Climate Science

CLIMATE SCIENCE FROM AN EMPIRICAL PERSPECTIVE / CLIMATE VARIABILITY AND CHANGE

MEANS, EXTREMES IN CLIMATE RECORDS - A STATISTICIAN'S DELIGHT

Background:

The descriptive definition of climate involves the statistical summary of weather over a sufficiently long time interval at a location, a state, the nation or the planet. The development of a statistical summary represents the empirical definition of climate. This "climatography" or statistical description of the climate of a locale involves the determination of means (normals) and extremes of a compilation of weather data over an extended time interval at a station or group of stations. The averages and variability that comprise the climatography also provide a baseline for detecting when a change in the climate occurs.

WHAT IS RECORDED

Detailed instrumental weather records have been collected and compiled in this country at many stations for more than a century. The National Weather Service and its predecessor, the U.S. Weather Bureau, have operated a network of weather observation stations and offices in or near many of the large cities in every state, commonwealth and territory under its jurisdiction. During the last two decades, over 1000 automatic weather stations have been installed around the nation to make systematic measurements of numerous weather elements, such as temperature, precipitation, humidity, air pressure, cloud cover, visibility, wind speed and wind direction. Some of these weather data are recorded hourly, while other data are recorded once a day at some fixed time. An additional cooperative observer network of approximately 8000 volunteer observers provides daily readings of such weather elements as daily maximum and minimum temperatures, and 24-hour precipitation totals. Last week's *Supplemental Information...In Great Depth* introduced us to where we could access the current *Preliminary Local Climatological Data* for nearly 300 "first-order stations" around the nation from off the Web. Recall that the following weather information, which pertain to these first-order stations, is collected at essentially all types of stations, including the cooperative observer stations:

- **DAILY MAXIMUM TEMPERATURE --** The highest temperature recorded during a calendar day defined as midnight to midnight local standard time.
- **DAILY MINIMUM TEMPERATURE --** The lowest temperature recorded during a calendar day.
- **24-HOUR ACCUMULATED PRECIPITATION --** The total depth of daily rainfall and melted frozen precipitation accumulated during a calendar day.
- **24-HOUR ACCUMULATED SNOWFALL --** The total depth of new snowfall accumulated

during a calendar day.

These daily data are used to compile monthly and annual averages of temperature, together with monthly and annual precipitation totals during that year. Ultimately, these data help define the location's empirical average climate. For example, the daily high temperatures observed for each of the 31 days at a particular weather station during the month of January are averaged to determine a monthly average high temperature for January. Similarly, a January monthly average minimum temperature is also calculated from the arithmetic average of the 31 daily low temperatures. The average monthly temperature is then determined as the average between the average monthly maximum and minimum temperatures for the given month. The annual average maximum, minimum and daily average temperatures are determined from the corresponding12 monthly averages. The monthly precipitation and snowfall totals are calculated from the sum of the daily values; likewise, the annual snowfall totals are calculated.

The monthly and annual data are published by NOAA's National Climatic Data Center (NCDC). As part of your investigations this week, you will become familiar with the wealth of climate information that is available in the annual issue of the *Local Climatic Data* that NCDC publishes for each of the nearly 300 cities around the United States and its territories.

"NORMALS" AND COMPARATIVE DATA

The annual summaries of the *Local Climatic Data* for the first-order stations include the normals and the extremes for the various weather elements at that particular location. While the weather is never truly *normal*, the term usually refers to a long-term average condition, typically of temperature or precipitation. By international convention, normals are computed for a standard three-decade (30-year) interval. Every 10 years this interval is shifted forward in time by a decade, and a new set of 30-year averages are computed. During the 1990s, the normals referred to the 1961 to 1990 interval, whereas during the first decade of the 21st century the 1971-2000 interval was used. Since July 2011, the normals for each station encompass the 1981-2010 interval.

Typically, the term normal is applied to the 30-year averages of temperature, precipitation, snow and heating/cooling degree-day unit data made for the reference interval, such as 1981-2010. Other weather elements, such as humidity measures (wet-bulb and dewpoint temperatures) and wind speed/direction data are averaged for the period of record and are included in the tabulation of "Normals and Comparative Data."

Recently, the National Weather Service has made the normals and extremes for a larger number of stations available in electronic format on the NOWData pages of the local National Weather Service Forecast Offices.

EXTREMES IN THE RECORD

Annual summaries also include the extremes in temperature, precipitation, and snow that have been observed at that current observing site. On each day, the observed daily weather data are compared with the long-term records that have been maintained at the weather station. At some stations, these daily weather records may extend back for more than a century. Since many of the weather stations have moved from city offices to airport locations, the noted extremes may not be the all-time extremes for that city.

For example, a record event report is made to the public if the day's temperature tied or exceeded the long-term record for that calendar date or season:

DAILY RECORD TEMPERATURES

- **RECORD HIGH MAXIMUM** The daily maximum temperature for that calendar day has never been that high of a value.
- **RECORD LOW MAXIMUM** The daily maximum temperature for that day has never been that low of a value.
- **RECORD HIGH MINIMUM** The daily minimum temperature for that day has never been that high of a value.
- RE**CORD LOW MINIMUM** The daily minimum temperature for that day has never been that low of a value.

