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FLASH-FLOOD IN PULA IN THE NIGHT BETWEEN 24 AND 25 SEPTEMBER 2010

Povodanj u Puli u noći s 24. na 25. rujna 2010. godine

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Abstract: A flash-flood event in the western part of Croatia during the night between 24 and 25 September 2010 is analyzed by means of satellite, radar, lightning and rain-gauge measurements and NWP model data. A relatively rare positioning of two Mediterranean cyclones induced a strong convergence zone in the Northern Adriatic. One of the heavy precipitation episodes stroke the town of Pula and the surrounding Istrian inland resulting in 176 mm of rain in less than 7 hours, the highest daily amount ever measured in Pula. Operational 8 km resolution hydrostatic ALADIN model forecast satisfyingly the existence of twin cyclones and precipitation maximum over the sea. The processes that led to the development of the secondary maximum inland were explored using the 2 km resolution non-hydrostatic ALADIN model.

Key words: flash flood, Istria, convective precipitation, convergence, Mediterranean cyclones, ALADIN

Sažetak: Povodanj u zapadnom dijelu Hrvatske u noći s 24. na 25. rujna 2010. analiziran je u ovom radu pomoću satelitskih i radarskih podataka, podataka o električnom pražnjenju te kišomjera, kao i pomoću numeričkog modela za prognozu vremena. Razmjerno rijedak položaj dvije mediteranske ciklone uzrokovao je pojavu izražene zone konvergencije u Sjevernom Jadranu. Jedna od epizoda s obilnom oborinom zahvatila je Pulu i njezino zaleđe, pri čemu je palo 176 mm kiše u manje od 7 sati, što je u Puli najveća ikad izmjerena dnevna količina oborine. Operativni hidrostatski ALADIN model rezolucije 8 km zadovoljavajuće je prognozirao postojanje dvije ciklone, kao i maksimum oborine iznad mora. Procesi koji su rezultirali sekundarnim maksimumom oborine nad kopnom razmatrani su nehidrostatskim modelom ALADIN rezolucije 2 km.

Ključne riječi: povodanj, Istra, konvektivna oborina, konvergencija, mediteranske ciklone, ALADIN

1. INTRODUCTION

During the night between 24 and 25 September 2010 heavy rain caused flash-flooding of the town of Pula and the surrounding area. In Valbandon, Fažana and Veli vrh 200 mm of rain fell in less than 7 hours causing extreme communal difficulties. In these extreme event vineyards, olive groves and roads were flooded, transport and electricity supplies were interrupted. Currents of muddy water damaged houses and streets and people had to be evacuated from their homes flooded by up to 1 m of water.

This study will show that the flooding was the result of a convective system which developed in the convergence zone caused by a specific placing of two Mediterranean cyclones. Generally, the Mediterranean region is recognized as one of the most cyclogenetic regions in the world (Campins et al., 2000; Alpert et al., 1990). According to Horvath et al. (2008), cyclones that cross the Adriatic are classified in 4 major types: Genoa cyclones, Adriatic cyclones, mixed Adriatic-Genoa and non-Genoa cyclones that are further divided into two sub-types. The major-type cyclones can exist simultaneously belonging to the theoretical category of twin or eyeglass cyclones, a phenomenon which appears and is documented worldwide. A case of cyclogenesis in the mid-Mediterranean, in the vicinity of the Alps, was simulated by Mesinger and Strickler (1982) who called it also an »eyeglasses cyclogenesis« literally translating the local Italian expression »ciclogenesi ad occhiali«. Further investigations of the twin cyclones show the orographic influence on the separation of centres in the Adriatic and the Tyrrhenian area, which is usually evident at levels below 700 hPa. (Brzović and Jurčec, 1997). Nevertheless, the most common twins are the simultaneous Genoa and Adriatic cyclones (Brzović, 1999), therefore classified in Horvath et al. (2008), as the 4th type of Mediterranean cyclones. Depending on the season and general synoptic conditions, the paths of the cyclones in the Mediterranean basin are different. On their way through this complex geography, they can produce a range of extreme weather phenomena such as heavy orographic precipitation, thunderstorms, supercells and mesoscale convective systems (Ivančan-Picek et al., 2003). The local intensity of the precipitation is also very much dependent on the available moisture. The heaviest rain events take place when the cyclone path is in such position that it produces the convergence of moist air supplying a large quantity of precipitable water (Lionello et al., 2006).

