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Witness: Steve Qi Hu
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Case No.: EM-96-149

ON BEHALF OF THE

MISSOURI PUBLIC SERVICE COMMISSION

UTILITY OPERATIONS DIVISION

SURREBUTTAL TESTIMONY

OF

STEVE QI HU, PH.D.

UNION ELECTRIC COMPANY

CASE NO. EM-96-149

Jefferson City, Missouri

April, 1999

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Q. Please state your name and business address.

A. My name is "Steve" Qi Hu, and my business address is 237 L.W. Chase Hall, University of Nebraska-Lincoln, Lincoln, Nebraska 68583-0728.

Q. Are you the same Steve Hu who submitted direct testimony on the need to adjust station temperatures and procedures used in correcting the St. Louis Lambert International Airport station temperature time series for the time period 1961-1997?

A. Yes, I am.

Q. What is the purpose of your surrebuttal testimony?

A. In my surrebuttal testimony, I will address the rebuttal testimony of Union Electric Company (UE) witness Mr. Allen Dutcher. Mr. Dutcher criticizes the adjustments which I made for biases in the daily mean temperatures recorded at the St. Louis Lambert International Airport station over the period 1961 through 1996.

Q. How did you identify the biases in the data?

A. I identified biases in the data series by comparison of the St. Louis Lambert International Airport station data with nearby weather stations (hereafter "reference stations") data. The biases identified from this comparison process are primarily from

three sources. One source of bias is due to sensor drifting resulting from degradation of the sensor quality during the usage; a second source of bias is due to a change in the type of sensor used; and a third source of bias is due to station location change. The location change may put the same station in a totally different environment and therefore cause inconsistencies in the station temperature series. By identifying any of these biases in station temperature series and removing them, one should expect that the temperature time series before the ASOS was in use in May 1996 to be consistent with the temperature observed by the ASOS unit after May 1996.

Q. In doing this, did you "re-write nearly four decades of weather history" for the St. Louis Lambert International Airport station, as UE's rebuttal witness Allen Dutcher alleges (lines 17-18, page 4)?

A. Absolutely not. As I said above, I was trying to identify the possible biases and did nothing with the weather history.

Q. At page 13 of Mr. Dutcher's rebuttal testimony, you were criticized for using only two stations which do not have a complete record covering the time period from 1961 to the present and therefore your results are incorrect. Is this a valid criticism?

A. No, it is not. Choosing the reference station is critical in this comparison process for identifying biases. The stations selected as the reference stations should be 1) as close to the St. Louis Lambert International Airport station as possible, and, equally importantly, 2) have as similar as possible environment to that surrounding the St. Louis Lambert International Airport station. It would be ideal to have as long a record as possible at these reference stations. However, this kind of ideal situation is rare in

weather station history. Only a very few stations in Missouri have long histories and they are not in the proximity of the St. Louis Lambert International Airport station.

The two reference stations that I selected in my comparison analysis satisfy these two criteria. The UE rebuttal testimony criticized my choice of these two stations and suggested using other stations, e.g., the St. Louis Science Center station and the Alton station in Illinois. UE actually used those stations in its analysis. It is important to point out that those stations are either a far distance from the St. Louis Lambert International Airport station or are in a very different environment from that at the St. Louis Lambert International Airport station. For example, both the St. Louis Science Center station and the Alton station are in areas with mostly grass surfaces and surrounded by developed trees. These stations will naturally measure a relatively cooler temperature for the same weather conditions than the St. Louis Lambert International Airport station would because of the differences in the surrounding environment. Trees and grassland absorb solar radiation and their evaporation and transpiration cool the environment. The dominant bare surface or paved surface at the St. Louis Lambert International Airport station absorbs and re-emits the heat and therefore makes for a hotter temperature environment. Comparison of stations in these two very different environments will undoubtedly exaggerate a warm or hot condition in the St. Louis Lambert International Airport station.

The two reference stations that I chose in my analysis are St. Charles 7SSW and St. Louis WSFO that have environmental conditions fairly close to those at the St. Louis Lambert International Airport station. Indeed, these stations do not possess a data record

over the period 1961 to the present, but because we are not re-writing the stations' weather histories there is no need for such a complete record.

The data record of these two reference stations is long enough to cover the time periods when potential biases might be introduced to the St. Louis Lambert International Airport station temperature data because of station moves and sensor upgrades in the 1970s and 1980s.

