Urban Growth as a Component of Global Change

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Overview

The goal of this research is to study urban areas in the context of global change research. As the scope of human influence on global change is beginning to be recognized, it is important to identify and understand the mechanisms of human-induced land transformation and its effects on the Earth's ecosystems. In particular, more attention must be paid to the extent of urbanization as a key land transformation process. To address this issue, this research is a multidisciplinary program involving mapping urban land cover using coarse resolution remotely sensed data, urban change detection analysis in a sample of cities using Landsat imagery, and statistical analysis combining land cover data with socio-economic data. The research attempts to answer the following questions:

(1) What is the utility of moderate to coarse resolution data for understanding urban land use and land use change, as compared to finer resolution Landsat data?

(2) What is the rate and amount of landscape conversion to urban uses that has occurred in the last ten years in cities across the globe? How have the shape, form and patterns of cities changed during the last decade?

(3) What factors explain the widely divergent rates of urbanization in cities around the globe?

The proposed research has important implications for understanding the causes and impacts of urban change processes and land conversion that is occurring in cities throughout the world at alarming rates. This information is vital to understanding the relatively unknown role of urban growth in global change processes.

Part 1: Mapping Urban Areas by Fusing Multiple Sources of Coarse Resolution Remotely Sensed Data

1.1 Introduction

The primary goal is to assess methodology for mapping urban land cover at 1 km resolution by fusing multiple sources of coarse resolution data. Two major tasks were involved in this study:

(1) to develop a supervised decision tree classification method by fusing 1 km MODIS data and two ancillary sources: the nighttime lights data (Elvidge et al. 1999) and gridded population density data (Tobler et al. 1995, Deichmann et al. 2001).

(2) to determine the best means for evaluating the accuracy of urban land cover maps produced over large regions.

1.2 Methodology

The method involved three main steps, as shown in Figure 1. In the first step, the nighttime lights data and gridded population density data were combined in a logistic regression model to produce a probability surface for urban areas. In the second step, a decision tree algorithm (C4.5, Quinlan 1993) was trained using a global set of training sites for 17 land cover classes (including urban) defined by the IGBP, and the trained tree was applied to the MODIS data. The output from this first stage provided a map of per-pixel probabilities for each of 17 classes. The class probabilities were then used as input to the third step, where Bayes' Rule was applied at every pixel. To do this, the probabilities of urban areas from the logistic regression were used as prior probabilities, and the final pixel label was assigned based on the maximum likelihood derived from the posterior probabilities.

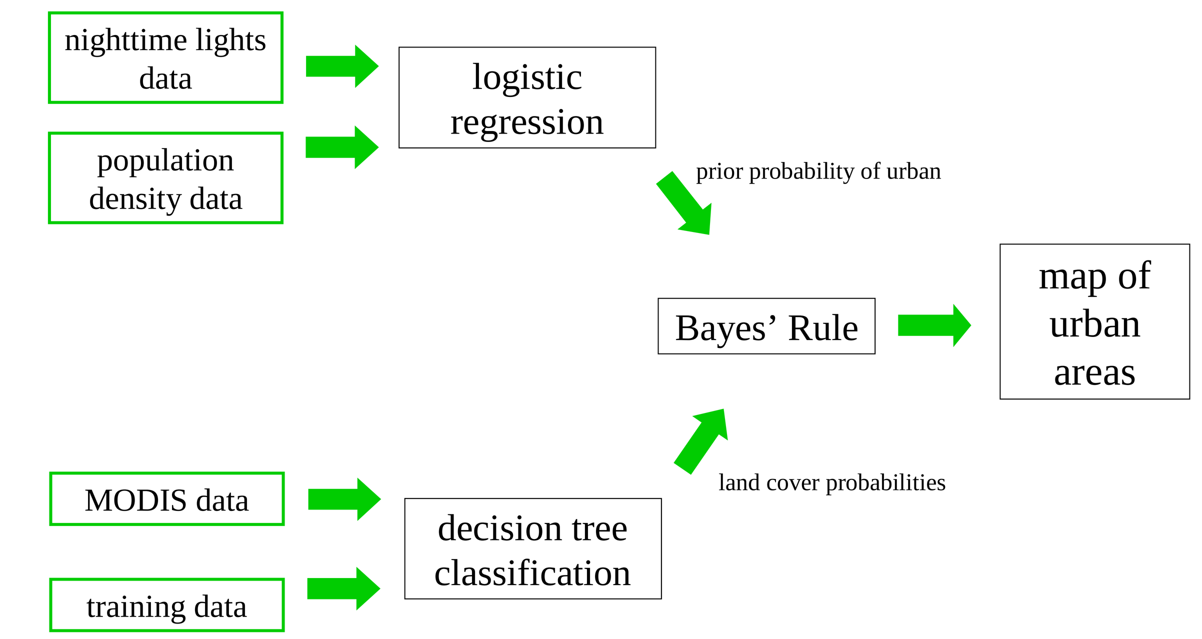


Figure 1: Methodology used to create the final Fused map.

