Mapping the Constructed Surface Area Density for China

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Abstract: Efforts to map the constructed surface area density of the world using nighttime satellite imagery have typically been validated using aerial photography or high resolution satellite imagery in the United States and extrapolating regression parameters to countries outside of the United States. In a previous study, we found China to have 'paved' more of the planet than any other country (~87,00 km^2). Here we use a google earth based web application to validate our estimates of anthropogenic impervious surface (constructed area density) in China using actual imagery of China. 'Paving the Planet' is a universal phenomenon – akin to clothing – and represents one of the primary anthropogenic modifications of the environment. Expansion in population numbers and economies combined with the increased use of automobiles has led to the sprawl of development and a wide proliferation of constructed impervious surfaces. 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. We present a new map of the density of constructed surface in China derived from DMSP nighttime lights and LandScan population count data.

1. Introduction

There are a growing number of approaches to using remotely sensed imagery to estimate and map Impervious Surface Area (ISA) (Liu et al., 2010). A seminal paper on the functional classification of urban land cover into Vegetation, ISA, and Soil (V-I-S) provides some of the motivation for these attempts to map ISA (Ridd, 1995). Spectral Mixture Analysis (SMA) and neural networks have been applied to ASTER images to produce representations of the ISA of Beijing, China at 15 m spatial resolution (Hu and Weng, 2009). Representations of ISA have also been used to model urban heat island effects in Hangzhou City, China (Wu and Cheng, 2007). These rough numbers provide an idea of actual ISA fractions in urban areas: 80-100% ISA occurs in the Central Business District (CBD), 30-60% ISA occurs in residential areas of large cities, and rural areas have low values in the 0-20% ISA (Li et al., 2009). The aforementioned studies (and many others) produce representations of ISA at fairly high spatial resolution. It is often difficult to apply these methods at national, regional, or global scales. The approach we present here uses coarse resolution nighttime imagery and population data to produce representations of ISA at national scales.

In an earlier study using only images in the United States we determined that globally approximately one half million kilometers had been 'paved over' by human activity (579,703 km^2) (Elvidge et. al. , 2007). This is nearly the same size as the country of Kenya (584,659 km^2) and larger than Spain (505,735 km^2) or France (546,962 km^2). China was the country found to have the most ISA (87,182 km^2) followed closely by the United States (83,881 km^2), and India (81,221 km^2). This study furthers these efforts by using high resolution imagery of China to estimate regression parameters specifically for China. An interesting question the paper pursues is: *Is China truly the country that has paved over more of the Planet than any other country?* Answering this question is of some interest because data products such as ISA that are derived substantially from nighttime satellite imagery serve as good proxy measures of myriad human activities including environmental impact, economic activity, energy consumption, and CO_2 emissions (Doll et. al. 2000; Ghosh et. al.; 2010; Ghosh et. al. 2010; Sutton, 2003).

The aforementioned studies of ISA were accomplished using global parameters for all regions of the world. In this investigation we focused on a particular region of the world, China, and developed regionally specific parameters in the hope that the skill of our model would be improved. Ultimately, we believe the best approach to developing global datasets of percent constructed area will use global datasets such as the Landscan and DMSP-OLS products in

tandem with regionally specific parameterizations to maximize accuracy. This is a preliminary investigation of the potential of this approach.

2. Methods

2.1. Data: Nighttime Lights, Landscan, and Google Earth

The basic methodological approach we used was to predict the fraction or percentage constructed area of a given pixel using a simple two variable multi-variate regression model. A pixel in both the Landscan and the DMSP OLS dataset is a 30 arcsecond grid cell (roughly 1 km^2). The predictor variables (independent variables) used were the nighttime lights DN and a population count from Landscan.

We used a radiance calibrated image of the world derived from scores of orbits of the DMSP OLS in 2010. This was a cloud-free composite derived from data collected by the F16 satellite at low, medium, and high gain settings. In addition we used the 2008 Landscan population grid developed at, and provided by, the Oak Ridge National Laboratory (Bhaduri et. al., 2002). The predicted (dependent) variable was 'percent constructed surface area density'. Constructed surface area density is a variable we have defined that we believe captures the idea of anthropogenic impervious surface. Essentially, constructed area density measures what fraction of a given area has been converted to rooftop, sidewalk, street, or parking lot (a surface built by humans that does not allow water to seep into the ground). We obtained actual values for 28 pixels using a web application we refer to as the Impervious Surface Mapper (also affectionately know as 'the light picker'). The impervious surface mapper uses the high resolution imagery available in Google Earth to enable the users to classify 225 points within each of these pixels.

