GLOBAL URBAN MAPPING USING POPULATION DENSITY, MODIS AND DMSP DATA WITH THE REFERENCE OF LANDSAT IMAGES

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ABSTRACT:

In recent decades, rapid rates of population growth and urban expansion affect local and regional ecosystems, climate, biogeochemistry, as well as food production. Ninety percent of urbanization will be concentrated in low-income countries. While timely information on human settlement distribution, location and size is more readily available for high-income countries, maps of settlements in low-income countries are often outdated, inaccurate or none existed. The main objective of the research is to improve understanding of the methodological and validation requirements for global urban mapping from low-resolution remote sensing data as a reference of fine resolution Landsat Enhanced Thematic Mapper (ETM+). This map was then compared against urban boundaries derived from ETM+ imagery and other six existed continental scale urban maps. The comparison highlights the map product using population density, MODIS and DMSP data with the reference of ETM+ was more accurate.

1. INTRODUCTION

1.1 General Instructions

Urban areas are expanding rapidly in many parts of the world. Urban encroachment upon agricultural and forest lands often leads to environmental degradation and a loss of natural productivity, leading some analysts to suggest that the present rate of urbanization constitutes a global crisis.

Approximately half of the World population lives in urban areas. Ninety percent of urbanization is occurring in low-income countries. These population shifts will affect large social, environmental, economic and public health impacts. There is therefore a need for timely information on human settlement distribution, location and size. While such information is more readily available for high-income countries, maps of settlements in low-income countries are often outdated, inaccurate or nonexistent. Mapping urban land cover is important because it reflects land-use patterns related to socio-economic activities that impacts the surrounding environments.

Previous studies of urban areas from remote sensing have consistently relied on fine resolution data (Landsat, SPOT, ASTER), which limits these studies to small areas and too expensive for most researchers to acquire and process at continental to Global scales. The continental scale maps of urban areas are the Digital Chart of the World (DCW) urban layer (Danko, 1992), and maps derived from the Defense Meteorological Satellite Program Operational Linescan System (DMSP-OLS) "low light" sensor or nighttime lights data (Elvidge et al., 1996), classification of Advanced Very High Resolution Radiometer (AVHRR) imagery (Hansen et al,1998), Global Land Cover mapping (GLC2000), population census data GRUMP (Global Rural Urban Mapping Project) and by fusing various imagery sources(Schneider, et al., 2003).

While the DCW urban data are extremely valuable, they were compiled from Operational Navigation Chart data from the 1960s and no longer provide an accurate representation of the current size of many cities especially fast developing cities in low-income countries.

The nighttime lights data possess "blooming" effects that inflate city boundaries. Applying detection frequency thresholds can reduce the effect, however, thresholding also attenuates large numbers of smaller lights (Small et al., 2005). Recent coarse resolution global urban mapping from AVHRR, GLC2000 and MODIS were unsatisfactory, because of tedious process of training data collection and inadequacies of classification algorism.

Threshold Gridded Population density, nighttime lights and NDVI from MODIS data as a reference of fine resolution ETM+ offer an opportunity for easily and correctly mapping urban areas (Alimujiang et al., 2007).

This paper describes ongoing efforts to produce reliable representations of urban areas at 1 km resolution, as part of a larger project of GLCNMO (Global Land Cover by National Mapping Organizations). The primary goal of this paper is to map GLCNMO urban land cover at 1km spatial resolution by Gridded Population density, DMSP and MODIS-NDVI data. Three major tasks were involved in this study. First, threshold Gridded population density, nightlight time and MODIS-NDVI data as a reference of fine resolution ETM+. The second task was to combine the urban map derived from Gridded population density with DMSP and MODIS-NDVI data. Third task was to validating the final urban mapping with fine resolution Landsat imagery also other six existed continental scale urban maps.

