Forecasting Corn Yields Using the NCEP

Dynamical Seasonal Forecast Model

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Introduction and Motivation

In areas of the United States and areas of other countries that have economies dominated by agriculture, being able to accurately predict the weather parameters that govern crop yields would be very beneficial. This would allow farmers to better prepare for the growing season. Knowledge of the temperature trends and precipitation amounts could determine the need for extra fertilizer, irrigation practices, or other timely measures, ultimately saving farmers time and money.

For example, in 1988, a La Niña year, a major drought in the Midwestern United States caused agricultural losses totaling $39 million. If a climate model, such as NCEP's seasonal forecast model, were able to predict a drought of this magnitude, farmers, food security specialists, and regional planners could be warned in advance. This would allow them to take action in order to minimize the effects of a drought and save millions of dollars. Researchers could even test adaptation strategies such as short-season crops. A seasonal forecast could also help farmers maximize crop yields when ideal conditions for growing are predicted by allowing them to plant more crops and employ more personnel to help with a larger than average harvest (Rosenzweig, 32).

This project attempts to use NCEP's dynamical seasonal forecast model to predict corn yields in central Iowa using the Growing Degree Days and precipitation amounts predicted by the model. To do this, we examined the accuracy of past forecasts and also examined the correlation we suspected between Growing Degree Days, precipitation, and corn yields.

Data Sources and Forecast Description

The following data sources are used in this project:

> Daily high temperatures
> Daily low temperatures
> Daily precipitation amounts
> Hindcast precipitation amounts
> Hindcast average monthly temperatures
> Crop yield data.

The daily high and low temperatures were obtained through Daryl Herzmann. We used data from 1980 – 1999 for the months of May, June, July, August, and September based on the growing season of corn. The years were chosen because this was the period that we had access to hindcast data. Based on the way the hindcast data is binned, we chose several points surrounding Johnston, Iowa to get a better representation of the area. We used data from Polk, Warren, Madison, Jasper, and Dallas counties. We averaged the data from the counties to get a spatial average around the grid point.

Due to the hindcast limitations of only producing averaged monthly temperatures, we needed to compute comparable data from the observations. We averaged the daily high and low temperatures and then computed the monthly average temperatures. According to Dr. Ray Arritt, the standard Growing Degree Day formulas are:

$$GDD = Tday - Tbase$$

$$Tday = (Tmax + Tmin) / 2 \quad (Tmax < 86 \ F \ and \ Tmin > 50 \ F)$$

$$Tbase = 50 \ F$$

Since we did not have daily hindcast temperatures, we could not use the standard Growing Degree Days formula. We found the number of Growing Degree Days from the average monthly temperature to compare to the output of the forecast. It is not possible to take into account the Tmax and Tmin values assumed by these equations with only a monthly average temperature. We realized that there would be some error in this method, so we compared this to the number of Growing Degree Days that actually occurred, incorporating the Tmax and Tmin.
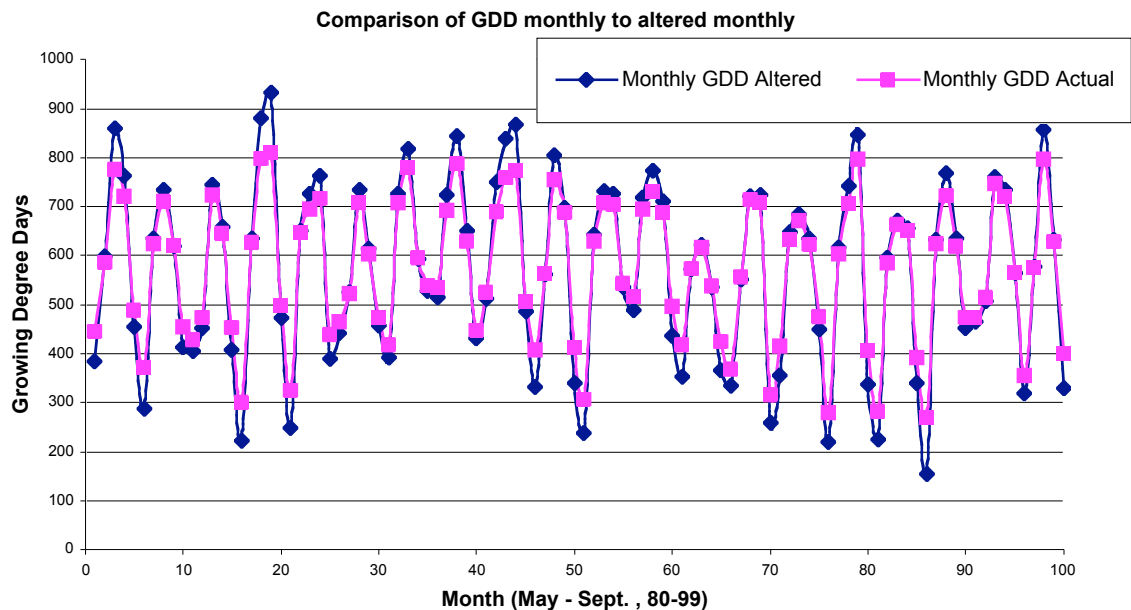

