Hyper-scale analysis of surface roughness

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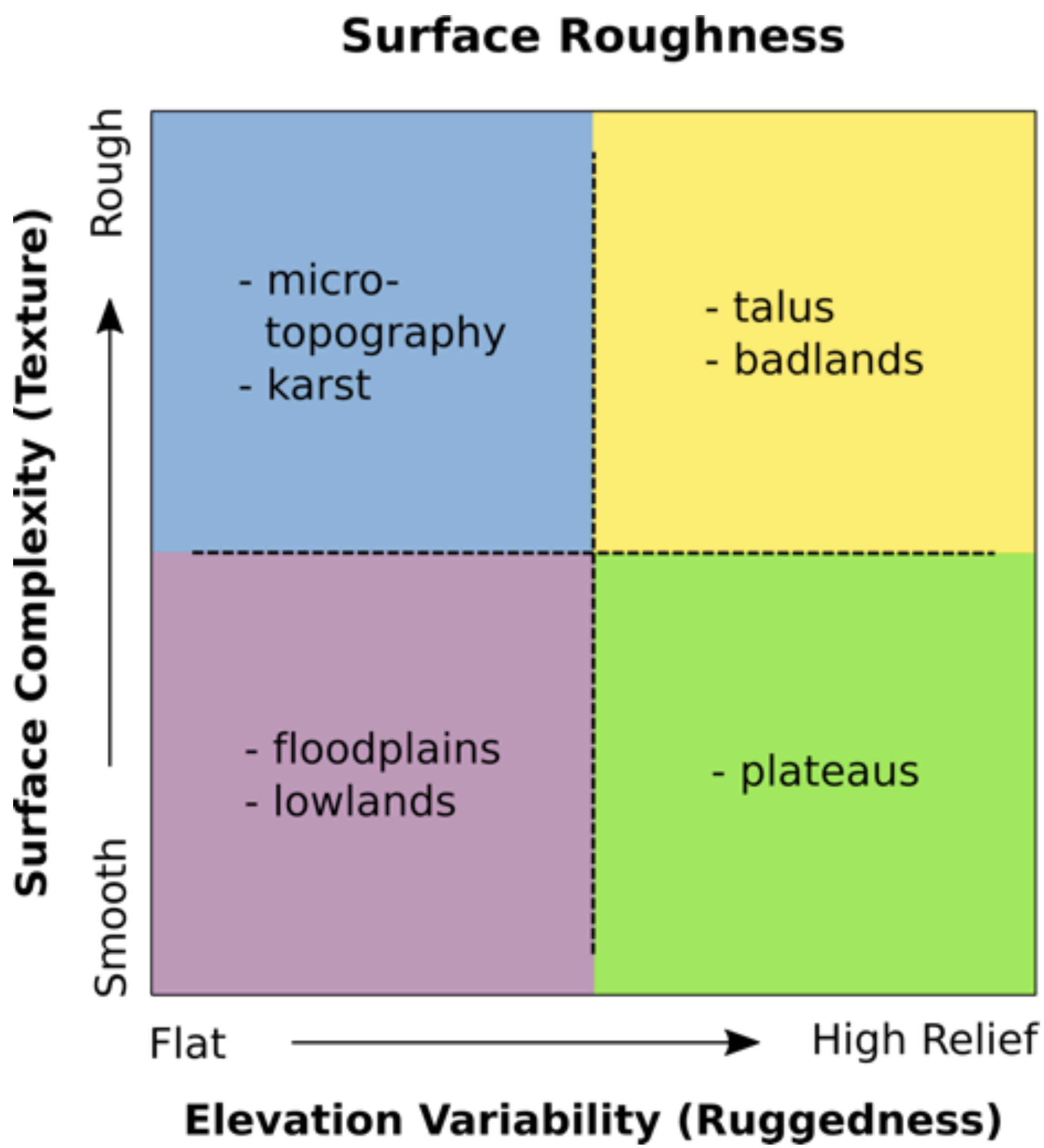
Surface roughness

- Surface roughness is an inherent characteristic of topography related to the ruggedness and complexity of the surface.
- Why is mapping the ***spatial pattern of roughness*** useful?
    - Transitions in roughness between neighbouring areas helps to distinguish landscape units;
    - This can be useful for understanding the topographic/geologic structure of landscapes and ultimately give insight into the process of formation;
    - Roughness has been applied in geological mapping, fire-behaviour modelling, and landslide studies.


Surface Roughness
Surface Complexity (Texture)
Rough
Smooth
- micro-
topography
- karst
- talus
- badlands
- floodplains
- lowlands
- plateaus
Flat
High Relief
Elevation Variability (Ruggedness)

Metrics of roughness

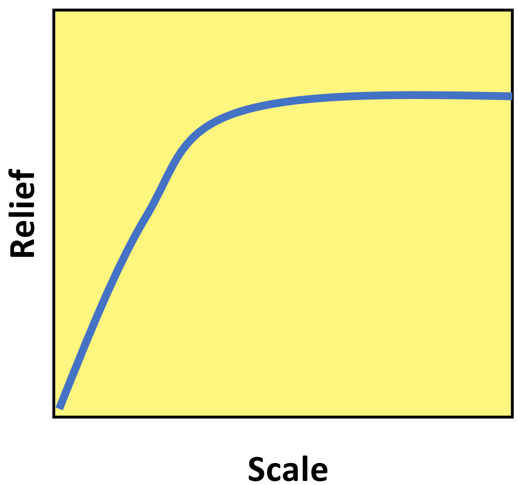
- **Elevation Variability**
  - Elevation range (relief),
  - Riley’s (1999) Topographic Ruggedness Index (TRI)
  - Standard deviation in elevation,
  - Standard deviation of topographic residuals

