AdriaClim

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

Project ID: 10252001

3.2.1 Summary description of modelling systems and results

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

Priority Axis: 2 - Climate change adaptation

Specific objective: 2.1 - Improve the climate change monitoring and planning of adaptation measures tackling specific effects, in the cooperation area

Work Package Number: 3

Work Package Title: Climate change monitoring (observing and modelling) systems

Activity Number: 3.2

Activity Title: Design and implementation of the integrated modelling systems

Partner in Charge: CMCC

Partners involved: ArpaE, ArpaFVG, CNR ISMAR, University of Bologna, IOF

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1. Aims and content of the document

The aim of the Deliverable is to describe the progress of the modelling activities foreseen in the framework of AdriaClim WP3. Planned, performed and ongoing actions are detailed together with the open issues to be solved.

The report is organized as follows. Section 2 introduces the modelling components of the Regional Earth System to be designed over the Adriatic Sea area. For each modelling component we describe the setting up in terms of physical and numerical choices and the preliminary results of a control run covering a target year, i.e. 2019, with the model working in stand-alone mode. Section 3 presents the selected pilot sites in the Croatian and Italian marine coastal areas where very high-resolution thermo-hydrodynamics models will be dynamically downscaled with a double aim: (i) investigate the past, present and future climate at coastal scales; (ii) enhance the scientific knowledge of the sea state and the physical and biogeochemical dynamics of the coastal areas to develop site-specific climate change indicators and adaptation plans.

2. The design of a Regional Earth system Model over the Adriatic Sea area

An innovative coupled modelling system covering the Adriatic region and reaching the mesoscales has been planned. It includes atmosphere, hydrology, ocean, wavesand biogeochemistry components which are represented in Figure 1.

This modelling system is expected to provide a step forward with respect to the state-of-art of the regional earth system modelling by offering a more comprehensiveand a higher resolution representation of all the relevant physical and biogeochemical processes and by solving their 2-way feedbacks.

The final purposes are:

(i) investigate and deepen the knowledge of the physical and biogeochemicaldynamics of the Adriatic basin in the present and future climate

(ii) assess climate change indicators for the Adriatic coastal marine areas andevaluate the climate change impacts on the meteo-hydro-marine extreme events

(iii) prevent the long term consequences of the climate change impacts with site specific adaptation plans.

These purposes will be achieved by developing a coupled regional earth system which reaches a high spatial resolution and solves all the key feedbacks among the earth system components which are usually neglected or parameterized.

Moreover a further dynamical downscaling will be proposed in the marine areas selected as pilot sites by means of very-high resolution thermo-hydrodynamics models which reach up to tens of meters as horizontal resolutions.

The wrapper of the modelling components is based on the CIME (Common Infrastructure for Modeling the Earth) infrastructure. CIME is a free software platform developed by NCAR and currently used by the Community Earth System Model, CESM, and the Energy Exascale Earth System Model, E3SM (Danabasoglu et al 2020; https://esmci.github.io/cime/versions/master/html/index.html). CIME provides all the tools and utilities (i.e. a case control system) needed to build a single-executable coupled Earth System Model. The suite is made of support scripts (to configure, build, run, and test), essential utility libraries and model components. The components of a coupled model can be either prognostic or data models, depending on the direction of the information flow. In the first case, the flow is bi-directional, while the second results in a read-only source providing forcings. The third model category (i.e. stub) is only used for test purposes or to turn off undesired components.

The setup of the CIME infrastructure for AdriaClim regional system is currently ongoing with an in-depth analysis and test of CESM's CIME, as well as its forks already tied to a limited domain (e.g. RCESM https://ihesp.github.io/rcesm1/index.html).

A set of scenarios with an incremental level of complexity has been designed, in order to: i) test the behaviour of the CIME platform; ii) separately test the behaviour of two prognostic components (i.e. NEMO and WRF); iii) test the integration of both in the same regional case and the mutual exchange of data; iv) configure all the surrounding models and terminate the configuration of the final coupled model.

The strategy to dynamically downscaled the AdriaClim Earth system has been defined and is summarized in Table1. A member of the ensemble of coupeld air-sea models over the Mediterranean region provided by the Med-CORDEX coordinated initiative (Ruti et al 2015), i.e. the named LMDZNEMOMED (L'Heveder et al 2013), will be used to drive the climate downscaling from regional (MEDCORDEX) to subregional (AdriaClim Earth system) scale. The LMDZNEMOMED model consists of the atmospheric model LMDz4-regional (Li et al., 2012) with 30km horizontal resolution and the ocean model NEMO NEMOMED8 (Beuvier et al., 2010; Herrmann et al., 2010) with 10km horizontal resolution. The AdriaClim Earth system is designed to solve the mesoscale processes which means a horizontal resolutionof around 6km is chosen for the atmospheric and land surface modeling components, 600m for the river routing, and 2km horizontal resolution for the marinehydrodynamics, the biogeochemostry and the waves models. These grid spacings ensure a proper resolution ratio to perform the climate downscaling between the Med-CORDEX RCM and the AdriaClim Earth system and (ii) make the AdriaClim Earth system able to represent the mesoscale processes and air-sea-land interactions occurring at these scales

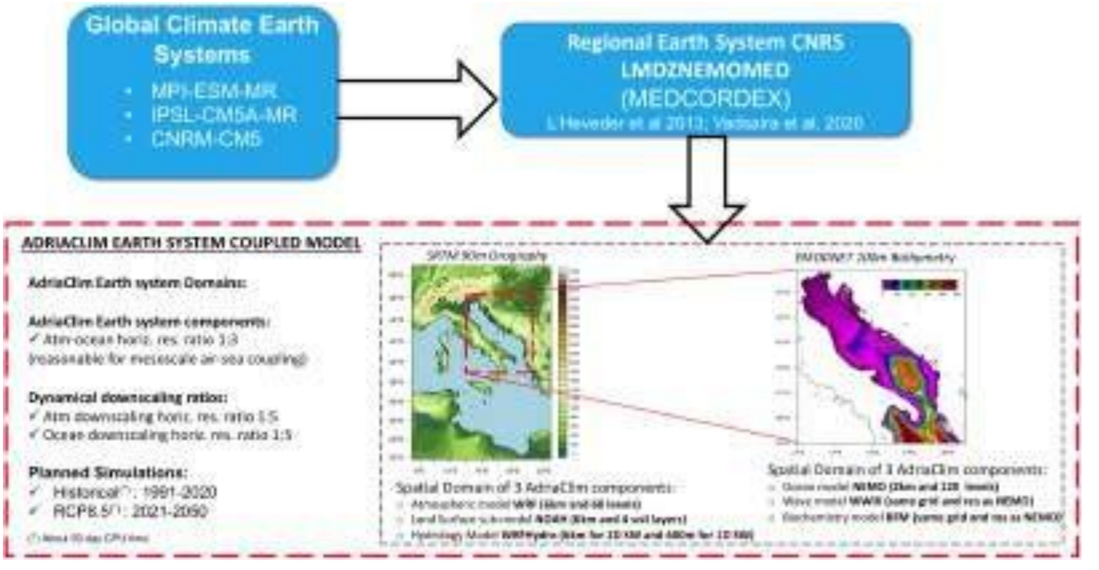


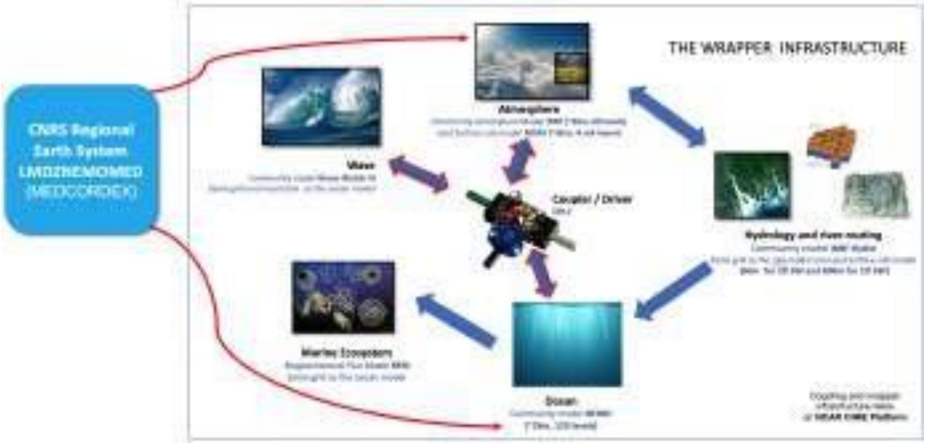
Table1: Tha AdriaClim strategy for climate downscaling and simulations

In the timeframe of the AdriaClim Project, a double strategy for performing the regional to sub-regional climate downscaling has been conceived:

- a long term strategy which consists of implementing an *online fully-coupled Regional Earth system Model RESM* over the Adriatic Sea as sketched in Figure1-Panel A
- an intermediate strategy which consists of implementing an *offline 1way-coupled Regional Earth system Model RESM* over the Adriatic Sea as sketched in Figure1-Panel B

Both strategies include the same modeling components with the same experimental configuration, the way they differ is the feedback mechanism among the models. The setting up of all the modeling components is underway and detailed in the next sub-sections.

Panel A



Panel B

Figure 1: The AdriaClim Regional Earth system Model RESM over the Adriatic Sea area Panel A: An online-fully coupled Adriatic RESM. Panel B: An offline-1way coupled Adriatic RESM

The atmospheric modelling component

A mesoscale configuration of the WRF-ARW model (Skamarock et al., 2008) based on version 3.5.1 has been set up over the Central Mediterranean Sea area as shown in Figure 2.
The experimental configuration chosen to perform a control run over the year 2019 isdetailed in Table 2.
The geographical domain covers a spatial area larger than the only Adriatic basin and the vertical air column is discretized up to half of the stratosphere in order to

include all the relevant synoptic patterns. The horizontal resolution reaches the mesoscale and is around 6km, i.e. 3 times the resolution of the eddy permitting ocean model configuration (section 2.2) which is a reasonable choice to capture mesoscale air-sea interactions (Jullien, 2020).
Sensitivity tests on the terrestrial datasets, e.g. the topography and the Land Use Categories, have been carried out. Both of them have been upgraded by considering the more recent and high-resolution NOAA SRTM Digital Terrain Model (90m res.) and the EEA Corine Land Use Categories (250m res.) which are found to ameliorate the near surface atmospheric field and the land surface fields (Verri et al., 2017).
Computationally speaking, the atmospheric component is the most expensive component of the designed Regional Earth System. Scalability tests have been performed to find the best balance between the CPU resources and the spatial and temporal details we aim to reproduce.

