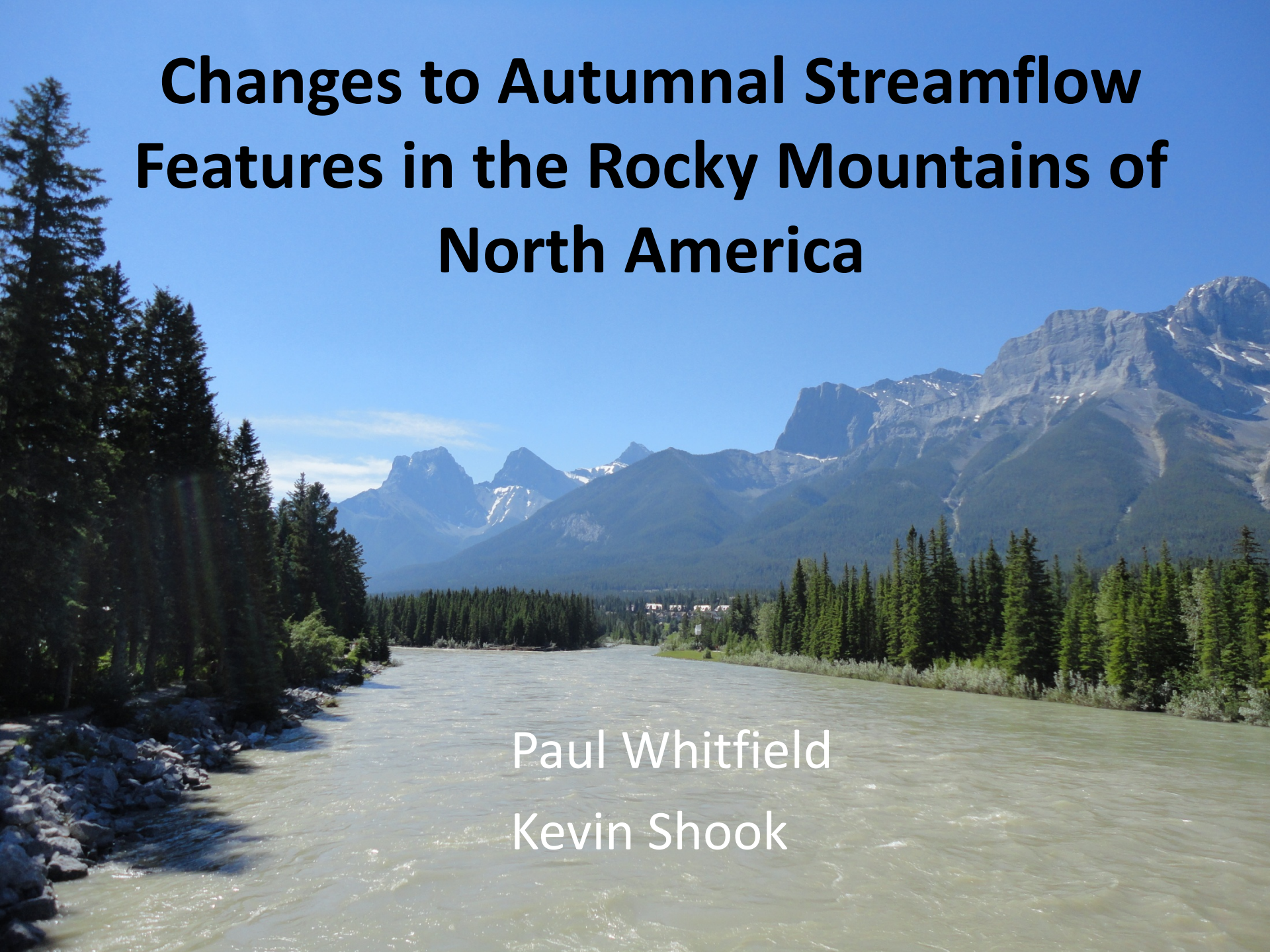
Changes to Autumnal Streamflow Features in the Rocky Mountains of North America



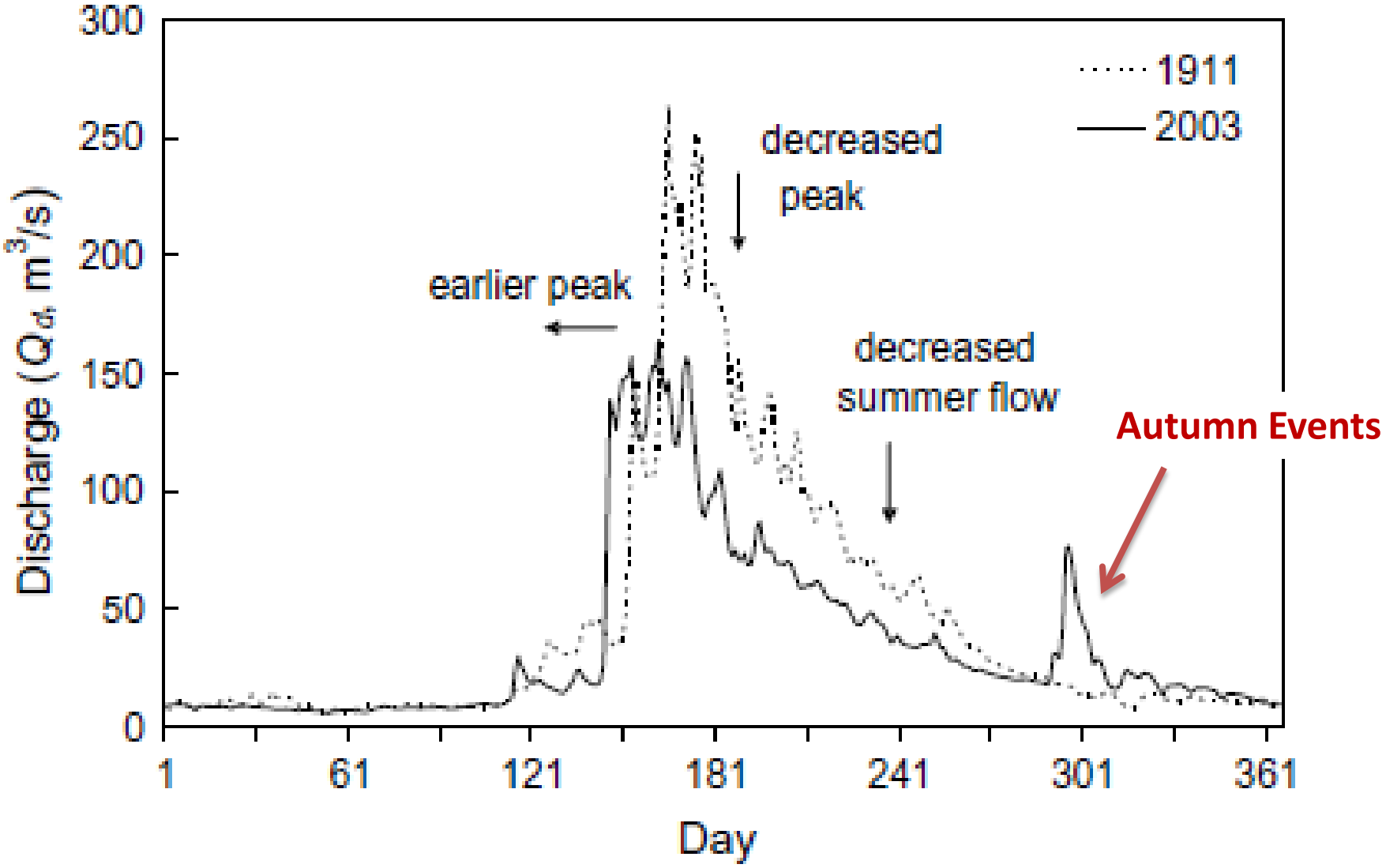
Paul Whitfield
Kevin Shook

Motivation

In a warming climate

- Earlier snowmelt
- Lower summer flows
- More rain & rain on snow events
- More runoff events in fall

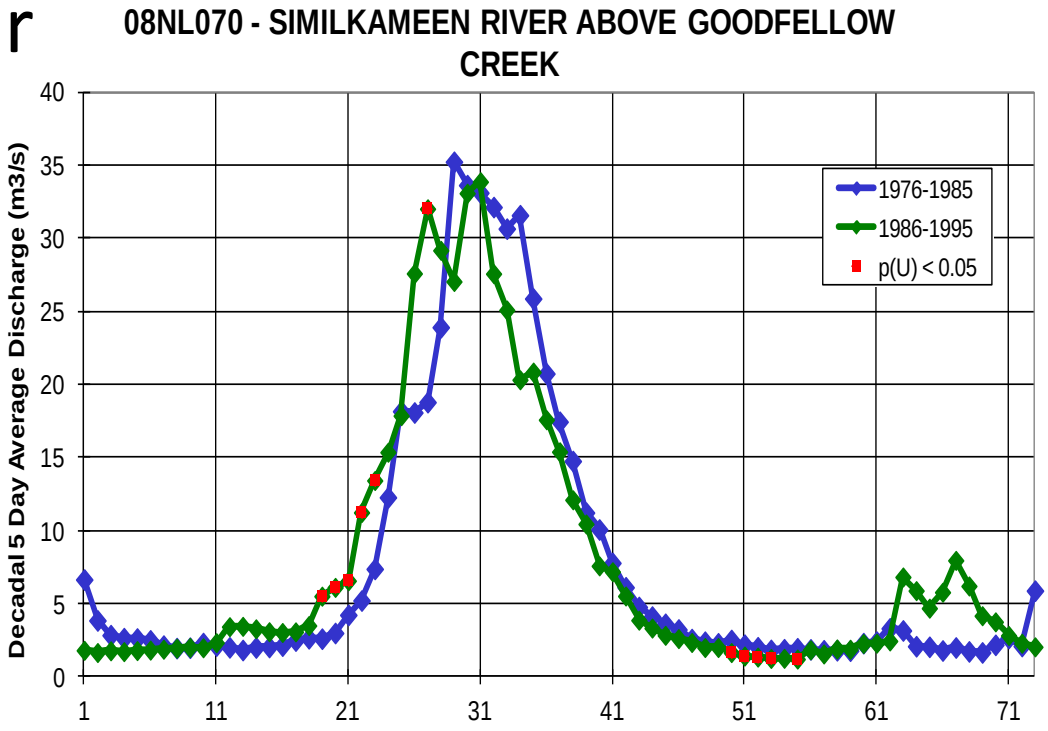
Background



Rood et al 2008.

