Identifying terrain conducive to enhanced orographic precipitation using wavelet analysis of Pacific Northwest U.S. topography

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Background

- Goal: Objectively characterize relative topographic roughness using spectral wavelet analysis.
- Recent research indicates orographic precipitation is enhanced more over rougher compared to smoother topography (Kirshbaum and Durran 2005; Colle 2008).
- Wavelet energy is used as analogue for roughness: Energy is lowest for areas of flat terrain, and highest for areas of rough terrain.

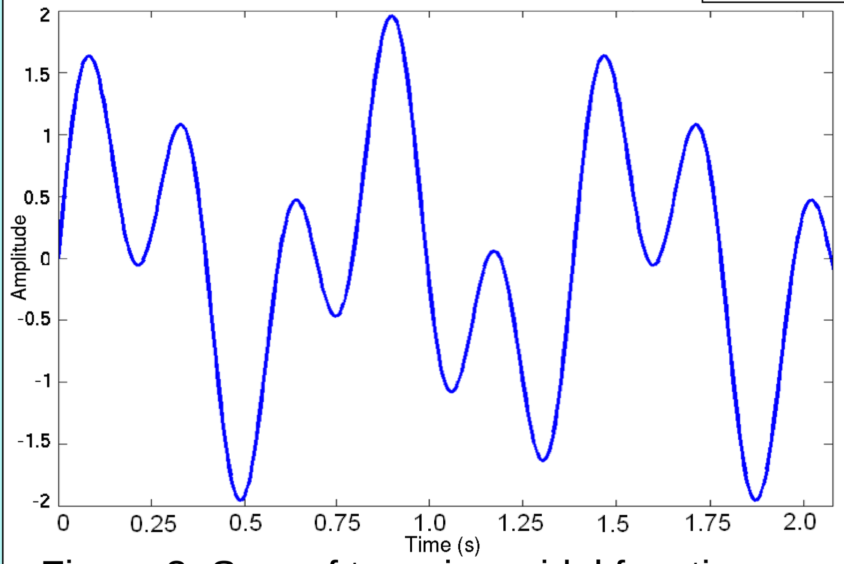
Figure 1 (left): Heightened roughness → High Energy

Figure 2 (right): Reduced roughness → Low Energy

Introduction to Spectral Analysis

- Fourier Analysis and Wavelet Analysis both perform spectral analysis of frequency.

Fourier Analysis → Extracts ***Sinusoidal*** Frequencies



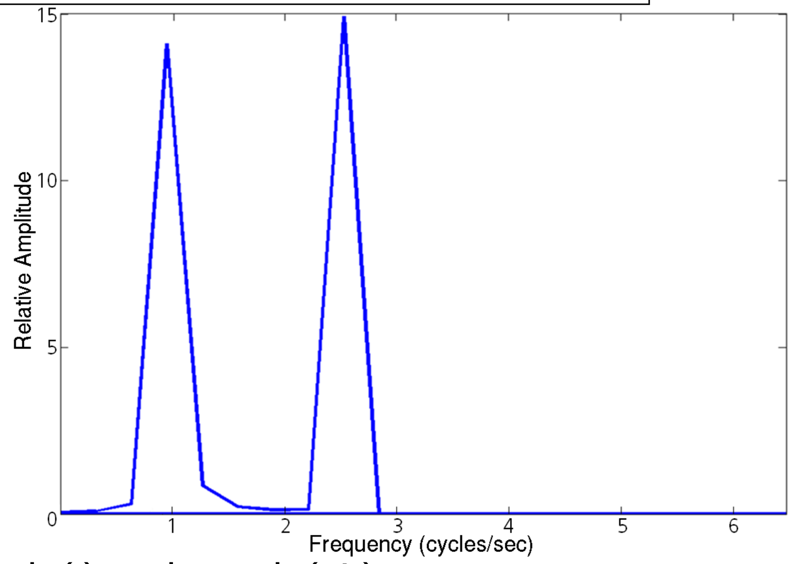


Figure 3: Sum of two sinusoidal functions y = sin(t) and y = sin(.4t).
Figure 4: Output of Fourier analysis shows the two dominant sinusoidal frequencies of the original signal – one spike each for y = sin(t) and y = sin(.4t).

