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Surface-to-Surface Comparison of NED, SRTM, Digital Photogrammetry and LIDAR Derived Digital Elevation Models: Implications for Geological Mapping, and Geographic Analysis

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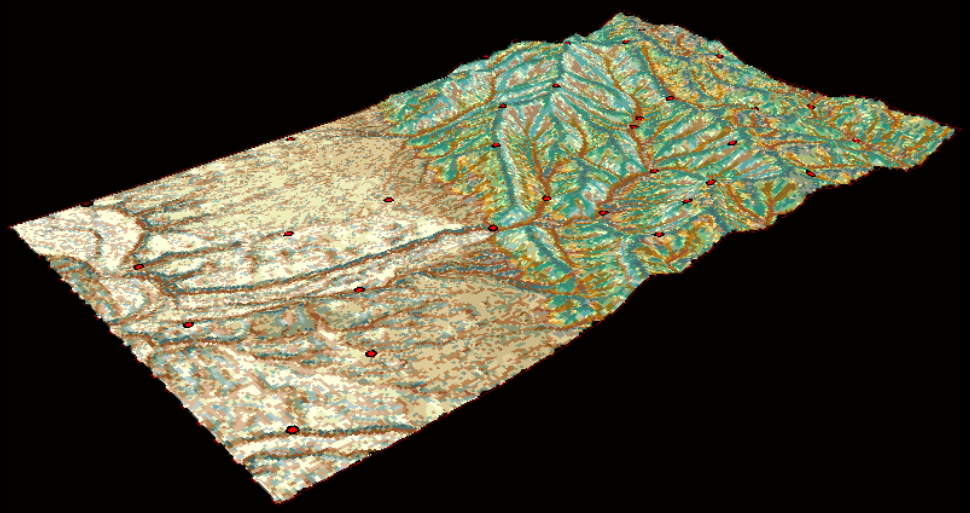

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Introduction

- **There are multiple sources of Digital Elevation Model (DEM) data available for mapping, modeling and analysis**
  - The National Elevation Dataset (NED)
  - Shuttle Radar Topography Mission (SRTM) - IFSAR
  - LIDAR
  - Photogrammetry – Digital or Analog
- **Each source contains varying degrees of error or uncertainty**
  - Error is defined as the difference between true elevation and the elevation value modeled in the DEM.
  - Errors in DEMs may be random (fluctuation in measurements) or systematic (consistent and repeatable: due to process).

Introduction

- **There are a numerous statistical measures of DEM error.**
  - One of the most common is Root Mean Squared Error (RMSE).
  - RMSE is often derived by comparing a DEM surface to GPS observations (point observations).
  - Correlation Coefficients are another simple measure of similarity
  - Standard suite of MIN, MAX, MEAN and STDEV of difference values
- **Point-to-surface measures of error often overlook spatial variation due to topographic and landcover conditions**
  - GPS and HARN sites are often selected based on “clear skies” and consistent slope conditions.
  - GPS observations are usually not made to include all landcover types

Objectives

- **The objectives of this study are to:**
    - Test several types of DEMs through point-to-surface comparisons and surface-to-surface comparisons,
    - Map the spatial variation of error,
    - Discuss the possible sources of the error including landcover and topographic considerations,
    - Describe implications for Geologic mapping and Geographic analysis.

Study Area

- The study area for this research is the Paine Run area within the Shenandoah National Park, Virginia. The area encompasses parts of the Browns Cove and Crimora VA Quadrangles (24K).

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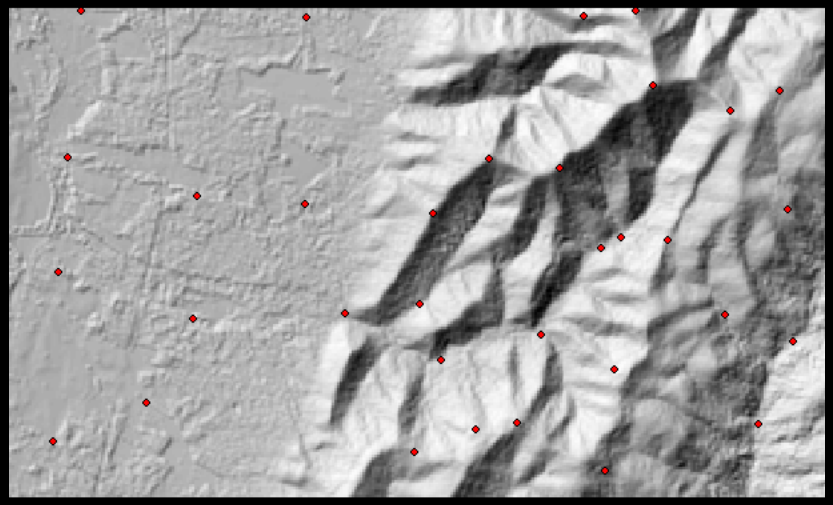
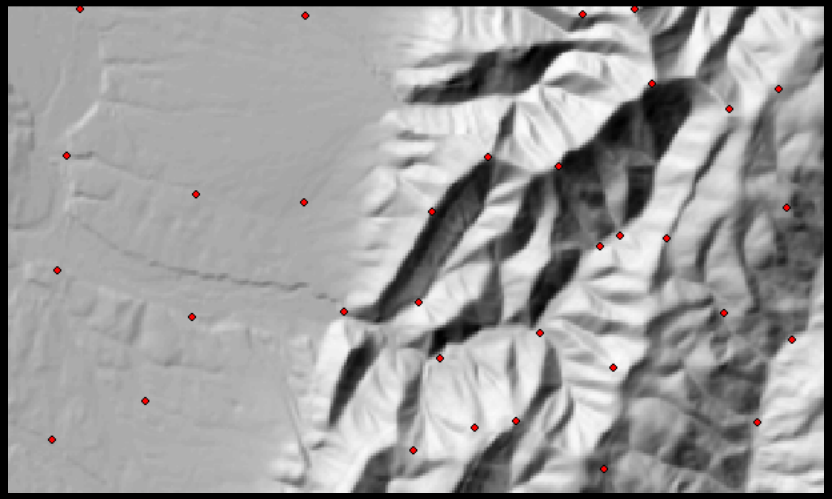
Study Area LIDAR Data

- The LIDAR was flown by EarthData (through the CSC Contract) in 3/04 for the purposes of geological process mapping and interpretation. Consequently, a 5m horizontal resolution was the specification. Both Bald Earth and First Return Data were collected and processed. The total area is approximately 60km² (10.5 x 5.5).



First Return Surface



Bald Earth Surface

Basic Elevation Statistics for the LIDAR Elevation Model

COUNT	AREA	MIN	MAX	RANGE	MEAN
66532	59878800.00	340.14	1026.92	686.78	569.77

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Study Area Datasets

- Datasets tested were the NED, SRTM, Contour Derived DEM (CDEM), and LIDAR.
  - LIDAR Collection: 3/04
  - SRTM Collection: 2/00
  - NED and CDEM: NED (LT4X Process) CDEM – Topogrid w/ Hydro and Spot Heights, Contours from photogrammetry based on 1963 aerial photos

- 34 GPS (X, Y, Z) point locations and the LIDAR will be used in this study as the “ground truth” datasets.
- Bald Earth LIDAR will be compared to NED, SRTM, and CDEM
- First Return (First Surface) LIDAR will also be compared to SRTM
- Prior to evaluation horizontal and vertical datum adjustment was performed then each was re-sampled to 30m resolution and projected to:

  UTM Zone17
  H- Datum: NAD 83
  V-Datum: NAVD88

Point-to-Surface Comparison Results (GPS Test)

- The table below shows the Expected RMSE (EX-RMSE) values (based on Metadata or production specifications), GPS-RMSE values and basic statistics for the GPS- test

  * GPS control for the LIDAR data includes on 4 points completed by the contractor

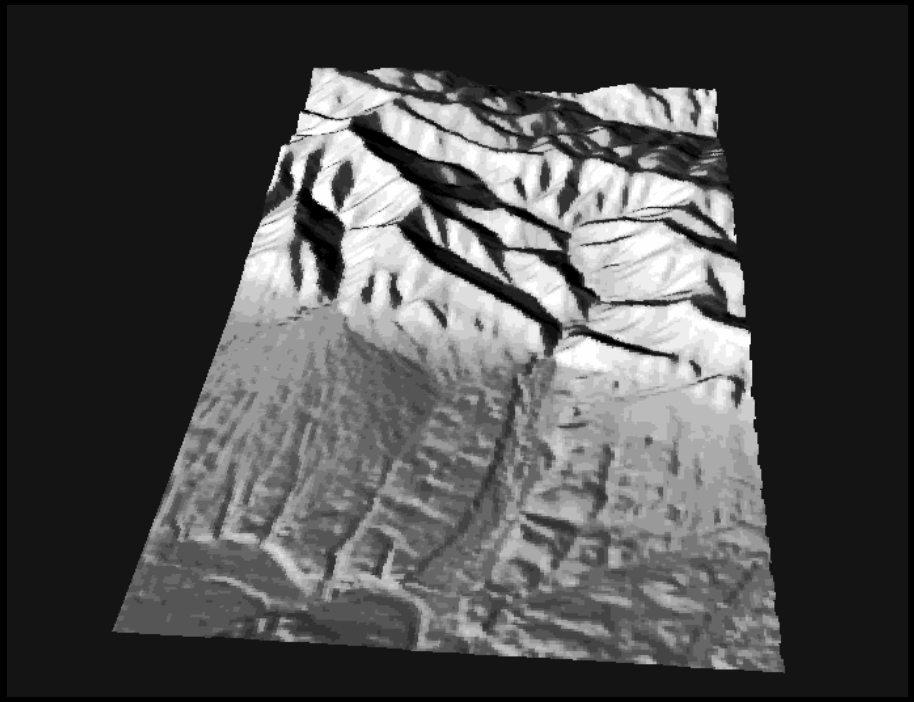
	LIDAR	NED	SRTM	CDEM
EX-RMSE	**0.096m**	**6.09m**	**16m**	**6.09m**
GPS-RMSE	**0.096m***	**6.69m**	**7.85m**	**6.46m**
STDEV	**0.110m**	**5.24m**	**7.86m**	**5.00m**
MEAN		**-4.25m**	**-1.30m**	**-4.17m**
MAX	**0.127m**	**4.51m**	**15.16m**	**2.89m**

Surface-to-Surface Comparison Methodology

- To evaluate DEM surfaces, the GPS point elevations and LIDAR surface were each subtracted from the test DEM dataset for an output containing the “difference” values.