The first and last records -- or simply, the daily record highs and lows -- are the most often reported, and are relatively obvious. The other records are reported less often and usually require some explanation. A record low maximum indicates that exceptionally cold conditions prevailed through the daylight hours, either because of a very cold air mass or because extensive cloud cover blocked solar heating. Record high minimums typically occur when a hot, humid air mass prevents overnight cooling, thereby keeping an elevated overnight minimum temperature.

MONTHLY AND SEASONAL RECORD TEMPERATURE EVENTS

Attention is given to those times when the maximum or minimum temperature exceeds the respective monthly temperature record. In addition, during meteorological spring (March, April, May), a low temperature record may be classified as "Low so late" or a record high temperature may be identified as "High so early". Similarly, during meteorological autumn (September, October, November) record temperatures could have the designations, "Low so early" or "High so late". No such designations are used during meteorological summer or winter other than monthly record exceeded.

ANNUAL RECORD TEMPERATURE EVENTS

Anytime the absolute lowest or highest temperature that was ever observed at the weather office is exceeded, the event would be identified as the "all time record low" or "all time high".

OTHER RECORD EVENTS

The public is usually informed when an exceptionally heavy precipitation event sets a daily, monthly or annual precipitation record. Such a record means that the amount of rain that has fallen on a given day, month or year is the greatest ever recorded for that given time interval. Snowfall records are similarly noted when applicable. However, in the latter case, the snowfall season used is from 1 July to 30 June rather than the calendar year as for total liquid equivalent precipitation.

On occasion, a station's record sea level pressure or record peak wind gust may be reported. Usually sufficient explanation is provided in these record event reports.

A WORD OF CAUTION

While a record event that eclipses a century old record may be newsworthy, one should realize that many of the first order weather stations may have moved from a city office to an airport office, resulting in a slightly different weather record. Changes in the types of thermometers also may pose a serious problem.

During the last several years, NOAA's National Climatic Data Center has undertaken a project called ThreadEx, for "threaded data extremes", in which climate bases have been assembled from the earlier 19th and 20th century data sets collected by the US Army Signal Service and the US Weather Bureau, predecessors to the current National Weather Service. The new ThreadEx records can be used by the public and researchers to study the longer-term climate extremes at a number of locations across the nation, especially where changes have occurred in station location . For access to the ThreadEx records for selected stations in your area, check http://threadex.rcc-acis.org/ for the daily temperature and precipitation records.

THE SIGNIFICANCE

What do these record weather events signify? One may think that some of these weather statistics are as obscure, detailed or complicated as some of the detailed baseball statistics that die-hard fans keep on their favorite player or club. While some of the weather and climate records may appear to have little meaning, they still provide benchmarks to be used to gauge the unusual behavior or severity of a particular weather event, just as the baseball statistics are used to judge athletic achievement. Furthermore, they can be used to judge how the climate variability or how the climate in a particular locale has been changing of the period of the instrumental record at that location.

Part 1: CLIMATE SCIENCE FROM AN EMPIRICAL PERSPECTIVE

Driving Question: *What observational weather data are collected to describe climate, and how are they organized and analyzed to provide an empirical view of a location's climate?*

Educational Outcomes: To identify the kinds of atmospheric data accumulated and analyzed to describe a location's climate. To learn where such information can be found for U.S. locations (including your own). To demonstrate how local climatic data can be analyzed to look for associations among weather elements.

This investigation examines the kinds of climatic data routinely acquired and analyzed by NOAA as the basis for describing climate at hundreds of locations nationwide. After completing this investigation, you should be able to:

- Describe and interpret information appearing in ***Local Climatic Data, Annual Summary with Comparative Data*** based on data collected at a local National Weather Service office.
- Explain how to access climate data from the National Climatic Data Center (NCDC).

Local Climatic Data

Climate data are systematically collected because they are extremely useful for many purposes. Farmers use their knowledge of weather and climate over a long period to determine what crops to plant and for guidance on when to plant and when to harvest. Utilities use climate data for planning production and distribution of energy supplies and the reallocation among types of such supplies. The building industry uses climate data in the design of structures, including their necessary strength, heating and cooling energy requirements, and the associated building codes that regulate them. Scientists modeling Earth's climate system employ derived products built on climatological data sets in model development and for verifying climate and climate change models. These are just a few of the uses of climate data.

In the U.S., weather data are gathered by NOAA's National Weather Service offices and other organizations and compiled at state, regional, and national centers for distribution to users. NOAA's National Climatic Data Center (NCDC) in Asheville, NC, is responsible for compiling and archiving U.S. data as well as being a depository for worldwide data on weather and the environment. This information, in turn, is made available to users on a variety of media.

A primary publication of NOAA's National Climatic Data Center (NCDC) based on weather data from local National Weather Service (NWS) offices is the ***Local Climatological Data*** (***LCD***). It is published for about 275 NWS observing sites in monthly and annual summaries and available free online.

The ***LCD, Annual Summary with Comparative Data***, for Grand Island, Nebraska (KGRI for the Year 2011 is used in this investigation). To retrieve Grand Island's LCD, go to: *http://www7.ncdc.noaa.gov/IPS/lcd/lcd.html*.

