Climate Science

Climate and Climate Variability from the Instrumental Record / Rice Growing and Climate Change

---

STATE, NATIONAL AND GLOBAL INSTRUMENTAL RECORDS

Background:

At times an announcement is made that the past month or season has been the warmest or coldest on record for a particular state, or the nation or even the planet. You can routinely check the site maintained by NOAA's National Climatic Data Center (NCDC) called "U.S. Climate at a Glance" and see how the statewide, regional and national temperatures and precipitation totals compare with averages for the 20th century. Similarly, graphics prepared by NCDC for the "State of the Climate: Global Analysis," show the variations in the global temperature anomalies (differences in actual annual and long-term average temperatures) over the last 132 years.

The question that comes to mind is how is the temperature of the state, nation or globe determined. We are aware that during the last 100 years, several thousand stations around the country have been taking temperature and precipitation observations. This period represents a relatively short time interval in Earth's history.

The "instrumental period of record" that is used to consider national or global temperatures depends upon the number of observing stations that would form a network that climatologists feel could adequately provide representative readings of the temperature of a large area. For the US, this period of record is usually considered by the National Climatic Data Center scientists to have started in 1895, when a sufficient number of cooperative stations were established to complement the US Weather Bureau stations. However, many climatologists maintain that the period of record for global temperatures can be extended back to 1880 or even 1850.

To determine the state, national or global average temperatures requires some area-weighting scheme that uses the station data.

STATE, REGIONAL AND NATIONAL RECORDS

Determination of statewide monthly and annual temperatures and precipitation commenced in the 1895 as the monthly data for all observing stations across each state were averaged numerically. This procedure, which does not represent a true area-weighted average, was continued for slightly more than half a century. In 1951, the national center that eventual became NCDC instituted a set of 344 climate divisions across the nation. These divisions, which generally correspond to the crop reporting districts developed by the US Department of Agriculture, are usually assumed to represent relatively uniform climatic conditions. In many instances especially across the central section of the nation, the boundaries of the division are determined by the county lines; see map. Depending upon state size or variations in climate, the number of divisions per state ranges from one (Delaware and Rhode Island) to ten (such as Texas, Idaho and Pennsylvania). Divisional average temperature and precipitation are computed for each division within the state, using data collected from those stations within the division that report both temperature and precipitation. Since cooperative observers often make their observations of maximum/minimum temperature and 24-hour precipitation in the morning, an adjustment is now made to correct the time of observation for these cooperative stations to conform with the calendar day used by those stations operated by the National Weather Service or the Federal Aviation Administration. Statewide monthly average temperatures and precipitation since 1951 are based upon the divisional average statistics weighted by area in the respective state.

(Using statistical techniques that involve comparing the current divisional averages with statewide averages, NCDC has extended the temperature and precipitation records for the individual divisions back to 1895. Additional statistics for the divisions for the period 1895 to present also include Palmer Drought Severity Index values, along with heating and cooling degree-day units. NOTE: NCDC will begin determining divisional and statewide averages of temperature and precipitation using a slightly different computational scheme beginning later in 2012.)

Recently, NCDC has computed regional average temperatures and precipitation for nine regions across the nation based upon the area weighted statewide averages. Monthly national average temperature and precipitation values are also computed in similar fashion.

GLOBAL RECORDS

NCDC also generates monthly temperatures for the Earth based upon temperature data collected from several thousand worldwide observing stations on land and ocean. The Global Historical Climatology Network is used for land, and sea-surface temperature anomalies over the oceans. Algorithms (computer programs) that account for spatial coverage and various observing methods are used to take the data from the irregularly distributed station locations and generate a uniformly spaced gridded data set. A time-series of temperature anomalies have been computed for the globe commencing in 1880. (Note: The red bars are the annual means, the blue line is a running mean and the black bars are uncertainty estimates.) Separate monthly and annual temperature anomalies for land and ocean are computed in addition to a combined mean for the entire globe. These temperature anomalies are calculated with respect to the 20th century (1901-2000). By using a temperature anomaly time-series, knowledge of the actual mean temperature of the Earth was not needed, as many areas of the world remain relatively inaccessible.

NASA's Goddard Institute for Space Studies (GISS) produces its own surface temperature analysis for use in climate modeling. A Global Land-Ocean Temperature Index is computed as a time series of temperature anomalies based upon the 1951-1980 averaging interval. The time series for the index runs from 1880 to the present. (Note: The dotted black line is the annual mean, the solid red line is the five-year running mean and the green bars show uncertainty estimates.) Although the observed temperature data essentially are the same as used by NCDC, differences in the area weighting averaging schemes cause slight differences between the time series produced by GISS and NCDC.

