Collaborative Tool for Collecting Reference Data on the Density of Constructed Surfaces Worldwide

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ABSTRACT

We have developed a web-based interface for the collection of surface cover type data using gridded point counts on displays of high spatial resolution color satellite imagery available in Google Earth. The system is designed to permit a distributed set of analysts to contribute gridded point counts to a common database. Our application of the system is to develop a calibration for estimating the density of constructed surface areas worldwide at 1 km^2 resolution based on the brightness of satellite observed lights and population count. The system has been used to collect a test data set and a preliminary calibration for estimating the density of constructed surfaces. We believe the web-based system could have applications for research projects and analyses that require the collection of surface cover type data from diverse locations.

Keywords: Google Earth, impervious surface area, nighttime lights, population density.

1. INTRODUCTION

Human beings around the world build, use and maintain constructed impervious surfaces for shelter, transportation and commerce. Construction represents one of the primary anthropogenic modifications of the environment. Expansion in population numbers and economies combined with the popular use of automobiles has lead to the sprawl of development and a wide proliferation of constructed impervious surfaces. The quantity of development that has occurred in recent decades is staggering. In the USA there are typically a million new homes and 16,000 kilometers of paved road built each year. The worldwide pattern of sprawl development will continue in the coming decades in response to both population growth and growth in living standards.

Constructed impervious surfaces are both hydrological and ecological disturbances. However, constructed surfaces are different from most other types of disturbances in that recovery is arrested through the use of materials that are resistant to decay and are actively maintained. The same characteristics that make impervious surfaces ideal for use in construction produce a series of effects on the environment. Impervious surfaces alter sensible and latent heat fluxes, causing urban heat islands. In heavily vegetated areas, the proliferation of ISA reduces the sequestration of carbon from the atmosphere. ISA alters the character of watersheds by increasing the frequency and magnitude of surface runoff pulses. The increased overland flow alters the shape of stream channels, raising water temperatures, and sweeping urban pollutants into aquatic environments. Hydrologic consequences of ISA include increased flooding, reductions in ground water recharge, and reductions in surface water quality. A widely accepted scale for the impacts of ISA on holds that watershed areas are stressed if they contain 1-10% ISA, impacted if they contain 10%-25% ISA and are degraded if they contain more than 25% ISA.

Spatial grids depicting the density of impervious surface area (ISA) were developed to address applications requiring specific measures or estimates of constructed areas. This includes hydrologic modeling for sizing urban drainage systems, flood prediction, and biodiversity analyses. The ratio of constructed area per person has also been proposed as an index for the human ecological footprint [1]. There are three basic remote sensing approaches to estimating ISA. The

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Sixth International Symposium on Digital Earth: Models, Algorithms, and Virtual Reality,
edited by Huadong Guo, Changlin Wang, Proc. of SPIE Vol. 7840, 78400K
© 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.872324

first approach is to map constructed areas using high spatial resolution imagery [2]. Typically ISA products derived from high spatial resolution imagery (in the +/- one meter range) cover small areas and to date there has not been a standardization of methods which would facilitate the merger of products generated by diverse organizations.

The second approach is to use moderate spatial resolution multispectral data (such as Landsat) to estimate the density of ISA. The U.S. Geological Survey (USGS) produced a 30-meter ISA density grid for the USA derived from Landsat as part of the National Land Cover Database (NLCD) [3]. The USGS used a combination of spectral and spatial methods to estimate the density of ISA. They used a sub-sample of high spatial resolution imagery to establish the methodology and to conduct an accuracy assessment. Noted sources of error for the product include the underestimation of ISA in areas having extensive tree cover and overestimation of ISA in areas with extensive bare ground. The advantage of extracting ISA from Landsat style data is that is possible to cover an entire region or country using a standardized methodology.

The third approach is to use indicators to estimate the density of ISA. One such indicator is population numbers based on data collected by government agencies [4]. The concept behind this is that where there are people – surely there is ISA. One can imagine using gridded population data to make gridded ISA data. However, not all population grids are well suited for this application. In particular, if the population tally is based on residency (where people sleep), the values are quite low in heavily built up commercial centers and transportation areas. Ambient Population products are likely better for this application since they estimate the average population over a typical diurnal cycle. Another indirect method is the estimation of ISA based on coverage coefficients developed for standard land cover classes, such as low density residential, high density residential, commercial / industrial.

