5.3

# DETECTING WARMING TRENDS IN THE U.S. MIDWEST USING A SYNTOPTIC CLIMATOLOGICAL APPROACH

Vanos, JK[1*]., Kalkstein, LK[1]., Perera, EM[2]., Sanford, T[2]., White-Newson, JL[2].
[1]Applied Climatologists In., Marco Island, FL
[2] Union of Concerned Scientists, Washington, DC

## 1. Introduction

In the year of 2012, over 34,000 high temperature records were broken at stations across the contiguous US. Although the summer of 2012 was overall not as hot as 2011, the full year of was deemed to be the hottest on record. In past years, the Midwest has been hit hard with many heat-related tragedies, such as in St. Louis and Kansas City, MO (July 1980); Milwaukee (1980); and Chicago (July 1995). Such tragedies could become more common as the planet warms, rather than once-per-decade events. Hence, more heat events akin to the 2003 European heat wave (killing ~70,000 people (Robine et al. 2008)) are possible. Climate models project that some regions will see more intense, more frequent, and longer-lasting extreme heat events in the second half of this century (O'Neill and Ebi 2009; Meehl and Tebaldi 2004).

From 1999 to 2003, a total of 3,442 deaths resulting from exposure to extreme heat were reported (CDC 2006a). This is probably an underestimate, as our previous research has shown that approximately 1,500 heat-related deaths occur in the U.S. during an average summer (Kalkstein, 2005). High temperatures can lead to dehydration, heat exhaustion, deadly heatstroke, kidney problems, lethargy, and poor work and athletic performance (Vanos et al. 2010; Epstein and Moran 2006). Very hot weather can also aggravate existing medical conditions, such as diabetes, respiratory disease, kidney disease, and heart disease (Basu 2009; Mastrangelo et al. 2007; Semenza et al. 1999). Urban residents, the elderly, children, outdoor workers, and people with impaired health and limited mobility are particularly susceptible to heat-related illness and death (Basu 2009; O'Neill and Ebi 2009; CDC 2008). Air pollutants, such as ozone and particulate matter, may also work in concert with heat, exacerbating its health effects (Basu 2009).

The goal of the study was to investigate whether the number of dangerously hot summer days – as well as cool, dry summer days – has changed in five large Midwestern cities, and five smaller cities, over the past six decades. We focused on the Midwest because it has numerous major population centers, and is projected to face more heat waves as the climate warms (O'Neill and Ebi 2009; Meehl and Tebaldi 2004). The report *("Heat in the Heartland: 60 Years of Warming in the Midwest*", UCS, 2012) presented the results of our original research to inform efforts to cope with the health risks of future climate change.

*Corresponding Author Address: Jennifer K. Vanos, Applied Climatologists, Inc. Marco Island, FL. 34145-5714; email: **vanosj@alumni.uoguelph.ca**

## 2. Methods

Weather types were categorized using Spatial Synoptic Classification (SSC; See Sheridan 2002, Greene et al. 2011). Surface weather observations from local airports of cloud cover, moisture, air temperature, air pressure, wind velocity, and air mass duration are used for classification. Analysis was completed for the summer season (JJA) over long-term periods up to 2010 (56-year average). We focused on three types of air mass: hot and humid (moist tropical, MT), an extreme subset of MT (moist tropical+, MT+), hot and dry (dry tropical, DT), and cool and dry (dry polar, DP). The DT and MT+ air masses are most important to human health, as they are associated with an increased risk of heat-related deaths (Sheridan and Kalkstein 2004).

The time series of the occurrence of each weather type and temperature characteristics within each air mass was constructed using standard ordinary least squares (OLS) regression. The changing weather types were evaluated based on the slope of the linear regression line, which represents the relative change in number of air masses in the given season per year. We analyzed data for 5 large cities as follows, with corresponding smaller cities in parentheses: *Chicago, IL (Peoria, IL), Cincinnati, OH (Lexington, KT), Detroit, MI (Toledo, OH), Minneapolis, MN (Rochester, MN), and St. Louis, MO (Columbia, MO).* The changes in characteristics of air and dewpoint temperatures were examined based on average 3AM and 3PM values within the three examined air masses.

The smaller cities were chosen in relatively close proximity to the large cities in order to investigate potential urban heat island (UHI) effects on our trends, as the smaller cities would be less susceptible to those effects. The same weather type usually affects both the large city and its smaller counterpart due to the macroscale dimensions of a weather type. The airport locations at the smaller cities were in relatively rural areas at least 10 miles from the city center. Research suggests that temperatures drop off dramatically as you travel 10 miles or more beyond a city's borders. (Urban Heat Islands 2012; Dixon and Mote 2003). We reasoned that if both the small and large cities in each pair experienced a similar warming trend, that trend is unlikely to be due primarily to a UHI effect. When both urban centers and more rural locations were found to have experienced similar warming trends, we could determine that the temperature trends in the Midwest cities are not likely due to urbanization effects alone.

