SEA-SURFACE TEMPERATURE EFFECTS ON 3D BURA FLOW

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Abstract: A nonhydrostatic numerical model with a higher order turbulence closure scheme is used to study the effect of the sea surface temperature (SST) on the nonlinear flow over a mountain in the presence of rotation. The low-level jet that develops on both flanks of the mountain is intensified by the Coriolis effect on the northern flank. Shooting flow develops down the slope ending over the sea while resembling a hydraulic jump. This is considered as bura like flow. Three different cases are addressed, the control run and two cases with the SST 10K colder, and 10K warmer than the control run. The maximum wind speeds that occur are around two times higher than the background wind speeds. Varying the SST induces changes to the flow that affect the position of the hydraulic jump and the extent and intensity of low-level jets that form on both flanks of the mountain. A hydraulic jump is modulated by orographicaly generated eddies.

Keywords *-sea surface temperature, bura, downslope wind, numerical modeling, low-level jet*

1. INTRODUCTION

Bura is a gusty, downslope wind which occurs at the eastern Adriatic. During the situations with very strong bura gust speed may exceed 60m/s. There are numerous studies related to bura wind, e.g. Ivancan-Picek and Tutiš (1996), Tutiš and Ivan an-Picek (1991). Several recent numerical studies deal with bura in 3D, e.g. Belušić (2004), Šahdan and Tudor (2004), while its basic theory is in Smith (1985,1987), Durran (1986), Smith and Sun (1987).

Enger and Grisogono (1998; henceforth EG98) showed in 2D simulations that the sea surface temperature (SST) in the lee of the mountain affects the propagation of the bura front (BF) and change the location of hydraulic jump (HJ) by modifying the local buoyancy frequency. The study of Grisogono and Enger (2004; henceforth GE04) found that, in the presence of Coriolis forcing, a double resonance phenomenon (wave breaking with differential vertical deflections off the flanks) may occur in the lee of the mountain, causing vigorous asymmetric eddies. The aim of this study is to determine the impact of both SST and the eddies on the bura evolution; hence, this is a superposition of EG98 and GE04.

2. MODEL SETUP

COAMPS (Hodur 1997), a nonhydrostatic fully compressible, local area mesoscale model with terrain influenced height based vertical coordinate is used. Horizontal dimensions of the computation domain are 250x100 grid points with grid spacing in x and y direction of 2.5km and 5km respectively. Integration time step of 7.5s is employed to ensure the linear stability criterion is met (e.g. Durran 1999). The model top is set at 15km and 35 vertical levels are used with minimum distance near the surface of 20m. Vertical resolution changes log-linearly from 20m to 500m above 1km. Fixed lateral boundary conditions are used in x direction and extrapolation boundary conditions in the y direction. The sponge layer is located at the uppermost 4km to prevent spurious reflections from the model top. A fourth order advection scheme is used. Mellor-Yamada level 2.5 turbulence closure scheme is employed.

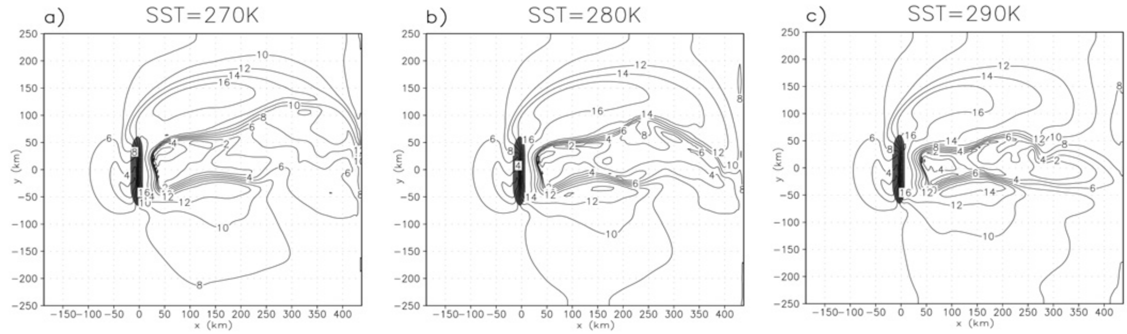

Figure 1. Horizontal wind speed (m/s) at 10m above surface at t=20h, panels a), b), and c) show airflow for SST=270K, 280K and 290K respectively. The mountain is shown shaded in light gray from 100m to the top at 1000m, x=y=0 at the mountain center (x=75, y=50 grid points). Sea resides from x>10km.

