Remote Sensing and Urban Growth Models – Demands and Perspectives

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ABSTRACT

Urban growth and land use change models are an important and innovative tool that support planning and development of sustainable urban areas. The data requirements for parameterization, calibration and validation of urban models are intense due to the complexity of the models and their objectives. In this study several urban land use change models are evaluated and their demands on spatial data sets are compared. These needs are discussed and evaluated based on the use of remotely-sensed high spatial and temporal resolution data. The results show especially the need for accurate urban land use information due to the Level II and III of the USGS/Anderson land cover/use classification scheme. An appropriate methodology for urban land use differentiation using high resolution remotely sensed data is presented and evaluated in test sites in the southern California city of Santa Barbara, USA. The approach is based on irregularly-shaped regions of homogenous urban land use as the defined mapping units. Within these regions, spatial and fractal metrics were applied to describe the land cover structure, to acquire urban land use information and to describe socioeconomic features. The application of one of the evaluated urban growth models is presented, based on a seventy-year time series of air photos. The urban growth process, as well as future predictions of land use change are well represented in the model based upon the concept of cellular automata and demonstrate the potential of a combined remote sensing and modeling approach.

1 INTRODUCTION

Current changes in urbanization patterns at all geographic scales are quite likely the most significant since the advent of accessible mass transit turned American cities inside out almost a century ago. Documented examples of these new patterns and processes are: urban deconcentration and centralization; the formation of exurbs and edge cities (Garreau 1988); the colonization of remote rural and wildland spaces; the emergence of new types of urban specializations (e.g., technopoles); increasing spatial segregation of races and income groups; increasing spatial mismatch between low-income residents and jobs; the spatial disintegration of labor markets; increasing threats from natural hazards as urban structures becomes more dispersed and internally complex; and the exposure of urban areas to more and new kinds of vulnerabilities brought about by their increasing dependence on technology (Hart 1991, Knox 1993).

The socioeconomic, natural, technological and social processes both drive and are profoundly affected by the evolving urban spatial structure within which they operate. Research into the understanding, representation and modeling of this complex system has a long tradition in geography and planning (Batty 1994, Alberti and Waddell 2000). However, during the last years, models of land use change and urban growth have been expanded and have become important and innovative tools for city planners, economists, ecologists and resource managers to support intelligent decisions so they can take timely and effective action for a sustainable development of urban regions. This development was mainly driven by increased resources and usability of multiple spatial datasets and tools for their processing (e.g. Geographic Information Systems). Community-based collaborative planning and consensus-building efforts in urban development have also been incorporated into urban planning at the local level (Klostermann 1999). The models have shown potential to support planning and management decisions in:

- Providing knowledge and understanding of the dynamics of the urban system (intuition structuring),
- Anticipating and forecasting future changes or trends of development,
- Describing and assessing impacts of future development,
- Exploration of different policies and optimization of urban planning and management.

The application, performance, and modeling results respectively strongly depend on the quality and scope of the data for parameterization, calibration and validation (Longley and Mesev 2000, Batty and Howes 2001). As land use change models simulate both the human and biological system, the requirements placed on the data are fairly complex and range from natural and ecological parameters to socioeconomic information and detailed land use/cover data with defined spatial and temporal accuracy. Concerning this, Longley and Mesev (2000) state that the understanding of physical and socioeconomic distributions through urban modeling still remains limited by the data available.

Remote sensing methods have been widely applied in mapping land surface features in urban areas (e.g. Haack et al. 1997, Jenson and Cowen 1999). In general, remote sensing techniques can provide spatially consistent datasets that cover large areas with both high detail and high temporal frequency, including historical time series. Despite such advantages, there are only a few studies that focus on integration of remote sensing data products in land use change model applications for urban environments. Under these considerations, this study explores and discusses the use of remote sensing techniques for urban land use change model applications. The investigations had three major objectives:

- A review of several urban land use modeling systems with different levels of complexity, structure and purpose that have been developed. These models are evaluated and compared concerning their data requirements. The review focuses on their demands on spatial datasets in general and the required spatial, temporal and thematic features of land use information in particular. The results will be used to formulate requirements and characteristics of remote sensing data products for application in these models.
- Under consideration of the model data requirements, we present and discuss an approach for spatial mapping of urban areas from high-resolution optical remote sensing data. The approach is applied and evaluated in test sites of the Santa Barbara, CA region and shows the potential for describing and acquiring land use and socioeconomic information in urban areas.
- Finally, we show an example of another parameterization and calibration of an urban growth model using remote sensing data. The SLEUTH model uses cellular automata and was applied in the Santa Barbara, CA region. The growth modeling was based on seventy-year time series of land use change derived from air photos. The growth process as well as future predictions of land use change can be well represented in the model and show the capability of the combined remote sensing/modeling approach.

The results shown in this paper (sections 3 and 4) were gathered in two independent studies. They are used to explore and discuss the potentials and perspectives of an integrated remote sensing and urban growth model application.

