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Mapping urbanization in the United States from 2001 to 2011

Lahouari Bounoua[a,*], Joseph Nigro[a,b], Ping Zhang[a,b,c], Kurtis Thome[a], Asia Lachir[d]

[a] Biospheric Sciences Laboratory, NASA GSFC, Greenbelt, MD 20771, USA
[b] Science Systems and Applications, Inc., Lanham, MD 20706, USA
[c] ESSIC, University of Maryland, College Park, MD 20742, USA
[d] Department of Environmental Sciences, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakesh 40000, Morocco

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ABSTRACT

We combine Landsat and MODIS data with the CIESIN population products to generate observation-based maps characterizing past (2001) and near-present (2011) land use change in the continental United States (CONUS) with emphasis on urban development characterized by impervious surface area (ISA).

At city-scale urbanization appears to implicitly include a 'cultural character' whereby depending on the region, cities are either built horizontally using large ISA per capita or becoming denser and possibly using vertical structures with small spatial footprints. This 'cultural character' is modulated by land availability, topography, coastlines proximity and land use policy regulation.

Regionally, the largest population and ISA change between 2001 and 2011 occurred in the South, while the most noticeable ISA per capita increases are observed in urban centers of the South and Midwest. The South has the highest population and population change, the greatest ISA extent and ISA change, while the Midwest is characterized by the highest per capita ISA use. All regions show an increase in ISA per capita during the decade except for the West which showed a decline.

Overall, by 2011 urbanization has sprawled 11% relative to 2001, and ISA per capita use decreases as cities' size increases.

1. Introduction

Urbanization represents a significant component of land cover and land use change that has important impacts on the local, regional and continental climate of the U.S. In terms of ecological impact, urbanization is one of the most significant and long lasting forms of land transformation and its extent of increase is proportional to population growth and economic development (Shepherd et al., 2013). Viewed from the perspective of the amount of space it currently occupies urbanization appears to be a minor form of land transformation. However, it occupies productive lands and its cumulative signature is reaching high levels in some regions; for example some studies report that about 15% of the best agricultural soils in California are urbanized (Imhoff, Lawrence, Stutzer, & Elvidge, 1997) and may already have implications on regional hydrological, biological and socio-economic properties of surrounding regions. Recent estimates suggest that the carbon lost to urbanization represents 1.8% of the continental total with urbanization occupying only 1.1% of the U.S. land (Bounoua, Zhang, Mostovoy, et al., 2015).

Given these seemingly conflicting attributes of low surface area but high former productivity of urban lands, it is worth providing a characterization of urbanization at a fine spatial resolution much needed for assessing the rate of change in impervious surfaces and modeling their impacts on the biological, hydrological and energy cycles. This is more so over larger scales where little (e.g.; Oleson et al., 2013) has been done to model the extent of impervious surface and its aggregate impact due in large part to lack of land cover data at space and time scale fine enough to resolve the urban metabolism in land surface models (LSMs).

It is acknowledged here that even though previous studies were constrained by the land surface models' coarse resolution, enormous effort has been deployed to incorporate sub-grid scale variability of biophysical parameters into LSMs (e.g., Los et al., 2000); and the need for a better description of impervious surfaces in landscapes was the motivating driver for finer and more accurate land cover and biophysical data not previously available. These land surface models require a detailed characterization of land cover elements and a specification of a set of biophysical parameters to which they are highly sensitive [e.g.; Bonan, Pollard, & Thompson, 1993, Bounoua, Masek, & Tourre, 2006].

Urbanization is often patchy and heterogeneous which makes it difficult to capture its spatial change. Landsat and MODIS provide an

* Corresponding author.
E-mail addresses: lahouari.bounoua-1@nasa.gov (L. Bounoua), joseph.d.nigro@nasa.gov (J. Nigro), ping.zhang-1@nasa.gov (P. Zhang), kurtis.thome@nasa.gov (K. Thome), asialachir@gmail.com (A. Lachir).

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Table 1
Datasets used in this study. (* ~463 m; ** ~5 km).

Dataset	Spatial Resolution	Time Period
MODIS Land Cover Type (MCD12Q1)	500-m*	2001, 2011
NLCD Impervious Surface Area	30-m	2001, 2011
CIESIN Gridded Population of the World (GPWv3)	2.5 arc-minute**	2000, 2005, 2010, 2015
ESRI/U.S. Census Bureau 1:500 K Urban Areas	n/a – vector (polygon)	2010
ESRI U.S. State Boundaries	n/a – vector (polygon)	2012

opportunity to map urban impervious surfaces within their vegetated surrounding. In this study, we combine Landsat and MODIS products along with population data to develop observation-based products characterizing decadal land cover and land use change (LCLUC) in the continental United States (CONUS) for 2001 and 2011. These LCLUC products allow us to characterize urbanization in the US and to better understand the nature of its change. They also help to break down and compare the change based on specified boundaries delineated by cities/urban areas, states, and regions. These maps along with their biophysical parameters may be used as lower boundary conditions for biophysical land surface models to assess the impact of urban transformation on surface climate.

In this paper, we present 2001 (labeled as past) and 2011 (labeled as near-present) maps at city-, state-, regional-, and continental-scales, highlighting spatially explicit decadal rates of change in population and how they relate to changes in impervious surface area (ISA) within the CONUS.

2. Data

Several datasets from different sources served as the basis for this study. Table 1 lists the specifications of each of them.