An elongated idealized mountain is given by half-length L_y=50km perpendicular to the flow, the maximum height is H=1000m along x_0=0km (75 grid points). In the x direction mountain is represented by a half Gaussian ridge with half width equal to L_x=10km that is cut off on its lee side. Sea resides immediately east of the mountain from x>10km. The background flow is constant westerly, U=8m/s. The flow is stably stratified with N=0.0132s^{-1}. These values are chosen to ensure nonlinearity of the flow regime by providing Froude number $Fr=U/(NH)$=0.6. The zero-level air temperature is set to 280K. The primary hydrostatic orographic wave has vertical wavelength $\lambda_z=2\pi HFr$=3768m. Coriolis parameter is constant throughout the domain with its magnitude corresponding to the latitude of 45N (f =10^{-4} s^{-1}). Relative humidity is set to 10% and is kept constant. Water vapor never approaches saturation and behaves like a passive tracer. In the control run SST was set to 280K. Two sensitivity tests were made with SST set to 270K and 290K.

3. RESULTS AND DISCUSSION

All results are discussed after t=20h of integration when the model reached a quasi-stationary state.

3.1. Low-level jet (LLJ)

The flow around and after the mountain is asymmetric around y=0km, Figs. 1 and 2. Two LLJs form on both flanks of the mountain Fig 2a)-c). The northern LLJ covers a larger area then the southern one and also has greater wind speeds, Fig. 2. This is consistent with the findings of GE04. The wind speeds in the northern LLJ exceed 16m/s that is twice the background flow. It is seen that the increase of the SST affects both LLJs (Fig.1, Fig.2d)-f)). The southern LLJ is strengthened by the increase of the SST (Fig.1). Along-flow extent of the northern LLJ is reduced (Fig.1) by the increase of the SST but its maximum speed remains the same. The increase of SST makes lee-side wake narrower and also decreases the extent of its meandering (Fig.1). Namely, with the increase of SST, the left and right flank's boundary layers get mutually closer. It seems that a further increase in SST could reduce the extent of the perturbation caused by the mountain but no other simulations were made in order to test this.

3.2. Bura Front (BF)

There is a shooting flow near the surface in the lee of the mountain Fig. 3. This flow is two times faster than the background flow and resembles bura flow on the eastern Adriatic. There is also a front related to the abrupt slowdown of the flow through HJ. This front, BF, is visible in the Fig. 3 as the area of strong horizontal wind speed gradient in the lee of the mountain. The HJ can be seen on the Fig. 3a)-c)

