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EVALUATION OF THE ALADIN/LACE MESOSCALE MODEL DURING THE MAP SOP EXPERIMENT

Provjera uspješnosti mezomodela ALADIN/LACE tijekom MAP SOP eksperimenta

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Abstract: The time series of temperature, wind speed and wind direction of the ALADIN/LACE (Limited Area Modelling for Central Europe) mesoscale model were compared with the radio-sounding data obtained above Zagreb during the Mesoscale Alpine Programme Special Observing Period (MAP SOP, Sept–Nov 1999). The evaluation was done at the 850 hPa level and at 988 m above mean sea level. The latter was chosen to test the usability of the Puntijarka station data as a substitute at 988 m during periods when radio-sounding observations are not available.

The forecast values of temperature and, to some extent, wind direction agree better with the observed data than the forecast values of wind speed. The forecast skill decreases with the forecast range. The modelled temperature is slightly overestimated; in contrast, wind speed is slightly underestimated. The accuracy of the prognostic temps (pseudoTEMP) of the direct ALADIN/LACE mesoscale model output is somewhat smaller at 988 m, very likely due to the influence of surface forcing.

The temperature measured at the Puntijarka station agrees better with radio-sounding data than wind speed and wind direction. The time series of temperature are subjected to a seasonal tendency variation, that makes these data usable only in periods when there is no tendency. In contrast, because of the existence of huge tendencies, raw wind speed and wind direction data are, in general, not suitable for the purpose of the model verification or initialisation.

Key words: ALADIN, MAP, Puntijarka, forecast skill

Sažetak: Provjera uspješnosti mezomodela ALADIN/LACE (LACE – Limited Area Modelling for Central Europe) napravljena je usporedbom vremenskih nizova temperature te smjera i brzine vjetra sa radiosondažnim podacima postaje Zagreb-Maksimir dobivenim tijekom izvođenja Mesoscale Alpine Programme Special Observing Period (MAP SOP) eksperimenta od rujna do studenog 1999. Evaluacija je napravljena na izobarnom nivou 850 hPa, kao i na visini 988 metara. Ta visina odabrana je tako da omogući testiranje upotrebljivosti podataka s postaje Puntijarka kao zamjenskih podataka za radiosondažna mjerenja na toj visini, u terminima kada visinska mjerenja nisu dostupna.

Prognostičke su vrijednosti temperature i do određene mjere smjera vjetra usporedivije s mjerenim podacima nego prognostičke vrijednosti brzine vjetra, a uspješnost prognoze u pravilu opada s duljinom prognostičkog razdoblja. Prognostički nizovi temperature pokazuju blagu precijenjenost, brzine vjetra blagu podcijenjenost, dok tendencija (bias) kod nizova smjera vjetra nije uočena. Točnost prognostičkih tempova (pseudotempova) nešto je manja na plohi 988 m, vjerojatno zbog utjecaja prizemnih tokova.

Podaci mjerenja temperature s postaje Puntijarka usporediviji su s radiosondažnim podacima nego podaci mjerenja brzine i smjera vjetra. U nizovima temperature uočen je sezonski hod njihove tendencije, što te podatke čini upotrebljivima samo u prijelaznim sezonskim razdobljima kada tendencija isčezava. Nasuprot tome, zbog uočenih velikih tendencija, sirovi podaci nizova brzine i smjera vjetra s postaje nisu upotrebljivi u svrhu verifikacije ili inicijalizacije samog modela.

Ključne riječi: ALADIN, MAP, Puntijarka, uspješnost prognoze

1. INTRODUCTION

Evaluation of a numerical model is a necessary procedure in the development of a numerical weather forecast. To test the quality of the model predictions of atmospheric parameters in space and time, in the evaluation process, different methods are used to compare the measured data and prognostic values of a model (Murphy and Epstein 1989; Daley, 1991). This paper presents an objective evaluation of a high-resolution ALADIN/LACE numerical model over the Zagreb area during the MAP SOP (September – November 1999).

The MAP SOP was divided into several IOP's (Intensive Observing Periods) during which some extra measurements were available (Binder and Schär, 1996). For special MAP IOP soundings, observations were made at 3- and 6-hourly time intervals.

The capability of the ALADIN model to predict heavy precipitation and strong wind events over the eastern side of the Alps during the MAP was presented in several papers (Ivančan-Picek and Jurčec, 2002; Tudor and Ivatek-Šahdan, 2002; Ivančan-Picek et al., 2003).

Forecast values of temperature, wind direction and wind speed were evaluated at the 850 hPa level and at 988 m, the latter being the height of the Puntijarka mountain station on the nearby Medvednica mountain. This made possible the inclusion of the standard measurements at this station into the analysis at that level to determine their compatibility with radio-sounding data. In case the difference proved small, the observed values from the Puntijarka station could be used as a substitute for sounding data in periods when they are not available.

