WP4
Forecast numerical modelling for coastal extreme weather and flooding risk management

Activity 4.3
Coupling of high-resolution meteorological and sea-waves models

D4.3.2 Wave model operative into the WRFAdria model

PROJECT AND ACTIVITY DETAILS

Project Acronym	AdriaMORE
Project title	Adriatic DSS exploitation for MOnitoring and Risk management of coastal Extreme weather and flooding
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Activity number	4.3
Activity Title	Coupling of high-resolution meteorological and sea-waves models
Work Package	WP4: Forecast numerical modeling for coastal extreme weather and flooding risk management
Activity Summary	Activity 4.3, within Work Package 4, is devoted to couple the WRF model to a wave model
Deliverable number	4.3.2
Deliverable Summary	This deliverable is aimed at describing the operative coupled WRF-SWAN model

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1. INTRODUCTION

Hydro-meteorological and other marine hazards triggered by meteorological events, affecting the Adriatic areas represent a dramatic threat which needs to be faced by enhancing monitoring and forecasting systems. In this respect, **AdriaMORE project** proposes increasing of the management capacity of the response to marine and coastal hazards in the Adriatic basin.

AdriaMORE goal is to improve an existing integrated hydro-meteorological risk management platform focusing on the Adriatic coastal areas of Italy and Croatia capitalizing the major achievements of ADRIARadNet and CapRadNet projects. The latter, successfully completed under the IPA Adriatic CBC Programme, were devoted to create a cross-border infrastructure of observing and forecasting systems for building real-time risk scenarios for civil protection purpose.

To this end, one of AdriaMORE's specific objective is to develop a wave model operative in the WRFAdria model over the Adriatic coastal. This objective has been performed within the action 4.3 of the WP4 of AdriaMORE project whose the main result is constituted by the **Output entitled "Forecast of the newly implemented numerical weather prediction model improved by assimilating coastal monitoring data, coupled with the wave model.".**

Two deliverables have contributed to the achievement of the above project Output:

- **deliverable 4.3.1** aimed at describing the meteorological model and wave model and how they are coupled;
- **deliverable 4.3.2** aimed at describing the operative coupled WRF-SWAN model.

The first is described in another document while the **deliverable 4.3.2**, subject of this paper, has been organized as follows.

In the **chapter 2** the operative models chain is described, which is developed in collaboration with the Oceanography Laboratory group at the Science of Life and Environment Department (Università Politecnica delle Marche).

In the **chapter 3** some examples both of marine and meteorological fields that can be chosen and visualized.

The references here used are listed in the **chapter 4**.

2. Description of the SWAN model operative into the WRFAdria model

In this section we will give a detailed description of the model chain developed in collaboration with the Oceanography Laboratory group at the Science of Life and Environment Department (Università Politecnica delle Marche).

The Air-Sea Adriatic Forecasting System (hereafter ASA) is a numerical weather and ocean prediction system, that produces short term forecasts for Italy and the Adriatic Sea.

Every day the system produces a +48h forecast starting from tomorrow at 00:00 UTC. The new bulletin is usually released between 14:00 and 15:00 UTC.

The Air-Sea Adriatic forecasting system is a coupled atmospheric-wave model.

The Weather Research and Forecasting model (WRF) is used for the atmosphere and the Simulating WAves Nearshore model (SWAN) for the waves. The two models are part of the Coupled Ocean-Atmosphere-Wave-Sediment Transport modeling system (COAWST) which is integrated by the Model Coupling Toolkit (MCT) to exchange data fields between models.

2.1 Models

The WRF (Skamarock et al., 2008) configuration for the Air-Sea Adriatic system has been chosen as the best compromise between computational efficiency and best forecast. The WRF is used in a nestdown configuration (Mazzarella et al., 2017): a mother domain at 15 km horizontal grid resolution covers large part of central Europe and a 3 km horizontal grid resolution covers Italy and the Adriatic Sea.

