Chapter 1
Geomatic Approaches for Modeling Land Change Scenarios. An Introduction

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Abstract Land change models can help scientists and users to understand change processes and design policies to reduce the negative impact of human activities on the earth system at scales ranging from global to local. With the development of increasingly large computing capacities, multiple computer-based models have been created, with the result that the specific domain covered by the umbrella term "modeling" has become rather vague. Even within the context of the spatiotemporal modeling of land use and cover changes (LUCC), the term "modeling" can have many different meanings. There is also an increasing interest in the literature in comparing the different land change models. One of the aims of this book is to contribute to these processes. We focus on geomatic modeling approaches applied in this context to land change, a term that has been used synonymously for a number of years with LUCC and seems to be overtaking it as the generally used term for this phenomenon. The objective of this book is also clear to see from the methods we have chosen and the subjects we address. This book deals first and foremost with spatially explicit data that can be mapped. However, its additional focus on land change and land change scenarios in the wider field of environmental and social dynamics give it a certain consistency with a view to practical applications.

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1 General Context

Planet Earth is being altered at an increasingly rapid pace by human activities such as fossil fuel combustion and CO_2 emissions, the increase in agricultural land at the expense of forests, the alteration of the water cycle and weather patterns, and the release of large amounts of nitrogen, phosphorus, plastic and black carbon into the biosphere. The effects of these human activities are being exacerbated by long term global geological processes. To emphasize the enormous impact of human activities on the earth and the atmosphere, Crutzen and Stoermer (2000) proposed the term "anthropocene" for the current geological epoch. Seen by many as a state-change in the earth system, the anthropocene concept bridges the gap between social and natural sciences in open systems of knowledge production. It covers the cumulative history of local and regional social changes and its connections to global processes. These changes have been linked to the development of extractive resource chains, resource use systems, urbanization and infrastructure, and technological diffusion, all of which show path dependency and emergent patterns visible in the landscape (Brondizio et al. 2016). New types of connectivity are still emerging, while the existing networks that underlie the changes continue to transform the landscapes (Lambin and Meyfroidt 2011; Brondizio et al. 2009). Meyfroidt et al. (2013) point out how local processes of land change can affect distant areas and how the influence of demand and policy often be felt in different regions. These authors use the term 'telecoupling' to describe this kind of relationship and propose combining place-based research and global modeling to evaluate the links between flows of products and services and land change. In this context, land change models can help scientists and users to understand change processes and design policies to reduce the negative impact of human activities on the earth system at scales ranging from global to local.

With the development of increasingly large computing capacities, multiple computer-based models have been created, with the result that the specific domain covered by the umbrella term "modeling" has become rather vague. Even within the context of the spatiotemporal modeling of land use and cover changes (LUCC), the term "modeling" can have many different meanings. There is a degree of confusion, for example, between modeling and simulation. Strictly speaking, modeling relates to understanding and expressing system behavior; in other words, modeling implies a simplified description of reality. By contrast, simulation refers to applying a model to a particular case study over a period of time. Many authors use modeling as a synonym for simulation. However, even if we agree that simulation is modeling a future state of a system, this definition is still extraordinarily ambiguous. A simulation may predict or prospectively model what will probably happen, but it may also be used to develop a scenario to support decision-making processes based on specific hypotheses or simple extrapolations.

Several books on land change modeling have been published in the last few years. These include among others, and in chronological order, the review by Verburg et al. (2006) of land-use and land-cover change modeling concepts and approaches, published in Lambin and Geist (2006). Koomen and Stillwell (2007) advanced the field of land use change modeling with contributions about explanatory, optimization, operational and new models. Paegelow and Camacho Olmedo (2008) introduced modeling approaches based on environmental dynamics, followed by a set of case studies. Murayama and Thapa (2011) and Murayama (2012), centering more on spatial analysis than modeling, analyzed the different GIS-based applications in land change models. Deng (2011) explored different models used in research into land system change. Heppenstall et al. (2012) and Arsanjani (2012) investigated agent and multi-based modeling. Lambin (2013) offered a general overview about modeling land use change in relation to environmental modeling in Wainwright and Mulligan (2013). The US National Research Council (2014), with a large number of contributors, published an outstanding report about the current state of land change modeling and the different approaches to it. The report also presented proposals regarding possible improvements. In their book on the monitoring and modeling of global changes, Li and Yang (2015) included among others a theoretical chapter about challenges in land change modeling. Cities and urban regions were at the heart of the theory and modeling approaches presented by White et al. (2015).