Last, we determined whether there were temporal trends in three-consecutive day runs of the oppressive air masses, since long strings of days within such air masses have been shown to increase heat-related mortality dramatically. We evaluated all trends based on slope and statistical significance ($p<0.05$).

## 3. Results and Discussion

The overall quantitative results are displayed in Table 1. General trends display hot humid days (MT, MT+) to be increasing the most rapidly in frequency (commonly found to be significant at $p<0.05$), with hot dry days (DT) also increasing, yet to a lesser extent. The coolest weather type of DP was found to be decreasing in all locations. Cincinnati, Detroit, and St. Louis saw significant increases in the number of MT+ (Figure 1) days each summer, even though these extreme air masses remain uncommon. Overall trends suggest a shift from drier to more humid air masses in the smaller cities – similar to what was found in the large cities.

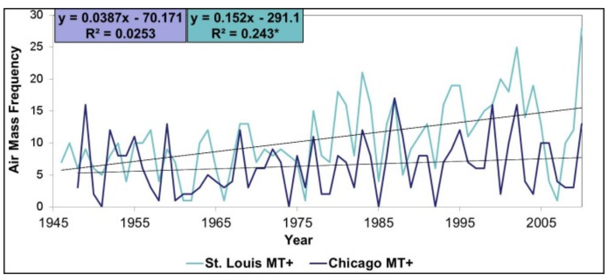


**Figure 1:** Frequency trends of the moist tropical+ (MT+) for St. Louis and Chicago. Trends indicate 10 and 2.4 more summertime MT+ days present in the respective cities today than 60 years ago.

Overnight (3AM) temperatures showed much stronger trends than afternoon (3PM) temperatures. All weather types are shown to be increasing in overnight (3AM) air and dewpoint temperatures, as well as in daytime (3PM) characteristics, yet to a lesser extent. Hence, the hot air masses have become hotter and more humid during the nighttime hours. In most large cities, afternoon temperatures associated with a given type of air mass did not increase greatly over time, and some cooled slightly. The only exception occurred in Cincinnati, where temperatures of all these air masses changed little, in both the afternoon and overnight.

This can be addressed by the fact that when a cooler air mass (e.g., moist moderate) warms and crosses the threshold into the moist tropical category, the temperature values will be at the lower end of the range to be deemed MT; hence, this would decrease the overall temperature averages within the MT air mass. This aids in explaining some non-intuitive trends where the frequencies of hot air masses were increasing, yet temperatures within these were not increasing to the same extent. Three-day consecutive analysis of the hottest weather types in sequence (DT and MT+) display that there is a greater prevalence of such heat waves in the last 60 years in all locations (See Table 1).

The results from the minor cities generally mirror the overall trends of the larger cities; hence, large scale warming seems most responsible rather than an UHI effect. Results of overnight air temperatures in the DP air mass for the two minor cities of Peoria and Columbia are depicted in Figure 2, displaying significantly increasing temperatures. As in the larger cities, nighttime air masses in the small cities have generally become hotter over time. Overall, the very hot and humid MT+, the hot and dry DT, and the cool and dry DP air masses in the small cities warmed notably in the nighttime, but not in the afternoon.

If the moisture content of these DT air masses increases, some may cross the threshold into the MT category. This can occur if warmer air, which can hold more water vapor, becomes more common. If DT air masses are becoming moister, as rising dew point temperatures suggest, then MT+ days should become more common. That may explain why the frequency of MT+ air masses is rising more rapidly than that of other types of air masses, and why DT air masses are becoming slightly less common.

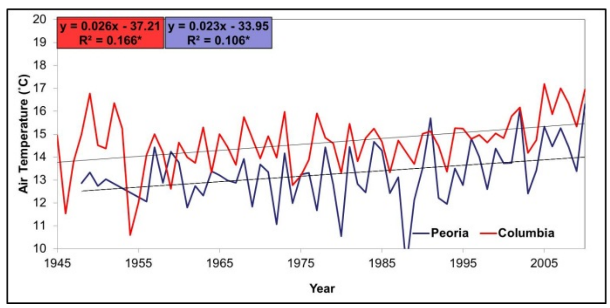


**Figure 2:** Overnight (3AM) air temperature increases in two minor cities: Peoria, IL and Columbia, MO for the dry polar air mass. Trends display that overnight temperatures have warmed within this air mass, being 1.5°C and 1.7°C greater, respectively, today than 60 years ago.

