

**Observing Atmospheric Visibility During the March–April
Transition in Seoul: Satellite-Matched Ground Observations and
Variability Beyond PM_{2.5}**

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Observation Location: Han River Basin, Seoul, South Korea

Study Period: March – April 2026

Date of Submission: April 2026

Abstract

Atmospheric visibility does not always match measured air quality. During repeated observations, the atmosphere sometimes appeared clear even when particulate matter levels were moderate, and at other times appeared hazy under similar measured conditions. This study examines how atmospheric visibility varies during the transition from March to April in Seoul, South Korea. Observations were conducted at a fixed site in the Han River basin, where urban structures and open water coexist. To ensure consistency, only ground-based observations that were matched with satellite data from the NASA GLOBE Observer Clouds program (HIMAWARI-9) were included. Meteorological variables and air quality data (PM_{2.5} and PM₁₀) were used as supporting information.

The results show that visibility does not respond in a simple or consistent way to individual variables. Although higher PM_{2.5} concentrations are sometimes associated with reduced visibility, the relationship is not consistent. Relative humidity also does not show a clear pattern. Instead, visibility reflects the combined influence of multiple atmospheric conditions. Differences between March and April were observed, with March showing greater variability and April showing relatively clearer conditions in some cases. However, overlapping observed patterns between the two months indicate that visibility cannot be explained by seasonal differences alone. Visual observations support these findings. Under hazy conditions, the atmosphere appears more diffuse, while clearer conditions show sharper boundaries. The plume from a combined heat and power plant provides a useful visual reference for interpreting airflow and atmospheric conditions. These observations show that visibility is not a direct indicator of air quality, but a dynamic result of interacting atmospheric conditions.

1. Introduction

Atmospheric visibility in urban environments does not always change in a simple or predictable way. During repeated observations, the atmosphere can appear clear even when particulate matter levels are moderate, and hazy under similar measured conditions. This difference between measured air quality and visual appearance raises an important question about how atmospheric conditions are experienced at ground level.

This question is particularly relevant during seasonal transition periods. In South Korea, atmospheric conditions during early spring change rapidly over short timescales. March often shows more variable conditions, while April often shows relatively clearer conditions as temperature increases and atmospheric mixing becomes more active. However, these patterns are not always consistent at the local scale, and short-term variability can produce different visual conditions even under similar measurements. Previous studies in South Korea have shown that atmospheric visibility is influenced by both particulate matter and meteorological conditions. In Seoul, visibility has been found to depend not only on PM_{2.5} concentration but also on factors such as relative humidity and atmospheric conditions (Kim et al., 2022). Similarly, studies in Korea have shown that visibility is affected by the interaction between particulate matter and meteorological factors rather than a single variable (Won et al., 2020). These findings suggest that visibility cannot be explained by individual variables alone, which motivates the need for direct observational approaches such as the one used in this study.

The observation site for this study is located in the Han River basin in Seoul, a mixed urban–riverine environment where buildings, open water, vegetation, and transportation infrastructure coexist within a relatively small area. Such environments provide a realistic setting for GLOBE observations, where atmospheric conditions are influenced by local surface characteristics and airflow patterns.

A combined heat and power (CHP) plant visible from the observation site provides a consistent visual reference. The visible plume is used as a qualitative indicator of airflow direction and atmospheric dispersion. It is not used as a measure of emissions, but as a visual tool to interpret how atmospheric conditions affect the appearance of airborne particles.

This study is based on repeated ground-based observations conducted at a fixed location and viewing direction. Observations were collected as part of the NASA GLOBE Observer Clouds program and matched with satellite data (HIMAWARI-9) to ensure consistency between ground observations and broader atmospheric conditions.

The main research question of this study is how atmospheric visibility varies under similar $\text{PM}_{2.5}$ conditions during the March–April transition, and what factors contribute to this variability. It is hypothesized that visibility is not determined by $\text{PM}_{2.5}$ concentration alone, but reflects the combined influence of multiple atmospheric factors, including humidity, temperature, and local airflow conditions.