Wavelet Analysis → Extracts ***Spatial*** Frequencies

Wavelet Transform	Spatial Scale
d1	1
d2	2
d3	4
d4	8

Figure 5 (above): Relative spatial scale values for a four-level wavelet analysis.

First Transform d1

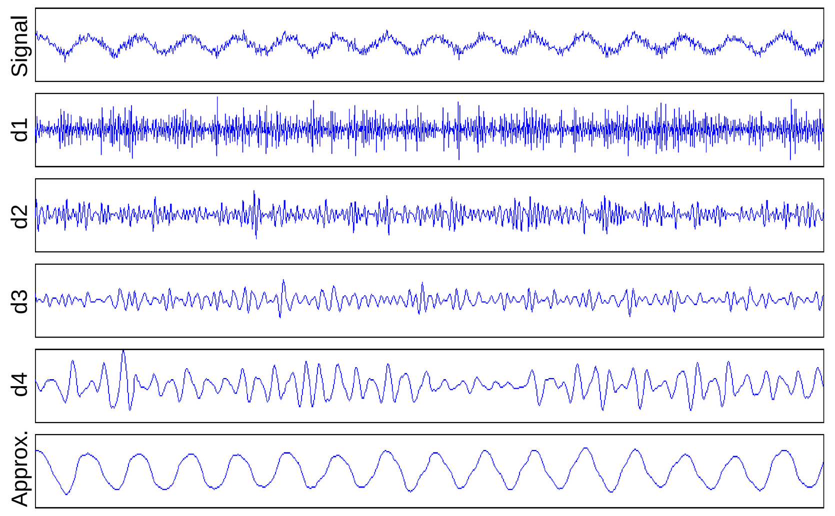
Highest Spatial Frequency = Smallest Spatial Scale

Wavelet Analysis

Last Transform dmax

Lowest Spatial Frequency = Largest Spatial Scale

One-Dimensional Wavelet Analysis



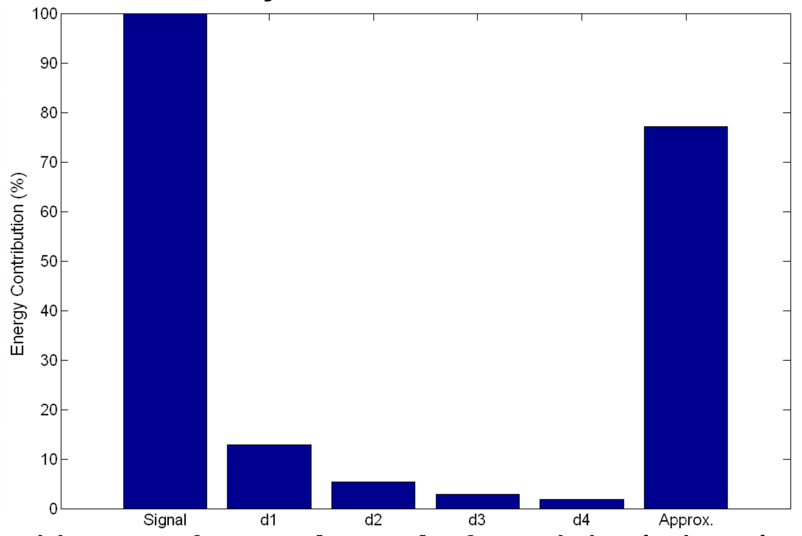


Figure 6 (left): Spatial frequencies are removed in transforms **d1** to **d4** for original signal **s**.
Figure 7 (right): Percentage of signal energy removed by **d1** to **d4**. “Approximation” value is remaining signal energy.

Introduction to Spectral Analysis (cont.)

