Landscape Evolution Modelling - LAPSUS

J.E.M. Baartman, A.J.A.M. Temme, J.M. Schoorl, L. Claessens, W. Viveen, W. van Gorp and A. Veldkamp

Wageningen University, Land Dynamics Group, P.O. Box 47, 6700 AA Wageningen, The Netherlands. E-mail: jantiene.baartman@wur.nl

ABSTRACT

Landscape evolution modeling can make the consequences of landscape evolution hypotheses explicit and theoretically allows for their falsification and improvement. Ideally, landscape evolution models (LEMs) combine the results of all relevant landscape forming processes into an ever-adapting digital landscape (e.g. DEM). These processes may act on different spatial and temporal scales. LAPSUS is such a LEM. Processes that have in different studies been included in LAPSUS are water erosion and deposition, landslide activity, creep, solifluction, weathering, tectonics and tillage. Process descriptions are as simple and generic as possible, ensuring wide applicability. Vegetation-effects can be included. Interactions between processes are turn-based: volumes of one process are calculated and used to update the DEM before another process starts. LAPSUS uses multiple flow techniques to model flows of water and sediment over the landscape. Though computationally costly, this gives a more natural result than steepest descent methods. In addition, the combination of different processes may create sinks during modelling. Since these sinks are not spurious, the model has been adapted to deal with them in natural ways. This is crucial for several purposes, for instance when studying damming of valleys by landslides, and subsequent infilling of the resulting lake with sediments from upstream.

Keywords: Landscape Evolution Modelling, LAPSUS, soil redistribution, erosion

INTRODUCTION

This extended abstract is merely a review of the work undertaken and developments into the future with the LAPSUS model. LAPSUS is a landscape evolution model (e.g. LEM erosion model) that combines the results of multiple landscape forming processes into one dynamic landscape. Spatial and temporal extent and resolution may vary from slope, catchment to basins, grids from 1 to 1000 m2, timesteps of multiple events, seasons, years, decades and simulation periods from years to millennial.

Interactions between processes are turn-based: volumes of one process are calculated and used to update the DEM before another process starts. Processes that have been included in LAPSUS are water erosion and deposition, landslide activity, creep, solifluction, physical weathering, frost weathering, tectonics and tillage (See Figure 1).

Process descriptions are as simple and generic as possible, ensuring wide applicability. Vegetation-effects are included to different degrees in different case studies. LAPSUS uses multiple flow techniques to model the flow of water and sediment over the landscape. This is computationally costly, but yields a more natural result than steepest descent methods, especially when combining multiple processes over multiple timesteps.

The combination of different processes may create sinks during modelling. Since these sinks are not spurious, the model has been adapted to deal with them in a natural way. This is crucial when studying damming of valleys by landslides, and subsequent infilling of the resulting lake with sediments from upstream.

RESULTS AND DISCUSSION

LAPSUS has been used for erosion and landscape evolution studies in many landscapes in many countries. LAPSUS has been founded in the year 2000 with the development, calibration and validation of the LAPSUS model and applications concerning land use in Spain and Ecuador (Schoorl et al., 2000, 2002, 2004, 2006; Schoorl and Veldkamp, 2001, 2006). Firstly, the model has been extended in order to cover the process of landsliding in New Zealand and Taiwan (Claessens et al., 2005, 2006a, 2006b, 2007a, 2007b). Secondly, issues of DEM resolution and the treatment of sinks and pits in the landscape have been investigated (Temme et al., 2006, 2009) as well as stretching the models time scale to landscape evolution time spans in South Africa (Temme and Veldkamp, 2009). Thirdly, different applications with specific processes have been developed, for example, the model has been used in regional nutrient balance studies in Africa (Haileslassie et al., 2005, 2006, 2007; Roy et al., 2004; Lesschen et al., 2005). aplying the model in desert environments of Israel (Buis and Veldkamp, 2008), using LAPSUS in combination with geostatistical tools and tillage in Canada (Heuvelink et al, 2006), investigating the faith of phosphor in the landscapes of the Netherlands (Sonneveld et al., 2006) and new developments concerning connectivity, agricultural terraces and land abandonment (Lesschen et al., 2007, 2009) and the processing of feedbacks between land use and soil redistribution (Claessens et al., 2009)

