Accelerated Snow and Glacier Melt in Washington State from Black Carbon Deposition

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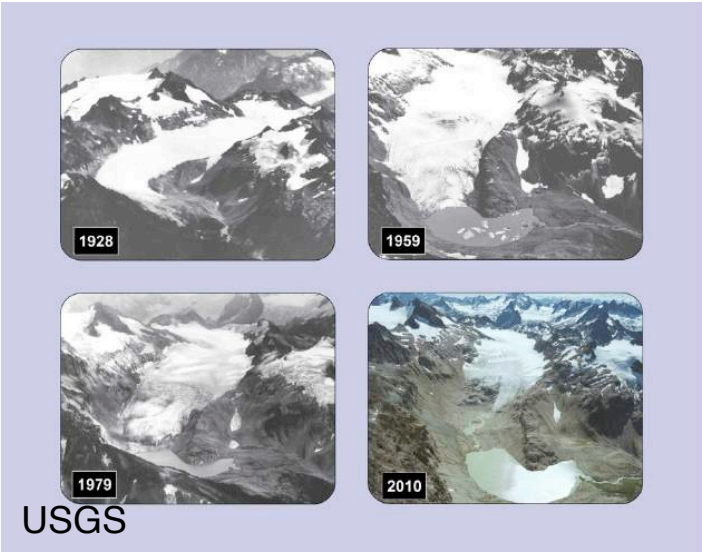
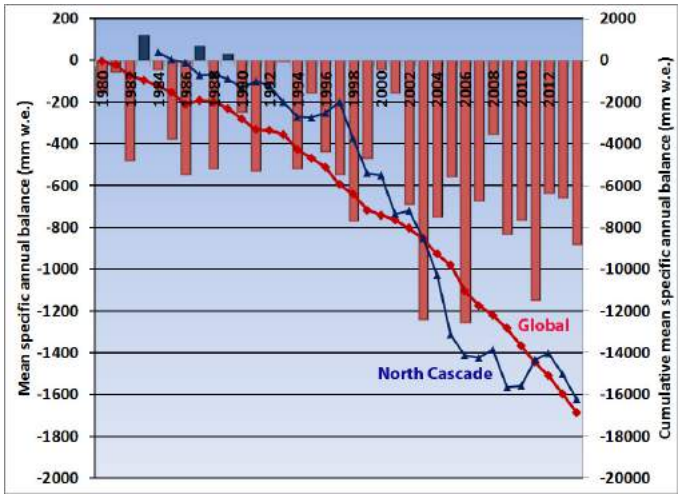
Glacier Retreat and Snowpack Decline in Washington State

South Cascade Glacier



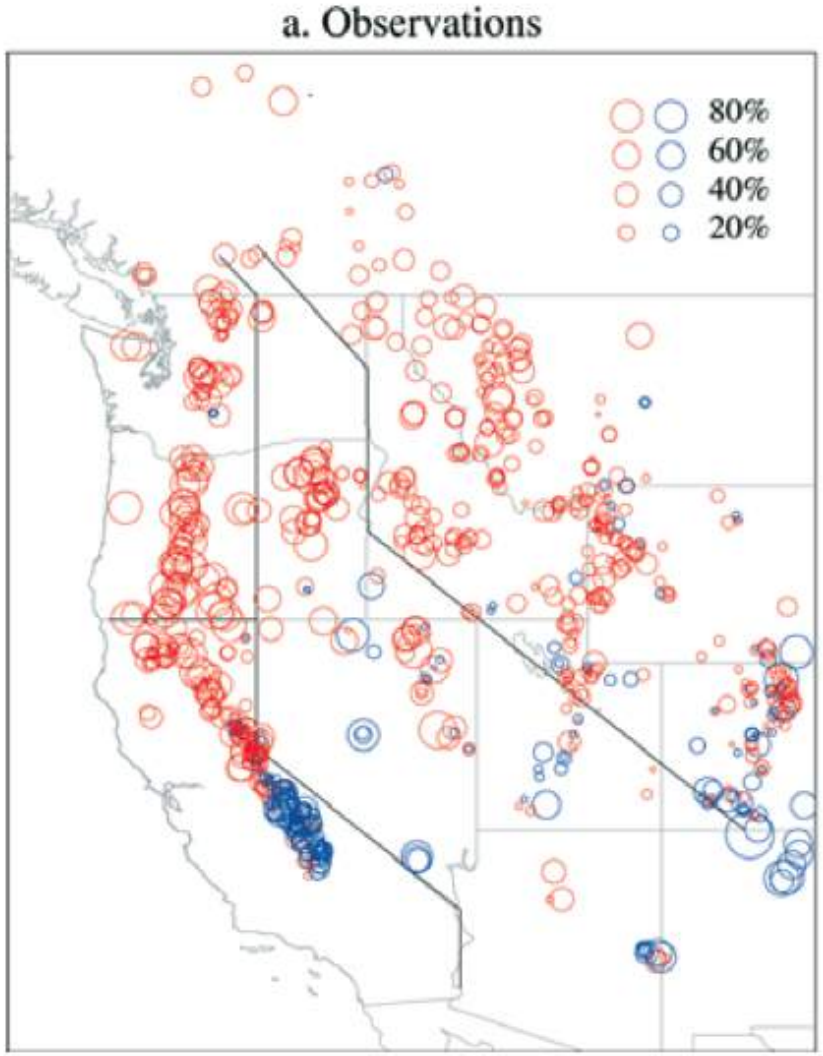
USGS

Glacier Mass Balance (North Cascades)



Pelto, 2015

Linear Trend in April 1 Snow Water Equivalent 1950-1997

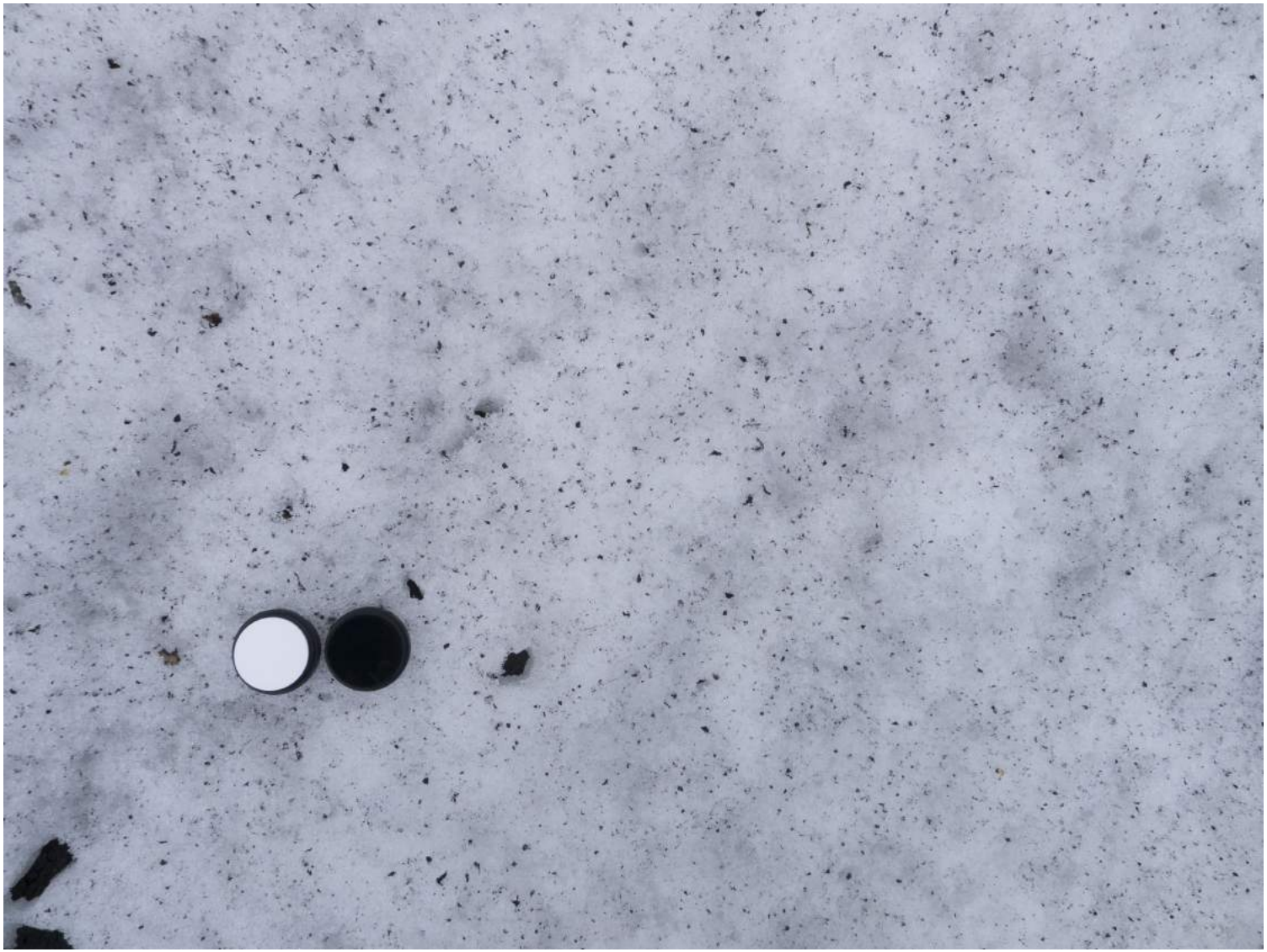


Mote et al., 2005


Is black carbon (and dust) deposition a major factor in observed snow and glacier melt in Washington State?

