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HORIZONTAL SCALE OF CLOSED BREEZE CELLS AT THE SOUTHERN BULGARIAN BLACK SEA COAST

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Abstract: The air quality problems at coastal areas are related most often to 1) formation of internal boundary layers over land at marine flows which confines the volume for dispersion of pollutants emitted near the ground and 2) to recirculation of pollution because of closed breeze cells. Studying the horizontal and vertical scales of the closed breeze cells helps to assess the air pollution that might be encompassed in the recirculation.
In order to evaluate the possible recirculation effect, we study the horizontal scale of observed closed sea breeze cells at the southern Bulgarian Black Sea coast. The vertical structure of the closed breeze cells on 5 August 2008, 5 September 2008 and 7 May 2009 is measured by a sodar at Ahtopol (42.084N, 27.9513E) synoptic station. Two other synoptic stations: Burgas (42.4975N, 27.4825E) and Karnobat (42.6558N, 26.9847E) are also situated within the innermost domain of Weather Research and Forecasting (WRF) model which covers the studied area. WRF is configured on 3 domains with horizontal resolution of 25 km, 5 km and 1 km and 43 vertical levels, using MYJ PBL scheme. Comparison is performed between data from the synoptic stations and corresponding in time model results near the ground. The temperature and relative humidity fields at 2 m (T2 and RH2) of the inner domain are used here to evaluate the horizontal scale of the sea breeze at different perpendicular to the coast transections with the latitudes of Ahtopol, Burgas and Karnobat. The characteristic "plateau"-type shape of the daytime variation of T2 occurs inland up to 45 km (in May) and 65 km (in August and September cases) at Ahtopol, which is new information compared to old climatological studies for the region.
Having the evaluation of the WRF results against measurements at several sites, allows further investigation of the phenomena based only on model results. Hovmoller diagrams of T2 and wind and vertical cross sections at different latitudes show the temporal, vertical and inland extend of the closed breeze cells. At Ahtopol WRF overestimates the diurnal T2 amplitudes in all 3 cases with the largest difference in August.

Key words: Sea breeze, closed breeze cells, WRF model, sea-breeze penetration inland, Bulgarian Black-sea coast

INTRODUCTION

Sea breeze (SB) is a local thermally driven circulation at the sea coasts and shores of large water bodies (e.g the Great Lakes). It is caused by different thermal conductivity of soil and water and establishes change of wind direction (in area affected by the SB) with period of 24 h. The most favourable conditons for the SB development are during the warm part of the year (when temperature difference land/sea is the bigest) and under high pressure systems and weak pressure gradient fields. The influence of the SB on local weather, air pollution, smog, thunderstorms, sport activities (Simpson, 1994), its morphodynamic effects on coastal processes and morphology (Masselink and Pattiaratchi, 1998) etc determine interest in studying through observations, development of theoretical approaches and numerical weather models (NWM) (Simpson, 1994, Abbs and Physick, 1992, Crosman and Horel, 2010). NWM are powerful tool to investigations of SB features, especially in areas where observations are sparse or not available.

METHODS

Numerical simulations of closed cell breeze events were performed with the Advanced Research core of Weather Research and Forecasting (WRF) model v.3.3.1 (Skamarock et al., 2008). The model was initialized with US National Center for Environmental Prediction Final Analyses (FNL) with 1x1 degree spatial and 6 h temporal resolution. The WRF was configured on 3 domains with grid step 25 km, 5 km and 1 km with horizontal grid dimensions of the outermost domain (domain 1, D1) 26x21, 36x36 (D2) and 111x111 (D3) points. The top of the modelled atmosphere was set at 50 hPa and the number of vertical levels was 42 as 30 of them are below 2000 m. The USGS 24-category was used for land use data set. The parameterisations of physical processes which were used in the simulations are listed in Table 1. Three cases (05.08.2008, 05.09.2008, 07.05.2009) were run with WRF and each of them consisted 36 h forecast (started at 12 UTC) as the first 12 h were considered as spin-up.

