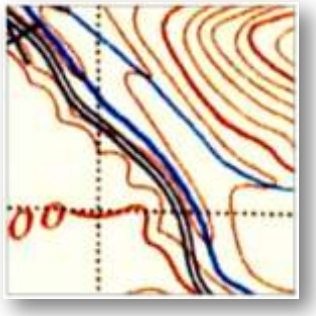
# A Detailed Examination of DTM Creation Methods and Sources



Adam Mosbrucker & Melinda Lamb
Geography 593: Dec. 2nd, 2010

# 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**

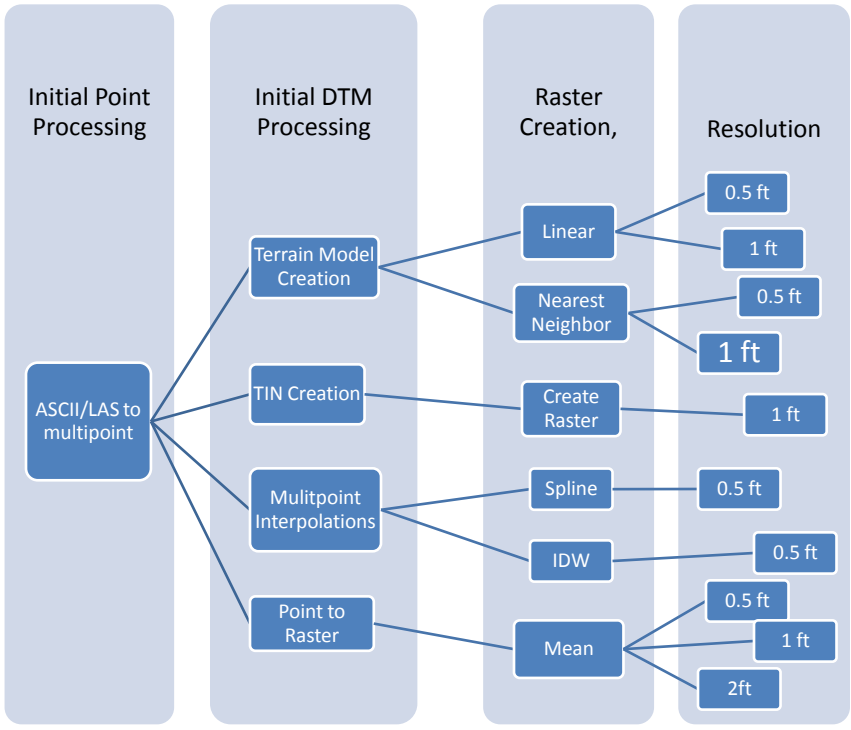
**In order to make sediment decisions on the lower Cowlitz River.**

# Datasets: DTM & GCPs

| | 2010 GCP | 2009 GCP | 2007 GCP | 1997 GCP | 1987 GCP | 1983 GCP |
|---|---|---|---|---|---|---|
| 1983 topo map | | | | | | |
| 1987 Vert. Aerial Photogrammetry | | | | | | |
| 1999 Vert. Aerial Photogrammetry | | | | | | |
| 2003 ALS 2003 (delivered) | | | | | | |
| 2003 ALS 2003 (reprocessed) | | | | | | |
| 2007 ALS (delivered) | | | | | | |
| 2009 ALS (delivered) | | | | | | |
| 2009 ALS (reprocessed) | | | | | | |
| 2010 TLS (processed) | | | | | | |
| 2010 Oblq. Aerial Photogrammetry | | | | | | |
| 2010 Oblq. Ground Photogrammetry | | | | | | |
| 1' NED | | | | | | |
| 1/3' NED | | | | | | |
| 1/9' NED ('03 LiDAR-based) | | | | | | |

