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The case for locally scale optimized land-surface parameters

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Land-surface parameters (LSPs) and scale

- The ***scale-dependency of most LSPs*** has been a persistent theme in geomorphometry for decades.

- Researchers have explored how LSP scaling can be utilized in environmental modelling applications to improve predictive soils, vegetation, and geological mapping.

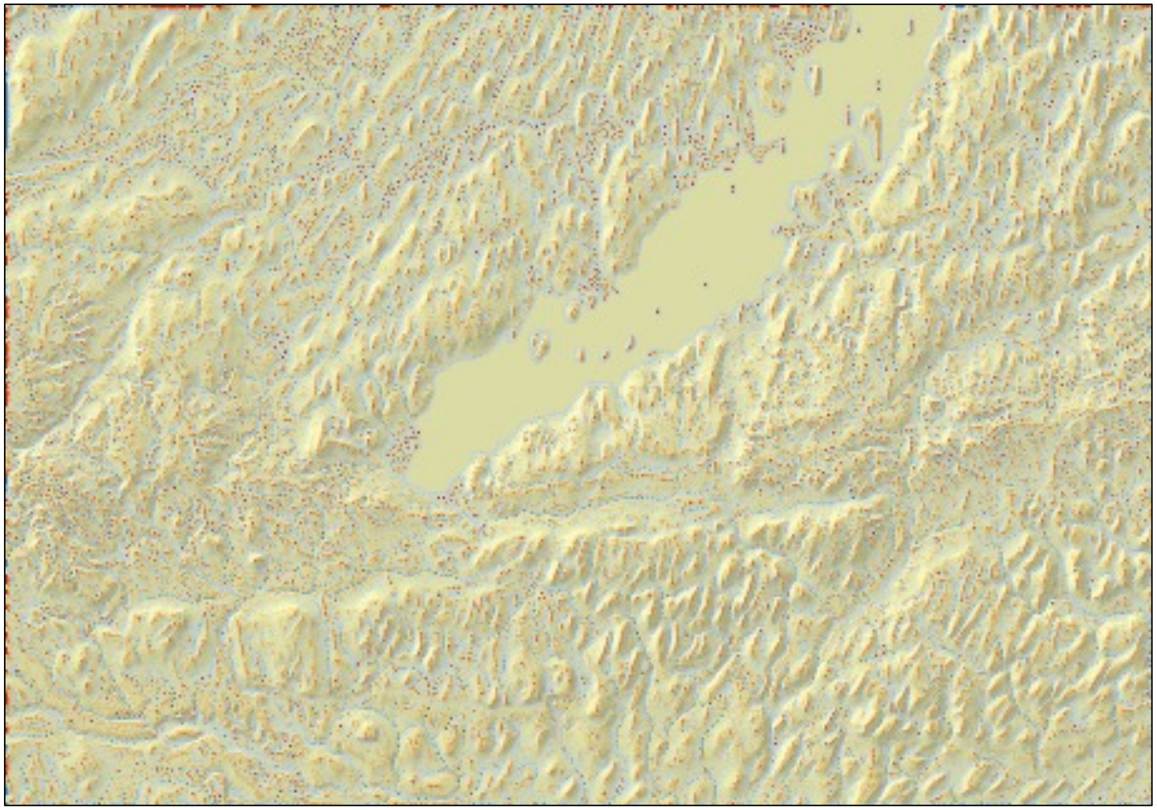
- Generally, adding ***multiscale topographic information can improve model outcomes***. Conceptually, it's best to ***match the scale*** of LSP representation with the scale of the landscape processes being modelled.

Land-surface parameters (LSPs) and scale

- Some LSPs are ***inherently scale dependent*** because they are ***defined over an area***, including:
  - Measures of local topographic position, e.g., deviation from mean elevation (*Dev*) and elevation percentile (*EP*)
  - Measures of topographic roughness/complexity and anisotropy
  - Measures of local relief/ruggedness/hypsometry

- Other LSPs, like slope, aspect, and curvatures, are ***sensitive to the scale of topographic detail***.
  - Are we interested in characterizing the pattern of slope for the microtopography, hillslope, valley, or mountain range?
  - To measure these LSPs at one scale, you must remove the topographic variability at smaller spatial scales.

Multi-scale land-surface parameters



An animation of deviation from mean elevation (*Dev*) measured using a wide range of window sizes, i.e., calculated using increasingly larger neighbourhoods.

Notice how different topographic features (landforms) are emphasized at different scales.

Multi-scale land-surface parameters

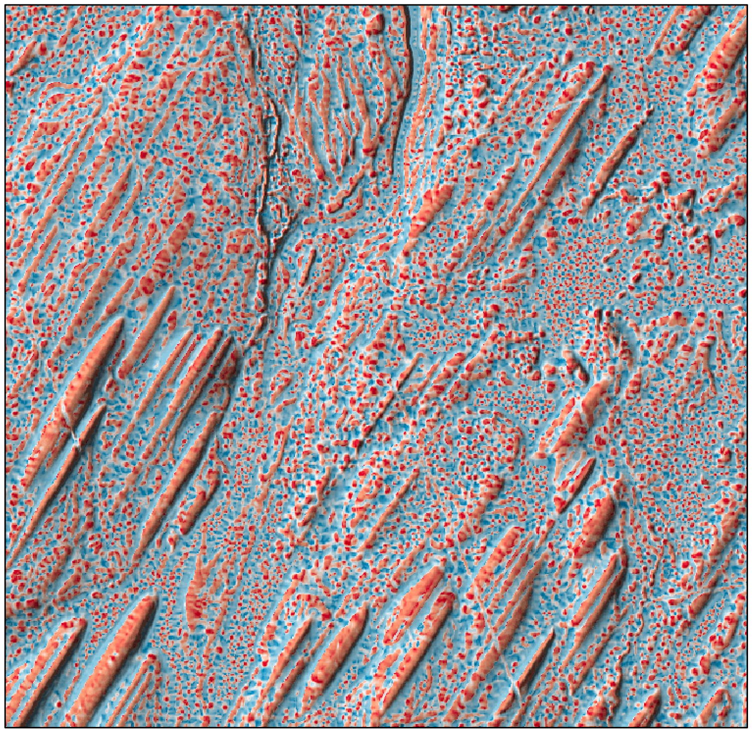
- There are many methods used for scaling DEM data and to measure LSPs across varying scale, including:
  - Changing DEM grid resolution through interpolation/resampling
  - Changing the measurement support by modifying the kernel size
  - Using geostatistical methods
  - Using fractals
  - Using object-based image segmentation
  - Using ***Gaussian scale-space theory*** or Gaussian pyramiding

Newman et al. 2022. Local scale optimization of geomorphometric land surface parameters using scale-standardized Gaussian scale-space Computers and Geosciences, 165, 105144 15 pp. DOI: 10.1016/j.cageo.2022.105144.

