AdriaClim

Climate change information, monitoring and management tools for adaptation strategies in Adriatic coastal areas

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Tools, procedures and dataset for all developed indicators

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1. Aims and content of the document

The aim of the Deliverable is to describe the performed activities in the framework of Activity 4.2 (WP4), which goal is to design, develop and provide data, indicators and tools aimed at supporting the adaptation plans (WP5). For this purpose, taking advantage of many datasets (e.g., observations, models and reanalyses), starting from a list of indicators proposed in D.3.4.1, for each Pilot Area a set of indicators, that could better characterize the future climate with respect to the past climate in the region of interest, has been computed. In this respect, a set of indicators is supplied at Adriatic level, while others depend on regional measures and therefore are designed with the aim of satisfying the local stakeholders' needs.

The developed activities are described in this report as follows. Section 2 presents the datasets and tools used for the computation of the indicators computed over the entire Adriatic region. Section 3 describes the climate indicators obtained at Adriatic and local level, referring to different categories: Atmospheric, Hydrological, Sea-State, and Biochemical Indicators.

2. Dataset and tools

In this section the datasets and tools used to derive Climate Change (CC) indicators at Adriatic scale are presented.

2.1 Dataset

The AdriaClim modelling data provided by WP3 (D.3.2.2) are here used to calculate the climate change (CC) indicators in each Pilot Area. Outputs from each modelling component (atmospheric, hydrology, ocean, wave and biogeochemical) are analyzed to derive the CC indicators both in the historical (1992-2011) and scenario (2031-2050) for each grid point (~6 km resolution). In addition, observational datasets and reanalyses have been used to calculate indicators on the historical timeseries, so that they can be used as benchmark for the indicators derived by the modelling outputs. After a preliminary literature study, aimed at finding the better reanalyses available at current date, in terms of spatial and temporal coverage at regional scale on the Adriatic basin, the following datasets (divided below per domain of application) have been used:

- Atmosphere: E-OBS[1], ERA5[2], ERA5 Land[3]
- Ocean and Biogeochemical: CMEMS[4]
- Hydrology: EFAS[5]

A more detailed description of each dataset is provided below:

- **E-OBS** is an observational dataset providing daily land-only atmospheric variables over Europe with finer spatial resolution (0.1° x 0.1°, ~10 km grid spacing). This product has been obtained by combining time series recorded by a huge number of stations distributed over the European Continent and collected from the European Climate Assessment & Dataset [6](ECA&D) project. For additional information please refer to Cornes et al. (2019).
- **ERA5** is a reanalysis dataset that provides a wide set of atmospheric variables from January 1950 to present, at high temporal (hourly) and spatial (0.25° x 0.25°, about 28 km) scale over the entire globe. The data are freely available on the Copernicus Climate Change Service (C3S) web platform (https://climate.copernicus.eu/). Additional information is provided by Hersbach et al. (2020).
- **ERA5-Land** is a downscaled dataset based on ERA5 ReAnalysis that provides a wide set of atmospheric-land variables from January 1950 to present, at high temporal (hourly) and spatial (0.1° x 0.1°, about 9 km) scale over the entire globe. The data are freely available on the Copernicus Climate Change Service (C3S) web platform (https://climate.copernicus.eu/). Additional information is provided by Muñoz (2019).
- **CMEMS**: is a European service providing a wide set of in-situ, satellite and model data about the physical and the biogeochemical ocean and the sea ice. It is composed of many data providers which build ocean models and provides observations about the global ocean and

[1] https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-gridded-observations-europe?tab=overview

[2] https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview

[3] https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=overview

[4] https://marine.copernicus.eu/

[5] https://www.efas.eu/en

[6] https://www.ecad.eu

for each one of the European seas. CMEMS reanalysis for the Mediterranean Sea were used for AdriaClim purposes. The spatial resolution of the reanalysis is 1/16˚ (ca. 6-7 km), with 72 vertical levels. More info in Simoncelli et al. 2019.

- **EFAS** is an operational early-warning system part of the COPERNICUS Emergency Management Service (CEMS) that provides gridded modelled sub-daily and daily hydrological time series forced with meteorological observations. Available from January 1991 to near real-time (six days delayed), the main dataset describes the hydrological processes by the river discharge, soil moisture for three soil layers, and snow water equivalent, into a domain that covers most of the European continent on a 5 × 5 km equal-area grid. For details, see Thielen et al. (2009) and Bartholmes et al. (2009).

In addition to these datasets, the Med-Cordex modelling data (L'Hevederet al 2013, Ruti et al., 2016), which provide the boundary conditions to the AdriaClim model, are also used to calculate the CC indicators with the aim of preliminarily testing the codes settled for the AdriaClim modelling outputs. Additional information regarding the impact on the skills of the AdriaClim domain led by the dynamical downscaling of the Med-Cordex dataset, cannot be provided since by construction, they don't share the same historical and projection periods as follows: historical 1970-2005/1991-2020 and projections 2006-2050/2021-2050 for the Med-Cordex/AdriaClim datasets.

The above-mentioned datasets have been made available on the CMCC ERDDAP Platform (http://erddap-adriaclim.cmcc-opa.eu/erddap/info/) in the framework of Activity 4.1.

2.2 Tools

In this section, the tools shared with the partners to calculate the CC indicators are discussed. In order to support the partners in the computation of a subset of indicators, codes have been made available through the GitHub project repository (https://github.com/ARPA-SIMC/adriaclim-indicators) and on the dedicated Google Drive Project folder (https://drive.google.com/drive/u/0/folders/1Bx6pT3rJklPus2BdL8bBAZ6liar8wkfc).

The codes provided permit to compute the following indicators:

1. **WSDI (days):** Warm Spell Duration Index - Number of days per period where, in intervals of at least 6 consecutive days with maximum temperature higher than the 90th percentile of maximum temperature (calculated for a 5-day window centered on each calendar day in the period used to calculate the threshold).
2. **HWN:** Number of times per period where, in intervals of at least 3 consecutive days of maximum temperature higher than the 90th percentile of maximum temperature (calculated for a 31-day window centered on each calendar day in the period used to calculate the threshold).
3. **HWTXdx (degC):** Maximum value between the averages of the maximum temperatures averaged for each heat wave. The heat wave is identified by the exceeding, for at least 3 consecutive days, of the 90th percentile of the maximum temperatures (calculated for a 31-day window centered on each calendar day in the period used to calculate the threshold)
4. **TXX (degC):** maximum value of daily maximum temperature
5. **TXN (degC):** minimum value of daily maximum temperature
6. **TG (degC):** Mean daily temperature
7. **TR (days):** Tropical Nights - number of days with a minimum temperature of 20 degC
8. **TX90p (days):** Number of days with daily temperature above the 90th percentile (calculated using a mobile window of 5 days in the reference timeframe)
9. **CDD (days):** Consecutive Dry Days - largest number of consecutive days with precipitation less than 1 mm
10. **FG (m/s):** Mean daily wind speed at 10 m
11. **RX1DAY (%):** Maximum 1-day precipitation amount
12. **RX5DAY (mm):** Maximum 5-day precipitation amount
13. **R95PTOT (%):** Precipitation fraction due to very wet days.
14. **PRCPTOT (mm):** Total Precipitation - precipitation sum in wet days (days with precipitation greater than or equal to 1 mm)
15. **RD-1 (m^3s^{-1}):** River Discharge - monthly average river discharge based on daily river discharge estimated at the river-mouth position. Adriatic Sea sections and Pilot Areas aggregate discharges of all rivers within the respective catchment area.
16. **RD-2 (m^3s^{-1}):** Mean River Discharge - climatology of monthly minimum river discharge based on daily river discharge estimated at the river-mouth position. Adriatic Sea sections and Pilot Areas aggregate discharges of all rivers within the respective catchment area.

17. **RD-3 (m^3s^{-1}):** Minimum River Discharge - climatology of monthly minimum river discharge based on daily river discharge estimated at the river-mouth position. Adriatic Sea sections and Pilot Areas aggregate discharges of all rivers within the respective catchment area.
18. **RD-4 (m^3s^{-1}):** Maximum River Discharge - climatology of monthly maximum river discharge based on daily river discharge estimated at the river-mouth position. Adriatic Sea sections and Pilot Areas aggregate discharges of all rivers within the respective catchment area.
19. **RD-5 (adimensional):** Standardized Flow Index (SFI) - computed as the Standardized Precipitation Index described in McKee et al. (1993), but replacing the monthly precipitation by RD-1.
20. **MH-1 (adimensional):** Standardized Precipitation Index (SPI) - described in McKee et al. (1993). Adriatic Sea sections and Pilot Areas aggregate the total precipitation over the respective catchment area.
21. **MH-2 (adimensional):** Standardized Precipitation and Evapotraspiration Index (SPEI) - an extension of the SPI which takes into account the balance of precipitation and potential evapotranspiration (PET). The PET must be calculated using the Hargreaves equation (Hargreaves & Samani, 1985) which is based only on daily average, minimum and maximum air temperature and other extraterrestrial parameters. Adriatic Sea sections and Pilot Areas aggregate the total precipitation and PET over the respective catchment area.
22. **MH-3 (consecutive days):** Number of Consecutive Days without Precipitation - time-series of consecutive days with precipitation under than 0.1 $mm.day^{-1}$ over, at least, 70% of the catchment area. Adriatic Sea sections and Pilot Areas aggregate MH–3 over the respective catchment area.
23. **SST (degC):** Adriatic Sea maps of Sea Surface Temperature long mean, standard deviation, minimum, maximum, 95th percentile and 5th percentile, based on daily model output.
24. **SSS (PSU):** Adriatic Sea maps of Sea Surface Salinity long mean, standard deviation, minimum, maximum, 95th percentile and 5th percentile, based on daily model output.
25. **MLD (m):** Adriatic Sea maps of Mixed Layer Depth long mean, standard deviation, minimum, maximum, 95th percentile and 5th percentile, based on daily model output.
26. **SL (m and mm/yr):** Adriatic Sea maps of Sea Level long mean, standard deviation, minimum, maximum, 95th percentile, 5th percentile and trend (**mm/yr**), based on daily model output. Sea Level was calculated as the sum of model Sea Surface Height and the average steric component over the Adriatic Sea basin. Sea Level was calibrated using SLA satellite data (database from 1993 to 2020).

27. **MHW (count, days and degC):** Adriatic Sea maps of Marine Heat Waves mean number (**count**), mean number trend (**count**), mean duration (**days**), mean duration trend (**days**), mean intensity (**degC**) and mean intensity trend (**degC**), based on daily model output.
28. **OHC (J/m^2):** Ocean Heat Content, long mean, standard deviation, minimum, maximum and trend (**J/m2yr**) based on daily model output, integrated horizontally over the Adriatic basin and vertically between 0 and 40m and between 40 and 300m. In addition, an annual time series of OHC and OHC anomaly was calculated.
29. **BO-4 (cycle/hr):** Brunt-Väisälä frequency, maximum Brunt-Väisälä frequency over the water column computed at Adriatic scale.
30. **BO-8** (count): Frequency of rough-sea conditions, computed as the number of days when conditions of significant wave height > 2.5 m are met. Monthly maps over the whole Adriatic basin.
31. **BO-9** (m): significant wave height, monthly maps of means and annual maps of 95th percentile over the whole Adriatic basin.
32. **BO-11** (s): mean wave period, monthly mean maps over the Adriatic basin.
33. **BO-6** (W/m2): Photosynthetically Active Radiation (PAR) at the sea surface, monthly means over the whole Adriatic basin.
34. **GO-1** (pH): Ocean pH on the water column. Monthly means over the whole Adriatic basin.
35. **GO-2** (mol(O2)): Oxygen concentration on the water column. Monthly means and 5th percentile over the whole Adriatic basin from daily outputs.
36. **GO-4** (mg/m3): Concentration of chlorophyll-a. Surface monthly maps and monthly means on the water column over the whole Adriatic basin.

