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Original Research Paper

An Observation Study for Cold and Freezing Injury of Sugarcane Based on China Meteorological Administration Land Data Assimilation System, CLDAS Temperature Data

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Abstract: Based on the China meteorological administration Land Surface Data Assimilation System (CLDAS), the CLDAS temperature product is examined and analyzed using remote sensing information, and a revised temperature model is established for the monitoring and evaluation of sugarcane chilling and freezing damage. The results show that: (1) The CLDAS temperature products are highly positively correlated with the measured temperatures of the stations; the correlation coefficients are all higher than 0.9; the root-mean-square error is1.5-2°C; the average absolute deviations are 1-1.5°C and the average relative deviation is 0-0.5°C; (2) The root-mean-square error between the revised CLDAS temperature and the measured temperature is less than 1 u; the average absolute deviation is less than 0.7 a and the average relative deviation change is less than 0.5 d, indicating that the revised CLDAS temperatures are close to the measured values and the fitting effect is particularly optimal in the low-temperature regions; (3). The revised CLDAS model is used to monitor and evaluate the cold and freezing injury of sugarcane in typical years. The results are basically consistent with the actual survey and can significantly improve the accuracy.

Keywords: Cold and Freezing Injury, Sugarcane, CLDAS, Temperature Correction

Introduction

China is the third largest sugarcane producer in the world. Since 2006, the sucrose yield in Guangxi has exceeded 60% of the whole country and sugarcane is the most important cash crop in Guangxi and has an important impact on the sugar industry of China. Cold and freezing injury is one of the main meteorological disasters affecting Guangxi sucrose production (Xu *et al*., 2020). Cold and freezing injury generally occurs in the sugarcane crushing season and large-range and serious cold and freezing injury will reduce the yield and sugar content to varying degrees. It will cause a serious shortage of raw materials in sugar enterprises, increase the sucrose recovery cost, and directly affect the sugarcane seed reserve and normal tillering of stubble cane. To this end, the composition of sugarcane yield in the next crushing season will be affected, bringing huge economic losses to the majority of sugarcane farmers and enterprises and affecting the stability of the domestic sugar market (Belintani *et al*., 2012; Tan *et al*., 2008). Therefore, it is of great significance to take disaster prevention and mitigation measures, as well as sucrose industry layout to effectively monitor cold and freezing injury of sugarcane.

Research on cold and freezing injury of sugarcane mainly contains four aspects: (1) Impact of cold and freezing injury of sugarcane. Many scholars have proved that cold and freezing injury can significantly affect the growth, physiology biochemistry, and expression of relevant genes of sugarcane (Dharshini *et al*., 2020; Sun *et al*., 2017); (2) Cold and freezing injury indexes of sugarcane. Using the meteorological data of different varieties of sugarcane in the main production regions of Guangxi in typical cold and freezing injury years, (Tan *et al*., 2014) established and improved the grade indexes of radiation (Continuous 2d minimum temperature ≤1.0°C) and advection (Continuous 5d minimum temperature ≤3.9°C) of cold and freezing injury of sugarcane, as well as the disaster damage indexes of sugarcane yield and sugar content. Based on the field investigation of multi-year frost disasters in sugarcane production regions of Guangxi, (Liang *et al*., 2016) established Guangxi local standard investigation specifications of sugarcane frost disaster by the field investigation and experience; (3) Risk zoning for cold and freezing injury of sugarcane. Based on the growth condition, damage degree, low temperature and freezing intensity, and geographic information data from1971-2000, He *et al*., (2007) analyzed the spatial distribution characteristics of low temperature and freezing injury of sugarcane in Guangxi at 1 km scale. Combined with the grade index for cold and freezing injury of sugarcane, (Tan *et al*., 2015) classified and evaluated the risk grade of cold and freezing injury of sugarcane at250 m scale based on the minimum temperature data, geographic information data, and surface reflectance data in winter cold and freezing injury process in Guangxi from 1961-2013; (4) Monitoring and evaluation of cold and freezing injury of sugarcane. Moderate-resolution Imaging Spectroscopy using (MODIS) remote sensing data has been more widely used in the monitoring and evaluation of chilling and freezing damage of sugarcane (Tan *et al*., 2008; Nihar *et al*., 2022). The monitoring models used are mainly the vegetation condition index (Thavorntam *et al*., 2023; Touhami *et al*., 2022), vegetation index difference (Kasimati *et al*., 2022; Weiss *et al*., 2020; Wang *et al*., 2020; Qian *et al*., 2019), surface reflectance (Li *et al*., 2022; Sun and Ming, 2019) and the ground temperature inversion of ground sensor data (Li *et al*., 2022; Sun and Ming, 2019; Dahiru and Hashim, 2020). However, the weather and topographic features are complex and diverse in Guangxi. Under multiple factors, it is difficult to obtain clear sky remote sensing data during the cold and freezing injury periods. The remote sensing data for post-disaster assessment is also unstable, resulting in greater uncertainty in the evaluation results of disasters.

