Topographic signatures of spatially-limited storm morphologies revealed from numerical landscape evolution modelling

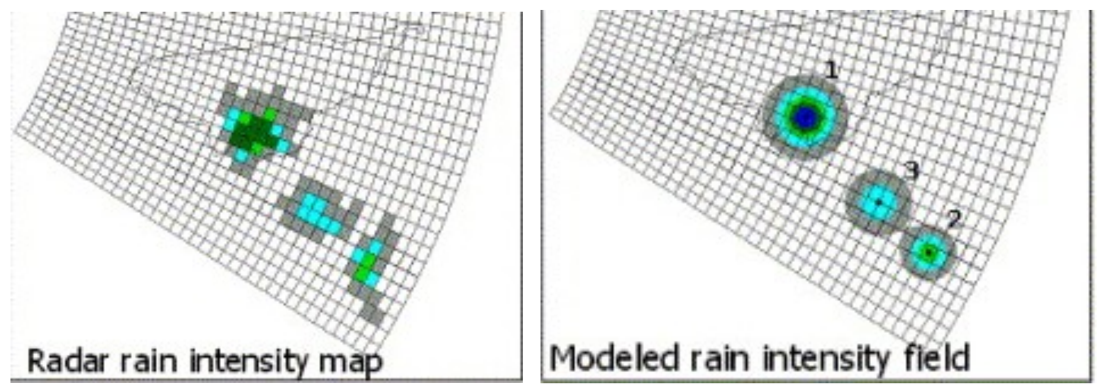
Declan A. Valters[1], Simon H. Brocklehurst[1,2], David M. Schultz[1,3]
[1]School of Earth, Atmospheric and Environmental Sciences, University of Manchester, United Kingdom.
[2]Basin Studies. [3]Centre for Atmospheric Science. declan.valters@manchester.ac.uk

1. Introduction

Topography records many imprints of changing tectonic and environmental conditions. Landscapes evolve in tandem with external forcings, but surprisingly little work has been done on how weather patterns such as storm dynamics, and the spatial patterns of rainstorms sculpt topography.

2. The Morphology of Storms

Storm morphology in mesoscale raincells has been described previously by several authors (e.g. Eagleson, 1984; Rodriguez-Iturbe et al., 1986; Morin et al., 2006). Though raincell shape is often complex, these analyses determine that a **circular shape is a good first order approximation of storm-cell morphology.**



Shape of rain cells derived from rainfall radar imaging. After Morin et al. (2006)

