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Application of mesoscale model (MEMO) to the greater Zagreb area during summertime anticyclonic weather conditions

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A high-resolution insight in the flow patterns is necessary for the study of various urban to regional scale phenomena. In this study the applicability of nonhydrostatic mesoscale model MEMO (version 6) to the greater Zagreb area under summertime anticyclonic weather conditions is evaluated. Results show that MEMO is able to simulate mesoscale wind flow reasonably well. Simulated wind fields gave a detailed illustration of the of up- and down-slope circulation generated on south-facing slopes of the Medvednica Mt.. However, daytime surface wind speeds seem to be better predicted than the nighttime ones. Therefore, a further investigation related to the choice of some of the input model parameters is needed.

Keywords: Mesoscale modeling, Zagreb

Introduction

A detailed insight in the mesoscale flow patterns is necessary for the study of various urban to regional scale phenomena, such as generation of local winds (sea-breeze, up- and down-slope winds, mountain–valley winds, etc.), urban heat islands, or air quality problems. The knowledge of synoptic-scale weather type alone is generally not sufficient to predict the smaller-scale wind fields (e.g. Kaufmann and Weber, 1996). Therefore, a reliable mesoscale model should be employed. State-of-the-science mesoscale meteorological models should employ nonhydrostatic assumption. Some of the three-dimensional Eulerian models satisfying this criterion are the Mesoscale Meteorological Model, version 5 (MM5), (Grell et al., 1995) and the MEsoscale MOdel (MEMO), (Moussiopoulos, 1994, 1995; Kunz and Moussiopoulos, 1995).

MEMO model performance over the various European regions is described in several papers (Moussiopoulos, 1995; Moussiopoulos et al., 1997a, 1997b). The objective of this study is to examine if it is applicable for the simulation of the mesoscale wind flow over the greater Zagreb area during summertime anticyclonic weather conditions. Apart from the development of local-scale circulations, such meteorological conditions are also favorable for the formation of photochemical smog episodes (Moussiopoulos, 1995; Kotroni et al., 1999), since they are devoid of significant cloud cover. According to the study of a summer cloudy period (Matthijsen et al., 1997), radiative effect of clouds led locally to boundary layer ozone reductions by as much as 22%, while the overall reduction of ozone was 4%. Further, local-scale circulations themselves influence the transport and vertical diffusion of the air pollutants (e.g. Moussiopoulos, 1985; Moussiopoulos et al., 1997a, Bischoff-Gauβ et al., 1998), and can therefore contribute to the occurrence of polluted episodes.

In this study two consecutive days (19 and 20 June, 2000) with the high pressure system established over the southeastern Europe were selected. The same period was characterized by the increase of ozone concentrations measured at the Puntijarka station, situated at the mountain Medvednica in the vicinity of Zagreb (Figure 1.).

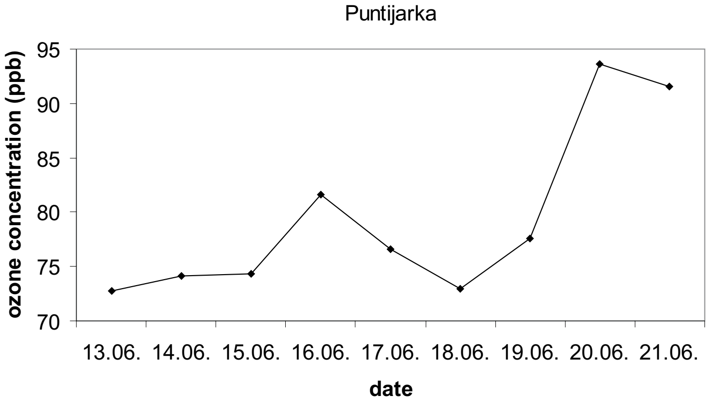


Figure 1. Daily mean measured ozone concentrations at Puntijarka (latitude 45° 54' 32'' N, longitude 15° 58' 23'' E, elevation 980 m). Samples are taken at the height of 6 m above the ground. ANSYCO ozonometer based on UV photometry is used. One may see a period with increased ozone concentrations (starting on 19 June), that is caused by favorable meteorological conditions.