Two-Dimensional Wavelet Analysis

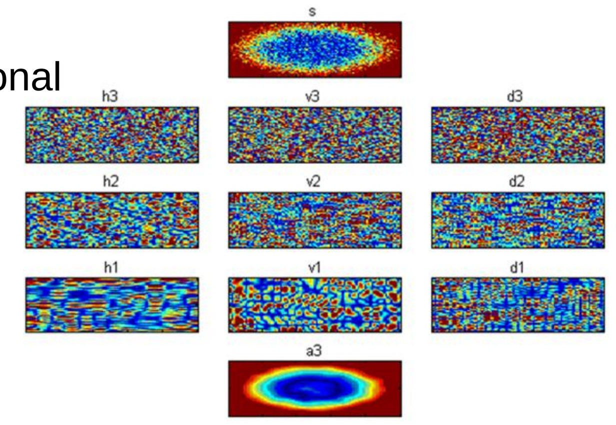


Figure 8 (left): Wavelet analysis of two-dimensional noised parabola. Approximation is **a3**.

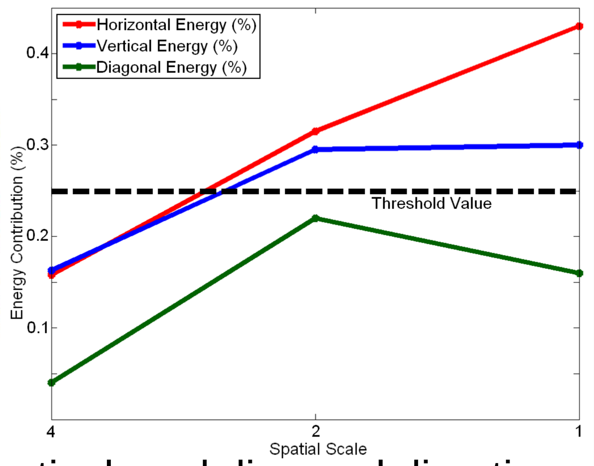


Figure 9 (right): Energy values for each transform. Threshold value is 0.25 %.

- Similar to 1-D, but separate analyses for horizontal, vertical, and diagonal directions. Maximum spatial scale is the scale of highest energy. In the example above, horizontal and vertical have max spatial scale of 1, while diagonal value is 2.
- Energy contribution values for each transform are shown on the y-axis of Figure 9. Energy threshold in Figure 9 discards max diagonal energy since it is < 0.25 %.

Data Set

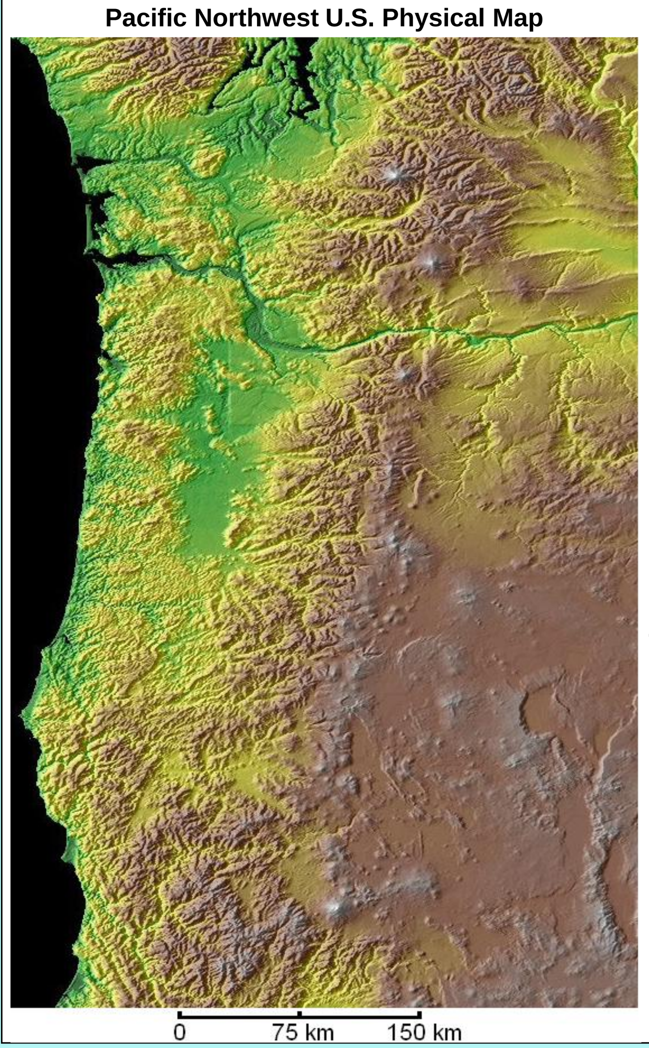


Figure 10 (left): Physical map of Pacific Northwest U.S.

