Analysis of Vertical Characteristics of shallow wind in Northeast of Horqin Grassland

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Abstract: In the present study, an investigation was conducted into the characteristics of variation in shallow wind across the northeast Horqin grassland by using the wind tower data from 2016 to 2020. The investigative results demonstrate that northwest wind is dominant at the layers of 3.5-101m, followed by southwest wind and southeast wind in order. In spring, the different wind direction accounts for the same proportion. In summer, southwest and northeast winds are dominant. West wind and northwest wind prevail in autumn. In winter, northwest wind is in dominance. With the increase in height, the frequency of each wind speed becomes dispersed. The horizontal wind speed is mostly 2-4m/s at the layer of low than 20m and 5-6m/s at the layer of over 34m. In general, there is downdraft at the layer of 10 m and updraft at the layer of 55m and 101 m, respectively.

1. Introduction

The near-surface layer is subjected to a significant influence from the surface, and micro-scale interaction occurs between the earth and the atmosphere[1]. For the study of near-surface layer, shallow wind is regarded as an important meteorological factor. Due to underlying surface conditions and surface tectonic characteristics, temporal and spatial changes occur to the micro-meteorological environment in the near-surface layer, as reflected in dynamics and heat. This leads to the variation in material and energy exchange on the surface, thus affecting local microclimate[2]. The micrometeorological environment is influenced by topography, surface conditions, vegetation cover, near-surface atmospheric turbulence, and subsurface thermodynamic effects. It is also affected by the entrainment process between the near-surface atmosphere and mixed layer, residual layer, stable boundary layer, etc. Besides, the micro-meteorological environment is highly volatile, transient and intermittent. Its time scale can reach the order of minutes or even seconds, and the speed and direction of wind can change significantly in a short period of time[3]. Whether at home and abroad, there have been a lot of observation and research conducted on the near-surface layer by using the equipment mounted on the meteorological tower, with constructive research results obtained. For example, to study the observed facts of material flux transport, particulate matter, and methane flux in the lower atmosphere, foreign scholars used Amazon Rainforest 325 m Meteorological Tower, Siberia 300 m Meteorological Tower, Wisconsin 447 m Meteorological Tower, respectively[4-6]. A comprehensive study[7-13] was carried out using the sounding data of 325 m meteorological tower in Beijing, 255 m meteorological tower in Tianjin, and 356 m meteorological tower in Shenzhen. It involved the quality control method of sounding data, the characteristics of wind and temperature changes near the ground, aerodynamic parameters, as well as the impact of urbanization on boundary layer atmosphere and air pollution. In addition, with plateaus, coastal areas, and desert hinterland as the research object, plenty of research have been conducted on the temporal and spatial effects of meteorological facts in the near-surface layer, the patterns of variation in meteorological factors at different heights and the micro-climate changes in the near-surface layer[14-17].

Horqin Right Front Banner is located in the east of Inner Mongolia, which is northwest to Songliao Plain on the leeward slope of the Great Khingan Range, featuring a flat terrain with an average altitude of 300 m. Its climate is largely affected by the blocking effect of the Great Khingan Range. In the past, the lack of high spatial-temporal resolution detection data made it difficult to carry out research on wind speed near the surface layer in this area. In this paper, five years' worth of three-dimensional ultrasonic wind detection data is used to analyze the pattern of temporal and spatial variations in wind speed in the near-surface layer of the northeast Horqin grassland, explore the atmospheric characteristics exhibited by the near-surface layer of the northeast Horqin grassland, and reveal the mechanism of local climate effect on the grassland underlying surface, which provides a practical reference for the study on the structure and mechanism of the boundary layer.

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2. Data and methods

2.1 Data sources

The data were detected by using the three-dimensional ultrasonic wind detection system in Horqin, which is located at the northeast edge of Horqin grassland, with an altitude of 198 m. There are neither buildings over 20 m within 1 km, nor high-altitude terrain within 100 km, but scattered mounds and puddles with an altitude of 100 m to 400 m around it, which constitute the underlying surface of the grassland. The observation data used in the system were gathered by the three-dimensional ultrasonic wind sensor with 7 layers (3.5, 10, 20, 34, 55, 75, and 101 m) above the ground, the model of which is R M.YOUNG 80000. The interval of data acquisition was set to 1 s, 1/32 s, and 1 min on average. By using the average data of 1 min, an analysis is conducted in this paper on the seasonal characteristics of wind speed in the surface layer of Horqin grassland, as well as the annual average diurnal variation in horizontal wind speed and vertical speed.