  Positive (+) values indicate that the tested DEM over-estimates the elevation

  Negative (-) values indicate that the tested DEM underestimates the elevation



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Surface-to-Surface Comparison Results (LIDAR Test)

- The table below shows the Expected RMSE values (EX_RMSE), GPS-RMSE values and basic statistics for the GPS- test and the LIDAR surface test (S-RMSE)

  * GPS control for the LIDAR data includes on 4 points completed by the contractor

	LIDAR	NED	SRTM	CDEM
EX-RMSE	0.096m	6.09m	16m	6.09m
GPS-RMSE	0.096m*	6.69m	7.85m	6.46m
STDEV	0.110m	5.24m	7.86m	5.00m
MEAN		-4.25m	-1.30m	-4.17m
MAX	0.127m	+/-20.20m	+/-15.24m	+/-15.55m
EX-RMSE	0.096m	6.09m	16m	6.09m
S-RMSE		7.31m	8.02m	7.04m
S-STDEV		6.52m	7.83m	6.10m
S-MEAN		-3.30m	1.73m	-3.52m
S-MAX		+/-42.66m	+/-33.29m	+/-35.85
COR-COEF		.9988	.9984	.9989

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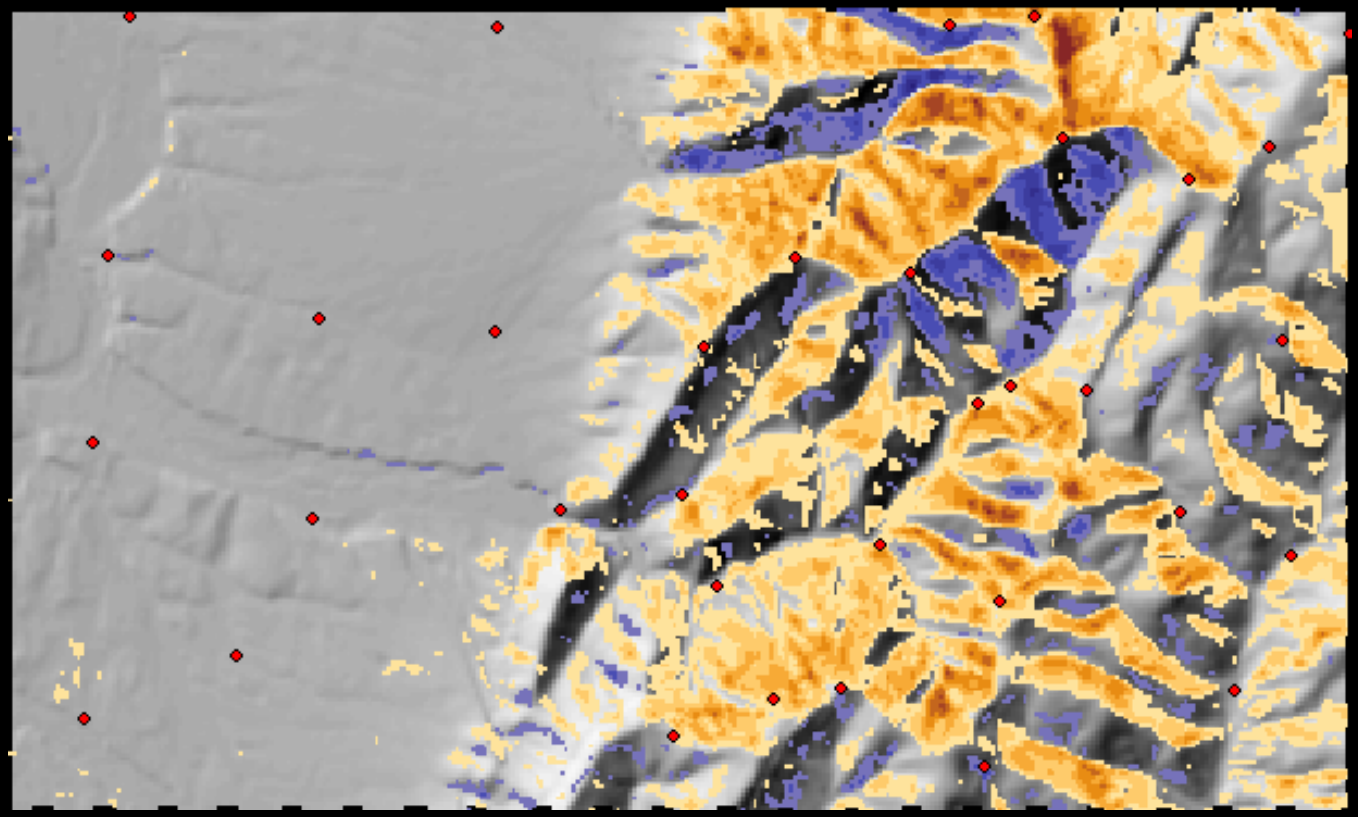
Surface-to-Surface LIDAR (BE) – NED (LT4X)

- Difference value grid overlying LIDAR shaded relief. Orange and red values depict pixels where NED underestimated elevations. Blue pixels show where NED overestimates elevations. Differences between -5 and 5m not shown.



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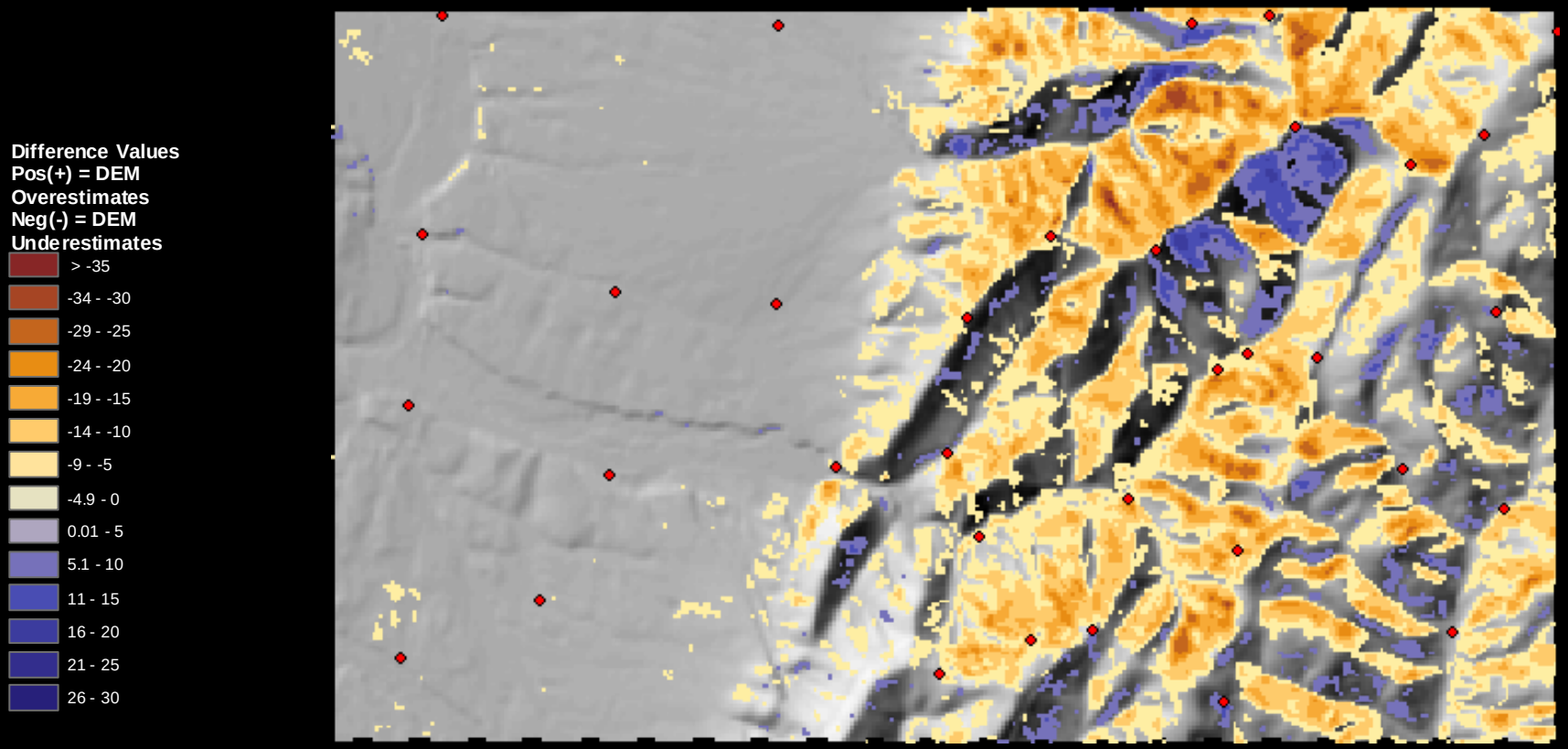
Surface-to-Surface LIDAR (BE) – CDEM (Topogrid)

- Difference value grid overlying LIDAR shaded relief. Orange values depict pixels where CDEM underestimated elevations. Blue pixels show where CDEM overestimates elevations. Differences between -5 and 5m not shown.



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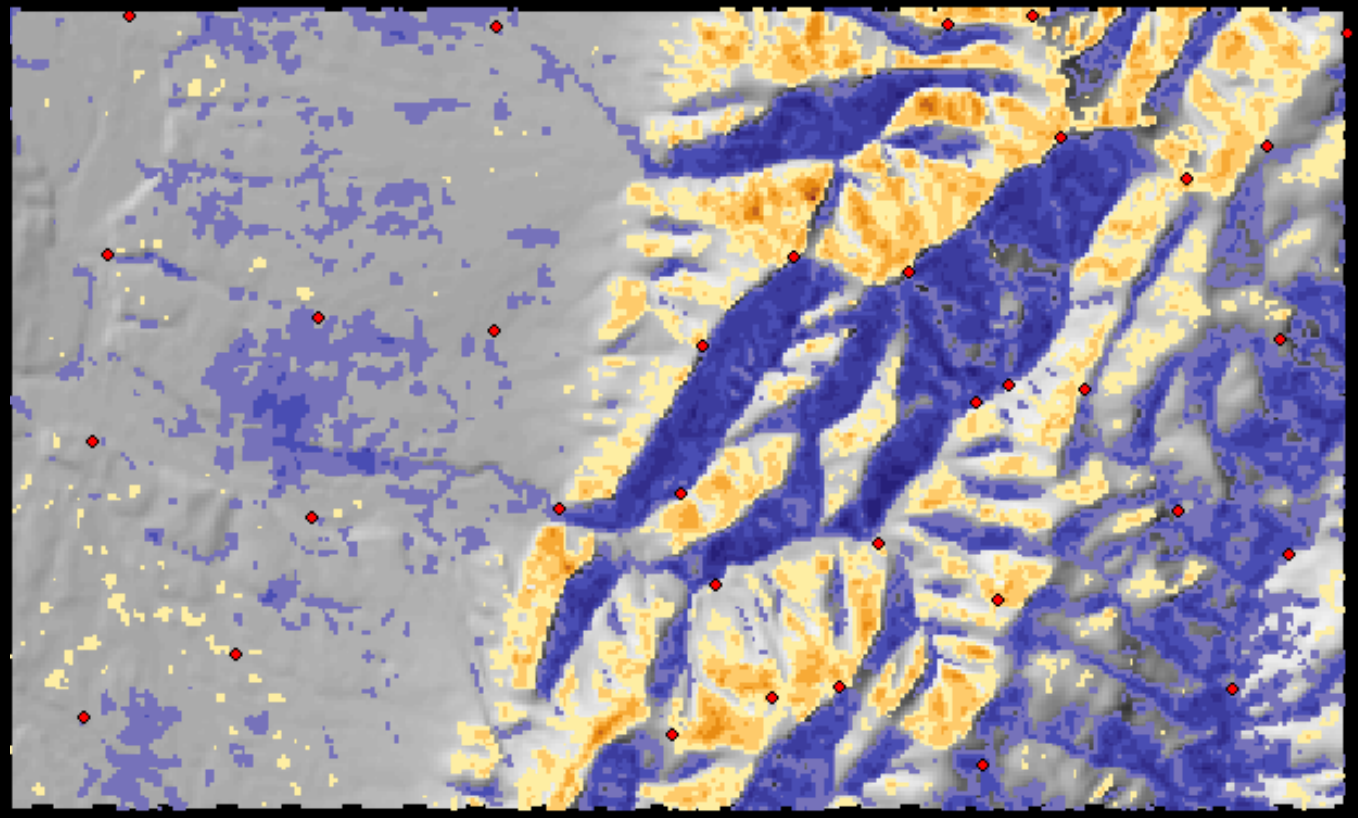
Surface-to-Surface LIDAR (BE) - SRTM

- Difference value grid overlying LIDAR shaded relief. Orange values depict pixels where SRTM underestimated elevations. Blue pixels show where SRTM overestimates elevations. Differences between -5 and 5m not shown.