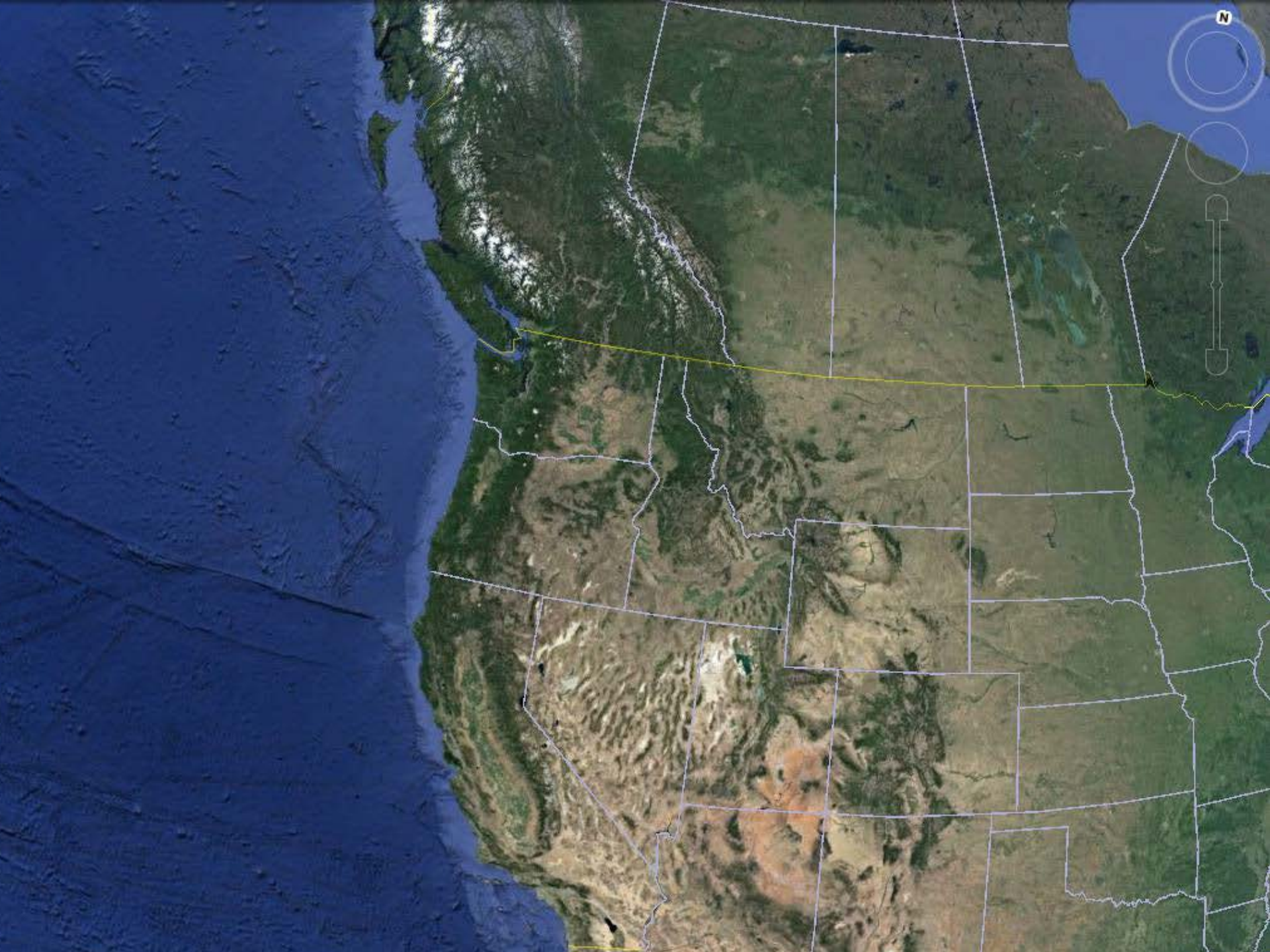
Aspects of the problem

- Change is intermittent
- Event timing irregular

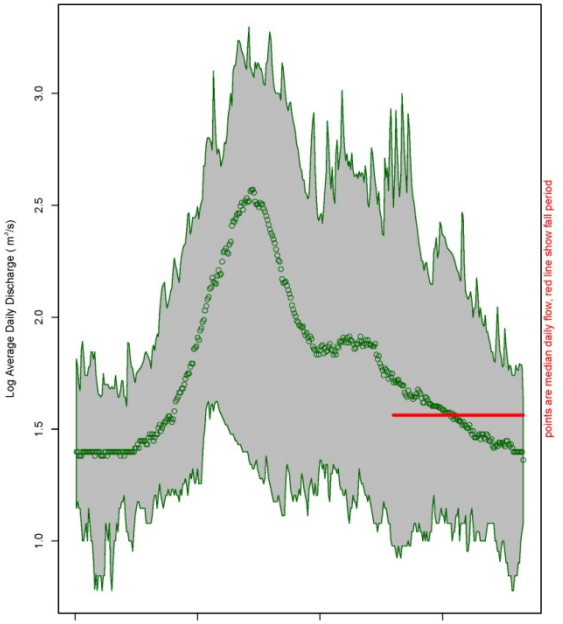


Leith & Whitfield 1998

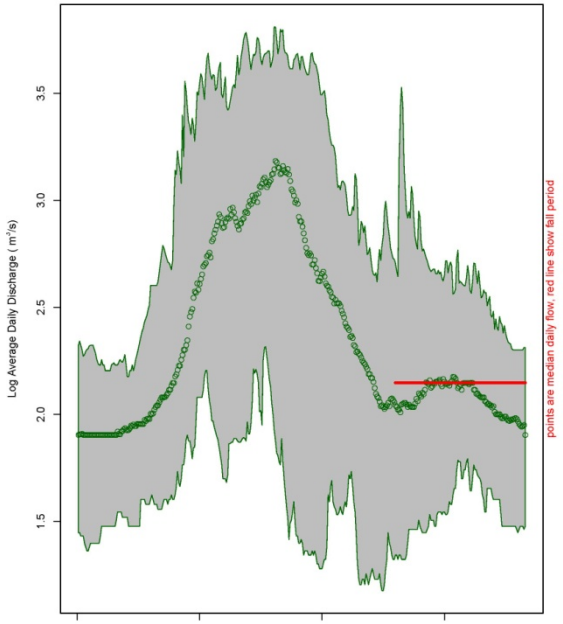
- Magnitude, frequency, duration


N

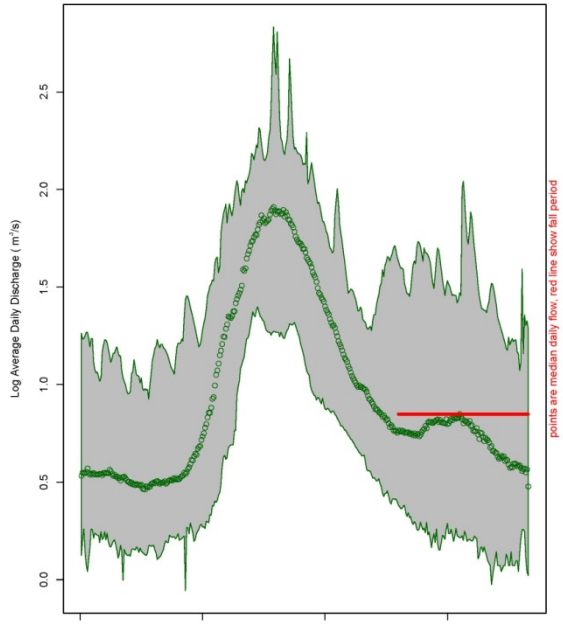
8378500 –PECOS R NR PECOS, NM [NM]



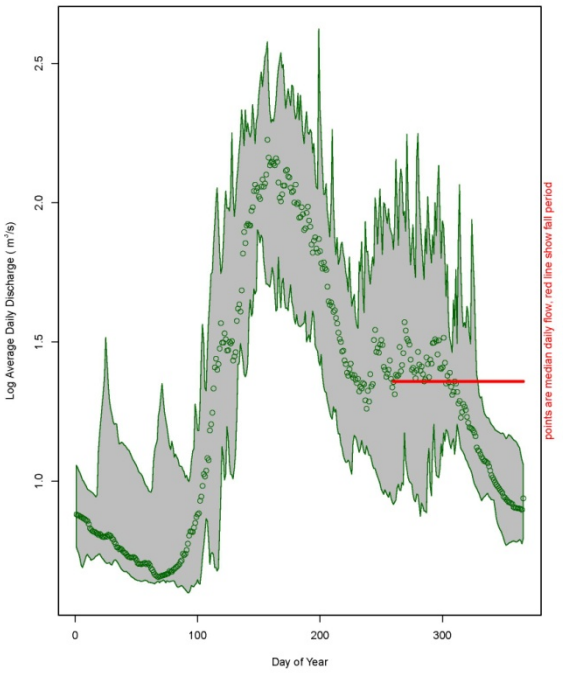
6620000 –NORTH PLATTE RIVER NEAR NORTHGATE, CO [CO]