MEMO model overview

Following is a short description of the MEMO model, while full details can be found elsewhere (Moussiopoulos, 1994, 1995; Kunz and Moussiopoulos, 1995). MEMO is the nonhydrostatic prognostic mesoscale model of the dynamics of the unsaturated atmospheric boundary layer. It may be driven with measured data or with the input files obtained by a larger-scale meteorological model. Possibility of driving the MEMO model with measured (radiosonde and surface) data is a great practical advantage of its use considering both, data availability and computer demands.

MEMO solves the continuity equation, the momentum equations and transport equations for scalars (such as pressure, humidity, thermal energy and turbulent kinetic energy), where thermodynamic variables are split into base-state parts and mesoscale perturbations. The mesoscale pressure perturbation is further split into three components. The first represents a large-scale horizontal pressure gradient in the considered mesoscale domain. The second is the hydrostatic part obtained by integrating the hydrostatic equation, where air density follows from the ideal gas law. Finally, the last component represents nonhydrostatic part.

In order to facilitate the formulation of boundary conditions at the lower boundary, a vertical coordinate is transformed to a terrain-influenced one:

$$\eta \equiv H \cdot (z'-h(x',y')) \;/\; (H-h(x',y')),$$

where (x', y', z') are Cartesian coordinates such that $z' = 0$ at the sea level. H and $h(x', y')$ are the temporally and spatially constant height of the model top boundary and altitude at the location (x', y'), respectively. At lateral boundaries, expanded radiation conditions are used as described by Kunz and Moussiopoulos (1995).

The discretized equations are solved numerically on a staggered grid in an »Arakawa C« arrangement. This arrangement carries wind components u, v, and w at the respective cell interfaces, and all other variables as volumetric cell averages at the cell center.

Meteorological conditions

According to diagnostic and prognostic synoptic charts, on 19 July, 2000 a high pressure system extends over southeastern Europe. Wind speeds over Croatia are weak and directions are variable. Humidity is low, only fair-weather cumulus clouds are found during the afternoon hours. Maximal air temperatures reach up to 27 °C.

On the following day, the high-pressure system still extends over southeastern Europe, but the anticyclone is weakening. Over Croatia pressure is gradually decreasing. Air is still dry and the skies are clear. Winds are weak. Maximal temperatures are up to 30 °C.

Finally, on 21 June the anticyclone is so weak that it is found only above the Mediterranean Sea. Over Croatia, pressure continues to decrease, and since morning hours southwestern winds predominate. Wind speeds are higher compared to the previous two days. Temperatures are high, up to 34 °C. In the afternoon hours, there are more convective clouds than during preceding days.

Model application and input data

In order to obtain an adequate description of the mesoscale wind flow under aforementioned meteorological conditions, a nested grid simulation was performed. Thus, coarse grid simulation results at horizontal resolution of 5 km were taken to generate boundary conditions for the fine grid simulations at horizontal resolution of 2 km. Numerical grids used for the coarse and fine simulations covered the areas of 250 x 250 km^2 and 100 x 100 km^2, respectively. Centers of both domains (Figures 2 and 3) corresponded to Maksimir measuring site (latitude 45° 49' N, longitude 16° 02' E).

Detailed topography data were derived from the GTOPO30 database (Gesch and Larson, 1996; Jet Propulsion Laboratory, 1997). For this purpose, a global Digital Elevation Model (DEM), developed through an international collaborative effort led by staff at the U.S. Geological Survey's EROS Data Center (EDC), was employed. Horizontal grid spacing corresponded approximately to 1 km.

