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Article

Effects of different initial and boundary conditions in ALADIN/HR simulations during MAP IOPs

STJEPAN IVATEK-ŠAHDAN* and BRANKA IVANČAN-PICEK

Meteorological and Hydrological Service, Zagreb, Croatia

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Abstract

In order to better understand the influence of initial and boundary conditions on the numerical model results for MAP IOP5 (heavy precipitation) and IOP15 (severe Bora wind), numerical experiments were performed using the operational ALADIN/HR (hydrostatic) limited area model. Three experiments were performed. For the reference experiment (ARPE), ARPEGE operational analyses from 1999 were used. The other two experiments (ECAR and ECMW) were initialized from the 4D-Var ECMWF MAP reanalysis. In ECAR, the surface analysis was used from ARPEGE. The results presented here emphasise the huge importance of initial low-level moisture for the convective precipitation during IOP5. The humidity distribution in the ECMW experiment shows predominantly more humid conditions over the Dinaric Alps than in ARPE and ECAR. As a result, the simulation based upon the ECMWF MAP reanalysis produces fairly realistic results. The intensive surface convergence in the wind field and the orographic lifting of warm and humid air from the Adriatic Sea resulted in heavy precipitation in western Croatia. On the other hand, the different initial conditions during the MAP IOP15, with respect to the wind fields only, do not have a significant influence.

Zusammenfassung

Um die Auswirkung der Anfangs- und Randbedingungen auf die Resultate des numerischen Modells für die MAP IOP5 (starker Sturm) und IOP15 (starke Bora) bestmöglich zu verstehen, wurden numerische Experimente mithilfe des operationellen hydrostatischen Limited-Area Modells für das begrenzte Gebiet ALADIN/HR durchgeführt. Es wurden drei Experimente durchgeführt. Für das Referenz-Experiment (ARPE) wurden die operativen Analysen ARPEGE aus dem Jahr 1999 genutzt. Die anderen zwei Experimente (ECAR und ECMW) wurden aus der 4D-Var ECMWF MAP Reanalyse initialisiert. Beim ECAR wurde eine Bodenanalyse von ARPEGE benutzt. Die hier angeführten Resultate betonen die wichtige Rolle der Feuchtigkeit in den unteren Schichten für Konvektionsniederschläge während der IOP5. Die Feuchtigkeitsverteilung weist auf prädominant feuchtere Bedingungen über den Dinarischen Alpen im Experiment ECMW als in den Experimenten ARPE und ECAR hin. Deshalb bietet die Simulation, die auf der ECMWF MAP Reanalyse beruht, ziemlich realistische Resultate. Eine intensive Bodenkonvergenz im Windfeld und ein orographisches Aufsteigen warmer und feuchter Luft vom Adriatischen Meer führten zu starken Niederschlägen im Westen Kroatiens. Andererseits haben die verschiedenen Anfangsbedingungen während der MAP IOP5, wenn man nur die Windfelder betrachtet, keinen bedeutenden Einfluss.

1 Introduction

Although the performance of numerical weather forecasts has greatly improved over the recent decades, the fine-scale process predictability in mountain regions continues to be a major challenge. High resolution allows a much more detailed representation of orographic forcing. Different high-resolution models are currently under intensive testing with the aim of becoming the next generation of operational weather forecast systems. One major expectation from these new tools is a better forecast of small-scale phenomena such as squall lines, or convective rain bands, and a more reliable precipitation distribution. In spite of the powerful tools available, the question is to what extent such phenomena are predictable. Little experience has been collected up to now. The impressive amount and high quality of data collected during the Mesoscale Alpine Programme (MAP) Special Observing Period (SOP) (BOUGEAULT et al., 2001) offer an opportunity to test, validate and improve different new high-resolution modelling and assimilation systems (RICHARD et al., 2003, 2005). The impact of the MAP reanalysis (MAP-RA) produced by ECMWF (KEIL and CARDINALI, 2004) on the quantitative precipitation forecast was minor but constantly positive (BUZZI et al., 2004).

The availability of the MAP data allows us to perform simulations of the most relevant MAP intensive observing periods (IOP's) to assess the impact of the different parameterizations, initial and boundary conditions on limited area model results. A lot of effort has been put into the evaluation of precipitation forecasts, but only a few studies have been devoted to the systematic evaluation of the whole SOP. BUZZI et al. (2003) per-

*Corresponding author: Stjepan Ivatek-Šahdan, Meteorological and Hydrological Service, Grič 3, 10000 Zagreb, Croatia, e-mail: ivateks@cirus.dhz.hr

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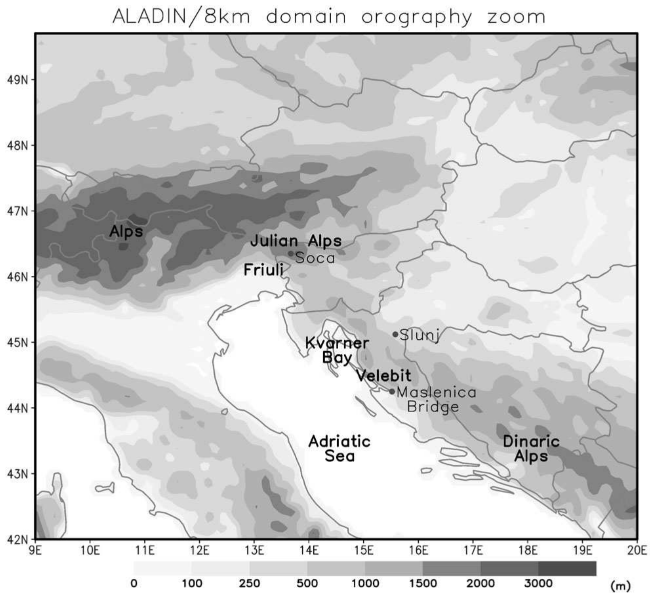


Figure 1: Orography representation in the ALADIN/HR 8 km domain and location of the meteorological stations.

formed an extensive comparison involving hydrostatic and non-hydrostatic models using operational SOP data. The results indicate a generally better performance of the non-hydrostatic, high resolution, convection resolving model compared with the hydrostatic model with parameterised convection.