3. Stochastic Storm Generator

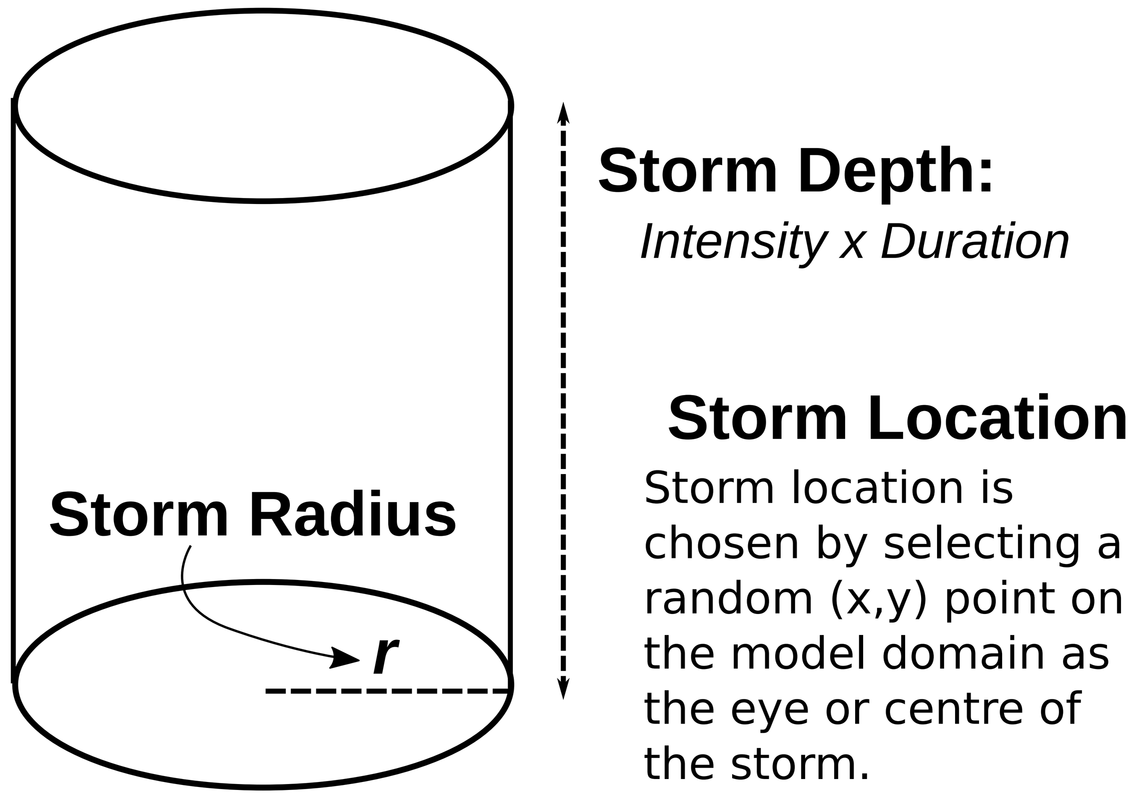
Exisitng stochastic models have already been incorporated into landscape evolution models that account for the variation in storm intensity and storm duration (Eagleson, 1987; Tucker and Bras. 2000). Here, a simple stochastic model for **spatial variation** is developed, based on a similar Poisson distribution for the radii of individual storm cells hitting the landscape.

The probability density function for rainstorm radius, *r*, is given by:

$$f(r) = \frac{1}{\bar{r}} \exp\left(-\frac{r}{\bar{r}}\right)$$

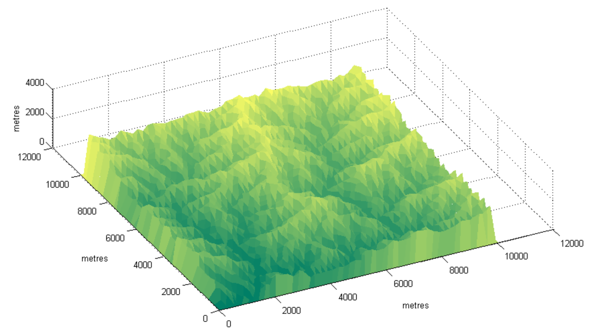
Similar proability density functions are used to select the rainfall **intensity**, storm **duration**, and **interstorm-period**, as per Tucker and Bras (2000).

This gives a simple raincell with a given radius and storm depth, which is a product of the storm duration and rainfall intensity. It is assumed that these parameters are independent of each other, and that the storm cells are stationary during each event.

