of DG-ECHO funding plans and aims to respond to the need for people and assets prevention from natural disasters in Mediterranean coastal areas undergoing to sea level rise and climate change

GENERAL OBJECTIVES

- Support civil protection at different levels and with different tools and methods, to produce exhaustive risk assessments for different periods and improve disaster risk reduction
- Improve governance and raising community awareness towards the impacts of sea level rise and related hazard
- Foster cooperation amongst science, affected communities and civil protection organizations within and between targeted Mediterranean areas



Lefkada Island

SPECIFIC OBJECTIVES

- Current risk management capabilities and actions are scanned to identify best practices, existing prevention protocols, lacks and room for improvement

- Advanced methods are used to develop multi-hazard assessments through a reanalysis of existing databases for the Mediterranean basin and for low-lying coastal areas placed at less than 2 m above sea level, characterized by high economic and environmental value

- Very high-resolution information for case studies are provided, to support civil protection planning and prevention activities at local level

- Multi-temporal scenarios of the inland extension of marine flooding and coastline position have been realized to evaluate the effects of sea level rise up to 2100. They result from the best available high resolution Digital Terrain Models (DTM), known rates of land subsidence and local sea level rise estimates

- SAVEMEDCOASTS has increased the cooperation amongst science, civil protection and decision-makers, favoring the creation of a cross-border network and introducing new practices to approach key actors, decision-makers, and stakeholders to the understating and use of information and methods, normally restricted to the scientific community

- Information is transferred to society, policy makers and stakeholders, through an open web platform populated with videos and photo galleries and project results

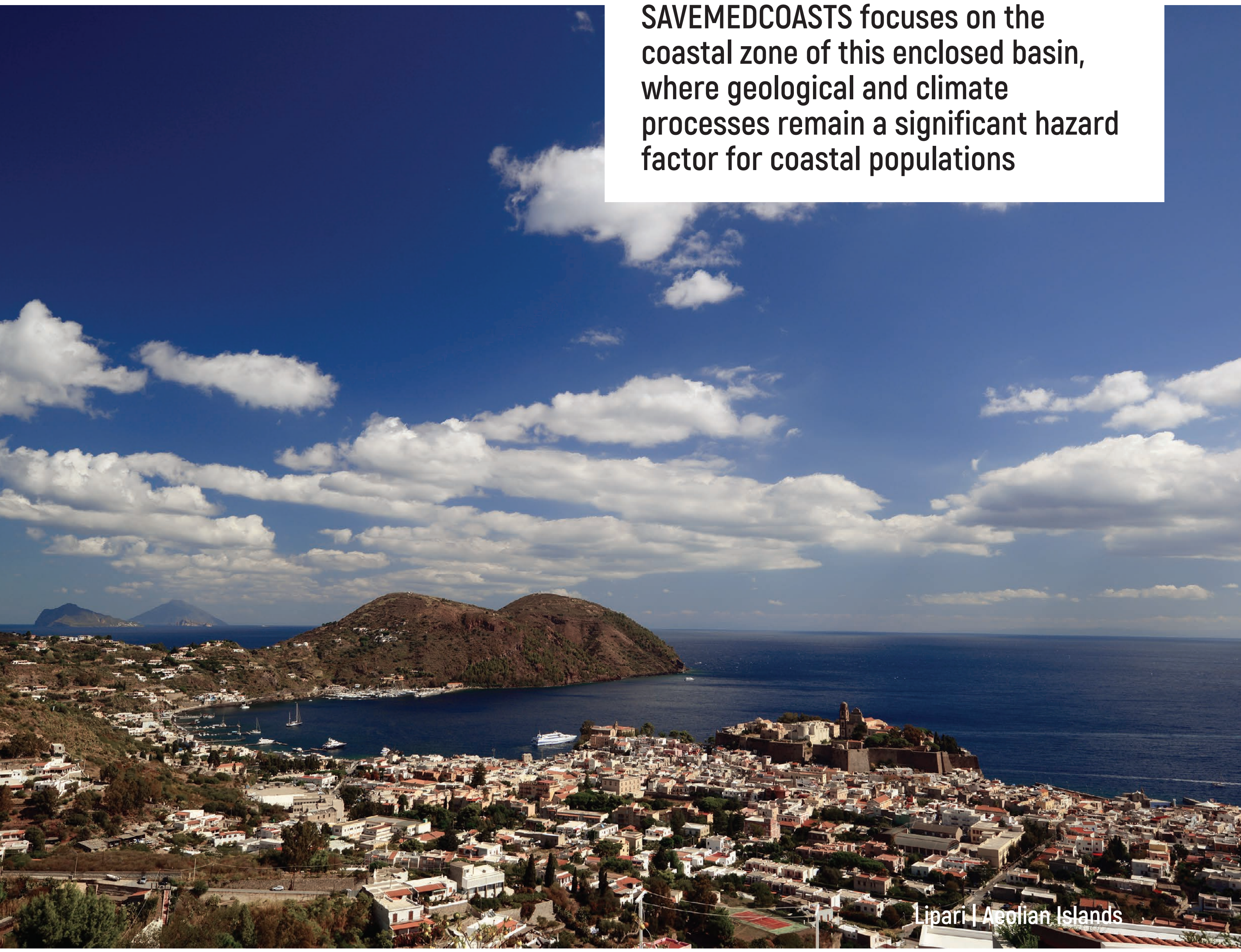
During the project lifetime, SAVEMEDCOASTS has provided an overview of the current relative sea level projections by 2100 for the Mediterranean region, focusing on specific pilot sites.
Results derived from the integration of the most updated scientific data that were transferred to stakeholders to raise their awareness on the ongoing changes

THE MEDITERRANEAN

The Mediterranean basin has been shaped by geological and climatic processes over the past millions of years that formed deep basins, arcuate fault-and-thrust belts and volcanism. This region preserves the traces of these changes that originated during cyclic climatic phases and the long-lasting tectonic convergence between the major Africa and Eurasia plates. This convergence, which is still active at rates of a few millimeters per year, is accompanied by active seismicity and land movements that characterize the mountain chains, the coasts and the inner zones, indicating a complex pattern of crustal stress and strain across the whole region. Seismicity and volcanism are also responsible for destructive tsunamis that have struck the coasts of the Mediterranean since historical times.

Sea level changes are the primary factors affecting the coastal evolution of the Mediterranean in the geological past.
During the Last Glacial Maximum (LGM), about 20.000 years ago, the sea level was about 130 m lower than today.
Then it rose sharply up to a level that remained about constant for some centuries before the industrial age.
After eighteenth century is ongoing a new phase of sea level rise, linked with global warming whose effects will have severe consequences along the coasts of the Mediterranean basin.

SAVEMEDCOASTS focuses on the coastal zone of this enclosed basin, where geological and climate processes remain a significant hazard factor for coastal populations



Lipari | Aeolian Islands

SEA LEVEL RISE PERCEPTIONS

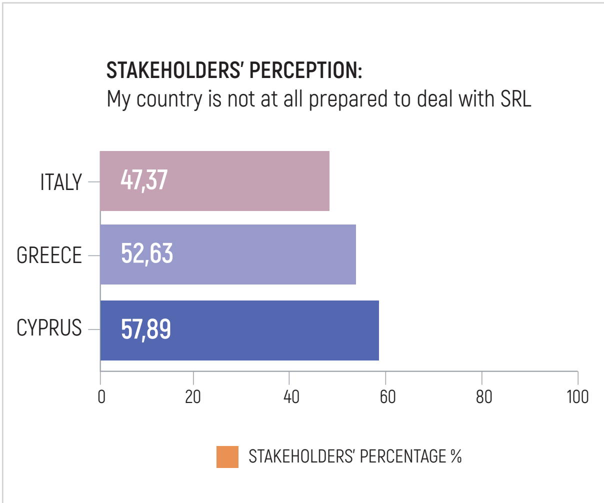
The stakeholder analysis is a key part of the SAVEMEDCOASTS project. We interviewed stakeholders from three countries to rise their awareness on sea level rise and coastal hazard and to transfer the scientific and technical information

STAKEHOLDER MAPPING AND ANALYSIS

142 key stakeholders and decision makers directly and indirectly affected by sea level rise, including representatives from a wide range of governmental and private organizations, businesses and industry, were identified and involved in SAVEMEDCOASTS.

SURVEY "PERCEPTIONS ON SEA LEVEL RISE"

Thirty-eight Italian, twenty Greek and nineteen Cypriot key stakeholders responded on the risks, impacts, gaps, needs and solutions to mitigate and address the phenomenon.
The survey resulted in a over 47% perception of feeling inadequately prepared to cope with SLR.



TWELVE FACE-TO-FACE INTERVIEWS

explored the perceptions of selected key stakeholders.
The semi-structured interviews focused upon exchanging knowledge and allowing information flow.
"I am surprised to realize through this interview that I did not know much about sea level rise, although I thought I knew! I am more aware on my need to be aware!" said a stakeholder after the SAVEMEDCOASTS face-to-face interview.

THREE COUNTRIES SPECIFIC FOCUS GROUPS

to identify the main gaps, needs and actions to be taken to address sea level rise in the three countries were implemented.
The analysis of the focus group outputs resulted in the identification of common attributes in the three countries.

