· Letter ·
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Features of visibility variation at Great Wall Station, Antarctica

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Abstract The variation of visibility at Great Wall Station (GWS) was analyzed using manual observational data for the period of 1986 to 2012. Results show that the frequencies of occurrence of high (⩾10 km) and low visibility (0—1 km) are 61.0% and 8.0%, respectively. Visibility at GWS shows an evident seasonal variation: The highest visibility between November and March, and the lowest visibility from June to October. Sea fog and precipitation are the main factors for low visibility during summer, whereas frequent adverse weather, such as falling snow, blowing snow, or blizzards, are responsible for low visibility in winter. The frequency of occurrence of low visibility has decreased significantly from 1986 to 2012. Conversely, the frequency of occurrence of high visibility has shown a significant increasing trend, especially during winter. The decreasing tendencies of fog, blowing snow, and snowfall have contributed to the increasing trend of high visibility during winter. Visibility at GWS exhibits significant synoptic-scale (2.1 to 8.3 d), annual, and inter-annual periods (2 a, 4.1 a, and 6.9 a to 8.2 a), among which the most significant period is 4.1 a. The visibility observed during 2012 indicates that instrumental observation can be applied in the continuous monitoring of visibility at GWS.

Keywords **Great Wall Station, Antarctica, visibility, sea fog, blowing snow**

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1 Introduction

Horizontal visibility is also called the meteorological optical range, which refers to the length of path in the atmosphere required to reduce the luminous flux of a parallel beam from an incandescent light, at a color temperature of 2 700 K, to 5% of its initial value[1]. A manually derived assessment of visibility is defined as the greatest distance that can be seen in any direction around the horizon, whereas instrumental visibility refers to an observation within a certain baseline extent. Visibility is closely related to the air content, i.e., the number of droplets and pollutant gases, by which the absorption and scattering of visible light could reduce the atmospheric visibility.

The GWS in Antarctica is located in the north of the Antarctic Peninsula, downstream of the center of cyclogenesis of extratropical cyclones in the South Pacific, and there is a cyclone passage on average every 3–4 days[2]. Consequently, weather related to low visibility (sea fog, rain, snow, blowing snow, and blizzards) occurs frequently and has a significant impact on aviation and maritime activities in this region. The Antarctic Peninsula region is one area that has demonstrated the most significant warming over the last 50 years[3]. The weather observations at GWS are particularly important for our understanding of the response and feedback processes of the Antarctic Peninsula to global climate change. Based on meteorological data from 1985, Chinese scholars have studied the short-term climatic characteristics of air temperature, humidity, wind, and pressure[4-6], and their inter-annual variability[7-8] in the context of climate change within this region. Synoptic case studies of sea fog, blizzards, and some other weather with low visibility have also been carried out[9-11]; however, the analysis

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of the characteristics of the variation of visibility has not yet been performed.

As one of the regular meteorological observations, visibility has been observed manually three times per day (08:00, 14:00, and 20:00 local time) since early 1985, and an additional observation (02:00 local time) has been included since December 1985. Instrumental visibility measurements using forward scatter sensors have the advantages of being objective and consistent at all times. There is a global trend to use instrumental readings, either as an aid or as a substitute for manual visibility observations. Therefore, a VAISALA PWD20 visibility sensor was installed at GWS in January 2012, and an experiment of continuous monitoring of visibility was undertaken for the first time.

Based on the historical manual observations since 1985, in this paper we analyze the seasonal and inter-annual variations of visibility, and discuss the relationship of these variations with regard to fog, blowing snow, falling snow, and some other adverse weather conditions. The strength and variations of different visibility periods are also explored using spectral analysis and wavelet analysis. Finally, PWD20 instrumental and manually derived visibility observations between January and May 2012 are compared and discussed.

2 Data and methods

The visibility observations used in this paper include the 6-hourly manually derived data from GWS obtained between 1986 and 2012, and the PWD20 instrumental observation from 21 January 2012 to 29 May 2012. Based on the daily average manual observations, the variation of visibility is analyzed and discussed. Spectral and wavelet analysis methods are used to analyze the variation periods. Wavelet analysis is a newly developed time-frequency analysis tool that can reveal accurately the instantaneous frequency structure transformation within a time series[12]. In this paper, the Morlet wavelet transform is used in the analysis of the strength and the characteristics of the variation of the visibility periods at GWS.

3 Variation characteristics

3.1 Seasonal variation

An obvious seasonal variation was revealed in the visibility observations at GWS from 1986 to 2011. The visibility in November−March is higher; the monthly mean visibility in December is 14.9 km, which is the highest of all the months. Meanwhile, June−October is a period with low visibility; the visibility in September is less than 12 km, which is the lowest in the year (Figure 1).

