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P1.33 THE COLUMBIA (MO) HEAT ISLAND EXPERIMENT OR "COHIX"

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1. INTRODUCTION

The effect of urban environments on local temperature and precipitation distributions have been examined in the past (e.g., Changnon, 1981; Segal and Arritt, 1992; Melhuish and Pedder, 1998). These studies have usually focused on cities that have very large populations. The "heat-island effect" produced by such cities can have profound impact, sometimes adversely, on the well-being of its residents (e.g., Karl and Knight, 1997). Studies have also examined the impact of agricultural practices on local environments (e.g., Raymond et al. 1994). The study of regional heat islands is a topic that has enjoyed renewed interest lately, especially within the context of global climate change (e.g., Gaffen and Ross, 1998; NAS, 2000; IPCC, 2001). Additionally, there are many examples of studies that explore the impact on local atmospheric phenomena by the unique distribution of regional geography (e.g., Colle and Mass, 1996; Doeskin and Weaver, 2000).

There is published work (e.g., Melhuish and Pedder, 1998; Pinho and Manso-Orgaz, 2000) that demonstrating that medium-sized and small urban areas may also be responsible for heat-island effects, although these would not be expected to be as pronounced as those of larger cities. There is also anecdotal evidence available to suggest that Columbia, MO, is responsible for a detectable heat-island effect. Columbia would be at the smaller end of the spectrum of urbanized areas and is composed of a downtown area and the University of Missouri campus. Intensive residential and retail development flank these two core regions.

There are two main objectives for the COlumbia Heat Island eXperiment (COHIX). The first was to determine the extent of the heat-island effect produced by Columbia, MO. Thermometers and rain gauges were deployed in and around the city to measure this effect and the variation in the strength of the heat-island with respect to seasonal variations. Additionally, precipitation was measured in order to determine whether there is an impact on local precipitation fields. The second was to provide undergraduate students in the Atmospheric Sciences Program at the University of Missouri with an opportunity to participate in the process of scientific discovery and research and to expose them to the principles of meteorological instrumentation and research. The experiment then served as a starting point for developing an experimentation/instrumentation course in the program.

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2. DATA AND METHODOLOGY

2.1 Data

Participants in the study provided the temperature and precipitation data. The temperatures were provided with a Radio Shack® Indoor/Outdoor Maximum-Minimum thermometer (Item #63 - 1014). This instrument resided indoors and included a 10 ft probe, which can be deployed outdoors. Participants in this study used a standard raised-edge bucket rain gauge. The Missouri Climate Center, the Columbia Regional Airport, two cooperative stations, and two automated weather stations in the Columbia area provided additional temperature and precipitation data. The Columbia Regional Airport (COU) is located approximately 7 miles south-southeast of the city.

2.2 Methodology

For the purposes of this study, Columbia MO was considered to be a small urban area. Here, we define a small city as one that has a population of more than 75,000 (but less than 200,000) residents and covers an area of roughly 25 miles^2. Excluding the transient student population, Columbia, MO has roughly 80,000 residents. This number is greater than 120,000 if the built-up areas surrounding the city limits are included, 140,000 when the student population is in residence. This is smaller than the urban area studied by Meluish and Pedder (1998), but considerably larger than that in the Pinho and Manso-Orgaz (2000) study.

Faculty, staff, and students (22 in all) in the Atmospheric Sciences Program were invited to participate in this study. Enlisting volunteer participants to measure local variations in climatic parameters has produced successful results in other locations (e.g., Doeskin and Weaver, 2000). These studies can also be used successfully as an educational vehicle for the university and local community (e.g., Doeskin, 2002).

Those volunteers who deployed instruments were ultimately selected on the basis of their location within the Columbia region, and their ability to accommodate proper deployment of the instrument. Students were given explicit instructions on how to deploy the instruments. Also included in the site selection was an attempt to concentrate some instruments in the south-central part of Columbia, which has less vegetation in comparison to other regions of the city.

To determine if the heat island effect was detectable given that each Radio Shack® instrument may not read the same value despite being subject to the same conditions, the instruments were compared to a standard instrument. The standard deviation among the set thermometers was calculated. The range in the set was 1.0 ^oF (1.3 ^oF) at room temperature (in an ice bath), and the standard deviation was 0.35 ^oF in the set for both trials. Thus, any heat-island effect would have to be significantly larger than the standard deviation after correcting the data to the standard. Also, a Radio-Shack® instrument was tested against an electronic thermometer used by the automated weather stations, and there was remarkable agreement between the two instruments. Rigorous statistical testing was not performed since the small sample sizes preclude producing statistically robust results.

