Original Research Article

Climatologies of mean wind in the Tibetan Plateau as revealed from a state-of-the-art global atmospheric reanalysis

Yongbin Li[1], Fangyong Xiao[1], Chao Liu[2], Gui La[2], Ciren Pingcuo[1]

1 State Grid Xizang Electric Power Co., Ltd, Xizang, China, 850000

2 Electric Power Research Institute of State Grid Xizang Electric Power Co., Ltd, Xizang, China, 850000

Abstract: This study investigates the mean wind speed characteristics over the Tibetan Plateau using ERA5 reanalysis data from 2014 to 2023. The analysis reveals significant spatial and seasonal variability in wind speeds, driven by the interaction of large-scale atmospheric circulations, particularly the westerly jet stream and the Asian summer monsoon, with the plateau's complex topography. The highest mean wind speeds, exceeding 4.5 m/s, are observed in the northern and central plateau, where the westerlies dominate, especially during the winter and early spring. In contrast, the southern and southwestern regions, shielded by the Himalayan range, experience much lower wind speeds, typically below 2.0 m/s, largely due to the monsoon's influence. These seasonal variations highlight the importance of understanding wind dynamics for renewable energy development and regional climate modeling. The study provides valuable insights for optimizing wind power generation and improving climate simulations in this key region.

Keywords: Tibetan Plateau; Mean wind speed; ERA5 reanalysis

1. Introduction

The Tibetan Plateau, often referred to as the "Roof of the World," is a vast and elevated landmass that significantly influences both regional and global climate systems. Its unique geographical and topographical features, with an average elevation exceeding 4,500 meters, make it a critical area for studying atmospheric circulation patterns. Wind speed, as a fundamental meteorological variable, plays a vital role in regulating the plateau's climate dynamics, influencing surface energy exchanges, moisture transport, and the formation of clouds. However, despite its importance, the spatial and temporal characteristics of wind speeds over the Tibetan Plateau remain relatively understudied, especially when compared to other climatic variables like temperature and precipitation.

Mean wind speed analysis is crucial for understanding the general behavior of atmospheric flows across the plateau, which in turn affects various natural processes and human activities. For instance, consistent wind patterns can influence local weather conditions, air quality, and energy generation potential.[1-4] In particular, the assessment of wind energy resources has gained attention in recent years, as many high-altitude areas of the Tibetan Plateau are considered promising sites for renewable energy development. Furthermore, understanding the seasonal variability of wind speeds is essential for improving weather forecasting and climate modeling, particularly in regions characterized by extreme topographical variation.[5,6]

This study aims to address the knowledge gap by providing a detailed analysis of mean wind speed characteristics over the Tibetan Plateau using ERA5 reanalysis data for the period 2014 to 2023. The ERA5 dataset offers high spatial and temporal resolution, making it an ideal tool for investigating wind speed patterns over this complex terrain. Specifically, the study will examine the spatial distribution and seasonal variability of mean wind speeds, shedding light on the dominant atmospheric processes that shape wind patterns across the plateau. The insights gained from this analysis will also have practical implications for renewable energy planning and the development of more accurate regional climate models.

2. Data and Methodology

This study utilizes the ERA5 reanalysis dataset, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). ERA5 offers a comprehensive, global atmospheric reanalysis dataset, providing hourly estimates of a wide range of atmospheric, land, and oceanic variables. For this analysis, we focus on the 10-meter height wind speed data, derived from the U and V wind components (representing east-west and north-south wind directions, respectively), which are combined to calculate the overall wind speed magnitude.

The Tibetan Plateau is located in southwestern China and spans approximately 2.5 million square kilometers, making it the world's largest and highest plateau. With an average elevation exceeding 4,500 meters, the plateau has a complex topography, including vast plains, mountain ranges (such as the Himalayas), and numerous valleys. These geographical features play a significant role in shaping regional wind patterns, as they interact with large-scale atmospheric systems like the westerly jet stream and the Asian monsoon. The plateau's topographic variation influences the intensity and direction of wind flows, leading to significant spatial variability in wind speeds. This study focuses on capturing these variations using ERA5 data to better understand the wind dynamics across the plateau.

3. Results

The spatial distribution of the mean wind speed over the Tibetan Plateau from 2014 to 2023 reveals considerable variability across different regions, primarily shaped by the plateau's complex topography and the influence of large-scale atmospheric circulations.