Figure 1. Overview of processes incorporated within the Lapsus modelling framework (see also www.lapsusmodel.nl)

CONCLUSIONS

Landscape evolution modelling allows for falsification and improvement of landscape evolution hypotheses and can make the consequences temporal and spatial explicit. Ideally, landscape evolution models (LEMs) combine the results of all relevant landscape forming processes into an ever-adapting digital landscape (e.g. DEM). These processes may act and interact on different spatial and temporal scales.

REFERENCES

❖ Buis, E. and A. Veldkamp, 2008. Modelling dynamic water redistribution patterns in arid catchments in the Negev Desert of Israel. *Earth Surface Processes and Landforms*, Volume 33, Issue 1, p. 107-122.

❖ Claessens, L., Lowe, D.J., Hayward, B.W., Schaap, B.F., Schoorl, J.M., and Veldkamp, A., 2006a, Reconstructing high-magnitude/low-frequency landslide events based on soil redistribution modelling and a Late-Holocene sediment record from New Zealand: *Geomorphology*, 74, p. 29-49.

❖ Claessens, L., Verburg, P.H., Schoorl, J.M., and Veldkamp, A., 2006b, Contribution of topographical based landslide hazard Modelling to the analysis of the spatial distribution and ecology of Kauri (Agathis australis): *Landscape Ecology* 21, p. 63 - 76.

❖ Claessens, L., Heuvelink, G.B.M., Schoorl, J.M., and Veldkamp, A., 2005, DEM resolution effects on shallow landslide hazard and soil redistribution modelling. Earth Surface Processes and Landforms, volume 30, p. 461-477.

❖ Claessens, L., A. Knapen, M.G. Kitutu, J. Poesen and J.A. Deckers. 2007. Modelling landslide hazard, soil redistribution and sediment yield of landslides on the Ugandan footslopes of Mount Elgon. *Geomorphology* Volume 90 (Issues 1-2), p 23 - 35.

❖ Claessens, L., Schoorl, J.M., and Veldkamp, A., 2007, Modelling the location of shallow landslides and their effects on landscape dynamics in large watersheds: an application for Northern New Zealand: *Geomorphology*, Volume 87, Issues 1-2, p 16 - 27.

❖ Claessens, L., J.M. Schoorl, P.H. Verburg, L. Geraedts and A. Veldkamp 2009. Modelling interactions and feedback mechanisms between land use change and landscape processes. *Agriculture, Ecosystems and Environment* 129 (1-3) 157-170.

❖ Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D. and J.P. Lesschen, 2005. Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. *Agriculture, Ecosystems and Environment* 108: p. 1 – 16.

❖ Haileslassie, A., Priess, J.A., Veldkamp, E., and J.P. Lesschen. 2006. Smallholders' soil fertility management in the Central Highlands of Ethiopia: implications for nutrient stocks, balances and sustainability of agroecosystems. *Nutrient Cycling in Agroecosystems*, 75: 135-146.

❖ Haileslassie, A., Priess, J.A., Veldkamp, E. and J.P. Lesschen, 2007. Nutrient flows and balances at the field and farm scale: Exploring effects of land-use strategies and access to resources. *Agricultural Systems* 94 (2), 459-470.

❖ Heuvelink, G.B.M., Schoorl, J.M., Veldkamp, A. and D.J. Pennock. 2006. Space-time Kalman filtering of soil redistribution. *Geoderma*, 133. p. 124 - 137.