Gaussian scale-space (GSS)

- GSS theory is a framework for multi-scale signal representation developed by the computer vision and image processing communities.
- It identifies structures at different scales by deriving a family of smoothed images (the ‘scale-space’), parametrized by the size of the smoothing kernel used for suppressing fine-scale structures.
- Gaussian filtering is used for smoothing because they guarantee that no artificial local extrema are created with increasing scale.
- Gaussian pyramiding is an example, but scale selection is dictate by the pyramiding sequence.

Gaussian scale-space (GSS)



Shape index extracted from a DEM at varying scale using a GSS to strip away topographic detail at smaller scales, extracted using the GSS tool in WhiteboxTools.

The importance of performance

- The more computationally performant a method for scaling a DEM is, the ***denser the scale-space can be sampled***.

- The field of computer vision has made many strides on this front:
  - Integral image transforms, fast approximate Gaussian filtering, utilizing the redundancy between adjacent filters, and efficient algorithm parallelization

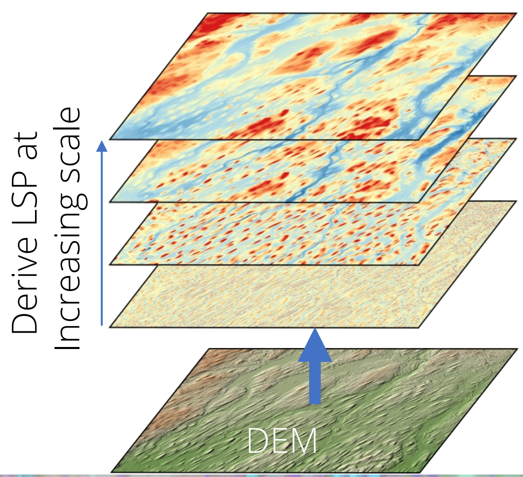
- In most cases, there is more variability in LSP scale signatures at smaller scales than large.

- Ideally, you want control over the density of scale-space sampling, rather than letting the scaling method dictate it, e.g., Gaussian pyramiding.

Scale selection for data reduction

- Data reduction is typically accomplished by using statistical procedures to identify the scales with the ***greatest predictive power*** or ***minimal correlation*** with other predictors.

A scale stack shows a
Topographic attribute
at multiple scales



Scale selection
(data reduction)

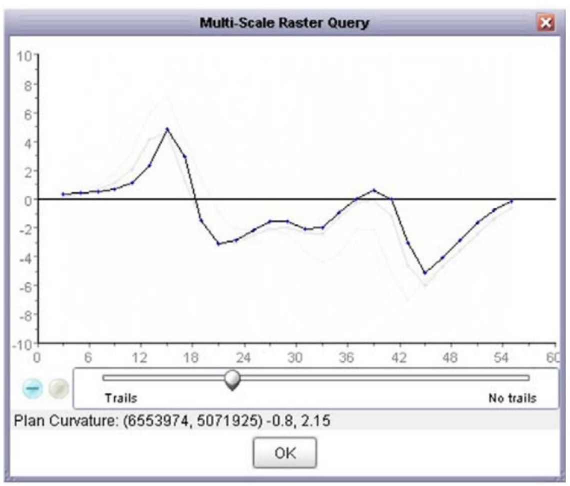
Identify the scaled LSP with the greatest potential for moving forward to the modelling stage

Model

Selected LSPs become model predictors along with other predictors

Locally optimized scale selection

- Wood (2009), in his LandSerf software, was one of the first to recommend using scale signatures to ***identify characteristic scales*** for each site. Scaling was achieved by using a ***best-fit quadratic surface of varying size***.



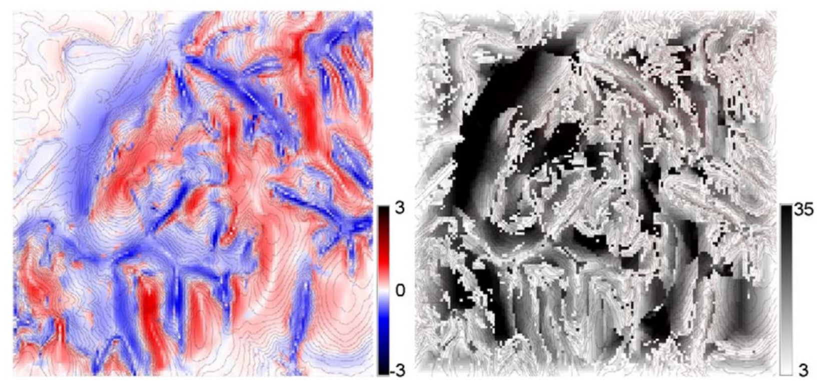
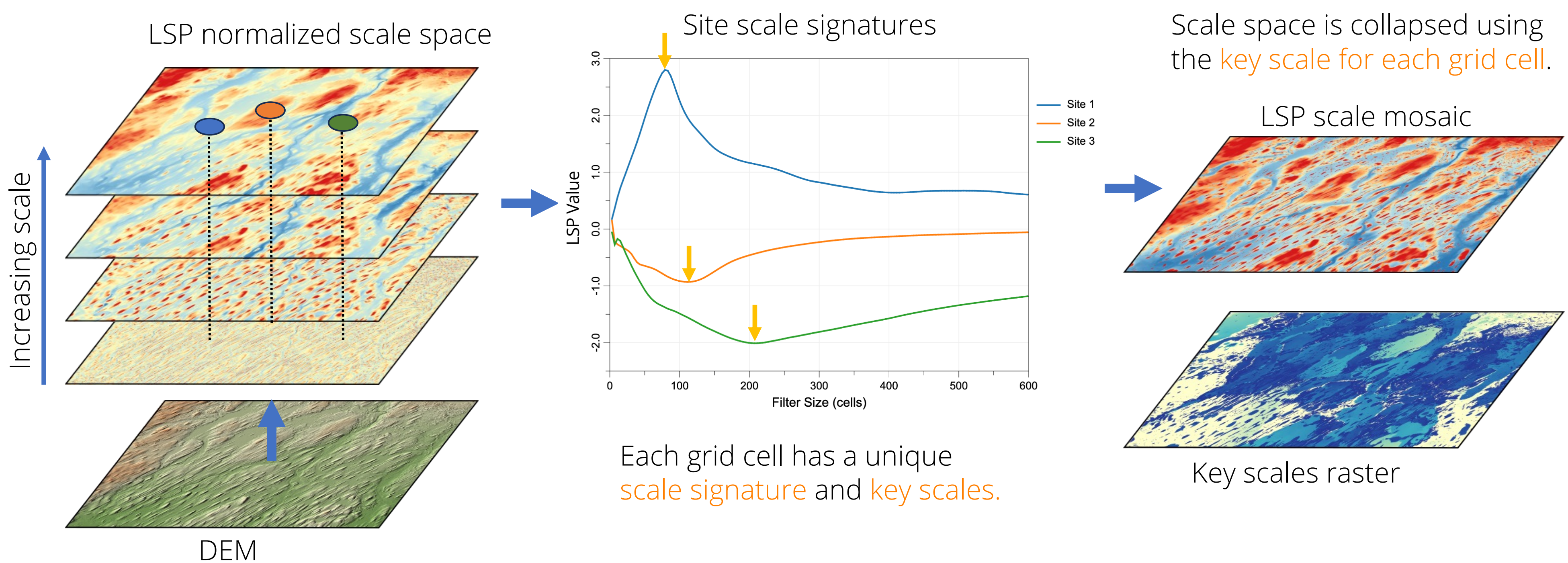


FIGURE 11 Maximum absolute profile curvature (per 100 m) measured over all scales between 75 m and 1.7 km (window sizes 3 to 35). The image to the right shows the window scale (in pixels) at which the most extreme value of profile curvature occurs. (See page 725 in Colour Plate Section at the back of the book.)

