Wind characteristic in the complex underlying terrain as studied with CALMET system

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Abstract: In the present study, the wind data during two synoptic processes observed by the surface wind tower in the Tibetan Plateau and the high spatial resolution model data simulated by CALMET were be evaluated, the horizontal and vertical distribution characteristic of the model wind data around the region of the wind tower point and the reference point were be analysed. Results showed that the wind observation data during the two processes in the near-surface boundary were a well consistency. The horizontal distribution of the wind fields were consistent at the moment of the maximum wind speed during the two processes. The trend of the ten minute mean wind speed were upward with time variations. The air was flowed from the mountain ridge to the mountain valley over the complex region. The vertical distribution of the wind speed had more relevant that the correlation coefficient w ere 0.6811 (α=0.05) in the observation tower point and 0.8304 (α=0.05) in the reference point between 16:00 pm Jan 30th and 16:00 pm Jan 31st. The advantages of using the advanced numerical models will be reflected over the extremely complex underlying terrain where the lack of observation stations.

1. Introduction

With the scientific progress, the demand for fining meteorological forecast has rapid growth in recent years. Especially, when the extreme weather systems are occurred, a more accurate model forecast is needed to guide the disaster prevention and hazard reduction work[1-2]. At present, the local downscaling wind prediction accuracy has not so exactly, the larger deviation of model data has showed up in complex underlying terrain or the area which difficult to deploy surface weather stations. These applications require fine-scale, near-surface wind predictions in regions where rugged terrain have a significant effect on the local wind field[3].Therefore, it has practical significance for study the fining numerical simulation during the extreme wind systems, improved the local downscaling wind prediction accuracy[4].
The horizontal and vertical distribution climatology in early study got a better result on flat terrain or the same underlying texture that used terrain height and surface roughness in the statistics, the requirements of measurement accuracy and the current theory had still a significant gap, and relied on the large amounts of observation data\textsuperscript{[5]}. Especially, the enhanced surface underlying roughness altered the flow field over spatial scales, terrain effects such as wind speed-up over ridges, flow channelling in valleys, flow separation around terrain obstacles\textsuperscript{[3]}, so it was difficult to give accurate advice. Hence, a large number of observatories and observational experiment need to be established and sustaining supported in rugged terrain, but it had taken lots of manpower and resources\textsuperscript{[6]}. So far, the refining near-surface wind field model data can achieve the purpose without a large number of observation stations, and decreasing the cost of spending greatly. In particular, these output products of numerical model had its advantages over the complex terrain conditions. Some researchers take advantage of numerical simulation to study wind energy resources and show the horizontal and vertical distribution of wind power\textsuperscript{[7]}, and the vertical wind speed can properly match the vertical profile data\textsuperscript{[8]}. The standard deviation of wind direction and wind speed estimation method using numerical model\textsuperscript{[9]}. Some researchers use the GRAPES model to study the distribution and diurnal variation of wind over south China\textsuperscript{[10]}.

The key factor in demonstration wind project is extreme wind weather event, and needed to be considered in different regions of China\textsuperscript{[4]}. The cost of the project and the impact of the engineering security structures is the key wind parameters, and the modern and flexible structure engineering projects have attached great attention to the parameters. The necessary groundwork on wind characteristic research is distinguished the reliability and representativeness wind data scientifically\textsuperscript{[11]}. Therefore, this paper is based on the wind observation data in the Tibetan Plateau. we investigate the ability of wind model for downscaling near-surface wind predictions from CALMET models, focused on the numerical simulation data under the complex terrain around the region that the wind tower point and the reference point are exist, studied the near-surface layer wind characteristics, discussed the vertical distribution of wind at the wind tower point and the reference point during two synoptic processes.

2. Methods and Materials

2.1. Data and information

The observation tower is built in the Tibetan Plateau near the river valley (Figure 1). The observation tower elevation is 2652 m, it located at the farm land along the river valley, and the observation tower altitude is 123 m.

The CALMET model is used and driven by WRF model output products, which the time resolution is 10 minute. There are 23 layers on the vertical direction within CALMET model, up to 3450 m on the top model layer. The time resolution from CALMET model processing is 10 minute, the output products are U, V and have 23 vertical layers. The reference point is chosen near the observation tower grid at upwind area along the river valley that the straight-line distance is about 1 km, and the type of the underlying terrain is similar to the observation tower point.

