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ABE 381

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Degree Days: Heating, Cooling, and Growing[1]

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Heating and Cooling Degree-Days

People often discuss how hot or cold it is. Usually, it is a question of comfort, and it is simple enough to measure the temperature. But in some industries, it is not enough to know the temperature; it is important to find a way of measuring the impact of the temperature.

For example, if you are in charge of a power company trying to run hundreds of thousands of air conditioners or heaters at the same time, it is a question of whether there will be enough power to run all those homes or enough fuel to run the generators. Understanding ***heating and cooling degree-days*** can take some of the guesswork out of these questions and allow engineers do their jobs more effectively and make good decisions about resources. Heating degree-days (HDD) are normally used by power companies to estimate the amount of energy required for residential or commercial space heating during the cold season. Cooling degree-days (CDD) are used to estimate the amount of air conditioning usage during the warm season.

There are different ways of measuring heating and cooling degree-days. In the simplest way to do this is, use a base temperature of 65 degrees Fahrenheit* for calculating both HDD and CDD. We assume that if the current air temperature is below 65°F, energy will be used for heating, and if it is above 65°F, energy will be needed for air conditioning. Therefore, a day with an average temperature of 55°F will correspond to 10 HDD, and a day with an average temperature of 75°F will correspond to 10 CDD.

* 65°F, which is equivalent to 18.3 degrees Celsius.

Growing Degree Days or Heat Units

Because the growth rate of many organisms is controlled by temperature, growers use a concept related to degree-days called ***growing degree-days*** (GDD), sometimes called ***heat units***. GDD are used to relate plant growth, development, and maturity to air temperature. This idea was introduced almost 300 years ago, in 1730, by the French scientist Rene A. F. de Réaumur (McMaster and Wilhelm, 1997). Since that time, GDD has been used as a means to predict the growth stages of many living things (Cross and

1. This document is ABE 381, one of a series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Published October 2007. To view the full range of publications available from the Florida Cooperative Extension Service, please visit the EDIS website at http://edis.ifas.ufl.edu.
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Zuber, 1972; Gilmore and Rogers, 1958; Klepper et al., 1984; McMaster and Smika, 1988; Russelle et al., 1984).

GDD is based on the idea that the development of a plant will occur only when the temperature exceeds a specific base temperature for a certain number of days. Each type of plant is adapted to grow best over its own specific base temperature, called T_{base}. Even cultivars of the same plant species sometimes have different T_{base}. In fact, the growth of insects can also be related to temperature. Table 1 lists values of T_{base} that researchers have determined for various crops and insects. Growth does not increase constantly with temperature. Just as there is a minimum, or base temperature for growth, there is also a maximum temperature at which growth shuts down.

Table 1. T_{base} for selected crops and insects

Crop	Base Temperature
Corn, sweet corn, sorghum, rice, soybeans, tomato	50 °F
Cotton	60 °F
Peanuts	56 °F
Potato, sunflower	45 °F
Wheat, barley, rye, oats, flaxseed, lettuce, asparagus	40 °F
Insect	**Base Temperature**
Alfalfa weevil	48°F
Black cutworm, European corn borer	50°F
Corn Rootworm	44°F
Green cloverworm	52°F

We count one GDD for every 24-hour period during which the average temperature is one degree greater than T_{base}. If the average temperature is two degrees above T_{base}, then we count two GDD, and so on. It is also important to remember that a Celsius degree-day is not the same as a Fahrenheit degree-day, because Celsius degrees are almost twice as "large" as Fahrenheit degrees. It takes nine Fahrenheit degree-days to make five Celsius degree-days.

GDD provides growers with a more scientific way of understanding how the daily warmth provided by the sun and plant growth are related. Growers can use the number of GDD or heat units required for a given crop and variety to reach maturity to estimate when to be ready for harvest. Researchers have also developed charts relating growth stages of certain crops, such as cotton, to GDD.

As mentioned above, there are different ways of calculating HDD, CDD, and GDD. These are discussed in the special section at the end of this publication.