2. METHODS OF ANALYSIS

Thus, forecast values of temperature, wind speed and wind direction were compared with the MAP radio-sounding data at the 850 hPa level, and with the observed Puntijarka mountain station data at 988 m. The times of interest analysed at both levels were 00 and 12 UTC. The data were linearly interpolated to corresponding levels. A standard comparison procedure was used for the +00, +12, +24, +36 and +48-hour forecast ranges (Tab. 1). Parts of the observations and pseudoTemp (prognostic temp) data were missing, while the Puntijarka station temperature data were available only at 12 UTC.

Table 1. ALADIN/LACE model forecast temperature at 850 hPa level for +00, +12, +24, +36, +48-hour forecast ranges (AL+00, ...AL+48) compared to the corresponding observed data (MAP)

Tablica 1. Prognostičke vrijednosti temperature ALADIN/LACE modela na nivou 850 hPa za prognostička razdoblja +00, +12, +24, +36 i +48 (AL+00,...,AL+48) uspoređene s odgovarajućim mjerenim podacima (MAP)

Forecast valid at	MAP	AL+00	AL+12	AL+24	AL+36	AL+48
18. 9. 00 UTC	12.8	12.6				
18. 9. 12 UTC	10.5	12.4	12.3			
19. 9. 00 UTC	12.2	12.0	11.9	11.1		
19. 9. 12 UTC	11.9	12.5	12.8	12.5	12.4	
20. 9. 00 UTC	11.4	12.3	12.8	12.5	12.6	12.2
20. 9. 12 UTC	13.3	14.7	14.4	14.3	13.5	13.5
21. 9. 00 UTC	15.5	15.2	16.8	15.9	12.7	10.9

Furthermore, an objective evaluation was made according to the following criteria (Bonta, 2000):

a) for temperature
1 - absolute error less than ±2°C
2 - absolute error between ±2–4°C
3 - absolute error more than ±4°C

b) for wind speed and direction
1 - wind speed absolute error less than ±2 ms^{-1}, wind direction less than ±30°
2 - wind speed absolute error between ±2–3 ms^{-1}, wind direction between ±30–50°
3 - wind speed absolute error more than ±3 ms^{-1}, wind direction more than ±50°

The analysis included a calculation of the ratio of overestimated and underestimated forecast values as well as the Puntijarka station data, for forecasts considering:
a) all prognostic values
b) only class 2 and 3 forecasts, according to the aforementioned criteria

3. ANALYSIS

3.1. Temperature

The time series of the ALADIN/LACE forecast temperature (AL+) and the Zagreb-Maksimir radio-sounding data (MAP) for October 1999, at the 850 hPa level and at 988 m, are presented in Figure 1. The temperature observed at the Puntijarka station, available only at 12 UTC, was included into the analysis at 988 m. The forecast values agreed well with the measured ones, except in the case of cold (October 4, 1999) and warm (October 20, 1999) front cases, when they differed up to 6.0 °C (AL+48), depending on the forecast range. The positive bias of the Puntijarka station temperature data in September and the first half of October was gradually lost in the second part of the month, and especially in November.

On days with the greatest errors, the model was late in forecasting a cold front (4 October, 1999) and too fast in forecasting a warm front (20 October, 1999). While on 4 October at 12 UTC, the model was late in the prediction of a cold front, the observed Puntijarka station value agreed well with the radio-sounding value.

The maximum absolute errors of forecast temperature in general increased with the forecast range (Tab. 2). They were mainly positive, reaching higher values at lower level, i.e. at

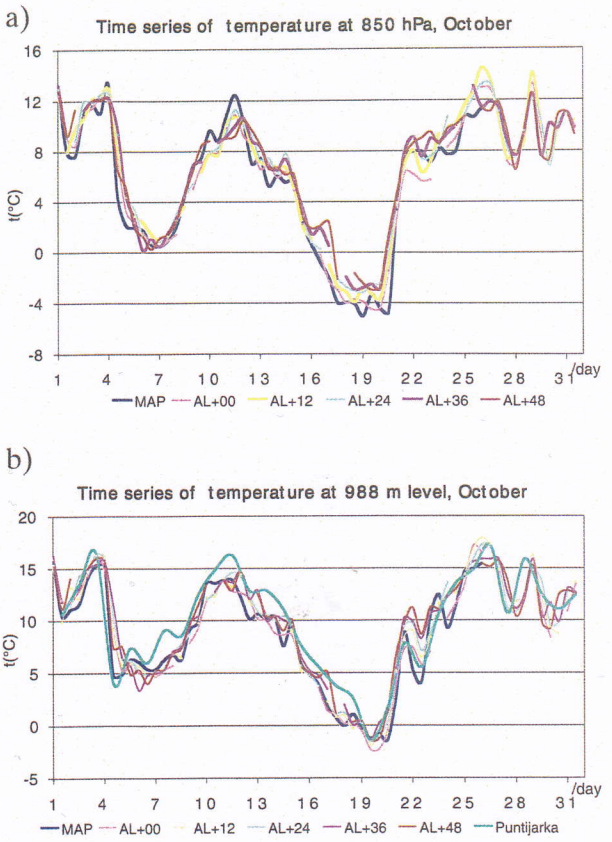

Figure 1. Temperature time series of the ALADIN/LACE model forecast (AL+00, ...AL+48) and observation (MAP) at: a) 850 hPa level ; b) 988 m height, for October 1999.

