MEMORANDUM

To: Paul English, CDPH and Erin Simms, CSTE

Re: Heat Vulnerability Assessment

From: ZevRoss Spatial Analysis

Date: April 2009

ABSTRACT

Temperatures and climate effects in urban areas are often described in terms of urban heat islands (UHI) and can be measured in a number of different ways. The occurrence of UHI “represents human-induced urban/rural contrast mainly caused by the replacement of vegetation by non-evaporating and impervious materials such as asphalt and concrete”(Pu et al. 2006). The growing concern with UHI and urban hotspots stems from this phenomena of increased surface temperatures and its effects on populations, but also from the profound impacts UHI can have on thermal, moisture, radiative and aerodynamic properties of a city as compared to its adjacent natural or sub-urban surroundings (Gluch, 2006). Here we discuss a number of methods for measuring land surface temperatures as well as provide descriptions of available data sources and our recommendations for completing heat vulnerability study.

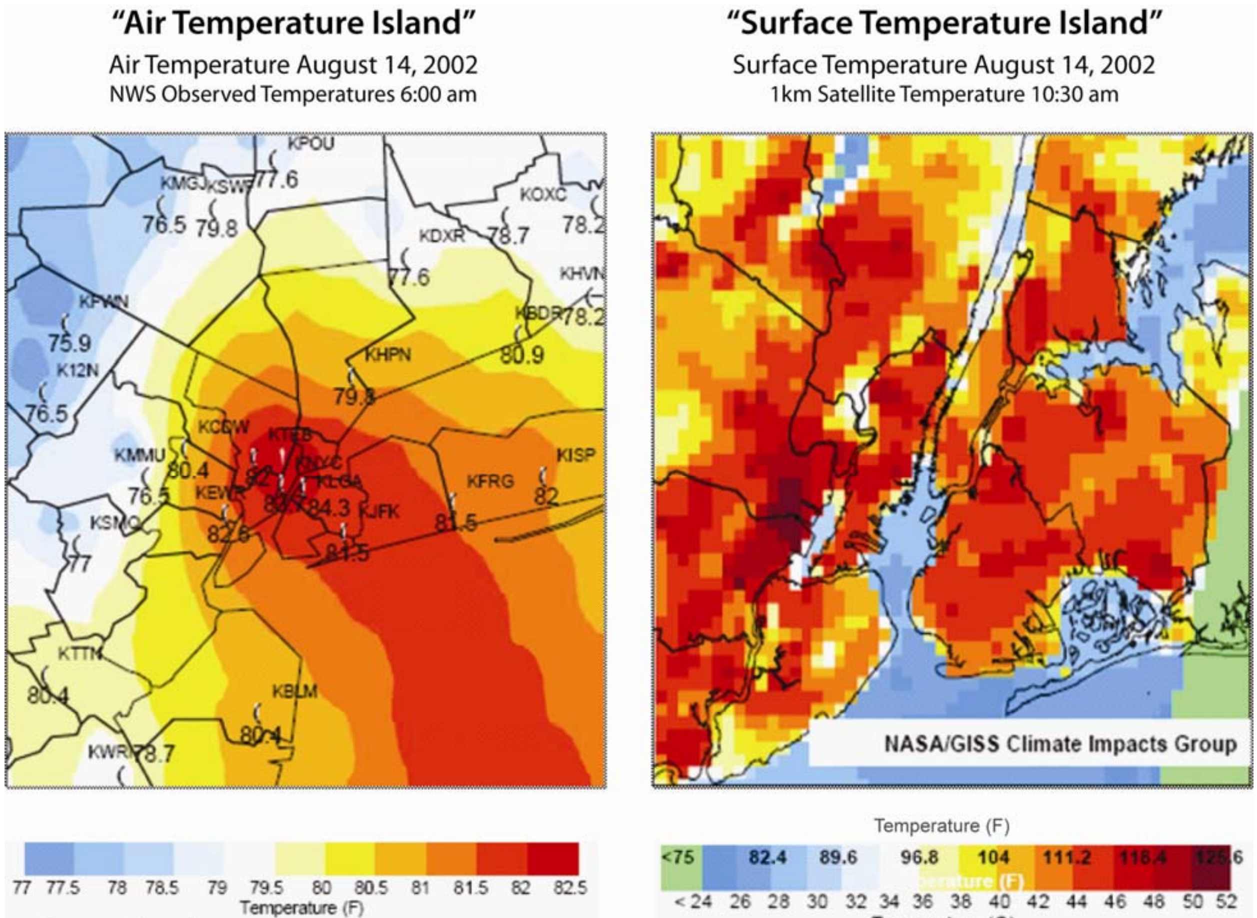
INTRODUCTION

Methodologies and data used to model land surface temperatures (LST) vary widely in scale and scope depending on a number of different factors. Traditional observations of UHI phenomena have been conducted using fixed thermometer readings and ground-based observations. In addition, remote sensing technology has made it possible to use satellite imagery to classify thermal patterns and observe relationships with land use change. Despite these opportunities, it is important to recognize that differences between temperatures captured with satellite imagery and near-surface temperature observations exist. Studies have shown variations by as much as 20 degrees Celsius in air temperature versus surface temperature. Research also indicates that temperatures taken from remotely sensed data correspond more accurately with canopy layer heat islands rather than surface heat islands[1]. Figure 1 compares an “Air Temperature Island” and a “Surface Temperature Island” in New York City using National Weather Service air temperature data and satellite-derived temperature data.

Another important factor affecting remotely-sensed UHI detection is the availability and resolution of data. Satellite imagery varies widely and decisions about data use should be based on scale, timeframe and budget constraints. For instance, a nationwide or global study of temperature trends would likely justify the use of remotely sensed National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer (NOAA/AVHRR) data due to its global coverage and revisit frequency.