In 2004 NOAA produced a one km^2 grid of ISA densities for the conterminous USA using indirect data sources to estimate ISA [5]. The input data included radiance calibrated nighttime lights, street and road density (from the U.S. Census Bureau) and three Landsat derived urban land cover classes from the early 1990's. The ISA estimates were calibrated using gridded point counts made of ISA from high spatial resolution aerial photography selected along transects crossing thirteen major urban centers. Using these data sources it was estimated that as of the year 2000-01 the USA held 112,000 square kilometers of constructed impervious surfaces, an area nearly the size of the State of Ohio.

As an extension of the methods used by NOAA in 2004, we produced the first global grid of ISA density based on satellite observed nighttime lights and Landscan population count data from the U.S. Department of Energy [5], [6]. The Landscan data are well suited for this type of analysis since they match the 30 arc second grid projection of the nighttime lights and are modeled to represent "ambient" population averaged over a twenty-four hour period rather than "residential" population. Another favorable aspect of using nighttime lights and Landscan together is that they do not share common inputs other than the SRTM topographic grid. The calibration of this first global ISA density grid was based on the Landsat derived ISA density data produced by the USGS [3]. The resulting product is freely available http://www.ngdc.noaa.gov/dmsp/download.html [7]. From this product we were able to estimate the total ISA of the world to be 579,703 km^2, slightly more that the area of France (546,962 km^2). The country found to have the most ISA was China (87,182 km^2) followed closely by the United States (83,881 km^2), and India (81,221 km^2). China and India's ISA footprints are population driven whereas the United States ISA footprint is more driven by affluence.

The major shortcoming of the 2007 global ISA grid was that the calibration did not include sites outside of the USA [7]. Today there are commercial sources for high spatial resolution satellite imagery for most urban areas on the planet. These sources would be ideal for developing an improved calibration for an updated global ISA density product. However, it would be very costly to select, purchase, manage and use the high spatial resolution imagery if purchased from the commercial sources. As an alternative, we have developed an interactive web interface to facilitate the collaborative collection of gridded point counts of constructed surface areas around the world using the high spatial resolution base imagery available in Google Earth. In this paper we describe the collaborative tool and present some preliminary results.

2. WEB TOOL DEVELOPMENT

The web-based collaborative mapping tool takes advantage of several technologies in order to create a virtual community for mapping impervious surfaces. Some of these technologies have been around for some time while others are much newer. The application leverages both javascript and php for scripting. MySQL is used as the database. A central component of the architecture is the Google Earth Application Programming Interface (API) and the Google Earth Plug-in released in May of 2008. The Google Earth API can be accessed via javascript and allows users to build web interfaces harnessing the 3D rendering capabilities Google Earth. Using this methodology the end-user need only install

a plug-in for their web browser, rather than the full desktop version of Google Earth. Additionally, use of the Google Earth API allows developers a significant level of control over the user experience and the data to be collected. It is much harder to provide this controlled user experience using the desktop version of Google Earth.

The collaborative mapping tool is generated via php. By using php dynamic features, such as authenticating users in order to keep track of who is mapping what areas of the globe, are possible. Once the tool is loaded into the users web browser the interaction is handled by javascript and the Google Earth API. Using these technologies the user can browse the globe and turn on various layers to add more information such as roads, borders, place names, and nighttime lights imagery. With access to this data and the globe a user can browse the earth and identify a location that is suitable for mapping. When a point is selected it is determined which 30 arc-second grid cell (from the nighttime lights grid) that point falls within. Once this is known an outline of the grid cell is drawn on the globe along with a 16 by 16 set of classification points to be mapped within the 30 arc-second grid cell. When the user clicks on one of the classification points a window pops up with classification choices (developed, tree/shrub, lawn, and other). The user selects the correct classification and submits it, which sends the information to a php application that writes to the MySQL database. This process uses AJAX to send the data to the database and wait for a response from the server. Using an AJAX request allows the user to be alerted of the success or failure of the selected point classification to be written to the database in a smooth and timely fashion.

The roads, borders, and place names layers are provided via the Google Earth API. However, the nighttime lights data must be supplied externally. To make this possible we have published several web mapping services (WMS) using Minnesota MapServer. When a user selects the nighttime lights layer it is added to the globe via a KML file that retrieves the data from the WMS.