COMPLETED

NOT YET COMPLETED




# Ground Control Points (GCPs)

# GCP Dataset: DGPS survey

*Date:* **8-3-2010**

*Stated accuracy:* **10-15 cm**

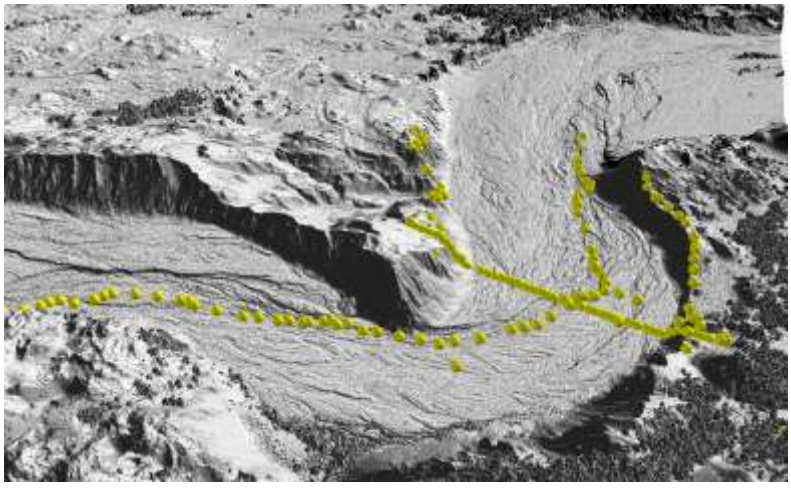
*Spatial reference:*

**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**

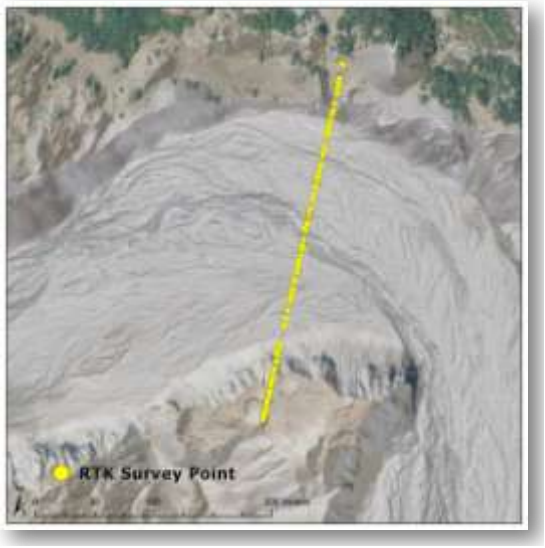
*Stated accuracy:* **1-5 cm**

*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**

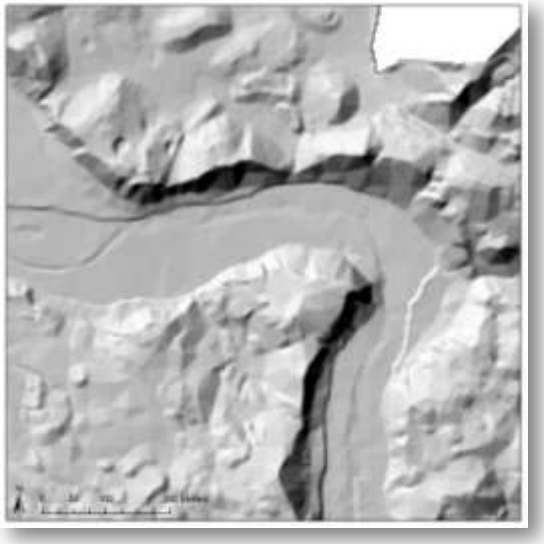
*Resolution:* **3 meter**

*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)**

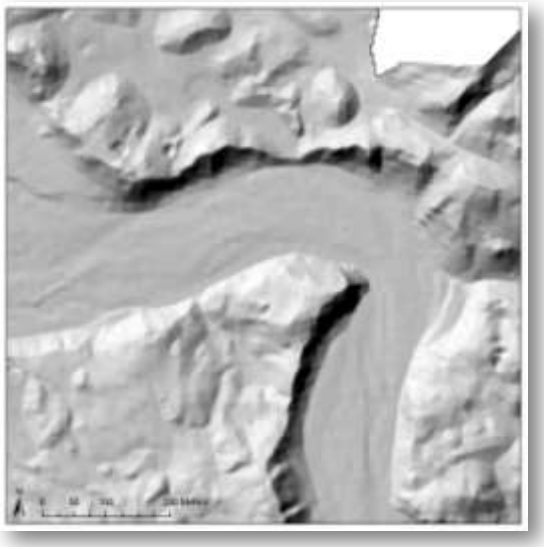
*Resolution:* **3 meter**

*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.**



# DTM Dataset: 1999 Photogrammetry

*Date:* **9-3-1999**

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

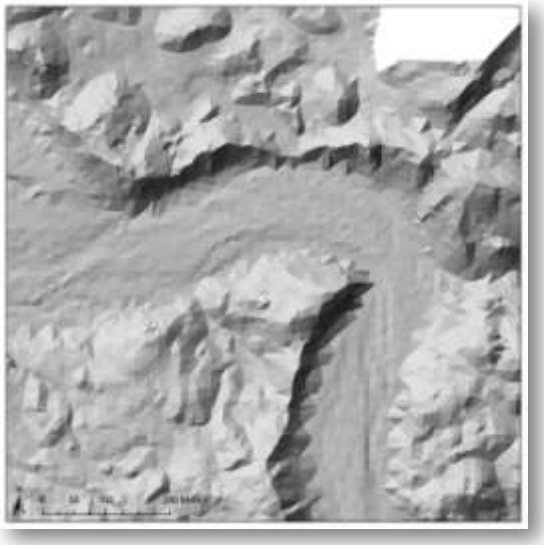
*Resolution:* **(3 meter)**

*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**

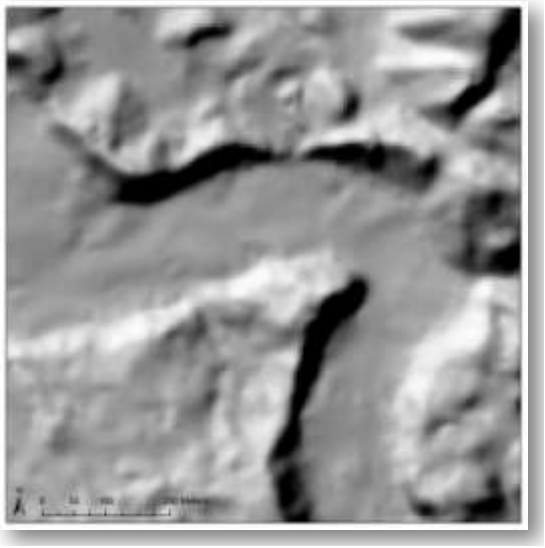
