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MAP IOP 15 CASE STUDY

Analiza vremenske situacije tijekom MAP IOP 15

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Abstract: The paper presents the ability of forecasting severe *bura* events on the Adriatic coast using the ALADIN model operationally used at the Croatian Meteorological Service. Both versions currently in use, the LACE and the Croatian version, as well as the dynamical adaptation of the surface wind field from the latter have been tested on a MAP IOP 15 case. The MAP IOP 15 took place between 5th and 10th November 1999. The strongest *bura* was recorded around 12 UTC on 7th November. Different versions of the same numerical model have been used on different domains and resolutions. The output surface wind fields from the 8-km resolution Croatian domain have been dynamically adapted to orography with a 2-km resolution, and both results have been compared to the measured data. The latter method proved to be very useful for locations where *bura* is the most severe, like the Maslenica bridge. The impact of a better representation of orography on the forecasted wind field in the mountainous parts of the coast is visible in the increased spatial variability of the field.

Key words: wind, severe *bura*, ALADIN, MAP IOP 15, Maslenica bridge, numerical modelling, dynamical adaptation

Sažetak: Rad predstavlja mogućnost prognoziranja jake bure na jadranskoj obali pomoću modela ALADIN, koji se operativno koristi u DHMZ. Obje verzije koje se trenutno koriste; i LACE i hrvatska, te metoda dinamičke adaptacije prizemnog polja vjetra, testirane su na slučaju MAP IOP 15. MAP IOP 15 odvijao se od 5. do 10. studenog 1999. godine. Najjača bura je zabilježena oko 12 UTC 7. studenog. Različite verzije istog numeričkog modela upotrijebljene su na različitim domenama i rezolucijama. Polja prizemnog polja vjetra dobivena na hrvatskoj domeni s korakom mreže 8 km, dinamički su adaptirana visini terena s korakom mreže 2 km, te su oba rezultata uspoređena s rezultatima mjerenja. Posljednja metoda pokazala se vrlo uspješnom za područja s najjačom burom kao što je Maslenički most. Utjecaj bolje reprezentacije visine tla u modelu na prognozirano polje vjetra u planinskim dijelovima uz obalu jasno je izraženo u prostornoj promjenjivosti prizemnog polja vjetra.

Ključne riječi: vjetar, jaka bura, ALADIN, MAP IOP 15, Maslenica, numeričko modeliranje, dinamička adaptacija

1. INTRODUCTION

The Croatian coast is lined with mountains that are relatively small in area, but rather steep, with tops above 1500 m, very close to the coastline. Orography plays an important role in controlling the weather, but orographically induced weather patterns in that area are poorly resolved or not resolved at all in large-scale models. This will be illustrated on an example of *bura*.

Bura is a strong, gusty and cold katabatic wind that blows along the Eastern Adriatic coast from the northeast quadrant. It is generated by the interaction of synoptic forcing with orography;

the wind is strongest downstream of the lowest passes in the mountain range and most frequent and strongest on the Northern Adriatic. Severe *bura* events occur several times a year. During these periods, vital transport connections become unavailable, especially ferry-boat traffic and the Maslenica, Pag and Krk bridges.

The mesoscale nature of severe *bura* wind resulting from the interaction of an intense Adriatic cyclone with the complex coastal terrain has been shown in Brzović (1999). *Bura* occurs when there is a strong pressure gradient between the inland and coastal parts of Croatia across the mountains. This is usually connected with a cold, high-pressure air mass advection from the Northeast and a cyclone development over the Mediterranean (near Genoa) or the Adriatic. Enger and Grisogono (1998) have shown that offshore *bura* propagation increases with the thermal difference between the warmer sea surface and the colder land up to more than 100 km. Statistics of cyclones do not show a frequent cyclone location in the Northern Adriatic, but it is likely that the large-scale model analyses used for such studies do not resolve the Adriatic cyclone (Brzović, 1999). The main local characteristics of *bura* appearance are its sudden occurrence and strong temporal and spatial variability (Brzović, 1999). Detailed statistical analyses of measured wind data during severe *bura* events have shown that the differences in the occurrence and duration of *bura* exist in different parts of the Adriatic coast (Brzović, Benković 1994). As the chosen weather feature is strongly influenced by local orography a better representation of orography in a meteorological model is expected to lead to better results when the model output is compared to the measured data. The motivation for this work was to see how the ALADIN model operationally used at the Croatian Meteorological Service was able to predict severe *bura* development on one of the most studied *bura* cases – the MAP (Mesoscale Alpine Project) IOP 15 (Intensive Observation Period) case. MAP IOP 15 started on 5th November 1999, at 00 UTC, and ended on 10th November 1999, at 00 UTC. The *bura* was strongest around 12 UTC on 7th November 1999. The capability of the ALADIN model to predict heavy precipitation and strong wind events during the MAP using verification against observations by intercomparison of the HRID vertical time cross-sections on the basis of ALADIN/LACE pseudotemps and TEMP messages had already been done (Ivančan-Picek and Glasnović, 2000).

ALADIN is a mesoscale limited-area model (LAM) based on the global IFS/ARPEGE model. It uses a spectral representation of the fields in the horizontal and a finite difference method in the vertical. The hydrostatic version of the model with a semi-implicit, semi-lagrangian, two-time level integration scheme was used. A different version of ALADIN had already been used to study the mesoscale environment of the local effects of the Dinaric Alps on the cold fronts arriving from the north in the case study of a cold air outbreak on 20th April 1997 over Croatia (Brzović, 1998/99).

The ability of the ALADIN version operationally used at the Croatian Meteorological Service to predict the temporal and spatial variability of *bura* has been examined on the MAP IOP 15 case. The next section describes the model. In Section 3, the integration domains are presented; model results are presented in Section 4; Section 5 explains the use of the dynamical adaptation method. The results are finally compared to the measurement data in Section 6, followed by Conclusions.

2. ABOUT THE ALADIN MODEL

ALADIN (Aire Limitee Adaptation Dynamique developement InterNational) is a limited-area model (LAM) built on the basis of the global IFS/ARPEGE (ARPEGE - Action de Recherche Petite Echelle Grande Echelle, IFS - Integrated Forecast System) model.