By combining direct observation with satellite-matched data, this study emphasizes how student-collected observations can contribute to understanding atmospheric variability. This approach highlights the role of citizen science in connecting ground-level experiences with large-scale atmospheric processes.

2. Methods

This study is based on repeated ground-based observations conducted at a fixed location, combined with meteorological data and satellite matching.

2.1 Observation Site

Observations were conducted in the Han River basin in Seoul, South Korea. The site represents a mixed urban–riverine environment where dense urban infrastructure is located adjacent to open water.

A combined heat and power (CHP) plant located within the observation field of view was used as a consistent visual reference point. The visible plume emitted from the facility was used as a qualitative indicator of airflow direction and local atmospheric conditions. The plume was not used as a measure of emission intensity or air pollution levels.

2.2 Observation Procedure and Data Selection

Ground-based observations were conducted repeatedly during March and April from the same location and in a consistent viewing direction. Photographs were taken under varying

atmospheric conditions to capture differences in visibility and atmospheric appearance.

Observations were conducted frequently during the observation period. However, not all observations were used in the final analysis. To ensure consistency between ground observations and atmospheric conditions, only observations that were successfully matched with satellite data were selected.

The final dataset includes the following satellite-matched observation dates:

- March: 2, 6, 9, 10, 11, 15, 17
- April: 2, 19

Data collection and data selection were treated as separate steps. Repeated observations were first conducted under various conditions, and a subset of observations was then selected based on satellite matching.

2.3 Satellite Matching

Satellite matching was conducted using the NASA GLOBE Observer Clouds program.

- Satellite: HIMAWARI-9
- Matching criteria: observation time and geographic location

Only observations with confirmed temporal and spatial alignment with satellite data were included in the analysis. This filtering step ensures that all analyzed observations correspond to consistent atmospheric conditions at both the ground and satellite observation scales.

2.4 Meteorological and Air Quality Data

Meteorological data were obtained from the Korea Meteorological Administration (KMA). The following variables were used:

- Temperature
- Relative humidity
- Wind direction
- Wind speed

- Visibility
- Total cloud cover

Air quality data, including PM₁₀ and PM_{2.5} concentrations, were obtained from publicly available air quality monitoring data (AirKorea). All meteorological and air quality variables used in the analysis correspond to the observation dates listed in Table 1. These data were used to provide contextual information for interpreting observed atmospheric conditions, rather than as direct inputs for statistical modeling.

3. Results

3.1 Data Overview and Environmental Context

A total of ten satellite-matched observations were analyzed, including two observations conducted on March 15 (morning and afternoon), resulting in nine observation days. These observations were selected from a larger set of repeated ground-based measurements conducted at a fixed observation point in the Han River basin in Seoul. The final dataset consists of eight observations from March and two observations from April, enabling a comparison of seasonal atmospheric conditions while maintaining temporal and spatial consistency through satellite matching.

The observation site is located within the Han River basin, a mixed urban–riverine environment where high-density urban structures, transportation infrastructure, vegetation, and open water surfaces coexist within a relatively small spatial scale. This setting is relevant because near-surface visibility can be influenced not only by particulate matter concentrations but also by local airflow patterns, humidity, and light scattering conditions. In this study, the Han River basin is not treated as a direct causal factor, but rather as an environmental context that may influence how atmospheric conditions are visually perceived.

The selected observations include temperature, relative humidity, wind speed, wind direction, total cloud cover, visibility, and particulate matter concentrations (PM_{2.5} and PM₁₀), as shown in Table 1. March observations were characterized by lower temperatures (−0.1°C to 10.7°C) and relatively higher humidity (50–88%), whereas April observations showed higher temperatures (10.1°C to 28.8°C) and lower humidity (21–51%). Visibility ranged from 809 m

to 2148 m, and PM_{2.5} concentrations ranged from 3 µg/m³ to 65 µg/m³ across the observation period.

