URBAN PATTERNS AND PROCESSES: A REMOTE SENSING PERSPECTIVE

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ABSTRACT

Remote sensing is a significant, yet under-used, data source for the study of urban phenomena; the key being that images are a freeze-frame view of the spatio-temporal urban patterns, albeit in unprecedented detail. Quantitative descriptors of the characteristics and geometry of urban land cover features (spatial metrics) can describe the structure of urban environments and so allow the detailed exploration of urban patterns and dynamics of change. Several examples are discussed of using remote sensing in the analysis of rapidly urbanizing areas in California. The studies focus on linking spectral pattern and material aging, urban land cover and land use, urban morphology and socio-economic characteristics, spatial pattern and growth process characteristics, and empirical observations and urban theory. Future emphasis is needed in the field of urban remote sensing to integrate the different levels of observations that, so far, has widely remain blind to pattern and processes.

INTRODUCTION

Understanding urban patterns, dynamic processes, and their relationships is a primary objective in the urban research agenda with a wide consensus among scientists, resource managers, and planners that future development and management of urban areas requires detailed information about ongoing processes. Central questions to be addressed are on how cities are spatially organized, where and when developments happen, and ultimately why and how did urban processes result in specific spatial pattern. Remote sensing, although challenged by the spatial and spectral heterogeneity of urban environments (Jensen and Cowen, 1999, Herold et al., 2004) seems to be an appropriate source of urban data to support such studies (Donney, et al., 2001, Herold et al., 2005). Detailed spatial and temporal information of urban morphology, infrastructure, land cover and use patterns, population distributions, and drivers behind urban dynamics are essential to be observed and understood. Urban remote sensing has attempted to provide such information. But, despite proven advantages, remote sensing based urban mapping and monitoring has largely focused on technical aspects of data assembly and physical image classification and thus has widely remained "blind to pattern and processes" (Longley, 2002, Lo, 2004). In fact, the comprehensive spatial and temporal detail provided by remote sensing observations and quantitative measurements of urban structures have only rarely been explored in the context of understanding, representation and modeling spatial process characteristics.

Traditional urban geographic research often approached urban change from a demographic or socio-economic perspective. These investigations generated significant contributions and raised compelling questions regarding urban areas. Related studies have focused on isolating the drivers of growth rather than the emerging geographic patterns of evolving urban landscapes. More recent advances in spatial urban modeling, i.e. based on complex systems theory, have provided important insight into urban dynamics (Clarke et al., 2002). Considering urban modelling developments in the recent years, dynamic spatial urban models provide improved abilities to assess future growth and to create planning scenarios, allowing us to explore the impacts of decisions that follow different urban planning and management policies (Klosterman, 1999). Yet, the application and performance of the models is still limited by the quality and scope of the data needed for their parameterization, calibration, and validation. Furthermore, urban modeling still suffers from a lack of knowledge and understanding of the physical and socioeconomic drivers that contribute to the pattern and dynamics of urban areas (Longley and Mesev, 2000, Batty and Howes, 2001, Herold et al., 2003, 2005, Dietzel et al., 2005). In that context, Longley and Tobon (2004) emphasize that extending the interests of urban geographers towards more direct, timely, spatially disaggregate urban indicators is key in developing the data foundations to a new, data rich and relevant urban geography.

SUMMARY OF THE PRESENTATION

The aim of this paper is to evolve a better understanding on what is possible to observe using urban remote sensing and how such information can be integrated to improve our theoretical knowledge about urban areas and their dynamics. Different approaches will be presented from California case studies. Their description will be brief and with a minimum of technical detail. But they emphasize different avenues taken to study urban patterns and link them with urban processes. Concluding discussions will attempt to structure the different indicators and approaches. The discussions will follow a main line of argumentation: urban remote sensing is missing key contributions and potentials to both scientific progress and applications if it remains widely focused on simply observing patterns or detecting changes without asking questions of how and why related to urban processes.