2.2. Impervious Surface Mapper (http://www.ngdc.noaa.gov/dmsp/imaps/isamapper)
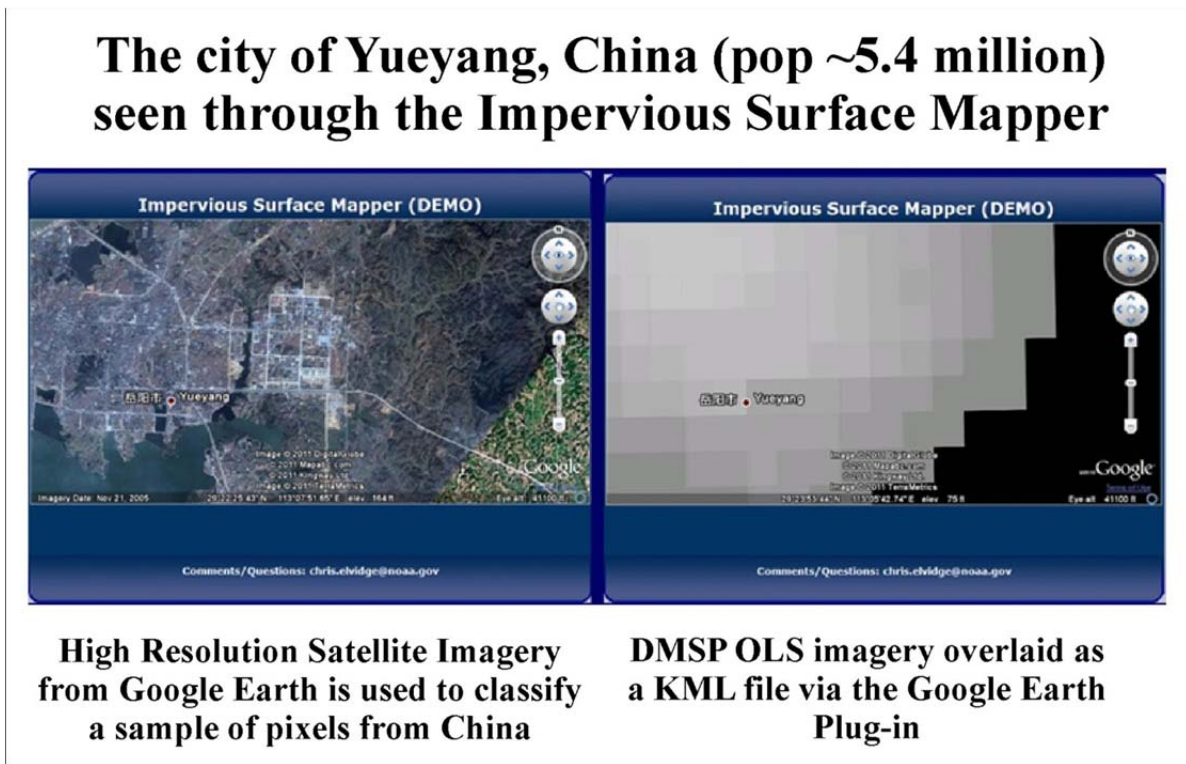
The impervious surface mapper is a web application that uses a google earth plug-in to allow users to zoom to any area of the world and choose a DMSP 'pixel' to collect gridded point count data to estimate the density of constructed surfaces and other land cover types listed in table 1.

Table 1: Classification Scheme for the Impervious Surface Mapper

Developed	Street/road	Tree/Shrub	Open Area	Flat Roof	Other Roof	Other Constructed	Lawn
Other	Unpaved Road	Tree/Bush	Open Area	Ag. Field	Water		

Typically, we would select grid cells along transects that traversed through the center of a city and extending across suburban, rural, and undeveloped areas. These 'transects' would almost invariably also traverse through the brightest pixels in the nighttime imagery (Figure 1). Once the user identifies a pixel he or she wishes to classify they initiate a command that draws a grid

of 225 red squares inside the pixel. The very center point of each of these squares is classified via a radio button check box using the scheme outlined in Table 1 (Figure 2).

