4-D Analysis of Grizzly Glacier
Trinity Alps, CA

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Undergraduate Thesis Humboldt State University – Department of Geology
Research Questions

• Is Grizzly Glacier a glacier or a perennial snowfield as previously suggested?

• How has the extent of ice changed through time?

• What is the volume of the glacier?

• What climatic factors might control these changes?

• Is Grizzly Glacier’s behavior similar to those of other systems in California?
Thompson Peak
Grizzly Glacier

Dates from dendrochronology and \( \text{Be}^{10} \) done by Graham (2013)

August 31, 2013
Thompson Peak

Area of ice: ~8.5 hectares (16 football fields)
Elevation: ~2560m (8400 ft)
Crevasses?
• Air photos and GPS surveys from various years compiled to assemble retreat rate
• Measurements made along north-south line from southern end to intersection of termini
• Photos from low precip years and late summer/fall
y = -0.7205x + 1642.1
R² = 0.7941

Average Retreat = -0.7 m/yr
Total Retreat since 1944 = 40m or ~20%
Data Availability Issues:
August 18, 1983

Grizzly Iceberg
Grizzly Glacier
Thompson Peak
• Thickness of ice is measured through crevasses or along edge of glacier  
• Measurements located with Trimble Juno GPS  
• Max measured depth (2013) = 11m
- Topcon RTK dGPS System
- Monopod with base stabilized by boulders
- 2013 base was near toe of glacier
2012 base was at Grizzly Lake

Thompson Peak

Grizzly Lake
• Rover is mounted to backpack
• Surveyor can then walk around and points are collected at 2-sec intervals
• Gray surface is made by combining depth of ice points with points taken in cirque into a TIN
• Blue surface is made from points collected on surface of glacier
• Low resolution in background is 10m DEM
Volumes were calculated with surface difference tool in ArcMap 10.2

- 2012 Volume: 245,000 m$^3$
- 2013 Volume: 207,000 m$^3$
- Change: -38,000 m$^3$ (-15.5%)
- Associated linear change: -4m (-2%)
Anomaly is divergence from mean

Bars are raw data, dashed lines are linear best fits, and solid lines are 10 year retrospective moving averages

Source: PRISM (2014)
Standardized Value \( Z_n = \frac{Y_n - \bar{Y}}{\sigma} \)
Grizzly Glacier:
- Shrinking
- Warming summer temperatures
- No trend in winter precipitation

Mt. Shasta Glaciers:
- Stable/Growing
- Warming summer temperatures
- Increase in winter precipitation
- Howat et al., 2006

Sierra Nevada Glaciers:
- Shrinking
- Warming temperatures
- No trend in winter precipitation
- Basagic and Fountain, 2011
Conclusions

• Grizzly Glacier is a glacier, not a perennial snowfield
• 2012-2013 volume change ≈ -15.5%
• Fall 2013 volume was 207,000 m³
• Total linear retreat since 1944 ≈ 40 m (20%)
• Average linear retreat rate ≈ 0.7 m/yr
• Average PRISM based warming rate ≈ 0.013 °C/yr
• Total PRISM based summer warming since 1900 ≈ 1.5 °C
• Glacier retreat correlates well with warming temperatures
• Conditions in the Trinities are more similar to the Sierra Nevada than Mt. Shasta, despite relative proximity
• More data are needed as this appears to be a very dynamic system
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Sources of error in estimates (in descending order)

• Manual GPS correction adjustment, human errors with GPS height vs. surface height
• Representation of bedrock surface via depths: GPS location of depths, and depth measurement errors
• Georeferencing methods used for air photos
• Hand drawing and measurement of termini
• Method of interpolation
• Void spaces made by crevasses
• Survival of snow to following year (accuracy of surfaces measured)
• GPS accuracy & precision
• Temperate Glacier Mass Balance
  • Controlled by Winter Precip and Summer Temperature (Leonard, 1989)
  • Data from single PRISM pixel containing Grizzly Glacier

• Parameter-elevation Regressions on Independent Slopes Model (PRISM)
  • Monthly climate data in 800m pixels extending to 1895
  • “Factors considered are location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of terrain (Daly et al., 2008).”
  • Validated with surface stations.
Red Rock Mountain is a SNOTEL snow monitoring site managed by the US Bureau of Reclamation ~15km east of the study area. Differences could be related to complex relation between TWP and snow pack, rain shadow effects, or 500m less elevation at RMS vs Grizzly.
Mt. Shasta (from Howat et al., 2006)

“Despite a regional warming trend over the past few decades, Mount Shasta’s ice volume has remained relatively stable due to a large increase in winter snow accumulation and strengthening correlation with positive El Nino phases.”

Prism Data

Glacier Data
Dots = observed, solid = modeled
y-axis is elevation
“Climate trends in PRISM data over the past century were statistically significant (p < 0.05) for winter and spring air temperatures (warming 0.07 °C and 0.19 °C decade⁻¹, respectively) and summer precipitation (increasing). Summer temperatures also warmed but the trend was not significant. There was no trend in winter precipitation.”

Winter precip not plotted because no trend

Average loss in fractional area from 1903-2004 is 55%
<table>
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<th>Year</th>
<th>Extent (m)</th>
<th>Date</th>
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<tr>
<td>103-163yr</td>
<td>490</td>
<td></td>
</tr>
<tr>
<td>1944</td>
<td>239</td>
<td>12-Aug</td>
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<tr>
<td>1955</td>
<td>240</td>
<td>29-Aug</td>
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<tr>
<td>1989</td>
<td>213</td>
<td>7-Sep</td>
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<td>1994</td>
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<td>2012</td>
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<tr>
<td>2013</td>
<td>200</td>
<td>(gps) 31-Aug</td>
</tr>
</tbody>
</table>

Grizzly Glacier Extent with Best Fit Line

\[ y = -0.7205x + 1642.1 \]

\[ R^2 = 0.7941 \]