GROWTH AND INNOVATION IN OCEAN ECONOMY

GAPS AND PRIORITIES IN SEA BASIN OBSERVATION AND DATA

D5.3.5 MedSea Checkpoint Challenge 4 (Climate and Coastal Protection): Description of Targeted Products, the methodology and the expert evaluation of fitness for purpose

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Author(s):	Lluís Gómez-Pujol (coord.)	SOCIB
	Joan Vallespir	SOCIB
	David March	SOCIB
	Joaquin Tintore’	SOCIB
	Rita Lecci	CMCC
	Antonio Bonaduce	CMCC
	Fabio Raicich	CNR
	Guillaume Valladeau	CLS
	Simona Simoncelli	INGV

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Executive Summary

This document summarizes the tasks developed by the Climate and Coast Protection challenge as part of the MedSea Checkpoint Project.
The report describes the methods developed for generating each targeted product requested by the contract tender. It specifies the main characteristics of the datasets, the main gaps in them and the problems associated with their use.

At this stage of the project, two clear conclusions can be drawn.

- There are no sediment data on the scale of the Mediterranean Sea that can address the challenge goal. Usable data for non-experts are rare; different institutions using different methods, with a lag in the spatial coverage and incongruent temporal coverage, provide diffuse data. There are few datasets, and those that are available require expert processing.
  The 10-year sea-level trends are not considered because this is too short a period to obtain useful values. First, the trend estimate is biased by the incomplete sampling of the 18.6-year lunar nodal cycle; and second, the small sample size means that the statistical error is large relative to the trend itself.

General scope of the Targeted Products

The primary aim of the Climate and Coastal Protection Challenge is to assess the possibility of producing the following products.

(a) Spatial layers for the following parameters for the past 10 years, the past 50 years and the past 100 years:
- Average annual change in temperature at the surface, mid-water and sea bottom. The terminology used in the contract tender is not commonly used among the scientific community. Therefore, for this Challenge, the average annual change in temperature is the trend in sea temperature change for each of the time periods cited above. Additionally, we interpreted the mid-water and sea-bottom temperature as the water temperature at the mid-depth and near-bed, respectively.
- Average annual sea-level rise at the coast. For this Challenge the average annual rise in the sea level is the trend in the sea-level rise for a specified time period.
- Sediment mass balance at the coast. For the purpose of this project, the sediment mass balance is interpreted as the sign and magnitude of the shoreline change for each of the time intervals cited above.

(b) Time series for the following parameters for the whole sea basin:
- Average annual sea temperature over the sea-basin surface, mid-water column and bottom. In our Challenge, this refers to the time series of the average temperature at the sea surface, mid-depth water column and near bed for the basin and/or the NUTS3 marine influence region.
- Average annual internal energy of the sea. In our Challenge, this refers to the time series of the average internal energy of the basin and/or the NUTS3 marine influence region.
- Average annual sea-level rise relative to the land. In our Challenge, this refers to the time series of the sea-level of the basin and/or the NUTS3 marine influence region.
- Annual sediment balance for each NUTS3.

Targeted Products catalogue for this Challenge

Name of Targeted product	Short description	Format
MEDSEA_CH4_Product_1	Spatial layer of sea temperature trend at the surface (units: °C/year) from observations (HadISST dataset) over periods of 10 (2003-2012) years, 50 years (1963-2012) and 100 years (1913-2012).	shapefile
MEDSEA_CH4_Product_2	Spatial layer of sea temperature trend at mid-depth and at sea-bottom (units: °C/year) from reanalysis (CMEMS Mediterranean Physics Reanalysis dataset) over period of 10 (2003-2012) years.	shapefile
MEDSEA_CH4_Product_3	Spatial layer of sea internal energy trend (units: J/m^2*year) from reanalysis (CMEMS Mediterranean Physics Reanalysis dataset) over period of 20 (1993-2012) years.	shapefile
MEDSEA_CH4_Product_4	Spatial layer of sea-level trend (units: mm/yr) from **reconstruction** over periods of 50 years (1963-2012) and 100 years (1913-2012).	shapefile
MEDSEA_CH4_Product_5	Spatial layer of sea-level trend (units: mm/yr) from **satellite altimetry** over period of 10 years (2003-2012).	shapefile
MERSEA_CH4_Product_6	Spatial layer of sea-level trend (units: mm/year) from **tide-gauges** over periods of 50 years (1963-2012) and 100 years (1913-2012).	shapefile
MEDSEA_CH4_Product_7	Report on Sediment Mass Balance at the Coast	pdf
MEDSEA_CH4_Product_8	Time series of annual average sea temperature at the surface (units °C) from observations (HadISST dataset) over periods of 10 (2003-2012) years, 50 years (1963-2012) and 100 years (1913-2012).	ascii
MEDSEA_CH4_Product_9	Time series of annual average sea temperature at mid-depth and at sea-bottom (units: °C) from reanalysis (CMEMS Mediterranean Physics Reanalysis dataset) over period of 10 (2003-2012) years	ascii
MEDSEA_CH4_Product_10	Time series of annual average sea internal energy (units: J/m^2) from reanalysis (CMEMS Mediterranean Physics Reanalysis dataset) over period of 20 (1993-2012) years.	ascii
MEDSEA_CH4_Product_11	Time series of annual average sea-level (units: mm) from **reconstruction** over periods of 50 years (1963-2012) and 100 years (1913-2012).	ascii
MEDSEA_CH4_Product_12	Time series of annual average sea-level (units: mm) from **time-gauges** over periods 50 years	ascii

	(1963-2012) and 100 years (1913-2012).	
MEDSEA_CH4_Product_13	Time series of annual average sea-level (units: mm) from **satellite altimetry** over period of 10 years (2003-2012.	ascii

Description of Characteristics and Data sources used by Targeted products

MEDSEA_CH4_Product_1

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
14	TEMP	Marine water	http://www.metoffice.gov.uk/hadobs/hadisst/

MEDSEA_CH4_Product_2

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
15	TEMP	Marine water	http://marine.copernicus.eu

MEDSEA_CH4_Product_3

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
15	TEMP	Marine water	http://marine.copernicus.eu

MEDSEA_CH4_Product_4

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
4	ASLV	Marine Water	http://www.psmsl.org
8	ASLV	Marine Water	http://www.aviso.oceanobs.com

MEDSEA_CH4_product_5

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
8	ASLV	Marine water	http://www.aviso.oceanobs.com http://marine.copernicus.eu
7	ASLV	Marine water	http://www.aviso.oceanobs.com

MEDSEA_CH4_Product_6

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
4	ASLV	Marine water	http://www.psmsl.org

MEDSEA_CH4_Product_7

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
	Sediment mass balance	Seabed	

MEDSEA_CH4_Product_8

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
14	TEMP	Marine water	http://www.metoffice.gov.uk/hadobs/hadisst/

MEDSEA_CH4_Product_9

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
15	TEMP	Marine water	http://marine.copernicus.eu

MEDSEA_CH4_Product_10

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
15	TEMP	Marine water	http://marine.copernicus.eu

MEDSEA_CH4_Product_11

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
4	ASLV	Marine Water	http://www.psmsl.org
8	ASLV	Marine Water	http://www.aviso.oceanobs.com

MEDSEA_CH4_Product_12

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
4	ASLV	Marine water	www.psmsl.org

MEDSEA_CH4_Product_13

Nb	Characteristics name (P02)	Environmental Matrix	Data source (URL)
8	ASLV	Marine water	http://www.aviso.oceanobs.com http://marine.copernicus.eu
7	ASLV	Marine water	http://www.aviso.oceanobs.com

Description of methodology to produce the Targeted Products

MEDSEA_CH4_Product_1

Sea surface temperature – production method

The HadISST database produced by the Met Office Hadley Centre was used to produce the map of the Sea Surface Temperature (SST) trend (units: °C/year) for periods of 10 years (2003-2012; MEDSEA_CH4_Product_1_1), 50 years (1963-2012; MEDSEA_CH4_Product_1_2) and 100 years (1913_2012; MEDSEA_CH4_Product_1_3). The spatial resolution of this dataset is a 1° latitude/longitude grid (*Rayner N.A. et al., 2003*). The SST data are taken from the Met Office Marine Data Bank (MDB) and the Comprehensive Ocean-Atmosphere Data Set (COADS) (now ICOADS). HadISST temperatures were reconstructed using a two-stage reduced-space optimal interpolation procedure, followed by superimposition of the quality-improved gridded observations onto the reconstructions to restore local detail (MetOffice).

Sea surface temperature trend estimate

A least squares method was used to calculate the SST trend map. The statistical model for a straight-line regression is given by the following equation:

$$Y_i = \beta_0 + \beta_1 X_1 + \varepsilon_i \qquad \text{i=1...n}$$

where Y_i and X_1 are the dependent and independent variables; β_0 is the estimate of the intercept and β_1 is an estimate of the slope (regression coefficient) of the line, that is, the trend in every grid point; and e_i is the statistical model residual error.

Sea-surface temperature trend – NUTS3 regionalization

Spatial layers were produced for NUTS3 regions from the components of the previous product. As a result, there are spatial layers for the surface sea temperature from the HadISST trend for the last 10 years (MEDSEA_CH4_Product_1_4), 50 years (MEDSEA_CH4_Product_1_5) and 100 years (MEDSEA_CH4_Product_1_6).

Because NUTS3 regions are terrestrial administrative boundaries, some processing was necessary to extend the influence of these regions into the sea. First of all, NUTS3 regions are official for EU member states and candidates, but Mediterranean non-EU states do not have NUTS3 regions. In order to obtain equivalent administrative boundaries for those states we used the regionalisation developed by the United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP) for the Transboundary Diagnostic Analysis in the Mediterranean Sea. Because the datasets we are dealing with are marine datasets and there are no data inland, the results for the first 10 nautical miles were taken into account, consistent with the definition of costal water in the EU Marine Strategy Directive. The boundary limit conflicts were solved using Thiessen polygons. The NUTS3 regionalization was implemented specifically for statistical purposes, taking into account the EU regional stats, as well as for coastal managers.

MEDSEA_CH4_Product_2

Mid-water and bottom temperature – production method

The CMEMS Mediterranean Physics Reanalysis was used to produce maps of the sea temperature trend (units: °C/year) at the mid-water (MEDSEA_CH4_Product_2_1) and sea bottom (MEDSEA_CH4_Product_2_2) for the 2003-2012 period. The sea bottom is considered the last level of the water column with available temperature values. The spatial resolution of this dataset is a 1/16° latitude/longitude grid.

Sea mid-water and bottom temperature trend estimate

[The regression equation and its explanation is repeated in each section. It is recommended that it is only provided once.] A least squares method was used to calculate the SST trend map. The statistical model for a straight-line regression is shown in the following equation:

$$Y_i = \beta_0 + \beta_1 X_1 + \varepsilon_i \qquad i=1.....n$$

where Y_i and X_1 are the dependent and independent variables, β_0 is the estimate of the intercept and β_1 is an estimate of the slope (regression coefficient) of the line, that is, the trend in every grid point, and e_i is the statistical model residual error.