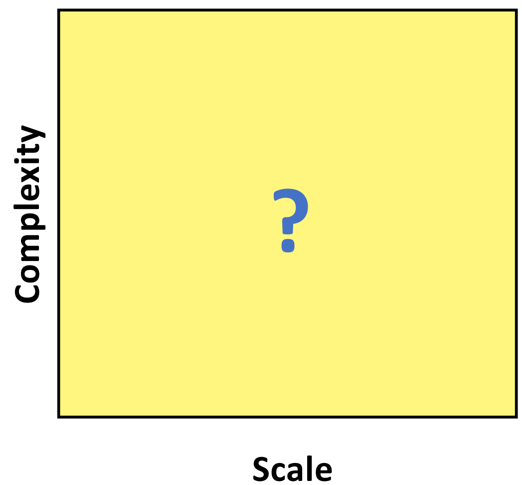
- **Surface Complexity**
  - Indices based on surface area or variability in normal vectors (or components of vectors, e.g. slope or aspect)
  - Standard deviation of slope
  - Stambaugh’s (2008) Topographic Roughness Index

For a good summary of roughness metrics, see: Grohmann, Smith, M.J., C.H., Riccomini, C., 2011. Multi-scale analysis of topographic surface roughness in the Midland Valley, Scotland. *IEEE Transactions on Geoscience and Remote Sensing*. 49:1200-1213. DOI:10.1109/TGRS.2010.2053546

Surface roughness and scale

- Surface roughness can only be ***quantified over an area***.
- The spatial distribution of roughness therefore ***varies with scale***.





Surface roughness and scale

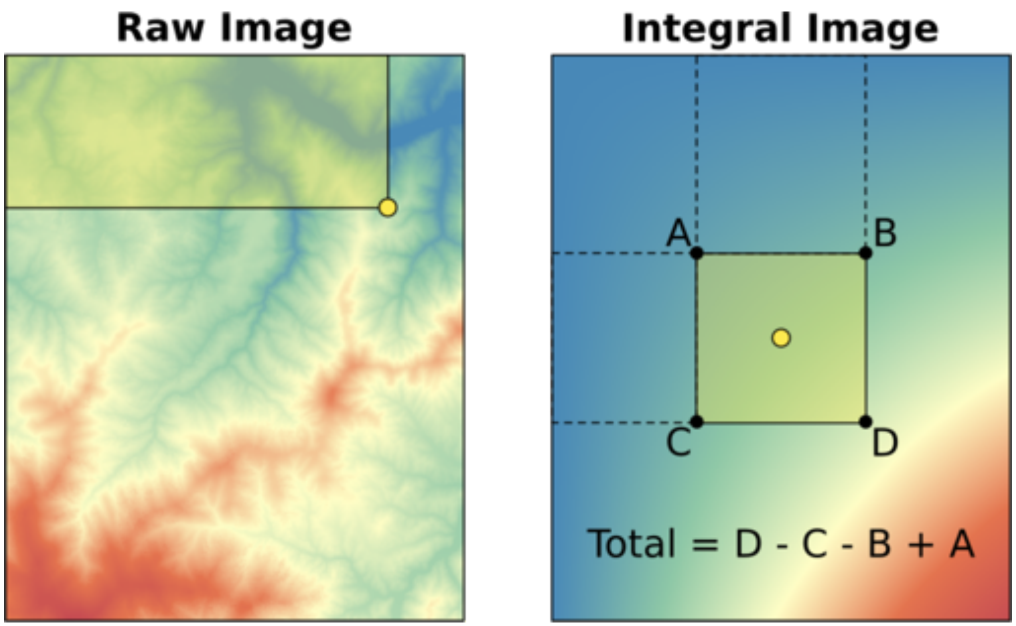
- Metrics of roughness are generally calculated using roving windows of a user-specified kernel size or through data resampling (grid size coarsening).

- This research aimed to develop a method to quantify ***spatial patterns of surface complexity*** with ***hyper-scale*** resolution.
  - Will allow for the study of scale-dependency in surface complexity.

Measuring hyper-scale roughness

- Roughness (surface complexity) is defined here as ***the neighbourhood-averaged difference in the normal vectors of the original DEM and an idealized surface, i.e. a smoothed DEM***.
  - Used to quantify roughness in surface metrology but never geomorphometry.
  - Average angular difference in vectors is measured in degrees.
- Smoothed surfaces were derived by applying a mean filter.
- An integral image approach was used in this study to improve the computational efficiency of the smoothing operation.

