Quantifying soil spatial variability for sustainable resource management

McGill

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Background

- B.Sc. (Agriculture) in Soil Science (East India; 2000 - 2004)
- M.Sc. (Agriculture) in Soil Science (South India; 2004 - 2006)-
  - Soil Pedology (soil formation and development)
  - Soil Mineralogy (soil mineralogical composition)
  - Spatial Variability
- Ph.D. in Soil Science (Canada; May 2007 – June 2011)-
  - Soil Physics
  - Soil Hydrology (vadose-zone hydrology)
  - Spatial Variability
  - Pedometrics (Pedology + mathematics/statistics)
- Environmental Research Scientist (Post doc) (CSIRO; July 2011 – April 2013)
- Assistant Professor (McGill University; May 2013- Present)

Challenges

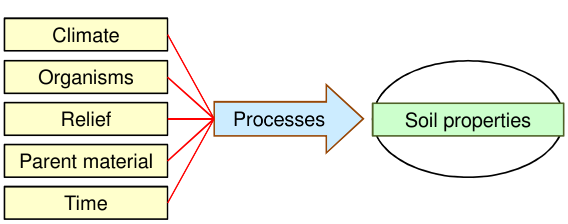
- **Change in -**
  - Population
  - Environment
  - Weather and Climate
  - Biodiversity
  - Land use and Land management
- **Threats to -**
  - Soil security (e.g. soil erosion, degradation)
  - Water security (e.g. accessibility and quality)
  - Food security
  - Agricultural and natural resources
  - Ecosystem and human health

Opportunities

- We can not control things beyond our reach (weather events, changing climate).
- What ever lost is lost and will not get back.
- We should not let it go what we have.
- We can manage natural resources better (soil, water).
- Manage wisely and efficiently, more sustainably.
- Need quantitative information of our natural resources.

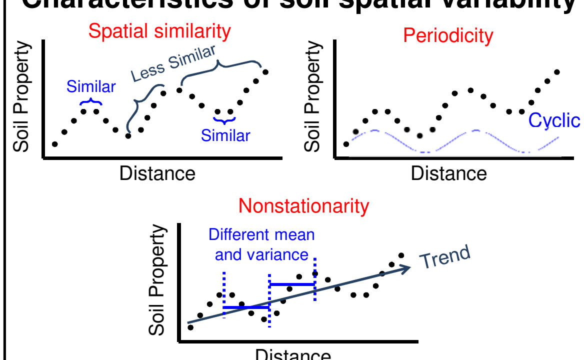
Soil and its formation

One of the 3 major natural resources



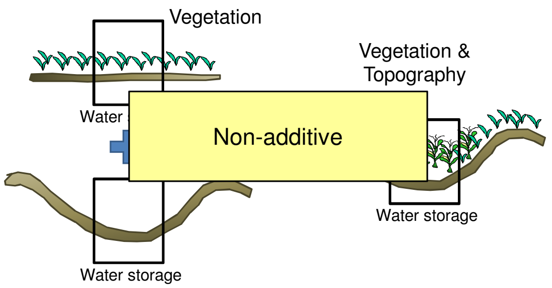
Soil properties vary from location to location

Characteristics of soil spatial variability



Characteristics of soil spatial variability

Nonlinearity



Characteristics of soil spatial variability

Nonlinearity

"No single medicine for all diseases"

- Methods to better analyze soil spatial variability.
- Use of the information to infer underlying soil processes.
- What does soil variability inform about soil development?
- Using information of soil variability for attribute prediction.

Soil spatial variability

- ✓ What is the dominant scale of variation?
- ✓ Where do I sample?
- ✓ Where do I monitor?
- ✓ How do I untangle complexity to produce better predictive relationship?
- ✓ How do I assess soil function at multiple scales?
- ✓ How do I meet user demand (farmers vs. catchment managers)?
- ✓ What do I know on the underling processes and the development of soil?