2.2 data processing

Due to sensor failure, the error code of collector, transmission conflict and other reasons, the data are clearly inaccurate. In order to ensure the reliability of data, the data was eliminated. The criteria of data rejection are as follows[8]: (1) It contradicts common sense, such as the wind direction exceeding 360 degrees or the wind speed being negative; (2) The extreme value of equipment detection is exceeded, such as a higher wind speed than 65 m/s; (3) Data are missing, such as both wind direction and wind speed being 0; (4) The continuity of temporal and spatial changes is not met, such as the circumstance where the difference between a certain wind speed and the adjacent time or level wind speed is more than 3 times that of two adjacent times or levels; (5) Duplicate data, such as the same set of data appearing twice or more at the same point of acquisition.

Table 1. Related technical parameters to wind tower three-dimensional ultrasonic wind detection system.

Parameter name		Technical indicators
layer		3.5, 10, 20, 34, 55, 75, 101m
Three-dimensional wind speed	Measuring range	0m/s～65m/s
	Maximum permissible error	±1.5%
	Resolution	0.01m/s
	Sampling frequency	1Hz～32Hz
	Data interval	1Hz, 32Hz, 1/60Hz
Three-dimensional wind direction	Measuring range	0°～360°
	Maximum permissible error	±2°
	Resolution	0.1°
	Sampling frequency	1Hz～32Hz
	Data interval	1Hz, 32Hz, 1/60Hz

2.3 Analytical method

The data spanned from January 2016 to December 2020. The time unit of data is Beijing time (BJT). The way of season division is as follows: March to May is defined as spring, June to August is defined as summer, September to November is defined as autumn, and December to February is defined as winter. The diurnal variation characteristics of meteorological facts were analyzed by using the mean value of all data in the same period of the whole year.

3. General characteristics of shallow wind

3.1 General characteristics of shallow wind direction

From the annual overall wind diagram (Fig1.), it can be seen that the northwest quadrant accounts for the largest proportion, followed by the southwest quadrant. The southeast quadrant accounts for the smallest proportion in the wind direction frequency of each height layer in the northeast of Horqin grassland. Specifically, northwest (NW) wind has the highest frequency, accounting for 12% in total, followed by west-northwest (WNW) wind, accounting for 8-12%, and north-northwest (NNW) wind, accounting for about 6-9% of all layers. The direction on the 7th layer (101m) is slightly different than on the 1st-6th layers. The maximum frequency of wind direction is about 22.5, which is dominated by west-southwest wind, followed by normal west wind.

In each layer, the frequency of the southwest wind direction and south-southwest wind direction is about 9%, and the total ratio of these two directions is 18%. The proportion of northeast wind and north-northeast direction is approximately 7%, accounting for 15% in total. In all directions, the frequency of wind directions in the southeast quadrant falls below 3%, and that of the north wind is also low, accounting for about 7%.

Since the northeast of Horqin grassland is dominated by the westerly belt in the northern hemisphere, the wind direction in the west quadrant is predominant, with the

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total wind direction in the range of 180-360 degrees accounting for 70%. Viewing from the north to the south, the wind direction in all northerly quadrants accounts for 70% of the total.

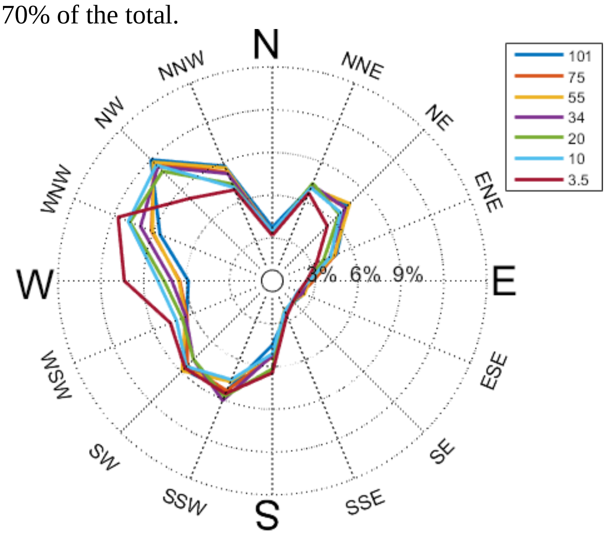

Figure 1. Wind direction frequency rose chart.