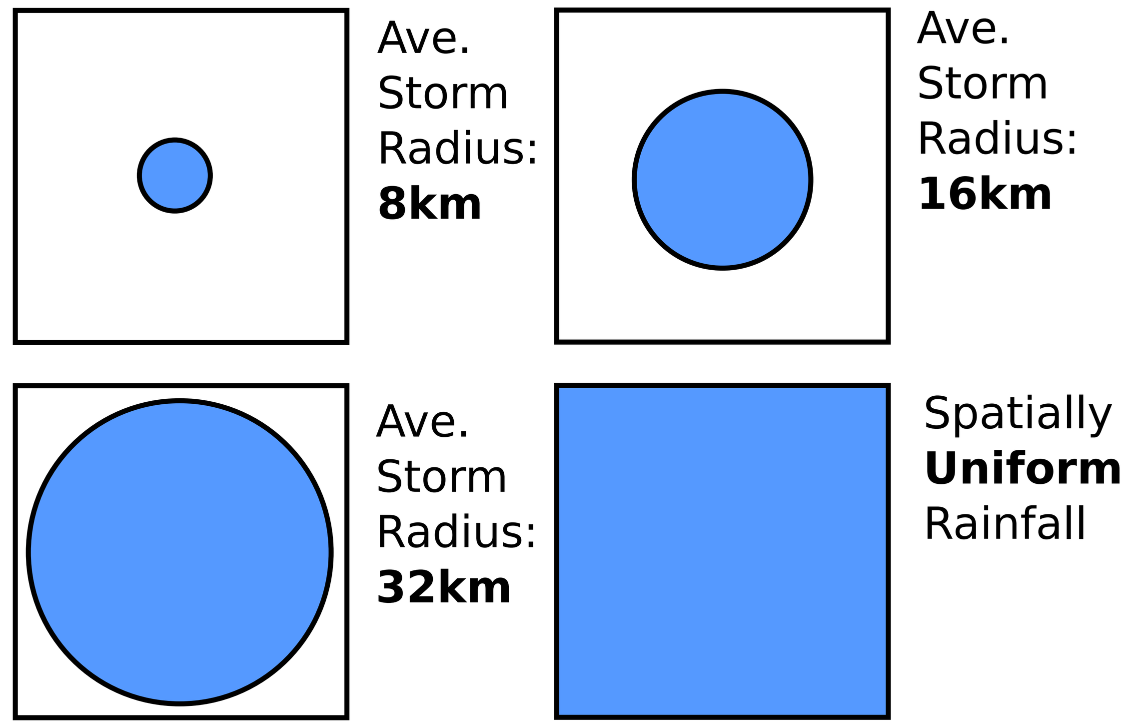


4. Landscape Evolution Model

The CHILD landscape evolution model is modified and used to conduct the experiments. CHILD is a 2.5D numerical model that uses a triangulated-irregular mesh to discretise the landscape surface. Synthetic landscapes are generated from an initial surface of random noise. A detachment-limited fluvial incision law is used to drive surface evolution.



