

The Numerical Simulating of Wind Energy Resources In China

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ABSTRACT: By using Canadian Wind Energy Simulating Toolkit (WEST), Chinese Wind Energy Atlas was created with a resolution of horizontally 5 km and vertically 10 m in this paper. Comparing with the observation data from 683 stations, results show that the simulation is much better at the low altitude areas in central and eastern China with a low average relative error (<20%), while presents unsatisfied at the complex terrain of the high-altitude, with a high average relative error over 60%. 11 stations impacted less by human activities were chosen in further study, the relative error is approximately under 12%. Our study presents a very similar result with the Solar and Wind Energy Resource Assessment project (SWERA) taken in charged by the United States Department of Energy's National Renewable Energy Laboratory (NREL) in Chinese Wind Energy Atlas Evaluation, only a difference of 2.4% between our research and their simulation in potential installed capacity dispersion. Thereby, WEST used in this paper shows a good ability in simulating the distribution of wind energy of China at low altitude in central and east China areas, while plays less satisfying in the western plateau. Both classification scheme and the parameter schemes in the atmosphere boundary-layer will be improved at the next step, therefore, it will suitable to assess the wind energy resources in China reasonably.

Keywords: Wind resource, Numerical simulation, WEST

1. INTRODUCTION

Since the 20th century, the world economy has developed rapidly and the energy demand doubles and redoubles, the energy industry develops on a large scale. The international community pays close attention to the environment, ecological problem that caused by mass use of fossil energy and nuclear energy, such as petroleum, coal, etc. The world has raised the upsurge of the renewable energy development. In the development and utilization of the renewable energy, wind energy is a kind of clean energy with the fastest developing speed. Wind-power electricity generation is the most ripest way to developing on a large scale and commercialized development prospect and have already become an important energy supplement in some countries. To choose the resource optimum farm location of wind is one of the essentials condition for wind-power electricity generation. The key for chosen the farm location is that really understand the wind energy resource state and its distribution and changing, analyze and look for suitable potential wind electric farm location, objective. Accurate wind energy resource assessment will bring a lot of help to large-scale wind electric farm construction.

In order to solve the restrictive problem of sparseness of observation stations and limited observation time period, the middle and small number value model developed fast. In this application farm, American and European countries have already developed several comparatively ripe assessment systems soft ware of the wind energy resources, e.g. WAsP [1] and MesoMap [2]. Denmark *RISø* national laboratory developed one tool software use for site

selection of analyze wind electric farm—WASP (Wind Atlas Analysis and Application Program). The core of software is one little yardstick linear wind farm diagnose mode, utilized examine wind materials to calculate regional wind resource around (slope of suitable comparatively smooth topography <0.03), but the error is relatively great in the complicated topography uses [3]. The MesoMap developed by the U.S. True Wind Solutions Company is an assessment system combined mesoscale numerical atmospheric simulation model (MASS) with mass-consistent wind flow model (Windmap). MASS is a non-hydrostatic numerical weather model, it is able to simulated many phenomena not captured in ordinary wind flow models, including mountain waves and channeling, convective winds, sea and lake breezes and downslope mountain winds. The MASS output is then used to drive Windmap, which normally operates at a scale of 100-1000 m. However, Mesomap requires massive calculating work and not good at simulating the nocturnal boundary-layer and only applicable under 50 m height.

A state-of-art wind mapping system, the Wind Energy Simulation Toolkit (WEST), was developed by the Meteorological Service of Canada (MSC) for the wind energy industry. In 2005, the China Meteorological Administration (CMA) and the Meteorological Service of Canada (MSC) have agreed to cooperate in wind resource simulation. Both sides will make the effort to improve WEST, and complete the wind energy atlas of China and the new atlas of Canada.

This paper will create the Chinese Wind Energy Atlas at a resolution of 5 kilometer. Through its validations, this paper will study how to improve and develop WEST for China wind resources assessment.

2. WIND ENERGY SIMULATION TOOLKIT

This method is based on a statistical-dynamical downscaling approach [4]. The basic assumption is that regional climate is associated with a distribution of basic large-scale weather situations and the local surface terrain situation. A set of basic weather situations is defined, using long-term global-dataset. Numerical simulations of these situations are performed by the Mesoscale Compressible Community Model (MC2) with high resolution terrain data to calculate the wind energy atlas [5].

2.1 Classification Scheme

For wind energy study, only the wind within the first hundred meters AGL (Above Ground Level) is of interest. The mid-latitudes surface wind is mainly influenced by the geostrophic wind, the stratification of the atmosphere and the surface parameters, like land use and roughness, and soil or sea surface temperature.

