Remote Sensing Glacier Depth and Correlating Cirque Curvature with Glacial Area

Glacier National Park, MT

by
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- Excel
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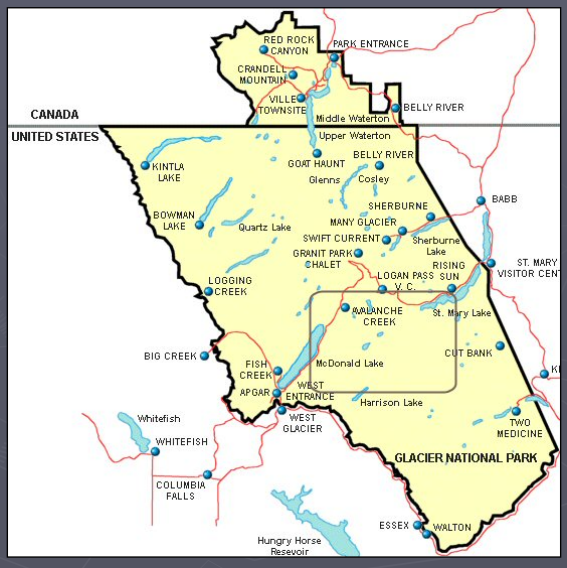
Study Area: Glacier National Park

Source: Greenwich 2000 Ltd.

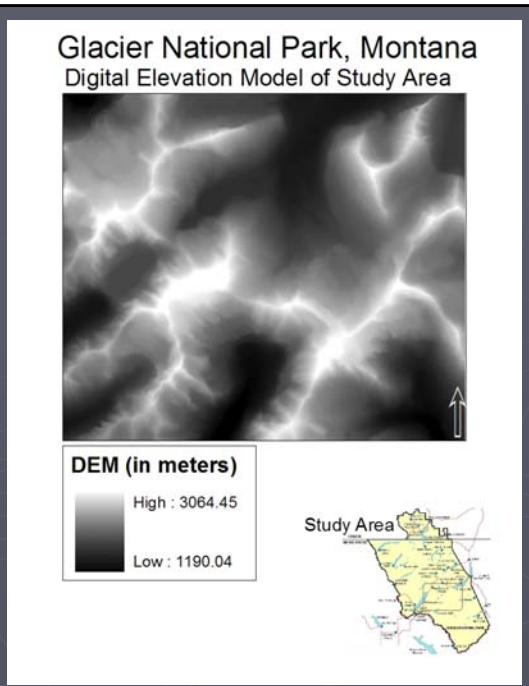
Study Area: Glacier National Park



Source: AreaTravelPackets.com

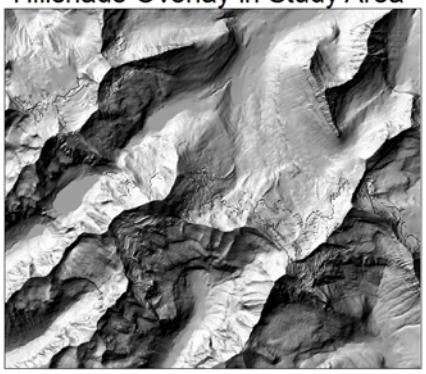
Study Area: Glacier National Park

Source: www.nps.gov/glac



Source: USGS

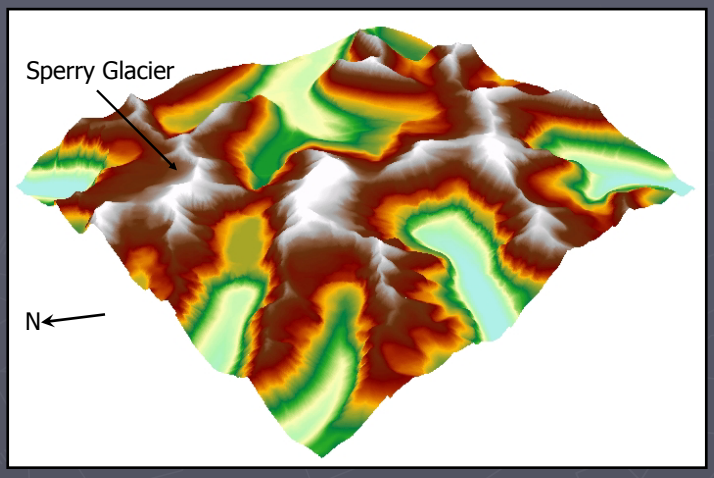
Glacier National Park, Montana
Hillshade Overlay in Study Area

