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Climate Change in St. Louis: Impacts and Adaptation Options

John Posey, East-West Gateway Council of Governments, USA

Abstract: This paper uses dynamically and statistically downscaled projections to assess potential changes in the climate of the St. Louis metropolitan area, USA. Two sets of downscaled projections are used. The North American Climate Change Assessment Program (NARCCAP) provides dynamically downscaled projections for the relatively high A2 emissions scenario. The United States Geological Survey (USGS) provides statistically downscaled projections for multiple emissions scenarios; for this analysis, the A2, and the somewhat lower B1 emissions scenarios were used. For both data sets, projections for the 1971-2000 period are compared with projections for the 2041-2070 time period to assess potential changes by mid-century. There is a consensus among the models that temperatures in the St. Louis region would be expected to rise in each season. There is also an agreement among most models that increased greenhouse gas (GHG) concentrations would be associated with increases in spring and winter precipitation. The biggest discrepancy between the downscaled projections regards summer precipitation, with NARCCAP projecting decreases in summer precipitation, and USGS projecting increases. There is also an agreement among most model runs that increases in heavy precipitation would be associated with rising GHG concentrations. Socio-economic implications include a rising risk of flooding in the St. Louis area, rising risk of heat stress, and increased energy use. Possible adaptation options include levee system repair, adoption of stormwater best management practices, energy conservation and a multi-faceted response to heat waves.

Keywords: Impacts, Adaptation, Urban, Transportation

Introduction

Urban planners are among those on the front lines of climate change adaptation. These are the professionals charged with planning and running transportation systems, stormwater systems, emergency response and public health systems. Unfortunately, information about changing climatic conditions is rarely available at a scale that would be useful to urban planners. The 2009 National Climate Assessment commented that "there is an indisputable need to improve understanding of climate system effects at these smaller scales, because these are often the scales of decision making in society" (Karl, Melillo and Peterson, 2009).

The metropolitan area is an appropriate scale for analysis of climate impacts, as decisions about urban infrastructure are often made at the metropolitan level. This paper uses dynamically downscaled climate projections from the North American Climate Change Assessment Program (NARCCAP) and statistically downscaled projections from the United States Geological Survey (USGS) to assess potential impacts on the St. Louis metropolitan area, USA.

Three research questions are investigated:

1. What changes in the climate of the St. Louis metropolitan area are projected to occur by the middle of the 21st Century?
2. What types of socio-economic impacts would be associated with the projected changes in the regional climate?
3. What kinds of adaptation options can be identified?

Six sections follow: first, a brief overview of related literature; second, an overview of climate in St. Louis; third, a description of the downscaled climate projections used in this analysis; fourth, a description of projected changes in temperature and precipitation in the St. Louis region; fifth, potential socio-economic impacts and adaptation options; and finally, a conclusion.

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Literature Review

Global climate models known as Atmospheric-Oceanic General Circulation Models (AOGCM) are used to project changes in climate given certain assumptions about greenhouse gas levels. While useful for describing climatic change at a global or continental scale, the models do not offer fine enough resolution to be of use in local planning. As Hayhoe et al. (2010) explain, "typical AOGCM resolution is too course to capture the nuances of regional-scale change. For that reason, downscaling techniques are often used to transform AOGCM output into higher-resolution projections on the order of tens rather than hundreds of square miles."

There are two general approaches to downscaling global climate projections (Daniels et al., 2012; Winkler et al., 2012). The first, *statistical downscaling*, relies upon statistical relationships between local and global climate. The second approach, *dynamical downscaling*, uses regional climate models (RCM) that take into account local topographical and hydrological features that can affect circulation patterns. Each approach has advantages and disadvantages. Data processing for statistical downscaling is less intensive than that for RCM. As a result, statistically downscaled projections can be offered for more emissions scenarios and for more global climate models. With more intensive data processing requirements, RCMs are more restrictive with respect to the number of global climate models and the number of emissions scenarios that are considered. Still, RCMs offer the advantage of taking local conditions into account.

Several recent projects have used AOCGM output, with or without downscaling, to produce climate projections at a sub-national scale. Horton, Gornitz and Bowman (2010), in a report for the New York City Panel on Climate Change, use AOGCM outputs without downscaling to assess potential impacts on the New York region. Outputs from 16 AOGCMs were used. For each model, projections for the model's grid cell containing New York City were extracted. Since different AOGCMs use grid cells of different sizes, the area covered by grid cells from the various AOGCMs ranged from about 7,500 square miles (~12,000 km) to about 68,000 square miles (~100,000 km). The 16 models broadly agreed in projecting rising temperatures, rising levels of precipitation, and continued sea level rise.

Hayhoe et al. (2010) use statistical downscaling techniques to develop projections for the City of Chicago. Aside from rising temperatures, the model projections generally pointed to rising winter and spring precipitation, with higher levels of uncertainty regarding summer precipitation.

The Wisconsin Initiative on Climate Change Impacts (2011) commissioned statistically downscaled projections from the Nelson Institute Center for Climatic Research at the University of Wisconsin. The analysis used 14 AOCGMs. The models projected annual average temperature rising between four and nine degrees (F) by mid-century. As in the Chicago study, projections pointed to increasing precipitation levels in winter and spring, with uncertainty about summer precipitation. The models also agreed in projecting more frequent extreme precipitation events.

Kunkel et al. (2013) use dynamically downscaled data from NARCCAP to assess potential changes in the climate of the Midwestern part of the United States under the A2 scenario. NARCCAP averages are presented on maps for an eight state region. On average, average annual temperatures are projected to increase between four and five degrees. For summer, the increase is projected in the range of four to six degrees, with the highest changes in the southern portion of the Midwest. In the aggregate, the NARCCAP ensemble projects increasing precipitation throughout the Midwest in winter and spring, with small increases in summer precipitation for the upper Midwest, and decreases in the southern portion of the region.

