A Detailed Examination of DTM Creation Methods and Sources

Study Area Overview

Mt. St. Helens - active volcano
- many eruptions in the past 30
- Major eruption in May 1980

Major eruption released 3.8 billion yds of material in a landslide. Toutle River was washed out.

Toutle is a tributary to the Columbia River, a major shipping route for the PNW.
### Purpose / Application

Extensive of DTM/survey data surrounding Mt. St. Helens has been gathered.

DTMs used to derive:
- volume calculation
- channel slope
- channel geometry

Often input into hydrologic, hydraulic, and sediment erosion & transport models.

In order to predict long-term (100 yrs) sediment loading.

In order to make sediment decisions on the lower Cowlitz River.

### Datasets: DTM & GCPs

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<td>1' NED</td>
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<td>1/3' NED</td>
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<td>1/9' NED ('03 LiDAR-based)</td>
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</tbody>
</table>

[| COMPLETED | NOT YET COMPLETED |]
Ground Control Points (GCPs)
GCP Dataset: DGPS survey

Date:  8-3-2010

Stated accuracy:  10-15 cm

Spatial reference:

- WGS 1984 geographic
- WGS 1984 height above ellipsoid

Processing methods:

- Differentially corrected and exported in needed coordinate systems using Trimble Pathfinder Office software.

Ground Control Points (GCPs)
**GCP Dataset: RTK DGPS survey**

Date: 10-20-2009  
Stated accuracy: 1-5 cm  
Spatial reference:  
NAD 1983 UTM Zone 10 North  
NAVD 1988 Geoid 2009  
Processing methods:  
Created feature class from delivered Excel file and reprojected as needed. Converted Geoid09 to Geoid03 vertical datum as needed.

**DTM Dataset: 1987 Photogrammetry**

Date: 1987  
Stated accuracy: N/A  
Resolution: 3 meter  
Spatial reference:  
NAD 1983 WA State Plane South  
Vertical N/A  
Processing methods:  
As delivered GRID. Creation methods were vertical aerial photogrammetry to contour to DEM.
**DTM Dataset: 1999 Photogrammetry**

Date: 9-3-1999

Stated accuracy: 1:14,000 (12 m)

Resolution: 3 meter

Spatial reference:

NAD 1983 WA State Plane South
NAVD 1988

Processing methods:

*As delivered GRID.* Created using photogrammetric methods from vertical air photos, then to contour, then to DEM.

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**DTM Dataset: 1999 Photogrammetry**

Date: 9-3-1999

Stated accuracy: 1:14,000 (12 m)

Resolution: (3 meter)

Spatial reference:

NAD 1983 WA State Plane South
NAVD 1988

Processing methods:

*XYZ ASCII to multipoint, then created terrain dataset.*
**DTM Dataset: 2003 LiDAR (ALS)**

Date: 9-19 to 10-2

Stated accuracy: 30 cm XY
15-30 cm Z

Resolution: 5 meter

Spatial reference:

NAD 1983 UTM Zone 10 North
NAVD 1988

Processing methods:

As delivered GRID.

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**DTM Dataset: 2003 LiDAR (ALS)**

Date: 9-19 to 10-2

Stated accuracy: 30 cm XY
15-30 cm Z

Resolution: (1.6 meter)

Spatial reference:

NAD 1983 UTM Zone 10 North
NAVD 1988

Processing methods:

Edited XYZ ASCII (last return) to multipoint, then created terrain dataset.
DTM Dataset: 2003 LiDAR (ALS)

Date: 9-19 to 10-2

Stated accuracy: 30 cm XY
15-30 cm Z

Point density: 0.15 pts m²
Point spacing: 2.6 m (last)
Resolution: 2 meter

Spatial reference:
NAD 1983 UTM Zone 10 North
NAVD 1988

Processing methods:
Terrain to raster using natural neighbor.