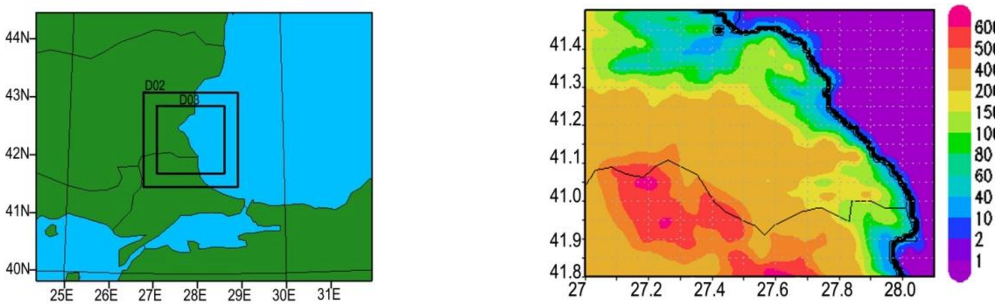


Figure 1. Domain configuration and terrain height of the innermost domain

The modelled temperature at 2 m (*T*2) and relative humidity (*RH*2) were compared with synoptic data (available at every 3h) at Ahtopol station, while for wind speed (*U*10) and wind direction (*WD*10) at 10 m were used data from automatic anemometer MS&E – Wind2 (available at every 1h). Vertical profiles of modelled WS and WD were compared with data from SCIENTEC Flat Array middle range instrument (MFAS) Sodar (available at every 10 min with 10 m vertical resolution and vertical range of 30-1000 m). The evaluation of breeze penetration inland was based only on model results.

Table 1. Physical parameterisations

Microphysics	8 (MO2 и 3) = Thompson graupel scheme (Thompson et al., 2004); 4(MO1) = WSM 5-class scheme (Hong et al., 2004)
lw radiation	1 = RRTM: Rapid Radiative Transfer Model (Mlawer et al., 1997)
sw radiation	2 = Goddard (Chou and Suarez, 1994)
surface layer	2 = Eta similarity (Janjic 1994)
land surface	2 = Noah LSM (Tewari et al., 2004)
ABL	2 = MYJ: Mellor-Yamada-Janjic TKE(Mellor and Yamada 1982, Janjic 1996, 2002)
cumulus convection	5 (only for D1 and D2) = Grell3D (improved version of Grell and Devenyi, 2002)

RESULTS

Establishment of the onshore winds on 7 May is at 8 UTC based on data from MS&E – Wind2 and in the model is 2 h earlier (Fig. 2 a). In August and September cases the SB onset, based on observations is at 7 UTC, while in WRF simulations is 1 h earlier. Both in observations and modelled *U*10 the calm zone is 1 h before establishment of easterly winds. Start of the evening shift in *WD*10 based on observations is at 14 UTC, 15 UTC and 15-16 UTC in May, August and September, respectively. The modelled evening shift is at 15 UTC in May and August and at 16 UTC in September.

The model correctly represents the typical plateau in time series of *T*2. Comparison bewteen modelled and observed mininal and maximal *T*2 (Table 2) at synoptic terms reveals that the minimal *T*2 is underpredicted by the model (within 0.9 K) while maximal *T*2 overpredictected within 0.7 K. The biggest temperature amlitude is in August case.

