

The Use of LiDAR Data to Analyze Snowpack with ArcGIS

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Table of Contents

Figures	2
Tables	2
Introduction	3
The Study Area	3
The Objective	4
Data Problems and Correction.....	4
Method Using ArcGIS.....	6
ASCII 3D to Feature Class	6
Create Tin.....	6
TIN to Raster	7
Minus Tool	8
Model Builder:	9
Analysis	10
Comparison to Field Observations.....	11
Comparison to SNOTEL Data.....	14
Discussion.....	14
2008 Data	14
Negative Raster Values	15
May 27 th 2009 Snow Differences	15
Bilinear Interpolation	15
Time differences	16
Conclusion.....	16
References	18

Figures

Figure 1: SNOTEL Site and Snow Survey Locations	3
Figure 2: Macro Created and Run to Classify the Raw LiDAR Data.....	5
Figure 3: Crop of LiDAR Data and Sectional View	5
Figure 4: Individual XYZ Data Points in ArcGIS.....	6
Figure 5: Tin of March 27 th LiDAR Data.....	7
Figure 6: Conversion of TIN to Raster	8
Figure 7: July 8 th 2009 Raster Subtracted from the March 27 th 2009 Raster.....	9
Figure 8: Model Builder to Automate the Process	9
Figure 9: March 18, 2009 Field, LiDAR BI, LiDAR No BI.....	12
Figure 10: March 27, 2009 Field, LiDAR BI, LiDAR No BI.....	12
Figure 11: May 27, 2009 Field, LiDAR BI, LiDAR No BI	13
Figure 12: March 27-March 18, 2009 Field, LiDAR BI, LiDAR No BI	13
Figure 13: 18 March Vegetation Observations Comparing Field, LiDAR BI and LiDAR no BI.....	16

Tables

Table 1: Output of Model Builder, Snow Survey Attribute Table	10
Table 2: Snow Survey Points with Raster Differences for Each Date Using Bilinear Interpolation	10
Table 3: Snow Survey Points with Raster Differences for Each Date Unconstrained.....	11
Table 4: Field and LiDAR Data Compiled.....	11
Table 5: SNOTEL Site LiDAR Values	14
Table 6: Compiled SNOTEL Analysis Values	14

Introduction

LiDAR data has many potential uses in water resources. Six LiDAR flights were flown over TW Daniels Experimental Forest. ArcGIS was used to analyze the data and calculate differences in snow depth. Results were compared to SNOTEL data and individual snow survey data. This project helps to solve the problem of using LiDAR to quantify the spatial distribution of snow over large areas that cannot be surveyed by hand. It has the possibility of providing pertinent information for water resources.

The Study Area

TW Daniels Experimental Forest is located 30 miles Northeast of Logan Utah. TWDEF elevation of approximately 2600 m. It lies at 41.86 degrees North and 111.50 degrees West. The TW Daniels Experimental Forest snow melt contributes to the Logan River and Bear Lake. Average annual precipitation is about 950 mm of which about 80% is snow (Mahat). Snow depths can reach 5 m in snow drifts. Vegetation is comprised of deciduous forest (aspen), coniferous forest (Engelmann spruce and subalpine fir), open meadows and shrub areas dominated by sagebrush (Mahat). **Figure 1** shows the location of the Snow Survey points along with the SNOTEL site location.

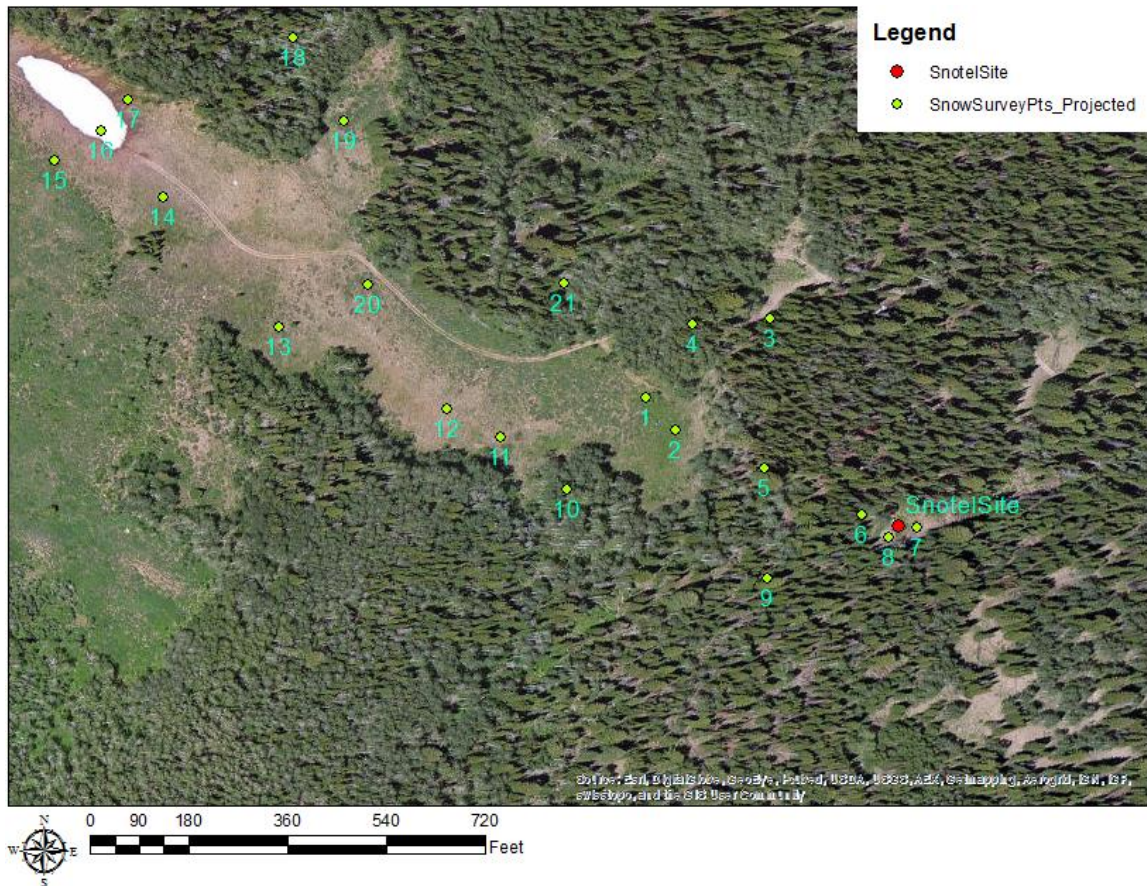


Figure 1: SNOTEL Site and Snow Survey Locations

The Objective

Vinod Mahat collected data to analyze the effect of vegetation on the accumulation and melting of snow at the TW Daniels Experimental Forest. This data that he collected was from the years 2007 to 2010.

LiDAR data was also collected for several dates that correlated with his ground measurements but was never processed or analyzed for accuracy or used in the UEB model.

The first objective of this project is to determine whether using ArcGIS the LiDAR data can be used to determine the snowpack. The accuracy of the LiDAR data will then be analyzed with the field snow depth measurements. The data will also be compared to SNOTEL data in respect to the station near the study area.

Data Problems and Correction

One of the key aspects to the results from LiDAR comes in the classification. The TWDEF data consisted of six flights. These flights were March 28th 2008, April 28th 2008, March 18th 2009, March 27th 2009, May 27th 2009, and July 8th 2009. Three of the flights had classifications done on the data. These were March 28, 2008, April 28, 2008 and July 8, 2009. The classification was not consistent through the three different data sets. It was discovered when comparing the different datasets to each other. Initially it appeared to be a datum issue. This was a viable explanation because of the lack of metadata included with the data. After projecting the data onto several different coordinate systems the results were inconclusive.

