Assessing Tectonic Tilt of the Teton Range, Wyoming and Idaho, Using Stream Topographic Analysis

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Abstract:

Topographic indices for quantifying tectonic tilt are used to determine the extent and cause of possible range tilting of the Teton Mountain Range, WY and ID. The Teton Range is a young, asymmetric range on the eastern edge of the Basin and Range and the southern edge of the thermally uplifted Yellowstone region. The thermal uplift, attributed to the Yellowstone hot spot, has caused regional tilt north of the Yellowstone area, and it may also cause regional tilt south of Yellowstone. The Teton Range is ideally situated to test this hypothesis. To determine the magnitude and direction of possible tilt we analyzed the transverse topographic symmetry (TTS) in 25 major basins within the Teton Range (13 on the western side and 12 on the east). The basins and their major streams were identified using ArcGIS basin and stream order algorithms to 10 m USGS Digital Elevation Models (DEMs). The algorithms defined the basins based on drainage divides; the stream analysis defined water flow through the basins. The TTS equals Ds/Dm where Ds is the distance from the midpoint of the basin to the midpoint of the stream meander and Dm is the distance from the ridge to the basin midpoint. Dm was determined by drawing transects, with equal elevation start and end points, from ridge to ridge. The TTS is evaluated for each transect and a vector is used to visualize the magnitude and direction of TTS for each transect. TTS was determined at approximately 100 m intervals in the primary E-W trending basins. If tilting of a basin has occurred, the stream will show a general pattern of down-tilt migration. Thermal uplift of the Yellowstone hotspot, if it influences tilt of the Tetons, will cause a general north-south, down-tilt trend. Understanding tectonic tilt in the Teton Range and evaluating the influence of the Yellowstone hotspot on it will help determine, temporally and spatially, past interactions between passage of the hotspot and Basin and Range faulting.

