Exhibit No.:	
Issue(s):	Weather
Witness:	Allen L. Dutcher
Sponsoring Party:	Union Electric Company
Type of Exhibit:	Rebuttal Testimony
Case No.:	ER-2012-0166
Date Testimony Prepared:	August 14, 2012

MISSOURI PUBLIC SERVICE COMMISSION

Case No. ER-2012-0166

REBUTTAL TESTIMONY

OF

ALLEN L. DUTCHER

ON

BEHALF OF

UNION ELECTRIC COMPANY
d/b/a Ameren Missouri

St. Louis, Missouri
August, 2012

Table of Contents

REBUTTAL TESTIMONY

OF

ALLEN L. DUTCHER

CASE NO. ER-2012-0166

I. INTRODUCTION AND SUMMARY

Q. Please state your name and business address.

A. My name is Allen L. Dutcher. My business address is 724 Hardin Hall, 3310 Holdredge Street, Lincoln, Nebraska.

Q. By whom and in what capacity are you employed?

A. I am employed by the University of Nebraska Lincoln ("UNL").

Q. Please describe your employment history with the University of Nebraska Lincoln.

A. I began my employment with the University of Nebraska-Lincoln in June of 1989 as an Operations Climatologist in the High Plains Regional Climate Center. I was promoted to State Climatologist in November of 1991. I continue to serve in that capacity.

Q. Please describe your duties and responsibilities as State Climatologist.

A. I am responsible for monitoring climatic conditions that can have a direct impact on Nebraska's economy. My typical duties include answering and responding to public requests for climate data, climate data reconstruction, drought monitoring, soil moisture monitoring, weather/climate forecasting, agricultural weather risk assessment, and climate product development.

In an average year, I participate in approximately 250 media interviews and respond to an additional 400 climate data requests, I have undergone weather/climate product training at the

National Climatic Data Center ("NCDC"), which is a division of the United States National Oceanic and Atmospheric Administration ("NOAA"). In addition, I am chairman of the Water Availability and Outlook Committee, which is one of three subcommittees that are part of the governor's Climate Assessment and Response Committee. I also provide weekly agricultural weather forecasts for UNL's Market Journal and KRVN Radio – Lexington. I am also a contributing author for UNL's CropWatch, a multidisciplinary newsletter that addresses topics that may have a direct impact on agricultural producer yields and net profit.

Q. Please describe your qualifications.

A. I received my B.S. at Iowa State University in 1985 with a major in Meteorology and a M.S. in Agricultural Climatology from Iowa State University in 1989. During graduate school, I was the Teaching Assistant for Introductory Meteorology and developed my research program on the topic of average time of observation bias corrections for long-term cooperative weather sites in Iowa.

After being hired at the University of Nebraska in 1989, I have worked on soil moisture modeling, thermal tracking of insect development, weather risk assessment, climate data reconstruction, automated weather data network station quality control techniques, developing drought monitoring tools, and answering climate data inquiries.

Q. What is the purpose of your rebuttal testimony?

A. The purpose of my rebuttal testimony is to respond to the direct testimony of Missouri Public Service Commission Staff ("Staff") witness Dr. Seoung Joun Won, and specifically his analysis of normal weather to use for weather normalization calculations. There is a long history of making specific weather adjustments as part of the weather normalization process for the purposes of establishing rates for Ameren Missouri, as is explained in the rebuttal testimony of Ameren Missouri witness Steven Wills.

Q. What are your primary conclusions?

A. I conclude that the Missouri Public Service Commission should continue to apply two weather corrections (1988 and 1996) that had previously been applied by both Ameren Missouri and Staff. Also, I recommend an additional weather correction for 2002. Finally, I conclude that Staff's new methodology for determining normal temperatures cannot be replicated and relies upon estimated data and so must be rejected at this time.

II. STAFF'S APROACH

Q. Did Dr. Won use a different methodology for setting normal weather than had been used in previous Ameren Missouri rate cases?

A. Yes, as Dr. Won testified, he relied upon normal temperatures for the period 1981 through 2010 published by the NCDC in July of 2011. Dr. Won did not apply the adjustments to that data that had been agreed upon in previous rate cases (these adjustments stemmed from a Double Mass analysis performed specifically for the weather station for Ameren Missouri's load, which I provided in an earlier Ameren Missouri case.)[1] As Company witness Steven Wills discusses in his rebuttal testimony, and as I also explain below, historically, the Staff had agreed to the adjustments I developed and has used them in every Ameren Missouri rate proceeding since they were initially developed. Instead of continuing to make these adjustments, Dr. Won changed the Staff's approach and relied on a "homogenization" procedure used by NCDC.

Q. Please explain the approach taken by Dr. Won in the Staff's direct case.

A. The methodology that Dr. Won employed in his attempt to determine the impacts of station moves and/or sensor changes for St. Louis Lambert International Airport weather

[1] Case No. EM-96-149

station ("Lambert Field") uses homogeneity techniques undertaken by the NCDC in their calculations of the 1981-2010 normal temperatures. This technique uses a "pairwise" comparison between available weather stations within close proximity to identify data discontinuities due to station moves and/or sensor changes at Lambert Field. These available stations include official NOAA weather stations and "cooperative" sites.[2] Pairwise comparison, in short, is a process where temperatures from one station are compared against surrounding stations, filtered to remove stations with low correlations, examined to identify when station discontinuities occur, and adjusted with a correction factor that accounts for the discontinuity.

The overall goal of the NCDC homogenization analysis was to develop an automated technique that identified change points[3] that impact the way a weather observation station records observations in relation to a large number of widespread neighboring weather observation stations. To understand why NCDC took this approach, one must understand the NCDC's dilemma. NCDC is required to develop 30-year normal temperatures for over 15,000 stations every 10 years and this work must be completed within a window of just 18 months. Manual inspection of data comparisons would be impossible due to time constraints, so NCDC had to develop a more expeditious computational method for identifying change points.

Compare that approach to the previous Double Mass analysis that I performed on the Lambert Field weather station. As a part of that work, I spent over 60 hours on data analysis to

---

[2] A cooperative station is a station at which observations are taken or other services rendered by private citizens, institutions, etc. Services rendered usually consist of taking instrumental or visual observations and transmitting reports. Data from cooperative stations is generally less reliable than that recorded at other weather stations.

[3] With the Double Mass analysis, one accumulates the differences of the weather readings between the target station and the reference station. That result is graphed. If there are no discontinuities between the two weather stations, the graph will contain a straight line. If there is a break in the line, then a change point or discontinuity has been identified. In order to have accurate comparisons of weather readings before and after the point in time when the discontinuity is identified, a correction must be applied to weather readings prior to the change point.

develop accumulated difference curves and associated regression results. Another 70 hours were spent documenting my findings. If the NCDC used a similar approach, it would require 900,000 (60 hours x 15,000 stations) man-hours to develop and analyze accumulated temperature difference curves. Given the NCDC's time constraints, they needed to devise a computer simulation method that could quickly identify major discontinuity shifts at all 15,000 weather stations. NCDC simply does not have time to perform at every weather station the type of analysis that I performed to identify and quantify the discontinuities at the Lambert Field station.

Q. Are the two methodologies similar?

A. The major difference between the two techniques is that the Double Mass analysis that I used accumulates the Delta T units (i.e., differences in temperature) over time using actual daily data and searches for a pivot point that indicates a relationship change (slope change) between two stations. The NCDC technique plots individual Delta T monthly values over time to identify a point in time where there is a relationship change.

It is important to note that the NCDC uses the daily Historical Climate Network ("HCN") to determine these break points by examining how Delta T behaves between comparison stations. I believe the NCDC homogeneity calculation is a valid technique for identifying major discontinuity events, but the correction factors Staff applied to the Lambert Field weather station do not match up with my findings. This is a significant red flag, because as I noted, my findings were based upon a specific examination of the Lambert Field station, as opposed to the more expeditious homogenization technique applied to 15,000 stations. That the correction factors used by the Staff do not match up is likely because NCDC used daily data to identify discontinuity events, but chose to use monthly HCN data to develop their correction factors.

Q. Why would this be a concern?

A. Because the monthly HCN data set that was used by the NCDC contains both homogeneity adjustments and time of observation adjustments, and thus their adjustments have been calculated using estimated data. It is more appropriate that, once discontinuity events are identified using the Double Mass technique, correction factors are determined by examining the actual physical temperature records and not through the use of estimates.

There are many similarities between the NCDC technique and the Double Mass technique that I have used in my current analysis and in my prior analysis. Both methods look at identifying abrupt changes in Delta T by identifying when distinct periods of temperature consistency between a target and comparison station abruptly change. The homogeneity pairwise method looks at daily data to identify discontinuities then uses the monthly HCN to develop adjustment corrections. The Double Mass analysis also uses daily data for pairwise comparison, but uses the same daily data to determine the appropriate correction to account for identified discontinuity events. With the Double Mass technique, potential discontinuity points are identified when the accumulated difference plot of comparison stations versus the target station indicates that a slope change has occurred on the same calendar date.

Q. If the two methodologies are similar, why is the Double Mass technique superior?

A. There are two major reasons why I feel that the Double Mass technique is superior to Staff's (meaning, NCDC's) technique. First, the Double Mass technique is simple to compute and the computation methodology remains static. Second, data derived from the Double Mass methodology will be consistent over time since the calculation methodology doesn't change. The same things cannot be said with regard to the NCDC homogeneity calculations, as history has shown that their monthly HCN data set has already undergone three revisions and it will likely be revised in the future. In contrast, the Double Mass analysis uses temperature data that the NCDC has determined to be official, with no further revisions required. This means that future analysis runs can replicate past findings without concern that historical observations will be altered in the future and subsequently eliminates the need of for recalculating previous results. The ability to be able to replicate results is critical. Otherwise, one cannot have a high degree of confidence in the methodology that was used.

While the NCDC homogeneity methodology can be used to identify significant station discontinuities, it is unlikely to properly identify or correct for smaller changes because they have not been documented within the sub-station history files. My technique (Double Mass) identifies “all’’ impacts, documented or undocumented, by accumulating temperature differences over time between the target station and a comparison station. If the target station shows duplicate accumulated temperature unit changes with a second nearby station, then a discontinuity point has been identified and the resultant change in the temperature relationship between the two stations can be quantified. These discontinuity points are only valid when the Double Mass analysis performed between comparison stations **do not** show the same slope change at the discontinuity dates identified when performing the same analysis on the target and comparison stations. In summary, the Double Mass approach produces a more accurate representation of temperature relationships between Lambert Field and surrounding comparison stations because it uses actual climate observations at each step of the calculation process and does not rely on estimated data – as does the homogenization approach -- to determine an appropriate correction factor.

Q. Does Dr. Won’s direct testimony explain why Staff prefers the pairwise technique?

A. It does not. Dr. Won is simply relying upon an assumption that the NCDC 1981-2010 normals (homogeneity) process is valid. Dr. Won agreed in his deposition that he could not duplicate NCDC's analysis and that he was relying upon the accuracy of NCDC adjustments.[4] Based upon that unproven assumption, the Staff has essentially decided to discard the previous Double Mass analysis that was performed by my office and the Missouri State Climatologist, and the subsequent agreement which allowed both sides to reanalyze the data to insure that a mutually agreeable temperature adjustment could be reached. Neither the Staff's workpapers, testimony, nor their responses to discovery in this case demonstrate that this homogenization approach is superior to the Double Mass analysis previously employed by both sides in Case No EM-96-149 and in every Ameren Missouri rate case thereafter. For the reasons discussed in my testimony, it is my opinion that the homogenization approach is inferior.

Q. Do you know how NCDC's comparison technique works?

A. From what can be discerned based on publicly available data, NCDC communications with the Staff, and my own contacts at NCDC, once data discontinuity points were identified, temperature data from the NCDC's monthly HCN data set was used to develop the discontinuity adjustments. The NCDC monthly HCN data set currently in operation is Version 3. That alone should be a warning flag to anyone using the data. Multiple revisions of data sets are typically a signal that some issue(s) arose in prior data sets and additional computations were needed to address those specific issues.

Q. Should Staff's use of monthly HCN data cause the Commission to doubt Dr. Won's results?

A. Yes. Because the monthly HCN data set was used by Staff, I have serious reservations about the validity of the Staff's calculations. This data set not only contains station

[4] Deposition of Dr. Won, August 6, 2012, p. 55, l. 5-10 and p. 61, l. 7-9.

discontinuity adjustments, it also contains time of observation adjustments (adjusting all temperature records from individual stations to midnight regardless of when the observations were actually made). This was done so that climate trend analysis across broad areas could be conducted after observation time discontinuities between stations had been addressed.

The monthly HCN data set used to develop monthly and daily normals by Staff contains time of observation adjustments to cooperative stations, as well as quality control estimates for missing and suspect data. In short, stations used for comparison against Lambert Field were cooperative sites that take morning or afternoon observations. The subsequent data set contains multiple adjustments that were used in the creation of monthly and daily normals. In simple layman's terms, adjustment **estimates** have been incorporated into the monthly HCN data set, including from cooperative stations which as noted earlier have inherent limitations due to the manner in which the data is collected.

Q. How does this compare to the stations you reviewed as part of your analysis?

A. The Double Mass analysis I used looks at the rate of accumulated temperature differences over time between two official stations. No data adjustment techniques (similar to the NCDC undertaking) are necessary. We are trying to measure the direct impacts of a station move or sensor change by using the highest correlated stations that are within close proximity of the target site (Lambert Field). As long as the comparison station doesn't undergo a discontinuity issue during the time period prior to and after a suspected move at the target station, a specific rate of change between the two stations can be identified and quantified without the use of estimates.

Q. Is the Double Mass technique commonly accepted and used by climatologists?

A. In one form or another, yes it is. Even NCDC's pairwise methodology is a form of a Double Mass analysis. The term "Double Mass" was brought to my attention by my former boss, Dr. Ken Hubbard, who found the technique in an engineering text book. We initiated the first attempt at the technique with a similar analysis for Lincoln Electric System ("LES") in 1993 when NOAA commissioned the new Automated Surface Observing System ("ASOS") site at the Lincoln Airport. NOAA's load models were failing and they needed to identify the cause of failure. We found a significant change in way temperatures were measured by the new ASOS sensor compared to the replaced Model HO83 sensor. By using nearby locations, we were able to successfully identify the rate of change and recommend the appropriate adjustments to the data. LES was able to apply that correction to their weather records and successfully account for the ASOS adjustment in their load models. Our results were documented and published in "Tripod," a former automated weather data network publication issued by the High Plains Regional Climate Center.

Other climatologists use the Double Mass technique. For example, the Double Mass technique was employed by Thomas B. McKee, State Climatologist for the state of Colorado, hired by the National Weather Service, Office of Meteorology under a NOAA grant, to investigate the difference between how the new ASOS sensors then being installed by NOAA measured temperatures in comparison to the old HO83 sensors that were to be replaced.[5] He examined a total of 76 stations using side-by-side comparisons and plotting the accumulated temperature differences between the new ASOS sensors and the old HO83 sensors from 1994-1995. He found that the majority of sites had a cool bias when the new ASOS sensor was compared to the old HO83 sensor, with an average cooling of 0.3 C (0.53 F). Of the 76 stations,

[5] Temperature Data Continuity with the Automated Surface Observing System. Alison D. Schrumpf and Thomas B. McKee, Climatology Report No. 96-2. June, 1996.

only nine were found to have a warm bias. In addition, he found that the ASOS sites were cooler than their former locations because the stations were relocated to more open areas that allowed for better air flow through the temperature sensor shield.

The third variation of the Double Mass technique is the NCDC pairwise comparison, which examines the temperature differences between stations to identify when temperature discontinuities occur. Their Double Mass method plots the daily differences to identify discontinuities, as opposed to my Double Mass technique which accumulates those differences to identify the same discontinuities and examine whether periods of discontinuity are occurring within the particular month.

Q. Did NCDC's methodology identify changes in both the maximum and minimum temperatures?

A. Staff has stated that its (NCDC's) analysis indicated no adjustment was necessary to maximum temperatures due to the 1996 ASOS installation. That is, they say that there was no discernible trend change for maximum temperatures when the station was relocated and the new ASOS sensor was installed. This is at odds with McKee's study of 76 ASOS stations which found that nearly 90% of the new ASOS stations were cooler (meaning their maximum temperatures do need to come down).

While Staff recommends no changes for maximum temperatures, they advocate for three minimum temperature adjustments. The first minimum temperature adjustment is for a 2002 St. Louis Lambert Field discontinuity and results in a recommended adjustment upwards of 0.7 degrees F from 1981 to the discontinuity date in 2002. Staff also found a 1996 ASOS installation required a cooling adjustment of 1.6 degrees F for minimum temperature from 1981 to the ASOS installation date in 1996. The third adjustment was for the 1989 discontinuity was 1.2 degrees F from 1981 to the discontinuity date in 1989.

Q. Have you conducted a new Double Mass analysis respecting Lambert Field?

A. Yes, I have. The results of that analysis are reflected in Schedule ALD-ER1.

Q. Did your new analysis find discontinuities that should be addressed?

A. Yes. My findings are based upon a Double Mass analysis using St. Charles, St Charles 7 SW, and the St Louis Science Center weather stations. The results indicate that the 2002 minimum temperature adjustment was between 0.00 degrees F and 0.09 degrees F, while the maximum temperature adjustment ranged from 0.57 degrees F to 0.63 degrees F. For the 1996 ASOS installation and Lambert Field station move, preliminary analysis indicates that minimum temperatures cooled 1.6 degrees F to 2.16 degrees F, while maximum temperature cooled 0.80 degrees F to 0.97 degrees F. The analysis for the 1989 discontinuity event is incomplete due to time constraints required since the Staff's direct case was only filed about 6 weeks ago.

Q. Staff's advocates that the 3 homogeneity points identified through their analysis require no adjustment to maximum temperatures. Is this theoretically possible when minimum temperatures required two large warming adjustments (>1 degree F) and one cooling adjustment (1.6 degrees F) for the identified discontinuities?

A. Not in my opinion. Let's be generous and say that 5% of the locations analyzed across the U.S. needed no adjustment to maximum temperatures for a recognized discontinuity. The odds that this could occur three consecutive times (for all three of the Lambert Field station changes) would be 5% x 5% x 5%, or 1.25 chances out of 10,000 -- .000125, or barely more than one-hundredth of one percent. It is possible by random chance that the three discontinuity events would indicate that no significant adjustments to maximum temperatures were necessary as advocated by Staff, but the statistics would indicate that it is extremely improbable.

In addition, it is important to remember that the location of the weather recording station prior to the ASOS installation at Lambert Field was several miles away and located within close proximity (< 25 feet) to a parking lot. The subsequent move to the open area between runways at the airport would strongly suggest that an abrupt change in the climatic conditions had occurred. Staff’s recommendation for a minimum temperature correction of 1.6 degrees F matches the correction factor I recommend in the previous case which addressed this matter. With such a substantial change occurring to the minimum temperature, I can’t reconcile how maximum temperatures could not be impacted. To put it simply, the weather station move in 1996 (from a parking lot to a grass surface) must have had an impact on maximum temperatures, typically a cooling effect.

Q. Did you examine the Staff's adjustments to see if they were properly calculated and applied?

A. Yes, I did. I ran Staff’s adjusted Lambert Field daily maximum and minimum temperature adjustments against St. Charles daily maximum and minimum temperatures. If Staff's proposed corrections had been properly calculated and applied, then the Double Mass accumulation plots between Lambert Field and comparison locations should result in a linear plot through the entire 30 year period, without any significant slope change. This is because the discontinuity would have been addressed and the adjustment would have brought it back to the linear trend..

Schedule ALD-ER1 contains Double Mass plots of my technique applied to three comparison sites in close proximity to Lambert Field, St Charles, St Charles 7 SW, and St Louis

Science Center. Also included is a Double Mass plot of the Staff's corrected Lambert Field daily data ran against the raw weather records for St Charles. If you overlay the plots of the minimum temperature (corrected vs. uncorrected), the 1996 correction proposed by Staff appears to eliminate the discontinuity due to the station and sensor change that occurred when the ASOS site was installed at the airport.

However, further examination of the 2002 discontinuity event reveals that Staff's minimum temperature adjustment results in an identical plot of the accumulated temperature units as the uncorrected plot. In short, Staff's correction does not appear to correct for the discontinuity associated with the 2002 event.

Further comparison of the both St Charles and St Charles 7 SW uncorrected minimum temperature accumulation plots against Lambert Field reveal that three (3) linear slope changes from 2001 through 2010 occurred at similar dates. This indicates that Lambert Field's temperature sensor may have been having measurement issues and needs to be investigated to see if additional adjustments are necessary.

Not surprisingly, the Double Mass plot of corrected maximum temperatures for Lambert Field was identical to the uncorrected plot for the same plot. We would expect this result because Staff indicated that their pairwise homogeneity analysis found that the three discontinuity dates had no significant temperature change and they didn't need to apply any corrections to adjust historical observations to current maximum temperature observations.

Both Double Mass plots of uncorrected accumulations of maximum temperature units reveals that both St Charles and St Charles 7 SW had a distinct slope change immediately in regard to the 1996 ASOS installation. With both stations indicating a significant slope change near the same date, I can confidently state that there was indeed a discontinuity at Lambert

Field, it can be measured, and the resultant change was significantly greater than zero. The Staff's conclusion that it was zero is simply not borne out by the facts, or this analysis.

Q. Do you have any other concerns with the use of NCDC's technique?

A. At this point in time, there is no option available to compare how the derivation of the new 1981-2010 normals compare to the 1971-2000 normals when using the same technique employed with the most recent normals' calculation. The NCDC has stated on their web-site that an internal consistency test has been run, but they have not made their results available to the public. Until they release this analysis to the scientific community, there is no way to know whether their new techniques used in the creation of the 1981-2010 normals is superior to the previous calculations employed in the creation of the 1971-2000 normals that became operational at the beginning of 2002.

Q. How did NCDC change their process for identifying discontinuities?

A. The calculation of daily normals by the NCDC during previous thirty-year normal period (1971 – 2000) used the monthly mean minimum and maximum temperatures and spline fit[6] a curve to that data to come up with **estimates** for daily normals. In short, monthly averages (Jan, Feb, …, Dec) were placed at the mid-point of each month, then a curve was fit to the data. Daily normals were derived by determining the intersection point for each of the 365 days of the year based upon the spline curve. Again, NCDC was relying upon estimates, as opposed to actual analysis specific to Lambert Field used in my analyses.

The NCDC has modified their calculations for the 1981-2010 normals period by dropping the spline fit methodology and creating "true" daily normals based upon actual daily data. Using information that has been provided by Staff in regard to their calculation of daily

[6] Spline fit methodology finds a curve for a set of data points. NCDC takes the monthly normal temperatures and put a value at the midpoint of each month and then fits a curve to those data points. They take the curve that is generated and find a daily normal derived from the intersection point of that day on the curve.

normals, it appears that Staff applied a uniform correction factor to daily data based upon monthly corrections. Staff's methodology is not consistent with previous renditions undertaken the NCDC that used the spline fit technique or their current methodology of calculating true daily normals.

Q. Have you been able to verify Staff's calculations?

A. I can't be certain as to the exact methodology that Staff employed in the calculation of daily normals, since they offered little written evidence in regard to their methodology in the initial analysis submission report or in response to subsequent discovery requests. When asked to provide this information, Staff did nothing more than provide a spreadsheet which fails to provide any evidence that they have accurately depicted the total impact of station moves and sensor changes at Lambert Field. In fact, Staff's entire weather analysis was summed up in five paragraphs, with one of them dedicated to introducing the topic.

Q. Is it appropriate to rely upon methodologies that cannot be replicated or reviewed by peers in the field?

A. No, it is not. Standard protocol at academic institutions and other reputable research institutions is that analysis is only valid if it can be defended to a panel of peers and replicated. The problem must be defined and analyzed, and then a solution to it must be found. The research process must be fully described from beginning to end, results must be detailed, and then the reason(s) why the results are relevant and/or superior must be given. This is required so that anyone attempting to duplicate the procedures used in the study can replicate the results of the researcher performing the analysis. The five paragraph description of Staff's techniques and adjustments is grossly insufficient.

Q. What additional information would need to be provided in order to review Staff's analysis?

A. The following information has not been provided in regard to their temperature adjustment calculations:

1. An average homogeneity adjustment plot has been supplied for maximum and minimum temperatures, yet individual station adjustment rates used to calculate the average adjustments can't be found. Therefore, it is impossible to determine the variability (spread) of the final correction adjustments. This significantly undermines the Staff's results because the more narrow the variability of the range, the more confidence one can have in the correction value proposed. Without this information, I cannot have confidence in these adjustments.
2. Staff indicates that it verified NCDC's adjustments through direct communication and its own review of daily observations. However, Dr. Won admitted twice in his deposition that he was unable to replicate or duplicate NCDC's analysis.[7] Dr. Won indicated that he "verified" the results by checking the consistency of the NCDC research, asking them to re-do the calculation and by looking for published papers on NCDC's homogenization pairwise comparison process.[8] While that type of verification might be appropriate in some settings, it is not sufficient to label something as "verified" in the scientific community. For the type of analysis being done to find normal weather, verification means replication of methodology, something Dr. Won did not do. Accordingly, there is no evidence that Staff's review of daily observations verifies NCDC's adjustments.

[7] Deposition of Dr. Won, p. 54, l. 5-10 and p. 60, l. 20 through p. 61, l. 1.
[8] Id, p. 61, l. 10 – 21.

3. Staff indicates NCDC provided a peer review paper that describes their homogenization procedure for removing discontinuities. Staff has provided no evidence that indicates the NCDC adjustments have been verified as valid by outside agencies (non NOAA affiliated). This is important because the NCDC does not have an independent advisory panel that insures their computational technique(s) and subsequent results are valid.
4. Staff has failed to describe in detail (writing) each step of their process they took in deriving their adjustments, despite being asked.
5. It is virtually impossible to replicate an analysis if you are lacking detailed information on how each step of the process has been handled. That Staff can't provide it means that the Commission cannot have confidence in it nor can they rely upon it for the purposes of this case.
6. Staff has not produced any evidence explaining why their technique improves on the previous Double Mass analysis performed by both sides in the earlier case where the adjustments were agreed upon, and as noted, have been used for several cases.
7. Staff has failed to explain how they will handle future discontinuity issues when they arise. How will they employ their proposed methodology to identify future discontinuity issues? Can their procedure be duplicated by other parties? How much time will be required to calculate discontinuity adjustments when they arise in the future?
8. Staff has failed to provide a logical explanation as to why no adjustments were necessary for maximum temperature at the three discontinuity points identified in the Staff Report, but yet minimum temperatures were adjusted in both positive and negative directions. At a bare minimum, I would expect that Staff could provide supporting evidence of why a station can move several miles without showing a need for a maximum temperature

adjustment, especially when minimum temperatures have shown that an adjustment is necessary to account for discontinuities. Second, is it even theoretically possible that minimum temperatures require three distinct adjustments, while maximum temperatures are not impacted and require no adjustment? The answer, in my opinion, is no.

Q. For future cases, do you have a recommendation for the Commission?

A. Based upon past history, potential discontinuities will arise with regard to Lambert Field temperature records in the future due to station relocation and/or sensor changes/replacement. The parties need to find a mutually agreeable methodology for addressing the impacts of these discontinuities. The methodology needs to be simple enough that it can be replicated by both sides or it should be run independently with both sides agreeing on the final correction results.

I advocate the continued use of the Double Mass approach since it is able to isolate "all" suspected discontinuity points. The initial development of the meteorological data base will require a thorough analysis of Lambert Field against surrounding stations to insure that any suspected discontinuity points are the result of a change at Lambert and not a comparison station. Discontinuities can then be adjusted in the historical daily weather data file that is used by both sides for weather normalization and load forecasting.

Once the historical data has been adjusted to the mutual satisfaction of both sides, the only requirement will be to address future discontinuities that will eventually arise at Lambert Field. In essence, the Double Mass analysis will need to be run on a periodic basis to identify the discontinuity date and the subsequent correction factor that needs to be applied to historical records to calibrate them to the current temperature recordings.

If the analysis is set up properly, periodic Double Mass analysis runs should be easily to complete within a one to two day time frame. The overall benefit would be that both sides would not have to spend valuable resources coming up with new ways to adjust data every time a question arises as to whether historical temperature records are adequately reflecting the way Lambert Field is reporting daily maximum and minimum temperatures.

Q. For purposes of this case, do you have a recommendation on which methodology should be used in the weather normalization process, and why?

A. Yes, I do. The Commission should adopt the results of my Double Mass analysis, for several reasons.

1. My Double Mass analysis is a more rigorous analysis than NCDC could possibly preform on all of its weather stations. It is a thorough statistical analysis that focuses many hours of effort in identifying and quantifying the parameters of the discontinuities at Lambert Field. NCDC cannot afford to do this at every weather station and doesn't really need to do so for its purposes.

2. The NCDC homogeneity process uses estimated data as part of its corrections for observation bias while my Double Mass methodology is based upon actual daily temperature data, making it inherently more accurate.

3. NCDC's homogeneity analysis cannot be replicated. Without replication, it cannot be scientifically validated and should not be relied upon to make adjustments in this case.

4. The data set used to adjust the normal temperatures has been revised three times and is likely to be revised in the future, whereas the data underlying my Double Mass analysis is final and very unlikely to change.

5. NCDC's homogeneity analysis also causes the illogical result that three measured discontinuity events would impact minimum temperatures but have no impact on maximum temperatures.

In short, the Double Mass analysis results in an answer that is scientifically sound and is capable of being reproduced and verified. The same cannot be said of the NCDC's homogeneity process, which makes it inappropriate for the Commission to rely upon it in this case.

Q. Does this conclude your rebuttal testimony?

A. Yes, it does.

BEFORE THE PUBLIC SERVICE COMMISSION
OF THE STATE OF MISSOURI

In the Matter of Union Electric Company d/b/a Ameren Missouri's Tariffs to Increase Its Annual Revenues for Electric Service.	)))	File No. ER-2012-0166

AFFIDAVIT OF ALLEN L. DUTCHER

STATE OF NEBRASKA

COUNTY OF LANCASTER

Allen L. Dutcher, being first duly sworn on his oath, states:

1. My name is Allen L. Dutcher and my office is located in Lincoln, Nebraska and I am State Climatologist for the School of Natural Resources at the University of Nebraska Lincoln.

2. Attached hereto and made a part hereof for all purposes is my Rebuttal Testimony on behalf of Union Electric Company, d/b/a Ameren Missouri, consisting of 21 pages and Schedule(s) ALD-ER1, all of which have been prepared in written form for introduction into evidence in the above-referenced docket.

3. I hereby swear and affirm that my answers contained in the attached testimony to the questions therein propounded are true and correct.

Allen L. Dutcher

Subscribed and sworn to before me this 13TH day of August, 2012.

Shellie J. Hanneman
Notary Public

My commission expires:

GENERAL NOTARY - State of Nebraska
SHELLIE J. HANNEMAN
My Comm. Exp. April 1, 2016

Using the Double Mass Analysis Technique to Isolate and Define Data Discontinuities for the St Louis Lambert International Airport Historical Temperature Records

By:

Allen Dutcher

Nebraska State Climatologist

Disclaimer Statement

The attached report attempts to address the issue of data reconstruction in regards to the St. Louis Lambert International Airport from 1981 through 2010. This analysis was performed by the Nebraska State Climatologist under a contractual agreement with Ameren. The results and conclusion expressed in this document have been compiled by the Nebraska State Climatologist and are not a reflection of the views expressed by the University of Nebraska-Lincoln.

Overview

The foundation of my Double Mass analysis technique has been previously described in the report I submitted in regards to Case No EM-96-149. The methodology is based upon the principle that two locations in close proximity will measure similar weather observations, but either the environment surrounding these locations are different or sensors at these sites measure air temperatures at a different rate. In either scenario, the Double Mass technique allows for the investigation, identification, and the adjustment factor to account for these discrete differences.

The basic principle of the Double Mass analysis is to compare temperature differences between 2 locations and accumulate those differences over time. If a strong correlation is found, the accumulated difference curve will project a straight line, with the deviations about that straight line due to seasonal factors (wind speed, relative humidity, and sunshine) that impact the flow of air across the sensors surface. As long as the relationship between the two stations remains linear after a discontinuity point is identified, the slope change can be derived and an adjustment can be calculated to correct historical observations to the target stations current mode of monitoring air temperatures.

The Double Mass methodology also looks at all comparison stations by also plotting Double Mass curves to examine whether a suspected discontinuity event is the result of a change at the target station or is the result of a change at one or more of the comparison stations. If several comparison stations exhibit similar slope changes at a suspected discontinuity point, then there is a high degree of certainty that the temperature measurement change occurred at the target station.

The Double Mass technique was employed by McKee (Appendix 2) when he investigated the difference between how the new ASOS sensor measured temperatures in comparison to the old HO83 sensors that were to be replaced. A total of 76 stations were investigated using side by side comparisons and plotting the accumulated temperature differences between the two sensors from 1994-1995. He found that the majority of sites had a cool bias when new ASOS sensor was compared to the old HO83 sensor, with an average cooling of 0.3 C (0.53 F). Of the 76 stations, only 9 were found to have a warm bias. In addition, he found that the ASOS sites were cooler than their former locations because the stations were relocated to more open areas that allowed for better air flow through the temperature sensor shield.

The Double Mass analysis technique allows for the intense scrutiny of station to station relationships, which is useful for data reconstruction and/or monitoring temperature relationships in real time. Not all discontinuities are the result of sensor changes or station moves. Electronic sensors, such as the temperature sensor at the St Louis Lambert International Airport are prone to drift. Drift is defined as a sensor that gradually fails at its upper or lower temperature measuring limits. Using the Double Mass technique on daily temperature data can identify these periods of drift, if they exist. If a relationship trend between the target station and comparison station exists prior to and after the suspected sensor drift issue, then the target station temperature records can be adjusted with an appropriate correction factor.

The methodology that Missouri PSC employed in their attempt to determine the impacts of station moves and/or sensor changes for St. Louis Lambert International Airport uses a Pairwise comparison technique developed by Menne and Williams (Appendix 3) which served as the foundation for the National Climatic Data Center (NCDC) to calculate the 1981-2000 normals for weather sites across the United States. This technique uses pairwise comparisons between stations to identify data discontinuities due to station moves and/or sensor changes. In short, temperatures from one station are compared against surrounding stations, filtered to remove stations with low correlations, examined to identify when station discontinuities occur, and then adjusted with a correction factor that accounts for the discontinuity.

The overall goal of the NCDC homogenization analysis was to develop an automated technique that identified change points that impact the way a station records observations in relation to neighboring stations. Understand the NCDC's dilemma. They are required to develop 30 year normals for over 15,000 stations every 10 years and it must be completed within a window of 18 months. Manual inspection of data comparisons would be impossible due to time constraints, so an efficient computational method for identifying change points was necessary.

The major difference between the two techniques is that the Double Mass analysis accumulates the Delta T units over time using daily data and searches for a pivot point that indicates a relationship change (slope change) between two stations. The NCDC technique plots individual Delta T monthly values over time to identify an adjustment factor for discontinuity events.

What is important to note is that the NCDC uses the daily Historical Climate Network (HCN) to determine these break points and that they were seeking to identify these by examining how delta T (difference in temperatures) behaves between comparison stations. I believe the NCDC homogeneity calculation is a valid technique for identifying major discontinuity events, but the correction factors they applied to St. Louis Lambert International Airport do not match up with my initial findings that are documented later in this report.

An important point should be mentioned in regards to McKee, Menne, and my Double Mass technique. Each method attempts to identify discontinuity events, whether they are documented or not. Appendix 4 lists all of the available information in regards to station visits for each location used in my analysis. Every discontinuity is not documented in the metadata files archived at the NCDC. If a non-published discontinuity exists, all 3 methodology variants should identify when and the length of the suspected event.

Double Mass Methodology

Daily temperature records from 1981-2010 were obtained for St Louis Lambert International Airport, which I call the target station. Three additional station in close proximity were selected as comparison stations; St Charles, St Charles 7 SW, St Louis Science Center. The data was acquired through the High Plains Regional Climate Center and duplicates the daily observations for the target and comparison stations listed in Staff's spreadsheet called: **stl1981-2010adjustmens.xlsx**.

Daily data from St Louis Science Center does not appear in Staff's spreadsheet and was not used in their analysis because the NCDC site listed it has having a poor correlation to St Louis Lambert International Airport temperature records. Even though I performed the Double Mass analysis between Lambert and the Science Center, I would not have selected it as a valid comparison site because over 30 percent of the data within the 30-year period analyzed was missing.

Before calculations of accumulated temperature differences can be attempted, I had to examine each of the stations daily observation records and remove data points where missing observations occurred. The removal of missing data will not impact the relationship between the target and comparison stations as long as the relationship prior to and immediately after missing data point(s) is consistent with the temperature unit accumulation trend established in the period prior to the identified missing data point(s). The treatment of missing data in this analysis is consistent with how McKee (Appendix 2) in his side by side comparison of the new ASOS sensor and replaced HO-83 sensor.

The accumulated temperature plots are accumulated over time and the subsequent plot is examined for abrupt slope changes that signify potential data discontinuity events. By examining the target vs comparison station(s) accumulation plots and comparison vs comparison station(s) accumulation plots, it is possible to identify what station is responsible for the indicated discontinuity event. If enough stations can be identified as highly correlated to the target station through slope linearity before and after the alleged discontinuity points, a precise measure of the slope change can be determined by the average change from all of the highly correlated stations involved in the analysis.

In theory, there is no distance limit from the target location when selecting highly correlated comparison sites if all are measuring the same atmospheric conditions. However, the farther one moves from the target location, the more likely it is that the correlation will diminish because specific weather events may occur at one site and not the other. This alters the temperature difference between the target and comparison site and may lead to non-linearity issues. In simple terms, it would be unlikely that a Double Mass temperature comparison between St Louis Lambert International Airport and New York City would yield a strong enough correlation to be quantified.

Plots of the Double Mass analysis for accumulated maximum and minimum temperature units between St Louis Lambert and the three (3) nearby stations (St Charles, St Charles 7 SW, and St Louis Science Center) appear in Appendix 1. The plots also appear in spreadsheet **Amerendm(new).xlsx** that I have provided to document the calculations performed using the Double Mass technique on daily temperature differences between St Louis Lambert International Airport and the 3 comparison sites.

Data Results

The Double Mass analysis I performed between St Louis Lambert International Airport and the 3 comparison sites (St Charles, St Charles 7 SW, and St Louis Science Center) can be found in the file **Amerendm(new).xlsx**, with Appendix 5 listing the data contained within the spreadsheet. The resultant Double Mass plots of minimum and maximum temperature accumulations can be found in Appendix 1 and also includes the 3 discontinuity dates identified by Staff.

Regression analysis for the discontinuity periods identified by Staff can be found at the top of sheets 2, 3, and 4 immediately to the right of the Double Mass analysis data. The plots contained below the regression analysis are the same plots that also appear in Appendix 1. The two additional plots are the result of applying the Double Mass technique between the Staff corrected St Louis Lambert International Airport daily data and the highest correlated minimum temperature station (St Charles) of the 3 sites I chose for the analysis. This corrected data appears in **Staffdm(new).xlsx** , along with the same regression analysis and graphical techniques employed in **Amerendm(new).xlsx**.

Staff advocates through their methodology that was described on pages 73-74 of their submitted testimony that the minimum temperature adjustment for the 2002 St. Louis Lambert International Airport discontinuity results in an adjustment upwards of 0.7 F from 1981 to the discontinuity date. They found the 1996 ASOS installation required a cooling adjustment of 1.6 F for minimum temperature from 1981 to the ASOS installation date. The third adjustment was for the 1989 discontinuity was 1.2 F from 1981 to the discontinuity date. The also indicated that the homogeneity analysis found that no significant adjustments were necessary to maximum temperatures during the entire 30 year period.

