**NASA DEVELOP National Program**



NASA Langley Research Center

*Summer 2015*

Heat-Health & Spatial Variation in Maricopa County, Arizona

Enhancing Extreme Heat Intervention and Preparedness Activities Using Remote Sensing and Spatial Analysis of Heat-Related Risks and Mortality in Maricopa County, Arizona

**Technical Report** 

Rough Draft – June 25, 2015

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# I. Abstract

[Placeholder - do not put anything here until the final draft submission. The abstract in the project summary is where the working draft of the abstract should “live”]

**Keywords**

Remote Sensing, Heat, Urban Climate, Spatial, Public Health, Vulnerability, Socioeconomic

# II. Introduction

**Project Objectives**

1. Create a climatology map of Maricopa County, Arizona to detect extreme heat anomalies on various scales (i.e. daily, monthly, seasonal) and the consistency between such events (where, how, and why variations between extreme heat events occur)
2. Determine current use and frequent users of relief resources in order to establish how this correlates with current socioeconomic vulnerability assumptions
3. Analyze these anomalies and survey results to determine where, when, and how relief efforts should intervene

**Current Issue - Urbanization & Heat-Related Risks**

With compounding issues from a warming climate and the vastly increasing rates of land use change to include more impermeable surfaces and less vegetative cover, dense urban areas around the globe are experiencing amplified urban heat island effects resulting in an increase in heat related and heat caused deaths (Anderson & Bell, 2010, Greene et al., 2011, Hartz et al., 2012, and Zhang et al. 2013). In Maricopa County, Arizona, the region is currently experiencing such a phenomenon. According to the U.S. Census, Maricopa County’s population increased from 308,700,000 people in 2010 to 318,860,000 people in 2014, adding more than 10,160,000 individuals in a period of four years (USCB, 2015 and Hondula, 2014). Maricopa County, Arizona is the leading megapolitan area in the U.S. for population growth and urbanization. On top of this, the area is specifically recognized for its high heat index (Hondula, 2014). The region’s hot desert climate and extended periods of high temperatures cause human health consequences to continually escalate and with the county’s increased rate of urbanization, extreme heat rises as a human health concern. (Coutts et al., 2007, Greene et al., 2011 and Hondula, 2014).

From 2006 - 2013 about 1,050 deaths due to extreme heat and the body’s inability to regulate its internal temperature were reported (MCDPH, 2014 and Uejio, 2011). Other common physical health symptoms include heat cramps and heat exhaustion (Harlan, 2006 and Uejio, 2011). Of all 50 states, Arizona has the greatest reported death rates related to extreme heat for individuals older than 24 (LoVeccho et al., 2005). Those who were considered to be the most vulnerable (lack of resources to cope with the environmental threat) mirror other cities facing this issue and included males, elderly, poor, homeless, socially isolated, and minorities (MCDPH, 2014, Harlan, 2006, Johnson & Wilson, 2009). Most heat-related illnesses and deaths were found in major cities at home, sports and recreational areas, construction and industrial sites, and streets and highways (MCDPH, 2014 and Davis et al., 2003). While county wide relief efforts exist, there is currently no policy explicitly related to monitoring and/or preventing heat caused and heat related deaths.

Recent studies examine this phenomenon in Maricopa county in terms of satellite data on temperature and surface features of larger time scales and socioeconomic factors predicted and assumed from statistical regressions (Dousset et al, 2011, Golden et al., 2008, Grossman-Clark et al., 2010, Harlan et al., 2012, and Hondula et. al, 2015). However, these studies have yet to examine the nuances of extreme heat days and nights, such as potential differences within the hot days themselves as well as throughout an entire season. On top of that, recent surveys conducted by MCDPH provide novel content in the actual distribution and use of relief aid resources, such as warning system deployment and cooling center location use. With our data we may then establish how these resources are used and how the daily heat threats vary in order to establish where future cooling centers and warning message systems should be deployed.

