

University College London, May 21-23, 2010

The Comparative Genetics of Cities:

Towards an Integrated Methodology for Pragmatic Urban Decision-making

GLOBAL INSTITUTE
of SUSTAINABILITY
Center for Sustainability Science Applications (CSSA)



The Comparative Genetics of Cities: **Towards an Integrated Methodology for Pragmatic Urban Decision-making**



Cities are becoming increasingly important globally as centers of social and economic life for the majority of world inhabitants. By 2030, about 60% of the global population will be living in urban areas and most of this growth will be absorbed by cities in the developing countries. In many parts of the world the rapid growth of urban populations is already overwhelming urban infrastructures, triggering unsustainable natural resource use and environmental damage, and posing serious challenges for urban governance. The problem of managing growth in cities is compounded by the potential vulnerabilities of their life-support and infrastructure systems to a changing climate. In fact, most solutions to mitigating and adapting to climate change involve dramatic transformations in the way cities are designed and managed, which would also necessitate unprecedented changes in the lifestyle of city-dwellers. There is now a critical need for an evidence-based and future oriented approach to urban planning and management. This approach would require new ways to collect complex city data streams, feed that information into models that help envision the future, and translate those visions into improved urban policies.



The workshop on Comparative Genetics of Cities will explore some of the advances made in examining urban futures with the help of data, models, and visualization technologies developed for two cities in two continents – Greater Phoenix and Greater London. Building on a recently-published Tyndall Centre report on the vulnerability of Greater London to climate change, and the U.S. National Science Foundation's

"Decision Center for a Desert City" project about water management in cities, the workshop offers different ways to present comparative urban data sets, with a particular emphasis on the heat island effect, water supply, land use, and transport. The following key questions will be addressed at the workshop:

- 1) How can urban decision-making be transformed by new data sets and analysis tools?**
- 2) Can cataloguing and classifying urban traits help city leaders learn from each other?**
- 3) Which tools are most appropriate and useful for which stages of urban development?**
- 4) How can we build multi-sector (corporate, government, NGO, academic) urban partnerships?**

The next few pages highlight some of the ongoing research on the future of Greater Phoenix carried out by researchers at Arizona State University. Although the selection of the projects and their presentation are inspired by the Tyndall Center report mentioned earlier, they are not similar or parallel efforts. Each of the two cities has unique trajectories shaped by different natural and historical settings. However, by examining the experience of two contrasting cities—London and Phoenix—we begin to create a methodology based on the assumption that if we could fully delineate all shared urban traits, we would discover patterns and pathways toward curing urban ills, which currently remain hidden. In addition, the comparative perspective will allow us to extend our methodologies beyond the two cities and encompass some of the more serious challenges in managing cities in the developing world.

Scenarios of Future Growth in Phoenix Metro

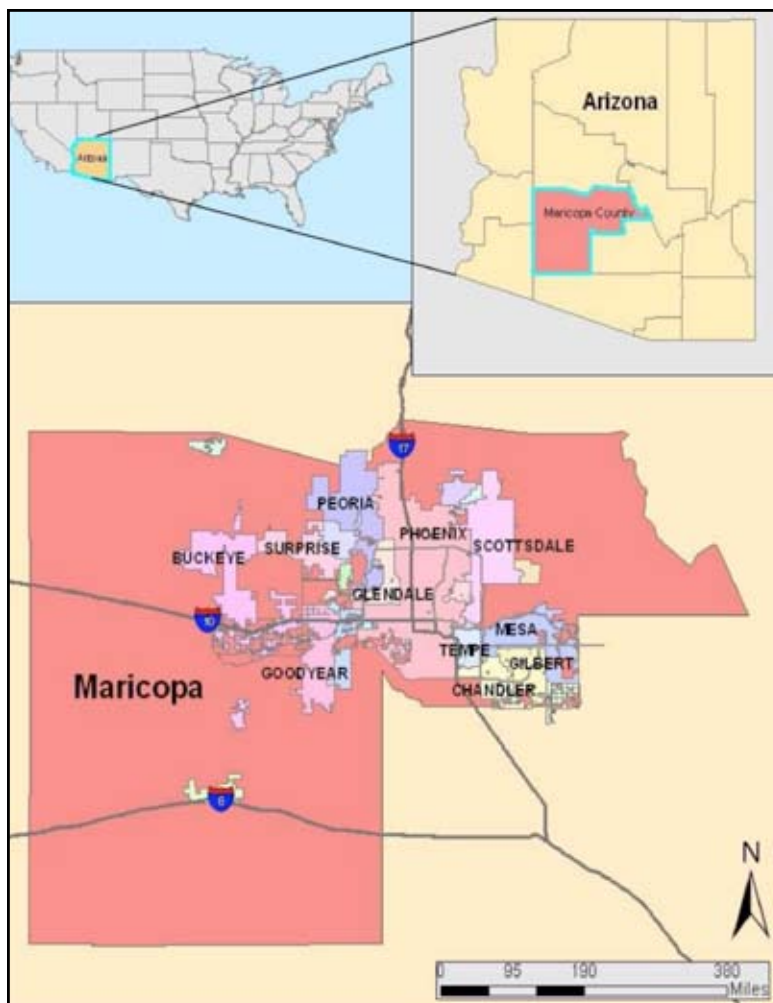
Spatial and temporal dimensions

The Phoenix metropolitan (statistical) area includes Maricopa and Pinal counties within an areal extent of 14,598 square miles. It was home to about 4.2 million people in 2008. Despite the vast urban distention the region is administratively divided into 33 cities and 35 unincorporated communities (see Figure 1). The region's home county, Maricopa, was the fastest growing county in U.S. from 1990 to 2000. The population build-up has sparked the growth of smaller cities in the county as well. Gilbert was ranked 2nd in population increase across all U.S. incorporated places, with Chandler (9th) and Scottsdale (15th) following close behind. According to unofficial projections, Phoenix is currently the fifth largest metropolitan region in the United States having surpassed Philadelphia sometime in 2005 (Wikipedia). Several of these cities, such as Paradise Valley and Sun City, are relatively small enclaves; others such as Phoenix, Mesa, and Scottsdale are large conurbations. These unique features make the Phoenix

metropolitan area an ideal candidate for studying sustainability issues related to rapid urbanization.

Modeling future household patterns

Several scenarios of urban growth for Maricopa County were generated as part of the Digital Phoenix project at Arizona State University. These scenarios were developed with the help of a micro simulation model called UrbanSim. UrbanSim explicitly models the behavior of households, employees, and developers, as they choose their activity location based on the collective choices made by other households, employees, and developers within a given policy environment. Each individual household and employee is a decision-making agent and is modeled separately within the simulated environment. Since UrbanSim generates over arching patterns of urban growth based on aggregation of decisions of individual "agents", it belongs in the category of models known as "agent-based" models.



One interesting policy scenario modeled within UrbanSim modeling environment was the option of holding all State land in Maricopa County off-limits to development for the next 30 years. Congress granted about 8.4 million acres by granting two sections of each township to benefit common schools when Arizona became a territory and another two sections when Arizona became a state. Today, about 8.1 million acres still remains in the Trust, most of it is outside the boundaries of Maricopa County. The Land Department is the entity charged with the fiduciary responsibility to manage and safeguard the land trust in accordance with the Trust's mission. The availability of large tracts of land around the urban area of Phoenix provides enormous leverage for the state of Arizona to direct future developments. The scenarios chosen for this exercise shows the difference in development patterns between allowing state lands to be auctioned as per current rules ("BAU" scenario) and the alternative of freezing all state owned lands in Maricopa county to 2005 levels ("State land" scenario).

As expected, limiting growth on the remaining State Trust land for the next 30 years creates a more compact pattern of development as seen in Figure 2.

Figure 1: Location of Maricopa County and Phoenix

Scenarios of Future Growth in Phoenix Metro ...cont.