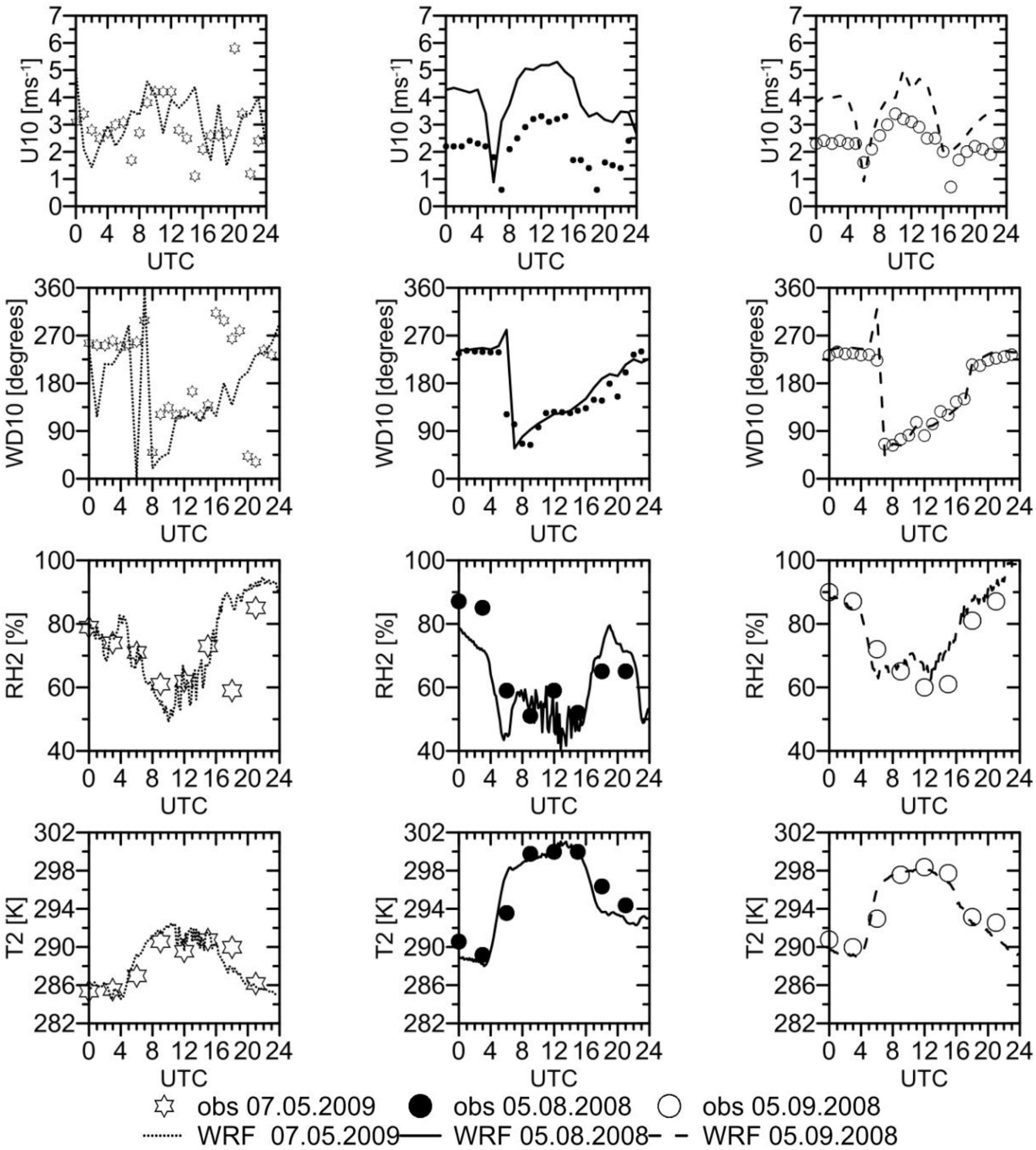


Figure 2 a. Comparison between modelled (output at every 1h) and measured (at every 3 h) *T*2, *RH*2 at Ahtopol station. *U*10 and *WD*10 were measured (at every 1 h) by automatic anemometer MS&E – Wind2

Table 2. Observed and modelled maximal and minimal *T*2 at synoptic terms and its amplitude at Ahtopol station

	T2min		T2max		Amplitude	
	obs	**WRF**	**obs**	**WRF**	**obs**	**WRF**
7.5.2009	285.4	284.9	290.8	291.5	5.4	6.6
5.8.2008	288.3	288.3	300.0	300.5	10.8	12.2
5.9.2008	290.0	289.2	298.4	298.1	8.4	8.9

Based only on modelled results the inland penetration is estimated using the *T*2 time series for different distances from the coast. We assume that the SB penetrates inland as far as in *T*2 diurnal pattern a plateau is observed due to penetration of cooler sea air mass interrupting the sinusoidal one that followa the heating of the earth's surface. The inland penetration in May case is 45 km (at Ahtopol latitude, φ=42.084) and over 65 km for August and September cases. Here, we illustrate the results only with the case of May.

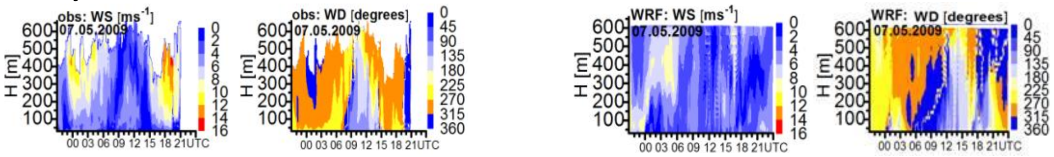


Figure 2 b. Comparison between observed (left) and modelled SB cell (May case)

SB vertical structure (observed by sodar and modelled) is presented in Fig 2b. The maximal WS is observed of 10 ms^{-1} at 250 m (11 UTC). The modelled one is 8 ms^{-1} at the same hour and height.

