Influence of orographic precipitation on the co-evolution of landforms and vegetation

EGU2020-5280

Ankur Srivastava[1], Omer Yetemen[2], Nikul Kumari[1], and Patricia M. Saco[1]

[1] Civil, Surveying and Environmental Engineering, The University of Newcastle, Callaghan, NSW, Australia
[2] Eurasia Institute of Earth Sciences, Istanbul Technical University, Istanbul, Turkey

Ankur.Srivastava@uon.edu.au

EGU General Assembly 2020

1. Introduction

- Topography plays an important role in controlling the amount and the spatial distribution of precipitation due to orographic lift mechanisms.
- Orography has implications on precipitation forming mechanisms (Houze *et al.*, 2012) and can affect climate regime and vegetation settings.

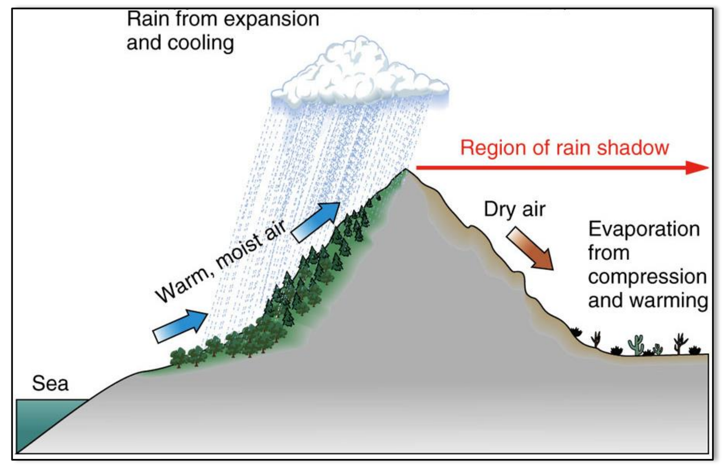


Figure 1. Orographic precipitation – a simple model

- Recent landscape modelling efforts show how the orographic effects on precipitation result in the development of asymmetric topography (Goren *et al.*, 2014; Han *et al.*, 2015).
- However, these modelling efforts do not include vegetation dynamics which can decrease sediment transport (Yetemen *et al.*, 2015).

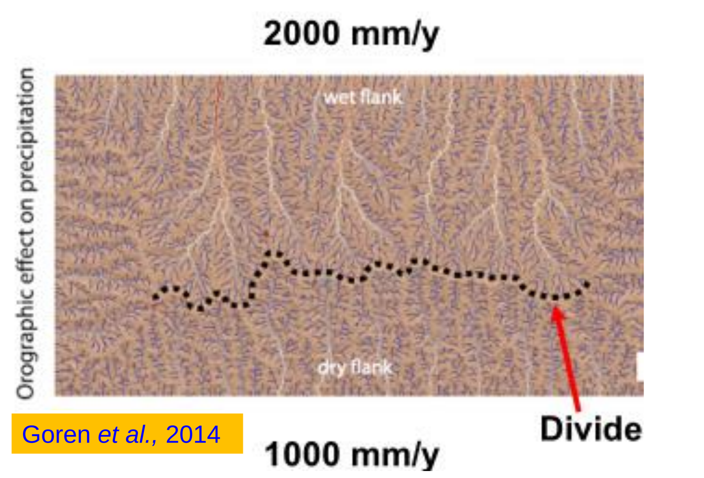


Figure 2. Simulations including orographic effect on precipitation. The main divide (dashed line) migrates toward the dry side

- In this study, our aim is to realistically represent the orographic-precipitation-driven ecohydrologic dynamics using a landscape evolution model (LEM).