[1] From the 2006 editorial Thermal remote sensing of urban areas: An introduction to the special issue, *Remote Sensing of the Environment* 104, 119-122. (Qihao Weng and Dale A Quattrochi).

However, a regional or local scale study might only involve the use of Landsat Thematic Mapper (TM) imagery that has a finer resolution and covers a smaller scale (Table 1).



Gaffin et al. (2006)

Two examples of using remotely sensed data to capture surface temperature

In an example of a local scale study using **Landsat TM and ETM+** images, Chen et al. explores the relationship between UHI and land cover changes in the Pearl River Delta in Guangdong Proving in southern China. Several classification indices, namely the *Normalized Difference Vegetation Index* (NDVI), *Normalized Difference Water Index* (NDWI), *Normalized Difference Bareness Index* (NDBaI) and *Normalized Difference Build-up Index* (NDBI) and temperature data were extracted from Landsat TM and ETM+ images to investigate the relationship between LST and land use/land cover changes. The results indicated that there was a positive correlation between NDBI and temperature and a negative correlation between NDVI, NDWI, NDBaI and temperature when NDVI is limited in range. A negative relationship between NDVI and LST has been extensively reported for urban and rural environments and is based on the premise that areas with "higher levels of latent heat fluxes are more representative of areas with significant vegetative cover as opposed to built up areas with little or no vegetation and low surface moisture availability" (Pu et al. 2006). This relationship confirms the cooling effect that parks have on urban areas.

ASTER images present another good, relatively high resolution source of thermal data. ASTER imagery has become more widely available and offers a unique opportunity for capturing thermal data due to its thermal infrared (TIR) instrument. A study by Lu used ASTER data and linear spectral mixture analysis (LSMA) to “unmix” TIR bands into hot and cold fraction images in Indianapolis, IN. A correlation analysis was performed between LST and the hot and cold fraction variables to reveal how LST relates to urban biophysical descriptors (imperviousness, vegetation and soil) and the thermal fractions (hot and cold objects). Lu found that impervious surface and LST are positively correlated while vegetation is negatively correlated with LST (Lu 2006). These studies help bolster the findings that percent impervious surface can act as a complementary metric for analyzing surface temperatures.

