P1.3 THE SEA/LAND BREEZE HODOGRAPHS ALONG THE NORTHERN CROATIAN COAST

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1. INTRODUCTION

Many studies analyzed the components of the sea/land breeze (SLB) system at different spatial and temporal scales resulting in a considerable amount of SLB-related knowledge (e.g. Miller et al, 2003). One of the specific SB characteristics is the clockwise (CW) rotation of a theoretical hodograph in time, on the northern hemisphere, due to Coriolis force veering (Haurwitz, 1947). Still, the deviations from the standard hodographs in the anti-clockwise (ACW) direction were reported at many stations around the world (e.g. Simpson, 1996). Along the very complex northern Croatian coast, the investigation of the measurements for two stations (Malinska and Senj), also revealed the ACW rotation (e.g., Orlić et al., 1988; Prtenjak and Grisogono, 2007) thus indicating distorted hodographs but without a further detailed analysis. Therefore we analyze the simulated surface wind field that is obtained by a three-dimensional (3D) nonhydrostatic numerical model for one particular, although typical, SLB case (18-20 June 2000, as in Prtenjak et al., 2006). In order to study the cause of the rotation in more detail an analysis on the diurnal base of modeled wind hodographs at several selected stations is performed.

2. DATA AND METHODS

The description of the 3D nonhydrostatic mesoscale meteorological model MEMO6 may be found in e.g. Kunz and Moussiopoulos (1995). It is widely utilized for simulations of coastal flows and it showed a reasonable ability to reproduce the mesoscale phenomena (e.g., Klaić et al., 2002; Prtenjak et al., 2006) as do the other state-of-the-art models used in similar studies (e.g. Mangia et al., 2004). The model has two horizontal grids; the coarse one (240 x 240 km^2) where horizontal resolution is $\Delta x = \Delta y$ = 2 km and the fine one (100 x 100 km^2) with $\Delta x = \Delta y$ = 1 km (Fig. 1). The model top is at 8000 m.

Here, the well-studied period (the control run, CR) covering the 18-20 June 2000 during a summertime anticyclone is further analyzed by the same numerical model as in Prtenjak et al. (2006). During the period examined, only a weak synoptic forcing is present over the northern Croatian coast, according to the surface and the upper-level diagnostic charts for Europe. During such sunny and dry weather conditions, complex SLB development is inevitable there. To assess the effects of topographic forcing on the mesoscale wind field, besides the CR simulation, the terrain sensitivity studies (two to be presented) are also performed. From the initial topography, the island surface is replaced by the sea surface making T1 test. The T2 test is formed with the initial orography being substituted with the idealized one where the maximum height of the land surface is 10 m. The simulations start from 00 UTC on 18 June, last three successive days, and the first ~12 hours that are affected by the model initialization are omitted from the analysis.

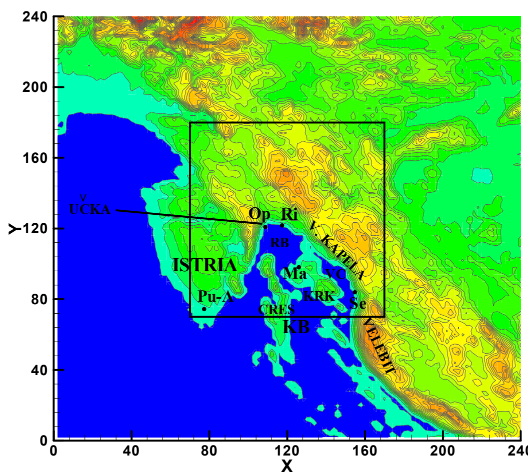

Figure 1. Coarse and fine (rectangle) model domains, Istria and Kvarner Bay (KB), showing the measuring sites (Pu-A = Pula-airport; Op = Opatija, Ri = Rijeka, Se = Senj, Ma = Malinska). Topography contours are given every 100 m between at 0 and 1700 m. Učka is a mountain situated at the eastern coast of Istria in the Rijeka Bay (RB), and between Krk island and mainland Velebit Channel (VC) is found.

Meteorological stations along the northern Croatian coast (Fig. 1) that have surface hourly measurements of wind are Pula-airport, Opatija, Rijeka, Senj and Malinska representing a variety of geographical details.

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3. RESULTS

A fine diurnal SLB analysis can only be made if the 24-hours wind regimes are examined. Hence, a particular attention is paid to the comparison among hodographs and model results for one day, i.e., 19 June 2000. The aim is to explain the basic local effects influencing the wind dynamics at the considered stations during the particular day.