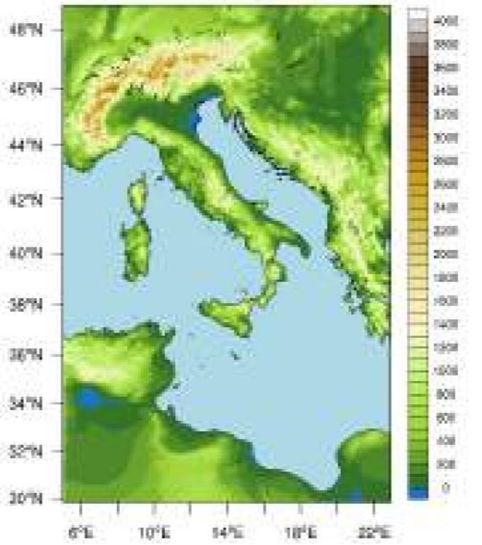


Figure 2: WRF ARW geographical domain and topography

SPATIAL DISCRETIZATION	
VERTICAL DISCRETIZATION	60 unevenly spaced ETA-levels (from ~1026 hPa to ~50 hPa)
HORIZONTAL DISCRETIZATION	*289X403 grid points, [5 to 23 ºE - 29.8 to 48.8 ºN], around 6km resolution*
GEOGRAPHICAL CONFIGURATION	
MAP PROJECTION	*Mercator plain coordinate based on a cylinder secant at ±30º N*
OROGRAPHY AND STATIC DATA	EuropeanEnvironmental Agency(EEA) 90m DTMs for orography + EEA Corine 250m res. for land use categories
PHYSICAL CHOICES	
HEAT RADIATIVE FLUXES PARAMETERIZATION	*RRTMG (2008) scheme*
PBL SURFACE SUB-LAYER TURBULENT FLUXES PARAMETERIZATIONS	Monin-Obukhov (Janjic Eta) scheme

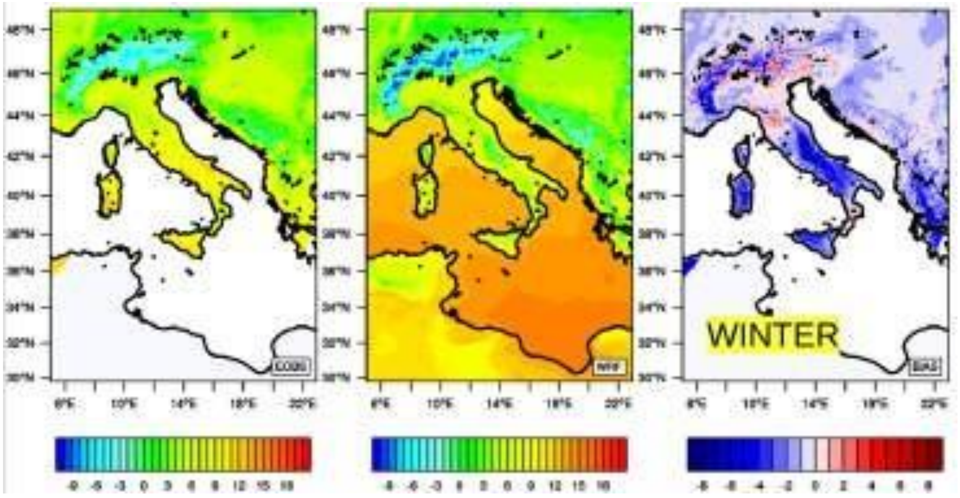
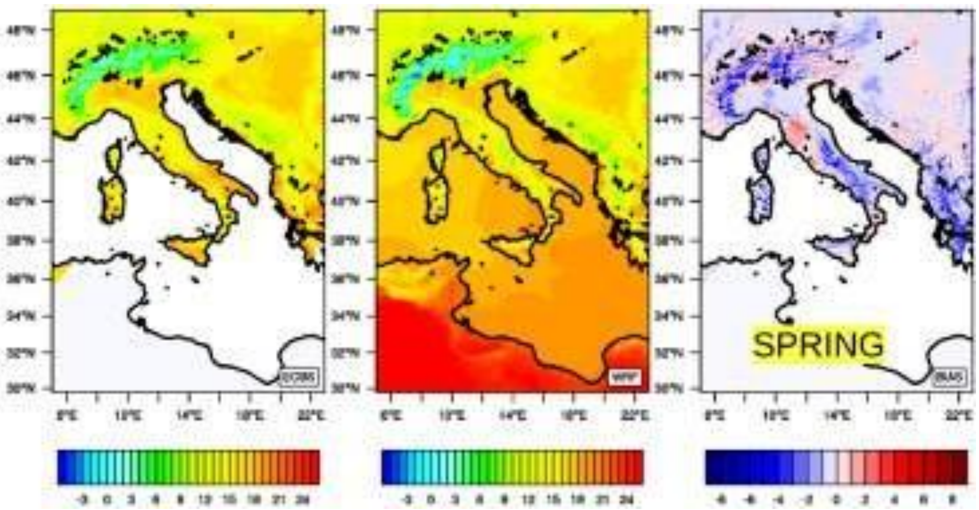
PBL MIXED SUBLAYER PARAMETERIZATION	Mellor-Yamada-Janjic (Eta) TKE scheme
CONVECTION/CUMULU SPARAMETERIZATION	Tiedtke scheme
MICROPHYSICS PARAMETERIZATION	*Morrison (2008)*
LAND SURFACE MODEL	2-way coupled NOAH sub-model

INITIAL AND BOUNDARY CONDITIONS	
INITIAL CONDITIONS	Computed by means of vertical and horizontal interpolation ofECMWF analysis provided as input fields
TOP BOUNDARY CONDITION	Constant pressure surface (50hPa)
BOTTOM BOUNDARY CONDITIONS	No slip
LATERAL BOUNDARY CONDITIONS	• Horizontal wind components, potential temperature, perturbation geopotential, perturbation volume mass and water vapor: *prescribed BC* (ECMWF coarse resolution fields are temporal and spatialinterpolated on WRF finer computational grid) in the “specified-zone” that is the last row or column of the outer edge along all four grid sides +relaxationzone in the inner 4 rows/columns • Vertical velocity: *zero-gradient BC* applied in the specified zone (the outermost row and column) • Microphysical variables, except water vapor, and all other scalars: *flow-dependent BCs applied in the specified zone*: this BC specifies zero (as they do not come from the parent model) on “inflow” and zero-gradient on “outflow”

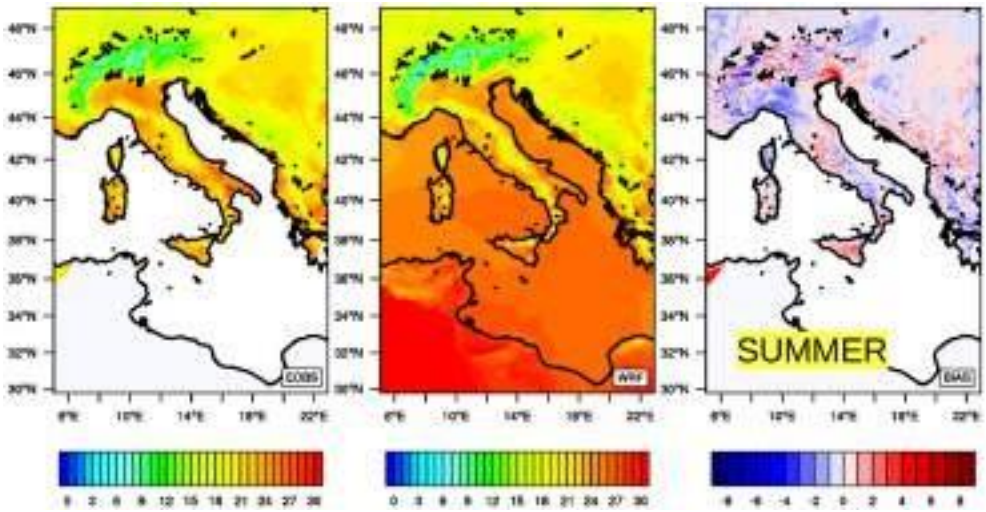
SIMULATION SET-UP & PERFORMANCE	
ATMOSPHERE, LAND SURFACE AND OCEAN FORCINGS	ECMWF analyses 0.1º res, 25 levels, 4 soil layers, 6h frequency. The SST and SSP are included
CONCATENATION PROCEDURE	chain of WRF 72 h long chunks with restart option
CPU TIME	CPU T=6’ 49’’ for 1day simulation with 12h output frequencyof instantaneous fields and 24h output frequency for average fields. Scalability tests suggest 432 cores

Table 2: WRF ARW setting up choices for the control run

A preliminary validation of the Control Run carried out over year 2019 with WRF working in stand-alone mode has started. This experiment is mostly based on Verriet al., 2017, with additional options for using WRF in climate mode.

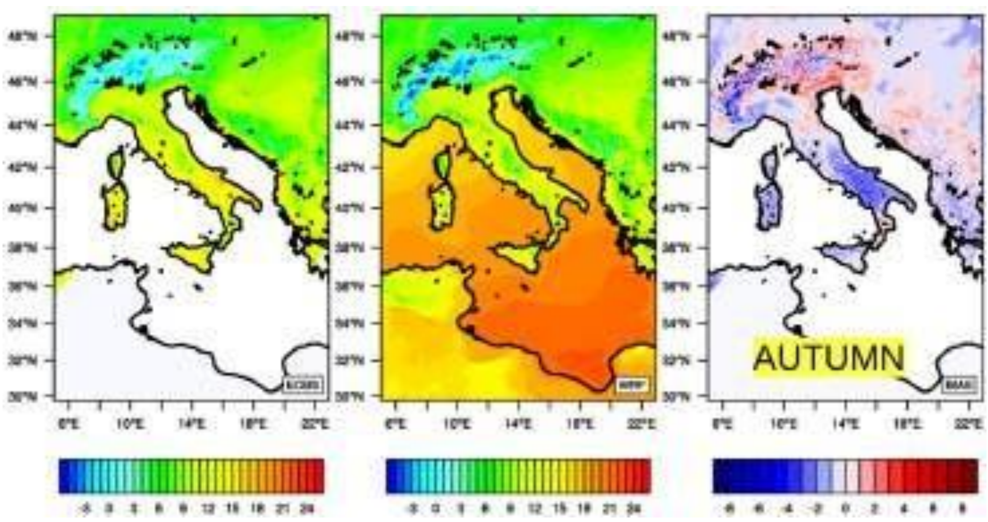
W I N T E R	
S P R I N G	

SUMMER

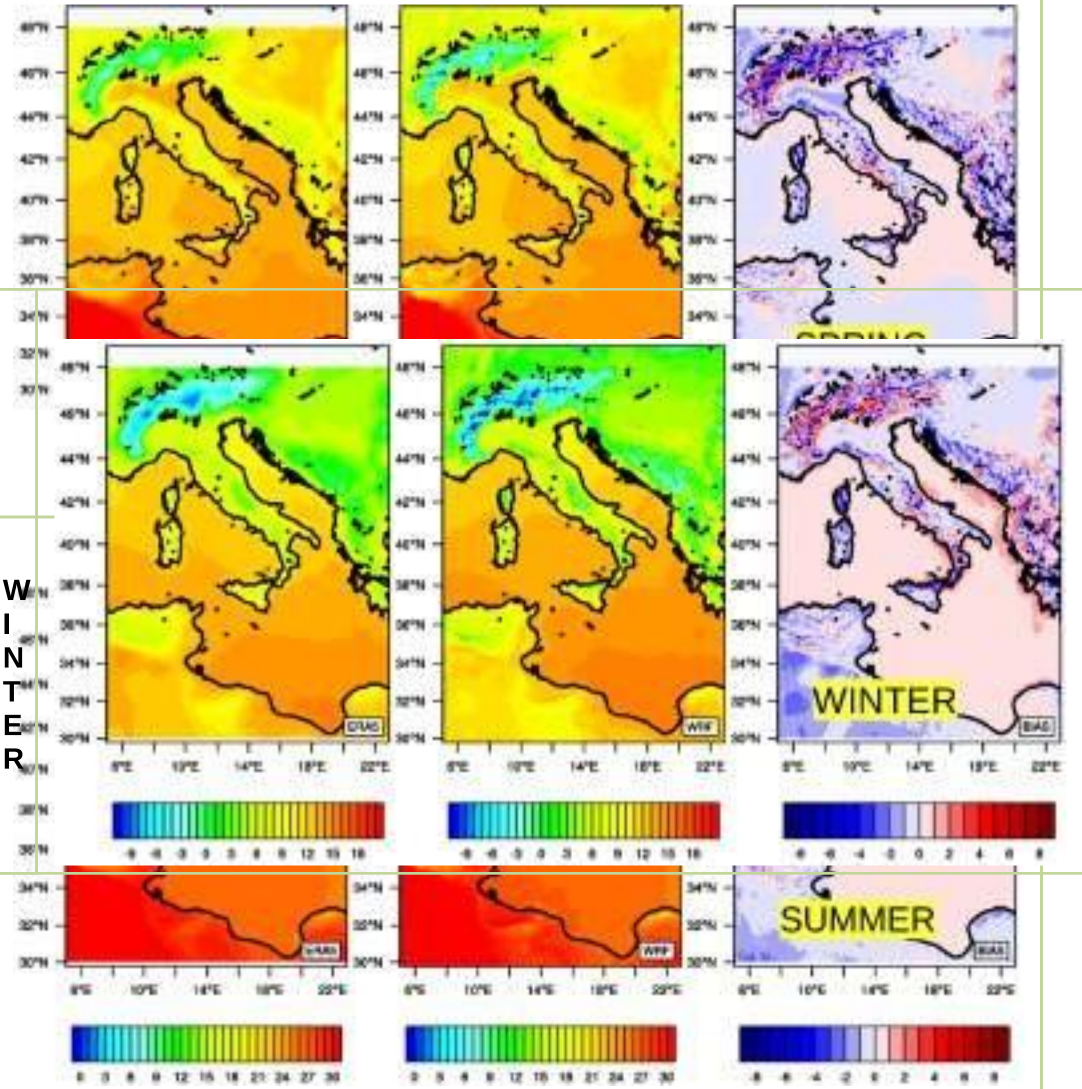


As an example, Figure 3 shows the seasonal validation of the air Temperature at 2mheight by comparison with i) the Copernicus E-OBS dataset which consists of scattered observations statistically interpolated over a regular grid with 10km resolution ii) the ECMWF ERA5 Renalises with horizontal spacing of 25km. The modelling results are promising if we consider the very irregular spatial distribution ofthe locations of the E-OBS stations (Figure 4) which makes the comparison meaningful only over the Emilia Romagna and Calabria regions, the Corsica island and the Eastern Adriatic coastal area.