2. DATA AND METHODOLOGY

2.1 Data

2.1.1 Data

Gridded population density data: Global Gridded population data compiled on a 30" x 30" latitude/longitude grid. Census counts were apportioned to each grid cell based on likelihood coefficients, which are based on proximity to roads, slope, land cover, nighttime lights, and other information.

DMSP-OLS data: The files are cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for calendar years. The products are 30 arc second grids, spanning -180 to 180 degrees longitude and -65 to 65 degrees latitude. A number of constraints are used to select the highest quality data for entry into the composites.

MODIS-NDVI data: MODIS/Terra Nadir BRDF Adjusted Reflectance 16 Day L3 global 1km SIN grid product (MOD43B4NBAR) data (MODIS) with seven bands (band 1-7) were used. MODIS data in 2003,starting from 3 December 2002 to 16 December 2003, were acquired from USGS in 10d x 10d of Sinusoidal format. These data were then mosaiced and reprojected into Geographic Latitude/Longitude. NDVI was calculated using following formula.

$$NDVI = \frac{NIR - R}{NIR + R} \qquad (1)$$

A Maximum Value Composition (MVC) was then applied to all NDVI images with the aim of selecting pixels less affected by clouds and other atmospheric perturbations (Holben, 1986).

2.2.2 Validation data and other existing urban map

Landsat Enhanced Thematic Mapper (ETM+) images, which were reasonably close in date to the time frame of the Population data imagery, were acquired from Global Land Cover Facility at the University of Maryland. We visually interpolate ETM data compare with 1km resolution GLCNMO urban map. Table.1 provides details of the most widely used global urban maps.

Data	Organization	Spatial resolution	Produce year
DCW	Defence Mapping Agency (US)	1:1 million	1993
MOD12Q1 V004 Land Cover	Boston University	1 km	2001
GLC2000	ECJC	1 km	2000
GRUMP	CIESIN	1 km	2002

Table.1 existing urban map

2.2 Methodology

In the sections that follow, we describe a methodology for creating continental scale maps of urban area using multiple sources of input data. For this work we limit our analysis to data in China. The methods involved three main steps as shown in Figure.1. In the first step, thresh gridded population density data, DMSP and MODIS-NDVI data with a reference of fine resolution Landsat ETM+. In the second step, using MODIS-DNVI data to exclude green area in the urban area. Finally using DMSP data to exclude rural area around urban. In this way, information from all three data sources was combined to create a final map of urban area and compared with other existed continental scale urban maps. Detail regarding each of the three steps area provided below.
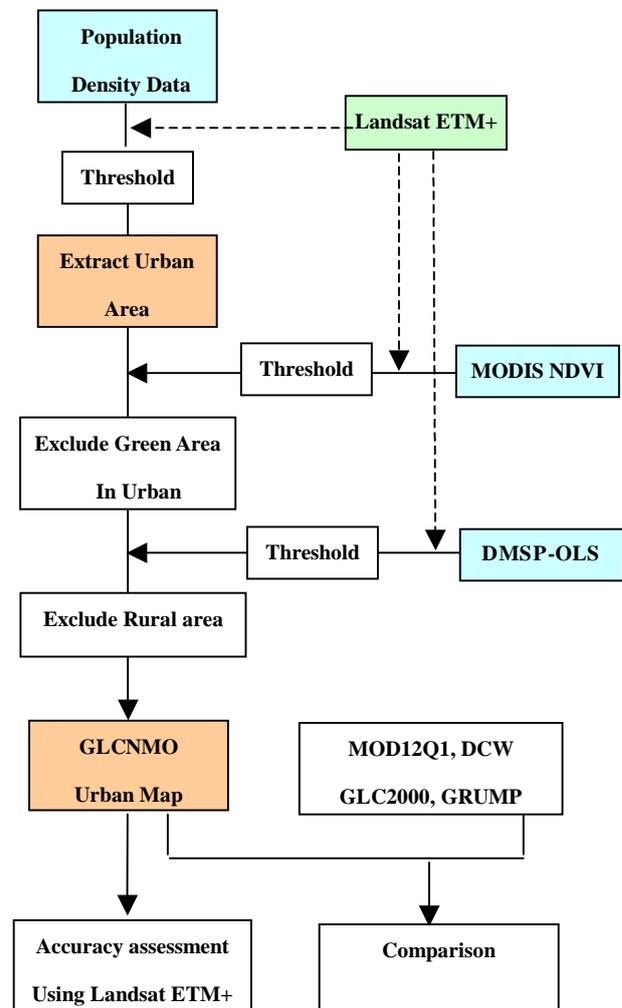