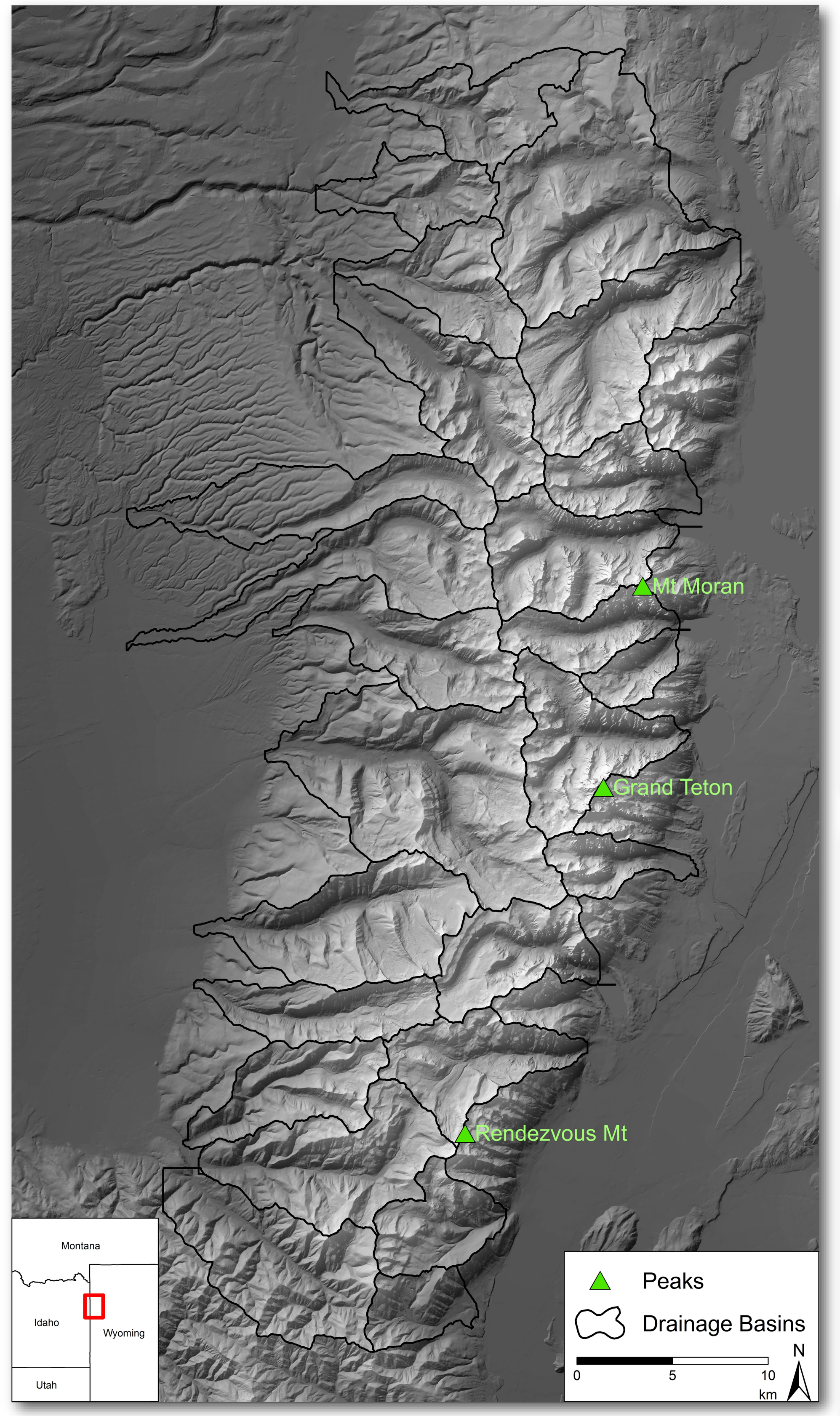

Figure 1. Study Area

Data was collected and analyzed across the entire Teton Mountain Range which sits on the border of Idaho and Wyoming. It is located just south of the Yellowstone hotspot and west of the Teton fault which makes this range an ideal location to test for possible causes of regional tilt using stream order analysis.

Methods:

To determine the direction of tilt occurring in the Teton Range, we applied the ArcGIS 'Contour,' 'Basin,' and 'Stream Order' spatial analyst tools to 10-m USGS Digital Elevation Models (DEM's). All data were projected into Universal Transverse Mercator (UTM) coordinates for more accurate analysis. To perform this series of steps, model builder was used in ArcGIS for a more efficient work flow (Figure 2a). The transverse topographic symmetry factor (TTS) was then calculated using the equation Ds/Dm (Figure 2b). Ds represents the distance from the midpoint of the drainage basin to the stream, and Dm represents the distance from the midpoint of the drainage basin to the ridge. Calculations of the TTS were completed on all tributaries, excluding first order streams based on the Strahler method. Transects were drawn at approximately 100-m intervals in ArcGIS using 20-m contours to define the starting and ending points. The start and endpoints of these transects have an equal elevation allowing the midpoint of each transect to be used as the midpoint of the drainage basin for each tributary. XY coordinates of start and endpoints, midpoints, and stream-transect intersections were calculated in ArcGIS using 'calculate geometry' tools. Distances to find Ds and Dm were calculated using the XY coordinates in Microsoft Office Excel (Figure 2c). The calculated TTS gives a value of the magnitude of the vector within a range from 0 to 1 with 0 meaning that the stream has not migrated at all from the midpoint and 1 implying that the stream has migrated to the edge of the basin. Trigonometric functions applied on the drawn transects find the azimuth of the line and the direction in which the stream has moved from the midpoint. Vectors were then created at each stream-transect intersection of each drainage basin (Figure 3d). Inverse distance weighting was applied to better visualize and predict direction of tilt throughout the entire range (Figures 3-6).

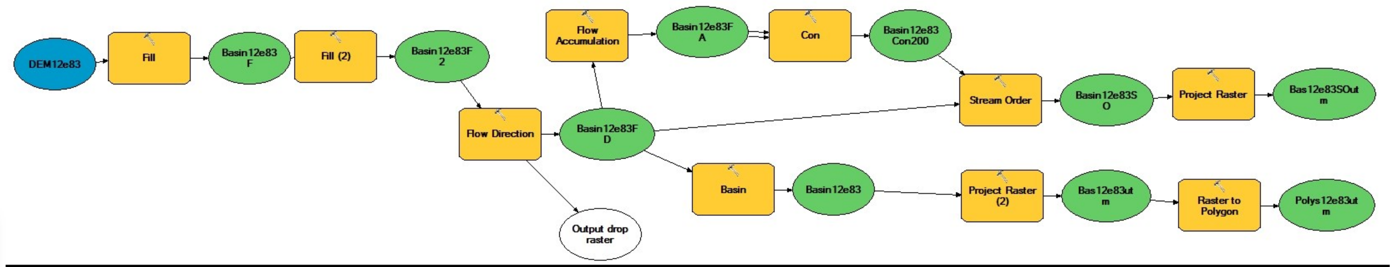

Figure 2a. GIS Model

A model was built in ArcGIS to perform a series of tasks for all 25 major drainage basins. A new DEM was inserted at the beginning of the model to gain the necessary feature classes for processing data.