Figure 1: Impervious Surface Mapper representation of Yueyang, China

Figure 2: The 225 point per pixel sampling scheme of the impervious surface mapper
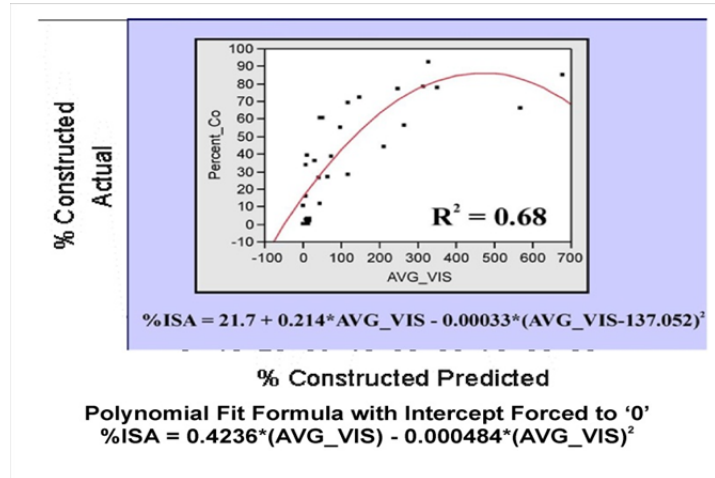
2.3. Regression model

The analytical approach we took is quite simple. The Impervious Surface Mapper web application generates a simple flat file table with the following columns: Pixel ID, Latitude, Longitude, Username, Time of Classification, DMSP OLS DN value, and Landscan Population Count. We collapse the table on pixel ID summing the number of occurrences of the 'developed' category of 'Street/Road' or 'Flat Roof' or 'Other Roof' or 'Other Constructed'. This resulted in a table with 28 records in which each record represented a pixel (recall this table was derived from 28 x 256 = 7,168 'point' classifications of the imagery in google earth). The three values for each pixel we used were: '% Constructed area', 'DMSP OLS DN', and 'Landscan Population count'. Using this table we conducted a simple multi-variate regression in which we used the light intensity measured by the DMSP OLS DN and the population density measured by Landscan

% Constructed Predicted

Regression Model for % constructed area density

% Constructed = 0.151*(DMSP OLS DN) + 0,00013*(Landscan)
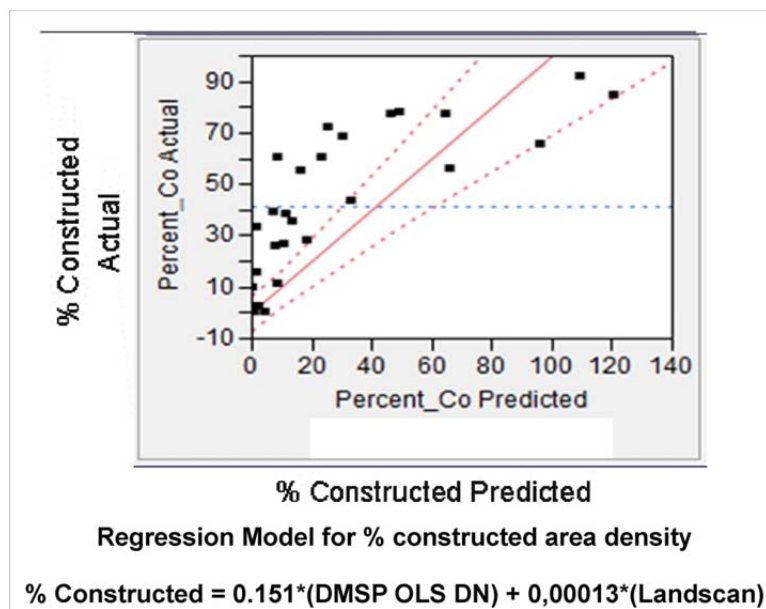
Population count to predict the percent constructed area. The regression was significant ($R^2 = 0.60$ with significant values for both the DMSP OLS DN and the Landscan Population count parameters) (Figure 3).

We did force the regression intercept to pass through a (0,0). This is justified in a theoretical sense in that we do not want negative values of % constructed area. We were not entirely satisfied with the linear modeling of what appears to be a non-linear relationship so we did try a quadratic model (Figure 4). We present aggregate results for both models in the results section.


