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Urban Surfaces and Heat Island Mitigation Potentials

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Abstract

Data on materials and surface types that comprise a city, i.e. urban fabric, are needed in order to estimate the effects of light-colored surfaces (roofs and pavements) and urban vegetation (trees, grass, shrubs) on the meteorology and air quality of a city. We discuss the results of a semi-automatic statistical approach used to develop data on surface-type distribution and urban-fabric makeup using aerial color orthophotography, for four metropolitan areas of Chicago, IL, Houston, TX, Sacramento, CA, and Salt Lake City, UT. The digital high resolution (0.3 to 0.5-m) aerial photographs for each of these metropolitan areas covers representative urban areas ranging from 30 km^2 to 52 km^2.

Major land-use types examined included: commercial, residential, industrial, educational, and transportation. On average, for the metropolitan areas studied, vegetation covers about 29-41% of the area, roofs 19-25%, and paved surfaces 29-39%. For the most part, trees shade streets, parking lots, grass, and sidewalks. At ground level, i.e., view from below the tree canopies, vegetation covers about 20-37% of the area, roofs 20-25%, and paved surfaces 29-36%.

1 Introduction

Mitigating urban heat islands reduces demand for cooling-energy use and prevents smog formation (Akbari et al, 2001). In order to develop effective heat island mitigation programs, it is important to accurately characterize the urban surface, particularly in terms of surface-type distribution and vegetative fraction. An accurate characterization of the surfaces will allow a better estimate of potential increases in surface albedo[2] (roofs, pavements) and urban vegetation, providing more accurate modeling of the impact of heat-island reduction measures on ambient cooling and urban air quality.

Researchers involved in the analysis of urban climate have tried to estimate the composition of various urban surfaces. In Sacramento, CA, Myrup and Morgan (1972) examined the city data in

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[2] When sunlight hits an opaque surface, some of the energy is reflected (this fraction is called albedo = a) and the rest is absorbed (the absorbed fraction is 1-a). Low-a surfaces become much hotter than high-a surfaces.

progressively smaller integral segments of macro-scale (representative areas of Sacramento), meso-scale (individual communities), micro-scale (land-use ordinance zones), and basic-scale (city blocks). The data used included the United States Geological Survey (USGS) photos, parks and recreation plans, city engineering roadways, and detailed aerial photos. The analysis covered 195 km^2 of the urban area. The calculated percentages of the land-use areas are as follows: residential 35.5%, commercial 7.2%, industrial 13.5%, streets and freeways 17.0%, institutional 3.2%, and open space and recreational 23.6%. The analysis found the average residential area to be about 22% streets, 23% roofs, 22% other impervious surfaces, and 33% green areas. Overall, for the city, they found 14% streets, 22% roofs, 22% other impervious surfaces, 36% green areas, and 3% water surfaces. Their research defined the "other impervious surfaces" to include highway shoulder strips, airport landing runways, and parking lots. Streets included curbs and sidewalks.

McPherson (1998) analyzed the fabric of Sacramento using aerial photos. For the low-density residential areas constituting about 90% of the total residential area, he reports that buildings cover about 29% of the area, paved surfaces 27%, trees and shrubs 19%, and grass and soil 24%. For commercial and industrial areas, buildings cover 25% of the area, paved surfaces 50%, trees 6%, and grass and soil 19%.

Aerial orthophotos and satellite imagery are also used to study various aspects of urban land use. Small (2001a) estimated the abundance of urban vegetation in several areas of New York City, using Landsat Thematic Mapper (TM) and 2-m resolution aerial photography. For some residential areas in Central Manhattan, he found a vegetation fraction of 20-40%. Small (2001b) also conducted investigations using high-resolution satellite imagery for the analysis of urban reflectance. Luvall *et al.* (2001) used high-resolution thermal infrared and visible data to measure characteristics of surfaces typical of the urban landscape for Sacramento, Salt Lake City and Baton Rouge. The same data were also used to measure the vegetation fraction and the reflectivity of the urban areas. Nowak *et al.* (1996) reviewed several methods for determining urban tree cover from aerial photographs. They found that urban tree cover is highest in cities that developed in naturally forested areas (15-55%; mean 31%), followed by grassland cities (5-39%; mean 19%), and desert cities (0.4-26%; mean 10%). For Sacramento the total green space was estimated at 61% and the tree cover at 14%.

Ellis *et al.* (2006) researched the role of urban landscapes in ecological functioning using historical aerial photography. For six urban sites (in densely populated rural China and in urban and suburban Baltimore, MD) each covering 1 km^2, percentages of vegetative and artificial surface land covers were determined. Findings from Baltimore, MD indicate that concurrent with population decreases, artificial surfaces decreases and vegetative surfaces increased. However, for the sites in China, there were increases in artificial surfaces and decreases in vegetation levels.

While satellite remotely sensed data have been used to study urban areas, it is still limited in its ability to identify the features that dominate these landscapes. Even the resolution of the IKONOS satellite data has not yet adequately characterized the fine resolution features of urban environments (Cihlar and Jansen 2001). Advances in techniques in the fusion of GIS data and remote sensing (Fauvel 2006, Mesev 2007), 3D modeling (Nichol and Wong 2005), subpixel (Fernandes et al. 2004) and textural classification (Soergaard and Moller-Jenson 2003) among others are promising, but have yet to characterize disaggregated urban features in a manner that is practical and accurate enough for applied city planning. Thus, widespread adoption of remote sensing has been limited in its potential use in the policy and planning domain (Cihlar and Jansen 2001, Mesev 2007).

In a series of studies, Akbari *et al.* (1999), Akbari and Rose (2001a,b), and Rose et al. (2003), characterized the fabric of Sacramento, Salt Lake City, and Chicago, and Houston using high-resolution aerial digital orthophotos covering selected areas in each city. **Figure 1** shows an example of a high-resolution orthophoto for Salt Lake City. The method they used differs from the remote-sensing based approaches since it did not classify the pixels, but rather it relied on statistical techniques to determine land cover percentages. Four major land-use types were examined: commercial, industrial, transportation, and residential. Although there were differences between the fabrics of these four metropolitan areas, some significant similarities were found.

Akbari *et al.* (1999) also reviewed the pros and cons of a variety of available data sources for analyzing the fabric of cities. These data sources included:

- Moderate Resolution (10 m) Advanced Thermal and Land Applications Sensor (ATLAS) used by NASA to collect high-resolution surface data in 15 channels (Quattrochi *et al.* 1998),
- High-resolution (0.5 m) black-and-white photographs,
- High-resolution (0.5 m) color infrared photography, and
- High-resolution (0.3 m) custom color digital orthophotos.

Of all data sources tested, the high-resolution custom color digital orthophotos offered the best platform for obtaining accurate estimate of urban fabric. To obtain these high-resolution photos a digital camera is flown aboard a low-altitude aircraft equipped with a Global Positioning System (GPS) and a computer for acquiring and storing data from both the camera and the GPS. The data collected by the GPS system along with topographical data are used in the process of orthorectification. Thus, errors created by the terrain and angle between the camera and location are minimized.

Using true color aerial photography at a 0.3 to 0.5-m pixel size, it is possible to identify clearly the materials and surfaces that make up the fabric of an area. Using a spectral-based classification procedure, similar to that used with ATLAS data, a semi-automatic procedure for classifying the surfaces of a city can potentially be developed for the high resolution data. In a color photograph, the red, green, and blue (RGB) band data can be used in a classification scheme. However, all three bands are in the visible spectrum and thus do not cover the entire solar and thermal radiative ranges. Therefore, cover types such as roads and roofs may not be disaggregated because they are the same color. Further, shadows in the imagery result in areas that would similarly be problematic due to their color leading to misclassification. For these reasons, limited information can be acquired from this data type based on RGB band values.

An advantage of custom aerial color photography is that flights can be scheduled as desired. Accordingly, the photos can be taken at solar noon, minimizing the inaccuracies introduced by shadows. In addition, the high resolution allows for the calibration of photographs (RGB bands) with laboratory-measured reference panels that can be placed under the flight path in the field. Another practical advantage of these photos is that they are fairly inexpensive and may already be available in cities with planning departments that have GIS capabilities.

In this paper, we summarize the results of a statistical method used for analysis of aerial color photography of Sacramento, CA, Salt Lake City, UT, Chicago, IL, and Houston, TX. The method was applied to several representative areas in these four cities to obtain urban surface characteristics data. Results from the analysis of representative areas were used to estimate the fabric of metropolitan areas and the extent of possible modifications in urban albedo and vegetation. These data can then be used in meteorological and air-quality modeling, and in planning for implementation of urban heat island mitigation projects.

2 Custom Remotely-Sensed Data for Fabric Analysis

For Sacramento, we obtain high-resolution orthophotos in three bands of RGB. Two flights were performed on sunny, cloud-free and clear days around solar noon to minimize the impact of shadows (August 20, September 7, and November 4, 1998). For both flights, the specially-equipped aircraft took off from Sacramento Executive Airport and flew at approximately 1.5 km altitude over selected areas. The color aerial photographs of Sacramento covered a total of about 65 km^2. All data were taken at 0.3-m resolution. For these flights, 14 different areas were selected to cover a broad spectrum of land-uses in Sacramento, as well as different neighborhood ages (recent vs. old) and densities (e.g., high- vs. low-density built-up areas).

For Chicago, we received the high-resolution (0.3m by 0.3m) custom orthophoto data from Northwestern University (Gray and Finster, 2000). These color orthophotos are apparently available for over 580 km^2 (225 mi^2) of metropolitan Chicago. The data we received included 14 distinct square-mile sectors selected to represent overall land use in the metropolitan Chicago area. The sampled areas included high-, medium-, and low-density residential, urban and suburban commercial, and southern and western industrial. Also, many of the selected areas displayed mixed land uses.

