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**Project Progress Report**

Year-1 (03/2013 – 03/2014)

(December 12, 2013)

Project Title:

**Understanding and Simulating Spatially Explicit Global Urban Expansion in the Context of Climate Change**

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**Introduction**

This project is to contribute to the NASA ROSES LCLUC program by generating a consistent global urban map series and developing an integrated modeling framework to project future urban expansion. Our goal is to improve the understanding of global historical urban expansion, its socioeconomic drivers, and potential future urban expansion. We propose an interdisciplinary research program to achieve our research goal through four objectives:

Objective 1: Building a consistent global urban map series. We will develop an algorithm to build a series of consistent maps of urban extent from 1992 to 2010 using NASA products and DMSP/OLS Nighttime Lights (NTL) data. The algorithm will include several key steps that address challenges in extracting urban areas from NTL data such as gas flare and overestimation. The global urban maps will be validated using finer spatial resolution satellite data in areas where urbanization is important and these high-resolution data are available.

Objective 2: Analyzing global urbanization and its driving forces and developing a region-specific macro-scale statistical model. Using the global urban maps, we will analyze the amount, rate, and patterns of urbanization and the temporal and spatial differences across national and sub-national boundaries, and explore socioeconomic and demographic forces driving these differences, such as population change and GDP growth. We will then develop a region-specific macro-scale statistical model for urbanization projection at the regional level. Special attention will be paid to the analysis in developing and underdeveloped countries, where methodological challenges exist and improvements are more needed.

Objective 3: Developing an integrated framework to project future urban expansion. We will combine the top-down macro-scale statistical model developed in Objective 2 with a bottom-up Cellular Automata (CA) based Urban Growth Model (UGM), and develop an integrated modeling framework to project urban expansion. The interaction between urbanization and its socioeconomic drivers will be considered in the projection through an embedded Global Change Assessment Model (GCAM) and the statistical model by using a set of consistent exogenous and GCAM projected variables.

Objective 4: Exploring scenarios of urbanization projection and its implications. We will construct alternative climate and socioeconomic scenarios to explore the robustness of the urbanization projection and improve our understanding of potential trajectories of future urbanization in the challenge of climate mitigation. Moreover, we will investigate the implication of spatially explicit urban projection by taking building energy use as an example.

**Year-1 (03/2013 – 12/2013) Project Summary**

**1. *A Cluster-based Method to Map Urban Area from DMSP/OLS Nightlights***
*1.1. Method*

As a keystone of our proposed activities, the project team developed a cluster-based method to estimate optimal thresholds and map urban extent using DMSP/OLS NTL and supplementary data. This method includes five major steps: data preprocessing, urban cluster segmentation, logistic model development, threshold estimation, and urban extent delineation

(Figure 1). First, we filtered NTL data by excluding water and gas flare pixels. Second, we identified potential urban clusters from filtered NTL data using a segmentation method. Third, we analyzed the relationship of optimal threshold derived from high spatial resolution land cover data with cluster size and NTL magnitude in each cluster, and built a logistic model for optimal threshold estimation. Fourth, we estimated the optimal threshold in each cluster using the logistic model. Finally, we mapped the urban extent according to the estimated threshold in each cluster.



*Figure 1. Flowchart of the cluster-based method*
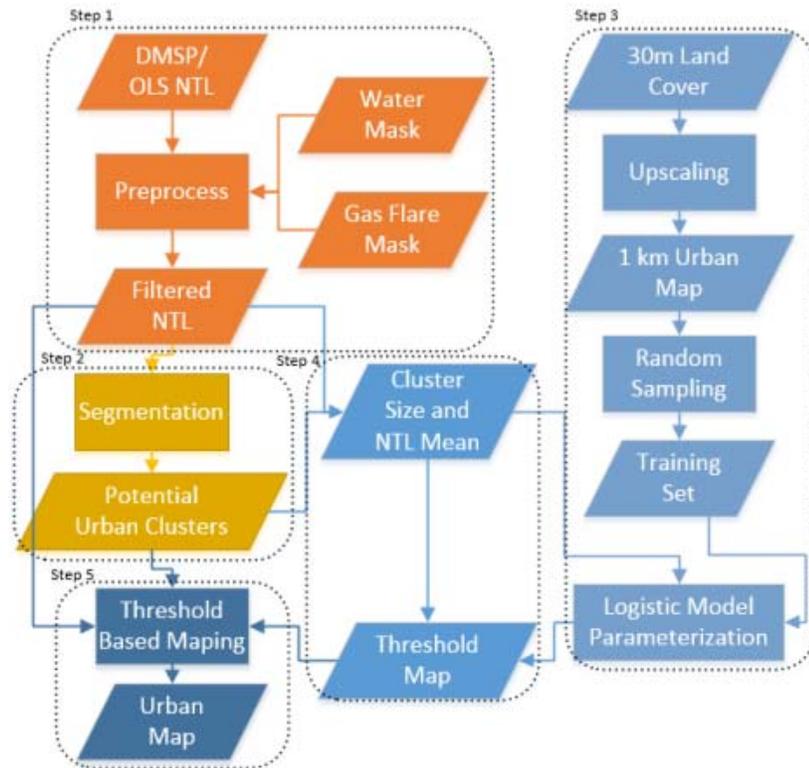
### 1.2. Experiments in USA and China