The MODIS (MCD12Q1) Land Cover Type 1 represents the 500 m International Geosphere Biosphere Program (IGBP) land cover classification, describing 17 distinct and dominant classes based on yearly input from MODIS on the NASA Terra- and Aqua platforms (Friedl et al., 2002, 2010). The NLCD Impervious Surface Area (ISA) is a Landsat-based product created by the Multi-Resolution Land Characteristics Consortium (MRLC) and represents the percentage impervious surface (road, building, parking etc.) for each 30 m × 30 m grid-cell (Homer, Huang, Yang, Wylie, & Coan, 2004, 2007). The CIESIN Gridded Population consists of estimates of human population count for each 2.5 arc-minute (~5 km) grid cell (CIESIN, 2005). The population counts are derived from more than 300,000 national and sub-national administrative units, extrapolated based on a combination of growth rates from United Nations statistics within these units and adjusted to match the United Nations (UN) national level population estimates. The U.S. Urban Areas (ESRI et al., 2010) and State Boundaries (ESRI and Tomtom, 2012) represent GIS-ready polygonal vectors used in the analysis to calculate zonal statistics for each gridded layer.

All datasets listed in Table 1 were processed to conform to a common Climate Modeling Grid (CMG) over the CONUS and are in a 2-dimensional array with the longitude varying from west (125.025W) to east (67.075W) and the latitude varying from north (49.475N) to south (25.025N) with an equal grid spacing of 0.05° (~5 km) (Bounoua, Zhang, Thome, et al., 2015). The CMG spatial resolution of 0.05° is determined by the availability of climate data for which the land cover products developed here will serve as lower boundary conditions. Over the CONUS the North American Land Data Assimilation System (NLDAS-2) climate drivers - interpolated in space from 0.125° × 0.125°–0.05° × 0.05° grid spacing will be used in modeling the impact of urbanization on the US surface climate.

3. Methodology

We combine the Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat data to develop a 13-class land cover and land use (LCLU) dataset where the built-up class in the 500 m MODIS (MOD12Q1) land cover product is replaced with the 30 m Landsat-based Impervious Surface Area (ISA) from the National Land Cover Dataset (NLCD) (Homer et al., 2004). The purpose is to characterize the

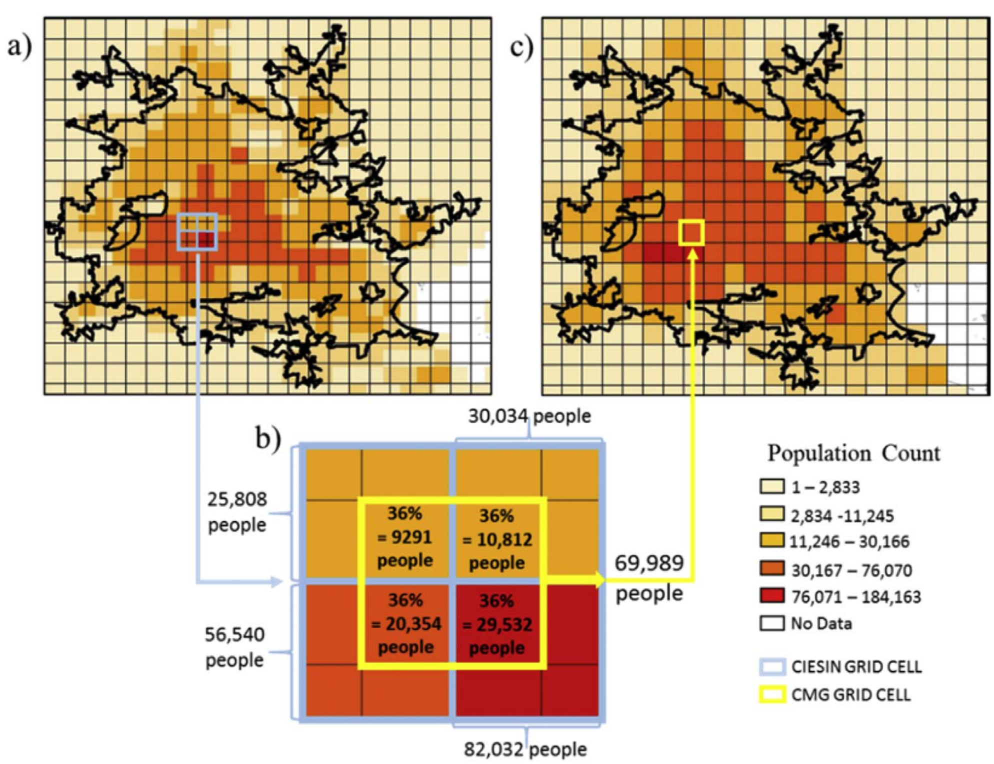

Fig. 1. Translation of the CIESIN Population Count to the CMG. The thick black line represents Houston's 1:500 K urban area boundary and the thin black lines represent the CMG grid. a) ~5 km CIESIN data; b) Population counts for four CIESIN pixels (light blue) that intersect a single 0.05° × 0.05° CMG pixel (yellow) along with the percentage of overlap. In this example, 36% of each of the four CIESIN pixels fall within the CMG pixel and so 36% of each of the four population counts was assigned to the CMG; c) The final CMG population layer with a population count assigned to each CMG pixel. This example shows the results from 2010 but this process was carried out for 2000, 2005, 2010 and 2015. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)