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A 0.25° × 0.25° Raster Dataset of Effective Accumulated Temperatures in Sino-Russian Cross Border Region of Heilongjiang River Basin between 2002 and 2020

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Abstract: A 0.25° × 0.25° Raster Dataset of effective accumulated temperatures (RDEAT) in the Sino-Russian border region of the Heilongjiang River basin was developed based on hourly 2-m temperatures from European Center for medium range weather forecasts (ECMWF) re-analysis 5 between 2002 and 2020. The base temperatures were 0 °C, 5 °C, 10 °C, and 15 °C. The results of a correlation analysis between this dataset and data obtained from observation *in situ* revealed a positive correlation with the validation dataset and that their inter-annual fluctuation were basically the same. The dataset included boundary data about the study area; the start and end dates of annual effective and effective accumulated temperatures between 2002 and 2020 of ≥ 0° C, ≥ 5 C, ≥ 10 °C, and ≥ 15 °C; and a validation dataset of effective accumulated temperatures. A dataset of 305 files comprising 19.9 MB of data has been archived in .shp, .tif, and .xlsx formats and compressed into a single file of 1.69 MB.

Keywords: Heilongjiang River basin; Sino-Russian cross-border area; effective temperature start and end date; effective accumulated temperature; 2002–2020

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[2] Zhou, Y. Z., Wang, J. L., Li, K., *et al*. Temperature dataset of effective temperature sum in the Sino-Russian cross border region of Heilongjiang River basin (2002–2020) [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2022. https://doi.org/10.3974/geodb.2022.04.05.V1. https://cstr.escience. org.cn/CSTR:20146.11.2022.04.05.V1.

Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: https://doi.org/10.3974/geodb.2022.04.05.V1 or https://cstr.escience.org.cn/CSTR:20146.11.2022.04.05.V1.

1 Introduction

Agricultural production has long been affected by natural climatic and environmental conditions, among which temperature is a key factor for crop growth and development. Any changes in temperature will affect the heating conditions of regional climatic resources. Air temperature is directly or indirectly related to variables such as solar radiation, light cycles, and soil temperature and plays a leading role in crop photosynthesis. It is also an important factor that affects crop productivity and quality. Temperature changes and their fluctuating effects play important roles in supporting research on farmland ecosystems. This is because they affect changes in agricultural resource heat and can lead to short-term or persistent secondary events, such as fire, frost, and drought. The occurrence of natural disasters has a greater impact on the sustainability of the entire ecosystem[1,2].

The cumulative effects of daily temperatures represent an important indicator of crop growth and potential productivity[3]. A statistical concept of the amount of heat storage required for plant growth and development was proposed by de Réaumur approximately 300 years ago[4]. Thereafter, a series of temperature-based evaluation indices were produced to support the scientific management of regional agriculture[5]. These statistical indices of historical temperature data aimed to help understand differences among crop growth conditions in various regions. Representative methods include average growing season temperature, the Huglin index, active accumulated temperature, and summed effective temperature. Annual average temperatures are measured during the growing seasons from April to October and from October to April of the following year in the northern and southern hemispheres, respectively, to form a macroscopic picture of the suitability of the local agro-climate[6]. The Huglin index is based on a temperature of 10 ºC to evaluate the climatic conditions required for viticulture and winemaking[7]. The active cumulative temperature refers to summed annual cumulative temperatures above zero when the daily average temperature is higher than a threshold that is usually 10 ºC. This method is of great significance to agroclimatic analysis and zoning investigations[8,9]. The method of summed effective temperatures is based on the concept of heat accumulation during plant growing seasons and describes the annual accumulation of the daily average temperature suitable for growth on days above biological zero, which represents the minimum requirements for plant growth and development[10]. Among these methods, that in which the accumulated effective temperature removes the "ineffective" part of regional heat resources (unsuitable for crop growth) and further corrects linear relationships between the two variations can be used to monitor the spatiotemporal growth conditions of crops and predict their future growth periods[11]. A corresponding temperature range can also be incorporated into the study of regional and even global thermal potential energy according to the growth temperature threshold of different crops[12].