A third time series of global and hemispheric temperature anomalies that incorporate land and marine data has been developed in the United Kingdom by the Climatic Research Unit at the University of East Anglia and the Hadley Centre for Climate Prediction and Research in the Meteorological Office. This time series is relative to the 1961-90 reference period means and extends back to 1850.

Currently, long term global precipitation time series are unavailable as precipitation observations were rarely taken aboard ships.

Climate and Climate Variability from the Instrumental Record

Driving Questions: *What can we determine from the instrumental record regarding the variability of climate? When might that variability indicate a change in climate?*

Educational Outcomes: Understanding climate and its variability are the first steps in making sense of what factors determine the mean state of the climate system, how it may have changed, and how it might change in the future. This course attempts to cover those key concepts of the boundary conditions that affect Earth's climate state and how the system varies within the limitations imposed by those constraints. We use the record of instrumental observations from the reliable length of readings to define that climate state and to identify its variability. From statistical analysis of the record, we then try to determine if and when a change has occurred or can be expected to occur in that climate state.

Objectives: After completing this investigation, you should be able to:

- Describe where climate data may be obtained and displayed.
- Show ways the climate record may be analyzed.
- Explain how climate analysis provides an understanding of climate variability and could lead to objective evidence of climate change (past and present).

The Instrumental Climate Record

The instrumental climate record is comprised of the recorded observations of temperature, precipitation, wind speed and direction, humidity, clouds, atmospheric pressure and the like taken from the beginnings of the invention of each instrument. However, a considerable period of time passed before each type of instrument was considered reliable. For example, Galileo Galilei (1569-1642) is credited with creating an instrument for measuring the changing temperature of the air. His mechanism consisted of a glass tube with a sealed bulb at one end that was warmed and the open end immersed in water. As the air volume in the tube cooled, water was drawn up into the tube. Subsequently, when the surrounding air temperature changed and the air in the tube came to equilibrium, the water level within the tube varied. This type of instrument really reacted to the sensible heat of the ambient environment. It is now termed a *thermoscope*.

Gabriel Daniel Fahrenheit (1686-1736) is credited with the invention of the true thermometer using a reliable liquid, mercury, in a narrow evacuated tube above a large bulb reservoir and based on a scale utilizing two fixed reference points. Only after the scientific community agreed on the reliability of the thermometer as a measuring device and reached consensus as to its representativeness in placement and use could the observations be considered comparable and valid. Because these actions came about through international conventions and the formation of national meteorological organizations, as well as the global spread of population, reliable widespread values of meteorological variables are considered to have been established by the late nineteenth century. **In this investigation, we will use temperature records to demonstrate ways in which climatic data acquired by use of reliable instrumentation are employed to examine climate and its variability**. We will assess some specific temperature records for the period from 1895 to the present in the climatological division of Nebraska that includes Grand Island, whose data appear in

Investigation 2 dealing with its local climatic data.

The temperature data we will analyze are monthly averages from the several sites within climatological division 5 ("central") of Nebraska. A *climatological division* is a region of a state considered to be homogeneous climatologically and containing a reasonable number of observing sites. **Here we will deal only with the July temperature averages;** each value thus being the average of 31 daily averages from approximately ten stations. The data are accessed from NOAA's National Climatic Data Center. These data represent the average temperature for what is normally the warmest month of the year in the area that includes and surrounds Grand Island, Nebraska for the reliable length of temperature readings.

The Nebraska climatological region 5 data were found from the RealTime Climate Portal, under the **Climate Information** section, subset Historical Information, "Climate Data Online" link. Then select *U.S. Divisional Data.* The resulting page provides a form to retrieve data by choosing, in this case, Division, State: Nebraska, Division: 05 — Central, Select Period Start: 07, 1895, Select Period End: 07, 2011, Static Graphs and Temperature, Show: July, then finally, **Submit**.

In statistics, there are several terms for the most representative or middle value of a series of data (including mean, median, and mode). ***Average,*** a sometimes vague term, is commonly used to denote the middle value of a set of data determined by dividing the sum of the values by the number of values used in the summation. This definition of average is synonymous with the term ***mean,*** which statisticians prefer using to precisely define a middle value so calculated. Finally, there is the term "normal" used in climatology. The climatological standard ***normal*** is the average (mean) of the 30 values of the variable measured within the most recent three-decade period, currently 1981-2010. Here we are using the average (mean) temperature for the month of July for each year. That average itself was the average of the daily average temperatures for the 31 days of each July. And each daily average was the average of that day's high and low temperatures.