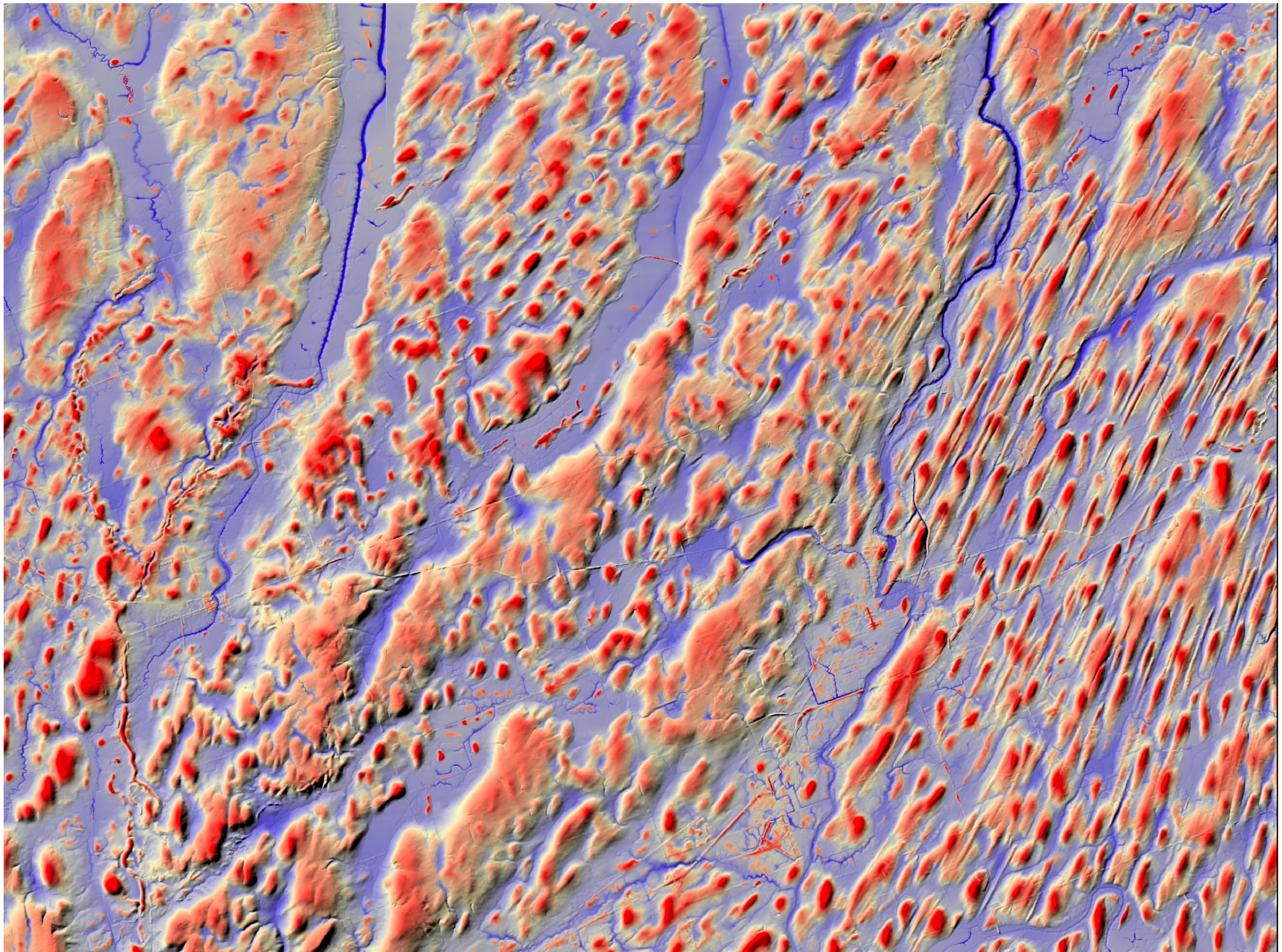
Locally optimized scale selection



Uniform vs. locally optimized LSP scale selection

- Using the 'uniform' multi-scale approach:
  - Scale selection is ***an empirical exercise*** based on finding scales that provide the optimal model performance, or minimal correlation among scaled LSPs.
  - Relatively few, uniform scales are ultimately presented to the model.

- Using locally optimized scale selection (scale mosaics):
  - Key scales are selected ***based on the unique topographic setting of a site***. Since topography is an expression of process, this approach to scale selection ***should be more representative of process scales***.
  - There is potential for every sampled scale to be represented in the final mosaic. A scale mosaic is therefore ***very information dense***.



A *Dev* scale mosaic for a complex drumlin field.

Measures *Dev* at the scale that a site is most deviated (i.e., elevated or low-lying) within its landscape context, which is a different scale for each grid cell in the DEM.

Defining key scales from scale signatures

- There may be other ways to identify key scales from scale signatures, but ***peaks/troughs and other inflection points*** are likely candidates.

