

Comparison of simulation models in terms of quantity and allocation of land change



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ARTICLE INFO

Article history:

Received 25 February 2014

Received in revised form

3 November 2014

Accepted 4 November 2014

Available online 21 April 2015

Keywords:

Quantity and allocation

Assessment

Validation

Land Change Model

Land use and cover change (LUCC)

ABSTRACT

Our article illustrates how to compare the outputs from models that simulate transitions among categories through time. We illustrate the concepts by comparing two land change models: Land Change Modeler and Cellular Automata Markov. We show how the modeling options influence the quantity and allocation of simulated transitions, and how to compare output maps from pairs of model runs with respect to a reference map of transitions during the validation interval. We recommend that the first step is to assess the quantity of each transition and to determine the cause of the variation in quantity among model runs. The second step is to assess the allocation of transitions and to determine the cause of the variation in allocation among model runs. The separation of quantity and allocation of the transitions is a helpful approach to communicate how models work and to describe pattern validation.

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1. Introduction

Land Change Models can be useful tools for environmental and geomatics research concerning land use and cover change (LUCC) (Paegelow et al., 2013). The simulation maps obtained from LUCC models help us to understand, forecast and anticipate the future evolution for a variety of applied environmental problems. One of the most important challenges is to clarify the validity of the outputs from the models.

A study area's rate and pattern of LUCC can influence a simulation's accuracy. If the real transitions among land categories constitute a small portion of the study area, then it can be difficult to predict the changes accurately, especially when the data have errors (Pontius et al., 2008; Pontius and Petrova, 2010). Furthermore, if the changes during the calibration interval are not stationary with the changes during the validation interval, then an extrapolation from the calibration interval to the validation interval will probably have systematic errors (Pontius and Neeti, 2010). Moreover, land changes involve complex processes that are shaped

by dynamic, non-linear human-nature interactions, which can be difficult for available variables and algorithms to capture (Pérez-Vega et al., 2012; Kolb et al., 2013).

The choice of the model is a subject of debate concerning the validation of models (Villa et al., 2007; Paegelow and Camacho Olmedo, 2008; Pontius et al., 2008; Fuller et al., 2011; Mas et al., 2011; Wang and Mountrakis, 2011; Sinha and Kumar, 2013). Some research attempts to test whether one model is more accurate than another model. However, a single model can create various outcomes depending on how the user chooses the model's parameters. If the choice of the parameters within a single model produces greater variation in accuracy than the choices among alternative models, then it makes little sense to report that one model is more accurate than another model (Pontius and Malanson, 2005). Model comparison can be challenging, because each model offers a variety of choices at each stage in a modeling application.

Our article concerns how to compare the outputs from models that simulate transitions among categories over time. We illustrate the concepts by comparing two models in the Selva version of the Idrisi software (Clark Labs 2006, 2010; Eastman, 2009). The models are Land Change Modeler (LCM) and Cellular Automata Markov (CA_MARKOV). For a comparison between the two models and also

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with other models, see Paegelow and Camacho Olmedo (2008) and Mas et al. (2014). For applications of LCM, see Aguejidad and Houet (2008), Dang Khoi and Murayama (2010), Fuller et al. (2011) and Sangermano et al. (2012). For applications of CA_MARKOV, see Paegelow and Camacho Olmedo (2005), Shirley and Battaglia (2008), Kamusoko et al. (2009), Mobaied et al. (2011), Behera et al. (2012), Memarian et al. (2012) and Nejadi et al. (2012). Our goals are to show: (1) how the modeling options influence the quantity and allocation of simulated changes, and (2) how to compare output maps from pairs of model runs with respect to a reference map of change during the validation interval.

2. Methods

2.1. Data

The study area is in Spain's Segura River Basin, which has undergone profound territorial and economic transformations in recent decades. The primary change by far has been the transition from rainfed crops to irrigated crops. This transition is driven by the development of water-related infrastructures and the increase in the water supply (Gómez and Grindlay, 2008; Gómez Espín et al., 2011). A secondary change has been urban growth, which is driven by the development of transportation and communication infrastructures.

Fig. 1 shows the specific study area, which consists of 2300 square kilometers in the Murcia province. The maps of land use and cover have four categories from the Corine Land Cover dataset: 1 Urban, industrial and transport uses; 2 Natural vegetation, unproductive land and water; 3 Irrigated crops; 4 Rainfed crops. The remainder of this article refers to these categories as: Urban, Natural, Irrigated, and Rainfed. Corine maps at 1990 and 2000 are used for model calibration. The calibrated model then simulates change from 2000 to 2006. The simulation output at 2006 and the Corine maps at 2000 and 2006 are used to validate the simulated changes.

Table 1 gives the Corine LUCC budget for the calibration and validation intervals (Pontius et al., 2004). The budget reflects the fact that the largest transition during both intervals is from Rainfed to Irrigated. Rainfed accounts for the vast majority of losses during both intervals. Irrigated accounts for the vast majority of gains during both intervals. Urban accounts for most of the remaining gains. Nearly all of the change is net change, as opposed to swap change.