Q. At page 4 of his rebuttal testimony, Mr. Dutcher states that one of the two reference stations did not even exist until 1975. Is it true that one of the two reference stations did not exist until 1975?

A. It is true that one of the two reference stations, St. Charles 7SSW, did not exist until 1975, and only the St. Louis WSFO station was available for the time period before 1975. Had a double mass analysis prior to 1975 been necessary, this would likely have had no effect on the result because of the following:

1) Since the purpose of my analysis is to identify possible biases due to the station location change and sensor drifting, there is no need to have a complete history record for the reference station.

2) I examined the records of both the St. Louis WSFO and St. Charles 7SSW stations and compared them with the St. Louis Lambert International Airport station records and found that the variations of the temperature records at St. Louis WSFO and St. Charles 7SSW stations are consistent with each other. This consistency has been shown in the double mass analysis results presented in my direct testimony. Those results revealed in a consistent manner the biases in the temperature record from the St. Louis Lambert International Airport station. Additionally, they both indicated the same value of

the biases. This consistency shows that the quality of the data of these two reference stations is reliable for the time period of interest. Because these two reference stations were unlikely to move or change in a simultaneous manner, any bias identified from using these two reference stations should result from the St. Louis Lambert International Airport station's change or move.

3) It is perfectly acceptable in mathematics to use piece-wise analysis when limitations on function structure and data information exist. In this particular case, it becomes natural to use the piece-wise analysis because I was trying to understand the effect of individual changes at the St. Louis Lambert International Airport station that caused the biases. The overall or total bias in the data of interest can be identified only with the knowledge of the individual effects and biases.

Q. You are criticized for using erroneous data in your analysis. How do you respond to that criticism?

A. The data that I used in my analysis were from the National Climatic Data Center (NCDC). This is the same NCDC from where UE's data were requested. The data that I obtained were subjected to a quality control. In Schedule 1 in my direct testimony, I cited Reek et al.'s 1992 paper describing the quality control method applied to the data that I used in my analysis.

Q. At page 13 of Mr. Dutcher's rebuttal, you are criticized for performing your own corrections for the observation time difference between the first order and the cooperative stations data series. How do you respond to that criticism?

A. First let me explain why this correction to the cooperative station data is necessary. Cooperative stations, e.g., the St. Louis WSFO and St. Charles 7SSW

stations, have their own observation time schedules which are different among the cooperative stations themselves and from the standard midnight-to-midnight schedule that is used at first order stations, e.g., the St. Louis Lambert International Airport station. Because of this difference, the 24-hour maximum and minimum temperatures observed by a cooperative station will be different from that observed by a first order station even if they are at the same location. They measure these quantities over different 24-hour periods.

To compare the data between the cooperative and first order stations the cooperative station data must be adjusted to take into account the shift in observation schedules. Karl, et al. (Reference: Karl, T.R., 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 temperatures for the United States*; **J. Climate and Appl. Meteor**; Vol. 25, pp. 145-160.) developed a method to estimate the monthly maximum, minimum and mean temperatures for cooperative stations. The method was developed based on data collected between the 1950s and the 1970s. There have been concerns raised about the change of the climate condition in the recent decades and accordingly the changes of the correction values developed based on old data from these time periods.

Karl, et al.'s method is used at NCDC for estimating corrections to monthly maximum, minimum and mean temperatures, not for daily data. However, daily data are what I used in my analysis, not the monthly data. The reason is simple: daily data provide more information, as well as more accurate information than monthly data do for the problem of identifying possible biases due to changes at a weather station. The method I

applied uses hourly data of the first order station and regroups the hourly data into 24-hour periods that match the 24-hour observation schedule of two cooperative stations. Maximum and minimum temperatures are then identified and used as the 24-hour maximum and minimum temperatures in the comparison analysis that I performed. By using the same 24-hour data in my analysis, the results of the analysis should be accurate.

Q. At pages 6-7 of his rebuttal testimony, Mr. Dutcher said that he conducted a comparison at the Lincoln Municipal Airport, in Lincoln, NE to determine the impact of the installation of ASOS and a physical location move and found 1.9 degrees F difference between ASOS measured temperature and a conventional station at that site. Would it be appropriate to use his results in this case?