Codes provided to compute the indicators from [1] to [14] are adapted to the AdriaClim Project' needs by the *MeteoLab open-source Matlab toolbox* (https://meteo.unican.es/trac/MLToolbox/wiki). These codes have been provided by the Fondazione CMCC - Centro Euro-Mediterraneo sui Cambiamenti Climatici, Regional Models and geo-Hydrological Impacts Division (REMHI). The adopted methodology aims at computing the indicators as defined by the *ETCCDI* (http://etccdi.pacificclimate.org/list_27_indices.shtml). These codes (https://github.com/ARPA-SIMC/adriaclim-indicators) have been tested for ERA5-Land daily data, therefore modifications are needed in case the input dataset is different. An example of the input data follows:

```
netcdf t2mean_1d_daily_ERA5Land_1950_2021 {
dimensions:
    time = UNLIMITED ; // (26207 currently)
    bnds = 2 ;
    longitude = 21 ;
    latitude = 20 ;
variables:
    int time(time) ;
            time:standard_name = "time" ;
            time:long_name = "time" ;
            time:bounds = "time_bnds" ;
            time:units = "hours since 1900-01-01 00:00:00.0" ;
            time:calendar = "gregorian" ;
            time:axis = "T" ;
    double time_bnds(time, bnds) ;
    float longitude(longitude) ;
            longitude:standard_name = "longitude" ;
            longitude:long_name = "longitude" ;
            longitude:units = "degrees_east" ;
            longitude:axis = "X" ;
    float latitude(latitude) ;
            latitude:standard_name = "latitude" ;
            latitude:long_name = "latitude" ;
```


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```
latitude:units = "degrees_north" ;
latitude:axis = "Y" ;
short t2m(time, latitude, longitude) ;
t2m:long_name = "2 metre temperature" ;
t2m:units = "K" ;
t2m:add_offset = 278.543999580124 ;
t2m:scale_factor = 0.0011884618227142 ;
t2m:_FillValue = -32767s ;
t2m:missing_value = -32767s ;
t2m:cell_methods = "time: mean" ;

