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Neutral models of landscape change as benchmarks in the assessment of model performance

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ABSTRACT

This paper introduces a methodological framework for performance assessment of spatial dynamic models by means of map comparison. The objective is to discern to what extent model performance, expressed by a variety of metrics, can be attributed to endogenously modeled processes or to exogenous model inputs. For this purpose, neutral models of landscape change are introduced that are subject to the same boundary conditions and constraints as the probed model, but otherwise are random except for a reluctance to change. The neutral models serve as benchmark and the difference in performance with the model under investigation can be attributed to the endogenous qualities of the model. Furthermore, the framework makes performance measures over multiple criteria and scales mutually comparable, thus providing insight in strengths and weaknesses of the model.

The framework is applied for the performance assessment of a Constrained Cellular Automata land use model for La Réunion (Fr.). Map comparison metrics of land use presence and structure are evaluated at multiple scales. For criteria of land use presence the land use model outperforms the neutral models only at coarse scales, but for criteria of land use structure it performs better on all scales.

1. Introduction

Assessing model performance is a continuous challenge for modelers of landscape dynamics. A common approach is historical validation (Rykiel, 1996) where a predicted map is compared to an actual map. Recently, numerous map comparison methods have been proposed that take into account the spatial relation between cells, as opposed to simple cell-by-cell overlap. These new methods consider for example proximity (Fewster and Buckland, 2001; Hagen-Zanker et al., 2005; Kuhnert et al., 2005), the presence of recognizable structures, i.e. features (Ebert and McBride, 2000; Power et al., 2001) and information contained at different scales, whereby coarser scales are found by aggregation (Costanza, 1989; Pontius et al., 2004; Remmel and Csillag, 2006), moving windows (Hagen-Zanker, 2006; Pijanowski et al., 2002) or wavelet decomposition (Briggs and Levine, 1997; Zepeda-Arce et al., 2000). Others have evaluated model performance on the basis of metrics summarizing the whole landscape (Barredo and Demicheli, 2003; Turner et al., 1989; White et al., 1997).

The diversity of these methods and their possibly conflicting outcomes calls for a methodological framework to apply them in a coherent fashion. This paper seeks to answer the following questions:

(1) How can diverse metrics of model goodness-of-fit be mutually compared to indicate strengths and weaknesses of the evaluated model?
(2) To what extent must goodness-of-fit be attributed to modeled processes or to boundary conditions and constraints?

The second question may seem more abstract, but in fact refers to a real and persistent problem; It is not uncommon for land use models to attain a percentage correct of about 95%, but this ‘very good performance’ is then due to the fact that the landscape at the end of the simulation period is largely identical to the given initial situation. Another common constraint on land use models is the total area per land use class. This is applied when in fact the model is not intended to represent the change in area (quantity) of land use classes, but only the spatial distribution. The exogenously imposed areas per land use class will influence model accuracy, regardless of the adequacy of the modeled processes. These issues have been only partially addressed before in studies that account for the impact of the initial situ-

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ation, but not for other constraints (Hagen, 2003; Pontius et al., 2004).

Neutral landscape models that are common in landscape ecological studies, may be useful to this problem. Neutral models are algorithms that create landscape patterns in absence of specific processes (With and King, 1997). Comparison of the performance of the investigated model to that of neutral models can help determining to what extent the model performance must be attributed to processes that are absent in the neutral model.

'Textbook' neutral landscape models (Turner et al., 2001, chapter 6) are not appropriate as reference for dynamic models however. These models create a landscape starting from a blank or randomized initial situation and therefore cannot account for the effect of the initial situation. A recent extension to neutral landscape models (Gardner and Urban, 2007) applies a mask to separate the landscape in static (not changing) and dynamic (changing) region. In that extension, however, the landscape in the dynamic region is still created from a blank initial situation and the model is therefore not adequate for the purpose of this paper either.

To resolve this shortcoming, this paper introduces a new class of neutral landscape models: *neutral models of landscape change*. These models do not create a landscape from a blank initial situation, but instead modify an existing initial landscape. These models are subject to the same boundary condition and constraints as the probed model and therefore pose an adequate reference level. Turner (1987) and Pontius et al. (2007) provide earlier applications of simple models of landscape change as benchmarks for more complex ones.