In this particular case the convergence line above the North Adriatic was the result of the interaction of the flows driven by the two cyclones placed in Tyrrhenian and Ligurian Sea, respectively. Remote sensing data including satellite, radar and lightning observations give the opportunity to monitor the relevant development. Finally, the ALADIN/HR model results show how well a numerical model can capture the details of such an event.

2. SYNOPTIC CONDITIONS

The large-scale situation preceding the event was characterized with a deep upper-level trough stretching from western Scandinavia to southern France with the secondary trough located in the

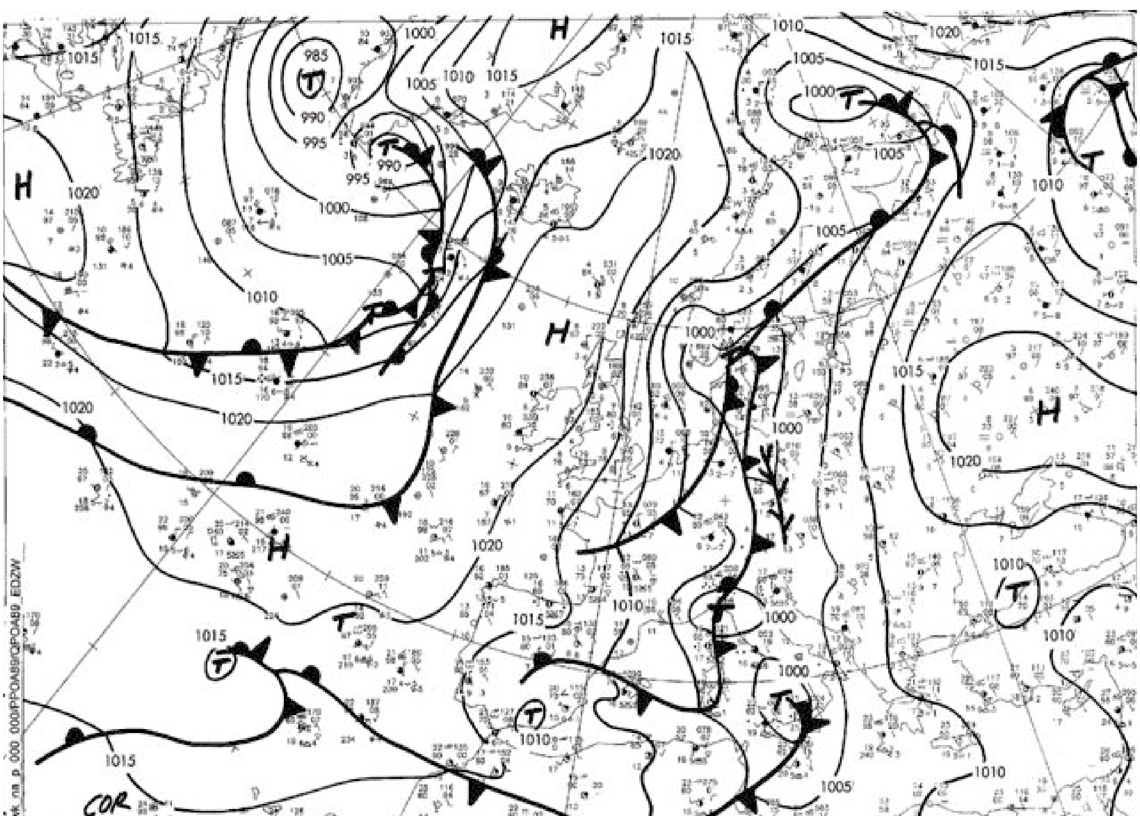


Figure 1. DWD surface analysis for 25 September 2010, 00 UTC

Slika 1. DWD prizemna analiza za 25. rujan 2010., 00 UTC

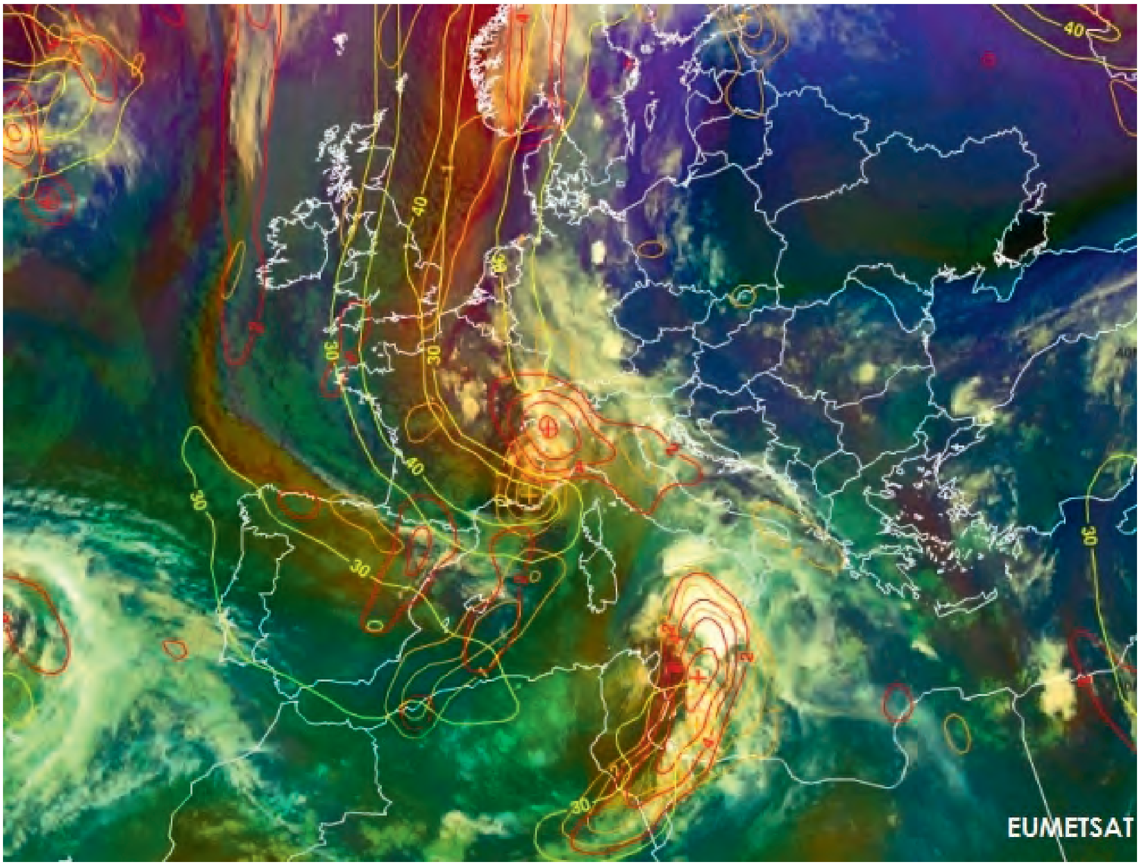
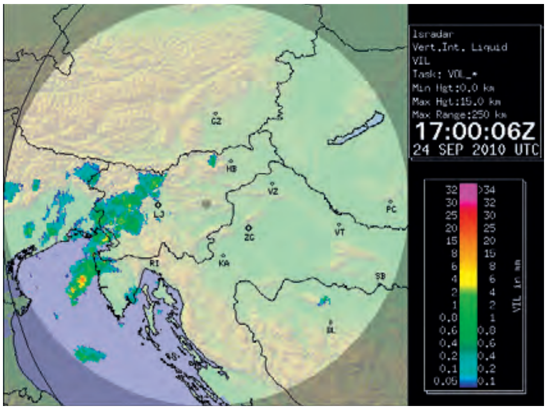


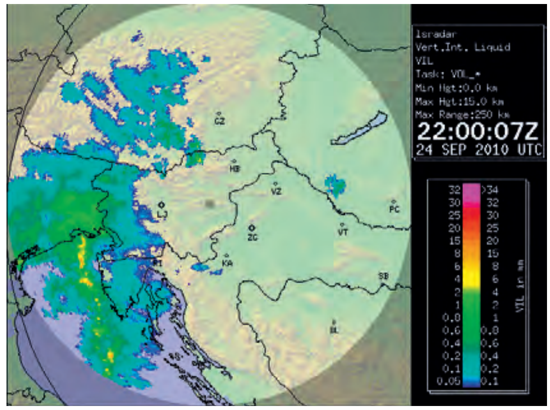
Figure 2. METEOSAT 9 Airmass RGB image for 24 September 2010, 18 UTC overlaid with ECMWF forecast PVA at 500 hPa (orange), PVA at 300 hPa (red) and isotachs at 300 hPa (yellow)