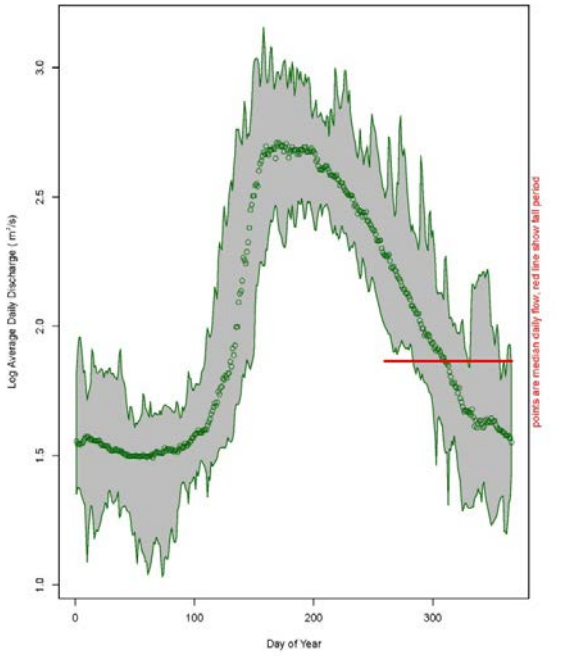
05AD003 – WATERTON RIVER NEAR WATERTON PARK [AB]



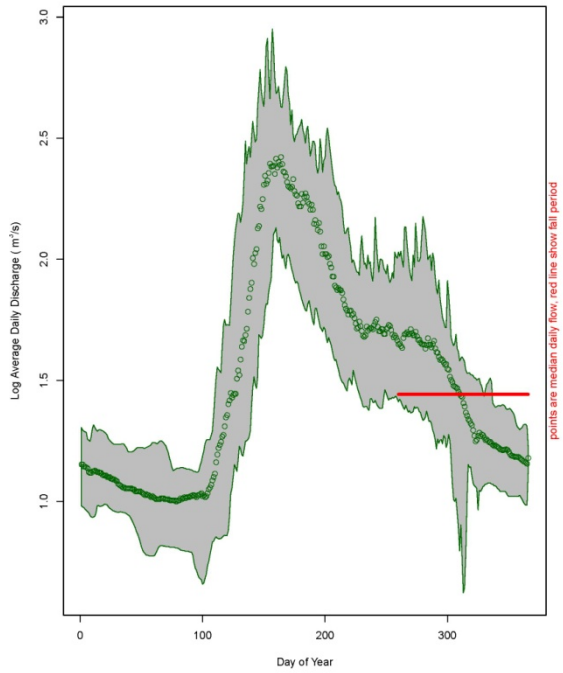
08KA013 – MORKILL RIVER BELOW HELLROARING CREEK [BC]



07AD002 – ATHABASCA RIVER AT HINTON [AB]



07EA004 – INGENIKA RIVER ABOVE SWANNELL RIVER [BC]



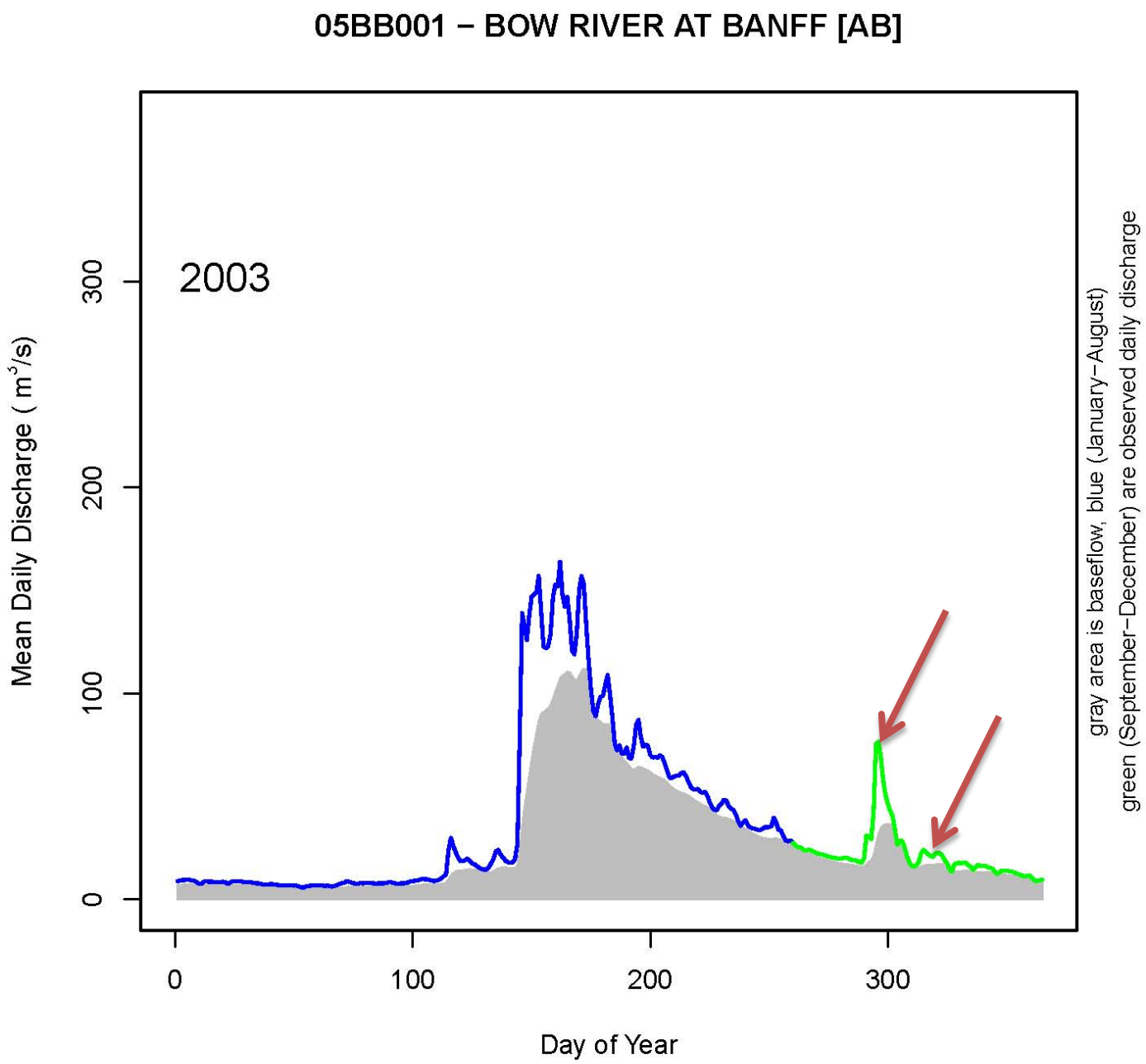
Autumnal events

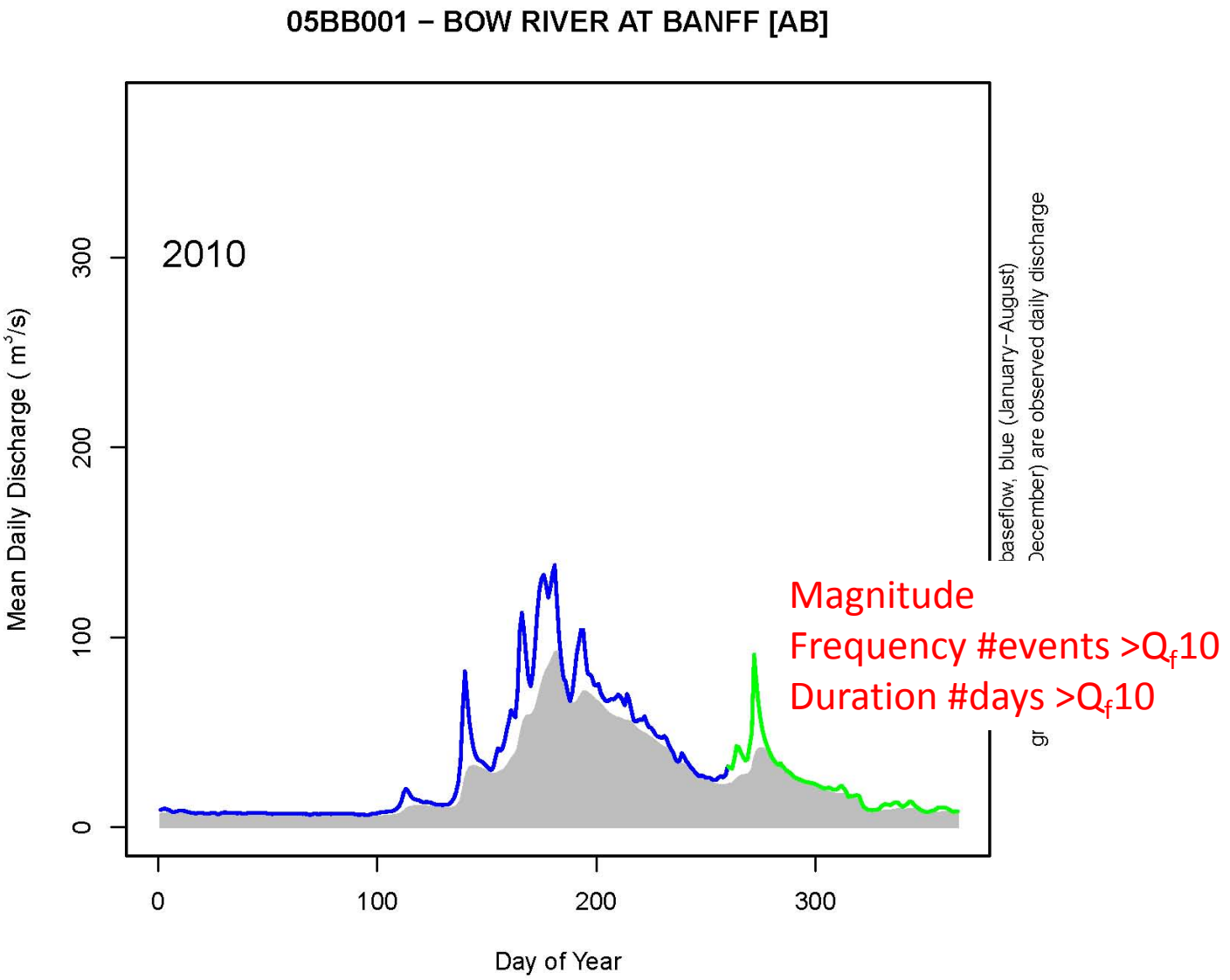
1 September – 31 December

- Rainfall events >10mm
- Snowfall events >10mm*
- Runoff >Q_f10 [anomaly]