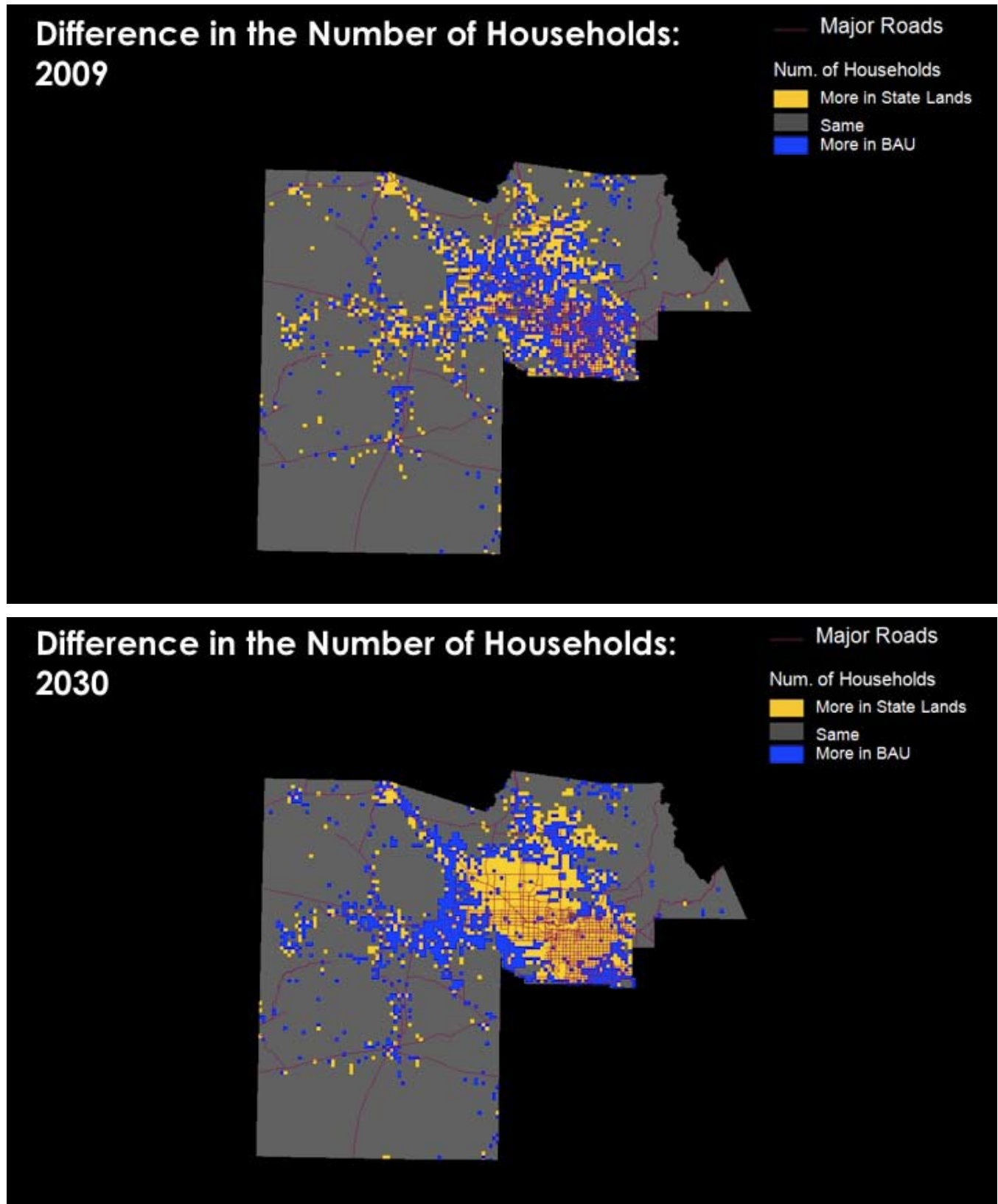


Figure 2: Difference in Growth of Households between the Business as Usual Scenario and Limiting Growth on State Trust Lands Scenarios between 2009 and 2030

Scenarios of Future Growth in Phoenix Metro ...cont.

Estimating Carbon Footprints

Knowing the consumption patterns of households can provide an effective means for determining carbon footprints at various spatial scales, from neighborhood to metropolitan regions. By shifting our focus from the spatial location of the source of carbon emissions (i.e., production centers) to the location of the source of consumption, we acknowledge that carbon emissions are equally deleterious regardless of where it occurs. In doing so we focus more on the patterns of consumption rather than production strategies as being among the most significant issues related to carbon emissions. Our approach, however, does not account for embedded energy related to building construction, and carbon emissions from natural gas, water, and sewage disposal. Our strategy also provides a particularly useful and straightforward path to future projections of carbon emissions. This is accomplished with the assumption that technologies of production are static and consumer lifestyle choices remain the same over time (but vary by type of households). Although these are limiting assumptions, the projections provide the upper range of estimates for future emissions considering changes in energy mix and production technologies. In addition to the projections that are instructive for the purposes of planning for GCC impacts, we also offer a new form of visualization that conveys more spatially-based information in a three-dimensional format than a color coded thematic map.

Household Categories		Basket of Goods (and their impact on CO ₂ emissions for each \$)	
Family size:	1-8	Food	
Income class:	1. Less than \$5,000	Cereals & Bakery products:	741 gCO ₂ /\$
	2. \$5,000-\$9,999	Meat, fish and protein:	1452 gCO ₂ /\$
	3. \$10,000-\$14,999	Dairy:	1911 gCO ₂ /\$
	4. \$15,000-\$19,999	Fruits and vegetables:	1176 gCO ₂ /\$
	5. \$20,000-\$29,999	Food away (eating out):	368 gCO ₂ /\$
	6. \$30,000-\$39,999	Others:	
	7. \$40,000-\$49,999	Household items:	459 gCO ₂ /\$
	8. \$50,000-\$69,999	Services:	178 gCO ₂ /\$
Race:	9. \$70,000 <		
	White Hispanic African American or Black American Indian, Alaska Native Asian		

Figure 3: All households are coded into categories depicted by a three-digit code. The first digit denotes the number of household members, the second digit represents the income class (from the eight shown above), and the last digit denotes the race / ethnicity of the head of household. The bar chart below shows the consumption of electricity and other consumables by the household categories indicate on the x-axis

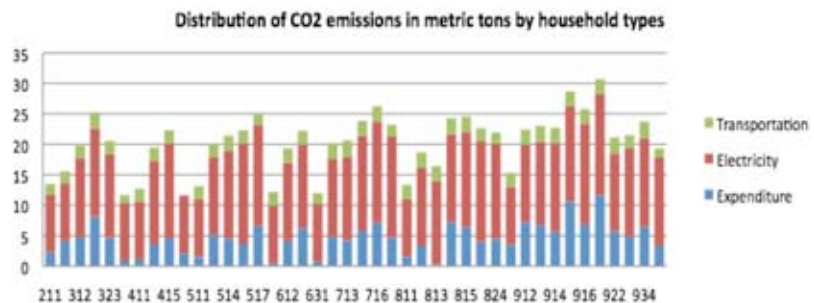


Figure 4: Distribution of CO₂ emissions in metric tons by household types

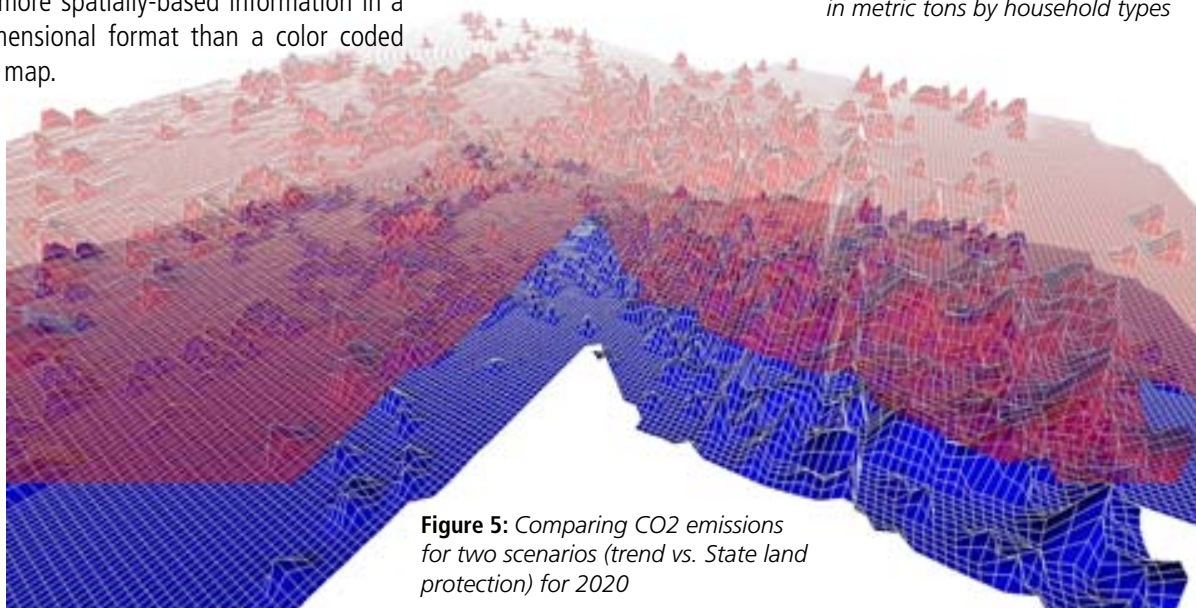
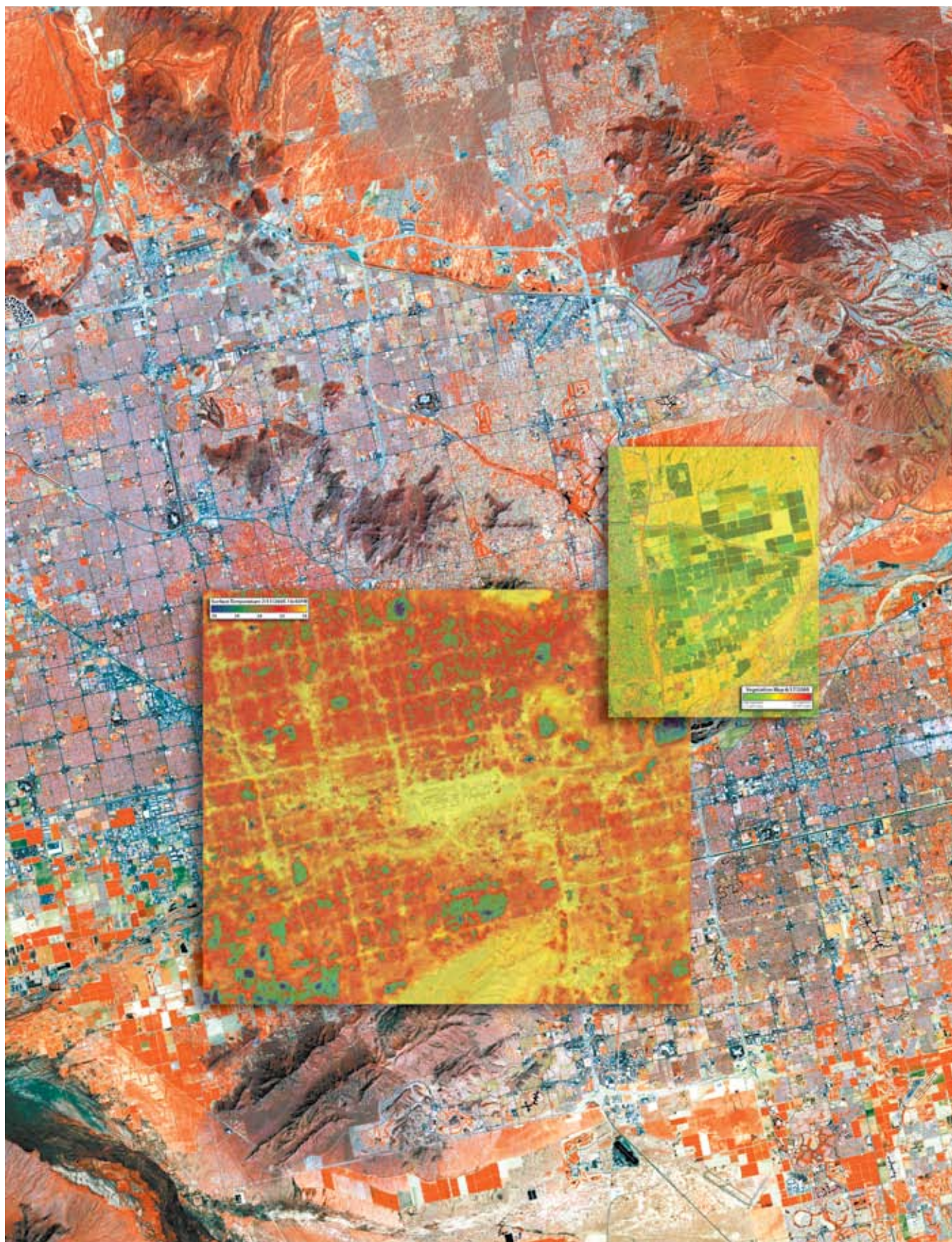


