# SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

| | |
|---|---|
| **Reporting year** | 1st year |
| **Project Title:** | The Adriatic decadal and inter-annual oscillations: modelling component |
| **Computer Project Account:** | spcrdena |
| **Principal Investigator(s):** | Cléa Denamiel |
| **Affiliation:** | Institute of Oceanography and Fisheries (IOF) |
| **Name of ECMWF scientist(s) collaborating to the project** (if applicable) | Ivica Vilibić (IOF); Ivica Janeković (University of Western Australia); Samuel Somot (Météo-France / CNRM-GAME); Manuel Bensi and Vedrana Kovačević (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS); Ivan Güttler (Meteorological and Hydrological Service – DHMZ) ; Darko Koračin (Faculty of Science of the University of Split, Croatia) |
| **Start date of the project:** | 01/01/2018 |
| **Expected end date:** | 01/01/2021 |

## Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

| | | Previous year | | Current year | |
|---|---|---|---|---|---|
| | | Allocated | Used | Allocated | Used |
| High Performance Computing Facility | (units) | / | / | 13,000,000 | 4763972.61 (36%) |
| Data storage capacity | (Gbytes) | / | / | 25,000 | |

## Summary of project objectives

(10 lines max)

The physical explanation of the thermohaline oscillations of the Adriatic-Ionian System (BIOS) is still under debate as they are thought to be generated by either pressure and wind-driven patterns or dense water formation travelling from the Northern Adriatic. The aim of the ADIOS project is to numerically investigate and quantify the processes driving the inter-annual to decadal thermohaline variations in the Adriatic-Ionian basin with a high resolution Adriatic-Ionian fully coupled atmosphere-ocean model based on the use and development of the Coupled Ocean–Atmosphere–Wave–Sediment Transport Modelling System. The Adriatic-Ionian model consists in two nested atmospheric grids of 15-km and 3-km and two nested ocean grids of 3-km and 1-km and will be run for a 30-year re-analysis period (1987-2017) as well as two 30-year RCP scenarios (2070-2100) via a surrogate climate change method.

## Summary of problems encountered (if any)

(20 lines max)

No major problem was encountered in terms of usage of the supercomputing facilities. However, as discussed in the section below, due to the general slowness of the modelling suite, a new strategy was implemented in order to be able to generate high resolution climate projections within the three years of this project.

## Summary of results of the current year (from July of previous year to June of current year)

This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

As planned, during the first six months of this ECMWF special project, our efforts were mostly concentrated in setting up the coupled climate model (AdriSC: Adriatic Sea and Coast) and starting the 30-year evaluation period run (1987-2017). However, given the relative slowness of the AdriSC modelling suite, a major change of strategy was implemented in order to be able to simulate climate projections (RCPs 4.5 and 8.5). In this report we will present the set-up of the AdriSC modelling suite in section 1 and then analyze some of the first results of the evaluation run obtained for the year 1987 in section 2. Finally, in section 3, we will discuss the new strategy chosen to run the climate projections for the Ionian-Adriatic Seas.

1) AdriSC modelling suite: climate component set-up

The first step of our project, started in January 2018, consisted in developing and optimizing the set-up of the AdriSC (Adriatic Sea and Coast) modelling suite used in our study and presented in the following section.

The chosen domains of the AdriSC modelling suite are presented in Figure 1 and are defined as follow: for the atmospheric model, a 15-km grid (horizontal size: 140 x 140) approximately covering the central Mediterranean basin and a 3-km grid (266 x 361) encompassing the entire Adriatic and Ionian Seas; for the ocean model, the same 3-km grid and an additional 1-km grid (676 x 730) allowing for a better representation of the complex geomorphology of the Adriatic Sea and most particularly of the Croatian coast. The vertical discretization of the grids is achieved via terrain-following coordinates: for the atmosphere, 58 levels refined in the surface layer (Laprise, 1992) and for the ocean, 35 levels refined near both the sea surface and bottom floor (Shchepetkin, 2009).