In this publication, we will discuss how growers can use the AgClimate website to find out how to predict GDD accumulation for the current season, and to review GDD for past seasons. *AgClimate* is a Web-based climate forecast and decision support system (Fraisse et al., 2006) developed by the Southeast Climate Consortium (SECC) in partnership with the Cooperative State Extension Service. The SECC is a coalition of six universities: Florida State University, University of Florida, University of Miami, University of Georgia, Auburn University, and University of Alabama-Huntsville. *AgClimate* offers a wide variety of information, including climate forecasts combined with risk management tools and information for selected crops, forestry, pasture, and livestock.

Those who wish to read a more general introduction to using AgClimate should consult our publication "Climate Forecast and Decision Making in Agriculture," available on the Internet at: http://edis.ifas.ufl.edu/AE267.

Using the AgClimate Website to Forecast GDD Accumulation

Growers often keep track of GDD as the growing season progresses to keep informed about in-season crop development. However, there may be advantages in forecasting GDD accumulation. It can be used to determine when a crop will flower or mature, and help growers in scheduling scouting activities, field application of chemicals or any other activity that needs to be performed during a specific development stage. Follow the following steps to forecast GDD accumulation in AgClimate.org:

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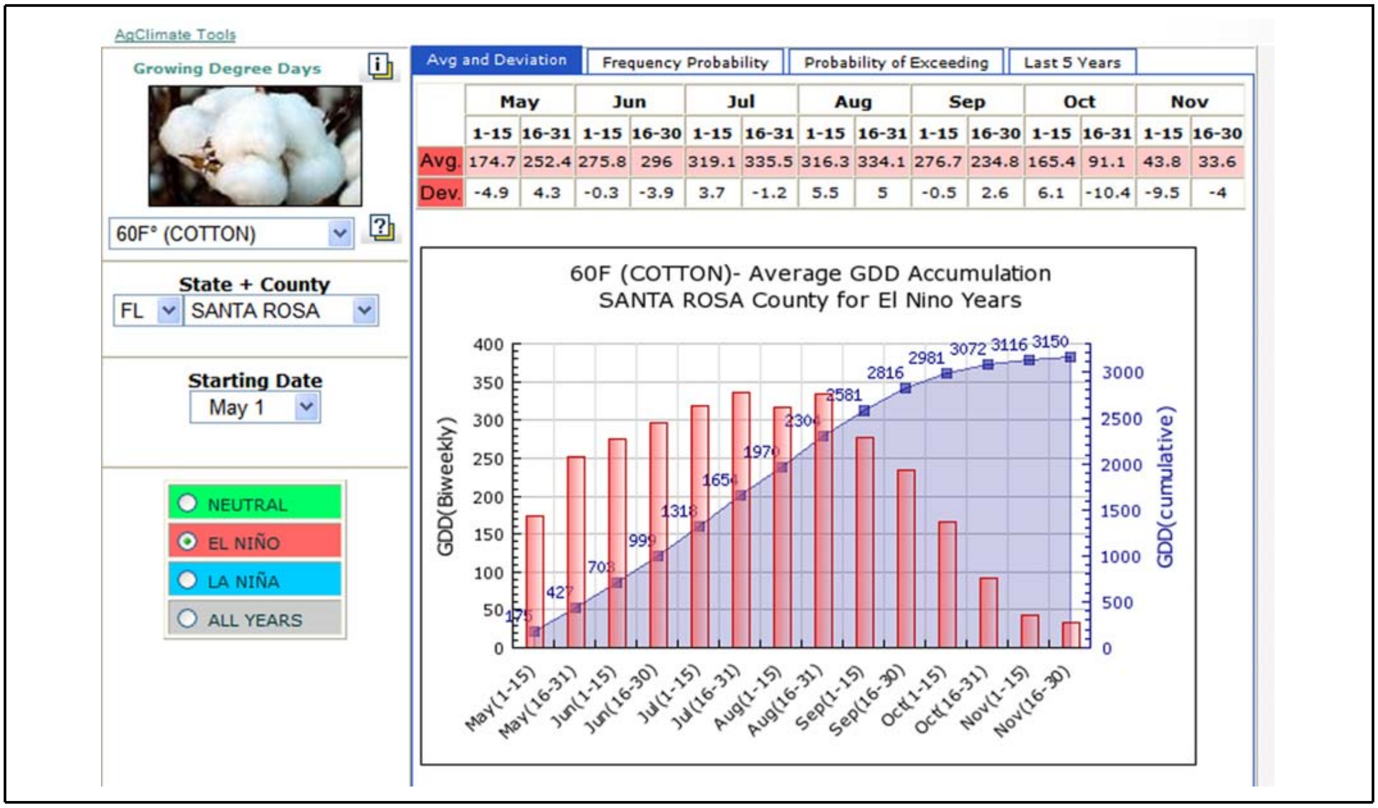