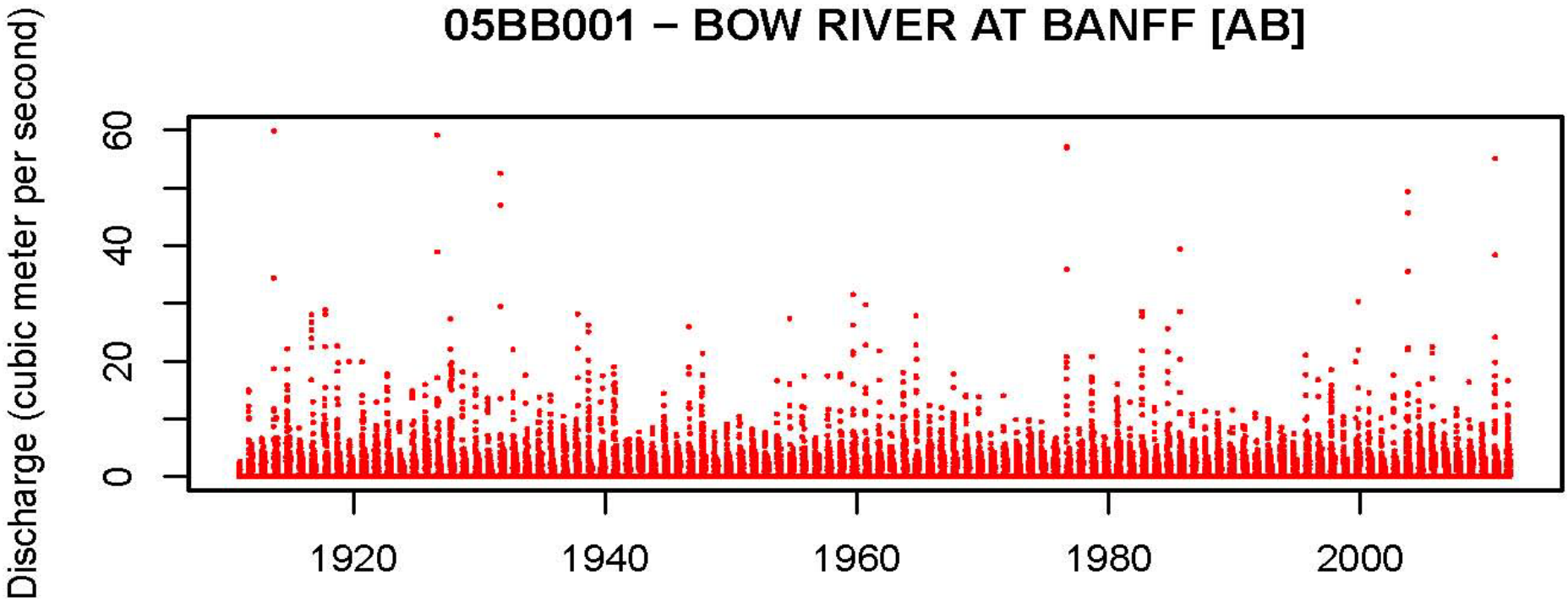
Method

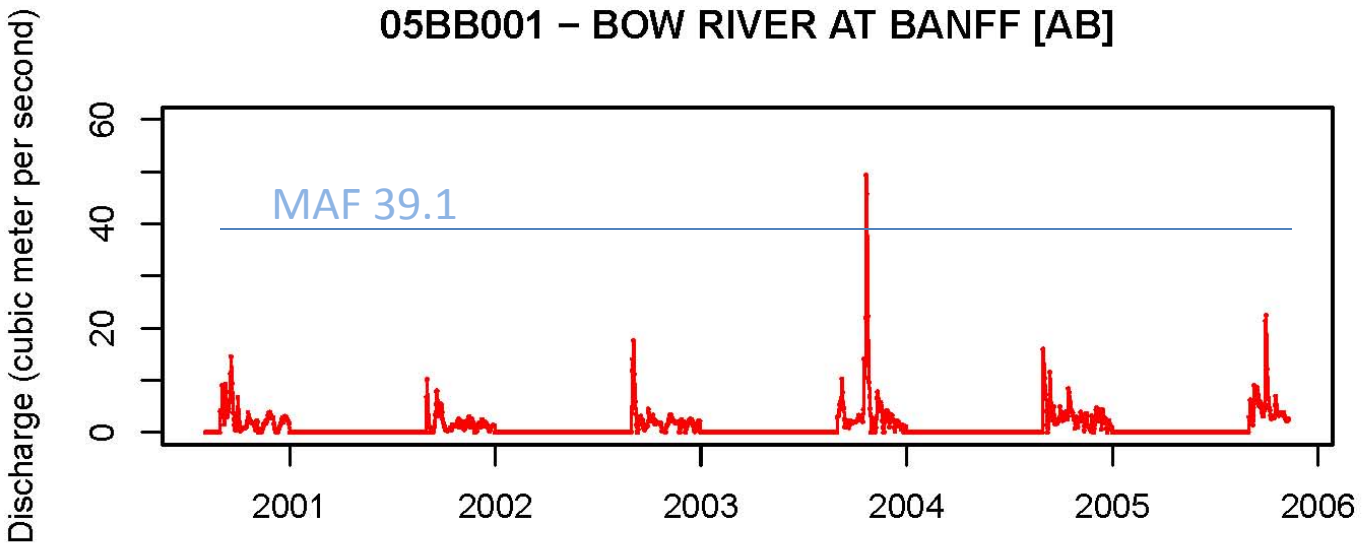
- Isolate flow events
- Remove base effect
- Seasonal Maximum (Mann-Kendall)
- Frequency & Duration (Logistic Regression)

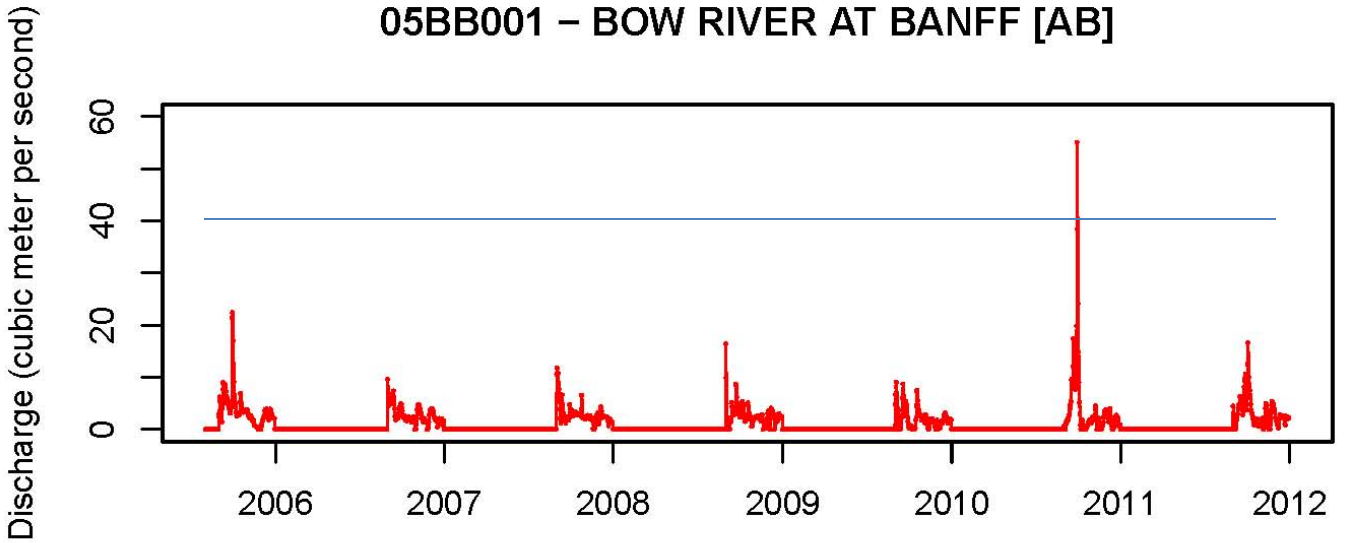

05BB001 – BOW RIVER AT BANFF [AB]
2003
Mean Daily Discharge (m³/s)
0
100
200
300
0
100
200
300
Day of Year
gray area is baseflow, blue (January–August)
green (September–December) are observed daily discharge