2 A REVIEW OF URBAN LAND USE CHANGE/GROWTH MODELS

Different land use change models have recently been described and compared in two reports. The first report was published by the US Department of Agriculture (USDA as a review and assessment of land use change models (Agarwal et al. 2000). The second report (EPA 2000) gives a summary of models for assessing the influence of community growth and change on land use patterns. The reports form the basis of the evaluation and comparison of different models concerning their data requirements. From the 36 different models that are described in the two reports we selected seven for analysis. We defined several criteria for our model selection:

- The models should perform land use modeling on the regional and local scale
- Model simulations should focus on spatial land use patterns with their purpose being to model urban land use change and growth,
- Model documentation should be available and sufficient for the comparison. Some models have a clear commercial background and are not documented in all necessary detail. Accordingly most of the selected models were developed and are still applied in the academic environment,
- The models should represent a variety of different structures, approaches and complexities.

The summary of the models is shown in Table 1. All models were developed and applied during the last several years. The model objectives and approaches are shown in the second column and represents the variety of purposes these models were designed for. Some models have more of a focus on research rather than on application. The spatial framework of the models is presented in the third column. The models use both vector- and raster-based techniques for spatial discrimination of the modeling entities or objects. For example, the *UrbanSim* model is a fairly complex approach for modeling urban development. It uses the parcel-level as the entity for land development modeling because it considers the household and its behavior as an agent in the change process. Another vector-based approach is used by the *What If* model. *What If* is designed for planning support systems and has an applied focus. The model entities are defined as areas of most common geometry as a result of a vector overlay of different data layers of different natural and human parameters.

Model Name / Developer	Purpose of the Model	Spatial Framework	Temporal Framework	Representation of Urban Land Uses[1]	Examples of other required spatial Datasets
CUF 2 - California Urban Future 2 / *Landis & Zhang 1998*	Deterministic and stochastic modeling framework for simulation of how growth and development policies might alter the location, pattern, and intensity of urban development	Raster-based: 100m x 100m grid cells	Fixed time steps for prediction of land use change based on historical calibration time frame, typical 5 or 10 years	1) Residential, divided in single- and multiple-family housing 2) Commercial 3) Industrial	1) Topography 2) Transportation infrastructure
LUCAS - Land Use Change Analysis System / *Berry et al. 1996*	Stochastic model used to examine the impact of human activities on land use and the subsequent impacts on environmental and natural resource sustainability	Raster-based, variable resolution, in previous studies 90m x 90m grid cells	Variable time steps, case study: 100 years prediction in 5 year time step	Landscape described by Anderson Level I classes = urban (residential, divided by density)	1) Topography 2) Population density 3) Transportation infrastructure
What If / *Klosterman 1999*	Deterministic planning support systems to support traditional planning activities such as land use planning, urban modeling and emerging modes of collaborative planning	Vector-based, model entities: uniform analysis zone as homogenous land units, derived from overlay of relevant layers of natural and human parameters	Variable time steps, case study: 25 years prediction, 5-10 years time steps, max. 5 periods of prediction	1) Residential, divided by density 2) Commercial 3) Industrial	1) Topography 2) Transportation infrastructure
UPLAN - Urban Growth Model / *Shabazian & Johnston 2000*	Land use evaluation and change analysis tool to help communities to create alternative development patterns based on local land development policies	Raster-based, variable resolution: 200x200 m for low density residential, all other land use categories: 50m x 50m	Variable time steps/ Case study: 20 to 40 years of prediction	1) Residential, divided by density 2) Commercial, divided by density 3) Industrial	1) Topography 2) Transportation infrastructure
UrbanSIM / *Waddell 1998*	Software-based, semi-empirical, object-oriented modeling system for integrated planning and analysis of urban development, incorporating the interactions between land use, transportation, and public policy	Vector-based, parcels as model entities for land development, 150m x 150m grid cells used to link environmental model	Variable time steps, case study 1 year time steps	Parcel Level Attributes: intensive amount of parameters for socioeconomic/land use characterization	Several biophysical and socioeconomic parameters
SLEUTH or Clarke Urban Growth Model / *Clarke et al. 1998*	Simulation of urban growth in order to aid in understanding how expanding urban areas consume their surrounding land and local environment	Raster based, case studies 30m x 30m, 50m x 50m, 1km x 1km grid cells	Yearly prediction, case studies: 90 years of future prediction	urban/non-urban, model development and application is focused on discrimination of several urban land use classes	1) Topography 2) Transportation infrastructure
LTM Land Transformation Model / *Pijankowski et al. 1997*	Simulation based on Cellular Automaton of land use change processes to forecast land use change based on ecological principles at the catchment scale	Raster based, different spatial scales for processes ($30x30m^2$ parcel, $100x100m^2$ plat, $300x300m^2$ block, $1000x1000m^2$ local)	Variable time steps, case study: 20-50 year prediction in 5-10 years time steps	Landscape described by Anderson Level I classes = urban (Residential, divided by density)	1) Locations of employment 2) Population distribution 3) Topography 4) Transportation infrastructure

Table 1: Comparison of purpose and spatial, temporal and thematic framework of seven urban growth/land use change models after EPA 2000, Agarwal et al. 2000 and model specific documents ([1]*The scheme of urban land use discrimination is either required by the model or was used in case studies).*

The other models use a raster-based approach. In the context of modeling a raster cell provides a generally different representation of the spatial information. The spatial entities are more abstract, whereas a vector-based model uses thematically defined spatial model objects such as parcels or homogenous land units. Accordingly, the raster-based models provide a more generalized or coarser representation of distributed urban objects such as single buildings or parcels, which are the spatial basis for most socio-economic parameters. On the other hand most continuous natural features (e.g. topography) are well represented by raster datasets.