Relationship b/w soil properties

- Difficult to measure (e.g. K_s, water retention)
- Relatively easy to measure (e.g. particle sizes, OC)
- Predictive relationship (e.g. pedotransfer functions)
- Variability in soil properties
- Variability in the relationship

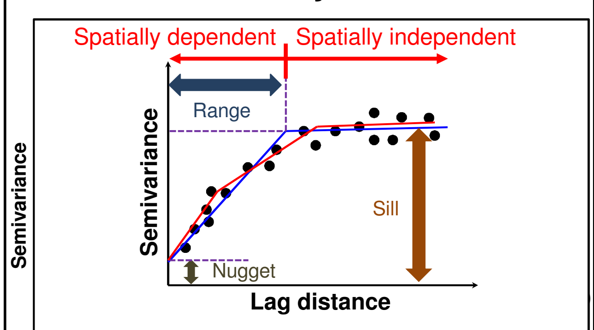
CANADIAN JOURNAL OF SOIL SCIENCE REVUE CANADIENNE DE LA SCIENCE DU SOL
2008, 89, 473-488

Spatial relationship between soil hydraulic and soil physical properties in a farm field

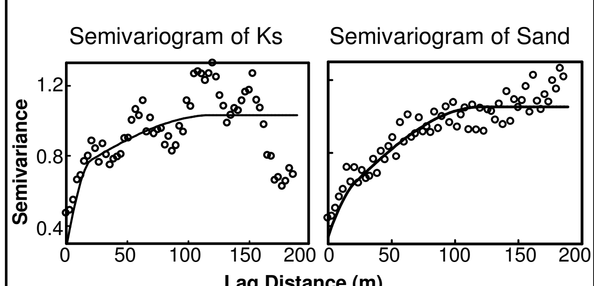
Asim Biswas and Bing Cheng Si

Department of Soil Science, University of Saskatchewan, Saskatoon, Saskatchewan, Canada S7N 5A8. Received 7 September 2008, accepted 6 May 2009.

Geostatistical analysis

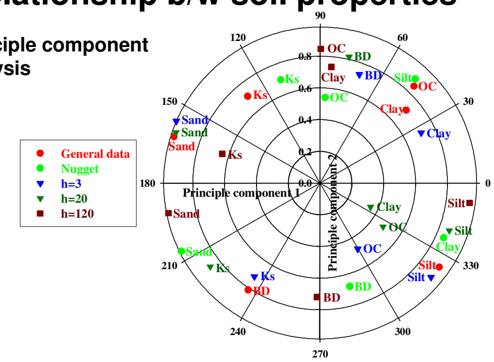


Geostatistical analysis



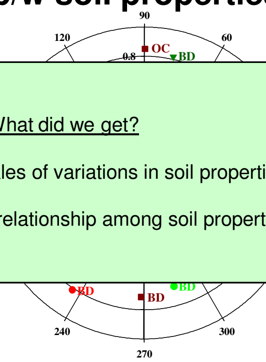
Relationship b/w soil properties

Principle component analysis



Relationship b/w soil properties

Principle component



What did we get?

Information on scales of variations in soil properties

The scale-varying relationship among soil properties

N-dynamics and landscape characteristics

Nonlin. Processes Geophys., 15, 397–407, 2008
www.nonlin-processes-geophys.net/15/397/2008/

Nonlinear Processes in Geophysics

Spatial relationship between δ^{15}N and elevation in agricultural landscapes

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Received: 28 September 2007 – Revised: 4 April 2008 – Accepted: 4 April 2008 – Published: 13 May 2008

Abstract. Understanding of the nitrogen (N) cycle and its spatial variability is important for managing ecosystems. Soil δ^{15}N, as an important indicator of different soil nitrogen cycling processes, may provide critical information about the spatial variability in soil N cycling. The objective of this study was to examine the dominant landscape

Parry, 1989). Variations in the nature and magnitude of N-cycling processes within a landscape ultimately control the availability of mineral N (NH_4^+ and NO_3^-) which is essential for agricultural production and likewise is the source of serious environmental pollution (e.g., NO_3^- contamination of groundwater and emissions of N_2O, an important greenhouse