Select in sequence, "Nebraska", "GRAND ISLAND", and "2011-ANNUAL". Then, midway down the page, click on the URL provided.

[Alternate paths to the Grand Island 2011 LCD Annual Summary in the event the above does not provide access: *http://cdo.ncdc.noaa.gov/annual/2011/2011GRI.pdf*, or, *http://cdo.ncdc.noaa.gov/annual/2011/* and click on "2011GRI.pdf"]

Upon retrieval, you will be viewing the front page of the 2011 LCD Annual Summary for Grand Island. Either print out pages 1, 2, 3 and 7 of the document for reference or refer to them onscreen to respond to the following.

1. Examine the temperature graph appearing on the report's front page. The first of each month is indicated by the vertical dashed line directly above the monthly label, starting with 1 January at the left. Daily temperature ranges are plotted as vertical lines on the graph. The top end of each line signifies the maximum daily temperature and the bottom end reports the day's minimum temperature. The lowest minimum temperature for 2011 was –12 °F. It occurred on **[(*12 January*) (*23 January*)(*6 December*)]**.

2. Locate on the temperature graph the highest maximum temperature reported at Grand Island for the Year 2011. It and the lowest minimum temperature for the year indicate that the annual temperature range at Grand Island in 2011 was about **[(*85*)(*105*)(*115*)]** F degrees.

3. A horizontal dark blue line is drawn on the temperature graph at 32 °F. Assuming that

frost occurs if the temperature falls to 32 °F or lower, the approximate date of the last spring frost in 2011 at Grand Island when the minimum temperature dropped to 29 °F was about **[(*10*)(*20*)(*28*)]** April. (Note: There were four dates in May 2011 when the minimum temperature dropped to 33 °F.)

4. The green curve drawn across the Daily Max/Min Temperature graph presents the normal (or average) maximum temperatures for every day of the year. The brown curve delineates the normal daily minimum temperatures. These normal values are based on the average of maximum or minimum temperatures over a recent 30-year period (1971-2000). According to the graph, the date of the last spring frost in 2011 was **[(*earlier than*)(*within a day or two of*)(*later than*)]** normal.

5. The middle graph on the ***LCD*** front page reports daily precipitation in liquid equivalence. The maximum precipitation in one calendar day in 2011 occurred on about 20 May. According to the graph, the amount was approximately **[(*1.3*)(*1.9*)(*2.4*)]** inches.

Examine page 2 of Grand Island *LCD, Annual Summary*, entitled “METEOROLOGICAL DATA FOR 2011”, and complete the following:

6. The lowest monthly average daily temperature (“Average Dry Bulb”) for 2011 occurred during **[(*January*)(*February*)(*December*)]**.

7. The average daily temperature during that month was **[(*18.6*)(*22.0*)(*22.6*)]** °F.
8. The highest monthly daily average temperature for the year (79.4 °F) occurred during **[(*June*) (*July*)(*August*)]**.

9. The monthly precipitation (water equivalent) ranged from November’s 0.21 in. to May’s 8.70 in. The total 2011 precipitation was **[(*8.70*)(*17.61*)(*27.16*)]** in.

Examine page 3 of the *LCD, Annual Summary* entitled “NORMALS, MEANS, AND EXTREMES”. The “Normals” presented are averages of observations taken during the 1971-2000 time period. “Mean” values are averages for the entire period of record of the weather element. **The values appearing on this page are commonly considered to be the “climate” of the station or region.** Complete the following:

10. The Highest Daily Maximum temperature ever recorded at Grand Island over its entire 65 years of record was **[(*104*)(*109*)(*110*)]** °F in August 1983.

11. The normal total annual precipitation at Grand Island is **[(*13.96*)(*25.89*)(*36.27*)]** in.

12. Comparing the actual annual value of a climate element with its normal value is a measure of *climate variability.* Comparison of the actual 2011 annual precipitation at Grand Island from Item 9 with the normal value in Item 11 shows a variability (or departure from the normal) of **[(*1.27 in. below*)(*1.27 in. above*)(*0 in. from*)]** normal.

13. Also included as part of the ***LCD, Annual Summary*** on page 7 is a brief narrative describing the location and climatic aspects of the area surrounding the local NWS

office. Its climate is described as predominantly **[(*maritime*)(*continental*)]** in nature. According to the description, Grand Island is within 50 miles of the center of the coterminous U.S.

14. According to the narrative, incursions of maritime tropical air from the Gulf of Mexico **[(*do*)(*do not*)]** make it to Grand Island.

15. The Grand Island narrative also describes evidence of local climate change due to anthropogenic activities, including increased farm irrigation and use of soil management techniques. The detected climate change includes **[(*reduced dust storms*)(*higher growing season humidities*)(*both of these*)]**.

Acquiring LCDs

The NCDC website you have already visited (*http://www7.ncdc.noaa.gov/IPS/lcd/lcd.html*) is your portal to all ***LCD, Annual Summary with Comparative Data*** and ***LCD, Monthly Summary*** publications.

From the NCDC website, examine both the ***Annual Summary*** and a ***Monthly Summary*** for the location closest to you. Examine its contents as you expand your knowledge of your local climate.