Figure 1 is the time series graph of July average temperature in degrees Fahrenheit from 1895 to 2011 for the central Nebraska climatological division (supplied by NOAA's National Climatic Data Center). The average July temperature of each year is shown by a small green square plotted at the mid-point of that year with the years connected by line segments. The series of red squares making a horizontal line is the average (mean) of these July averages.

1. The average of all the July temperatures, denoted by the line of plotted red squares, is about **[(*74.5*)(*75.1*)(*77.2*)]** °F.

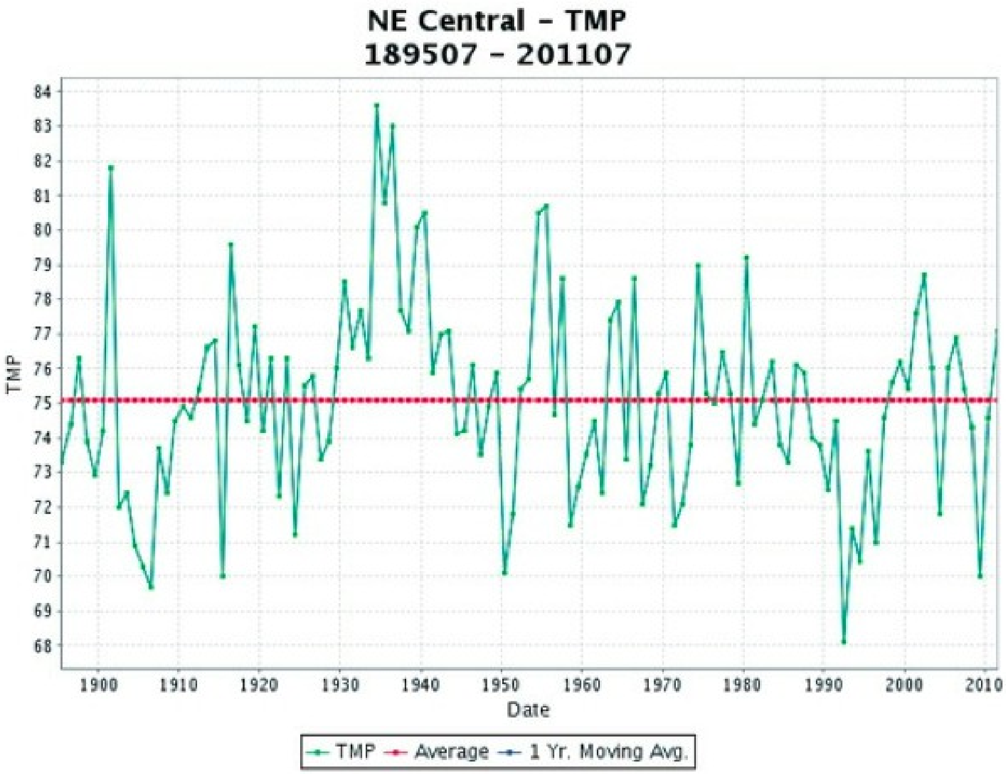

Figure 1.
Nebraska Central climatological division average July (month 07) temperatures from 1895 to 2011. TMP is abbreviation for temperature. [NOAA/NCDC]

2. Of the 117 years of average July temperatures reported in Figure 1, **[(*1*)(*5*)(*10*)(*20*)]** of the individual green squares appear(s) superimposed on a red square (i.e. only a green square appears that year). That is, the average of such an individual year is the same as the overall average.

3. In Investigation 2 the ***Local Climatic Data, Annual Summary*** publication for Grand Island, Nebraska, gave the average July temperature ("average dry bulb") for Grand Island in 2011 as 79.4 °F. From Figure 1, the 2011 central climatological division which contains Grand Island had an average July temperature that was **[(*less than*)(*equal to*)(*greater than*)]** the Grand Island value. The more urban nature of Grand Island compared to the rural area probably accounts for the difference.

4. The departure of the average July temperature of individual years from the long-term average is the variability. The maximum July average temperature in this series is about **[(*75.1*)(*80.5*) (*83.6*) (*84.3*)]** °F. This occurred in 1934.

5. The minimum July average temperature was 68.1 °F which occurred in **[(*1906*)(*1933*) (*1971*) (*1992)*].**

6. The ***range*** is defined as the difference between the maximum and minimum values, and is one simple measure of the variability of data. For the average July temperatures of this

period, the range was **[(*0.7*)(*8.4*)(*15.5*)(*29.3*)]** F°.