Figure 5: Comparing CO₂ emissions for two scenarios (trend vs. State land protection) for 2020



PHOENIX, ARIZONA — MARCH, 2003

COLOR RED REPRESENTS VEGETATION



Contribution of Land Use Changes to Near Surface Air Temperatures During Recent Summer Extreme Heat Events in the Phoenix Metropolitan Area

Introduction

The goal of our urban regional atmospheric modeling is to improve the performance of the Weather Research and Forecasting (WRF) model for the Phoenix (Arizona, USA) metropolitan region to enable scenario simulations and process studies that are of interest to urban planners and the scientific community. For example, recent efforts (Grossman-Clarke *et al.* 2010) focused on the understanding of the contribution of historic land use/cover (LULC) changes to 2 m air temperatures (T_{2m}) in the Phoenix Metropolitan area during extreme heat events (EHEs).

During three decades of rapid urbanization the population of the Phoenix metropolitan region increased by ~45% per decade from about 971,000 to nearly 4 million currently. This increase in population was accompanied by an increase in minimum nighttime air temperature differences between urban and rural sites of up to 10 K (Brazel *et al.* 2007). It is expected that the population will grow to ~10 million by 2050. Between 1900 and 1995 there was a transition from predominantly irrigated agricultural to suburban land use in the region. However, currently large tracts of undeveloped Sonoran desert are being converted to urban land use.

Expansion of cities to accommodate increasing population has global, regional and local effects on weather and climate due to LULC changes and accompanying effects on physical processes governing energy, momentum, and matter exchange between land surfaces and the atmosphere. Urbanization significantly impacts regional air temperatures, wind fields, the evolution of the planetary boundary layer and precipitation, subsequently influencing air quality, human comfort, and health.

Here the WRF model is applied in order to investigate how historic (1973-2006) LULC changes during a period of rapid urbanization of Phoenix contributed to the spatial extent and intensity of four most recent summer EHEs in the region. Multi-day EHEs strongly influence human comfort and health in the Phoenix region.

Arizona led the United States in deaths from heat exposure between 1993-2002 (Harlan *et al.* 2006).

EHE	MAXIMUM	MINIMUM
25-28 June 1979	47.2	26.7
07-09 June 1985	46.1	27.8
21-23 June 1988	46.7	31.7
03-05 July 1989	47.8	30.6
25-28 June 1990	50.0	33.9
26-29 July 1995	49.5	31.7
12-16 July 2003	46.7	35.6
12-17 July 2005	46.7	33.9
21-24 July 2006	47.8	35.0
03-06 July 2007	46.7	33.9

Table 1: EHEs and the highest recorded maximum and minimum daily temperatures (°C) during each period for Phoenix Sky Harbor station (1961-2008).

EHEs were identified based on three criteria that are related to the exceedance of two T_{2m} thresholds (T_1 , T_2 ; 97.5th and 81st percentile of the distribution of maximum temperatures) for recorded summer time air temperatures (June to August) between 1961 and 1990 (Huth *et al.* 2000). For the National Weather Service's Sky Harbor Airport station, in the center of the Phoenix urban region, T_1 and T_2 are 45.5 °C and 43.3 °C, respectively. Table 1 lists the ten EHEs identified for the Phoenix metropolitan region between 1961 and 2008 plus their highest recorded maximum and minimum temperatures.

Land use data and scenario simulations

Landsat satellite Multi spectral Scanner System data for 1973, 1985, 1998, and 2005 were analyzed to derive LULC using the procedure of Stefanov *et al.* (2001). The data were incorporated into WRF (Figure 1) by including three urban land use classes: urban built-up, urban mesic residential and urban xeric residential, which are distinguished by the type of vegetation and irrigation (no vegetation, well watered flood or overhead sprinkler irrigated, and drought-adapted vegetation with drip irrigation, respectively).

Hourly anthropogenic heat flux values were added to the urban sensible heat fluxes in WRF. They are based on the monthly energy consumption and average vehicle kilometers traveled per person (Sailor and Lu 2004). Maximum values for the built up urban, xeric and mesic residential areas are ~30, 35 and 20 W m⁻². In order to sustain landscape vegetation in Phoenix, irrigation is necessary for most months of the year. For urban vegetation, as well as irrigated agricultural land, the soil moisture content was adjusted in WRF.

Simulations were conducted for four EHEs during the last decade (Table 1), i.e. For 12-16 July 2003, 12-17 July 2005, 21-24 July

Contribution of Land Use Changes to Near Surface Air Temperatures During Recent Summer Extreme Heat Events in the Phoenix Metropolitan Area ...cont.

2006 and 03-07 July 2007. The simulations for each EHE were carried out with the LULC data for 1973, 1985, 1998 and 2005. 2-way nested WRF model runs with four domains and resolutions of 54, 18, 6 and 2 km, respectively were performed. The lowest prognostic level was approximately 10 m AGL. The innermost domain included the Phoenix metropolitan area, surrounding desert and agricultural land.

Results and Discussion

The results indicate consistent significant contributions of urban development and accompanying LULC changes to extreme temperatures for the four EHEs. Simulations suggest new urban developments caused an intensification and expansion of the area experiencing extreme temperatures, but mainly influenced nighttime temperatures with an increase of up to 10 K. Nighttime temperatures in the existing urban core showed changes of up to ~2 K with the ongoing LULC changes. Daytime temperatures were not significantly affected where urban development replaced desert land (increase by ~1 K), however maximum temperatures increased by ~2 to 4 K when irrigated agricultural land was converted to suburban development. This study shows that regional atmospheric models provide a useful tool to understand complex interactions that underlie observed atmospheric responses. In recent years a better description of urban surface processes in mesoscale atmospheric models has been emphasized and increasingly allows the application of the models to improve understanding of regional to neighborhood meteorological processes.

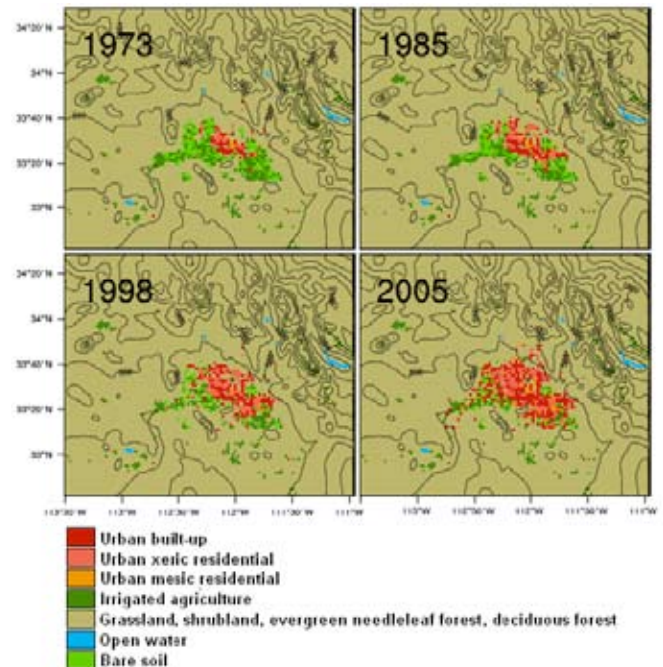


Figure 6: Topography (contour from 0 to 3000 m interval 250 m) and LULC for 1973, 1985, 1998 and 2005 (2 km x 2 km grid resolution).