The examples emphasize the variety of indicators describing urban characteristics and changes available from earth observations. They include the mapping and monitoring of spatial, spectral, and temporal urban patterns in both the physical built up environment and vegetation. In general, remote sensing adds an inductive, bottom up perspective to understanding urban patterns and processes. It incorporates “real world” remote sensing-based measurements of urban form and dynamics rather than generalized consideration, as are commonly used in traditional spatial theories and models of urban spatial structure and change. Certainly, the patterns obtained from remote sensing data may represent an aggregate outcome of many different processes at work. Often it is difficult to disentangle the effects of the different variables and trends of interest. Thus, the remote pattern measurements have to be clearly structured to the operational scale of urban change processes. A conceptual attempt summarizing the case studies presented here is shown in Figure 1.

The most elementary *pixel scale* reflects changes in urban material characteristics, e.g. aging processes reflected in spectral characteristics. The *land cover* level reflects dynamics in common urban land cover objects such us building constructions, expansion of roads, decreasing urban vegetation patches or similar changes. If land cover changes are aggregated to larger areas, they can reflect or lead to changes in urban *land use*. Examples are infill development and redevelopment, or evolving brownfields. Urban land use dynamics are intrinsically linked with socio-economic, political, or demographic drivers and thus provide a useful platform for studying urban dynamic processes. On a coarser level, *urban areas* reflect an agglomeration of urban land uses usually arranged in distinct intra-urban patterns. Growing urban areas reflect spatio-temporal patterns of expanding urban land uses into rural areas. Urban growth of one particular city is usually directly link with changes in other urban agglomeration, e.g. gravity relationships or regional polarization within a system of cities. Linking remote sensing pattern measurements across scales strongly depends on the process of interest and remains a critical research question. But, earth observation may have the potential to establish such relationships. For example, a new urban development driven by population growth will basically be observed on all relevant scales.

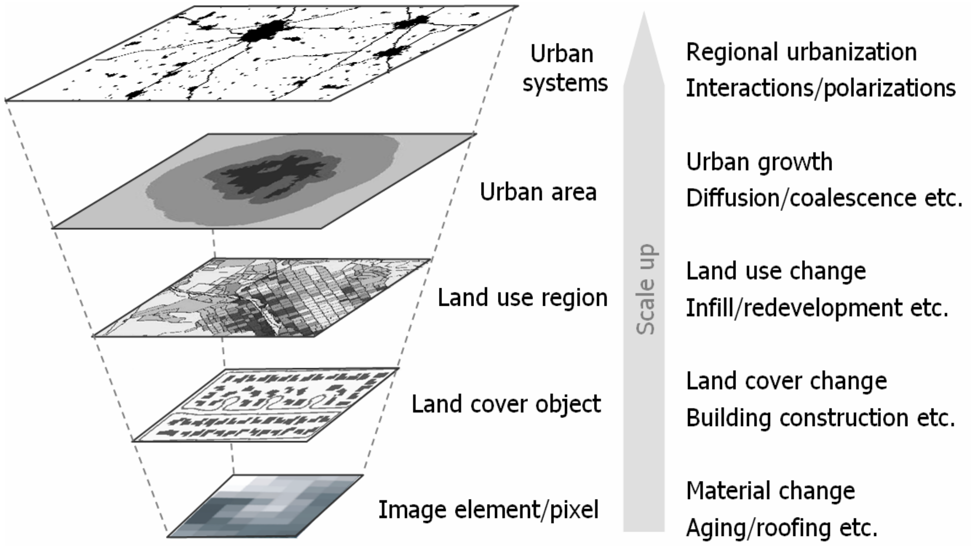

Figure 1: Observing multi-scale dynamics for mapping and modeling of urban growth processes with remote sensing.