7. Another issue in a long time series of data such as this one is the nature of variations in the data. For example, are there clear cycles of variation? If the values varied in a totally random way, one would expect swings from above to below average and vice versa occurring every year or at least every couple of years. One would not expect consistent runs of above or below average values and
certainly not much above or below for extended periods. Using this general context, consider the periods 1902 to 1911, 1929 to 1943, and 1988 to 1997. Do these consecutive-year periods seem to imply total randomness in year-to-year variability? **[(*Yes*)(*No*)]**

Operating within Earth's climate system are many interacting processes, some of which serve to maintain certain departures (positive feedbacks) and some to dampen those departures (negative feedbacks.) Evidence exists in the Central Nebraska July temperature for both types of behavior.

The traditionally accepted climate period of the most recent three decades (30 years) of record for climatic values would dictate 1981-2010 as the current climatic normal period. Draw vertical lines on your graph at 1981 and at 2010 to display this span of years. Using the July average temperatures from these years, the following statistics were derived:

mean:	74.2 °F
maximum:	78.7 °F
minimum:	68.1 °F

8. The 1981-2010 mean July temperature is **[(*less than*)(*equal to*)(*greater than*)]** the average of all July temperatures for 1895-2011.

9. The range of July temperatures for 1981-2010 is **[(*4.9*)(*10.6*)(*14.5*)]** F°.

1901-1930	74.6 °F
1911-1940	76.6 °F
1921-1950	76.4 °F
1931-1960	76.6 °F
1941-1970	75.2 °F
1951-1980	75.2 °F
1961-1990	74.9 °F
1971-2000	74.2 °F

10. The mean and range for the 1981-2010 period **[(*are*)(*are not*)]** equal to those for the 1895-2011 period.

In fact, one could compute the mean for each of the climatic normal periods within the entire length of this temperature record. Those mean values are given below:

1901-1930	+0.08 F°/yr
1911-1940	+0.19 F°/yr
1921-1950	0.00 F°/yr
1931-1960	−0.19 F°/yr
1941-1970	−0.02 F°/yr
1951-1980	−0.01 F°/yr
1961-1990	−0.01 F°/yr
1971-2000	−0.06 F°/yr
1981-2010	+0.02 F°/yr

A major concern facing humankind at present is the potential for global warming. This concern comes from the recent worldwide examination of trends in surface temperatures. We can consider these issues from our brief look at the localized summer temperatures of central Nebraska as a data "game". (By no means should this be considered a rigorous climate investigation but only a very limited example of how climate data are used to answer possible questions.)

11. Let us take "climate change" for our purpose here to imply simply a change of the mean temperature from one climatic normal period to another. Compare the mean of the most recent
period, 1981-2010, to those of the preceding periods listed above. The 1981-2010 mean July temperature is **[(*less than or equal to any*)(*greater than any*)]** of the prior climatic periods listed.

12. If merely any change of mean value is considered a different climate regime, has there been a "climate change" over any of these periods? **[(*Yes*)(*No*)]**

13. Next, consider the magnitude of the difference from the others in the group and also recall the variability displayed in the graph of the total group of temperature values. Given the small difference of the 1981-2010 mean from those others and the overall nature and size of departures over the entire period of record (variance), could one conclusively be sure that real change had occurred? **[(*Yes*)(*No*)]**

14. If we are concerned about "global warming," compare the mean for the 1981-2010 period to those of the other periods listed. The 1981-2010 period mean July temperature is **[(*tied with one other period with the lowest value*)(*lower than several others*)(*in the middle of the values*)(*higher than most others*)]**.

    One caution on these results, while there may be global trends, climate patterns are non-uniform geographically on the regional and local levels. Thus, while some areas may be clearly warming, others may be cooling, with only the overall average showing warmer values.

Another more definitive statistical procedure is to search for trends in data values. Is the time series of values of a climatological quantity uniformly increasing or decreasing and if so by how much? Clearly this may be difficult to detect from the graph alone given the variability displayed from year to year. The idea is to find a “line of best fit” to the entire series of data. While graphically placing a line is possible, different individuals may disagree on the placement. A rigorous statistical procedure exists however, called linear regression or least squares fitting of a line. Basically, the procedure minimizes the total sum of squared differences of each point from the line position. For further details, refer to standard statistical discussions.

The *trend* is given by the slope of the best fit line. If the slope is positive, values are generally increasing with time. A negative slope means values are generally decreasing. The magnitude of the slope value gives the rate of change, e.g. here in degrees per year. The slope values for the climatic periods are:

1901-1930	1911-1940	1921-1950	1931-1960	1941-1970	1951-1980	1961-1990	1971-2000	1981-2010
+0.08 F°/yr	+0.19 F°/yr	0.00 F°/yr	−0.19 F°/yr	−0.02 F°/yr	−0.01 F°/yr	−0.01 F°/yr	−0.06 F°/yr	+0.02 F°/yr

15. Consider the values of the trends for each climatic period. These July average temperature trends are **[(*all decreasing*)(*mixed with both increases and decreases*)(*all increasing*)]**.

