WRF's wind power ensembles for a wind farm located in a coastal area of Turkey

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Abstract: Short-term wind forecasts are obtained for a wind farm located in a coastal area of Turkey. The simulated month is March when the plant is under strong south-westerly gusts. We performed multi-scale simulations using WRF's different PBL parameterizations as well as LES. WRF ensembles with different planetary boundary layer (PBL) parameterizations showed little spread for wind speed forecasts. Statistical error analysis is performed and ramp events are analyzed. Model forecasts for ramps in general were poor. Complex topography of the study area also affects PBL parameterization's performance, especially the accuracy of wind forecasts were poor in late afternoons.

1. Introduction

In this study, Weather Research and Forecasting (WRF) model developed by National Center for Atmospheric Research (NCAR) developed is used to perform wind power forecasts for a wind farm located in western Turkey. The simulation results are compared with field observations that are turbine hub measurements of wind velocity.

Initial and boundary conditions used two different global data sets. Data from European Center for Medium Range Weather Forecasts (ECMWF) and the National Centers for Environmental Prediction (NCEP) were used to carry out simulations.

ECMWF initial data, provided in 0.75 degree (about 75 km) space and 6-hour time resolution, has 128 latitude circles from equator to pole and 37 pressure levels (1000 mbar to 1 mbar) and use a predictive model, observation data sets and 4-D data assimilation and is called ERA-Interim Reanalysis data set. ERA-Interim data is available from year 1979. Although data is originally in GRIB1 format, NetCDF format can be obtained too (http://apps.ecmwf.int/datasets/data/interim_full_daily/).

The second data set is NCEP FNL (Final) Operational Global Analysis data that has resolution of $1^o x 1^o$ (about 110 km) and is available in 6-hour intervals. NCEP GFS model was used to prepare FNL data. Analysis data has 26 pressure levels (from 1000 mbar to 10 mbar). The data may originally be obtained in GRIB format (http://rda.ucar.edu/datasets/ds083.2/).

In this study, in addition to initial and boundary conditions, standard surface data (land use, soil types and topography data) were used. High resolution (250 m) Corine (Coordination of Information on the Environment) land use data used here was prepared in 2006 by the European Environment Agency (http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-clc2006-250-m-version-12-2009#tab-gis-data). Corine's 44 different land use type was converted to WRF's 24 different land use types (USGS). 100 m resolution topography data was obtained from Shuttle Radar Topography Mission (SRTM) (http://earthexplorer.usgs.gov/). Geographic Information Systems was used to convert SRTM data to a usable form.

WRF version 3.6 was used in this study. Model study area, has been chosen as a wind farm located in the Aegean region of western Turkey. Outermost computing area is bounded by Greece in the east, Anatolia in the west, the Black Sea in the north and Mediterranean Sea in the south. Six nested grids were used in the WRF model (Figure 1).