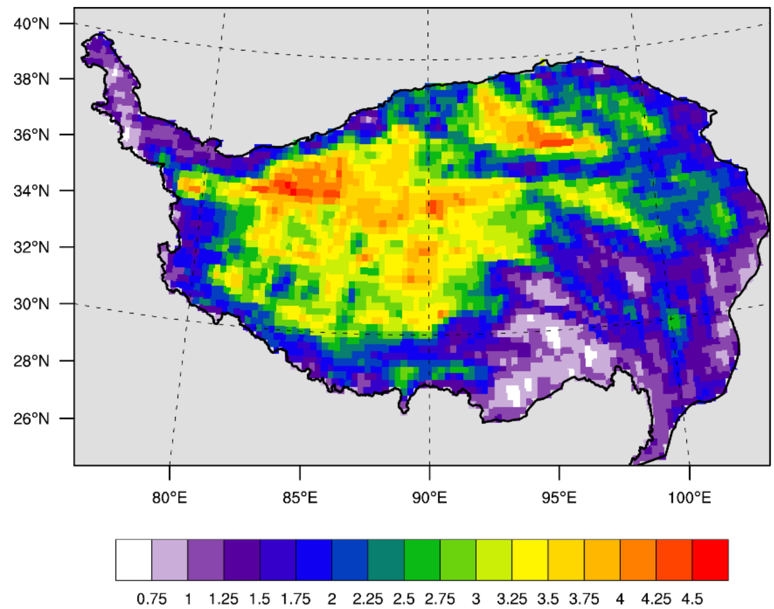

Figure 1. The mean annual wind speed over the Tibetan Plateau during 2014-2023 (units: m/s).

Figure 1 shows that the northern and central parts of the Tibetan Plateau, particularly areas between 33°N and 36°N, experience the highest mean wind speeds, with values often exceeding 4.5 m/s. These regions are generally more exposed to the westerly jet stream, which is the dominant atmospheric circulation in this area, especially during the winter and spring months. The relatively flat terrain at high altitudes in these areas allows for less disruption of wind flows, resulting in stronger and more consistent wind patterns.

The spatial patterns of mean wind speeds across the plateau align with the region's topographical features and atmospheric dynamics. High wind speeds in the northern and central plateau can be attributed to the dominance of large-scale wind systems like the westerly jet stream, while low wind speeds in the south and southwest are largely a result of the Himalayan barrier and monsoonal effects. This spatial distribution of mean wind speeds provides valuable insights into how the plateau's unique geography interacts with atmospheric circulations, influencing local weather conditions and broader climate dynamics.

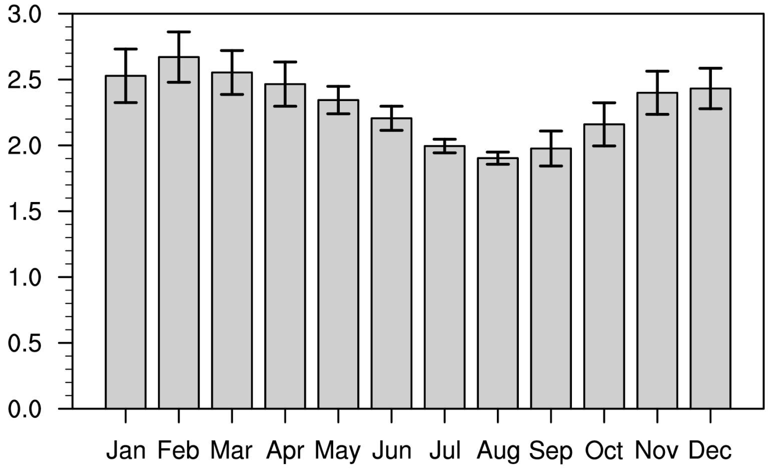

Figure 2. The monthly mean wind speed over the Tibetan Plateau during 2014-2023 (units: m/s). The vertical lines on each bar indicate the interannual variability.

