Study of wind characteristic in Tibet with numerical simulation

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Abstract: In order to analyze the model simulation results and studied the impact of the horizontal resolution in model during different weather process in complicated topography area in Tibet, the mean wind observation data from wind tower and high-resolution numerical model data were be used, the characteristics of the mean wind and the turbulent kinetic energy (TKE) in the near-surface boundary layer around the region of the wind tower point and comparison point were analyzed. The results showed that the mean wind observation data were a well consistency. With time variations, the mean value of ten minute wind speed were an upward trend over time during different strong wind weather systems. The air flow and the spatial distribution of TKE were consistent around the region of the wind tower point and comparison point. The air flowed from high elevation areas (mountain ridge) to the low elevation areas (mountain valley) during different resolution numerical model data. Comparative analysis of different resolutions simulation results, the higher-resolution simulation result showed more clear in the characteristics of the air flow. The correlation had increased considerably between the different times of the mean value of the ten minute wind speed or TKE on the vertical layers, as well as the bias was decreased.

1. Introduction

With the rapid economic growth and scientific development and people's living standard improving, the demand for precise meteorological forecast has rapid development. In particular, when the strong wind systems and other extreme weather events are occurred, a more accurate forecast is needed to guide the disaster prevention and hazard reduction work[1-2]. At the moment, the local small-scale wind simulation accuracy has not so exactly, the larger bias of simulation data has showed up in complex terrain or the area which difficult to deploy Observatory. Hence, the study has practical significance for the precise numerical simulation about strong wind systems, improved the forecast accuracy of the local area, as well as the disaster prevention and hazard reduction work [3].

The spatial distribution climatology in early process used terrain height and surface roughness to research in the statistics, but only get a better result on flat terrain or the same texture, the limitations
of the theory still great on the accuracy and the requirements of measurement accuracy had difficult to achieve unless the large amounts of observational data [4]. In particular, the surface boundary layer has a very complex underlying terrain, the influence of near-surface wind field is greatly, so as to difficult to get accurate information. Therefore, a lot of observation station and a large number of observational experiment need to be set up and ongoing maintenance in the complex underlying terrain, but it takes a lot of manpower and resources [5]. At the present time, the precise numerical simulated near-surface wind field data can achieve the purpose with a limited number of observatories, and reducing costs greatly. Especially, numerical methods can reflect its advantages on the case of complex underlying terrain. Li use numerical simulation to study wind energy resources in Jiangsu Province and show the spatial distribution of wind power[6]. Steven use numerical simulation to study local wind speed and wind direction, proving the simulation diagnostic tests can diagnose accurately, and the vertical wind speed can properly match the vertical profile data[7]. Xin use numerical simulation to study the standard deviation of wind direction and wind speed estimation method[8].

Extreme wind events are the key factors that need to be considered in demonstration wind project in different regions of China [5]. The key wind parameters determine the cost of the project and impact on the security of engineering structures seriously, and have attached great attention in modern and flexible structure engineering projects, distinguishing the reliability and representativeness wind data is the necessary groundwork on wind study scientifically[9]. As a result, this article is based on the mean wind observation data that the station is established in Tibet, focused on the result of numerical simulation around the region of the wind tower point and comparison point under the complex underlying terrain in Tibet, studied the characteristics of near-surface layer simulated wind data, discussed the different horizontal resolution in model whether have the impact on result analysis during different weather process in complicated topography area. Furthermore, results of this article expect to provide reference on the future scientific research in strong wind events under the complex underlying terrain.

2. Methods and Materials

2.1. Data and information

Observation tower is built in complicated topography area in Tibet near the river valley (Fig.1b), where the local electric power transmission is difficult. The latitude and longitude of the observation tower is 29.9623°N 94.7823°E, the elevation of the observation tower is 2652 m, located within the farm land at downwind areas along the river valley and the altitude of the tower is 123 m (Fig.1a). Numerical mode is using WRF model, driven by FNL (1°×1°) reanalysis data, which the time resolution is 6 h. There are 50 layers on the vertical direction within WRF model, up to 50 hPa on the top model layer and the triple nested grid is used. The time resolution of the output data from mode processing is 10 minutes, the output variable value are U, V and TKE in 16 height layers, and U, V in 10 m at near-surface layer. Comparison point is chosen near the observation tower at upwind areas along the river valley that the straight-line distance is about 1 km, and the type of underlying terrain is similar to the observation tower point.

The process of observational records in this Article is 30th Jan 2020 to 31st Jan 2020, 10th Mar 2020 to 11th Mar 2020, respectively. Meanwhile, the process of numerical simulation is carried out at the same time. Notably, in order to analyze the model simulation results and study the impact of the horizontal resolution by model, the first simulation horizontal resolution is set to 0.009°*0.009°, and the second simulation horizontal resolution is set to 0.0045°*0.0045°.

