# Radiosonde-Based Analysis of Spatiotemporal Distribution Characteristics of Atmospheric Dispersion Conditions in Xinjiang (Postprint)

**Authors:** Sun Mingjing, Li Xia

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## Abstract

Based on data from 14 radiosonde stations in Xinjiang during 2010–2019, this study statistically analyzed the spatiotemporal distribution characteristics of maximum atmospheric mixing layer height (hereinafter referred to as mixing layer height), ventilation volume, average boundary layer wind speed, and atmospheric self-purification capacity index over the past decade, and investigated the relationships between these physical parameters and air quality. The results indicate: (1) The monthly distributions of all aforementioned parameters display an inverted 'V' pattern, with larger values during the summer half-year and smaller values during the winter half-year, indicating that atmospheric diffusion capacity in Xinjiang is strongest in summer and weakest in winter, with particularly pronounced differences in mixing layer height and ventilation volume between winter and summer. (2) Atmospheric diffusion capacity in Southern Xinjiang is generally superior to that in Northern Xinjiang; the self-purification capacity, ventilation volume, and mixing layer height in Southern Xinjiang exceed those in Northern Xinjiang in both summer and winter. (3) In Northern Xinjiang, all stations except Altay station exhibit significant negative correlations between the aforementioned physical parameters and Air Quality Index (AQI), i.e., stronger atmospheric diffusion capacity corresponds to better air quality. In Southern Xinjiang, only Hotan station passes the 0.01 significance level test, but shows a positive correlation, i.e., stronger atmospheric diffusion capacity corresponds to poorer air quality, which is attributed to different air pollution sources between Northern and Southern Xinjiang.

## Full Text

# Spatial and Temporal Characteristics of Atmospheric Diffusion Conditions in Xinjiang Based on Radiosonde Data

**SUN Mingjing[1,2], LI Xia[1], ZHAO Keming[1,2], JU Chenxiang[1], AN Dawei[2], SHI Junjie[2], XU Tingting[2]**

[1]Institute of Desert Meteorology, China Meteorological Administration, Urumqi 830002, Xinjiang, China
[2]Xinjiang Meteorological Observatory, Urumqi 830002, Xinjiang, China

**Abstract:** Based on data from 14 radiosonde stations and their corresponding surface meteorological automatic observation stations in Xinjiang, China, from 2010 to 2019, the temporal and spatial distribution characteristics of air mixing depth, ventilation rate, mean wind speed in boundary layer, and air self-cleaning ability index in the past 10 years were analyzed. The correlation between meteorological parameters and air quality was discussed based on the air quality index (AQI) data of 10 air quality monitoring stations in Xinjiang from 2015 to 2019. Results show that (1) the monthly distributions of the maximum mixing depth, the ventilation rate, the mean wind speed in the boundary layer, and the index of atmospheric self-cleaning ability had an inverted "V" shape, thereby indicating that the atmospheric diffusion ability of Xinjiang is strong in summer and weak in winter. (2) With regard to the spatial distribution of atmospheric diffusion conditions in Xinjiang, two different diffusion areas are found in southern and northern Xinjiang due to different topographies. The atmospheric diffusion conditions in southern Xinjiang are generally better than those in northern Xinjiang. Whether in winter or summer, southern Xinjiang has greater self-cleaning ability, ventilation capacity, and mixing depth than northern Xinjiang does, but the mean wind speed in the boundary layer is the same in southern and northern Xinjiang. This condition is mainly due to the great difference of non-adiabatic heating on the ground caused by different sunshine duration and intensity. (3) An analysis of the correlation between the above parameters and AQI shows that the atmospheric diffusion conditions of stations in northern Xinjiang are significantly negatively correlated with AQI except Altay station, and they all passed the 0.01 confidence test. The conditions are not consistent in southern Xinjiang; only Hotan station passed the 0.01 confidence test, thus indicating a significantly positive correlation, which is the opposite of northern stations in Xinjiang. This result occurred because the causes of air pollution in northern and southern Xinjiang are different. The main pollution sources in southern Xinjiang during spring are sand and dust, especially at Hotan station, where sand and dust increase under good atmospheric diffusion conditions, resulting in poor air quality. In northern Xinjiang, pollution is mostly due to the stable atmospheric stratification, which results in failed coal smoke emission from urban factories. The strong atmospheric diffusion ability will help the dilution and diffusion of pollutants and improve the air quality.