Slika 1. Vremenski nizovi prognostičkih vrijednosti temperature modela ALADIN/LACE (AL+00,..., AL+48) i mjerenja (MAP) u listopadu na a) 850 hPa; b) 988 m, za listopad 1999.

988 m. The reason for that is a generally greater oscillation of temperature closer to the ground, as well as the probable influence of surface forcing and the quality of its parameterisation in the model.

The maximum deviation between the observed temperature at the Puntijarka station and the radio-sounding measurements in October and November was smaller then the maximum model absolute temperature error.

The classification of the model forecast quality at 850 hPa level is shown in Figure 2. The percentages of class 1 temperature pseudoTemps, according to Bonta's criteria, in a balanced 3-monthly average, equal 91.37% (AL+00), 87.77% (AL+12), 84.06% (AL+24), 81.02% (AL+36) and 80.15% (AL+48). The total ratio of overestimated and underestimated values

Table 2. Maximum absolute temperature forecast errors of the ALADIN/LACE model for: a) 850 hPa level and b) 988 m height during the MAP period

Tablica 2. Maksimalne apsolutne greške prognostičkih vrijednosti temperature modela ALADIN/LACE za plohe: a) 850 hPa i b) 988 m tijekom MAP razdoblja

a)

850 hPa	AL+00	AL+12	AL+24	AL+36	AL+48
Sept	2.7	2.8	2.7	3.0	-4.6
Oct	3.3	3.9	5.0	5.8	6.0
Nov	-3.0	5.0	-3.7	-4.3	4.8

b)

988 m	AL+00	AL+12	AL+24	AL+36	AL+48	Punt
Sept	4.0	4.0	4.5	4.2	4.7	5.2
Oct	4.5	4.5	5.7	6.8	6.0	3.5
Nov	-5.7	7.1	5.8	6.1	7.2	2.9

(Ov/Un) is 67.3 / 32.7. The forecast values for longer forecast ranges showed a somewhat greater tendency of overestimation. The same ratio was computed including class 2 and 3 forecasts only, in order to investigate the behaviour of the model in situations with greater absolute errors (e.g. cases of fronts, intensive local phenomena etc.). This information could be easily lost in a general data analysis (e.g. by a small but permanent tendency in stable synoptic situations with small absolute errors) and, therefore, class 1 cases with small errors were excluded from the analysis. This latter ratio is even higher and equals 79.81 / 20.19, but for this ratio very few data were available.

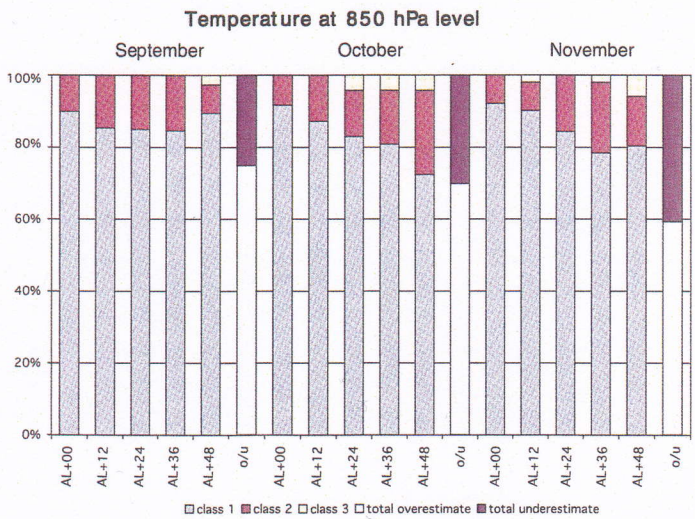

Figure 2. Percentages of the temperature forecast errors of the ALADIN/LACE model at the 850 hPa level classified according to Bonta's classes. The quality of the forecast decreased with the forecast range. The existence of an underestimation tendency was recorded as well.

Slika 2. Postotci apsolutnih grešaka prognostičkih vrijednosti temperature modela ALADIN/LACE na 850 hPa klasificiranih u kvalitativne klase po Bonti. Točnost prognoze smanjuje se s duljinom prognostičkog razdoblja, uz postojanje blage tendencije precijenjenosti.

A classification of the accuracy of the forecast temperature values at 988 m, as well as of the values observed at the Puntijarka station, is presented in Figure 3. The forecast values were slightly overestimated and the quality decreased with the forecast range. The result for the Puntijarka station data in September and October 1999 is comparable with the result achieved for the forecast values, showing even the same tendency. However, a considerable high closeness to radio-sounding data in November should be noticed, as well as the absence of any tendency.