Fig. 1. Growing Degree Days are calculated using a max and min temperature threshold. This will result in small errors in the estimated growing degree days due to the hindcast model only issuing average monthly temperatures.

From figure 1, it is evident that there is an overestimation for Growing Degree Days in July and August when using the monthly average temperature instead of the actual daily high and low temperature with Tmax < 86 F and Tmin > 50 F. There is an underestimation for Growing Degree Days for May and September when using the same

method. When looking at the total Growing Degree Days for the year there is only a slight overestimation since the overestimation in July and August and the underestimation in May and September balance out.

To get a base value for optimal precipitation and Growing Degree Day values, we used the climatological average based on the 30-year normals from the National Weather Service. This 30-year period does not exactly match up with the 20 years of data we obtained from the hindcast. This could result in small errors in our base values.

Crop yield data was obtained from a website maintained by Dr. Robert Wisner, from Iowa State Agriculture Extension Economics. We recorded the yearly crop yields for each of the 5 counties, and then spatially averaged them.
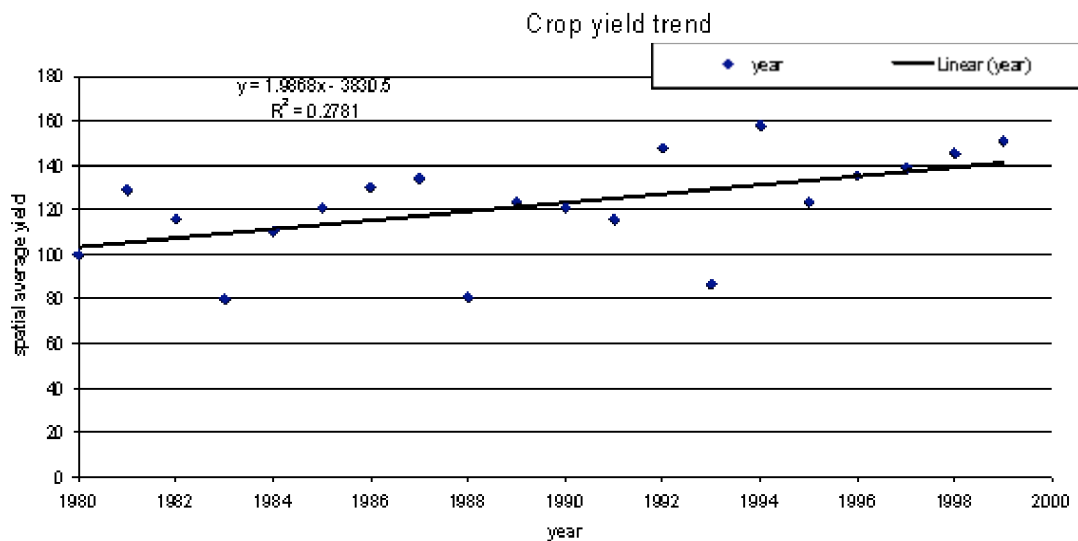

Fig. 2. Technology advances have helped to steadily increase the corn yields over the past 20 years. This would skew the results of our comparisons.