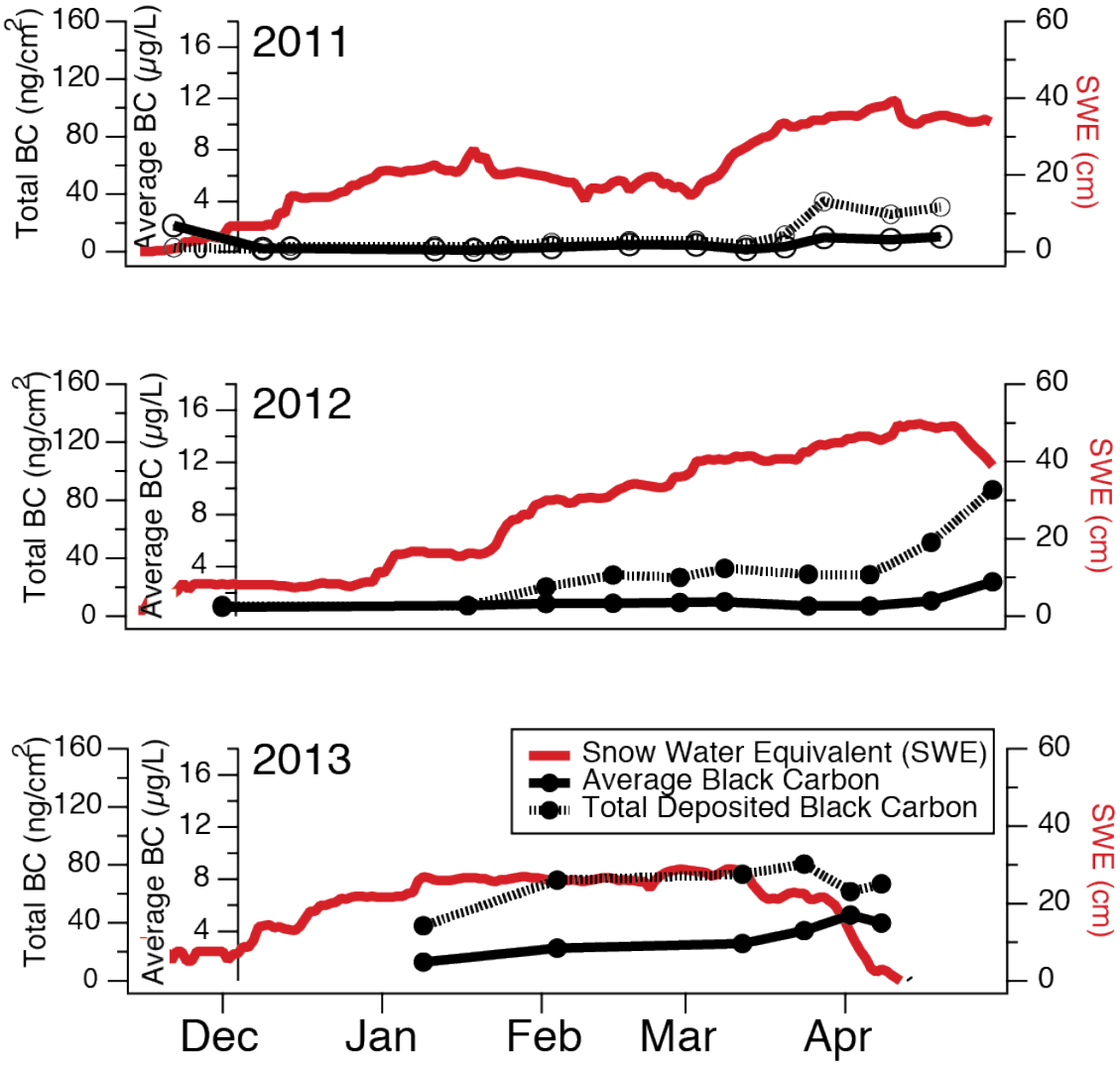
Black carbon (soot): produced by incomplete combustion of fossil and bio fuels.

Black carbon, burned woody debris, dust and organic matter can darken the snow surface and accelerate melt.



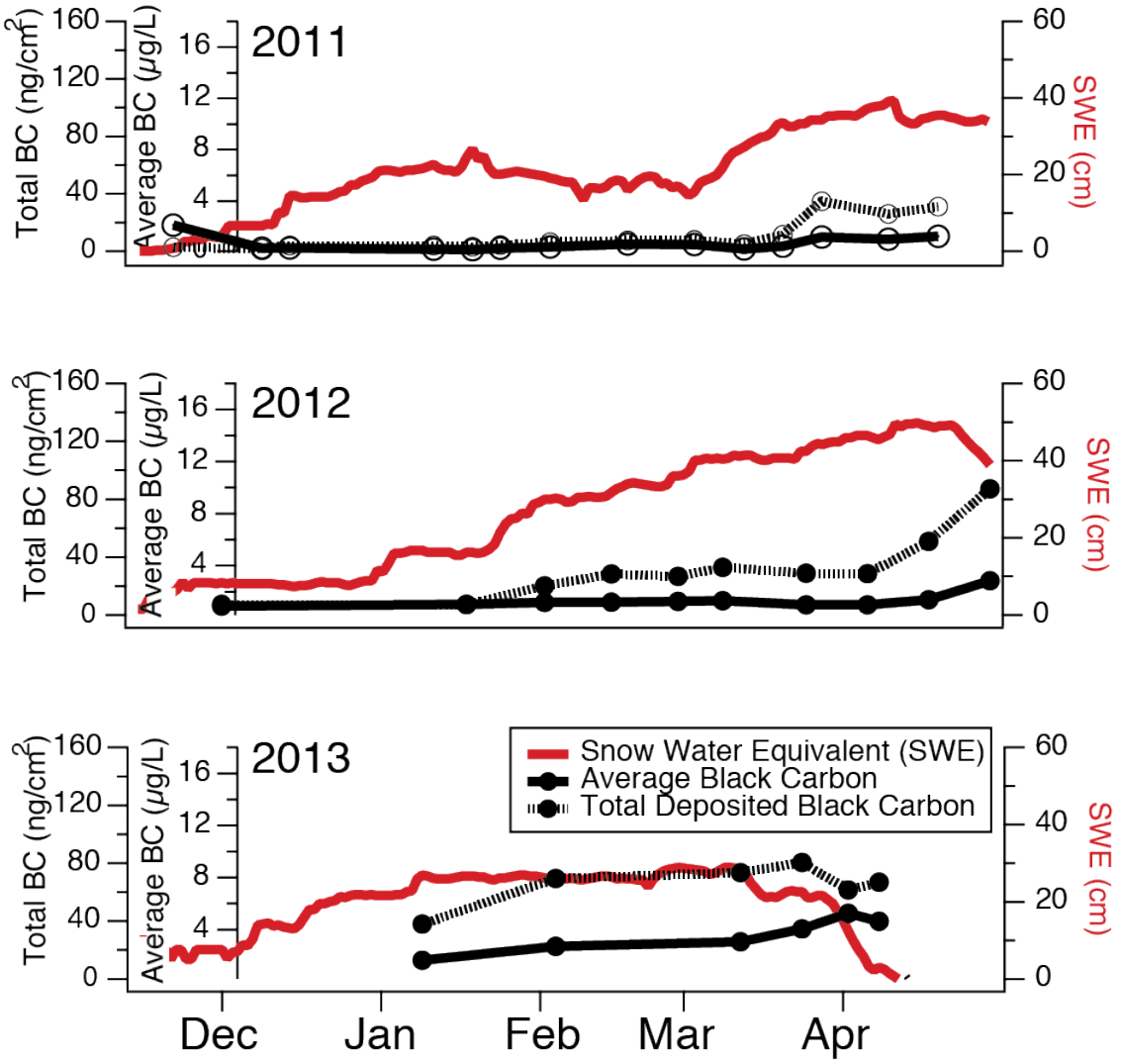
Study Sites in Washington State (2009-2014)

Black Carbon in the Seasonal Snowpack at Blewett Pass, WA

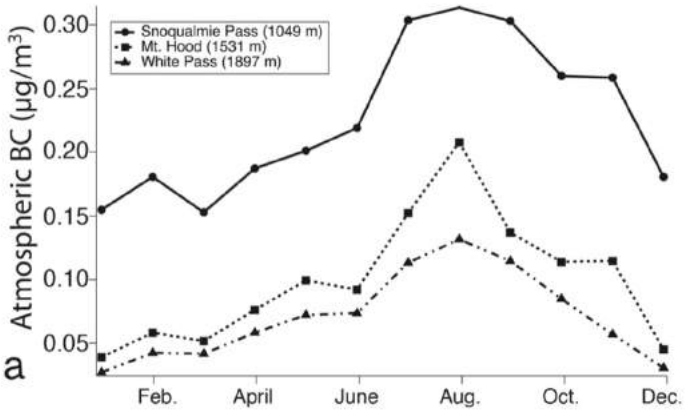


Delaney et al., 2015

Black Carbon in the Seasonal Snowpack at Blewett Pass, WA



Atmospheric BC



Highest concentrations during the spring:

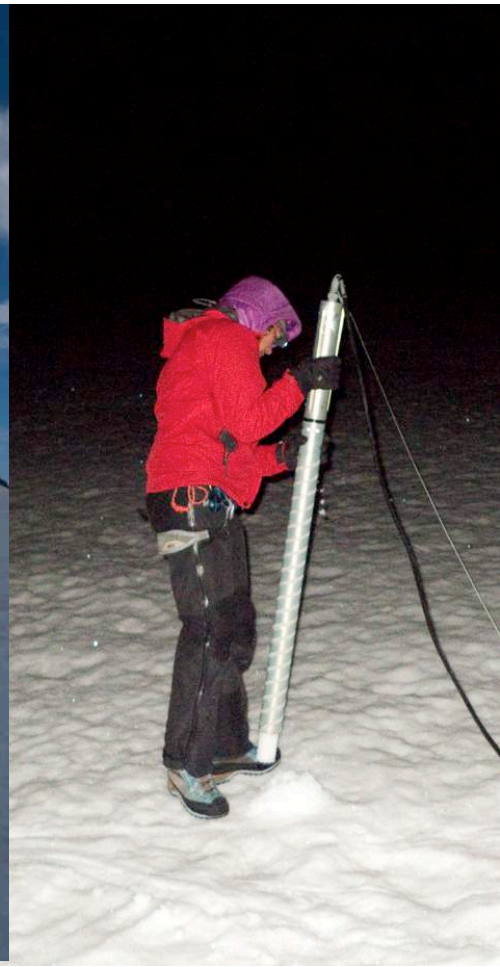
- Higher atmospheric BC concentrations
- Melt consolidation