Using the technologies above we are able to provide a dynamic user environment for mapping ISA. This tool will allow us to easily create an online community of users to help collect data. Additionally, it is all sent to one master database where it can be stored and accessed for future use. This type of tool could also be completed using other technologies currently available given the developer's preferences and available resources.

3. DATA COLLECTION

The analyst begins a session by loading the url into a web-browser (Figure 1). Then the analyst can then display a nighttime lights dataset (Figure 2) and begin zooming in to an area of interest. The analyst can obtain additional geographic orientation by displaying road and boundary vectors (Figure 3). The boundary vectors include the names of major cities. As the analyst begins to consider which area to select for the gridded point count they can turn the nighttime light on and off to review the features visible in the Google Earth base images. When the analyst selects a location the system outlines the 30 arc second grid cell that contains the selected point (Figure 4). As the analyst continues to zoom in on the selected grid cell a set of 256 evenly spaced sampling points are drawn. The analyst clicks on the sampling points to pull up the window used to select the cover type and submit the data to the database (Figure 5).

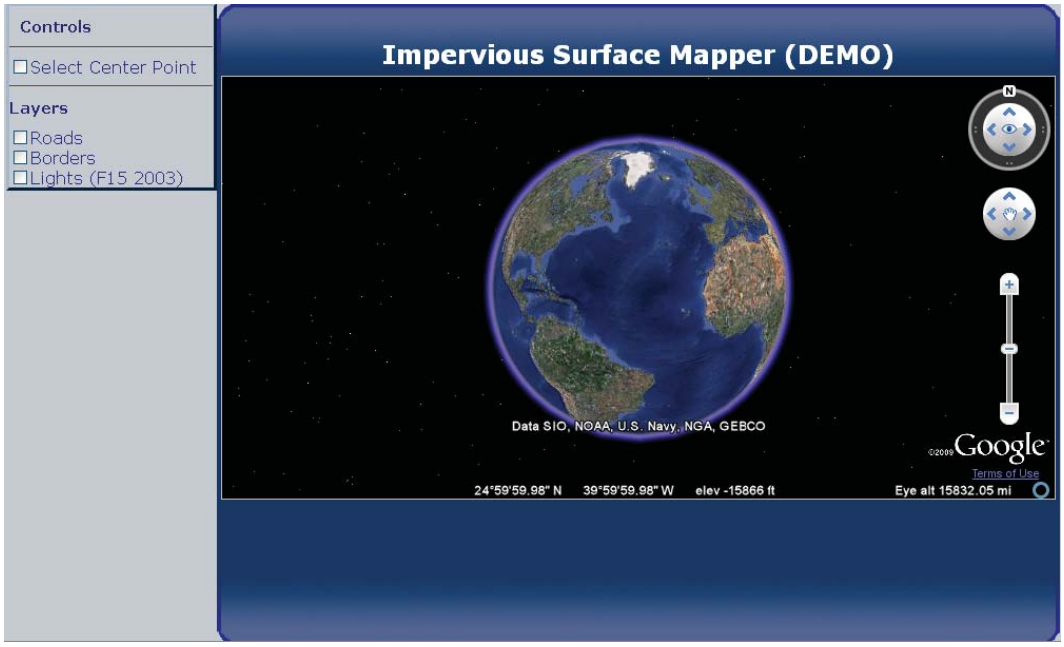

Fig. 1. This is the view the analyst has upon opening the url in a web browser.