Slika 2. METEOSAT 9 Airmass RGB za 24. rujan 2010., 18 UTC zajedno sa prognostičkim poljem ECMWF - PVA na 500 hPa (narančasto), PVA na 300 hPa (crveno) i izotahe na 300 hPa (žuto)

Mid-Mediterranean. In the evening of 24 September, a well developed cyclone moved eastwards over the Tyrrhenian Sea. Six hours later, around midnight of 25 September, the upper-level trough moved toward the east. At the rear side of the western trough, in the strong northerly flow, the cold air was penetrating over France into the West Mediterranean. Due to large pressure gradients in the mid-levels at the front side of the trough, southerly and south-westerly winds over northern Italy and northern Adriatic were rather strong. The area of northern Adriatic and Istrian peninsula was hence undergoing the advection of warm and humid air while in the large area of Mid-Mediterranean cold advection prevailed as the clear sign of the ongoing cyclogenesis. The secondary trough over the Central Mediterranean did not move significantly maintaining a persistent southerly and south-easterly flow. Associated with the two upper-level systems, at the surface level two low-pressure centres emerged, one in Tyrrhenian Sea and the other in the Genoa Bay, as depicted in the surface analysis chart (Fig. 1).

In Figure 2, the Airmass RGB composite shows the convective clouds affecting the large area around the fully developed southern cyclone at 18 UTC on 24th September 2010. This particular satellite composite, based upon data from infrared and water-vapour channels from Meteosat Second Generation, nicely resolves airmass characteristics in cloud-free areas and reveals cloud height in cloudy areas. On the other hand, the reddish area over the Northern Sea and France shows the intrusion of dry stratospheric air with high potential vorticity to the Alpine region where the cyclogenesis was going on. Pronounced positive vorticity advection (PVA) maxima both in 300 and 500 hPa triggered and maintained strong convection in the unstable air over the Western Alps and the Mid-Mediterranean. The PVA fields were derived from the ECMWF (Europen Centre for Medium-range Weather Forecast) forecast fields.





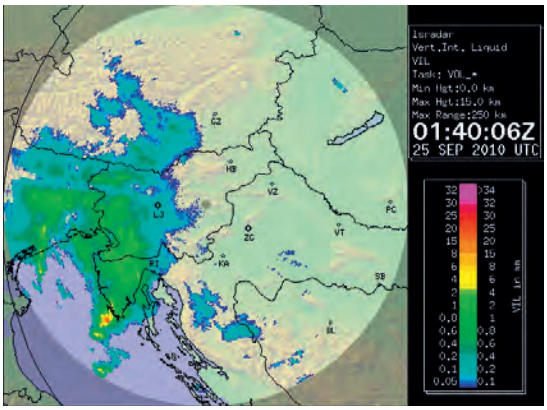


Figure 3. Lisca Radar vertically integrated liquid in mm for 24 September 2010 at 17:00 UTC (left), 22:00 UTC (right) and 25 September 2010 01:40 UTC (botom left).

Slika 3. Oboriva voda u vertikalnom stupcu izmjerena radarom na Lisci u mm za 24. rujan 2010. u 17:00 UTC (lijevo), 22:00 UTC (desno) i 25. rujan 2010. u 01:40 UTC (dolje lijevo).

3. MESOSCALE INVESTIGATION

In the afternoon of the 24 September scattered showers in northern Adriatic basin started. Due to persisting warm and moist flow, showers intensified and spread to the whole area. According to the Lisca radar data, the only measurements available over the sea, the hourly precipitation amounts exceeded 50 millimetres. Since there are no radars along the Adriatic coast these were the only data available for the analysis of the development in northern Adriatic. Radar echoes in Figure 3. show that until 22:00 UTC most of the convective activity took place over the sea.

Since the low-level synoptic conditions were characterized by the south-easterly flow at the front side of a cyclone moving eastwards through the Tyrrhenian Sea, the formation of the second cyclone in gulf of Genoa caused the strong convergence along the western coast of Istrian peninsula creating the favourable environment for enhanced convection (Holton, 1992). The convergence line is present in low troposphere up to 850 hPa and one at 925 hPa is depicted in Figure 4.