For the data acquisition in Salt Lake City, the Digital Airborne Imagery System (DAIS) was used. The bands of the DAIS sensor are similar to those of the IKONOS satellite system and of Landsat Thematic Mapper 4/5 data (Jensen 1996). The wavelengths represented by each of the four bands of the DAIS sensor are 450–530 nm (Blue), 520–610 nm (Green), 640–720 nm (Red), and 770–880 nm (Near Infrared, NIR) (Akbari and Rose 2001a). The orthophotos were acquired with a DAIS sensor on-board a specially modified Cessna 421c twin engine plane. The majority of the imagery was acquired on September 26, 1999 under sunny, cloud-free conditions between approximately 2 and 4 pm mountain time. A second flight was required since there were some small gaps in some of the imagery acquired in September. This second flight occurred on November 11, 1999 under similar conditions. For each of these flights, the aircraft took off from Salt Lake City Airport 2 and flew at an altitude of approximately 2,470 m (8,100 ft). The total area of the imagery acquired during these flights was 34 km^2. An area about 15 km^2 was selected for detailed analysis. All data were taken at a 0.5-m resolution.

The Houston data was acquired with a sensor onboard a specially modified aircraft. The greater part of the imagery was acquired on January 24, 2002 under sunny, cloud-free conditions between approximately 10 am and 4 pm Central Standard Time (CST). Originally, the data collection was scheduled for September 2001, but because of restrictions imposed by Federal Aviation Administration (FAA) the data could not be acquired until January 2002. Because of a relatively higher sun angle, a September flight would have yielded better results, but the January data were still quite adequate. The total area of the imagery acquired during this flight was 52 km^2 (20 mi^2). Of that, an area about 23 km^2 was selected for detailed analysis. All data had a resolution of 0.3-m.

3 Method of Analysis for Custom Color Digital Orthophotos

Because of the large volume of data, reviewing all of them visually and in detail is very difficult and time-consuming. Hence, a semi-automated method was deemed necessary to classify the data. The method involved four steps:

1) visually inspecting aerial orthophotos and preparing a list of various surface-types identifiable in the photos;
2) grouping surface types and categories into major components;
3) randomly sampling a subset of data for each region via a Monte-Carlo statistical approach, and visually inspecting each sample and assigning a surface classification to it; and
4) extrapolating the results to metropolitan areas, using USGS land-cover/land-use (LULC) as a basis.

3.1 Identification of Surface-Types

Each aerial orthophoto was visually inspected using ERDAS/Imagine software (ERDAS 1997). The purpose of this visual exercise was to identify qualitatively all surface-types and land-covers that can be seen at the resolution of the data. The surface-types that are shown in **Table 1** were visually identified and used in the analysis.

Although more details can be seen in the photos, the categories identified in Table 1 covered most surfaces of interest. In general, the “Other features” category was a very small fraction (less than 1%) of the selected samples. Also, a distinction was made between category 1, “Unidentified,” and category 30, “Other feature”: those surfaces classified as “Unidentified” could not be accurately identified, whereas those in the “Other feature” category could. This distinction was necessary to avoid assigning the known features incorrectly.

3.2 Grouping the Surface-Types

The grouping of surface-types was done differently for the categories corresponding to “above-the-canopy” and “under-the-canopy” views. The primary criterion for grouping above-the-canopy categories was the requirements for meteorological modeling. Thus, surface-types consisting of similar materials were grouped together since they have similar physical characteristics. However, the under-the-canopy categories were grouped based on requirements for implementation of heat-island reduction measures. Therefore, the under-the-canopy categories show the actual and functional land-cover categories according to their composition. Hence, there is a difference in the definition of the categories for the above-the-canopy and under-the-canopy views within the same category type.

The above- and under-the-canopy groupings are summarized in **Table 2.** In order to calculate areas of various surfaces under the canopy, the areas beneath the trees were assigned to surface-types that trees shade. In these calculations it was assumed that the total area occupied by tree trunks was negligible. Also, a "Private-ownership paved surfaces" category was added to distinguish between those surfaces owned privately and those owned publicly. Obviously, this grouping can be rearranged depending on specific needs.

3.3 Identification of Random Samples

Once the surface-types have been identified, as in Table 1, we calculated the fractional areas covered by each surface type. We used a Monte-Carlo statistical method for this purpose. The method is a simple process of randomly selecting pixels, visually identifying their surface-types, and calculating their land-cover fractions. The results were summarized as percentages for various surfaces. Initially, when the number of sample points is small, there is a large fluctuation in the computed percentage of various surface areas. As the number of sample points being examined increases, these fluctuations become smaller and approach asymptotic values. The process is stopped when the fluctuations in the percentages of each and all surface-types is acceptably small (here, less than 1%).

To locate the sample points randomly in a given region, ERDAS Imagine's capability to generate random numbers was used to create some 400–600 points for each scene (ERDAS 1997). This is the range of number of points at which the area percentages stabilize (Akbari et al. 2003). Note that the scene area and number of sample points should be selected in a coordinated fashion so that a reasonable distribution of random points is achieved. That is, the scene area should be selected so that a large number of surfaces are included and the randomly selected points are distributed at reasonable densities.

Once these points have been generated they are sequentially recalled by the software, and each is visually inspected and assigned to one of the surface-types listed in Table 1. Given the fine resolution of these images, the surface-type can almost always be identified. Even shaded surfaces can be relatively easily identified from continuity and context. Those surfaces that were not possible to identify were entered in the "Unidentified" category.

In the Monte-Carlo approach, as the sample size is increased the standard errors of the estimates of percentages for each land-cover area are expected to decrease. We performed a statistical exercise to evaluate the impact of sample size on standard deviation of estimate. In this exercise, we calculated the standard deviation of the observations progressively for all observations (samples 1–400), the last 300 observations (samples 101–400), the last 200 observations (samples 201–400), and the last 100 observations (samples 301–400). **Table 3** shows an example of this analysis for both above and under the canopy for the Downtown Houston area. It can be clearly observed that the standard deviations become progressively smaller, indicating convergence toward the population mean. Based on this analysis, the estimated 95% confidence interval is less than 10% of the percentage for almost all surface-types.

3.4 Extrapolation of Data for Climate Simulation

For meteorological and air-quality modeling purposes, the region of interest needs to be characterized in terms of land use and land cover. We used the USGS LULC data to extrapolate the limited data obtained from the analysis of aerial photos to the entire area of each of the four metropolitan areas. The USGS LULC data classify the surface at 200-meter resolution into many different urban and non-urban categories. It is based on the Anderson (1976) system for the classification of level II data. LULC classifications for urban areas include residential, commercial and service, industrial, transportation and communications, industrial and commercial, mixed urban or built-up land, and other mixed urban and built-up land. The following steps were taken in order to extrapolate the data from aerial photographs to metropolitan areas:

1. We first grouped data from aerial photographs into LULC categories (e.g., residential, commercial/services, industrial, etc);
2. We then calculated the average characteristics (fabric) for each category; and
3. We assigned the properties of the observed land-use categories (OLUC) from the analysis of the aerial orthophotos to those of the USGS LULC data set.

4 Results

Metropolitan Chicago, IL

The results for the Chicago are summarized in **Tables 4** and **5**. In the commercial section of downtown Chicago, the top view (above-the-canopy) shows that vegetation (trees, grass, and shrubs) covers 18% of the area, whereas roofs cover 15–25% and paved surface (roads, parking areas, and sidewalks) 50–54%. The under-the-canopy fabric consists of 53–59% paved surfaces, 15–25% roofs, and 14–18% grass. In the industrial areas, above the canopy, vegetation covers 4–17% of the area, whereas roofs cover 29–41%, and paved surfaces 27–30%. Residential areas exhibit a wide range of variations among their various surface-types. On the average, above the canopy, vegetation covers about 44% of the area (ranging from 24% to 80%), roofs 26% (ranging from 8% to 37%), and paved surfaces 26% (ranging from 12% to 35%).

Greater Houston, TX

The results for Houston are summarized in **Tables 6** and **7**. In the industrial areas, the percentage of grass tends to increase and the percentage of parking decrease as the area's distance from the center of the city increases. In the commercial section of downtown Houston, the top view (above-the-canopy) shows that vegetation (trees, grass, and shrubs) covers 5% of the area, whereas roofs cover 28% and paved surface (roads, parking areas, and sidewalks) 58%. (The under-the-canopy fabric consists of 58% paved surfaces, 34% roofs, and 4% grass.) The surface-type percentages in the office park commercial area were 27% trees and grass, 31% roofs, and 33% paved surfaces. The surface-type percentages in the shopping mall commercial area were 16% trees and grass, 27% roofs, and 50% paved surfaces. In the intensive industrial areas, vegetation covers 22% of the area, whereas roofs cover 21%, and paved surfaces 31%. In the suburban industrial areas vegetation covers 43% of the area, whereas roofs cover 9% and paved surfaces 19%. Residential areas exhibit a wide range of variations among their surface-types. On the average, for single-family residential areas, vegetation covers about 61% of the area, roofs cover about 17%, and paved surfaces about 18%. The averages for multi-family residential areas are: 24% vegetation, 28% roofs, and 39% paved surfaces.

Metropolitan Sacramento, CA

These results are shown in **Tables 8** and **9**. In downtown Sacramento, the top view (above-the-canopy) shows that vegetation (trees, grass, and shrubs) covers 30% of the area, whereas roofs cover 23% and paved surface (roads, parking areas, and sidewalks) 41%. The under-the-canopy fabric consists of 52% paved surfaces, 26% roofs, and 12% grass. In industrial areas, vegetation covers 8-14% of the area, whereas roofs cover 19-23%, and paved surfaces 29-44%. The surface-type percentages in the office area were 21% trees, 16% roofs, and 49% paved surfaces. In commercial areas, vegetation covers 5-20%, roofs 19-20%, paved surfaces 44-68% (about 25-54% are parking areas). Residential areas exhibit a wide range of percentages among their various surface-types. On the average, vegetation covers about 36% of the area (ranging 32%-49%), roofs cover about 20% (12%-25%), and paved surfaces about 28% (21%-34%).