Elevated BC in 2013 post-wildfire

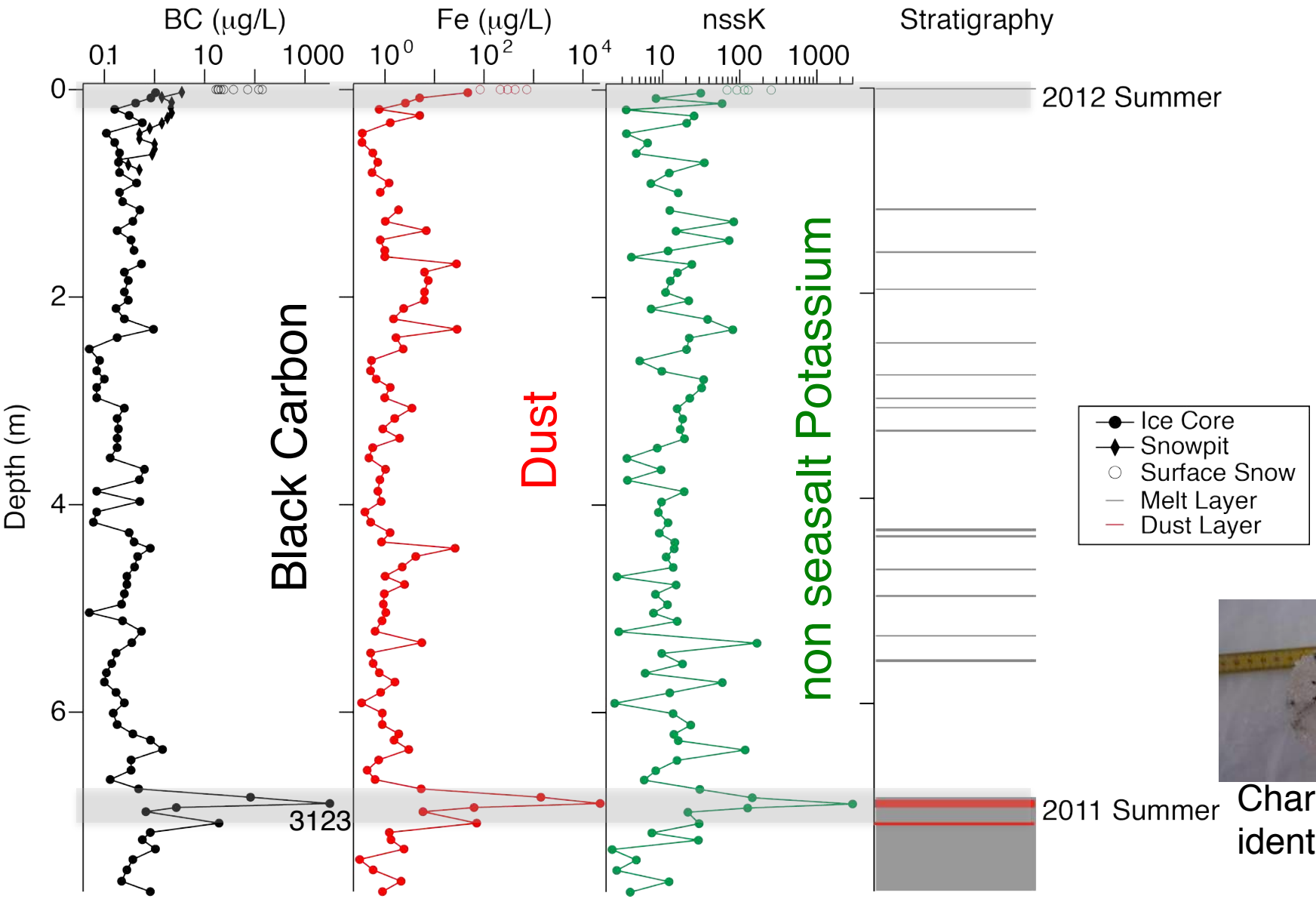
Delaney et al., 2015

Wildfire

Snow Dome, Mt. Olympus, Washington



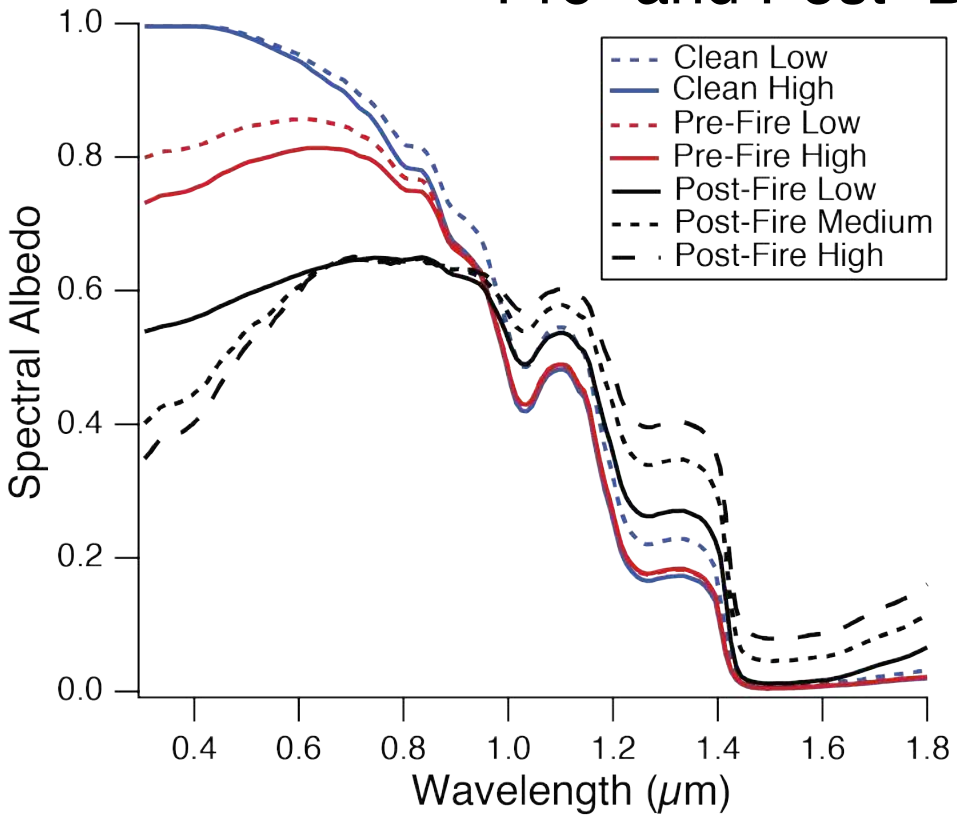
Black Carbon and Dust Deposition on Snow Dome, Mt. Olympus



Charcoal identified

Kaspari et al., 2015

Albedo Reductions and Estimated Radiative Forcing and Melt Pre- and Post- Big Hump Fire

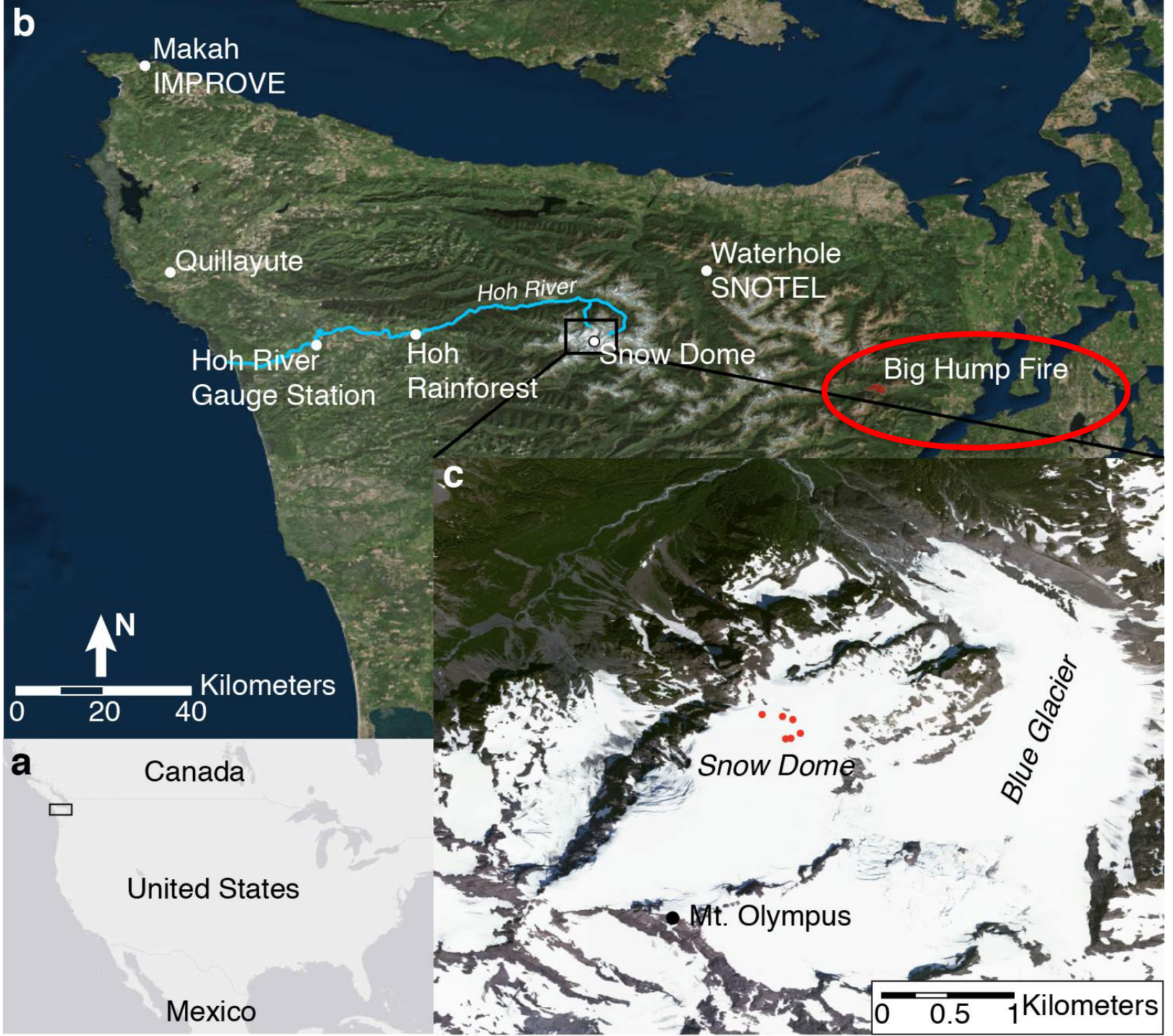


Post-fire melt is 2-3 X greater than pre-fire melt

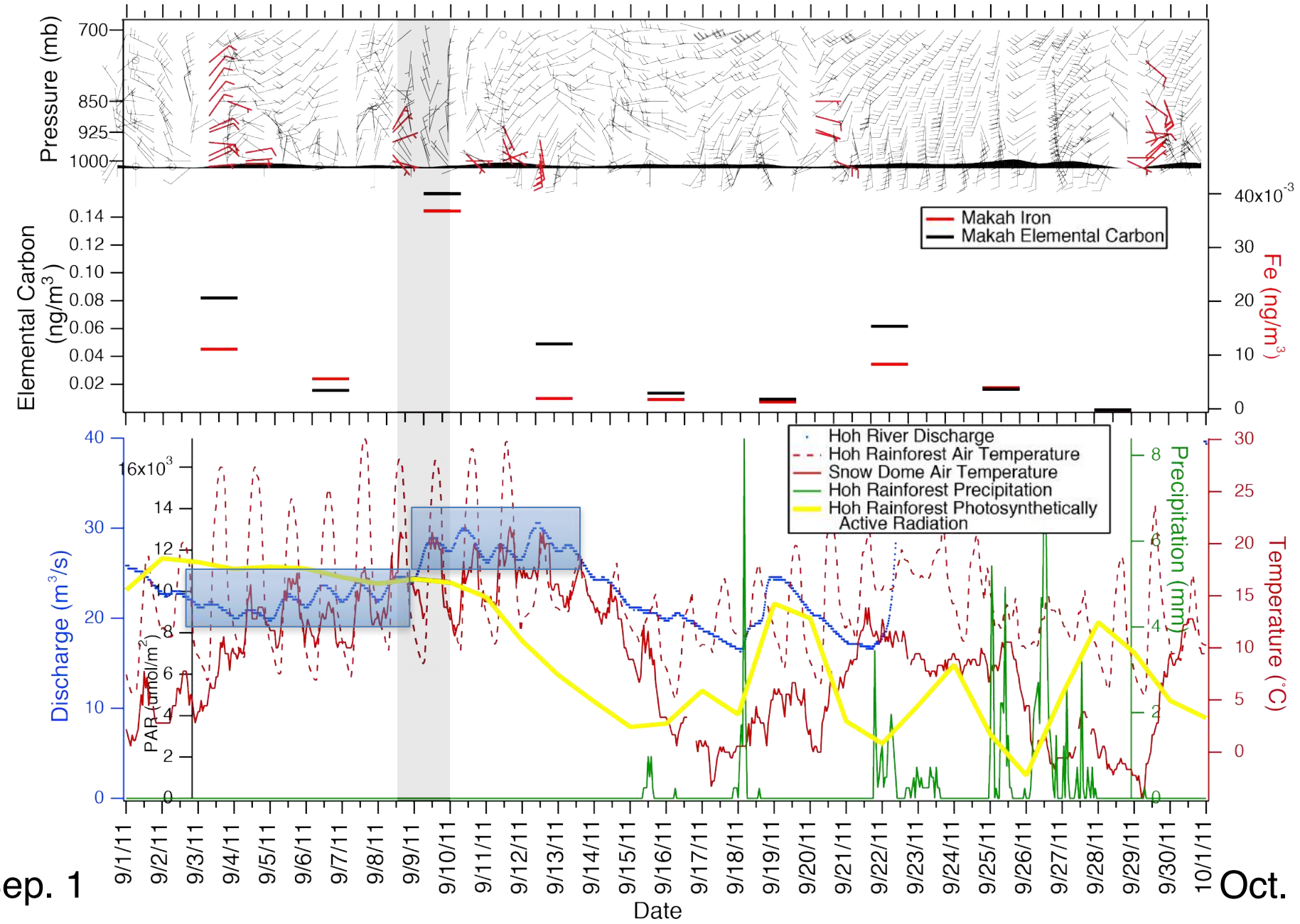
Radiative Forcing: SBDART [Ricchiazzi et al., 1998]
Melt: [Painter et al., 2013]