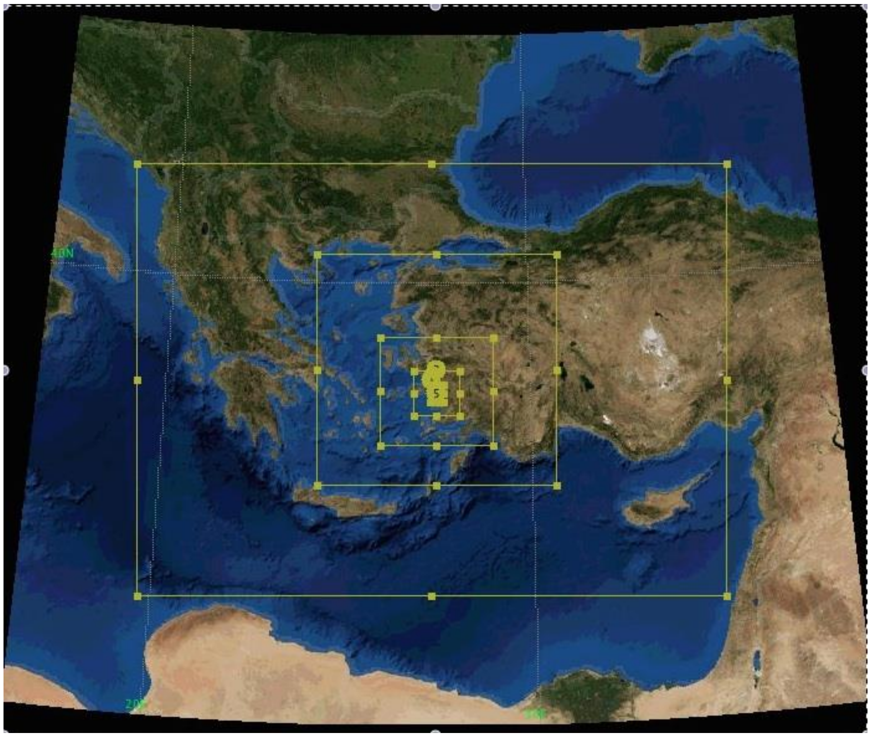


Figure 1. WRF work area and nested domains.

Detailed information about computational domains (number of grids in east-west and north-south directions, resolution in the horizontal direction, topography and land use data) are given in Table 1. 50 mbar was chosen as the top of the atmosphere and 50 sigma levels was used in vertical direction. The same setup was used in all simulations.

Moeng et al. (2007) examined nested LES using WRF's standard LES closure (TKE model) and were not successful in predicting wind speeds shear-driven simulations. Several new SFS stress models recently implemented into WRF have shown improvements in single-domain simulations (Mirocha et al. 2010). Here, we explore their performance in wind farm simulations.

Table 1. Detailed information about the nested grids used in WRF simulations (N_x shows the number of grids points used in the east-west direction, N_y shows the number of grid points used in north-south direction)

Domain no	N_x	N_y	Grid resolution (m)	Topography resolution	Landuse resolution
1	60	44	24300	5 min. (~9 km)	5 min. (~9 km)
2	73	70	8100	2 min. (~4 km)	2 min. (~4 km)
3	103	97	2700	30 sec. (~0.9 km)	30 sec. (~0.9 km)
4	127	118	900	30 sec. (~0.9 km)	30 sec. (~0.9 km)
5	115	130	300	3 sec. (~0.1 km)	250 m.
6	103	118	100	3 sec. (~0.1 km)	250 m.

The topography of 5th nested grid is shown in Figure 2. As it can be seen from the figure that the wind farm is located in a very narrow valley and close to the mountain edge. Therefore, we have encountered some convergence problems during simulations, and we have overcome them by changing various parameters in WRF model.

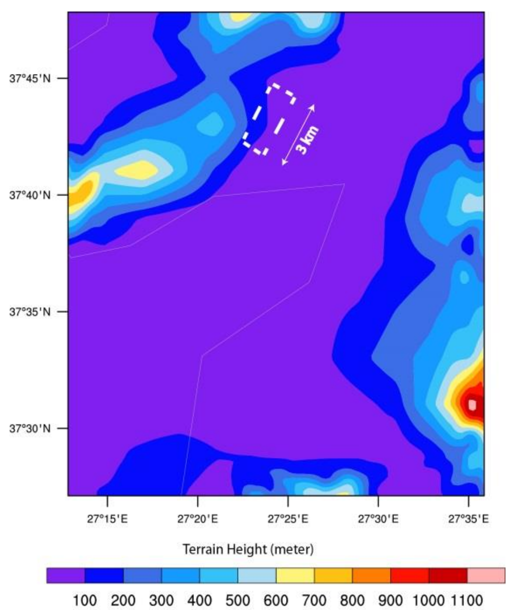


Figure 2. 5th nested grid (from outside to inside) used in WRF simulations and the location of the wind farm shown with white dotted lines.

10-minute wind velocity data in March 2012 was obtained from over-the-turbine cup anemometers. When the data was examined carefully, it was realized that wind mainly blows from north-east direction in 6 March 2012 14: 00 - 7 March 2012 14:00 period and it mainly blows from south-west direction in 2 March 2012 18: 00 - 3 March 2012 18: 00 period. For these time intervals, 48-hour test simulations were performed starting from 1 day earlier (24-hour spin-up) and results were compared with wind turbine observations.

In the simulations, 1st, 2nd, 3rd, 4th and 5th computational domains used Planetary Boundary Layer (PBL) parameterizations, 6th calculation domain (100 m) used Large Eddy Simulation (LES) parameterizations. We have tried two PBL parameterizations, namely MYJ (Mellor-Yamada-Janjic) and Mellor-Yamada-Nakanishi-Niino (MYNN) models. For LES, Non-linear Backscatter and Anisotropy (NBA) model was used. In all simulations, surface layer physics was set to 'Eta-similarity' and surface physics was set to 'Noah land surface model'.

