Analysis of Aircraft Observations of Winter Aerosol Vertical Distribution in Turpan and Ruoqiang (Postprint)

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Abstract

Using a total of 14 complete sets of airborne aerosol detection data from Turpan in winter 2019 and Ruoqiang in winter 2020, combined with macro-scale weather data and air pollution data, this study investigates the vertical variation patterns of aerosol particle number concentration and mean particle diameter above the two regions during aircraft ascent or descent phases, and analyzes the particle size distribution characteristics at different altitudes. The results show: (1) Significant differences exist in winter aerosol particle number concentration and particle diameter between the two regions. Under conditions without obvious weather processes, the mean aerosol particle number concentration in Ruoqiang (5354 cm^{-3}) is significantly higher than that in Turpan (3948 cm^{-3}); regarding mean particle diameter, the difference in mean values is not substantial, however, the number of large-diameter particles appearing in Turpan (0.16 m) is higher than in Ruoqiang (0.13 m). This was most evident after the strong wind event on December 15, 2019, when the maximum particle diameter reached 0.21 m, which is largely associated with dust aerosols. From the perspective of vertical variation, aerosol particle number concentrations in both regions increase with altitude, with each layer in Ruoqiang generally higher than in Turpan; however, the near-surface particle diameter in Turpan shows a significant decrease with increasing altitude, while the variation throughout the entire layer in Ruoqiang is minimal. (2) Aerosol particle number concentration and mean particle diameter in both Turpan and Ruoqiang are significantly influenced by weather processes such as strong winds and precipitation, as well as by temperature inversion layers. The upper layers in both regions are primarily dominated by imported aerosols, while the differences in the lower layers are mainly due to atmospheric environmental pollution caused by emissions of anthropogenic aerosol particles in the Turpan region. (3) The particle size distributions in both Turpan and Ruoqiang show broadly consistent variation trends within the 0.10–3.00 m range, predominantly characterized by small particle sizes, with the spectral distribution exhibiting relatively obvious changes influenced by weather processes. (4) From the comparison of three-modal particle size similarity, it can be concluded that for both Turpan and Ruoqiang, the number spectrum distribution shows little difference in the first mode, with the average similarity in Ruoqiang being 50.330%, slightly higher than that in Turpan at 46.770%. During periods with obvious weather processes, the similarity of the aerosol number spectrum in Turpan for the second and third modes (less than 0.020%) drops sharply, whereas the similarity for the second mode in Ruoqiang still meets the 95% confidence level, but changes become prominent in the third mode, with similarity falling below 0.020%.

Full Text

Aircraft Observation and Analysis of Vertical Distribution of Aerosols in Winter in Turpan and Ruoqiang

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Abstract

This study investigates the vertical variation of aerosol particle number concentration and average particle diameter during aircraft ascent and descent phases over two locations, using a total of 14 complete airborne aerosol detection datasets from Turpan City in winter 2019 and Ruoqiang County in winter 2020, combined with macro-scale weather data and air pollution monitoring data. The characteristics of particle size distribution at different altitudes were also analyzed. The results indicate: (1) Significant differences exist in winter aerosol particle number concentration and diameter between the two locations. Under conditions without obvious weather processes, the mean aerosol particle number concentration in Ruoqiang (5354 cm^{-3}) is substantially higher than in Turpan (3948 cm^{-3}). While the difference in mean particle diameter is small, Turpan exhibits more large-diameter particles (0.21 m), particularly evident after strong wind events on December 29, with maximum particle diameters reaching 0.13 m, likely associated with dust aerosols. (2) Both locations show increasing aerosol particle number concentration with altitude, with Ruoqiang consistently higher than Turpan at all levels. However, near-surface particle diameter in Turpan decreases significantly with height, whereas Ruoqiang shows minimal variation throughout the atmospheric column. (3) Aerosol particle number concentration and average diameter in both areas are significantly influenced by weather processes such as strong winds and precipitation, as well as by temperature inversion layers. The upper layers in both regions are dominated by transported aerosols, while lower-layer differences primarily result from anthropogenic aerosol emissions in the Turpan area that have led to atmospheric environmental pollution. (4) The particle size distribution trends in the 0.10–3.00 m range are generally consistent between the two locations, predominantly featuring small particles, with the spectrum distribution showing noticeable changes due to weather processes. (5) Comparison of three-modal particle size similarity reveals that in the first mode, both Turpan and Ruoqiang show similar number spectrum distributions, with Ruoqiang’ s average similarity (50.330%) slightly higher than Turpan’ s (46.770%). However, the third mode shows prominent variations, with similarity below 0.020%. During significant weather processes, the similarity of Turpan’ s aerosol number spectrum in the second and third modes drops sharply (below 0.020%), while Ruoqiang’ s second-mode similarity still meets confidence thresholds.