My preliminary findings were based upon Double Mass analysis using St. Charles, St Charles 7 SW, and the St Louis Science Center indicate the 2002 minimum temperature adjustment was between 0.00 F and 0.09 F, while the maximum temperature adjustment ranged from 0.57 F to 0.63 F. For the 1996 move, preliminary analysis indicates that minimum temperatures cooled 1.6 F to 2.16 F, while maximum temperature cooled 0.80 F to 0.97 F. The analysis for the 1989 discontinuity event is incomplete due to time constraints required in responding to Staff's evidence submission. It should also be noted that a more precise estimates are likely if additional stations within reasonable proximity to St. Louis are put through the Double Mass technique plots

Staff has stated that their (NCDC's) analysis indicated no adjustment was necessary to maximum temperatures due to the 1996 ASOS installation. That is, there was no discernible trend change for maximum temperatures when the station was relocated and the new ASOS sensor was installed. However, there was a cooling bias for minimum temperatures. Based on the McKee study, Staff is advocating that the station move completely offset the cool bias that is a predominate feature of changing from the old HO83 sensor to the new ASOS sensor.

In addition, it is important to remember that the formal location of the weather recording station prior to the ASOS installation at St Louis Lambert International Airport was several miles away and located within close proximity (< 25 feet) of their staff's parking lot. The subsequent move to the open area between runways at the airport would imply that an abrupt change in local microclimate had occurred. Staff's recommendation for a minimum temperature correction of 1.6 F matches the correction factor I recommend in 1999. With such a substantial change occurring to the minimum temperature, I can't reconcile how maximum temperatures could not be impacted.

Appendix 1 contains Double Mass plots of my technique applied to three comparison sites in close proximity to St Louis Lambert International Airport, St Charles, St Charles 7 SW, and St Louis Science Center. Also included is a Double Mass plot of the Staff's corrected St Louis Lambert International

Airport daily data ran against the raw weather records for St Charles. If you overlay the plots of the minimum temperature (corrected vs uncorrected), the 1996 correction proposed by staff appears to eliminate the discontinuity due to the station and sensor change that occurred when the ASOS site was installed at the airport.

However, further examination of the post 2001 discontinuity event reveals that Staff's minimum temperature adjustment results in an identical plot of the accumulated temperature units as the uncorrected plot. In short, Staff's correction does not appear to resolve the discontinuity associated with the 2001 event. I was actually surprised that corrected and uncorrected temperature data Double Mass plots were identical after the 2001 event. I would have expected that Staff's corrected data would have resulted in some type of change to the Double Mass slope after 2001.

Further comparison of the both St Charles and St Charles 7 SW uncorrected minimum temperature accumulation plots against St Louis Lambert International Airport reveal that three (3) linear slope changes from 2001 through 2010 occurred at similar dates. This indicates that St. Louis Lambert's temperature sensor may have been having measurement issues and needs to be investigated to see if additional adjustments are necessary.

Not surprising, the Double Mass plot of corrected maximum temperatures for St Louis Lambert International Airport was identical to the uncorrected plot for the same plot. We would expect this result because Staff indicated that their pairwise homogeneity analysis found that the 3 discontinuity dates had no significant temperature change and they didn't need to apply any corrections to adjust historical observations to current maximum temperature observations.

The Double mass plots of uncorrected accumulations of maximum temperature units reveals that both St Charles and St Charles 7 SW had a distinct slope change immediately in regards to the 1996 ASOS installation. With both stations indicating a significant slope change near the same date, I can confidently state that there was indeed a discontinuity at St Louis Lambert International Airport, it can be measured, and the resultant change was significantly greater than zero.

If Staffs proposed corrections have been properly calculated and applied, then the Double Mass accumulation plots between St. Louis Lambert International Airport and comparison locations should have resulted in a linear plot through the entire 30 year period, absent of significant slope changes. Their minimum temperature adjustments for the 1989 and 1996 discontinuity events appear to do a respectable job of correcting for discontinuities, but a significant discontinuity continues from 2002 through 2010.

Staff has advocated that no maximum temperature discontinuity adjustments are necessary, but visual inspection of their adjusted daily data Double Mass plots show periods of sustained linearity up to the 1996 discontinuity event. Immediately following the suspected 1996 event, the accumulated temperature differences plot shows a break from the pre-1996 slope trend to a new slope trend post-1996.

Each one of the unadjusted Double Mass analysis plots that I have provided in Appendix 1 for maximum temperatures also show that the linear trend changed when the ASOS was made operational at St Louis Lambert International Airport in 1996. All three sites used as a comparison show a slope change for maximum temperature on the suspected data validating that Staff's proposed maximum temperature adjustments are incorrect.

Double Mass Analysis Conclusions

In the 1999 Double Mass analysis that I performed on St. Louis Lambert International Airport, over 60 hours were spent on data analysis to develop accumulated difference curves and associated regression results. Another 70 hours were spent writing up my findings. If the NCDC used a similar approach, it would require 900,000 (60 hours x 15,000 stations) man hours to develop and analyze accumulated temperature difference curves. Given the NCDC's time constraints, they needed to come up with a computer simulation method that could quickly identify major discontinuity shifts

There is little dissimilarity between the NCDC technique and the "Double Mass" technique that I have used in the current analysis and the prior analysis undertaken in 1999. Both methods look at identifying abrupt changes in Delta T by identifying when distinct periods of temperature consistency between a target and comparison station abruptly change. The clear delineation between the two techniques is that the Double Mass technique can identify discontinuity points, while the NCDC relies on daily data to identify discontinuity points and then uses average monthly maximum and minimum temperature relationships to derive adjustment factors for discontinuity events.

There are two major reasons why I feel that the Double Mass technique is superior to Staff's (NCDC'S) technique. First, the Double Mass technique is simple to compute and the computation methodology remains static. Second, data derived from the Double Mass methodology will be consistent over time since the calculation methodology doesn't change. The same thing can't be said in regards to the NCDC homogeneity calculations, as past history has shown that their monthly HCN data set has went through three revisions.

Appendix 6 contains a HCN version 2 document by Menne and others that introduces the data set and the important estimation techniques employed by the NCDC to adjust for discontinuities and time of observation bias corrections. Also contained in this Appendix 6 is the a description of the new 1981-2010 normals and the corrections that appear in the latest update of the HCN data set, Version 3. It is important to understand that the NCDC has applied adjustments to their HCN data set and some of those corrections were estimates, unlike my Double Mass analysis which relies solely on actual climatic observations during every step of the process used to develop discontinuity adjustments.

If one looks at past history, NCDC has revised this data base on prior occasions and it will likely be revised in the future. The Double Mass analysis uses temperature data that the NCDC has determined to be official, with no further revisions required. This means that any future analysis would be able to replicate past findings without concern that historical observations will be altered in the future and subsequently eliminates the need of for recalculating previous results.

The NCDC homogeneity methodology is very efficient at identifying significant station discontinuities, but may not properly identify or correct smaller changes because they have not been documented within the sub-station history files. My technique (Double Mass) identifies "all" impacts, documented or undocumented, by accumulating temperature differences over time between the target station and comparison station. If the target station shows duplicate accumulated temperature unit changes with a second nearby station, then a discontinuity point has been identified and the resultant change in the temperature relationship between the two stations can be quantified. These discontinuity points are only valid when the Double Mass analysis performed between comparison stations does not show a slope change at the discontinuity dates identified when performing the same analysis the target and comparison stations.

By advocating that the NCDC 1981-2010 normals process is valid, Staff has essentially decided to refute the 1999 Double Mass analysis that was performed by my office, the Missouri State Climatologist, and the subsequent agreement which allowed both sides to reanalyze the data to insure that a mutually agreeable temperature adjustment could be reached I have yet to find evidence in Staff's analysis and disclosure requests that indicates why NCDC's techniques are superior to the technique previously employed by both sides in 1999.

The Double Mass analysis I used looks at the rate of accumulated temperature differences over time between two stations. No data adjustment techniques (similar to the NCDC undertaking), are necessary. We are trying to measure the direct impacts of a station move or sensor change by using the highest correlated stations that are within close proximity of the target site. As long as the comparison station doesn't undergo a discontinuity issue during the time period prior before and after a suspected move at the target station, a specific rate of change between the two stations can be identified and quantified.

Staff has stated that their (NCDC's) analysis indicated no adjustment was necessary to maximum temperatures due to the 1996 ASOS installation. That is, there was no discernible trend change for maximum temperatures when the station was relocated and the new ASOS sensor was installed. However, there was a cooling bias for minimum temperatures. Based on the McKee study, Staff is advocating that the station move completely offset the cool bias that is a predominate feature of changing from the old HO83 sensor to the new ASOS sensor.

Staff advocated that the Pairwise Homogeneity method identified 3 discontinuity points during the 30 year period analyzed. All three discontinuity points needed minimum temperature adjustments, but maximum temperatures were found to have no discernible trend change and needed no adjustment. Is this theoretically possible when two warming and one cooling adjustment were required to address suspected minimum temperature discontinuities?

Let's be generous and say that 5% of the locations analyzed across the U.S. needed no adjustment for a recognized discontinuity point. The odds that this could occur randomly 3 consecutive times would be 5% x 5% x 5%, or 1.25 chances out of 10,000. It is possible by random chance that the 3 identified discontinuity events would require no significant adjustment to maximum temperature historical records as advocated by Staff? Yes, but the statistics would indicate that it is highly improbable.

At this point in time, there is no option available to compare how the derivation of the new 1981-2010 compares to the 1971-2000 period when using the most current technique employed by the NCDC. The NCDC has stated on their web-site that an internal consistency test has been run, but they have not made their results available to the public. Until they release this analysis to the scientific community, there is no way to know whether their new techniques used in the creation of the 1981-2010 normals is superior to the previous calculations employed in the creation of the 1971-2000 normals that became operational at the beginning of 2002..

The calculation of daily normals by the NCDC during previous thirty year normal periods used the monthly mean minimum and maximum temperatures and spline fit a curve to that data to come up with estimates for daily normals. In short, monthly averages (Jan, Feb, ..., Dec) were placed at the mid-point of each month, then a curve was fit to the data. Daily normals were derived by determining the intersection point for each of the 365 days of the year based upon the spline curve.

The NCDC has modified their calculations for the 1981-2010 normals period by dropping the spline fit methodology and creating "true" daily normals based upon actual daily data. Using information that has been provided by Staff in regards to their calculation of daily normals, it appears that they applied a uniform correction factor to daily data based upon monthly corrections. Their methodology is not consistent with previous renditions undertaken the NCDC that used the spline fit technique or their current methodology of calculating true daily normals.

I can't be certain as to the exact methodology that Staff employed in the calculation of daily normals, since they offered little written evidence in regards to their methodology in the initial analysis submission report or subsequent disclosure requests. Attaching a spreadsheet to answer a methodology question doesn't provide evidence that they have accurately depicted the total impact of station moves and sensor changes at St. Louis Lambert International Airport. In fact, Staff's entire weather analysis was summed up in 5 paragraphs, with one of them dedicated to introducing the topic.

Based upon the data provided so far by Staff, the following information has not been provided in regards to their temperature adjustment calculations:

1. An average homogeneity adjustment plot has been supplied for maximum and minimum temperatures, yet individual station adjustment rates used to calculate the average adjustments can't be found. Therefore, it is impossible to determine the variability (spread) of the final correction adjustments.

2. Staff indicates that it verified NCDC's adjustments through direct communication and its own review of daily observations. I can find no evidence from the information supplied by Staff that verifies that their review of daily observations verifies NCDC's adjustments.

3. Staff indicates NCDC provided a peer review paper that describes their homogenization procedure for removing discontinuities. No evidence has been provided that indicates the NCDC adjustments have been verified as valid by outside agencies (non NOAA affiliated). This is

important because the NCDC does not have an independent advisory panel that insures their computational technique(s) and subsequent results are valid.

4. Staff has failed to describe in detail (writing) each step of their process they took in deriving their adjustments. It is virtually impossible to replicate an analysis if you are lacking detailed information on how each step of the process has been handled.

5. Staff has not produced any evidence in regards to why their technique improves on the 1999 Double Mass analysis performed by both sides in the 1999 dispute.

6. Staff has failed to mention how they will handle future discontinuity issues when they arise. How will they employ their proposed methodology to identify future discontinuity issues? Can their procedure be duplicated by outside affiliations? How much time is required to calculate discontinuity adjustments when they arise in the future?

7. Staff has failed to provide a logical explanation as to why no adjustments were necessary for maximum temperature at the 3 discontinuity points identified in their write up, but yet minimum temperatures were adjusted in both positive and negative directions. At a bare minimum, I would expect that Staff could provide supporting evidence of why a station can move several miles without showing a need for a maximum temperature adjustment, especially when minimum temperatures have shown that an adjustment is necessary to account for discontinuities. Second, is it even theoretically possible that minimum temperatures require 3 distinct adjustments, while maximum temperatures are not impacted and require no adjustment?

Based upon past history, potential discontinuities will arise in regards to St Louis Lambert International Airport temperature records in the future due to station relocation and/or sensor changes/replacement. Both sides need to find a mutually agreeable methodology for addressing the impacts of these discontinuities. The methodology needs to be simplistic enough that it can be replicated by both sides or it should be run independently with both sides agreeing on the final correction results.

I am advocating the use of the Double Mass approach since it is able to isolate "all" suspected discontinuity points. The initial development of the meteorological data base will require a thorough analysis of St. Louis Lambert International Airport against surrounding stations to insure that any suspected discontinuity points are the result of a change at Lambert and not a comparison station. Discontinuities can then be adjusted in the historical daily weather data file that is used by both sides for weather normalization and load forecasting.

Once the historical data has been adjusted to the mutual satisfaction of both sides, the only requirement will be to address future discontinuities that will eventually arise at St Louis Lambert International Airport. In essence, the Double Mass analysis will need to be run on a periodic basis to identify the discontinuity date and the subsequent correction factor that needs to be applied to historical records to calibrate them to the current temperature recordings.

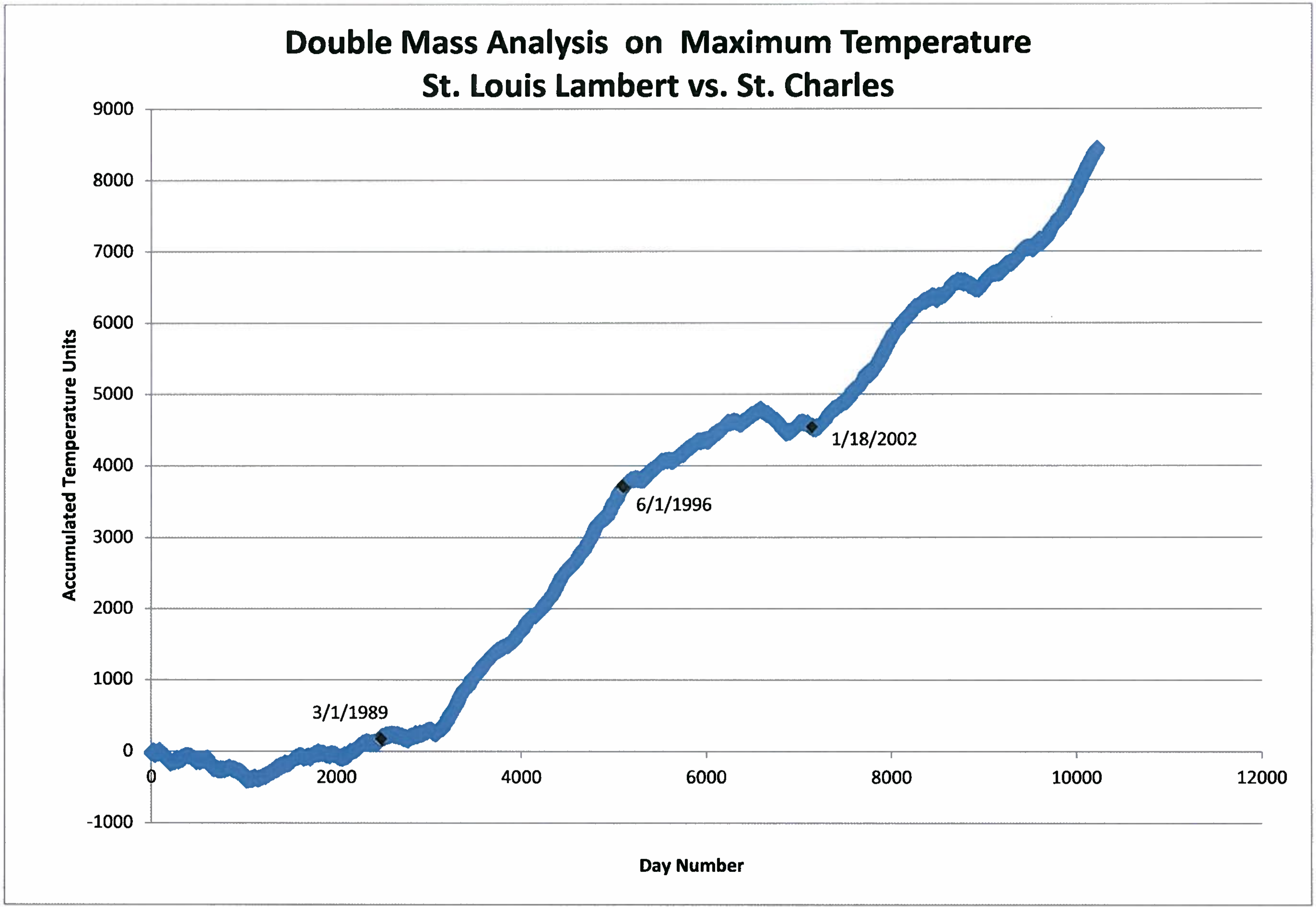
As stated at the beginning of this document, the Double Mass technique allows for intensive scrutiny of temperature records for isolating discontinuities due to station moves, sensor changes, and/or sensor drift issues. If the analysis is set up properly, periodic Double Mass analysis runs should be easily to complete within a 1-2 day time frame. The overall benefit would be that both sides would not have to spend valuable resources coming up with new ways to adjust data every time a question arises in regards to the whether historical temperature records are adequately reflecting the way St. Louis Lambert International Airport is reporting daily maximum and minimum temperatures.

Acknowledgement

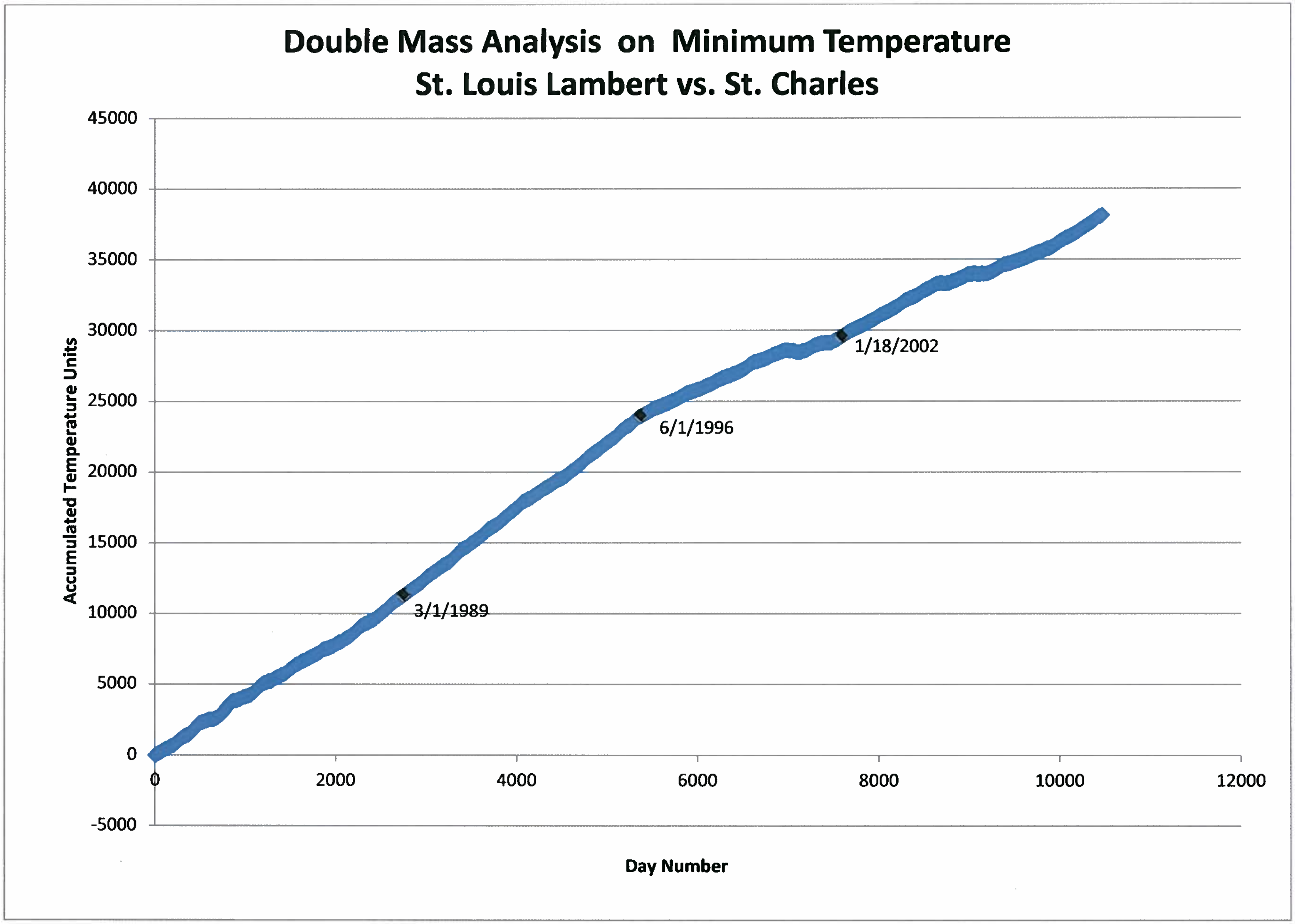
I would like to thank Ameren – St Louis for providing me the opportunity to apply my Double Mass methodology in an attempt to quantify the impacts of temperature data discontinuities on the St Louis Lambert International Airport temperature records. The primary reason for accepting the opportunity to perform my analysis was to show that the Double Mass technique can be used effectively for climate data reconstruction.

In order for climatologist to accurately quantify past climate trends, temperature discontinuities must be isolated and addressed. By developing and applying these methodologies to historical climate data, we can quantify how historical temperature observations would look if they were adjusted to present conditions. Only then can climatologists accurately quantify the impacts of a changing climate.

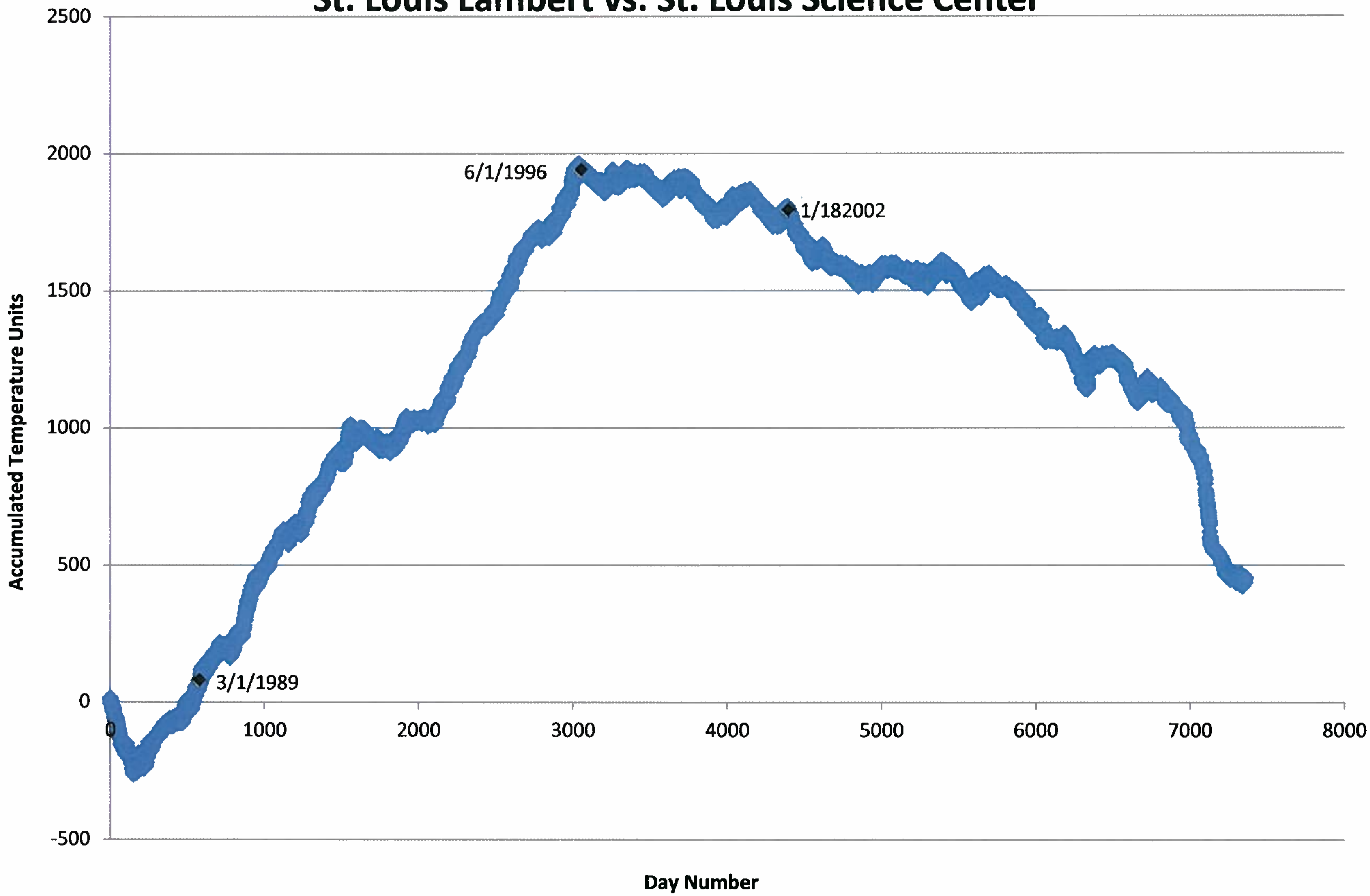
Appendix 1

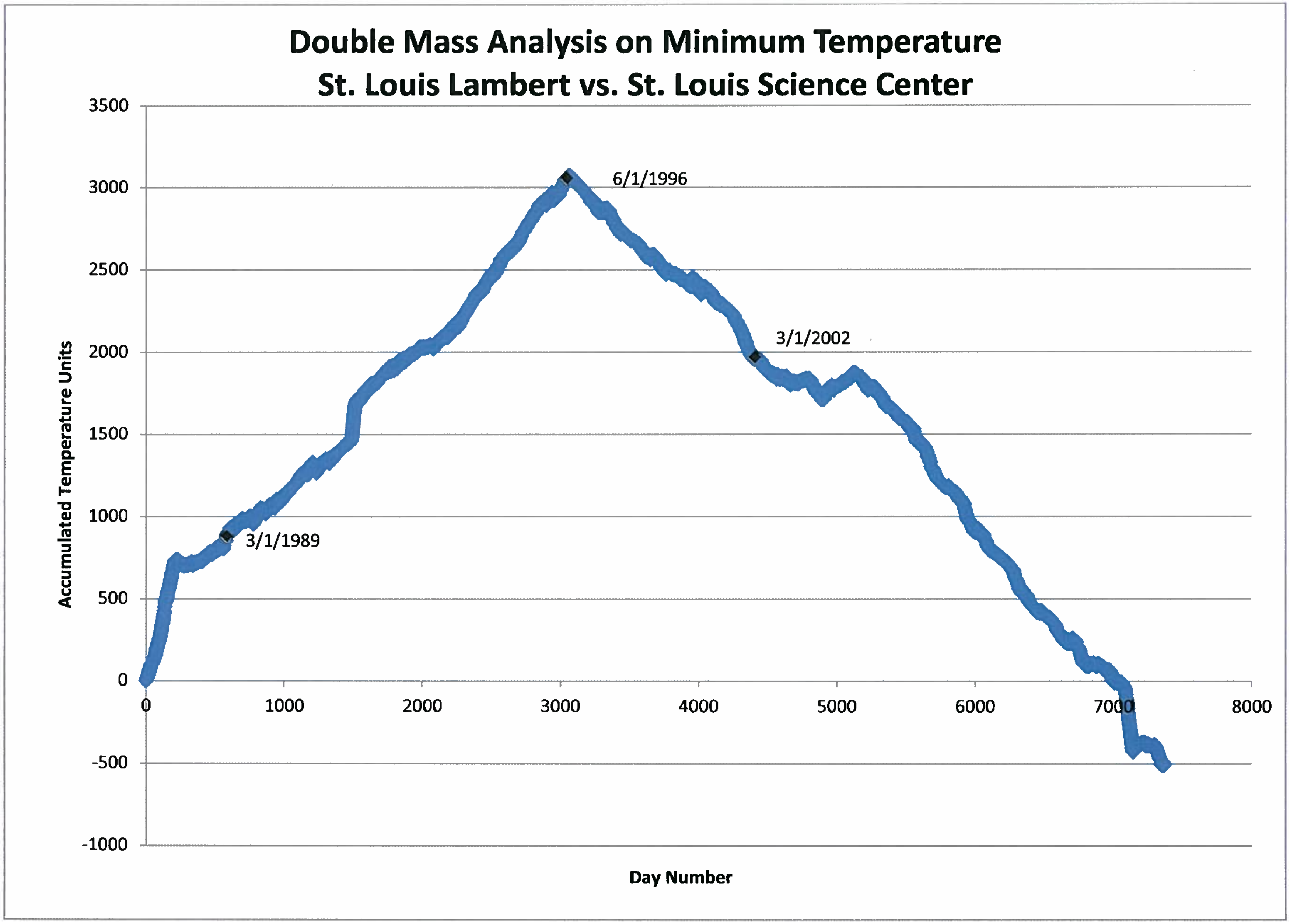


Double Mass Analysis on Maximum Temperature
St. Louis Lambert vs. St. Charles
Accumulated Temperature Units
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
0
2000
4000
6000
8000
10000
12000
Day Number
3/1/1989
6/1/1996
1/18/2002

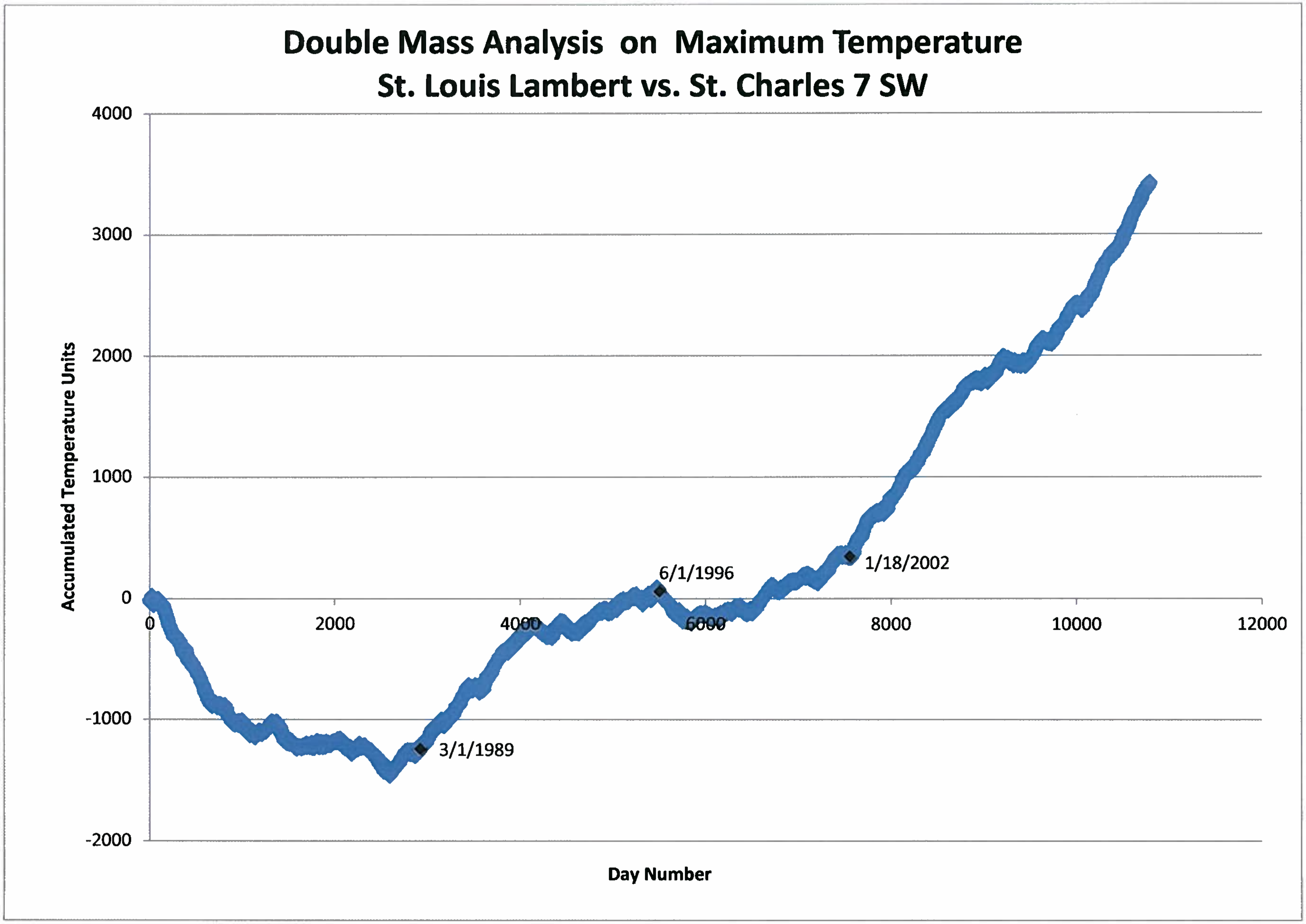

Double Mass Analysis on Minimum Temperature
St. Louis Lambert vs. St. Charles
Accumulated Temperature Units
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
-5000
0
2000
4000
6000
8000
10000
12000
3/1/1989
6/1/1996
1/18/2002
Day Number

Double Mass Analysis on Maximum Temperature St. Louis Lambert vs. St. Louis Science Center

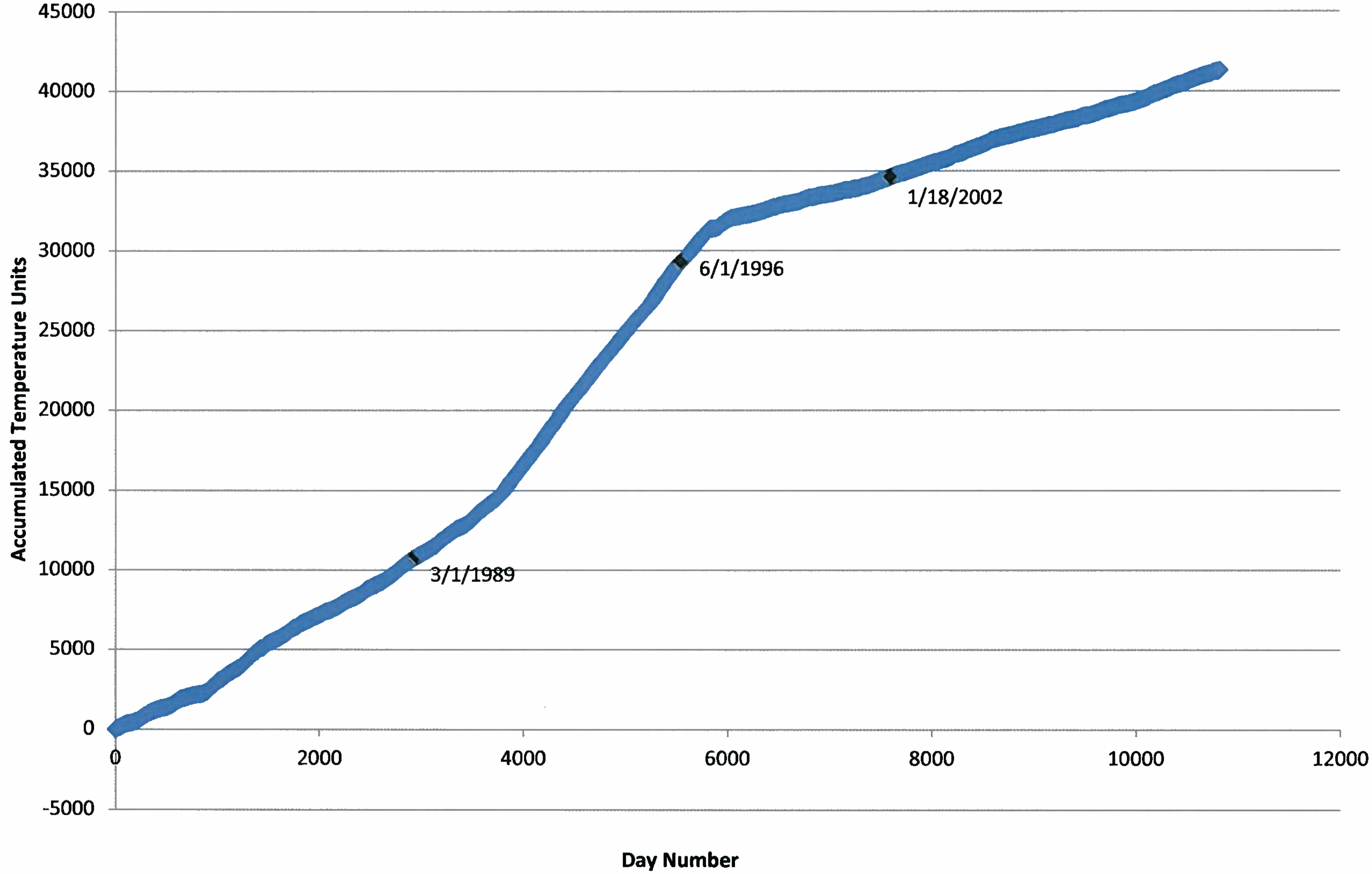


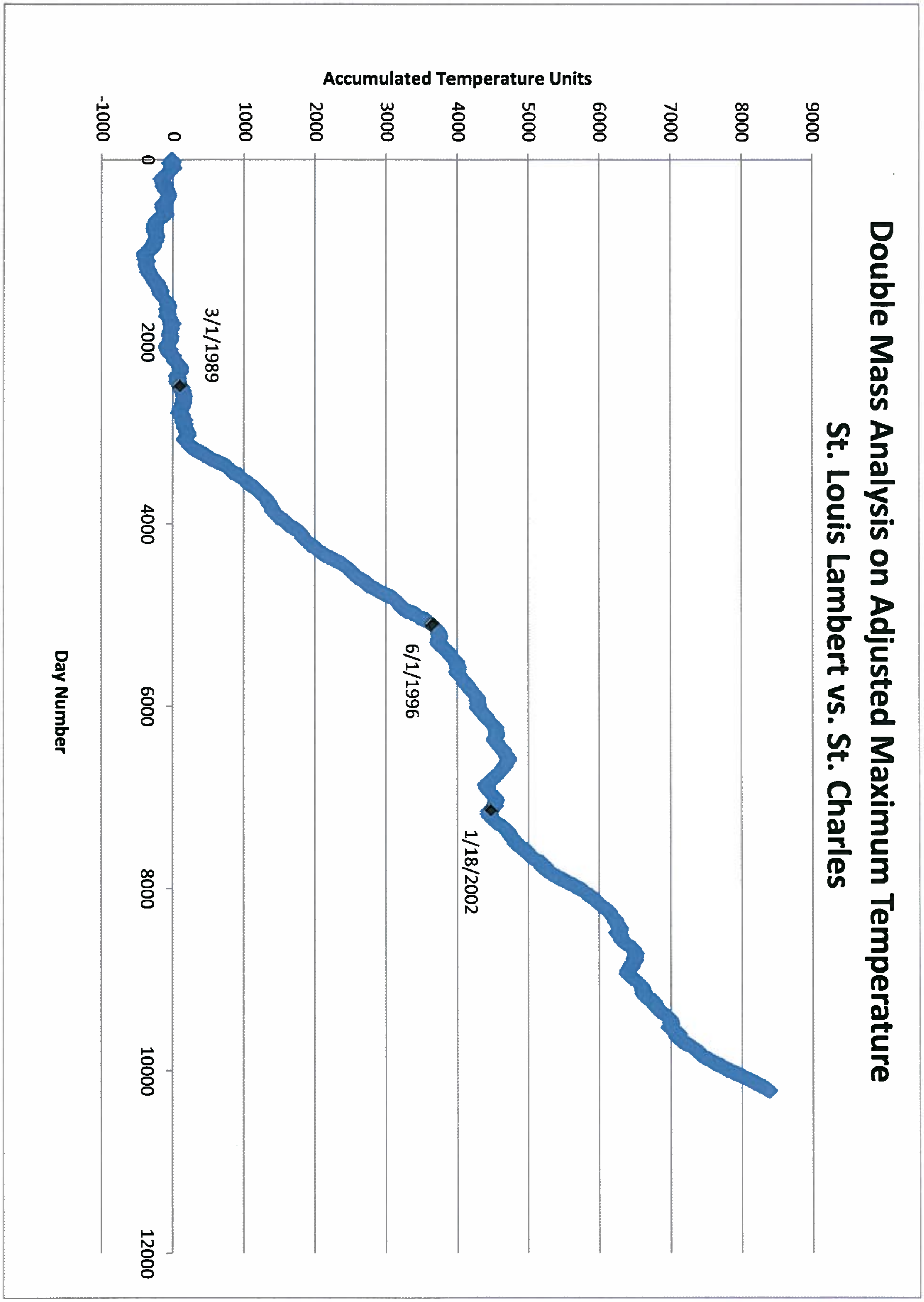


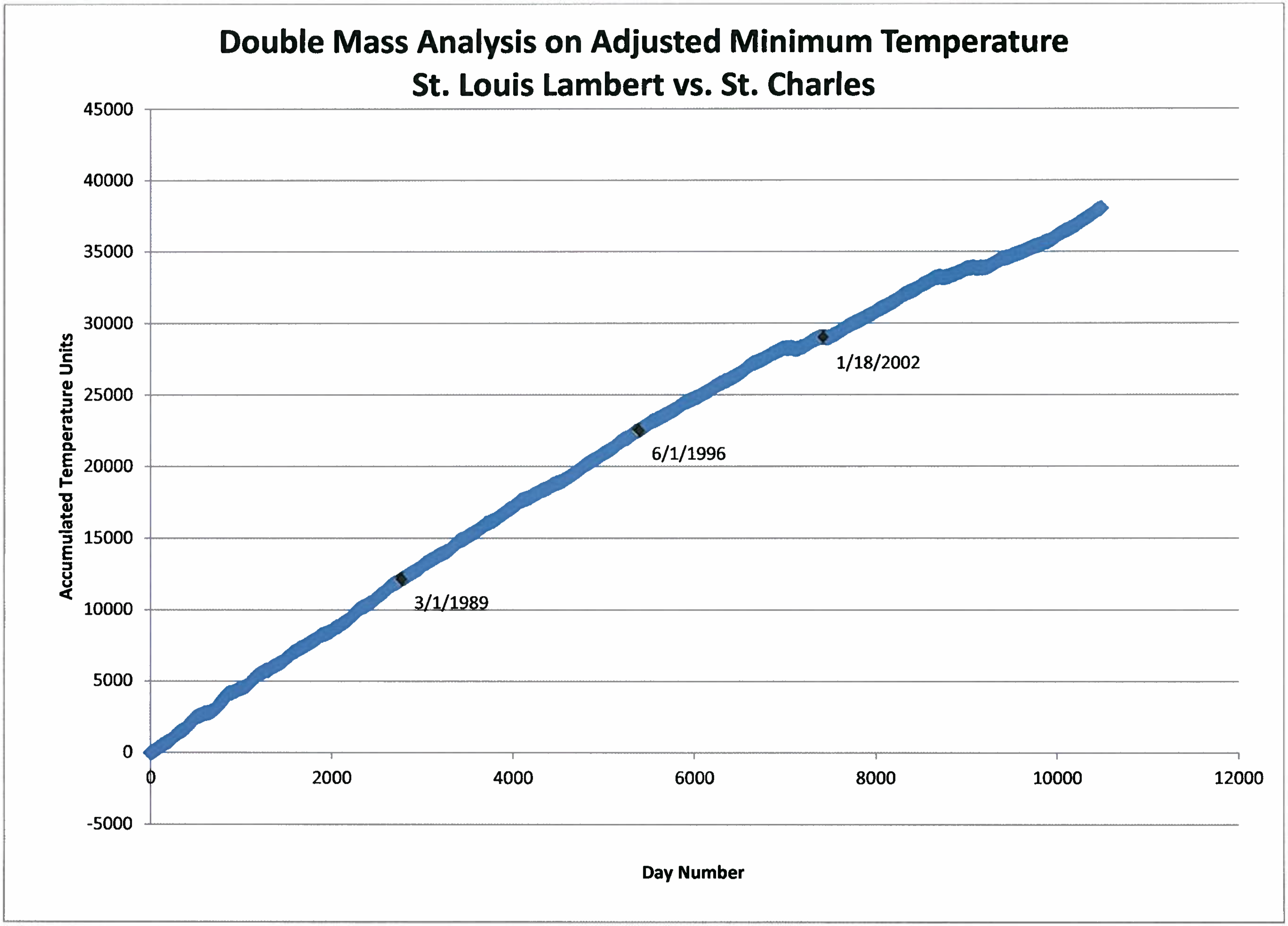
Double Mass Analysis on Minimum Temperature
St. Louis Lambert vs. St. Louis Science Center
Accumulated Temperature Units
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
0
1000
2000
3000
4000
5000
6000
7000
8000
Day Number
3/1/1989
6/1/1996
3/1/2002