Sea temperature trend NUTS3 regionalization

Spatial layers for NUTS3 regions were produced from the components of the previous product . As a result, there is a spatial layer for the NUTS3 bottom sea temperature trend from CMEMS for the last 10 years (MEDSEA_CH4_Product_2_3).

Because NUTS3 regions are terrestrial administrative boundaries, some processing was necessary to extend the influence of these regions into the sea. First of all, NUTS3 regions are official for EU member states and candidates, but Mediterranean non-EU states do not have NUTS3 regions. In order to obtain equivalent administrative boundaries for those states we used the regionalisation developed by the United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP) for the Transboundary Diagnostic Analysis in the Mediterranean Sea. Because the datasets we are dealing with are marine datasets and there are no data inland, the results for the first 10 nautical miles were taken into account, consistent with the definition of costal water in the EU Marine Strategy Directive. The boundary limit conflicts were solved using Thiessen polygons. The NUTS3 regionalization was implemented specifically for statistical purposes, taking into account the EU regional stats, as well as for coastal managers.

MEDSEA_CH4_Product_3

Sea Internal Energy – production method

The CMEMS Mediterranean Physics Reanalysis was used to produce maps of the internal energy trend (units: J/m^2*year) for the 1993-2012 period. The spatial resolution of this dataset is a 1/16° latitude/longitude grid.
The internal energy of oceans is defined (*Oort et al., 1989*) by

$$eq: 1 IE_i = \iiint \rho c_0 T dxdydz,$$

where IE_i is the internal energy value for the basin in the i-th year, $\overline{HC}_{rp}$ ρ = 1025 kg/m^3 is the in-situ density (*Sorgente et al., 2011*; *Samelson, 2011*; *Lecci, 2012*), c_0 = 4187J/Kg*K (*Oort et al., 1989*; *Peixoto J.P. and Oort A.H., 1992; Lecci, 2012*) is the specific heat at constant pressure for ocean water and T is the temperature.

Sea Internal Energy trend estimate

A least squares method was used to calculate the SST trend map. The statistical model for a straight-line regression is shown in the following equation:

$$Y_i = \beta_0 + \beta_1 X_1 + \varepsilon_i \qquad i=1.....n$$

where Y_i and X_1 are the dependent and independent variables; β_0 is the estimate of the intercept and β_1 is an estimate of the slope (regression coefficient) of the line, that is, the trend in every grid point; and e_i is the statistical model residual error.

Sea Internal Energy trend NUTS3 regionalization

Because NUTS3 regions are terrestrial administrative boundaries, some processing was necessary to extend the influence of these regions into the sea. First of all, NUTS3 regions are official for EU member states and candidates, but Mediterranean non-EU states do not have NUTS3 regions. In order to obtain equivalent administrative boundaries for those states we used the regionalisation developed by the United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP) for the Transboundary Diagnostic Analysis in the Mediterranean Sea. Because the datasets we are dealing with are marine datasets and there are no data inland, the results for the first 10 nautical miles were taken into account, consistent with the definition of costal water in the EU Marine Strategy Directive. The boundary limit conflicts were solved using Thiessen polygons. The NUTS3 regionalization was implemented specifically for statistical purposes, taking into account the EU regional stats, as well as for coastal managers.

MEDSEA_CH4_Product_4

Sea-level reconstruction method

The method used to reconstruct the sea-level field during the last century is the reduced-space optimal interpolation described by *Kaplan et al. (2000)*, applied as in *Church et al. (2004)* and *Calafat and Gomis (2009)* for global and regional sea-level reconstructions, respectively. In the first step, called feature extraction, spatial information is obtained from the satellite data that will provide the spatial variability for the reconstruction using singular value decomposition (SVD), as shown in equation (1). The altimetry data are organized into a matrix containing m spatial grid points by n time steps to obtain an m*n matrix (Z). The Z matrix can be separated into three matrices using SVD:

$$Z = ULV^T, \qquad (1)$$

where U is an m*n matrix that contains the left singular vectors of the Z matrix (eigenvectors of the covariance matrix Z^TZ (EOFs)); L is an n*n diagonal matrix that contains the singular values (γ, square root of the eigenvalues of the covariance matrix) of Z; and V is an n*n matrix in which the columns are the right singular vectors of Z (eigenvectors of the covariance matrix ZZ^T)(*Bjornsson and Venegas, 1997*). The expression (1) can be approximated as

$$Z_M = U_M L_M {V_M}^T, \qquad (2)$$

where L_M is the diagonal matrix that contains the largest eigenvalues in the reduced phase space. U_M is a matrix in which the columns are the EOFs corresponding to the eigenvalues contained in L_M, respectively. The leading U_M eigenvectors define the reduced space of the main modes of large-scale variability in which we search for an analyzed solution. The discarded part of the total space is assumed to be contaminated by noise (*Kaplan et al., 2000*).
The SVD divides the initial field into a space-dependent component U(x,y) and a time-dependent component V(t). It is thus possible to approximate the initial Z(x,y,t) matrix, considering only the lowest modes ("M") that explain most of the variance:

$$Z_M(x,y,t) = U_M(x,y) * L_M * {V_M}^T(t) = U_M(x,y) * \tilde{\alpha}(t), \qquad (3)$$

where $\tilde{\alpha}(t)$ is determined by the satellite data and is an m*n matrix in which the rows are the time series of the amplitude for the lowest EOFs (*Calafat and Gomis, 2009*). Instead, we want to estimate

$$Z_M(x,y,t) = U_M(x,y) * \alpha(t)\,, \qquad (4)$$

with $\alpha(t)$ estimated starting from the tide-gauge data.

The second step of this method is to find the set of $\tilde{\alpha}(t)$ that best fits the tide-gauge data by optimal interpolation, as described by *Kaplan et al. (2000)*. For each time step (month) in the record, the reduced-space optimal interpolation solution for $\alpha(t)$ is the one that minimizes the cost function

$$S(\alpha) = (HU_M\tilde{\alpha} - Z^0)^T R^{-1}(HU_M\tilde{\alpha} - Z^0) + \tilde{\alpha}^T\Lambda^{-1}\tilde{\alpha}\,, \qquad (5)$$

where Z^0 is a matrix of the available tide-gauges observations, in which the rows represent each available tide-gauge available and the columns represent the time steps; H is a transfer operator from the full grid representation of the satellite altimetry field to the available observations; Λ is a diagonal matrix of the eigenvalues of the covariance matrix; and R is the error covariance matrix represented by two terms:

$$R = \Sigma + HU'L'^{U'^T H^T}. \qquad (6)$$

The term Σ is the data error covariance matrix that accounts for the sampling error. The second term in R contains the covariance of the truncated modes, which accounts for the errors introduced by ignoring higher-order EOFs in the reconstruction.
Tide-gauge observations are relative to their own local datum. Following *Church et al. (2004)*, we consider the change in height between adjacent time steps to eliminate the cross-correlation. In (4), the EOFs are functions of space only and the amplitudes are functions of time only. Thus, for the adjacent times t_n and t_{n+1}, we can rewrite (4) as

$$Z_M{*}(x,y,t_{n+1})-Z_M{*}(x,y,t_n)=U_M(x,y)\cdot[\alpha(t_{n+1})-\alpha(t_n)] \qquad (7)$$

$$\Delta Z_M{*} = U_M(x,y)\cdot\Delta\alpha(t_n). \qquad (8)$$

Because of the first term in the formulation of the cost function (5), the minimization of S will constrain the solution to be close to the observed data (within the uncertainty defined by observational error). The second term confines the energy distribution over the modes of variability to that found in the data (i.e., a derived temporal coefficient of a given eigenvector cannot have more variance than the corresponding eigenvalue; *Kaplan et al., 2000*).
The changes in the amplitudes of the leading EOFs between each time step can be obtained by minimizing the cost function (5). Minimizing S gives the optimal interpolation solution:

$$\Delta\alpha=PU_M{}^TH^TR^{-1}\Delta Z^0\,, \qquad (9)$$

where

$$\Delta Z^0=Z^0(x,y,t_{n+1})-Z^0(x,y,t_n) \qquad (10)$$

and

$$P=(U_M{}^TH^TR^{-1}HU_M+\Lambda^{-1})^{-1}, \qquad (11)$$

thus providing a theoretical estimate of the error covariance in the solution (Kalman gain).
Once the changes in amplitude of the EOFs have been obtained for each time step, the amplitudes α can be obtained by integrating backward in time, as described by *Church et al. (2004a)* and *Calafat and Jorda (2011)* for global and regional cases, respectively.
The reduced-space optimal interpolation solution can be converted into its full grid representation by substituting the estimated amplitudes α(t) in the expression (3) to obtain the whole sea-level reconstruction.

Sea-level trend estimate

Here we describe the method used to estimate the sea-level trend over the temporal periods required.
Spada and Galassi (2012) use basic statistics to define the sea-level linear trend as the regression coefficient estimated using the least squares method. In the case of a linear fit applied to a sea-

level time-series, the regression coefficient r, considered as the best estimate of the sea-level rate, is given by the equation

$$r = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x^2 - \left(\sum_{i=1}^{n} x_i\right)^2}, \qquad (12)$$

with i=1,...n, where n is the number of sea-level records considered and y_i is a measure of the sea level at time x_i. The standard error of the regression coefficient is a measure of the uncertainty of the obtained estimate. *Spada and Galassi (2012)* describe the formal uncertainty of the estimated sea-level rate by defining a 95 percent confidence interval (μ) for the slope, given by

$$\mu = \frac{\sigma}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2}} t_{0.975,k}, \qquad (13)$$

where x is the average of the x_i's and $t_{0.975}$ is the 0.975–th quartile of the Student t-distribution with k = n-2 degrees of freedom. In Eq. (13), σ is defined by

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{k}} \qquad (14)$$

where y_i is the actual sea-level value and $\hat{y}_i$ the estimated value.
Thus, to account for uncertainties on the rate r, the sea-level trend is given by

$$trend = r \pm \mu. \qquad (15)$$

The sea-level trend estimates are expressed as mm yr^{-1}.

Sea-level trend NUTS3 regionalization

Spatial layers for NUTS3 regions were produced from the components of the previous product. As a result, there is a spatial layer for the NUTS3 Sea-Level trend from the reconstruction for the last 50 years (MEDSEA_CH4_Product_4_3) and the last 100 years (MEDSEA_CH4_Product_4_4).

Because NUTS3 regions are terrestrial administrative boundaries, some processing was necessary to extend the influence of these regions into the sea. First of all, NUTS3 regions are official for EU member states and candidates, but Mediterranean non-EU states do not have NUTS3 regions. In order to obtain equivalent administrative boundaries for those states we used the regionalisation developed by the United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP) for the Transboundary Diagnostic Analysis in the Mediterranean Sea. Because the datasets we are dealing with are marine datasets and there are no data inland, the results for the first 10 nautical miles were taken into account, consistent with the definition of costal water in the EU Marine Strategy Directive. The boundary limit conflicts were solved using Thiessen polygons. The NUTS3 regionalization was implemented specifically for statistical purposes, taking into account the EU regional stats, as well as for coastal managers.