Metropolitan Salt Lake City

The results of this analysis are summarized in **Tables 10** and **11**. In the commercial section of downtown Salt Lake City, the top view (above-the-canopy) shows that vegetation (trees, grass, and shrubs) covers 13% of the area, whereas roofs cover 23% and paved surface (roads, parking areas, and sidewalks) 55%. The under-the-canopy fabric consists of 65% paved surfaces, 24% roofs, and 3% grass. In the industrial areas, vegetation covers 25% of the area, whereas roofs cover 19%, and paved surfaces 46%. The surface-type percentages in the new commercial area were 19% trees and grass, 23% roofs, and 55% paved surfaces. Residential areas exhibit a wide range of percentages among their various surface-types. On the average, vegetation covers about 46% of the area (ranging from 44% to 52%), roofs cover about 20% (ranging from 15% to 24%), and paved surfaces about 25% (ranging from 21% to 27%).

5 Extrapolation to Regional Scale

We assigned the observed land-use categories (OLUC) in each metropolitan area to those of the USGS LULC categories. Since our aerial photos were mostly concentrated on urban areas, we had several samples of Residential and Commercial categories and only limited samples for Industrial, Industrial/Commercial, and “Mixed-Urban or Built-up Land.” For these types of areas, we assigned the characteristics of the aerial orthophotos based on our best judgments.

Chicago, IL

The average characteristics of various LULC categories are listed in **Table 12**. The data indicate that about 53% of the 2500 km^2 analyzed in this study is residential. Commercial service and industrial areas taken together constitute another 31% of the total area.

Tree cover in metropolitan Chicago is highest in the Residential land-use category (1), at 11%. It is followed by the Other Mixed Urban or Built-up Land (6) category at 7%. The percentage of roof coverage differs by about 15% for all of the land-use categories. In the Residential (1) category, roads covered 17% on average. Also notable is the high percentage of parking area in the Industrial (3) category of metropolitan Chicago. The highest increase in grass coverage is in the Industrial (3) category at 16%. This shows a significant difference in the vegetative coverage of the three cities.

Table 13 summarizes the percentage of each LULC category. **Table 14** summarizes the results of our analysis into four aggregate groups of “Vegetation,” “Roofs,” “Pavements,” and “Other.” The total roof area as seen above the canopy comprises about 26% of the urban area (about 600 km^2), total paved surfaces (roads, parking areas, sidewalks) comprise 33% (about 750 km^2), and total vegetated area about 33% (750 km^2). The actual total roof area as seen under the canopy comprises about 27% of the urban area (about 680 km^2), total paved surfaces (roads, parking areas, sidewalks, and private surfaces) comprise 35% (about 880 km^2), and total vegetated area (only grass and bushes) about 27% (680 km^2).

Houston, TX

The data indicate that about 56% of the 3430 km^2 analyzed in greater area Houston is residential (see Table 12). Commercial service and industrial areas taken together constitute another 19% of the total area.

Tree cover in Houston is highest in the Residential land-use category (1), at 17%. It is followed by the Other Mixed Urban or Built-Up Land (7) and Mixed Urban or Built-Up Land (6) categories at 8%. The percentage of roof cover differs less than 10% for all of the land-use categories except for categories 3 and 4. In the Residential (1) category, roads covered 10% on average and grass covers 32% of the area. Also notable is the high percentage of parking area in almost all categories but residential areas of Houston.

The total roof area as seen above the canopy comprises about 21% of the urban area (about 736 km^2), total paved surfaces (roads, parking areas, sidewalks) comprise 29% (about 997 km^2), and total vegetated area about 39% (1325 km^2). The actual total roof area as seen under the canopy comprises about 21% of the urban area (about 732 km^2), total paved surfaces (roads, parking areas, sidewalks, and private surfaces) comprise 29% (about 1002 km^2), and total vegetated area (only grass and bushes) about 37% (1274 km^2).

Sacramento, CA

About half of the 800 km^2 of urban area analyzed in metropolitan Sacramento is residential. Commercial service and industrial areas taken together constitute another 25% of the total urban area.

Tree cover in the Residential (1) category in Sacramento is about 15% and in the Other Mixed Urban or Built-up Land (7) and Mixed Urban or Built-up Land (6) categories is about 27%. The percentage of roof coverage in all areas but Transportation/Communication (4) is 19% to 24%. In the Residential (1) category, roads cover 13% on average.

The total roof area as seen above the canopy comprises about 19% of the urban area (about 150 km^2), total paved surfaces (roads, parking areas, sidewalks) comprise 39% (about 310 km^2), and total vegetated area about 28% (230 km^2). The actual total roof area as seen under the canopy comprises about 20% of the urban area (about 160 km^2), total paved surfaces (roads, parking areas, sidewalks, and private surfaces) comprises 45% (about 360 km^2), and total vegetated area (only grass and bushes) about 20% (160 km^2).

Salt Lake City, UT

About 65% of the 560 km^2 analyzed in this study is residential. Commercial service and industrial areas taken together constitute another 22% of the total area.

Tree cover in Salt Lake City is highest in the Residential land-use category (1), at 20.5%. It is followed by the Other Mixed Urban or Built-Up Land (7) and Mixed Urban or Built-Up Land (6) categories at 18.5% and 16.5%, respectively. The percentage of roof coverage differs less than 5% for all of the land-use categories except for category 7.

The total roof area as seen above the canopy comprises about 19% of the urban area (about 106 km^2), total paved surfaces (roads, parking areas, sidewalks) comprise 30% (about 170 km^2), and total vegetated area about 41% (230 km^2). The actual total roof area as seen under the canopy comprises about 22% of the urban area (about 120 km^2), total paved surfaces (roads, parking areas, sidewalks, and private surfaces) comprise 36% (about 200 km^2), and total vegetated area (only grass and bushes) about 33% (180 km^2).

6 Potentials for Surface Modifications

To estimate the potentials for additional tree planting, we assumed that trees can potentially shade 20% of the roof area, 20% of roads, 50% of sidewalks, 30% of parking areas. The validity of these assumptions should be checked in more detail for each city.

The potential for increasing the albedo of cities can be large. The albedo of roofs and pavements can be increased by using reflective roofing materials (e.g., white coating, lighter-colored roofs) and reflective paving materials (e.g., light-colored concrete and aggregates). To estimate potentials for changing the albedo of metropolitan areas, we assumed two different scenarios. One scenario is based on a modest change in the albedo of impermeable surfaces, while the other is based on an aggressive increase in the albedo of all surfaces. These scenarios are summarized in **Table 15**.

Chicago, IL

In the commercial and industrial areas, existing trees shade about 0–5% of the grass area and 0–10% of all paved surface areas. In some residential areas, trees shade up to 12% of grass and up to 15% of the paved surfaces. The fraction of roof areas shaded by trees is less than 1%. Based on our assumptions, we estimate an additional 14% tree cover for the entire city. An additional tree cover of 14% is about 350 km^2 of the urban area. Assuming that an average tree can have a horizontal cross-section of about 50 m^2, these calculations suggest a potential for an additional 7 million trees in metropolitan Chicago. (For a detailed reference for the potential of tree-planting in metropolitan Chicago, the reader is referred to McPherson *et al.*, 1994.)

Impermeable surfaces (roofs and pavements) comprise about 62% of the total area of metropolitan Chicago. The potential change in the albedo of the city is summarized in **Table 16**. Under the low-albedo scenario, the overall residential and commercial albedo is changed by 6.2% and 9.7% respectively; the average albedo of the city is increased by 7.4%. For the high-albedo scenario, the overall albedo of residential and commercial areas changes by 13.9% and 18.9%, and the average albedo of the city is increased by 15.7%. Like urban vegetation, increasing albedo would reduce the ambient temperature and in turn reduce ozone concentration in the city.

Houston, TX

The potential exists for a 12% increase in tree cover for the entire city. An additional tree cover of 12% is about 410 km^2 of the urban area or about 8 million trees. Houston Advanced Research Center (HARC) and other local organization in Houston have suggested that a more realistic figure would be around 4 million additional trees in the region.

Under the low-albedo scenario for the Houston Greater Area, the overall residential and commercial albedos change by 0.055 and 0.095, respectively; the average albedo of the city increases by 0.076. For the high-albedo scenario, the overall albedo of residential and commercial areas changes by 0.121 and 0.198, and the average albedo of the city is increased by 0.135.

Sacramento, CA

Based on our assumptions, we estimate an additional 15% tree cover for the entire city. An additional tree cover of 15% is about 120 km^2 of the urban area or 2.4 million additional trees in Sacramento (approximately 1 additional tree per 330 m^2).

Under the low-albedo scenario for Sacramento Metropolitan Area, the overall residential and commercial albedos change by 0.054 and 0.113, respectively; the average albedo of the city increases by 0.082. For the high-albedo scenario, the overall albedo of residential and commercial areas changes by 0.118 and 0.203, and the average albedo of the city is increased by 0.158.

Salt Lake City, UT

Based on our assumptions, we estimate an additional 13% tree cover for the entire city. An additional tree cover of 13% is about 70 km^2 of the urban area or an additional 1.4 million trees in Salt Lake City.

Impermeable surfaces (roofs and pavements) comprise about 49% of the total area of Salt Lake City. Under the low-albedo scenario, the overall residential and commercial albedos change by 0.052 and 0.107 respectively; the average albedo of the city increases by 0.067. For the high-albedo scenario, the overall albedo of residential and commercial areas changes by 0.117 and 0.192, and the average albedo of the city is increased by 0.135. Like urban vegetation, increasing albedo would reduce the ambient temperature and in turn reduce ozone concentration in the city.

7 Discussion

The data obtained from the Chicago, Houston, Sacramento, and Salt Lake City flyovers suggest that it is possible to characterize the fabric of a region of interest accurately and cost-effectively. However, depending on the purpose of the application and the availability of funds, a separate decision must be made for each city or region as to the most appropriate combination of data sources, i.e., a combination of aerial photographs, USGS LULC, and satellite/aircraft data such as DAIS, ATLAS, IKONOS, Landsat, or AVHRR.