There is an urgent need for a stable temperature monitoring data source to monitor and evaluate the freezing injury of sugarcane. CLDAS, China meteorological administration land data assimilation system, developed by the National Weather Information Center, is the only real-time operation business system in the field of land data assimilation. It can provide atmospheric-driven data with continuous time and space and higher spatial resolution, such as temperature, rainfall, and radiation and the spatial resolution has been increased to 1 km in the V2.0 version. The accuracy of temperature variation data has been effectively verified (Huang *et al*., 2021; Han *et al*., 2020; Mostafazadeh and Zabihi, 2016) and successfully used for monitoring low-temperature disasters of rice (Chen *et al*., 2018). However, there are few reports on the monitoring of sugarcane chilling and freezing injury. To fill the gap, this study aims to establish a revised model of CLDAS temperature data on the basis of fully verifying the accuracy of CLDAS temperature data by using CLDAS temperature data and combining it with remote sensing of sugarcane planting background information. Based on this, a typical sugarcane freezing weather process in Guangxi is selected to assess its effectiveness in monitoring and evaluating the freezing damage of sugarcane. This study can provide a scientific basis for the application of CLDAS temperature data in the prevention and mitigation of sugarcane disasters.

Materials and Methods

Data

CLDAS Temperature Data and Pretreatment

CLDAS is the only real-time running business system in the field of land data assimilation system field in China. It can provide high-resolution atmospheric-driven data that is fused with a lot of actual observations and are close to real atmospheric conditions and ground model products, with higher accuracy. CLDAS atmospheric data contain six elements: Temperature, air pressure, humidity, wind velocity, rainfall, and shortwave downward radiation and cover Asia region (0-65° N, 60-160° E), with 1 h time resolution and 1 km space resolution. Among them, the temperature product is formed by combining multi-mesh 3D variational technology with observation data from automatic ground stations using the European Centre for Medium-range Weather Forecasts (ECMWF) numerical analysis/forecast product as a background field. It was evaluated using regular observation data from 2,400 national automatic stations with optimal quality. The storage unit of CLDAS temperature data is Kelvin and it is converted into centigrade by the formulat = T-273.15. Since the daily minimum temperature is required for monitoring and evaluating freezing injury of sugarcane, the hourly temperature data of CLDAS is synthesized into daily data, and the daily minimum temperature is calculated.

Remote Sensing Background Information of Sugarcane Plantation

Background information on sugarcane plantations in guangxi was provided by the guangxi institute of meteorological disaster reduction. Using USA land resources satellite landsat8, the environmental disaster reduction satellite HJ-1, and some remote sensing data of high-resolution No. 1 satellite GF-1, the spectral and image characteristics of sugarcane in different terrains and different growth periods are analyzed and a remote sensing interpretation model of sugarcane is established for recognition and classification. The identification information of sugarcane is verified by using field survey data and the identification accuracy rate can exceed 90%.

Data from Weather Station

The meteorological data is the daily minimum temperature of 90 weather stations in guangxi from December-February, 2209-2015, provided by the guangxi meteorological information center.

Methods

Monitoring Indexes of Cold and Freezing Injury of Sugarcane

The used monitoring indexes of cold and freezing injury of sugarcane refer to the literature (Tan *et al*., 2014) (Table 1).