Here is the original graph of the crop yield vs. year. You can see that the crop yields on average are increasing each year due to increasing technologies and improved farming techniques. Later on we will attempt to correlate the Growing Degree Days, precipitation amount, and crop yields. In order to do this we need a constant base line for crop yields that is free from these increases. To compensate for the increases in yields, we fit a trend line to the 20 years of data (See fig. 3), and adjusted the yields to reflect this.
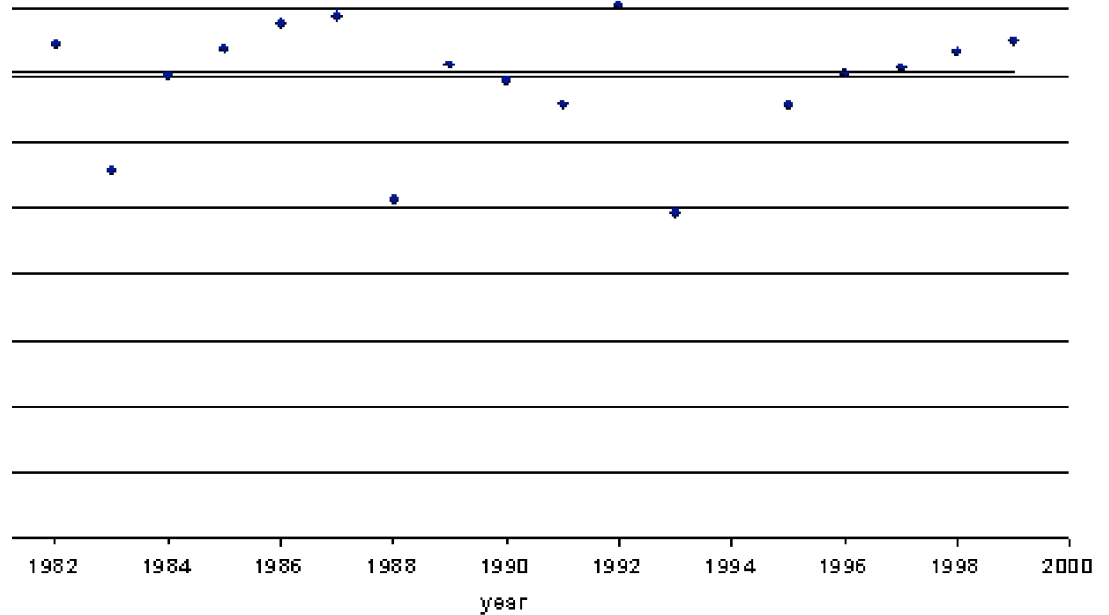
Fig. 3. This trend line was adjusted to offset technology advances.

Analysis

Crop yields are highly dependent on precipitation as well as temperatures. To get a general idea of how they influence the yield, we wanted to come up with some sort of index to combine the two. Originally we added the average yearly Growing Degree Days and average yearly precipitation together and plotted this with the yearly yields (See figure 4).
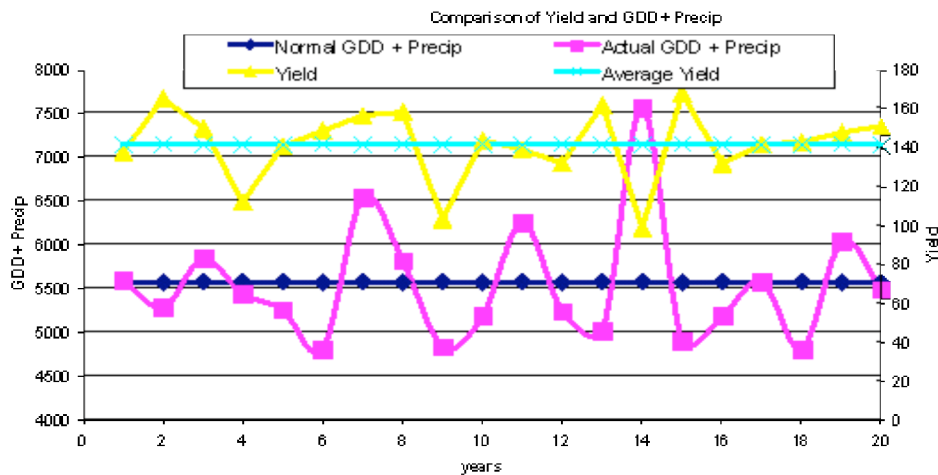

Fig. 4. This graph shows the sum of the GDD and precip for each year, and the normal value, with the axis on the right. Also plotted is the adjusted yield and average yield according to the left y-axis.