In some specific cases, precipitation fields were found to be extremely sensitive to initial conditions (LASCAUX et al., 2004; BUZZI et al., 2004). However, no real effort was made to compare the results with the operational forecast.

The purpose of this study is to verify the impact of different initial and boundary conditions on the forecasting of two of the most interesting MAP IOPs for the eastern part of the Alps and the Dinaric Alps. The numerical simulations of the precipitation system during MAP IOP5 and the extreme bora wind case during MAP IOP15 have been performed with the operational ALADIN/HR (hydrostatic) limited area model.

This paper presents the results of different case study simulations (heavy precipitation IOP5 and strong wind IOP15) aimed at identifying the strengths and weaknesses of this operational hydrostatic model. Particularly, the sensitivity of the results to the initial and boundary conditions is reported. The model characteristics and the numerical set-up are presented in section 2. Sections 3 and 4 are devoted to the analysis and quantitative assessment of the simulation results. Section 5 provides a conclusion.

2 Modelling

2.1 Model characteristics

ALADIN (Air Limitée Adaptation Dynamique Développement InterNational) is a limited-area model built on the basis of the global model ARPEGE/IFS (ARPEGE – Action de Recherche Petite Échelle Grande Échelle, IFS – Integrated Forecast System). The model uses the spectral technique for the horizontal representation of fields (BUBNOVA et al., 1993). The physical parameterization package includes vertical diffusion parameterization (LOUIS et al., 1982) with shallow convection (GELEYN, 1987). Convective and stratiform cloud processes are treated separately by a Kessler-type large-scale precipitation scheme and a modified Kuo-type deep convection scheme. The transport of moisture and heat vertically in the soil are parameterized in two layers (GIARD and BAZILE, 2000).

ALADIN was one of the limited-area models operationally used at MOC (MAP Operational Centre) during MAP. In the Croatian National Meteorological and Hydrological Service, ALADIN/HR runs operationally at 00 and 12 UTC with 8 km horizontal resolution, using the 54-hour integration of the ALADIN full physics package.

2.2 Numerical set-up

The simulations were carried out with the operational hydrostatic ALADIN/HR model. Three experiments were performed. Different global-model analyses were used to produce initial and boundary conditions with the operational version of the ARPEGE global model in 2004. Afterwards, the output files were dynamically adapted first to the ALADIN/LACE domain with 12.2-km resolution, and afterwards to the ALADIN/HR domain with 8 km resolution, using a 54-hour integration with the operational ALADIN/HR model set-up. For the reference experiment (ARPE), the 1999 operational analyses of the ARPEGE global model were used, as well as the 3D-Var for the upper-air fields and CANARI (OI-analysis) for the surface fields. The other two experiments (ECAR and ECMW) had the same upper-air fields, from the 4D-Var ECMWF MAP reanalysis. In the ECAR experiment, the surface fields (soil temperature, soil wetness and snow depth) were taken from the 1999 operational surface analysis (as for ARPE). In the ECMW experiment, the initial surface fields were taken from the ECMWF MAP reanalysis.

3 Results for the MAP IOP5 case

During MAP IOP5, heavy precipitation occurred on the eastern side of the Alps in the early morning of 4 October 1999 (IVANČAN-PICEK et al., 2003). This was the most interesting precipitation event in the eastern part of the Alps during the MAP SOP. Intensive precipitation was associated with a narrow band of strong