A. No. Mr. Dutcher's result from a side-by-side comparison of an ASOS and a conventional station at Lincoln Municipal Airport in Lincoln, NE is not likely to apply to this case. The actual sensor conditions at St. Louis Lambert International Airport station were not known at the time when it was decommissioned in May 1996 as well in the time period before the decommissioning. The physical condition of the station can dramatically affect the temperature measurements taken by the sensors at that station. The station replaced by ASOS in Mr. Dutcher's comparison was a fairly new unit, whereas the measuring unit at the St. Louis Lambert International Airport station may not be in a similar condition during the operation years to the one used in Mr. Dutcher's comparison. These differences in sensor/unit conditions introduce differences in observed temperatures and hence, differences in temperatures measured by the station and ASOS.

One fact that is supportive to the above notion is the finding in Dr. Thomas McKee's work of comparison of observations from 15 pairs of conventional HO-83 stations (HO-83 is the sensor model type used by weather stations before ASOS was commissioned and it is still used by cooperative stations) and ASOS in different regions in the nation. McKee and his collaborators found that: "The HO-83 has a warm bias of approximately 0.5 degrees F deduced from co-located sites and temperature comparisons with high winds," and "ASOS is cooler than the HO-83, on an average, at 15 stations by approximately 1.1 degrees F in maximum temperature and 0.8 degrees F in minimum temperature." (Schedule 1 attached hereto)

I used average temperature in my analysis. Because the average temperature is calculated from the arithmetic mean of the maximum and minimum temperatures, McKee's findings indicate that for daily mean temperature ASOS is cooler than the HO-83 by approximately 0.95 degrees F. This is, in fact, in the range of the bias I found from my analysis presented in my direct testimony of 0.75 degrees F.

Q. At pages 12-14 of Mr. Dutcher's rebuttal testimony, you are criticized for not using the double mass analysis over the data history from 1960 through the present. What is your response to this criticism?

A. This criticism is based on a misunderstanding of the key issue in this matter, which I discussed in the opening of this surrebuttal testimony. I was working on identifying potential causes to biases in the recent temperature data series *not* re-writing the station data history.

It is, in fact, a misunderstanding of the double mass analysis method when Mr. Dutcher applied it over all the data in the time period from 1960 through the present. The

double mass analysis method can help to identify changes in one of the two comparison entities of the same physical nature, e.g., air temperature as in this case. It cannot, however, tell which of the two entities has a bias. When using this method in comparison of temperatures at the St. Louis Lambert International Airport station and the other stations, Mr. Dutcher found many, and to some degree more than can be handled, slope changes in the double mass results. He then admitted in his testimony that it is difficult to identify what was causing those slope changes as they may be due to either changes at the St. Louis Lambert International Airport station or changes in the reference stations that he chose in the comparison. The purported results of Mr. Dutcher's analysis are difficult to use to help solve the existing problem.

In my analysis, I identified the suitable reference stations and focused on the periods when the St. Louis Lambert International Airport station was subjected to known changes. With a focused subject and knowing that the reference stations data were reliable for those time periods, I was able to identify the biases induced to St. Louis Lambert International Airport station temperature data due to the identified changes.

Q. In Mr. Dutcher's rebuttal testimony, he found *at least* five changes of slopes in the double mass analysis within the 1961 to 1972 time period. Why did you not include any of these changes in your analysis?

A. My evaluation is that these changes were not significant in causing biases. For example, as I showed in my direct testimony, there was a major station location change in 1985. My analysis, presented in Schedule I in my direct testimony, clearly showed that the location change in 1985 had an insignificant impact on the temperature measured by the station. In fact, it is questionable to me whether the slope changes that Mr. Dutcher

claims to have found in this earlier period could indeed be resulting from possible changes to the reference stations used in his analysis.

Q. On page 13 of Mr. Dutcher's rebuttal testimony he indicates that "[t]he ... 1972-1978 time period had an average daily minimum temperature bias that was .9 degrees F cooler than the post-ASOS period." Did you find this estimated difference to be reliable?

A. My review of Mr. Dutcher's work papers indicates that he used monthly average temperatures in his double-mass type of analysis, not daily temperatures. Monthly temperatures can be used to indicate whether or not there are any significant changes that would need further investigation. With the assistance of Mr. Dennis Patterson, a similar analysis using monthly average temperatures was performed for the entire period in question (1961 to present). Before discussing the results of that analysis, it is critical to the issue of making adjustments for bias that the double mass analysis be done using daily, not monthly, temperature observations. Therefore, I reject Mr. Dutcher's estimate as not being based on the use of proper and reliable data.

