WP5
Integration and testing of DSS for coastal flood and extreme weather early warning

Activity 5.4
Pilot Action around Neretva river estuary coastline area

D5.4.1
PAC: Pilot Action around the Neretva river estuary coastline area

PROJECT AND ACTIVITY DETAILS

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Activity Title	Pilot Action around Neretva river estuary coastline area
Work Package	WP5: Integration and testing of DSS for coastal flood and extreme weather early warning
Activity Summary	Activity 5.4, within work package 5, is devoted to test the developed modeling modules on a severe weather event chosen during the pilot action around the of the Neretva river estuary coastline area
Deliverable number	5.4.1
Deliverable Summary	This deliverable is aimed at describing the case study of the Croatian pilot action by means forecast and observation results

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Table of contents

Introduction

This report is aimed at describing the case study as well as forecast and observational results during the Pilot Action along Croatian coastlines (called PAC) devoted to the Dubrovnik region near the estuary of the Neretva river.

Will be described in the following sections one relevant case study that affected the Dubrovnik coastal area on June 1, 2019.

The PAC preparations activities have been started since the beginning of the project by completing successfully the WP3 and WP4.

In the framework of WP3 activities a weather radar composite software able to ingest and process data from systems with different features was developed and a WEB interface has been arranged where the instantaneous rainfall estimates for the Croatian and Italian composites are displayed in real-time.

In the framework of WP4 activities was implemented a coupled model, containing both a meteorological and a wave model, respectively called WRF and SWAN, adapted and calibrated over the target basin on a case study-basis. Moreover, was operationally implemented the CHyM hydrological model with *waveheight* module able to read sea level measurements in input, to modify the friction of the river flow in the river outlet, enhancing the coastal flood prediction capability.

In order to overcome to the objective foreseen for Deliverable 5.4.1, the CETEMPS Meteorological Model WRFAdria has been updated to a new version where the Croatian wind profiler data, located at Dubrovnik weather station, have been assimilated, adapted and calibrated over the target basin on a case study-basis. Moreover, the AdriaMORE new version of the CHyM hydrological model has been tested to predict the PAC hydro-meteorological identified event.

To this aim, the present document is organized as follows:

Paragraph 1: contains a description of the estuary of the Neretva river;
Paragraph 2: is devoted to the description of the major hazards that affect the estuary of the Neretva river area;
Paragraph 3: is devoted to the description of the case study occurred on 1st June 2019;
Paragraph 4: is devoted to the description and meteorological model results of the case study;
Paragraph 5: is devoted to the hydrological forecast description for the selected case study.
The references are available at the end of the document.

These activities have been carried out by CETEMPS and Meteorological and hydrological service of Croatia, the latter as partner of AdriaMORE project. It is worth recalling that the Centre of Excellence (CETEMPS) of the University of L’Aquila is a joint effort of the Dept. of Physics and the Dept. of Electrical Engineering, funded by the Ministry of Education and University of Italy starting from 2001. The research activity concerns mainly remote sensing, atmospheric physics, meteorology and hydrology. CETEMPS has a contractual agreement with the LP Region Abruzzo to support the accomplishment of some technical activities of AdriaMORE project.

1. Description of the estuary of the Neretva River

Delta, or the characteristic shape of the Neretva River estuary, attracts a great number of visitors due to the beauty of this nature park and its natural resources. The Neretva delta covers approximately 20,000 hectares of magnificent landscape, see **figure 1.1**.

Great amounts of water in the Neretva and Trebišnjica basins (in natural hydrological, economical, hydro-geological and climate conditions) are of crucial importance for the existence of the greatest Mediterranean swamp on the eastern Adriatic coast. The regulation of river Neretva and its affluents changed the erosion intensity in Neretva and Trebišnjica trough and basin, thereby causing bank disappearance important for the Delta.

Figure 1.1: Delta Neretva region in Croatia

Regime and quality of the ground water in the basin were modified by: building hydro power plants in the basins, constructing roads and urban centres in the Delta, gravel exploitation in the watercourse, sand in the estuary, swamp drying and transforming them into agricultural soil. In the region of Neretva delta separated swamp remains in the intensively cultivated and populated environment can be found. The beautiful swamp landscapes are: reduced former bogland areas, swamps, lakes and lagoons, fish feeding points. Salting of the Little Neretva basin, soil subsidence in the Delta, uncompleted of amelioration system, increased amounts of fecal waters from urban centres and landfills and digging of prohibited canals, that deepens the basin and enables greater flow of salty water seriously threatens the Delta environment and development of traditional production activities such as: agriculture, fishing, hunting and tourism.

