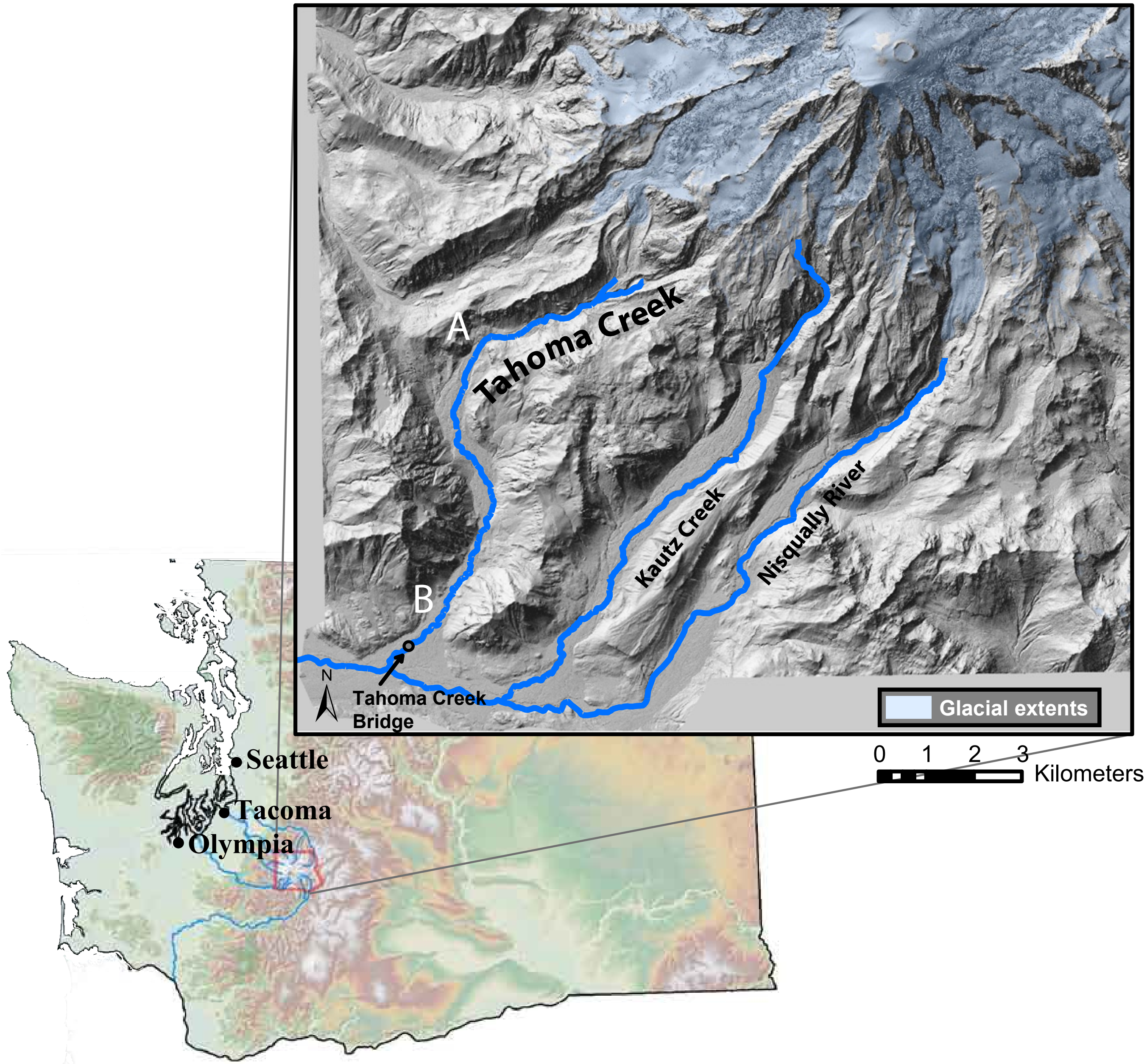
Sediment fluxes in a changing climate

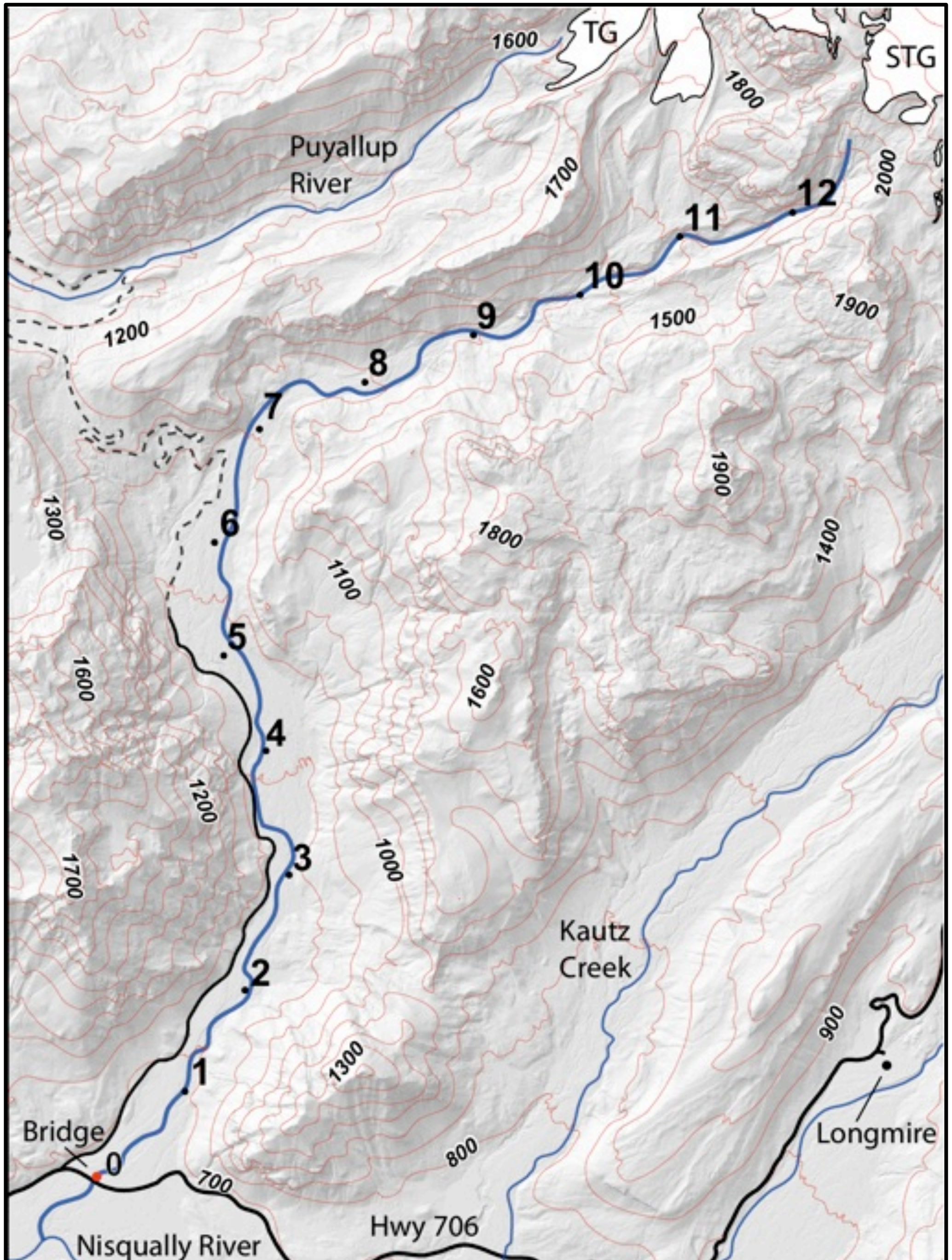
Tahoma Creek over daily to centennial time-scales

Overview

- **General background**
- **Part 1 – Sediment transport in a steep stream**
  - LiDAR analysis of geomorphic change, bed load transport
  - Development of sediment rating curve
- **Part 2 – Historical analysis of Tahoma Creek**
  - Dendrochronologic reconstruction of debris flows
  - Relationship to climatic drivers



Tahoma Creek
A
B
Kautz Creek
Nisqually River
N
Tahoma Creek
Bridge
Glacial extents
0 1 2 3
Kilometers
Seattle
Tacoma
Olympia



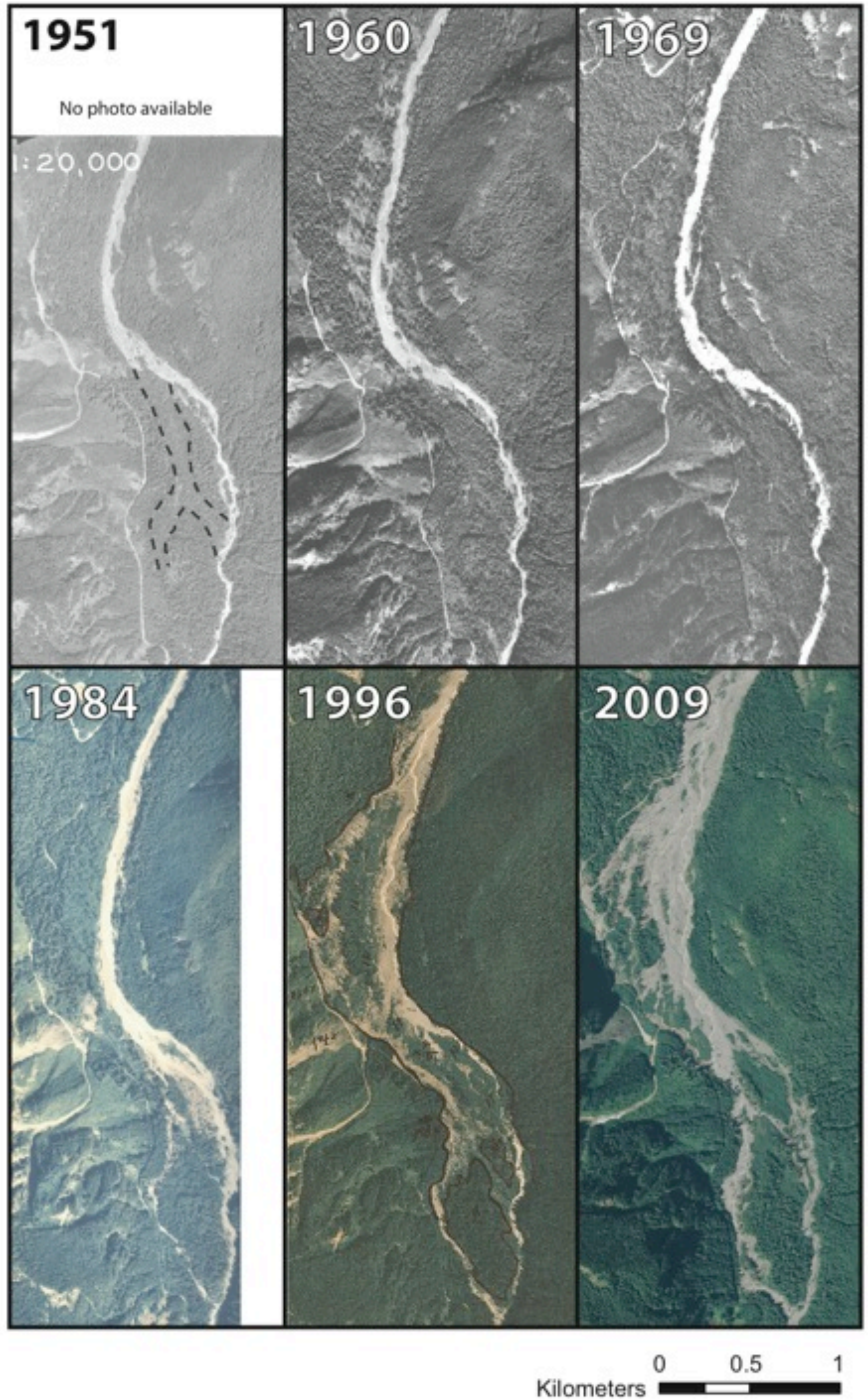
TG
STG
1600
1800
Puyallup
River
1700
2000
12
11
10
9
1500
1900
1200
8
7
1300
6
1800
1900
1400
1100
5
1600
1600
4
1200
3
1000
1700
Kautz
Creek
2
900
1300
1
Longmire
Bridge
0
800
700
Hwy 706
Nisqually River