Integral image transform

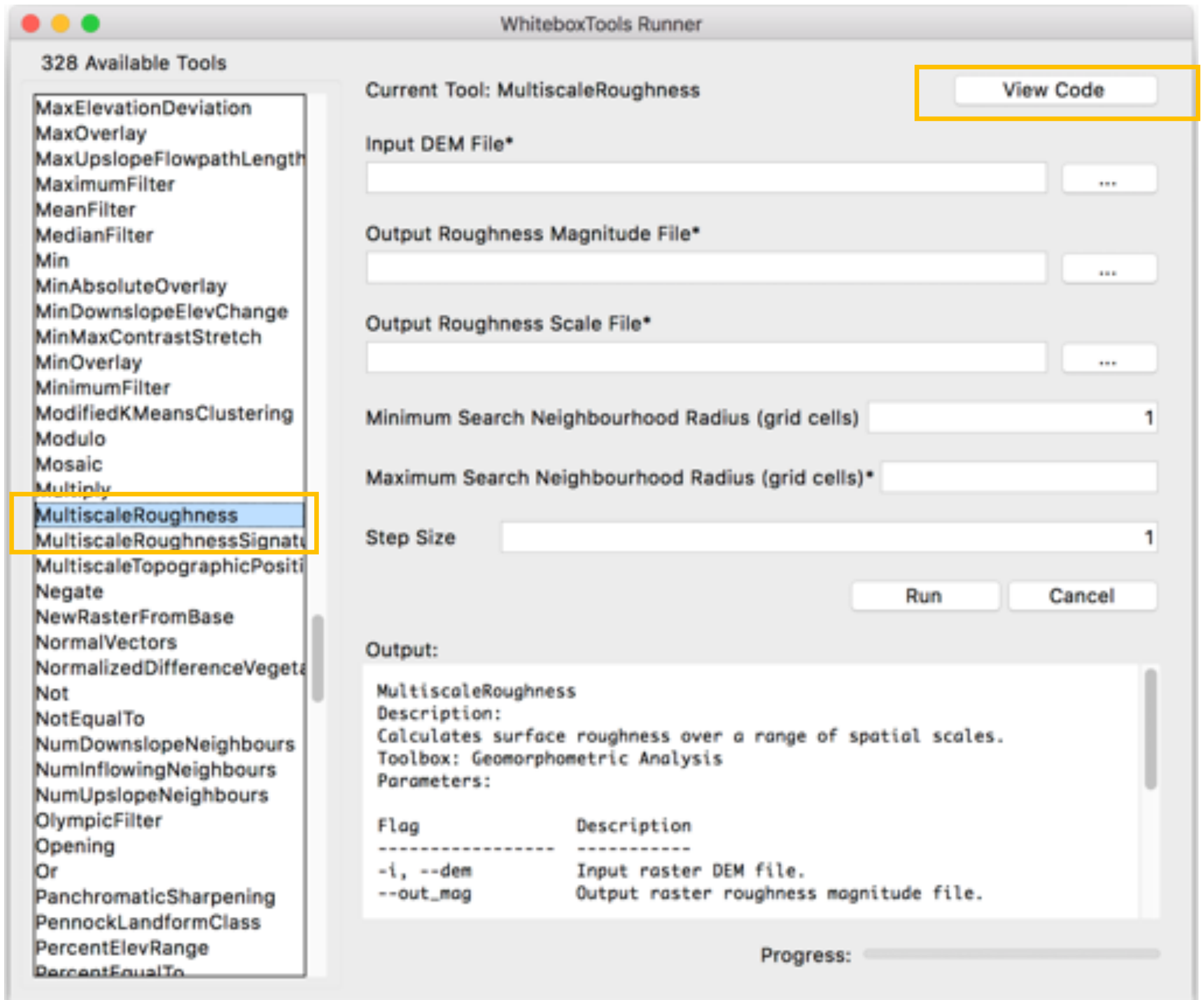


- Simple one-pass transform
- Sums of underlying surface can be calculated in three operations for any sized rectangles
- Offers filtering with constant-time complexity for arbitrary sized kernels
- Care needed in handling DEM NoData values and numerical overflows

Crow, F.C., 1984, January. Summed-area tables for texture mapping. In *ACM SIGGRAPH computer graphics* (Vol. 18, No. 3, pp. 207-212). ACM.
Lewis, J.P., 1995, May. Fast template matching. In *Vision interface* (Vol. 95, No. 120123, pp. 15-19).

WhiteboxTools™

- Open source project coded in Rust and compiled to native code.
- Parallelized tools.
- Command-line interface, Python interface, and basic GUI.
- QGIS plugin is available.

