

PROJECTING FUTURE CHANGE IN GROWING DEGREE DAYS OF WINTER WHEAT

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ABSTRACT

Southwest Oklahoma is one of the most productive regions in the Great Plains where winter wheat is produced. To assess the effect of climate change on the growing degree days (GDD) available for winter wheat production, we selected from the CMIP5 archive, two of the best performing Global Climate Models (GCMs) for the region (MIROC5 and CCSM4) to project the future change in GDD under the Representative Concentration Pathway (RCP) 8.5—a “business as usual” future trajectory for greenhouse gas concentrations. Two quantile mapping downscaling methods were applied to both GCMs to obtain local scale projections. The downscaled outputs were applied to a GDD formula to show the GDD changes between the historical period (1961–2004) and the future period (2006–2098) in terms of mean differences. The results show that at the end of the 2098 growing season, the increase in GDD is expected to be between -2.0 and 6. Also, depending on the GCM used, Southwest Oklahoma is expected to see an increase in future GDD under the CCSM4 GCM and a mix of increase, no change and decrease under the MIROC5 GCM.

1. INTRODUCTION

Without cultivation of crops, modern civilizations would cease to exist. Farmers today each have to feed 155 people, which is almost 6 times as many people than 50 years ago (USDA). The Environmental Protection Agency (EPA) states that less than 1% of the United States’ population farms as an occupation (2013). The rest of the population heavily relies on these people to provide them with food. Not only is wheat grown and consumed in the U.S., it is also exported. More specifically, 40% of the wheat grown in the Great Plains is exported (McKlusky 2011).

Winter wheat has become one of the most prevalent crops grown in the Red River Basin area of Southwest Oklahoma (**Figure 1**). This region has one of the globe’s highest risk of heat stress by 2070 (IPCC 2014b). Winter wheat can serve as a forage, grain or dual-purpose crop. Its many uses include grazing (animals), pastas, bread,

pastries and many other consumed products. For humans, grains, like winter wheat, are a large part of the diet. According to the Intergovernmental Panel on Climate Change (IPCC 2014b), since 1999, a marked increase in crop loss attributed to climate-related events such as drought, extreme heat and storms have been observed across North America with significant negative economic effects. Therefore, examining how the changing climate affects agriculture, food supply and people’s lives is important.

Growing Degree Days (GDD) is a popular term and measurement used in the field of agriculture. It is used to relate plant growth, development, and maturity (Parthasarathi et al. 2013). A growing degree day is a measurement of the accumulation of heat above a specific base temperature which in the case of winter wheat is 0 C (273 K). The specific base temperature is winter wheat’s lower threshold temperature. This is then accumulated over the crops’ growth season. Days that are warmer-than-normal increase the plant growth rapidly and vice versa (Miller et al. 2001). Days at or below the base temperature contribute no GDD. This measurement plays an important role in plant development of plants because each stage of development requires a specific amount of accumulated GDD. Parthasarathi et al. (2013)