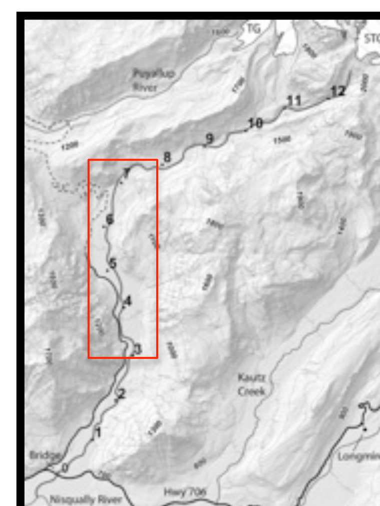
~30 Debris flows since 1967

Two major pulses:

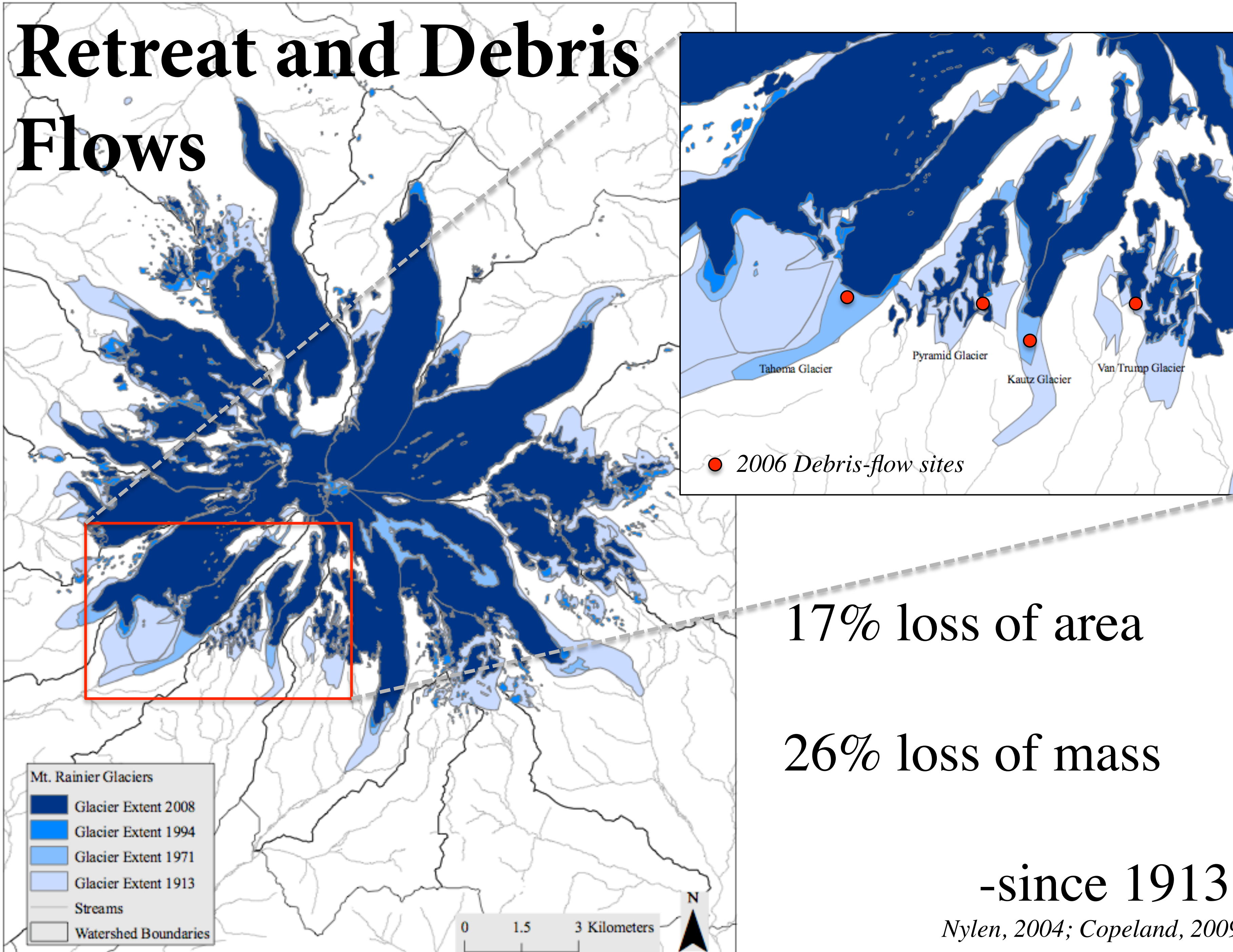
1967-1972

1986-1992





Retreat and Debris Flows

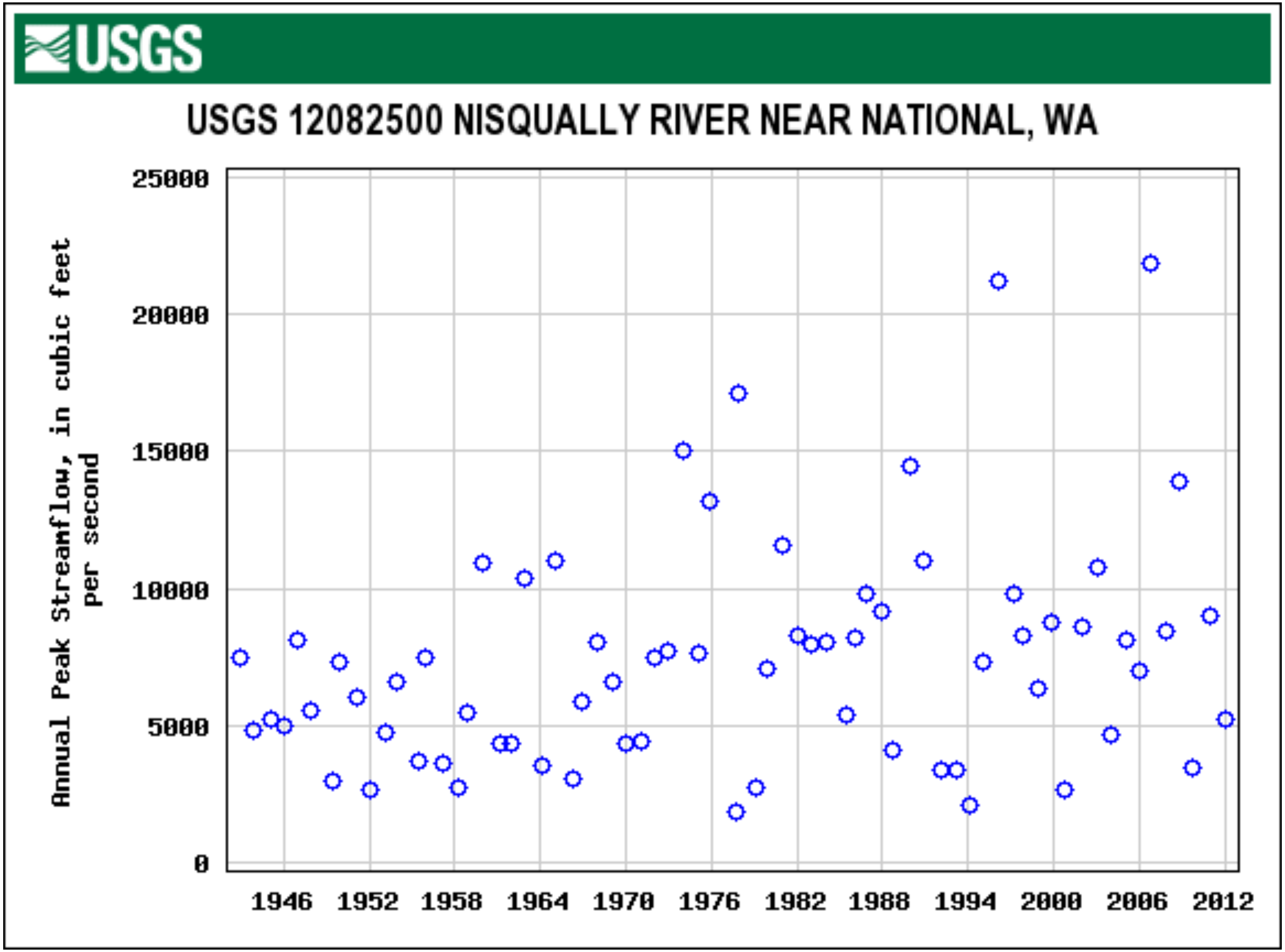


17% loss of area

26% loss of mass

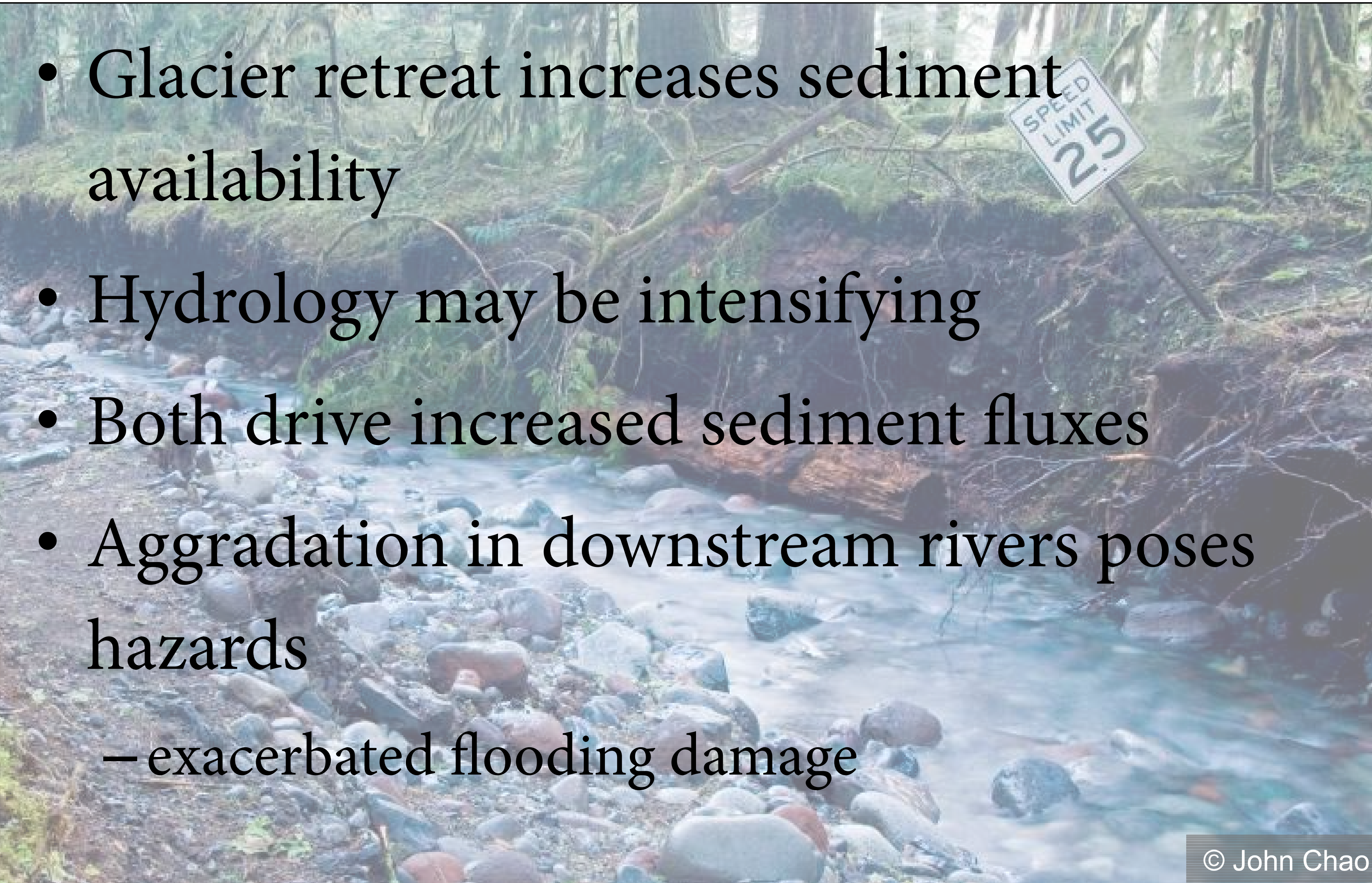
-since 1913

Nylen, 2004; Copeland, 2009

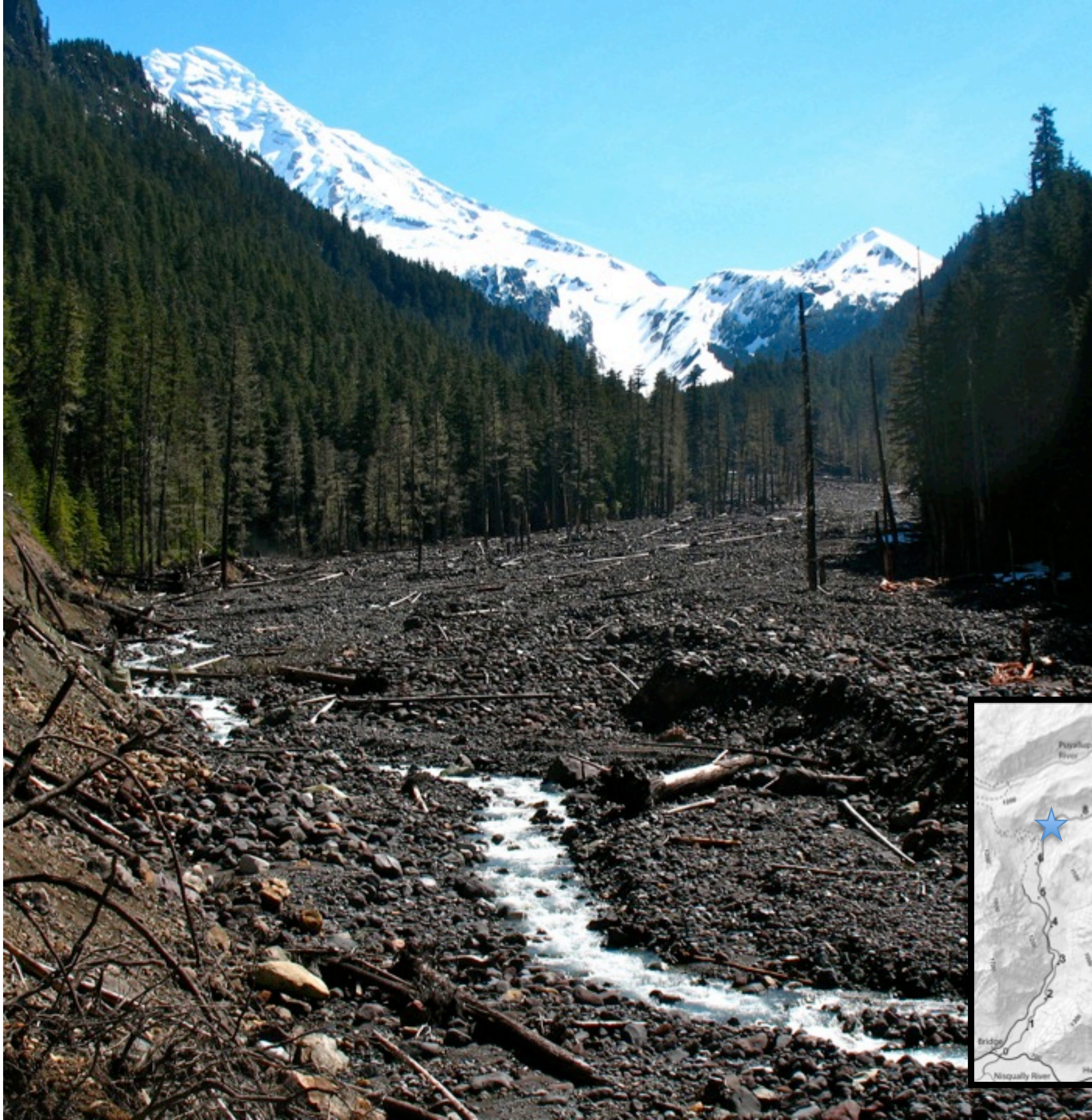

USGS
USGS 12082500 NISQUALLY RIVER NEAR NATIONAL, WA
Annual Peak Streamflow, in cubic feet per second
25000
20000
15000
10000
5000
0
1946
1952
1958
1964
1970
1976
1982
1988
1994
2000
2006
2012

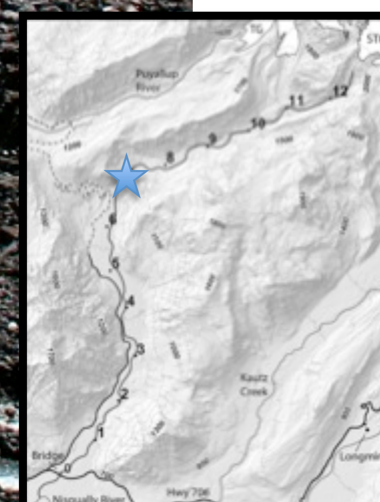
Regional Concern

- Glacier retreat increases sediment availability
- Hydrology may be intensifying