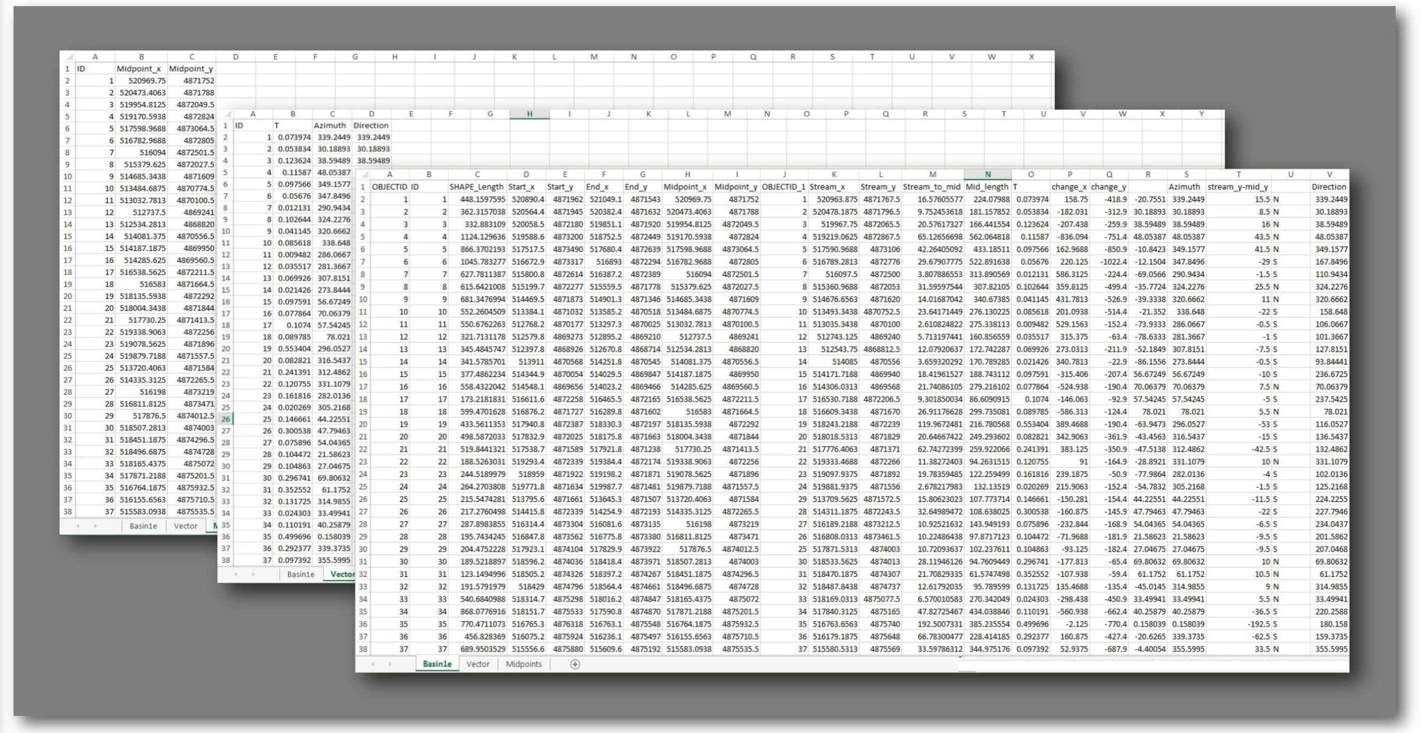

Figure 2b. Using Excel Spreadsheets

XY coordinates of transect start and endpoints, midpoints, and stream-transect intersections were calculated in ArcGIS and exported into Microsoft Excel. Ds and Dm values were calculated in Excel along with the azimuth of the transect and the direction in which the stream has migrated using trigonometric functions.