The wind field above Istria forms the daytime convergence zone. At Pula-airport (Fig. 2a), the diurnal wind vectors rotate in the CW direction since the hodograph shape is under the influence of convergence zone mentioned above. Comparing the CR with T1 test, only small changes can be noticed (Fig. 2b). Above the station in T1 test, the wind is stronger around the noon and weaker in the afternoon as compared to the CR. The largest difference appears between the CR and T2 test. In the latter (Fig. 2b), the southwesterly winds blow almost for 24 hours over Pula-airport because the convergence zone develops near the eastern part of Istria, far away from the station (Prtenjak et al., 2006).

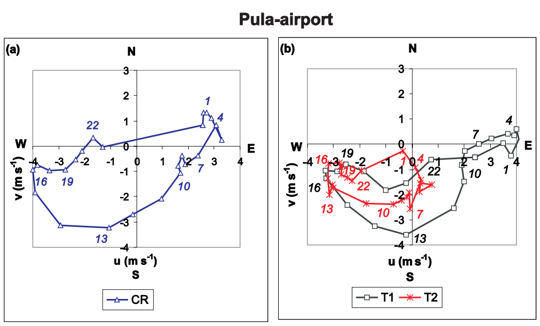

Figure 2. Surface wind hodographs for Pula-airport on 19 June 2000 for (a) the control run (CR) and (b) for the T1 test (without islands) and T2 test (idealized topography lower than 10 m everywhere). The wind vectors are directed toward the origin of the coordinate system. The numbers represent local standard time.

In Opatija, comparing the morning wind speed in the CR and T1 test, it is seen that the absence of islands increases the wind speeds (Figs. 3a and 3b). The larger speeds cause stronger advection of the cold marine air that is followed by the lower surface air temperature during the day. Due to the smaller land-sea temperature difference, the wind speed decreased by ~50% in the afternoon. An additional reason for the overall low wind speed is the absence of both the channeling of the air flow and the mesoscale eddies near Opatija inside the Rijeka Bay. The largest difference exists between the CR and T2 test with pronounced CW rotation of the hodograph (Figs. 3a and 3b).

In Rijeka, the simulated CR wind hodograph has the CW rotation (Fig. 3c). The hodograph for T1 test displays significant differences compared to the CR (Figs. 3c and 3d). In the CR, the daytime mesoscale eddy with the CW rotation in the surface wind field forms inside the Rijeka Bay (Prtenjak et al., 2006). A superposition between the eddy and the daytime onshore flow creates a more pronounced CW rotation in the CR wind than in T1 test. As for Opatija, the onshore flow in T1 test has a larger morning wind speed (by 25 %) than in the CR due to the small roughness length of the sea surface. During the afternoon, the stronger advection of the marine air is caused by the higher wind speeds. Consequently, the sea-land temperature difference is smaller, as is the daytime wind speed, than in the CR. Removing the topography in T2 test, the southwesterly SB is enhanced by the background wind without nighttime offshore flow (Figs. 3c and 3d).

At Senj, the modeled wind hodograph for the day examined mimics the shape and the ACW rotation of the climatological hodograph satisfactory (Prtenjak and Grisogono, 2007). In the CR, the wind in the Velebit channel blows along the mainland coast in front of Senj (Prtenjak et al., 2006). In T1 test, the channeled flow is not found, and the ACW rotation is still present in the wind hodograph (Figs. 3e and 3f). While the morning SB is stronger, the afternoon SB is weaker in T1 test and more perpendicular to the coastline when compared to the CR. Such diurnal wind speed arrangement is connected with the lower sea-land temperature difference due to the stronger marine air advection before noon (as in the case of Opatija and Rijeka). The steep topography with the mountain pass near Senj secures favorable conditions for ACW veering in the daily wind. After sunrise (approximately during 8-13 h), upslope southeasterly wind develops and twists the southwesterly SB in the ACW sense (Figs. 3e and 3f). During the afternoon (13-19 h) the diminishing slope wind is replaced by the valley wind. The SB and valley winds coincide, and therefore, there is no significant modification in the afternoon wind directions. During the evening, downslope NW wind begins and together with the easterly land breeze forms the offshore flow. The daily wind cycle is completed by the superposition of the fully formed mountain wind, land breeze and downslope northeasterly winds. The T2 test once again differs significantly from the typical wind hodograph (Figs. 3e and 3f). Orlić et al. (1988) argued that the mountain/valley and slope winds presumably appear around Senj and their associated pressure gradient would be closely parallel to the coast. The results of numerical experiments are in agreement with this hypothesis, reproducing the anomalous wind regime around Senj. The results show that the terrain-gradient forcing produces the ACW rotation in Senj (compare the CR and T2 test in Figs. 3e and 3f).