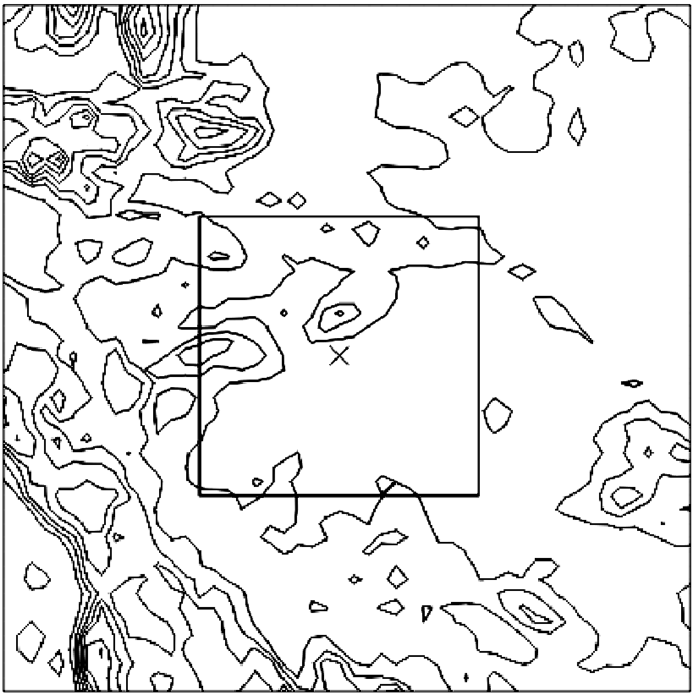


Figure 2. The 250 × 250 km^2 coarse grid domain for the greater Zagreb area. Domain is centered at 45° 49' N and 16° 02' E. The cross indicates the location of the Maksimir measuring site. Topography contours are given for every 200 m. The position of the fine grid domain is also indicated.

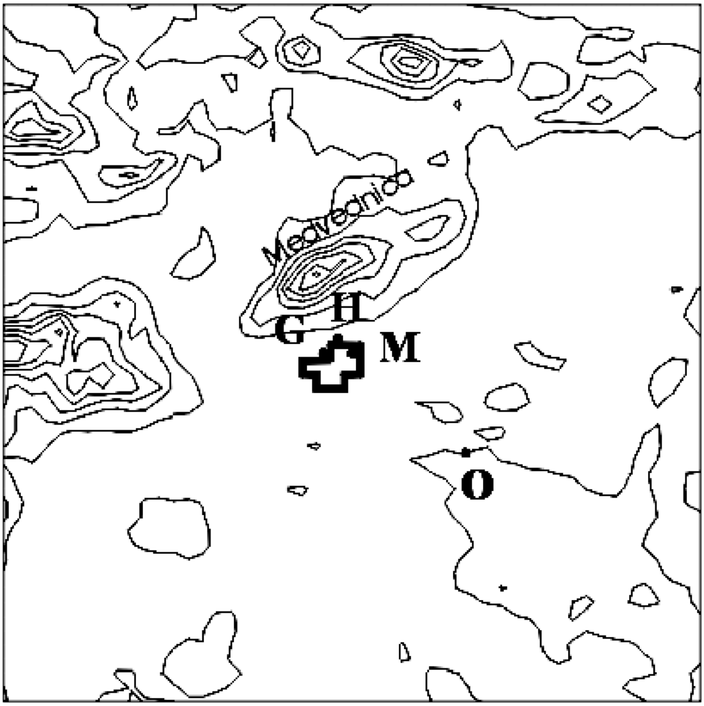


Figure 3. The 100 × 100 km^2 fine grid domain for the greater Zagreb area. Topography contours are given for every 100 m. The densely urbanized part of Zagreb is also shown. Circles indicate positions of available meteorological measuring sites (see Table 2). Mountain Medvednica is situated northward from the city.

Landuse data were taken from the Global Land Cover Characteristics (GLCC) database (Steinwand, 1994; Sellers et al., 1996; Steinwand et al., 1995). GLCC includes 94 different landuse categories and employs the Lambert Azimuthal Equal Area geographical projection (optimized for Europe) with a horizontal resolution of 1 km. In the present study original 94 landuse types were reduced to 7 more general types. Thereafter, a percentage of each landuse type was attributed to each grid square. Landuse types together with corresponding roughness lengths, short-wave albedos, evaporation parameters, volumetric heat capacities and thermal soil conductivities (Moussiopoulos, 1985) are listed in Table 1.