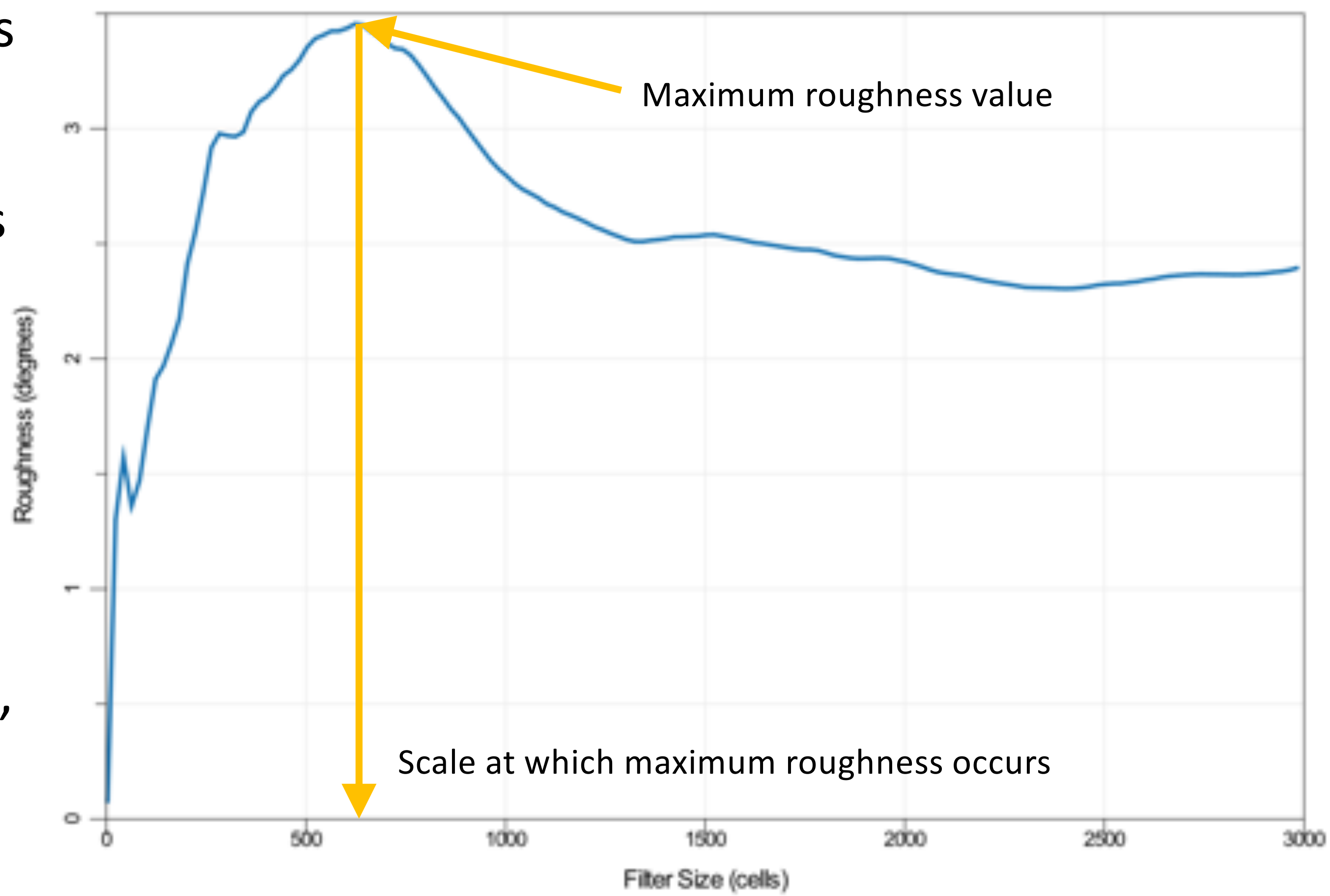


http://www.uoguelph.ca/~hydrogeo/WhiteboxTools/index.html

Python interface

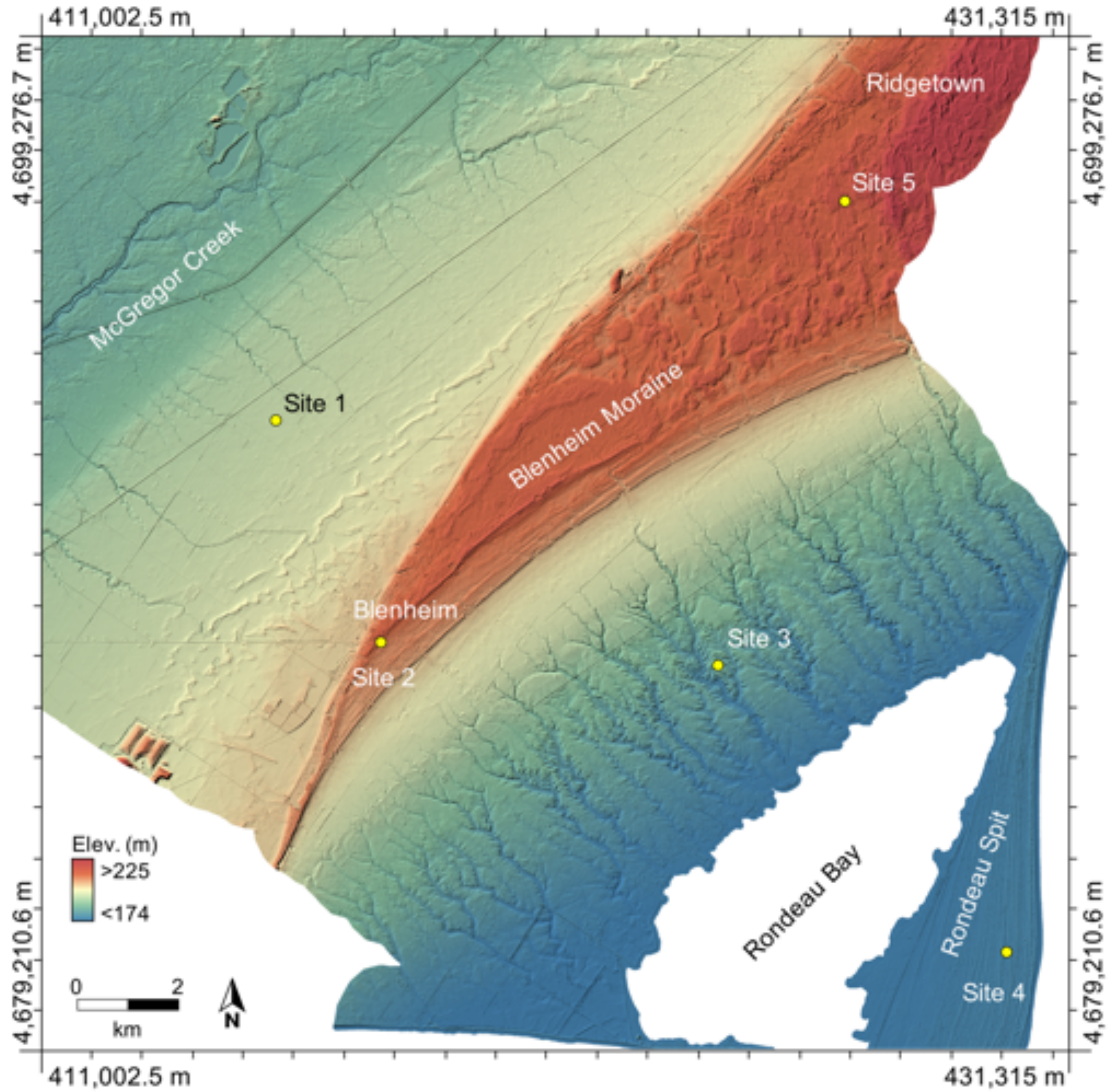
```python
from WBT.whitebox_tools import WhiteboxTools

wbt = WhiteboxTools()
wbt.work_dir = "/path/to/data/" # Sets the working directory
wbt.multiscale_roughness(
dem="dem.tif",
out_mag="output_magnitude.tif",
out_scale="ouput_scale.tif",
min_scale=1,
max_scale=200)
```

- The scale signature is measured for each grid cell and the maximum roughness and scale of max. roughness are recorded.
- Alternatively, we could measure the number of peaks, minimum roughness, etc.