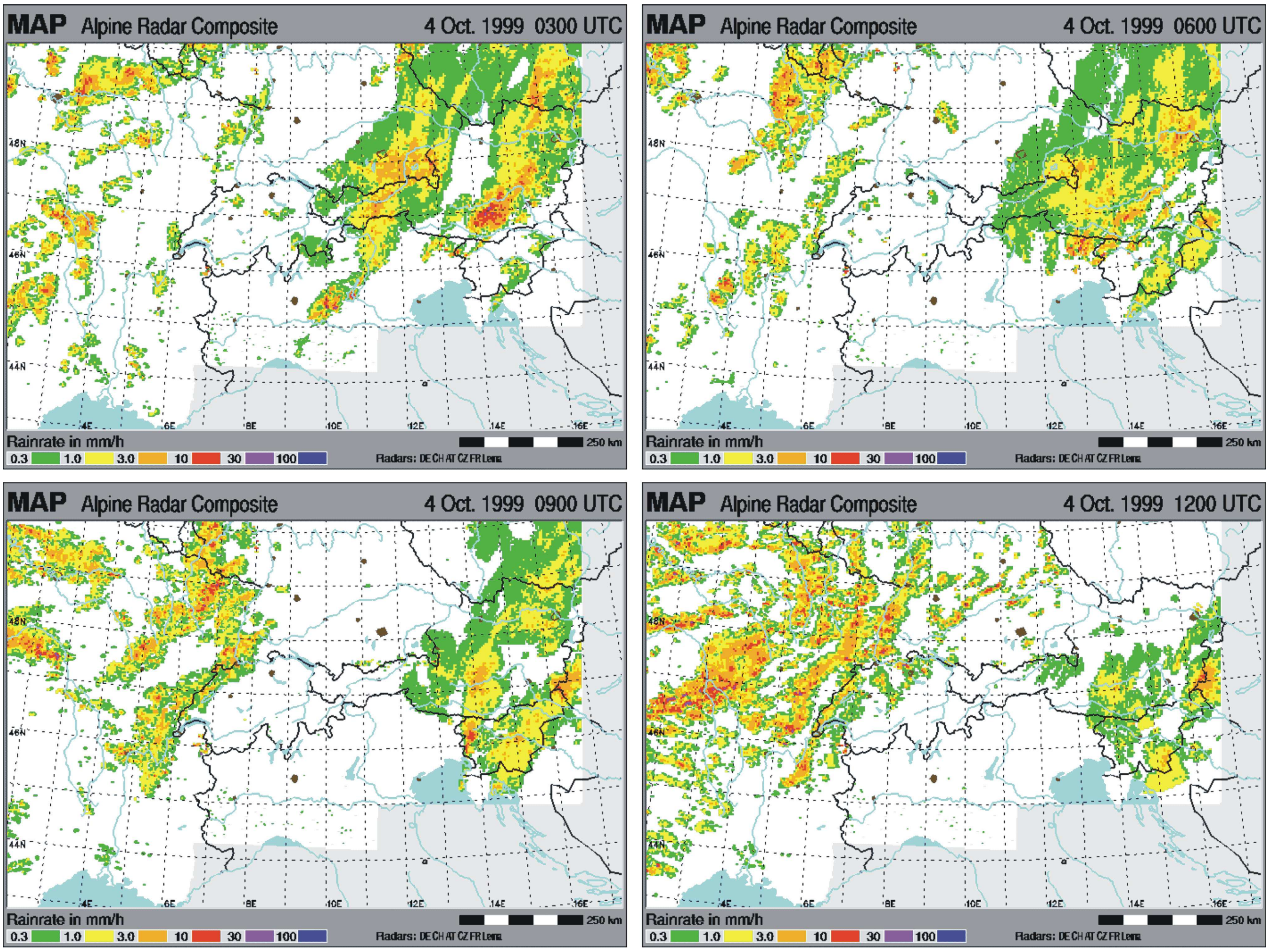


Figure 2: Precipitation rate (mm/h) from the Alpine radar composite-time evolution for 4 October 1999, 03 to 12 UTC.

convective activity along the frontal zone in the Slovenia/Croatia border area. The spatial precipitation distribution was very inhomogeneous (PRADIER et al., 2002; VRHOVEC et al., 2004b). Orographic influence on convectively unstable air advected by the warm and humid current from the Mediterranean caused a large amount of rain. VRHOVEC et al. (2004a) highlight the importance of orographic representation in models. The removal of the Dinaric Alps resulted in the disappearance of the precipitation maximum located in the Julian Alps, as the flow was no longer forced to converge to this region. Intensive precipitation (100–200 mm/12 h) was associated with a narrow band of strong convective activity along the frontal zone. The 24-hour rainfall amount on that day in western Croatia was at many places larger than the mean monthly amount, with a maximum of 122 mm/24 h in Slunj (Fig. 1). A squall line following the front formed over western Slovenia, resulting in a precipitation maximum of 241 mm/24 h, measured at the Soča station (Fig. 1). The results of the mesoscale wind field predicted by the ALADIN/HR model indicate that it was caused by frontal modification influenced by low tropospheric convergence of the warm southerly wind and the colder northerly bora wind following the splitting process due to the north Alpine orographic blocking (IVANČAN-PICEK et al., 2003).

Fig. 2 presents the time evolution of the precipitation system visible in the Alpine radar composite (MAP Data Centre). The four panels depict the time evolution of the precipitation pattern observed in the morning of 4 October 1999, between 03 and 12 UTC. A narrow north-south oriented frontal precipitation band developed over the Friuli region (Italy) and moved eastward towards Slovenia and Croatia. Two distinguished precipitation bands have been observed.

The precipitation fields deduced from the Alpine radar composite can be compared with the model fields shown in Fig. 3. The 54-h model simulation starts at 00 UTC, on 3 October 1999. Three experiments were performed (see Section 2). The agreement of the forecasts with the precipitation observations is remarkable. The eastward displacement of the system is quite accurately reproduced by the model. A zone of stronger precipitation along the south-eastern slopes of the Alps is recognizable in the forecast. The 3-hour accumulated precipitation forecasts from ARPE and ECAR (at 06 UTC)