During the night the entire system started moving eastwards and at 01:40 UTC convective activity developed within the cloud system near the tip of Istria. The intense convective system protruded into the Istrian land, continued its path along the trajectory perpendicular to the convergence line and in the next 6 hours caused severe damages along the way. Particularly, the highest 24-hourly rainfall of 198.9 mm was measured in Vodnjan, a village northeast of Pula, 170.2 mm in Juršići, 8 kilometers further north and 162 mm in Gologorica, a settlement deep inland. In Pula, the largest town of the region, the measured rain-gauge precipitation reached 176 mm (Fig. 5). This is the highest daily amount on record. Moreover, 120 mm of that total amount was recorded in only 3 hours, between 01:00 and 04:00 UTC.

Besides the strong large-scale horizontal convergence, a favourable environmental vertical wind shear, within the flow veering from south-easterly at the ground level to south-westerly at the top of the troposphere, sustained the convection. The area was therefore affected by the continuous advection of moisture in the warm sector of the system. Total precipitable water reached values greater than 30 mm over the coastal areas and greater than 35 mm over the sea and also over the horn of Istria giving the indication for the high

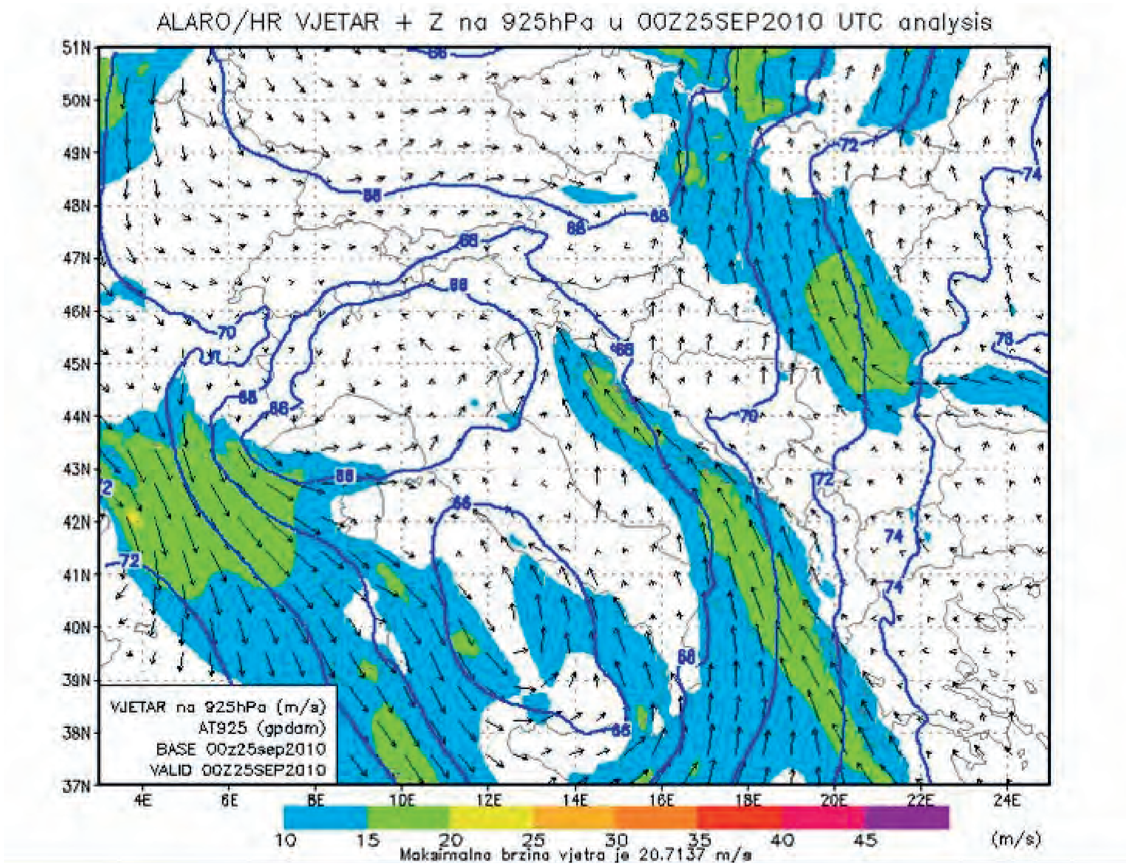


Figure 4. Horizontal wind at 925 hPa ALADIN/HR model analysis in 8 km resolution for 00 UTC on 25 September 2010

Slika 4. Horizontalni vjetar na 925 hPa plohi, analiza ALADIN/HR modela na 8 km rezoluciji za 25. rujan 2010. u 00 UTC

precipitation amounts. Similar values of precipitable water were measured in vertical soundings in San Pietro Capofiume, Udine and Zadar stations at 00 UTC on 25th September 2010.

