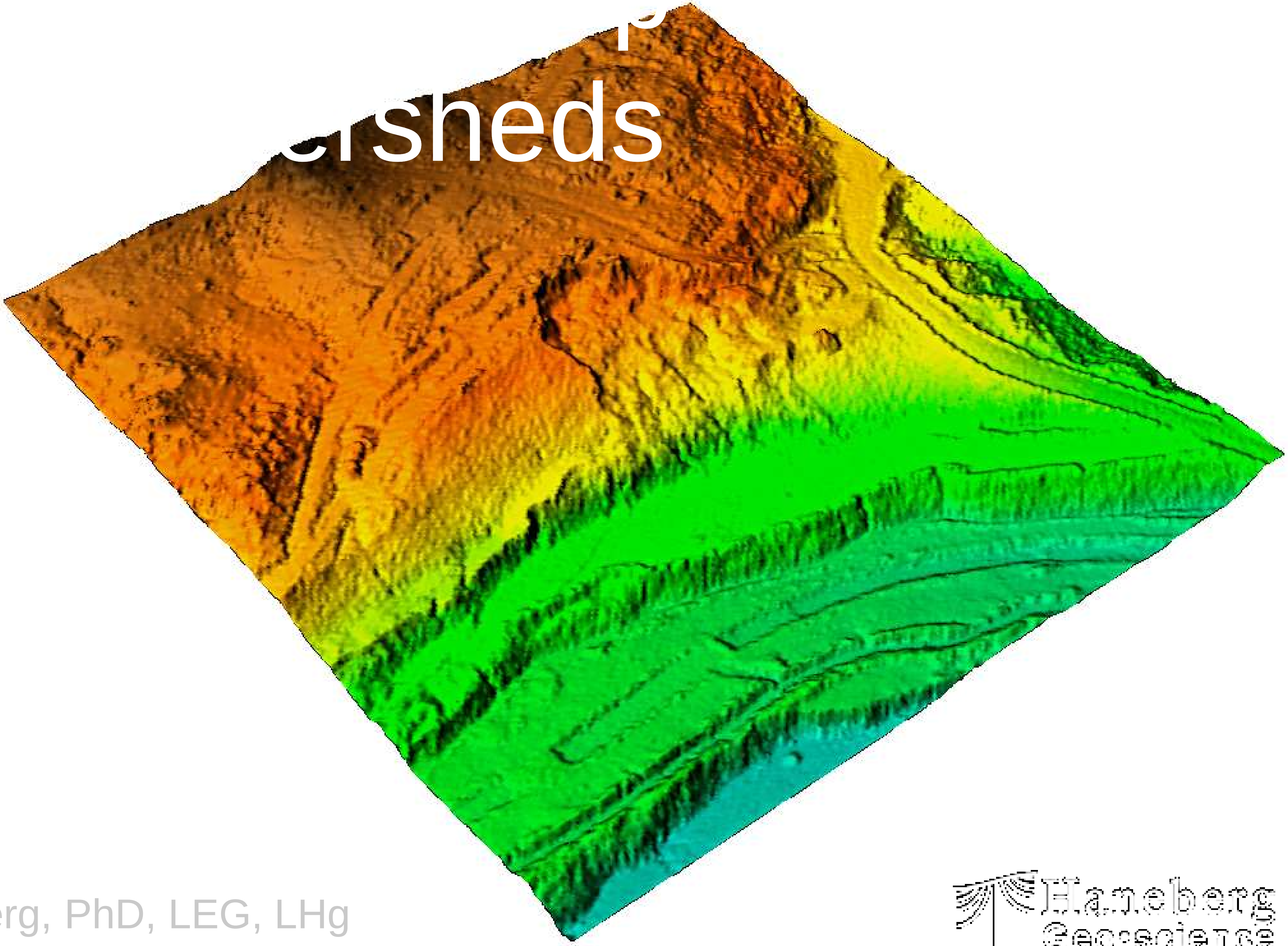
Leveraging LiDAR for site-specific geologic applica p foreste ersheds



William C Haneberg, PhD, LEG, LHg

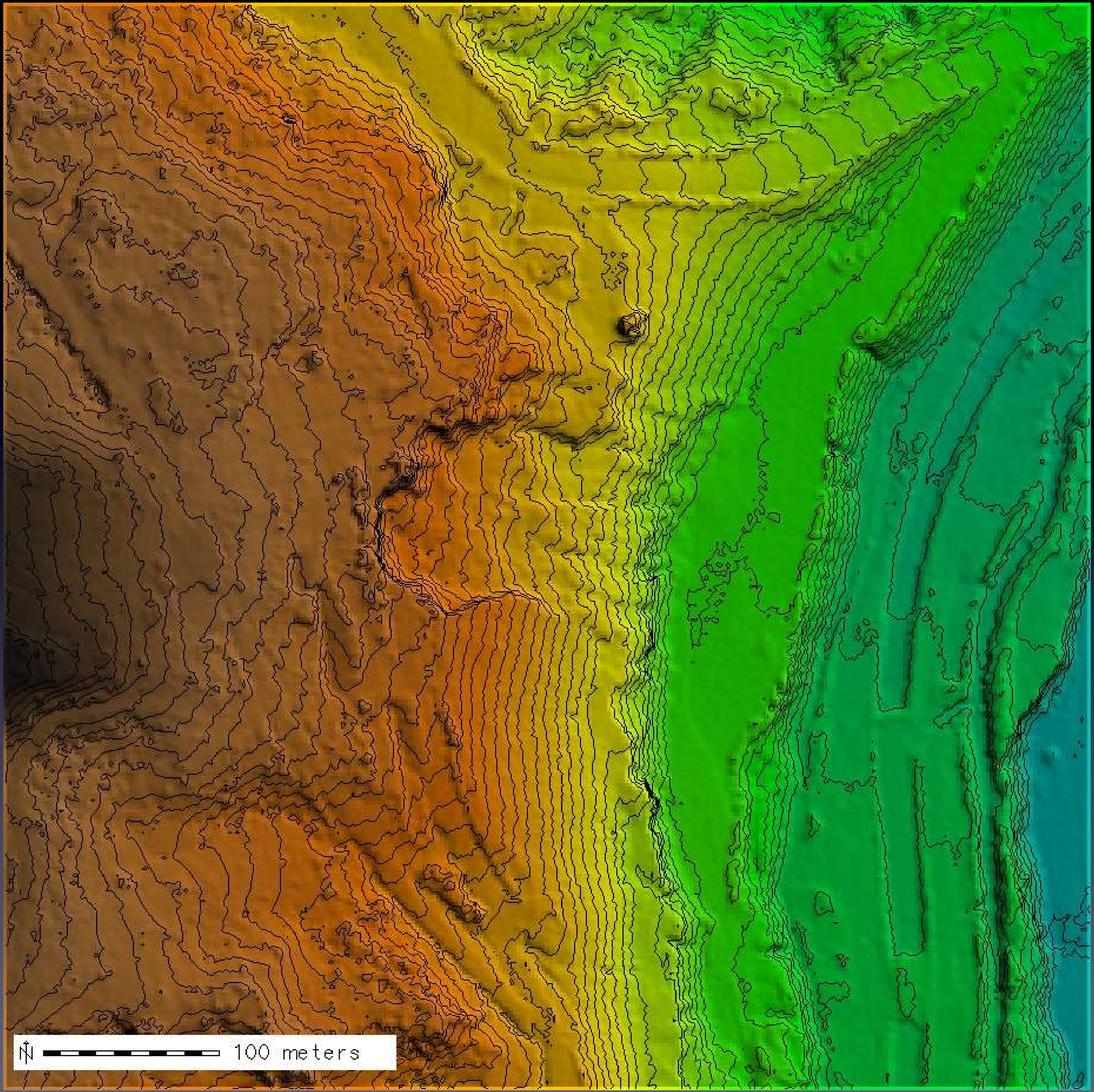
Haneberg Geoscience

Levers

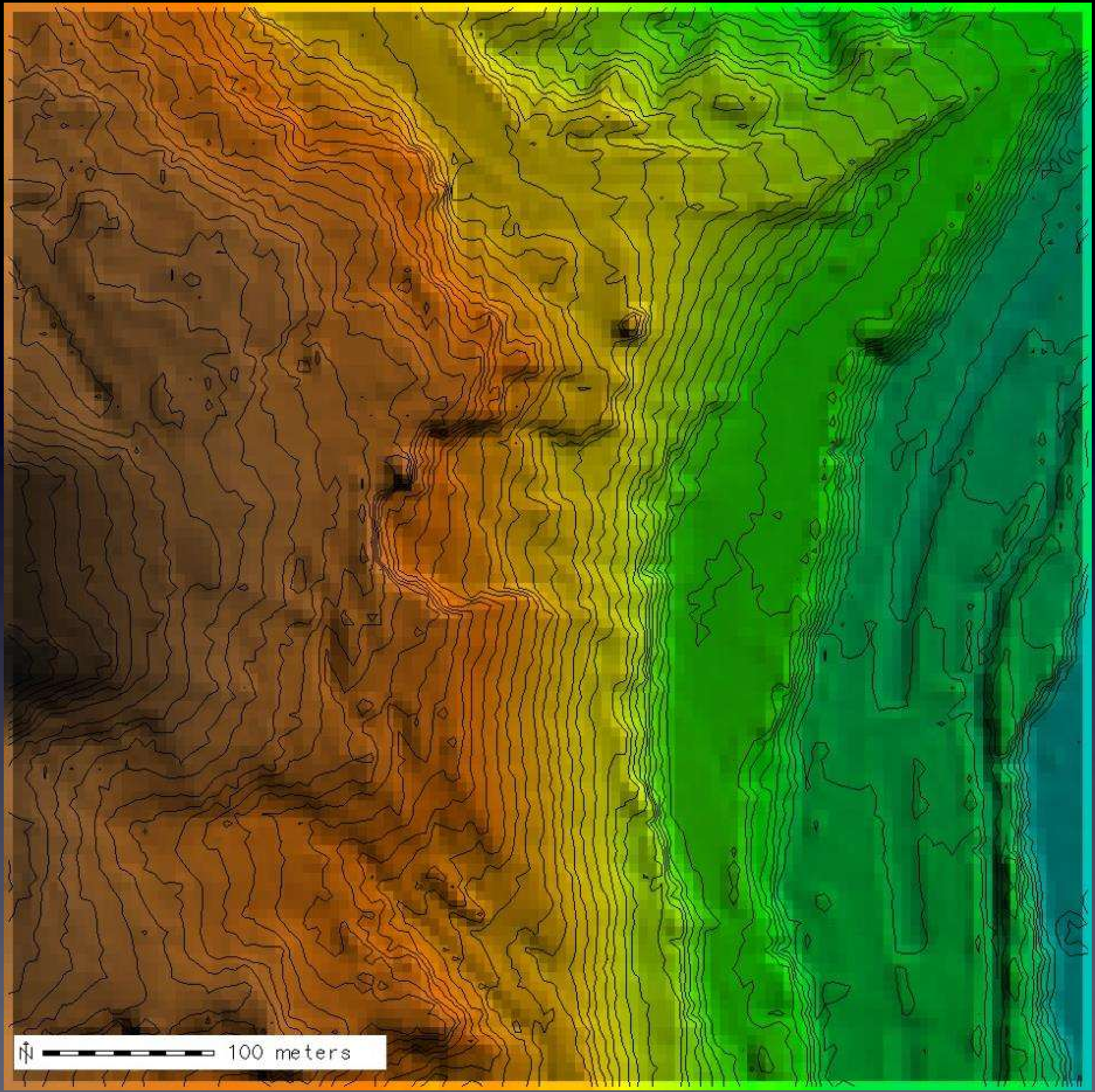
- Understand DEM resolution and mappability
- Work with point clouds to incorporate ground strike density and variability information
- Create geologically optimal DEMs
- Create derivative maps to elucidate morphology
- Employ multilayered virtual mapping technology
- Use quantitative models where appropriate
- Include geologic input as early as possible in projects

Resolution & mappability

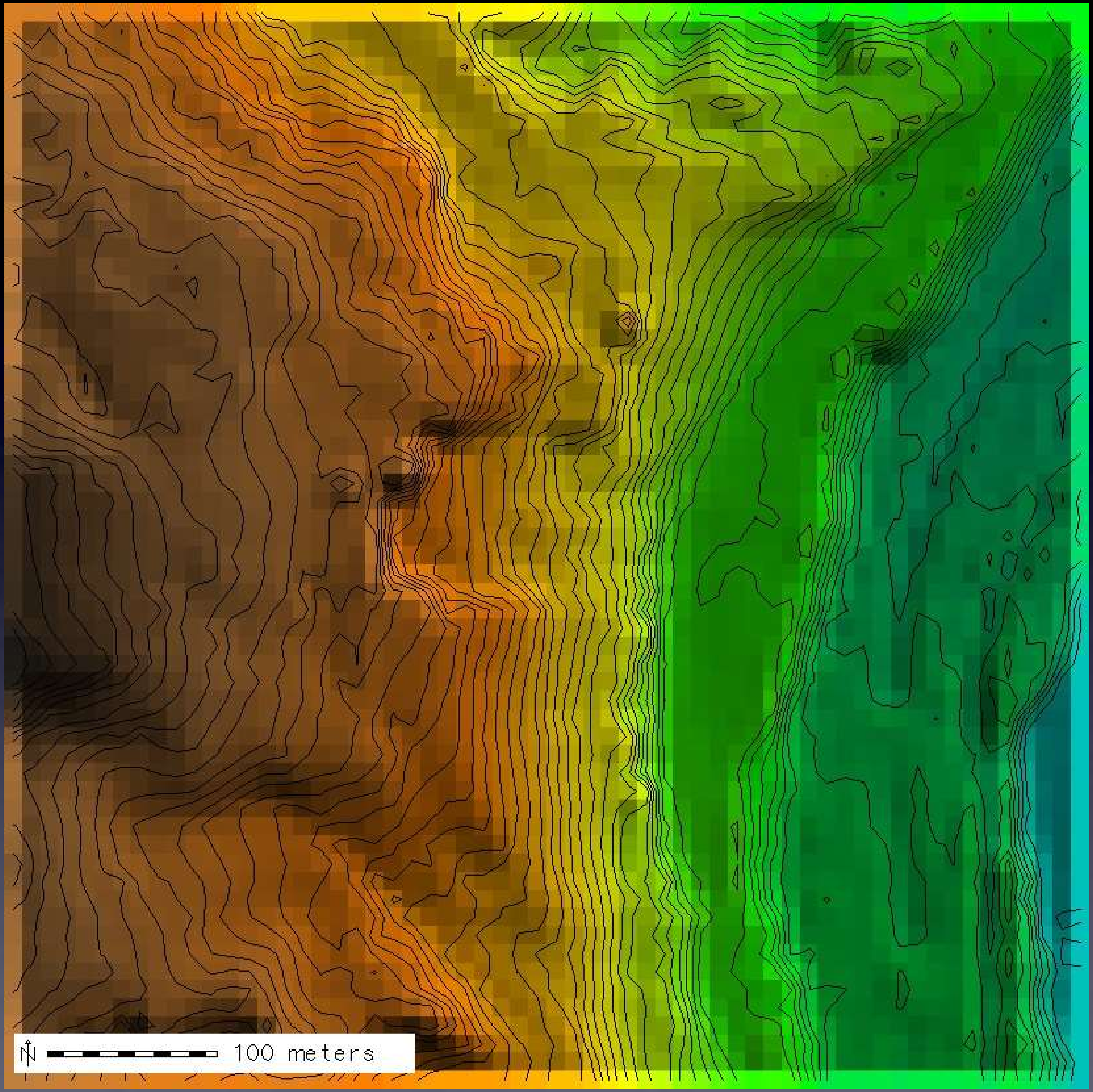
- We often describe the raster size of a DEM as its resolution
- But, this is not the same as the ability of a DEM to resolve a geologic feature like a landslide or fault scarp
- What is the smallest landform that might be identified and mapped on a DEM product of a given resolution?