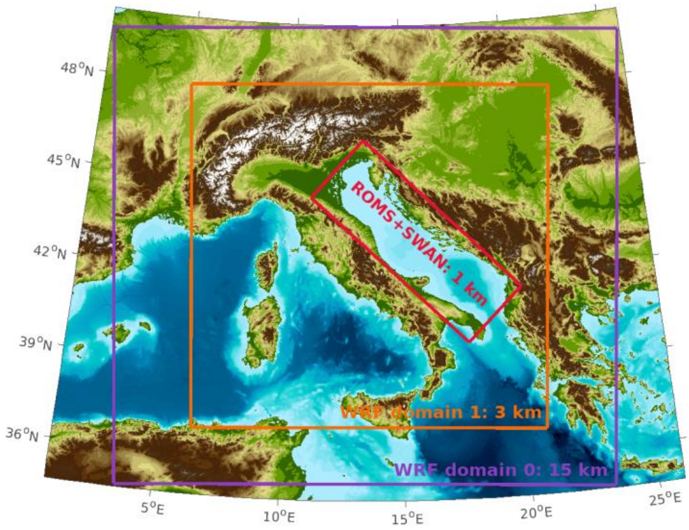

Figure 1. Configuration of the domains.

The model is initialized by NCEP analyses and forecast at 0.25° spatial resolution. A 3DVAR data assimilation of conventional data (Maiello et al., 2014) is used to improve the Initial Condition for the mother domain.

The SWAN domain comprises the whole Adriatic Sea basin with 1 km horizontal grid resolution. The only open lateral boundary is located at the strait of Otranto (grid points located into the Ionian Sea have been masked out).

To warm-up the SWAN model a hotstart file from the previous run is used. The lateral open boundary conditions are provided from the operational forecasting system SWAN-ITA (Cacciamani et al., 2012).

The two models run simultaneously on a High Performance machine with 2 Intel® Xeon® CPU E5-2680 v2 @ 2.80GHz processors in hyperthreading configuration for a total of 40 thread siblings. WRF is the component which requires the higher computational resources, hence it has been assigned 30 siblings, whereas SWAN has been assigned 2.

	N.threads	Tiling	Δt (s)	Coupling
WRF	30	5x6	adapt*	600
SWAN	4	auto	600	600

* average WRF timestep ~21 s

Table 1. Summary of the computational resources assigned to each model.

The time interval between coupling of models is 600 s.

The table below summarizes the physical parameters exchanged between models by means of MCT:

WRF to SWAN		WLEV	Water level (m)
U10	U-wind at 10 m (ms^{-1})	VELX	U-velocity (ms^{-1})
V10	V-wind at 10 m (ms^{-1})	VELY	V-velocity (ms^{-1})
SWAN to WRF		ZO	Sea surface elevation (m)
HSIGN	Significant wave height (m)		
WLENP	Peak wave length (m)		
RTP	Relative peak period (s)		

Table 2. Summary of the physical parameters exchanged between models.

2.2 More about WRF

WRF is a numerical weather prediction (NWP) and atmospheric simulation system designed for both research and operational applications. WRF is supported as a common tool for the university/research and operational communities by NCAR. The development of WRF has been a multi-agency effort among the National Center for Atmospheric Research's (NCAR) Mesoscale and Microscale Meteorology (MMM) Division, the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Prediction (NCEP) and Earth System Research Laboratory (ESRL), the Department of Defense's Air Force Weather Agency (AFWA) and Naval Research Laboratory (NRL), the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma, and the Federal Aviation Administration (FAA), with the participation of university scientists. WRF is maintained and supported as a community model to facilitate wide use internationally, for research, operations and teaching.

The key features of the WRF–ARW model include:

- *Equations:* Fully compressible, Euler nonhydrostatic. Conservative for scalar variables.
- *Prognostic Variables:* Velocity components u and v in Cartesian coordinate, vertical velocity w, perturbation potential temperature, perturbation geopotential, and perturbation surface pressure of dry air.
- *Vertical Coordinate:* Terrain-following, dry hydrostatic-pressure, with vertical grid stretching permitted. Top of the model is a constant pressure surface.
- *Horizontal Grid:* Arakawa C-grid staggering.

