ANALYSIS OF VARIATION CHARACTERISTICS RELATED TO METEOROLOGICAL DISASTERS IN SOLAR GREENHOUSE GRAPES OF CAO FEI DIAN, CHINA

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Abstract. To master the characteristics of changes related to meteorological disasters in *Cao Fei Dian*'s solar greenhouse grapes and effectively reduce the risk of meteorological disasters, data from the *Cao Fei Dian* National Meteorological Observation Station from 1978 to 2017 were used. The change trends and periodic characteristics of the frequency of low temperature, strong wind, and insufficient sunlight during the grape growing period in the solar greenhouse were statistically analyzed on an annual and monthly scale using the climate tendency rate and Morlet wavelet analysis methods. Forty-year analysis in solar greenhouses showed: 357 low temperature, 127 strong wind, and 227 insufficient sunlight events during grape cultivation. Decadal trends were -4.48, -2.59, and +1.15 events/decade for low temperatures, strong winds, and insufficient sunlight, respectively, with 4-9 and 12-15-year cycles. Monthly trends indicated a decrease in low temperatures (-0.95 to -2.26 events/decade) in January, February, and December, and strong winds (-0.12 to -0.76 events/decade) from November to May, with cycles of 3-19 years. Insufficient sunlight in January, June, November, and December increased by 0.26 to 0.40 events/decade, with 3-16-year cycles.
Keywords: *low temperature, strong wind, insufficient sunlight, frequency, climate tendency rate, change period*

Introduction

Meteorological disasters are one of the main factors affecting agricultural production, significantly impacting the safety of food, fruits, and vegetables in China. To mitigate meteorological disasters to some extent and create greater economic benefits, more and more farmers are turning to cultivating crops in solar greenhouses, especially high-value crops such as fruits and vegetables. In developed countries with advanced facility agriculture, such as the Netherlands, the United States, Japan, and Israel, the standardization level of agricultural facilities is high, and there is advanced development in integrated environmental control and agricultural mechanization technologies. Research in these countries primarily focuses on the economic, social, and environmental

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risks associated with agricultural practices (Mikulsen et al., 2016; Li et al., 2020). In contrast, facility agriculture in China mainly comprises simple solar greenhouses and plastic tunnels, which have relatively poor resistance to natural disasters. Consequently, research emphasis is placed on the analysis of meteorological disaster variation characteristics and disaster prevention measures (Zhao et al., 2022).

However, due to construction cost considerations, most solar greenhouses have a simple structure with poor robustness, lack supplemental lighting and temperature control equipment, and rely solely on basic infrastructure such as film, felt, and walls to maintain the microclimate inside, which still poses certain meteorological disaster risks. In recent years, there have been many studies in China on meteorological disasters in solar greenhouses. Cheng (2015) believes that insufficient sunlight can create a low-temperature and high-humidity environment inside the greenhouse, which is very likely to limit crop growth or cause diseases. Li et al. (2015) used historical data to analyze the trends of disasters such as low temperatures, prolonged rainfall, insufficient sunlight, and strong winds in the Xiqing District of Tianjin in the past 45 years. Yang et al. (2012) referred to the meteorological disaster indicators of facility agriculture in Jiangsu Province and statistically analyzed the occurrence and characteristics of insufficient sunlight in the province. Wu et al. (2023) conducted a detailed analysis of the variation characteristics of meteorological disasters affecting solar greenhouse vegetables in the Inner Mongolia Autonomous Region from 1991 to 2020, integrating meteorological disaster indicators such as low temperature, strong wind and snow disasters. Guo et al. (2022) combined the indicators of crop cold damage and drought disasters to analyze in detail the frequency of cold damage and drought in soybeans in the three northeastern provinces over the past 60 years. Wang et al. (2021) used basic meteorological data and meteorological disaster monitoring data to study the trends of extreme low temperatures, droughts, hail, and other disasters in facility agriculture in Qingyang, Gansu, from 1990 to 2020. Zhao et al. (2022) analyzed the spatiotemporal characteristics of agricultural meteorological disasters such as drought, flood, wind-hail, low temperature-frost, and typhoon in China from 1978 to 2018 according to different geographical divisions.

Cao Fei Dian is located in the eastern part of Hebei, China, adjacent to Beijing and Tianjin, has nearly 20,000 acres of solar greenhouses, making it one of the main off-season fruit and vegetable production areas in the Tangshan region and an important supplier of fruits and vegetables to the Beijing-Tianjin area (Liu et al., 2015). *Cao Fei Dian*, situated along the Bohai Sea coast, predominantly has saline-alkali soil, which, after improvement, is highly suitable for grape cultivation. This has led to a year-by-year increase in the area of grape cultivation in solar greenhouses, significantly enhancing the local farmers' income. Due to climate differences across regions, the research findings on meteorological disasters are not universally applicable, especially since the types of meteorological disasters vary significantly depending on the crop. Currently, research on meteorological disasters in solar greenhouse grapes in the *Cao Fei Dian* area is still a gap. Clarifying the characteristics of these disasters is crucial for improving the quality of local grapes, reducing the risk of meteorological disasters, and ensuring the income of farmers.

Materials and Methods

Data Source

The type of solar greenhouse studied in this paper is one of the most common and largest-scale greenhouses in *Cao Fei Dian* and across the country. The greenhouse is

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75 m in length, 9 m in width, and has a ridge height of 3.5 m. The east, west, and north sides are constructed with double-layer brick walls filled with a 0.1 m thick straw mat in between. The north wall is 0.5 m thick, while the east and west walls are 0.24 m thick. The top of the greenhouse is a steel structure covered with polyethylene plastic film. Ventilation openings are located on the east and west sides, and a temporary ventilation opening, equal in length to the greenhouse and adjustable in width, is situated at the top near the north wall. The greenhouse lacks heating facilities and supplementary lighting equipment. Climate control within the greenhouse relies primarily on measures such as ventilation, shading, and the use of coverable shading and insulation quilts to mitigate the impact of adverse weather conditions (*Figure 1*).

Figure 1. *Exterior and interior photographs of Cao Fei Dian grape solar greenhouses*

Based on field surveys and relevant studies (Xiao et al., 2021), the annual growth period for *Cao Fei Dian* solar greenhouse grapes extends from November to the following June. Therefore, for the research process, data for the daily minimum temperature, daily maximum wind speed, and sunlight duration were selected for the period of solar greenhouse grape growth from November to the following June, covering the years 1978 to 2017. The data were obtained from the *Cao Fei Dian* National Meteorological Observation Station.

Research Methods

The study employed the least squares method to calculate the climate tendency rates of meteorological disaster occurrences at different time scales (Xiao et al., 2019). This method provides a visual representation of their changing trends over time. Wavelet analysis (Tian et al., 2020) was utilized to investigate the change cycles of meteorological disaster occurrences in the time series. This analytical approach allows for a detailed examination of the periodic characteristics and variations in the frequency of meteorological disasters over different time scales.