The *UrbanSim* model uses a raster approach if the urban land development module is linked to the ecological system in order to represent the different scale and characteristics of processes and variables. In general, the spatial resolution demands of the raster-based models vary according to the purpose and the characteristics of studies for which they are applied. The grid cell resolutions used range from 30m x 30m to 100m x 100m. Some models use coarser spatial accuracy for special land use classes (*UPLAN* model) or for scale dependent description of processes like the *LTM*- and *UrbanSim* models.

The time intervals and lengths of period for future prediction can describe the temporal framework of the models as shown in Table 1. For most of the models these parameters are variable. The temporal model intervals range from 1 year to 10 years with time frame of prediction between 5 to 10 or up to 100 years. An exception is the *CUF-2* model. Its modeling time intervals and the prediction period are strictly defined by the calibration time frame, usually 5 to 10 years.

Another important characteristic is the issue of how the models discriminate and parameterize the urban area in the form of urban land use classes. The parcel-based approach of *UrbanSim*-model usually does not require the definition of urban land use categories. The important socioeconomic features are parameterized on the level of parcels that also represents the urban land use information. The spatially and thematically more generalized approach of the other models use different land use categories. They represent different land use patterns and features of the urban environment and socioeconomic characteristics that are usually described as model parameters for every category. The models *LUCAS* and *LTM* focus on describing the impact of urban growth on the surrounding environment. Accordingly, they require a land use/cover map following Level I of the Anderson et al. (1976) classification scheme that separates just one urban land use class. The heterogeneity of the urban area is reflected by an additional dataset of population density that is required by the model.

The *CUF-2*, *What If* and *UPLAN* models focus on the description and simulation of urban growth and change patterns for different urban land use categories for model applications in the community planning level. They use a much higher level of inner-urban discrimination and require a separation and parameterization of urban land use classes following the Level II and III of the Anderson et al. (1976) classification scheme such as different densities and building structures of residential areas, commercial or industrial districts. The application of the *SLEUTH*-model so far separates just one urban land use category but the development and future applications of the model will include a more detailed description of the urban land use structures and their changes respectively. In addition to the land use information, the models require additional spatial data such as topography and the transportation infrastructure as summarized in the last column of Table 1.

3 REMOTE SENSING FOR MAPPING URBAN GROWTH MODEL PARAMETERS

Several studies have demonstrated the potential of remote sensing methods as source of information specifically useful for analysis of the urban/suburban environment with focus on land cover/use, socioeconomic information and transportation infrastructure (Barnsley et al., 1993; Rao 1996, Henderson and Xia, 1997; Jensen and Cowen, 1999, Donnay et al. 2001). Only a few studies have focused their remote sensing analysis on application in urban land use change models such as Acevedo et al. (1996) and Clarke et al. (1996). Under consideration of the requirements of the investigated models, this section discusses the potential contribution of remote sensing techniques on the basis of a specific example. The analysis focuses on the acquisition and description of urban land use and socioeconomic information.

In general, the mapping of urban areas by remote sensing is a rather complex process due to the heterogeneity of the urban environment, typically consisting of built up structures (e.g. buildings, transportation nets), several different vegetation covers (e.g. parks, gardens, agricultural areas), bare soil zones and water bodies (Barnsley et al., 1993). Traditionally, visual interpretations of high-resolution air photos could provide comprehensive information for mapping of urban areas. The basis of the data analysis was the interpreter’s knowledge of spatial arrangements of urban land cover features (e.g. texture, pattern, shapes, densities) that were used to characterize several urban structures and feature types (Bowden et al. 1975; Haack et al. 1997). With the beginning of the availability of satellite remote sensing imagery with high temporal and spatial resolution, the analysis methods became more objective and suitable for application over large areas using temporally consistent datasets. Furthermore, the improvements in spatial and spectral sensor resolutions during the last several years can be considered to be a new era in urban remote sensing (Hepner et al. 1998, Tanaka & Sugimura 2001).