The project team calibrated and test the above methodical framework on two representative regions, the contiguous US and China. The two regions have different urbanization patterns. In particular, urbanization extent and density in China varies greatly across the space, attributable to the heterogeneous socioeconomic development whereas these parameters are more uniform in the US. The different urbanization densities and patterns in the US and China provide ideal testbeds for evaluating the global applicability of the proposed urban mapping method.

We first derived optimal thresholds required in the logistic models based on randomly selected training data, and then delineated urban extents in the US and China using the filtered NTL data and potential urban cluster maps (Figure 2, top). The result shows the spatial patterns of urban area in the US in 2006 and China in 2005. The total urban areas are 160,000 km2 and 37,000 km2 in the US in 2006 and China in 2005, respectively. The urban pattern in the US is more heterogeneous with centers spotted across the country whereas in China, the urban area tends to aggregate in eastern coastal regions. The urbanized area occupies about 2% of the total area in the US. The urbanization extent in terms of urban area percentage varies from lower than 0.5% in states in the US census region of Mountain and West North Central, such as Montana, Wyoming, South Dakota and North Dakota, to higher than 10% in Eastern Coastal states such as New Jersey, Massachusetts, Connecticut, and Maryland. The urbanized area occupies less than

1% of total land area in China, and varies in extent from lower than 0.1% in some western provinces such as Xizang, Qinghai, and Xinjiang, to about 2% in eastern coastal provinces such as Jiangshu and Guangdong. It is as high as 10% in municipalities such as Beijing and Shanghai.



*Figure 2. Urban extents mapped from NTL (top) and high-resolution land cover data (bottom)*

### 1.3. Evaluation

A general comparison of our new products with Landsat derived high-resolution urban area maps (Figure 2, bottom) indicates that our method can delineate most of the large urban centers in both the US and China, and the extent of the urban areas from NTL and high-resolution land cover data matches relatively well (Figure 2). We also selected four cities of different sizes in the US and China to evaluate urban extents mapped from NTL data using our method. A visual comparison shows that our proposed method can map the urban extents relatively well for example cities and the mapped urban extents tend to be less fragmented compared to those from high-resolution land cover data due to the lower spatial resolution of NTL data.

In addition to the comparison of overall pattern, we compared the derived urban extents using this cluster-based method to those from the 1 km reference urban map at the cluster level (Figure 3). Our method performs well at the cluster level (Figure 3, left) both in the US and China, for example, with a $R^2$ of 0.98 and RSME 28 in USA. The performance in USA is slightly superior to that in China (Figure 3, right).
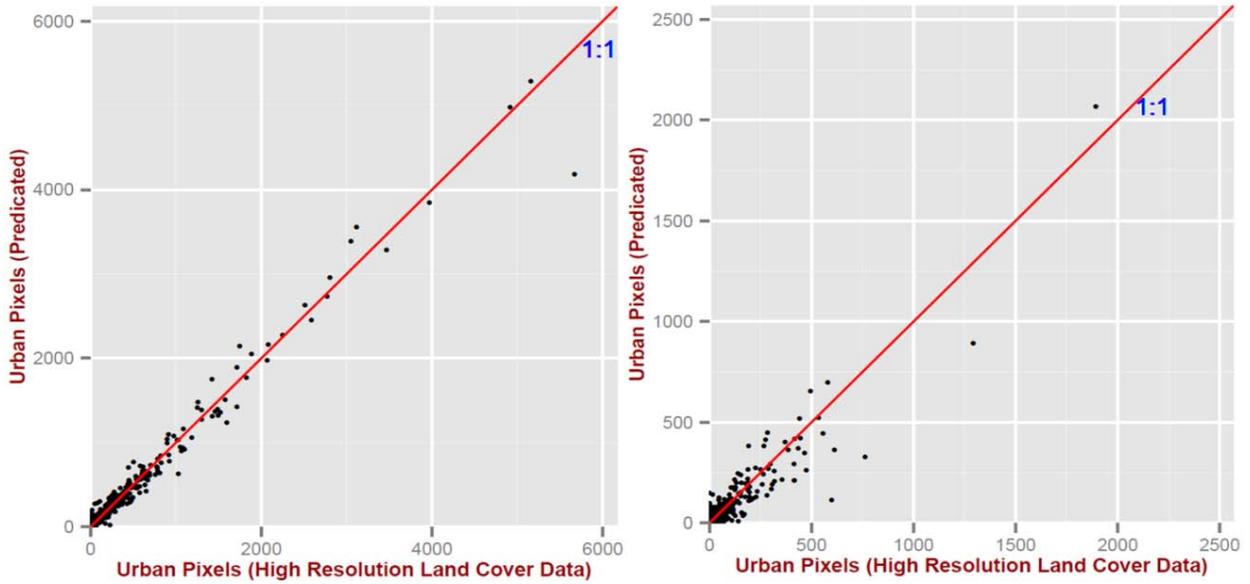