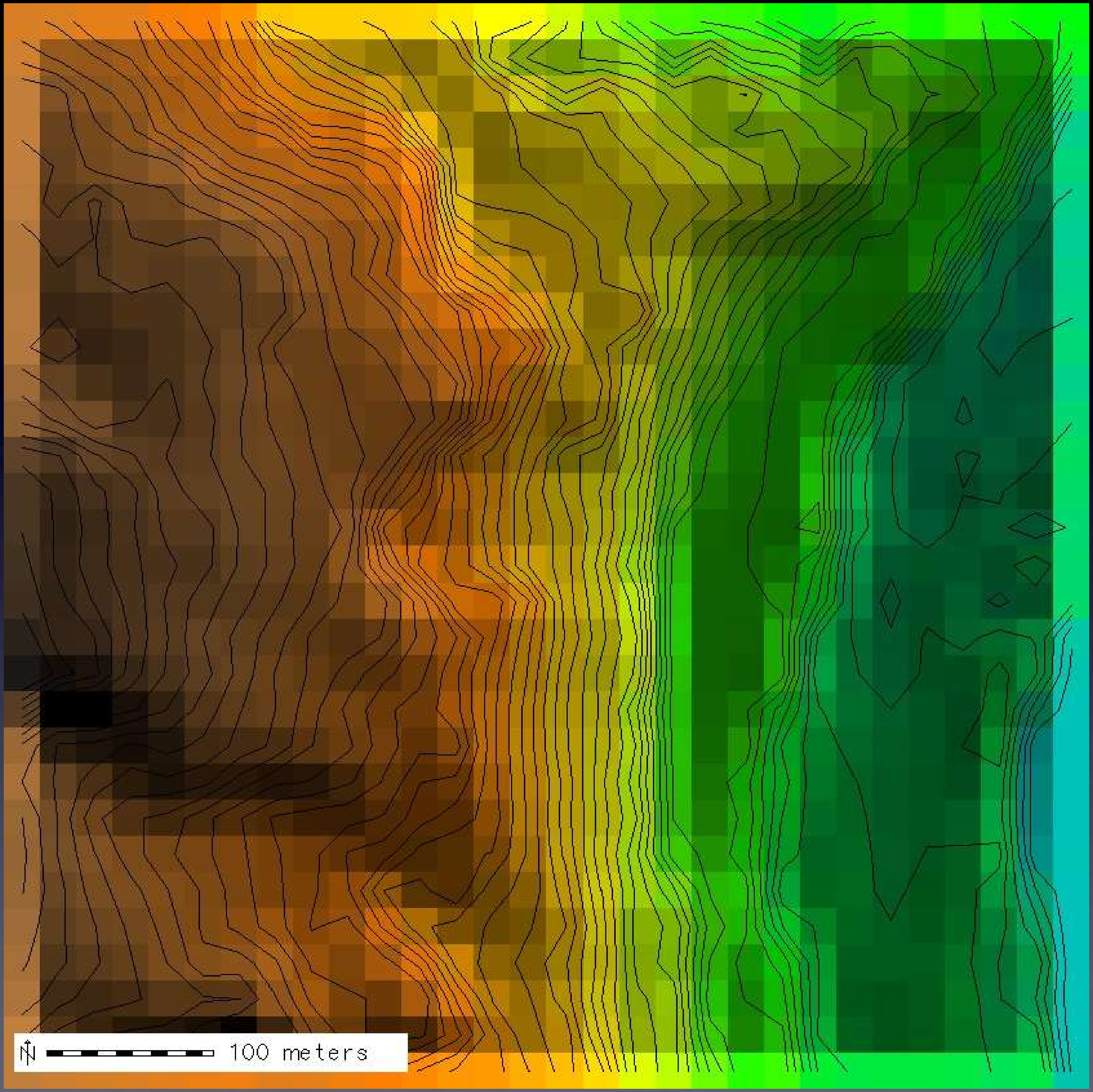
2 m



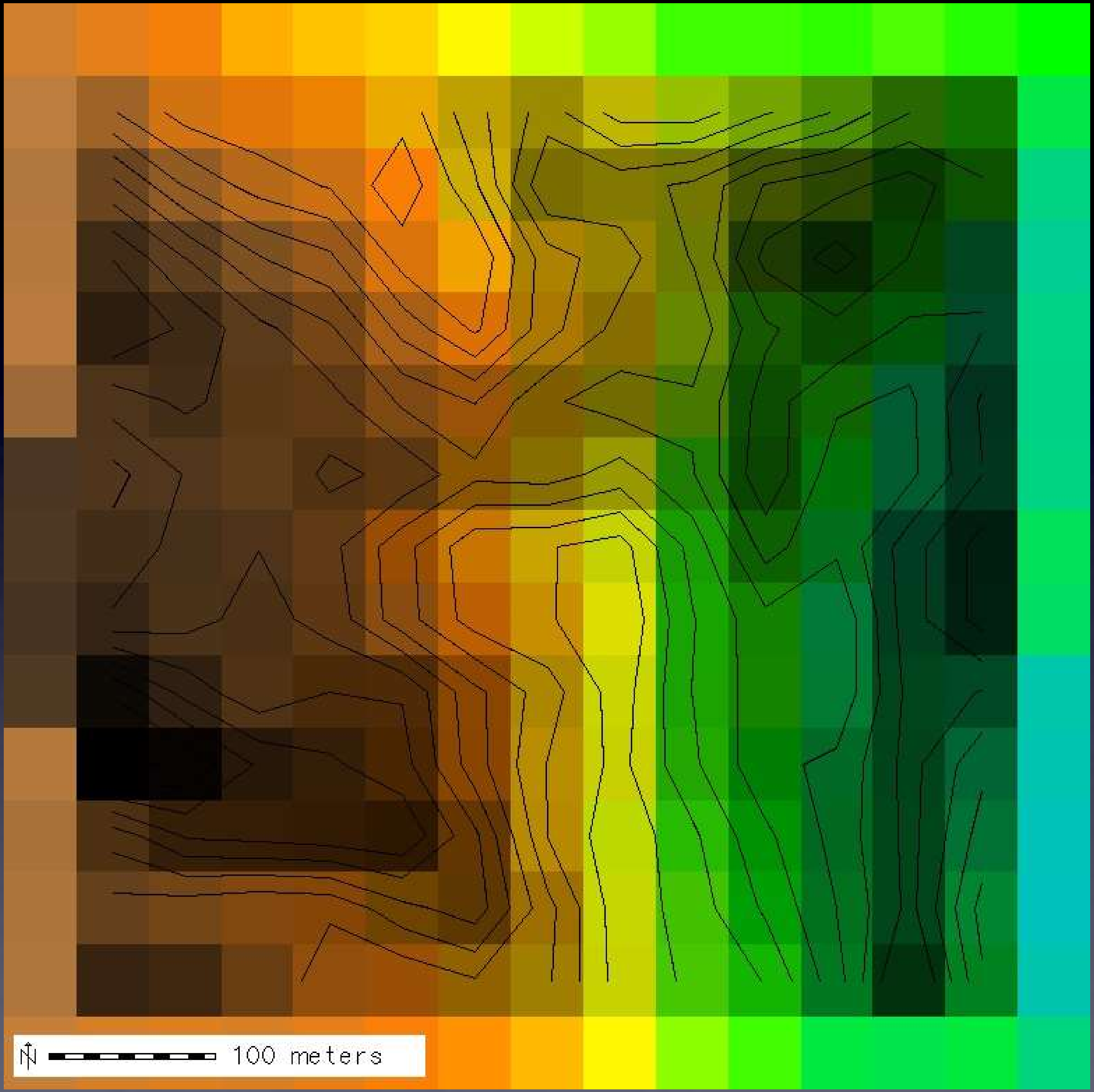
5 m



10 m



20 m

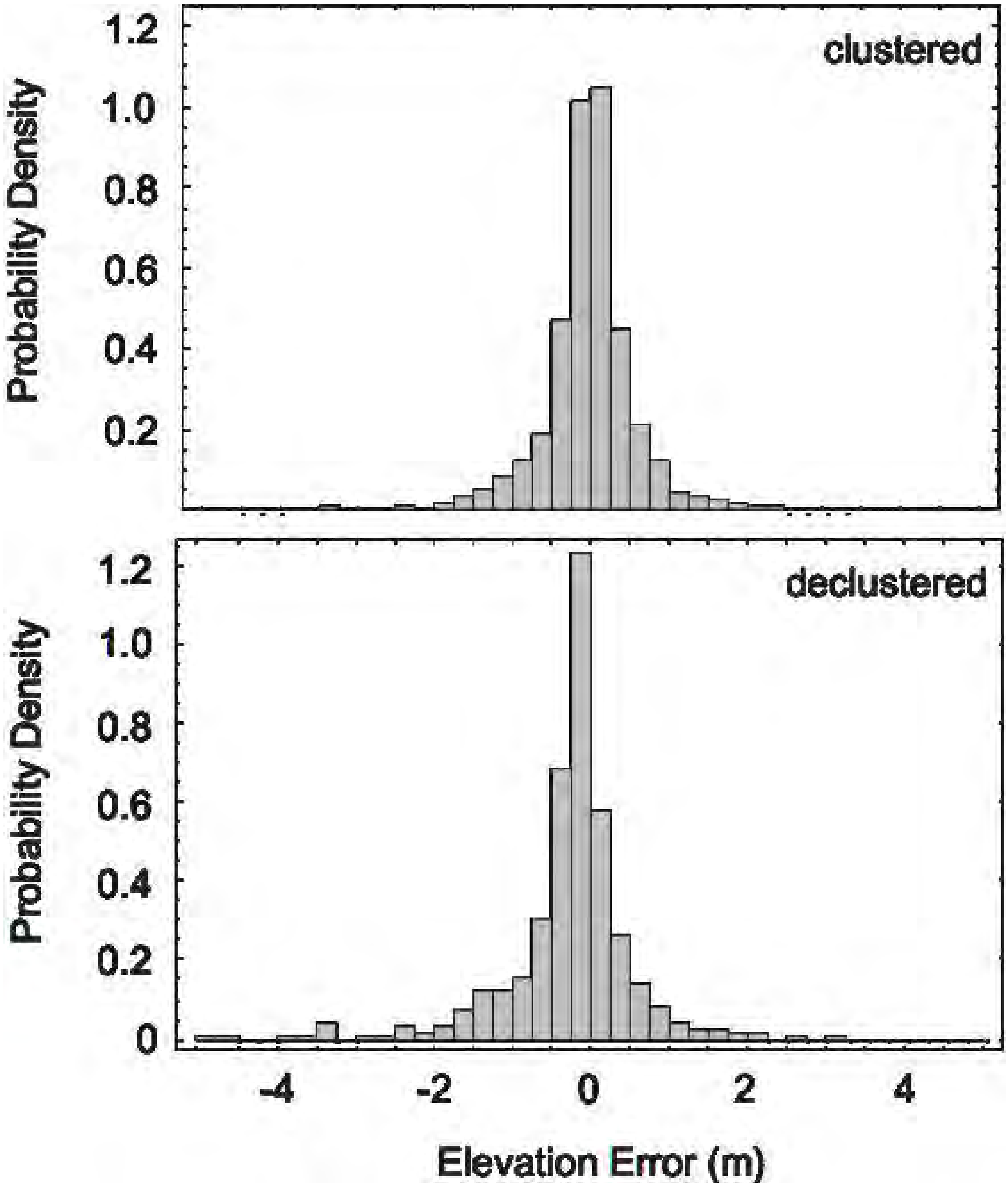


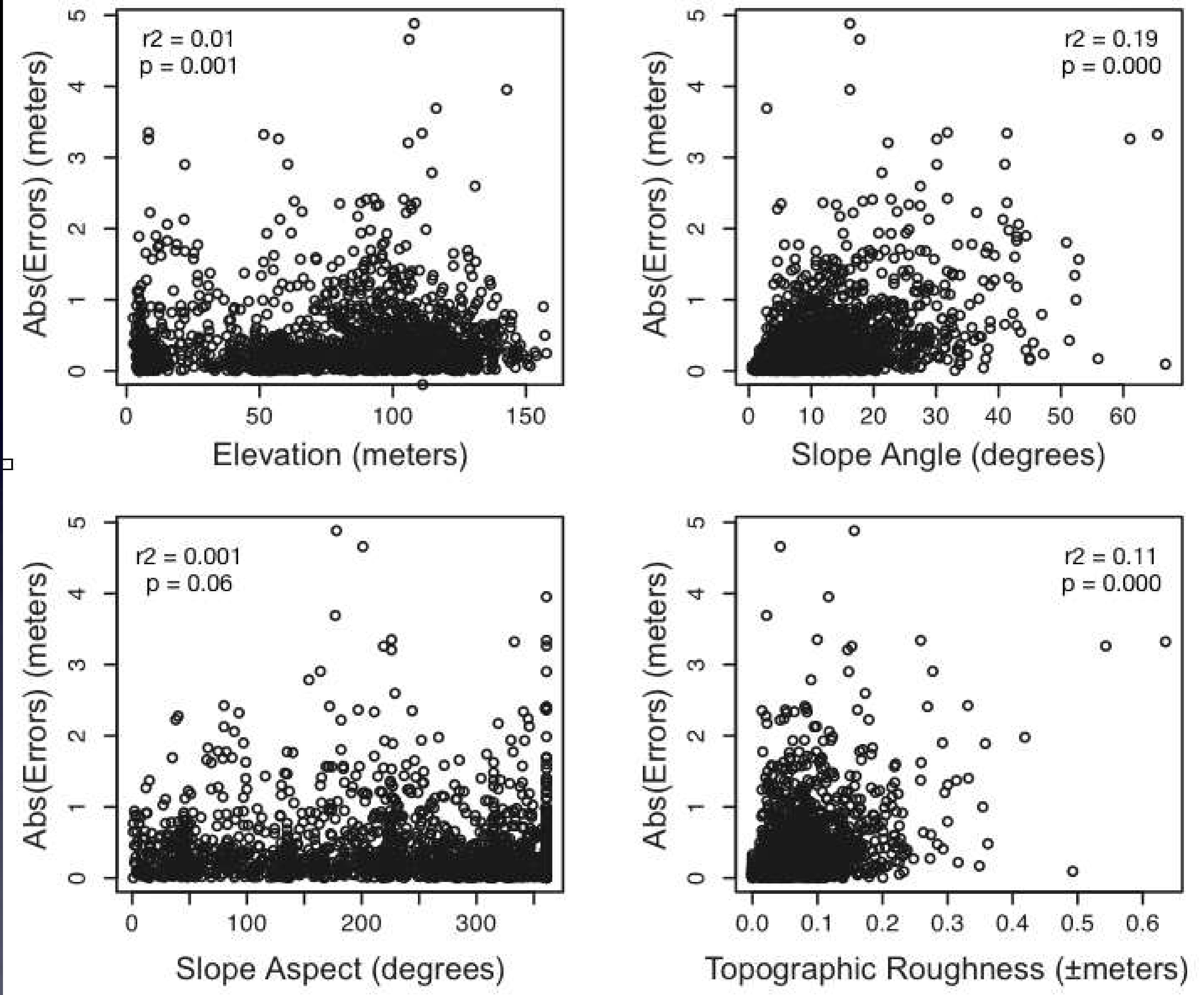
40 m

- The smallest landforms identifiable using a DEM are likely to have characteristic lengths about 10x the DEM raster size
- Features between 2x and 10x may be represented as highs or lows but are not likely to be recognized as mappable landforms
- Features < 2x will aliased and not identifiable (spatial extension of the Nyquist frequency)

LiDAR accuracy

LiDAR Quality	Flying Altitude	FEMA Contour Interval	Typical LiDAR Spot Spacing	Vertical RMSE
High	3000’	1.0’	3.3’	0.3’
Standard	4500’	2.0’	4.5’	0.6’
Low	6500’	3.3’	6.5’	1.0’


clustered
declustered
Probability Density
Probability Density
1.2
1.0
0.8
0.6
0.4
0.2
0
-4
-2
0
2
4
Elevation Error (m)


r2 = 0.01
p = 0.001
Abs(Errors) (meters)
Elevation (meters)
0
50
100
150
0
1
2
3
4
5
r2 = 0.19
p = 0.000
Slope Angle (degrees)
0
10
20
30
40
50
60
r2 = 0.001
p = 0.06
Slope Aspect (degrees)
0
100
200
300
r2 = 0.11
p = 0.000
Topographic Roughness (±meters)
0.0
0.1
0.2
0.3
0.4
0.5
0.6

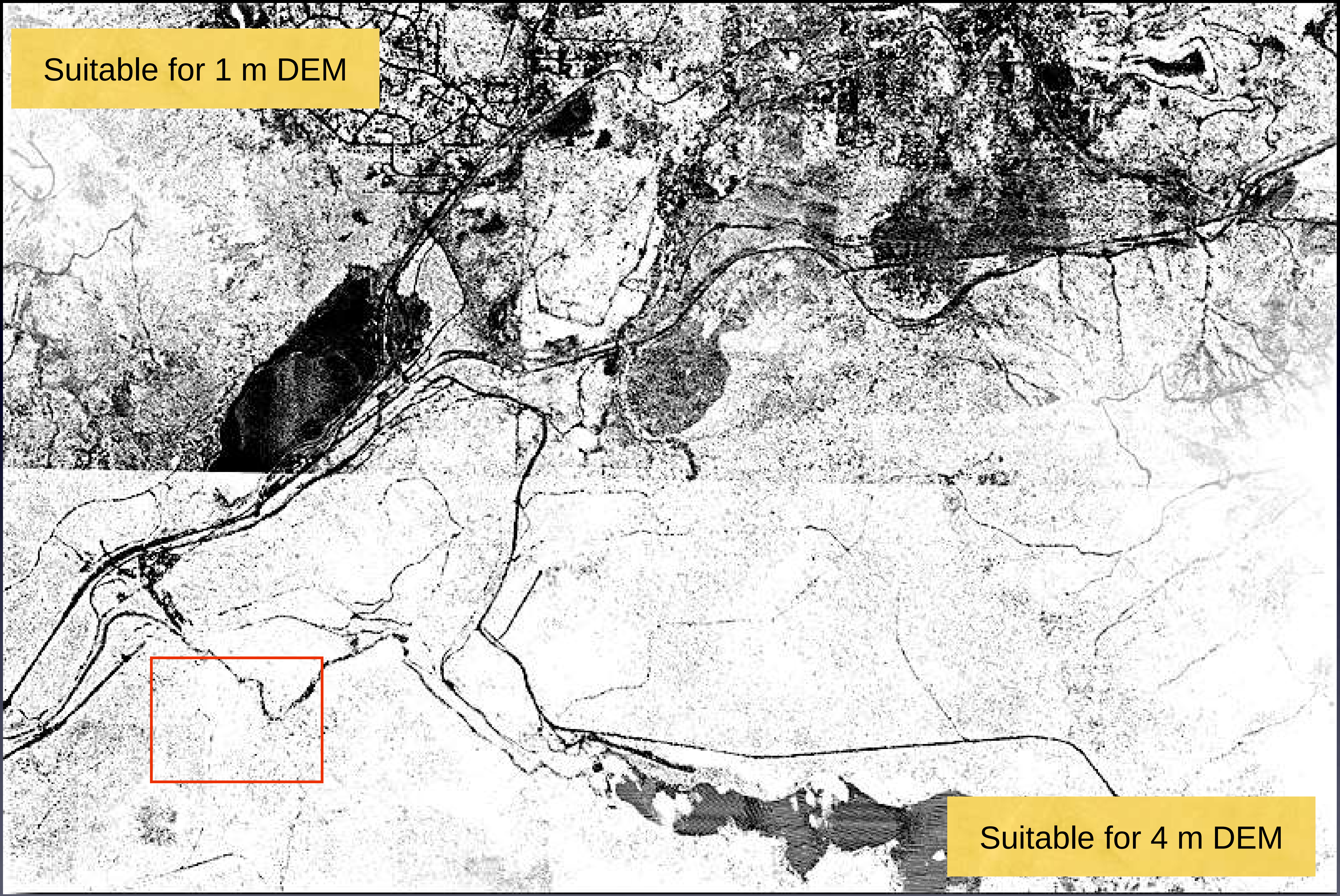
- LiDAR accuracy (repeatability?) depends on both operational/instrumental and geomorphological factors