The participants collected the maximum and minimum temperature once daily at 0300 UTC (10:00 pm LDT - or 0400 UTC after the switch back to standard time). This data was recorded and then averaged, with the goal of first determining if the heat island existed in the mean data field. The strength of the heat island effect is defined as:

$$HI = T_{ic} - T_{os} \qquad (1)$$

where T_{ic} is the mean temperature recorded by the "inner city" units and T_{os} is the mean temperature recorded by the instruments more than 1 mile outside the city limits. The mean temperatures of the instruments between these regions are compared with the variables above in order to examine the distribution of the heat island effect.

3. RESULTS USING MONTHLY MEANS

The analysis of the COHIX project data started with July 2000. Table 1 shows the results after examining the data from 1 July 2000 to 30 June 2001. Table 2 shows the observed mean monthly temperatures and precipitation values and their departures from the 1961 - 1990 means at COU.

3.1 July and August 2000 results

The monthly mean temperature for July (August) was below (above) normal (Table 2). The precipitation amounts for July were close to normal for the month (Table 2), while August experienced several heavy rainfalls that resulted in a total rainfall amount of 9.11 inches (a new all-time August record for COU). While this implies cloudier-than-normal conditions prevailing for August, many of these rainfalls were associated with overnight thunderstorms in the first 21 days. Then, the latter half of the month experienced sunny (mostly clear), hot, and dry days.

There was a difference of 2.7 and 2.8 ^oF between the mean of the inner city and outside city stations (HI) for the maximum (Tmax) and minimum (Tmin) temperatures for July (Table 1), respectively. All the inner city stations recorded monthly mean temperatures that were higher than the highest means recorded outside the city for Tmax or Tmin. The largest difference between the warmest individual inner city station and the coolest outer city station (HI_{max}) was 3.3 ^oF and 4.7 ^oF for Tmax and Tmin, respectively (Table 1). During August, HI was stronger for Tmax than that found for July (3.4 ^oF), while Tmin produced a weaker signal (1.9 ^oF). The August HI_{max} values were 4.8 ^oF (3.3 ^oF) for Tmax (Tmin).

The precipitation variance was defined as the ratio of the highest monthly value divided by the lowest in the region of study. For July, that value was 2.13, or the highest value was more than twice the value of the lowest amount (the maximum exceeded the minimum by 113%). During August, the precipitation amounts across the Columbia, MO, region were more uniformly distributed than July values, and the variation was 16% across the region, which was remarkably low considering the high precipitation amounts. This also reflects the fact that for the first part of the month a stationary front lay across north central Missouri. Thus, even in the summertime (July and August), the precipitation distributions across the mid-Missouri region seemed to be strongly influenced by larger-scale features and there is little evidence of any urban-scale influence on the precipitation field.

Table 1. The mean maximum and minimum temperatures (^oF) occuring in various regions in the Columbia, MO area for July 2000 - June 2001. Tb represents the mean temperature of instruments between the "inner city" and the outside city region. Ts are the temperatures of instruments inside the city south of the University of Missouri campus.

Month Mx/Mn	Tic	Tos	Tb	Ts	HI	HI_{max}
Jul 00	88.1/68.8	85.4/66.0	85.7/68.6	88.0/68.4	2.7/2.8	3.3/4.7
Aug 00	92.2/70.9	88.8/69.0	88.8/70.8	91.6/70.3	3.4/1.9	4.8/3.3
Sep 00	81.8/58.0	80.5/54.9	81.0/56.0	81.4/55.9	0.7/3.1	3.6/6.0
Oct 00	72.0/51.5	71.1/49.1	71.2/50.3	71.5/50.1	0.9/2.4	3.1/3.5
Nov 00	50.3/33.4	48.5/29.9	49.6/32.3	50.3/32.2	1.8/3.5	2.3/5.5
Dec 00	31.5/14.9	29.4/10.5	30.4/13.2	30.7/12.9	2.1/4.4	5.6/6.4
Jan 01	39.5/24.0	38.4/21.3	38.7/22.0	39.8/23.2	1.1/2.7	3.4/3.3
Feb 01	46.2/26.2	44.1/23.2	45.4/24.7	47.3/25.1	2.1/3.0	3.4/3.1
Mar 01	52.6/32.0	51.4/29.2	53.1/30.9	54.4/31.2	1.2/2.8	3.0/3.6
Apr 01	74.2/52.9	72.8/50.1	74.6/50.0	75.1/48.7	1.4/2.8	4.0/2.4
May 01	77.8/58.2	75.8/55.5	76.9/57.0	77.1/56.7	2.0/2.7	3.8/4.1
Jun 01	85.4/64.3	81.6/61.5	83.6/63.0	85.3/62.9	3.8/2.8	6.8/5.0

