Original Research Article

Analysis of extreme wind speed characteristics over the tibetan plateau based on ERA5 reanalysis data

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Abstract: This study analyzes the extreme wind speed characteristics over the Tibetan Plateau using ERA5 reanalysis data from 2014 to 2023. The spatial distribution of extreme wind speeds reveals that the northern and central regions experience the highest wind speeds, with maximum values exceeding 15 m/s, driven primarily by the influence of the westerly jet stream. In contrast, the southern plateau, particularly near the Himalayas, shows much lower extreme wind speeds, typically below 5 m/s, due to the Himalayan barrier and the stabilizing effect of the Asian summer monsoon. Extreme wind speeds exhibit strong seasonal variability, peaking in winter and early spring when the westerlies are strongest, and reaching their lowest values in summer due to the monsoon. These findings offer important insights into the risks associated with extreme wind events and their potential impact on infrastructure, renewable energy development, and climate resilience strategies in the region.

Keywords: Tibetan plateau; Extreme wind speeds; ERA5 reanalysis

1. Introduction

Extreme wind events are a significant meteorological phenomenon that can have substantial impacts on both natural environments and human activities. Over high-altitude regions like the Tibetan Plateau, extreme wind speeds are particularly important to study due to their potential influence on infrastructure, agriculture, and the environment, as well as their role in regional climate systems. The Tibetan Plateau, with its vast expanse and average elevation exceeding 4,500 meters, plays a crucial role in modulating atmospheric circulation, particularly influencing the westerly jet stream and the Asian monsoon. However, research on the characteristics of extreme wind events in this region remains limited, especially in comparison to studies on temperature and precipitation patterns.[1,2]

The study of extreme wind speeds is essential for several reasons. First, extreme winds can cause significant damage to infrastructure, particularly in exposed regions where settlements and transportation networks are vulnerable. Second, extreme wind events can lead to increased soil erosion, affect vegetation, and disrupt agricultural practices. Third, understanding the occurrence and distribution of extreme winds is vital for climate risk management and improving regional weather forecasts. Additionally, studying how these events vary spatially and temporally can provide insights into the broader atmospheric processes driving wind dynamics over the plateau.[3]

This study aims to fill the gap in the understanding of extreme wind speed patterns across the Tibetan Plateau by using ERA5 reanalysis data to analyze wind speed extremes from 2014 to 2023. The focus is on examining the spatial distribution of maximum wind speeds and their seasonal and interannual variability. By identifying the regions most prone to extreme wind events and understanding the factors influencing these extremes, the study will contribute to better preparedness and risk mitigation strategies for the plateau's local communities and infrastructure. Additionally, the results will offer insights into how large-scale atmospheric circulations, particularly the westerly jet stream, interact with the region's complex topography to produce extreme wind conditions.

2. Data and methodology

The analysis of extreme wind speeds in this study is based on the ERA5 reanalysis dataset, developed by the European Centre for Medium-Range Weather Forecasts (ECMWF).[4] ERA5 offers high-resolution, hourly reanalysis data that assimilates a wide range of observational data, including satellite measurements, surface observations, and atmospheric models, to provide accurate estimates of global meteorological variables. For this study, we focus on the 10-meter wind speed data, derived from the U and V wind components, which represent the east-west and north-south wind directions, respectively. The wind speed (WS) magnitude is calculated as:

$$\mathrm{WS} = \sqrt{\mathrm{U}^2 + \mathrm{V}^2} \tag{1}$$

where: U is the zonal wind component (east-west direction). V is the meridional wind component (north-south direction).

The ERA5 dataset's high temporal and spatial resolution, along with its consistency in data assimilation, makes it ideal for analyzing extreme wind speeds over the Tibetan Plateau, where direct observational data are often sparse due to the region's remoteness and harsh environmental conditions.

The Tibetan Plateau, located in southwestern China, is the world's highest and most extensive plateau, covering an area of approximately 2.5 million square kilometers. The plateau's average elevation of over 4,500 meters and its complex topography, including high mountain ranges like the Himalayas and expansive flatlands, significantly influence regional wind patterns.

This study focuses on the entire Tibetan Plateau, with specific attention to areas where extreme wind speeds are likely to occur. The interaction between large-scale atmospheric circulations, such as the westerly jet stream, and local topographic features is expected to result in significant spatial variability in wind extremes across the region.