***Figure 3. Comparison of urban extents from the cluster-based method and 1 km reference urban map at the cluster level in the US (left) and China (right)***
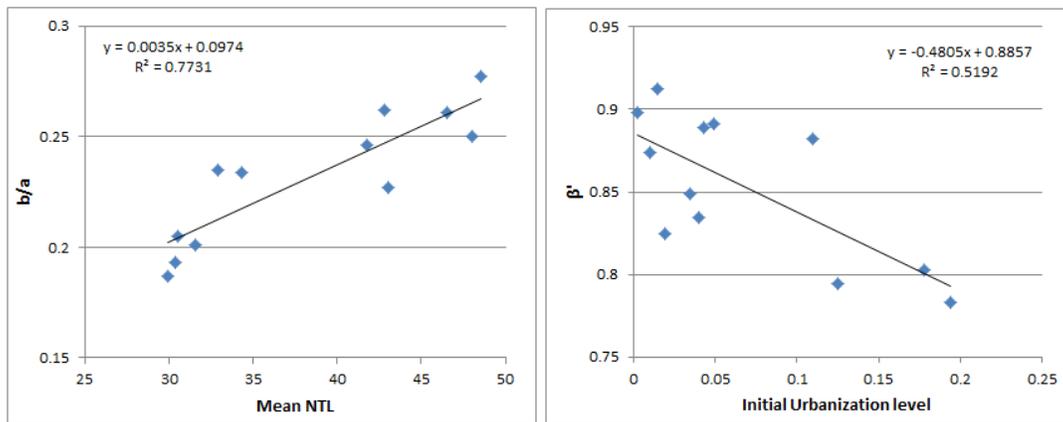
## 2. Global Urban Map
### 2.1. Country Specific Parameters

To build the global urban map using the cluster-based method, the project team estimated the country-specific parameters ($a/b$ and $\beta'$) required for the logistic model (Eq. 1 and 2). Through a sensitivity analysis performed for $a/b$ and $\beta'$, we examined how changes in these parameters impact optimal thresholds. We found that both parameters can have important impacts on optimal thresholds in both countries when they deviate from derived values. With USA and China grouped into 12 regions, we studied the relationship between these parameters and initial urbanization characteristics (Figure 4). The developed relationship was then used to derive the country-specific parameters to estimate the global urban areas. It is worth to note that the derived optimal thresholds are not highly sensitive to the parameter choices in the logistic model when these parameters are sufficiently close to the optimal values, which lends further strength to this methodology in global applications.

$$NTL_{thld} = \frac{1}{1 + e^{-\beta'(x' - x'_{middle})}}(NTL_{max} - NTL_{min}) + NTL_{min} \qquad (1)$$

$$x' = \ln(S^{\frac{a}{b}} \cdot NTL_{mean}) \qquad (2)$$

$y = 0.0035x + 0.0974$
$R^2 = 0.7731$

$y = -0.4805x + 0.8857$
$R^2 = 0.5192$

*Figure 4. The relationship between parameters in logistic model and mean NTL magnitude of urban cluster and initial urbanization level*