3.2 General characteristics of shallow wind speed

The wind speed in each layer was segmented at an interval of 1m/s to analyze the frequency of wind speed in each wind speed section (Fig2. Upper), and to calculate the frequency of horizontal wind speed falling below a certain wind speed value (Fig2. Lower). Based on the proportion of a certain wind speed and the frequency of wind speed, the wind speed distributionat all layers of shallow wind in the northeast of Horqin grassland can be determined[9]. As shown in the figure, the frequency of each wind speed section becomes dispersed with the increase in height. The frequency peak of horizontal wind speed below 20m concentrates at 2-4m/s. The proportion of wind speed below 8m/s at 3.5, 10, and 20m is 92.2%, 86.4%, and 78.9% respectively, while that of wind speed above 12m/s is 1%, 2.4%, and 3.2% respectively. The frequency peak of horizontal wind speed above 34m concentrates at 5-6m/s. The wind speed below 8m/s at 34, 55, 75, and 101m accounts for 66.6%, 56.1%, 50.1%, and 46.1% respectively, while that above 12m/s accounts for 5.2%, 8.3%, 14.1%, and 18.1% respectively.

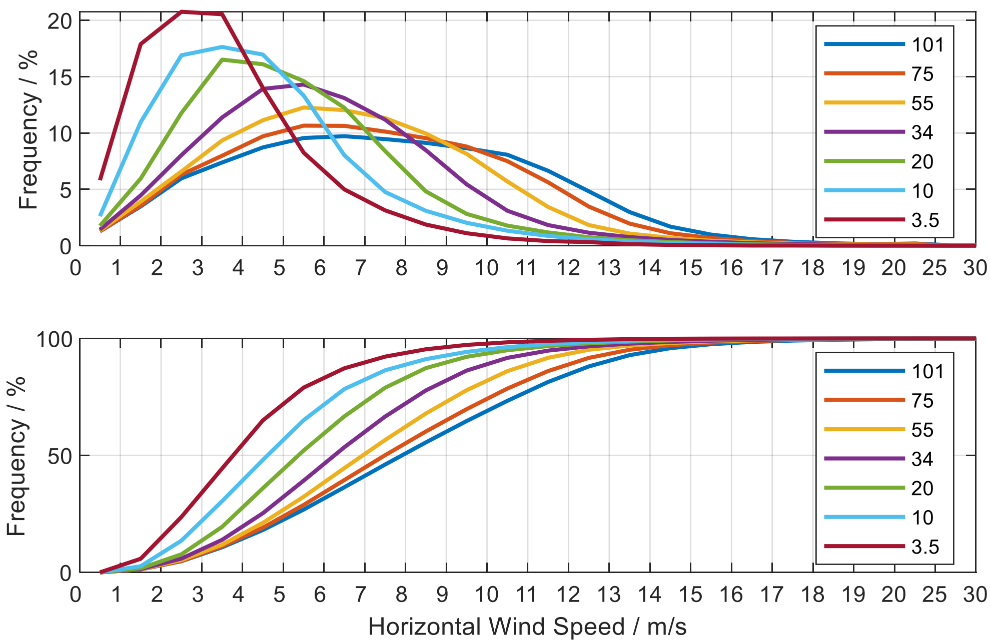

Figure 2. The frequency of horizontal wind speed

3.3 General characteristics of vertical velocity of shallow wind

As shown in the annual overall wind speed box diagram (Fig3.), the vertical velocity is basically distributed between 2m/s. Besides, the two-digit vertical velocity at the heights of 3.5, 20, 34, and 75m is close to 0m/s, while that at the layer of 10m falls below 0m/s. That is to say, the layer is dominated by a downward flow. The double-digit vertical velocity at the layers of 55 and 101m exceeds 0m/s, which means that the layer is generally updraft. As revealed by the interquartile spacing, the distribution of vertical velocity concentrates at layers below 34m, indicating the relative stability of vertical velocity. In addition, the distribution of vertical velocity becomes dispersed when the layer exceeds 55m, indicating that the change in vertical velocity begins to increase.