- *Time Integration:* Time-split integration using a 2nd- or 3rd-order Runge-Kutta scheme with smaller time step for acoustic and gravity-wave modes. Variable time step capability.
- *Spatial Discretization:* 2nd- to 6th-order advection options in horizontal and vertical.
- *Top Boundary Conditions:* Gravity wave absorbing (diffusion, Rayleigh damping, or implicit Rayleigh damping for vertical velocity). Constant pressure level at top boundary along a material surface. Rigid lid option.
- *Bottom Boundary Conditions:* Physical or free-slip.
- *Earth's Rotation:* Full Coriolis terms included.
- *Mapping to Sphere:* Four map projections are supported for real-data simulation: polar stereographic, Lambert conformal, Mercator, and latitude-longitude (allowing rotated pole). Curvature terms included.
- *Nesting:* One-way interactive, two-way interactive, and moving nests. Multiple levels and integer ratios.
- *Nudging:* Grid (analysis) and observation nudging capabilities available.

Model physics:

- *Microphysics:* Schemes ranging from simplified physics suitable for idealized studies to sophisticated mixed-phase physics suitable for process studies and NWP.
- *Cumulus parameterizations:* Adjustment and mass-flux schemes for mesoscale modeling.
- *Surface physics:* Multi-layer land surface models ranging from a simple thermal model to full vegetation and soil moisture models, including snow cover and sea ice.
- *Planetary boundary layer physics:* Turbulent kinetic energy prediction or non-local scheme
- *Atmospheric radiation physics:* Longwave and shortwave schemes with multiple spectral bands and a simple shortwave scheme suitable for climate and weather applications. Cloud effects and surface fluxes are included.

The WRF system is summarized in the following figure:

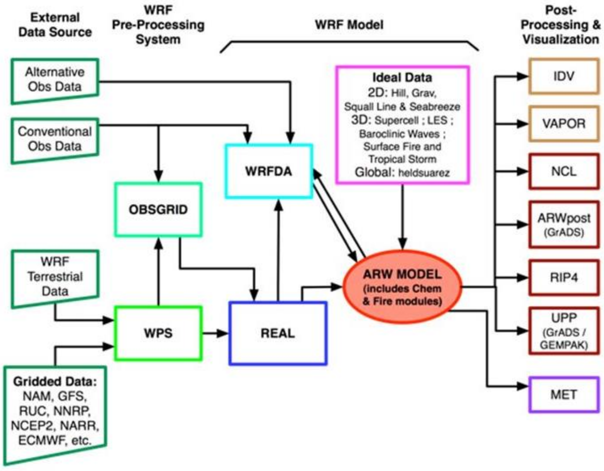

Figure 2. Flow chart of the WRF-ARW model.

2.3 More about SWAN

SWAN is a third generation spectral wave model specifically designed for shallow water that solves the spectral density evolution equation. SWAN simulates wind wave generation and propagation in coastal waters and includes the processes of refraction, diffraction, shoaling, wave-wave interactions and dissipation due to whitecapping, wave breaking and bottom friction.

The wave model solves the action balance equation:

$$\frac{\partial N}{\partial t} + \frac{\partial c_x N}{\partial x} + \frac{\partial c_y N}{\partial y} + \frac{\partial c_{\sigma N}}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S_w}{\sigma}$$

where $N(\sigma, \theta, x, y, t)$ is the action density spectrum, σ is the relative radiant frequency (as observed in a frame moving with the ocean current), θ is direction normal to wave crest, *x* and *y* are coordinate space and *t* is time. The action density is defined as the wave energy density *E* divided by the relative frequency $(N = E/\sigma)$ and is solved because the action density is conserved in the presence of currents. The group velocities in x and y directions c_x and c_y in the second and third terms represent the propagation of the action density in geographic space, the fourth term represents changes in relative frequency due to variations in depth and currents with a propagation speed c_σ in frequency space and the fifth term allows depth and current-induced refraction with a speed c_θ in directional space. The S_w term represents sources and sinks of wave energy density.

2.4 More about the Model Coupling Toolkit (MCT)

The MCT coupler allows the transmission and transformation of various distributed data between component models using a parallel coupled approach. MCT is a program written in Fortran90 and works with the MPI communication protocol. It is compiled as a set of libraries, which are linked to the model executable.