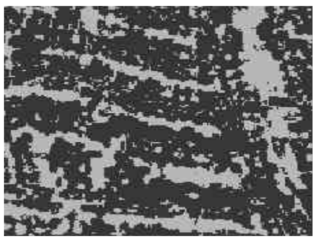
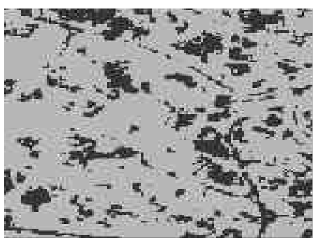
	**Commercial and industrial (Comm):** Commercial and industrial areas (Comm) are dominated by large building structures and extensive impervious cover (paved areas). Property parcels are spatially aggregated into large built up tracts, interspersed with areas of sparse vegetation cover.
	**Residential with high density built up structure (ResHD):** The high-density residential (ResHD) test sites represent a common land use pattern of an area of low and medium income and high population, in which single family residences are sited along a regular street pattern. The vegetated zones composed of landscaped lawns, shrubs and trees surrounding each residence and parks or other recreational areas are associated with each neighborhood. Similar to the Comm test sites, no single parcel shapes are identifiable in the ResHD cover type, but mean structure and parcel sizes are distinctly smaller.
	**Residential with low density built up structure (ResLD):** Vegetation is dominant in the ResLD test sites. The residential structures are larger, with enclosed large single-family dwellings (including ranches) surrounded by extensive vegetated tracts common in this cover type. Compared to the ResHD areas the population density is lower and the mean income is higher. In contrast to the patterns found in the Comm and ResHD sites, single parcels within the ResLD sites are not spatially aggregated and they form independent built up patches.

Table 2: Characteristics and spatial distribution of vegetation (gray) and built up areas (black) in the classified air photos for the three investigated urban land use categories.

Multispectral optical remote sensing allows for separation of diverse urban land cover types (including built up areas, vegetation and water). However, different urban land use classes (e.g. residential, commercial) or socio-economic information, as required by the models, are hard to discriminate by applying “per-pixel” analysis methods. In fact, the spatial and textural context is the most important information for detailed urban area characterization (Mesev et al. 1995, Webster 1995). In this context we present an approach of using spatial or landscape metrics as quantitative measures of spatial structures and pattern to describe urban features in test sites of the Santa Barbara, CA region. A more detailed description of the method can be found in Herold & Menz (2001). The approach requires the introduction and consideration of some important issues:

Spatial Resolution
The approach is based on the description of spatial structures and pattern of built up areas. The acquisition and separation of these structures requires data exhibiting very high spatial resolutions (Welch 1982). Such data are quite recently available from new satellite sensor systems, such as IKONOS 2. As this study was implemented before such data were publicly available, we undertook development and evaluation of this approach employing digitized aerial color infrared photographs (scale 1:130 000). After digitizing, these images have a geometric resolution on the order of 3 meters, similar to currently available data from recent space-borne systems.

Spatial Metrics
Spatial or landscape metrics can be defined as quantitative indices to describe structures and patterns of a landscape (O’Neill et al. 1988). Their development is based on information theory measures and fractal geometry. In this study, landscape metrics were calculated using the public domain *Fragstats* program (McGarical and Marks 1994). Six landscape metrics that describe different spatial land cover features were selected for the analysis: the percentage of the area covered by a class relative to the total landscape area

(%LAND, in percent), the patch density of a land cover class (PD, in numbers per hectare), the patch size standard deviation of a land cover class (PSSD, in hectares), the contagion index (CONT, in percent, see McGarical and Marks 1994), edge density of a land cover class (ED, in meters per hectare) and the area weighted mean patch fractal dimension (AWMPFD).

Homogeneous Urban Patches

A basic approach in the investigations is the definition and spatial discrimination of areas of similar urban structure for the application of the landscape metrics that measure the spatial structures and pattern in a given region (Barnsley and Barr 1997). This concept was chosen according to the approach of "Photomorphic Regions" as developed for visual air photo interpretation. These regions are defined as image segments with similar properties according to their size, shape, tone/color, texture and pattern (Peplies 1974). Accordingly, for the application of the landscape metric approach these regions can generally be defined as areas of homogeneous urban land use structures as entities for the data analysis.

Using a supervised classification approach, test sites in the area of Santa Barbara, CA could be clearly separated into vegetation and built up areas. The six selected landscape metrics were calculated on the basis of the binary land cover classification for the following three urban land use categories in homogenous areas of; commercial and industrial (Comm); residential with high density built up structure (ResHD); residential with low density built up structure (ResLD) as well as for a test site of urban growth. The characteristics and spatial distribution of built up and non-built (vegetation) zones in the different test sites are shown in Table 2. The test sites were selected due to their importance in representing typical spatial and socioeconomic patterns found in urban areas, especially in the Santa Barbara, CA region.

Comparative evaluation of the landscape metrics shows distinctive differences between the three land use categories concerning the dominance of one land cover class (%LAND), the patch density and size (PD and PSSD) and their spatial pattern and fragmentation (CONT, ED, AWMPFD, Fig.1). As determinants of land cover features for the spatial measurements, the domination of a land cover class (built up or vegetation), housing density, mean housing and plot size as well as the spatial aggregation of the built up areas can be identified. This information can be used for a detailed characterization of these areas in terms of urban land use and socio-economic issues, e.g. a classification based on the metric information can provide urban land use maps (intra-urban discrimination) with an accuracy required for several urban growth models (see section 2).

