Temporal Variation of Atmosphere Visibility Over Haikou City of 60 Years

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Abstract. To explore the temporal characteristics of atmospheric visibility in Haikou city, the capital city of Hainan Province, based on the monitoring data from 1957 to 2016 (60 years), the characteristics of atmospheric visibility were analyzed. The results showed that: 1) The average atmospheric visibility in 1957-2016 was 18.89 km and the trend was 0.16 km/decade; 2) the highest atmospheric visibility appeared in the summer and the lowest appeared in the winter, while the mean values of atmospheric visibility monitoring in spring and autumn were closer; (3) the rate of atmospheric visibility of "good" (> = 20 km) and "poor" (<4 km) showed different variations; 4) The Ridit values of Haikou city was close to 0.5 during the study period, indicating the trend of the atmosphere visibility was not significant change; 5) the atmospheric visibility of 20%, 50% and 80% revealed downward trends. In general, the visibility of Haikou city was stay in a higher level. In 2016, the variation of visibility showed a certain upward trend. It indicated that, in recent years, a certain role in the control of air pollutants has implemented over Haikou city.

1. Introduction
Atmospheric visibility is defined as the maximum horizontal distance between the eye and the visible target [1], which not only reflects to the regional atmospheric quality [2-3], but is closely related to the satisfaction of the residents. In recent years, with the haze days increased frequency, atmospheric visibility reduction has become a public concern [4]. Changes in atmospheric visibility temporal and spatial trends and seasonal and diurnal variations have attracted the attention of a large number of researchers. During the haze in London, Brimblecombe [5] for the first time study the changes in atmospheric visibility. Followed by relevant research reports continue to emerge. Scholars on the atmospheric visibility focused on large cities, heavily polluted areas and some industrial developed areas. Chang et al. [7] studied six large cities in China, revealing atmospheric visibility from the 1970s to the beginning of the 21st century, showing a downward trend.

Rapid urbanization process and economic development have led to a sharp increase in resource consumption, and many areas were facing severe atmospheric visibility reduction challenges, which
were particularly prominent in coastal cities. Haikou City, located in the southern part of China, is the largest population density, one of the most dynamic city. In the past 60 years, especially after the reform and opening up, Haikou City has experienced rapid economic development and rapid urbanization level. However, the study of the change of atmospheric visibility in this area is rarely reported. Haikou City, as a typical city in Hainan Province, study take in this city will not only provide support for this region, it will helpful for other areas with similar environmental conditions.

Based on the data of 60 years (1956-2016), we analyzed the variations of the atmospheric visibility over Haikou city, mainly discusses the following questions: 1) calculate the change rule of atmospheric visibility, and the change trend; 2) analyze atmospheric visibility in different seasons, the monthly characteristics; 3) use of different levels of visibility to analyzed the characteristics of the visibility; 4) Ridit analysis and cumulative percentage and other methods to calculate the overall visibility.

2. Materials and methods

2.1. Data
Atmospheric visibility and weather data are available from the National Oceanic and Atmospheric Administration (NOAA, https://www.climate.gov/) and the data monitoring interval is 1 hour.

2.2. Analytical methods
The study used five kinds of statistics and analysis methods: 1) statistical analysis of the annual variation of atmospheric visibility and diurnal variation; 2) analysis of atmospheric visibility monthly "better" (> 19.9 km), "poor" (<4 km); 3) using the SPSS 19.0 software for atmospheric visibility Ridit analysis; 4) calculating the atmospheric visibility Cumulative percentiles; 5) using the method [12], to calculate the atmospheric visibility and atmospheric pollutant regression equation, in order to make the regression equation more typical, eliminate fog, rain and other effects of visibility of the special weather is screen out. Because the higher air humidity has a strong deterrent effect, the relative humidity which > 90% of the monitoring data group is also removed [13].

