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Performance evaluation of WRF/CALMET integrated model in expanding inflow wind field to air quality models

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ABSTRACT: The necessity of having comprehensive information on wind field in a particular area is important for various reasons. How air pollutants are scattered and released is one of the most important ones. In this study we explore the efficiency and usefulness of integrating WRF mesoscale numerical model with CALMET meteorological calculation model in order to generate high accurate wind field in a region centered in Tehran in a five days period from 5th to 10th July 2014. On the first stage three dimensional wind fields of the region were processed using WRF model and the result made available to CALMET model as an initial guess. On the second stage the WRF model was put aside and surface meteorological data along with the atmosphere above the Mehrabad metrological station were processed using SMERGE and READ62 model respectively; the results used directly in CALMET model. Finally, the CALMET model was implemented using the combination of WRF model data and observational data. Then the efficiency of mentioned methods was explored using statistical analysis, comparing temperature profiles, wind speed and simulated data with observational data of Imam Khomeni airport metrological station in the intended period. Results of the statistical indexes which were used in this study including index of agreement (IOA), mean bias error (MBE), root mean-square error (RMSE) and mean absolute error (MAE) indicate the high power of WRF/CALMET integrated model in simulating wind field of the region so that the value of index of agreement for wind speed in the first stage is 0.70-0.85, in the second stage is 0.59-0.83 and in the third stage is 0.76-0.90. Generally the results of this study shows that using and combining the outputs of WRF model with observational data as input for CALMET model is an efficient way for generating accurate metrological data for studying air quality modeling specially in countries like Iran in which the upper atmosphere data is hardly measured.

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1. INTRODUCTION

The most common way of characterizing wind speed is through in-situ measurements, which are not always available to the desired extent and only allow a specific point determination of the magnitude and direction of the wind [1]. In addition, use of these measurements is a major obstacle in developing countries, which do not have a dense network of meteorological stations [2]. As a result, the most common way to characterize the wind spatially is to interpolate point-specific measurements.

However, this method has limited validity because, in many cases, interpolation can only be performed when the characteristics of the landscape are uniform and there is a dense distribution of wind speed measuring stations [3]. Therefore, a possible solution for the determination of the magnitude and direction of wind fields is utilization of different types of simulations, depending on the desired spatial resolution of the results, the number of in-situ measurements (meteorological stations), and the complexity of the landscape (topography and roughness of the surface), among others [4].

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In order to simulate wind field in a particular zone, the existing models are divided into two groups: Prognostic (Dynamic) and Diagnostic (Kinematics). The diagnostic models themselves follow two simulation attitudes: simplified solutions of steady state condition of equations of motion (such as linear techniques) and purposeful analysis of meteorological information considering the physical constrains (e.g., the mass consistence). Diagnostic models take into account by the available observations, topography of terrain as well as constraints such as conservation of mass. Since the diagnostic models interpolate observational data, they are critically dependent on the quality and the density of these observations. Despite their limitations, diagnostic models have been used extensively in air quality modeling studies. Prognostic meteorological models (in which primitive equations that govern the state of the atmosphere are solved), are being increasingly used to provide the meteorological inputs for air quality modeling studies. However, the problem of the full prognostic model is a formidable one and uncertainties in inputs as well as simplifying assumptions in the prognostic model formulations can cause predictions

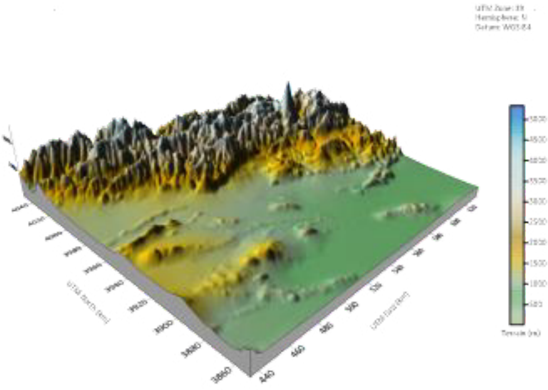

Fig. 1. The CALMET model domain with terrain elevations.

Table 1. Statistical verification for the CALMET and WRF simulation at Imam Khomeini airport meteorological monitoring site.

Model	Wind speed			Temp.		
	RMSE	MBE	IOA	MBE	MAE	IOA
WRF	1.56	-0.33	0.63	-0.4	1.56	0.81
CM(1)	1.34	-0.28	0.62	-0.23	1.13	0.88
CM(2)	1.29	-0.20	0.70	-0.19	0.95	0.88
CM(WRF)	1.33	-0.20	0.77	-0.24	0.91	0.90
CM(WRF + OBS)	0.91	-0.14	0.85	-0.08	0.48	0.95

which do not match actual observations. It is of course possible to incorporate observations into prognostic models through analysis/observational nudging, to improve the prediction of the certain variables. Also, the computational costs and required computer time needed to run the prognostic models are still high. One solution is to use a combination of both prognostic and diagnostic models, thereby complementing their individual advantages. The computational costs involved in running a coarse prognostic meteorological model and ingesting its output to a fine resolution diagnostic model simulation, are significantly lower than running a fully nested prognostic meteorological model with horizontal resolutions comparable to those of the diagnostic model. Ultimately the success of the coupled prognostic/diagnostic modeling approach would lie in its evaluation with actual observations [5, 6].