Validation and Revision of CLDAS Temperature Data

Using temperature data observed from weather stations, CLDAS temperatures from December 2009-2013 were revised by linear regression method. Then, using the daily minimum temperature data of 90 ground meteorological stations in Guangxi in December, January, and February from 2009-2013, the corrected CLDAS temperatures were independently tested for an independent sample, including correlation coefficient (*R*), Root Mean Square Error (*RMSE*), Mean Absolute Error (*MAE*) and mean relative deviation (Bias) as follows: (Ying *et al*., 2021):

$$R = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{X_i-\overline{X}}{s_X}\right)\left(\frac{Y_i-\overline{Y}}{s_Y}\right)$$

$$RMSE = \frac{1}{n}\sum_{i=1}^{n}(X_i-Y_i)^2$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|X_i-Y_i|$$

where, n is the number of samples; X_i and Y_i are the observed values of two variables; $\overline{X}$ and $\overline{Y}$ are the mean values of two variables respectively; s_X and s_Y are the standard deviations of two variables, respectively.

Table 1: Monitoring indexes and disaster damage index of advection type of cold and freezing injury grade of sugarcane

Serial number	Disaster level	Slight	Moderate	Serious	Severe
1	The minimum temperature //°C	2.0~4.0	0.0~1.9	-1.5~ -0.1	<-1.5
2	Duration of daily minimum temperature ≤4°C in the process // d	5~8	9~15	16~28	≥28
3	Accumulated harmful temperature of daily minimum temperature ≤4°C in the process//°C	10.0~50.0	50.1~300.0	300.1~900.0	≥900.1
4	Characteristics of	Leaves were dark green, chilling injury without obvious injury, but growth point became black and necrosis. The lateral bud of the tip became soft and profile was yellowish brown and sugarcane bud's of underground the stem was not damaged	Tips of most leaves and 1/3-1/2 of leaf area was withered and white. The growth point and sugarcane buds of the tip became black and necrosis. Sugarcane buds at middle and lower parts were injured, while buds underground stem we're not affected obviously	Leaves were mostly withered and white, and only leaves of sheath and near trigeminal mouth of sheath had spotted green. the Growth point and most of the sugarcane buds were dead and sugarcane buds of underground stem at joints one and two we're not damaged	Leaves were withered and white and lateral bud of sugarcane stem was dead. a Vertical section of sugarcane stem the internode showed yellow bacon or boiled status. Buds of underground stem joints one and two were frozen to death, while some buds at joints three and four were frozen to death, and vertical section was boiled status
4	Yield loss // %	≤5.0	5.0~10.0	10.0~20.0	>20.0
5	Sugar loss // %	0.2~0.5	0.6~1.0	1.1~2.0	>2.1

Results

CLDAS Temperature Correction

Test Results of CLDAS Temperature Data

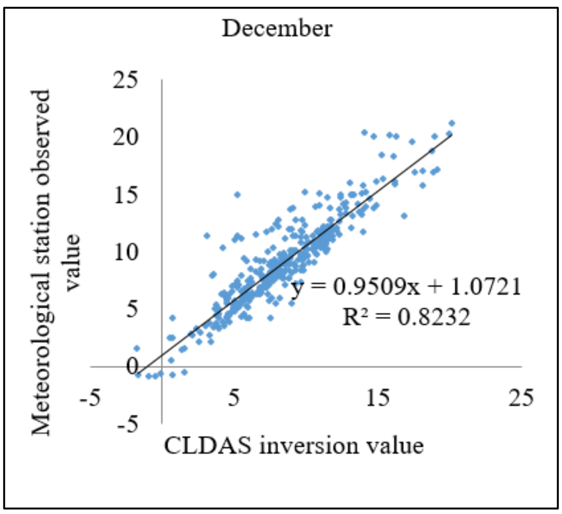
According to the principle of effective monitoring of meteorological data of 10 km, the corresponding CLDAS temperature data of the meteorological stations were extracted. The concentrated occurrence of sugarcane freezing injury is from December-February. The daily minimum temperature and CLDAS temperature data of 90 surface meteorological stations in Guangxi from December to February 2009-2013 were selected as their correlation coefficient, deviation, and root mean square error (Table 2). The results showed that the CLDAS temperature had an extremely significant positive correlation with actual site temperature during the cold and freezing injury of sugarcane. The correlation coefficients are all higher than 0.9, with an RMSE of1.5-2°C an MAE of 1-1.5°C, and a Bias of 0-0.5°C.