Keywords: aerosol; aircraft detection; vertical distribution; aerosol particle number concentration; particle diameter

1 Introduction

Aerosols (with diameters of 0.01-100 m) constitute a multiphase system comprising the atmosphere and suspended solid and liquid particles [1]. It is well known that solar radiation represents the Earth’ s most important energy source. Aerosols influence solar radiation through absorption and scattering, thereby exerting heating or cooling effects on the atmosphere, which alters atmospheric thermal conditions. This not only affects atmospheric dynamic structures but also holds significant implications for atmospheric circulation, precipitation distribution, and medium-to-long-term weather forecasting. Since the Industrial Revolution, global industrialization has led to continuous increases in emissions of industrial waste gases and chemical pollutants, causing severe air pollution and threatening human health. PM2.5, also known as fine particulate matter, can directly enter human lungs and deposit in alveoli. Consequently, the increasing aerosol load not only pollutes the environment but also accelerates impacts on global climate change trends. Compared with the 20th century, concentrations of these anthropogenic aerosols have shown an exponential growth trend [2]. In some severely polluted regions of central China, the direct radiative effects of aerosols on atmospheric temperature profiles and circulation have become prominent, with varying impacts on aerosol layer height, thickness, and optical properties. Therefore, environmental and climate changes caused by aerosols have received widespread attention from both the public and the scientific community.

Aircraft-based observations of atmospheric aerosols using airborne particle detection equipment emerged in the 1970s. In China, airborne detection began relatively later, initially focusing on environmental effects. Wang Xihong et al. [3] studied salt aerosols, providing reference for environmental effect models and climate change assessment predictions through research on particle size distribution, chemical composition, and radiative (optical) properties. Regarding dust aerosols, Gao Weidong et al. [4] found that aerosol concentrations during dust storms in the Tarim region were much greater than during non-dust storm periods. Tian Lei et al. [5] calculated and analyzed the effects of dust aerosols on solar radiation and atmospheric counter-radiation, concluding that dust has a certain weakening effect on total solar radiation. Shen Yanbo et al. [6] conducted observational analysis of aerosol particle number concentration in the Dunhuang area, examining the relationship between aerosol particle number concentration and dust weather for two underlying surfaces (gobi desert and oasis farmland), as well as differences in number concentration. Additionally, Gao Yuxiao et al. [7] analyzed the correlation between MODIS aerosol optical depth and ground monitoring station PM2.5 concentration data, finding good correlation. Fan Xuewei et al. [8] studied the effects of aerosols on ice clouds using CALIOP Level 3 monthly mean products and Level 2 daily mean products, concluding that latitude is closely related to ice cloud distribution.

With the continuous deployment of high-performance aircraft and improved stability of airborne detection equipment, direct aircraft observation of aerosol particles has become an indispensable means of understanding aerosol basic characteristics [9]. Zhang Qiang et al. [10] analyzed 11 flight observation datasets from Beijing, concluding that vertical distribution characteristics of aerosols are closely related to meteorological conditions. Huang Mengyu et al. [11] found that regional distribution characteristics of aerosol particles differ significantly across regions; for example, Beijing' s aerosol particle number concentration exceeds 6000 cm^{-3}, with fine-mode particles mainly distributed within the boundary layer, while Shanxi' s aerosol particle number concentration is 1000 cm^{-3}, primarily accumulation-mode particles [12]. Zhu Shouzheng et al. [13] conducted flight experiments using an airborne high-spectral-resolution lidar system based on an iodine molecular filter to study aerosol variation trends in the Qinhuangdao area, aerosol distribution under different underlying surface types, and high-value areas of Qinhuangdao aerosols, finding good correlation among the three. Zhao Delong et al. [14] used a King Air aircraft platform equipped with a single-particle soot photometer (SP2) for continuous observations of a pollution process in Beijing during autumn 2016, concluding that the pollution process was primarily a haze pollution event dominated by PM2.5, with maximum values reaching 432 $g \cdot m^{-3}$.

