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The impact of increased horizontal resolution of ALADIN NWP model on reproduction of wind regimes in the complex terrain

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Introduction

In the complex terrain of eastern Adriatic where wind climate is governed by regional and local winds, it is beneficial to utilize a chain of numerical models to refine wind predictions. Verification of these mesoscale flows is a challenging task for which adequate approaches still need to be revised and defined.

Traditionally used statistical scores (MBIAS, RMSE, MAE, etc.) seem to be insufficient for that purpose since small spatial and temporal errors of generally well simulated phenomena can profoundly change the verification results. Therefore, besides moment-based verification, we used spectral analysis as a supplementary verification method to provide a scale dependent measure of model performance.

The verification process was performed on 16 stations from different climate regions of Croatia. As majority of stations is situated in very complex terrain near the coast or in mountainous hinterland, we expect to find a significant amount of energy at mesoscale, corresponding to diurnal and sub-diurnal scales. The distribution of energy in different frequency bands provides the information about exposure of measurement locations to non-local featuers, as well as the model ability to reconstruct the observations.

Objectives

Main objectives of this study are to:

- determine whether an increase of model horizontal resolution and/or complexity improves the wind forecast accuracy
- quantify contributions of different sources of error to RMSE and assess changes with model horizontal resolution
- perform a scale dependent evaluation of model performance both in temporal and spatial domains

Data and methods

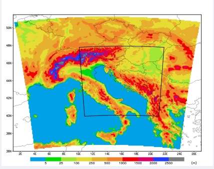

Fig1. ALADIN model 8 km and 2 km domains.

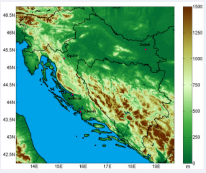

Fig2. Location of representative stations inside Croatian territory.

Model	AL8-ALADIN / ALARO 8 km	DA2-ALADIN / DADA 2 km[1]	AL2-ALADIN / ALARO 2 km
Cycle	AL32T3	AL29T2-mxl	AL36T1
Type	hydrostatic	hydrostatic	non-hydrostatic
Grid points	229 x 205	439 x 439	439 x 439
Vert. levels	37	15	37
Initialization	00 UTC	00 UTC	00+06 UTC
Range/Output-LBCf	72h/3h	72h/3h	24h/1h
Spin-up allowed	9 h	9 h	3 h

Table1. Basic information about verified model versions with spin-up period based on lead time dependant KE spectra analysis.

Statistical and spectral verification were performed for three different model versions (Fig1., Table1.) using measured 10-min wind speed and direction data from Jasenice, Šibenik, Ogulin and Osijek stations (Fig2.) in period 2010-2012. RMSE and systematic error (MBIAS - ratio of mean modeled and observed wind speed) were averaged over monthly periods to show their seasonal variability. Since the magnitude of RMSE is affected by uncertainty both in time and space, we have performed the decomposition according to the following relation[2]:

$$\overline{(f-o)^2} = \left(\bar{f}-\bar{o}\right)^2 + \left(\sigma_f-\sigma_o\right)^2 + 2\sigma_f\sigma_o\left(1-r_{fo}\right)$$

where first term on the right side stands for the bias of the mean (BM), second term for the bias of the standard deviation (BSD) and third term for dispersion or phase error (PHE).

Power spectral density (PSD) was calculated using the periodogram-based Welch method on segments with 50% of overlap. In order to assess the relative strength of circulation of diurnal and other periods (by numerical integration over chosen frequency bands), we have devided the spectral range into the following bands[3]: sub-diurnal (SUB; 6 h < T < 22 h), diurnal (DIU; 22 h < T < 26 h) and larger than diurnal (LTD; 26 h < T < 7 d).

Finally, the 3-hourly (AL8 and DA2) and 1-hourly (AL2) forecasts were used to calculate kinetic energy spectra with ECTO software at levels in lower, middle and higher troposphere.

Results

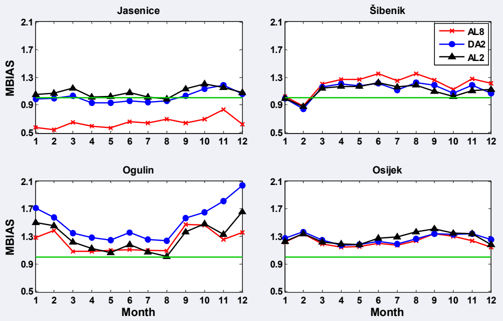

Fig3. Monthly averaged values of MBIAS for ALADIN/ALARO 8 km (AL8), ALADIN/DADA 2 km (DA2) and ALADIN/ALARO 2 km (AL2) forecasts at representative stations (green line points out to the ideal value of MBIAS which equals one – no systematic error).

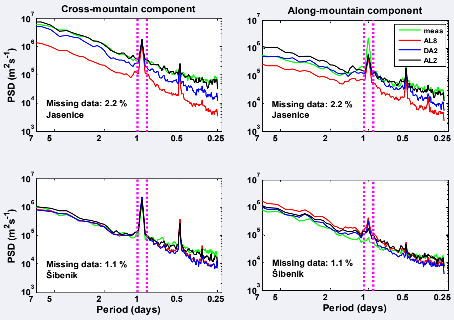

Fig6. Power spectral density (PSD) of cross-mountain and along-mountain wind components for measurements (meas), ALADIN/ALARO 8 km (AL8), ALADIN/DADA 2 km (DA2) and ALADIN/ALARO 2 km (AL2) forecasts at Jasenice and Šibenik stations.