ALADIN keeps the same vertical discretisation, grid point dynamics and physics as the global ARPEGE model. Like ARPEGE, ALADIN uses the spectral technique for the horizontal representation of fields. In this case, it is possible to use a double Fourier representation, which has the advantage of performing fast Fourier transforms in both directions. To ensure an isotropic resolution, the Fourier series are limited by an elliptic truncation (Machenhauer and Haugen, 1987). A hybrid pressure-type η co-ordinate (Simmons and Burridge, 1981) on 31 model levels has been used in the vertical with the finite difference method. Primitive prognostic equations have been solved for the wind components, temperature, specific humidity and surface pressure using the two-time-level, semi-implicit, semi-lagrangian integration scheme.

The problem of obtaining bi-periodicity in the fields to use periodic Fourier expansion functions in both directions has been solved in ALADIN by the creation of an artificial extension zone (E zone) in which the fields are "interpolated" between the values at opposite edges. It is defined as an outer belt only for this mathematical reason. Its size has been chosen to avoid too sharp slopes at the boundaries of the domain.

The physical parameterisations package includes a vertical diffusion parameterisation (Louis *et al.*, 1982) with shallow convection (Geleyn, 1987); convective and stratiform processes are treated separately by a Kessler-type large-scale precipitation scheme and a modified Kuo-type deep convection scheme. Radiation is parameterised according to Geleyn and Hollingsworth (1979) and Ritter and Geleyn (1992). The transport of moisture and heat vertically in the soil are parameterised in two layers.

The LAM ALADIN is in fact only a version of ARPEGE using about 70% of the common code, the main differences being the geometry, the bi-periodicitisation and the coupling with the large-scale solution and the bi-Fourier transforms.

The Central-European countries (Austria, Czech Republic, Croatia, Hungary, Slovakia and Slovenia) have joined efforts and resources in the LACE (Limited Area model for Central Europe) project to have an operational version of ALADIN run on a domain covering Central Europe and the surrounding areas. The ALADIN model has been quasi-operational since 31st May 1994, and has been run operationally since 1st July 1996 on the LACE domain twice a day (00 and 12 UTC runs) for 48 hour forecasts.

LAM needs time-dependent boundary conditions determined from a large-scale model integration because it needs information about the state of the atmosphere outside of its integration domain and this information is transferred through the data at the boundaries. This large-scale model can be a global or a limited area model. Initial and boundary conditions for the ALADIN model on the LACE domain are obtained by interpolation from the analyses and forecasts of the global model ARPEGE with the 6-hour coupling frequency used at the time. To ensure a continuous transition from large-scale to small-scale data, an intermediate zone is defined – the coupling zone – where a large-scale solution computed with the global ARPEGE, or bigger LAM model is mixed with the solution resulting from the ALADIN integration following the relaxation technique (Davies, 1976). The central zone represents the region of meteorological interest, where the forecast is fully adapted to small-scale conditions.

3. INTEGRATION DOMAINS

The operational model outputs from the integration of the ALADIN model on the LACE domain are used for weather forecasting in the national meteorological centres of the LACE member states. Among the outputs are the so-called "coupling" files that contain initial and boundary conditions for local ALADIN suites in the meteorological services of LACE member states. They serve also as input for integration on the Croatian HRv8 domain. ALADIN was ported on a network of PCs (the so called "cluster") in August 2000 and it was first used for integration on the Slovenian domain on a daily basis. In November 2000, the Croatian HRv8 domain was created, which covered the Adriatic further south than the Slovenian domain and the 8 dynamical adaptation domains were created at the same time. Since January 2001, ALADIN has been pre-operationally run at 00 UTC on the Croatian domain.

The LACE and Croatian domains used in operational suite are shown in Figure 1. The LACE domain is centred in Central Europe and extends to below Sicily to the south, to the Baltic Sea to the north, from France in the west to the middle of the Black Sea in the east. The LACE domain is a horizontal conformal Lambert grid defined by the SE corner (2.18, 34.00), NE corner (39.08, 55.62) and centre (17.00, 46.24). The grid contains 229 points in the x and 205 points in the y direction (240 in x and 216 in y, with an extension zone) with a grid size of 12.176 km in both directions.

For the purpose of this study, the coupling files produced in the operational run on the LACE domain were used for integration on the HRv8 domain with the AL12T1 cycle (CYCORA). The Croatian (HRv8) domain covers the Alps, the Dinaric Alps and part of the Adriatic Sea. It is a horizontally conformal Lambert grid defined by the SE corner (8.39, 41.79), NE corner (18.89, 49.44) and centre (15.00, 45.85). The grid contains 127 points in the x and 109 points in the y direction (144 in x and 120 in y, with an extension zone) with an 8-km resolution in both directions. Although extended coverage of the Adriatic Sea to the south would be desirable, it was impossible due to the size of the domain covered by the LBC files which are operationally distributed from the ALADIN/ LACE centre in Prague.

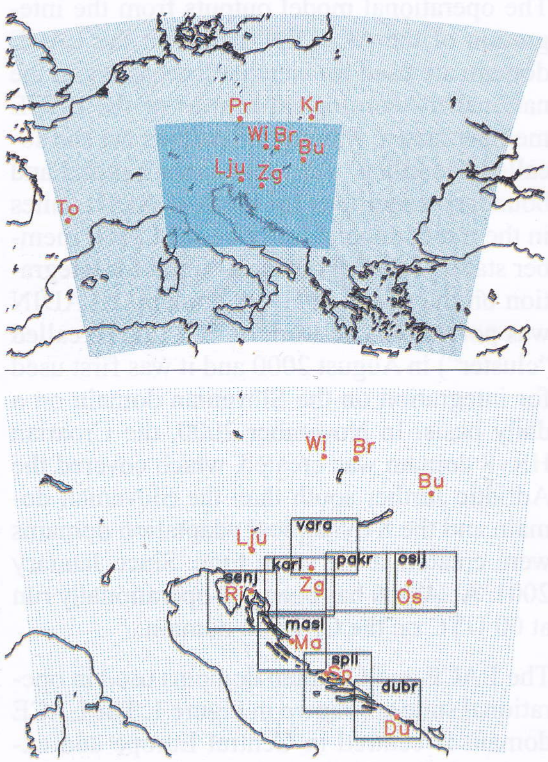


Figure 1. ALADIN/LACE (12-km resolution) and ALADIN/HR (8-km resolution) domains, every fifth grid point is shown (top). ALADIN/HR (8-km resolution) and Dynamical adaptation (2-km resolution) domains for the surface wind fields (bottom).