We suspected that deviations from the average Growing Degree Days plus precipitation would result in below normal crop yields; the question is how large of a deviation in Growing Degree Days plus precipitation would it take to have a negative impact on crop yields. From the graph, we can see that on a few occasions large deviations from the normal Growing Degree Days plus precipitation did result in below average corn yields. For example, in 1993, Growing Degree Days plus precipitation is significantly above normal, mostly due to extreme amounts of precipitation that occurred that year. Also, in 1988, Growing Degree Days plus precipitation is well below normal due to a drought that year. In both cases crop yields were very low. However, in other years when there were large deviations in Growing Degree Days plus precipitation, crop yields did not seem to be affected and were normal to above normal. For example, in 1985, 1986, 1990, 1992, 1994, and 1998 this was the case and crop yields remained normal to above normal. We thought this was rather unusual so we decided to take a closer look at each individual year.

In 1985, the deviation in Growing Degree Days plus precipitation was due to slightly below normal Growing Degree Days (-168 days) and below normal precipitation (-4.73 inches). In 1986, the deviation in Growing Degree Days plus precipitation was due to slightly above normal Growing Degree Days (+99 days) and well above normal precipitation (+6.81 inches). In 1990, the deviation in Growing Degree Days plus precipitation was due to well above normal precipitation (+5.77 inches), with near average Growing Degree Days. In 1992, the deviation was due to below normal Growing Degree Days (-371 days), with near average precipitation. In 1994, the deviation in Growing Degree Days plus precipitation was due to slightly below normal Growing Degree Days (-122 days) and below normal precipitation (-4.31 inches). Finally, in 1998, the deviation in Growing Degree Days plus precipitation was due to slightly above normal precipitation (+3.04 inches) and slightly above normal Growing Degree Days (+79 days).

In every one of these years, Growing Degree Days and precipitation were either:

> Both above normal
> Both below normal
> One above or below normal with the other near normal

contributing to the deviations in Growing Degree Days plus precipitation. For comparison, in 1993 the deviation in Growing Degree Days plus precipitation was caused by extreme above normal amounts of precipitation while well below normal Growing Degree Days actually made the deviation less amplified. In 1988, the opposite was true; deviations in Growing Degree Days plus precipitation were caused by extreme below normal precipitation while well above normal Growing Degree Days made the deviation in Growing Degree Days plus precipitation less amplified. This helps explain why in some years with large deviations in Growing Degree Days plus precipitation crop yields were well below normal while in other years with large deviations in Growing Degree Days plus precipitation crop yields do not seem to be affected and are normal to above

normal. Because of this, we will try to look at Growing Degree Days, precipitation, and yields, in a different way. The next graph shows the absolute value of the departures in Growing Degree Days from the average plus the absolute value of the departures in precipitation amounts from the average compared to the corn yield.
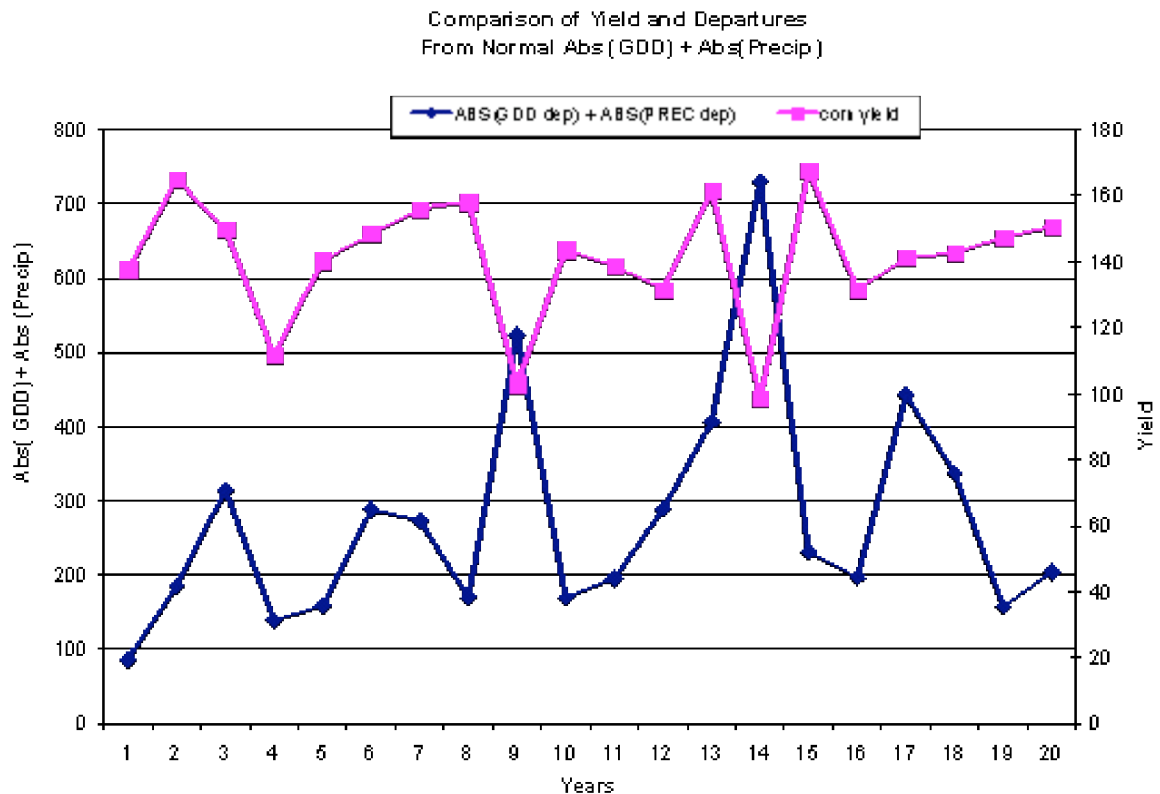

