Research Progress and Outlook of Low Temperature Chilling Injury in Northeast China

HAO Tian-yi* WANG Shi-gong SHANG Ke-zheng LI Jing-xin
Gansu Key Laboratory for Drought Climate Change and Disaster Reduction College of Atmospheric Science in Lanzhou University Lanzhou 730000 China

Abstract  Focused on the major agro-meteorological disaster in northeast China area—low temperature chilling injury the research progresses of low temperature chilling injury in northeast China were reviewed systematically. The basic concepts which included the connotation and extension of chilling damage the circulation characteristics and effect factors which formed summer low temperature in northeast China the prediction forecast and defense of low temperature chilling injury were summarized and done the outlook.

Key words Northeast China low temperature chilling injury Circulation characteristics Effect factors Prediction Defense

China is in East Asia monsoon zone. It is one of main fragile climate zones in the world and is also one of countries where the meteorological disasters are the most serious. The northeast of China is one of important marketable grain production bases. The total yield of grain stabilizes about 7 000 × 10^4 t which occupies 15% of national grain yield. However the heat resources in the zone in the growth season aren't sufficient and most areas use the one year maturation pattern. The agricultural meteorological disasters happened frequently and the influence of summer low temperature chilling injury was great. We mainly summarized the research progress of low temperature chilling injury in northeast China and the important research results in every period.

1 Regional characteristic of northeast China and the planting situation of crops

The northeast of China in the administrative region includes Heilongjiang Jilin Liaoning and Hulun Buir League Xing'an League Tongliao City Chifeng City in the east of Inner Mongolia. Greater Khingan Mountain Lesser Khingan Mountain and Changbai Mountain pass through the whole region. The east and west are Changbai Mountain and Greater Khingan Mountain. Lesser Khingan Mountain is in the north and the south edge closes to Liaodong Gulf. The terrain is that the west is low and the east is high. The northeast area of China belongs to the temperate zone humid sub-humid continental monsoon climate. The sowing areas of crops in northeast China in turn are the corn paddy rice soy bean wheat broomcorn and millet. The areas of corn paddy rice and soy bean occupy above 80%. The regional distribution is that the south middle parts are mainly the corn paddy rice broomcorn and the east part mainly plants the soy bean paddy rice corn. The north part mainly plants the soy bean and the wheat. To adapt to the regional variation of heat quantity condition in the planting variety aspect the south and southwest parts are the late maturity. The middle west parts are the middle late maturity and the east mountain zone the north part are the middle early maturity or the extremely early maturity.

2 Type and index of chilling injury

For the definition of low temperature chilling injury there isn't the uniform view at present but the basic meaning is consistent. It is the disaster which causes the production reduction when the durative or short-time low temperature is below the low limit temperature of crops growth in the crops growth period. Feng Shaoyin et al. studied the chilling injury problem in the growth period of paddy rice in Yanbian earliest. Took Yanji as the representation according to the appearance time of chilling injury and the hazard characteristics on the paddy rice physiology the chilling injury was divided into 4 types: the prior period the middle period the later period and the parallelism period. Liang Rongxin et al. studied the chilling injury in the south of Heilongjiang Province. According to the different hazard situations of crops in the low temperature years 4 kinds of chilling injury meteorological types were divided. Considered other influence factors which were the sunshine the precipitation the drought and the frost Pan Tiefu et al. divided the low temperature chilling injury in Jilin Province into the low temperature rainy type the low temperature drought type the low temperature early frost type and the low temperature type. The division of chilling injury types which is now used widely is carried out by the different hazard mechanisms at the different stages of crop growth period because of suffered from the low temperature. 3 types were divided: 1 Delayed type chilling injury. It was the durative low temperature which appeared in the long time in the vegetative growth period of crops. It made that the procreation period delayed and the crops couldn't normally...
mature before the first frost. Then it caused the production reduction. ② Barrier type chilling injury. It was the low temperature which was short and declined sharply in the procreation growth period of crops. It made that the physiological activity of generative organs was damaged. It induced the abnormal maturity and the production reduction. ③ Mixed type chilling injury. It was that the delayed type chilling injury and the barrier type chilling injury both appeared in the crops growth period. It could cause the greater production reduction.

