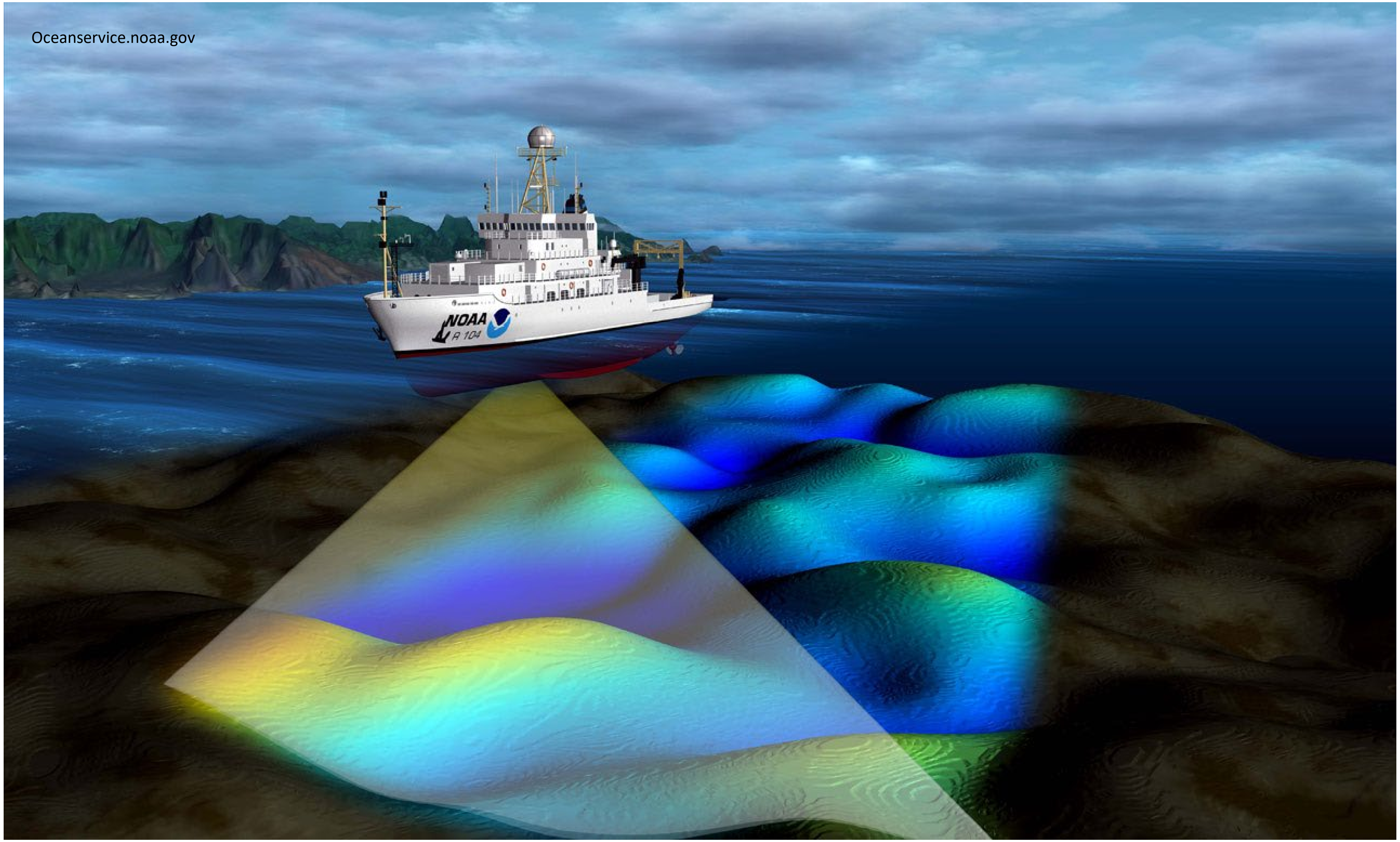
A New Toolset for Multiscale Seabed Characterization