Double Mass Analysis on Maximum Temperature
St. Louis Lambert vs. St. Charles 7 SW
Accumulated Temperature Units
4000
3000
2000
1000
0
-1000
-2000
0
2000
4000
6000
8000
10000
12000
3/1/1989
6/1/1996
1/18/2002
Day Number

Double Mass Analysis on Minimum Temperature
St. Louis Lambert vs. St. Charles 7 SW




Double Mass Analysis on Adjusted Maximum Temperature
St. Louis Lambert vs. St. Charles
Accumulated Temperature Units
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
0
2000
4000
6000
8000
10000
12000
Day Number
3/1/1989
6/1/1996
1/18/2002


Double Mass Analysis on Adjusted Minimum Temperature
St. Louis Lambert vs. St. Charles
Accumulated Temperature Units
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
-5000
0
2000
4000
6000
8000
10000
12000
3/1/1989
6/1/1996
1/18/2002
Day Number

Appendix 2

2.7

CLIMATE DATA CONTINUITY – WHAT HAVE WE LEARNED FROM THE ASOS AUTOMATED SURFACE OBSERVING SYSTEM

Nolan J. Doesken, Thomas B. McKee and Christopher Davey

Colorado State University, Fort Collins, Colorado

1. INTRODUCTION

Climatologists first began to hear about National Weather Service plans for replacing their decades-old network of airport weather stations with the Automated Surface Observing System (ASOS) in the mid and late 1980s. There was immediate concern, of course, about what impacts this nationwide change might have on data resources for monitoring our nation's climate. Concern changed to dismay in the early 1990s as the first stations were deployed in the central U.S. and reports of large biases and gross mis-measurement of basic climate elements began to spread.

The National Weather Service did not welcome criticism or open discussion about the apparent problems with ASOS initially, most likely because of the pressures to appear successful in their massive nationwide modernization program. Frustrated NWS field personnel did not help matters. Considering this attitude, it was quite remarkable that the Climate Data Continuity Program (CDCP) was ever developed and funded. But in 1991, with NOAA funding through the ESDIM (Environmental system Data and Information Management) Program, the Climate Data Continuity Program was launched. This program has overseen a 10-year evaluation of ASOS data by scientists outside of NOAA which eventually contributed to several improvements to ASOS and which made public the changes and differences in ASOS climate data compared with previous NWS airport observations.

This paper is not intended to be a comprehensive summary of project accomplishments but rather a brief listing of some of the data comparisons that were performed and some of the findings. A list of publications and reports containing more details from the Climate Data Continuity Program are listed at the end of this report.

**Corresponding author address*: Nolan J. Doesken, Atmospheric Science Department, Colorado State University, Fort Collins, CO 80523-1371; e-mail: nolan@atmos.colostate.edu

2. SUMMARY OF ANALYSES PERFORMED AND CONCLUSIONS FROM CDCP

Temperature: ASOS temperature data received the majority of the attention through much of the 10-years of CDCP analysis. ASOS temperatures were compared to the conventional temperature measurements from the NWS HO-83 hygrothermometer measurement system first at 10 sites in the central U.S. and then at 5 more sites nationwide. Due to a moratorium on ASOS station commissioning during the winter of 1994-1995, there was a period of several months when many stations in the U.S. were operating ASOS and their conventional station at the same time. This afforded the unexpected but much needed opportunity to do temperature overlap studies at 76 of sites across the U.S. The results consistently showed ASOS to have a cool bias compared with the previous HO-83 hygrothermometer of approximately 0.3° C for collocated sites. However, this value varied greatly from station to station largely due to changes in station location and exposure associated with ASOS installation. In general, most ASOS sites were installed in locations on the airport grounds that were cooler than their previous locations.

Dewpoint: Detailed comparisons of dewpoint temperatures were limited to the initial 13 stations in the Central U.S. No systematic biases were found. However, erratic behavior and sporadic large differences between ASOS and the conventional HO-83 chilled mirror cast doubt on ASOS observations. We recommended that the chilled-mirror technique be replaced with a measurement technique that would be more stable in the field.

Precipitation: In the very first months of ASOS data collection in the Central U.S. it was noted that the ASOS heated tipping bucket gauge did not perform well in several ways and was particularly poor at measuring the water content of snow. Figure 1 dramatically points out the poor gauge reporting for precipitation falling at temperatures well below freezing.

When it became obvious that the ASOS Heated Tipping Bucket precipitation gauge was inadequate for all-weather precipitation measurements, NWS announced publicly that ASOS precipitation measurements were only accurate for rainfall and not for the measurement of the water content of snow.

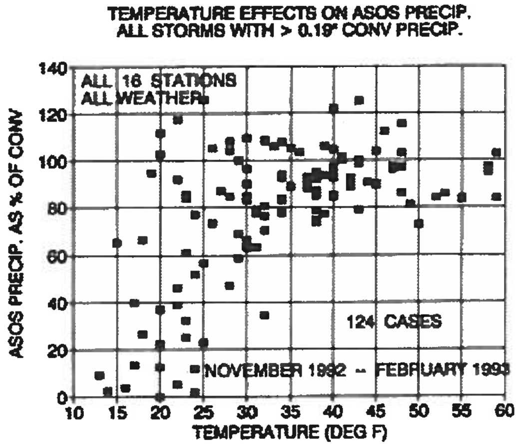


Figure 1. ASOS precipitation as a percent of CONV plotted as a function of temperature for each significant precipitation event.

Some local NWS offices have been routinely checking ASOS measurements against other nearby gauges and at some stations have been editing precipitation readings for several years to try to compensate for ASOS deficiencies. Unfortunately, the augmentation and editing of precipitation data has not been conducted uniformly across the U.S. As a result, there are now archived data for several years for some ASOS sites clearly showing less precipitation during the winter months than other sites where precipitation reports have been manually edited. It is difficult to determine which stations have edited data, and the performance of gauges has varied. The use of ASOS precipitation data will be compromised and affected for many years to come as a result of this problem. Only now in 2002 is real progress being made to replace the ASOS heated tipping bucket precipitation gauge with a gauge that will perform more reliably in all weather conditions.

After the initial and very bad year of ASOS precipitation measurements during the winter 1992-1993 several modifications were made to the tipping bucket gauge. These changes did not solve the winter snow problem but they definitely improved the gauge performance for measuring rain. After these modifications were made, another 13 sites at selected locations across the country were tested comparing ASOS precipitation measurements to nearby standard rain gauges and weighing gauges. In this second comparison, results were much more similar although difference of more than 4% were not uncommon even for rain. A small number of sites continued to show larger differences with ASOS precipitation totals once again lower than conventional measurements. Two sites were more than 10% low. One was due to one large storm and the other appeared to be a poor or faulty gage.

Wind: Tom Lockhart, who passed away in 2001 after a short illness, carried out detailed wind comparisons as a part of CDCP. His basic findings were that wind direction and speed were quite similar. The primary concern was with wind gust information which was due to firmware in the ASOS which allowed a 5-second average. A 3-second average wind would have been more compatible with the predecessor instrument. There were problems with some of the early ASOS wind sensors, but they were corrected.

Ceiling and Visibility: Jon Cornick, a graduate student at Colorado State University examined relationships between ASOS ceiling and visibility observations compared to conventional measurements during the first year of ASOS data collection. He found that observations compared well much of the time but found occasional and sometimes large differences particularly during adverse weather conditions.

Snow: Snowfall and snow depth were not measured by ASOS and therefore there was no need for climate data continuity evaluations. However, one of the final activities currently being supported by ESDIM CDCP funds is a comparison of manual snowfall/snow depth measurements compared to the output of an ultrasonic sensor designed for measuring snow depth. Preliminary results should be available soon.

The climate data continuity of some other observational elements were examined early in the project. For example, cloud amount as observed by ASOS and as estimated by satellite were compared to manual evaluations of cloud amounts. The results did not yield a reliable method for incorporating conventional manual cloud cover assessments with ASOS skycover evaluations. Much of the problem was due to the fact that that ASOS ceilometer could not detect or report clouds above 12,000 feet above ground level (AGL). At this time, NWS is moving ahead with plans to replace the original ASOS ceilometer with an instrument capable of reporting the presence of clouds up to 25,000 feet AGL. This will hopefully improve the ASOS cloud cover assessment.

3. ASOS DATA – PROS AND CONS

The introduction of ASOS was a great frustration to many climatologists – not because we are opposed to automation and its obvious advantages to the NWS, but because many important elements of long-term climate monitoring were interrupted or at least compromised. From a climatological perspective, we've summarized some of the advantages and disadvantages that ASOS has introduced. Also we are listing a few opportunities presented by ASOS that have not yet been taken advantage of.

3.1. Advantages

- ASOS has better instrument exposure at many sites.
- In general, ASOS stations have more uniform station sitings.
- ASOS has better high-resolution data. One-minute data are archived for many stations compared to the traditional hourly observations.
- Observations can be taken continuously every 24-hours at all stations. No more part-time stations.
- Acceptable high-quality observations are recorded approximately 90% of the time. This allows the weather service office personnel more time to do other work.
- More consistent wind data.
- ASOS has overall improved observational consistency nationwide.
- Increase in number of stations nationwide.

Despite frustration with ASOS where it replaced conventional staffed weather stations, ASOS observations were welcomed from new locations that previously did not have round-the-clock monitoring.

3.2. Disadvantages

- NWS credibility as the premier source of high quality weather observations adhering to high standards was severely shaken initially. Gradually, credibility is being restored, but not completely.
- Discontinuities in long-term records have crippled research efforts and complicated (at least for now) various climatic applications such as utility load forecasting.
- The loss of snowfall data from major city weather stations was a great loss that we have not yet recovered from. For engineering and design applications, the loss of total Snow Water Equivalent measurements may compromise national assessments of structural snow loads for many years to come.
- The change in methods of determining cloud cover and the lack of cloud information above 12,000 feet has made it impossible to continue consistent analyses of cloud cover and the number of clear, partly cloudy or cloudy days.
- Changes in visibility are only measured for ranges up to ten miles. For many areas in the West, this is inadequate.
- No assessment of cloud types or significant phenomenon.
- The loss of information on the frequency and duration of various weather types such as snow and ice pellets, and freezing precipitation (Some progress in these areas is being made with newer sensors).
- The loss of quantitative hail data. First-order stations were the only national source of the time and duration of hail and maximum hail stone size. No other consistent data source exists to replace this loss.

4. OPPORTUNITIES THAT WERE LOST

Solar radiation is a critical meteorological and climatological element and should have been added to the ASOS instrument suite. Had they been included, solar radiation measurements would have become immediately useful for applications including in aviation and airport operations.

Climatologists advised NWS to consider a dual-gauge system form measuring both rainfall rate and total amount in order to assure better quality and consistency of this important element. This could have avoided the 10 years of frustration with ASOS precipitation data quality – a frustration that will continue for decades for those analyzing long-term data.

5. CLIMATE DATA CONTINUITY PROGRAM – COMMENTS AND REFLECTIONS

The move towards automation of surface weather observations was inevitable and appropriate and has been advantageous in many ways. However, the various negative impacts on climate data were also inevitable and of great significance to the country and should have been incorporated into ASOS planning during the 1980s in a more open way.

In the process of assessing climate data continuity between different sensors, station locations, and observing systems, a great deal is learned about just how essential a consistent instrument exposure is. Exposure differences quickly and easily mask instrument performance differences. Climate data continuity really incorporates both. For some elements, like temperature and humidity, it does not take much change to produce a detectable difference.

Not all elements show consistent biases. Simple histograms of observed differences are extremely effective in showing the nature of the differences (Figure 2).

When conducting climate data continuity studies, you learn a lot the first day you begin comparing data. In particular, systematic biases can be spotted almost immediately. However, the differences in observed elements often vary both diurnally and seasonally. Much of what will be learned on the nature of the differences will only be available after the first year. Even then, much of what you are going to learn in the first year, but you don't know for sure what you have learned until you have completed two full years of comparison. If year one and year two results are very similar, it is usually quite certain that a stable and predictable relationship has been found. If results from the second year differ significantly from the first – then more work remains. The bottom line is that overlap studies for critical continuous elements are very important and should be carried out for at least two years before establishing long-term transfer functions.

In some specific examples, a change in location of one mile or less may lead to a different frequency distribution of temperature with synoptic events such that a simple additive bias does not exist to adjust one record to be consistent with another.

The inevitable result of ASOS is that now there is a constant and steady march of new instrumentation that will gradually be fielded to improve ASOS – dewpoint, all weather precipitation gauges, new ceilometer freezing rain indicator, etc. The introduction of each new sensor will require climate data continuity testing.

Finally, and not surprisingly, we quickly learned that the commissioning of ASOS was not the first time discontinuities were introduced to our climate records at First Order Stations. Pre-ASOS data were not all consistent either, especially at many of the larger airports where changes in instruments and exposures have changed many times in the past. As many climatologists have long known, data from First Order weather stations are often inadequate for long-term evaluations of climate variability and trends.

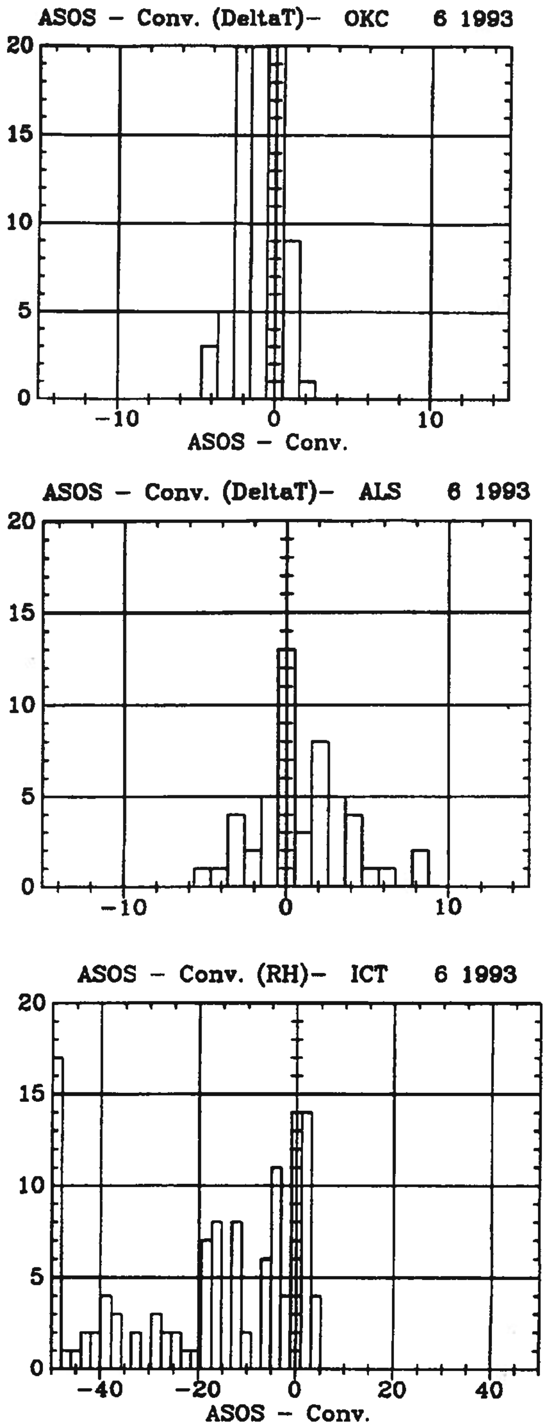


Figure 2. Histogram frequency distribution of ASOS minus Conventional observations. Example of tight dewpoint depression differences (top), a broad relationship (middle), and a weird relative humidity differences (bottom).

6. CONCLUSION

One of the most important outcomes from 10 years of ASOS climate data continuity studies is a greatly increased awareness within the NWS of the importance of data continuity and the importance of building data continuity assessments into the inevitable instrument upgrade process. If there was any doubt of the value of climate data continuity for anything other than purely academic applications, the emerging derivatives industry has certainly made that clear. The NWS Office of Climate, Water and Weather has now taken over the important responsibility of NWS climate data continuity. Climatologists need to continue to work closely with the NWS to assure this process is adequately funded and continued into the future.

7. ACKNOWLEDGEMENTS

This research was supported by NOAA, NWS, Office of Meteorology under grants NA90RAH00077, NA37RJ0202 (Item 9) and NA67RJ0152 (Amendment 25).

8. PUBLICATIONS

List of Climate Data Continuity Publications prepared by the Colorado Climate Center:

McKee, T.B., N.J. Doesken, J. Kleist, 1992: Climate data continutiy with ASOS – 1992 final report (A precommissioning comparison of temperature and precipitation). Climo Report 92-4, December, 78 pp.

McKee, T.B., N.J. Doesken and J. Kleist, 1994: Climate data continuity with ASOS --1993 Annual Report (Sept. 1992-August 1993). Climo Report 94-1, Feburary, 95 pp.

McKee, T.B., N.J. Doesken and J.Kleist, 1994: Climate data continuity with ASOS --1994 Annual Report (Sept. 1993 – August 1994). Climo Report 94-3, December, 67 pp.

McKee, T.B., N.J. Doesken, and J. Kleist, 1996: Climate data continuity with ASOS (Report for Period Sept 1994 - March 1996). Climo Report 96-1, March, 117 pp.

Schrumpf, A.D., and T.B. McKee. 1996: Temperature data continuity with the Automated Surface Observing System (ASOS). Climo Report 96-2, Atmos Sci Paper No. 616, June, 242 pp.

Butler, R.D., and T.B. McKee, 1998: ASOS heated tipping bucket performance assessment and impact on precipitation climate continuity. Climo Report 98-2, Atmos Sci Paper No. 655, June, 83 pp.

McKee, T.B., N.J. Doesken, C.A. Davey, and R.A. Pielke, Sr., 2000: Climate data continuity with ASOS. Report for period April 1996 through June 2000. Climo Report 00-3, November, 77 pp.

Appendix 3

Homogenization of Temperature Series via Pairwise Comparisons

MATTHEW J. MENNE AND CLAUDE N. WILLIAMS JR.

NOAA/National Climatic Data Center, Asheville, North Carolina

(Manuscript received 2 October 2007, in final form 2 September 2008)

ABSTRACT

An automated homogenization algorithm based on the pairwise comparison of monthly temperature series is described. The algorithm works by forming pairwise difference series between serial monthly temperature values from a network of observing stations. Each difference series is then evaluated for undocumented shifts, and the station series responsible for such breaks is identified automatically. The algorithm also makes use of station history information, when available, to improve the identification of artificial shifts in temperature data. In addition, an evaluation is carried out to distinguish trend inhomogeneities from abrupt shifts. When the magnitude of an apparent shift attributed to a particular station can be reliably estimated, an adjustment is made for the target series. The pairwise algorithm is shown to be robust and efficient at detecting undocumented step changes under a variety of simulated scenarios with step- and trend-type inhomogeneities. Moreover, the approach is shown to yield a lower false-alarm rate for undocumented changepoint detection relative to the more common use of a reference series. Results from the algorithm are used to assess evidence for trend inhomogeneities in U.S. monthly temperature data.

1. Introduction

Discontinuities in a climate series can be induced by virtually any change in instrumentation or observation practice. The relocation, replacement, or recalibration of an instrument, for example, can lead to an abrupt shift in time-ordered observations that is unrelated to any real change in climate. Likewise, alterations to the land use or land cover surrounding a measurement site might induce a sudden or "creeping" change (Carretero et al. 1998; Karl et al. 1988) that could limit the degree to which observations are representative of a particular region. Such artifacts in the climate record ultimately confound attempts to quantify climate variability and change (Thorne et al. 2005). Unfortunately, changes to the circumstances behind a series of climate observations are practically inevitable at some point during the period of record. For this reason, testing for artificial discontinuities or "inhomogeneities" is an essential component of climate analysis. Often, the test results can then be used to adjust a series so that it more closely reflects only variations in weather and climate.

Numerous approaches have been employed to detect discontinuities in climate series (Peterson et al. 1998a), and comparison studies have recently proliferated (e.g., Ducré-Robitaille et al. 2003; DeGaetano 2006; Reeves et al. 2007, hereafter R07). The goal of this work is to describe an automated homogenization algorithm for monthly data that builds on the most efficient changepoint detection techniques using a holistic design approach. For example, the algorithm relies upon a pairwise comparison of temperature series in order to reliably distinguish artificial changes from true climate variability, even when the changes are undocumented (Caussinus and Mestre 2004). Consequently, the procedure detects inhomogeneities regardless of whether there is a priori knowledge of the date or circumstances of a change in the status of observations (Lund and Reeves 2002). In addition, the algorithm employs a recursive testing strategy to resolve multiple undocumented changepoints within a single time series (Menne and Williams 2005, hereafter MW05). Last, the procedure explicitly looks for both abrupt "jumps" as well as local, unrepresentative trends in the temperature series (DeGaetano 2006).

The organization of the paper is as follows: additional background on the design considerations for constructing this "pairwise" homogenization algorithm is provided in section 2. In section 3, the specific components of the algorithm are described. In section 4, an assessment of the

Corresponding author address: Dr. Matthew Menne, 151 Patton Avenue, NOAA/National Climatic Data Center, Asheville, NC 28801.
E-mail: matthew.menne@noaa.gov

DOI: 10.1175/2008JCLI2263.1

Schedule ALD-ER1

algorithm's skill at changepoint detection and how this skill compares to previous studies is provided by means of simulated temperature series. Because of recent interest in land use change and its impact on the temperature record (e.g., Peterson and Owen 2005; Kalnay et al. 2006; Parker 2006; Pielke et al. 2007), the algorithm was also applied to historical temperature data from the U.S. Cooperative Observer (Coop) Network to assess the frequency of local, nonrepresentative trends as discussed in section 5. Some concluding remarks are offered in section 6.

2. Design considerations for the pairwise algorithm

a. Relative changepoint testing

Conrad and Pollak (1962) state that "*a climatological series is relatively homogeneous with respect to a synchronous series at another place if the temperature differences (or precipitation ratios) of pairs of homologous averages constitute a series of random numbers*" (i.e., white noise). The assumption is that similar variations in climate occur at nearby locations because of the spatial correlation inherent to meteorological fields (Livezey and Chen 1983). A statistically significant and persistent violation of relative homogeneity is presumed to be artificial or, at least, to have origins other than the background variations in weather and climate. Relative homogeneity testing is therefore conducted primarily to distinguish artificial breaks from real climate variability, although it may also improve the power of detecting artificial shifts. The reason is that when two temperature series $\{X_t\}$ and $\{Y_t\}$ are highly correlated [i.e., Corr $(X_t, Y_t) = \rho > ½$], the variance of their differences will be lower relative to the original series.

To carry out relative homogeneity testing, a reference series is commonly constructed by averaging values from locations near the target site whose observations are in question (Karl and Williams 1987; Alexandersson and Moberg 1997; Vincent 1998). Unfortunately, the homogeneity of the reference series cannot be taken for granted because undocumented changepoints may be present in any one of the averaged series (Hanssen-Bauer and Førland 1994; MW05). Strategies for reducing changepoint attribution errors have included assessing the homogeneity of the reference series itself (McCarthy et al. 2008) and building a reference from previously adjusted series (González-Rouco et al. 2001). Unfortunately, conducting a separate assessment of reference series homogeneity fails to exploit the enhanced sensitivity of relative homogeneity testing, and many small-amplitude changepoints may go undetected in the reference series only to be later attributed to the target series. Similar problems may arise when adjusted data are used to build a reference series because artifacts from the original imperfect reference series can be transferred to the adjusted data themselves.

Alternatively, relative homogeneity testing can be implemented via a pairwise comparison of individual climate series (Jones et al. 1986; Slonosky et al. 1999; Menne and Duchon 2001; Caussinus and Mestre 2004). In pairwise testing, the cause of undocumented changepoints can be traced more directly, that is, without first testing the reference series or assuming it is homogeneous. Unfortunately, implementing pairwise testing has usually required a manual review of the results. For example, Jones et al. (1986) conducted an arduous station-by-station homogenization by manually determining the cause of changepoints in paired difference series. Caussinus and Mestre (2004) computed the locations of changepoints in difference series automatically, but still deferred to an analyst to attribute the cause. In contrast, an automated approach was developed for the pairwise algorithm, as described in section 3.

b. Distinction between documented and undocumented changepoints

In the absence of station history records, the date of inhomogeneity must be treated as an unknown parameter. In such cases, a systematic search through all values in a series is required to identify the dates of statistically significant discontinuities. The systematic nature of the search necessitates the use of a more conservative set of critical values relative to the standard values that are appropriate for testing the significance of known changes to observation practice (Lund and Reeves 2002). This means that tests for undocumented changepoints are less sensitive than comparable tests for documented changes. It follows that to maximize the power of changepoint detection, station histories should be exploited whenever possible.

The strategy used by the pairwise algorithm is to first identify all evidence of changepoints using the less sensitive tests for undocumented changepoints. Where possible, the results are then combined with information about documented changes whose impact may go undetected by these less sensitive tests. An important benefit of this approach is that all possible changepoints are identified before estimates of their magnitude are made.

c. Resolving multiple undocumented changepoints

While the issue of accurately resolving multiple undocumented changepoints remains an active area of statistical research (R07), two approaches are in operative use. The first, more common approach uses a recursive testing procedure (e.g., Vincent 1998) to overcome the "at most one changepoint" assumption behind most hypothesis tests for undocumented changepoints. The second approach relies on a penalty function to constrain the number of changepoints resolved through an optimization routine used to maximize the contrast between sequential mean levels of a series (e.g., Caussinus and Mestre 2004).

A recursive testing approach is used in the pairwise algorithm for the following two reasons: First, the approach is associated with a low probability of false changepoint detection without requiring an analyst to interpret the results (cf. Caussinus and Mestre 2004). Second, MW05 noted that when the recursive hypothesis test method is carried out using a semihierarchical splitting algorithm (Hawkins 1976), the power of changepoint detection can be comparable to that of optimal algorithms.

Recursive testing is based on a hierarchic, binary segmentation of the test series whereby a series is split at the location where the test statistic reaches a maximum, that is, the point at which the separation between the mean before and after the breakpoint is greatest. Then, the subsequences on either side of the first split are likewise evaluated, and the process is repeated recursively until the magnitude of the statistic does not exceed the chosen significance level in any remaining subsequences (or the sample size in a segment is too small to test). A semihierarchic implementation of this method means that each splitting step is followed by a merging step to test whether a split chosen at an earlier stage has lost its importance after subsequent breakpoints are identified, thereby more closely approximating an optimal solution.

d. Impact of local, unrepresentative trends

Ideally, a changepoint detection method would differentiate trend changes from step changes. In practice, however, many of the commonly used tests for undocumented changepoints are not robust to the presence of trends in the test data because they are based solely on comparing the means of two sequential intervals. Use of such tests in the presence of trends can lead to falsely detected step changes as well as to inaccurate estimates of the magnitude of a shift when it occurs within a general trend (DeGaetano 2006; Pielke et al. 2007). Conversely, methods that directly account for both step changes and trend changes (e.g., Vincent 1998; Lund and Reeves 2002; Wang 2003) are characterized by much lower powers of detection than the simpler difference in means tests.

While no one test clearly outperforms others under all circumstances, the standard normal homogeneity test (SNHT; Alexandersson 1986) has been shown to have superior accuracy in identifying the position of a step change under a wide variety of step and trend inhomogeneity scenarios relative to other commonly used methods (DeGaetano 2006; R07). For this reason, the pairwise algorithm uses the SNHT along with a verification process that identifies the form of the apparent changepoint (e.g., step change, step change within a trend, etc.). In fact, the pairwise testing procedure is similar to the Vincent (1998) and R07 forward and backward regression methods, respectively, but is more easily adaptable to a recursive testing approach for resolving multiple undocumented changepoints, and at the same time retains the higher power of detection of the SNHT.

3. Description of the pairwise algorithm

The pairwise algorithm is executed according to the following six steps:

(i) Select a set of "neighbors" for each "target" series in the network, and form pairwise difference series between the target and its neighbors.
(ii) Identify the timing of shifts in all target-minus-neighbor difference series using SNHT.
(iii) Verify each apparent shift identified by SNHT in the pairwise differences (e.g., does the apparent shift look more like a trend?).
(iv) Attribute the cause of shifts in the set of target-minus-neighbor difference series to the various "culprit" series.
(v) Quantify the uncertainty in the timing of shifts attributed to each culprit series.
(vi) Estimate the magnitude of the identified shifts for use in adjusting the temperature series to reflect the true background climate signal.

Each of these steps is described in some detail below.

a. Selection of neighbors and formulation of difference series

The pairwise algorithm starts by finding the 100 nearest neighbors for each temperature station within a network of stations. These neighboring stations are then ranked according to their correlation with the target. The first differences of the monthly anomalies are used to calculate the correlation coefficients [i.e., Corr $(X_t - X_{t-1}, Y_t - Y_{t-1})$] in order to minimize the impact of artificial shifts in determining the correlation (Peterson et al. 1998b). A series must simply be positively correlated with the target series to be eligible as a neighbor. Eligible neighbors could also be restricted to those series for whom $\rho \geq ½$. This restriction effectively occurs in practice for monthly temperature values from the U.S. Cooperative Observer Network where more than 99.5% of the monthly temperature series from the 100 nearest neighbors are correlated at this level (and $\rho \geq 0.8$ in 90% of cases).

From all eligible neighbors, the set used for the pairwise analysis is selected using a two-step process. First, an account is made of the years and months for which both the target and its 40 most highly correlated neighbors report monthly mean maximum and minimum temperature data. Then, beginning with the 41st most highly correlated neighbor, the algorithm assesses whether an additional neighbor adds any data for the years and months that have fewer than seven viable neighbors. If the neighbor in question provides records for such data-sparse periods, it replaces the least correlated of the original 40 with the new neighbor provided that the addition does not remove data for other data-sparse periods. This process ensures that, whenever possible, at least seven neighbors are available at all times during the target station's period of record (the rationale for attempting to make at least seven target–neighbor comparisons is provided in section 4).

Next, time series of differences $\{D_t\}$ are formed between all target–neighbor monthly temperature series. To illustrate this, take two monthly series $\{X_t\}$ and $\{Y_t\}$, that is, a target and one of its correlated neighbors. Following Lund et al. (2007), these two series can be represented as

$$X_{mT+\nu} = \mu_\nu^X + \beta^X(mT+\nu) + \delta_{mT+\nu}^X + \varepsilon_{mT+\nu}^X \quad (1)$$

and

$$Y_{mT+\nu} = \mu_\nu^Y + \beta^Y(mT+\nu) + \delta_{mT+\nu}^Y + \varepsilon_{mT+\nu}^Y, \quad (2)$$

where μ represents the monthly mean anomaly at the specific series, $T = 12$ represents the months in the annual cycle, $\nu \in \{1, \ldots, 12\}$ is the monthly index, $m =$ the year (or annual cycle) number, and the ε_t terms denote mean zero error terms at time t for the two series. The δ_t terms represent shift factors cause by station changes, which are thought to be step functions. Following Lu and Lund (2007), these shift factors are of the form

$$\delta_{nT+\nu}^X = \begin{Bmatrix} \Delta_1^X, 1 \le t < c_1^X \\ \Delta_2^X, c_1^X \le t < c_2^X \\ \vdots \\ \Delta_k^X, c_{k-1}^X \le t < n^X \end{Bmatrix} \quad \text{and}$$
$$\delta_{nT+\nu}^Y = \begin{Bmatrix} \Delta_1^Y, 1 \le t < c_1^Y \\ \Delta_2^Y, c_1^Y \le t < c_2^Y \\ \vdots \\ \Delta_k^Y, c_{k-1}^Y \le t < n^Y \end{Bmatrix}, \quad (3)$$

where $n =$ the total number of values common to $\{X_t\}$ and $\{Y_t\}$, and Δ and c represent the size and time of a shift, respectively. Because the timing of the level shifts is often unknown in climate networks, the goal of the pairwise algorithm is to reveal the shift times $\{c_1, c_2, \ldots, c_{k-1}\}$ not only for $\{X_t\}$ and $\{Y_t\}$, but for all of the series in the network no matter how complete the station metadata. Once the timing of the shifts is known, their magnitudes $\{\Delta_1, \Delta_2, \ldots, \Delta_{k-1}\}$ can be estimated.

Differencing the $\{X_t\}$ and $\{Y_t\}$ yields the $\{D_t\}$ series, which has the form

$$D_{mT+\nu} = (\mu_\nu^X - \mu_\nu^Y) + (\beta^X - \beta^Y)(mT+\nu) + (\delta_{mT+\nu}^X - \delta_{mT+\nu}^Y) + \varepsilon_{mT+\nu}^X - \varepsilon_{mT+\nu}^Y. \quad (4)$$

In reality, it is unrealistic to assume that β^X and β^Y are stationary in t given the nature of multidecadal variations in climate series; however, it may be that $\beta^X \approx \beta^Y$ in general. This assumption is evaluated further in subsequent steps because if $\beta^X \neq \beta^Y$, then a local, unrepresentative trend (i.e., creeping inhomogeneity) is present in $\{X_t\}$ and/or $\{Y_t\}$. At present, the periodicity in (4) is considered to be negligible, especially since $\{X_t\}$ and $\{Y_t\}$ are first deseasonalized.