Figure 1. Growing degree-days or heat units accumulation tool (http://www.agclimate.org)

1. Navigate to the Growing Degree days tool

Select “AgClimate Tools” in the main menu and click on “Growing Degree Days” under the Crop Development set of tools.

2. Select a crop

The following base temperatures are available for GDD forecasting: 40°F, 50°F, 56°F, and 60°F. Once a temperature is selected, GDD is calculated and results displayed in the form of tables and graphs.

3. Select a county and state

Users can select any county in the states of Alabama, Florida, or Georgia.

4. Select a starting date

Select a starting date for the forecast from the left-side menu. Default dates are offered for each crop type, but these may not be the best dates for all applications.

5. Select the ENSO phase

The AgClimate website uses the current best forecast of the El Niño Southern Oscillation (ENSO) by default. However, users have the option of evaluating alternate forecasts if they wish by selecting any climate phase of interest from Neutral, El Niño, or La Niña.

Figure 1 shows the expected GDD accumulation over a seven-month period for a cotton crop planted on May 1 in Santa Rosa County, FL, during El Niño years. Users can examine this information in different ways by selecting one of the four tabs located on the top of the results window. Each one is discussed below.

Average and Deviation

This tab provides users with a **forecast of the average expected conditions** based on their selections for base temperature, county, starting date, and ENSO phase. On the chart, the vertical bars show the forecasted number of growing degree-days for two-week intervals over a seven-month period. The

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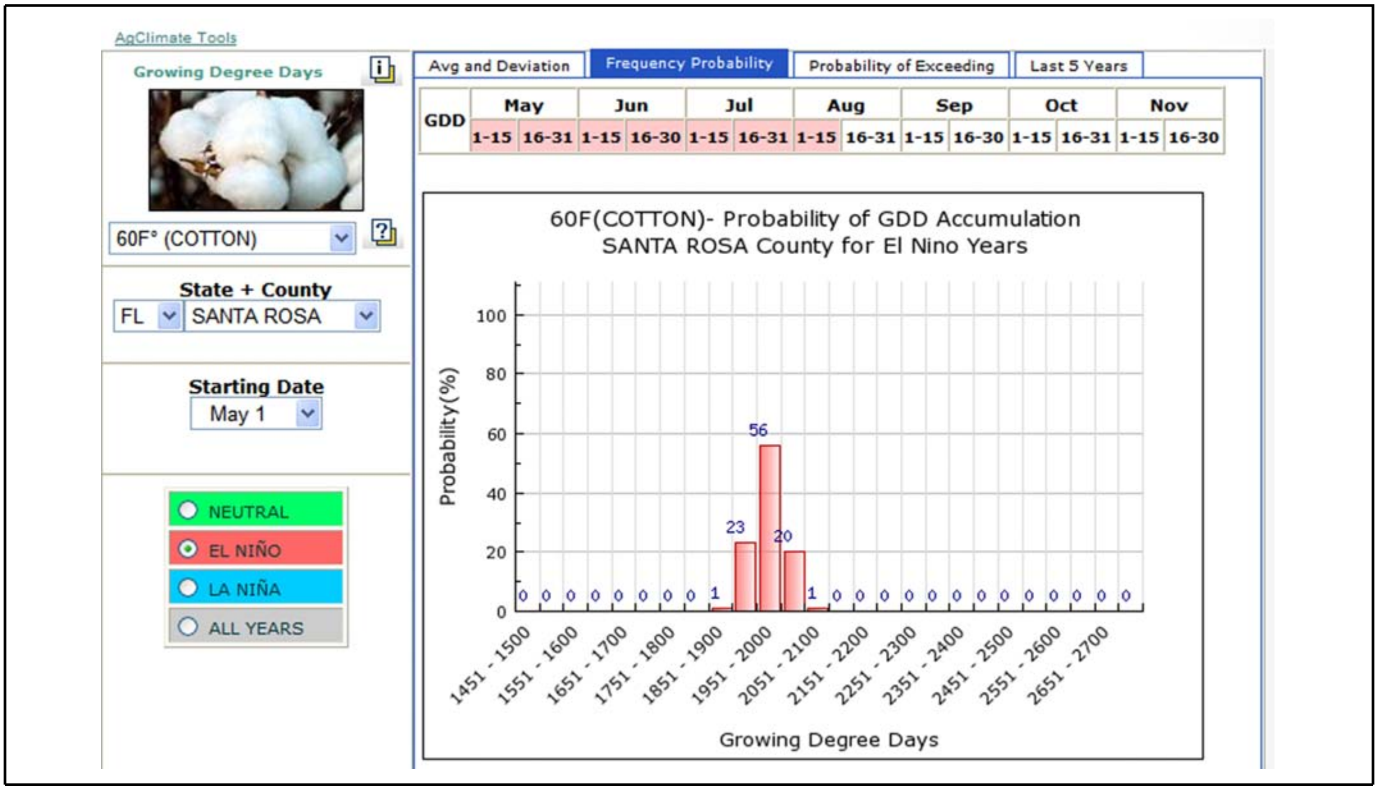