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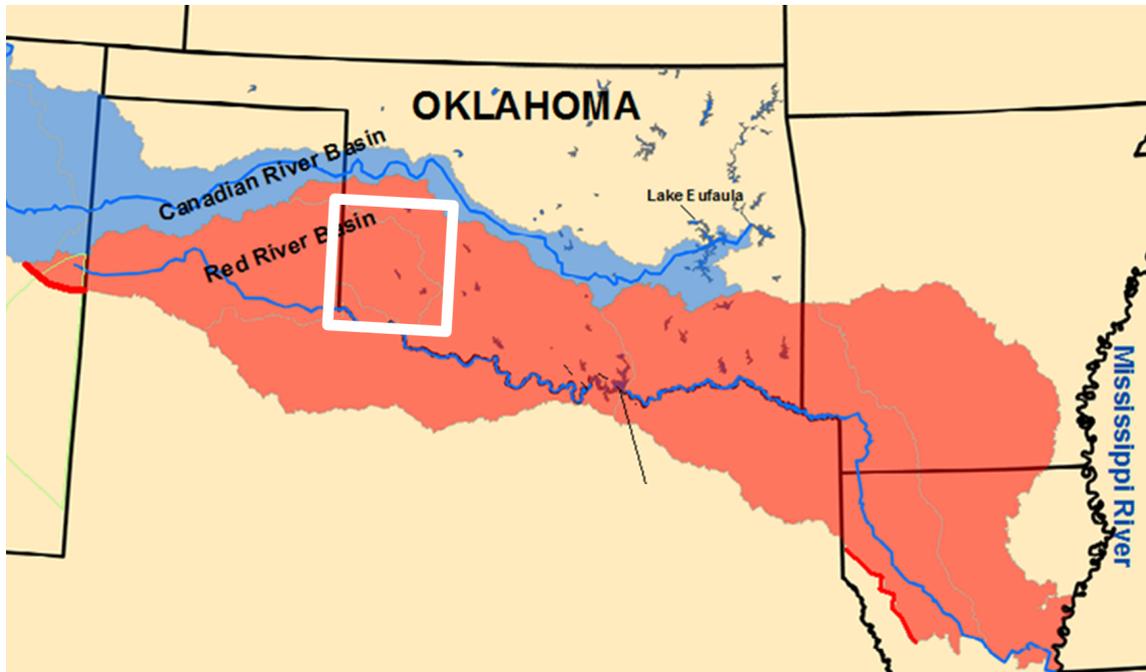


Fig. 1 Red River Basin. The white square marks the boundaries of the study.

points out “the amount of heat required to complete a given organism’s development does not vary; the combination of temperature (between thresholds) and time will always be the same.” The quality of wheat can be affected by temperature increases. Climate scientists use Global Climate Models (GCMs) to project the climate using a 3D grid over the globe. Currently, they provide a horizontal resolution of 100–350 km. GCMs represent physical processes in the atmosphere, ocean, & land surface. However, GCMs are limited by their coarse spatial resolution and the need to use parameterizations (known properties of physical processes must be averaged over the larger scale).

A solution to the GCMs’ spatial resolution shortcoming is downscaling. Downscaling is a procedure in which coarse scale GCM datasets are refined into local scale datasets. There are two types of downscaling approaches, dynamical and statistical, both are widely used in impact-related research work (Li et al. 2010), and have been conducted at various spatial and temporal scales. In the statistical approach (used in this manuscript), large-scale climate features from the GCMs (predictors) are statistically related to local scale climate variables (predictands).

Branzuela (2015) explains downscaling as a two-step process. The first step is the

development of statistical relationships by relating local climate variables to large-scale predictors. The second step is the application of these relationships to the output of GCM experiments to simulate local climate characteristics of the future. The limitation of this process is that it assumes that the statistic relationships in the past are applied to the future. These relationships are likely to change. It is mentioned in the first book of the 2014 IPCC Report that many studies have been conducted at various scales evaluating the impacts on agriculture and its effects on communities. However, there are not many articles written on the Red River of the South Basin (RRB – **Figure 1**). Most of them focus on Red River Basin of the North and many others focus on other river systems. However, Dr. Carlos F. Gaitán Ospina, Dr. Derek Rosendahl and other scientists are currently conducting a project on the RRB.

2. DATA AND METHODS

Statistically downscaled data of daily maximum and daily minimum temperature (in Kelvin) over the RRB was provided by the south Central Climate Science Center. The local scale projections were derived from two GCMs: the

Community Climate System Model 4 (CCSM4, UCAR 2014) and the Model for Interdisciplinary Research on Climate 5 (MIROC5, Watanabe et al. 2010). These two models were chosen because they performed appropriately over the South Central U.S. during the historical period (Sheffield et al. 2013). The future projections used, assume the Representative Concentration Pathway (RCP) 8.5—a “business as usual” future trajectory for greenhouse gas concentrations, whereby radiative forcing in the atmosphere increases by 8.5 watts/m² by the end of the century. The downscaling time-series were obtained using the Cumulative Density Function Transfer (CDFt – Michelangeli et al. 2009) and Equidistant Quantile Mapping (EDQM – Li et al. 2010). The GDDs were calculated for the 1961–2004 and 2006–2098 periods, instead of the historical (1961–2005) and future (2006–2099) periods. The reason for using these year ranges is because the last full growing season of each period cannot be accounted for because each growing season overlaps onto the next year.