In this study, The NCEP/NCAR reanalysis data is chosen to use for the weather situations classification. The reanalysis data used in this study covers a period of 30 years (1971-2000) with a time sampling of every 6 hours. The dataset is in a latitude-longitude grid (2.5 degrees of grid spacing) at 17 pressure levels in vertical (from 1000 to 10 mb). The atmospheric state is defined at 4 nominated 'near-surface' heights above sea level (ASL): 0, 1500, 3000, and 5500 m, since only the near-surface wind is of interest. The respective pressures at these heights will be approximately 1000, 850, 700 and 500mb, so these values are used as nominated pressures. The geostrophic wind is then calculated at the 4

nominated heights using the interpolated pressure, temperature, and humidity. In this study, the weather situations are classified according to the associated geostrophic wind direction and speed at 0 m ASL, and the vertical shear of wind-speed between the sea level and 1500 m ASL. The geostrophic wind direction is classified into 16 sectors, and each sector is divided into 14 speed classes (with class limits as: 2, 4, 6, 8, 10, 12, 14, 16, 18, 22, 26, 30, and > 34 m/s). The vertical shear of the geostrophic wind (or wind-speed difference between 1500 and 0 m ASL) is also considered in the classification scheme. Each class of a sector and speed interval is then divided into two classes according to the sign (positive or negative) of shear, except for the smallest wind-speed interval. There is a maximum of 432 possible classes and the frequency of occurrence of each class.

2.2. Mesoscale Model

The Mesoscale Compressible Community Model (MC2) is used for mesoscale modelling within the simulation procedure. The control equation of MC2 is fully elastic compressible non-hydrostatic and limited area Euler equation [6], [7], [8]. Its numerical scheme is the semi-implicit semi-Lagrangian (SISL) time scheme and solution of the system. The physical processes parameterization contains planetary boundary layer based on turbulent kinetic energy, fully implicit vertical diffusion, stratified surface layer based on similarity theory, prediction of surface temperature over land (force-restore method), diurnal cycle with solar and infrared fluxes at ground modulated by diagnostic clouds, solar and infrared radiation schemes fully interactive with clouds, shallow convection parameterization ,

kuo-type deep convection scheme, grid-scale condensation in supersaturated layers [9].

To initialize the model, vertical profiles of temperature and geostrophic wind (at 4 levels: 0, 1500, 3000, 5500 m ASL) corresponding to each class are set at the centre of the model domain. They are interpolated to the model levels (28 levels) using a cubic interpolation up to 5500 m ASL. The initial condition for the rest of the grid points of the model is obtained by using a hydrostatic and geostrophic approximation. And then the three-dimensional atmospheric state is established and ready for the model integration. The model starts with this initial condition and with the lateral boundary conditions keep constant in time.

2.3 Statistical Module

The simulated results for each class are weighted with their occurrence frequency to build a database of statistics. As each mean is weighted by the frequency of geostrophic wind classes, it represents the wind climate for the entire analyzed period (30 years). There are 28 vertical levels in the model, unevenly distributed from the surface to 20 km ASL. To ensure a higher vertical resolution in the boundary layer, 10 of the 28 levels are set within the first 1.5 km AGL. The statistics can be calculated for any height in the surface region, by interpolating wind-speed to the target height from the model level closest to that height, with an assumption of a logarithmic profile of surface wind (near neutral stability condition).

3. MODELLING PROJECT

To produce the Chinese Wind Energy Atlas, we divided up the whole China into

53 domains for simulation. This study was set up at a grid spacing of 5 km to every domain. There are 175×175 grid-points and 28 vertical levels non-uniformly distributed from the surface to 20 km ASL (with 10 levels within the first 1.5 km). The first wind level is about 50 m AGL. The terrain information (elevation, land use, etc.) used in this mesoscale simulations is from the USGS 1 km database. Finally, China wind atlas is completed by merging the simulation results of the 53 domains.

4. RESULTS AND ANALYZE

4.1 Simulated Results

This paper use NCEP/NCAR reanalysis data covering a period of 30 years (1971-2000) with a time sampling of every 6 hours for the meteorology stations. By the MC2 simulation and statistics, the China wind atlas with the resolution of horizontally 5 km and vertically 10 m is completed (e.g. Fig. 1).