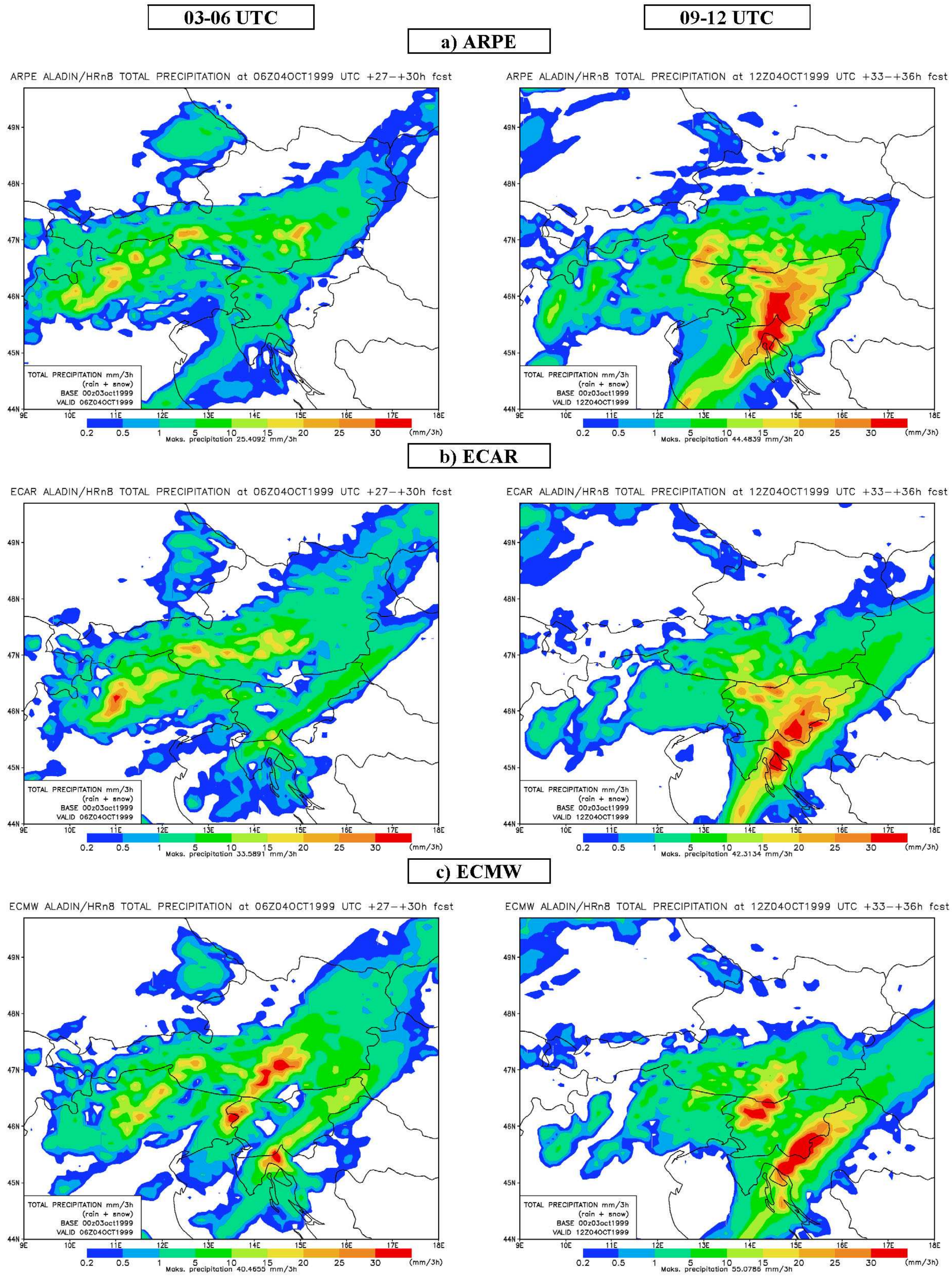


Figure 3: 3-hour accumulated precipitation (mm/3 h) at 06 and 12 UTC, on 4 October 1999, for the a) ARPE, b) ECAR and c) ECMW run of the ALADIN/HR model forecast at 00 UTC, 3 October 1999.