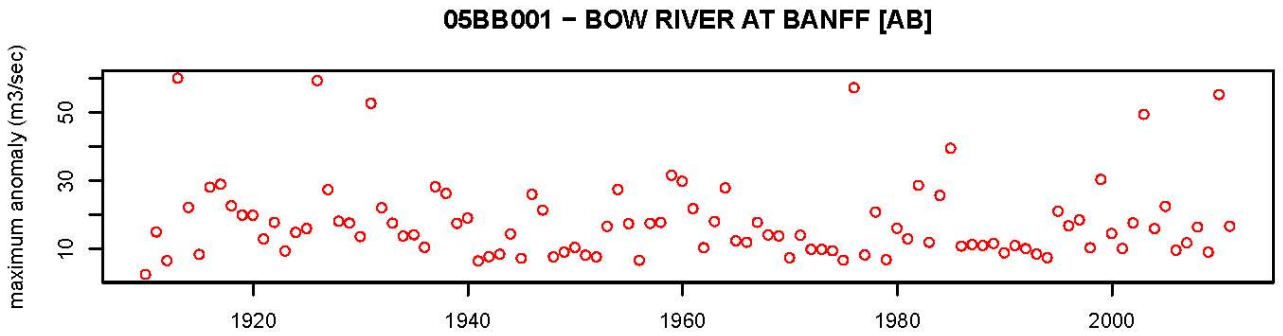

05BB001 – BOW RIVER AT BANFF [AB]
2010
Mean Daily Discharge (m³/s)
0
100
200
300
0
100
200
300
Day of Year
baseflow, blue (January–August)
December) are observed daily discharge
gr
Magnitude
Frequency #events >Qf10
Duration #days >Qf10

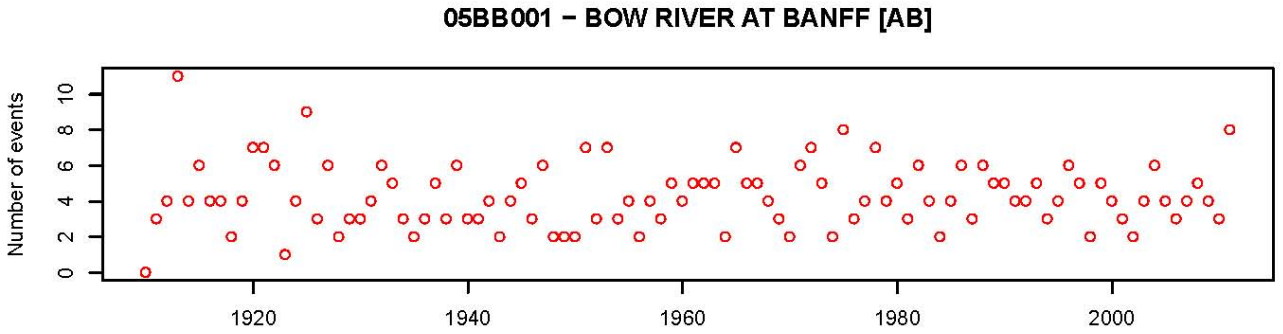
Daily Anomaly

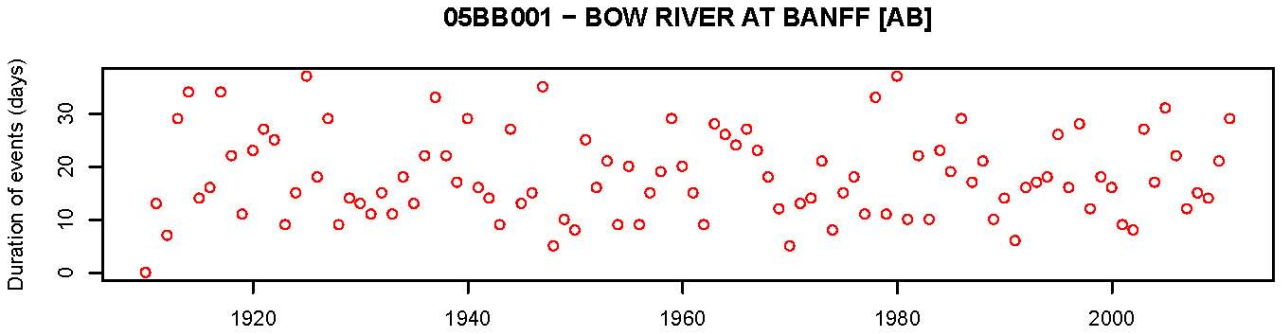


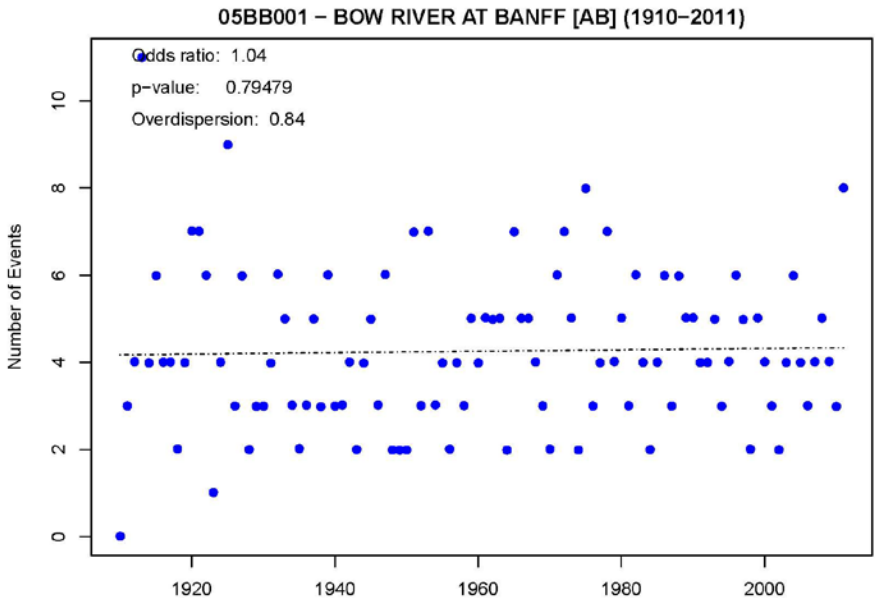

05BB001 – BOW RIVER AT BANFF [AB]
Discharge (cubic meter per second)
0
20
40
60
MAF 39.1
2001
2002
2003
2004
2005
2006

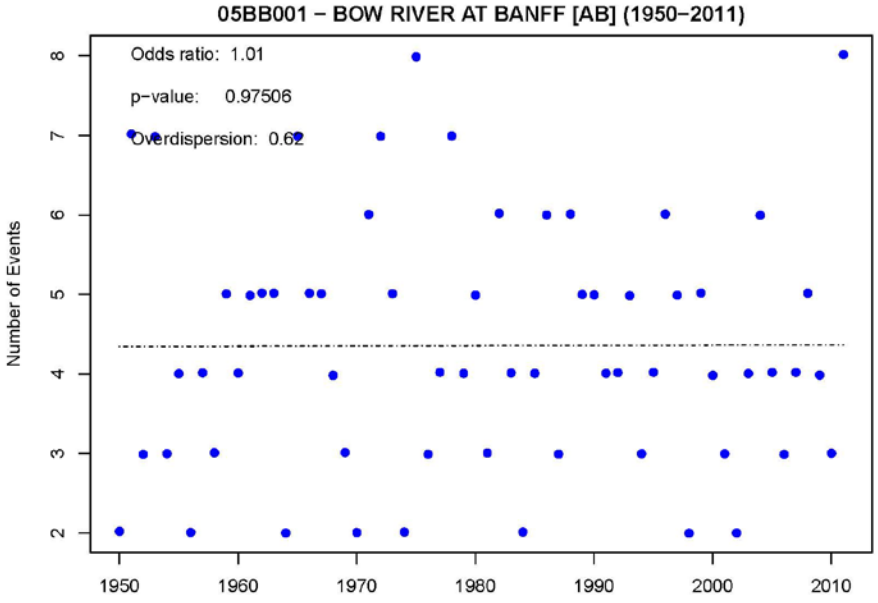

05BB001 – BOW RIVER AT BANFF [AB]
Discharge (cubic meter per second)
0
20
40
60
2006
2007
2008
2009
2010
2011
2012

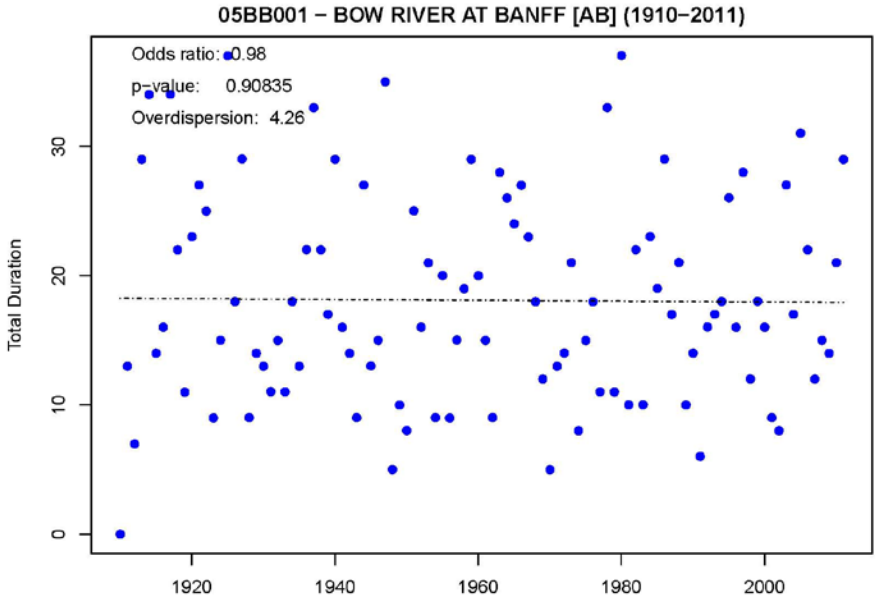

05BB001 – BOW RIVER AT BANFF [AB]
maximum anomaly (m3/sec)
10
30
50
1920
1940
1960
1980
2000