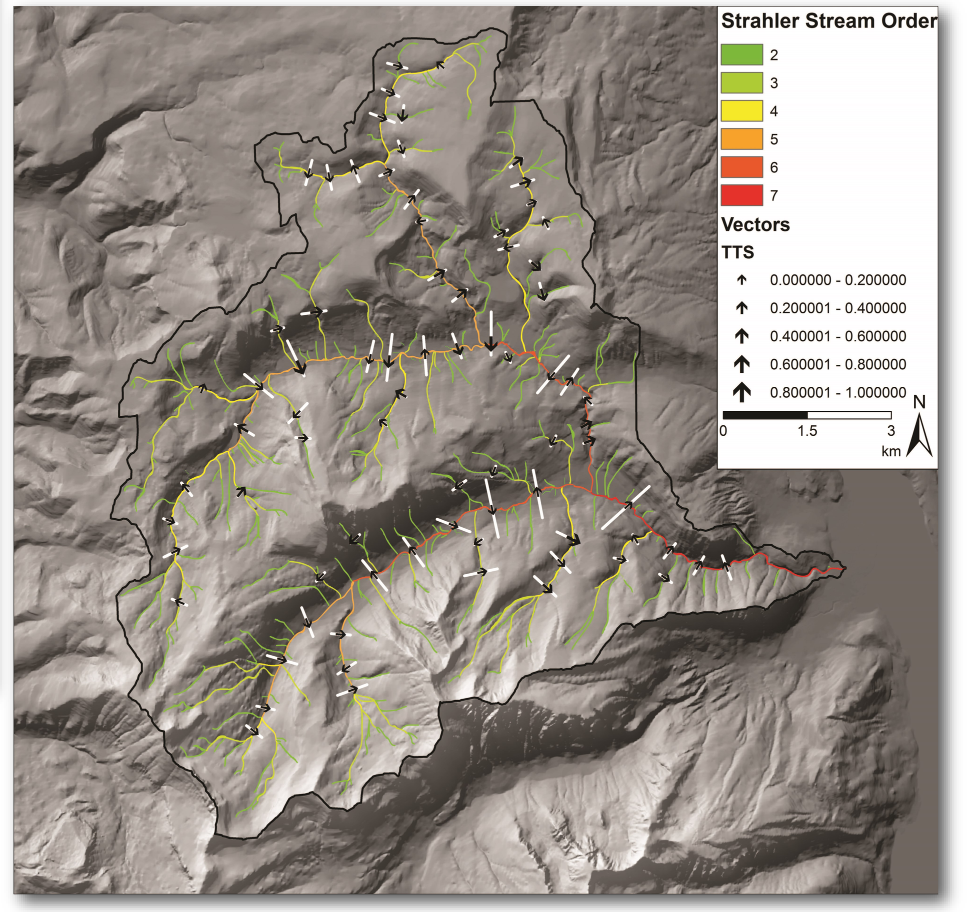

Figure 2c. Vectors

Vectors were created at stream-transect intersections by using the data calculated in excel with the vector pointing in the direction in which the stream is moving and the size of the arrows based upon the calculated TTS value. The most north-eastern basin contains an anomaly found nowhere else in the entire mountain range. This basin contains a stream capture that cut across the drainage divide. For a stream capture to cut across the basin divide a lake needed to have formed. Field work performed earlier this year found previously undocumented lake deposits in the area. These deposits provide evidence for the presence of a long lived lake. Upon further review of the area a mapped landslide or a glacial moraine could have been the cause of the lake formation. Further research into the Quaternary geology of the area is needed to determine the actual cause of the lake and the unusual drainage patterns.