In the vertical direction, 25 layers were assumed allowing for finer resolution at lower altitudes. The depth of the lowermost layer was 20 m. In order to better incorporate the larger scale forcing the model top was set at H = 6000 m above the sea level.

Simulation was performed for the June 18 – 20, 2000 period, with a first day taken for the pre-run purposes. The model (version 6) was driven with

Table 1. Landuse types and corresponding values of model parameters employed in this study (after Moussiopoulos, 1985).

Model parameter / Landuse type	Roughness length (m)	Short-wave albedo	Evaporation parameter	Volumetric heat capacity (J m^{-3}K^{-1})	Thermal soil conductivity (m^{2}s^{-1})
Water	0.001	0.0	1.0	4.18×10^6	0.0
Arid land	0.01	0.22	0.01	2.68×10^6	1.0×10^{-6}
Few vegetation	0.02	0.22	0.05	2.68×10^6	1.0×10^{-6}
Farmland	0.02	0.22	0.15	2.86×10^6	0.7×10^{-6}
Forest	0.12	0.10	0.20	1.17×10^6	0.8×10^{-6}
Suburban	0.5	0.23	0.10	2.20×10^6	1.3×10^{-6}
Urban	0.8	0.20	0.05	2.34×10^6	2.0×10^{-6}

Table 2. Available meteorological measuring sites.

Name	Symbol	Latitude	Longitude	Elevation (m)
Grič	G	45° 49' N	15° 59' E	157
Horvatovac	H	45° 50' N	16° 00' E	182
Maksimir	M	45° 49' N	16° 02' E	123
Oborovo	O	45° 41' N	16° 15' E	101

the radiosonde soundings data for Maksimir, which were available for 0000 and 1200 UTC. Time increments of 30 and 15 seconds were used for the coarse and fine grid calculations, respectively. CPU time required on an IBM RISC/6000 workstation (model 43P-240) at the Aristotle University, Thessaloniki, was approximately 150 hours.

Results and discussion

Figure 4 illustrates measured and modeled surface winds for available measuring sites (Table 2). Predicted wind directions are in good agreement with measurements for 19 June 2000, while for the next day the agreement is slightly poorer. Both measured and modeled wind directions at Grič, Horvatovac and Maksimir indicate the existence of the up- and down-slope winds. Due to this local wind system caused by the nearby Medvednica mountain (Figure 3), nighttime down-slope winds have an enhanced southward component. During the daytime wind direction is reversed, and consequently, the northward flow dominates.

Wind speed is overestimated at Oborovo for both days. (Later discussion with the staff of Meteorological and Hidrological service of Croatia (Premec,

2001) suggested a general doubt regarding the quality of the measurements at Oborovo station.) On the other hand, the agreement is very good for Maksimir for 19 June 2000 and satisfactory for Grič, Horvatovac and Maksimir for the next day. Correlation coefficients (R) between the measured and the modeled hourly surface wind speeds for both days are statistically significant at 5% level for Maksimir (R = 0.45), Horvatovac (R = 0.41) and Grič (R = 0.40), while mean absolute error for the wind speed varies from 1.0 ms^{-1} (Maksimir)