16. The greatest trend value (greatest change in magnitude, whether positive or negative) was during the periods **[(*1901-1930 and 1941-1970*)(*1911-1940 and 1931-1960*)(*1921-1950 and 1981-2010*)]**.

The maximum average July temperature in central Nebraska occurred in 1934. This was the infamous “Dust Bowl” period of severe drought in the central U.S. brought on by persistent dry conditions which aided in solar heating becoming predominantly sensible heating, resulting in a large Bowen ratio. The 1911-1940 period ending with the Dust Bowl time is reflected in that period’s trend. Perhaps as remarkable is the obvious trend from about 1934 to 1950 of declining temperatures. This does not show in the values above due to the placement across the arbitrarily chosen climatic periods.

Let us now consider the recent attention to the global warming issue. From Figure 1, a warming trend appears to fill much of the most recent time, since 1992. Is this evidence of the much discussed anthropogenic influence on climate? The following statistics can be found for values from two selected, nearly decadal periods:

	1993 – 2002	2001 – 2009
mean:	74.5 °F	75.2 °F
maximum:	78.7 °F	78.7 °F
minimum:	70.4 °F	70.0 °F
trend:	+0.86 F°/yr	−0.66 F°/yr

17. In terms of the mean and extremes, does there appear to be any substantial difference between these two chosen periods? **[(*Yes*)(*No*)]**

18. The variation in the trend produced by the selective inclusion of the years of data does greatly affect perceived trend statistics however. For which period would the trend suggest a more alarming warming swing? **[(*1993-2002*)(*2001-2009*)]**.

19. Compare these two period trends, 1993-2002 and 2001-2009, to those 30-year climatological period trends listed above. The 1993-2002 trend is **[(*much less than*)(*approximately equal to*) (*much greater than*)]** the largest trend value of the prior climatic periods listed.

Therefore, overall recent conditions (1993-2011, the present), at least in Nebraska's central climatological division, have not been the largest change of temperature that were experienced. And the temperatures experienced were not the warmest seen in the record. In fact, this period from 1993 to 2011 contained one of the lowest July average temperatures recorded in central Nebraska. It should be clear that selection of historical values must be carried out using standard statistical procedures as a guide and not arbitrarily to produce a desired effect.

One last issue; the overall trend for the entire 1895-2011 period gives a value of 0.00! [In Figure 1, such a trend line would be superimposed on the red average line.] In other words, from this particular instrumental temperature record, there is no demonstrable trend of increasing summer temperature values. But, too, this is only one set of data from one climatological division in Nebraska.
Summary: A variety of ways in which recorded temperature values can be analyzed has been demonstrated. Although limited to July temperatures in one climatological division, they are intended as examples of how empirically acquired climatic data can be examined to determine climate variability, which in turn can lead to objective evidence of climate stability or climate change in the past and present.

While statistical analyses inform past and current climate, predicting climate change in the future requires a dynamic approach. As mentioned in Investigation 1A, while the empirical approach allows us to construct descriptions of climate, the dynamic approach is what enables us to seek explanations for climate. Explanations lead to predictions, including prognostications of change. Considering Earth's climate system dynamically as a physical system makes it possible to leap-frog into the future via computer models to make potentially useful climate change predictions.

The USGCRP ***Global Climate Change Impacts in the United States*** report presents climate-change predictions on the regional scale. As an example, the report shows in **Figure 2** that climate models predict that Nebraska's central climatological division's summer temperatures will rise 6 F° or more compared to a 1960s and 1970s baseline. And recall from Investigation 2A that the 1981-2010 state-wide annual temperature maximums and minimums have increased.

Great Plains Projected
Summer Temperature Change by 2080-2099

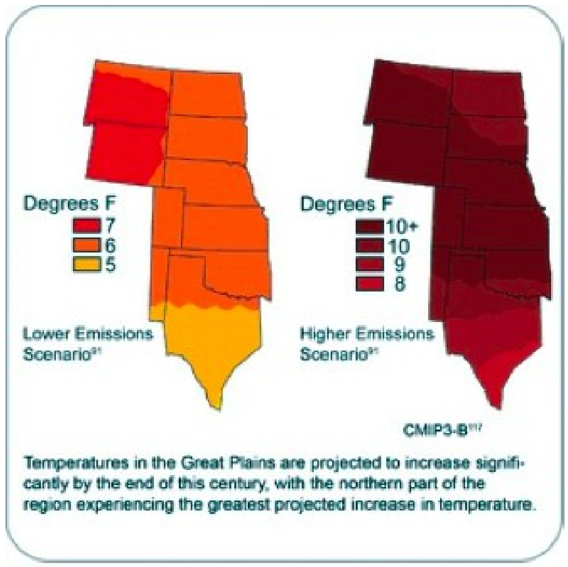

Figure 2.
Projected summer temperature change in the Great Plains. [USGCRP].