Fog, falling snow, blowing snow, and other adverse weather conditions associated with frontal cyclone systems can reduce visibility significantly. Statistics on the observations from 1986 to 2011 show that good visibility (⩾10 km) accounts for 61% of the time, whereas low visibility (0–1 km) accounts for 8%. Frequent fog and blowing snow/blizzards are the main factors that contribute to reduction of visibility in summer and winter, respectively. Most fog at GWS is advection-cooling fog. The location in the south of the Southern Ocean Front and Antarctic circumpolar low-pressure zone determines the characteristics of the weather leading to fog at GWS. The most important synoptic pattern for fog at GWS is “high in the East and low in the West”. The duration of sea fog conditions depends on the duration of the high-pressure system over the Antarctic Peninsula[9]. The average duration of foggy conditions is about 10 h; the shortest is only 10 min, whereas the longest can last for several days. Climate statistics show that on average at GWS, there are 145 d annually with fog. These include light fog (52 d), where horizontal visibility is greater than or equal to 1 km, but less than 10 km[1], and heavy fog (93 d) with horizontal visibility less than 1 km[1] (hereinafter the same). Fog occurs most frequently during September to March, while there are fewer fog days during April through August. On average, January/June has the most/least fog days with 15 d and 9 d, respectively (Figure 2). In summer, precipitation is mainly in the form of rain, and blowing snow occurs rarely. In winter, precipitation is mainly snow and the thickness of snow cover on the ground steadily increases. Subject to the frequent cyclonic winds, blowing snow and blizzards occur frequently in winter. Statistics show that on average there are 71 d of blowing snow each year and that it occurs more frequently in June to October. August/September have the most days of blowing snow (12 d), whereas there is no blowing snow in January (Figure 2). The occurrence of fog and blowing snow is much greater in winter than in summer; thus, visibility during winter is significantly lower than in the summer.

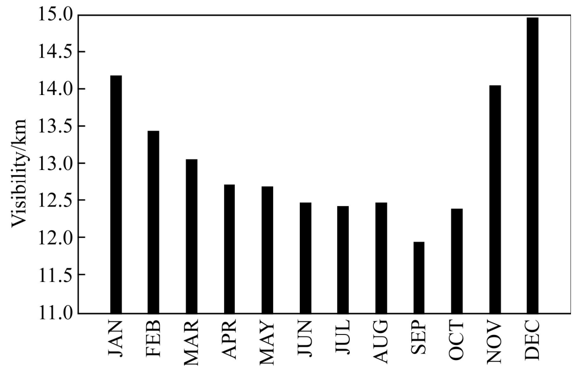

Figure 1 Average monthly variation of visibility at GWS.

3.2 Inter-annual variation and trend analysis

The inter-annual variation is calculated using the manually derived observations at GWS from 1986 to 2011 (Figure 3). There is a significant inter-annual variability, which can be divided broadly into four phases. The first phase is 1986–1989, where the annual average visibility increases consistently. The second phase is 1990–1995, where the variation of annual average visibility is very small with a 2-year period. The third phase is 1996–2008, where the annual average visibility exhibits large fluctuations with a 4-year period. The fourth phase is 2009–2011, where the annual average visibility increases rapidly (Figure 3a).

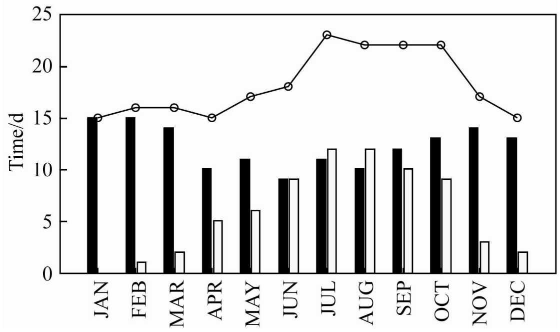

Figure 2 Average monthly variation of days of fog and blowing snow and their totals at GWS.

There has been a significant increasing trend in the annual average visibility at GWS since 1986, and the average rate of 1.5 km·(10 a)$^{-1}$ is significant at the 0.05 level. The four seasonal visibilities also show significant increasing trends; the rate in winter is up to 1.9 km·(10 a)$^{-1}$, which is the fastest among the four seasons (Table 1).