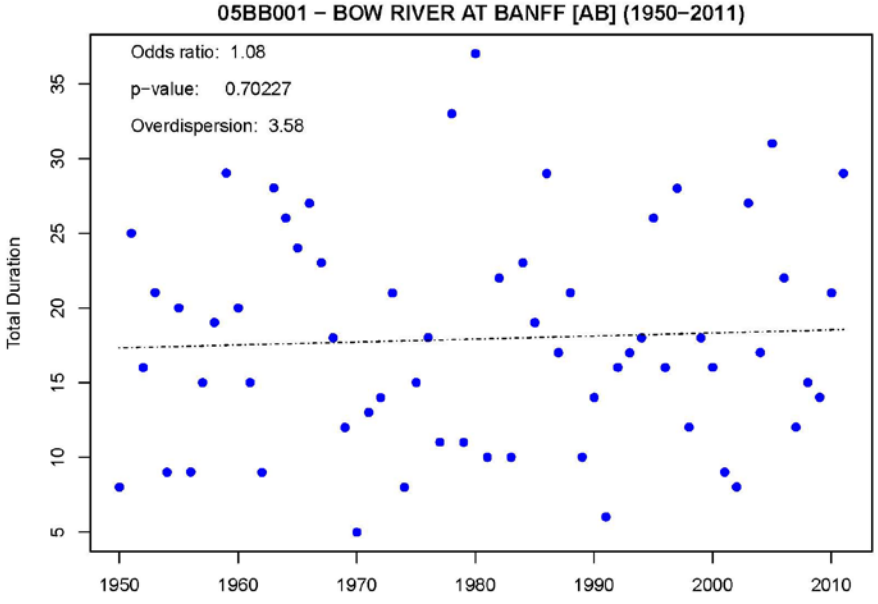

05BB001 – BOW RIVER AT BANFF [AB]
Number of events
0
2
4
6
8
10
1920
1940
1960
1980
2000


05BB001 – BOW RIVER AT BANFF [AB]
Duration of events (days)
0
10
20
30
1920
1940
1960
1980
2000


05BB001 – BOW RIVER AT BANFF [AB] (1910–2011)
Odds ratio: 1.04
p-value: 0.79479
Overdispersion: 0.84
Number of Events
0
2
4
6
8
10
1920
1940
1960
1980
2000

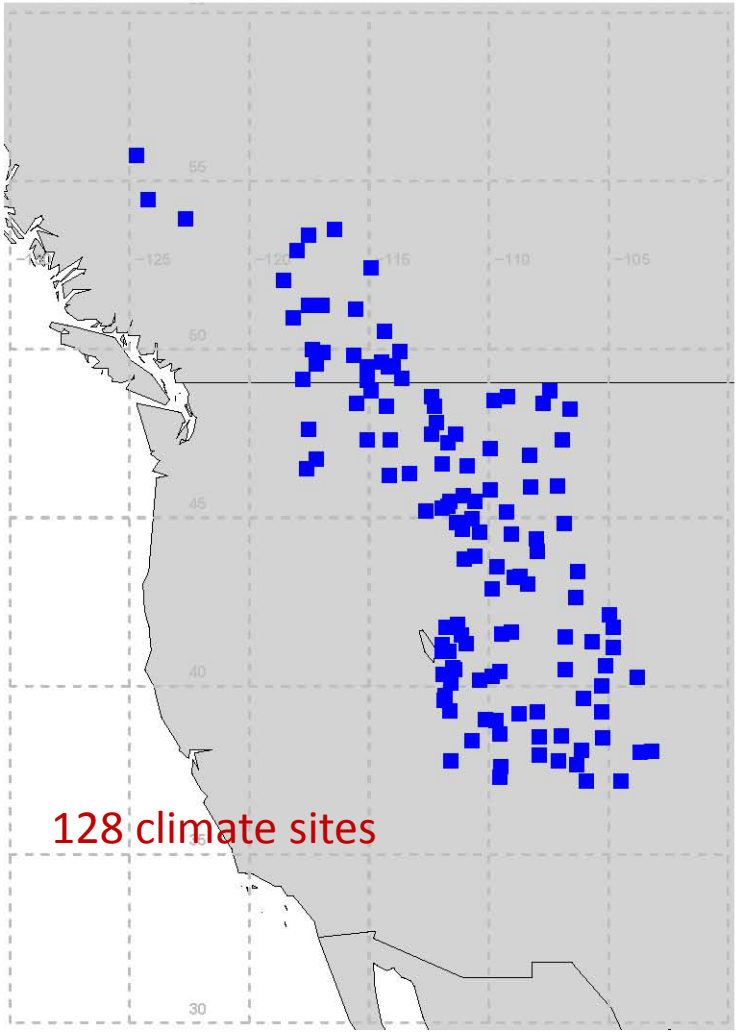

05BB001 – BOW RIVER AT BANFF [AB] (1950–2011)
Odds ratio: 1.01
p-value: 0.97506
Overdispersion: 0.62
Number of Events
2
3
4
5
6
7
8
1950
1960
1970
1980
1990
2000
2010


05BB001 – BOW RIVER AT BANFF [AB] (1910–2011)
Odds ratio: 0.98
p-value: 0.90835
Overdispersion: 4.26
Total Duration
0
10
20
30
1920
1940
1960
1980
2000

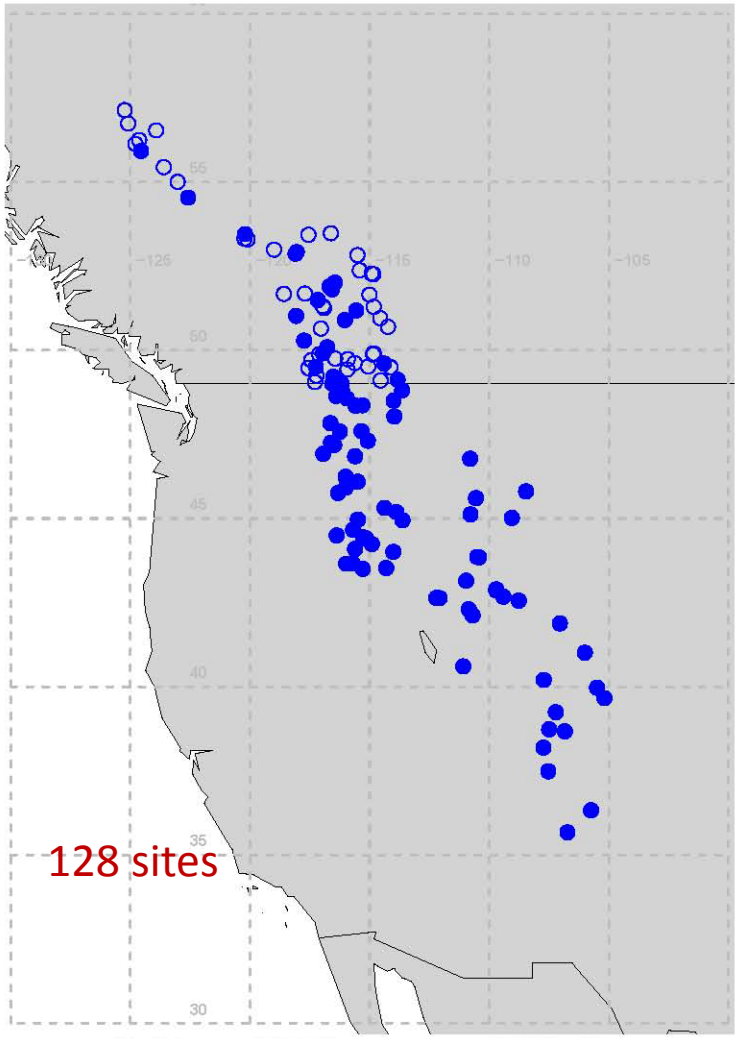

05BB001 – BOW RIVER AT BANFF [AB] (1950–2011)
Odds ratio: 1.08
p-value: 0.70227
Overdispersion: 3.58
Total Duration
5
10
15
20
25
30
35
1950
1960
1970
1980
1990
2000
2010