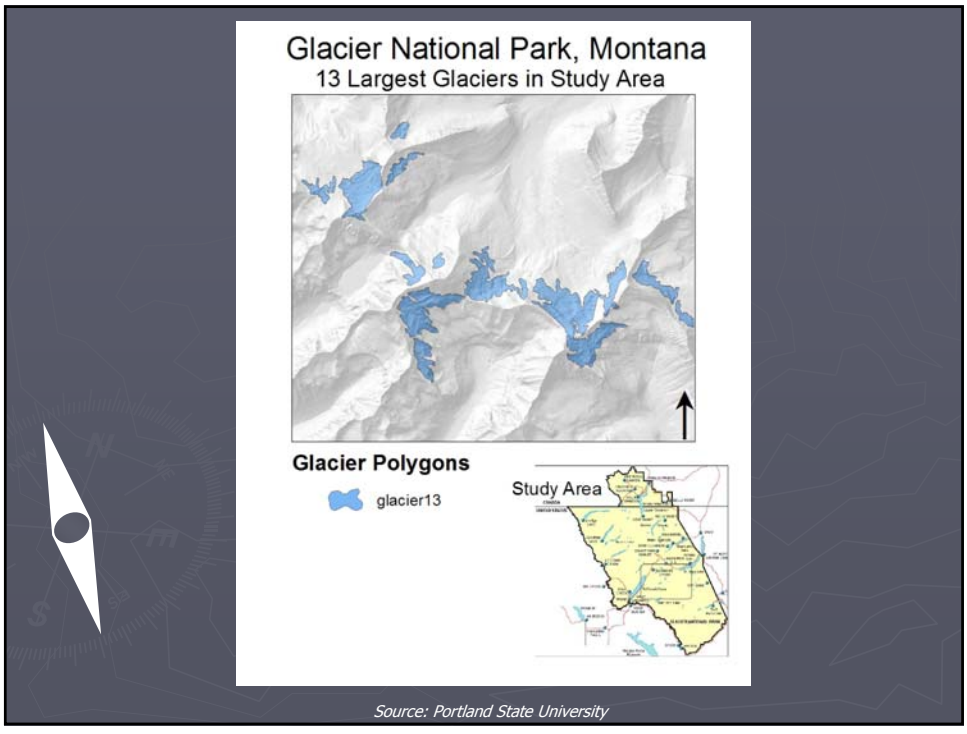


1:74,045

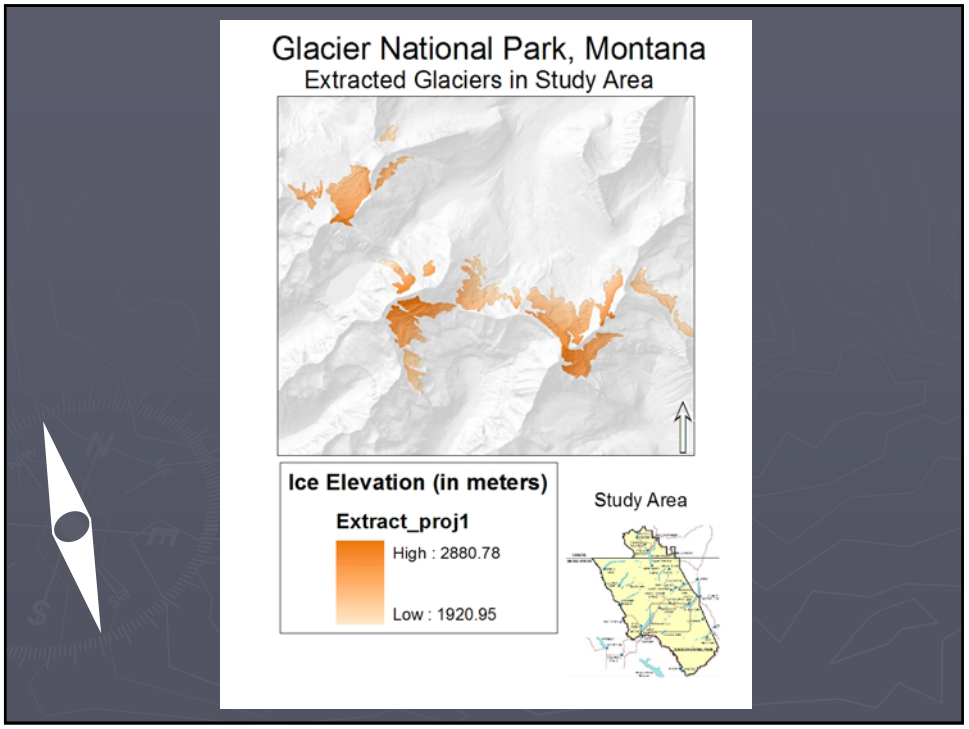
Site Map

ArcScene image of Study Area





Source: Portland State University



Jackson Glacier

Source: National Park Service

Source: Russ Finley

Sperry Glacier, at base of Mt. Edwards Glacier National Park

Morton Elrod photo 1907
Courtesy Glacier NP Archives

Lisa McKeon photo, 2001 *USGS*

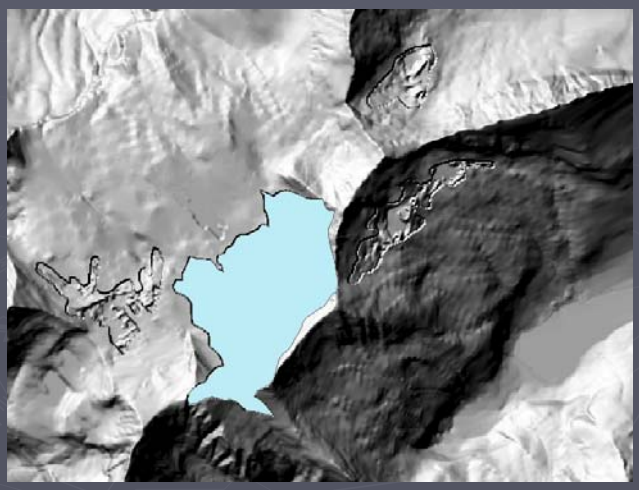
Prior Cirque Research

- Cirque width, high steep walls, facing northeast determine glacier locations[1]
- Eastward cirque aspect caused by leeward slopes[2]
- Morphometric analysis using GIS, C++, and R was useful in delineating landforms[3]
- Correlations between cirque morphology and solar radiation and glacier area[4]