3.2 September - November 2000 results

This season was cooler and drier than normal, with the exception of October, a month that was warmer than normal for temperature and fairly close to the climatological average for precipitation (Table 2). November was quite cold across the state (8th coldest on record for COU) as large-scale troughing prevailed over the mid-western US.

The HI values for this season were smaller for Tmax than for Tmin across all months (Table 1) than in the previous season. For September and October, Tmax were slightly less than 1 ^oF warmer in the city of Columbia as compared to the outside, while Tmin were nearly 2.5 ^oF warmer in the city. During November, however, HI was comparable to that of August despite cloudier conditions, with Tmins showing the stronger signal. An examination of HI_{max} (Table 1) values reveal that these are comparable to those in the warmer months. This suggests that the coverage of the heat island effect may have shrunk in area during the cooler months.

The precipitation distributions for September and October (not shown) both show a maximum over the southeastern part of the urban area, while the November precipitation in Columbia, MO does not show a maximum that is discernable above the synoptic distribution for Missouri precipitation. During both September and October, the precipitation amounts and distribution were similar to that of the synoptic-scale distribution, except for the distinct maximum described above. The September maximum was smaller in scale but greater than the background values measured by the volunteer network than was the October maximum, and this is made more clear by examining the variability in precipitation amounts. Precipitation amounts were more variable across the Columbia region during September (93%) versus those of October (27%) or November (23%).

Table 2. Monthly mean temperatures (^{o}F) and precipitation (inches) and their departures from normal (1961-1990) for the 1 July 2000 to 30 June 2001 period for the Columbia Regional Airport (COU). The middle column contains climatological values only.

Month	Temp / Dprtr	Mean Max. / Min.	Pcpn / Dprtr
Jul 00	75.8 / -1.6	88.6 / 66.2	4.09 / +0.42
Aug 00	78.5 / +3.3	86.7 / 63.8	9.11 / +5.83
Sep 00	67.8 / -0.1	78.8 / 57.0	1.75 / -2.11
Oct 00	59.9 / +3.4	67.6 / 45.5	3.60 / +0.38
Nov 00	38.7 / -5.4	53.6 / 34.6	1.74 / -1.19
Dec 00	19.8 / -12.0	40.3 / 23.2	0.87 / -1.60
Jan 01	29.3 / +1.8	36.6 / 18.5	2.69 / +1.24
Feb 01	33.2 / +1.1	41.4 / 22.8	4.41 / +2.57
Mar 01	39.9 / -3.2	53.3 / 33.0	1.09 / -2.08
Apr 01	61.3 / +6.6	65.7 / 43.7	3.39 / -0.44
May 01	65.1 / +1.5	74.1 / 53.1	6.37 / +1.36
Jun 01	71.2 / -0.8	82.8 / 61.2	5.24 / +0.92

3.3 December 2000 - February 2001 results

December 2000 was the second coldest December (12^{o} F less than the 30 year mean - see Tables 1 and 2) on record for the Columbia, Missouri, region (Table 2) as a large-scale trough was responsible for very cold weather throughout the entire midwest. The most pertinent feature for the discussion below was the persistent snow cover that was established in the Columbia region around 12 December and persisted through the rest of the month. January and February were characterized by a more zonal flow regime over the midwest and the result was slightly warmer than normal temperatures throughout Missouri, including Columbia (Table 2).