2. Model Theory

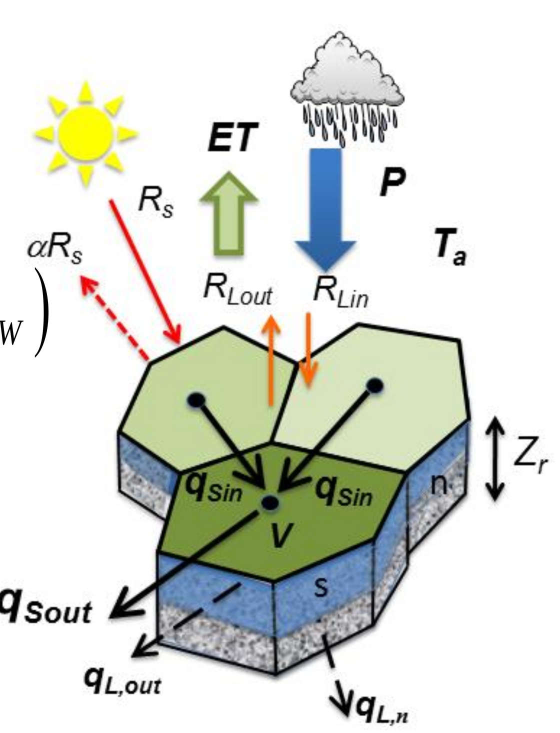
We used the **Channel-Hillslope Integrated Landscape Development model (CHILD)** landscape evolution model (LEM) coupled with a vegetation dynamics component Bucket Grassland Model (BGM) that explicitly simulates above- and below-ground biomass.

Radiation balance: $$R_n = (1-\alpha)R_{SW} + \left(\downarrow R_{LW} - \uparrow R_{LW}\right)$$

Energy balance: $$\frac{dS_h}{dt} = R_n - H - \lambda ET(s)$$

Water balance: $$nZ_r\frac{ds}{dt} = I(s) - ET(s) - D(s)$$

Vegetation dynamics: $$\frac{dB}{dt} = k_g ET(s,V,T) - k_d B$$



Tucker *et al.*, 2001

Figure 3. Illustration of the modelled energy, water fluxes, and ecohydrologic state variables in a Voronoi cell used in the CHILD-BGM model

3. Model Settings

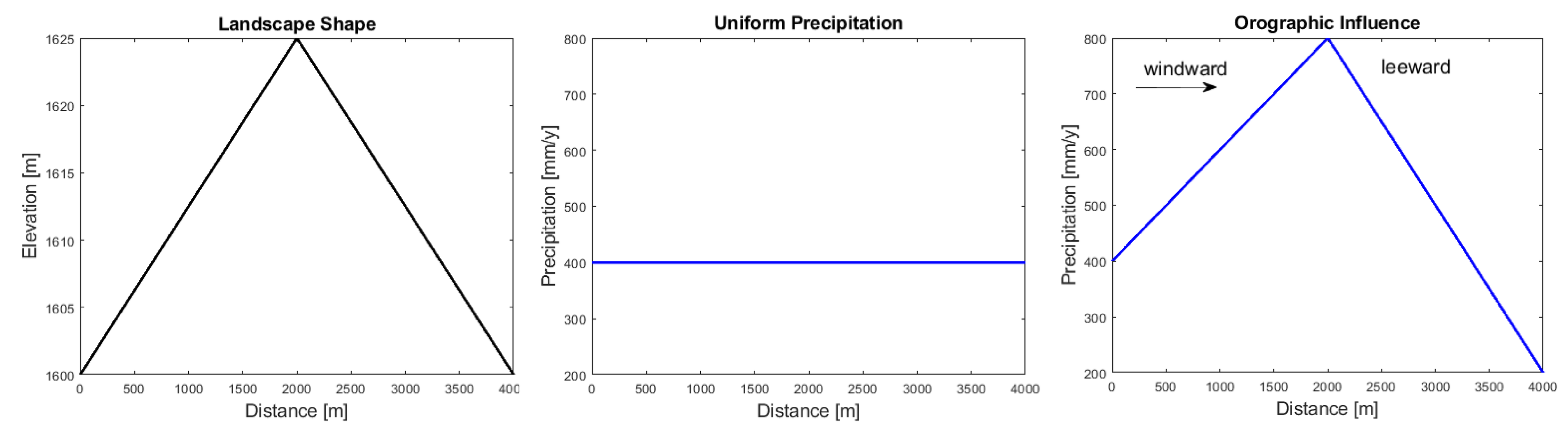


Figure 4. Landscape elevation profile and precipitation patterns used in the simulations