Figure 2 illustrates the monthly mean wind speed over the Tibetan Plateau, averaged across the region for each month from January to December. The wind speeds exhibit a clear seasonal pattern, with the highest mean wind speeds occurring during the winter and early spring months. In these months, wind speeds range between 2.5 and 2.7 m/s, with February experiencing the highest wind speed of approximately 2.7 m/s. The elevated wind speeds during this period are likely influenced by the strong winter westerly jet stream, which is more active over the Tibetan Plateau due to the seasonal pressure gradient between the plateau and surrounding regions. The wind speeds gradually decrease from May to August, with the lowest values occurring in July and August, where wind speeds drop to around 1.9 m/s. The interannual variability is particularly pronounced during the winter and early spring months. These variations could be linked to fluctuations in large-scale atmospheric circulation patterns, such as the strength of the westerlies or shifts in the jet stream.

4. Conclusion and discussion

This study provides a detailed analysis of the mean wind speed characteristics over the Tibetan Plateau using ERA5 reanalysis data from 2014 to 2023. The findings highlight significant spatial and seasonal variability in wind speeds across the plateau, driven by the interaction between large-scale atmospheric circulations and the region's complex topography.

The northern and central regions of the Tibetan Plateau exhibit the highest mean wind speeds, often exceeding 4.5 m/s, primarily due to the influence of the westerly jet stream. In contrast, the southern and southwestern regions, particularly near the Himalayas, experience much lower wind speeds, typically below 2.0 m/s, due to the topographic barrier of the mountain range and the stabilizing effect of the Asian summer monsoon.

Wind speeds are highest during winter and early spring (December to April), when the westerly jet stream is strongest, and lowest during the summer months (July and August), when the Asian summer monsoon brings more stable atmospheric conditions. This seasonal pattern is evident across most of the plateau, with wind speeds in the northern regions remaining higher year-round compared to the southern plateau.

The results of this study underline the critical role of atmospheric circulation and topography in shaping wind patterns over the Tibetan Plateau. The westerly jet stream, which dominates the plateau during the winter and spring months, is a key driver of high wind speeds, particularly in the northern and central regions. The plateau's relatively flat terrain in these areas allows for the free flow of winds, leading to consistently higher wind speeds.

In contrast, the southern plateau, shielded by the Himalayas, experiences significantly lower wind speeds due to the barrier effect of the mountain range. Additionally, the influence of the Asian summer monsoon further reduces wind speeds in the southern plateau during the warm months, as moist, stable air masses suppress the intensity of wind systems. The interplay between these large-scale atmospheric systems and local topographical features creates a highly varied wind regime across the plateau.

While ERA5 reanalysis data provide high-resolution insights into wind speeds over the Tibetan Plateau, there are limitations to consider. The 31-kilometer spatial resolution of ERA5 may not fully capture the small-scale wind patterns influenced by the plateau's complex topography, particularly in regions with steep mountain slopes or narrow valleys. Future studies could benefit from the use of higher-resolution models or ground-based observations to more accurately represent these local wind phenomena.

Additionally, this study focuses on mean wind speeds and does not delve into the characteristics of extreme wind events, which are also important for understanding the region's climate risks. Future research could explore the occurrence and impacts of extreme wind speeds, as well as the potential effects of climate change on both mean and extreme wind patterns.

References

[1] Petersen E L, Troen I. Wind conditions and resource assessment[J]. Wiley Interdisciplinary Reviews: Energy and Environment, 2012, 1(2): 206-217.

[2] Philippopoulos K, Deligiorgi D. Application of artificial neural networks for the spatial estimation of wind speed in a coastal region with complex topography[J]. Renewable Energy, 2012, 38(1): 75-82.

[3] Jin L, Li Z, He Q, et al. Observation and simulation of near-surface wind and its variation with topography in Urumqi, West China[J]. Journal of Meteorological Research, 2016, 30(6): 961-982.

[4] Finardi S, Tinarelli G, Faggian P, et al. Evaluation of different wind field modeling techniques for wind energy applications over complex topography[J]. Journal of Wind Engineering and Industrial Aerodynamics, 1998, 74: 283-294.

[5] Garès P A, Pease P. Influence of topography on wind speed over a coastal dune and blowout system at Jockey's Ridge, NC, USA[J]. Earth Surface Processes and Landforms, 2015, 40(7): 853-863.

[6] Şen Z. Areal assessment of wind speed and topography with applications in Turkey[J]. Renewable energy, 2001, 24(1): 113-129.