Slika 1. Domene ALADIN/LACE (korak mreže 12 km) i ALADIN/HR (korak mreže 8 km), prikazana je svaka peta točka mreže modela (gore). Domena ALADIN/HR (rezolucija 8 km) i domene za dinamičku adaptaciju (rezolucija 2 km) prizemnog polja vjetra (dolje).

The operational version of the ALADIN model for integration on the LACE domain used at the time was AL11, before the CYCORA fix (the new CYclogenesis COnvection RAdiation scheme), introduced on 30[th] November 1999. For integration on the Croatian domain, AL12 was used (with the CYCORA fix).

The output surface wind fields on the Croatian domain are dynamically adapted to the orography with a 2-km resolution. The method of dynamical adaptation is based on the fundamental and essential assumption that the wind at the surface depends on synoptic forcing and terrain configuration (Žagar and Rakovec, 1999) and works in the following way: The meteorological fields are first interpolated from the input 8-km resolution to the dynamical adaptation 2-km resolution grid. Then, the same file (the same meteorological data) is used as a initial file and as a coupling file that contains boundary conditions for the model. Then, the model is integrated for 30 minutes using a 60-second time step (for 30 time steps) giving the fields time to adapt to the high-resolution, lower-boundary conditions (orography and land/sea mask). The number of vertical levels is reduced and the diabatic part of the physics in the model is omitted to accelerate calculation. The data at the edges of the dynamical adaptation domain (the intermediate or coupling zone) remain the same as in the driving model, while the impact of the adaptation is strongest in the central part of the domain. By this method, some of the small-scale phenomena can be described disregarding the general description of the problem. Dynamical adaptation is run operationally for the 4 domains along the coast and for the one inland; they cover the areas with strong terrain influence on local wind where the terrain is poorly represented in the 8-km resolution model. The representation of terrain height in the Croatian domain and in the operationally used dynamical adaptation domains is shown in Figure 2.

Bura strongly depends on the local upstream terrain configuration; it is strongest downstream of the low passes in the mountain range. In the neighbouring areas in the lee of the tops it is significantly weaker. *Bura* is the consequence of a synoptic forcing interaction with a mountain in the immediate vicinity of the sea. During winter, the sea is warmer than the ground,

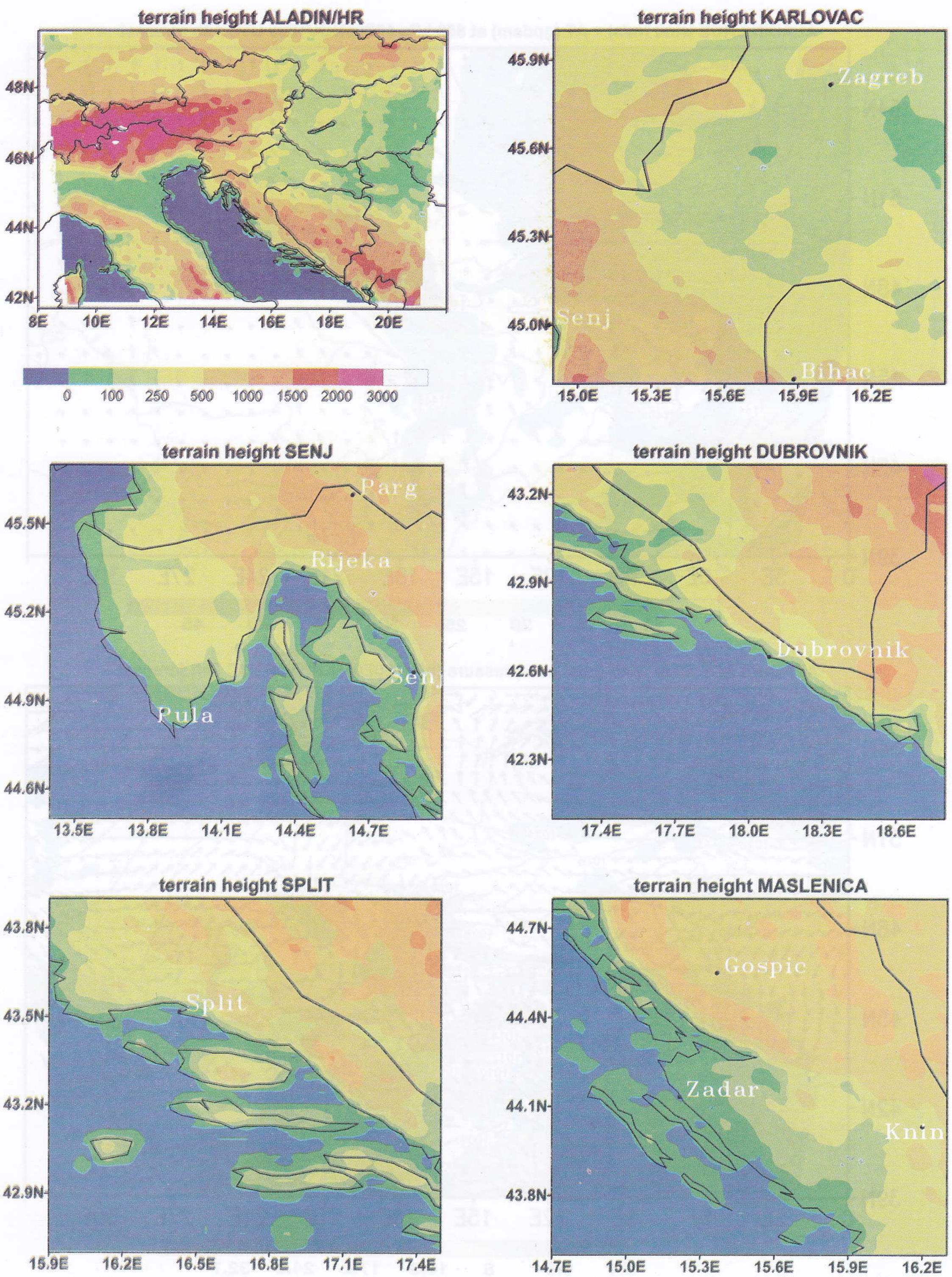


Figure 2. The representation of terrain height in the HRv8 domain (8-km resolution) and in Dynamical adaptation domains (2-km resolution).