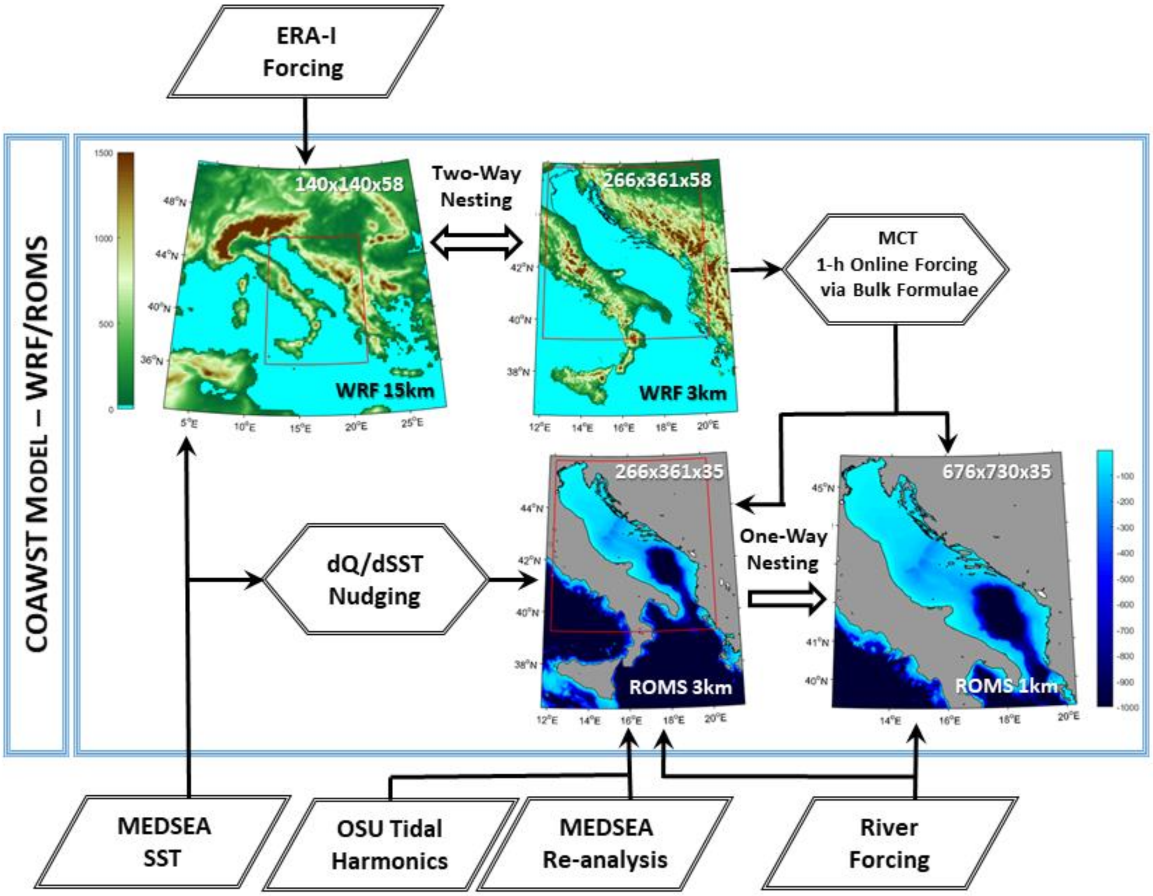

Figure 1: Flow chart of the climate component of the AdriSC modelling suite representing the coupling between the two different models (WRF and ROMS), their grids (plotted with topography/bathymetry data) and their forcing.

A single Digital Terrain Model (DTM) incorporating offshore bathymetry from ETOPO1 (Amante and Eakins, 2009), nearshore bathymetry from navigation charts CM93 2011, topography from GEBCO 30 arc-second grid 2014 (Weatherall et al., 2015) and coastline data generated by the Institute of Oceanography and Fisheries (Split, Croatia), is providing the terrain data of all the presented grids. For the ocean grids (3km and 1km), in order to reduce the horizontal pressure gradient errors generated by the use of terrain-following coordinates with sharp bathymetric gradients, a Linear Programming (LP) method developed by Dutour Sikirić et al. (2009) is applied to smooth the bathymetry in order to minimize the roughness factors while keeping the bathymetric features of the DTM.