// global attributes:
:CDI = "Climate Data Interface version 1.9.8 (https://mpimet.mpg.de/cdi)" ;
:Conventions = "CF-1.6" ;
```

The scripts can be used with two different Software:

- MATLAB (developed by MathWorks; https://it.mathworks.com/products/matlab.html; not open source)
- Octave (https://octave.sourceforge.io/; which is open source)

Both are programming and numeric computing platforms widely used in the scientific community. An example of indicator computed with this tool is provided by Figure 1, which shows the *TG* anomaly distribution over the Apulia and Marche Pilot Areas, computed on the Med-Cordex data between the 30-years projection (mean 2021-2050) and 30-years historical (mean 1981-2010) periods.

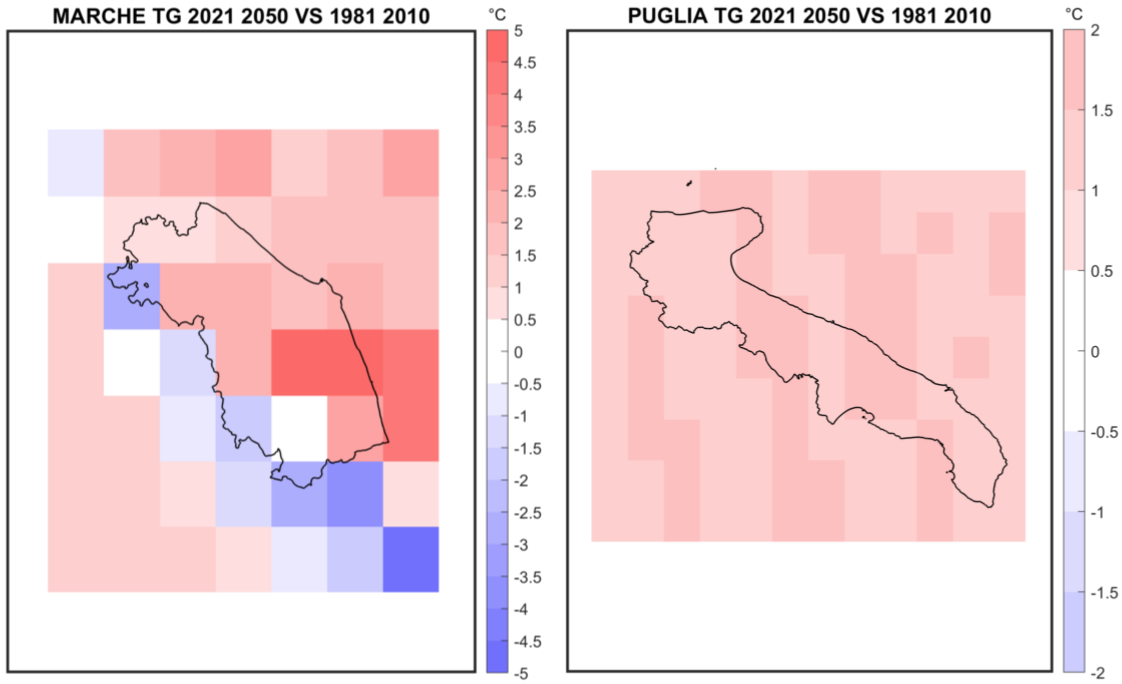

Fig.1 Mean daily temperature (TG) anomaly (projection compared to historical period; 2021-2051 / 1981-2010) computed over the Marche (left) and Puglia (right) Region using Med-Cordex data.

Codes provided to compute the indicators from [15] to [22] are provided by UNIBO and were developed using the Wolfram's Mathematica computational language. The RD climate indicators were computed using the EFAS dataset as reference for the historical period, while the MH were computed using the ERA5 dataset. For the AdriaCLIM historical and projection periods, these climate indicators were computed using AdriaCLIM WRF-Hydro and WRF downscaling simulations, respectively. All datasets available at AdriaCLIM ERDDAP repository.

Codes provided to compute the indicators from [23] to [28] are provided by CMCC OPA division and were developed using Python computational language. These indicators were computed using the CMEMS Reanalysis dataset as reference for the historical period, MedCordex IPSL model and AdriaClim ocean model over the historical and projection periods. All datasets available at AdriaClim ERDDAP repository.

Indicators from [29] to [36] are computed by UNIBO and were developed using Python computational language. The codes used to compute these indicators can be found in the Github repository: https://github.com/menta78/adriaClimIndicators. These indicators were computed using CMEMS Reanalysis dataset as reference for the historical period and AdriaClim ocean model over historical and projection periods.

It is worth mentioning that the codes mentioned above are only a part of the tools developed in the AdriaClim Project, since many partners decided to settle their own codes for computing the indicators in the Pilot Areas. In this respect, CMCC[7] and UNIBO[8] developed additional codes capable of handling heavier data faster and easily, taking advantage of Python[9], Anaconda[10], CDO[11], and Mathematica[12] tools, which are recognized by the scientific community to be very efficient open-source packages. This was necessary to compute a subset of CC indicators, usable by all partners, on the entire AdriaClim domain for the datasets mentioned in Section 2.

3. CC Indicators

All the partners provided the CC indicators, following a few guidelines provided. The indicators, based on the data provided by the WP3 and chosen among those selected in activity 3.5 by each pilot (D.3.5.1), are computed in agreement with the definitions provided by the Expert Team on Climate Change Detection and Indices (ETCCDI[13]) and the European Climate Assessment (ECA) Projects[14]. Absolute values and several statistics, such as mean value, median, percentile, trends, anomalies and seasonality are provided for each indicator for each grid point at different

[7] https://www.cmcc.it/it

[8] https://www.unibo.it/it

[9] https://www.python.org/

[10] https://www.anaconda.com/

[11] https://zenodo.org/record/7112925

[12] https://www.wolfram.com/

[13] https://www.wcrp-climate.org/etccdi

[14] https://www.ecad.eu/

aggregation timescales (e.g., monthly, seasonal, annual). More specifically, the indicators, linear trends and anomalies (the latter only for the AdriaClim and Med-Cordex climate models) are computed and provided to the ERDDAP AdriaClim Platform[15], which in turn supplies data to the AdriaClim Geoportal (https://geoportale-adriaclim.datamb.it/), which is configured to calculate a set of additional statistics (e.g., mean value, median, percentile and seasonality), which can be eventually shown and downloaded by the users. The Mann Kendall test (Kendall, 1975) with a 95% confidence level should be used to evaluate the statistical significance of the increase/decrease trend of the climate indicators computed in the AdriaClim Project. Moreover, in order to decontaminate the trend estimation by the presence of serial correlation, the Python Package *xarrayMannKendall*[16], based on Moreno and Constantinou (2021) and applied in Moreno et al. (2021), has been suggested. The Trends, significance and uncertainties are computed by this package. In particular, linear trends are calculated using a linear least-squares regression for spatially integrated time series. All the observed trends are assessed using a Theil–Sen estimator, while the statistical significance uses a modified Mann–Kendall test. This statistical test takes into account autocorrelations within the time series. Finally, the reported uncertainties correspond to the standard error using the effective sample size from the Mann–Kendall test, that is the standard deviation of the time series divided by the square root of the effective sample size. Finally, in order to measure in the climate models the “anomaly” (or difference) between the indicator’s mean value in the future scenario and its mean value in the historical period for each grid point, a common available period among the datasets has been chosen for the projection (2031-2050) and the baseline (1992-2011).

Additional guidelines are provided on the data format in order to follow a unique strategy among the partners:

- Indicators should be provided in NETCDF or CSV Format
- Metadata should be included in the NETCDF file or added to the CSV as TXT

[15] https://erddap-adriaclim.cmcc-opa.eu/erddap/index.html

[16] https://github.com/josuemtzmo/xarrayMannKendall

- Indicators should be computed over each grid point at different aggregation time (e.g., daily, annual, monthly, seasonal).

Moreover, the "csv" and "NETCDF" files have to follow a specific format reported below. The "csv" standard for the indicators is reported below.

The **indicators timeseries** should be structured in the "csv" file as follows (Figure 2):

1st Column: Time

2nd Column: Latitude

3rd Column: Longitude

4th Column: Indicator

The number of rows is N_points x N_timesteps (sorted by ascending time),

where:

N_points is the number of grid points in the area of interest

N_timesteps is the number of timesteps

	A	B	C	D
1	Time	Lat	Lon	tg
2	1991-01-01	42.22970581	11.94861031	13.28977962
3	1991-01-01	42.22970581	12.0109272	12.55308395
4	1991-01-01	42.22970581	12.07324314	12.29548248
5	1991-01-01	42.22970581	12.13556004	11.62981392
6	1991-01-01	42.22970581	12.19787598	11.7705099
7	1991-01-01	42.22970581	12.26019287	12.373514
8	1991-01-01	42.22970581	12.32250977	12.86283385
9	1991-01-01	42.22970581	12.38482666	13.0871618
10	1991-01-01	42.22970581	12.4471426	13.22473471
11	1991-01-01	42.22970581	12.5094595	13.19575229
12	1991-01-01	42.22970581	12.57177639	13.2326462
13	1991-01-01	42.22970581	12.63409233	13.40130222
14	1991-01-01	42.22970581	12.69640923	13.10308186
15	1991-01-01	42.22970581	12.75872612	12.11099352
16	1991-01-01	42.22970581	12.82104301	11.63185408
17	1991-01-01	42.22970581	12.88335896	11.26831205
18	1991-01-01	42.22970581	12.94567585	9.627015498
19	1991-01-01	42.22970581	13.00799274	9.392285909

Fig.2 Example of 2D-indicator structure provided in csv format

While in case of vertical profiles (Figure 3):

1st Column: Time

2nd Column: Latitude

3rd Column: Longitude

4th Column: Depth Level

5th Column: Indicator

The number of rows is *N_points x N_depths x N_timesteps* (sorted by ascending time),

Where:

N_points is the number of grid points in the area,

N_timesteps is the number of timesteps

N_depths points is the number of depth layers.

	A	B	C	D	E
1	Time	Lat	Lon	Level	Value
2	1992-01-01	44	13	0	0.3504718542
3	1992-01-01	44	13	-5	0.3507904318
4	1992-01-01	44	13	-10	0.351934737
5	1992-01-01	44	13	-20	0.3548030188
6	1992-01-01	44	13	-30	0.360334284
7	1992-01-01	44	13	-50	0.3574525802
8	1992-01-01	44	13	-75	0.2896574491
9	1992-01-01	44	13	-100	0.1900210785
10	1992-01-01	44	13	-125	0.1191119244
11	1992-01-01	44	13	-150	0.07441647818

Fig.3 Example of 3D-indicator structure provided in csv format

While, the **anomalies** should be structured using a fictitious time as reference in order to be ERDDAP friendly (Figure 4):

1st Column: Fictitious Time (i.e., start date of raw timeseries)

2nd Column: Latitude

3rd Column: Longitude

4th Column: Indicator

	A	B	C	D
1	Ref_Time	Lat	ton	tg
2	2020-01-01	42.22970581	11.94861031	0.9130325799
3	2020-01-01	42.22970581	12.0109272	0.9025739309
4	2020-01-01	42.22970581	12.07324314	0.9913134948
5	2020-01-01	42.22970581	12.13556004	0.9837208468
6	2020-01-01	42.22970581	12.19787598	0.965203074
7	2020-01-01	42.22970581	12.26019287	0.9391243232
8	2020-01-01	42.22970581	12.32250977	0.9620121559
9	2020-01-01	42.22970581	12.38482666	0.9604029037
10	2020-01-01	42.22970581	12.4471426	0.9618168406
11	2020-01-01	42.22970581	12.5094595	1.011072168
12	2020-01-01	42.22970581	12.57177639	1.062789982
13	2020-01-01	42.22970581	12.63409233	1.034990587
14	2020-01-01	42.22970581	12.69640923	1.028184705
15	2020-01-01	42.22970581	12.75872612	1.050807016

Fig.4 Example of structure of indicators' anomaly provided in csv format

Moreover, an extra column should be added for the vertical levels, if necessary.

Finally, the **trends** should have the following structure:

1st Column: Fictitious Time 1991-01-01 (historical) and 2020-01-01(projection)

2nd Column: Latitude

3rd Column: Longitude

4th Column: Trend

5° Column: pvalue

Metadata for each indicator should include the following information:

Dataset type.

adriaclim_dataset: model | indicator | observation

For "model" datasets: the name of the dataset used.

adriaclim_model: WRF | NEMO | SHYFEM | EOBS | …

For "indicator" datasets: a comma-separated list of models.

adriaclim_scale: local | pilot | adriatic | med | global

adriaclim_timeperiod: 3h | 6h | daily | monthly | yearly | seasonal | 20y | 30y

For indicators only. A comma separated list of values is allowed.

adriaclim_type: timeseries | anomaly | trend

To explicitly set dataset’s institution and title on ERDDAP:

institution: CMCC | ARPAE ...

title: description