The resultant idea was to reprocess the dates that had been classified along with the other data. This resulted in several benefits to the project. The 2009 and 2008 data was now available for analysis. All of the lidar data was processed using the same Macro, ensuring a consistency between the different flights. Each of the data was cropped using a fence tool in Microstation, creating output dataframes to the same dimensions. This eased the analysis and processing time in Microstation and ArcGIS. The last benefit of reprocessing the data was the coordinate system was saved with the files, eliminating the doubt of the incorrect datum.

The macro that was set up can be seen in **Figure 2**. This Macro starts by assigning all of the individual points to a default class. Then it steps through the process of triangulating between the points to determine the ground elevation or, in this case, the snow elevation. It then removes the points that are outliers. These are points that refracted or reflected and brought back an unrealistic value. The purpose of the first macro process was to identify the digital elevation model (DEM) of ground only. After the first macro was completed it was adapted to classify the vegetation. For identifying the vegetation coverage everything that wasn't ground or a low or high point was pushed into the medium vegetation class. This identified the points that reflected off of the trees. It was then output as a vegetation only point cloud for each of the flights. This data is now available to be used for other studies.

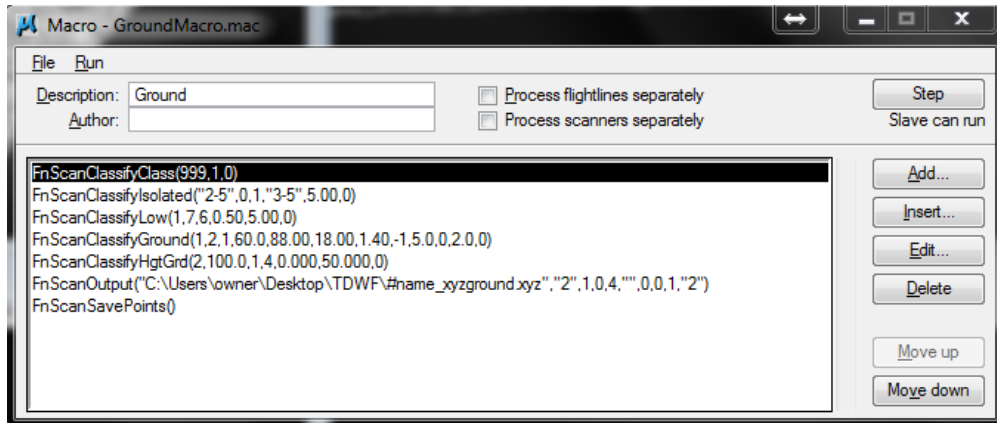


Figure 2: Macro Created and Run to Classify the Raw LiDAR Data

The key point to this process was outputting the new classification into a format that could be used in ArcGIS. The format that was used was an XYZ point file referencing the original coordinate system of WGS 84 Zone 12N. **Figure 3** is the Microstation output after running the Macro with a sectional view to visualize the classification details.

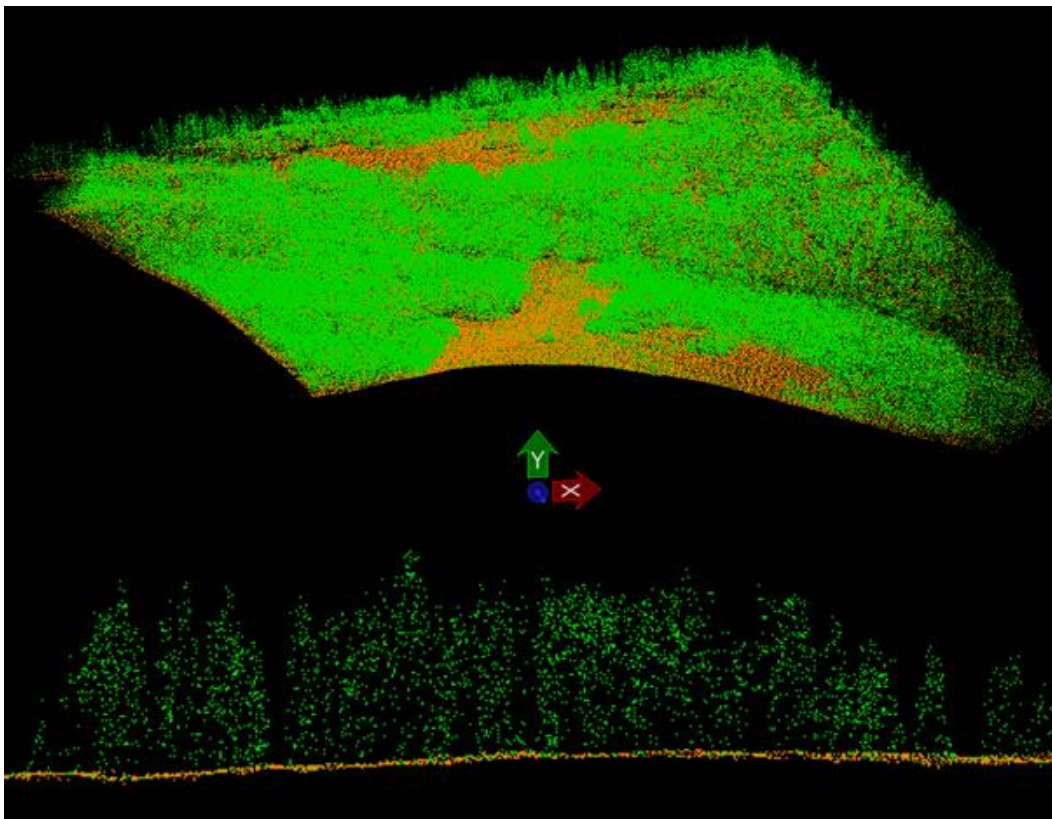


Figure 3: Crop of LiDAR Data and Sectional View

Method Using ArcGIS

For ease of explanation of methods used, the data will be presented with maps that were created using the March 27th 2009 data. This date was chosen and compared to the July 8th 2009 data, representing the dry ground DEM.

ASCII 3D to Feature Class

The data in XYZ format was imported into ArcGIS using the ASCII 3D to Feature Class tool. Using the LiDAR data output from MicroStation the XYZ file was imported to a feature class that could be analyzed. The following, **Figure 2**, shows the XYZ data that has been magnified to aid in the observation of the point cloud density. Comparing **Figure 4** to **Figure 1** the low point density can be identified in the areas covered by vegetation versus the open areas.