This paper presents both statistically and dynamically downscaled projections for the St. Louis region. Individual model outputs are reported as well as averages, to show ranges and levels of agreement among the models.

The St. Louis Region

The St. Louis Metropolitan Statistical Area (MSA) is home to about 2.8 million people, spread out over 6,400 square miles. Located in the central portion of the U.S. mainland, the MSA includes 7 counties in Missouri, and another 8 in Illinois. The nation's two largest navigable rivers, the Mississippi and the Missouri, flow through the region. Map 1 shows the 15 counties of the MSA, with Illinois counties shaded more darkly.

Over the last century, the average annual temperature in St. Louis has been 13.4 degrees (C), with about 957 mm of precipitation (National Weather Service, 2012a; National Weather Service, 2012b). Seasonal averages are shown in Table 1.

Map 1

Downscaled Data Sets

This paper uses both statistically and dynamically downscaled data sets. Dynamically downscaled projections are taken from the North American Regional Climate Change Assessment Program (NARCCAP) (Mearns et al., 2009; Mearns et al., 2011). Statistically downscaled projections are from a dataset developed for the U.S. Geological Survey (USGS) by Katherine Hayhoe (Stoner et al., 2012).

NARCCAP is an international program coordinated by the University Consortium for Atmospheric Research (UCAR). Phase II of the project consists of RCM runs nested in AOGCM. These Phase II projections are the ones used in this analysis. Projections are available to registered users from the Earth System Grid (http://www.earthsystemgrid.org/ project/NARCCAP.html).

NARCCAP modelers couple different global climate models with different RCMs. The global climate models and RCMs that produced outputs used in this paper are shown in Table 2. Eight different RCM/GCM couplings were available for this analysis, and results for each coupled pair are presented. A description of the RCMs used by NARCCAP is given by Wehner (2012).

NARCCAP offers downscaled projections for the period 1971-2000 and 2041-2070, allowing for a comparison of the recent past with projected conditions in the middle of the 21st century. The projections used in this paper take the form of simulated weather conditions at three hour intervals throughout the life of a 30 year period. Comparing outputs from the historic and future model runs shows what changes are projected by the different models.

NARCCAP offers data at a resolution of 50 square kilometers, although each RCM uses its own grid system. For this paper, the point closest to downtown St. Louis was selected from each RCM/GCM output, and projected changes in temperature and precipitation were analyzed for this point.

Currently, NARCCAP projections are available only for the Special Report on Emissions Scenarios (SRES) A2 scenario. This scenario, sometimes referred to as a “business as usual” scenario (Beniston, 2006) assumes that GHG concentrations will rise to about 850 ppm by 2100. (In 2013, the atmospheric GHG concentration reached 400 ppm.)

The USGS data set uses a statistical downscaling technique known as asynchronous quantile regression to determine how local weather observations relate to simulated weather data produced by AOGCMs. The model used to produce the USGS data set is known as the asynchronous regional regression model (ARRM). Quantile regression differs from Ordinary Least Squares (OLS). OLS estimates the change in a dependent variable’s mean that is expected to occur in response to a change in the independent variable. By contrast, quantile regression estimates the change in a dependent variable at a given quantile in response to a change in the independent variable. The most common use of quantile regression is median regression, which estimates the change in the median value of y given a one unit change in x. Quantile regression can also be used to model the tail of the distribution, i.e., how the 90^{th} or 95^{th} percentile of y would be expected to change in response to a change in x.

In the case of ARRM, observed weather data is separated by month. Each month’s time series is transformed into a probability distribution by ordering observations from high value to low value:

> For a time series containing N values there are N ranks in each vector. A model can be constructed by regressing the value at rank n_i of the simulated vector onto the value of the same rank of the vector containing observed values….The regression is asynchronous, i.e., data values that are regressed against each other did not necessarily occur on the same calendar day, but rather correspond by quantile or rank.” (Stoner et al., 2013)

For a full discussion of the methodology, see Stoner et al., 2013.

The USGS data set offers projections for daily maximum and minimum temperature. From these values, an average temperature was estimated. Also available are projected daily precipitation totals. Projection data from 10 different AOCGMs listed in Table 2 were used in this study. To make the USGS projections comparable to NARCCAP, projections for the period 1971-2000 were compared with projections from 2041-2071. Also for purposes of comparability with NARCCAP, projections for the A2 scenario were selected. In addition, results were obtained for the lower emission B1 scenario, which assumes a rise in GHG concentrations to about 600 ppm by 2100. The USGS data are offered at a resolution of approximately 12 km.

Results

Temperature: NARCCAP projections for changes in temperature are shown in Table 3. There is agreement among each of the model couplings that temperatures would increase in each season under the A2 scenario. Among all the model couplings, the average increase in summer temperature is projected to be 3.5 degrees Celsius. The range for projected increase in summer temperatures was 2.2 degrees to 5.5 degrees. The average winter temperature increase is 2.5 degrees. The increases in winter temperature projected by the models ranged from 1.5 degrees to 3.3.

USGS projections for changes in temperature under the A2 scenario are shown in Table 4a. With only one exception, all projections show temperature increases for every season. The lone exception is the Spring projection for BCM, which projects a decline of 0.7 degrees. The other nine models show increases in Spring temperature ranging from 2.0 to 3.4 degrees.

As with NARCCAP, all models project increases in average summer temperatures, although the BCM shows no change when rounded to one decimal point. The average change in summer temperature for all ten models is 2.4 degrees. Other than the BCM projection, the projected change in average summer temperature ranges from 1.5 to 3.6 degrees.