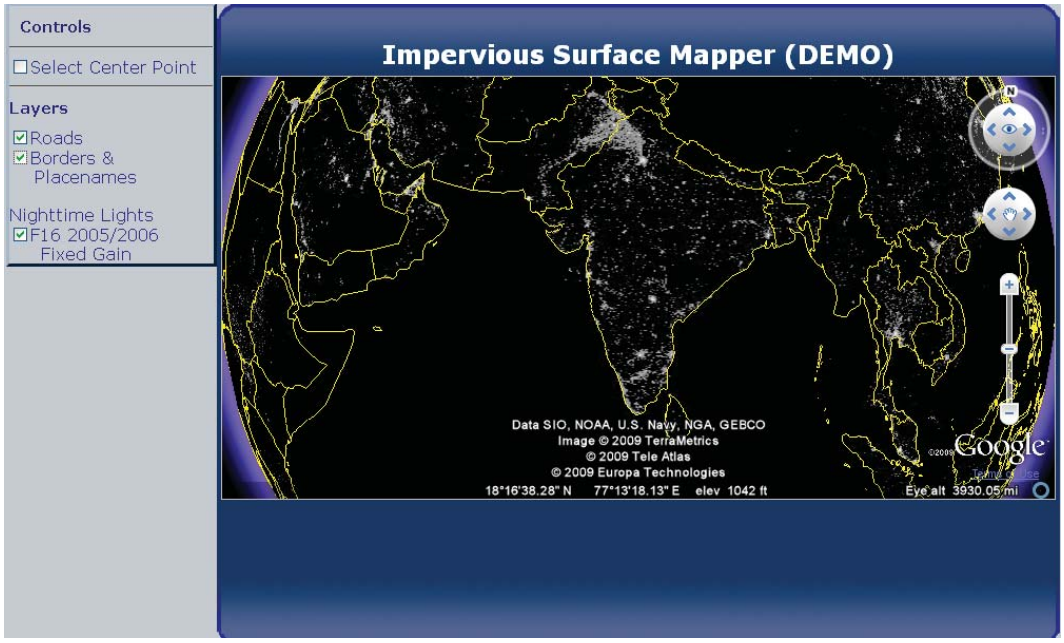

Fig. 2. As the analyst begins to move towards their area of interest they can display nighttime lights plus basic geographic vectors such as roads, borders and placenames. This image is centered on India.

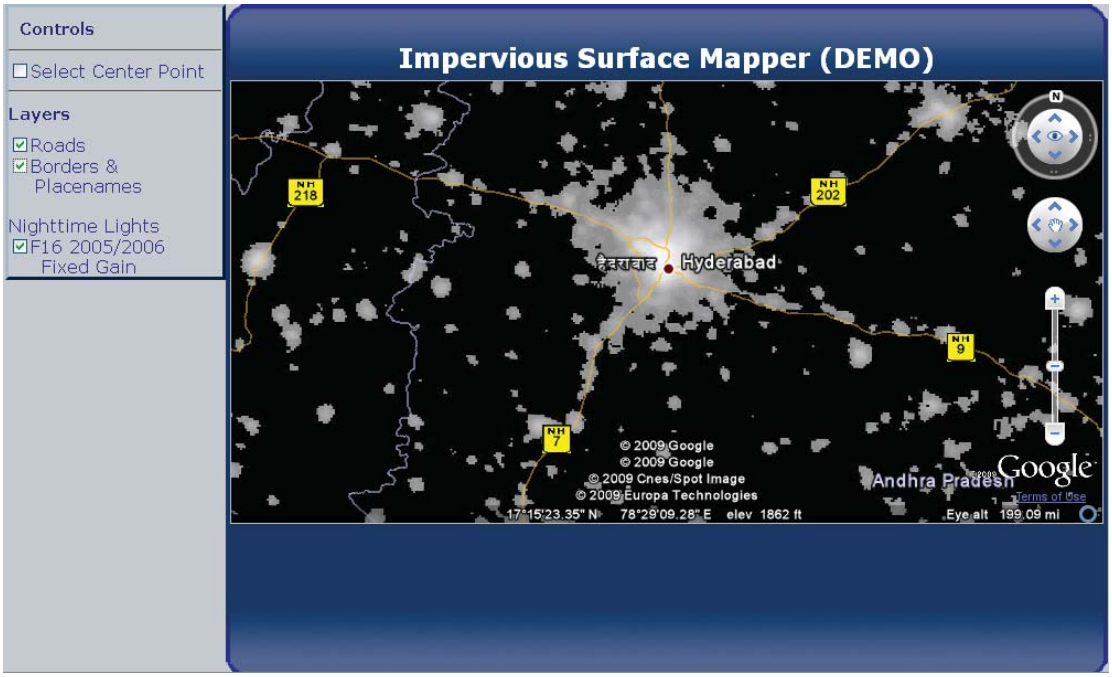

Fig. 3. As the analyst continues to zoom in towards their area of interest road and placenames become visible. This image is centered on Hyderabad, India.

