Wind Simulation in A Complex Terrain by Numerical Weather Prediction Method Using Large Eddy Simulation

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ABSTRACT

Researchers are interested in wind resource assessment studies for mountainous terrains using numerical weather prediction methods. In present study the wind over Martigny located in Switzerland, has been simulated using weather research and forecasting model. Due to high resolution of the simulation (100 m), large eddy simulation is employed to perform turbulence modelling. The objective of this study is to assess the credibility of model in wind simulation and to examine the effect resolution and two different sub-grid scale turbulence models. The results reveal that model is able to properly generate the wind in comparison with the data obtained from wind measurement stations. The results also show a promising simulation for the region, located within a wide and flat valley. However, the discrepancies between the results and those obtained from the wind station are bold for regions at mountainous peaks. At the time at which the maximum wind speed occurs, it is found that the wind error decreases from 22m/s to 17m/s by changing the sub-grid scale model from Smagronisnky3D to turbulence kinetic energy 1.5 model. Also the predicted wind speed declines from 17m/s to 7m/s by reducing the the vertical size of the grid-cells.

Key Words

Wind, Numerical Weather Prediction, WRF, Large Eddy Simulation, wind resource assessment

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Introduction

Wind resource assessment in a mountainous and complex area is one of the concerns in renewable energy field. Wind potential assessment was initially done by data collection method [1]. This method is very limited due to the limited number of measuring stations and the challenges in installing measuring towers in mountainous areas. Therefore, researchers have used numerical simulation in order to predict wind characteristics in complex terrains [1, 2]. One of the challenges in using numerical methods is the discrepancies in estimation of the average wind speed by a numerical model and the actual wind observed in the region.

Numerical weather prediction[2] method is one the numerical methods employed for wind prediction. Nevertheless, NWP method is quite complex and its performance is influenced by various factors. Steffel et al. showed that previous wind resource assessments of Switzerland using NWP with low resolutions underestimated the wind energy potential of this country [3]. They claimed that the lack of accuracy in predicted wind potential was because of the complexity of the terrain in Switzerland. Thus Jafari et al., Kruyt et al. and Pickering et al. tried to improve the simulations using more advanced NWP models [4-6]. They showed that by increasing the size of grid cells (horizontal resolution) performance of NWP models improves. Their results also indicate that by increasing the resolution to 300m, the potential wind energy predicted in this area increases. However, even by 300m resolution, a high bias is observed in some specific locations. It is expected that by performing high-resolution simulations (on a scale of 100m and less) the error of predicted wind speed decreases [4].

Hence, the purpose of this study is to achieve a simulation with results similar to reality and to perform simulations in WRF with 100m resolution using large eddy simulation[3] method. In addition, the effect of using the sub-grid scale[4] turbulence models i.e. the Turbulence Kinetic Energy model (TKE 1.5) and the Smagorinsky3D SGS model while using LES is investigated. On the other hand, the high aspect ratio of grid cells (ratio of height to length of grid cells) in WRF at steep areas will lead to skewness error [7] and it is necessary to investigate the effect of changing this ratio on improving WRF performance. . This type of research has been done in very rare cases. Performing the simulation in a very complex terrain is the next key features of this research. In this research, the WRF model, which is very powerful in performing simulations in a wide range of resolutions has been selected to perform a simulation in 100*m* resolution.

[2] NWP

[3] LES

[4] SGS

Methodology

For this study, three realistic simulations with a horizontal resolution of 100m in a complex terrain were performed. The effect of changing the SGS turbulence model and also changing the height of the grid cells have been investigated. A 15 × 15 km^2 domain in Martigny (Rhone valley) with a complex topography is selected for these simulations. The output of Cosmo1 model with 1km resolution have been used as initial data. The data of four measuring stations in the area, owned by the Meteoswiss[5], would be used for results validation.