RICE GROWING AND CLIMATE CHANGE

Driving Question: *How might large-scale climate change affect agriculture in a specific region?*

Educational Outcomes: To describe the possible impact of higher temperatures associated with climate change on the heat intolerance of rice growing. Demonstrate that both temperature means and variabilities (spreads of temperature values about their means) can impact rice production. To explain that other climate-change factors can adversely impact rice and other food production.

Objectives: After completing this investigation, you should be able to:

- Demonstrate how climate might change in the future.
- Describe the possible implications of increased variability in climate.
- Explain how agricultural productivity might be vulnerable to climate change.

Climate Change Impacts of Agriculture: A Case Study

Global-scale climate change is likely to affect all sectors of society, including agriculture and food production. To understand the potential impact of climate change on agriculture, we need to consider the ways in which climate might change in the future. The climate record indicates that climate change may consist of long-term trends in average values of weather measures (i.e., temperature, precipitation), changes in the frequency of weather extremes, or both.

This investigation focuses on how higher July temperatures, more variable July temperatures, or both, might impact the cultivation of rice in southern China. Rice production is highly climate sensitive, most notably in terms of temperature (and also because about 75% of the world's production involves irrigation). We will use a simple climate model for average daily July temperatures at Nanning (22.6 degrees N, 108.2 degrees E), located in a rice-growing area of southern China with a tropical monsoonal climate.

The production of rice is extremely important. It is the staple food for almost half of the world's population, especially in tropical Latin America, East, South and Southeast Asia (**Figure 1**). It is the grain with the second highest worldwide production, after maize ("corn") according to the U.N. Food and Agricultural Organization. Since large proportions of maize crops are grown for other than human consumption, rice is probably the most important grain with regards to human nutrition and caloric intake.

It is estimated that in 2004, 600 million metric tons of paddy rice were produced world wide. (Final milled rice is about 68% of the weight of paddy rice.) That year the top producer was China, which had about 26% of the world's production. India with 20%, Indonesia at 9% and Bangladesh followed. In 2011, 653 million tons of paddy rice was produced according to the United Nation's Food and Agriculture Organization (FAO).

Figure 1.
Worker transplanting rice seedlings in Korea. (IRRI Images)

A. Temperature Requirements for Rice

Recent research suggests the possibility that the heat intolerance of rice may make it difficult to maintain or increase production of this food staple. Studies of the growth of two common species of rice at elevated temperatures, consistent with proposed projections of temperature change, indicated that the fertility of rice spikelets (flower shoots that become the seeds, i.e. edible rice grains) may be at risk. Spikelet flowering at a control temperature of 29.6 °C, was compared to that at 33.7 °C and 36.2 °C. Results showed a 7% reduced spikelet fertility per degree rise above 29.6 °C in one species, and a 2.4% reduction per degree in the other species with increasing rate of reduction as temperatures rose. Both species became sterile when the temperature reached 33.7 °C at flowering *(http://jxb.oxfordjournals.org/cgi/content/ abstract/erm003v1)*. A recent study at the International Rice Research Institute (IRRI) has shown that each one degree Celsius increase in the minimum temperatures at night can decrease rice yield by about 10 percent.

Adaptations of rice species or its environment will be needed if the higher extremes of Intergovernmental Panel on Climate Control (IPCC) projections become reality. The IPCC models imply that global average temperatures may be from 1 to 6 C° higher by the end of the 21st century.

For the Northern Hemisphere, July on average is the warmest month of the year, making it the month when crops are at the greatest risk to stress caused by episodes of excessively high temperatures. As already indicated, the temperatures at flowering time for planted rice are crucial in the development of the grains and thus the total crop produced.

Figure 2.
Nanning is located in major rice growing area of southern China. [Adapted from CIA World Factbook]

We will consider Nanning as it is in the world's greatest rice growing country and the most populous country on the planet (see **Figure 2** map, and **Figure 3** view of Nanning-area rice fields). The control temperature used in the rice study quoted is also near the average monthly high temperature for Nanning based on the temperature record for the 1951-2008 period. The average daily temperature, the average of the high and low for the day, provides the data series employed in our climate model. The series of average July monthly temperatures from 1951 to 2008 in Nanning yields an average of 28.4 °C. This value is near the experimental study's rice control value (29.6 °C) and less than the values shown to be harmful under warmer conditions. For simplicity, we will consider our conclusions for the model based on the Nanning temperature series average.