Figure 1 provides an example $\{D_t\}$ series formed between mean monthly maximum temperature anomalies from Chula Vista, California, and nine highly correlated neighbor series. The reduction in the variance of the $\{D_t\}$ series relative to the original target series is clearly evident. The variety of overlapping periods and relative shifts between the records from Chula Vista and its neighbors is common in surface temperature records.

b. Identification of undocumented changepoints

After all difference series have been formed, the SNHT is used to identify undocumented changepoints in each $\{D_t\}$ using the semihierarchical splitting algorithm and a 5% significance level ($\alpha = 0.05$). The SNHT evaluates the null hypothesis (H_0) that a $\{D_t\}$ series has a constant mean against the alternative hypothesis (H_A) that there is an undocumented step change on date c. To account for the possibility of multiple changepoints, the difference series is assumed to consist of K segments, each bounded by two changepoints (c_{k-1} and c_k). In the pairwise algorithm, SNHT takes the form

$$H_0: \{D_t\} \to N(\mu_k, \sigma^2), \; c_{k-1}+1 \le t \le c_k, \quad (5)$$

$$H_A: \begin{cases} \{D_t\} \to N(\mu_1, \sigma^2), \; c_{k-1}+1 \le t \le c \\ \{D_t\} \to N(\mu_2, \sigma^2), \; c+1 \le t \le c_k \end{cases}, \quad (6)$$

where $N(\mu, \sigma^2)$ refers to a random normal variable with a mean μ and variance σ^2, and $\mu_1 \neq \mu_2$. For convenience

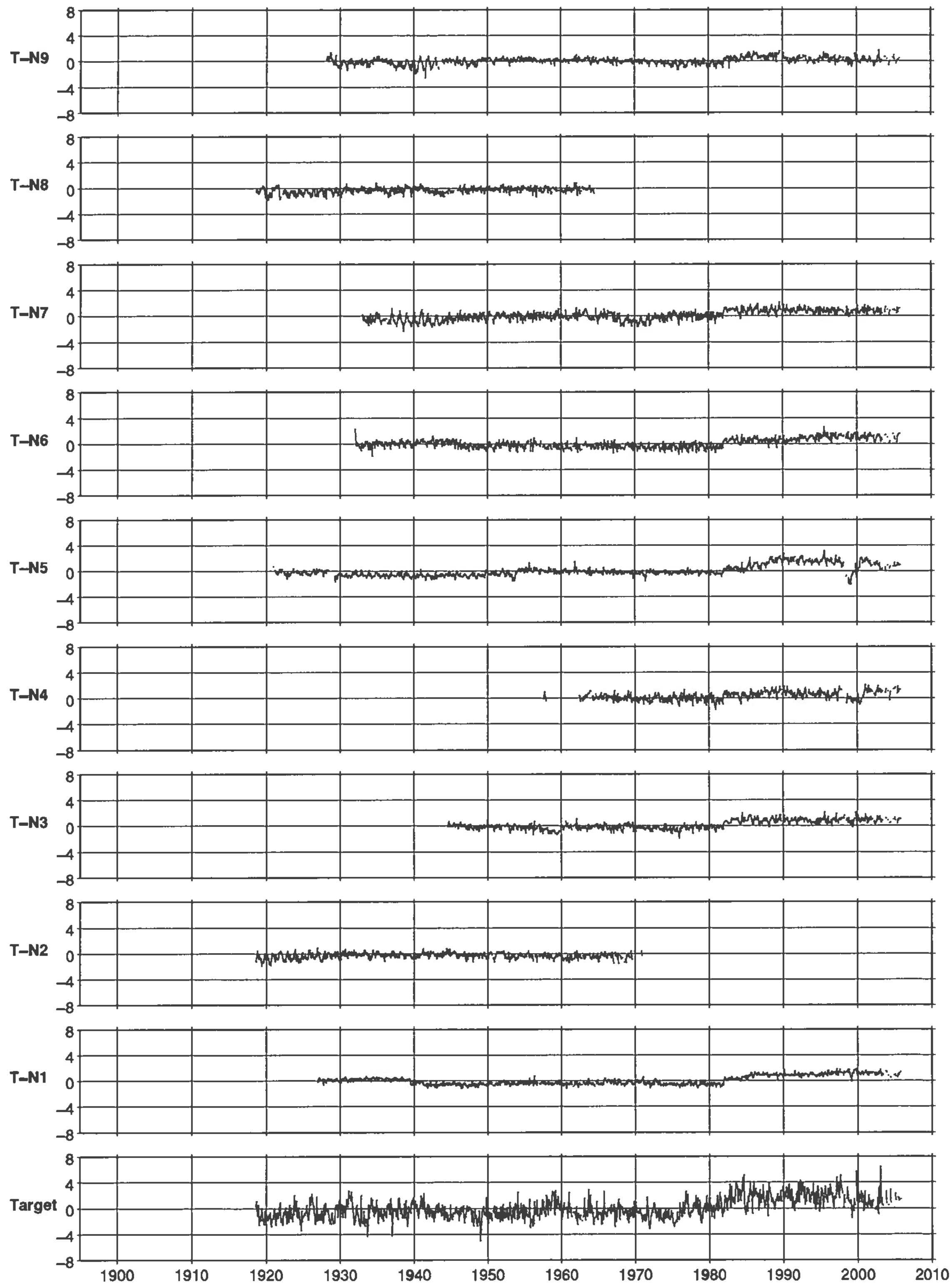


FIG. 1. Mean monthly maximum temperature anomalies for Chula Vista (target) and differences between monthly temperature anomalies at Chula Vista and nine neighboring series (T-N1 through T-N9).

TABLE 1. Hierarchy of changepoint models for a temperature difference series $\{D_t\}$, where the subscript t refers to the time step of the series (e.g., 1 month), μ refers to the mean, β refers to the trend, and ε_t represents a random error term.

Model	Description	Schematic of model	Number of parameters p required to fit model
M1	$D_t = \mu + \varepsilon_t$		1
M2	$D_t = \mu + \beta t + \varepsilon_t$		2
M3	$D_t = \begin{cases} \mu_1 + \varepsilon_t, t \le c \\ \mu_2 + \varepsilon_t, t > c \end{cases}$		3
M4	$D_t = \begin{cases} \mu_1 + \beta t + \varepsilon_t, t \le c \\ \mu_2 + \beta t + \varepsilon_t, t > c \end{cases}$		4
M5	$D_t = \begin{cases} \mu_1 + \beta_1 t + \varepsilon_t, t \le c \\ \mu_2 + \beta_2 t + \varepsilon_t, t > c \end{cases}$		5

we define $c_0 = 1$ and $c_K = n$, the total number of values in the $\{D_t\}$ series. The unsubscripted c in (6) refers to the assignment of an undocumented changepoint between two previously established changepoints (c_{k-1} and c_k) as the semihierarchal splitting algorithm iterates through the succession of splitting and merging steps, ultimately converging on a solution of K segments bounded by $K - 1$ shifts.

c. *Classification of breakpoints identified by the SNHT test*

The result of step b is a set of $K - 1$ apparent changepoints for each $\{D_t\}$ series. Because the SNHT assumes that each series is of the form

$$\{D_t\} = \mu_k + \varepsilon_t, c_{k-1} + 1 \le t \le c_k, \quad \text{for} \quad k = 1, K, \quad (7)$$

the next step determines whether this piecewise stationary model is justified for each changepoint. The determination is made by fitting a hierarchy of potential models for all segments centered on each kth breakpoint. The five models (M1–M5) are described in Table 1 (after R07). The model that minimizes the Bayesian information criterion (BIC; Schwarz 1978) is selected as the best representation for each changepoint.

Procedurally, the BIC is calculated by fitting M1–M5 to every segment $c_{k-1} + 1$ to c_{k+1} for all $k = 1, K$. The BIC is defined as

$$\mathrm{BIC}(p) = -2\log(L) + \log(n')p, \quad (8)$$

where p is the number of parameters required to fit the model, n' is the number of data points in the segment from $c_{k-1} + 1$ to c_{k+1}, and L is the likelihood of the model in question. For the models listed in Table 1,

$$-2\log(L) = n'\log(\mathrm{SSE}/n'), \quad (9)$$

where SSE refers to the sum of squared errors for the particular model fit.

In some cases, one or more of the original $K - 1$ changepoints may be eliminated from the solution for a particular $\{D_t\}$ series. For example, if the true model between the values of $c_{k-1} + 1$ and c_{k+1} is a constant increasing trend (M2), the SNHT may have identified an apparent jump in the middle of the trend interval, whereas the BIC is likely to be lower for M2 than for any of the other four models. In such a case, the false changepoint time is removed from $\{c_1^D, c_2^D, \ldots, c_{k-1}^D\}$ and K is decremented. Alternatively, the use of the BIC may determine that the $\{D_t\}$ segment between $c_{k-1} + 1$ and c_{k+1} more appropriately follows M4 (step change within a constant trend) or M5 (a step change separated by different trends). If so, there is evidence of a relative trend between the two series, and the magnitude of the step change Δ required in subsequent steps e and f should be calculated using the higher dimension models (M4 and M5) to avoid calculating a biased estimate of the step.

d. *Attribution of shifts in the difference series*

Given that breaks in a difference series will be induced by discontinuities in either $\{X_t\}$ or $\{Y_t\}$, the next step is to identify the series responsible for a particular discontinuity. To begin, an array of change dates by station is formed, and all of the changepoint dates detected in the $\{D_t\}$ series are temporarily assigned to both $\{X_t\}$ and $\{Y_t\}$. Specifically, a count is incremented for the date of shift each time a station is implicated by a break in one of its difference series. The resulting array of change dates by station is then "unconfounded" by systematically identifying those stations that are common to numerous difference series with the same date of change. More specifically, the station/date with the highest overall changepoint count is identified. This station is then tagged as the "culprit" or "perpetrator," that is, as the cause of the breaks on the date with the highest breakpoint count. The corresponding count on that particular change date is then decremented for all of the perpetrator's neighbors, and the process is repeated using the updated shift–date tallies. The procedure continues recursively until no station/shift date count is greater than one for any station/date in the period of record.

e. *Assignment of undocumented changepoint dates*

Although undocumented shifts are assigned to a perpetrating series in step d, the date of an undocumented changepoint returned by the SNHT is subject to sampling variability. As illustrated in Fig. 2, the degree of this sampling variability is a function of the magnitude of changepoint, with larger changepoints associated with more precise estimates of the date of change.

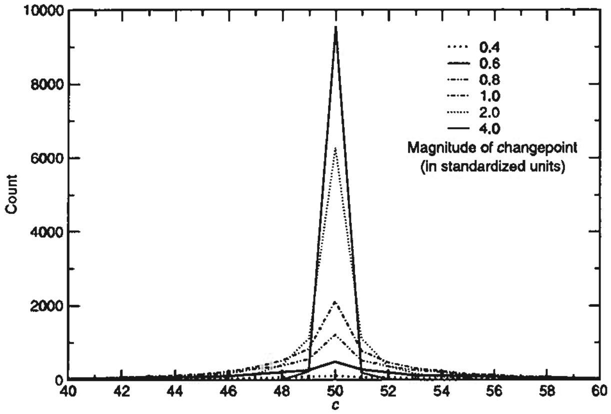


FIG. 2. Histogram of the most likely changepoint date identified by the SNHT for 10 000 series with $n = 100$ and a step change Δ at position 50. The magnitude of Δ was varied systematically from 0.2 to 4.0.

This means that testing a group of target–neighbor difference series often leads to a range of undocumented changepoint dates clustered around the time of the actual change. The simulations summarized in Fig. 2 were used to estimate the confidence limits of a changepoint date as a function of the magnitude of step change.

To determine which change dates likely refer to the same discontinuity, an interim estimate of step-change magnitude is therefore necessary. The estimate is calculated using the most appropriate change model (M3, M4, or M5) according to the BIC, which is used to determine the range of uncertainty for a particular undocumented shift date. The cluster of dates falling within overlapping confidence limits is then conflated to a single date at the target in one of two ways: 1) it is assigned to the date of a known event in the target station's history that occurs within the confidence limits for a shift of that magnitude, or 2) it is assigned to the most common changepoint date that falls within these simulated confidence limits, which means that the discontinuity appears to be truly undocumented.

f. Calculation of adjustments

Steps a–e are necessary simply to identify undocumented changepoints in all temperature series. In many applications, however, station histories also may be available, which might provide additional information regarding possible discontinuities. When available, the dates of documented events should be combined with evidence of undocumented changepoints because the impact of documented events may be too subtle for the tests for undocumented shifts to detect. Potential adjustments can then be calculated for all undocumented and documented shifts at the same time.

Adjustments are determined by calculating multiple estimates of Δ using segments from neighboring series that are homogeneous for at least 24 months before and after the target changepoint. (When two changepoints occur within 24 months in the target series, an adjustment is made for their combined effect.) The range of pairwise estimates for a particular step change is considered to be a measure of the confidence with which the magnitude of the discontinuity can be estimated. As in step e, the step model found to be most appropriate (i.e., M3, M4, or M5) according to the BIC can be used to calculate a final estimate of the shift for each relevant $\{D_t\}$ segment to avoid biased estimates of Δ when a relative trend is also present. At least three separate pairwise estimates of step-change magnitude are required for each target changepoint because the distribution of estimates is used to determine the significance of the adjustment (when fewer than 3 estimates are available, the shift is considered "unadjustable"). Moreover, because the distribution of step-change estimates is not necessarily symmetric, the median estimate is used to adjust the target series.

The consistency of the pairwise estimates for Δ is determined by comparing the median estimate to either the 5th percentile (median > 0) or to the 95th percentile (median < 0) of all estimates, subject to an initial outlier check. Because fewer than 20 estimates may be available for any given changepoint, a multiple of the difference between the median and the first quartile (Q_1) or between the median and third quartile (Q_3) serves as an estimate of the 5th or 95th percentile, respectively. A factor of 2.5 is used because it approximates a one-tailed test at the 5% ($\alpha = 0.05$) significance level (assuming independent estimates). When the median and the tail of the distribution closest to zero are of the same sign (i.e., median $-$ Q1 $\times$ 2.5 or median $+$ Q3 $\times$ 2.5), the step change is considered to be significant, and an adjustment is made to the target series. This approach is similar to the Tukey (box plot) outlier test (Tukey 1977), but allows for asymmetry in the distribution of estimates. Alternatively, one could simply use the median Δ estimate when all estimates are of the same sign. Both approaches appear to yield comparable results.

g. Example of changepoint detection and adjustment

Application of the pairwise algorithm to the group of series shown in Fig. 1 revealed two significant changepoints in Chula Vista maximum temperatures, both of which were associated with documented station moves, first on 1 January 1982 and then again on 25 April 1985. Difference series between the pairwise-adjusted mean monthly maximum temperatures for Chula Vista and its neighbors are shown in Fig. 3, which suggests that the algorithm has removed the major step inhomogeneities from all series in the group.

4. Evaluation of the algorithm

To evaluate the performance of the pairwise algorithm more generally, temperature series were simulated under a number of trend and step-change scenarios. The simulations were designed to test the skill of changepoint detection as well as to facilitate comparison of the results to previous investigations regarding the use of a reference series as well as the identification of the type of changepoint.

a. Evaluation under monthly temperature simulations

The performance of the pairwise algorithm was first evaluated using two different sets of simulated monthly temperature anomalies. One set was comprised of series with step changes, while the second set contained series with both trend and step inhomogeneities. Both sets consisted of 1000 groups of 21 correlated "red noise" series generated as in MW05. The average correlation between each series within a group was about 0.7. For all series the mean (μ) was zero and the standard deviation (σ) was one; the number of values in each series (n) was equal to 1200, the equivalent of 100 yr of monthly means.

A random number of step changes was imposed on each series at random dates. The number of steps per series varied symmetrically about a peak frequency of 5, with as few as 0 and as many as 10. The magnitude of each step change was also assigned randomly by sampling from the standard normal distribution, which means that about two-thirds of the imposed steps were equal to one σ or less. As discussed in MW05, the standard normal distribution is a good proxy for the distribution of known impacts to U.S. temperature series (Karl and Williams 1987). All imposed step changes were treated as undocumented, and 10 neighbors were identified by the pairwise algorithm for all 21 series in the groups.

In the "monthly steps and trends" simulations, a trend inhomogeneity was added to roughly 60% of the simulated series. The magnitude of this trend was varied randomly from 0.001σ month^{-1} up to about 0.18σ month^{-1}, while the trend interval varied randomly from 2 months up to the full period of record. Usually the trend inhomogeneity did not initiate with a step change, although steps frequently occurred randomly within the intervals of a creeping inhomogeneity. In total, about 25% of all series segments were characterized by a trend.

Figure 4 illustrates the impact of random step-only shifts on one group of simulated series. Prior to imposing step changes, the true trend in each series was zero. After imposing shifts, the trends ranged from -7.62σ century^{-1} to $+4.34\sigma$ century^{-1}. The pairwise algorithm correctly identified 34 of the 43 imposed step changes. Of the nine shifts not identified, six had a magnitude of less than 0.3σ, which is below the sensitivity of most tests for undocumented changepoints (DeGaetano 2006; Ducré-Robitaille et al. 2003). Furthermore, the largest undetected changepoint ($+0.696\sigma$) was preceded 10 time steps earlier by another undetected changepoint of -0.451σ; that is, the two changepoints essentially masked one another. The overall effectiveness of the pairwise adjustments is evident in Fig. 5, which depicts the 10 series after homogenization by the pairwise algorithm. Note that changepoints have been adjusted relative to the latest mean level in each series, the convention in climate data homogenization. In general, the adjusted series all have trends much closer to the true "climate" trend of zero.

Table 2 more generally summarizes the detection skill of the pairwise approach for both the step-only and the step-/trend-change scenarios. The hit rate (the ratio of the number of changepoints correctly identified relative to the total number imposed) is roughly 67% for both scenarios. The false-alarm rate (FAR; the ratio of falsely detected changepoints to the total number detected) is 6.77% for the step-only scenario (only slightly higher than the expected type-I error rate at the α = 0.05 significance level) and 19.65% for the step/trend scenario. The increase in false alarms when trend inhomogeneities are present occurs for two main reasons. First, the beginning or end of a trend inhomogeneity is often identified as a step change by the pairwise algorithm. Second, short interval trends of about 24 months or less tend to be virtually indistinguishable from step changes and are therefore adjusted as an abrupt change. Indeed, the largest magnitude false alarms under the steps-and-trend inhomogeneity simulations result from short interval, but large magnitude trend inhomogeneities that are approximated by a step change.

Histograms indicating the magnitude of hits, misses, and false alarms for the step-only and step/trend simulations are shown in Figs. 6 and 7, respectively. In both cases, changes in excess of 0.5σ are readily detected, and most misses are generally less than 0.5σ. The number of false alarms is also generally small, suggesting that they will have little impact on the homogenized trends for the simulated series.

Regarding the series trends, two measures of error are provided in Table 2. The first is the root-mean-square error (RMSE) for a trend calculated using the unadjusted series and the second is the RMSE for trends calculated using the adjusted series. As shown in the

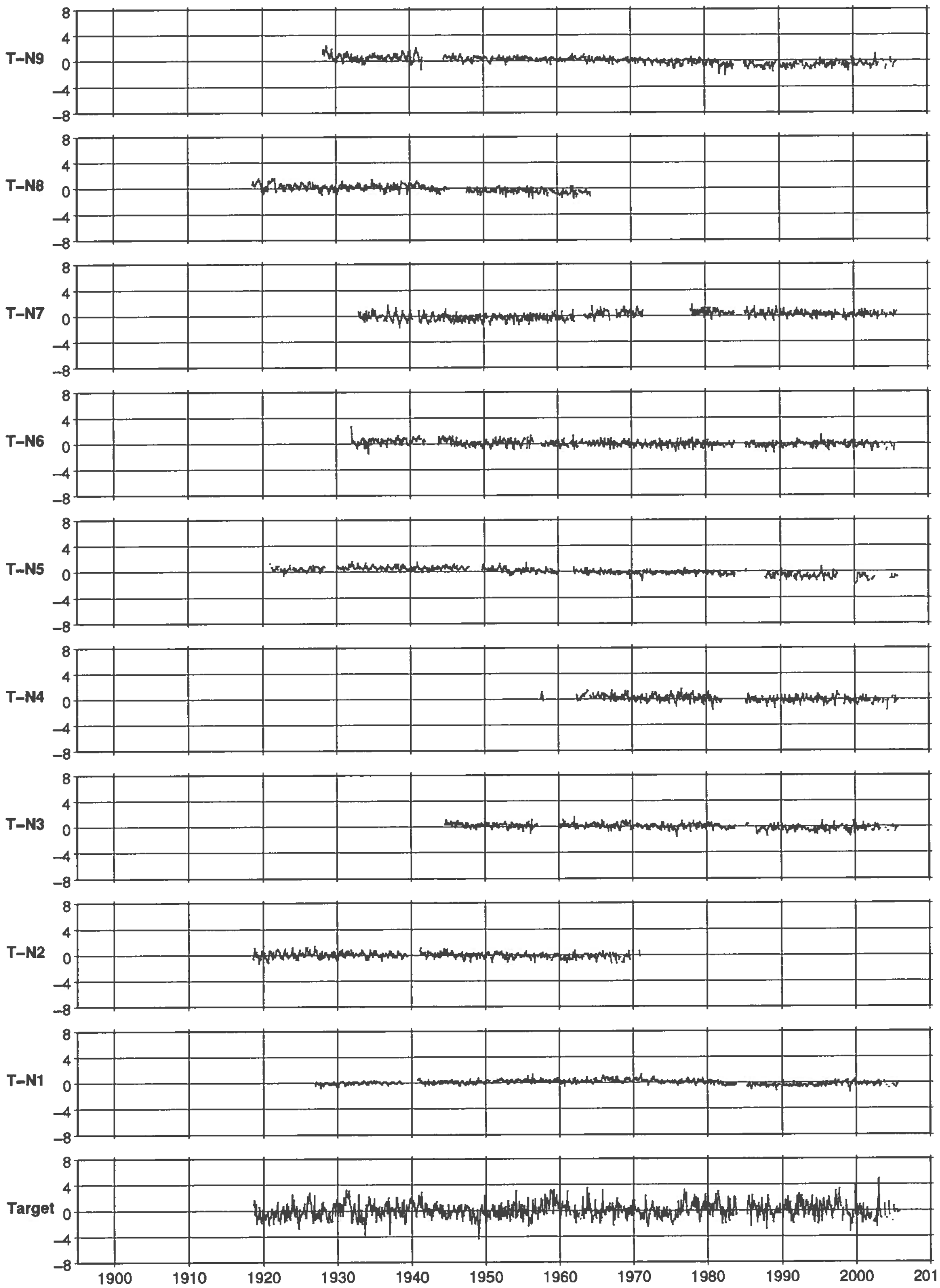


FIG. 3. As in Fig. 1, following adjustments by the pairwise algorithm.

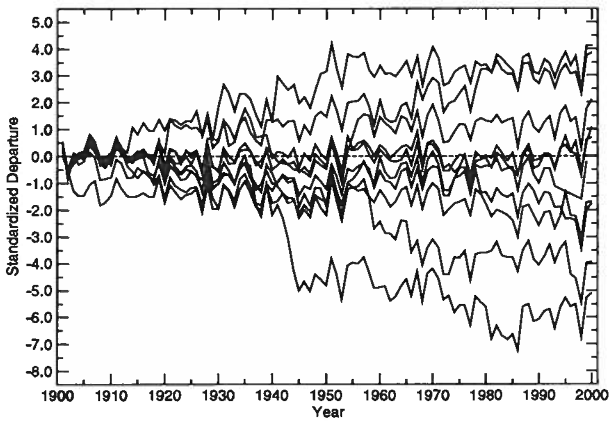


FIG. 4. "Annual" averages of simulated monthly series with a random number of changepoints imposed at random times and with random magnitudes. The true trend in all 10 correlated series is zero. Simulations are treated as beginning in January 1901 and ending December 2000.

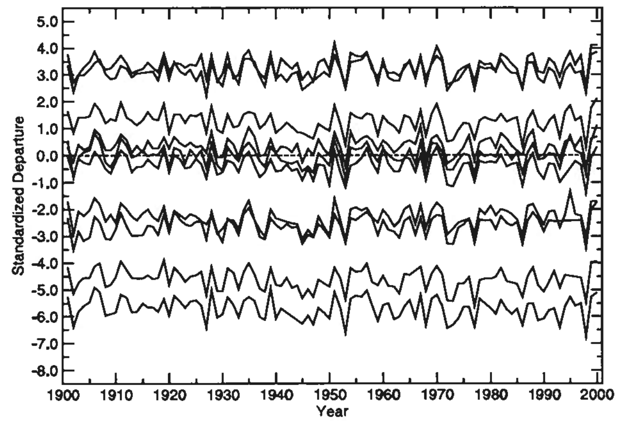


FIG. 5. As in Fig. 4, after homogenization by the pairwise algorithm.

table, the pairwise homogenization process greatly reduces the error associated with the calculation of the true background climate trend. Table 2 also indicates that the RMSE for changepoint estimates in series with trends is about as good as in the series with no trend inhomogeneities, which suggests that the model identification is reasonably successful at identifying step changes that occur within local trends. A more thorough assessment of changepoint-type identification is provided in section 4c.

b. Pairwise versus reference series changepoint detection skill

The use of a reference series is the most widely employed approach to relative changepoint detection, and MW05 evaluated the implications of such an approach for undocumented changepoint detection. The pairwise approach was therefore evaluated using the same simulations and scenarios as in MW05 to directly compare its skill of undocumented changepoint detection against the reference series approach. Table 3 depicts the seven scenarios evaluated in MW05. Each case was comprised of 1000 groups of six correlated series (one target and five neighbors) with $n = 100$ values. Of the three reference series formulations evaluated by MW05, the one based on a correlated weighted average of the five neighbors (Alexandersson and Moberg 1997) is compared here. As in the pairwise algorithm, the SNHT was used to test the target-minus-weighted-average reference $\{D_t\}$ series ($\alpha = 0.05$). All changepoints detected in the $\{D_t\}$ series were attributed to the target series to test the consequences of assuming reference series homogeneity.

Table 4 summarizes the pairwise and reference series detection skill for the MW05 target series. Two statistics are presented for each case: the FAR (previously described) and the correct changepoint (CRC) power statistic (R07), which is the percentage of time that either (a) the changepoint date in the target series was selected within ± 2 time steps of the correct date or (b) the target was correctly identified as homogeneous. Basically, the CRC is synonymous with hit rate except that it also credits the number of times that the target series was successfully identified as homogeneous.

In general, the pairwise algorithm has a much higher success rate in identifying homogeneous target series than the reference series approach as indicated by the higher CRC percentages for cases 1, 3, and 5. This is true when the neighbor series are themselves homogeneous as in cases 1 and 5, but especially when all the neighbors have changepoints as in case 3, which cause numerous inhomogeneities in the reference series. More generally, Table 4 indicates the degree to which

TABLE 2. Changepoint detection and magnitude estimation skill for monthly temperature. RMSE of Δ and β expressed in standardized units (σ). The RMSE of β is calculated with respect to the true trend of zero.

Case study	HR (%)	FAR (%)	RMSE of Δ (σ)	RMSE of β for unadjusted values (σ)	RMSE of β for adjusted values (σ)
Monthly data with step changes	67.11	6.77	0.284	2.455	0.401
Monthly data with step and trend changes	67.56	19.65	0.313	2.899	0.757

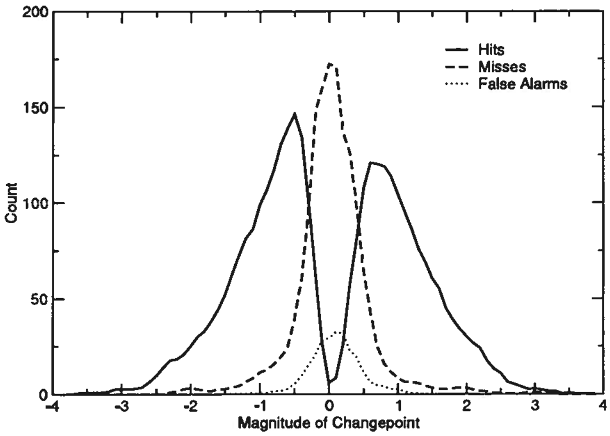


FIG. 6. Changepoint detection results for the monthly "step only" simulations.

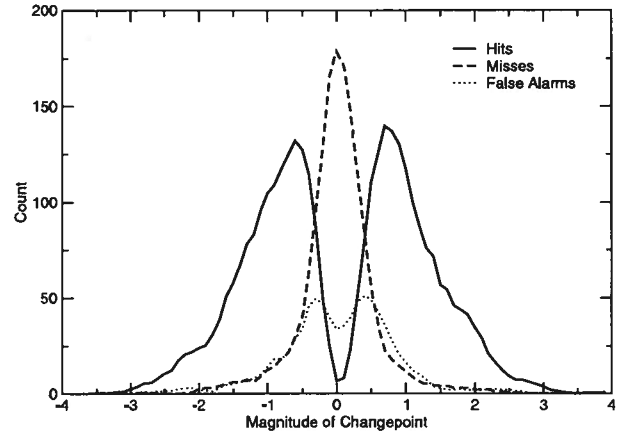


FIG. 7. Changepoint detection results for the monthly steps and trends simulations.

the pairwise approach limits the number of false alarms whenever the neighboring series are impacted by undocumented changepoints as evidenced by the low FAR for cases 4 and 6 relative to the reference series approach.

As shown in Fig. 8, the pairwise hit rate meets or exceeds that of the reference series approach when there are at least seven viable neighbors available at all times during a target station's history. (This is the foundation for the number of neighbors selected for comparison as described in section 3a.) The relatively steep increase in the power of detection as the number of comparisons increases illustrates an advantage of pairwise testing, namely, that there are multiple chances to detect a changepoint in any particular target series. If the SNHT misses a changepoint in one target–neighbor difference series, or if it misidentifies the date, there are a number of additional chances to test for the same undocumented break. The chances are not completely independent, however, because any two $\{D_t\}$ series with a common target will have an expected correlation of 0.5 (Menne and Duchon 2001). Moreover, the power of pairwise detection can be further improved by increasing the sample size between changepoints, which can be achieved by testing serial monthly values rather than annual or seasonal averages. This accounts for the higher hit rate in the "monthly" simulations, that is, 67% (Table 2) compared to the rate of a little less than 50% shown in Fig. 8 when 10 neighbors are available.

c. *Skill in identifying the type of changepoint*

The magnitude of a step change will not be accurately estimated if the type of changepoint has been misidentified. Consequently, the skill of the pairwise algorithm in classifying changepoint type was assessed for the range of models in Table 1. As in section 4b, a set of 1000 groups of target and neighbor series with $n = 100$ values were used for each scenario. In this case different magnitudes of trend and step parameters, that is, c, Δ, β, β_1, and β_2, were imposed on the target series as shown in Table 5; the five neighbor series, in contrast, were always homogeneous (M1). The magnitudes of the parameters imposed on the target series were the same as those used by R07, although only a portion of the results are summarized here.

A comparison of the CRC's in Table 5 for the $\Delta = 1\sigma$ simulations indicates that the pairwise algorithm correctly identified more than 85% of these step changes regardless of whether the target series followed M3, M4, or M5. Moreover, the algorithm also correctly identified more than 85% of the M2 (constant trend) target series as homogeneous (no steps). On the other hand, there is

TABLE 3. Number of changepoints imposed on each target and/or neighbor series for various case studies. The cases comprise 1000 simulations of six correlated series with $n = 100$ as described in MW05.

	Number of imposed changepoints	
Scenario	Target series	Each neighbor series
Case 1 (null case)	0	0
Case 2	2	0
Case 3	0	2
Case 4	2	2
Case 5 (null case with missing values)	0	0
Case 6	0–6*	0–6*
Case 7	6**	0

* The number of changepoints in each series is symmetrically distributed about a peak frequency of 3.

** Changepoint position and magnitude are fixed as in Caussinus and Mestre (2004): +2.0 at c = 20, +2.0 at c = 40, −2.0 at c = 50, −2.0 at c = 70, +2.0 at c = 75, and +2.0 at c = 85.

TABLE 4. Skill scores from the pairwise homogenization algorithm for the case studies described in Table 3. The subscripts "pw" and "ref" refer to the pairwise and reference series approaches, respectively.

Case study (and scenario description)	CRC_{pw} (%)	FAR_{pw} (%)	CRC_{ref} (%)	FAR_{ref} (%)
Case 1 (homogeneous target and neighbor series)	99.5	100.0	88.8	100.0
Case 2 (two random changepoints in target; homogeneous neighbor series)	44.0	5.6	55.4	21.0
Case 3 (homogeneous target series; two random changepoints in each neighbor series)	95.2	100.0	0.0	100.0
Case 4 (two random changepoints in all series)	37.3	8.5	50.3	46.0
Case 5 (homogeneous target and neighbor series with missing values)	100.0	Undefined (zero false alarms)	87.2	100.0
Case 6 (up to six changepoints in all series)	31.6	7.0	45.4	41.0
Cse 7 (six changepoints in target [$\Delta=2\sigma$]; homogeneous neighbors)	84.6	1.1	70.4	6.0

more variability in the skill of classifying the type of changepoint as indicated by the correct type percentages shown in bold. The percentages indicate that the algorithm had somewhat less success in classifying M4- and M5-type changepoints relative to M3-type changepoints and series that follow M2.

Under the M2 scenarios, the pairwise algorithm correctly classified more than 85% of the $\{D_t\}$ series when β was greater than or equal to 0.01 (a slope yielding a change of 1σ in 100 time steps), but less than 50% when $\beta = 0.005$ (a change of 0.5σ in 100 time steps). The reason for the difference is that the BIC does not always distinguish a sloped line from a flat line when β is small. This kind of misclassification, however, does not impact the CRC because there is no step change assigned to the target. On the other hand, when β is larger, the SNHT tends to partition the $\{D_t\}$ trend into one or more step-type changes. The BIC correctly reclassifies most of these breaks as M2, but also cannot always distinguish a trend (M2) from a step change (M3, M4, or M5). Consequently, the pairwise algorithm classifies only 91% of M2 target series as homogeneous (no step) when β = 0.01 and 86.9% when $\beta = 0.02$. The impact of this type of misclassification is to inadvertently remove some of the unique target series trend as a step adjustment, thereby bringing the target series more in line with the regional background climate trend captured by the neighbors (DeGaetano 2006; Pielke et al. 2007).

For target series under M3 (step change with no trend), the overall power of detection is a function of the magnitude of the step, as shown in previous investigations (e.g., DeGaetano 2006). In the pairwise algorithm, most (> 88%) of the $\{D_t\}$ series with a step change of 1σ or greater were correctly identified as M3, and the CRC exceeds 90% in such cases. On the other hand, many (about 45%) of the 0.5σ magnitude step changes are misclassified as a trend change (M2).

When the target series follows M4 (step change within a constant trend), the pairwise CRC varies between 85% and 90% for the 1σ step changes, close the M3 rate. However, in the M4 simulations, the algorithm frequently (about 80% of the time when $\beta = 0.005$) misclassifies the $\{D_t\}$ series as M3, especially when β is small. This type of misclassification also leads to a biased estimate of the magnitude of the jump by aliasing the unique target trend on to the estimate of the step change. Much like a false alarm when the target follows M2, the biased estimate would bring the adjusted target more in agreement with the background trend captured by the neighbors (DeGaetano 2006; Pielke et al. 2007).

Under M5, the target series has a step change within a trend change, but there is also a change in trend coincident with the step. In this scenario, the CRCs are comparable to the M4 simulations, but in this case, the pairwise algorithm tended to misclassify the $\{D_t\}$ series as M3 or M4 in roughly equal proportions. Consequently, some of the target series trends would be

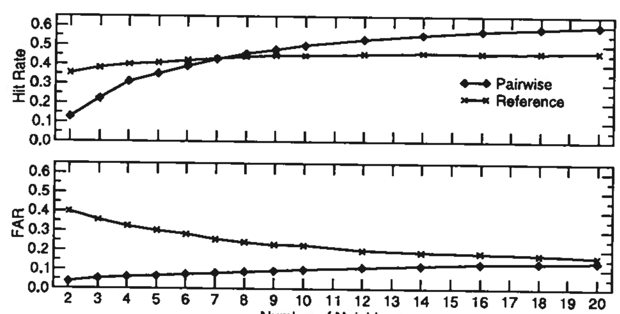


FIG. 8. Relationship between the hit rate (HR) and FAR for changepoints attributed to the target series as a function of the number of neighbors used to compute a composite reference series or in pairwise comparisons. Results are based on 1000 groups of series (n = 100) simulated under case 6 (between 0 and 6 random changepoints added to the target and all neighbor series).

TABLE 5. Changepoint detection and model identification results (%) for 1000 sets of five target–neighbor difference ($\{D_t\}$) series (n = 100). Parameters were added as indicated to the target series and c = 50 for the target simulated under M3, M4, and M5. The neighbor series always followed M1 (constant mean with no breaks). CRC refers to the pairwise algorithm's detection results for the target series. The percentage of $\{D_t\}$ identified correctly is given in bold.

Δ	β / β_1	β_2	M1	M2	M3	M4	M5	CRC
Target series follows M2								
	0.005		51.25	**44.36**	3.86	0.24	0.30	95.70
	0.010		2.45	**88.23**	7.30	0.72	1.31	91.00
	0.020		0.55	**85.75**	3.48	4.56	5.67	86.90
Target series follows M3								
0.5			11.71	45.16	**39.03**	1.66	2.44	30.30
1.0			0.06	4.83	**88.59**	1.82	4.70	90.90
2.0			0.00	0.10	**93.21**	1.85	4.85	99.90
Target series follows M4								
1.0	0.005		0.04	6.56	80.08	**5.24**	8.08	89.30
1.0	0.010		0.06	7.32	51.07	**24.56**	16.99	87.90
1.0	0.020		0.05	7.46	19.75	**52.87**	19.87	85.50
Target series follows M5								
1.0	0.010	0.015	0.11	8.16	34.84	33.17	**23.72**	87.11
1.0	0.010	0.020	0.07	8.45	25.17	33.51	**32.79**	86.20
1.0	0.010	0.030	0.07	7.47	19.34	23.22	**49.91**	85.70

aliased onto the estimate of the M5 step changes, as in the case of the M4 target series simulations.

Overall, the results in Table 5 are consistent with the changepoint-type identification capabilities of the generalized methods investigated by R07, namely, that it is more challenging to classify M4- and M5-type changepoints. As shown in R07, the lower identification skill occurs even when changepoint tests specifically designed for these types of change are used, that is, Wang (2003) for M4 and Lund and Reeves (2002) for M5. Nevertheless, from Table 5 and results (not shown) based on directly testing a target series as in R07, it appears that the pairwise approach (SNHT plus BIC) has comparable skill at model identification compared to the methods evaluated by R07. The advantage of the pairwise approach is that the SNHT's superior power of detection is exploited.

The skill of identifying changepoint type, like the power of detection, can also be improved by increasing the sample size of the test series, that is, by testing serial monthly series. For example, the percentage of correctly identified M4 difference series is about 70% at $\beta = 0.02$ when $n = 240$ and $c = 120$ versus 50% for $n = 100$ and $c = 50$. Similarly, when $\beta_1 = 0.01$ and $\beta_2 = 0.03$ under M5, the percentage of series correctly identified increases to 75% for $n = 240$ versus about 50% for $n = 100$. In addition, the skill of changepoint detection and identification increases with increasing correlation between series, which reduces the variance of the $\{D_t\}$ series. As noted by DeGaetano (2006), the correlation between temperature series in the United States is typically higher than in the simulations used here.

5. Application to U.S. temperature series

A number of recent studies have focused on the impact of land use change on the temperature record (e.g., Peterson and Owen 2005; Kalnay et al. 2006; Parker 2006; Pielke et al. 2007), yet no general assessment of the frequency of the various types of changepoints in observed temperature series has been conducted. For this reason, the pairwise algorithm was applied to monthly temperature series from the Coop Network in order to assess relative frequency of the type of inhomogeneity (including local trends) in U.S. temperature records. Monthly mean maximum and minimum values from over 7000 stations covering the period from 1895 to 2006 were used, although the specific period of record varied from station to station. The nature of the shifts for a commonly used subset of the Coop network, that is, the U.S. Historical Climatology Network (HCN; Easterling et al. 1996) was examined in detail.

An analysis of the more than 100 000 $\{D_t\}$ series segments used to calculate the shift magnitudes for HCN temperature series indicates that about 50% of the step changes follow M3 (step change with no trend), while approximately 40% follow M5 (step change accompanied by a trend change) and about 10% follow M4 (step change within a general trend). While these percentages were calculated on a segment-by-segment basis, the models M4 and M5 also minimized the BIC statistic about 50% of the time when calculated across each series' full period of record (shown in Table 7). In other words, the trend models appear to be a better fit about 50% of the time even for observed $\{D_t\}$ that are generally decades long and incorporate shifts identified in both HCN targets and their Coop neighbors (and are thus highly penalized by the BIC).

