MECHANISMS PRODUCING HEAVY PRECIPITATION EVENT IN THE SOUTHERN ADRIATIC AREA

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(Dated: 26 August 2011)

I. INTRODUCTION

Heavy precipitation events (HPEs), usually associated with devastating flash floods, are the most ubiquitous hazardous weather phenomena in the Mediterranean region. Two climatic maximums of the yearly precipitation are located over the eastern part of the Adriatic Sea. The mean annual precipitation > 3000 mm has been recorded over the Northern and Southern Adriatic and its mountainous hinterland (Zaninović, 2008). Daily surface rainfall greater than 200 mm is not uncommon. Most of these intense precipitation events occur during the autumn season between October and December.

The present study is an examination of the mesoscale causes of intensification of extreme precipitation event occurred in the morning hours on 22 November 2010 over Dubrovnik, Croatia and the surrounding area of the southern Dinaric Alps mountain range. The rain gauge measurements in Dubrovnik exceeded 160 mm / 24 h, with a peak intensity of 71.5 mm/h. The event caused severe flash floods, landslides, interruption of traffic and electricity supply as well as other infrastructural damage costing more than 25 million EUR.

The purpose of the research is to identify the main mesoscale features and mechanisms responsible for the generation of this heavy precipitation event in the Southern Adriatic area.

II. CLIMATOLOGICAL CHARACTERISTICS

The precipitation regime characteristics over the broader Dubrovnik area show the huge spatial differences (Gajić-Čapka, 2010). Annual mean precipitation ranges from about 600 mm over the islands to more than 5000 mm in the southeastern Montenegro (Magaš, 2002). The maximum is reached on the high mountains (Orjen over 5000 mm, Crkvice 4926 mm at height of 940 m, Radoičić even 5155 mm).

The complex orographic structure in the broader Dubrovnik area favours the lifting of the low-level unstable air and initiation of condensation processes. This region is one of the rainiest parts in Europe.

III. CASE OF 22 NOVEMBER 2010

The precipitation occurring in the morning on 22 November 2010 is described through 10-min rain gauge data recorded in Dubrovnik. Rainfall amount was 160 mm in less then 5 hours (between 8 and 12 h). Maximum amount for the interval of 60 minutes (71.5 mm) has the return period of 25 years.

The mechanisms responsible for the formation of convection have been analyzed though satellite data and numerical experiments performed with the WRF model, which was set up at the convection-resolving resolution (2 km) in the innermost domain. The areas corresponding to the two nested model domains each with 40 vertical levels are shown in Figs 1 and 2 and the main model features include Betts-Miller convection scheme, Morrison microphysics and Noah land-surface model.

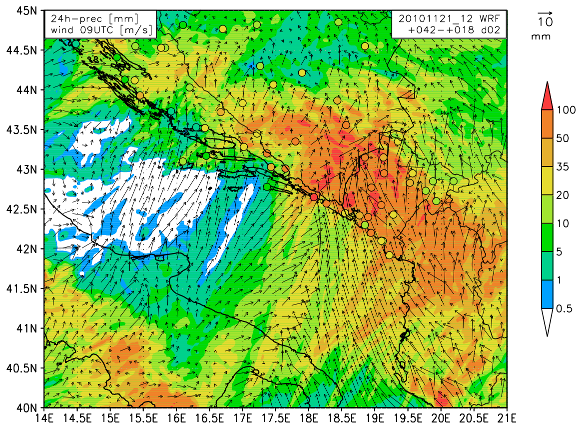

FIG. 1: 24-h observed (circle) and modelled precipitation (mm, shaded as in legend) from 22 to 23 November 2010, 06 UTC and 10-m wind vectors at 09 UTC 22 November 2010. The area corresponds to the inner model domain (2 km grid spacing).