An example of using ambient temperature data to measure the urban heat island

An alternative to using remotely sensed imagery to measure near-surface temperature is described in Gaffin et al 2008. Gaffin used historical and recent temperature data to analyze intra-city and sub-urban trends in New York City over time. They used downloadable NOAA/NCDC historical climate data to model variations in temperature and wind speed, and National Centre for Atmospheric Research (NCAR) data to perform hourly calculations for a select number of years. The study area included five case areas in the surrounding boroughs of New York and a Central Park location. A heightened nocturnal and lowered daytime UHI signal was found in all case areas. Seasonal trends indicated that summer and fall generally had the greatest heat island effects. The strength of this study exists in its use of an urban weather station network as well as its employment of historical weather data. Gaffin estimated that 33% of the increased warming of New York City over the last century is due to UHI effects (Gaffin et al. 2008).

DATA

Numerous sources of data exist for use in thermal and/or temperature-effects studies. Historical and recent temperature data can be downloaded from NOAA/NCDC for many geographies (by air basin, county, etc) and over various time periods. Remotely-sensed data comes in varied formats and can be easy to obtain depending on the type, level and timeframe of data needed. Spatial and temporal resolutions of remotely-sensed data are of key importance when determining project parameters. A small-scale study likely requires higher-resolution data to detect variation within a given area while a nationwide or global study lacks the need for similar precision and therefore can benefit from coarser data. Landsat is a commonly used source of free data, each tile covers a relatively large area and has a resolution of 60 x 60. The major limitation with Landsat, however, is that imagery covers only the daytime. Common alternatives to Landsat include MODIS and ASTER. MODIS remotely sensed data has proven to be a useful dataset for thermal capture due to its twice daily over-flight and its atmospherically-corrected product. The downside to MODIS data is its low-resolution (1km x 1km). ASTER thermal data, on the other hand, is higher resolution than MODIS (90m x 90m) and can be scheduled to take images at relevant dates/times but because it only provides observations when scheduled, there are limited amounts of historic clear-sky imagery available. The table below gives a brief overview of commonly used imagery for thermal capture and land use/land cover classification.

Table 1

IMAGERY*	REVISIT	COST[2]	RESOLUTION**	BANDS	SWATH WIDTH
Landsat 4/5 TM	16 days	Free	Bands 1-5, 7: 30 x 30m **Band 6: 120 x 120m**	7	185 km
Landsat 7 ETM	16 days	Free	Bands 1-5, 7: 30 x 30m **Band 6: 60 x 60m** Pan: 15 x 15m	8	185 km
MODIS	Twice daily	Free	Bands 1-2: 250 x 250m Bands 3-7: 500 x 500m Bands 8-36: 1 x 1km **Bands 20-23, 31-32: thermal**	36	varies
ASTER	Varies	$80 - $165 per granule	Bands 1-3: 15 x 15m Bands 4-9: 30 x 30m **Bands 10-14: 90 x 90m**	14	60 km
AVHRR	Twice daily	Free	Bands 1-5: 1.1 x 1.1km **Bands 4-5: thermal**	5	2700 km

* This is a list of some of the most commonly used imagery; however, other images exist and should be regarded on a per project basis

** Bands highlighted in bold are thermal bands

DATA SOURCES

Landsat	http://glovis.usgs.gov/ http://edcsns17.cr.usgs.gov/EarthExplorer/ http://eros.usgs.gov/products/satellite/landsat_ortho.php
MODIS	http://glovis.usgs.gov/ https://wist.echo.nasa.gov/~wist/api/imswelcome/
ASTER	http://glovis.usgs.gov/ https://lpdaac.usgs.gov/lpdaac/get_data/data_pool
AVHRR	http://edcsns17.cr.usgs.gov/EarthExplorer/
Quickbird	http://www.digitalglobe.com/
IKONOS	http://www.geoeye.com/CorpSite/