Additionally, height tidal constituents (m2, s2, n2, k2, k1, o1, p1, q1) – extracted from the OSU Tidal Inversion Software (OTIS – Egbert, Bennett, and Foreman,1994; Egbert and Erofeeva, 2002) Mediterranean and Black Seas (2011) 1/30° regional solution, are imposed on the offshore boundaries of the 3-km ocean grid. A total of 54 river flows (only 49 for the 1-km ocean grid) are imposed over at least 6 grid points (18 grid points for the Po river delta) with river mouths located along the coastline of: Greece (Acheloos and Arachthos), Albania and Montenegro (Bistrica, Vjosa, Seman, Shkumbini, Erzen, Mat, Ishem, Drin and Bojana), Croatia and Slovenia (Kupari, Ombla, Neretva, Cetina, Jadro, Krka, Zrmanja, Senj, Crikvenica, Bakarac, Rječina, Raša, Mirna, Dragonja and Rižana), Italy (Timavo, Isonzo, Vivapa, Tagliamento, Livenza, Piave, Brenta, Adige, Po, Reno, Lamone, Foglia, Metauro, Esino, Musone, Potenza, Chienti, Tronto, Pescara, Sangro, Trigno, Biferno, Cervaro, Ofanto, Bradano, Cavone, Agri, Sinni, Crati, Noce, Sele, Volturno, Garigliano and Tevere) and Sicily (Oreto, Platani and Simeto). The river flow monthly climatology is principally based on the RivDis database (Vörösmarty et al., 1996) and the studies from Malačič and Petelin (2009), Pano and Avdyli (2002), Pano et al. (2010), Janeković et al. (2014) and Ljubenkov (2015). The inter-annual variability of the flows is derived from Ludwig et al. (2009).

The AdriSC modelling suite is based on a modified version of the Coupled Ocean-Atmosphere-Wave-Sediment-Transport (COAWST V3.3) modelling system developed by Warner et al. (2010) which couples (online) the Regional Ocean Modeling System (ROMS svn 885) (Shchepetkin & McWilliams, 2005, 2009) and the Weather Research and Forecasting (WRF v3.9.1.1) model (Skamarock et al., 2005) via the Model Coupling Toolkit (MCT v2.6.0) (Larson et al., 2005) and the remapping weights computed – between the 15-km and 3-km atmospheric grids and the 3-km and 1-km ocean grids, with the Spherical Coordinate Remapping and Interpolation Package (SCRIP). As identical 3-km grids are used for both the atmosphere and ocean models, the WRF 15-km grid never exchanges data with the ROMS model. However, in the typical configuration of the model, the ROMS 3-km grid should provide Sea Surface Temperature (SST) to the WRF 15-km grid. As the ROMS 3-km grid covers only a small area of the WRF 15-km grid and the ROMS SST can differ from the imposed WRF SST, the final WRF SST fields of the 15-km grid can present some important discontinuities along the offshore boundaries of the ROMS 3-km grid. A solution to this problem is to impose the same SST forcing to WRF and ROMS models. Another well-known problem in the ROMS community is that, with optically clear water like the Adriatic Sea, the absorption of the shortwaves reaching the seafloor in shallow water generates a warming SST trends. A solution to this problem is to impose a heat flux correction via the calculation of the kinematic surface net heat flux sensitivity to a SST of reference (measured/assimilated etc.). This procedure is hereafter referred as dQ/dSST. Finally, in ROMS model, the two-way nesting of the grids can dramatically increase the computation time and the AdriSC ROMS grids are only one-way nested which can again create some discontinuities in the SST fields imposed on the WRF grids as, for any given area, the SCRIP procedure always imposed the highest resolution fields from the ROMS grids.

As the treatment of the SST clearly requires some special attention, some modelling choices have to be made (see Figure 1): in the AdriSC modelling suite, it was decided that the daily SST from an Ocean Regional Circulation Model (which ideally assimilates SST from remote sensing products) will be imposed directly to the WRF grids and used as reference for the calculation of dQ/dSST. This means that all the exchange routines from ROMS to WRF in the COAWST code were commented and that the Matlab code developed by Pierrick Penven to derive dQ/dSST from the atmospheric fields and the SST of reference (http://www.brest.ird.fr/Roms_tools/get_dqdsst.m) was implemented in Fortran in the ROMS model. Furthermore, as WRF imposed a constant value of SST between two forcing time steps, the imposed SST is linearly interpolated every 6h between two days in order to smooth the transition between the two daily states.

In addition to the SST treatment, two other modifications of the ROMS model code were made: (1) the astronomic tide theory was modified in order to be consistent with the OSU Tidal Prediction Software (OTPS) and (2) the use of the PnetCDF library, implemented in the WRF model, was extended to the ROMS model.