The chilling injury index was the standard which judged the chilling injury occurrence and the possible damage degree in one year. In China the chilling injury index was studied deeply and broadly. A lot of researches proved that the sum of monthly mean temperature (or the anomaly) during May–September and the accumulated temperature (≥ 10 °C accumulated temperature) in the crops growth season had the close relationship with the crops yield. It was the relationship between the total heat amount in the crops growth season and the total yield. It should point that the influence of total heat amount on the yield was great. But the influences of low temperature on the different growth periods were different. For the climate conditions in the different regions and the different crops classes the index wasn't unique. Meanwhile many scholars studied respectively on the indexes of low temperature chilling injury in the different regions the different climate conditions the different types and the different growth stages. The pointed index values of low temperature chilling injury were gained.

3 Period and distribution rule of low temperature chilling injury

The temperature in the northeast of China had the good consistence. The researches showed that summer temperature in northeast China since the 1950s experienced 3 stages: the cold period the normal period and the warm period. From the middle of 1950s to the 1970s it was the cold period and the normal period was during the 1980s–1990s. After the 1990s it was the warm period. Ding Shisheng thought that the appearance of low temperature chilling injury had the cluster and the probability in the warm period was very large. Meanwhile he pointed that the chilling injury in most areas of northeast China had the long period which was bigger than 70 years and the short period which was about 3.18 years except the north of Heilongjiang. For the scale characteristic of summer low temperature in the northeast of China the consistent thought was that the appearance of summer low temperature chilling injury in northeast China wasn’t a kind of local temporal phenomenon but was a kind of disastrous weather climate phenomenon whose time-space scale was great. As far as the average condition was concerned the horizontal scale could reach 40 latitudes in south-north and 40 longitudes in east-west. Many researches showed that the northeast of China was one of zones where the warming was very obvious in the great background of global climate warming. But this kind of warming mainly showed that the temperature in winter increased and the warming in summer wasn’t obvious as in winter. The researches of Lou Xiulong et al. showed that the temperature in the 1980s continuously rose and the grain yield increased sharply. Moreover the temperature variation in 2 climate key periods presented the rise trend. In the background that the climate became warm the occurrence frequency and intensity of chilling injury both declined. Since the climate became warm in the 1980s although the low temperature decreased the temperature fluctuation was great and the planting areas of thermophilous crops in the north of China enlarged. Moreover the northward shift of crops planting north boundary also increased. All of above increased the risk of chilling injury especially the barrier type chilling injury.

The regional distribution characteristics of low temperature chilling injury were mainly affected by the geographical latitude and the terrain. The researches showed that the occurrence frequencies of summer low temperature chilling injury and serious low temperature chilling injury in northeast China increased as the latitude heightened. The frequency in the mountain zone was bigger than in the plain area in the same latitude. However Liu Chuanfeng et al. thought that the frequency of serious low temperature chilling injury decreased as the latitude heightened. The low temperature chilling injury in the north of northeast China in summer was the most serious and the half low temperature chilling injury in the middle of northeast China belonged to the serious low temperature chilling injury. The low temperature chilling injury in the south of northeast China in summer was the lightest. The occurrence times of summer low temperature chilling injury in every province were equivalent and were about 3–4 years one time. According to the interannual division the low temperature chilling injuries in the 1950s and the 1970s were more serious. Then it was the 1960s and the 1980s in turn. After the 1990s the low temperature chilling injury rarely occurred.