You also can acquire local climate data based on observations made as recently as yesterday. Go to your local NWS office website via *http://www.nws.noaa.gov/organization.php*. At your local station's website, under the Climate heading to the left, click on "Local". Select the product, location, and timeframe for the data you are seeking. Then click on Go.

Climate Normals Update

Climate Normals are three-decade averages of climatological variables, including temperature and precipitation, used as references for comparing observational data. These are updated at the end of each decade. NOAA's National Climatic Data Center (NCDC) released the 1981-2010 Normals on July 1, 2011, replacing the 1971-2000 Normals used through 2011. Comparison of selected 1971-2000 Annual Normals with 1981-2010 Annual Normals for Grand Island, Nebraska follows in **Table 1**:

Table 1. Comparison of selected "Old" and "New" Grand Island Annual Normals		
	Annual Normals	
Element	1971-2000	1981-2010
Maximum Temperature (°F)	61.1	62.4
Mean Temperature (°F)	49.9	50.8
Minimum Temperature (°F)	38.6	39.3
Cooling Degree Days	1027	1035
Heating Degree Days	6385	6198
Precipitation (in.)	25.89	26.66
Snow (in.)	32.9	29.0

16. Comparison of the 1971-2000 and 1981-2010 Annual Normals shows that Grand Island's climate normals **[(*remained the same*)(*changed*)]** from the earlier period to the later period.

17. The changes, if any, in temperature or temperature-related annual normals at Grand Island are consistent with that of a **[(*cooling*)(*steady*)(*warming*)]** local climate.

Figure 1 provides a comprehensive color-coded view of temperature changes between the 1971-2000 and 1981-2010 Normals.

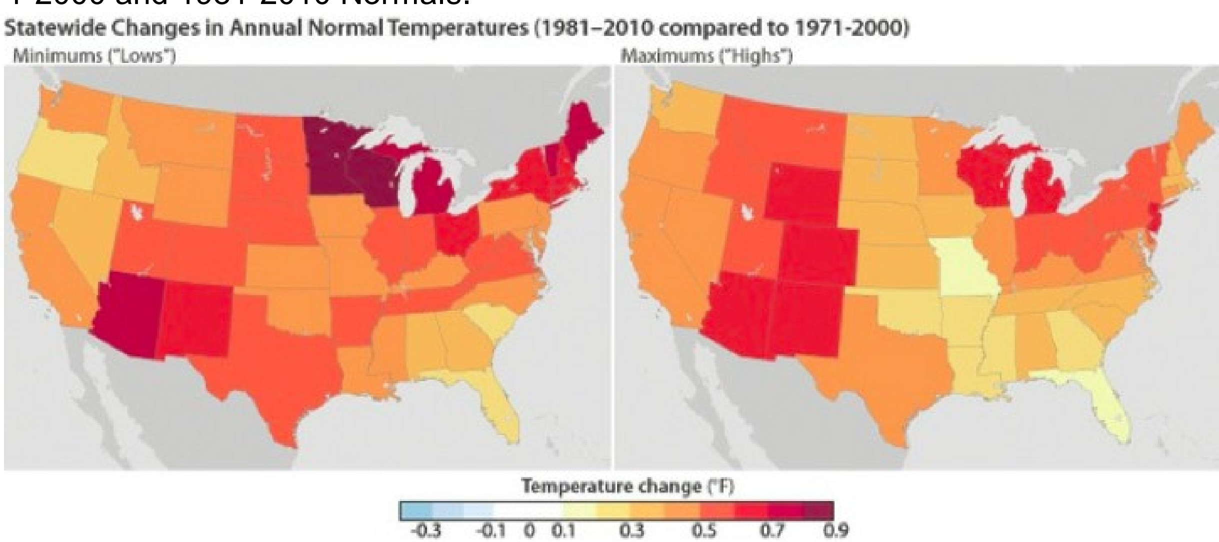

Figure 1.
Changes in annual normal temperatures. [NCDC/NOAA]

18. Comparison of Grand Island's "old" and "new" temperature normals given in Table 1 with Figure 1 shows that Grand Island's local change trends **[(*were*)(*were not*)]** generally consistent with state, regional (several-state), and coterminous U.S. changes.

19. Figure 1 reveals a pattern of changes in annual normal minimum and maximum temperatures at state levels across the coterminous U.S. that is best described as general **[(*cooling*)(*mixed cooling and warming*)(*warming*)]**.

20. Figure 1 shows that the greatest temperature changes occurred in the statewide annual normal **[(*minimum*)(*maximum*)]** temperatures.

Summary:

Observational data are the feedstock of the processes employed to describe climate from an empirical perspective. Included in the analysis of such data are the calculations of normals, typically covering the most recent three decades, to provide a frame of reference for evaluating individual observations and for looking for trends. While the focus in this investigation has been on U.S. climatic data, countries worldwide are also engaged in climatic data gathering under the auspices of the World Meteorological Organization.

A word of caution: What might be happening at the local scale should not simply be extrapolated to the state, regional or global scale, or vice versa. Climate change, if any, is not uniform across local, regional, and global scales. Local climate warming or cooling might be the reverse of what is happening at other localities or at regional or global scales.