AUTUMN



SPRING / WINTER / SUMMER



AUTUMMN

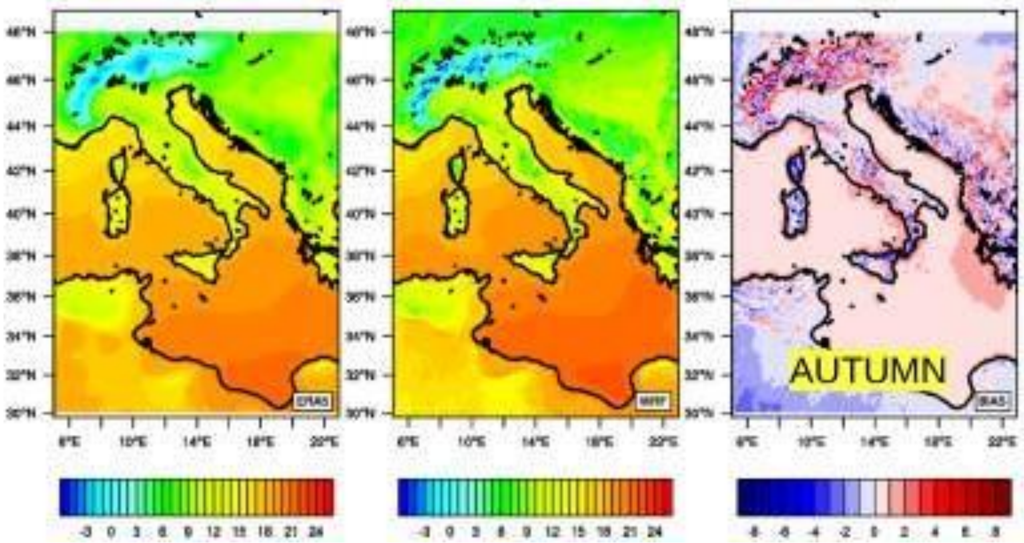


Figure 3: Top Seasonal Panels: WRF ARW seasonal comparison of modelled Temperature at 2m height with Copernicus E_OBS data (0.1deg regular grid). Left panel: Copernicus E_OBS data. Middle panel: seasonal WRF T2m. Right panel: BAIS between WRF T2m and E_OBS T2m.
Bottom Seasonal Panels: WRF ARW seasonal comparison of modelled Temperatureat 2m height with ERA5 Reanalises (0.25 deg regular grid). Left panel: ERA5 Reanalises. Middle panel: seasonal WRF T2m. Right panel: BAIS between WRF T2m and ERA5 Reanalises T2m

Locations of E-OBS Stations

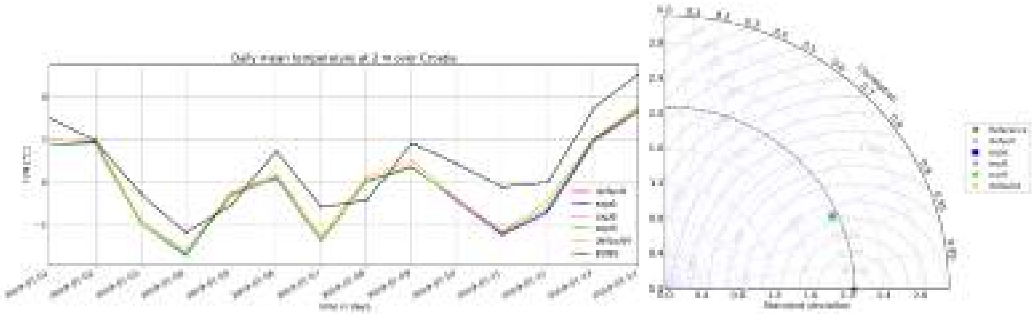
Figure 4: Spatial distribution of Copernicus E-OBS v22 stations for 2m air Temperature over 2019

A sensitivity analysis was performed. Specifically, in Table 3 are reported the main features of some of the tests performed starting for the control run experiment.
Each test was obtained modifying from the reference namelist one single parameter in order to evaluate the effects of this modification in the temperature and precipitation performance over a time window two-week long.

WRF AdriaClim EXP Configuration	**Code version**	**Changes to the reference namelist**
Experiment d_3	V3.5.1	reference
Experiment d_4	V4.2.1	reference
Experiment 6	V3.5.1	Shift the highest pressure levels From 50 hPa (default) to 10 hPa
Experiment 7	V3.5.1	Lower Time stepping From 4*dx (default) to 6*dx ([1])
Experiment 8	V3.5.1	Map projection From Mercator (default) to Lambert
Experiment 9	V3.5.1	Convection Parameterization From Kain-Fritsch(default) to Tiedtke scheme

Table 3: description of some of the tests performed for the sensitivity analysis with WRF model ([1]) About the Experiment 7 it doesn't provide output because it crashes before being completed.

At first, the validation of the performances was carried out evaluating the hourly 2-meter temperature over a two-week period considered for the sensitivity analysis. Validation was performed over two different areas: Croatia, and Veneto. This preliminary validation was carried out by comparing the areal value of the experiment with a gridded observational dataset (E-OBS v22). In the following Figures 5 and 6 are reported time plot and diagram Taylor (Taylor,



2001) for the different areas investigated

Figure 5: Time plot and Taylor diagram of daily mean temperature at 2 m over Croatia

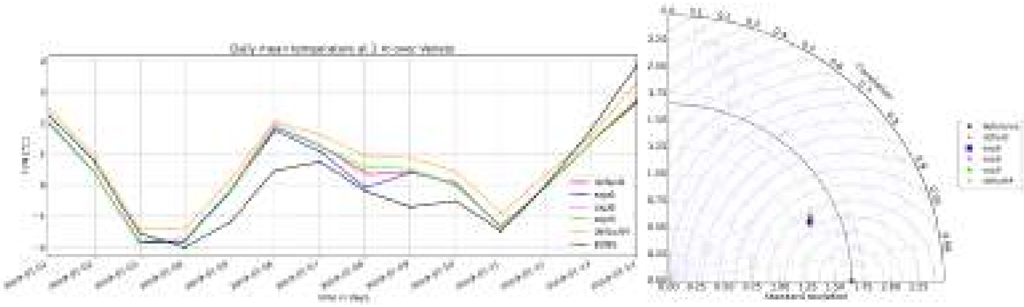


Figure 6: Time plot and Taylor diagram of daily mean temperature at 2 m over Veneto

Sensitivity analysis reports that all the simulation performed capture quite well the pattern of the 2-meter temperature data with small variation among them over the different area analyses. Moreover, the differences with observations are remarkable (in absolute terms) especially for South Italy and Abruzzo. It is also important to mention that partially these differences can be due to the lack of in situ observations for E-OBS over these areas. For a more detailed analysis are also reported belowthe values of the following averaged statistical performance indicators: MAE, MSE and RMSE (Figure 7 and 8).

Veneto

	MAE	MSE	RMSE	CORRELATION	BIAS

Default 3.5	0.6	0.5	0.7	0.9	0.2
Esp6	0.5	0.4	0.7	0.9	0.2
Exp 8	0.7	0.8	0.9	0.9	-0.5
Exp9	0.6	0.5	0.7	0.9	0.2
Default 4.2.1.	0.7	0.8	0.9	0.9	0.6

Figure 7: Statistical indices of comparing WRF results with E-OBS for the Veneto region

Croatia

	MAE	MSE	RMSE	CORRELATION	BIAS
Default 3.5	4.3	19.6	4.4	0.9	-4.3
Esp6	5.4	30.5	5.5	0.8	-5.4
Exp 8	5.6	33.3	5.8	0.7	-5.6
Exp9	5.4	30.3	5.5	0.8	-5.4
Default 4.2.1.	5.2	28.5	5.3	0.8	-5.2

Figure 8: Statistical indices of comparing WRF results with E-OBS for the Veneto region

For the Veneto area the best configuration, based on the performance indicators selected is the Experiment 6.
For the Croatia area the best configuration, based on the performance indicators selected is the Default 3.5.

The compliance of the advanced Land Surface model NOAH-MP (Niu et al., 2011) with the adopted WRF ARW version (i.e. v 3.5.1) is under investigation to replace thecurrently embedded but less skilled Land Surface model NOAH.
In the following months, an additional validation will be carried out considering different observational datasets (satellite and in situ data) and by focusing on the near surface atmospheric fields which are relevant for the coupling with the hydrology and ocean components (daily cumulated precipitations, short wave radiation, evaporation, 2m relative humidity, 10m wind, 2m air temperature).

2.2 The hydrology modelling component

The fully distributed Weather Research and Forecasting Hydrological modelling WRF-Hydro system (Gochis et al., 2013) has been implemented over the same WRFdomain. The WRF-Hydro model is expected to be an innovative component of the regional climate system because it includes several modules (details in Figure 9) which solve the lateral routing of surface and subsurface water (shallow water systems), the aquifer water storage-discharge, the interaction between surface and subsurface water flow.
A detailed catchment routing grid is computed using a GIS procedure starting with NOAA SRTM 90m topography data. The catchment grid is reproduced with a high level of accuracy: the

drainage directions are first drawn and the river network is then refined by identifying all the branches and the hierarchy of tributaries using Strahler’s

method (1952). We chose a grid spacing equal to 600m, which is 10 times higher than the WRF and NOAH spatial grid. The aquifer water storage is switched on.
Figure 10 shows the main watersheds of the rivers flowing into the Adriatic basin. Table 4 summaries the experimental configuration.
As a next step we plan to replicate the WRF Control Run over the year 2019 with WRF and WRF-Hydro working in fully coupled mode, to compare the modelling findings and to point out the expected benefits of the 2way feedbacks in the coupled system.
A specific effort will be devoted to identify the tunable coefficients of both NOAH and WRF-Hydro parameterizations which need to be customised for the active catchments. Both manual and automated calibration procedures, e.g. the PEST software, will be used.

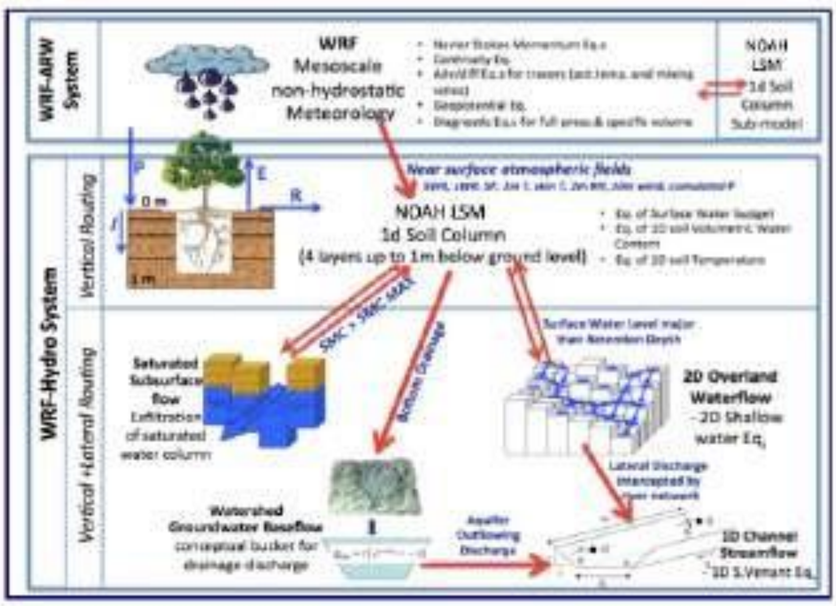


Figure 9: The WRF+WRF-Hydro coupled system. Picture from Verri et al., 2017

Figure 10: The watersheds of the rivers flowing into the Adriatic basin

SPATIAL DISCRETIZATION	
VERTICAL DISCRETIZATION	4 soil layers [0-0.1 m; 0.1-0.3m; 0.3-0.6m; 0.6-1.0m]
HORIZONTAL DISCRETIZATION	*289X403 (2890X4030) grid points, [5 to 23 ºE - 29.8 to 48.8 ºN],* aggregation factor 10. *NOAH horiz. resolution is 6km. The routing gridof the 2D and 1D Shallow water systems has 600m horiz. resolution*
GEOGRAPHICAL CONFIGURATION	
MAP PROJECTION	*Mercator plain coordinate based on a cylinder secant at ±30º N*
OROGRAPHY AND STATIC DATA	EuropeanEnvironmental Agency(EEA) 90m DTMs for orography +EEA Corine 250m res. for land use categories
PHYSICAL CHOICES	
SURFACE ROUTING	Two-Dimensional diffusive wave (Ogden et al. 1997)
SUBSURFACE ROUTING	Activated
CHANNEL ROUTING (No feedback to LSM)	One-dimensional diffusive wave
GROUNDWATER (No feedback to LSM)	Conceptual bucket model
SIMULATION SET-UP & PERFORMANCE	
ATMOSPHERE, LAND SURFACE AND OCEAN FORCINGS	ECMWF analyses 0.1º res, 25 levels, 4 soil layers, 6hfrequency, including SST and SSP
CONCATENATION PROCEDURE	chain of 72 h long chunks with restart option