These observations reflect both differences between March and April and substantial variability within each period. While general patterns can be identified, overlapping conditions between the two months indicate that visibility cannot be interpreted based on seasonal differences alone.

Table 1. Summary of meteorological and air quality conditions for satellite-matched observations

Month	Date	Time	Temp (°C)	RH (%)	Wind Dir (°)	Wind Speed (m/s)	Cloud Cover (0–10)	Visibility (m)	PM ₁₀ (µg/m ³)	PM _{2.5} (µg/m ³)
March	02-Mar	13:00	4.6	88	70	5.8	10	2,148	7	3
March	06-Mar	16:00	2.8	70	250	3.1	9	876	52	36
March	09-Mar	11:00	5.2	54	320	3.7	1	958	59	43
March	10-Mar	8:00	-0.1	70	50	1.8	6	1,030	47	31
March	11-Mar	8:00	0.8	60	50	1.4	4	1,963	42	27
March	15-Mar	10:00	7.8	62	160	1.8	10	959	52	39
March	15-Mar	17:00	10.7	50	200	3.5	5	1,222	61	40
March	17-Mar	10:00	8.8	53	50	1.8	0	809	90	65
April	02-Apr	22:00	10.1	51	270	2.1	0	1,043	75	43
April	19-Apr	13:00	28.8	21	180	2.9	3	1,903	62	24

Notes. Temp: air temperature; RH: relative humidity; Wind Dir: wind direction (degrees); Wind Speed: wind speed (m/s); Cloud Cover: total cloud cover (0–10 scale); Visibility: horizontal visibility (m); PM₁₀ and PM_{2.5}: particulate matter concentrations (µg/m³). Meteorological data were obtained from the Korea Meteorological Administration (KMA), and PM₁₀ and PM_{2.5} data were obtained from AirKorea.

3.2 Temporal Variation in PM_{2.5} and Visibility

Figure 1 shows the time series of PM_{2.5} concentration and visibility across the observation period. March observations exhibit substantial variability in both PM_{2.5} and visibility. PM_{2.5} increases from a low value of 3 µg/m³ on March 2 to a peak of 65 µg/m³ on March 17, while visibility fluctuates between 809 m and 2148 m. High PM_{2.5} levels are not consistently associated with the lowest visibility. For example, on March 11, visibility reaches 1963 m despite moderate PM_{2.5} levels (27 µg/m³), whereas on March 17, high PM_{2.5} (65 µg/m³)

corresponds to relatively low visibility (809 m). This pattern shows that $PM_{2.5}$ alone does not determine visibility conditions.

Short-term variability is also observed within a single day. On March 15, visibility increases from 959 m to 1222 m as relative humidity decreases from 62% to 50%, while $PM_{2.5}$ remains relatively stable (39–40 $\mu\text{g}/\text{m}^3$). This indicates that factors other than particulate concentration can influence visibility over short timescales. In April, atmospheric conditions appear more stable. $PM_{2.5}$ ranges from 24 $\mu\text{g}/\text{m}^3$ to 43 $\mu\text{g}/\text{m}^3$, while visibility remains relatively high, particularly on April 19 (1903 m), which coincides with low humidity (21%) and higher temperature (28.8°C).