Scenario	BC (ug/L)	Gravimetric Dust (mg/L)	Optical Grain Radius (um)	Broadband Albedo	Daily Mean Radiative Forcing (W/m2)	Daily SWE Reduction (mm)
Clean low	-	-	393	0.77		
Clean high	-	-	520	0.75		
Pre-fire low	140	62	520	0.68	40	10
Pre-fire high	280	124	520	0.65	56	14
Post-fire low	3123	62	520	0.53	112	29
Post-fire medium	3123	900	520	0.51	121	31
Post-fire high	3123	1872	520	0.50	124	32

Kaspari et al., 2015


b
Makah
IMPROVE
Quillayute
Hoh River
Waterhole
SNOTEL
Hoh River
Gauge Station
Hoh
Rainforest
Snow Dome
Big Hump Fire
N
Kilometers
0
20
40
c
Snow Dome
Blue Glacier
Mt. Olympus
0
0.5
1
Kilometers
a
Canada
United States
Mexico

Black Carbon Deposition Coincident with Discharge Increase

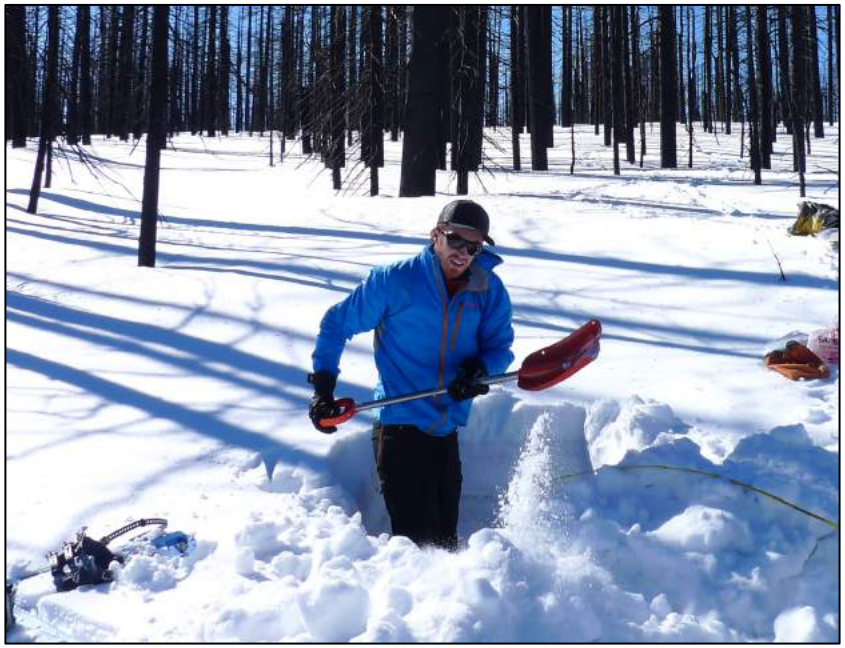


Sep. 1

Oct. 1

Kaspari et al., 2015

Post-wildfire Black Carbon Deposition on the Snowpack in the Cascade Range, Washington State



2013: 0.5 years post fire

2015: 2.5 years post fire

Post-wildfire Black Carbon Deposition on the Snowpack in the Cascade Range, Washington State

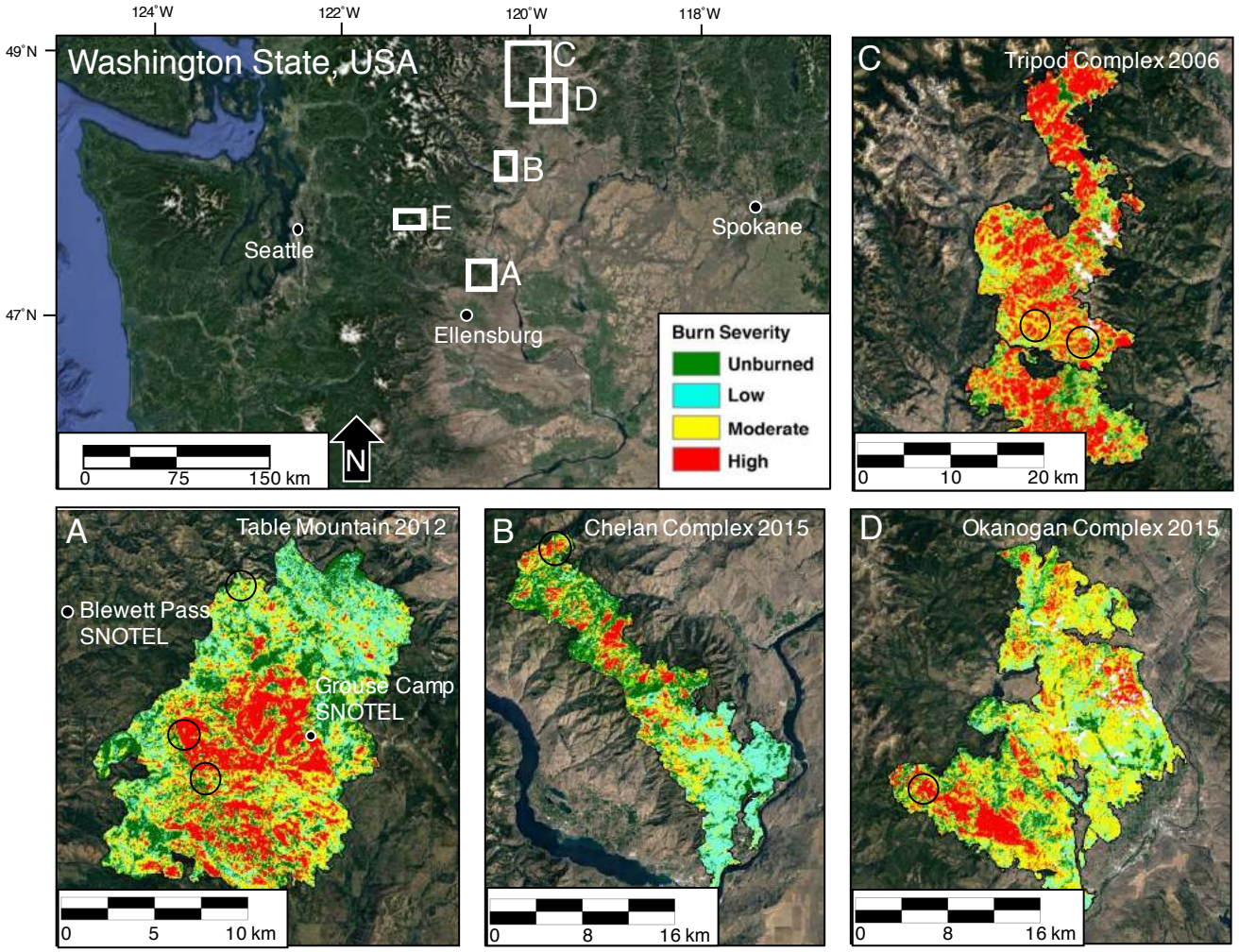
Study sites

Four **burn sites** in eastern Cascades:

- Tripod (2006)
- Table Mountain (2012)
- Chelan (2015)
- Okanogan (2015)

Two **unburned sites**:

- Stevens Pass
- Tronsen Meadow



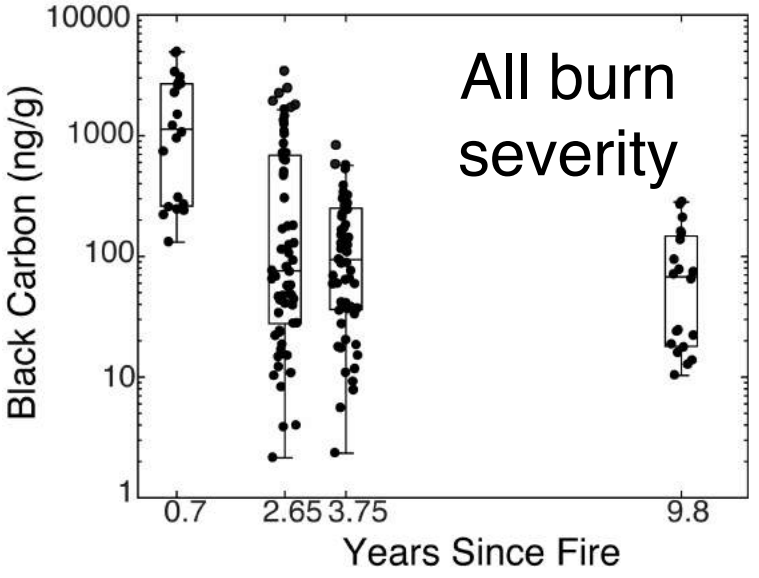
Uecker and Kaspari, in prep.