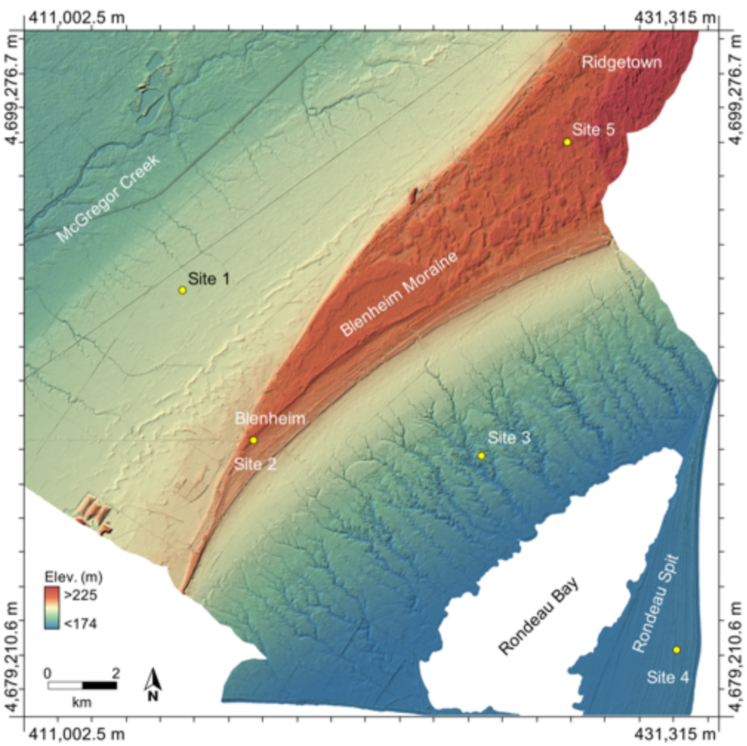


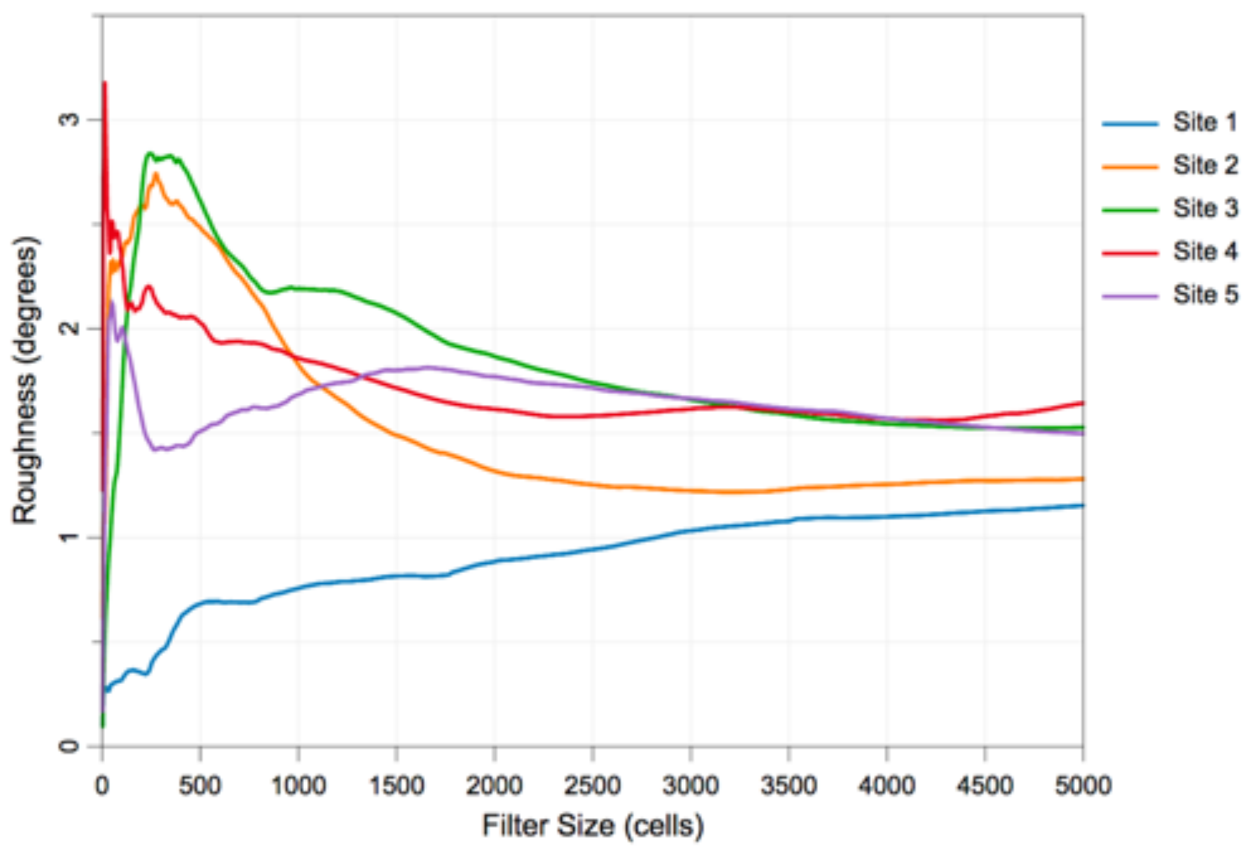
Study Site

- 2.5 m resolution (8026 × 8125 rows by columns) LiDAR DEM of Rondeau Bay area, located in Southwestern Ontario, Canada, along the northern coast of Lake Erie