4 Influence elements of low temperature chilling injury in northeast China

4.1 Relationship between summer temperature in northeast China and the global temperature The low temperature chilling injury in northeast China often happens in summer in the low temperature year. The low temperature in summer was the direct influence element of low temperature chilling injury occurrence. Even if in the years when other agricultural production conditions were normal the serious low temperature weather in summer was easy to cause the low temperature chilling injury of crops. Therefore summer low temperature in northeast China was the large climate background which caused the low temperature chilling injury of crops. The appearance of summer low temperature in northeast China wasn’t an isolated small scale phenomenon but had the abnormal close relationship with the global temperature. Zhang Mingli et al. analyzed the relationships between 2 typical chilling injury years (1972 and 1976) the warm summer year and the global temperature. They pointed that the temperature variation in northeast China and the
global mean temperature variation were same-phase. In general, the temperature variation in northeast China lagged 1-2 seasons than the global temperature variation. The researches of Zhang Mingli et al.\[14\] pointed that the distribution of global temperature field in northeast China cold summer was mainly the meridional distribution and the heat quantity exchange in south-north was large. In the warm summer, it was mainly the longitudinal distribution. The zones where the correlations with northeast China temperature were great were the middle of Eurasia, the north of Continental North America, equator Eastern Pacific and India. Except Eurasia, other areas were the negative correlations. Wang Chunyi et al.\[21\] analyzed the relationship between summer temperature sequences in 10 representative stations in northeast China during 1901-2002 and summer temperature in the northern hemisphere. They pointed that the zones where the correlation with summer temperature in northeast China was great mainly distributed in the middle high latitudes of northern hemisphere and the tropical subtropical zones. In the middle high latitudes the positive correlation had 3 big value centers: the eastern half of Eurasia, the eastern half of North America and Mediterranean zone of Western Europe. At present, the uniform conclusions were that summer temperature in northeast China presented the positive correlation with the east of Eurasia, the east of North America and presented the negative correlation with the equator tropical subtropical zones. It was clear that the temperature variation in northeast China wasn’t only the self oscillation process but had the obvious related relationship with the severe fluctuation of global temperature. The low temperature chilling injury in northeast China was the local performance of global climate abnormality and the variation trend was consistent with the global temperature variation. The global chilling period was also the occurrence period of low temperature chilling injury cluster in northeast China. This was the large scale climate background of low temperature chilling injury occurrence in northeast China.\[26\] 4.2 Circulation characteristics of summer low temperature chilling injury year in northeast China. The low temperature science research coordination group in northeast China systematically studied the circulation characteristics in cold summer year and warm summer year in northeast China. They gained a main factor that the cold air from the polar region was very active and the power of warm air was weak which may cause the cold summer in northeast China. The durative stabilization of myriametric wave trough (ridge) in the east coast of Asia was an important circulation condition which formed the cold (warm) summer in northeast China. Wang Chunyi et al.\[21\] studied the atmospheric circulation characteristics of cold summer in northeast China. The results showed that ① Sea-level pressure field in the northern hemisphere: summer temperature in northeast China and the sea-level pressure field in the northern hemisphere had 3 correlative zones. They were respectively in the negative correlation zone near Baikal Lake, the positive correlation zone of North Pacific and the negative correlation zone near Caspian Sea. ② Circulation in the middle layer (500 hPa) of troposphere: the durative low temperature in summer in northeast China was because that there was a stable myriametric wave trough in the prior period (November-February in the next year) in the upper stream zone (30°-50° E) and it moved eastward with the speed (20-30 longitudes per month) in spring (March-April). Moreover, it stabilized in northeast China in summer (May-September). ③ The high-layer circulation (100 hPa) of troposphere: 100 hPa polar vortex in the northwest hemisphere weakened in the tropical low temperature year in northeast China and the polar vortex in the northeast hemisphere obviously reinforced. The polar vortex leaned toward Pacific in the eastern hemisphere and developed strongly. The circumpolar westerly circulation roughly presented the tricrism situation and northeast China was in the rear of myriametric wave trough. The subtropical high in South Asia abnormally weakened. This kind of situation was favorable for the southward diffusion of cold air in the low layer. Zhou Lihong et al.