River Neretva delta can be divided into three morphological parts: karst area, lowland Delta area and shore. Delta is characterized by its specific edge with abrupt angle alteration and solid limestone, that form circumferential area. Limestone form specific peaks that break out from quaternary Delta sediments. Neretva delta has specific widenings that are of Dinaridi spread. The area of Neretva delta is of approximately 170 km^2, partially (120 km^2 i.e. 70%) in Croatia.

For the Delta creation large amounts of river deposit and minimum amount of marine environment energy at the river estuary are necessary. According to estimates made at the beginning of 20th century Neretva river yearly produced around 500 000 m^3 of river deposit. Today, land and offshore relief in the area of Neretva estuary and valley is the result of tectonic movements, climate changes, sea level fluctuations during the geological history and erosion and sedimentation processes conditioned by them. Neo-tectonic movements from earlier Pliocene up to present time had crucial influence on the Delta creation. The base of the lower Neretva river flow origin is tectonically predisposed, but it is probably connected to a firmer fault zone vertical to the Dinaridi spread, along which the water formed Neretva's valley. Also, the global oscillations in the sea level are important, i.e. the sea level is a global boundary above which the erosion processes of the cliffs prevail. Underneath the boundary the accumulation processes of material predominate.

Neretva and Trebišnjica river basins territorially belong to two countries, Bosnia and Hercegovina and Croatia. Neretva springs 5 km south of Jabučica hill nearby Zelengora mountain on the altitude of 1.095 m. Neretva is 213 km long, but only 22,3 km are in Croatia. Its orographic riverside is 5.580 square kilometers and its complete riverside area is 10.100 square kilometers wide (Margeta and Fistanić, 2000). Climate characteristics of Neretva basin area vary depending on the sea distance. Lower area closer to the sea has Mediterranean climate, central area has continental and the most distant and highest area has mountain climate. Average annual value of precipitation is 1650 mm, and it varies within the limits from 1500 to 1800 mm per year. Temperature varies from -29 to +43 ^{o}C, and annual evaporation is from 500 to 900 mm. Average annual river flow is 269 m^3/s, with the lowest at 44 m^3/s and highest at 2170 m^3/s. Coefficient of water runoff is around 0,871 (Margeta and Fistanić, 2000) Karst structure of Neretva and Trebišnjica river basins conditions karst terrain characteristics and the way the rainfall water distils. Rainfall water flows through underground and surface courses is a factor of great importance for the values of ecological parameters. These parameters are of crucial influence for the development and biocenoses maintenance and very important for genesis of most morphological karst appearances, that are particular for that area. There are plenty of underground caves, pits, water springs, abyss, estavels, springs and karst fields on the different altitudes in the Delta region. Flood waters on the karst field that occur occasionally are of great importance for the quality water springs in the lower parts of the river basins including Delta edges.

2. Major hazards that affect the estuary of the Neretva river area

For the upper part of Neretva river basin intensive surface water flow is characteristic, and on the other side for the middle part of Neretva and Trebišnjica river basins underground water flow is specific (Mišetić and colleagues, 2005). Main natural underground water accumulations are formed in the mountain morphostructures (Čvrsnica, Čabulja, Prenj, Veležand others). The most complex character of a water flow is in the lower Neretva flow where underground inflow of water from karst field basins is intensive, especially from Popovopolje and Bačini lakes. Natural surface water accumulations that appeared every rainy period on the eastern and western sides of Neretva river are very important. Karst fields are mainly tectonically predisposed and shaped by egsogenic factors and processes (Milanovic and colleagues, 2004). Left and right side of Neretva basin and area of Trebišnjica basin are manly built from carbon rocks. For the left side of Neretva river (upstream from Konjic) Boračko lake is significant. Waters from karst field basins from which Bune, Bunice and Bregave springs are watered, are planned to be redirected by canals and tunnels towards Bileći. Realizing those plans – conducting water into Trebišnjica river basin would have catastrophic effects on Buna, Bunica and even drying Bregava spring, and it would damage Neretva's delta.