Extinction coefficient $\beta_{ext}$ reference Koschmieder's research method to come [1]:

$$\beta_{ext} = \frac{3.912}{V}$$  \quad (1)

Where $\beta_{ext}$ is the extinction coefficient (km$^{-1}$); $V$ is the atmospheric visibility (km).

2.3. Data processing
Data analysis and image analysis are performed using SPSS 19.00 and EXCEL 2010.

3. Results and analysis

3.1. Yearly Variation
Table 1 shows the mean value of the atmospheric visibility and annual trends of the atmospheric visibility in Haikou City from 1957 to 2016. Overall, the average atmospheric visibility in 1957-2016 was 18.89 km, and the trend was 0.16 km / decade, indicating that there was no significant change in atmospheric visibility over time. Figure 1 shows the annual average of Haikou City's atmospheric visibility 1957-2016, showing that the overall trend of change from 1956 to 2012 was relatively stable. From 2012 to 2016, the increase of atmospheric visibility increased due to the increase of air pollution control.

Further analysis show that, the 1950s was the best visibility of atmospheric visibility, the early 1960s, there was an upward trend in atmospheric visibility, the results similar to other regional studies [12]. General explanation of this phenomenon was the industrial scale was small and the economic development was slow in the 1960s. It was rarely affected by air pollution. Visibility was in line with
the level of economic development at that time. In the early 1970s, Haikou city had been affected by air pollution to a certain extent, and the atmospheric visibility had a significant downward trend. As can be seen from Table 1, the mean value of visibility in Hangzhou was reduced from 20.44 km in 1956-1964 to 16.44 km in 1973-1976. From the early 1980s to the mid-1990s, with the implementation of the reform and opening-up policy, Haikou city began to develop at a high speed, and the development mode was mainly in the tertiary industry. Haikou City maintained a high level of atmospheric visibility, even though most parts of the country had a decreased trend of atmospheric visibility. After 2006, with the implement the environmental protection issued by the government, atmospheric visibility has an increased trend.

**Table 1.** Summary statistics of visibility in Haikou for decades during 1956 to 2016.

| Year       | 1957-1964 | 1973-1976 | 1977-1986 | 1987-2006 | 2007-2016 | 1957-2016 | 60-year trend |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|--------------|
| Haikou     | 20.44     | 16.44     | 17.20     | 18.36     | 20.07     | 19.66     | 18.89 0.16km/decade |

**Figure 1.** Variations of yearly value of visibility during 1956-2016 in Haikou city.

3.2. Seasonal and monthly variation

The highest atmospheric visibility appears in the summer, followed by spring and autumn, while the lowest value appears in the winter, as shown in Figure 2. The maximum atmospheric visibility was related to its high temperature and low humidity. The concentration of air pollutants in summer was relatively low, which was the main factor leading to high atmospheric visibility. Due to the heavy rainfall in summer, accompanied with intensity of high wind speed, the air pollutant was lower than other seasons, which lead to the highest visibility in summer. The low atmospheric visibility in winter was directly related to the higher concentration of pollutants. Dan Xue et al. [15] showed that the concentration of atmospheric particulate matter in the winter was the maximum, haze days appeared frequency in cold seasons. The atmosphere visibility in spring and autumn was similar. Further observation showed that atmospheric visibility showed the highest value in July, and the lowest value in January, from January to June showed a slow upward trend, during Jun and Jul there was a rapid increase, followed by during Aug to Dec it showed a gentle downward. The change of atmospheric visibility displayed an opposite variation to the change of atmospheric particle concentration [13-14]. The results are similar to those of previous studies [15].
3.3. Monthly Percentage of Atmospheric Visibility at Different Levels

The rate of atmospheric visibility of "good" (> = 20km) and "bad" (<4km) has a greater impact on tourists and residents. Figure 3 shows the proportion of "good" and "poor" visibility per year during 1956-2016. It can be seen from Figure 3 that the atmospheric visibility of the "bad" level was relatively stable over the period 1956-2006, and the variation is larger. The rate of "Good" level of atmospheric visibility in 1956-1966 was increased, while during 1973-1990 it showed a downward trend, after 1990 the rate of “good” visibility showed a steady trend maintained at 50%. "Good" atmospheric visibility is sensitive to air pollution. The results of previous studies show that the "good" atmospheric visibility of the emergence of the tour is conducive to improving the degree of preference for the landscape. As a famous tourist city, to enhance the visibility of the atmosphere, especially the "good" level of atmospheric visibility ratio, is an important task of urban construction and management.