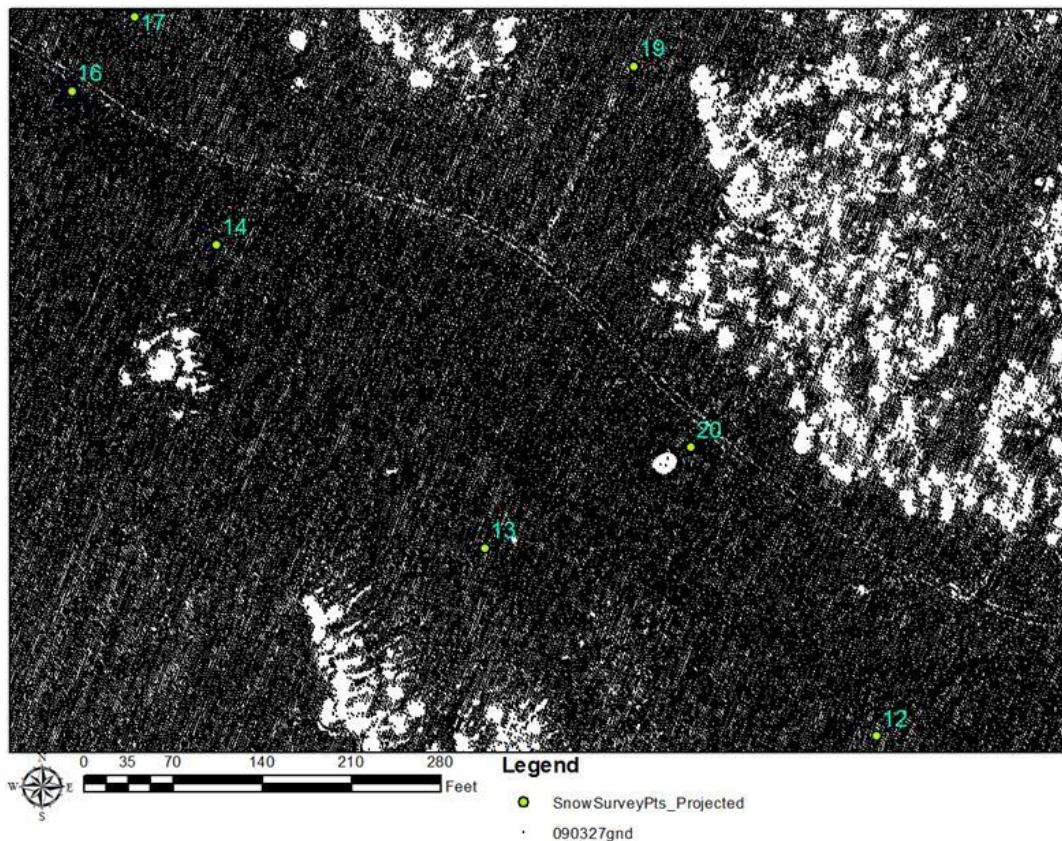


Figure 4: Individual XYZ Data Points in ArcGIS

Create Tin

The individual point LiDAR data was then triangulated to an irregular network using the Create Tin tool. The elevation is represented in meters in **Figure 5**. Several features show up in the snow TIN such as drifts and trails. Southwest of the snow survey point 13, drifts can be seen. Also the snowmobile trail to the study area can be seen weaving through the snow survey points. When comparing **Figure 5** to **Figure 1** and **Figure 4** the rough areas shown in the tin are covered by dense vegetation.

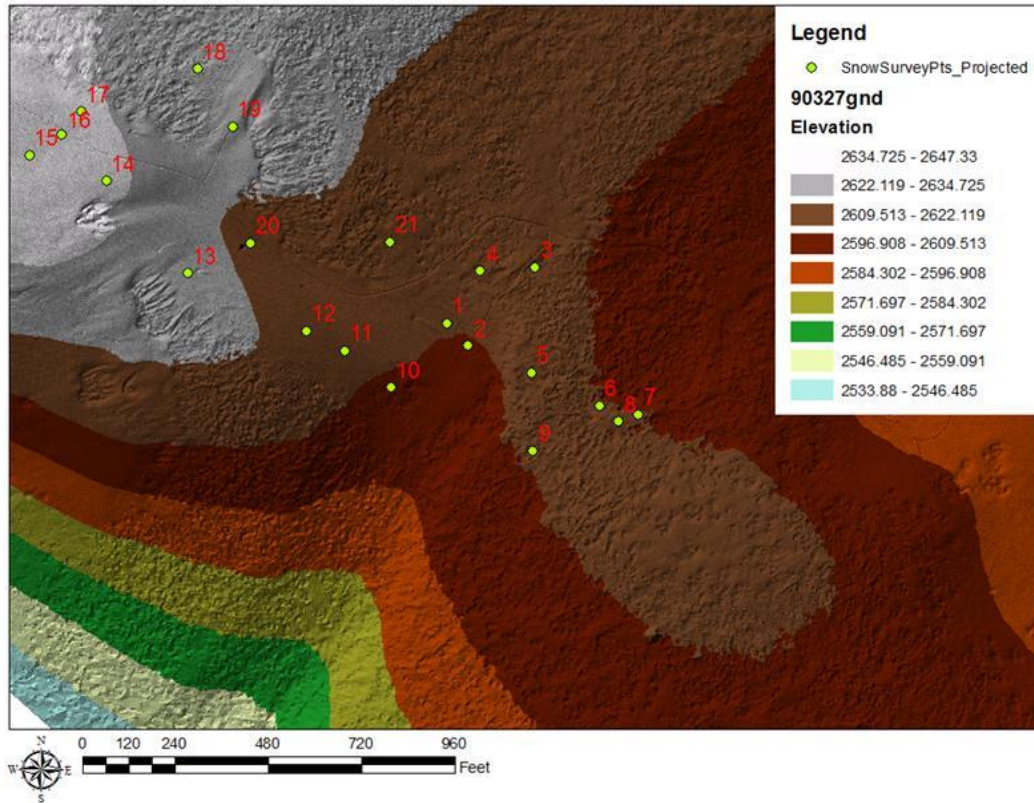


Figure 5: Tin of March 27th LiDAR Data

TIN to Raster

The Raster file was created by interpolating the cell values from the elevation TIN. Some inaccuracy was caused by this interpolation but eased the process of comparing it to the July 8th 2009 dry ground.

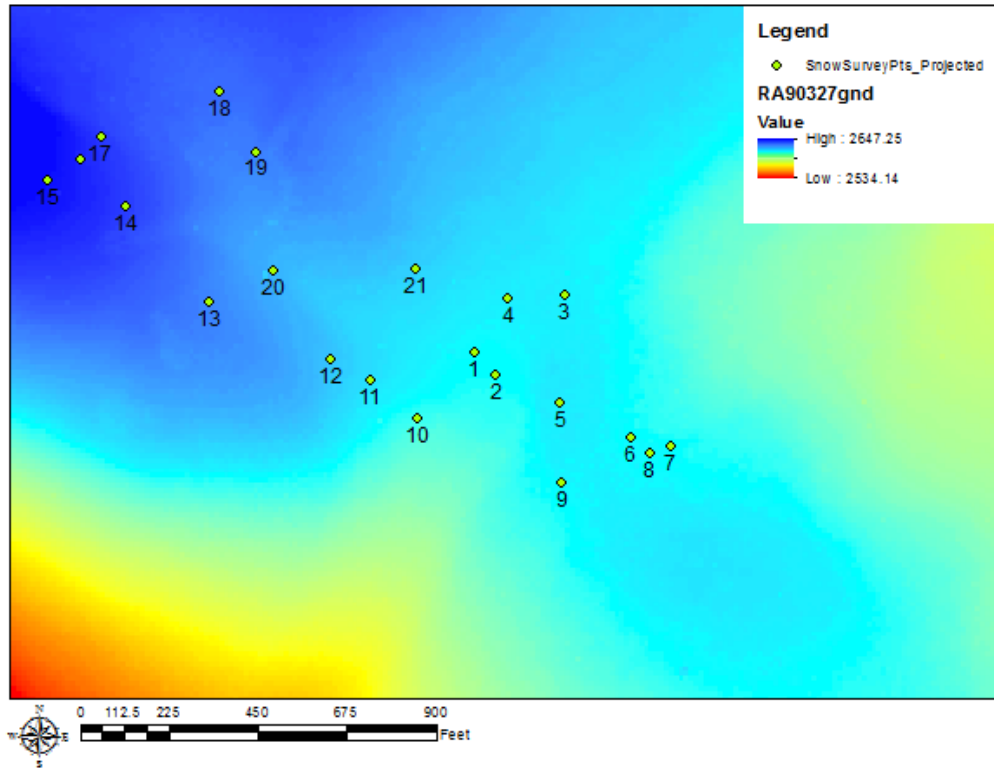


Figure 6: Conversion of TIN to Raster

Minus Tool

The same process was used for the July 8th 2009 data. With the LiDAR data in Raster format the minus tool could be used to find the height difference between the two flight dates. This produced a cell-by-cell value for comparison to the individual snow depth measurements and SNOTEL site. It was interesting, when looking at the drift southwest of snow survey point 13, that the windblown area was still visible.