A previous UCS report showed that the risk of dangerously hot weather in the Midwest is likely to grow as the climate warms due to anthropogenic factors (UCS, 2011). While our analysis shows that dangerous summer air masses have become more common, our analysis was not designed to determine if this change is due to anthropogenic warming. However, increasing heat intensity is only one of the public health risks associated with climate change. Many more are expected, including worsening ozone pollution, degraded water quality, more outbreaks of waterborne diseases, more bacterial and viral diseases transmitted by mosquitoes, ticks, and fleas, and droughts, floods, and related crop failures (UCS 2011).

**Table 1:** Summary statistics for large and small cities.

| City/ Weather Type | Weather Type Frequency | | 3am $T_a$ | | 3am $T_d$ | | 3pm $T_a$ | | 3pm $T_d$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Chicago** | **Slope** | **$R^2$** | **Slope** | **$R^2$** | **Slope** | **$R^2$** | **Slope** | **$R^2$** | **Slope** | **$R^2$** |
| **DP** | -0.119 | 0.135* | -0.007 | 0.021 | -0.031 | 0.0140* | 0.027 | 0.144* | 0.007 | 0.008 |
| **DT** | 0.024 | 0.011 | -0.005 | 0.002 | -0.033 | 0.04 | 0.023 | 0.04 | 0.025 | 0.026 |
| **MT+** | 0.038 | 0.025 | -0.002 | 0.001 | -0.001 | 0 | 0.015 | 0.060^ | 0.007 | 0.009 |
| **Peoria** | | | | | | | | | | |
| **DP** | -0.069 | 0.065* | 0.011 | 0.042 | 0.016 | 0.028 | 0.023 | 0.106* | 0.030 | 0.125* |
| **DT** | 0.010 | 0.001 | -0.004 | 0.002 | -0.019 | 0.01 | 0.026 | 0.034 | 0.010 | 0.003 |
| **MT+** | 0.094 | 0.152* | -0.007 | 0.012 | 0.021 | 0.056^ | 0.013 | 0.077* | 0.018 | 0.096* |
| **Detroit** | | | | | | | | | | |
| **DP** | -0.203 | 0.332* | -0.02 | 0.088* | -0.012 | 0.015 | 0.028 | 0.105* | 0.01 | 0.011 |
| **DT** | 0.065 | 0.050^ | -0.028 | 0.085^ | -0.054 | 0.084^ | 0.046 | 0.173* | 0.011 | 0.006 |
| **MT+** | 0.066 | 0.059^ | 0.002 | 0 | 0.007 | 0.007 | 0.023 | 0.098* | 0.027 | 0.110* |
| **Toledo** | | | | | | | | | | |
| **DP** | -0.167 | 0.344* | 0 | 0 | -0.011 | 0.013 | 0.023 | 0.054^ | 0.006 | 0.004 |
| **DT** | 0.048 | 0.038 | 0.004 | 0.004 | 0.005 | 0.001 | 0.038 | 0.057^ | 0.05 | 0.092* |
| **MT+** | 0.063 | 0.048^ | 0.001 | 0 | 0.021 | 0.069^ | 0.014 | 0.043 | 0.021 | 0.062^ |
| **Minneapolis** | | | | | | | | | | |
| **DP** | -0.068 | 0.057^ | -0.01 | 0.035 | -0.016 | 0.034 | 0.009 | 0.017 | -0.007 | 0.009 |
| **DT** | 0.045 | 0.022 | -0.027 | 0.101* | -0.014 | 0.008 | -0.007 | 0.004 | -0.012 | 0.007 |
| **MT+** | 0.025 | 0.016 | -0.012 | 0.018 | 0.005 | 0.004 | 0.014 | 0.050^ | 0.019 | 0.071* |
| **Rochester** | | | | | | | | | | |
| **DP** | 0.022 | 0.004 | -0.003 | 0.006 | 0.038 | 0.211* | 0.022 | 0.148* | 0.019 | 0.085* |
| **DT** | -0.058 | 0.067* | -0.018 | 0.041 | -0.052 | 0.067 | 0.001 | 0 | -0.011 | 0.005 |
| **MT+** | 0.012 | 0.005 | -0.016 | 0.059^ | 0.01 | 0.017 | 0 | 0 | 0.009 | 0.022 |
| **St. Louis** | | | | | | | | | | |
| **DP** | -0.06 | 0.098* | -0.001 | 0 | 0.012 | 0.016 | 0.03 | 0.149* | 0.026 | 0.093* |
| **DT** | 0 | 0 | -0.002 | 0 | 0.029 | 0.060^ | 0.038 | 0.132* | 0.066 | 0.181* |
| **MT+** | 0.152 | 0.243* | -0.011 | 0.052^ | 0.009 | 0.028 | 0.018 | 0.176* | 0.005 | 0.014 |
| **Columbia** | | | | | | | | | | |
| **DP** | -0.118 | 0.135* | 0.021 | 0.137* | 0.047 | 0.165* | 0.026 | 0.166* | 0.037 | 0.187* |
| **DT** | 0.024 | 0.011 | 0.053 | 0.273* | 0.049 | 0.108* | 0.031 | 0.111* | 0.034 | 0.114* |
| **MT+** | 0.038 | 0.025 | -0.008 | 0.02 | 0.015 | 0.058^ | -0.003 | 0.008 | 0.011 | 0.088* |
| **Cincinnati** | | | | | | | | | | |
| **DP** | -0.033 | 0.019 | 0.002 | 0.001 | 0.013 | 0.016 | -0.001 | 0 | -0.003 | 0.001 |
| **DT** | -0.029 | 0.013 | -0.007 | 0.015 | -0.018 | 0.023 | 0.005 | 0.008 | -0.01 | 0.022 |
| **MT+** | 0.033 | 0.054^ | -0.01 | 0.013 | 0 | 0 | 0.002 | 0.001 | -0.006 | 0.008 |
| **Lexington** | | | | | | | | | | |
| **DP** | -0.035 | 0.023 | 0 | 0 | 0.02 | 0.040^ | 0.013 | 0.038 | 0.006 | 0.005 |
| **DT** | -0.009 | 0.001 | 0.002 | 0.001 | -0.002 | 0 | 0.019 | 0.031 | 0 | 0 |
| **MT+** | 0.038 | 0.068* | -0.016 | 0.042 | -0.003 | 0.003 | 0.009 | 0.021 | -0.002 | 0.002 |