The Heilongjiang River basin is a watershed spanning China, Russia, Mongolia, and North Korea. The Sino-Russian border area along the Heilongjiang-Usuli River includes administrative units such as Heilongjiang province, Amur oblast, Jewish autonomous oblast, and Primorsky Krai (Figure 1). As the main agricultural production area in the entire basin, the area has abundant natural resource reserves, excellent geographical and climatic conditions, and profound potential for the development of agricultural resources. The climate in Heilongjiang province is a temperate continental monsoon. Since the beginning of the 21st century, the average temperatures have been approximately 4 ºC, with average precipitation of

530–760 mm, and other meteorological conditions with distinctive seasonal characteristics[13]. In terms of geographic conditions, the Songnen and Sanjiang plains are located on the west and east sides of the province. These plains are fertile enough to cultivate crops such as soybeans, rice, corn, and potatoes. Planting crops in the Russian Far East is affected by environmental factors such as cold temperatures and permafrost. Hence, planting has mainly been concentrated in the southern and eastern administrative regions with better natural conditions, such as temperate continental and oceanic monsoon climates. The Zeya-Bureya and Khanka Lake plains occupy a vast area below an altitude of 500 m, and these are the key agricultural areas in the Far East. The rain and heat conditions of these fields are suitable for cultivating soybeans, rice, and cereals (such as barley, oats, and buckwheat). Fruit planting is also being vigorously developed in the Jewish autonomous oblast[14]. Judging from the current cross-border agricultural development in the study area, cooperation to develop agricultural production has continuously deepened between the two regions. Agricultural cooperation between Heilongjiang province and Russia includes an area of more than 9.5 million acres, and over 200 enterprises are engaged in agricultural development in the Russian Far East. Agricultural technical exchanges between the research institutes and the import and export of dominant crop varieties are increasing. The annual amount of soybeans imported into Heilongjiang province mainly from Amur, has significantly increased annually, and this has alleviated the demand gap for such crops in China[15]. In the context of climate change, temperature and other factors of agro-meteorological resources in both countries are constantly changing, and the frequency and severity of agricultural natural disasters are also increasing. The consequences of these have significantly affected agricultural trade cooperation and product safety in cross-border areas. Therefore, the heat resources required to grow and develop crops in this area requires investigation. Relevant basic data about disaster prevention and reserve farmland potential in the study area should be studied from the perspective of climatic conditions. Furthermore, theoretical references are required to analyze agricultural production activities.

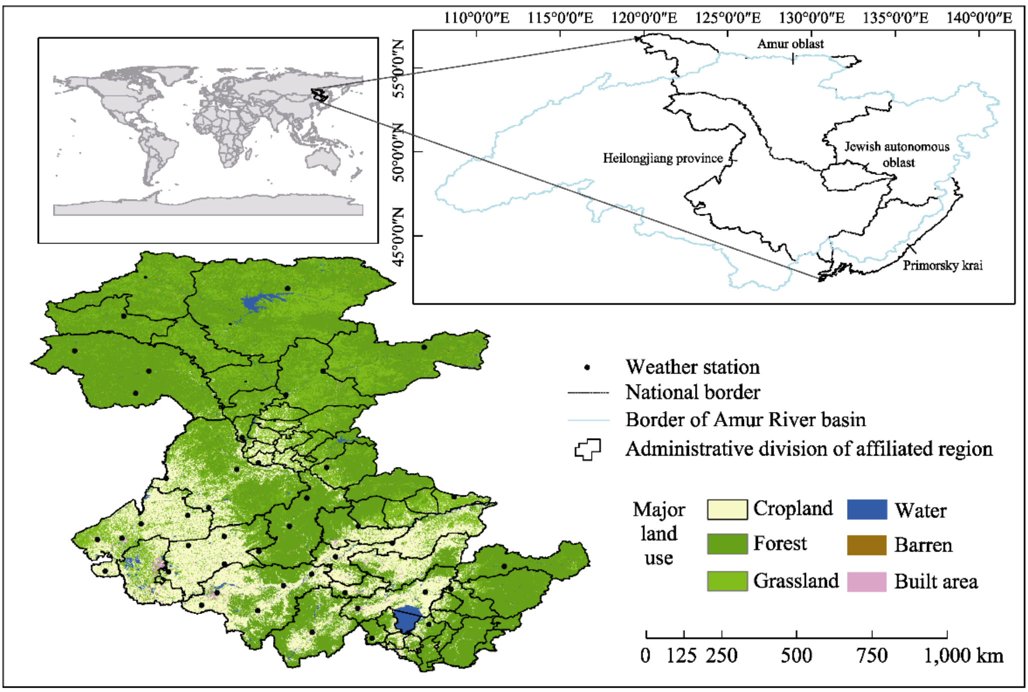


Figure 1 Geographical status of the study area

2 Metadata of the Dataset

Table 1 shows a metadata summary of the dataset[16]. It includes the full and abbreviated names of the dataset, authors, year, temporal and spatial resolution, data format, size, files, publisher, and sharing policies.