Figure.1 Flow chart of GLCNMO-Urban Map

2.2.1 Processing Gridded Population density data.

The global spatial distribution of human population is extremely nonuniform. A major challenge for applying population density data to delineate urban area is choosing appropriate threshold. We made use of representative twenty-eight cities' Landsat ETM + images that were reasonably close in date to the 2000s time frame of the Population data imagery.

We resample the Gridded Population imagery from its 1 km resolution to the 30m resolutions of the Landsat ETM data. As a reference of Landsat ETM+ imagery, different threshold were given based on continental scale(Table 2).

These results demonstrate that, for cities at different levels of development, quite different thresholds are required when using Gridded population imagery to delineate areas that approximate

the urban areas seen in Landsat TM imagery. Higher thresholds are required with higher levels of population density continents, like Asia, Africa and South America. Lower thresholds are required with higher levels of economic development places, like North America and Europe.

Region	Threshold value		
	Population density	NDVI	DMSP
Asia	800 person/km^2	0.52	10
Europe	500	0.72	20
Africa	800	0.52	5
North America	500	0.62	20
Eastern part of US	500	0.72	20
South America	500	0.52	10
Oceania	500	0.52	20

Table.2 Threshold value

2.2.2 Exclude of green area in urban using MODIS-NDVI

In our Landsat analysis, the trees and meadows of Golden Gate Park were classified as non-urban, even though the social use of the park as a whole is urban. MODIS-NDVI data was used to exclude green area in the urban. For example, large parklands amidst urban areas (i.e. Golden Gate Park, Kamakura park around Tokyo metropolitan or Mount Tamalpais in San Francisco study area) or mixed agricultural–industrial zones (as on the outskirts of Beijing) to be considered not urban.

Generally, the cities of developing regions exhibit the least complex, most compact, least porous and densest urban forms. Cities of developed regions display diametrically opposed tendencies. Therefore high NDVI threshold were given to cities in developed regions, like North America and Europe. Lower NDVI threshold were given to cities in developing regions, like Asia, South America and Africa.

2.2.3 Exclude rural area using DMSP data

Asian cities manifest the densest population, followed by South American cities. Rural areas with high population density excluded using the threshold of DMSP data. For cities at different levels of development, quite different thresholds are required.

3. RESULTS

Representative results for GLCNMO urban areas in figure.2 created by Gridded population density data, nighttime lights (DMSP) and MODIS. While it is difficult to assess the quality of the results at continental scales, regional views show that the sizes and shapes of cities area in good agreement with the expected urban morphology of each region.

3.1 Accuracy assessment

Effective use of classified maps requires thorough analysis and quantification of map quality. Each raster 1 km urban map (DMSP-OLS, DCW, GLC2000, MOD12Q1 GLCNMO, GRUMP) was coregistered to uniform Goode`s Interrupted Homolosine projection. Figure 3 shows a subset of each of the seven maps under test for Chengdu. Fig.3 shows that GLCNMO urban map result by Gridded populations density, DMSP and MODIS data are quite well.
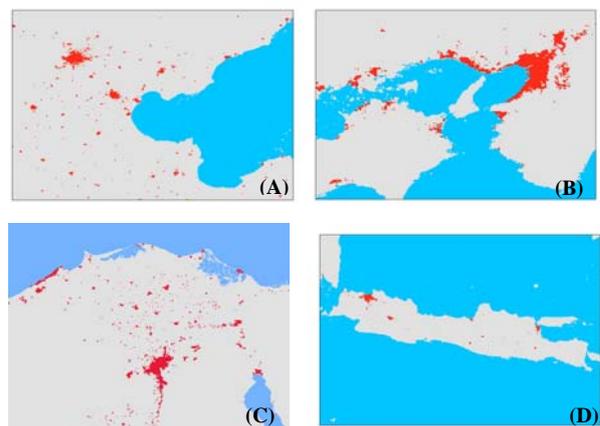

