Six Global Maps of Urban Land Cover — Comparison and Validation

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Introduction

The UN Population Division predicts that by 2007, an unprecedented one half of the world's 6.5 billion people will dwell in urban centers. Urban growth in less developed regions is expected to account for nearly all of the global population increase over the next three decades. A clear understanding the extent and spatial distribution of today's urban agglomerations is critical for coping with the ecological, social, and economic consequences of what promises to be the most rapid urbanization in world history.

By employing satellite remote sensing imagery, geographical information systems (GIS), and traditional ground-based census data, six groups from government, industry, and academia in both the EU and the US have created global maps that can be used to describe contemporary urban land cover at coarse resolution (~ 1 km). Although most of these maps share common satellite imagery and census sources, they differ by as much as an order of magnitude in their estimates of the Earth's total urban land cover (from 0.27 – 3.52 million km^2). Through comparison and validation at national, regional, and global scales, this study offers those who would use such maps a first glimpse of their relative merits.

Data Sets

The six products under review and their acronyms for the purposes of this extended abstract are: ***GLC2000*** (Global Landcover 2000) from the European Space Agency and a consortium of regional collaborators, ***MODISLC*** (Moderate Resolution Imaging Spectroradiometer Land Cover 2001v4) from Boston University and NASA, ***GRUMP*** (Global Rural-Urban Mapping Project) a beta-product from Columbia University, ***DCW*** (Digital Chart of the World) from US mapping agencies, ***LIGHTS*** (Nighttime Lights) from the US National Oceanographic and Atmospheric Administration, and ***LANDSCAN*** (LandScan 2004) from the US Department of Energy.

Four of these products are thematic land cover maps that include an urban category—GLC2000, MODISLC, DCW, and GRUMP. The urban classes from GLC2000 and MODISLC are derived from classification of LIGHTS data and a combination of multi-spectral, multi-temporal coarse resolution optical and thermal satellite imagery. By contrast, DCW is a GIS-product that was created by digitizing a large collection of maps and charts from the 1980's through the mid-1990's. Of the six products, GRUMP is the only one devoted solely to urban mapping. GRUMP integrates DCW, LIGHTS, ground-based census data, and a variety of ancillary GIS data sets.

The final two products —LIGHTS and LANDSCAN — map continuous fields rather than a discrete set of classes. LIGHTS uses data from a nighttime imaging satellite to model the fraction of cloud-free satellite observations that were illuminated by permanent human settlements in a given year. LANDSCAN models the ambient human population using high resolution imagery (1–5 m), land cover, DCW, and GIS products similar GRUMP's inputs. To create urban maps from LIGHTS and LANDSCAN, US metropolitan regions serve as training data for establishing thresholds above which LIGHTS and LANDSCAN pixels are classified as urban (14% illuminated for LIGHTS and 523 persons/km^2 for LANDSCAN). Because the training data came only from the US, this method is biased towards developed countries. Ultimately, LIGHTS and LANDSCAN maps based on a range of thresholds will be examined.