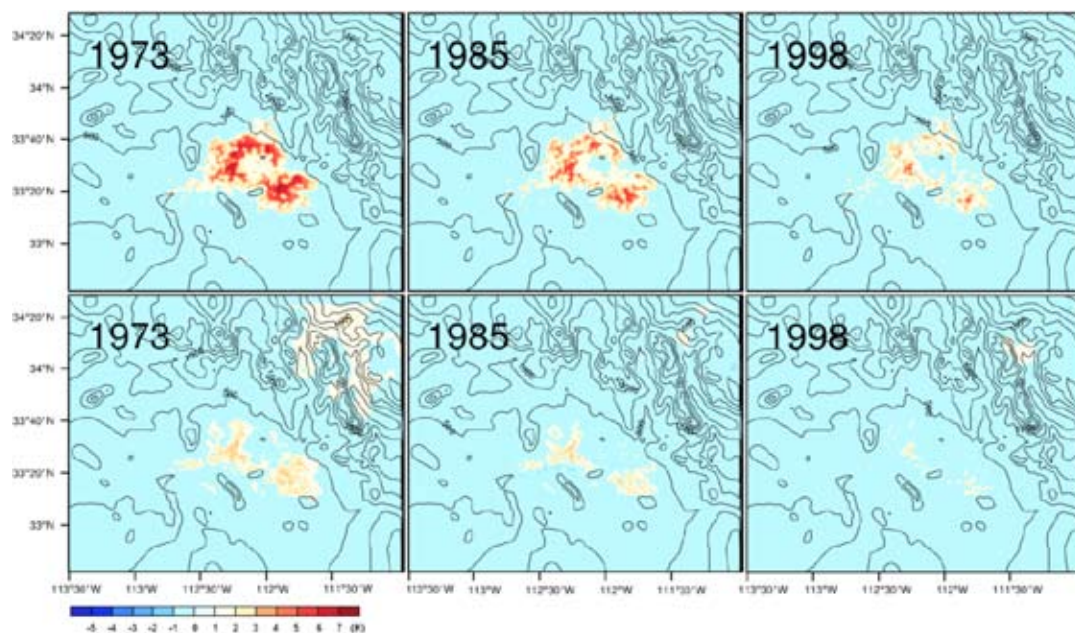


Figure 7: .shows the average difference (18 simulated days of the considered EHEs) T2m between 2005 LULC and (columns) historic LULC data (1973, 1985, 1998) for (top row) 0500 LST (~daily minimum temperatures) and (bottom) 1700 LST (~daily maximum temperatures).

Comparative Study of Surface temperature between London, UK and Phoenix, USA

Urban climate studies have been concerned about the difference in observed ambient air temperature between cities and their surrounding rural regions. This study aims to compare and investigate the difference of surface temperature and urban heat islands (UHIs) between London, UK and Phoenix, USA.

Data used in this study is ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer). We used the AST_08 product, and applied the formula (band Surface Kinetic Temperature /10)-273.15 to obtain the surface temperature map (as figures below) with unit centigrade. Data selected are Sept. 2003 and July 2006 for London, and June 2003 and March 2007 for Phoenix.

The scenes cover an area of around 64 km by 64 km. Results show that the temperature range in the London region is from 12 to 48 in year 2003, and from -6 to 69 in year 2006. The average temperature rose by 9 centigrade. For the Phoenix region, the average temperature decreased from the two time

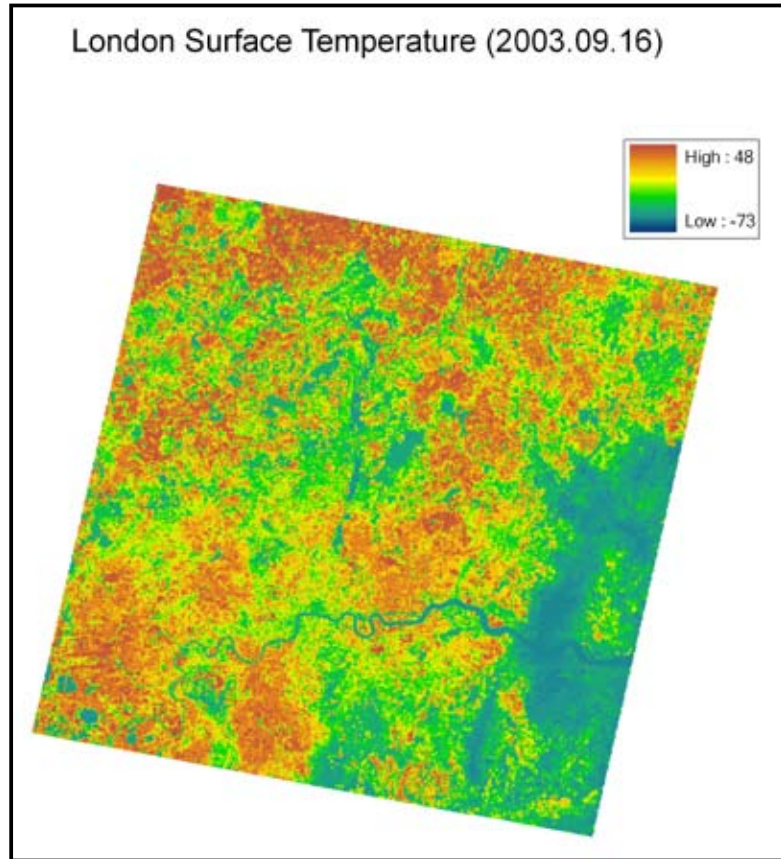


Figure 8: 2003 ASTER scene of surface temperature for London

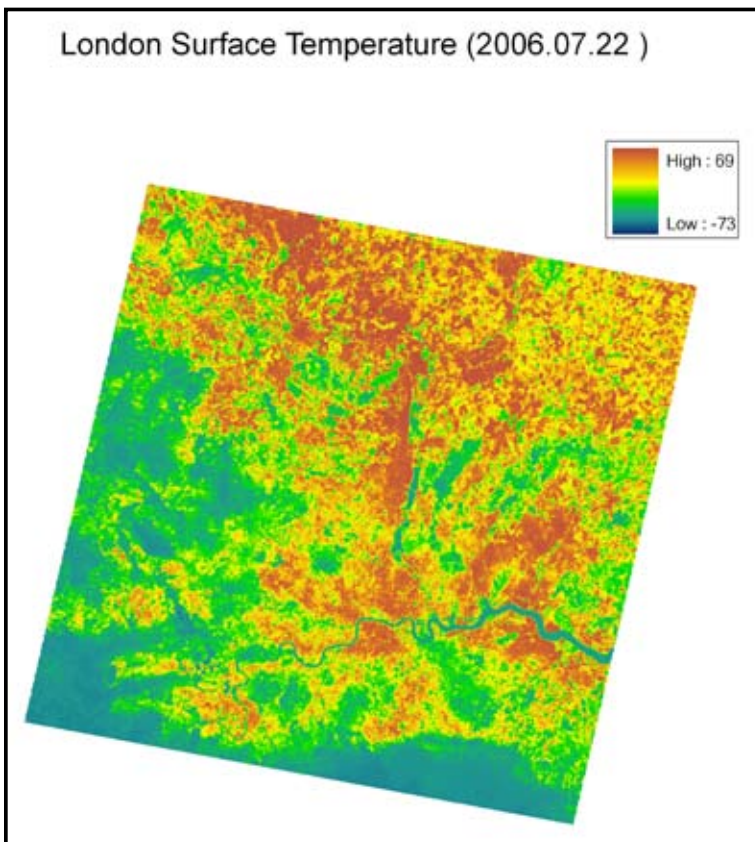


Figure 9: 2006 ASTER scene of surface temperature for London

Comparative Study of Surface temperature between London, UK and Phoenix, USA ...cont.

points, i.e. June 2003 to March 2007, potentially because the different seasons of the scenes affect the accuracy of the results. The temperature range is 14 to 39 in year 2003, and -4 to 19 in year 2007. Viewed from the difference between London and Phoenix, the overall surface temperature in Phoenix is lower than London. Perhaps the relative cooler mountain areas in Phoenix average the mean values. Future work includes the selection of a study area comparable for both London and Phoenix, e.g. Urban area, or urban to rural area. The imagery need to be carefully selected for the same time/season of different years (currently the data used for Phoenix are from the existing 100 cities database). Finally, in the current initial results, background data were involved in data statistics, and needs to be excluded in the future analysis.

(Note: the lowest value of -73 is due to the background of the scene; for the lowest temperature of the regions of the two cities, please see the text).