The percentages of temperature pseudoTemps that satisfied class 1, expressed in a balanced mean, are 87.05% (AL+00), 79.86% (AL+12), 79.71% (AL+24), 78.10% (AL+36), 77.21% (AL+48), exhibiting a regular decrease with the forecast range, despite monthly variations. The average of differences lower than ±2°C for the Puntijarka station measurements is 75.31%, a value lower than the corresponding

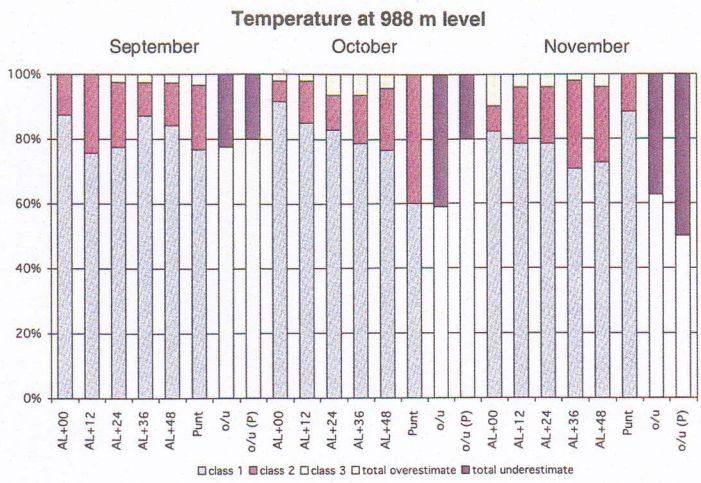

Figure 3. Percentages of the temperature forecast errors of the ALADIN/LACE model at 988 m as well as the deviation of Puntijarka station measurements from radio-soundings data classified according to Bonta's classes. Forecast values are slightly overestimated and the quality decreases with forecast range. The result for the Puntijarka station data in September and October is comparable with the result achieved for forecast values. However, a considerably high closeness to radio-sounding data in November should be noticed as well as lack of any tendency.

Slika 3. Postotci apsolutnih grešaka prognostičkih vrijednosti temperature modela ALADIN/LACE na 988 m, kao i odstupanja mjerenja na Puntijarci od radiosondažnih podataka klasificiranih u kvalitativne klase po Bonti. Prognostičke vrijednosti su blago precijenjene, a njihova kvaliteta se smanjuje s duljinom prognostičkog razdoblja. Rezultati dobiveni za podatke s Puntijarke su u rujnu i listopadu slični onima dobivenima za prognostičke vrijednosti. Međutim, u studenom se može primijetiti velika usporedivost dvaju nizova mjerenih podataka kao i nedostatak bilo kakve tendencije.

value for pseudoTemps, but quantitatively, the difference between class 1 averages from the Puntijarka station and pseudoTemp data is rather small, excluding the "first guess" of the model from the conclusion. The total ratio of overestimated and underestimated values of forecast temperature at 988 m was 64.52% / 35.48%. The same ratio, using only class 2 and class 3 prognostic values, was significantly higher and equalled 88.15% / 11.85%. By eliminating class 2 and 3 prognostic values, the Ov/Un ratio for class 1 prognostic values would be a bit more balanced, but still high.

Considering that a similar result was achieved at the 850 hPa level, maybe it is reasonable to conclude that the model overestimates temperature values. In unstable synoptic situations, when class 2 and 3 forecasts occur, that conclusion is more then obvious. These situations in Zagreb are usually connected with a frontal influence and intensive small-scale temperature variations. As there are other tools for forecasting unstable synoptic situations beside the temperature forecast, their appearance and development can be determined very accurately in time. Thus, from a forecaster's point of view, it might be possible to correct the temperature forecast in line with the above conclusions.

The ratio of overestimated and underestimated values of the Puntijarka station measurements equals 70.37% / 29.63%. This ratio was characterised by a monthly variation (see Figure 3), indicating the existence of variability in connection with seasonal changes in the boundary layer – the atmosphere system. Namely, in the early afternoon in summer, the lowest 100 m temperature profile is usually superadiabatic, and above that level, to 988 m, adiabatic (presuming that the 988 m level is inside the mixing layer). However, on the Medvednica mountain, the vertical temperature gradient is smaller than in the boundary layer. Accepting that this is a good description of the situation in September and the first part of October, this would be the main reason for an overestimation of the Puntijarka station measurements compared with the radio-sounding data. In the second part of October and November, the height of the mixed layer above Zagreb was below 988 meters. Therefore, the vertical temperature gradient was smaller and more comparable with the gradients on the Medvednica mountain. The result is a greater similarity of compared measured data at the analysed level.