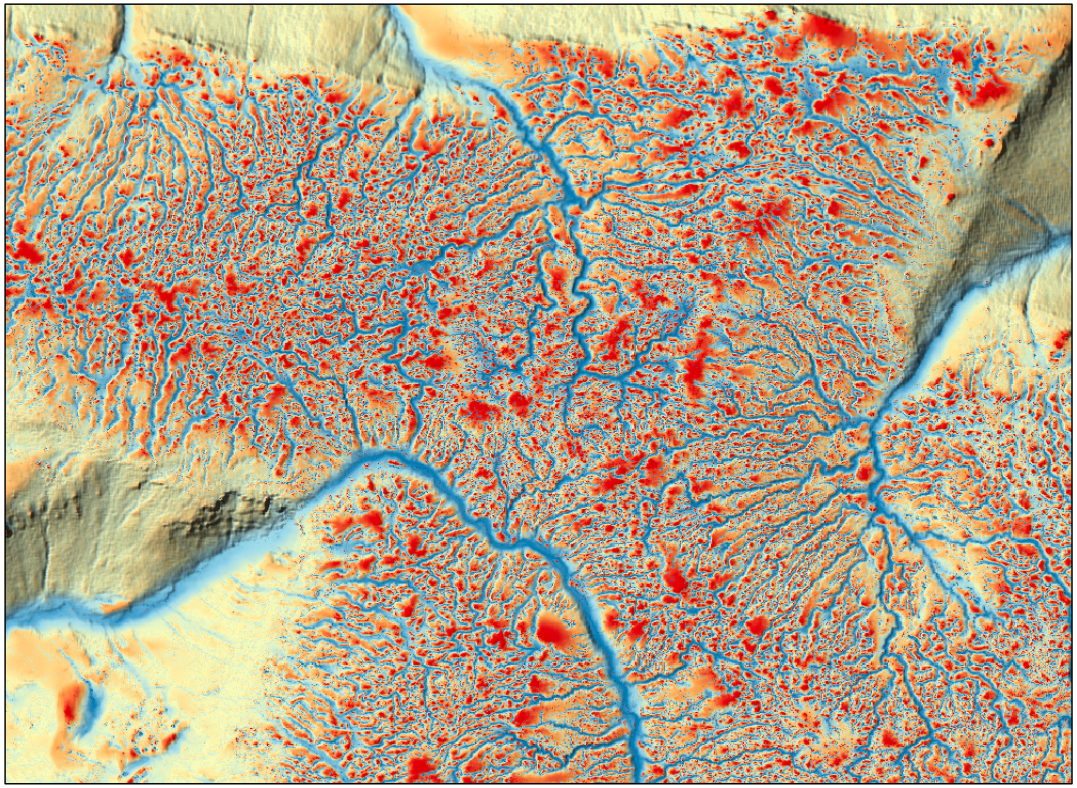
- An ideal method does not require saving each image in the scale stack—use an ***'online' algorithm***.

- Because ***local topography determines the representation scale***, we can be less precise about defining the measurement scale.
  - We can define broad scale ranges, e.g., 'gullies in this area range in width from 1 to 15 m'.

Defining key scales from scale signatures

Gullies with a range of widths dissect the Kinder Scout peat plateau.

An elevation percentile (EP) scale mosaic maps gullies more effectively than any single-scale EP raster would.