USGS projections for the B1 scenario are shown in Table 4b. As with the A2 scenario, a single model projects small decreases in average Spring and Summer temperatures. Aside from BCM, each of the other nine models projects increases in average temperature for each season. Since emissions are assumed to be lower under the B1 scenario, projected temperature increases are not as great as with the A2 scenario. The average projected increase in summer temperature is 1.8 degrees, with a range (excluding BCM) of 1.03 to 2.75. The average projected increase in winter temperature is 2.5 degrees, with a range from 1.1 to 5.37 degrees.

Precipitation: NARCCAP projections for seasonal changes in precipitation are shown in Table 5. Six of the eight model couplings project an increase in annual precipitation levels, with a four percent average increase.

Seven of the eight model runs project an increase in winter precipitation. The average increase for the eight model runs is 10 percent, with projected change ranging from -0.9 percent to +23.5 percent. Seven of the eight models also project increases in springtime precipitation. The average change in spring precipitation is projected to be 8.8 percent, with a range of -1.5 percent to +23.3 percent.

Six of the eight model runs show a decline in summer precipitation, while two project an increase. On average, the models project an 8.2 percent decline in summer precipitation (range -29.2 percent to +23.6 percent). Six of the eight models project increases in autumn precipitation as well, though the magnitude of change is smaller than for the other seasons.

USGS projections for changes in precipitation under the A2 scenario are shown in Table 6a. As with NARCCAP, the ten models on average show an increase in annual precipitation. The average change in annual precipitation in the USGS/A2 projections is 4.5%. As with NARCCAP, there is a fairly strong consensus among the models, with nine of the ten models projecting increases in annual precipitation.

Eight of the ten USGS models agree with the NARCCAP ensemble in projecting increases in spring precipitation, with an average increase of 7.5 percent. For winter precipitation there is less agreement, as just six of the ten USGS models project an increase. The average projected change in winter precipitation is 5.8 percent.

The biggest discrepancy between NARCCAP projections and USGS projections is for summer precipitation. While NARCCAP, on balance, projected a decrease in summer precipitation, most of the USGS models project an increase. For the USGS/A2 projections, the average change is +2.2%. Of the four seasons, then, uncertainty about the direction of change is greatest for summer.

The downscaled model results for the B1 scenario are broadly in agreement with those for the A2 scenario, particularly with respect to the direction of change. In the B1 scenario, seven of the 10 models project an increase in winter precipitation, eight of ten project an increase in spring precipitation, seven of 10 project an increase in summer precipitation, and six of 10 project an increase in autumn precipitation. Eight of the ten B1 projections indicate an increase in annual precipitation, compared with nine of 10 for A2. The biggest discrepancy between the A2 and B1 scenarios for the USGS projections regards summer precipitation. On average, the USGS ensemble projects an average change of +7.6 percent for the B1 scenario, while the average change for the A2 scenario is -0.2. Much of the difference in projected average change for summer can be accounted for by the GFDL model, which projects a decrease from 270mm to 157mm for A2, while projecting a change from 266mm to 214 for B1.

Heating Degree Days/Cooling Degree Days: Table 5 shows projected changes in heating degree days (HDD) and cooling degree days (CDD). As noted earlier, the NARCCAP data used in this paper offered temperature projections at three hour increments, or eight observations for each day in the 30 year period. The average of these eight observations was taken to determine the daily average.

Table 7 shows unanimity among the NARCCAP model runs that the A2 scenario would result in a decrease in the number of HDDs, and an increase in the number of CDDs. For HDD, the projected percentage decrease in HDDs fell in a fairly tight band, ranging from -13.4 percent to -19.1 percent. For CDD, there was a greater variety of projected increases. Two of the model runs projected a doubling of CDDs, while the other six model runs projected increases ranging from 47 percent to 76 percent. In six of the eight model runs, the decrease in HDDs was greater than the increase in CDDs.

Table 8a shows changes in HDD and CDD under the A2 scenario according to USGS projections. As with NARCCAP, there is unanimity among the models regarding a projected increase in CDD, and decrease in HDD. The range for USGS/A2 projections is a bit wider than NARCCAP, with the models projecting decreases in HDD in the range of 10 percent to 26 percent. For CDD, seven of the ten models in USGS/A2 project an increase within the range seen in NARCCAP data. Table 8b shows changes in HDD and CDD under the B1 scenario, according to USGS projections. There remains unanimity among models regarding the direction of change for both HDD and CDD. As with other temperature variables, changes are not as pronounced as in the A2 scenario.

Heavy Precipitation: Table 9a shows NARCCAP projected changes in the number of days with more than one inch (2.54cm) of precipitation. Seven of the eight models project an increase in the number of annual one inch precipitation events. On average, the models project an increase of one additional day per year with more than an inch of precipitation, or an increase of about 16 percent.

USGS projections for the A2 and B1 scenarios are shown in Table 9b and 9c, respectively. USGS projections agree with NARCCAP regarding the direction of change. Under both the A2 and B1 scenarios, models call for about one additional day per year of one inch precipitation. Eight of the ten USGS models project increases in heavy precipitation under the A2 scenario. Nine of ten project increases under the B1 scenario. Interestingly, the USGS models are evenly split as to whether the increase in the number of heavy precipitation events would be greater under the A2 or B1 scenarios.

Socio-Economic Impacts and Adaptation

Flooding: Increases in winter and spring precipitation suggest an increasing risk of both riverine flooding and ponding. This risk is amplified by the potential for an increase in the number of heavy precipitation events.

St. Louis has experienced severe flooding many times in its history. The 1993 Mississippi River flood killed 50 people and caused more than $15 billion in damage nationwide (National Weather Service, 2008). The 2011 Mississippi River Flood placed severe strains on levee systems south of St. Louis, causing the U.S. Army Corps of Engineers to demolish a levee near Birds Point, Missouri in order to relieve pressure on levees in more populated areas (Olson and Morton, 2012). A storm related to Hurricane Ike in 2008 caused as much as eight inches to fall on portions of the St. Louis region, flooding thousands of homes and businesses (Wilson, 2008).