At the initialization phase each model decomposes its own domain into sections (or segments) that are distributed to processors assigned for that component. Each grid section on each processors initializes into MCT and the coupler compiles a global map to determine the distribution of model segments. Each segment also initializes an attribute vector that contains the fields to be exchanged and establishes a router to provide an exchange pathway between model components.

During the run phase of the simulation the models will reach a predetermined syncronization point, fill the attribute vectors with data and use MCT send and receive commands to exchange fields.

3. Examples of the operative products

In the following, three examples of marine products that can be visualized at the link http://oceanlab.univpm.it/bulletin.html.

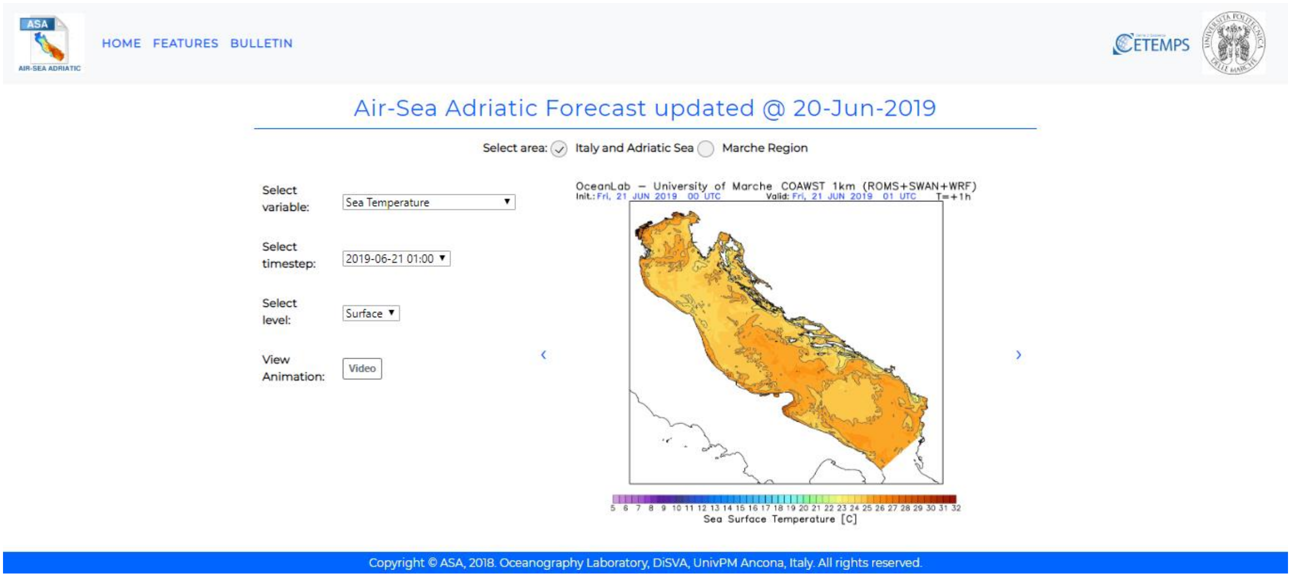

Figure 3. Sea temperature field @ 01:00 of June 21 2019 over the selected area "Italy and Adriatic Sea".