2. Results

The locations of wind turbines in this field are shown in Figure 3.

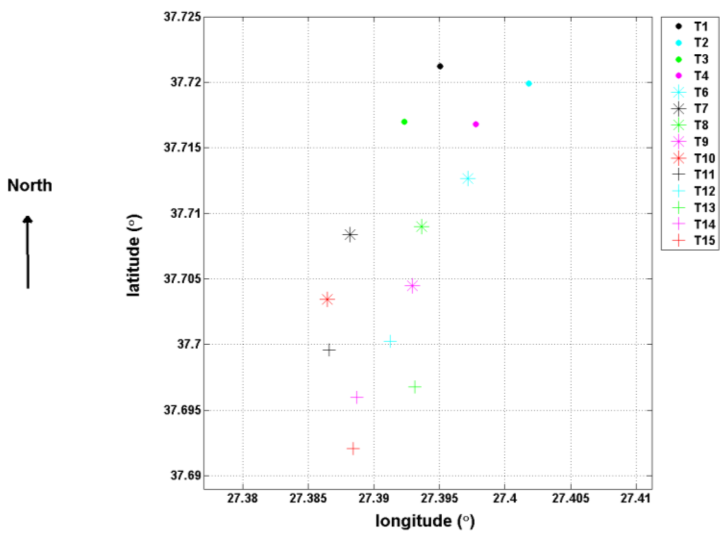


Figure 3. The locations of the wind turbines in the wind farm.

A. South-westerly wind conditions (2-3 March 2012)

The turbine wake effect is lowest for front-row turbines in this direction. Therefore, turbine wind velocity data of T11 and T14 are selected for comparisons with WRF simulations. Results are shown in Figure 4. The convention for naming results is 'initial condition - PBL parameterization (for nests 1.-5.) - LES parameterization (if available, for nest 6)' (e.g. FNL-MYNN-LES). For FNL-MYJ and FNL-MYNN, domain-5 results were used and for FNL-MYNN-LES, domain-6 results were used. Here one should remember that domain-6 has the highest resolution (100 m). Figure 4 shows that ramp events (known as rapid increase in wind speed in a short period of time) are better predicted by the LES model. For quantitative comparison, mean absolute errors (mae) over the simulation period were calculated (Table 2). It is shown that MYJ model estimates result in lowest errors for both turbines. When MYNN and MYNN-LES results are compared, MYNN-LES performs better in predicting observations.

Table 2. Comparisons of mean absolute errors calculated for T11 and T14 over the periods of 2-3 March 2012 and 6-7 March 2012.

	2 MARCH 18:00 - 3 MARCH 18:00			6 MARCH 14:00 - 7 MARCH 14:00	
	T11	**T14**		**T1**	**T4**
	mae (m/s)	*mae (m/s)*		*mae (m/s)*	*mae (m/s)*
FNL-MYJ	1.288	1.209		0.862	1.072
FNL-MYNN	1.332	1.362		1.267	1.378
FNL-MYNN-LES	1.314	1.251		1.232	1.394
ERA-MYNN-LES	---	---		1.167	1.275