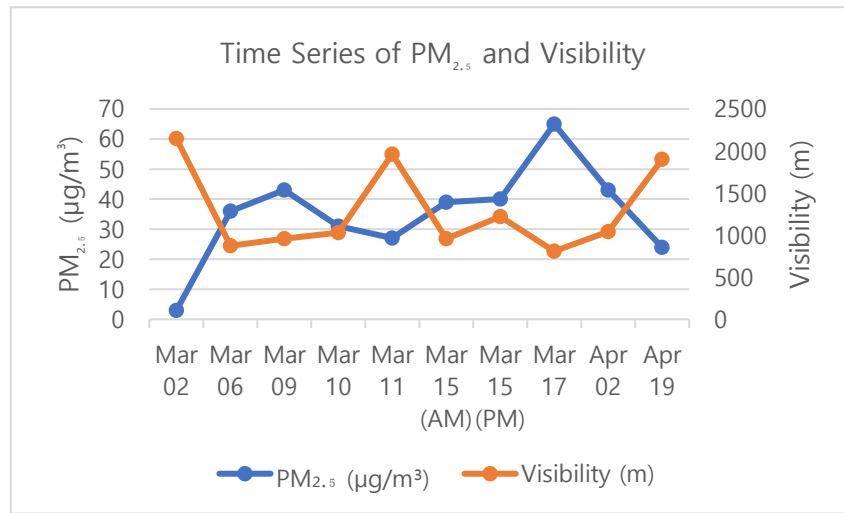


Figure 1. Time series of $PM_{2.5}$ concentration and visibility during the observation period, showing observed patterns of variability and a weak relationship between the two variables.

3.3 Relationship between $PM_{2.5}$ and Visibility

Figure 2 presents the relationship between $PM_{2.5}$ concentration and visibility. A weak negative relationship is observed, where higher $PM_{2.5}$ concentrations are generally associated with reduced visibility. However, the data points are widely scattered. For example, at $PM_{2.5}$ concentrations around 40 $\mu\text{g}/\text{m}^3$, visibility ranges from approximately 950 m to over 1200 m. Relatively high visibility is also observed at moderate $PM_{2.5}$ levels, particularly in April.

These results show that $PM_{2.5}$ contributes to visibility reduction but does not fully explain the observed variability.

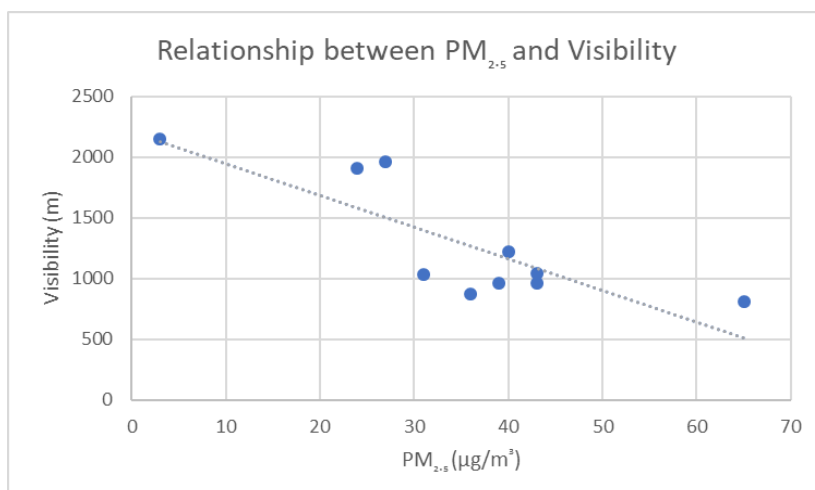


Figure 2. Relationship between PM_{2.5} concentration and visibility, showing a weak negative trend and widely scattered observed patterns.

3.4 Relationship between Relative Humidity and Visibility

Figure 3 shows the relationship between relative humidity and visibility. No clear linear relationship is observed between relative humidity and visibility. While some lower visibility values occur under moderate to high humidity conditions (approximately 50–70%), the overall distribution remains scattered. For example, relatively high visibility is observed under both low humidity (21%) and moderate humidity (60%). This indicates that relative humidity alone does not consistently determine visibility conditions.