Figure. 2. Four regional views of GLCNMO shown in grey. A. Eastern part of China showing Beijing, Tianjing, B Southern part of Japan showing Osaka. C. Nile River Basin showing Cairo in Egypt. D. Java island in Indonesia showing Jakarta.
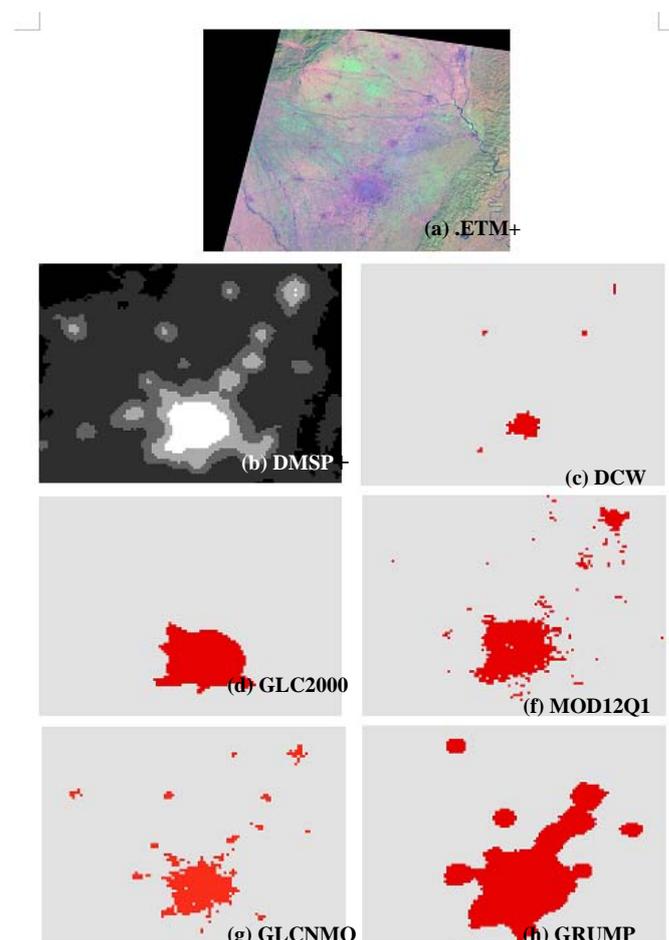

Figure 3: Chengdu mapped by the five settlement maps under test, with the high resolution Landsat ETM.

The Chengdu area showing (a) 30m Landsat imagery (urban areas appear purple); (b) the nighttime lights data (white boundary represents commonly used threshold); (c) the urban map from DCW; (d) the urban data from the GLC2000; (e) MOD12Q1 V004 Land Cover urban map; (f) GLCNMO Urban

map produced in this research and (g) The urban map from GRUMP.