Technical interventions for draining of already mentioned karst fields have caused drying and/or decreasing spring abundance on Delta edges in comparison to values determined in 1960s, because significant draining interventions were conducted using canals and tunnels from karst fields. During June 2006 certain springs were observed and decreased abundance was determent in comparison to earlier abundances (Zelenika and Trenc, 2006). The Prud spring is the largest of observed springs, and the water was contained because of Opuzen, part of Metković, Pelješac, Mljet and Korčula water supply, and the rest of the water flows with a Norin river. Although the spring abundances along the right side of Delta are reduced, on this side there is more sweet water in comparison with the left side, for that reason on the right side of the Norina and Desenka basins there are five main protected sites on the area of 1620 ha (Vego I Radavić) in the categories of ornithology reservation (Pod Gredom, Prud I Orepak), ornithologic-ichthyologic reservation (Neretva's delta), i.e. protected landscape (Modrooko and Desne lake).

By the latest hydro-geological prospections of springs on the left and right Delta edges, the observed springs on the carbon cliffs were determined, also the water was of good quality for watering, but the amounts were insufficient during the vegetation period of crops. (Zelenika and Trenc, 2006). The quality of underground waters in the quarter aqueous layers of a lower Neretva river course is not acceptable for the crops watering. Quarter layers in the Delta, including areas: between Vid and Metković, Kuti, Koševo and Vrbovci, are analyzed on the field and in the laboratory examining the core collections obtained from bores that were unfortunately shallow (Hrvatskevode)

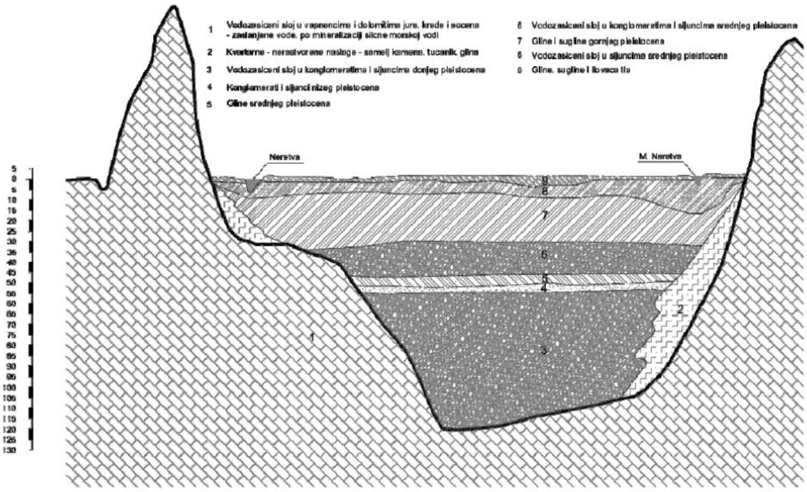

Figure 2.1:. Hydro-geological profiles of the Neretva river estuary

On the profile shown on the **figure 2.1** the relation of particular lithological formations of watered limestone and dolomites from Jurassic, Cretaceous and Eocene, to conglomerate watered layers with lower and middle Pleistocene gravel, Holocene sand, upper and middle Pleistocene clay, to clay soil. Latest explorations on the well field next to Neretva basin on the Gabela field supplying Neum with the drinking water supply show valuable results about salting underground waters (Džeba and colleagues, 2003). The ways of mixing sea and fresh water in the surface courses and in alluvial aqueous were examined. Based on five years of exploring of the Neretva river, results have shown layered type of sweet water course above the sea "wedge" that goes deeply upstream in the river basin. Under the influence of flux and reflux and water flow from upper part of river basin, "wedge" shifts upstream and downstream, and also up and down. "

Sea retracting into the river basin (**figure 2.2**) was also measured and examined. In fact, during rainy (winter) period, when there are more river basin inflows, the sea is completely pressed out of the river basin. By the end of spring and at the beginning of the summer river basin inflow is decreased. The river basin has minimal inflow at the end of the summer that is the result of hydro power plant operation regime. When the river basin reaches 50 m^3/s, the river is completely salted (Džeba and colleagues 2003).

Figure 2.2: Neretva river basin, estuary into the Adriatic Sea

The organic soil degradation (moss), the lack of river deposit sediments and other soil processes that occur during the agricultural crop cultivating, are the results of soil settling in the Delta region of about. 0,5 m in the last several years.