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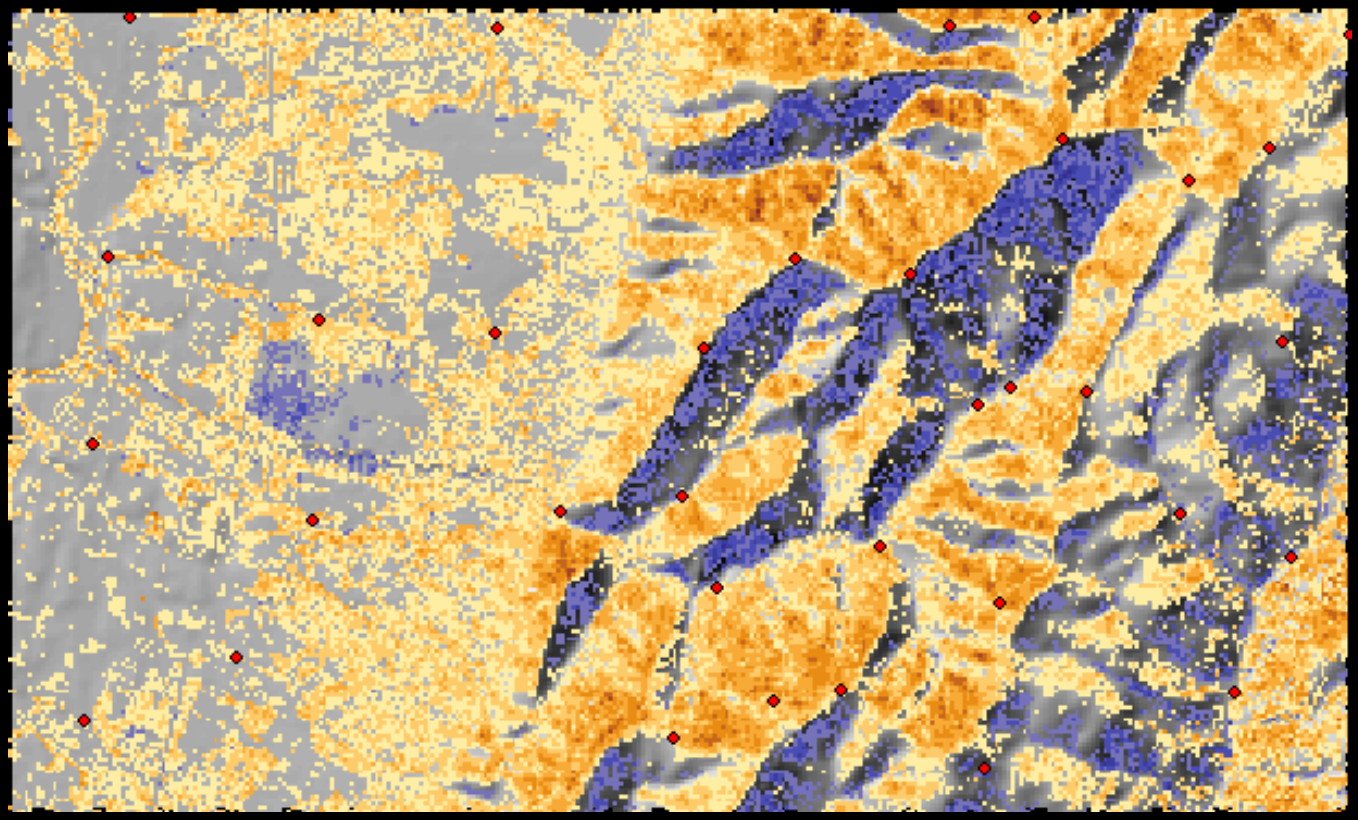
Surface-to-Surface LIDAR (FR) - SRTM

- Difference value grid overlying LIDAR shaded relief. Orange values depict pixels where SRTM underestimated elevations. Blue pixels show where SRTM overestimates elevations. Differences between -5 and 5m not shown.



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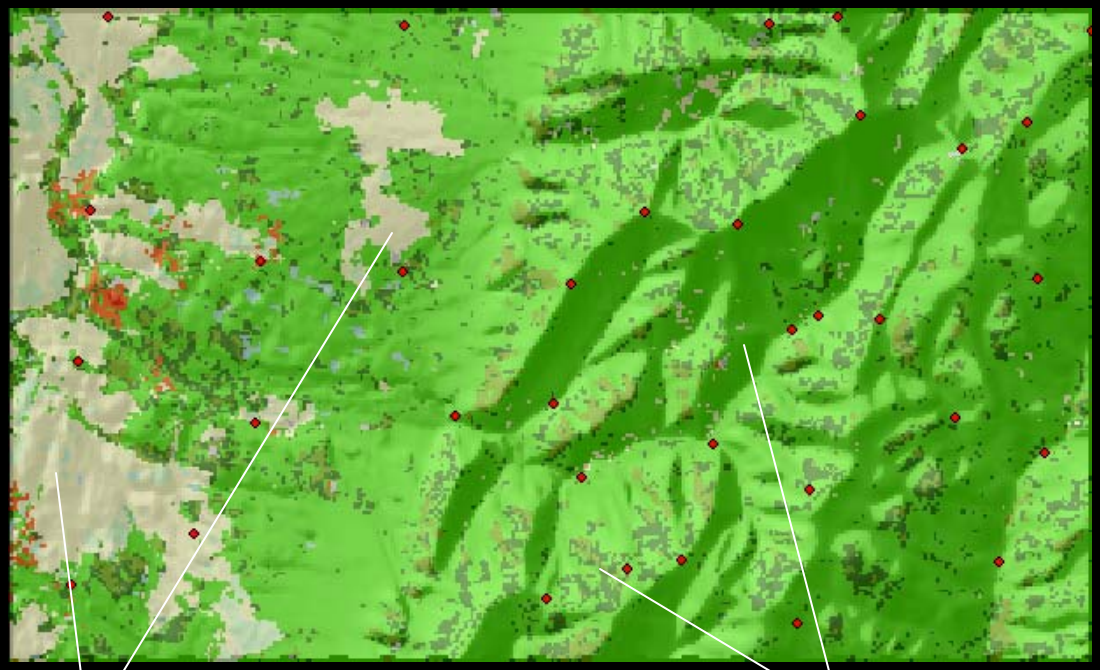
Elevation errors and correlation with landcover type

- The study area is covered mainly by forest types, but also includes significant areas of pasture.

11. *Open Water –*	.07%
21. *Low Intensity Residential –*	.5%
23. *Commer/Indust/Trans -*	.01%
33. *Transitional –*	.23%
41. *Deciduous Forest –*	71.6%
42. *Evergreen Forest –*	3.9%
43. *Mixed Forest -*	11%
81. *Pasture/Hay –*	10.5%
82. *Row Crops –*	1.5%
91. *Woody Wetlands –*	.38%
92. *Emergent Herbaceous Wetlands -*	.07%

Total Forested area accounts for 86.5%



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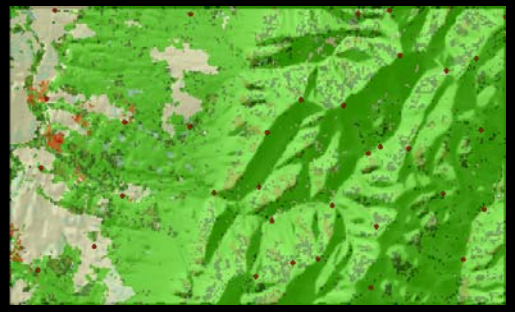
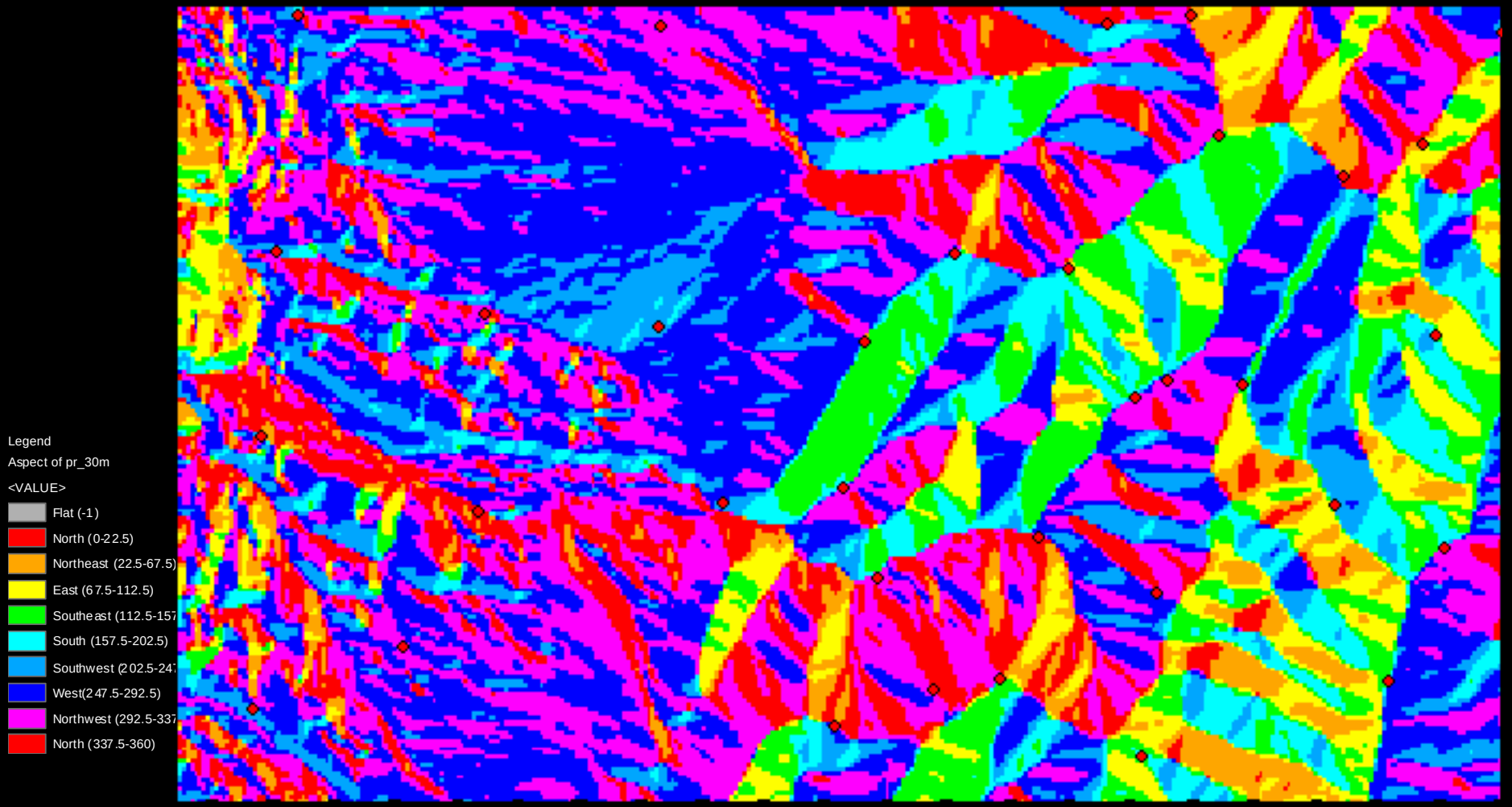
Elevation Differences and Landcover Classes

