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Neutral models as a way to evaluate the Sea Level Affecting Marshes Model (SLAMM)

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ABSTRACT

A commonly used landscape model to simulate wetland change – the Sea Level Affecting Marshes Model (SLAMM) – has rarely been explicitly assessed for its prediction accuracy. Here, we evaluated this model using recently proposed neutral models – including the random constraint match model (RCM) and growing cluster model (GrC), which consider the initial landscape conditions instead of starting with a blank or randomized initial map as traditional neutral models do. Thus, the SLAMM's performance, due to processes accounted for in the model, could be more accurately assessed. RCM allocates change randomly in space, while in the GrC, change allocation is prioritized at the locations with pairs of to-be-increased land type and to-be-reduced land type adjacent to each other. The metrics we applied to evaluate the SLAMM vs. the neutral models accounted for five main components in map comparison: (1) reference change simulated correctly as change (hits), (2) reference persistence simulated correctly as persistence (correct rejections), (3) reference change simulated incorrectly as change to the wrong category (wrong hits), (4) reference change simulated incorrectly as persistence (misses), and (5) reference persistence simulated incorrectly as change (false alarms). These methods improved the way that we currently evaluate land change models, where we either do not compare to a neutral model, or the neutral model does not have the same boundary conditions and constraints as the assessed dynamics models. The results showed that the SLAMM could simulate wetland change more accurately compared to the GrC and RCM at a 10-year time step for the lower Pascagoula River basin, Mississippi, with higher hits and correct rejections, and lower misses and false alarms. The magnitude of simulated changes using the SLAMM was 46% of reference changes. The number of wrong hits for the SLAMM was also lower than those for the neutral models after combining some land or water types into broader categories. After the aggregation, the SLAMM performance improved substantially. How the errors of this relatively short-term simulation propagate into longer-term predictions requires further investigation. This study also showed the importance of implementing elevation data with high vertical accuracy, and conducting local calibration when we apply the SLAMM.

1. Introduction

Coastal wetlands are dynamic landforms that are subject to changes due to factors from the upland and the ocean. One of the most important of these factors is accelerated relative sea-level rise (RSLR). RSLR is driven by a myriad of geological and climatological processes, including the melting of ice sheets, the thermal expansion of water as a result of global warming, and the subsidence of the marsh surface due to sediment compaction or tectonic processes. Coastal wetlands can become submerged and will disappear if marsh surface vertical accretion rates do not keep up with the rising rates of relative sea level; thus, are potentially vulnerable to accelerated RSLR. Wetland losses can detrimentally impact coastal ecosystems by increasing their vulnerability to storm surge and flooding (e.g., Lee et al., 1992; Nicholls et al., 1999; Zhang et al., 2012; Barbier et al., 2013), coastline retreat, changes in nutrient cycling (e.g., Bruland, 2008; Perez et al., 2011; Ardón et al., 2013), declines in net primary and secondary productivity (Day et al., 1997; Martin et al., 2000), salt water intrusion (Warne and Stanley, 1993; Martin et al., 2000; Day, 2005), fluctuations

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in species composition (Deegan and Thompson, 1985; Martin et al., 2000), habitat loss for fisheries and wildlife, and loss of recreational, aesthetic and ecosystem service values (e.g., Costanza et al., 2008; Engle, 2011; Jordan and Peterson, 2012).

Predicting how coastal wetlands respond to RSLR is not only of scientific interest due to the complexity of physical, chemical and biological processes and interactions involved in coastal wetland evolution (Wiegert et al., 1981), but is also important for policy making and resource management. Therefore, a suite of models have been developed for this purpose (e.g., Morris and Bowden, 1986; Park et al., 1989; Costanza et al., 1990; Martin et al., 2000; Reyes et al., 2000; Morris et al., 2002; D'Alpaos et al., 2007; Kirwan and Murray, 2007; Mudd et al., 2009; Ross et al., 2009; Stralberg et al., 2011; Fagherazzi et al., 2012; Rogers et al., 2012; Hagen et al., 2013; Schile et al., 2014). These models vary in structure, complexity and ease of application. Simpler models capture the key characteristics of wetland dynamics empirically, require fewer data, and are easily applied, but interaction and feedback of geomorphological and ecological processes are missing (Kirwan and Guntenspergen, 2009). More complicated models account for the important interactions and feedback among vegetation, sediment, hydrology and sea level mechanistically, but generally require more data, and are difficult to implement, especially at broader spatial scales (e.g., Martin et al., 2000; Reyes et al., 2000).