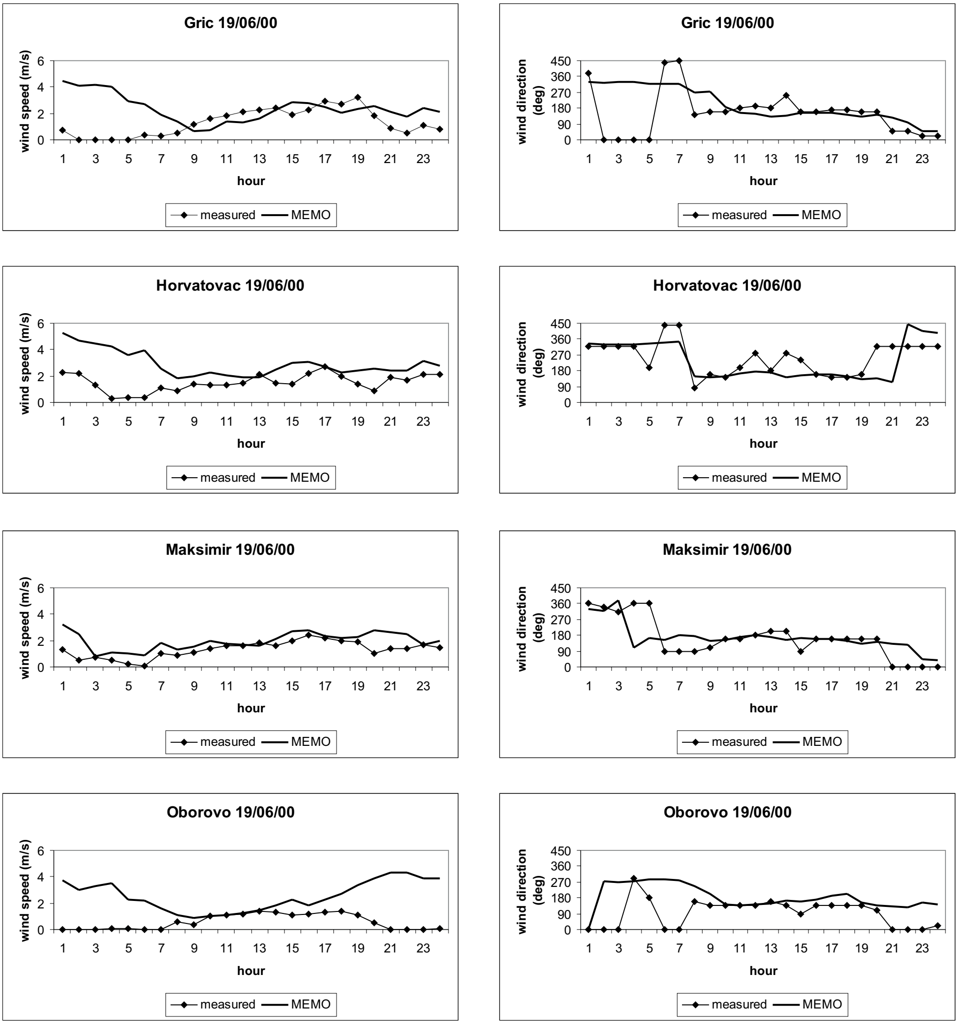


Figure 4. Modeled versus measured hourly averaged surface winds. In order to show exact discrepancies between the modeled and measured values, wind directions spanning a range from 0 to 90 degrees are sometimes enlarged by 360 degrees.