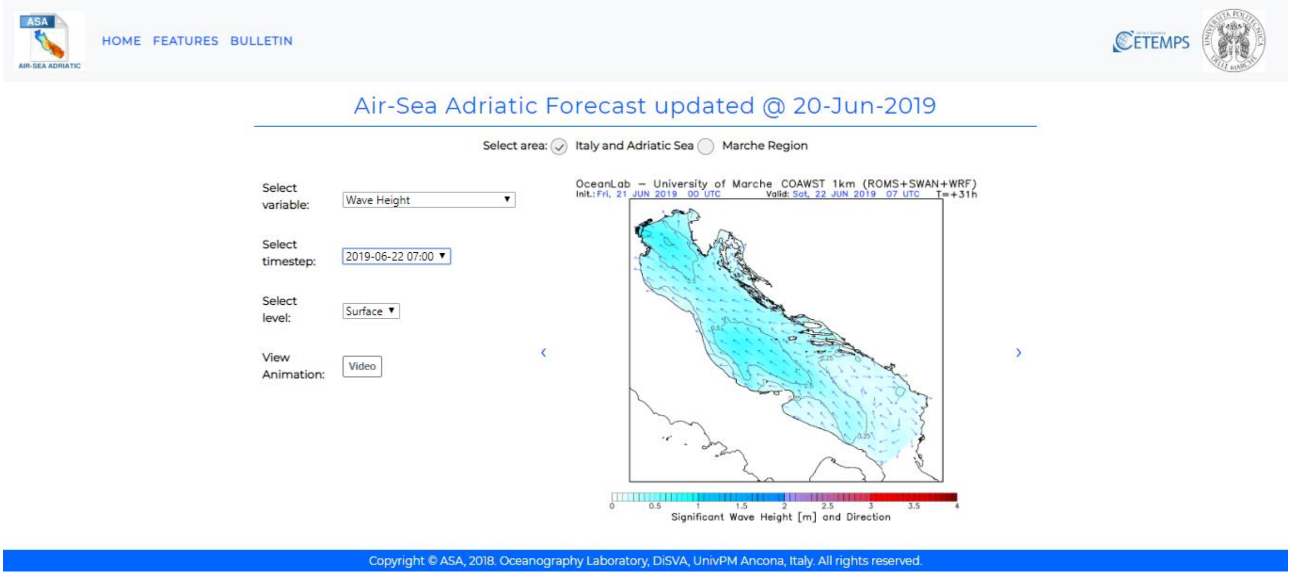

Figure 4. Wave height field @ 07:00 of June 22 2019 over the selected area "Italy and Adriatic Sea".

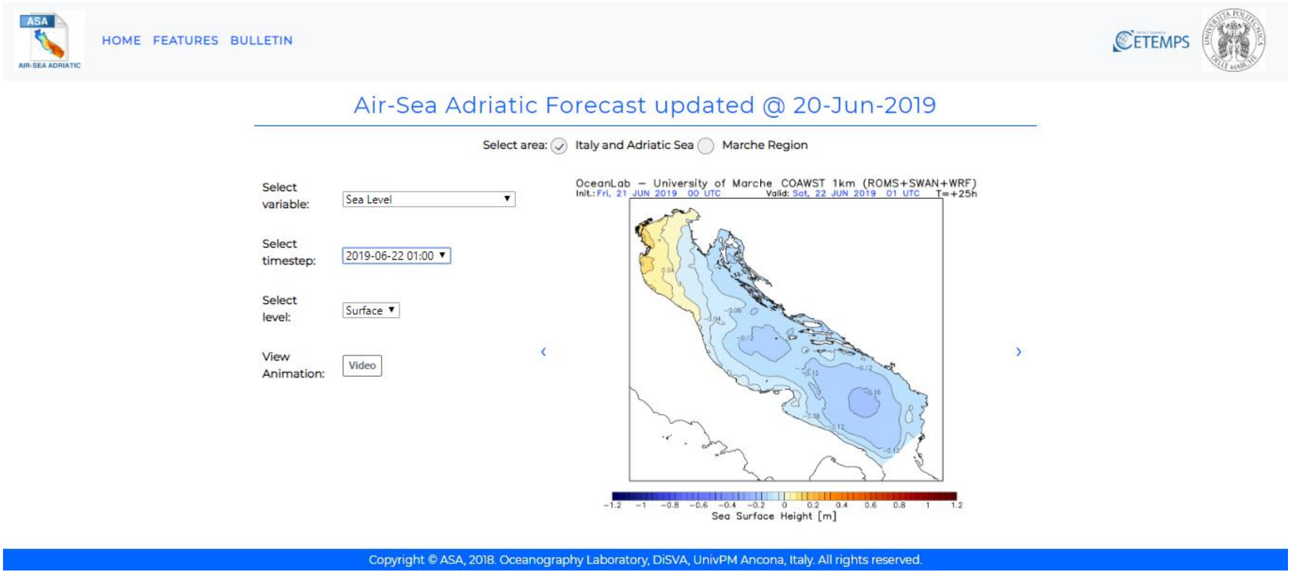

Figure 5. Sea level field @ 01:00 of June 22 2019 over the selected area "Italy and Adriatic Sea".