This project focuses on a subset of the Red River region located at Southwest Oklahoma (**Figure 1**) where most of the winter wheat in Oklahoma is grown. The coordinates for this domain are 34.05 to 35.95N and -99.95 to -98.05W. The region covers a 20 x 20 grid with data every 1/10 of a degree to provide a more detailed analysis. However, winter wheat is not grown in every area of the domain. The specific locations within the domain where winter wheat is grown can vary from year-to-year.

The Food and Agriculture Organization (FAO) shows two different ranges for the number of days in the growing season of winter wheat. The first source, by Steduto et al. (2013), shows a range from 180–250 days, and the second source, from the organization’s web page shows a range from 180–300 days (FAO 2015).

A guide by the United States Department of Agriculture (USDA; 1997) was used to decide a designated growing season for this research. According to it, the Oklahoma winter wheat planting period is from September 3–November 2. The most active period for planting is September 22–October 12.

The median date of the general planting and active planting periods is June 20, which was used as the planting date for the project. The general harvesting period is from June 5–July 5. The most active period for harvesting is from June 15–June 25. Using a growing season from

October 2–July 20 results in a growing season of 261 days.

The GCMs were also chosen for this project because the calendar used is the Julian calendar, and it is a no leap calendar. The days of the year are identified as 1–365 per year and accumulate over the time period. The downscaled data from the CCSM4 and MIROC5 GCMs use this no-leap year calendar. The data obtained from the ongoing project goes from days 1–15,695. As mentioned before though, only the days of the growing season are used in this project. These were identified for all of the periods using the following formula:

$$t = 261 + 365 * (i - 1)$$

Where t is the time, 261 is the length of the growing season, 365 is the number of days in a year, (i-1) is the year minus 1.

The formula used for calculating the number of GDDs was:

$$GDD = ((TMIN + TMAX)/2) - 273$$

This calculates the daily amount of GDD. This is then applied to everyday of the growing season of every period evaluated, and accumulated daily throughout the growing season.

4. RESULTS & ANALYSIS

For **Figures 2a-5b**, the use of a range of 22–31 GDD was used in the legend to accommodate the results of the historical and future periods. The X-axis was assigned “Longitude” and the Y-axis was assigned “Latitude”

4.1 Historical Period

This historical period consists of the growing seasons from 1961–2004. When applying the analysis to the downscaled output from the CCSM4 model, the range of GDD in the domain is from 23–27. As seen in **Figure 2a and 2b**, there is not a substantial difference between the outputs, and for each downscaling method the outputs look very similar. Both results are obtained using the CCSM4 GCM. **Figure 2a** was the result of applying the CDFt downscaling method, and **Figure 2b** was the result of applying the EDQM downscaling method. There was not a definitive