**Study Area and Study Period**

Maricopa County is a 9,203 square mile range located in the southwestern portion of Arizona and lies within the Basin and Range Province (Rasmussen, 2012 and Golden, et al., 2008). This landscape includes steep, linear mountain ranges that alternate with lengthy deserts created from sand filling in the basins (Rasmussen, 2012). Due to Arizona’s diverse landscape, arid climate, and sparse cloud cover, the temperature varies dramatically from season to season and from daytime to nighttime. Located in an arid subtropical climate, Maricopa County has an average annual temperature of 71.25 °F, an annual high temperature of 88.5 °F, and the highest average high during the month of July at 108 °F (U.S. Climate Data, 2015 and USA, 2015). The county also has an annual average humidity of 80.59%, a UV index of 6.4, a heat index of 72 °F (giving how hot it feels by comparing temperature and humidity where exposure to full sunshine can increase this value by 15 °F), and a comfort index of 46/100, with higher numbers being more comfortable than lower (Sperlings Best Places, 2014, USA, 2015, and National Weather Service, 2014). The hottest temperature was 122 °F on July 27 and 28 in 1995 and the average number of days per year where the high temperature was 100 °F or more was 116 days (Mesa.AZweather, 2014). 104-128°F is NOAA’s Heat Index “danger” zone and serves as an appropriate threshold for severe heat stress as anything higher will likely result in sunstroke and heatstroke (Harlan, 2003). Maricopa county has an average of 296 sunny days a year and receives an annual average precipitation of 8.92 inches with the greatest amount received in the months of March, July, and December (USA, 2015, U.S. Climate Data, 2015, and Sperlings Best Places, 2014). In most cases, the majority of heat distress calls occur during the hot and moist North American Monsoon period later in the summer when the ground gets excessively heated and that moisture-filled air rises along the mountain ranges to produce thunderstorms (Golden et al., 2008 and Sperlings Best Places, 2014).

This research focuses on the extreme heat during the hottest months of the year from May through October during the period between 2006 and 2014. Our climatology goes back to 2002 to include more reference data.

**National Applications Addressed**

Our project primarily addresses Health & Air Quality as well as Climate. The results of this project primarily contribute to the public health facet, as it will help Maricopa County ensure its residents are safe during the periods of extreme heat.

**Project Partners**

Partnering with this project is the Arizona Department of Health Services (ADHS), the Environmental Remote Sensing and Informatics Lab (ERSL) at Arizona State University (ASU), and the Center for Policy Informatics (CPI) at ASU. ADHS coordinates the statewide heat safety task force, for which the Maricopa County Department of Public Health and ASU are active participants, and leads the state’s participation in CDC’s Building Resilience against Climate Effects initiative. Decision support tools and project findings will be shared through statewide heat safety meetings.

# III. Methodology

DATA ACQUISITION

Our primary data comes from the AQUA/MODIS satellite, as these pass over times, 1:30 AM and 1:30 PM, more closely proximate the true minimum and maximum daily temperature values as compared to the TERRA/MODIS satellite. Data was acquired for the months of May through October from 2002-Present from the AQUA land surface temperature and emissivity Level 3 product at 1km resolution at nadir (MYD11A1 Grid: h08v05). Although our study period begins in 2006, we are using data back to 2002 to include a wider range for establishing a sense of climatology. When survey data is incorporated, satellite data will only be analyzed from 2006-Present. These data were downloaded from the LP DAAC FTP collection using a Python script in the ‘dnppy’ module. From this loosely based climatology we will determine surface and/or air temperature anomalies that will serve as the dates of collection for the subsequent Landsat 8 and ASTER images. Landsat 8 will also be collected from the FTP server with a similar Python script and will include all bands. ASTER images, unprocessed, will come from the LP DAAC source as well and will correlate with the Landsat 8 dates as closely as possible. Ideally we will only use Landsat 8 and ASTER images on the same day.

Shapefiles of Maricopa County (including county borders and census blocks) will be collected from the ASU Repository of GIS data.

Ground truthing data to cross reference remotely sensed air temperature is available through the University of Utah’s MesoWest database. Utilizing the MesoWest API and python scripting, the data for 285 weather observation stations throughout Maricopa County was obtained from 2006-Present for the months of May through October. The data was then georeferenced in ArcMap and organized in a custom built geodatabase.

As a means of comparison and to put the above data in further context for analysis, we will gather information on the percent of impermeable surfaces as well the percent tree cover from the National Land Cover Database, hosted by USGS. NCEP Reanalyses data will also be utilized to determine the synoptic atmospheric conditions in the desert southwest during extreme heat events in Maricopa County. The reanalyses will be generated using Matlab.

CASPER survey data from the Maricopa County Department of Health from 2006 - 2015.