**Keywords:** atmospheric diffusion conditions; self-cleaning ability index; ventilation; mixing depth

## Introduction

Xinjiang, located at the western gateway of China, serves as an important portal for China' s opening-up to the west and a vital security barrier in northwestern China. Under the new situation, Xinjiang is not only "an important energy base and transportation corridor of the motherland" but also the "core area of the Silk Road Economic Belt," holding an irreplaceable strategic position for achieving the "Two Centenary Goals" and the great rejuvenation of the Chinese nation [?]. Due to the Tianshan Mountains dividing Xinjiang centrally, two distinct pollution zones have formed in southern and northern Xinjiang. Spring features frequent sand and dust weather, with dust pollution being more severe in southern Xinjiang than in northern Xinjiang. In winter, the stable atmospheric stratification hinders the diffusion of air pollutants, and coal smoke pollution in cities intensifies, being more severe in northern Xinjiang than in southern Xinjiang [?]. Wind can cause sand and dust in southern Xinjiang, deteriorating air quality, but can also disperse pollutants accumulated in the boundary layer of northern Xinjiang, improving air quality. Thus, the same atmospheric diffusion conditions may have opposite effects in different regions. Therefore, understanding the distribution of atmospheric diffusion capacity is crucial for pollution prevention and control, especially in Xinjiang with its complex terrain.

In recent years, many scholars have studied different atmospheric diffusion conditions. Among them, the mixing layer height is an important parameter characterizing atmospheric diffusion conditions [?, ?], playing a significant role in the transport and diffusion of pollutants. Studies have shown that China' s mixing layer height is generally smaller in winter and larger in summer. Low-altitude cities in southern China are relatively stable with small variation amplitudes, whereas northern cities and high-altitude cities in southern China show large variation amplitudes [?, ?]. It is mainly influenced by dynamic lifting conditions caused by weather systems and solar altitude angle. Additionally, ventilation is also an important physical quantity in atmospheric diffusion condition research [?, ?]. China' s ventilation generally shows a distribution pattern of high in the north and low in the south, high in the west and low in the east. Urumqi in Xinjiang, due to its inland location and relative enclosure by mountains on three sides, has low ventilation [?], making it prone to heavy pollution weather. The National Climate Center has developed the atmospheric self-cleaning ability index to characterize atmospheric environmental capacity [?, ?], which is widely applied in air pollution meteorological services. It is unrelated to air pollution emissions and only represents the atmosphere' s capacity to ventilate, diffuse, and remove pollutants through precipitation. It incorporates the effects of mixing layer height and ventilation [?]. Compared with the national atmospheric environmental capacity, Xinjiang' s atmospheric self-cleaning ability value is relatively low, especially evident during high-pollution seasons [?].

In Xinjiang, most research on atmospheric diffusion conditions has focused on the capital Urumqi, the important economic belt urban agglomeration on the northern slope of the Tianshan Mountains, or a specific region [?, ?, ?, ?, ?], lacking comprehensive research on diffusion conditions across the entire region. With the development of the "Three Lines and One Permit" compilation work, the industrial development layout across Xinjiang will face new adjustments. Planning the baseline of atmospheric environmental quality requires numerous scientific decision-making bases [?]. Therefore, conducting research on atmospheric diffusion conditions across Xinjiang is particularly urgent. Based on data from 14 radiosonde stations, this paper analyzes the spatial and temporal distribution characteristics of the atmospheric self-cleaning ability index across Xinjiang and preliminarily explores its relationship with air quality, aiming to provide a scientific basis for adjusting Xinjiang' s industrial development layout and preventing and controlling atmospheric pollution.