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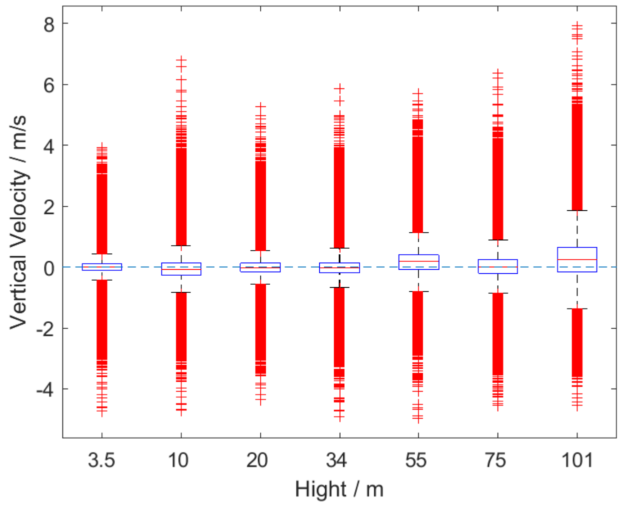


Figure 3. Vertical wind speed box diagram

4. Seasonal variation of shallow wind

4.1 Seasonal variation in wind direction

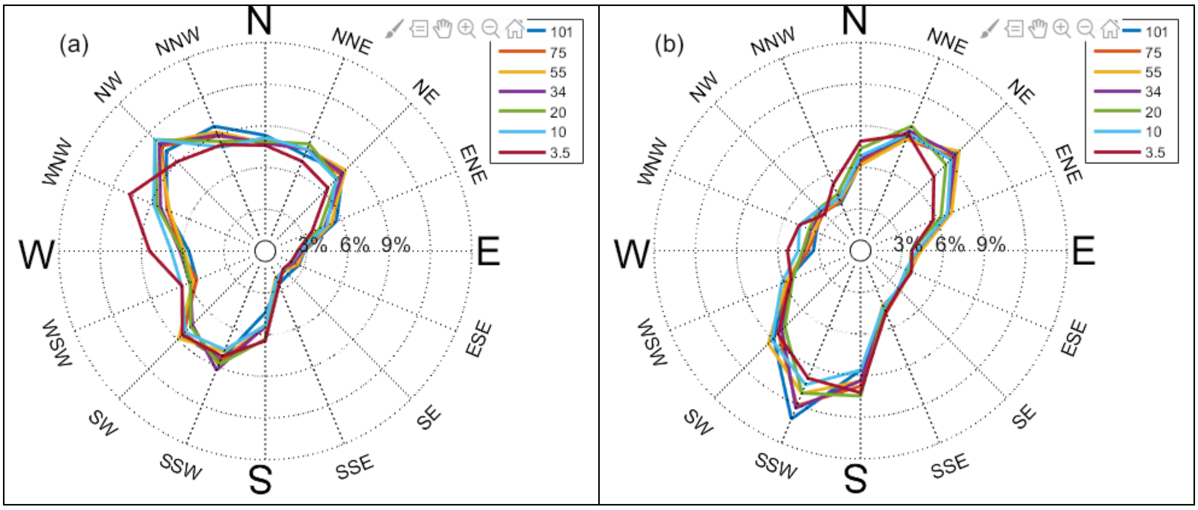
The shallow wind direction in the northeast of Horqin grassland shows distinctive seasonal characteristics (Fig.4). The proportion of each direction is equal in spring, southwest (SW) and northeast (NE) winds dominate in summer, northwest (NW) and westerly (W) winds dominate in autumn, and winter winds are mainly concentrated in the northwest (NW) direction.

In spring, there is a relatively average frequency distribution of the main wind direction in the northeast of Horqin grassland, with Northwest (NW), Southwest (SW), and Northeast (NE) in dominance. Besides, the wind direction frequency from due east (E) to southeast by South (SES) is the lowest, all of which fall below 3%. The frequency of wind direction in the west by Southwest (WSW) is lower, accounting for about 6%. As for other wind directions, they reach above 6%, and the Northwest (NW) direction with the highest wind direction frequency accounts for 11%.