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Disaster Indicators

Wang et al. (2014) conducted a statistical analysis of the losses caused by meteorological disasters such as low temperatures, strong winds, and insufficient sunlight to vegetables in solar greenhouses through a questionnaire survey. The majority of respondents believed that low temperature freezing damage and insufficient sunlight had a significant impact on the yield and quality of greenhouse vegetables, with 45.6% and 53.7% of respondents respectively considering that the impact of low temperature freezing damage exceeded 15%, and 37.8% and 35.4% respectively for insufficient sunlight. The impact of strong winds on crop yield and quality was considered relatively minor by comparison, but it was seen as causing the greatest damage to the structure of the greenhouses; more than 70% of respondents believed that the impact of strong winds and insufficient sunlight on the storage, transport, and sale of greenhouse vegetables was below 20%, while over 50% believed that the impact of low temperature freezing damage on vegetable storage exceeded 30%. The costs of defending against and remedying strong winds, low temperature freezing damage, and insufficient sunlight accounted for an average percentage of 20.3%, 15.8%, and 13.0% of all costs for meteorological disaster defense and remediation, respectively. Based on the average annual total production value of the solar greenhouse vegetable industry in Hebei Province of China during the survey period (2004-2013), the meteorological service benefits of strong wind disasters were the highest, averaging 294.1 million yuan per year, followed by low temperature freezing damage and insufficient sunlight, with the total benefits averaging close to 1 billion yuan per year.

Cao Fei Dian experiences widespread low temperatures during the winter season. However, the warming and insulation capabilities of local solar greenhouses are limited. From November to the end of February each year, the growth period of *Cao Fei Dian* solar greenhouse grapes occurs before bud break, requiring a minimum temperature of 0°C for grape growth. As previously mentioned, the structure of the solar greenhouses discussed in this study is simple and lacks heating equipment. Through surveys and interviews with farmers, it has been understood that under current management conditions, these solar greenhouses can achieve a temperature increase of 12-16°C. Therefore, when the external temperature falls below -12°C, there is a risk of low temperature disasters inside the greenhouse, with the risk increasing as the external temperature drops further. When the external temperature drops to or below -12.0°C, there is a risk of frost damage to grapes within the greenhouse. Previous studies (Wei et al., 2003) have indicated that -12.0°C is the critical threshold for most solar greenhouse crops. The geographical location, surrounded by the sea on three sides, makes the region prone to strong winds. When the wind speed exceeds 12.0 m/s, there is a risk of varying degrees of damage to the greenhouse structure (Yang et al., 2012; Chen et al., 2019). Insufficient sunlight weakens the warming effect of solar greenhouses (Wei et al., 2008). Prolonged insufficient sunlight can impact grape dormancy and photosynthesis during the growth period (Han et al., 2015; Li et al., 2017). Based on this, the paper intends to investigate the characteristic effects of three meteorological disasters—low temperatures, strong winds, and insufficient sunlight—during the growth process of solar greenhouse grapes. Drawing on relevant research findings and practical production surveys, three meteorological disaster indicators have been identified (*Table 1*).

Statistical data indicate that, during the period from 1978 to 2017, *Cao Fei Dian* experienced a total of 27 hail occurrences, most of which were concentrated in July and August. During the growth period of solar greenhouse grapes (from November to the following June), there were only 4 occurrences of hail; therefore, this study did not consider hail as a primary meteorological disaster affecting solar greenhouse grapes. However, it is undeniable that hail poses a significant risk of damage to other crops in solar greenhouses.

Table 1. *Statistical Table of Meteorological Disaster Indicators for Solar Greenhouse Grapes in Cao Fei Dian*

Disaster Types	**Low Temperature Events**	**Strong Wind Events**	**Insufficient Sunlight Events**
Disaster Indicators	Tmin≤-12.0°C	Vmax≥12m/s	SH(=0) ≥2d

Note: Tmin represents the daily minimum temperature, Vmax represents the daily maximum wind speed, and SH (=0) represents the number of days with continuous sunlight duration equal to 0

Wavelet Analysis

The wavelet analysis method is a time-frequency localization optimization technique with a fixed window area, where both the time and frequency windows can be adjusted. This method features multi-resolution characteristics in time and frequency, enabling the detailed revelation of signal variations in both the time and frequency domains. Wavelet analysis of the time coefficients of disaster indices allows for the grasp of their periodic changes over time, providing a deeper understanding of the periodic variations in disaster frequencies and predicting future trends. Utilizing the wavelet analysis method, scholars have conducted extensive research: Gao et al. (2014) investigated the spatiotemporal distribution and evolution patterns of major meteorological disasters during the maize development stages in Northeast China from 1961 to 2010; Maru et al. (2021) studied the periodic characteristics of drought event frequencies in the Awash Basin of Ethiopia between 1983 and 2016; Mondol et al. (2022) researched the impact of periodic changes in precipitation on rice yields in the Barind tract and Teesta floodplain regions, located in the northwest region of Bangladesh from 1979 to 2018, while also assessing the strength of the relationship between irrigation and rice production.

Let $f(t)$ represent a measurable function varying over time; then, the continuous wavelet transform of the function $f(t)$ is defined as:

$$\omega_f(a,b) = |a|^{-\frac{1}{2}} \int_R f(t)\overline{\Psi}\left(\frac{t-b}{a}\right)dt \tag{Eq.1}$$

$$\overline{\Psi}(t) = (1-t^2)e^{-\frac{t^2}{2}} \tag{Eq.2}$$

In *Equation 1*, a represents the scaling factor, reflecting the wavelet's period length, where 1/a is equivalent to frequency; b is the time parameter, indicating the translation in time relative to t; and $\overline{\Psi}$ denotes the mother wavelet function, the mathematical expression of which is given by *Equation 2*. Through computation, the relative strengths at various scales within a time series can be determined. The scale corresponding to the peak values in the wavelet spectrum is termed the principal time scale of the series, reflecting the main periodicity of the time series.

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Results and Analysis

Frequency Analysis of Disaster Occurrences by Year

Based on historical meteorological data in *Cao Fei Dian*, a comprehensive analysis reveals a total of 727 occurrences of low temperature, strong wind, and insufficient sunlight events during the solar greenhouse grape growth period from 1978 to 2017. The analysis, depicted in *Figure 2*, highlights that low temperature events have the highest prevalence, accounting for 50.21% and totalling 357 occurrences over the past four decades. Following closely is insufficient sunlight, constituting 31.93% and accumulating 227 occurrences, while strong wind events contribute 17.86%, with a cumulative total of 127 occurrences.

