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Comparison of scale and scaling issues in integrated land-use models for policy support

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ABSTRACT

Recently an increasing number of integrated land-use models have become available that support policy making. Inevitably, their model components represent processes that act on different scales and that use different levels of detail to represent those processes. Therefore, it is a challenge to integrate them properly. In this paper we analyse and compare scaling issues from four integrated models that are explicitly spatial and dynamic. All have a strong agricultural component and are developed to support policy making. From these examples we find that scaling issues in model integration typically involve trade-offs among four factors: (1) the scale at which end users or policy makers require information; (2) the scale at which processes take place and the representation of those processes in a single model; (3) the way to integrate model components representing processes occurring at different scales; and (4) the limitations posed by practical restrictions such as data limitations and computation speed. Furthermore we conclude that the complexity of the model components and the spatial and temporal resolutions applied in the models are generally related to the size of the study area, while its thematic resolution is mostly driven by user requirements. Finally we argue that more detail does not necessarily generate better results and might even give a false impression of the model's accuracy.

1. Introduction

Today's world is increasingly more complex and changing rapidly. Numerous processes occurring at different spatial and temporal scales act and react upon each other, making it difficult to understand and assess the impact of interventions on the human-environment system (Cash et al., 2006). Nonetheless, planners and policy makers face the challenge of making decisions in this complex system. They are not only confronted with interventions in their own sector, but must consider the impact of interventions in other sectors as well as a range of external factors not directly influenced by policy interventions, such as climate change and global socio-economic developments.

In the past decade several integrated models have been developed with the aim to support planning and policy making in the field of (agricultural) land use (WUR and MNP, 2007; Van Ittersum et al., 2008; Sieber et al., 2008; Van Delden et al., 2010). These models have in common that they are interdisciplinary and are as such able to assess the impact of policy interventions on a broad range of sectors. However, as their model components represent processes that act on different scales this poses challenges for their integration, because the interaction between the various processes and scales at which they occur is often not straightforward (Van Delden et al., 2011).

In this paper we analyse four integrated land-use models for policy support: the LUMOCAP Policy Support System (Van Delden et al., 2010), WISE (Rutledge et al., 2008; Huser et al., 2009), the MedAction Policy Support System (Van Delden et al., 2007), and the DeSurvey Integrated Assessment Model (Van Delden et al., 2009) and compare the following scale and scaling issues in developing these models:

- At what scale(s) does the model allow input and provide results to ensure relevance to policy-makers?
- How is a process represented in a model? What is the level of detail used to represent a process?
- How are models, representing processes at different scales, connected?
- What other limitations related to scale and scaling issues were encountered in their development?

The paper is organised as follows: section two clarifies the concepts and definitions that are being used. Section three describes the four integrated models and elaborates on the scaling issues encountered and choices that were made during their develop-

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ment. Section four compares and discusses the approaches used. Section five draws conclusions and provides directions for further research.

2. Concepts and definitions

Scale and scaling issues have been dealt with in many different disciplines, among others hydrology (Kirkby, 1999), coastal hydraulics (De Vriend, 1991), ecology (Wilson et al., 1999) and social sciences (Gibson et al., 2000). In physics, as perhaps the extreme example, scientists have conceptualised time and space scales ranging over more than 60 orders of magnitude, from the first moments of the big bang (10^{-43} s) to the present time (10^{17} s), and from electrons (10^{-30} kg) to the universe (10^{55} kg). It is clear that, although there are attempts to unify understanding across these scales, the dominant theory in any context is very much constrained by the inherent scale of the process of interest. Within the more restricted range of bio-physical and socio-economic processes, dominant system behaviour changes at characteristic thresholds, many of which are associated with typical scales. For example, catchment dynamics are dominated by hillslope processes in small areas without developed stream channels, and by the behaviour of those channels in areas large enough to support them (Smith and Bretherton, 1972).

A sharp delimitation of scales is often not possible (Steinhardt and Volk, 2003). Moreover, the scale at which processes operate cannot be seen in isolation, as processes have an impact on or are affected by processes at other scales as well. For example, Dasgupta (1997 in Gibson et al., 2000) argues that economics tries to explain 'the various pathways through which millions of decisions made by individual human beings can give rise to emergent features of communities and societies', such as rate of inflation, national income, formation of prices and cultural values. On the other hand he points out that individual decisions at any particular point in time are affected by these emergent features. Another example can be found in land-use change, where impacts of climate change (scales of decades to centuries) are intertwined with market price developments and changes in policies (scales of months to years).