# 1 Data and Methods

## 1.1 Data Description

The meteorological data used in this paper consist of second-level radiosonde data from 14 stations in Xinjiang (Fig. 1), with meteorological elements mainly including temperature, height above ground, wind speed, and wind direction, with a vertical resolution of 1 second. Additionally, surface meteorological observation data from these 14 stations are used, mainly including daily maximum surface temperature and precipitation. Air quality monitoring data include daily air quality index (AQI) data from 10 cities in Xinjiang (selected cities with both radiosonde and air quality monitoring stations for correspondence), obtained from the National Urban Air Quality Real-time Release Platform of the Ministry of Environmental Protection (http://106.37.208.233:20035/).

## 1.2 Calculation Methods

**1.2.1 Mixing Layer Height** The maximum mixing depth (MMD) reflects the maximum atmospheric capacity in which pollutants can be diluted. It characterizes the dilution and diffusion of pollutants in the vertical direction and is one of the important indicators of atmospheric diffusion capacity. When the atmospheric boundary layer height is low, it acts like a lid limiting the vertical mixing of pollutants [?]. This paper uses the dry adiabatic method [?] and the stepwise approximation method proposed by Wang Shigong et al. [?] to calculate daily mixing layer height: (1) Identify the daily maximum temperature in surface temperature data; (2) On the logarithmic pressure chart (Fig. 2), start from the point of daily maximum surface temperature at 08:00, rise along the dry adiabatic line, and intersect with the sounding temperature profile between 09:00-18:00. The height of intersection point D from the ground is the mixing layer height for that day.

**1.2.2 Boundary Layer Ventilation** Boundary layer ventilation (V) is the sum of the product of different heights within the mixing layer and the corresponding wind speeds at those heights (using equal intervals in this paper), expressing the atmosphere' s ability to remove pollutants under the combined action of atmospheric dynamics and thermodynamics. The smaller the value, the less conducive to pollutant diffusion. The calculation method is as follows:

$$V = \int_0^h u(z)\, dz$$

where $h$ is the boundary layer mixing layer height (m), and $u(z)$ is the horizontal wind speed ($\mathrm{m \cdot s^{-1}}$) at height $z$ (m) above the ground.

**1.2.3 Boundary Layer Average Wind Speed** Boundary layer average wind speed (U) is a measure of the average rate of horizontal transport of air within the mixing layer, equal to the ventilation divided by the mixing layer height.

**1.2.4 Atmospheric Self-Cleaning Ability Index** This paper adopts the atmospheric self-cleaning ability index developed by the National Climate Center [**?**], with the calculation formula as follows:

$$ASI = \frac{V \times R \times C_s}{S}$$

where $ASI$ is the atmospheric self-cleaning ability index ($\mathrm{t \cdot d^{-1} \cdot km^{-2}}$), $V$ is ventilation ($\mathrm{m^2 \cdot s^{-1}}$), $R$ is precipitation rate ($\mathrm{mm \cdot d^{-1}}$), $C_s$ is the air quality control standard for typical pollutants ( $\mathrm{g \cdot m^{-3}}$), and $S$ is the unit area ($\mathrm{km^2}$). The rainout constant is $5 \times 10^{-5}\ \mathrm{s^{-1}}$, and the subscript $s$ indicates base area.

## 2 Results and Analysis

### 2.1 Temporal and Spatial Distribution Characteristics of Atmospheric Diffusion Parameters

**2.1.1 Mixing Layer Height** To obtain the temporal variation characteristics of mixing layer height in Xinjiang over the past 10 years, monthly and seasonal averages were calculated for the 14 radiosonde stations. The monthly variation shows an obvious inverted "V" shape (Fig. 3), with the maximum value (3139 m) appearing in June and the minimum value (580 m) appearing in December. The mixing layer height in Xinjiang shows large differences between winter and summer, with the maximum appearing in summer (2533 m in July), followed by spring (1623 m) and autumn (712 m), and the minimum appearing in winter (2423 m). This occurs because mixing layer height characterizes the maximum height at which lower-level air is transported to higher levels through thermal turbulence and thermal convection, influenced by surface heating, wind speed, and cloud cover (Fig. 2). In summer, Xinjiang experiences strong solar radiation and long sunshine hours, with less cloud and more wind, corresponding to large mixing layer heights. In winter, solar radiation is greatly weakened, and continuous cloudy fog or snowy weather often occurs along the Tianshan Mountains in northern Xinjiang (acting like a cloud cover over the near-surface layer). Combined with surface snow cover, these factors all weaken boundary layer development to some extent, resulting in minimum values in winter, consistent with previous research results [**?**, **?**].