Initial Topography and Simulation Duration

Dimensions	: 1000 m by 4000 m
Grid size	: 50 m
Initial Max Height	: 25 m
Uplift	: Uniform 0.1 mm/y
Outlet	: Two open-boundary edges
Simulation duration	: 800000 years

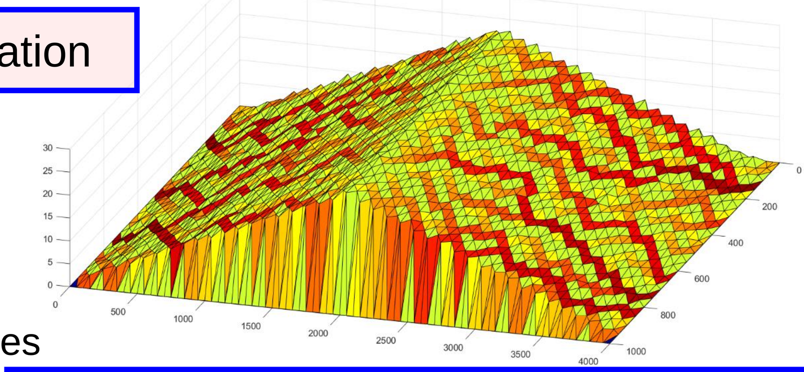


Figure 5. Initial topography used in CHILD

Vegetation Cover Fraction for Uniform and Orographic Precipitation

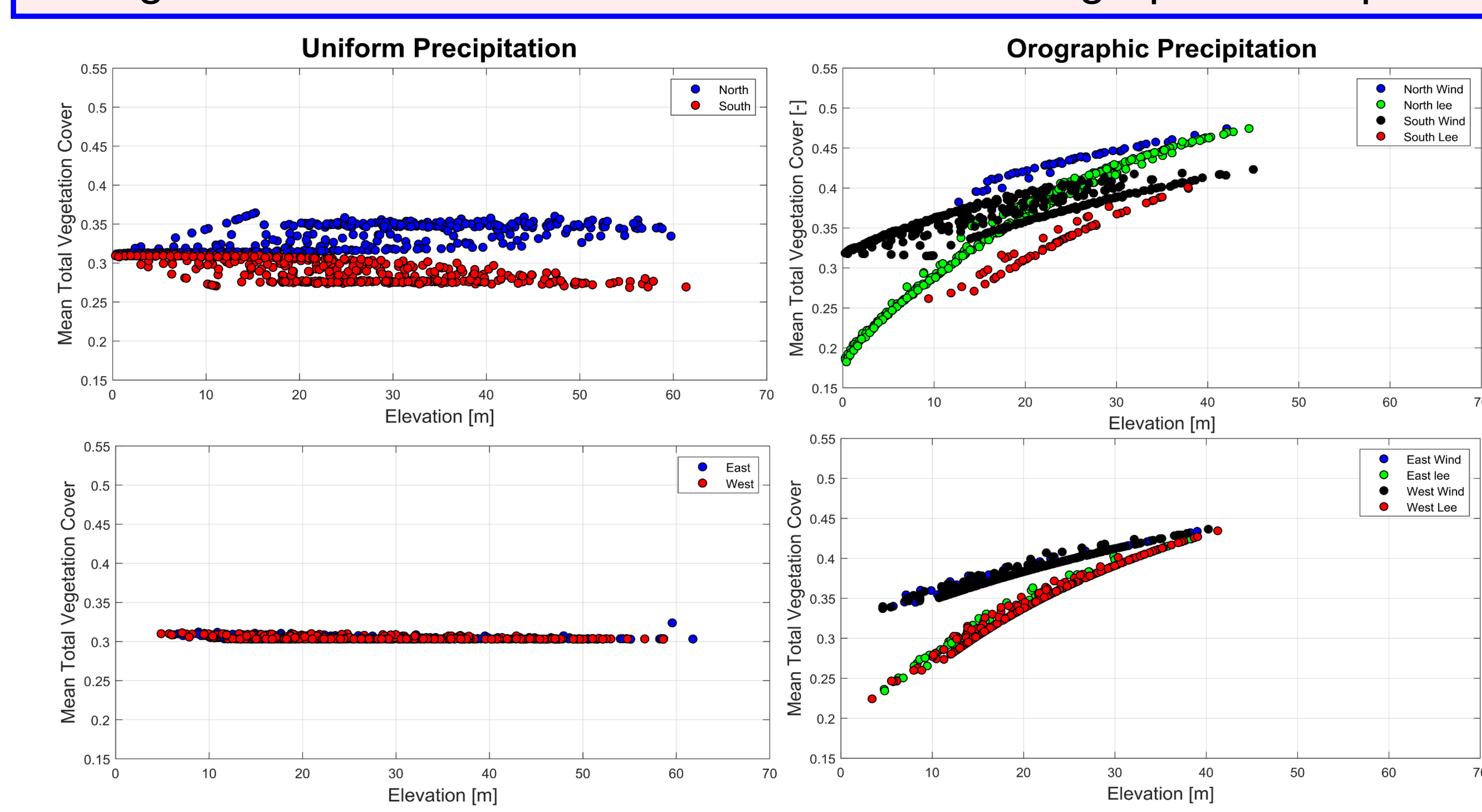
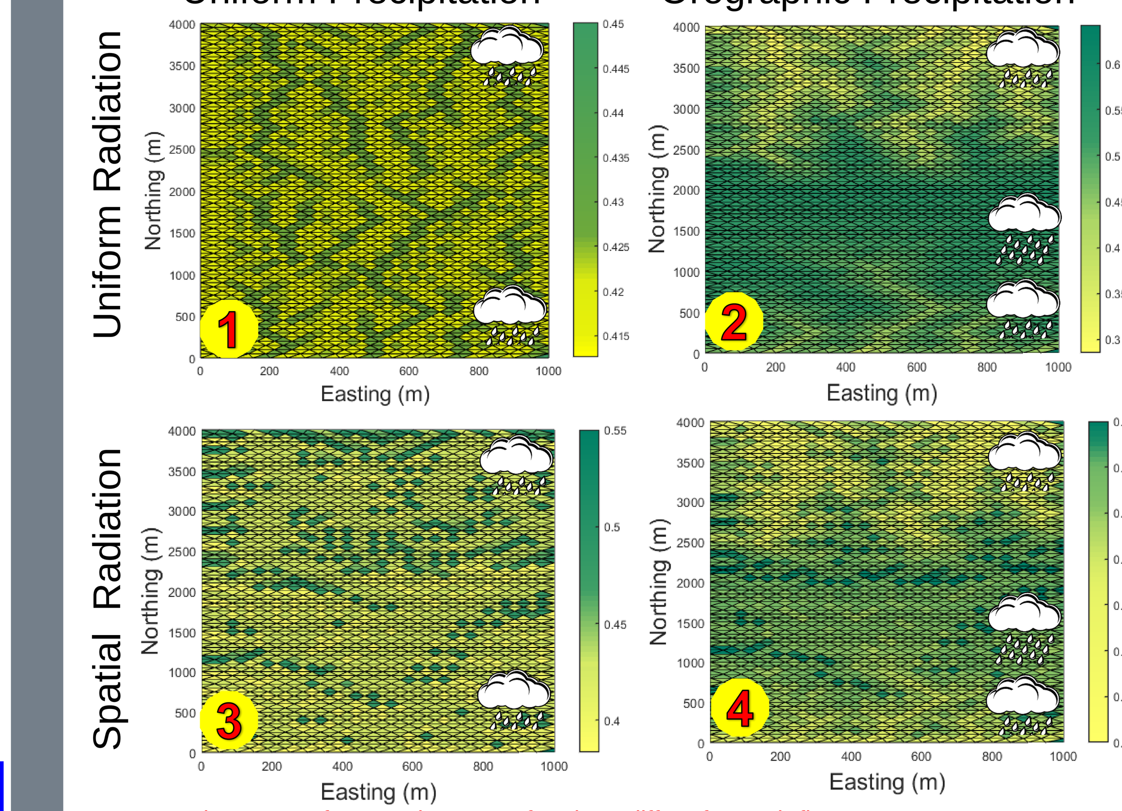