- STDEV values are greatest in Forested land cover type as well as Transitional Areas (rock outcrops) in mountains.



NED							SRTM_BE					
VALUE	MIN	MAX	RANGE	MEAN	STD		VALUE	MIN	MAX	RANGE	MEAN	STD
11	-3.74	2.91	6.66	-0.29	1.57		11	-5.33	6.05	11.38	-0.15	2.51
21	-4.26	4.36	8.62	0.11	1.34		21	-4.46	13.45	17.91	0.17	2.40
23	0.46	4.63	4.17	2.34	1.53		23	-2.93	5.17	8.10	1.15	2.82
33	-21.07	18.75	39.82	1.30	6.73		33	-16.21	21.60	37.80	3.70	7.49
41	-42.67	25.57	68.24	-3.48	6.67		41	-29.72	33.30	63.02	2.99	7.99
42	-34.91	9.65	44.56	-3.97	6.30		42	-27.69	20.30	48.00	-2.42	7.35
43	-35.98	17.77	53.75	-5.70	7.60		43	-26.79	26.81	53.60	-2.00	8.12
81	-35.99	24.86	60.86	-0.28	2.22		81	-14.06	29.35	43.41	-0.81	4.04
82	-31.90	12.96	44.86	-0.20	2.55		82	-13.07	9.33	22.41	-2.06	1.95
91	-3.76	5.36	9.13	-0.17	1.41		91	-5.56	12.35	17.91	4.40	3.40
92	-3.86	3.63	7.49	0.16	1.65		92	-5.15	6.17	11.32	-1.66	2.11
CDEM							SRTM_FR					
VALUE	MIN	MAX	RANGE	MEAN	STD		VALUE	MIN	MAX	RANGE	MEAN	STD
11	-3.96	2.31	6.27	-0.89	1.50		11	-17.44	1.41	18.85	-4.29	4.45
21	-4.42	3.79	8.22	-0.22	1.28		21	-22.99	6.18	29.18	-4.23	4.79
23	-0.14	4.74	4.88	2.02	1.38		23	-17.74	3.12	20.85	-5.65	6.66
33	-22.36	15.32	37.68	0.04	5.88		33	-21.61	15.77	37.38	-1.13	6.36
41	-34.77	22.28	57.06	-3.60	6.17		41	-35.30	24.10	59.40	-5.70	8.00
42	-34.97	8.57	43.54	-5.00	6.14		42	-35.54	13.17	48.71	-8.60	6.76
43	-35.86	15.51	51.37	-6.21	7.20		43	-34.11	18.42	52.53	-9.54	8.17
81	-22.71	20.01	42.72	-0.53	2.11		81	-25.22	21.78	47.00	-3.10	4.19
82	-19.84	11.01	30.85	-0.40	2.15		82	-22.94	8.91	31.86	-2.92	2.86
91	-3.98	4.02	7.99	-0.55	1.52		91	-19.79	11.33	31.12	-3.93	6.53
92	-4.52	2.88	7.40	0.18	1.70		92	-15.56	2.34	17.90	-3.12	2.93

Aspect Effect on Elevation Models



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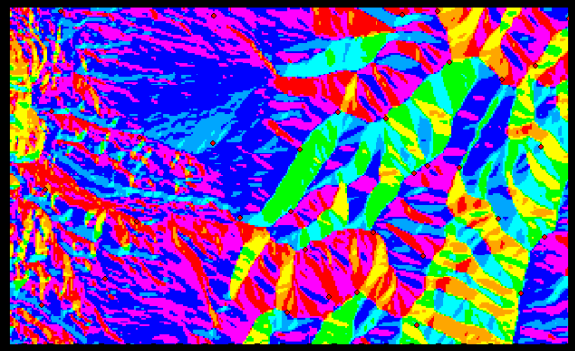
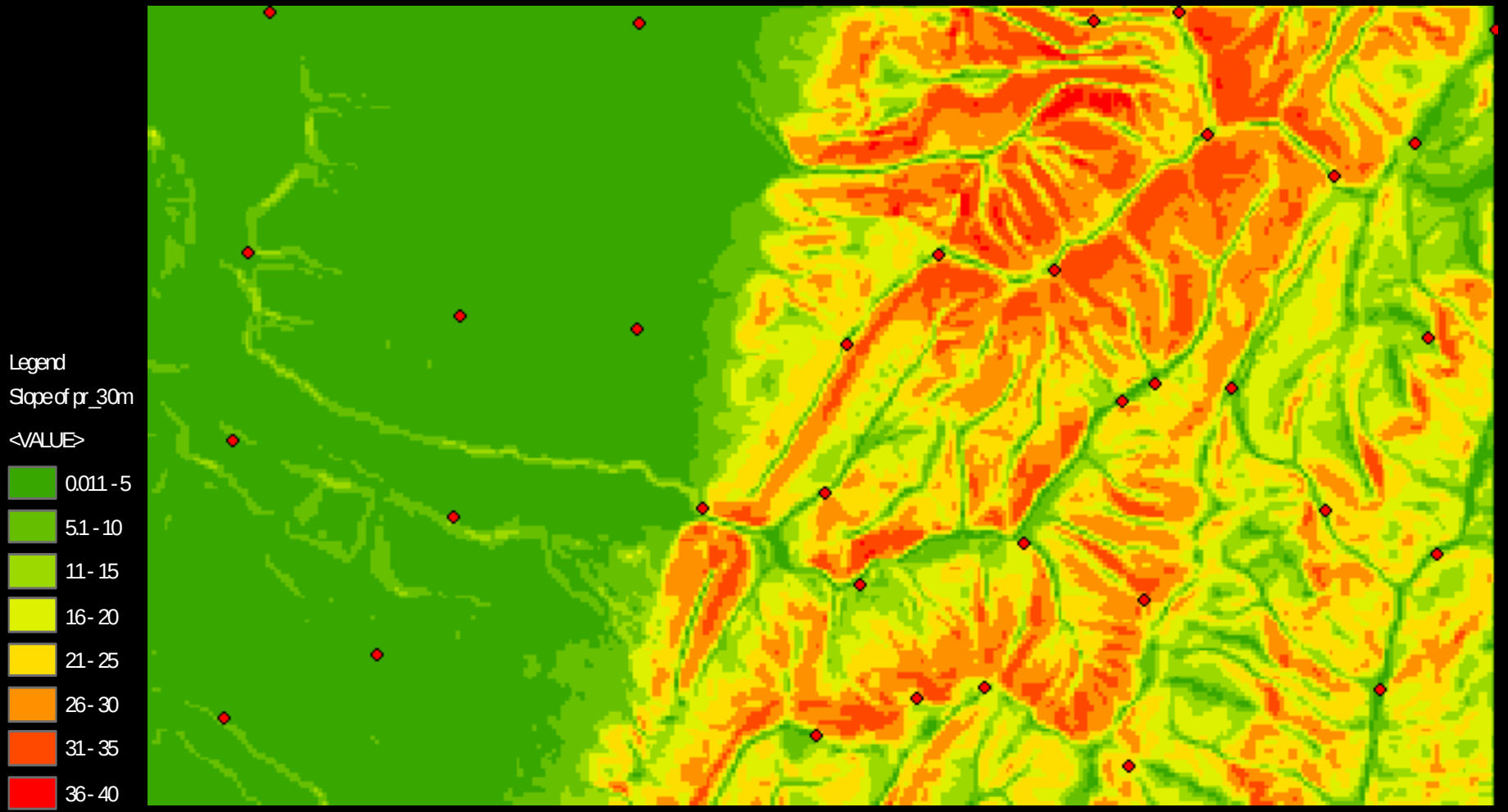
Elevation difference correlated to Aspect

- MEAN and STDEV difference values are greatest in N&NE areas for the NED and S&SE areas for the SRTM data. Note less difference in SRTM vs. FR data in areas with S&SE aspect.



NED							SRTM_BE					
VALUE	MIN	MAX	RANGE	MEAN	STD		VALUE	MIN	MAX	RANGE	MEAN	STD
NORTH	-35.91	6.94	42.86	-8.00	7.77		NORTH	-18.75	27.31	46.05	3.17	6.76
NE	-42.67	7.39	50.06	-8.78	8.24		NE	-20.95	29.72	50.67	-0.02	5.89
EAST	-35.99	12.28	48.27	-5.05	5.66		EAST	-26.45	18.78	45.23	-6.63	6.49
SE	-15.43	24.86	40.29	0.98	4.56		SE	-33.30	11.37	44.67	-12.16	6.88
SOUTH	-11.50	25.57	37.07	2.97	4.81		SOUTH	-30.21	13.43	43.64	-10.10	6.68
SW	-23.09	19.76	42.85	0.07	3.73		SW	-26.84	16.41	43.26	-3.65	5.17
WEST	-29.09	15.89	44.98	-2.35	3.83		WEST	-22.91	22.18	45.09	-0.06	5.08
NW	-35.98	10.65	46.62	-5.36	6.29		NW	-20.65	28.10	48.75	2.57	6.60
CDEM							SRTM_FR					
VALUE	MIN	MAX	RANGE	MEAN	STD		VALUE	MIN	MAX	RANGE	MEAN	STD
NORTH	-33.74	5.30	39.04	-7.04	7.00		NORTH	-35.30	12.27	47.57	-11.31	7.56
NE	-31.54	10.82	42.36	-6.97	7.02		NE	-34.82	15.54	50.36	-7.47	6.45
EAST	-26.38	13.74	40.12	-2.91	4.84		EAST	-26.95	22.74	49.69	1.88	6.09
SE	-14.23	20.01	34.24	1.74	4.30		SE	-23.29	22.91	46.20	3.03	6.50
SOUTH	-13.94	22.28	36.23	1.98	4.52		SOUTH	-23.86	24.10	47.96	1.95	6.66
SW	-24.63	14.78	39.41	-1.55	3.75		SW	-23.77	19.62	43.40	-3.35	5.73
WEST	-31.13	9.63	40.76	-3.47	4.38		WEST	-27.80	16.67	44.47	-6.93	5.27
NW	-35.86	6.43	42.29	-5.85	6.33		NW	-35.54	16.70	52.25	-9.96	6.72