MEDSEA_CH4_Product_5

Sea-level reconstruction method

To calculate the mean sea level (MSL), the global or basin MSL time series must be distinguished from the regional maps of MSL slopes. In both cases, these calculations are available mission by mission for the period being considered, or by combining several altimetry missions covering the entire altimetric period.

Time series for each mission
To calculate the MSL time series for each mission (TOPEX/Poseidon, Jason-1, Jason-2), a grid of mean sea-level anomalies (SLA=SSH-MSS) was calculated for each cycle (~10 days) to distribute the measurements equally across the surface of the oceans. The global or basin mean for each grid was calculated by weighting each box according to its latitude and the area covering the ocean; this reduced the significance of the boxes at high latitudes, which covered a smaller area, and of the boxes that overlapped with land. This provided the time series per cycle, which was then filtered with a low-pass filter to remove signals of less than 2 or 6 months, and the annual and semi-annual periodic signals were also adjusted. The MSL slope was deduced from this series using the least squares method.

Time series combining missions
The global MSL for the entire altimetric period was calculated by combining the time series data from all three TOPEX/Poseidon, Jason-1 and Jason-2 missions before filtering out the periodic signals. The three missions were linked during the 'verification' phases of the Jason-1 and Jason-2 missions to calculate very precisely the bias in global MSL between these missions. It was decided to connect TOPEX/Poseidon and Jason-1 to Jason-1's cycle 11 (May 2002) by subtracting a bias of 5.46 cm from the Jason-1 MSL. This bias was computed as the difference in the average global MSL between the two missions for a common period over a few cycles, centered on cycle 11 of Jason-1:

corrected MSL (Jason-1) = MSL (Jason-1) – bias (Jason-1, T/P).

Similarly, the Jason-2 MSL was connected to the Jason-1 MSL on Jason-2's cycle 11 (October 2008) by subtracting a bias of -7.34 cm from Jason-2's MSL and also by taking into account the bias between Jason-1 and TOPEX/Poseidon:

corrected MSL (Jason-2) = MSL (Jason-2) – bias (Jason-2, Jason-1) – bias (Jason-1, T/P).

The global MSL reference series was obtained by filtering out the periodic signals for the entire altimetric period (Fig. 1).

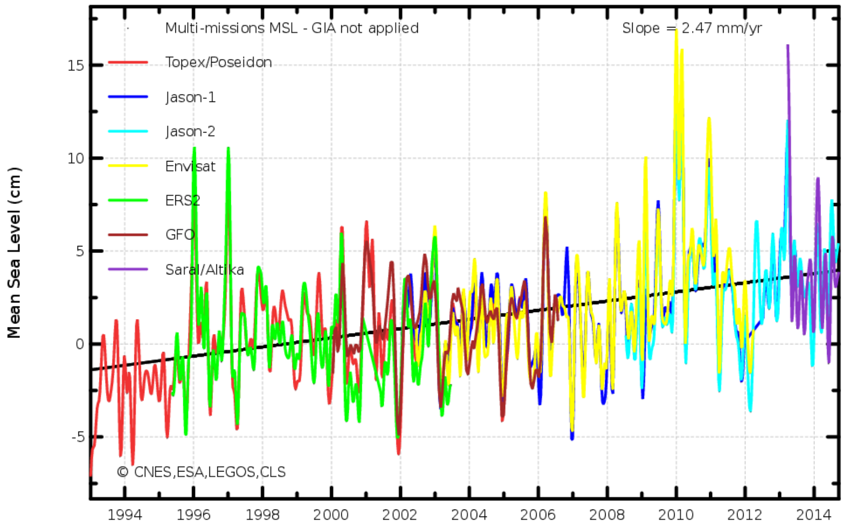

Figure 1 **Monitoring of mono-mission and multi-mission Mean Sea Level in the Mediterranean Sea**

Maps for each mission

The regional MSL slopes for each mission were estimated using SLA grids for each cycle and each mission, as defined above for the time series. The regional slopes were estimated using the least squares method at each grid point after adjusting the periodic signals (annual and semi-annual). The map of these points was deduced from the slope grid, as well as the map of the corresponding formal adjustment error.

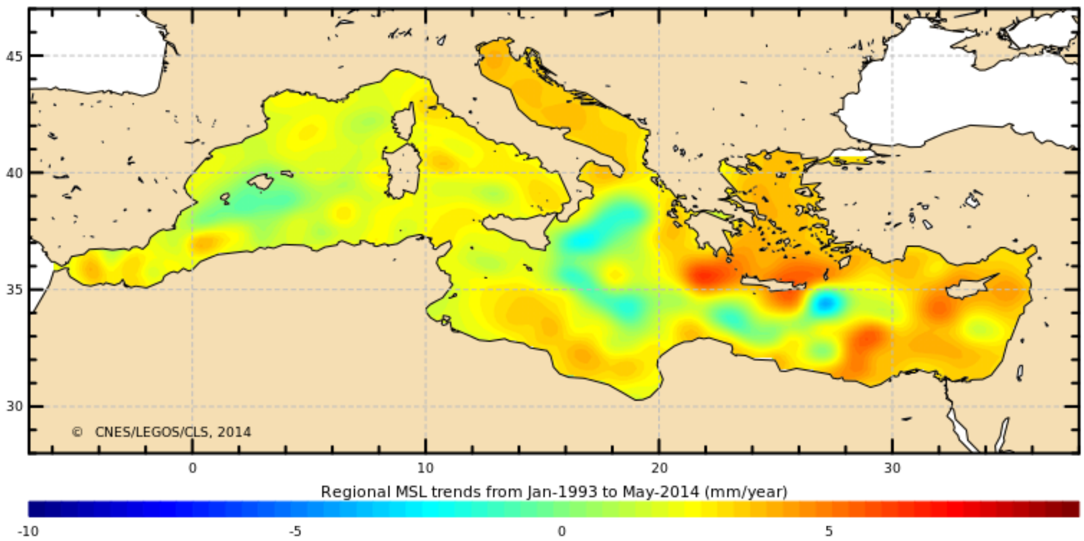

Figure 2 **Regional Mean Sea Level from January 1993 to May 2014 in the Mediterranean Sea**

Maps combining missions

Lastly, the regional MSL slopes for the entire altimetric period were calculated using the Ssalto/Duacs multi-mission gridded data, which not only enabled the slopes to be estimated at a good resolution (1/3 of a degree on a Mercator grid), but also enabled the local MSL slopes above 66° to be estimated using data from the ERS-2 and ENVISAT missions. To estimate the regional slopes, we used the same methodology as for the grids for each mission (Fig. 2).

Sea-level trend estimate

The MSL slope, equivalent to the sea-level trend, was calculated from this series using the least squares method.

Sea-level trend NUTS3 regionalization

Spatial layers for NUTS3 regions were produced from the components of the previous product. As a result, a spatial layer for the NUTS3 Sea-Level trend was obtained from satellite data for the last 10 years (MEDSEA_CH4_Product_5_2).

Because NUTS3 regions are terrestrial administrative boundaries, some processing was necessary to extend the influence of these regions into the sea. First of all, NUTS3 regions are official for EU member states and candidates, but Mediterranean non-EU states do not have NUTS3 regions. In order to obtain equivalent administrative boundaries for those states we used the regionalisation developed by the United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP) for the Transboundary Diagnostic Analysis in the Mediterranean Sea. Because the datasets we are dealing with are marine datasets and there are no data inland, the results for the first 10 nautical miles were taken into account, consistent with the definition of costal water in the EU Marine Strategy Directive. The boundary limit conflicts were solved using Thiessen polygons. The NUTS3 regionalization was implemented specifically for statistical purposes, taking into account the EU regional stats, as well as for coastal managers.

MEDSEA_CH4_Product_6

Sea-level from tide-gauges – compilation method

The characteristic involved in this product is the "Sea Level" (ASLV), in particular the "Surface elevation monthly mean (unspecified datum) of the water body" (ASLVMNMO).

The observations for the Mediterranean Sea were retrieved from the PSMSL (www.psmsl.org; Woodworth and Player, 1993; Holgate et al., 2013). Initially, other data banks were examined, namely those of ISPRA (www.isprambiente.it) and SONEL (www.sonel.org). Both data banks provide data that allow to compute monthly means that are not present in the PSMSL data bank, thus increasing the length of several time series. However, in spite of this, those time series still cannot pass the selection criterion for the trend estimates, namely more than 80% valid annual means in 1913-2012 for 100-yr trends and in 1963-2012 for 50-yr trends. As a consequence, ISPRA and SONEL data were not taken into account.

The PSMSL data bank was established in 1933 and is composed of the relative monthly MSL on a global scale. It is compiled from the data published in the Publications Scientifiques issued from 1939 to 1968 by IAPO, which later became IAPSO (IAPO, 1939-1963; IAPSO, 1968). There are two main groups of time series, namely the RLR and the "metric" data. The RLR data are characterized by known vertical references. In principle, the RLR data are more reliable; however, several metric time series are homogeneous and usable. The problem should be addressed in each case. Although not formally included in the PSMSL data, other "ancillary" data are available through their website, consisting of year-only time series extracted from the IAPO Publications up to No. 24. These data are quite old (from the late 19th century to 1959) and their documentation is sometimes insufficient and their quality low (Spencer et al., 1988).

If the RLR and metric data are considered together, 199 time series are available for the Mediterranean, and if the RLR time series are considered alone there are 131. There are also 17 ancillary time series from stations not included in the PSMSL data bank, mainly along the northwest coast of Africa.

In general, the original data consist of 24 hourly values (either instantaneous or mean values) or high and low waters (up to 4 per day). In the past, individual data were obtained by digitizing paper diagrams, with uncertainties of around 5-10 mm (depending on the tide-gauge reduction ratio), while modern data are obtained by digital instruments and uncertainties are normally lower than 1 mm. The monthly means are only provided when at least 15 days of data per month are available. The uncertainties in the monthly means are further decreased by averaging the hourly data (roughly 700 values per month), or high and low waters (roughly 100 per month). Thus, in the worst situation, a monthly mean is affected by uncertainty of 1 mm (the precision of the PSMSL data); the uncertainty in the annual means can generally be neglected.
Note that the vertical movements of the ground affect the tide gauges. They are site-specific and may be quite severe in the Mediterranean due to tectonics. Consequently, analysis of the sea-level observations alone is only adequate for producing information at a local level. A coherent basin-scale analysis is made difficult by the inhomogeneous spatial and time data distributions; therefore, observations should be integrated into a model.

Sea-level trends from tide-gauge estimates

Trends were estimated using annual means to avoid bias due to incomplete annual cycles in the case of missing monthly values. Following GLOSS recommendations, an annual mean was computed when at least 11 months were available; therefore, missing years often appear in the time series despite the presence of monthly data. As discussed above, an annual mean is generally affected by an almost negligible statistical uncertainty.
The possibility of estimating mean sea-level trends depends on data availability, which is affected by two main limitations, namely gaps in the time series and a lack of data during the most recent years because of data latency. As data for 2013 and 2014 are often missing from the PSMSL data bank, it was agreed to use 2012 as the last year of the analyzed periods.
The estimate of sea-level trends over 10 years is not considered here because it is too short a period to obtain useful values, for at least two reasons.

