Relationship between Atmospheric Mixing Layer Thickness and Stability and Air Pollution in Urumqi (Post-print)

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Abstract

Using meteorological observation data from four 10-level 100 m gradient meteorological towers in Urumqi from June 2013 to April 2014 and [WTBX]AQI[WTBZ] data from seven environmental monitoring stations, the characteristics of atmospheric mixing layer height and stability were calculated and analyzed, and the relationship between atmospheric mixing layer height, stability, and pollution was investigated. The results show that: the mixing layer height in Urumqi is higher in suburban areas and lower in urban areas in summer, and decreases sequentially from south suburb—urban area—north suburb with decreasing terrain in winter; it ranges between 1,559-1,772 m in summer and 526-1,156 m in winter. Statistical analysis of mixing layer height at 500 m intervals from the surface to above 2 km shows the highest frequency occurs in the 500-1,000 m range; monthly variation indicates that from June to September it is basically above 500 m, with each height interval exceeding 10% probability, while from October to February of the following year the probability above 1,500 m decreases significantly; diurnal variation reaches its maximum at noon 13:00-16:00, then declines rapidly in the afternoon and evening. The larger sensible heat flux during daytime provides sufficient thermal conditions, which also demonstrates that unstable stratification dominates during the day, while stable stratification prevails at night. Atmospheric stability classification results show that the proportion of unstable conditions (classes A-C) is similar between suburban and urban areas in summer, while in winter the proportion of stable conditions (classes E, F) is largest in the north suburb and weakest in the urban area. [WTBX]AQI 指数 is highest in winter, increasing sequentially from south suburb—urban area—north suburb, which is related to increased pollutants during the heating period and the higher terrain of the south suburb relative to the north suburb favoring diffusion and transport. Overall, the spatial distribution of atmospheric mixing layer height in Urumqi is closely related to meteorological elements, atmospheric stability,

terrain, etc., and has an important influence on the distribution of AQI[WTBZ] index, which has significant guiding importance for forecasting near-surface air pollution conditions.

Full Text

Abstract

Meteorological observation data from four meteorological towers (each 100 meters high with ten layers) and Air Quality Index (AQI) observation data from seven environmental monitoring stations in Urumqi City, Xinjiang, China, were collected during the period from June 2013 to April 2014 to analyze the characteristics of atmospheric mixed layer thickness and stability in this region, as well as their relationship with atmospheric pollution. The results indicated that the thickness of the mixed layer was higher in suburban areas and lower in urban areas during summer, and it decreased along with the terrain from the southern suburbs to the urban areas, and then to the northern suburbs in winter. The thickness of the mixed layer ranged between 1559 and 1772 meters in summer, and between 526 and 1156 meters in winter. When measured at 500-meter intervals from the ground up to 2 km, the mixed layer showed the highest emergence frequency at heights between 500 and 1000 meters. In terms of monthly variation, the mixed layer was basically above 500 meters from June to September, with the probability at each height interval being more than 10%. The probability above 1500 meters was significantly reduced from October to the following February. Regarding daily variation, the mixed layer thickness peaked from 13:00 to 16:00 PM and dropped rapidly after 16:00 PM. Large sensible heat transfer provided sufficient thermal conditions during the daytime, which was also reflected by the fact that unstable stratification occurred mainly during the day while stable stratification occurred at night. When atmospheric stability was classified, the percentage of unstable conditions (A-C) was almost the same between suburban and urban areas in summer, but in winter the percentage of stable conditions (E, F) was highest in the northern suburbs while weakest in urban areas. The AQI index was highest in winter, and it increased along with the decreasing terrain from the southern suburb to the urban area, and then to the northern suburb, which was related to the fact that there were more pollutants during the heating period, and the higher terrain in the southern suburbs favored pollutant diffusion. In general, the spatial distribution of atmospheric mixed layer thickness was related to meteorological elements, atmospheric stability, and terrain, and it had great influence on the distribution of AQI index. This study provided important information for the prediction of air pollution conditions.

Keywords: Urumqi; pollution; thickness of atmospheric mixed layer; atmospheric stability

1. Introduction

Atmospheric pollution has become a major environmental issue affecting urban development and human health. Since the 1980s, research on atmospheric mixed layer thickness has received increasing attention from scholars both domestically and internationally. Previous studies have calculated and analyzed mixed layer thickness using various methods, including conventional meteorological observation data, numerical models, and remote sensing techniques. However, research on the relationship between mixed layer thickness and air pollution under different terrain conditions in arid regions remains limited.

Urumqi, located in an arid region with complex terrain, experiences severe atmospheric pollution, particularly during winter heating periods. The city' s unique topographical features, surrounded by mountains with elevation differences, significantly influence atmospheric circulation and pollutant dispersion. Understanding the characteristics of atmospheric mixed layer thickness and its relationship with air quality is crucial for improving pollution forecasting and environmental management in this region.

2. Data and Methods

2.1 Observation Data

The study utilized data from four 100-meter meteorological towers equipped with sensors at ten vertical levels, providing continuous measurements of temperature, wind speed, and wind direction. Additionally, AQI data from seven environmental monitoring stations across Urumqi were collected for the period from June 1, 2013, to May 16, 2014.