Based on our experience, it is estimated that in cities the size of Chicago, Houston, Salt Lake City, and Sacramento, between 10 and 50 km^2 of aerial photography would suffice for reasonably good characterization of the fabric. The companies that perform this type of data collection are flexible in designing flight paths and selecting flight times that suit the needs of projects such as our studies. This permits better planning of the flight track and its timing thereby minimizing shadows and focusing on areas of interest, e.g., specific land-uses or land-covers. This process is recommended for any city interested in implementing heat-island reduction strategies or in modeling their meteorological and air-quality aspects.

Apart from possible human error in analyzing the data (minimized to the extent possible by repeating the analysis and developing standard analytical processes and protocols), there exist two other sources of error in determining the fabric of a city. First, the error introduced by use of the Monte-Carlo approach is typically less than 1% (for a 95% confidence interval). This error can be controlled by studying the relationship between the sample size and standard error of estimate for each aerial frame studied. Second, errors may be introduced when mapping the fabric data obtained from aerial orthophotos into USGS LULC categories. We performed an analysis of this source of error using imagery from one of the areas acquired in the Salt Lake City flight and found it to be insignificant (Akbari and Rose 2001b). Potential errors related to the accuracy of USGS LULC data are not addressed in this paper. Finally, USGS data are typically older than the recent aerial orthophotos, thereby introducing discrepancies between USGS data and aerial orthophotos. Another issue associated with USGS data, is the error introduced by the limited range of categories in the dataset. If the data set included the differing types of residential (multi-family and single-family), commercial (office parks and shopping), and industrial (intensive and light) categories, the extrapolation would yield more accurate results. The 200-m x 200-m cell size of the USGS LULC data is another limitation, since it does not capture all variations in the urban landscape.

8 Summary and Conclusions

To estimate the impact of light-colored surfaces (roofs and pavements) and urban reforestation (trees, grass, shrubs) on the meteorology and air quality of a city, it is essential to characterize accurately the surface components of an urban area. This consists of the characterization of the area fraction of various surface-types and the vegetative cover. We devised a statistical method for developing data on surface-type distribution and city-fabric makeup using aerial color orthophotography. We applied the method to obtain fabric data for four metropolitan areas of Chicago, IL, Houston, TX, Sacramento, CA, and Salt Lake City, UT. The digital aerial 0.3-m to 0.5-m resolution photographs for each of these metropolitan areas covers representative urban areas ranging from 30 km^2 to 52 km^2.

Major land-use types examined included: commercial, residential, industrial, educational, and transportation. On average, for the metropolitan areas studied, vegetation covers about 29-41% of the area, roofs 19-25%, and paved surfaces 29-39%. For the most part, trees shade streets, parking lots, grass, and sidewalks. At ground level, i.e., view from below the tree canopies, vegetation covers about 20-37% of the area, roofs 20-25%, and paved surfaces 29-5%. Land-use/land-cover (LULC) data from the USGS was used to extrapolate these results from neighborhood scales to metropolitan area.

The potential appears to be large for additional urban vegetation in these four metropolitan areas. If we assume that trees can potentially shade 20% of the roof area, 20% of roads, 50% of sidewalks, and 30% of parking areas, the possibility exists to increase tree cover for the entire area Chicago, Houston, Sacramento, and Salt Lake City about 14%, 12%, 15%, and 13%, respectively. As climate and air-quality simulations have indicated, planting these additional trees can have a significant impact on cooling urban areas and potentially improving ozone air quality.

The potential is also relatively large for increasing albedo of the metropolitan areas. For illustration proposes, if we assume that the albedo of residential roofs can increase by 0.10, commercial roofs by 0.20, roads and parking areas by 0.15, and sidewalks by 0.10, the albedo of Chicago, Houston, Sacramento, and Salt Lake City can then be increased by about 0.07, 0.06, 0.08, and 0.067, respectivley. Like urban vegetation, increasing albedo would reduce ambient temperatures and in turn reduce ozone concentrations in the city.

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References

Akbari, H., L. S. Rose, and H. Taha. 2003. “Analyzing the land cover of an urban environment using high-resolution orthophotos,” Landscape and Urban Planning. 63 (1): 1-14.

Akbari, H., M. Pomerantz, and H. Taha. 2001. "Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas," *Solar Energy*, **70**(3): 295-310.

Akbari, H. and L. S. Rose. 2001a. “Characterizing the Fabric of the Urban Environment: A Case Study of Salt Lake City, Utah,” LBNL-47851, Lawrence Berkeley National Laboratory, Berkeley, California (February).

Akbari, H. and L. S. Rose. 2001b. “Characterizing the Fabric of the Urban Environment: A Case Study of Chicago, Illinois” LBNL-49275, Lawrence Berkeley National Laboratory, Berkeley, California (October).

Akbari, H., L. S. Rose, and H. Taha. 1999. "Characterizing the Fabric of the Urban Environment: A Case Study of Sacramento, California," LBNL-44688, Lawrence Berkeley National Laboratory, Berkeley, California (December).

Anderson, J.R, E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper no. 964. Washington, DC. U.S. Government Printing Office.

Cihalar, J. and L.J.M Jansen. 2001. "From Land Cover to Land Use: A Methodology for Efficient Land Use Mapping over Large Areas," Professional Geographer. 53(2):275-289.

Ellis, E.C., H. Wang, H.S. Xiao, K. Peng, X.P. Liu, S.C. Li, H. Ouyang, X, Cheng, and L.Z. Yang. 2006. "Measuring long-term ecological changes in densely populated landscapes using current and historical high resolution imagery," Remote Sensing of Environment. 100:457-473.

ERDAS. 1997. *ERDAS Field Guide*, 4th Edition, Atlanta, Georgia, ERDAS, Inc.

Fauvel, M., J. Chanussot, and J.A. Benediktsson. 2006. "Decision fusion for the classification of urban remote sensing images," IEEE Transactions on Geoscience and Remote Sensing. 44(10):2828-2838.

Fernandes, R., R. Fraser, R. Latifovic, J. Cihlar, J. Beaubienb, and Y. Duc. 2004. "Approaches to fractional land cover and continuous field mapping: A comparative assessment over the BOREAS study region," Remote Sensing of Environment. 89:234-251.

Gray, K. and M. Finster. 2000. "The Urban Heat Island, Photochemical Smog, and Chicago: Local Features of the Problem and Solution," Department of Civil Engineering, Northwestern University, Evanston, IL.

Jensen, J.R. 1996. *Introductory Digital Image Processing: A Remote Sensing Perspective*, 2nd edition, Upper Saddle River, New Jersey, Prentice-Hall.

Luvall, J., D. Quattrochi, D. Rickmann, and M. Estes. 2001. "EPA/NASA Urban Heat Island Pilot Project," Global Hydrology and Climate Center, Marshall Space Flight Center, Huntsville, AL.

McPherson, E. G. 1998. " Structure and Sustainability of Sacramento's Urban Forest," J. of Arboriculture, 24 (4), pp. 174-190.

McPherson, E.G., D.J. Nowak, and R.A. Rowntree.1994. "Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project," Forest Service, U.S. Department of Agriculture. NE-186.

Mesev, V. 2007. "Fusion of point-based postal data with IKONOS imagery," Information Fusion. 8:157-167.

Myrup, L. O. and D. L. Morgan, 1972. "Numerical Model of the Urban Atmosphere, Volume I: The City-Surface Interface," Department of Agricultural Engineering, Department of Water Science and Engineering, University of California, Davis, California 95616 (October).

Nichol, J. and M.S. Wang. 2005. "Modeling urban environmental quality in a tropical city," Landscape and Urban Planning. 73:49-58.

Nowak, D. J., R. A. Rowntree, E. G. McPherson, S. M. Sisinni, E. R. Kerkmann, and J. C. Stevens. 1996. "Measuring and Analyzing Urban Tree Cover," Landscape and Urban Planning, 36, pp. 49-57.

Quattrochi, D, J. Luvall, M. Ester, C.P. Lo, S. Kidder, J. Hafner, H. Taha, R. Bornstein, Gillies, R., and K. Gallo. 1998. Project Atlanta (Atlanta land use analysis: temperature and air quality): a study of how urban landscape affects meteorology and air quality through time. Preprint Volume. Second AMS Urban Environment Conference, Albuquerque, NM.

Rose, L.S., H. Akbari, and H. Taha. 2003. "Characterizing the Fabric of the Urban Environment: A Case Study of Greater Houston, Texas" LBNL-51448, Lawrence Berkeley National Laboratory, Berkeley, California (January).

Small, C. 2001a. "Estimation of Urban Vegetation Abundance by Spectral Mixture Analysis," Int. J. Remote Sensing, 22 (7), pp. 1305-1334.

Small, C. 2001b. "Multiresolution analysis of urban reflectance," IEEE/ISPRS joint workshop on Remote Sensing and Data Fusion over Urban Areas, 8-9 November 2001, Paper 23, Rome, Italy.

Soergaard, H., and L. Moller-Jensen. 2003. "Towards a spatial CO2 budget of a metropolitan region based on textural image classification and flux measurements," Remote Sensing of Environment, 87:283-294.

Table 1. Visually identifiable features of interest in the Houston region (based on aerial orthophotos).

Category	Description	Category	Description
1	Unidentified	16	Swimming pool
2	Tree covering roof	17	Auto covering road
3	Tree covering road	18	Private-ownership paved surfaces
4	Tree covering sidewalk	19	Parking deck
5	Tree covering parking	20	Alley
6	Tree covering grass	21	Water
7	Tree covering dry/barren land	22	Grass on roof
8	Tree covering Other	23	Train tracks
9	Tree covering alley	24	Auto covering parking
10	Roof	25	Recreational surface
11	Road	26	Residential driveway
12	Sidewalk	27	Awning
13	Parking area	28	N/A
14	Grass	29	N/A
15	Dry/barren land	30	Other feature (not of interest)

Table 2. Major surface-types.