The model thus forecasted temperature with significant accuracy, but also showed an overestimation tendency with no general dependence on the stability or instability of synoptic situations. However, full independence of the model tendency in each synoptic situation should be investigated throughout the various synoptic situations, which was not done in this case.

Table 3. Maximum wind speed forecast errors (ms^{-1}) of the ALADIN/LACE model for: a) 850 hPa and b) 988 m during the MAP period

Tabelica 3. Maksimalne apsolutne greške prognostičkih vrijednosti brzine vjetra (ms^{-1}) modela ALADIN/LACE za plohe: a) 850 hPa i b) 988 m tijekom MAP razdoblja

a)

850 hPa	AL+00	AL+12	AL+24	AL+36	AL+48
Sept	-8.4	-8.4	-8.0	-7.0	-10.8
Oct	-4.8	-6.5	7.8	7.2	-7.2
Nov	-7.6	-7.5	-12.6	-8.4	-11.3

b)

988 m	AL+00	AL+12	AL+24	AL+36	AL+48	Punt
Sept	-7.5	-7.5	8.4	7.3	8.3	-11.7
Oct	-7.6	8.1	8.1	7.5	7.7	-17.5
Nov	-7.0	5.5	-6.1	6.5	8.9	-15.4

3.2. Wind speed

In an extensive wind speed analysis it is important not to identify the same absolute errors in different wind speed values, because their importance is not the same. Therefore, some attention has been given to analysing relative wind speed errors. This presumption will be commented later on in the text.

The forecast wind speed agreed well with the observed sounding values. The Puntijarka station measurements differed markedly from the radio-sounding data, reaching even extreme errors (up to 17.5 ms^{-1}), except in cases with weak winds. The greatest difference between the observed radio-sounding and station values was more than twice bigger than the maximum forecast error in the analysed period. The maximum forecast absolute errors did not grow monotonously with the forecast range, but rather exhibited a slightly irregular character, reaching similar values (Tab. 3).

The percentages of the wind speed forecast at the 850 hPa level that satisfied class 1, expressed in a balanced mean, equal 64.44% (AL+00), 61.48% (AL+12), 57.46% (AL+24), 53.73% (AL+36), 46.97% (AL+48). Accuracy was, therefore, the greatest for the model analysis (AL+00) and gradually falling with the forecast range (Fig. 4). The percentage of class 3 (absolute error >3ms^{-1}) describes the predicted character well enough to draw the same conclusion. The total ratio of overestimation and underestimation equals 35.99% / 64.01%. Underestimation was even more expressed for class 2 and 3 forecasts, where it equals 29.59% / 70.41%.

The percentages of class 1 wind speed forecast values at 988 m, in a balanced mean, equal 66.42% (AL+00), 65.69% (AL+12), 62.50% (AL+24), 62.96% (AL+36), 51.49% (AL+48), regularly falling with the forecast range (Fig. 5). The total ratio of overestimated and underestimated forecasts equals 39.46%/60.54%. The

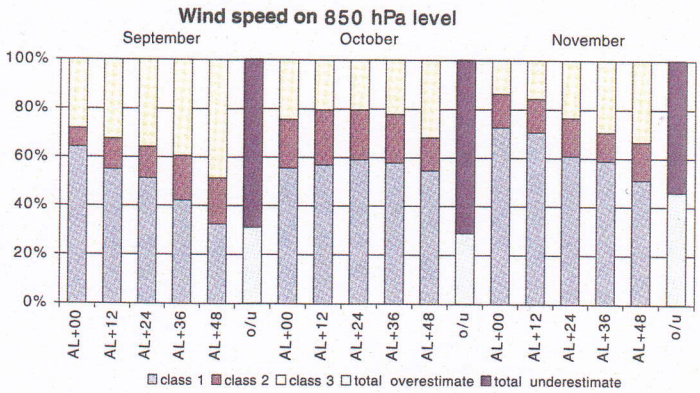

Figure 4. Percentages of the wind speed forecast errors of the ALADIN/LACE model at the 850 hPa level classified according to Bonta's classes. The quality of the forecast, besides smaller irregularities, decreased with the forecast range. The existence of an underestimation tendency was recorded.

Slika 4. Postotci apsolutnih grešaka prognostičkih vrijednosti brzine vjetra modela ALADIN/LACE na 850 hPa klasificiranih u kvalitativne klase po Bonti. Točnost prognoze smanjuje se s duljinom prognostičkog razdoblja, uz postojanje blage tendencije podcijenjenosti.