- Both drive increased sediment fluxes
- Aggradation in downstream rivers poses hazards
  - exacerbated flooding damage




TG
STG
Puyallup River
11
12
9
8
6
5
4
3
2
1
0
Bridge
Kautz Creek
Longmire
Nisqually River
Hwy 706





STG
Puyallup River
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2
0
Kautz Creek
Bridge
Longmire
Hwy 706
Nisqually River

Part 1 – Sedimen Transport

Using repeat LiDAR to measure sediment transport in a steep stream. Anderson and Pitlick

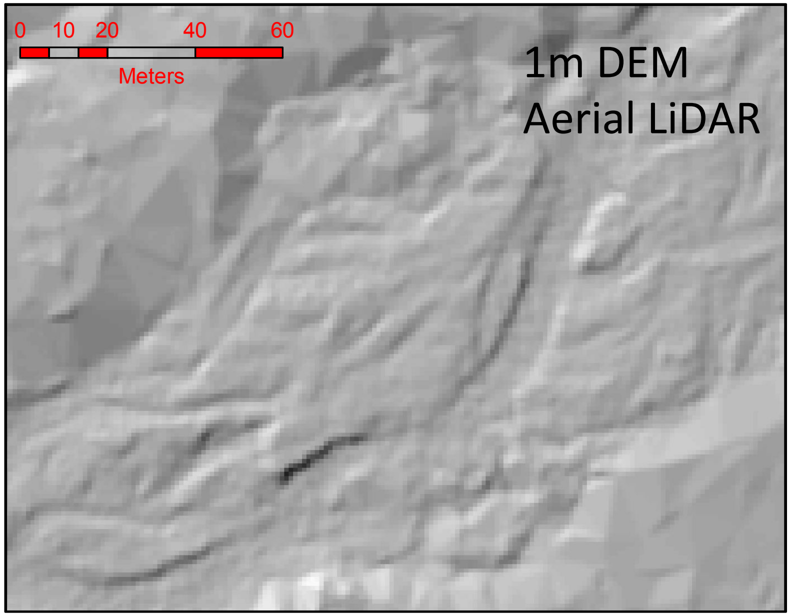
Background

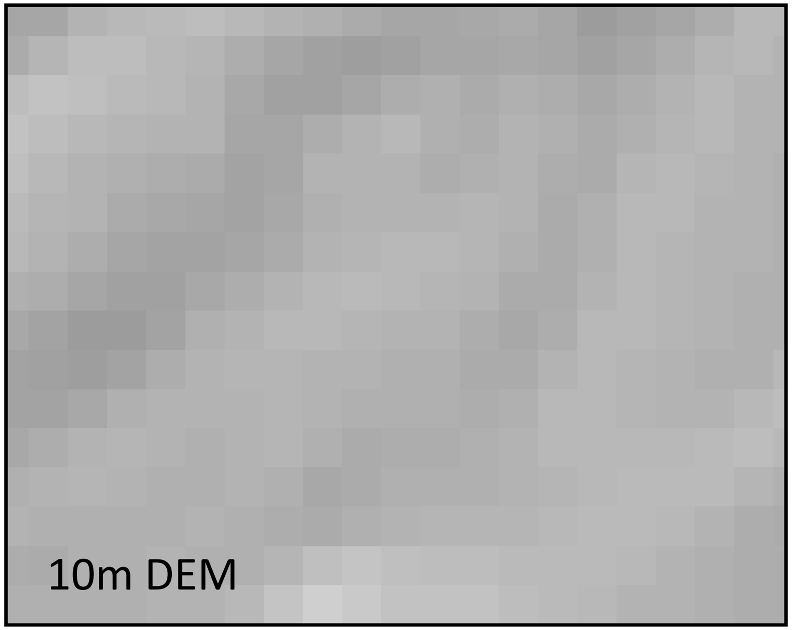
- Bed load transport through steep streams controls timing, pace of response to glacial retreat
- Bed load transport is hard to measure, hard to predict
  - Particularly in steep streams