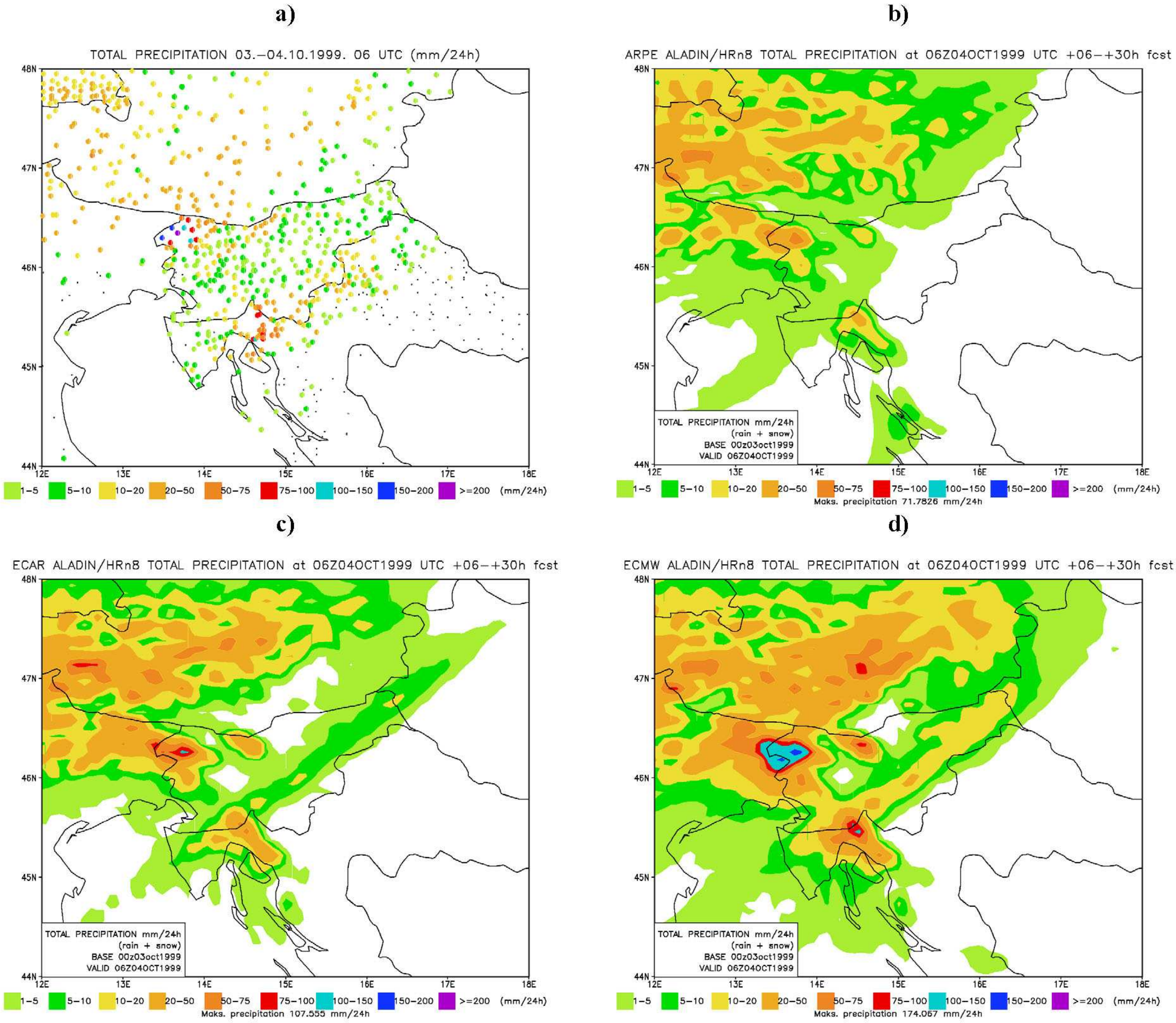


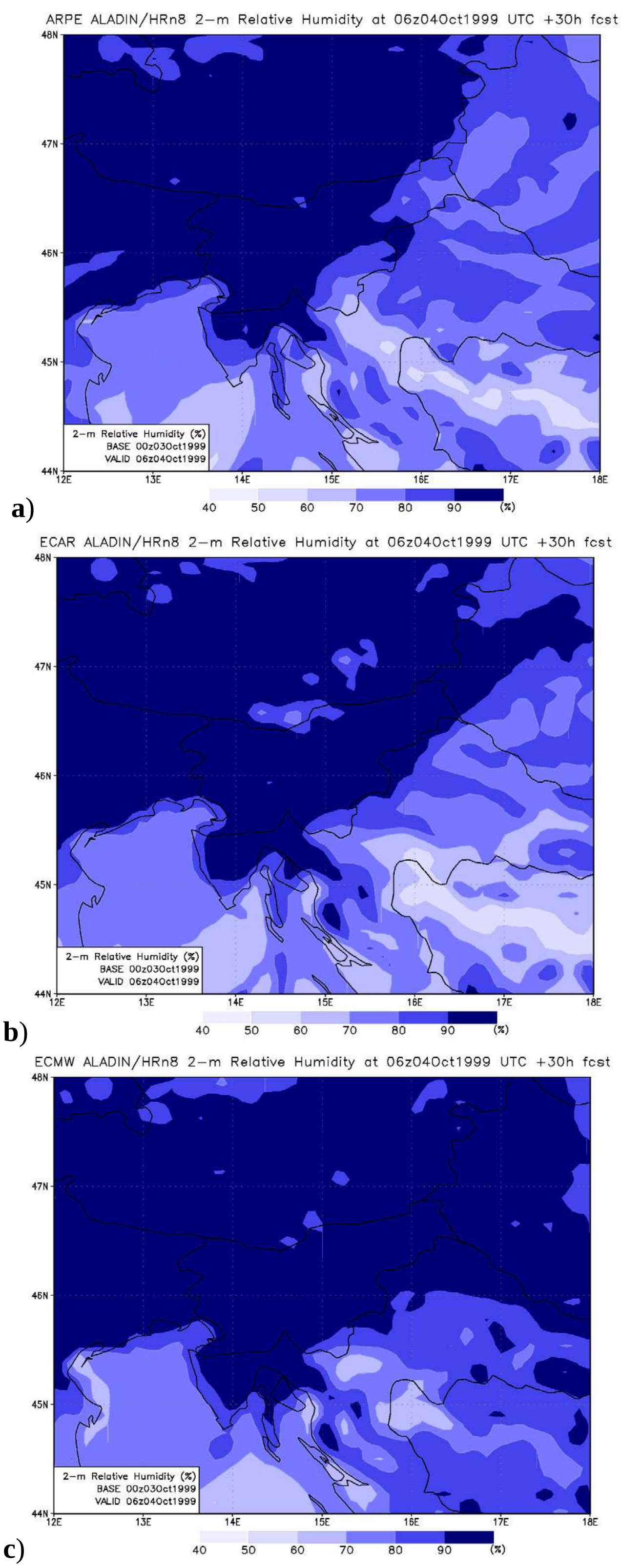
Figure 4: 24-hour accumulated precipitation (mm/24 h), from 3 October 1999, 06 UTC to 4 October, 06 UTC for the: a) observations, b) ARPE, c) ECMW and d) ECAR run of the ALADIN/HR model.

reproduce the heavy precipitation band over Slovenia and western Croatia. The maximum precipitation location underpredicts the width and intensity of the convective lines. The high rainfall values in the Soča region are missed by the forecast. Only the ECMW forecast predicts two distinguished precipitation bands: one in western Slovenia and another one in the Slovenia/Croatia border area. The result of the 12 UTC simulation was an increase in the two separate precipitation bands. The other two simulations produced only wider zones of stronger precipitation.

In the following, the description of the precipitation model results is limited to a selection of precipitation fields, 24-hour accumulated, between 3 and 4 October 1999, 06 UTC. Alpine radar composite data (Fig. 2) and rain gauge measurements available over that time period (Fig. 4a) have been used to asses the model results shown in Fig. 4b, c, d. The basic pattern of precipitation distribution is in agreement with the observations. However, there are differences in the location and predicted peaks. A zone of stronger precipitation along the Slovenia/Croatia border is recognizable in the ECMW and ECAR forecasts.

The ARPE control case in Fig. 4b is based on the ARPEGE 1999 operational analysis (3D-Var), while the other two experiments, ECMW and ECAR, in Fig. 4c and d, show the results starting from ECMWF MAP-RA (4D-Var) for upper-level fields with different surface fields (Section 2). The predicted peaks (the Soča region and western Croatia) in all three experiments are located almost exactly over the observed maxima.

The main errors in the ARPE experiment (Fig. 4b) are the deficit of precipitation in western Croatia, and the underestimation of the heaviest precipitation, with



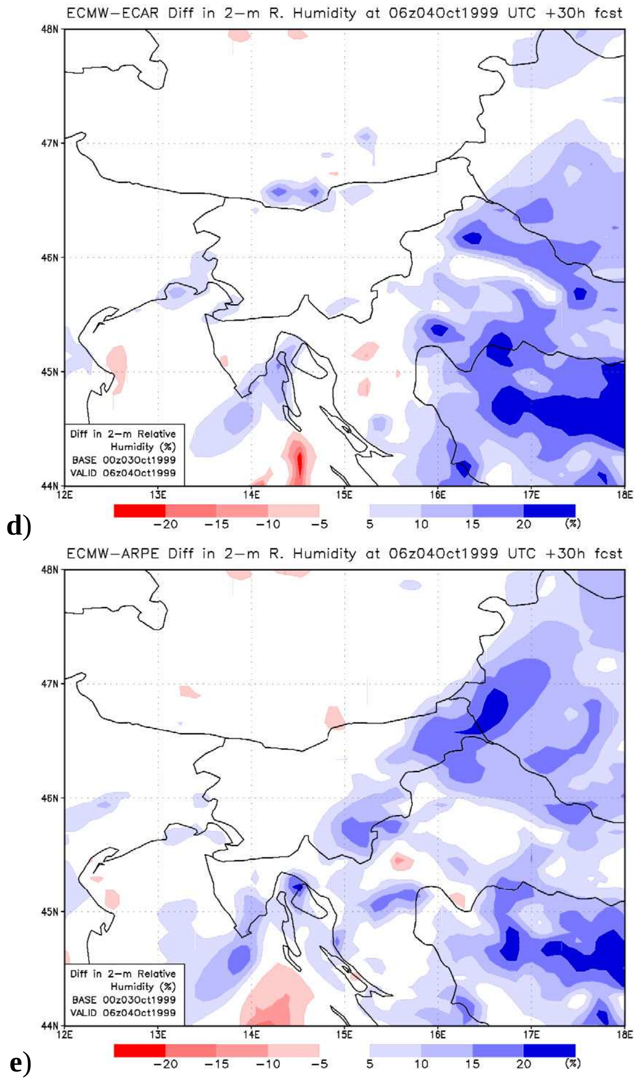


Figure 5: 2-m relative humidity (%) for the: a) ARPE, b) ECAR and c) ECMW run of the ALADIN/HR model. Analysis difference of 2-m relative humidity (%) between (d) ECMW – ECAR and (e) ECMW – ARPE, at 06 UTC, on 4 October 1999.