For the indicators and variables provided as NETCDF, the metadata should be internally added to each file, while for those indicators and variables that are provided in csv format, they should be provided in an external TXT or NETCDF file. The nomenclature of the metadatum is settled to correctly read the data in the geoportal. It is worth to mention that the purpose of the “adriaclim_scale” metadatum is to give to the users a subjective order of magnitude of the spatial scale at which the dataset targets, so "pilot" could be a synonym of "administrative region". Moreover the “adriaclim_model” metadatum does not refer only to models but to a generic dataset used (e.g., EOBS, ERA5-Land, WRF etc.).

In this respect, the following files’ nomenclature is suggested in order to be easily interpreted by the users:

adriaclim_{source}_{dataset_type}_{variable}_{elaboration_type}_{scenario}_{time_agg}_{domain}_{Year_start}_{Year_end}.csv

adriaclim_{source}_{dataset_type}_{variable}_{elaboration_type}_{scenario}_{time_agg}_{domain}_{Year_start}_{Year_end}.nc

where:

source: EOBS | ERA5Land | WRF | NEMO | BFM | WRFHydro

version: specify source version (to be specified in the internal metadata)

dataset_type: model | indicator | observation | reanalysis

variable: tas | ssh | cdd | … |

scenario: hist | proj | anomaly (for reanalysis and observations insert hist)

domain: local | pilot | adriatic | med | global

institution: CMCC | ARPAE | Unibo | etc. (to be specified in the internal metadata)

title: description of the indicators/variable

elaboration_type: timeseries | an | trend | 95p | mean | max | …

time_agg: 3h | 6h | daily | monthly | yearly | seasonal | none

Year_start: First year of the reference timeseries

Year_end: Last year of the reference timeseries

Here a few examples:

adriaclim_WRF_indicator_tg_mean_hist_yearly_Puglia_1991_2020.nc
adriaclim_WRF_indicator_tg_max_proj_yearly_ER_2021_2050.nc
adriaclim_WRF_indicator_tg_anomaly_hist_yearly_Marche_1991_2020.nc
adriaclim_WRF_indicator_tg_mean_difference_none_Marche_1991_2050.csv
adriaclim_EOBS_indicator_tg_mean_hist_yearly_adriatic_1991_2020.csv

As done for the "csv format" the NETCDF files should also follow a few guidelines:

- Longitude and Longitude must be one-dimensional in order to be suitable with ERDDAP and the GEOPORTAL
- Indicators should be computed over each grid point at different aggregation time (e.g., daily, annual, monthly, seasonal)
- Metadata should be included in each dataset, as done for "csv".

To properly settle the data, it is essential for the ERDDAP system to read the CSV and NETCDF files and add additional information to the metadata. An example of indicator loaded on ERDDAP is shown in Figure 5.

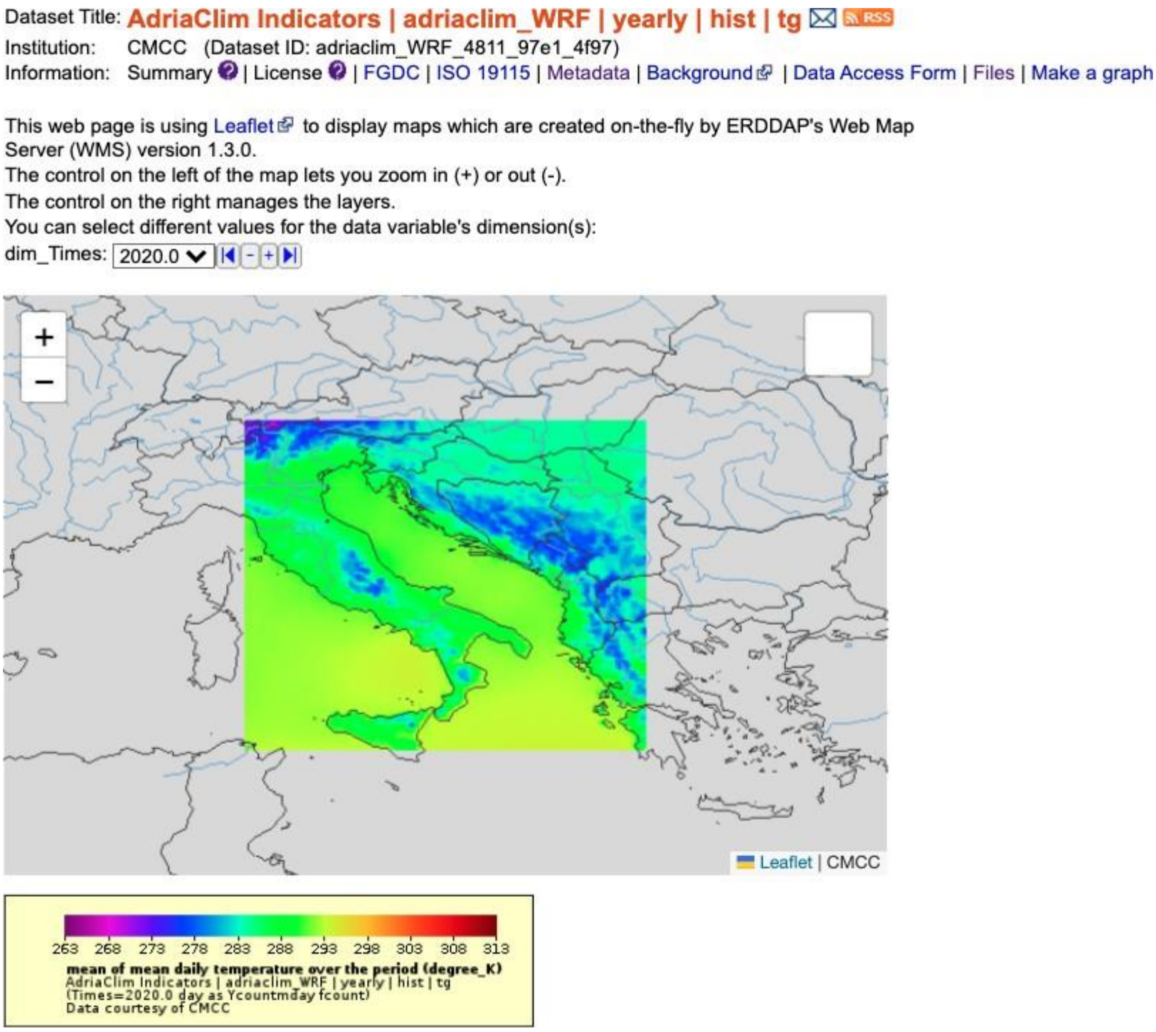

Fig.5 Example of indicator loaded on ERDDAP (https://erddap-adriaclim.cmcc-opa.eu/erddap/wms/adriaclim_WRF_4811_97e1_4f97/index.html)

The indicators can be easily downloaded on ERDDAP in different formats (netcdf, CSV, ESRIcsv, JSON, text and more). ERDDAP also supports temporal and spatial subsetting or, for tabular data, via other constraints, and allows users to create customizable maps and graphs, and then to generate images in PNG format, transparent PNG, PDF and more.

ERDDAP is not only a web application, but also a RESTful web service: indeed, for every web page with a form, there is a corresponding ERDDAP web service that is designed to be easy for other applications to use. In this way, it can return user-interface results as a table of data in different - computer-program friendly - file types, the most common of which are:

- CSV;
- JSON;
- mat;
- NetCDF-3 binary;
- htmlTable (an HTML web page with the data in a table);
- Google Earth kml.

Additionally, ERDDAP is compatible with the current WMS 1.3.0 standard (GetCapabilities, GetMap - opaque, GetMap - transparent), and then it is able to provide a basic WMS service for each dataset configured.

It also offers RSS and email/URL subscriptions services.

3.2 CC Indicators at Adriatic Scale

The CC indicators provided at AdriaClim scales are provided for each grid point at different aggregation timescales. A summary of the indicators' characteristics available for each Pilot Area is provided by Table 1.

Ind.	Definition	Domain of Application	Dataset	Time Aggreg.	Spatial Res.	Temporal coverage	Ref. Period	Anomalies (projection vs baseline)	Trends (periods)	Other statistics
sdii	Simple daily intensity index per time period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon	ERA5-Land	Yearly Monthly	0.1x0.1 degrees	1950-2020			1992-2011	Mean, Median, Standard

		[10 - 22] Lat [37 -47]		Seasonal					(baseline)	deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim_WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
su	Summer days index per time period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2)	1992-2011 (baseline); 2031-2050	Mean, Median, Standard deviation, Seasonality (provided by

		[37.29-46.89]						1981-2010 (baseline); 2021-2050 (projection) n)	(project ion)	the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim _WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baselin e); 2031-2050 (project ion)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
tr	Tropical nights index per time period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baselin e)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baselin e)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baselin e); 2031-2050 (project ion)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim _WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baselin e); 2031-2050 (project ion)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)

tg	Mean of mean daily temperature over the period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim_WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
fg	Mean of mean daily wind speed over the period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon	ERA5-Land	Yearly Monthly	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation,

		[10 - 22] Lat [37 -47]		Seasonal						Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim_WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
txx	Maximum value of daily maximum temperature over the period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline);	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)

		[37.29-46.89]						2021-2050 (projection)		
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim _WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projectio)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
txn	Minimum value of daily maximum temperature over the period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim _WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
hwdi	-Heat wave duration index	Adriatic	E-OBS	Yearly			1981-2010		1992-2011	Mean, Median,

	wrt mean of reference period -Heat waves per time period	Lon [10.05-21.95] Lat [37.05-46.95]		Monthly Seasonal	0.1x0.1 degrees	1950-2020			(baseline)	Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020	1981-2010		1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)	1981-2010	1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim _WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)	1991-2020	1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
cdd	-Consecutive dry days index per time period -Number of cdd periods with more than 5days per time period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by

		Lat [37 -47]								the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim_WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
csu	-Consecutive summer days index per time period -Number of csu periods with more than 5days per time period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline);	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)

								2021-2050 (projection)		
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim _WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
cwd	-Consecutive wet days index per time period -Number of cwd periods with more than 5days per time period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim _WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
r95p	Very wet days wrt 95th	Adriatic	E-OBS	Yearly			1981-2010		1992-2011	Mean, Median,

	percentile of reference period	Lon [10.05-21.95] Lat [37.05-46.95]		Monthly Seasonal	0.1x0.1 degrees	1950-2020			(baseline)	Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020	1981-2010		1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)	1981-2010	1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim_WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)	1991-2020	1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
r95ptot	Precipitation percent due to R95p days	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020	1981-2010		1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020	1981-2010		1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by

		Lat [37 -47]								the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)	1981-2010	1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim_WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)	1991-2020	1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
rx1day	Highest one day precipitation amount per time period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline);	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)

								2021-2050 (projection)		
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim _WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
rx5day	Highest five-day precipitation amount per time period	Adriatic Lon [10.05-21.95] Lat [37.05-46.95]	E-OBS	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10 - 22] Lat [37 -47]	ERA5-Land	Yearly Monthly Seasonal	0.1x0.1 degrees	1950-2020			1992-2011 (baseline)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.24-21.66] Lat [37.29-46.89]	Med-Cordex	Yearly Monthly Seasonal	~6km	1970-2005 (historical); 2006-2050 (projection)		1) 1992-2011 (baseline); 2031-2050 (projection) 2) 1981-2010 (baseline); 2021-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
		Adriatic Lon [10.02-21.98] Lat [37-46.97]	Adriaclim _WRF	Yearly Monthly Seasonal	~30 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal)
RD-1	River Discharge	Adriatic Sea,	EFAS	Monthly	Single Position	1991-2020	1992-2011			Trend (provided by

		4 Adriatic Sea Sections, PA Emilia-Romagna, and 86 rivermouth positions								the Geoportal)
			AdriaCLIM_WRF-Hydro	Monthly	Single Position	1992-2020	1992-2011			Trend (provided by the Geoportal)
						2022-2050	2031-2050			Trend (provided by the Geoportal)
