Dynamical downscaling of wind resources in complex terrain of Croatia

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Abstract:

Global model reanalysis or forecast data needs to be downscaled to provide information for regional interpretation. This is especially true in complex terrain of Croatia, where a significant portion of the wind energy potential is related with phenomena resulting from the interaction of the mountains and the lower troposphere, such as Bora, the local downslope windstorm.

Dynamical downscaling of ERA-40 reanalysis data to 8 km grid resolution was performed with the use of spectral, full-physics, prognostic mesoscale ALADIN model. In addition, the downscaled data was dynamically adapted to 2 km grid resolution over Croatia. The resulting wind climatology covers the 1992-2001 period, with 60-min data frequency at any height in planetary boundary layer, including wind speed, wind direction, and maximal gusts. The greatest average wind speeds and absolute wind speed maximums are associated with mountaintops and lee areas where gap flows and gravity-wave breaking take place during Bora episodes.

The modeled wind field is compared with the observed time-series on a number of surface stations, reflecting various climate regions of Croatia. The performed verification suggests that the downscaling is successful and that the approach proposed provides an accurate tool for calculation of wind resources in complex terrain of Croatia.

1. Introduction

Global model reanalysis data are usually available on one to two degrees horizontal grid resolution. While this data may be useful for assessment of wind resources above the planetary boundary layer (roughly above 1000 m), the estimation of near surface winds from global models is subjected to poorer performance. The reason for that is that model formulation and bottom boundary conditions (terrain, surface heterogeneities) are not designed to resolve phenomena on scales smaller than hundreds of kilometers and a couple of hours. However, it is these scales (2 - 200 km) that significantly contribute to wind climatology over complex terrain of Croatia (Fig. 1), where mesoscale phenomena such as Bora[1], "Jugo"[2], local mountain flows and sea-breeze circulations are often in act. Among these, Bora and "Jugo" are especially important, since the relative frequency and strength of these phenomena, as indicated by analysis of measured data, have a potential to account for by far the largest portion of wind resource in the region. Since these winds are strongly determined by the orographic perturbation and are of high spatial and temporal variability (especially Bora), the ability of the mesocale models, such as ALADIN, to simulate the related non-linear dynamics and thermal properties (i.e. static stability) of the air-masses involved [1], seems to be a strong advantage of dynamical downscaling compared with other methods of creating wind resource maps in the region. Therefore, in order to give more reliable wind resource estimate over Croatia, additional spatial and temporal scales were introduced though dynamical downscaling with the use of mesoscale

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[1] *Bora is a gusty, northeasterly downslope windstorm that is more often in winter, when might easily reaches gale force strength. Gusts are up to 220% of the 10-min wind speed and the strongest gusts measured reached category five hurricane strength (~250 km/h).*
[2] *"Jugo" is a Croatia name for local warm and humid southeasterly wind that belongs to the family of sirocco winds, but is channeled along the Adriatic basin by the Dinaric Alps.*

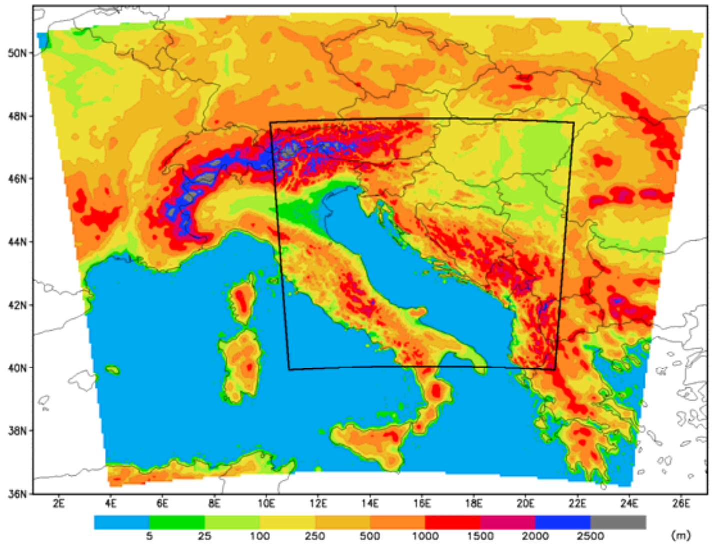

Figure 1: Outer and inner computational domains of ALADIN/HR model setup with model orography at 8 km and 2 km horizontal grid resolution respectively.

model ALADIN. The paper is organized as follows. Details of the methodology are presented in Sec. 2. The results of dynamical downscaling and its verification are described in Sec. 3, while Conclusions are made in Sec. 4.

2. Methodology

Dynamical downscaling was performed with a Croatian version of the ALADIN model, ALADIN/HR. ALADIN is a spectral model, with terrain-following hybrid pressure levels, a two-time-level semi-implicit semi-Lagrangian advection scheme a local turbulence scheme [2] and a set of comprehensive physical parameterizations [3]. The global model ERA-40 reanalysis data [4] of the European Centre for Medium-Range Weather Forecasts (ECMWF), available at ~125 km horizontal grid resolution and 6-hr frequency, was used as initial and lateral boundary

Figure 2: Measurement stations selected for verification of downscaling results representing different climate regimes of Croatia.

conditions data.