In terms of model parameterizations and physics, the optimal configuration of Adriatic high-resolution WRF models described by Kehler-Poljak et al. (2017) is used with: the Morison 2 moment scheme microphysics scheme (Morrison et al., 2005), the MYJ Planetary Boundary Layer (Janjić, 1994), the Dudhia (Dudhia, 1989) and RRTM (Mlawer et al., 1997) short and long-wave radiation schemes, the Eta surface layer scheme (Janjić, 1994) and the Five-layer thermal diffusion scheme for soil temperature (Dudhia, 1996). In addition, the Kain-Fritch cumulus parameterization (Kain, 2004) is applied to the 15-km grid. Concerning the ROMS model, the Flather (Flather,1976), Chapman (Chapman, 1985) and Orlanski (Orlanski, 1976; Raymond and Kuo 1984) conditions are used to impose respectively the barotropic velocity, the surface elevation and the baroclinic fields at the open boundaries. Furthermore, two nudging relaxation zones are used to relax the baroclinic structure (with a minimum folding time of 3 days) toward the fields provided by the ocean climatology (Marchesiello et al., 2001): (1) a ten-grid point wide area along the open boundaries is used for all the fields and (2) an area covering the bathymetry deeper than 2000m is used for the temperature and salinity fields only, in order to minimize the numerical diapycnal mixing. A sponge area is also defined in such a way that the horizontal viscosity is four times bigger at the open boundary of the grids than seven grid points away from it. The other parameterizations used in ROMS are: a Multidimensional Positive Definite Advection Transport Algorithm (MPDATA – Smolarkiewicz, 1984; Smolarkiewicz and Clark, 1986; Smolarkiewicz and Grabowski, 1990) for the tracer advection, a third-order scheme for the horizontal momentum advection and the GLS gen (Umlauf and Burchard, 2003) turbulence closure scheme.

The AdriSC modelling suite was compiled with the Intel 17.0.3.053 compiler, the PNetCDF 1.8.0 library and the MPI library (mpich 7.5.3) on the ECMWF's High Performance Computing Facility (HPCF). In addition, ecFlow 4.9.0 – the work flow package used by all ECMWF operational suites, was set-up to automatically and efficiently run all the modules of the AdriSC modelling suite in a controlled environment. In terms of workload, no hyper-threading is used and the COASWT model optimally run on 260 CPUs with both the WRF and ROMS grids decomposed in 10 x 13 tiles. Due to the high resolution of the grids (up to 3-km for the atmosphere and 1-km for the ocean), the optimal configuration was found to produce a month of model results per day.

2) Evaluation period: 1987-2017

Since the 25th of May 2018, the AdriSC modelling suite runs continuously for the evaluation period (1987-2017) with perfect re-starts every day. The modified COAWST model – exchanging WRF fields with ROMS grids every hour, is used to generate hourly outputs with boundary conditions provided: (1) 6 hourly to the WRF 15-km grid by the ERA-Interim re-analysis fields and (2) daily to the ROMS 3-km grid by the Mediterranean Forecasting System (MFS) re-analysis MEDSEA fields (Pinardi et al., 2003, Pinardi and Coppini 2010, Tonani et al 2014) which also provides 6 hourly interpolated SST fields to the WRF 15-km and 3-km grids. In addition, the skin temperature of the ERA-I data is extracted near the river mouths and imposed as river temperature in the ROMS grids.

Figure 2: Adriatic dense water formation linked to direct cooling (Vested et al., 1998) in zones 1 and 2 and to open-ocean convection (Gačić et al., 2002, 2010) in the deep Southern Adriatic pit (zone 3).

One of the main reason for setting up a dedicated high resolution Adriatic coastal coupled model is that the regional circulation models (RCMs) are generally enable to reproduce the BIOS cycles and most particularly the dense water formation in the northern part of the Adriatic (i.e. zone 2, see Figure 2). As previous studies documented dense water formation in zone 2 during the winter of 1987 (Beg-Paklar, 2001), the results of the evaluation run obtained for the year 1987 are already partially analyzed in order to check the capability of the model to reproduce the event. Figure 3 is showing the daily averaged bottom potential density associated with the wind vectors at 10m before the dense water formation (02/01/1987) and during four different events of strong Bora winds (18/01/1987, 23/02/1987, 04/03/1987 and 30/03/1987). From these results, it is clear that: (1) the WRF model is capable of representing the strong Bora events (more than 20m/s wind speed within the red boxes) and (2) the ROMS model seems to properly respond to the forcing as the bottom density is increased within zone 2 for each additional Bora event.