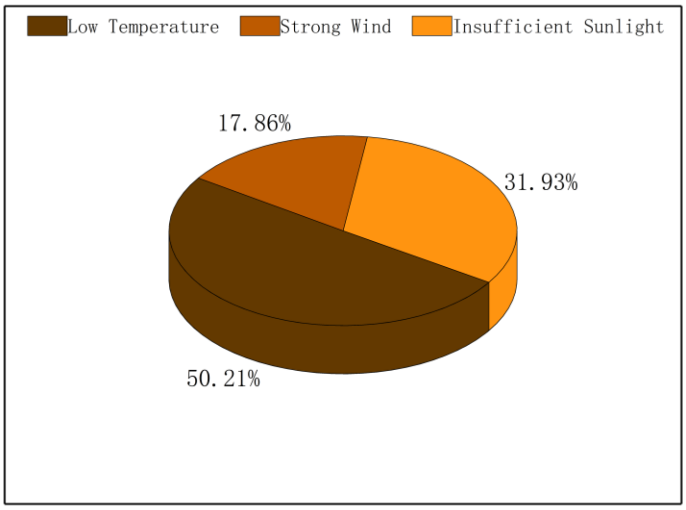

Figure 2. *Comparison chart of total incidents of Low Temperature, Strong Wind, and Insufficient Sunlight Disasters in solar greenhouse grape cultivation*

To comprehensively understand the variability in the frequency of low temperatures, strong winds, and insufficient sunlight, a statistical analysis was performed on the annual occurrence frequency of these elements in solar greenhouse grapes from 1978 to 2017, as depicted in *Figure 3*. This figure illustrates that prior to 1985, the incidence of low temperature disasters was notably more frequent, signifying a period of heightened disaster occurrences. The most frequent occurrences were in 1980 and 1981, each with 31 instances. After 1985, there was an overall decrease in the frequency of low temperatures, although with significant fluctuations. The overall trend for strong wind disasters followed a similar pattern to that of low temperatures, with the highest incidence occurring in 1979, recorded at 16 instances. Conversely, the trend for insufficient sunlight differed; before 1985, such occurrences were infrequent, but there was a considerable increase thereafter, peaking in 2002 with 13 instances. Linear fitting results show that from 1978 to 2017, the frequencies of low temperatures and strong winds exhibited a downward trend, with climate tendency rates of -0.448 occurrences/year and -0.259 occurrences/year, respectively. In contrast, the frequency of insufficient sunlight displayed an upward trend, with a climate tendency rate of 0.115 occurrences/year. Both the decreasing and increasing trends were statistically significant at the 0.01 level, denoting highly significant changes in these trends.

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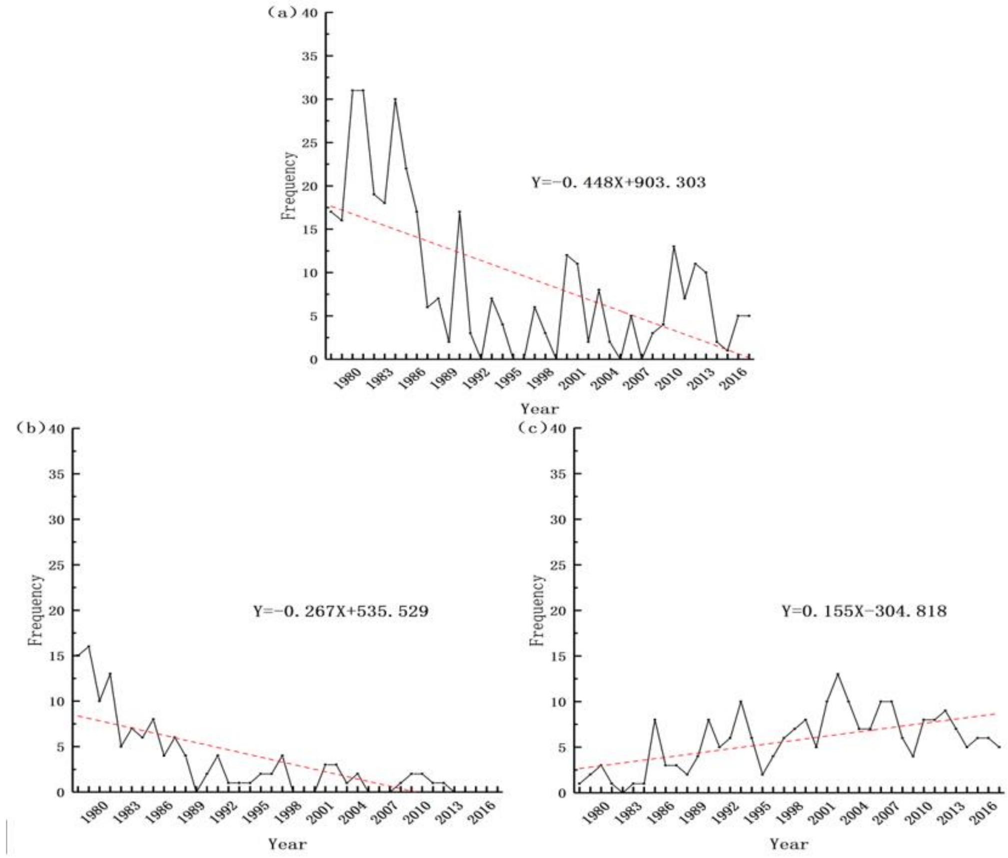

Figure 3. *Trends in the Annual Frequency of Major Meteorological Disasters for Solar Greenhouse Grapes: (a) Low Temperatures, (b) Strong Winds, (c) Insufficient Sunlight*

Utilizing wavelet analysis to analyze the periodicity of disaster variations enables the identification of "increase-decrease" cycles in past disaster occurrence frequencies. These cycles of disaster frequency changes could span several years, a decade or more, or even several decades, and may also include shorter cycles of a few years to a decade nested within longer cycles spanning several decades. Through the analysis of these cycles in disaster frequency, it is possible to some extent to predict whether the coming years or decades will experience a period of higher or lower frequency of such disasters, thus forecasting the trend in disaster variation characteristics.

The periodic variation in the frequency of disasters was analyzed using the wavelet analysis method (Li et al., 2017; Zhang et al., 2023). The primary cycles at each scale were determined based on wavelet variance (Shi et al., 2017). Due to space constraints, the wavelet variance graphs are omitted, and the same applies to the subsequent monthly analysis. The periodic variation in the annual frequency of low temperatures, strong winds, and insufficient sunlight in solar greenhouse grapes (*Figure 4*) reveals that all three types of meteorological disasters exhibit a phenomenon of nested long and short cycles. For the period 1978–2017, the annual frequency of low temperatures (*Figure 4a*) shows interannual variation cycles of 5 years and 8 years, and a decadal variation cycle of 15 years. Wavelet variance comparison identified 15 years as the primary cycle. The current phase of the low temperature frequency, as indicated by the unclosed contour lines of the first primary cycle, is at the end of a 'high-low' oscillation, soon entering a 'high' value

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phase. The annual frequency of strong winds (*Figure 4b*) shows interannual variation cycles of 5 years and 9 years, and a decadal variation cycle of 12 years, with 12 years identified as the primary cycle. The current phase of the strong wind frequency is in the 'low' value stage of the 'high-low' oscillation of the first primary cycle. The annual frequency of insufficient sunlight (*Figure 4c*) has interannual variation cycles of 4 years and 7 years, and a decadal variation cycle of 14 years, with 7 years as the primary cycle. Since 1978, it has been undergoing a 'low-high' oscillation change and is currently in the 'high' value stage of the first primary cycle. Based on the oscillation characteristics of the contour lines corresponding to the first primary cycle, it is predicted that the current stage is likely to be a high-incidence year for low temperatures and insufficient sunlight, while strong wind disasters may occur less frequently.