Q. What analysis from 1961 through 1997 did you perform with the assistance of Mr. Patterson?

A. The analysis involved a comparison of monthly average temperatures at the St. Louis Lambert International Airport station to the monthly average temperatures of weather stations within the St. Louis and surrounding area the average monthly temperatures of which are included in the United States Historical Climatology Network (USHCN). The USHCN includes monthly average temperatures from cooperative stations that have been adjusted for: 1) time of observation so that the data are consistent

with a midnight-to-midnight observation schedule; and 2) known observation bias, station moves and contain estimated values for missing/outlier data. (The USHSN data is available at http://www.ncdc.noaa.gov/ol/climate/research/ushcn/ushcn.html)

Mr. Patterson selected seven weather stations from the USHCN group for comparison to the St. Louis Lambert International Airport station. The reasons for selecting these seven stations are discussed in his surrebuttal testimony. The monthly average temperatures from these seven stations were averaged, and compared to the monthly average temperatures from the St. Louis Lambert International Airport station.

Q. How was this analysis of monthly average temperatures used in your investigation of temperature bias for the period from 1961 through 1997?

A. The analysis involved a comparison to the unadjusted average monthly temperatures at the St. Louis Lambert International Airport station. A double-mass comparison was used by Mr. Patterson to illustrate the changes that had occurred at the St. Louis Lambert International Airport station since 1961. In addition, a comparison was made of the same set of USHCN stations to average monthly temperatures at the St. Louis Lambert International Airport station that included my corrections for the biases that were estimated by applying double mass analysis to daily observations on mean temperatures. The purpose of this comparison was as a check to the corrections.

Q. What were the results of the analysis of the double-mass comparison on the unadjusted monthly average temperature data from the St. Louis Lambert International Airport station?

A. The station history of the St. Louis Lambert International Airport station disclosed that the station location changed four times during the 38-year period of 1961

through 1997. These changes occurred January 1978, January 1985, February 1988 and June 1996. The double-mass comparison on average monthly temperatures did not indicate any slope changes prior to the January 1978 station location change. In addition, because there were no reported changes of sensors or locations over this period, it is my opinion that there is no reason to do a more detailed double mass analysis for periods prior to January 1978.

Q. What were the results of the analysis of the double-mass comparison on the adjusted monthly average temperature data from the St. Louis Lambert International Airport station?

A. After doing a double mass analysis for January 1978, January 1985 and February 1988, I determined that corrections were needed for January 1978 and February 1988, but not for January 1985. The estimated correction for January 1978 was 0.3 degrees F and for February 1988 was 0.45 degrees F. Thus, the total correction prior to the installation of ASOS at the St. Louis Lambert International Airport station in May of 1996 is for 0.75 degrees F. The double-mass comparison done on monthly average temperatures indicated that the bias corrections had resolved the problem of consistency over the entire period from 1961 through 1997.

Q. Does your 0.75 degrees F adjustment represent only an adjustment for location change in May 1996 and exclude an adjustment for ASOS as inferred by Mr. Dutcher's testimony at page 15?

A. No, it would be incorrect to draw that conclusion. My 0.75 degrees F adjustment is a cumulative effect of adjusting readings after January 1979 to be consistent with readings prior to that date, and adjusting readings after February 1988 to

be consistent with readings prior to that date. Application of the two adjustments makes the readings after February 1988 consistent with readings prior to that date. It appears at this time that the 0.75 degrees F correction to the data being read just prior to the May 1996 ASOS change is likely to have included most, if not all of the correction needed to make readings after May 1996 consistent with that data. Again, this correction value is in alignment with McKee's 0.95 degrees F average adjustment for ASOS.

Q. Is it your testimony that, after your corrections, a residual bias for the May 1996 change to ASOS does not exist?

A. Until data is developed to do a proper double mass analysis on daily mean temperatures for the May 1996 ASOS change, I cannot be certain that some residual bias does not exist. What I am certain of is that the estimate made by UE of a 2 degrees F bias for location and sensor changes is not reliable. This is because the data period used for the double mass analysis was too short (4 months) and the reference stations used by UE were not sufficiently comparable to the St. Louis Lambert International Airport station. To do a proper double-mass analysis requires at least one year of daily mean temperatures prior to and after the change in location or sensors. If available, three years of data on either side of a change is preferable.