RD-2	Mean River Discharge	Adriatic Sea, 4 Adriatic Sea Sections, PA Emilia-Romagna, and 86 rivermouth positions	EFAS	Monthly Climatology	Single Position	1991-2020	1992-2011			P05, Q1, Median, Mean, Q3, P95
			AdriaCLIM_WRF-Hydro	Monthly Climatology	Single Position	1992-2020	1992-2011	1992-2011 (baseline); 2031-2050 (projection)		P05, Q1, Median, Mean, Q3, P95
						2022-2050	2031-2050			P05, Q1, Median, Mean, Q3, P95
RD-3	Minimum River Discharge	Adriatic Sea, 4 Adriatic Sea Sections, PA Emilia-Romagna, and 86 rivermouth positions	EFAS	Monthly Climatology	Single Position	1991-2020	1992-2011			P05, Q1, Median, Mean, Q3, P95
			AdriaCLIM_WRF-Hydro	Monthly Climatology	Single Position	1992-2020	1992-2011	1992-2011 (baseline); 2031-2050 (projection)		P05, Q1, Median, Mean, Q3, P95
						2022-2050	2031-2050			P05, Q1, Median, Mean, Q3, P95
RD-4	Maximum River Discharge	Adriatic Sea, 4 Adriatic Sea Sections, PA Emilia-Romagna, and 86 rivermouth positions	EFAS	Monthly Climatology	Single Position	1991-2020	1992-2011			P05, Q1, Median, Mean, Q3, P95
			AdriaCLIM_WRF-Hydro	Monthly Climatology	Single Position	1992-2020	1992-2011	1992-2011 (baseline); 2031-2050 (projection)		P05, Q1, Median, Mean, Q3, P95
						2022-2050	2031-2050			P05, Q1, Median, Mean, Q3, P95

RD-5	Standardized Flow Index (SFI)	Adriatic Sea,	EFAS	Monthly	Single Position	1991-2020	1992-2011			
		4 Adriatic Sea Sections, PA Emilia-Romagna, and 86 rivermouth positions	AdriaCLIM _WRF-Hydro	Monthly	Single Position	1992-2020	1992-2011	1992-2011 (baseline); 2031-2050 (projection)		
						2022-2050	2031-2050			
MH-1	Standardized Precipitation Index (SPI)	Adriatic Sea,	ERA5	Monthly	Single Position	1991-2020	1992-2011			
		4 Adriatic Sea Sections, and PA Emilia-Romagna.	AdriaCLIM _WRF	Monthly	Single Position	1992-2020	1992-2011	1992-2011 (baseline); 2031-2050 (projection)		
						2022-2050	2031-2050			
MH-2	Standardized Precipitation and Evapotranspiration Index (SPEI)	Adriatic Sea,	ERA5	Monthly	Single Position	1991-2020	1992-2011			
		4 Adriatic Sea Sections, and PA Emilia-Romagna.	AdriaCLIM _WRF	Monthly	Single Position	1992-2020	1992-2011	1992-2011 (baseline); 2031-2050 (projection)		
						2022-2050	2031-2050			
MH-3	Consecutive Days without Precipitation	Adriatic Sea,	ERA5	Daily	Single Position	1991-2020	1992-2011			
		4 Adriatic Sea Sections, and PA Emilia-Romagna.	AdriaCLIM _WRF	Daily	Single Position	1992-2020	1992-2011	1992-2011 (baseline); 2031-2050 (projection)		
						2022-2050	2031-2050			
BO-8	Frequency of rough sea conditions	Adriatic Sea	CMEMS AdriaClim _WW3	Monthly	~2 km	1992-2011	2031-2050	1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Count of days when Hs>2.5 m
BO-9	Significant Wave Height	Adriatic Sea	CMEMS	Monthly	~2 km	1992-2011	2031-2050	1992-2011 (baseline);	1992-2011 (baselin	Mean, 95p

			AdriaClim _WW3					2031-2050 (projection)	e); 2031-2050 (project ion)	
BO-11	Mean Wave Period	Adriatic Sea	CMEMS AdriaClim _WW3	Monthly	~2 km	1992-2011	2031-2050	1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baselin e); 2031-2050 (project ion)	Mean
BO-4	**Brunt-Väisälä frequency**	Adriatic Sea	CMEMS Reanalysis	Monthly	~4km	1983 - 2019	1992 - 2011	1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baselin e); 2031-2050 (project ion)	Mean, Median, Standard deviation, Seasonality (provided by the Geoportal).
			AdriaClim _NEMO	Monthly	~2 km	1992 - 2020	1992 - 2011	1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baselin e);	Max Value along water column
						2022 - 2050	2031 - 2050		2031-2050 (project ion)	
BO-6	**Photosynthetic Active Radiation**	Adriatic Sea	AdriaClim _NEMO	Monthly	~2 km	1992-2011	2031-2050	1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baselin e); 2031-2050 (project ion)	Mean
GO-1	**pH**	Adriatic Sea	AdriaClim _BFM	Monthly	~2 km	1992-2011	2031-2050	1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baselin e); 2031-2050 (project ion)	Mean
GO-2	**Oxygen concentration**	Adriatic Sea	AdriaClim _BFM	Monthly	~2 km	1992-2011	2031-2050	1992-2011 (baseline);	1992-2011	Mean

								2031-2050 (projection)	(baseline); 2031-2050 (projection)	
GO-4	**concentration of chlorophyll-a**	Adriatic Sea	AdriaClim _BFM	Monthly	~2 km	1992-2011	2031-2050	1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Mean
SST	Sea Surface Temperature: statistics over time periods	Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	CMEMS Reanalysis	Monthly 20 years	~4km	1992-2011				Mean, Standard deviation, 5%, 95%, min, max.
		Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	Med-Cordex	Monthly 20 years	~12km	1992-2011 (historical); 2031-2050 (projection)				Mean, Standard deviation, 5%, 95%, min, max.
		Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	Adriaclim NEMO	Monthly 20 years	~2 km	1992-2011 (historical); 2031-2050 (projection)				Mean, Standard deviation, 5%, 95%, min, max.
SSS	Sea Surface Salinity: statistics over time periods	Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	CMEMS Reanalysis	Monthly 20 years	~4km	1992-2011				Mean, Standard deviation, 5%, 95%, min, max.

		Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	Med-Cordex	Monthly 20 years	~12km	1992-2011 (historical); 2031-2050 (projection)				Mean, Standard deviation, 5%, 95%, min, max.
		Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	Adriaclim NEMO	Monthly 20 years	~2 km	1992-2011 (historical); 2031-2050 (projection)				Mean, Standard deviation, 5%, 95%, min, max.
MLD	Mixed Layer Depth: statistics over time periods	Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	CMEMS Reanalysis	Monthly 20 years	~4km	1992-2011				Mean, Standard deviation, 5%, 95%, min, max.
		Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	Med-Cordex	Monthly 20 years	~12km	1992-2011 (historical); 2031-2050 (projection)				Mean, Standard deviation, 5%, 95%, min, max.
		Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	Adriaclim NEMO	Monthly 20 years	~2 km	1992-2011 (historical); 2031-2050 (projection)				Mean, Standard deviation, 5%, 95%, min, max.
SL	Total Sea Level: statistics over time periods	Adriatic Lon [12 to 20.98] Lat	CMEMS Reanalysis	Monthly 20 years	~4km	1992-2011			1992-2011 (baseline); 2031-2050 (projection)	Mean, Standard deviation, 5%, 95%, min,

		[40.167 to 45.875]								max.
		Adriatic Lon [12 to 20.98] Lat [40.167 to 45.875]	Med-Cordex	Monthly 20 years	~12km	1992-2011 (historical); 2031-2050 (projection)			1992-2011 (baseline); 2031-2050 (projection)	Mean, Standard deviation, 5%, 95%, min, max.
		Adriatic Lon [12 to 20.98] Lat [40.167 to 45.875]	Adriaclim NEMO	Monthly 20 years	~2 km	1992-2011 (historical); 2031-2050 (projection)			1992-2011 (baseline); 2031-2050 (projection)	Mean, Standard deviation, 5%, 95%, min, max.
MHW	Marine Heat Waves: statistics over time periods	Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	CMEMS Reanalysis	20 years	~4km	1992-2011			1992-2011 (baseline); 2031-2050 (projection)	Number, duration, intensity.
		Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	Adriaclim NEMO	20 years	~2 km	1992-2011 (historical); 2031-2050 (projection)			1992-2011 (baseline); 2031-2050 (projection)	Number, duration, intensity.
OHC	Ocean Heat Content over Adriatic Basin: statistics over time periods and annual mean time series *two vertical integrations: 0 to 40m and 40 to 300m	Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	CMEMS Reanalysis	20 years	~4km	1992-2011		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050 (projection)	Number, duration, intensity.
		Adriatic Lon [12 to 20.98]	Med-Cordex	20 years	~12km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baseline); 2031-2050	Number, duration, intensity.

		Lat [39 to 45.875]							(project ion)	
		Adriatic Lon [12 to 20.98] Lat [39 to 45.875]	Adriaclim NEMO	20 years	~2 km	1992-2011 (historical); 2031-2050 (projection)		1992-2011 (baseline); 2031-2050 (projection)	1992-2011 (baselin e); 2031-2050 (project ion)	Number, duration, intensity.

Table 1. Indicators provided at Adriatic scale and related characteristics.

In the figures below (Figs. 6-11) statistics related to a subset of computed indicators are shown, which relate to both the atmospheric, hydrological, sea-state and biogeochemical domains.

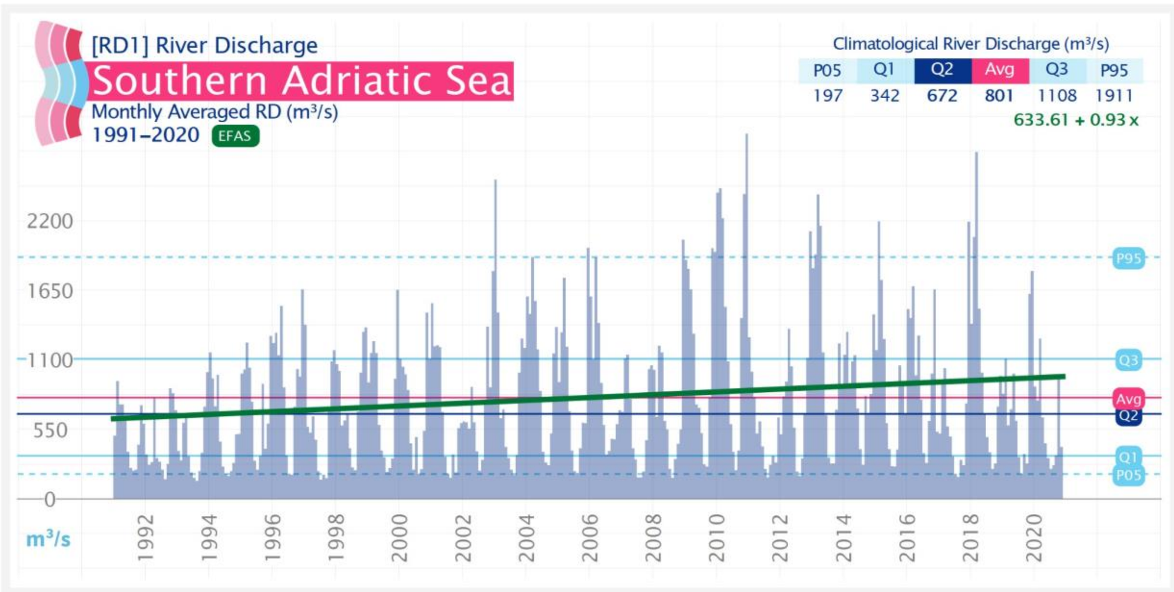

Fig.6 - RD-1 Monthly total river discharge ($m^3.s^{-1}$, dark blue bars) into the Southern Adriatic Sea (13 rivers aggregated, 1991-2020) and its trend (green line) and distribution parameters: average (Avg, magenta line), median (Q2, blue line), 1st (Q1) and 3rd (Q3) quantiles (blue area), and bottom (P05) and top (P95) 95th percentiles (light blue area). The respective yearly average river discharges are presented in the embedded table.

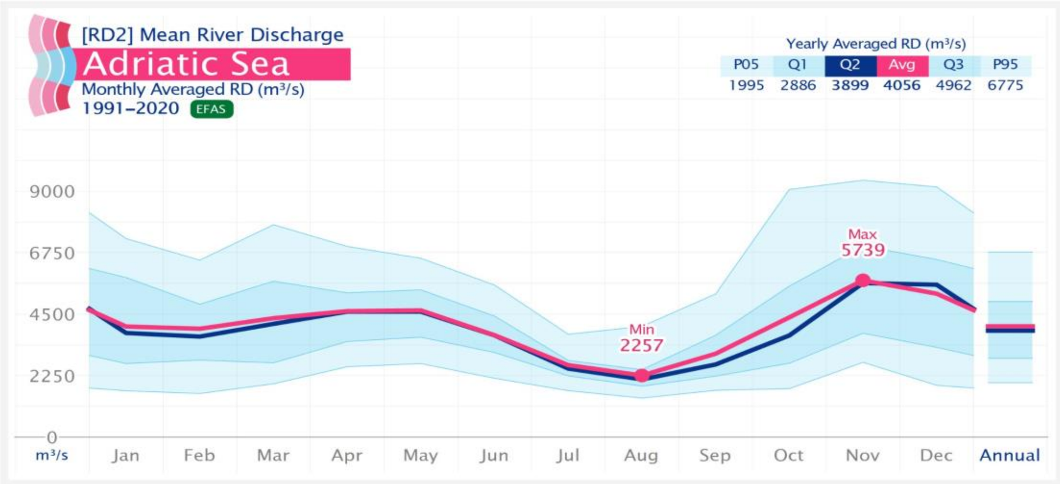

Fig.7 - RD-2 Climatology of the total river discharge (m^3/s^{-1}) into the Adriatic Sea (1991-2020). The sum of all 86 monthly averaged river discharges are shown by average (Avg, magenta line), median (Q2, blue line), 1st (Q1) and 3rd (Q3) quantiles (blue area), and bottom (P05) and top (P95) 95th percentiles (light blue area). The respective yearly averaged river discharges are presented in the last column and in the embedded table. Other Climate Indicators, as RD-3 and RD-4, have similar presentation.

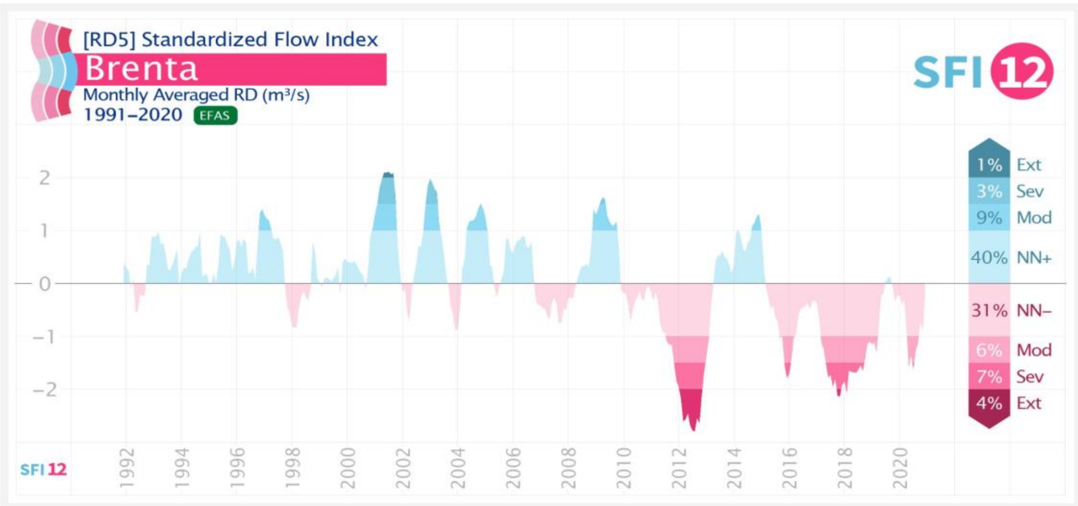

Fig.8 - RD-5 Standardized Flow Index (SFI) for Brenta River analyzed from 1991 to 2020 with a 12-month timescale. Positive values represent wet months (blue areas), while negative values represent dry months (red areas). The intensity scale ranges from Near Normal (NN+ and NN-) to Moderate (Mod ± 1.0), Severe (Sev ± 1.5) and Extreme (Ext ± 2.0), and have their respective frequencies presented in the sidebar. Other Climate Indicators, as MH-1 and MH-2, have similar presentation.

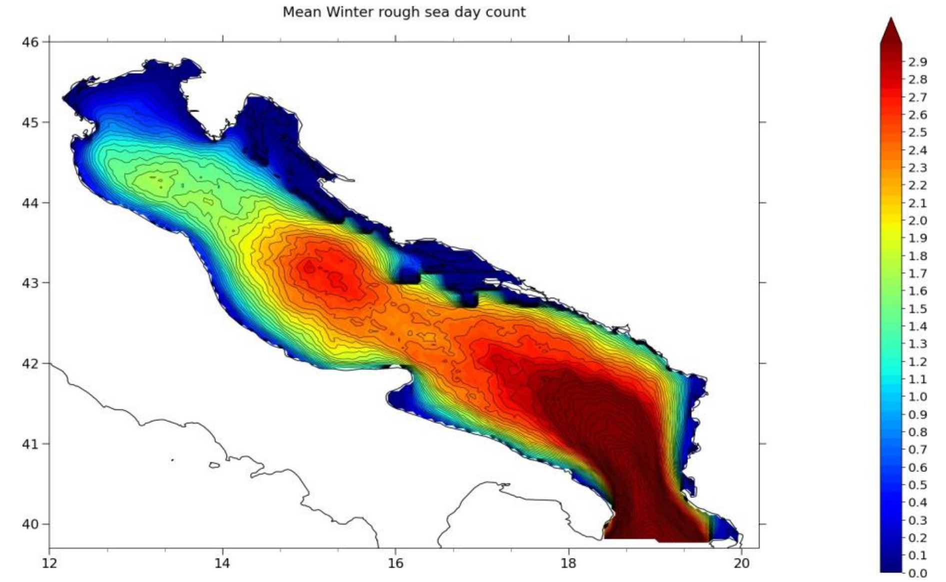

Fig.9 - BO-8, Frequency of rough-sea conditions, computed as the number of days when conditions of significant wave height > 2.5 m are met. The number of days is counted monthly. The figure reproduces the winter (JFM) mean computed from the CMEMS reanalysis.

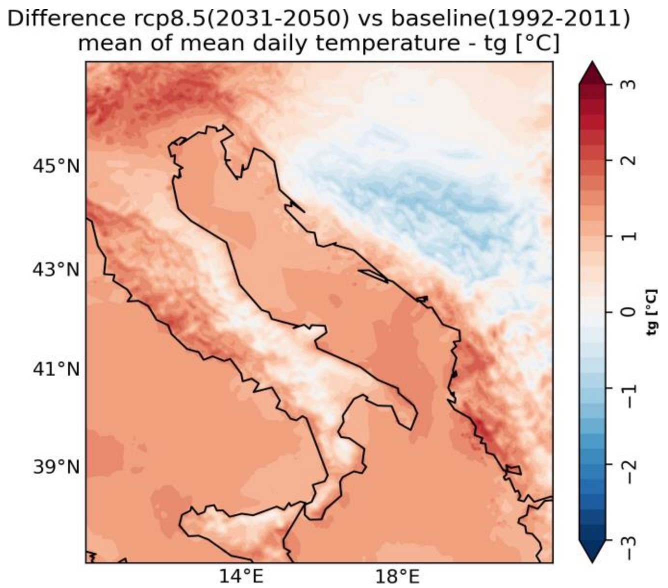

Fig.10 - Difference map between the TG averaged on the projection period (2031-2050) and the TG averaged on the baseline (1992-2011) over the Adriatic basin from WRF AdriaClim simulations.

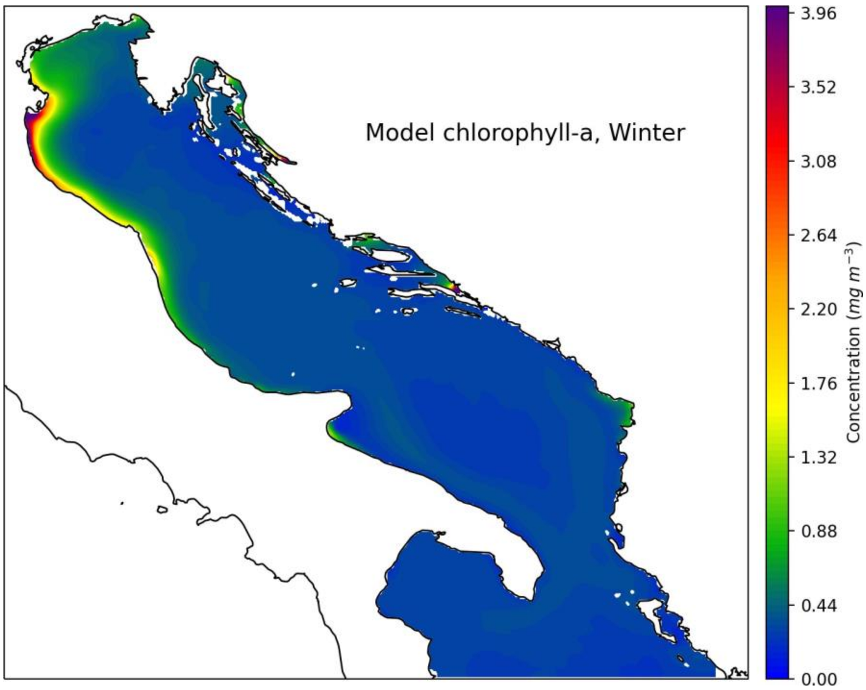

Fig.11 - Mean surface concentration of chlorophyll-a during Winter (DJF) during 1992-2011.

3.2 Additional indicators adopted in the Pilot Areas

Most of the Pilot Areas decided to take advantage of the indicators computed at Adriatic scale (described in Table 1) and only a few of them developed additional indicators (Table 2). Therefore, this section aims to provide details only on the additional indicators computed for specific regions.