CPU TIME	CPU T=7min for 1day simulation of the fully coupled WRF-WRFHydro with 12h output frequency of instantaneous fields and 24h output frequency for average fields. Tests performed with 648 cores

Table 4 WRF HYDRO setting up choices for the control run

2.3 The ocean modelling component

The numerical model used is the Nucleus for European Modelling of the Ocean, NEMO (Madec 2008), that is a three-dimensional finite difference numerical model adopting the Boussinesq and hydrostatic approximations and using the non-linear free surface with split explicit formulation. The area covered by the model grid is the Adriatic Sea from 12 to 21°E and 39 to 45.8°N with a horizontal resolution of about
2.2 km. Figure 11 shows the geographical domain and the bathymetry. Table 5 summaries the setting up choices for the control run.

SPATIAL DISCRETIZATION	
VERTICAL DISCRETIZATION	120 unevenly spaced z-levels (partial steps, 0.5 m to 2831.61 m)
HORIZONTAL DISCRETIZATION	432 x 331 grid points, [12 to 20.98 ºE; 39.0 to 45.88 ºN], around 2.2km resolution
GEOGRAPHICAL CONFIGURATION	
MAP PROJECTION	regular spherical coordinates
BATHYMETRY DATA	EMODNET, 3.75 arcsec.
PHYSICAL CHOICES	
Free surface equation	Linear free surface
lateral diffusion for tracers	Bi-laplacian operator horizontal eddy diffusivity for tracers = -3.0e-7 m2/s
lateral viscosity on momentum	Bi-laplacian operator horizontal bi-laplacian eddy viscosity = -5.0e-7 m4/s
Vertical mixing	TKE scheme to compute vertical eddy diffusivity andviscosity coefficients
advection scheme for tracer	MUSCL scheme
INITIAL AND BOUNDARY CONDITIONS	

INITIAL CONDITIONS	Temperatrure and Salinity are interpolated from CMEMS Mediterranean Sea model version; MEDSEA_ANALYSIS_FORECAST_PHY_006_013

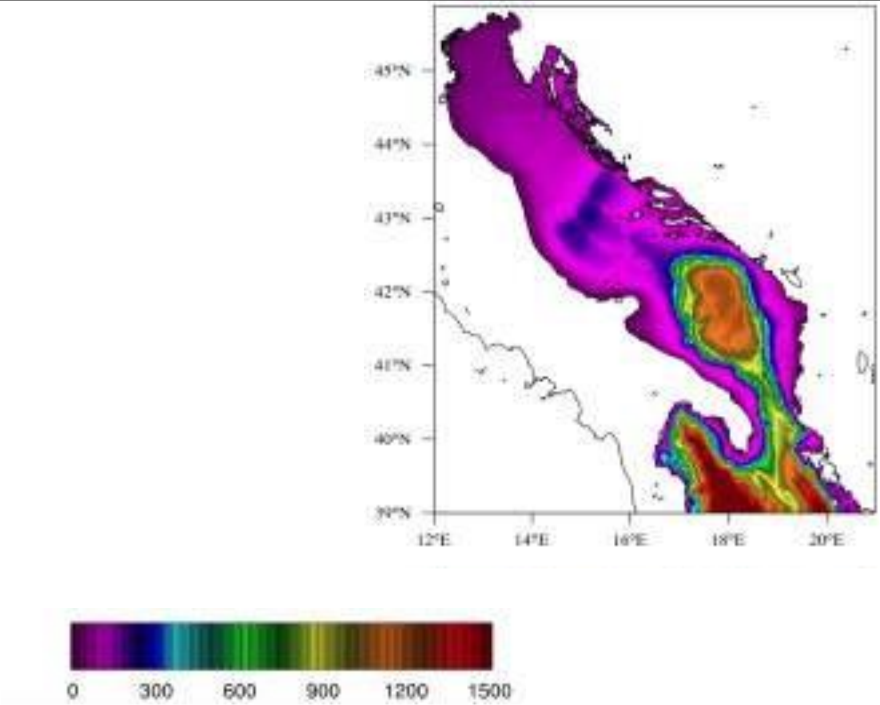


Figure 11: NEMO geographical domain and bathymetry

SURFACE BOUNDARY CONDITION	MFS bulk formulation of the fluxes entering the SBC for temperature. Relative wind velocity enters the momentum SBC. The river saliity and runoff rate enter the SBC for salinity and vertical velocity. River runoff climatologies to be replaced with WRFHydro simulated runoff when working in coupled mode
LATERAL COASTAL BOUNDARY CONDITION	No slip along the coastline.
BOTTOM BOUNDARY CONDITIONS	nonlinear friction
LATERAL OPEN BOUNDARY CONDITIONS	Flather scheme for barotrophic component, Dirichlet scheme for the other fields. 3D temperature, salinity, U and V for baroclinic component obtained from CMEMS Mediterranean Sea model version: MEDSEA_ANALYSIS_FORECAST_PHY_006_013
SIMULATION SET-UP & PERFORMANCE	
ATMOSPHERE AND OCEAN FORCINGS	ECMWF analyses 0.1º res, 25 levels, 4 soil layers, 6hfrequency. MEDSEA_ANALYSIS_FORECAST_PHY_006_013 Temperature, Salinity, Zonal and Meridional currents.
CONCATENATION PROCEDURE	NEMO rebuild tool with weekly restart
CPU TIME	CPU T=1’ 50” for 1day simulation with 24h output frequencyof instantaneous fields using 144 cores

Table 5: NEMO setting up choices for the control run

The release of 62 Adriatic and Ionian rivers in total, 53 flowing into the Adriatic Sea and 9 into the Ionian Sea, has been implemented into Nemo model domain (Figure 12). Model rivers are parameterized as “surface sources” of water at the estuary border grid points while no temperature information is prescribed. The assumption of no temperature differences between river inflow and the marine environment is generally valid as river plumes are controlled by the salinity gradients. The runoff and salinity values are prescribed at river outlets in the vertical velocity and salt flux boundary conditions of the NEMO code.
Some highlights are reported below:

- All river mouths are “point sources” except for 2 of them: Marecchia to Tronto rivers (Tronto excluded) in the Marche region and Vibrata to Fortore rivers (Fortore excluded) in the Abruzzo and Molise regions which are “diffused sources”, i.e. the runoff was split across several grid points
- For all rivers except Po river, monthly climatologies of discharge are considered/computed. The monthly discharges have been interpolated on daily basis according to the Killworth procedure (1996) consisting of the computation of the so called monthly “pseudo values” whose linear interpolation preserves the correct average value.
- The Po river discharge consists of daily averages based on observations recorded at Pontelagoscuro station with 30minute frequency (around 40km

usptream of the delta mouths

- The Po river discharge is unequally subdivided between the nine grid points representing the nine branches of the delta (Po di Goro, Po di Gnocca, Po di Tolle, Po di Bastimento, Po di Scirocco, Po di Bonifazi, Po di Dritta, Po di Tramontana, Po di Maistra) according to percentages in Provini et al. (1992)
- a constant salinity value is prescribed at all river mouths parameterizing the effects of tidal mixing inside the river estuaries. Values chosen are equal to 15 psu for all rivers, except 17 psu for the Po river. These constant salinity values are the result of sensitivity tests performed on the basis of salinity profiles measured at river mouths (Simoncelli et al. 2011) and at the center of the basin (Oddo et al. 2005)

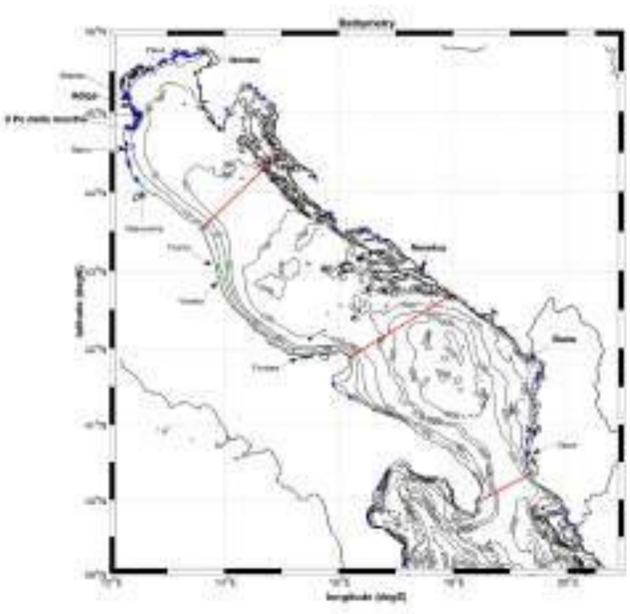


Figure 12: Model domain and details on areas of interest. The *red lines* define the three Adriatic sub-regions and the Otranto channel. *Black isolines* show the bathymetry. *Blue stars* indicate the model river mouths treated as point sources, green stars indicate the model river mouths which border the two diffusive sources

The Appendix A provide the full list of the adopted climatological datasets for rivers flowing into the Nemo domain with the related time window for computing the monthly climatologies. Most of them are taken from Verri et al 2018, except the monthly climatologies of the Adige, Isonzo, Reno, Tronto, Brenta and Piave which come from more recent databases.

The model was integrated for the year 2019. The above-mentioned surface and atmospheric forcing were used with the specified parameters summarized in Table 4.The model results were compared with the available CTD observations in the Adriatic Sea. There are a total 31 stations obtained from the SeaDatanet data server.The model temperature and salinity comparison are given in Figure 13. The upper panel profiles show the temperature and the lower panel profiles show the salinity comparison with model results for selected dates. While the model performs better inthe lower part of the basin, there are still some improvements for the upper part ofthe water column. Considering that there is a very limited number of sensitivity experiments, the results are very promising as an initial step for the circulation model development. The model needs to be advanced in the shallow waters along the eastern coast where the influence of the riverine sources is critical.

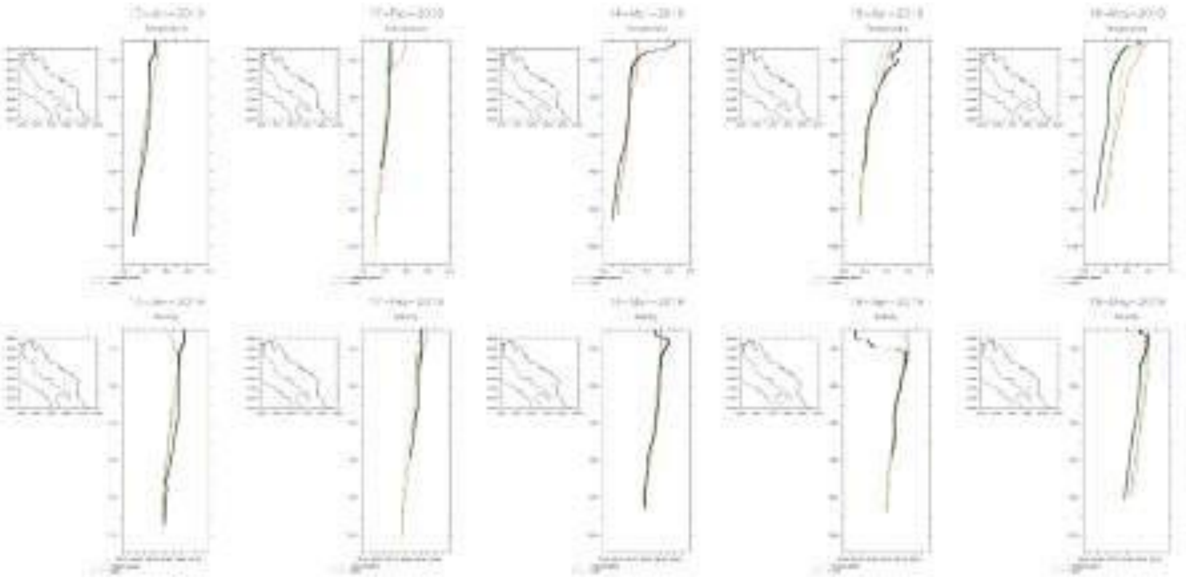


Figure 13: Upper panel: Temperature profiles Lower panel: Salinity profiles for specified dates. The observation is shown by black line, model results for Richardson number dependent vertical diffusion is red line and model results for TKE scheme vertical diffusion is green line.