Part 2: CLIMATE VARIABILITY AND CHANGE

Driving Question: *What is climate change? Is there short-term evidence that human activity can modify climate? How can we objectively determine modification of climate due to human activity?*

Educational Outcomes: To describe what is meant by climate variability and climate change. To describe how human activities can significantly change one or more climate measures, and how stopping particular human impacts might result in the climate measures returning to their original states.

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

- Distinguish between climate variability and climate change.
- Describe one instance of climate change likely to be caused by human activity.

Materials: Red and blue pencils, ruler or other straight edge.

Climate Variability and Climate Change

Earth's climate changes when the amount of energy contained in its climate system varies. Determinations of whether or not Earth's climate has changed, is changing, or is likely to change are elusive tasks. While recognizing that the geological and historical record shows an evolving climate, we face daunting challenges in our attempts to evaluate recent climate trends (e.g., global temperature rise) and computer climate model products as evidence of short-term variations in the climate or of persistent change in the climate system. **When we study climate, we must ask, "Are we observing statistical fluctuations of climate measures in a steady climate state or are we witnessing real change in the mean climate state?"** We can start looking for answers to this question by defining what we mean by climate variability and climate change. The more precisely we describe what we are looking for, the more likely we will know when we find it.

Climate variability refers to variations about the mean state and other statistics (such as standard deviation, statistics of extremes, etc.) of the climate on all time and space scales beyond that of individual weather events [adapted from IPCC]. It is often used to describe deviations in climate statistics over a period of time (e.g., month, season, year) compared to the long-term climate statistics for the same time period. For example, a particular year's average temperature will very likely differ from the mean annual temperature for a recent 30-year period. Such variability may be due to natural internal processes within the climate system or to variations in natural or anthropogenic external forcing.

Climate change refers to any change in climate over time, whether due to natural forcing or as a result of human activity [adapted from IPCC]. It refers to a significant change in the climatic state as evidenced by the modification of the mean value or variability of one or more weather measures
persisting over several decades or longer. **Global climate change occurs ultimately because of alterations in the planetary-scale energy balance between incoming solar energy and outgoing heat energy (in the form of infrared radiation)**. The mechanisms that shift the global energy balance result from a combination of changes in the incoming solar radiation, changes in the amount of solar radiation scattered by the Earth system back to space, and adjustments in the flow of infrared radiation from the Earth system to space, as well as by changes in the climate system's internal dynamics. Such mechanisms are termed ***climate forcing mechanisms***.

Climate change can occur on global, regional, and local scales. The prime (and most pressing) example of climate change is global warming, recognized almost universally as mostly due to increasing atmospheric carbon dioxide via burning of fossil fuels. Among examples of anthropogenic climate forcing at a more regional level include changes in Earth's surface reflection of sunlight back to space due to land use and even the subtle impact of aircraft contrails (as will be examined later in this investigation). Local climate data can provide evidence of climate modification through human activity as seemingly innocuous as changes in local farming practices. As you recall, the narrative section of the National Climatic Data Center's ***Local Climatic Data (LCD), Annual Summary*** for Grand Island, Nebraska, reports that the increased use of irrigation and soil management techniques in local farming reduced the frequency of dry season dust storms while increasing growing-season atmospheric humidities.

Determining Climate Variability and Climate Change

The scientific, objective investigation of climate and climate change requires the use of clearly defined terms. We have already defined climate in terms of its empirical and dynamic aspects.

We will use the term ***climate variability*** to describe the variations of the climate system around a mean state (e.g., average temperature of a single month compared to the average monthly temperature for that month as determined from several decades of observations). Typically, the term is used when examining departures from a mean state determined by time scales from several decades to millennia or longer.

The AMS CEM can be employed to illustrate climate variability. Go to the RealTime Climate Portal and click on "AMS Conceptual Energy Model". Then click *Run the AMS CEM.* Set the model for one atmosphere, 100% Sun's energy, 200 cycles, and Introductory mode, and click on "Run". The on-screen visualization includes, above the graph, the Mean and Standard Deviation of energy units residing in the imaginary planet's climate system (surface and atmosphere) over the 200-cycle run. The graph displays curves drawn to report numbers of energy units in the planetary system at the end of each cycle (jagged blue curve) as well as the 5-cycle running mean (smoother green curve).

1. According to the CEM depicting the planet's climate system and space above, at the end of the 200th cycle there were **[(*4*)(*5*)(*6*)]** energy units residing in the climate system. Note that this is the same value for the 200th cycle as depicted in the graph below the window. **Figure 1** is an abridged version of the graph portion of the on-screen image that displays the jagged blue curve reporting the number of energy units in the planetary climate system at the end of each cycle.

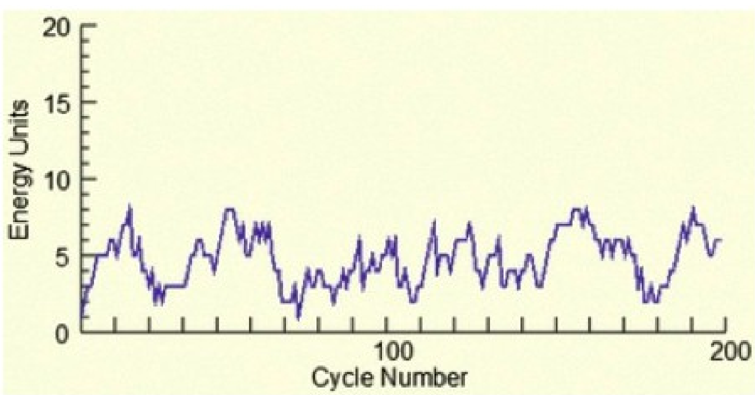

Figure 1.
Energy units residing in Earth system over 200-cycle run of AMS CEM.