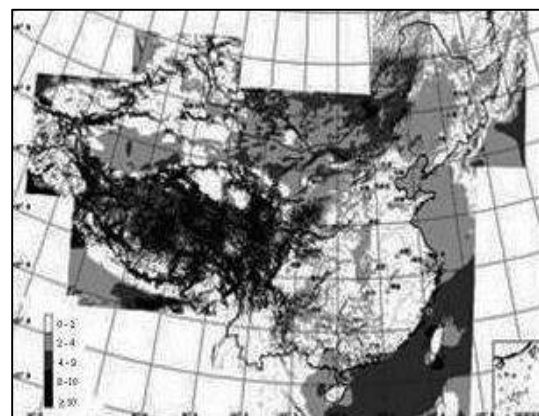


Fig.1: Mean wind-speed (m/s) in China produced by WEST

Figure 1 shows the mean wind-speed in China at 80 m height produced by WEST. It can be seen that the areas with high

wind-speed are the northern of Xinjiang, Inner Mongolia and the northwestward of Gansu province, where wind resources are rich. The following one is the southeast costal areas where the mean wind-speed is over 7m/s, especially in the coast of Zhejiang and Fujian province. In west of Heilongjiang, the east of Jilin, the north of Heibei, Liaotung peninsula and the southwest, the speed is high relatively. In addition, the wind power is weakened by thin air density in Tibetan Plateau even with a high wind speed. All the results are similar to the China atlas made by with the observed data from more than 600 meteorological stations.

4.2 Results Analyze

The simulated results are compared with the data at a height of 10 m AGL, obtained from 683 meteorological stations in China. The mean absolute difference between the observed and simulated sets of wind data is 0.95 m/s. The correlation coefficient is about 0.43 (e.g. Fig. 2).

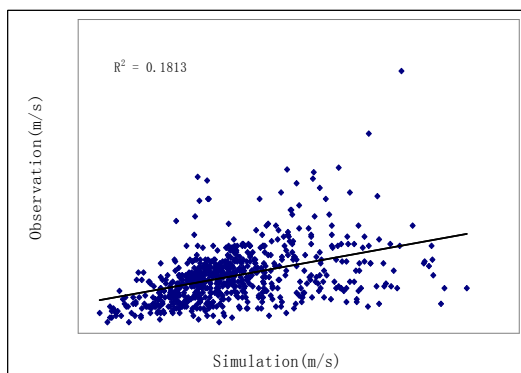


Fig.2: Correlation coefficient of the mean wind-speed between the simulations and observations

The number of stations which the relative error less than 20% is 239, it's almost one third of all the stations (e.g.

Fig.3). Among these stations, there are 148 stations with relative error less than 10%. The number of stations which the relative error larger than 60% is 222, it's also about one third of all the stations (e.g. Fig. 4). Among these stations, there are 144 stations

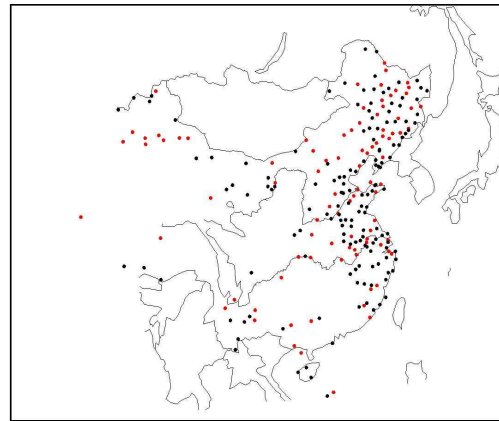


Fig.3: Stations which relative error less than 20%

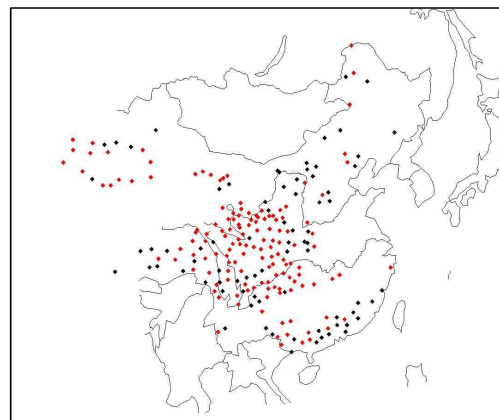


Fig.4: Stations which relative error larger than 60%

with relative error over 100%.

Figure 3 and Figure 4 show that the stations with satisfied simulation results are mostly located in the eastern and the costal area of China. In those areas, there are many extensive plain, with an averaged elevations are lower than 500 m ASL, such as Dongbei plain, Huabei plain, Yangzi plain. Stations

with large errors, on the other way, are located in the western of China, where have many extensive mountains, hills, and highlands cover plain, such as Qingzang plateau, Huangtu plateau, Yungui plateau, Tianshan mountains, Kunlun mountains and Qilian mountains. Especially in the north verge of Qingzang plateau, the result is not satisfied.