- First, the trend estimate is biased by the incomplete sampling of the 18.6-year lunar nodal cycle, even though its amplitude is relatively small (less than 1 cm).
- Second, the small sample size makes the statistical error comparatively large relative to the trend itself; for instance, the 2003-2012 trends for the two centennial stations of Marseille and Trieste are 5.9±5.6 mm/y and 7.3±8.6 mm/y, respectively (error corresponding to 95% confidence).

Therefore, the 50-year trends were estimated for the 1963-2012 period (MEDSEA_CH4_Product_6_2) and the 100-year trends for the 1913-2012 period (MEDSEA_CH4_Product_6_3). The number of RLR plus metric data per year varies between 30 and 102 during the past 50 years (1963-2012) and between 5 and 102 during the last 100 years (1913-2012); the number of RLR data alone varies between 21 and 83 in 1963-2012 and between 4 and 83 in 1913-2012. To retain as many time series as possible, an 80% (arbitrary) threshold of valid annual means was defined; that is, 40 years from 1963-2012 and 80 years from 1913-2012.

Table 1 summarizes the 10 RLR time series that passed the availability criterion for the 50-year trend analysis, displaying the PSMSL station code, station name, NUTS 3 region code, geographical coordinates, the start and end years, and the percentage of annual means available.
The following should be noted.

a) After comparison with the Split Gradska Luka station, the Split Rt. Marjana station, which was eligible according to the abundance criterion, exhibited questionable data after 2008, and these data were therefore discarded. Because the two stations are very close to each other, it was decided to keep the Split Gradska Luka only to represent NUTS region HR035.
b) Although more than 80% of the annual means were available for Venezia Punta della Salute station, the data were discarded because the latest annual mean available from the PSMSL is in 2000, thus the most recent period is not represented.
c) No attempt was made to merge the time series belonging to stations located at the same position or very close to each other, because no information was available on the local vertical land motion, which may differ significantly even at a short distance.

Trends were estimated as the slopes of the linear fit of the annual MSL. The error consists of 1.96 times the slope standard error, corresponding to the 95% confidence level.

Table 1 List of stations used for 50-year trend estimates.

A – PSMSL code
B – station name
C – NUTS 3 region code
D – percentage of annual means available for 1963-2012
E – 1963-2012 trend ± error (mm/yr)

A	B	C	D	E
761	ROVINJ	HR036	96	0.71 ± 0.62
353	BAKAR	HR031	98	1.23 ± 0.73
352	SPLIT - GRADSKA LUKA	HR035	98	1.17 ± 0.69
760	DUBROVNIK	HR037	90	1.15 ± 0.61
503	ALEXANDRIA	-----	84	1.86 ± 0.69
61	MARSEILLE	FR824	88	1.25 ± 0.50
154	TRIESTE	ITH44	100	1.35 ± 0.63
488	TARIFA	ES612	86	1.66 ± 0.78
496	MALAGA	ES617	92	2.52 ± 0.76
498	CEUTA	ES630	86	0.95 ± 0.52

Similarly, Table 2 summarizes the two RLR time series that passed the availability criterion for the 100-year trend estimate.

Table 2 List of stations used for 100-year trend estimates.

A – PSMSL code
B – station name
C – NUTS 3 region code
D – percentage of annual means available for 1913-2012
E – 1913-2012 trend ± error (mm/yr)

A	B	C	D	E
61	MARSEILLE	FR824	93	1.17 ± 0.24
154	TRIESTE	ITH44	94	1.20 ± 0.25

Sea-level trend from tide-gauges – NUTS3 regionalization

Spatial layers for NUTS3 regions were produced from the child components of the previous product. As a result, there is a spatial layer for the NUTS3 Sea-Level trend from tide-gauges for the last 10 years (MEDSEA_CH4_Product_6_1), the last 50 years (MEDSEA_CH4_Product_6_2) and the last 100 years (MEDSEA_CH4_Product_6_3).
Because NUTS3 regions are terrestrial administrative boundaries, some processing was necessary to extend the influence of these regions into the sea. First of all, NUTS3 regions are official for EU member states and candidates, but Mediterranean non-EU states do not have NUTS3 regions. In order to obtain equivalent administrative boundaries for those states we used the regionalisation developed by the United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP) for the Transboundary Diagnostic Analysis in the Mediterranean Sea. Because the datasets we are dealing with are marine datasets and there are no data inland, the results for the first 10 nautical miles were taken into account, consistent with the definition of costal water in the EU Marine Strategy Directive. The boundary limit conflicts were solved using Thiessen polygons. The NUTS3 regionalization was implemented specifically for statistical purposes, taking into account the EU regional stats, as well as for coastal managers.

MEDSEA_CH4_Product_7

No comprehensive and complete dataset was available to draw conclusions or estimate the sign and magnitude of shoreline change and its values along the Mediterranean shoreline. To document and explain the lack of data and to explore the state-of-the-art on this issue in the Mediterranean, the report is presented as a product instead of a spatial layer or a time series.

MEDSEA_CH4_Product_8

Basin Sea surface temperature time series – production method

The HadISST database produced by the Met Office Hadley Center was used to produce basin-averaged times series of SST (Fig. 3) for periods of 10 (2003-2012; MEDSEA_CH8_Product_1_1), 50 (1963-2013; MEDSEA_CH4_Product_8_2) and 100 years (1913_2012; MEDSEA_CH4_Product_8_3). The spatial resolution of this dataset is a 1°latitude/longitude grid (Rayner N.A. et al., 2003). The SST data were taken from the Met Office Marine Data Bank (MDB) and the Comprehensive Ocean-Atmosphere Data Set (COADS) (now ICOADS). HadISST temperatures were reconstructed using a two-stage reduced-space optimal interpolation procedure, followed by superimposition of the quality-improved gridded observations onto the reconstructions to restore local detail (MetOffice).

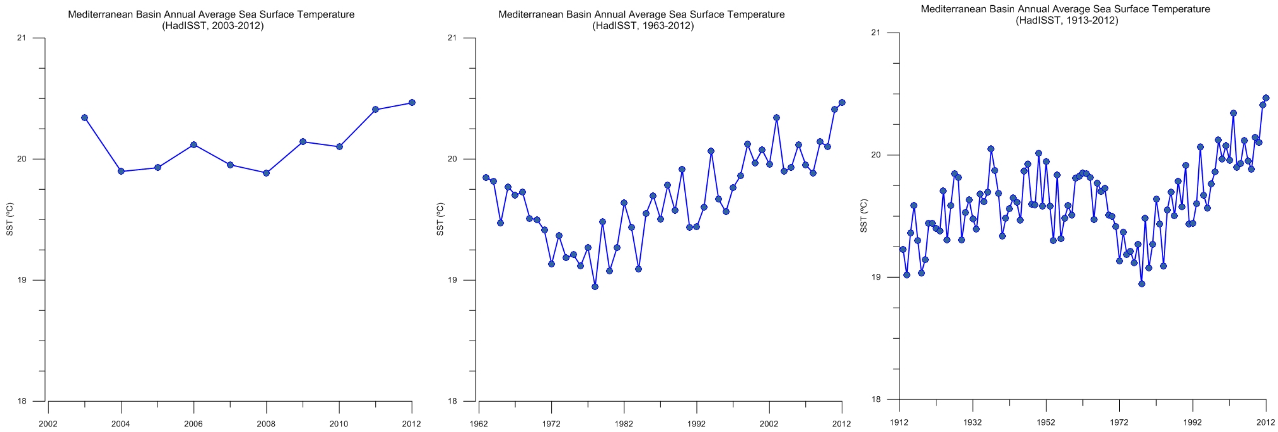

Figure 3 **Basin averaged times series of Sea Surface Temperature (°C) from HadISST for the periods of the last 10 (left panel), 50 (central panel) and 100 years (right panel).**

NUTS3 regionalized Sea surface temperature time series – production method

Time series for NUTS3 regions were produced, resulting in NUTS3 SST time series for the last 10 years (MEDSEA_CH4_Product_8_4), last 50 years (MEDSEA_CH4_Product_8_5) and last 100 years (MEDSEA_CH4_Product_8_6).

MEDSEA_CH4_product_9

Basin mid-water and bottom temperature time series – production method

The CMEMS Mediterranean Physics Reanalysis was used to produce basin time-series of **the** Sea Temperature trend (Fig. 4) at mid-water (MEDSEA_CH4_Product_9_1) and sea bottom (MEDSEA_CH4_Product_9_2) for the 2003-2013 period. The sea bottom is considered as the last level of the water column with available temperature values. The spatial resolution of this dataset is a 1/16° latitude/longitude grid.

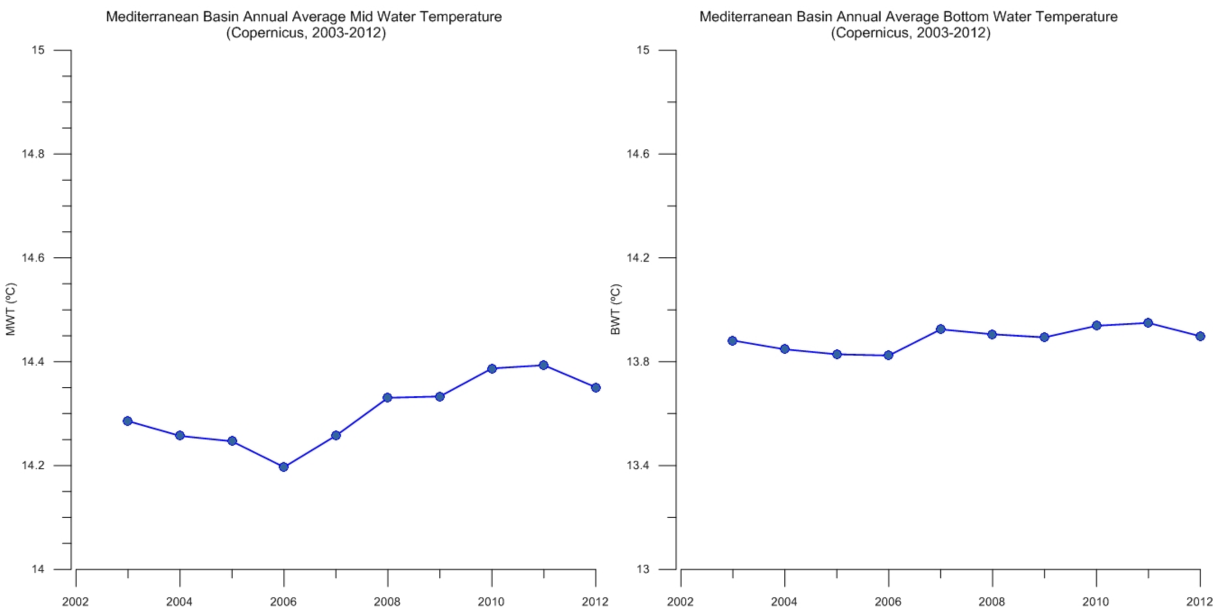

Figure 4 **Basin averaged times series of mid-water (left panel) and sea bottom (right panel) temperature (°C) from CMEMS Mediterranean Physics Reanalysis for the last 10 years.**

NUTS3 regionalized Sea bottom temperature time series – production method

Time series for NUTS3 regions were also produced from the components of the previous product. As a result, there are NUTS3 sea bottom temperature time series for the last 10 years (MEDSEA_CH4_Product_9_3). Time series for mid-water were not produced because the NUTS3 marine influence area does not reach the Mediterranean mid-water location.