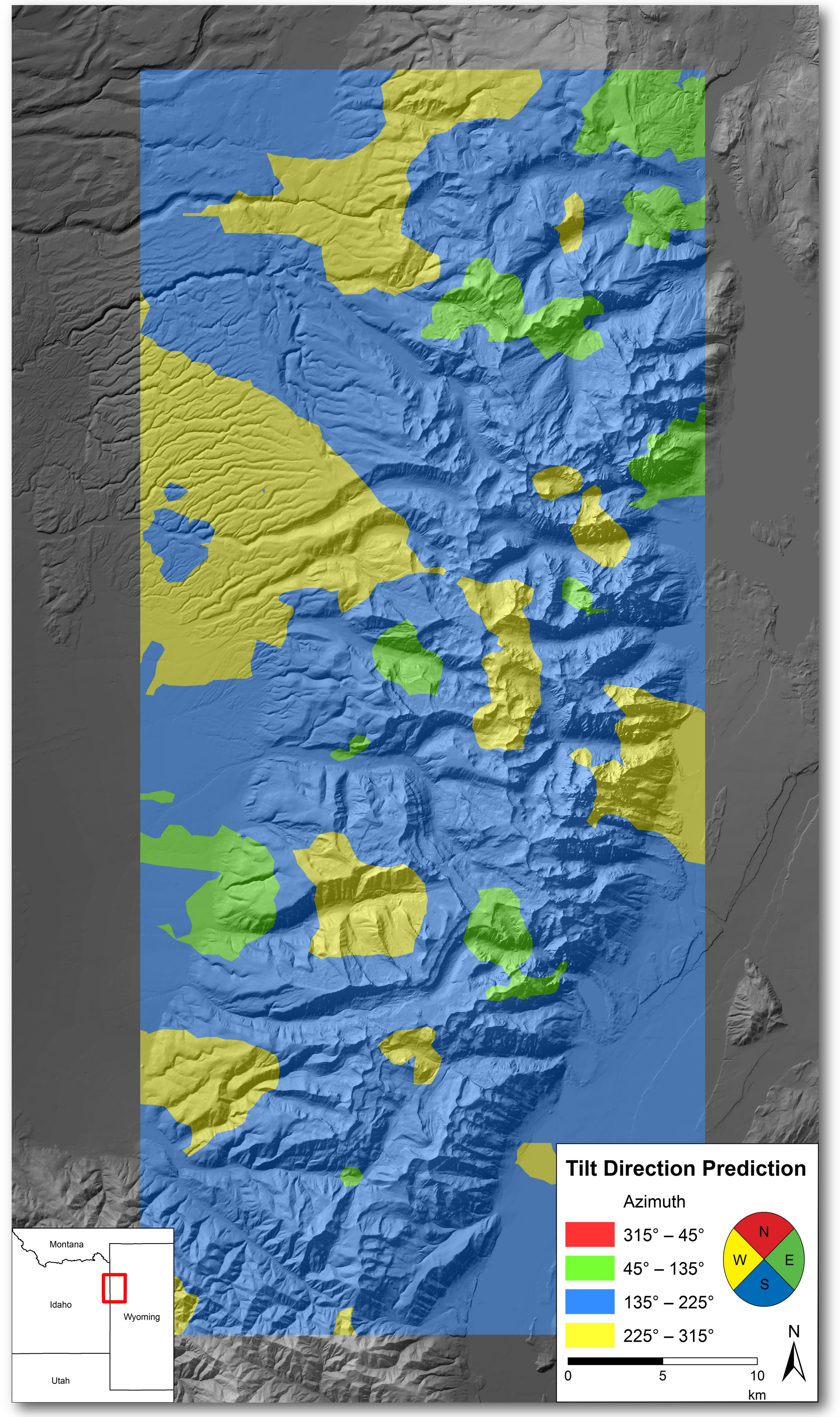

Figure 3. Inverse Distance Weighting using First Order Polynomial Analysis

This representation of tilt data is a first order polynomial analysis using inverse distance weighting of the transect data with a minimum 10 nearest neighbors. The representation suggests that no northward tilt occurs in the Teton Range in measureable quantities. This result led to the further use of statistical tools to determine if using higher order polynomials would give to different results (Figures 2 & 3).