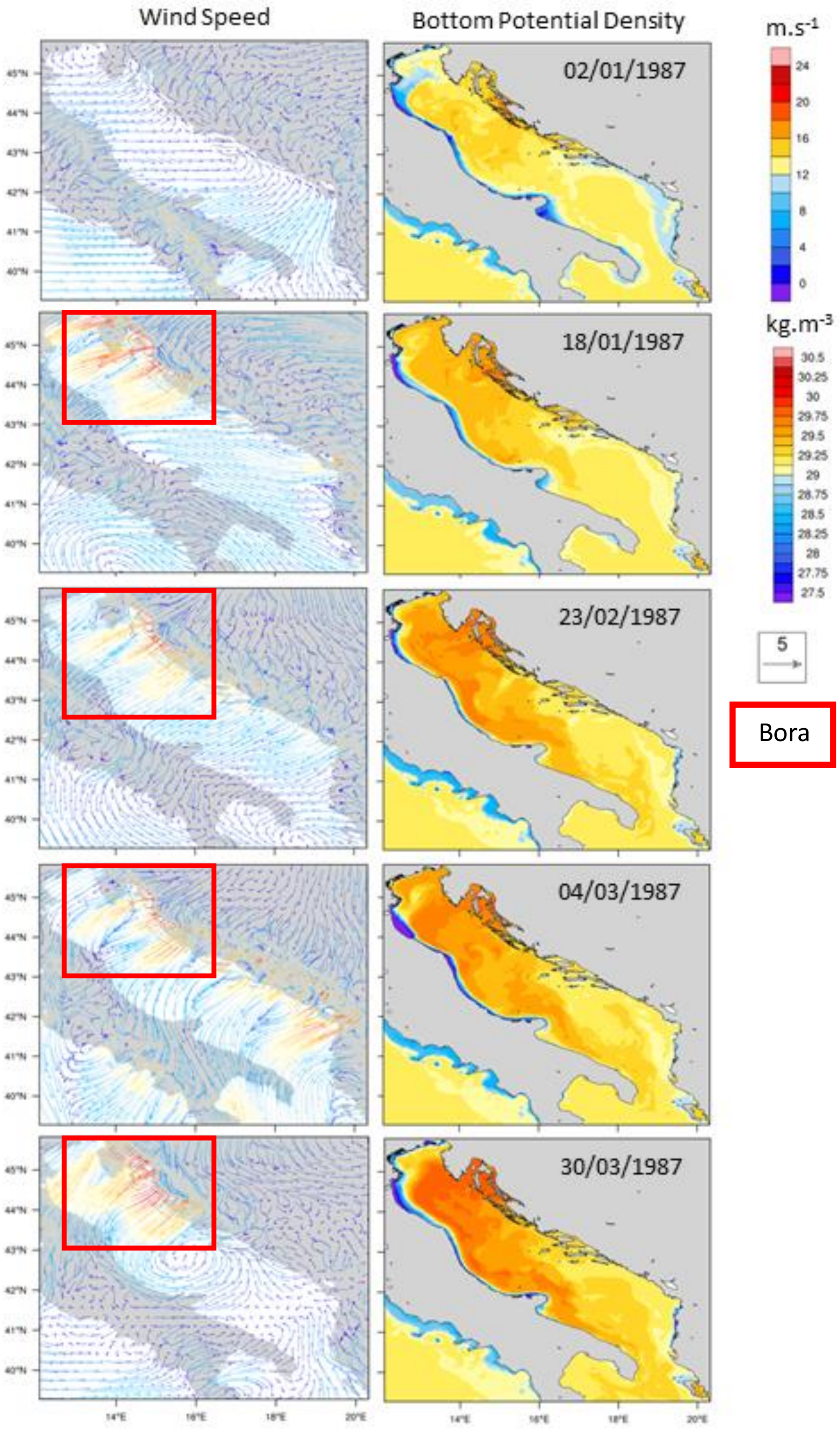

Figure 3: Dense water generation in zone 2 during four strong Bora events in 1987.

In addition to the generation of dense water, the ROMS model seems to also reproduce its cascading along the Italian coastline towards the Otranto strait. Even if the evaluation simulation is at a too early stage to assess whether or not this dense water will be responsible for the oscillation of the BIOS, these first results are extremely encouraging as they show that the models can reproduce the documented dense water formation events within zone 2.