Further analysis of mixing layer heights in different regions reveals significant differences between southern and northern Xinjiang (Fig. 4). The maximum monthly average mixing layer height in northern Xinjiang stations ranges from 2711-2927 m, while in southern Xinjiang and Hami stations, the maximum mixing layer height mainly ranges from 3176-3797 m. The mixing layer height in southern Xinjiang is significantly greater than that in northern Xinjiang, possibly due to terrain differences. Northern Xinjiang radiosonde stations are mostly distributed in plains or mountainous areas, while southern Xinjiang stations are mostly distributed around the Taklimakan Desert, where solar radiation is stronger in summer and non-adiabatic heating effects are more significant. On the other hand, the large latitudinal span between southern and northern Xinjiang results in longer solar radiation duration in southern Xinjiang than in northern Xinjiang, leading to generally greater mixing layer heights in southern Xinjiang. The monthly average mixing layer height in Karamay is generally greater than other stations in northern Xinjiang, approaching those in southern Xinjiang. For minimum monthly average mixing layer height, southern Xinjiang is also generally greater than northern Xinjiang, with southern Xinjiang values appearing between 577-897 m and northern Xinjiang mostly appearing between 274-434 m. Only Beitashan station shows a minimum in January. Beitashan station, at 1654 m altitude, is the only station above 1500 m among the 14 radiosonde stations. Its minimum monthly average mixing layer height appears in January, possibly related to its mountainous terrain, with specific reasons requiring further analysis.

**2.1.2 Boundary Layer Ventilation** As seen from the ventilation calculation formula, it is related to the mixing layer height and corresponding average wind speed at each layer within the mixing layer. Therefore, its monthly distribution is similar to that of mixing layer height (figure omitted), also showing an inverted "V" shape. The maximum value appears in June (20751 $m^2 \cdot s^{-1}$), and the minimum value appears in December (1898 $m^2 \cdot s^{-1}$). Seasonally, the maximum appears in summer (17861 $m^2 \cdot s^{-1}$), followed by spring (15977 $m^2 \cdot s^{-1}$) and autumn (15363 $m^2 \cdot s^{-1}$), with the minimum appearing in winter (7839 $m^2 \cdot s^{-1}$), consistent with the distribution characteristics of mixing layer height. The monthly average ventilation of all 14 stations reaches its maximum around June (Fig. 5), with little difference between southern and northern Xinjiang. However, the minimum values show significant regional differences, appearing in December for northern Xinjiang and eastern Xinjiang' s Hami, but in January for southern Xinjiang. Ventilation is not only closely related to mixing layer height but also to the number of windy days in Xinjiang. Research shows that Xinjiang has the most windy days in spring and summer, accounting for 68% of the year, followed by autumn, and the least in winter, accounting for 7% [?]. Thus, the seasonal distribution of windy days corresponds well with ventilation. Studies have pointed out that ventilation in China' s plateau and northwest regions is relatively large [?], which is also verified in this paper. Xinjiang' s summer ventilation is much greater than that of inland coastal provinces, while winter ventilation is much smaller (summer ventilation in Zhejiang ranges between 6000-7500 $m^2 \cdot s^{-1}$, winter around 5500 $m^2 \cdot s^{-1}$ [?]). Therefore, Xinjiang' s atmospheric diffusion conditions are poor in winter, prone to pollution weather, while summer diffusion conditions are good, with less pollution.

