Growing degree days at the Russian Far East

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Abstract

Concept of degree-days called growing degree-days (GDD) as a measure of the intensity of the growing season was used for assessment of thermal resources for the locations in the southern part of the Russian Far East. Daily maximum and minimum temperatures were used for calculating GDD at 17 locations of the Far East. Base temperatures of 0, 5, 10 and 15 °C as commonly used lower threshold temperatures, and upper threshold of 30 °C were utilized for assumption of growing degree days. GDD increases from north to south, from mountainous locations to the plain, and moving off the coast. Thermal conditions in the southern part of the study area cover the demands of all the plants cultivated here; low thermal resources are observed in the north, in the elevated areas and in the coastal regions. Temporal variability of GDDs shows mainly positive temporal changes over the 1966-2005 period; positive trend is observed for GDD0, indicating that study area has experienced a stretching of the warm period. GDD15 indicating thermal resources of summer season vary little or reveal zero trend.

1. Introduction

Air temperature is one of the main environmental factors for distribution, growing, biological development and yield production of the plant species (Cross & Zuber 1972, Russelle et al. 1984; Gordon & Bootsma 1993) and may be the main limiting factor for plant growth especially at temperate zones and high latitudes (Førland et al. 2004). Cumulative effect of daily temperatures over the long period reacts on the plants and their development (Wang 1960, Schwartz et al. 2006), may be estimated by index which illustrate heat accumulation necessary for development processes and named as growing degree days (GDDs).

Important changes have occurred in global climate during the 20th century. Marked increase in surface air temperature since 1970 (IPCC 2007) correlates with other climate and environmental characteristics first of all with increasing climatic variability and has a clearly visible ecological response: in natural and managed ecosystems from the species to the community level, in agriculture first of all in crop production, and in people living as well (Bootsma 1994, Karing et al. 1999, Schwartz et al. 2006). Changed climatic conditions and consequently agroclimatic resources forces mankind to find decision for possibilities of agriculture adaptation to all possible environmental changes (Karing et al. 1999).

The objective of the present study is to evaluate GDDs as one of the main climatic growing index for the locations at the southern part of the Russian Far East with the extreme annual temperature amplitude using daily maximum and minimum temperatures. The growing degree-days are analyzed and their linear trends are estimated for period from 1966 to 2005.

2. Methods and study area

Concept of degree-days named growing degree-days (GDD) as a measure of the intensity of the growing season is one of the widely used to determine development of living things and plant species first of all. GDD is based on the idea that the development of a plant or other organisms first of all poikilotherms will occur only when the temperature exceeds a specific base temperature for a certain number of days. It ignores additional environmental factors and different respond of plants to the same temperature during various stages of their life cycle but it has been widely used due to practical utility in agriculture, phenological and other studies (Wang 1960). Now GDD is used as a method to predict the growth stages of major crops like soya bean, maize, wheat (particularly temperate crops); it is also useful in taking precautionary measures against insect pest and diseases attack on crops (Gilmore & Rogers 1958, Wang 1960, Russelle et al. 1984, Gordon & Bootsma 1993, Bootsma 1994, Yang et al. 1995, McMaster & Wilhelm 1997, Roltsch et al. 1999, Cesaraccio et al. 2001, Førland et al. 2004, Matzarakis et al. 2007, Fealy & Fealy 2008). It may be calculated on the basis of long-term average daily mean temperature or it may be computed on data of a given year and in this case it will take into account weather variability.

There are several methods of GDD calculation including model estimation with their advantages and shortcomings (Roltsch et al. 1999). Method with using hourly temperature data (Cesaraccio et al. 2001) is the most accurate but needs data only from an automatic weather network. Assumption of GDD with mean temperature calculated as average from minimum and maximum daily temperatures is the most common in agricultural and phenological researches (Gilmore & Rogers 1958, Bootsma 1994, McMaster & Wilhelm 1997, Matzarakis et al. 2007, Fealy & Fealy 2008):

$$GDD = \sum_{i=1}^{m}(T_i - T_{base}),$$

where GDD – growing degree days, ^{o}C; $T_i = (T_{max} + T_{min})/2$ – mean temperature, ^{o}C; T_{base} – base or threshold temperature, ^{o}C; i = 1, 2, ... m – days with temperature higher threshold temperature T_{base} in warm period; T_{max} – the daily maximum air temperature, ^{o}C; T_{min} – the daily minimum air temperature, ^{o}C (Gordon & Bootsma 1993, Bootsma 1994, McMaster & Wilhelm 1997). Thus all temperatures under the diurnal temperature curve and over threshold value are summed during period with this base temperature.