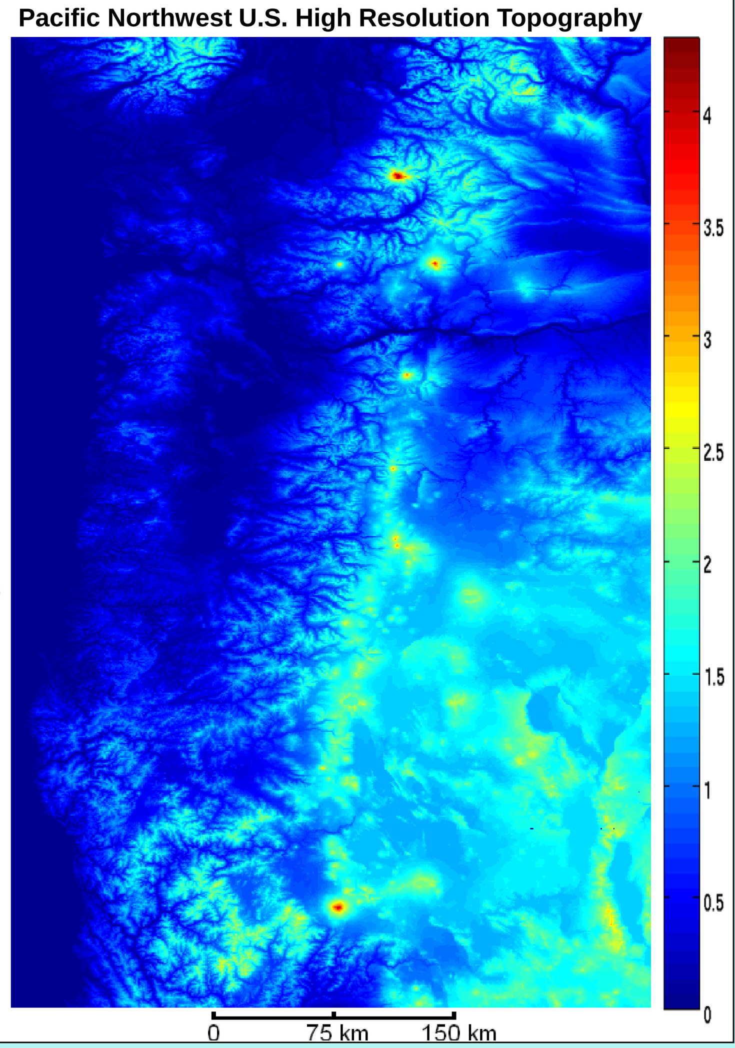