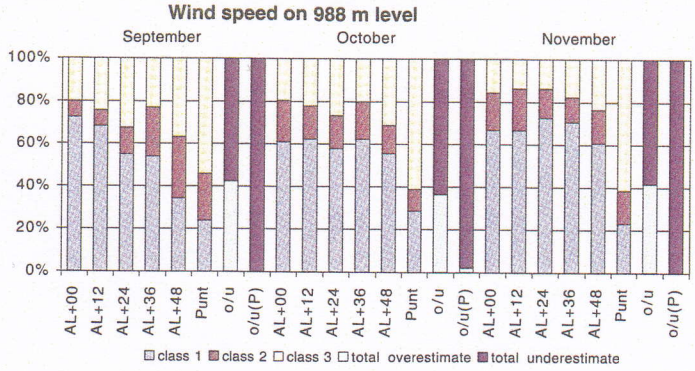

Figure 5. Percentages of the wind speed forecast errors of the ALADIN/LACE model at 988 m level as well as the deviation of Puntijarka station measurements from radio-soundings data classified according to Bonta's classes. Forecast values are slightly underestimated and the quality decreases with forecast range. The Puntijarka station data is not comparable with radio-sounding values, with the tendency of high underestimation due to surface friction (and location of the station).

Slika 5. Postotci apsolutnih grešaka prognostičkih vrijednosti brzine vjetra modela ALADIN/LACE na 988 m, kao i odstupanja mjerenja na Puntijarci od radiosondažnih podataka klasificiranih u kvalitativne klase po Bonti. Prognostičke vrijednosti su blago podcijenjene, a njihova kvaliteta se smanjuje s duljinom prognostičkog razdoblja. Podaci sa Puntijarke nisu usporedivi sa radiosondažnim mjerenjima zbog velike tendencije podcijenjenosti uslijed utjecaja prizemnog trenja (i lokacije same postaje).

same ratio for only class 2 and 3 prognostic values equals 36.68% / 63.32%. So, if the ALADIN/LACE model produced an error greater than 2ms^{-1}, which happened in roughly 45% of the cases in the analysed period at both levels, according to this analysis, in 67% percent of those cases (the average of two levels), the forecast value of wind speed would be underestimated. This result showed that a wind speed forecast of higher wind speeds (when bigger errors occur) is subjected to an underestimation tendency. This conclusion and the fact that the total overestimation and underestimation ratios are well balanced at both levels, imply that the forecasted wind speed is slightly underestimated in both stable and unstable synoptic situations.

The percentage of the Puntijarka station measurements, which differed by $<\pm 2$ms^{-1}, is only about 25%, compared with 55% of those that differed by $>\pm 3$ ms^{-1}. This clearly indicates that the raw observed wind speed data at the Puntijarka station were absolutely incomparable with the radio-soundings data at the same level – very likely due to surface friction. This conclusion is further confirmed by the fact that nearly all values exhibit an underestimation tendency (the ov/un ratio for the Puntijarka station data equals 0.63% / 99.37%).

The importance of relative wind speed errors in the evaluation of a model is of double character. As already mentioned, the same absolute error $|\Delta v|$ has different significance and weight for different wind speed values. Thus, an absolute wind speed error of 5ms^{-1} has more weight in cases with small wind speeds, than in situations with strong wind speed events. Because of the non-linearity of the wind speed dynamic equations, an absolute error $|\Delta v|$ in time t will, in general, integrated to time $t+\Delta t$, produce a bigger error in events with greater than in events with smaller wind speeds. Therefore, for strong or extreme wind speed events, the existence of a 5ms^{-1} absolute error can not be blamed so much on the model, compared with weak wind speed situations. However, the accuracy of prognostic wind speed values in strong wind events can not be treated as being of smaller importance, because many branches of the public sector, especially tourism, traffic, maritime affairs (navigation) and the energy sector, strongly depend on its quality.

3.3. Wind direction

The wind direction forecast values mostly agreed well with the radio-sounding data. Absolute errors at both levels tended to be grouped between 15–30°, depending on the forecast range. The differences between the Puntijarka station data and the sounding data were somewhat bigger and mostly negative in the analysed period. The maximum absolute wind direction forecast errors showed a somewhat irregular tendency, but generally increased with the forecast range (Tab. 4). The maximum differences between the Puntijarka station data and the radio-sounding data reached similar values.

Absolute errors are shown and analysed as errors greater than 180°. Namely, it is true that an absolute error of 272.7° can be interpreted as -87.3°, without making a mathematical mistake. But since for an analysed term, there was

Table 4. Maximum absolute wind direction forecast errors of the ALADIN/LACE model for: a) 850 hPa level and b) 988 m height during the MAP period

Tablica 4. Maksimalne apsolutne greške prognostičkih vrijednosti smjera vjetra modela ALADIN/LACE za plohe: a) 850 hPa i b) 988 m tijekom MAP razdoblja

a)

850 hPa	AL+00	AL+12	AL+24	AL+36	AL+48
Sept	64.6	66.2	70.2	112.0	120.0
Oct	137.6	-197.8	-189.2	166.3	272.7
Nov	-81.2	-112.8	86.2	-110.2	-155.9

b)

988 m	AL+00	AL+12	AL+24	AL+36	AL+48	Punt
Sept	60.8	-54.0	-119.2	85.6	194.0	-161.1
Oct	-98.4	-178.4	-203.4	-228.4	-178.4	-148.5
Nov	-100.1	-133.4	167.6	-146.8	157.4	147.4

a tendency in all forecast values of a significant overestimation of wind direction values, it is considered that the model overestimated this forecast value as well (somewhat more than in other prognostic values made for that term). It can be concluded that the model, in making the mentioned mistake, did not observe well enough the physical reasons responsible for the recorded profile of wind direction (not shown) and therefore, the real absolute error really equalled 272.7°.