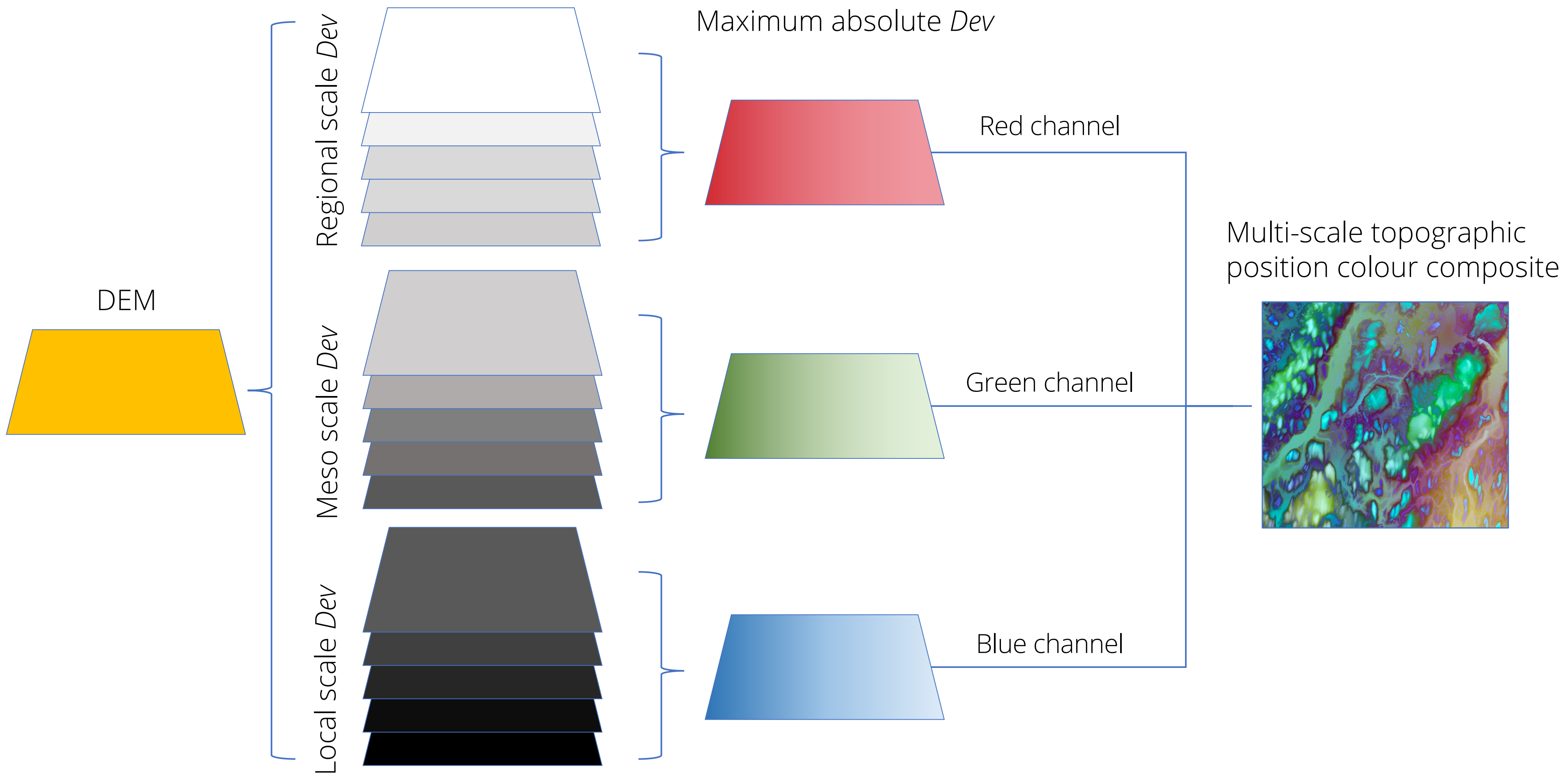


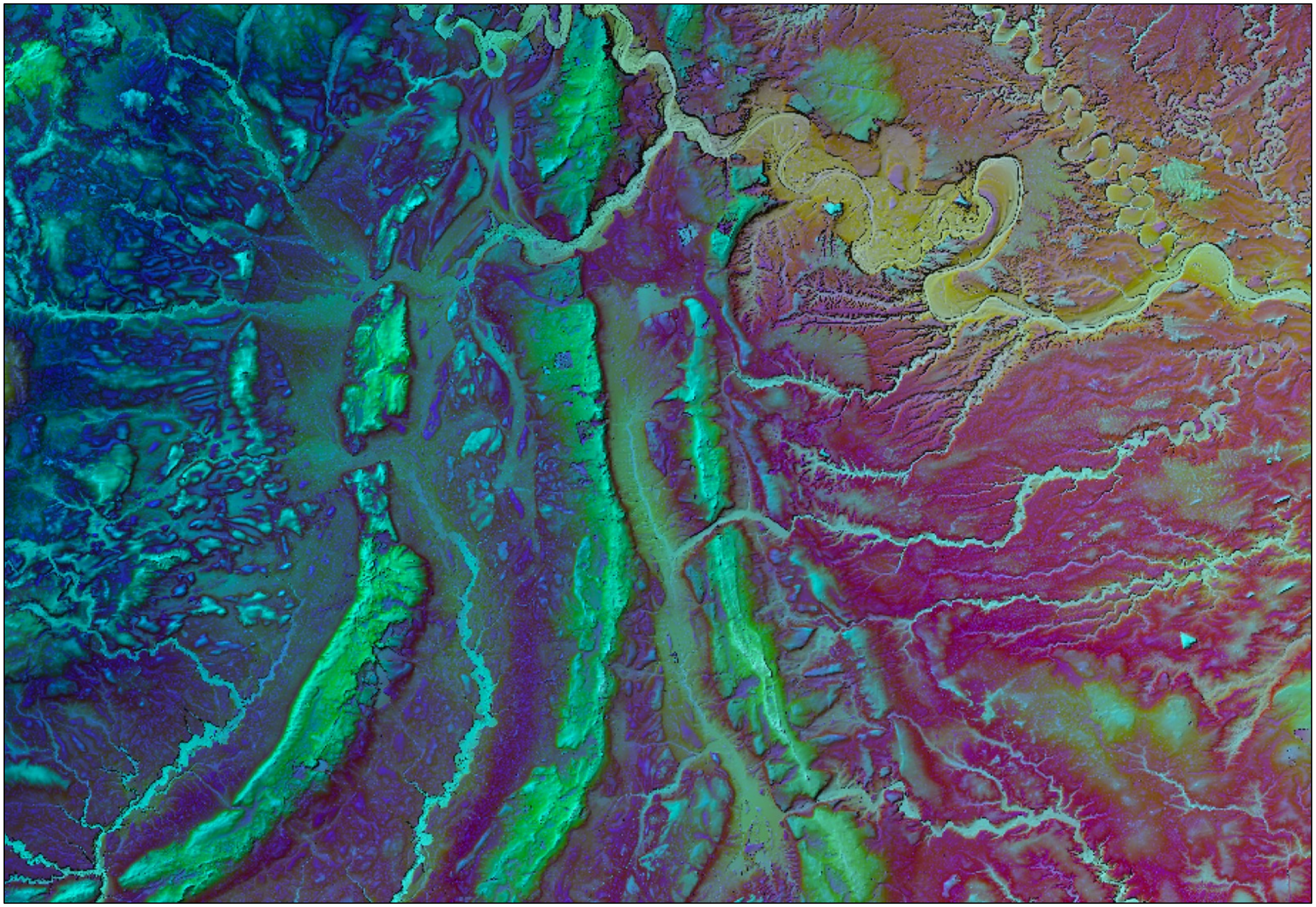
Elevation percentile scale mosaic (6-142 m)

Defining key scales from scale signatures

- I’m not suggesting that we need to collapse the entire scale-space defined by the DEM extent into a single scale mosaic.

- Instead, we can use ***broadly defined scale ranges*** that are associated with different landscape processes and landforms. (Lindsay et al. 2015)
  - e.g., local, intermediate, and regional scales

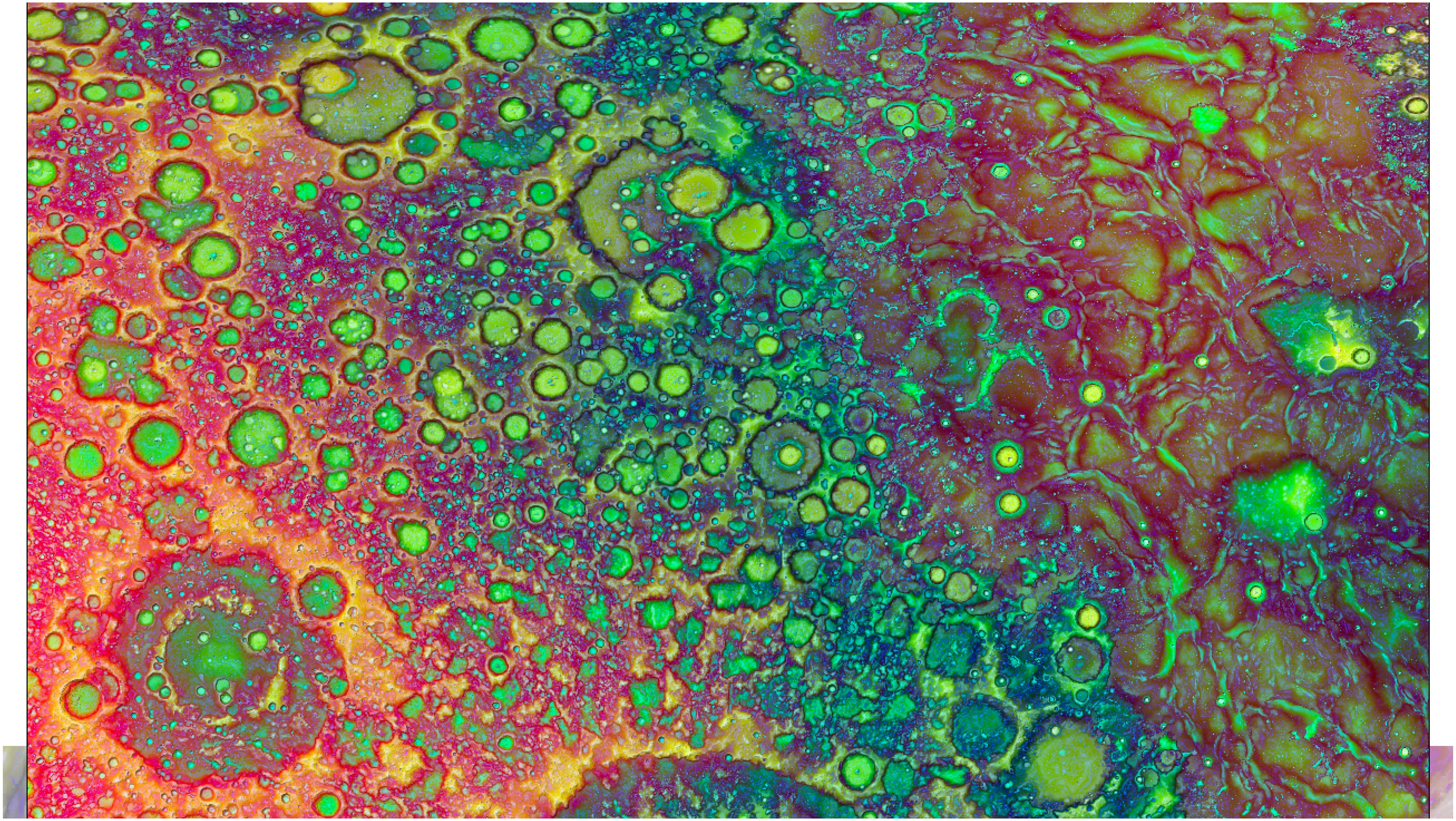

DEM
Regional scale *Dev*
Meso scale *Dev*
Local scale *Dev*
Maximum absolute *Dev*
Red channel
Green channel
Blue channel
Multi-scale topographic position colour composite



Multi-scale topographic position images have been used for landscape interpretation.