LIMITATIONS

Working with high-resolution imagery poses challenges, particularly in urban environments where the heterogeneity of cities are quite different from more traditional conservation-based applications. The scale and timing of a project are of key importance since obtaining certain data can prove difficult due to overflight schedules and cloud cover. There are almost always issues with clouds that can alter a data acquisition. In general, it can be challenging to obtain several same-day images with less than the industry-standard 10 percent cloud cover. Image processing and classification times can be lengthy depending on what level of data is acquired, and in general, a maximum amount of processing core and RAM are required for these tasks. And as mentioned above, a further limitation of deriving LST from

[2] Imagery costs can vary depending on the type or level of data received.

remotely-sensed data is that it is widely believed that temperatures taken from remotely sensed data correspond more accurately with the canopy layer heat islands[3].

RECOMMENDATIONS

Below are several recommendations and estimates of time for investigating heat vulnerability. We've tried to provide reasonable ranges of the effort necessary for each category but, of course, actual effort would need to be estimated on a project-specific basis and would depend on the extent of the area analyzed, data type and availability etc.

1. **Use ASTER or Landsat imagery to extract land surface temperatures and land use descriptors**

A major focus of this work will be on developing a high-resolution surface temperature layer from a high-resolution data sources (ASTER or Landsat). ASTER imagery contains nine Visible and Near Infrared (VNIR) and Shortwave Infrared (SWIR) bands and five thermal infrared (TIR) bands, allowing for both urban land use descriptors and thermal images to be extracted from the data. Using multiple algorithms, retrieve LST from ASTER's TIR bands; non-TIR bands can be used to develop vegetation, impervious surface, and soil fraction images for comparison and analysis with thermal data. Apply thermal metrics to demographic data and create surface of vulnerable populations.

	Task	***Effort (Days)***
1	Collect and assemble ASTER data (process, geometric correction, etc.)	7 - 10
2	Extract, analyze, and compare thermal/land use metrics	4 - 6
	Post-processing (edge-matching, geo-referencing, converting, etc)	4 - 6
3	Analysis of thermal/land use data and demographic data	2 - 4
4	Write-up of results	1 - 2
5	TOTAL	18-28

2. **Temperature variation in urban vs. non-urban setting using location monitors**

Comparing urban and non-urban temperatures over time is a commonly used method for determining urban heat islands (Gaffin et al. 2008). Using NCDC daily data for selected time and place, evaluate temporal and spatial temperature and wind speed changes. Analyze hourly temperature data for diurnal UHI effects as well as intra-city and urban vs. non-urban relationships.

[3] From the 2006 editorial Thermal remote sensing of urban areas: An introduction to the special issue, *Remote Sensing of the Environment* 104, 119-122. (Qihao Weng and Dale A Quattrochi).

	Task	*Effort (Days)*
1	Collect and assemble temperature data	4 – 7
2	Model UHI trends, temperature variations, etc.	5- 9
3	Write-up of results	3 -5
4	TOTAL	12-21

3. **Use NLCD impervious surface coverage as a surrogate for urban heat island**s

Studies have shown that an increase in urban intensity or imperviousness typically lend to higher land surface temperatures (Yuan 2007). NLCD impervious surface data provides a coarse and easy to manage alternative to remotely sensed imagery. Using NLCD impervious data and census data, compare and analyze demographic figures against percent impervious to create a surface of populations at risk.

	Task	*Days*
1	Collect and assemble NLCD impervious surface data for area of interest	1 - 3
2	Model impervious surface data with demographic data to create vulnerability surface	2 - 4
3	Write-up of results	1 - 2
4	TOTAL	4-9

REFERENCES

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