International forecasters expect the sea level rising on the Neretva river estuary by approximately 0,5 m as a result of climate changes, eternal glaciers melting and salty water volume increase in the next 40 years. For that reason it is necessary to adequately protect the precious lower Neretva river area by drafting and adopting ecologically most acceptable urban plans. Except building needed banks on adequate routs it is recommended to regularly water Delta region by muddy waters, that will provide sedimentation of important river deposits in the Delta region. Each hydro power plant in the basin has predicted technology and dynamics of sediment removal from its accumulations for the protection of useful water accumulation spaces by a certain project.

Since the project regulations of the sediment removal in the accumulation lakes are not in use, the new, improved, agreed and determined dynamic program for sediment release through each water gate and sediment transport through Neretva river basin to estuary is needed, considering the power plant and downstream water and bank users interests, and also providing needed deposits for the Delta that were missed during decades and caused significant damages.

Since the earlier tunnels for flood water were closed by bank deposits made to regulate the Neretva river, the amelioration project makers should participate in the analysis and correcting technical solutions of deposit removals from accumulation lakes, and they should also draft technically doable and economical solution of deposit distribution in the Delta region.

3. 1st June 2019: case study description

Two case studies have been selected for comparison of the WRF model outputs with and without assimilation of upper air wind data of wind profiler (hereafter WP) at Dubrovnik weather station. Results of validation tests have been discussed in the already delivered with reports on activity 4.1. One of the aforementioned case studies has been also chosen as case study for the PAC: it is 1st June 2019.

Day 1st June 2019 was the coldest day in June 2019 at Dubrovnik weather station. A cut off is visible in the field of 500 hPa surface heights over Adriatic Sea. A core of relative cold air circulate over that area. A weak hydrostatic instability is visibly over Adriatic sea (**figure 3.1**).

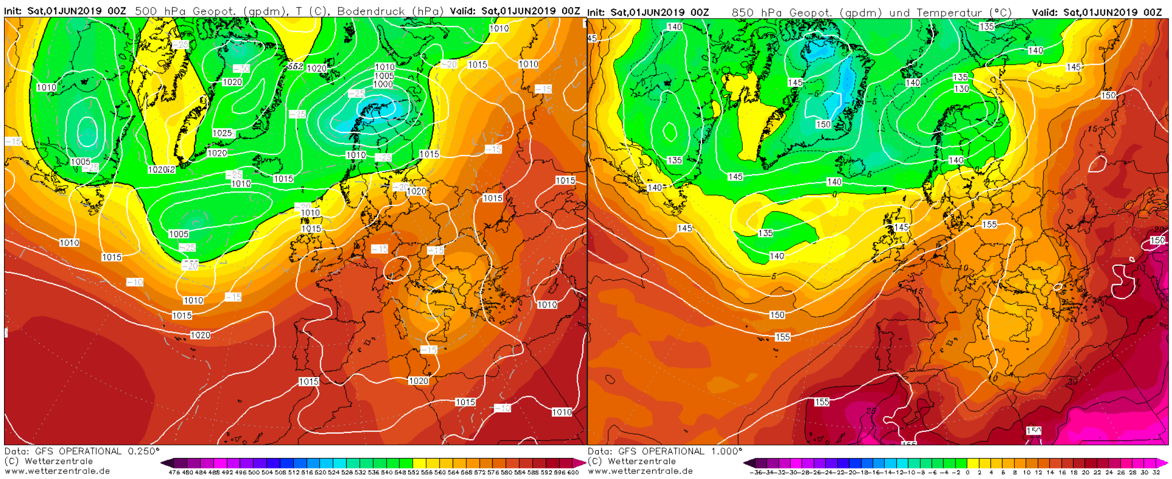

Figure 3.1: Geopotential height at 500 hPa (on the left) and temperature (°C) at 850 hPa (on the right) at 00UTC of Saturday 1 June 2019

Moreover, the ESTOFEX portal issued a level 1 across S-Bulgaria mainly for large hail and a level 1 across parts of Moldova and S-Ukraine mainly for large hail and a low-end tornado threat as shown in the following **figure 3.2**.