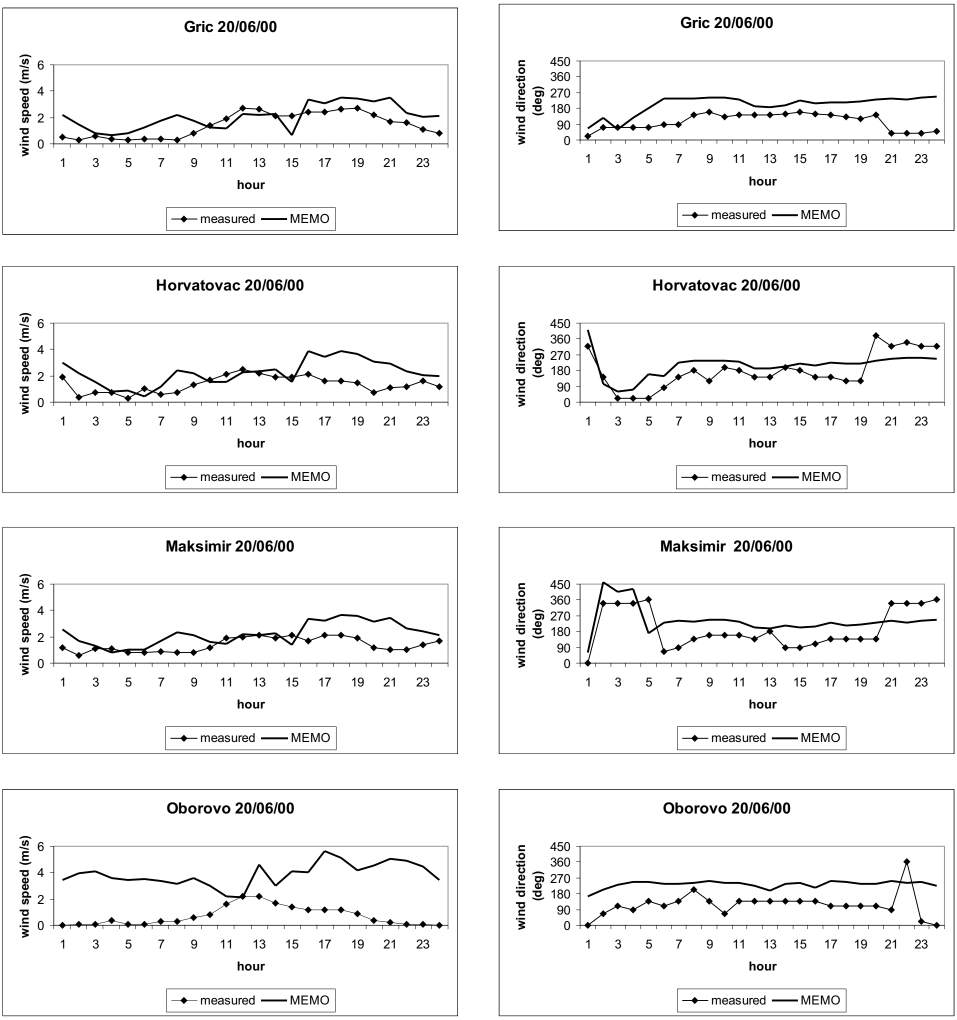
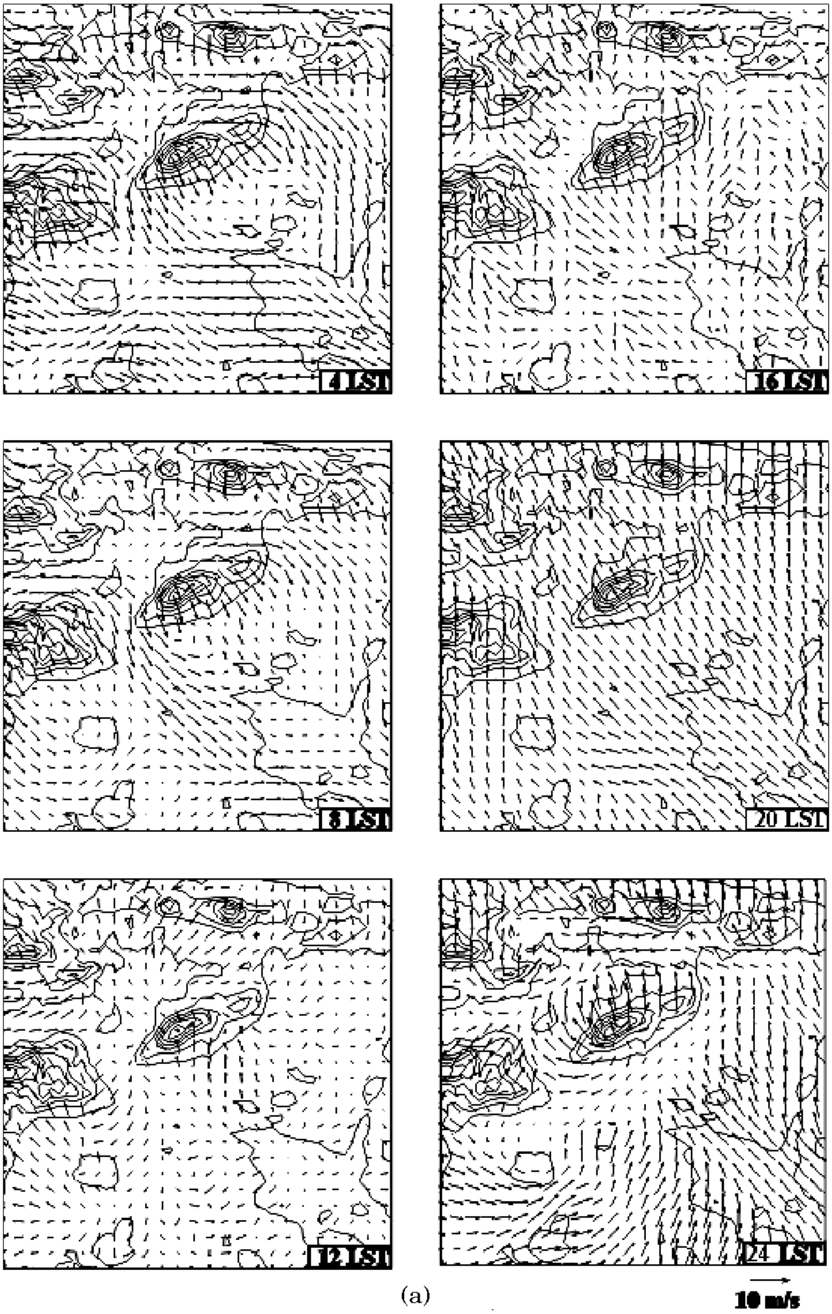