Table 1 Metadata summary of the dataset of summed effective temperatures in the Sino-Russian cross border region of Heilongjiang River basin between 2002 and 2020

Item	Description
Dataset full name	0.25°×0.25° raster dataset of effective accumulated temperature in the Sino-Russian cross border region of Heilongjiang River basin (2002–2020)
Dataset short name	EffecAccTemp_CR_2002-2020
Authors	Zhou, Y. Z. 0000-0002-6826-151X, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, zhouyz@lreis.ac.cn Wang, J. L. 0000-0002-5641-0813, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, wangjl@igsnrr.ac.cn Li, K. 0000-0001-6234-6806, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, lk@lreis.ac.cn Grigorieva, E. A. 0000-0002-7811-7853, Institute for Complex Analysis of Regional Problems, Far-Eastern Branch, Russian Academy of Sciences, eagrigor@yandex.ru
Geographical region	Including 4 administrative regions located in the Sino-Russia cross-border area among Heilongjiang River basin (the entire Heilongjiang province and Jewish autonomous oblast, part of Amur oblast and Primorsky krai)
Year	2002–2020
Temporal resolution	Yearly
Spatial resolution	0.25°×0.25°
Data format	.shp, .tif, .xlsx
Data size	1.69 MB (after compression）
Dataset files	The dataset includes the four parts below: (1) the boundary data of the study area; (2) the beginning/end date of annual effective temperature during 2002–2020 (≥0 ºC, ≥5 ºC, ≥10 ºC and ≥15 ºC); (3) the effective accumulated temperature during 2002–2020 (≥0 ºC, ≥5 ºC, ≥10 ºC and ≥15 ºC); (4) the validation dataset of effective accumulated temperature
Foundations	Chinese Academy of Sciences (XDA2003020302); Chinese Academy ofEngineering (CKCEST-2022-1-41)
Data computing environment	Python, ArcGIS
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11 A Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	***Data*** from the Global Change Research Data Publishing & Repository includes metadata, datasets (in the *Digital Journal of Global Change Data Repository*), and publications (in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the 'ten per cent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[17]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS/ISC, GEOSS

3 Methods

This study was based on global hourly 2 m air temperature data released by the European Center for medium range weather forecasts (ECMWF)[1] between 2002 and 2020. The validation dataset comprised corresponding accumulated temperatures in Heilongjiang

[1] European Centre for Medium-Range Weather Forecasts. https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5.

province between 2002 and 2018 calculated by Grigorieva *et al.* from grid data with spatial resolution of 0.25° × 0.25° and Russian data derived from daily temperature data gathered at meteorological stations between 2002 and 2011.

3.1 Algorithm Principle

The effective accumulated temperature (EAT) is an evaluation index that is closely associated with plant growth. It reflects the heat resource reserves required for the growth of target plants that are likely to thrive by counting the cumulative daily average temperatures above biological zero (effective temperature). The index consists of information about time and temperatures affecting plants during the growing season. Thus, changes in the index will impact the phenology period, which will lead to changes in regional agricultural production and results. The specific combination calculation is shown below as Equation 1 and 2. Several studies have discussed that using hourly temperature data to calculate the daily average temperature represents more accurate results than daily ones, so that the computational results of the elements can be more precisely characterized[18,19]. Therefore, we calculated daily average temperatures Equation 3 as follows:

$$EAT = \sum_{i=1}^{m}(T_i - T_{\text{base}}) \tag{1}$$

$$T_i = (T_{\max} + T_{\min}) / 2 \tag{2}$$

$$T_i = \sum_{k=1}^{24} T_k / 24 \tag{3}$$

where T_i is the daily average temperature (ºC) on day *i* calculated by different statistical methods, and T_{base} is the base temperature (ºC) suitable for a target crop to thrive, $i = 1, 2, \ldots,$ m is the range of daily average temperatures ≥ growth base temperature, $T_{\max}$ and $T_{\min}$ are the highest and lowest temperatures (ºC) of a day, and T_k is hourly temperature data within a day.

3.2 Technical Route

Figure 2 shows the overall flow of this study, which comprised data acquisition and preprocessing, selection of crop growth limit temperature, determination and accumulation of effective temperature starting and ending time, and quality inspection results.