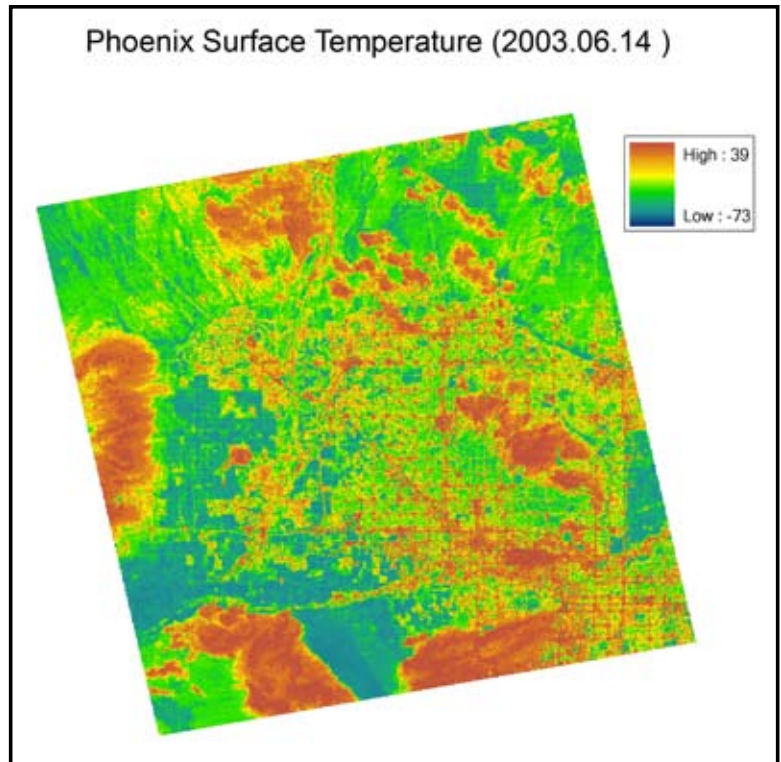


Figure 10: 2003 ASTER scene of surface temperature for Phoenix

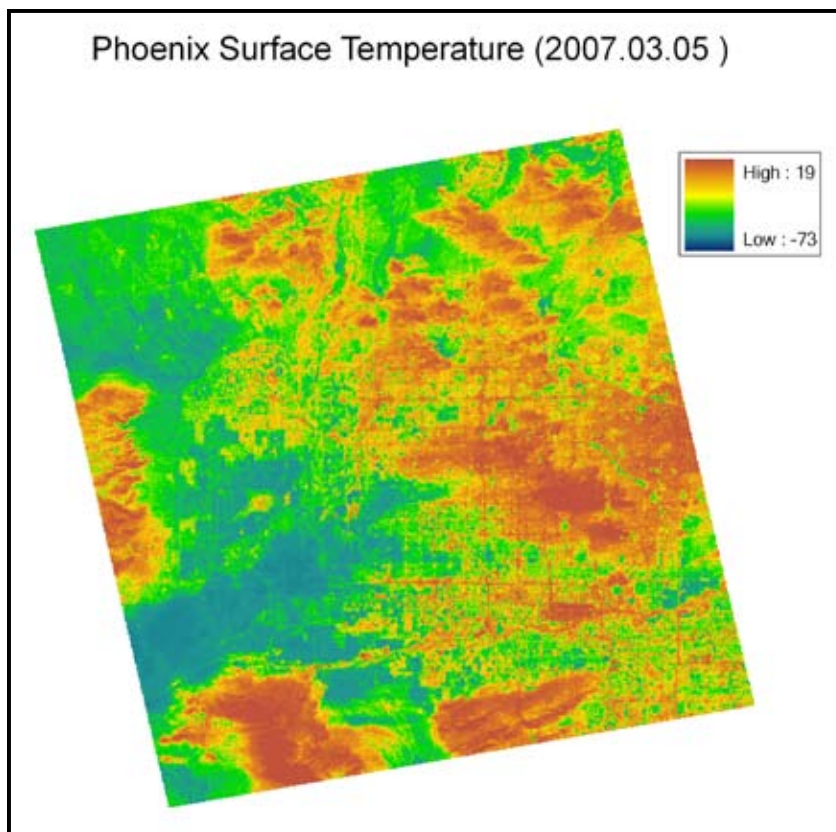


Figure 11: 2007 ASTER scene of surface temperature for Phoenix

Food and Urban Agriculture

Background

Urban and peri-urban agriculture have been persistent features of our landscapes. Increasing consumer concerns about the food supply — both in relation to food security and the environmental impacts associated with food production and transportation from distant locations — are leading to increases in local agriculture, typically through farmers' markets and community gardens. In addition, the recent economic recession and subsequent income and food insecurity could have prompted the increase of such urban agriculture and food provisioning systems. These practices may also have important repercussions for urban resilience in the face of global change.

Findings

We have started to examine the relationship between spatially explicit sociodemographic data and sub sectors of urban and peri-urban agriculture in Phoenix, AZ. We found that community gardens were found in more socioeconomically disadvantaged areas than farmers' markets (e.g., lower median household income, more renters, fewer college graduates, and more minorities in neighborhoods surrounding gardens than markets). We believe that these types of urban agriculture are thus serving different populations and are responding to different trends. Community gardens are a response to food insecurity related to economic insecurity, while markets are more of a response to discontent with the conventional food system among the socioeconomically advantaged. However, interview data suggest that community gardens are more important in building community ties than alleviating food insecurity.

Furthermore, we recognize that these subsystems are only a small component of urban agriculture and we have also started to look at how bigger industries such as dairies are responding to these economic and environmental pressures.

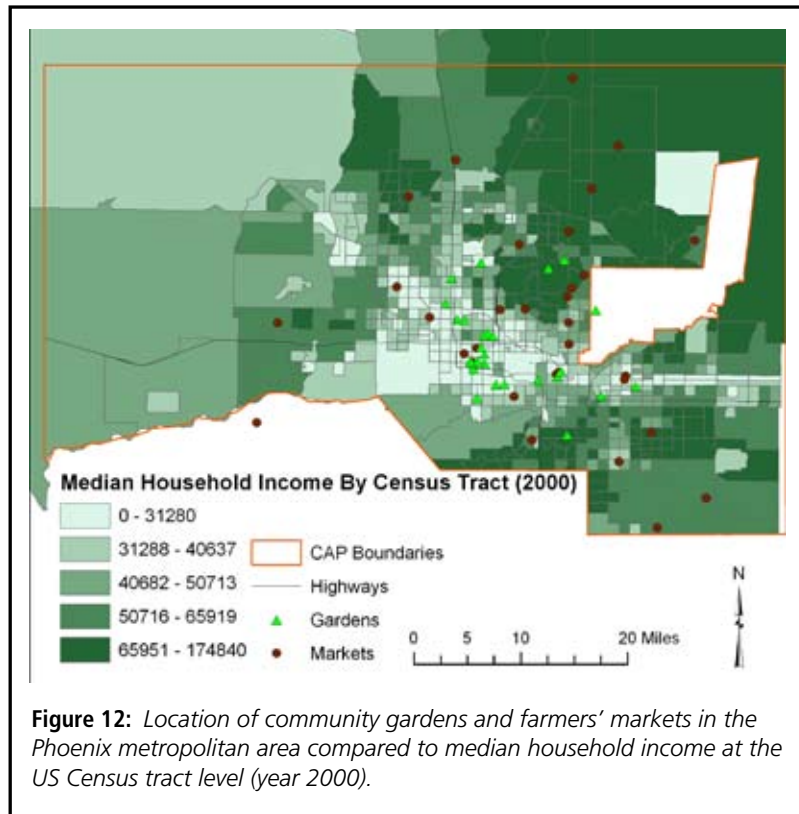


Figure 12: Location of community gardens and farmers' markets in the Phoenix metropolitan area compared to median household income at the US Census tract level (year 2000).

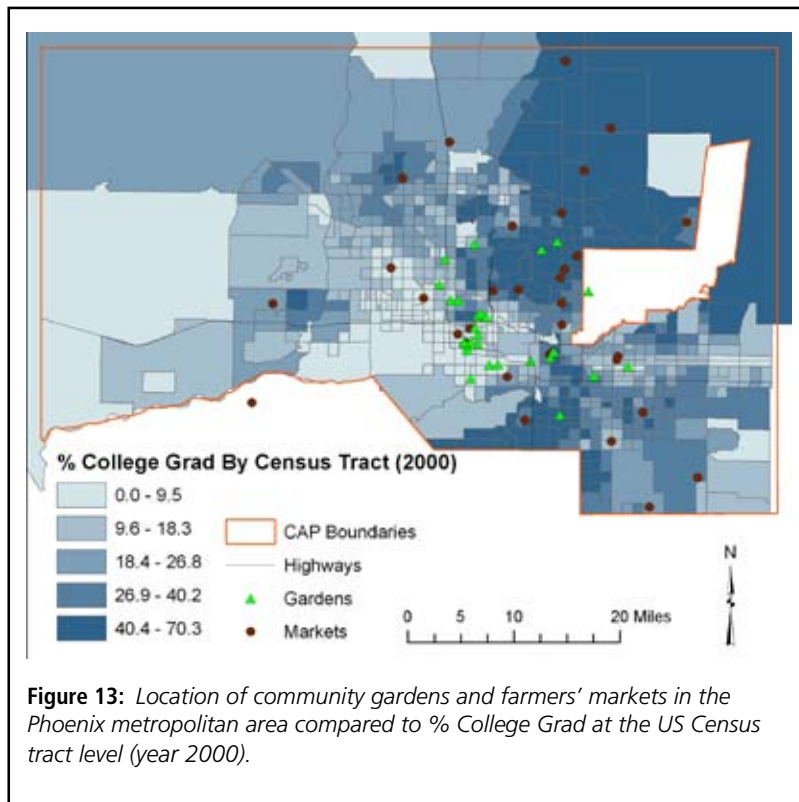


Figure 13: Location of community gardens and farmers' markets in the Phoenix metropolitan area compared to % College Grad at the US Census tract level (year 2000).