Surface-Type	**Categories Included***	**Surface-Type**	**Categories Included**
		Above-the-canopy view	
Roof	10, 27	Tree cover	2–9
Road	11	Grass	6, 14
Parking area	13, 19	Barren land	15
Sidewalk & driveway	12, 26	Miscellaneous	16–18, 20, 21, 23–25, 30
		Under-the-canopy view	
Roof	2, 10, 19, 22, 27	Private-ownership paved surfaces	18, 26
Road	3, 9, 11, 17, 20	Grass	6, 14
Parking area	5, 13, 24	Barren land	7, 15
Sidewalk	4, 12	Miscellaneous	8, 16, 21, 23, 25, 30

* Surface-type categories are defined in Table 1.

Table 3. The impact of sample size on estimates of area percentages of land-use categories for Downtown Houston. The entries show the "sample mean" in percentage of areas; the numbers in parenthesis are standard deviations of the means. Note that the above-the-canopy percentages show the "bird's-eye" view of the surfaces; under-the-canopy percentages are the actual land-use types.

	Above the Canopy				Under the Canopy			
Sample Size **Surface-type**	1–400	101–400	201–400	301–400	1–400	101–400	201–400	301–400
Roof	26.1 (3.4)	26.8 (0.8)	26.5 (0.6)	26.9 (0.3)	32.0 (3.5)	32.7 (0.6)	32.8 (0.5)	33.1 (0.3)
Road	27.9 (4.1)	27.6 (1.0)	28.0 (0.6)	27.7 (0.6)	29.3 (4.1)	29.3 (1.0)	29.4 (0.8)	28.9 (0.6)
Parking area	26.9 (8.3)	24.9 (0.9)	24.7 (0.8)	24.0 (0.3)	22.9 (7.6)	21.2 (0.9)	21.0 (0.8)	20.4 (0.5)
Sidewalk	3.1 (1.6)	4.0 (0.5)	3.9 (0.3)	4.1 (0.1)	3.1 (1.6)	4.0 (0.5)	3.9 (0.3)	4.1 (0.1)
Grass	4.1 (2.1)	3.3 (0.2)	3.2 (0.2)	3.2 (0.1)	4.8 (1.9)	4.1 (0.4)	3.9 (0.2)	3.8 (0.1)
Barren land	0.9 (0.9)	1.2 (0.9)	1.5 (0.9)	2.3 (0.3)	1.1 (1.0)	1.5 (0.9)	1.9 (0.8)	2.6 (0.3)
Tree cover	2.0 (0.8)	2.3 (0.5)	2.2 (0.4)	1.9 (0.1)				
Private surfaces					2.0 (0.9)	1.9 (0.3)	1.7 (0.1)	1.7 (0.1)

Table 4. Above-the-canopy view of metropolitan Chicago, IL. Entries are rounded to nearest 0.1. Numbers in parenthesis show the standard deviations of the last 100 samples.

Area	Surface Type (% of total cover)							
	Roof	Road	Parking Area	Sidewalk Driveway	Tree Cover	Grass	Barren Land	Misc.
1. Commercial								
1.1. Woodfield Mall	15.0	11.4	40.1	2.5	0.5	17.5	7.9	5.1
	(0.32)	(0.29)	(0.27)	(0.12)	(0.10)	(0.29)	(0.26)	(0.22)
1.2. Lincolnwood	25.0	18.5	29.2	2.5	4.8	12.9	3.4	3.7
	(0.51)	(0.44)	(0.56)	(0.19)	(0.33)	(0.27)	(0.11)	(0.38)
2. Industrial								
2.1. Cicero	41.2	7.1	20.3	1.5	0.0	3.8	16.2	10.0
	(0.44)	(0.50)	(0.45)	(0.07)	(0.00)	(0.29)	(0.34)	(0.18)
2.2. Stockyards	28.6	7.0	23.2	1.1	0.5	16.4	16.4	6.7
	(0.78)	(0.34)	(0.49)	(0.09)	(0.05)	(0.46)	(0.63)	(0.17)
3. Residential								
3.1. Rogers Park	28.2	11.7	5.2	3.6	9.8	37.8	2.3	1.3
	(0.30)	(0.16)	(0.23)	(0.24)	(0.18)	(0.36)	(0.10)	(0.12)
3.2. Kennedy Interchange Area*	30.3	16.8	4.2	3.2	11.3	33.9	0.0	0.3
3.3. Wrigleyville	32.4	20.3	4.2	4.8	13.0	21.2	0.6	3.3
	(0.47)	(0.59)	(0.11)	(0.30)	(0.39)	(0.53)	(0.11)	(0.15)
3.4. Garfield Park	19.2	13.8	3.7	7.1	5.9	35.3	8.5	6.5
	(0.28)	(0.21)	(0.17)	(0.26)	(0.15)	(0.42)	(0.25)	(0.42)
3.5. Lincoln Park*	33.8	17.4	3.6	4.6	8.5	29.5	0.0	2.5
3.6. Blue Island/Pilsen	34.4	22.1	3.7	7.7	3.7	25.2	1.7	1.4
	(0.85)	(0.19)	(0.13)	(0.39)	(0.16)	(0.21)	(0.08)	(0.07)
3.7. Interchange 55/90/94	36.5	24.3	6.2	4.2	3.9	20.5	1.5	3.0
	(0.29)	(0.38)	(0.16)	(0.15)	(0.16)	(0.35)	(0.12)	(0.10)
3.8. Oak Lawn	15.2	19.0	0.3	5.0	16.6	42.6	0.9	0.6
	(0.36)	(0.46)	(0.02)	(0.14)	(0.46)	(0.45)	(0.07)	(0.07)
3.9. Stony Island	20.8	18.2	2.9	7.3	4.7	39.9	0.3	5.9
	(0.30)	(0.33)	(0.12)	(0.30)	(0.25)	(0.53)	(0.02)	(0.16)
3.10. Naperville	8.0	9.2	0.0	2.3	29.5	50.4	0.3	0.3
	(0.26)	(0.18)	(0.00)	(0.19)	(0.40)	(0.48)	(0.12)	(0.02)
4. Transportation	10.4	32.5	19.1	0.0	0.8	9.0	4.9	23.2
4.1. Trans. Interchange 55/90/94	(0.17)	(0.34)	(0.45)		(0.09)	(0.30)	(0.18)	(0.76)

* The standard deviations for this area are not documented in the original report.

Table 5. Under-the-canopy view of metropolitan Chicago, IL. Entries are rounded to nearest 0.1. Numbers in parenthesis show the standard deviations of the last 100 samples.

Area	Surface Type (% of total cover)							
	Roof	**Road**	**Parking Area**	**Sidewalk**	**Private Surface**	**Grass**	**Barren Land**	**Misc.**
1. Commercial								
1.1. Woodfield Mall	15.0 (0.32)	11.9 (0.26)	44.4 (0.27)	2.5 (0.12)	0.0 (0.00)	17.8 (0.29)	8.1 (0.25)	0.3 (0.02)
1.2. Lincolnwood	25.0 (0.51)	20.5 (0.34)	30.1 (0.58)	2.0 (0.23)	0.8 (0.06)	14.3 (0.37)	3.4 (0.11)	3.9 (0.15)
2. Industrial								
2.1. Cicero	41.2 (0.44)	7.1 (0.51)	20.6 (0.46)	1.5 (0.07)	2.1 (0.14)	3.8 (0.28)	16.2 (0.33)	7.6 (0.22)
2.2. Stockyards	28.6 (0.79)	7.5 (0.53)	24.8 (0.46)	1.1 (0.09)	3.2 (0.15)	17.0 (0.42)	16.4 (0.64)	1.3 (0.09)
3. Residential								
3.1. Rogers Park	28.2 (0.30)	12.4 (0.17)	5.4 (0.27)	4.7 (0.17)	0.8 (0.07)	45.1 (0.43)	2.8 (0.09)	0.5 (0.05)
3.2. Kennedy Interchange Area*	30.6	20.0	4.2	3.2	0.3	37.1	0.0	4.5
3.3. Wrigleyville	32.4 (0.47)	23.3 (0.53)	4.2 (0.11)	4.8 (0.30)	0.6 (0.17)	23.3 (0.30)	0.6 (0.12)	10.6 (0.77)
3.4. Garfield Park	19.2 (0.28)	15.0 (0.29)	3.7 (0.18)	7.1 (0.26)	3.1 (0.27)	38.7 (0.52)	8.5 (0.25)	4.8 (0.23)
3.5. Lincoln Park*	33.8	18.5	4.3	4.6	0.0	30.6	0.0	8.2
3.6. Blue Island/Pilsen	34.4 (0.85)	22.3 (0.21)	4.0 (0.15)	7.7 (0.39)	0.3 (0.13)	26.9 (0.26)	1.7 (0.08)	2.6 (0.10)
3.7. Interchange 55/90/94	36.5 (0.29)	26.4 (0.41)	6.8 (0.15)	4.2 (0.15)	0.6 (0.05)	22.3 (0.27)	1.5 (0.12)	1.8 (0.16)
3.8. Oak Lawn	15.2 (0.36)	20.7 (0.40)	0.3 (0.02)	3.2 (0.13)	2.6 (0.10)	48.1 (0.39)	0.9 (0.07)	9.0 (0.42)
3.9. Stony Island	21.1 (0.33)	22.9 (0.38)	2.9 (0.12)	4.7 (0.26)	2.9 (0.13)	43.4 (0.44)	0.3 (0.02)	1.8 (0.14)
3.10. Naperville	8.0 (0.26)	9.5 (0.17)	0.0 (0.00)	2.0 (0.17)	0.3 (0.02)	63.9 (0.58)	0.3 (0.12)	16.0 (0.54)
4. Transportation								
4.1. Trans. Interchange 55/90/94	10.4 (0.18)	34.4 (0.41)	19.9 (0.29)	0.0	0.0	9.0 (0.31)	4.9 (0.18)	21.3 (0.54)

* The standard deviations for this area are not documented in the original report.

Table 6. Above-the-canopy view of Greater Houston, TX. Entries are rounded to nearest 0.1%. Numbers in parenthesis show the standard deviations of the last 100 samples.