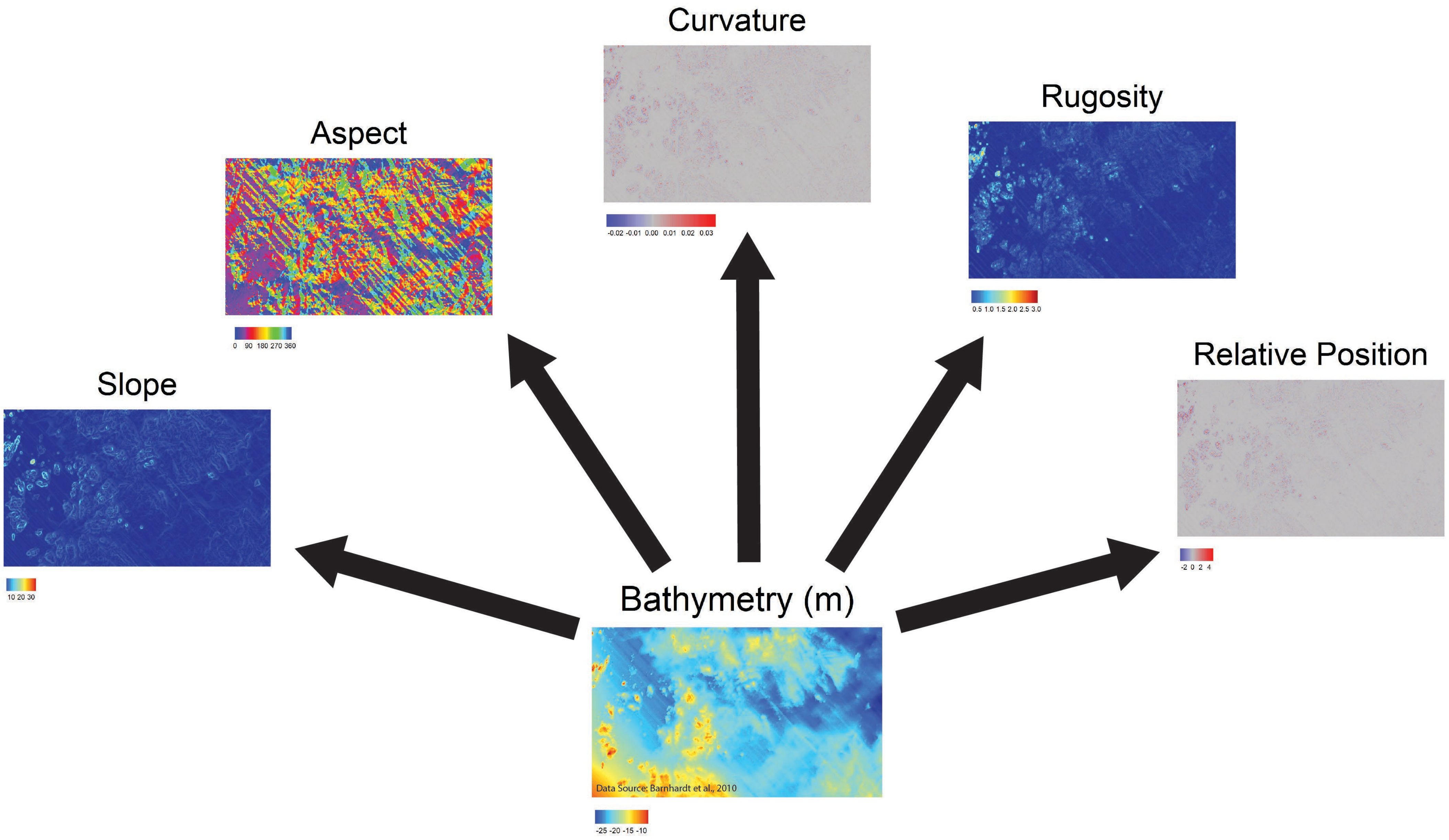
Continental Shelf Characterization, Assessment and Mapping Project

By: Alexander Ilich,
Benjamin Misiuk, Vincent Lecours, and Steven A. Murawski

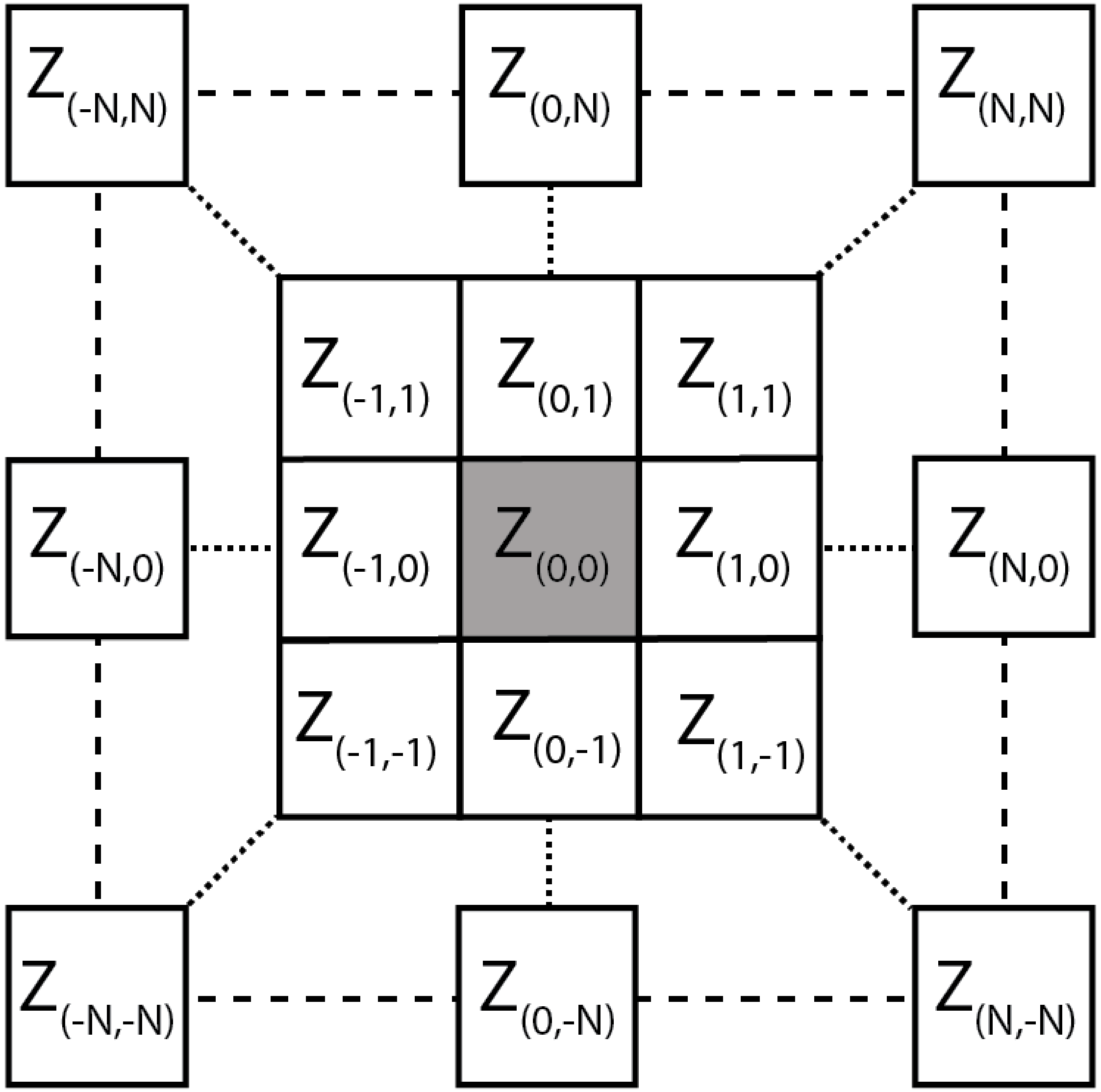
Bathymetry



Terrain Attributes



Altering the Spatial Scale: Focal Window Size



Adapted from Wilson et al. (2007)