Food and Urban Agriculture ...cont.

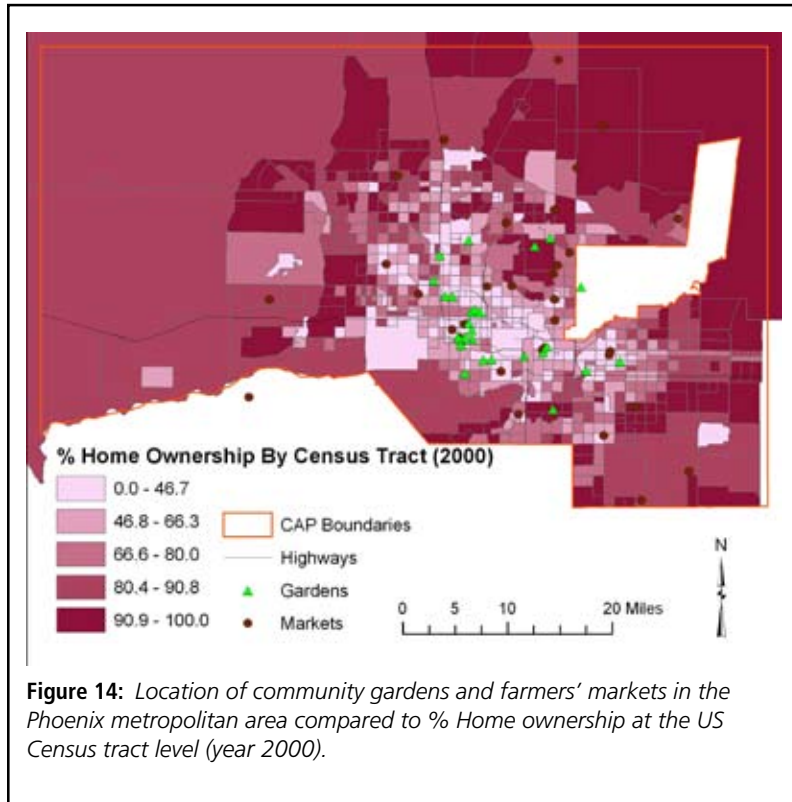


Figure 14: Location of community gardens and farmers' markets in the Phoenix metropolitan area compared to % Home ownership at the US Census tract level (year 2000).

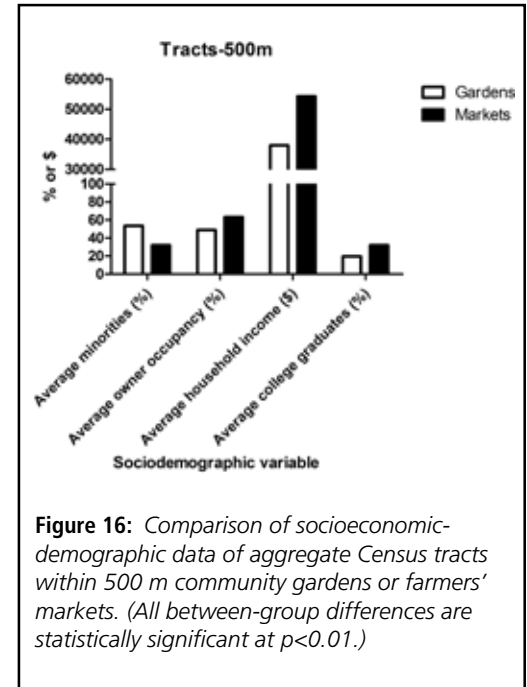


Figure 16: Comparison of socioeconomic-demographic data of aggregate Census tracts within 500 m community gardens or farmers' markets. (All between-group differences are statistically significant at $p < 0.01$.)

Future Directions

Future research should focus on comparing these results with other urban areas and examine if these correlations with sociodemographic data exist, and if responses to environmental and economic pressures are similar. Many unanswered questions remain about the current role of urban agriculture in shaping the dynamic socio-ecological relationships of cities, and the various ecosystem services trade-offs entailed by transitions to local agriculture. We need a better understanding of the feedbacks between such farming, urban communities, and external pressures and uncertainties in order for policy-makers to properly utilize urban agriculture in increasing the sustainability and adaptive capacity of cities and food systems in the face of mounting environmental stresses. For example: what role can urban agriculture play in closing phosphorus and nitrogen cycles, what role can urban farming have in simultaneously decreasing urban heat island and increasing food security, and how does a transition towards increased urban agriculture affect potentially constrained urban water supplies?

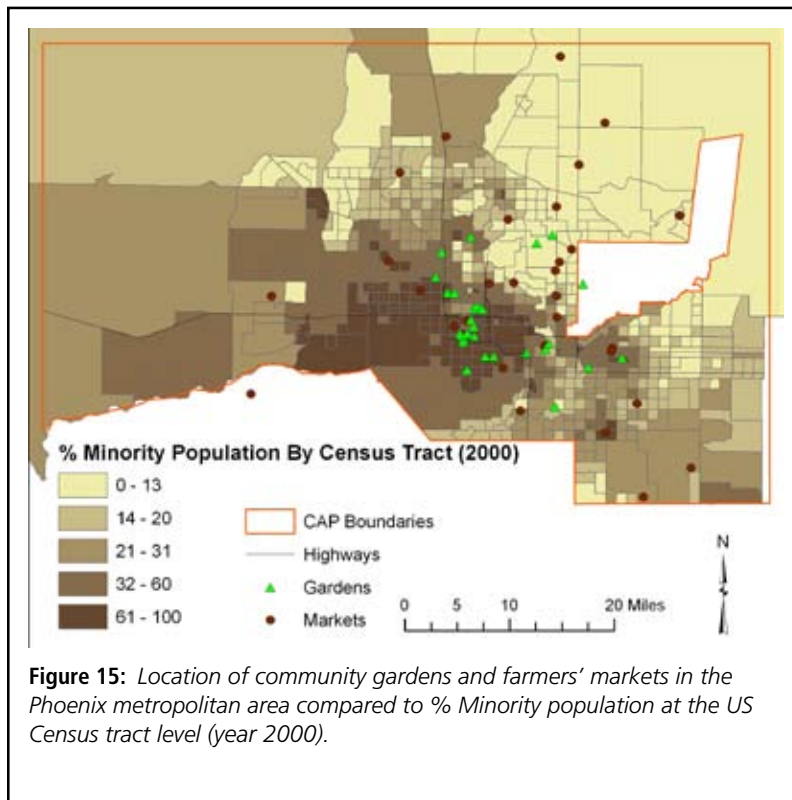


Figure 15: Location of community gardens and farmers' markets in the Phoenix metropolitan area compared to % Minority population at the US Census tract level (year 2000).

Comparative Vegetation Greenness of London and Phoenix

Background

This study aims to compare and investigate the difference of vegetation cover between London, UK and Phoenix, USA, by assessing spectral reflectance data captured by satellite-borne imagery. Data used in this study is from the ASTER satellite platform and were acquired on April 7, 2000 and September 9, 2005 for London, and May 5, 2000 and April 1, 2005 for Phoenix. The scenes cover an area of around 64 km by 64 km. We used the AST_L1B product, and applied the Normalized Difference Vegetation Index (NDVI) to obtain vegetation spatial distribution maps (see figures); NDVI values can vary between -1.0 and +1.0, with higher NDVI values indicating denser and healthier vegetation.

Findings

The results show that the mean NDVI in the London is 0.299 in year 2000, and 0.352 in year 2004. The increase of 18 percent is quite likely due to the seasonal difference between the two images. Un-surprisingly, the overall NDVI in Phoenix is much lower than that in London. In the Phoenix region, the mean NDVI is -0.008 in year 2000, and 0.092 in year 2005. Here, too, the difference may be due to seasonal effects, since vegetation in April could be more abundant due to the lower temperatures and temporal proximity to the winter rainy season. "Hot spots" of vegetation appear to be oppositely located in the two cities; in the case of London, the most vegetation is situated outside the urbanized core, whereas in Phoenix many areas of great vegetation occur inside the urbanized core, as well as in the agricultural areas of the urban periphery, while the surrounding desert shows little greenness. This is not, however, the full picture; native desert vegetation does not show as strong a spectral response in the red and near infrared bands (which are used to calculate NDVI) as more lush, mesic vegetation. Thus, NDVI does not fully capture the full array of vegetation in a city like Phoenix.