3) Climate projections

The climate scenarios (RCP 4.5 and 8.5) were originally thought to be forced with coupled RCM results from the MED-CORDEX experiments. Unfortunately, after discussion with different institutes producing the results, we realized that the fields were not saved at high enough frequency (and with high enough vertical distribution) to be used as boundary conditions. Given this fact and the slowness of the AdriSC modelling suite (1 month of simulation per day), it was judged impossible to follow the classical climate downscaling approach as presented in MED-CORDEX: one 50-year historical run and at least two 100-year scenario runs. It was thus decided to use a surrogate climate change approach (Schär et al., 1996) in order to run the climate projections. This method is based on the perturbation of the boundary conditions extracted from re-analysis fields (in our case ERA-I and MEDSEA) with the trend of temperature (and probably salinity for the ocean) extracted from the results of global (or in our case regional) climate model projections. Within this framework, the team of Professor Christopher Schär was contacted and agreed to collaborate with us in order to set-up the climate projection forcing.
Given this methodology, the planned climate projection simulations are as follow: 30-year RCP 8.5 and 30-year RCP 4.5 (2070-2100). Ideally, another 30-year simulation should be done between 2040-2070, where results from RCPs 4.5 and 8.5 are similar. This last simulation will be done pending other available resources than the ECMWF supercomputing ones.

In conclusion, during this first six months of project, the AdriSC model was set-up and started producing the results of the evaluation run. Some of the first results have already been analyzed in order to successfully demonstrate the capability of the models to reproduce dense water formation in the Northern Adriatic. Finally, a new strategy for climate projection, replacing the original downscaling one, has been implemented in order to be able to produce the necessary climate projection runs. Given the above achievements and adjustments, we are positive that we can fulfill the aim of our project with the allocated resources of the 3-year project.

References:

Amante, C. and Eakins, B.W. (2009). ETOPO1 1 arc-minute global relief model: procedures, data sources and analysis. NOAA Technical Memorandum NESDIS NGDC-24.

Beg Paklar, G., Isakov, V., Koračin, D., Kourafalou, V., Orlić, M. (2001). A case study of bora-driven flow and density changes on the Adriatic Shelf (January 1987), Continental Shelf Research, Volume 21, Issues 16–17, pp 1751-1783.https://doi.org/10.1016/S0278-4343(01)00029-2.

Chapman, D.C. (1985). Numerical treatment of cross-shelf open boundaries in a barotropic coastal ocean model. Journal of Physical Oceanography 15 (8), 1060–1075.

Dudhia, J. (1989). Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model. J. Atmos. Sci., 46, pp 3077-3107.

Dudhia J (1996). A multi-layer soil temperature model for MM5. Preprints, the sixth PSU/NCAR mesoscale model users's workshop, 22–24 July 1996, Boulder, CO, pp 49–50. Available from http://www.mmm.ucar.edu/mm5/mm5v2/whatisnewinv2.html

Dutour Sikiric, M., Janeković, I., Kuzmić, M. (2009). A new approach to bathymetry smoothing in sigma-coordinate ocean models. Ocean Modelling, 29, pp 128–136. doi:10.1016/j.ocemod.2009.03.009

Egbert, G.D. and Erofeeva, S.Y. (2002). Efficient inverse modeling of barotropic ocean tides, J. Atmos. Ocean. Tech., 19, 183 – 204.

Egbert, G. D., Bennett, A. F., Foreman, M. G. G. (1994). Topex/Poseidon tides estimated using a global inverse model, J. Geophys. Res., 99, 24,821 – 24,852.

Flather, R.A. (1976). A tidal model of the north-west European continental shelf. Memoires de la Societe Royale des Sciences de Liege 6 (10), 141–164.

Gačić, M., Borzelli, G.L.E., Civitarese, G., Cardin, V., Yari, S. (2010). Can internal processes sustainreversals of the ocean upper circulation? The Ionian Sea example, Geophys. Res. Lett., 37, L09608, doi:10.1029/2010GL043216.

Gačić, M., Civitarese, G., Miserocchi, S., Cardin, V., Crise, A., and Mauri, E. (2002). The open-ocean convection in the Southern Adriatic: a controlling mechanism of the spring phytoplankton bloom, Cont. Shelf Res., 22, pp 1897–1908.