Fig. 5. Absolute value of GDD departure plus absolute value of precip departure gives a clearer picture of when significant departures in precip have a highly negative result on yields.

From figure 5, we can see that the deviations in 1993 and 1988 are larger than the other years. This gives us a clearer picture of how precipitation and Growing Degree Days effect crop yields. It seems that only in extreme instances of droughts and floods can we clearly see a correlation between the deviation and the corn yield. In other years, the correlation is either very subtle or unclear. In some years, in which yields were poor, there is a small deviation from normal, however in other years when there are relatively large deviations, there are still good crop yields. From this we may be able to assume that when a certain threshold is achieved, corn yields begin to be negatively affected. As stated by Steven W. Ritchie, "Highest yields will be obtained only where environmental conditions are favorable at all stages of growth." We can assume this is the explanation for having high yields and large deviations, or having low yields with near normal seasonal conditions. Timing of precipitation plays a very important role in crop yields. We cannot see this from looking at our yearly average data. This may pose a problem when forecasting yields using seasonal forecasts.

Results

Our analysis of the forecast data had some interesting results. We immediately noticed that the forecast had a significant warm bias in the summer months. July and August forecast temperatures were consistently 5 to 10 degrees above the observed data (See figure 6)
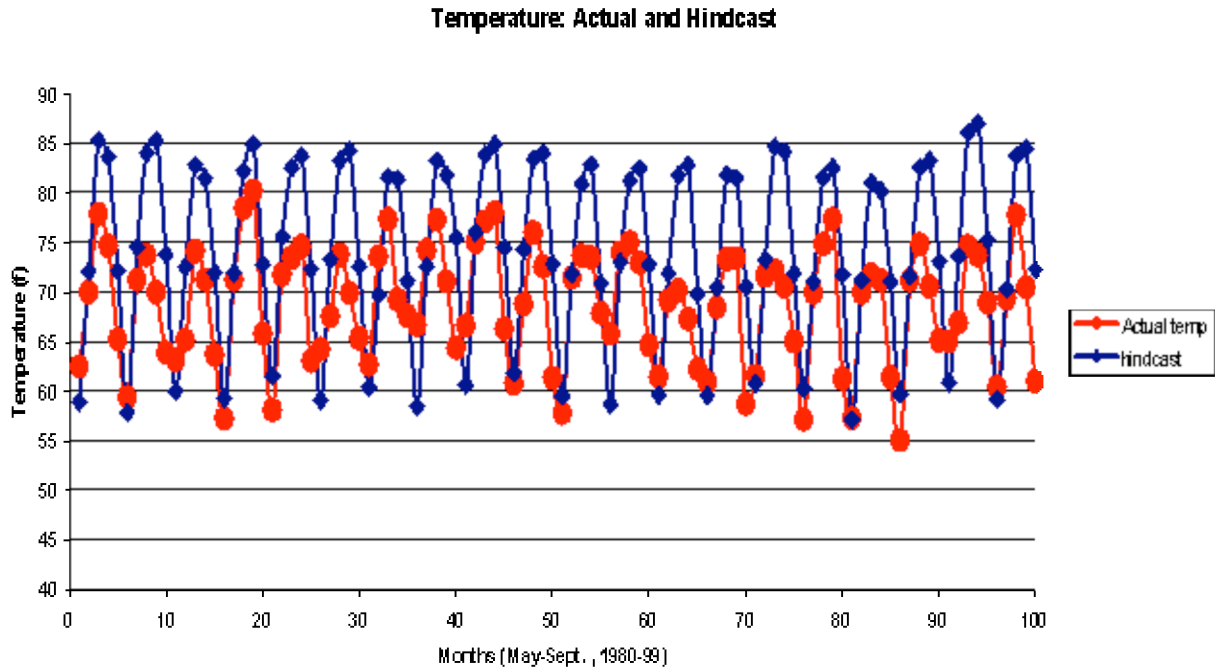