Looking at the results there are some negative values present. These values could have easily come from several factors in the process. This will be addressed in the results section.

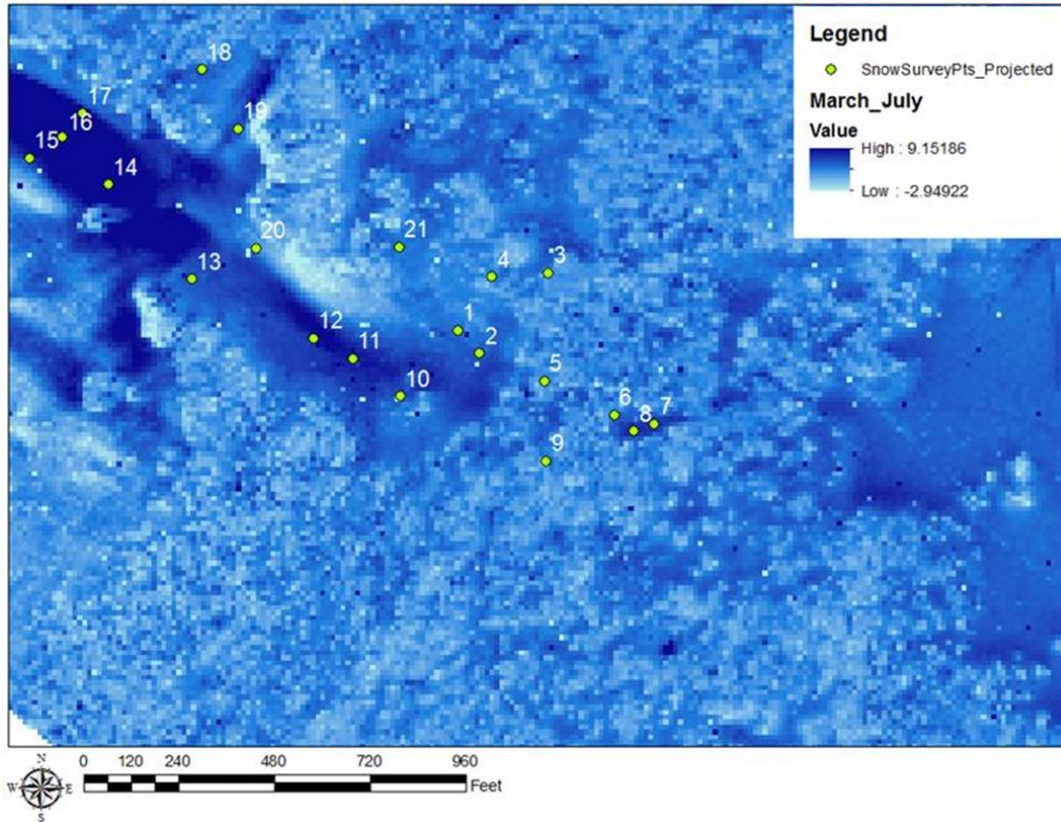


Figure 7: July 8th 2009 Raster Subtracted from the March 27th 2009 Raster

Model Builder:

To decrease the processing time, a model was built. The model automates the process that was performed above. The toolbox was created and named LiDAR. The process takes the same steps for the data then subtracts the July data. A final step was added onto the process using the Extract Multi Values to Points tool. This tool made the query between the snow survey points and the minus raster a simple task. The model building process is shown in **Figure 8**.

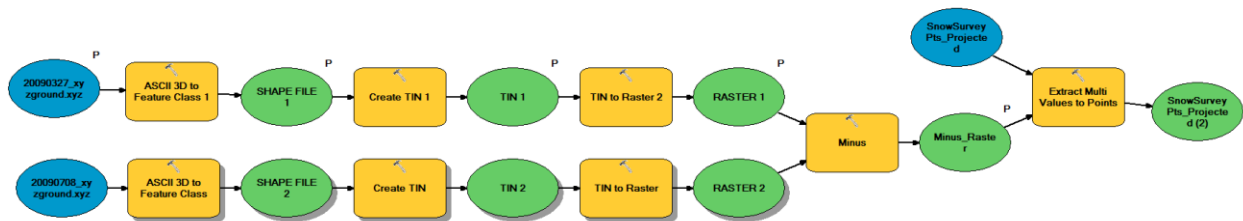


Figure 8: Model Builder to Automate the Process

The minus raster value at each snow survey point was then added to the snow survey point attribute table. The attribute table and calculated values were added to Excel by exporting the table. The values were output using meters, which compare with the individual survey points. **Table 1** shows a sample of the raster differences between March and July at each of the survey locations.

OBJECTID_1 *	Shape *	OBJECTID	Date_	Time_	lat	long_	Elevation	NoName	GPS_Number	Survey_Poi	March_July_1
1	Point	1	1/16/2007	12:33:21PM	41.86497	-111.50757	8602 ft		39	1	1.801924
2	Point	2	1/16/2007	12:37:05PM	41.86481	-111.50737	8596 ft		40	2	1.983611
3	Point	3	1/16/2007	12:46:45PM	41.86537	-111.50674	8640 ft		41	3	3.920555
4	Point	4	1/16/2007	12:56:47PM	41.86534	-111.50726	8641 ft		42	4	1.52767
5	Point	5	1/16/2007	01:05:22PM	41.86462	-111.50677	8649 ft		43	5	1.506128
6	Point	6	1/16/2007	01:09:53PM	41.86439	-111.50612	8611 ft		44	6	1.759909
7	Point	7	1/16/2007	01:17:58PM	41.86433	-111.50575	8646 ft		45	7	2.393839
8	Point	8	1/16/2007	01:24:02PM	41.86428	-111.50594	8630 ft		46	8	2.420125
9	Point	9	1/16/2007	01:40:05PM	41.86407	-111.50675	8648 ft		47	9	1.387941
10	Point	10	1/16/2007	01:48:01PM	41.86451	-111.5081	8625 ft		48	10	1.711797
11	Point	11	1/16/2007	01:56:21PM	41.86477	-111.50854	8641 ft		49	11	2.649606
12	Point	12	1/16/2007	02:04:33PM	41.86491	-111.5089	8645 ft		50	12	2.630949
13	Point	13	1/16/2007	02:14:46PM	41.86531	-111.51003	8675 ft		51	13	2.095318
14	Point	14	1/16/2007	02:20:41PM	41.86596	-111.51081	8702 ft		52	14	3.627128
15	Point	15	1/16/2007	02:36:11PM	41.86614	-111.51154	8733 ft		53	15	2.371722
16	Point	16	1/16/2007	02:43:44PM	41.86629	-111.51123	8729 ft		54	16	3.865442
17	Point	17	1/16/2007	02:47:37PM	41.86645	-111.51105	8726 ft		55	17	3.122143
18	Point	18	1/16/2007	02:53:02PM	41.86676	-111.50995	8690 ft		56	18	1.837564
19	Point	19	1/16/2007	02:56:52PM	41.86635	-111.50961	8686 ft		57	19	1.960797
20	Point	20	1/16/2007	03:00:45PM	41.86553	-111.50944	8655 ft		58	20	1.451882
21	Point	21	1/16/2007	03:05:51PM	41.86554	-111.50812	8652 ft		59	21	1.67189

Table 1: Output of Model Builder, Snow Survey Attribute Table

Analysis

The Extract Multi Values to Points tool has an option to do a bilinear interpolation of values at point locations. When this was done, the values of the cells were calculated from the adjacent cells with valid values using bilinear interpolation. **Table 2** displays the data with the bilinear interpolation included. These values were compared to the unconstrained data of **Table 3** as well to the field snow depth data.