*Resolution:* **5 meter**

*Spatial reference:*

**NAD 1983 UTM Zone 10 North**
**NAVD 1988**

*Processing methods:*

**As delivered GRID.**



# DTM Dataset: 2003 LiDAR (ALS)

*Date:* **9-19 to 10-2**

*Stated accuracy:* **30 cm XY**
**15-30 cm Z**

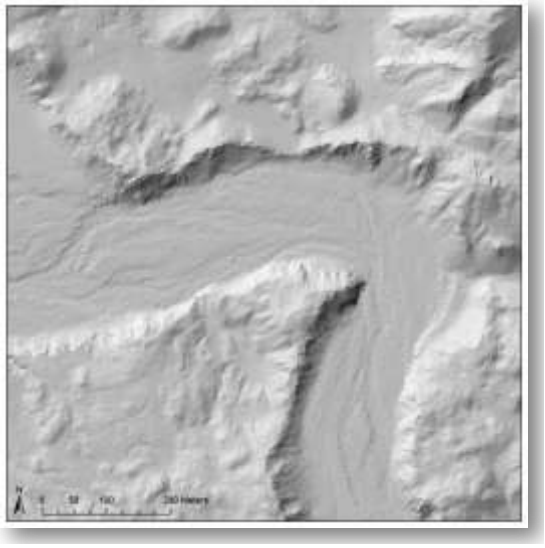
*Resolution:* **(1.6 meter)**

*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**

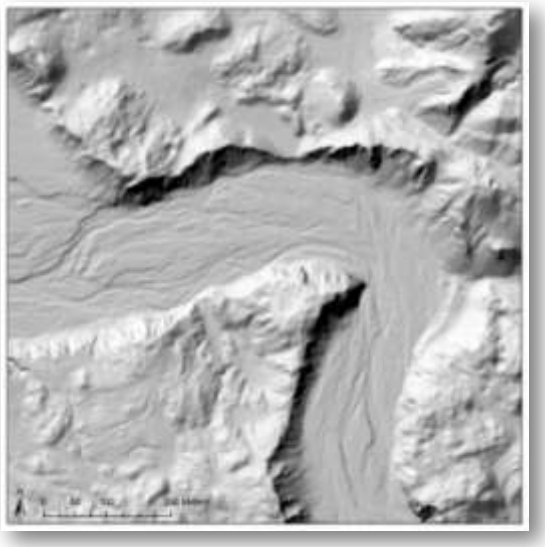
*Point density:* **0.15 pts $m^{-2}$**
*Point spacing:* ***2.6 m (last)***
*Resolution:* **2 meter**

*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**

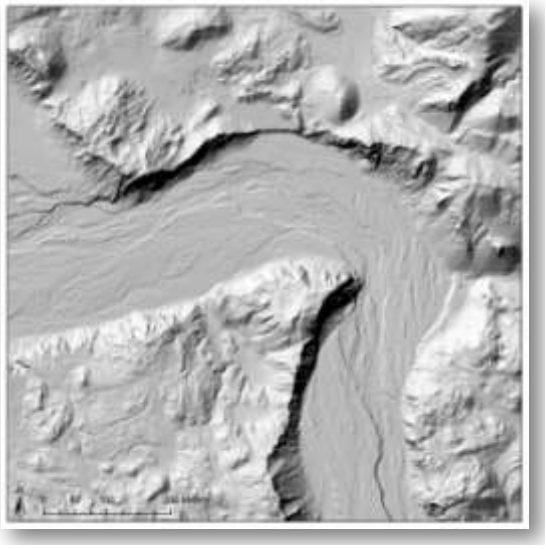
*Point density:* **5.89 pts $m^{-2}$**
*Point spacing:* ***41.2 cm***
*Raster resolution:* **1 m**

*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**

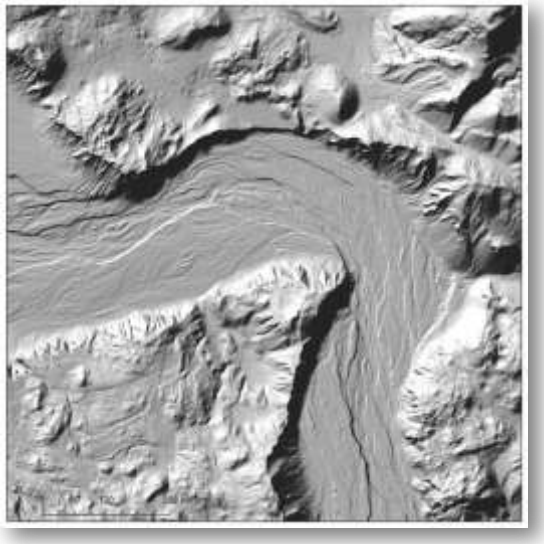
*Point density:* **9.45 pts $m^{-2}$**
*Point spacing:* ***1.1 cm***
*Raster resolution:* **1 m**

