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A morphology independent methodology for quantifying planview river change and characteristics from remotely sensed imagery

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ABSTRACT

Remotely sensed imagery of rivers has long served as a means for characterizing channel properties and detection of planview change. In the last decade the dramatic increase in the availability of satellite imagery and processing tools has created the potential to greatly expand the spatial and temporal scale of our understanding of river morphology and dynamics. To date, the majority of GIS and automated analyses of planview changes in rivers from remotely sensed data has been developed for single-threaded meandering river systems. These methods have limited applicability to many of the earth's rivers with complex multi-channel planforms. Here we present the methodologies of a set of analysis algorithms collectively called Spatially Continuous Riverbank Erosion and Accretion Measurements (SCREAM). SCREAM analyzes planview river metrics regardless of river morphology. These algorithms quantify both the erosion and accretion rates of riverbanks from binary masks of channels generated from imagery acquired at two time periods. Additionally, the program quantifies the area of change between river channels and the surrounding floodplain and area of islands lost or formed between these two time periods. To examine variations in erosion rates in relation to local channel attributes and make rate comparisons between river systems of varying sizes, the program determines channel widths and bank curvature at every bank pixel. SCREAM was developed and tested on rivers with diverse and complex planform morphologies in imagery acquired from a range of observational platforms with varying spatial resolutions. Validation and verification of SCREAM-generated metrics against manual measurements show no significant measurement errors in determination of channel width, erosion, and bank aspects. SCREAM has the potential to provide data for both the quantitative examination of the controls on erosion rates and for the comparison of these rates across river systems ranging broadly in size and planform morphology.

1. Introduction

The analysis of river planform properties and dynamics has long used aerial photography and increasingly incorporates satellite imagery. Traditionally, extracting a representation of a river, such as banklines or a centerline, relied on labor-intensive efforts by a human analyst to digitize the river channel. The development of supervised and semi-automated methodologies for extracting a binary representation of rivers from pixel-based images (e.g. Brumby et al., 1999; Dey & Bhattacharya, 2013; Dillabaugh, Niemann, & Richardson, 2002; Hamilton, Kellndorfer, Lehner, & Tobler, 2007; Marra, Kleinhans, & Addink, 2014; McFeeters, 1996; Merwade, 2007; Quackenbush, 2004; Smith & Pavelsky, 2008; Xu, 2006) and the wealth of freely available imagery offers the potential to greatly expand both the temporal and spatial scale of river analysis (Fisher, Bookhagen, & Amos, 2013). In response to the greater availability of imagery, expanded use of Geographic Information Systems (GIS) and image processing software packages, a number of published and freely distributed methodologies for extracting river metrics from imagery have become available over the past decade. Examples of such tools include, but are not limited to, the ArcGIS-based River Planform Statistics Toolbox (Aalto, Lauer, & Dietrich, 2008), the Interactive Data Language (IDL)-based RivWidth code (Pavelsky & Smith, 2008), the Matlab-based width and centerline ChanGeom code (Fisher et al., 2013), and Matlab-based channel centerline and curvature codes (Legleiter & Kyriakidis, 2006). Table 1 provides a representative summary of the range of measurements these and other published methodologies generate. The ever-expanding availability of high-resolution topographic data has led to the development of geomorphic change detection (GCD) and DEMs of difference (DoD) methods to quantify both lateral and vertical changes in river systems

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Table 1
Summary of representative river analysis methods and metrics.