4. PRECIPITATION FORECASTING

A large-scale analysis of synoptic situation was made using data from Deutcher Wetterdienst and model data from the European Centre for Medium-Range Weather Forecasts (ECMWF), while the mesoscale analysis was based on the ALADIN (Aire Limitèe Adaptation Dynamique developmènt InterNational) forecast model. The capability of the ALADIN model to predict heavy precipitation events over the eastern side of the Alps during MAP (Mesoscale Alpine Program) was verified by comparing the HRID (High Resolution Isentropic Diagnosis) vertical time cross-sections based on vertical-sounding measurements and the ALADIN/LACE prognostic pseudo-TEMPs (Ivančan-Picek et al., 2003). This study is concerned mainly with the analysis of meteorological fields.

Forecast of the event was based on the meso-scale hydrostatic ALADIN/HR model that runs at the Meteorological and Hydrological Service of Croatia, 2 times a day (starting from 00 and 12 UTC analyses) with horizontal resolution of 8 km on 37 levels in the vertical (Ivatek-Šahdan and Tudor, 2004) up to 72 hours in advance. Model version used for operational 8 km resolution forecast uses prognostic treatment of TKE and prognostic condensates (cloud water and ice, rain and snow) but diagnostic convective precipitation parameterization (Geleyn et al, 1994). The analysis shown here is based on the model run initialized with the 00 UTC analyses on 24 September 2010.

Surface pressure forecast (Fig. 5) was in good agreement with the analyses in terms of position and intensity of the two lows (Fig. 1). Thus the frontal systems and the large-scale convergence west of Istria were predicted correctly. The model predicted heavy rain in the area of northern Adriatic both stratiform and convective (Fig. 6). The

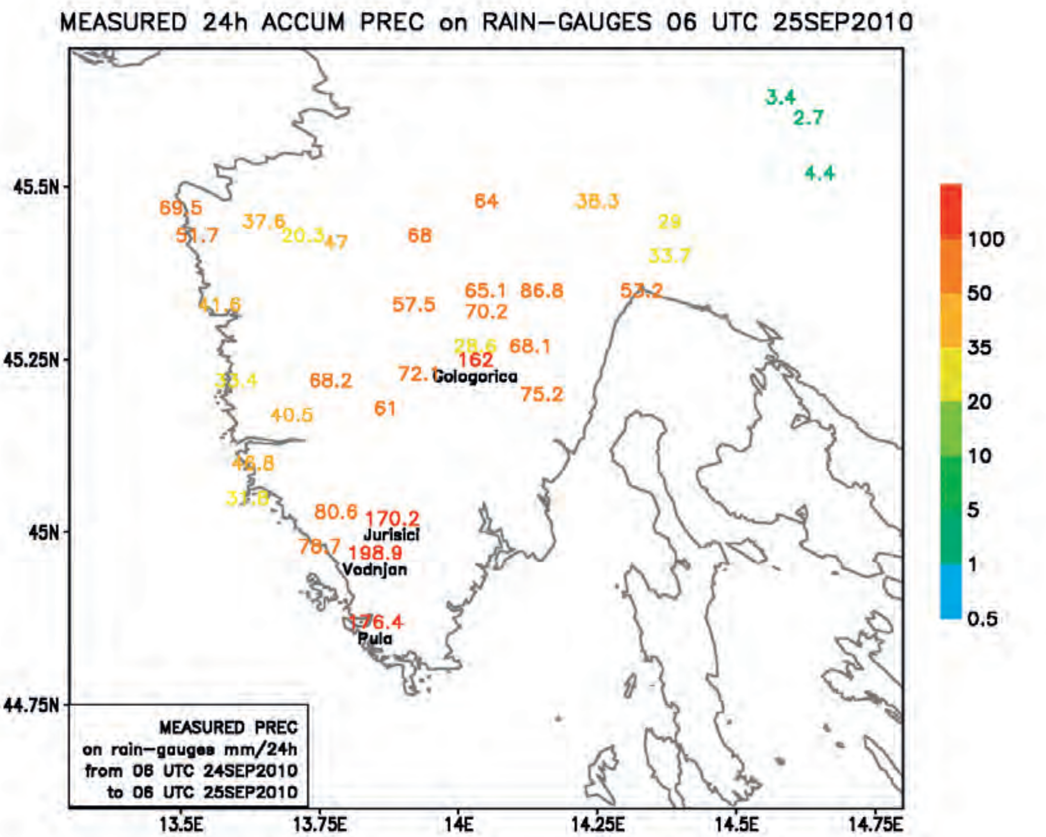


Figure 5. 24 hours rain-gauge precipitation accumulation measured on 25 September 2010 in Istrian area