The percentages of class 1 forecasts (< 30°) in a balanced mean equal 88.89% (AL+00), 80.74% (AL+12), 78.36% (AL+24), 76.12% (AL+36), 63.64% (AL+48), showing regular behaviour within the forecast range (Fig. 6). The greatest errors, like in the time series of other quantities, were recorded on days with a frontal influence. The total ratio of overestimated and underestimated wind direction values equals 49.63% / 50.37%. Nevertheless, it seems that a monthly variation of those ratios could exist, but this conclusion would require a more extensive analysis. The same ratio for class 2 and 3 forecasts equals 47.33% / 52.67%. A good balance of those ratios in the analysed period suggests that there was no general tendency in either stable or unstable synoptic situations.

Percentages of class 1 forecasts (< 30°), in a balanced mean, equal 83.21% (AL+00), 75.91% (AL+12), 72.79% (AL+24), 67.41% (AL+36), 66.42% (AL+48), showing regular

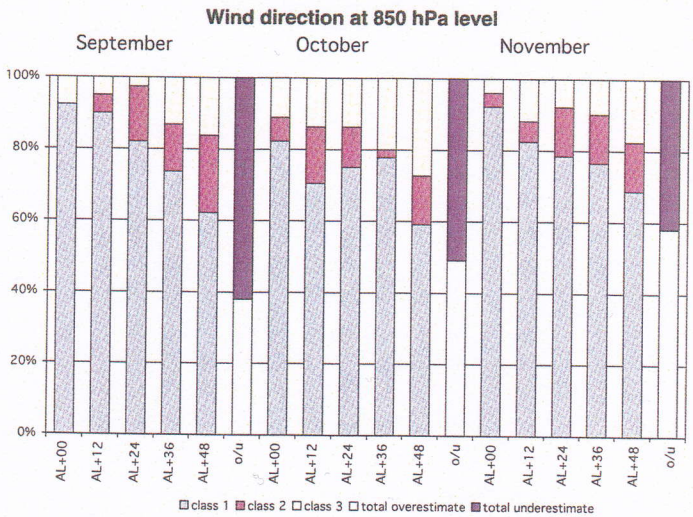

Figure 6. Percentages of the wind direction forecast errors of the ALADIN/LACE model at the 850 hPa level classified according to Bonta's classes. The quality of the forecast, besides smaller irregularities in October, decreased with the forecast range. No significant tendency was recorded.

Slika 6. Postotci apsolutnih grešaka prognostičkih vrijednosti smjera vjetra modela ALADIN/LACE na 850 hPa klasificiranih u kvalitativne klase po Bonti. Kvaliteta prognostičkih vrijednosti smanjuje se s duljinom prognostičkog razdoblja, dok znatnija tendencija nije uočena.

behaviour within the forecast range (Figure 7). The total ratio of overestimated and underestimated wind direction forecast values equals 53.25% / 46.75%. Taking only class 2 and 3 forecasts, the same ratio equals 50.55% / 49.45%. The lack of tendencies, with a high percentage of class 1 forecast values at both analysed levels, indicates that the model

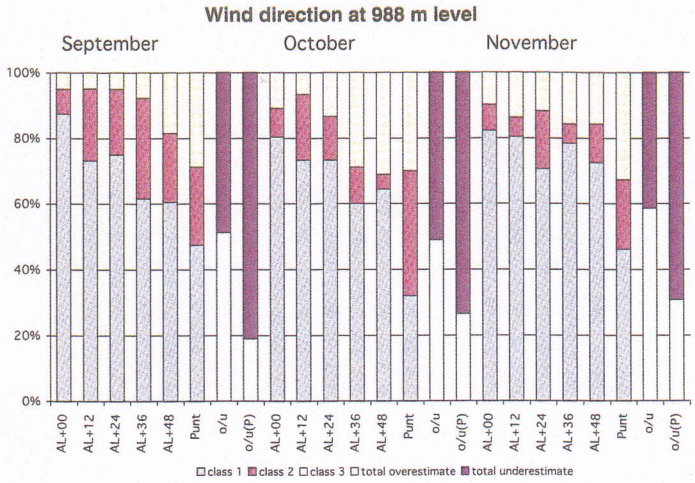

Figure 7. Percentages of the wind direction forecast errors of the ALADIN/LACE model at 988 m level as well as the deviation of Puntijarka station measurements from radio-soundings data classified according to Bonta's classes. Forecast values exhibit no tendency and their quality in general decreases with forecast range. The Puntijarka station data is not comparable with radio-sounding values, with the tendency of high underestimation (turning left) due to surface friction.