In order to study the effect of vertical resolution, the horizontal length of cells is considered to be constant (100m) and the top pressure is set to be 100hPa for two and 400hPa for one simulation. Accordingly, the minimum heights of the cells near the ground (hereinafter referred to as vertical resolution) are 47m for first and second simulations and 37m for third simulation. To investigate the effect of using each of the SGS turbulence models the Turbulence Kinetic Energy model[6] is used in the first simulation and the Smagorinsky 3D SGS model is used for second and third simulations. Table 1 shows the characteristics of these simulations.

Table 1: summary of simulations

Simulation	SGS model	Vertical Resolution (m)
1	TKE1.5	47
2	Smagorinsky3D	47
3	Smagorinsky3D	37

Discussion and Results

After performing three simulations with a resolution of 100m in the Martigny, the wind speed per hour at the height of ten meters above the ground was compared with wind measurement data at four stations. Figure 1 shows the results for all stations.

[5] The Federal Office of Meteorology and Climatology

[6] TKE 1.5

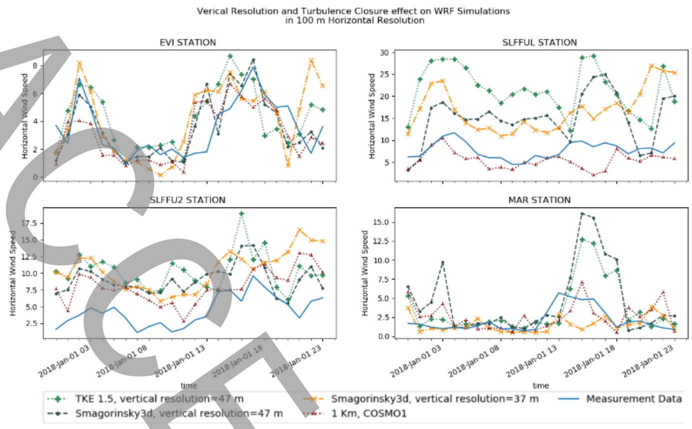

Figure 1: Comparison of wind speed in three simulations with wind speed measured at 4 station on January 1, 2018

At the EVI station, the simulations perform reasonably well (Figure 1). In the region of Evionnaz, due to the flatness of the terrain, the model can simulate the wind with a high accuracy. The simulations using the Smagorinsky SGS model are more time-consistent with the measurement data than the TKE1.5 model. This issue may be due to the poor performance of TKE1.5 in sloping areas and needs further study in future. Also simulations with the lower vertical resolution are more successful in predicting deceleration than simulations with the higher vertical resolution. In SLFFUL and SLFFU2 stations, the first two simulations have poorer performance in terms of maximum wind speed prediction compared to the third simulation. Predicting excessive wind speed near the surface is a well-known problem in WRF [8-10]. One of the reasons for the error in the heights in WRF, may be due to the smoothing of the topography and losing some of the drag forces [8, 10]. At the MAR station located in a narrow valley throughout the day until noon all three simulations follow the pattern of measurement data. However, at 1 pm two simulations with a vertical resolution of 47m despite following the trend of the measurement data, show a relatively large error.

Conclusions

In the present study, the NWP method was performed for the windy complex region of Martigny (Rhone Valley) in Switzerland using WRF model. Three real simulations were performed. One of the key features of this research is the implementation of a real simulation in WRF with high resolution (100m) using the LES method. In this study, the effects of grid cell height (vertical resolution) and SGS turbulence model of TKE1.5 and Smagorinsky3D have been investigated.

Measured data of four wind speed measuring stations in the domain is used. The results of simulations in these stations showed that depending on the type of topography of the region, the performance of simulations were different such that the simulated wind speed for the flat area had an acceptable agreement with the measurement data. However, in the narrow valley and on the mountain tops when the wind speed was increasing, discrepancy between the simulations and measurements was observed. Yet on average, the error due to the change of the SGS model from TKE1.5 to Smagorinsky, decreased from 10.37m/s to 8.37m/s and due to the reduction of the vertical height of grid cells from 47m to 37m, error reduced to 1.125m/s. This shows that increasing resolution to 100m increases the accuracy of wind simulation and therefore the predicted wind potential of a domain in Switzerland. Also increasing the resolution up to 50m or more should be investigated in order to remove the error in mountain tops.

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