6.21 BOUNDARY LAYER HEIGHT DETERMINATION UNDER SUMMERTIME ANTICYCLONIC WEATHER CONDITIONS OVER THE COASTAL AREA OF RIJEKA, CROATIA

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INTRODUCTION

The atmospheric boundary layer height is a fundamental parameter characterising the structure of the lower troposphere. The determination of this parameter is important in applications that range from meteorological modelling and forecasting to dispersion problems of atmospheric pollutants. Since substances emitted into the atmospheric boundary layer are dispersed horizontally and vertically through the action of turbulence, they are well-mixed over this layer that is widely known as "mixing layer". There are two basic approaches for the practical estimation of this height; the first approach suggests profile measurements, either in-situ or by remote sounding (sodar, clear-air radar, lidar) and the second one, the use of models with only a few measured parameters as input. As far as the second approach is concerned, the majority of the models use relatively crude estimates of the roughness length that is often based on constant values for land cover (*Scaudt and Dickinson*, 2000). Consequently, the model results are not quite accurate. The present work aims firstly to evaluate the effect of alternative calculations of the roughness length on the non-hydrostatic mesoscale model (MEMO) performance, based on the use of satellite data, and secondly, to estimate the mixing layer height and analyze its variability in relation to underlying topography and land use.
Rijeka, a region with complex topography and several islands in its surroundings, offers the opportunity to examine the above mentioned relationships. The non-hydrostatic mesoscale model MEMO was applied under summertime anticyclonic weather conditions during two multi-day periods characterised by stagnant meteorological conditions. The results proved MEMO capable of simulating mesoscale wind flow reasonably well, however, the use of AVHRR satellite data for calculating the roughness length based on the calculation of the NDVI parameter, optimised the model performance and resulted to a more accurate determination of the mixing layer height.

AREA SELECTED & CASE SPECIFICATION

The Greater Rijeka Area (GRA), a mountainous area located in the western part of Croatia and characterised by complex topography is the study area. Wind field simulations for two different multi day periods, (a) 19-20 June 2000 and (b) 6-7 September 1999, characterised by anticyclonic weather conditions, were performed using the non-hydrostatic mesoscale model MEMO (Kunz and Moussiopoulos, 1995). During these periods, the surface pressure was larger than 1015 hPa, while the diurnal variation of the pressure was low (less than 4 hPa per 24 hours). In order to account for all relevant orographic influences on the flow field, a nested system based on the expanded radiation boundary condition was applied, while the horizontal domain was extended to include a reasonable portion of land and sea masses (Moussiopoulos et al., 1993). Coarse grid simulations covered an area of 250×250 km^2 with a horizontal grid spacing of 5 km, while the fine grid simulations were performed within an area of 100×100 km^2 at a horizontal resolution of 2 km. Simulation domains are shown in Figure 1.

Meteorological input information, consisting of vertical profiles of wind speed, wind direction and temperature was obtained from the Udine radiosonde station (latitude 46.03N, longitude 18.13E, elevation 94 m Above Sea Level).

A detailed orography data set for the study area, was derived from the GTOPO30 database (*Bliss and Olsen*, 1996), that is a global Digital Elevation Model (DEM) with a horizontal grid of approximately 1 km, developed at the U.S. Geological Survey's EROS Data Center (EDC). The land use data set originated from the Global Land Cover Characteristics (GLCC) database (*Belward*, 1996) developed by the U.S. Geological Survey (USGS) with 1 km spatial resolution. The University of Nebraska-Lincoln (UNL) GLCC Land Cover database includes 24 land cover species and uses the Lambert Azimuthal Equal Area geographical projection (optimised for Europe).