N-dynamics and landscape characteristics

Nonlin. Processes Geophys., 15, 397–407, 2008
www.nonlin-processes-geophys.net/15/397/2008/

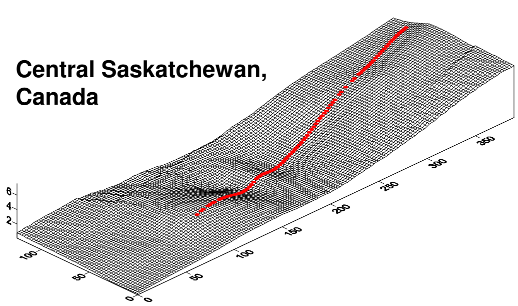
Nonlinear Processes

N- Dynamics

- isotopes of nitrogen
- isotopic fractionation in physical, chemical and biological processes
  - nitrification
  - denitrification
  - ammonia volatilization
- favour lighter ^{14}N and depleted first
- N pool develops distinctly different δ^{15}N signals

N-dynamics and landscape characteristics

Central Saskatchewan, Canada

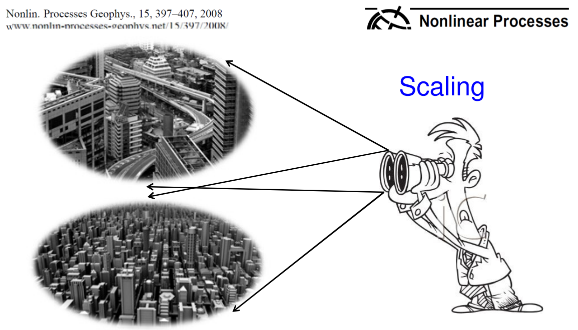


N-dynamics and landscape characteristics

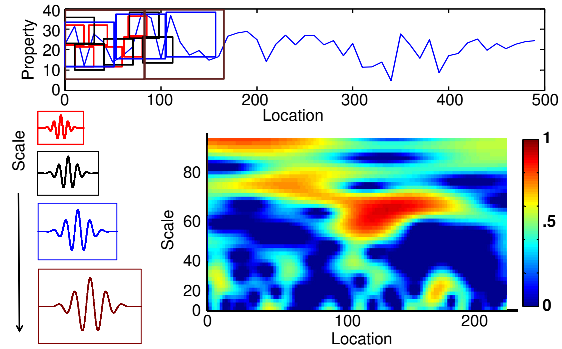
Wavelet Transform

Distance (m)

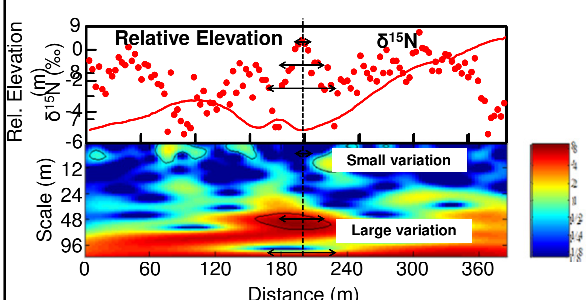
N-dynamics and landscape characteristics



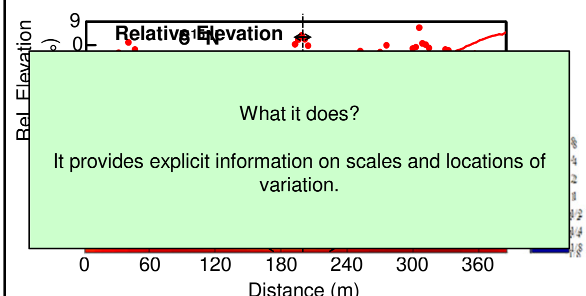
Wavelet transform



N-dynamics and landscape characteristics



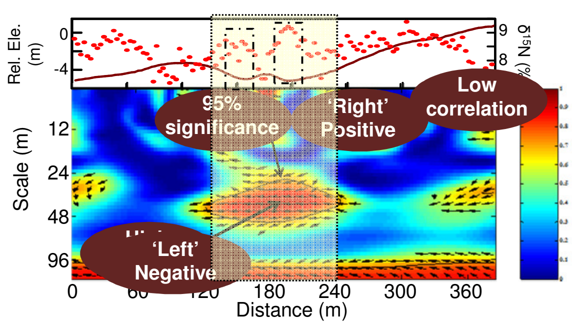
N-dynamics and landscape characteristics