The synoptic environment was characterized by a deep cut-off low moving from northern Europe over the Alps and western Mediterranean with an upper-level jet approaching the southern Adriatic area from the southwest. The associated frontal system covered most of the central Europe and the mid-Mediterranean. During the passage of the cold front over the southern Italy and Adriatic Sea, a secondary cyclone developed and a meso-scale convective system grew within (Tudor et al., 2011).

At the same time, one SW LLJs was elongated from Italy toward middle Adriatic and another S-SE LLJs at the Otranto strait (Fig. 2). The analysis of the surface wind field shows the channelling effects of the southern Adriatic mountains and Otranto strait.

Those two LLJs caused later on the appearance of the low-level wind convergence over the South Adriatic (Fig.1 and Fig.3). This process was connected with the strengthening of the S-SE LLJs at the Otranto strait. The upslope flow, very moist as a result of a fetch over the sea (2-m relative humidity is over 90%), impinges on the coastal orography. Persisting for about four hours, the convergence line contributed to large precipitation amounts in the Southern Adriatic area.

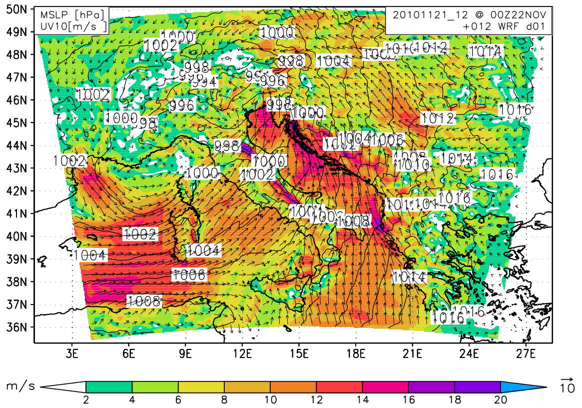

FIG. 2: WRF model sea level pressure (solid line, 2 hPa interval), wind vectors and wind speed (shaded as in legend), 00 UTC 22 November 2010. The area corresponds to outer model domain (8 km grid spacing).

Romero *et al.* (2000) have pointed out the role of the nearby mountain ridges in enhancing the low-level jet and/or inducing upwind low-level convergence.

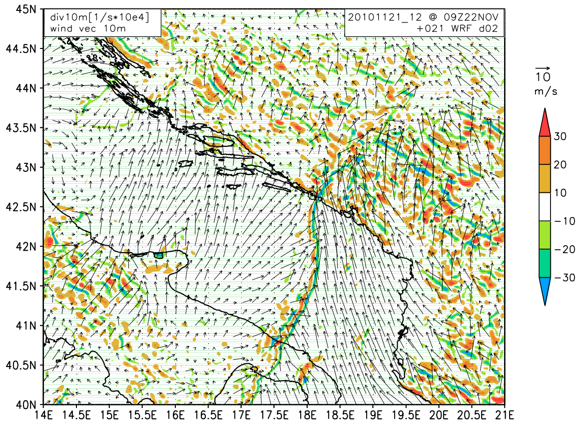

FIG. 3: WRF model 850 hPa wind vectors and divergence (shaded as in legend), 09 UTC 22 November 2010.

In the upper levels convergence is evident also from the satellite images. In Fig. 4, showing the 6.2 μm image at 08 UTC, black regions are the regions of very dry air along the jet streams. The two jets are converging over the south Adriatic and the strongest convective development occurs in the left exit region of both jets.

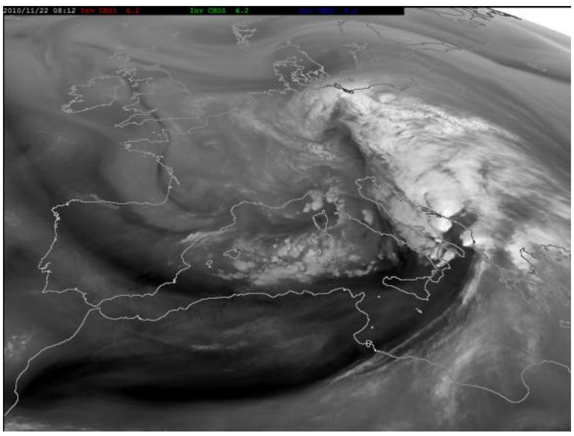

FIG. 4: Meteosat 9 WV 6.2 μm image, 08 UTC 22 November 2010.