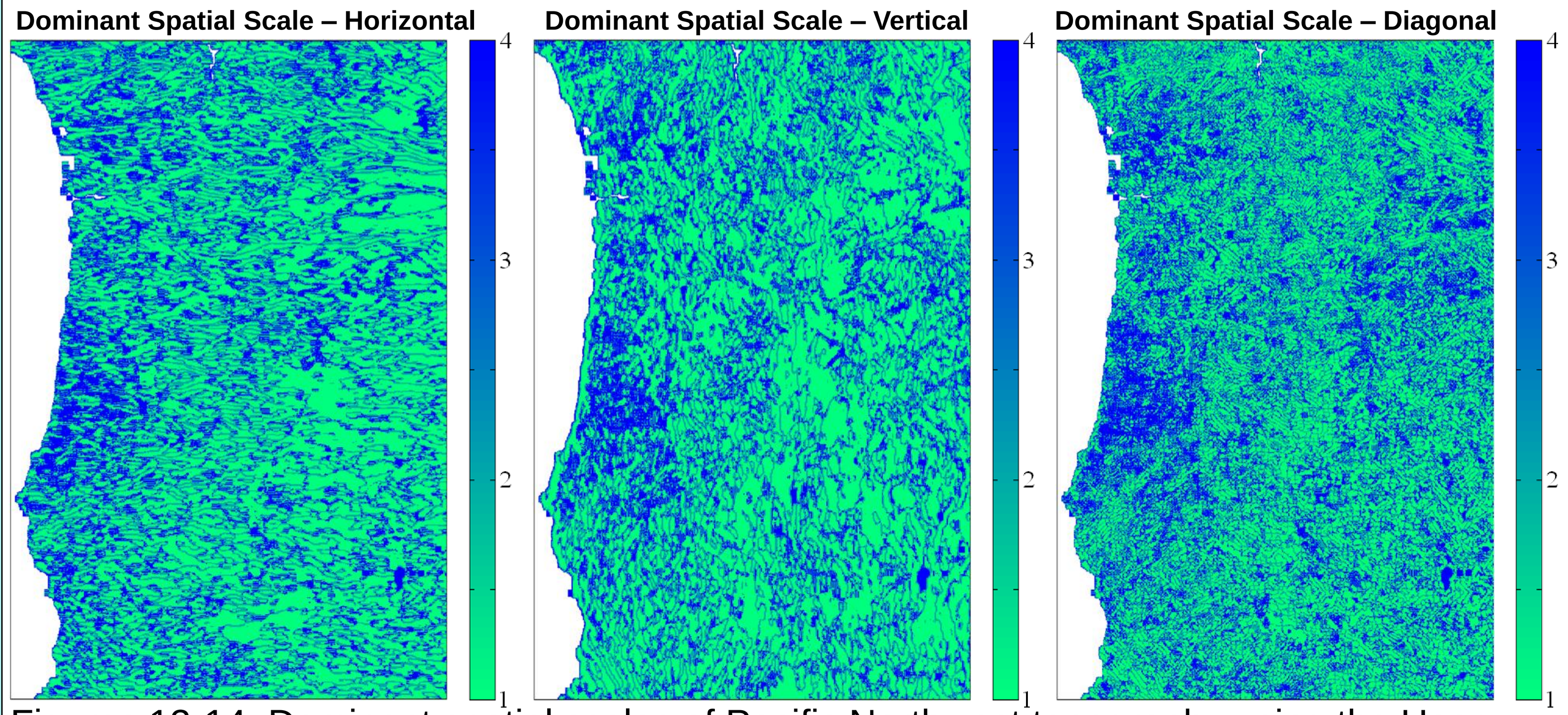