a maximum exceeding 200 mm/24 h, in the Soča region (72 mm/24 h was predicted). The results of the ECMW and ECAR experiments (Fig. 4 c, d) are very similar, distinguishing two maxima in the precipitation fields. In the ECMW simulation, the area with heavy precipitation (more than 100 mm/24 h) is much bigger than in the ECAR simulation (the maximum amount was 108 mm/24 h). The ECMW reproduced the almost exact amount of maximum precipitation in the Soča region (more than 170 mm/24 h), well matching the ob-

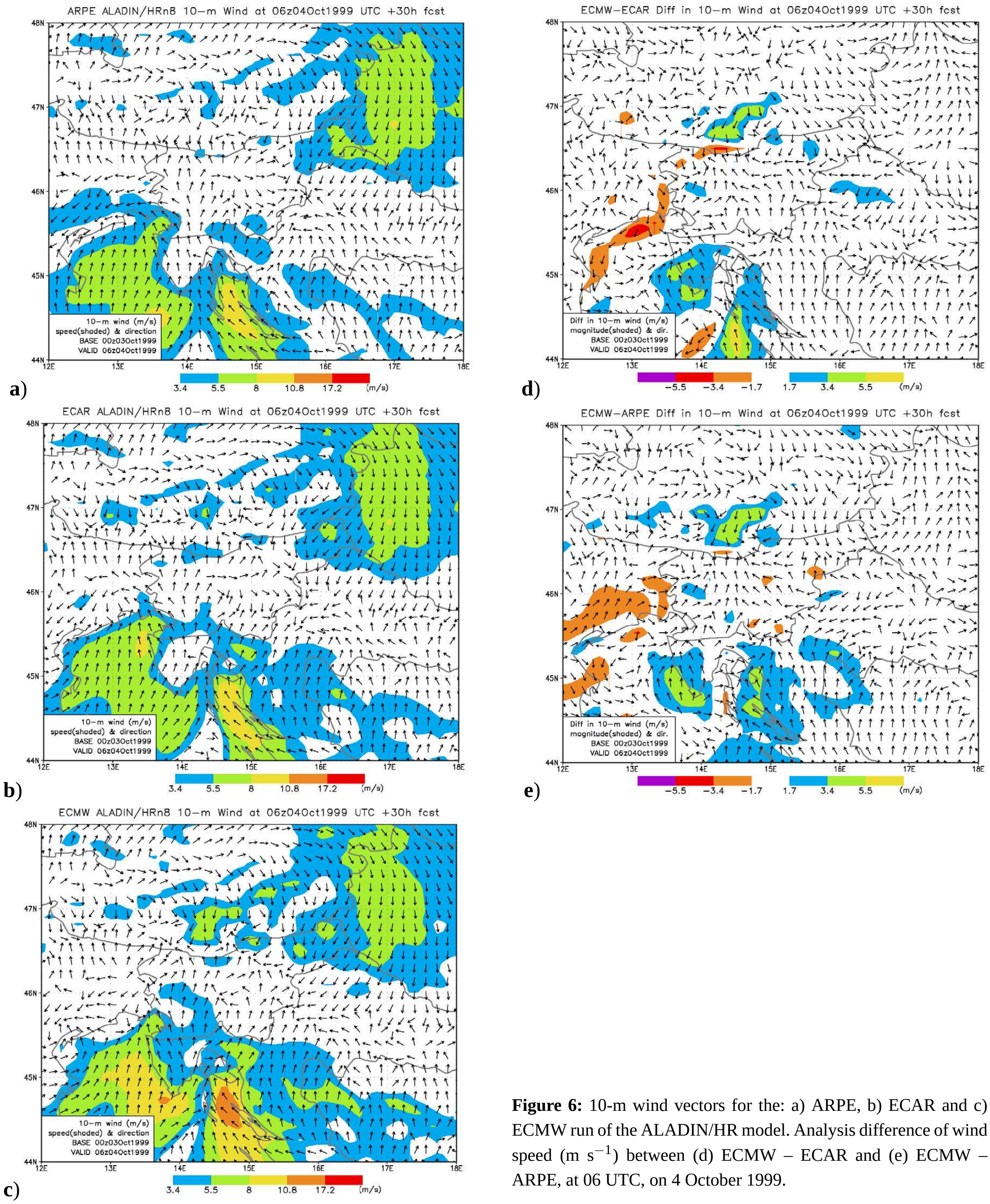


Figure 6: 10-m wind vectors for the: a) ARPE, b) ECAR and c) ECMW run of the ALADIN/HR model. Analysis difference of wind speed (m s^{-1}) between (d) ECMW – ECAR and (e) ECMW – ARPE, at 06 UTC, on 4 October 1999.

served precipitation accumulations. These remarkable differences between the ECAR and ECMW simulations prove the importance of the surface initial fields in correctly predicting convective precipitation.

To understand the differences in the precipitation forecasts for MAP IOP5, the low-level humidity and wind fields were inspected (Figs. 5 and 6). The 2-m relative humidity distribution (Fig. 5a, b, c) in the ECMW experiment shows predominantly more humid conditions over the Dinaric Alps than in the ARPE and ECAR simulations. Locally, the differences are more than 20 %. Those expected results are due to moister conditions in the southern Alpine region and over the Adriatic Sea in the MAP reanalysis (KEIL and CARDINALI, 2004).