It can be seen from the statistics of low visibility (0–1 km)/(1–10 km) distribution in 1986–2011 at GWS that it occurs: 735/2 678, 864/2 700, 676/3 018, 675/2 575 times in autumn, winter, spring, and summer, respectively. Low visibility occurs more frequently in winter and autumn. However, there is a decreasing tendency both in the 0–1 km and in the 1–10 km low visibility. In addition, the decreasing tendency in 1–10 km visibility is more significant. All of the annual and four seasonal average results are significant at the 0.01 significance level (Table 1).

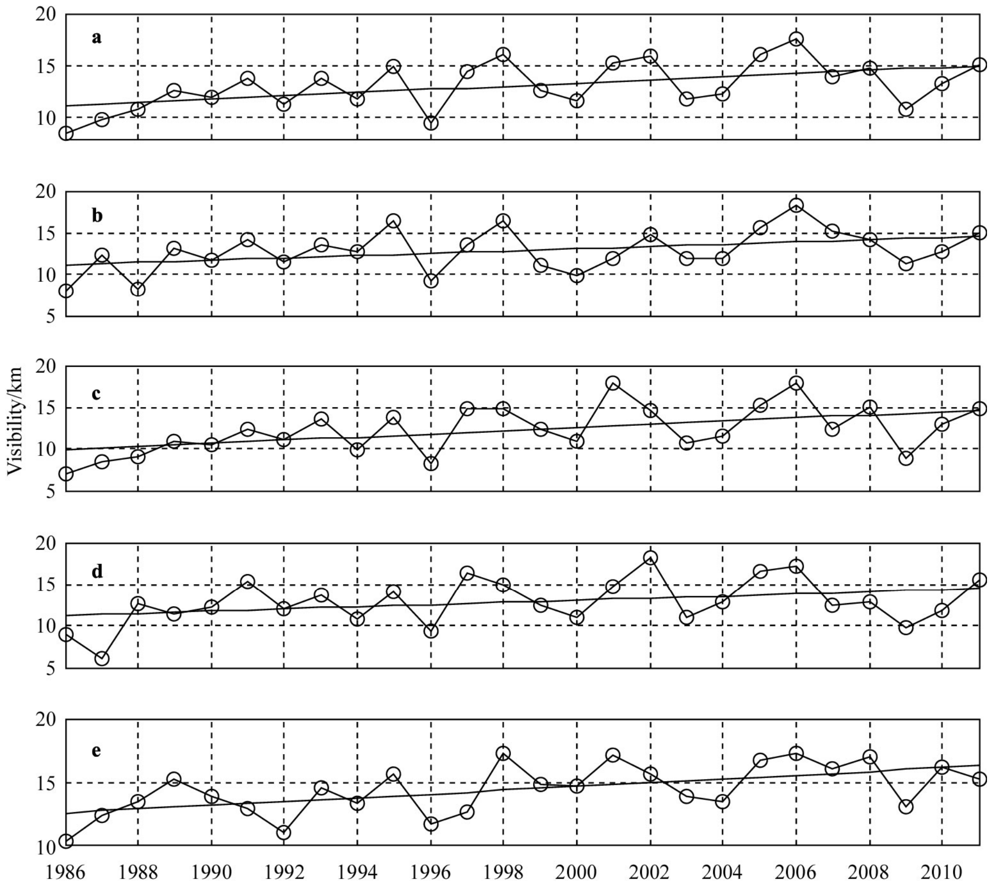

Figure 3 Variation of annual and seasonal average visibility at GWS. Figures from top to bottom are annual (**a**), autumn (**b**), winter (**c**), spring (**d**), and summer averages (**e**), respectively.

GWS is located in the region of the Antarctic Peninsula where a significant warming trend has occurred during the last half-century, and there is certainly a close relationship between the variation of local visibility and atmospheric environmental change. To establish the possible factors for the variation in visibility, Table 1 shows the tendencies of fog, blowing snow, and precipitation days from 1986 to 2011. The increasing trend of annual visibility is due mainly to the decrease in the number of days of fog and blowing snow; the tendency for which has reached −17.0 and −9.0 d·(10 a)$^{-1}$, respectively. The most significant tendency occurs in winter, when the tendencies of fog, blowing snow, and precipitation are −6.6 d·(10 a)$^{-1}$, −3.3 d·(10 a)$^{-1}$ and −19.7 mm·(10 a)$^{-1}$, respectively. This indicates that fog, blowing snow, and snow fall reduction are the leading factors in the increase of visibility during winter. The increasing tendency in spring is related mainly to the reduction in the number of days of fog and blowing snow (−4.0 and −6.3 d·(10 a)$^{-1}$), whereas the increasing visibility in summer and autumn is due, at least in part, to the decreasing tendency in fog days (−2.6 and −3.7 d·(10 a)$^{-1}$). Only a qualitative discussion is offered here, based on the aspects of fog, blowing snow, blizzards, and precipitation, because there are still many other factors that contribute to the variation of visibility, such as aerosols and water vapor, etc. These factors have complex interactions and need further analysis in future work.