Slika 2. Visina terena u domeni HRv8 (korak mreže 8 km) i u domenama za dinamičku adaptaciju (korak mreže 2 km).

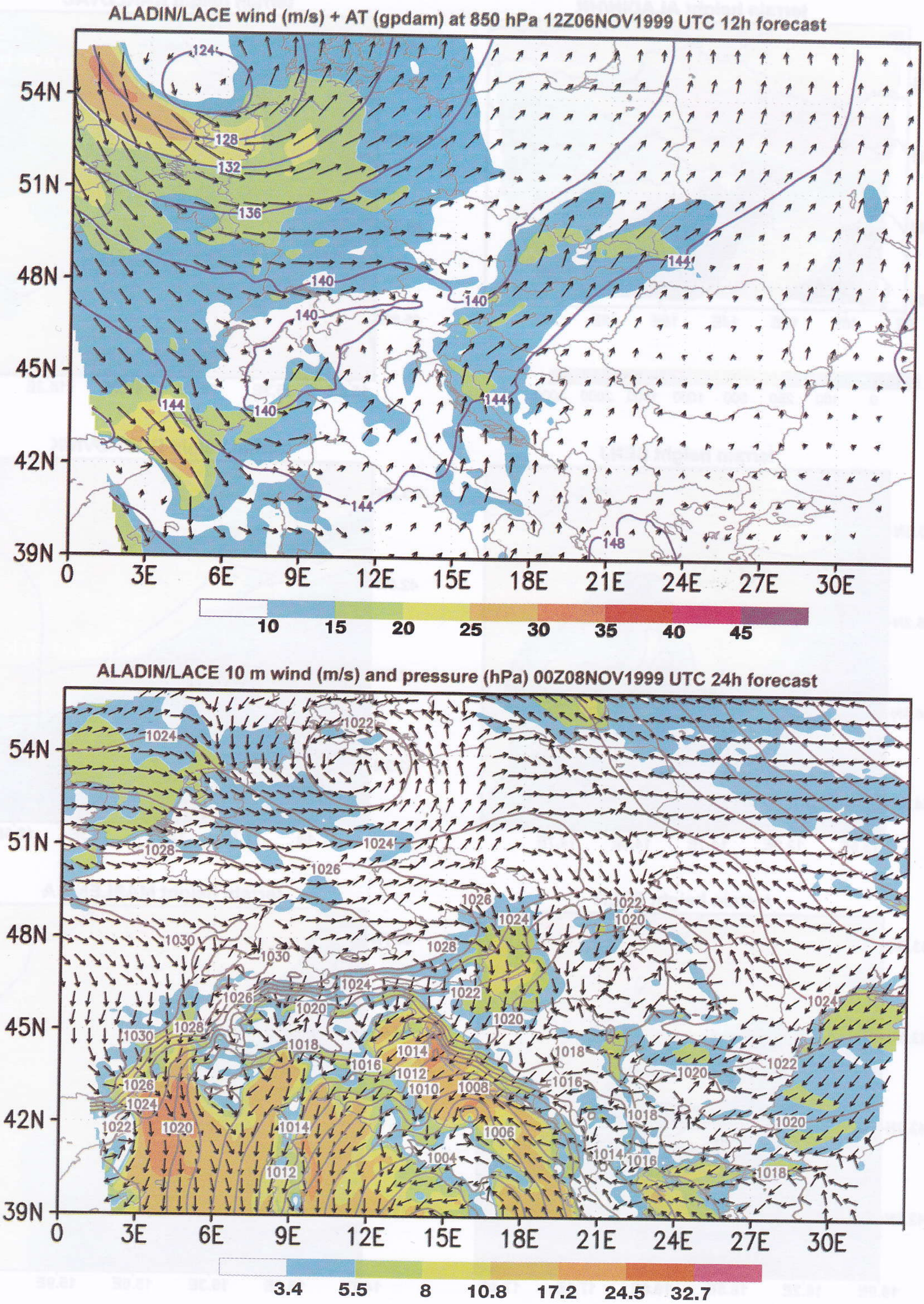
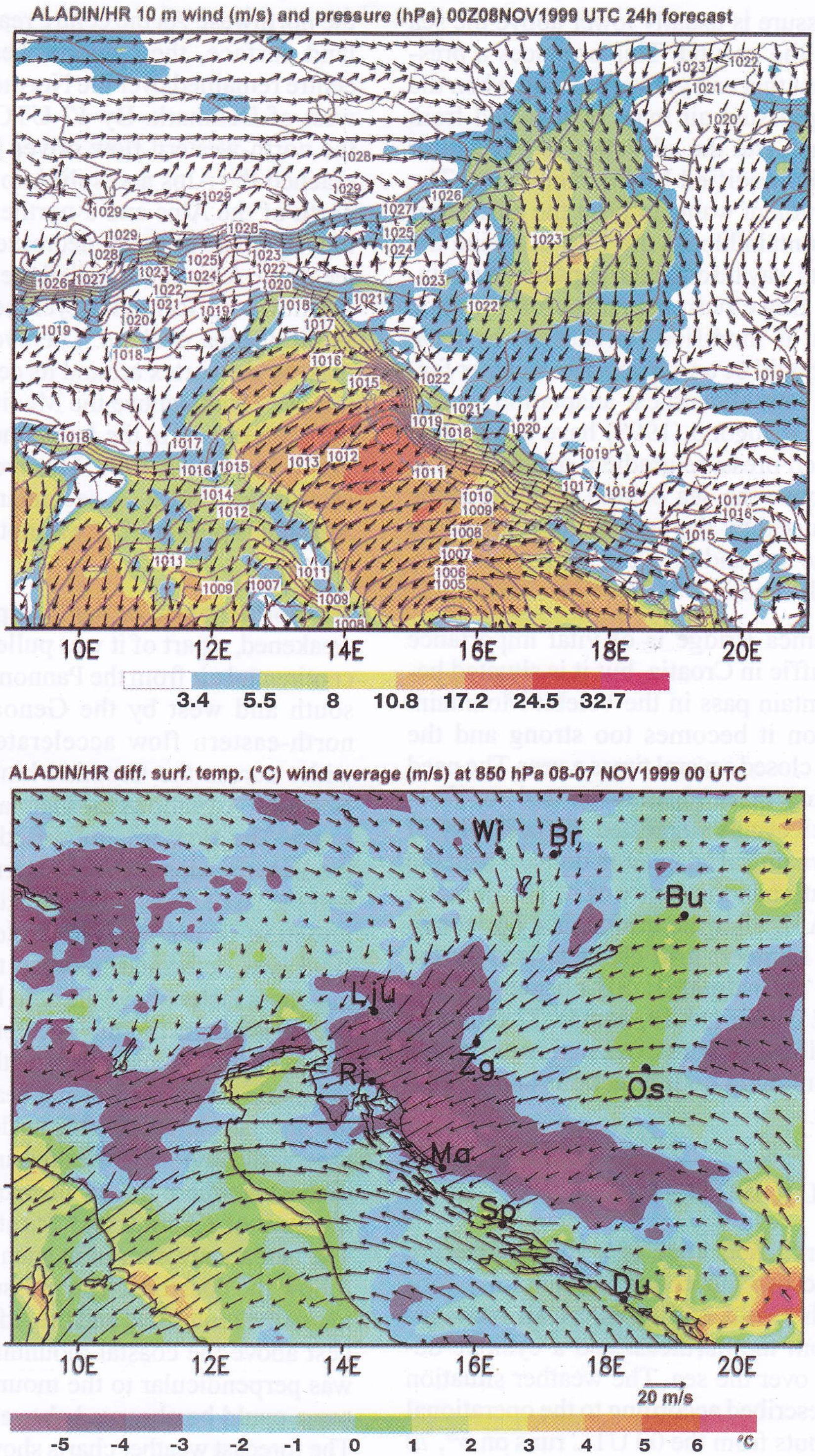