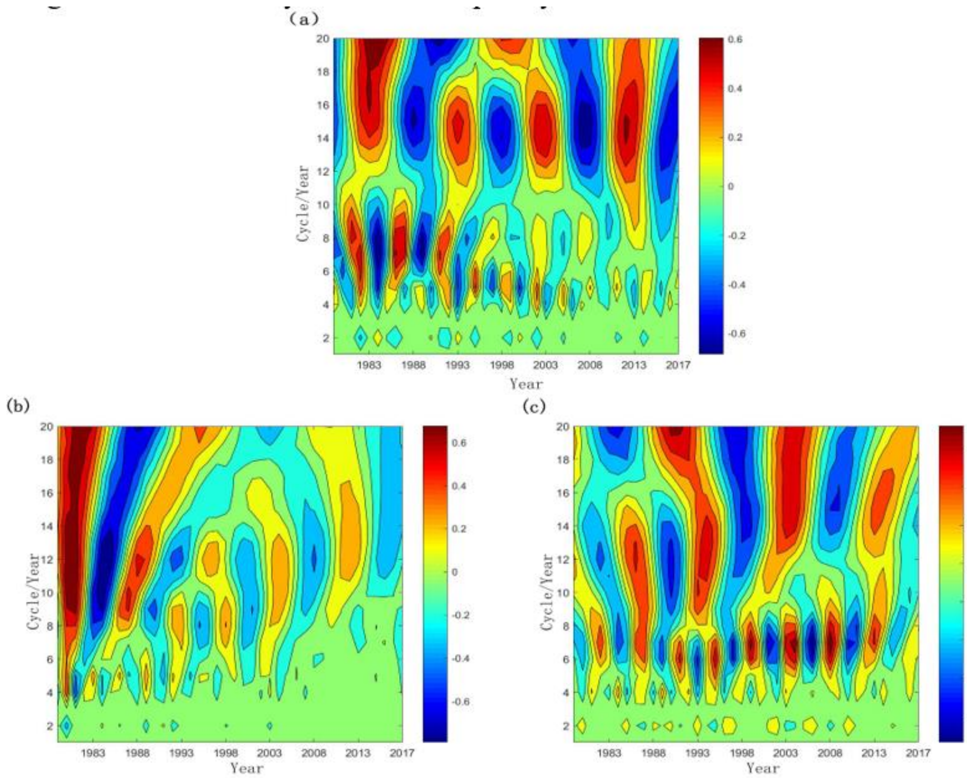

Figure 4. *Periodic Variations in the Annual Frequency of Major Meteorological Disasters for Solar Greenhouse Grapes: (a) Low Temperatures, (b) Strong Winds, (c) Insufficient Sunlight*

Analysis of Monthly Disaster Frequency

After analyzing the annual frequency trends of major meteorological disasters, this study further examined the disaster frequency on a monthly scale to more accurately grasp the patterns of disaster changes. *Figure 5* shows the cumulative monthly distribution of low temperature, strong wind, and insufficient sunlight disasters during the growth period of solar greenhouse grapes from 1978 to 2017. For low temperatures (*Figure 5a*), the main occurrences are in January, February, and December, with cumulative frequencies of 216, 72, and 67 times respectively, indicating that January is the most common month for low-temperature disasters. There are a few instances of low-temperature disasters in November, occurring only 2 times. Strong winds (*Figure 5b*) occur in all months, with

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the highest frequency in March to May. April sees the most occurrences, totalling 35 times, while November has the least, with 6 times. Insufficient sunlight (*Figure 5c*) shows a distribution pattern almost opposite to that of strong winds, with the highest and second-highest frequencies being 48 and 42 times, occurring in December and January, respectively. The lowest and second-lowest frequencies are 15 and 17 times, occurring in April and May, respectively.

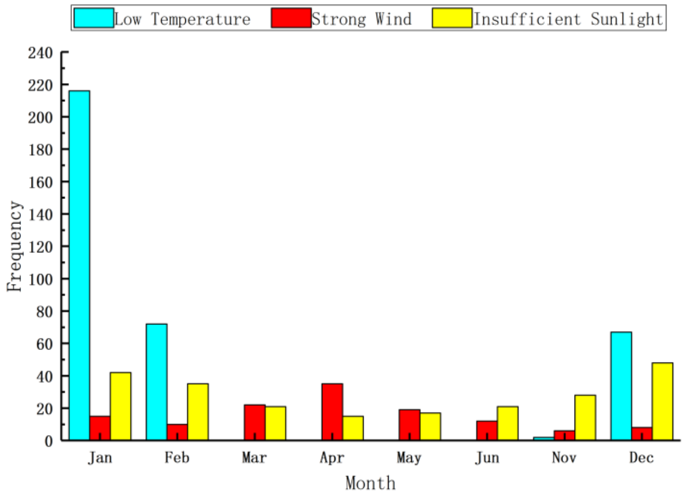

Figure 5. *Monthly Statistics of Major Meteorological Disasters for Solar Greenhouse Grapes*

Figure 6 presents the trends in the frequency of low temperatures in January, February, and December from 1978 to 2017. The peak frequencies of low-temperature disasters in January, February, and December occurred in 1982, 1980, and 1981, with 18, 10, and 10 occurrences, respectively. The frequency of low-temperature disasters in January, February, and December shows a significant decreasing trend over time, with climate tendency rates of -2.26 occurrences/decade, -1.28 occurrences/decade, and -0.95 occurrences/decade, respectively. All decreasing trends have passed the significance test at the 0.01 level.

Figure 7 depicts the periodic changes in the monthly frequency of low temperature disasters for solar greenhouse grapes. It is evident that there is a nesting of long and short cycles in the monthly frequency of low temperatures. The figure shows that from 1978 to 2017, the January low temperature frequency has an interannual variation cycle of 5 years and a decadal variation cycle of 14 years, with the 14-year cycle being the primary cycle. The contour lines for the 14-year cycle show a 'high-low' oscillation, with the 'low' value phase ending in 2017, indicating the current phase is likely the 'high' value phase of the oscillation. The February low temperature frequency has variation cycles of 5 years, 8 years, and 16 years, with the 8-year cycle as the primary cycle. The 'high-low' oscillation under the primary cycle was particularly evident before 1993, then weakened, indicating that the primary cycle was most stable before 1993. The December low temperature disaster frequency has variation cycles of 7 years and 15 years, with the 7-year cycle as the primary cycle, showing similar contour line characteristics to February.