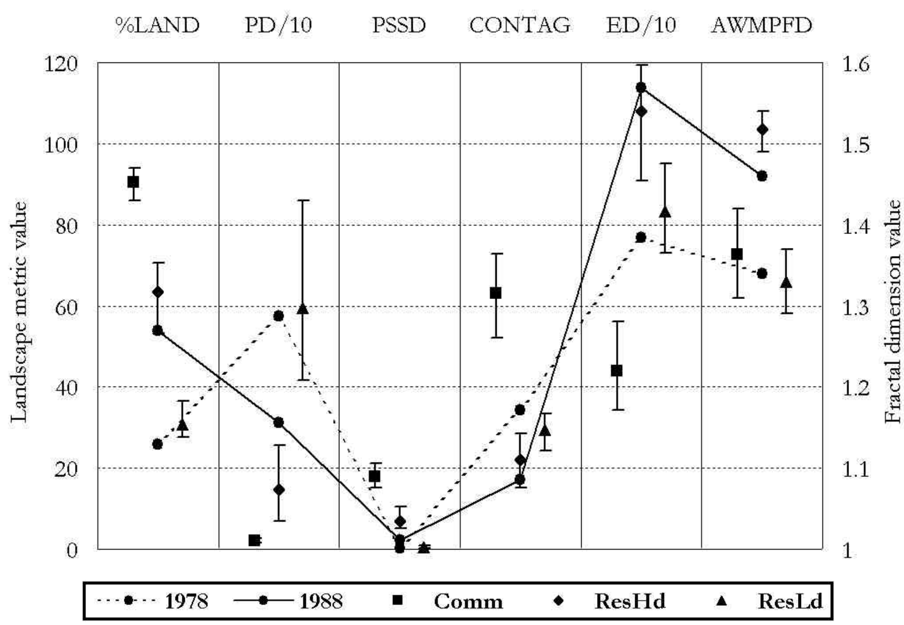


Fig 1: Representation of the three investigated land use structures and of changes in urban land use for six landscape metrics in the La Cumbre test site area (Santa Barbara, CA) between 1978 and 1988

(Note: The metrics presented for the three land use structures result from four different test sites each and are shown as minimum, mean and maximum. The measures of the "urban growth test site" La Cumbre are the connected points for two years. All metrics, except the Contagion Index (CONT), are referred to as structures of the class "built up". The Patch Density (PD) and the Edge Density (ED) values were rescaled (by dividing them by a factor of ten) to adjust them to the first y-scale (landscape metric value). The secondary y-axis (fractal dimension value) is only related to the "area weighted mean patch fractal dimension" (AWMPFD)).

Changes in urban land use, shown for the La Cumbre test site based on a set of two air photos from 1978 and 1988 (Fig.1), were described using the landscape metric information. In the test site, landscape pattern changed due to the spread of structures to previously vegetated zones. The landscape metrics show a rising percentage of the built up zones on the total landscape area, as well as increasing spatial aggregation of the built up patches (Fig.1). The urban growth in previously non-built up zones resulted in a higher fragmentation of the landscape. The results indicate the capability of high resolution optical remote sensing data for the mapping of urban land use and socioeconomic features and their temporal change components.

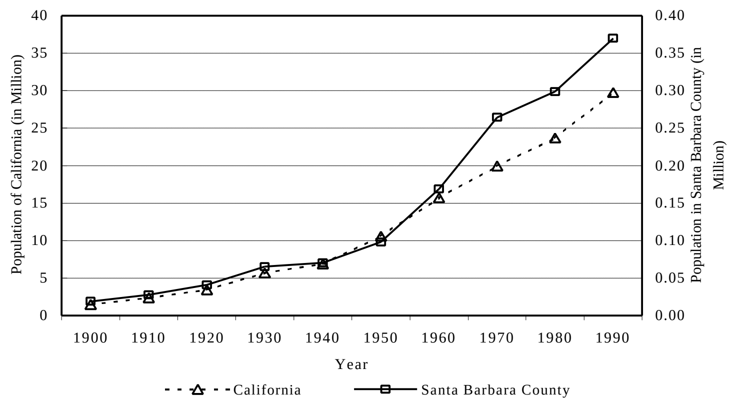


Fig. 2: Population growth in California and Santa Barbara County between 1900–1990, after U.S. Census (1999).

4 APPLICATION OF THE *SLEUTH* MODEL FOR MODELING URBAN GROWTH

An urban growth model was applied to simulate the growth in the Santa Barbara, CA region. The simulation was based on the Clarke Urban Growth Model (*UGM*) that simulates the combined influences of topography, adjacency, and transportation networks on the patterns of urbanization though time (Clarke et al. 1996). The model is described in detail in Clarke et al. 1997. The model uses cellular automata to model the urban expansion based on growth rules in a gridded representation of geographic space on a cell-by-cell basis. The model is able to control the behavior of the system by several parameters and by modification of the growth rules (Clarke et al. 1996). The land cover change deltatron model is tightly coupled with the *UGM*. The models together are referred to as *SLEUTH* by reference to the models input data requirements: Slope, Land cover, Exclusion, Urban, Transportation, Hillshade (Candau et al. 2000, see section 2).