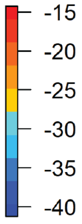
MultiscaleDTM R Package: Overview

- MultiscaleDTM is an open-source R package that can calculate terrain attributes
- Allows for calculation of terrain attributes at multiple spatial scales
- Allows for repeatable, well documented workflows utilizing free, open-source software
- Implemented in R to streamlines integration with statistical analyses
- Interactive 3D visualization tool
- Implements existing and new rugosity measures that are decoupled from slope

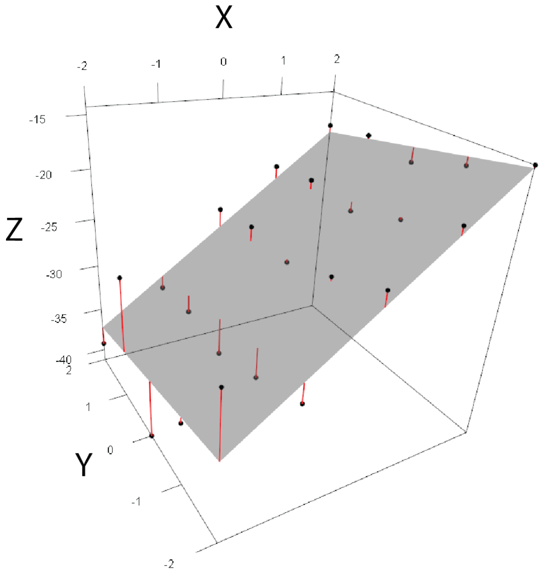
Adjusted Standard Deviation

Depth (m)

Y	-39	-34	-26	-22	-18
	-28	-33	-25	-21	-17
	-41	-34	-26	-22	-18
	-35	-32	-24	-20	-16
	-26	-30	-22	-18	-14
			X		



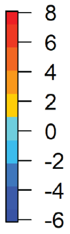
Fit a plane using ordinary least squares →



Extract residuals →

Residuals (m)

Y	-2	-1	2	1	1
	8	-2	2	1	0
	-6	-4	0	-1	-2
	-1	-3	0	0	-1
	7	-2	1	1	0
			X		



Calculate standard deviation ↓

Rugosity = 7.4 m

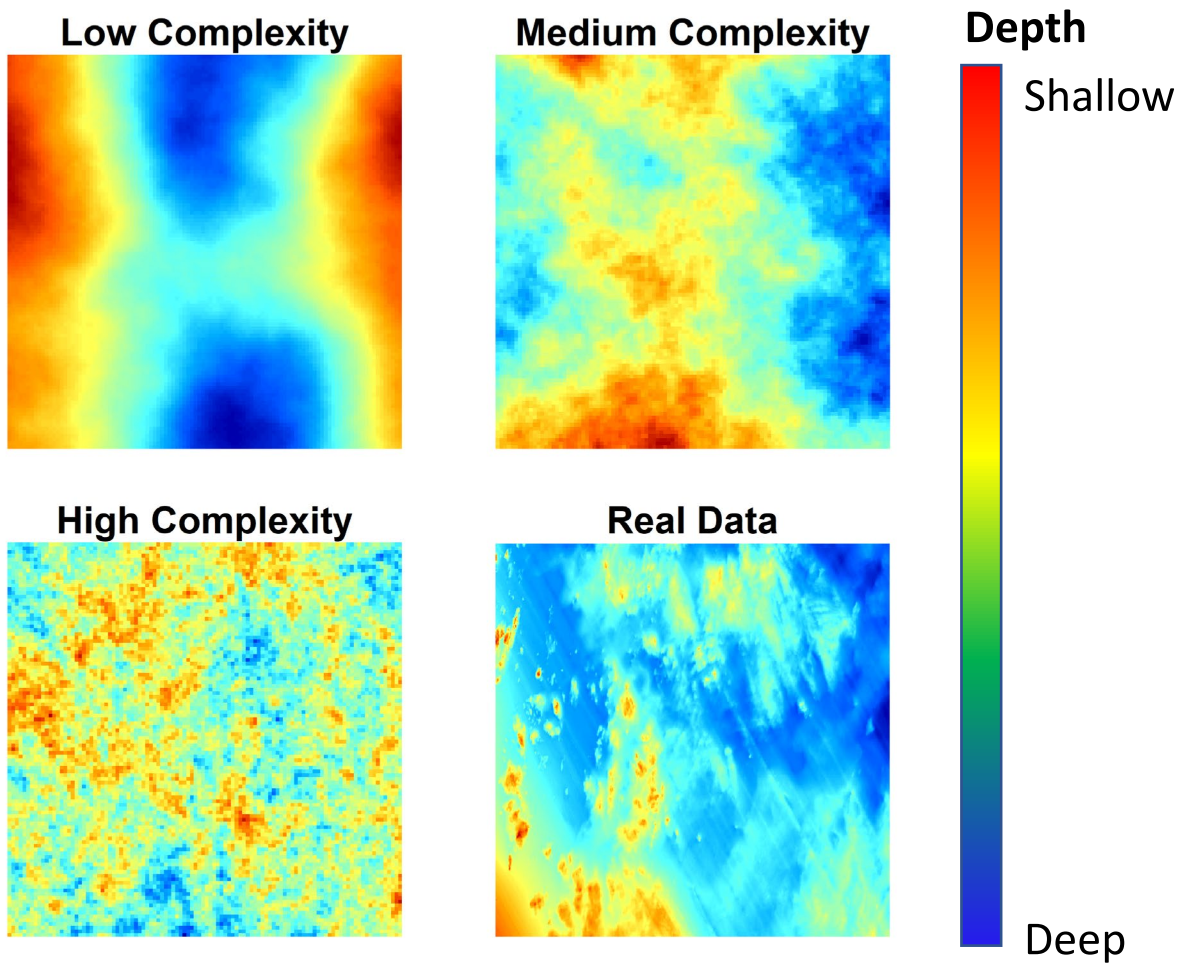
Calculate standard deviation ↓

Adjusted Rugosity = 2.9 m

Rugosity Analysis

Problem: Measures of rugosity can often be confounded with slope

Objective: Test several rugosity measures to evaluate how well they measure rugosity independent of slope