Given the rising risk of riverine flooding, one key adaptation measure is to ensure that levees protecting the area are structurally sound. In 2009, the Federal Emergency Management Agency (FEMA) notified regional officials that it no longer had confidence in the ability of levees protecting the Illinois counties of Madison, Monroe and St. Clair. As a result, FEMA announced its intention to deaccredit the levees (Southwest Illinois Flood Prevention District, 2012). This would force many homes and businesses in the area to purchase flood insurance, and would also be likely to negatively affect property values (Posey and Rogers, 2009). In response, the Southwest Illinois Flood Prevention District was formed in 2009, with funding from a sales tax secured by a referendum in the three counties. Multi-jurisdictional levee improvement projects such as this should be considered one facet of adapting to changing flood risk.

A second adaptation measure is to adopt best management practices for stormwater. The U.S. Environmental Protection Agency (2011) recommends several such practices to reduce risk of flash floods and ponding. These include the use of rain gardens, bioswales, permeable pavement, and riparian buffers. The planting of street trees also has benefits for stormwater management (Maco and McPherson, 2003).

A third adaptation option would be to participate in the National Flood Insurance Program's (NFIP) Community Rating System (CRS). CRS is a program that offers reduced flood insurance rates to residents of communities that take specific steps to reduce vulnerability to flooding. Larger discounts are available to more proactive communities. Since CRS creates an incentive for using effective stormwater management practices, it too may be considered an adaptation to the rising risk of floods (Posey, 2009).

Heat Stress: The heat wave of 2012 killed more than 20 residents of St. Louis. Rising summer temperatures are likely to increase the risk of heat-related mortality and morbidity. O'Neill et al. (2009) offer several suggestions for reducing public health impacts associated with hotter summers. These include heat wave warning systems, making air conditioned environments accessible and public education. McPherson et al. (2005) note that street trees can be effective in reducing the urban heat island effect.

Energy: Most of the models project a decrease in HDD that is greater than the increase in CDD. This suggests that net energy use may decline as a result of a warmer climate. However, we should be cautious about concluding that there will be a net benefit with respect to energy costs. Many homes in the St. Louis region are heated by natural gas. By contrast, almost all homes in the region are cooled by electricity. Thus, the net change in energy costs depends on the future relative price of these fuels.

In addition, while winter costs are likely to decline, electricity use in summer will probably increase as temperatures rise. Additional analysis would be required to determine whether the increase in CDD would place a strain on the capacity of the region's electrical system.

Energy conservation is a potential adaptation to challenges associated with rising summer energy demands. Insulation, programmable thermostats, green roofs, white roofs and energy efficient appliances reduce electrical costs, and have the added co-benefit of reducing greenhouse gas emissions. Developing programs to increase the use of these conservation measures may be a reasonable adaptation to warmer summer conditions.

Other challenges: Changing temperatures and precipitation patterns could create challenges for other sectors in the region as well. Agriculture could be stressed by hotter, drier summers, requiring changes in crops or farming techniques. Roads could be impacted by rising heat stress, and traffic patterns disrupted by more intense precipitation (Alhassan,and Ben-Edigbe, 2011; Cools, Moons and Wets, 2010; Meyer and Weigel, 2010). Public health could be affected by changes in infectious disease vectors. Additional analysis on each of these areas would be beneficial to the region.

In addition, although it is beyond the scope of this article, it should be noted that climate change in other parts of the world could have the potential to affect St. Louis. For example, declining global agricultural productivity could affect food security in St. Louis, and water shortages elsewhere could lead to changes in migration patterns.

Conclusion

This paper has addressed three research questions. First, the paper analyzed potential changes in the climate of the St. Louis region. Using statistically and dynamically downscaled climate projections, the analysis found broad agreement that temperatures in St. Louis would rise under the A2 emissions scenario. While the NARCCAP data set did not include projections for other scenarios, the USGS data set projected temperature rise under the B1 scenario as well. Temperatures are projected to rise in each season. There was also agreement among most models that precipitation would be projected to rise in winter and spring. The highest uncertainty was for summer precipitation, for which most NARCCAP projections suggested a decrease, while most USGS projections indicate an increase. There was also broad agreement among the models that events with an inch or more of precipitation would be more frequent under the A2 scenario, and most models in the USGS data set projected increases in the number of heavy precipitation events under to B1 scenario as well.

Second, the paper explored in a qualitative manner the types of socio-economic impacts that could be anticipated if the projections correspond to future conditions. These included an increased risk of heat-related mortality and morbidity, increased material stress on pavements, rising energy costs in summer, and increased risk of flooding. This includes both riverine flooding from increases in winter and spring precipitation, as well as flash floods and ponding from intense precipitation events.

Third, the paper identified adaptation options. Public health programs such as heat wave warning systems and public education campaigns and efforts to make air conditioners or air conditioned environments more accessible were among the options for reducing the harms associated with rising summer heat. Levee maintenance and repair will only increase in importance if the risk of riverine flooding increases. Stormwater best management practices such as rain gardens, bioswales and open space preservation can reduce runoff during heavy precipitation events. Street trees are an adaptation option that addresses both the urban heat island effect and stormwater management issues.

Uncertainty about future conditions remains very high. Given the high uncertainty, it would not be appropriate to attempt to generate specific point estimates for future conditions. Rather, the approach taken in this paper is to determine the direction of change projected in the models, using multiple models and downscaling techniques to assess the robustness of the projections. In this way, potential challenges confronting local planners may be identified in a qualitative manner. The identification of potential challenges can suggest strategies that planners can adopt to address the harmful impacts of climate change. An awareness of the direction of change allows planners to develop scenarios, allowing planners to develop solutions that are robust across a range of outcomes. In addition, an awareness of the reality of climate change may be useful for building support for measures to build more resilient infrastructure.