\[24\] summarized and gained the circulation characteristics in the low temperature chilling injury year in northeast China. Western Pacific subtropical high was weak. It displayed that the position of subtropical high western extension ridge point leaned to the east and the north boundary of subtropical high leaned to the south. The intensity index of subtropical high was smaller. The position of polar vortex leaned to the south which made that the cold air was active in the low latitude. The longitudinal circulation indexes in Eurasia and Asia were smaller and the meridional circulation indexes were bigger. The development of meridional circulation made that the south-north exchange of cold and warm air was severe and then the low temperature in northeast China was easy to happen. Some researches\[14,25-26\] gained the main circulation characteristics of typical chilling injury year. Western Pacific subtropical high was weak and the position leaned to the east and the south. The position of polar vortex center leaned to the eastern hemisphere and developed strongly. 500 hPa longitudinal circulation was weaker and the meridional circulation was prevalent. The myriametric wave trough stably maintained in northeast China. In addition, some scholars studied the relationship between the circulation abnormality in the previous winter spring and summer low temperature in northeast China. Then it gained the important circulation factors to forecast the low temperature in summer. The intensity position and the configuration between the polar vortex and the subtropical high had the domination role on summer low temperature in northeast China. The low temperature weather in summer in northeast China is often formed by the westerlies long wave, the myriametric wave circulation or the common effect of two systems\[25,26\]. 4.3 Relationship between summer low temperature chilling injury in northeast China and the sea temperature. For the thermal inertia of sea was great and the time-space scale of sea temperature abnormality was great, the sea temperature abnormality induced the climate abnormality by affecting the atmospheric circulation. The large scale weather climate phenomenon of summer low temperature in northeast China must have the close relationship with the sea temperature abnormali-
ty. At present, the researches which were about the influence of sea temperature on the cold summer in northeast China basically revolved around the influence of sea temperature in Pacific Ocean. The consensus was that the influence of Northwest Pacific sea temperature field on summer temperature in northeast China was the most direct and the correlation was the greatest. It also illustrated that summer low temperature in northeast China was a kind of large scale weather climate phenomenon whether in the time or in the space. The researches of some scholars showed that Eastern Pacific in the equator was the key sea zone where affected the temperature in summer in northeast China. When the sea temperature in Eastern Pacific in the equator was the positive anomaly, the probability of summer low temperature in northeast China was comparatively great. Zeng Shaomei et al. considered that the sea temperature variation in the equator Eastern Pacific firstly spread from the equator Eastern Pacific to the west. Then it expanded northward and affected the east of Asia the northeast of China. The lagging time increased as the longitude heightened and needed about 10 months when reached 40° N. The researches of low temperature science research coordination group in northeast China pointed that summer temperature in northeast China had the positive correlation with the sea temperature of equator Eastern Pacific in the prior year and presented the negative correlation with the sea temperature in the same period in the year in the zone. Especially when the large-scale negative anomaly which continued above 2 years appeared in east zone of Equatorial Pacific summer temperature in northeast China in future was obviously low (for example in 1957, 1972 and 1976). Other researches showed that the tropical Western Pacific warm pool was the key sea zone where affected summer temperature in northeast China and the sea surface temperature variation in winter in the prior period was the strong signal which predicted summer low temperature chilling injury in northeast China. The other key sea zone was Western Pacific in the middle latitude and the sea temperature variation in spring in the prior period also had the close relationship with summer low temperature in northeast China. The low temperature chilling injury in the northeast zone and the sea temperature field in winter had an anti-correlation zone near the west wind drift area. It illustrated if the temperature in the west wind drift area in winter was high, the low temperature happened in northeast China in summer in the next year. Conversely, it was the high temperature.