Scales of Expression:

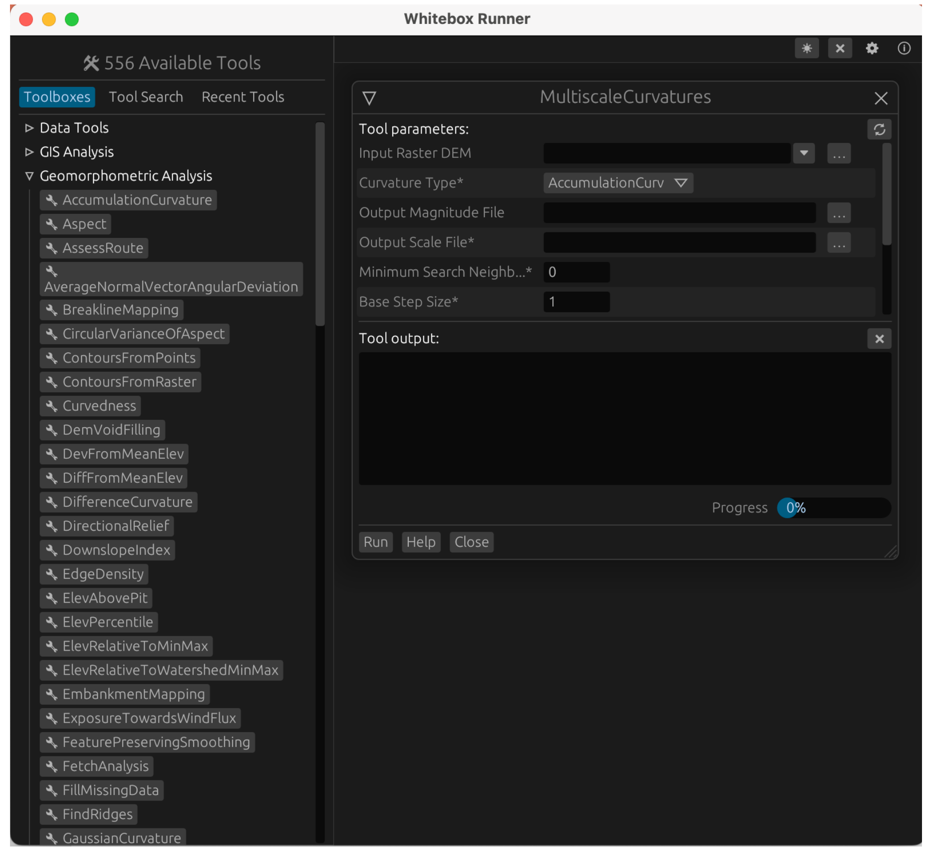
- Local
- Intermediate
- Regional
- Local and intermediate
- Local and regional
- Intermediate and regional
- All scales



WhiteboxTools functions that produce scale mosaics

- *GaussianScaleSpace & MultiscaleCurvatures*
- Relative topographic position: *MaxDifferenceFromMean, MaxElevationDeviation, MultiscaleElevationPercentile*
- Roughness/complexity: *MultiscaleRoughness, MultiscaleStdDevNormals*
- Topographic anisotropy: *MaxAnisotropyDev*
- *MultiscaleTopographicPositionImage*