DATA PROCESSING AND ANALYSIS

**Task 1: Remote Sensing Climatology of Maricopa County Surface Temperatures to Determine Extreme Heat Days and Nights**

*Processing*

The MODIS product downloaded already controls for quality via the quality control band. The current Kelvin (K) values range from 7500 - 65535 and band math will need to be performed to apply the scale factor of 0.02 for true K values. For optimization, data will not need to be converted to Fahrenheit (F) at this point. Each ‘hdf’ file will need to be converted into ‘tif’ format and projected into ‘Sinusoidal’ in order to ensure each file is in the same projection. This conversion and projection definition will be performed with the ‘extract\_from\_hdf’ functions in the ‘dnppy’ module. As a final processing step, MODIS images will be subset to fit the contour line of Maricopa County using the ‘clip\_to\_shape’ function in the ‘dnppy’ module.

*Analysis*

The MODIS data is stored as a daytime and a nighttime surface temperature for each pixel. Once we pre-process the MODIS data, we will have a loosely based climatology of surface temperatures in Maricopa County for the specified date range.

Once this is completed, our team will look at converting these surface temperature values into air temperature for a more accurate analysis of temperature’s relation to human health issues. In doing so, we will determine a linear relationship between surface temperature and air temperature based on a line of best fit of ground truth weather data. Using our ground truth MesoWest temperature data, we can utilize the ‘apply\_linear\_correction’ function in the ‘dnppy’ to apply a linear correction over the entire raster. Part of our analysis will determine the validity of such a method by examining the decay rate of the interpolation (i.e. is there a point where the remotely sensed data does not consistently match up with the ground truth data and if so what is this threshold).

**Task 2: Model Predictions for Current State of Resource Use**

*Processing*

Survey results will need to be converted from ArcMap ‘.xlsx’ format into a ‘.csv’ format for analysis in RStudio. Once in RStudio data columns will be stacked appropriately for the particular analysis and subsets will be created to facilitate a more organized data analysis approach.

*Analysis*

In RStudio we will perform ordinal least squares regressions, such as binary logistic regression or ordered logistic regression, in order to determine what demographic factors relate to certain uses of relief aid. A binary logistic regression will look at the likelihood of AC use (with the outcome variable as ‘yes’ or ‘no’) versus various predictor variables (age, income, class, residence, etc.). We are also interested in examining income (along with other potential predictor variables) versus the likelihood of visiting a cooling center by using an ordered logistic regression, where the likelihood of visiting a cooling center is the outcome variable and categories of responses are ordered (such as “Very Likely”, “Somewhat Likely”, etc.). Another set of binary logistic regressions will examine who is hearing the warning messages and who is acting on these messages.

**Task 3: Maps of Heat Duration and Recurrence**

*Processing*

MODIS data used in Task 1 (remote sensing climatology of Maricopa County) will be utilized and will therefore go through the same processing as it is the same data. Anomalous day temperature values will need to be exported as a ‘.csv’ format and stacked appropriately for analysis in RStudio. For the purposes of classification and normalized differences, Landsat 8 and ASTER images will first be converted to reflectance by using the conversion information in the metadata files in order to ensure normalized results over the time periods using the following equations:

*ρλ'* = *MρQcal* + *Aρ*

and

,

where *Mρ* represents the multiplicative value, *Qcal* represents the band being converted, and *Aρ* represents the additive value. We will need to make sure the sun elevation angle (SE) is converted from degrees to radians to ensure proper calculations. Additionally, the Landsat data will be interpreted both in terms of brightness temperature and surface temperature, so the ‘atsat\_bright\_temp\_8’ and ‘surface\_temp\_8’ will be used. If possible we will perform a similar algorithm to convert both Landsat and ASTER to air temperature using the ground truth weather data.

*Analysis*

Temperature anomalies will be determined from our loosely based climatology of Maricopa County from 2002 - Present. We are using a literature based threshold of 104°F(313.15 K)and will use temperature data in the ‘.csv’ format in RStudio to extract all images above this specified critical value. For anomalous days we will compare consistency between other anomalous days (i.e. when they occur, how they vary from each other, etc.). A One-Way ANOVA will be performed in RStudio to compare how average heat values compare on all hot days, where temperature is the independent variable and the dates of extreme heat days are the levels. If averages are deemed significantly different, a Post-Hoc Tukey test will be performed to determine which hot days are statistically significant. These dates will provide options for analysis with finer resolution data, such as Landsat 8 and ASTER.