[1]Graf, 1976; [2]Evans, 1977; [3]Bonk 2002; [4]Chueca and Julian, 2004

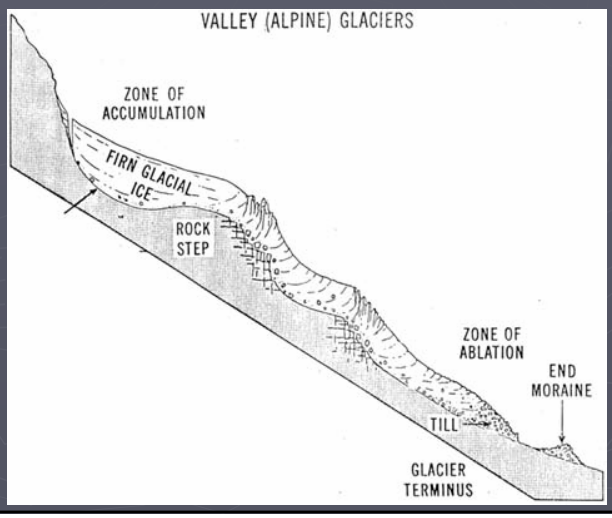
Methods:
Remote Sensing of Ice Depth

- Area



Methods:
Remote Sensing of Ice Depth

- Surface slope



Methods:
Slope-derived Ice Depth

- $T_b / \rho g \sin \alpha = h$

where T_b = 1 bar=100,000N/m^2= kgm/s^2/m^{2*}

and ρ = 890 kg/m^{3*}

and g = 9.8 m/s^2

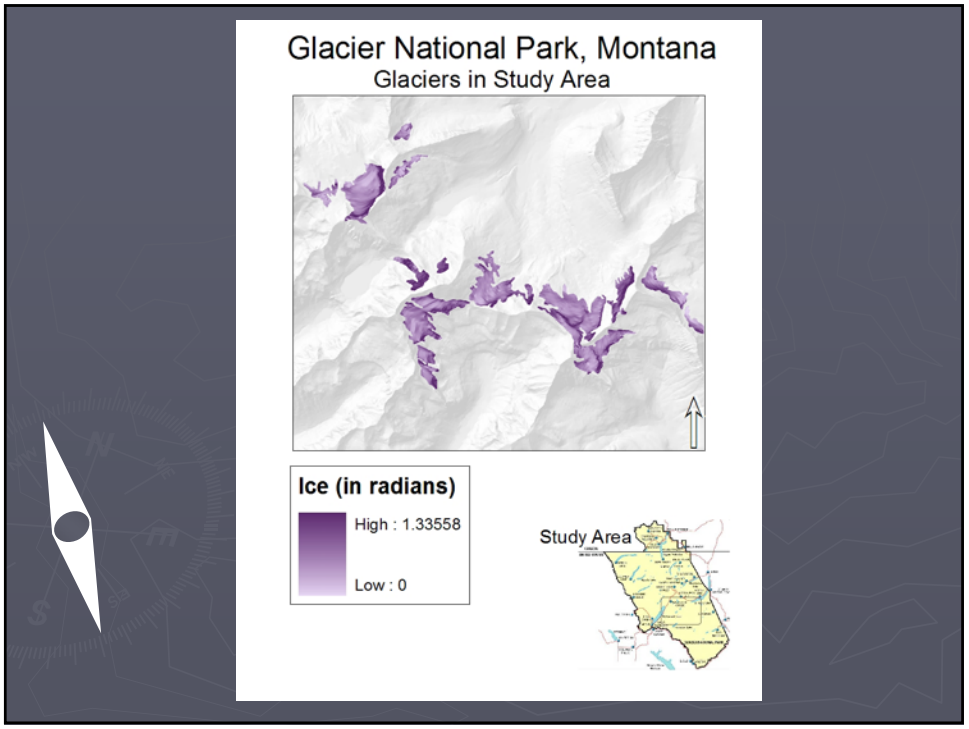
- 11.46526m^3 / sin α = h

*Assumption based on data from Paterson

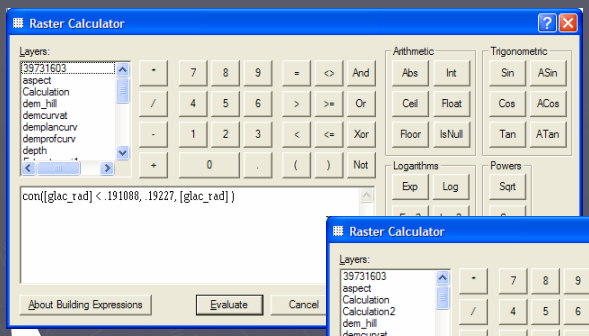
Source: Paterson 1994

Methods:
Ice Depth Calculations

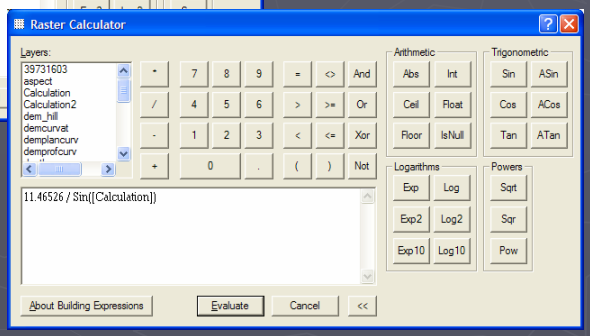
- Reproject in UTM – bilinear resampling
- Slope tool – calculated in degrees
- Convert degrees to radians
- Use derived ice depth formula using radians value