*Spatial reference:*

**NAD 1983 WA State Plane South**
**NAVD 1988 Geoid 2003**

*Processing methods:*

**As delivered bare earth.**



# DTM Dataset: 2009 LiDAR (ALS)

*Date:* **10-22 to 10-27**

*Stated accuracy:* **3.2-7.1 cm XY**
**0.4-15 cm Z**

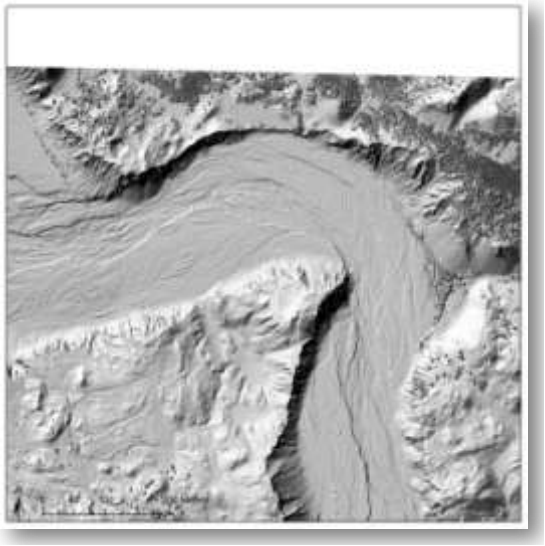
*Point density:* **9.45 pts $m^{-2}$**
*Point spacing:* ***1.1 cm***
*Raster resolution:* **15 cm**

*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**

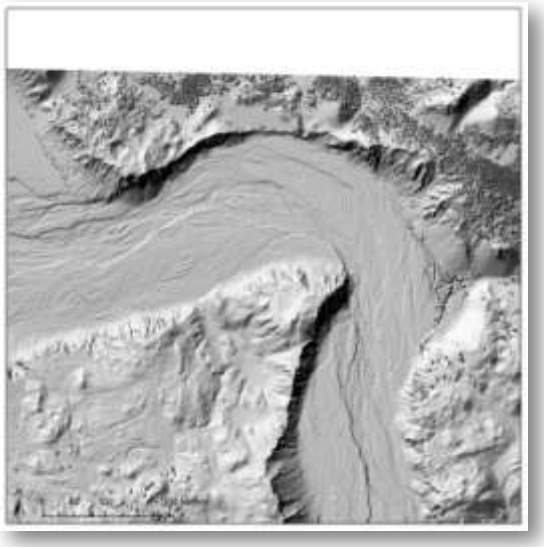
*Stated accuracy:* **3.2-7.1 cm XY**
**0.4-15 cm Z**

*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.**



# DTM Dataset: 2009 LiDAR (ALS)

*Date:* **10-22 to 10-27**

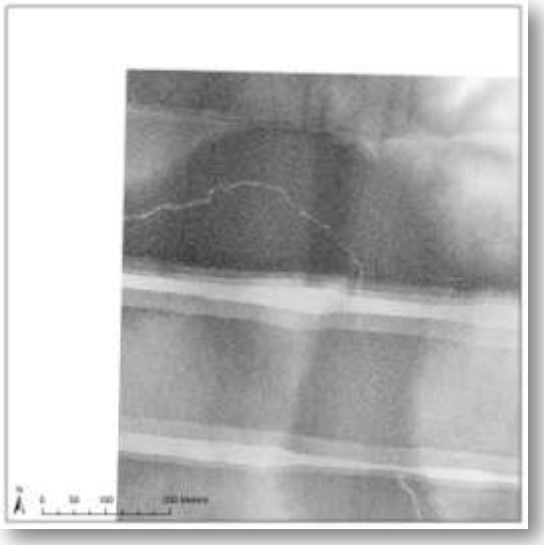
*Stated accuracy:* **3.2-7.1 cm XY**
**0.4-15 cm Z**

*Point density:* **9.45 pts $m^{-2}$**
*Point spacing:* ***1.1 cm***
*Raster resolution:* **30 cm**

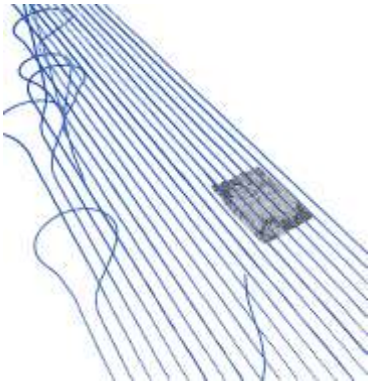
*Spatial reference:*

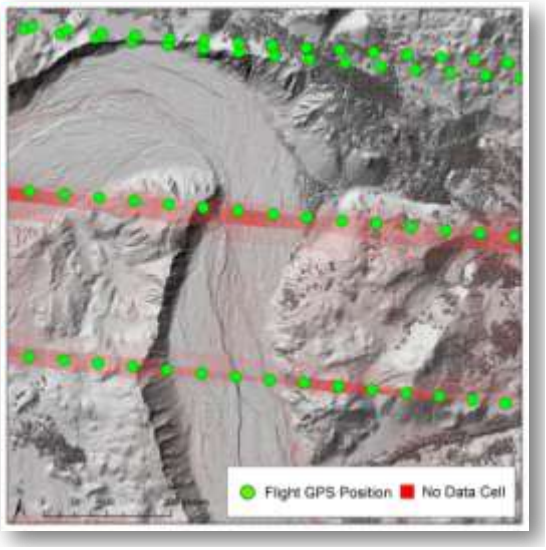
**NAD 1983 WA State Plane South**
**NAVD 1988 Geoid 2003**