- Vendor supplied QA/QC data are likely to be non-representative of accuracy in areas of geologic interest

- Accuracy and/or repeatability may be important issues in monitoring, change detection, and quantitative modeling applications

Ground strike density

- LiDAR ground strikes are typically clustered and/or sparse in forested areas
- Average ground strike densities can be misleading if they include open areas
- Use point clouds to evaluate ground strike density and DEM reliability in geologically critical areas (where you <u>really</u> want to map something)
- Create optimal DEMs for landform mapping

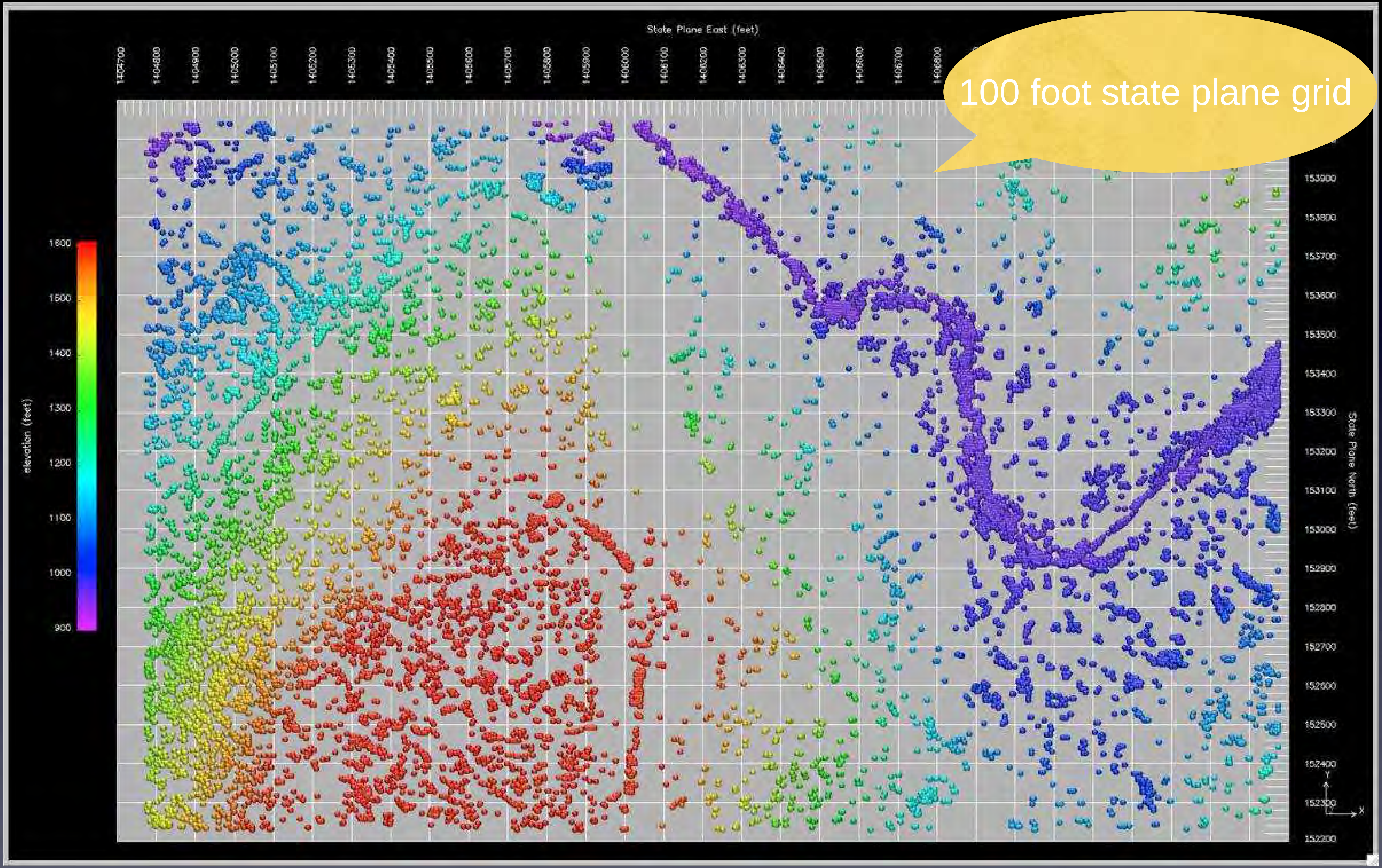


Suitable for 1 m DEM

Suitable for 4 m DEM

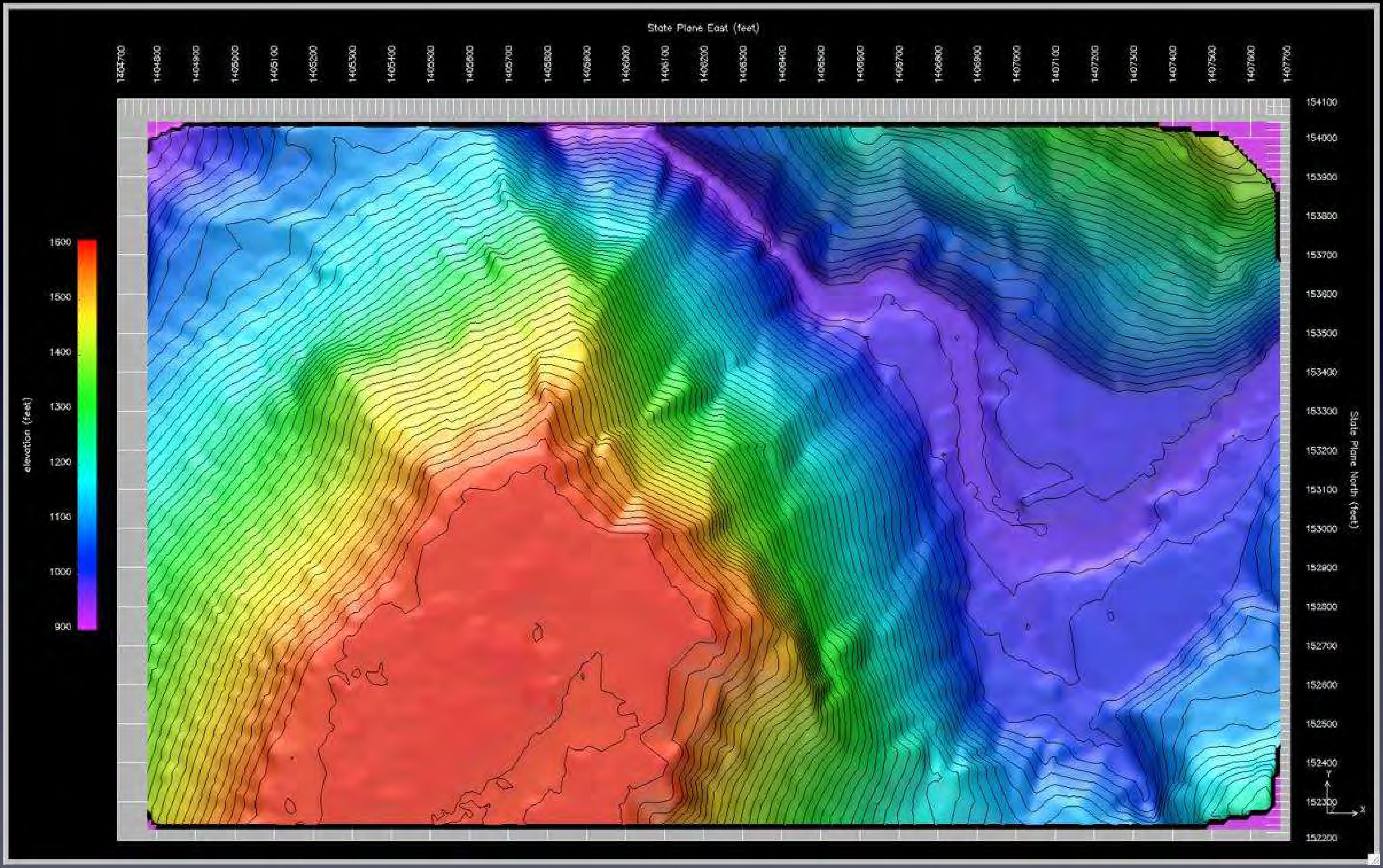
Data source: King County

Ground strikes colored by elevation

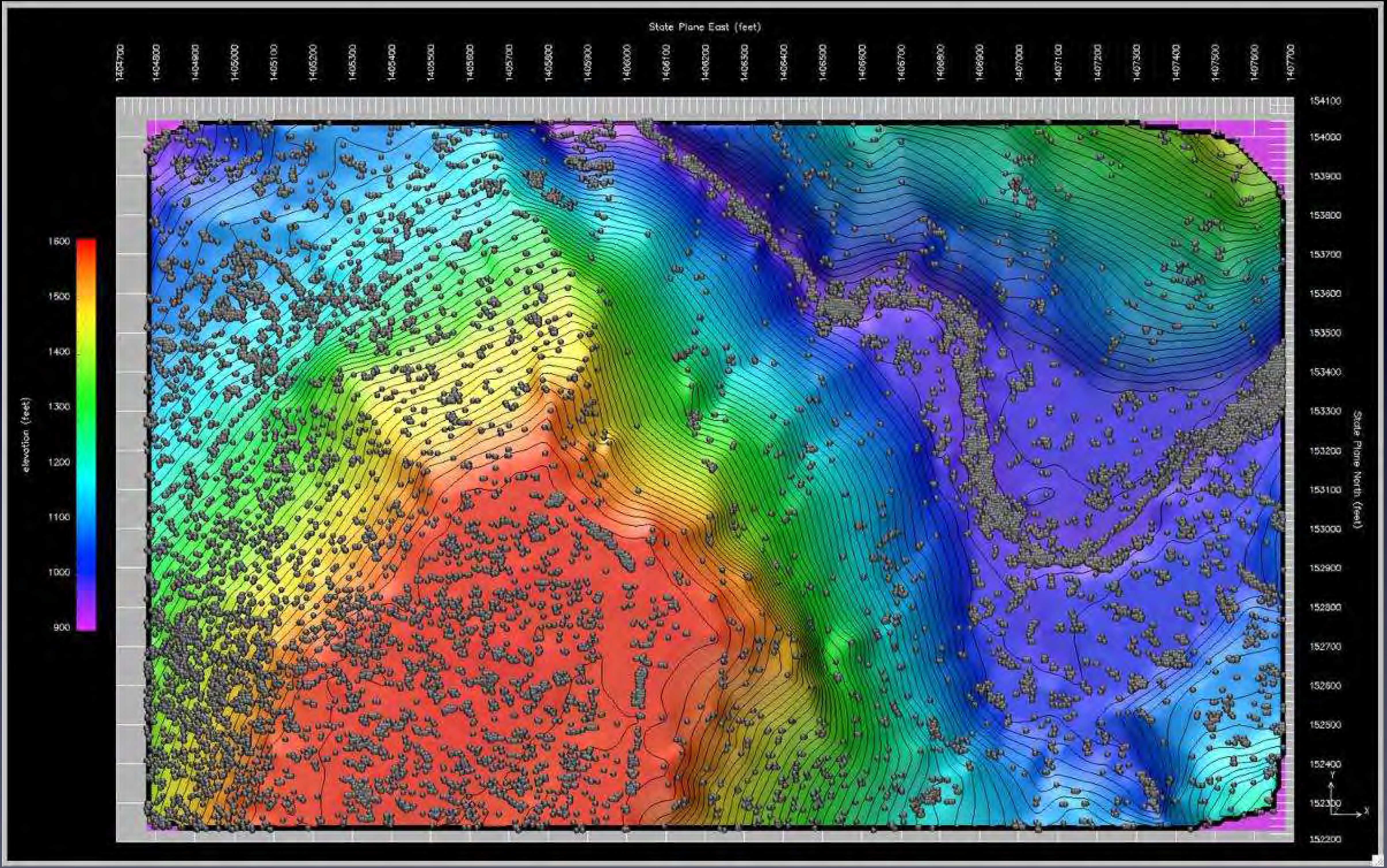


100 foot state plane grid

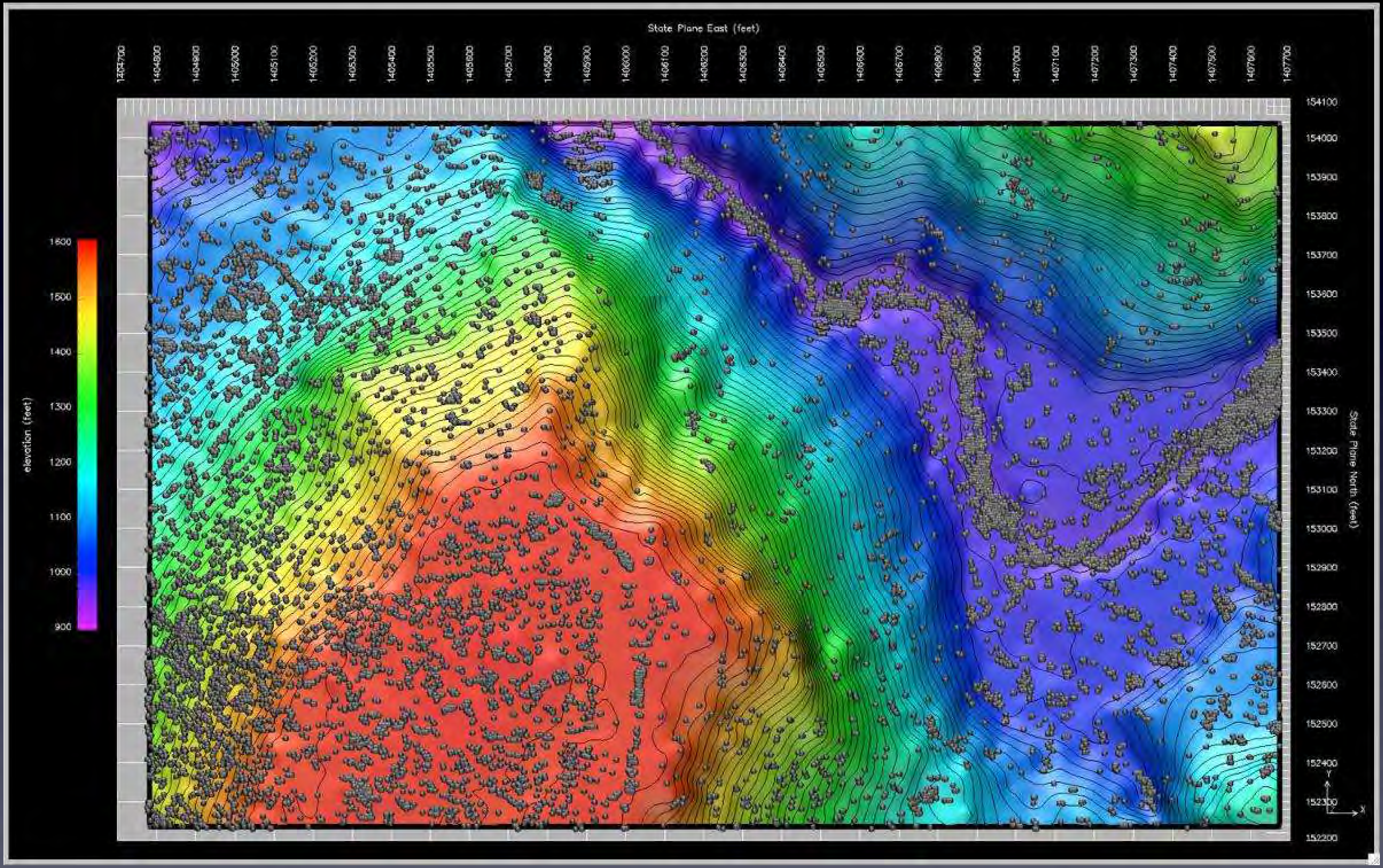