The ALADIN/HR model setup chosen included a hydrostatic version with 37 vertical levels (the lowest level at 17 m) and 8 km horizontal grid resolution. The pre-processing included spatial and temporal interpolation and a digital filter initialization. Since experiments with dynamical downscaling of ERA-40 data with ALADIN model to resolutions of ~10 km showed that there is no advantage in using computationally more demanding nesting strategy with an intermediate domain [5;6], direct nesting was chosen, allowing a large spin-off time (12 hr). Then, the ALADIN model output was used to dynamically adopt [7] the wind fields to 2 km horizontal grid resolution over Croatia. The dynamical adaptation was run hourly for 30 timesteps, each of 60s, with all physical parametrizations switched off except for the PBL parametrization.

Model verification was performed using 10m wind measurements from 5 stations representing different climate regimes of Croatia (Fig. 2). Slavonski Brod was chosen as representative for continental Croatia, very urban (continental) climate was represented by station Zagreb Maksimir and maritime climate was represented by stations in Novalja, Split Marjan and Dubrovnik. Traditional scores including root-mean square error, mean error, mean absolute error and multiplicative bias were calculated according to well known relations.

3. Results

3.1 Spatial distribution of wind resource

Mean wind speed values at 10m AGL are shown on Fig. 3. The regions with the highest average wind speed are mountaintops areas and regions west of the Velebit range. More specifically, the first include primarily mountains of Velebit and Lička Plješevica. The latter include the western slopes of the Velebit mountain, with a peak through the Vratnik pass. While mountaintops are common regions of increased wind resources, the enhanced wind resources on the foothills of Dinaric Alps are primarily due to Bora, by the far the strongest wind in the region [8]. Channeling of the flow through the Vratnik pass, a well known region of frequent and

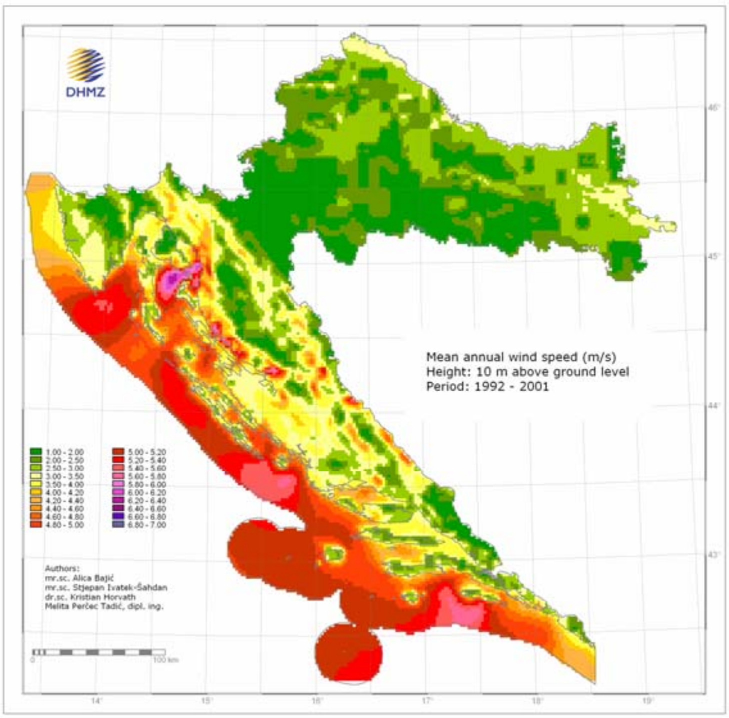

Figure 3: Spatial distribution of mean wind speed [ms^{-1}] at 10m AGL, as a direct model output of dynamical downscaling to 2 km horizontal grid resolution over the period 1992-2001.

severe Bora, additionally contributed to the higher wind resource in that area, while the extension of enhanced wind resource offshore appears to be associated with its hydraulic character [9]. On the other hand, the inexistence of such protrusion in the southern part of Velebit range is explicable in terms of different Bora character, which is predominantly associated with strong upstream blocking, gravity-wave breaking, overturning and creation of local critical levels in the lee (e.g. see [10]). Due to Bora gustiness, next generation of wind resource studies in Croatia should include the study of Bora turbulence using state-of-the-art numerical models and advanced observations, since the highly gusty nature of Bora can result in switching off the wind turbines even for 10-min wind speeds of 15ms^{-1} (L. Horvath, personal communication).

The lowest wind resources are found in parts of continental Croatia, Istria peninsula, Lika and hinterland of Ploče area. In addition to the fact that these regions are not favorable for the onset of the two most frequent and most intensive winds (Bora and „Jugo"), low-level blocking and boundary layer separation that take place on the eastern slopes of Velebit and Biokovo mountains have a potential to additionally contribute to low wind resources found in those areas.