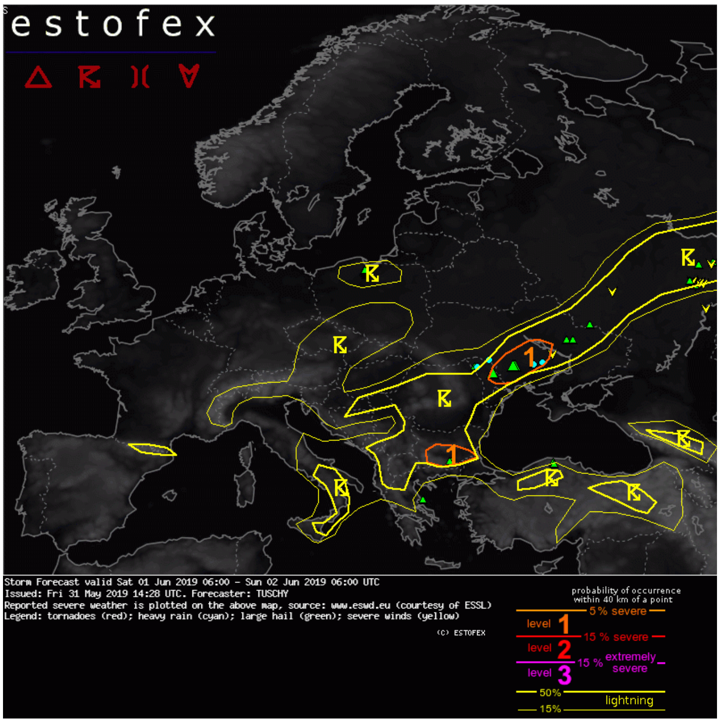

Figure 3.2: Storm ForecastValid: Sat 01 Jun 2019 06:00 to Sun 02 Jun 2019 06:00 UTC
Issued: Fri 31 May 2019 14:28

