Geoderma 209–210 (2013) 57–64

Contents lists available at SciVerse ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Separating scale-specific soil spatial variability: A comparison of multi-resolution analysis and empirical mode decomposition

Asim Biswas [a,*], Hamish P. Cresswell [b], Henry W. Chau [c], Raphael A. Viscarra Rossel [b], Bing C. Si [c]

[a] Department of Natural Resource Sciences, McGill University, 21111 Lakeshore Road, Ste-Anne-de-Bellevue, QC, H9X 3V9, Canada
[b] CSIRO Land and Water, Canberra, ACT 2601, Australia
[c] Department of Soil Science, University of Saskatchewan, Saskatoon, Saskatchewan S7N 5A8, Canada

ARTICLE INFO

Article history:
Received 5 June 2012
Received in revised form 20 November 2012
Accepted 9 June 2013
Available online 1 July 2013

Keywords:
Scale
Discrete wavelet transform
Nonstationary
Nonlinear
Intrinsic mode function

ABSTRACT

Soil spatial variability is scale dependent. In separating soil spatial variability at multiple scales, wavelet based multi-resolution analysis (MRA) is an established method, whereas empirical mode decomposition (EMD) has just been introduced in soil science. A careful comparison between these methods is necessary and is the goal of this research. Here a brief description of the methods is provided and they are compared using soil water storage (SWS) data observed along a 576 m transect. The MRA separated the variations of a spatial series into predefined scale intervals, each of which contributed differently to the overall variance of the series. EMD separated the overall variation into different mode functions (known as Intrinsic Mode Functions; IMFs) representing different scales as they are present in the series. The EMD did not use any predefined basis (such as mother wavelet in wavelet transform) for scale separation. The proportion of overall variance contributed at each scale was used to identify the most dominant scale. Correlation between the scale components (MRA products and IMFs) and different factors controlling SWS along the transect enabled identification of the dominant controls of SWS and the scales at which they occur.

1. Introduction

Soil varies considerably from location to location (Nielsen et al., 1973). Soil spatial variability is generally a product of the combined effect of soil physical, chemical, and biological processes that operate in different intensities and scales (Entin et al., 2000; Goovaerts, 1998). Adequate understanding of soil variability as a function of space and scale is necessary for developing logical, empirical and physical models of soil landscape processes (Corwin et al., 2006; Wilding et al., 1994).

Geostatistical analysis has been used to describe the variability of a soil property (Burgess and Webster, 1980; Webster and Oliver, 2001) or the correlation between two soil properties (Goovaerts and Webster, 1994) as a function of spatial scales. Spectral analysis, which approximates the spatial series by a sum of sine and cosine functions, has been used to quantify variations at different scales by converting spatial information into frequency information. The squared amplitude of the approximations at a particular frequency (equal to the frequency of the sine or cosine function) or scale (= sampling interval / frequency) represents the variance contribution of that frequency component towards the total variance in the spatial series (Brillinger, 2001; Koopmans, 1974). These methods assume stationarity in the mean and/or variance of the data over the spatial extent of sampling. However, the existence of a spatial trend creates nonstationarity in the spatial series. Wavelet analysis (Mallat, 1999) of a nonstationary spatial series produces a set of coefficients, known as wavelet coefficients. Each coefficient is nominally associated with a scale and location and can be used to view the information content of the data series at various spatial resolutions through a process called multi-resolution analysis (MRA). This generally enables visualization of structures prevailing at different spatial scales as one can see the sub-cellular structures of living bodies using a microscope (Hubbard, 1998; Walker, 1999). Wavelet based MRA has been used widely in different fields of science, including soil science (Lark and Webster, 1999, 2001; Lark et al., 2004), to separate scale specific variations. One of the advantages of wavelet analysis is that it does not rely on any stationarity assumption about the data series. However, this analysis assumes the controlling processes of the spatial series are linear (Huang et al., 1998). There is another MRA based on wavelet packet analysis that has also been used to represent complex soil variation at different scales (Lark, 2006, 2007). In wavelet packet analysis the spatial series can be decomposed to a greater or lesser number of spatial scales (Percival and Walden, 2000). In this paper, we will limit our scope by discussing only the discrete wavelet based MRA.

Another advanced analysis technique, the empirical mode decomposition (EMD), has recently been used in soil science (Biswas and Si, 2011a; Biswas et al., 2009) to separate the spatial variability at multiple scales. The EMD extracts oscillations from the data series into a finite and often small number of mode functions (intrinsic mode functions;

* Corresponding author . Tel.: +1 514 398 7620; fax: +1 514 398 7990.
E-mail addresses: asimbiswas@gmail.com, asim.biswas@mcgill.ca (A. Biswas).

0016-7061/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geoderma.2013.06.003

IMFs) according to different spatial scales (Huang and Wu, 2008; Huang et al., 1998). Each IMF represents the realizations of underlying soil processes operating at similar scales and controlling the variability of soil properties at that scale. Therefore, the overall variability in any soil property can be seen at different spatial resolutions. One of the main advantages of this method is that the EMD does not depend on any pre-assumed base function (e.g., unlike wavelet transform, which uses mother wavelet as the base function). Moreover, this method is known to deal with different types of spatial series including those that are nonstationary and nonlinear (Huang et al., 1998).