**2.1.3 Boundary Layer Average Wind Speed** The monthly distribution of boundary layer average wind speed still shows an inverted "V" shape (figure omitted), with the maximum appearing in June (5.8 $m \cdot s^{-1}$) and the minimum appearing in December (2.7 $m \cdot s^{-1}$). However, its monthly variation amplitude is relatively smaller compared with mixing layer height and ventilation. The seasonal distribution differs from the above variables, with the maximum appearing in spring (5.8 $m \cdot s^{-1}$), followed by summer (5.6 $m \cdot s^{-1}$) and autumn (4.5 $m \cdot s^{-1}$), and the minimum appearing in winter (2.9 $m \cdot s^{-1}$). The maximum monthly boundary layer average wind speed across Xinjiang basically appears around June (Fig. 6), while the minimum appears in December for northern Xinjiang and January for southern Xinjiang. Comparing southern and northern Xinjiang reveals little difference in boundary layer average wind speed, with no obvious pattern. This indicates that for Xinjiang, the timing of maximum and minimum wind speeds within the mixing layer is basically consistent between southern and northern Xinjiang, with similar wind speeds, providing no significant reference for temporal or spatial division of atmospheric diffusion conditions.

### 2.2 Temporal and Spatial Distribution Characteristics of Atmospheric Self-Cleaning Ability Index

The monthly variation of the atmospheric self-cleaning ability index (Fig. 7) shows an obvious inverted "V" shape, very similar to the ventilation distribution (Fig. 5) because Xinjiang has little precipitation with small magnitude, and precipitation' s contribution to atmospheric self-cleaning ability is limited. The atmospheric self-cleaning ability mainly depends on ventilation, as detailed in formula (3). In winter months (December-February), the atmospheric self-cleaning ability index shows smaller values, 不利于大气污染物的清除, while the remaining months show relatively larger values, conducive to pollutant removal. Seasonally (Fig. 8), the self-cleaning ability is greatest in summer (8.8 $t \cdot d^{-1} \cdot km^{-2}$), followed by spring (4.5 $t \cdot d^{-1} \cdot km^{-2}$) and autumn (1.4 $t \cdot d^{-1} \cdot km^{-2}$), and smallest in winter (0.3 $t \cdot d^{-1} \cdot km^{-2}$), consistent with the seasonal distribution of mixing layer height and ventilation. Research shows that atmospheric self-cleaning ability is highest in spring, followed by autumn, and lowest in winter in Heilongjiang [?], while in the Sichuan Basin it is strongest in spring, followed by winter, and weaker in summer and autumn [?]. These differences arise because ventilation and precipitation removal capacity vary by season. In comparison, Xinjiang' s atmospheric self-cleaning ability is more affected by ventilation and less by precipitation.

Figure 7 shows the monthly distribution of atmospheric self-cleaning ability index at each radiosonde station in southern and northern Xinjiang. The maximum values at northern Xinjiang stations range between 10.2-13.2 $t \cdot d^{-1} \cdot km^{-2}$, while southern Xinjiang stations range between 11.1-13.5 $t \cdot d^{-1} \cdot km^{-2}$. The minimum values in northern Xinjiang range between 0.3-1.1 $t \cdot d^{-1} \cdot km^{-2}$, while southern Xinjiang ranges between 0.9-1.8 $t \cdot d^{-1} \cdot km^{-2}$. Overall, the self-cleaning ability index in southern Xinjiang is greater than that in northern Xinjiang. Additionally, the peaks of self-cleaning ability at southern Xinjiang stations mostly appear in May, while those in northern Xinjiang mostly appear in June, indicating that the self-cleaning ability in southern Xinjiang begins to strengthen about one month earlier than in northern Xinjiang when transitioning from winter to summer.