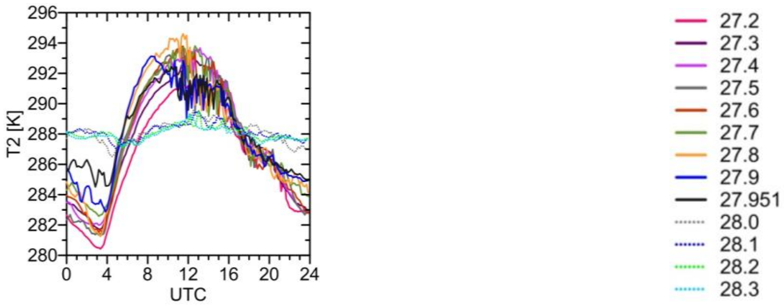


Figure 3. Time series of *T*2 at different longitudes (φ=42.084) on May 7, 2009

The modelled inland penetration of SB is presented through horizontal cross-section of modelled *T*2 and *U*10 at 0 UTC and 12 UTC (Fig. 4). Development of the process (07.05.2009), modelled by WRF (Fig 5.) through different latitudes is presented with Hovmoller diagrams.

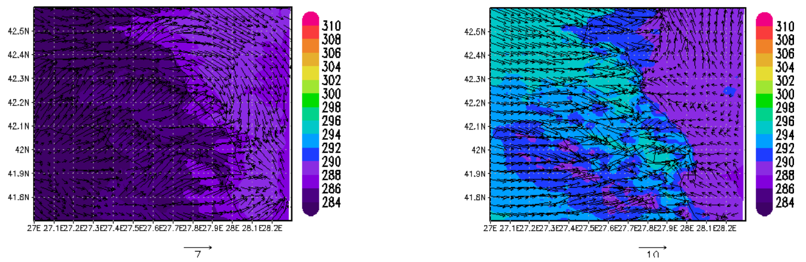


Figure 4. Modelled *T*2 and *U*10 for 7 May 2009 at 00 UTC (left) and 12 UTC (right)

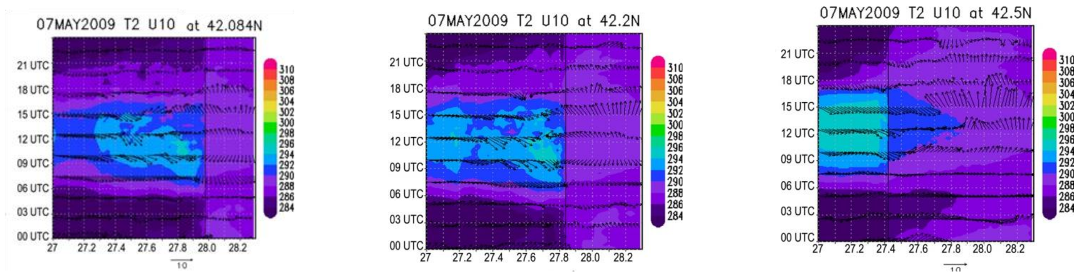
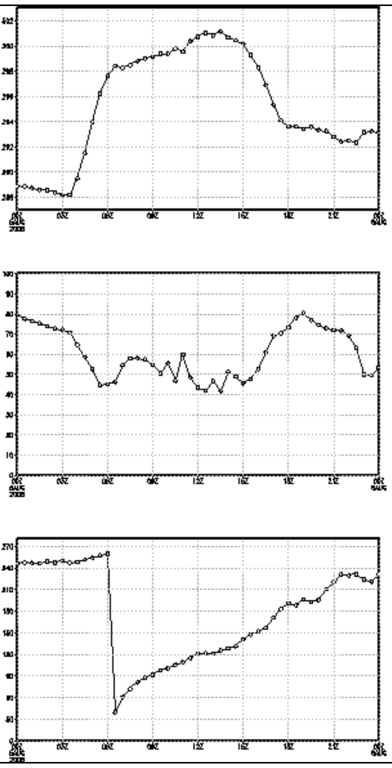
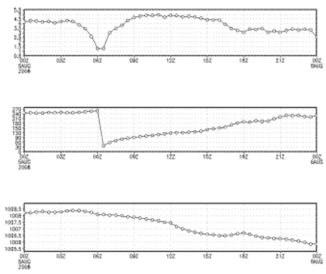


Figure 5. Hovmoller diagrams of *T*2 (shaded) and wind (vector) at different latitudes (07.05.2009)

CONCLUSION

WRF (with MYJ PBL scheme) is used to simulate the close breeze cell in 3 cases in the area of Ahtopol. Comparison between modelled and obseved *U*10 reveals that it is overpredicted by the model. The calm zones in *U*10 diurnal pattern are 1 h before the onset of the SB both inmeasurements and observations. The SB onset is simulated with 1 h ealier for August and September cases while in May with 2 h. The evening shift in *WD* is delayed with 1 h in the model. The plateau in T2 diurnal pattern is accurately represented by WRF. Based on model results the SB penetration inland (at Ahtopol latitude) is estimaed to 45 km for May case and over 65 km August nad September cases.

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