Historical Period (1961–2004) Mean GDD of SW OK

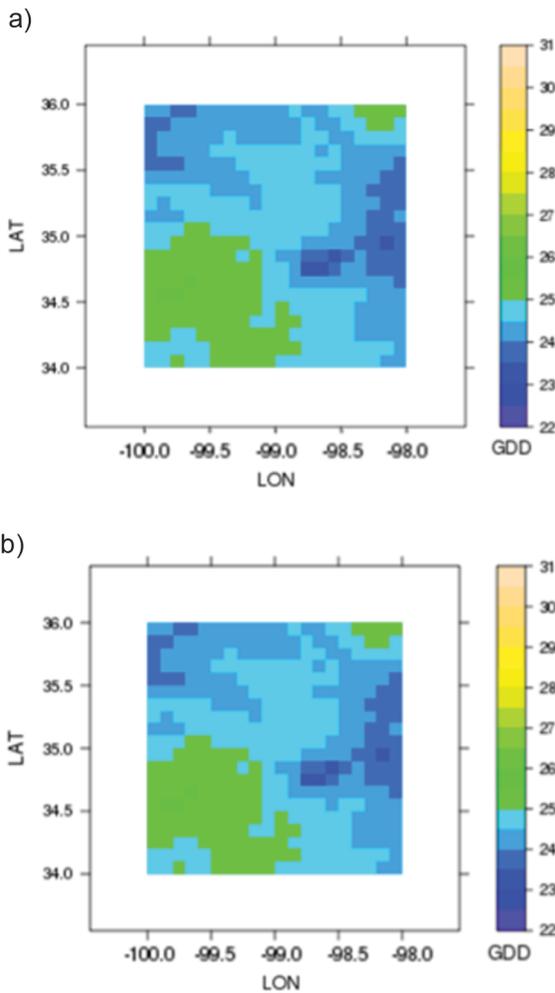


Fig. 2. (a) This plot demonstrates the results of applying the CDFt downscaling method to the CCSM4 GCM. (b) This plot demonstrates the results of applying the EDQM downscaling method to the same GCM in (a).

pattern seen in these outputs, but the Southwest of the domain is in the Northern part the range (25.5–27 GDD) identified for this GCM. The East and Northwest of the domain were in the lower part of the range (23–25 GDD).

When applying the analysis to MIROC5, the range of GDD results in a range of 22–28. As seen in **Figure 3a and 3b**, the outputs of each downscaling method look very similar. **Figure 3a** was the result of applying the CDFt downscaling and **Figure 3b** was the result of applying the EDQM downscaling method. There is not a

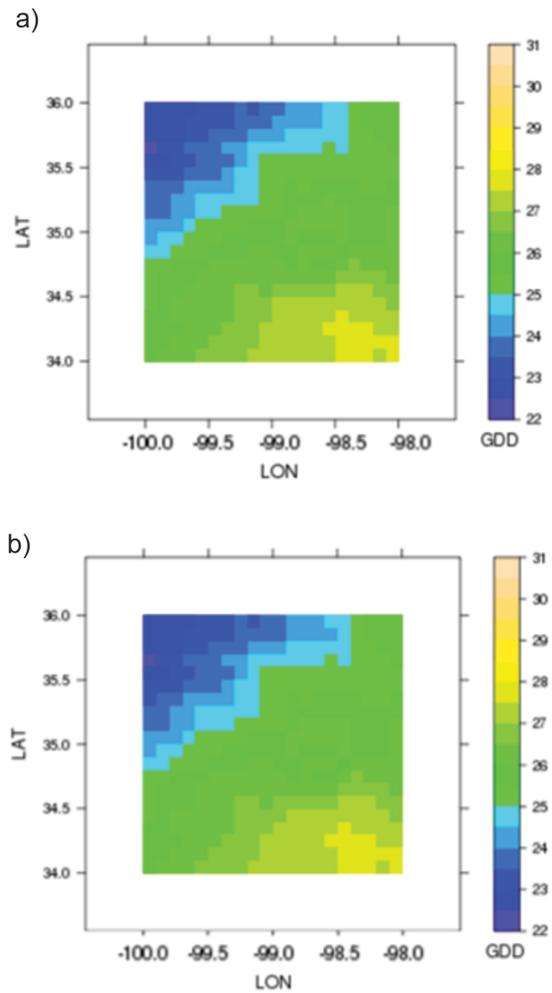


Fig. 3. (a) These are the results of applying the CDFt downscaling method to the MIROC5 GCM. (b) These are the results of using the same GCM in (a) and CDFt downscaling method.

substantial difference between the outputs. The pattern seen in this output is a gradient which increases from the Northwest part of the domain to the Southeast part of the domain (22–28 GDD, respectively).

Projections for the two downscaling techniques using the same GCM may not differ, but the projections from the two downscaled GCMs differ substantially from each other. They both are within a very similar range, but they show completely different patterns in their domains as seen in **Figures 2a–3b**. MIROC5 projections

shows higher GDD throughout most of its domain and there is a gradient increasing from the Northwest part of the domain to the Southeast part of the domain.