2.2. Components of models

2.2.1. Quantity of change

LCM and CA_MARKOV use a Markov matrix to extrapolate the quantity of each simulated transition. The MARKOV module in the Idrisi software computes a Markov

matrix based on the maps at the two time points that define the calibration interval. The rows of the matrix show the host categories at the time point t_0 and the columns show the claimant categories at the time point t_1 . The Markov matrix records the proportion of each host category at time t_0 that transitions to a claimant category at time t_1 . Persistence of each category is shown in a diagonal entry of the matrix. Changes are in the off-diagonal entries of the matrix. The calibrated matrix is then used to extrapolate the quantity of each simulated transition beyond time t_1 . If the duration of the calibration interval is equal to the duration of the validation interval, then the application of the Markov matrix is a straightforward application of matrix multiplication.

For our case study, the calibration interval is ten years from $t_0 = 1990$ to $t_1 = 2000$, while the validation interval is six years from $t_1 = 2000$ to $t_2 = 2006$. Table 2 shows how Idrisi accounts for this difference in durations. For each Markov entry, Idrisi interpolates a curve from t_1 to $t_1 + (t_1 - t_0)$, which means in our case from 2000 to 2010. The interpolated curve allows Idrisi to compute the proportion at any year between t_1 and $t_1 + (t_1 - t_0)$. For example, Table 2 shows that the proportion of Rainfed transition to Irrigated during 2000–2010 is 0.2525, which is set to be identical to the proportion during the decade of the calibration interval. The interpolated curve is then used to compute the proportion at any year between 2000 and 2010. For example, the proportion at the year 2006 is 0.1696. A more detailed description of the MARKOV module is in the Idrisi Selva Help System, Mas et al. (2011, 2014) and Sinha and Kumar (2013).

2.2.2. Allocation of change

The Markov extrapolation specifies the target number of pixels for transition during the validation interval, then LCM and CA_MARKOV allocate those transitions spatially within the study area. To accomplish the allocation, both models use maps that specify the priority for each pixel to experience gain of a particular claimant category.

LCM uses a transition potential map for each group of transitions in order to allocate the simulated transitions. Table 3 shows how we placed the transitions into four groups. For example, the first group is called urban gain, which contains three transitions to Urban. Table 3 shows seven transitions of the possible twelve transitions among four categories. We ignore five small transitions. Specifically, we assume that Urban never loses and that Irrigated never transitions to Natural or Rainfed. LCM uses a multi-layer perceptron (MLP) to create a transition potential map for each transition group (Eastman et al., 2005). The MLP reads maps of independent variables and maps of the transitions during the calibration interval to produce a map of transition potential for each group. Our independent variables are topographic variables, protected areas, distance to irrigation canals, and accessibility to roads and human settlements. CA_MARKOV uses a suitability map for each claimant category in order to allocate the simulated transitions. We used multi-criteria evaluation (MCE) and the same independent variables to create one suitability map for each of the four categories (Eastman et al., 1995).

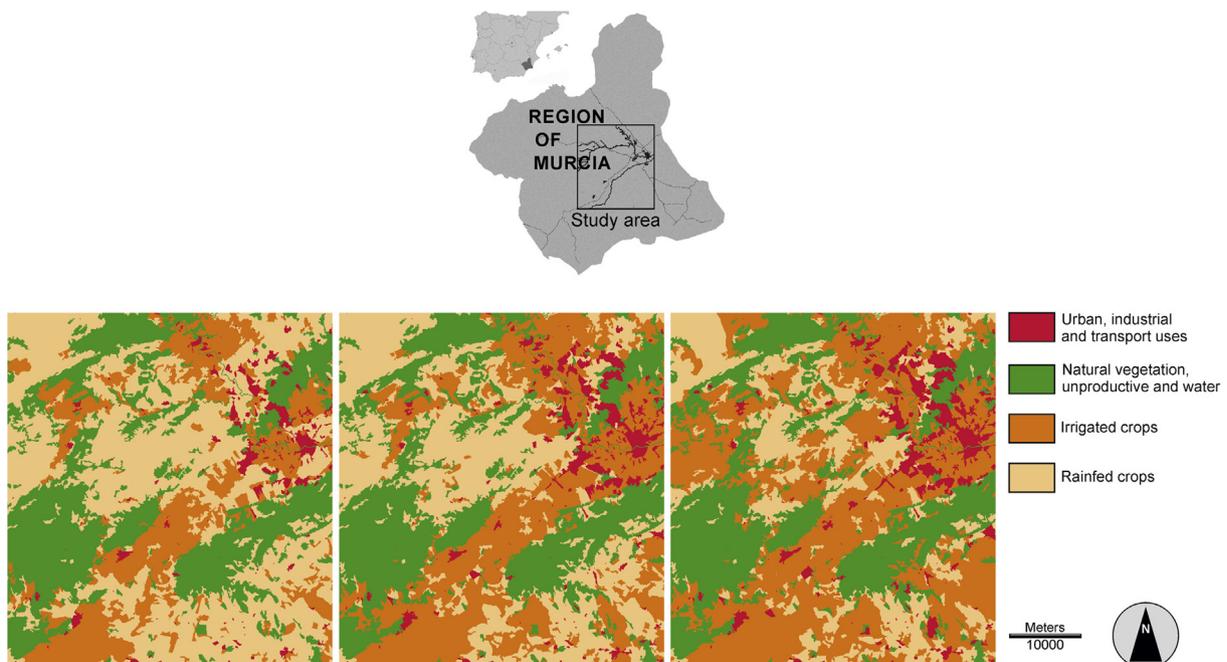


Fig. 1. Land categories at 1990 on left, at 2000 in middle and at 2006 on right in southern Spain. Source: Corine Land Cover.

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