The results of the mesoscale wind field indicate that the heavy precipitation event was caused by a frontal modification influenced by a low tropospheric convergence formation between the warm southerly wind and the colder northerly bora wind following the splitting process resulting from the north Alpine orographic blocking. Fig. 6 gives further insight into this evolution. The south-eastern flow originating from the Adriatic Sea impinged the Kvarner bay and western Croatia, and a convective line formed, perpendicular to the low-level flow. Some differences between the three experiments are present in the 10-m wind forecast shown in Fig. 6d, e. In the ECMW simulation, the northern Adriatic flow is up to 7 m s^{-1} stronger compared to the other two experiments. Such a condition was favourable for higher moisture transportation inland from the sea. The simulation based upon the ECMWF MAP reanalysis produces fairly realistic results. As opposed to the ECMW, the deficit in low-level humidity over the Dinaric Alps in the ECAR and ARPE simulations resulted in weaker precipitation. Heavy precipitation in western Croatia was the consequence of a shallow mesoscale orographic process caused by surface convergence in the wind system, and the orographic lifting of warm and humid air from the Adriatic Sea. The results presented here, therefore, emphasise the huge importance of the initial low-level moisture and wind field for convective precipitation.

4 Results for the MAP IOP15 case

The MAP IOP15 was studied, particularly the orographic effects on the rapid cyclogenesis that took place south of the Alps, and the intense but rather brief precipitation occurrences over the Po Valley and the northern Apennines (BUZZI et al., 2003). But, during the MAP IOP15 extreme weather situation, a strong flow across the Dinaric Alps occurred (IVATEK-ŠAHDAN and TUDOR, 2004; GRUBIŠIĆ, 2004). The sensitivity of the surface flow to the initial conditions during the IOP 15 extreme bora case was also studied and the sensitivity of the surface flow to the initial conditions is reported. The synoptic setting, within which the gusty, northeasterly, downslope bora wind developed along the eastern Adriatic on 7 November 1999, followed an explosive lee cyclogenesis over the western Mediterranean Sea. In the northern Adriatic a severe bora started developing early on 7 November 1999. The bora continued to strengthen throughout the day, reaching its maximum on November 8, around 00 UTC, and gradually spreading southwards. Locally, the observed maximum wind gusts at the Maslenica Bridge – south of the Velebit Mountain (Fig. 1) – exceeded 40 m s^{-1}, and the mean hourly wind exceeded 25 m s^{-1} (Fig. 7d).

The ALADIN/HR model accurately captured the onset and cessation of the bora. The numerical model results of the ARPE, ECAR and ECMW experiments (Fig. 7a, b, c) show the wake structure within the bora flow over the Adriatic, with several separate low-level jets (GRUBIŠIĆ, 2004; IVANČAN-PICEK et al., 2005). The bora was forecast to start in the early morning of 7 November. Wind velocities were forecast to exceed 20 m s^{-1}, with gusts up to 33 m s^{-1}. Strong pressure gradients across the Dinaric Alps created local drag, providing intense local acceleration and strong wind (TUTIŠ and IVANČAN-PICEK, 1991). In the corresponding numerical experiments (ARPA, ECAR, ECMW) shown in Fig. 7, the different initial and boundary conditions did not yield significantly different wind speeds near the steep orography along the Croatian coast. Some differences in the low-level flow structure were located over the open sea.

Fig. 8 shows the results of the corresponding experiments for the Maslenica Bridge, where the strongest wind speeds were observed. The model captured well the onset and cessation of the bora while the agreement between the simulated and observed wind speed maxima was less successful. The 8 km resolution forecasts produced too weak winds for the location of the Maslenica Bridge, just downstream of the Velebit Mountain pass. The discrepancies between the observed and simulated wind speed are related to the local differences between true and model orography. The results are further improved when including a new approach of the 2-km high-resolution dynamical adaptation for the mountainous parts of Croatia (ŽAGAR and RAKOVEC, 1999; IVATEK-ŠAHDAN and TUDOR, 2004). Special care was taken that the terrain height in the model is close to the actual height of the mountain peaks and passes, which resulted in a much better prediction of local wind speed.

To summarise, with respect to the wind fields only, the numerical experiments presented here do not yield significantly different wind speeds from those observed and there are no significant differences between models.

5 Conclusion

The purpose of this study was to verify the impact of different initial and boundary conditions in forecasting the two most interesting MAP IOPs case studies for the eastern part of the Alps and the Dinaric Alps, performed with the operational ALADIN/HR mesoscale model. Numerical simulations have been performed of