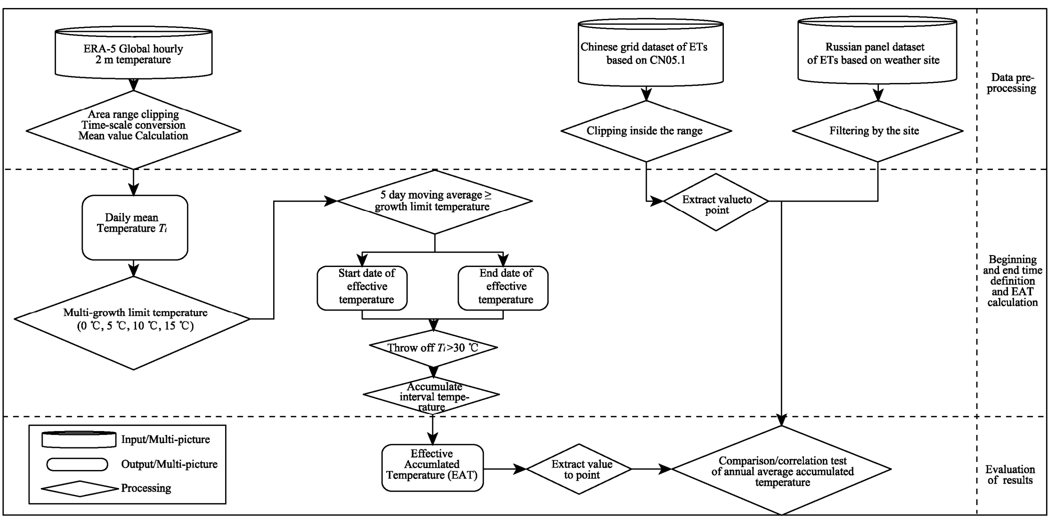


Figure 2 Flowchart of effective accumulated temperature algorithms

3.2.1 Data Preprocessing

We used Python language and the ArcGIS platform to completely batch crop ERA-5 data throughout the study period based on the vector range of the area to prepare the original data for this dataset. We then averaged hourly temperatures throughout a 24-h day to obtain daily average temperatures in the region between 2002 and 2020. Simultaneous preprocessing included clipping raster and filtering panel data according to the type of validation data.

3.2.2 Selection of Growth Base Temperature

Plants can adapt to various temperatures over long periods. They start to develop at surrounding temperatures that exceed a specific value and will rarely grow below it. Table 2 shows the temperatures that limit the growth of the main economic crops.

Table 2 Base temperatures associated with the growth stages of several major commercial crops[20]

Crop type	Growth base temperature (℃) T_{base}	Crop type	Growth base temperature (℃) T_{base}
Cabbage	0	Corn	10
Pea	4.5	Soybean	10
Wheat	5	Rice	15
Potato	7		

Notes: Considering the crops actually planted in the study area, we selected T_{base} 0 ℃, 5 ℃, 10 ℃, and 15 ℃ to characterize baseline effective accumulated temperatures.

3.2.3 Identification of Start and End Times of Effective Temperatures

We used a 5-day moving average above the defined limit temperature to determine the start and end dates of the summed effective temperature in a specific year. The starting (terminating) range of valid temperatures was quite long. In the first sequence of the starting range, the first date with T_i above the limit temperature was selected as the start time. In the last sequence of the ending range, the last date was taken as when T_i exceeded the defined temperature limit (end time).

3.2.4 Calculation and Evaluation of EAT

The maximum upper limit temperature also affects the growth of crops. Heatwaves caused by extremely high temperatures can retard and thus inhibit the growth and development of various crops[21,22]. Considering experimental data and related literature[11, 20, 23] about various developmental stages of the main crops in the study area, T_i = 30 ℃ was selected as the upper temperature limit of the effective accumulated temperature statistics in the study area.

When T_i was greater than T_{base}, the difference between $T_i \leq 30$ ℃ and the four T_{base} values were accumulated to obtain the annual EAT (Figure 3). Thereafter, correlations between the results and verification data based on measured data were analyzed to evaluate the quality and effect of this data on the characterization of heat resources in the study area.