1.3 Results

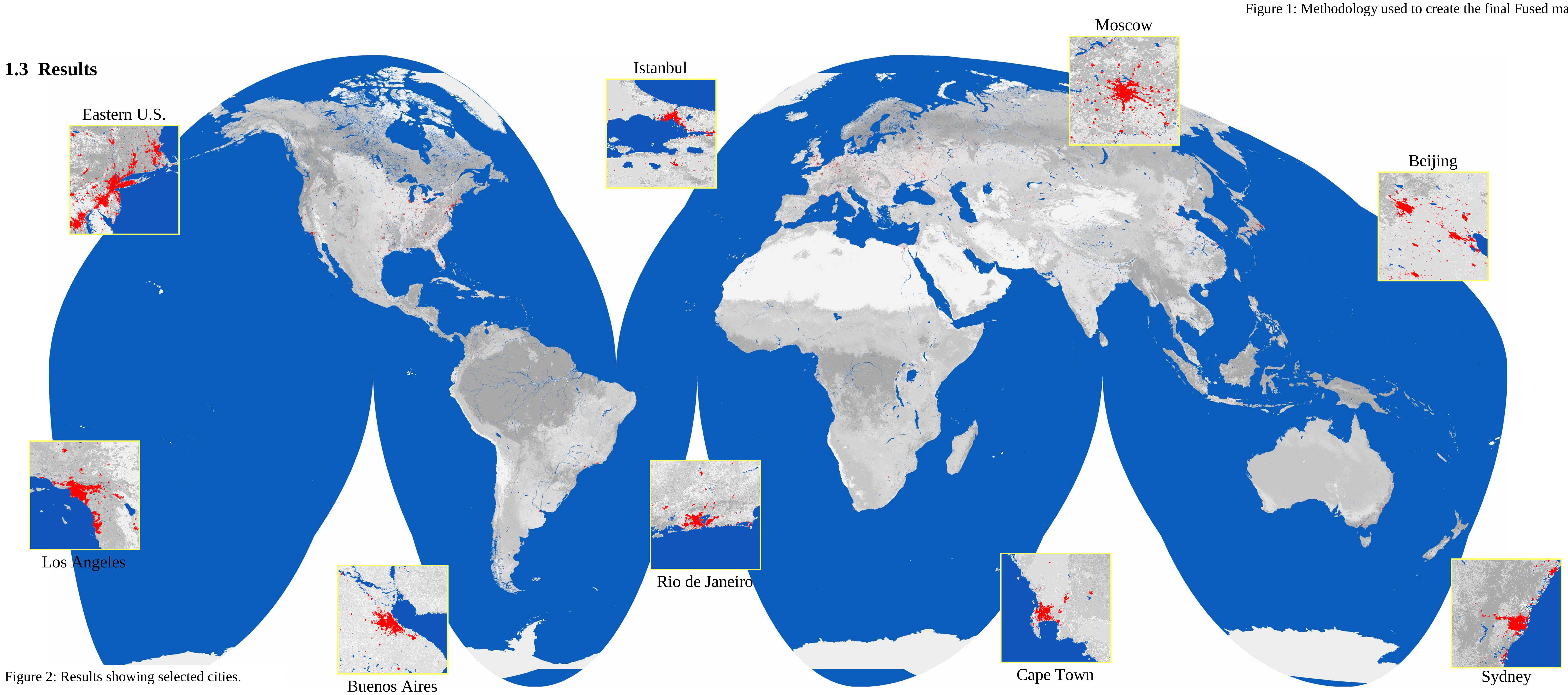


Figure 2: Results showing selected cities.