2. According to Figure 1, and ignoring the initial "spin up" of the model, the number of energy units residing in the planetary climate system at the end of each cycle rose and fell between **[(*1 and 7*)(*1 and 8*)(*2 and 9*)]**. The range (the largest minus the smallest in a set of values) was 7. Range is a measure of variability.

3. In the on-screen image, note the mean number of energy units in the planetary climate

system for the 200 cycles as reported above the graph. On Figure 1, draw a solid horizontal straight line representing that mean value of **[(*1.66*)(*3.2*)(*4.7*)]** energy units.

4. Shade with colored pencils the areas between the line depicting the mean and the jagged blue curve. Color those areas above the mean red and those below the mean blue. Visually, it should be apparent that the total shaded area above the mean line is equal to the total shaded area below the mean line. The departures of the jagged curve from the mean line represent the energy-unit variability of the system for that particular 200-cycle run. A statistical measure of the magnitude of this variability is **standard deviation** (SD). The greater the spread of observed values from the mean, the greater the SD. According to the on-screen image, this 200-cycle run exhibits a SD of **[(*1.66*)(*3.2*)(*4.7*)]**.

5. Draw on the Figure 1 graph horizontal dashed lines representing +1 SD (mean plus SD value = 6.36) and –1 SD (mean minus SD value = 3.04) from the mean. **Figure 2** shows a plot of a normal distribution by SD (or σ). [A normal distribution is a frequency graph of a set of values, usually represented by a bell-shaped curve symmetrical about the mean (μ).] According to the Figure 2 graph, **[(*4.1%*)(*68.2%*)(*95.4%*)]** of the observed values fall between +1 SD and –1SD of the mean. On Figure 1, compare the shaded areas between +1 SD and –1 SD with the total shaded area to confirm that this appears to be correct.

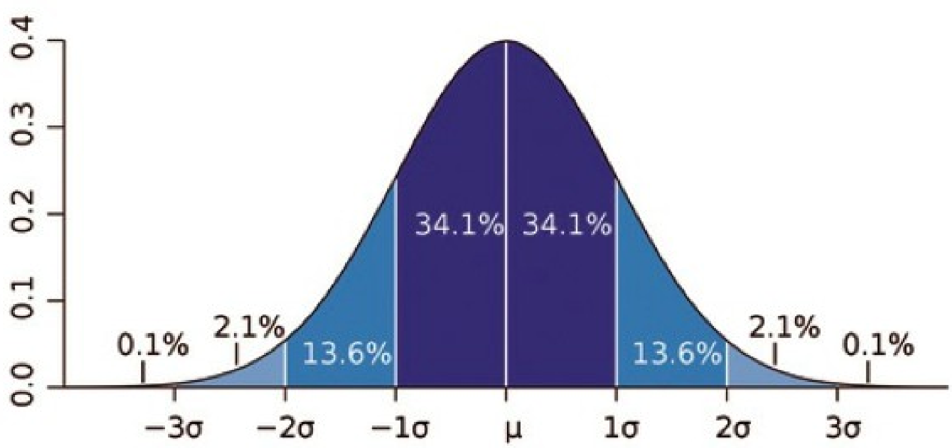

Figure 2.
Normal Distribution by Standard Deviation (SD or σ – Greek letter Sigma) [Mwtoews, Wikipedia]

6. Draw horizontal dashed lines on Figure 1 representing +2 SD (mean plus 2 SD = 8.02) and –2 SD (mean minus 2 SD = 1.38). Figure 2 shows that **[(*4.1%*)(*68.2%*)(*95.4%*)]** of observed values can be expected to fall between +2 SD and –2SD. On Figure 1, compare the shaded areas between +2 SD and –2 SD with the total shaded area to confirm that this appears to be correct.

7. Figure 2 presents percentage values within SD intervals that show 4.4% of observed values can be expected to have values greater than +2 SD or lower than –2 SD from the mean. Your analysis of the Figure 1 curve **[(*does*)(*does not*)]** show observed values

beyond 2 SDs.

8. Because the CEM settings were kept the same throughout the 200-cycle run (one atmosphere, 100% Sun's energy), the variability observed **[(*is*)(*is not*)]** due to a change in the system. So, it can be described as natural variability.

Climate Change?

Climate change, as used in this course, refers to any sustained change in the long-term statistics of climate elements (such as temperature, precipitation or winds) lasting over several decades or more, whether due to natural variability or as a result of human activity.

This definition follows the ***AMS Glossary of Meteorology, 2nd edition, 2000***, and that used by the Intergovernmental Panel on Climate Change (IPCC). (While this course employs the definition given here, keep in mind that climate change is defined by some to mean a change of climate that can be attributed directly or indirectly to human activity only. The context in which the term appears will usually inform the reader of the definition employed.)