In summer, Southwest (SW) and Northeast (NE) are the dominant wind directions in the northeast of Horqin grassland. Specifically, the frequency of southwest by South (SSW) wind direction is the highest, approaching 12%, and the south (S) and Southwest (SW) wind directions exceed 9%. The three wind directions account for 20% of the total. From the North (N) to the East by Northeast (ENE), the four wind directions account for more than 6%, the Northeast (NE) accounts for 9.2%, and the other two and four quadrants account for less than 6%.

In autumn, the high-frequency wind direction in the northeast of Horqin grassland concentrates in the second and third quadrants. The frequency of wind direction from W to NW is approximately 12%. The frequency of wind direction from SW to SSW is about 9%. The frequency of W and WSW exceeds 6%. The frequency of NE and NNE wind directions approaches 6%, and other wind directions fall below 6%. The SE wind is the least frequent in autumn, accounting for only 2%.

In winter, the northwest wind is the dominant wind direction in the northeast of Horqin grassland. Specifically, W and WNW wind direction account for over 16%, while NNW accounts for about 12%. Except for the W direction accounting for more than 16% at the layer of 3.5m, the frequency of other directions falls below 8%. The SE wind direction accounts for the smallest proportion, while the frequency of wind direction in the fourth quadrant accounts for merely 6% or so.



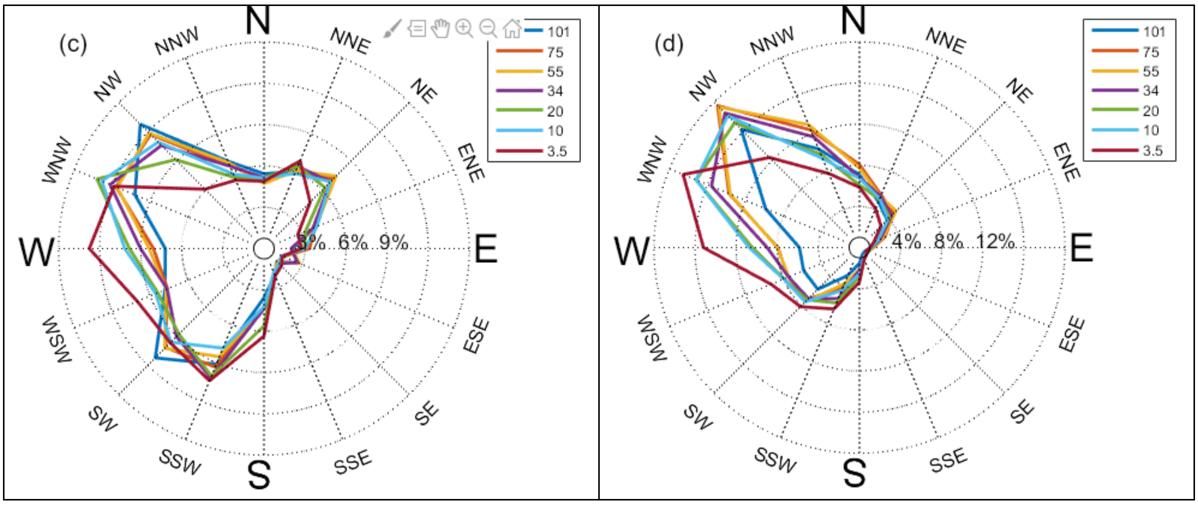


Figure 4. Rose chart of wind direction frequency in each season (a, b, c and d represent spring, summer, autumn and winter respectively)

4.2 seasonal variation of wind speed

Depending on the season, all horizontal wind speed data were analyzed from 0 m / s to 12 m / s with an interval of 2 m/s. As shown in **Fig5**, the frequency is about 4m/s for 10-101m shallow wind speed in the northeast of Horqin grassland during all of the four seasons.