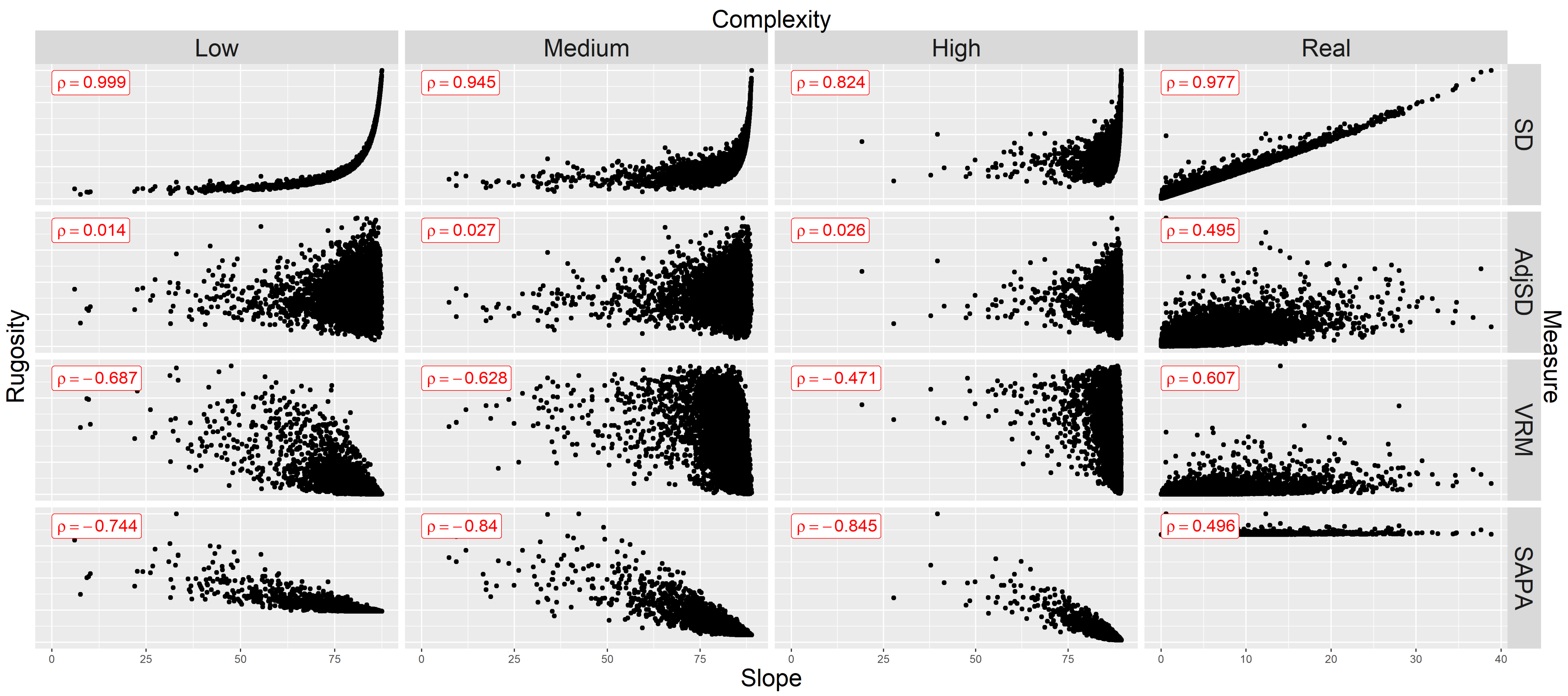
(Data Sources: Barnhardt et al., 2010 & Lecours et al.,2017)

- Calculate the slope and 4 rugosity measures
  - Standard Deviation (SD)
  - Adjusted Standard Deviation (AdjSD)
  - Vector Ruggedness Measure (VRM)
  - Surface Area to Planar Area Ratio (SAPA)

- Do this at two different spatial scales
  - Fine scale – 3 x 3 window
  - Broad scale – 17 x 17 window