Q. Given data availability at the time of your study, do you still believe that the biases which you identified in your direct testimony are the best that can be determined for correcting the total bias in the St. Louis Lambert International Airport station temperature series due to its location changes and sensor changes from 1961 through 1997?

A. Yes, I do. The biases identified in my analysis are due to both the location change and sensor changes at the St. Louis Lambert International Airport station. As I discussed at the beginning of this testimony, these are the biases in the temperature series before the ASOS was in commission, and the adjustments proposed in my direct testimony are the best that could have been made at the time. At this time I would recommend that a double mass analysis be done using: 1) at least one year of daily mean temperatures prior to and after the May 1996 change; and 2) properly determined reference stations. The purpose of the study would be to determine whether or not there is any residual bias from the May 1996 change.

Q. Do you expect there to be much residual bias?

In the study performed by McKee and associates, on 15 sites located throughout the United States, it was determined that:

1) ASOS provides more accurate temperature measurement of the environment (in the sense that "no temperature bias exists between ASOS and a calibrated field standard");

2) The HO-83 sensors had a "warm bias of approximately 0.5 degrees F deduced from co-located sites;"

3) "Local effects due to changes in instrument location are key;"

4) ASOS is cooler than HO-83, on average at the 15 locations by "approximately 1.1 degrees F in maximum temperature and 0.8 degrees F in minimum temperature."

In terms of average temperature, the average difference over the 15 sites is 0.95 degrees F and includes both the HO-83 sensor bias and difference due to location changes. Clearly my estimate of a 0.75 degrees F change is consistent with the 0.95

degrees F change found by McKee, but UE's estimate of a 2 degrees F change is not. Thus, if there is any residual bias, I expect it to be less than 0.5 degrees F.

Q. Does this complete your surrebuttal testimony?

A. Yes, it does, unless there is a need for supplemental surrebuttal. After Dennis Patterson, Michael S. Proctor and I reviewed UE's rebuttal testimony on weather, data requests were written and submitted to the UE. The Staff has not yet received responses. Once UE responds, there may be a need to supplement my surrebuttal testimony.

Climate Data Continuity Project Ends

Update as of 10/95

Two sets of stations are included in the Climate Data Continuity Project (CDCP). The CDCP studies temperature and humidity comparisons of the ASOS hygrothermometer and the HO-83. One set, listed in the table below, will be used to compare daily maximum and minimum, six-hourly and dewpoint temperatures from June 1, 1994 through August 31, 1995.

Climate Data Continuity Study Comparison Sites

Daily Maximum and Minimum Temperatures

Number	Site ID	Station Name
1.	AMA	Amarillo, TX
2.	AST	Astoria, OR
3.	BRO	Brownsville, TX
4.	BTR	Baton Rouge, LA
5.	COS	Colorado Springs, CO
6.	DDC	Dodge City, KS
7.	GLD	Goodland, KS
8.	GRI	Grand Island, NE
9.	ICT	Wichita, KS
10.	LNK	Lincoln, NE
11.	OKC	Oklahoma City, OK
12.	PWM*	Portland, ME
13.	SYR	Syracuse, NY
14.	TOP	Topeka, KS
15.	TUL	Tulsa, OK

* Station commissioned in August, 1994

The second set will include additional sites broadly distributed across the U.S. Results from the first set of 15 sites are now available for the first 12-month period—June 1, 1994, through May 31, 1995. Preliminary findings include the following:

- No temperature bias exists between ASOS and a calibrated field standard.
- The HO-83 has a warm bias of approximately 0.5 degrees F deduced from co-located sites and temperature comparisons with high winds.
- The HO-83 is affected by solar heating deduced from co-located sites.
- Local effects due to changes in instrument location are key.
- ASOS is cooler than the HO-83, on average, at 15 locations by approximately 1.1 degrees F in maximum temperature and 0.8 degrees F in minimum temperature.
- ASOS relative humidities are 0% to 3% lower than the HO-83 due to cooler air temperature and similar dewpoint temperature.

The CDCP study is managed in the NWS by Andy Horvitz and is conducted by Thomas McKee, Nolan Doesken, and John Kleist at Colorado State University and by Norman Canfield at the University of Maryland. For more information, contact Thomas McKee at 303/491-8545.

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