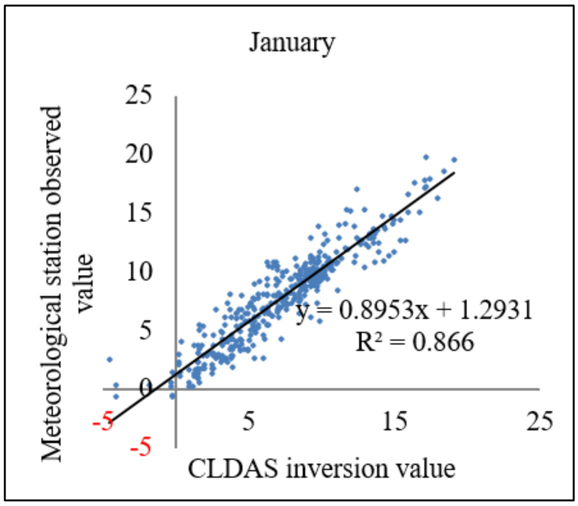
Table 2: Statistics of CLDAS temperature data and the observed value of meteorological station in guangxi

Month	Correlation coefficient (R)	Root Mean Square Error (RMSE)	Mean Absolute deviation (MAE)	Average relative deviation (Bias)
12	0.907**	1.835	1.183	0.135
1	0.931**	1.597	1.154	0.270
2	0.928**	1.946	1.220	0.132

Table 3: Statistics of CLDAS temperature data and the observed value of meteorological station in guangxi

Month	Correlation coefficient (R)	Root Mean Square Error (RMSE)	Mean Absolute deviation (MAE)	Average relative deviation (Bias)
12	0.907	0.641	0.617	0.102
1	0.931	0.676	0.578	0.226
2	0.928	0.750	0.657	0.095





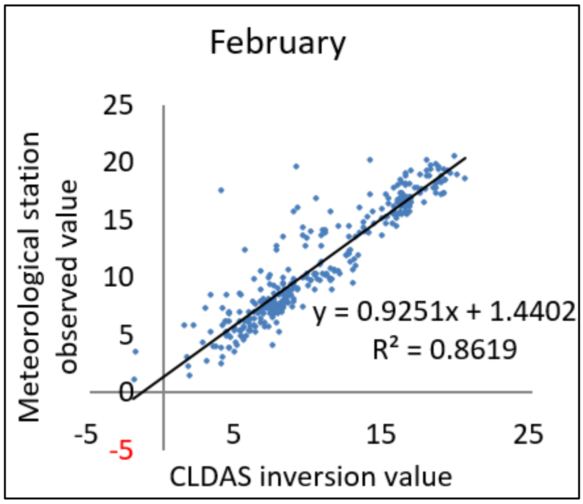


Fig. 1: Scatter diagram and correction model between CLDAS

Corrected Model Results of CLDAS Temperature Data

The examination and analysis results of the CLDAS temperature data show that it is positively correlated with the ground truth data with a small deviation between the two and deviation differences in different months. Compared with the monitoring index of sugarcane frost damage, the sugarcane damage has a critical temperature of 1.0°C and a lethal temperature of -.6°C. A1°C deviation may affect the accuracy of the assessment and directly using CLDAS temperature monitoring to assess the frost damage of sugarcane cannot meet the accuracy requirements. As such, the monitoring and evaluation of cold and freezing injury of sugarcane using CLDAS temperature could not meet the accuracy requirement. It is necessary to correct CLDAS temperature data before utilization. A scatter

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plot between CLDAS temperature and the observed temperature at the weather station and a monthly corrected model of CLDAS temperature from December to February were plotted using data from 2009-2013 (Fig. 1).