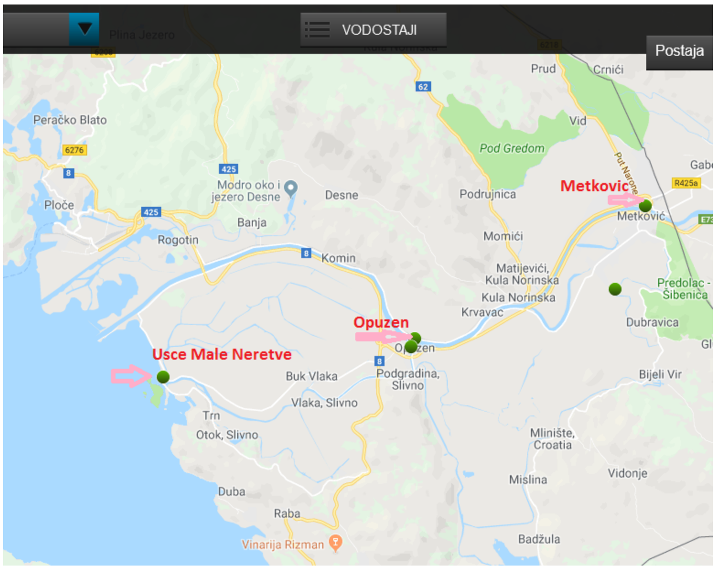

Figure 3.3: Hydrological station at “Estuary of Small Neretva”
on the sea coast

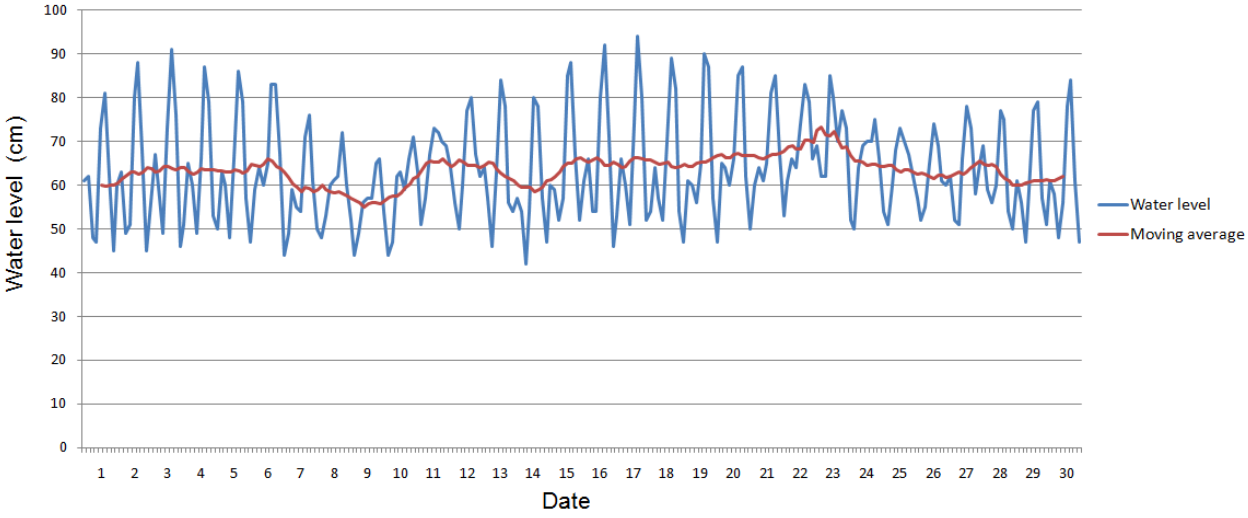

Figure 3.4: Presentation of water level (blue line) just on estuary of Mala Neretva River for June 2019, also representative for the whole the Neretva River delta. 24-hour period smoothing is represented by red line

In **figure 3.3** is shown the location of the Hydrological station at "Estuary of Small Neretva" on the sea coast.

From **figure 3.4** is obvious a strong influence of tides on water level in the Neretva delta during the whole June 2019 including June, 1 the pilot study. Precipitation amounts in the area were very small for the whole month thus variations of water level were strongly connected to sea level variations i.e. sea tides as well as wind direction and speed changes during a day i.e. sea and land breeze respectively which is also quasi periodic. Protection against salinization of the water in the Neretva delta is big issue. It is become even more and more important by expecting sea rise and flooding because of global warming. This are is one of the most vulnerable region on the Adriatic Coast due to very low elevation (mostly below 1m), somewhere even there are depressions.

4. Meteorological forecast

In the **figures 4.1 and 4.2** some Meteorological Model WRFAdria results are shown for the selected case study.

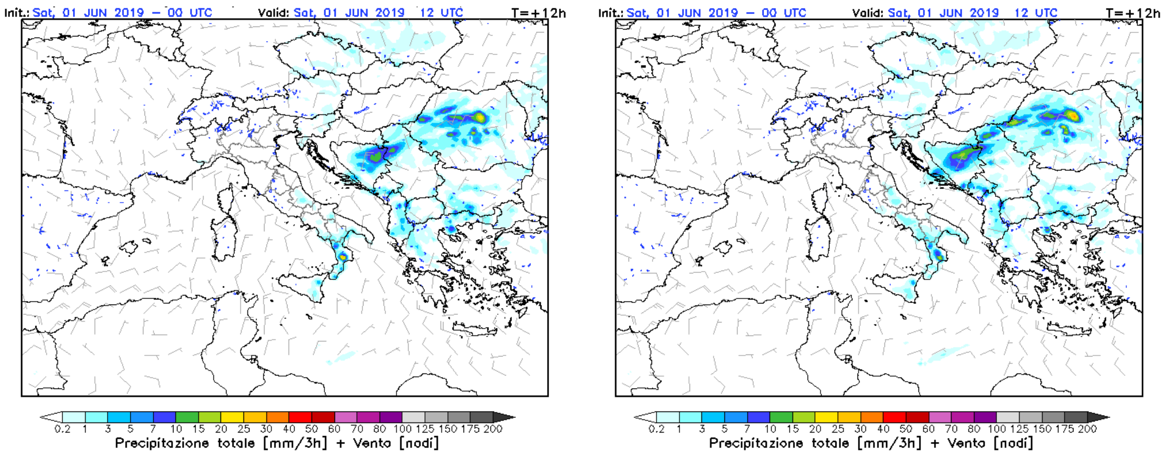

Figure 4.1: 3h accumulated precipitation and wind at 12UTC of Saturday 1 June respectively with WP data assimilated (on the left) and no WP data (on the right)