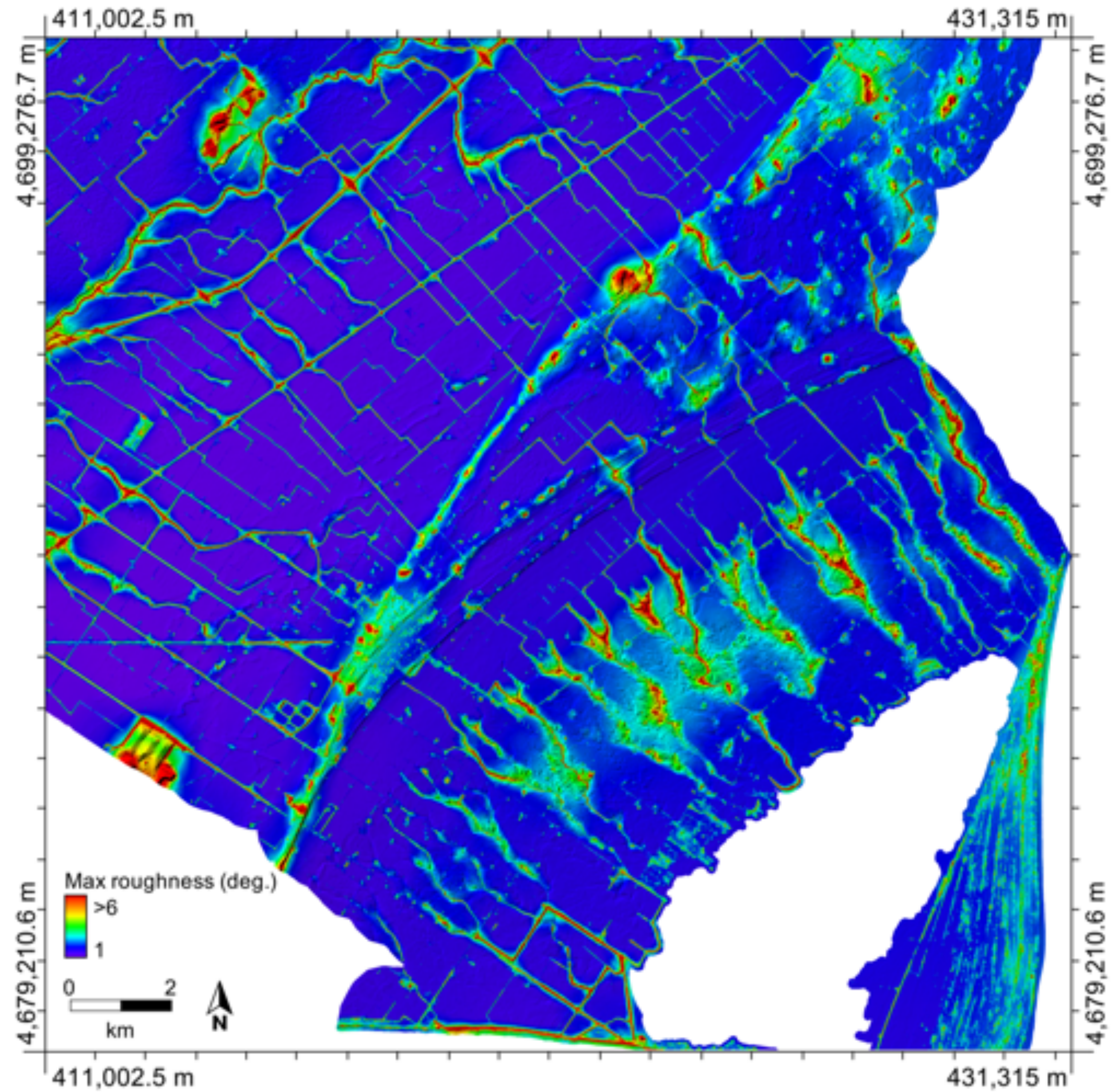
Scale signatures of roughness





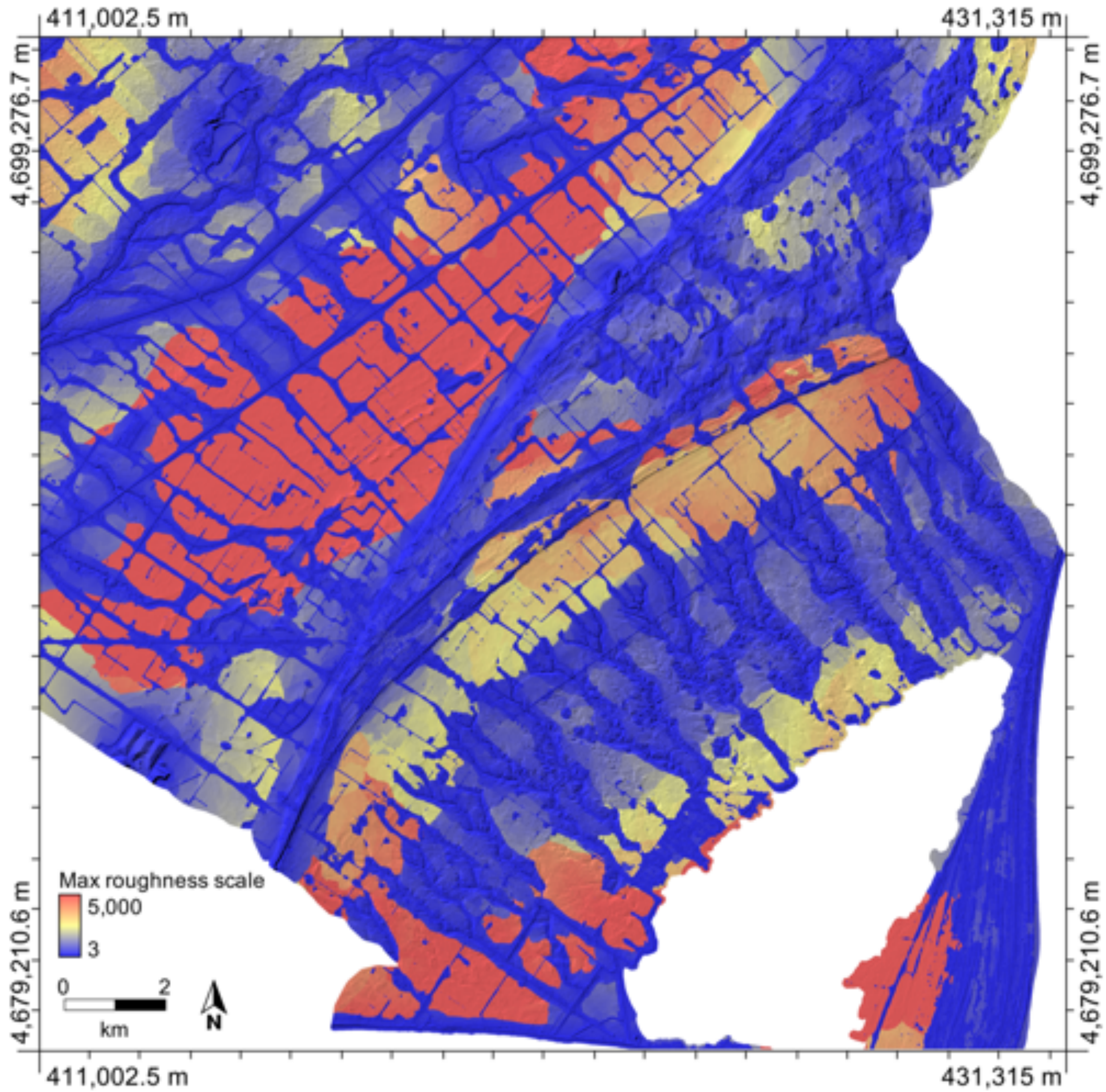
Maximal roughness

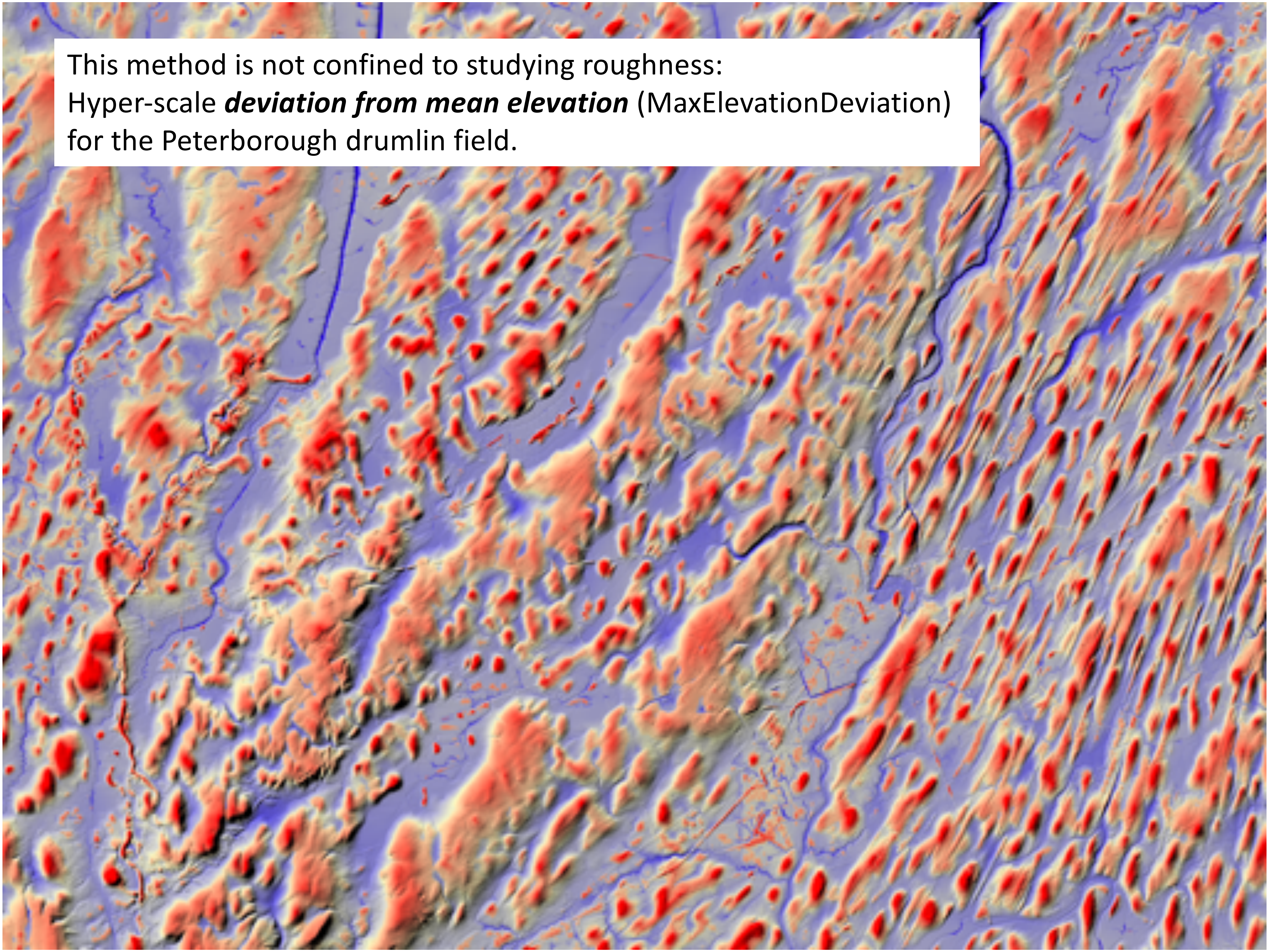
- Roughness measured at scales from 3 × 3 to 5000 × 5000 in 59 min.
- The distribution of maximal roughness.
- It is a scale-mosaic where each pixel is measured at an 'optimal' scale for the site.
- Roughness was highest associated with the gullies, the dunes on the spit, the terrace, and anthropogenic alterations (roads, drainage ditches).