The Sea Level Affecting Marshes Model (SLAMM) is a landscape model that simulates the dominant processes involved in wetland conversions and shoreline modifications during long term sea-level rise, including inundation, erosion, overwash, vertical accretion, salinity, and soil saturation (Clough et al., 2010). It has been used by government agencies, including the U.S. Environmental Protection Agency (EPA) (Park et al., 1989; Park, 1990) and U.S. Fish and Wildlife Service (Clough, 2010; Clough and Larson, 2009), conservation organizations, including the Nature Conservancy and National Wildlife Federation (Glick et al., 2007, 2010), and academic researchers (Craft et al., 2009; Geselbracht et al., 2011; Chu-Agor et al., 2010). The SLAMM is commonly used because: (1) it is open source and has a well-designed interface for implementation; (2) it implements empirical calculations so that computation time is substantially decreased, compared to those models using direct calculation based on mechanisms (Costanza et al., 1990; Reyes et al., 2000; Martin et al., 2002; Fagherazzi et al., 2012), and (3) a relatively small amount of publically available data are required to run the model. The SLAMM has, however, rarely been explicitly evaluated as to how accurately it can simulate wetland change before it is applied to predict future wetland change. One explicit evaluation was performed for the SLAMM 2 at Pelican Pass, Louisiana using 1973 data to simulate the landscapes for 1986 (13-year simulation). The results were compared to the "observed" landscapes derived from a 1986 Landsat MSS image (Park et al., 1991), with predictions within 1% of those "observed" (Park et al., 1991; Lee et al., 1992).

Assessment of landscape models generally requires comparison of model simulations and observations (reference map) (e.g. Pontius et al., 2004, 2007, 2008, 2011). Both two-map and three-map comparisons have been applied. The simulated land cover of the whole landscape is generally very similar to the actual land cover, no matter how accurately a model simulates changes, as the changes only apply to a small portion of the whole area, known as persistence. A two-map comparison, comparing the reference map and simulated map at the end of the simulation, generally leads to an illusion of high accuracy simply due to land cover persistence. Accounting for persistence provides insights on how a model actually performs in simulating changes. A three-map comparison, involving the reference map at the start of the simulation, the reference map at the end of the simulation, and the simulation map at the end of the simulation, can reveal the accuracy of the land change model vs. a null model that predicts complete persistence (Brown et al., 2013).

Neutral models are useful tools for testing the effect of a particular modeled process on observed patterns (Caswell, 1976), as they create landscape patterns in the absence of specific processes (Pontius et al., 2004; Hagen-Zanker and Lajoie, 2008). Comparisons between a landscape model and a neutral model simulation will provide insights into how processes that are in the landscape model but are absent from the neutral model, affect the model performance.

Traditional neutral models (Turner et al., 2001; Gardner and Urban, 2007) create a landscape from a blank or randomized initial map, without accounting for the initial land cover. Therefore, the generated landscape is not an appropriate reference map for dynamic models that do consider the prior information. More appropriate neutral models have been suggested by Hagen-Zanker and Lajoie (2008), which modify an existing initial landscape subject to the same boundary conditions and constraints as dynamic models, and take into consideration spatial adjacency.

In this study, we aim to evaluate how well the SLAMM predicts wetland change by comparing the model outputs with those from the neutral models, accounting for the sustained land from the initial map. We discuss the error sources of the SLAMM and how the errors in the decadal simulation propagate to longer-term predictions. We also offer suggestions as to how we should apply the SLAMM to make its wetland predictions more informative.

2. Methods and data

2.1. Study area

Our study area is the lower Pascagoula River basin, which is located in south-eastern Mississippi, USA, and is a micro-tidal estuary with a mean tidal range of 46 cm (Christmas, 1973, p. 26) (Fig. 1). The eastern distributary of the Pascagoula River has experienced more intense anthropogenic disturbance, is bordered by a large shipyard and is regularly dredged to allow for commercial shipping traffic. In contrast, the western distributary has experienced little anthropogenic modification and contains large areas of coastal wetlands dominated by *Juncus roemerianus* and *Spartina alterniflora* (Peterson et al., 2007). The Pascagoula watershed contains about 35% of the total marsh habitat in coastal Mississippi (MDEQ, 2001).

2.2. SLAMM simulation

We applied the SLAMM version 6.2 to predict the wetland landscape in 2007, based on the baseline wetland map of 1996. The spatial data required for the SLAMM include: elevation, slope, initial wetland, and optional dike maps. We downloaded LiDAR-derived elevation data from 2005, with a vertical accuracy of 12 cm (NAVD88 datum), and ground horizontal resolution of 4 m, from the Coastal Service Center (http://www.csc.noaa.gov/dataviewer, last accessed February 18, 2014). The data were provided by the Mississippi Department of Environmental Quality (MDEQ). The LiDAR collection surveys were conducted prior to hurricane Katrina and were intended for flood studies. Pre-Katrina LiDAR data, instead of post-Katrina LiDAR data, were chosen as they were the elevation data available closest to 1996, before Katrina (made landfall in southeast Louisiana on August 29, 2015), therefore would better represent elevation for 1996 when our initial wetland map was obtained. Storm impacts on coastal wetlands were simulated in overwash processes in the SLAMM. A slope map was produced from the elevation data using the "surface function" in ArcGIS 10.1 (ESRI