REFERENCES

Alhassan, H.M. and J. Ben-Edigbe, 2011. “Highway capacity prediction in adverse weather”, *Journal of Applied Sciences*, 11(12), pp. 2193-2199.

Beniston, M., 2004. Climatic Change and its Impacts: An Overview Focusing on Switzerland. Boston: Kluwer Academic Publishers.

Cools, M., E. Moons and G. Wets, 2010. “Assessing the impact of weather on traffic intensity”, *Climate, Weather and Society*, 2(1), pp. 60-68.

Daniels, AE, J.F. Morrison, L.A. Joyce, N.L. Crookston, S-C Chen, S.G. McNulty, 2012, Climate Projections FAQ. U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-277WWW.

Hayhoe, K., J. VanDorn, T. Croley, N. Schlegal and D. Wuebbles, 2010. “Regional Climate Projections for Chicago and the US Great Lakes”, *Journal of Great Lakes Research* 36, pp. 7-21.

Horton, R., V. Gornitz and M. Bowman, 2010. “Chapter 3: Climate Observations and Projections”, *Annals of the New York Academy of Sciences* 1196, pp. 41-62.

Intergovernmental Panel on Climate Change, 2000. Summary for Policymakers: Emissions Scenarios. A Special Report of IPCC Working group III.

Karl, T, J. Melillo and T. Peterson, 2009, *Global Climate Change Impacts in the United States*. New York: Cambridge University Press.

Kunkel, K., L. Stevens, S. Stevens, L. Sun, E. Janssen, D. Wuebbles, S. Hilberg, M. Timlin, L. Stoecker, N. Westcott, and J. Dobson, 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment, Part 3. Climate of the Midwest U.S. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. NOAA Technical Report NESDIS 142-3. http://www.nesdis.noaa.gov/technical_reports/NOAA_NESDIS_Tech_Report_142-3-Climate_of_the_Midwest_U.S.pdf

Maco, S. and E.G. McPherson, 2003. “A Practical Approach to Assessing Structure, Function, and Value of Street Tree Populations in Small Communities”, *Journal of Arboriculture* 29(2), pp. 84-97.

McPherson, G., J. Simpson, P. Peper, S. Maco and Q. Xiao, 2005. “Municipal Forest Benefits and Costs in Five U.S. Cities”, *Journal of Forestry* 103(8), pp. 411-416.

Mearns, L.O. et al.(2011) *The North American Regional Climate Change Assessment Program dataset*, National Center for Atmospheric Research Earth System Grid data portal, Boulder, CO. Data downloaded 2012-09-13.

Mearns L.O., W.J. Gutowski, R. Jones, L-Y Leung, S. McGinnis, A.M.B. Nunes, Y Qian, 2009, "A Regional Climate Change Assessment Program for North America", *EOS* 90(36), pp. 311-312.

Meyer, M. and B. Weigel, 2011. “Climate change and transportation engineering: preparing for a sustainable future”, *Journal of Transportation Engineering*, 137, pp. 393-404.

National Weather Service, 2008. The Great Flood of 1993. http://www.crh.noaa.gov/lsx/?n=1993_flood

Accessed August 21, 2012.

National Weather Service, 2012a St. Louis MO - Monthly and Seasonal Mean Temperatures. www.crh.noaa.gov/images/lsx/climate/stl/temp/temp_stl_monthly_seasonal_averages.xs Accessed August 17, 2012

National Weather Service, 2012b St. Louis MO - Monthly and Seasonal Precipitation Totals. www.crh.noaa.gov/images/lsx/climate/stl/precip/precip_stl_monthly_seasonal_.xls Accessed August 17, 2012

O'Neill, M., R. Carter, J. Kish, C. Gronlund, J. White-Newsome, X. Manarolla, A. Zanobetti and J. Schwartz. "Preventing Heat-Related Morbidity and Mortality: New Approaches in a Changing Climate", *Maturitas* 64(2), 98-103.

Olson, K.R. and L.W. Wright Morton, 2012, "The Impacts of 2011 Induced Levee Breaches on Agricultural Lands of Mississippi River Valley", Journal *of Soil and Water Conservation*, 67:1, pp. 5A - 10A.

Posey, J, 2009, "The Determinants of Vulnerability and Adaptive Capacity at the Municipal Level: Evidence from Floodplain Management Programs in the United States", *Global Environmental Change*, 19, pp. 482-493.

Posey, J. and W.A. Rogers, 2010, The Impact of Special Flood Hazard Area Designation on Residential Property Values, *Public Works Management and Policy*, 15:2, pp. 81-90.

Schwartz H., 2011. Adapting to Climate Change: Another Challenge for the Transportation Community. In: Wenger J (ed). *Adapting Transportation to the Impacts of Climate Change: State of the Practice 2011.* Transportation Circular E-C152, Transportation Research Board of the National Academies, Special Task Force on Climate Change and Energy.

Stoner, A.M.K., K. Hayhoe, X. Yang and D.J. Wuebbles, 2012. An asynchronous regional regression model for statistical downscaling of daily climate variables. *International Journal of Climatology*, 33:11, pp. 2473-2494.

U.S. Environmental Protection Agency, 2011. Stormwater Best Management Practices. http://www.epa.gov/oaintrnt/stormwater/best_practices.htm Accessed September 27, 2013

Wehner, M.F., 2012, Very Extreme Seasonal Precipitation in the NARCCAP Ensemble: Model Performance and Projections, *Climate Dynamics*, DOI: 10.1007/s00382-012-1393-1.