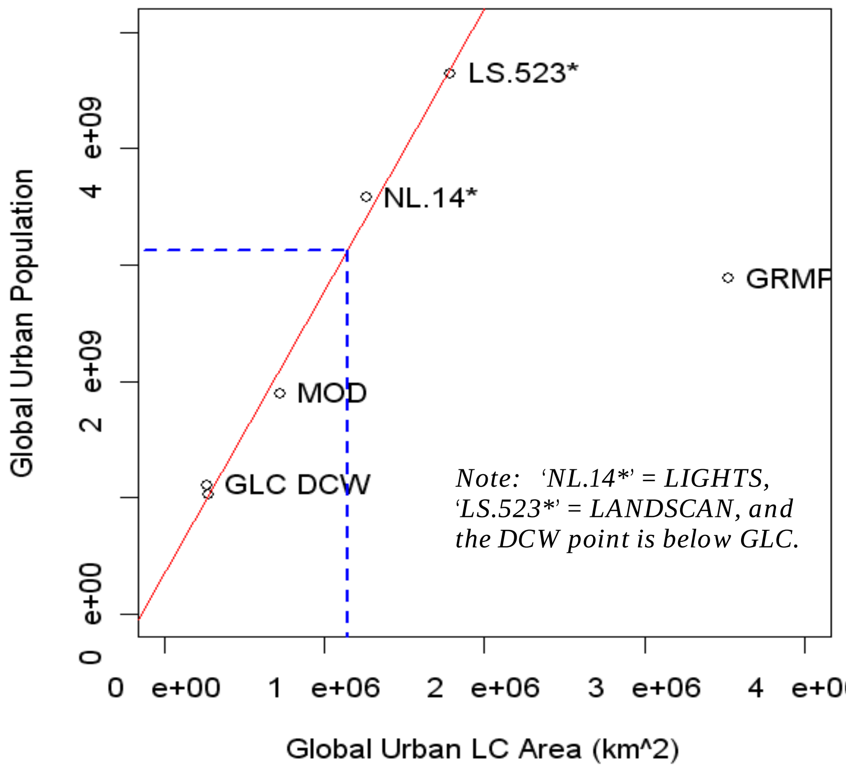
Methods

This research consists of a comparison and a validation phase. The comparison phase begins by moving the six global urban maps into a common analysis environment (geographic projection at 30' arc-seconds resolution) which brings each map's projection, spatial resolution, and registration into agreement while minimizing distortion and information loss. Next, the extent (total urban surface area) and spatial structure (number and size distribution of urban agglomerations) from each of the six products are compared at global, regional, and national scales. Overlaying LANDSCAN atop the urban maps creates an estimate of urban population and urban population density, which can then be compared with national and regional figures from both the UN and the World Bank. Unfortunately, these urban population estimates rely on LANDSCAN — a dataset that is also one of the validation subjects. To address this conflict, population estimates will also be made from Columbia University's Gridded Population of the World (GPW), although GPW is at one-fifth the spatial resolution of the six global maps.

The second phase of analysis will be a validation of the six global maps. The backbone of the effort will come from a stratified random sample of 160 world cities mapped at 30m spatial resolution and spanning the full range of global ecoregions, city sizes, and political and economic zones. After completing a traditional accuracy assessment using these cities, medium resolution products will be used to better characterize the fraction of urban land cover within improperly labeled pixels from the target maps. Finally, validations will be performed over a small sample of regional land cover maps at 100 m resolution in order to establish the accuracy of the target maps in smaller cities, towns, inter-urban zones.

Initial Results

The figure on page four summarizes some of the early results at the global scale. The x-axis is the estimate of the total surface area in urban land cover (millions of km^2), and the y-axis is the estimate of the world's urban population based on overlaying LANDSCAN atop each of the urban maps (billions of persons). Despite the wide range in global urban land cover estimates (0.27 – 3.52 million km^2), when GRUMP is excluded a characteristic average global urban population density of 2,400 persons/km^2 emerges with an adjusted R^2 of 0.989 (red line). This density figure is remarkably close to that calculated by the World Bank (2,500 persons/ km^2) in an independent, non-spatially explicit study now in the final stages of preparation. The dashed blue line marks the UN's total urban population for 2000, and an estimate of the urban area (1.14 million km²) using an average urban density of 2,400 persons/km².



Discussion

In addition to reducing the large uncertainly in the total extent and spatial distribution of urban land cover, this project aims to deliver several metrics and composite data sets, including: (1) a composite map of urban land cover based on an analysis of the regional error structure of the six input maps, (2) a country-level correction factor to be used in international comparisons of the 50-year UN urban population time series (such comparisons are now difficult because of high variance in national urban classification schemes), (3) a table of country-scale metrics that covers the total urban land cover, the urban population, the urban and rural population densities, and the size distribution of urban agglomerations. This research is a first step in the longer-term project of building a predictive model of urban growth within a spatially explicit framework that functions globally at coarse resolutions (1 km). Such a model would prove invaluable in coping with the ecological and social consequences of the coming urban explosion.