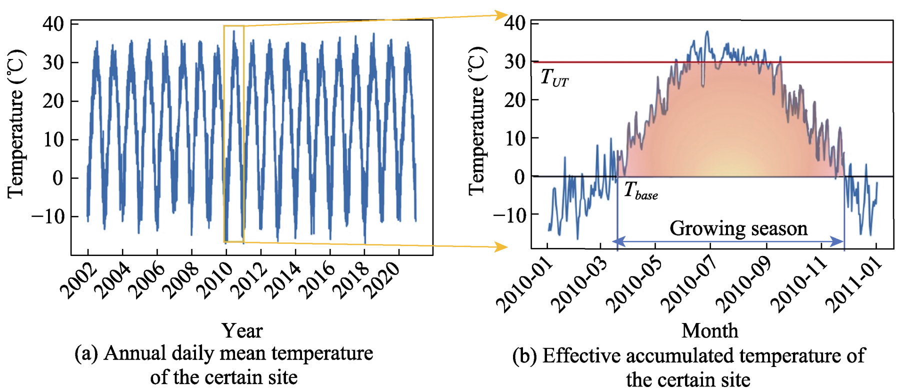


Figure 3 Schematic diagram of the study

4 Data Results and Data Validation

4.1 Data Composition

The EAT data products in the Sino Russian cross-border areas of Heilongjiang River basin between 2002 and 2020 are single band data files. The names of the EAT start time, EAT end time, and EAT are at T_{base} EAT_firstday_0.25°_YYYY.tif, at T_{base}EAT_lastday_0.25°_YYYY.tif, and at T_{base}EAT_0.25°_YYYY.tif, respectively. Among the names, 0.25 ºC represents the product spatial resolution of 0.25° × 0.25°, and YYYY is product time in a specific year. The more information about the product is shown in Table 3.

Table 3 Product attributes

Number	Attribute	Value	Number	Attribute	Value
1	Data type	float	4	Pixel value	0–4,000
2	Row	67	5	Pixel size	0.25°×0.25°
3	Column	50	6	Coordinated system	WGS 84

4.2 Data Results

4.2.1 Spatio-temporal EAT Profiles

The annual spatial distribution and variation trends of the four types of EAT in the study area were obtained through the previous data processing process. Figure 4 shows the results at 0 ºC.

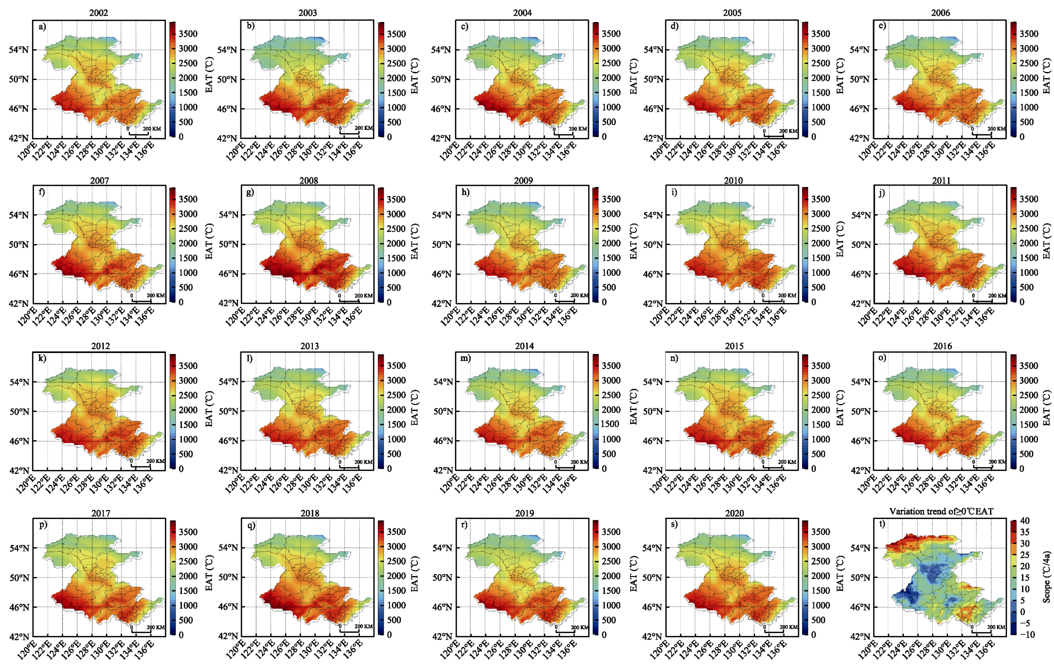
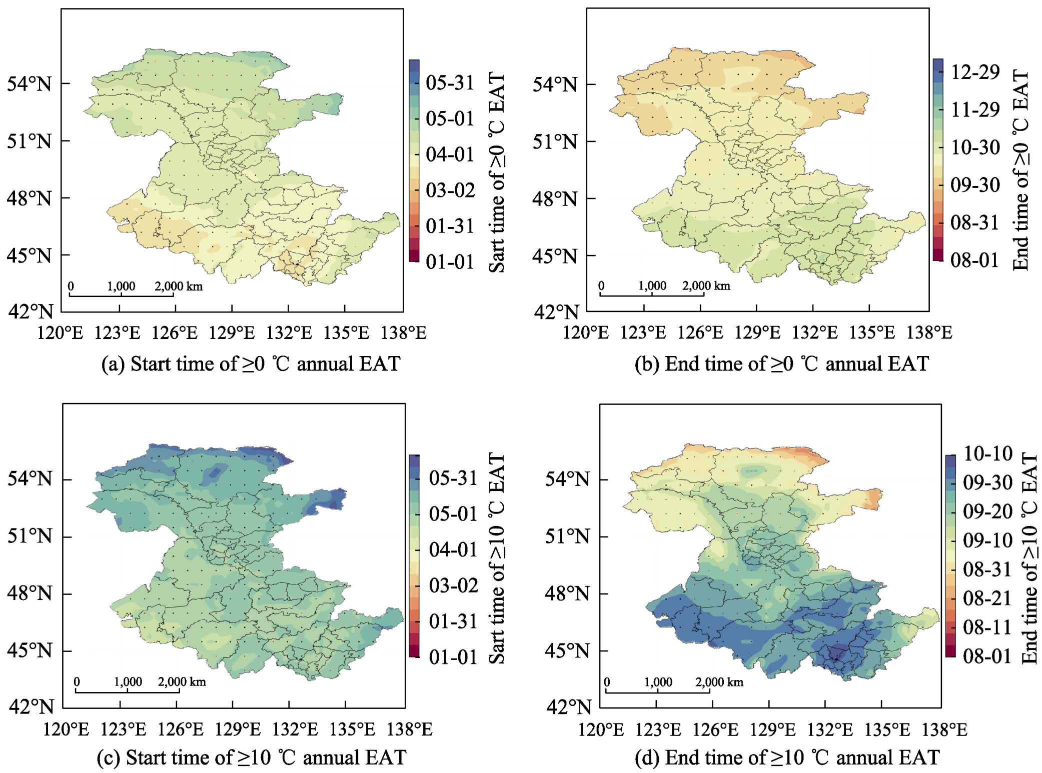