Additionally, we will perform a Chi-squared goodness-of-fit test to determine if there is an association between proportions of extreme heat days and nights over the year range 2002-2015. If deemed necessary, we may also do a similar test for proportions over the month range May - October in a single year. As a final test of the anomalies we will look at the duration of an extreme heat event in number of days. Once we have a chance to look at the data we will determine if counts will be compared within a month or within a whole season over the year range. As a statistical test, we will consider the duration as count data and therefore will use the non-parametric alternative to a One-Way ANOVA, the Kruskal-Wallis test. Again, if values are deemed to include statistically significant results we will use a post-hoc pairwise assessment with the ‘kruskalmc()’ function in the ‘pgirmess’ package in RStudio.

On anomalous heat days in which Landsat 8 and ASTER images are available, we will use these images to create maps of heat duration and recurrence on a finer scale with either brightness temperature or surface temperature (whichever allows consistent analyses between Landsat 8 and ASTER). Using the Thermal Infrared Bands 10 (10.60 - 11.19 μm) and 11(11.50 - 12.51 μm) in Landsat 8 and Bands 14 (10.250–10.950 μm) and 15 (10.950–11.650 μm) in ASTER we will first map surface temperature by applying color ramps to these bands in ENVI. We will compare these maps to already generated maps by Sharon Harlan et al. in the publication “Neighborhood Effects on Heat Deaths: Social and Environmental Predictions of Vulnerabilities in Maricopa County, Arizona.” We will visually analyze how daily anomalies compare with current maps (i.e. where are shifts occurring).

To further this analysis, we will do a supervised classification of both the Landsat 8 and ASTER images that have been pre-processed and converted into reflectance to determine what surface features are under these hot spots. Over various timescales of extreme heat anomalies we may do a normalized difference of images in the same band (determined based on the classification under a hotspot) to see what features are different within these heat events in this image over time in a specified wavelength with the following equation:

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where Day 1 and Day 2 will be determined by which day holds the higher pixel value of interest and where *x* represents the band number. As an added measure, we will look at the National Land Cover Database’s information on percent of impermeable surfaces and percent of tree cover in the study area to see if there is a temporal shift in surfaces that corresponds to a shift in hotspot locations. With this we are specifically interested in what differences may occur between extreme heat days rather than extreme heat days versus status quo.

**Task 4: Revised Heat Vulnerability Maps**

*Processing*

Data for this task will be generated from the previous tasks, there will be no additional processing information before analysis.

*Analysis*

Using the spatial data from the surveys and the surface/air temperature data for extreme heat anomaly days (specific satellite data determined after we see what the results looks like), we will overlay both of these in ArcGIS with census block boundaries to visually explore how heat fluctuations vary with respect to socioeconomic concerns and what this means for vulnerability areas.

If analysis allows, we will conduct a series of regressions in RStudio including a combination of socioeconomic factors and percent land cover values to try and determine what causes the variations between heat events. This will allow suggestions on the future effective adaptive capacity of current relief efforts, primarily cooling center locations and warning message deployment.

# IV. Results & Discussion

N/A at this point

# V. Conclusions

N/A at this point

# VI. Acknowledgments

Special thanks to David Hondula for his heavy involvement as the science advisor, helping to guide the project through completion and Dr. Kenton Ross as our NASA science advisor, providing logical and step-wise methods to complete certain aspects of the project and stay on task. Additional thanks go out to Emily Adams and Dan Wozniak, our Center Lead and Assistant Center Lead, for keeping our project progressing, as well as to Jeff Ely, whose geoinformatic expertise of the dnppy module made our data processing of large data sets possible. A special thanks to fellow participant Grant Mercer, whose python expertise has been invaluable to our team. This material is based upon work supported by NASA through contract NNL11AA00B and cooperative agreement NNX14AB60A.

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# VIII. Content Innovation

**Some options under consideration:**

As of now the following content innovation features are under consideration and will be refined as our project progresses:

Data Profile

Executable Papers

Featured Multimedia for this Article (video and podcast options)

Glossary Viewer

Inline Supplementary Material (figures, tables, computer code)

Interactive Map Viewer

# IV. Appendices

Will include in final draft.