Figure 3. Geopotential, wind speed and vectors at 850 hPa for 12 UTC on 6th November 1999 (top left). 10 m wind and mean sea level pressure for 00 UTC on 8th November 1999 on the LACE domain (top right). The same for the Croatian domain (bottom left). Cold air advection (bottom right); vectors represent wind averaged during 24 hours, at 850 hPa, for the 7th November 1999 00 UTC run, averaged in time from analysis to 24 hr forecast (for the first 24 hours of integration outputs, only fields from analysis, 03, ... 21 and 24 forecast hours are taken). The 2 m-temperature difference (shaded) between the +24 hr forecast and analysis is also shown.



Slika 3. Geopotencijal brzina i vektori vjetra na plohi 850 hPa za 12 UTC 6. studenog 1999 (gore lijevo). Prizemni vjetar i tlak na srednjem nivou mora za 00 UTC 8. studenog 1999 na domeni LACE (gore desno). Isto za hrvatsku domenu (dolje lijevo). Advekcija hladnog zraka (dolje desno); vektori predstavljaju vjetar osrednjen kroz 24 sata na izobarnoj plohi 850 hPa za prognozu od 7. studenog 1999 u 00 UTC, vjetar je osrednjen u vremenu od analize do 24 h prognoze (iz izlaznih datoteka tijekom prvih 24 sata integracije uzeta su za prognostičke termine analiza, 03, ..., 21 i 24 sata). Također je prikazana razlika u temperaturi na 2 m iznad tla između 24-satne prognoze i analize.

and air pressure is usually lower above the sea than above the ground. This produces a pressure gradient that can get very strong when the cold, high-pressure air mass is advected from the northeast. But the advection is blocked or significantly modified by the mountains. The pressure gradient wants to push the air further but the mountain blocks the flow allowing the air to find its way through the gaps in the mountain range. Since *bura* depends on a synoptic forcing that is modified (or shaped) by local terrain, it should be an appropriate weather feature to see how dynamical adaptation works. Enger and Grisogono (1998) have shown that the enhanced pressure gradient due to the low pressure above the sea behind the orographic obstacle caused by the temperature difference between the sea and the land brings *bura* further from the coast.

The Maslenica Bridge is of vital importance for road traffic in Croatia, but it is situated below a mountain pass in the Velebit Mountain. The *bura* on it becomes too strong and the bridge gets closed several times a year. The need for exploring these phenomena and for forecasting such events suggested the necessity of having a dynamical adaptation domain with the bridge location in the centre of it. The domain, named MASL after the bridge, is a horizontal conformal Lambert grid characterised by the following co-ordinates: SE corner (14.62, 43.56), NE corner (16.40, 44.83), 72 points in both directions (80 with extension zone) with a 2-km resolution in both directions and 15 vertical levels.

4. MODEL RESULTS

Bura occurs when there is a strong pressure gradient across the coastal mountains, connected with a cold, high-pressure air mass advection from the northeast and a cyclone development over the sea. The weather situation has been described according to the operational model outputs from the 00 UTC runs on 6th, 7th and 8th November 1999 on the LACE domain and the model outputs from the integration on the Croatian domain for the 00 UTC runs for 6th and 7th November. The initial and boundary conditions for the Croatian domain have been obtained from the LACE output.