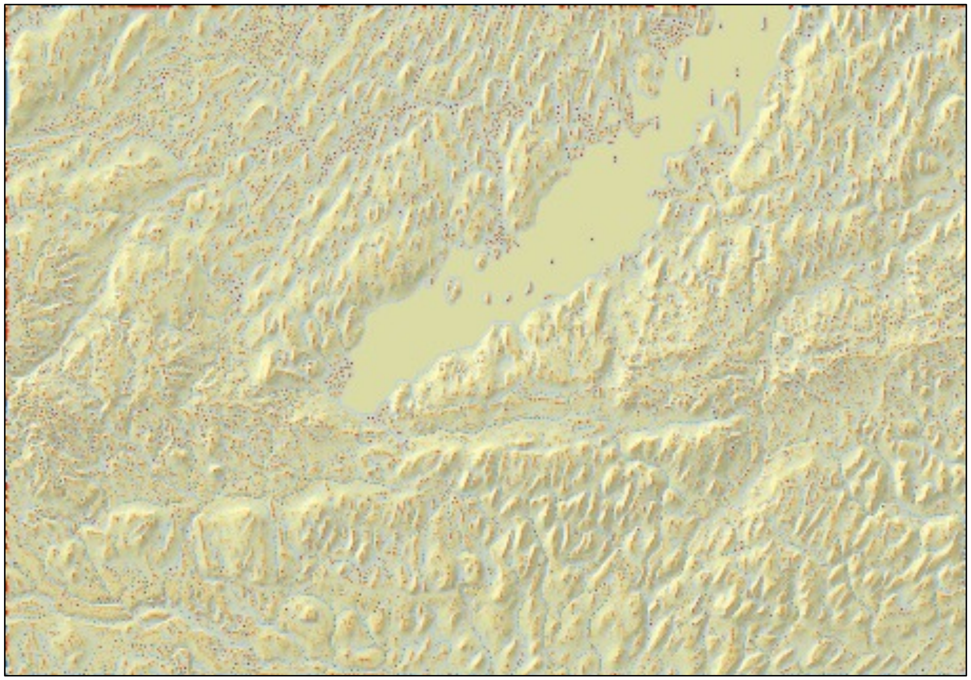
www.whiteboxgeo.com/



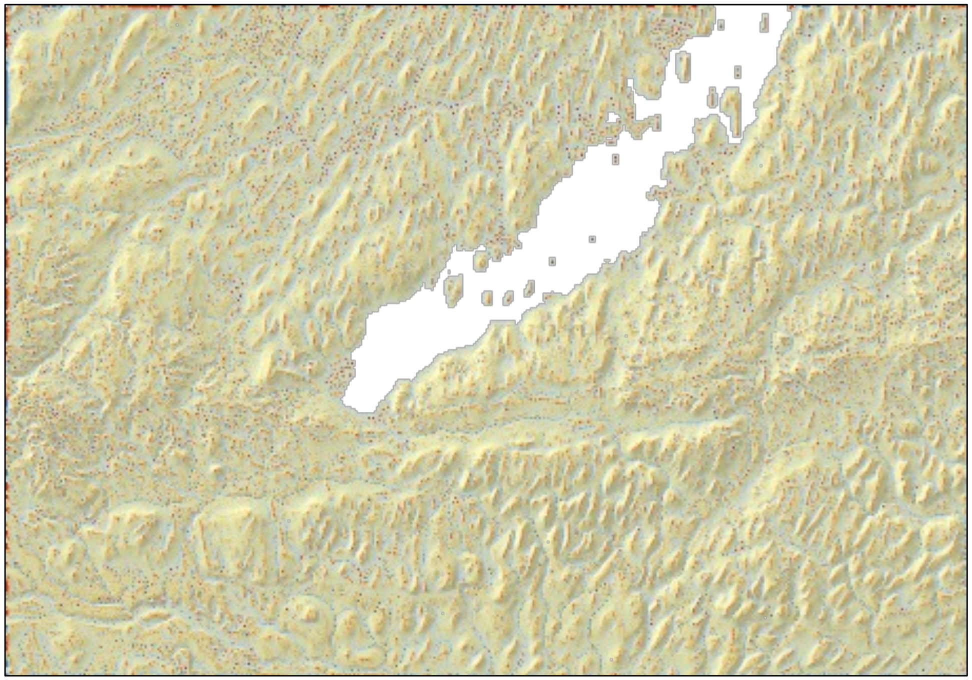
Characteristics of LSP scale mosaics

- Scale mosaics are extremely ***information dense*** compared with individual uniform-scale LSPs.
- They are largely ***continuous***, unless the scale range is very large.
- Key scales are selected ***based on the unique topographic setting*** of a site, i.e., topographic characteristics are the sole basis for selection.
- Because topography is an expression of process, scale mosaics should be ***more representative of process scales*** than the statistically based approach of the traditional uniform scale selection approach.

Uniform-scale *Dev* (homogeneous scale)



Dev scale mosaic (heterogeneous scale)



No sparse sub-set of frames from the homogeneous stack (left) can capture the range of topographic features in this complex landscape as well as the single top frame of the heterogeneous scale mosaic (right).

Lindsay et al. (2015; 2018) *Geomorphology*; Newman et al. (2018a, 2018b, 2022a, 2022b)

Characteristics of LSP scale mosaics

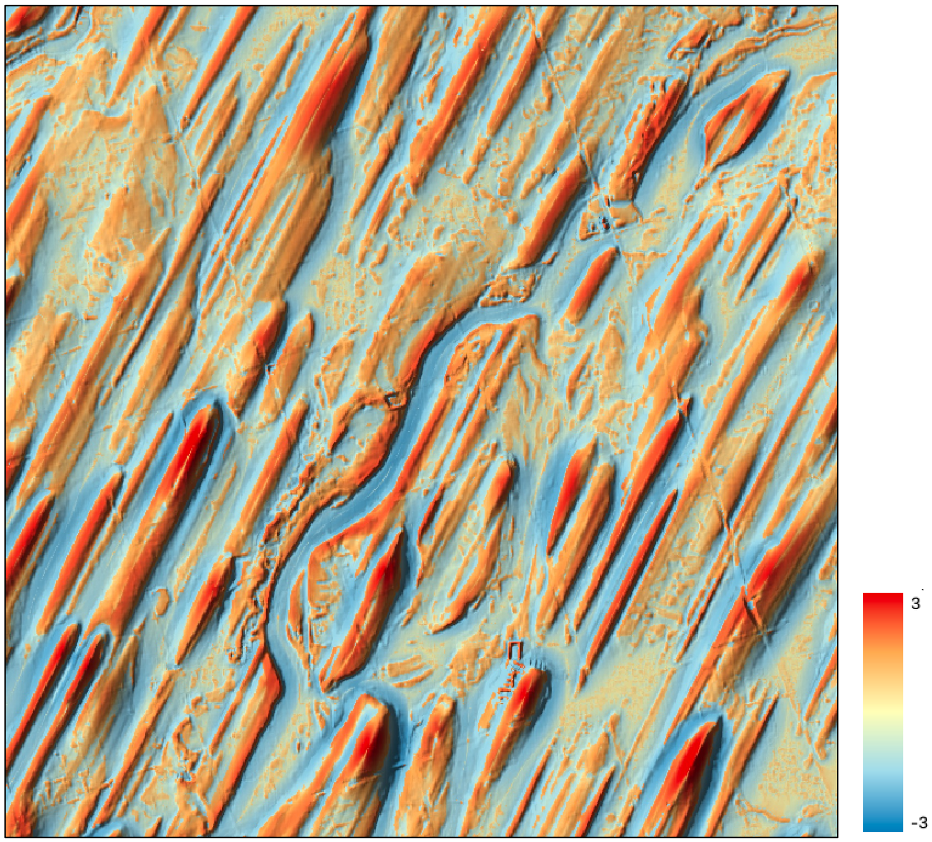
- Scale mosaics are well ***suited to mapping in complex, heterogeneous landscapes*** that have been shaped by geomorphic processes operating at widely ranging spatial/temporal scales.

- They ***produce a key-scale raster*** as an ancillary dataset.

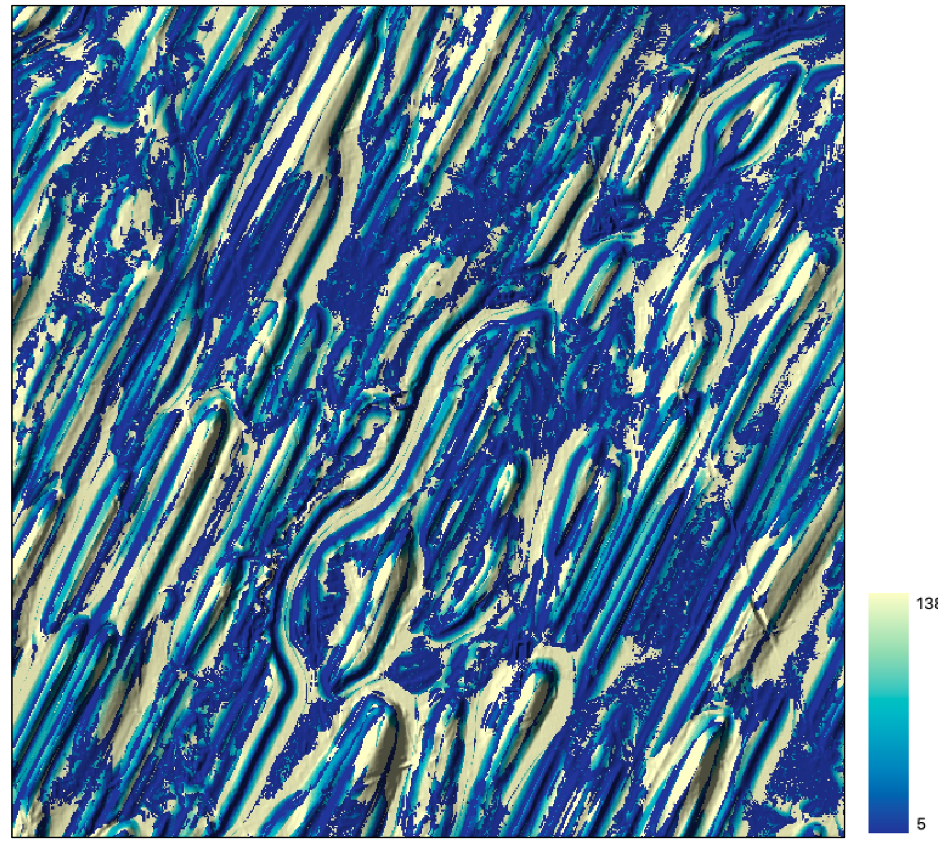
- Characteristic scales derived using this approach can ***vary widely over short distances***, even in low-complexity terrains (Lindsay and Newman, 2018).