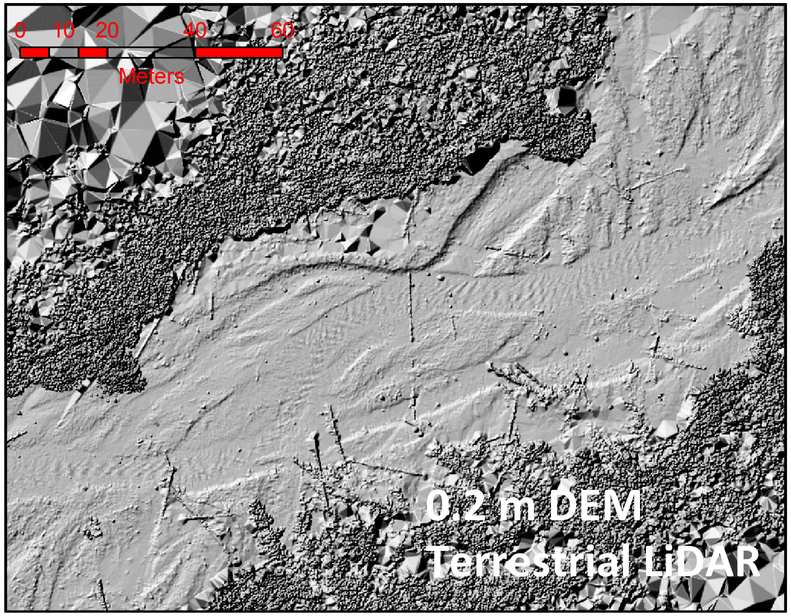

A.
B.

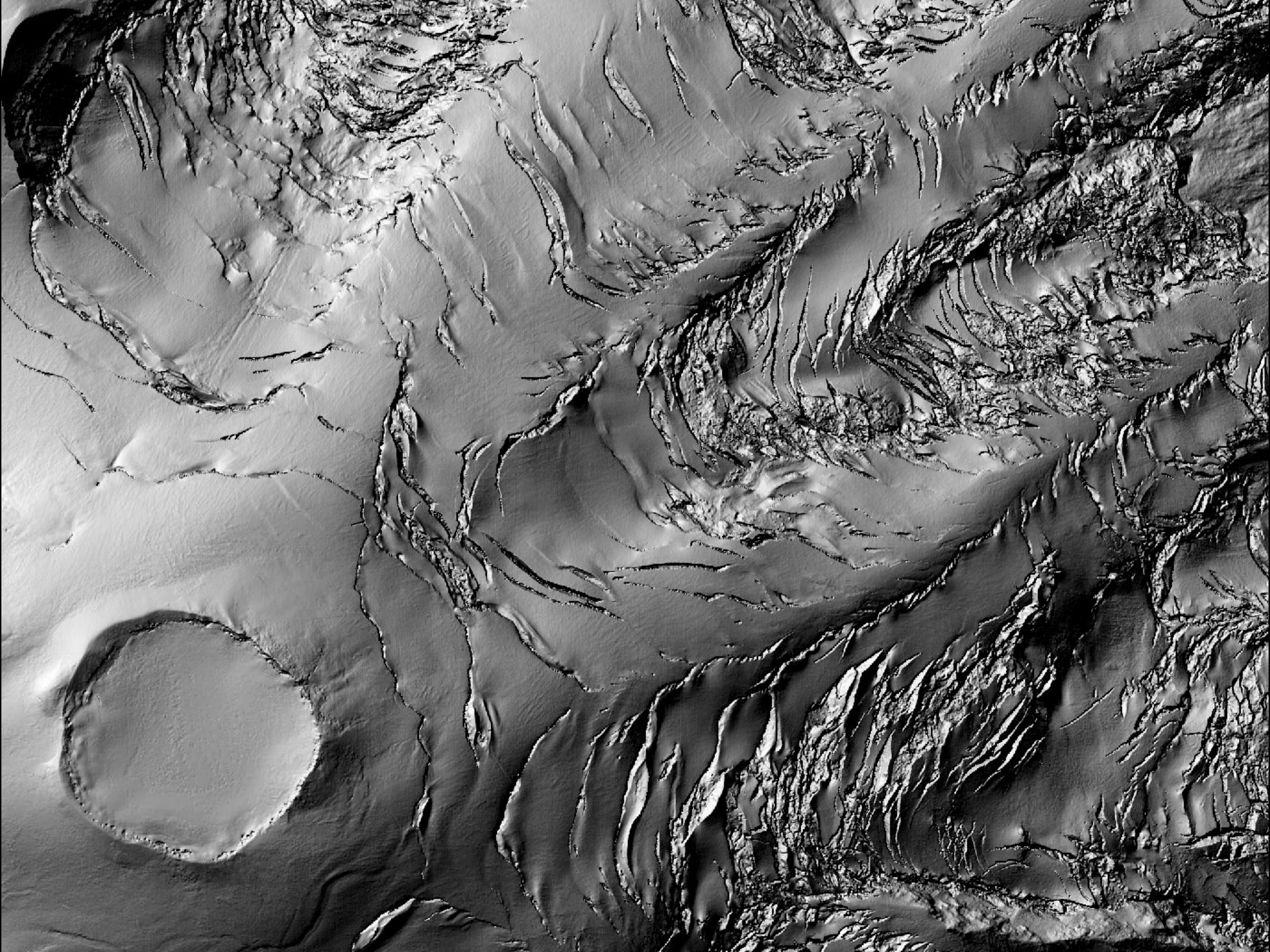
Lasers

- High-resolution topographic surveys have the potential to improve our understanding of everything, ever