When the relationship between the sea temperature in Indian Ocean and low temperature cold summer in northeast China was studied, it found that SST basic anomaly space type was that Northwest Pacific and Southeast Pacific Arabian Sea respectively presented the obvious reverse variations. Northern Pacific and Northern Indian Ocean sea-level pressure anomaly had a kind of seesaw phenomenon which was called as Northern Pacific-Northern Indian Ocean Oscillation (PIO). The phenomenon had the close relationship with Eastern Asian cold summer. For example in June when PIO index was in the trough period Eastern Asian cold summer happened and had the obvious positive correlation with the temperature in northeast China.

4.4 Relationship between northeast China cold summer and ENSO. In the 1980s, the relationship between summer low temperature in northeast China and ENSO gradually induced the attention. At present, the mechanism that El Nino event affected summer temperature in northeast China had no verdict. The researches in the prior period showed that El Nino had the good corresponding relationship with summer low temperature in northeast China. Therefore, there was a common idea that they had the close relationship. As the climate became warm in recent years the appearance frequency of northeast China low temperature decreased and the intensity weakened. In the strong El Nino event year summer low temperature in northeast China didn’t appear (for example 1997) but the high temperature appeared. The relationship between El Nino and summer low temperature in northeast China became more complicated and wasn’t the simple linear relationship. The researches in recent years pointed that the most obvious low temperature abnormality which was caused by ENSO in northeast China didn’t happen in summer but was from autumn in the same year to spring in next year. For the complexity of ENSO combined with the variation influence on the atmospheric circulation especially the characteristic quantity of subtropical high, the influence of different types ENSO event on summer low temperature in northeast China was studied. Zhang Jiquan et al. studied and proved that the cold summer was easy to appear in the year when El Nino phenomenon happened or El Nino year and the surrounding years were the occurrence years of low temperature chilling injury. Liu Shi et al. thought that El Nino year corresponded with summer high temperature in the next year in northeast China and La Nina year had the better corresponding relationship with summer low temperature in the next year in northeast China.

To clear the relationship between ENSO and summer low temperature chilling injury in northeast China, firstly it should know the occurrence rule and mechanism of ENSO event. At present, the researches on ENSO had much uncertainty and the uniform standard on the occurrence of ENSO event didn’t be formed. Secondly, there wasn’t the certain theory evidence on how the occurrence of ENSO event in the low latitude affected summer temperature in northeast China in the middle and high latitudes. Therefore, the researches on ENSO and the low temperature chilling injury in northeast China were only primary. It also illustrated that maybe ENSO wasn’t the main factor which affected summer temperature in northeast China and there were other factors.

4.5 Main systems affecting summer low temperature in northeast China and the characteristics of underlaying surface

4.5.1 Polar vortex. In the low temperature chilling injury year in northeast China the cold air in the polar region was strong. In the composite chart in 100 hPa the polar vortex obviously leaned to Pacific in the eastern hemisphere and developed strongly. Western Pacific subtropical high abnormally leaned to the south or was weak. This kind of situation was favorable for
the southward diffusion of cold air in the low layer from the polar region and caused the durative low temperature in northeast China. Zhang Shaoqing et al. [39] pointed out that when the polar vortex area of the hemisphere expanded, the temperature in Jilin was low. Conversely, the temperature was high. The depth of polar vortex center and the temperature in northeast China presented the anti-correlation. The deeper (shallower) the height value of center was, the higher (lower) the temperature in northeast China was. The cold period in the middle and high latitudes in the northern hemisphere corresponded with the expansion of polar vortex and lessening of temperature gradient in the high latitude. At this time, the cold air in the polar region was active and the southward transportation was strong. But the situation in the warm period was opposite. Therefore, the influence of polar region on the low temperature in northeast China in the middle latitude was mainly via the activity of cold air in the polar region and the southward expansion [40]. Some researches [41] analyzed and judged the position of polar vortex from the daily 100 hPa frequency distribution of polar vortex during January–May and judged the cold summer year in northeast China by referring the intensity of South Asia high.