Arpae Emilia-Romagna manages a regional observing system which encompasses different measurement stations (tide-gauges, multiparametric stations, and a wave buoy) for the continuous monitoring of the environmental state of marine, coastal and transitional areas. Among others, the Porto Garibaldi tide-gauge located in Porto Garibaldi (Ferrara, Emilia-Romagna) and the Nausicaa Buoy, installed in front of the Cesenatico municipality (Emilia-Romagna), have been operational since 2009 and 2007, respectively. The consistency and statistical significance of the time series of these stations are crucial to understanding the evolution of climate and marine ecosystems over the long term, providing valuable information for sustainable management of marine resources and mitigation of climate change.

The Geological, Soils and Seismic Area of the Emilia-Romagna Region is responsible for the development and maintenance of the Coastal and Marine Information System (called SIC), that was created with reference to the Erosion guideline delivered by the EU Commission in 2004, and that became institutional through the ICZM Emilia-Romagna Guidelines (D.G.R. 20 January 2005, n.645). The SIC collects monitoring and survey data concerning geological, geomorphological aspects, the coastal dynamics and protections. A lot of information, concerning coastal erosion and subsidence, derives from systematic monitoring carried out by Arpae on behalf of the region. Inside the SIC, studies developed cartographies and spatial indicators to support coastal management and interventions, the flood risk management plan, according to the EU Flood directive (DIR 2007/60), and the coastal early warning.

The following indicators were calculated on historical observations:

SSS (Sea Surface Salinity): Monthly and yearly average salinity derived from daily values of salinity measured at Porto Garibaldi tide gauge station. The indicator was estimated on the dataset from 2009 to 2022 for the Emilia-Romagna Region. The available observed time series has 10-minute intervals and is stored in the Arpae database. Mean, Maximum, and 95% Percentile were also estimated. the

SL (Total Sea Level): Monthly and yearly Total Sea Level derived from daily values of sea level measured by the tide-gauge of Porto Garibaldi (Ferrara). The indicator was estimated on the dataset from 2009 to 2022 for the Emilia-Romagna Region. The available observed time series has 10-minute intervals and is stored in the Arpae database. Mean, Maximum, and 95% Percentile were also estimated.

ST-TEn (Total energy of sea-storm events): Analysis of the total observed energy of sea-storm events that occurred on the Emilia-Romagna coasts based on significant wave heights measured by the Nausicaa Buoy located in front of Cesenatico Municipality. The storm events were selected with a Hs >1.35m (corresponding to the 95th percentile of the time series), a minimum duration of 4 hours, and a calm period between two consecutive storms (events are independent) of 12 hours below the threshold (1.35m). The yearly indicator was calculated for the period 2007-2022.

ST-MDu (Mean sea storm duration): Mean duration of sea-storm events that occurred on the Emilia-Romagna coasts were defined by significant wave heights measured by the Nausicaa Buoy located in front of Cesenatico Municipality. The storms were selected as follows: Hs >1.35m (corresponding to the 95th percentile of the time series), the minimum duration of 4 hours, and 12 hours below the threshold (1.35m) as a calm period between two consecutive storms (events are independent). Based on the storm duration, the mean duration over each year was estimated. The yearly indicator was calculated for the period 2007-2022 for the Emilia-Romagna Region.

ST-TDu (Total duration of sea-storm events): Total duration of sea-storm events that occurred on the Emilia-Romagna coasts were defined by significant wave heights measured by the Nausicaa Buoy located in front of Cesenatico Municipality. The storms were selected as follows: when Hs >1.35m (corresponding to the 95th percentile of the time series) for a minimum duration of 4 hours signifying a sea-storm event, and with Hs for 12 hours below the threshold (1.35m) signifying a calm period between two consecutive storms (events are independent). Based on the storm duration, the total duration was estimated as the sum of the duration of the storms over each year. The yearly indicator was estimated for the period 2007-2022 for the Emilia-Romagna Region.

ST-NE (Number of sea-storm events): Monthly, seasonal, and yearly numbers of sea-storm events were estimated with the same methodology of MD-SS and TD-SS (above). The number of events was defined for each month and aggregated yearly and seasonal. Minimum, mean, maximum, and 95% percentile were calculated for the period 2007-2022 for the Emilia-Romagna Region.

BO-8 (Frequency of rough sea conditions): The frequency of rough-sea conditions was estimated as the number of days when conditions of significant wave height > 1.35 m are met. Duration of the time that significant wave height measurements spent above 1.35 m were recorded in hours, which were then combined and computed to express the duration values as days. This was computed for each month, year, and once for all years (2007-2022) combined for the Emilia-Romagna Region.

BO-9 (Significant wave height): Analysis of the significant wave height on the Emilia-Romagna coast was conducted by examining significant wave height values measured by the Nausicaa Buoy, located in front of Cesenatico Municipality. Mean, maximum, and 95th percentile of significant wave height values were estimated yearly and monthly based on the available measured dataset with 30-minute intervals.

Tp (Peak wave period): The peak wave period analysis was conducted using the observed dataset at the Nausicaa buoy located in front of Cesenatico (Emilia-Romagna) in the period 2007-2022. Based on the observed data with a 30-minute data interval, monthly and yearly values of the following statistics were estimated for the Emilia-Romagna Region: minimum, maximum, and mean.

Tm (Mean wave period): The mean wave period analysis was conducted using the observed dataset at the Nausicaa buoy located in front of Cesenatico (Emilia-Romagna) in the period 2007-2022. Based on the observed data with a 30-minute data interval, monthly and yearly values of the following statistics were estimated for the Emilia-Romagna Region: minimum, maximum, and mean.

TXX: Maximum sea surface temperature – maximum value of daily maximum temperature. Monthly/seasonal/yearly maximum sea surface temperature values were calculated based on daily values. Minimum, mean, and maximum daily values were averaged to have one value of max temperature per day per statistical category, which was then used to calculate monthly, seasonal and yearly averages. It was calculated on the observed dataset of Nausicaa Buoy for the period 2007-2022 for the Emilia-Romagna Region.

TXN: Minimum sea surface temperature – minimum value of daily maximum temperature. Monthly/seasonal/yearly minimum sea surface temperature values were calculated based on daily values. Minimum, mean, and maximum daily values were averaged to have one value of minimum temperature per day per statistical category, which was then used to calculate monthly, seasonal and yearly averages. It was calculated on the observed dataset of Nausicaa Buoy for the period 2007-2022 for the Emilia-Romagna Region.

SST (Sea Surface Temperature): The sea surface temperature analysis was conducted using the observed data at the Nausicaa buoy in the period 2007-2022. Minimum, maximum, and average values were estimated for the Emilia-Romagna Region for the entire available period (2007-2022) based on the observed dataset with a 30-minute interval. Monthly, yearly and seasonal statistics were estimated.

ASPE (Coastal Erosion): The Accumulation (A), Stability (S), Precarious balance (P), Erosion (E) Index 2012-2018 analysis concern the entire Emilia-Romagna coastline between the Po di Goro river mouth and Cattolica (Tavollo river mouth). ASPE defines the condition of the regional coastal area as it would appear if beach-feeding works were not carried out, also considering the conditions of defense structures, if present. The indicator aim is to highlight the critical points of the coastal area considering any interventions carried out (like sand contributions/withdrawals), the conditions of the rigid defense structures, where present, and the lowering of the soil linked to subsidence.

Be-W (Beach width: 2014 and 2019). The Beach width analysis concerns the emerging beach free from permanent infrastructures (representing the space free for the damping of the waves) of the entire Emilia-Romagna coastline, between the Po di Volano river mouth and Cattolica (the Tavollo river mouth). The “Beach width” is a fundamental parameter in the management of storm surge risks, because it expresses the extension of the beach on which the damping of the wave motion can take place before interesting artifacts and infrastructures.

Be-WV (Beach width variation 2014-2019). The “Beach width variation 2014-2019" analysis concern the emerged beach free from permanent infrastructures (representing the space free for the damping of the waves) of the entire Emilia-Romagna coastline, between the Po di Volano river mouth and Cattolica (the Tavollo river mouth). The rates of width change in the temporal interval 2014-2019 have been calculated along transepts perpendicular to the shoreline and 10 m spaced and assigned to the points of intersection between every transept with the 2019 shoreline. The “Beach width variation” parameter consent to define the speed of the morphological changes that are affecting the coast and therefore to identify possible risks and situations of fragility related to storm surges.

Be-H (Average Beach Height: 2014 and 2019). The Beach average height analysis concerns the entire Emilia-Romagna coastline between the Po di Volano river mouth and Cattolica (the Tavollo river mouth). The parameter calculation has been fulfilled along transepts perpendicular to the shoreline and 10 m spaced. The heights are derived from the DTM model (Lidar dataset). The points here reported are those of intersection between the transepts and the shoreline.