* Indicates statistical significance at the p<0.05 level. ^ Indicates statistical significance at the p<0.10 level.
Grey potions indicate agreement in trend between large and smaller paired cities.

Climate change affects each city and state in unique ways, and policy makers must be aware of local patterns (Grimmond et al. 2010). Successful heat-response plans require collaboration among many agencies and organizations, city-specific criteria on the risks of extreme heat and methods to reach residents most at risk, and a communication plan. Under a higher-emissions scenario, nine major cities – including the five in this report – are projected to see at least 60 days over 90°F each year, and 20 days topping 100°F, by the last 30 years of this century (Hayhoe et al. 2009).

With fewer cool summer days on the calendar, residents experience less relief from hot weather. Additionally, differences between daytime and nighttime temperatures appear to be narrowing in most cities. This trend is important in understanding the impact of high heat on human health, both now and in the future, as a lack of nighttime heat relief has been linked to increases in heat-related illness (O'Neill and Ebi 2009; Poumadere et al. 2005). Local preparedness is critical to protecting public health and saving lives during extreme heat events (UCS 2012). Scientists also project that heat waves in North America and Europe will become more intense, more frequent, and longer-lasting (IPCC 2012).

## 4. Conclusions

Extreme heat events became more intense and more common in the Midwest over the past six decades. Midwesterners have experienced these changes in weather during their lifetimes. While we did not design our study to determine whether such changes stem from human activities, our findings are consistent with projected warming trends.

Heat waves, which are also becoming more common, further affect human health. Rising overnight temperatures are also problematic, because a lack of nighttime relief increases the risk of heat-related complications. A comprehensive national strategy is needed to create climate-resilient communities and reduce UHI effects, provide adaptation strategies, and reduce emissions that are driving climate change. We can also make choices – both as individuals and as a society – that minimize our future health risks from dangerously hot weather.

## 5. References


Basu, R. 2009. High ambient temperature and mortality: A review of epidemiologic studies from 2001 to 2008. *Environmental Health* 8(40):1–13.

Basu, R., F. Dominici, and J.M. Samet. 2005. Temperature and mortality among the elderly in the United States: A comparison of epidemiological methods. *Epidemiology* 16(1):58–66.

Basu, R., and J.M. Samet. 2002. Relation between elevated ambient temperature and mortality: A review of the epidemiologic evidence. *Epidemiologic Reviews* 24(2):190–202.

Centers for Disease Control and Prevention (CDC). 2006a. Heat-related deaths: United States, 1999–2003. *MMWR Weekly* 55(29):796–798.

Dixon, P.G., and T.L. Mote. 2003. Patterns and causes of Atlanta's urban heat island-initiated precipitation. *Journal of Applied Meteorology* 42:1273–1284.