### 2.3 Relationship Between Atmospheric Diffusion Conditions and Air Quality

The temporal and spatial distribution of atmospheric diffusion conditions analyzed above basically conforms to Xinjiang' s geographical and climatic characteristics, reflecting the region' s atmospheric diffusion capacity to some extent. However, whether these conditions correspond well with air quality at various stations is crucial for further suggestions on air pollution control. The correlation coefficients between AQI and the self-cleaning ability index, mixing layer height, and boundary layer average wind speed show obvious differences between southern and northern Xinjiang. Overall, the correlations between different physical parameters and AQI are good. From the perspective of the entire region, mixing layer height shows the best correlation with AQI in northern Xinjiang, eastern Xinjiang, and Hotan in southern Xinjiang, followed by the atmospheric self-cleaning ability index, and finally the boundary layer average wind speed. However, Urumqi station is an exception: the correlation between boundary layer average wind speed and AQI is the best, followed by mixing layer height and self-cleaning ability index. This may be because the difference between maximum temperatures on cloudy/foggy/snowy days and sunny days in Urumqi winter is large (solar radiation reaching the ground is greatly weakened on cloudy/foggy/snowy days, resulting in low daily maximum temperature, while sunny days have high daily maximum temperature), leading to large differences in daily mixing layer height. After monthly averaging, this 反而 cannot well reflect atmospheric diffusion conditions, so the correlation coefficient between mixing layer height and AQI is not as good as that with boundary layer average wind speed.

The relationship between atmospheric diffusion conditions and AQI is not uniform across southern Xinjiang stations. Aksu and Korla did not pass the significance test. Kashgar station shows a significant negative correlation between its self-cleaning ability index and mixing layer height with AQI, passing the 0.05 confidence test, but boundary layer average wind speed did not pass the significance test. Hotan station shows significant positive correlations for all three parameters, all passing the 0.01 confidence test, which is completely opposite to the relationship at northern Xinjiang stations. That is, in Hotan, stronger atmospheric diffusion capacity leads to poorer air quality, while weaker atmospheric diffusion capacity leads to better air quality.

## 3 Discussion

The atmospheric self-cleaning ability index, mixing layer height, ventilation, and boundary layer average wind speed in Xinjiang have unique temporal and spatial distribution characteristics that can serve as important references for air pollution prevention and control. Atmospheric diffusion capacity is strongest in summer and weakest in winter, with southern Xinjiang stronger than northern Xinjiang in both winter and summer. This is mainly due to differences in sunshine duration and intensity causing large differences in ground non-adiabatic heating, leading to differences in mixing layer height and consequently large disparities in diffusion conditions. Compared with inland coastal cities, Xinjiang has the best diffusion capacity in summer, making pollution weather unlikely, while winter diffusion capacity is the worst, conducive to pollution weather occurrence. This is also attributed to different climatic backgrounds between Xinjiang (continental climate zone) and inland coastal cities (monsoon zone).

The relationship between atmospheric diffusion capacity and pollutants cannot be generalized. The causes of pollution differ between southern and northern Xinjiang, and the role of diffusion conditions varies accordingly. Some cities, such as Urumqi and Altay, have both commonalities and unique characteristics in the relationship between their atmospheric diffusion conditions and pollutants compared with other stations across Xinjiang. Therefore, local special factors should be considered in air pollution prevention and control according to local conditions.

## 4 Conclusions

Unlike previous local or regional studies in Xinjiang, this paper statistically analyzed physical parameters such as atmospheric self-cleaning ability index, mixing layer height, ventilation, and boundary layer average wind speed from 14 radiosonde stations across Xinjiang, obtaining an overview of atmospheric diffusion capacity distribution across the region. It preliminarily revealed different meteorological conditions for pollutant diffusion in southern and northern

Xinjiang, laying a foundation for more in-depth air pollution research in the future. The main conclusions are as follows:

1) The atmospheric self-cleaning ability across Xinjiang is strongest in summer, followed by spring and autumn, and weakest in winter. The atmospheric self-cleaning ability in southern Xinjiang is better than that in northern Xinjiang in both winter and summer. The time when self-cleaning ability gradually improves from winter to summer in southern Xinjiang is about one month earlier than in northern Xinjiang.