Wilson, D.A., 2009, Hurricane Ike and Impact of Localized Flooding in St. Louis County, September 14, 2008. In: Criss RE, Kusky TM (eds) Finding the Balance between Floods, Flood Protection and River Navigation: Proceedings of a conference held November 11, 2008 at St. Louis University. St. Louis University, Center for Environmental Sciences.

Winkler, J.A., R.W. Arritt, S.C. Pryor, 2012, Climate Projections for the Midwest: Availability, Interpretation and Synthesis. In *U.S. National Climate Assessment Midwest Technical Input Report*, J. Winkler, J. Andresen, J. Hatfield, D. Bidwell and D. Brown, eds. Available from the Great Lakes Integrated Sciences and Assessment (GLISA) Center, http://glisa.msu.edu/docs/nca/mtit_future.pdf

Wisconsin Initiative on Climate Change Impacts, 2011. Wisconsin's Changing Climate: Impacts and Adaptation. Nelson Institute for Environmental Studies, University of Wisconsin-Madison and Wisconsin Department of Natural Resources.

APPENDIX 1:

Tables

Table 1: Historic Climate Averages, St. Louis Region

	Temperature (C)	Precipitation (mm)	Heating Degree Days	Cooling Degree Days
Winter	0.9	174.0		
Spring	13.2	288.5		
Summer	25.3	270.3		
Fall	14.5	223.3		
Annual	13.4	957.1	4682	1589

Source: National Weather Service

Table 2A: Climate Models (NARCCAP)

Abbreviation	Name	Organization	Type
CRCM	Canadian Regional Climate Model	OURANOS/UQAM	RCM
HRM3	Hadley Regional Model 3	Hadley Centre, UK	RCM
RCM3	Regional Climate Model 3	UC Santa Cruz	RCM
WRFG	Weather Research & Forecasting Model	Pacific Northwest National Lab.	RCM
CCSM	Community Climate System Model	National Center for Atmospheric Research	GCM
CGCM	Third Generation Coupled Global Climate Model	Canadian Centre for Climate Modeling and Analysis	GCM
GFDL	Geophysical Fluid Dynamics Laboratory	Geophysical Fluid Dynamics Laboratory	GCM
HAD3	Hadley Centre Coupled Model 3	Hadley Centre, UK	GCM

Table 2B: Climate Models (USGS)

BCM	Bergen Climate Model	Bjerknes Centre for Climate Research, Norway	
CCSM	Community Climate System Model	National Center for Atmospheric Research	GCM
CGCM47	Third Generation Coupled Global Climate Model	Canadian Centre for Climate Modeling and Analysis	GCM
CGCM63	Third Generation Coupled Global Climate Model	Canadian Centre for Climate Modeling and Analysis	GCM
CRNM	Centre National de Recherches Meteorologiques	Centre National de Recherches Meteorologiques	GCM
ECHAM	European Centre, Hamburg	Max Planck Institute for Meteorology	GCM
ECHO		Meteorological Institute, University of Bonn	GCM
GFDL	Geophysical Fluid Dynamics Laboratory	Geophysical Fluid Dynamics Laboratory	GCM
HADCM3	Hadley Centre Coupled Model 3	Hadley Centre, UK	GCM
PCM	Parallel Climate Model	US Department of Energy	GCM
RCM=Regional Climate Model; GCM=Global Climate Model			

Table 3

	CRCM/ CCSM	WRGH/ CCSM	CRCM/ CGCM	WRFG/ CGCM	HRM3/ GFDL	HRM3/ HAD3	RCM3/ CGCM	RCM3/ GFDL	AVG.	Avg. Change (Degrees)
Historic										
Winter	-0.1	-4.7	-1.7	1.1	-1.3	0.5	-1.6	-5.1	-1.6	
Spring	14.2	13.1	10.7	12.5	11.3	12.8	9.2	7.9	11.5	
Summer	29.1	25.6	25.4	23.3	24.6	25.8	24.4	22.4	25.1	
Autumn	14.5	12.2	12.6	12.5	12.4	13.9	11.9	10.1	12.5	
Annual	14.4	11.6	11.7	12.3	11.7	13.2	11.0	8.8	11.9	
Future										
Winter	2.3	-1.4	0.8	2.6	1.6	2.8	0.7	-2.3	0.9	2.5
Spring	16.7	14.8	12.7	13.8	14.3	14.8	11.3	9.5	13.5	2.0
Summer	32.8	28.6	29.0	25.6	30.1	29.1	27.6	25.9	28.6	3.5
Autumn	17.3	15.6	15.6	15.0	15.1	16.9	15.1	12.1	15.3	2.8
Annual	17.3	14.4	14.5	14.2	15.3	15.9	13.7	11.3	14.6	2.7

Table 4a: USGS Projections: Change in Temperature, A2 Scenario, St. Louis Region

HISTORIC	BCM	CCSM	CGCM47	CGCM63	CRNM	ECHAM	ECHO	GFDL	HADCM3	PCM		Average	Average Change (Degrees)
Winter	0.2	0.1	0.2	0.4	0.4	0.7	0.3	0.5	0.2	0.4		0.4	
Spring	12.8	13.0	12.9	13.1	13.0	12.8	12.9	12.6	12.6	12.8		12.9	
Summer	25.3	24.8	24.9	25.2	25.0	24.9	23.9	25.0	24.6	24.8		24.9	
Fall	14.5	14.4	14.3	14.3	14.4	14.3	14.0	14.4	14.1	14.3		14.3	
FUTURE	BCM	CCSM	CGCM47	CGCM63	CRNM	ECHAM	ECHO	GFDL	HADCM3	PCM			
Winter	5.6	3.3	2.7	3.1	4.0	2.7	5.1	2.4	3.4	2.1		3.4	3.1
Spring	12.1	15.6	15.7	16.0	15.5	14.8	16.3	15.6	14.7	14.0		15.0	2.2
Summer	25.3	27.3	27.2	27.7	28.3	27.1	27.0	28.7	27.5	26.2		27.2	2.4
Fall	21.1	16.9	16.4	16.4	17.5	16.6	17.6	16.5	16.4	15.5		17.1	2.8