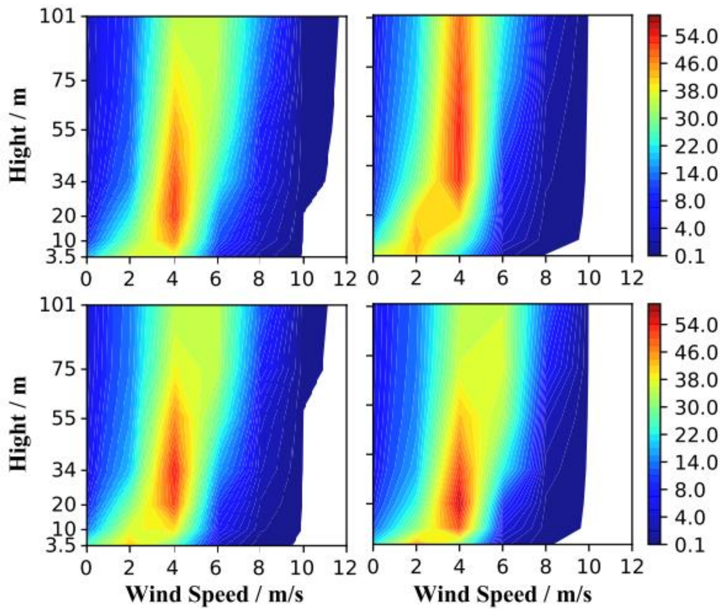


Figure 5. Statistics of wind speed frequency with height in different seasons

In spring, the frequency of wind speed at the layer of 3.5m is concentrated around 1-3m/s. The frequency of wind speed at layers of 10-55m is concentrated around 4m/s, and the frequency of occurrence can reach more than 50%. The frequency range of wind speed above 75m starts to become larger, and the wind speed is mainly 3-6m/s.In summer, the speed of shallow wind in the northeast of Horqin grassland is relatively small, the wind speed concentrating at 2 m / s at the layers of 3.5-10 m, and increasing progressively to 2-4 m / s at the layers of 10-20 m. The maximum frequency of wind speed at the layers of 20-101m is about 4 m / s. There is a similarity shown by the frequency pattern of wind speed in autumn and winter. The frequency of wind speed concentrates at 2m / s at the layer of 3.5m, changing slowly from the range of 10-101m to a high wind speed. The frequency of wind speed in winter concentrates more significantly than in autumn. Due to the low temperature in winter, high air density, and small shallow wind thickness [10], the maximum frequency of wind speed is at the layer of 20 m (57.5%), while it is at the layer of 34 m in autumn (54.7%).

5. diurnal variation of wind speed at vertical height

5.1 diurnal variation of horizontal wind speed

There are distinctive characteristics of diurnal variation in meteorological facts in the shallow wind, which is conducive to understanding the physical mechanism of the boundary layer[11]. As shown the trend of diurnal variation in average wind speed of shallow wind at different heights(Fig6. Upper), reveals a diurnal variation trend of strong daytime wind and weak nighttime wind at the layer of low than 20m, a diurnal variation trend of weak daytime wind and strong nighttime wind at the layer of over 55m, and a weak diurnal variation characteristic at the layer of 34m.

At the layer of 3.5m, the wind speed increases incrementally to 6m/s at around 9: 00 am each day and then decreases at around 15: 00 pm, maintaining a low wind speed of 4m/s at around 19: 00 am. The diurnal variation trend of wind speed below 20m shows similarity to that at the layer of 3.5m, except that the time at which wind speed increases in the daytime is gradually advanced to around 7 o'clock, and that the time at which wind speed decreases at night is gradually delayed to around 17 o'clock. At the layers of over 55m, the diurnal variation trend of wind speed is opposite to that of the lower layer, showing a trend of first declining and then rising. The wind speed gradually drops from around 7: 00 in the morning, and then increases progressively after 17: 00 in the evening, with the average wind speed, maintained at 7-8m/s during the night until the next morning.

The diurnal variation in wind speed anomaly is shown in (Fig6. Lower). After sunrise in the morning, the surface temperature gradually rises with the continuous heating of the ground, and the turbulent flow on the surface increases. Meanwhile, the turbulent transport causes the momentum exchange between the upper and lower layers, and there is a gradual increase in wind speed[12]. After sunset in the evening, the surface temperature gradually decreases, solar radiation diminishes, the surface temperature drops slowly, the shallow wind-induced disturbance is reduced, and turbulent transport declines. At the same time, the level of air density increases, and the viscous force of the surface increases progressively. The turbulent momentum transport and viscous friction force lead to the gradual reduction in lower wind speed. However, the drag from the lower layer of shallow wind decreases, and the wind speed in the upper layer rises.