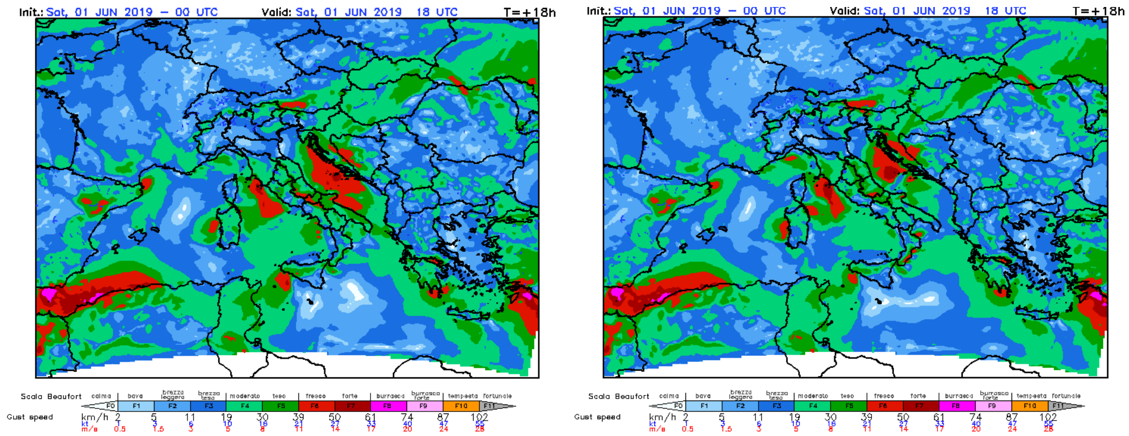

Figure 4.2: Wind gusts at 18UTC of Saturday 1 June respectively with WP data assimilated (on the left) and no WP data (on the right)

5. Hydrological forecast

The hydrological forecast was issued the day before the event (on May 31[sth]), resulting from a CHyM hydrological simulation initialized with 5 days where precipitation and temperature field were taken from the WRFAdria model previous simulations. The meteorological forecast was provided from the WRFAdria simulation for the following 72 hours. The forecasted rainfall fields from the WRFAdria model has been interpolated over the 330 m CHyM grid as shown in **figure 5.1**. As shown in the previous section, maxima precipitation peaks over the Neretva basin were around 30 mm in 24h, while strong winds with intensity between F5 and F6 affected the Croatian coastal area. The precipitation amount itself is not sufficient to produce a significant discharge peak over the Neretva final path. However, a weak stress signal is given by the BDD index (**figure 5.2**) in the final Neretva grid-points, due to strong winds action on the sea.