Typically in general assessments of climate and temperature impact on plant vegetation 0, 5, 10 and 15 ^{o}C are taken as base or threshold temperatures (Gordon & Bootsma 1993, Karing et al. 1999, Gordeev et al. 2006, Fealy & Fealy 2008, Grigorieva 2008) due to the close relationship of these temperatures with the onset and end of the main crops development. In the work by Gordeev et al. (2006), as in many other papers by Russian or by former USSR's researchers, thresholds 0, 5, 10 and 15 ^{o}C have stable meanings as, respectively: warm period; heat supply of the vegetation period for the main cold-resistant wild and cultivated plants; heat supply for the period of active plant growth; heat supply for the heat-loving plants (Gordeev et al. 2006).

High temperatures may decline or even stop development rate and main physiological functions of plants up to temperature or thermal stress and survival of plants or plant organs and poikilotherms (Wang 1960, Bootsma 1994, Roltsch et al. 1999). Cross and Zuber (1972) suggested to use optimum of 30 ^{o}C; excess temperature above 30 ^{o}C must be subtracted to account for high temperature stress. In modern analysis this value is used as upper temperature threshold T_{UT} (Russelle et al. 1984, McMaster & Wilhelm 1997, Matzarakis et al. 2007). In the present paper the heat accumulation necessary for development process is described using GDD for four different lower thresholds 0, 5, 10 and 15 ^{o}C and with account of temperature upper limit 30^{o}C.

The study area is the south of the Far Eastern Russia region, which has middle latitude monsoon climate characterized by an extreme continental annual temperature regime. Annual temperature here varies between -5.4 ^{o}C at Ekimchan to 5.7 ^{o}C at Pogranichnyi. The annual temperature range is from 28.2 ^{o}C at the coastal part of the study area to 52.7 ^{o}C at the continent.

The data used for 17 hydrometeorological stations (HMS) are daily maximum and minimum air temperature. The observational base is quite limited by very rare network of weather stations with data available that results in a paucity of observations in general. Data used consistes of year-long records from each site during 1966-2005.

3. Results

Using degree days as the heat unit, the thermal resources are calculated for each location with threshold temperatures described previously providing a useful indicator for assessing crop development at the Russian Far East (Fig. 1).

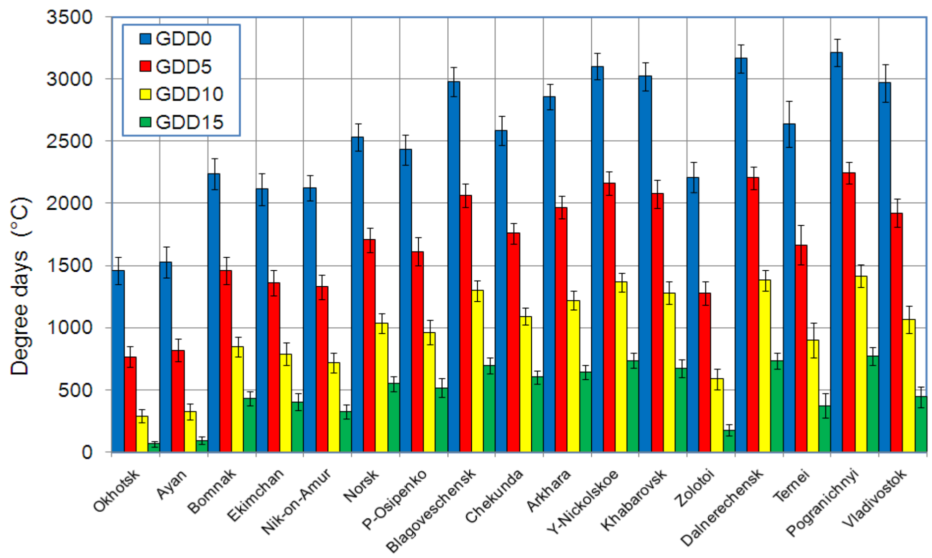

Fig. 1: GDDs at the Russian Far East for period 1966-2005

Analyzing the calculated data, we establish that the highest mean value GDD0, used to characterize warm period (Gordeev et al. 2006), is recorded at the continental southern part of the study area in Pogranichnyi (3212 ^{o}C), that is twice higher than the corresponding value of 1459 ^{o}C observed in Okhotsk – coastal location at the north with minimum thermal supply. High values are calculated mainly for the continental stations at the south Dalnerechensk, Yekaterino-Nickolskoe, Blagoveschensk and Khabarovsk.

Coastal areas have considerably lower thermal provision varying from 1530°C in Ayan, northern coast of the Okhotsk Sea, to 2208 °C in Zolotoi, and to 2968 °C in Vladivostok, southern coast of the Japan Sea. Lower thermal reserve is observed in mountains at Bomnak and Ekimchan (2236 and 2114 °C respectively).