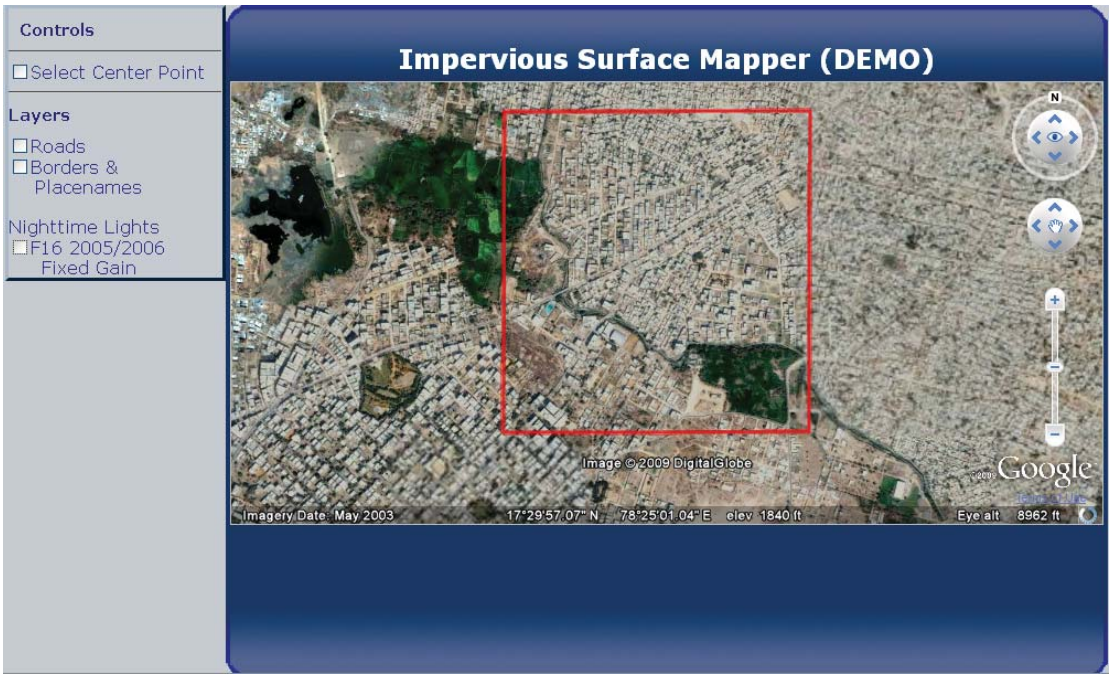

Fig. 4. When the analyst selects a center point for the point count the outline of the 30 arc second grid cell is defined and marked in red. The selected location here is in Hyderabad, India.