2 Our Perspective

The wide range of land change models can be classified according to their theoretical basis and their purpose. As with GIS, which can be divided into raster and vector approaches, land change models can be classified from a conceptual point of view into those based on spatial patterns (pattern-based models, PBM) and those based on the decisions and interactions of economic agents (agent-based models, ABM). The classification of available modeling software is complicated by the fact that most programs are based on hybrid approaches and offer a wide range of options. Models can also be classified on the basis of the techniques they incorporate, such as Markov chains, suitability maps, pattern based indices, neighborhood relationships like Cellular Automata (CA), etc. Other authors group models together on the basis of their purpose, dividing them into models that produce predictions, projections and normative or exploratory scenarios. Other authors distinguish models by focusing on the way they relate simulation to present and past land use/cover (LUC), splitting them into two main categories: path-dependent scenarios (also called trend or business-as-usual (BAU) scenarios) and contrasting scenarios. Several reviews about land change modeling approaches and their classifications can be found in the literature (Baker 1989; Lambin 1997; Irwin and Geoghegan 2001; Agarwal et al. 2002; Parker et al. 2003; Brown et al. 2004;

Verburg et al. 2006; Koomen and Stillwell 2007; Murayama and Thapa 2011; Kelly et al. 2013; Li and Yang 2015).

The result is that it is impossible to propose one single method for classifying models that meets all the needs and takes into account all the different situations. For practical purposes, we therefore decided to choose an existing classification, which is widely accepted by the international researchers in the literature, i.e. the classification proposed by the US National Research Council (2014). The NRC groups the models into five main categories, plus a hybrid category, which includes models that combine different approaches into a single modeling framework:

1. Inductive pattern-based models (PBM). Land change is modeled empirically using statistical and machine learning methods and observations of past land change to calibrate functions which describe the relationship between these changes and the set of drivers.
2. Cellular approach which integrates maps for suitability for land use/cover with neighborhood effects and information about the expected quantity of change.
3. Sector-based economic models based on the supply and demand for land according to economic sectors and activities and trade between regions.
4. Spatially disaggregate economic approach. Models designed to identify the causal economic relationships impacting the spatial equilibrium within land systems.
5. Agent-based models (ABM) which simulate the decisions regarding land change taken by actors that interact with each other and with their environment to make changes in the land system.

The land change models presented in this book are orientated more towards PBM than ABM and according to the NRC classification can be divided into two groups of PBM and constraint CA based models.

There is an increasing interest in the literature in comparing the different land change models (Pontius et al. 2008; Kelly et al. 2013; Mas et al. 2014; van Vliet et al. 2016; Prestele et al. 2016). One of the aims of this book is to contribute to this process. As the title of this book suggests, we focus on geomatic modeling approaches applied in this context to land change, a term that has been used synonymously for a number of years with LUCC and seems to be overtaking it as the generally used term for this phenomenon. The objective of this book is also clear to see from the methods we have chosen and the subjects we address. This book deals first and foremost with spatially explicit data that can be mapped. However its additional focus on land change and land change scenarios in the wider field of environmental and social dynamics give it a certain consistency with a view to practical application.

3 Structure of the Book

This book is divided into five parts: Part I *Concepts and tools*, Part II *Methodological developments,* Part III *Case studies,* Part IV *Technical notes* and Part V *Modeling software*.