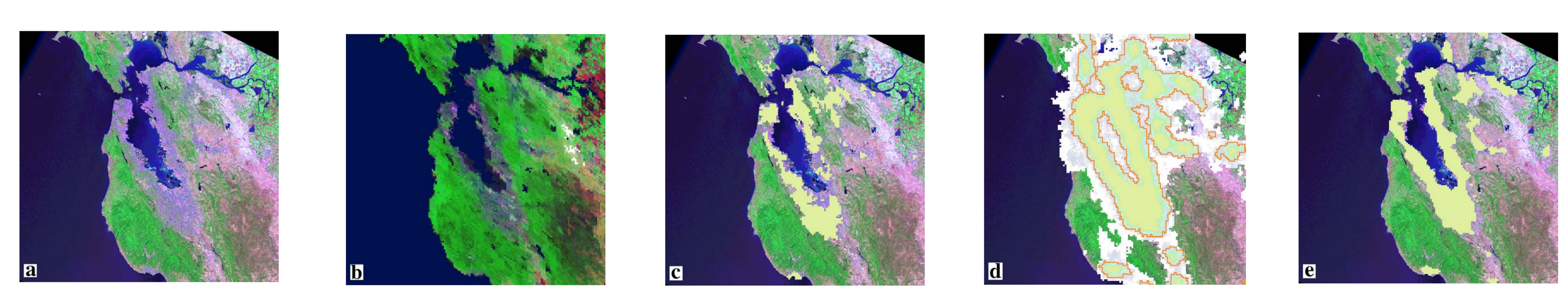


Figure 3: Subset of the San Francisco, California area showing (a) Landsat imagery, (b) MODIS data, (c) the urban boundary data from the DCW, (d) the thresholded nighttime lights data, and (e) the final Fused map.

1.4 Accuracy Assessment

Use of coarse resolution data over large geographical areas makes conventional "ground truth" methods impractical. Moreover, it is difficult to coregister ground truth data to classified maps. For this work, the Fused map is compared against three sources (Figure 3): (1) the Digital Charts of the World urban data (DCW, Danko 1992), (2) the radiance calibrated nighttime lights data (Elvidge et al. 1999), thresholded, and (3) a regional, fine resolution map of urban areas in the U.S., the National Land Cover Data (NLCD, Vogelmann et al. 2001). Three maplet-based methods assessing city size and location were used to supplement overall accuracy statistics (please refer to publication for figures).

Part 2: Mapping Urban Change in a Cross Section of Global Cities

2.1 Introduction

To provide a quantitative basis for investigating both the drivers and impacts of this change, an accurate account of the amount of change in urban areas must be developed. A secondary objective is to understand how the shape of cities has changed, and whether urbanization has occurred in a radial, leap-frog or diffuse pattern. These questions will be addressed as change detection analysis using satellite remote sensing.

2.2 Study Areas

A key requirement is to create a geographically comprehensive sample. Investigation will focus on a target population of countries with accessible economic data (necessary for Part 3). To further define the target, it is critical to select cities of regional importance in terms of land cover change and economic status. Using population as a proxy, 165 cities with over 1 million inhabitants have been identified in the countries of interest (Figure 4). A final sample of 40 cities will be selected from this group after determining availability of remote sensing data.

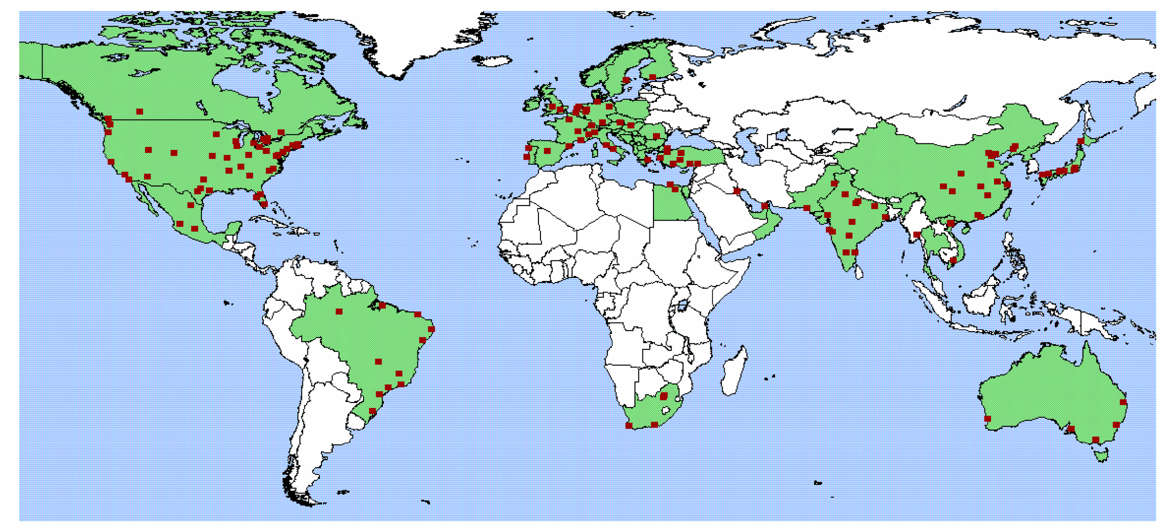


Figure 4: The sampling scheme, dictated by reliable socioeconomic data (selected countries shown in green), and cities with populations over 1 million (red points).