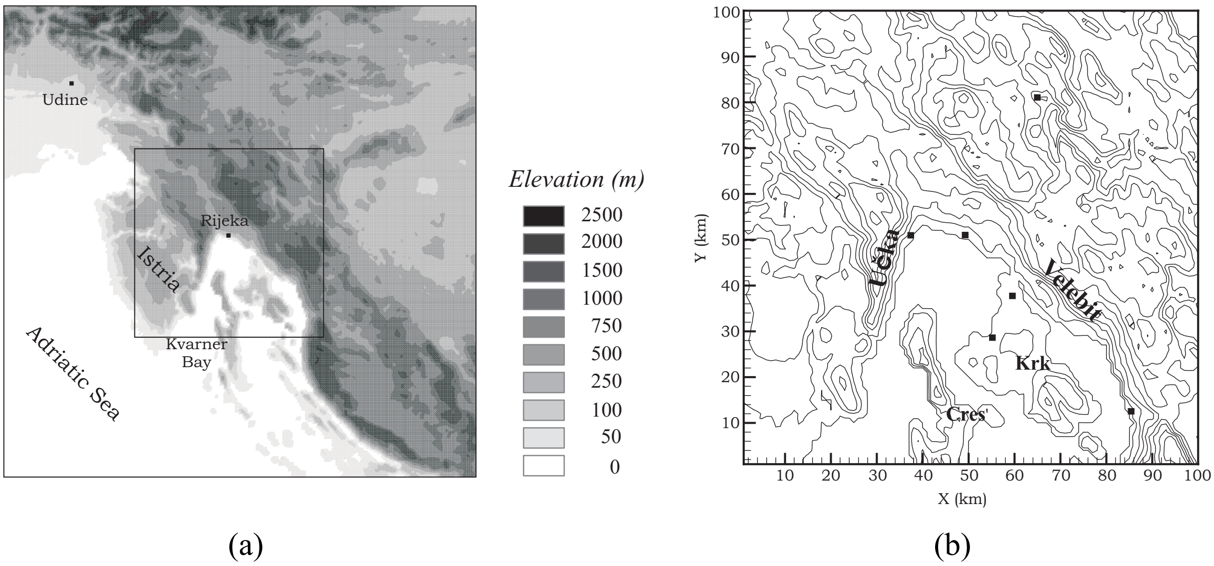


Figure 1. (a) Configuration of nested grids. The outer frame indicates the coarse grid and the inner one the fine domain. (b) Topography contours for the fine grid are given for every 100 m. Domain centre is in Rijeka 45.33° N, 14.45° E, 120m above sea level and the bullets indicate positions of the routine measuring sites.

Among a number of physical parameters involved in the parameterisation of the boundary layer is the aerodynamic roughness length (z_o). This parameter is most often assigned a constant value regardless of seasonal changes and spatial variability. However, an objective estimation of this parameter can be achieved by using satellite data. In this study, the roughness length was derived by application of simple empirical relationships between satellite radiometry and vegetation physiology. More precisely, data from the NOAA-AVHRR instrument were used and the Normalized Difference Vegetation Index (NDVI), a parameter that indicates vegetation biomass level, was calculated by the formula, NDVI = [(NIR - Red) / (NIR + Red)], where NIR and Red are radiances in the NIR and Red spectral bands, respectively. Following, the roughness length was calculated by the formula (*Gupta et al.,* 2002), $z_o = \exp(-5.5 + 5.8\cdot\mathrm{NDVI})$. Since the z_o is strongly dependent on the seasonal variations, it was calculated for two different time periods (June 2000 and September 1999) that correspond to the simulated ones. The z_o values ranged between 0.025 and 2.6 m. The highest values correspond to areas covered by forests, while the minimum ones to the water body.

RESULTS AND DISCUSSION

A. Evaluation of the effect of using the roughness length derived from NOAA-AVHRR satellite data on the non-hydrostatic mesoscale model (MEMO) performance

