Fractal behavior of soil water storage at multiple depths

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Introduction

- Spatio-temporal variability of soil water storage (SWS) has important hydrologic and climatic applications.
- It has been described using the principle of self similarity (scaling properties).
- Scaling properties have been used to transfer information from one scale to another for the surface layer (Mascaro et al., 2010).
- Examining subsurface layer scaling properties is required to transfer information for the whole soil profile and to understand deep layer soil water dynamics.

Objective

To examine the scaling properties of SWS at multiple depths. The information can be used in modeling of soil water dynamics and plant growth.

Materials and Methods

- Study Site: St. Denis National Wildlife Area (SDNWA) within the Prairie Pothole Region of North America (Fig. 1).

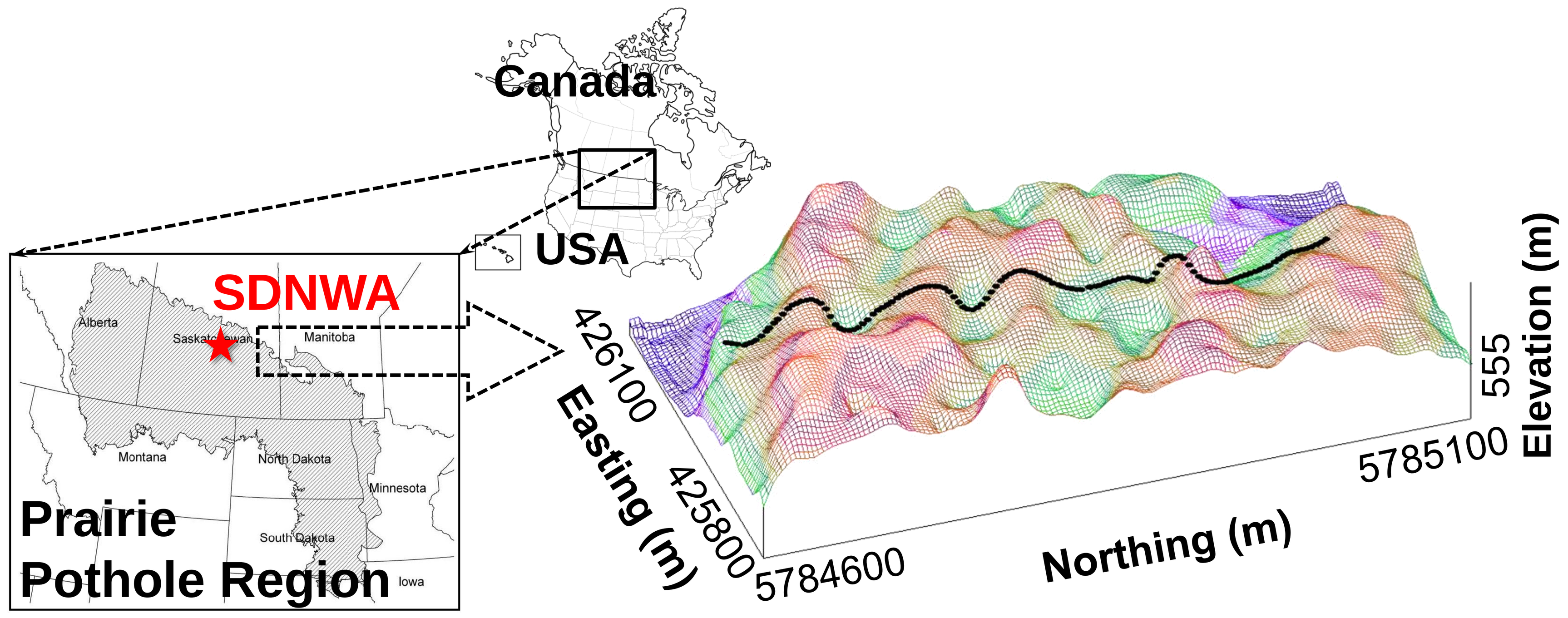

Fig. 1: Geographic location and transect position at the study site.

- SWS measurement: 128 points along a transect at 4.5-m intervals down to 1.4-m depth (0.2-m increments) using time domain reflectometry and neutron probe for 5 years.
- Landscape: Hummocky (Fig. 1); Soil: Borolls to Aquolls; Parent material: Loamy glacial till; Vegetation: Mixed grass.
- Data analysis: Multifractal analysis (Evertsz and Mandelbrot, 1992) was used to examine the statistical similarity in the spatial patterns of SWS over a range of scales using multiple fractal dimensions (scaling indices).