4.2 Future Period

Everything that was done in the historical period was applied here except for the time period. Instead, this period consists of the growing seasons from 2006 to 2098.

When applying the analysis to CCSM4, the range of GDD results in the domain has a range of approximately 28–31. Using the EDQM method, there is one grid that is in the 27.5 GDD, but it is not a significant difference since it is just one grid box. This can be seen by looking closely at **Figure 4a** and **4b**. The two outputs from each downscaling method look very similar. However, there was a slight gradient in both. The gradient increases from the Northeast to the Southwest part of the domain, 28–31, respectively.

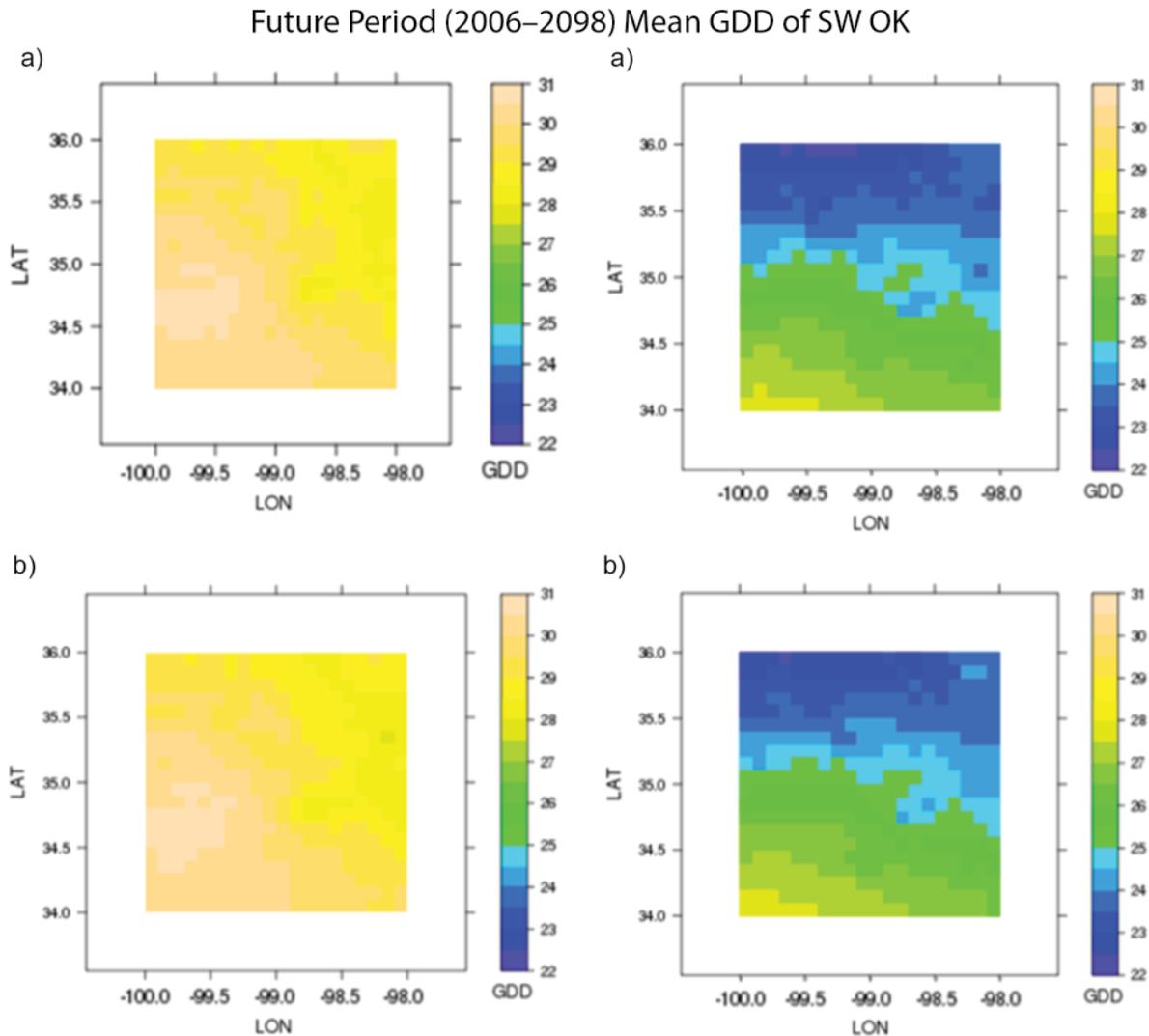


Fig. 4. (a) This plot demonstrates the results of applying the CDFt downscaling method to the CCSM4 GCM. (b) This plot demonstrates the results of applying the EDQM downscaling method to the same GCM in (a)