Part I is composed of four chapters each of which focuses on a specific stage in modeling: calibration, simulation, validation and scenarios, authored by the book's editors and collaborators. The aim is to present the basic ideas and to offer a general overview of the concepts, methods and techniques used in land change modeling. Although there are no clearly defined boundaries between calibration and simulation, and despite the fact that calibration and validation share several tools, the authors try to set out a clear position regarding the concepts and stages in land change modeling. The chapters on calibration, simulation and validation are therefore all presented in the same way. A theoretical and methodological review analyzes the approaches used to set the parameters in the different steps in the calibration and simulation processes; while the chapter on validation describes the set of concepts and tools used in this process. The first three chapters also contain coordinated flowcharts and diagrams to explain the procedures in graphic form. The different approaches for estimating parameters are complemented by a table with a comparative analysis of the selected LUCC models. These models are practically applied in the chapters in Parts II and III of this book and described and explained in Parts IV and V. The chapter about scenarios aims to provide an insight into the intricate world of scenario planning and serve as a guide to the scenario modeling process. The chapter seeks to clarify the definition of inter-related and often mixed-up terms such as scenario, prediction, forecast and storyline. Given the extraordinary amount of scenario planning techniques and models found in the literature, the chapter content has been structured in such a way as to alleviate what some authors have described as methodological chaos.

Parts II and III are a collection of fourteen chapters written by researchers from Brazil, Colombia, France, Mexico, Spain, the United Kingdom and the United States. A first group of seven chapters (Part II) focuses on recently proposed methodological developments that have enhanced modeling procedures and results. The first chapter assesses the impact of using one or two time points in the calibration process and the second chapter discusses the impact of using multiple training dates in Markov chain models. The next chapter discusses the possibility of including genetic algorithms in the calibration phase as a means of improving it. The group of methodological developments also includes two chapters about the influence of spatial scale in land change modeling, focusing in one chapter on different experiments in data and parameters, and in the second on the comparison between different land use and cover maps. The last two chapters present and discuss the benefits encountered in participatory-based modeling in two very different areas, one in Spain and the other in Mexico.

A second group of chapters (Part III) has been labeled as case studies although they also offer interesting and innovative methodological proposals. The first chapter tackles the extremely complex case of land dynamics in the Gaza Strip. This is followed by a chapter focusing on land-use modeling in a cross-border region at the heart of Europe (formed by the city of Strasbourg in France and the city of Kehl in Germany). Issues and pressures suffered by natural protected areas within or near large metropolitan areas are analyzed in a chapter about the Madrid region and its recently declared Sierra de Guadarrama National Park. From this point, we cross the Atlantic to present three case studies in North and South America. The first deals with the challenges faced when modeling an area under redevelopment (in this case a former air base in California) as opposed to the more common modeling studies of urban expansion processes. This is followed by research from Chile which highlights the importance of its timber sector and explores various issues related to its future and the difficulties in modeling it. This part ends with a chapter dedicated to future intra-urban transport alternatives for the city of Bogota, Colombia. As is the case in most big cities in the developing world, Bogota faces extraordinary challenges when it comes to balancing growth and sustainability, in which public transport can tip the scales in favor of a desirable future or on the contrary towards an unsustainable horizon.

All these chapters deal with spatiotemporal data and use some of the best-known software packages for LUCC modeling. Each contribution follows a similar structure, even if the modeled object, methods, kind of model and purpose vary a great deal.

The book finished with two parts about *Technical Notes* and *Modeling Software*. Both parts have been written by a large number of scientists each contributing with their respective expertise in each of the technical notes and software presented. The Technical Notes section (Part IV) aims to describe in a simple and intuitive way some of the most frequently used methods in the calibration, simulation and validation stages in selected LUCC models. In each technical note, a short description of the method is followed by technical details with highlighted illustrations and, in some cases, with a complementary example or application.

The chapters on Modeling Software in Part V offer a compilation of short presentations of the packages presented in this book, authored by their designers. These include some of the best-known LUCC models: CA_MARKOV, Land Change Modeler (LCM) (both in TerrSet), Dinamica EGO and CLUMondo, as pattern-based models (PBM); and Metronamica, APoLUS, SLEUTH and LucSim as constraint cellular automata-based models (CCAM). The short presentations all follow the same structure. After the introduction, there is a description of the methods implemented in the model, followed by some examples of applications, a final consideration and a technical summary.

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