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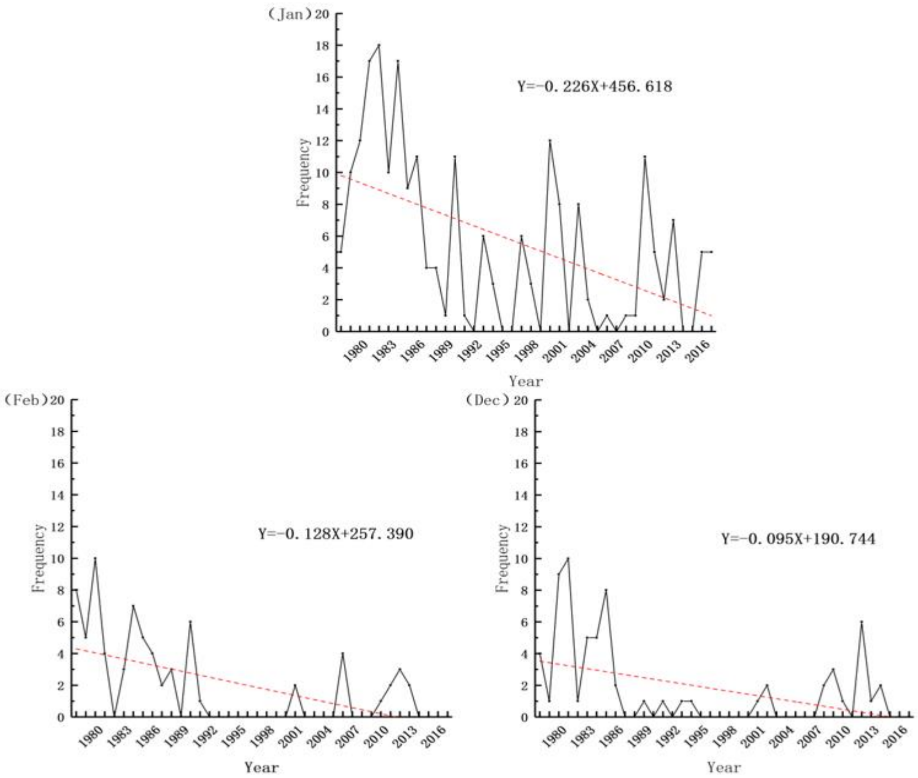

Figure 6. *Trend of Monthly Frequency Changes in Low Temperature Disasters for Solar Greenhouse Grapes*

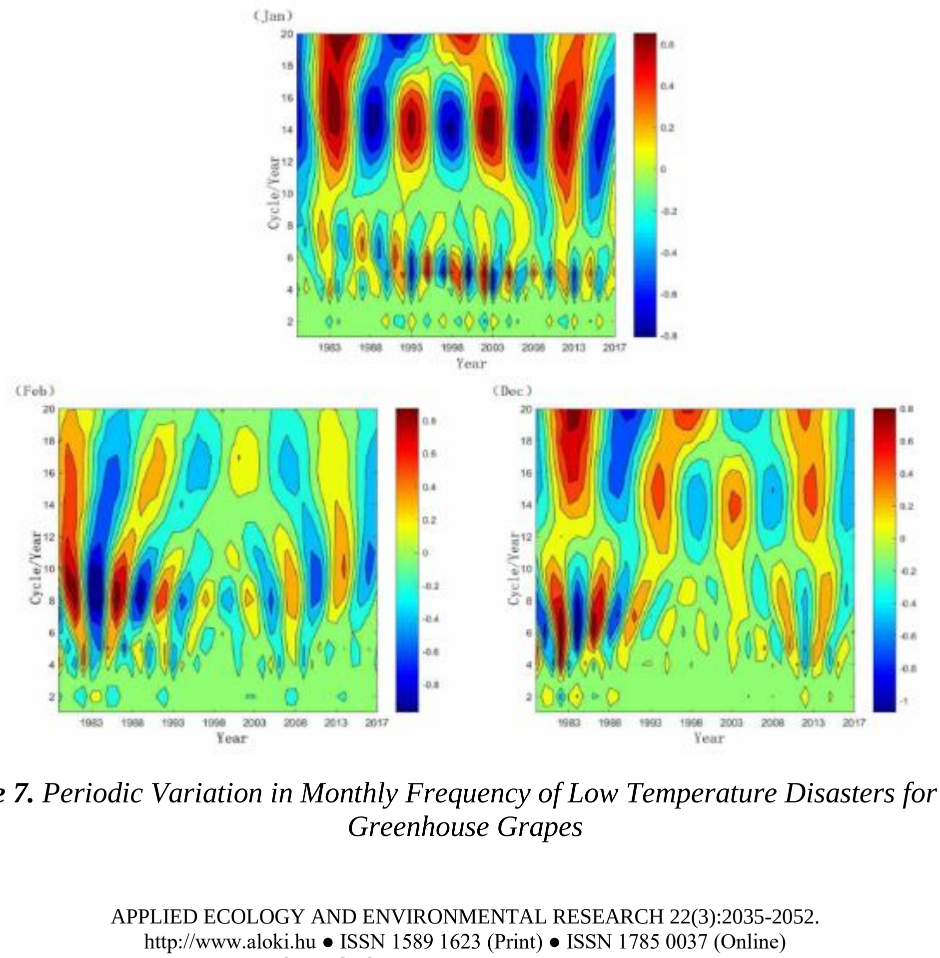

Figure 7. *Periodic Variation in Monthly Frequency of Low Temperature Disasters for Solar Greenhouse Grapes*

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The trend graph for monthly frequencies of strong wind disasters in solar greenhouse grapes (*Figure 8*) indicates that during the period 1978 to 2017, strong wind disasters were more frequent in all months before 1990, with the highest annual frequencies for each month mostly concentrated before 1990. April experienced the highest annual frequency of strong wind disasters, with 7 occurrences, which is the maximum value recorded among all months. The highest frequencies in other months ranged only from 2 to 4 occurrences. After 1990, the frequency of strong wind disasters in each month was relatively lower, with several years in succession without any strong wind disasters. Over the past 40 years, there has been a varying degree of decreasing trend in the frequency of strong winds in each month. The climate tendency rates for January to May are -0.33 occurrences/decade, -0.24 occurrences/decade, -0.48 occurrences/decade, -0.76 occurrences/decade, and -0.49 occurrences/decade, respectively, all of which passed the significance test at the 0.01 level, indicating a very significant decreasing trend. The climate tendency rates for November and December are -0.12 occurrences/decade and -0.14 occurrences/decade, respectively, which passed the significance test at the 0.05 level. However, the trend for June did not pass the significance test.

From the periodic variation graph of monthly frequencies of strong wind disasters in solar greenhouse grapes (*Figure 9*), it is evident that the frequency of strong wind disasters in each month exhibits interannual and decadal variation cycles at different time scales. Specifically, January has an interannual cycle of 7 years and a decadal cycle of 12 years, with the 12-year cycle being the primary cycle; February has an interannual cycle of 4 years and decadal cycles of 10 years and 19 years, with 19 years as the primary cycle; March has interannual cycles of 3 years and 7 years, and a decadal cycle of 12 years, with 7 years as the primary cycle; April has only an interannual cycle of 9 years; May has an interannual cycle of 6 years and a decadal cycle of 12 years, with 6 years as the primary cycle; June has interannual cycles of 4 years and 9 years, and decadal cycles of 13 years and 19 years, with 19 years as the primary cycle; November has an interannual cycle of 5 years and a decadal cycle of 14 years, with 5 years as the primary cycle; December has interannual cycles of 3 years, 5 years, and 9 years, and a decadal cycle of 16 years, with 9 years as the primary cycle. Based on the oscillation of the contour lines under the primary cycle, the oscillation of the contour lines for monthly strong wind frequencies became unstable after 1995-2000, and the range of the contour lines around zero value is large, making it difficult to predict whether the current stage of monthly strong wind disasters is a high-incidence or low-incidence phase.