*Processing methods:*
**LAS (last return) to multipoint, direct to point to raster**



# DTM Dataset: 2009 LiDAR (ALS)






# DTM Dataset: 2009 LiDAR (ALS)

*Date:* **10-22 to 10-27**

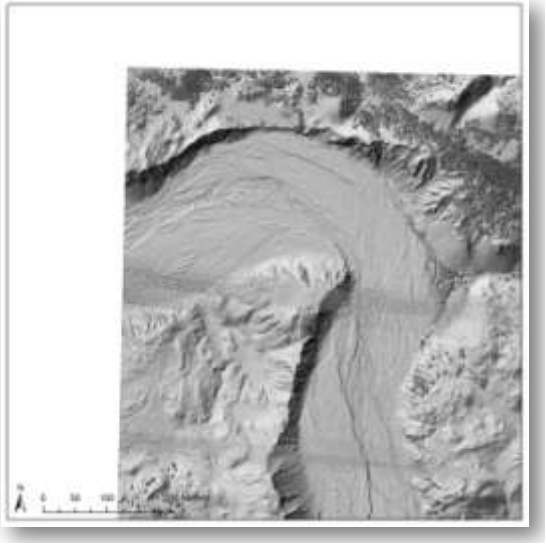
*Stated accuracy:* **3.2-7.1 cm XY**
**0.4-15 cm Z**

*Point density:* **9.45 pts $m^{-2}$**
*Point spacing:* ***1.1 cm***
*Raster resolution:* **30 cm**

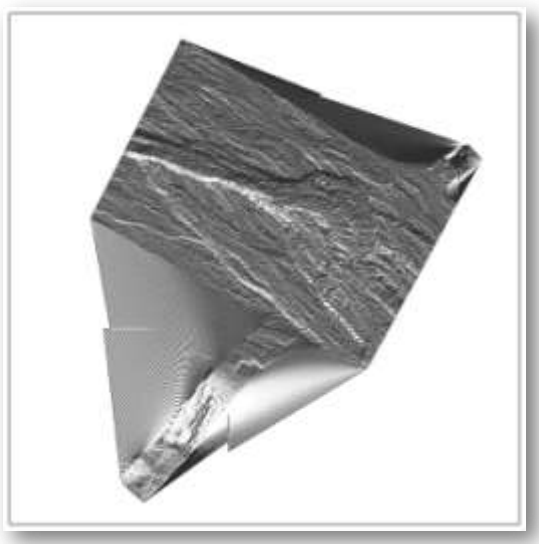
*Spatial reference:*

**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

| | 2010 GCP | 2009 GCP | 2007 GCP | 1997 GCP | 1987 GCP | 1983 GCP |
|---|---|---|---|---|---|---|
| 1983 topo map | | | | | | |
| 1987 Vert. Aerial Photogrammetry | | | | | | |
| 1999 Vert. Aerial Photogrammetry | | | | | | |
| 2003 ALS 2003 (delivered) | | | | | | |
| 2003 ALS 2003 (reprocessed) | | | | | | |
| 2007 ALS (delivered) | | | | | | |
| 2009 ALS (delivered) | | | | | | |
| 2009 ALS (reprocessed) | | | | | | |
| 2010 TLS (processed) | | | | | | |
| 2010 Oblq. Aerial Photogrammetry | | | | | | |
| 2010 Oblq. Ground Photogrammetry | | | | | | |
| 1' NED | | | | | | |
| 1/3' NED | | | | | | |
| 1/9' NED ('03 LiDAR-based) | | | | | | |

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**

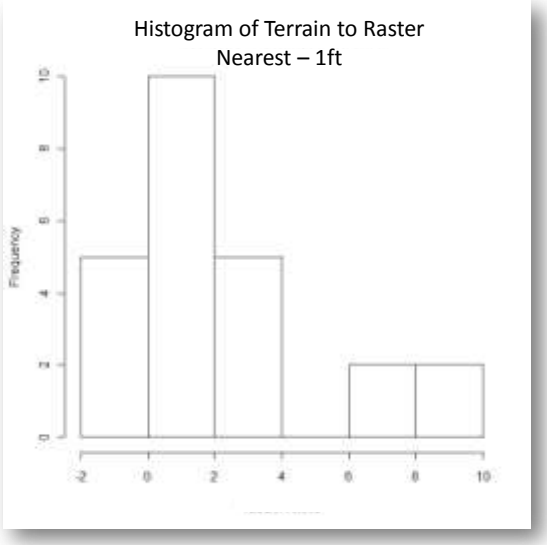
# Methods: Statistical Analysis

*Tests Used:* **ANOVA**
**TukeyHSB-**
**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 DTMs**