On 6th November 1999, the deep Atlantic cyclone approached the European landmass from the northwest. As the centre reached the cooler land surface, the cyclone weakened and its centre remained over the Northern Sea surface, west of Denmark. By 12 UTC the same day, the north-western flow driven by this cyclone reached the Alps and split into a western flow north of the Alps and a northern flow west of the Alps. The pressure decreased rapidly in the lee of the Alps and it pulled the western arm of the flow and formed a cyclone, better known as the Genoa cyclone. The cyclone deepened making the vortex around its centre stronger as it moved south above the Mediterranean along the western side of the Apennine peninsula during 7th November 1999. The cyclone was wider east of the centre. A secondary centre in the Adriatic is possible but was not detected in this case.

The northern arm of the flow passed the Alps, weakened, a part of it was pulled alongside the continental air from the Pannonian valley to the south and west by the Genoa cyclone. The north-eastern flow accelerated and became wider across the Croatian hinterland and the Northern Adriatic as the Genoa cyclone moved south. The flow was modified on the way by the Dinaric Alps on the Eastern Adriatic coast and the Apennines on the west, causing a perturbation in the pressure field. The pressure field was deformed because the air pressure increases faster above the cold land surface, especially where the air decelerates during its ascent up the mountain than on the lee side of the mountain above the warmer sea surface, where the flow accelerates during its descent. This was especially obvious in the area around the Istrian peninsula where the air pressure was lower in the bays of Kvarner and Trieste than in Istria. The isobars are curved in such a way that they follow the coastline. The pressure gradient between the hinterland and the Adriatic was strongest above the coastal mountains but the flow was perpendicular to the mountain range. The same could be observed above the Apennines. The forecast weather charts show that the southern warm and moist wind on the eastern side of the Genoa cyclone from the Strait of Otranto collided with the cold and dry north-eastern wind and formed a cyclone in the Southern Adriatic (not shown). The pressure low and a vortex of this cyclone developed around 21 UTC on 7th November 1999 and persisted until 03 UTC the next day in the integration on the

Croatian domain (Fig. 3 – only the 24-hour forecast chart for 00 UTC is shown). The cyclone also existed in the +24 hours of the 00 UTC run on the 7th November 1999 forecast fields valid for 00 UTC on 8th November from the integration on the LACE domain, but it did not exist in the analysis fields of the 00 UTC run on the 8th of November because the LACE analysis was actually just the ARPEGE analysis interpolated on a LACE grid (with DFI - digital filter initialisation, that filters out the small-scale waves). ARPEGE, because of its coarse resolution in the area, did not "catch" the Adriatic cyclone.

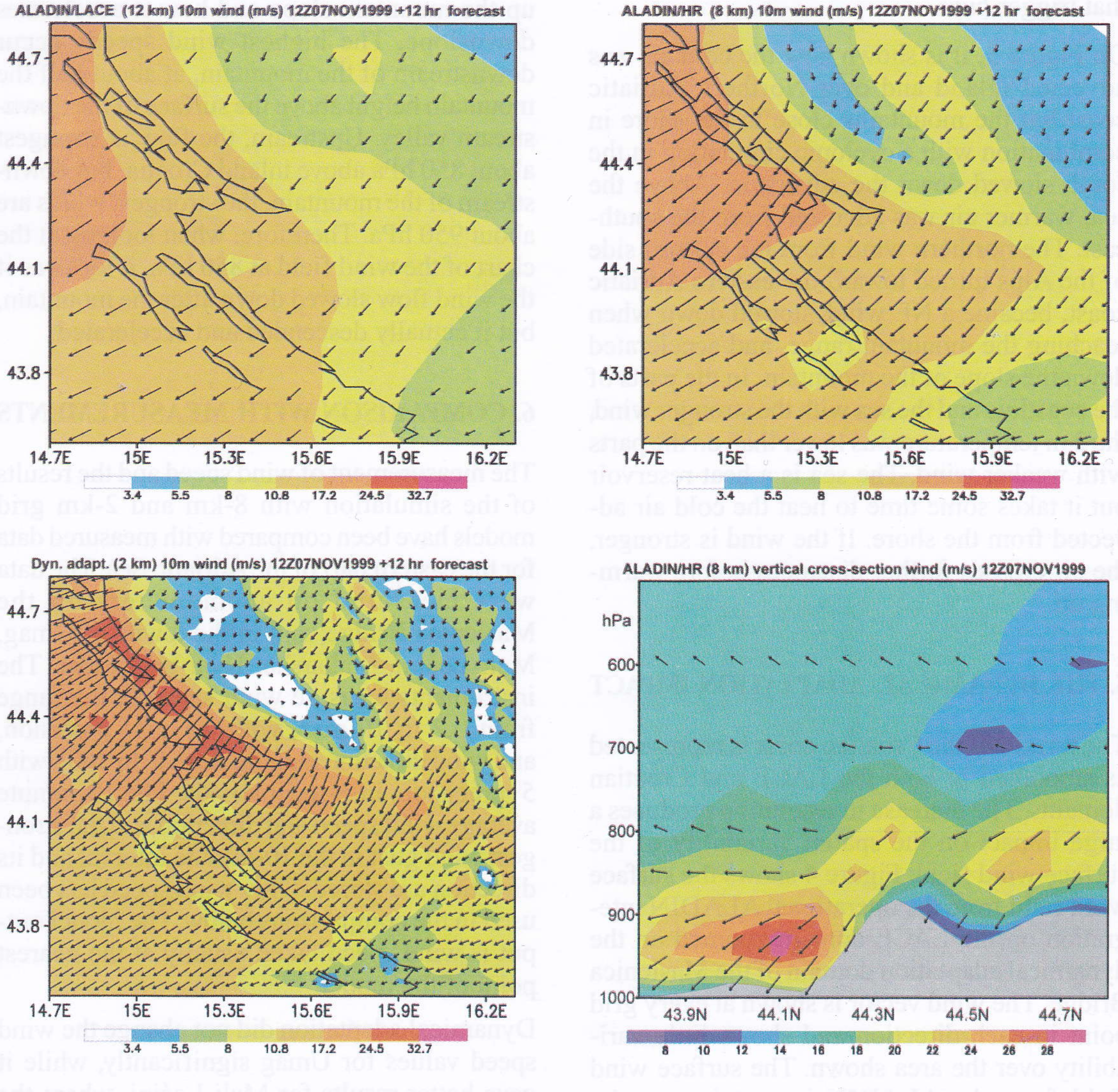


Figure 4. Surface wind fields (10 m agl) from ALADIN/LACE (top, left), ALADIN/HR (top, right) and Dynamical adaptation (bottom, left) and the meridional cross-section from ALADIN/HR (bottom, right) on vertical pressure levels from 975 to 600 hPa, for 15.5 east longitude and latitude from 43.8 to 44.8, with terrain height along that profile for the 7th November 1999 00 UTC run. The 12-hr forecast is shown as wind velocity (vector) and as wind speed (shaded).