Undeniably, many regions face extreme scarcity in observations of aerosol vertical distribution due to limitations in detection equipment and funding. Moreover, atmospheric aerosol spatiotemporal distributions are complex and diverse, necessitating continuous aerosol detection and analysis across different regions to compensate for spatial data gaps. Xinjiang, located in the hinterland of the Eurasian continent, serves as a strategic resource hub and Eurasian corridor. In advancing the magnificent “Belt and Road” initiative, the nation aims to transform Xinjiang into the “core area of the Silk Road Economic Belt,” making it a pivotal transportation, commercial logistics, and cultural-educational center on the Silk Road. Turpan, the gateway to Urumqi, enjoys a superior geographical location. In December 2019, the city’ s air quality index (AQI) once ranked last nationally. Ruoqiang, located in the southeastern part of Bayingolin Mongol Autonomous Prefecture on the southeastern edge of the Taklamakan Desert, experienced a strong dust weather event in January 2020 with visibility below 100 m, creating conditions like being in a sea of sand. Haze and dust weather [15] have received high attention from governments at all levels, with many scholars dedicated to effectively reducing atmospheric haze phenomena. As haze events intensify, more detection flights have been conducted under hazy conditions, yielding research results on aerosol mechanisms in haze weather [16-18]. Previously, high-performance aircraft-based aerosol detection flights in Xinjiang were virtually nonexistent. Since the end of 2019, aerosol detection flights have been conducted in Turpan and Ruoqiang, analyzing aerosol particle number concentration, vertical distribution, and average particle diameter, which is significant for understanding the spatiotemporal distribution and physical-chemical characteristics of atmospheric aerosols in both locations.

2 Study Area

Turpan is an olive-shaped intermountain basin oriented east-west in the eastern Tianshan Mountains, surrounded by mountains on all sides, extending from Alashankou in the west to the western mouth of the Qijiaojing Canyon in the east. With long sunshine duration (approximately 3200 hours annually), dry, hot, and windy conditions, it belongs to a typical continental warm temperate desert climate characterized by high evaporation, low precipitation, mild winters with little cold, wind, and snow, making it one of the most arid and low-rainfall regions in China and worldwide. Due to Turpan’ s greatly undulating terrain with elevation differences reaching 5600 m and large temperature amplitude, multiple windy days occur, making soil dust from strong winds and surrounding small industrial sources the primary aerosol contributors.

Ruoqiang is located within Bayingolin Mongol Autonomous Prefecture in Xinjiang Uygur Autonomous Region, bordering Qiemo County to the west and Yuli County, Shanshan County, and Hami City to the north. The area features alternating mountains and basins with diverse terrain. Ruoqiang has a warm temperate continental climate characterized by cold winters, hot summers, dryness, and low rainfall, with abundant solar resources, long sunshine duration, and large diurnal temperature variation. The average annual precipitation is only 28.5 mm. Due to its western adjacency to the eastern Taklamakan Desert and southeastern connection with the Kumtag Desert, its geographical location is relatively special compared with other northern Xinjiang regions, providing abundant sand sources. Fine particles smaller than 2.5 m in its soil reach 46.770%, making it a major and potential source of atmospheric dust aerosols

[19].