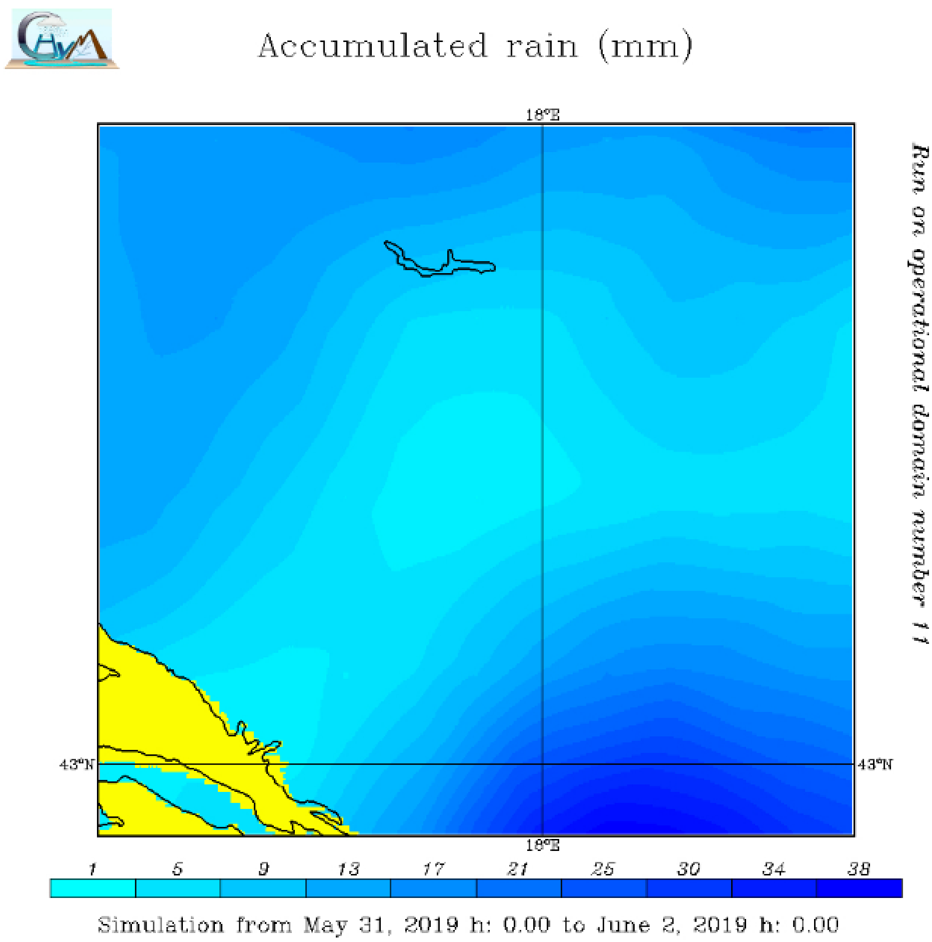

Figure 5.1: Accumulated precipitation (mm) during the PAC case study

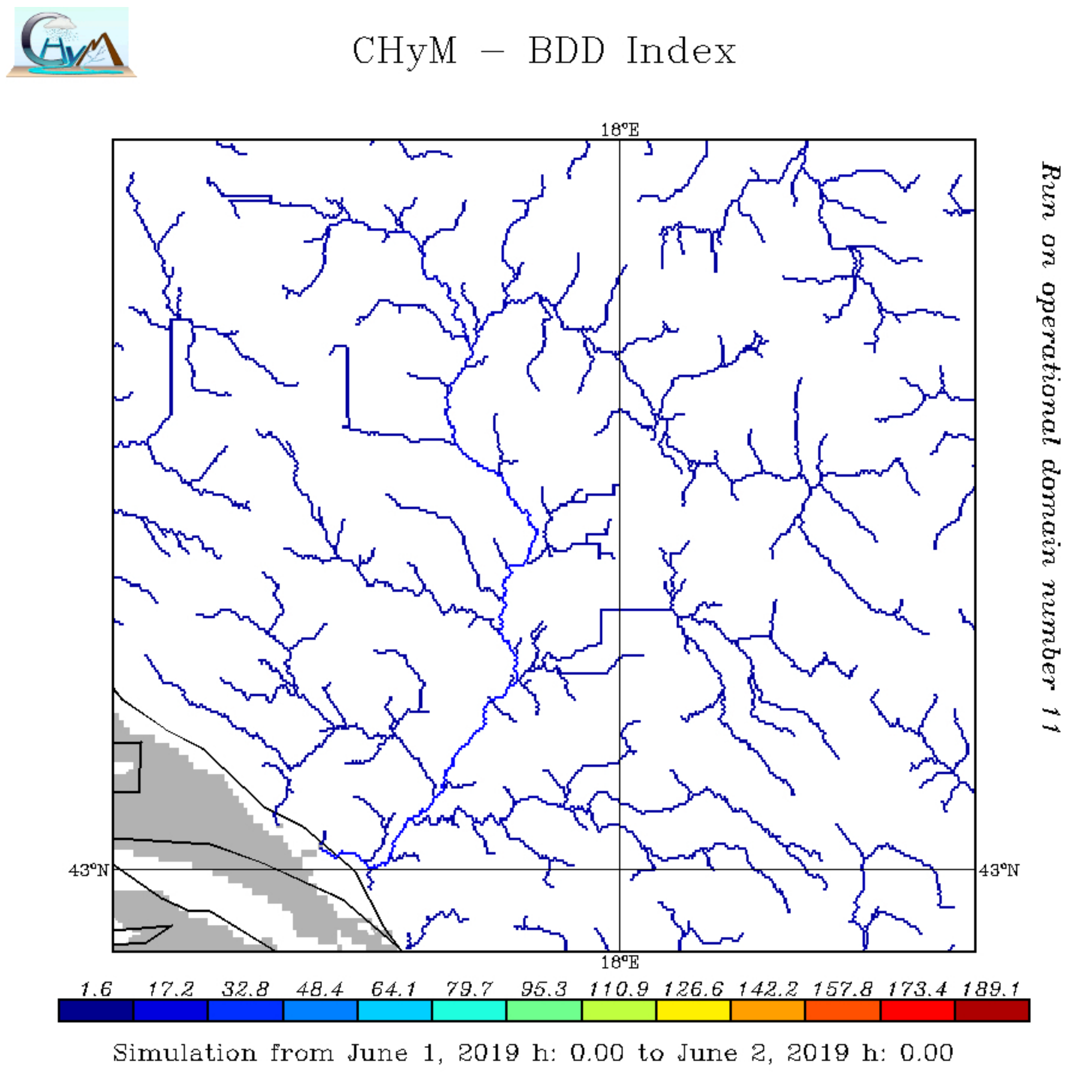

Figure 5.2: BDD stress index map for 1st June 2019 2019

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