The HI values for December were as large as those for the summer months (Table 1), but like the fall season, the Columbia region affected was smaller in area but effect was greater for Tmin. December also showed the largest HI_{max} values. This may be related to the persistent snow cover that remained in place for much of the month fundamentally altering characteristics of the underlying surface and, thus, the radiation balance at the earth's surface. During January and February, the strength (Table 1) of the heat island effect was more typical of the values for the fall season.

In spite of the low precipitation totals for December, the precipitation amounts varied from a maximum of 1.23 inches in Columbia to a minimum of 0.51 inches outside the city, which represents a variance of 141%. Amounts across the city were fairly uniform throughout the winter season and the amounts were consistent with the statewide distribution of precipitation. The precipitation amounts for January and February were less variable across the city, 38% and 22% for January and February, respectively. However, a small scale, but discernable maximum in the precipitation field can be found over the southeast part of Columbia, Missouri.

3.4 March - June 2001 results

A northwesterly upper-air pattern persisted over Missouri for most of March resulting in below normal temperatures for Columbia (Table 2). This flow regime deprived storms of moisture from the Gulf of Mexico as they crossed the state. Thus, precipitation values were below normal for most of Missouri. For April and the first part of May, ridging persisted over the midwestern states, resulting in warmer than normal conditions for Columbia (Table 2) despite the fact that a strong trough and cold conditions persisted over the midwest during the latter part of May and into June. April precipitation amounts were close to normal, but during May and June COU was wetter than normal. During much of June, however, daytime conditions were mostly sunny with intermittent bouts of rain associated with the passage of synoptic systems.

The strength of the heat island for the spring months was similar to that of the other months when examining HI or HI_{max} (Table 1). However, there was a difference in the area coverage of the heat island as the effect expanded during these months and by May and June the area coverage was similar to that of July and August of 2000 (not shown). Also, the strength of the heat island effect was quite large during June, and the effect was larger for the maximum temperatures than for the minimum temperatures. Table 1 supports the assertion of an expanded heat island when comparing the values of Tb (temperatures at stations inside the city limits but not in the inner domain) to those of the inner (Tic) and outer (Tos) city stations. During the latter part of the fall and throughout the winter months, the values of Tb were closer to those of Tos. Then during the spring season, Tb values were closer to Tic as they were during July and August of 2000.

Examining the precipitation distributions across the Columbia region reveals that during the spring months and June the precipitation amounts were not as variable as they were during other months. The precipitation variability in the region as defined by this study ranged from 54% in March to 32% in April. The precipitation distributions were also similar to that of the synoptic variations, and the precipitation maximum found previously was found only during April.

4. SUMMARY, DISCUSSION, CONCLUSIONS

The heat island effect has been studied extensively for larger cities, but there are comparatively few studies examining this effect for smaller urban areas. In this study, 20 instruments were bought and 17 were distributed throughout the Columbia, MO, region to examine the impact of the city and the University of Missouri campus on the surface temperature fields. Daily data was gathered from 1 July 2000 to 30 June 2001. This experiment provided University of Missouri undergraduate students with an opportunity to participate in meteorological research. Students helped to gather the data, check the data for quality, and process it. Some students also participated in lecture sessions, as this experiment served as the blueprint for developing an instrumentation and experimentation course in the atmospheric science program at the University of Missouri.

Examining the HI data revealed that there was a discernable urban influence in the local temperature fields on the order of 2 - 3 ^{o}F. This difference grows to 3 - 6 ^{o}F when comparing the HI_{max} values. These values are consistent with those found by Pinho and Manso - Orgaz (2000) for a smaller city. Thus, the investigators are confident that their result is robust even though no rigorous statistical testing was performed due to the small sample size. It should also be noted that the heat island effect found here is larger than the spread in the instrument sample, the standard deviation of the sample, and even the precision of the instruments used (+/- 1^{o} C or 1.8 ^{o}F for the Radio-Shack® instrument).

That the heat island effect is not of the magnitude expected for a city of Columbia's size may be partially due to the fact that Columbia has made an effort to increase the amount of green-space within city limits over the last 15 years. The assertion that green-space can reduce the heat island effect is supported by Table 1 when comparing the values of Ts (stations in the southern part of the city where there has been more intensive development and decreasing green-space) to those of Tic, Tos, and Tb. The values of Ts are more similar to Tic than those of Tb or Tos. However, another possible reason for the results found here may be that no instruments were deployed in the center of town where there are more buildings and more concrete and asphalt covered surfaces. No instruments were deployed in this area since proper instrument deployment, data collection, and instrument integrity could not be guaranteed.