9. Determining whether or not climate change has occurred requires comparison of **[(*climate means*) (*climate variability*)(*both of these*)]** as determined from empirically acquired climatic data for the same locality.

Return to the AMS CEM. Set the model for two atmospheres, 100% Sun's energy, 200 cycles, and introductory mode, and click on "Run". Only the atmosphere setting is different from the AMS CEM scenario examined in the first part of this investigation when it was set at one atmosphere. The two-atmosphere setting can be thought of as representing a doubling of atmospheric CO_2 compared to the one-atmosphere setting.

10. Compare this model product with that of the one-atmosphere model run. With two atmospheres, the mean is **[(*2.36*)(*4.7*)(*10.7*)]** energy units. This higher mean, compared to the one-atmosphere model run, suggests the doubling of the atmosphere has brought about a sustained change in the planetary climate system, that is, it seems to exemplify climate change.

11. The two-atmosphere model run produced a SD of **[(*2.36*)(*4.7*)(*10.7*)]**.

Knowing the means, SDs, and numbers of cycles for the one-and two-atmosphere scenarios, a statistical test can be applied to make a determination to some level of confidence that the differences in the two model products are due to other than chance. The **Student's *t*-test** is commonly employed to make such a determination. Go to: *http://www.graphpad.com/quickcalcs/ttest1.cfm*. To use this *t*-test calculator, in Step 1 click on the "Enter mean, SD and N" button, in Step 2 enter under Group 1 one-atmosphere values of mean, SD, and N (200) used earlier in this investigation, and under Group 2 enter the two-atmosphere values of mean, SD, and N (200). After being sure "Unpaired *t* test" is selected in Step 3, click on "Calculate now" in Step 4.

12. The Unpaired *t* test results that appear report a two-tailed P value of less than **[(*0.0001*) (*0.001*) (*1.0*)]**. The P value is a probability, and can have a value ranging from zero to one. The smaller the P value, the greater the probability that the difference between sample means is due to something other than chance or coincidence. The smaller the P value, the more confident you can be that the two samples you compared are from different populations, that is, they are significantly different.

13. On the same Unpaired *t* test results page, the P value reported indicates the difference between the means of the two samples is considered to be statistically **[(*not significant*)(*significant*) (*extremely significant*)]**.

14. This indicates with a high level of confidence that the difference of the one-atmosphere and two-atmosphere scenarios is due to some factor, not simply chance or coincidence. We can therefore say or infer with a high level of confidence that the addition of a second atmosphere (or doubling of CO_2) resulted in **[(*no climate change*) (*climate change*)]**.

Optional: To become more familiar with these basic statistics being applied to the AMS CEM output, compare different pairs of runs of the model including using the “random” mode and changing other settings (one at a time). Make the comparisons by calculating the *t* test.

Aircraft Contrails, Cirrus Clouds, and Climate Variability and Change:

The advent of jet aircraft and the huge growth in air traffic after World War II resulted in an increase in cirrus clouds formed by contrails from engine exhaust. A question of considerable interest to atmospheric scientists has been whether or not the increase in contrails and related cirrus clouds has impacted weather and climate. If the increase in contrails has impacted climate, it is obviously an example of anthropogenic climate change. **Figure 3** shows the prevalence of contrails as well as indications that under certain conditions contrails seed a more expansive cloud cover.

Aircraft contrails are clouds that form when hot jet engine exhaust containing considerable quantities of water vapor (a combustion product) mixes with the cold high-altitude air. They are the most visible anthropogenic atmospheric constituents in regions of the world with heavy air traffic.