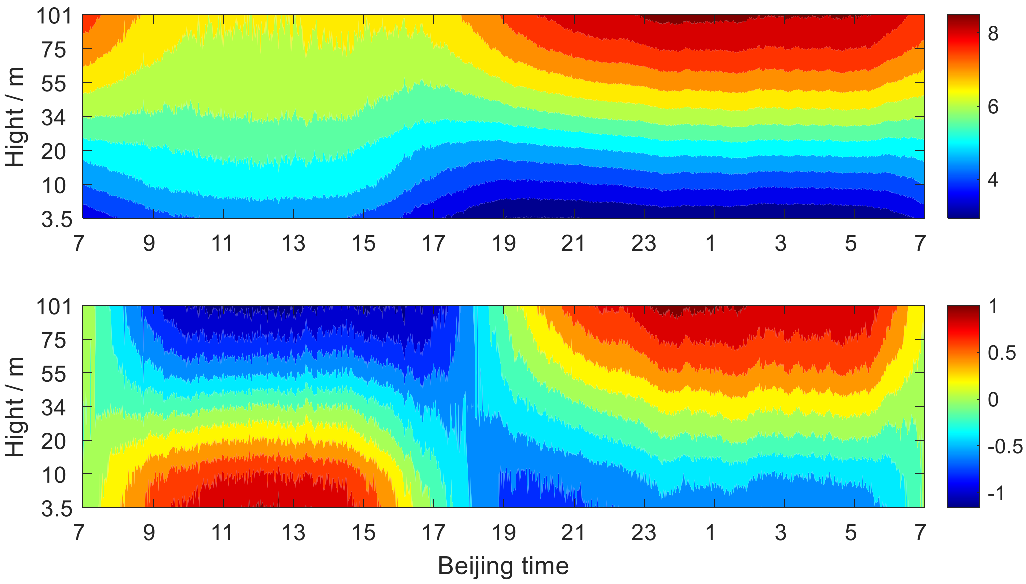


Figure 6. Vertical profile of horizontal wind speed (upper) and horizontal wind speed anomalies (lower) diurnal variation (unit m/s)

5.2 Diurnal variation of vertical speed

Fig7. Upper shows the diurnal variation trend of vertical velocity average of shallow wind in northeast Horqin grassland. It can be seen from the figure that the diurnal variation in the average vertical velocity of shallow wind at the layers of lower than 34m is dominated by the downward flow. Specifically, the downward flow at the layers of 10m is most significant, with the downward flow decreasing during the day and increasing at night. However, the variation in vertical airflow is insignificant at layers of 3.5, 20, and 34m. It can be found that there is a slight updraft in the daytime and a slight downward flow at night. At the layers of 55-101m, the vertical airflow shows a predominant updraft. At the layer of 55m, the updraft trend gradually diminishes from around 7: 00 a.m. After reaching a low point at around 19: 00 a.m., it slowly increases, peaking at around 0: 00 the next day until around 7: 00 the next day. At the layer of 101m, there is a strong updraft. It rises at 10 am and then increases at a slow pace beyond the bottom. After peaking at around 00 am the next day, it gradually decreases.