3.2 Per-pixel comparison

The per-pixel agreement between the Landsat ETM+ data and the other six maps of urban land cover was examined at the level of individual cities. Producer's, User's and overall accuracies were calculated and displayed in table.3.
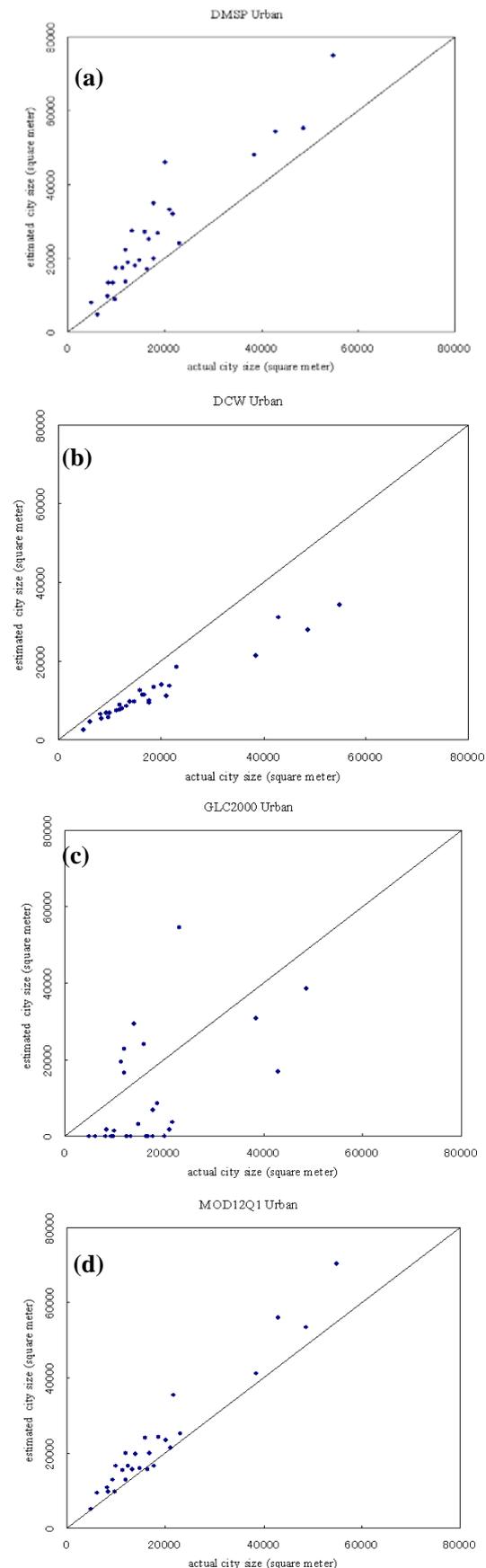
Urban map	Urban Class		Non-Urban Class		Overall Accuracy (%)
	PA (%)	UA (%)	PA (%)	UA (%)	
DMSP	81	59	71.1	89.3	73.4
DCW	87	47	55.1	91.5	64.7
GLC2000	66.9	50.8	64.7	78.5	65.1
MOD12Q1	63.8	68.9	69.4	65.1	65.7
GLCNMO	83.5	84.8	80.8	80	81.5
GRUMP	51	88.8	75.7	29.1	55.7

Table 3 Result of per-pixel comparison of each urban map

The user's accuracy represents the error of commission; pixels that are non-urban but which the map mislabels as urban. The producer's accuracy measures errors of omission; pixels that are truly urban, but which the map mislabels as non-urban.
For the nighttime lights data the user's accuracy for the urban class is substantially lower than the producer's accuracy. Because of the nature of the nighttime lights data (i.e., they are a depiction of light sources and not urban land cover), many pixels fall outside the true city boundaries. This results in a low user's accuracy. On the other hand, the nighttime lights data have no problem capturing the "true" urban pixels correctly, which results in a high producer's accuracy. Because the DCW are outdated, the user's accuracies are high for the non-urban class of this map. This result occurs because the DCW map misses many areas of new growth and suburbs (figure.3-c). In GLC2000 data, many urban areas in China are misclassifying to water and other class types, so the user's accuracies are low for the non-urban class. GRUMP shows the lowest overall accuracy despite user's accuracy for urban class is the highest (88.8%) in other five global maps. The main reason is non-urban user's accuracy of 29.1% shows that only less then one third of non-urban pixels were mapped correctly. This suggests that GRUMP overestimates consistently urban area. MODIS fusion map suggested urban area overestimated in most cases and underestimation in others. Finally, the largest user's, producer's and overall accuracies for both urban and non-urban classes were produced by GLCNMO urban map with values above 80% in all cases. This indicates accurate classification of both urban and non-urban sample pixels.