TIN with linear interpolation

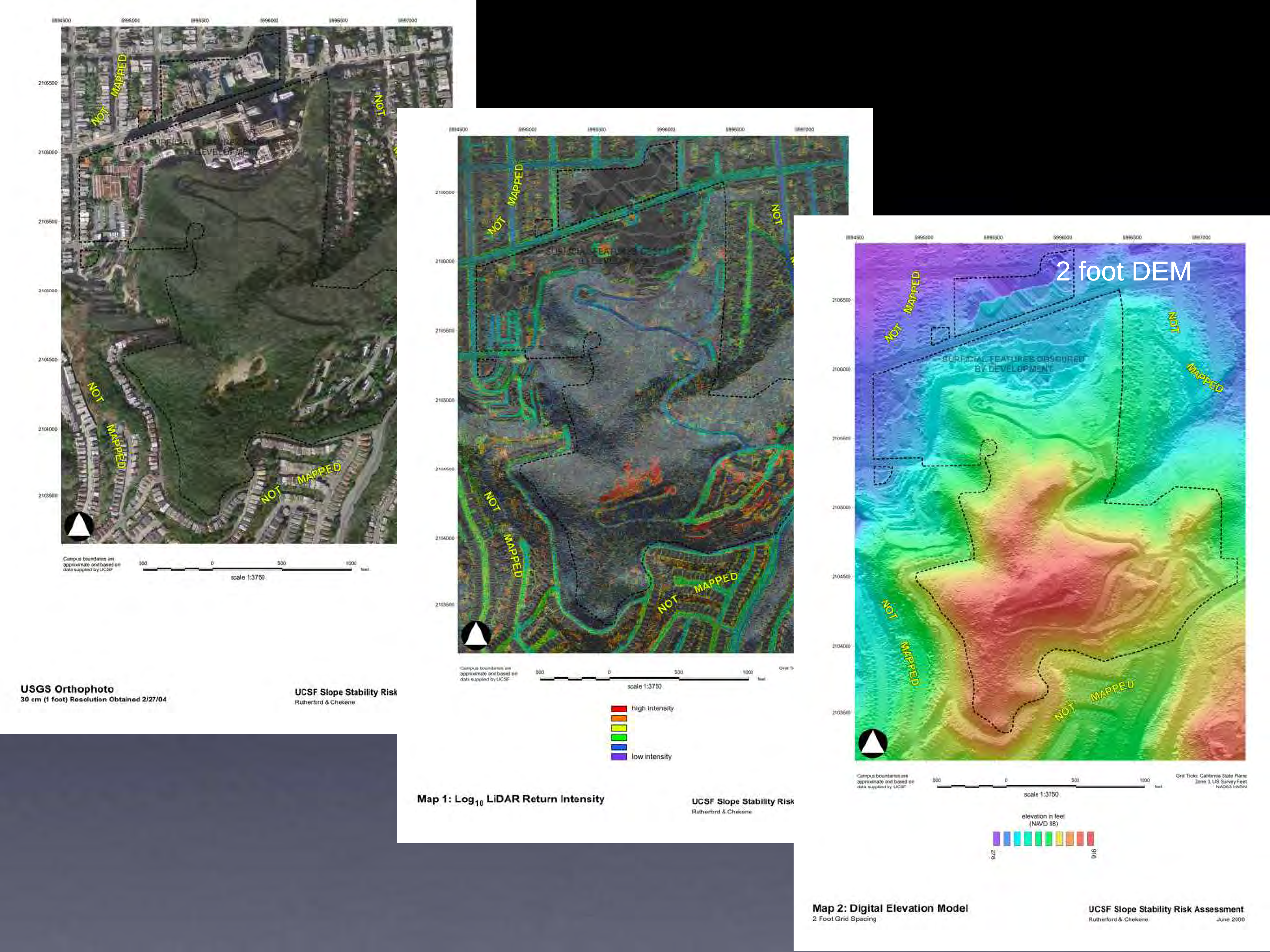


Linear natural neighbors



Splines (minimum curvature gridding)





2 foot DEM

USGS Orthophoto
30 cm (1 foot) Resolution Obtained 2/27/04

UCSF Slope Stability Risk
Rutherford & Chekene

Map 1: Log$_{10}$ LiDAR Return Intensity

UCSF Slope Stability Risk
Rutherford & Chekene

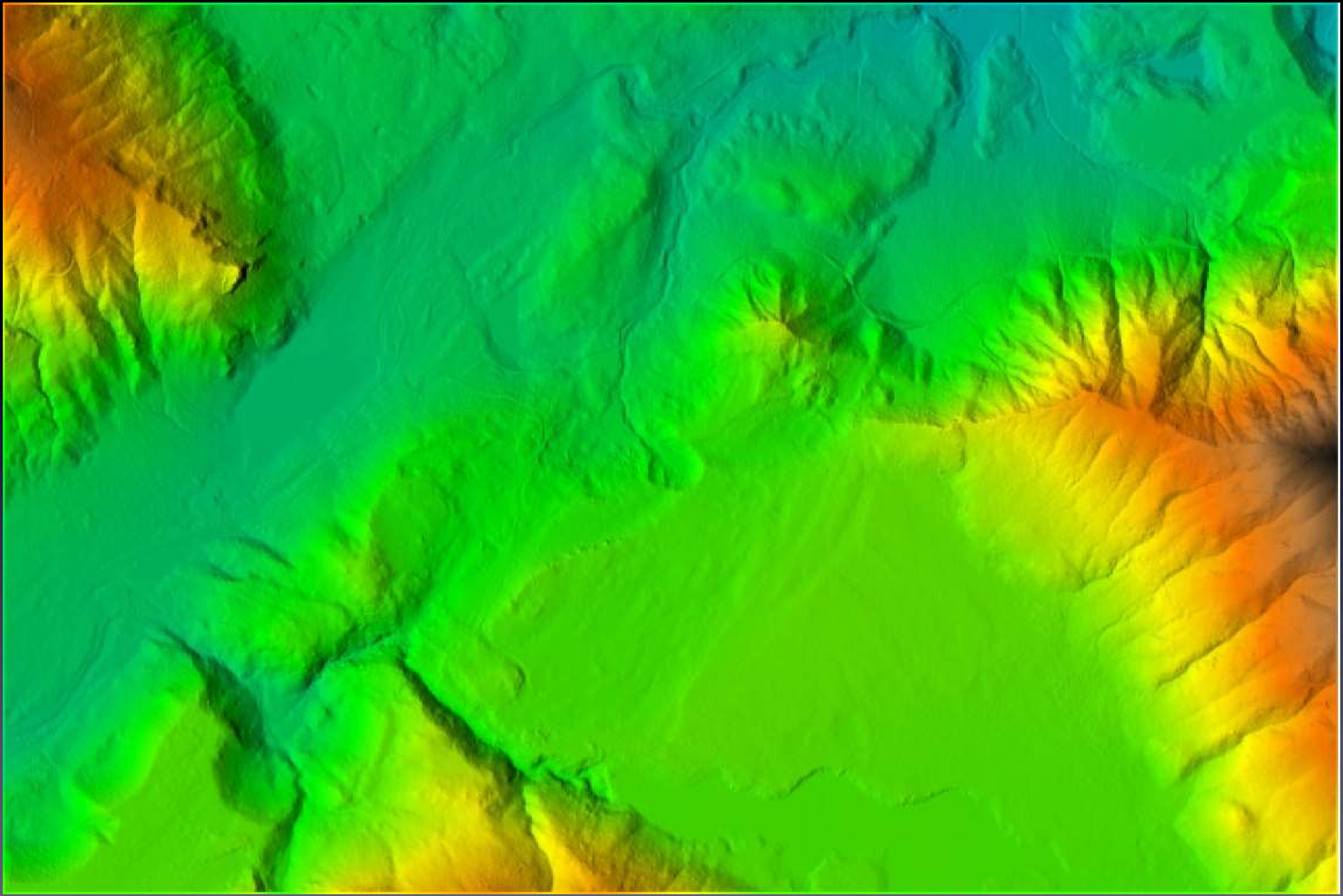
Map 2: Digital Elevation Model
2 Foot Grid Spacing

UCSF Slope Stability Risk Assessment
Rutherford & Chekene June 2006

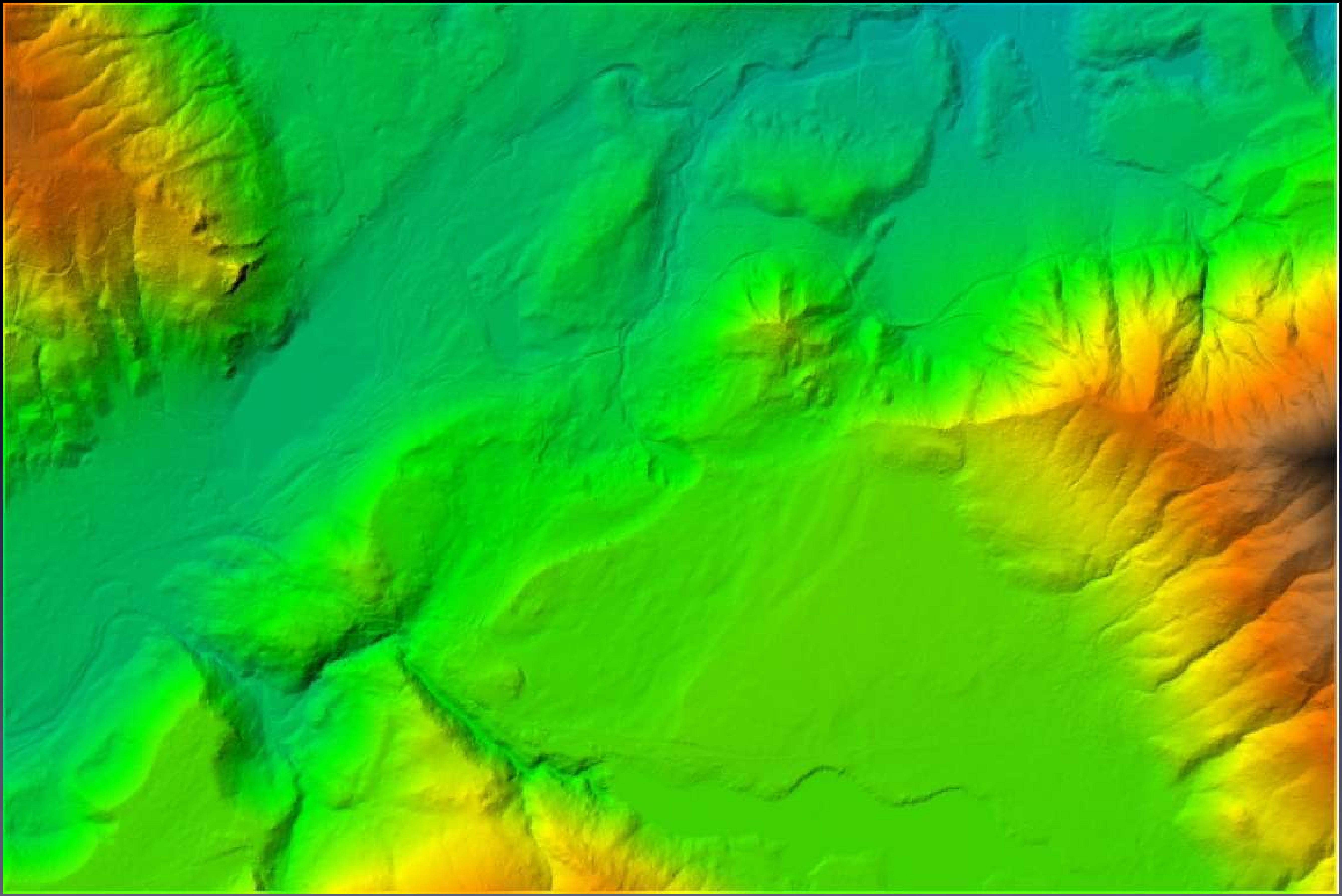
Derivative maps

- Recast DEM content to accentuate landforms
  - Contours (smoothed/unsmoothed DEM)
  - Shaded relief (multiple illumination angles)
  - Slope angle and/or aspect
  - Roughness (various definitions)
  - Curvature (plan and/or profile)
- What properties are likely to accentuate landforms of interest? There are no cookbook answers!