MEDSEA_CH4_Product_10

Basin sea internal energy time series – production method

The CMEMS Mediterranean Physics Reanalysis was used to produce basin-level time series of Internal Energy (units: J/m2) for the 1993-2012 period (MEDSEA_CH4_Product_10_1) (Fig. 5). The spatial resolution of this dataset is a 1/16° latitude/longitude grid.
The Internal Energy of oceans is defined (*Oort et al., 1989*) by

$$\text{eq: } 1 \mathrm{IE_i} = \iiint \rho c_0 T dxdydz,$$

where IE_i is the Internal Energy value for the basin in the i-th year, $\overline{HC}_{rp}$ ρ = 1025 kg/m3 is the in-situ density (*Sorgente et al., 2011; Samelson, 2011; Lecci, 2012*), c_0 = 4187 J/Kg*K (*Oort et al., 1989; Peixoto J.P. and Oort A.H., 1992; Lecci, 2012*) is the specific heat at constant pressure for ocean water, and T is the Temperature.

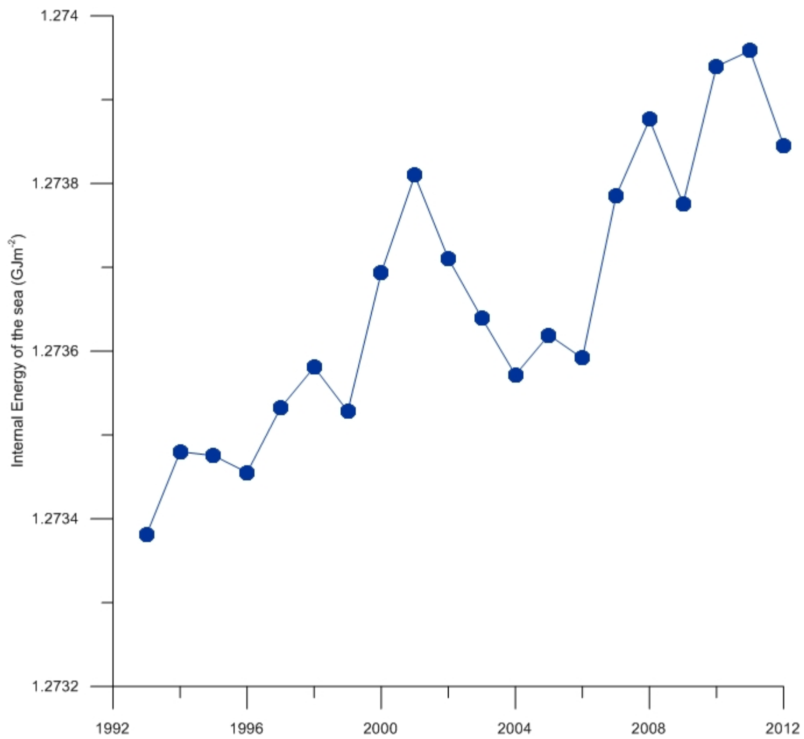

Figure 5 **Basin averaged times series of internal energy (GJm^2) from CMEMS Mediterranean Physics Reanalysis for the last 20 years.**

NUTS3 regionalized sea internal energy time series – production method

Time series for NUTS3 regions were produced from the components of the previous products. As a result, there are NUTS3 sea internal energy time series for the last 20 years (MEDSEA_CH4_Product_10_2).

MEDSEA_CH4_product_11

The sea-level field during the last century was reconstructed using the reduced-space optimal interpolation described by Kaplan et al. (2000), and applied as in Church et al. (2004) and Calafat and Gomis (2009) for global and regional sea-level reconstructions, respectively. Please see the detailed methodology in the description of MEDSEA_CH4_Product_4.

The reduced-space optimal interpolation solution can be converted into its full grid representation by substituting the estimated amplitudes $\alpha(t)$ in expression (3), to obtain the whole sea-level reconstruction.

The year-by-year averaged results for the basin were used as inputs for generating the sea-level time series (Fig. 6) from the reconstruction for the last 50 years (1963-2012; MEDSEA_CH4_Product_11_1) and the last 100 years (1913_2012; MEDSEA_CH4_Product_11_2).

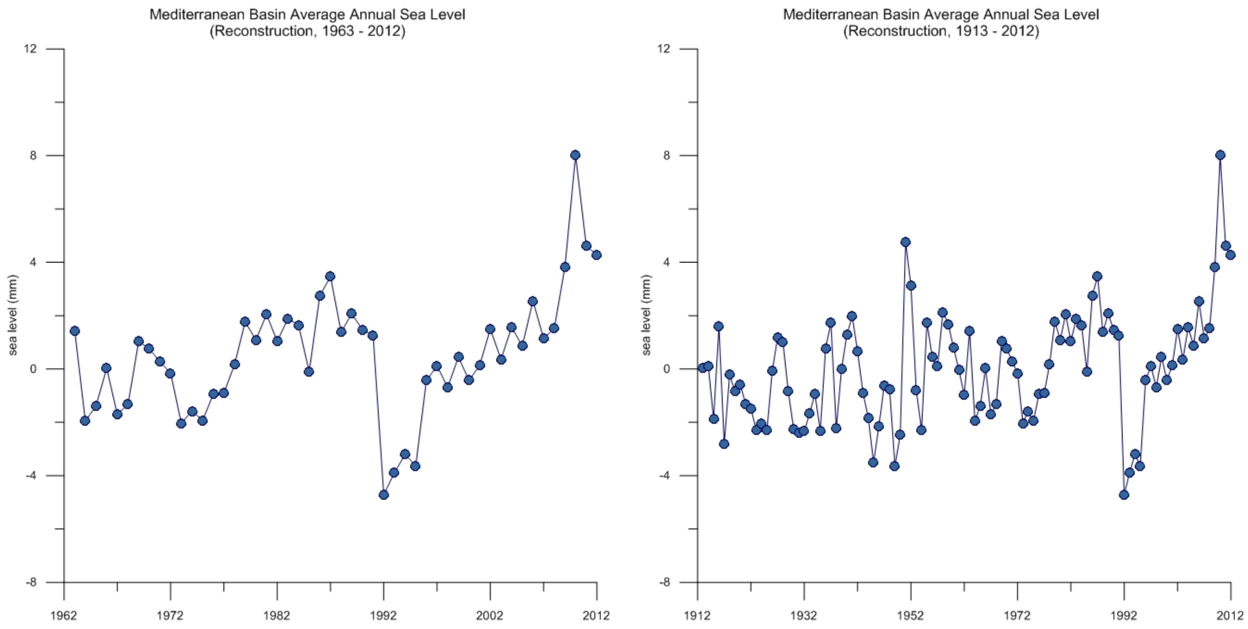

Figure 6 **Basin averaged times series of sea level (mm) from Copernicus-MyOCean CMCC reconstruction over 50 years (left panel) and 100 years (right panel)**

NUTS3 regionalized sea level from reconstruction **of** time series – production method

Time series for NUTS3 regions were produced from the components of the previous product: the NUTS3 sea-level time series from the reconstruction for the last 50 years (MEDSEA_CH4_Product_11_3) and for the last 100 years (MEDSEA_CH4_Product_11_4).

MEDSEA_CH4_Product_12

NUTS 3 regionalized sea level from time-gauge time series – production method

Please refer to the description of the method for MEDSEA_CH4_Product_6.
Because tide-gauge locations can be directly associated with NUTS3 regions, we used this input directly to generate the NUTS3 sea-level time series from the reconstruction for the last 50 years (1963-2012; MEDSEA_CH4_Product_12_2) (Fig. 7) and the last 100 years (1913_2012; MEDSEA_CH4_Product_12_3) (Fig. 8).

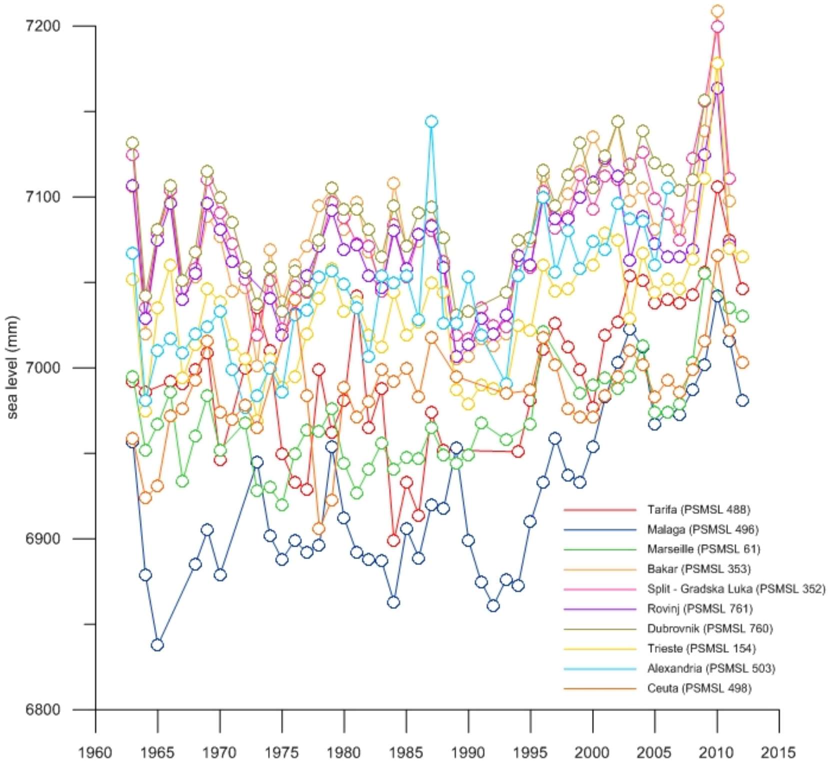

Figure 7 **Basin averaged times series of sea level (mm) from PSMSL tide-gauges over a 50-year period.**