Figure 7. Mean total vegetation cover plotted as a function of elevation

- As a result of insolation, NFS have denser canopy than SFS (Yetemen *et al.*, 2015; Srivastava *et al.*, 2019).
- In NFS (SFS), gentler slopes on lower elevations produce less (more) vegetation than higher elevations.

4. Results

Influence of Solar Radiation and Precipitation Patterns on Simulated Mean Vegetation Cover

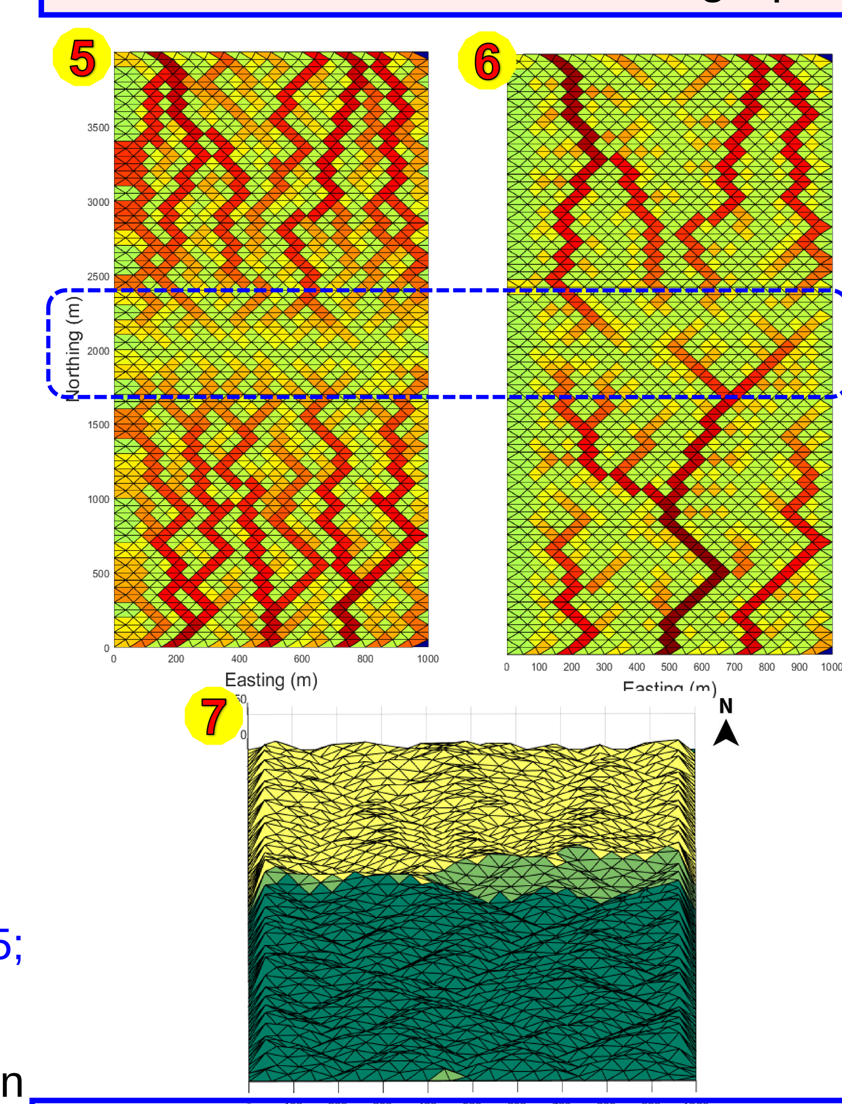


Note: The range of vegetation cover fractions differs for each figure

Figure 6. Vegetation cover for uniform and spatial radiation

1. Enhanced network control in vegetation patterns due to flow concentration.
2. Vegetation cover is enhanced on the windward side due to orographic precipitation. As there is more (less) amount of rainfall on windward (leeward) side high (low) vegetation cover is observed.
3. Aspect control on vegetation pattern is identified, north-facing slopes (NFS) hold denser canopy than south-facing slopes (SFS). Presence of more dark green pixels on NFS which have lower insolation than on SFS. Distinct differences between scenarios 1 and 3 suggest that the spatial variability of solar radiation drives the vegetation pattern.
4. Aspect control on vegetation pattern is also identified as vegetation on NFS is denser than on SFS. Further, NFS on windward side benefits more than NFS on leeward side due to orographic effect.

Influence of Orographic Precipitation on Reach Capture



Dark green = Windward directions
Yellow = Leeward direction
Light green = Pixels converted to windward

Figure 8. Divide migration in uniform and orographic precipitation

5. Initial topography for the simulations corresponding to orographic precipitation.
6. Final topography after reaching steady state (800,000 years) for the orographic precipitation.
7. The vegetation response to orographic rainfall provides greater erosion protection on the windward side than the leeward side.