3 Data and Methods

The data used in this study consist of atmospheric aerosol data from aircraft ascent and descent phases above the airports, combined with hourly visibility data corresponding to each flight hour (Table 2). Since Ruoqiang lacks environmental monitoring stations, only Turpan Environmental Protection Bureau data are listed for corresponding time periods. The PM2.5 and PM10 hourly concentration data were obtained from monitoring stations of the Ministry of Ecology and Environment (http://www.aqistudy.cn/historydata/). It is evident that Ruoqiang' s visibility (mean 15.5 km) is significantly better than Turpan' s (mean 6.7 km) during corresponding ascent/descent periods. In four of Turpan' s detection flights, PM2.5 reached Level 3 light pollution (101-150), and in one flight reached Level 4 moderate pollution. Level 4 moderate pollution may have certain impacts on the cardiovascular and respiratory systems of healthy populations.

Analysis of Turpan' s PM2.5 data shows PM2.5/PM10 ratios of 76.1%, 50.5%, 48.4%, 66.7%, 69.7%, 48.8%, and 49.0% for the seven flights, indicating that small particles (smaller than 10 m) account for half or more of the total, demonstrating that excessive emissions of anthropogenic aerosol particles from industrial development around Turpan may have exacerbated local atmospheric environmental pollution. Figure 2 shows the flight trajectories of the operational aircraft.

3.1 Airborne Detection Instrumentation

The flight detection utilized a King Air 350 aircraft manufactured in the United States, with a modified maximum ceiling of 8400 m, cruise speed of 400 km $\cdot$ h^{-1}, climb rate of 400 m $\cdot$ min^{-1}, maximum detection range of 3700 km, and maximum payload of 7200 kg. The aircraft was equipped with a Particle Measurement System from the U.S.-based Droplet Measurement Technologies company. The aircraft conducted detection flight missions in Turpan and Ruoqiang during the winters of 2019 and 2020. Instrumentation included: a cloud radar, passive aerosol spectrometer probe, cloud condensation nuclei counter, cloud combination probe, precipitation particle imaging probe, hot-wire liquid water content sensor, and aircraft integrated meteorological monitoring system.

This paper primarily processes and analyzes meteorological elements and passive aerosol spectrometer detection data (Figure 1). The aircraft integrated meteorological measurement system primarily measures temperature, air pressure, dynamic pressure, relative humidity, wind direction, wind speed, and other meteorological and aircraft flight parameters, with a sampling frequency of 1 Hz. The passive aerosol spectrometer probe utilizes Mie scattering principles to measure aerosol particle size spectra and concentration, thereby obtaining atmospheric aerosol particle distribution characteristics. The measurement range is 0.10-3.00 m, with minimum resolution of 0.01 m and sampling volume of 1 $\mathrm{L \cdot min^{-1}}$. Channel spacing corresponds to particle diameter ranges: 0.10-0.18 m, 0.18-0.30 m, 0.30-0.60 m, and 0.60-3.00 m, with intervals of 0.02 m, 0.10 m, 0.20 m, and 0.01 m, respectively.

3.2 Flight Overview and Data

Table 1 presents the general flight conditions and actual weather conditions for 14 flights with complete detection data. Aircraft takeoff and landing occurred at Turpan Jiaohe Airport (elevation 214 m) and Ruoqiang Loulan Airport (elevation 891 m). To reduce instrumental errors and differences in ascent/descent speeds, average values were calculated for each altitude layer using $±$50 m bins. The calculated altitudes for Turpan and Ruoqiang were 400–4000 m and 1000–4600 m, respectively.

The passive aerosol spectrometer data were processed to calculate corresponding results using the following methods:

- **N** represents aerosol particle number concentration ($\mathrm{cm^{-3}}$)
- **n** represents particle number concentration in channel i ($\mathrm{cm^{-3}}$)
- **D** represents the median diameter of channel i (m)
- **D** represents average particle diameter (m)

3.3 Kolmogorov-Smirnov Nonparametric Test (KS Test)

The KS test is a nonparametric test commonly used to determine whether a sample distribution is consistent with a predetermined distribution, or whether the probability distributions of two samples are identical. Unlike t-tests and other methods, the KS test does not require knowledge of the data distribution. When sample sizes are small, the KS test is particularly common in nonparametric analysis to determine whether two datasets differ. When two distributions are similar, the distance between them is naturally very small. This statistic describes the maximum distance. The principle assumes that two data distributions are consistent. When the actual observed value D exceeds the critical value D(n,α) (where n is sample size and α is confidence level), the null hypothesis is rejected, indicating the data originate from different distributions. This paper selects a confidence level of $\alpha = 0.05$. Generally, when the P-value is below 0.05, the null hypothesis is rejected.

