

Review of “Watershed zonation approach for tractably quantifying above-and-belowground watershed heterogeneity and functions”

Author(s): Haruko M. Wainwright et al.
MS No.: hess-2021-228

L. Band, University of Virginia

General comment:

This paper describes methods to form multi-dimensional clusters of hillslopes from a set of raster data sets describing watershed properties for an instrumented Rocky Mountain watershed in order to organize and reduce the dimensionality of environmental data. The East River watershed is an alpine glaciated basin, and is an important US Department of Energy (DOE) funded observatory to study hydrologic, biogeochemical, and critical zone processes. The site is characterized by innovative and extensive observations and is used as a test-bed to develop and test a set of earth systems watershed models. As such the paper will be of interest to readers. However, there are a set of clarifications, conceptual, and analytical issues that can be addressed to strengthen the paper.

Specific comments (scientific questions/issues):

The study hypothesizes that a set of above and below ground properties co-vary in space, that these covarying properties can be spatially clustered, and have distinct associations with land surface processes and function. These hypotheses are widely accepted and observed, and are the basis of the catena concept. The study is also premised on the assumption that hillslopes provide an organizing template to co-occurring and co-evolved land surface properties, and are therefore a fundamental unit to characterize and simulate the behavior of land surface processes, including the interactions of water, carbon, nutrients and energy. The premise is in agreement with a number of publications over the last few decades, citing the (relatively) closed drainage boundary conditions provided by divides forming fundamental water and solute sources, and lower variation in topographic aspect, and hence, the radiation environment. The hypotheses may need to be restated to demonstrate what new information or concepts are being developed and tested.

The paper investigates whether unsupervised clusters at the hillslope scale generated by three different approaches produce a coherent, organizing template for the multiple spatial variables, and can capture observable variance in two land surface and watershed and behaviors: drought sensitivity and nitrogen export. A single hillslope partition is generated as a template to form clusters, using mean values of the spatial data coverages, without considering within unit variance. More detail should be given to justify the scale of the hillslope partition, as larger or smaller hillslopes may yield different distributions of mean parameter values, and resulting clusters based on altered between and within unit variance. Additional information can be included in a table in the paper or supplement: number of hillslopes, characteristics (e.g. area, relief, etc). It would be useful to inspect the balance of between- and within-unit variance, to demonstrate how much of the total landscape variance is captured by the hillslope partition. The effects of variable hillslope sizes and numbers on the representation of watershed heterogeneity and impacts on coupled water and carbon cycling has previously been investigated in similar Rocky Mountain watersheds (e.g. Band et al., 1991, 1993; and others).

Given the high topographic relief, strong topoclimate gradients in radiation and water balance, and intercorrelation of a number of the spatial datasets used, it is likely that any partitioning of the landscape (hillslopes or grid cells) would produce a reasonable clustering, and may have distinct association with specific landscape functions. The three hypotheses stated in the introduction could be strengthened if the concept of an optimal scale of hillslope partitioning was posed, or included the scale dependence of results. This may require multiple hillslope partitions (different extents of the stream network), and

consideration of subhillslope scale variance – essentially generating multiple realizations of the methods used in the paper across scales.

Soils are often the weak link in distributed watershed data, as discussed by the author. While bedrock geology is used instead of soils in this study, available soil data (SSURGO downloaded from the USDA web soil survey site) shows substantially more spatial detail than the bedrock maps. While SSURGO soils data important to water storage and flow are often highly generalized based on the mapping methods and cartographic presentation, there have been a number of methods published over the last decades to develop estimates of soil properties at resolutions comparable to available terrain information (e.g. Zhu et al, 1997), and more recently Chaney et al (2016, 2019) published a 30m soil property dataset for CONUS. The authors should better outline why soils, a central critical zone component, were not used as part of the clustering. Similarly, while aspect was discussed in the paper as a central influence on critical zone behavior, it was not included. While potential radiation may explain much of the information aspect may convey, aspect is a simpler and more widely available measure (but needs to be treated as a circular variable or transformed into a linear surrogate, such as the widely used “southness”).

The goals of the clustering are an important driver of the methods. Much of the hydrologic and biogeochemical behavior of watersheds is based on sub-hillslope processes. As an example, the role of riparian areas in modulating both runoff and nutrient export has been heavily cited (e.g. McGlynn and McDonnell, 2003a,b). The last line of the paper suggests the zonation methods presented can guide experimental plot placement to better quantify and understand water/element export contributions. Plots are subhillslope scales, and position within the internal flow structure of the hillslope is a critical control. This is a major tenet of the critical zone approach.

Technical corrections, clarifications:

1. P.7, paragraph 185: it is not clear how the clusters were aligned or compared between the clustering methods. I presume the unsupervised clusters are developed independently between methods. Are you renumbering according to similarity?
2. Spell out acronyms the first time used (e.g. NDVI, NDWI, etc) even if these are well known by some communities
3. Figure 1: Clarify the position of the subcatchments. It is given as ordered from right to left (better to state east to west), but Slate River and Coal Creek cannot be distinguished as they appear to be equally “left” or west. A simple label would obviate this.
4. Figure 4: It is not clear if these plots are aggregated over all clustering methods or are for one.
5. P.11, paragraph 255: Incomplete sentence “The Rock and Gothic subcatchments, which are predominantly within conifer dominated Zone 3 (Figure b).” Figure 5b?
6. Figure 6d,e: y-axis is given as MG/m³. Is this a concentration or a mass export? Typo in units? Perhaps MG/km²? Figure 6e is unconvincing as there are two widely separated clusters of points that are interpreted as a trend.

Citations:

L.E. Band, D.L. Peterson, S.W. Running, J.C. Coughlan, R. Lammers, J.Dungan and R.R. Nemani, 1991. "Ecosystem processes at the watershed level: Basis for distributed simulation," Ecological Modeling, 1991, v.56, p.171- 196.

L.E. Band, P. Patterson, R.R. Nemani and S.W. Running, 1993. "Forest ecosystem processes at the watershed scale: 2. Adding hillslope hydrology." Agricultural and Forest Meteorology, 1993, v.63, p.93-126.

Chaney, N. W., Minasny, B., Herman, J. D., Nauman, T. W., Brungard, C., Morgan, C. L. S., et al. (2019). POLARIS soil properties: 30-m probabilistic maps of soil properties over the contiguous United States. *Water Resources Research*, 55, 2916–2938. <https://doi.org/10.1029/2018WR022797>

NW Chaney, EF Wood, AB McBratney, JW Hempel, TW Nauman, ... 2016. POLARIS: A 30-meter probabilistic soil series map of the contiguous United States. *Geoderma* 274, 54-67

BL McGlynn, JJ McDonnell, 2003. Quantifying the relative contributions of riparian and hillslope zones to catchment runoff. *Water Resources Research* 39 (11)

BL McGlynn, JJ McDonnell, 2003. Role of discrete landscape units in controlling catchment dissolved organic carbon dynamics. *Water Resources Research* 39 (4)

A. Zhu, L.E. Band, R. Vertessy and B. Dutton, 1997. Soil property derivation using a soil land inference model (SoLIM). *Soil Science Society America Journal*, v.61(2), p.523-533.