Figure 11 (right): Elevation map for the Pacific Northwest U.S. – elevation in km with 1-km horizontal resolution.

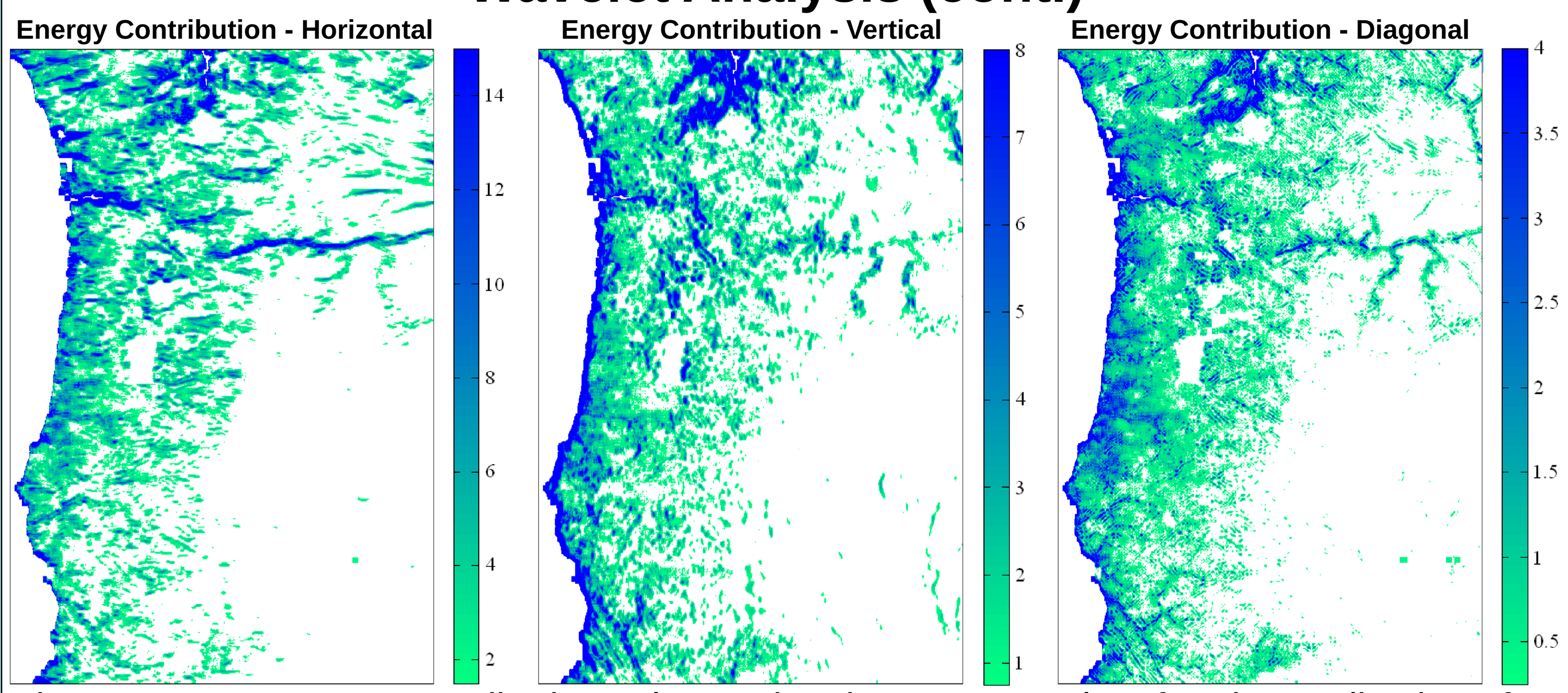
Wavelet Analysis

- Two-dimensional wavelet analysis is performed in each direction of the Pacific Northwest 1-km elevation signal: horizontal, vertical, and diagonal.
- The wavelet analysis estimates the following:
  i. The **Dominant Spatial Scale** is the spatial scale of the wavelet transform that removed the most signal energy.
  ii. The **Energy Contribution** is the energy percentage removed by the transform that contributed most to the signal.



Figures 12-14: Dominant spatial scales of Pacific Northwest topography using the Haar wavelet – horizontal (left), vertical (center), and diagonal (right).

Wavelet Analysis (cont.)



Figures 15-17: Energy contribution values using the Haar wavelet after the application of an energy threshold. Areas with contributions less than 1.5% (horizontal), 0.75% (vertical), and 0.25% (diagonal) are plotted white.

- Low energy returns are found for the Willamette Valley and areas east of the Cascades, while high returns are found along the Cascade range and the Columbia River gorge.

Future Research

- Apply wavelet analysis to high-resolution topography from the U.S. Geological Survey’s National Elevation Dataset (terrain maps at 30 meter, 10 meter, and 3 meter resolutions).