To further evaluate the pairwise adjustments for these types of shifts, the adjusted series were also manually inspected. In brief, this entailed graphing each HCN series and its Coop neighbors as in Fig. 3, and then subjectively deeming the adjusted series as plausible or implausible. This subjective evaluation revealed that roughly 15%–20% of the adjusted series exhibited

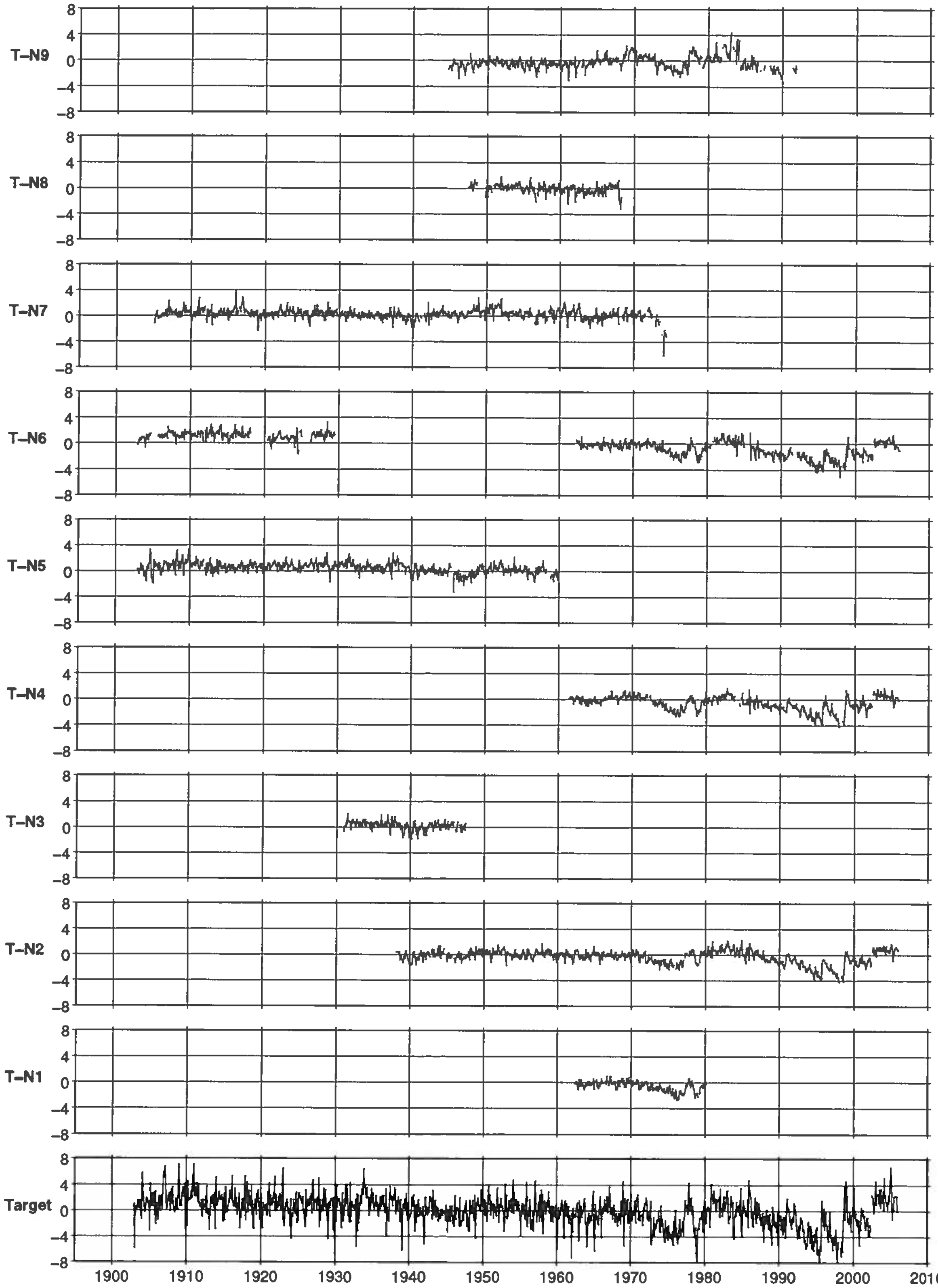


FIG. 9. Mean monthly minimum temperature anomalies (°C) for Cheesman (target) and differences between monthly temperature anomalies at Cheesman and nine neighboring series (T-N1 to T-N9).

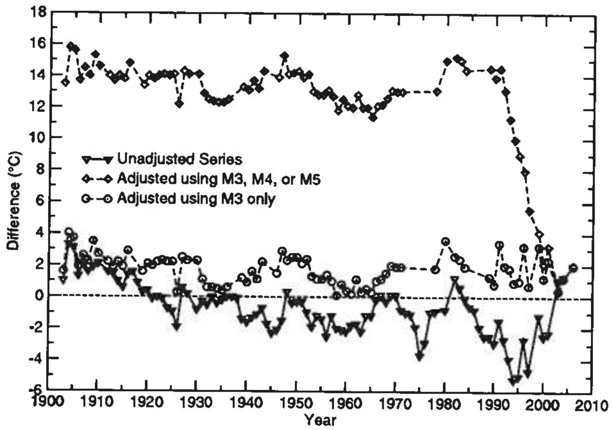


FIG. 10. Differences between annual minimum temperatures at Cheezman and 20 neighboring stations, and following adjustments for step changes using the most appropriate model determined by the pairwise algorithm (M3, M4, or M5) and using M3 only.

physically unrealistic trends that were clearly inconsistent with neighboring stations. The minimum temperature series at Cheesman, Colorado, is an extreme example. As shown in Fig. 9, a sawtooth pattern is evident in the $\{D_t\}$ series formed between the Cheesman series and its neighbors. The increasing difference between Cheesman and the surrounding stations (particularly after 1980) sometimes exceeded 4°C in 5 yr, a relative change that was easily classified as M5 (step change with a trend change) by the pairwise algorithm. The consequence of adjusting the series using M5 (i.e., removal of the step and retention of the trend) is shown in Fig. 10. The result is clearly unrealistic.

Given that preserving local trends (i.e., trend inhomogeneities) can often result in undesirable adjusted series, the pairwise algorithm was modified to employ the more commonly used M3 adjustment for all step changes (DeGaetano 2006). (Note that M3, M4, and M5 were still employed to detect step changes.) The impact of the M3-only approach on the Cheesman series is also shown in Fig. 10. Although the sawtooth signature remains in the adjusted data, the trend at Cheesman using the M3 adjustments is clearly in sync with the average of trends in surrounding series. A similar visual inspection of all HCN temperature series suggests that an M3-only adjustment approach works well for all situations in which there is evidence of a step change because any associated trend inhomogeneity is consistently aliased onto estimates of the step change in a way that favors the background climate signal.

The same result occurs when M3 alone is used to adjust the simulated series in the "monthly steps and trends" simulations, as shown in Table 6. From a comparison of the RMSE for the adjusted trends in Tables 2 and 6, it is evident that using M3 for all step-change adjustments removes the impact of most trend inhomogeneities because the error for the adjusted trends is roughly the same for the step-only and steps and trends simulations. Still, while the temperature series that result using the M3-only adjustments arguably approximate the best theoretical climate series for each location, the local trend signal is nevertheless aliased out of the original series, thus limiting the use of the adjusted series in some attribution studies of observed temperature change. Ultimately, a better solution would be to remove trend inhomogeneities via trend adjustments and step inhomogeneities via step adjustments. Unfortunately, unlike step changes that occur at the same time within a group of target/neighbor $\{D_t\}$ series, a trend inhomogeneity at a given target station may begin and end at different times with respect to each of its neighbors. This makes identifying the true interval of trend inhomogeneity more difficult than detecting step changes, and is beyond the scope of this paper.

In any case, another reason to use only M3-type adjustments is that it appears that at least some apparent trends may in fact be artifacts of unidentified step changes. This conclusion comes from an evaluation of the capability of the BIC statistic to determine the true dimensions of the simulated target-minus-neighbor period of record $\{D_t\}$ series when the shifts are treated as wholly undocumented (and identified by the pairwise algorithm) versus when the shift times are known perfectly. Table 7 summarizes the frequency that each model minimized the BIC statistic in the 420 000 unique $\{D_t\}$ series that comprise each set of monthly simulations. Based on these results, it appears that M5 rarely minimizes the BIC when there are no relative trends in the simulated data, but M4 is identified as the "best" model in over 16% of cases when the shifts are treated as undocumented. Conversely, when there is perfect

TABLE 6. Changepoint detection and magnitude estimation skill for monthly temperature series using a constant mean model (M3) for all step change adjustments regardless of the identified type.

Case study	HR(%)	FAR (%)	RMSE of Δ (σ)	RMSE of β for unadjusted values (σ)	RMSE of β for adjusted values (σ)
Monthly data with step changes	67.22	6.77	0.291	2.455	0.401
Monthly data with step and trend changes	67.58	20.14	0.349	2.899	0.488

TABLE 7. Frequency (%) that the model minimizes the BIC statistic for the period of record difference series formed between all target and neighbor series.

Scenario	Model				
	M1	M2	M3	M4	M5
Observed HCN monthly temperatures (pairwise identification of steps)	5.12	10.06	34.18	25.29	25.35
Monthly step-only simulations (pairwise identification of steps)	0.45	0.27	78.58	16.71	3.99
Monthly steps-only simulations (perfect knowledge of steps)	0.45	0.34	96.24	2.96	0.00
Monthly steps and trends simulations (pairwise identification of steps)	0.09	0.27	20.47	17.21	61.96
Monthly steps and trends simulations (perfect knowledge of steps)	0.09	0.41	41.79	21.72	35.99

knowledge of the timing of all shifts no matter how small, M4 rarely minimizes the BIC when only shifts occur (in this case M5 was selected as the "best" model in only 2 of 420 000 cases).

The sloped models more frequently minimize the BIC in the steps and trends scenarios than in the steps-only simulations. Given that in this case approximately 63% of the full $\{D_t\}$ series have a trend segment somewhere in the period of record, Table 7 suggests that the frequency of M3-type models is nevertheless underestimated when shifts are treated as undocumented (because of unidentified step changes). However, when there is perfect knowledge of all shifts in the monthly steps and trends simulations, the models minimize the BIC in way that suggests that the frequency of M3 solutions is approximately correct (although M4 is selected too often at the expense of M5). Based on these results, we conclude that, while perhaps prevalent, the frequency of apparent trend inhomogeneities in the HCN is inflated by the presence of unidentified (i.e., small and perhaps unidentifiable) step changes.

6. Conclusions

Our evaluation of the pairwise algorithm suggests that it is a robust, reliable, and accurate approach to detecting step-type inhomogeneities under a wide variety of circumstances. Relative to the more traditional use of a climate reference series, a pairwise approach to undocumented changepoint detection reduces the number of false alarms in general and is particularly successful at identifying homogeneous segments. In addition, unlike the reference approach, there are no requirements for a group of series to have a common base period. As a result, the estimation of step-change magnitude is not confined to the shortest homogeneous interval within a group of neighboring series. In this regard, the pairwise method is similar to the graph theory approach used by Christy et al. (2006) except that the pairwise algorithm makes no attempt to compare climate series that do not overlap in time.

Moreover, because each climate series is paired with a unique set of neighboring series in the algorithm, it is possible to determine whether more than one nearby station series shares a particular shift date because both stations will have been implicated multiple times on or about the same date. This property of the algorithm is important when a widespread and near simultaneous change in observation practice occurs in a network. Such a situation arose in the U.S. Cooperative Network when liquid-in-glass thermometers were replaced with electronic thermistors at roughly two-thirds of sites during the mid- and late 1980s (Quayle et al. 1991; Hubbard and Lin 2006). Of course, if a change is implemented on exactly the same date at all stations, relative homogeneity testing will not be effective.

Results from applying the pairwise algorithm to observed temperature series suggest that while there is evidence of relative trends between series in the U.S. surface temperature record, some apparent trends may be an artifact of unidentified, small shifts. Although there is some interest in preserving such trend inhomogeneities for land use/land change impact studies (e.g., Pielke et al. 2007), the results of this analysis indicate that physically implausible trends can result when apparent trend inhomogeneities are preserved. On the other hand, if the goal is to produce an accurate estimate of the background climate signal, all identified shifts can nevertheless be removed using the step-only model. While this necessarily leads to the aliasing of any associated trend inhomogeneity onto the estimate of the step change, a reliable estimate of the background climate signal is obtained.

Finally, we reiterate that the pairwise algorithm was designed to solve the practical problem of adjusting temperature series to remove the impacts of artificial changes in a holistic way. Because the algorithm is modular, it is possible to enhance its various components. For example, shifts in the target-minus-neighbor difference series might be resolved using optimal methods (e.g., Caussinus and Mestre 2004) and/or by incorporating tests for periodicity in the serial monthly difference series. The latter may be important because the monthly adjustments calculated by the pairwise algorithm are currently constant for all months. Although the increased sample size afforded by testing serial monthly data likely overwhelms any benefit to testing seasonal values separately (cf. Karl and Williams 1987; Begert et al. 2005; Brunet et al. 2007), there is evidence that bias changes often have impacts that vary seasonally and/or synoptically (Trewin and Trevitt 1996; Guttman and Baker 1996). As shown by Della-Marta and Wanner (2006), it is possible to estimate the differential impacts indirectly by evaluating the magnitude of change as a function of the frequency distribution of *daily* temperatures. Such a method requires knowledge of the timing of shifts as a starting point, which can be provided by the pairwise results.

Acknowledgments. Thanks to Russell Vose, Imke Durre, and Tamara Houston for constructive comments on earlier drafts for this manuscript. The reviews by Dr. Robert Lund and an anonymous reviewer also greatly improved the paper. Partial support for this work was provided by the Office of Biological and Environmental Research, U.S. Department of Energy (Grant DE-AI02-96ER62276).

REFERENCES

Alexandersson, H., 1986: A homogeneity test applied to precipitation data. *J. Climatol,* **6,** 661–675.

——, and A. Moberg, 1997: Homogenization of Swedish temperature data. Part I: Homogeneity test for linear trends. *Int. J. Climatol.,* **17,** 25–34.

Begert, M., T. Schlegel, and W. Kirchhofer, 2005: Homogeneous temperature and precipitation series of Switzerland from 1864 to 2000. *Int. J. Climatol.,* **25,** 65–80.

Brunet, M., and Coauthors, 2007: Temporal and spatial temperature variability and change over Spain during 1850–2003. *J. Geophys. Res,* **112,** D12117, doi:10.1029/2006JD008249.

Carretero, J. C., and Coauthors, 1998: Changing waves and storms in the northeast Atlantic? *Bull. Amer. Meteor. Soc.,* **79,** 741–760.

Caussinus, H., and O. Mestre, 2004: Detection and correction of artificial shifts in climate series. *J. Roy. Stat. Soc.,* **53C,** 405–425.

Christy, J. R., W. B. Norris, K. Redmond, and K. P. Gallo, 2006: Methodology and results of calculating central California surface temperature trends: Evidence of human-induced climate change? *J. Climate,* **19,** 548–563.

Conrad, V., and L. W. Pollak, 1962: *Methods in Climatology.* Harvard University Press, 459 pp.

DeGaetano, A. T., 2006: Attributes of several methods for detecting discontinuities in mean temperature series. *J. Climate,* **19,** 838–853.

Della-Marta, P. M., and H. Wanner, 2006: A method of homogenizing the extremes and mean of daily temperature measurements. *J. Climate,* **19,** 4179–4197.

Ducré-Robitaille, J.-F., L. A. Vincent, and G. Boulet, 2003: Comparison of techniques for detection of discontinuities in temperature series. *Int. J. Climatol.,* **23,** 1087–1101.

Easterling, D. R., T. R. Karl, E. H. Mason, P. Y. Hughes, and D. P. Bowman, 1996: United States Historical Climatology Network (U.S. HCN) monthly temperature and precipitation data. ORNL/CDIAC-87, NDP-019/R3, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN, 280 pp.

González-Rouco, J. F., J. L. Jiménez, V. Quesada, and F. Valero, 2001: Quality control and homogeneity of precipitation data in the southwest of Europe. *J. Climate,* **14,** 964–978.

Guttman, N. B., and C. B. Baker, 1996: Exploratory analysis of the difference between temperature observations recorded by ASOS and conventional methods. *Bull. Amer. Meteor. Soc.,* **77,** 2865–2873.

Hanssen-Bauer, I., and E. J. Førland, 1994: Homogenizing long Norwegian precipitation series. *J. Climate,* **7,** 1001–1013.

Hawkins, D. M., 1976: Point estimation of the parameters of a piecewise regression model. *Appl. Stat.,* **25,** 51–57.

Hubbard, K. G., and X. Lin, 2006: Reexamination of instrument change effects in the U.S. Historical Climatology Network. *Geophys. Res. Lett.,* **33,** L15710, doi:10.1029/2006GL027069.

Jones, P. D., S. C. B. Raper, P. M. Kellyo, T. M. L. Wigley, R. S. Bradley, and H. F. Diaz, 1986: Northern Hemisphere surface air temperature variations: 1851–1984. *J. Climate Appl. Meteor.,* **25,** 161–179.

Kalnay, E., M. Cai, H. Li, and J. Tobin, 2006: Estimation of the impact of land-surface forcings on temperature trends in eastern United States. *J. Geophys. Res.,* **111,** D06106, doi:10.1029/2005JD006555.

Karl, T. R., and C. N. Williams Jr., 1987: An approach to adjusting climatological time series for discontinuous inhomogeneities. *J. Climate Appl. Meteor.,* **26,** 1744–1763.

——, H. F. Diaz, and G. Kukla, 1988: Urbanization: Its detection and effect in the United States climate record. *J. Climate,* **1,** 1099–1123.

Livezey, R. E., and W. Y. Chen, 1983: Statistical field significance and its determination by Monte Carlo techniques. *Mon. Wea. Rev.,* **111,** 46–59.

Lu, Q., and R. B. Lund, 2007: Simple linear regression with multiple level shifts. *Can. J. Stat.,* **35,** 447–458.

Lund, R., and J. Reeves, 2002: Detection of undocumented changepoints: A revision of the two-phase regression model. *J. Climate,* **15,** 2547–2554.

——, C. Gallagher, X. L. Wang, Y. Feng, Q. Lu, and J. Reeves, 2007: Changepoint detection in periodic and autocorrelated time series. *J. Climate,* **20,** 5178–5190.

McCarthy, M. P., H. A. Titchner, P. W. Thorne, S. F. B. Tett, L. Haimberger, and D. E. Parker, 2008: Assessing bias and uncertainty in the HadAT-adjusted radiosonde climate record. *J. Climate,* **21,** 817–832.

Menne, M. J., and C. E. Duchon, 2001: A method for monthly detection of inhomogeneities and errors in daily maximum and minimum temperatures. *J. Atmos. Oceanic Technol.,* **18,** 1136–1149.

——, and C. N. Williams Jr., 2005: Detection of undocumented changepoints using multiple test statistics and composite reference series. *J. Climate,* **18,** 4271–4286.

Parker, D. E., 2006: A demonstration that large-scale warming is not urban. *J. Climate,* **19,** 2882–2895.

Peterson, T. C., and T. W. Owen, 2005: Urban heat island assessment: Metadata are important. *J. Climate,* **18,** 2637–2646.

——, and Coauthors, 1998a: Homogeneity adjustments of in situ atmospheric climate data: A review. *Int. J. Climatol,* **18,** 1493–1517.

——, T. R. Karl, P. F. Jamason, R. Knight, and D. R. Easterling, 1998b: First difference method: Maximizing station density for the calculation of the long-term global temperature change. *J. Geophys. Res.,* **103,** 25 967–25 974.

Pielke, R. A., Sr.,and Coauthors, 2007: Documentation of uncertainties and bias associated with surface temperature measurement sites for climate change assessment. *Bull. Amer. Meteor. Soc.,* **88,** 913–928.

Quayle, R. G., D. R. Easterling, T. R. Karl, and P. Y. Hughes, 1991: Effects of recent thermometer changes in the Cooperative Station Network. *Bull. Amer. Meteor. Soc.,* **72,** 1718–1723.

Reeves, J., J. Chen, X. L. Wang, R. Lund, and Q. Lu, 2007: A review and comparison of changepoint detection techniques for climate data. *J. Appl. Meteor. Climatol.,* **46,** 900–915.

Schwarz, G., 1978: Estimating the dimension of a model. *Ann. Stat.,* **6,** 461–464.

Slonosky, V. C., P. D. Jones, and T. D. Davies, 1999: Homogenization techniques for European monthly mean surface pressure series. *J. Climate,* **12,** 2658–2672.

Thorne, P. W., D. E. Parker, J. R. Christy, and C. A. Mears, 2005: Uncertainties in climate trends: Lessons from upper-air temperature records. *Bull. Amer. Meteor. Soc.,* **86,** 1437–1442.

Trewin, B. C., and A. C. F. Trevitt, 1996: The development of composite temperature records. *Int. J. Climatol.,* **16,** 1227–1242.

Tukey, J. W., 1977: *Exploratory Data Analysis.* Addison-Wesley, 688 pp.

Vincent, L. A., 1998: A technique for the identification of inhomogeneities in Canadian temperature series. *J. Climate,* **11,** 1094–1104.

Wang, X. L., 2003: Comments on "Detection of undocumented changepoints: A revision of the two-phase regression model." *J. Climate,* **16,** 3383–3385.

Appendix 4

Some web services will be unavailable August 4, 2012

MMS: Multi-Network Metadata System

Stn Name: ST LOUIS LAMBERT INTL AP
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.7525 (38°45'09.0"N)
Longitude: -90.3736 (90°22'24.96"W)
Elevation: 531.00 FEET (GROUND)
POR: 1929-01-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237455
- FAA LOCATION IDENTIFIER: STL
- ICAO ID: KSTL
- NCDC STATION ID NUMBER: 20011882
- NWSLI: STL
- WBAN NUMBER: 13994

(Logged in as guest)

Display Combined
Sort Values

Tab Remarks: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Latitude	Longitude	Elevation	Relocation	County	Climate Division	Time Zone
[2012-02-20]	Current	38.752500 (38° 45'09"N)	-90.373600 (90° 22'24"W)	AIRPORT: 618 FEET BAROMETRIC: 564.72 FEET GROUND: 531 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Topographic Details: LEVEL, NEAR THE END OF THE PRIMARY INSTRUMENT RUNWAY.						
[2002-01-18]	2012-02-20	38.752500 (38° 45'09"N)	-90.373610 (90° 22'24"W)	AIRPORT: 618 FEET BAROMETRIC: 564.72 FEET GROUND: 531 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Topographic Details: LEVEL, NEAR THE END OF THE PRIMARY INSTRUMENT RUNWAY.						
[1996-06-01]	2002-01-18	38.752500 (38° 45'09"N)	-90.373610 (90° 22'24"W)	AIRPORT: 618 FEET BAROMETRIC: 564.72 FEET GROUND: 568 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: BATRON ATC OUTSIDE & 2.1 MI E OF PO AT BRIDGETON, MO.						
		Topographic Details: TOPO- SLIGHTLY ROLLING URBAN LOCATION ERY SLIGHTLY WOODED.						
[1989-03-01]	1996-06-01	38.750000 (38° 45'00"N)	-90.366670 (90° 22'00"W)	AIRPORT: 618 FEET BAROMETRIC: 564.72 FEET GROUND: 568 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: BATRON ATC OUTSIDE & 2.1 MI E OF PO AT BRIDGETON, MO.						
		Topographic Details: TOPO- SLIGHTLY ROLLING URBAN LOCATION ERY SLIGHTLY WOODED.						
[1988-07-11]	1989-03-01	38.750000 (38° 45'00"N)	-90.366670 (90° 22'00"W)	AIRPORT: 618 FEET BAROMETRIC: 564.72 FEET GROUND: 535 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: BATRON ATC OUTSIDE & 2.1 MI E OF PO AT BRIDGETON, MO.						
		Topographic Details: TOPO- SLIGHTLY ROLLING URBAN LOCATION ERY SLIGHTLY WOODED.						
[1982-01-01]	1988-07-11	38.750000 (38° 45'00"N)	-90.366670 (90° 22'00"W)	AIRPORT: 618 FEET BAROMETRIC: 564.72 FEET GROUND: 535 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1978-01-01]	1982-01-01	38.750000 (38° 45'00"N)	-90.366670 (90° 22'00"W)	AIRPORT: 618 FEET BAROMETRIC: 564.72 FEET GROUND: 535 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1977-12-31]	1978-01-01	38.750000 (38° 45'00"N)	-90.383330 (90° 22'59"W)	BAROMETRIC: 564.72 FEET GROUND: 564 FEET	---	ST. LOUIS	-	CENTRAL (+6)
[1977-11-29]	1977-12-31	38.750000 (38° 45'00"N)	-90.383330 (90° 22'59"W)	BAROMETRIC: 564.72 FEET GROUND: 564 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1959-01-01]	1977-11-29	38.750000 (38° 45'00"N)	-90.383330 (90° 22'59"W)	GROUND: 564 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1947-11-30]	1959-01-01	38.750000 (38° 45'00"N)	-90.383330 (90° 22'59"W)	GROUND: 577 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1947-11-01]	1947-11-30	38.750000 (38° 45'00"N)	-90.383330 (90° 22'59"W)	BAROMETRIC: 577 FEET GROUND: 577 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1939-01-01]	1947-11-01	38.750000 (38°	-90.383330 (90°	BAROMETRIC: 577 FEET	---	ST.	02 - NORTHEAST	CENTRAL

Schedule ALD-ER1

		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE			
		PRCP	F&P	---	FISCHER/PORTER RRNG	---			---
[Unknown]	1978-05-10	PRCP	UNKNOWN	PRIMARY	UNKNOWN - PRECIP	PRECIPITATION		---	COOP SOD
		TEMP			UNKNOWN - TEMP	TEMPERATURE			
		PRCP	UNIV	---	UNIVERSAL RRNG	---			---

Schedule ALD-ER1

Some web services will be unavailable August 4, 2012

MMS: Multi-Network Metadata System

Phenomena Other Considerations Map Remarks Files Related
Identity Updates Location Other Party Data Products Data Programs Equipment
[Stn Name] [Networks] [Stn IDs] [Stn Type] [All Tables]

Stn Name: ST LOUIS LAMBERT INTL AP
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.7525 (38°45'09.0"N)
Longitude: -90.3736 (90°22'24.96"W)
Elevation: 531.00 FEET (GROUND)
POR: 1929-01-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237455
- FAA LOCATION IDENTIFIER: STL
- ICAO ID: KSTL
- NCDC STATION ID NUMBER: 20011882
- NWSLI: STL
- WBAN NUMBER: 13994

(Logged in as guest)

Display Combined
Sort Values

Tab Remarks: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Stn Name	Name Type	Stn Type	COOP	WBAN	FAA	ICAO	WMO	NCDC	NWSLI	MMS
[2012-02-20]	Current	ST LOUIS LAMBERT INTL AIRPORT	COOP NAME	ASOS, ASOS-NWS, COOP, COOPERATIVE SUB-NETWORK- AB, FCWOS, LAND SURFACE	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
		LAMBERT-ST LOUIS INTERNATIONAL AP	PUB NAME									
[2011-04-15]	2012-02-20	ST LOUIS LAMBERT INTL AP	COOP NAME	ASOS, ASOS-NWS, COOP, COOPERATIVE SUB-NETWORK- AB, FCWOS, LAND SURFACE	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
		LAMBERT-ST LOUIS INTERNATIONAL AP	PUB NAME									
[2002-01-18]	2011-04-15	ST LOUIS LAMBERT INTL AP	COOP NAME	ASOS, ASOS-NWS, COOP, COOPERATIVE SUB-NETWORK- AB, FCWOS, LAND SURFACE	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1996-06-01]	2002-01-18	ST LOUIS WSCMO AP	COOP NAME	ASOS, ASOS-NWS, COOP, COOPERATIVE SUB-NETWORK- B, FCWOS, LAND SURFACE	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1995-01-01]	1996-06-01	ST LOUIS WSCMO AP	COOP NAME	COOP, COOPERATIVE SUB-NETWORK- B, FCWOS, LAND SURFACE	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1994-04-12]	1995-01-01	ST LOUIS WSCMO AP	COOP NAME	COOP, COOPERATIVE SUB-NETWORK- B, FCWOS, LAND SURFACE	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1989-03-01]	1994-04-12	ST LOUIS WSCMO AP	COOP NAME	COOP, COOPERATIVE SUB-NETWORK- B, LAND SURFACE, WSCMO	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1988-07-11]	1989-03-01	ST LOUIS WSCMO AP	COOP NAME	COOP, COOPERATIVE SUB-NETWORK- B, LAND SURFACE, WSCMO	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									

Schedule ALD-ER1

[1981-04-16]	1988-07-11	ST LOUIS WSCMO AP	COOP NAME	COOP, LAND SURFACE, WSCMO	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1980-01-01]	1981-04-16	ST LOUIS WSMO AP	COOP NAME	COOP, LAND SURFACE, WSCMO	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1978-01-01]	1980-01-01	ST LOUIS WSMO AP	COOP NAME	COOP, LAND SURFACE, WSMO	237455	13994	STL	KSTL	72434	20011882	STL	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1976-01-01]	1978-01-01	ST LOUIS WSMO AP	COOP NAME	COOP, LAND SURFACE, WSMO	237455	13994	---	---	---	20011882	---	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1974-10-17]	1976-01-01	ST LOUIS WSMO AP	COOP NAME	COOP, LAND SURFACE, WSO	237455	13994	---	---	---	20011882	---	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1974-06-11]	1974-10-17	ST LOUIS WSFO AP	COOP NAME	COOP, LAND SURFACE, WSO	237455	13994	---	---	---	20011882	---	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1973-01-01]	1974-06-11	ST LOUIS WB AP	COOP NAME	COOP, LAND SURFACE, WSO	237455	13994	---	---	---	20011882	---	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1971-12-01]	1973-01-01	ST LOUIS WB AP	COOP NAME	COOP, LAND SURFACE, WBAS	237455	13994	---	---	---	20011882	---	12306
		ST LOUIS LAMBERT INTL AP	PRINCIPAL NAME									
[1947-11-01]	1971-12-01	ST LOUIS WB AP	COOP NAME	COOP, LAND SURFACE, WBAS	237455	13994	---	---	---	20011882	---	12306
		ST LOUIS LAMBERT FIELD	PRINCIPAL NAME									
[1929-09-01]	1947-11-01	ST LOUIS LAMBERT FIELD	PRINCIPAL NAME	LAND SURFACE, WBAS	---	13994	---	---	---	20011882	---	12306
[1929-07-16]	1929-09-01	ST LOUIS LAMBERT FIELD	PRINCIPAL NAME	WBAS	---	---	---	---	---	20011882	---	12306

Schedule ALD-ER1

Some web services will be unavailable August 4, 2012

MMS: Multi-Network Metadata System

Phenomena Other Considerations Map Remarks Files Related
Identity Updates Location Other Party Data Products Data Programs Equipment
[Equation] [Factor] [Factor/Equation]

Stn Name: ST LOUIS LAMBERT INTL AP
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.7525 (38°45'09.0"N)
Longitude: -90.3736 (90°22'24.96"W)
Elevation: 531.00 FEET (GROUND)
POR: 1929-01-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237455
- FAA LOCATION IDENTIFIER: STL
- ICAO ID: KSTL
- NCDC STATION ID NUMBER: 20011882
- NWSLI: STL
- WBAN NUMBER: 13994

(Logged in as guest)

Display Combined
Sort Values

Tab Remarks: View (0)
Misc. Data: View (1)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Equip Type	Equipment Model	Priority	Equipment Name	Phenomenon	Elevation	Serial Number	Data
[2012-02-20]	Current	PRCP	PCPN	PRIMARY	AWPAG	PRECIPITATION	---	00410	COOP HPD
			PCPNX		PCPNX			---	COOP SOD
			SRG	BACKUP	STANDARD RAIN GAGE				
		SNOW	SNOWSTICK	PRIMARY	SNOW MEASURING STICK	SNOW DEPTH			
			SNSRG		SNSRG	SNOW WATER EQUIVALENCY			
		TEMP	ATEMP		ATEMP: ASOS HYGROTHERMOMETER	TEMPERATURE			
			PSY	BACKUP	PSYCHROMETER				
		MISC	MISC1	---	MISCX: MISCELLANEOUS EQUIP NO 1	---			---
[2002-01-18]	2012-02-20	PRCP	AHTB	PRIMARY	AHTB	PRECIPITATION		---	COOP SOD
									COOP HPD
			SRG	BACKUP	STANDARD RAIN GAGE				COOP SOD
		TEMP	ATEMP	PRIMARY	ATEMP: ASOS HYGROTHERMOMETER	TEMPERATURE			
			PSY	BACKUP	PSYCHROMETER				
[1995-07-01]	2002-01-18	PRCP	UNIV	PRIMARY	UNIVERSAL RRNG	PRECIPITATION		---	COOP SOD
									COOP HPD
		TEMP	MXMN		MAX-MIN THERMOMETERS	TEMPERATURE			COOP SOD
[1988-07-11]	1995-07-01	PRCP	UNIV	PRIMARY	UNIVERSAL RRNG	PRECIPITATION		---	COOP SOD
		TEMP	MXMN		MAX-MIN THERMOMETERS	TEMPERATURE			
[1982-01-01]	1988-07-11	PRCP	UNIV	PRIMARY	UNIVERSAL RRNG	PRECIPITATION		---	COOP SOD
		TEMP	UNKNOWN		UNKNOWN - TEMP	TEMPERATURE			
[Unknown]	1982-01-01	PRCP	UNIV	PRIMARY	UNIVERSAL RRNG	PRECIPITATION		---	COOP SOD
		TEMP	UNKNOWN		UNKNOWN - TEMP	TEMPERATURE			

Schedule ALD-ER1

Some web services will be unavailable August 4, 2012

MMS: Multi-Network Metadata System

Stn Name: ST LOUIS SCIENCE CTR
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.6291 (38°37'44.76"N)
Longitude: -90.2706 (90°16'14.16"W)
Elevation: 545.00 FEET (GROUND)
POR: 1968-06-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237452
- NCDC STATION ID NUMBER: 20011858
- NWSLI: SSCM7

(Logged in as guest)

Display Combined
Sort Values

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Context	Remark	Owner	Entered By	Entry Date	Modified By	Mod. Date
[2012-06-18]	Current	GENERAL REMARK	UPDATED EQUIPMENT, CHANGED F&P TO FPR-E. UPDATED FOR THE PAPERLESS DATA COLLECTION SYSTEM. ALSO UPDATED STN INFO, OBSERVER DATA AND OB INFO.	---	INGEST_USER	2012-06-25	---	---
[2004-08-01]	Current	GENERAL REMARK	ALL EQUIPMENT MOVED 275 FT S; COMPATIBLE. UPDATE CONTACT POINT, OBSERVATION AND EQUIPMENT SECTIONS.	---	INGEST_USER	2005-01-05	jarnfield	2005-04-25
[1986-10-01]	Current	RIVER BASIN (COOP NETWORK)	MISSISSIPPI	NCDC	INITIAL SHIPS CONVERSION	2004-01-12	JKLEIN	---
[1968-06-01]	1978-05-10	RIVER BASIN (COOP NETWORK)	MISSISSIPPI	NCDC	INITIAL SHIPS CONVERSION	2004-01-12	JKLEIN	---

Schedule ALD-ER1

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)

National Climatic Data Center
U.S. Department of Commerce

Some web services will be unavailable August 4, 2012

MMS: Multi-Network Metadata System

Phenomena | Other Considerations | Map | Remarks | Files | Related
Identity | Updates | Location | Other Party | Data Products | Data Programs | Equipment

[Updates]

Stn Name: ST LOUIS SCIENCE CTR
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.6291 (38°37'44.76"N)
Longitude: -90.2706 (90°16'14.16"W)
Elevation: 545.00 FEET (GROUND)
POR: 1968-06-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237452
- NCDC STATION ID NUMBER: 20011858
- NWSLI: SSCM7

(Logged in as guest)

Tab Remarks: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Effective Date	Update Provided By	Source Description	Source Version	Native ID	Description of Update	Entered By	Entry Date	Modified By	Modified Date
[2012-06-18]	Current	2012-06-18	NWS	CSSA	10	LSX20619479	CHANGE	INGEST_USER	2012-06-25	---	---
[2006-05-05]	Current	2006-05-05	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2006-05-05	KWARNICK	2007-04-12
[2005-12-28]	Current	2005-12-28	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2005-12-28	KWARNICK	2007-03-15
		2005-12-28	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2005-12-28	---	---
		2005-12-28	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND obs_scd MISSING HISTORICAL RECORDS	SHEARS	2005-12-28	MSLAGLE	2006-11-02
		2005-12-28	IMC PERSONEL	AD HOC	---	---	MOVE COOPERATIVE SUB-NETWORKS TO STN_STN_TP	SHEARS	2005-12-28	MSLAGLE	2006-12-12
[Unknown]	Current	2007-02-28	JDA	AD HOC	0A	---	Correct problems in station names	JARNFIEL	2007-02-28	KMATHEWS	2008-01-16
[2004-08-01]	2012-06-18	2004-08-01	NWS	CSSA	9	---	LOCALIZED EQUIP MOVE (COMPATIBLE & SAME NAME)	AWHETZEL	2005-01-27	INGEST_USER	2012-06-25
		2004-08-01	NWS	CSSA	9	---	LOCALIZED EQUIP MOVE (COMPATIBLE & SAME NAME) -- RESOLVE PROBS PRESENTED IN "DATA PROD" GRID	JARNFIELD	2005-04-25	INGEST_USER	2012-06-25
		2004-08-01	---	CSSA	9	---	LOCALIZED EQUIP MOVE (COMPATIBLE & SAME NAME)	INGEST_USER	2005-01-05	INGEST_USER	2012-06-25
[1999-01-01]	2004-08-01	1999-01-01	---	B44	8	---	10. UPDATE CONTACT POINT, MGMNT, CORRECT LONGITUDE, REMARKS	INITIAL SHIPS CONVERSION	2004-01-12	INGEST_USER	2005-01-05
[1988-07-11]	1999-01-01	---	---	B44	---	---	GENTLY ROLLING HILLS. LARGE CITY PARK SURROUNDED EQUIP. PARK MOSTLY GRASSY WITH PATCHY WOODED AREAS &	INITIAL SHIPS CONVERSION	2004-01-12	EMASON	---

Schedule ALD-ER1

							SEVERSL SM LAKES. B44 UPDATE.				
[1986-10-01]	1988-07-11	---	---	B44	---	---	GENTLY ROLLING HILLS. LARGE CITY PARK SURROUNDED EQUIP. PARK MOSTLY GRASSY WITH PATCHY WOODED AREAS & SEVERSL SM LAKES	INITIAL SHIPS CONVERSION	2004-01-12	JKLEIN	---

Schedule ALD-ER1

MMS: Multi-Network Metadata System

Stn Name: ST LOUIS SCIENCE CTR
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.6291 (38°37'44.76"N)
Longitude: -90.2706 (90°16'14.16"W)
Elevation: 545.00 FEET (GROUND)
POR: 1968-06-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237452
- NCDC STATION ID NUMBER: 20011858
- NWSLI: SSCM7

(Logged in as guest)

Display Combined
Sort Values

Tab Remarks: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Latitude	Longitude	Elevation	Relocation	County	Climate Division	Time Zone
[2012-06-18]	Current	38.629100 (38° 37'44"N)	-90.270600 (90° 16'14"W)	GROUND: 545 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ST LOUIS SCIENCE CTR FOREST PK WITHIN AND 4.2 MILES W OF PO AT ST LOUIS MO						
		Topographic Details: GENTLY ROLLING HILLS. LARGE CITY PARK SURROUNDS EQUIPMENT. FOREST PARK IS MOSTLY GRASSY WITH PATCHY WOODED AREAS AND SEVERAL SMALL LAKES.						
[2004-08-01]	2012-06-18	38.629100 (38° 37'44"N)	-90.270600 (90° 16'14"W)	GROUND: 545 FEET	S/275/FEET	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ST LOUIS SCIENCE CTR FOREST PK WITHIN AND 4.2 MILES W OF PO AT ST LOUIS MO						
		Topographic Details: GENTLY ROLLING HILLS. LARGE CITY PARK SURROUNDS EQUIPMENT. FOREST PARK MOSTLY GRASSY WITH PATCHY WOODED AREAS AND SEVERAL SMALL LAKES.						
[1999-01-01]	2004-08-01	38.631390 (38° 37'53"N)	-90.270560 (90° 16'14"W)	GROUND: 540 FEET	---	ST. LOUIS (CITY)	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ST LOUIS SCIENCE CTR FOREST PK WITHIN AND 4.2 MILES W OF PO AT ST LOUIS MO						
		Topographic Details: GENTLY ROLLING HILLS, LARGE CITY PARK SURROUNDS EQUIPMENT. PARK MOSTLY GRASSY WITH PATCHY WOODED AREAS AND SEVERAL SMALL LAKES.						
[1988-07-11]	1999-01-01	38.633330 (38° 37'59"N)	-90.266670 (90° 16'00"W)	GROUND: 540 FEET	---	ST. LOUIS (CITY)	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ST LOUIS SCIENCE CENTER FOREST PARK, WITHIN & 4.2MI W OS PO AT ST KO						
[1986-10-01]	1988-07-11	38.633330 (38° 37'59"N)	-90.266670 (90° 16'00"W)	GROUND: 540 FEET	W/4.1/MILES	ST. LOUIS (CITY)	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ST LOUIS SCIENCE CENTER FOREST PARK, WITHIN & 4.2MI W OS PO AT ST KO						
[1968-06-01]	1978-05-10	38.616670 (38° 37'00"N)	-90.183330 (90° 10'59"W)	GROUND: 449 FEET	---	ST. LOUIS (CITY)	02 - NORTHEAST PRAIRIE	CENTRAL (+6)