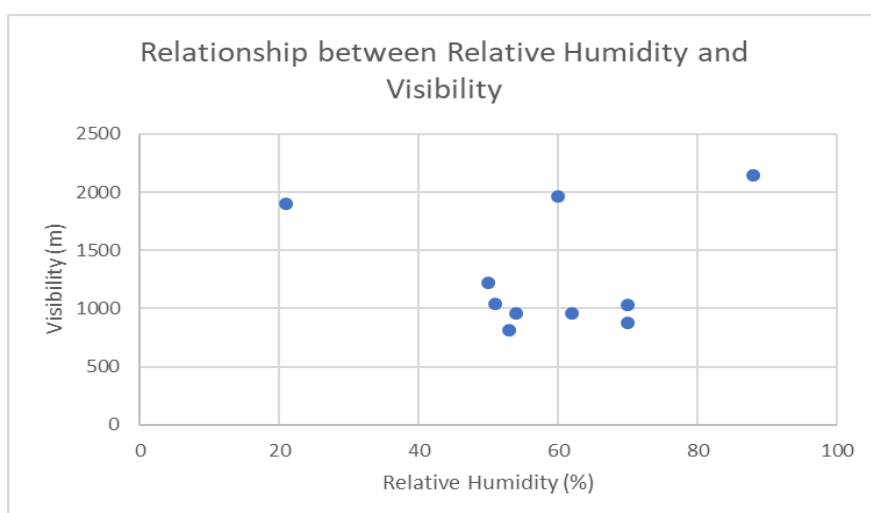
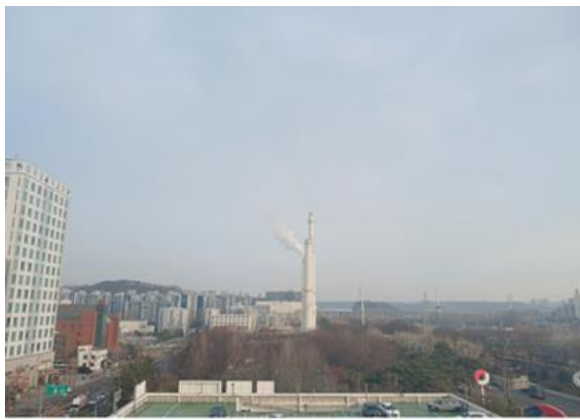


Figure 3. Relationship between relative humidity and visibility, showing no clear relationship and scattered observed patterns.

3.5 Integrated Interpretation of Visibility Variation

Taken together, the results show that neither $PM_{2.5}$ concentration nor relative humidity alone can fully explain the observed variability in visibility.

Visibility appears to be influenced by multiple interacting atmospheric factors, and the observed variability cannot be explained by individual variables or by simple seasonal differences alone. These patterns are reflected in both the temporal variability shown in Figure 1 and the weak or inconsistent relationships observed in Figures 2 and 3. These patterns are also visually supported by representative ground-based observations, as shown in Figure 4.



(a) Hazy condition in March



(b) Moderate atmospheric condition observed in March



(c) Clear condition in April



(d) Plume observed under hazy conditions in March

Figure 4. Representative ground-based observations under different atmospheric conditions, showing observed patterns of visibility differences between hazy and clear conditions.

As shown in Figure 4, March observations exhibit reduced visibility and lower contrast, while

April conditions show clearer backgrounds and improved visibility. Under hazy conditions, the plume appears more diffuse, with less distinct boundaries. These visual patterns are consistent with the quantitative results, where no single variable fully explains visibility variation. Although March images generally show reduced visibility and April images clearer conditions, similar visual patterns can be observed across both months, reinforcing that visibility does not follow a simple seasonal pattern.

4. Discussion

4.1 Interpretation of Results

The results show that atmospheric visibility cannot be explained by a single variable. Although higher PM_{2.5} concentrations are sometimes associated with reduced visibility, this relationship is not consistent across observations. Relative humidity also does not show a clear or predictable pattern.

Instead, the findings suggest that visibility reflects the combined influence of multiple atmospheric factors, including particulate concentration, humidity, temperature, and local airflow conditions. The variability observed within March, as well as the differences between March and April, indicates that visibility is influenced more by short-term atmospheric changes than by simple seasonal trends.