OBJECTID_1 *	Shape *	OBJECTID	Date_	Time_	lat	long_	Elevation	NoName	GPS_Number	Survey_Poi	Mar27_Mar18	Mar27_Jul8	Mar18_Jul8	May27_Jul8
1	Point	1	1/16/2007	12:33:21PM	41.86497	-111.50757	8602 ft		39	1	0.365683	1.797452	1.431769	-0.023181
2	Point	2	1/16/2007	12:37:05PM	41.86481	-111.50737	8596 ft		40	2	0.391103	1.991874	1.600771	-1.83089
3	Point	3	1/16/2007	12:46:45PM	41.86537	-111.50674	8640 ft		41	3	0.168274	3.49769	3.329416	1.465032
4	Point	4	1/16/2007	12:56:47PM	41.86534	-111.50726	8641 ft		42	4	0.304555	1.582505	1.277951	0.273994
5	Point	5	1/16/2007	01:05:22PM	41.86462	-111.50677	8649 ft		43	5	0.247537	1.529757	1.282221	0.570923
6	Point	6	1/16/2007	01:09:53PM	41.86439	-111.50612	8611 ft		44	6	0.385352	1.820586	1.435234	0.086513
7	Point	7	1/16/2007	01:17:58PM	41.86433	-111.50575	8646 ft		45	7	0.524778	2.41005	1.885272	0.833829
8	Point	8	1/16/2007	01:24:02PM	41.86428	-111.50594	8630 ft		46	8	0.51797	2.420286	1.902316	1.128856
9	Point	9	1/16/2007	01:40:05PM	41.86407	-111.50675	8648 ft		47	9	0.292752	1.447402	1.15465	-2.161556
10	Point	10	1/16/2007	01:48:01PM	41.86451	-111.5081	8625 ft		48	10	0.085181	1.877059	1.791878	0.566069
11	Point	11	1/16/2007	01:56:21PM	41.86477	-111.50854	8641 ft		49	11	0.356084	2.656437	2.300353	0.797072
12	Point	12	1/16/2007	02:04:33PM	41.86491	-111.5089	8645 ft		50	12	0.345671	2.618951	2.27328	0.801201
13	Point	13	1/16/2007	02:14:46PM	41.86531	-111.51003	8675 ft		51	13	0.412959	2.096813	1.683854	0.312469
14	Point	14	1/16/2007	02:20:41PM	41.86596	-111.51081	8702 ft		52	14	0.317855	3.627071	3.309216	1.916716
15	Point	15	1/16/2007	02:36:11PM	41.86614	-111.51154	8733 ft		53	15	0.32568	2.388537	2.062856	0.648056
16	Point	16	1/16/2007	02:43:44PM	41.86629	-111.51123	8729 ft		54	16	0.321492	3.882232	3.56074	2.256814
17	Point	17	1/16/2007	02:47:37PM	41.86645	-111.51105	8726 ft		55	17	0.254253	3.112465	2.858212	1.63075
18	Point	18	1/16/2007	02:53:02PM	41.86676	-111.50995	8690 ft		56	18	0.336245	1.881967	1.545722	0.243163
19	Point	19	1/16/2007	02:56:52PM	41.86635	-111.50961	8686 ft		57	19	0.319735	1.91048	1.590746	0.268207
20	Point	20	1/16/2007	03:00:45PM	41.86553	-111.50944	8655 ft		58	20	0.30256	1.439904	1.137344	-0.071513
21	Point	21	1/16/2007	03:05:51PM	41.86554	-111.50812	8652 ft		59	21	1.403066	1.646888	0.243823	-0.041203

Table 2: Snow Survey Points with Raster Differences for Each Date Using Bilinear Interpolation

SnowSurveyPts

OBJECTID_1 *	Shape *	OBJECTID	Date	Time	lat	long	Elevation	NoName	GPS_NUmber	Survey_Poi	Mar27_Mar18	Mar27_Jul8	Mar18_Jul8	May27_Jul8
1	Point	1	1/16/2007	12:33:21PM	41.86497	-111.50757	8602	ft	39	1	0.385742	1.805176	1.419434	-0.028076
2	Point	2	1/16/2007	12:37:05PM	41.86481	-111.50737	8596	ft	40	2	0.397705	1.998047	1.600342	-2.651855
3	Point	3	1/16/2007	12:46:45PM	41.86537	-111.50674	8640	ft	41	3	0.170166	1.311035	1.140869	0.57251
4	Point	4	1/16/2007	12:56:47PM	41.86534	-111.50726	8641	ft	42	4	0.319092	1.511475	1.192383	0.156738
5	Point	5	1/16/2007	01:05:22PM	41.86462	-111.50677	8649	ft	43	5	0.286621	1.5354	1.248779	0.597412
6	Point	6	1/16/2007	01:09:53PM	41.86439	-111.50612	8611	ft	44	6	0.391357	1.784912	1.393555	0.131348
7	Point	7	1/16/2007	01:17:58PM	41.86433	-111.50575	8646	ft	45	7	0.527344	2.420654	1.893311	0.775879
8	Point	8	1/16/2007	01:24:02PM	41.86428	-111.50594	8630	ft	46	8	0.485596	2.368408	1.882813	1.309814
9	Point	9	1/16/2007	01:40:05PM	41.86407	-111.50675	8648	ft	47	9	0.216797	1.270264	1.053467	0.223145
10	Point	10	1/16/2007	01:48:01PM	41.86451	-111.5081	8625	ft	48	10	0.313965	2.056885	1.74292	0.514648
11	Point	11	1/16/2007	01:56:21PM	41.86477	-111.50854	8641	ft	49	11	0.357422	2.662598	2.305176	0.786133
12	Point	12	1/16/2007	02:04:33PM	41.86491	-111.5089	8645	ft	50	12	0.329834	2.557861	2.228027	0.764893
13	Point	13	1/16/2007	02:14:46PM	41.86531	-111.51003	8675	ft	51	13	0.425049	2.105469	1.68042	0.317627
14	Point	14	1/16/2007	02:20:41PM	41.86596	-111.51081	8702	ft	52	14	0.318848	3.626953	3.308105	1.908936
15	Point	15	1/16/2007	02:36:11PM	41.86614	-111.51154	8733	ft	53	15	0.3479	2.285645	1.937744	0.552734
16	Point	16	1/16/2007	02:43:44PM	41.86629	-111.51123	8729	ft	54	16	0.318848	3.890137	3.571289	2.256348
17	Point	17	1/16/2007	02:47:37PM	41.86645	-111.51105	8726	ft	55	17	0.246582	3.181396	2.934814	1.699219
18	Point	18	1/16/2007	02:53:02PM	41.86676	-111.50995	8690	ft	56	18	0.397217	2.020508	1.623291	0.324463
19	Point	19	1/16/2007	02:56:52PM	41.86635	-111.50961	8686	ft	57	19	0.297607	1.94043	1.642822	0.334228
20	Point	20	1/16/2007	03:00:45PM	41.86553	-111.50944	8655	ft	58	20	0.309326	1.409912	1.100586	-0.101318
21	Point	21	1/16/2007	03:05:51PM	41.86554	-111.50812	8652	ft	59	21	0.326416	1.600586	1.27417	-0.100342

Table 3: Snow Survey Points with Raster Differences for Each Date Unconstrained

Comparison to Field Observations

The model builder outputs were compiled into **Table 4**. The raster DEM's of March 18th 2009, March 27th 2009, and May 27th 2009 were used to find the snow depth by subtracting the raster DEM of July 8th 2009. The dates March 27th 2009 and March 18th 2009 were also compared. By comparing these dates the difference in snow depth was analyzed in that month. This comparison was used as a check to identify if comparing to the July 8th 2009 ground DEM was accurate. **Table 4** includes the snow depth calculated from the field observations for the four scenarios. It includes the LiDAR data with and without bilinear interpolation. The table shows the vegetation type for each of the survey site locations that were tested.