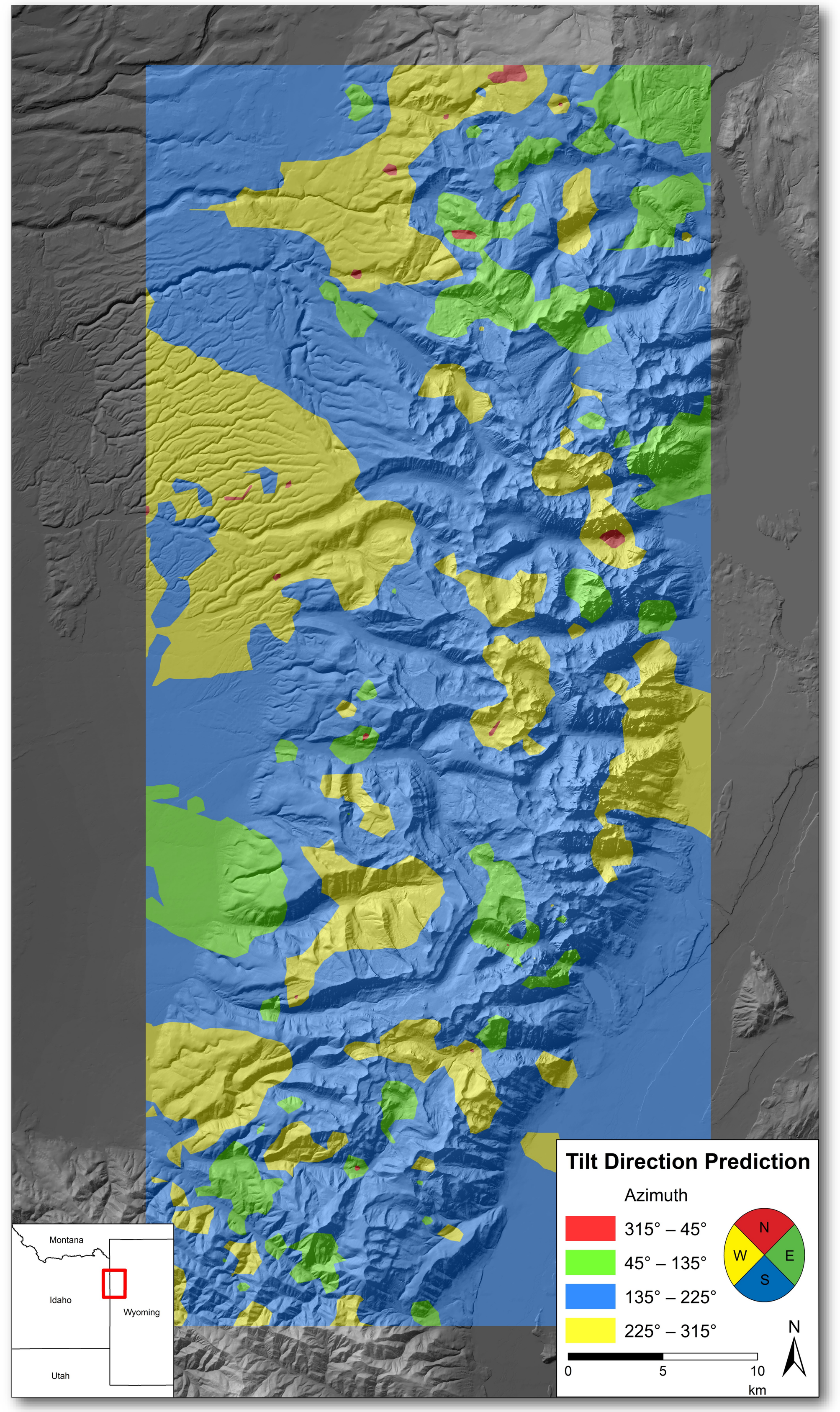

Figure 4. Inverse Distance Weighting using Second Order Polynomial Analysis

The default second order polynomial suggests further variation in the tilt expressed in the Teton Range than did the first order. The small amount of northward tilt remains eclipsed by the large amount of southward tilt. Areas that tilt both west and east are larger in size and more connected than some of the more isolated areas seen in the third order polynomial tilt map (Figure 3).