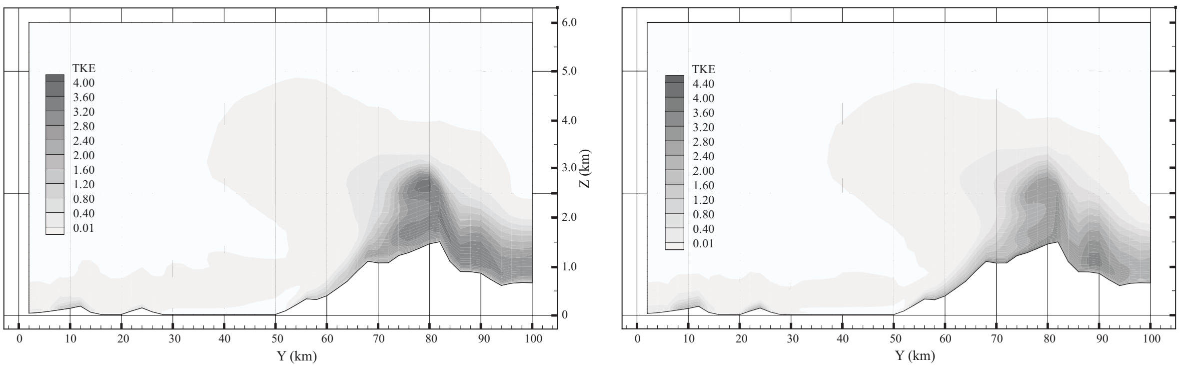
The model performance was assessed by calculation of both the RMSE that represents the average error produced by the model or else, the mean difference between observed and predicted values (*Sivacoumar et al.*, 2001) and the index of agreement (d) that determines the degree to which the observed value is accurately estimated by the simulated one (*Elbir*, 2003). The values of d vary between 0.0 when there is no agreement between the observed and the predicted values and 1.0 that represents a perfect agreement between the observed and the predicted values. Therefore, for a good prediction the value of d should be close to 1.0 and of RMSE close to 0.0. The results for the wind speed and the temperature are given in Table 1. The differences of d and RMSE from the corresponding values calculated when the estimate of the roughness length is based on constant values for each land cover, are given as well. It is obvious that the model performance is in general better in the case of using satellite data, since the roughness length is not considered the same for a given land cover, but is represented by a surface with a spatial resolution of 1.1 km. Moreover, the values of d and RMSE were most optimised in the Rijeka airport station, where the d′ value is 0.24 and the RMSE′ -1.31. As far as the wind speed is concerned, in Pazin the model simulated the reality quite better compared to the other measuring stations, since both the d and RMSE values correspond to the maximum (0.71) and minimum (0.84) respectively. Concerning the temperature, the model performance was proved better in Malinska.

Table 1. Model performance evaluation (d, RMSE) for the period 19-20 June 2000 for the wind speed and the temperature using aerodynamic roughness length derived from AVHRR satellite data. $d' = d - d_1$ and $RMSE' = RMSE - RMSE_1$ where d_1 and $RMSE_1$ are the values calculated when the estimate of the roughness length is based on constant values for each land cover

	Wind speed				**Temperature**			
Stations	d	d′	RMSE (m/s)	RMSE′ (m/s)	d	d′	RMSE (K)	RMSE′ (K)
Pula	0.64	-0.10	1.39	-0.06	0.90	0.08	3.57	-0.10
Rijeka	0.43	0.07	1.51	-0.59	0.84	-0.01	2.25	-0.11
Malinska	0.61	0.14	1.21	-1.18	0.92	0.01	1.97	-0.06
Rijeka airport	0.64	0.24	1.02	-1.31	0.77	0.06	2.24	-0.61
Senj	0.33	0.01	1.63	-0.87	0.75	-0.01	2.11	-0.15
Pazin	0.71	0.11	0.84	-0.98	0.86	0.02	4.31	-0.05
Average	***0.56***	***0.08***	***1.27***	***-0.83***	***0.84***	***0.02***	***2.74***	***-0.18***