Slika 5. 24-satna akumulirana oborina izmjerena na kišomjernim postajama 25. rujna 2010 na području Istre

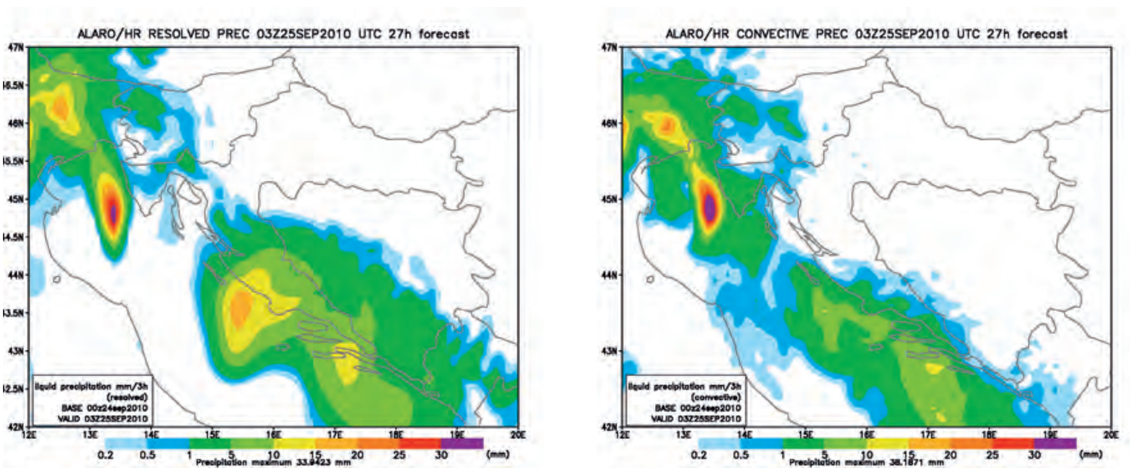


Figure 6. Forecast 3-hourly accumulated resolved (left) and convective (right) precipitation forecast by ALADIN/HR model valid at 03 UTC on 25 September 2010.

Slika 6. Prognostička 3-satna akumulirana razlučena (lijevo) i konvektivna (desno) oborina iz modela ALADIN/HR u 03 UTC za 25. rujan 2010.