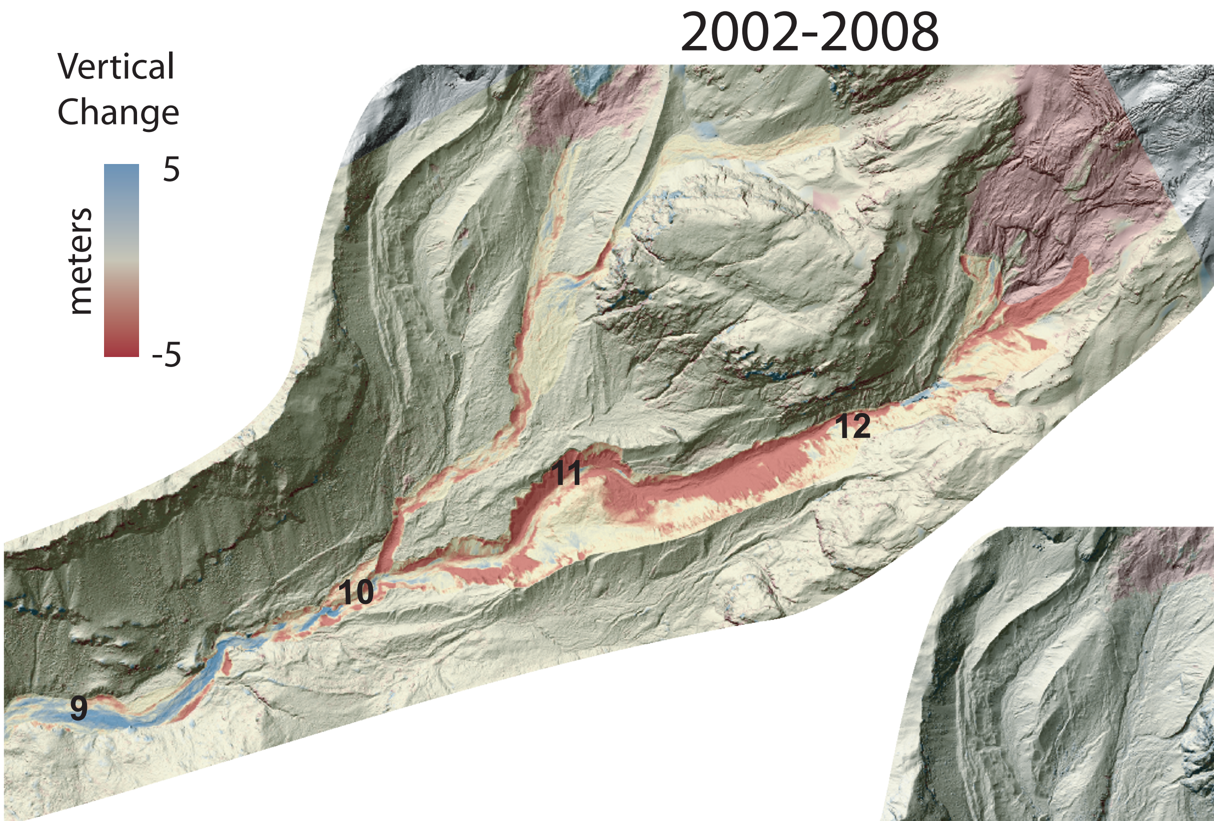


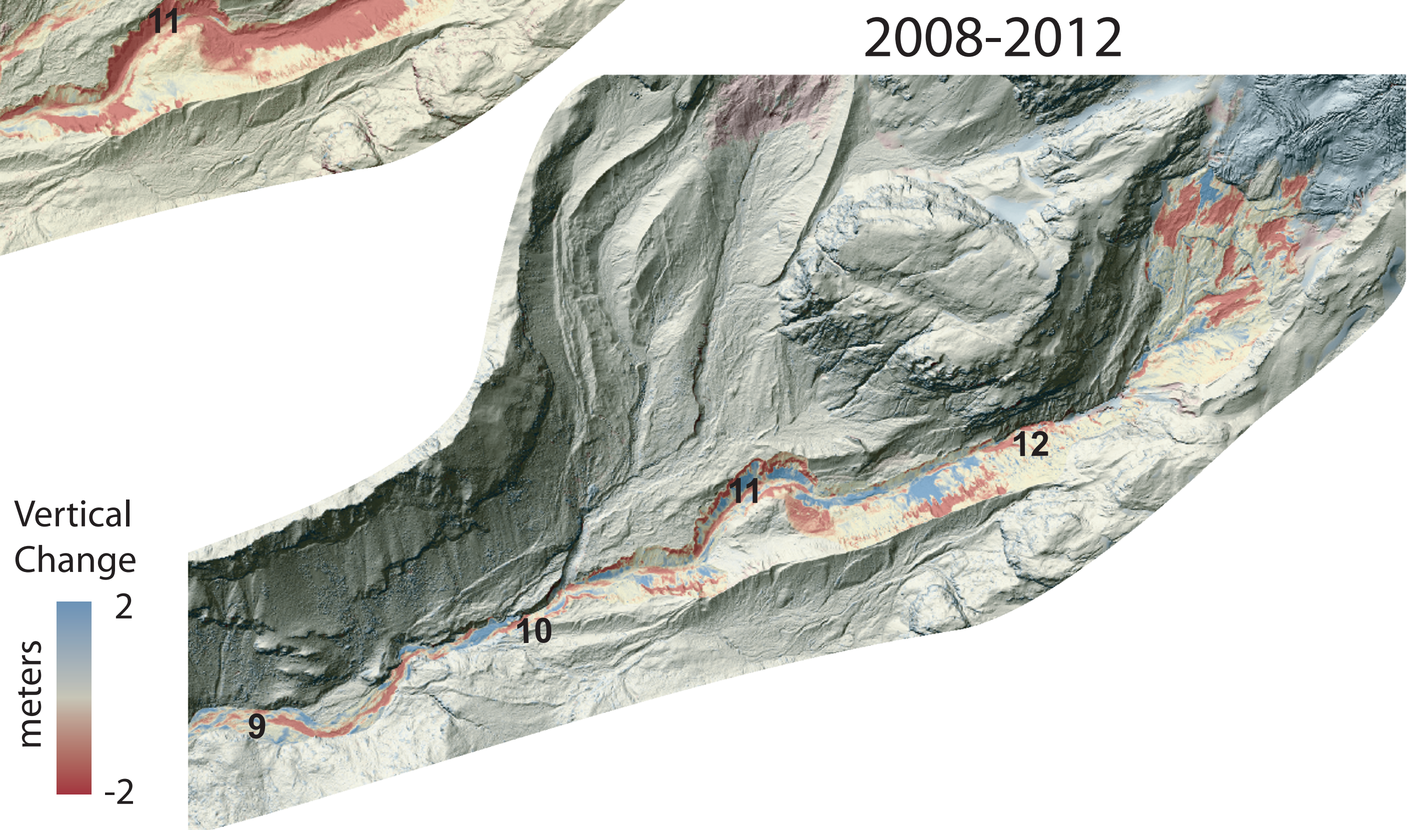






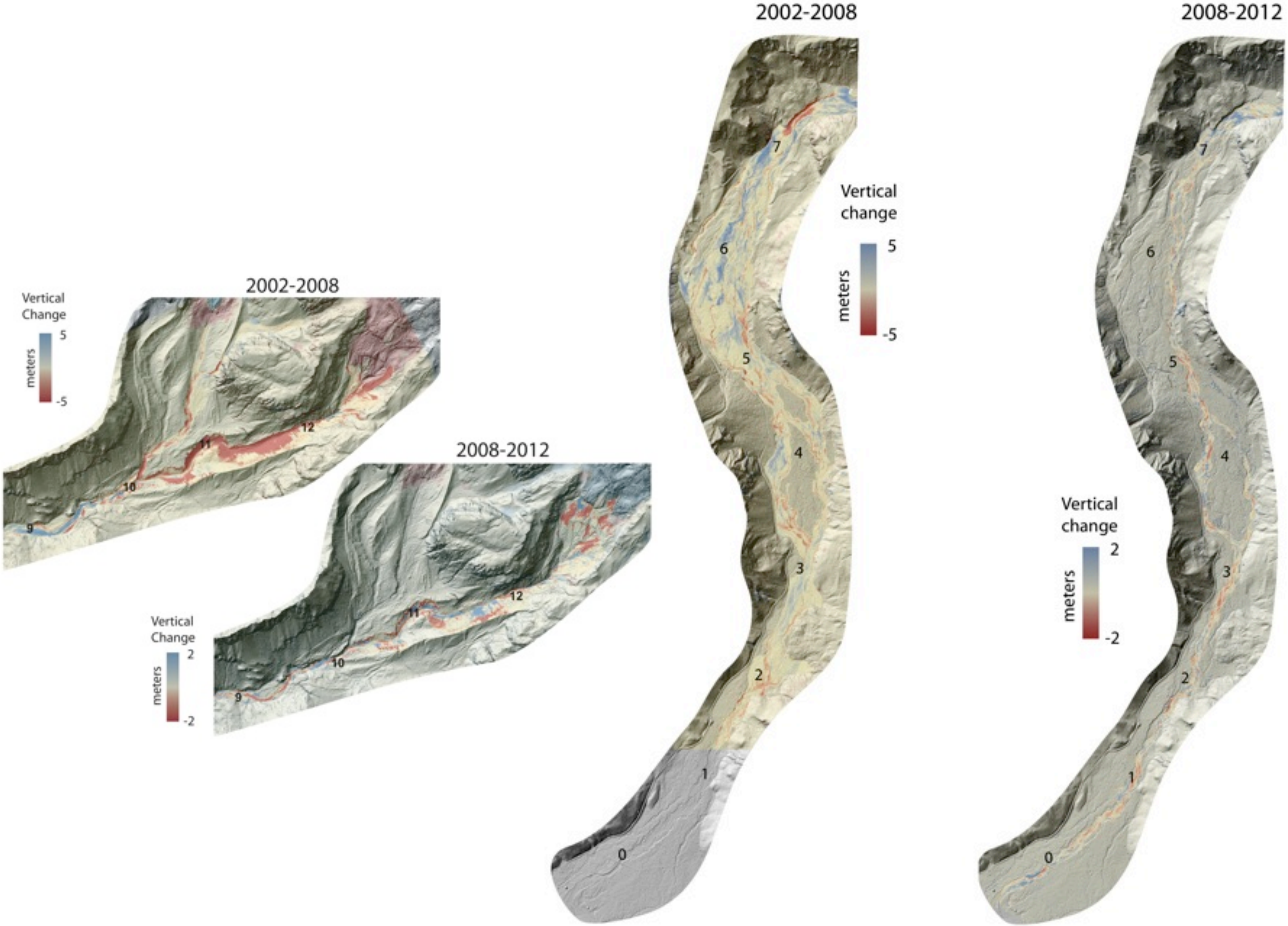
Morphologic Budgeting





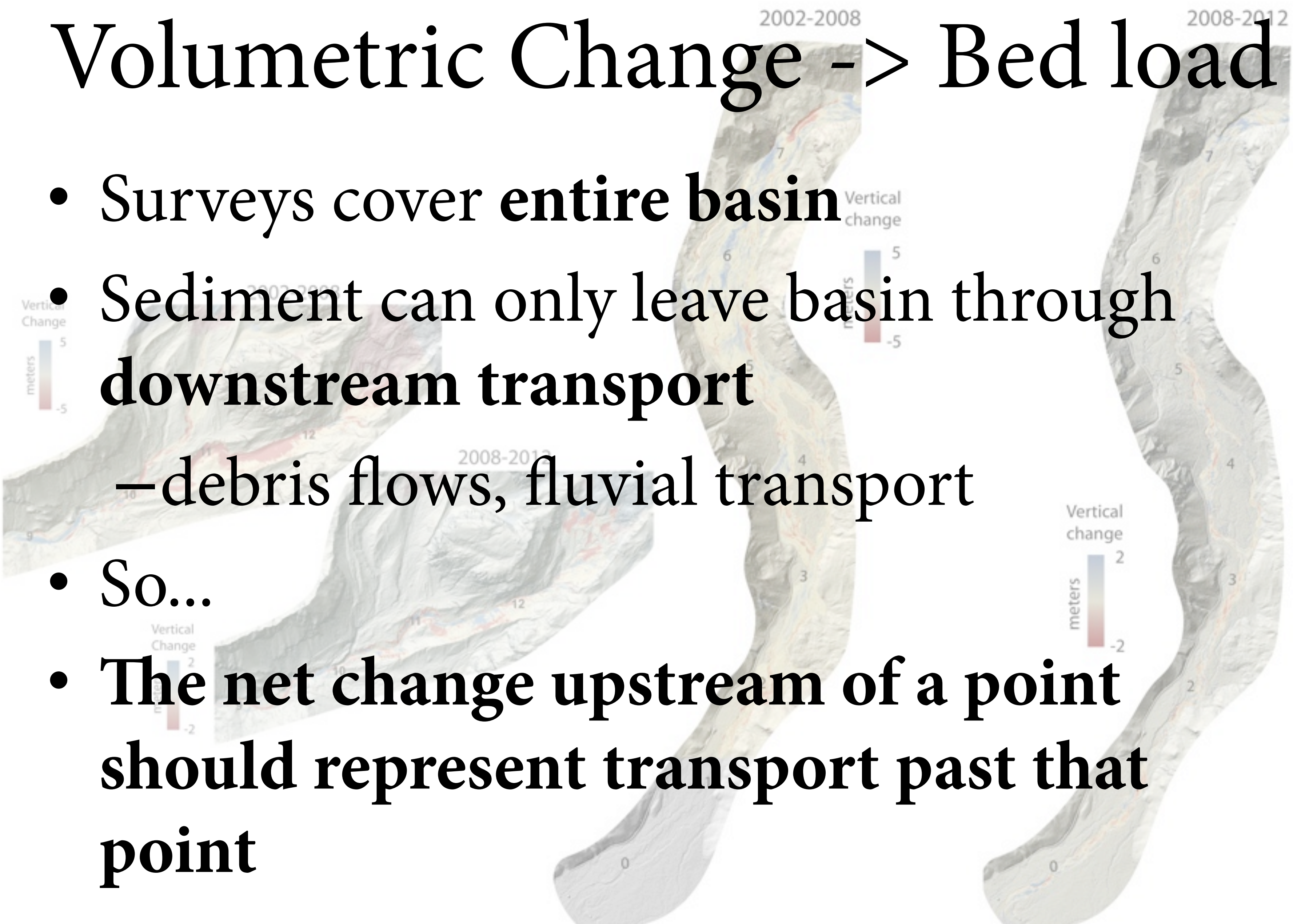
Overview

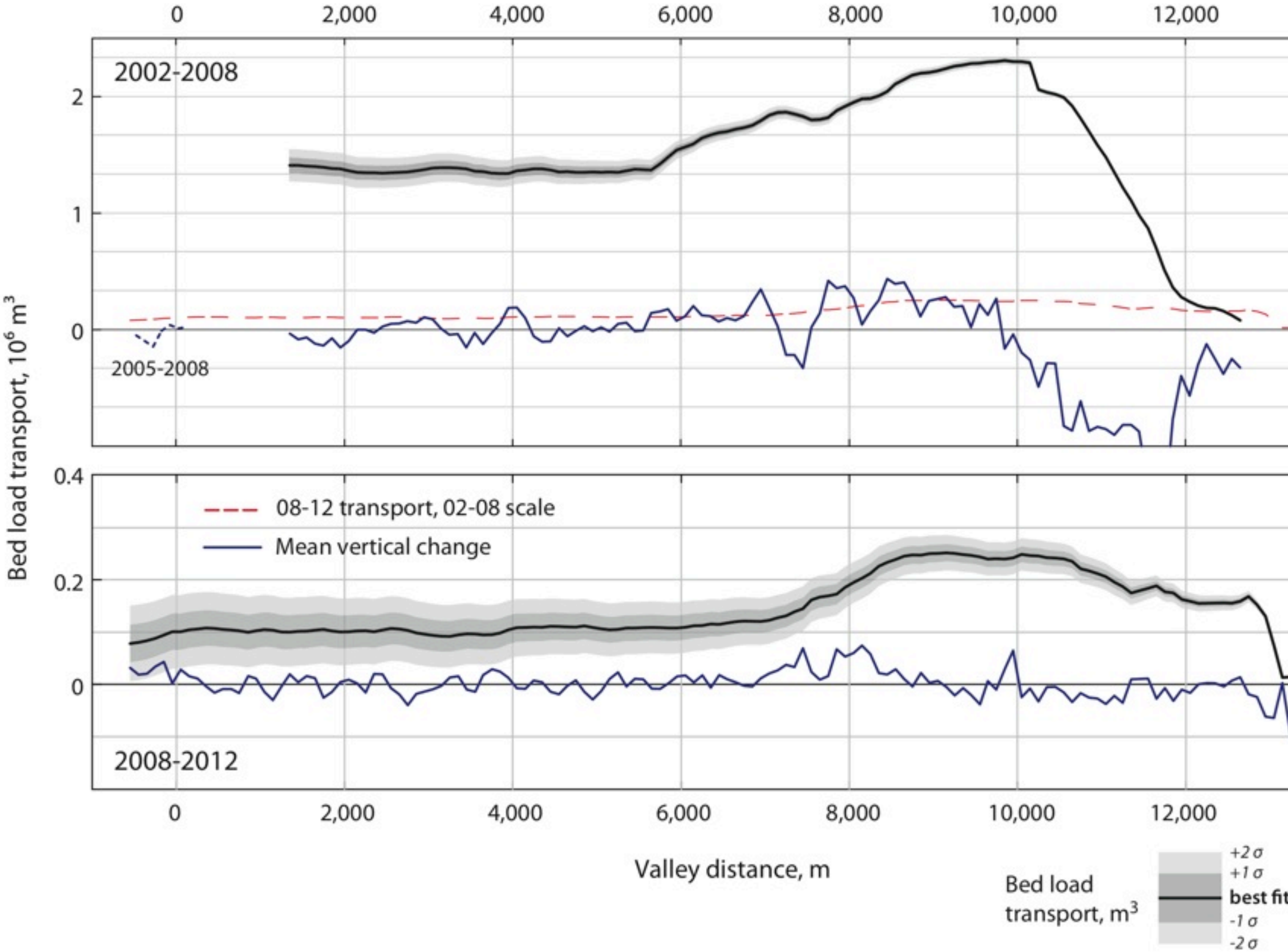
- LiDAR flown in 2002, 2008, 2012
- Create '02-'08 and '08-'12 DoDs
- Estimate bed load transport
- Use transport rates, hydrology to create sediment rating curve


2002-2008
Vertical Change
meters
5
-5
9
10
11
12
2008-2012
Vertical Change
meters
2
-2
9
10
11
12
2002-2008
Vertical change
meters
5
-5
0
1
2
3
4
5
6
7
2008-2012
Vertical change
meters
2
-2
0
1
2
3
4
5
6
7

Volumetric Change -> Bed load

- Surveys cover **entire basin**
- Sediment can only leave basin through **downstream transport**
  - debris flows, fluvial transport
- So...