Veg type	S.N.	18-Mar-09			27-Mar-09			27-May-09			March 27-March 18		
		Field Depth of Snow (m)	LiDAR Mar18-Jul8 (no Bilinear) (m)	Mar18-Jul8 (Bilinear) (m)	Field Depth of Snow (m)	LiDAR Mar27-Jul8 (no Bilinear) (m)	Mar27-Jul8 (Bilinear) (m)	Field Depth of Snow (m)	LiDAR May27-Jul8 (no Bilinear) (m)	LiDAR May27-Jul8 (Bilinear) (m)	Field Depth Change Mar27-Mar 18	LiDAR Mar27-Mar18 (no Bilinear) (m)	LiDAR Mar27-Mar18 (Bilinear) (m)
Sage	1	1.65	1.419434	1.43177	2.02	1.805176	1.797452	0.2333	-0.02808	-0.02318	0.3700	0.38574	0.36568
Sage	2	1.80	1.600342	1.60077	2.29	1.998047	1.991874	0.5133	-2.65186	-1.83083	0.4933	0.39771	0.3911
Conifer	3	1.14	1.140869	3.32942	1.50	1.311035	3.49769	0.4975	0.57251	1.46498	0.3603	0.17017	0.16827
Aspen	4	1.57	1.192383	1.27795	1.79	1.511475	1.582505	0.5500	0.15674	0.27399	0.2217	0.31909	0.30456
Conifer	5	1.32	1.248779	1.28222	1.65	1.5354	1.529757	0.7633	0.59741	0.57093	0.3357	0.28662	0.24754
Open	6	1.75	1.393555	1.43523	2.13	1.784912	1.820586	0.7500	0.13135	0.08652	0.3783	0.39136	0.38535
Open	7	1.98	1.893311	1.88527	2.49	2.420654	2.41005	0.8050	0.77588	0.83382	0.5067	0.52734	0.52478
Open	8	1.77	1.882813	1.90232	2.29	2.368408	2.420286	1.2633	1.30981	1.12884	0.5170	0.4856	0.51797
Conifer	9	1.44	1.053467	1.15465	1.78	1.270264	1.447402	0.4067	0.22315	-2.16174	0.3463	0.2168	0.29275
Aspen	10	1.84	1.74292	1.79188	2.13	2.056885	1.877059	0.6133	0.51465	0.56608	0.2913	0.31397	0.08518
Grass	11	2.37	2.305176	2.30035	3.13	2.662598	2.656437	0.8333	0.78613	0.79707	0.7650	0.35742	0.35608
Grass	12	2.51	2.228027	2.27328	3.18	2.557861	2.618951	0.8667	0.76489	0.80121	0.6717	0.32983	0.34567
Sage	13	1.91	1.68042	1.68385	2.21	2.105469	2.096813	0.2967	0.31763	0.31247	0.2950	0.42505	0.41296
Drift area	14	3.40	3.308105	3.30922	3.76	3.626953	3.627071	2.0167	1.90894	1.91672	0.3550	0.31885	0.31786
Drift area	15	3.04	1.937744	2.06286	3.50	2.285645	2.388537	1.8033	0.55273	0.64806	0.4575	0.3479	0.32568
Drift area	16	2.52	3.571289	3.56074	3.26	3.890137	3.882232	2.5833	2.25635	2.25681	0.7400	0.31885	0.32149
Drift area	17	1.77	2.934814	2.85821	2.19	3.181396	3.112465	0.5867	1.69922	1.63074	0.4250	0.24658	0.25425
Aspen	18	1.72	1.623291	1.54572	2.27	2.020508	1.881967	0.4000	0.32446	0.24316	0.5500	0.39722	0.33625
Sage	19	1.93	1.642822	1.59075	2.31	1.94043	1.91048	0.5267	0.33423	0.26821	0.3800	0.29761	0.31974
Sage	20	1.48	1.100586	1.13734	1.88	1.409912	1.439904	0.0700	-0.10132	-0.07151	0.4000	0.30933	0.30256
Aspen	21	1.74	1.27417	0.24382	2.14	1.600586	1.646888	0.3150	-0.10034	-0.0412	0.3977	0.32642	1.40307

Table 4: Field and LiDAR Data Compiled

Plots were then created for each of the four scenarios to compare the accuracy of each method to the field observation. These are shown in **Figures 9-12**.

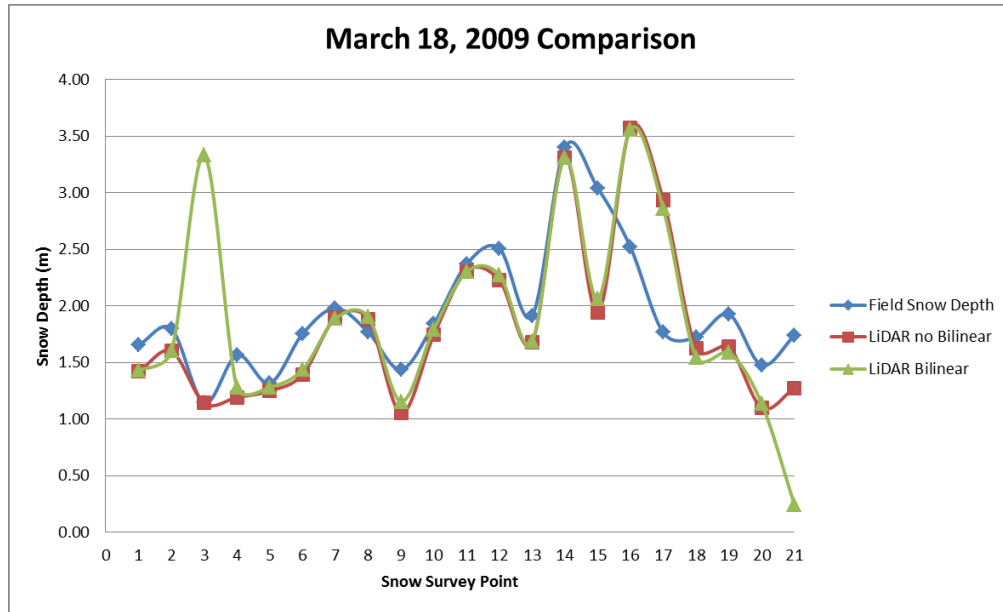


Figure 9: March 18, 2009 Field, LiDAR BI, LiDAR No BI

The LiDAR data seems to follow the trend of the field snow depth through the majority of the individual points but doesn't meet the accuracy and consistency that was expected. The low values are analyzed in the discussion section.