Figure 2. Degree-days or heat units accumulation probability distribution for cotton planted on May 1st through August 14th in Santa Rosa County, during El Niño years.

data table above the chart gives the numerical values that correspond to the bars.

The running total for the season is displayed on the chart as a line with the area below shaded to show what the total accumulation is predicted to be as the season progresses. The blue numbers just above the running total line are the accumulated GDD shown on the graph. Figure 1 shows a total of 3150 DGG accumulated from May 1 through November 30.

Users may toggle between the average values and the deviations by clicking on **"Avg."** or **"Dev."** on the leftmost column of the data table. The data row that corresponds to the graph is highlighted.

The meaning of the deviations display may be less obvious that the averages display. Deviations indicate the amount by which the growing degree-days forecasted for a specific ENSO phase differ from the average growing degree-days for all years. Positive deviations indicate more degree-days for the location, or warmer conditions than normal. Negative deviations indicate fewer degree-days or cooler conditions than normal. Deviations are displayed for two-week intervals throughout the season, and the actual values are shown in the data table. No deviations are displayed when the "All Years" climate forecast is selected because the deviations are calculated as differences from all years.

Frequency Probability

The frequency probability tab provides more detailed information about the GDD forecast. The average we just discussed provides an estimate of GDD accumulation for a series of dates, but each one of those is based on a probability distribution. This probability distribution is shown here both in a table and on a graph. The frequency probability tab allows users to look at this background for each date, so there is a lot more information on this tab.

The user has already selected a start date in the left-side menu, but by clicking on a date in the table shown in figure 2, the user can select an end date as well and look at the probability distribution or GDD accumulation from the start date through the selected end date.