Figure 3: Regression Model predicting '% Constructed Area'

$$\%ISA = 21.7 + 0.214*AVG\_VIS - 0.00033*(AVG\_VIS-137.052)^2$$

Polynomial Fit Formula with Intercept Forced to '0'
$$\%ISA = 0.4236*(AVG\_VIS) - 0.000484*(AVG\_VIS)^2$$

Figure 4: Polynomial fit of %ISA using DMSP OLS

3. Results

Implementation of the model was accomplished by simply applying these regression parameters to the DMSP OLS and Landscan datasets for the areas of China (Figure 5). A more detailed picture of this estimate of percent constructed area is shown for Beijing and Shanghai (Figure 6). It is interesting to note that even in the very heart of these large cities the fraction of land cover that is impervious is often much less than 50%.
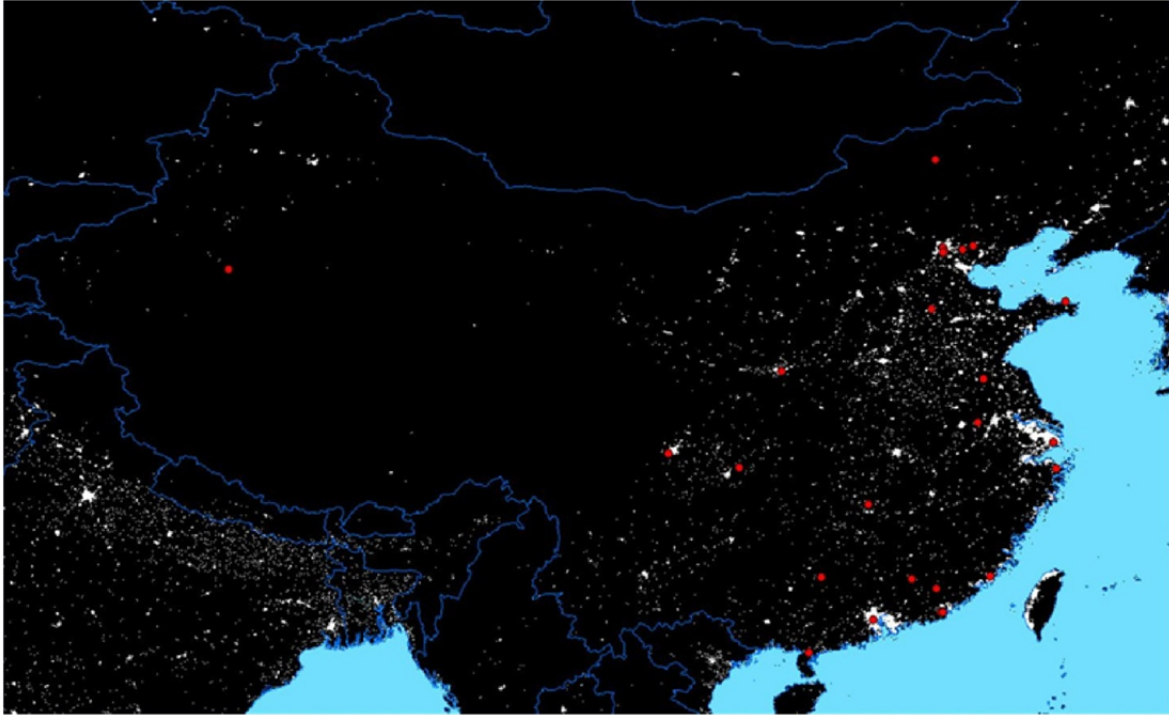
Figure 5: Simple Linear Regression model applied to DMSP OLS and Landscan for China