Schedule ALD-ER1

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)

National Climatic Data Center
U.S. Department of Commerce

Some web services will be unavailable August 4, 2012

MMS: Multi-Network Metadata System

Phenomena | Other Considerations | Map | Remarks | Files | Related
Identity | Updates | Location | Other Party | Data Products | Data Programs | Equipment

[Equation] [Factor] [Factor/Equation]

Stn Name: ST LOUIS SCIENCE CTR
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.6291 (38°37'44.76"N)
Longitude: -90.2706 (90°16'14.16"W)
Elevation: 545.00 FEET (GROUND)
POR: 1968-06-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237452
- NCDC STATION ID NUMBER: 20011858
- NWSLI: SSCM7

(Logged in as guest)

Display Combined
Sort Values

Tab Remarks: View (0)
Misc. Data: View (1)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Equip Type	Equipment Model	Priority	Equipment Name	Phenomenon	Elevation	Serial Number	Data
[2012-06-18]	Current	PRCP	FPR-E	PRIMARY	FPR-E	PRECIPITATION	---	70163208	COOP HPD
			SRG		STANDARD RAIN GAGE			---	COOP SOD
		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE			
			CRS	---	COTTON REGION SHELTER	---			---
			MXMN		MAX-MIN THERMOMETERS				
[2004-08-01]	2012-06-18	PRCP	F&P	PRIMARY	FISCHER/PORTER RRNG	PRECIPITATION		---	COOP HPD
			SRG		STANDARD RAIN GAGE				COOP SOD
		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE			
		DAA	TOUCH	---	ENCODER/TOUCH-TONE PHONE	---			---
		TEMP	CRS		COTTON REGION SHELTER				
			MXMN		MAX-MIN THERMOMETERS				
[1999-01-01]	2004-08-01	EVAP	EVAP-C	PRIMARY	EVAP-C: PAN, ANEMOMETER, GAGE, SIXS	EVAPORATION		---	COOP SOD
			SIXES		SIXES THERMOMETER - EVAP				
			WIND		WIND (ANY)				
		PRCP	F&P		FISCHER/PORTER RRNG	PRECIPITATION			COOP HPD
			SRG		STANDARD RAIN GAGE				COOP SOD
		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE			
		DAA	TOUCH	---	ENCODER/TOUCH-TONE PHONE	---			---
[1995-07-01]	1999-01-01	EVAP	PAN-LEVEL	PRIMARY	PAN WITH LEVEL GAGE	EVAPORATION		---	COOP SOD
			SIXES		SIXES THERMOMETER - EVAP				
			WIND		WIND (ANY)				
		PRCP	F&P		FISCHER/PORTER RRNG	PRECIPITATION			COOP HPD
			SRG		STANDARD RAIN GAGE				COOP SOD
		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE			
[1989-08-25]	1995-07-01	EVAP	PAN-LEVEL	PRIMARY	PAN WITH LEVEL GAGE	EVAPORATION		---	COOP SOD
			SIXES		SIXES THERMOMETER - EVAP				
			WIND		WIND (ANY)				
		PRCP	SRG		STANDARD RAIN GAGE	PRECIPITATION			
		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE			
		PRCP	F&P	---	FISCHER/PORTER RRNG	---			---
[1986-10-01]	1989-08-25	PRCP	SRG	PRIMARY	STANDARD RAIN GAGE	PRECIPITATION		---	COOP SOD

Schedule ALD-ER1

MMS: Multi-Network Metadata System

Stn Name: ST LOUIS SCIENCE CTR
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.6291 (38°37'44.76"N)
Longitude: -90.2706 (90°16'14.16"W)
Elevation: 545.00 FEET (GROUND)
POR: 1968-06-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237452
- NCDC STATION ID NUMBER: 20011858
- NWSLI: SSCM7

(Logged in as guest)

Display: Combined
Sort Values

Tab Remarks: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Stn Name	Name Type	Stn Type	COOP	NCDC	NWSLI	MMS
[2004-08-01]	Current	ST LOUIS SCIENCE CENTER	COOP NAME	COOP, COOPERATIVE SUB-NETWORK- AB, LAND SURFACE	237452	20011858	SSCM7	12282
		ST LOUIS SCIENCE CTR	PRINCIPAL NAME					
[1986-10-01]	2004-08-01	ST LOUIS SCIENCE CTR	COOP NAME	COOP, COOPERATIVE SUB-NETWORK- AB, LAND SURFACE	237452	20011858	SSCM7	12282
		ST LOUIS SCIENCE CTR	PRINCIPAL NAME					
[1978-05-31]	1986-10-01	ST LOUIS SCIENCE CTR	PRINCIPAL NAME	LAND SURFACE	---	20011858	---	12282
[1978-05-10]	1978-05-31	ST LOUIS GATEWAY ARCH	COOP NAME	LAND SURFACE	---	20011858	---	12282
		ST LOUIS SCIENCE CTR	PRINCIPAL NAME					
[1974-12-31]	1978-05-10	ST LOUIS GATEWAY ARCH	COOP NAME	COOP, LAND SURFACE	237452	20011858	---	12282
		ST LOUIS SCIENCE CTR	PRINCIPAL NAME					
[1969-01-01]	1974-12-31	ST LOUIS GATEWAY ARCH	COOP NAME	COOP, LAND SURFACE, SPL	237452	20011858	---	12282
		ST LOUIS SCIENCE CTR	PRINCIPAL NAME					
		ST LOUIS GATEWAY	S2K FLAG I NAME					
[1968-06-01]	1969-01-01	ST LOUIS GATEWAY ARCH	COOP NAME	COOP, LAND SURFACE	237452	20011858	---	12282
		ST LOUIS SCIENCE CTR	PRINCIPAL NAME					

Schedule ALD-ER1

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)
National Climatic Data Center
U.S. Department of Commerce

Some web services will be unavailable August 4, 2012

MMS: Multi-Network Metadata System

Phenomena | Other Considerations | Map | Remarks | Files | Related
Identity | Updates | Location | Other Party | Data Products | Data Programs | Equipment

[Updates]

Stn Name: ST CHARLES
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. CHARLES
Latitude: 38.8147 (38°48'52.92"N)
Longitude: -90.5169 (90°31'00.84"W)
Elevation: 467.00 FEET (GROUND)
POR: 1948-08-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237397
- NCDC STATION ID NUMBER: 20011884
- NWSLI: SCHM7

(Logged in as guest)

Tab Remarks: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Effective Date	Update Provided By	Source Description	Source Version	Native ID	Description of Update	Entered By	Entry Date	Modified By	Modified Date	History
[2009-02-24]	Current	2009-02-24	NWS	CSSA	11	LSX90224318	CHANGE	INGEST_USER	2009-03-09	JSKIDMORE	2009-03-25	History
[2007-01-05]	Current	2007-01-05	MSLAGLE	AD HOC	NONE	---	HISTORICAL CORRECTIONS TO SHORT VERSION OF PRINCIPAL NAME	MSLAGLE	2007-01-05	MSLAGLE	2007-04-20	
[2006-05-05]	Current	2006-05-05	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2006-05-05	KWARNICK	2007-03-05	
		2006-05-05	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2006-05-05	KWARNICK	2007-04-12	
[2005-12-28]	Current	2005-12-28	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2005-12-28	KWARNICK	2007-03-15	
		2005-12-28	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2005-12-28	---	---	
		2005-12-28	IMC PERSONEL	AD HOC	---	---	MOVE COOPERATIVE SUB-NETWORKS TO STN_STN_TP	SHEARS	2005-12-28	MSLAGLE	2006-12-12	
[Unknown]	Current	2007-02-28	JDA	AD HOC	0A	---	Correct problems in station names	JARNFIEL	2007-02-28	KMATHEWS	2008-01-16	
[2002-02-21]	2009-02-24	2002-02-21	---	B44	10	---	10. CHANGE UPDATE LAT/LON SRC, EXPO, TOPO	INGEST_USER	2009-03-09	SJOHNSON	---	
[2000-07-01]	2002-02-21	2000-07-01	---	B44	9	---	10. UPDATE TELEPHONE NUMBER AND EXPOSURE	INITIAL SHIPS CONVERSION	2004-01-12	SJOHNSON	---	
[1990-08-20]	2000-07-01	---	---	B44	---	---	B-44 UPDATE TO ADD MMTS AND DELETE MXMN.	INITIAL SHIPS CONVERSION	2004-01-12	RPOWELL	---	
[1988-05-01]	1990-08-20	---	---	B44	---	---	CHANGE OBSERVER.	INITIAL SHIPS CONVERSION	2004-01-12	JKLEIN	---	
[1986-04-21]	1988-05-01	---	---	B44	---	---	STN NOT MOVED, B44 VALIDATION> LOCATED WHERE THE MISSISSIPPI RIVER FLOOD PLAIN MEETS THE STEEP ROLLING HILLS WITHIN THE CITY OF ST CHARLES. WOODED.	INITIAL SHIPS CONVERSION	2004-01-12	JKLEIN	---	

Schedule ALD-ER1

MMS: Multi-Network Metadata System

Phenomena Other Considerations Map Remarks Files Related
Identity Updates Location Other Party Data Products Data Programs Equipment

Stn Name: ST CHARLES
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. CHARLES
Latitude: 38.8147 (38°48'52.92"N)
Longitude: -90.5169 (90°31'00.84"W)
Elevation: 467.00 FEET (GROUND)
POR: 1948-08-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237397
- NCDC STATION ID NUMBER: 20011884
- NWSLI: SCHM7

(Logged in as guest)

Display Combined
Sort Values

Tab Remarks: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Latitude	Longitude	Elevation	Relocation	County	Climate Division	Time Zone
[2009-02-24]	Current	38.814700 (38° 48'52"N)	-90.516900 (90° 31'00"W)	GROUND: 467 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Topographic Details: LOCATED NEAR FLOOD PLAIN AND STEEP ROLLING HIILS WITHIN CITY OF ST CHARLES. SRG IN VICINITY OF CLARIFYING TANKS						
[2002-02-21]	2009-02-24	38.814720 (38° 48'52"N)	-90.516940 (90° 31'00"W)	GROUND: 467 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ELM POINT WATER PLANT WITHIN AND 2.7 MILES NW OF PO AT ST CHARLES MO						
		Topographic Details: LOCATED NEAR FLOOD PLAIN & STEEP ROLLING HILLS WITHIN CITY OF ST CHARLES. SRG IN VICINITY OF CLARIFYING TANKS.						
[2000-07-01]	2002-02-21	38.814720 (38° 48'52"N)	-90.516940 (90° 31'00"W)	GROUND: 467 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ELM POINT WATER PLANT WITHIN AND 2.7 MILES NW OF PO AT ST CHARLES MO						
		Topographic Details: LOCATED NEAR FLOOD PLAIN AND STEEP ROLLING HILLS WITHIN CITY OF ST CHARLES						
[1990-08-20]	2000-07-01	38.783330 (38° 46'59"N)	-90.500000 (90° 30'00"W)	GROUND: 467 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ELM POINT WATER PLANT WITHIN AND 2.7 MI NW OF PO AT ST CHARLES, MO						
		Topographic Details: TOPO-LOCATED WHERE THE MISSISSIPPI RIVER FLOOD PLAIN MEETS THE STEEP ROLLING HILLS WITHIN THE ITY OF ST CHARLES. WOODED.						
[1988-05-01]	1990-08-20	38.783330 (38° 46'59"N)	-90.500000 (90° 30'00"W)	GROUND: 467 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ELM POINT WATER PLANT, WITHIN & 2.7 MI NW OF PO AT ST CHARLES, MO						
		Topographic Details: TOPO- LOCATED WHERE THE MISSISSIPPI RIVER FLOOD PLAIN MEETS THE STEEP ROLLING HILLS WITHIN THE CITY OF ST CHARLES. WOODED.						
[1986-04-21]	1988-05-01	38.783330 (38° 46'59"N)	-90.500000 (90° 30'00"W)	GROUND: 467 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ELM POINT WATER PLANT, WITHIN & 2.7 MI NW OF PO AT ST CHARLES, MO						
[1980-07-01]	1986-04-21	38.783330 (38° 46'59"N)	-90.500000 (90° 30'00"W)	GROUND: 466 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1971-05-01]	1980-07-01	38.783330 (38° 46'59"N)	-90.500000 (90° 30'00"W)	GROUND: 469 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1964-04-01]	1971-05-01	38.766670 (38° 46'00"N)	-90.483330 (90° 28'59"W)	GROUND: 469 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1960-04-01]	1964-04-01	38.800000 (38° 48'00"N)	-90.483330 (90° 28'59"W)	GROUND: 522 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1958-08-01]	1960-04-01	38.783330 (38° 46'59"N)	-90.500000 (90° 30'00"W)	GROUND: 512 FEET	---	ST. CHARLES	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
[1958-07-31]	1958-08-01	38.783330 (38° 46'59"N)	-90.483330 (90° 28'59"W)	GROUND: 489 FEET	---	ST. CHARLES	-	CENTRAL (+6)
[1952-10-01]	1958-07-31	38.783330 (38°	-90.483330 (90°	GROUND: 489 FEET	---	ST.	02 - NORTHEAST	CENTRAL

Schedule ALD-ER1

		46'59"N)	28'59"W)			CHARLES	PRAIRIE	(+6)
[1948-08-01]	1952-10-01	38.783330 (38° 46'59"N)	-90.483330 (90° 28'59"W)	GROUND: 522 FEET	---	ST. CHARLES	01 - NORTHWEST PRAIRIE	CENTRAL (+6)

Schedule ALD-ER1

MMS: Multi-Network Metadata System

Phenomena | Other Considerations | Map | Remarks | Files | Related
Identity | Updates | Location | Other Party | Data Products | Data Programs | Equipment
[Equation] [Factor] [Factor/Equation]

Stn Name: ST CHARLES
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. CHARLES
Latitude: 38.8147 (38°48'52.92"N)
Longitude: -90.5169 (90°31'00.84"W)
Elevation: 467.00 FEET (GROUND)
POR: 1948-08-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237397
- NCDC STATION ID NUMBER: 20011884
- NWSLI: SCHM7

(Logged in as guest)

Display Combined
Sort Values

Tab Remarks: View (0)
Misc. Data: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Equip Type	Equipment Model	Priority	Equipment Name	Phenomenon	Elevation	Serial Number	Data
[2002-02-21]	Current	PRCP	SRG	PRIMARY	STANDARD RAIN GAGE	PRECIPITATION	---	---	COOP SOD
		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE		1720	
[2000-07-01]	2002-02-21	PRCP	SRG	PRIMARY	STANDARD RAIN GAGE	PRECIPITATION		---	COOP SOD
		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE		1720	
[1990-08-20]	2000-07-01	PRCP	SRG	PRIMARY	STANDARD RAIN GAGE	PRECIPITATION		---	COOP SOD
		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE			
[1986-04-21]	1990-08-20	PRCP	SRG	PRIMARY	STANDARD RAIN GAGE	PRECIPITATION		---	COOP SOD
		TEMP	MXMN		MAX-MIN THERMOMETERS	TEMPERATURE			
[Unknown]	1986-04-21	PRCP	UNKNOWN	PRIMARY	UNKNOWN - PRECIP	PRECIPITATION		---	COOP SOD
		TEMP			UNKNOWN - TEMP	TEMPERATURE			

Schedule ALD-ER1

MMS: Multi-Network Metadata System

Stn Name: ST CHARLES
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. CHARLES
Latitude: 38.8147 (38°48'52.92"N)
Longitude: -90.5169 (90°31'00.84"W)
Elevation: 467.00 FEET (GROUND)
POR: 1948-08-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237397
- NCDC STATION ID NUMBER: 20011884
- NWSLI: SCHM7

(Logged in as guest)

Display Combined
Sort Values

Tab Remarks: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Stn Name	Name Type	Stn Type	COOP	NCDC	NWSLI	MMS
[2000-07-01]	Current	ST CHARLES ELM POINT	COOP NAME	COOP, COOPERATIVE SUB-NETWORK- AB, LAND SURFACE	237397	20011884	SCHM7	12308
		ST CHARLES	PRINCIPAL NAME					
[1988-05-01]	2000-07-01	ST CHARLES	COOP NAME	COOP, COOPERATIVE SUB-NETWORK- AB, LAND SURFACE	237397	20011884	SCHM7	12308
		ST CHARLES	PRINCIPAL NAME					
[1986-04-21]	1988-05-01	ST CHARLES	COOP NAME	COOP, COOPERATIVE SUB-NETWORK- AB, LAND SURFACE	237397	20011884	---	12308
		ST CHARLES	PRINCIPAL NAME					
[1948-08-01]	1986-04-21	ST CHARLES	COOP NAME	COOP, LAND SURFACE	237397	20011884	---	12308
		ST CHARLES	PRINCIPAL NAME					

Schedule ALD-ER1

MMS: Multi-Network Metadata System

Phenomena Other Considerations Map Remarks Files Related
Identity Updates Location Other Party Data Products Data Programs Equipment

[Updates]

Stn Name: ST CHARLES 7 SSW
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.68556 (38°41'08.016"N)
Longitude: -90.52306 (90°31'23.016"W)
Elevation: 450.00 FEET (GROUND)
POR: 1974-11-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237398
- NCDC STATION ID NUMBER: 20011867
- NWSLI: STCM7

(Logged in as guest)

Tab Remarks: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Effective Date	Update Provided By	Source Description	Source Version	Native ID	Description of Update	Entered By	Entry Date	Modified By	Modified Date
[2010-05-17]	Current	2010-05-17	NCDC/SMCNEILL	AD HOC	---	---	Station river name beg_dt changed to match most recent lat/lon against which the GIS lookup was performed	SMCNEILL	2010-05-17	---	---
[2010-03-18]	Current	2010-03-18	NCDC/SMCNEILL	AD HOC	---	---	Station river name additions from ESRI ArcGIS software	SMCNEILL	2010-03-18	---	---
[2006-05-05]	Current	2006-05-05	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2006-05-05	KWARNICK	2007-03-05
		2006-05-05	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2006-05-05	KWARNICK	2007-04-12
[2005-12-28]	Current	2005-12-28	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2005-12-28	KWARNICK	2007-03-15
		2005-12-28	IMC PERSONEL	AD HOC	---	---	Fix of the stn_obs_rpt_scd AND STN_OBS_RPT_MTHD MISSING HISTORICAL RECORDS	SHEARS	2005-12-28	---	---
		2005-12-28	IMC PERSONEL	AD HOC	---	---	MOVE COOPERATIVE SUB-NETWORKS TO STN_STN_TP	SHEARS	2005-12-28	MSLAGLE	2006-12-12
[2002-02-21]	Current	2002-02-21	---	B44	4	---	10. CHANGE INSTITUTION NAME, ADD 2ND OBSVR,LAT/LON SRC, EXPO	INITIAL SHIPS CONVERSION	2004-01-12	SJOHNSON	---
[1997-07-01]	2002-02-21	1997-07-01	---	B44	3	---	10. UPDATE ADDRESS, PHONE, EQUIP LOCATION, ADD MMTS, NOT PHYSICAL MOVE	INITIAL SHIPS CONVERSION	2004-01-12	SJOHNSON	---

Schedule ALD-ER1

MMS: Multi-Network Metadata System

Phenomena Other Considerations Map Remarks Files Related
Identity Updates Location Other Party Data Products Data Programs Equipment
[Equation] [Factor] [Factor/Equation]

Stn Name: ST CHARLES 7 SSW
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.68556 (38°41'08.016"N)
Longitude: -90.52306 (90°31'23.016"W)
Elevation: 450.00 FEET (GROUND)
POR: 1974-11-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237398
- NCDC STATION ID NUMBER: 20011867
- NWSLI: STCM7

(Logged in as guest)

Display Combined
Sort Values

Tab Remarks: View (0)
Misc. Data: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Equip Type	Equipment Model	Priority	Equipment Name	Phenomenon	Elevation	Serial Number	Data
[2002-02-21]	Current	PRCP	SRG	PRIMARY	STANDARD RAIN GAGE	PRECIPITATION	---	---	COOP SOD
		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE			
			MXMN	BACKUP	MAX-MIN THERMOMETERS				
		RIVR	RIVX	---	RIVX: OTHER RIVER EQUIPMENT NO. 1	---			---
[1997-07-01]	2002-02-21	PRCP	SRG	PRIMARY	STANDARD RAIN GAGE	PRECIPITATION		---	COOP SOD
		TEMP	MMTS		MMTS ELECTRONIC SENSOR	TEMPERATURE			
			MXMN	BACKUP	MAX-MIN THERMOMETERS				
		RIVR	RIVX	---	RIVX: OTHER RIVER EQUIPMENT NO. 1	---			---
[1988-07-11]	1997-07-01	PRCP	SRG	PRIMARY	STANDARD RAIN GAGE	PRECIPITATION		---	COOP SOD
		TEMP	MXMN		MAX-MIN THERMOMETERS	TEMPERATURE			
[Unknown]	1988-07-11	PRCP	UNKNOWN	PRIMARY	UNKNOWN - PRECIP	PRECIPITATION		---	COOP SOD
		TEMP			UNKNOWN - TEMP	TEMPERATURE			

Schedule ALD-ER1

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)
National Climatic Data Center
U.S. Department of Commerce

Some web services will be unavailable August 4, 2012

MMS: Multi-Network Metadata System

Phenomena Other Considerations Map Remarks Files Related
Identity Updates Location Other Party Data Products Data Programs Equipment

Stn Name: ST CHARLES 7 SSW
Country: UNITED STATES
State/Prov: MISSOURI
County: ST. LOUIS
Latitude: 38.68556 (38°41'08.016"N)
Longitude: -90.52306 (90°31'23.016"W)
Elevation: 450.00 FEET (GROUND)
POR: 1974-11-01 => Current
Climate Div: 02 - NORTHEAST PRAIRIE

IDS:
- COOP NUMBER: 237398
- NCDC STATION ID NUMBER: 20011867
- NWSLI: STCM7

(Logged in as guest)

Display Combined
Sort Values

Tab Remarks: View (0)

Click on a Begin Date to view individual record.
Click on a Column Header to sort by that column.

Begin Date	End Date	Latitude	Longitude	Elevation	Relocation	County	Climate Division	Time Zone
[2002-02-21]	Current	38.685560 (38° 41'08"N)	-90.523060 (90° 31'23"W)	GROUND: 450 FEET ZERO DATUM: 413.58 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ST LOUIS COUNTY WATER CO WITHIN AND 3 MILES N OF PO AT CHESTERFIELD MO						
		Topographic Details: SITE LOCATED IN RIVER VALLEY, NEARLY LEVEL DUE TO CLOSENESS OF THE MISSOURI RIVER						
[1997-07-01]	2002-02-21	38.685560 (38° 41'08"N)	-90.523060 (90° 31'23"W)	GROUND: 450 FEET ZERO DATUM: 413.58 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ST LOUIS COUNTY WATER CO WITHIN AND 3 MILES N OF PO AT CHESTERFIELD MO						
		Topographic Details: SITE LOCATED IN RIVER VALLEY, NEARLY LEVEL DUE TO CLOSENESS OF THE MISSOURI RIVER						
[1988-07-11]	1997-07-01	38.683330 (38° 40'59"N)	-90.516670 (90° 31'00"W)	GROUND: 450 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)
		Location Description: ST LOUIS COUNTY WATER CO OUTSIDE & 5.0 MI WNW OF PO AT ST. LOUIS, MO						
		Topographic Details: TOPO- SLIGHTLY ROLLING MORE SO TO THE E MOSTLY FLAT NEAR THE STN DUE TO THE CLOSENESS OF THE MO RIVER.						
[1974-11-01]	1988-07-11	38.683330 (38° 40'59"N)	-90.516670 (90° 31'00"W)	GROUND: 449 FEET	---	ST. LOUIS	02 - NORTHEAST PRAIRIE	CENTRAL (+6)

Schedule ALD-ER1

Appendix 5

Spreadsheet: **Amerendm(new).xlsx**

Sheet 1. Actual temperature observations for St. Louis Lambert, St Louis Science Center, St Charles, and St Charles 7 SW

Sheet 2. Double Mass Analysis of St Louis Lambert vs St Louis Science Center. Column A-E contains the historical temperature records for St Louis Lambert. Column G-K contains the historical temperature records for St Louis Science Center. Column M-O contains date information. Column P is St Louis Lambert maximum temperatures and Column Q is St Louis Science Center maximum temperatures. Column R is day count number. Column S is accumulated temperature unit differences. All missing data in this section have been removed so that temperature relationships could be determined through regression analysis. Column U-W contains date information. Column X is St Louis Lambert minimum temperatures and Column Y is St Louis Science Center minimum temperatures. Column Z is day count number. Column AA is accumulated temperature unit differences. All missing data in this section have been removed so that temperature relationships could be determined through regression analysis. Regression equations to the right of Column AA represent the regression analysis results of examining the periods Staff defined as data discontinuity points. Attached plots contain day count number (x-axis) and accumulated temperature units (y-axis).

Sheet 3. Double Mass Analysis of St Louis Lambert vs St Charles. Column A-E contains the historical temperature records for St Louis Lambert. Column G-K contains the historical temperature records for St Charles. Column M-O contains date information. Column P is St Louis Lambert maximum temperatures and Column Q is St Charles maximum temperatures. Column R is day count number. Column S is accumulated temperature unit differences. All missing data in this section have been removed so that temperature relationships could be determined through regression analysis. Column U-W contains date information. Column X is St Louis Lambert minimum temperatures and Column Y is St Charles minimum temperatures. Column Z is day count number. Column AA is accumulated temperature unit differences. All missing data in this section have been removed so that temperature relationships could be determined through regression analysis. Regression equations to the right of Column AA represent the regression analysis results of examining the periods Staff defined as data discontinuity points. Attached plots contain day count number (x-axis) and accumulated temperature units (y-axis).

Sheet 4. Double Mass Analysis of St Louis Lambert vs St Charles 7 SW. Column A-E contains the historical temperature records for St Louis Lambert. Column G-K contains the historical temperature records for St Charles 7 SW. Column M-O contains date information. Column P is St Louis Lambert maximum temperatures and Column Q is St Charles 7 SW maximum temperatures. Column R is day count number. Column S is accumulated temperature unit differences. All missing data in this section have been removed so that temperature relationships could be determined through regression analysis. Column U-W contains date information. Column X is St Louis Lambert minimum temperatures and Column Y is St Charles 7 SW minimum temperatures. Column Z is day count number. Column AA is accumulated temperature unit differences. All missing data in this section have been removed so that temperature relationships could be determined through regression analysis. Regression equations to the right of Column AA represent the regression analysis results of examining the periods Staff defined as data discontinuity points. Attached plots contain day count number (x-axis) and accumulated temperature units (y-axis).

Spreadsheet: **Staffdm(new).xlsx**

Sheet 1. Staff's corrected St Louis Lambert International Airport daily temperature data and St Charles raw daily temperature data.

Sheet 2. Sheet 2. Double Mass Analysis of St Louis Lambert Staff corrected temperature records ve St Louis Charles. Columns A-C and I-J contains date information, missing data points have been removed. Column D contains Staff adjusted St Louis Lambert maximum temperatures. Column E contains St Charles maximum temperatures. Column L contains Staff adjusted St Louis Lambert minimum temperatures. Column E contains St Charles minimum temperatures. Column F and H are the day count number. Columns G and O are the accumulated temperature units for maximum and minimum temperature, respectively. Attached plots contain day count number (x-axis) and accumulated temperature units (y-axis).

Appendix 6

THE U.S. HISTORICAL CLIMATOLOGY NETWORK MONTHLY TEMPERATURE DATA, VERSION 2

BY MATTHEW J. MENNE, CLAUDE N. WILLIAMS JR., AND RUSSELL S. VOSE

New bias adjustments reduce uncertainty in temperature trends for the United States.

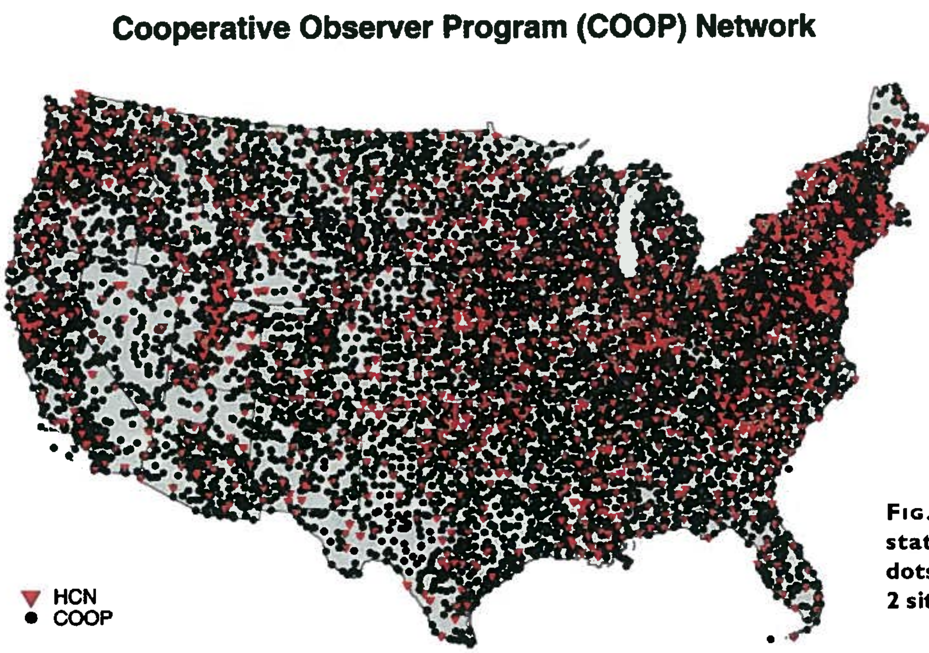


FIG. 1. Distribution of COOP stations in the CONUS (black dots) and the U.S. HCN version 2 sites (red triangles).

Since 1987, the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center (NCDC) has used observations from the U.S. Historical Climatology Network (HCN) to quantify national- and regional-scale temperature changes in the conterminous United States (CONUS). To that end, U.S. HCN temperature records have been "corrected" to account for various historical changes in station location, instrumentation, and observing practice. The HCN is actually a designated subset of the NOAA Cooperative Observer Program (COOP) Network—the HCN sites having been selected according to their spatial coverage, record length, data completeness, and historical stability. The U.S. HCN, therefore, consists primarily of long-term COOP stations whose temperature records have been adjusted for systematic, nonclimatic changes that bias temperature trends.

In support of its climate monitoring and assessment activities, NCDC has recently developed an improved U.S. HCN dataset (hereafter called HCN version 2). In this paper we describe the HCN version 2 temperature data in detail, focusing on the quality-assured dataset sources as well as the bias adjustment techniques employed in version 2 to further reduce uncertainty in the U.S. instrumental temperature record. The HCN bias adjustments are discussed in the context of their effect on U.S. temperature trends and in terms of the differences between version 2 and its widely used predecessor (now termed HCN version 1).

DATA. *Network development.* The U.S. HCN is a reference station network (Collins et al. 1999), that is, a subset of long-term climate stations managed as part of a larger network—in this case the COOP Network shown in Fig. 1.

Schedule ALD-ER1

The original HCN stations were identified in the mid-1980s by examining station records (and metadata) from the COOP Network with the goal of maximizing record length, data completeness, and stability in station location (Quinlan et al. 1987). To be designated as part of the HCN, a COOP station was ideally required to be active circa 1987 and to have a period of record of at least 80 years. In practice, these criteria were sometimes relaxed to provide a more uniform distribution of stations across the country and to incorporate the recommendations of the nation's state climatologists. The resulting network contained 1,219 COOP stations, 84 of which were composites formed using consecutive records from two or more stations to achieve the minimum period of record goal.

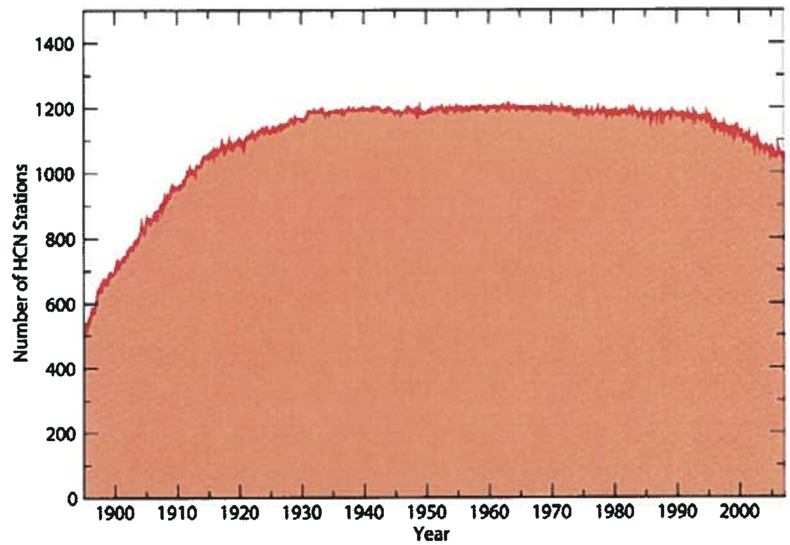


FIG. 2. Number of U.S. HCN stations with temperature records.

The actual subset of stations constituting the HCN has changed twice since 1987. By the mid-1990s, station closures and relocations had already forced a reevaluation of the composition of the U.S. HCN as well as the creation of additional composite stations. The reevaluation led to 52 station deletions and 54 additions, for a total of 1,221 stations (156 of which were composites). Since the 1996 release (Easterling et al. 1996), numerous station closures and relocations have again necessitated a revision of the network. As a result, HCN version 2 contains 1,218 stations, 208 of which are composites; relative to the 1996 release, there have been 62 station deletions and 59 additions.

Figure 1 depicts the locations of the 1,218 stations in HCN version 2. Consistent with previous releases, the spatial distribution is reasonably uniform across the CONUS, although station density is higher across the eastern CONUS than in the intermountain west.

AFFILIATIONS: MENNE, WILLIAMS, AND VOSE—NOAA/NCDC, Asheville, North Carolina

CORRESPONDING AUTHOR: Matthew J. Menne, NOAA/NCDC, 151 Patton Ave., Asheville, NC 28801

E-mail: matthew.menne@noaa.gov

The abstract for this article can be found in this issue, following the table of contents.

DOI:10.1175/2008BAMS2613.1

In final form 5 December 2008

Moreover, as depicted by Fig. 2, the composition of the network is not uniform in time. For example, there is a rapid increase in the number of stations reporting until about 1925, with spatial coverage increasing most prominently in the west during these early years. The number of stations reporting remained relatively consistent until the end of the twentieth century, after which it has declined because of station closures.

Source data. To maximize data completeness, HCN version 2 was derived from the following five complementary source datasets archived at NCDC:

- DSI-3200: U.S. Cooperative Summary of the Day,
- DSI-3206: U.S. Cooperative Summary of the Day (pre-1948),
- DSI-3210: U.S. Summary of the Day First Order Data,
- DSI-3220: U.S. Summary of the Month, and
- U.S. HCN version 1 monthly data.

The first three datasets contain daily records, while the last two consist of monthly means. Each source contains "estimated" values and quality assurance (QA) flags; however, to standardize QA across data sources, neither the estimated values nor the quality flags were employed in building HCN version 2. Instead, each daily data source was subjected to the suite of QA reviews listed in Table 1. The QA checks were performed in the order in which they appear in the table, with each procedure operating on only those values that did not fail any of the preceding tests. The thresholds were selected and the performance of each check was evaluated using the

Schedule ALD-ER1

method outlined in Durre et al. (2008). Collectively, the daily QA system had an estimated false-positive rate of 8% (i.e., the percent of flagged values that appear to be valid) and a miss rate of less than 5% (the percent of true errors that remain undetected). Monthly means were then derived from the quality-assured daily data, with a requirement that no more than nine values be flagged or missing in any given month.

Table 1. Quality assurance checks applied to daily data.

Data problem	Description of check
Simultaneous zeros	Identifies days on which both maximum and minimum temperature are −17.8°C (0°F)
Duplication of data	Identifies duplication of data between entire years, different years in the same month, different months within the same year, and maximum and minimum temperature within the same month
Impossible value	Determines whether a temperature exceeds known world records
Streak	Identifies runs of the same value on >15 consecutive days
Gap	Identifies temperatures that are at least 10°C warmer or colder than all other values for a given station and month
Climatological outlier	Identifies daily temperatures that exceed the respective 15-day climatological means by at least six standard deviations
Internal inconsistency	Identifies days on which the maximum temperature is less than the minimum temperature
Interday inconsistency	Identifies daily maximum temperatures that are less than the minimum temperatures on the preceding, current, and following days as well as for minimum temperatures that are greater than the maximum temperatures during the relevant 3-day window
Lag-range inconsistency	Identifies maximum temperatures that are at least 40°C warmer than the minimum temperatures on the preceding, current, and following days as well as minimum temperatures that are at least 40°C colder than the maximum temperatures within the 3-day window
Temporal inconsistency	Determines whether a daily temperature exceeds that on the preceding and following days by more than 25°C
Spatial inconsistency	Identifies temperatures whose anomalies differ by more than 10°C from the anomalies at neighboring stations on the preceding, current, and following days
"Mega" inconsistency	Looks for daily maximum temperatures that are less than the lowest minimum temperature and for daily minimum temperatures that are greater than the highest maximum temperature for a given station and calendar month

The five sources were subsequently merged by COOP station number to form a comprehensive dataset of serial monthly temperature values. Duplicate records between data sources were eliminated based on a simple dataset priority scheme (i.e., DSI-3200 had the highest ranking, followed by DSI-3206, and so on). The resulting merged dataset was then subjected to the three additional monthly QA checks listed in Table 2; together, these checks had a false-positive rate of 15% for maximum temperature and 10% for minimum temperature. Note that the two spatial checks were performed after the climatological check; furthermore, each was applied iteratively until no additional spatial inconsistencies were detected. The monthly QA reviews removed fewer than 0.2% of monthly maximum and minimum temperature values.

SOURCES AND ASSESSMENT OF TEMPERATURE BIAS IN THE U.S. HCN. The process of removing systematic changes in the bias of a climate series is called homogenization, and the systematic artificial shifts in a series are frequently referred to as "inhomogeneities." In the HCN, there are a number of causes behind inhomogeneities, including changes to the time of observation, station moves, instrument changes, and changes to conditions surrounding the instrument site. An assessment of each of these causes is discussed below.

Bias caused by changes to the time of observation. The majority of the COOP Network observers (and also HCN) are volunteers who make observations at times that are more convenient than local midnight. However, the time at which daily maximum and minimum temperatures are observed has a systematic effect on the calculation of the monthly mean (Baker 1975; Karl et al. 1986). This "time of observation bias" would be of little concern with regard to tempera-

Schedule ALD-ER1

Table 2. Quality assurance checks applied to monthly data.	
Data problem	**Description of check**
Climatological outlier	Identifies temperatures that exceed their respective climatological means for the corresponding station and calendar month by at least five standard deviations
Spatial inconsistency	Compares z scores (relative to their respective climatological means) to concurrent z scores at the nearest 20 neighbors located within 500 km of the target; a temperature fails if (i) its z score differs from the regional (target and neighbor) mean z score by at least 3.5 standard deviations and (ii) the target's temperature anomaly differs by at least 2.5°C from all concurrent temperature anomalies at the neighbors
Spatial inconsistency	Identifies temperatures whose anomalies differ by more than 4°C from concurrent anomalies at the five nearest neighboring stations whose temperature anomalies are well correlated with the target (correlation >0.7 for the corresponding calendar month)

ture trends provided that the observation time at a given station did not change during its operational history. As shown in Fig. 3, however, there has been a widespread conversion from afternoon to morning observation times in the HCN. Prior to the 1940s, for example, most observers recorded near sunset in accordance with U.S. Weather Bureau instructions. Consequently, the U.S. climate record as a whole contains a slight positive (warm) bias during the first half of the century. A switch to morning observation times has steadily occurred since that time to satisfy operational hydrological requirements. The result has been a broad-scale reduction in mean temperatures that is simply caused by the conversion in the daily reading schedule of the Cooperative Observers. In other words, the gradual conversion to morning observation times in the United States during the past 50 years has artificially reduced the true temperature trend in the U.S. climate record (Karl et al. 1986; Vose et al. 2003; Hubbard and Lin 2006; Pielke et al. 2007a).