3.3 Settlement size

A second measure of map quality can be obtained from estimates of city size. This method compares the area mapped as urban for a given city at 1km resolution against the Landsat ETM+ data at a 30m resolution Figure.4.
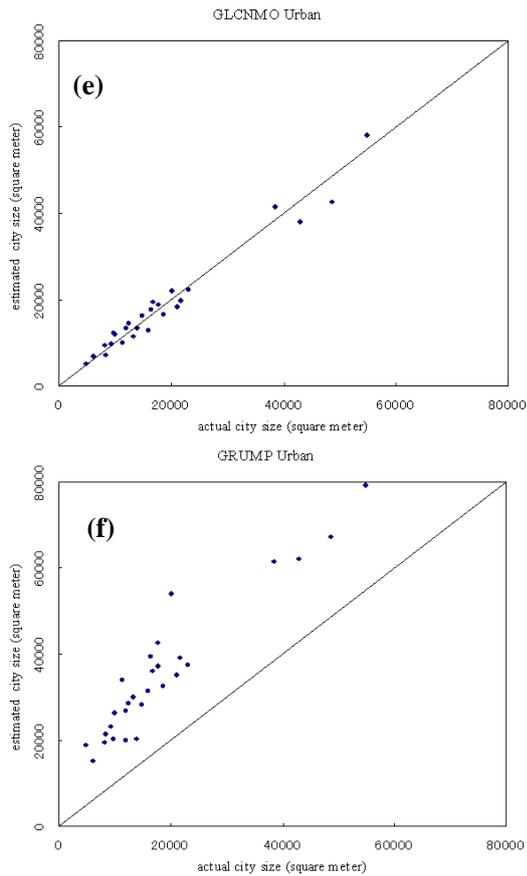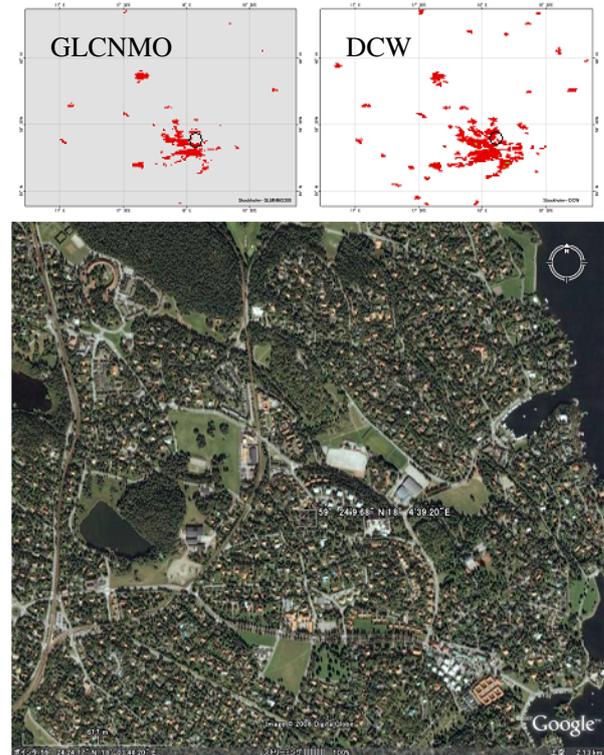
Figure.4. A comparison Landsat ETM-estimated settlement size against estimated settlement size by DMSP, DCW, CLC2000, MOD12Q1, GLCNMO and, GRUMP
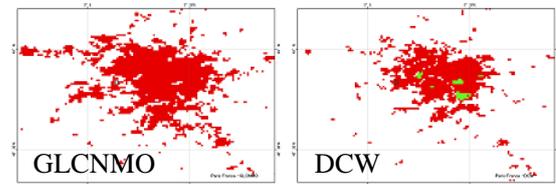
The nighttime lights data (Figure.4a) systematically overestimates city size because of the blooming problem. The DCW map underestimated city sizes (Figure. 4b), since recent decades, urbanization has been increasing a lot. In the GLC2000 map (Figure. 4c) slightly underestimates in some cases and overestimation in others, also we find many cities estimated city size become zero, which means these cities are misclassified to other class types. MODIS fusion map (Figure. 4d) overestimated in most cases and underestimated in some other area. In GLCNMO (Figure. 4e) the sizes of the 28 cities are estimated without much bias. In the case of GRUMP (Figure. 4f), the area overestimation is due to the use of unthresholded nighttime lights data.