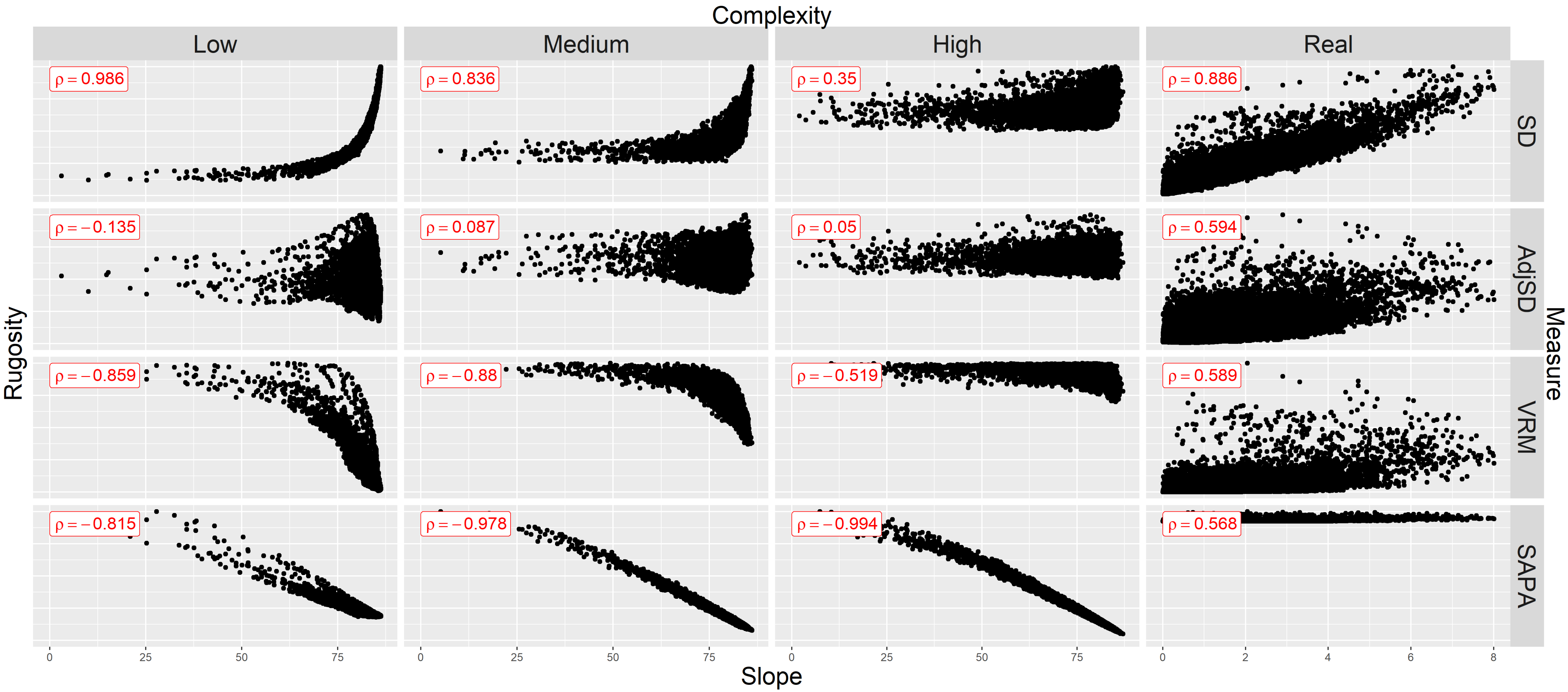
- Measure the rank correlation (ρ) between slope and rugosity.

Fine Scale



Complexity
Low
Medium
High
Real
ρ = 0.999
ρ = 0.945
ρ = 0.824
ρ = 0.977
ρ = 0.014
ρ = 0.027
ρ = 0.026
ρ = 0.495
ρ = −0.687
ρ = −0.628
ρ = −0.471
ρ = 0.607
ρ = −0.744
ρ = −0.84
ρ = −0.845
ρ = 0.496
SD
AdjSD
VRM
SAPA
Measure
Rugosity
0 25 50 75
0 10 20 30 40
Slope

Broad Scale



Complexity
Low
Medium
High
Real
ρ = 0.986
ρ = 0.836
ρ = 0.35
ρ = 0.886
ρ = −0.135
ρ = 0.087
ρ = 0.05
ρ = 0.594
ρ = −0.859
ρ = −0.88
ρ = −0.519
ρ = 0.589
ρ = −0.815
ρ = −0.978
ρ = −0.994
ρ = 0.568
SD
AdjSD
VRM
SAPA
Measure
Rugosity
0 25 50 75
0 25 50 75
0 25 50 75
0 2 4 6 8
Slope

Conclusions

- MultiscaleDTM is an open-source R package that allows for the calculation of various terrain attributes at multiple spatial scales of analysis

- Although marine applications discussed here, all methods are also relevant to the terrestrial environment

- The proposed adjusted standard deviation method provided the lowest magnitude rank correlation with slope regardless of complexity or spatial scale for the simulated data

- For the real world data, all slope-corrected rugosity measures had very similar rank correlations with slope

Acknowledgments

Robert Hijmans

C-SCAMP Group

Murawski Lab

Josh Kilborn

Ted Switzer

Alastair Graham

Jozef Minár

Anne and Werner Von Rosenstiel

Peter Betzer

Joni James

Beverly Young

Beverly Knight

Larry and Diana Foster

Continental Shelf Characterization, Assessment and Mapping Project

Contact Information and Resources

Email : ailich@usf.edu

MultiscaleDTM github page:
https://github.com/ailich/MultiscaleDTM.

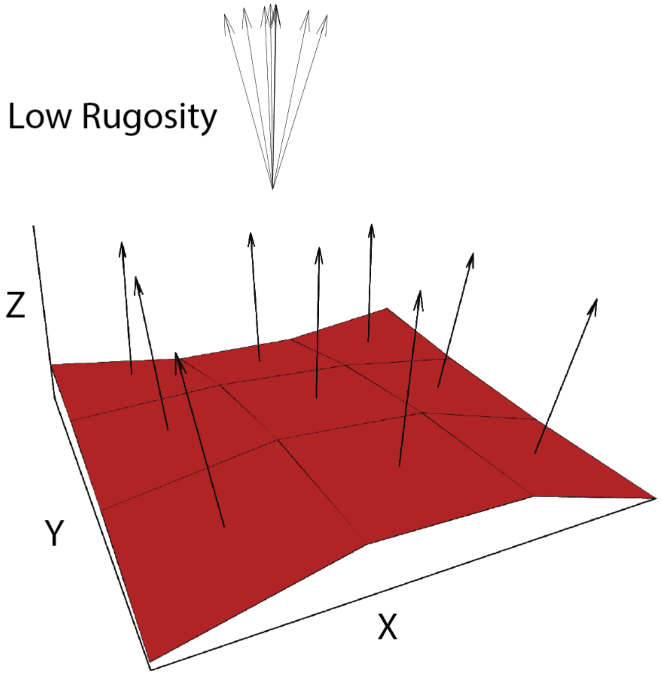
Interactive Tools:
https://ailich.shinyapps.io/Terrain_Attributes_Explorer_App/