The other three following examples of meteorological products can be visualized at the link http://oceanlab.univpm.it/bulletin.html.

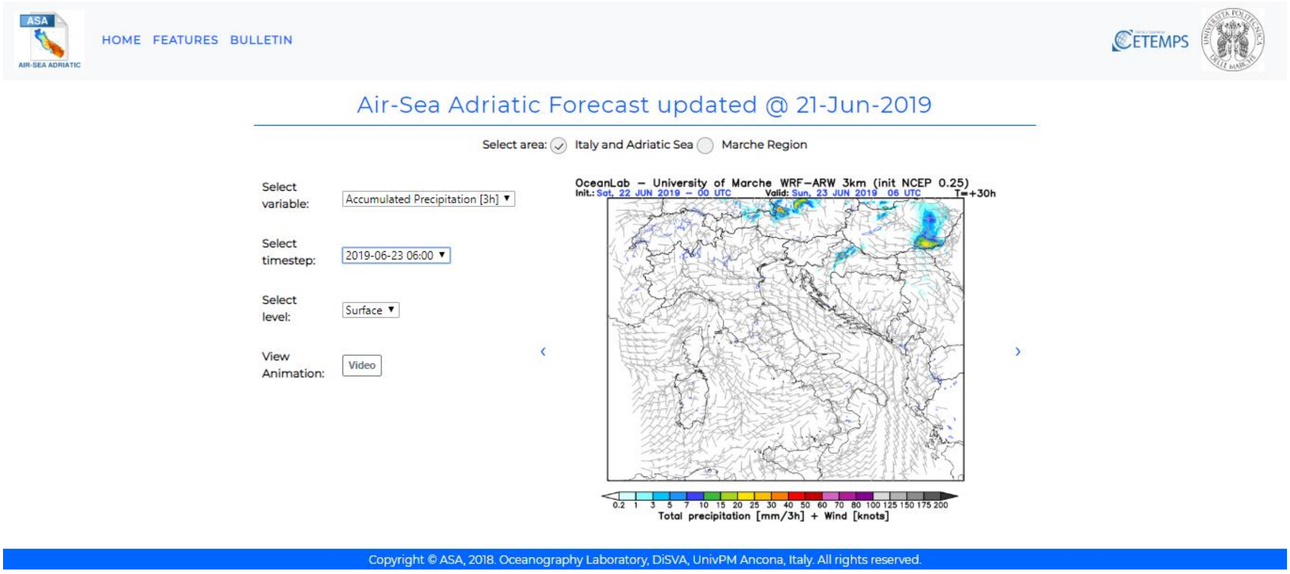

Figure 6. Accumulated precipitation (3h) @ 06:00 of June 23 2019 over the selected area “Italy and Adriatic Sea”.