DTM Dataset: 2007 LiDAR (ALS)

Date: 10-22 to 10-27

Stated accuracy: 4.6-7.6 cm XY
0.6-13 cm Z

Point density: 5.89 pts m²
Point spacing: 41.2 cm
Raster resolution: 1 m

Spatial reference:
NAD 1983 WA State Plane South
NAVD 1988 Geoid 2003

Processing methods:
As delivered GRID.
DTM Dataset: 2009 LiDAR (ALS)

Date: 10-22 to 10-27
Stated accuracy: 3.2-7.1 cm XY
0.4-15 cm Z
Point density: 9.45 pts m$^2$
Point spacing: 1.1 cm
Raster resolution: 1 m

Spatial reference:
NAD 1983 WA State Plane South
NAVD 1988 Geoid 2003

Processing methods:
As delivered bare earth.

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DTM Dataset: 2009 LiDAR (ALS)

Date: 10-22 to 10-27
Stated accuracy: 3.2-7.1 cm XY
0.4-15 cm Z
Point density: 9.45 pts m$^2$
Point spacing: 1.1 cm
Raster resolution: 15 cm

Spatial reference:
NAD 1983 WA State Plane South
NAVD 1988 Geoid 2003

Processing methods:
LAS (last return) to multipoint, to terrain dataset, to terrain to raster.
DTM Dataset: 2009 LiDAR (ALS)

Date: 10-22 to 10-27
Stated accuracy: 3.2-7.1 cm XY 0.4-15 cm Z
Point density: 9.45 pts m^2
Point spacing: 1.1 cm
Raster resolution: 30 cm
Spatial reference:
NAD 1983 WA State Plane South
NAVD 1988 Geoid 2003
Processing methods:
LAS (last return) to multipoint, to TIN, to create raster.

Processing methods:
LAS (last return) to multipoint, direct to point to raster
DTM Dataset: 2009 LiDAR (ALS)

Date: 10-22 to 10-27
Stated accuracy: 3.2-7.1 cm XY
0.4-15 cm Z
Point density: 9.45 pts m$^2$
Point spacing: 1.1 cm
Raster resolution: 30 cm
Spatial reference:
NAD 1983 WA State Plane South
NAVD 1988 Geoid 2003
Processing methods:
LAS (last return) to
multipoint, interpolation (spline,
IDW) to raster creation
# DTM Dataset: 2010 LiDAR (TLS)

## Datasets: DTM & GCPs

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<td>1/7 NED</td>
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<tr>
<td>1/7 NED (‘03 LiDAR-based)</td>
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**Legend:**
- **COMPLETED**
- **NOT YET COMPLETED**
DTM Dataset: NED

Date: Compilation

Stated accuracy: 2.44 m RMSE Z

Raster resolution: 3, 10, 30 meter

Spatial reference: NAD 1983 GCS

Methods: Statistical Analysis

Tests Used: ANOVA
Tukey HSB- post hoc

Assumptions: Equal sample sizes
Normal Distributions
Equal Variance

2009 Subsamples: n=25
12 Categories

Subsample randomly generated from points with values for all 12 DTM's
Results: 2009 LiDAR Derivatives

ANOVA:

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F value</th>
<th>Pr(&gt;F)</th>
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<tr>
<td>Treatment</td>
<td>11</td>
<td>872.57</td>
<td>79.325</td>
<td>7.4408</td>
<td>&lt;0.001</td>
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<td>Residuals</td>
<td>276</td>
<td>2942.36</td>
<td>10.661</td>
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Tukey HSB:

Found Last Raster to be significantly different from all the other rasters.

<table>
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<tr>
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<td>Terrain-Linear.5-LAST</td>
<td>&lt;0.001</td>
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<tr>
<td>Terrain-Linear1-LAST</td>
<td>&lt;0.001</td>
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<tr>
<td>Terrain-Nearest.5-LAST</td>
<td>&lt;0.001</td>
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<td>Terrain-Nearest-LAST</td>
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<td>LAST-BareEarth</td>
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Results: 2009 LiDAR Derivatives