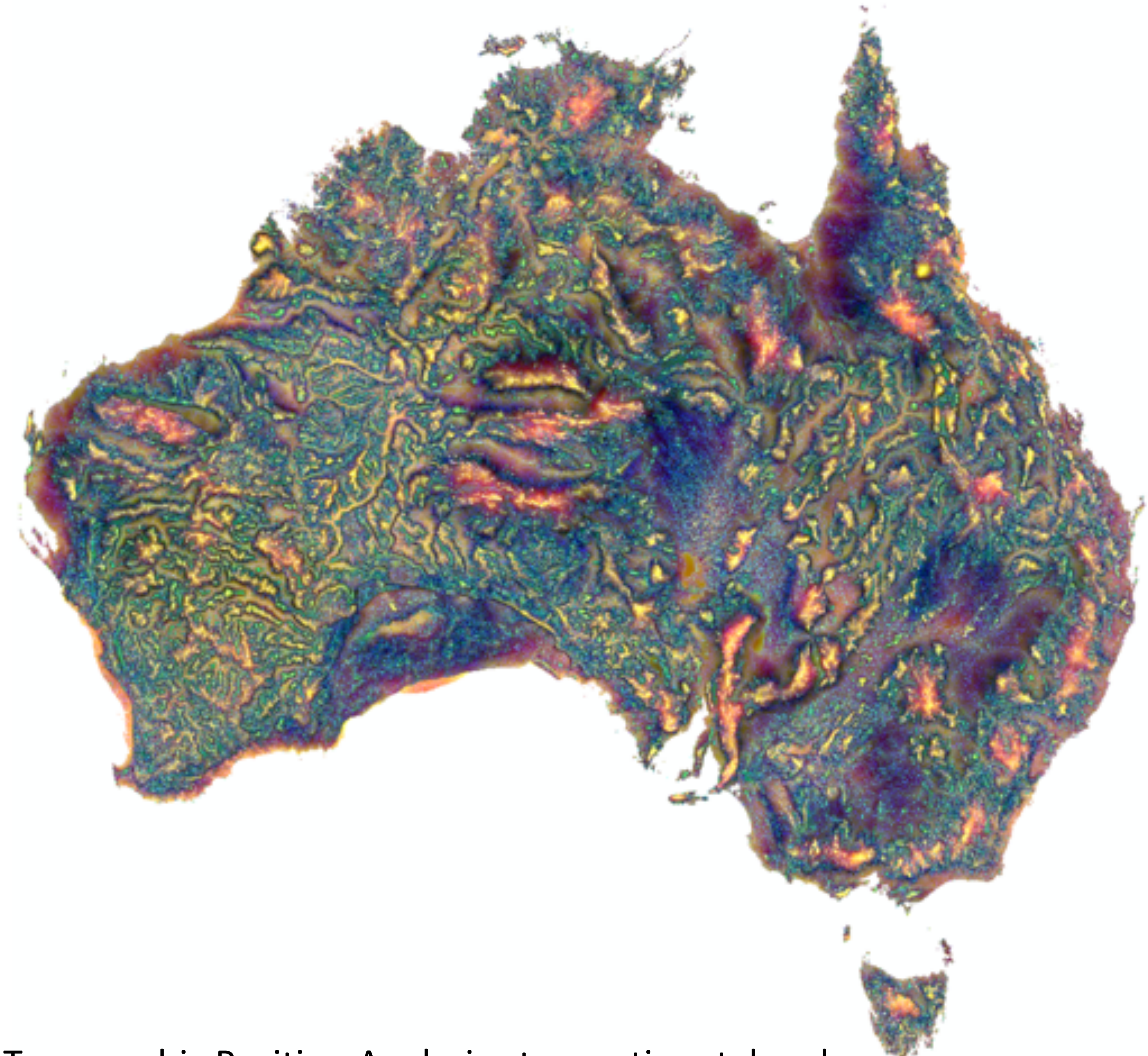
Scale of maximal roughness

- The mosaic of spatial scales reveals information about the topographic character of the landscape.
- Could also be useful for choosing heterogenous ***scales for DEM smoothing***.
- The wide range of max. roughness scale shows that there is ***no single optimal kernel size*** that can be chosen to characterize topographic texture.

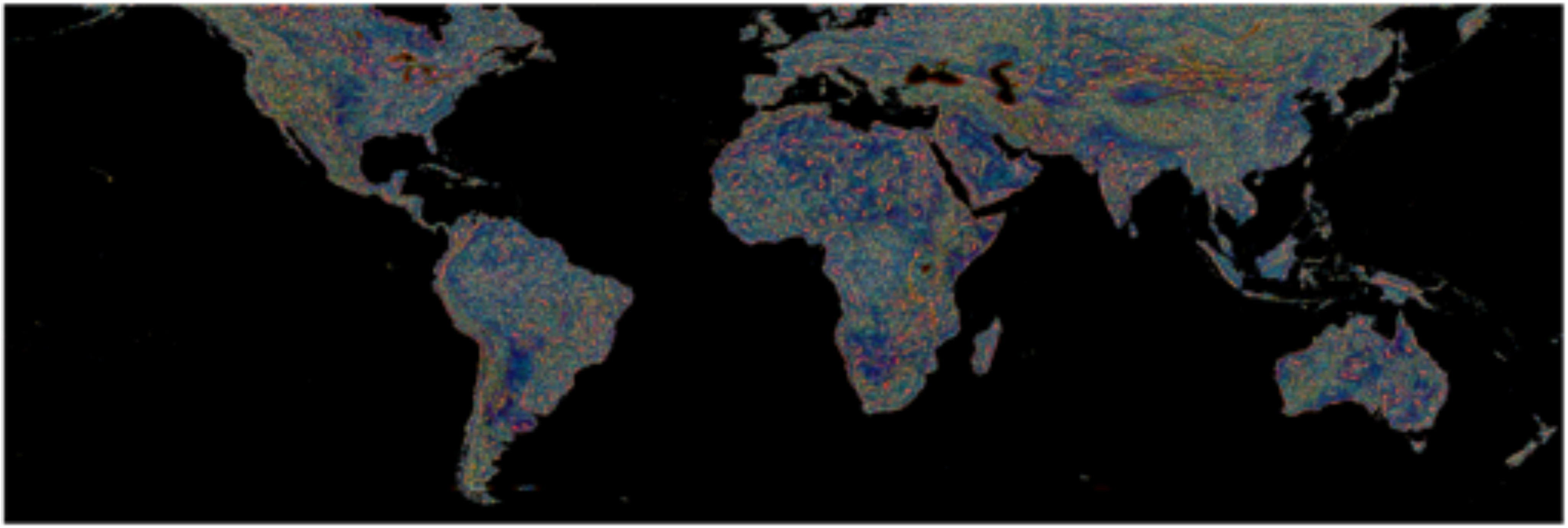




This method is not confined to studying roughness:
Hyper-scale ***deviation from mean elevation*** (MaxElevationDeviation)
for the Peterborough drumlin field.



Multi-scale Topographic Position Analysis at a continental scale
30 m resolution (image courtesy of Geoscience Australia)



Multi-scale Topographic Position Analysis at the continental scale
(courtesy of John Wilford, Geoscience Australia).

Conclusions

- This study demonstrated an application of the ***integral-image approach to measure surface roughness*** (topographic complexity) across a broad range of spatial scales with ***extremely fine scale resolution*** (hyper-scale).
- This allows for characterization of maximal surface roughness at spatial scales that are ***optimal for each individual grid cell*** within a DEM.
- The information contained within the scale map can provide ***additional useful information for landscape interpretation***.

Related papers

- Lindsay J, Cockburn J, Russell H. 2015. An integral image approach to performing multi-scale topographic position analysis. *Geomorphology*, 245: 51-61. DOI: 10.1016/j.geomorph.2015.05.025
- Lindsay JB. 2016. The practice of DEM stream burning revisited. *Earth Surface Processes and Landforms*, 41(5): 658–668. DOI: 10.1002/esp.3888
- Newman DR, Lindsay JB, Cockburn JM. 2018. Evaluating metrics of local topographic position for multiscale geomorphometric analysis. *Geomorphology*, 312(1): 40-50. DOI: 10.1016/j.geomorph.2018.04.003.
- Newman D, Lindsay JB, Cockburn JMH. 2018. Measuring hyperscale topographic anisotropy as a continuous landscape property. *Geosciences*, 8(8) 1-14. DOI: 10.3390/geosciences8080278.

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http://www.uoguelph.ca/~hydrogeo/index.html

Slides available at: https://www.uoguelph.ca/~hydrogeo/publications.html