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Verifying Corn Growing Degree Day CFS Forecasts

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ABSTRACT

The Climate Forecast System (CFS) issues long term forecasts that can help make important decisions in regards to planting, applying herbicides, and harvesting. We hypothesized that the CFS forecasts thermal times are lower than observations because of a warming climate in Iowa. Observed maximum and minimum temperature data was obtained from NWS COOP stations. Thermal time was calculated for both the CFS forecasts and observations, and them were compared. For the three year period looked in this study, the statewide average for the CFS was 390 GDD, 15% less than observations. On average for August, the CFS was within 1% of observations. However, the CFS forecasted 115 GDD plus for the months of April and September. Studies have suggested that the climate in the Midwest region have been warming during the spring and autumn months, but remaining the same during the summer months; and this would agree with the results in this study.

1. Introduction

Accurate long-term forecasts would help farmers make better decisions to know when to plant crops and to maximize their yield. The Midwestern Regional Climate Center (MRCC) has valuable resources to help farmers in Iowa to make important decisions. One such tool is the Corn Growing Degree Day support decision tool. This tool shows the total thermal time accumulated on the
current date, projected thermal time for the rest of the growing season, last spring freeze dates and first fall freeze dates of the past 36 years (1981-2016), and then compares to the 30 year (1981-2010) climatological average. The support decision tool also shows when crops will reach the silking stage and the black layer. The MRCC states that this tool will help farmers assess climate risk (early/late freeze events), activity planning, and marketing.

Corn has a various number growth stages that farmers can use to assess how well the corn is coming along and to make timely applications of herbicides and fungicides, and when it is about time for harvest. Plants grow at faster rates in warmer conditions (until it gets too warm). Thermal time is the accumulation of heat above a specific base temperature. The base temperature is the minimum temperature at which plant development starts. One use of thermal time is for growing degree day (GDD). A growing degree day is a weather based indicator that is used to predict certain stages of crop development. According to Dekalb (2015), the very first stage is VE which is crop emergence which occurs around 100 growing degree days (GDD, units are in °F.day for this study), sometimes called growing degree units (GDU). The next stages are when the leaves fully emerge, and the leaf collar is visible. V1 is for the first full leaf emergence, V2 for the second full leaf emergence and so on. VT is when the tassel begins, and shortly after the tassel stage silking occurs (stage R1). The R stages describe the development of the kernel with R6 being the final stage called the black layer stage. The black layer develops when a layer of cells turns black where the kernel is attached to the cob. Nutrient transfer cells collapse preventing movement of sugars into the kernel. The black layer means that grain fill is complete, and the corn has reached maturity. According to Carter (2017), the black layer stage is the indicator of when the crop reaches physiological maturity. It takes around 2600-2700 GDDs for the crop to reach maturity, but the exact thermal time for crop maturity varies depending on the cultivar used.

Farmers today and more so in the future face having to produce more yield on less land. One way farmers have been able to produce more yield per stalk of corn is by changing the corn phenology, adopting a longer season cultivar. A study done by Sacks and Kucharik (2011) shows that the period in between corn planting to full maturity was about 12 days longer in the year 2005 than in 1980 due to the longer season cultivar. Longer season cultivars require more thermal time for the
corn to reach full maturity because more time goes into grain fill in the stalk of corn. The number of ears per stalk of corn stays the same, but the size of each ear increases and thus an increase with yield per acre. It was also stated that the corn planting date in 2015 generally was ten days earlier than in the year 1980. With having a longer growing season, farmers have a choice of corn planting earlier in the growing season or have their corn reach full maturity later in the growing season.

According to Edwards (2012), the state of Iowa has specific dates to when farmers can plant corn to be eligible for crop insurance. The earliest planting date for corn in the state of Iowa is April 11th and the final planting date is May 31st. Farmers planting before the earliest planting date will not receive replanting payments if something were to happen. If planted after the final planting date, farmers would receive a reduced guarantee. The crop insurance dates are determined by the average growing season throughout Iowa with the growing season defined as the time between the last spring freeze and the first fall freeze.