3.4. Ridit Analyze

The Ridit value curve reflects the trend of atmospheric visibility. When the Ridit value is greater than 0.5, the atmospheric visibility of the year is above the average level, and when the Ridit value is less than 0.5, the atmospheric visibility is less than the average and there is a downward trend. The Haikou City in 1956-2016, the variation Ridit values were at 0.5, indicating that the trend of atmospheric visibility during the study period were not obvious.
Figure 4. The Ridit value of Haikou city during 1956-2016.

3.5. Cumulative percentiles
From Figure 5 we can see that the atmospheric visibility of 20%, 50%, and 80% were in a gentle upward trend, the 50% got the highest rising rate, followed by 20% and 80% with the rate of 0.049, 0.037 and 0.0065 km/year, respectively. However, the R-square values of the cumulative percentage calculation and trend analysis were less than 0.2, indicating that the linear regression contribution was low. The influence of air pollution on the visibility of a city is strong. It can be seen that the biggest influencing factors of atmospheric visibility in Haikou are not the concentration of air pollutants, but the meteorological factors such as humidity and temperature. From the extinction coefficient point of view, the increase was less than 0.001 km$^{-1}$, in the second proof, changes in atmospheric visibility and temperature, humidity, wind speed and other changes.

Figure 5. The variation of the best 20%, 50% and worst 20% visibility in Haikou city during 1956-2016.
4. Conclusion

Haikou City in 1956-2016, the average atmospheric visibility of 18.89 km, the highest value in the summer, the lowest value in the winter, was down "V" font. The presence of "good" and "poor" levels of atmospheric visibility ratio has a greater impact on the lives of residents and even the psychological feelings of residents. The study found that the "poor" level of atmospheric visibility in the spring and winter appear higher frequency, and "good" level of atmospheric visibility appears in the winter frequency is relatively low. Summer to early autumn atmospheric visibility in the "good" ratio higher than the average ratio, indicating that in this season in Haikou City trip can get a better feeling. For the analysis of the different levels of atmospheric visibility, most investigators only analyze the ratio of greater than 20 km visibility and less than 4 km visibility [16-20]. This study analyzes and clearly shows the percentage of visibility at all levels within Haikou City. The method of analysis and related research results enriched predecessors 'research, which has guiding significance for practice and has high reference value for residents and tourists' life and tour behavior guidance.

Researchers have found that atmospheric visibility is related to the concentration of atmospheric particulates. The results showed that atmospheric visibility can well reflect the trend of air quality, removing the meteorological factors [21-22]. Numerical simulations of atmospheric visibility are commonly used to calculate the extinction coefficient for atmospheric visibility [23]. However, due to the lack of long time observation and high density of the comprehensive observation the results were hard to verify. Previous studies have shown that the atmospheric visibility decreases as the light scattering effect of atmospheric particles increases. It is pointed out that the concentration of air pollutants has a certain correlation with atmospheric visibility [24]. Wei Huang et al. [25] analyzed the relationship between atmospheric visibility, air pollutants and mortality in Shanghai. Among them, the correlation between atmospheric visibility and atmospheric pollutant concentration was also analyzed. This study provides a more specific and in-depth analysis of the influencing factors of atmospheric visibility changes in different seasons, and provides the basic data for the regulation of energy use in the relevant seasons.

However, due to limited data, the special characteristic in different area in Haikou city (such as: city center, suburbs, suburbs, etc.) was not be analyzed. More researches need to be further carried out.

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