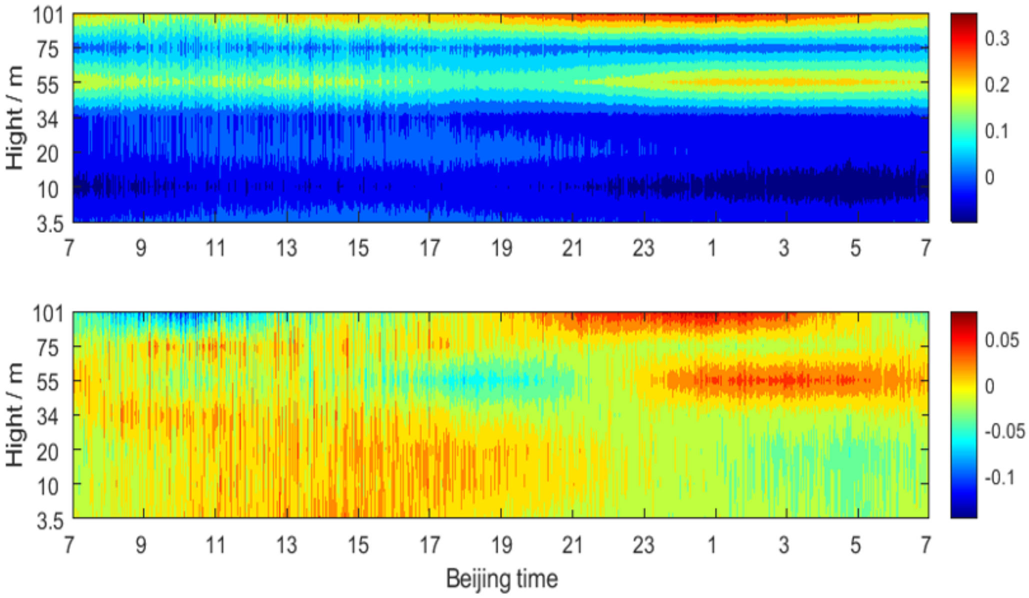


Figure 7. Vertical profile of vertical velocity (upper) and vertical velocity anomalies (lower) diurnal variation (unit m/s)

The diurnal variation trend of vertical velocity at different heights of shallow wind is shown in Fig7 Lower. It can be seen from the figure that the characteristics of diurnal variation in horizontal wind speed on the vertical profile are consistent with the diurnal variation in average vertical speed. At the layers of 34m and 75m, it shows a positive anomaly in the daytime and a negative anomaly at night. The anomaly of vertical velocity is insignificant at the layer of 5m. After 15 o'clock, the negative anomaly starts to increase gradually. Then, it turns into a positive anomaly at around 23 o'clock, which is maintained until the early hours of the next morning. The maximum value of negative anomaly in vertical velocity at 101m is reached after 7: 00 in the morning. Remaining so at about 0 at 13: 00, it turns into a positive anomaly at 19: 00 and then increases progressively. After peaking at about 0: 00 the next day, the positive anomaly gradually decreases. The vertical velocity and anomaly tend to go downwards, the mechanism of which will be further explored in the follow-up study.

6. Conclusion

Based on the data sourced from an ultrasonic wind measurement system of a wind tower located in the northeast of Horqin grassland over the recent five years, the characteristics of shallow wind change are analyzed, focusing mainly on the statistical characteristics of seasonal change in the shallow wind and the pattern of diurnal change in vertical height. Finally, the following conclusions are drawn.

The annual wind direction at each height accounts for the largest proportion in the northwest quadrant, followed by the southwest quadrant and southeast quadrant in order. The change in wind direction shows distinctive seasonal characteristics. In spring, all directions account for the same proportion. In summer, southwest and northeast winds are dominant. In autumn, northwest and westerly winds are dominant. In winter, the northwest wind is dominant.

The frequency of occurrence of each wind speed segment becomes dispersed with increasing height, and the peak frequency of horizontal wind speed is concentrated at 2-4m/s when the layer is lower than 20m. To be specific, a wind speed of less than 8m/s accounts for over 78% and the wind speed above 12m/s accounts for only 3.2%. The peak frequency of a higher horizontal wind speed concentrates at 5-6m/s when the layer is higher than 20m, with the wind speed below 8m/s accounting for less than 67%, and the wind speed above 12m/s accounting for 5.2% to 18.6%. In the four seasons, the highest frequency of wind speed ranging from 10 to 101m is around 4m/s, and the wind speed at a height of 3.5m is slightly lower.

Shallow wind exhibits different variation characteristics, which depend on vertical height. The horizontal wind speed below 20m shows a diurnal variation trend of strong daytime wind and weak nighttime wind. At the layer of above 50m, it displays a diurnal variation trend of weak daytime wind and strong nighttime wind. When the height reaches 34m, the diurnal variation characteristics are insignificant. In general, the vertical velocity shows a downward trend at the layer of 10m, and updraft at the heights of 55 and 101m. The diurnal variation of vertical velocity shows a positive anomaly in the daytime and a negative anomaly at night in the middle and lower layers. In contrast, it shows a negative anomaly in the daytime and a positive anomaly at night in the upper layer.

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