Figure 3.
Workers in the rice fields, Nanning, China. [*http://blog.travelpod.com/travel-blog-entries/ksshepard/1/1238117400/tpod.html#pbrowser/ksshepard/1/1238117400/filename=workers-in-the-rice-fields.jpg*]

B. 1. Nanning Climate Model

This investigation utilizes a simple statistical climate model of Nanning's July average daily temperatures, displayed graphically in **Figure 4**. The horizontal axis is the temperature in degrees Celsius and the vertical axis is the probability of a particular temperature's occurrence. The probability of occurrence increases upward. **Curve A** represents the frequency of occurrence of daily average July temperatures during the present climatic regime. You may recognize this model distribution as "normal" (also termed bell-shaped or Gaussian). This model was used in Investigation 2.

Based on the 58-year record, the Nanning mean daily temperature in July is 28.4 °C. Further analysis of the data employed in determining Curve A indicates that about two-thirds of all average daily temperatures occur within 0.6 Celsius degree of 28.4 °C (plus or minus one standard deviation), that is, between 27.8 °C and 29.0 °C. Assuming no change in climate, Curve A can be used to estimate the relative frequency of any average daily temperature occurring during July at Nanning.

1. Curve A depicts the probability of occurrence curve of average July daily temperatures. It shows that the most frequently (most likely) occurring average daily temperature in July is **[(*26.2*) (*28.4*) (*28.8*)]** °C. Draw a vertical straight line on the graph at this temperature value.

2. Assuming the rice tolerance study described earlier is applicable, temperatures that were above 29.6 °C resulted in reduced rice growth. On the same graph, draw a vertical line at 29.6 °C to depict the harmful threshold. According to Curve A, and the position of the line you just drew, there **[(*is*)(*is not*)]** a possibility that under current climatic conditions a July could occur with a high enough daily average temperature to reduce rice growth.

3. The same rice tolerance study showed that both rice species studied became sterile when the temperature reached 33.7 °C during flowering. Draw a vertical straight line at that value on the graph. According to the graph, it **[(*is likely*)(*is highly unlikely*)]** that under current climatic conditions a July could occur with a high enough daily average temperature to make the flowers sterile.

B. 2. Nanning Climate Model — 4 C° Warmer Than Present

Recent runs of global climate models predict that the global mean annual temperature could rise between 1 and 6 Celsius degrees by the end of this century. **Let us assume in this investigation that this global-scale warming translates into a warming of 4 Celsius degrees in Nanning's July mean daily temperature**. Let us also assume initially that the variability of July average daily temperatures remains the same; that is about two-thirds of all values will occur within ±0.6 Celsius degree of the new July mean daily temperature.

4. The new July overall mean daily temperature is 32.4 °C (28.4 °C + 4 Celsius degrees = 32.4 °C).

In the warmer climate that experienced no change in variability, about two- thirds of all mean daily temperatures would be expected to fall between 31.8 °C and **[(*33.0*)(*33.4*)(*33.8*)]** °C.

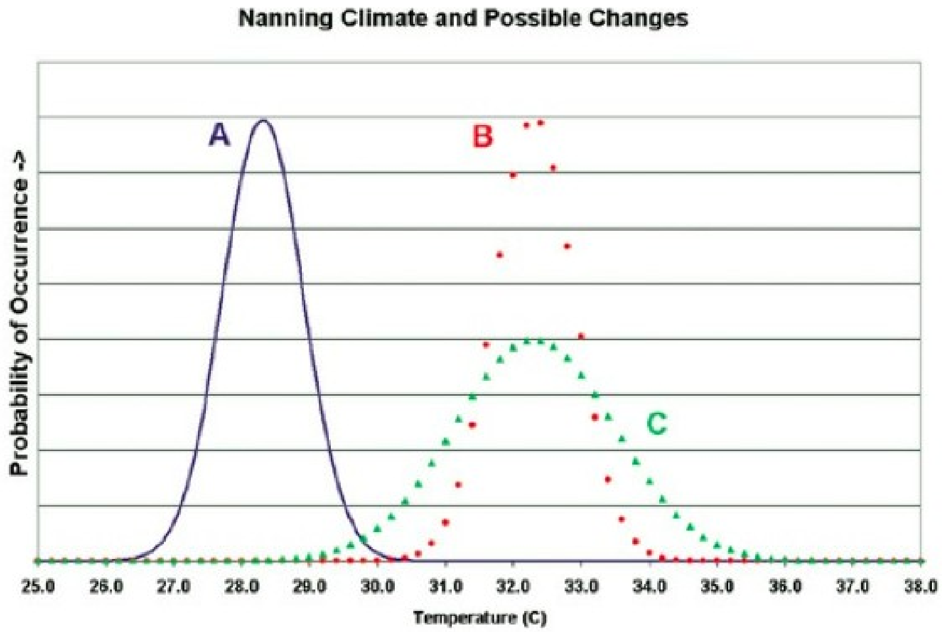

Figure 4.
Climate model of Nanning, China July mean daily temperatures.