The heat island itself does vary with the seasons as is shown by Table 1. The heat island effect does expand in area extent during the warmer months and contracts during the colder months. The HI values are similar for all months whether the means of all the inner city and stations outside the city are used, or the warmest (coldest) station from the former (latter) group are compared. It also appears that the heat island effect is stronger in the maximum (minimum) temperatures during the summer (winter) months. Finally, December 2000 stands out as a month in which the heat island effect was strongest. This may be due to the fact that this month was the second coldest December in the history of Columbia, and was associated with an unusually persistent snow cover during that month. The persistent snow cover would fundamentally alter the regional surface radiation balance as snow cover is well known to be a strong reflector (emitter) of shortwave (longwave radiation). Also, snow cover in the regions outside the city stay fresher for a longer period of time, while snow is removed from large portions of Columbia's surface area. What snow remains in Columbia becomes dirtier more quickly since the city maintenance department liberally spreads black cinders on the roads to improve vehicle traction on snow covered roads and absorb more sunlight.

Examining the precipitation fields demonstrated that there was no persistent feature present that could be attributed to the urban area specifically and which stood out from the synoptic-scale precipitation distribution. A maximum was present in the monthly precipitation totals during six of the 12 months. However, more study is being performed since these results do not preclude the possibility that other regional features (e.g., the Ozark Mountains or other topography) may be influential in local precipitation distributions.

5. REFERENCES

Changnon, S.A., 1981: *METROMEX: A review and summary*, *Meteor. Monogr.* No. 40, Amer. Meteor. Soc., 181 pp.

Colle, B., and C. Mass, 1996: An observational and modeling study of the interaction of low-level southwesterly flow with the Olympic Mountains during COAST IOP4. *Mon. Wea. Rev.*, **124**, 2152 - 2175.

Doeskin, N. J., and J.K. Weaver, 2000: Microscale rainfall variations as measured by a local volunteer network. Preprints of the 12th conference on Applied Climatology, 8 - 11 May, 2000, Asheville, NC.

Doeskin, N.J., 2002: The educational opportunities from the Community Collaborative Rain and Hail Study (CoCo RAHS). Preprints of the 11th Symposium on Education, 82nd Annual Meeting of the American Meteorological Society, 13 - 17 January, Orlando, Florida.

Gaffen, D., and R. Ross, 1998: Increased summer-time heat stress in the U.S., *Nature*, **396**, 529 - 530.

Guinan, P., 2000: *August 2000 weather and its impacts on Missouri's agriculture.* A report issued for University of Missouri Extension / Commercial Agriculture. (http://www.mcc.missouri.edu/aggwx.html)

Houghton, J.T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, D. Xiaosu, K. Maskell, C. A. Johnson, 2001: *Climate change 2000: Climate Change: The Scientific Basis. The contribution of working group I to the Inter-governmental Panel on Climate Change.* Cambridge University Press, 896 pp. (Abbr. as IPCC, 2001 in the text)

Karl, T.R., and R.W. Knight, 1997: The 1995 Chicago heat wave: How likely is a recurrence? *Bull. Amer. Meteor. Soc.*, **78**, 1107 - 1120.

Melhuish, E., and M. Pedder, 1998: Observing an urban heat island by bicycle. *Weather*, **53**, 121 - 128.

NAS, 2000: *Climate Change Impacts on the United States: The potential consequences of Climate Variability and Change, A report of the National Assessment Synthesis Team, 2000.* U.S. Global Change Research Program.

Pinho, O.S., and M.D. Manso-Orgaz, 2000: The urban heat island in a small city in coastal Portugal. *Int. J. Biomet.*, **44**, 198 - 203.

Raymond, W.H., R.M. Rabin, and G.S. Wade, 1994: Evidence of an Agricultural Heat Island in the Lower Mississippi River Floodplain. *Bull. Amer. Meteor. Soc.*, **75**, 1019 - 1026.

Segal, M., and R.W. Arritt, 1992: Nonclassical mesoscale circulations caused by surface sensible heat flux gradients. *Bull. Amer. Meteor. Soc.*, **73**, 1593 - 1604.