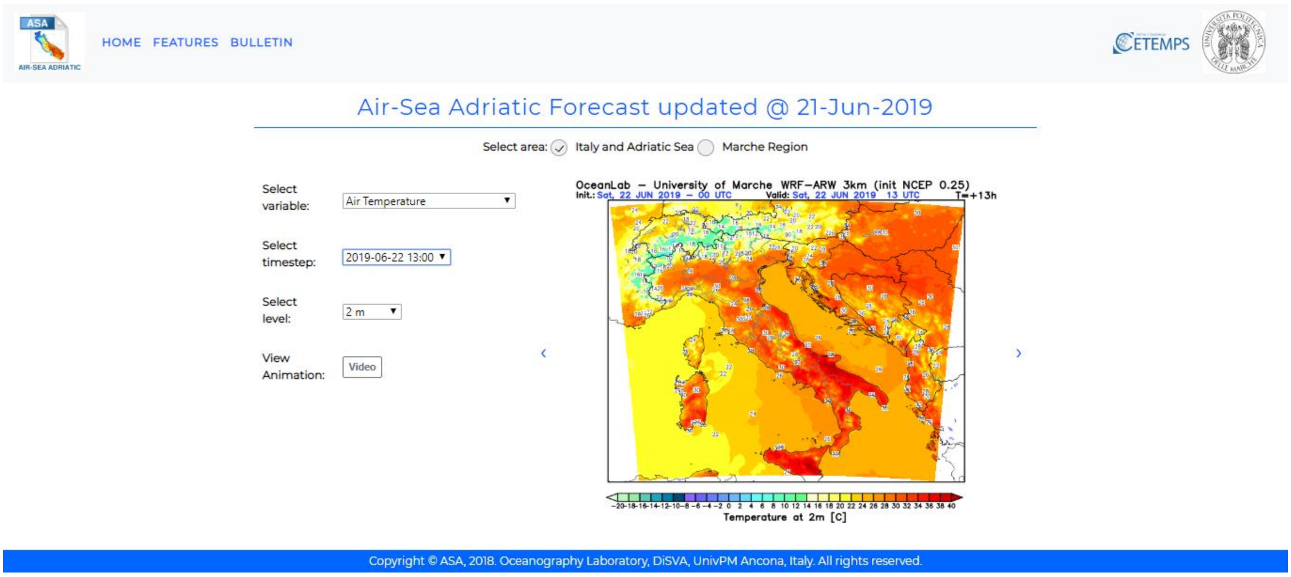

Figure 7. 2m air temperature @ 13:00 of June 22 2019 over the selected area “Italy and Adriatic Sea”.

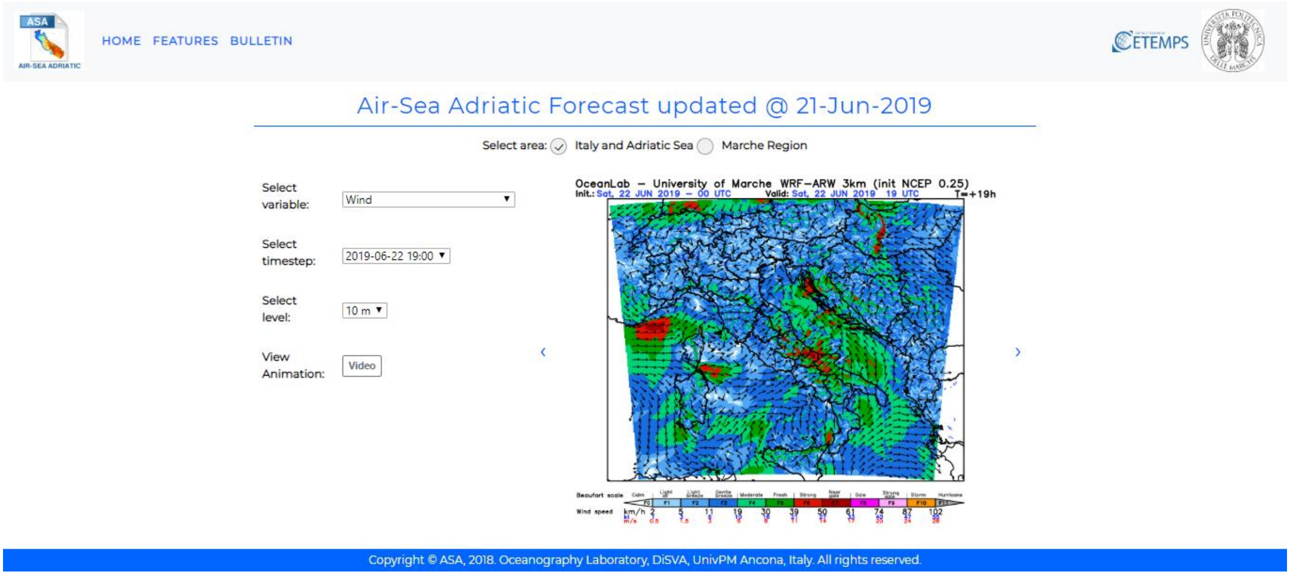

Figure 8. 10 m wind @ 19:00 of June 22 2019 over the selected area "Italy and Adriatic Sea".

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