The data from 2014-2015 is used for the independent sample test of the correction model and the error between the revised CLDAS temperature and observed temperature of meteorological stations is analyzed (Table 3). The revised CLDAS temperature and the RMSE, MAE, and Bias observed temperature of the meteorological station from December to February were respectively smaller than 1, 0.7, and 0.5°C. Compared with the data before correction, the corrected temperature is closer to the actual temperature and the error is small. Air temperature is a comprehensive index that responds to the high-temperature state of the ground and is also one of the key indexes to assess the loss of crop freezing damage. However, due to the topography of the sugarcane areas and the sparse distribution of meteorological observation stations, the actual disaster damage in the sugarcane area cannot be accurately obtained. The use of an accurate air temperature model to derive the minimum temperature of the subsurface can timely and effectively reverse the freezing damage process of the sugarcane area, which is of practical significance for the monitoring and evaluation of the freezing and frost damage and disasterprevention and mitigation in the sugarcane area.

Temperature Monitoring at Representative Station

Sugarcane in northern and western Guangxi is prone to cold and freezing injury of sugarcane. Using the corrected equations for monthly temperatures, the temperatures in January, February, and December 2014 in Rongshui County, guangxi (North Gui region), and Tandong County (West Gui region) are extrapolated (Fig. 2). As shown in Fig. 2 the modified CLDAS temperature is closer to the actual values and the fitting effect is especially optimal in low-temperature regions.

Monitoring and Evaluation of Cold and Freezing Injury of Sugarcane in Typical Year

Affected by strong cold air, the coldest weather appeared in Guangxi from January 16-29, 2016 and sugarcane suffered from cold and freezing injury in many cities and counties. Based on the CLDAS temperature correction model, the spatial distribution chart of the daily temperature ≤4.0°C from 20-28th during the cold and freezing injury process is fitted (Fig. 3). Fig. 3 shows the change of daily minimum temperature from 20-28th in the process. On January 20, the temperature in northeast Guangxi began dropped and on the 24th, the temperature ≤4.0°C gradually expanded from northeast to southwest. Starting from the 25th, the temperature in some regions of southwest Guangxi rose again and on the 28th, the temperature in most areas of Guangxi returned to normal levels.