Slope Effects of Elevation Models



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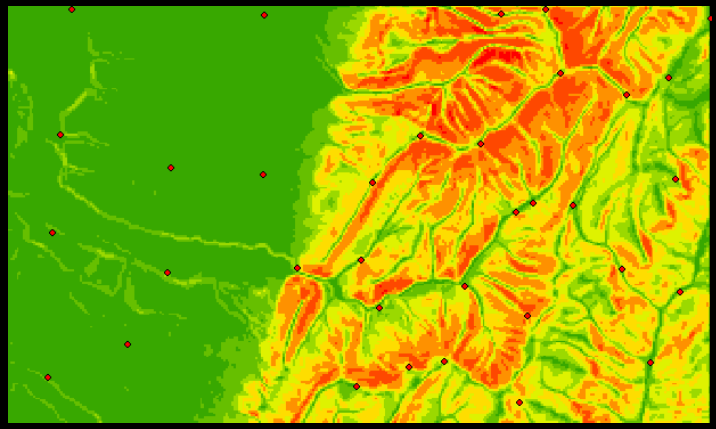
Slope Statistics

- MEAN and STDEV difference values are greatest in N&NE areas for the NED and S&SE areas for the SRTM data. Note less difference in SRTM vs. FR data in areas with S&SE aspect.



NED-BE							SRTM-BE					
CLASS	MIN	MAX	RANGE	MEAN	STD		CLASS	MIN	MAX	RANGE	MEAN	STD
5	-21.71	15.89	37.60	-0.78	1.69		5	-14.74	24.24	38.98	1.48	3.60
10	-29.22	19.76	48.98	-1.91	3.45		10	-18.62	26.30	44.92	2.18	5.60
15	-32.92	18.58	51.50	-3.16	5.06		15	-24.99	27.45	52.44	2.21	7.36
20	-36.82	24.27	61.08	-4.34	6.23		20	-22.62	30.21	52.83	2.02	8.41
25	-40.22	18.40	58.62	-5.67	7.40		25	-29.72	28.26	57.98	1.42	9.72
30	-40.20	24.86	65.06	-6.35	9.47		30	-28.10	28.53	56.63	1.34	11.32
35	-42.67	25.57	68.24	-6.98	12.02		35	-27.31	33.30	60.60	3.46	13.30
40	-37.73	6.65	44.37	-19.14	9.38		40	-27.69	23.48	51.18	-9.38	11.79
CDEM							SRTM-FR					
CLASS	MIN	MAX	RANGE	MEAN	STD		CLASS	MIN	MAX	RANGE	MEAN	STD
5	-17.92	9.63	27.56	-1.06	1.72		5	-23.36	16.16	39.52	-5.12	4.88
10	-16.90	14.34	31.24	-2.24	3.14		10	-26.79	22.88	49.66	-6.24	6.02
15	-25.77	14.78	40.55	-3.41	4.57		15	-33.86	24.10	57.96	-5.78	7.13
20	-30.31	19.89	50.20	-4.59	5.92		20	-31.39	19.70	51.08	-6.24	7.82
25	-35.86	14.92	50.78	-5.92	7.15		25	-34.82	22.74	57.56	-7.08	8.94
30	-35.37	18.74	54.11	-6.65	8.76		30	-32.77	21.33	54.10	-6.94	10.62
35	-34.17	22.28	56.46	-6.36	10.78		35	-35.54	22.91	58.45	-4.19	12.85
40	-34.97	3.79	38.77	-17.40	9.07		40	-32.49	16.47	48.96	-16.38	11.19

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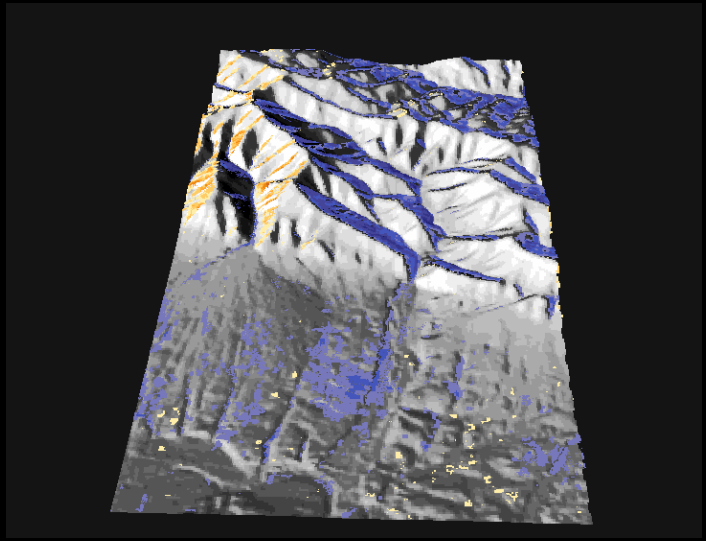
Results of SRTM- LIDAR Spatial Comparison

- SRTM
  - Overestimates elevations in areas with Forested Landcover Classes
  - Overestimates elevations in areas with Southeastern Aspect
  - Underestimates elevations in areas with Northwestern Aspect
  - Increasing inaccuracy with slopes greater than 20°-25°



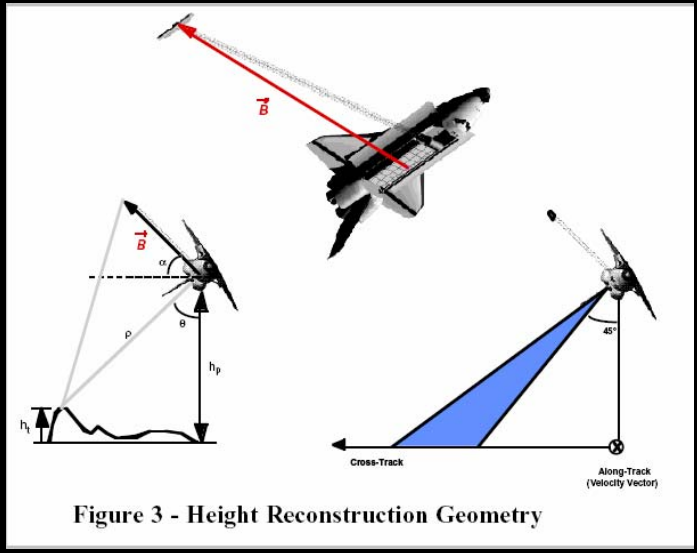


Figure 3 - Height Reconstruction Geometry

Results of NED and CDEM – LIDAR Spatial Comparison

NED

Overestimates elevations in areas with Northwestern Aspect

Overestimates elevations in areas with Forested Landcover Classes

Increasing inaccuracy with greater slope particularly 30° slopes and above

Note that the variable density and type of vegetation indicated in CIR orthophoto, may indicate generalization in 30m NLCD data.

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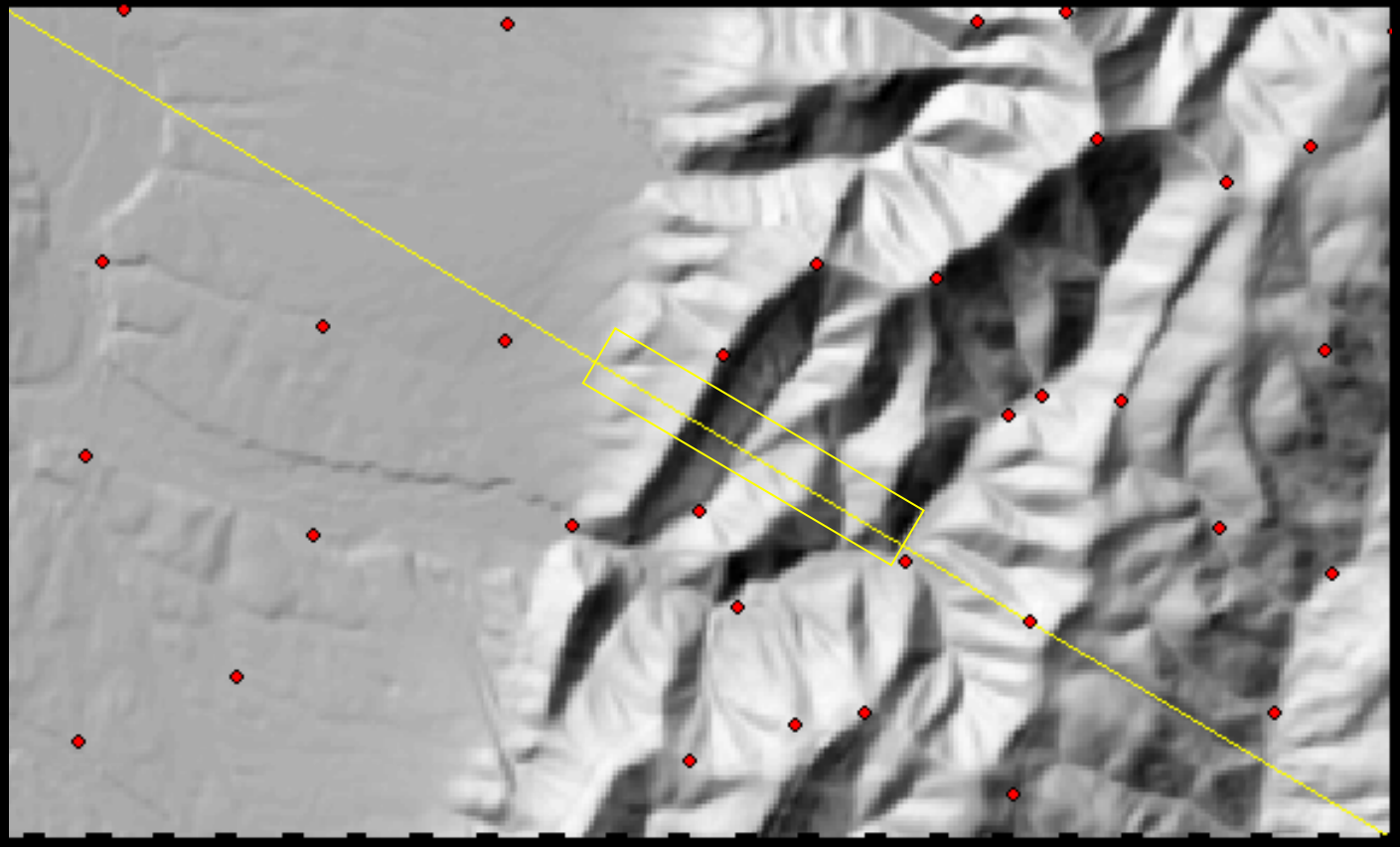
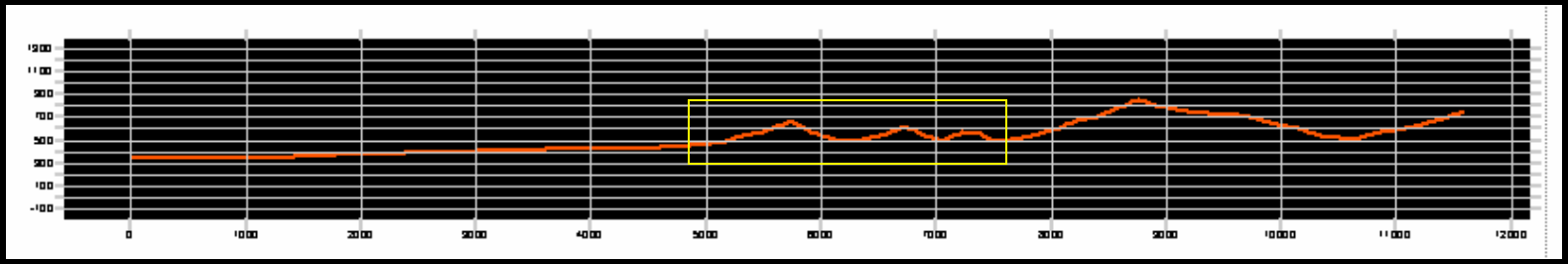
Topographic Surface Profile Comparison