To identify extreme wind events, we focus on the maximum wind speed recorded at each grid point for every year from 2014 to 2023. This approach allows us to analyze the annual maximum wind speeds across the Tibetan Plateau and capture the most intense wind events in each year.

The maximum wind speed for each year is calculated from the hourly wind speed data at each grid point, providing a detailed spatial map of the most extreme wind events observed over the 10-year period. The results are then averaged to generate a mean annual maximum wind speed map, highlighting the regions where extreme wind speeds are consistently high.

3. Results

The spatial distribution of extreme wind speeds across the Tibetan Plateau, based on the mean annual maximum wind speeds from 2014 to 2023, reveals distinct regional variations. These variations are primarily influenced by the plateau's topography and its interaction with large-scale atmospheric circulation patterns, particularly the westerly jet stream and local topographical effects such as mountain ranges and valleys.

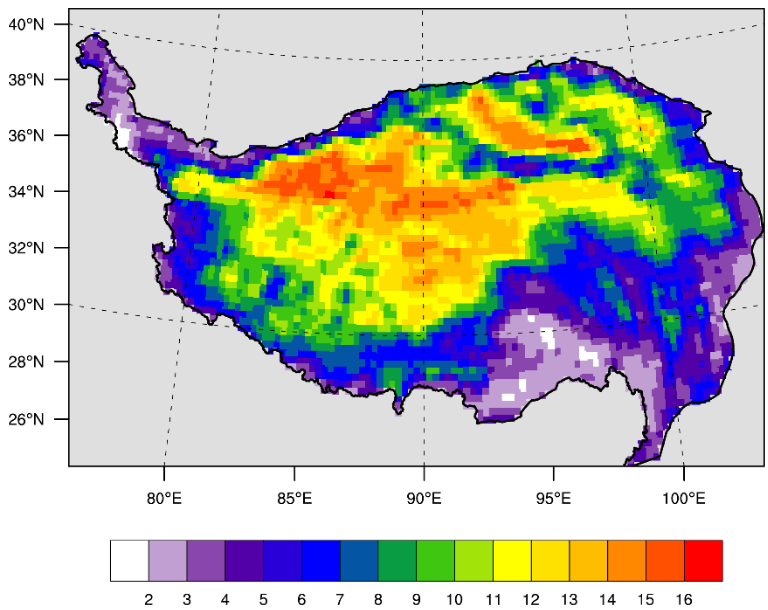

Figure 1. Multi-year mean annual maximum wind speed over the Tibetan Plateau during 2014-2023 (units: m/s).

The northern and central parts of the Tibetan Plateau experience the highest extreme wind speeds, with mean annual maximum wind speeds ranging from 13 to 16 m/s. These regions are characterized by relatively flat, high-altitude terrain, which allows for the free flow of strong winds, especially during the winter months when the westerly jet stream is most active.[5] Areas between 33°N and 36°N, particularly near the Qaidam Basin and the northern slopes of the Kunlun Mountains, show some of the highest recorded maximum wind speeds, often exceeding 15 m/s. These areas are directly exposed to the influence of the westerlies, which intensify during winter and early spring, driving extreme wind events. The central plateau, especially around 90°E and 34°N, also experiences high maximum wind speeds, with values typically between 13 and 15 m/s. The relatively open terrain and the persistent influence of the westerly flow contribute to the frequent occurrence of extreme wind events in this region. Additionally, local topographic features, such as gentle slopes, can enhance wind speeds by funneling airflow.

The southern and southwestern parts of the Tibetan Plateau, particularly those near the Himalayan range, exhibit the lowest extreme wind speeds, typically below 5 to 8 m/s. These regions are significantly shielded from large-scale wind systems by the Himalayas, which act as a natural barrier, preventing strong winds from penetrating into the southern plateau. The areas adjacent to the Himalayan mountains, especially those south of 30°N, show consistently low extreme wind speeds. This is due to the barrier effect of the Himalayas, which block the westerlies and prevent high winds from reaching the southern plateau. Additionally, the Asian summer monsoon further suppresses wind speeds during the warm season by bringing more stable, moisture-laden air to this region.[6]