- There is potential for ***every sampled scale to be represented*** in the final mosaic. This is the reason for the high information density of scale mosaics.

Profile curvature scale mosaic



Key-scale raster



The scale mosaic hypothesis

- *LSP scale mosaics based on locally optimized scale selection criteria can provide model predictors with denser information, that are better representative of landscape process scales, and thereby can improve modelling.*

- There's still a lot of work to do towards testing this hypothesis, but early findings are very encouraging.

- Newman et al. (2023) has demonstrated how these locally adaptive, scale-optimized LTPs can offer more predictive power for modelling soil properties.

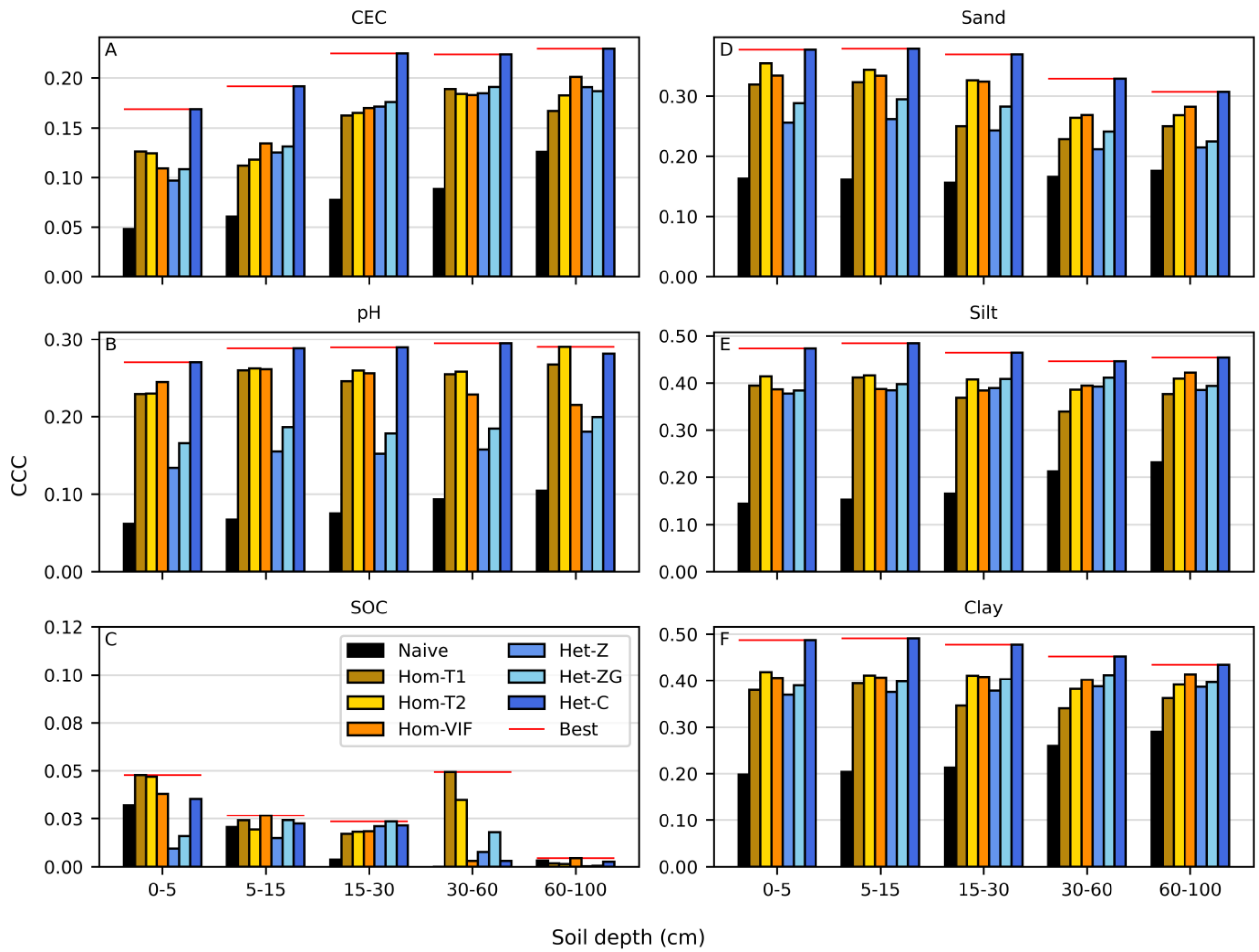


Table 1
The name and properties of the seven data sets used as independent variables.

Feature Set	Scaling Type	*n* features (1 or 2 per LSP listed in §2.2)
Naive	Unscaled	9
Hom-T1	Homogeneous	9
Hom-T2	Homogeneous	18
Hom-VIF	Homogeneous	18
Het-Z	Heterogeneous	9
Het-ZG	Heterogeneous	18
Het-C	Heterogeneous	18

Naïve: scale determined by DEM resolution.
Hom-T1: top scale with strongest correlation with the dependent soil property for each LSP selected.
Hom-T2: top two scales for each LSP.
Hom-VIF: feature selection method that reduces multicollinearity.
Het-Z: Single-range scale mosaic for LSPs.
Het-ZG: Single-range scale mosaic and key-scale raster.
Het-C: Local/broad scale range mosaics.

Newman, Saurette, Cockburn, Drăguţ, Lindsay. 2023. Environmental Modelling & Software, 160, 105612 13 pp. DOI: 10.1016/j.envsoft.2022.105612.

The scale mosaic hypothesis

- Importantly, these gains in model performance were achieved by selecting key scales ***based on topography alone***, in contrast to the uniform-scale stack approach, which selects scales from the stack by maximizing correlation with the dependent variables.

- Therefore, to achieve similar or improved model performance, when performance was not a criterion for scale selection for LSP scale mosaics, is ***supportive of the hypothesis***.

Summary

- There’s no reason to treat scale as a spatially uniform parameter in complex landscapes.
- LSP scale mosaics are a way of acknowledging the heterogeneity in process scale using locally-optimized scale selection methods to represent topographic properties.
- The relative density of information in LSP scale mosaics has the potential to improve many modelling applications, including soils, vegetation, landform, and geological mapping.
- But I need your help to test **The Scale Mosaic Hypothesis.**

Acknowledgements and other odds and ends

- Funding for this work has been provided by NSERC.
- I'd like to acknowledge the efforts of my Dan Newman and Prof. Lucian Dragut.
- ***I'll be giving a workshop*** later this week focused on the Whitebox geospatial analysis software; I'll also cover some of the multiscale LSP tools in Whitebox.
- If this is an area that interests you, ***I'm looking to take on new Masters and PhD students for next year***. Please contact me!