Spatial distribution of change

Rocky Mountain Climate 1960–2010



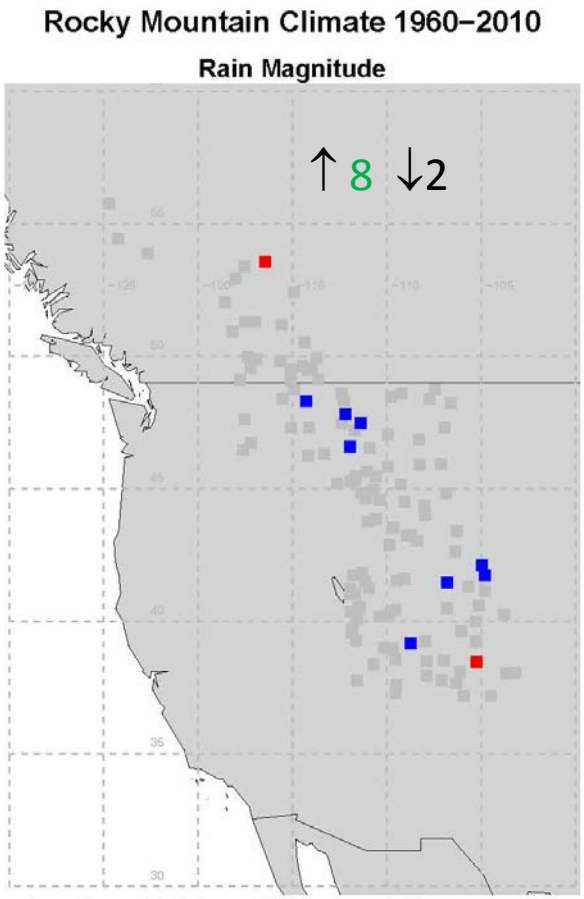
Rocky Mountain Hydrologic Stations

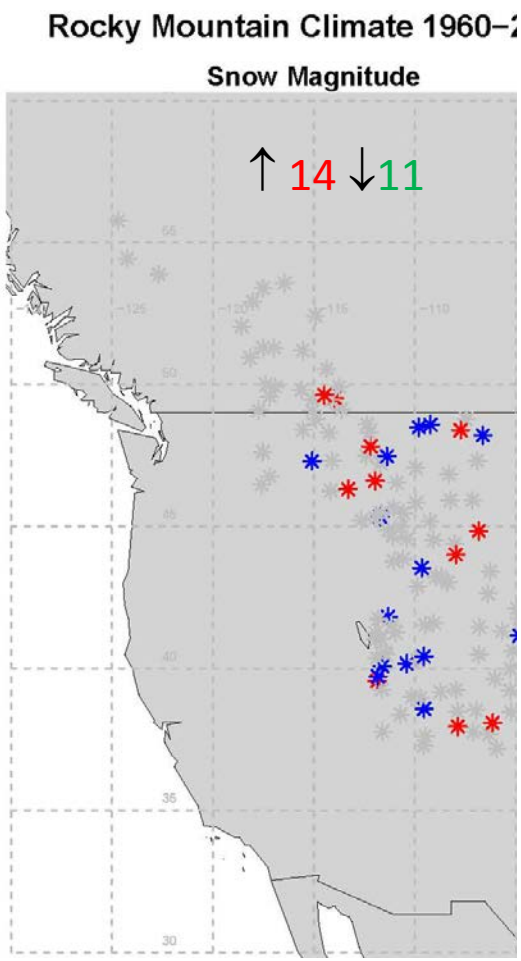


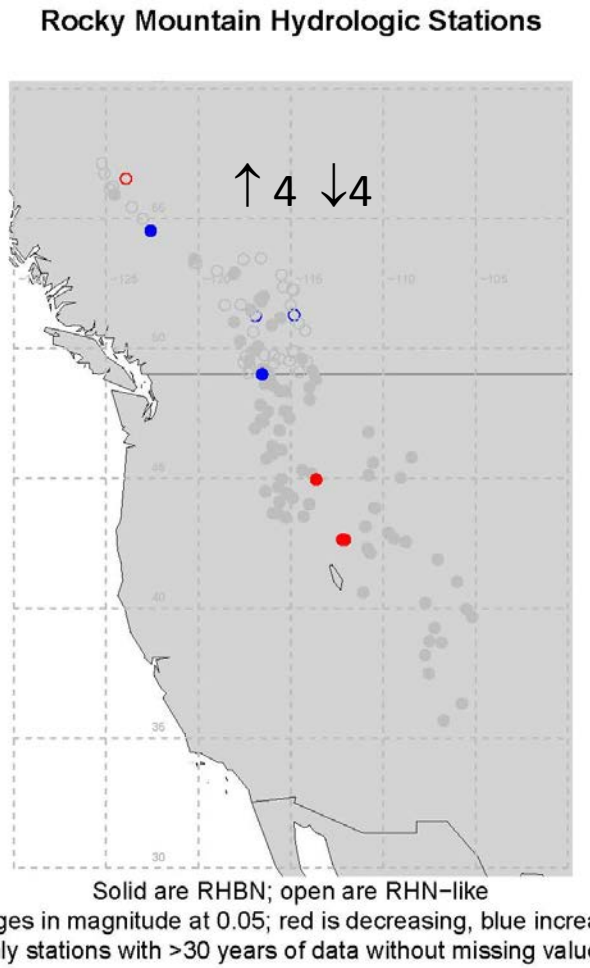
Solid are RHBN; open are RHN–like

Only stations with >30 years of data without missing values

Maximum Magnitude

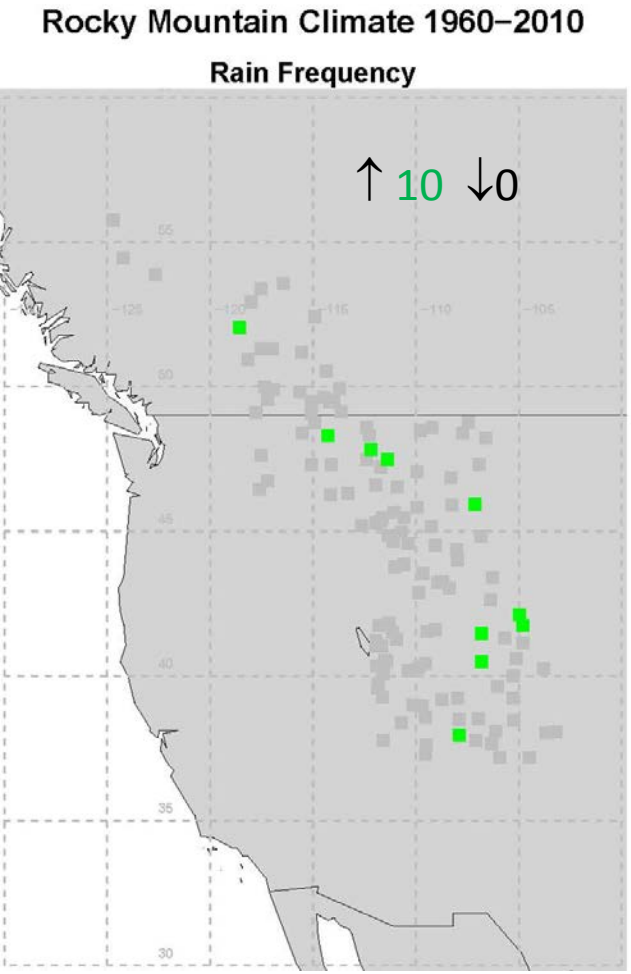


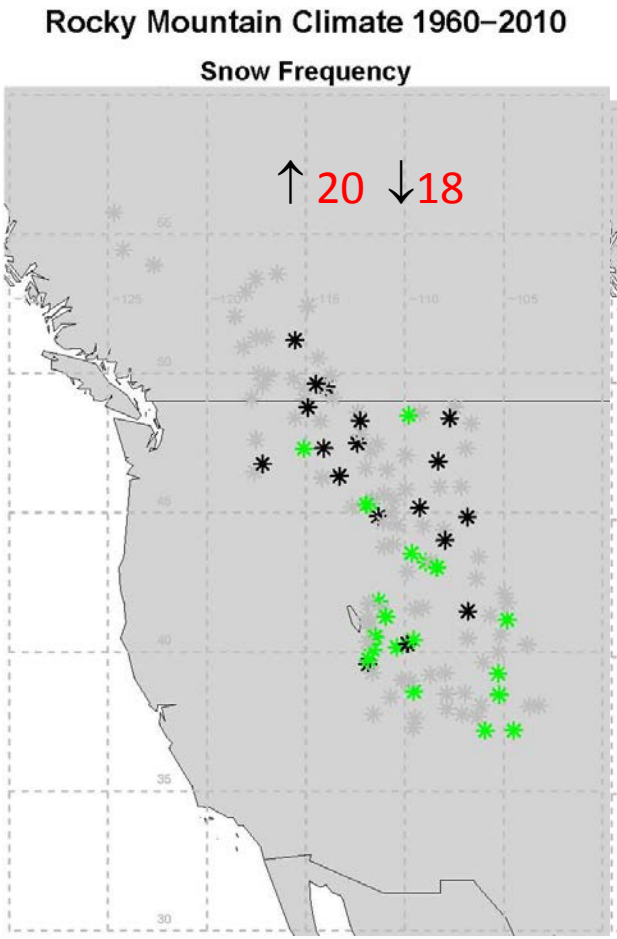


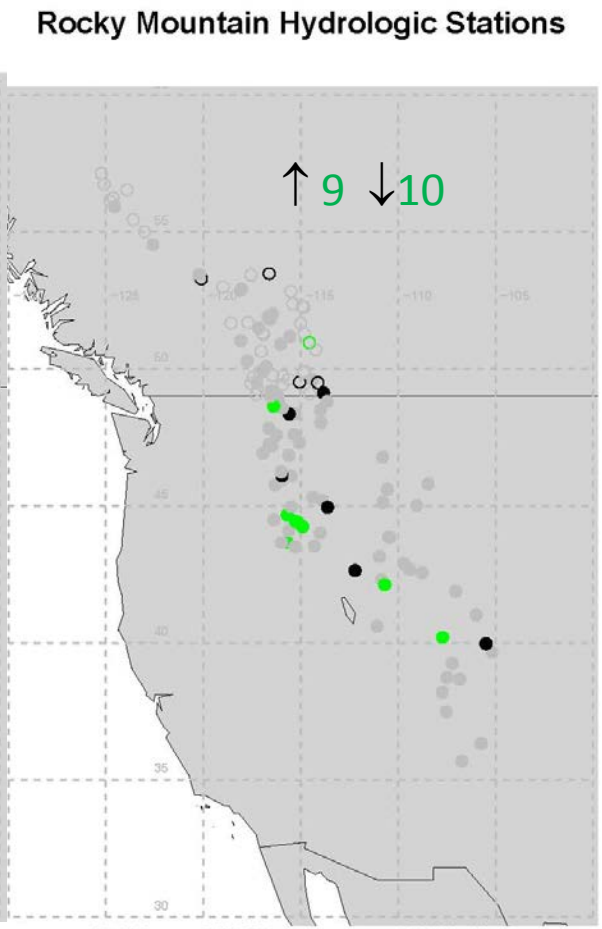