Slika 4. Polje prizemnog vjetra (10 m iznad tla) u modelu ALADIN/LACE (gore lijevo), ALADIN/HR (gore desno) i dinamičku adaptaciju (dolje desno) i meridionalni vertikalni presjek polja vjetra prikazano je vektorski, a brzina vjetra osjenčano za izobarne plohe od 975 do 600 hPa za zemljopisnu dužinu 15.5 i širinu od 43.8 do 44.8 iz ALADIN/HR za 12-satnu prognozu modela pokrenutog za 00 UTC 7. studenog 1999.

The shortage of the area covered for the Croatian domain is the most obvious when this cyclone is considered. A further spread of the domain to the south is prevented by the size of the domain covered by the coupling files that are operationally produced in the LACE centre in Prague. This affects *bura* prediction because it prevents the use of the model on this domain for exploring the cyclogenesis in the Southern Adriatic, which is one of the synoptic forcings that trigger *bura*.

On Figure 3, it is shown how the cold air was advected inland and over Northern Adriatic coast but the mountains close to the shore in combination with a cyclonic circulation in the south slowed down the advection. Above the sea, warmer air was advected from the southeast. The northern wind from the eastern side of the Alps turned toward the eastern Adriatic coast, became a NE wind, slowed down when reaching the mountain range, and accelerated down the slope of the mountain. In the parts of the coastline and the sea with the stronger wind, the 2 m temperature was lower than on the parts with weaker wind. The sea is a heat reservoir but it takes some time to heat the cold air advected from the shore. If the wind is stronger, the air crosses further distances before warming up.

5. THE DYNAMICAL ADAPTATION IMPACT

The terrain of the Croatian coast is represented as smoothed in both the LACE and Croatian domains. The increase in resolution produces a large impact on the spatial variability of the surface wind field. Figure 4 shows the surface wind field from the operational ALADIN integration on the LACE domain zoomed on the dynamical adaptation domain of the Maslenica Bridge. The wind vector is shown at every grid point in each direction and shows little variability over the area shown. The surface wind field from the ALADIN integration on the Croatian domain zoomed on the same domain is shown on Figure 4: the wind velocity and speed show more variation in the area and in some parts significantly differ from the LACE fields. The dynamical adaptation of the latter is presented in Figure 4 showing a huge variability of the surface wind in the area as a consequence of the higher-resolution representation of the complicated local orography.

The meridional cross-section of wind velocity (vectors) and wind speed (shaded) at vertical pressure levels from 975 to 600 hPa, for 15.5 E longitude, with terrain height along that profile for 7th November 1999, 12 UTC, are also shown in Figure 4. The wind vectors represent the horizontal wind speed and direction, not the vertical wind component. Following the terrain top from right to left (along the flow), it can be seen how the wind is weaker when "climbing" up the mountain slope and how it accelerates downslope. The highest wind speeds occur downstream of the mountain, at about half the mountain height above the surface of the downstream valley. Upstream, the flow is strongest about 850 hPa above inland Croatia, but downstream of the mountain, the strongest winds are about 950 hPa. Therefore, when looking at the chart of the wind field at 850 hPa, it looks as if the wind flow slowed down after the mountain, but it actually descended and accelerated.

6. COMPARISON WITH MEASUREMENTS

The measurement of wind speed and the results of the simulation with 8-km and 2-km grid models have been compared with measured data for the eastern part of the Adriatic Sea. The data were measured on anemometers on the Maslenica Bridge, and in the towns of Umag, Mali Lošinj, Makarska, Hvar and Zadar. The instruments measure wind speed in the range from 0.2 to 70 ms^{-1}, with 0.1 ms^{-1} precision, and wind direction ranging from 0^0 to 360^0, with 5^0 precision, in 1-sec intervals. The 10-minute average wind speed and direction and the strongest wind gust in the 10-minute interval and its direction are stored. Only wind speed has been used in the comparisons below. The model output is wind speed taken usually at the nearest point of the model.

Dynamical adaptation did not change the wind speed values for Umag significantly, while it gave better results for Mali Lošinj, where the measured wind was weaker than forecasted by the ALADIN/HR model, maybe due to the location of the measuring site.

The location of the Maslenica Bridge is very important for road traffic – with wind speeds of the magnitude shown the bridge gets closed. The ALADIN/HR forecast produced too weak winds for this bridge just downstream (in the case of *bura*) the mountain pass on the Velebit