The model surface currents overlapped on salinity was also shown in Figure 14. The model generated currents are agreeing with the oceanographic features of the region. The model shows different size eddies and jet-like pattern along the coast. The cyclonic circulation over the southern Adriatic is evident in the model results. The low salinity band along the western coast are also successfully represented in the model. It seems that communication of the model with the fields provided at the southern open boundary is working.

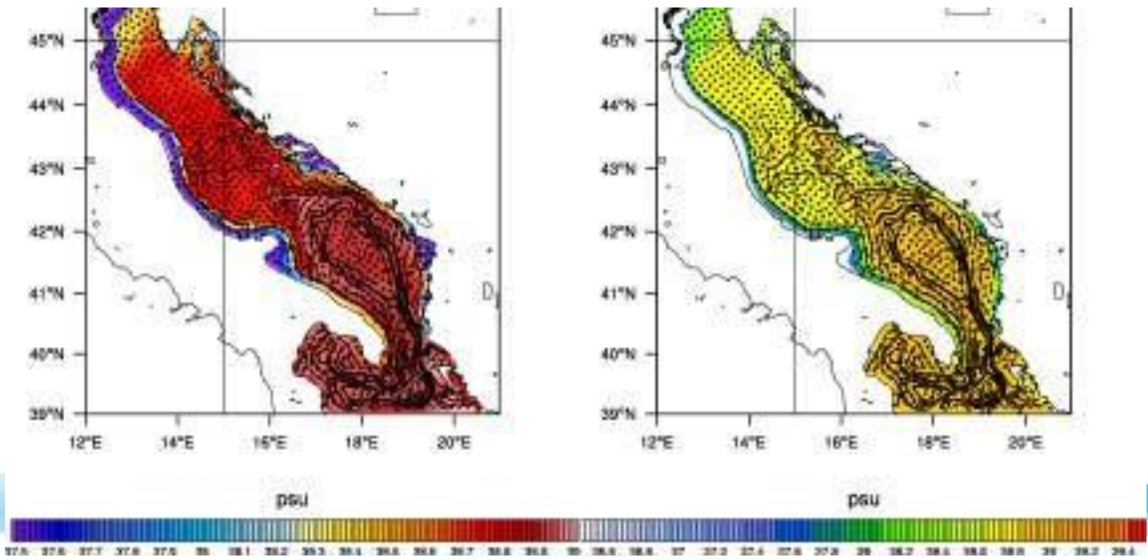


Figure 14. Left: Surface current overlapped on salinity field. Right: current at 60 m overlapped on salinity.

We plan to perform some additional steps to reach the final experimental set-up of the NEMO model. Among them:

- Merge the Emodnet (2020) bathymetry dataset with accurate bathymetry surveying in the coastal areas where available
- River release upgrades: we will try to (i) replace the partitioning of the Pontelagoscuro runoff among the Po river branches based on Provini (1992) with more updated and reliable percentages if available; (ii) replace the selected monthly climatologies of the main Croatian and Italian rivers (Appendix A) with more reliable ones if available
- Sensitivity on the NEMO numerical schemes and parameterizations

For what regards enhancing the bathymetry accuracy in coastal areas, Arpae Emilia-Romagna will make available an accurate topography and bathymetry surveying covering the entire Emilia-Romagna littoral.
The most recent survey was carried out in 2018 in the context of the nourishment project of the regional coasts performed by the Emilia-Romagna Region. The monitoring activities involved the entire regional coast, from Cattolica to the Po di Goro mouth.
The relief was carried out on cross-shore and along-shore beach transects by covering more than 1000 km of beach. The topography surveying covered the entire area of the emerging beach until the last point towards the land and was carried out by means of a centimetre rod and GPS. The bathymetry surveying extended up to the bathymetric depth of 8-10 m and was carried out by means of a multibeam Eco sounder placed on board a boat (dual frequency satellite receivers GNSS). The geodetic framework of the survey was performed with reference to the ETRS89-ETRF200 reference system by using the novel Coastal Geodetic Network realized in the 2016-2017.

2.4 The wave modelling component

A regional configuration of the third-generation spectral wave model WaveWatch III (hereafter WWIII) version 3.14 has been implemented over the Adriatic Sea, covering the same domain of the ocean model described in the previous section. WWIII and NEMO models Adriatic Sea implementation share also the same bathymetry (Figure 11), land sea mask and horizontal grid resolution.
WWIII implementation considers a spectral discretization of 30 frequency bins ranging from 0.05Hz (corresponding to a period of 20s) to 0.79Hz (corresponding to a period of about 1.25s) and 24 equally distributed directional bins (15° directional increment), a time step of 180 seconds and closed boundaries in the South Adriatic Sea.
In our application WWIII has been implemented following WAM Cycle4 model physics (Gunther et al. 1993). Wind input and dissipation terms are based on Janssen's quasi-linear theory of wind-wave generation (Janssen 1989, 1991): the surface waves extract momentum from the air flow and therefore the stress in the surface layer depends both on the wind speed and the wave-induced stress.

The dissipation source term was based on Hasselmann's (1974) white-capping theory according to Komen et al. (1984). The non-linear wave-wave interaction was modelled using the Discrete Interaction Approximation (DIA, Hasselmann et al. 1985).

SPATIAL DISCRETIZATION	
VERTICAL DISCRETIZATION	N.A.
HORIZONTAL DISCRETIZATION	432 x 331 grid points, [12 to 20.98 ºE 30.0 to 45.88 ºN], around 2.2 km resolution
SPECTRAL DISCRETIZATION	30 frequency bins ranging from 0.05Hz to 0.79Hz and 24 equally distributed directional bins
GEOGRAPHICAL CONFIGURATION	
MAP PROJECTION	regular spherical coordinates
BATHYMETRY DATA	EMODNET, 3.75 arcsec.
PHYSICAL CHOICES	
Model Physics	WAM Cycle4 (Gunther et al. 1993)
Wind input and dissipation terms	Janssen’s quasi-linear theory of wind-wavegeneration (Janssen 1989, 1991)
Dissipation source term	Based on Hasselmann's (1974) white-capping theory according to Komen et al. (1984)
Non-linear wave-wave interaction	Discrete Interaction Approximation (DIA,Hasselmann et al. 1985)
INITIAL AND BOUNDARY CONDITIONS	
INITIAL CONDITIONS	None
SURFACE BOUNDARY CONDITION	N.A.
BOTTOM BOUNDARY CONDITIONS	N.A.
LATERAL OPEN BOUNDARY CONDITIONS	Closed
SIMULATION SET-UP & PERFORMANCE	
ATMOSPHERE FORCING	ECMWF analyses 0.1º res, 25 levels, 4 soil layers, 6h frequency.
CONCATENATION PROCEDURE	Daily jobs
CPU TIME	CPU time = 2min for 1day simulation (using 180 sec timestep) with daily outputs of instantaneous hourly fields

Table 6: WWIII setting up choices for the control run

A control experiment has been run in order to test the WWIII standalone implementation in the Adriatic Sea. The experiment has been run for 2 years in 2019and 2020, no initial conditions have been provided, so a 10 days spin-up period should be considered. The wind forcing has been provided by means of

ECMWF 6-hours analysis fields at 0.1º horizontal resolution and closed lateral boundaries have been considered for the actual implementation. More details on the model configuration can be found in Table 6.

The model results have been compared to mono-mission satellite-based along-track significant wave height observations CMEM product WAVE_GLO_WAV_L3_SWH_NRT_OBSERVATIONS_014_001 in terms of hourlysignificant wave height. The observational datasets include the following satellites: AltiKa, CFOSAT, Cryosat-2, HY-2B, Jason-3, Sentinel-3A and Sentinel-3B. Since observations are available only starting from July 2019, the first 6 months of the simulation are not included in the present validation.

Figure 15 shows a scatter plot of significant wave height, model versus observations,for the period July 2019 to December 2020 and main validation statistics. It is evidentthat the model is underestimating the significant wave height with a negative bias

~=-0.26 m, Root Mean Square Error ~=0.35m; Scatter Index ~=0.2.

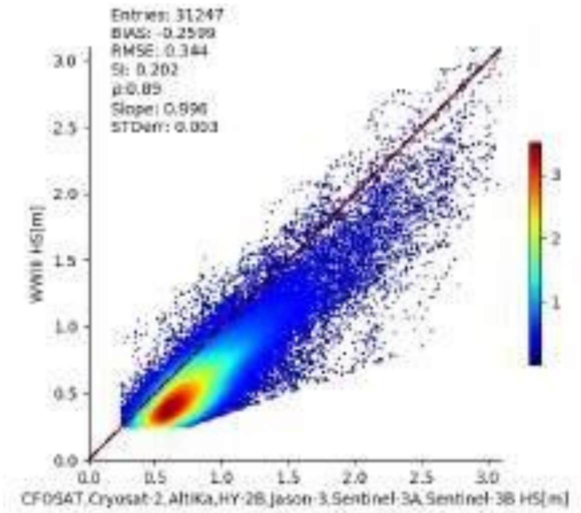


Figure 15: Scatter plot of significant wave height Hs [m], model versus observations, colours represent the probability density. Statistics derived from this validation are reported in the figure.

In addition to the control run, two experiments have been carried out in order to improve the model solution: one experiment reducing the model time step from 180 to 60 seconds and one experiment enlarging the directional frequency bins from 24 to 36. Since both experiments did not provide improved results with respect to the initial control run, next steps would be devoted to check and improve the model implementation in order to better represent the significant wave height in particular toreduce the overall negative model bias.

Further steps would be to include the wave model in the full coupled system and compare the results of the coupled with the un-coupled model.

The marine biogeochemical modelling component

The numerical biogeochemical model will be coupled offline to the regional NEMO implementation over the Adriatic Sea and with the circulation model in the PS3

(Emilia Romagna coastal area) Pilot Area. The model derives from the perlagic

Biogeochemical Fluxes Model, so-called BFM (Vichi, Pinardi and Masina, 2007) with the addition of a bethic return component more recently added (Vichi M., Lovato T., Butenschön M., Tedesco L., Lazzari P., Cossarini G., Masina S.,Pinardi N., Solidoro C., Zavatarelli M. (2020). The Biogeochemical Flux Model (BFM):Equation Description and User Manual. BFM version 5.2. BFM Report series N. 1, Release1.2, June 2020, Bologna, Italy, http://bfm-community.eu, pp. 104).
BFM is a biomass and functional group based marine ecosystem model, representing, in Eulerian coordinate, the pelagic (water column) lower trophic levels marine biogeochemical system by a selection of chemical and biological processes that simulates the pelagic (water column) dynamics in the marine ecosystem.
The carbon, nitrogen, phosphorus and silicon biogeochemical cycles are solved independently over a variety of living and non-living functional groups (phytoplankton, micro- and mesozooplankton, bacteria, particulate and dissolved organic matter, inorganic nutrients). The model has been recently updated with a benthic module describing the Biogeochemical processes associated with the dynamics of benthic fauna and bacteria.