# Results: 2009 LiDAR Derivatives

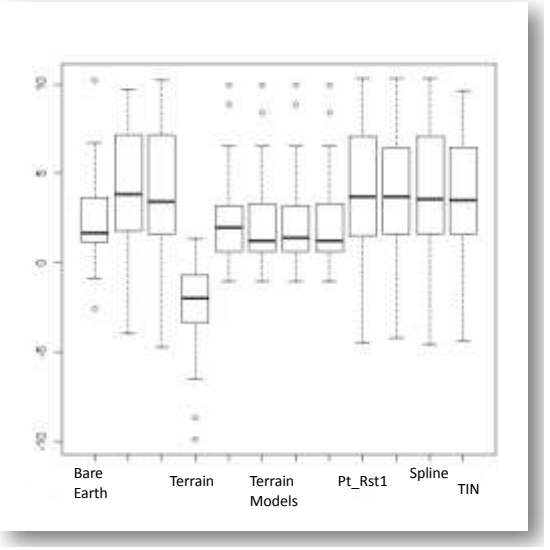
*ANOVA:*

| | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| Treatment | 11 | 872.57 | 79.325 | 7.4408 | >0.001 |
| Residuals | 276 | 2942.36 | 10.661 | | |

*TukeyHSB:*

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

| | *p adj* |
|---|---|
| ***Terrain-Linear.5-LAST*** | ***<0.001*** |
| ***Terrain-Linear1-LAST*** | ***<0.001*** |
| ***Terrain-Nearest.5-LAST*** | ***<0.001*** |
| ***Terrain-Nearest-LAST*** | ***<0.001*** |
| ***PT_R1-LASTTR09*** | ***<0.001*** |
| ***PT_R2-LASTTR09*** | ***<0.001*** |
| ***SPL-LASTTR09*** | ***<0.001*** |
| ***TIN-LASTTR09*** | ***<0.001*** |
| ***LAST-CUB2*** | ***<0.001*** |
| ***LAST-BareEarth*** | ***<0.001*** |




# Results: 2009 LiDAR Derivatives

| | RMSE | Mean | Max | Min |
|---|---|---|---|---|
| **TIN to Raster** | 5.16 | 3.83 | 9.64 | -4.38 |
| **Pt. to Raster-IDW** | 5.43 | 3.98 | 10.24 | -4.73 |
| **Pt. to Raster – 1 ft** | 5.36 | 3.93 | 10.32 | -4.46 |
| **Pt. to Raster – 2ft** | 5.10 | 3.83 | 10.28 | -4.21 |
| **Pt. to Rst – 1ft resample to 2ft** | 5.43 | 4.25 | 9.71 | -3.97 |
| **Pt. to Raster - Spline** | 5.46 | 4.00 | 10.32 | -4.61 |
| **Terrain Dataset** | 3.71 | -2.40 | 1.37 | -9.95 |
| **Delivered-Bare Earth** | 3.64 | 2.49 | 10.18 | -2.58 |
| **Terrain to Rst –Linear 0.5ft** | 3.71 | 2.44 | 9.95 | -1.09 |
| **Terrain to Rst –Linear 1ft** | 3.64 | 2.30 | 9.96 | -1.09 |
| **Terrain to Rst –Nearest 0.5ft** | 3.69 | 2.35 | 9.95 | -1.09 |
| **Terrain to Rst –Nearest 1ft** | 3.64 | 2.24 | 9.96 | -1.09 |

# Results: RTK Points, 2009 Terrain Models

*ANOVA:*

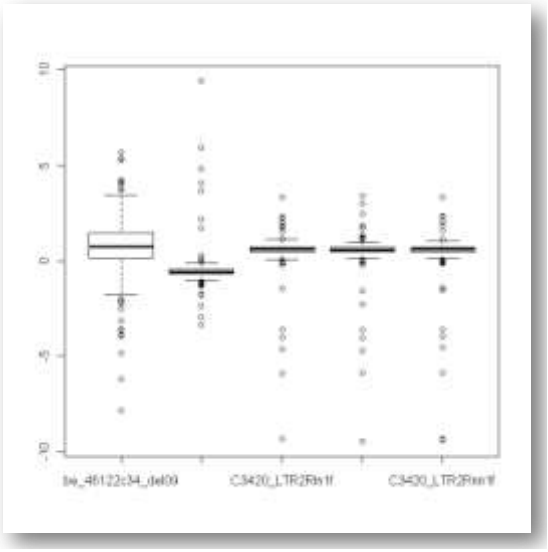
| | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| Treatment | 4 | 38.17 | 9.54 | 2.79 | 0.025 |
| Residuals | 560 | 1914.13 | 3.41 | | |