The values of '% constructed area' pixels were summed for China using both the simple multivariate linear model and the polynomial model (Table 2). Both models produce an extimate for the total ISA of China that is lower than the estimate of ISA for the United States. These results suggest the United States probably has the dubious distinction of being #1 for having paved over more of the planet than any other country. By using China specific regression parameters we have made a new estimate that is 45% smaller than a previous estimate using United States derived regression parameters.
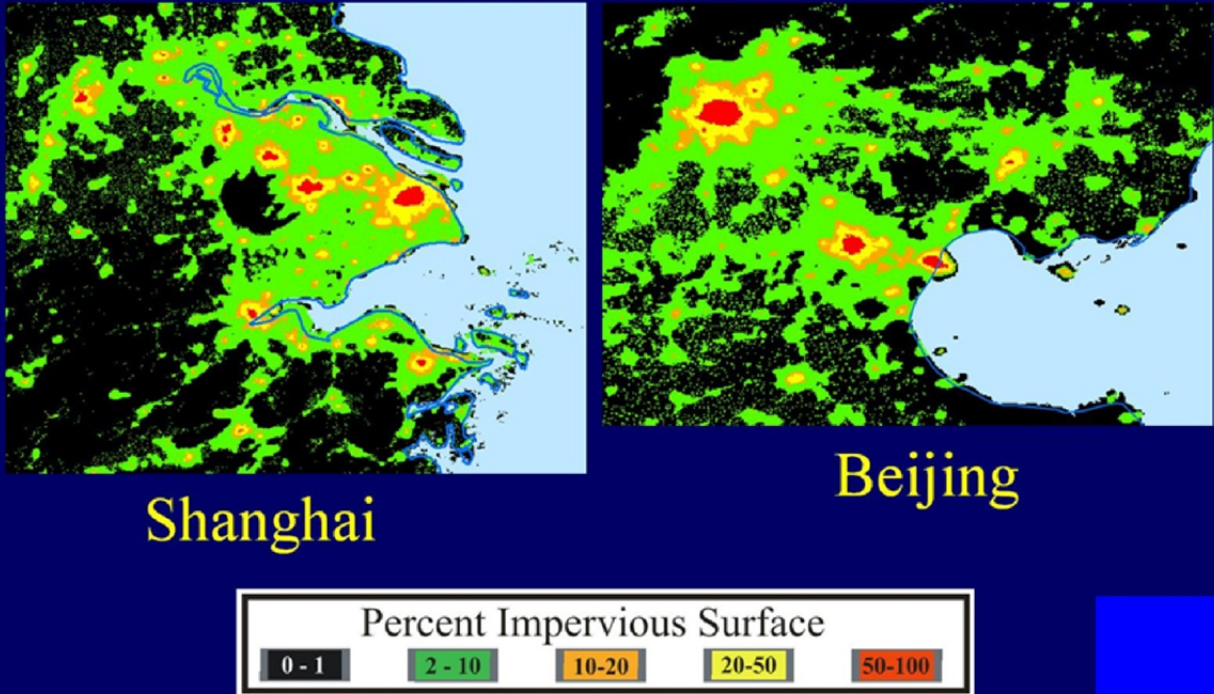
Figure 6: Estimation of Impervious Surface Area for Hanoi and HCMC, Viet Nam

Table 2: Who is number 1 for 'paving the planet'?

Estimated ISA of China using U.S. parameters	87,182 km^2
Estimated ISA of China using Chinese Parameters (Linear mulitvariate)	48,070 km^2
Estimated ISA of China using Chinese Parameters (polynomial using DMSP only)	70,672 km^2
Estimated ISA of U.S. using U.S. parameters (linear)	83,881 km^2

4. Discussion and Conclusion

In this paper we used a web-based tool for the collection of reference data on the density of constructed surfaces 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. This development opens up new possibilities for widely dispersed collaborations.

The preliminary ISA density grid of China for the year 2010 is available at: http://www.ngdc.noaa.gov/dmsp/download.html. We believe the development of regionally specific regression parameters for estimating the fraction of impervious surface from global data products such as the DMSP OLS and Landscan has great potential for dramatically improving the accuracy of estimation of the fraction of ISA regionally and globally. We are still exploring how the relative relationships of nighttime lights and population density contribute to the variation of the percentage of impervious surface around the world. For example a similar study of S.E. Asia resulted in these regression parameters (R^2 = 0.87; $\beta1$ = .182, $\beta2$ = .00063); whereas, this study of China using the same variables and parameter estimation methodology produced these parameters (R^2 = 0.60; $\beta1$ = .151, $\beta2$ = .00013). Nonetheless, even if identifying this relationship remains elusive we believe the identification of a simple set of regionally varying parameters for the globe would be useful in its own right for the improvements in the accuracy of estimation alone. We are convinced that global representations of ISA that can be updated on an annual basis would be widely used as a spatially explicit proxy measure of myriad human activities and impacts on the environment.

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