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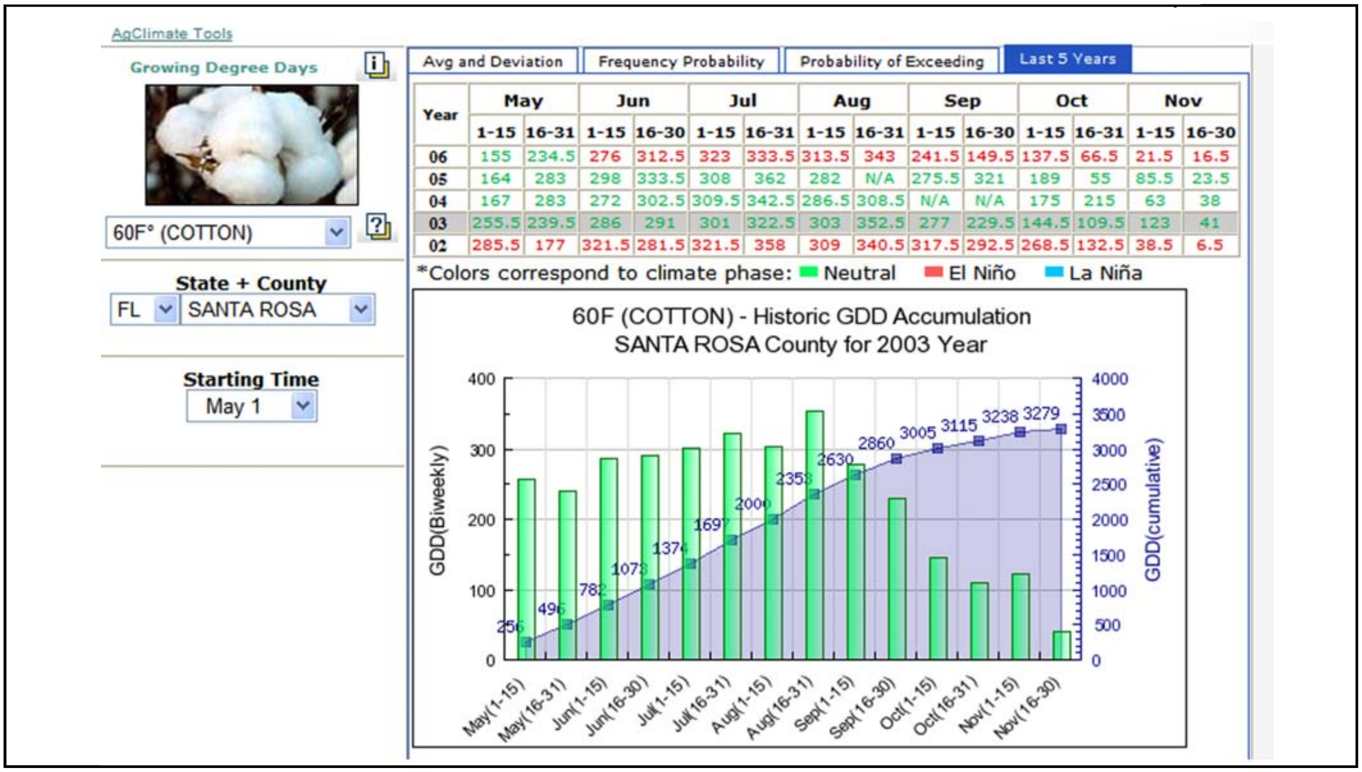

Figure 3. Degree-days or heat units accumulation for cotton planted on May 1st in Santa Rosa County during the 2004 growing season.

Figure 2 shows the GDD accumulation from May 1 through August 15 for a cotton crop in Santa Rosa County during El Niño years. If we looked at the average GDD accumulation by August 15 using the "Avg and Deviation" tab, we would see that 1970 degree-days are expected by this date. On the graph in figure 2, we see the probabilty distribution from which this average is taken. It shows that there is a 23% chance that the GDD accumulation by August 15 will be between 1901 and 1950, a 56% chance of total GDD between 1951 and 2000, and a 20% chance of total GDD betweeen 2001 and 2050.

The probability distribution shows that there is some uncertainty in the average GDD forecast and provides additional information about that uncertainty. The probability distribution indicates that around the average or expected value from the forecast, there is a substantial possibility that the actual number of degree-days will be more or less than the average.

Probability of Exceedance

The probability of exceedance tab also requires that a forecast time period is selected by choosing a start date on the left and then clicking on an end date in the data table at the top of the tool. The selected time period will be highlighted and the appropriate forecast displayed.

In the probability of exceedance tab, the tool provides the probability that the number of degree-days will be greater than indicated thresholds, 150, 300, 450, etc., between the selected start date and the selected end date.

Last 5 Years

The previous tabs we have discussed allow users to look at estimates of future GDD accumulation. The "Last 5 Years" tab allows users to view historical data from recent years. It shows, both in a table and in a graph, the recorded degree-days for two-week periods and the seasonal totals for the most recent five years for the location and crop they have selected.

By clicking on a year in the leftmost column of the table, a user can select the data that will appear on the graph. The selected values will be highlighted in a color that corresponds to the climate phase that occurred during that period. The bars on the graph

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correspond to the numbers highlighted in the table. Seasonal accumulations from the start date through successive two-week periods for seven months are displayed as a line graph with the values displayed within the graph.