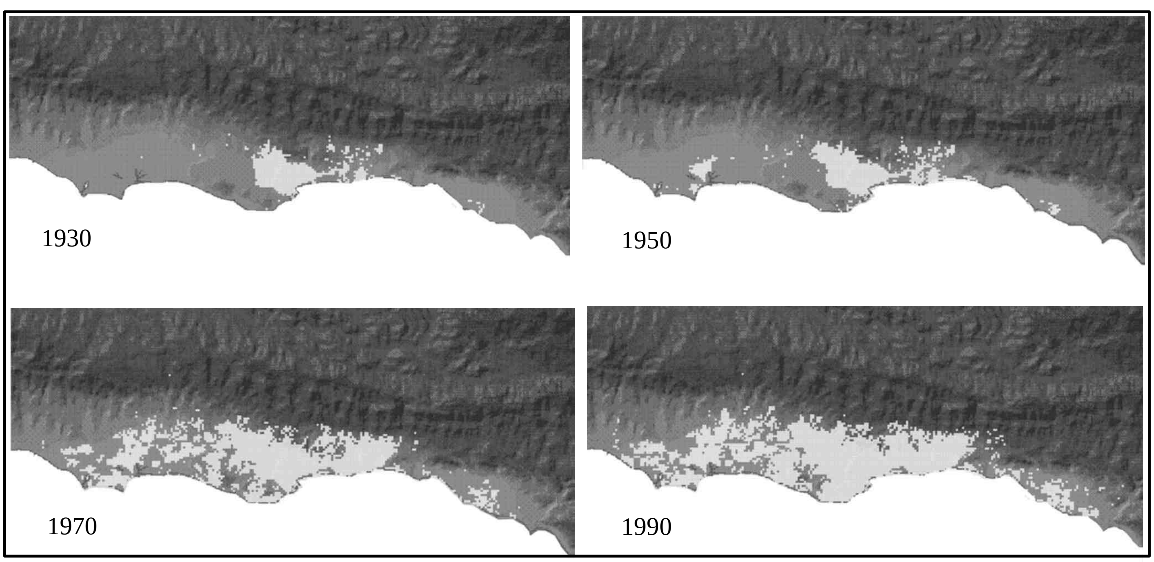


Fig. 3: The historical growth of the urban area (shown in light gray) in the Santa Barbara, CA region shown with digital elevation model background.

The growth of the Santa Barbara, CA region was studied from 1929, the first year for which an air photo of the area is available. The urban development in the area was driven by significant growth in population that is reflected in Figure 2. Another increase in population is indicated between 1950 and 1990. The data which with to perform the simulation were partly available from standard data products of US governmental agencies like the USGS 7.5“ DEM and the Census Bureau TIGER road data. The most important parameter in growth modeling were the temporal layers of land use information, in this case the distribution of urban and non-urban areas. This information was gathered from visual interpretation analysis of 7 sets of historical air photos acquired in 1929, 1943, 1954, 1967, 1976, 1986, and 1997. The observed land use pattern (distribution of urbanized and non-urbanized land) formed the basis for model calibration as it represents the spatial and temporal growth pattern in the Santa Barbara region. Once the model is calibrated it can be used for prediction of future developments based on different user-defined scenarios.

Figure 3 shows the growth in the Santa Barbara, CA region as simulated by the *SLEUTH* model. In 1929, the city of Santa Barbara covered just a small area around the future central business district. A small extension of the urban area is found by 1950 that is caused by population growth and the military installations of World War II. Until 1970 the intensive population growth and the establishment of several commercial sectors caused a significant expansion of the urban space to the west (Goleta). This trend of westward expansion continues today and has resulted in urbanization of most sections of the coastal plain in front of the East West mountain range that forms a physical limit to any further landward expansion. To the east, down the coast, expensive real estate, and prevalent property owner involvement with city government, prevents any major urban expansion (Montecito). The calibrated model was used to predict future land use development, assuming the growth stays constant for the future. The results of the predictive modeling are shown in Figure 4. This scenario represents the modeled urban area if all open space, except parks, are allocated as vacant land. The further growth of the urban area mainly appears in the “hot spots” of the west (Goleta) and the east (Carpinteria) of the coastal plane.

Fig. 4: Predicted urbanized areas in the 2050 modeled for the scenario that all area is considered vacant land except parks (dark gray = urbanized in 1997, lighter gray = urbanized in 2050).

The approach used in this case study just predicts the change in the extent of the urban area. It does not differentiate between different urban land use classes. This issue is currently under investigation as both models and the input data from remote sensing images will be modified and extended to allow for modeling of intra-urban land use transformations, in addition to the physical growth limits of the urban area (Clarke et al. 1998). The results of this analysis are included in research co-operations with Santa Barbara city planners to support the management and planning of this region.