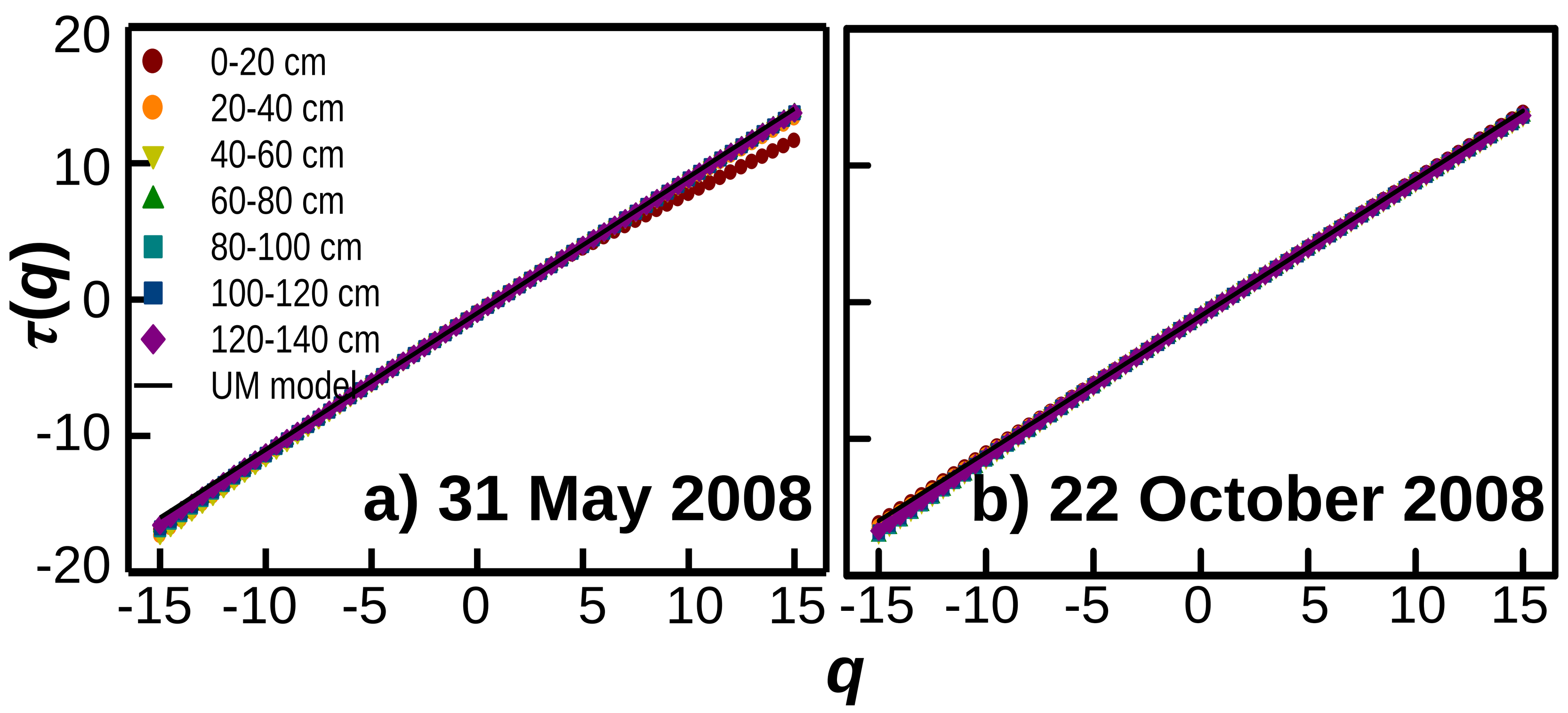

Fig. 2: The $\tau(q)$ curve of SWS during a) wet period (31 May 2008) and b) dry period (22 October 2008) at different depths. The black solid line is the reference UM model.

- The linearity of $\tau(q)$ or the probability of mass exponents is used to examine the degree of fractality (i.e., monofractal (linear) or multifractal (curved)) by comparing with the reference 1:1 type UM model (Fig. 2). q is the statistical moment.
- The $f(q)$ curve or the multifractal spectrum is used to portray the variability in SWS. A wide spectrum (large $\alpha_{max} - \alpha_{min}$) indicates heterogeneity in the local scaling indices (α) and thus in the distribution of SWS (Fig. 3).