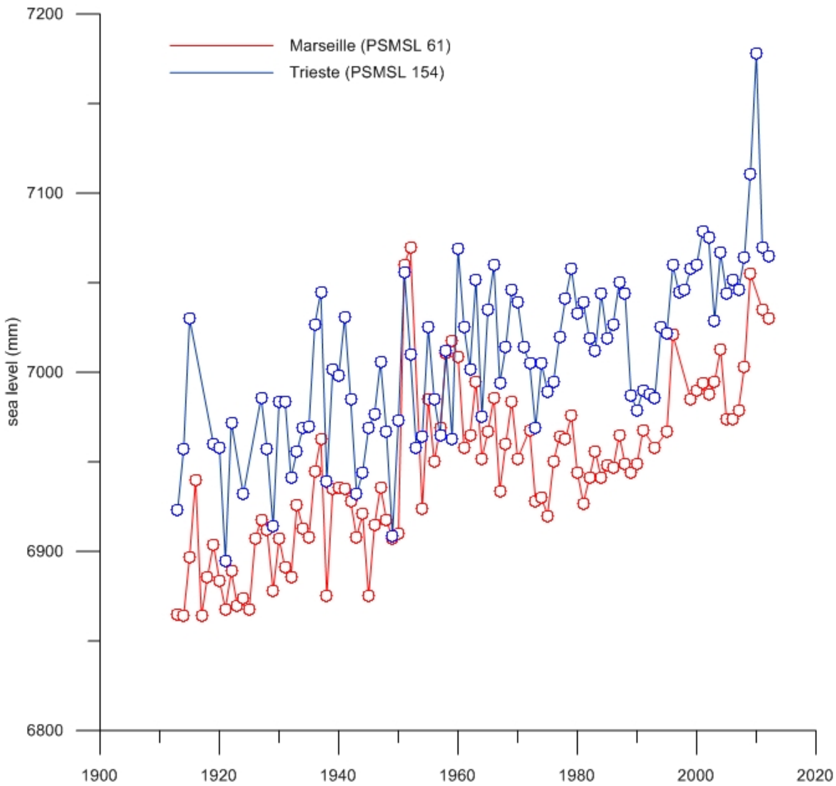

Figure 8 **Basin averaged times series of sea level (mm) from PSMSL tide-gauges over a 100-year period.**

MEDSEA_CH4_Product_13

Basin sea level from satellite time series – production method

To calculate the MSL, the global or basin MSL time series must be distinguished from the regional maps of MSL slopes. In both cases, these calculations are available mission by mission for the period being considered, or by combining several altimetry missions covering the entire altimetric period.

Time series for each mission

To calculate the MSL time series for each mission (TOPEX/Poseidon, Jason-1, Jason-2), a mean grid of sea-level anomalies (SLA=SSH-MSS) first had to be calculated for each cycle (~10 days) to distribute the measurements equally across the ocean surface. The global or basin mean for each grid was calculated by weighting each box according to its latitude and the area of ocean it covered; this reduced the significance of the boxes at high latitudes, which covered a smaller area, and of the boxes that overlapped land. This gave the time series per cycle, which was then filtered with a low-pass filter to remove signals of less than 2 or 6 months, and the annual and semi-annual periodic signals were also adjusted.

Time series for combined missions

The global MSL for the entire altimetric period was calculated by combining the time series from all three TOPEX/Poseidon, Jason-1 and Jason-2 missions before filtering out the periodic signals. The three missions were linked during the 'verification' phases of the Jason-1 and Jason-2 missions

to calculate very precisely the bias in the global MSL between these missions. It was decided to connect TOPEX/Poseidon and Jason-1 to Jason-1's cycle 11 (May 2002) by subtracting a bias of 5.46 cm from the Jason-1 MSL. This bias was computed as the difference in the averages of the global MSL between the two missions on a common period over a few cycles, centered on cycle 11 of Jason-1: Corrected MSL (Jason-1) = MSL (Jason-1) - bias (Jason-1, T/P).
Similarly, the Jason-2 MSL was connected to the Jason-1 MSL on Jason-2's cycle 11 (October 2008) by subtracting a bias of -7.34 cm from Jason-2's MSL and by taking into account the bias between Jason-1 and TOPEX/Poseidon: Corrected MSL (Jason-2) = MSL (Jason-2) - bias (Jason-2, Jason-1) - bias (Jason-1, T/P). The global MSL reference series was obtained by filtering out the periodic signals for the entire altimetric period.

The year-by-year averaged results for the basin were used as inputs for generating the basin sea-level time series from satellite for the last 10 years (1963-2012; MEDSEA_CH4_Product_13_1) (Fig. 9).

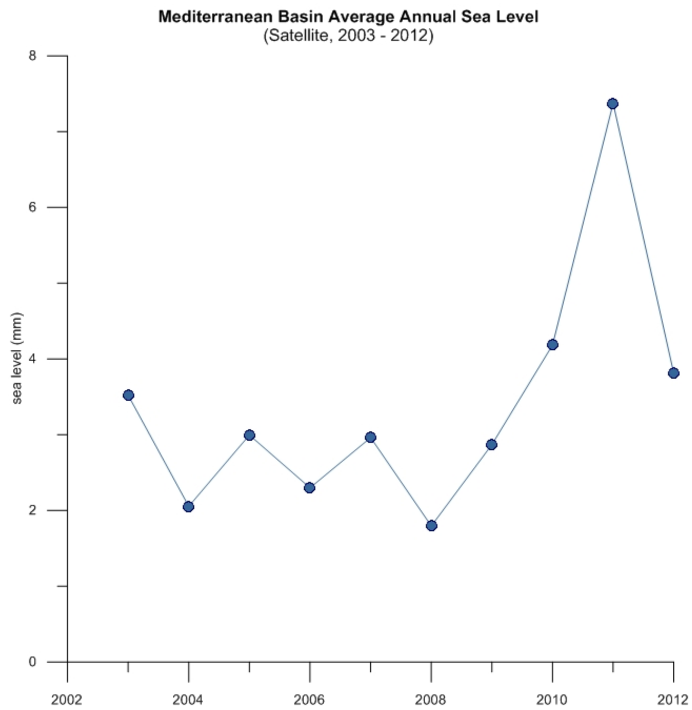

Figure 9 **Basin averaged times series of sea level (mm) from satellite over the last 10 years.**

NUTS3 regionalized sea level from satellite time series – production method

Time series for NUTS3 regions were produced from the components of the previous product. As a result, there is a spatial layer for the NUTS3 sea level from the reconstruction of the time series for the last 10 years (MEDSEA_CH4_Product_13_2).

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Expert evaluation of Targeted Product quality and gaps in the input data sets

The objective is to provide an expert evaluation of the "fitness for purpose and use" for each Targeted Product. The coordinator asked the challenges teams to answer to the following points:

1. Assign an overall product quality score with respect to scope (fitness for purpose) and explain why according to the scale in Table A.
2. Explain what is (are) the most important characteristic(s) for the Targeted Product quality (if all characteristics are important please say so);
3. Explain what is (are) the quality element(s) (see Annex 1) of the most important characteristic(s) that affects the Targeted Product quality;
4. Explain the limitations on the quality of Targeted products due to the input data set used;
5. Explain which characteristics "fails the most" to meet the scope of the Targeted Product;
6. Provide an expert judgement to describe for each Targeted Product the most important **gaps in the input data sets**.

SCORE	MEANING
1	EXCELLENT → it meets completely the scope of the Targeted Product
2	VERY GOOD → it meets more than 70% of the scope of the Targeted Product
3	GOOD → it meets less than 50% of the scope of the Targeted Product
4	SUFFICIENT → it does not really meet the scope but it is a starting point
5	INADEQUATE → it does not really fulfil the scope, not usable

Table A Targeted Products quality scores and their meaning.

MEDSEA_CH4_Product_1

1) The overall product quality score with respect to scope is very good (2). The HadISST dataset is the only dataset that provides SST observations for the Global Ocean over a very long period (1870-ongoing). A limitation is that the data have a low spatial resolution of 1 degree (~100 km).
2) The most important characteristic is TEMP (P02), and TEMPAV01 (P01) in particular because it refers to the sea surface temperature of the water body obtained by the advanced very high resolution radiometer (AVHRR).
3) The quality element that most affects the product quality is the low spatial resolution (1 degree).
4) The limitations on the quality of the product due to the input dataset used (fitness for use) are that the product is not suitable to represent the SST close to the coast, and the computation of trends only considers a few points due to the low resolution of the dataset.
5) The HadISST dataset is the only one that provides SST for a very long period (1870-ongoing).

6) The most important gap is the low spatial resolution in the Mediterranean Sea;

MEDSEA_CH4_Product_2

1) The overall product quality score is good (3). The CMEMS Mediterranean Physics Reanalysis dataset is the only dataset that provides the temperature of the Mediterranean Sea for mid and bottom water and with a high spatial resolution (1/16 degrees, ~6.25 km). A limitation is the low temporal coverage of 27 years (1987-2013).
2) The most important Characteristic is TEMP (P02), and TEMPPR01 (P01) in particular because it refers to the temperature of the water body.
3) The quality element that most affects the product quality is the short temporal coverage (1987-2013).
4) The product is not suitable to represent mid and bottom temperatures for the last 50 (1963-2012) and 100 years (1913-2012).
5) The CMEMS Mediterranean Physics Reanalysis dataset is the only one to provide mid and bottom temperatures for the Mediterranean Sea with a high spatial resolution (~6.25 km).
6) The most important gap is the relatively short time span.

MEDSEA_CH4_Product_3

1) The overall product quality score is excellent (1). The CMEMS Mediterranean Physics Reanalysis dataset is the only dataset that provides the temperature of the whole water column for the Mediterranean Sea and with a high spatial resolution (1/16 degrees, ~6.25 km). This allowed the internal energy t be computed for the last 20 years (1993-2012).
2) The most important Characteristic is TEMP (P02), and TEMPPR01 (P01) in particular because it refers to the temperature of the water body.
3) The product quality is very high due to the availability of the CMEMS ocean reanalysis dataset. The dataset has been extensively validated using in situ and satellite observations, and the results of this validation are contained in the Quality Information document at http://marine.copernicus.eu/documents/QUID/CMEMS-MED-QUID-006-004.pdf. However, the reanalysis system only assimilates observations in the first 1000 m of the water column, so the accuracy decreases below this depth.
4) There are no major limitations on the quality of product due to the input dataset used. However, because the numerical model was not adjusted by assimilating observations below 1000 m, the resulting trends should be carefully considered.
5) The CMEMS Mediterranean Physics Reanalysis dataset is the only one to provide daily temperature values for the whole water column at a high spatial resolution (~6.25km) for the Mediterranean Sea over 27 years.
6) There is no gap for this product.

MEDSEA_CH4_Product_4

1) The overall product quality score is good (3). Sea-level reconstructions allowed us to merge the spatial and temporal information provided by remote sensing and in-situ observations. In the Mediterranean Sea, the lack of in-situ observations in the Southern part of the basin is an issue that affects all scientific studies that aim to describe the sea-level variability and

trends in the basin. As a consequence, the sea-level trends obtained from the reconstruction are also affected by this lack of information.