4 Results

4.1 Statistical Characteristics of Aerosols

Table 3 presents statistical calculations of aerosol particle number concentration and average particle diameter during takeoff and landing phases for the 14 detection flights in Turpan and Ruoqiang. Analysis of the first seven Turpan detection flights shows that aerosol particle number concentration varied within a narrow range, maintaining approximately 3900 $\mathrm{cm^{-3}}$. After the strong wind process in the early morning of December 29, the minimum aerosol particle number concentration of 1263 cm^{-3} appeared, which was the lowest value among the first seven detections. This process simultaneously produced extreme values for maximum, minimum, and mean average particle diameter, indicating that the wind process broke the previous colloidal structure of aerosols, causing a brief increase in particle number concentration. However, during the dissipation process, large-diameter particles were significantly scavenged by gravity, reducing concentration, while numerous small-diameter particles remained, thereby increasing number concentration and particle diameter.

From the air pollution index perspective, PM2.5 approached moderate pollution, with the AQI reaching its maximum across the seven detection flights, demonstrating that after strong wind processes, natural-source aerosols combined with anthropogenic-source aerosols increased particle number concentration and worsened air pollution. The actual weather on January 10 was overcast turning to light snow, with snowfall beginning at 23:00 and lasting over ten hours. Shanshan County recorded maximum snowfall of 9.8 mm, breaking historical records as the largest snowfall in over 100 years since station establishment. The January 10 detection flight data show that number concentration increased with altitude. The day was cloudy, with floating dust occurring from 00:00–06:00 and light snow in mountainous areas. Weather processes significantly impact the vertical distribution of aerosol particle number concentration. First, before weather processes, there are slow updrafts that cause aerosol particle number concentration to be 3–4 times higher than average. Second, weather processes have obvious scavenging effects on aerosols, reducing number concentration while diameter remains unchanged. Third, temperature inversions exist, making the vertical distribution of number concentration relatively stable. Finally, after weather processes (Figure 5), high-level transported aerosols are replenished in time, and number concentration at each altitude gradually increases, slowly restoring the original stable colloidal structure.

Overall, both Turpan and Ruoqiang show transported aerosols in upper layers and localized aerosols in lower layers. Differences may be caused by strong wind weather and rapid industrial development in Turpan in recent years, which have accelerated anthropogenic aerosol emissions. From the perspective of vertical variation in number concentration, under clear or cloudy weather conditions, Ruoqiang' s aerosol number concentration is generally greater than Turpan' s. Turpan' s near-surface particle radius shows obvious fluctuations with height, while Ruoqiang shows almost no change, indicating that compared with Turpan, Ruoqiang has relatively fewer large-diameter particles, dominated by numerous small dust aerosols. Its geographical location also determines that this region has less industrial activity and fewer anthropogenic activities, thus fewer anthropogenic-source aerosol particles emitted by human activities.

4.2 Vertical Distribution Characteristics of Aerosol Particle Number Concentration and Average Diameter at Different Altitudes

Atmospheric aerosols consist of particles of many different scales, making the distribution of number concentration across different size ranges one of the most important physical quantities for describing aerosols, known as particle size distribution. Different microphysical processes such as hygroscopic growth, coagulation, and aggregation can cause significant changes in particle size distribution. Similarly, meteorological elements such as temperature, relative humidity, wind direction, and wind speed have extremely important effects on the aggregation, dissipation, and hygroscopic capacity of aerosol particles in horizontal and vertical directions [20].

Figures 3 and 4 present the vertical distributions of aerosol particle number concentration and average particle diameter during takeoff and landing phases for each flight in Turpan and Ruoqiang, respectively. To reduce instrumental errors and differences in ascent/descent speeds, average values were calculated for each altitude layer using $±$50 m bins. The calculated altitudes for Turpan and Ruoqiang were 400–4000 m and 1000–4600 m, respectively. Figure 5 shows the vertical distributions of aerosol particle number concentration, temperature, and relative humidity for detection flights on December 15 and 24, 2019 (takeoff) and December 29, 2019 (landing).