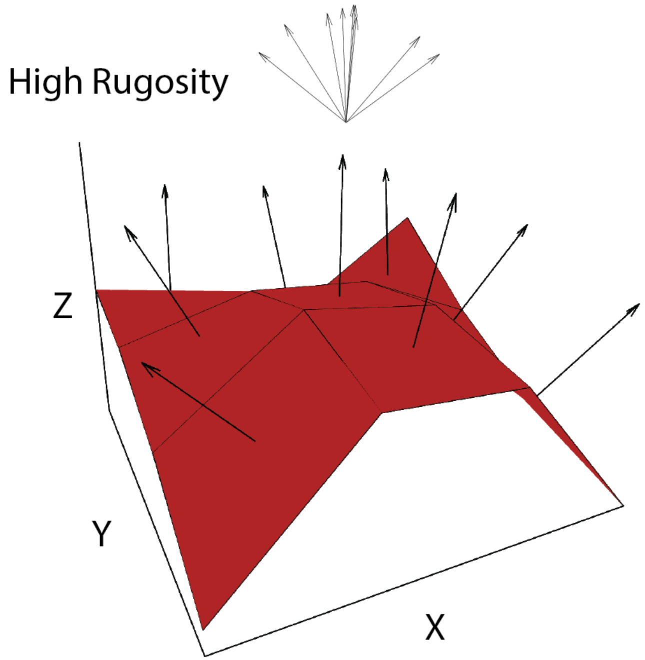
Additional Slides

MultiscaleDTM R Package: Included Algorithms

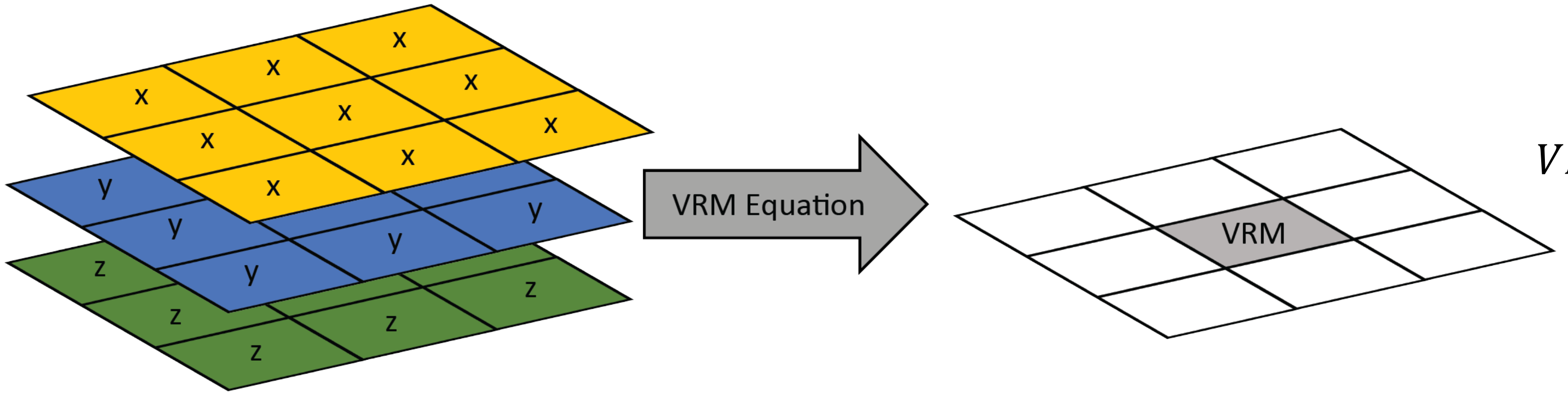
- **Multiscale Slope/Aspect** (Misiuk et al., 2021)
- **Quadratic Surface Estimation** (Evans, 1980; Wood, 1996)
  - **Slope**
  - **Aspect**
  - **Curvature** (Minár et al., 2020)
    - Profile (along slope)
    - Plan (across slope)
    - Twisting
    - Max/Min/Mean
  - **Morphometric Features**
- **Surface Area** (Jenness, 2004)
- **Rugosity**
  - Vector Ruggedness Measure (Sappington et al., 2007)
  - Slope Corrected Surface Area to Planar Area Ratio (Du Preez, 2015)
  - Adjusted Standard Deviation
- **Relative Position**
  - Topographic Position Index (Weiss, 2001)
  - Bathymetric Position Index (Lundblad et al., 2006)
  - Relative Difference from Mean Value (Lecours et al., 2017)

Vector Ruggedness Measure (VRM)