Area	**Surface-Type (percent of total cover)**							
	Roof	Road	Parking Area	Side-walk	Private Surfa-ces	Grass	Barren Land	Misc.
1. University of Houston	11.9 (0.3)	7.1 (0.1)	29.4 (0.8)	2.5 (0.2)	10.6 (0.4)	30.1 (0.3)	4.1 (0.2)	4.3 (0.4)
2. Industrial								
2.1 West of Jersey Village	11.3 (0.4)	5.1 (0.3)	7.2 (0.2)	0.5 (0.0)	17.5 (0.2)	40.4 (0.4)	15.4 (0.3)	2.6 (0.2)
2.2 East of Downtown	21.1 (0.4)	4.9 (0.2)	25.3 (0.5)	0.0 (0.0)	3.1 (0.1)	13.1 (0.4)	13.1 (0.3)	19.3 (0.5)
2.3 Northwest of Downtown	21.8 (0.4)	10.4 (0.4)	21.6 (0.5)	0.0 (0.0)	6.5 (0.2)	21.3 (0.4)	14.0 (0.6)	4.4 (0.3)
2.4 Southeast of Downtown	7.1 (0.2)	4.5 (0.2)	20.1 (0.4)	0.0 (0.0)	0.8 (0.1)	26.9 (0.6)	23.2 (0.7)	17.4 (0.3)
3. Commercial								
3.1 Downtown	28.0 (0.3)	28.5 (0.6)	25.4 (0.3)	4.2 (0.1)	1.8 (0.1)	3.4 (0.1)	2.9 (0.3)	5.8 (0.2)
3.2 Garden Oaks Shopping Center	38.8 (0.5)	7.2 (0.2)	27.9 (0.3)	1.0 (0.1)	7.0 (0.3)	9.0 (0.6)	3.6 (0.1)	5.4 (0.5)
3.3 Greenspoint Mall	16.1 (0.2)	18.4 (0.5)	44.5 (0.4)	0.5 (0.1)	5.6 (0.3)	9.5 (0.1)	3.3 (0.2)	2.0 (0.2)
3.4 Bingle	38.4 (0.6)	5.4 (0.1)	36.3 (0.3)	0.8 (0.1)	7.7 (0.6)	5.9 (0.1)	0.3 (0.0)	5.4 (0.2)
3.5 Park Ten Place	24.5 (0.9)	4.3 (0.2)	18.1 (0.5)	0.3 (0.0)	12.5 (0.3)	27.3 (0.4)	3.8 (0.2)	9.2 (0.4)
4. Residential								
4.1 Gulfton	29.1 (0.5)	10.1 (0.5)	27.5 (0.3)	3.1 (0.2)	6.5 (0.2)	16.6 (0.9)	2.3 (0.2)	4.7 (0.2)
4.2 Plum Creek	27.8 (0.3)	5.7 (0.4)	27.5 (0.4)	3.6 (0.1)	8.2 (0.3)	17.2 (0.3)	4.1 (0.2)	5.9 (0.5)
4.3 Adam School	16.2 (0.4)	8.1 (0.3)	0.5 (0.1)	5.5 (0.2)	28.5 (0.3)	37.9 (0.5)	1.0 (0.1)	2.3 (0.2)
4.4 Strawberry Mall	20.7 (0.3)	8.8 (0.3)	2.6 (0.3)	5.2 (0.3)	24.1 (0.5)	35.5 (0.3)	1.0 (0.1)	2.1 (0.2)
4.5 Cinco Ranch	21.9 (0.4)	16.9 (0.2)	1.1 (0.1)	7.7 (0.3)	19.5 (0.5)	29.8 (0.8)	0.8 (0.2)	2.4 (0.1)
4.6 Sugarland	7.5 (0.4)	9.4 (0.3)	0.0 (0.0)	4.7 (0.4)	14.3 (0.6)	55.1 (0.7)	0.8 (0.1)	8.3 (0.3)

Table 7. Under-the-canopy view of Greater Houston, TX. Entries are rounded to nearest 0.1%. Numbers in parenthesis show the standard deviations of the last 100 samples.

Area	**Surface-Type (percent of total cover)**							
	Roof	Road	Parking Area	Side-walk	Private Surfa-ces	Grass	Barren Land	Misc.
1. University of Houston	11.9 (0.3)	7.1 (0.1)	29.9 (0.7)	3.3 (0.2)	0.3 (0.1)	37.5 (0.4)	4.1 (0.2)	6.1 (0.2)
2. Industrial								
2.1 West of Jersey Village	11.3 (0.4)	5.1 (0.3)	8.0 (0.3)	0.3 (0.0)	0.3 (0.0)	56.6 (0.3)	15.7 (0.3)	2.8 (0.2)
2.2 East of Downtown	21.1 (0.4)	4.9 (0.2)	25.8 (0.4)	0.0 (0.0)	0.0 (0.0)	13.4 (0.4)	13.4 (0.3)	21.4 (0.5)
2.3 Northwest of Downtown	22.3 (0.3)	10.4 (0.4)	22.1 (0.6)	0.3 (0.0)	0.0 (0.0)	24.9 (0.4)	14.0 (0.6)	6.0 (0.3)
2.4 Southeast of Downtown	7.1 (0.2)	4.5 (0.2)	20.1 (0.4)	0.0 (0.0)	0.0 (0.0)	27.4 (0.7)	23.2 (0.7)	17.7 (0.4)
3. Commercial								
3.1 Downtown	34.3 (0.3)	29.6 (0.6)	22.0 (0.5)	4.2 (0.1)	1.8 (0.1)	3.9 (0.1)	3.1 (0.3)	1.0 (0.1)
3.2 Garden Oaks Shopping Center	39.0 (0.5)	7.2 (0.2)	29.2 (0.3)	1.3 (0.2)	0.5 (0.2)	13.2 (0.8)	3.6 (0.1)	5.9 (0.2)
3.3 Greenspoint Mall	19.9 (0.3)	18.9 (0.5)	41.4 (0.6)	0.5 (0.1)	1.5 (0.1)	11.8 (0.3)	3.3 (0.2)	2.6 (0.1)
3.4 Bingle	38.6 (0.6)	5.6 (0.2)	42.7 (0.2)	0.8 (0.1)	0.5 (0.1)	8.7 (0.2)	0.5 (0.1)	2.6 (0.4)
3.5 Park Ten Place	24.5 (0.9)	4.3 (0.2)	19.1 (0.4)	0.5 (0.0)	0.3 (0.0)	34.9 (0.5)	3.8 (0.2)	12.5 (0.4)
4. Residential								
4.1 Gulfton	29.4 (0.5)	10.4 (0.6)	28.8 (0.3)	3.1 (0.2)	0.8 (0.2)	18.4 (1.0)	2.3 (0.2)	6.8 (0.4)
4.2 Plum Creek	28.5 (0.3)	6.4 (0.4)	33.2 (0.2)	3.6 (0.1)	0.3 (0.0)	21.3 (0.5)	4.4 (0.2)	2.3 (0.1)
4.3 Adam School	17.2 (0.4)	8.1 (0.3)	0.5 (0.1)	1.0 (0.1)	6.3 (0.2)	58.5 (0.8)	1.0 (0.1)	7.3 (0.6)
4.4 Strawberry Mall	21.2 (0.3)	10.1 (0.3)	2.8 (0.3)	0.8 (0.1)	5.7 (0.3)	52.8 (0.3)	1.0 (0.1)	5.4 (0.1)
4.5 Cinco Ranch	22.4 (0.4)	17.2 (0.2)	1.3 (0.1)	2.9 (0.1)	6.1 (0.3)	43.5 (0.7)	0.8 (0.2)	5.8 (0.4)
4.6 Sugarland	7.8 (0.3)	11.4 (0.4)	0.0 (0.0)	1.6 (0.2)	5.5 (0.3)	65.2 (0.4)	0.8 (0.1)	7.8 (0.3)

Table 8. Surface-types in Sacramento, CA (Above-the-canopy view). Entries are rounded to nearest 0.5. Numbers in parentheses show the standard deviations of the estimates.

Area	Surface-Type (percent of total cover)							
	Roof	Road	Parking Area	Side-walk	Tree Cover	Grass	Barren Land	Misc.
1. *Downtown Sacramento*	23.0 (0.32)	23.0 (0.64)	12.0 (0.33)	6.0 (0.28)	22.5 (0.38)	7.5 (0.18)	3.0 (0.11)	3.0
2. *Industrial Areas*								
2.1 Richards Boulevard Area	23.5 (0.51)	7.5 (0.18)	20.0 (0.90)	1.5 (0.08)	8.0 (0.19)	6.0 (0.25)	19.5 (0.69)	14.5
2.2 Port of Sacramento Area	19.0 (0.36)	10.5 (0.20)	32.0 (0.44)	1.5 (0.15)	3.0 (0.21)	5.5 (0.16)	15.5 (0.27)	13.0
3. *Typical Office Area*								
3.1 Sacramento County Branch Center Area	16.0 (0.44)	12.0 (0.20)	33.5 (0.49)	3.0 (0.18)	4.5 (0.20)	16.5 (0.62)	10.5 (0.31)	3.5
4. *Typical Commercial Areas*								
4.1 Florin Shopping Center Area	19.0 (0.30)	11.5 (0.44)	54.0 (0.64)	2.0 (0.10)	3.0 (0.13)	2.0 (0.10)	6.5 (0.19)	2.0
4.2 California Exposition Area	20.5 (0.53)	16.0 (0.28)	25.0 (0.38)	3.5 (0.18)	8.0 (0.15)	11.5 (0.20)	9.5 (0.23)	6.5
5. *Typical Residential Areas*								
5.1 Pocket Road Area	25.0 (0.28)	14.5 (0.31)	1.5 (0.07)	12.5 (0.29)	12.0 (0.33)	25.5 (0.29)	3.5 (0.11)	5.0
5.2 Jack Davis Park Area	19.5 (0.85)	13.0 (0.39)	2.0 (0.19)	8.5 (0.18)	14.5 (0.37)	27.5 (0.54)	11.0 (0.31)	4.0
5.3 Hagginwood Park Area	11.5 (0.31)	15.5 (0.51)	5.0 (0.21)	5.5 (0.16)	11.0 (0.19)	23.5 (0.42)	21.5 (0.66)	6.5
5.4 Elk Grove Area	16.5 (0.19)	11.0 (0.31)	1.0 (0.09)	9.0 (0.62)	1.5 (0.14)	31.0 (0.32)	19.5 (0.32)	10.0
5.5 Del Paso Area	22.0 (0.72)	11.0 (0.29)	18.5 (0.76)	5.0 (0.23)	20.0 (0.17)	13.5 (0.20)	4.5 (0.26)	6.0
5.6 Tahoe Park Area	20.5 (0.86)	10.5 (0.53)	2.5 (0.11)	10.0 (0.23)	23.5 (0.66)	22.0 (0.29)	8.0 (0.21)	3.0
5.7 East Downtown Area	23.5 (0.36)	17.5 (0.27)	9.5 (0.28)	4.5 (0.17)	27.0 (0.45)	7.0 (0.41)	2.0 (0.15)	8.5
5.8 Carmichael Area	20.5 (0.60)	13.0 (0.37)	3.5 (0.14)	5.5 (0.17)	20.5 (0.23)	28.5 (0.70)	4.0 (0.24)	4.5

Table 9. Surface-types in Sacramento, CA (Under-the-canopy view). Entries are rounded to nearest 0.5. Numbers in parenthesis show the standard deviations of the estimates.