The process of observational records in this paper is from Jan 30\textsuperscript{th} 2020 to Jan 31\textsuperscript{st} 2020, and from Mar 10\textsuperscript{th} 2020 to Mar 11\textsuperscript{st} 2020, respectively. The WRF and CALMET model are carried out at the same period.

2.2. Statistical analysis

Correlation coefficients were evaluated using Student’s t-test. The 95% confidence intervals were calculated for the t distributions, unless otherwise noted.
3. Results and discussion

3.1. Analysis of observation data
Visible from figure 2, the wind observation data changed with time variations, the wind speed during the two processes in the near-surface boundary were a well consistency. The correlation coefficients was 0.8212 ($\alpha=0.05$) and the trend of the ten minute mean wind speed was upward. The wind velocity changed greatly in the day time, and changed smoothly in the night time. In the first process, the wind speeds had two peaks from Jan 30th to Jan 31st, the one wind speed was 12.26 m/s, and the other wind speed was 11.47 m/s. In the second process, the wind speeds also had two peaks from Mar 10th to Mar 11st, the one wind speed was 11.06 m/s, and the other wind speed was 11.83 m/s.

3.2. Analysis of simulation data
CALMET model simulation data have been analyzed and the vertical distribution between the observation tower point and the reference point during the two processes in the complex underlying area of the Tibetan Plateau, this article choose the moment of the maximum wind speed during the two processes to discuss, the time points were 16:00 pm Jan 30th and 16:00 pm Jan 31st, as well as 16:30 pm Mar 10th and 15:10 pm Mar 11st. The horizontal and vertical distribution of wind field were analyzed.
Figure. 3. The horizontal distribution of the wind field in 10 m layer ((a)16:00 pm Jan 30th and (b)16:10 pm Mar 10th)

Visible from figure 3a, the air was flowed from southwest to northeast in the south region and flowed from northeast to southwest in the north region of the observation tower point and the reference point at 16:00 pm Jan 30th. The air met between the area of the observation tower point and the reference point, and then the wind speed decreased. It showed that the air was flowed from the mountain ridge to the mountain valley. At 16:00 pm Jan 31st, the air flow direction was consistent. Visible from figure 3b, the horizontal distribution of the wind speed at 16:30 pm Mar 10th and 15:10 pm Mar 11th was consistent with the first weather process.

The above analysis showed that the horizontal distribution of the wind field simulated by CALMET model were consistent at the moment of the maximum wind speed during the two processes.

Visible from the vertical distribution of the wind speed in the observation tower point and the reference point at different height layers (Figure 4a). the wind speed increased from 10 m to 30 m layer in the observation tower point at 16:00 pm Jan 30th, and decreased from 40 m to 100 m, and then increased up to 500 m. Likewise, in the observation tower point and the reference point at 16:00 pm Jan 31st, the change trends were more consistent in the vertical direction at the time of 16:00 pm Jan 30th. In the reference point at 16:00 pm Jan 30th, the change trend was decreased up to 50 m and then increased up to 500 m. Figure 4b shows that the change trends of the wind speed were increased and then decreased both in the observation tower point and the reference point at 16:30 pm Mar 10th and 15:10 pm Mar 11th.

Table 1. The vertical statistical parameter of the wind speed at the time of the maximum wind speed between the observation tower point and the reference point during the first simulation process

| Parameters          | Date       | Value  |
|---------------------|------------|--------|
| Bias (m/s)          | 16:00 pm Jan 30th | -0.81  |
|                     | 16:00 pm Jan 31st | -0.48  |
| Mean absolute bias (m/s) | 16:00 pm Jan 30th | 1.99   |
|                     | 16:00 pm Jan 31st | 1.33   |
| Correlation Coefficient | 16:00 pm Jan 30th | 0.3754 |
|                     | 16:00 pm Jan 31st | 0.2180 |
Table 2. The vertical statistical parameter of the wind speed at the time of the maximum wind speed between the observation tower point and the reference point during the second simulation process

| Parameters                  | Date         | Value  |
|-----------------------------|--------------|--------|
| Bias (m/s)                  | 16:30 pm Mar 10th | 0.39   |
|                             | 15:10 pm Mar 11th | 0.45   |
| Mean absolute bias (m/s)    | 16:30 pm Mar 10th | 0.39   |
|                             | 15:10 pm Mar 11th | 0.45   |
| Correlation Coefficient     | 16:30 pm Mar 10th | 0.8242 |
|                             | 15:10 pm Mar 11th | 0.0987 |