4. DISCUSSION

The above analysis shows that we can make comparatively accurate urban map at a coarse resolution remote sensing data. However, misclassified pixels occurred when compared with ETM+ and high-resolution urban map from Google earth. Especially in developed regions like North America and Europe, some residential area with lots of green or near big park were misclassified as green area (Figure.5).

Northern part of Sweden

Paris in France

Figure.5 high-resolution urban map from Google earth

5. CONCLUSION

These results demonstrate that, for cities at different levels of development, quite different thresholds are required when using Grid population imagery to delineate areas that approximate the urban areas seen in Landsat TM imagery. Higher thresholds are required with higher levels of population density continents. Lower thresholds are required with higher levels of economic development places. We have shown that it is not possible to settle upon a single threshold that can be used to delineate urban boundaries across the board, it leaves open the possibility that thresholds can be chosen for continents at comparable levels of Population density, development and urbanization.

Compared with any other existed 1km resolution continental scale urban map, GLCNMO is more accurate. The Grid population image fusion with nighttime lights DMSP and NDVI offers a useful perspective for monitoring the extent and level of urbanization at a global scale.

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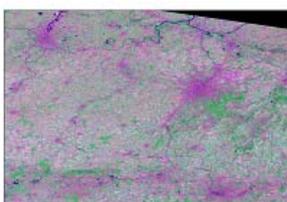
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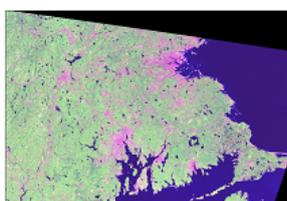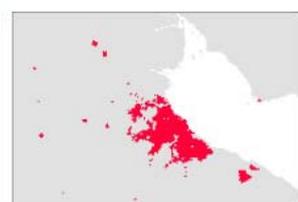
ACKNOWLEDGEMENTS

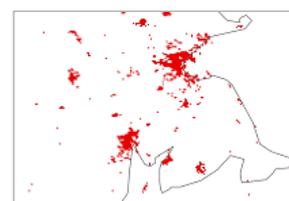## APPENDIX

Comparison GLCNMO with Landsat ETM+
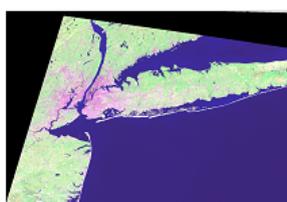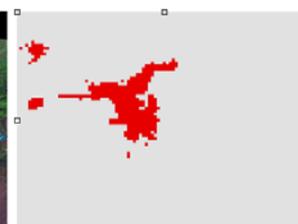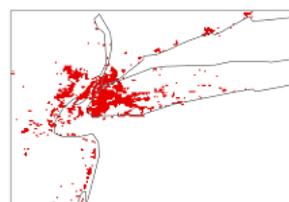
Buenos Aires in Argentina

Brussels in Belgium

Urumqi in China

Boston in U.S.A

Sao Paulo in Brazil

New York in U.S.A