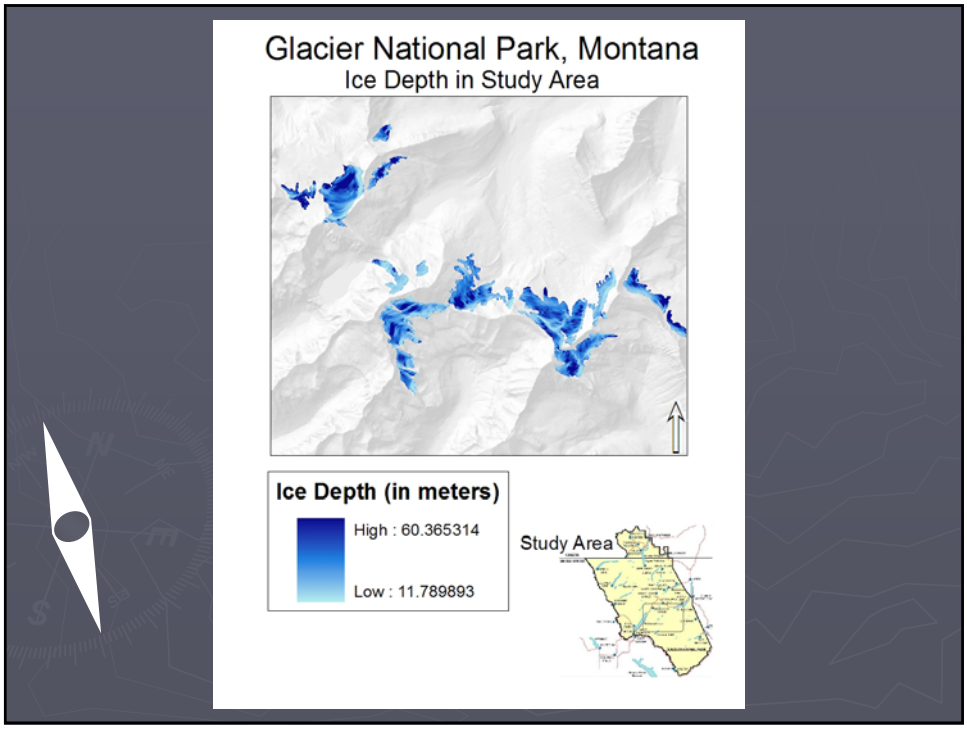
Raster Calculator

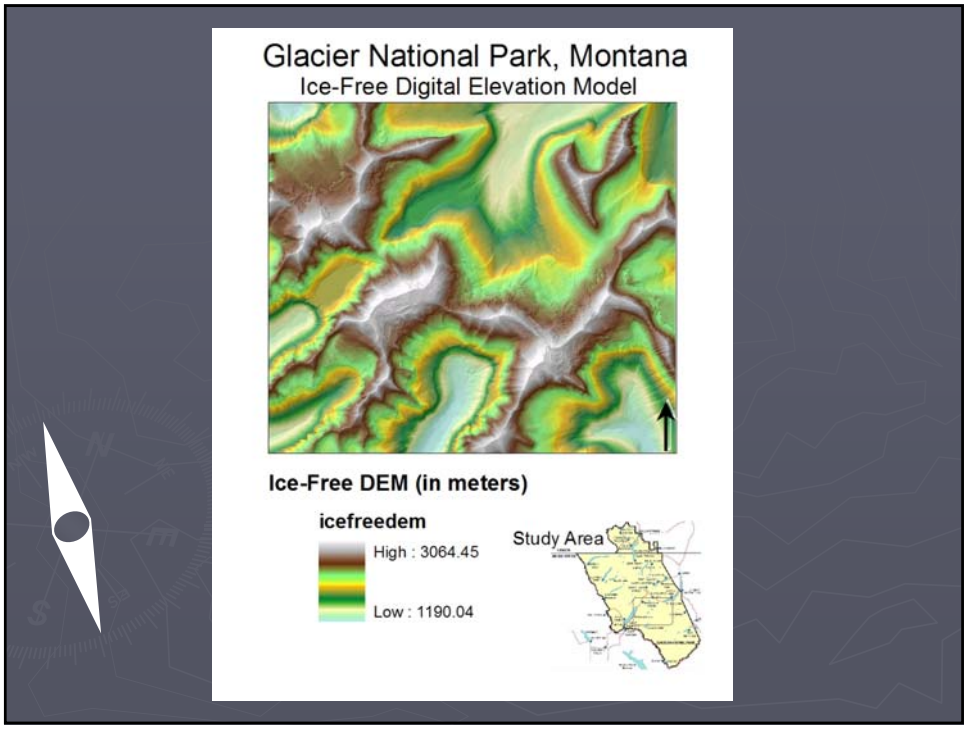


Setting the limit



Depth calculation

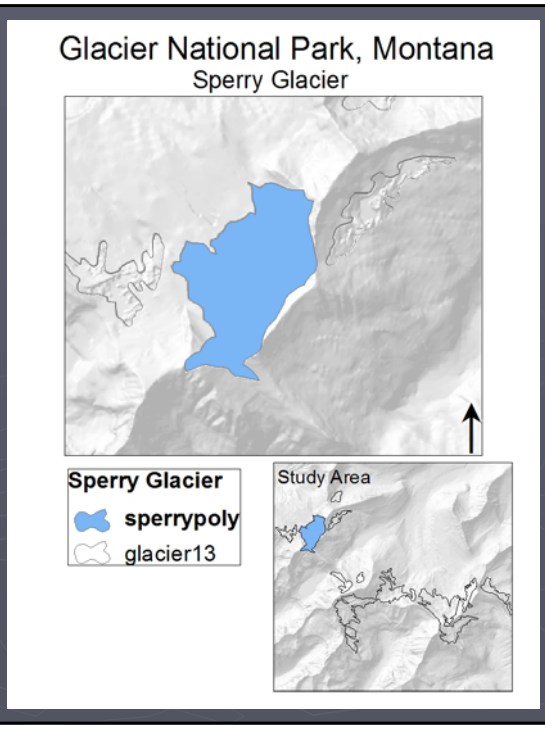

Glacier National Park, Montana
Ice Depth in Study Area
Ice Depth (in meters)
High : 60.365314
Low : 11.789893
Study Area


Glacier National Park, Montana
Ice-Free Digital Elevation Model