IV. SATELLITE - BASED RAINFALL ESTIMATE

In order to identify the precipitation systems and to estimate the intensity of the precipitation during the period of interest, meteorological products derived from the satellite data were used. The analysis of these products provided valuable information especially over the sea, where no other observation data were available. Convective Rainfall Rate (CRR) product (http://www.nwcsaf.org/HTMLContributions/SUM/SAF-NWC-CDOP-INM-SCI-ATBD-05_v3.1.1.pdf), derived by the algorithm developed within the SAF NWC (Satellite Application Facility on support to Nowcasting and Very Short-Range Forecasting**)**, estimates rainfall rates of the convective systems, using the 10.8 and 6.2 μm MSG SEVIRI channels at night, whereas during daytime 0.6 μm channel is added to the algorithm. The CRR algorithm is based on the assumption that the higher and thicker the clouds are, the higher is the probability of precipitation occurence and its intensity. In the regions where radar data are available CRR is calibrated by the calibration matrices generated from both SEVIRI and radar data. Therefore, CRR can be compared to the precipitation rates measuered by the radars, which was especcially important in this case, because of the lack of radar data over the east Adriatic coast and the Adriatic Sea. CRR product is derived from each Meteosat 9 scan, every 15 minutes. From 0530 UTC on the hourly raifall rates were higher than 10 mm/h whereas in several time-steps rainfall rate was between 30 and 50 mm/h over the land (Fig. 5).

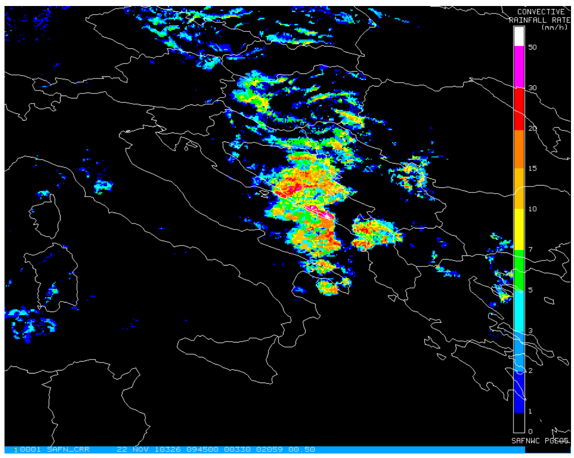

FIG. 5: CRR satellite product, 0945 UTC 22 November 2010 (colours stand for values in mm/h according to the scale).

From the image in Fig. 5, showing the instantenuous convective rainfall rate at 0945 UTC, it is evident that rainfall rate in Dubrovnik region was between 30 and 50 mm/h, whereas on the border with Montenegro it was even exceeding 50 mm/h. These amounts correspond to maximum measured rainfall rate of 71.5 mm/h in Dubrovnik. Over the sea the rainfall rates were lower than over the land, but still exceeding 20 mm/h in some time-steps. The rainfall rate in Dubrovnik area remained extremely high untill 1215 UTC, reaching up to 50 mm/h in some pixels, but at that time rain was already concentrated over the land with only very low rainfall rates over the sea (Fig. 6).