2.2. T test (statistic test)

If prob.< α, H₀ is rejected and H₁ is accepted, that is, there is significant influence between the independent variable on the dependent variable with = 0.05. If prob.> α, the result will be the opposite.
3. Results and discussion

3.1. Analysis of observation data

The wind speed changed during time series that observed by observation tower could be visible from figure 2, two weather process had a better consistency, the correlation coefficients was 0.8212 ($\alpha=0.05$) and there was an increasing trend. The $R^2$ of the 1st weather process was 0.0373, so the increase trend was not significant. The $R^2$ of the 2nd weather process was 0.2829 and the increase trend was significant ($\alpha=0.05$). The specific performance of the wind speed changes during time was: larger wind velocity changed during the daily, and smaller wind velocity changed during the night. From table 1, the wind speeds were increasing in the period from 10:00 am to 16:00 pm 30th Jan, the maximum wind speed was 12.26 m/s(Table 1), and decreasing in the period from 16:00 pm 30th Jan to 1:00 am 31st Jan. Followed, the wind speed increased again in the period from 11:00 am to 16:00 pm 31st Jan, the maximum wind speed was 11.47 m/s, then decreasing in the period after 16:00 pm 31st Jan. In the second process, the wind speeds increased in the period from 12:00 am to 16:00 pm 10th Mar, the maximum wind speed was 11.06 m/s, and then decreasing in the period from 16:30 pm to 21:00 pm10th Mar. Followed, the wind speeds increased again in the period from 11:00 am to 15:10 pm 11th Mar, the maximum wind speed was 11.83 m/s, then decreasing in the period after 15:10 pm 11th Mar.

Table.1 Maximum wind speed of two weather process

| Data                        | First       | Second      |
|-----------------------------|-------------|-------------|
| Time                        | 30th Jan    | 31st Jan    | 10th Mar | 11th Mar |
| Wind speed (m/s)            | 12.26       | 11.47       | 11.06    | 11.83    |

3.2. Analysis of simulation data

In order to analyzed the model simulation results and studied the impact of the horizontal resolution in model during different weather process in complicated topography area in Tibet, this article chose the moment of maximum wind speed during different weather process, the time point were 16:00 30th Jan and 16:00 31st Jan, as well as 16:30 10th Mar and 15:10 11th Mar. The wind speed, wind direction, the space distribution of the turbulent kinetic energy(TKE) were analyzed.

Fig.1 Observation tower in Tibet (a) and the terrain height of model (b) (★ comparison point, ▲ observation tower point)
From figure 3, the air flowed from northeast to southwest in the north region of observation tower point and comparison point at 16:00 30th Jan, and flowed from southwest to northeast in the south region of observation tower point and comparison point, it met at the space of observation tower point and comparison point and then decreased. It showed that the air flowed from high elevation air (mountain ridge) to the low elevation areas (mountain valley). At 16:00 31st Jan, the air flow direction was consistent with the previous time. From the spatial distribution of wind speed in different height layers (Figure illustration), the air flow direction was also consistent that flowed from high elevation areas to the low elevation areas. Furthermore, the wind speed data on the vertical height layers in observation tower point and comparison point were analyzed (Table 2), the correlation coefficient of vertical variation of wind speed was 0.8543 (α=0.05), the mean bias was 1.92 m/s at 16:00 30th Jan. The correlation coefficient was 0.5024 (α=0.05) and the mean bias was 1.56 m/s at 16:00 31st Jan. It showed that the change trends were more consistent in vertical direction between observation tower point and comparison point at the same time. The space distribution of turbulent kinetic energy (TKE) could be visible from figure 4a-b, the two moment space distribution of TKE were more consistent, the value was high-low-high distribution from southwest to northeast. The correlation coefficient of vertical variation of TKE was 0.9944 (α=0.05) and the mean bias was 0.11 m²/s² at 16:00 30th Jan (Table 3). The correlation coefficient was 0.9543 (α=0.05) and the mean bias was 0.08 m²/s² at 16:00 31st Jan. It also showed that the change trends were more consistent.

Table 2 The different height of wind speed in the time of maximum wind speed during the first simulation process

| Location | Comparison Point (m/s) | Wind Tower Point (m/s) | Bias (m/s) |
|----------|------------------------|------------------------|------------|
| 30th Jan | 16:00                  | 31st Jan               | 16:00      |
| 10       | 0.69                   | 2.22                   | 1.53       |
| 26       | 0.75                   | 2.53                   | 1.78       |
| 91       | 2.56                   | 1.53                   | -1.73      |
| 179      | 5.01                   | 3.08                   | -2.41      |
| 291      | 6.69                   | 4.89                   | -2.48      |
| 429      | 7.81                   | 6.11                   | -2.29      |

Table 3 The different height of Turbulence Kinetic Energy in the time of maximum wind speed during the first simulation process

| Location | Comparison Point (m²/s²) | Wind Tower Point (m²/s²) | Bias (m²/s²) |
|----------|-------------------------|--------------------------|--------------|
| 30th Jan | 16:00                   | 31st Jan                 | 16:00        |
| 26       | 0.34                    | 0.37                     | 0.01         |
| 91       | 1.02                    | 0.77                     | -0.29        |
| 179      | 0.93                    | 0.83                     | -0.22        |
| 291      | 0.61                    | 0.55                     | -0.09        |
| 429      | 0.35                    | 0.32                     | -0.03        |