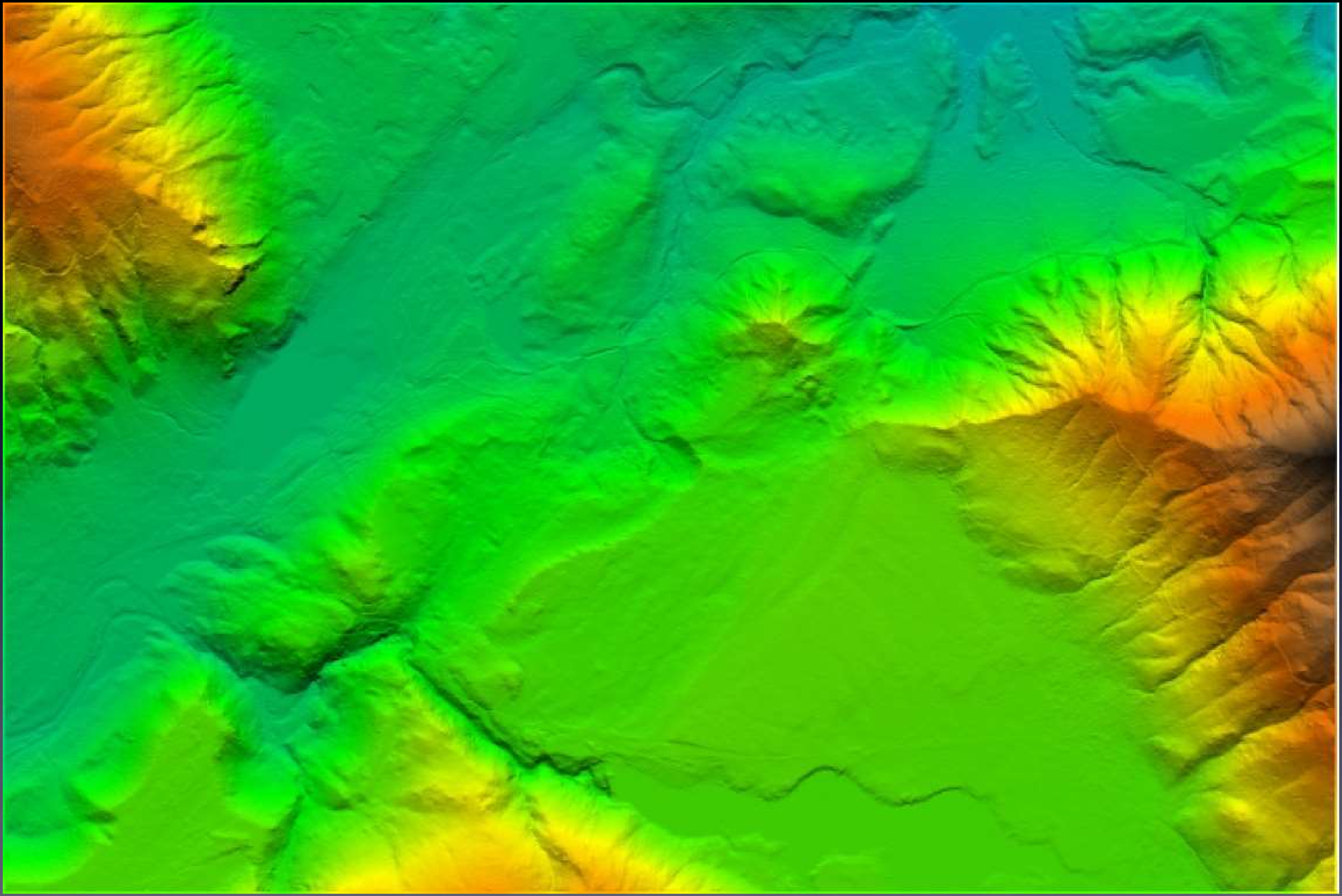
45°/270°



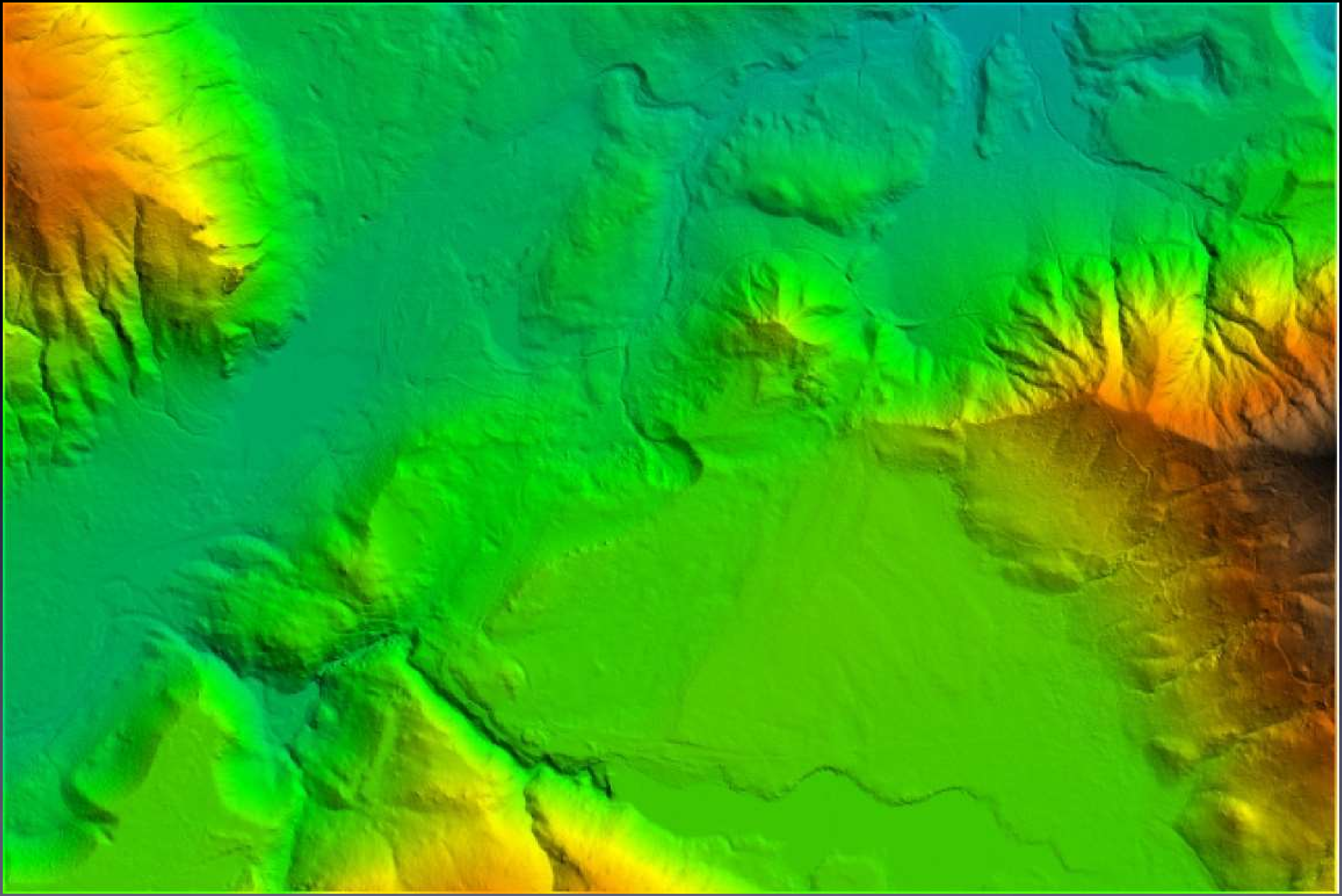
45°/315°



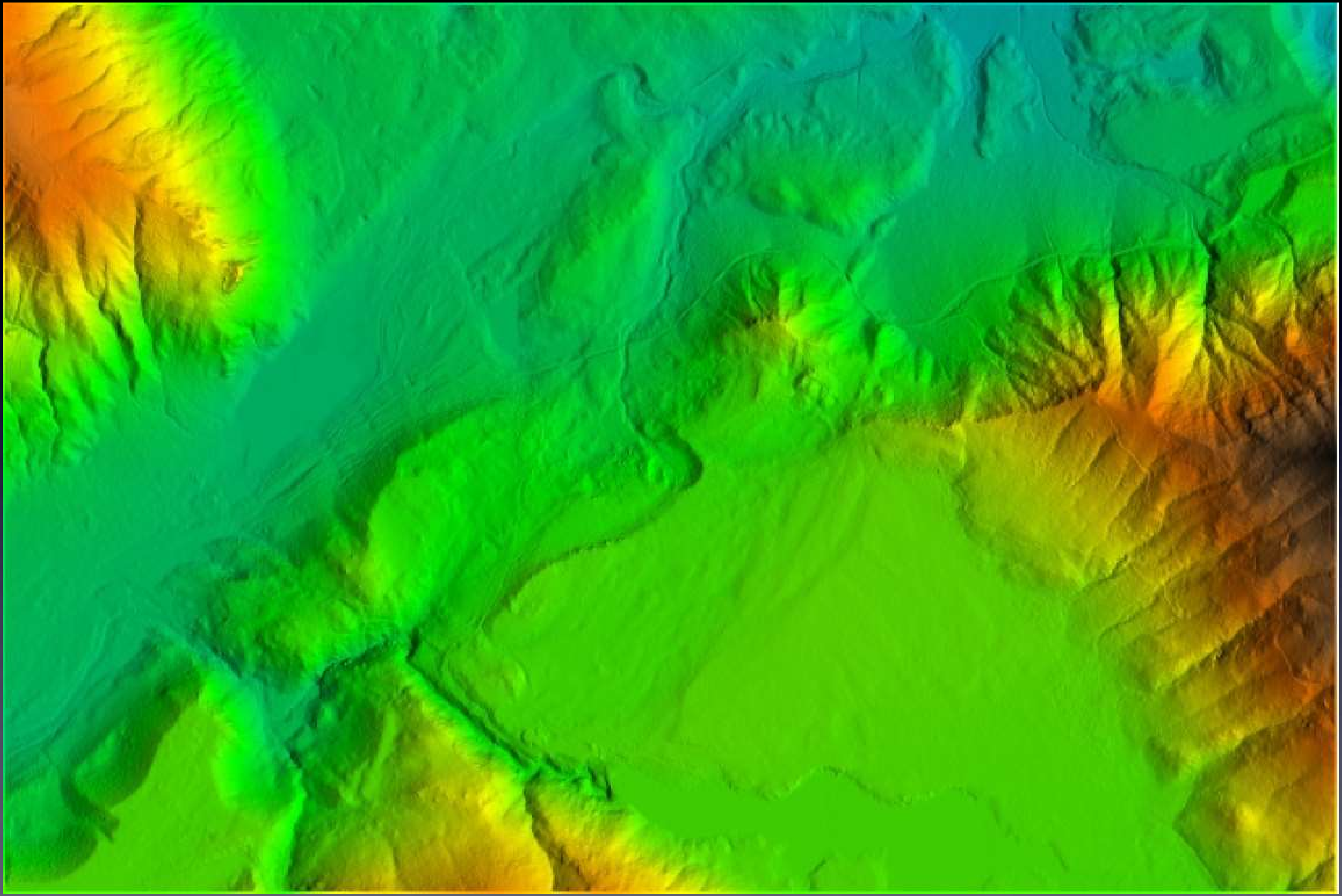
45°/000°



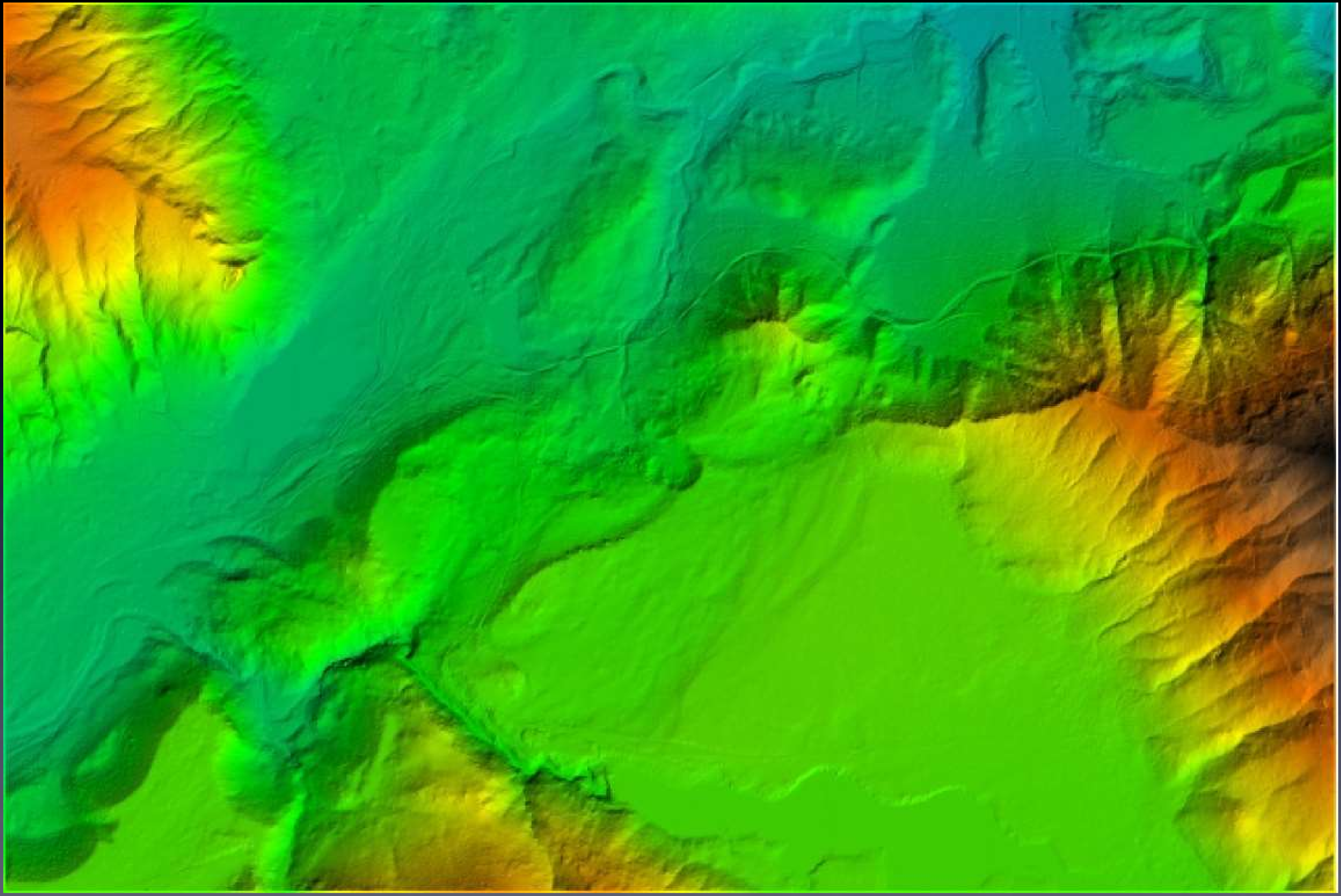
45°/045°



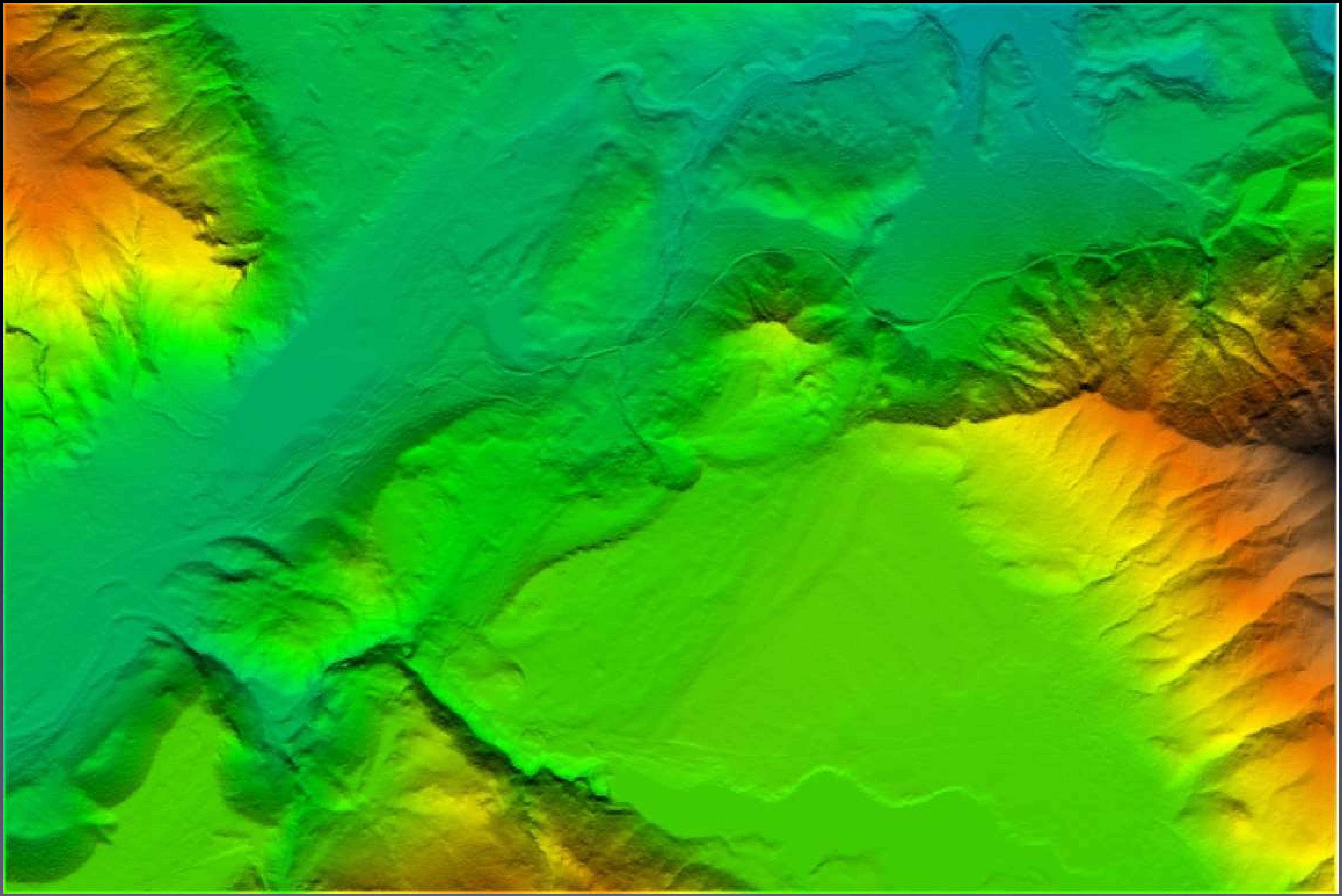
45°/090°