Figure 4 Spatial distribution at ≥0 ºC EAT (4a–4s) and trend (4t) variations between 2002 and 2020

The spatial profiles at ≥0 ºC EAT in the study area generally increases from north to south and regions with values >3,000 ºC are mainly distributed on the east and west sides of Heilongjiang province, the southern Amur oblast, and the western Primorsky Krai in the Russian Far East, which is generally consistent with the distribution of cultivated land in the study area. The area with low values is located at a high altitude in the northwest Amur oblast, where the accumulated temperature is below 1,000 ºC year-round. In terms of trends of accumulated temperature variations over 19 years, the trends in EAT variations increased in most of the studied regions. The larger range (>20 ºC; Figure 4a) appeared in the southern Amur oblast, the northern Jewish autonomous oblast, and the adjacent areas of Heilongjiang province and Primorsky Krai. However, the interannual accumulated temperatures in northern Heilongjiang and at the border of Amur oblast were relatively stable, and the trends in some areas within the range were slightly downward (5–10 ºC; Figure 4a).

Analysis of distribution and change of start and end times

Figure 5a and 5b shows that the earliest start and end times and place where the EAT was ≥0 ºC were March and mid-September, respectively, and the corresponding latest times were May and early November, respectively. The duration of EAT was the shortest in the northeast region of Amur oblast, relatively longer in southern Heilongjiang province, and longest in the southwest and east of the province adjacent to Russia. We compared the two periods over the past 20 years. The results showed that the duration of the average accumulated temperature in the agricultural growing areas in the east and west of Heilongjiang province, the Jewish autonomous prefecture of Russia, and the west of Primorsky Krai was longer (earlier start and later end times) over the past 10 years than in the previous period. In contrast, the duration of accumulated temperatures in the south of Amur oblast was shorter than in the earlier period.



(a) Start time of ≥0 ℃ annual EAT
(b) End time of ≥0 ℃ annual EAT
(c) Start time of ≥10 ℃ annual EAT
(d) End time of ≥10 ℃ annual EAT

Figure 5 Start (5a, 5c) and end (5b, 5d) time of ≥0 ºC and ≥10 ºC annual EAT between 2011 and 2020 (Black and red dots represent advance or delay compared with previous stage, respectively; EAT: effective accumulated temperature)

The effective temperature >10 ºC in the study area in the recent 10 years began and ended in mid-April at the earliest and early October at the latest, respectively. The effective temperature starts before May in most flat areas of Heilongjiang province and approximately 10 days later in high altitude areas from the northwest to the southeast. The corresponding data in the Russian Far East began after May, whereas the starting time of the accumulated temperature in some agricultural growing areas in the south of Amur State and the west of Primorsky Krai was slightly earlier. In terms of the distribution of the accumulated temperature end time, the Southern Part of Heilongjiang province, the Jewish autonomous oblast, and most of Primorsky Krai was generally after the end of September. The end time of the accumulated temperature was around the first 10 days of September in the Amur Region except where it was adjacent to Heilongjiang province. We found that the start and end times of the two periods over the past 10 years were early. A northern delay accounted for >90% of the early and delayed accumulated ending temperatures in both Primorsky Krai and Heilongjiang province. Early occurrence was mainly located in the east and west of Heilongjiang province and the Sino-Russian border area.