To conclude, the main argument of this paper is that urban remote sensing can add a significant new perspective to understand urban patterns and processes. This potential has been widely neglected in the past. The remote sensing technology has proven operational capabilities and many studies have provided mapping and monitoring products but rarely have asked the question of land change process behind observed patterns and dynamics. Remote sensing may provide the answers to questions asked in the early days of urban geography. Better theorical understanding on the internal structures of cities, the link between urban form and socio-economic and demographic characteristics, and the spatio-temporal behavior of cities and urban systems are of particular importance for progress in the field urban geography. Remote sensing is not expected to address all questions but both traditional urban geographic research could benefit by being used in combination, with the traditional perspective helping to narrow down the possibilities suggested by the detailed analysis of urban form and their changes. Better process understanding and improved concepts will ultimately help in solving contemporary urban problems through providing information needed for sustained urban planning and management.

If there is interest for more details on the studies and the arguments, the reader is referred to the following publications that will be published in the near future:

Herold, M., Hemphill, J. and K.C. Clarke (accepted): Remote sensing and urban growth theory, in Weng, Q. and D. Quattrochi (eds.): Urban remote sensing, Chapter 10, Taylor & Francis, forthcoming.

Liu, X. and M. Herold (accepted): Estimating population distributions in urban areas, in Weng, Q. and D. Quattrochi (eds.): Urban remote sensing, Chapter 13, Taylor & Francis, forthcoming.

Herold, M. et al., (in review): Urban patterns and processes: a remote sensing perspective, Photogrammetrie, Fernerkundung, Geoinformation, Special issue on urban remote sensing edited by M. Moeller, intended for issue 4/2006.

REFERENCES

Batty, M. and D. Howes 2001. Predicting temporal patterns in urban development from remote imagery, Donnay, J.P., Barnsley, M.J. P.A. and Longley (eds.). Remote sensing and urban analysis, Taylor and Francis, London and New York 185-204.

Clarke, K.C., Parks, B.O., and M.P. Crane 2002. Geographic information systems and environmental modeling. Prentice Hall, New Jersey.

Dietzel, C., Herold, M., Hemphill, J.J. and Clarke, K.C. 2005. Spatio-temporal dynamics in California's Central Valley: Empirical links urban theory. International Journal of Geographic Information Sciences, 19, 2, 175-195.

Donnay, J.P., Barnsley, M.J. and Longley, P.A. 2001. Remote sensing and urban analysis. In: Remote sensing and urban analysis, Donnay, J.P., Barnsley, M.J. and P.A. Longley (eds.). Taylor and Francis, London and New York, pp. 3-18.

Herold, M., Goldstein, N.C., and Clarke, K.C. 2003. The spatiotemporal form of urban growth: measurement, analysis and modeling. Remote Sensing of Environment, 86, pp. 286-302.

Herold, M., Roberts, D., Gardner, M. and P. Dennison (2004). Spectrometry for urban area remote sensing - Development and analysis of a spectral library from 350 to 2400 nm, Remote Sensing of Environment, 91, 3-4, 304-319.

Herold, M., Couclelis, H., and Clarke, K.C. 2005. The role of spatial metrics in the analysis and modeling of land use change. Computers, Environment and Urban Systems. 29, 4, 369-399.

Jensen, J.R. and Cowen, D.C. 1999. Remote sensing of urban/suburban infrastructure and socio-economic attributes. Photogrammetric Engineering and Remote Sensing, 65, pp. 611-622.

Klosterman, R.E. 1999. The What if? Collaborative planning support system, Environment and Planning B: Planning and Design 26, 393-408.

Lo C.P. 2004. Testing Urban Theories Using Remote Sensing, GIScience and Remote Sensing, 41 2, 95-115.

Longley, P.A. 2002. Geographical information systems: Will developments in urban remote sensing and GIS lead to 'better' urban geography? Progress in Human Geography 26, pp. 231-239.

Longley, P.A., and Mesev, V. 2000. On the measurement of urban form. Environment and Planning A, 32, pp. 473-488.

Longley P.A. and C Tobon 2004. Spatial dependence and heterogeneity in patterns of hardship: An intra-urban analysis Annals of the Association of the American Geographers 94 3: 503-519.