

PROGRESS REPORT

Full Title: Understanding Impacts of Desert Urbanization on Climate and Surrounding Environments to Foster Sustainable Cities Using Remote Sensing and Numerical Modeling

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Accomplishments and Activities to date

1. Ron Rindfuss who has been serving as Project Consultant came to ASU and worked with the project team members between Feb 8, 2015 (Sunday) and Feb 12, 2015 (Thursday). He worked closely and interactively with Dr. Myint (PI), Dr. Brazel (Collaborator), and Chao Fan (NASA funded GRA). Dr. Myint, Chao Fan, and Dr. Brazel had a few Skype meetings and teleconference calls with him before he visited ASU. We attempted to get some major items done and some results out before Ron actually came to ASU so that we could make major decision to make changes and complete the global study as soon as possible with regards to population and urban heat island (UHI) effect in desert cities.
2. Huei-Ping Huang (Co-I) and Samy Kamal, PhD student funded by this NASA funded project, used a mesoscale atmospheric model called Weather Research and Forecasting (WRF) to quantify the changes in precipitation and regional airflow pattern associated with land-surface changes due to urbanization in Las Vegas study area. This initial case study used NLCD data in 1992 and 2006. In this study, WRF model and its embedded land surface and urban canopy model are used to simulate effects of urbanization on the local climate of the Las Vegas metropolitan area. High resolution simulations are performed with a 3 km horizontal resolution over the city. With identical lateral boundary conditions, three land use land cover (LULC) maps for 2006, 1992, and hypothetical 1900, are used in multiple simulations. The differences in the simulated climate among

those cases are used to quantify the urban effect. The study found that urbanization in Las Vegas produces a classic urban heat island (UHI) at night but a minor cooling during the day. The daytime cooling is similar to that identified by previous studies for Phoenix, Arizona, indicating that it is a common characteristic of desert cities undergoing urbanization. An analysis of the surface energy balance helps illustrate the major roles of the decreases in surface albedo of solar radiation and increases in the effective emissivity of longwave radiation in shaping the local climate change in Las Vegas. In addition, the emerging urban structures are found to have a mechanical effect of slowing down the climatological wind field over the urban area due to an increased effective surface roughness. The slowing down of the diurnal circulation leads to a secondary modification of temperature, which exhibits a complicated diurnal dependence. A manuscript that reports the results and findings of this study has been revised and resubmitted to Journal of Applied Meteorology and Climatology.

(a) Samy Kamal, Huei-Ping Huang, and Soe W. Myint, 2015. The influence of urbanization on the climate of Las Vegas 3 metropolitan area: A numerical study, Journal of Applied Meteorology and Climatology (minor revision).

3. The classified LCLU layers over the five selected cities have been transferred to Karen Seto (Co-I). She has hired Burak Guneralp as Post-doc Research Associate to simulate urbanization for the selected cities. Karen Seto and Burak Guneralp have completed a land change model to predict future desert cities and their surrounding environments

using different environmental and planning scenarios. We have received simulated land cover land use maps over the three selected cities for 2030 by the end of 2014.

4. The classified LCLU layers over the five selected cities have been transferred to Hui-Ping Huang (Co-I) and Samy Kamal, PhD student funded by this NASA funded project in summer 2014. We have completed regional climate change of each city in summer 2015 using WRF model. A draft journal manuscript that reports the typical changes in the meteorological state, including temperature, precipitation and wind pattern, associated with land-use changes due to urbanization and the circle of influence of urban effects and answers how universal are the urban effects on regional climate will be done in less than a month. In addition, selected WRF simulations for the projection for the future of these five cities have also been completed. We have answered the following research question: what will the future precipitation, temperature and regional airflow patterns in arid and semiarid environments be around desert cities using the predicted land cover and land use change (LCLUC) for 2030?. The third manuscript will also be finished in a few months.
5. Classification of detailed urban land cover classes using 3 QuickBird data over Las Vegas was completed (object-oriented approach). We selected three study areas for using the LUMPS model – strip (84% accuracy), high density residential area on fringe of the city (82% accuracy) and low/medium density residential area in North Las Vegas (74% accuracy). Please note that no ancillary data were used for classification. This study uses remotely sensed data and weather observations to investigate the effect of land cover patterns on urban energy fluxes in semi-arid Las Vegas, Nevada. Specifically, we examine how the components of the surface energy balance vary with land cover composition during the summer. We chose three sub-areas of Las Vegas, Nevada, for our

analysis: the urban core, including "The Strip", the urban fringe at the western border of the city, and an industrial area north of the urban core. We used a GeoEye-1 satellite image covering these areas for October 12, 2011 and an object-oriented classification method to extract six land cover classes from the image. With this land cover classification and observations from the nearby McCarran International Airport weather station as input, we ran the Local-Scale Urban Meteorological Parameterization Scheme (LUMPS) to model the urban energy balance for each sub-area. To validate our model, we correlated the modeled sensible heat fluxes with remotely sensed surface temperatures from a Landsat 8 image for August 3, 2013. We analyzed LUMPS output for the three sub-areas with respect to heating rates, Bowen ratios, cumulative evapotranspiration, and cooling efficiency, i.e., the tradeoff between outdoor water used and atmospheric cooling achieved. We related our results to previous LUMPS studies in Phoenix, Arizona, to see how the two desert cities compare. Our study highlights how anthropogenic changes in land cover, from a desert environment to various urban forms, translates into distinct local climates. A manuscript that reports the above results and findings is under preparation.