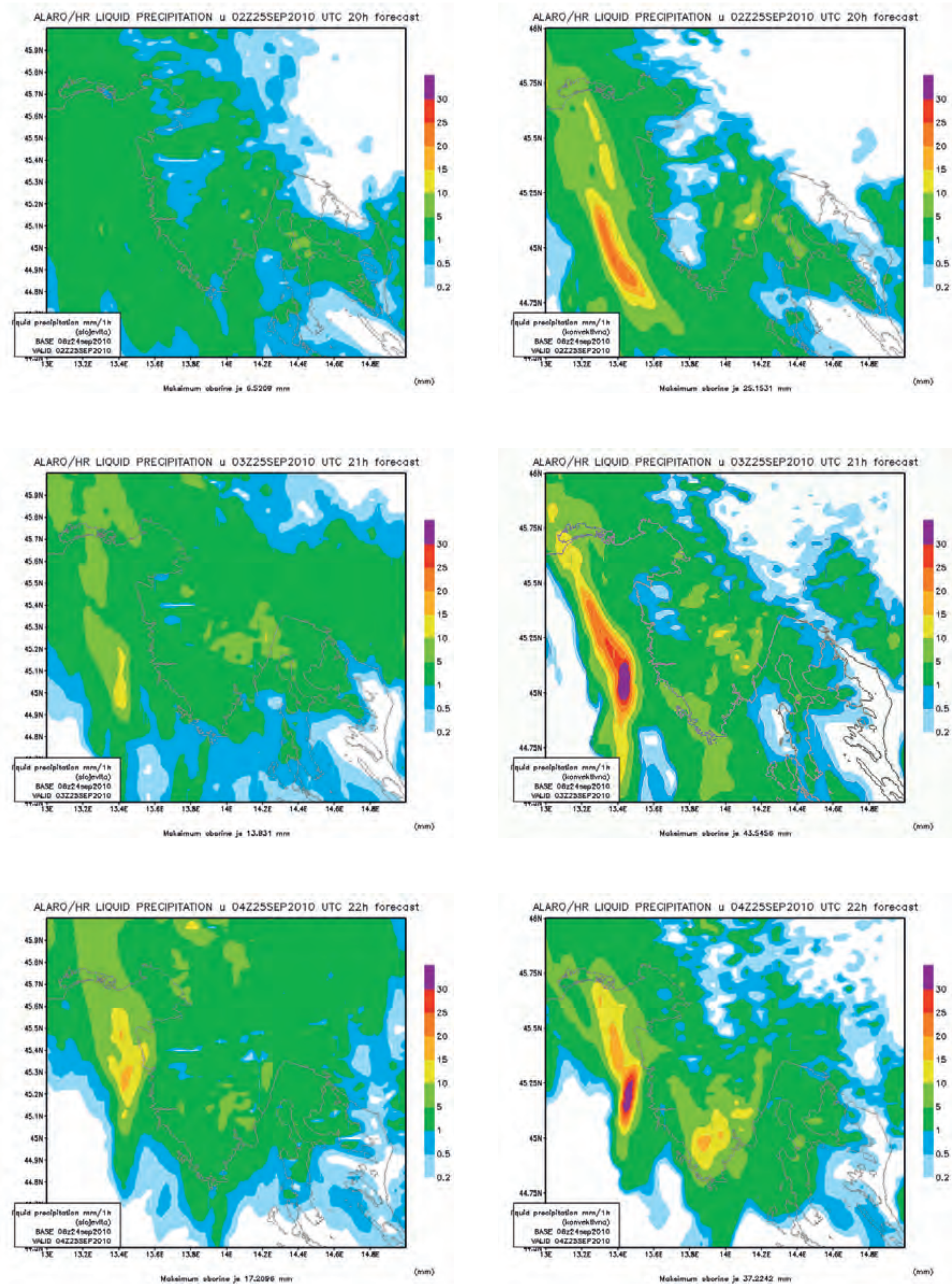


Figure 7. Hourly accumulated resolved precipitation (left) and convective precipitation (right) forecast by non-hydrostatic ALADIN/HR model in 2 km resolution valid at 02 UTC (upper), 03 UTC (middle) and 04 UTC (lower) on 25 September 2010.

Slika 7. Prognostička satna akumulirana razlučena oborina (lijevo) i konvektivna oborina (desno) dobivena nehidrostatskom verzijom modela ALADIN/HR na 2 km rezoluciji za 25. rujan 2010. u 02 UTC (gornji red), 03 UTC (srednji red) i 04 UTC (donji red).

maximum over the sea was forecast correctly, but with the delay of 3 hours.

Nevertheless, there was no indication of the secondary precipitation maximum over Istria, which caused the flash-flood. The processes that lead to the development of the secondary rainfall maximum were further explored using the 2 km resolution non-hydrostatic ALADIN model. This model version employs prognostic deep convection parametrization that enables memory, advection and diffusion of prognostic variables that describe the convection processes: updraft and downdraft vertical velocities and mesh fractions (Gerard, 2007). The model set-up is described in detail in Tudor and Ivatek-Šahdan (2010).
It can be noted that the precipitation is mostly convective, especially the inland maximum (Figure 7). Maximum over the sea corresponds nicely and is advected towards the east with the convergence line.

5. CONCLUSION

A relatively rare positioning of the two Mediterranean cyclones induced a strong convergence zone in northern Adriatic. Intense convective activity developed during the night between 24 and 25 September. One of the heavy precipitation episodes stroke the south-western part of Istria peninsula amounting 176 mm of rain in less than 7 hours, the highest daily amount ever measured in the town of Pula. The resulting flash-flood caused heavy damage in the area of concern.
Operational 8 km resolution hydrostatic ALADIN model forecast the precipitation maximum over the sea with a delay 3 hours, but in the correct position. There was no indication of the secondary maximum over the Istrian land, which caused the flash-flood. Using the 2 km resolution non-hydrostatic ALADIN model the secondary maximum over the Istrian land appeared, although remarkably underestimated.
Flash flood events arise from high to extremely high rainfall rates. (Doswell et al, 1996.)

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