Fig. 6. This seasonal forecasting model has an obvious warm bias in the months of July and August.

Knowing that the bias was consistent through the 20-year period, we decided to make a correction factor. We found the average difference between the hindcast and actually temperature for each month.

Month	Correction Factor (F)
May	-3.13
June	2.37
July	9.27
August	11.54
September	6.64

Table 1. A correction factor is needed to increase the accuracy of the models temperature forecast.

This gave a much better relationship between the hindcast and actual temperatures. We added this number to each of the hindcast temperatures (See figure 7). This offset both the warm and cool biases of the model. The r-squared value increased from 0.66 to 0.75.
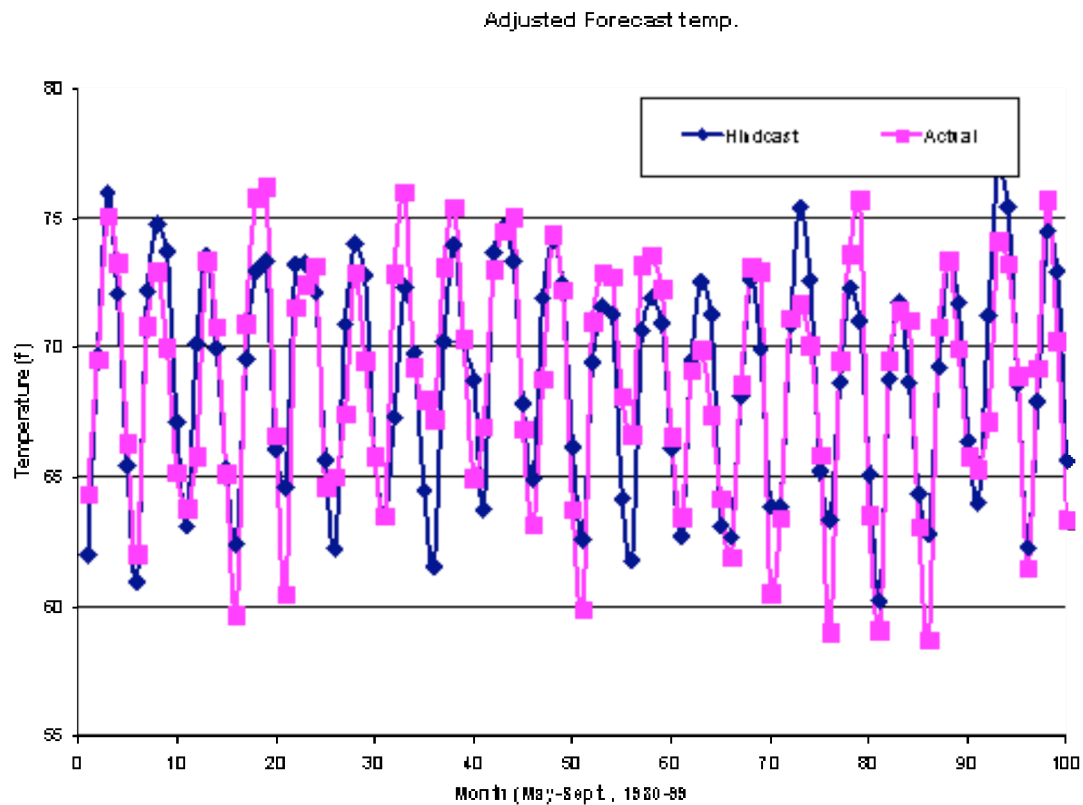
Fig. 7. With the correction factor added in, the model has a much better correlation with the actual observed temperatures.