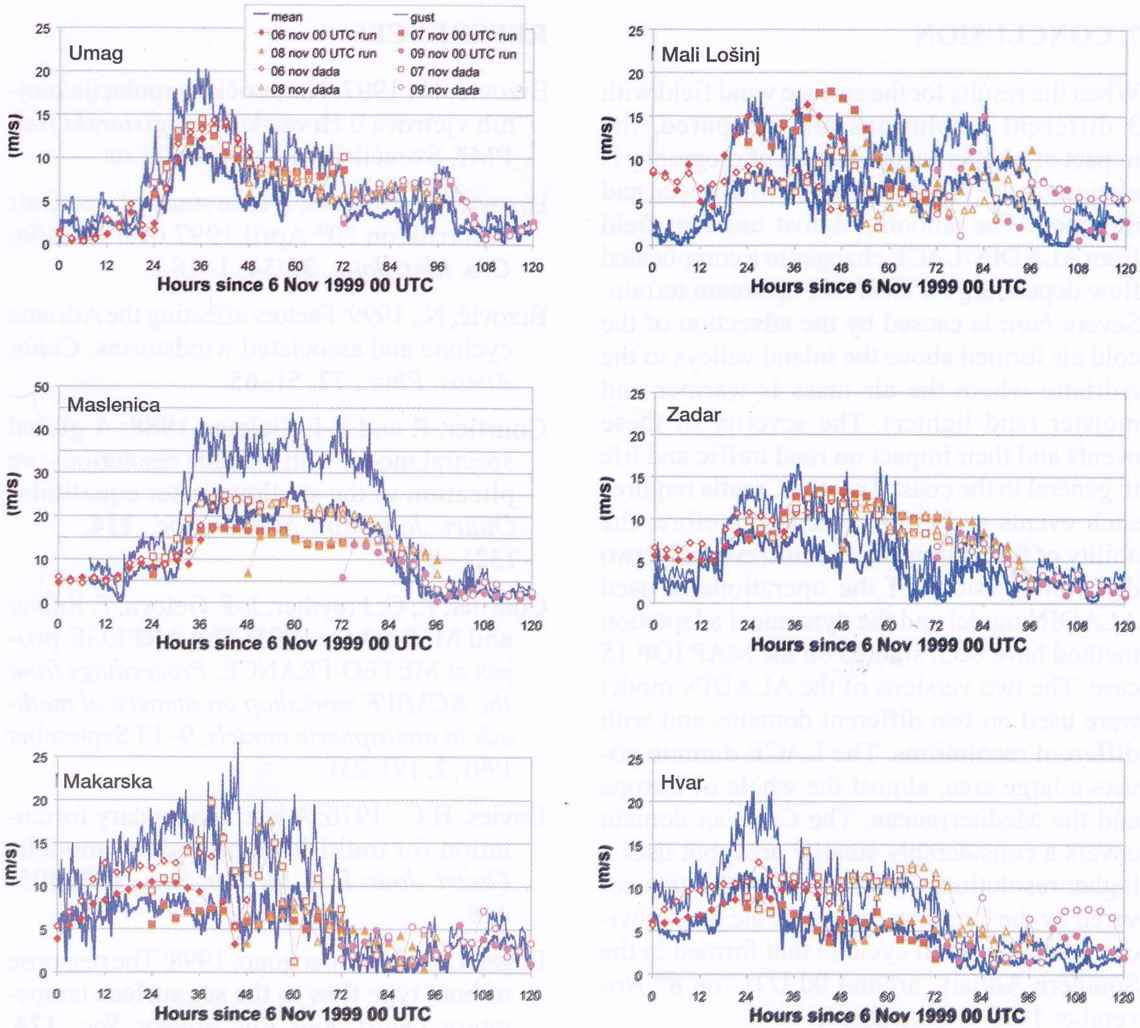


Figure 5. Wind measurement data, ALADIN Croatia forecasts and Dynamical adaptation of surface wind for Umag, Mali Lošinj, Maslenica, Zadar, Makarska and Hvar for the period from 6th to 11th November 1999, 00 UTC. The ALADIN Croatia forecast data are from the ALADIN 48-h forecast 00 UTC runs for 6th, 7th, 8th and 9th November 1999 and DADA data are from the Dynamical adaptation of the forecasts on the Senj, Maslenica and Split domains.

Slika 5. Mjereni podaci vjetra, prognoza ALADIN Hrvatska i dinamička adaptacija prizemnog vjetra za Umag, Mali Lošinj, Maslenicu, Zadar, Makarsku i Hvar za razdoblje od 6. do 11. studenog 1999 u 00 UTC. Podaci ALADIN Hrvatska odnose se na 48-satne prognoze modelom ALADIN za 00 UTC termine za 6, 7, 8. i 9. studeni 1999, a podaci DADA odnose se na dinamičku adaptaciju tih prognostičkih polja na domenama Senj, Maslenica i Split.

Mountain. Dynamical adaptation gave wind speeds that correspond much better to the measurements.

The ALADIN/HR forecast produced too strong winds in general for Zadar, not in the immediate vicinity of the Velebit Mountain. Dynamical adaptation gave better results and followed the temporal changes in wind speed. On the whole, there is still much space for improvement. The measurement point is situated in the city and is protected from *bura*.

For the towns of Makarska and Hvar, the ALADIN/HR forecast wind speed values were closer to the measured data than the dynamical adaptation values; the latter method overestimated the wind speed for those locations.

7. CONCLUSION

When the results for the surface wind field with 3 different resolutions are compared, the impact of a better representation of orography is obvious in the variability of the wind speed and direction. The smooth, almost uniform field from ALADIN/LACE changes to a complicated flow depending on local and upstream terrain. Severe *bura* is caused by the advection of the cold air formed above the inland valleys to the Adriatic where the air mass is warmer and moister (and lighter). The severity of these events and their impact on road traffic and life in general in the coastal part of Croatia requires such events to be forecasted. Therefore, the ability of forecasting severe *bura* events by two different versions of the operationally used ALADIN model and the dynamical adaptation method have been studied on the MAP IOP 15 case. The two versions of the ALADIN model were used on two different domains and with different resolutions. The LACE domain covers a large area, almost the whole of Europe and the Mediterranean. The Croatian domain covers a considerably smaller area, but uses a higher resolution. The shortage of the area covered by the Croatian domain is the most obvious when the small cyclone that formed in the Southern Adriatic around 00 UTC on 8th November 1999 is considered.

Further, the impact of the method of dynamical adaptation of the surface wind fields has been studied on the same case. The output surface wind field from the integration on the Croatian domain has been dynamically adapted to a 2-km resolution representation of orography giving a wind field that shows significantly more spatial variability in areas with complicated orographic features.

Overall, the operational version of the ALADIN model on the Croatian domain gives satisfactory results that are (in some cases) improved by the dynamical adaptation procedure. For locations hit by extremely severe *bura*, the method definitely brought some progress. The obvious lack of comparison of the modelled wind direction to the measured one is a consequence of the unavailability of a large number of data for that parameter. Some other case might give different results, giving inspiration for further studies.

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