We define scale as a characteristic dimension in either space or time or both, of an observation or a process, following Jewitt and Görgens (2000). As already stated by Neef (1963) and described by Steinhardt and Volk (2003), scale-specific approaches require scale-specific investigation methods and result in scale-specific information and insights. Therefore modellers need to decide on the representation of processes in a model and as such make decisions on the spatial and temporal extent, the spatial level(s) and the hierarchy by which they are ordered, and the amount of detail incorporated. Levels refer to locations along a scale (Gibson et al., 2000) and detail relates to the spatial, temporal and thematic resolution(s) and the complexity by which processes are represented. In this paper we define complexity as the number of variables, relations and processes modelled (Van Delden et al., 2011), the spatial resolution as the grid size, the temporal resolution as the length of the time steps on which a model operates, and the thematic resolution as the number of classes in a categorical map (Castilla et al., 2009).

Linking models that represent processes occurring at various scales raises questions regarding the hierarchical nature of the relationships among them. Scaling is defined as the process of extrapolating or translating information across scales (Blöschl and Sivapalan, 1995). Mechanisms through which this can be done include top-down or a bottom-up approaches. Top-down approaches are those where the coarser scale influences the finer. Bottom-up approaches are those where coarser-scale processes emerge from processes at the finer scales.

Current approaches to modelling land-use change at a high spatial resolution frequently use bottom-up approaches such as Cellular Automata (CA) (RIKS, 2011), Activity-Based Modelling (Van Vliet et al., 2011) or Agent Based Modelling (Robinson et al., 2007). Each of these approaches has its own scale issues, which have been defined, investigated and described in literature (see for example Kirman, 1992 and Ménard and Marceau, 2005). Over the past decade, integrated models linking various aspects of land-use change and allocation, have gained in importance. Examples of models linking land use and economics are presented by Rutledge et al. (2008), Van Ittersum et al. (2008) and Van Delden et al. (2008); examples of models linking land-use and bio-physical processes by Schulze (2000), Forsman et al. (2003) and Van Delden et al. (2007). From linking different models, new scaling issues arise, while the issues within the individual components remain present.

3. Four integrated models for policy support

For this study we selected four integrated models. All models included in the analysis are dynamic spatial simulation models that allow for feedback mechanisms between their components. Time is represented as discrete steps and interaction between different model components can take place during each time step. They are implemented within the Geonamica software platform for spatial modelling and (geo)simulation (Hurkens et al., 2008) and available as operational software packages. Characteristics of the four models are described below and summarized in Table 1.

3.1. LUMOCAP—Dynamic Land Use change MOdelling for CAP impact assessment on the rural landscape

The LUMOCAP Policy Support System (PSS) is developed to assess the impact of the Common Agricultural Policy (CAP) (CEC, 2009) on the land use and landscapes of the 27 countries of the European Union (Van Delden et al., 2010). The system incorporates models for agricultural economics, national and regional interaction of population and jobs, land-use allocation, crop choice and suitability. It uses scenarios for climate change, socio-economic developments and policy alternatives as external drivers. It encompasses processes operating on four spatial scales: EU 27, national, regional and local, reflected by the four spatial levels of the model (Fig. 1). The LUMOCAP PSS models processes at the local level at two different spatial resolutions: a 1 km resolution for the entire European Union and a 200 m resolution for specific case regions. The temporal resolution of all models is one year and the time horizon of the system is 2030.

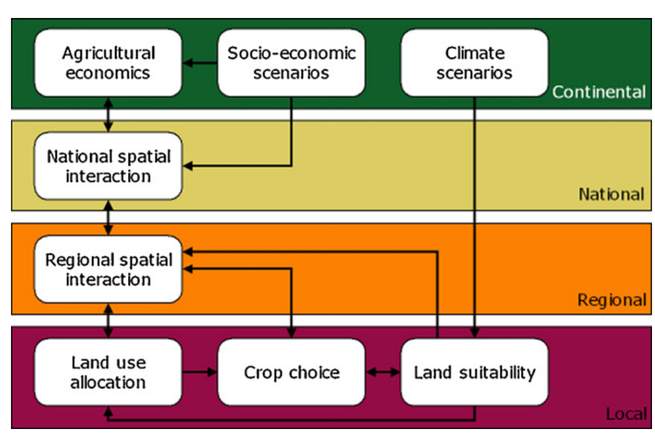

Fig. 1. System diagram of the LUMOCAP PSS. Arrows represent the flows of information between model components.