Figure 3 shows degree-days accumulation for cotton planted on May 1 in Santa Rosa County, during the 2003 growing season. Note that the color of the bars in the graph changed, indicating neutral conditions from May through November of 2003.

Special Section: Methods for Calculating HDD, CDD, and GDD

Standard or Averaging Method

The simplest form of degree-day calculation is by the standard, also called averaging or rectangle method, which uses simple averaging. Degree-days for a single day using the standard method can be calculated using the following formulae:

$$CDD = \left(\frac{(T_{MAX} + T_{MIN})}{2}\right) - 65$$

$$HDD = 65 - \left(\frac{(T_{MAX} + T_{MIN})}{2}\right)$$

$$GDD = \frac{(T_{Max} + T_{Min})}{2} - T_{base}$$

In these equations, the average or mean temperature is calculated by adding together the high for the day and the low for the day, and then dividing the result by 2 and T_{base} is the minimum developmental threshold temperature. If the average temperature is equal to 65°F then both HDD and CDD are equal to zero. In the case of GDD, if the average temperature is less than or equal to T_{base}, then GDD is equal to zero.

Examples:

- Calculate CDD and HDD given T_{Max} = 87°F and T_{Min} = 63°F

  $T_{Avg.}$ = (87 + 63) / 2 = 75 degrees

  CDD = 75 - 65 = 10 degrees

  HDD = 0 degrees

- Calculate GDD base 60°F given T_{Max} = 78°F and T_{Min} = 52°F

  $T_{Avg.}$ = (78 + 52) / 2 = 65 degrees

  GDD base 60 = 65 - 60 = 5 degrees

- But look what happens given T_{Max} = 70°F and T_{Min} = 42°F

  $T_{Avg.}$ = (70 + 42) / 2 = 56 degrees

  GDD base 60 = 56 - 60 = -4 = 0 degrees

In the last example the maximum temperature was higher than the base of 60°F, but no degree days were accumulated. Because of this the averaging method tends to underestimate early season GDD accumulation.

Modified Growing Degree-Days

The standard method for calculating growing degree-days can be modified to consider the upper developmental threshold (T_{cutoff}) or other T_{cutoff} temperature adjustments. T_{cutoff} is the temperature above which the rate of growth or development begins to decrease or stop, most commonly assumed to be equal to 86°F.

Other literature may refer to the upper developmental threshold as ceiling, the upper cutoff, the upper developmental cutoff, or cutoff. In this case GDD for a single day can be calculated using T_{Max} if $T_{Max} \leq T_{cutoff}$ or by the following formula if $T_{Max} > T_{cutoff}$.

$$GDD = \frac{(T_{Cutoff} + T_{Min})}{2} - T_{base}$$

Sine Curve Method

Although it is simple to calculate the degree-days accumulated based on the average temperature, calculating degree-days for the daily temperature fluctuations that occur in nature is more difficult. Nevertheless, since hourly temperature

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records are not always available several methods are used to estimate degree-days through the use of daily minimum and maximum temperatures. All are approximations of the actual number of degree-days accumulated for a given set of daily temperatures, and therefore do not provide the exact degree-day values. However, most are adequate considering the accuracy of weather instruments used and the precision required for management decisions.

The *sine* or *Baskerville-Emin (BE)* method uses a sine curve, fitted to the maximum and minimum temperature profile, to simulate how the daily temperature would vary. The area under the curve and above the base temperature is then calculated. This gives a better estimate of the heat accumulation, but uses a more complex calculation than the standard method.

Hourly Average Integration

The *Hourly Average Integration* methods are usually implemented on automated dataloggers. They use average hourly temperatures to calculate a hourly heat accumulation. These are then summed up over the day to give a daily GDD. Some systems use 15-minute and even 5-minute average temperatures.

A Note about How AgClimate Calculates GDD

Since long-term weather records used for estimating GDD accumulation do not include hourly temperature, the standard or averaging method that takes into consideration daily average temperature based on the minimum and maximum temperatures is used in *AgClimate*. Upper threshold or cutoff temperatures are not considered.

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