5 CONCLUSION

During recent years urban growth/land use change models have been developed and extended as important and innovative tools in urban planning and management. The complexity, structure and purpose of the models require various datasets for parameterization, calibration and validation. The demands of the different models explored can be summarized as:

- Accurate land use and socioeconomic information and representation are one of the most important issues for the modeling of land use change. Based on the intended purposed and application of the model they usually require:
    - Anderson Level I classification accuracy (raster data) with one urban class and additional information about residential and population density for regional modeling of the impacts of urban growth for the ecological/natural system,

  - Anderson Level II and III classification accuracy (mainly raster representation) for urban land use classes for modeling of urban land use change on the local/community level. The land use classes are often parameterized by socioeconomic variables,
  - Various socio-economic variables are assigned on the parcel level (vector representation) for object-oriented modeling of behavior of different agents of land development.
- The raster-based models use different spatial resolutions for the description of different features and processes. The spatial representation of urban land use classes ranges from 30m x 30m to 100m x 100m.
- The temporal resolution or time step modeling and the accuracy of the model calibration vary between 1 and 10 years.
- Other generally required datasets are the transportation infrastructure and topography.

Remote sensing techniques can be considered an important data source of several model parameters, especially in the context of applied use of these models. The case studies presented in this paper show the importance of remote sensing data historical time series as an important data source for the parameterization and calibration of urban growth models, an essential condition for the prediction of future development and scenario modeling. It also indicates the capabilities of innovative digital remote sensing data analysis using spatial metrics. Considering the availability of high resolution space-borne remote sensing imagery as an appropriate source of data, this approach can be used to acquired data that meet the spatial, temporal and thematic requirements of most urban land use change models with regard to using an inner-urban discrimination of several urban land use and socioeconomic categories.

In conclusion, with the data and methods available, there is a clear demand for the combined use of remote sensing and modeling in urban management and planning. However, the potentials and approaches have to be evaluated and extended in further investigations, especially in combination of both presented techniques to support applications in urban management and planning.

REFERENCES

Acevedo, W., Foresman, T.W., and Buchanan, J.T., 1996. Origins and Philosophy of Building a Temporal Database to Examine Human Transformation Processes, Proceedings, ASPRS/ACSM Annual Convention and Exhibition, Baltimore, MD, April 22-24, 1996.

Agarwal, C. Green, G.L. Grove, M. Evans, T. and Schweik, C. 2000. A Review and Assessment of Land-Use Change Models: Dynamics of Space, Time, and Human Choice, published jointly by the US Forest Service and the Center for the Study of Institutions, Population, and Environmental Change (CIPEC), Indiana University.

Alberti M. and Waddell P. 2000. An Integrated Urban Development and Ecological Simulation Model, Integrated Assessment, in press, http://www.odot.state.or.us/tddtpau/papers/P2T2.4.2fnl.pdf, access: April 2001.

Anderson, J.R., E.E. Hardy, J.T. Roach, and Witmer, R.E. 1976. A Land Use and Land Cover Classification Scheme for Use with Remote Sensor Data. U.S. Geological Survey Professional Paper 964.

Barnsley, M.J.,Barr S.L., Hamid A., Muller P.A.L., Sadler G.J. and Shepherd, J.W. 1993. Analytical Tools to Monitor Urban Areas. Geographical Information Handling-Research and Applications. Ed. Mather, P.M., pp. 147-184.

Barr, S. and Barnsley, M. 1997. A region-based, graph-oriented data model for the inference of second order information from remotely-sensed images, International Journal of Geographical Information Science, 11, 6, pp. 555-576.

Batty, M. 1994. A chronicle of scientific planning: The anglo-american modeling experience, in Journal of the American Planning Association, 60, 1, pp. 7-12.

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

Berry M. W., Flamm R. O., Hazen B. C. & MacIntyre R. L. 1996. The Land-Use Change and Analysis System (LUCAS) for Evaluating Landscape Management Decisions, IEEE Computational Science & Engineering, 3, 1, pp. 24-35.

Bowden, L. W. (eds.) 1975. Urban environments: inventory and analysis, in Bowden, L. W. et al. (eds.). Manual of Remote Sensing, Ed. 1, Volume 2, pp. 1815-1880.

Candau, J., Rasmussen, S. and Clarke, K. C. 2000. A coupled cellular automaton model for land use/land cover dynamics. 4th International Conference on Integrating GIS and Environmental Modeling(GIS/EM4): Problems, Prospects and Research Needs. Banff, Alberta, Canada, September2 – 8.

Clarke, K. C. , Hoppen, S. and Gaydos, L. 1997. A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area' Environment and Planning B: Planning and Design, vol. 24, pp. 247-261.

Clarke, K. C. and Gaydos, L. 1998. "Long term urban growth prediction using a cellular automaton model and GIs: Applications in San Francisco and Washington/Baltimore", International Journal of Geographical Information Science, 12, 7, pp. 699-714.