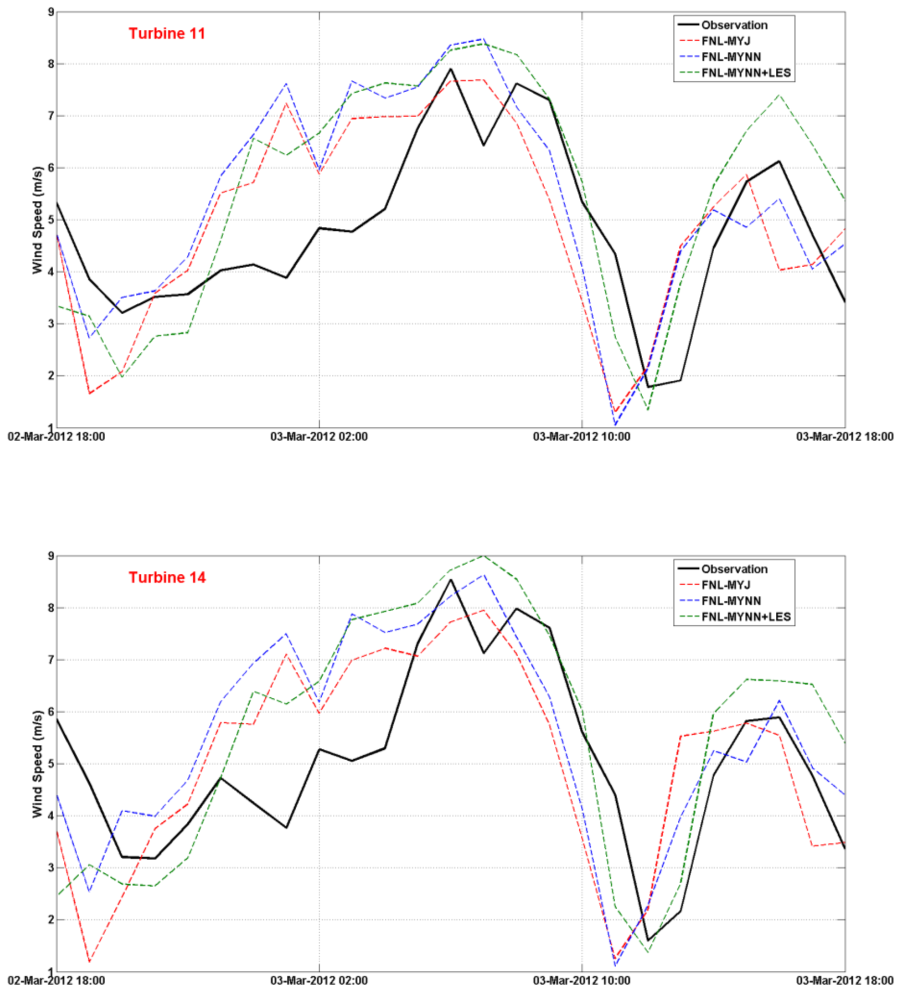
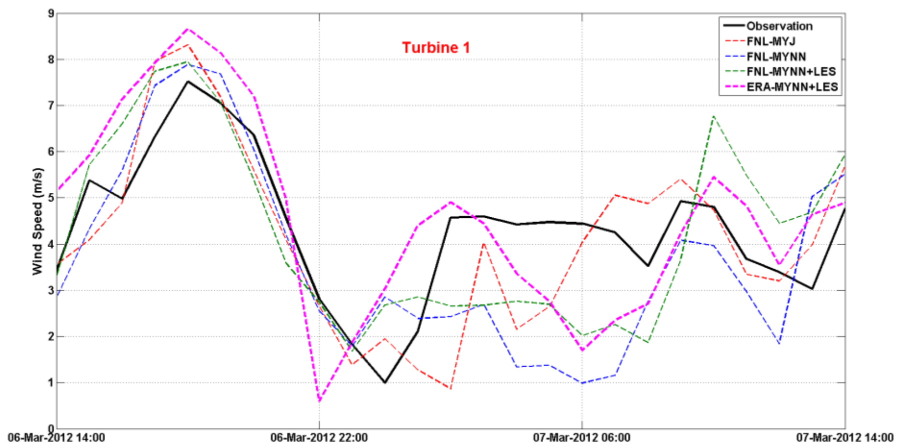


Figure 4. Comparison of 24 hours simulation data with observational data over the period 2 March 2012 18: 00 – 3 March 2012 18:00; a) Turbine 11, b) Turbine 14.

B. North-easterly wind conditions (6-7 March 2012)

The turbine wake effect is lowest for front-row turbines in this direction. Therefore, turbine wind velocity data of T1 and T4 are selected for comparisons with WRF simulations. Results are shown in Figure 5. For FNL-MYJ and FNL-MYNN, domain-5 results were used and for FNL-MYNN-LES, domain-6 results were used. Simulation results show that over the period 7 March 02:00-10:00, all models failed to predict the observation data. When surface velocity vectors are examined (Figure 6) it is observed that down-slope currents from mountain top and north-easterly winds come together on the wind farm area and models cannot predict this complex behavior. For quantitative comparison, mean absolute errors (mae) over the simulation period were calculated (Table 2). For both turbines, MYJ model gives the best result. To improve MYNN model results, two methods were tried separately: 1) LES model has been run by adding domain 6 to the computation, 2) the initial condition is changed from GFS-FNL to ERA-Interim. Table 2 shows that MYNN-LES model was helpful in reducing the error for turbine T1. Second method, using ERA-Interim data instead of GFS-FNL data as initial condition, gave even better results (Table 2).