Results and Discussion

- Surface (0–0.2 m) SWS exhibited multifractal behavior (multi-scaling) during the wet period (e.g., spring, early summer; Fig. 2a and 3a).
- This indicates the requirement for multiple scaling indices to transfer spatial variability information from one scale to another.
- Behavior gradually became monofractal (mono-scaling) with increasing depth (Fig. 2a and 3a).
- This means a single scaling index will be sufficient to upscale/downscale spatial variability information.
- In contrast, all soil layers during the dry period (e.g., later summer, fall) exhibited monofractal behavior (mono-scaling; Fig. 2b and 3b).
- This may be due to the strong evaporative demand from growing vegetation equalizing spatial patterns.
- This behavior repeated over five years.
- There was strong similarity between the scaling indices of the surface and subsurface layers.

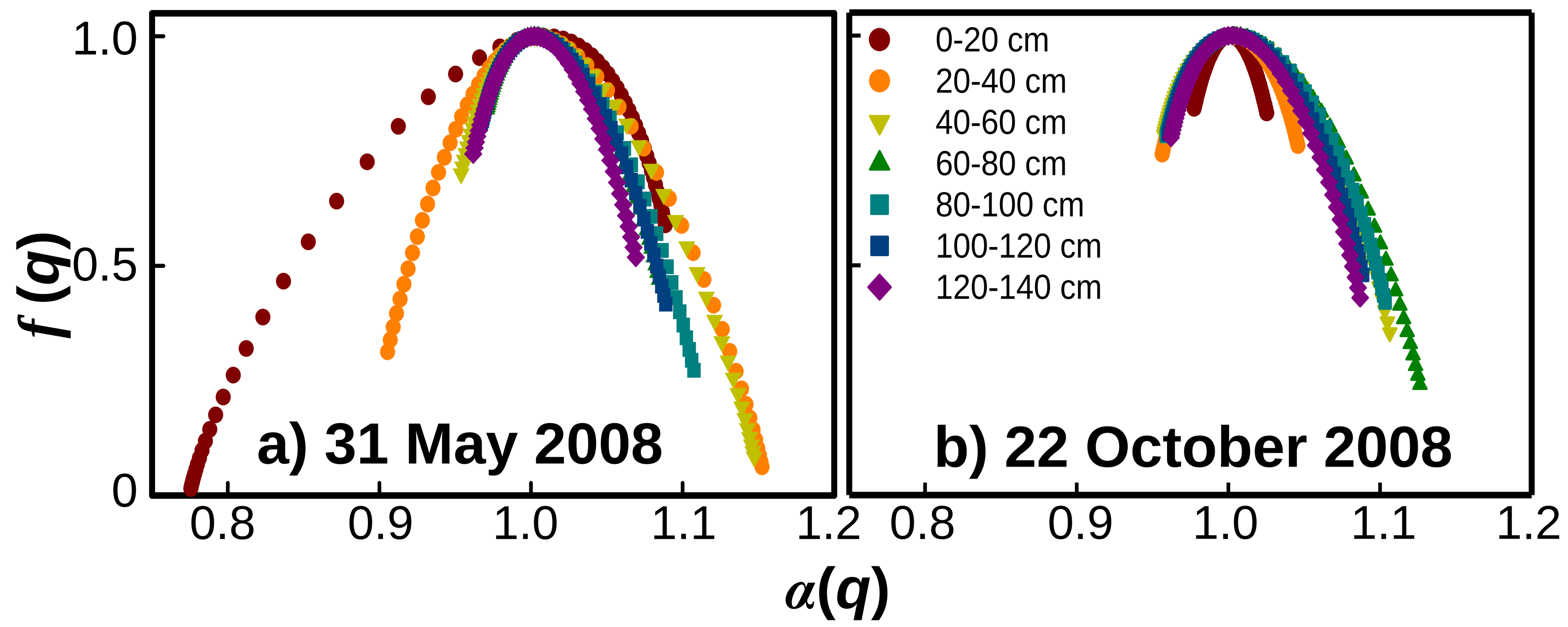

Fig. 3: The $f(q)$ or multifractal spectrum of SWS during a) wet period (31 May 2008) and b) dry period (22 October 2008) at different depths.

Conclusion

In the landscape studied, scaling properties from the surface SWS data can be used to scale SWS in deeper layers enabling inference on spatial and temporal variation in profile soil water dynamics.

References

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Further information

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