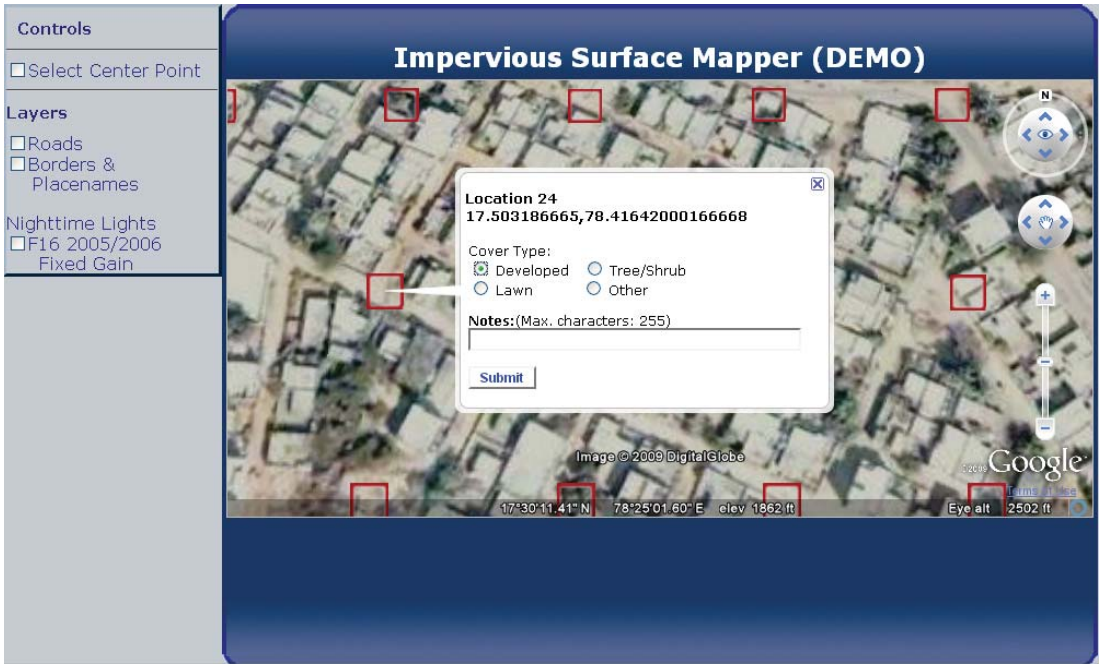

Fig. 5. As the analyst continues to zoom in the individual sample points for the point count are drawn in red. The analyst clicks on points one at a time to pull up the entry window. The analyst selects the cover type and submits the point. Once the database entry is complete the sample point is redrawn as green.

4. RESULTS

As an initial test twenty gridded point counts were collected along transects across Washington DC (USA), Mexico City (Mexico), Milan (Italy), Hyderabad (India) and Beijing (China). The brightness of the nighttime lights and the Landscan population counts were extracted for the twenty points and linear regression was developed. The linear regression was highly significant with an R^2 value of 0.88. The constructed surface area density is estimated as (0.0923*DN lights) + (0.0006*population count). The correspondence of the estimated ISA density to the observed density values (Figure 6) is encouraging.

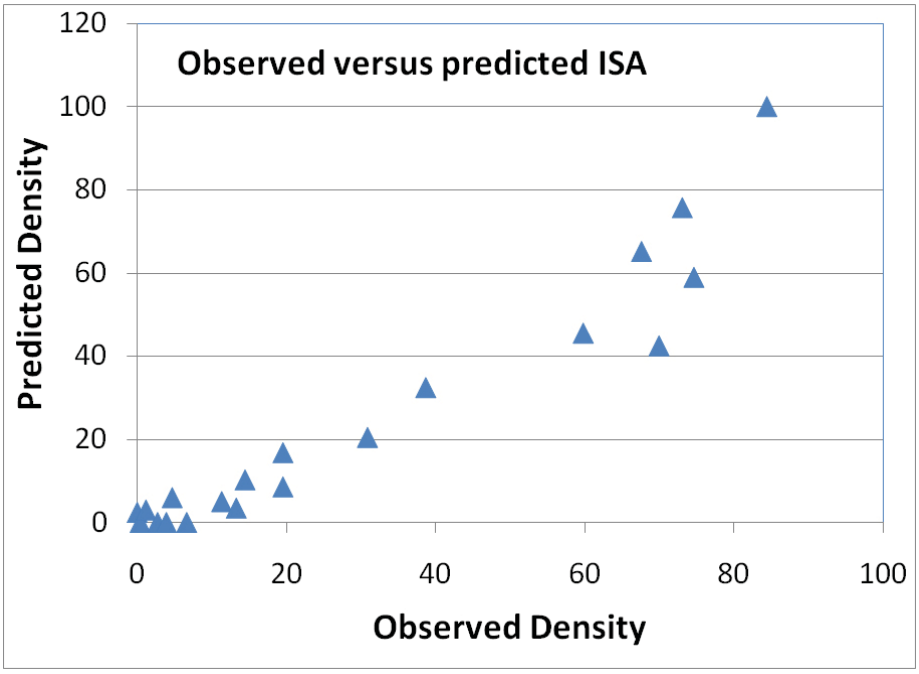

Fig. 6. Preliminary results obtained using twenty point counts collected in the USA, Mexico, Italy, India and China.

5. CONCLUSIONS

A primary shortcoming of the previous global constructed area density grid was that the reference data came from the USA only [7]. We have developed a web-based tool for the collection of reference data on the density of constructed surfaces for human settlements worldwide with gridded point counts made on high spatial resolution imagery available in Google Earth. Originally, much of the base imagery present in Google Earth was from Landsat (30-meter resolution). However, an increasing number of areas – especially urban areas – have high-resolution imagery from the Digital Globe Corporation. While there are some compression related distortions present in the Digital Globe imagery as rendered by Google Earth, our assessment is that the images are suitable for extraction of gridded point counts of surface cover types. For our project, using Google Earth vastly reduces the cost that would be associated with selecting, purchasing and managing the high spatial resolution imagery required to measure constructed area densities. We believe that the web-based tool we have developed could be useful for other projects which require surface cover data that can be visually identified in high spatial resolution satellite imagery.

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