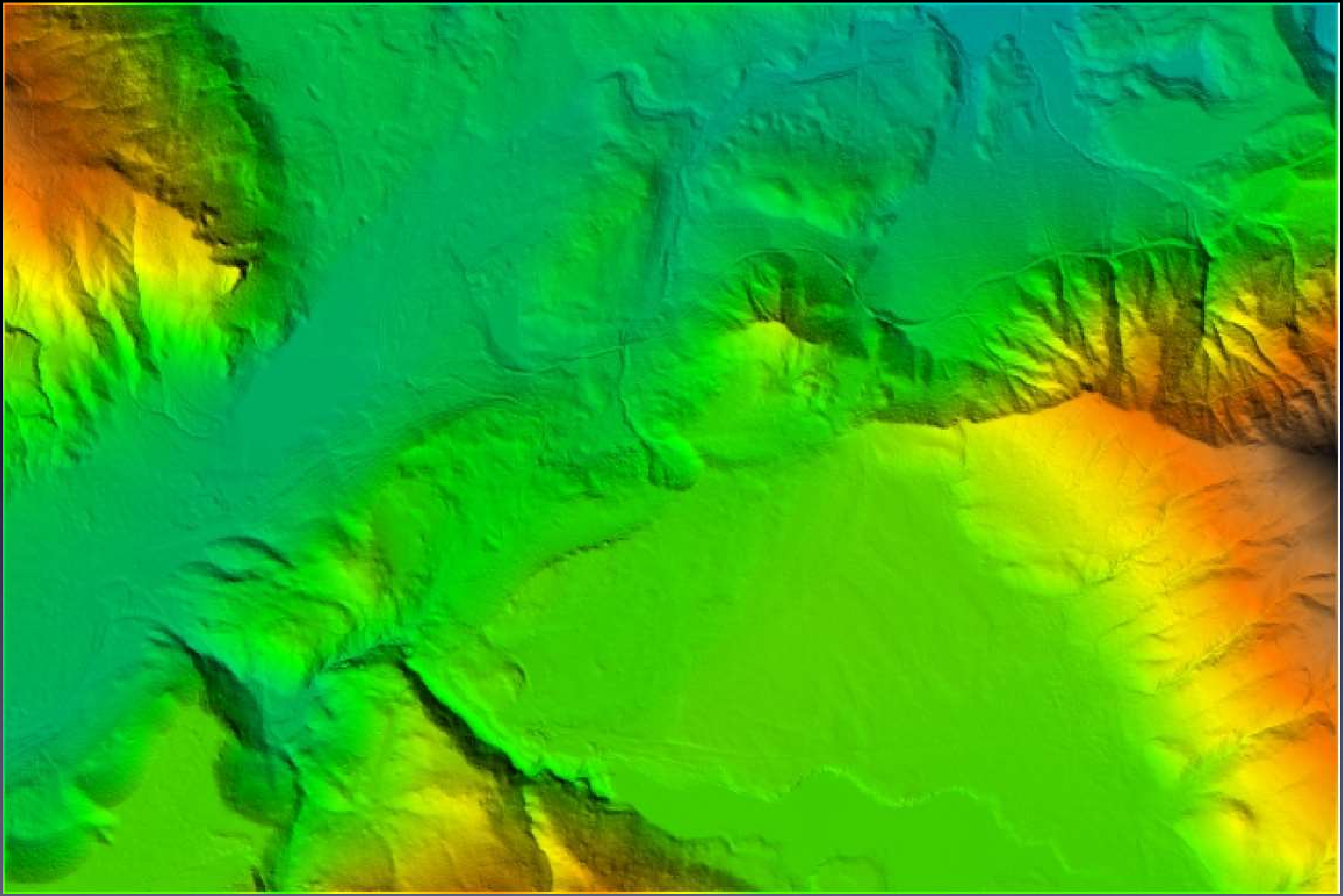
45°/135°



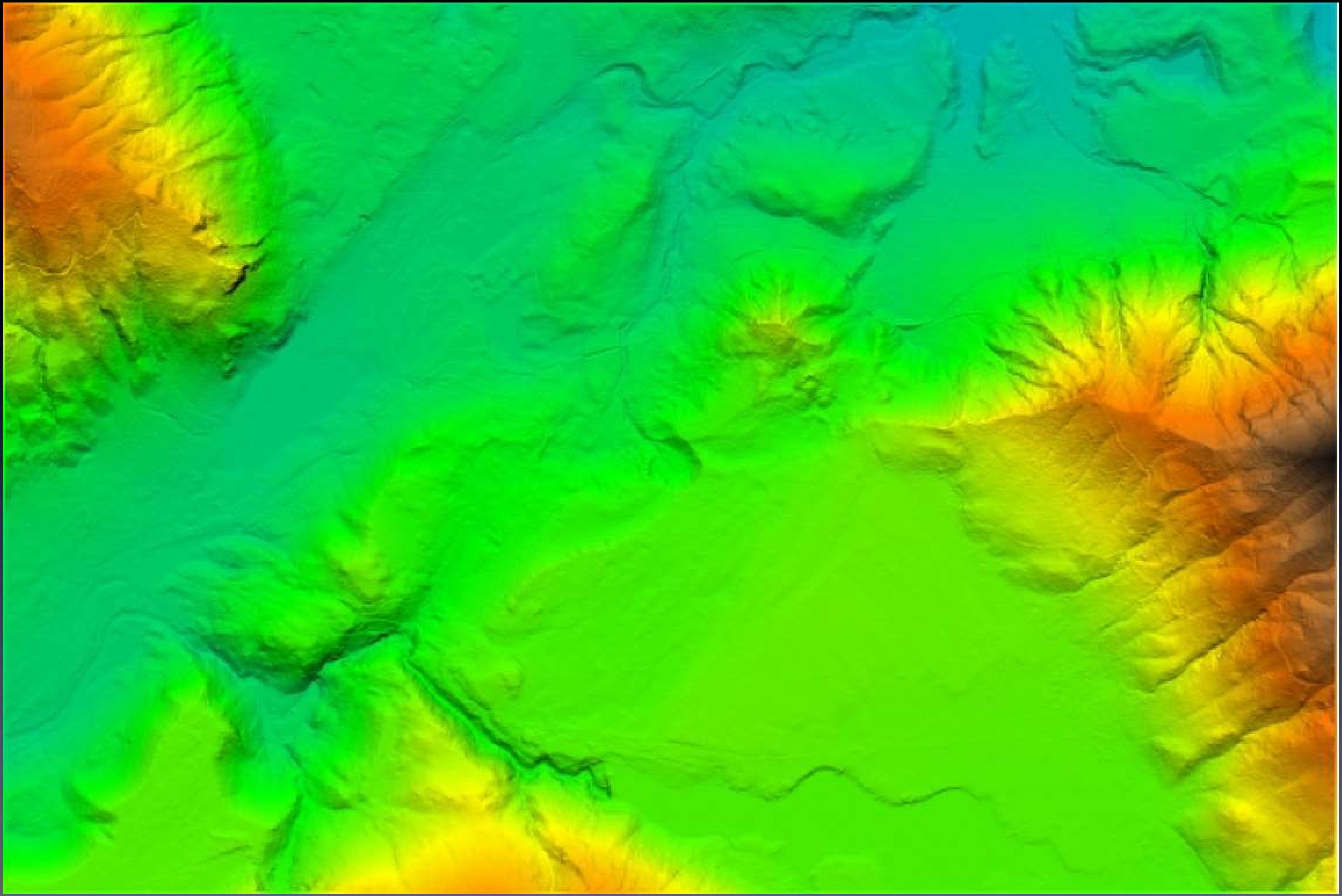
45°/180°



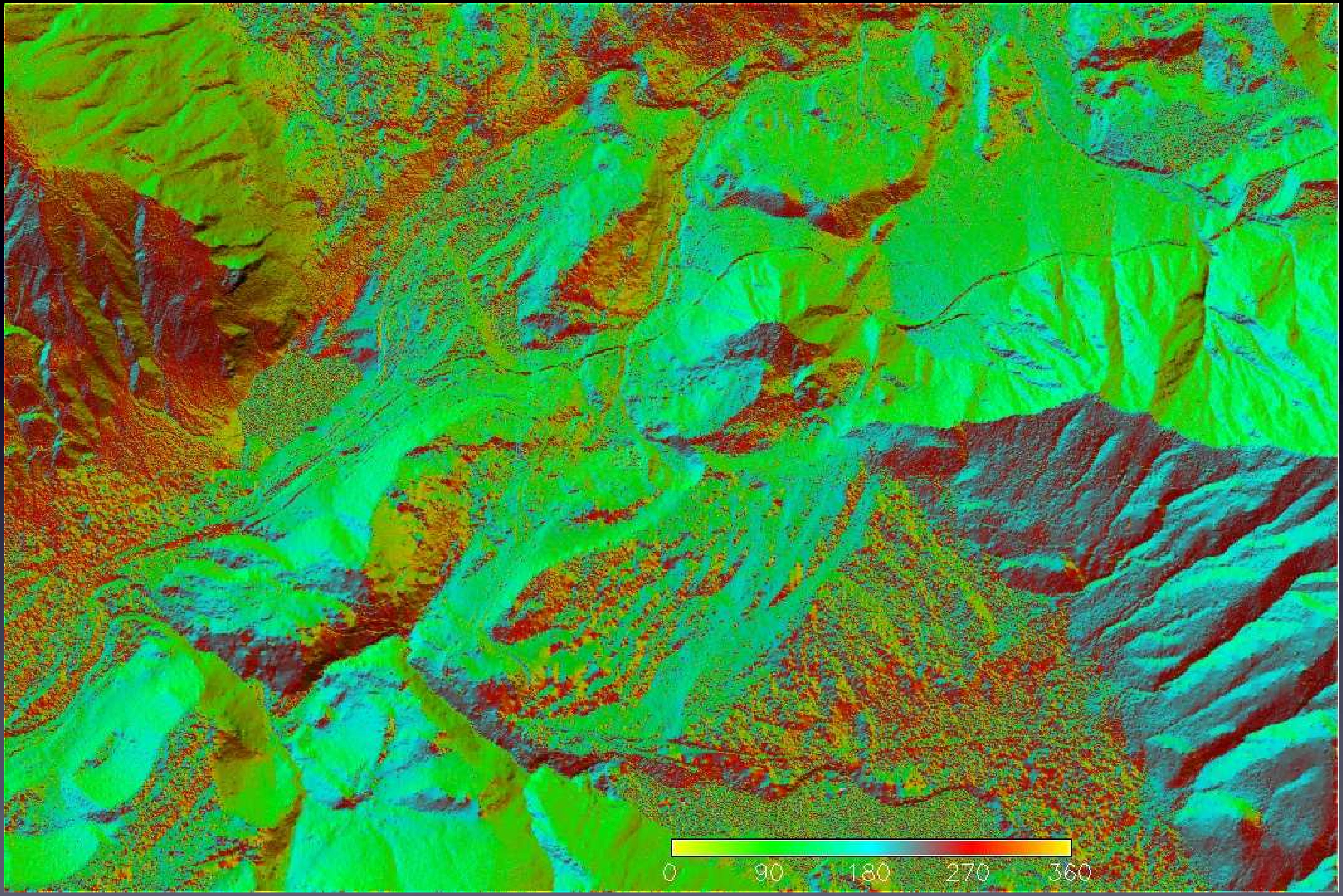
45°/225°



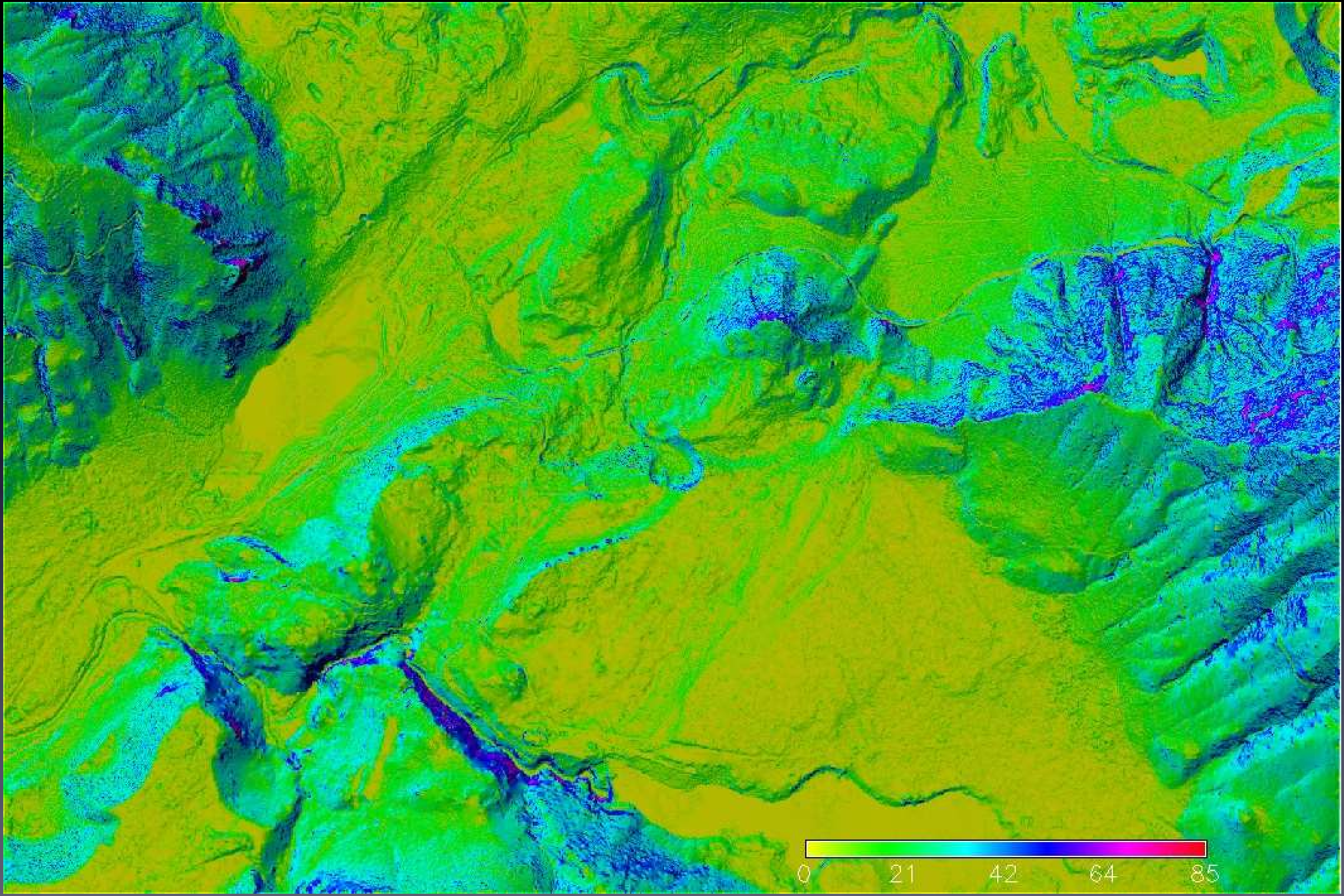
Composite omnidirectional 45°/270° through 45°/090°