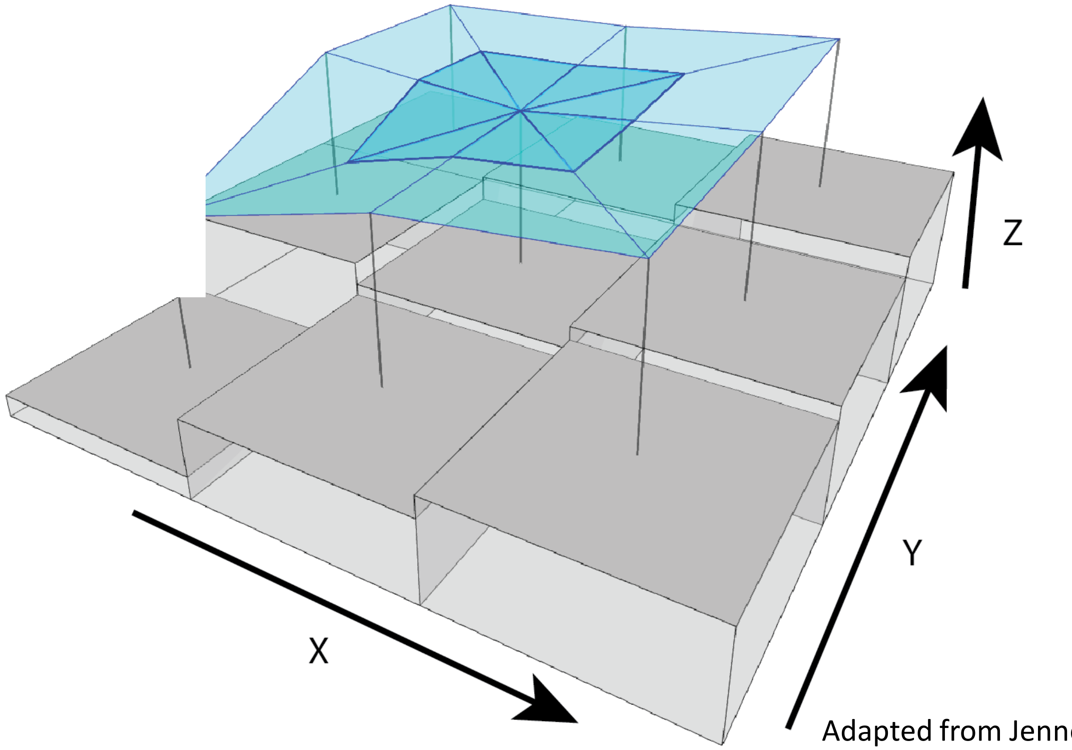
VRM quantifies rugosity by measuring the dispersion of vectors normal to the terrain surface.



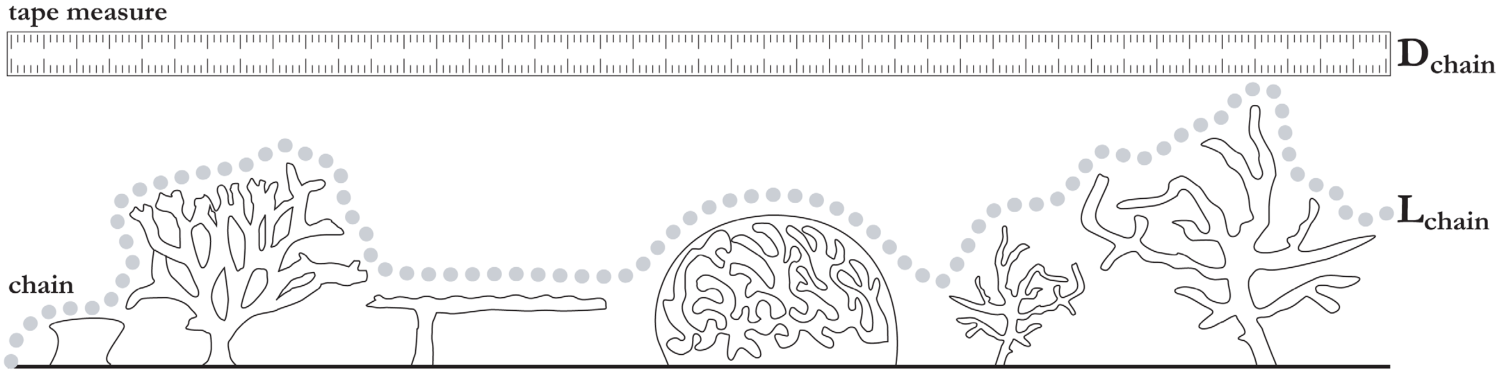
$$VRM = 1 - \frac{\sqrt{\sum(x)^2 + \sum(y)^2 + \sum(z^2)}}{n}$$

Adapted from Sappington et al. (2007) and Habib (2021)

Surface Area to Planar Area (SAPA)



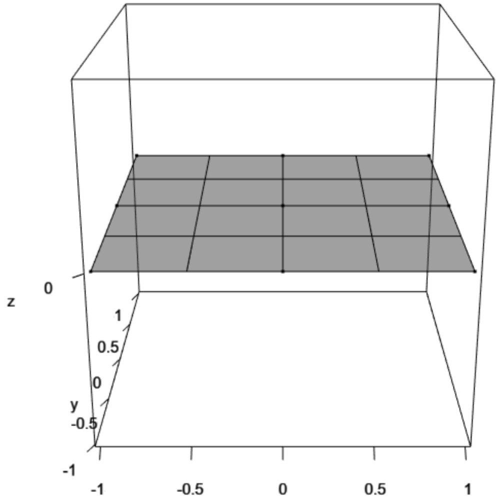
Adapted from Jenness (2004)



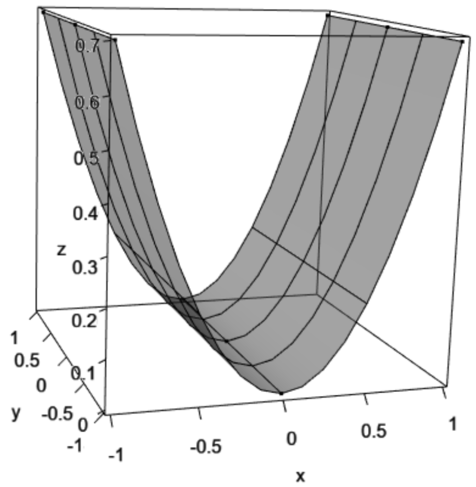
(Friedman et al., 2012)