To account for this time of observation bias (TOB) in the HCN version 2 monthly temperatures, the adjustment method described in Karl et al. (1986) was used. The robustness of this method, which was also used to produce version 1, has been verified by Vose et al. (2003). In particular, because the TOB adjustment requires documentation of changes to the observation schedule, Vose et al. (2003) verified the accuracy of the U.S. HCN time of observation history using an independently generated source of metadata (DeGaetano 2000). In addition, the predictive skill of the Karl et al. (1986) approach to estimating the TOB was confirmed using hourly data from 500 stations during the period 1965–2001 (whereas the approach was originally developed using data from 79 stations during the period 1957–64). Given these verifications, the Karl et al. (1986) TOB adjustment procedure was used in HCN version 2 without modification.

To calculate the effect of the TOB adjustments on the HCN version 2 temperature trends, the monthly TOB-adjusted temperatures at each HCN station were converted to an anomaly relative to the 1961–90 station mean. Anomalies were then interpolated to the nodes of a 0.25° × 0.25° latitude–longitude grid using the method described by Willmott et al. (1985). Finally, gridpoint values were area weighted into a mean anomaly for the CONUS for each month and year. The process was then repeated for the unadjusted temperature data, and a difference series was formed between the TOB-adjusted and unadjusted data, as shown in Fig. 4.

Figure 4 indicates that removing the time of observation bias progressively elevates the mean U.S. temperature relative to the raw value during the period that coincides with the gradual shift to morning observation times in the network. The net effect of the TOB adjustments is to increase the overall trend in maximum temperatures by about 0.015°C decade^{-1} (±0.002) and in minimum temperatures by about 0.022°C decade^{-1} (±0.002) during the period

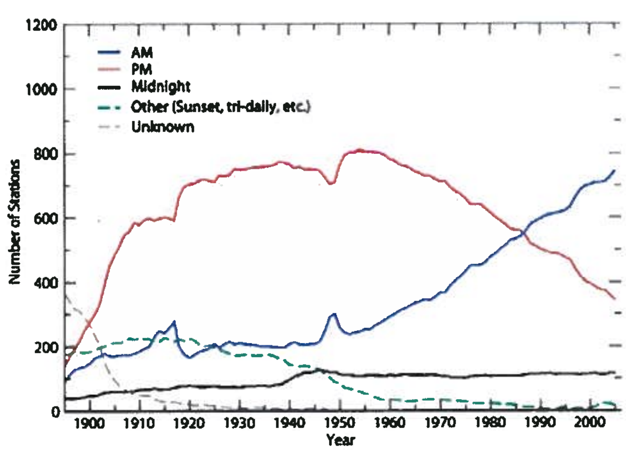


Fig. 3. Changes in the documented time of observation in the U.S. HCN.

Schedule ALD-ER1

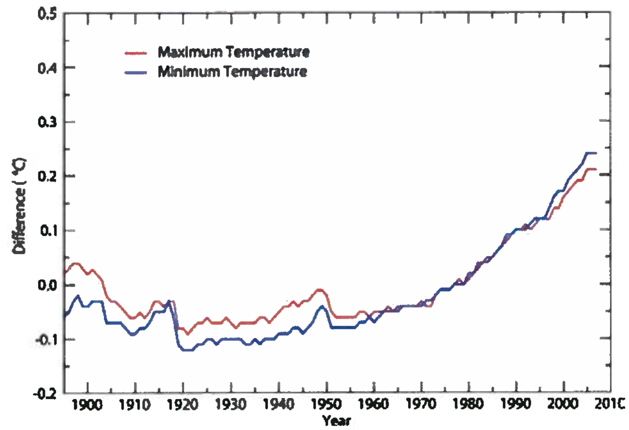


FIG. 4. Average annual differences over the CONUS between the TOB-adjusted data and the unadjusted (raw) data.

1895–2007. This net effect is about the same as that of the TOB adjustments in the HCN version 1 temperature data (Hansen et al. 2001), which is to be expected since the same TOB-adjustment method is used in both versions.

Bias associated with other changes in observation practice. In addition to changes in the time of observation, most surface weather stations also experience changes in station location or instrumentation at various times throughout their histories. Such modifications generally entail alterations in sensor exposure and/or measurement bias that cause shifts in the temperature series that are unrelated to true climate variations. In HCN version 1, the effects of station moves and instrument changes were addressed using the procedure described by Karl and Williams (1987). Because this procedure addressed changes that are documented in the NOAA/NCDC station history archive, the HCN version 1 homogeneity algorithm was called the Station History Adjustment Program (SHAP).

Unfortunately, COOP station histories are incomplete. As a result, discontinuities may occur with no associated record in the metadata. Since undocumented discontinuities remain undetected by methods like SHAP, a new homogenization algorithm was developed for the HCN version 2 temperature data (Menne and Williams 2009). This new algorithm addresses both documented and undocumented discontinuities via a pairwise comparison of temperature records, which avoids problems associated with the use of reference series in undocumented changepoint detection (Menne and Williams 2005). In the pairwise approach, comparisons are made between numerous combinations of temperature series in a region to identify and remove relative inhomogeneities (i.e., abrupt changes in one station series relative to many others).

The pairwise approach works best when there are many neighboring series available for comparison with each target series. Thus, to maximize the number of potential neighbors for each HCN station, all COOP temperature series were used as input by the pairwise algorithm. In contrast, the SHAP used in HCN version 1 was restricted to intercomparing only HCN series, in large part because digital monthly COOP temperature data (and metadata) were more limited back in the 1980s. Since that time, digitization efforts under the Climate Data Modernization Program (CDMP 2001) have markedly increased the volume of digital station data and histories available for the early years of the Cooperative Observer Program, as shown in Fig. 5. As noted in the "Data" section, these historical temperature values were merged with other COOP Network data sources, which effectively increased the density of the observations (as well as the correlation between all series tested), thereby improving the ability of the pairwise algorithm to detect relative inhomogeneities.

As in HCN version 1, homogeneity testing in HCN version 2 was conducted separately on monthly-mean maximum and minimum temperature series. Figure 6 depicts the frequency and magnitude of shifts detected by the pairwise algorithm for each variable. Overall, the pairwise algorithm identified around 6,000 statistically significant changepoints in maximum temperature series and roughly 7,000 shifts in minimum temperature series. Since there are approximately 120,000 station years of temperatures in the HCN version 2 dataset, this represents an aver-

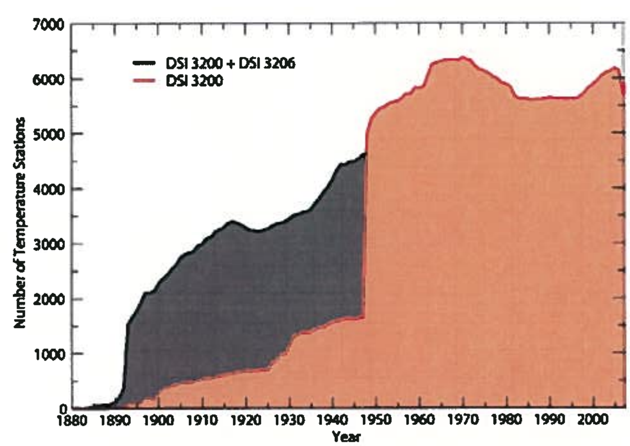


FIG. 5. Digital data availability for COOP stations before (DSI 3200) and after (DSI 3200 + 3206) the digitization efforts of the Climate Data Modernization Program.

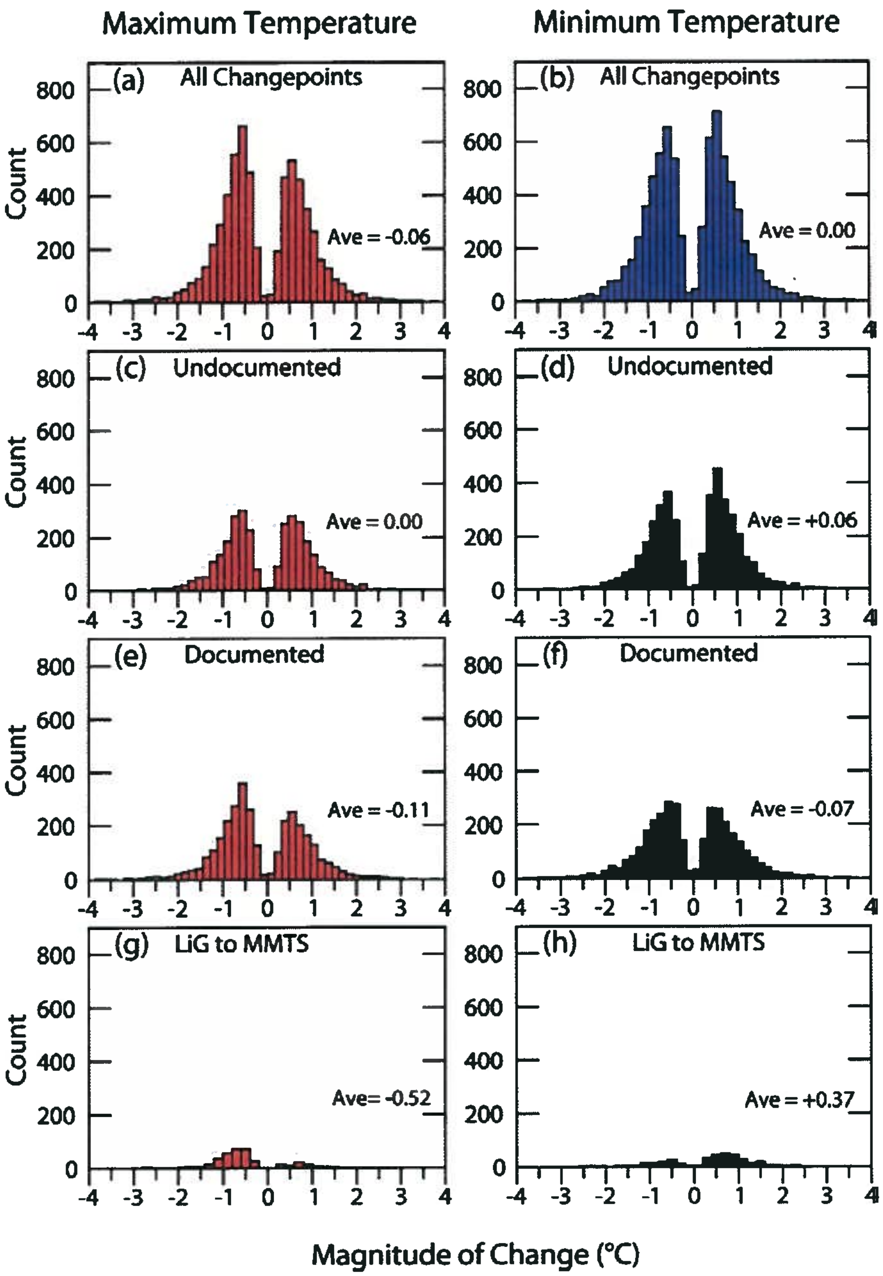


Fig. 6. Histograms of the magnitude of changepoints (shifts) in U.S. HCN mean monthly maximum and minimum temperature series: (a), (b) all changepoints; (c), (d) undocumented changepoints; (e), (f) changepoints associated with documented station changes; (g), (h) changepoints associated with the transition from LiG thermometers to the MMTS. A negative shift indicates that the inhomogeneity led to a decrease in the mean level of the temperature series relative to preceding values.

age of about one significant artificial shift for every 15–20 years of station data. In terms of the adequacy of the HCN metadata, about half of the identified inhomogeneities are undocumented.

Most of the documented changes in the HCN are associated with station relocations. In theory, minor station moves or other changes to sensor exposure would be expected to have a more pronounced effect on minimum temperatures than on maximum temperatures. The reason is that minimum temperatures generally occur near sunrise when calm and stable atmospheric boundary layer conditions are prevalent, at which time near-surface temperature fields are strongly coupled to the local surface characteristics (Oke 1987). On the other hand, during daylight hours, the boundary layer is more commonly well mixed and microclimate differences between nearby locations should be less evident. The larger number of shifts detected in minimum temperature series relative to maximum temperature series is consistent with this reasoning.

Whereas station changes can cause either an artificial rise or drop in temperature, the distribution of shifts identified in HCN version 2 is not necessarily symmetric about zero. For example, there are about 400 more negative shifts than positive shifts in maximum temperature series (Fig. 6a). Most of this asymmetry appears to be associated with documented changes in the network (Fig. 6e) and, in particular, with shifts caused by the transition from liquid-in-glass (LiG) thermometers to the maximum–minimum temperature system (MMTS; Fig. 6g). Quayle et al. (1991) concluded that this transition led to an average drop in maximum temperatures of about 0.4°C and to an average rise in minimum temperatures of 0.3°C for sites with no coincident station relocation. [These averages were subsequently used in version 1 to adjust the records

Schedule ALD-ER1

from HCN stations that converted to the MMTS, primarily during the mid- and late 1980s (Easterling et al. 1996).] More recently, Hubbard and Lin (2006) estimated a somewhat larger MMTS effect on HCN temperatures and advocated for site specific adjustments in general, including those sites with no documented equipment move.

Notably, the pairwise algorithm in HCN version 2 allows for such site-specific adjustments to be calculated for all types of station changes. The subsets of changes associated with the conversion to the MMTS are shown in Figs. 6g and 6h. The pairwise results indicate that only about 40% of the maximum and minimum temperature series experienced a statistically significant shift (out of ~850 total conversions to MMTS). As a result, the overall effect of the MMTS instrument change at all affected sites is substantially less than both the Quayle et al. (1991) and Hubbard and Lin (2006) estimates. However, the average effect of the statistically significant changes (−0.52°C for maximum temperatures and +0.37°C for minimum temperatures) is close to Hubbard and Lin's (2006) results for sites with no coincident station move.

For HCN version 2 as a whole, the combined effect of all adjustments for documented and undocumented temperature changes is to increase the average U.S. trend in maximum temperatures by about 0.031°C decade^{-1} (±0.007) over the period of record relative to the values adjusted only for the TOB (Fig. 7). In contrast, the effect of the pairwise homogenization algorithm on minimum temperature trends is effectively zero over the period of record. As Fig. 7 indicates, the most significant effect of the adjustments on maximum temperatures begins after 1985, which coincides with the beginning of the changeover to the MMTS. The trend in the difference between the fully adjusted maximum temperature data and the TOB-adjusted data reflects the cumulative effect of the individual instrument changes.

Although the majority of MMTS changes occurred during the mid- and late 1980s, about 10% of HCN stations made the switch after 1994 (the last update to the HCN version 1 digital metadata). In addition, a number of sites (about 5% of the network) converted to the Automated Surface Observation System (ASOS) after 1992. Like the MMTS, ASOS maximum temperature measurements have been shown to be lower relative to values from previous instruments (e.g., Guttman and Baker 1996). Such results are in agreement with the pairwise adjustments produced in HCN version 2; that is, an average shift in maximum temperatures caused by the transition to ASOS in the HCN of about −0.44°C. The combined effect of the

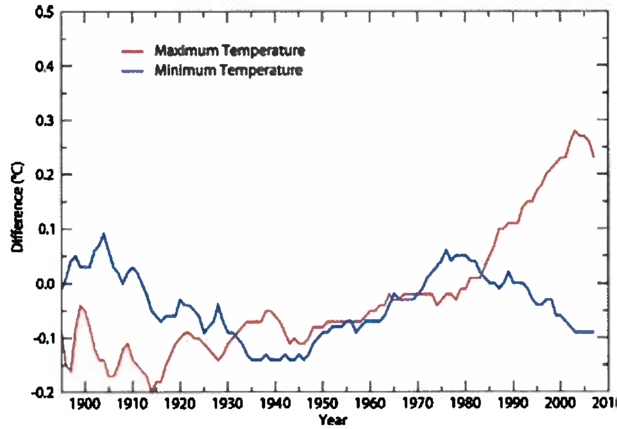


FIG. 7. Average annual differences over the CONUS between the fully adjusted (TOB + pairwise) HCN data and the TOB-only adjusted data.

transition to MMTS and ASOS appears to be largely responsible for the continuing trend in differences between the fully and TOB-only adjusted maximum temperatures since 1985. On the other hand, while the effect of ASOS on minimum temperatures in the HCN is nearly identical to that on maximum temperatures (−0.45°C), the shifts associated with ASOS are opposite in sign to those caused by the transition to MMTS, which leads to a network-wide partial cancellation effect between the two instrument changes. Undocumented changes, which are skewed in favor of positive shifts, further mitigate the effect of the MMTS on minimum temperatures.

Bias associated with urbanization and nonstandard siting. In HCN version 1, the regression-based approach of Karl et al. (1988) was employed to account for the effect of the urban heat island (UHI) bias on temperatures in the HCN (which they found to be important for minimum temperatures only). In contrast, no specific urban correction is applied in HCN version 2. The reason is that adjustments for undocumented changepoints in HCN version 2 appear to account for much of the changes addressed by the Karl et al. (1988) UHI correction used in HCN version 1. In fact, as discussed in the next section, including adjustments for undocumented changepoints actually has a greater impact on minimum temperatures than the HCN version 1 UHI correction. Moreover, adjusting for both documented and undocumented changepoints effectively removes most of the local, unrepresentative trends at individual HCN stations that may arise from gradual changes to the environment. The minimum temperature time series for Reno, Nevada (Fig. 8), illustrates this effect. Specifically, the unadjusted data suggest that the station developed a local

Schedule ALD-ER1

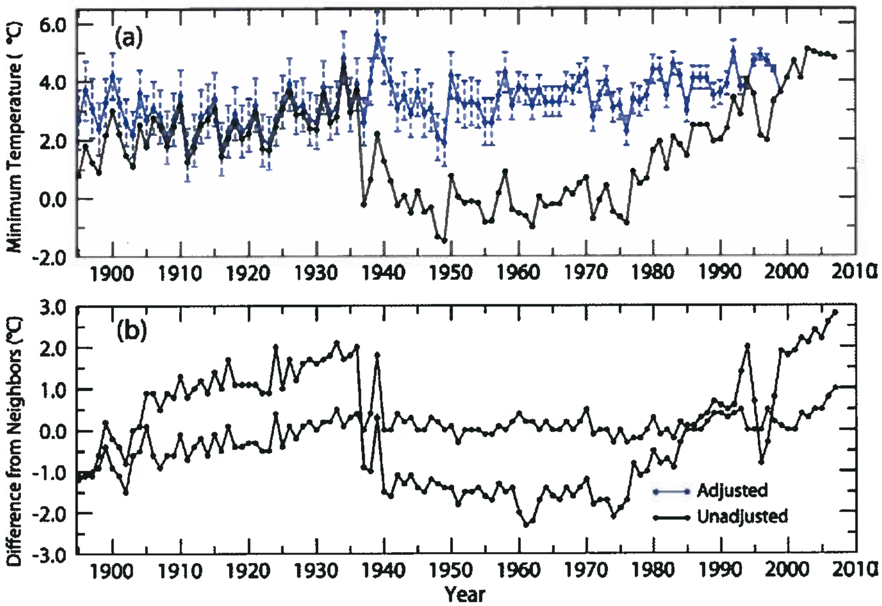


Fig. 8. (a) Mean annual unadjusted and fully adjusted minimum temperatures at Reno, Nevada. Error bars depict a measure of the cumulative uncertainty (95% confidence limits) in the pairwise algorithm's bias adjustments. The estimated uncertainty was determined using 100 Monte Carlo simulations in which a value within the range of pairwise estimates for the magnitude of each shift was randomly selected and used to adjust the series accordingly. (b) Difference between minimum temperatures at Reno and the mean from its 10 nearest neighbors.

trend beginning in the 1970s, possibly as a result of a growing urban heat island influence. In contrast, the fully adjusted HCN version 2 data indicate that the relative trend changes have been largely removed. (Notably, the Reno series is also characterized by major step changes during the 1930s and 1990s caused by station relocations. Both abrupt changes were also removed by the HCN version 2 adjustments.) For these reasons, the average CONUS minimum temperature trend calculated from the 30% most urban HCN stations (based on population metadata) are about the same as that calculated from the remaining more rural locations (i.e., 0.071° and 0.077°C decade^{-1}, respectively) during the period 1895–2007.

It is important to note, however, that although the pairwise algorithm uses a trend identification process to discriminate between gradual and sudden changes, trend inhomogenieties in the HCN are not actually removed with a trend adjustment. Rather, the pairwise approach uses a simple difference in means in the target minus neighbor series (before and after a step change) to estimate the magnitude of the shift, even when there was a relative trend between the two series (as in the case of Reno). Ideally, trend inhomogeneities would be removed with gradual adjustments and step changes with abrupt adjustments. Unfortunately, unlike relative step changes, which occur simultaneously in all difference series formed between an HCN temperature series and those of its neighbors, a trend inhomogeneity may begin and end at different times with respect to its various neighbors. This makes it difficult to robustly identify the true interval of a trend inhomogeneity (Menne and Williams 2009).

Use of a simple difference in means test does, however, address both gradual and sudden changes, producing what arguably approximates the "best objective hypothetical climate record available for the corrected station" (Pielke et al. 2007b). More generally, accounting for both sudden and gradual changes is critical because spurious results may occur if only the sudden changes are corrected (e.g., Fig. 10 in Menne and Williams 2009). The reason is that, in some cases, gradual and sudden changes may not reflect station moves and the effect of urbanization but rather some kind of microclimate peculiarity, such as the growth and removal of a single tree. In such an instance, correcting for the sudden change, but not for the gradual change, would likely produce unrealistic adjusted temperature values. Even in a case such as the Reno observations, preserving the local trend (i.e., not adjusting for the gradual change) would result in a "double counting" of the UHI signal, because the station likely experienced urbanization effects when it was located in the city and then again after its relocation in the mid-1930s to an airport site (whose surroundings became urbanized much later).

One implication of using a difference in means test to adjust for all changepoints is that local trends are "aliased" onto the estimates of step changes (DeGaetano 2006). To quantify the influence of this aliasing effect, the pairwise approach was modified such that only abrupt shifts were removed, thereby creating a "nonproduction" version of HCN in which local trends were retained (see Menne and Williams 2009 for details). In the case of minimum

Schedule ALD-ER1

temperature, the resulting distribution of documented shifts became somewhat less skewed in favor of negative changes, while the distribution of undocumented shifts became more skewed in favor of positive changes (relative to the results presented in Fig. 6). The reason for these distributional changes is that there is an apparent and sizable preference for relative trends between HCN stations and their neighbors to be negative. In other words, there is a general tendency for HCN minimum temperature trends to be smaller relative to surrounding COOP stations. This means that the local trend aliasing effect, on the whole, is removing more negative than positive trend inhomogeneities at HCN stations, despite cases like Reno. Thus, whereas there are apparent residual trend inhomogeneities that remain in some HCN series, they are more likely to be negative than positive and, collectively, there appears to be little evidence of a positive bias in HCN trends caused by the UHI or other local changes. It should be noted, however, that if there is a regional signal that affects a number of stations, its effect will be largely preserved by the homogenization procedure.

A number of recent articles have also raised concerns about the site characteristics of U.S. HCN stations by way of photographic documentation (e.g., Davey ahnd Pielke 2005; Pielke et al. 2007a,b). Moreover, there is evidence that a large fraction of HCN sites have poor ratings with respect to the site classification criteria used by the U.S. Climate Reference Network (A. Watts 2008 personal communication; refer also to www.surfacestations.org[1]). In at least one study (i.e., Mahmood et al. 2006), photographic documentation and other sources of information regarding the exposure characteristics of COOP and HCN sites were used to link poor siting with measurement bias. Such evidence raises legitimate questions about the representativeness of temperature measurements from a number of U.S. HCN sites. However, from a climate change perspective, the primary concern is not so much the absolute measurement bias of a particular site but rather the changes in that bias over time, which the TOB and pairwise adjustments effectively address (Vose et al. 2003; Menne and Williams 2009).

The goal of the HCN version 2 adjustments (and homogenization in general) is not to ensure that observations conform to an absolute standard but rather to remove the effect of relative bias changes that occur during a station's history of observation. In this regard, photographic documentation, though valuable, is most valuable when it is used to document the timing and causes of such shifts in bias through time. Ultimately, the magnitude of relative changes in the bias of observations, whatever the source, cannot be inferred from the metadata. Instead, the effect of station changes and nonstandard instrument exposure on temperature trends must be determined via a systematic evaluation of the observations themselves (Peterson 2006), generally through relative comparisons. Such an analysis suggests that the effect of undocumented changes appears to be at least as significant as documented changes in the HCN and that homogeneity testing for both types of shifts is critical.

Bias assessment of estimates for missing monthly temperature values. As in HCN version 1, HCN version 2 provides estimates for missing monthly maximum and minimum temperatures. Estimates are generated using an optimal interpolation technique known informally as FILNET (short for "fill in the network"), which makes use of the fully adjusted temperature values at neighboring COOP stations. In essence, the FILNET procedure iterates to find an optimal set of neighboring series that minimizes the confidence limits for the difference between the target series and the average of neighboring series (optimized separately for each calendar month). The difference between the target and neighbor average is used as an offset in the interpolation to account for climatological differences between the target and neighbors. The FILNET technique is also used to estimate data in a series where changepoints occur too close together in time (i.e., less than 24 months apart) to reliably estimate the magnitude of shift identified by the pairwise algorithm.

To assess the performance of FILNET, estimates were generated for all mean monthly maximum and minimum temperatures in the HCN and compared with the observed values. Specifically, both the mean difference and the mean absolute difference between the estimated and observed values were calculated separately for each decade in the HCN period of record. As shown in Fig. 9, the mean difference between the FILNET estimates and the observed values is less than 0.1°C in all decades. In addition, the mean absolute difference between the FILNET estimates and the observed values decreases with time as the density of stations in the COOP Network increases. For the period of record as a whole, the mean difference between FILNET estimates and the observed

[1] Site classifications are based on a modification of Leroy (1999), as described in the U.S. Climate Reference Network (2002) Site Information Handbook.

Schedule ALD-ER1

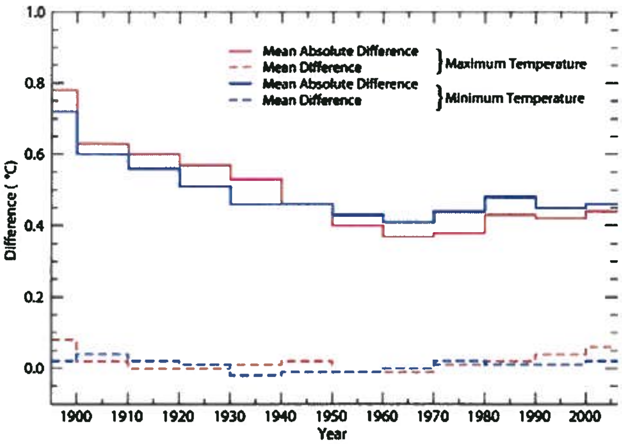


Fig. 9. Difference (by decade) between FILNET estimates and observed monthly values at all U.S. HCN stations.

monthly values in the HCN is 0.01°C, while the mean absolute difference is slightly less than 0.5°C. As shown in Fig. 10, the FILNET procedure has virtually no systematic effect on HCN temperature trends.

COMPARISON OF U.S. HCN VERSIONS 1 AND 2 MONTHLY TEMPERATURES.

To assess the basic temperature differences between HCN versions 1 and 2 at the national scale, the annual CONUS averages from the two datasets were compared using the same gridding procedure described in the "Sources and assessment of temperature bias in the U.S. HCN" section. Because the HCN version 1 release provides an optional UHI correction, two difference series were formed for each variable: (i) HCN version 2 minus HCN version 1 (with TOB and SHAP adjustments), and (ii) HCN version 2 minus HCN version 1 (with TOB, SHAP, and UHI adjustments).

Figure 11 indicates that there is a decreasing trend in the difference series for minimum temperatures before 1970. The trend is especially evident when the UHI adjustment is excluded from HCN version 1. The existence of this trend can be traced to the effect the SHAP adjustments had on minimum temperatures in HCN version 1. Specifically, the SHAP adjustments are limited to documented changes that have a preference for downward shifts (Fig. 6). When these shifts are removed, a mean warming is introduced into the SHAP-adjusted temperature record relative to the raw and TOB-only adjusted data (see also Hansen et al. 2001). Notably, the HCN version 1 UHI adjustment depresses HCN temperature series as a function of population growth, thereby indirectly compensating for much (but not all) of the SHAP-induced warming. In contrast, the undocumented changepoints in minimum temperatures identified in HCN version 2 are skewed in favor of positive shifts, which collectively compensate for the negatively skewed documented shifts (the only changes known to the SHAP). For this reason, the HCN version 2 pairwise adjustments do not increase the minimum temperature trend relative to the TOB-adjusted data (Fig. 7).

Figure 11 also suggests a divergence between HCN versions 1 and 2 temperatures after 1985, a difference associated with the adjustments for the MMTS instrument change in HCN version 1. As discussed in the "Bias associated with other changes in observation practice" section, the HCN version 1 MMTS correction appears to be too large when the effect on the full subset of HCN sites is considered (i.e., when stations with documented moves coincident to MMTS installation are included). However, as Fig. 11 indicates, maximum temperatures recover from the apparent overcorrection in version 1 after the mid-1990s. Unfortunately, this recovery is accidental; in fact, it appears to be a consequence of two factors: first, the HCN version 1 metadata were last updated with the Easterling et al. (1996) release; second, the continued conversion to MMTS (and later Nimbus)—as well as the introduction of ASOS—have artificially (but unknown to SHAP) cooled maximum temperatures to a level that currently compensates for the HCN version 1 overcorrection.

TEMPERATURE TRENDS FROM THE U.S. HCN.

Figure 12 depicts the U.S. annual time series for maximum, minimum, and mean [(maximum + minimum)/2] temperature during the period 1895–2007. In general, all variables exhibit a slight increase

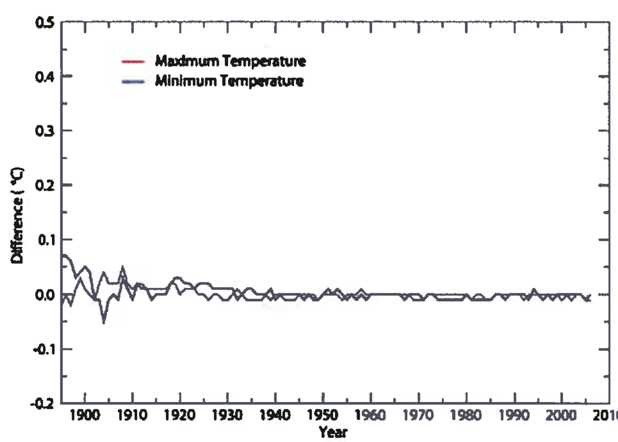


Fig. 10. Average annual differences over the CONUS between the fully adjusted HCN data with estimates for missing values (TOB + pairwise + FILNET) and the fully adjusted data without missing data estimates (TOB + pairwise).

Schedule ALD-ER1

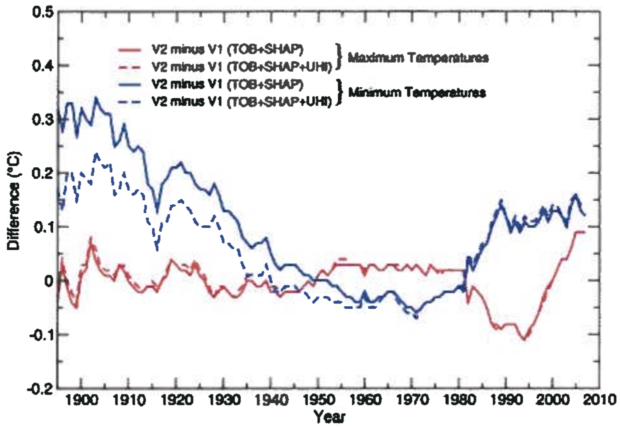


FIG. 11. Average annual differences over the CONUS between HCN version 2 and HCN version 1 (Revision 3; Easterling et al. 1996)

until the early 1930s, followed by a slight decrease until the early 1970s, and finally a more prominent increase into the early twenty-first century. Interannual variability is markedly lower from the mid-1950s to the mid-1970s, the so-called benign climate period (Baker et al. 1993). For maximum temperature, the two highest ranking years are 1934 and 2006; for minimum temperature, the two highest values occurred in 1998 and 2006.

Table 3 summarizes U.S. annual and seasonal (linear) trends in maximum and minimum temperature for the raw, TOB, and fully adjusted (TOB + pairwise) HCN version 2 data as well as the fully adjusted HCN version 1 data (TOB + SHAP + UHI). On an annual basis, the HCN version 2 trend in maximum temperature is 0.064°C decade^{-1}, and the trend in minimum temperature is 0.075°C decade^{-1} (both of which are comparable to the global mean trend of ~0.060°C decade^{-1} for the same period). Trends in both variables are largest in winter and lowest in fall, and increases in the minimum exceed those in the maximum in all seasons except spring. For reasons described in the "Bias caused by changes to the time of observation" section and "Bias associated with other changes in observation practice" section, trends in the adjusted data always exceed those in the raw data. However, as discussed in last section, the HCN version 2 trends in minimum temperature are somewhat smaller than the fully adjusted HCN version 1 trends.

In Fig. 13, the geographic distribution of linear trends in maximum and minimum temperatures for the period 1895–2007 are shown both for the adjusted HCN version 2 data and for the raw data. Geographically, maximum temperature (Fig. 13a) has increased in most areas except in parts of the east central and southern regions. Minimum temperature (Fig. 13c) exhibits the same pattern of change, though the pockets of decreasing temperature are displaced slightly to the south and west relative to maximum temperature. Figures 13b and 13d suggest that the raw data exhibit more extreme trends as well as larger spatial variability; in other words, the bias adjustments tend to have a spatial smoothing effect on rates of change. The reduction in the extent of negative trends is a function of removing the time of observation bias and of the adjustments associated with the MMTS instrument change.

Despite the more coherent pattern, Pielke et al. (2007a,b) argue that homogenized data are not useful for calculating regional trends because the homogenized series lack independence, noting, in

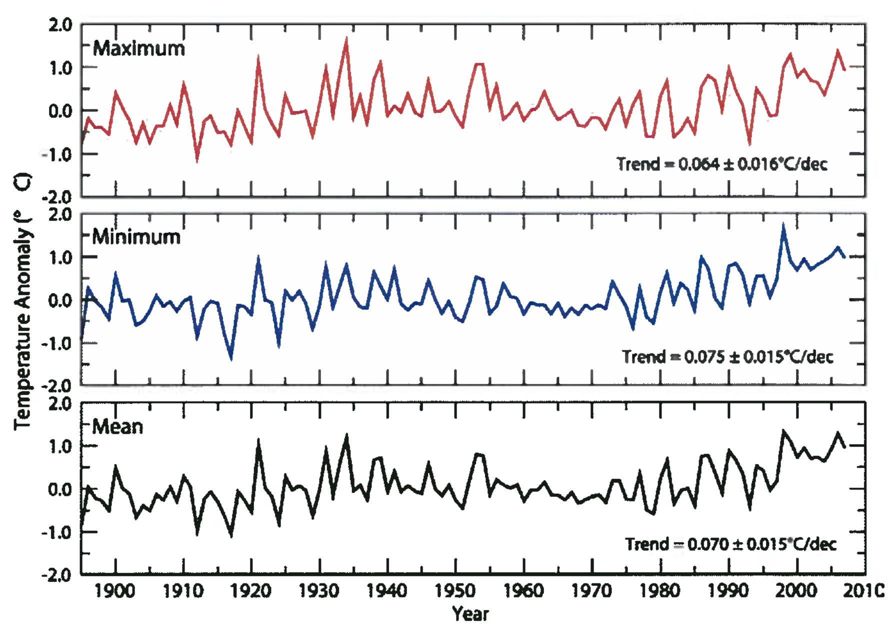


FIG. 12. Time series of annual temperature anomalies from HCN version 2 averaged over the CONUS. Base period is 1961–90. The trends include 95% confidence limits (± one standard error) that were calculated by adding the error in the least squares regression coefficient for the series trend and a factor quantifying the uncertainty in the adjusted temperature values (as described in Fig. 8).

Schedule ALD-ER1

Season	Maximum temperature	Minimum temperature
	Fully adjusted—Version 2 (TOB + Pairwise)	
Annual	0.064	0.075
Dec–Feb	0.101	0.107
Mar–May	0.082	0.066
Jun–Aug	0.044	0.067
Sep–Nov	0.025	0.054
	Unadjusted (Raw)—Version 2	
Annual	0.018	0.054
	Adjusted for TOB only—Version 2	
Annual	0.033	0.076
	Fully adjusted—Version 1 (TOB + SHAP + UHI)	
Annual	0.063	0.090

Table 3. U.S. annual and seasonal temperature trends (°C $decade^{-1}$) 1895–2007 for adjusted and unadjusted temperature series.

particular, that the site-specific information that would have been obtained from a well-sited, stable station cannot be derived retrospectively. Nonetheless, Pielke et al. (2007b) state that the adjusted temperature series "may well be the best objective hypothetical climate record available." We believe that it follows that the adjusted series can be used to infer patterns of climate variability and change at the surface (which is one of the principal motivations behind climate data homogenization). Moreover, the increase in interstation correlation in the adjusted data relative to the unadjusted data is negli-

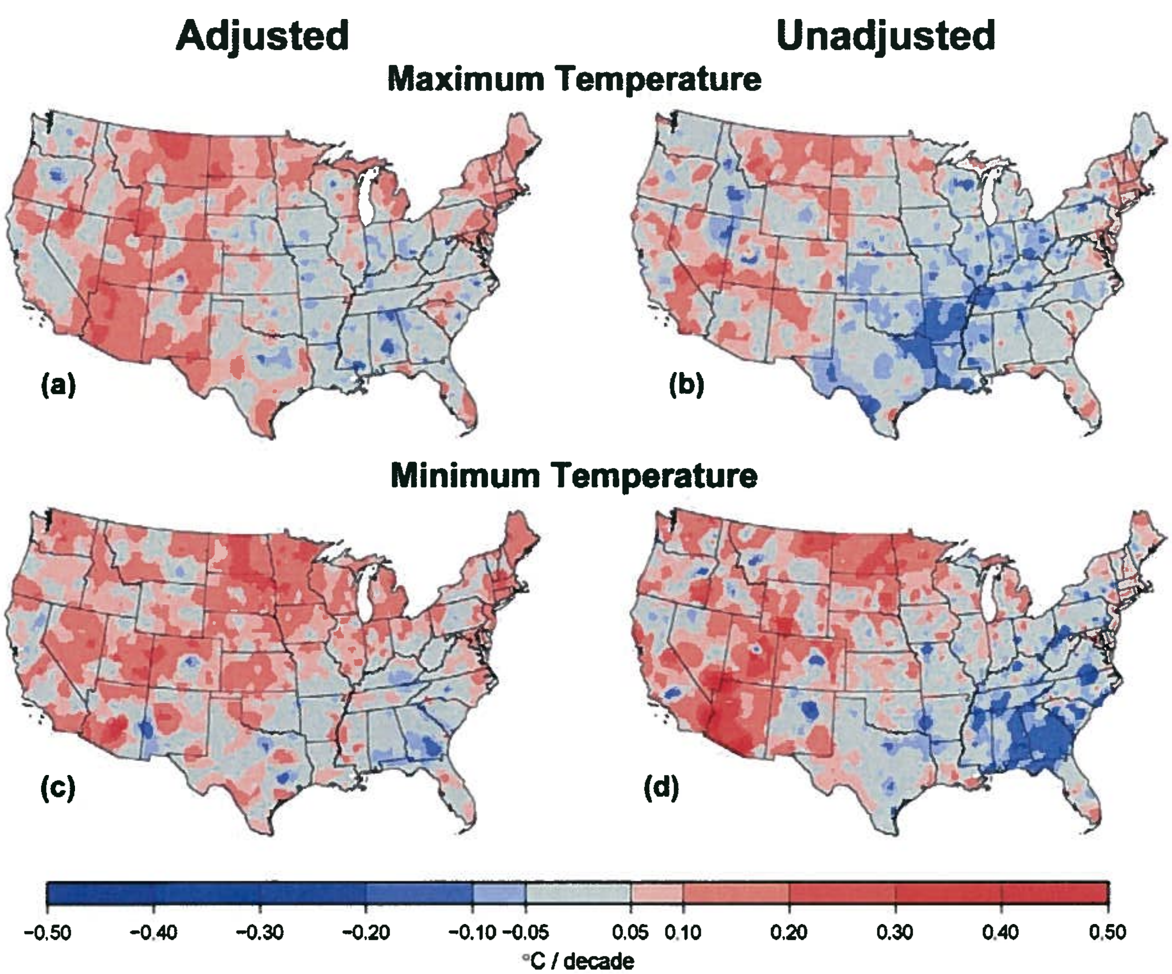


Fig. 13. Geographic distribution of linear trends in HCN version 2 temperatures for the period 1895–2007. (a) adjusted maximum temperatures; (b) unadjusted maximum temperatures; (c) adjusted minimum temperatures; (d) unadjusted minimum temperatures.

gible (accounting for the effect of shifts). It is likely for this reason that Vose and Menne (2004) found that the same basic relationship exists between station density and the error in calculating the mean U.S. temperature trend, whether unadjusted or adjusted data are used. In addition, the Vose and Menne (2004) assessment of the network density required to capture the overall U.S. trend is about an order of magnitude less than the current configuration of the HCN. This suggests that temperature observations from the HCN should be sufficient to calculate regional trends in most areas. In any case, all COOP temperature series are homogenized by the HCN version 2 pairwise algorithm, which expands the pool of adjusted series beyond the HCN subset. Consequently, if there is a concern about the characteristics of a particular HCN site or inadequate station density in some areas, adjusted COOP temperature series can supplement the HCN. This is only one of the benefits of this unique climate network, made possible by the efforts of dedicated volunteers for more than a century.

