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An extensive analysis of hillslope-to-channel length variability at different scales

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While drainage density is generally computed as an average property of a basin (counting the total length of streams in a catchment and dividing by the relative drainage area), it is acknowledged that this traditional definition poses some problems concerning the scale at which this average should be computed, and its application completely clouds local and regional variations of drainage density over different scales. Additionally, since in the averaging process many sub-basins with different characteristics are blended, the spatial organization of local drainage density in relation with the channel network is completely neglected. This suggested the adoption of a surrogate measure for drainage density, which is the inverse of twice the local distance along the flow path from each injection point to the channel head. This raster-based measure allows to create maps that are capable to reveal spatial patterns of variation of drainage density related to valley-ridge alternation, macro-scale geology and soil texture, and vegetation.

Through the use of this quantity, we are able in this work to perform an extensive analysis of land dissection patterns which occur both at the hillslope and catchment scale on a significant set of natural basins located in central Italy (Apennines ridge).

At the hillslope scale we search for the existence of recurring shapes describing the distribution of hillslope to channel distances. We determine its average, variance and skewness, calculated over a specific domain for each channel head, constituted by its draining hillslope (thus not requiring the definition of a characteristic integral scale as usually done in previous works). Small average hillslope-to-channel distances (high drainage density) are associated with zones which are able to rapidly convey water to the channel network and are responsible for quick storm runoff contribution. Additionally, travel time variance of water particles in a hillslope strongly depends on the overall shape of the hillslope distribution. For example, in zones with large variance of hillslope lengths – often combined with positive skewness – the effect of geomorphologic heterogeneity (source zone dispersion) is known to overwhelm other factors such as the heterogeneity of hydraulic conductivities.

Moving to the catchment scale, we observe how the metric features of single hillslopes combine to shape the overall hydrologic response. We consider the variations in space of the moments of distance-to-channel distribution both with the geometric distance among hillslope centroids and as function of the distance of each channel head to the outlet. Highly spatially correlated moments may result as the typical expression of almost uniform geological formations which overlay large regions. However, as we deal with larger networks randomly draining different geological regions, the resulting correlation structure is rapidly broken.

Therefore the extensive survey conducted over hillslope-length distributions provides a fundamental support for the comprehension of effective processes which rule runoff generation both at the local and catchment scales.