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A spectral clustering search algorithm for predicting shallow landslide size and location

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Key Points:

- A general deterministic search algorithm predicts discrete shallow landslides
- Size, shape, and location of synthetic and observed landslides are reproduced
- Many failure shapes possible at a site, local variations define which occurs

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Abstract The potential hazard and geomorphic significance of shallow landslides depend on their location and size. Commonly applied one-dimensional stability models do not include lateral resistances and cannot predict landslide size. Multidimensional models must be applied to specific geometries, which are not known a priori, and testing all possible geometries is computationally prohibitive. We present an efficient deterministic search algorithm based on spectral graph theory and couple it with a multidimensional stability model to predict discrete landslides in applications at scales broader than a single hillslope using gridded spatial data. The algorithm is general, assuming only that instability results when driving forces acting on a cluster of cells exceed the resisting forces on its margins and that clusters behave as rigid blocks with a failure plane at the soil-bedrock interface. This algorithm recovers predefined clusters of unstable cells of varying shape and size on a synthetic landscape, predicts the size, location, and shape of an observed shallow landslide using field-measured physical parameters, and is robust to modest changes in input parameters. The search algorithm identifies patches of potential instability within large areas of stable landscape. Within these patches will be many different combinations of cells with a Factor of Safety less than one, suggesting that subtle variations in local conditions (e.g., pore pressure and root strength) may determine the ultimate form and exact location at a specific site. Nonetheless, the tests presented here suggest that the search algorithm enables the prediction of shallow landslide size as well as location across landscapes.

1. Introduction

Shallow landslides generally involve only the colluvial soil mantle (less than a few meters deep) and are often translational, failing along a quasi-planar surface [e.g., *Rogers and Selby*, 1980; *Lehre*, 1982; *Glade*, 1998; *Robison et al.*, 1999; *Guimaraes et al.*, 2003; *Baum et al.*, 2005; *Chigira and Yagi*, 2006]. Often triggered by extreme precipitation events, they can be the primary sources of debris flows, which sweep downslope with the capability to destroy property and cause loss of life (see review in *Sidle and Ochiai* [2006]). Shallow landslides also play an important role in landscape evolution. They are a primary cause of erosion in steep landscapes, and when mobilized as debris flows can carve valley networks [e.g., *Dietrich and Dunne*, 1978; *Benda and Dunne*, 1997; *Stock and Dietrich*, 2006]. The linkages between shallow landslides and debris flow initiation are complex, as a landslide may (a) mobilize as a debris flow, (b) trigger a debris flow upon entering a headwater channel, (c) transport sediment into channel heads and channels and only subsequently cause a debris flow, or (d) make sediment available on the hillslope to future hydrogeomorphic events [*Sidle and Ochiai*, 2006]. While the details of these processes may not be completely understood, two key characteristics that determine the importance of a shallow landslide, both in terms of hazard and geomorphic significance, are its location and size. Location and size affect the amount of sediment that is mobilized, the distance that the landslide debris then travels, the potential for mass gain (bulking up) or loss in transit, and the scale of local morphological change [*Benda and Cundy*, 1990; *Fannin and Wise*, 2001]. Moreover, *Hungr et al*. [2008] suggest that the volume of a shallow landslide controls the extent of the hazard area, the intensity of impact within it and the vulnerability of elements at risk. Location and size together thus determine the downslope effects, particularly the potential hazard for people and property.