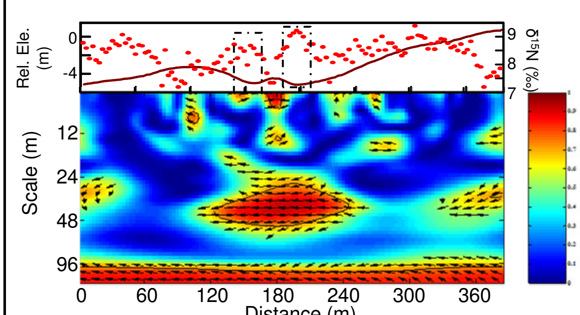
What it does?

It provides explicit information on scales and locations of variation.

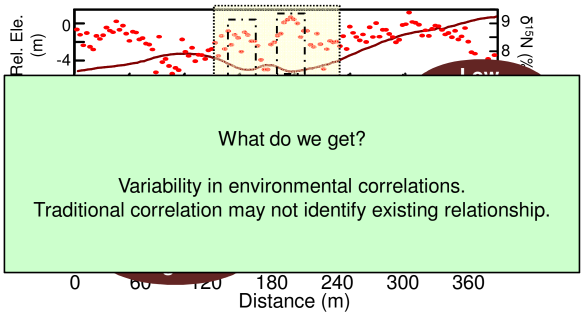
N-dynamics and landscape characteristics



N-dynamics and landscape characteristics



N-dynamics and landscape characteristics



What do we get?

Variability in environmental correlations.
Traditional correlation may not identify existing relationship.

Similarity of the spatial pattern

Journal of Hydrology 408 (2011) 100–112

Contents lists available at ScienceDirect

Journal of Hydrology

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

Scales and locations of time stability of soil water storage in a hummocky landscape

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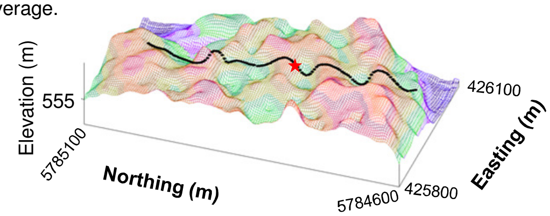
SUMMARY

Different factors and processes operating in different intensities and at different space–time scales result in strong spatio-temporal variability in soil water storage. However, there is similarity between the overall spatial patterns of soil water storage measured at different times, which has been identified as time stability. The objective of this study was to examine the scales and locations of time stability of soil-water storage spatial patterns at different seasons and depths in a hummocky landscape. Soil water storage was measured up to 140 cm depth over a 4-year period using time domain reflectometry and a neutron probe along a transect in the St. Denis National Wildlife Area, Saskatchewan, Canada. The transect was 576 m long with 128 sampling points (4.5 m sampling interval) and traversed several knolls and depressions.

Similarity of the spatial pattern

- ✓ Similar relationship can be developed over time.
- ✓ Intra-season, inter-season, and inter-annual.
- ✓ The wet locations stay wet and dry locations stay dry over time.
- ✓ Identify the location with soil water storage stays close to field average.



Similarity of the spatial pattern

- ✓ Similar relationship can be developed over time.
- ✓ Intra-season, inter-season, and inter-annual.
- ✓ The wet locations stay wet and dry locations stay dry over time.

Such representative locations can be used to monitor or validate remote sensing measurements.