COMMON ATTRIBUTES

THEMATIC CATEGORY	Gaps/needs identified with regards to SLR	Actions to address SLR
LEGISLATIVE	- Need of legislations and policies - Lack of national strategic planning	- Strategic planning - Risk assessment
INFORMATION	- Lack of knowledge, data, scenarios - Need of awareness raising	- Stakeholder engagement
RESEARCH-SCIENTIFIC	- Need of data collection and processing	- Mitigation measures (site-specific) - Research-Data collection-Monitoring
COOPERATION INVOLVEMENT PARTICIPATION	- Lack of collaboration and exchange of information among scientific community and stakeholders/ decision-makers	- Transnational cooperation and exchange of good practices and know-how

SITE SPECIFIC STAKEHOLDERS WORKSHOPS

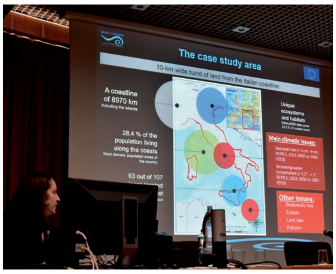
with Lefkada, Lipari and Cinque Terre stakeholders resulted in the identification and prioritization of site-specific measures to address sea level rise in each area.
The workshop methodology was based on a risk assessment and decision support structure (DeCyDe-4-SLR method) taking into account the socio-economic, environmental, and health and safety parameters.

SOLUTION ORIENTED POLICY TOOLS

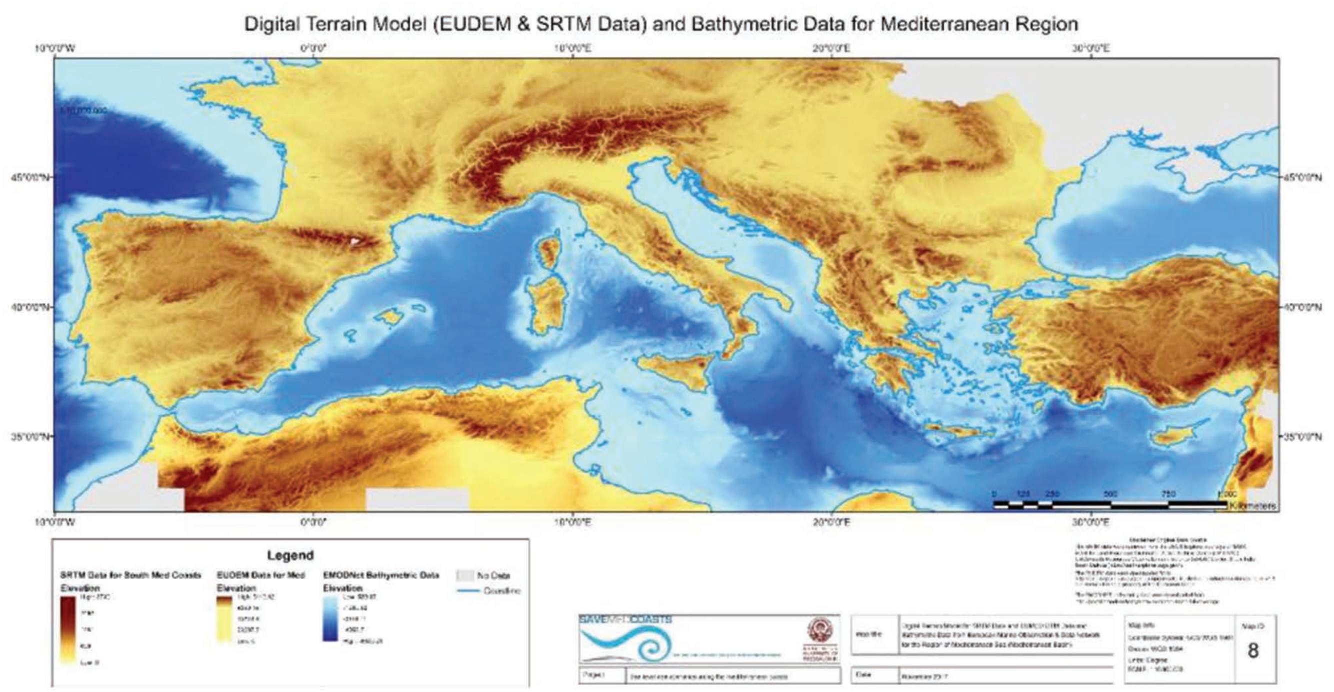
one for each country, were developed after the stakeholder analysis and engagement process.
The Cyprus Policy tool, including risks, gaps and needs, and measures to address SLR, is presented below as an example. SAVEMEDCOASTS face-to-face interview.

CYPRIOT POLICY TOOL

RISKS	GAPS & NEEDS	MEASURES
SLR not yet identified, therefore risk cannot be assesed	Lack of information, knowledge and expertise	Include SLR in national research priorities
Irreversible consequences	Lack of research to collect SLR data	Strategic Action Plan
Beaches could become less attractive to tourism	Lack of a national strategy and action plan address SLR	Infrastrucutre projects should take into account SLR
Increase of insurance fees and compensation	Lack of stakeholder awareness on SLR and how it affects them	Implement global and national mitigation measures
Damages to buildings adjacent to the sea	Insufficient consideration of the problem and the planning level	Study the frequency and intensity of floods
Pressure on infrastructure	Need to adopt prevention measures	Assess SLR risks via field measurements & time series
Beach erosion Beach landscape change	Need to raise awareness in the general public	Stakeholder awareness raising
Increase in extreme storm phenomena	Need to transfer scientific knowledge to decision makers	Research previous data and recent projections
Financial impacts on business and land value		Field measurements to better understand SLR
Coastal protection infrastructure might be ineffective in future		
Socio-economics consequences and emotional risk		
Risk to aquifer		
Risk to biodiversity		
Decrease in agricultural land productivity		
Increased risk of floods		



MAPPING
THE MEDITERRANEAN



High resolution Marine and Digital Terrain Model of the Mediterranean region by bathymetric and topographic data sets.

The topography of the Mediterranean coasts is characterized by many coastal plains that are the most exposed zones at flooding risk in the next decades

To evaluate the location and the dimensions of the zones most prone to marine inundation in response to sea level rise, storm surges and tsunamis, SAVEMEDCOASTS realized high-resolution base coastal maps of the Mediterranean basin containing height and bathymetry information.
Elevation maps (Digital Terrain Models – DTM - and Digital Surface Models - DSM) are a crucial requirement for the assessment of flooding scenarios of a specific region. The produced maps have been used to support the development of multi temporal scenarios of marine coastal flooding. SAVMEDCOASTS used the following datasets for the creation of the base coastal maps:

COASTLINE: Coastline_4326 provided by the National Centers for Environmental Information (NOAA) with an approximately accuracy of 50 m. The coastlines by Open Street Map are also used

DTM / DSM: EUDEM DTM released by the Copernicus mission for the Euro-Mediterranean region (grid of 25 m, horizontal accuracy better than 5 m and vertical accuracy of 2.9 m).
The SRTM 1 Arc-Second Global DTM / DSM data was used for the remaining areas, like North Africa (grid of 30 m, horizontal accuracy of 8.8-12.6 m and vertical accuracy of 5.6-9.0 m)

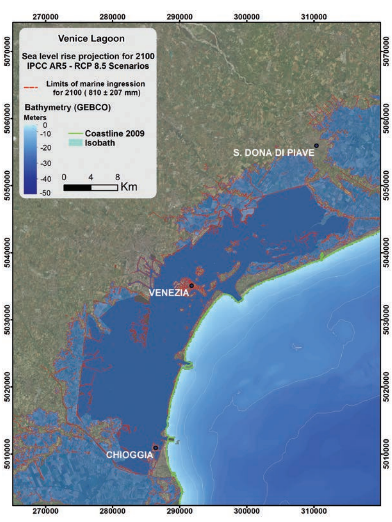
SAVEMEDCOASTS maps have been created in the World Geodetic Reference Projection (latest revision 1984 - WGS 84; EPSG: 4326).
The raster files are in the GEOTIFF format, while the vector files are in the ESRI © Shapefile format.

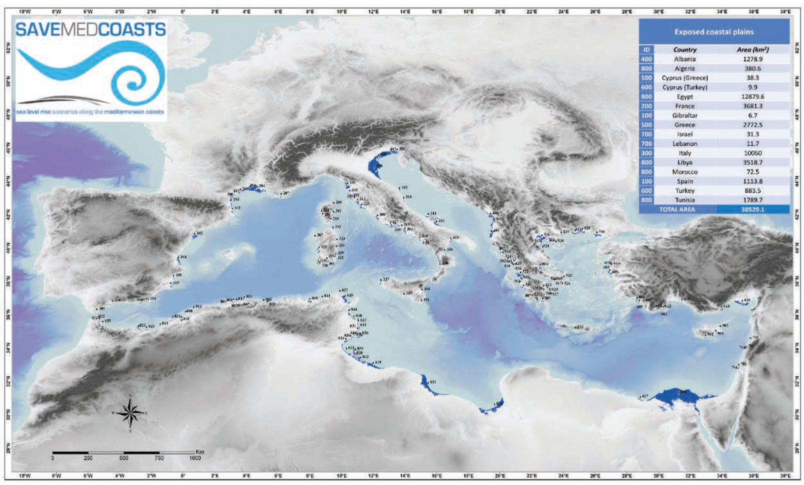
BATHYMETRY: seafloor data released by the European Observation and Data Network (EMODnet), with a resolution of 0.125 arc-minute (about 250 x 250 m grid). Very high resolution bathymetric data from previous projects were used in pilot sites (grid about 10x10 m, vertical accuracy better than 1 m)

SEA LEVEL
RISE

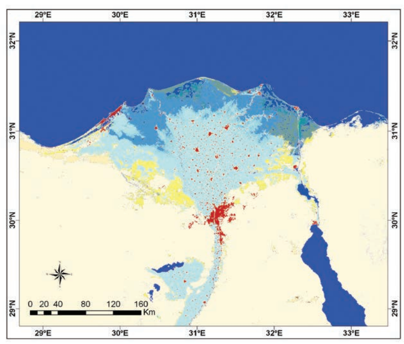
To estimate the sea-level rise for 2100 for the different coastal zones of the Mediterranean, SAVEMEDCOASTS used the regional sea level projections, released in the Fifth Assessment Report of the IPCC-AR5 (www.ipcc.ch)