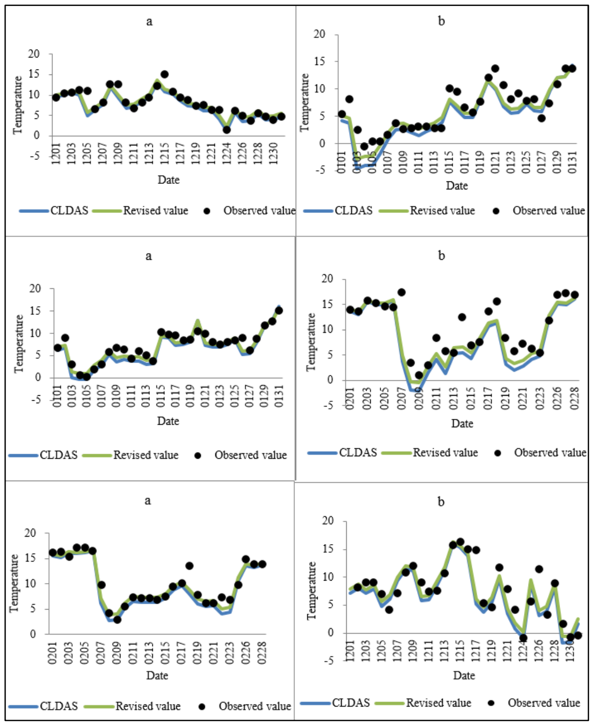
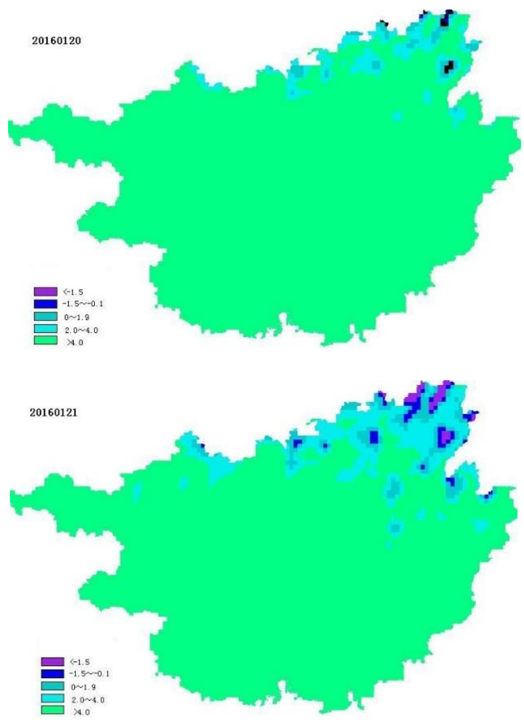
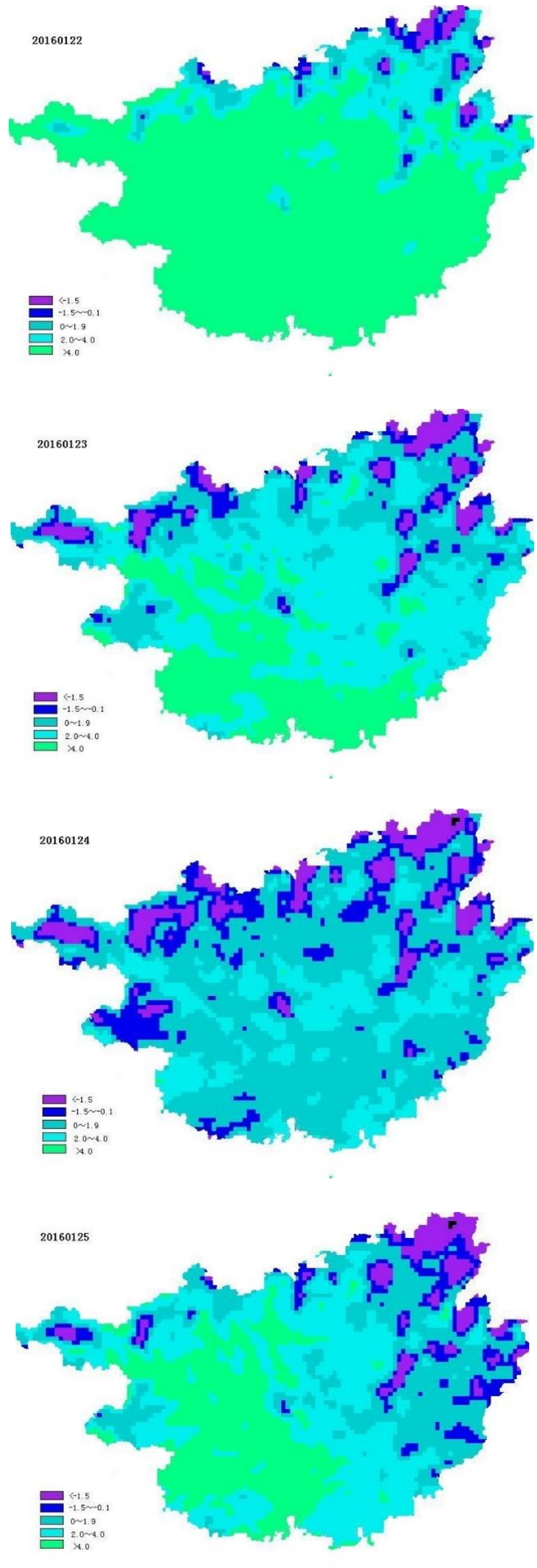


Fig. 2: Scatter diagram and modified model between CLDAS temperature data and observed value; (a) Rongshui station; (b) Tiandong station