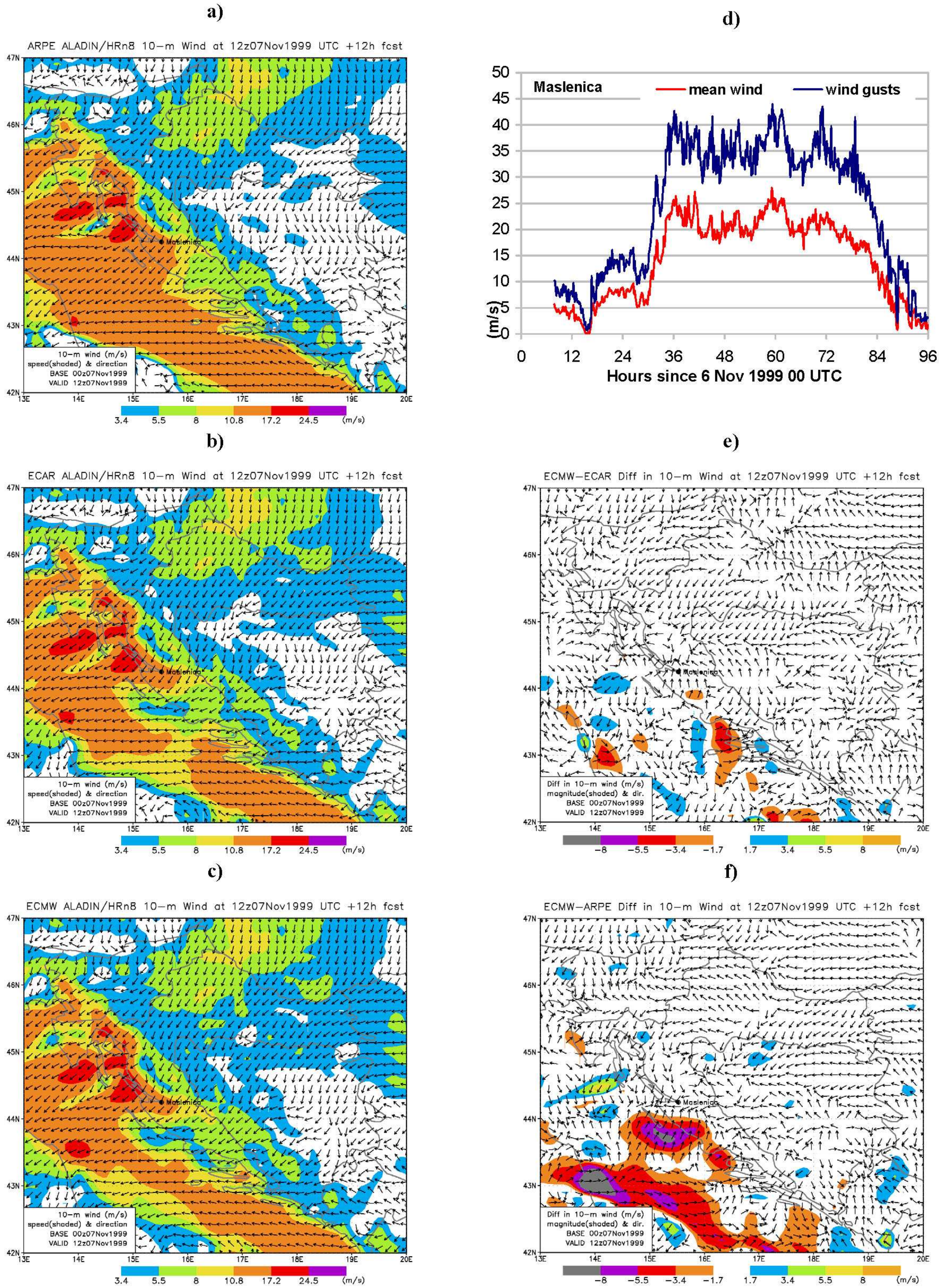


Figure 7: 10-m wind vectors for the: a) ARPE, b) ECAR and c) ECMW run of the ALADIN/HR model. Time traces of mean wind speed and wind gusts for the Maslenica Bridge meteorological station during the period 6 to 9 November 1999, 00 UTC (d). Analysis difference of wind speed (m s^{-1}) between (e) ECMW – ECAR and (f) ECMW – ARPE, at 12 UTC, on 7 November 1999.

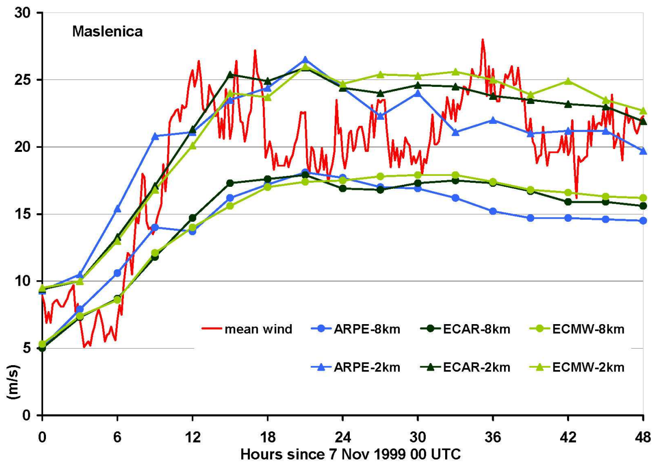


Figure 8: Time traces of mean wind speed data measurement, ALADIN/HR 8 km resolution forecasts (circle markings) and 2-km resolution dynamical adaptation (triangle markings), for the Maslenica meteorological station for the period from 7 to 9 November 1999, 00 UTC: results of the ARPE, ECAR and ECMW experiments.

the heavy precipitation system during the MAP IOP5 and the extreme severe bora wind case during the MAP IOP15.

The results of the numerical experiments show a higher sensitivity to the initial and boundary conditions for the MAP IOP5 heavy precipitation case. The simulation based upon the operational ARPEGE analysis produces fairly realistic results whereas the two simulations based on the ECMWF MAP reanalysis prove the importance of surface initial fields in the correct prediction of convective precipitation. The results presented here emphasize the huge importance of initial low-level moisture for the convective precipitation during IOP5. The humidity distribution in the ECMW experiment shows predominantly more humid conditions over the Dinaric Alps than in the ARPE and ECAR experiments. The intensive surface convergence in the wind field and the orographic lifting of warm and humid air from the Adriatic Sea resulted in heavy precipitation in western Croatia. Therefore, the simulation based upon the ECMWF MAP reanalysis produces fairly realistic results. The role of the surface processes, especially in triggering the precipitation phase, should be investigated. The results of the introduction of the MAP-RA are not easily interpreted (see also Buzzi et al., 2004; Keil and Cardinali, 2004), but in a documented MAP IOP5 case its effect was to improve the precipitation fields. Low-level moisture is very important for convective precipitation, but some differences in low-level wind should not be neglected, either.

Looking only at the wind field forecast near the steep orography along the Croatian coast, the different initial conditions during the MAP IOP15 do not have a significant influence.

The current operational mesoscale model precipitation forecast is generally satisfactory in terms of timing and distribution when a large-scale flow (including the humidity field) is well described in the initial and boundary conditions. When, on the other hand, convection is dominant, especially in pre- and post-frontal flow situations the simulation of precipitation tends to be under- or overestimated. The realistic precipitation amounts and distribution need to be modelled by new non-hydrostatic models at very high resolution. The sensitivity to initial conditions is expected to increase even more with the use of such models.

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