2) The temporal distribution characteristics of atmospheric mixing layer height and ventilation are basically consistent with the atmospheric self-cleaning ability index, with maximum values appearing in summer and minimum values in winter, showing large differences between winter and summer. Summer mixing layer height is 2871 m, while winter is 712 m. The mixing layer height in southern Xinjiang (3176-3797 m) is significantly higher than that in northern Xinjiang (2711-2927 m). Xinjiang' s ventilation in spring (15977 $m^2 \cdot s^{-1}$) and summer (17861 $m^2 \cdot s^{-1}$) is much greater than in winter (7839 $m^2 \cdot s^{-1}$), and also much greater than inland coastal cities (summer ventilation in Zhejiang ranges between 6000-7500 $m^2 \cdot s^{-1}$, winter around 5500 $m^2 \cdot s^{-1}$ [?]). In summer, there is no significant difference in ventilation between southern and northern Xinjiang, but in winter, ventilation in southern Xinjiang is significantly greater than in northern Xinjiang.

3) The temporal distribution characteristics of boundary layer average wind speed differ from the above three physical variables in that its maximum appears in spring (5.8 $m \cdot s^{-1}$), followed by summer (5.6 $m \cdot s^{-1}$), with the minimum still appearing in winter (2.9 $m \cdot s^{-1}$). Its temporal characteristics and numerical values show little change between southern and northern Xinjiang, providing no significant reference for temporal or spatial division of atmospheric diffusion conditions.

4) The atmospheric diffusion capacity across Xinjiang (self-cleaning ability index, mixing layer height, ventilation, boundary layer average wind speed) is correlated with AQI, but the performance differs between southern and northern Xinjiang. In northern Xinjiang, these indices are basically significantly negatively correlated with AQI. In southern Xinjiang, most stations did not pass the 0.05 significance test; only Hotan station passed the 0.01 confidence test for all three physical parameters, but they are significantly positively correlated. Overall, mixing layer height has the best correlation with AQI, followed by self-cleaning ability index and boundary layer average wind speed, though different stations show slight differences due to their particularities.

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## Figures

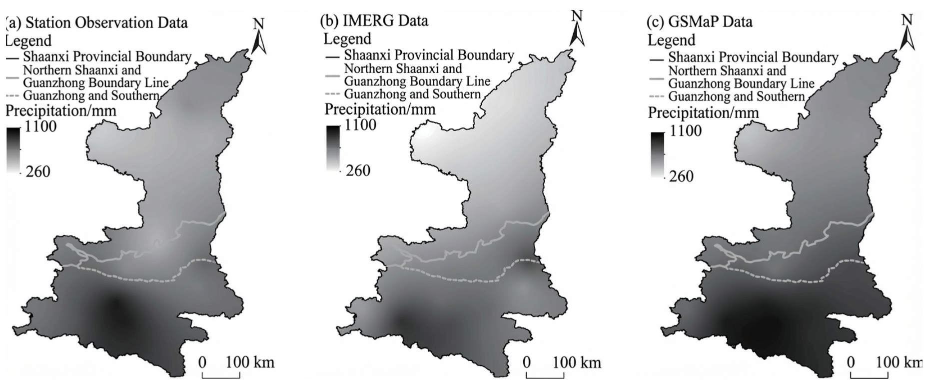


Figure 1: Figure 2

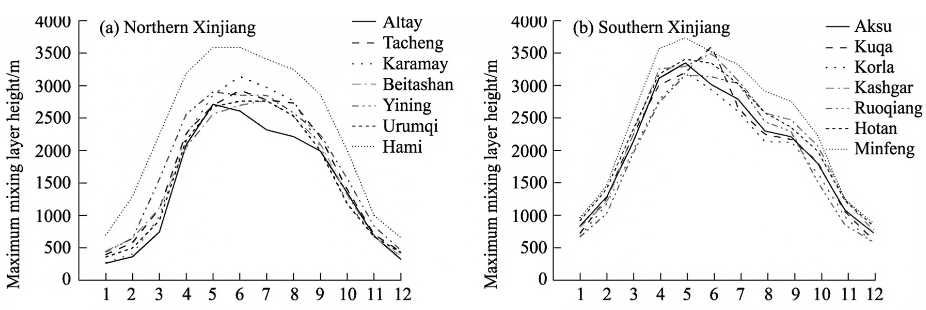


Figure 2: Figure 3

*Source: ChinaXiv —Machine translation. Verify with original.*