*RMSE, Mean:*

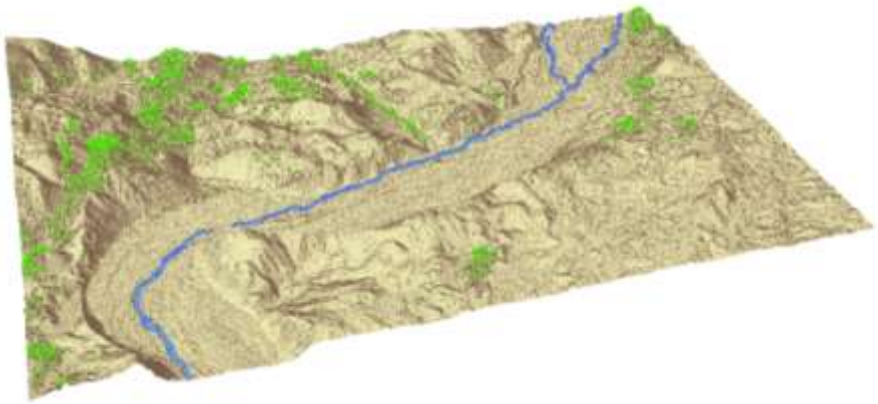
| | |
|---|---|
| Terrain-linear, 0.5 | 1.75, -0.26 |
| Terrain-linear, 1ft | 1.72, 0.27 |
| Terrain-nearest, 0.5 | 1.75, 0.27 |
| Terrain-nearest, 1ft | 1.72, 0.28 |
| Bare Earth | 2.33, 0.54 |

*TukeyHSB:*

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




# Digital Terrain Models (DTMs)



# Digital Terrain Models (DTMs)

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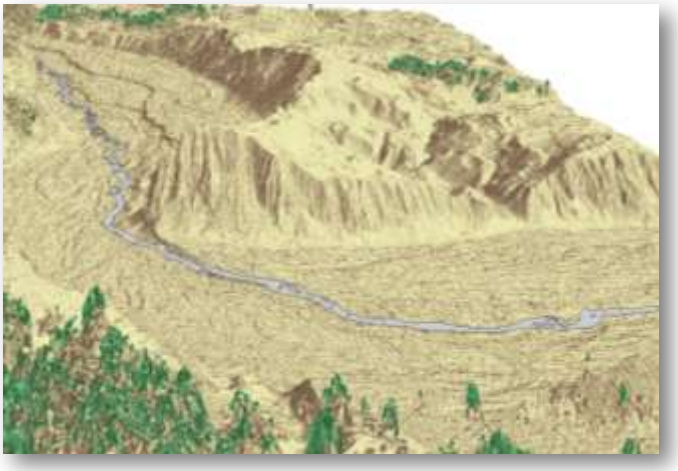


# Results: 2003 Lidar Derivatives

*ANOVA:*

| | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| Treatment | 2 | 263 | 131.26 | 1.0483 | 0.3514 |
| Residuals | 417 | 52212 | 125.21 | | |

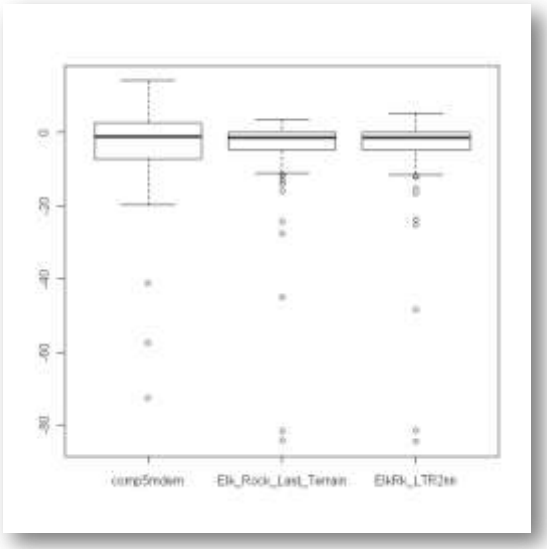
*RMSE:*

| | |
|---|---|
| Terrain Nearest | 3.66 |
| Delivered 5m | 3.43 |
| Terrain Last | 3.62 |

*TukeyHSB:*

**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.**




# Results: NED

*ANOVA:*

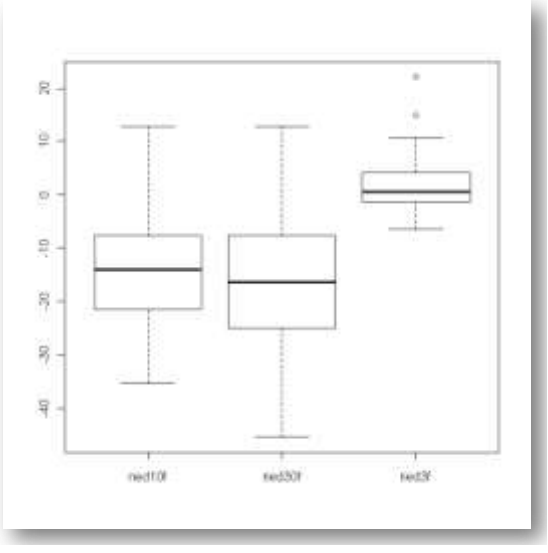
| | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| Treatment | 2 | 13383 | 6691.6 | 67.749 | <0.001 |
| Residuals | 216 | 21334 | 98.8 | | |

*RMSE:*

| | |
|---|---|
| NED 3 | 1.55 |
| NED 10 | 5.37 |
| NED 30 | 6.09 |

*TukeyHSB:*

| | | p adj |
|---|---|---|
| 30 – 10 | no difference | 0.55 |
| 3-10 | significant dif. | <0.001 |
| 3-30 | significant dif. | <0.001 |