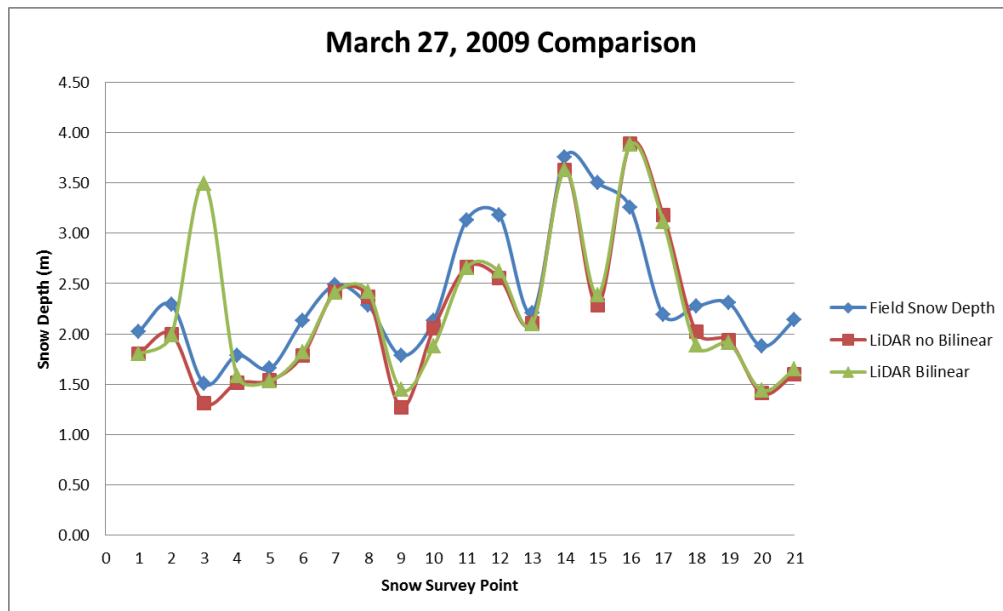


Figure 10: March 27, 2009 Field, LiDAR BI, LiDAR No BI

Again, the LiDAR data follows the trend of the field observation. The accuracy was still not as expected. **Figure 10** shows how the LiDAR data that did not use the bilinear interpolation appears to match the

field snow depth better than the bilinear interpolation values. The spikes in the bilinear LiDAR points are discussed in the bilinear interpolation section under Discussion.

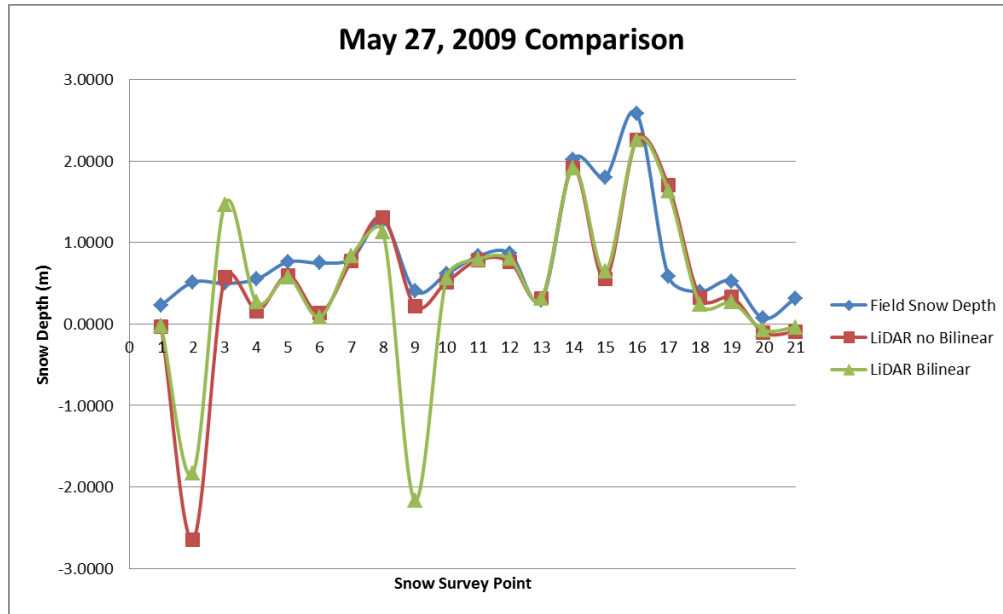


Figure 11: May 27, 2009 Field, LiDAR BI, LiDAR No BI

A similar trend is seen in **Figure 11** as was observed in **Figure 9 and 10**. This time there are several spikes in the negative value. A possible explanation for this is explained in the May 27th Snow Differences under the Discussion section.

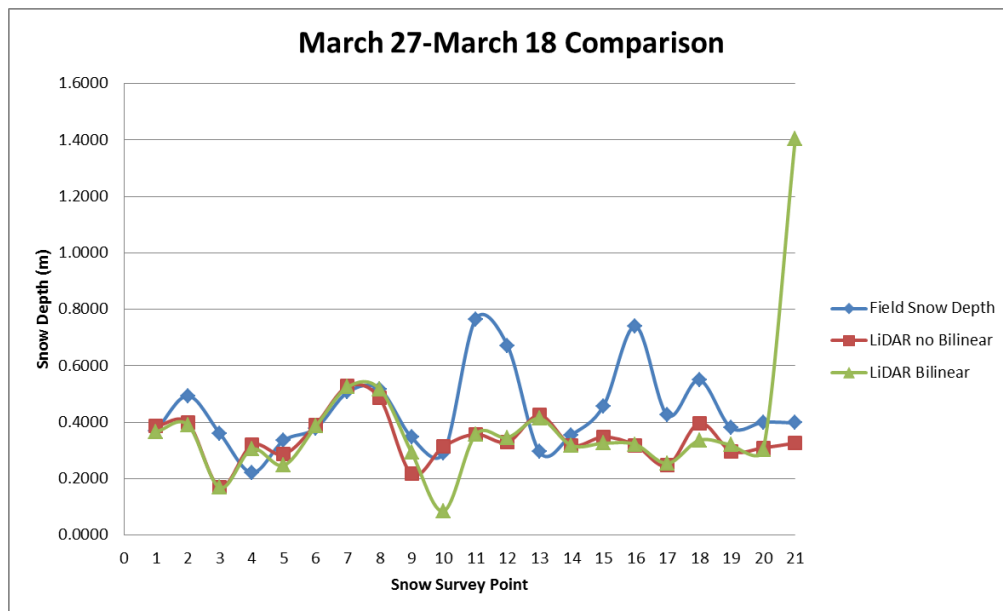


Figure 12: March 27-March 18, 2009 Field, LiDAR BI, LiDAR No BI

Through a collection of the tables above, it is recognized that the Field Snow Depth correlates with the LiDAR data. The values tend to depart from each other and then realign. The data from **Figure 12** appears to not correlate as well. After a closer analysis of the scale it is significantly smaller than the

other Tables. The snow survey points 1, 6, 7, and 8 have an accuracy and correlation between the LiDAR data and field measurements that seem promising.

Comparison to SNOTEL Data

The SNOTEL data that was used in comparison to the LiDAR data was found at the SNOTEL site: USU Doc Daniel. The SNOTEL site, as shown in the Figures above, is in close proximity of snow observation points 7 and 8. Using the Extract Multi Values to Points tool again the LiDAR values were found in **Table 5** at the SNOTEL site. The twenty four hour value range is presented in the Site ID of the SNOTEL site in **Table 6**. The LiDAR data compared to the actual SNOTEL site is within the accuracy that was expected.

This method was not as effective as comparing to the field measured points. This is due to the amount of points that were available. If this process was to be used on other large data sets without field measurements to compare to, SNOTEL data would be a reasonable check of accuracy. This would help conclude datum problems and classification issues.