In recent years, the CALMET weather forecast model has had good performance in wind field simulations and pollution studies, especially in areas larger than 50 square kilometers; It also has the ability to run anywhere in the world for each user-specified modeling period, which indicates the high flexibility of this model [7]. As a result of the good flexibility of the CALMET model, over the past several years, multiple studies have been done on wind field simulations, using this model [1-7]. However, the ability of this model to perform wind field simulations using WRF weather forecast data and in complex topographic conditions has not been evaluated thoroughly. Therefore, in this research, we first simulate the meteorological parameters of the region using the WRF mesoscale model and then, by correlating this model with the CALMET weather forecast model, we determined the 3D wind field in the region. Some of the reasons behind doing the simulations of this research are to find the answer to the following questions, what is the difference between the results of the CALMET weather forecast model and the results of the WRF mesoscale model. What is the effect of the CALMET model on improving the predicted meteorological parameters by the WRF model? How can using realistic observational data and their combination with the predicted data in the CALMET model, improve the results? What is the effect of Using WRF's output parameters as upper air data for Air quality models? What is the effect of changing the setting of the affecting parameters of CALMET model simulation in a specified area?

2. RESEARCH METHOD

The selected area for the WRF model has a horizontal distance of 15 km in the latitude range of 26 to 41 degrees north and a longitude of 44 to 63 degrees east and runtime of the model was 126 hours and the first 6 hours were to model stabilization. This model was launched with Layman's micro-physics scheme and Goddard and RRTM schemas were used for short and long wavelengths, respectively. The Noah land surface model was used to calculate heat and moisture in the underlying layers of the soil and the MYJ schema was used to indicate the planetary boundary layer on the domain. The initial and boundary conditions of the meteorology required for the WRF model are derived from the FNL final analysis, stored in the NCEP/NCAR databases of the National Oceanic and Atmospheric Administration of the United States, with a six-hour time-step and a spatial-step of one degree. To extract the meteorological data, required by the CALMET model, 120 of the available parameters in the WRF's output of the CALWRF model, were used (Numerical Analysis Data WRF Data Processing Program). In Fig. 1, the topographic map and usage of the studied area, are presented.

3. RESULTS AND DISCUSSION

The results of the statistical evaluation, using the comparison of the measured and observed wind and temperature data of the weather station in Imam Khomeini airport, for the WRF data and the different stages of modeling by the CALMET model in the first layer of the model (10 meters above ground level) are presented in Table 1. As indicated in this table, the index values of the IOA agreement for the temperature and speed of wind in the meteorological evaluation of the WRF model, are in the range of 0.72-0.90 and 0-51.77, respectively. According to the results of the IOA index and other statistical indicators presented in Table 5, it is observed that the output of the WRF model is in accordance with the criteria, provided by the United States US Environmental Protection Agency. By comparing the CM(1) and CM(2) methods, it can be seen that ignoring the upper air data in the lower layers of the domain, for the extraction of wind field data by weighting these data, actually improves the output result of the wind field, in such a way that the mean value of the IOA index for wind speed in CM(2) increased to 0.8 in comparison with CM(1). Also observing the criteria stated by CM(2) and CM(1) indicates the acceptable accuracy of the output data of the CALMET model in producing the wind field in the specified region. It should be noted that due to the low density of main and upper air synoptic stations in the region, and using the data of only one station for modeling and taking into account the complex topographic conditions of the region and the fact that the accuracy of the flow models depends on the input data of the model, the improvement of 0.08 in the IOA index and little improvement of the MBE, MAE and RMSE parameters in CM(2) relative to CM(1), can be considered as a significant effect on the improvement of modeling conditions, considering the physical conditions of the CALMET model.

4. CONCLUSIONS

In this study, the feasibility and efficiency of using the output of the WRF mesoscale model as the input of the CALMET model in obtaining exact wind field for air quality examinations was studied. Initially, operation procedure, limitations and capabilities of the CALMET model were studied; then, correlation of the WRF meteorological numerical model with the CALMET weather forecast model to obtain a 3D wind field in the region is described in four different ways. Each of the four simulations that were used in this study (CM(1), CM(2), CM(WRF) and CM(WRF+OBS)) were compared with observation data from Imam Khomeini Airport's meteorological station, as well as with each other in the span of 5 days (5th to 10th of January, 2014). The four proposed statistical indicators by US Environmental Protection Agency (MBE, RMSE, MAE, and IOA) have been used to analyze the performance of the conducted simulations. The results of the four statistical indicators used in the analysis of the weather forecast modeling in this region, illustrate the precision of the WRF model in predicting the weather data in this area as well as the accuracy of the CALMET model in simulating the weather data of this area by matching the WRF data with the topographic and land-use data, that were used in this study. By comparing the CM(1) and CM(2) methods, it is obvious that in the case that the chosen area has a high density of upper-air and surface meteorological networks, the conditions of the wind field can greatly improve by changing the setting of CALMET wind field generation and by logically weighing the surface and upper-air data. However, in developing countries such as Iran, which do not have dense meteorological networks and upper air data are rarely measured at its meteorological stations, the use of large-scale WRF output data as the initial guess of the CALMET weather forecast model with small-scale and high resolution, is an attractive and useful way of producing an accurate wind field in that area. Also, considering the obtained results of the CM method (WRF+OBS), it would be clear that using a combination of surface meteorological data with WRF model data in simulating the wind field through the CALMET model, leads to the production of a more precise 3D model of this wind field. In general, the results of this study shows that combining meteorological surface data and the output data of WRF model, to simulate wind field through CALMET model, is a very efficient, effective and precise method of producing a 3D wind field, that can be considered the most important parameter in the air quality models in order to estimate the concentration of discharged pollutants from the sources and the way in which they are distributed in the atmosphere.

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