Figure 10 presents the trend graph for the monthly frequency of insufficient sunlight disasters in solar greenhouse grapes from 1978 to 2017. As illustrated, the frequency of insufficient sunlight disasters in most months has significantly increased after the year 2000. In February 2001, there were four occurrences of insufficient sunlight disasters, marking the highest frequency recorded for any month over the years. From 1978 to 2017, the frequency of insufficient sunlight in each month showed varying degrees of increasing trends. January, June, and December passed the significance test at the 0.01 level, with climate tendency rates of 0.34 occurrences/decade, 0.28 occurrences/decade, and 0.40 occurrences/decade, respectively, indicating a highly significant increase. November passed the significance test at the 0.05 level, with a climate tendency rate of 0.26 occurrences/decade. However, the trends from February to May did not pass the significance test.

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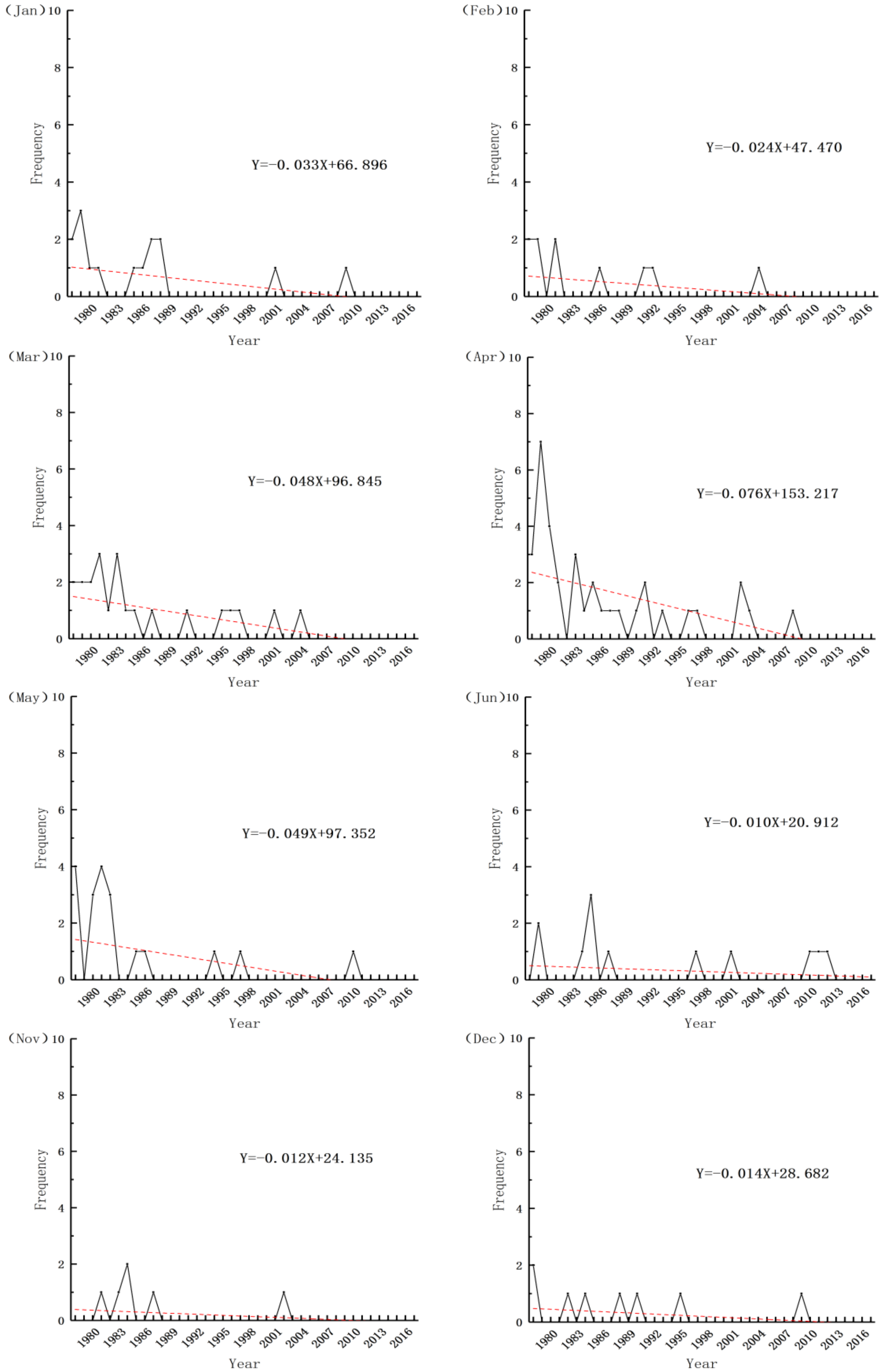

Figure 8. *Trend of Monthly Frequency Changes in Strong Wind Disasters for Solar Greenhouse Grapes*

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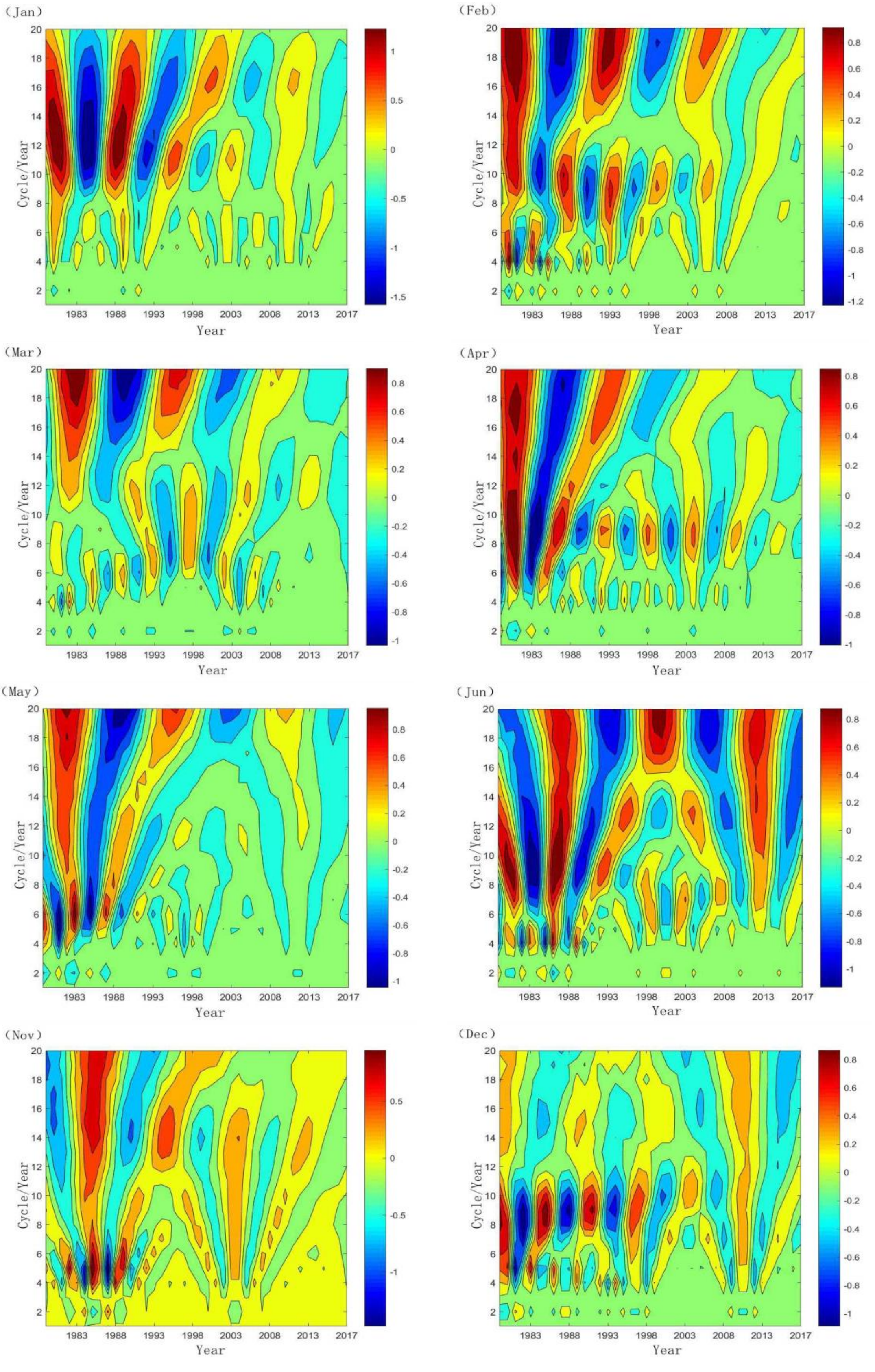