Similarity between depths

Soil & Water Management & Conservation

Depth Persistence of the Spatial Pattern of Soil Water Storage in a Hummocky Landscape

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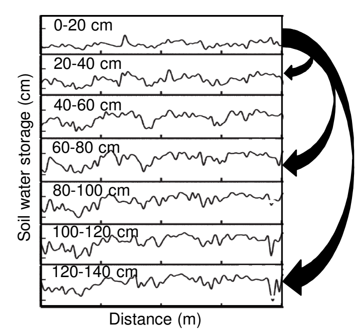
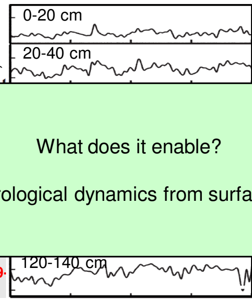
SSSAJ, 2011, 75: 1099-1109

Information on surface soil water is readily available either from satellite images or from other surface measurements. Understanding the relationships between soil water at the surface and subsurface layers can help understand hydrological processes at depth. The objective of this study was to examine the similarities in the overall and scale specific spatial patterns of soil water storage at different depths. Soil water content was measured at the 20-cm depth increments, from the surface to a depth of 140 cm, using a neutron probe and time-domain reflectometry along a transect traversed over several knolls and depressions at St. Denis National Wildlife Area (SDNWA), Saskatchewan, Canada. High soil water storage was observed in depressions and low water storage on knolls creating an inverse spatial pattern relative to elevation. High Spearman rank correlation coefficients between the surface and subsurface soil layers indicated strong similarity in the overall spatial pattern of soil water at different depths. Soil water contents in layers close in vertical distance had stronger similarity than that of layers far apart. Wavelet coherency analysis indicated strong similarity in the large-scale (>72 m) spatial patterns of soil water at the surface layer and deeper layers during recharge period. However, large-scale similarity was weaker

Similarity between depths



Similarity between depths



What does it enable?

Whole profile hydrological dynamics from surface measurements.

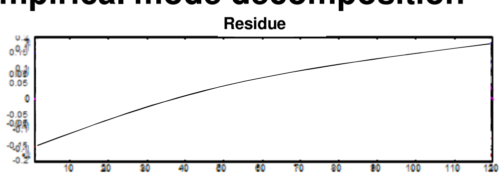
SSSAJ, 2011, 75: 1099

Separating scale-specific variations

- Scale-specific spatial variations
- Identify dominant scales and their relative contribution to overall variability

Empirical mode decomposition

Empirical mode decomposition



Separating scale-specific variations

Soil Physics

Revealing the Controls of Soil Water Storage at Different Scales in a Hummocky Landscape

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SSSAJ, 2011, 75: 1295-1306

Soil water storage is controlled by topography, soil texture, vegetation, water routing processes, and the depth to the water table. Interactions among these factors may give rise to scale-dependent nonstationary and nonlinear patterns in soil water storage. The objectives of this study were to identify the dominant scales of variation of nonstationary and nonlinear soil water storage and delineate the dominant controls at those scales in a hummocky landscape using the Hilbert–Huang transform (HHT). Soil water storage (up to 140 cm) was measured along a 128-point transect established at St. Denis National Wildlife Area, Saskatchewan, Canada, using time domain reflectometry and a neutron probe. Empirical mode decomposition was used to decompose the measured soil water storage series into six different intrinsic mode functions (IMFs) according on their characteristic scales. The first IMF represented the variations at small scales, the second IMF might characterize the variations associated with microtopography and the landform elements. The IMF 3 was highly correlated with elevation and had the largest variance contribution toward the total variance among all the IMFs. The fourth IMF was correlated to organic C (OC), showing the long-term history of water availability, which may be a reflection of topographic setting or the elevation. The fifth and sixth IMFs were associated with elevation, soil texture, and OC but they contributed a small fraction of the total variance. Therefore, decomposition made through HHT was physically meaningful and provided improved prediction of soil water storage from topography, soil texture, and OC.