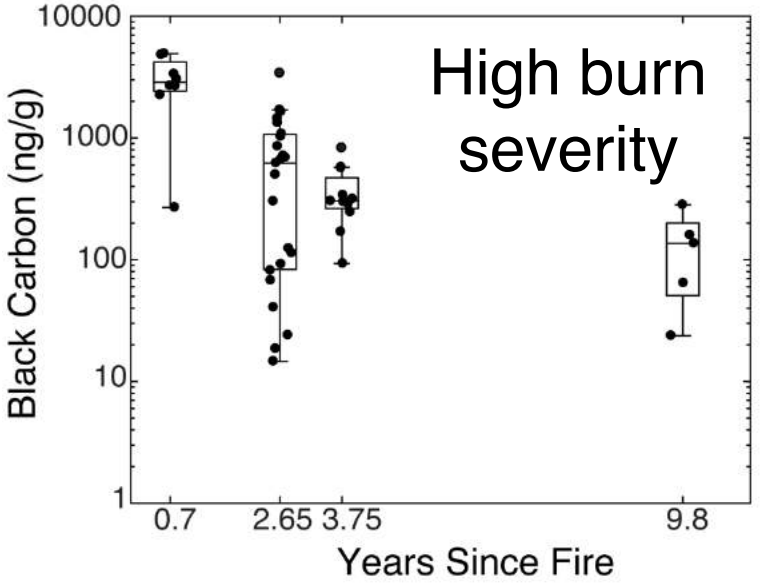
Modified from MTBS.gov

Variations in Black Carbon Deposition Over Time

Okanogan Complex, burned in 2015

Tripod Complex, burned in 2006



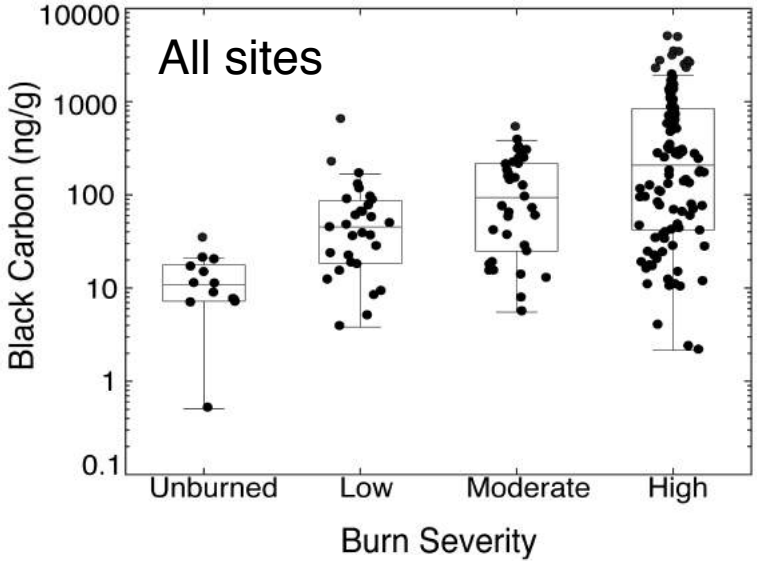


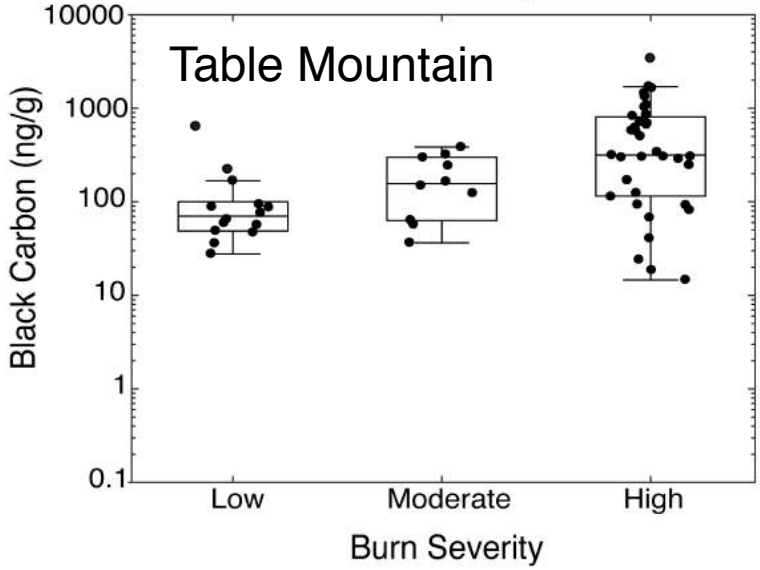
Uecker and Kaspari, in prep.

Variations in Black Carbon Deposition with Burn Severity

Low burn severity, Table Mountain

High burn severity, Table Mountain

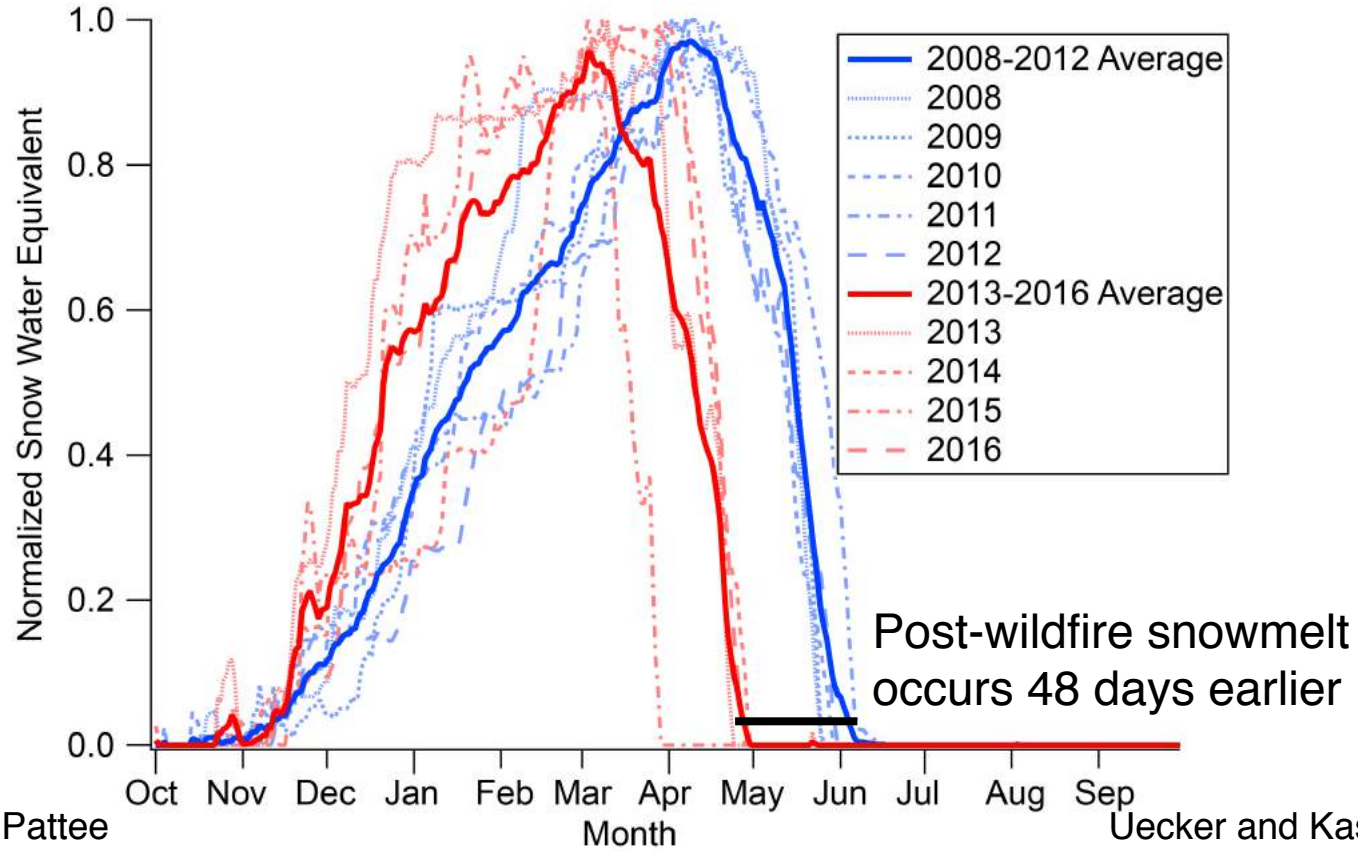




Uecker and Kaspari, in prep.

Earlier Snowmelt in the Post-Fire Environment

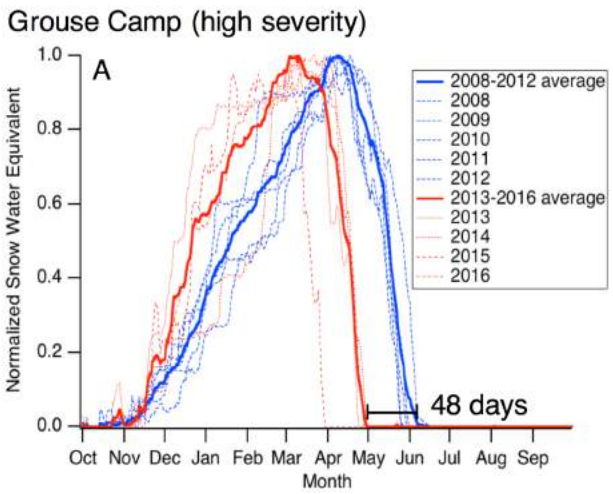
Grouse Camp SNOTEL, Table Mountain

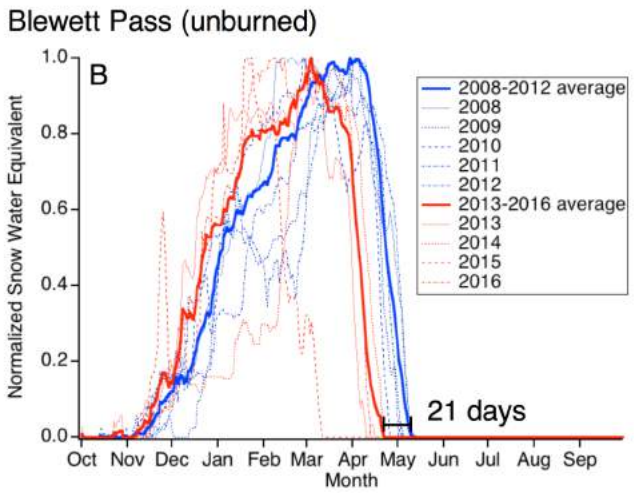


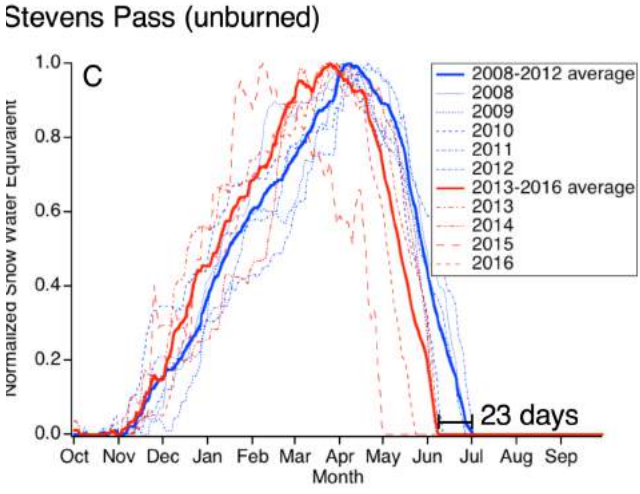
Photos from Scott Pattee

Uecker and Kaspari, in prep.

- At Grouse Camp the 2008-2012 average date of snow all gone (SAG) occurs ~48 days earlier than the SAG between 2013-2016.
- In unburned areas the 2008-2012 average date of snow all gone (SAG) occurs ~22 days earlier than the SAG between 2013-2016.
- Post wildfire effects accelerated snowmelt by ~26 days.