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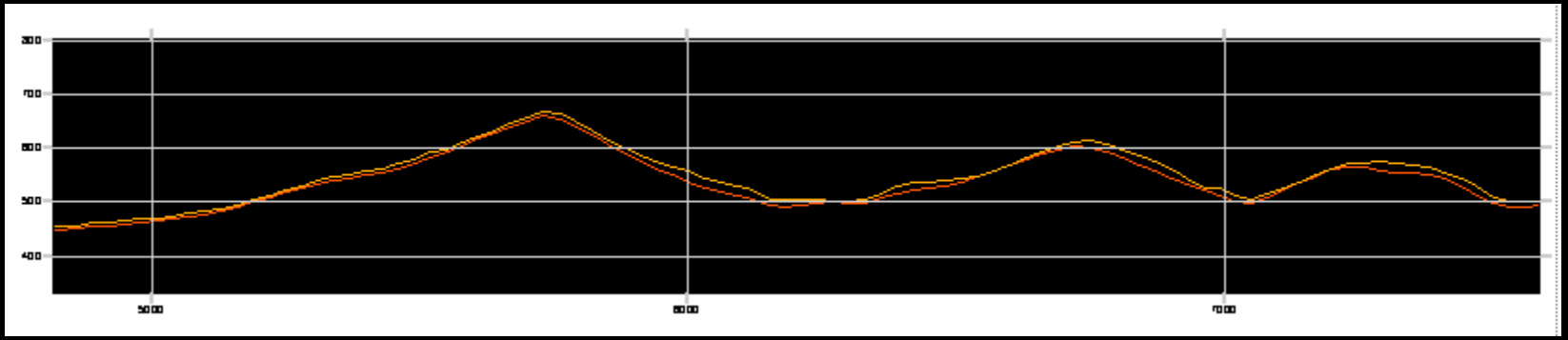
LIDAR Profile Comparison - BE vs. FR



- LIDAR BE (in red) compared to LIDAR FR (in orange)

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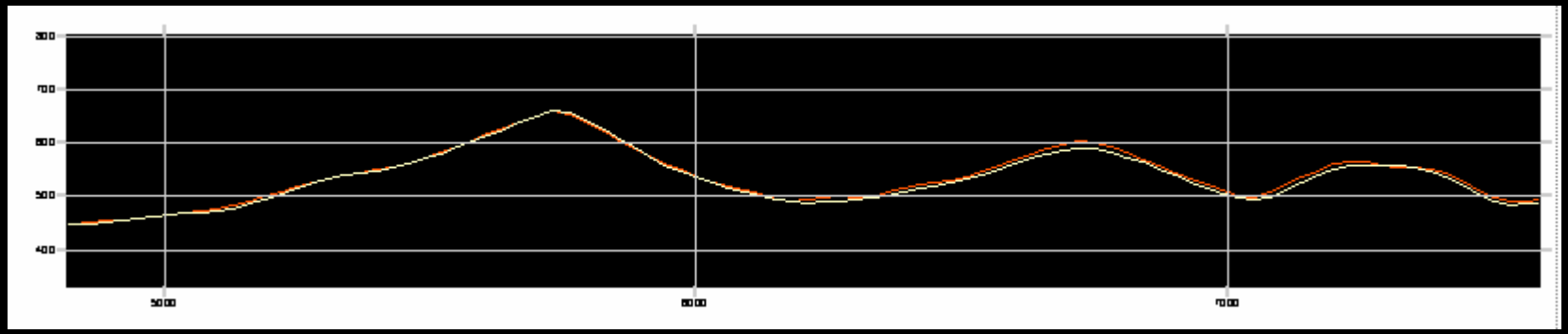
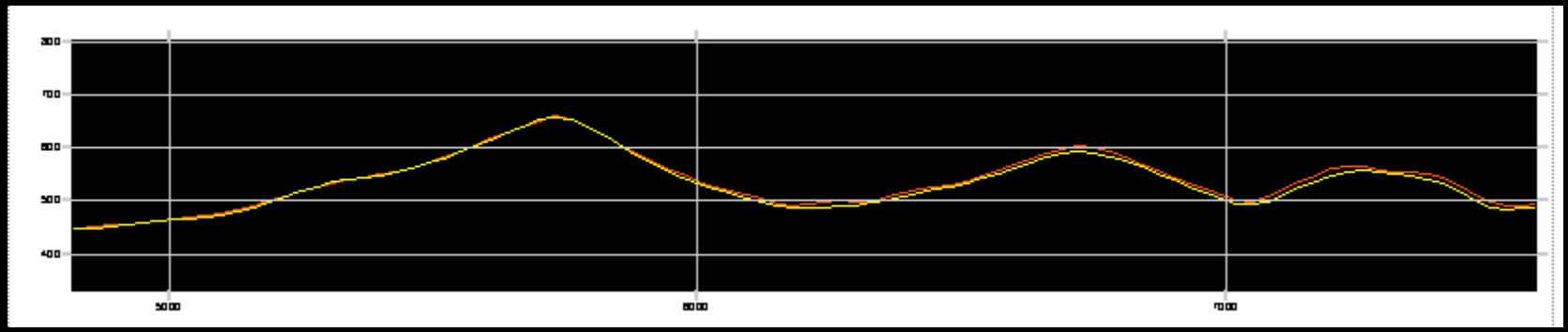
NED and CDEM Profiles vs. LIDAR



- NED (in yellow) compared to LIDAR (in red)



- CDEM (in yellow) compared to LIDAR (in red)

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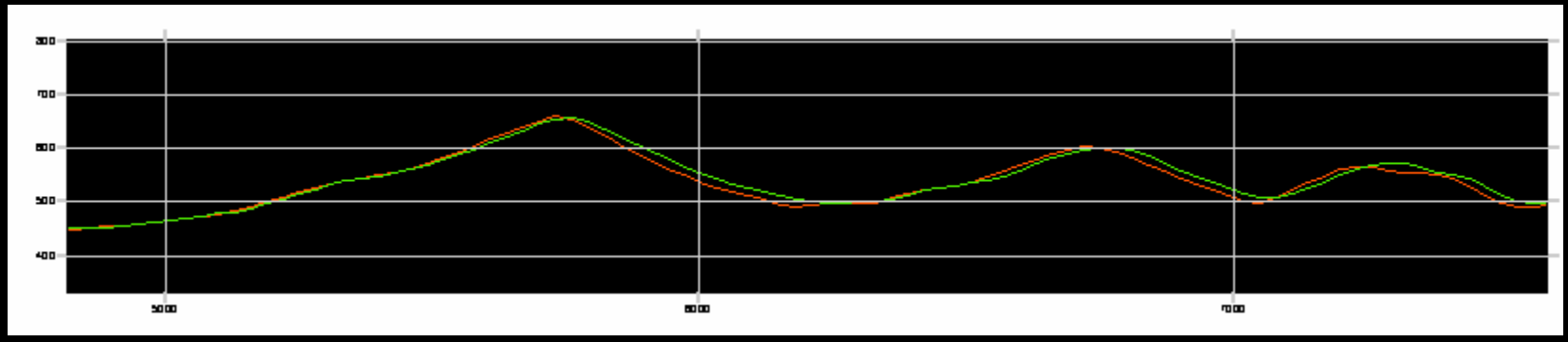
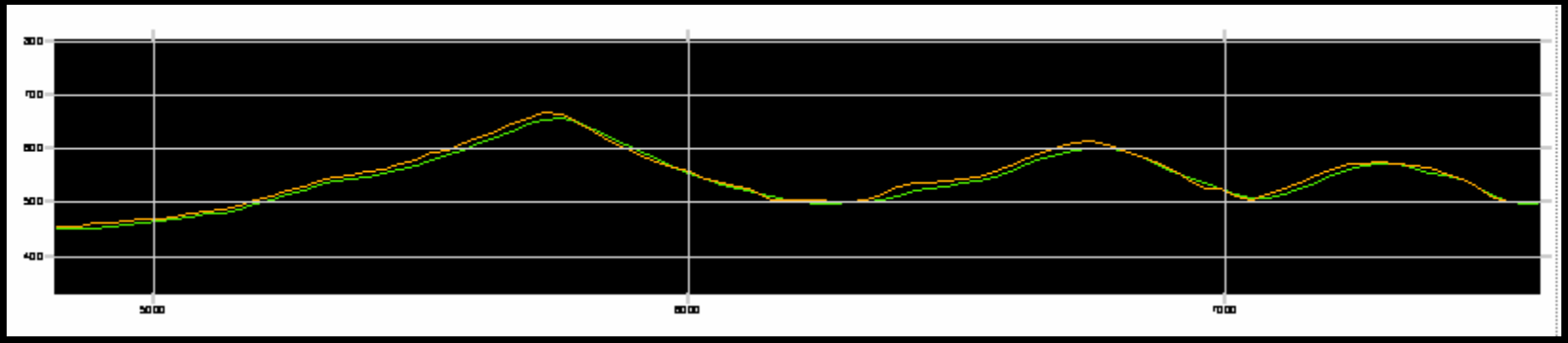
SRTM vs. LIDAR BE and SRTM vs. LIDAR FR



- SRTM (in green) compared to LIDAR BE (in red)



- SRTM (in green) compared to LIDAR FR (in orange)

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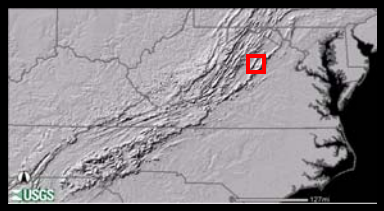
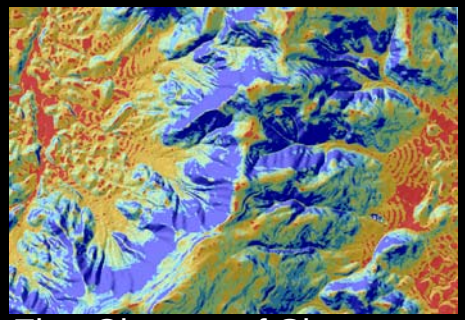
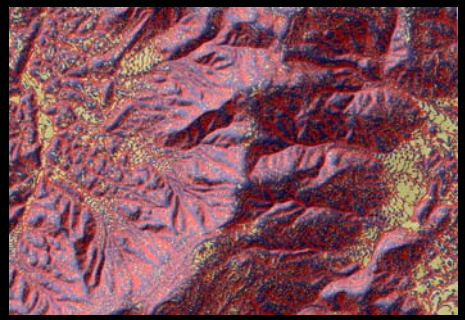
Geomorphometric Processing of DEMs

Measuring and classifying Slope and Curvature to develop surficial geologic units. Bentonville quadrangle in the Shenandoah National Park, Virginia.