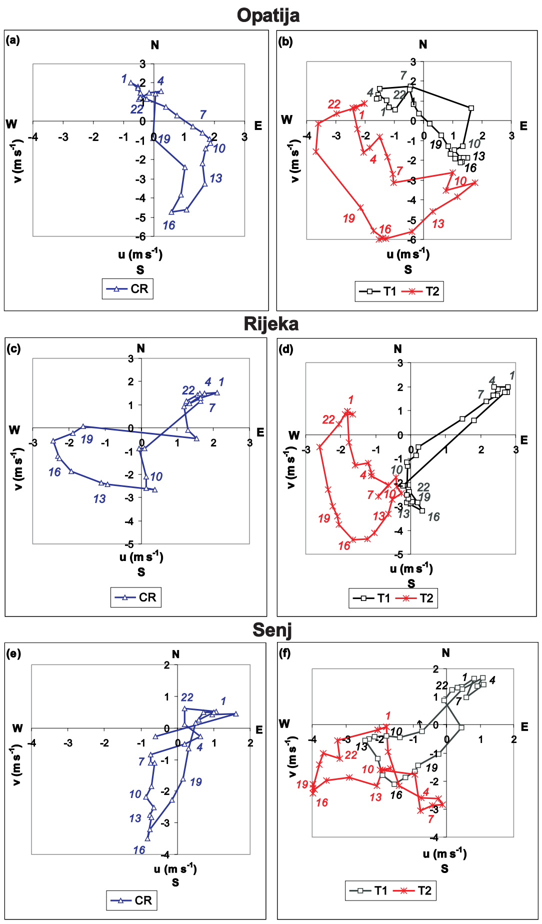

Figure 3. Same as Fig. 2 except for Opatija (a,b), Rijeka (c,d), and Senj (e,f).

Malinska is placed also in the area where the prevailing ACW rotation still exists (Fig. 4). The coastal station is influenced by two mesoscale features the mesoscale eddy inside Rijeka Bay and the convergence zone above the northeastern part of Krk (Prtenjak et al., 2006). The numerical results show that the ACW rotation of the wind hodograph in the CR is mostly due to the convergence zone generated eastward of Malinska. Therefore, the morning northwesterly winds are twisted toward east during the afternoon. Although the geometry of the coastline is conserved in T2 test, the very low topography (≤ 10 m) is unable to generate the convergence zone above Krk. In this case the hodograph shows only the CW rotation (Fig. 4).

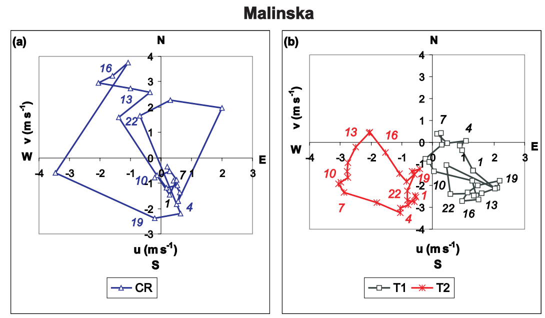

Figure 4. Same as Fig. 2 except for Malinska.

3. CONCLUSIONS

A typical coastal atmospheric boundary layer evolution at the northern Croatian coast is addressed here. The diurnal evolution of the sea breeze hodographs in the area has been analyzed during a typical period of 18-20 June 2000. For this purpose, the results of the 3D nonhydrostatic numerical mesoscale model (MEMO6) are used. The characteristics of the wind hodographs on the 24-hour base are explained using the simulation results for both the control period and two additional sensitivity tests. Thus, several statements reported by Prtenjak et al. (2006) and Prtenjak and Grisogono (2007) have been additionally examined and confirmed. Hence, in Pula-airport and Malinska, the diurnal winds are connected with the convergence zones, while Rijeka, Opatija and Senj are influenced by the slope winds. According to the above results, the authors believe that these findings will help designing a future research and measurement experiments because of the importance of a better understanding of coastal phenomena in a densely populated area such as the one considered here.

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