Ice-Free DEM (in meters)
icefreedem
High : 3064.45
Low : 1190.04
Study Area

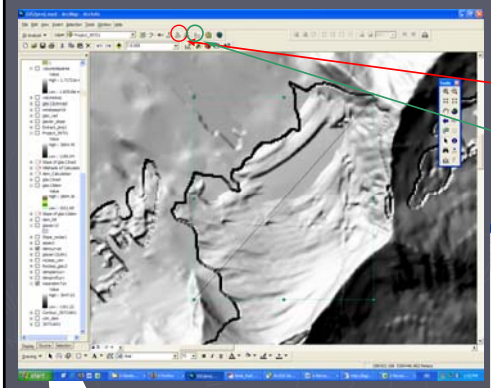
Methods:
Depth Calculation Via Volume

- $V^* = 3.93A^{1.124}$
  - A is total area of glacier (m^2)
  - V is total volume of glacier (m^3)

Source: Driedger and Kennard 1986

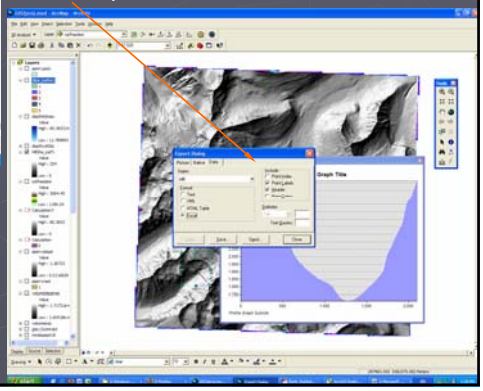


Methods: Curvature from Profiles



3-D Analyist toolbar:

1. Interpolate line tool
2. Create profile graph
3. Export data as excel file

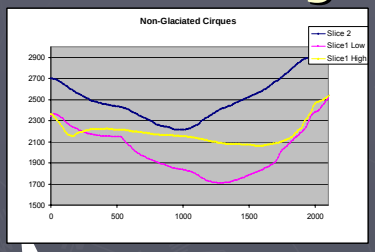


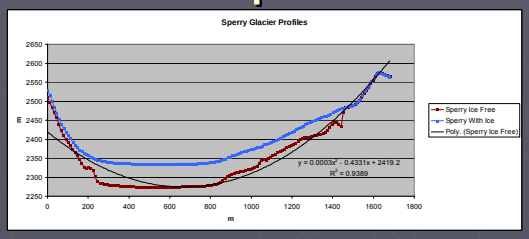
4. Plot data on scatter plot
5. Add trendline and include 2nd order polynomial equation

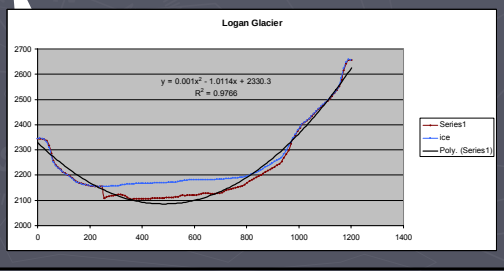
Analyzing Polynomial Equations

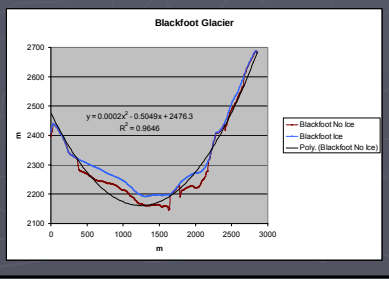
- The trendline of each profile generated a polynomial equation
- The second derivative of the coefficients of said polynomials are essentially the curvature value (acceleration)