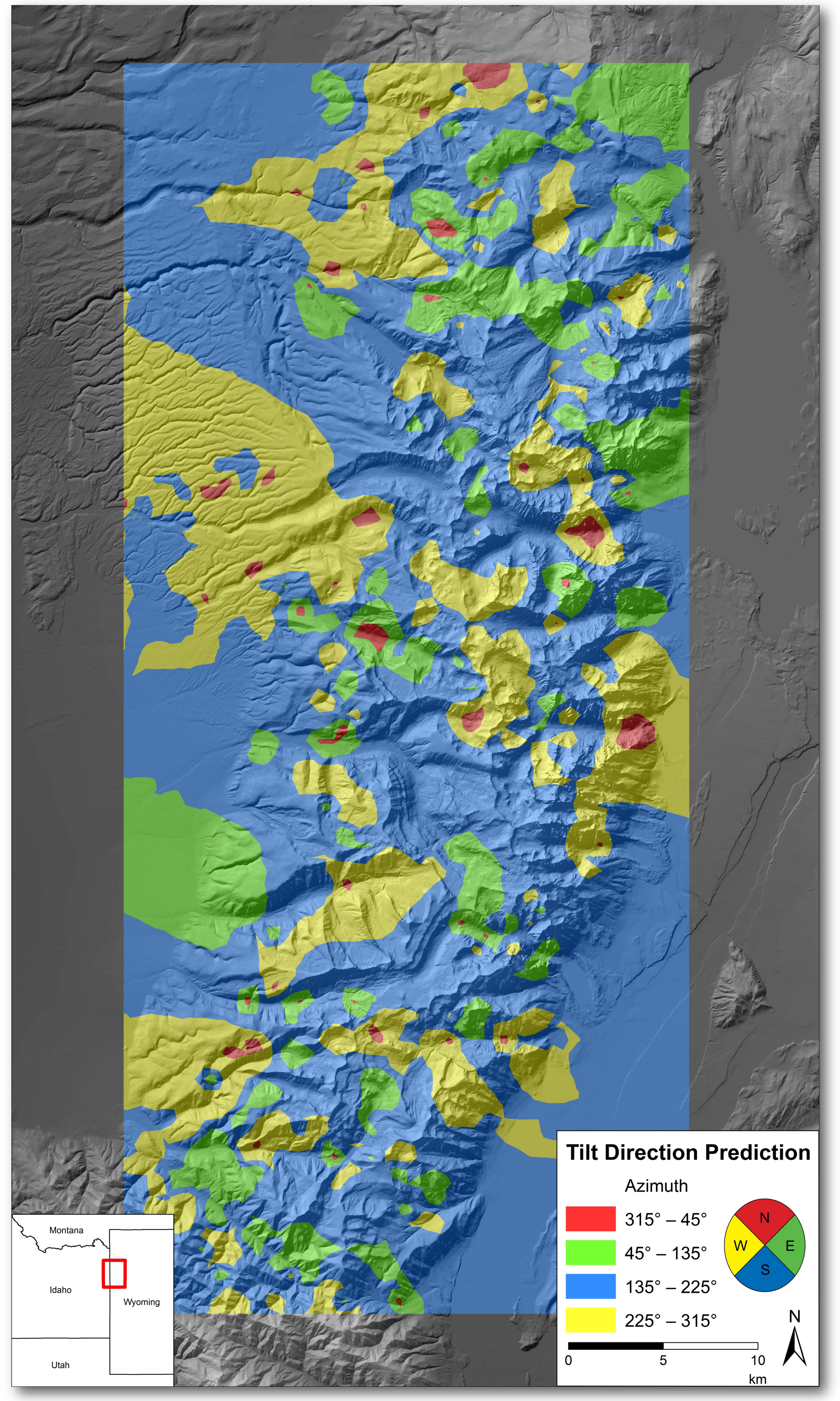

Figure 5. Inverse Distance Weighting using Third Order Polynomial Analysis

To further analyze the data, a third order polynomial analysis suggests more areas that tilt both to the east and the west. Some isolated areas suggest greater northward tilt, however those areas remain small when compared to the general southward trend seen across the entire mountain range.