This weak relationship between individual variables and visibility can be explained by the interaction of multiple atmospheric processes. For example, humidity can enhance light scattering under certain conditions, but its effect depends on the presence and composition of airborne particles. Similarly, PM_{2.5} concentration alone does not determine visibility, because particle size distribution, chemical composition, and atmospheric mixing conditions also influence how light is scattered and absorbed (Seinfeld & Pandis, 2016). These combined effects help explain why visibility can vary even under similar measured conditions. These interactions can vary depending on local atmospheric conditions, including wind patterns and mixing processes, which influence how particles are distributed and how light is scattered in the atmosphere. These findings are consistent with previous studies conducted in South Korea, which have shown that visibility is influenced by the interaction of particulate matter and meteorological conditions rather than by a single variable (Kim et al., 2022; Won et al., 2020).

However, while previous studies have primarily relied on statistical or model-based approaches, this study demonstrates similar patterns through direct ground-based observation and satellite-matched data.

4.2 Observational Insights and GLOBE Relevance

A key strength of this study is the use of repeated ground-based observations at a fixed location. These observations capture how atmospheric conditions are directly experienced, rather than relying only on numerical measurements.

Visual observations provide important additional context. Under hazy conditions, distant objects appear less distinct and the plume from the CHP plant becomes more diffuse. Under clearer conditions, both distant features and plume boundaries are more sharply defined. These differences reflect changes in atmospheric scattering and help explain variations in visibility that are not fully captured by PM_{2.5} or humidity alone.

By matching ground-based observations with satellite data from the NASA GLOBE Observer Clouds program, this study connects local observations with broader atmospheric patterns. This approach shows how student-collected data can contribute to scientific understanding when combined with satellite observations. It also highlights the value of citizen science in describing how atmospheric conditions are actually experienced at the surface.

4.3 Limitations and Future Work

This study is based on a limited number of satellite-matched observations, which restricts the ability to generalize the results. In addition, visibility was evaluated through observation rather than direct measurement of atmospheric optical properties.

Future work with a larger dataset and additional atmospheric variables, such as vertical mixing and atmospheric stability, would help to further clarify the factors influencing visibility. Increasing the number of satellite-matched observations would also improve the reliability of the analysis.

5. Conclusion

This study examined atmospheric visibility during the transition from March to April using satellite-matched ground-based observations collected at a fixed site in the Han

River basin in Seoul. By linking local observations with satellite data, the analysis ensured consistency between ground-level conditions and broader atmospheric context.

The results show that visibility cannot be reliably explained using a single atmospheric variable. Although higher PM_{2.5} concentrations are sometimes associated with reduced visibility, the relationship is weak and inconsistent. Relative humidity also does not show a clear relationship with visibility in this dataset. These findings indicate that visibility does not respond in a simple or linear way to individual variables.

Instead, visibility reflects the interaction of multiple atmospheric conditions. Variations in particulate concentration, humidity, temperature, and short-term atmospheric state together shape how visibility is observed. This is supported by both the temporal variability and the weak relationships between individual variables and visibility.

The comparison between March and April further shows that visibility does not follow a simple seasonal pattern. While general differences between the two months are observed, variability within each period indicates that visibility is strongly influenced by short-term and local atmospheric conditions.

Visual observations support these findings. Under hazy conditions, the atmosphere appears more diffuse and contrast is reduced, whereas clearer conditions produce sharper boundaries and improved visibility. The plume observed in this study shows similar patterns, appearing more diffuse under hazy conditions and more clearly defined under clearer conditions. Although this study is based on a limited number of observations and does not include direct measurement of atmospheric optical properties, the results provide a consistent pattern across multiple observations.

Overall, this study demonstrates that visibility cannot be used as a direct indicator of air quality. Instead, it should be understood as a dynamic outcome of interacting atmospheric conditions. By combining satellite-matched data with repeated ground-based observations, this study highlights the importance of short-term variability, local environmental context, and direct visual observation in interpreting atmospheric

conditions.

Acknowledgements

The author acknowledges the NASA GLOBE Observer Clouds program, the Korea Meteorological Administration (KMA), and AirKorea for providing data used in this study.

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