3.2 Conventional verification statistics

Multiplicative BIAS and root mean square error (RMSE), inferred from direct model output of the dynamical downscaling during the 10-yearly period and 10m wind speed measured data from the selected stations, is averaged over monthly bins (Fig. 4), while 10-yearly averages are listed in Table 1. As expected, multiplicative BIAS (MBIAS) and RMSE values are the highest for the station Zagreb Maksimir, which is in highly urban area of the capital, surrounded by higher urban obstacles to the west. Since the urban roughness is not represented in the ALADIN/HR model, the simulated values are strongly overestimated. Therefore, the surface results of dynamical downscaling in highly urban areas can not be considered accurate without post-processing corrections, if the height of analysis is below the urban vertical mixing lengthscale.

The verification scores for other measurement stations indicate much higher accuracy. For station of Slavonski Brod in flat terrain, average 10-yearly MBIAS shows systematic underestimation of modeled surface 10m winds of only 1%. Similarily, RMSE is the smallest on the same station, with its average value equaling less than 1% of the measured average 10m wind speed value. The model accuracy is slightly lower on coastal stations, where these values are close to 10%. The most likely reason for that result is underestimation of stronger wind events (V > 6 ms^{-1}) in the coastal region. Namely, if data is binned into classes of wind speed (not shown), stronger modelled wind speeds (such as Bora and "Jugo") are underestimated in comparison to weaker wind speeds (V < 6 ms^{-1}) that are of more accurate amplitudes.

Since stronger winds are highly important for wind resource and annual wind energy production yield, further advances in the accuracy of wind resource estimates should seek to minimize the uncertainties in modelling Bora and Jugo winds, through the use of higher resolution full-physics

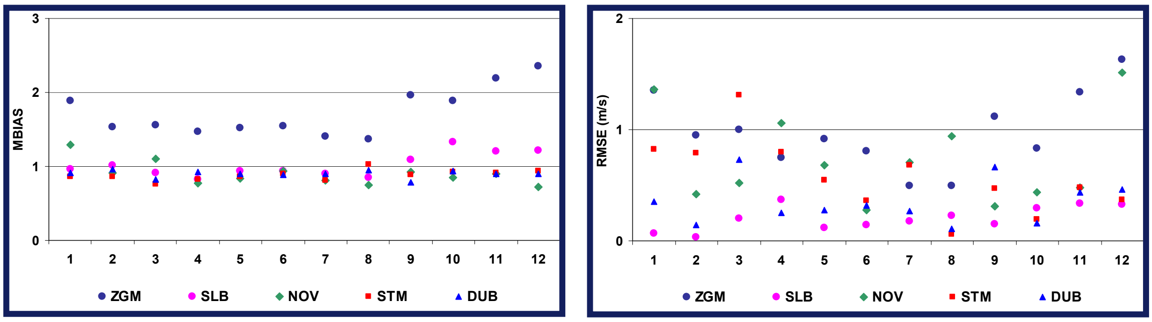

Figure 4: Multiplicative BIAS (left) and RMSE [ms^{-1}] (right) values for surface 10m wind speed over a 10-yearly period (1992-2001) and selected stations of Zagreb Maksimir (ZGM), Slavonski Brod (SLB), Novalja (NOV), Split Marjan (STM) and Dubrovnik (DUB) (cf. Fig. 2), as inferred by a direct model output.

Table 1: Average multiplicative BIAS (MBIAS), root-mean square error (RMSE) and mean 10m wind speed values over a 1992-2001 period and for selected stations (cf. Fig. 4), as inferred by direct model output. MBIAS of unity (MBIAS=1) means there is no BIAS in the modelled data.

	ZGM	SLB	NOV	STM	DUB
MBIAS	1,69	0,99	0,91	0,87	0,90
RMSE [ms^{-1}]	0,98	0,01	0,41	0,56	0,35
VOBS [ms^{-1}]	1,42	1,72	4,32	4,40	3,35

simulations and enhanced model formulation of planetary boundary layer parameterizations in complex terrain.

4. Conclusions

Dynamical downscaling of wind resource in Croatia was sucessfully performed. The areas with the highest wind resource are mountaintops, such of Velebit and Lička Plješevica, and western slopes of Velebit, due to frequency and strength of downslope Bora wind in the area. On the other hand, the lowest wind resources are found in parts of continental Croatia, Istria peninsula, Lika and hinterland of Ploče area. The greatest accuracy of direct model output of surface 10m wind speed is obtained in flat terrain (BIAS, RMSE ~ 1%), followed by coastal and mountain areas (BIAS, RMSE ~10%). The results are least accurate in highly urban areas. Nevertheless, further enhancement of the accuracy of modeled surface wind speed may be reached through postprocessing of the downscaled data.

In mountain and coastal areas, models on higher resolution could be applied for enhanced accuracy, provided they can account for the non-linear dynamics of stratified airflows over mountains and thermal properties of air masses involved. Due to its high gustiness and importance for wind resources, turbulent properties of Bora are to be included into next generation wind resource and annual energy production yield studies.

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