Slika 7. Postotci apsolutnih grešaka prognostičkih vrijednosti smjera vjetra modela ALADIN/LACE na 988 m, kao i odstupanja mjerenja na Puntijarci od radiosondažnih podataka klasificiranih u kvalitativne klase po Bonti. Prognostičke vrijednosti ne pokazuju znatniju tendenciju, a njihova kvaliteta se smanjuje s duljinom prognostičkog razdoblja. Podaci sa Puntijarke nisu usporedivi sa radiosondažnim mjerenjima zbog velike tendencije podcijenjenosti (skretanje ulijevo) uslijed utjecaja prizemnog trenja.

followed the behaviour and dynamics of the atmospheric processes in the wind direction field quite well.

The Puntijarka station measurements did not, on average, differ from the radio-sounding data more than 30° in only about 42.50% of cases. The ratio of overestimated and underestimated values equals 25.16% / 74.84%. In case of wind direction, an underestimated value means a smaller value (0–360° on the wind rose). Therefore, wind in the boundary layer, in the greatest majority of cases, turned left while approaching the ground, which is recognised as influence of friction on the flow, due to the closeness of ground itself.

Altogether, wind direction is, alongside with temperature, the most accurately predicted quantity of the ALADIN/LACE model.

4. CONCLUSIONS

The evaluation of the time series of temperature, wind speed and wind direction of the ALADIN/LACE mesoscale model above Zagreb, during the MAP field experiment, showed that the model was highly capable of predicting the state and dynamics of low-level atmosphere. The forecast values of temperature and, to some extent, wind direction agreed better with the radio-sounding values than the forecast values of wind speed. The forecast skill accuracy more or less regularly decreased with the forecast range. The forecast values of temperature were slightly overestimated, as opposed to the wind speed data, which were slightly underestimated. In the forecast values of wind speed the existence of a general tendency was not recorded. The accuracy of forecast values was somewhat smaller at 988 m, very likely due to the influence of surface forcing, resulting from turbulent fluxes and friction. In the model, they have to be parameterized, which is always a source of error. The greatest absolute errors were connected with frontal systems and local phenomena of smaller vertical and time scale, and, for wind direction, also in situations with weak wind speeds.

At the 988 m level, measurements from the Puntijarka mountain station were evaluated as well. The observed station temperature data agreed better with the sounding data than the wind speed and wind direction data. The temperature forecasts were overestimated in the observed period; in contrast, the model wind speed and wind direction were underestimated. A recorded tendency of a monthly variation in temperature existed due to a seasonal variation of the difference in vertical gradients above the Zagreb-Maksimir observatory and the Medvednica mountain. Because of this, raw temperature data might be used as a substitute for radio-soundings data only partly in autumn and, probably, spring. By removing tendencies, temperature data for other periods, as well as data of other measured quantities could be used for the same purpose.

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REFERENCES

Binder, P. and Ch. Schär, Eds., 1996: MAP Design Proposal, available at http://www.map.ethz.ch/

Bonta, I., 2000: The evaluation of the ALADIN model on some interesting synoptic situations with emphasis on a winter inversion event, a strong wind and a convective situations. 9th International ALADIN Workshop, 6–8 November, 2000, 3–9.

Bougeault, P., et al 2001: The MAP Special Observing Period. *Bull. Am. Meteorol. Soc.*, **82**, 433–462.

Daley, R., 1991: Atmospheric Data Analysis. Cambridge University Press, Cambridge, 457 pp.

Ferretti, R., T., Paolucci, G., Giuliani, T., Cherubini, L., Bernerdini and G., Visconti, 2003: Verification of high-resolution real-time forecasts over the Alpine region during the MAP SOP. *Q. J. R. Meteorol. Soc.*, **129**, 587–607.

Ivančan-Picek, B. and V. Jurčec, 2002: Adriatic vortex generation observed during MAP SOP and predicted by the mesoscale ALADIN/LACE model. *Hrvatski meteorološki časopis*, **37**, 15–26.

Ivančan-Picek, B., D. Glasnović, and V. Jurčec, 2003: Analysis and ALADIN prediction of a heavy precipitation event on the Eastern side of the Alps during MAP IOP5. *Meteorologische Zeitschrift*, **12**, 103–112.

Murphy, A. and E. Epstein, 1989: Skill scores and correlation coefficients in model verification. *Monthly Weather Review*, **117**, 572–581.

Tudor, M. and S. Ivatek-Šahdan, 2002: MAP IOP 15 case study. *Hrvatski meteorološki časopis*, **37**, 1–14.

White,G.B., et al 1999: Short-term forecast validation of six models. *Weather and Forecasting*, **14**, 84–108.

Wilks, D., 1995: Statistical methods in the atmospheric sciences: An introduction. Academic Press.