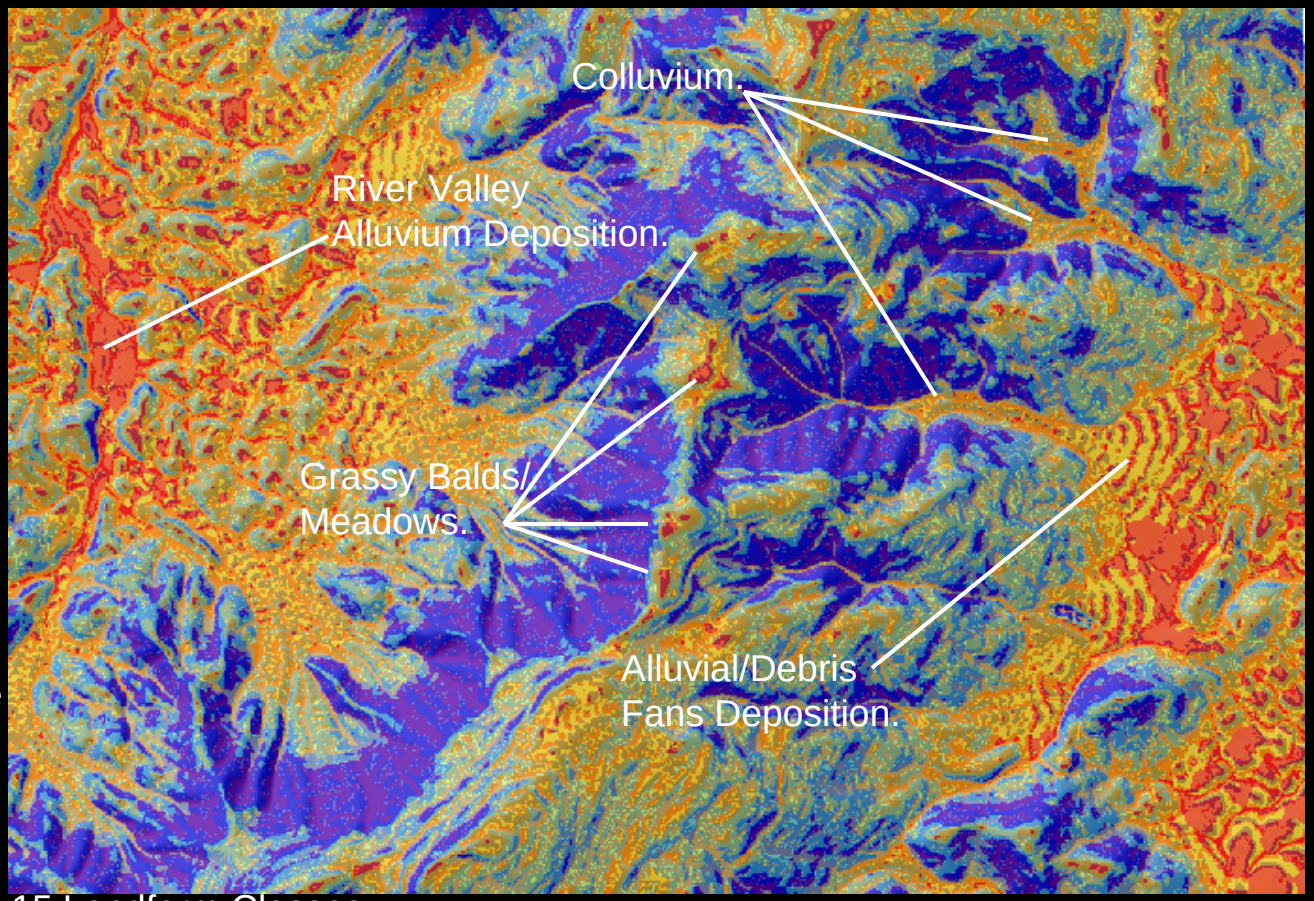




Five Classes of Slope



Three Classes of Curvature
Convex
Concave
Flat



15 Landform Classes

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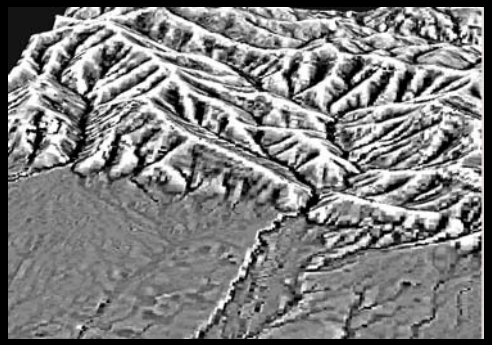
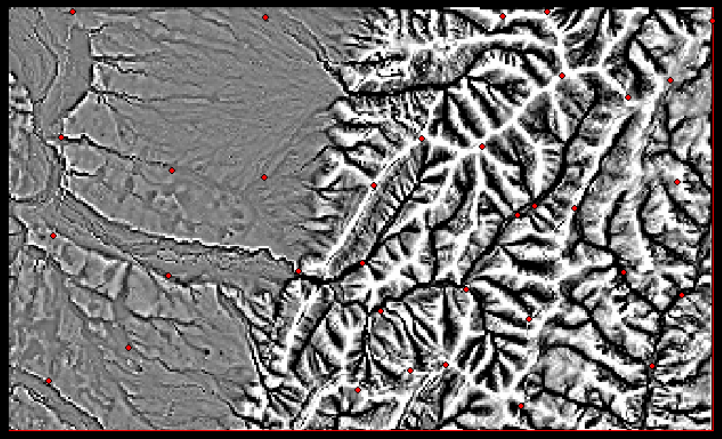
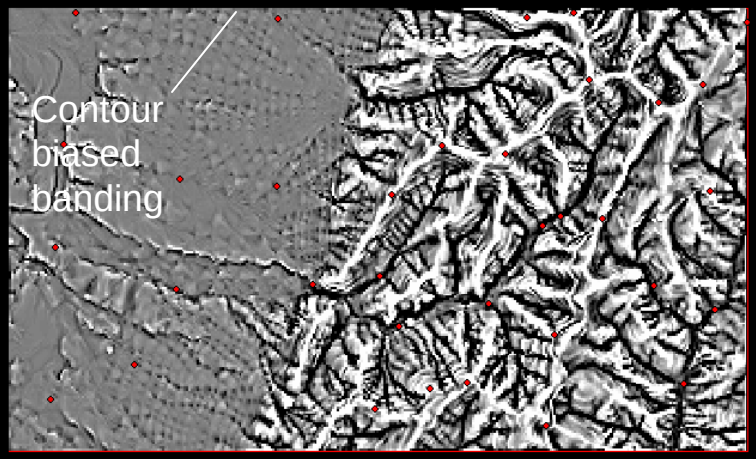
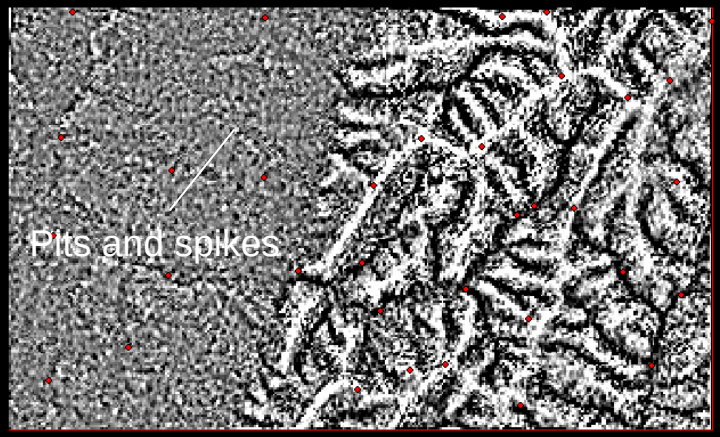
Derivatives of Elevation: Curvature

- Qualitative analysis of differences in derivative measures of DEM data. Curvature example depicts contour biasing in NED (CDEM) and ‘pitted’ result of SRTM in visual comparison.









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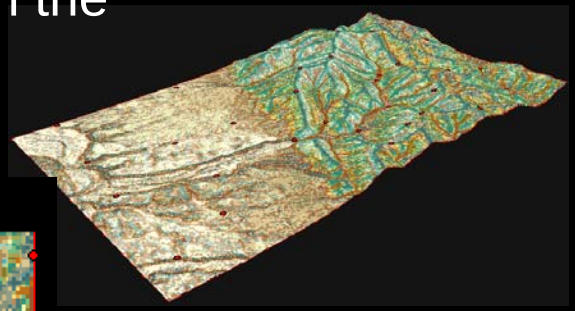
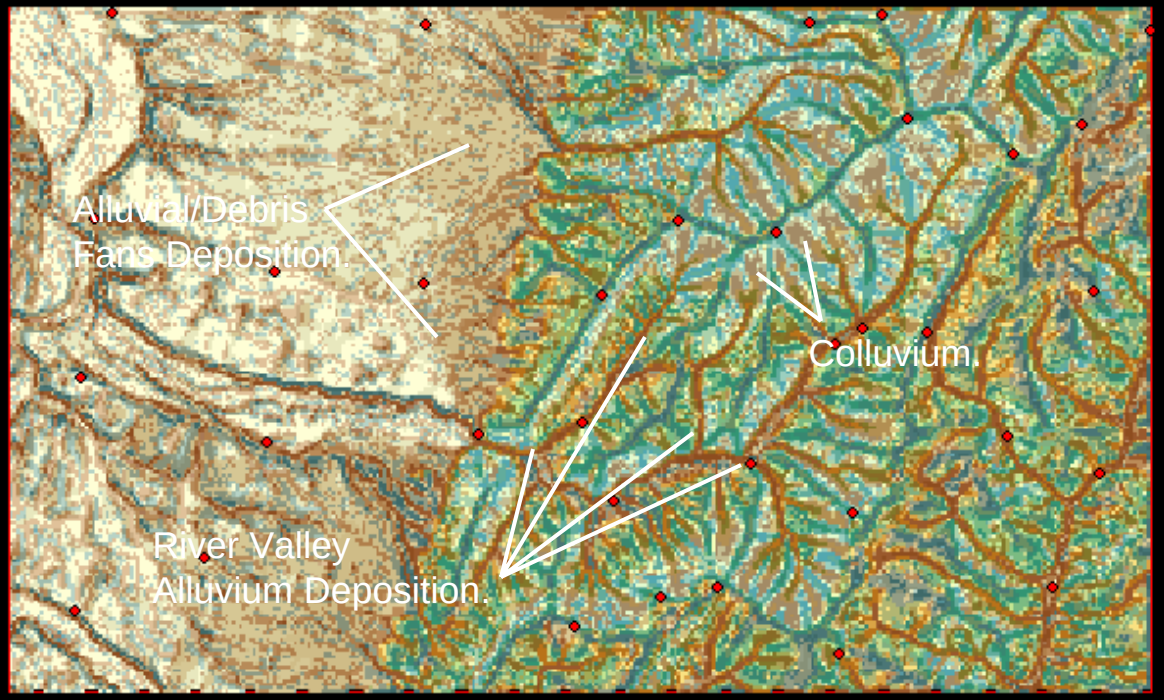
Geomorphometric Processing of DEMs

Measuring and classifying Slope and Curvature to develop surficial geologic units. Paine Run area in the Shenandoah National Park, Virginia.