❖ Lesschen, J.P.,, Asiamah, R.D., Gicheru, P., Kante, S., Stoorvogel, J.J. & Smaling, E.M.A. 2005. Scaling Soil Nutrient Balances - Enabling mesoscale approaches for African realities. *FAO Fertilizer and Plant Nutrition Bulletin* 15, FAO, Rome.

❖ Lesschen, J.P.; Stoorvogel, J.J.; Smaling, E.M.A.; Heuvelink, G.B.M.; Veldkamp, A. , 2007. A spatially explicit methodology to quantify soil nutrient balances and their uncertainties at the national level Nutrient Cycling in Agroecosystems 78 (2). - p. 111 - 131.

❖ Lesschen J.P., J.M. Schoorl, L.H. Cammeraat, 2009. Modelling runoff and erosion for a semi-arid catchment using a multi-scale approach based on hydrological connectivity. *Geomorphology*, In Press, Accepted Manuscript, Available online 12 March 2009

❖ Roy, R.N., R.V. Misra, J.P. Lesschen,, E.M. Smaling, 2004. Assessment of soil nutrient balances: Approaches and Methodologies. *Fertilizer and Plant Nutrition Bulletin 14*, FAO, Rome.

❖ Schoorl, J.M., Boix Fayos, C., de Meijer, R.J., van der Graaf, E.R., and Veldkamp, A., 2004. The 137Cs technique on steep Mediterranean slopes (Part 2): landscape evolution and model calibration: *Catena*, v. 57, p. 35-54.

❖ Schoorl, J.M., Veldkamp, A., and Bouma, J., 2002, Modelling water and soil redistribution in a dynamic landscape context: *Soil.Sci.Soc.Am.J.*, v. 66, p. 1610-1619.

❖ Schoorl, J.M., and Veldkamp, A., 2001, Linking land use and landscape process modelling: a case study for the Alora region (South Spain): *Agric.Ecosyst.Environ.*, v. 85, p. 281-292.

❖ Schoorl, J.M., Sonneveld, M.P.W., and Veldkamp, A., 2000, Three-dimensional landscape process modelling: the effect of DEM resolution: *Earth Surf.Proc.Landforms*, v. 25, p. 1025-1034.

❖ Schoorl, J.M., L. Claessens, M. Lopez Ulloa, G.H.J. de Koning & A. Veldkamp, 2006. Geomorphological Analysis and Scenario Modelling in the Noboa – Pajan Area, Manabi Province, Ecuador. *Zeitschrift Fur Geomorfologie, Suppl.*-Vol. 145, p. 105 - 118.

❖ Schoorl, J.M.,, and Veldkamp, A., 2006, Multi-Scale Soil-Landscape Process Modeling, in Grunwald, S., ed., *Environmental Soil-Landscape Modeling: Geographic Information Technologies and Pedometrics*: Boca Raton, FL, CRC press, Taylor and Francis Group, p. 417 – 435.

❖ Sonneveld, M.P.W. Schoorl, J.M.,and A. Veldkamp, 2006. Evaluating The Fate Of Phosphorus In Apparent Homogeneous Landscapes Using a High-Resolution DEM. *Geoderma* 133, p. 32 - 42.

❖ Temme, A.J.A.M., Schoorl, J.M., and Veldkamp, A., 2006, Algorithm for dealing with depressions in dynamic landscape evolution models: *Comp.Geosci*., 32, p. 452 - 461.

❖ Temme, A.J.A.M., Heuvelink, G.B.M., Schoorl, J.M. and Claessens, L. 2009. Chapter 5: Geostatistical simulation and error propagation in geomorphometry. In: *Geomorphometry: Concepts, Software, Applications*. Eds: Hengl, T., Reuter, H.I., Elsevier, (*Developments in Soil Science 33*) - p. 121 - 140.

❖ Temme, A.J.A.M., Veldkamp, A. 2009. Multi-process Late Quaternary landscape evolution modelling reveals lags in climate response over small spatial scales. Earth Surface Processes and Landforms 34 (4), p. 573 - 589.