Table 1 Variation tendency of meteorological elements from 1986 to 2011 at GWS

Annual or seasonal average	Visibility /(km·(10 a)$^{-1}$)	Low visibility (0–1 km)/(1 –10 km) days /(d·(10 a)$^{-1}$)	Heavy/light fog days /(d·(10 a)$^{-1}$)	Blowing snow/blizzard days/(d·(10 a)$^{-1}$)	Precipitation /(mm·(10 a)$^{-1}$)	Air pressure /(hPa·(10 a)$^{-1}$)
Annual average	1.5***	−7.1/−90.7***	−17.0*/5.4	−9.0	4.2	0.2
Autumn(March−May) average	1.4**	−0.1/−22.8***	−3.7/2.8	0.2	10.0	−0.3
Winter(June−August) average	1.9***	−5.3/−24.8***	−6.6*/−1.3	−3.3	−19.7**	0.4
Spring(September−November) average	1.3*	1.6/−22.1***	−4.0/0.3	−6.3**	9.2	0.3
Summer(December−February) average	1.5***	−3.2/−19.1***	−2.6/3.6	0.3	4.7	−0.6

Notes: *significant at 0.10 level; **significant at 0.05 level; ***significant at 0.01 level

4 Period analyses

The power spectrum is analyzed on the daily average visibility at GWS from 1986 to 2011. It shows that there are significant inter-annual, annual, half-yearly, and synoptic-scale periods (figures not shown). In addition, wavelet analysis is used and similar results are obtained. Figure 4b presents the wavelet full spectrum for different characteristic periods, which could reflect the strength of different periods among the entire study period. The most significant periods are the inter-annual periods: 2 a (748 d), 4.1 a (1 496 d) and 6.9–8.2 a (2 516–2 992 d), of which the 4.1 a cycle exhibits the strongest signal. In addition, the 2.1–8.3 d synoptic-scale cycle is also significant at the 95% confidence level.

Figure 4a shows a two-dimensional wavelet analysis of the daily average visibility at GWS. Among the inter-annual periods, the 4.1 a period is the most significant, indicating that the visibility at GWS may be correlated with El Niño Southern Oscillation. The power spectrum of the synoptic-scale period is not very strong; however, it is significant at 95% confidence level over most time of the series. Wavelet analysis was used to calculate the band-pass filtering of the 3–10 days oscillation. This oscillation is significant most of the time (not shown), and the transit of cyclones every 3–4 days, on average, is mainly responsible for this significant synoptic period. Quasi-bi-weekly (10–20 d) and intra-seasonal oscillations (30–60 d) were not found to be significant during the study period.

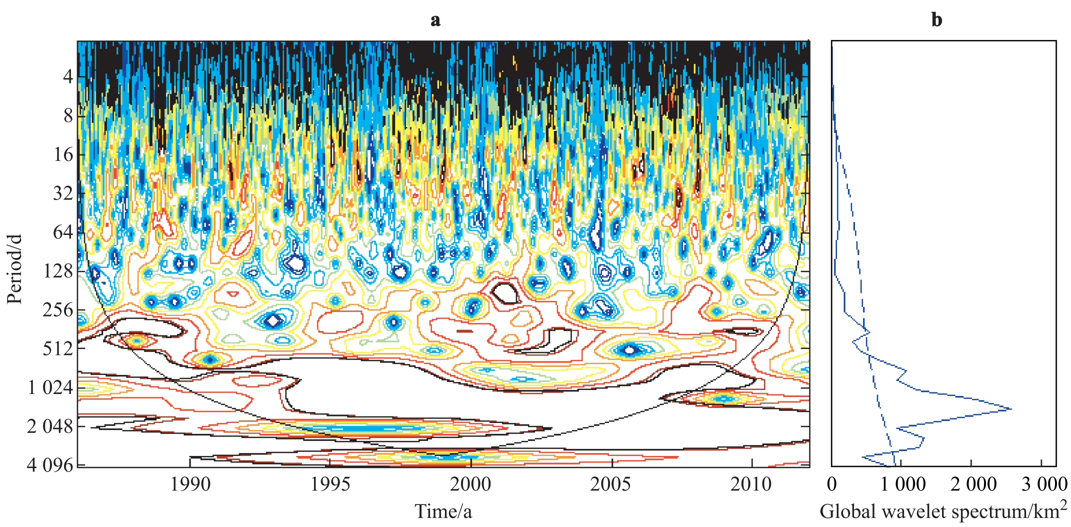

Figure 4 Wavelet analysis of daily average visibility at GWS from 1986 to 2011. **a**, Wavelet power spectrum; the black contours show the 95% confidence level. **b**, Global wavelet spectrum (solid line) and 95% confidence level (dashed line).