- **The net change upstream of a point should represent transport past that point**





2002-2008
2005-2008
08-12 transport, 02-08 scale
Mean vertical change
2008-2012
Bed load transport, 10^6 m^3
Vertical change, m
Valley distance, m
Bed load transport, m^3
+2 σ
+1 σ
best fit
-1 σ
-2 σ
0
2,000
4,000
6,000
8,000
10,000
12,000
0.4
0.2
2
1
4
-2
-4
-6

Development of rating curve

- **LiDAR provides estimates of total loads over two distinct time periods**
- **Stream gaging provides estimate of hydrology of those two periods**
- **Bed load transport is a function of stream flow**

Development of rating curve

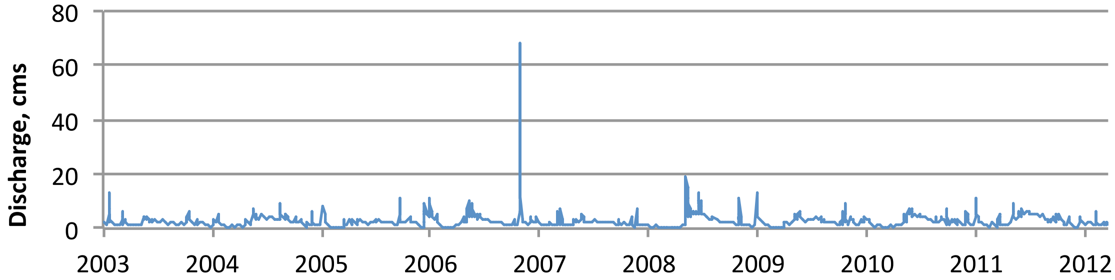
- Assume sediment transport goes as

$$q_s = a(q - q_{crit})^b$$

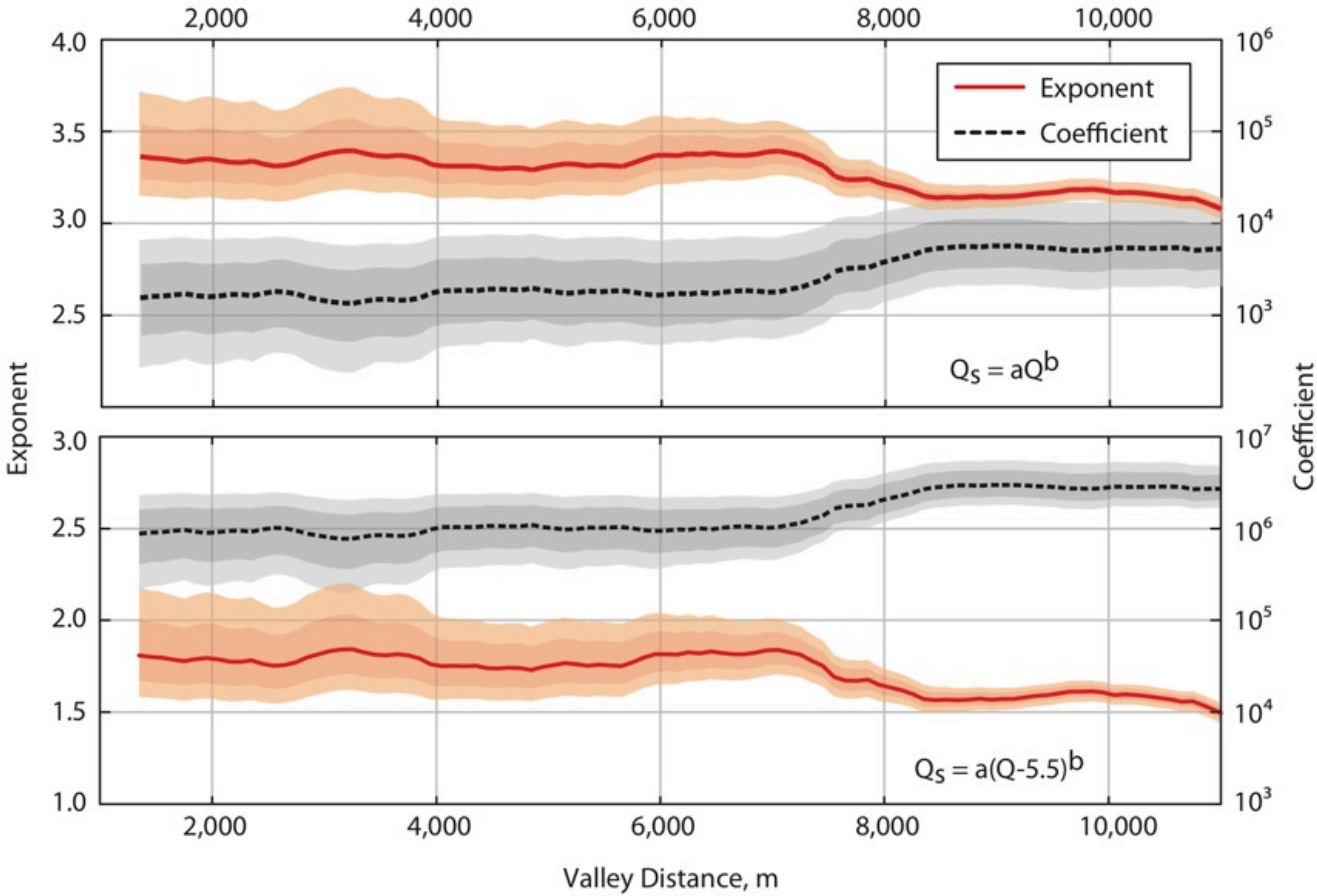
- Use daily mean discharge, two total loads and reasonable q_{crit} to solve for **a** and **b** using paired equations