Results:
Profiles across glaciated and non-glaciated cirques

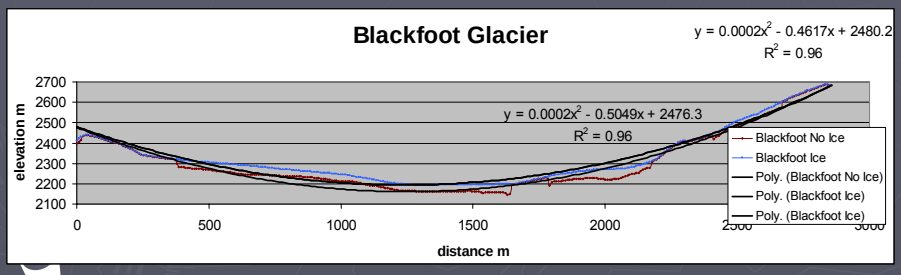




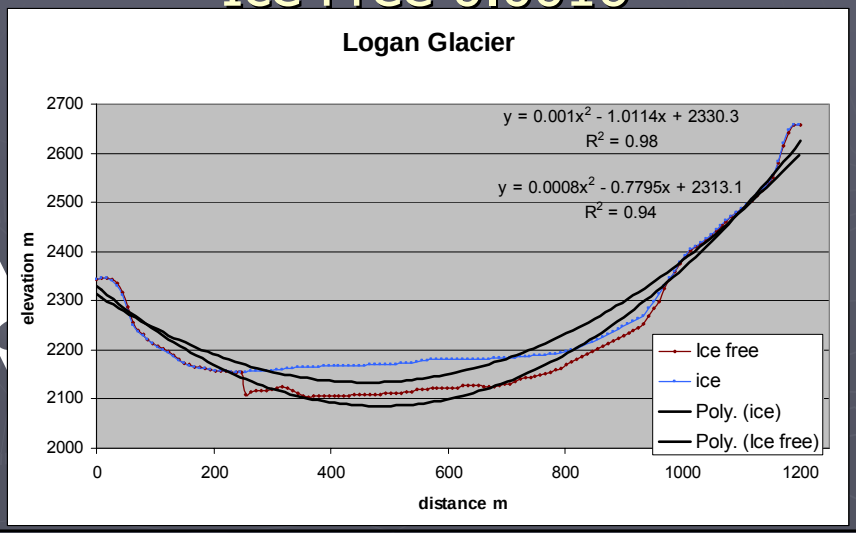




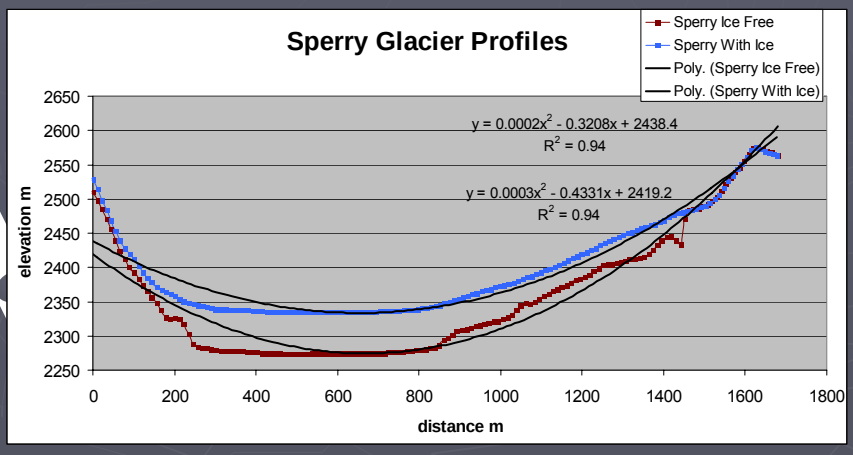
Results:
Curvature Ice 0.0004
Ice Free 0.0004



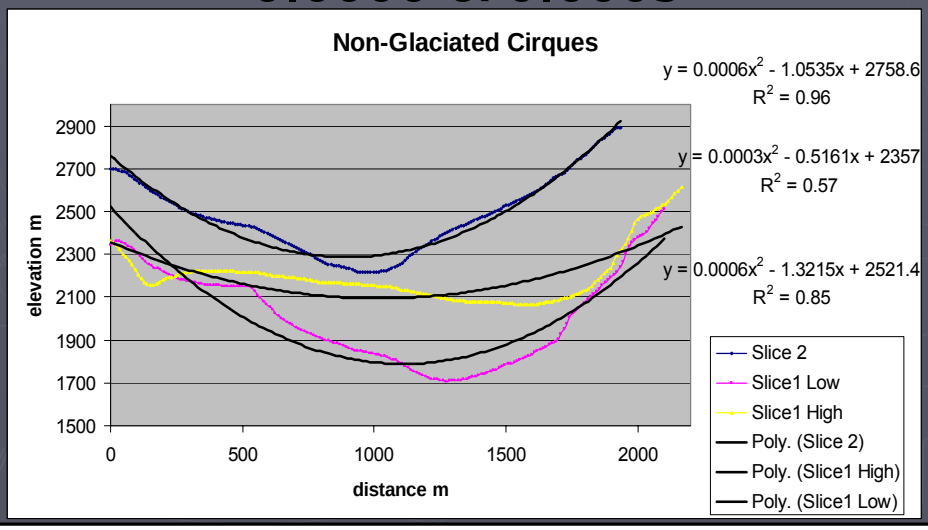
Results:
Curvature Ice 0.002
Ice Free 0.0016