These data consist in ensemble mean values and upper 95% and lower 5% confidence bounds of the sea level obtained by adding the contributions from geophysical sources driving long-term sea level changes. Particularly, we used sea level projections based on two different Representative Concentration Pathways, RCP 2.6 and RCP 8.5, corresponding to projected CO_2 concentration and other greenhouse gas in the atmosphere. The total sea levels are estimated by the sum of: i) the thermosteric/dynamic contribution (21 CMIP5 coupled atmosphere-ocean general circulation models AOGCMs), ii) the surface mass balance and dynamic ice sheet contributions from Greenland and Antarctica, iii) the glacier and land water storage contributions, iv) the glacial isostatic adjustment and v) the inverse barometer effect. Finally, by combining sea level rise trend with vertical land movements (VLM) from geological or geodetic data of GNSS stations located near the coastal zones, we realized the relative **the relative sea level projections for 163 main coastal plains of the Mediterranean basin**, previously identified by geospatial analysis. For the pilot sites in Italy and Greece, we used very high resolution DTM and regional IPCC sea-level projections to realize **detailed marine flooding scenarios for 2050 and 2100** for five zones at Lipari island, two zones at Cinque Terre and two zones of Lefkada island. Scenarios include the contribution of land subsidence (or uplift). Some examples of the obtained projected local sea level rise up to 2100, shown in the maps here below.

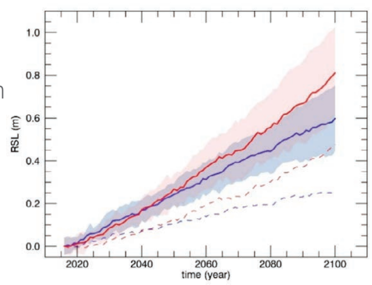




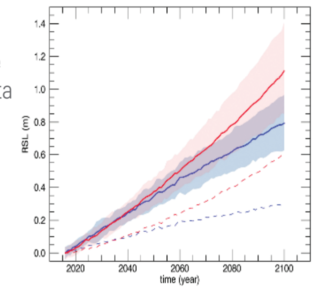
The 163 main coastal plains of the Mediterranean region (in dark blue) highlighted by the geospatial analysis of topographic and bathymetric data. The total exposed area is about 38.529 km2, roughly corresponding to 5.5 million soccer fields.



338
Venice
Lagoon



818
Nile
delta

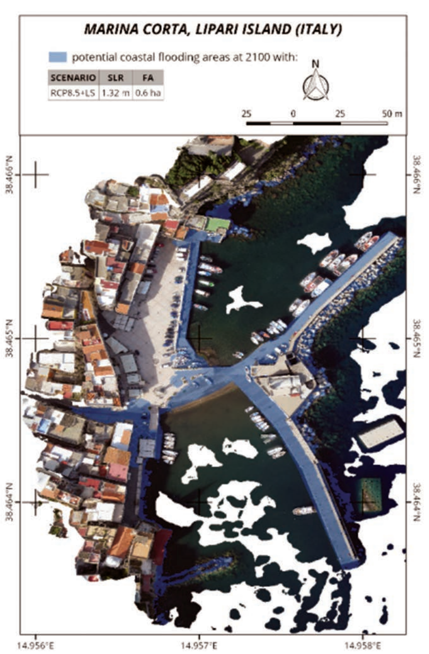


IPCC and RCP

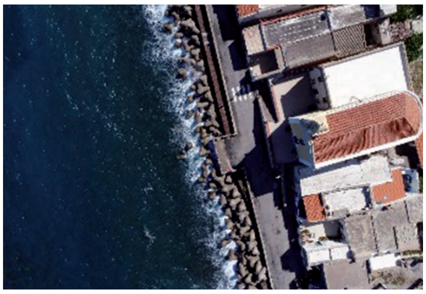
The Intergovernmental Panel on Climate Change (IPCC) is a body of the United Nations, dedicated to provide climate change projections and the related political and socio-economic impacts.
Representative Concentration Pathways, also called RCPs, correspond to different projected CO_2 concentration and other greenhouse gas in the atmosphere. Four commonly used pathways, namely RCP2.6, RCP4.5, RCP6 and RCP8.5, describe different expected future climate. These are related to potential range of radiative forcing values for the year 2100, relative to pre-industrial values (2.6, 4.5, 6.0 and 8.5 W/m2, respectively)

ULTRA HIGH RESOLUTION
SEA LEVEL RISE SCENARIOS

For the realization of the sea level rise scenarios in the two UNESCO sites of Lipari Island and Cinque Terre in Italy and Lefkada Island in Greece, very high and ultra-high resolution DTM/DSM and ortho-images have been generated operating compact and powerful drones (UAV). The generated DSMs and orthophotos have an accuracy of 2-3 cm/pixel. High quality data supported a detailed assessment of the expected marine flooding scenarios due to relative sea level rise by 2100 and the impacts of storm surges in a rising sea level environment. Images support the evaluation of the derived potential economic loss.

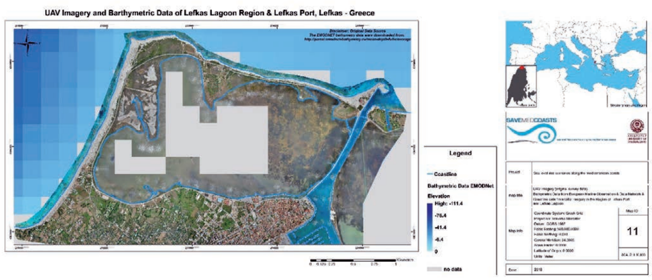


Potential flooding scenario for 2100 (RCP 8.5) at Marina Corta (Lipari Island, Italy) due to sea level rise and land subsidence. The flooded area (highlighted in blue), is estimated with respect to the mean sea level and projected on a high-resolution orthophoto realized by UAV flights.

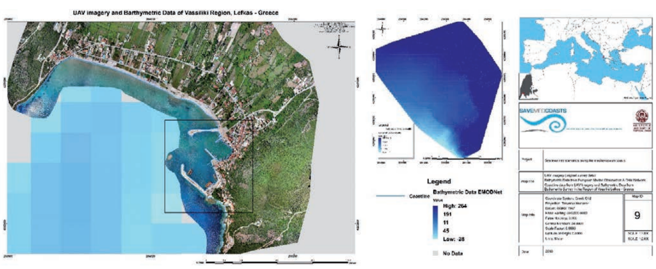


The DTM and the DSM

A Digital Terrain Model (DTM) is an elevation raster grid representing the surface of bare-earth. A Digital Surface Model (DSM) is an elevation raster grid representing the surface of land including also vegetation and man-made artifacts. The main difference between DTM and DSM is their elevation content: the first one describes only the bare-earth, while the second also vegetation, buildings, roads and other features of the Earth surface



UAV imagery and bathymetric data of Lefkas lagoxon and Lefkas port, Greece.



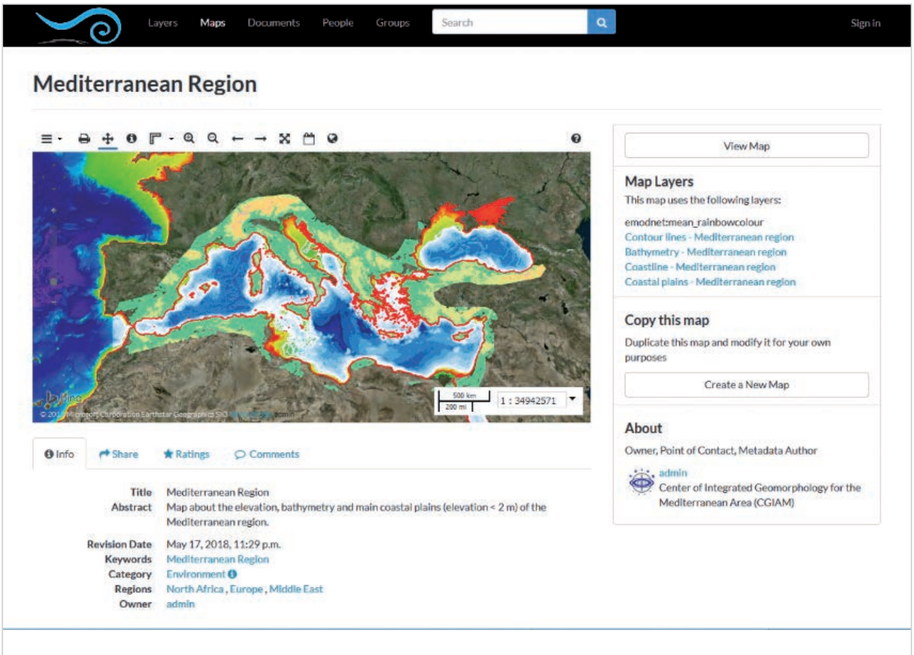
UAV imagery and bathymetric data of Vassiliki bay, Lefkas, Greece.

3D UAV imagery and bathymetric data of the coast of Vernazza, Italy.

UAV

Unmanned Aerial Vehicles (UAV), also called Drones, are powerful tools for topographic surveys and in general for geoscience applications. Within SAVEMEDCOASTS we used lightweight UAVs equipped with high resolution cameras that captured hundreds of aerial photos from about 70 meters of elevation in pilot sites. The photos were analyzed by using a sofisticated software which allowed to create **2D and 3D orthophotos, DTM** and **DSM** to support the realization of flooding scenarios. A **Digital Surface Model (DSM)** is an elevation raster grid representing the surface of land including also vegetation and man-made artifacts. So, the main difference between DTM and DSM is their elevation content: the first one describes only the bare-earth, while the second also vegetation, buildings, roads, etc.