Morphometric Features

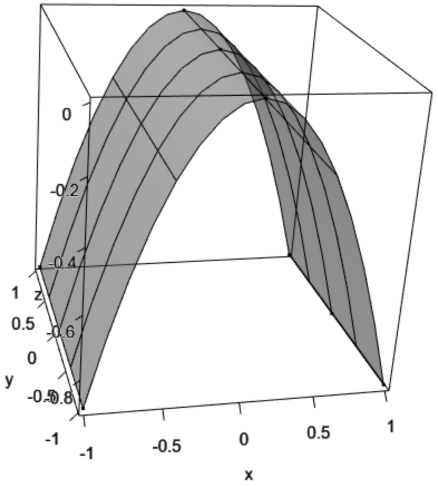
Planar



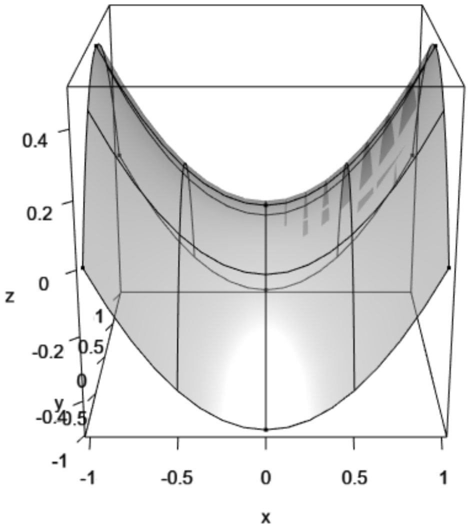
Channel



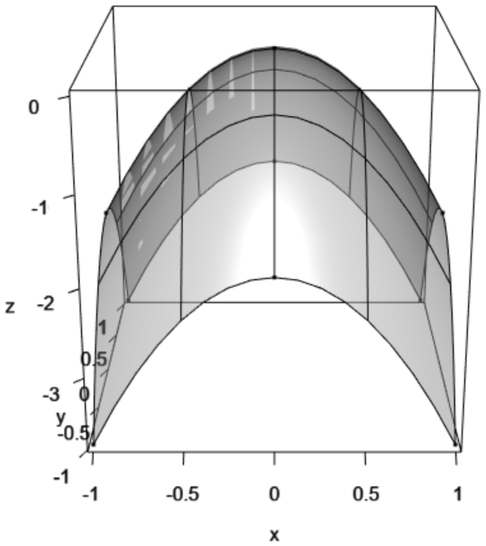
Ridge



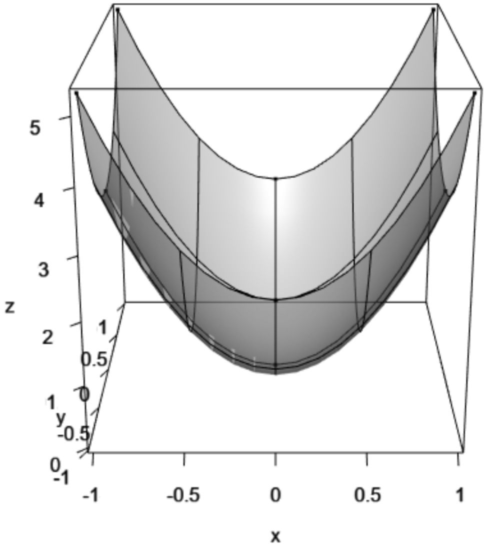
Pass



Peak



Pit



By fitting a quadratic surface to a local area six unique morphometric features can be determined (Wood, 1996)

References

Barnhardt, W.A., Ackerman, S.D., Andrews, B.D., and Baldwin, W.E., 2010, Geophysical and sampling data from the inner continental shelf; Duxbury to Hull, Massachusetts: U.S. Geological Survey Open-File Report 2009-1072, 1 DVD-ROM. (Also available at https://pubs.usgs.gov/of/2009/1072/.)

Du Preez, C., 2015. A new arc–chord ratio (ACR) rugosity index for quantifying three-dimensional landscape structural complexity. Landscape Ecol 30, 181–192. https://doi.org/10.1007/s10980-014-0118-8

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift f¨ur Geomorphologic Suppl-Bd 36, 274–295.

Friedman, A., Pizarro, O., Williams, S.B., Johnson-Roberson, M., 2012. Multi-Scale Measures of Rugosity, Slope and Aspect from Benthic Stereo Image Reconstructions. PLOS ONE 7, e50440. https://doi.org/10.1371/journal.pone.0050440

Habib, M., 2021. Quantifying Topographic Ruggedness Using Principal Component Analysis. Advances in Civil Engineering 2021, e3311912. https://doi.org/10.1155/2021/3311912

Jenness, J.S., 2004. Calculating landscape surface area from digital elevation models. Wildlife Society Bulletin 32, 829–839. https://doi.org/10.2193/0091-7648(2004)032[0829:CLSAFD]2.0.CO;2

Lecours, V., Devillers, R., Simms, A.E., Lucieer, V.L., Brown, C.J., 2017. Towards a Framework for Terrain Attribute Selection in Environmental Studies. Environmental Modelling & Software 89, 19–30. https://doi.org/10.1016/j.envsoft.2016.11.027

Lundblad, E.R., Wright, D.J., Miller, J., Larkin, E.M., Rinehart, R., Naar, D.F., Donahue, B.T., Anderson, S.M., Battista, T., 2006. A benthic terrain classification scheme for American Samoa. Marine Geodesy 29, 89–111.

Minár, J., Evans, I.S., Jenčo, M., 2020. A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-Science Reviews 211, 103414. https://doi.org/10.1016/j.earscirev.2020.103414

Sappington, J.M., Longshore, K.M., Thompson, D.B., 2007. Quantifying Landscape Ruggedness for Animal Habitat Analysis: A Case Study Using Bighorn Sheep in the Mojave Desert. The Journal of Wildlife Management 71, 1419–1426. https://doi.org/10.2193/2005-723

Walbridge, S., Slocum, N., Pobuda, M., Wright, D.J., 2018. Unified geomorphological analysis workflows with benthic terrain modeler. Geosciences 8, 94.

Weiss, A., 2001. Topographic Position and Landforms Analysis. Presented at the ESRI user conference, San Diego, CA.

Wilson, M.F., O'Connell, B., Brown, C., Guinan, J.C., Grehan, A.J., 2007. Multiscale Terrain Analysis of Multibeam Bathymetry Data for Habitat Mapping on the Continental Slope. Marine Geodesy 30, 3–35. https://doi.org/10.1080/01490410701295962

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.