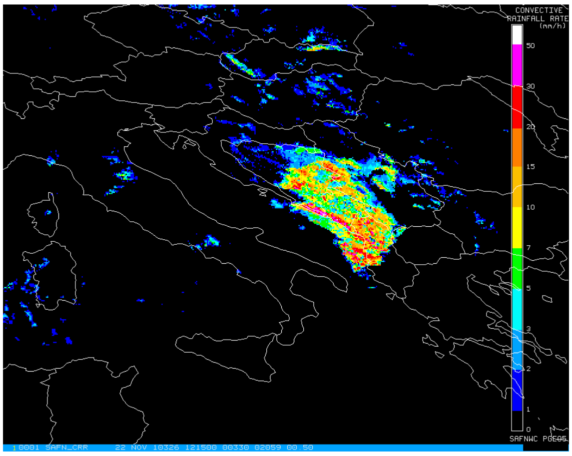

FIG. 6: CRR satellite product, 1215 UTC 22 November 2010 (colours stand for values in mm/h according to the scale).

V. INFLUENCE OF THE OROGRAPHY

To better evaluate the role of the Dinaric Alps over the Southern Adriatic in the generation of precipitation, a sensitivity run was performed with and without orography. The orography withheld from simulations corresponds to the northern part of the Dinaric Alps (roughly north of the Montenegro – Albanian border), leaving the southern part of the range influencing the development of the associated low-level jet.

The 24-hour accumulated precipitation over the whole area of the northern Dinaric Alps is much smaller than in the control run (Fig. 7). Thus, the largest part of the mountain-range-scale precipitation appears to be due to the orographic lift of the moist impinging low-level flow. The very area of Dubrovnik and hinterlands, however, still received over 50 mm of rain. This shows that besides the orographic lift other mesoscale factors, such as the low-level (moisture) convergence, contributed to the measured precipitation maximum over the Dubrovnik area.

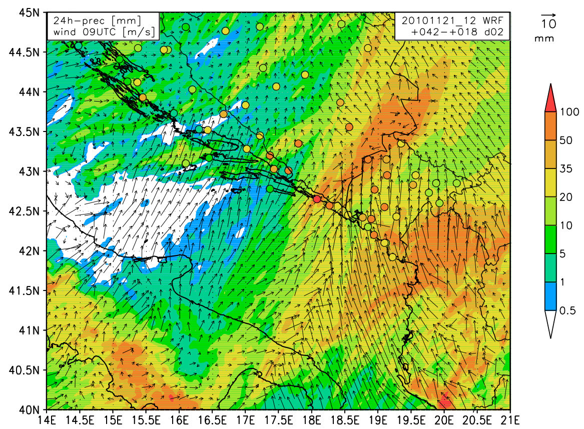

FIG. 7: 24-h observed (circle) and modelled precipitation in the simulation with no orography (mm, shaded as in legend) from 22 to 23 November 2010, 06 UTC and 10-m wind vectors at 09 UTC 22 November 2010.

VI. RESULTS AND CONCLUSIONS

This study identified some features responsible for the heavy rainfall observed along the south Adriatic coast in the Dubrovnik area.

Comparison of the modelled precipitation, in the simulations with and without orography, with the measured and satellite-estimated precipitation leads to the conclusion that convergence-caused cloudiness and precipitation were additionally enhanced by the effect of orography.

Combination of the low-level convergence and the orographic effect led to the most extreme precipitation along the south Adriatic coast in the area of Dubrovnik and south Montenegro and the adjacent mountain range (over 70mm/h). Precipitation over the sea was less prominent but still extreme with hourly rainfall rates above 20 mm/h in some periods, according to the satellite data.

This shows that besides the orographic lift other mesoscale factors, such as the low-level (moisture) convergence, contributed to the measured precipitation maximum over the Dubrovnik area. This study identified some similar features responsible for the heavy rainfall observed in other Mediterranean heavy precipitation events (Mastrangelo et al., 2011). However, more research is needed to determine if a given convergence line will be able to lift air to the level of free convection and hence generate moist convection.

VII. ACKNOWLEDGMENTS

This work was supported by Grant 004-1193086-3036 of the Ministry of Science, Education and Sports, Republic of Croatia. The authors wish to thank SAF NWC community, especially the colleagues from Spanish Meteorological Agency (AEMET), for providing the CRR data for the research.

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