EXPLORING MAPS
AND SCENARIOS



A Web-GIS is a Geographic Information System based on web platform, designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data

The SAVEMEDCOASTS web-mapping system was launched in October 2017 to provide specialists, stakeholders, decision makers and common people project results in a simple way.

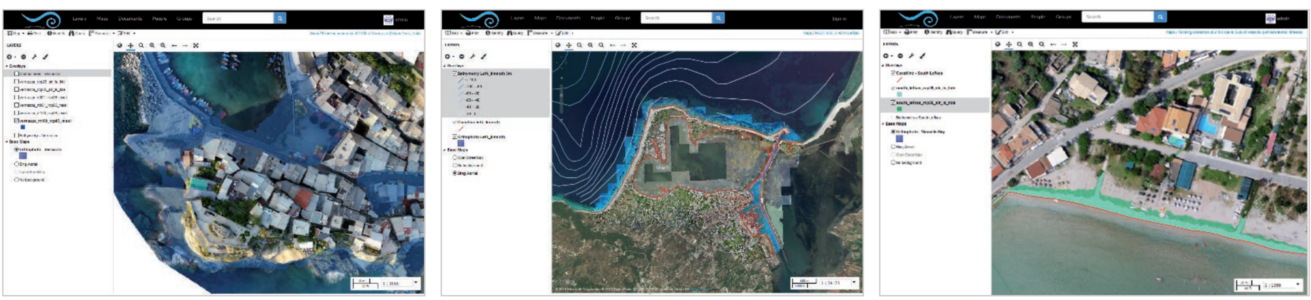
It is accessible online through the project website homepage www.savemedcoasts.eu or directly at webgis.savemedcoasts.eu.

The WebGIS platform is based on open-source solutions realized according the European standards (INSPIRE Directive).
It provides a geospatial data-sharing hub for the project partners, as well as a user-friendly tool for creating interactive maps available for interested users.

The WebGIS is populated with current and new acquisition data for the Mediterranean region.
For the Italian (Cinque Terre and Lipari Island) and Greek (Lefkada Island) pilot sites, ultra-high resolution orthophotos and digital terrain models by UAV surveys are available.

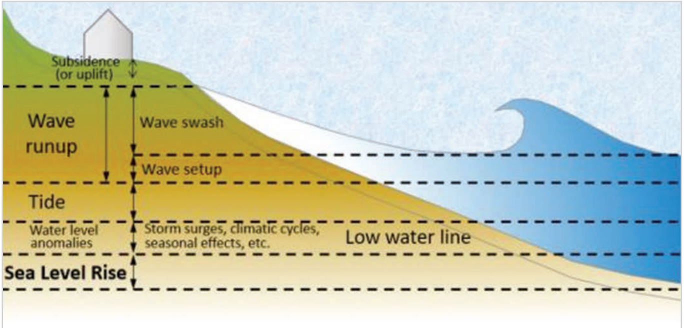
A SET OF 38 LAYERS AND 13 MAPS

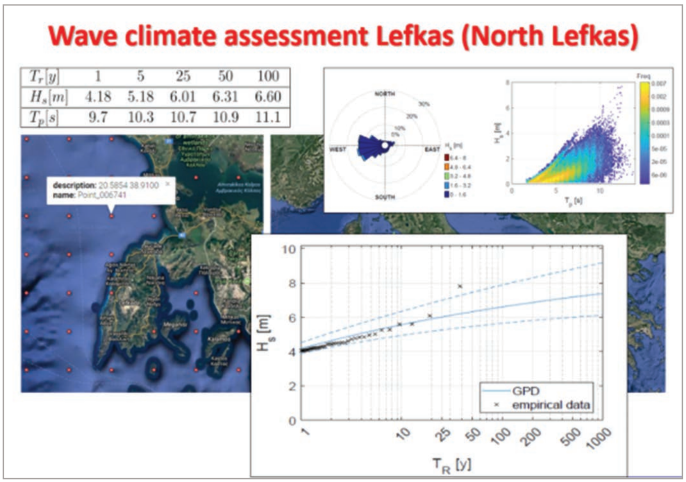
of geospatial data supported the realization of high-resolution maps of marine flooding scenarios for sea level rise and storm surges. The latter in ordinary and extreme conditions



Examples of available maps in the SAVEMEDCOASTS WebGIS

STORM SURGES SCENARIOS
IN RISING SEA LEVELS





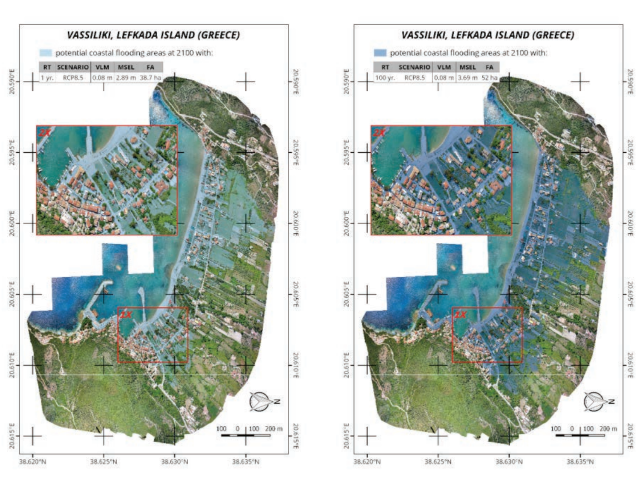
Potential effects of sea level rise combined with higher frequency and intensity storm surges due to climate change, or during tsunamis, is a challenging task. However, process-based models able to consider global and local contributions of the above- mentioned phenomena in reference to possible future scenarios may contribute to define an effective address for policy makers and planners to tackle this threat looming over coastal sites.

To achieve this goal, SAVEMEDCOASTS realized assessments of coastal flooding extension due to the combined effects of sea level rise with ordinary and extreme storm surge events in the pilot sites. The marine wave climate assessment and storm surge data for the study areas were evaluated through a Forecast/Hindcast procedure. The system was developed by the Department of Environmental, Chemistry and Civil Engineering of University of Genoa for the period 1979-2016 for the Mediterranean Sea.

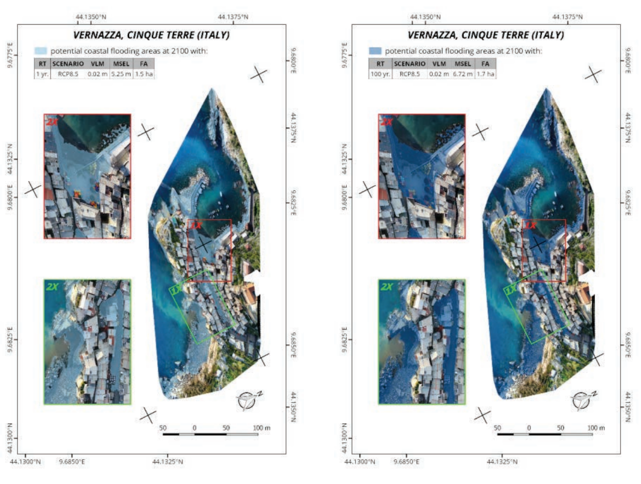
Maps with ordinary and extreme storm surge events on a littoral prone to erosion are realized for the pilot sites. Scenarios are based on the evaluation of the maximum super-elevation level (MSEL) at 2100 due to combined effects of sea level rise and vertical land movement. For each pilot case, four scenarios are considered with extreme possible combinations between return time and RCP expected for 2100. Each map shows the longshore distribution and extension of the flooding area and provides numerical information on the considered scenario. The return time (1 or 100 yr.), the IPCC scenario (RCP 2.6 or 8.5), the rate of land subsidence, the MSEL in meters and the estimated flooding area extension (FA) expressed in hectares, are estimated.

WHAT IS THE RETURN TIME OF AN EVENT?

The "return time" (or "return period" or "recurrence interval") is a measurement of the probability that an event (e.g. flood, earthquake, wind storm, etc.) of a given magnitude will occur in a certain time interval.
For instance, if a flood has a return time of 100 years, there is a 1 in 100 chance (1%) that this will occur in any single year. It does not mean that such event will occur once every 100 years. The higher the return time is, the lower is the probability that such event will occur



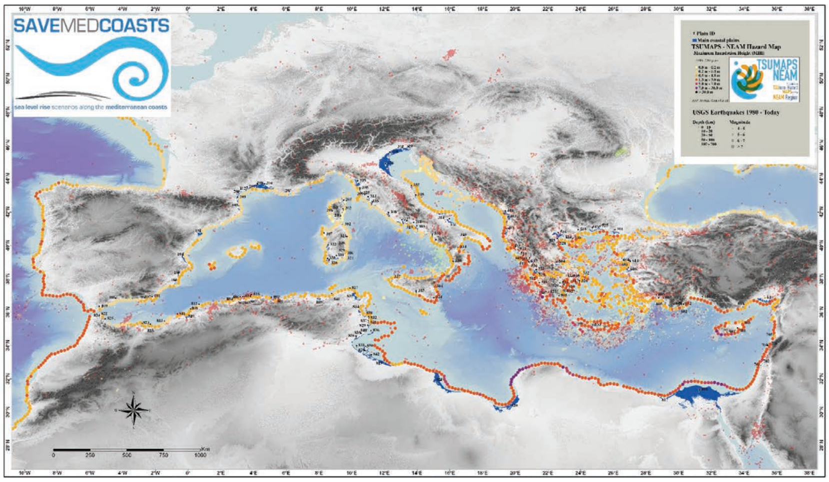
Potential storm surges scenarios at 2100 (RCP 8.5, Return Time 1 and 100 years) for Vassiliki (Lefkada, Greece)