$$Q_{s1} = \int_{t1}^{t2} a(q - q_{crit})^b$$

$$Q_{s2} = \int_{t2}^{t3} a(q - q_{crit})^b$$

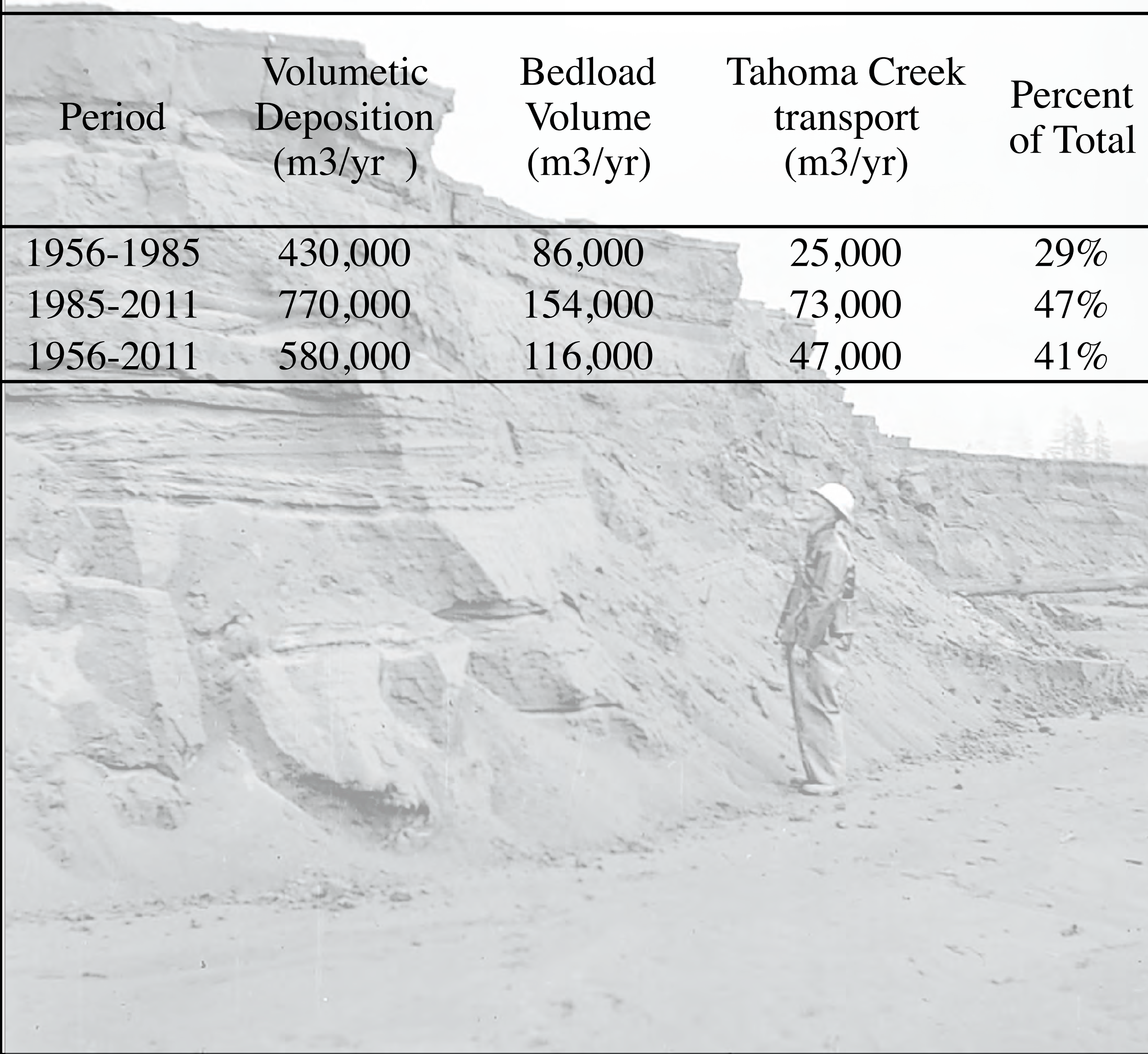


Cumulative sum of $q_s = a(q - q_{crit})^b$



Exponent
Coefficient
$Q_S = aQ^b$
$Q_S = a(Q-5.5)^b$
Valley Distance, m
2,000
4,000
6,000
8,000
10,000
4.0
3.5
3.0
2.5
2.0
1.5
1.0
10^3
10^4
10^5
10^6
10^7

Period	Volumetic Deposition (m3/yr)	Bedload Volume (m3/yr)	Tahoma Creek transport (m3/yr)	Percent of Total
1956-1985	430,000	86,000	25,000	29%
1985-2011	770,000	154,000	73,000	47%
1956-2011	580,000	116,000	47,000	41%



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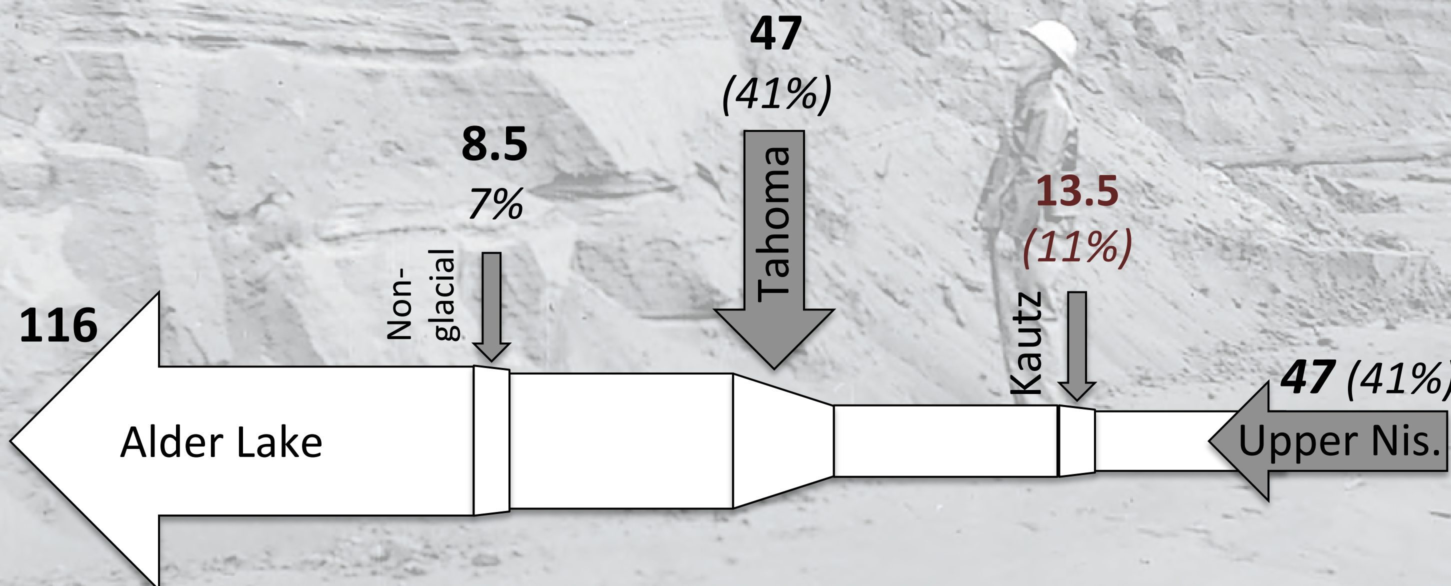


Coarse sediment fluxes, 1000s of m^3/yr

Disadvantages

- **Cost**
- **Time** - Interval between surveys

Advantages

- **Static measurement** of topography
- **Integrated transport rates** over many event
- **Most accurate for high flows, active basins**
  - works best where most methods struggle most
- **Works for any integrated sediment loads**

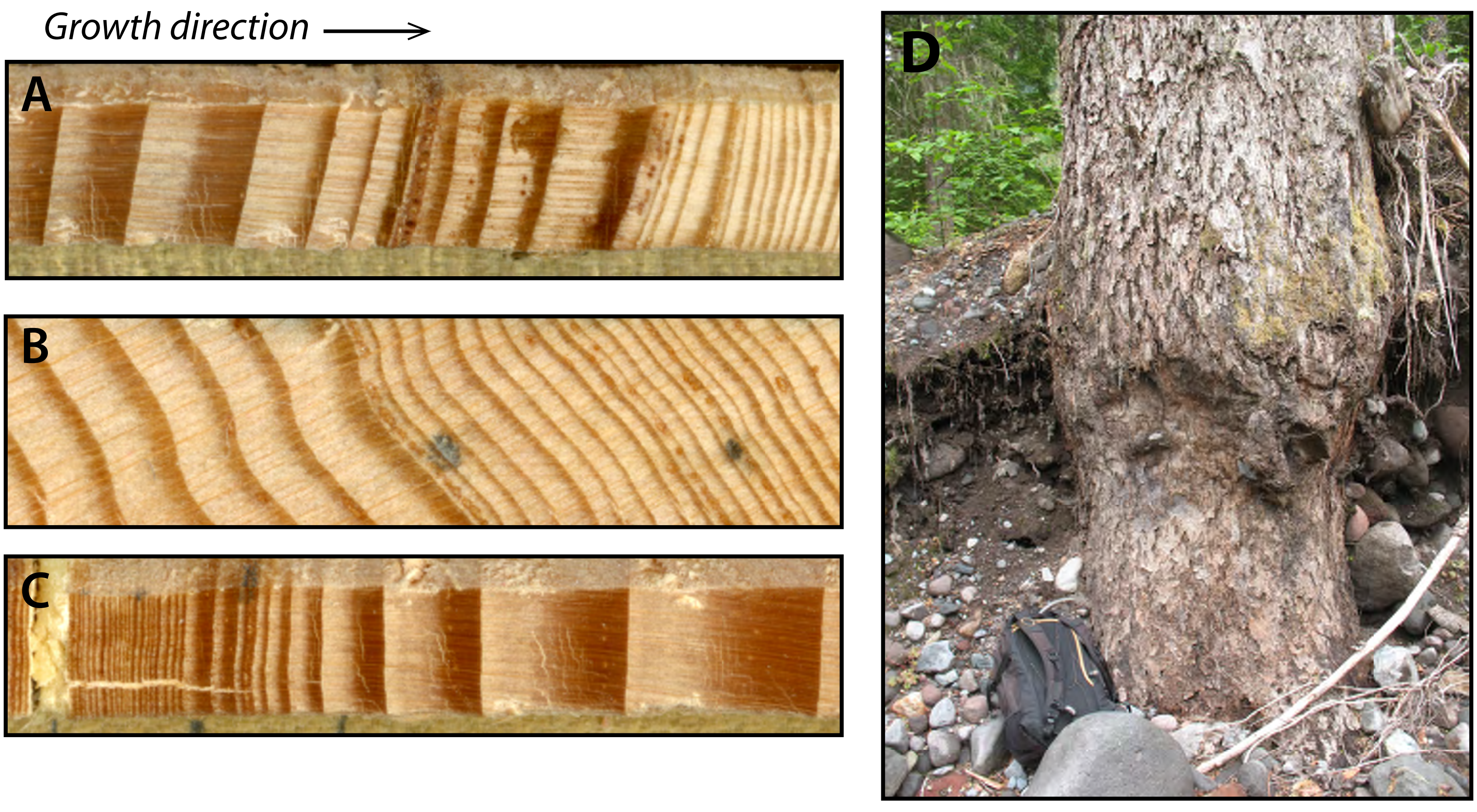

Part 2 – Dendrochronology+
The geomorphic impacts and historical precedence of debris flows within Tahoma Creek, Mount Rainier, WA. Anderson and Kennard

Overview

- Are debris flows more frequent in a warming climate?
  - Higher sediment availability
  - More triggering events