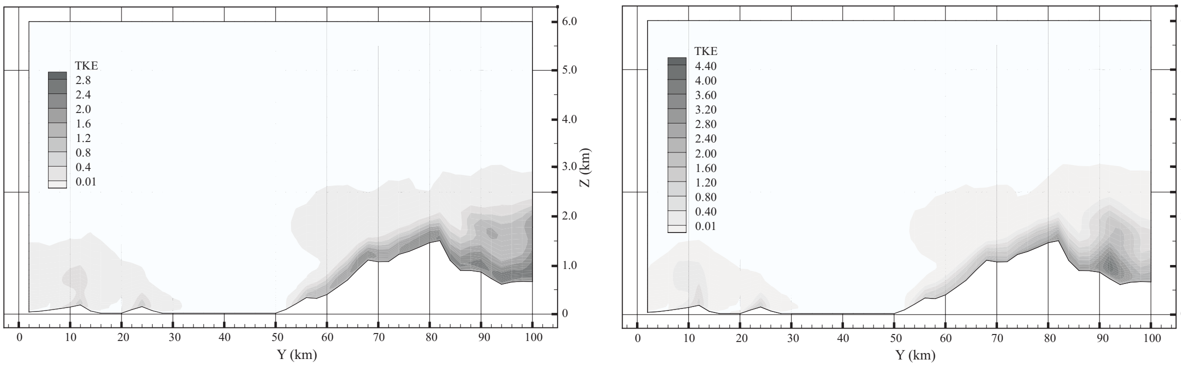
B. Mixing layer height determination

In this work, the mixing layer height was determined based on the calculation of the turbulent kinetic energy (TKE). Turbulent kinetic energy is one of the most important variables in land-surface processes because it is a measure of the turbulence intensity and it is directly related to the transport of momentum, heat, and moisture through the boundary layer. According to *Seibert et al.* (2000) the level at which the turbulent kinetic energy decreased to 5% of its maximum value is often used as a definition of the mixing height. In Figure 2 the simulated TKE of the fine domain on a south-north vertical cross section across the urban area of Rijeka for the 19th of June 2000 at 15 LST is shown. In Figure 2(a) where the roughness length values are considered constant for each land cover category, the maximum value for TKE is 3.88 and it is observed over the mountainous area of Rijeka, where the weak synoptic offshore flow contrasts with the thermally induced flows increasing in that way the turbulence. The mixing layer height in that area is about 1500 m over the top of the mountain. Over the area where the islands are located, the mixing layer height is about 300 m, whereas over the sea the turbulent kinetic energy is near zero, since a constant sea surface temperature was considered as an input to the model. In Figure 2(b) where the roughness length values derived from satellite data the maximum value for TKE is 4.20 and is observed near the mountain slope. This spatial re-allocation of the maximum value of the turbulent kinetic energy is the result of the increase in the roughness length values, since the greater aerodynamic roughness, the greater the turbulence that arises when wind passes over a roughness element. Over the islands, the situation practically remains unchanged with only a slight increase of the TKE and of the mixing layer height that is now about 400m.



(a) (b)

Figure 2. Simulated turbulent kinetic energy (TKE) on a south-north vertical cross section across the town of Rijeka for the 19th of June 2000 at 15 LST using roughness length values (a) constant for each land cover category and (b) derived from satellite data



(a) (b)

Figure 3. Simulated turbulent kinetic energy (TKE) on a south-north vertical cross section across the town of Rijeka for the 7th of September 1999 at 15 LST using roughness length values (a) constant for each land cover category and (b) derived from satellite data

Figure 3 shows the simulated TKE of the fine domain on a south-north vertical cross section across the urban area of Rijeka, for the 7th of September 1999 at 15 LST. The weak synoptic conditions that dominated at that time the study area allowed the development of local circulation phenomena which re-allocated the maximum values of the TKE to the north compared to the structures observed during June 1999. The mixing layer height over the insular area remains practically the same for the different calculations of the roughness length (about 1 km). On the contrary, the model results indicate differences on the structure of the boundary layer over the mountainous area for both cases. There is a noticeable difference between the maximum values of TKE that is about 2.8 for the first case (Figure 3(a)) and 4.2

for the second one (Figure 3(b)), respectively. On the other hand, the mixing layer height difference between the two cases is about 100 m over the top of the mountain, with the higher value (800 m) observed in the second case.

CONCLUSIONS

A three dimensional high order closure model for a complex coastal terrain was applied to simulate the boundary layer dynamics over the Greater Rijeka Area. The results demonstrated a successful multi-days simulation in the area and revealed (a) the variation of the boundary layer under different meteorological conditions and model physical parameterization and (b) the positive effect of the use of remote sensing data on the model performance. However, further improvement could be achieved by the introduction of more parameters derived from satellite data such as albedo, emissitivity etc.

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