2.3 Methodology

For this work, the identification of changes in urban areas is accomplished in three phases.

1) Image preprocessing:
Imagery for each city is collected for two time periods, 1990 and 2000, and geometric registration is performed.

2) Change detection using unsupervised methods:
After consideration of several methods, an unsupervised multi-date k-means clustering of stable and changed land cover classes was selected to determine the quantity and type of land use/land cover changes. A post-processing segmentation algorithm is used to incorporate spatial information and remove noise.

3) Accuracy assessment.
To validate the maps of land use change, ground-based accuracy assessment is performed. Because of the large number of cities in this study, time and cost limitations, only 10 of 40 cities will be assessed.

2.3 Initial Results

Change detection analysis has been completed for the following cities: Hangzhou, Beijing and Chengdu, China; Belem and Manaus, Brazil; and Vancouver, Calgary, Toronto and Waterloo, Canada. When possible, results from relevant remote sensing studies conducted by other researchers will be incorporated as well. Land cover change results from Guangzhou, China, Atlanta, Georgia, and Phoenix, Arizona, have already been obtained.

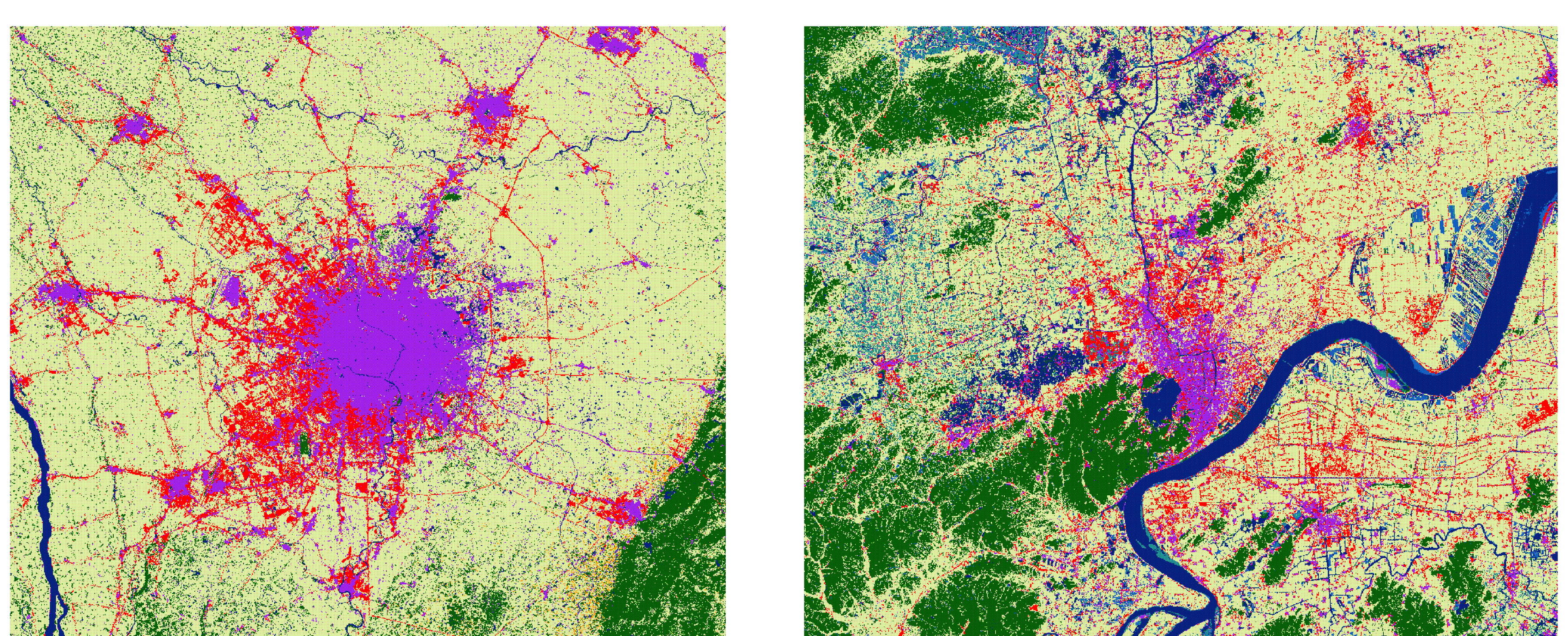
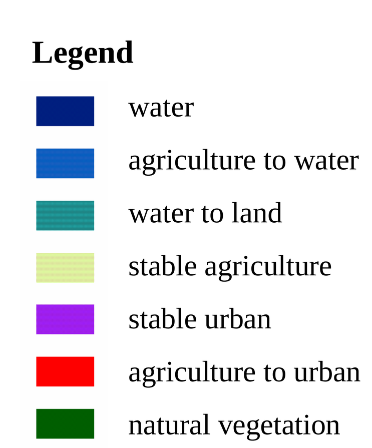