(a) Middel, A., S. Kaplan, A.J. Brazel, and S.W. Myint, 2015. Impact of Land Cover on Local Climate - The Case Study of Las Vegas, Nevada (under preparation).

6. We have explored how and if spatial pattern or spatial autocorrelation (e.g., clustered, dispersed) of buildings and impervious surface influences surface temperatures in Las

Vegas. This is treated as an initial case study to understand if spatial configuration or spatial arrangements of a land cover type play an important role in lowering or escalating surface or air temperatures. While the relationship between fractional cover of anthropogenic features (i.e., buildings, impervious surfaces) and the UHI has been well studied, relationships of how spatial arrangements (e.g., clustered, dispersed) of buildings and impervious surface areas influence urban warming are not well understood. The goal of this study is to examine how spatial arrangements of buildings and impervious surface areas influence and shape surface temperature in different urban settings. The study area selected is the Las-Vegas metropolitan area in Nevada, located in the Mojave Desert. An object-oriented approach was used to identify buildings and impervious using a Geoeye-1 image acquired on October 12, 2011. A spatial autocorrelation technique (i.e., Moran's I) that can measure spatial pattern (clustered, dispersed) was used to determine spatial configuration of buildings. A daytime temperature layer in degree Celsius, generated from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image, was integrated with Moran's I values of anthropogenic cover fractions to achieve the goals set in the study. To avoid uncertainty and properly evaluate if spatial pattern of buildings and impervious surface areas has an impact on urban warming, the relation between Moran's I values and surface temperatures was observed at different levels according to their fractions (e.g., 0-0.1, 0.5-0.6, 0.9-1). There is a negative correlation exists between spatial pattern of anthropogenic features and surface temperatures implying that more clustered buildings and impervious surface areas have less impact on the urban heat island (UHI) effect. A manuscript that reports the above study has been published in *Ecosystem Health and Sustainability* by Ecological Society of America.

(a) Myint, S.W., B. Zheng, E. Talen, C. Fan, S. Kaplan, A. Middel, M. Smith, H. Huang, and A. Brazel. 2015. Does the spatial arrangement of urban landscape matter? Examples of urban warming and cooling in Phoenix and Las Vegas. *Ecosystem Health and Sustainability* 1(4):15. <http://dx.doi.org/10.1890/EHS14-0028.1>.

7. We used a global population dataset (i.e., GRUMP/PLACE III data) and global biophysical data (MODIS global data of NDVI and LST) to explore if and how surface temperatures are related to the pattern of demographic growth and other socio-economic parameters in different cities and examine the relationship between desert population, surface temperatures and vegetation. We used Koeppen-Geiger climate classification map to extract desert cities in BSh (dry arid climate found in the low latitudes) and BWh (dry arid climate found in the low latitudes). We agreed to use daytime and nighttime surface temperatures on July 1 (a monthly composite) that represent summer period and on Dec 1 that represent winter period. A 30 to 35 km buffer zone around each city or a group of cities that are closer than 30 km was created to extract rural surface temperatures to compute UHI values. We compute the mean elevation of each city, Mc_i , where $i = \text{city}$. Let R_i be the elevation pixels in the rural buffer for city i . For each rural buffer pixel (R_i) for city i compute the difference between its elevation and the mean for the city: $DR_i = Mc_i - R_i$. This can have a negative or positive value. We look at the values of these differences for each city. If any city has a large number (more than 10%) of negative numbers, flag the city and let's talk about it. Mean (MR_i) and standard deviation ($STDR_i$) of the rural buffer pixels (30-35 km buffer around each city) for each city I were

computed. Threshold value $(d_i) = (MR_i) + 2(STD_i)$. If any 30m x 30m rural buffer elevation pixel, R_i , has a value greater than (d_i) , then the respective temperature pixel (500m x 500m) is excluded from the calculation of the day and night urban heat indices for that city. Compute the day and night urban heat indices for that city (difference between city temperature and temperatures in the buffer). These will be the 2STD heat indices. We exclude values higher or lower than the threshold. If any 30m x 30m rural buffer elevation pixel, R_i , has an absolute value greater than (d_i) . We tested 1 STD, 1.5 STD, and 2 STD, and found that they are highly correlated. Hence, we selected 2 STD. We have also tried a constant elevation threshold. Let CT = the constant elevation threshold. If any 30m x 30m rural buffer elevation pixel, R_i , has an absolute value greater than CT, then the respective temperature pixel (500m x 500m) will be excluded from the calculation of the day and night urban heat indices for that city. If all the 30m x 30m rural buffer elevation pixels have an absolute value greater than CT, then that city, i , will not be included in any of the regression analyses. We tested 300m, 500m and 700m (300CT, 500CT and 700CT heat indices), and came to know that they are also highly correlated. We continued to explore socio-economic parameters in relation to UHI in desert cities. In both summer and winter daytime, the majority of desert cities experience the oasis effect of negative UHIs. At night, summer and winter, far fewer, but some, have negative UHIs. The vegetation planted in desert cities relative to the bare soil in the rural countryside plays an important role in creating the oasis effect in desert cities, as was expected from some case studies. But our findings suggest that there are a wide variety of other factors also responsible, including being near a large water body, being at higher elevations, not having experienced a rainy monsoon, and not having a highly developed