The CFS forecasts are issued on the first of each month (typically). A study done by Dai et. al (2015) showed warming climate trends in the Midwest from 1980 to 2013. Their results showed that the rate of warming during the growing season was around 0.15°C per decade for the Midwest region. Early season maximum temperatures for southeast Iowa increased while northwest Iowa either stayed steady or decreased. Early season minimum trends across Iowa varied but overall were slightly increasing. Late season maximum temperature trends across Iowa greatly increased. Late season minimum temperature trends either stayed steady or fell in southeast Iowa while northwest Iowa increased greatly. Since there is an overall warming trend in Iowa, climate based forecasts will then forecast cooler than what was observed.

This study focuses on the accuracy of the CFS forecast and looks for any biases or trends that it may have. With a warming trend in recent years in Iowa, would that lead to corn GDD forecasts (based off the climatological average) to forecast colder than what verifies? The hypothesis is that the CFS forecasts are cold biased.

2. Data and Methods
The purpose for this study is to compare CFS forecasts thermal time with observed values to test the accuracy of the forecast in the state of Iowa.
Selected Stations

One station was selected out of each crop reporting district in Iowa making a total of nine stations.

Table 1: List of stations used for this study

<table>
<thead>
<tr>
<th>District</th>
<th>Town (metar code)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Le Mars (KLRJ)</td>
</tr>
<tr>
<td>2</td>
<td>Forest City (KFXY)</td>
</tr>
<tr>
<td>3</td>
<td>Decorah (KDEH)</td>
</tr>
<tr>
<td>4</td>
<td>Denison (KDNS)</td>
</tr>
<tr>
<td>5</td>
<td>Ames (KAMW)</td>
</tr>
<tr>
<td>6</td>
<td>Maquoketa (KOQW)</td>
</tr>
<tr>
<td>7</td>
<td>Red Oak (KRDK)</td>
</tr>
<tr>
<td>8</td>
<td>Chariton (KCNC)</td>
</tr>
<tr>
<td>9</td>
<td>Mount Pleasant (KMPZ)</td>
</tr>
</tbody>
</table>

Each location was picked to best represent each of the nine crop reporting districts in Iowa. Due to concerns with microclimates, major cities and cities near or in river valleys were not picked. Out of the remaining cities that had observed weather data, the city was selected based on either how close they were to the center point of the district or personal interest.

b.) Climate Forecast System (CFS)

The main purpose for this study is to test the accuracy of the CFS forecasts. According to NOAA, the CFS is a model that represents the atmosphere, oceans, and land interactions (NOAA, 2017). The CFS bridges together climate and weather forecasting. The archived CFS forecasts came from Larry...
Biehl of Purdue University. The data was available from February 2015 through September of 2017. These 90 day forecasts are issued on the first of each month. The growing season in Iowa starts in April and lasts into October, so forecasts outside this timeframe were discarded. To keep things consistent, October of 2015 and 2016 were discarded as well since October 2017 was not available at the time.

The CFS forecast came in .tif file format, a gridded picture of North America. The forecast pixel resolution size is 38 by 76 (row:column). Pixel 1:1 corresponds to a latitude of 56.69° north and longitude of 131.72° west. It was determined that each pixel south and east approximated to 1° in latitude and longitude.

c.) NWS COOP

The National Weather Service (NWS) Cooperative Observer Program (COOP) is a network of thousands of weather stations across the United States that is run by volunteers. NOAA states that the NWS COOP generally report just temperature and precipitation values, but some measure other quantities (2017). The NWS COOP stations are much more numerous than other kinds of reporting stations (like AWOS or ASOS).

Observed thermal time only depends on maximum and minimum temperatures. The maximum and minimum data received from the Iowa Environmental Mesonet came from the NWS COOP. Most of the data used for this study from NWS COOP was already quality controlled, up to June 1st, 2017. However, none of the sites had missing data for the dates after June 1st, 2017.

The max and min data times used was from April 1st through September 30th of the years of 2015, 2016, and 2017, corresponding to the CFS forecast.

d.) Procedure and Analysis

Total accumulated thermal time (denoted as \( \Theta \), seen in equation 1) is the summation of all GDD in a growing season.

\[
1.) \quad \Theta = \sum GDD = \sum \left[ \left( \frac{T_{\text{max}} + T_{\text{min}}}{2} \right) - T_{\text{base}} \right]
\]

Corn has two thresholds for calculating GDD. Temperatures must get above the base temperature before corn development can occur. Base temperature is defined as the minimum temperature that development will occur and for corn, the base temperature is 50°F. If the max temperature is above 86°F, then \( T_{\text{max}} \) is set to 86°F since corn does not grow any faster. Likewise, if the min temperature is below the base temperature, then \( T_{\text{min}} \) equals \( T_{\text{base}} \).
After all the thermal times for both the NWS COOP data and the CFS forecasts were calculated, then they were compared to each other. The average thermal time was calculated by averaging over the 3 year period.