Fig.3 The space distribution of ten minute mean wind speed (16:00 30th Jan (a) and 16:00 31st Jan (b))
It could be visible from the space distribution wind speed and TKE simulation data at 16:30 10th Mar and 15:10 11th Mar during the second weather process. It showed that the air also flowed from high elevation air (mountain ridge) to the low elevation areas (mountain valley). The correlation coefficient calculated by vertical variation of wind speed between observation tower point and comparison point was 0.9050 ($\alpha=0.05$), the mean bias was 0.08 m/s at 16:30 10th Mar (Table 4). The correlation coefficient was 0.9757 ($\alpha=0.05$), the mean bias was 0.05 m/s at 15:10 11th Mar. The two moment space distribution of TKE were more consistent, the value was also high-low-high distribution from southwest to northeast (Figure illustration). The correlation coefficient of vertical variation of TKE between observation tower point and comparison point was 0.9999 ($\alpha=0.05$), the mean bias was 0.06 m$^2$/s$^2$ at 16:30 10th Mar (Table 5), the correlation coefficient was 0.9994 ($\alpha=0.05$) and the mean bias was 0.06 m$^2$/s$^2$ at 15:10 11th Mar.

These results indicate that the simulation data which the air flowed and the space distribution of TKE were consistent in the moment of maximum wind speed during first and second weather process in observation tower point and comparison point, the air flowed from high elevation areas to the low elevation areas. But comparative analysis of different resolutions simulation results, the higher-resolution simulation result showed clearer in the characteristics of the air flow, the correlation had increased considerably between the different times of the mean value of the ten minute wind speed or TKE on the vertical layers, as well as the bias was decreased.

Table 4 The different height of wind speed in the time of maximum wind speed during the second simulation process

| location layers(m) | Comparison Point (m/s) | Wind Tower Point (m/s) | Bias (m/s) |
|--------------------|------------------------|------------------------|-------------|
|                    | 10th Mar 16:30 | 11th Mar 15:10 | 10th Mar 16:30 | 11th Mar 15:10 | 10th Mar 16:30 | 11th Mar 15:10 |
| 10                 | 1.20          | 0.90          | 1.16          | 0.93          | -0.04          | 0.03          |
| 26                 | 1.37          | 1.00          | 1.38          | 1.07          | 0.01           | 0.07          |
| 91                 | 1.58          | 1.14          | 1.58          | 1.09          | 0              | -0.05         |
| 179                | 1.70          | 1.08          | 1.74          | 1.01          | 0.04           | -0.07         |
| 291                | 1.55          | 0.80          | 1.70          | 0.82          | 0.15           | 0.02          |
| 429                | 0.99          | 0.48          | 1.25          | 0.59          | 0.26           | 0.11          |

Table 5 The different height of Turbulence Kinetic Energy in the time of maximum wind speed during the second simulation process

| location layers(m) | Comparison Point (m$^2$/s$^2$) | Wind Tower Point (m$^2$/s$^2$) | Bias (m$^2$/s$^2$) |
|--------------------|-------------------------------|-------------------------------|---------------------|
|                    | 10th Mar 16:30 | 11th Mar 15:10 | 10th Mar 16:30 | 11th Mar 15:10 | 10th Mar 16:30 | 11th Mar 15:10 |
| 26                 | 0.029          | 0.018          | 0.052          | 0.040          | 0.023          | 0.022          |
| 91                 | 0.013          | 0.009          | 0.023          | 0.020          | 0.010          | 0.011          |
| 179                | 0.004          | 0.003          | 0.007          | 0.007          | 0.003          | 0.004          |
| 291                | 0.001          | 0.001          | 0.001          | 0.002          | 0.0          | 0.001          |
| 429                | 0.0003         | 0.001          | 0.0003         | 0.001          | 0              | 0              |

Fig.4 The space distribution of TKE in 179 m layer (16:00 30th Jan (a) and 16:00 31st Jan (b))
4. Conclusion

1) The wind speed changed during time series that observed by observation tower during two weather process had a better consistency. There were increasing trend during two weather process. The specific performance of the wind speed changes during time series was: larger wind velocity changed during the daily, and smaller wind velocity changed during the night.

2) The air flowed and the space distribution of TKE simulation data were consistent in the moment of maximum wind speed during first and second weather simulation process in observation tower point and comparison point, the air flowed from high elevation areas (mountain ridge) to the low elevation areas (mountain valley).

3) Comparative analysis of different resolutions simulation results, the higher-resolution simulation result showed clearer in the characteristics of the air flow, the correlation had increased considerably between the different times of the mean value of the ten minute wind speed or TKE on the vertical layers, as well as the bias was decreased.

The data that high-resolution numerical model simulated were analyzed in this article, the advantages of using numerical models were reflected on the extremely complex terrain at high-elevation conditions where the lack of observatories in Tibet. The precise numerical simulated near-surface wind field data could achieve the purpose with a limited number of observatories. The method of this article will provide reference on the future scientific research in Tibet.

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