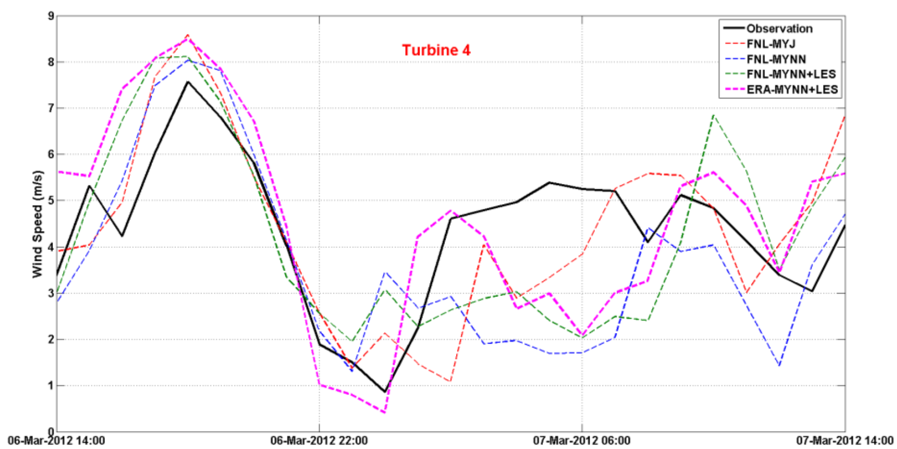


Figure 5. Comparison of 24 hours simulation data with observational data over the period 6 March 2012 14: 00 – 7 March 2012 14:00; a) Turbine 1, b) Turbine 4.

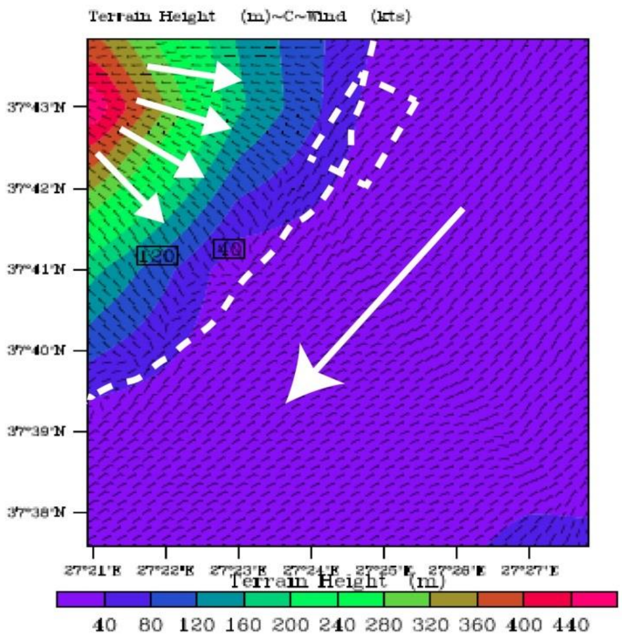


Figure 6. Instantaneous surface wind velocity vectors shows that cross-flow conditions form over the wind farm in the period 7 March 2012 02: 00-10: 00 hours.

3. Summary

In this study, WRF simulations were used to predict wind conditions at a wind farm located in eastern Turkey and WRF predictions were compared with observational wind data. In addition to widely used WRF-PBL parameterizations, a fairly recent addition to WRF model, WRF-LES simulations were carried out. WRF-LES simulations resulted in better predictions compared to WRF-PBL simulations. On the other hand, all models had difficulties in predicting cross-flows developed in lower mountain slopes. After obtaining met-tower observational data in the same field, more detailed comparisons will be made. In addition, using more advanced LES models is expected to improve simulation results. After achieving success in WRF-PBL and LES parameterizations, real-time wind turbine predictions will be performed.

4. References

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5. Acknowledgement

This work is supported by Turkish National Science Foundation, TUBITAK project no. 113Y197.