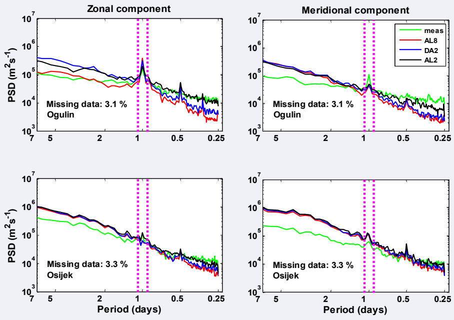

Fig7. Power spectral density (PSD) of zonal and meridional wind components for measurements (meas), ALADIN/ALARO 8 km (AL8), ALADIN/DADA 2 km (DA2) and ALADIN/ALARO 2 km (AL2) forecasts at Ogulin and Osijek stations.

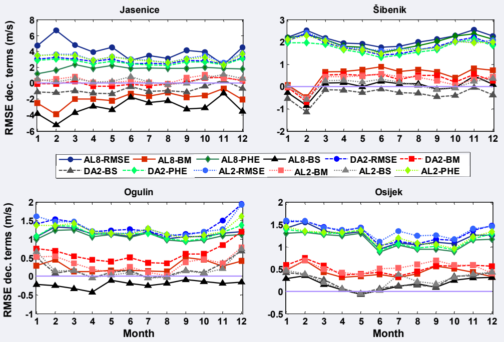

Fig4. Monthly averaged values of RMSE components for ALADIN/ALARO 8 km (AL8), ALADIN/DADA 2 km (DA2) and ALADIN/ALARO 2 km (AL2) forecasts at representative stations (violet line points out to the ideal value of RMSE which equals zero – no error).

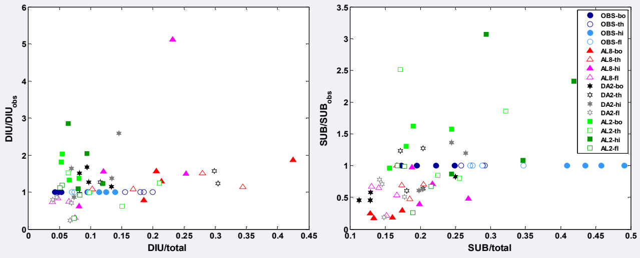

Fig8. Spectral power at each station in diurnal (DIU) and sub-diurnal (SUB) spectral bands normalized by the spectral power in the same spectral range of observations plotted against the share of power in particular spectral band. Figure legend associates symbols to various data sets (modeled or measured) and groups of stations (bo - bora dominated coastal stations, th - coastal stations with significant portion of thermally driven flows, hi - highland valley and mountain stations, ft – flat terrain stations).

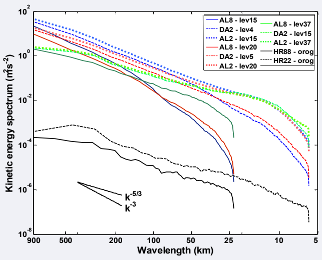

Fig9. Kinetic energy spectrum for three different model versions (Table1.) in lower, middle and higher troposphere. Normalized orography spectra for HR88 and HR22 domains are also added.

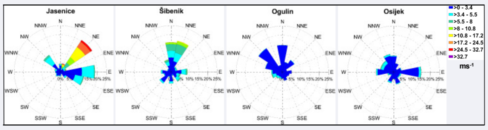

Fig5. Wind roses for representative stations of four indentified groups with different wind regimes.

Based on wind climate characteristics (Fig5.) and spectral decomposition in the frequency domain (Fig6-8.) we have classified 16 stations into four different groups, so here we present the results for representative stations of these groups.

Increasement of horizontal resolution of DA2 and AL2 forecasts has led to improvement over AL8 at coastal groups of stations (Fig3-4.). Benefits of increasing the model complexity at 2 km horizontal resolution can be seen for Šibenik station (th-group).

Phase errors are major source of RMSE errors (Fig4.) and their contribution generally increases with model resolution and complexity.

All modeled spectra overestimate amount of power in LTD spectral band at two continental groups of stations (Fig7-8.) and underestimate it in SUB range. Increasement of horizontal resolution and model complexity has improved the share and amount of power in DIU and SUB ranges at coastal stations (Fig7, 9.).

The kinetic energy spectra compare well to the theoretical and experimental evidence gathered in midlatitudes (Fig9.).

References

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Conclusions

Based on various statistical scores and spectral measures, it was found that increase of horizontal resolution and model complexity improves the wind forecast accuracy in coastal part of Croatia, especially at bora dominated stations.

The largest portion of RMSE errors can be attributed to phase errors, whose share increases with model horizontal resolution and complexity.

Spectral analysis in frequency domain has shown that most significant increase of accuracy was found for diurnal and sub-diurnal periods of motions in cross-mountain direction.

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