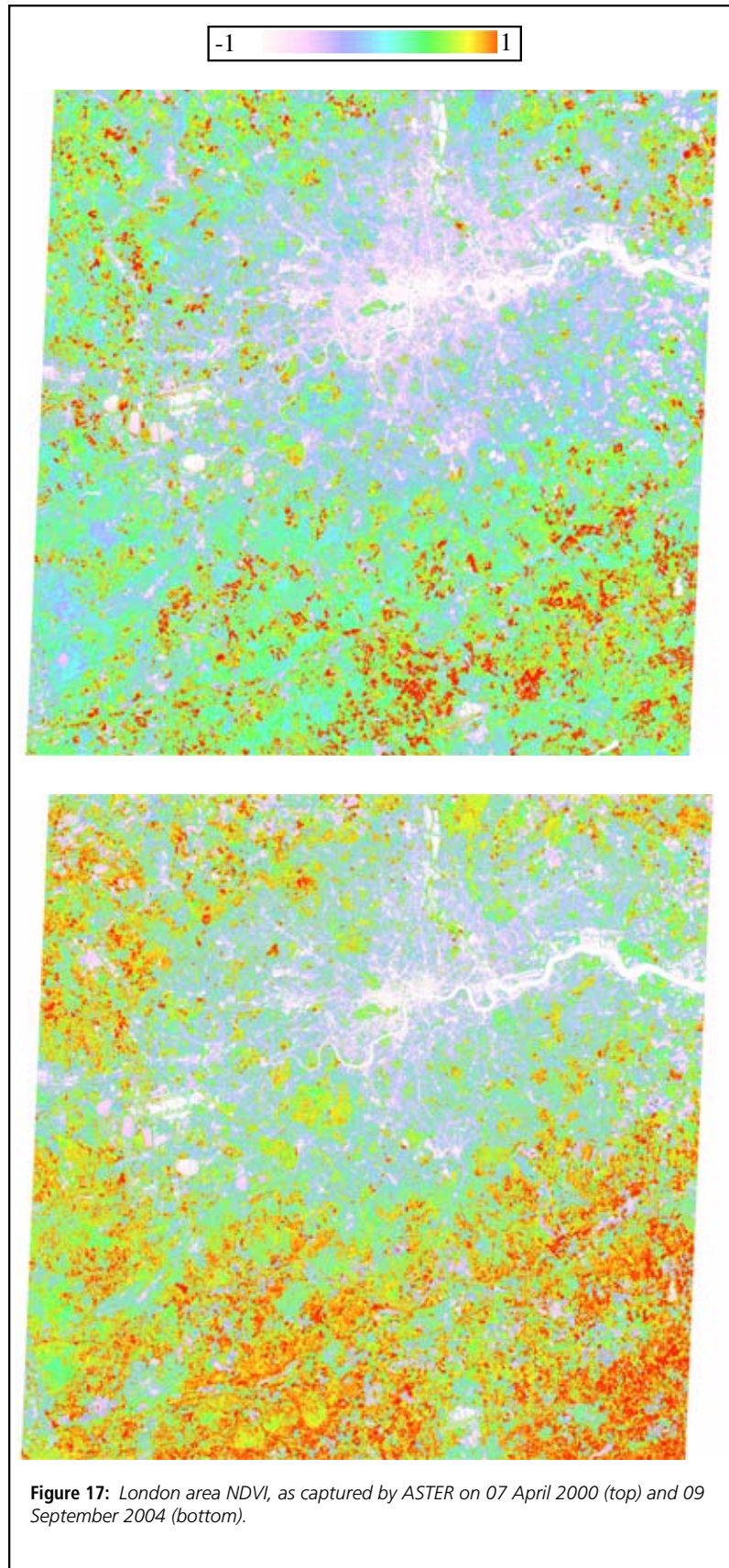


Figure 17: London area NDVI, as captured by ASTER on 07 April 2000 (top) and 09 September 2004 (bottom).

Comparative Vegetation Greenness of London and Phoenix ...cont.

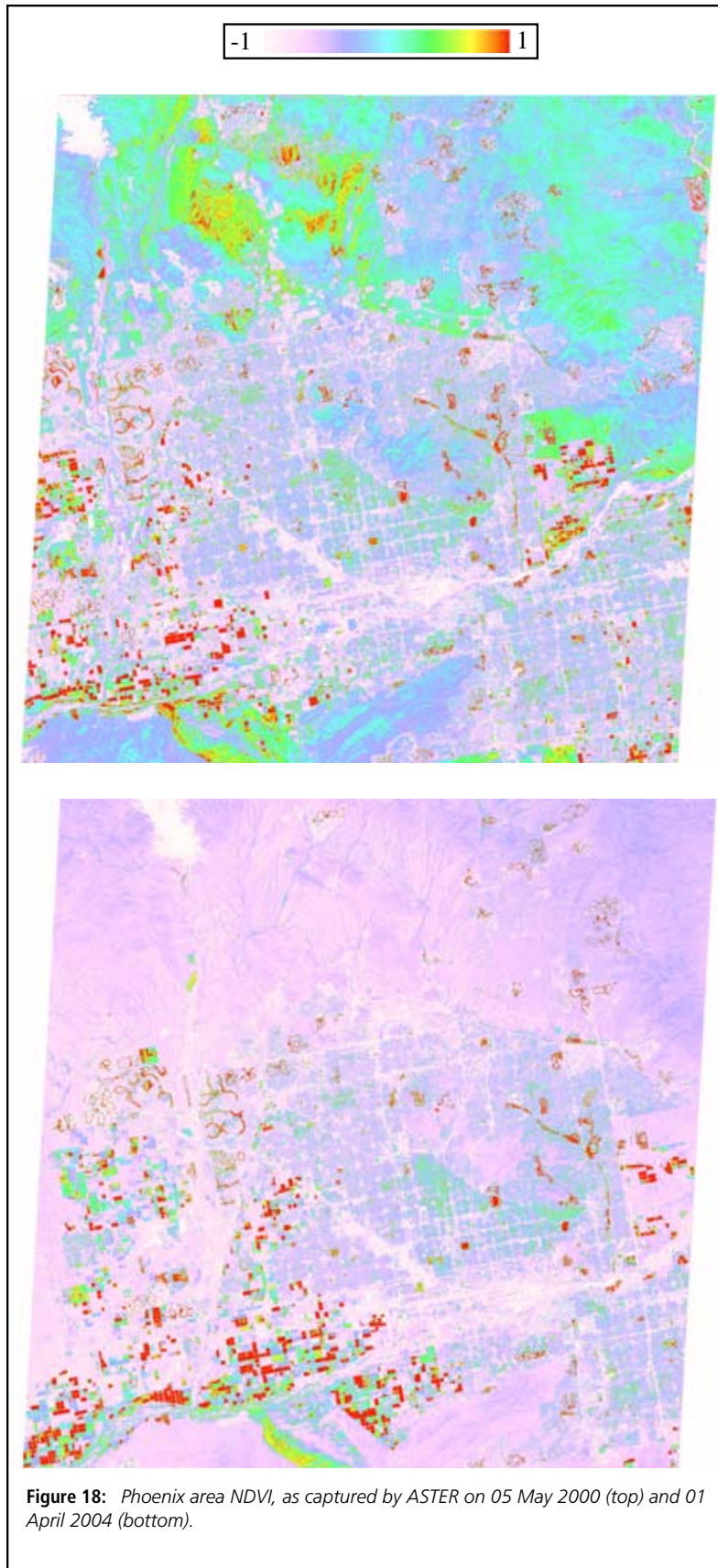


Figure 18: Phoenix area NDVI, as captured by ASTER on 05 May 2000 (top) and 01 April 2004 (bottom).

Future Directions

Future work includes the selection of a comparable study area, both spatially (e.g. Urbanized area, or urban to rural area) and temporally (e.g., same time/season among compared images). Here, the data we used was limited by what was available in the existing 100 Cities database. Collecting and analyzing a long-term data set should also be a priority, as it would allow for longitudinal studies of seasonal vegetation dynamics and fluctuations in greenness: do ebbs and flows in greenness follow the same seasonal trends in both cities? Also, more detailed spatial analysis of greenness hot spots is needed, allowing for comparison of greenness trends with socioeconomic indicators; what correlations exist between socioeconomic factors and vegetation cover? Finally, this work can yield interesting insights when linked to other projects, such as urban agriculture. In an arid environment like Phoenix, water use is a key concern, yet lush vegetation is a result of significant outdoor watering strategies. Identifying areas of vegetation greenness can offer targeted intervention areas when a transition towards edible landscapes and non-decorative vegetation from the current landscape covers take place, thereby allowing for a potential higher use of already irrigated landscapes.

How Can We Develop Tools for More Targeted CO₂ Mitigation in cities?



Some estimates argue that 80% of global carbon dioxide emissions originate from urban areas (Churkina, 2008). However, these are not uniformly distributed and transportation emissions in particular contribute to large variations in emissions from different parts of cities (VandeWeghe & Kennedy, 2007).

Tools are now available to better understand these emissions at finer spatial scales. Inspired by work done in London by Duncan Smith and CASA and