	Method									
	Planform Statistics Toolbox[a]	RivWidth[b]	ChanGeom[c]	Centerline polygons[d]	Centerline curvature[e]	Area based change[f]	CWT[g]	Outer bank displacement[h]	SCREAM	SCREAM output
Morphology	S	S/M	S	S	S	S/M	M	M	S/M	
Metric										
Linear rates of lateral channel migration	Intervals	–	–	Polygons	–	–	–	–	–	–
Linear rate of bank erosion	–	–	–	–	–	–	–	XS	– Bank pixel/segment averages	– Raster/text
Linear rate of bank accretion	–	–	–	–	–	–	–	–	Bank pixel/segment averages	Raster/text
Area of erosion	–	–	–	–	–	Entire river reach	–	–	Entire river reach/segments	Text
Area of accretion	–	–	–	–	–	Entire river reach	–	–	Entire river reach/segments	Text
Change as % of channel area	–	–	–	–	–	Entire river reach	–	–	Entire river reach/segments	Text
Percentage of banks eroding and accreting	–	–	–	–	–	–	–	–	Segments	Text
Spatial and temporal patterns of bank change	–	–	–	–	–	–	XS	–	–	–
Channel width	Intervals	CP	CP	–	–	–	–	–	Bank pixel/segment averages	Raster/Text
Total width of multi-thread channels	–	CP	–	–	–	–	–	XS	Segment averages	Text
Centerline curvature	Intervals	–	–	–	Continuous	–	–	–	–	–
Bank curvature	–	–	–	–	–	–	–	–	Bank pixel	Raster/text
Bank aspect	–	–	–	–	–	–	–	–	Bank pixel	Raster/text
Sinuosity	–	–	–	–	–	–	–	–	Continuous/segment averages	Text
Channel elongation	Intervals	–	–	–	–	–	–	–	–	–
Number of islands	–	–	–	–	–	–	–	–	Segments	Text
Total island area	–	–	–	–	–	–	–	–	Segments	Text
Total length of banks	–	–	–	–	–	–	–	–	Segments	Text
Total length of island perimeters	–	–	–	–	–	–	–	–	Segments	Text
Number and location of cutoffs and avulsions	–	–	–	–	–	–	–	–	Entire river reach	Text

S — single-thread channel.
M — multi-thread channel.
XS — cross section.
CP — centerline pixel.
[a] Aalto et al. (2008); Lauer & Parker (2008b).
[b] Pavelsky & Smith (2008).
[c] Fisher et al. (2013).
[d] Micheli et al. (2004); Micheli & Kirchner (2002).
[e] Güneralp & Rhoads (2008); Legleiter & Kyriakidis (2006).
[f] Peixoto et al. (2009).
[g] Continuous wavelet transforms; Mount, Tate, Sarker, & Thorne (2012).
[h] Baki & Gan (2012); Hossain, Gan, & Baki (2013).

(James, Hodgson, Ghoshal, & Latiolais, 2012; Wheaton, Brasington, Darby, & Sear, 2010). The temporal and spatial availability of data sets needed for this type of analysis, however, are still limited enough that the analysis of remotely sensed imagery remains a critical tool for studies of multi-temporal river dynamics.

Current methodologies have the potential to add great efficiency to the analysis task of river planview metrics, but a lack of method standardization in river change studies still persists (Hooke, 1980; Lawler, 1993; Peixoto, Nelson, & Wittmann, 2009). This problem arises from variation in data sources, analysis tools, and the objectives of the individual studies. This lack of methodological consistency between studies greatly confounds inter-study comparisons and data compilation efforts. Furthermore, the diversity of metrics used to quantify change complicates the comparison of results of planview river changes between studies. Reported measures include: lateral migration, erosion, accretion, area change as a percentage of river area, change in area per unit river length, river path length, sinuosity, curvature, radius of curvature, width, and areal changes in river channel position (Table 1). Bank erosion and channel migration rates represent the most commonly reported metrics and can be, but are not necessarily, synonymous. Bank erosion measurements quantify the material removed from the exposed face of a riverbank, and are reported as a linear distance per interval of time (e.g., meter (m) per year (yr)). Channel migration measures the net movement of a channel resulting from the change in river location due to the combined effects of erosion and deposition (Leopold, 1973; Leys & Werritty, 1999).

Numerous studies using remotely sensed data have determined lateral migration rates based on the lateral change in the river centerline position, commonly calculated as the midpoint between opposite banks (e.g. Aalto et al., 2008; Constantine, Dunne, Ahmed, Legleiter, & Lazarus, 2014; Konrad et al., 2011; Lauer & Parker, 2008b; Legleiter & Kyriakidis, 2006; Mount & Louis, 2005; Shields, Simon, & Steffen, 2000) or directly digitized by the analyst (e.g. Brice, 1977; Constantine, Dunne, & Hanson, 2009; Hooke & Harvey, 1983; Hooke & Yorke, 2010; Micheli, Kirchner, & Larsen, 2004; Micheli & Larsen, 2011; Micheli & Kirchner, 2002). For a single-threaded channel with a constant width and no positional errors in