SNOTELSite										
OBJECTID *	Shape *	Site	x	y	Mar27_Jul8_BI	Mar18_Jul8_BI	May27_Jul8_BI	Mar27_Jul8	Mar18_Jul8	May27_Jul8
1	Point	SnotelSite	45800	463484	2.270752	1.784395	0.651808	2.294678	1.798096	0.72168

Table 5: SNOTEL Site LiDAR Values

Site ID	Vegetation	3/18/2009 (m)	3/27/2009 (m)	5/27/2009 (m)
7	Open	1.885272	2.41005	0.833816
8	Open	1.902316	2.420286	1.128844
SNOTEL LiDAR BI	Open	1.784395	2.270752	0.651808
SNOTEL LiDAR	Open	1.798096	2.294678	0.72168
SNOTEL SITE	Open	1.905-1.9304	2.4384-2.5146	0.8382-.9398

Table 6: Compiled SNOTEL Analysis Values

Discussion

There are several issues that need attention when looking at the data. These include;

1. 2008 Data
2. Negative Values in Rasters
 - a. LiDAR Classification
3. May 27th 2009 Snow Differences
4. Bilinear Interpolation
5. Time Differences

2008 Data

The 2008 data was full of problems from the beginning. It had a very poor original classification. Then with the data reclassified, the dates did not line up with available field observations. The field observations were a day to a week apart from the flights. In seeing how the snow moved and changed so frequently it was decided to only analyze the 2009 data. The 2009 LiDAR data was directly correlated with the day of the field observations.

Negative Raster Values

When the Raster values were subtracted from the July 8th 2009 data there were several individual points that resulted in a negative value. Analysis of **Figure 7** and its legend illustrate this issue. To help understand the problem it is easiest to review the analysis process. Millions of individual points were classified to a ground classification. This was done for each data set that was compared. If this was done perfectly then only ground points would be available. Ensuring that no vegetation is part of the ground is a difficult task.

A good diagnostic would be looking at cross sections of the July 8th data. There is a very viable chance that some vegetation was classified as ground. Most likely occurring in areas of thick vegetation where triangulating between ground points is the most difficult. In this data there is a very likely chance that there was some misclassification.

The July 8th data is the best place to start looking for classification issues because if any vegetation is classified as ground it will result in a comparison base DEM that is higher than expected. This is where the resulting negative snow depths would stem from. When using this data it is recommended to go through each set of points and view the cross sections. A factor of safety would need to be established, as getting a perfect classification is difficult.

May 27th 2009 Snow Differences

The May snow differences showed several outlying points that can be seen in **Figure 11**. This was with and without the bilinear interpolation. The data did not match the observed field data as well as the other dates. This could be caused by a similar problem that has occurred in the Geomatics lab at USU when LiDAR was collected over water.

When LiDAR is collected over water, reflective, or shiny areas, the LiDAR is often refracted and reflected giving unstable results. During May it is assumed, spring time with the snow beginning to melt. This is a possible solution to the strange values that were observed. Further analysis could prove this by observing where the sun hits. If this time matches the time of day that the LiDAR data was collected then this proposition is plausible. Also, the temperature at that specific time could be an explanation for the data.

Bilinear Interpolation

The bilinear Interpolation was not always effective when looking at snow depths. **Figure 4** presents this when comparing the bilinear no and bilinear columns. Approximately 60 percent of the time, not using bilinear interpolation was closer to the field observed data. There are several cases that show that the bilinear interpolation case was not effective. This was shown in several of the figures but a specific example is **Figure 12** where the last point spikes. This could be caused by a poor classification of the surrounding points used in the interpolation. Using the values displayed in **Table 4**, a correlation of the bilinear and unconstrained methods would decrease the difference between the LiDAR and field observations.

Figure 13 represents an interesting initial inspection of the use of bilinear interpolation in the tree areas. It was not nearly as effective as the unconstrained. This supports the idea that there is some ground/

vegetation classification problems with the data. Bilinear interpolation aided in analyzing the classification but seems to only have minimal benefits when extracting values from DEM rasters.

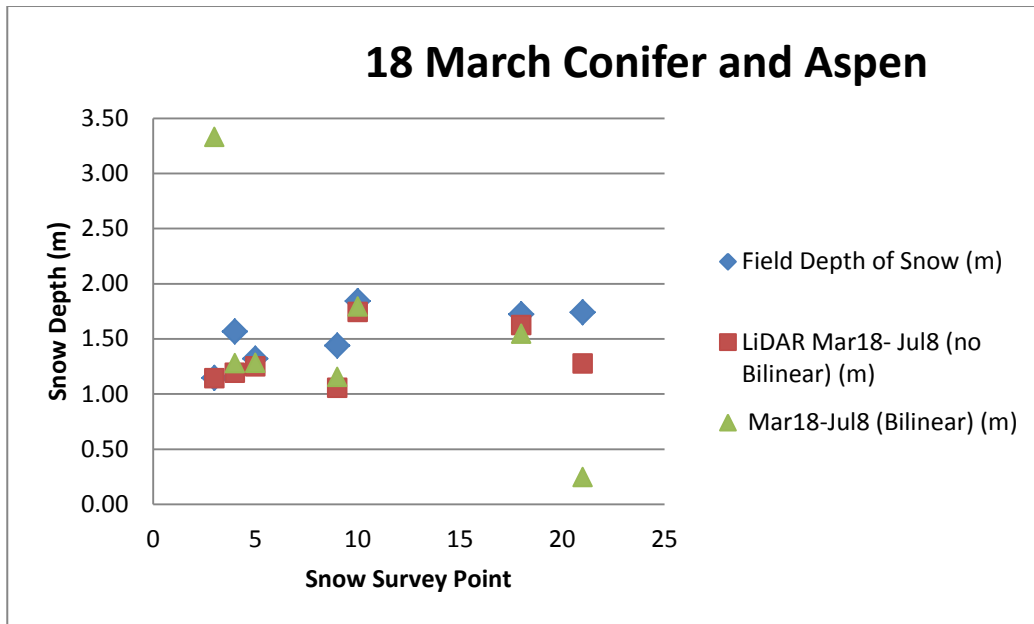


Figure 13: 18 March Vegetation Observations Comparing Field, LiDAR BI and LiDAR no BI

Time differences

There is no reference that was found correlating the time between the LiDAR data and the field observation data. Having both of these sets of data taken as close as possible to one another would have improved the accuracy of the results. In the SNOTEL data, the 24 hour data varied by 0.127 meters. This variation could cause a relatively large difference in the data values, specifically in areas open and susceptible to wind. With the variables of temperature, wind, and sun the snow depths can change quickly.

Conclusion

The TWDEF data shows a lot of potential for being used to quantify the spatial distribution of snow over the study area. Some development could be done to improve the accuracy of the data to the field data. Researching and finding the time the flight was conducted and correlating it with the field observations could aid in decreasing the error in depths. A closer look at the July 8th 2009 LiDAR classification will improve the accuracy and dissolve the negative values found in the data. With a reclassification, the use of a bilinear interpolation would need to be analyzed but most likely is only effective in the open areas. In this project it aided in discovering problems in the classification.

SNOTEL data was an effective check of the accuracy. It would be very beneficial when using LiDAR flights over a large area to check against. With the ability to have 24 hour results to compare to, time record would be key to correlating the results.

Knowing how much snow is available is very important for many water resources studies and planning. Using the tools in ArcGIS and this LiDAR data, the possibility of knowing the snow depth over large extents is possible and a great resource.

References

Mahat, Vinod, "Effect of Vegetation on the Accumulation and Melting of Snow at the TW Daniels Experimental Forest" (2011). *All Graduate Theses and Dissertations. Paper 1078*.
<http://digitalcommons.usu.edu/etd/1078>

USU Daniel Forest LiDAR data from 2008 and 2009 provided by USU Geomatics Lab.

United States Department of Agriculture. Natural Resources Conservation Service. Utah SNOTEL Site, USU Doc Daniel. <http://www.wcc.nrcs.usda.gov/nwcc/view>.