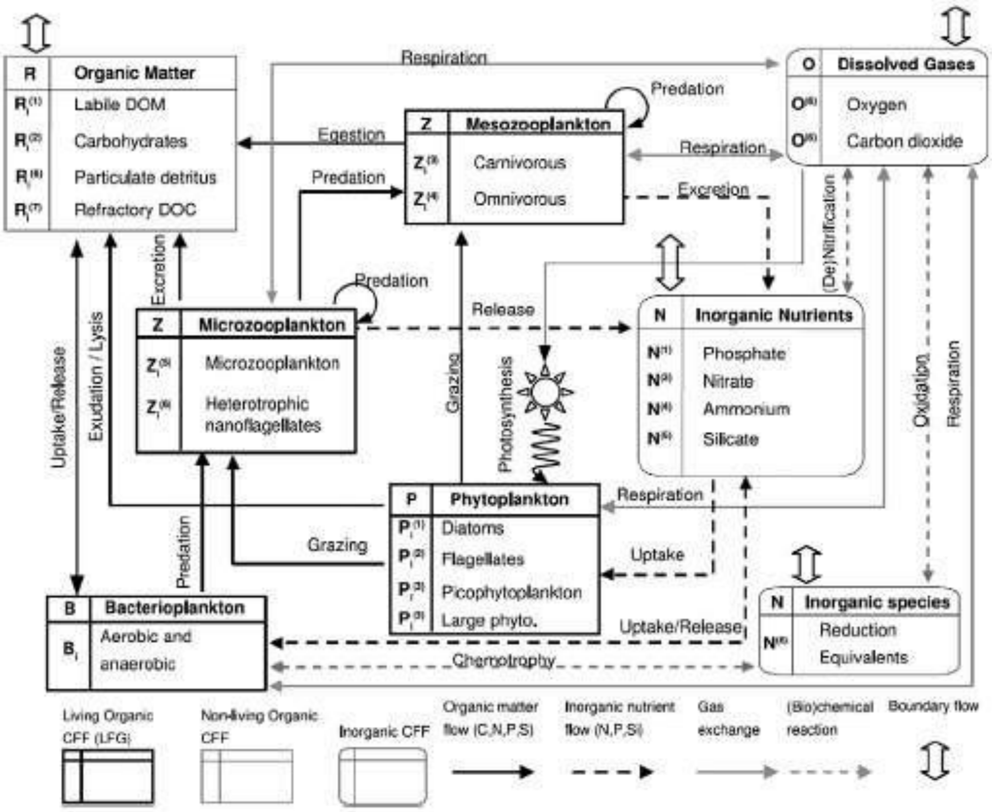


Figure 16: General overview of the matter fluxes among the BFM state variables. Square boxes represent the model functional groups exchanging Carbon (C), Nitrogen (N), Phosphorus (P), Silicon (Si) and Oxygen (O). Organic matter (C, N, P, Si) flows are indicated by solid black arrows. N, P and Si nutrient uptake/remineralisation flows are indicated by the dashed black arrows. Solid grey arrows mark the gas C (carbon dioxide) and O flows. Purely biochemical processes

are indicated by the dashed grey arrows. Small double arrows above the boxes mark boundary (water-atmosphere and water-sediment) flows

The complete pelagic model consists of about 56 variables and it can be coupled offline or online to the NEMO model. Being AdriaCLIM modelling dedicated to climate downscaling, we will try the offline coupling first, with a subsampling of the current and temperature fields from NEMO by an approximate factor of 2. The major problem will be the specification of the lateral boundary conditions which will be taken from the CMEMS reanalysis or analyses for the standalone run, before coupling with the atmosphere and land runoff from WRF and WRF-HYDRO.
The benthic component of BFM is an 11 equation benthic return or closure model component that recycles the organic matter by benthic degradation. This is a key issue in the northern Adriatic where dissolbved nutrient maxima are found near the bottom due to the benthic regeneration processes.

SPATIAL DISCRETIZATION of pelagic and benthic components	
VERTICAL DISCRETIZATION	Pelagic:120 unevenly spaced z-levels (partial steps, 0.5 m to 2831.61m) Benthic: 1 layer
HORIZONTAL DISCRETIZATION	215 x 170 grid points at the approx. resolution of 4.4 km(approximately one every two points of the NEMO grid)
GEOGRAPHICAL CONFIGURATION	
MAP PROJECTION	*The same of NEMO model, i.e. regular spherical coordinates*
BATHYMETRY	Same as NEMO
PHYSICAL PARAMETERIZATIONS	
Horizontal diffusivity	Laplacian, proportional to NEMO values
Vertical diffusivity	From the NEMO model, saved hourly
INITIAL AND BOUNDARY CONDITIONS	
INITIAL CONDITIONS	From NEMO run and CMEMS reanalyses
TOP BOUNDARY CONDITION	Surface shortwave radiative flux from NEMO, gas transfer bulkformulas
BOTTOM BOUNDARY CONDITIONS	Parametrized fluxes with the benthic compartment
LATERAL BOUNDARY CONDITIONS	Flux Relaxation LBC for all the biogeochemical variablesRiver biochemical fluxes from historical data bases
LAND LATERAL FLUXES	
RUNOFF	WRF-Hydro simulation

LOADING	Develop the runoff-loading relationship for Adriatic rivers
SIMULATION SET-UP & PERFORMANCE	
CONCATENATION PROCEDURE	none
CPU TIME	Still to be determined

Table 7: WWIII setting up choices for the control run

3. *The design of the dynamical downscaling for the marine pilot areas*

The Climate Change Monitoring System conceived by AdriaClim WP3 project identifies 9 coastal pilot sites (shown in Figure 17) aiming to:

(i) provide valuable insights on the past, present and future physical and biogeochemical state of the sea at coastal scales;
(ii) assess climate change indicators for the Adriatic coastal pilots
(iii) estimate the climate change impacts on meteo-hydro-marine extreme events and prevent their long term consequences with site-specific adaptations plans.

High resolution finite-difference and finite-element thermo-hydrodynamics models will be set up over the marine pilot areas. An innovative dynamical downscaling method which may reach very high spatial detail in a seamless way has been conceived for six of the AdriaClim pilot sites (i.e. PS1, PS2, PS3, PS4, PS5 and PS6 in Fig.17) with a two-step strategy. First the coastal thermo-hydrodynamics modelingwill be dynamically downscaled from consolidated and reliable regional climate models in the framework on the MEDCORDEX ensemble, in particular we consider the LMDZNEMOMED RCM (L'Heveder et al 2013) already detailed in Section2 and the CMCC COSMO_CLM–NEMO_MFS RCM (Cavicchia et al 2015) which reaches even higher resolution with respect to the previous one. As a second step, the addedvalue of using the output fields of the AdriaClim Regional Earth System as climate forcings will be evaluated by comparison with the CMCC RCM fields used in the first step.
The planning of the dynamical downscaling approaches and the underway modellingactivities for each pilot site are described in the following sub-sections.
Most of the proposed dynamical downscaling approaches will be based on the the SHYFEM finite element thermo-hydrodynamic model (Umgiesser et al., 2014). The open-source model SHYFEM is freely available on the web pages http://www.ismar.cnr.it/shyfem and https://github.com/SHYFEM-model. The horizontal discretization of the state variables is carried out with the finite element method, with the subdivision of the numerical domain in triangles varying in form andsize. Such a method has the advantage of representing in detail complicated bathymetry and irregular boundaries in coastal areas. Thus, it can solve the combined large-scale oceanic and small-scale coastal dynamics in the same discrete domain by using unstructured meshes.

Figure 17: The marine pilot sites in the Adriatic basin

The pilot site of Emilia-Romagna coastal area

The Emilia-Romagna pilot site (ER-PS, indicated as PS3 in Fig.17) extends approximately between 12.2° and 13.5° of longitude and 43.9° and 45.3° of latitude. The model has been previously developed in a PhD Thesis for storm surge and NBS solutions (Alessandri, 2020) and the area of application is shown in Fig. 18.
The domain is characterized by a gently sloping bathymetry, with a maximum depth of about 54 m at the eastern corner. Frequently, the winds are very strong and they trigger storm surge events along the entire coastal area with high risk for population and huge economic losses. The high river discharge, due to the presence of the Po (the main freshwater source in the Adriatic Sea) and other minor rivers, influence thedynamics of this coastal pilot area. Moreover, the nutrient rich discharge of the Po river can trigger, especially during Summer, eutrophication processes (mostly in Po delta system lagoons) with consequent anoxic and/or hypoxic conditions, with deadlyconsequences for the local biomass and economic losses for fishers and mussels/clams farmers.
The need to study the evolution of the hazards threatening the entire ER coastal area justify the use of a coupled dynamic model downscaling approach to study the past, present and future state of the coupled physical and biochemical model in the ER-PS. The unstructured grid hydrodynamic model Shyfem for the entire ER domain will be coupled with the BFM model (Vichi, Pinardi and Masina, 2007) already described for the entire Adriatic Sea. Once the BFM model is coupled with Shyfem, biogeochemical observations analyzed during the AdriaClim project will be used to calibrate and validate the coupled system.
At an initial stage, the system will be forced with ECMWF and the regional model fields for the year 2019. Once data from the AdriaClim regional climate coupled model will be available, the Shyfem-BFM coupled system will be forced with these higher resolution data to assess the added value of the downscaling approach.

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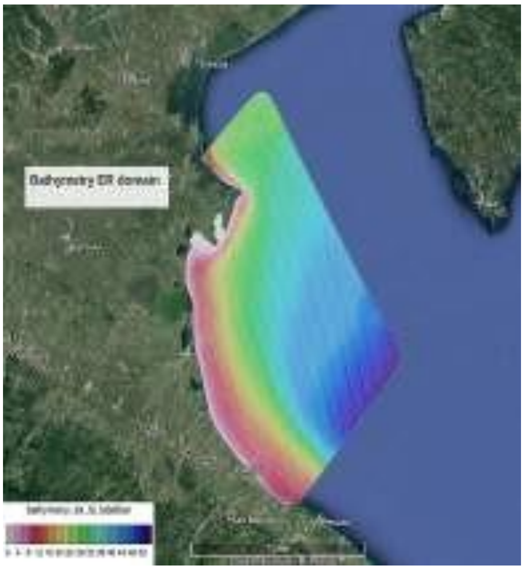

Figure 18: domain and bathymetry of the Emilia-Romagna pilot site.

The pilot site of Marano-Grado Lagoon and Friuli Venezia Giulia coastal area

Dynamic downscaling in the Friuli Venezia Giulia coastal area will be performed with the SHYFEM finite element hydrodynamic model.
The model has been already applied to simulate hydrodynamics in the Mediterranean Sea (Ferrarin et al., 2018), in the Adriatic Sea (Bellafiore et al., 2018), and in several coastal systems (see Umgiesser et al., 2014 and references therein). The good performance of the SHYFEM model in simulating water levels, currents, salinity, and water temperature in the Marano-Grado lagoon and the FVG coast was demonstrated by Ferrarin et al. (2010, 2016).
The numerical computation is performed on a spatial domain that represents part of the northern Adriatic Sea and the lagoon of Marano-Grado by means of the unstructured grid shown in Figure 19. To adequately resolve the river-sea continuum,the unstructured grid also includes the lower part of the other major rivers flowing into the considered system. The use of elements of variable sizes, typical of finite element methods, is fully exploited, in order to suit the complicated geometry of the basin, the rapidly varying topographic features, and the complex bathymetry of the lagoon systems. The numerical grid consists of 33,100 triangular elements with a resolution that varies from 4 km in the open-sea to a few hundred meters along the coast and tens of meters in the inner lagoon channels. The bathymetry of the northern Adriatic Sea and the Marano-Grado lagoon was obtained by merging several datasets, having different spatial resolution and obtained using different measurement approaches.
The boundary conditions for stress terms (wind stress and bottom drag) follow the classic quadratic parameterization. Heat fluxes are computed at the water surface. Water fluxes between air and sea consist of the precipitation and runoff minus evaporation computed by the SHYFEM model. Smagorinsky's formulation (1963) is used to parameterize the horizontal eddy viscosity. For the computation of the

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vertical viscosities, a turbulence closure scheme was used. This scheme is adapted from the k-ε module of GOTM (General Ocean Turbulence Model) described by Burchard and Petersen (1999).
The model will be forced by boundary and surface conditions obtained by the AdriaClim Regional Earth System and other available databases.