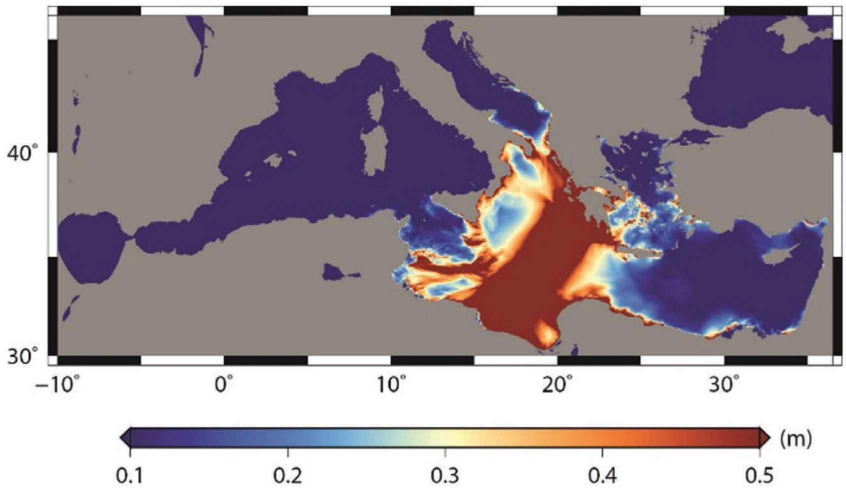
Potential storm surges scenarios at 2100 (RCP 8.5, Return Time 1 and 100 years) for Vernazza (Cinque Terre, Italy)

TSUNAMI HAZARD
IN A SEA LEVEL RISE LANDSCAPE

The Mediterranean basin has been affected by tsunamis in historical times as described in ancient chronicles, and until recently, they were still part of the living memory of the population



Local (mean value of the) maximum inundation height (MIH) expected to be overcome on the average every 2500 years in the Mediterranean basin. In blue are the 163 main coastal plains prone to coastal hazard identified by SAVEMEDCOASTS. Some of these plains are highly exposed to tsunami risk.
About tsunami hazard in the Mediterranean region read more on www. http://www.tsumaps-neam.eu/

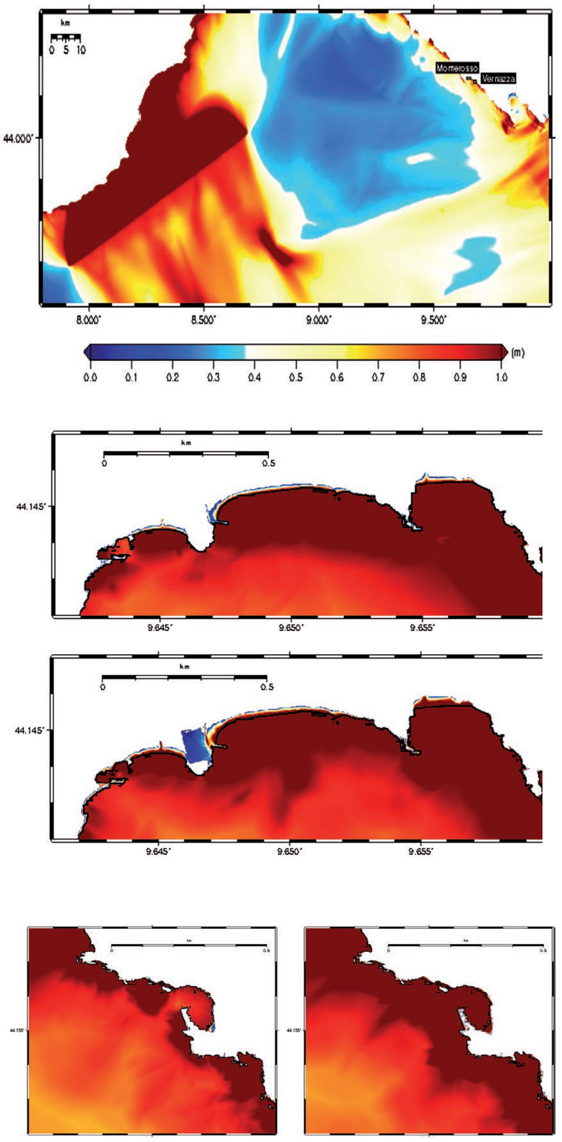


Numerical simulation of a tsunami propagation in the Mediterranean caused by a M=8.5 earthquake, possibly similar to the 365 C.E. western Crete event. The color palette shows the simulated offshore wave height (meters). The coastal plains of North Africa, southwestern Greece and southeastern Italy are particularly exposed to tsunamis originated from earthquakes located along the Hellenic Arc subduction zone.

The consequences of tsunami within this basin are particularly severe because of the short distances between the tsunamigenic sources and the nearest exposed coasts so that alarms by the NEAMTWS Tsunami Service Providers and by National Tsunami Warning Centers (http://www.ioc-tsunami.org/) need to be launched within a few minutes before impact.
The tsunami risk in the Mediterranean Sea is enhanced by the high presence of people living along the shores, critical infrastructures, like harbors and communication lines, tourism and cultural heritage sites.
About 300 potential tsunami events have been reported for this area for the last four millennia. About 10% of reported tsunami in the world occur here, and about 7% of the largest historical earthquakes across the region in the last few thousand years have triggered tsunami. Also active volcanoes caused tsunamis, like during the eruption of Stromboli of 30 December 2002 in the Aeolian Islands.
Evidences of past large tsunamis are given by marine sediments interbedded in lagoonal settings, mega-boulders of up to 40 t deposited up to tenths of meters inland and mega washover fans, like those extending for several square kilometers up to 2 m above sea level along the northern coasts of Lefkada Islands (Greece). The three most recent tsunamis in this active region occurred on May 21, 2003 in Algeria, after the magnitude 6.8 Zemmouri-Boumerdes earthquake, on July 20, 2017 in Turkey in the Bodrum/Kos area, related to a magnitude 6.6 earthquake, and on October 25, 2018, due to an earthquake of magnitude 6.8 located offshore of Zakynthos, with the Zemmouri-Boumerdes one being largest of the three, yet relatively moderate.
The zone between the eastern Mediterranean Sea and the Aegean Sea, corresponding to the Hellenic Arc subduction, is the one of the most seismically active in the region. Likely, this was the source of the July 21, 365 C.E. magnitude >8 earthquake that generated a destructive tsunami that hit most part of the Mediterranean coasts. SAVEMEDCOASTS capitalized the results of TSUMAPS-NEAM project (funded by DGECHO, Grant Agreement ECHO/SUB/2015/718568/PREV26) to focus on the main coastal plains more exposed to tsunami hazard and provide high resolution scenarios for pilot sites.

In a sea level rise condition for 2100, however, the tsunami hazard would be enhanced with respect to TSUMAPS-NEAM estimates.

Numerical simulations of tsunami generation from local earthquakes, and of propagation and eventually inundation on high resolution topo-bathymetric models have been performed for the pilot sites of Cinque Terre (Monterosso and Vernazza) and Lipari.



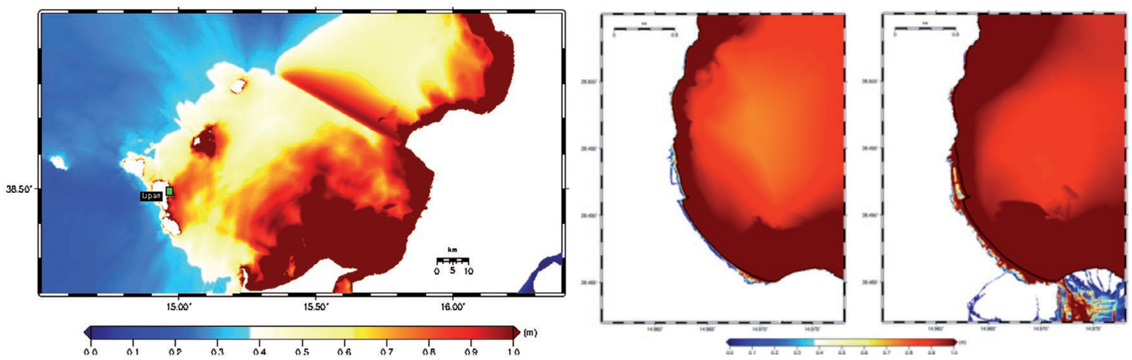
Maximum wave height achieved by the tsunami in Aeolian Islands. The numerical simulation is relative to a M=7.5 earthquake in the SE Tyrrhenian Sea. The color palette shows the simulated offshore wave height (meters). The inundation obtained with and without the sea level rise is shown.

The Tsunami-HySEA code used a GPU-optimized solver for the non-linear shallow water (NLSW) equations. It was developed by the EDANYA Group of the Applied Mathematics Department of University of Malaga (Spain). Bathymetric and onshore grids were obtained by combining and resampling high resolution bathymetric data from SCANCOAST and DPC-INGV projects (0,5 m/ pixels, acquired by multibeam technique), EMODNET (115 m/pixel), LiDAR MATTM (2 m/pixel) and high resolution UAV aerial photogrammetry data (0,02 m/pixel).

For the Cinque Terre site, we implemented a seismic source possibly similar to the 1887 Liguria earthquake (Mw 6.3), but increasing the fault size and slip to simulate an earthquake of Mw 7.5. For the Lipari site, we implemented a seismic source simulating an earthquake scenario in the area of the 1905 central Calabria earthquake (Mw 7). The fault source is shaped according to the position of the so-called Coccorino fault and the fault size and slip were dimensioned to simulate an earthquake of Mw 7.5. For each site, two tsunami propagation simulations have been executed, one using the present-day bathymetry and one imposing the expected sea level rise predicted for 2100 (0.56 m for Cinque Terre and 1,32 m for Lipari, respectively).