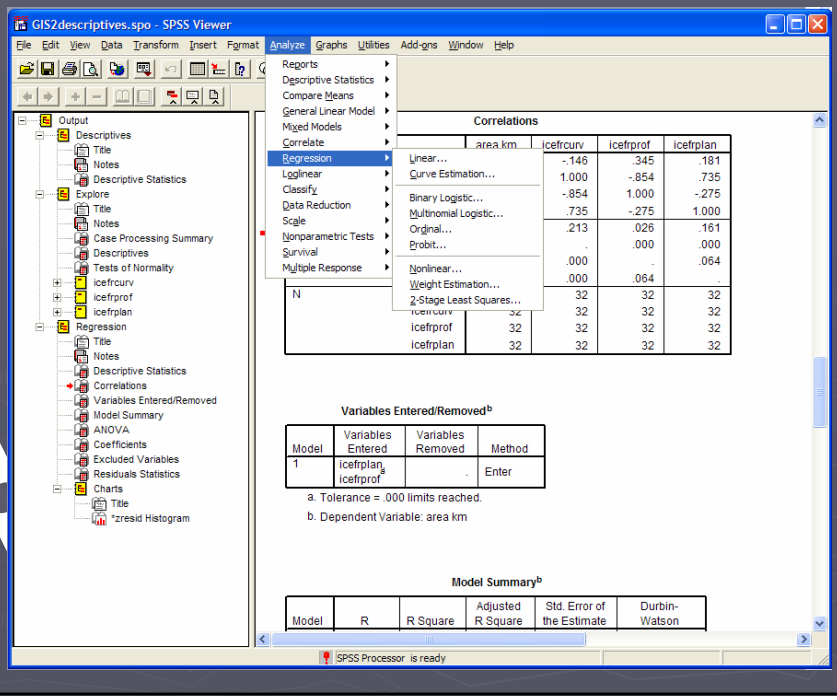


Results:
Curvature Ice 0.0004
Ice Free 0.0006



Results:
Ice Free Cirque Curvature
0.0006 & 0.0003





Curvature with Ice

Correlations

		area km	precip	sol rad	plan curvature	profile	curvature	aspect	low temp mean
Pearson Correlation	area km	1.000	.048	.586	.043	.287	-.161	-.289	.091
	precip	.048	1.000	.160	.767	-.435	.620	.319	-.972
	sol rad	.586	.160	1.000	-.132	.416	-.321	.101	-.070
	plan curvature	.043	.767	-.132	1.000	-.706	.896	-.125	-.804
	profile	.287	-.435	.416	-.706	1.000	-.947	-.033	.490
	curvature	-.161	.620	-.321	.896	-.947	1.000	-.037	-.672
	aspect	-.289	.319	.101	-.125	-.033	-.037	1.000	-.229
	low temp mean	.091	-.972	-.070	-.804	.490	-.672	-.229	1.000
Sig. (1-tailed)	area km	.	.398	.000	.407	.056	.190	.055	.309
	precip	.398	.	.191	.000	.006	.000	.038	.000
	sol rad	.000	.191	.	.237	.009	.036	.291	.353
	plan curvature	.407	.000	.237	.	.000	.000	.247	.000
	profile	.056	.006	.009	.000	.	.000	.430	.002
	curvature	.190	.000	.036	.000	.000	.	.421	.000
	aspect	.055	.038	.291	.247	.430	.421	.	.104
	low temp mean	.309	.000	.353	.000	.002	.000	.104	.
N	area km	32	32	32	32	32	32	32	32
	precip	32	32	32	32	32	32	32	32
	sol rad	32	32	32	32	32	32	32	32
	plan curvature	32	32	32	32	32	32	32	32
	profile	32	32	32	32	32	32	32	32
	curvature	32	32	32	32	32	32	32	32
	aspect	32	32	32	32	32	32	32	32
	low temp mean	32	32	32	32	32	32	32	32

SPSS Regression Analysis

Correlations

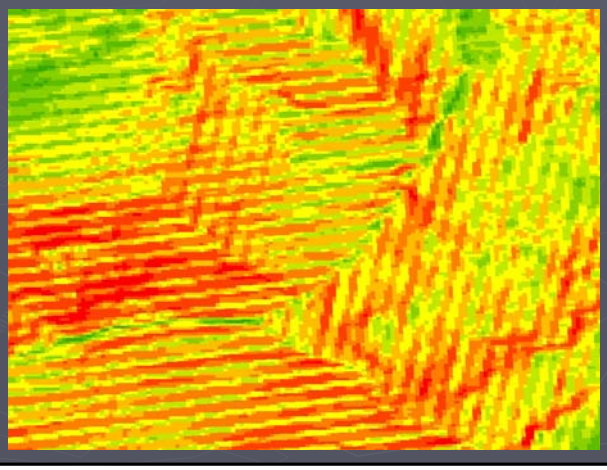
		area km	icefrcurv	icefrprof	icefrplan
Pearson Correlation	area km	1.000	-.146	.345	.181
	icefrcurv	-.146	1.000	-.854	.735
	icefrprof	.345	-.854	1.000	-.275
	icefrplan	.181	.735	-.275	1.000
Sig. (1-tailed)	area km	.	.213	.026	.161
	icefrcurv	.213	.	.000	.000
	icefrprof	.026	.000	.	.064
	icefrplan	.161	.000	.064	.
N	area km	32	32	32	32
	icefrcurv	32	32	32	32
	icefrprof	32	32	32	32
	icefrplan	32	32	32	32

Results of Analysis

- 0.345 = Pearson's correlation of curvature with area
- Based on the means at 32 elevation classes on all glaciers

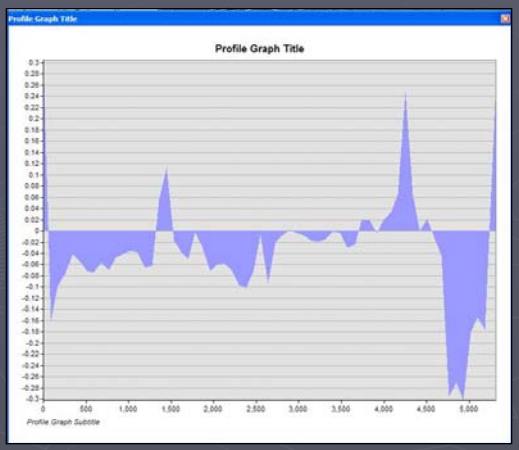
Problem #1

- Slope Calculation Tool
  - Initially generated lines that did *not at all* represent reality



Problem #2

- Curvature tool in 3-D and Spatial analyst was too refined for our scale
- Varying the cell size did not really improve results



Future Work

- Advanced GIS analysis in GRASS

$$\omega_p = -\frac{f_{xx}f_x^2 + 2f_{xy}f_xf_y + f_{yy}f_y^2}{p\sqrt{q^3}}$$

- Collect the curvature value at numerous elevations along glaciers & tabulate the data
- Update aerial photography/DEM's

Source: Bonk, 2002

Conclusions

- Remote Sensing is a useful tool for depth calculations especially with repeat aerial photography
  - Glaciological methods are limiting
  - Ground-truthing still required
- Curvature analysis requires advanced calculations or tool modifications
  - Profile slice good manual technique

Data Sources

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