4.2.2 Analysis of Variations in Proportions of EAT Areas

According to the EAT thermal standard of ≥10 ºC, the study area was dynamically divided into annual intervals corresponding to 10 ºC EAT ranges of >1,400 ºC, 1,400–1,100 ºC, 1,100–800 ºC, and < 800 ºC). Figure 6 shows statistical changes in the proportions of areas with these values between 2002 and 2020.

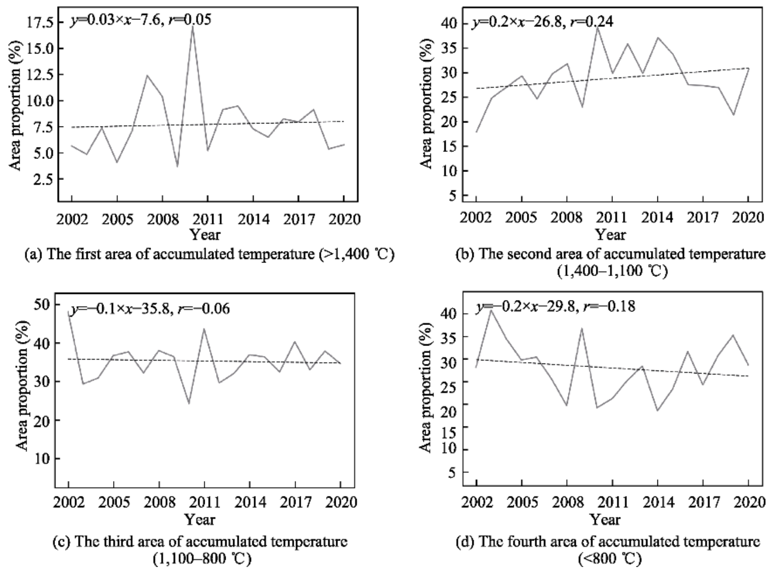


Figure 6 Proportions of areas in zones based on the EAT standard of ≥10 ºC

Figure 6 shows that the four accumulated temperature zones accounted for approximately 7.5%, 27.5%, 35%, and 30%, respectively, of the study area. The changes in trends during the first and third intervals were relatively stable, whereas the interannual changes in the second and fourth accumulated temperature regions slightly increased and decreased, respectively. Among the time points with obvious annual fluctuation in each region, the area of high EAT in the first and second regions exceeded 15% and 35% in 2010, respectively. However, the area of EAT <1,100 ºC accounted for approximately 70% of the entire study area during 2009.

4.3 Data Validation

The EAT values of Heilongjiang province between 2002 and 2018 were calculated based on the daily average temperatures in the CN05.1 data produced by the National Climate Center according to the above processing procedures and compared with the present results. The CN05.1 data were derived from the information accumulated at 2,400 national meteorological stations in mainland China between 1961 and 2018 using thin plate spline interpolation. The accumulated temperatures described in previous reports correlated with the results generated by the Chinese Ecosystem Research Network. The validation data comprised four corresponding datasets from the Southern Russian Far East between 2002 and 2011 based on daily temperature data recorded at meteorological stations. We extracted grid data products of the study area and Heilongjiang province based on the location of each meteorological station using bilinear interpolation during data pre-processing verification. We then analyzed correlations between these and the results from the Russian Far East (Figure 7, 8).

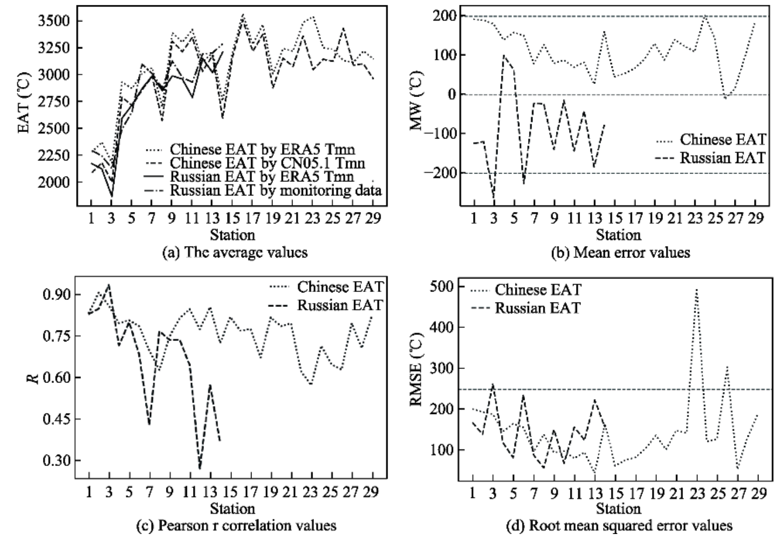


Figure 7 Validation at ≥ 0 ºC EAT (Tmn in Figure 7a means mean temperature)