Table 4b: USGS Projections: Change in Temperature, B1 Scenario, St. Louis Region

HISTORIC	BCM	CCSM	CGCM47	CGCM63	CRNM	ECHAM	ECHO	GFDL	HADCM3	PCM		Average	Average Change (Degrees)
Winter	0.26	0.29	0.29	0.35	0.39	0.72	0.56	0.54	0.36	0.41		0.4	
Spring	12.8	13.04	12.86	13.17	12.94	12.81	13.08	12.5	12.71	12.8		12.9	
Summer	25.2	24.99	24.9	25.16	24.98	24.88	24.29	25	24.5	24.7		24.9	
Fall	14.5	14.42	14.31	14.25	14.48	14.25	14.24	14.5	14.22	14.4		14.3	
Annual	13.2	13.19	13.09	13.2325	13.2	13.165	13.04	13.1	12.9475	13.1		13.1	
FUTURE	BCM	CCSM	CGCM47	CGCM63	CRNM	ECHAM	ECHO	GFDL	HADCM3	PCM			
Winter	5.63	1.56	2.24	2.41	3.59	2.94	3.38	1.64	3.55	1.74		2.9	2.5
Spring	10.9	14.93	15.29	15.13	15.21	14.84	15.7	14.7	17.54	13.7		14.8	1.9
Summer	24.9	26.53	26.41	27.14	27.47	26.74	27.04	27.1	27.18	25.7		26.6	1.8
Fall	20.3	15.71	15.45	15.9	16.68	16.75	16.74	16	13.63	15.2		16.2	1.9
Annual	15.4	14.68	14.8475	15.145	15.74	15.318	15.72	14.9	15.475	14.1		15.1	2.0

Table 5: NARCCAP Projections: Change in Seasonal Precipitation, St. Louis Region, A2 Scenario (mm)

	CRCM/ CCSM	WRGH/ CCSM	CRCM/ CGCM	WRFG/ CGCM	HRM3 /GFDL	HRM3 /HAD3	RCM3/ CGCM	RCM3/ GFDL	Avg.	Avg. Change (Percent)
HISTORIC										
WINTER	155.6	127.3	206.5	153	211.2	186.8	190.9	186.2	177.2	
SPRING	283.4	230.9	304.8	260	282.4	297.7	331.9	313.4	288.1	
SUMMER	171.6	144.2	219.3	184.5	270.9	264.5	305.2	339	237.4	
AUTUMN	177.8	190.5	192	171.9	248.8	188.3	199.8	219.6	198.6	
ANNUAL	788.4	692.9	922.6	769.4	1013.3	937.3	1027.8	1058.3	901.2	
FUTURE										
WINTER	167.2	141.5	210.9	162.2	260.9	202.9	189.1	225.1	195	10.0
SPRING	287.9	250	300.1	274	346.5	366.9	334.9	346.4	313.3	8.8
SUMMER	147	104.5	175.8	161.7	191.8	327	311.7	323.7	217.9	-8.2
AUTUMN	188.2	184.8	201.9	195.4	280.2	215	191.3	234	211.4	6.4
ANNUAL	790.3	680.8	888.8	793.3	1079.4	1111.8	1026.9	1129.1	937.6	4.0

Shaded cells indicate projected increase.

Table 6A: USGS Projections, Change in Seasonal Precipitation, A2 Scenario, St. Louis Region (mm)

PAST	BCM2	CCSM3	CGCM3_T47	CGCM3_T63	CNRM	ECHAM5	ECHO	GFDL	HADCM3	PCM		Average	Average Change (Percent)
WINTER	178.8	183.1	197.1	197.9	182.0	191.9	187.1	188.6	198.6	180.5		188.6	
SPRING	289.5	301.1	289.1	291.6	288.5	289.0	287.0	300.6	311.6	299.1		294.7	
SUMMER	261.1	267.3	281.8	275.4	254.5	291.2	277.2	269.8	247.6	289.2		271.5	
FALL	251.4	235.3	236.7	210.7	230.0	213.7	224.8	249.3	246.3	202.2		230.0	
ANNUAL	980.8	986.9	1004.7	975.6	954.9	985.9	976.2	1008.3	1004.1	971.0		984.8	
FUTURE	BCM2	CCSM3	CGCM3_T47	CGCM3_T63	CNRM	ECHAM5	ECHO	GFDL	HADCM3	PCM			
WINTER	212.3	206.1	196.4	205.1	177.1	201.8	177.7	196.8	198.1	223.1		199.5	5.8
SPRING	316.7	335.7	319.2	304.0	274.4	333.4	276.6	311.7	320.3	377.1		316.9	7.5
SUMMER	297.0	321.6	274.0	231.7	274.4	317.9	299.2	156.7	236.2	301.9		271.0	-0.2
FALL	266.4	218.8	253.6	280.3	221.2	246.9	229.5	228.5	257.6	218.9		242.2	5.3
ANNUAL	1092.3	1082.2	1043.2	1021.1	947.1	1100.0	983.0	893.6	1012.2	1121.0		1029.6	4.5

Shaded cells indicate projected increase.

