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Review

Divergent projections of future land use in the United States arising from different models and scenarios

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ABSTRACT

A variety of land-use and land-cover (LULC) models operating at scales from local to global have been developed in recent years, including a number of models that provide spatially explicit, multi-class LULC projections for the conterminous United States. This diversity of modeling approaches raises the question: how consistent are their projections of future land use? We compared projections from six LULC modeling applications for the United States and assessed quantitative, spatial, and conceptual inconsistencies. Each set of projections provided multiple scenarios covering a period from roughly 2000 to 2050. Given the unique spatial, thematic, and temporal characteristics of each set of projections, individual projections were aggregated to a common set of basic, generalized LULC classes (i.e., cropland, pasture, forest, range, and urban) and summarized at the county level across the conterminous United States. We found very little agreement in projected future LULC trends and patterns among the different models. Variability among scenarios for a given model was generally lower than variability among different models, in terms of both trends in the amounts of basic LULC classes and their projected spatial patterns. Even when different models assessed the same purported scenario, model projections varied substantially. Projections of agricultural trends were often far above the maximum historical amounts, raising concerns about the realism of the projections. Comparisons among models were hindered by major discrepancies in categorical definitions, and suggest a need for standardization of historical LULC data sources. To capture a broader range of uncertainties, ensemble modeling approaches are also recommended. However, the vast inconsistencies among LULC models raise questions about the theoretical and conceptual underpinnings of current modeling approaches. Given the substantial effects that land-use change can have on ecological and societal processes, there is a need for improvement in LULC theory and modeling capabilities to improve acceptance and use of regional- to national-scale LULC projections for the United States and elsewhere.

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1. Introduction

Projections of future land-use and land-cover (LULC) change are useful for scientists, decision-makers, and other stakeholders who want to understand the effects of LULC change on societal and ecological issues. In recent years, there has been an explosion in both the creation and application of LULC models, operating at scales from local to global. Among these efforts, there are many more local- and regional-scale LULC projections than there are national-scale applications, due to difficulties in producing moderate-to fine-resolution, spatially explicit, multi-class LULC projections for large areas. However, several spatially explicit LULC projections have been produced in recent years for the conterminous United States (Theobald, 2005; Bierwagen et al., 2010; Wear, 2011; Radeloff et al., 2012; Sohl et al., 2014), plus several global-scale projections that include coverage of the United States. (Strengers et al., 2004; Fujino et al., 2006; Van Vurren et al., 2007; Clarke et al., 2007; Riahi et al., 2007; Hurtt et al., 2011; Kram and Stehfest 2012; West et al., 2014). Projections of future LULC can enable land managers to visualize future landscapes and optimize landscape planning to account for potential effects on a variety of ecological and social processes (Heistermann et al., 2006), and results from these models have been used to assess biodiversity (Theobald, 2005; Sohl, 2014; Martinuzzi et al., 2013), hydrology (Viger et al., 2011; Martinuzzi et al., 2014), carbon and biogeochemistry (Zhao et al., 2013; Tan et al., 2015), many other ecosystem services (Lawler et al., 2014), and the emergence of novel ecosystems (Martinuzzi et al., 2015) at scales from local to national.

Among current LULC models and projections there is considerable variability in terms of their conceptual underpinnings, scenario frameworks, thematic foci, spatial characteristics, and modeling methodologies. Unfortunately, assessment of different models and modeling approaches is difficult. The lack of reference data for future time periods means that direct validation of LULC models is impossible, and even the quantification of uncertainties in future projections is notoriously difficult (Dendoncker et al., 2008). The complexity, variability, and lack of quantification (or communication) of uncertainty have caused a situation where the LULC models themselves are becoming common, but their actual application for decision-making has been lacking (Couclelis, 2005; Zellner, 2008; TeBrommelstroet, 2010; Sohl and Claggett, 2013). Model comparison provides an alternative means for quantifying uncertainty, based on the assumption that confidence in predictions should increase with their consistency across multiple models, and also provides insights into the sensitivity of model outputs to model structure and parameterization (Rastetter, 2003). Schmitz et al. (2014) used such an approach to compare future global trajectories of cropland change projected by 10 different agro-economic land use change models.

In the current study, our goal was to review and compare spatially explicit LULC projections available for the conterminous United States. This continental focus allowed us to explore projected changes for multiple LULC classes, examine the spatial patterns of these projected changes, and assess potential conceptual and methodological issues with current LULC models.

2. Data and methods

We analyzed publicly available spatially explicit LULC projections covering the conterminous United States (CONUS) (Table 1). Four available sets of projections were specifically designed to model CONUS LULC change. The FORE-SCE projections (named for the use of the FOREcasting SCEnarios of land-use change model) employed a story-and-simulation approach (Alcamo et al., 2006) to produce four spatially explicit LULC scenarios as part of a U.S. Geological Survey project assessing carbon impacts of LULC change (Sleeter et al., 2012; Sohl et al., 2014). Lawler et al. (2014) used an econometric approach (hereafter referred to as the “NRI Econometric Model”, due to the model’s reliance on National Resources Inventory data (Nusser and Goebel, 1997) for model parameterization) to model two baseline and three policy scenarios, and then assess LULC impacts on ecosystem services. The U.S. Forest Service used a similar econometric model to produce three county-based LULC scenarios as part of the Resources Planning Act (RPA) 2010 assessment (Wear, 2011) (referred to as the “FS-RPA” hereafter). The Integrated Climate Land Use Scenario (ICLUS) projections used a demographic growth model coupled with a spatial allocation model (Spatially-Explicit Regional Growth Model (SERGoM); Theobald, 2005) to generate urban land-use scenarios consistent with the Intergovernmental Panel on Climate Change (IPCC’s) Special Report on Emissions Scenarios (SRES) storylines (Bierwagen et al., 2010).

At the global scale, integrated assessment models (IAMs) have been used to model LULC interactions with climate and socioeconomic driving forces, typically at coarse spatial resolutions with 0.5° or larger grid cells. Scenarios of LULC change for the United States were extracted from four sets of global projections based on IAMs. The Integrated Model to Assess the Global Environment (IMAGE 2.2; Strengers et al., 2004) was used to create global LULC projections consistent with storylines of the SRES (Nakicenovic and Swart, 2001) as part of the IPCC’s Fourth Assessment report (AR4). An updated IMAGE 2.4 model was used to produce global LULC projections for the OECD Environmental Outlook to 2050 (Kram and Stehfest, 2012; OECD, 2012) (referred to as the “OECD” scenarios hereafter). As with the IPCCs AR4 report, four different global integrated assessment models (IAMs) (Smith and Wigley, 2006; Riahi et al., 2007; Van Vurren et al., 2011; Hijoka et al., 2008) were used to address LULC change for the four Representative Concentration Pathways (RCP) scenarios (Moss et al., 2010) as part of the IPCC Fifth Assessment report (AR5). Hurtt et al. (2011) used these projections and the History Database of the Global Environment (HYDE) LULC database (Goldewijk et al., 2011) to produce harmo-