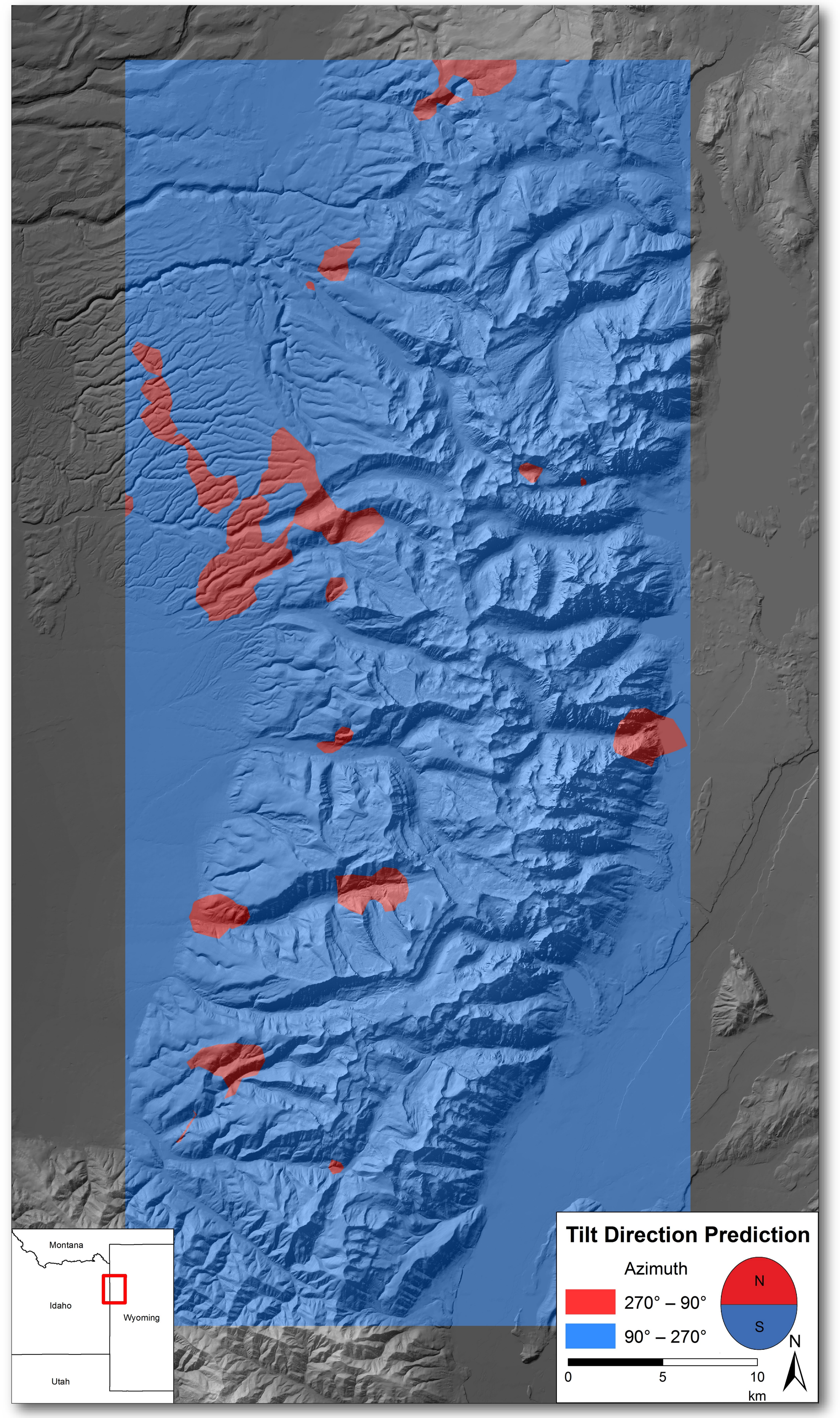

Figure 6. North versus South Tilt Directions

In an effort to show the dramatic difference in the tilt seen in the Teton Range, tilt has been categorized to only be north or south facing. By separating the tilt into these two directions the regional southern trend becomes clearly visible. The widespread regional tilt to the south corroborates the hypothesis that the Yellowstone hotspot is the cause of regional movement.

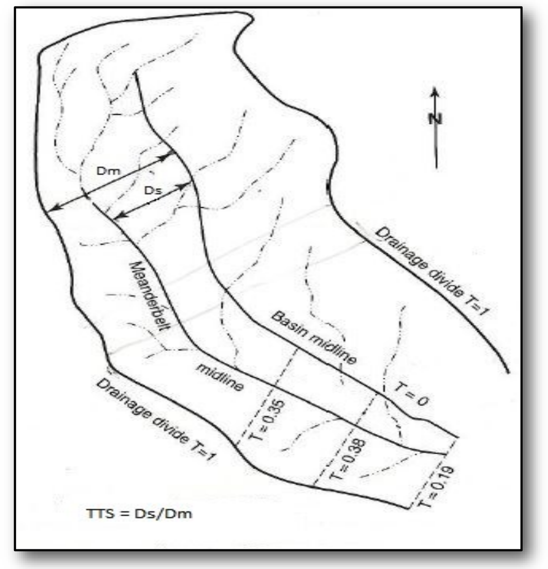

Figure 2d. Transverse Topographic Symmetry Factor

This technique allows for a quick method of accurate basin analysis. This method utilizes the natural topography to measure the distance that a stream migrates from the center of a basin. The amount and direction of shift of the stream from basin center provides information about the tilt effecting the area.

Conclusions:

- The data derived from the first second, and third order polynomial inverse distance weighting equations corroborates the hypothesis that the Yellowstone Hotspot is the primary source of the tilt found within the Teton Mountain Range.
- The southern tilt is expressed throughout the entire mountain range, and is not based around the hinge point of the Teton Fault.

Future Research:

- This research allows for further investigation in the Teton Range of a stream capture in the north-eastern most basin. The further research of this stream capture may lead to new information regarding paleotopography in the area.
- To further support the hypothesis that uplift described in the Tetons is regional rather than local, analysis could be performed in the neighboring Gros Ventre Mountain Range to determine if the same results could be produced.
- The raster data could be converted to vector data to allow for the geometric analysis of the area above and below the streams to be done. If the converted data suggests that the area above the streams is larger than the area beneath them; it corroborates the hypothesis that southward tilt dominates the area.
- Analysis of the Teton Fault could determine how the Teton fault affects the mountain range, and the relationship with the Yellowstone hotspot. The analysis of the fault could also explain the reasons why large sections of the Tetons tilt towards the west or east respectively.
- The tectonic tilt mapping could be useful in understanding Quaternary mass wasting scenarios in the parts of the Range prone to these events.

Acknowledgements:

- The data were collected using the ESRI ArcGis software and the analysis performed could not have been done without the software.
- The help of Dr. Grant Willis, head of the geologic mapping program for the Utah Geological Survey, proved invaluable in determining the areas of future research in the Teton Range and in the interpretation of data found while doing field work.

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