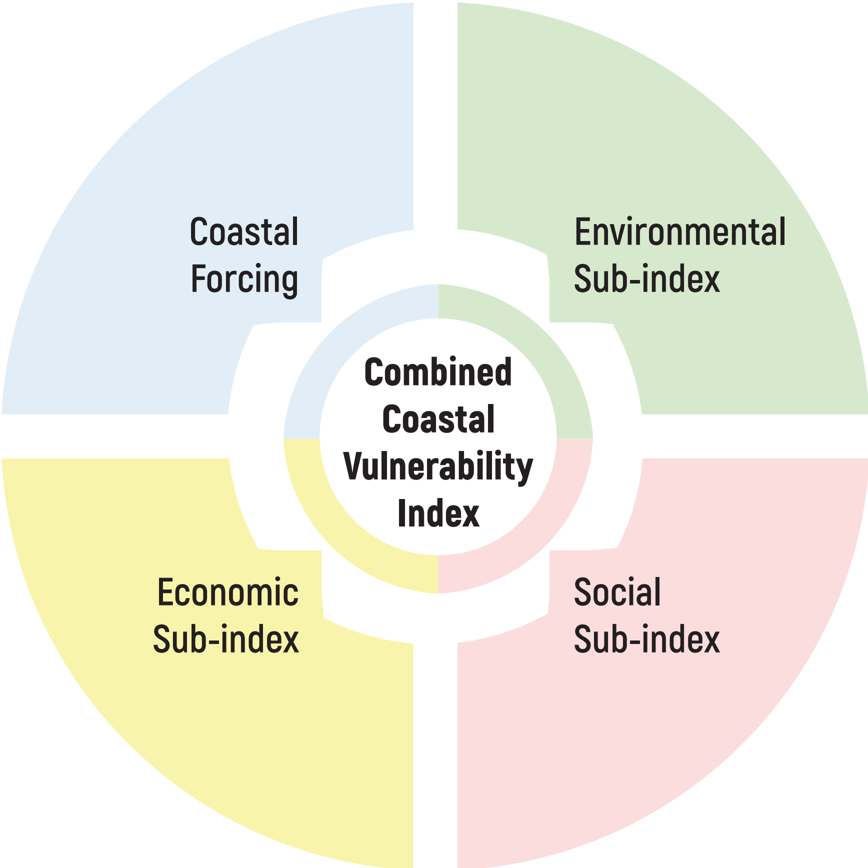
From the simulated scenarios, the inundated area is definitely increased by the sea level rise, as expected.
The figures show the maximum wave height achieved by the tsunami at Monterosso during the propagation within the simulation domain, comparing the inundation obtained through the simulations with (bottom) and without (top) the sea level rise.

This type of setup is a tool now ready for further application. Its efficiency has been here demonstrated with some individual scenarios. Nevertheless, this tool can be used in the future for thoroughly assessing, site by site, the tsunami hazard sensitivity to the sea level rise with consideration of many more scenarios describing the natural earthquake variability and of all the involved uncertainties, in a fully probabilistic approach.
A prioritization of the coastal plains featuring both relatively high tsunami hazard according to TSUMAPS-NEAM, and which are more exposed to sea level rise according to the results of SAVEMEDCOASTS, will make this task entirely feasible.



Maximum wave height achieved by the tsunami in two locations at the Cinque Terre (Vernazza and Monterosso) for a M=7.5 earthquake in the Ligurian Sea. The color palette shows the simulated wave height (meters).

EXPOSURE, VULNERABILITY AND RISK ASSESSMENT
TO SEA LEVEL RISE



1 McLaughlin, S., Cooper, J.A.G., 2010. A multi-scale coastal vulnerability index: A tool for coastal managers? Environ. Hazards 9, 233–248.

2 Peltier, W.R., 2004. Global glacial isostasy and the surface of the ice-age Earth: the ICE-5G (VM2) model and GRACE. Annu. Rev. Earth Planet. Sci. 32, 111–149.

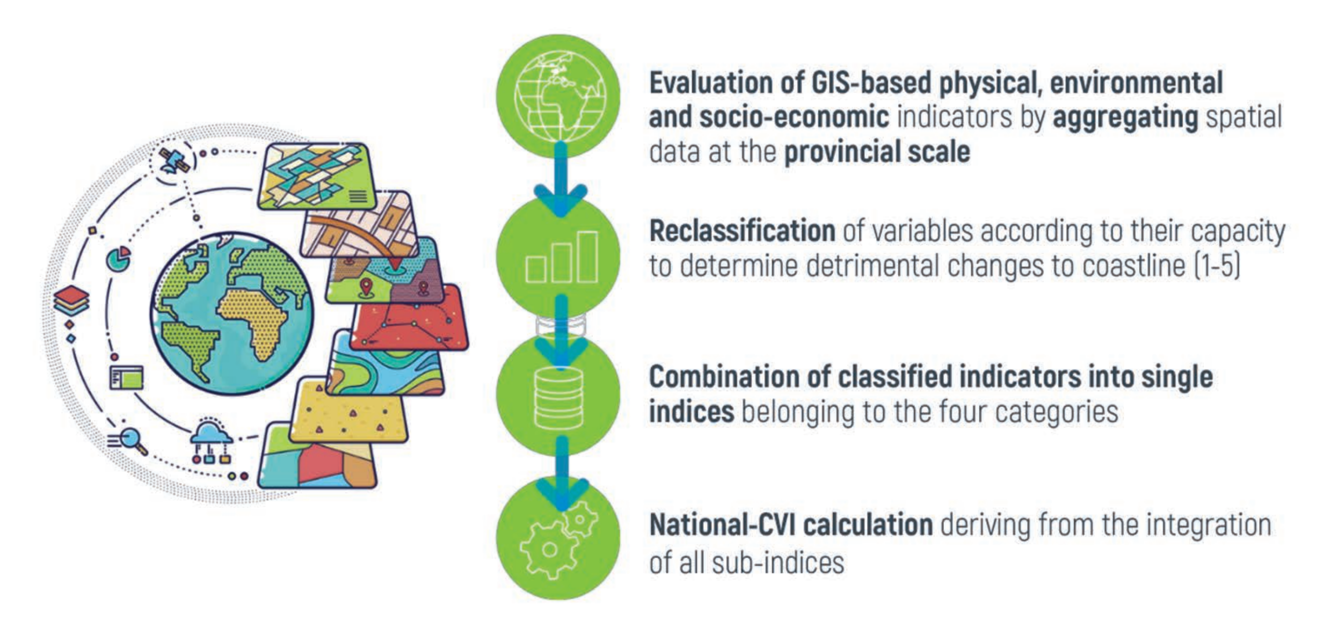
3 ISTAT, 2018a. L'indice di vulnerabilità sociale e materiale - 8milaCensus - Istat. http://ottomilacensus.istat.it/fileadmin/download/Indice_di_vulnerabilit%C3%A0_sociale_e_materiale.pdf

Rising sea levels and increasing extreme events related to climate change are causing serious threats to coastal areas, affecting both natural and human systems

There is a growing evidence that socio-economic dynamics (e.g. unplanned urbanization, land use and demographic changes) would increase coastal flood risk in the next decades.
Understanding how natural and human-induced drivers concur to determine exposure, vulnerability and risks in coastal areas is of paramount importance for mainstreaming effective climate adaptation and risk reduction policies into coastal zone management.
In the frame of the SAVEMEDCOASTS project risk assessment approaches were designed and tested to provide guidance and operative criteria for exposure, vulnerability and risk assessment and mapping under changing climate and land-use scenarios. The overall aim was to identify, map and prioritize natural and human targets at higher risk from climate-related hazards (sea level rise inundation and storm surge flooding) in vulnerable (flood-prone) coastal areas, providing a knowledge base for national-scale adaptation planning and disaster risk management. Specifically, one of the main analysis focused on the application the Coastal Vulnerability Index (CVI, McLaughlin and Cooper, 2010[1]), which was applied to estimate the vulnerability of the Italian shoreline to inundation, combining a composite set of physical, environmental and socio-economic indicators calculated at the coastal provinces scale (NUTS3) for a baseline and future 2050 scenario.
The traditional index is modified to account for future climate-related and land use changes under the RCP8.5, and to tailor its structure to the selected case study and data availability.