From the perspective of vertical variation in particle diameter for the seven Turpan detection flights (Figure 3), particle diameter changes very little whether at low or mid-high altitudes, with average particle diameter around 0.11 m. From Table 3, it can be seen that on December 29, the number of large-diameter particles was significantly higher than in the other six detection flights, with weather processes after floating dust weather causing floating dust dominated by fine sand aerosols to dissipate slowly.

From the vertical distribution of number concentration and particle diameter in the seven Ruoqiang detection flights (Figure 4), changes in number concentration and particle diameter are not obvious. The floating dust weather on January 8 caused aerosol particle number concentration to first decrease and then increase, with average particle diameter slightly increasing.

4.3 Aerosol Particle Size Distribution Characteristics

Figure 6 shows the particle size distribution of aerosols at specified altitudes for each flight in Turpan and Ruoqiang. Due to large variations in number concentration, logarithmic coordinates are used to facilitate analysis and discussion. As seen in Figure 6, the overall variation trends of particle size distribution in the 0.10–3.00 m range are generally consistent between the two locations, primarily dominated by small particles, with spectrum distribution showing obvious changes due to weather processes.

From the seven Turpan detection flights, the particle size distribution on December 15 (Figure 6a) shows that under the influence of a temperature inversion layer, convective motion development was suppressed. High temperature and low humidity were unfavorable for particle condensation growth but facilitated diffusion to higher levels or the ground, leading to increased number concentration of small-diameter particles at high levels and near the surface, deteriorating near-surface air quality and increasing the AQI, indicating severe air pollution. The particle size distribution on December 24 (Figure 6b) shows that the snowfall process had a significant impact on aerosol number concentration, breaking its original spectrum distribution. The existence of the temperature inversion layer hindered convective motion, suppressed diffusion of aerosol particles in the lower atmosphere, and destroyed its original vertical distribution. The other five flights showed second- and third-mode similarities of 23.640% and 31.550%, respectively.

From the seven Ruoqiang detection flights, the overall particle size distribution showed minimal change, but the floating dust weather on January 8 resulted in a significantly higher number of large-diameter particles than in the other six detection flights, with particles in the 1.00–3.00 m range dominating.

4.4 Similarity of Aerosol Particles in Different Modes

To quantitatively understand the aerosol number spectrum distribution characteristics in Turpan and Ruoqiang, the KS test was applied to aerosol number spectra in different modes to understand their distribution patterns. The 0.10-3.00 m diameter range was divided into three modes: 0.10–0.20 m, 0.20–1.00 m, and 1.00–3.00 m. The similarity of number spectra between each effective detection flight was calculated for each mode.

From Tables 4 and 5, it is evident that whether in Turpan or Ruoqiang, the number spectrum distribution shows little difference in the first mode, with maximum similarity reaching 100.000% in both locations. Ruoqiang’ s average similarity is 50.330%, slightly higher than Turpan’s 46.770%. However, the third mode shows prominent variations, with similarity below 0.020%. During significant weather processes, the similarity of Turpan’ s aerosol number spectrum in the second and third modes drops sharply to below 0.020%, with extremely low similarity. The existence of the temperature inversion layer breaks its original spectrum distribution. In contrast, Ruoqiang’ s second-mode similarity in the January 8 detection flight still meets confidence thresholds, with number spectrum only changing significantly in the third mode.

5 Discussion

In recent years, multi-channel approaches such as ground-based measurements, sounding balloons, and satellite remote sensing retrievals have become common for obtaining aerosol data. Numerous scholars have conducted series of studies on particle concentrations, geographical locations, weather conditions, and pollution status. Since fine particles affect not only radiative balance and environmental quality but also threaten human health, aircraft, as the most effective atmospheric detection instrument carrier, have efficiently advanced mesoscale weather observation and cloud microphysics research. The continuous deployment of high-performance aircraft equipped with detection instruments has filled gaps in spatial data structures for aerosols and other particles of different scales. Aircraft can travel large distances in short periods to obtain spatial data structure information for different parameters, while also conducting real-time, insitu, precise, and detailed observations, making them widely used in mesoscale observation and cloud microphysics research. High-performance aircraft can also use satellite relay systems to transmit detection data in real time, playing an important role in supplementing meteorological data for sparsely populated areas such as oceans and deserts.