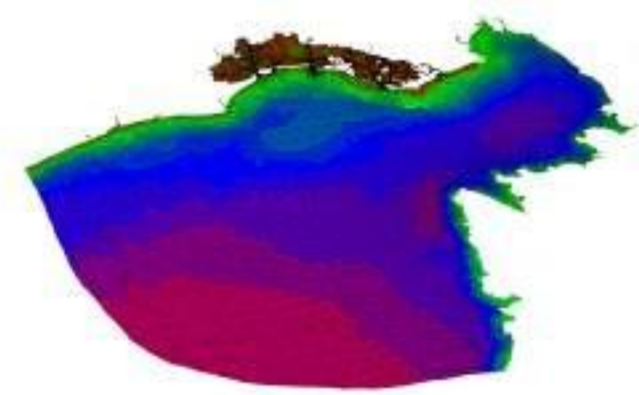
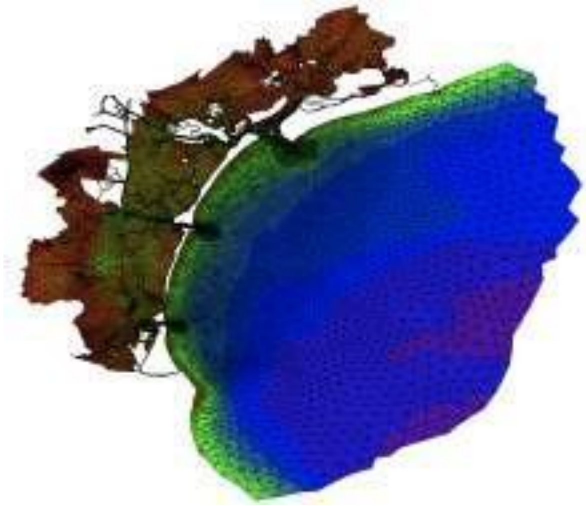


Figure 19: Unstructured grid of the SHYFEM model application to the FVG pilot site.

The pilot site of Venice lagoon and Veneto coastal area

Dynamic downscaling in the Venice Lagoon and Veneto coastal area will be performed with the SHYFEM finite element hydrodynamic model.
The model has been already applied to simulate hydrodynamics in the Mediterranean Sea (Ferrarin et al., 2018), in the Adriatic Sea (Bellafiore et al., 2018), and in several coastal systems (see Umgiesser et al., 2014 and references therein). The good performance of the SHYFEM model in simulating water levels, currents, salinity, and water temperature in the Venice Lagoon was demonstrated by Umgiesser et al. (2004) and Ferrarin et al. (2010, 2013, 2021).
The water circulation in the Venice Lagoon, induced by tide, wind, and water, heat and salt fluxes, was simulated by the unstructured model SHYFEM applied over a spatial domain that represents the entire Lagoon and its adjacent shore. The model adequately reproduces the complex geometry and bathymetry of the Venice Lagoon using unstructured numerical meshes composed of triangular elements of variable form and size, going down to a few meters in the channels (Figure 20). The bathymetry was obtained by merging several datasets, having different spatial resolution and obtained using different measurement approaches (Madricardo et al., 2017).
The boundary conditions for stress terms (wind stress and bottom drag) follow the classic quadratic parameterization. Heat fluxes are computed at the water surface. Water fluxes between air and sea consist of the precipitation and runoff minus evaporation computed by the SHYFEM model. Smagorinsky's formulation (1963) is used to parameterize the horizontal eddy viscosity. For the computation of the vertical viscosities, a turbulence closure scheme was used. This scheme is adapte from the k-ε module of GOTM (General Ocean Turbulence Model) described by Burchard and Petersen (1999).

The model will be forced by boundary and surface conditions obtained by the



AdriaClim Regional Earth System and other available databases.
Figure 20: Unstructured grid of the SHYFEM model application to the pilot site of the Venice Lagoon and the Veneto coastal area.

The pilot site of Apulia coastal area

For the Apulia pilot, a modelling system based on the SHYFEM model will be used. The unstructured grid is Arakawa B with triangular meshes (Bellafiore and Umgiesser, 2010; Ferrarin et al., 2013), which provides an accurate description of irregular coastal boundaries. The peculiarity of unstructured meshes is the ability of representing several scales in a seamless fashion, reaching higher resolution where necessary.
Starting from the experience of the implementation of SHYFEM in operational short-term forecasting for the entire Apulia region (SANIFS, Southern Adriatic Northern Ionian coastal Forecasting System, Federico et al., 2017, http://sanifs.cmcc.it/; Figure 21 shows the spatial domain and bathymetry), CMCC will apply similar methodology and extend the capabilities for climate simulations.
The Apulia coastal area includes climate change hotspots which will be investigated with the climate downscaling approach: (i) the estuary of the Ofanto river and itsshelf sea and (ii) the marine protected area of Torre Guaceto. The Apulia harbours will be also considered as critical areas for evaluating the climate change impacts.
The modelling systems will be three-dimensionally downscaled from consolidated and reliable regional/global climate ensembles, e.g. EURO-CORDEX and CMPI6 datasets. The atmospheric variables required to compute the forcing at the air-sea interface are 2 m air temperature (T2M), 2 m dew point temperature (D2M), total cloud cover (TCC), mean sea level atmospheric pressure (MSL), and meridional and zonal 10 m wind components (U10M and V10M) and total precipitation (TP).
The ocean variables to be provided at the lateral open boundaries are the sea surface height, 3D temperature and salinity, and 3D total velocities.

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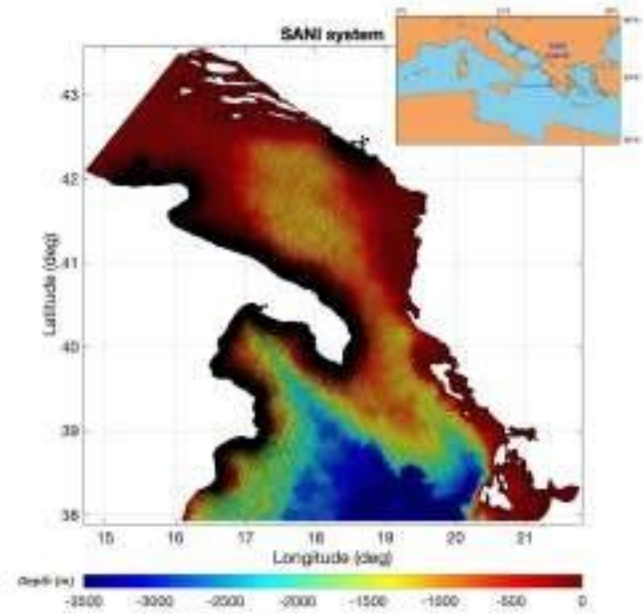

Figure 21: Horizontal grid with bathymetry overlapped of the SANIFS modelling system

The pilot site of Split-Dalmatia coastal area

Implementation of high resolution modelling system for the Split-Dalmatia coastal area is underway. System consists of hydrodynamic (ROMS), dispersion and ecological (BFM) modules and will be used, together with in situ and laboratory experiments, to study structural and functional features of the microbial food web (MFB) and occurrences of the harmful algal blooms in the Kaštela Bay.
Physical conditions in the Split-Dalmatia coastal area have been modelled with ROMS (Regional Ocean Modeling System, www.myroms.org), while dispersion model for the same area is based on Ichtyop (Lett et al., 2008). Model domain covers the middle Adriatic coastal area with horizontal resolution of 165 m in the E-Wdirection and 231.5 m in the N-S direction (Figure 22). Complex bathymetry with depths of up to 60 m in the channel area between Island of Brač and the mainland and depths of over 100 m in the southwestern part of the domain significantly affects the flow. The experimental configuration chosen to perform a control run over year 2019 is given in Table 8. ASHELF-2 ROMS model (Figure 23) is implemented to provide lateral boundary conditions for high-resolution ROMS model. Horizontal scalar fields with resolution of 8 km (air pressure, air temperature, relative humidity, cloudiness, precipitation and shortwave radiation) and vector fields with resolution of
2 km (wind) from operational ALADIN model (Tudor et al. 2013; Termonia et al., 2018) are used to force both ROMS models together with tides, river inflows and water mass exchange at the open boundaries.

SPATIAL DISCRETIZATION	
VERTICAL DISCRETIZATI	21 unequally spaced s-levels

ON	
HORIZONTAL DISCRETIZATION	475 x 121 grid points, dx=163.25 m, dy=231
GEOGRAPHICAL CONFIGURATION	
MAP PROJECTION	regular spherical coordinates
BATHYMETRY DATA	DART bathymetry (Rixen et al., 2006), 7.5 arcsec.
PHYSICAL CHOICES	
lateral diffusion for tracers	Harmonic horizontal diffusion Harmonic mixing coefficient = 0.05 m^2/s
lateral viscosity on momentum	Harmonic horizontal viscosity Harmonic mixing coefficient = 0.5 m^2/s
Vertical mixing	GLS mixing (Umlauf and Burchard, 2003)
advection scheme for tracer	MPDATA (Smolarkiewicz and Margolin, 1998)
INITIAL AND BOUNDARY CONDITIONS	
INITIAL CONDITIONS	Temperatrure and salinity are interpolated from ASHELF-2fields.
SURFACE BOUNDARY CONDITION	Fairall et al. (1996)
LATERAL COASTALBOUNDARY CONDITION	No slip
BOTTOM BOUNDARY CONDITIONS	nonlinear friction
LATERAL OPEN BOUNDARY CONDITIONS	Nudging for 3D T, S and baroclinic U, V components usingASHELF-2 fields Free-surface – Chapman (1985) Barotrophic U,V component – Flather (1976)
SIMULATION SET-UP & PERFORMANCE	
ATMOSPHERE AND OCEAN FORCINGS	ALADIN-HR (Tudor et al., 2013; Termonia et al., 2018)

Table 8: ROMS setting up choices for the control run in Split-Dalmatia costal area(PS6).

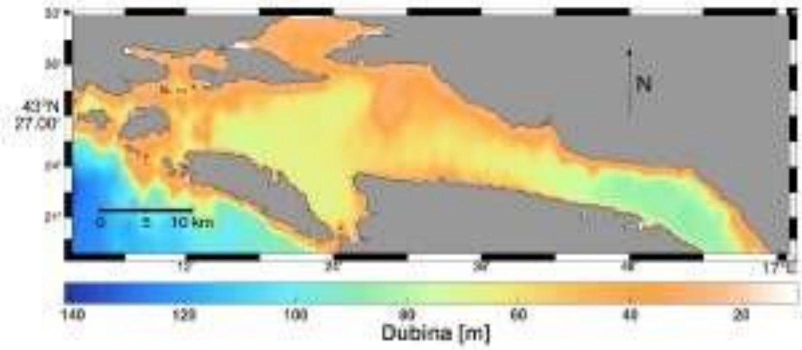

Figure 22. Bathymetry in high-resolution middle Adriatic coastal domain.

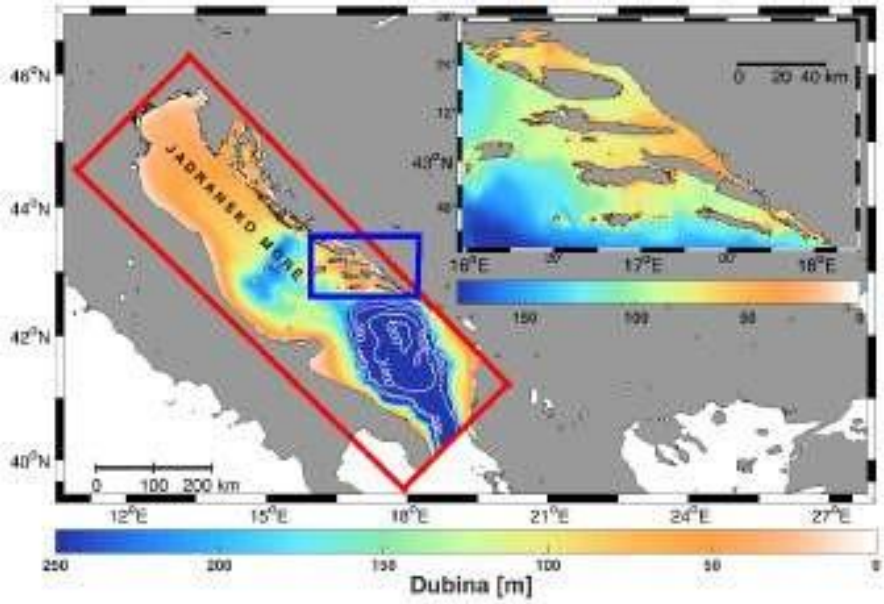

Figure 23. The Adriatic Sea bathymetry with denoted Adriatic model domain (red rectangle) and ASHELF-2 domain (blue rectangle). ASHELF-2 bathymetry is shown in detail in the upper right corner.

Results of several test simulations with the ROMS and Ichthyop model in the ASHELF-2 domain for the year 2019 are shown in Figs. 24 and 25.