The specific aim is to forecast the coastal evolution and to develop and update the regional flood risk maps in the coastal area, as arranged in D.Lgs. 49/2010, national transposition law of Floods Directive (2007/60/EC). The indicator has the purpose of highlighting the sectors of coast where the emerging beach is in a fragile condition due to the low altitudes. Indirectly, it expresses the lack of available sediment and the propensity of the back territories to be reached by water during storm surges and the risk of loss of territory due to sea level rise.

Be-HC (Beach closure height 2014 and 2019). The "Beach closure height" analysis concerns the entire Emilia-Romagna coastline between the Po di Volano river mouth and Cattolica (the Tavollo river mouth). The parameter calculation has been fulfilled along transepts perpendicular to the shoreline and 10 m spaced, the heights are derived from a DTM model (Lidar dataset). The specific aim is to forecast the coastal evolution and to develop and update the regional flood risk maps in the coastal area, as arranged in D.Lgs. 49/2010, national transposition law of Floods Directive (2007/60/EC).The indicator has the purpose of highlighting the sectors of coast where the emerged beach is in a fragile condition due to the low altitudes. Indirectly, it expresses the lack of available sediment and the propensity of the back territories to be reached by water during storm surges and the risk of loss of territory due to sea level rise.

TSE (Total shoreline evolution: 2011-2014 and 2014-2019). The "Total shoreline evolution” has been processed for the temporal intervals 2011-2014 and 2014-2019. The analysis concerns the entire Emilia-Romagna coastline between the Po di Volano river mouth and Cattolica (the Tavollo river mouth). The indicator calculation has been fulfilled using the Digital Shoreline Analysis System (DSAS) - Version 5.1 By U.S. Geological Survey. The parameters consent to define the speed of the morphological changes in the Emilia-Romagna shoreline, to analyze the sand material movement along the coast and situations of chronic deficiency of sediment, in order to identify preventive and mitigating measures.

Se-A (Annual shoreline evolution: 2011-2014 and 2014-2019). The "Annual shoreline evolution 2011-2014" has been processed for the temporal intervals 2011-2014 and 2014-2019. The analysis concerns the entire Emilia-Romagna coastline between the Po di Volano river mouth and Cattolica (the Tavollo river mouth). The indicator calculation has been fulfilled using the Digital Shoreline Analysis System (DSAS) - Version 5.1 By U.S. Geological Survey. The total variation has been divided to obtain a yearly trend. The parameters consent to analyze the annual rate of change in the Emilia-Romagna shoreline, the sand material movement along the coast and identify situations of chronic deficiency of sediment.

Each indicator is uploaded on ERDAPP node in csv format. As mentioned in Section 3, the file name contains all the necessary information, indicating the name of the measurement station where data are retrieved (Nausicaa, Porto Garibaldi, ecc…) or the dataset used to calculate the indicators (ex: RER means observation database of Regione Emilia-Romagna).

The further indicators that will be estimated on historical observations for the Emilia-Romagna Pilot follow:

- Dissolved oxygen (ARPAE)
- Warming of sea-surface temperatures (ARPAE)
- Beach height average variation 2014-2019 (RER)
- Beach height closure variation 2014-2019 (RER)
- Damages to public and private goods caused by extreme events/storms (RER)
- Damage to coastal protection (RER)
- Number of sea-storm events with impact x year (RER)
- Floodable areas/shoreline length (RER)

Moreover, to have a better representation of processes and dynamics of the Po River Delta that will surely strongly influence variables such as temperature and salinity, the numerical model SHYFEM with high-resolution is going to be run on the domain of Emilia-Romagna Region. The model includes the Po Delta branches and extends up to PonteLagoscuro where is located an hydrological station. The following indicators will be therefore estimated based on the output of the simulations:

- Temperature
- Salinity

The meteoclimatic indicators calculated over the Veneto domain, for the coastal provinces of Venice, Padua and Rovigo, are listed in the table below. These indices are calculated from data from ARPA Veneto's automatic meteoclimatic stations, which were installed in the early 1990s on the coastal plain. Moreover, additional codes developed in R by ISPRA have been used for the computation of Mean Sea Level Rise and Extreme Events Analysis in Punta della Salute tide gauge station, representing Venice city center.

Indicators and computations such as trends, averages, and anomalies are calculated punctually, for different station points. For a selection of indicators, they are spatialized on a regular grid with spatial resolution of 1 km. For indicators that are not based on fixed thresholds but on percentiles, the reference period used is the 30-year period 1991-2020. The temporal grouping for calculating indicators can be annual, seasonal and monthly.

The maximum number of stations available for precipitation indicators is 43 for absolute indices and 26 for indices based on percentiles. For temperature-based indicators, the maximum number of stations available is 43 for absolute indices and 26 for percentile-based indices.

Moreover, additional Python codes developed by ISPRA have been used for the computation of indicators for the Emilia Romagna Pilot. They are devoted to the computation of indicators to evaluate suitability for aquaculture with regard to waves, currents, and temperature, as well as chlorophyll and dissolved oxygen. All datasets were obtained from the AdriaClim ERDDAP repository. These indicators are calculated using two types of datasets: historical data, covering roughly the period from 1992 to 2020, and projected data spanning from 2022 to 2050. Please note that some parameters lack projected data and CMEMS data are used as an alternative.

In addition to the above-mentioned indicators, additional 16 indicators have been developed by ARPA Veneto for the Veneto Pilot, shown in Table 2. Among them, only 5 indicators are not previously described. Their definitions are listed below:

TNd (average minimum temperature). The average daily minimum temperature. The minimum temperature is chosen from 96 daily temperature values, one measurement every 15 minutes.

TXd (average maximum temperature). The average of the daily maximum temperatures. The maximum temperature is chosen from 96 daily temperature values, one measurement every 15 minutes.

SU30 (summer days). Annual count of days when daily maximum temperature > 30degC. The 30degC threshold differs from the 25degC threshold, indicated by this indicator from the ETCCDI definition, to better suit the Italian climate.

R95PDAY (Days with heavy rainfall). Number of days with cumulative precipitation exceeding that of the 95th percentile.

SDII (Simple daily intensity index). Represents the average daily intensity of precipitation and is obtained from the ratio of total precipitation in a certain period, to the number of rainy days in the same period.

SLR (Relative Mean Sea Level Rise). Represents the trend of mean sea level, calculated through the Seasonal Trend decomposition using Loess (STL method), a decomposition of mean sea level using a Local Polynomial Regression.

EE (Sea Level Extreme Events analysis). Return period and return level of extremes calculated through the Generalized Pareto Distribution and del Peak Over threshold Method (GPD-POT), the Generalized Extreme Value Distribution on annual maxima (GEV) and the Joint Probability Method (JPM) with the decomposition of astronomical tide and the meteorological one.

Ind.	Definition	Pilot Area	Domain of Application	Dataset	Time Aggreg.	Spatial Res.	Temporal coverage	Ref. Period	Anomalies (periods)	Trends (periods)	Other statistics
WSDI	Warm Spell Duration Index	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year	26 station points	1991-2022	1991-2020		1992-2011	average, anomaly 1992-2011
						Grid 1 km	1993-2022	1991-2020		1993-2011	average 1993-2011
HWN	Number of heat waves	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year and seasons	26 station points	1991-2022	1991-2020		1992-2011	average, anomaly 1992-2011
HWTXdx	Maximum value between the averages of the maximum temperatures averaged for each heat wave	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year	26 station points	1991-2022	1991-2020		1992-2011	average, anomaly 1992-2011
TDd	Mean daily temperature (same of TG)	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year, seasons and months	44 station points	1991-2022			1992-2011	average, anomaly 1992-2011
						Grid 1 km	1993-2022			1993-2011	average 1993-2011
TNd	Average minimum	Veneto	Provinces of Venice,	ARPA Veneto	Year, seasons and	44 station points	1991-2022			1992-2011	average, anomaly 1992-2011

	temperature		Padua and Rovigo	automatic stations	months	Grid 1 km	1993-2022			1993-2011	average 1993-2011
TXd	Average maximum temperature	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year, seasons and months	44 station points	1991-2022			1992-2011	average, anomaly 1992-2011
						Grid 1 km	1993-2022			1993-2011	average 1993-2011
TR	Tropical nights	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year	44 station points	1991-2022			1992-2011	average, anomaly 1992-2011
					Year, seasons and months	Grid 1 km	1993-2022			1993-2011	average 1993-2011
SU30	Summer days	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year	44 station points	1991-2022			1992-2011	average, anomaly 1992-2011
					Year, seasons and months	Grid 1 km	1993-2022			1993-2011	average 1993-2011
TX90p	Hot days	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year, seasons and months	26 station points	1991-2022	1991-2020		1992-2011	average, anomaly 1992-2011
						Grid 1 km	1993-2022	1991-2020		1993-2011	average 1993-2011
CDD	Consecutive Dry Days	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year and seasons	43 station points	1991-2022			1992-2011	average, anomaly 1992-2011
RX1day	Maximum 1-day precipitation amount	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year, seasons and months	43 station points	1991-2022			1992-2011	average, anomaly 1992-2011
						Grid 1 km	1993-2022			1993-2011	average 1993-2011
RX5day	Maximum 5-days precipitation amount	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year, seasons and months	43 station points	1991-2022			1992-2011	average, anomaly 1992-2011
						Grid 1 km	1993-2022			1993-2011	average 1993-2011
