Preserving meander bend geometry through scale

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Abstract: Stream meander geometry is a function of hydrologic, geologic, and anthropogenic forces. Meander morphometrics are used in geomorphic classification, ecological characterization, and tectonic and hydrologic change detection. Thus, detailed measurement and classification of meander geometry is imperative to multiscale representation of hydrographic features, which raises important questions. What meander geometries are important to preserve in multi-scale databases? How are geometries measured? How are they preserved? Is the choice between preservation of geometry or use of classification attributes? Questions related to multiscale measurement and representation of hydrographic features continue to emerge with increased spatial and temporal data collection.

A key metric for understanding meander bend geometry is sinuosity. The most common measure of sinuosity is the length of a feature divided by the distance between stream head and mouth. The measure relays deviation from a straight line but nothing about meander wavelength. There is not a clear consensus on methods for measuring meander geometry, much less efficiently, at scales made viable with increased data resolution. Here we propose a method for automated characterization of meander wavelength or bend radius. The method, termed Scale-Specific Sinuosity (S^3), is a derivation from the Richardson plot. The Richardson (1961) plot is a classic means of calculating fractal dimension of natural line features and describes feature length (ℓ) given increasing vertex spacing, or step size (S), plotted on a log-log plot. The S^3 metric is defined as negative one times the slope of a Richardson plot for a given stride length. This paper demonstrates utility of S^3 for estimating changes in sinuosity with scale change.

Introduction: Increasing availability of fine-resolution data clearly presents opportunities for broad study of surface processes. Meander wavelength is an important metric for stream and geomorphic classification and for hydrologic and ecologic monitoring. Meander wavelength is often measured by heads up assessment of individual features using a ruler. While authors have approached the challenge of digitizing and automating measurement (Gutierrez & Abad, 2014; Speight, 1965), the studies are not clearly applicable to a range of feature scales and environments. Without a clear strategy, broad repeatable studies of morphometric dynamics are not viable. If strategies for meander geometry are unclear, so too are what geometries are important. It has been proposed that bend radius is a function of stream width (Williams, 1986). The conclusion is arguable, yet if we assumed it to be true, increasingly rapid and anthropogenic influences on earth's surface and hydrologic budgets indicate a deviation from geologically controlled conditions. This is a problem of meander geometry measurement scale.

Another challenge for stream morphometrics is representation through multiple scales. Multi-dimensional visualization as applied to navigation, research, or recreation poses rapidly approaching challenges to multiscale representation. As we fly from the stratosphere to a headwater stream in Google Earth, how does the content and geometry of a feature representation change if it is to remain useful for analytics? Geographic representation of surface water can influence perception of the landscape and resulting decisions. Looking down from the virtual stratosphere one may not recognize the presence of wetlands, the density of headwater streams in forested mountains, or the extent of riparian and hyporheic zone accompanying a meandering stream.

Measurement of morphometrics is made more desirable by the challenge of global changes in hydrologic conditions. Growing cities, increased agricultural production, varying weather patterns, to name a few forces, are affecting surface water distribution and behavior. To understand how the changes are taking place and the extent or scale of change, automated meander morphometric measurement is required.

Scale-Specific Sinuosity (S^3): The S^3 metric is computed as -1 times the slope of the Richardson plot at a given step length (S). The Richardson plot is often used to determine a fractal dimension of a feature, calculated as one plus the absolute slope of a line fit to the plot (Mandelbrot, 1967). The method returns a single value that represents a feature that may traverse variable geomorphic domains and is thus affected by sample size and resolution (Goodchild, 1980).

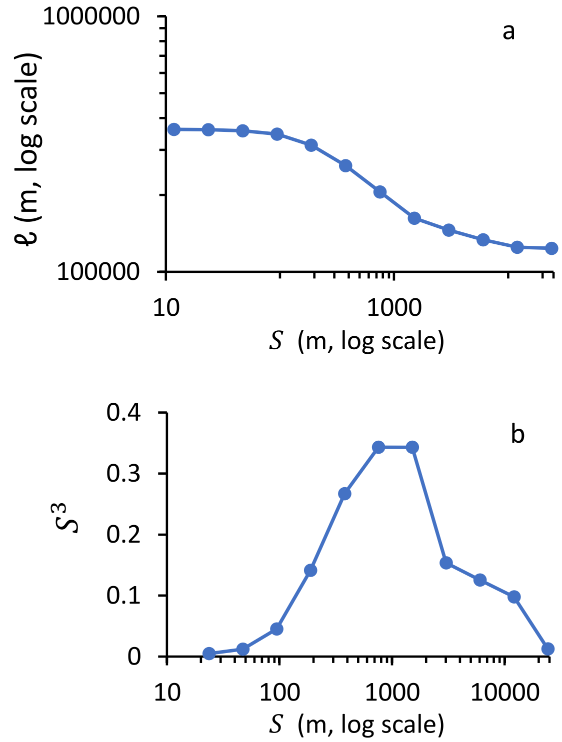

Figure 1. a) Feature length (ℓ) plotted against step size (S) on a Richardson plot and b) S^3 plot for the Cannonball River in North Dakota.

It is proposed here that a plot of S^3 values against S in log scale (Figure 1b) reflects the feature scale deviation from self-similarity and the variation in bend size being removed as S increases and therefore estimates the dominant meander wavelength of the feature. S^3 is an attribute easily measured at different scales and communicable through scale-specific representations. The S^3 curve can be described as a vector or function for easy intra or inter-feature comparison and analysis.

The proposed method of meander wavelength characterization could be used to compare separate features or segments of a feature to identify geomorphic region boundaries or change in hydrologic condition. The S^3 metric could also be useful for determining appropriate line simplification strategies for multi-scale representation. The S^3 vector or function could be represented at larger scales as an attribute where feature occlusion is typically an issue. Feature change detection is also possible and important moving forward.

Summary: Automated measurement of meander bend geometry at a range of scales is important for hydrologic, ecologic, and geomorphic research and monitoring as well as hydrographic multi-scale representation.

The Scale-Specific Sinuosity (S^3) metric has the potential to characterize meander bend geometries, identify changes in hydrologic and geomorphic conditions, and guide hydrographic multi-scale representation.

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Citations

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