Fig. 5. (a) These are the results of applying the CDFt downscaling method to the MIROC5 GCM. (b) These are the results of using the same GCM in Fig. 5a and CDFt downscaling method.

Mean GDD Difference between Historical and Future Period of SW OK
(2006–2098) and (1961–2004)

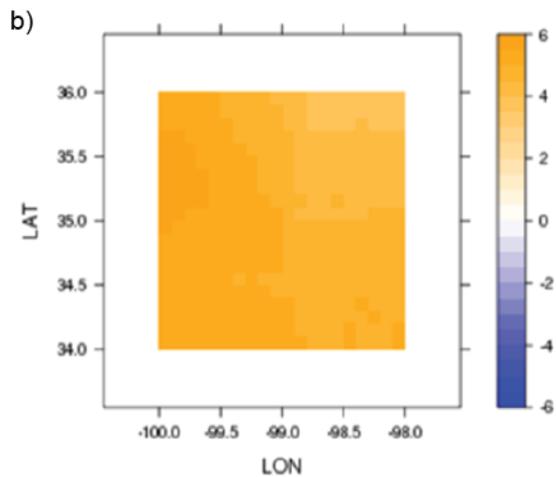
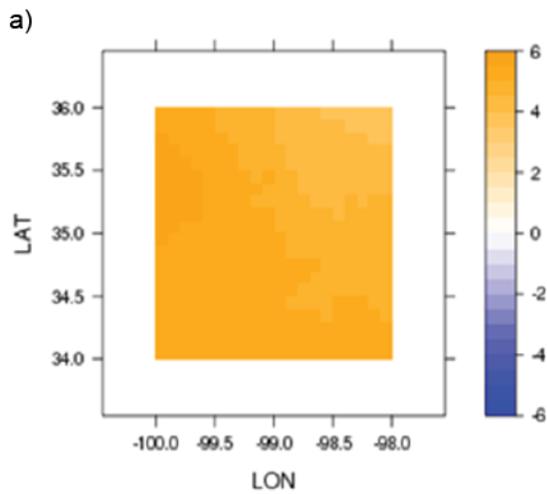


Fig. 6. (a) This plot demonstrates the results of applying the CDFt downscaling method to the CCSM4 GCM. (b) This plot demonstrates the results of applying the EDQM downscaling method to the same GCM in (a).

When applying the analysis to MIROC5, the range of GDD results in a range of 22–28.5. The outputs of each downscaling method look very similar as well as seen in **Figure 5a** and **5b**. Between these outputs, no significant difference exists because they both have the same range and very similar distribution of GDD. The pattern seen in this output is a gradient which increases from the Northern part of the domain to the Southern part of the domain, 22–28.5, respectively.