Janeković, I., Mihanović, H., Vilibić, I., Tudor, M. (2014). Extreme cooling and dense water formation estimates in open and coastal regions of the Adriatic Sea during the winter of 2012. Journal of Geophysical Research, 119, 3200-3218, doi:10.1002/2014JC009865

Janjić, Z. (1994). The Step-Mountain Eta Coordinate Model: Further developments of the convection, viscous sublayer, and turbulence closure schemes. Monthly Weather Rev. 122:927–945. doi:10.1175/1520-0493(1994) 1222.0.CO;2

Kain, J. S. 2004. The Kain-Fritsch convective parameterization: an update. J. Appl. Meteorol. 43, 170–181.

Kehler-Poljak, G., Telišman Prtenjak, M., Kvakić, M., Šariri, K., Večenaj, Ž. (2017). Interaction of Sea Breeze and Deep Convection over the Northeastern Adriatic Coast: An Analysis of Sensitivity Experiments Using a High-Resolution Mesoscale Model. Pure and Applied Geophysics,174,4197–4224. https://doi.org/10.1007/s00024-017-1607-x

Lalaurette F. 2002. Early detection of abnormal weather conditions using a probabilistic extreme forecast index. Q. J. R. Meteorol. Soc. 129: 3037–3057.

Laprise R. (1992). The Euler Equations of motion with hydrostatic pressure as independent variable. Mon. Wea. Rev., 120, 197–207.

Larson, J., Jacob, R., Ong, E. (2005). The Model Coupling Toolkit: A New Fortran90 Toolkit for Building Multiphysics Parallel Coupled Models. The International Journal of High Performance Computing Applications, 19 (3), pp 277-292. doi:10.1177/1094342005056115

Ljubenkov, I. (2015). Hydrodynamic modeling of stratified estuary: case study of the Jadro River (Croatia). Journal of Hydrology and Hydromechanics, 63(1), 29-37, doi: https://doi.org/10.1515/johh-2015-0001

Malačič, V. and Petelin, B. (2009). Climatic circulation in the Gulf of Trieste (northern Adriatic). J. Geophys. Res., 114, C07002, doi:10.1029/2008JC004904.

Marchesiello, P., McWilliams, J. C., Shchepetkin, A. (2001). Open boundary conditions for long-term integration of regional oceanic models. Ocean Modell., 3, 1–20.

Morrison, H., Curry, J. A., Khvorostyanov, V. I. (2005). A new double-moment microphysics parameterization for application in cloud and climate models. Part I: Description. J. Atmos. Sci., 62, 1665-1677.

Orlanski, I. (1976). A simple boundary condition for unbounded hyperbolic flows. J. Comput. Phys., 21, 251-269.

Pano, N. and Abdyli, B. (2002). Maximum floods and their regionalization on the Albanian hydrographic river network. International Conference on Flood Estimation. CHR. Report II,17 Bern, Switzerland, pp.379-388.

Pano, N., Frasheri, A., Avdyli, B. (2010). The Climatic Change Impact in Water Potential Processe on the Albanian Hydrographic River Network. International Congress on Environmental Modelling and Software. 266. https://scholarsarchive.byu.edu/iemssconference/2010/all/266

Petroliagis and Pinson, 2012. Early indication of extreme winds utilising the Extreme Forecast Index. ECMWF Newsletter 132, Summer 2012, pp 13–19.

Pinardi, N., Allen, I., Demirov, E., De Mey, P., Korres, G., Lascaratos, A., Le Traon, P-Y., Maillard, C., Manzella, G. and Tziavos C. (2003). The Mediterranean ocean Forecasting System: first phase of implementation (1998-2001). Annales Geophysicae, 21, 3-20, doi:10.5194/angeo-21-3-2003.

Pinardi, N. and Coppini, G. (2010). Operational oceanography in the Mediterranean Sea: the second stage of development. Ocean Science, 6, 263-267.

Raymond, W. H. and Kuo, H. L. (1984). A radiation boundary condition for multi-dimensional flows. Quart. J. R. Met. Soc., 110, 535-551.

Schär, C., Frei, C., Lüthi, D., Davies, Huw C. (1996). Surrogate climate-change scenarios for regional climate models. Geophysical Research Letters, 23 (6). https://doi.org/10.1029/96GL00265

Shchepetkin, A. F., and McWilliams, J.C. (2005). The regional oceanic modeling system: A split-explicit, free-surface, topography-following-coordinate ocean model. Ocean Modell., 9, 347–404.