The precipitation data also did not give promising results (See figure 8). We found very little correlation between the forecasted precipitation amounts and the actual precipitation measurements. The r-squared value is 0.012.
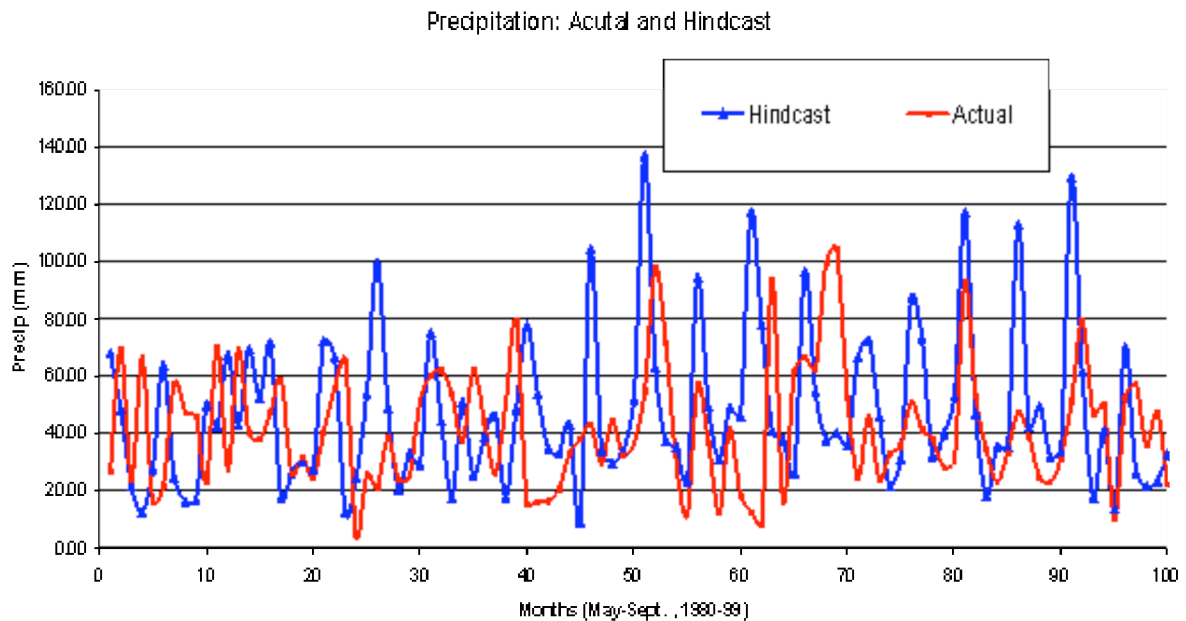
Fig. 8. Little correlation was found in the precipitation forecast and observations.

Interpretation of the Results

One of the main goals of this project was to find an index based on observed precipitation and Growing Degree Days to forecast crop yields. This was very hard to do because of the major inconsistencies in crop yields. The main observation that we obtained was that once the absolute value of Growing Degree Day deviation from normal plus the absolute value of precipitation deviation from normal reached this threshold (approximately 500) the crop yields are negatively influenced. Below this threshold the crop yields were unpredictable because of precipitation timing issues. So only when our season forecasts tells us that the absolute value of Growing Degree Day deviation from normal plus the absolute value of precipitation deviation from normal is above 500 can we forecast a below normal yield for the year. However, many improvements are needed in our seasonal forecasts before such assumptions are made.

Another main goal of this project was to determine the usefulness of the NCEP Dynamical Seasonal Forecast Model. Unfortunately the errors in the monthly amounts of precipitation and temperature were significant. The overall warm bias that was presented in the monthly average temperatures could be determined and corrected to give us a fairly accurate temperature forecast. As above once the warm bias was removed our r-squared improved to 0.75. The precipitation amounts were another matter. There was no identifiable model bias found in our data and the precipitation forecasts were overwhelmingly inaccurate. This discovery was quite discouraging since precipitation plays possibly the most important role in determining crop yields. Even if our seasonal forecast model was able to produce near accurate precipitation amounts the timing issue still makes it very difficult to make any predictions for crop yields.

In conclusion, major improvements are needed to the NCEP Dynamical Seasonal Forecast Model before it can be a reliable tool for crop yield prediction. Also the timing of precipitation needs to be addressed somehow in the model to achieve more accurate forecasts for crop yields.

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