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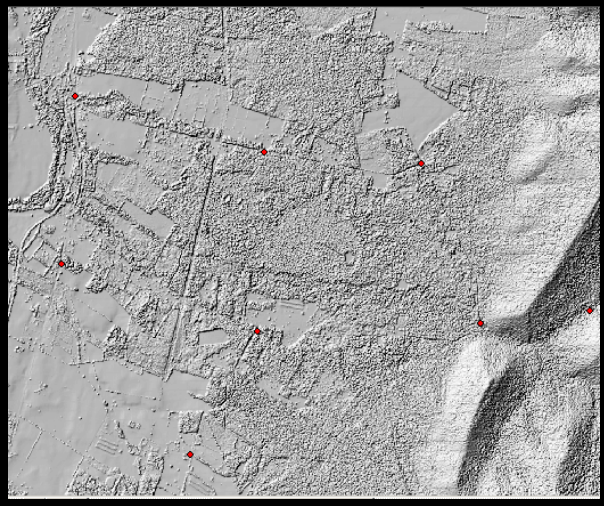
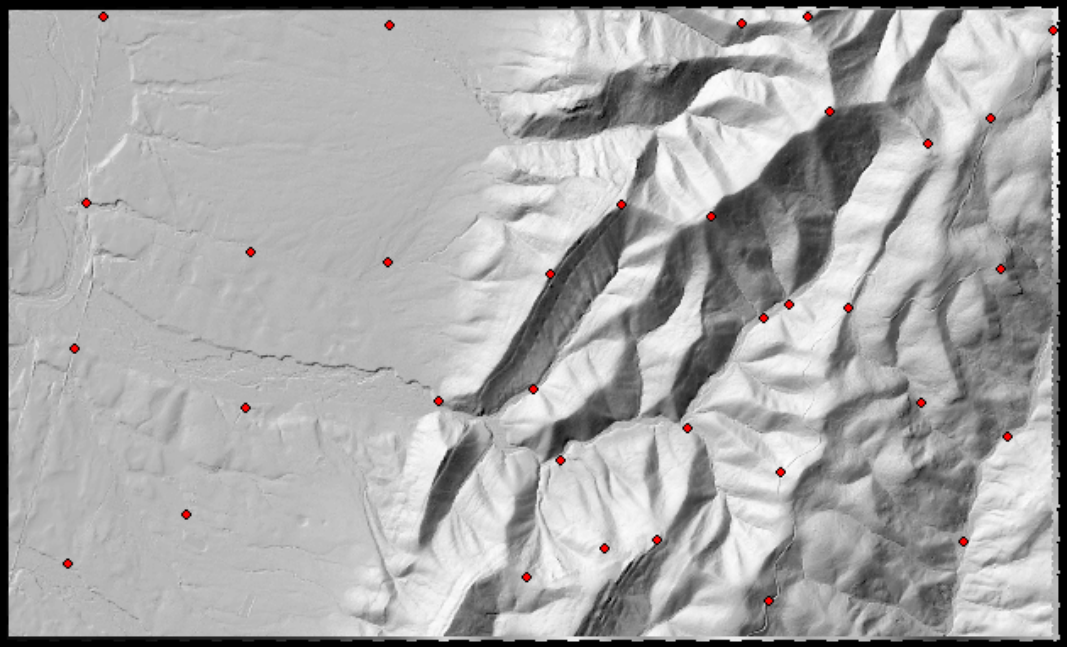
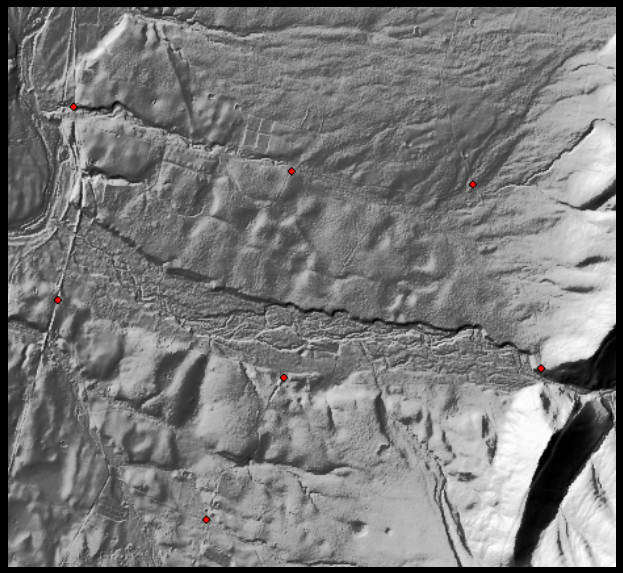
Geologic Mapping Interest in LIDAR

One benefit to using LIDAR is in mapping dikes and fault traces in low relief areas.







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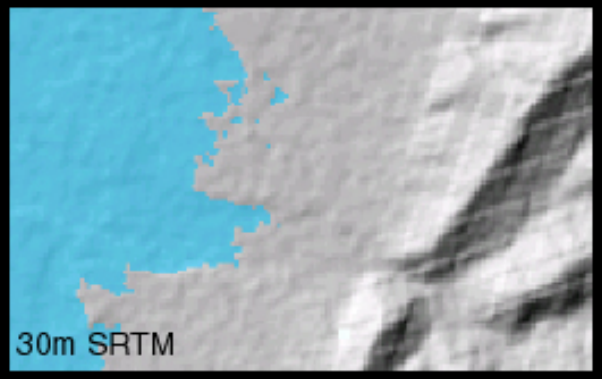
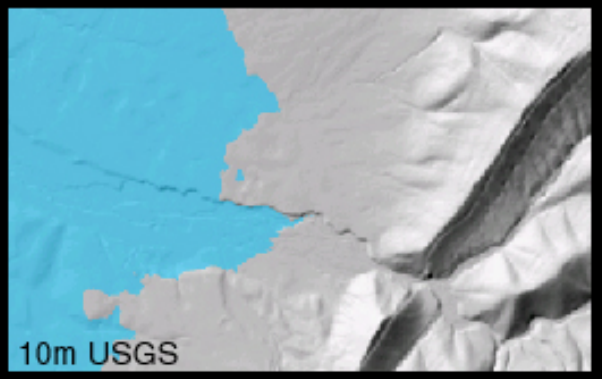
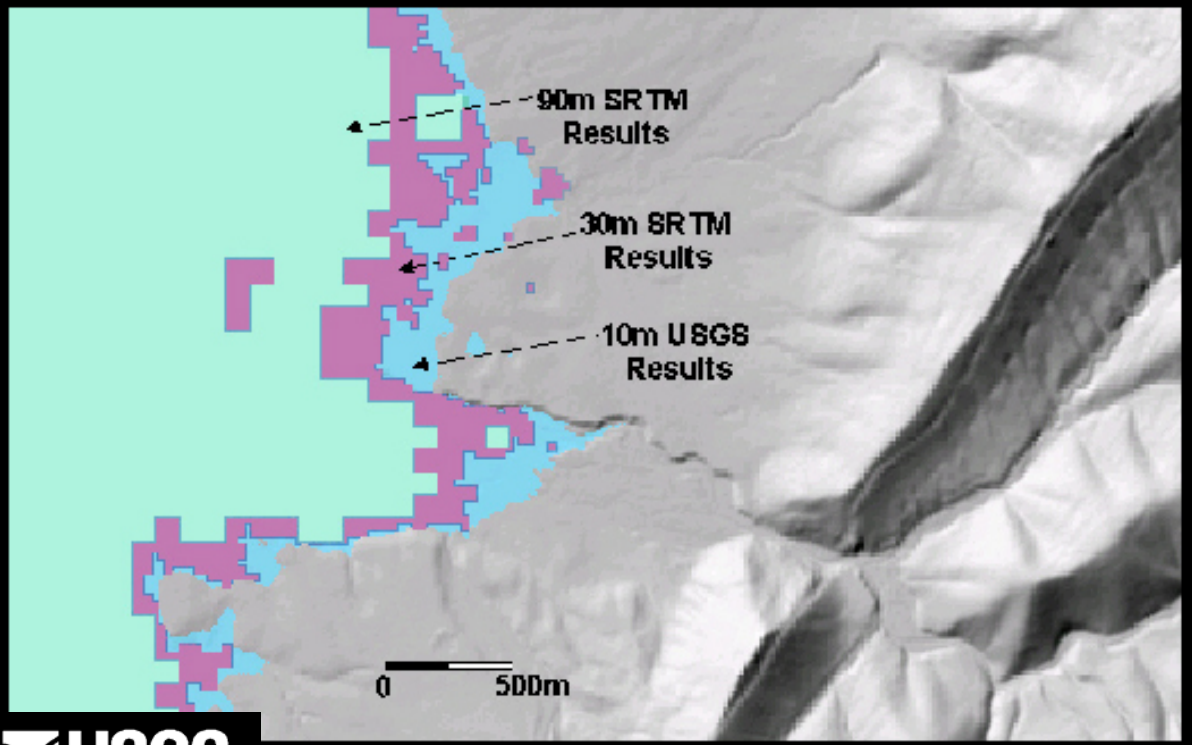
Evaluation of DEM Methodologies on Natural Hazard and Environmental Models







Comparison of model results using 90m and 30m SRTM data and USGS high resolution 10m DEM data.

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Conclusion

- There is a need to continue research into spatial variability of error in the SRTM data. Is LIDAR available for other study areas for future comparison studies?
- Are there less expensive ways of creating high-resolution DEM data (desktop photogrammetry?)
- Serious concern is the age of the NED data (contours older than revision dates)
- How significant are differences in models using different DEM data
    - Do the costs justify using one DEM source over another?
- Alternatives for international study areas where hazards and geologic mapping projects are underway:
    - ASTER vs. SRTM vs. 1:50,000 contours for international areas