Ebi, K.L., T.J. Teisberg, L.S. Kalkstein, L. Robinson, and R.F. Weiher. 2004. Heat watch/warning systems save lives: Estimated costs and benefits for Philadelphia, 1995–98. *Bulletin of the American Meteorological Society* 85(8): 1067–1073.

Epstein, Y., and D.S. Moran. 2006. Thermal comfort and the heat stress indices. *Industrial Health* 44(3):388–398.

Grimmond, C.S.B., M. Roth, T.R. Oke, Y.C. Au, M. Best, R. Betts, G. Carmichael, H. Cleugh, W. Dabberdt, R. Emmanuel, E. Freitas, K. Fortuniak, S. Hanna, P. Klein, L.S. Kalkstein, C.H. Liu, A. Nickson, D. Pearlmutter, D. Sailor, and J. Voogt. 2010. Climate and more sustainable cities: Climate information for improved planning and management of cities (producers/capabilities perspective). *Procedia Environmental Sciences* 1:247–274.

Hayhoe, K., J. VanDorn, V. Naik, and D. Wuebbles. 2009. Climate change in the Midwest: Projections of future temperature and precipitation. Cambridge, MA: Union of Concerned Scientists. Online at *www.ucsusa.org/assets/documents/global_warming/midwest-climate-impacts.pdf*.

Intergovernmental Panel on Climate Change (IPCC). 2012. *Managing the risks of extreme events and disasters to advance climate change adaptation: A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley, eds. New York, NY: Cambridge University Press.

Kalkstein, L.S. 2005. The 2003 European Heat Wave and Analog Studies for U.S. Cities. IN: Harvard Medical School, UNDP, SwissRE, Climate Change Futures: Health, Ecological, and Economic Dimensions, 53-58.

Mastrangelo, G., U. Fedeli, C. Visentin, G. Milan, E. Fadda, and P. Spolaore. 2007. Pattern and determinants of hospitalization during heat waves: An ecologic study. *BMC Public Health* 7(147):200.

Meehl, G.A., and C. Tebaldi. 2004. More intense, more frequent, and longer lasting heat waves in the 21$^{st}$ century. *Science* 305(5686):994–997.

O'Neill, M.S., and K.L. Ebi. 2009. Temperature extremes and health: Impacts of climate variability and change in the United States. *Journal of Occupational and Environmental Medicine* 51(1):13–25.

Poumadere, M., C. Mays, S. Le Mer, and R. Blong. 2005. The 2003 heat wave in France: Dangerous climate change here and now. *Risk Analysis* 25(6):1483–1494.

Robine, J.M., S.L.K. Cheung, S. Le Roy, H. Van Oyen, C. Griffiths, J.P. Michel, and F.R. Herrmann. 2008. Death toll exceeded 70,000 in Europe during the summer of 2003. *Comptes Rendus Biologies* 331(1):171–178.

Semenza, J.C., J.E. McCullough, W.D. Flanders, M.A. McGeehin, and J.R. Lumpkin. 1999. Excess hospital admissions during the July 1995 heat wave in Chicago. *American Journal of Preventive Medicine* 16(4):269–277.

Sheridan, S.C. 2002. The redevelopment of a weather-type classification scheme for North America. *International Journal of Climatology* 22(1):51–68.

Sheridan, S.C., and L.S. Kalkstein. 2004. Progress in heat watch-warning system technology. *Bulletin of the American Meteorological Society* 85(12):1931–1941.

Sherwood, S.C., and M. Huber. 2010. An adaptability limit to climate change due to heat stress. *Proceedings of the National Academy of Sciences* 107(21):9552–9555.

Vanos, J.K., J.S. Warland, T.J. Gillespie, and N.A. Kenny. 2010. Review of the physiology of human thermal comfort while exercising in urban landscapes and implications for bioclimatic design. *International Journal of Biometeorology* 54(4):319–334.

Union of Concerned Scientists (UCS). 2011. Climate change and your health: Rising temperatures, worsening ozone pollution. Cambridge, MA. Online at *www.ucsusa.org/global_warming/science_and_impacts/impacts/climate-change-andozone-pollution.html,* accessed May 7, 2012.

Union of Concerned Scientists (UCS) 2012. Climate change and your health: Heat in the Heartland: 60 Years of Warming in the Midwest. Online at *http://www.ucsusa.org/global_warming/science_and_impacts/impacts/global-warming-and-heat-waves.html.* Accessed Jan 12, 2012.

Urban Heat Islands. 2012. Online at *www.urbanheatislands.com*, accessed April 20, 2012.