Figure 9. *Periodic Variation in Monthly Frequency of Strong Wind Disasters for Solar Greenhouse Grapes*

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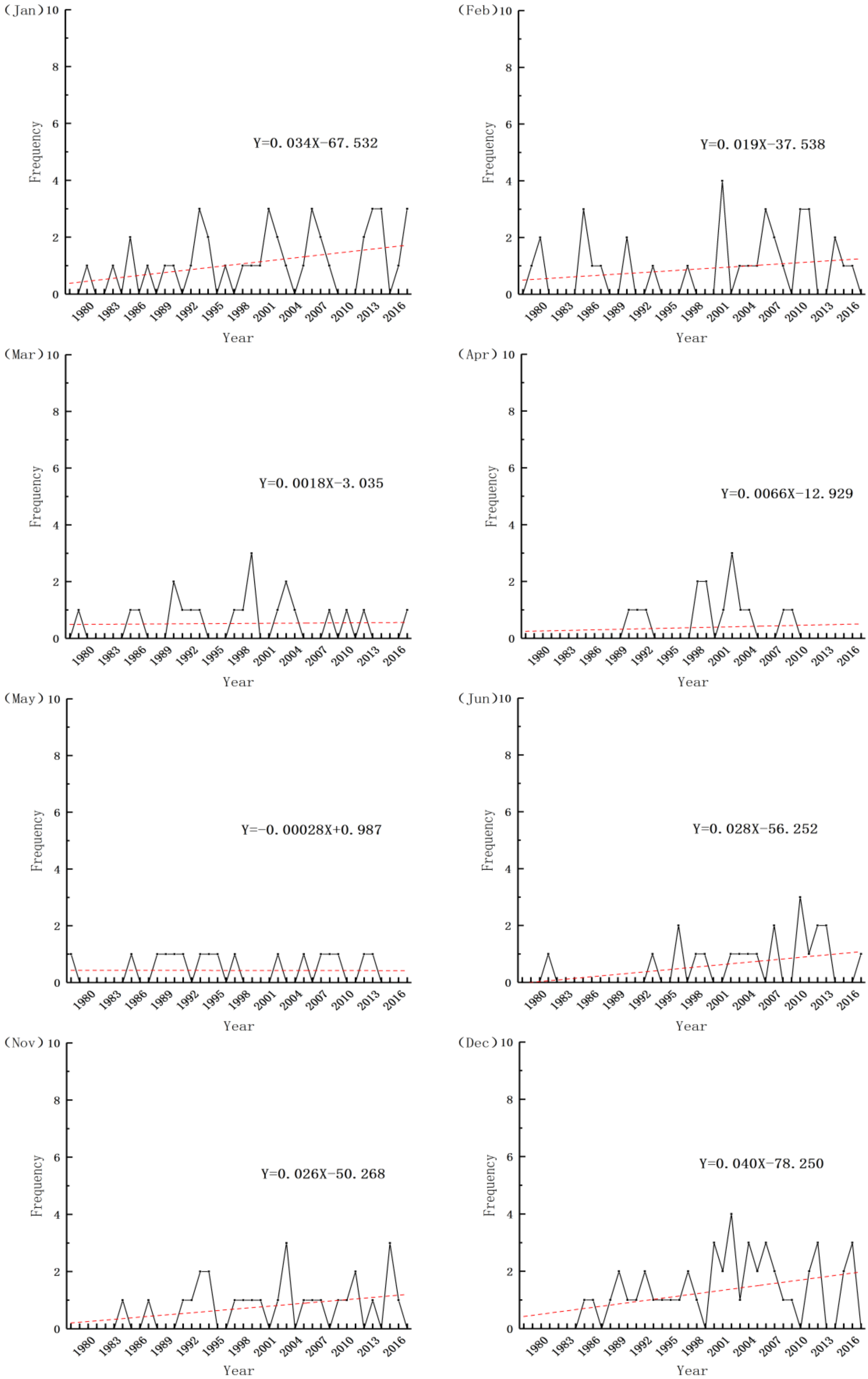

Figure 10. *Trend of Monthly Frequency Changes in Insufficient Sunlight Disasters for Solar Greenhouse Grapes*

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Figure 11 depicts the periodic variation in the frequency of insufficient sunlight disasters in solar greenhouse grapes from 1978 to 2017.