NATIONAL-CVI: THE METHODOLOGICAL APPROACH

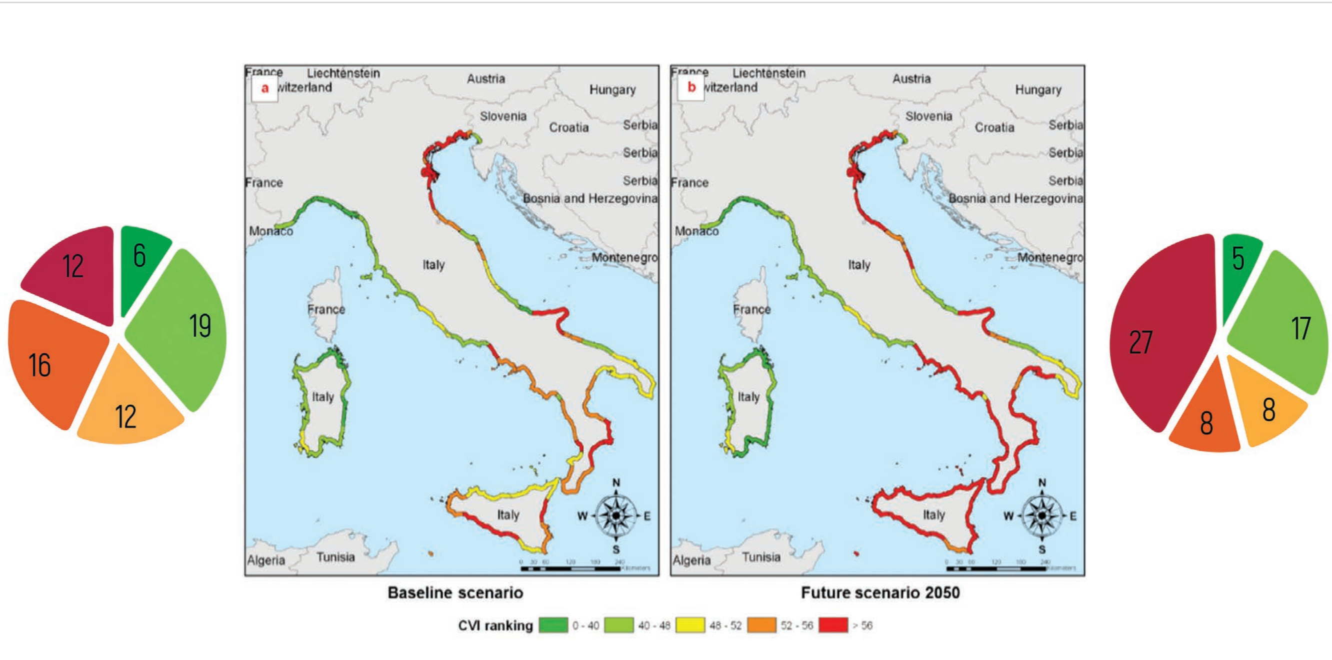
According to the multi-scale CVI methodology by McLaughlin and Cooper (2010), the proposed national-CVI formulation is based on the aggregation of a wide array of indicators belonging to 4 main categories: i) **coastal forcing**, representing the nature of coastal processes (i.e. extreme Sea Level indicator), providing information related to the combined effect of relative sea level rise calculated by integrating sea level rise with glacial isostatic adjustment effect[2], tides, and water level fluctuations due to climate extremes; ii) **environmental features**, representing the resistance or susceptibility of coastlines to physical variations (i.e. shoreline evolution trend, distance from shoreline, elevation, coastal slope, geological coastal type, land roughness, conservation designation, coastal protection structures); iii) **social condition**, standing for the society's ability to cope with (and recover from) the impacts of natural or climate disasters (i.e. social and material vulnerability index provided by ISTAT[3]); iv) **economic variables**



(i.e. land use patterns and gross value added -GVA) reflecting the distribution of human activities exposed to climate related hazards along coastal systems. Once key indicators are selected, the national-CVI can be calculated through the following operational steps.

RESULTS

By integrating information concerning the four sub-indices, the national-CVI was calculated both for baseline and for future 2050 scenario. Most vulnerable areas are located along the North Adriatic coast (Emilia Romagna and Marche regions), mainly due to the high value assumed by the coastal forcing sub-index, underlining the strong vulnerability of this area to inundation. The rest of the Southern coast of Italy shows moderate to very high sco res, highlighting the critical vulnerability level of this region linked with negative environmental, social and economic conditions. By comparing the baseline with future scenario, an increase in the overall vulnerability is observed, with very high and high vulnerability scores spreading along the Eastern coast and expanding in neighboring provinces in the South and Southeast coasts, as well as in Sicily. This shift is shown in the pie charts representing the number of Italian coastal provinces belonging to each vulnerability class. This pattern is mainly driven by the rise in vulnerability scores of the coastal forcing (against the RCP8.5 emission scenario) and economic sub-indices, highlighting rising critical situations linked with future climate threats combined with land use changes.

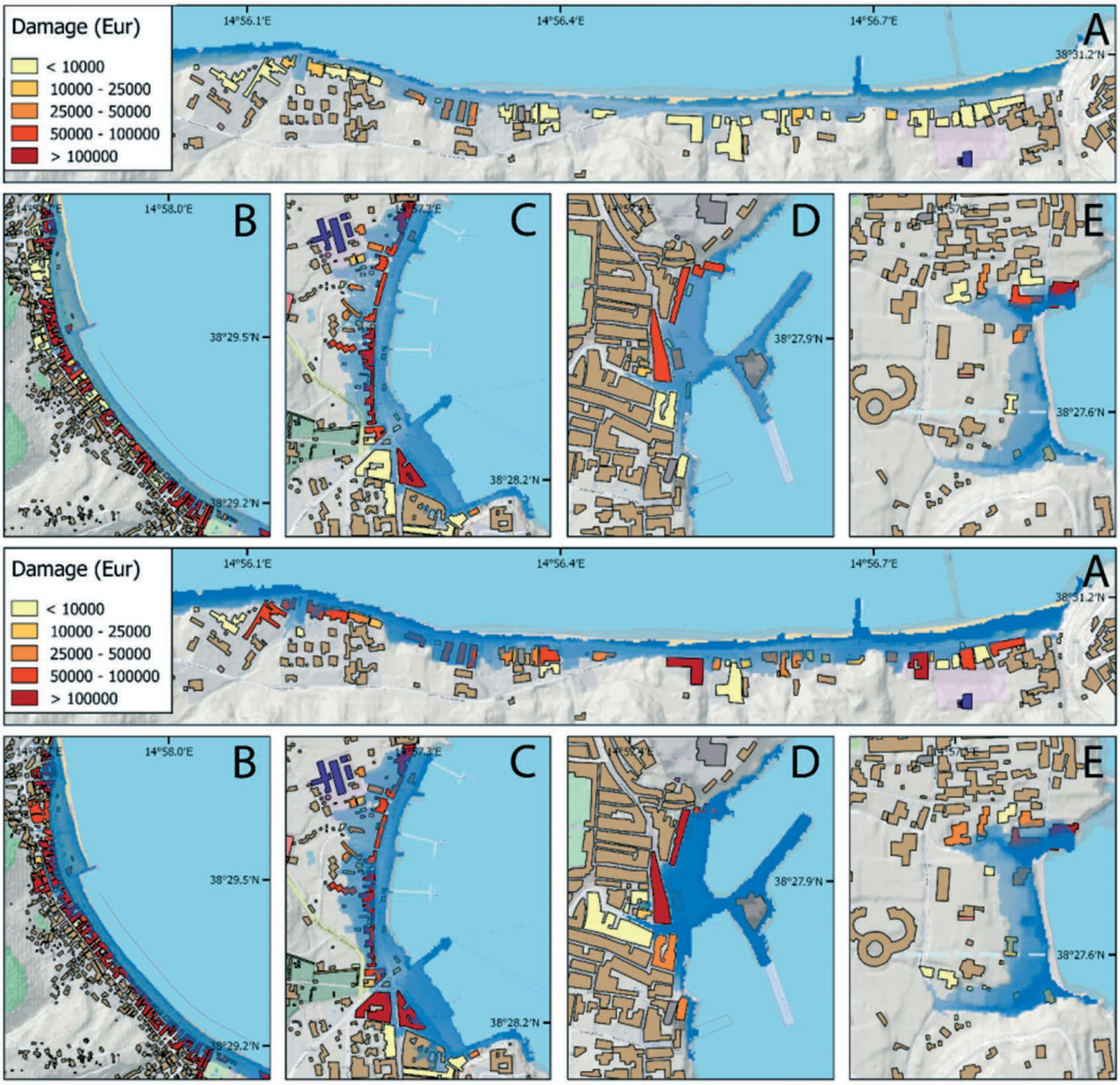


ASSESSING THE SOCIO ECONOMIC IMPACT FACTOR
TO PLAN ADAPTATION MEASURES

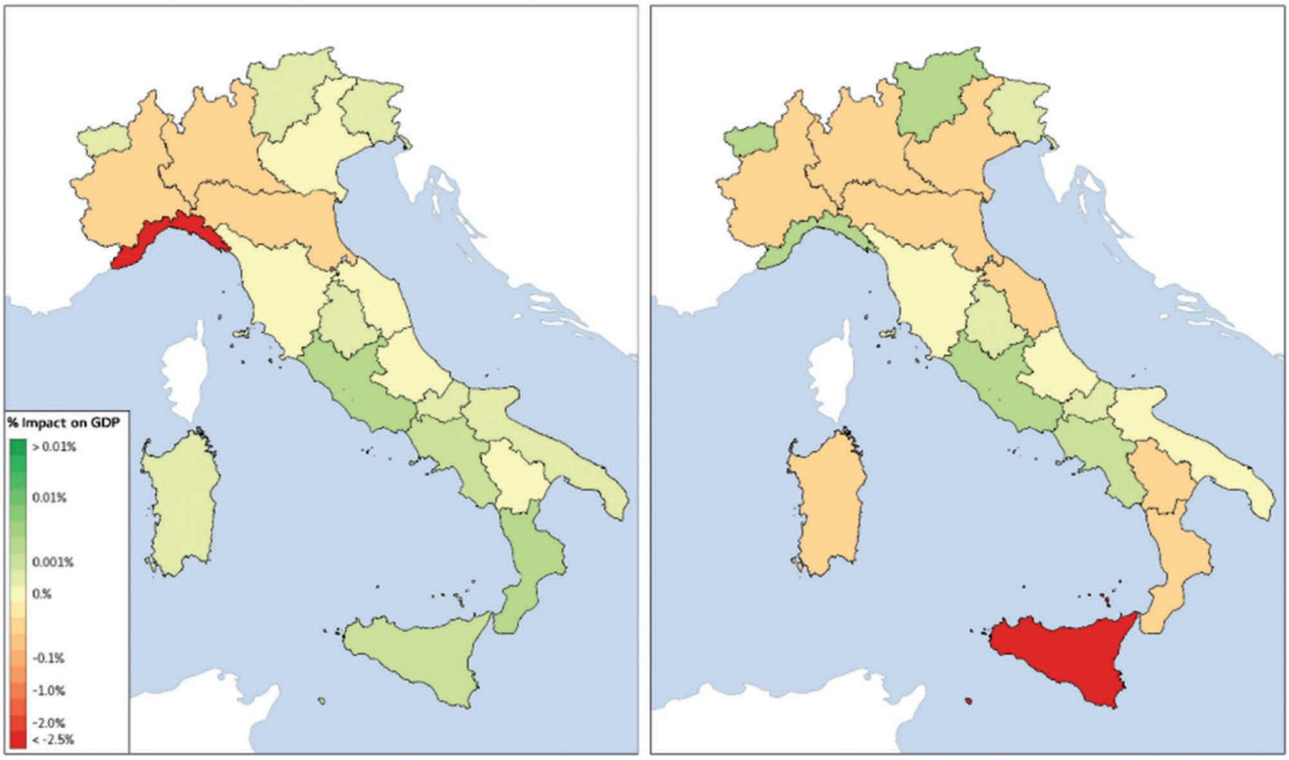
The SAVEMEDCOASTS project provides a solid, robust and replicable methodology for the assessment of the direct and indirect economic impacts of coastal flood risk and ESLs scenarios on vulnerable coastal areas in the Mediterranean region