The vertical statistical parameter of the wind speed at the time of the maximum wind speed between the observation tower point and the reference point at 16:00 pm Jan 30th and 16:00 pm Jan 31st were calculated (Table 1), the bias were -0.81 m/s and -0.48 m/s, the mean absolute bias were 1.99 m/s and 1.31 m/s, the correlation coefficient were 0.3754 and 0.2180. Furthermore, the correlation of the vertical distribution of the wind speed in different times were investigated, the correlation coefficient were 0.6811(α=0.05) in observation tower point and 0.8304 (α=0.05) in the reference point between 16:00 pm Jan 30th and 16:00 pm Jan 31st. It showed that the vertical distribution of the wind speed had more relevant in the observation tower point or the reference point between 16:00 pm Jan 30th and 16:00 pm Jan 31st, but had less relevant between the observation tower point and the reference point either at 16:00 pm Jan 30th or 16:00 pm Jan 31st.

Figure 4. The vertical distribution of wind speed (a)16:00 pm Jan 30th blue solid line(the observation tower point) and blue dashed line(the reference point),16:00 pm Jan 31st red solid line(the observation tower point) and red dashed line(the reference point); (b)16:30 pm Mar 10th blue solid line (the observation tower point) and blue dashed line (the reference point),15:10 pm Mar 11th red solid line (the observation tower point) and red dashed line (the reference point)
The vertical statistical parameter of the wind speed at the time of the maximum wind speed between the observation tower point and the reference point at 16:30 pm Mar 10th and 15:10 pm Mar 11th were calculated (Table 2), the bias were 0.39 m/s and 0.45 m/s, the mean absolute bias were 0.39 m/s and 0.45 m/s, the correlation coefficient were 0.8242 (α=0.05) and 0.0988. It showed that the wind speed which appeared the whole layers from 10 m to 500 m in the observation tower point was greater than that in the reference point between 16:30 pm Mar 10th and 15:10 pm Mar 11th. Furthermore, the correlation of the vertical distribution of the wind speed in different times were also investigated, the correlation coefficient were 0.9484 (α=0.05) in the observation tower point and 0.1755 in the reference point. It showed that the vertical distribution of the wind speed had more relevant in the observation tower point between 16:30 pm Mar 10th and 15:10 pm Mar 11th, or between the observation tower point and the reference point at 16:30 pm Mar 10th, but had less relevant between the observation tower point and the reference point 15:10 pm Mar 11th, or in the reference point.

The results above indicate that the model data which the horizontal distribution of the wind field were consistent at the moment of the maximum wind speed during the two weather processes, the air was flowed from the mountain ridge to the mountain valley. the vertical distribution of the wind speed had more relevant in the observation tower point or the reference point between 16:00 pm Jan 30th and 16:00 pm Jan 31st, had more relevant in the observation tower point between 16:30 pm Mar 10th and 15:10 pm Mar 11th, or had more relevant between the observation tower point and the reference point at 16:30 pm Mar 10th. But the vertical distribution of the wind speed had less relevant between the observation tower point and the reference point at 15:10 pm Mar 11th, or in the reference point, and had less relevant between the observation tower point and the reference point either at 16:00 pm Jan 30th or 16:00 pm Jan 31st.

4. Conclusion

1) The wind observation data changed with time variations, the wind speed during the two processes in the near-surface boundary were a well consistency. The trend of the ten minute mean wind speed during the two processes were upward. The wind velocity changed greatly in the day time and changed smoothly in the night time.

2) The simulation data which the horizontal distribution of the wind field were consistent at the moment of the maximum wind speed during the two processes, the air was flowed from the mountain ridge to the mountain valley.

3) The vertical distribution of the wind speed had more relevant in the observation tower point or the reference point between 16:30 pm Mar 10th and 16:00 pm Jan 31st, in the observation tower point between 16:30 pm Mar 10th and 15:10 pm Mar 11th, and between the observation tower point and the reference point at 16:30 pm Mar 10th. The vertical distribution of the wind speed had less relevant between the observation tower point and the reference point at 15:10 pm Mar 11th, or in the reference point, as well as had less relevant between the observation tower point and the reference point either at 16:00 pm Jan 30th or 16:00 pm Jan 31st.

This study constitutes evaluation of CALMET model at high spatial resolution and complex terrain in the Tibetan Plateau especially under extreme wind events. The advantages of using the advanced numerical models will be reflected over the extremely complex underlying terrain where the lack of observation stations. The fining near-surface wind field model data can achieve the purpose without a large number of observation stations. This paper will provide reference on the future scientific research in the Tibetan Plateau.

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