Spatial distribution of the GDD5, used to describe heat supply of the vegetation period, is the same as for the previously described index. GDD5 varies from 767 ° C in Okhotsk at the northern coastal part of the study area to 2246 °C in Pogranichnyi at the southern continental part, data scattering is three times. GDD5 is lower in the mountains and on the sea shores of the study area; continental regions have higher values than those coastal.

The highest value of the GDD10 in Pogranichnyi (1416 °C) is five times as much the result for Okhotsk (290 °C). Large difference in GDD10 is between continental and coastal parts at the same latitude, this value is more expressed for the southern locations – up to 2.3 between Yekaterino-Nickolskoe and Zolotoi. Far to the north continental stations are situated in the mountains, and the contrast between continent and coast is not so large.

Thermal supply for the heat-loving plants (Gordeev et al. 2006) is described by GDD15. Eleven-time difference in GDD15 values between north and south – from 67 ° C in Okhotsk to 771 °C in Pogranichnyi – shows the intense and the largest contrast in the climatic characteristics between two extreme geographical points at summer period. Spatial distribution of previous GDDs and GDD15 is very similar but with a significant reduction in the absolute values.

Assessment of temporal changes of GDDs was done for the period 1966-2005. The significance of the trends was tested using Fisher F-test. Calculated F values are more than empirical F-value 4.08 for all GDDs' at the northern coastal stations (Okhotsk and Ayan), two continental HMS (Poliny-Osipenko and Blagoveschensk) and for all southern – coastal (Zolotoi, Ternei and Vladivostok) and continental ones (Dalnerechensk and Pogranichnyi). The results are large showing statistically significant positive trend at these locations. At the same time null-hypothesis was confirmed for all GDDs' at the coastal location Nickolaevsk-on-Amur and continental HMS (Bomnak, Ekimchan, Norsk, Chekunda, Arkhara, Yekaterino-Nickolskoe and Khabarovsk).

4. Discussion

The mean value of growing degree days varies considerably following the main geographical pattern of temperature distribution: the magnitude of the GDDs increases from north to south, moving off the coast, and from mountainous locations to the plain. The largest contrast is revealed for extremely different latitudinal locations Pogranichnyi (44°24') and Okhotsk (59°11' N). This spatial difference in thermal supply increases from the warm period to summer, – from two to eleven times. Significant spatial gradient is established for areas located at the same latitude that is explained by the influence of large water reservoirs (seas of the Pacific Ocean). Contrast for all degree days (0, 5, 10 and 15 °C) between Yekaterino-Nickolskoe at the continent (47°44' N, 130°58' E) and Zolotoi at the sea shore (47°19' N, 138°59' E) – is 1.4, 1.7, 2.3 and 4.2 times respectively. This difference is revealed in less degree further to the north, where mountainous influence is expressed at the continent. Thus, for example, GDDs gradient from

Bomnak (54°43' N, 128°56' E, 357 m asl) to Nickolaevsk-on-Amur (53°09' N, 140°41' E, 46 m asl) is 1.05, 1.1, 1.2 and 1.3 times. Ekimchan (53°04' N, 132°56' E, 540 m asl) shows even lower value for thermal resources of the warm period in comparison with the coastal stations due to its higher elevation.

Interannual variability of GDDs shows positive statistically significant temporal changes over the 1966-2005 period, confirming global warming trend. The most significant positive trend is observed for GDD0, indicating that study area has experienced a stretching of the warm period. But for some locations zero trend is marked as evidence that global climate change has regional features, expressed in some specific characters at the study area. It is known that global warming is emphasized mostly for winter time, and even cooling may be observed at some locations especially in summer (e.g. Grigorieva & Tunegolovets 2005) that is corroborated by our research. The largest increase in temperature has taken place in the southern part of the Sea of Japan near Ternei showing local spot with strong positive trend.

5. Conclusions

The study area at the south of the Far Eastern Russia region is characterized by an extreme continental annual temperature regime that is revealed in low winter temperatures and nevertheless high thermal supply of warm period. This study sets out to apply a conception of the growing degree days to this region to get valuable information for agricultural management. It is marked that the mean value of growing degree days varies considerably from one location to other following the main geographical characteristics of temperature distribution: the magnitude of the GDDs increases from north to south, moving off the coast, and from mountainous locations to the plain. Temporal variability of GDDs shows positive temporal changes over the period from 1966 to 2005, confirming the global warming trend. The most significant positive trend is observed for the sum of temperatures during warm season GDD0, indicating that study area has experienced a stretching of the warm period. GDD15 indicating thermal resources of summer season vary little or reveal zero trend.

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