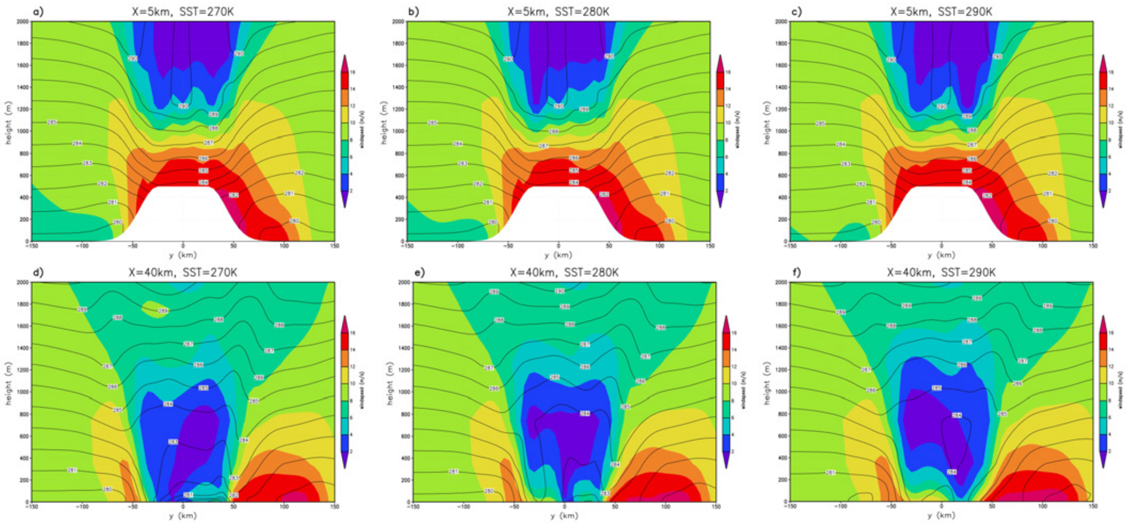

Figure 2. Vertical cross section perpendicular to the mean flow at *t*=20h, along *x*=5km and *x*=40km from the mountain top at panels a)-c) and d)-f) respectively. Panels d)-f) show flow over the sea. Cases for SST=270K, 280K and 290K are shown from left to right. Potential temperature is shown in contours, K, horizontal wind speed is shaded, m/s.

as steep rising of isentropes in the lee of the mountain. The region where HJ occurs is not as localized horizontally as is in EG98 and spreads here over 20km in the control run. The extent of this region increases with the increase of SST Fig. 2. In order to compare the response of the surface BF to changes in SST, we defined the location of the BF as the place where the near-surface wind speed drops below 8m/s. Using such definition of the BF it can be seen in Fig.3a)-c) that the BF moves further away from the mountain as the SST increases, in accord with EG98. In the control run the BF is located 38km away from the mountain, Fig. 3b). With SST 10K warmer than zero height land surface temperature the BF 46km away Fig. 3c) while for SST 10K lower, the BF is located 33km away from the mountain Fig. 3a). This gives the range of 13km which is considerably less than in the results obtained by EG98 for a 2D case (60-70 km). Another difference from EG98 is that even the relatively cooler SST, Fig. 3a, yields an offshore propagation of BF, which is not the case in EG98. The discrepancy can be explained by the interaction between the BF and lateral eddies that form on the flanks of the mountain. Of course, the latter could not be captured in the 2D study of EG98.

The BF itself is not stationary but oscillates back and forth over a distance of 10km (not shown here). The BF is not parallel with the mountain rather its northern flank is generally closer to the mountain. There are indications of wave motions of the front connected with the meandering of the lee side flow.

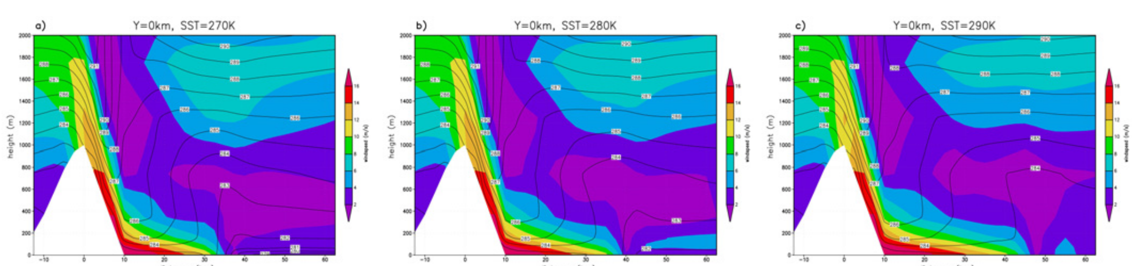

Figure 3. Vertical along-stream cross section through the center of the mountain (*y*=0km) at *t*=20h. Panels a),b), and c) show horizontal wind speed (shaded),m/s, and potential temperature (contours), K, for SST=270K, 280K and 290K respectively. Sea resides at *x*>10km.

4. CONCLUSIONS

The SST affects the bura flow characteristics – the LLJ and BF propagation. The influence on the BF propagation is much less (five times) than indicated by findings for 2D case (EG98). The difference is due to interaction of the BF with orographically generated vortices. The increase in SST increases the extent and intensity of the southern (weaker) LLJ, but decreases the area of the northern LLJ. Maximum speed of the northern LLJ is unaffected by the change in SST. This study may have important implications for understanding seasonal variations of the bura basic properties.

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