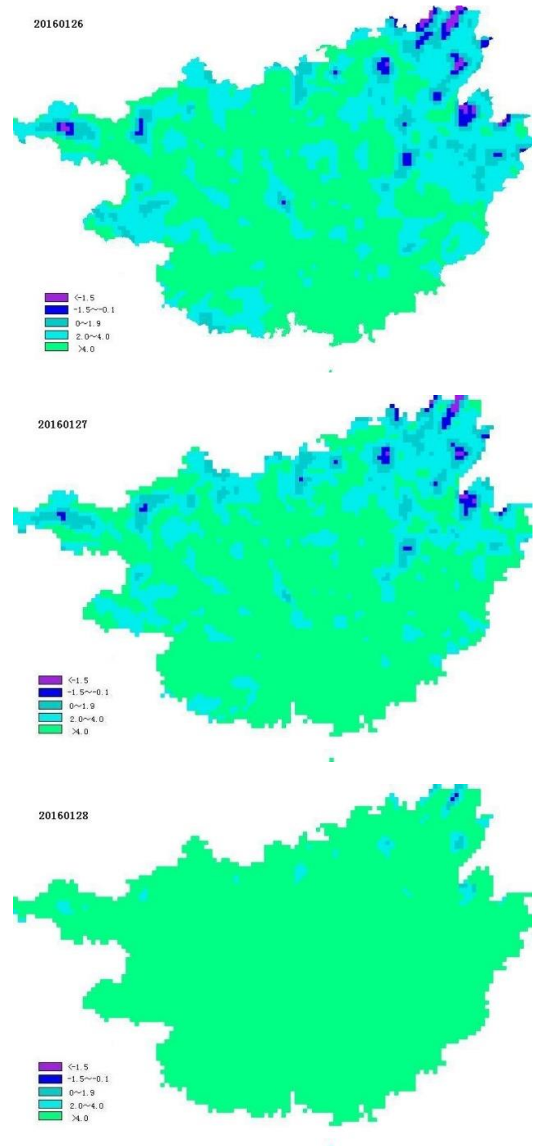


Fig. 3: Grade distribution of the minimum temperature from January 20-28, 2016

Based on the monitoring indexes of sugarcane cold damage and the background of remote sensing planting of sugarcane in Guangxi, CLDAS is used to calculate the spatial distribution of the days ≤4.0°C during the cold dew and wind from January 20-28, 2016, and the specific distribution of the cold damage disaster levels of sugarcane in this process is understood (Fig. 4). The results show that during the low-temperature process, sugarcane in northern Guangxi such as Rongan, Rongshui, Liucheng, Liujiang, and Yongfu, western Guangxisuch as Laibin and Xincheng, southern Guangxi such as Yizhou, Luocheng, Tianyang and Tian, southern Guangxisuch as Fusui and Chongzuo were affected in different ranges. The cold and freezing injuries of most cities and counties were mainly affected slightly.

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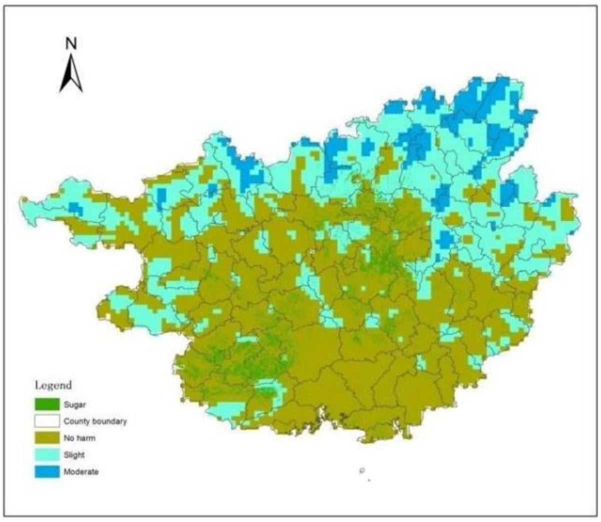

Fig. 4: Spatial distribution of cold and freezing injury of sugarcane from January 16-29, 2016

According to the disaster situation investigation report of the strong cold wave weather process issued by each meteorological bureau of Guangxi in 2016, the field sampling survey in main sugarcane plantation areas implemented by the Guangxi Meteorological Bureau and the data from sugar enterprise and disaster statistics departments, sugarcane in most regions of Guangxi was damaged, mainly with slight cold and freezing injury. Although the reduction of temperature in the process is large, the damage to sugarcane is still very small, and even some sugarcane-producing areas are not affected. In the field investigation of Laibai, Guibei Liuzhou, and Hechi, Guizhong, it was found that the sugarcane leaves in the affected area remained green and there were no obvious symptoms of cold and freezing injury. Most of the sugarcane buds also had no injury symptoms and the growth points of most stubble cane were not obviously affected. However, the root sections of some sugarcane slightly were boiling and yellow. In addition, some perennial roots may be damaged by fungi and their interior may turn red. The lower internode longitudinal section of sugarcane plants was boiling, yellowish than normal levels and sugarcane sugar decreased. The investigation in the baize of west guangxi and guigang of central guangxi showed that injury symptoms were not obvious. In some fields, the sugarcane became slightly yellow and some of the growing points of sugarcane were frozen. The top leaves were frozen and withered, with light injury. It was basically consistent with the monitoring and evaluation results of CLDAS temperature data.