4.5.2 Western Pacific subtropical high. The abnormality of summer temperature in northeast China related with the intensity and position of Western Pacific subtropical high. When the intensity of summer subtropical high weakened, the position tilted to the east and the south, which was favorable for the appearance of low temperature in northeast China. Conversely, the subtropical high was strong and the position tilted to the west and the north, which was favorable for the appearance of high temperature in northeast China [12][36][42]. In the weak stage of Western Pacific subtropical high long-period oscillation, the serious low temperature chilling injury was easy to appear in northeast China.

4.5.3 South Asia high. The prior researches [40–44] showed that the intensity of South Asia high in 100 hPa and the temperature in northeast China during June–September had the positive correlation. When South Asia high was weak, the cold low in the polar region was mainly active in the middle latitude and summer temperature in northeast China was low. Conversely, when South Asia high was strong, the cold low in the polar region retreated to the polar zone, summer temperature was high. The relationship between the intensity of summer South Asia high and the sea temperature in the cold water zone and the west wind draft zone in the equator Eastern Pacific in winter spring in the prior period was close. The interaction of South Asia high and polar vortex affected summer temperature in northeast China.

4.5.4 Indian monsoon low pressure. The monsoon low pressure in summer India–Pakistan zone and appearance of durative low temperature in the large area in northeast China in the same period had the close relationship. When the sea-level India–Pakistan monsoon low pressure was deep and the durative low temperature wasn’t easy to appear in summer in northeast China. Therefore, the low temperature chilling injury didn’t happen. Conversely, if the sea-level low pressure in India–Pakistan zone was weak, the durative low temperature chilling injury in the large area was easy to appear in summer in northeast China. In addition, the depth of monsoon low pressure in India–Pakistan zone in the low layer and the intensities of South Asia high subtropical high presented the anti-correlation [43].

4.5.5 Northeast cold vortex. Sun Li et al. [46] analyzed the relationship between the durative activity of summer northeast cold vortex and the characteristic of atmospheric circulation abnormality. They pointed that the durative activity of northeast cold vortex was a key factor which caused summer low temperature in northeast China and they were both the anti-correlation distribution. In addition, in summer of cold vortex active year, the positive-negative-positive anomaly wave train in south-north and east-west direction that northeast China was the center could appear in 500 hPa height field. It related with the large-scale circulation background that the power of East Asia blocking high was strong and the position of Western Pacific subtropical high tilted to the south. Summer low temperature in northeast China was easy to appear in the above circulation situation. Many researches [46–47] analyzed the relationship between northeast cold vortex and the atmospheric circulation in northeast China. The abnormal activity of cold vortex had the important influence on East Asia atmospheric circulation even the circulation in the whole northern hemisphere. Then it indirectly caused summer temperature abnormality in northeast China.

4.5.6 Underlaying surface. Firstly, the ocean is the biggest underlaying surface in the earth. The important influence of sea temperature on summer low temperature in northeast China has been discussed. At present, the researches about the influence of sea ice on summer temperature in northeast China weren’t more. The conclusions were that summer temperature in northeast China was low when the snow area in the northern hemisphere and the sea ice area in Atlantic increased. Conversely, when the ice snow area reduced, summer temperature in northeast China was high. Secondly, the snow condition on the land had the certain relationship with summer temperature in northeast China. Fu Congbin [48] studied the difference of snow area in the northern hemisphere in the typical cold summer year and warm summer year in northeast China. He gained that the variation of snow area in Eurasia had the important role on summer temperature in northeast China. Zhang Shaoqing [46] pointed out that when the snow-covered area in Eurasia in spring was big, the area of polar vortex in spring was big in future and the frontal zone of polar front tilted to the south. Moreover, summer Western Pacific subtropical high South Asia high were weak. In most areas of China, the temperature in summer was low. Conversely, the temperature was high. Zhang Dong et al. [34] used the method that the model combined with the actual situation statistics to analyze the relationship between the snow in Qinghai–Tibet Plateau and summer temperature in China. The results showed that the more snow in Qinghai–Tibet Plateau would cause summer low temperature in the year in the north of China especially the northeast zone.
5 Monitoring prediction and defense of low temperature chilling injury in northeast China