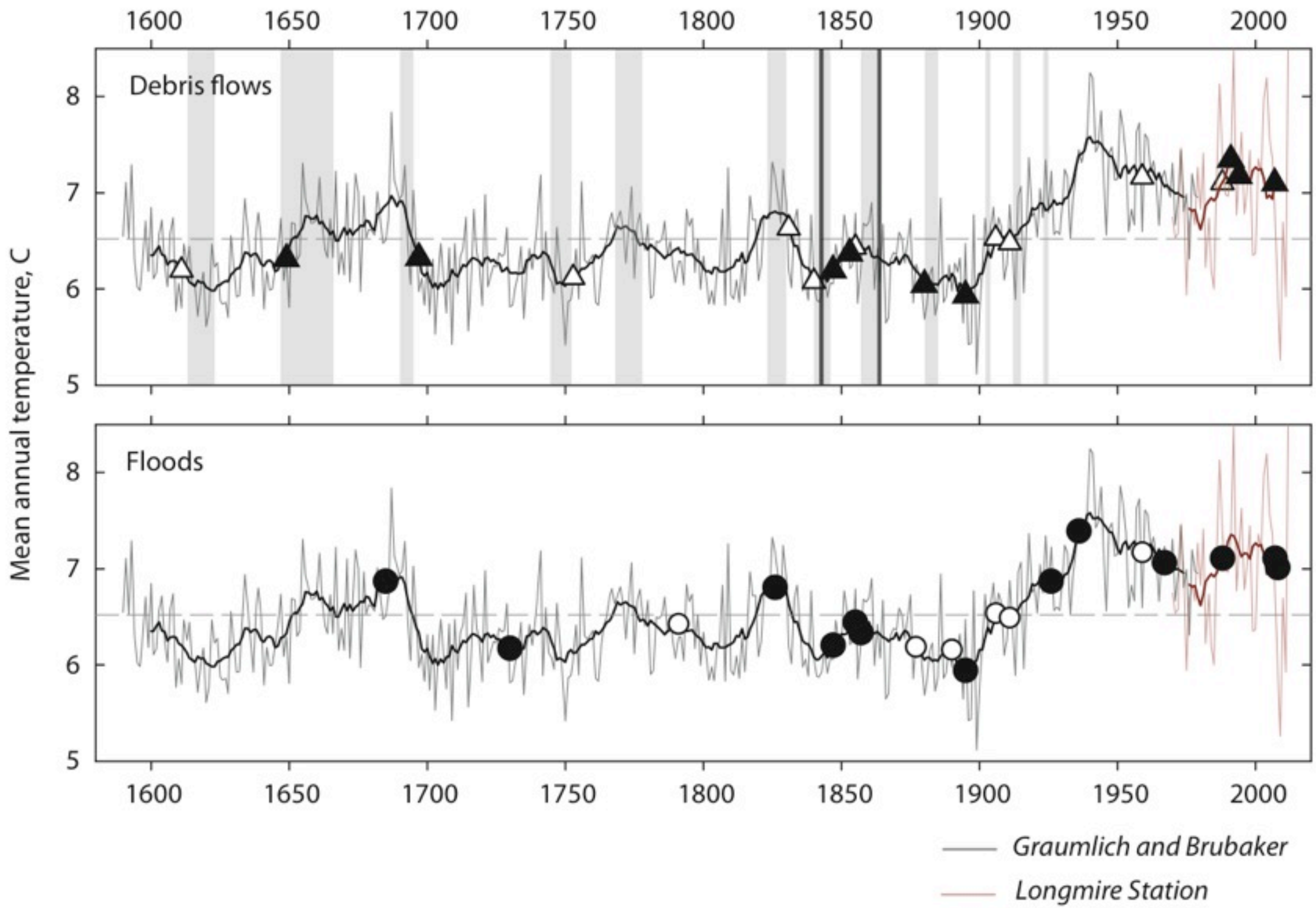
- Need:
  - Baseline data of historical frequency
  - Understanding of climatic controls

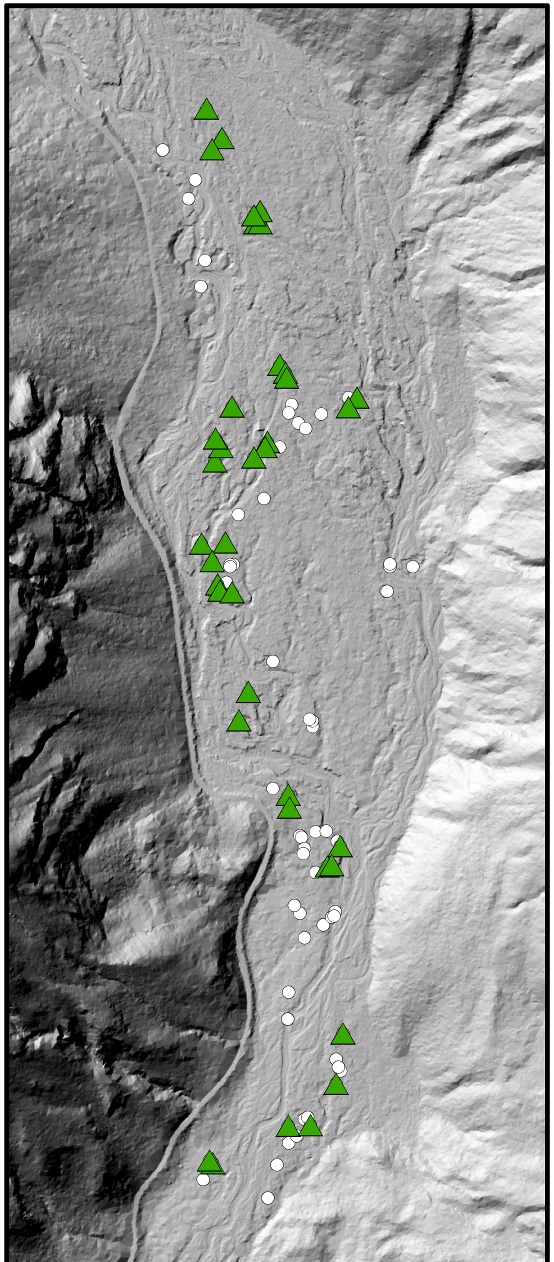
Dendrochronology



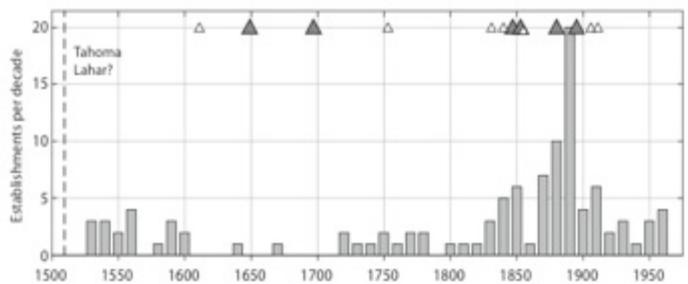
Year	*Event Type*	*disturbances recorded*	*Sample depth*	*Percent affected*	*Establishments*
1508	Tahoma Lahar?	**3**	**9**	**33%**	*na*
1530-1563	Establishment	*na*	*na*	*na*	**12**
1611	*Debris flow*	*2*	*33*	*6%*	*na*
1643	Landslide	**4**	**38**	**11%**	*na*
1649	Debris flow	**5**	**38**	**13%**	*na*
1685	Flood	**4**	**44**	**9%**	*na*
1697	Debris flow	**6**	**45**	**13%**	*na*
1730	Flood	**5**	**51**	**10%**	*na*
1753	*Debris flow*	*5*	*55*	*9%*	*na*
1791	*Flood*	*4*	*66*	*6%*	*na*
1826	Flood	**7**	**73**	**10%**	*na*
1831	*Debris flow*	*4*	*73*	*5%*	*na*
1840	*Debris flow*	*5*	*81*	*6%*	*na*
1847	Debris flow, flood	**7**	**84**	**8%**	*na*
1853	Debris flow	**7**	**87**	**8%**	*na*
1855	Flood, debris flow?	**7**	**87**	**8%**	*na*
1877	*Flood*	*4*	*98*	*4%*	*na*
1880	Debris flow	**7**	**101**	**7%**	*na*
1890	*Flood*	*4*	*120*	*3%*	*na*
1895	Debris flow, flood	**12**	**129**	**9%**	*na*
1870-1896	Establishment	*na*	*na*	*na*	**38**
1905-8	*Floods, debris flows?*	*11*	*135*	*8%*	*na*
1911-12	*Debris flow, flood*	*5*	*136*	*4%*	*na*
1925-6	Flood	**11**	**144**	**8%**	*na*
1936	Flood	**9**	**148**	**6%**	*na*
1959-60	Flood, debris flow?	**16**	**155**	**10%**	*na*
1966-1968	Outburst floods?	**16**	**158**	**10%**	*na*
1988	Flood, debris flow?	**8**	**158**	**5%**	*na*
1991	Debris flow	**20**	**158**	**13%**	*na*
1993-1995	Debris flows	**19**	**158**	**12%**	*na*
2007	Flood, debris flow	**14**	**151**	**9%**	*na*
2008-2009	Floods	**13**	**151**	**9%**	*na*

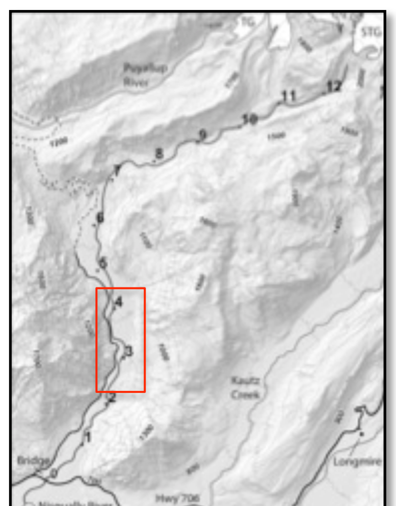
Temperature, Glacial Mass Balance





Post-LIA colonization
(*1870-1896*)





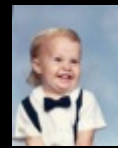
Debris Flow Summary

- **Debris flows occur in decades following glacial retreat**
  - Increased sediment availability (?)
  - Increased frequency of outburst floods (??)
- **Post-LIA debris flows were likely as destructive as modern debris flows**
  - Some indication of increased intensity

Synthesis

- **Tahoma Creek does not show clear evidence of functioning outside of historical range of variability**
  - **May function as conduit; look to depositional zones**

Questions?



References

Copeland, B. 2009. Recent Periglacial Debris Flows from Mount Rainier, Washington. M.S. Thesis, Oregon State Univ.

Nylen, T.N. 2004. Spatial and Temporal Variations of Glaciers (1913-1994) on Mt. Rainier and the Relation with Climate. M.S. Thesis, Portland State University, 111p.