\[ \text{2.) } \% \text{ error} = 100\% \left( \frac{\text{OBS} - \text{CFS}}{\text{CFS}} \right) \]

Percent error will determine how well the CFS forecast did in comparison to observations. For equation 2, OBS stands for the averaged observed values while CFS is the CFS forecast values. 0% error means that the CFS forecast had no error. Positive percent error values mean the CFS forecast went lower than observations while negative values mean the CFS forecasted higher than observations.

3. Results

All nine locations were analyzed to determine average observed thermal time, average forecasted thermal time, and average percent error for each month, for the six month period. It was also determined average thermal time per day and how many times the CFS forecast forecasted lower than observed.

![State Average by month](image)

Figure 2: Three year state average by month where GDD off is the difference of observed total thermal time to forecasted thermal time. Positive values mean observed was higher than forecasted.
a.) Statewide Comparisons

Using the averages for all nine stations, the statewide averages were determined.

The totaled state average percent error for the three years was 15.4% meaning that the observed thermal time from April 1<sup>st</sup> through September 30<sup>th</sup> was 15.4% higher than forecasted by 390 GDD. To give another perspective, the average observed thermal time per day for the state was around 16 GDD while the forecast thermal time thermal time per day was 14 GDD. If corn needed 2600 GDD’s to reach full maturity, then it would be about 22 days sooner than when the CFS had forecasted. If corn was planted on April 1<sup>st</sup>, the CFS forecast would have corn reach maturity on September 29<sup>th</sup>, but the corn would actually be mature by September 7<sup>th</sup>.

The CFS forecast was around observations for July and August while it performed well below observations for April and September (See Figure 2). The CFS forecast always forecasted lower at all locations in the months of April and September while forecast were lower about half the time for July and August (see Figure 4).

![Figure 3: Percent occurrence of when the CFS forecasted lower than observations.](image)

Out of 162 months (18 months for each location), 31 times did the CFS have a higher thermal time than observations. 19% of the forecasts going above observations clearly indicates that the CFS trends to forecast lower thermal times. Looking at Figure 3, around 50% occurrence of the forecast going above observations is ideal. Outside of August and July, the CFS forecast almost always under-performed. For the state, it appeared that the CFS did better in southwest Iowa than in northeast Iowa (see Figure 4). However, that is not a clear trend and more locations would need to be added to establish a clear northeast to southwest trend of accuracy.
b.) Denison’s Results

Out of the nine locations, Denison was where the CFS forecast was closest to observations. The average growing season thermal time observed for Denison was 2900 GDD while the CFS forecast had 2750 GDD; a percent error of 5.5%. For the six month study, the average thermal time per day was 16 GDD whereas the CFS forecast had 15 GDD. With defining full maturity reached at 2600 GDD, the CFS forecast had corn reaching maturity seven days later than what occurred. If corn was planted on April 1st, then the CFS forecast would have corn reach maturity by September 19th, whereas the corn would be mature by September 12th.

Denison is a more difficult location since it resides in western Iowa where there are a lot of hills (Loess Hills area). Temperatures can have some variation in hilly terrain, especially on calm nights. With that, thermal times will likely be different for corn on top of a hill as opposed to corn in a valley.

(see appendix)

c.) Chariton’s Results

The average thermal time for Chariton was 3040 GDD whereas the forecasted thermal time was 2860 GDD, giving a percent error
of 6.3%. For the six month study, the average thermal time per day was 17 GDD where the CFS had 16 GDD. Using 2600 GDD to mark when full maturity occurs, the CFS would have had corn reach full maturity six days later than when the corn actually hit maturity. If corn was planted on April 1st, then it would reach maturity by September 6th, whereas the CFS forecasted to reach maturity by September 12th.

Chariton has a few differences from Denison in that generally there are more trees and less hills in Chariton. According to U.S. Climate Data (2017), Denison and Chariton have very similar climates for the study period (April through September) with the only major difference is that Chariton receives more rain. With a similar climate and if the southwest to northeast accuracy trend theory is true (see Figure 3), then one would expect to see similar results for Chariton.