2) Due to their different spatial and temporal coverage, both characteristics involved in the realization of this product are equally important. In-situ sea-level observations provide seminal information about the sea level in the Mediterranean, covering a period of approximately 100 years. Satellite altimetry data span only two decades (1993-ongoing) over a continuous spatial domain.
3) The quality elements that most affect the product quality are:
    - Spatial extent, because in-situ data are almost absent in the Southern part of the basin; and
    - Completeness, because in-situ data time series are often affected by significant gaps, and consequently it is not possible to consider the entire observational dataset in the reconstruction.
4) The principal limitations on the quality of the product due to the input dataset used (fitness for use) are:
    - Spatial extent, because sea-level in-situ observations are spatially discontinuous by definition. The lack of in-situ data in the Southern part of the basin can lead to underestimation of the sea-level temporal amplitudes used in the reconstruction.
    - Temporal extent, because sea-level remote-sensing data are available for the last 20 years, which is a relatively short period compared with the time window covered by the reconstruction. This period also represents the training period in which the EOFs are computed to determine the sea-level spatial variability in the reconstruction. Consequently, the temporal extent of the remote-sensing data can affect the assumption that EOFs are stationary in time.
5) The characteristics and respective dataset that most fails to meet the scope of the Targeted Product (fitness for use) is the PSMSL dataset, which contains the in-situ sea-level records.
6) Sea-level reconstructions allowed us to merge the spatial and temporal information provided by remote sensing and in-situ observations. **The lack of in-situ observations in the Southern part of the Mediterranean basin is an issue that affects all scientific studies that aim to describe the sea-level variability and trends in the basin**. As a consequence, the sea-level trends obtained from the reconstruction are also affected by this lack of information.

MEDSEA_CH4_Product_5

1) The overall product quality score is **excellent** (1). The global MSL was calculated by combining the time series from all three TOPEX/Poseidon, Jason-1 and Jason-2 missions since the first TOPEX/Poseidon mission (1992). As Jason-2 is still in flight, the computation of 10-year sea-level trends from satellite altimetry is relevant to these input data.
2) The most important characteristic for the product quality is the sea level (ASLVNL60). Its accuracy and the methodology applied to build the product are also very important. In fact, the altimeter datasets are checked and evaluated before dissemination thanks to Cal/Val activities, thus they are considered reliable for 10-year sea-level monitoring.
3) The quality elements that affect the Targeted Product quality are the spatial resolution, time resolution and completeness.

4) The limitations on the quality of the Targeted product due to the input dataset used (fitness for use) are:
    - different results regarding the 10/50/100-year sea-level trends;
    - data gaps in the resulting maps and datasets; and
    - large errors in the estimates of sea-level trends.
5) The characteristic ASLVNL60 used for this product generation does not fail to meet the scope of the Targeted Product. Both AVISO and Copernicus datasets are available for different case studies (AVISO provides along-track data while Copernicus provides gridded products). The differences between these datasets give access to different space/time resolution information, and the latter can be combined with in-situ measurements to provide added-value products. In the framework of this WP, altimeter datasets are used to compute 10-year sea-level trends over the Mediterranean Sea, and the resulting time series can be compared to tide-gauge measurements to provide key performance indicators.
6) The most important gaps in the input datasets are the unavailability of altimeter data and the geographical coverage due to the repetitiveness of the altimeter mission.

MEDSEA_CH4_Product_6

1) The overall product quality score is sufficient (4). The number of useful sea-level time series is extremely low compared with the number of available time series in the PSMSL data bank. A historical bank of data from different countries cannot be assumed to provide uniform time and space data coverage. Moreover, local vertical land motion makes it impossible to combine the time series without introducing information external to the database.
2) There is only one characteristic (ASLVMNMO).
3) The quality elements (Annex 1) that affect the Targeted Product quality are the **time extent** and **completeness**. The time series are often affected by significant gaps in both time periods, the last 50 years and the last 100 years. The time series often start too late or end too early to estimate sea-level trends over 10 years, which is why this period was not considered here. In fact, this period is too short to obtain useful values for two reasons:
    - the trend estimate is biased by the incomplete sampling of the 18.6-year lunar nodal cycle, even though its amplitude is relatively small (less than 1 cm); and
    - the small sample size makes the statistical error comparatively large relative to the trend itself; for instance, the 2003-2012 trends for the two centennial stations of Marseille and Trieste are 5.9±5.6 mm/y and 7.3±8.6 mm/y, respectively (error corresponding to 95% confidence).
4) The limitations on the quality of the Targeted Product due to the input dataset used (fitness for use) are related to their time extent (time series often include too few annual means for a reliable estimation of 50-year and 100-year trends) and completeness (time series often include too few annual means for a reliable estimation of 50-year and 100-year trends).
5) There is only one Characteristic (ASLVMNMO) and one dataset (PSMSL).
6) Gaps are represented by a) the low number of time series in the Mediterranean Sea; b) the relatively short time span of most of the available time series; and c) the frequently missing monthly means, and therefore years, even in relatively long time series.

MEDSEA_CH4_Product_7

1) In contrast to the sea-level and sea-surface temperature datasets, there is a lack of valid data on the sediment mass balance and coastal erosion accretion at a basin level. The EUROSION dataset provides a qualitative estimate of the sediment mass balance, coded as stable, eroded or accreted, but does not specify the time extent, methods and approaches used. Other available data from the EMODnet Portal, OneGeology Portal and the European Atlas of the Seas provide data (i.e., sediment type, deep-sea water bathymetries) that do not fulfil the minimum requirements for a sediment mass balance assessment. Therefore, **the overall product quality score is inadequate (5)**, despite the challenge having explored the existence of alternative data sources and datasets, as described in the report entitled "D5.3.5.1 Sediment Mass Balance Data Assessment in the Mediterranean".
2) There are no usable characteristics for generating this product.
3) To justify why we did not construct the requested product, we pursued two approaches: (1) a specific survey of the national agencies dealing with coastal protection, and (2) a scientific literature survey. In both cases, the quality of the exploitable characteristics in the resulting datasets is doubtful.
4) The main limitations of the resulting products relate to the type and nature of the available data. First, the specific surveys (i.e., surveys originating from national agencies or the scientific literature) identified a plethora of data sources that would be appropriate for the Tender request. However, in most cases the data were neither visible nor easily available. Locating and accessing them to determine their usefulness and value for the purposes of the Tender or potential use by non-expert users would require additional analyses and supplementary effort. The data from specific surveys indicate that the resolution for the spatial layers of sediment mass balance is only adequate for 10% of Mediterranean NUTS3 regions. Only four regions have adequate temporal resolution. We discarded local studies that could provide time series at a specific location, but not at the scale requested by the tender. Second, our scientific literature survey showed that despite the existence of numerous studies in the Mediterranean, they are usually local and with an incoherent frequency. Furthermore, the studies use very different methods, making it very difficult to use and compare the resulting data. There is some additional concern over whether the locations surveyed are sufficiently representative for use as NUTS3 regional indicators.
5) Regarding the limitations of this product, both the scientific literature survey and the specific surveys showed persistent differences in the amount and quality of data between countries and between the northern and southern coasts of the Mediterranean.

MEDSEA_CH4_Product_8

1) The overall product quality score with respect to scope is **very good (2)**. The HadISST dataset collects SST observations for the Global Ocean and is the only dataset that covers a very long period (1870-ongoing). A limitation concerns the data's low spatial resolution of 1 degree (~100 km).
2) The most important characteristic is TEMP (P02), and TEMPAV01 (P01) in particular because it refers to the sea surface temperature of the water body obtained by the AVHRR.
3) The quality element that affects the product quality is the low **spatial resolution** (1 degree)

4) The limitation on the quality of the product due to the input dataset used (fitness for use) is that the product is not suitable to represent the sea-surface temperature close to the coast because of the low resolution of the dataset.
5) The HadISST dataset is the only one to provide SSTs over a very long period (1870-ongoing).
6) The gap is the low spatial resolution in the Mediterranean Sea.

MEDSEA_CH4_Product_9

1) The overall product quality score is **good (3)**. The CMEMS Mediterranean Physics Reanalysis dataset is the only one that provides mid and bottom water temperatures for the Mediterranean Sea with a high spatial resolution (1/16 degrees, ~6.25 km). A limitation concerns the low temporal coverage of 27 years (1987-2013).
2) The most important Characteristic is TEMP (P02), and TEMPPR01 (P01) in particular because it refers to the temperature of the water body.
3) The quality element that affects the product quality is its short temporal coverage (1987-2013).
4) The product not suitable to represent the mid and bottom temperature for the last 50 (1963-2012) and 100 years (1913-2012).
5) The CMEMS Mediterranean Physics Reanalysis dataset is the only one to provide mid and bottom water temperatures for the Mediterranean Sea with a high spatial resolution (~6.25km).
6) The main gap is the relatively short time span.

MEDSEA_CH4_Product_10

1) The overall product quality score is **excellent** (1). The CMEMS Mediterranean Physics Reanalysis dataset is the only dataset that provides the temperature of the Mediterranean Sea for the entire water column and with a high spatial resolution (1/16 degrees, ~6.25 km). This allowed us to compute the internal energy for the last 20 years (1993-2012).
2) The most important Characteristic is TEMP (P02), and TEMPPR01 (P01) in particular because it refers to the temperature of the water body.
3) The product quality is very high due to the availability of the CMEMS ocean reanalysis dataset. The dataset was extensively validated using in situ and satellite observations and the results of this validation are contained in the Quality Information document at http://marine.copernicus.eu/documents/QUID/CMEMS-MED-QUID-006-004.pdf. However, as the reanalysis system only assimilates observations for the first 1000 m, the data accuracy is reduced below this depth.
4) There are no major limitations on the quality of the product due to the input dataset used. However, the resulting trends should be carefully considered because the numerical model is not adjusted by the assimilation of observations below 1000 m.
5) The CMEMS Mediterranean Physics Reanalysis dataset is the only one to provide daily temperature values for the entire water column of the Mediterranean Sea at a high spatial resolution (~6.25 km) over 27 years.
6) There is no gap for this product.

MEDSEA_CH4_Product_11

1) The overall product quality score is **good (3)**. Sea-level reconstructions allowed us to merge the spatial and temporal information provided by remote sensing and in-situ observations. In the Mediterranean Sea, the lack of in-situ observations in the Southern part of the basin affects all scientific studies that aim to describe the sea-level variability and trends in the basin. As a consequence, the sea-level trends obtained from the reconstruction may also be affected by this lack of information.
2) Both of the characteristics involved in the realization of this product are equally important because of their different spatial and temporal coverage. The in-situ sea-level observations provide seminal information about the sea level in the Mediterranean, and cover a period of approximately 100 years. The satellite altimetry data span only two decades (1993-ongoing) over a continuous spatial domain.
3) The quality elements that affects the most the product quality are:
    - **Spatial extent,** because in-situ data are almost absent in the Southern part of basin; and
    - **Completeness,** because in-situ data time series are often affected by significant gaps, and consequently it is not possible to consider the entire observational data-set in the reconstruction.
4) The principal limitations on the quality of the product due to the input dataset used (fitness for use) are:
    - **Spatial extent**, because sea-level in-situ observations are spatially discontinuous by definition. The lack of in-situ data in the Southern part of the basin can lead to underestimation of the sea-level temporal amplitudes used in the reconstruction.
    - **Temporal extent**, because sea-level remote-sensing data are only available for the last 20 years, which is a relatively short period compared with the time window covered by the reconstruction. This period also represents the training period in which the EOFs are computed to determine the sea-level spatial variability in the reconstruction. Consequently, the temporal extent of the remote-sensing data can affect the assumption that EOFs are stationary in time.
5) The characteristic and respective dataset that most fails to meet the scope of the Targeted Product (fitness for use) is the PSMSL dataset, which contains the in-situ sea-level records.
6) Sea-level reconstructions allowed us to merge the spatial and temporal information provided by remote sensing and in-situ observations. In the Mediterranean Sea, **the lack of in-situ observations in the Southern part of the basin affects all scientific studies that aim to describe the sea-level variability and trends in the basin**. As a consequence, the sea-level trends obtained from the reconstruction are also affected by this lack of information.