Fast flight speeds, large temperature differences between high and low altitudes, and flight turbulence impose special requirements on the design and measurement technology of airborne detection instruments, such as high sensitivity, low lag effect, and high measurement precision. Additionally, intense mechanical vibrations in aircraft also demand high measurement precision.

6 Conclusions

This study utilizes 14 complete aerosol detection datasets from Turpan in winter 2019 and Ruoqiang in winter 2020 to investigate variations in aerosol particle number concentration and average particle diameter in the 0.10–3.00 m range during aircraft ascent and descent phases over both locations, providing particle size distribution characteristics at various altitudes during takeoff and landing phases. The main conclusions are:

(1) Winter aerosol particle number concentration and average particle diameter show significant differences between Turpan and Ruoqiang. Under conditions without obvious weather processes, Ruoqiang’ s maximum aerosol particle number concentration (11829 cm^{-3}) and mean value (5354 cm^{-3}) are significantly higher than Turpan’ s (maximum 8045 cm^{-3}, mean 3948 cm^{-3}), while its minimum value (2276 cm^{-3}) is generally lower than Turpan’ s (1421 cm^{-3}). Regarding average particle diameter, the difference between the two locations is small, but Turpan has more large-diameter particles (0.21 m) than Ruoqiang (0.16 m), particularly evident after strong winds on December 29, with maximum particle diameter reaching 0.13 m, which is closely related to dust aerosols.

(2) Aerosol particle number concentration and average particle diameter in both locations are significantly affected by weather processes such as strong winds and precipitation, as well as temperature inversion layers. Strong wind processes cause aerosol particle number concentration to increase. Before snowfall processes, slow updrafts cause aerosol particle number concentration to be 3–4 times higher than average. Dry, low-humidity conditions prevent supersaturated aerosol particles from

hygroscopically growing into micro-cloud droplets, so particle diameter changes are not obvious. Under temperature inversion layer influence, convective motion is hindered, diffusion of aerosol particles in the lower atmosphere is suppressed, and vertical distribution is disrupted, thereby worsening Turpan' s air pollution index.

(3) Overall, both Turpan and Ruoqiang have transported aerosols in upper layers and localized aerosols in lower layers. Differences may be caused by strong wind weather and rapid industrial development in Turpan in recent years, which have accelerated anthropogenic aerosol emissions. From the perspective of vertical variation in number concentration, under clear or cloudy weather conditions, Ruoqiang' s aerosol number concentration is generally greater than Turpan' s, with both increasing with altitude. However, Turpan' s near-surface particle radius fluctuates obviously with height, while Ruoqiang shows almost no change. This indicates that compared with Turpan, Ruoqiang has relatively fewer large-diameter particles, dominated by numerous small dust aerosols. Its geographical location also determines that this region has less industrial activity and fewer anthropogenic activities, thus fewer anthropogenic-source aerosol particles emitted by human activities.

(4) The particle size distribution (0.10–3.00 m diameter) in Turpan and Ruoqiang shows generally consistent variation trends, primarily dominated by small particles, with spectrum distribution showing obvious changes due to weather processes. Comparison of three-modal particle size similarity reveals that in the first mode, both Turpan and Ruoqiang show little difference in number spectrum distribution, with maximum similarity reaching 100.000% in both locations. Ruoqiang' s average similarity is 50.330%, slightly higher than Turpan' s 46.770%. During significant weather processes, the similarity of Turpan' s aerosol number spectrum in the second and third modes drops sharply to below 0.020%, with extremely low similarity, indicating that the temperature inversion layer breaks its original spectrum distribution. In contrast, Ruoqiang' s second-mode similarity in the January 8 detection flight still meets confidence thresholds, with number spectrum only changing significantly in the third mode, with similarities of 28.340% and 15.440%, respectively.

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Note: Figure translations are in progress. See original paper for figures.