(See Appendix)

d.) Decorah’s Results

The average thermal time for Decorah was 2920 GDD whereas the CFS forecasted 2220 GDD, giving a percent error of 31.7%. For the six months, the average thermal time per day was 16 GDD while the forecasted was 12 GDD. Using 2600 GDD for the maturity mark, corn would reach maturity on September 11th if planted on April 1st. The CFS forecast would indicate that farmers would need to use a colder season cultivar so that the corn could reach maturity before the end of the growing season. The CFS was at 2220 GDD by September 30th, 380 GDD short of the 2600 GDD mark.

Decorah is another tricky place because, it is very hilly. According to U.S. Climate Data (2017), Decorah’s climate is a little cooler than Denison (within the six months of this study). The average highs for each month in Decorah is within 1°F from Denison, but the average lows for each month is 4-5°F colder than Denison’s. Decorah had the biggest percent difference of observed verse forecasted thermal times. (See Appendix)

4. Conclusion and Discussion

This study focused on testing to see how accurate the CFS forecasts were. There was a clear trend that the CFS forecast were forecasting lower thermal times than what was observed for the three years of this study. The CFS forecasted 5% to 32% below observed thermal times across Iowa for the growing season in the years of 2015, 2016, and 2017. Examining the month by month analysis, the CFS forecasts did well during the summer months (especially August), but forecasted 120 to 140 GDD lower for April
and September (the transition seasons). With the years and locations examined for this study, the CFS forecast never forecasted higher thermal times than observed thermal times for the months of April and September. With these results, the question now is why did the CFS forecasts do so well for the summer months (July and August) and perform so poorly for the transitions seasons (April and September)?

The CFS forecast is a climate based forecast so if the climate has changed in the past few decades, then that would affect the accuracy of the forecast. The standard climatology currently used is a 30 year average from 1980 through 2010. This study looks at the years of 2015, 2016, and 2017, so if there is a clear warming trend, the CFS forecast would not account for it. A warming trend would mean that the past few years (i.e., the years of this study), would be above average and that would lead to the CFS forecasts underperforming thermal time. With the results showing the CFS forecast performing well for the summer months and performing poor for the transition season, that would infer that the summer months have stayed steady, but the transition seasons having a warming trend. The study done by Dai et. al (2015) shows that there has been a warming trend in Iowa for early spring and fall.

With a cold bias, is there any benefit from a forecast that under-forecasts? There is more than just thermal time that affects when a corn reaches maturity and the quality of the yield. The ideal temperature for corn development is 86°F. Anything higher and the corn does not grow at a faster rate. Temperature too warm may actually end up hurting corn development. A study done by Kucharik and Serbin (2008) showed that a warmer than average summer may hinder yields. Their study suggested that yields were reduced by 10% to 20% for every two degrees Fahrenheit warmer in the summer months. To have the greatest value of GDD accumulated per day, the temperature needs to be at or above 86°F for the period. Looking at temperatures alone, warmer conditions would lead to higher thermal time accumulation, but corn can succumb to heat stress. If corn does not receive enough water in warmer conditions, the corn will not be able to support a healthy plant temperature and cannot photosynthesize enough to produce the yield the farmers want. In the study by Kucharik and Serbin (2008), modest increases of rainfall would lead to 5-10% higher yield which would help off-set the loss of yield due to heat stress.
c) Future Work

Looking at more sites in each crop reporting district in Iowa would help see clearer trends with the performance of the CFS forecast. Expanding to three test sites per crop reporting district in Iowa would help establish a better average for each crop reporting and a better state average. Since each pixel does not exactly match up with each crop reporting district in Iowa, there would be a need to determine which pixel each test location fell in. For each of the three test sites, it would be ideal to have one in a city, one in a field, and one in a river valley. The three different kinds of terrain would help give a range of possible thermal times in each crop reporting district.

Another aspect worth considering is how the climate has changed in Iowa. Since climatology is based off the 30 year average, then calculating observed thermal time for each year from 1981 through 2010 would help decide on if a warming trend has developed, and how significant. The main thing to look at would be to see on how much a warming trend has developed during April and September.

5. Acknowledgements

I would like to thank Dr. Brian Hornbuckle for his guidance, Dennis Todey for giving me this topic and help with understanding the context of the CFS files, Daryl Herzmann for his help with reading the CFS files into Matlab, and Victoria Walker with her help with writing out Matlab code.

6. References


Appendix
Three year average of each city for study, starting from district 1.