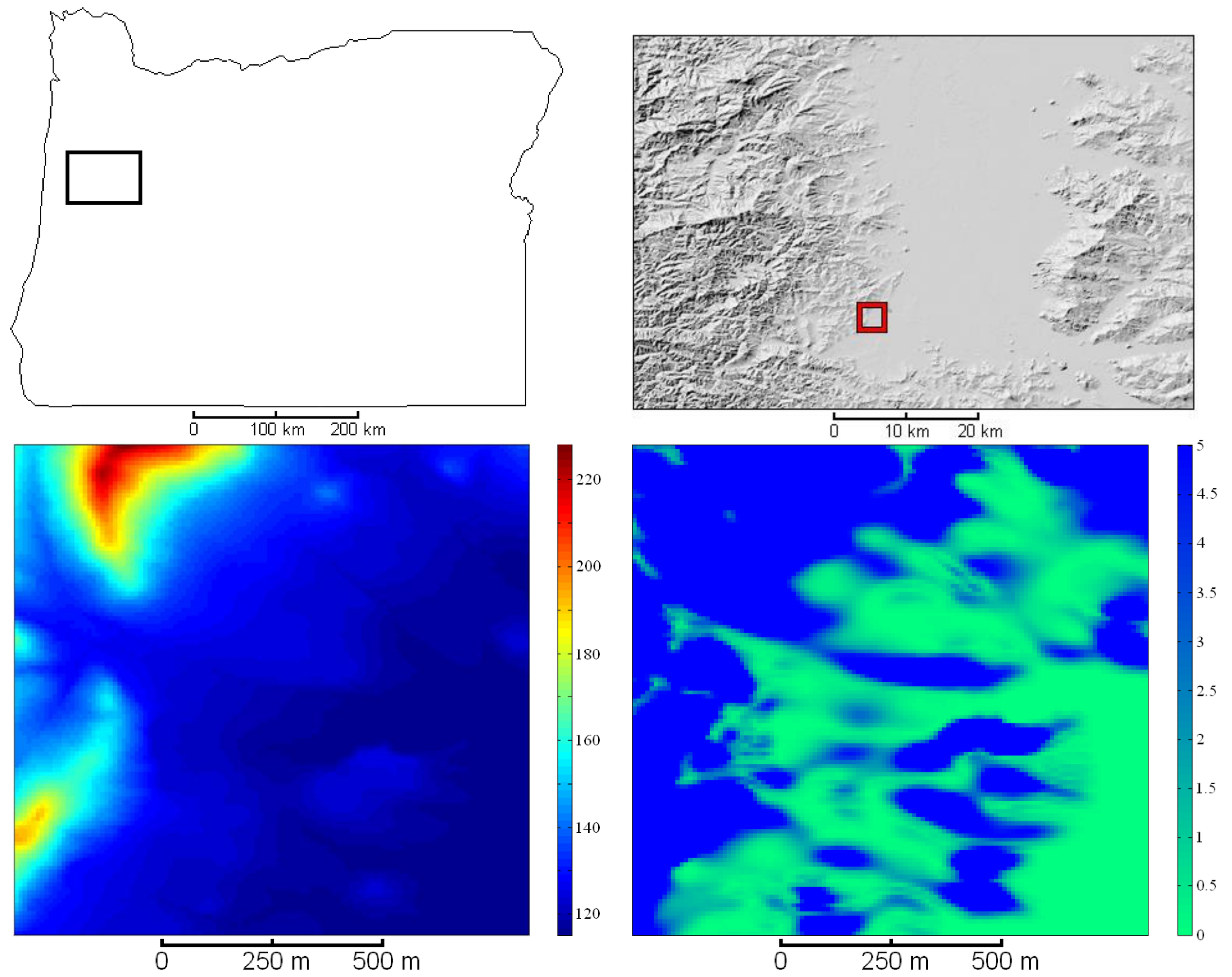


Figure 18 (upper left): Outline of Oregon

Figure 19 (upper right): Figure 18 subset

Figure 20 (bottom left): Elevation plot in meters of red box shown in Figure 19.

Figure 21 (bottom right): Percent energy contribution (horizontal) for elevation data in Figure 20.

- The presence of higher energy values in areas of rougher terrain is consistent with the findings of the 1-km resolution analysis.

Conclusions

- Wavelet analysis is an effective means at objectively characterizing relative topographic roughness.
- The energy contribution of the dominant spatial frequency of topography is an objective indicator of roughness. For example, the highly variable terrain of the Cascade Mountains returns a higher energy value than the flatter terrain of the Willamette Valley.
- The value of the dominant spatial frequency (spatial scale) does not appear to be a clear indicator of terrain variability.
- Future work will compare the degree of precipitation enhancement as a function of terrain roughness.

Thanks to Brett F. Sanders for software support. This study was supported by NSF grant ATM-0544766.