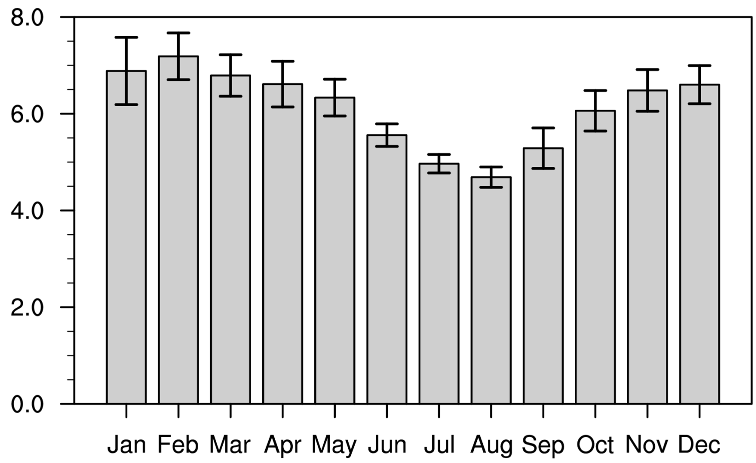

Figure 2. The monthly maximum wind speed over the Tibetan Plateau during 2014-2023 (units: m/s). The vertical lines on each bar indicate the interannual variability.

Figure 2 presents the monthly maximum wind speeds averaged over the period 2014 to 2023. The maximum wind speeds exhibit clear seasonal variability, with the highest values occurring during the winter and spring months and the lowest values during summer. The highest maximum wind speeds are observed in March and April, where the average values reach approximately 6.5 to 7.0 m/s. These months correspond to the period of strong westerly jet activity, which enhances wind intensity over the Tibetan Plateau.

4. Conclusion and discussion

This study provides a comprehensive analysis of the extreme wind speed characteristics over the Tibetan Plateau, utilizing ERA5 reanalysis data from 2014 to 2023. The northern and central parts of the Tibetan Plateau experience the highest extreme wind speeds, with values exceeding 15 m/s, driven by the strong influence of the westerly jet stream. In contrast, the southern and southwestern regions, particularly those adjacent to the Himalayas, exhibit the lowest extreme wind speeds, typically below 5 m/s, due to the Himalayan barrier and the stabilizing influence of the Asian summer monsoon. Extreme wind speeds are highest during the winter and early spring (December to March), particularly in the northern and central regions, when the westerly jet stream is strongest. The summer months (June to August) experience the lowest extreme wind speeds across the plateau due to the dominance of the Asian summer monsoon, which brings more stable atmospheric conditions. Autumn marks a gradual return to stronger winds as the westerlies regain strength.

The spatial and seasonal variability in extreme wind speeds has significant implications for infrastructure planning and climate risk management in the Tibetan Plateau. Regions with consistently high extreme wind speeds, particularly in the northern plateau, are at greater risk of wind-related damage to infrastructure such as roads, power lines, and buildings. In these areas, it is essential to incorporate wind risk assessments into the planning and construction of infrastructure to ensure that buildings and facilities can withstand extreme wind events.

In contrast, the southern plateau, with its lower extreme wind speeds, faces fewer risks from extreme wind events. However, the region's susceptibility to other climate-related hazards, such as heavy precipitation and landslides associated with the Asian monsoon, should still be factored into risk assessments.

This study focuses primarily on the spatial and seasonal variability of extreme wind speeds. Future research could expand on these findings by exploring the synoptic conditions associated with extreme wind events, such as specific weather patterns or cyclonic systems that contribute to the development of these events.

References

[1] Huang X, Han S, Shi C. Evaluation of three air temperature reanalysis datasets in the alpine region of the Qinghai–Tibet plateau[J]. Remote Sensing, 2022, 14(18): 4447.

[2] You Q, Fraedrich K, Ren G, et al. Inconsistencies of precipitation in the eastern and central Tibetan Plateau between surface adjusted data and reanalysis[J]. Theoretical and applied climatology, 2012, 109: 485-496.

[3] Hoffmann C, Funk R, Reiche M, et al. Assessment of extreme wind erosion and its impacts in Inner Mongolia, China[J]. Aeolian Research, 2011, 3(3): 343-351.

[4] Hersbach H, Bell B, Berrisford P, et al. The ERA5 global reanalysis[J]. Quarterly Journal of the Royal Meteorological Society, 2020, 146(730): 1999-2049.

[5] Schiemann R, Lüthi D, Schär C. Seasonality and interannual variability of the westerly jet in the Tibetan Plateau region[J]. Journal of climate, 2009, 22(11): 2940-2957.

[6] Li J F, Xie G, Yang J, et al. Asian Summer Monsoon changes the pollen flow on the Tibetan Plateau[J]. Earth-Science Reviews, 2020, 202: 103114.