Figure 4. (cont.)

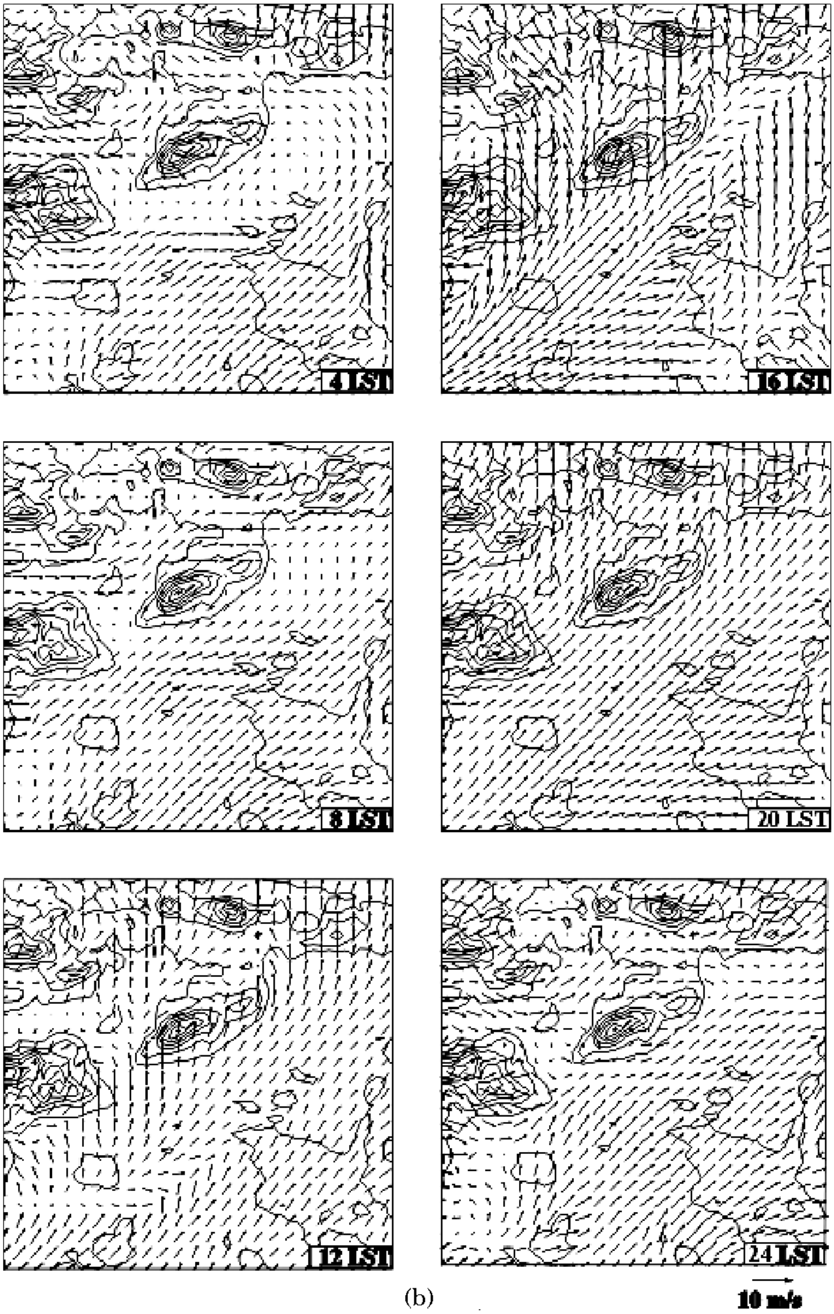
to 1.2 ms^{-1} (Grič). Wind speed generally seems to be better predicted for the midday, when incoming solar radiation is intense, compared to nighttime, when long-wave radiative cooling is dominating. This indicates the need of further investigation. Therefore, sensitivity tests with different choices of model parameters listed in Table 1 will be done in future work. However, results show that MEMO model is capable of describing mesoscale wind flow reasonably well over the area of interest.