MEDSEA_CH4_Product_12

1) The overall product quality score is **sufficient (4)**. The number of useful sea-level time series is extremely low compared with the number of available time series in the PSMSL data bank. A historical bank of data from different countries cannot be assumed to provide uniform time and space data coverage. Moreover, local vertical land motion makes it impossible to combine the time series without introducing information external to the database.
2) There is only one characteristic (ASLVMNMO).

3) The quality elements (Annex 1) that affect the Targeted Product quality are the **time extent** and **completeness**. The time series are often affected by significant gaps in both time periods, the last 50 and 100 years. The time series often start too late or end too early to estimate sea-level trends over 10 years, which is why it was not considered here. In fact, this period is too short to obtain useful values for two reasons:
    a. the trend estimate is biased by the incomplete sampling of the 18.6-year lunar nodal cycle, even though its amplitude is relatively small (less than 1 cm); and
    b. the small sample size makes the statistical error comparatively large relative to the trend itself; for instance, the 2003-2012 trends for the two centennial stations of Marseille and Trieste are 5.9±5.6 mm/y and 7.3±8.6 mm/y, respectively (error corresponding to 95% confidence).
4) The limitations on the quality of the Targeted Product due to the input dataset used (fitness for use) are related to their time extent (time series often include too few annual means for a reliable estimation of 50-year and 100-year trends) and completeness (time series often include too few annual means for a reliable estimation of 50-year and 100-year trends).
5) There is only one Characteristic (ASLVMNMO) and one dataset (PSMSL).
6) Gaps are represented by a) the low number of time series in the Mediterranean Sea; b) the relatively short time span of most of the available time series; and c) the frequently missing monthly means, and therefore years, even in relatively long time series.

MEDSEA_CH4_Product_13

1) The overall product quality score is **excellent (1)**. The global MSL is calculated by combining the time series from all three TOPEX/Poseidon, Jason-1 and Jason-2 missions since the first TOPEX/Poseidon mission (1992). As Jason-2 is still in flight, the computation of 10-year sea-level trends from satellite altimetry is relevant to these input data.
2) The most important characteristic for the product quality is the sea level (ASLVNL60). Its accuracy and the methodology applied to build the product are also very important. In fact, the altimeter datasets are checked before dissemination thanks to Cal/Val activities, thus they are considered reliable for 10-year sea-level monitoring.
3) The quality elements that affect the Targeted Product quality are the spatial resolution, time resolution and completeness.
4) The limitations on the quality of the Targeted Product due to the input dataset used (fitness for use) are:
    - different results regarding the 10/50/100-year sea-level trends;
    - data gaps in the resulting maps and datasets; and
    - large errors in the estimates of sea-level trends.
5) The characteristic ASLVNL60 used for this product generation does not fail to meet the scope of the Targeted Product. Both AVISO and Copernicus datasets are available for different case studies (AVISO provides along-track data while Copernicus provides gridded products). The differences between these datasets give access to different space/time resolution information, and the latter can be combined with in-situ measurements to provide added-value products. In the framework of this WP, altimeter datasets are used to compute 10-year sea-level trends over the Mediterranean Sea, and the resulting time series can be compared to tide-gauge measurements to provide key performance indicators.

6) The most important gaps in the input datasets are the unavailability of altimeter data and the geographical coverage due to the repetitiveness of the altimeter mission.

TP	CH4
1	2
2	3
3	1
4	3
5	1
6	4
7	5
8	2
9	3
10	1
11	3
12	4
13	1

Table B Summary of the quality scores associated with each Targeted Product according to the experts' evaluations and the evaluation scheme presented in Table **A.**

Annex 1: List of products and components

MEDSEA_CH4_Product_1
Title: Spatial layer of Sea Temperature Trend at the Surface from HadISST
Component MEDSEA_CH4_Product_1_1 → 10yrs basin trend at the surface
Component MEDSEA_CH4_Product_1_2 → 50yrs basin trend at the surface
Component MEDSEA_CH4_Product_1_3 → 100yrs basin trend at the surface
Component MEDSEA_CH4_Product_1_4 → 10yrs NUTS3 trend at the surface
Component MEDSEA_CH4_Product_1_5 → 50yrs NUTS3 trend at the surface
Component MEDSEA_CH4_Product_1_6 → 100yrs NUTS3 trend at the surface

MEDSEA_CH4_Product_2
Title: Spatial layer of Mid-water and Bottom Sea Temperature Trend from Reconstruction
Component MEDSEA_CH4_Product_2_1 → 10yrs basin trend at mid-water
Component MEDSEA_CH4_Product_2_2 → 10yrs basin trend at the sea bottom
Component MEDSEA_CH4_Product_2_3 → 10yrs NUTS3 trend at the sea bottom

MEDSEA_CH4_Product_3
Title: Spatial layer of Sea Internal Energy Trend from Reanalysis
Component MEDSEA_CH4_Product_3_1 → 20yrs basin trend at the surface
Component MEDSEA_CH4_Product_3_2 → 20yrs NUTS3 trend at the surface

MEDSEA_CH4_Product_4
Title: Spatial layer of Sea Level Trend from Reconstruction
Component MEDSEA_CH4_Product_4_1 → 50yrs basin trend
Component MEDSEA_CH4_Product_4_2 → 100yrs basin trend
Component MEDSEA_CH4_Product_4_3 → 50yrs NUTS3 trend
Component MEDSEA_CH4_Product_4_4 → 100yrs NUTS3 trend

MEDSEA_CH4_Product_5
Title: Spatial layer of Sea Level Trend from satellite
Component MEDSEA_CH4_Product_5_1 → 10yrs basin trend
Component MEDSEA_CH4_Product_5_2 → 10yrs NUTS3 trend

MEDSEA_CH4_Product_6
Title: Spatial layer of Sea Level Trend from Low Temporal Resolution Tide-Gauges
Component MEDSEA_CH4_Product_6_1 → 50yrs location trend
Component MEDSEA_CH4_Product_6_2 → 100yrs location trend
Component MEDSEA_CH4_Product_6_3 → 50yrs NUTS3 trend
Component MEDSEA_CH4_Product_6_4 → 100yrs NUTS3 trend

MEDSEA_CH4_Product_7
Title: Report on Sediment Mass Balance at the Coast in the Mediterranean
Component MEDSEA_CH4_Product_7_1 → Sediment Mass Balance at the Coast from Experts Survey and Scientific Literature Review
Component MEDSEA_CH4_Product_7_2 → Sediment Mass Balance at the Coast from Experts Survey and Scientific Literature Review (10 years)
Component MEDSEA_CH4_Product_7_3 → Sediment Mass Balance at the Coast from Experts Survey and Scientific Literature Review (50 years)

MEDSEA_CH4_Product_8
Title: Times Series of Annual Average Sea Temperature from HadISST
Component MEDSEA_CH4_Product_8_1 → 10yrs basin average at the surface
Component MEDSEA_CH4_Product_8_2 → 50yrs basin average at the surface
Component MEDSEA_CH4_Product_8_3 → 100yrs basin average at the surface
Component MEDSEA_CH4_Product_8_4 → 10yrs NUTS3 average at the surface
Component MEDSEA_CH4_Product_8_5 → 50yrs NUTS3 average at the surface
Component MEDSEA_CH4_Product_8_6 → 100yrs NUTS3 average at the surface

MEDSEA_CH4_Product_9
Title: Times Series of Annual Average Sea Temperature from Reconstruction
Component MEDSEA_CH4_Product_9_1 → 10yrs basin average at mid-water
Component MEDSEA_CH4_Product_9_2 → 10yrs basin average at the sea-bottom
Component MEDSEA_CH4_Product_9_3 → 10yrs NUTS3 average at the sea-bottom

MEDSEA_CH4_Product_10
Title: Times Series of Annual Average Internal Energy from Models
Component MEDSEA_CH4_Product_10_1 → 20yrs basin annual average of internal energy
Component MEDSEA_CH4_Product_10_1 → 20yrs NUTS3 annual average of internal energy

MEDSEA_CH4_Product_11
Title: Times Series of Annual Average Sea Level from Reconstruction
Component MEDSEA_CH4_Product_11_1 → 50yrs basin average
Component MEDSEA_CH4_Product_11_2 → 100yrs basin average
Component MEDSEA_CH4_Product_11_3 → 50yrs NUTS3 average
Component MEDSEA_CH4_Product_11_4 → 100yrs NUTS3 average

MEDSEA_CH4_Product_12
Title: Times Series of Annual Average Sea Level from Tide Gauges
Component MEDSEA_CH4_Product_12_1 → 50yrs NUTS3 average
Component MEDSEA_CH4_Product_12_2 → 100yrs NUTS3 average

MEDSEA_CH4_Product_13
Title: Time Series of Annual Average Sea Level from Satellite
Component MEDSEA_CH4_Product_13_1 → 10yrs basin average
Component MEDSEA_CH4_Product_13_2 → 10yrs NUTS3 average

Annex 2: Definitions

From the MedSea Literature Survey we have extracted the following definitions:

Characteristic

In this document, a "characteristic" is a distinguishing feature which refers:

1. either to a variable derived from the observation, the measurement or the numerical model output of a phenomenon or of an object property in the environment;
2. or to the geographical representation of an object on a map (ie a layer such as a protected area, a coastline or wrecks) by a set of vectors (polygon, curve, point) or a raster (a spatial data model that defines space as an array of equally sized cells such as a grid or an image).

Environmental matrices

This concept is introduced to avoid ambiguities when using a characteristic name such as "temperature". The environment matrix is the environment to which a characteristic is related and we define them to be:

1. Air,
2. Marine Waters,
3. Fresh Waters,
4. Biota/Biology,
5. Seabed,
6. Human activities.

Quality principles

- ✓ ***Spatial extent***
  Box or geographic region bounding the datasets
- ✓ ***Spatial resolution*** :
  Size of the smallest object that can be resolved on the ground. In a raster dataset, the resolution is limited by the cell size.
- ✓ ***Spatial Accuracy***
  Requested closeness of coordinate values to values accepted as or being true e.g. on the base of instrumentation used

- ✓ ***Time extent***
  Time interval represented by the dataset or by the collection.
- ✓ ***Time resolution***
  Size of the smallest interval of time that can be resolved.
- ✓ ***Time Accuracy***
  Requested closeness of temporal values to values accepted as or being true.

- ✓ ***Usability***
  The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.
- ✓ ***Completeness***
  Degree of absence of data in a dataset
- ✓ ***Logical Consistency***
  Degree of adherence to format required
- ✓ ***Thematic Accuracy***
  Requested closeness of characteristic values to values accepted as or being true (the so called attribute of a data entity eg "wave height"). It includes the correctness of the classification of features or of their associations...