Figure 5: Examples of land cover change maps for (a) Chengdu, China, and (b) Hangzhou, China for 1990 to 2000.



Part 3: Modeling the Rates of Urban Growth

3.1 Introduction

Monitoring and documenting urbanization is only the first step in addressing the issue of global land cover change. The second objective of this study is to determine the mechanisms of land cover change. Assessment of land cover conversions caused by human actions requires scientists to understand the political, social, economic, cultural and environmental factors that motivate behavior and affect the direction and intensity of land and natural resource use. This is generally done by building a model that links human activity and land use (Lonergan 1994).

This component of the research will attempt to integrate land cover change information (Part 2) with county level socioeconomic and demographic data to develop a statistical model of the variables correlated with land conversion.

3.2 Methodology

The modeling of land use change mechanisms will rely on a common statistical method, the general linear model. Linear models, primarily regression analysis, are concerned with the study of the dependence of one variable on one or more explanatory variables, with a view to estimating and/or predicting the value of the dependent variable in terms of the known or fixed values of the explanatory variables (Gujarati 1995). The dependent variable, y_i, is modeled as:

$$y_i = \alpha + \sum_{i=1}^{n} \beta_i x_i + \varepsilon_i$$

where x_i is value of each independent variable for the *i*th county, the a and b coefficients are determined empirically using ordinary least squares methods, and e_i is the random error term. In this research, the dependent variable y_i will be the amounts of land cover change for each metropolitan area determined from remote sensing imagery.

During analysis, the task will be to determine which data are appropriate as explanatory variables, and which model is appropriate and statistically significant given the collected data. There is no doubt that a number of global and local variables are at play in driving land use change in cities across the globe (Knox 1996). The question, however, is whether a set of common independent variables can be determined as mechanisms of change for all cities in the population set, at what scale this set of relationships should be modeled, and if this relationship can be generalized across cities in a meaningful way within a predictive model.

A general set of independent variables has been identified in the literature. These variables include:

(1) degree of industrialization and economic growth,
(2) shifts in the labor market,
(3) levels of affluence and income,
(4) transportation infrastructure development and amount of accessibility,
(5) population change,
(6) political framework,
(7) continental physiography, such as elevation and water bodies.

Initial research shows that urban extent often surpasses the county boundary of the core city and encompasses several surrounding counties (e.g. China, U.S., Brazil, India). To model urban growth thus requires analysis of several counties per city, which will be aggregated to form one unit of analysis, the metropolitan area.

References

Danko, D.M., 1992. The Digital Chart of the World, *Photo. Eng. Rem. Sens.*, 58, pp. 1125-1128.

Deichmann, U., Balk, D. and Yetman, G., 2001. Transforming population data for interdisciplinary usages: From census to grid. Available at http://sedac.ciesin.org/plue/gpw.

Elvidge, C.D., Baugh, K.E., Dietz, J.B., Bland, T., Sutton, P.C., and Kroehl, H.W., 1999. Radiance calibration of DMSP-OLS low light imaging data of human settlements, *Rem. Sens. Env.*, 68, pp. 77-88.

Knox, P. 1996. Globalization and Urban Change. *Urban Geography*, 17, pp. 115-117.

Lonergan, S. and Prudham, S. 1994. Modeling global change in an integrated framework: a view from the social sciences. In W.B. Meyer and B.L. Turner (Eds.), *Changes in Land Use and Land Cover*, pp. 411-436. New York: Cambridge University Press.

Quinlan, J.R., 1993. *C4.5: Programs for Machine Learning*, Morgan Kauffman.

Tobler, W.R., Deichmann, U., Gottsegan, J. and Maloy, K. 1995. The global demography project, *National Center for Geographic Information and Analysis*, 95-6, University of California, Santa Barbara.

Vogelmann, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K., Van Driel, N., 2001. Completion of the National Land Cover Data for the US from Landsat TM and ancillary data, *Photo. Eng. Rem. Sens*, 67, pp. 650-654.