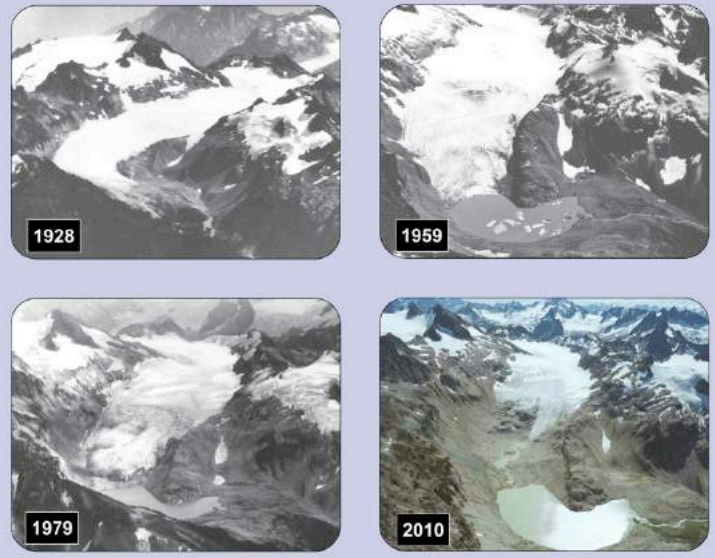






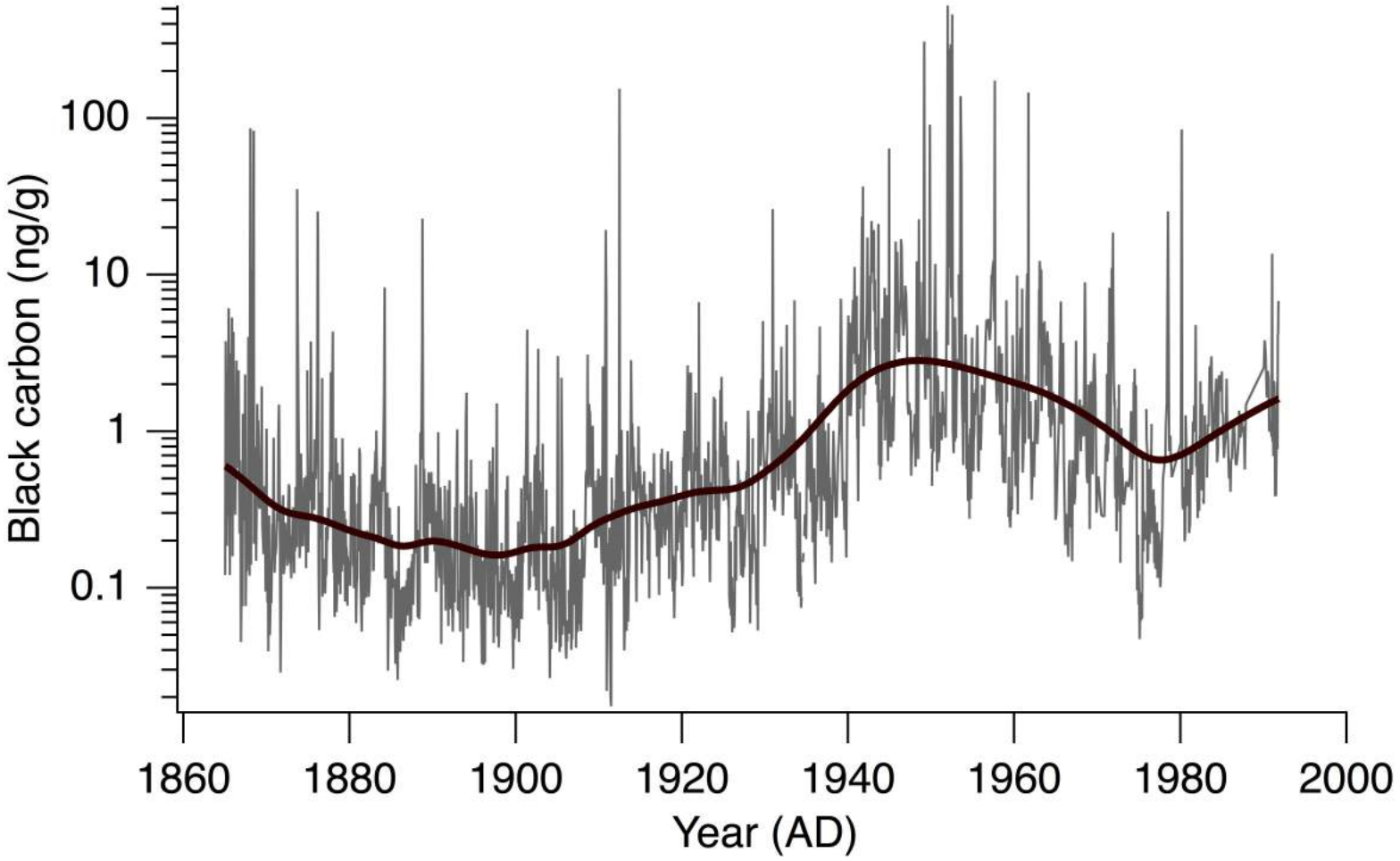
**2015, an anomalously low snow year, is not included in averages*

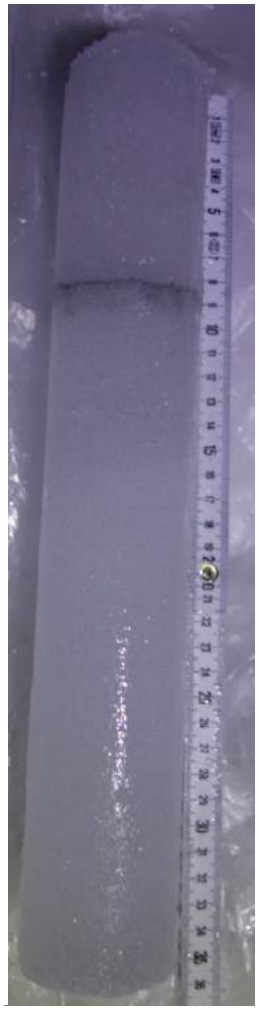
20th Century Black Carbon and Dust Deposition in the North Cascades from the South Cascade Ice Core



158 m ice core drilled in 1994 by the USGS

Historical Black Carbon from the South Cascade Ice Core





Pittenger and Kaspari., in prep.

Conclusions/Implications

- Highest black carbon concentrations in snow in Washington State are associated with fire activity (during and post-fire).
- 80% of forest fires in the western U.S. occur in the seasonal snow zone [*Gleason et al.*, 2013]
- Precipitation changing from snow to rain=
  Smaller spring snowpack and continued glacier retreat=
  More concentrated impurities
- Area burned by wildfire in this region is projected to double by the 2040s and triple by the 2080s [Littell et al., 2009]
- Fire related melt is likely to increase

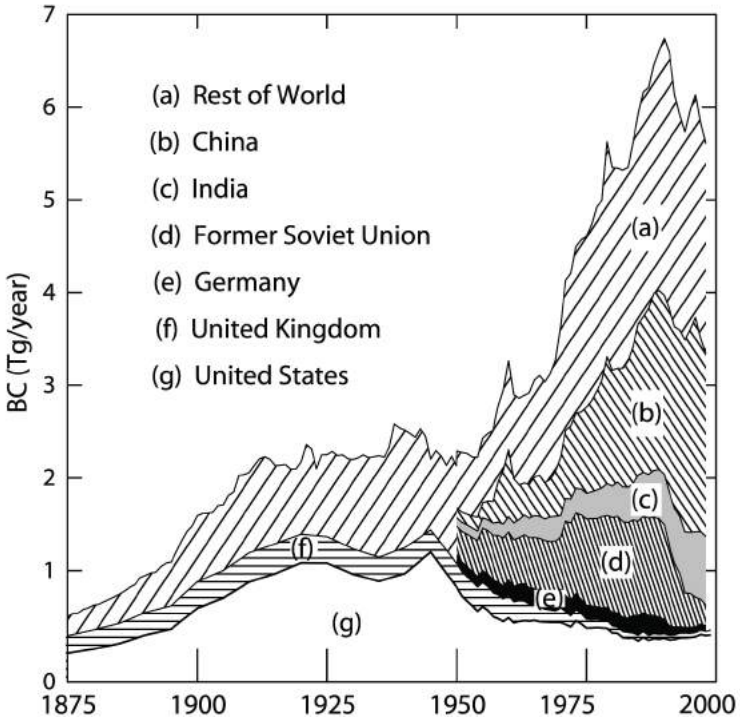
USGS science for a changing world

State of Washington Water Research Center

NSF

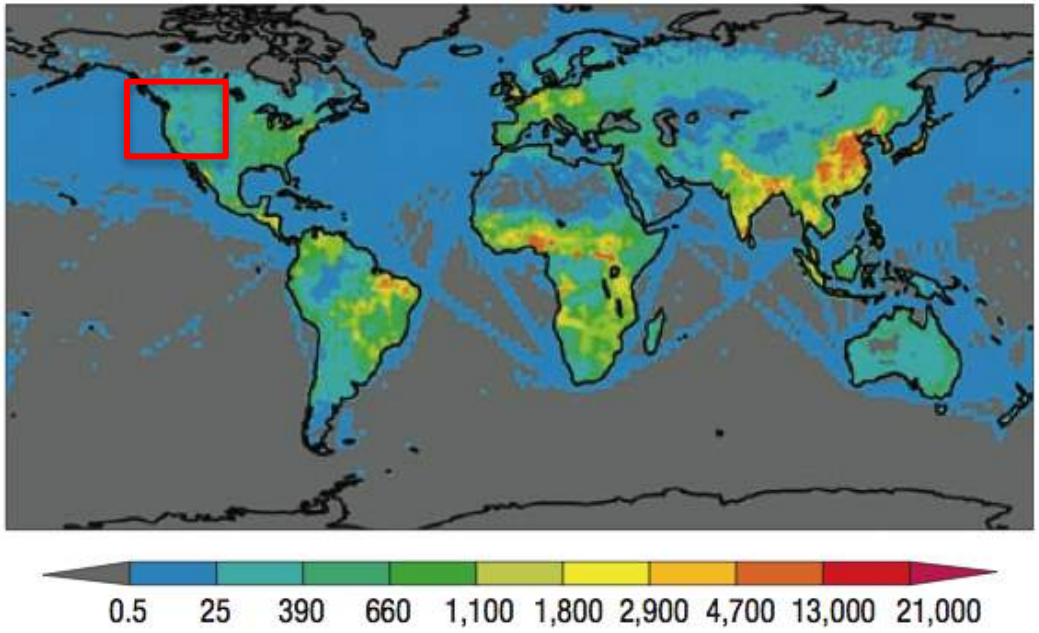
NATIONAL PARK SERVICE

Estimated Fossil Fuel Black Carbon Emissions



Novakov et al., 2003

Black Carbon Emission Strength (tons/yr: 1996)