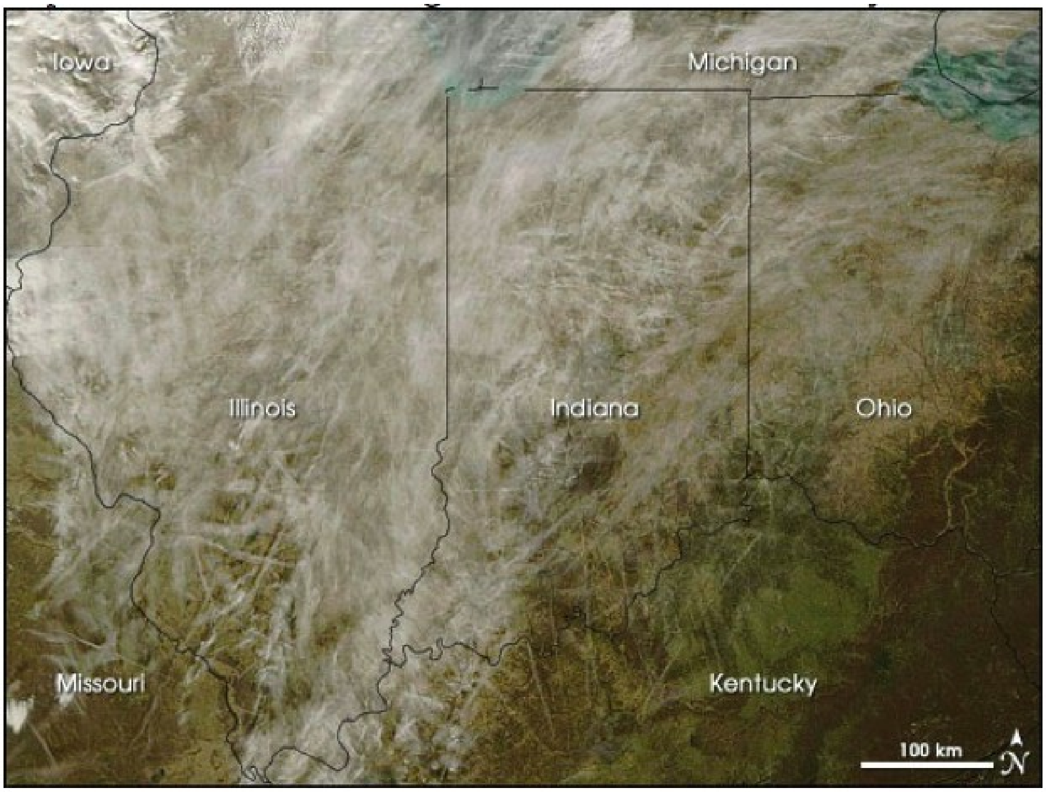

Figure 3.

NASA MODIS image of contrails over MidwesternU.S. [NASA] *http://earthobservatory.nasa.gov/IOTD/view.php?id=7161*

Because contrails and related cirrus clouds triggered by contrails reflect solar radiation and absorb and emit infrared radiation, it is reasonable to expect that their persistence and pervasiveness likely impact climate. They not only may be affecting climate at the current time, but their impact can be expected to increase as it is projected that jet air traffic will grow in the decades ahead.

A Possible "9-11" Climate Lesson

The date 11 September 2001, or simply "9/11," marks one of the darkest days in our country's history. By 9:30 EDT on that morning, it became clear to officials at the Federal Aviation Administration (FAA) that something was terribly wrong. One immediate response to prevent the possibility of other aircraft being used as destructive weapons was the remarkably quick national grounding of all commercial, military, and private aircraft. Within an hour or so, the more than 4000 aircraft in U.S. airspace and international flights headed to this country were directed to the airports nearest them. By the afternoon of 9/11, the only contrails visible on satellite images were those coming from the President's Air Force One and its two fighter jet escorts on their way to Washington, DC.

U.S. skies remained essentially clear of aircraft for more than a day. In general, the grounding remained in effect until 13 September. The grounding totally ended when

Washington's Reagan National Airport finally opened on 4 October.

The 9/11 aviation shutdown gave scientists unique opportunities to study a few isolated contrails developing without interference from neighboring contrails and to acquire evidence of possible climate shifts. A study of particular significance to climate change was conducted by Prof. David Travis (University of Wisconsin-Whitewater) comparing surface air temperatures across the country during the aircraft grounding with those before 9/11.

The Travis analysis showed that during the absence of contrails (the 11-13 September time period when skies were generally clear), the difference between the highest temperature during the day and the lowest temperature at night increased 3 Fahrenheit degrees on average and as much as 5 Fahrenheit degrees in areas of the country where contrails were usually most common. This led Travis to conclude that contrails and related cirrus clouds influenced climate by increasing the reflection of incoming solar radiation back to space during the day, thereby reducing heating at Earth's surface, and then absorbing some of the upwelling infrared radiation from Earth's surface at night. A considerable amount of the absorbed radiation is emitted back towards Earth's surface, where it has a heating effect. Together, these two processes potentially reduce the diurnal (daily) temperature range. Travis speculated that climatologically there is a net cooling effect because there are generally more flights and contrails during the day than at night.

15. Recalling the perspectives of climate as described in Investigation 1A, Prof. Travis's study of observed surface air temperatures across the country was essentially a(n) **[(*dynamically*) (*empirically*)]** based investigation.

16. Because of the distribution of contrails as displayed in Figure 3, any climate change brought on by the occurrence of contrails might best be described as **[(*regional*) (*global*)]** in scale.

While Travis's statistical treatment of climatic data in his study does show a greater temperature range and a higher mean temperature when contrails were absent, it is not clear that the evidence demonstrates unequivocally the impact of contrails on climate. A 2008 study, "Do contrails significantly reduce daily temperature range?" by Gang Hong et al, Texas A&M University, reports that the increase of the average daily temperature over the United States during the 11-14 September 2001 aircraft grounding period was within the range of natural temperature variability observed from 1971 to 2001.

Hong's study concluded that the missing contrails may have affected the daily temperature range, but their impact is probably too small to detect to a level of statistical significance. Hong showed that the diurnal temperature range is governed primarily by lower altitude clouds, winds, and humidity. Specifically, the unusually clear and dry air masses covering the Northeastern U.S. in the days following the terrorist attacks favored unusually large daily temperature ranges.

Summary: The studies referred to in this investigation are presented to demonstrate the challenges of identifying and discriminating between natural climate variability and climate change. The AMS CEM was employed to illustrate climate variability and climate change.

Studies of the 11-14 September 2001 time period when contrails were temporarily absent over the U.S. potentially provided a unique opportunity for detecting climate change, if any, due to contrail impact. Careful studies of probable causes of unusually large daily temperature ranges at the time ascribe whatever differences that were detected as explainable within the range of natural variability of atmospheric conditions.