Both MRA and EMD have been used in soil science to separate the overall variation in a soil property into multiple scales. The output (e.g., scale component of MRA and IMF of EMD) has been used to examine the scale-specific variance contribution and identify dominant scales and the control at that scale. For example, Lark and Webster (1999) used MRA to separate the overall variation in soil electrical conductivity and clay content into multiple scales. Lark et al. (2004) calculated the scale-specific wavelet variance in soil properties and nitrous oxide gas emission from soil to identify the most dominant scale. The authors identified the scale-specific controls of nitrous oxide gas emission from soil at different parts of the landscape from the wavelet correlation between MRA decomposed scale components of soil properties and gas emission (Lark et al., 2004). EMD has been used to decompose the overall variation in soil water storage (SWS) at multiple scales (Biswas et al., 2009). The output or the IMFs were used to examine the variance contribution at different scales and to identify the dominant controls of SWS at those scales (Biswas and Si, 2011a). Both methods have showed considerable promise in examining the scale specific soil spatial variability. However, the efficacy of these methods can only be examined by comparing them side-by-side using a single data set. The goal of this paper is to compare the well established wavelet based MRA with EMD in revealing the scale specific variations hidden in a spatial series. The methods are described and then compared using observations of SWS.

2. Materials and methods

2.1. Study site

SWS measured along a transect of 128 points (4.5 m regular interval) at St. Denis National Wildlife Area (SDNWA), Saskatchewan, Canada (Fig. 1) was used to compare MRA and EMD. The measurements of SWS were part of a larger project and have been used in other publications (Biswas and Si, 2011a, b, c; Biswas et al., 2012). We have used the spatial series of SWS measured along the transect (on one day) as an example to compare the methods. A detailed description of the study site, measurement of SWS and the calibration of measurement instruments can be found in Biswas and Si (2011a, b, c) and Biswas et al. (2012). Briefly, the study area is located within the Prairie Pothole Region of North America, the largest wetland landscape in North America encompassing approximately 780,000 km^2 area from the North-Central United States to South-Central Canada (Fig. 1). The wetlands and the knolls in this area form a 'hummocky' landscape with slopes varying from 10 to 15%. A transect of 576 m was established over several rounded knolls and depressions representing different landform cycles in the study area (Fig. 1). The landform units along the transect were

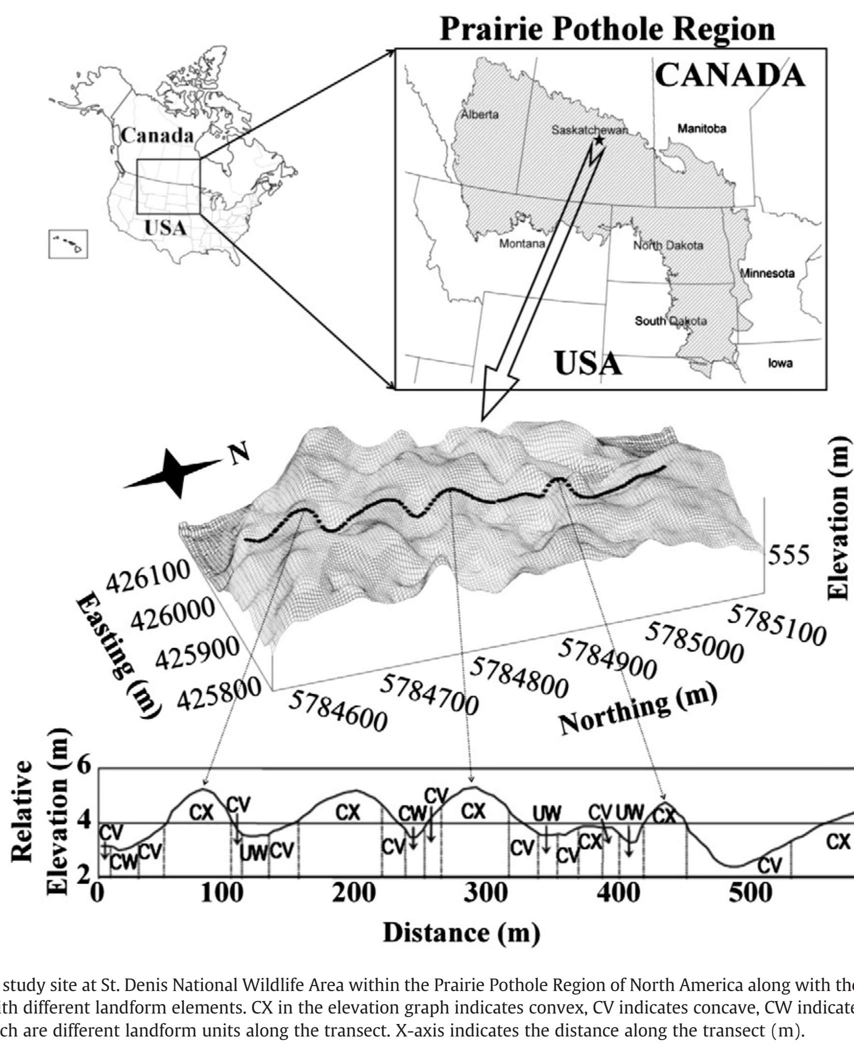

Fig. 1. Geographic location of the study site at St. Denis National Wildlife Area within the Prairie Pothole Region of North America along with the 3-dimensional and cross sectional view of the transect identified with different landform elements. CX in the elevation graph indicates convex, CV indicates concave, CW indicates cultivated wetland and UW indicates uncultivated wetlands, which are different landform units along the transect. X-axis indicates the distance along the transect (m).