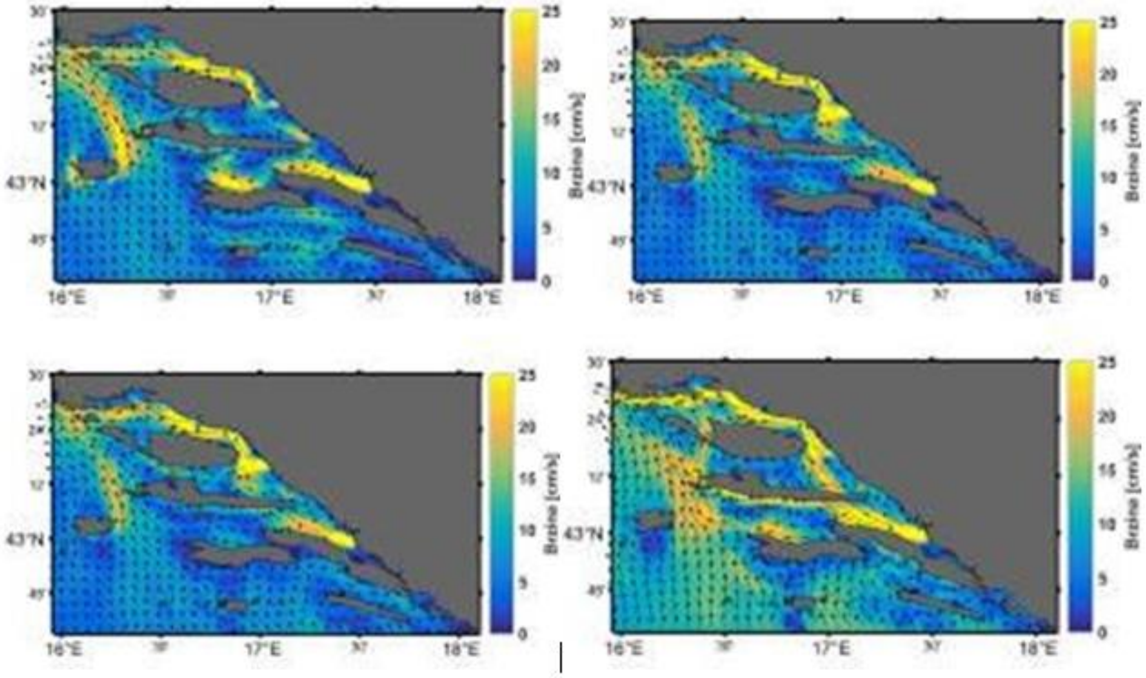
16°E
17°E
18°E
43°N
Brzina [cm/s]
0
5
10
15
20
25

Figure 24. Surface currents modelled in the ASHELF-2 domain for April, May, October and November 2019.

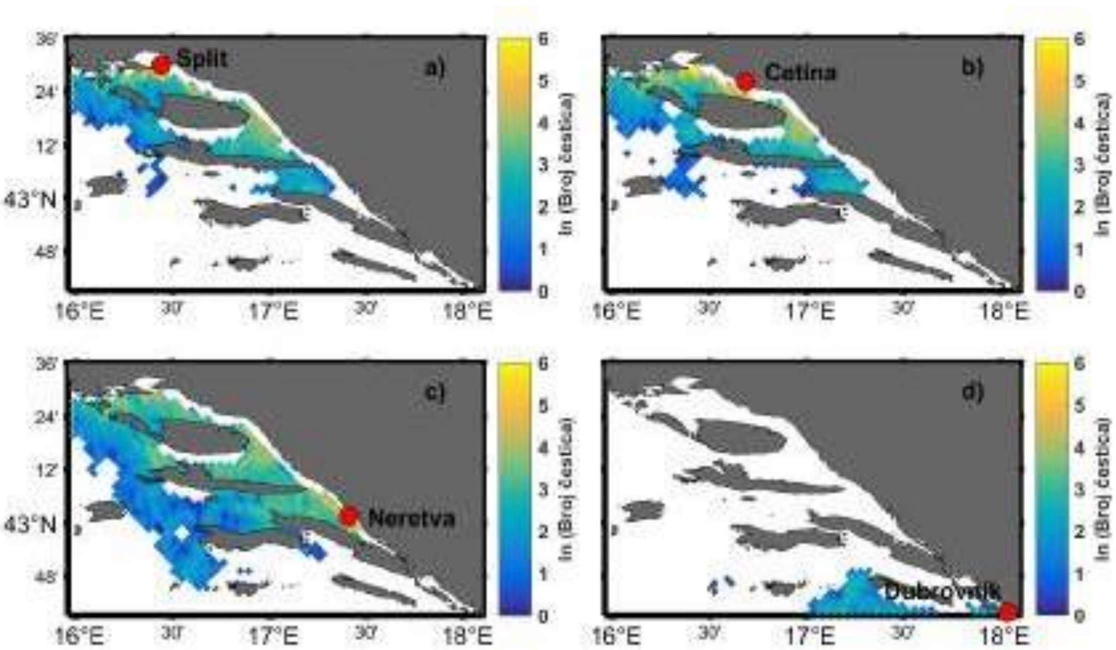

Figure 25. Spatial distribution of the passive particles released on 1st April 2019. fromlocation of Split, Dubrovnik and river mouths of Cetina and Neretva after 30 days of spreading.

The pilot site of Dubrovnik-Neretva coastal area

Implemented modelling system will be used, together with conducted in situ measurements, to study salt wedge intrusions in the Neretva River estuary. Physical conditions in the area will be modelled with ROMS (Regional Ocean Modeling System, www.myroms.org), while Dispersion of passive particles is based on Ichtyop (Lett et al., 2008). The experimental configuration chosen to perform a control run over the year 2019 is given in Table 7.

SPATIAL DISCRETIZATION	
VERTICAL DISCRETIZATION	21 unequally spaced s-levels
HORIZONTAL DISCRETIZATION	253 x 170 grid points, dx=dy=200 m
GEOGRAPHICAL CONFIGURATION	
MAP PROJECTION	regular spherical coordinates
BATHYMETRY DATA	DART bathymetry (Rixen et al., 2006), 7.5 arcsec.
PHYSICAL CHOICES	
lateral diffusion for tracers	Harmonic horizontal diffusion, Harmonic mixing coefficient = 0.05 m2/s
lateral viscosity on momentum	Harmonic horizontal viscosity Harmonic mixing coefficient = 0.5 m2/s
Vertical mixing	GLS mixing
advection scheme for tracer	MPDATA (Smolarkiewicz and Margolin, 1998)
INITIAL AND BOUNDARY CONDITIONS	
INITIAL CONDITIONS	Temperatrure and salinity are interpolated from ASHELF-2fields.
SURFACE BOUNDARY CONDITION	Fairall et al. (1996)
LATERAL COASTALBOUNDARY CONDITION	No slip
BOTTOM BOUNDARY CONDITIONS	nonlinear friction
LATERAL OPEN BOUNDARY CONDITIONS	Nudging for 3D T, S and baroclinic U, V components withASHELF-2 fielfd Free-surface – Chapman (1985) Barotrophic U,V component – Flather (1976)
SIMULATION SET-UP & PERFORMANCE	

ATMOSPHERE AND OCEAN FORCINGS	ALADIN-HR (Tudor et al., 2013; Termonia et al., 2018

Table 7. ROMS setting up choices for the control run in Dubrovnik-Neretva costal area (PS5).

Appendix A

River	Dataset	ReferencePeriod	DischargeBasin	Mean Annual Discharge(m^3s^{-1})
Thyamis (Greece)	GRDC	*1963-1978*	Ionian Sea	51.39
Vjiose (Albania)	Albanian Hydrometeorological Institute	*1948-1987*	Adriatic Sea	189
Seman (Albania)	Albanian Hydrometeorological Institute	*1948-1987*	Adriatic Sea	86
Shkumbi (Albania)	Albanian Hydrometeorological Institute	*1948-1991*	Adriatic Sea	58.7
Erzen (Albania)	Albanian Hydrometeorological Institute	*1949-1992*	Adriatic Sea	16.9
Ishm (Albania)	Albanian Hydrometeorological Institute	*1968-1992*	Adriatic Sea	19.8
Mat (Albania)	Albanian Hydrometeorological Institute	*1951-1986*	Adriatic Sea	87.4
Buna/Bojana(Albania-Montenegro)	Albanian Hydrometeorological Institute	*1965-1985*	Adriatic Sea	675
Bistrica (Albania)	Albanian Hydrometeorological Institute	*1949-1987*	Ionian Sea	32.1
Pavla (Albania)	Albanian Hydrometeorological Institute	*1951-1991*	Ionian Sea	6.69
Neretva (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	366.86
Ombla (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	27
Cetina (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	88.28
Zrnovnica (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	1.76
Jadro (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	7.18
Krka (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	56.51
Zrmanja (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	40.10
Dubracina (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	4.14

Rjecina (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	7.22
Rasa (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	1.58
Mirna (Croatia)	Pasaric et al (2004)	*1947-2000*	Adriatic Sea	7.91
Isonzo (Italy)	CNR ISMAR	*2000-2008*	Adriatic Sea	53,73
Bocca di Primero (Italy)	ARPA VENETO		Adriatic Sea	10.28
La Fosa (Italy)	ARPA VENETO		Adriatic Sea	10.28
Canale di Morgo (Italy)	ARPA VENETO		Adriatic Sea	10.28
Pto Buso (Italy)	ARPA VENETO		Adriatic Sea	10.28
Zellina (Italy)	ARPA VENETO		Adriatic Sea	10.28
Pto Lignano (Italy)	ARPA VENETO		Adriatic Sea	10.28
Tagliamento (Italy)	ARPA VENETO		Adriatic Sea	96.92
Sile (Italy)	ARPA VENETO		Adriatic Sea	52.92
Canale Nicessolo (Italy)	ARPA VENETO		Adriatic Sea	22.7
Canale dei Lovi (Italy)	ARPA VENETO		Adriatic Sea	22.7
Livenza (Italy)	ARPA VENETO		Adriatic Sea	88.33
Piave (Italy)	CNR ISMAR	2004- 2008	Adriatic Sea	25.72
Pto di Lido (Italy)	ARPA VENETO		Adriatic Sea	17.27
Pto di Malamocco (Italy)	ARPA VENETO		Adriatic Sea	17.27
Pto di Chioggia (Italy)	ARPA VENETO		Adriatic Sea	17.27
Brenta (Italy)	CNR ISMAR	2004- 2015	Adriatic Sea	67.14
Adige (Italy)	CNR ISMAR	*1916- 2015*	Adriatic Sea	217.54
Po di Levante (Italy)	ARPA EMR		Adriatic Sea	21.67
Po di Volano (Italy)	ARPA EMR		Adriatic Sea	6
Reno (Italy)	CNR ISMAR	*1997- 2004*	Adriatic Sea	20,84
Lamone (Italy)	ARPA EMR		Adriatic Sea	12.06
Fiumi Uniti (Italy)	ARPA EMR		Adriatic Sea	12.06
Bevano (Italy)	ARPA EMR		Adriatic Sea	6
Savio (Italy)	ARPA EMR		Adriatic Sea	12.06
Rubicone (Italy)	ARPA EMR		Adriatic Sea	6
Uso (Italy)	ARPA EMR		Adriatic Sea	6
Marecchia to Tronto, Tronto excluded (Italy)	Raicich (1996)	*1956-1965*	Adriatic Sea	121.92
Tronto (Italy)	CNR ISMAR	*2005- 2009*	Adriatic Sea	10,90
Vibrata to Fortore +Pescara+Sangro +Trigno+Biferno (Italy)	Raicich (1996)	*1956-1965*	Adriatic Sea	190
Fortore (Italy)	Raicich (1996)	*n.r.*	Adriatic Sea	12.25
Cervaro (Italy)	Raicich (1996)	*n.r.*	Adriatic Sea	2.92
Ofanto (Italy)	Raicich (1996)	*n.r.*	Adriatic Sea	14.92
Bradano (Italy)	CNR IRPI	*1929-1971*	Ionian Sea	5.85
Basento (Italy)	CNR IRPI	*1933-1971*	Ionian Sea	13.23
Crati (Italy)	CNR IRPI	*1926-1966*	Ionian Sea	26.2

Sinni (Italy)	CNR IRPI	*1937-1976*	Ionian Sea	20.58
Agri (Italy)	Autorita' di bacino Basilicata	*n.r.*	Ionian Sea	9.14
Neto (Italy)	ARPA CAL	*n.r.*	Ionian Sea	6.22

Table A1: River runoff climatological values selected for the Adriatic and Ionian rivers

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