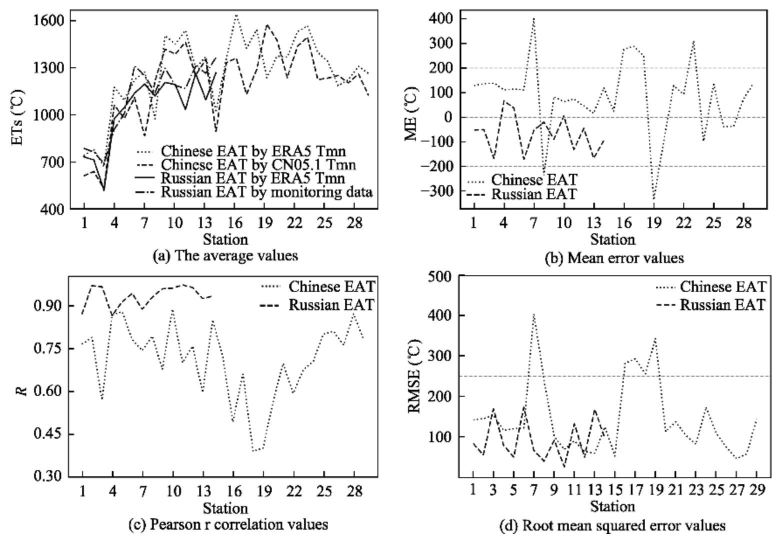


Figure 8 Validation of EAT ≥10 ºC (Tmn in Figure 8a means mean temperature)

These comparison and verification results show that the calculated EAT values of ≥0 ºC and ≥10 ºC during 2002–2020 were basically consistent with the multi-year average values of corresponding results based on CN05.1 and measured temperature data, except the data from individual stations that significantly differed (Figure 7a, 8a). The mean errors between data (Figure 7b, 8b) show that the calculated results at most stations in Heilongjiang province and the Russian Far East of Russia were respectively overestimated and underestimated compared with the control data. The ME values among 37 stations were all within −200 ºC to approximately 200 ºC, whereas Stations 7, 8, 19, and 23 in Heilongjiang province and Stations 3 and 6 in the Russian Far East were not. The Pearson correlation results (Figure 7c, 8c) of accumulated temperature data show that correlation coefficients (rho; *r*) at most stations were >0.45, which basically reflects inter-annual fluctuation and changes in the accumulated temperatures in the study area over the past 20 years. The root mean squared error corresponding to each group was within 50% of the maximum values at most sites (Figure 7d, 8d) and the maximum deviation in the ranges in the two datasets did not exceed 500 ºC. These findings indicated that our results fit the accumulated temperature results calculated based on the measured data. Therefore, our results can be used as basic data to reflect annual heat resources required by various crops in this region.

5 Discussion and Conclusion

We aimed to determine the start and end points of effective temperatures at the Sino-Russian border area of the Heilongjiang River basin between 2002 and 2020 and the annual effective accumulated temperatures of each growth period. We therefore reanalyzed, processed, and converted 2 m hourly temperature data in ERA5. The daily average temperatures and the base temperatures of crop growth (0 ºC, 5 ºC, 10 ºC, and 15 ºC) were then calculated. We systematically analyzed the spatial distribution of these two items from the perspectives of land surface types and geomorphic conditions and macroscopically described the dynamic evolution law of the EAT zones at all levels. The results showed that the EAT was mainly located in the southern plain of the study area, which was basically consistent with the distribution of the agricultural land in the study area. Trends in accumulated temperature changes in most of the study area show a steady increase over the past 20 years, and the corresponding situation in the northwest area was the most obvious at EATs of 0 ºC, 5 ºC, and 10 ºC. This information could be combined with other factors to analyze and excavate the reserve potential of non-farming areas. This will strengthen the ability to guarantee agricultural development and food security across the border between China and Russia under uncertainties such as climate change and international issues.

Author Contributions

Wang, J. L. designed the algorithms of dataset. Zhou, Y. Z., Li, K., and Grigorieva, E. A. contributed to the data processing and analysis. Wang, J. L., Zhou, Y. Z., and Li, K. wrote the data paper.

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Conflicts of Interest

The authors declare no conflicts of interest.

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