The evaluated model in the case study is a Constrained Cellular Automata (CCA) land use model (Engelen et al., 2003; White et al., 1997; White and Engelen, 1993) calibrated for the island La Réunion. The comparison methods used within the framework combine the wavelet decomposition approach of Briggs and Levine (1997) with the structure indicator maps of Hagen-Zanker (2006). This is the first application where these two approaches are combined. This combination is particularly suited to test and demonstrate the methodological framework since it presents diverse indicators of model performance at multiple scales.

2. Methods

2.1. General procedure

The performance of spatial models is assessed by running them for a period in the past and comparing the output of the model to reality. Model and reality are compared on a number of criteria that are evaluated at multiple scales. These diverse indicators of model performance are normalized to the real change that occurred over the simulation period, measured according to the same criteria. This means of normalization reflects the need to account for persistence already observed by Tobler (1970) and is inspired by recent findings of Pontius et al. (2008) that model performance correlates strongly with the amount of change over the simulation period.

The comparison is not just made for the evaluated model, but also for one or more neutral models of landscape change. These models are subject to the same boundary conditions and constraints as the evaluated model. Otherwise the neutral models are conservative, which means that they minimize change. What constitutes minimal change remains ambiguous, therefore multiple neutral models of landscape change may be applied. The model performance is expressed relative to that of the neutral models of landscape change.

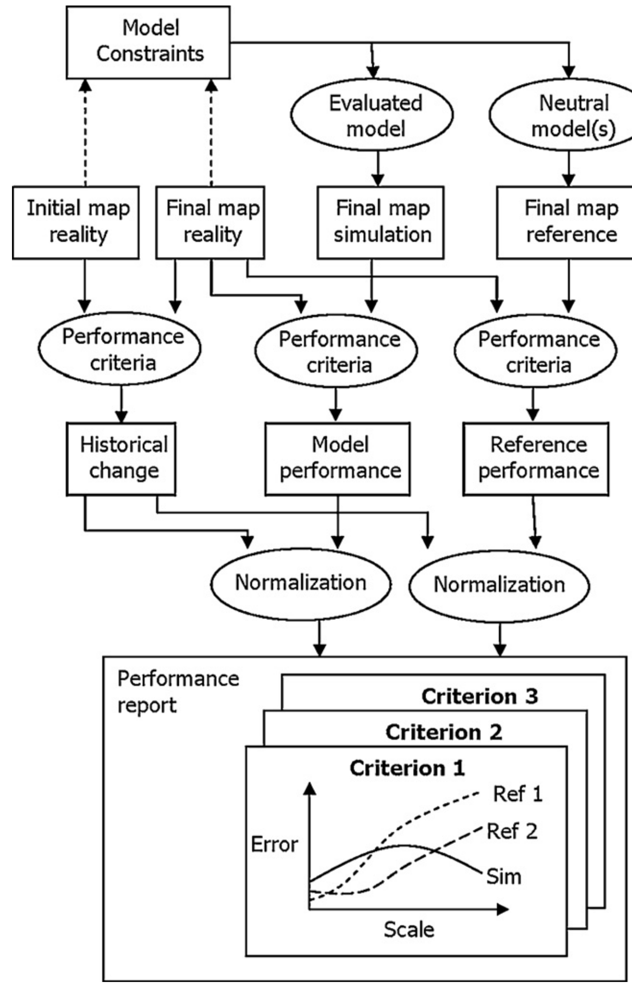

Fig. 1. Flowchart of model performance evaluation. The dashed lines indicate that model constraints are not necessarily based on the initial and final map of reality, but in the current case they are.

Fig. 1 presents a flowchart of the general procedure. The specific neutral models, performance criteria and means of normalization that are applied in this paper are given in the following sections.

2.2. Neutral models of landscape change

This section introduces two neutral models of landscape change. Both neutral models modify the initial map to the effect that it has the same composition (total area per class) as the simulated map. This is the same constraint that is also applied in the evaluated model. Both neutral models follow the notion of changing as little as possible, the difference is that the random constraint match model places change at randomly selected locations, whereas the growing clusters model also places new cells of a class adjacent to existing cells of that class.

Pseudo code of both models is given in Appendix A.

2.2.1. Neutral model: random constraint match

The random constraint match model finds locations of change randomly and evolves towards a 'speckled' map of small clusters.

The model first assesses for each class how many cells it is under- or overrepresented in the initial map relative to the constraints. For each overrepresented class it then randomly selects the surplus cells on the initial map. Then, the underrepresented classes are randomly distributed over the selected cells on the initial map.