Table 6B: USGS Projections, Change in Seasonal Precipitation, B1 Scenario, St. Louis Region (mm)

PAST	BCM2	CCSM3	CGCM3_47	CGCM3_63	CNRM	ECHAM5	ECHO	GFDL_20	HADCM3	PCM	Average	Average Change (Percent)
WINTER	181.3	180.2	192.8	202.2	182.4	192.2	187.5	189.2	191.7	183.4	188.3	
SPRING	289.9	295.4	292.1	286.6	288.4	290.5	289.8	303.6	297.6	310.6	294.5	
SUMMER	260.2	264.3	271.5	270.9	250.6	291.0	277.0	265.6	260.6	284.1	269.6	
FALL	250.5	234.0	233.0	213.6	230.4	213.7	224.8	251.8	246.2	191.8	229.0	
ANNUAL	981.9	973.9	989.5	973.3	951.9	987.3	979.1	1010.3	996.1	969.9	981.3	
FUTURE	BCM2	CCSM3	CGCM3_47	CGCM3_63	CNRM	ECHAM5	ECHO	GFDL_20	HADCM3	PCM	Average	Average Change (Percent)
WINTER	217.3	190.6	222.2	224.3	164.1	222.1	173.4	172.1	211.4	209.5	200.7	6.6
SPRING	304.1	308.1	312.1	318.8	274.3	316.0	268.0	305.0	348.8	345.4	310.1	5.3
SUMMER	281.8	341.1	294.8	230.3	331.8	318.3	300.0	213.6	228.7	360.4	290.1	7.6
FALL	263.4	230.2	253.8	240.7	224.0	241.0	227.8	185.2	242.2	195.7	230.4	0.6
ANNUAL	1066.7	1070.0	1083.0	1014.0	994.3	1097.5	969.2	875.9	1031.1	1110.9	1031.3	5.1

Shaded cells indicate projected increase.

Table 7: NARCCAP Projections: Change in Heating Degree Days and Cooling Degree Days, St. Louis Region, A2 Scenario

	1971-2000			2041-2070			Change			
	HDD	CDD		HDD	CDD		HDD	CDD		Net
WRFG/CCSM	5905	1541		4852	2352		-1053	811		-242
WRFG/CGCM	4940	1043		4218	1567		-722	524		-198
RCM3CGCM	5941	1179		4927	1913		-1014	734		-280
RCM3GFDL	7012	810		6049	1467		-963	657		-306
HRM3GFDL	5542	1252		4444	2477		-1098	1225		127
HRM3HAD3	4895	1591		4009	2429		-886	838		-48
CRCMCCSM	4898	2417		4011	3419		-887	1002		115
CRCMCGCM	5715	1455		4716	2275		-999	820		-179
Average	5606	1411		4653	2237		-953	826		-126

Table 8A: USGS Projections: Change in Heating Degree Days and Cooling Degree Days, St. Louis Region, A2 Scenario

	1971-2000			2041-2070			Change			Net
	HDD	CDD		HDD	CDD		HDD	CDD		
BCM	5498	1088		4039	1447		-1459	358		-1101
CCSM	5532	1033		4353	1629		-1179	596		-583
CGCM47	5553	1061		4491	1571		-1062	510		-552
CGCM63	5487	1088		4388	1681		-1099	593		-505
CRNM	5483	1059		4221	1834		-1262	775		-487
ECHAM	5479	1042		4634	1591		-846	549		-296
ECHO	5714	1017		4077	1816		-1637	799		-838
GFDL	5544	1081		4644	1907		-900	826		-74
HADCM3	5388	925		4504	1626		-1389	753		-636
PCM	5522	1027		4991	1380		-531	353		-178
Average	5520	1042		4434	1648		-1136	611		-525

Table 8B: USGS Projections: Change in Heating Degree Days and Cooling Degree Days, St. Louis Region, B1 Scenario

	1971-2000			2041-2070			Change			
	HDD	CDD		HDD	CDD		HDD	CDD		NET
BCM	5506	1085		4274	1309		-1232	224		-1007
CCSM	5496	1063		4888	1441		-608	378		-230
CGT47	5552	1058		4707	1366		-846	308		-538
CGT63	5486	1086		4681	1535		-806	449		-356
CNR	5485	1059		4403	1644		-1081	584		-497
ECHAM	5490	1044		4589	1554		-901	510		-391
ECHO	5543	1013		4449	1676		-1094	663		-431
GFDL	5544	1081		4890	1564		-653	483		-171
HADCM3	5346	928		4431	1524		-915	597		-318
PCM	5538	1022		5095	1257		-443	234		-208
Average	5499	1044		4641	1487		-857	443		-414

Table 9: Days Per Year with 1 Inch (2.54 cm) or more of Precipitation

Table 9A: NARCCAP Projections

	Historic	Future
CRCMCCSM	2.1	1.9
CRCMCGCM	4.0	4.8
HRM3GFDL	7.6	8.8
HRM3HAD3	7.3	10.0
RCM3CGCM	8.3	8.4
RCM3GFDL	7.2	9.0
WRFGCCSM	5.8	6.6
WRFGCGCM	6.7	7.6
Average	6.1	7.1

Table 9B: USGS Projections, A2 Scenario

	Historic	Future
BCM2_A2_PR	5.8	7.5
CCSM3_A2_P	4.7	6.0
CGCM3_T47	5.8	5.7
CGCM3_T63	5.2	6.1
CNRM_A2_PR	4.0	5.5
ECHAM5	4.8	6.7
ECHO	4.0	5.7
GFDL20	6.5	5.1
HADCM3	5.4	6.4
PCM	4.5	6.4
Average	5.1	6.1

Table 9C: USGS Projections, B1 Scenario

	Historic	Future
BCM2_B1_PR	5.7	7.2
CCSM3_B1_P	4.6	5.5
CGCM3_T47	5.4	6.3
CGCM3_T63	5.4	7.1
CNRM_B1_PR	4.0	5.1
ECHAM5_B1	5.0	7.2
ECHO_B1_PR	4.2	4.5
GFDL_20_B	6.5	5.0
HADCM3	5.6	6.9
PCM_B1_PR	4.6	6.8

ABOUT THE AUTHOR

Dr. John Posey: Director of Research, East-West Gateway Council of Governments, St. Louis, Missouri, USA

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