Abbreviations: EMD, empirical mode decomposition; HHT, Hilbert–Huang transform; HSA,

Separating scale-specific variations

IMF	% Var. Cont.	Correlation				
		Re. Ele.	Sand	Silt	Clay	OC
1	6	0.00	0.02	-0.08	0.08	-0.01
2	10	-0.38**	-0.11	0.10	0.03	0.38**
3	**41**	**-0.70****	-0.07	0.00	0.12	0.58**
4	6	-0.22*	-0.26**	0.11	0.26**	0.31**
5	5	0.55**	-0.59**	0.43**	0.36**	0.11
6	4	0.37**	-0.57**	0.38**	0.39**	0.31**

* $P < 0.05$; ** $P < 0.01$

Var. Cont.- variance contribution, Re. Ele.-relative elevation, OC- organic carbon

Separating scale-specific variations

IMF	% Var. Cont.	Correlation				
		Re. Ele.	Sand	Silt	Clay	OC

What does it enable?

Scale-specific correlation.
Dominant controlling factors at different scales.

Var. Cont.- variance contribution, Re. Ele.-relative elevation, OC- organic carbon

Separating scale-specific variations in two dimensions

One property may vary at one scale, while others at other scales

Bi-dimensional empirical mode decomposition

Separating Scale-Specific Spatial Variability in Two Dimensions using Bi-Dimensional Empirical Mode Decomposition

SSSAJ, 2013, 77: 1991-1995

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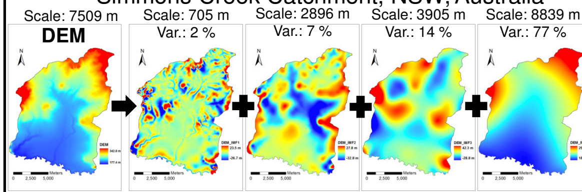
Empirical mode decomposition (EMD) has been used to separate the spatial variability in soil properties at different scales in one dimension. The objective of this note is to illustrate the use of a two-dimensional extension of the EMD (known as bi-dimensional empirical mode decomposition or BEMD) to separate the spatial variability at different scales. A digital elevation model (DEM)

Separating scale-specific variations in two dimensions

Simmons Creek Catchment, NSW, Australia



One property may vary at one scale, while others at other scales

Separating scale-specific variations in two dimensions

What does it enable?

Scale-specific predictions
Multi-scale digital soil mapping

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Underlying soil processes

- Anisotropic soil spatial variations

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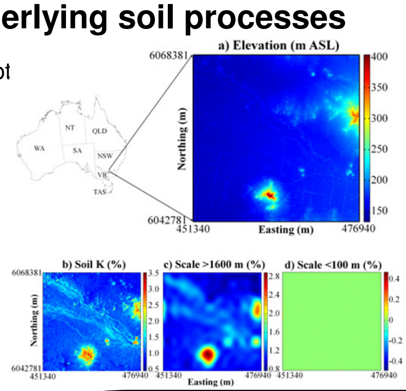
Contents lists available at ScienceDirect
Geoderma
journal homepage: www.elsevier.com/locate/geoderma

Curvelet transform to study scale-dependent anisotropic soil spatial variation

Asim Biswas [a,b,*], Hamish P. Cresswell [b], 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

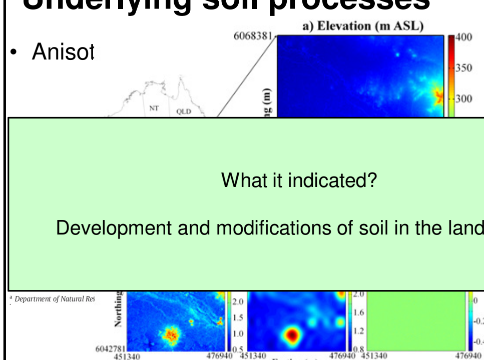
Underlying soil processes

- Anisot



Underlying soil processes

- Anisot

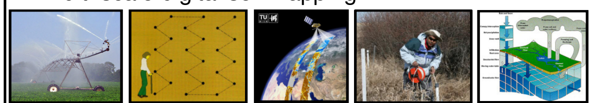


What it indicated?

Development and modifications of soil in the landscape.

Summary

- Optimize sampling strategy and experimental design
  - Scales of hydrological processes
- Identify representative locations for monitoring
- Previously hidden predictive relationship
- Infer at depth from surface measurements
- Identify environmental controls at different scales
- Scale-specific prediction
- Multi-scale digital soil mapping



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Thank You

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