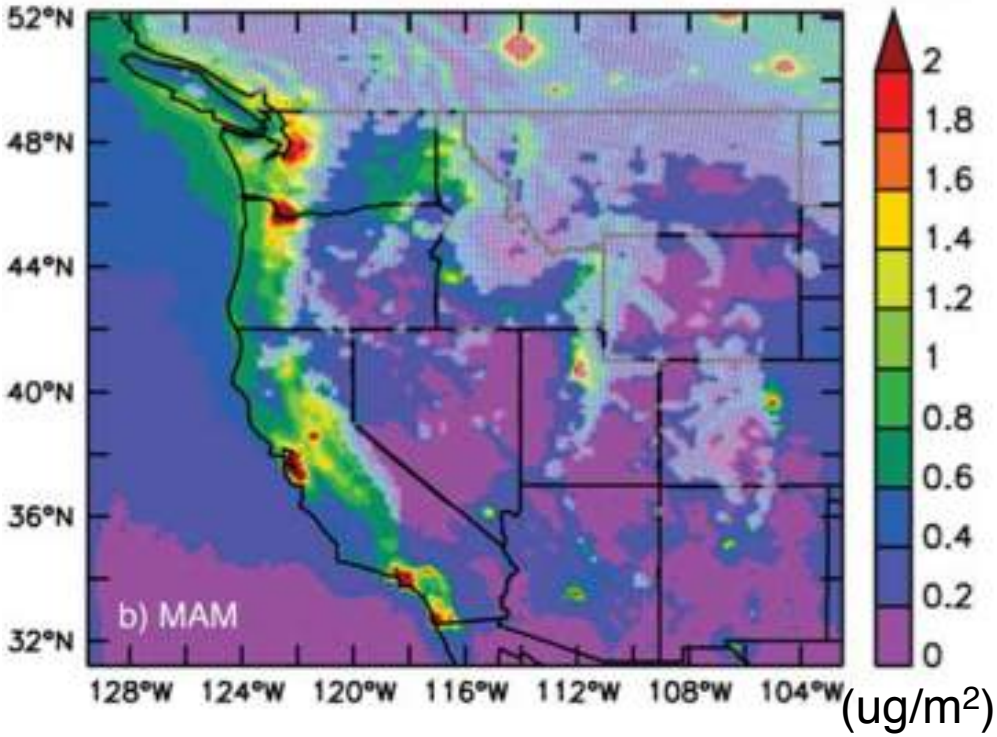
Ramanathan and Carmichael, 2008

Why Focus on Black Carbon in the Pacific Northwest?

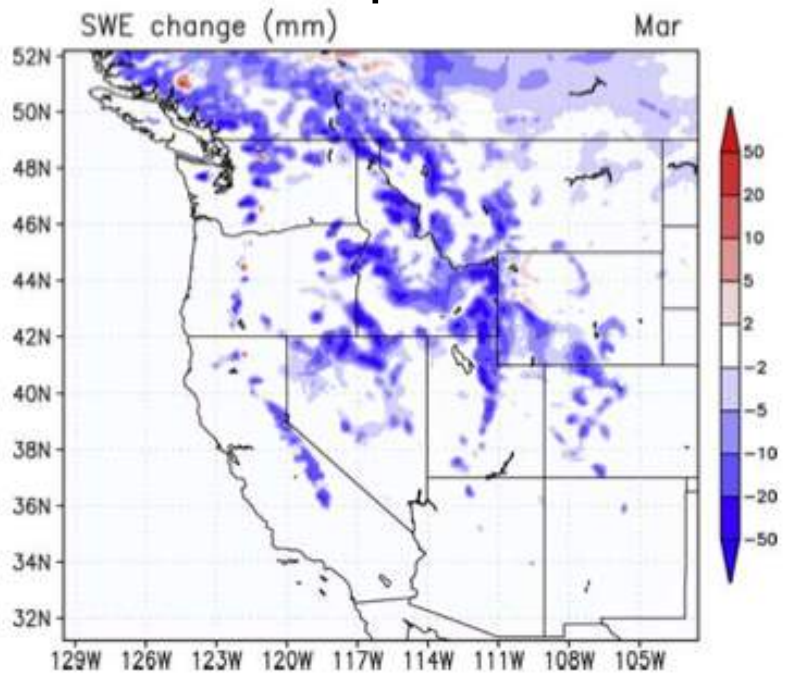
- Glaciated region of continental US
- Snowpack and glaciers are warm
- Low elevation= close to regional emissions
- Downwind of large BC sources

Model Results of Black Carbon in the Pacific Northwest

March- May Black Carbon Deposition



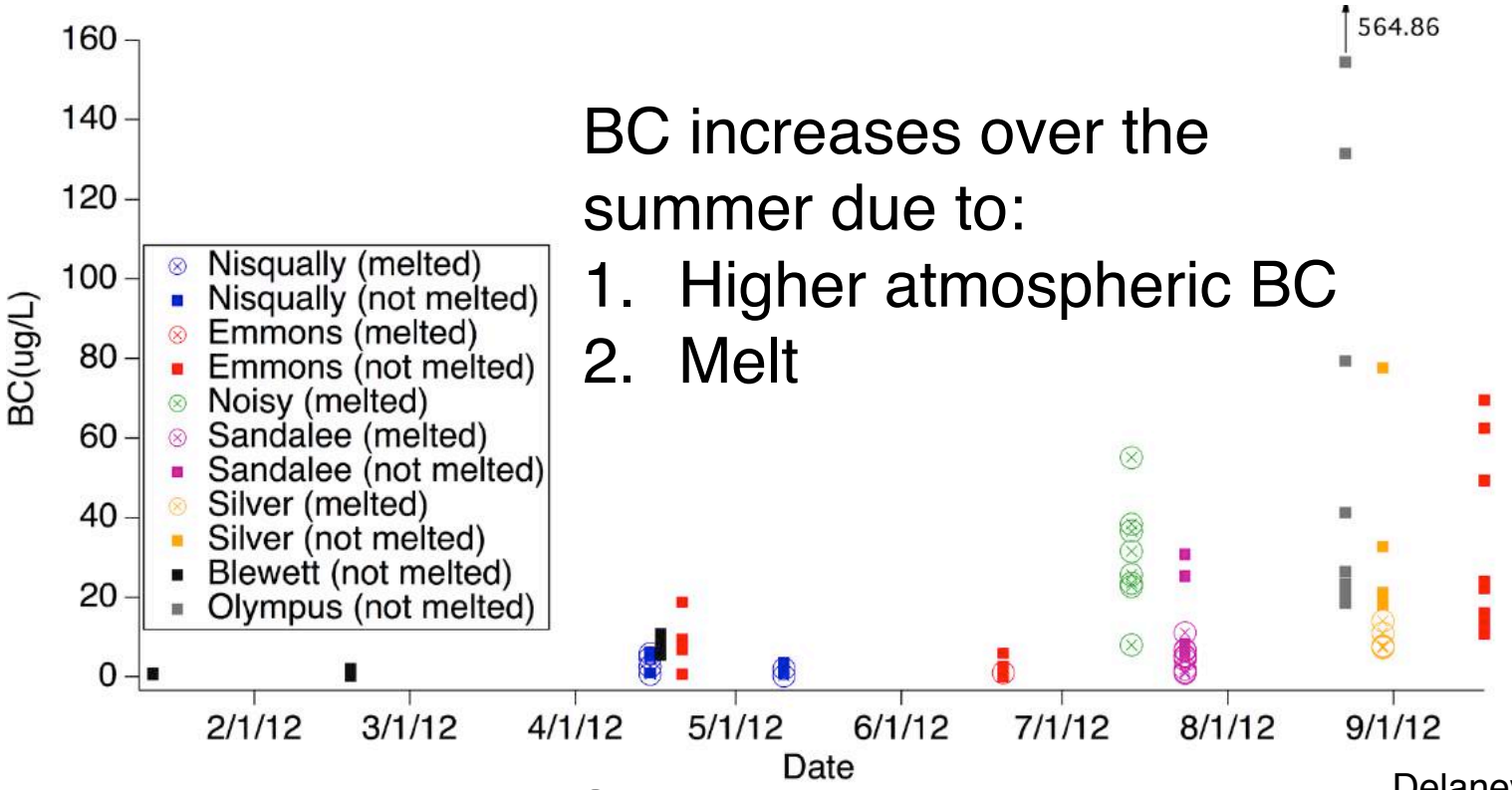
Change in Spring Snow Water Equivalent due to BC Deposition



But nearly no observations

From *Qian et al.* [2009]

Black Carbon Concentrations in Surface Snow on Washington's Glaciers

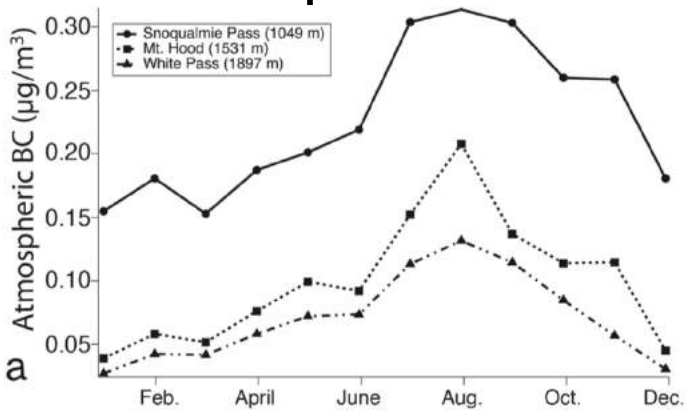


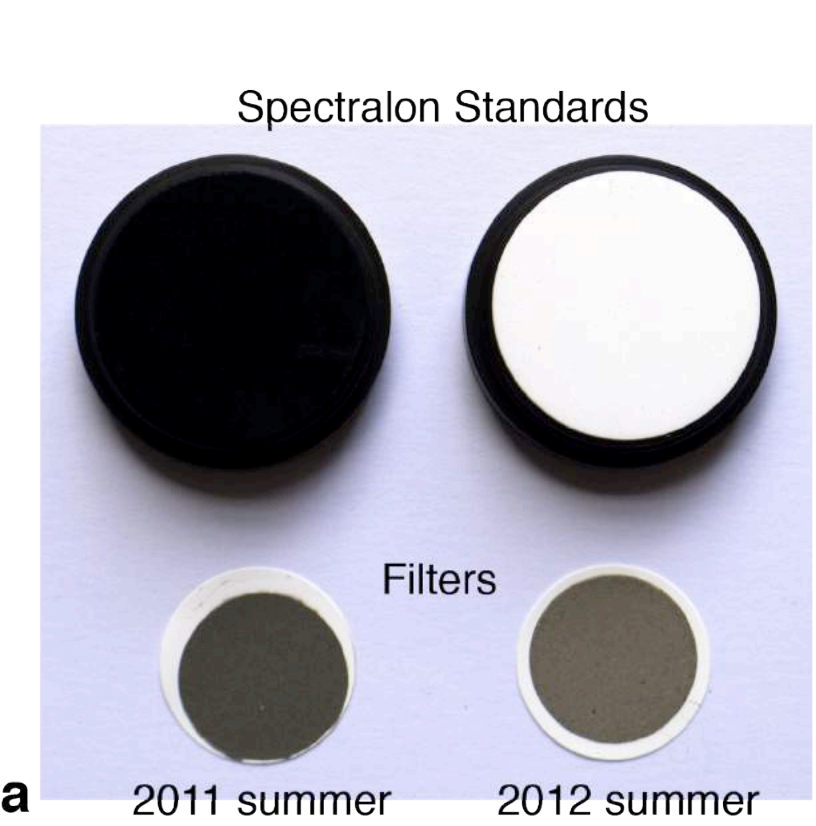
BC increases over the summer due to:

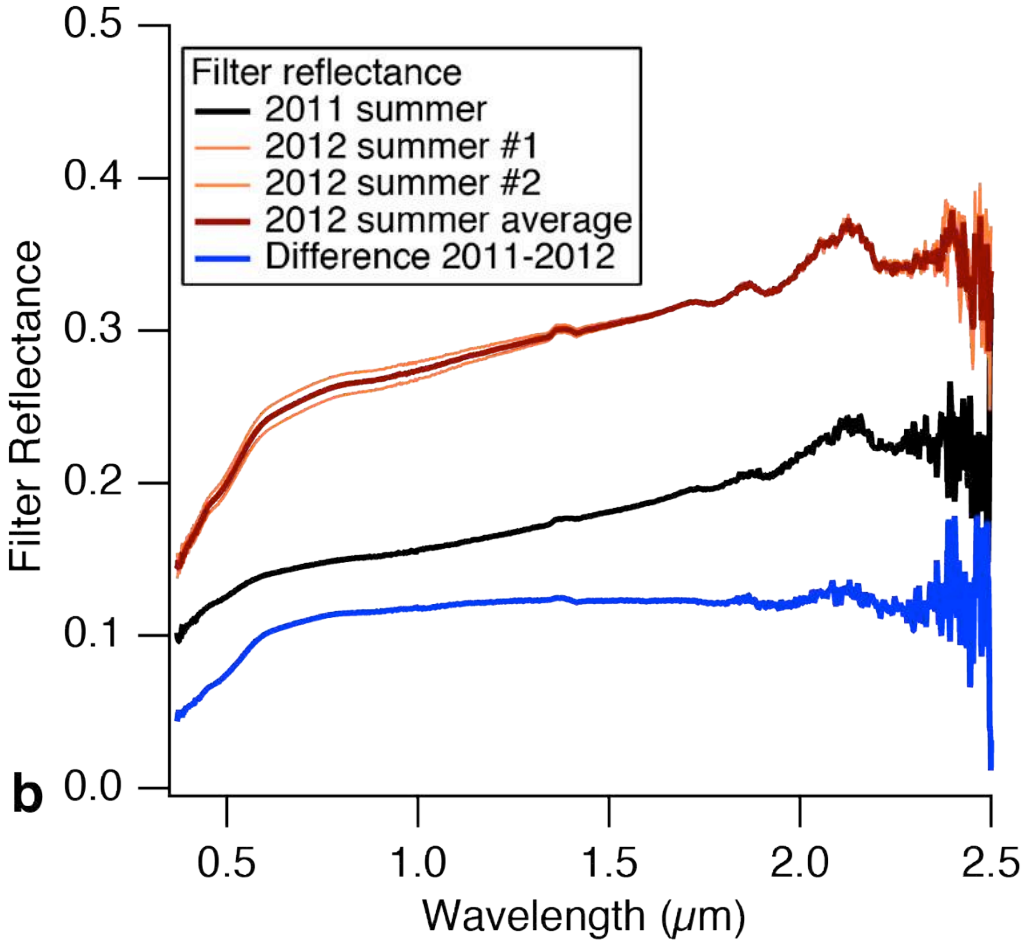
1. Higher atmospheric BC
2. Melt

Delaney et al., in prep.

Atmospheric BC




Spectralon Standards
Filters
2011 summer
2012 summer
a


Filter reflectance
2011 summer
2012 summer #1
2012 summer #2
2012 summer average
Difference 2011-2012
Filter Reflectance
0.0
0.1
0.2
0.3
0.4
0.5
0.5
1.0
1.5
2.0
2.5
Wavelength (μm)
b

Black Carbon and Dust Methods

Samples kept frozen until just prior to analysis

Black Carbon

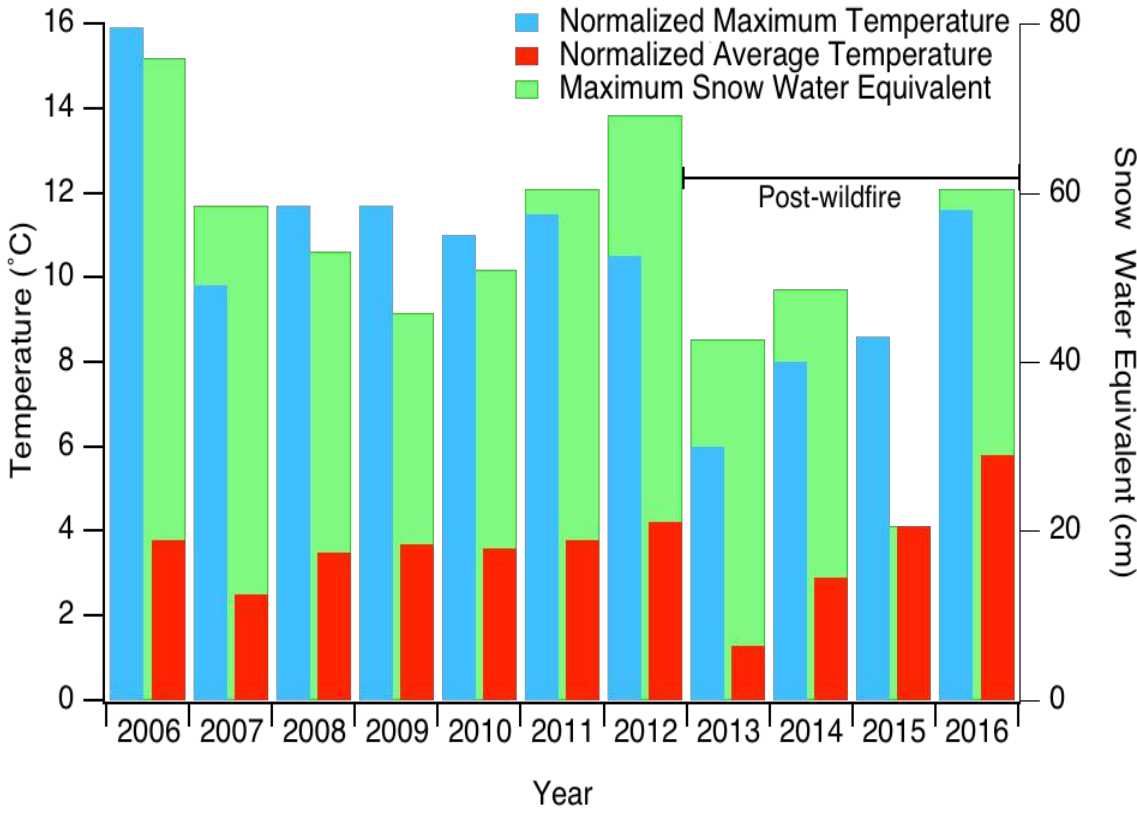
- Nebulized using a Cetac U5000 AT+
- Analyzed using a Single Particle Soot Photometer (SP2)
  - Particles ~80-500nm
  - BC concentrations corrected based on Aquadag standards (Wendl et al., 2014)

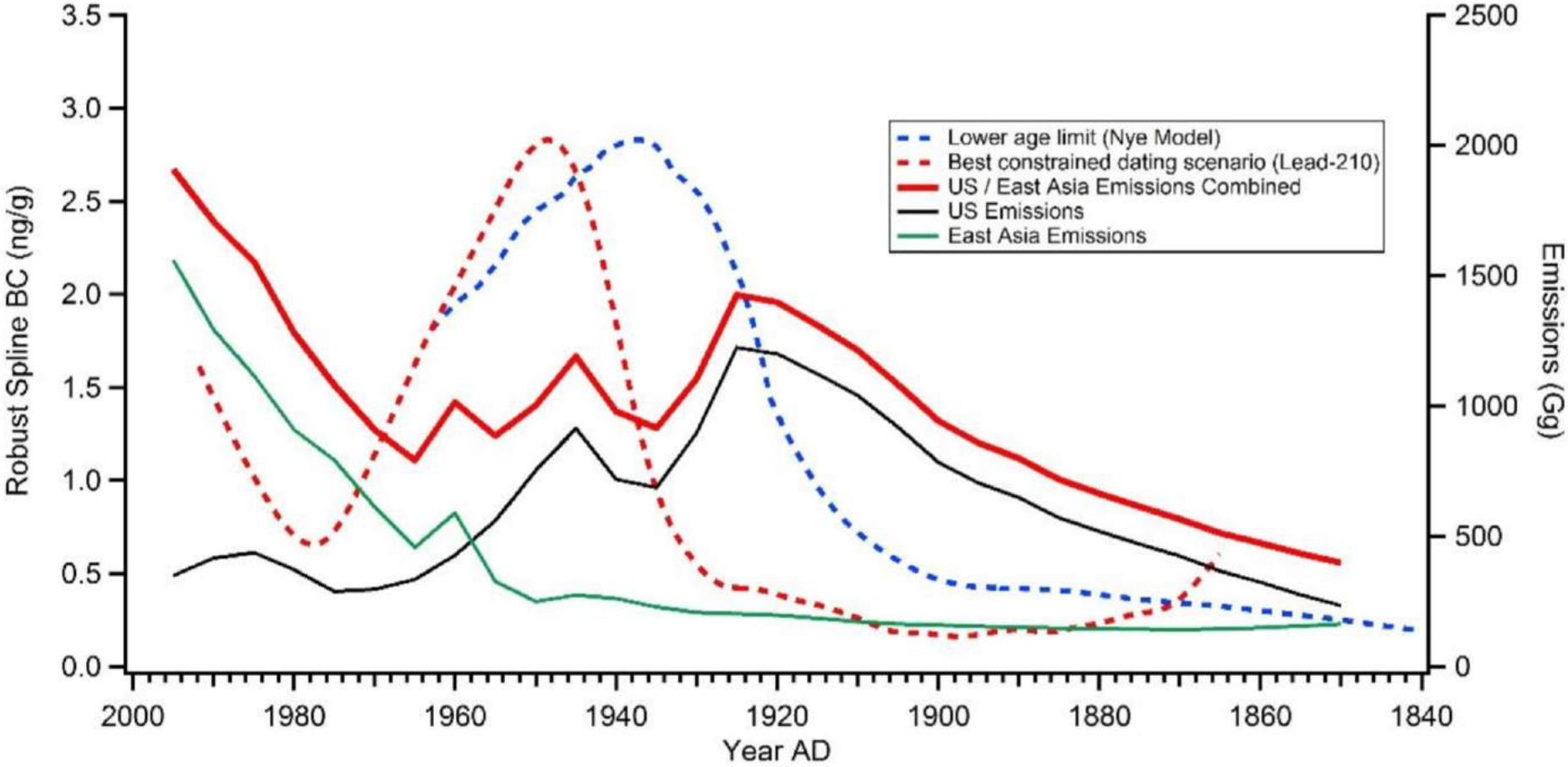
'Dust'

- Iron (Fe) via ICP-SMS
- Gravimetric impurities (.45µm Millipore filters)

Post-wildfire accelerated snowmelt

- Temperatures standardized for period following peak snowpack
- Average to lower than average temperatures in post-wildfire years
- Temperature does not appear to be driving earlier snowmelt




Lower age limit (Nye Model)
Best constrained dating scenario (Lead-210)
US / East Asia Emissions Combined
US Emissions
East Asia Emissions
Robust Spline BC (ng/g)
Emissions (Gg)
Year AD
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2500
2000
1500
1000
500
0
2000
1980
1960
1940
1920
1900
1880
1860
1840