R95pTOT	Precipitation fraction	Veneto	Provinces of Venice,	ARPA Veneto	Year, seasons and	26 station points	1991-2022	1991-2020		1992-2011	average, anomaly 1992-2011

	due to very wet days.		Padua and Rovigo	automatic stations	months	Grid 1 km	1993-2022	1991-2020		1993-2011	average 1993-2011
R95pDAY	Number of days with cumulative precipitation exceeding that of the 95° perc.	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year, seasons and months	26 station points	1991-2022	1991-2020		1992-2011	average, anomaly 1992-2011
PRCPTOT	Total Precipitation	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year, seasons and months	43 station points	1991-2022			1992-2011	average, anomaly 1992-2011
						Grid 1 km	1993-2022			1993-2011	average 1993-2011
SDII	Simple daily intensity index	Veneto	Provinces of Venice, Padua and Rovigo	ARPA Veneto automatic stations	Year, seasons and months	43 station points	1991-2022			1992-2011	average, anomaly 1992-2011
						Grid 1 km	1993-2022			1993-2011	average 1993-2011
SLR	Relative Sea Level Rise	Veneto	Venice	ISPRA tide gauge Punta della Salute, Ancona, Otranto; CNR ISMAR tide gauge Trieste Molo Sartorio, ARPAE tide gauge Porto Garibaldi	months		1924-2023			1992-2011	Seasonal Trend Decomposition using LOESS (STL method)
EE	Sea Level Extreme Events	Veneto	Venice	ISPRA tide gauge station of Punta della Salute	Year, season, months,		1989-2023			1989-2020	GPD POT, GEV, JPM
Be-H	Average beach height	Emilia-Romagna	Emilia-Romagna coastline (from Po di Volano river	RER	yearly	10 m	2014				no other statistics

			mouth to Cattolica)								
			Emilia-Romagna coastline (from Po di Volano river mouth to Cattolica)	RER	yearly	10 m	2019				no other statistics
Be-HC	Beach height closure	Emilia-Romagna	Emilia-Romagna coastline (from Po di Volano river mouth to Cattolica)	RER	yearly	10 m	2014				no other statistics
			Emilia-Romagna coastline (from Po di Volano river mouth to Cattolica)	RER	yearly	10 m	2019				no other statistics
Be-W	Beach width	Emilia-Romagna	Emilia-Romagna coastline (from Po di Volano river mouth to Cattolica)	RER	yearly	10 m	2014				no other statistics
			Emilia-Romagna coastline (from Po di Volano river mouth to Cattolica)	RER	yearly	10 m	2019				no other statistics

Be-WV	Beach width variation	Emilia-Romagna	Emilia-Romagna coastline (from Po di Volano river mouth to Cattolica)	RER	yearly	10 m	2019-2014				no other statistics
TSE	Total Shoreline evolution	Emilia-Romagna	Emilia-Romagna coastline (from Po di Volano river mouth to Cattolica)	RER	yearly	20 m	2011-2014				no other statistics
		Emilia-Romagna	Emilia-Romagna coastline (from Po di Volano river mouth to Cattolica)	RER	yearly	20 m	2014-2019				no other statistics
Se-A	Annual shoreline evolution	Emilia-Romagna	Emilia-Romagna coastline (from Po di Volano river mouth to Cattolica)	RER	yearly	20 m	2011-2014				no other statistics
		Emilia-Romagna	Emilia-Romagna coastline (from Po di Volano river mouth to Cattolica)	RER	yearly	20 m	2014-2019				no other statistics
ASPE	Coastal erosion	Emilia-Romagna	Emilia-Romagna coastline (from Po di Goro river mouth to Cattolica)	RER	yearly		2012-2018				no other statistics

ST-TEn	Total energy of Sea storm events	Emilia-Romagna	Nausicaa Buoy Long: 12.47587 Lat: 44.214583	Observation (Nausicaa Buoy)	yearly	1 local station	2007-2022				no other statistics
ST-MDu	Mean Sea storm duration	Emilia-Romagna	Nausicaa Buoy Long: 12.47587 Lat: 44.214583	Observation (Nausicaa Buoy)	yearly	1 local station	2007-2022				Mean
ST-TDu	Total Sea storm duration	Emilia-Romagna	Nausicaa Buoy Long: 12.47587 Lat: 44.214583	Observation (Nausicaa Buoy)	Monthly yearly	1 local station	2007-2022				no other statistics
ST-NE	Number of sea storm events	Emilia-Romagna	Nausicaa Buoy Long: 12.47587 Lat: 44.214583	Observation (Nausicaa Buoy)	Monthly Seasonal yearly	1 local station	2007-2022				no other statistics
TXX (degC)	Maximum value of daily maximum temperature	Emilia-Romagna	Nausicaa Buoy Long: 12.47587 Lat: 44.214583	Observation (Nausicaa Buoy)	Monthly Seasonal yearly	1 local station	2007-2022				no other statistics
TXN (degC)	Minimum value of daily maximum	Emilia-Romagna	Nausicaa Buoy	Observation (Nausicaa Buoy)	Monthly Seasonal	1 local station	2007-2022				no other statistics

	temperatur e		Long: 12.47587 Lat: 44.214583		yearly						
SL	Total Sea Level: statistics over time periods	Emilia-Romag na	Porto Garibaldi Station 12.249444 Lat: 44.676667	Observatio n (Porto Garibaldi Station Tide Gauge)	Monthl y yearly	1 local station	2009-2022				Mean Maximum 95% Percentile
SSS (PSU)	Sea Surface Salinity: statistics over time periods	Emilia-Romag na	Porto Garibaldi Station Long: 12.249444 Lat: 44.676667	Observatio n (Porto Garibaldi Station Tide Gauge)	Monthl y yearly	1 local station	2009-2022				Mean Maximum 95% Percentile
BO-9	Significant Wave Height:stati stics over time periods	Emilia-Romag na	Nausicaa Buoy Long: 12.47587 Lat: 44.214583	Observatio n (Nausicaa Buoy)	Monthl y yearly	1 local station	2007-2022				Mean Maximum 95% Percentile
BO-8	Frequency of rough sea conditions	Emilia-Romag na	Nausicaa Buoy Long: 12.47587 Lat: 44.21458	Observatio n (Nausicaa Buoy)	Yearly Total	1 local station	2007-2009				Count of days when Hs>=1.35 m
SST	Sea Surface Temperatur e: statistics over time periods	Emilia-Romag na	Nausicaa Buoy Long: 12.47587 Lat: 44.214583	Observatio n (Nausicaa Buoy)	Monthl y Season al Yearly	1 local station	2007-2022				Minimum Mean Max

Tp	Peak wave period: statistics over time periods	Emilia-Romagna	Nausicaa Buoy Long: 12.47587 Lat: 44.214583	Observation (Nausicaa Buoy)	Monthly Yearly	1 local station	2007-2022				Minimum Mean Max
Tm	Mean wave period: statistics over time periods	Emilia-Romagna	Nausicaa Buoy Long: 12.47587 Lat: 44.214583	Observation (Nausicaa Buoy)	Monthly Yearly	1 local station	2007-2022				Minimum Mean Max
hs	significant height of wind and swell waves	Emilia-Romagna	Emilia-Romagna	AdriaClim RESM	Hourly	Latitude: 2.319km Longitude: 1.642km	1992-2020	1992-2020			-Minimum -Average -Max - Percentage of suitability for aquaculture
vozocrtx	Sea Water X Velocity, m/s	Emilia-Romagna	Emilia-Romagna	AdriaClim RESM	daily	Latitude: 2.319km Longitude: 1.642km	1992-2020 & 2022-2050	1992-2020 & 2022-2050			-Minimum -Max - Percentage of suitability for aquaculture
vomecrty	Sea Water Y Velocity, m/s	Emilia-Romagna	Emilia-Romagna	AdriaClim RESM	daily	Latitude: 2.319km Longitude: 1.642km	1992-2020 & 2022-2050	1992-2020 & 2022-2050			-Minimum -Max - Percentage of suitability for aquaculture
votemper	Sea Water Potential Temperature, degree_C	Emilia-Romagna	Emilia-Romagna	AdriaClim RESM	daily	Latitude: 2.319km Longitude: 1.642km	1992-2020 & 2022-2050	1992-2020 & 2022-2050			-Minimum -Max - Percentage of suitability for aquaculture
o2	Mole concentration of Dissolved Molecular Oxygen in	Emilia-Romagna	Emilia-Romagna	CMEMS	daily	Latitude: 4.637km Longitude: 3.284km	1999-2019	1999-2019			-Minimum -Average -Max

	sea water, MMol' 'M-3										- Percentage of suitability for aquaculture
chl	Mass concentration of chlorophyll a in sea waterr, mg' 'M-3	Emilia-Romagna	Emilia-Romagna	CMEMS	daily	Latitude: 4.637km Longitude: 3.284km	1999-2019	1999-2019			-Minimum -Average -Max - Percentage of suitability for aquaculture

Table 2. Additional indicators computed for specific Pilot Areas and related characteristics.

References

Bartholmes, J., Thielen, J., Ramos, M. & Gentilini, S., 2009. The european flood alert system EFAS – Part 2: Statistical skill assessment of probabilistic and deterministic operational forecasts. *Hydrology and Earth System Sciences*, 13(2), pp. 141-153. https://doi.org/10.5194/hess-13-141-2009

Cornes, R., van der Schrier, G., van den Besselaar, E. J. M., & Jones, P. D., 2018. An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, J. Geophys. Res. Atmos., 123. https://doi.org/10.1029/2017JD028200

Josué Martínez Moreno, & Navid C. Constantinou, 2021. josuemtzmo/xarrayMannKendall: Mann Kendall significance test implemented in xarray. (Version v.1.0.0). Zenodo. http://doi.org/10.5281/zenodo.4458777

Josué Martínez-Moreno, Andrew McC. Hogg, Matthew H. England;Navid C. Constantinou, Andrew E. Kiss;Adele K. Morrison, 2021. Global changes in oceanic mesoscale currents over the satellite altimetry record. Nature Climate Change, doi:10.1038/s41558-021-01006-9

L'Hévéder, B., Li, L., Sevault, F. et al., 2013. Interannual variability of deep convection in the Northwestern Mediterranean simulated with a coupled AORCM. Clim Dyn 41, 937–960. https://doi.org/10.1007/s00382-012-1527-5

Hargreaves, G.H., and Samani, Z.A., 1985. Reference crop evapotranspiration from temperature. *Applied Engineering in Agriculture*, 1 (2), pp. 96-99. https://doi.org/10.13031/2013.26773

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D. and Simmons, A., 2020. The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, 146 (730), pp. 1999-2049. https://doi.org/10.1002/qj.3803

McKee, T.B., Doesken, N.J. and Kleist, J., 1993. The relationship of drought frequency and duration to time scales. Proceedings of the 8th Conference on Applied Climatology, 17 (22), pp. 179-183.

Muñoz Sabater, J., 2019. ERA5-Land hourly data from 1981 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), 10.24381/cds.e2161bac.

Ruti, P. M., Somot, S., Giorgi, F., Dubois, C., Flaounas, E., Obermann, A., Dell'Aquila, A., Pisacane, G., Harzallah, A., Lombardi, E., Ahrens, B., Akhtar, N., Alias, A., Arsouze, T., Aznar, R., Bastin, S., Bartholy, J., Béranger, K., Beuvier, J., Bouffies-Cloché, S., Brauch, J., Cabos, W., Calmanti, S., Calvet, J.-C., Carillo, A., Conte, D., Coppola, E., Djurdjevic, V., Drobinski, P., Elizalde-Arellano, A., Gaertner, M., Galàn, P., Gallardo, C., Gualdi, S., Goncalves, M., Jorba, O., Jordà, G., L'Heveder, B., Lebeaupin-Brossier, C., Li, L., Liguori, G., Lionello, P., Maciàs, D., Nabat, P., Önol, B., Raikovic, B., Ramage, K., Sevault, F., Sannino, G., Struglia, M. V., Sanna, A., Torma, C., & Vervatis, V. (2016). Med-CORDEX Initiative for Mediterranean Climate Studies, *Bulletin of the American Meteorological Society*, *97*(7), 1187-1208. doi: https://doi.org/10.1175/BAMS-D-14-00176.1

Simoncelli, S., Fratianni, C., Pinardi, N., Grandi, A., Drudi, M., Oddo, P., & Dobricic, S., 2019. Mediterranean Sea Physical Reanalysis (CMEMS MED-Physics) (Version 1) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS). https://doi.org/10.25423/MEDSEA_REANALYSIS_PHYS_006_004

Thielen, J., Bartholmes, J., Ramos, M. & deRoo, A., 2009. The European Flood Alert System – Part 1: Concept and development. *Hydrology and Earth System Sciences*, 13 (2), pp. 125-140. https://doi.org/10.5194/hess-13-125-2009