   This results in divide movement due to differences in shear stress and vegetation differences on windward and leeward sides, which leads to basin reorganization through reach capture.

5. Conclusions

- Vegetation patterns are strongly affected by rainfall patterns and variability in solar radiation.
- The competition between the increased shear stress due to increased runoff and vegetation protection affect the migration of the divide (i.e., the boundary between leeward and windward flanks).
- Our findings suggest that there exists a strong coupling between climate and landform evolution processes, and that orographic precipitation can imprint its influence on landforms in semi-arid ecosystems.

References

Goren, L., S. D. Willett, F. Herman, and J. Braun (2014), Coupled numerical-analytical approach to landscape evolution modeling, Earth Surf Proc Land, 39(4), 522-545.
Han, J. W., N. M. Gasparini, and J. P. L. Johnson (2015), Measuring the imprint of orographic rainfall gradients on the morphology of steady-state numerical fluvial landscapes, Earth Surf Proc Land, 40(10), 1334-1350.
Houze, R. A. (2012), Orographic Effects on Precipitating Clouds, Rev Geophys, 50.
Srivastava, A., Yetemen, O., Kumari, N., Saco, P. M., 2019. Aspect-controlled spatial and temporal soil moisture patterns across three different latitudes. Proc. of the 23rd International Congress on Modelling and Simulation (MODSIM2019), Canberra, Australia, pp. 979-985.
Tucker, G. E., S. T. Lancaster, N. M. Gasparini, and R. L. Bras (2001a), The Channel-Hillslope Integrated Landscape Development model (CHILD), in Landscape Erosion and Evolution Modeling, edited by R. S. Harmon and W. W. Doe III, pp. 349–388, Kluwer Acad., N. Y.
Yetemen, O., E. Istanbulluoglu, J. H. Flores-Cervantes, E. R. Vivoni, and R. L. Bras (2015), Ecohydrologic role of solar radiation on landscape evolution, Water Resour Res, 51(2), 1127-1157, doi: 10.1002/2014wr016169.