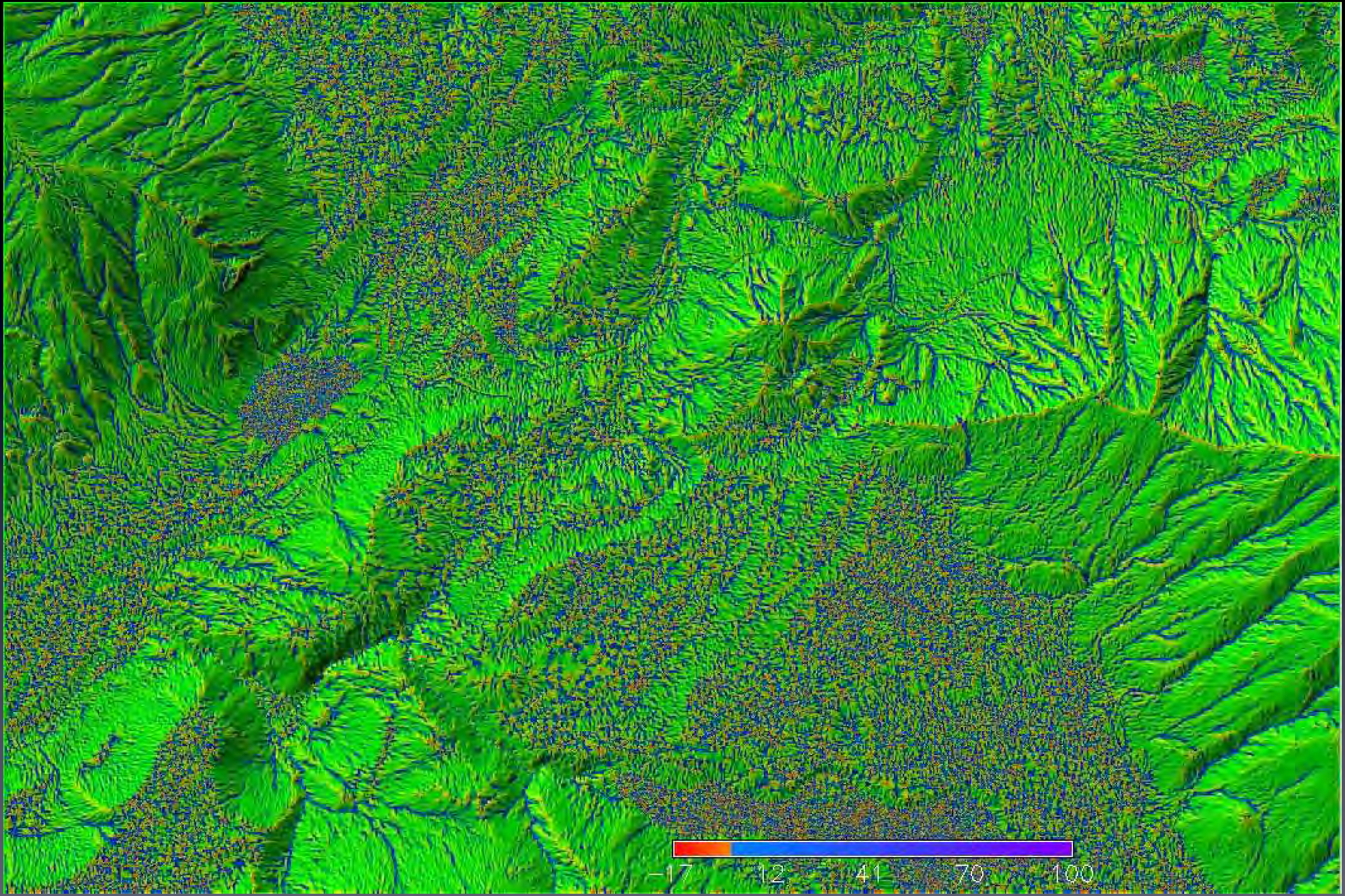
Slope aspect



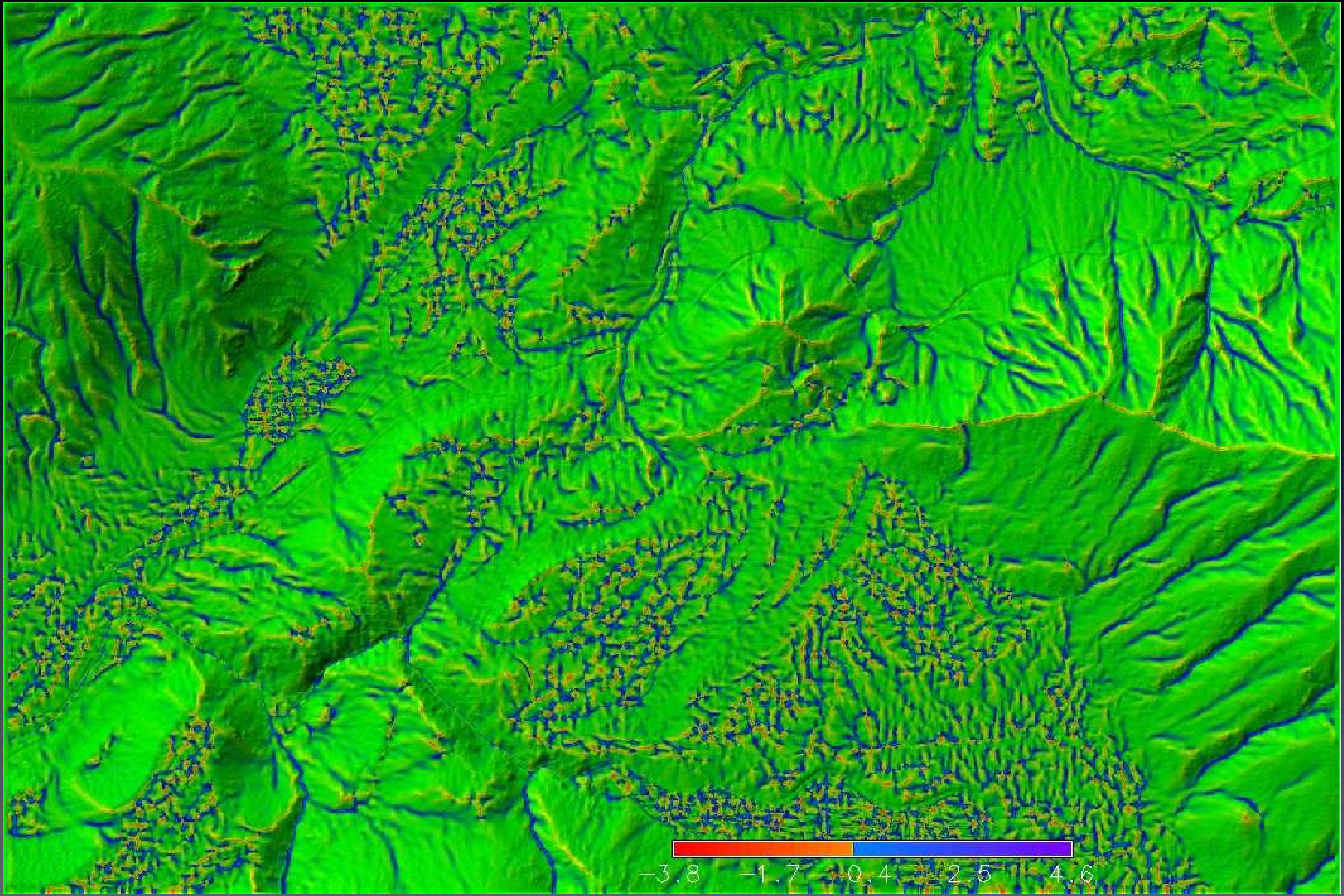
Slope angle



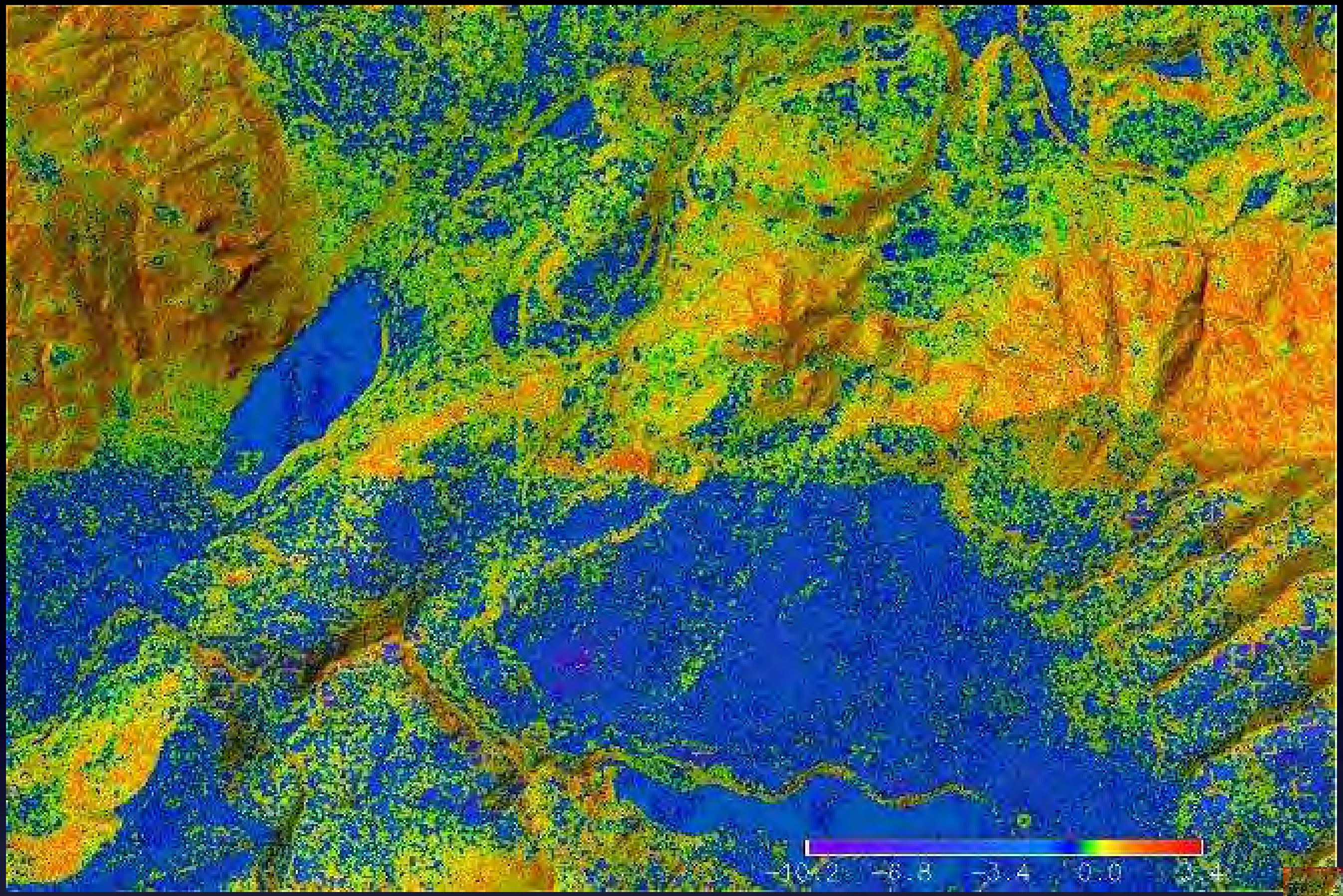
Plan curvature (5 x 5 raster moving window)



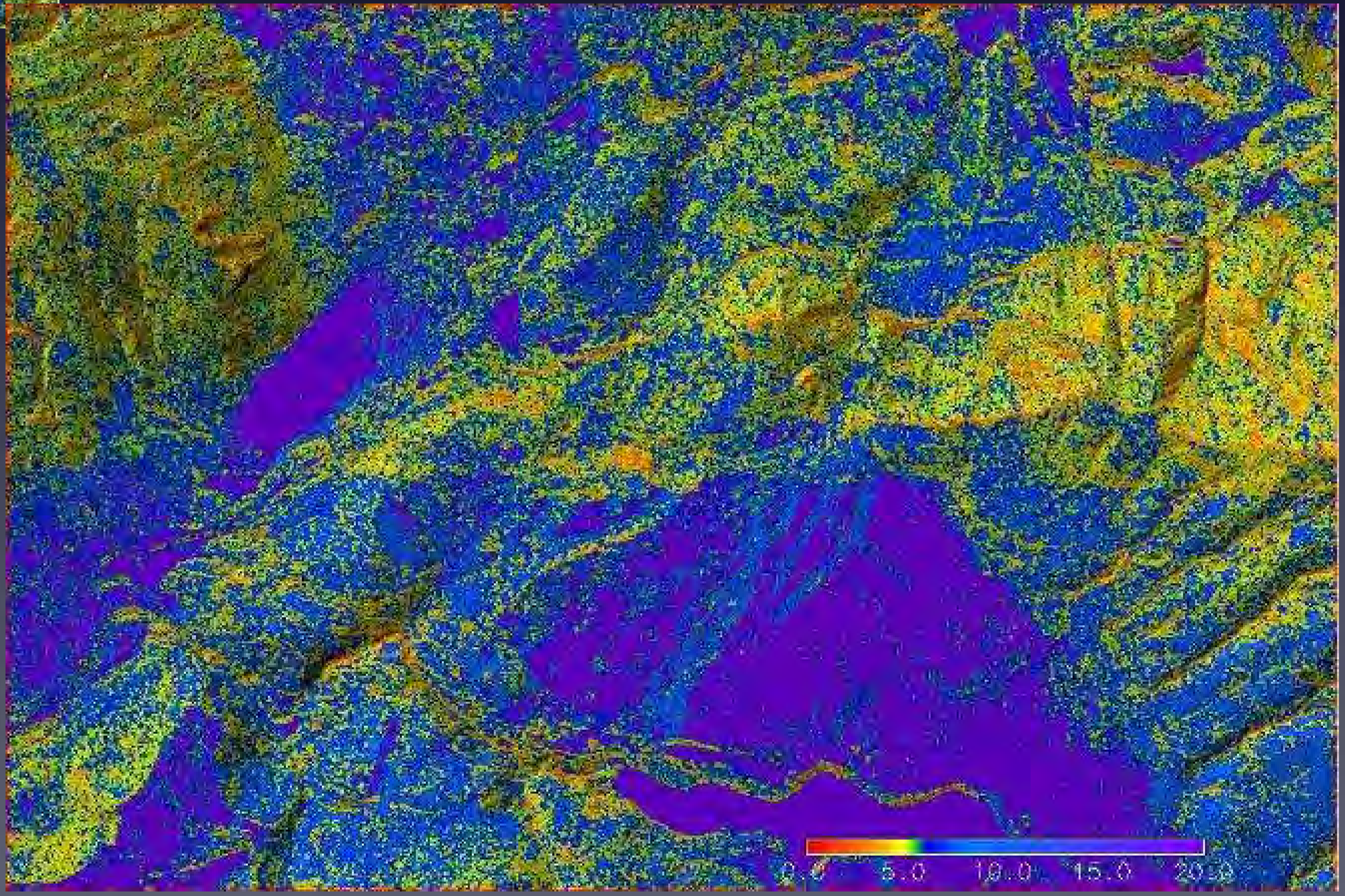
Plan curvature (11 x 11 raster moving window)



Roughness (log residual 3 x 3)

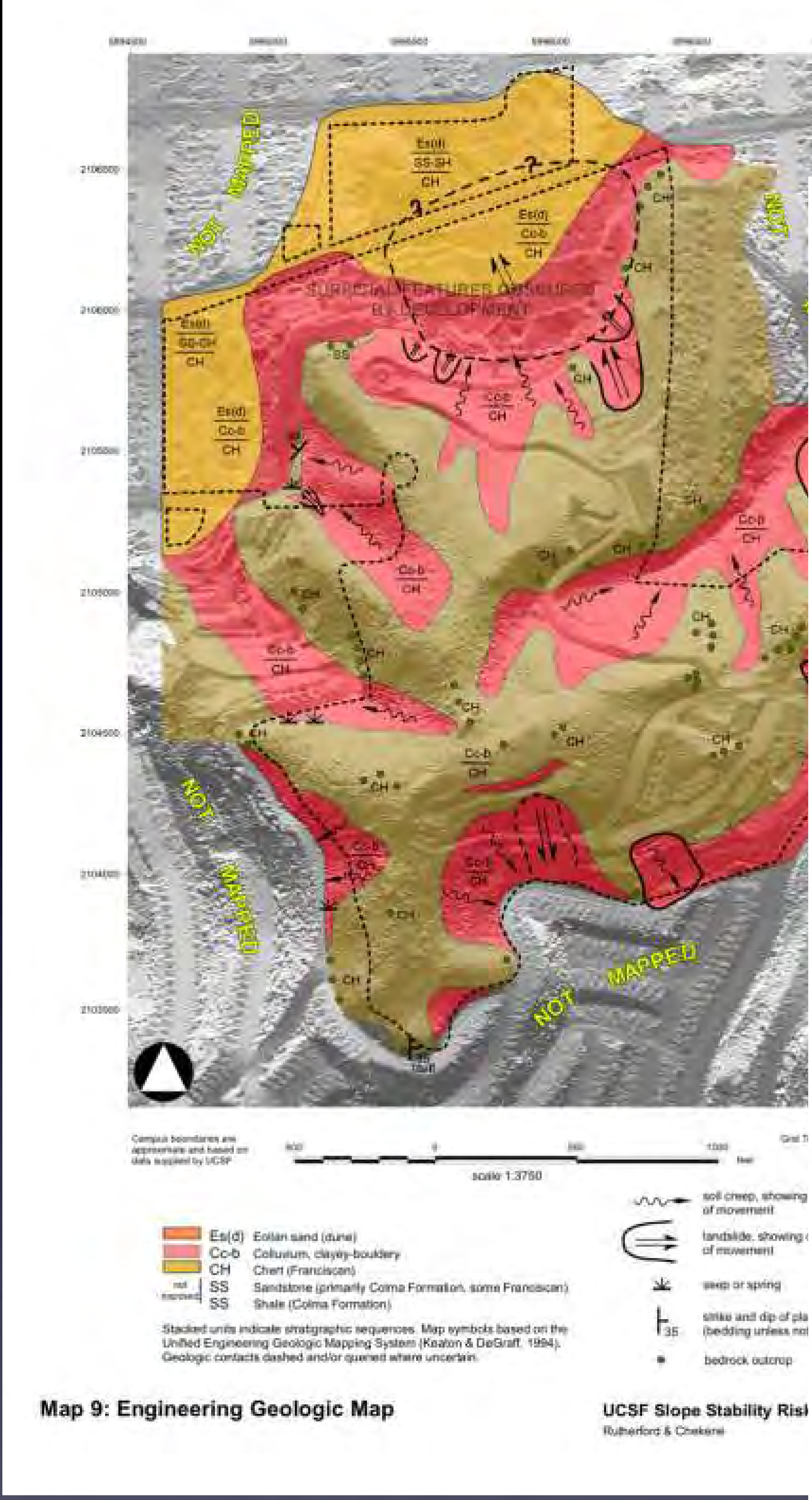


Roughness (eigenvalue ratio 3 x 3)



Virtual mapping

- Assemble all the layers in a vector drawing program
  - GIS capable if possible
  - Non-LiDAR data, too (outcrop locations, orthopotos, etc)
- Put a blank layer on top and map landforms
- Alternate underlying layers to accentuate features of interest (illumination direction, slope angle, curvature, etc)
- Refine and revise
- Go to the field
- Refine and revise again



Campus boundaries are approximate and based on data supplied by UCSF

scale 1:3750

- 🟧 Es(d) Eolian sand (dune)
- 🟥 Cc-b Colluvium, clayey-bouldery
- 🟨 CH Chert (Franciscan)
- not exposed SS Sandstone (primarily Colma Formation, some Franciscan)
- not exposed SS Shale (Colma Formation)

Stacked units indicate stratigraphic sequences. Map symbols based on the Unified Engineering Geologic Mapping System (Keaton & DeGraff, 1994). Geologic contacts dashed and/or queried where uncertain.