SUMMARY AND CONCLUSIONS. Overall, the collective effect of changes in observation practice at U.S. HCN stations is of the same order of magnitude as the background climate signal (e.g., artificial bias in maximum temperatures is about $-0.04°C$ decade^{-1} compared to the background trend of about $0.06°C$ decade^{-1}). Consequently, bias adjustments are essential in reducing the uncertainty in U.S. climate trends. The bias changes that have had the biggest effect on the climate network as a whole include changes to the time of observation (which affects both maximum and minimum temperature trends) and the widespread conversion to the MMTS (which affects primarily maximum temperatures). Adjustments for undocumented changes are especially important in removing bias in minimum temperature records. Tests for undocumented shifts, however, are inherently less sensitive than in cases where the timing of changes is known through metadata. Thus, metadata are exceedingly valuable when it comes to adjusting and evaluating climate trends.

Trends in the HCN version 2 adjusted series are more spatially uniform than in unadjusted data. This indicates that the homogenization procedures remove changes in relative bias and that the background climate signal is more accurately represented by the homogenized data. It is important to point out, however, that although homogenization generally ensures that climate *trends* can be more confidently intercompared between sites, the effect of relative biases will still be reflected in the *mean* temperatures of homogenized series. The reason is that, by convention, temperatures are adjusted to conform to the latest (i.e., current) observing status at all stations. This detail helps to explain why Peterson and Owen (2005) found evidence of a systematic difference in mean temperatures at rural versus urban HCN stations but little evidence of a comparable difference in their homogenized trends. Moreover, while changes in observation practice have clearly had a systematic effect on average U.S. temperature trends, homogeneity matters most at the station level where even one change in bias can have a drastic effect on the series trend (which can occasionally be missed by changepoint tests). Therefore, the goal behind the HCN version 2 dataset (and future improvements) is to make the adjustments as site specific and comprehensive as possible, which is especially valuable in the development of widely used products, such as the U.S. Climate Normals.

Finally, the U.S. HCN data will be updated monthly and fully reprocessed periodically to detect and adjust for shifts from the recent past (see www.ncdc.noaa.gov/oa/climate/research/uschcn/ for further information, including access to the data and uncertainty calculations). Plans are also in place to ensure that U.S. HCN monthly means are internally consistent with NCDC's global daily dataset (the Global Historical Climatology Network—Daily dataset). Still, there is always room for improvement in the field of climate data homogenization. For example, although the monthly adjustments used in HCN version 2 are constant for all months, there is evidence that bias changes often have effects that vary seasonally and/or synoptically (Trewin and Trivitt 1996; Guttman and Baker 1996). As shown by Della-Marta and Wanner (2006), it is possible to estimate the differential effects indirectly by evaluating the magnitude of change as a function of the frequency distribution of daily temperatures. Daily adjustments are thus a promising area for future HCN development.

ACKNOWLEDGMENTS. The authors wish to thank Anthony Watts for his considerable efforts in documenting the current site characteristics of U.S. HCN stations. The authors also thank Tom Peterson, Tami Houston, and three anonymous reviewers whose helpful comments greatly improved this manuscript. Partial support for this work was provided by the Office of Biological and Environmental Research, U.S. Department of Energy (Grant DE-AI02-96ER62276).

REFERENCES

Baker, D. G., 1975: Effect of observation time on mean temperature estimation. *J. Appl. Meteor.*, **14**, 471–476.

——, D. L. Ruschy, and R. H. Skaggs, 1993: Agriculture and the recent benign climate. *Bull. Amer. Meteor. Soc.*, **74**, 1035–1040.

CDMP, 2001: Annual report. Climate Database Modernization Program Rep., 8 pp. [Available online at www.ncdc.noaa.gov/oa/climate/cdmp/files/annual-report2001.pdf.]

Climate Reference Network, 2002: Site information handbook. NOAA/NESDIS CRN Series X030, CRN Rep. NOAA-CRN/OSD-2002-0002R0UD0. [Available online at ftp://ftp.ncdc.noaa.gov/pub/data/uscrn/documentation/program/X030FullDocumentD0.pdf.]

Collins, D. A., S. Johnson, N. Plummer, A. K. Brewster, and Y. Kuleshov, 1999: Re-visiting Tasmania's reference climate stations with a semi-objective network selection scheme. *Aust. Meteor. Mag.*, **48**, 111–122.

Davey, C. A., and R. A. Pielke Sr., 2005: Microclimate exposure of surface-based weather stations. *Bull. Amer. Meteor. Soc.*, **86**, 497–504.

DeGaetano, A. T., 2000: A serially complete simulated observation time metadata file for U.S. daily Historical Climatology Network stations. *Bull. Amer. Meteor. Soc.*, **81**, 49–67.

——, 2006: Attributes of several methods for detecting discontinuities in mean temperature series. *J. Climate*, **19**, 838–853.

Della-Marta, P. M., and H. Wanner, 2006: A method of homogenizing the extremes and mean of daily temperature measurements. *J. Climate*, **19**, 4179–4197.

Durre, I., M. J. Menne, and R. S. Vose, 2008: Strategies for evaluating quality assurance procedures. *J. Appl. Meteor. Climatol.*, **47**, 1785–1791.

Easterling, D. R., T. R. Karl, E. H. Mason, P. Y. Hughes, and D. P. Bowman, cited 1996: United States Historical Climatology Network (U.S. HCN) monthly temperature and precipitation data. ORNL/CDIAC-87, NDP-019/R3. [Available online at http://cdiac.ornl.gov/epubs/ndp019/ndp019.html.]

Guttman, N. B., and C. B. Baker, 1996: Exploratory analysis of the difference between temperature observations recorded by ASOS and conventional methods. *Bull. Amer. Meteor. Soc.*, **77**, 2865–2873.

Hansen, J., R. Ruedy, M. Sato, M. Imhoff, W. Lawrence, D. Easterling, T. Peterson, and T. Karl, 2001: A closer look at United States and global surface temperature change. *J. Geophys. Res.*, **106**, 23 947–23 963.

Hubbard, K. G., and X. Lin, 2006: Reexamination of instrument change effects in the U.S. Historical Climatology Network. *Geophys. Res. Lett.*, **33**, L15710, doi:10.1029/2006GL027069.

Karl, T. R., and C. N. Williams Jr., 1987: An approach to adjusting climatological time series for discontinuous inhomogeneities. *J. Climate Appl. Meteor.*, **26**, 1744–1763.

——, C. N. Williams Jr., P. J. Young, and W. M. Wendland, 1986: A model to estimate the time of observation bias associated with monthly mean maximum, minimum, and mean temperature for the United States. *J. Climate Appl. Meteor.*, **25**, 145–160.

——, H. F. Diaz, and G. Kukla, 1988: Urbanization: Its detection and effect in the United States climate record. *J. Climate*, **1**, 1099–1123.

Leroy, M., 1999: Classification d'un site. Météo-France, Direction des Systèmes d'Observation. Tech. Note 35, 12 pp.

Mahmood, R., S. A. Foster, and D. Logan, 2006: The geoprofile metadata, exposure of instruments, and measurement bias in climatic record revisited. *Int. J. Climatol.*, **26**, 1091–1124.

Menne, M. J., and C. N. Williams Jr., 2005: Detection of undocumented changepoints using multiple test statistics and composite reference series. *J. Climate*, **18**, 4271–4286.

——, and ——, 2009: Homogenization of temperature series via pairwise comparisons. *J. Climate*, **22**, 1700–1717.

Oke, T. R., 1987: *Boundary Layer Climates*. 2nd ed. Routledge, 435 pp.

Peterson, T. C., 2006: Examination of potential biases in air temperature caused by poor station locations. *Bull. Amer. Meteor. Soc.*, **87**, 1073–1080.

——, and T. W. Owen, 2005: Urban heat island assessment: Metadata are important. *J. Climate*, **18**, 2637–2646.

Pielke, R. A., Sr., and Coauthors, 2007a: Documentation of uncertainties and biases associated with surface temperature measurement sites for climate change assessment. *Bull. Amer. Meteor. Soc.*, **88**, 913–928.

——, and Coauthors, 2007b: Unresolved issues with the assessment of multidecadal global land surface temperature trends. *J. Geophys. Res.*, **112**, D24S08, doi:10.1029/2006JD008229.

Quayle, R. G., D. R. Easterling, T. R. Karl, and P. Y. Hughes, 1991: Effects of recent thermometer changes in the Cooperative Station Network. *Bull. Amer. Meteor. Soc.*, **72**, 1718–1723.

Quinlan, F. T., T. R. Karl, and C. N. Williams Jr., 1987: United States Historical Climatology Network

Schedule ALD-ER1

(HCN) serial temperature and precipitation data. NDP-019, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN.

Trewin, B. C., and A. C. F. Trevitt, 1996: The development of composite temperature records. *Int. J. Climatol.*, **16,** 1227–1242.

Vose, R. S., and M. J. Menne, 2004: A method to determine station density requirements for climate observing networks. *J. Climate,* **17,** 2961–2971.

——, C. N. Williams Jr., T. C. Peterson, T. R. Karl, and D. R. Easterling, 2003: An evaluation of the time of observation bias adjustment in the U.S. Historical Climatology Network. *Geophys. Res. Lett.,* **30,** 2046, doi:10.1029/2003GL018111.

Willmott, C. J., C. M. Rowe, and W. D. Philpot, 1985: Small-scale climate maps: A sensitivity analysis of some common assumptions associated with grid-point interpolation and contouring. *Amer. Cartogr.,* **12,** 5–16.

Schedule ALD-ER1

Summary of Recent Changes in the GHCN-M Temperature Dataset and Merged Land-Ocean Surface Temperature Analyses

2 May 2011

Global Historical Climatology Network-Monthly Dataset:
The Global Historical Climatology Network-Monthly (GHCN-M) has been the official land surface mean temperature dataset since its release and has been widely used in several international climate assessments, as well as NCDC's climate monitoring activities. Effective May 2, 2011, the GHCN-M version 3 dataset of monthly mean temperature replaced GHCN-M version 2 monthly mean temperature dataset. Beginning with the April 2011 State of the Climate Report, GHCN-M version 3 will be used for NCDC climate monitoring activities, including calculation of global land surface temperature anomalies and trends. It will also be merged with the Extended Reconstruction Sea Surface Temperature (ERSST) version 3b dataset to form the merged land and ocean surface temperature dataset, which is used to calculate the global average temperature from 1880 to present.

The GHCN-M version 3 monthly mean temperature dataset introduces a number of changes that include: consolidating "duplicate" series, updating records from recent decades, and the use of new approaches to quality assurance and homogenization (the process of removing the impact of non-climatic changes in climate time series). These improvements have enhanced the overall quality of the dataset; nonetheless, conclusions regarding global land surface temperature change are little affected by this release.

Description of Major Changes in Version 3

Removal of Station Duplicates: A unique feature of the GHCN-M version 2 dataset is the presence of duplicate station records for approximately one-third of its stations. The dataset contains 2,706 stations that have two or more separate sets of observations informally referred to as "duplicates." The term notwithstanding, the two or more duplicate mean temperature series attributed to a single station are, in fact, similar *but not exact* copies of each other. Duplicates occur because there are often multiple sources of temperature data for any given observing station. For some stations included in GHCN-M version 2, data attributed to a single station were provided in ten or more different databases. These various sources of data often overlap in time, and while the values between sources are generally similar, they are often not identical. The differences most commonly result from the many different ways in which monthly mean temperature can be calculated. In GHCN-M version 3, duplicates are combined into single station series based on a process whereby the longer duplicate time series were given higher preference.

Data Additions to the GHCN-M database: In GHCN-M version 3, additions to the historical record were made to fill in data gaps during the 1990s and first decade of the 21st century by incorporating the most recently available data from World Weather Records (WWR) as well as additional data from NCDC's Monthly Climatic Data of the World (MCDW). Inclusion of observations from WWR and MCDW made it possible to increase by nearly 500, the number of existing GHCN-M stations having at least 9 months of data each year during the 1990s.

Changes to the Quality Control Process: The GHCN-M version 3 quality control checks can be grouped into three general categories: basic integrity, outlier, and spatial consistency. Once an observation fails a quality control check, the value is excluded from subsequent checks during that processing cycle. The quality control flags are included in the version 3 dataset for any value identified to be in error, providing information on the type of error associated with a value. The quality control flag is one of three types of metadata information included in the GHCN-M version 3 dataset. It is appended to each observation along with a measurement flag and a source flag. Details on the quality control, measurement, and source flags are available in the version 3 README file.

Bias Corrections: Surface weather stations are frequently subject to minor relocations throughout their history of operation. They may undergo changes in instrumentation, observing practices may vary through time, and the land use/land cover in the vicinity of an observing site can be altered by either natural or man-made causes. Any of these kinds of modifications to the circumstances behind temperature measurements have the potential to alter a thermometer's microclimate exposure characteristics or otherwise change the bias of measurements relative to those taken under previous circumstances. This can result in an abrupt shift in the mean level of temperature readings that is unrelated to true climate variations and trends. The removal of the impact of these non-climatic changes in climate series is called homogenization. The process of homogenization of the GHCN-M version 3 data is conducted through use of the Pairwise Homogeneity Adjustment algorithm. This was initially applied to the U.S. Historical Climatology Network Version 2 dataset and is described in Menne and Williams, 2009 and Menne et al. 2009.

Merging of GHCN-M Version 3 Land Surface Temperatures with ERSST Version 3b:
The GHCN-M version 3 station land surface temperature anomalies are averaged within a 5° by 5° grid box to obtain gridded anomalies, which are then merged with the ERSST version 3b 5° by 5° gridded sea surface temperature anomalies (see next paragraph) to get a more complete picture of global temperature variability and trends.

Even during the periods of greatest station density, there are many areas where land surface observations are unavailable. Observations can be estimated in such areas using a variety of interpolation techniques. A method developed by van den Dool et al. (2000) and applied to the development of a merged land and ocean surface temperature dataset (Smith et al. 2008) is used to estimate temperature anomalies in areas with little-to-no data. This method uses spatial pattern recognition (Empirical Orthogonal Teleconnections) to fill in the areas with little-to-no data, and it forms the basis for global surface temperature calculations used in NCDC's climate monitoring activities.

In high latitude areas, the method of spatial pattern recognition is less effective at filling in areas with sparsely reported climate observations. Prior to GHCN-M version 3, the global merged land and ocean surface temperature gridded dataset would set these areas to missing, regardless of whether land-only data was available for the grid point. With the release of GHCN-M version 3, the land surface temperature observations will be included in the merged dataset in these high-latitude areas.

REFERENCES:

Menne, M.J., and C.N. Williams, Jr. (2009), Homogenization of temperature series via pairwise comparisons. *J. Climate*, **22**, 1700-1717.

Menne, M.J., C.N. Williams, and R.S. Vose (2009), The United States Historical Climatology Network Monthly Temperature Data - Version 2. *Bulletin of the American Meteorological Society*, **90**, 993-1107.

Smith, T. M., R.W. Reynolds, T.C. Peterson, and J.H. Lawrimore (2008), Improvements to NOAA's Historical Merged Land-Ocean Surface Temperature Analysis (1880-2006). *J. Climate*, **21**, 2283-2293. doi: 10.1175/2007JCLI2100.1

van den Dool, H. M., S. Saha, Å Johansson (2000), Empirical Orthogonal Teleconnections. *J. Climate*, **13**, 1421–1435.

NOAA's 1981-2010 Climate Normals

NOAA's National Climatic Data Center (NCDC) released the 1981-2010 Normals on July 1, 2011. Climate Normals are the latest three-decade averages of climatological variables, including temperature and precipitation. This new product replaces the 1971-2000 Normals product. Additional Normals products; such as frost/freeze dates, growing degree days, population-weighting heating and cooling degree days, and climate division and gridded normals; will be provided in a supplemental release by the end of 2011.

Obtaining the 1981-2010 Climate Normals

Users can access the 1981-2010 Climate Normals via ftp or http. It is highly recommended that users first download and read the readme.txt file which describes all file information and where each file is located.

Pre-release Webcast

NCDC hosted a webcast on June 13, 2011 with over 150 participants. This webcast focused on what users can expect to see when the 1981-2010 Climate Normals are released on July 1, 2011. Presentation materials for this webcast are available here:

Normals-Webcast-061311.pdf

For more information on this webcast, such as viewing a recorded version of the webcast, please contact Robin Evans.

FAQs

1.

1.

What are Normals?

Schedule ALD-ER1

In the strictest sense, a "normal" of a particular variable (e.g., temperature) is defined as the 30-year average. For example, the minimum temperature normal in January for a station in Chicago, Illinois, would be computed by taking the average of the 30 January values of monthly-averaged minimum temperatures from 1981 to 2010. Each of the 30 monthly values was in turn derived from averaging the daily observations of minimum temperature for the station. In practice, however, much more goes into NCDC's Normals product than simple 30-year averages. Procedures are put in place to deal with missing and suspect data values. In addition, Normals include quantities other than averages such as degree days, probabilities, standard deviations, etc. Normals are a large suite of data products that provide users with many tools to understand typical climate conditions for thousands of locations across the United States. (top)

---

2. **When will the 1981 - 2010 Normals be available?**

The new Normals are being made available in two releases. Core Normals were released on July 1, 2011. Supplemental Normals will be available by January 2012. Initial access to both releases will be via file transfer protocol (FTP). We expect to provide more advanced (and user-friendly) Web services and selection capabilities to the new Normals from NCDC's Web site by November 2011 for the core Normals and April 2012 for the supplemental Normals. (top)

---

3. **What are considered "core" Normals?**

The core 1981 - 2010 Normals are the most-widely used Normals as identified by NCDC in close consultation with the National Weather Service (NWS) and a wide array of climate data users. Specifically, core Normals refer to the daily and monthly station-based Normals of temperature, precipitation, snowfall, snow depth, and heating and cooling degree days. Generally, this coincides with the key products produced for each observation station called CLIM81 and CLIM84 released for the 1971 - 2000 Normals (except for snowfall and snow depth Normals). (top)

---

4. **What are "supplemental" Normals?**

Supplemental Normals are a catchall category for all Normals products that will not be released in the core Normals release. An example is our population-weighted degree day normals product, which cannot be computed until the U.S. Census Bureau releases its final population figures. (top)

---

5. **Why does NOAA produce Normals?**

NOAA's computation of climate Normals is in accordance with the recommendation of the World Meteorological Organization (WMO), of which the United States is a member. While the WMO mandates each member nation to compute 30-year averages of meteorological quantities at least every 30 years (1931 - 1960, 1961 - 1990, 1991 - 2020, etc.), the WMO recommends a decadal update, in part to incorporate newer weather stations. Further, NOAA's NCDC has a responsibility to fulfill the mandate of Congress "... to establish and record the climatic conditions of the United States." This responsibility stems from a provision of the Organic Act of October 1, 1890, which established the Weather Bureau as a civilian agency (15 U.S.C. 311). (top)

---

6. **What are Normals used for?**

Meteorologists and climatologists regularly use Normals for placing recent climate conditions into a historical context. NOAA's Normals are commonly seen on local weather news segments for comparisons with the day's weather conditions. In addition to weather and climate comparisons, Normals are utilized in seemingly countless applications across a variety of sectors. These include: regulation of power companies, energy load forecasting, crop selection and planting times, construction planning, building design, and many others. (top)

---

7. **What changes are being made in the computation of the 1981 - 2010 Normals versus previous versions?**

Several changes and additions have been incorporated into the 1981-2010 Normals. Monthly temperature and precipitation normals are based on underlying data values that have undergone additional quality control. Monthly temperatures have also been standardized to account for the effects of station moves, changes in instrumentation, etc. These enhancements are described in more detail in the following peer-reviewed papers:
ftp://ftp.ncdc.noaa.gov/pub/data/ushcn/v2/monthly/menne-etal2009.pdf
and
ftp://ftp.ncdc.noaa.gov/pub/data/ushcn/v2/monthly/menne-williams2009.pdf

Unlike the 1971-2000 Normals, daily data were used extensively in the computation of daily temperature and precipitation normals as well as heating and cooling degree day normals, providing greater precision of intra-seasonal features. In previous installments, daily precipitation normals were computed as a spline fit through the monthly values. For 1981-2010, this metric will be replaced with a suite of metrics, including daily probabilities of precipitation as well as month-to-date and year-to-date precipitation normals. New products in the 1981-2010 Normals include normals derived from hourly data values. More details can be found in Arguez et al. 2011 which can be accessed here:
ftp://ftp.ncdc.noaa.gov/pub/data/aarguez/Normals/1981-2010/Arguez-Extended-Normals-AMS2011.pdf (top)

---

8. **What qualifies or disqualifies a station to be included in Normals products?**

Normals are computed for as many NWS stations as reasonably possible. Some stations do not have sufficient data over the 1981 - 2010 period to be included in Normals, and this is the primary reason a station may not be included. Normals are computed for stations that are part of the NWS's Cooperative Observer Program (COOP) Network. Some additional stations are included that have a Weather Bureau -- Army -- Navy (WBAN) station identification number including the Climate Reference Network (CRN). Normals are only computed for stations in the United States (including Alaska and Hawaii) as well as U.S. territories, commonwealths, compact of free association nations, and one Canadian CRN station. (top)

---

9. **How many stations will be included in the normals?**

The 1981-2010 Climate Normals includes normals for over 9800 stations. Temperature-related normals are reported for 7500 stations and precipitation normals are provided for 9300 stations, including 6400 that also have snowfall normals and 5300 that have normals of snow depth. (top)

---

10. **What do climate Normals tell us about global warming or climate change?**

Normals were not designed to be metrics of climate change. In fact, when the widespread practice of computing Normals commenced in the 1930s, the generally-accepted notion of the climate was that underlying long-term averages of climate time series were constant. Changes from one installment of Normals to the next do, nonetheless, provide some evidence of climate change impacts. However, care must be taken when interpreting changes between one Normals period and the other.

Schedule ALD-ER1

Differences between the reported 1971-2000 Normals and the 1981-2010 Normals may be due to station moves, changes in methodology, changes in instrumentation, etc. that are not reflective of real changes in the underlying climate signal. Rather than inferring climate change impacts from Normals, we recommend users instead look at trends in U.S. Historical Climatology Network (USHCN) time series: http://www.ncdc.noaa.gov/oa/climate/research/ushcn (top)

---

11. **What portion of the difference from the new Normals and the previous Normals was due to climate change?**

Compared to the previous Normals, the new Normals includes the decade of the 2000s and loses the decade of the 1970s. As the 2000s were warmer than the 1970s, this has had a warming influence on the Normals. Comparing these decades using our best data set for climate change analysis, the USHCN, we find that the decade of the 2000s was about 1.5F warmer than the 1970s. For maximum, minimum and mean temperature the difference, respectively, was 1.37F, 1.55F and 1.46F. As the Normals are an average of three decades, this would warm the new Normals by approximately 0.5F. The difference between these values and the actual difference between the reported 1971-2000 Normals and the new Normals are caused by station moves, changes in observing practices or instruments, etc. (top)

---

12. **How can I obtain historic Normals from previous Normal periods?**

To obtain 1961 - 1990 climate Normals or earlier versions, please contact NCDC's User Engagement & Services Branch. (top)

---

13. **What are Heating and Cooling Degree Days? What are Growing Degree Days?**

Heating and cooling degree days are metrics of energy demand associated with the variation of mean temperature across space and time. Growing degree days are metrics of agricultural output, also as a function of mean temperature. The computation of degree days involves certain threshold temperatures, e.g., 65°F for heating and cooling degree days. These thresholds are referred to as base temperatures. (top)

---

14. **How can I obtain Heating and Cooling Degree Day Normals set to different base temperatures? And for Growing Degree Units?**

While NCDC utilizes 65°F as the base temperature for the standard calculation of heating and cooling degree days, NCDC's climate normal products include alternative computations of heating and cooling degree days for various base temperatures. In addition, growing degree days are computed for various crop-specific base temperatures. Please contact NCDC's User Engagement & Services Branch for more information. (top)

---

15. **How can I obtain hourly, daily, and monthly Normals for additional weather elements such as dew point, sea level pressure, and wind?**

The vast majority of weather stations utilized in Normals only routinely report air temperature and precipitation. A smaller set of stations have fairly complete records of additional variables such as dew point temperature, sea level pressure, and wind speed and direction. For 262 first order stations, we provide hourly normals of temperature, dew point temperature, heat index, wind chill, heating and cooling degree hours, sea level pressure, and wind. (top)

---

16. **How does the transition to ASOS affect the computation of Normals?**

Schedule ALD-ER1

Automated Surface Observing System (ASOS) stations were implemented in the mid -1990s, largely replacing human observers. As a result, there are inhomogeneities in the 1981-2010 underlying data records due to changes in observing practices. These inhomogeneities are accounted for to the extent possible by quality control and the standardization of monthly temperature values. See the Menne et al. (2009) and Menne and Williams (2009) for more information. (top)

17.
How do the Normals compare to Alternative Normals and Dynamic Normals?

In response to observed climate change, NOAA's NCDC has been investigating a suite of experimental products that attempt to provide a better estimate of "normal" than the traditional 30-year average Normals of temperature and precipitation. This project is known as Alternative Normals. This project is parallel to the computation of NOAA's official 1981 - 2010 Normals and is ongoing. There are no plans to discontinue the computation of official Normals every ten years in response to results obtained from the Alternative Normals project. For more information on Alternative Normals, please contact NCDC's Anthony Arguez. Dynamic Normals refers to a tool available on NCDC's Web site that allows users to create their own Normals for a particular station by selecting customized start and end years for the averages. This tool has not been updated since 2001 and there are no plans to update this tool in the foreseeable future. For more information on Dynamic Normals, please contact NCDC's User Engagement & Services Branch. (top)

18.
NOAA's Climate Prediction Center has already changed their Normals to the 1981 - 2010 base period? Why are those Normals not available?

Many organizations, including NOAA's Climate Prediction Center (CPC), develop their own averages and change base periods for internal use. However, NCDC's climate Normals are the official United States Normals as recognized by the World Meteorological Organization and the main Normals made available for a variety of variables. Below is a brief summary of changes to the CPC products due to the change in climate base period from 1971 - 2000 to 1981 - 2010:

Climate Monitoring:

- In January 2011, the CPC completed development of new climate normals based on the 1981 - 2010 period. This effort was done for all of the Climate Data Assimilation System (CDAS) and Global Ocean Data Assimilation (GODAS) data products that are used for real-time monitoring of the global climate system.
- This new climate base period was used to prepare numerous operational climate monitoring products, including the Climate Diagnostics Bulletin (CDB) and ocean monitoring products in February 2011. For example, the CDB and ocean products released in February 2011 that describe conditions during January, 2011 use climate anomalies based on the new climate base period.
- A notification of this change to the CPC normals was placed on the CPC website prior to the change in January 2011.

Climate Prediction:

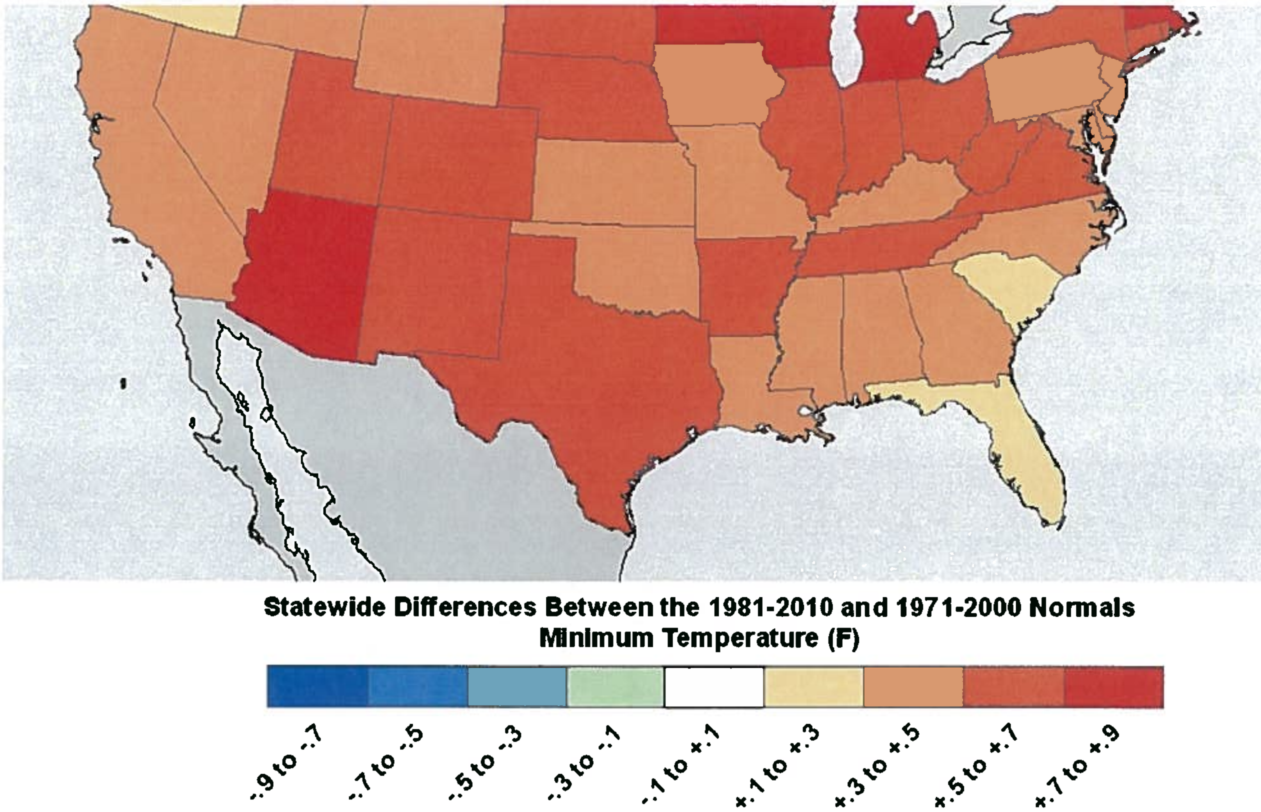
- CPC normals for stations and climate divisions, which are used in CPC's operational forecasts, will be officially updated in mid-May.
- CPC normals for heating and cooling degree days will be updated in mid-June.

(top)

Changes in Normals

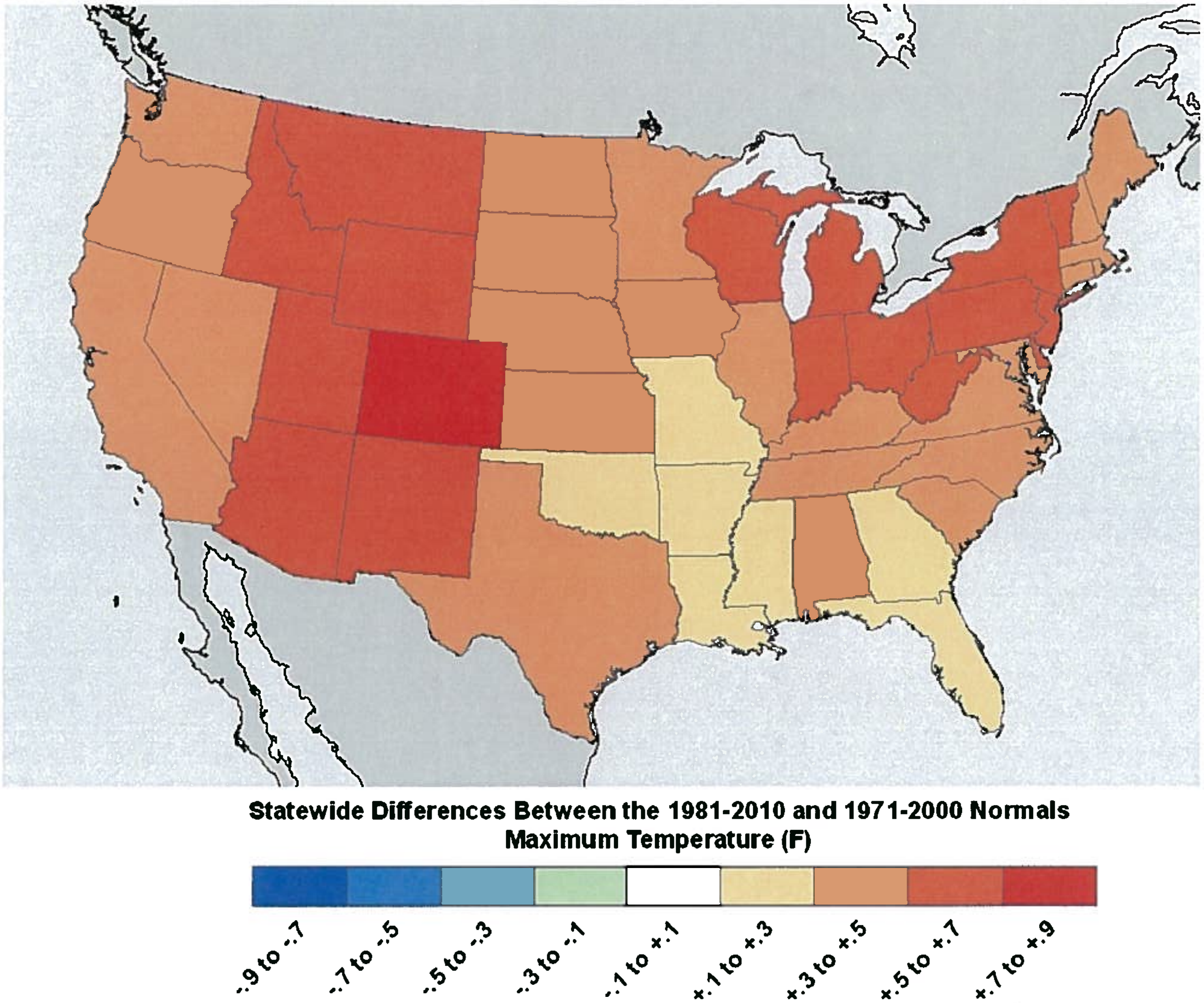
When comparing the 1981-2010 Normals to the 1971-2000 Normals computed using the same methodology, both maximum temperatures and minimum temperatures are about 0.5F warmer on average in the new normals. The averaged annual statewide changes in maximum and minimum temperatures are shown in Figures 1 and 2, respectively.

Schedule ALD-ER1

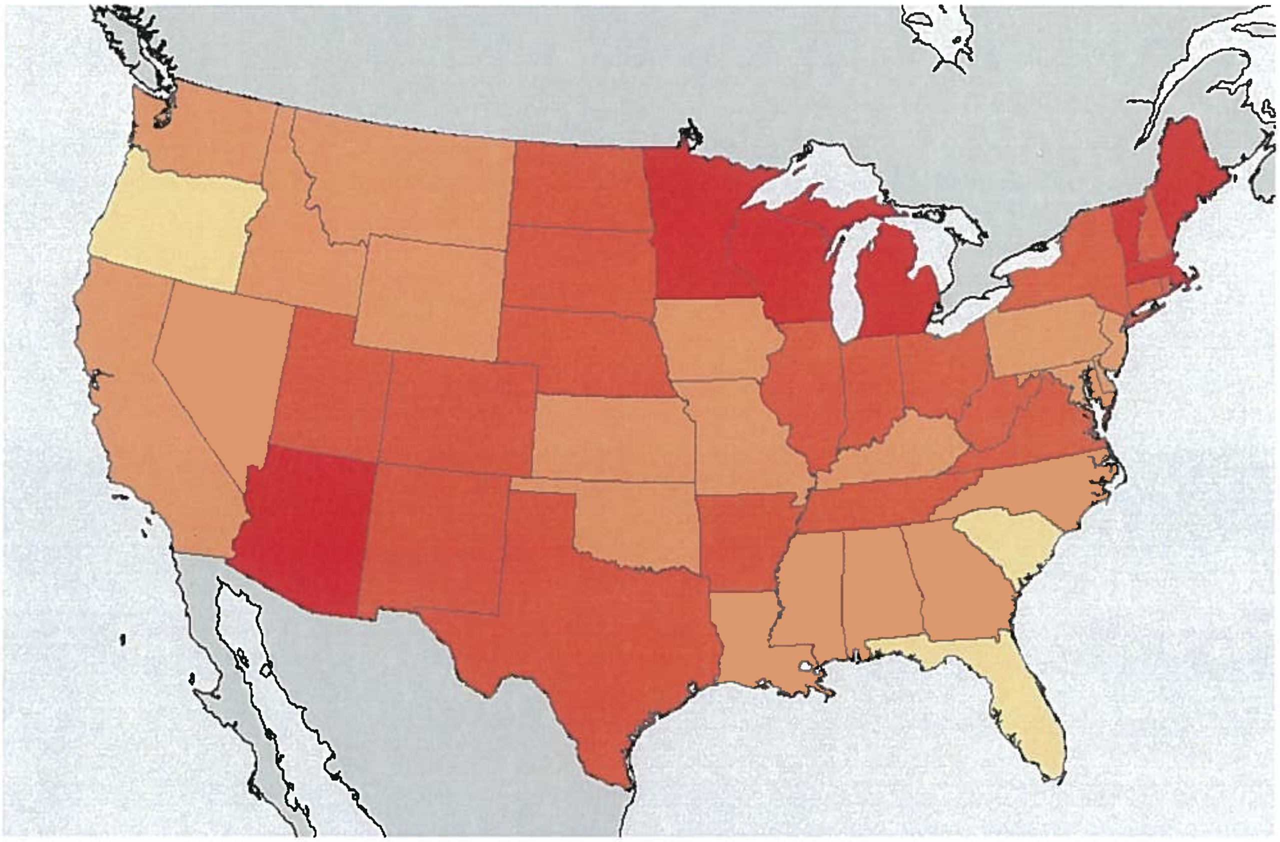


Statewide Differences Between the 1981-2010 and 1971-2000 Normals
Minimum Temperature (F)

Schedule ALD-ER1



Schedule ALD-ER1



Statewide Differences Between the 1981-2010 and 1971-2000 Normals
Minimum Temperature (F)

Contact

For general questions about Normals or help accessing the 1971 - 2000 product, please contact NCDC's User Engagement & Services Branch at 828-271-4800, option 2. For questions regarding the development of the 1981 - 2010 Normals, please contact Anthony Arguez.

Schedule ALD-ER1