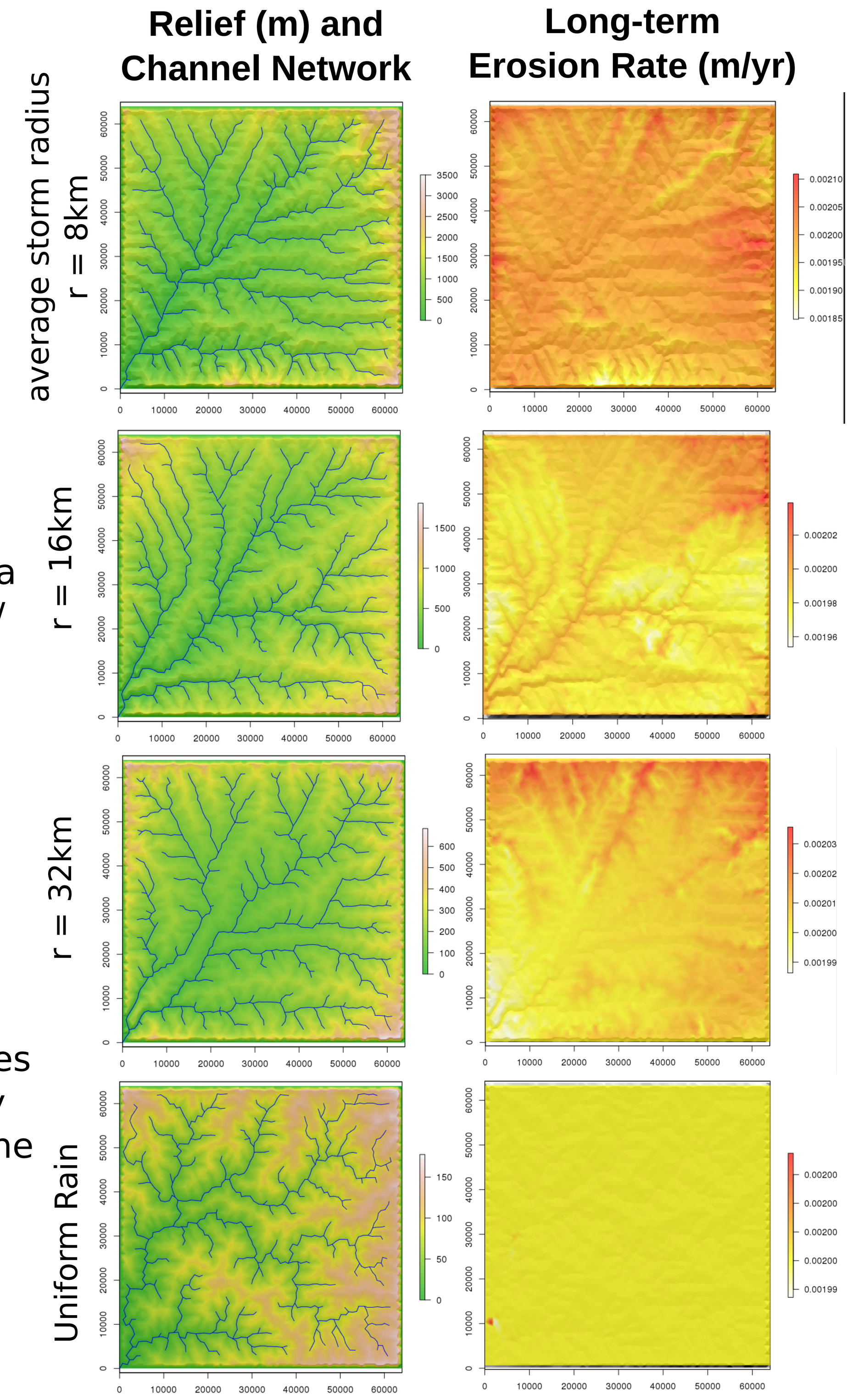
5. Experiment Design



Four experiments were run across a 64x64km model domain, one control experiment with spatially uniform rainfall input, and three others with increasing average storm radii of 8, 16, and 32km. When variable storm radii are used, the location of the storm varies randomly each iteration, such that the entire landscape domain receives water input over the course of the simulation. Rainfall intensity is adjusted with each simulation to maintain comparable mean annual rainfall.

6. Topographic Outcomes

Notably, landscapes evolving under spatially limited storm morphologies do not appear to reach true steady state.



- Relief is higher in small-storm landscapes.
- Channel networks differ: sub-basins have a smaller area/ length ratio under small-storm evolution. (Valleys are more elongate)
- Erosion rates vary spatially throughout the landscape, never quite reaching steady-state.

7. Future Work

•Topographic analysis of landscapes with chi and k_sn metrics.

•Analysis of real landscapes for meteorological signatures.

•Study of short-term geomorphic effects of convective storms.

github.com/decvalts

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References

Eagleson, P. S. (1984). The distribution of catchment coverage by stationary rainstorms. Water Resources Research, 20(5), 581-590.

Rodríguez-Iturbe, I. (1986). Scale of fluctuation of rainfall models. Water Resources Research, 22(9S).

Eagleson, P. S., Fennessey, N. M., Qinliang, W., & Rodriguez-Iturbe, I. (1987). Application of spatial Poisson models to air mass thunderstorm rainfall. Journal of Geophysical Research: Atmospheres, 92(D8), 9661-9678.

Tucker, G. E., & Bras, R. L. (2000). A stochastic approach to modeling the role of rainfall variability in drainage basin evolution. Water Resources Research, 36(7), 1953-1964.

Morin, E., Goodrich, D. C., Maddox, R. A., Gao, X., Gupta, H. V., & Sorooshian, S. (2006). Spatial patterns in thunderstorm rainfall events and their coupling with watershed hydrological response. Advances in Water Resources, 29(6), 843-860.