5. In Figure 4, connect the set of small red dots (plotted at a 0.2 C° interval) with a smooth line to produce a new model distribution (identical in shape to Curve A) representing the warmer July climate. The curve is already labeled with a red **"B"**. Draw a vertical straight line at 32.4 °C representing the new July mean daily temperature. The peak of **Curve B** (the highest probability of occurrence) is **[(*the same as*)(*different from*)]** the highest point on Curve A indicating that the likelihood of the respective mean daily temperature is the same for both models.

6. Both curves have the same width indicating that the variability or spread of temperatures about the mean is **[(*the same*)(*different*)]** for both models.

7. The area under each curve is directly proportional to the total number of occurrences of the temperatures represented. Compare Curve B with the position of the 29.6 °C harmful threshold line you drew. The comparison shows that the warming would reduce rice production in the Nanning area during **[(*some*)(*most*)(*essentially all*)]** years.

8. Because of the 4 C° warming, the rice species in the research study that is more temperature sensitive (7% reduced spikelet fertility per degree above threshold) would likely see an average of about **[(*7%*)(*20%*)(*28%*)]** reduction in spikelet fertility.

9. According to Curve B and the position of the line you drew showing the temperature (33.7 °C) when both rice species during flowering become sterile, there **[(*is*)(*is not*)]** a possibility that under the higher temperatures a July could occur with a high enough daily mean temperature to totally decimate rice production via those species.

B. 3. Nanning Climate Model — Warmer and More Variable

10. Now assume that in addition to the 4 Celsius-degree rise in the July daily mean temperature, the new climatic regime features much greater variability (spread) in daily mean temperatures. In this
new model, the variability about the mean is arbitrarily doubled so that about two-thirds of all values will occur within ±1.2 Celsius degrees of the overall mean July daily temperature of 32.4 °C, that is, between **[(*30.0*)(*31.2*)(*31.8*)]** °C and 33.6 °C.

11. In Figure 4, connect the set of small green triangles (also plotted at a 0.2 C°-interval) with a smooth line to graphically represent the warmer and more variable July climate. This has already been labeled curve **"C". Curve C** is broader than Curves A and B indicating **[(*increased*) (*decreased*)]** variability of average daily temperature.

12. The high point of Curve C is **[(*lower than*)(*equal to*)(*higher than)*]** the high points of Curves A and B.

13. This indicates that there is a(n) **[(*reduced*)(*increased*)]** probability of occurrence of a daily average temperature equal to the peak mean daily temperature for July.

14. The area under Curve C to the right of the 33.7 °C (temperature at which both rice species during flowering become sterile) vertical line you drew on the map is **[(*greater than*)(*less than*)(*the same as*)]** the area under Curve B to the right of 33.7 °C.

15. This comparison indicates that with a 4 Celsius-degree increase in July mean daily temperature ***and*** an increase in temperature variability, the probability of occurrence of lethal conditions for rice production of these species would **[(*increase*)(*decrease*)(*not change*)]**.

Note that the comparison of Curves B and C indicates the increased variability depicted by Curve C can also result in higher production of rice due to the increase in the probability of more years experiencing cooler July temperatures. There could even be a few years when the July daily mean temperature is below the 29.6 °C harmful threshold!

16. This investigation indicates that an evaluation of the potential impact of climate change on agriculture must take into account possible changes in climatic **[(*averages*)(*variabilitv*)(*both of these*)]**.

Summary: Climate change can result in major, perhaps devastating, impacts on agricultural productivity. Scenarios concerning rice production show that literally hundreds of millions of people are at risk in the coming decades due to reduced rice production. Temperature change is only one factor affecting rice production. Rising sea level, reduced water resources, and potential pests in rice-growing areas are also of grave concern.

For a detailed report published on 17 October 2011, "Rice Production and Global Climate Change: Scope for Adaptation and Mitigation Activities", by the International Rice Research Institute, go to: *http://irri.org/climatedocs/presentation_Lists/Docs/12_Wassmann.pdf*.