Area	Surface-Type (percent of total cover)							
	Roof	Road	Parking Area	Sidewalk/ Driveway	Private Surfaces	Grass	Barren Land	Misc.
1. *Downtown Sacramento*	26.0 (0.26)	31.0 (0.58)	10.5 (0.21)	10.5 (0.45)	0.5 (0.02)	12.0 (0.27)	3.5 (0.12)	6.0
2. *Industrial Areas*								
2.1 Richards Boulevard Area	23.5 (0.51)	7.5 (0.18)	22.5 (0.82)	1.5 (0.10)	3.5 (0.30)	9.5 (0.29)	22.0 (0.59)	10.5
2.2 Port of Sacramento Area	19.0 (0.36)	10.5 (0.19)	34.0 (0.45)	1.5 (0.13)	5.0 (0.20)	6.0 (0.17)	17.5 (0.19)	6.5
3. *Typical Office Area*								
3.1 Sacramento County Branch Center Area	16.0 (0.44)	12.0 (0.20)	36.0 (0.40)	3.0 (0.25)	1.5 (0.11)	18.5 (0.22)	11.0 (0.28)	2.0
4. *Typical Commercial Areas*								
4.1 Florin Shopping Center Area	19.0 (0.30)	11.5 (0.44)	56.5 (0.63)	2.0 (0.10)	1.0 (0.10)	2.0 (0.07)	6.5 (0.21)	1.5
4.2 California Exposition Area	21.0 (0.49)	17.0 (0.34)	27.0 (0.61)	3.5 (0.20)	2.5 (0.17)	16.0 (0.21)	9.5 (0.24)	3.5
5. *Typical Residential Areas*								
5.1 Pocket Road Area	25.0 (0.28)	15.0 (0.33)	2.0 (0.08)	7.0 (0.18)	9.0 (0.21)	35.0 (0.40)	3.5 (0.11)	4.0
5.2 Jack Davis Park Area	19.5 (0.85)	14.5 (0.58)	3.0 (0.17)	6.5 (0.15)	3.0 (0.18)	34.0 (0.79)	13.0 (0.30)	6.5
5.3 Hagginwood Park Area	11.5 (0.31)	16.5 (0.48)	6.0 (0.24)	5.0 (0.13)	4.0 (0.43)	28.0 (0.38)	24.0 (0.69)	5.0
5.4 Elk Grove Area	16.5 (0.19)	11.0 (0.33)	1.0 (0.09)	5.0 (0.34)	9.0 (0.35)	32.5 (0.20)	19.5 (0.31)	5.0
5.5 Del Paso Area	23.0 (0.62)	11.5 (0.27)	22.0 (0.68)	5.0 (0.31)	4.0 (0.31)	25.0 (0.57)	5.0 (0.33)	4.0
5.6 Tahoe Park Area	21.5 (0.87)	12.0 (0.52)	2.5 (0.13)	6.5 (0.15)	6.0 (0.66)	35.0 (0.30)	9.0 (0.27)	6.5
5.7 East Downtown Area	28.0 (0.51)	27.0 (0.33)	7.5 (0.24)	7.0 (0.28)	4.5 (0.30)	9.5 (0.34)	2.5 (0.09)	14.0
5.8 Carmichael Area	21.0 (0.56)	15.5 (0.42)	4.0 (0.10)	3.0 (0.32)	5.0 (0.16)	40.0 (0.61)	4.0 (0.23)	7.5

Table 10 Above-the-canopy view of Salt Lake City, Utah. Entries are rounded to nearest 0.1%. Numbers in parenthesis show the standard deviations of the last 100 samples.

Area	Surface Type (percent of total cover)							
	Roof	Road	Parking Area	Sidewalk/ Driveway	Tree Cover	Grass	Barren Land	Misc.
1. Downtown Commercial	22.5	24.7	26.5	4.3	10.9	2.3	5.8	3.0
	(0.2)	(0.4)	(0.8)	(0.2)	(0.6)	(0.1)	(0.1)	
2. New Commercial	23.1	15.6	35.5	4.0	1.9	16.9	2.2	0.8
	(0.4)	(0.4)	(0.3)	(0.1)	(0.1)	(0.5)	(0.1)	
3. Industrial Area	19.1	13.8	29.4	0.3	2.0	22.9	10.1	2.5
	(0.3)	(0.3)	(0.2)	(0.0)	(0.2)	(0.7)	(0.3)	
4. Downtown Mixed-Use	21.5	20.7	11.4	2.7	16.5	23.1	2.7	1.6
	(0.6)	(0.4)	(0.4)	(0.1)	(0.2)	(0.3)	(0.1)	
5. University Area	12.9	10.2	15.2	3.6	18.5	22.3	15.5	1.8
	(0.2)	(0.4)	(0.2)	(0.2)	(0.5)	(0.3)	(0.4)	
6. Typical Residential Areas								
6.1. Old Residential	23.9	13.1	3.0	11.6	28.7	16.4	1.3	2.0
	(0.6)	(0.2)	(0.4)	(0.4)	(0.3)	(0.1)	(0.7)	
6.2. Low-Density Residential	14.9	9.0	2.1	9.8	13.4	37.8	9.8	3.3
	(0.4)	(0.3)	(0.2)	(0.3)	(0.3)	(0.5)	(0.3)	
6.3. Med-Density Residential	19.5	14.0	2.0	10.8	19.3	24.5	7.3	2.8
	(0.3)	(0.3)	(0.2)	(0.5)	(1.1)	(0.8)	(0.6)	
6.4. Newer Residential	24.1	16.1	0.0	11.1	21.4	23.9	0.5	3.0
	(0.3)	(0.4)	0.0	(0.3)	(0.2)	(0.5)	(0.1)	

Table 11. Under-the-canopy view of Salt Lake City, Utah. Entries are rounded to nearest 0.1%. Numbers in parenthesis show the standard deviations of the last 100 samples.

Area	Surface Type (percent of total cover)							
	Roof	Road	Parking Area	Side-walk	Private Surfaces	Grass	Barren Land	Misc.
1. Downtown Commercial	24.2 (0.3)	27.8 (0.6)	31.1 (0.7)	6.6 (0.3)	0.3 (0.0)	3.3 (0.1)	5.8 (0.1)	1.0
2. New Commercial	23.1 (0.4)	15.6 (0.4)	36.0 (0.3)	4.0 (0.1)	0.0 0.0	18.0 (0.5)	2.7 (0.2)	0.5
3. Industrial Area	19.1 (0.3)	14.1 (0.3)	31.4 (0.2)	0.3 (0.0)	0.3 (0.1)	24.4 (0.6)	10.1 (0.3)	0.5
4. Downtown Mixed-Use	21.8 (0.6)	22.3 (0.4)	12.5 (0.3)	2.4 (0.1)	1.1 (0.1)	30.8 (0.5)	2.7 (0.1)	6.6
5. University Area	13.5 (0.3)	11.4 (0.5)	19.8 (0.3)	4.1 (0.3)	0.3 (0.0)	31.0 (0.6)	19.8 (0.4)	0.3
6. Typical Residential Areas								
6.1. Old Residential	30.5 (0.6)	18.1 (0.3)	4.8 (0.6)	9.1 (0.4)	4.8 (0.2)	29.7 (0.5)	2.0 (0.2)	1.0
6.2. Low-Density Residential	17.0 (0.5)	10.0 (0.2)	3.3 (0.2)	4.9 (0.2)	7.5 (0.4)	46.3 (0.6)	10.5 (0.3)	0.5
6.3. Med-Density Residential	20.3 (0.3)	14.5 (0.3)	3.3 (0.2)	6.3 (0.3)	7.5 (0.2)	39.8 (0.6)	7.8 (0.5)	0.8
6.4. Newer Residential	27.6 (0.4)	16.8 (0.4)	2.8 (0.2)	4.8 (0.3)	8.0 (0.3)	38.4 (0.6)	0.5 (0.1)	1.0

Table 12. Calculated above the canopy surface area percentages by USGS /LULC categories.