2.2 Calculation of Mixed Layer Thickness

Mixed layer thickness was calculated using conventional meteorological observation data. The calculation methods considered various stability parameters and meteorological conditions. The towers were located in different areas: southern suburbs (YNLJ), urban area (LYS), northern suburbs (HGS), and another suburban site (MD), allowing for comprehensive spatial analysis.

2.3 Analysis Methods

The study analyzed both seasonal and diurnal variations of mixed layer thickness. Statistical methods were employed to determine the frequency distribution at different height intervals. Atmospheric stability was classified into categories (A-F) based on standard meteorological criteria, with categories A-C representing unstable conditions and E-F representing stable conditions. The relationship between mixed layer thickness, atmospheric stability, and AQI was investigated using correlation analysis.

3. Results

3.1 Seasonal Variation Characteristics

The mixed layer thickness exhibited significant seasonal differences. During summer (June-September), the thickness ranged from 1559 to 1772 meters, while in winter (December-February), it decreased substantially to between 526 and 1156 meters. This seasonal variation is primarily attributed to differences in solar radiation and surface heating between summer and winter.

When analyzed at 500-meter vertical intervals from the surface to 2000 meters, the highest frequency of occurrence was observed in the 500-1000 meter range. From June to September, the probability of the mixed layer occurring above 500 meters exceeded 10% at each height interval. However, from October to February, the probability above 1500 meters decreased significantly.

3.2 Daily Variation Characteristics

The mixed layer thickness showed clear diurnal variation patterns, with the highest values occurring between 13:00 and 16:00 PM, followed by a rapid decrease after 16:00 PM. This pattern aligns with the daily cycle of surface heating and sensible heat flux. The maximum sensible heat flux values were recorded at the southern suburban site (263.6 W · m ^{2}), followed by the urban site (258.6 W · m ^{2}) and northern suburban site (219.6 W · m ^{2}).

Unstable stratification (A-C categories) dominated during daytime hours (08:00-20:00), accounting for 13.6-17.1% of observations across different sites. In contrast, stable stratification (E-F categories) was more prevalent during nighttime (20:00-08:00), representing 35.5-44.8% of observations.

3.3 Spatial Distribution and Terrain Effects

The spatial distribution of mixed layer thickness was closely related to terrain features. In summer, suburban areas exhibited greater mixed layer thickness compared to urban areas. In winter, the thickness decreased progressively from the southern suburbs to the urban center and then to the northern suburbs, following the topographic gradient.

The terrain difference between southern and northern suburbs was approximately 400 meters. The southern suburban site (G" EH) showed the highest mixed layer thickness values, while the northern suburban site (HGS) showed the lowest. This terrain-induced variation significantly affected pollutant dispersion capabilities.

3.4 Relationship with Air Quality Index

The AQI demonstrated a strong relationship with mixed layer thickness and atmospheric stability. The highest AQI values occurred in winter, corresponding to the period of lowest mixed layer thickness. The spatial distribution of AQI showed an inverse relationship with terrain elevation, with lower AQI values in the higher-elevation southern suburbs and higher values in the lower-elevation northern suburbs.

When AQI exceeded 200, indicating heavy pollution, the mixed layer thickness was typically below 1500 meters. During severe pollution episodes (AQI > 200), the percentage of stable atmospheric conditions increased significantly, particularly in the northern suburbs where stable conditions (E-F categories) accounted for over 42.6% of observations.

4. Discussion

The results demonstrate that atmospheric mixed layer thickness in the Urumqi region is controlled by a combination of thermal conditions, atmospheric stability, and terrain features. The substantial seasonal variation reflects the continental arid climate characteristics, with strong surface heating in summer promoting deep mixed layers and winter cooling resulting in shallow, stable layers.

The terrain plays a crucial role in modulating these effects. The higher elevation of southern suburbs enhances turbulent mixing and pollutant dispersion, while the lower-elevation northern suburbs tend to trap pollutants, especially under stable winter conditions. This explains the observed spatial gradient in AQI values.

The daily variation pattern, peaking in early afternoon, is consistent with the solar radiation cycle and associated sensible heat flux. The rapid decrease after 16:00 PM marks the transition from unstable daytime conditions to stable nocturnal conditions, which has important implications for evening and early morning air quality.

5. Conclusions

This study reveals significant seasonal, daily, and spatial variations in atmospheric mixed layer thickness over Urumqi. The thickness ranges from 1559-1772 m in summer and 526-1156 m in winter, with the highest frequency occurring at 500-1000 m heights. Daily peaks occur between 13:00-16:00 PM. Atmospheric stability shows distinct daytime unstable and nighttime stable patterns.

The spatial distribution is strongly influenced by terrain, with higher elevations favoring deeper mixed layers and better pollutant dispersion. The AQI is inversely related to mixed layer thickness, with the highest pollution levels occurring in winter when the mixed layer is shallowest and most stable, particularly in lower-elevation areas.

These findings provide valuable insights for air quality forecasting and pollution control strategies in Urumqi and similar arid, topographically complex regions.

Future research should focus on integrating these observations with numerical models to improve predictive capabilities.

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