Clarke, K. C., Hoppen, S., and Gaydos, L. J. 1996. Methods and techniques for rigorous calibration of a cellular automaton model of urban growth, Proceedings, Third International Conference/Workshop on Integrating GIS and Environmental Modeling CD-ROM, Santa Fe, NM, January 21-26, 1996. Santa Barbara, CA: National Center for Geographic Information and Analysis. http://www.ncgia.ucsb.edu/conf/SANTA_-FE_CD-ROM/main.html, access: May 1999.

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

EPA – Environmental Protection Agency, 2000. Projecting land use change: A summary of models for assessing the effects of community growth and change on land use pattern, http://www.epa.gov/cbep/tools/-reportfinal3.pdf, access: April 2001.

Garreau, J. 1988. Edge city: Life on the new frontier. New York, Doubleday, 546 p.

Haack, B. N., Guptill, S. C., Holz, R. K., Jampoler, S. M., Jensen, J. R. and Welch, R. A. 1997. Urban analysis and planning, in Philipson et al. eds. Manual of photographic interpretation, 2. Ed, pp. 517-554.

Hart, J. F. (ed.) 1991. Our Changing Cities. The John Hopkins University Press. Baltimore.

Henderson, F. M. and Xia Zong-Guo 1997. SAR Applications in Human Settlement Detection, Population Estimation and Urban Land Use Pattern Analysis: A Status Report. IEEE Transactions on Geoscience and Remote Sensing, Vol. 35, No. 1, pp. 79-85.

Hepner, G. F., Houshmand, B., Kulikov, I. and Bryant, N. 1998. Investigation of the integration of AVIRIS and IFSAR for urban analysis, Photogrammetric Engineering and Remote Sensing, 64, 8, pp. 813 – 820.

Herold, M. And Menz, G. (2001). Fernerkundung und Landschaftsmaße – Untersuchungen zur raumstrukturellen Analyse urbaner Regionen, in Erdkunde, in press.

Jensen, J. R. and Cowen, D. C. 1999. Remote sensing of urban/suburban infrastructure and socio-economic attributes, Photogrammetric Engineering and Remote Sensing, 65, 5, pp. 611-622.

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

Knox, P. L. 1993. The Restless Urban Landscape. ed. Paul L. Knox. Englewood Cliffs: Prentice-Hall.

Landis, J. & Zhang, M. 1998. The second generation of the California urban futures model: Part 1: Model logic and theory, Environment and Planning B, 30, pp. 657-666.

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

McGarigal, L. and Marks, B. J. 1994. FRAGSTATS Manual: spatial pattern analysis program for quantifying landscape structure, URL: ftp://ftp.fsl.orst.edu/pub/fragstats.2.0, access: Januray 2001.

Mesev, T.V., M. Batty, P.A. Longley, and Y. Xie, 1995. Morphology from imagery: detecting and measuring the density of urban land use. Environment and Planning A, 27, pp. 759-780.

O'Neill , R.V., J.R. Krummel, R.H. Gardner, G. Sugihara, B. Jackson, D.L. Deangelis, B.T. Milne, M.G. Turner, B. Zygmunt, S.W. Christensen, V.H. Dale, and R.L. Graham. 1988. Indices of landscape pattern. Landscape Ecology 1:153-162.

Peplies, R. W. 1974. Regional analysis and remote sensing: a methodological approach, in Estes, J. E. (eds.). Remote sensing: techniques for environmental analysis, pp. 277-291.

Pijankowski, B.C, Long D. T., Gage. S. H. and Cooper. W. E. 1997. A Land transformation model: conceptual elements spatial object class hierarchy, GIS command syntax and an application for Michigan's Saginaw Bay watershed, http://www.ncgia.ucsb.edu/conf/landuse97/, access: April 2001.

Rao, K. M. L. 1996. Regional network planning and orientation for rural transportation using remote sensing technique, International Journal of Remote Sensing, 17, 17, pp. 1991-1022.

Shabazian, D. and Johnston, R. 2000, UPLAN - Urban Growth Model (UC Davis, Information Center for the Environment), http://snepmaps.des.ucdavis.edu/uplan/, access: April 2001.

Tanaka, S. and Sugimura, T. 2001. A new frontier of remote sensing from IKONOS images, International Journal of Remote Sensing, 22, 1, pp. 1-5.

U.S. Census Bureau, Population Division 1999. Selected historical census data, http://www.census.gov/population/www/censusdata/pop-hc.html 1999, access: June 1999.

Waddell, P. 1998. UrbSim - The Oregon Prototype Metropolitan Land Use Model, in Proceedings of the ASCE Conference Transportation, Land Use, and Air Quality: Making the Connection Portland, Oregon, May 1998. http://www.urbansim.org/Papers/ASCE%20Model.pdf, access: April 2001.

Webster, C. J. 1995. Urban morphological fingerprints, Environment and Planning B, 22, pp. 279-297.

Welch, R. 1982. Spatial resolution requirements for urban studies. International Journal of Remote Sensing, Vol. 3, No. 2, pp. 139-146.