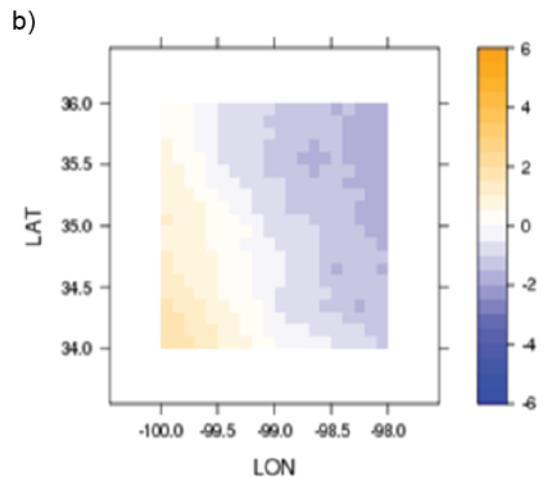
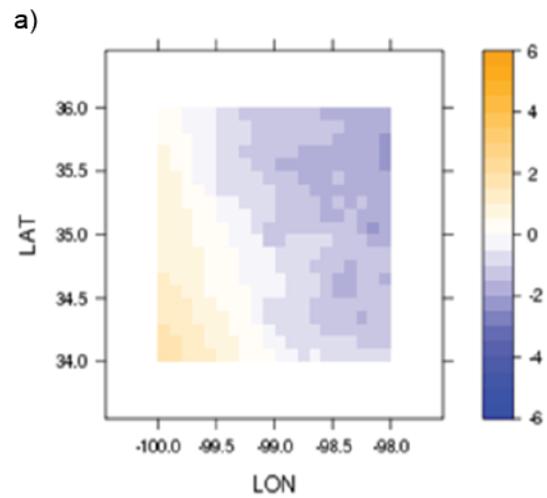


Fig. 7. (a) These are the results of applying the CDFt downscaling method to the MIROC5 GCM. (b) These are the results of using the same GCM in (a) and CDFt downscaling method.

For the historical period, the outputs for the same GCM may not differ much, but the projections from the two GCM's differ substantially from each other. The ranges between the outputs of each GCM are not the same, except that a section of the domain in the MIROC5 GCM outputs is projected to have 28 GDD. This is demonstrated in **Figures 4a–5b**. CCSM4 projects a higher range of GDD when compared to MIROC5. They both have a gradient that is similar though it may not look like it.

4.3 Mean differences

By subtracting the values from the historical period and future period, the difference fields were found. The legend for the GDD range and colors were adjusted to accommodate the new values (-6, +6). The range starts off from a dark blue, transitions to white and then to orange.

When applying the analysis to CCSM4, the range of GDD results in the domain has a range of 3.5–6.0. When each of the downscaling methods are applied, the results only show an increase in GDD in the future. An increase in GDD can be seen from Northeast to West in the domain, 3.5–6, respectively.

When applying the analysis to MIROC5, the range of GDD results in the domain has a range of a bit less than -2.0 to 2.0. These outputs show a gradient increasing from the Northeast to the Southwest of the domain.

These outputs show that the CCSM4 model, regardless of the downscaling method, projected a larger number of GDD in the future when compared to MIROC5 as demonstrated in **Figures 6a–7b**. The CCSM4 GCM provides a more extreme projection in regards of GDD.

5. CONCLUSION

Using the CCSM4 GCM, Southwest Oklahoma is expected to accumulate more GDD within the designated domain. It is projected that the mean GDD will increase by 3.5–6.0 GDD for the future period of 2006–2098. However, this range is distributed throughout the domain in a slight gradient which increases from Northeast to West in the domain. This means that the winter wheat on the West side of the domain will accumulate more heat units than the rest of the domain.

Using the MIROC5 GCM, Southwest Oklahoma is expected to accumulate anywhere from a decrease in GDD to an increase in GDD for the domain. When applying the analysis to MIROC5, the range of GDD results in the domain has a range of a bit less than -2.0 to 2.0. These outputs show a gradient increasing from the Northeast to the Southwest of the domain. This means that the winter wheat in the Northeast of the domain will accumulate less heat units in the future period, Southwest will accumulate more heat units in the future period, and no change in the accumulation in GDD will occur in the rest of the domain.

The outputs of a single GCM look similar to one another when the CDFt and EDQM method are applied. When the results of the two GCMs were compared, they varied in range of GDD and pattern of GDD. Projected change in GDD of winter wheat varies greatly depending on the GCM used.

There are several limitations of this project including the stationarity of statistical downscaling; two GCMs used as opposed to many that are available; two downscaling methods were used as opposed to many that are available; and other factors in growth of winter wheat such as precipitation, soil type, wheat variety, infestations and many more were not taken into account.

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