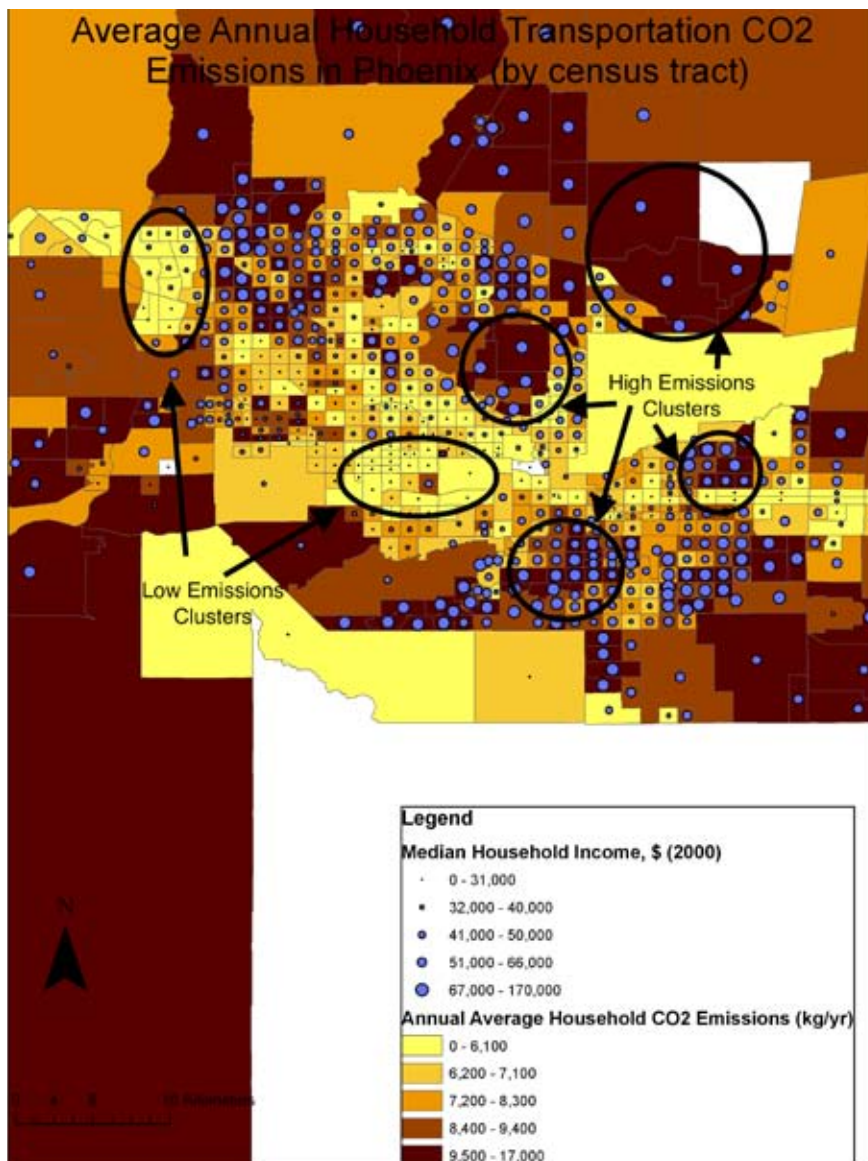


Figure 19: Annual CO₂ emissions from household transportation in Phoenix (average kg CO₂/household). Phoenix census tracts are shaded according to the average CO₂ emissions per household from private vehicle operations in 2001. Some examples of clusters of high and low emissions households are identified. Blue dot sizes correspond to the median household income in each census tract according to 2000 census data.

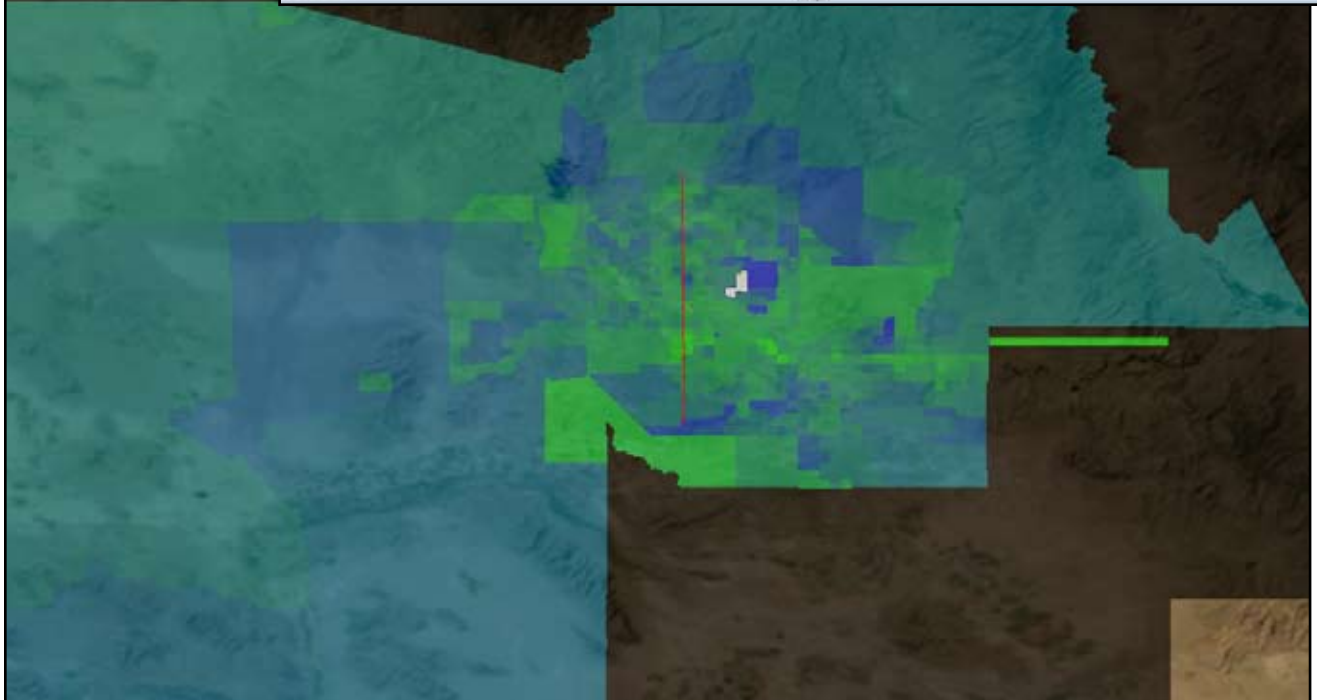
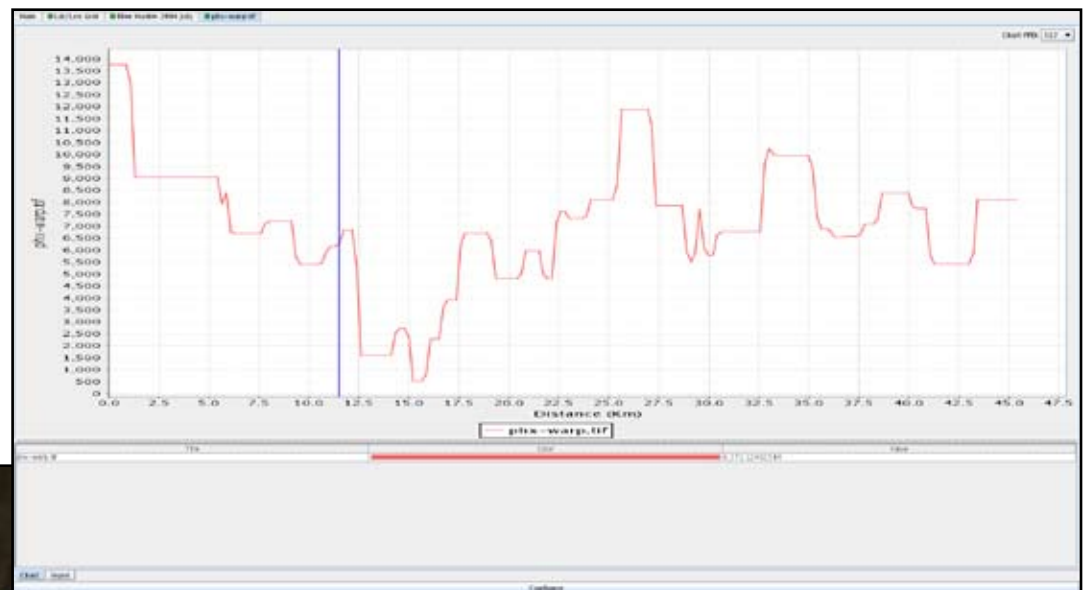
How Can We Develop Tools for More Targeted CO₂ Mitigation in cities? ...cont.

presented at the January 2010 meeting prior to this workshop, we developed a similar approach to understand transportation emissions in Phoenix and see how this type of analysis could be applied to other cities.

Using U.S. National Household Travel Survey data, we generated a map for Phoenix household transportation emissions. Through this are able to identify clusters of high and low emissions households that could inform more targeted mitigation efforts. Current efforts are under way to develop predictive emissions models based on characteristics of urban form and demographics.

These data were also rasterized and then uploaded to the JEarth tool developed by ASU's Mars Space Flight Facility. Ultimately we hope to use the JEarth platform to provide open access and on-the-fly analytic capabilities for understanding emissions across transects in multiple city. Incorporation of remotely sensed pollution data is also a possibility through MODIS satellite data.

Figure 20: CO₂ emissions displayed in the analytical GIS application JEarth. The graph shows CO₂ fluctuations along a North-South transect through the center of the Phoenix Metropolitan area (red line on map).



Acknowledgments

This report was produced by the Arizona State University Center for Sustainability Science Applications (CSSA), which is affiliated with ASU's Global Institute of Sustainability (GIOS) and the School of Earth and Space Exploration (SESE).

Arizona State University Research Contributors:

Dr. Subhrajit Guhathakurta¹, Dr. Susanne Grossman-Clarke², Lela Prashad³, Laura Biggar⁴, Edward Burgess⁴, Wen-Ching Chuang⁴, Arijit Guha⁴, Genevieve Metson⁴, Sainan Zhang⁴, Robin Cleland⁵, Benjamin Jewell⁵

¹*School of Sustainability and School of Geographical Sciences and Urban Planning*

²*Global Institute of Sustainability*

³*School of Earth and Space Exploration*

⁴*School of Sustainability*

⁵*School of Human Evolution and Social Change*

Research support:

Spring 2010 ASU School of Sustainability Urban Remote Sensing Reading Group

Technical support from the ASU Mars Space Flight Facility:

Scott Dickenshied, Eric Engle, Dale Noss

Graphic Design and Printing by the Mars Education Print Team:

Chris Capages, Meg Hufford