USGS LULC	Tree Cover	Roof	Road	Sidewalk	Parking Area	Barren Land	Grass	Misc.
Chicago								
1. Residential	10.7	25.9	17.3	5.0	3.4	1.6	33.6	2.5
2. Commercial/Service	2.7	20.0	15.0	2.5	34.7	5.7	15.2	4.4
3. Industrial	0.3	34.9	7.1	1.3	21.8	16.3	10.1	8.4
4. Transportation/Communications	0.8	10.4	32.5	0.0	19.1	4.9	9.0	23.2
5. Industrial and Commercial	2.7	26.8	12.8	1.8	26.2	9.9	14.7	5.2
6. Mixed Urban or Built-Up Land	7.3	24.8	16.4	4.3	12.4	4.0	27.4	3.5
7. Other Mixed Urban or Built-Up Land	0.5	28.6	7.0	1.1	23.2	16.4	16.4	6.7
Houston								
1. Residential	16.9	20.5	9.8	5.0	9.9	1.7	32.0	4.3
2. Commercial/Service	6.9	29.2	12.8	1.4	30.4	2.8	11.0	5.6
3. Industrial	7.0	15.3	6.2	0.1	18.6	16.4	25.4	10.9
4. Transportation/Communications	0.8	10.4	32.5	0.0	19.1	4.9	9.0	23.2
5. Industrial and Commercial	7.5	26.5	6.3	0.3	25.3	7.8	16.9	9.6
6. Mixed Urban or Built-Up Land	7.9	24.9	6.8	1.5	26.5	6.0	18.8	7.6
7. Other Mixed Urban or Built-Up Land	7.9	24.9	6.8	1.5	26.5	6.0	18.8	7.6
Sacramento								
1. Residential	14.7	19.4	12.7	8.0	4.9	10.2	24.5	5.6
2. Commercial/Service	9.6	19.8	15.5	3.7	31.1	7.3	9.3	3.8
3. Industrial	8.1	23.4	7.3	1.3	20.0	19.7	6.0	14.3
4. Transportation/Communications	0.0	5.0	80.0	1.0	10.0	4.0	0.0	0.0
5. Industrial and Commercial	2.8	19.2	10.3	1.3	32.1	15.6	5.6	13.1
6. Mixed Urban or Built-Up Land	26.8	23.7	17.6	4.5	9.5	2.1	7.1	8.7
7. Other Mixed Urban or Built-Up Land	26.8	23.7	17.6	4.5	9.5	2.1	7.1	8.7
Salt Lake City								
1. Residential	20.5	19.7	12.3	10.8	2.2	5.8	26.1	2.7
2. Commercial/Service	10.4	19.5	16.8	4.0	25.7	7.8	13.8	1.9
3. Industrial	2.0	19.1	13.8	0.3	29.4	10.1	22.9	2.5
4. Transportation/Communications								
5. Industrial and Commercial	2.0	21.1	14.7	2.2	32.5	6.2	19.9	1.7
6. Mixed Urban or Built-Up Land	16.5	21.5	20.7	2.7	11.4	2.7	23.1	1.6
7. Other Mixed Urban or Built-Up Land	18.5	12.9	10.2	3.6	15.2	15.5	22.3	1.8

Table 13. USGS land use/land cover (LULC) percentages for fur cities: Sacramento, CA, Salt Lake City, UT, Chicago, IL, and Houston, TX.

	Sacramento	Salt Lake City	Chicago	Houston
Total Metropolitan Area (km^2)	809	624	2521	3433
LULC (%)				
Residential	49.3	59.1	53.5	56.1
Commercial/Service	17.1	15.0	19.2	5.1
Industrial	7.2	4.9	11.5	9.3
Transportation/Communication	11.4	9.8	7.7	2.9
Industrial and Commercial	0.3	0.0	0.1	4.8
Mixed Urban or Built-up Land	5.2	1.9	0.4	3.5
Other Mixed Urban or Built-up Land	9.5	9.4	7.6	18.3

Table 14. Comparison of the fabric of Chicago, IL, Houston, TX, Sacramento, CA, and Salt Lake City, UT.

City	Vegetation	Roofs	Pavements	Other
Above-the-canopy				
Metropolitan Chicago	30.5	24.8	33.7	11.0
Greater Houston	38.6	21.4	29.0	10.9
Metropolitan Sacramento	28.6	18.7	38.5	14.3
Metropolitan Salt Lake City	40.9	19.0	30.3	9.7
Residential Chicago	44.3	25.9	25.7	4.1
Residential Houston	48.9	20.5	24.7	6.0
Residential Sacramento	39.2	19.4	25.6	15.8
Residential Salt Lake City	46.6	19.7	25.3	8.5
Under-the-canopy				
Metropolitan Chicago	26.7	24.8	37.1	11.4
Greater Houston	37.1	21.3	29.2	12.4
Metropolitan Sacramento	20.3	19.7	44.5	15.4
Metropolitan Salt Lake City	33.3	21.9	36.4	8.5
Residential Chicago	35.8	26.9	29.2	8.1
Residential Houston	47.4	21.1	23.9	7.6
Residential Sacramento	32.8	19.8	30.6	16.8
Residential Salt Lake City	38.6	23.9	31.6	6.0

Table 15. Two albedo modification scenarios.

Surface-Type	High-Albedo Change	Low-Albedo Change
Residential Roofs	0.3	0.1
Commercial Roofs	0.4	0.2
Roads	0.25	0.15
Parking Areas	0.25	0.15
Sidewalks	0.2	0.1

Table 16. Net change in the urban albedo for high- and low-albedo scenarios.

Area	Chicago	Houston	Sacramento	Salt Lake City
High-Albedo Scenario				
Residential	0.139	0.121	0.118	0.117
Commercial/Service	0.189	0.198	0.203	0.192
Industrial	0.179	0.108	0.164	0.185
Transportation/Communications	0.160	0.160	0.247	
Industrial and Commercial	0.181	0.159	0.185	0.207
Mixed Urban or Built-Up Land	0.155	0.161	0.160	0.172
Other Mixed Urban or Built-Up Land	0.164	0.161	0.172	0.122
Average over the Entire Area	**0.157**	**0.135**	**0.158**	**0.135**
Low-Albedo Scenario				
Residential	0.062	0.055	0.054	0.052
Commercial/Service	0.097	0.095	0.113	0.107
Industrial	0.079	0.053	0.089	0.103
Transportation/Communications	0.088	0.088	0.146	
Industrial and Commercial	0.087	0.074	0.103	0.115
Mixed Urban or Built-Up Land	0.072	0.076	0.081	0.094
Other Mixed Urban or Built-Up Land	0.075	0.076	0.093	0.068
Average over the Entire Area	**0.074**	**0.063**	**0.082**	**0.067**

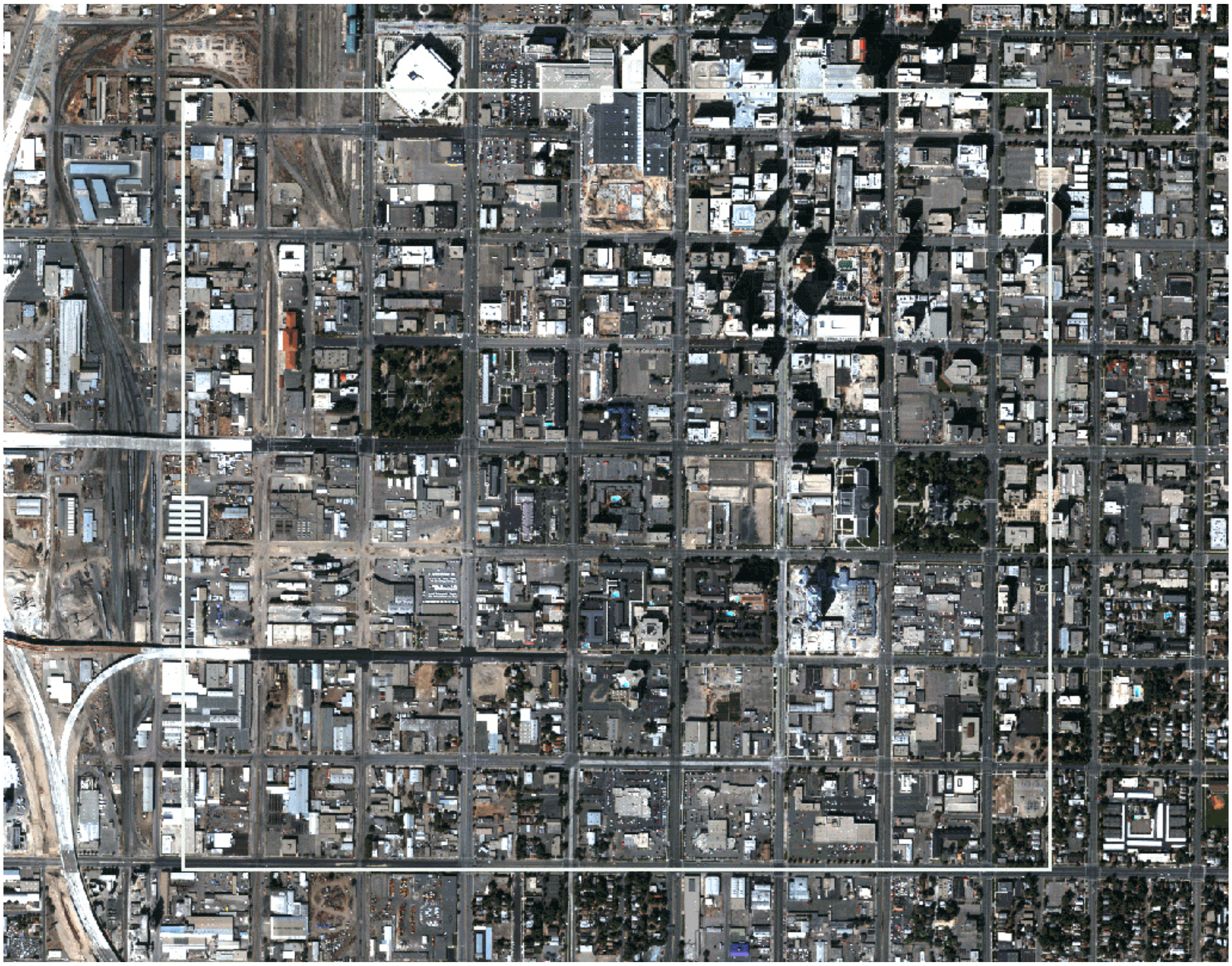

Figure 1. Aerial orthophoto of a commercial area in downtown Salt Lake City.