Figure 5 shows modeled surface winds (10 m above the ground) for the fine grid domain. These wind flow patterns allow a further insight in the di-



(a)

Figure 5. Modeled surface winds for greater Zagreb area (fine grid domain) for 19 June, 2000 (a) and 20 June, 2000 (b). Wind vectors are shown at resolution of 4 km.



(b)

Figure 5. (cont.)

urnal cycle of up- and down-slope wind circulation patterns that form on the south-facing slopes of mountain Medvednica during the summer anticyclonic conditions. During the 19 June and the first part of the next day, the up- and down-slope circulation pattern is undisturbed. However, local flow seems to be modified during the second part of 20 June due to the larger scale influences. This is in accordance with above described synoptic situation that prevailed during the selected period. Weakening of the high-pressure field that began on 20 June resulted in southwestern synoptic scale wind flow that was already established over Croatia in morning hours of 21 June.

Conclusions

A high-resolution insight in the mesoscale flow patterns is necessary for the study of various urban to regional scale phenomena. Results of the present study show that the nonhydrostatic prognostic model MEMO is able to simulate a mesoscale wind flow under summertime anticyclonic weather conditions over the greater Zagreb area reasonably well. Therefore, it will be used for the analysis of photochemical smog formation that occurred during the selected period.

However, surface wind speeds seem to be better predicted during daytime than for the nighttime. Modeled nighttime values are often overpredicted. Apart from the model employment of the Monin-Obukhov similarity theory (Zilitinkevich and Calanca, 2000; Weidinger et al., 2000), discrepancies could also arise due to improper input parameters. Therefore, a further investigation related to the choice of input model parameters (such as volumetric heat capacity, thermal soil conductivity and evaporation parameter) is needed.

Simulated wind fields may give a detailed picture of the geographically generated local winds. For the mountain Medvednica a diurnal variation of up- and down-slope circulation is well described by model results. The existence of the same circulation is confirmed by measurements.

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SAŽETAK

Primjena mezoskalnog modela (MEMO) na šire područje Zagreba pri ljetnim anticklonalnim vremenskim uvjetima

Zvjezdana Bencetić Klaić i Theodoros Nitis

Pri proučavanju različitih pojava u rasponu od urbane do regionalne skale, neophodan je uvid u mezoskalno strujanje s visokom rezolucijom. U ovoj studiji ispitana je primjenjivost nehidrostatskog mezoskalnog modela MEMO (verzija 6) na šire područje Zagreba pri anticiklonalnim vremenskim uvjetima. Rezultati pokazuju da se MEMO modelom prilično dobro može simulirati mezoskalni tok. Modeliranim poljima vjetra dobiven je detaljan uvid u cirkulaciju obronka koja nastaje na južnim padinama Medvednice. Međutim, čini se da su dnevne vrijednosti brzine vjetra tijekom dana bolje prognozirane od noćnih. Stoga je neophodno daljnje istraživanje vezano uz izbor nekih od ulaznih parametara modela.

Ključne riječi: Mezoskalno modeliranje, Zagreb

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