Discussion

CLDAS temperature products have high accuracy and the actual temperature on site is an extremely significant positive correction. The correction coefficient is greater than 0.9, with RMSE of 1.5-2°C, MAE of 1-1.5°C and Bias of 0-0.5°C. Based on the linear regression equation, a modified model of CLDAS temperature in the cold and freezing injury of sugarcane from December to February is established. After correction, RMSE, MAE, and Bias between CLDAS temperature and observed temperature of the meteorological station from December-February were respectively less than 1, 0.7, and 0.5°C. The independent quadrat test results showed that the modified CLDAS temperature was closer to the actual value and the fitting effect was especially better in low-temperature regions. The daily minimum temperature was calculated by using the CLDAS correction model and the cold and freezing injury of sugarcane in typical years were monitored and evaluated according to the cold and freezing injury indexes of sugarcane. The monitoring and evaluation results were basically consistent with the actual situation.

There were some verification reports on CLDAS temperature data. Zhang *et al*. (2017) analyzed the CLDAS temperature data in Inner Mongolia region from May to August. It was found that the average bias of CLDAS daily average temperature from meteorological stations was 0.57°C. Chen *et al*. (2019) analyzed the CLDAS temperature data in Guangxi from March and September. It was found that the difference between the daily average temperature of CLDAS and the observation value of the meteorological station in March was -0.1-0.8°C and the average difference was 0.3°C. The difference in September was -0.35-0.46°C and the average difference was only 0.09°C. From the errors between the daily minimum temperature of CLDAS and the observation values of Guangxi meteorological stations from December-February of 2009-2013, their RMSE, Bias, and MAE were respectively 1.5-2, 1-1.5 and 0-0.5°C, respectively. The results of comparative analysis showed that CLDAS has a high degree of fitting to ground temperature and the fitting error of daily average temperature is less than the fitting accuracy of daily minimum temperature. In addition, there are certain differences in the errors between CLDAS temperature and actual on-site temperature in different months, further verifying the necessity of monthly calibration models.

The daily variation analysis results of CLDAS data show that there is a certain error between the occurrence time of CLDAS minimum temperature and actual minimum temperature, which is generally less than 1h. Since the daily minimum temperature is used for the low-temperature cold injury, this phenomenon did not the accuracy of CLDAS temperature data of cold and freezing injury of sugarcane. In addition, the current resolution of CLDAS data was 1 km, while the resolution of remote sensing data for the extraction of the sugarcane plantation area was 30 m. When the two kinds of data with different spatial resolutions were used for spatial analysis and statistics, the statistics of edge pixel information had certain errors. The resampling process of CLDAS data can be carried out, but further selection research is needed, so that the information loss of the sampling method can be avoided at the maximization degree.

Conclusion

CLDAS temperatures are examined and CLDAS temperatures before and after revision are compared with the actual temperatures measured at the weather stations. It was found that CLDAS temperatures before and after revision were highly positively correlated with the measured temperatures of the stations. The root mean square error from 1.5-2°C before the revision is corrected to an error of less than 1°C; the mean absolute deviation from 1-1.5°C to less than 0.7°C and the mean relative deviation from 0-0.5°C to less than 0.5°C. Then the corrected CLDAS model is used for the monitoring and assessment of the sugarcane chilling and freezing process in typical years. The results are basically consistent with the actual situation and the results of (Zhang, 2017; Dan *et al*., 2023).

Due to the limited information, meteorological observations from other times can actually be added to further improve the effectiveness of the revision. In addition, the regional distribution and climatic characteristics can also be considered to further optimize the sliding training scheme, which is the future research on cold damage monitoring and forecasting of sugarcane in Guangxi.

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Author's Contributions

Yanli Chen: Designed and performed the experiments, analyzed the data, and prepared the paper. Revised the manuscript.

Yongming Luo: Designed and performed the experiments, analyzed the data, and prepared the paper.

Ying Xie and Zhaomin Kuang: Participated in collecting the materials related to the experiment.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

Conflict of Interest

The authors declare that they have no competing interests. The corresponding author affirms that all of the authors have read and approved the manuscript.

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