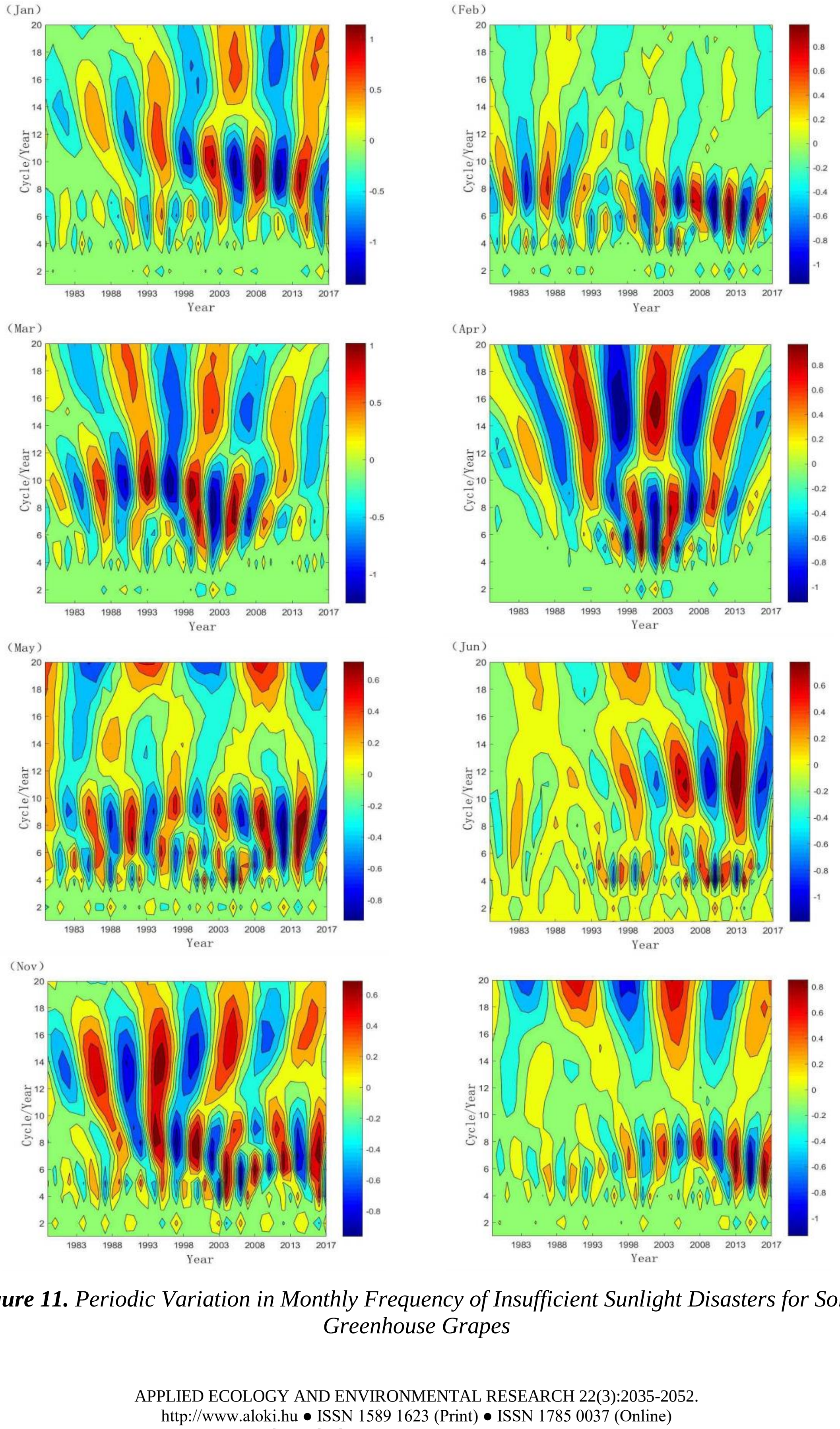

Figure 11. *Periodic Variation in Monthly Frequency of Insufficient Sunlight Disasters for Solar Greenhouse Grapes*

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The graph shows that in the periodic variation of monthly insufficient sunlight disaster frequencies, January has decadal variation cycles of 10 years and 16 years, with the 10-year cycle being the primary cycle; February has an interannual variation cycle of 7 years; March has an interannual cycle of 3 years and decadal cycles of 10 years and 16 years, with the 10-year cycle as the primary cycle; April has decadal cycles of 5 years and 8 years and a decadal cycle of 15 years, with the 15-year cycle as the primary cycle; May has decadal cycles of 6 years and 9 years and a cycle of 14 years, with the 9-year cycle as the primary cycle; June has a decadal cycle of 4 years and a cycle of 11 years, with the 11-year cycle as the primary cycle; November has a decadal cycle of 7 years and a cycle of 14 years, with the 7-year cycle as the primary cycle; December has interannual cycles of 3 years and 7 years, with the 7-year cycle as the primary cycle. The primary cycle variations after 2000 have been relatively stable, with a clear alternating pattern of positive and negative changes between contour lines. It is predicted that under the primary cycle, January, March, and December will be in the 'low' value zone, indicating a phase with fewer insufficient sunlight disasters, while February, April, May, June, and November will be in the 'high' value zone, indicating a phase with more frequent insufficient sunlight disasters.

Conclusion and Discussion

(1) Low temperatures, strong winds, and insufficient sunlight are the three main types of meteorological disasters during the growth period of solar greenhouse grapes in *Cao Fei Dian*. Among these, low temperatures occurred most frequently, with a cumulative total of 357 instances from 1978 to 2017, surpassing the combined occurrences of insufficient sunlight and strong winds. Low temperatures and strong winds were more frequent before 1985, while the trend was opposite for insufficient sunlight. Over the past 40 years, the annual frequencies of low temperatures and strong winds have shown a significant decreasing trend, with climate tendency rates of -4.48 occurrences/year and -2.59 occurrences/year, respectively. In contrast, the frequency of insufficient sunlight showed an increasing trend, with a climate tendency rate of 1.15 occurrences/year. From 1978 to 2017, the annual frequencies of low temperatures, strong winds, and insufficient sunlight exhibited interannual variation cycles of 4 to 9 years and decadal variation cycles of 12 to 15 years.

(2) Low temperature disasters typically occur from December to February, with the highest frequency in January. Over the past 40 years, there were 357 instances of low temperatures, with 216 occurrences in January. The frequencies of low temperatures in January, February, and December all show a significant decreasing trend over time, with climate tendency rates of -2.26 occurrences/decade, -1.28 occurrences/decade, and -0.95 occurrences/decade, respectively. The monthly frequencies of low temperatures over the past 40 years have interannual variation cycles of 5 to 8 years and decadal variation cycles of 12 to 14 years.

(3) Strong wind disasters occur from November to June, with the period from March to May being more frequent, and April having the highest frequency. The monthly frequencies of strong winds all show varying degrees of decreasing trends. The climate tendency rates for January to May are -0.33 occurrences/decade, -0.24 occurrences/decade, -0.48 occurrences/decade, -0.76 occurrences/decade, and -0.49 occurrences/decade, respectively, indicating a highly significant decreasing trend. The climate tendency rates for November to December are -0.76 occurrences/decade and -

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0.49 occurrences/decade, respectively, showing a significant decreasing trend. The frequencies of strong winds in January to March, May to June, and November to December have different scale variation cycles of 3 to 6 years, 7 to 9 years, 10 to 14 years, and 16 to 19 years, while April has only a 9-year variation cycle.

(4) Insufficient sunlight disasters are more concentrated from November to February, with the highest frequency in December. The frequencies of insufficient sunlight in all months show an increasing trend over time, with climate tendency rates for January, June, and December of 0.34 occurrences/decade, 0.28 occurrences/decade, and 0.40 occurrences/decade, respectively, indicating a highly significant increasing trend. The climate tendency rate for November is 0.26 occurrences/decade, showing a significant increasing trend. The trends from February to May did not pass the significance test. The frequencies of insufficient sunlight in January, March to June, and November to December have different scale variation cycles of 3 to 6 years, 7 to 9 years, 10 to 11 years, and 14 to 16 years, while February has only a 7-year variation cycle.

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