Shchepetkin, A. F., and J. C. McWilliams (2009). Correction and commentary for "Ocean forecasting in terrain-following coordinates: Formulation and skill assessment of the regional ocean modeling system" by Haidvogel et al., J. Comput. Phys., 227, pp. 3595–3624. J. Comput. Phys., 228, 8985–9000. doi:10.1016/j.jcp.2009.09.002

Smolarkiewicz, P. K. (1984). A fully multidimensional positive definite advection transport algorithm with small implicit diffusion. J. Comp. Phys., 54, 325-362.

Smolarkiewicz, P. K. and Clark, T. L. (1986). The multidimensional positive definite advection transport algorithm: further development and applications. J. Comp. Phys., 67, 396-438.

Smolarkiewicz, P. K., and Grabowski, W. W. (1990). The multidimensional positive definite advection transport algorithm: nonoscillatory option. J. Comp. Phys., 86, 355-375.

Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Barker, D. M., Wang, W., Powers, J. G. (2005). A Description of the Advanced Research WRF Version 2. NCAR Technical Note NCAR/TN-468+STR, doi:10.5065/D6DZ069T.

Skamarock, W.C. (2004). Evaluating Mesoscale NWP Models Using Kinetic Energy Spectra. Mon. Wea. Rev., 132, 3019–3032, https://doi.org/10.1175/MWR2830.1

Tonani M., A. Teruzzi, G. Korres, N. Pinardi, A. Crise, M. Adani, P. Oddo, S. Dobricic, C. Fratianni, M. Drudi, S. Salon, A. Grandi, G. Girardi, V. Lyubartsev and S. Marino, 2014. The Mediterranean Monitoring and Forecasting Centre, a component of the MyOcean system. Proceedings of the Sixth International Conference on EuroGOOS 4-6 October 2011, Sopot, Poland. Edited by H. Dahlin, N.C. Fleming and S. E. Petersson. First published 2014. Eurogoos Publication no. 30. ISBN 978-91-974828-9-9.

Tsonevsky and Richardson (2012). Application of the new EFI products to a case of early snowfall in Central Europe. ECMWF Newsletter 133, Autumn 2012, p 4.

Umlauf, L., Burchard, H., (2003). A generic length-scale equation for geophysical turbulence models. Journal of Marine Research 61, 235–265.

Vörösmarty, C., Fakers, B., Tucker, B. (1996) River Discharge Database, Version 1.0 (RivDIS vLO), Volumes 0 through 6. A contribution to IHP-V Theme 1. Technical Documents Series. Technical report, UNESCO, Paris, France.

Warner, J.C., Armstrong, B., He, R., and Zambon, J.B., (2010). Development of a Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) modeling system: Ocean Modeling, v. 35, no. 3, p. 230-244.

Weatherall, P., Marks, K. M., Jakobsson, M., Schmitt, T., Tani, S., Arndt, J. E., Rovere, M., Chayes, D., Ferrini, V. and Wigley, R. (2015). A new digital bathymetric model of the world's oceans. Earth and Space Science, 2, 331–345, doi:10.1002/2015EA000107.

## List of publications/reports from the project with complete references

Conferences:

Denamiel, C. and Villibić, I. (2018). The Adriatic Decadal and Inter-Annual Oscillations: Modelling Component. Poster presentation at Ocean Science meeting, Portland, Oregon, USA.

Denamiel, C. and Villibić, I. (2018). Adriatic Decadal and Inter-Annual Oscillations: AdriSC Modelling Suite. Oral presentation at HYMEX meeting, Lecce, Italy.

## Summary of plans for the continuation of the project

(10 lines max)

Our first short term goal (the next 6 to 12 months, pending availability of the results), is to perform the evaluation of the AdriSC modelling suite results obtained for the 1987-2017 period. Several in-situ measurements including ADCPs, CTDs, etc., as well as remote sensing products, will be used to perform a skill assessment of the climate component of the AdriSC modelling suite. Concurrently (the next 6 months), it is also planned to prepare the forcing for the climate projection simulations (within the surrogate climate change framework) with the expertise of the team of Professor Christopher Schär. Finally, during the remaining of the project, the climate projection simulations will be run (using all the remaining allocated resources) and a more thorough analysis of the results will start being performed.