5 Comparison between instrumental and manual observation

The manually derived and PWD20 instrumental visibility observations at 02:00, 08:00, 14:00, and 20:00 local time from January to May 2012 are compared (Figure 5). These data reveal a consistent trend. The correlation coefficient is 0.79 and the average visibilities are 14.7 and 12.0 km, respectively. However, the manual result was 2.7 km higher. For periods when visual visibility was less than 20 km, the correlation coefficient is 0.80, the average visibility is 10.0 and 9.1 km, and the deviation between the two is only 0.9 km.

Inevitably, the observations from the two methods occasionally differ. There are several reasons that contribute to the differences. First, the PWD20 measuring range is 0–20 km; hence, it could not capture visibility information beyond 20 km. Second, the manually derived observation is affected significantly by subjective judgment, vision, environmental lighting conditions, and the size of the target angle, whereas the instrumental observation has higher resolution and accuracy. Third, the instrumental visibility refers to the observation within a limited sampling volume of 0.1 L for the forward scatter sensor. Hence, it is representative when the surface air is uniform, but in other conditions, the representative capability is not very good. For the manual observation, all directions around the horizon circle are assessed. Finally, the manual readings are nearly instantaneous observations by the weather observer, whereas the instrumental results are taken as 10-minute means from the sensor. Overall, the PWD20 visibility sensor could monitor the variation of atmospheric visibility at GWS consistently and automatically.

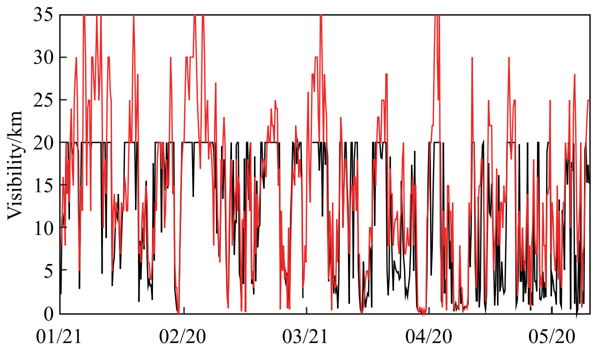

Figure 5 Comparison of manual observations (red line) and PWD20 results (black line) from January to May 2012.

6 Conclusions

Based on the above investigation, the following conclusions can be drawn.

(1) The frequency of occurrence of high visibility (⩾10 km) and low visibility (0−1 km) at GWS accounts for 61% and 18% of the time, respectively. Based on the 26-year annual average, there are 145 fog days and 71 blowing snow days at GWS.

(2) There is a significant seasonal variation in the visibility. Visibility in November to March is the highest of the year, whereas visibility in June to October is the lowest.

(3) There are significant increasing trends in visibility, annually and in each of the four seasons at GWS. The increasing trend in winter is the fastest, which is attributed to the reduction in the number of days of fog, blowing snow, and falling snow that dominate visibility in winter. Both the frequency of occurrence of 0–1 km and of 1–10 km visibility shows a decreasing tendency and the decreasing tendency in 1–10 km visibility is more significant.

(4) The power spectrum and wavelet analyses indicate consistently that apart from the synoptic-scale period (2.1–8.3 d), which is related to the frequency of cyclones, there are also significant annual and inter-annual periods (2 a, 4.1 a, 6.9–8.2 a) in the visibility at GWS, of which the 4.1 a period is the most significant. Further analysis and study of the periods is needed in the future.

(5) The instrumental observation experiments show that the PWD20 has high precision when the visibility ranges from 0 to 20 km, and that it could be used for continuous monitoring of visibility at GWS. It is noted that the sensor should be fixed at a height of 1.5 m or higher, to maintain distance from the thick snow cover during winter. The snow cover on the land surface should also be cleaned as quickly as possible. It is also important to conduct a statistical comparison through parallel runs.

Finally, because the weather observers at GWS change each year, there will inevitably be some differences in subjective judgment, which could introduce discrepancies to this analysis.

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