# Results: 1987 and 1999 Grids

*Mean:*

**1987 Grid** **127 ft**

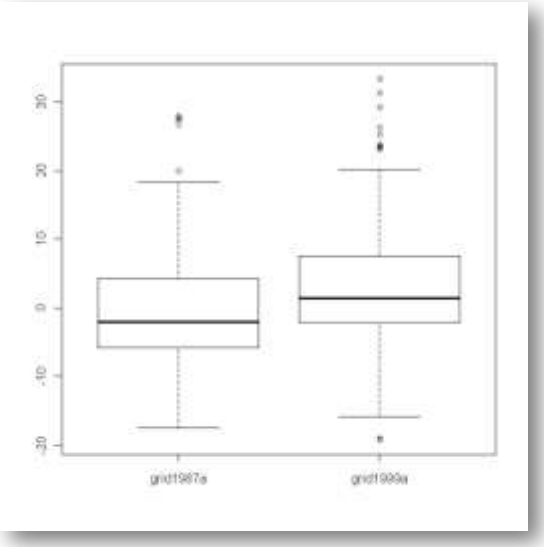
**1999 Grid** **155 ft**

*RMSE:*

**1987 Grid** **11.3 ft**

**1999 Grid** **12.5 ft**

**No Statistical Tests Run**




# Conclusion

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

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

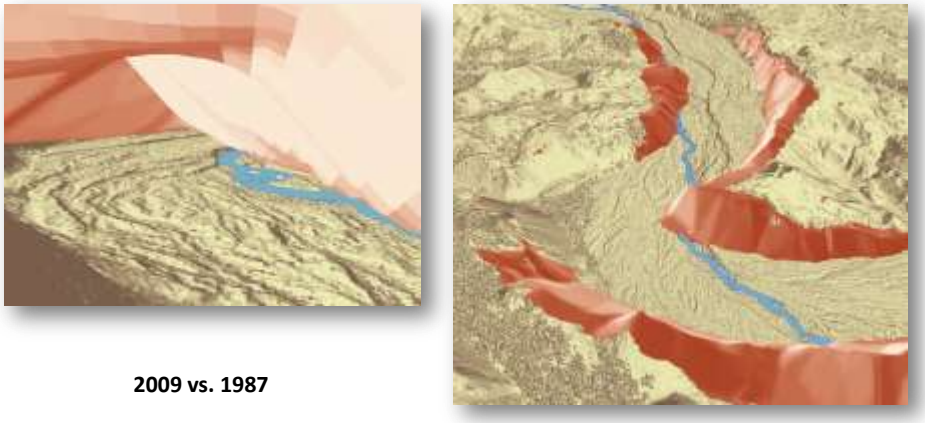
•*RTK statistics support observations that the delivered bare earth raster has been subjected to further filtering of the last return LAS file.*

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

• *Stated RMSE s lower than project derived values due to limited ground truthing.*

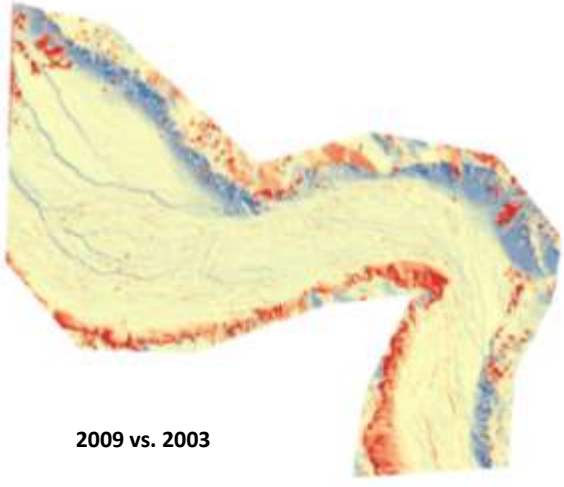
• *Given a study area of 1 km$^2$, volume calculations can vary as much as 457,000 m$^3$*

# Application: Surface Differencing



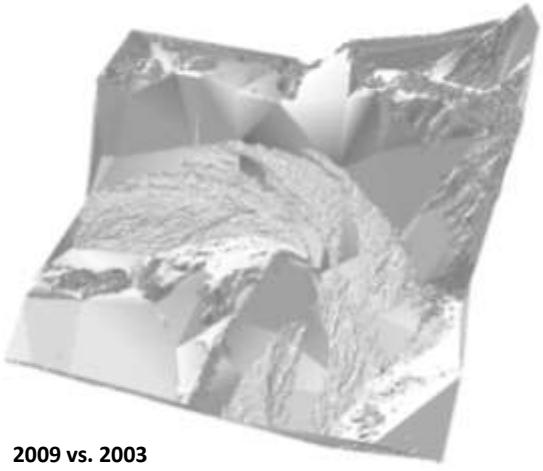
2009 vs. 1987

# Application: Surface Differencing



2009 vs. 2003

# Application: Surface Differencing



**2009 vs. 2003**

# Data Sources

- **USGS – Cascades Volcano Observatory**
- **USGS – Seamless Server** **http://seamless.usgs.gov/**
- **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**