soil creep, showing
of movement

landslide, showing
of movement

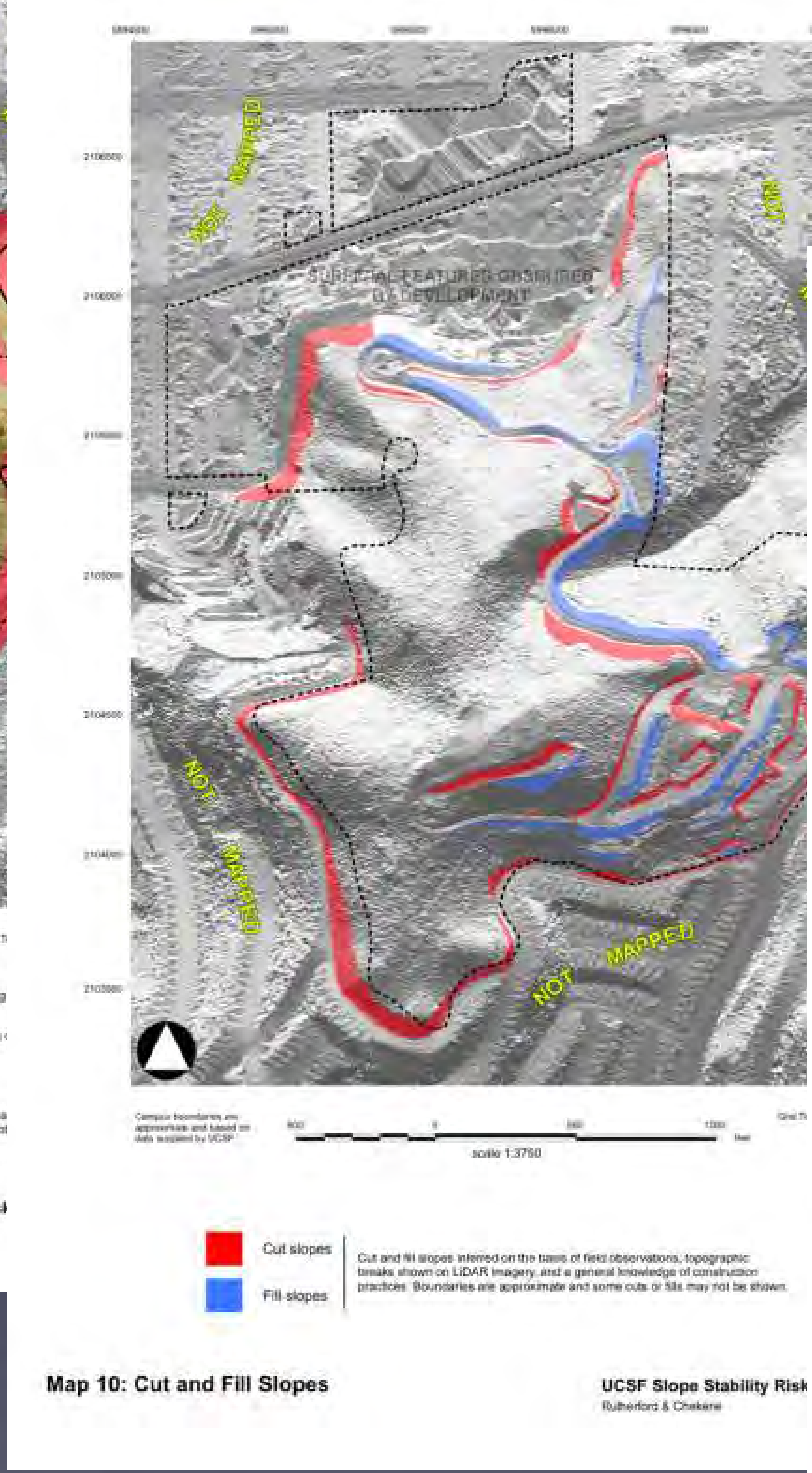
seep or spring

strike and dip of pla
(bedding unless not

bedrock outcrop

Map 9: Engineering Geologic Map

UCSF Slope Stability Risk
Rutherford & Chekene



Campus boundaries are approximate and based on data supplied by UCSF

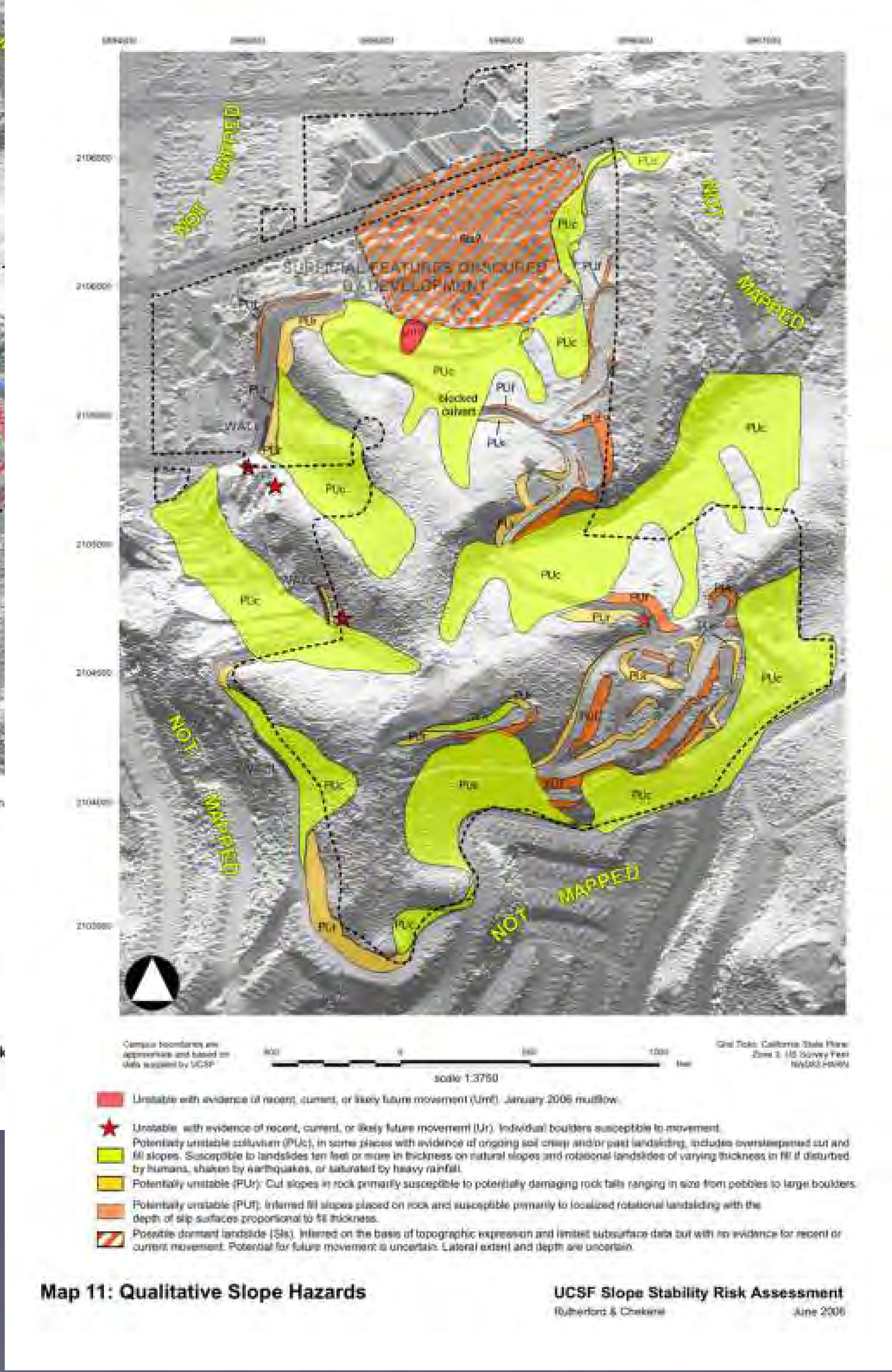
scale 1:3750

- 🟥 Cut slopes
- 🟦 Fill slopes

Cut and fill slopes inferred on the basis of field observations, topographic breaks shown on LiDAR imagery, and a general knowledge of construction practices. Boundaries are approximate and some cuts or fills may not be shown.

Map 10: Cut and Fill Slopes

UCSF Slope Stability Risk
Rutherford & Chekene



Campus boundaries are approximate and based on data supplied by UCSF

scale 1:3750

Grid Ticks: California State Plane
Zone 3, US Survey Feet
NAD83 HARN

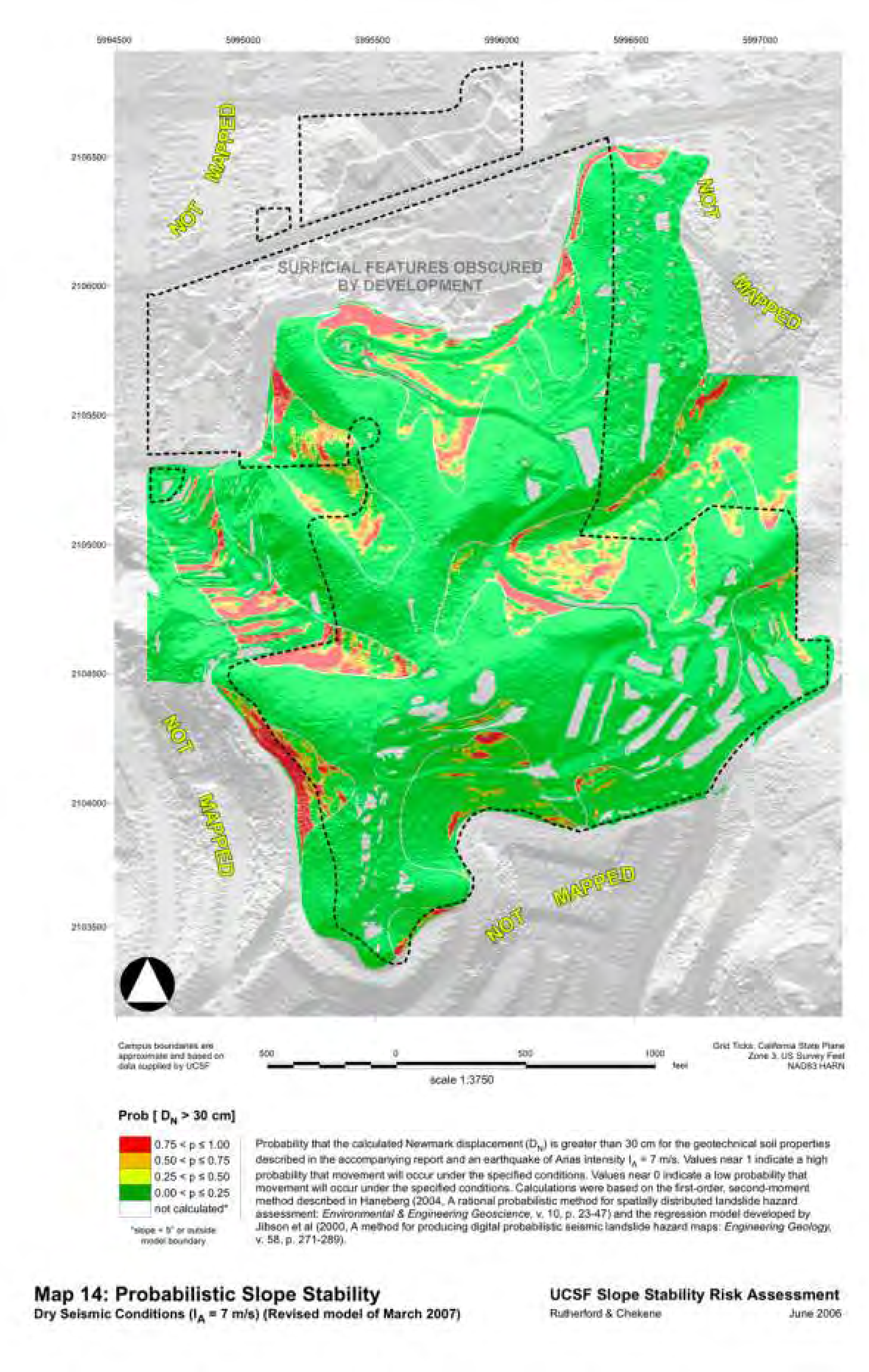
- 🟥 Unstable with evidence of recent, current, or likely future movement (Umf). January 2006 mudflow.
- ★ Unstable, with evidence of recent, current, or likely future movement (Ur). Individual boulders susceptible to movement.
- 🟩 Potentially unstable colluvium (PUc), in some places with evidence of ongoing soil creep and/or past landsliding, includes oversteepened cut and fill slopes. Susceptible to landslides ten feet or more in thickness on natural slopes and rotational landslides of varying thickness in fill if disturbed by humans, shaken by earthquakes, or saturated by heavy rainfall.
- 🟨 Potentially unstable (PUr): Cut slopes in rock primarily susceptible to potentially damaging rock falls ranging in size from pebbles to large boulders.
- 🟧 Potentially unstable (PUf): Inferred fill slopes placed on rock and susceptible primarily to localized rotational landsliding with the depth of slip surfaces proportional to fill thickness.
- ▨ Possible dormant landslide (Sls). Inferred on the basis of topographic expression and limited subsurface data but with no evidence for recent or current movement. Potential for future movement is uncertain. Lateral extent and depth are uncertain.

Map 11: Qualitative Slope Hazards

UCSF Slope Stability Risk Assessment
Rutherford & Chekene June 2006

Process Based Hazard Models

- PISA-m: Map-based probabilistic infinite slope stability
- Haneberg, 2004, *Environmental & Engineering Geoscience*
- Incorporates input uncertainties using probability distributions
- Similar to USFS LISA
- FOSM approximations
- Calculates FS mean, standard deviation, Prob FS ≤ 1 plus seismic results
- Geotechnical input defined by engineering geologic map units
- Thin colluvium over bedrock
- Thick colluvium in hollows
- Three scenarios for UCSF
- Wet static, wet seismic, dry seismic
- Other models are available (*e.g.,* TRIGRS, SHALSTAB, SINMAP, WEPP)



Campus boundaries are approximate and based on data supplied by UCSF

Grid Ticks: California State Plane
Zone 3, US Survey Feet
NAD83 HARN

Prob [$D_N > 30$ cm]

🟥	$0.75 < p \le 1.00$
🟧	$0.50 < p \le 0.75$
🟨	$0.25 < p \le 0.50$
🟩	$0.00 < p \le 0.25$
☐	not calculated*

*slope < 5° or outside model boundary

Probability that the calculated Newmark displacement (D_N) is greater than 30 cm for the geotechnical soil properties described in the accompanying report and an earthquake of Arias intensity $I_A = 7$ m/s. Values near 1 indicate a high probability that movement will occur under the specified conditions. Values near 0 indicate a low probability that movement will occur under the specified conditions. Calculations were based on the first-order, second-moment method described in Haneberg (2004, A rational probabilistic method for spatially distributed landslide hazard assessment: *Environmental & Engineering Geoscience*, v. 10, p. 23-47) and the regression model developed by Jibson et al (2000, A method for producing digital probabilistic seismic landslide hazard maps: *Engineering Geology*, v. 58, p. 271-289).

Map 14: Probabilistic Slope Stability
Dry Seismic Conditions (I_A = 7 m/s) (Revised model of March 2007)

UCSF Slope Stability Risk Assessment
Rutherford & Chekene
June 2006

Campus boundaries are approximate and based on data supplied by UCSF

Grid Ticks: California State Plane
Zone 3, US Survey Feet
NAD83 HARN

Prob [$D_N > 30$ cm]

🟥	$0.75 < p \le 1.00$
🟧	$0.50 < p \le 0.75$
🟨	$0.25 < p \le 0.50$
🟩	$0.00 < p \le 0.25$
☐	not calculated*

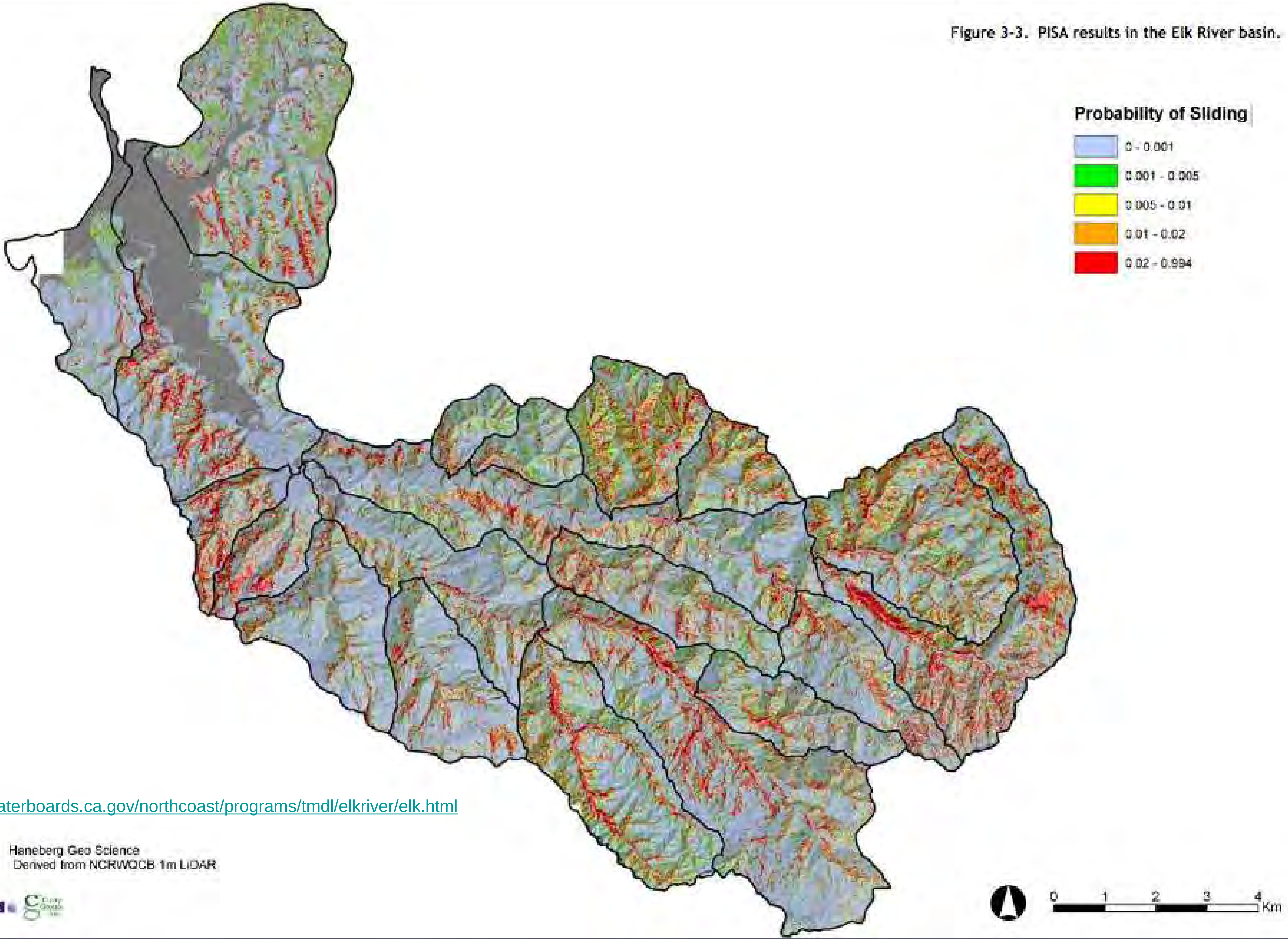
*slope < 5° or outside model boundary

Probability that the calculated Newmark displacement (D_N) is greater than 30 cm for the geotechnical soil properties described in the accompanying report and an earthquake of Arias intensity $I_A = 7$ m/s. Values near 1 indicate a high probability that movement will occur under the specified conditions. Values near 0 indicate a low probability that movement will occur under the specified conditions. Calculations were based on the first-order, second-moment method described in Haneberg (2004, A rational probabilistic method for spatially distributed landslide hazard assessment: *Environmental & Engineering Geoscience*, v. 10, p. 23-47) and the regression model developed by Jibson et al (2000, A method for producing digital probabilistic seismic landslide hazard maps: *Engineering Geology*, v. 58, p. 271-289).

Map 13: Probabilistic Slope Stability
Wet Seismic Conditions (I_A = 7 m/s) (Revised model of March 2007)

UCSF Slope Stability Risk Assessment
Rutherford & Chekene
June 2006

Figure 3-3. PISA results in the Elk River basin.



http://www.waterboards.ca.gov/northcoast/programs/tmdl/elkriver/elk.html

Sources:
PISA: Haneberg Geo Science
Shaded Relief: Derived from NCRWQCB 1m LiDAR

Parting words

- Take control of the data and be active users
- Incorporate geologic concerns into project specs
- Understand resolution, mappability, and accuracy
- Use the data and derivatives to their full potential
- Utilize virtual mapping technologies to leverage field time (especially in cold wet climates!)
- Take advantage of process based mod evaluate unprecedented or rare conditions

Haneberg Geoscience