Results aim to provide both quantitative and qualitative information to support the identification, mapping and prioritization of adaptation actions on natural and human targets at potentially high risk from climate-related hazards (e.g. sea level rise, coastal inundation and storm surge flooding) in flood-prone areas. Robust information is provided to support the development of a knowledge base for national-scale CCA plans and Disaster Risk Management (DRM). The methodology proposed in SAVEMEDCOASTS is applied to vulnerable coastal areas with the characterization of coastal flooding hazard scenarios in the pilot cases in Italy (Cinque Terre and Lipari Island) and Greece (Lefkas).

In particular, SAVEMEDCOASTS combines: (i) the **identification** and **characterization** of hazard-prone areas potentially inundated by SLR and ESLs for the RCP2.6 and RCP8.5 climate scenarios and for 1-year and 100-year return periods (RPs); (ii) the **evaluation** of the exposure to coastal flooding and ESLs, expressed in terms of water depth and; (iii) the **assessment** of the coastal flood risk and economic damage, expressed in terms of economic losses to physical asset and to the gross regional product (GRP) of Italian regions.



Inundation depths in Lipari for flood return period of 100 years in pilot areas: A) Acquacalda, B) Canneto, C) Marina Lunga, D) Marina Corta and E) Baia Portinenti. Top row according to SLR for scenario RCP 2.6 and bottom row according to RCP 8.5.



Indirect losses distribution due to economic shock from coastal inundations in the two pilot regions of Liguria (left) and Sicily (right) for the scenario RCP 8.5, RP 100 years.

DIRECT DAMAGES TO ASSETS

The results of the risk assessment for the pilot are presented by maps displaying the intensity of hazard and the distribution of exposed elements for each scenario. In addition, statistical information is calculated for absolute and relative damage maps with support of GIS software (ArcGIS, QGIS) and statistical analysis tools. The assessment is also based on the characterization of the inundated areas.

The above figure displays the water depth in the Lipari Island study area under the climate scenarios RCP 2.6 and 8.5 and to a RP of 100 years. The estimation of the economic damage is performed after excluding churches and monuments, for which an appropriate damage function is not available. The largest increases in damage are estimated in Acquacalda and Baia Portinenti (15-20% increase for RP1y and 12% for RP100y). In Canneto, the increase is respectively 9% and 8%, while at Marina Corta and Marina Lunga the smallest changes are verified between the different climate scenarios (2-5% for RP1y and 4% for RP100y).

DIRECT AND INDIRECT DAMAGES ON GROSS REGIONAL PRODUCT

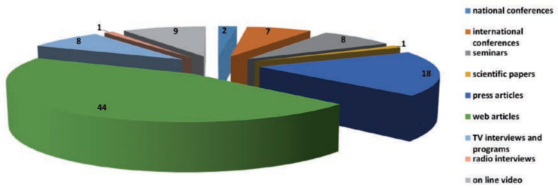
The assessment of the hazard scenarios is done after the characterization of the magnitude of coastal flooding events over both the Liguria and Sicily regions. The impact on the considered productive sector is calculated by first measuring the extent and depth of water overlaying the cells of each productive sector (i.e., agricultural, industrial and services) at the regional level. In addition, changes in the direct economic impact on residential assets are calculated at regional level. The change is relatively small for Liguria when comparing RCP2.6 and RCP8.5 scenarios for a flood event with a 1 year RP (+6%); for Sicily, however, the impact is relatively much larger (+27%). However, the increase is similar for both regions when considering a flood event of 100 years RP (+20% in both regions).

In general, services are the economic sector most negatively affected in the regions directly impacted by the assessed coastal flood events. Because our CGE model allows for the exchange of goods and services between regions, service demand is slightly shifted from the directly affected regions (e.g., Liguria or Sicily) to the other Italian regions. Particularly the neighboring ones. In contrast, the industrial productivity is generally reduced over all the Italian territory. This can be explained by the fact that services are at the same time the most affected sector in Liguria and Sicily and those that use intensively industrial products. The strong decrease of services production in Liguria and Sicily more than offset the very tiny increase of services in the other regions as the consequence of the regional substitution and determine an overall decrease of the industrial production.

In general, even if some regions and sectors may slightly benefit under a particular flood scenario (e.g., Lazio region), the overall benefits over the whole Italian territory do not compensate for the GDP and production losses at the country level. In fact, it is estimated that, for whole Italy, the GDP reduction is around 1.27 billion Euros for the flood scenario RCP 8.5, RP100 years in the Liguria region, and around 1.96 billion Euros for the same flood scenario in the Sicily region.

SAVEMEDCOASTS
UNDER THE SPOTLIGHTS

SAVEMEDCOASTS adopts a Website and the most popular social media for external dissemination activities.



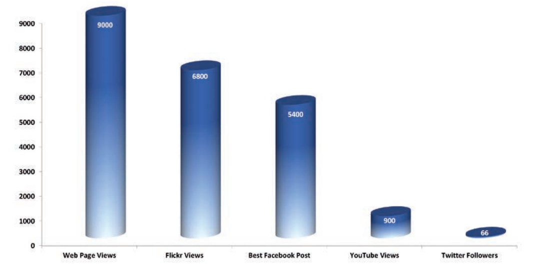
Website and social media enhanced the impact of SAVEMEDCOASTS, facilitating its visibility at multiple levels and reaching a wide audience, everywhere and at any time

Communication was particularly directed toward coastal populations and stakeholders according to the SAVEMEDCOASTS Communication plan "transferring scientific knowledge to society to improve the quality of life".

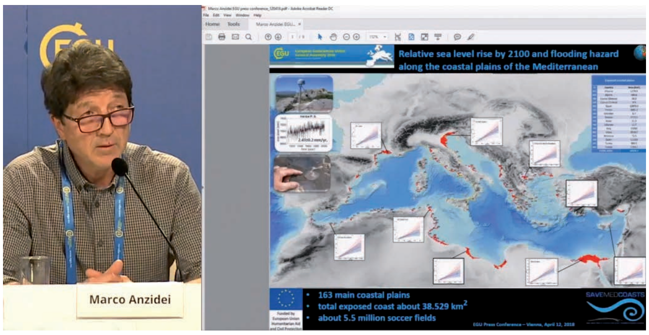
SAVEMEDCOASTS reached stakeholders, decision-makers, scientific communities, non-governmental organizations, private companies, public sectors, civil society and media, all at national or local levels.

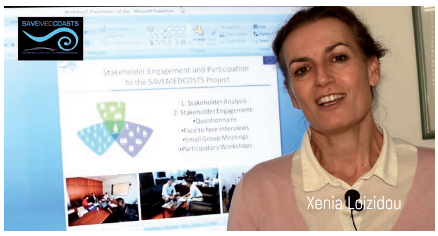
Social media also facilitated contacts with other EU and not EU projects.

A set of videos published on the YouTube channel of SAVEMEDCOASTS and collected in a special DVD, have improved the impact of the project activities facilitating its visibility.



SAVEMEDCOASTS numbers on the dissemination action (January 2017-December 2018)





RESULTS
AND NEXT STEPS

SAVEMEDCOASTS established the foundations to understand the effects of climate change along the coasts of the Mediterranean, focusing on sea level rise, land subsidence, storm surges and tsunamis

We list the most relevant project achievements:

- The standardization of a methodology for database, mapping, relative sea level projections, types of scenarios, stakeholder analysis, socio economic and risk assessment and communication
- The development of a WebGIS and the database structure for descriptive information necessary to create sea level rise projections and scenarios for specific location, including storm surges and tsunamis
- The developed tools prove that scenarios are crucial information useful at various stages. Especially for the Integrated Coastal Zone Management, coastal hazard mitigation, protection of people and infrastructures

To improve the general objective there are few next steps that SAVEMEDCOASTS should perform, among others:

1. The dissemination of the output to other interested countries/stakeholders
2. The continuous improvement of communication and awareness on coastal hazard to stakeholders and local affected communities
3. The integration in the analysis of new data to improve high resolution scenarios in other areas of the Mediterranean region not yet investigated, using new Lidar data sets, new high-resolution satellites, and additional information
4. To update the relative sea level projections for 2100 on a regular basis (e.g. yearly), using new releases of IPCC climatic projections and results from the latest relevant scientific studies on sea level rise and land subsidence
5. The improvement of the modeling of storm surges and tsunamis in a sea level rise environment is major issue for hazard mitigation and other very practical reasons
6. The continuous transfer of updated information to National Environmental Agencies and Civil Protection Organizations, to respond to the need for people and assets prevention from natural disasters in Mediterranean coastal areas related to sea level rise, storm surges and tsunamis

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SAVEMEDCOASTS
sea level rise scenarios along the mediterranean coasts

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