Since most meteorological observatories were disturbed, in varying degrees, by urbanization, the observation data show poor representation for wind energy evaluation. We analyzed observation data at 10m high from 11 stations (1971--2000) influenced little by human activities. By comparing the observed data of average wind speed with the simulation results both at 10m height, results show that, the mean relative error (RE) is about 12%(see Table I).

Table I: Comparing the simulation results (SIM) with observation data (OBS) from 11 stations (S) impacted less by human activities.

S	Height (m)	Average wind speed at 10 m		
		OBS (m/s)	SIM (m/s)	RE (%)
Ma	1770.4	4.4	4.4	0
Wu	3043.9	5.1	6.4	25
Da	7.3	3.3	3.4	3
Don	18.7	3.4	4.2	24
Lu	9.6	3.6	4.2	17
Xi	22.0	5.2	4.2	-19
Yan	5.0	4.4	3.7	-16
Xu	41.9	2.4	2.3	-4
Wei	19.3	3.5	3.4	-3
Hai	63.9	3.4	2.8	-18
Xia	37.7	3.2	3.4	6

The results indicated that the simulation ability is better in central and east China, especially in low altitude with flat plain, while performs poor in the high altitude with complex landform by using WEST. We think the uncertainty of WEST itself contribute mostly for poor simulation. The second reason is the urbanization may reduce the reliability of observation data from meteorological observatories. Thirdly, terrain affection is also needs to take consideration.

The high-resolution wind energy resource maps for specific regions of eastern China were created at the United States Department of Energy's National Renewable Energy Laboratory (NREL) as part of the Solar and Wind Energy Resource Assessment (SWERA) project [10]. NREL's Wind Resource Assessment and Mapping System (WRAMS) is a combination of analytical, numerical, and empirical methods using Geographic Information System (GIS) mapping tools and data sets.

The methods for converting the wind resource to wind electric potential (WEP) as follows: propose the practicable wind energy area is one place in which the annual wind power density (WPD) is over 300 W/m^2 at 50 m height, we can also call it moderate-to-excellent area. Thus the annual wind power density over 400 W/m^2 can be regarded as good-to-excellent area. Using a conservative assumption of 5 MW per km^2 , the potential installed capacity can be calculated by this way.

For better comparing with the results of wind energy evaluation in NREL, we also did not consider Xinjiang, Tibet, Qinghai, Yunnan, Taiwan in WEST as NREL did (see Table II). Seen from this table, the simulation results is similar to NREL, especially in areas in which the

annual wind power density over 300 W/m^2 , only 2.4% error exists in the contrast. Thus, we can say that the simulation by using WEST is as comparable as the NREL results combination of analytical, numerical, and empirical methods. Results show that simulation in WEST represent preferably different distribution of wind energy.

Table II: Comparing the WEST results with NREL results at 50m height.

Wind Power Density	Potential Wind Capacity	NREL	WEST
≥ 300 (W/m^2)	Area (km^2)	650,000	665,000
	WEP (MKW)	3,250	3,330
≥ 400 (W/m^2)	Area (km^2)	284,000	310,000
	WEP (MKW)	1,420	1,550

5. CONCLUSIONS AND DISCUSSIONS

5.1 Conclusions

I The Wind Energy Simulation Toolkit (WEST) has good ability to simulate the wind power distribution by comparing with observed result in mid-east China at low altitude areas, but plays less satisfying in western plateau of China where has the rich wind energy resources, so it's needed to modify for applying in China.

II WEST is suitable to simulate the distribution of wind energy resource with flat terrain and low-altitude, but the simulating ability is not very good in complex terrain and high-altitude, especially in mountain areas.

III WEST assumption is that the surface wind is mainly influenced by the large-scale pressure's dynamic effect comparing with thermodynamic effect. Climate situations states are classified according to the geostrophic wind direction and speed, and don't calculate the infection of thermodynamic effect. So that WEST simulated results are much better in plain area compare with plateau area. Because of the thermodynamic effect may be very important in highland and mountain areas, so the simulation base on the weather situation which classified only with dynamic effect may be produce large errors.

5.2 Discussions

Above all, both classification scheme and the parameter schemes in the atmosphere boundary-layer will be improved at the next step, therefore, it will suitable to assess the wind energy resources in China reasonably.

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