## 2.2. Global Urban Map

Based on the logistic model and country-specific parameters, the project team calculated the optimal thresholds in all potential urban clusters across the world. The urban extent was then delineated according to the derived optimal thresholds (Figure 5). We are also intensively evaluating the global urban map through the available high spatial resolution land cover and land use data and other global urban maps such as 500m MODIS urban map. The preliminary results indicate that the cluster-based method and country-specific parameters performs well through the evaluation, e.g. the comparison with the Europe Corine Land Cover data at 100 m spatial resolution.
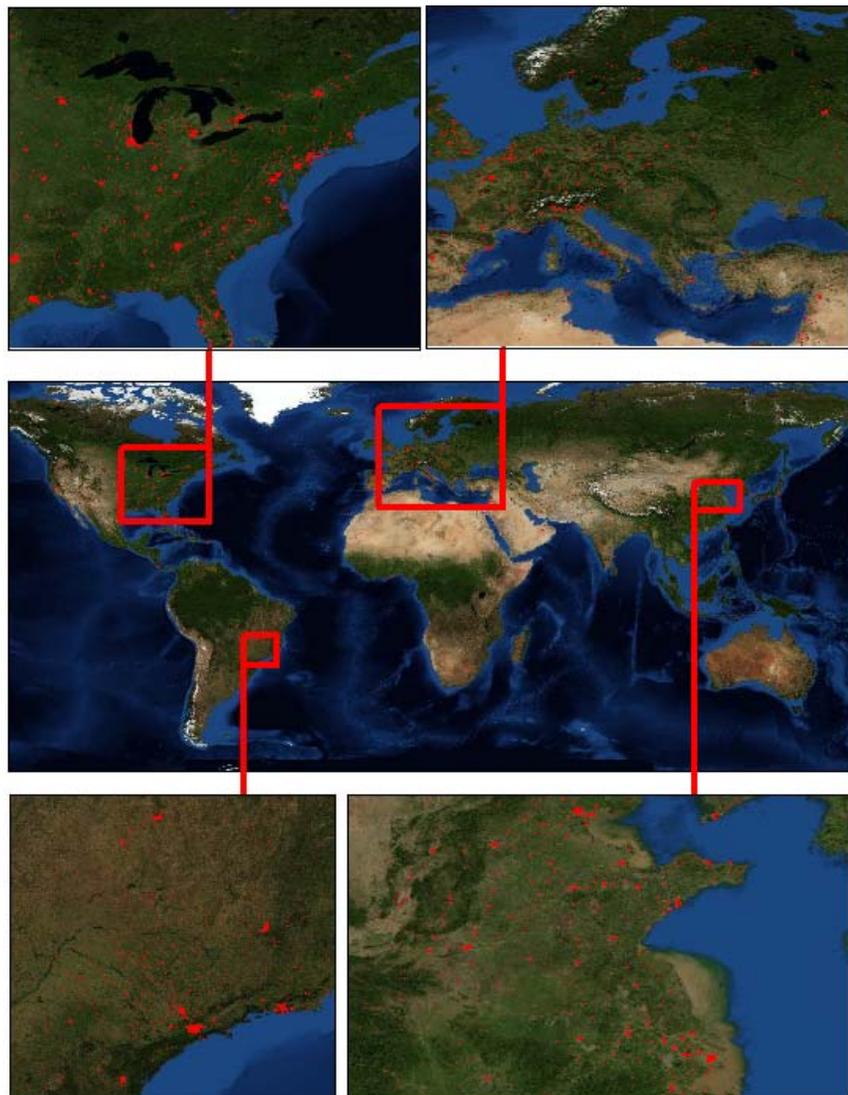


*Figure 5. Global urban area derived from NTL*

### 3. *Time Series of Urban Maps*

The project team is working on extending the cluster-based method to develop a time series of urban maps from the nightlight data over two decades. We have developed an initial framework to automatically build a consistent nighttime lights time series data, which is required for long-term global urban series using our cluster-based method, through several key steps, (1) developing inter-calibration functions, (2) calibrating time series image products using inter-calibration functions, (3) combining intra-annual images, and (4) correcting inter-annual images. We are currently improving and implementing this framework to build the time-series of consistent nightlight data.

### 4. *Publications and Presentations*

*Publications:*
- Yuyu Zhou, Steven J. Smith, Chris Elvidge, Kaiguang Zhao, Allison Thomson, Marc Imhoff, 2013. A Cluster-based Method to Map Urban Area from DMSP/OLS Nightlights. Remote Sensing of Environment. In review.
- Yuyu Zhou, et al. A new global urban map from Nightlights. Environmental Research Letters. In preparation.

*Presentations:*
- Understanding and Simulating Global Urban Expansion in the Context of Climate Change, NASA LCLUC 2013 Annual Spring Science Team meeting, Rockville, Maryland, USA, April 2-4, 2013
- Mapping Global Urban Area from DMSP/OLS Nightlights using a Cluster-based Method, AAG 2014 Annual Meeting, Tampa, Florida, USA, April 8-12, 2014