economy. As the first to examine UHI at a global scale without resorting to using idiosyncratic case studies with inconsistent measurement approaches, the methodology used in this study –LST from MODIS and urban extent/population data from GRUMP – permits global examination of UHI phenomena and allows other socio-economic and biophysical variables to be brought into the analysis. As such, it opens the possibility of examining UHI distributions and correlates for a wide variety variables. And it does so with consistent measurement of LST and obtains temperature measurement for all pixels in the rural land buffer rather than just a few points. To what extent should desert cities be encouraged to take steps to lower LST, thus moving to lower UHIs? Given that higher urban temperatures are associated with elevated health risks, the answer would be yes. If lower urban LSTs could be accomplished with building and road materials that strongly reflect solar radiation, with cooling devices that minimize heat build-up, and motor vehicles that emit less heat, then such policies should be encouraged. If the approach is by having more trees and shrubs that are irrigated, the caution needs to be exercised. Of greatest concern would be the source of water and its abundance, with worries involving the nature of underground aquifers and locations downstream from rivers. A manuscript that reports the above findings has been prepared and will be submitted soon to a peer reviewed journal.

(a) Rindfuss, R. S.W. Myint, A.J. Brazel, B. Zhang, and C. Fan, 2015. Urban heat islands: Global variation and determinants in BWh and BSh desert cities (submitted).

8. We also investigated the spatiotemporal patterns of the UHI across multiple desert cities in several countries, and to examine the impacts of biophysical and socioeconomic factors on the UHI. The overall goals of this study are (1) to better understand the impact that the change of spatial distribution and patterns of land use and land cover (e.g., manmade features, vegetation, natural landscapes) within and around desert cities have on the surrounding environments with regards to climate change, and (2) to use this knowledge to support adaptive management in a desert environment and foster sustainable desert cities and their surrounding desert environments in an era of climate variability, uncertainty, and change. We will look at the variability of rural and urban temperatures and associated changes in socioeconomic and biological conditions for a selection of differing desert city regions in the sub-tropics of the globe, using remote sensing and geospatial approaches to answer the following research questions: (1) What are the patterns and rate of change of land cover/land use (LCLU), including desert urbanization, vegetation change and agriculture expansion within and around select desert cities, over time (1985-2010)? (2) What is the relationship between surface temperatures and a) desert urban growth, b) the rate of change of agriculture and c) land cover around desert cities? (3) What is the level of the oasis effect of desert cities and how does the effect in desert environments vary over space and time? (4) How are urban heat island (UHI) and vegetation cover difference between urban and rural related to desert city population? (5) Are surface temperatures related to the pattern of demographic growth in different cities? If yes, how? We found that the surface temperature difference between urban and rural areas is inversely correlated with the NDVI difference. In other

words, larger differences in the greenness between urban area and its rural surroundings lead to a weaker urban heat sink effect. The greener the city is, the cooler the city is in comparison to the desert lands surround the city, and the stronger the urban heat sink effect tends to be. This in part corroborates the finding by others that the difference in the greenness between urban and suburban areas is inversely associated with the daytime UHI for cities across a wide range of climate and geographical zones not restricted to those in arid regions. Instead of NDVI, vegetation fractional cover and EVI were employed to represent the green biomass and vegetation activity. Surprisingly, population is negatively related to the urban-rural temperature difference. In other words, the more population a city has, the cooler the city is compared to the suburban area. This contradicts the finding that the heat island intensity is related positively to the logarithm of the population, as reported in Oke (1973) where he showed that the positive relationship hold for cities in North American and Europe. This is obviously not the case in desert cities. While anthropogenic activities contribute in part to the heat island formation, desert residents also provide cooling effect by bringing greenery into the city, which is a fundamental factor that contributes to the formation of urban heat sink. The relationship varies from city to city, which explains the opposite conclusion made in Oke (1973). Recently, a global study assessed the heat island in 419 cities, and found little evidence that the intensity of heat island is a function of the total population in the city (Peng et al. 2011), that in addition to population, other factors play a more important role in explaining the heat island intensity. The intensity of the urban heat sink also varies with city size. As Figure 4a shows, the difference in greenness decreases exponentially as city size increases. The decline in the NDVI difference (RUVD) is due to the replacement

of agricultural lands and shrub lands with impermeable surfaces, which in turn elevates the surface temperature in the urban area, causing a weaker heat sink effect. A manuscript that reports the above findings have been under preparation.

(a) Myint, S.W., K. Seto, C. Fan, S. Kaplan, H Huang, A. Rahman, A. Brazel, A. Middel, B. Zhang, 2015. Land cover land use change and urban heat island in desert cities (under preparation).