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<th>Mean</th>
<th>Max</th>
<th>Min</th>
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<td>TIN to Raster</td>
<td>5.16</td>
<td>3.83</td>
<td>9.64</td>
<td>-4.38</td>
</tr>
<tr>
<td>Pt. to Raster-IDW</td>
<td>5.43</td>
<td>3.98</td>
<td>10.24</td>
<td>-4.73</td>
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<tr>
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<td>10.32</td>
<td>-4.46</td>
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<td>5.10</td>
<td>3.83</td>
<td>10.28</td>
<td>-4.21</td>
</tr>
<tr>
<td>Pt. to Rst – 1ft resample to 2ft</td>
<td>5.43</td>
<td>4.25</td>
<td>9.71</td>
<td>-3.97</td>
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<td>Pt. to Raster - Spline</td>
<td>5.46</td>
<td>4.00</td>
<td>10.32</td>
<td>-4.61</td>
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<td>Terrain Dataset</td>
<td>3.71</td>
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<td>1.37</td>
<td>-9.95</td>
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<td>2.49</td>
<td>10.18</td>
<td>-2.58</td>
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<td>3.71</td>
<td>2.44</td>
<td>9.95</td>
<td>-1.09</td>
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Results: RTK Points, 2009 Terrain Models

ANOVA:

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<tr>
<th>Treatment</th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
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<th>Pr(&gt;F)</th>
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<td>2.79</td>
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<td>Residuals</td>
<td>560</td>
<td>1914.13</td>
<td>3.41</td>
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RMSE, Mean:
- Terrain-linear, 0.5  : 1.75, -0.26
- Terrain-linear, 1ft : 1.72, 0.27
- Terrain-nearest, 0.5 : 1.75, 0.27
- Terrain-nearest, 1ft : 1.72, 0.28
- Bare Earth         : 2.33, 0.54

Tukey HSB:
Significant difference between Terrain-linear0.5 and Bare Earth models.

Digital Terrain Models (DTMs)
Digital Terrain Models (DTMs)
Results: 2003 Lidar Derivatives

ANOVA:

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<th>F value</th>
<th>Pr(&gt;F)</th>
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<td>131.26</td>
<td>1.0483</td>
<td>0.3514</td>
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<td>Residuals</td>
<td>417</td>
<td>52212</td>
<td>125.21</td>
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</table>

RMSE:
- Terrain Nearest: 3.66
- Delivered 5m: 3.43
- Terrain Last: 3.62

Tukey HSB:
This test found no pair wise differences between the treatments as is expected from the ANOVA results.

The lack of significant differences here is likely due to the control points being generated in 2010 and at a date closer to 2003.

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Results: NED

ANOVA:

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<th>F value</th>
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<td>13383</td>
<td>6691.6</td>
<td>67.749</td>
<td>&lt;0.001</td>
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<td>216</td>
<td>21334</td>
<td>98.8</td>
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</table>

RMSE:
- NED 3: 1.55
- NED 10: 5.37
- NED 30: 6.09

Tukey HSB:

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>30 – 10</td>
<td>no difference</td>
<td>0.55</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>3-10</td>
<td>significant dif.</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>3-30</td>
<td>significant dif.</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
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</table>
Results: 1987 and 1999 Grids

Mean:
- 1987 Grid: 127 ft
- 1999 Grid: 155 ft

RMSE:
- 1987 Grid: 11.3 ft
- 1999 Grid: 12.5 ft

No Statistical Tests Run

Conclusion

• RMSE indicates terrain datasets are most accurate, however there is no statistical difference between most methods.

• RTK points and 2009 are most closely related temporally and statistically.

• RTK statistics support observations that the delivered bare earth raster has been subjected to further filtering of the last return LAS file.

• Creating maximum resolution rasters based on point spacing can cause numerous no data cells and does not improve accuracy.

• Stated RMSEs lower than project derived values due to limited ground truthing.

• Given a study area of 1 km², volume calculations can vary as much as 457,000 m³
Application: Surface Differencing

2009 vs. 1987

Application: Surface Differencing

2009 vs. 2003
Application: Surface Differencing

2009 vs. 2003

Data Sources

- USGS – Cascades Volcano Observatory
- USGS CLICK http://lidar.cr.usgs.gov/
- USDA / NRCS Geospatial Data Gateway http://datagateway.nrcs.usda.gov/
- UNAVCO Plate Boundary Observatory
- University of Colorado at Boulder
- USDA – Agricultural Research Service
- US Army Corps of Engineers