The monitoring of agricultural low temperature chilling injury involved the different regions, the different crops and the characteristic that it wasn’t easy to find the low temperature chilling injury of crops according to the appearance. At present, the monitoring of crops low temperature chilling injury was still the weak link. The monitoring technologies of crops low temperature chilling injury could divide into the remote sensing monitoring method, the growth speed monitoring method and the biomass monitoring method, etc. The present forecast was the experience forecast based on the previous research results and the statistical model forecast was established. One was the forecast model of weather situation and main influence system variation, and the other was the simulated model of crops growth. Yang Qing et al. (2003) established the method that used the sea temperature field in Northern Pacific in the previous winter to forecast the quantitative space distribution of summer temperature in northeast China based on the singular value decomposition technology. Wang Chunyi et al. (2003) used the standard values of subtropical high area index in winter 500 hPa height field near Ural Mountain in winter and the sea temperature field in the west wind draft zone in winter to establish the regression model of summer low temperature chilling injury in northeast China. At present, the comprehensive business system of summer low temperature in northeast China and drought flood prediction has been brought into the operation and gained the good forecast effect.

Wang Chunyi et al. (2003) divided the defense technologies of crops low temperature chilling injury into two classes. The first class was the defense technology before crops sowing which was called as the active defense or the strategic defense technology. The second class was in the growth process of crops. It has monitored that the crops would have the low temperature chilling injury or the frost. This defense technology and measure was also called as the emergency defense technology. Sun Yunting (2003) used the probabilistic decision the linear plan methods and proposed the measures suggestions that was adjusting the crops variety layouts and the variety match to avoid or decrease the chilling injury. Yuan Laifu (2003) emphasized the success experience of low temperature chilling injury defense in northeast China. Many scholars analyzed and summarized the detail measures on the low temperature chilling injury defense.

6 Research outlook of low temperature chilling injury in northeast China

The low temperature chilling injury is a great meteorological disaster beside the drought and flood in China. For it involves the meteorology and agriculture in the great background of climate variation, it is complicated to know the rule index and biological mechanism of chilling injury occurrence. In China, the researches on the low temperature chilling injury start later and it still faces a lot of formidable tasks and challenges. The modern information technologies need be applied in the monitoring research and business of chilling injury. The applications of monitoring means and data which include the satellite every kind of remote sensing technologies should be reinforced. The deep researches of disaster need be reinforced. The climate variation research combines with the research on the biological internal mechanism of crops variation and the concurrency the inter-influence of disaster are considered. Meanwhile, the index research is also important in the great background that the global climate becomes warm. The research means need be various. The establishment of exact agricultural meteorological model must be strengthened and the new research methods should be introduced. The research results must be gradually transformed into the business and the comprehensive business system of monitoring prediction evaluation defense should be established. The relative agricultural meteorological service system should be built.

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According to the above process, the automatic monitoring and early warning business system of paddy rice low temperature cold damage in Ningxia was developed and applied into the monitoring and early warning business of paddy rice low temperature cold damage in 2007 and 2008. According to the monitoring results, the monitoring and early warning material was issued in the metaphase of late July, the end of early August, early September, and the countermeasures suggested were put forward. The monitoring and early warning results of cold damage basically corresponded with the actual occurrence situation in 2007 and 2008 and made the active contributions to reduce the cold damage hazard.

5 Conclusions and discussion

With the support of GIS by using the improved small grid reckoning method to count the daily average and lowest temperature, applying the multitemporal remote sensing data to extract the paddy rice planting zone combining the paddy rice planting area with paddy rice low temperature cold damage index and the weather forecast data, the low temperature cold damage of paddy rice was monitored and done the early warning. The automatic monitoring and early warning system was developed which was very efficient for the business service could improve the work efficiency of business workers and had the high popularization application value.

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