Numbers black green>expected red >2 * expected

Frequency



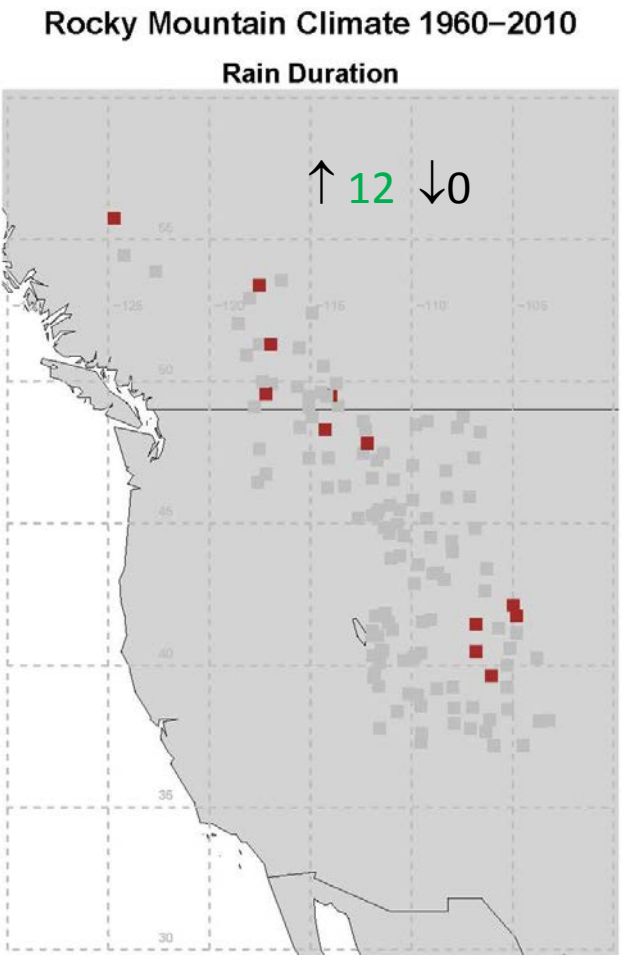


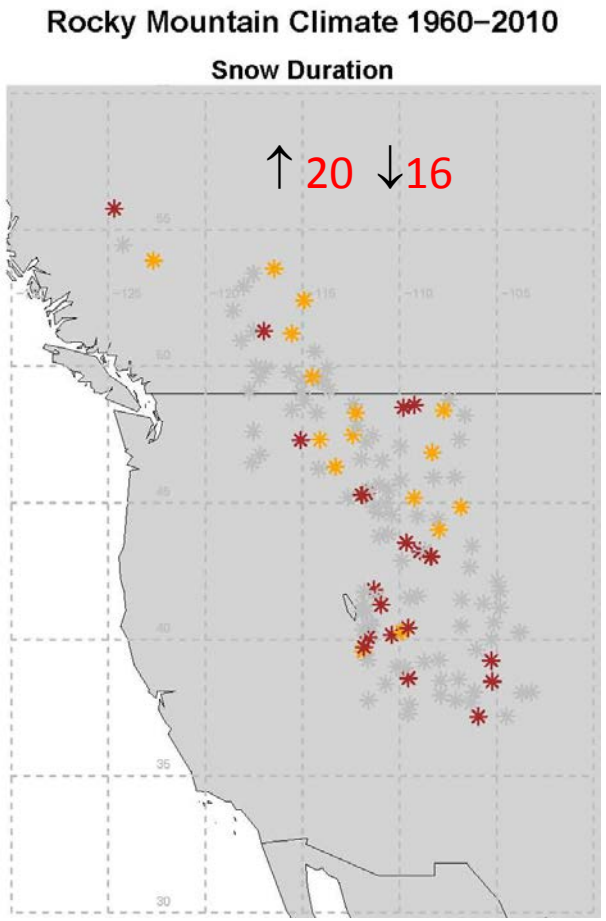


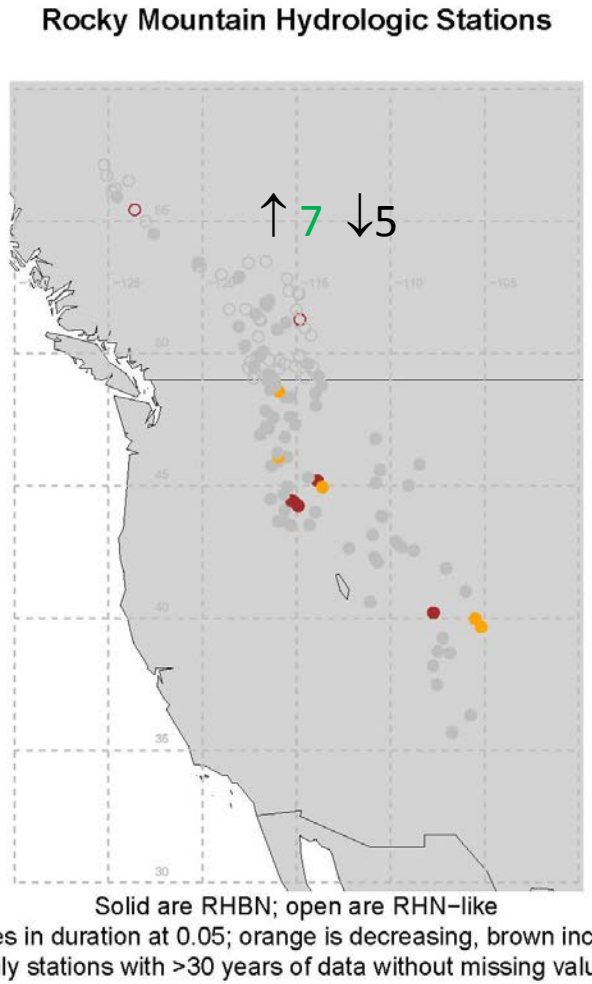
Solid are RHBN; open are RHN–like
Changes in frequency at 0.05: black is decreasing, green increasin
Only stations with >30 years of data without missing values

Numbers black green>expected red >2 * expected

Duration

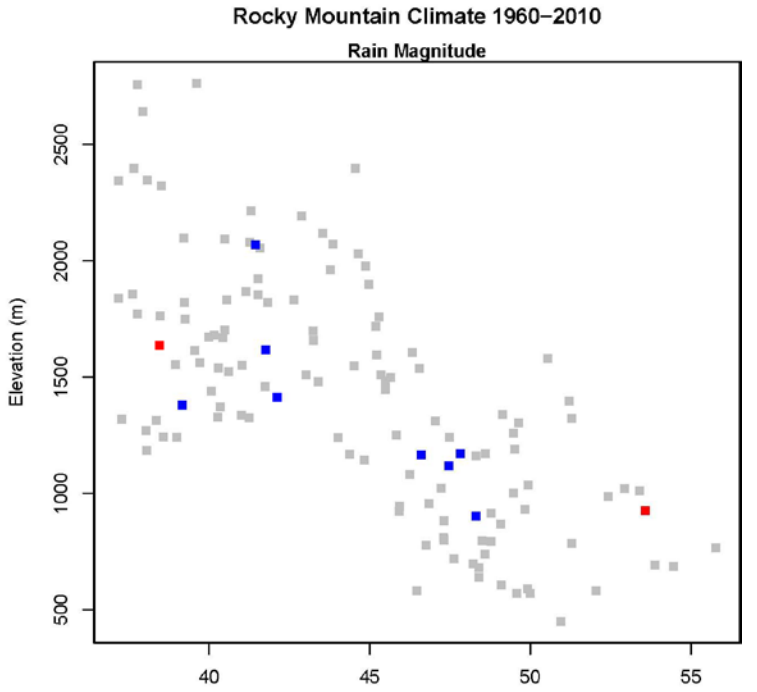


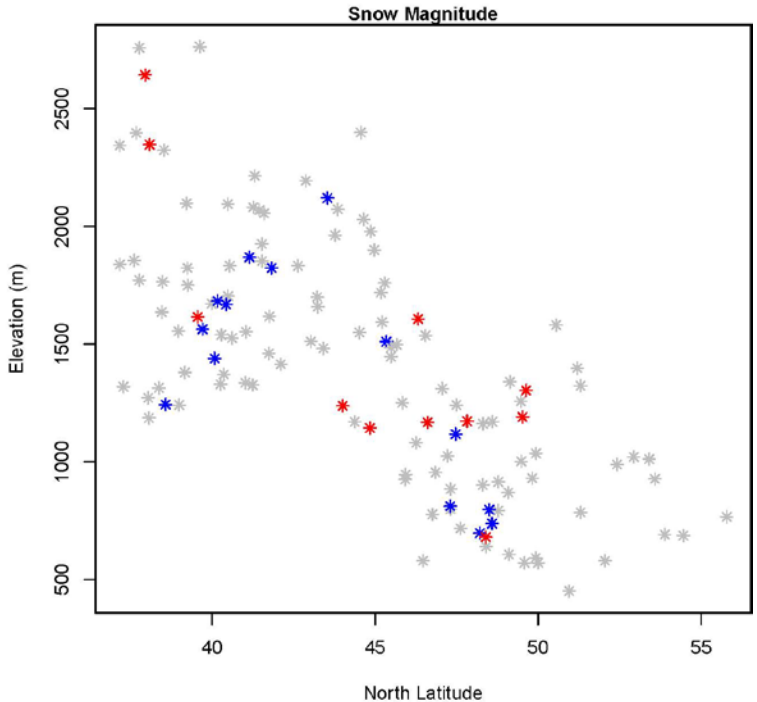


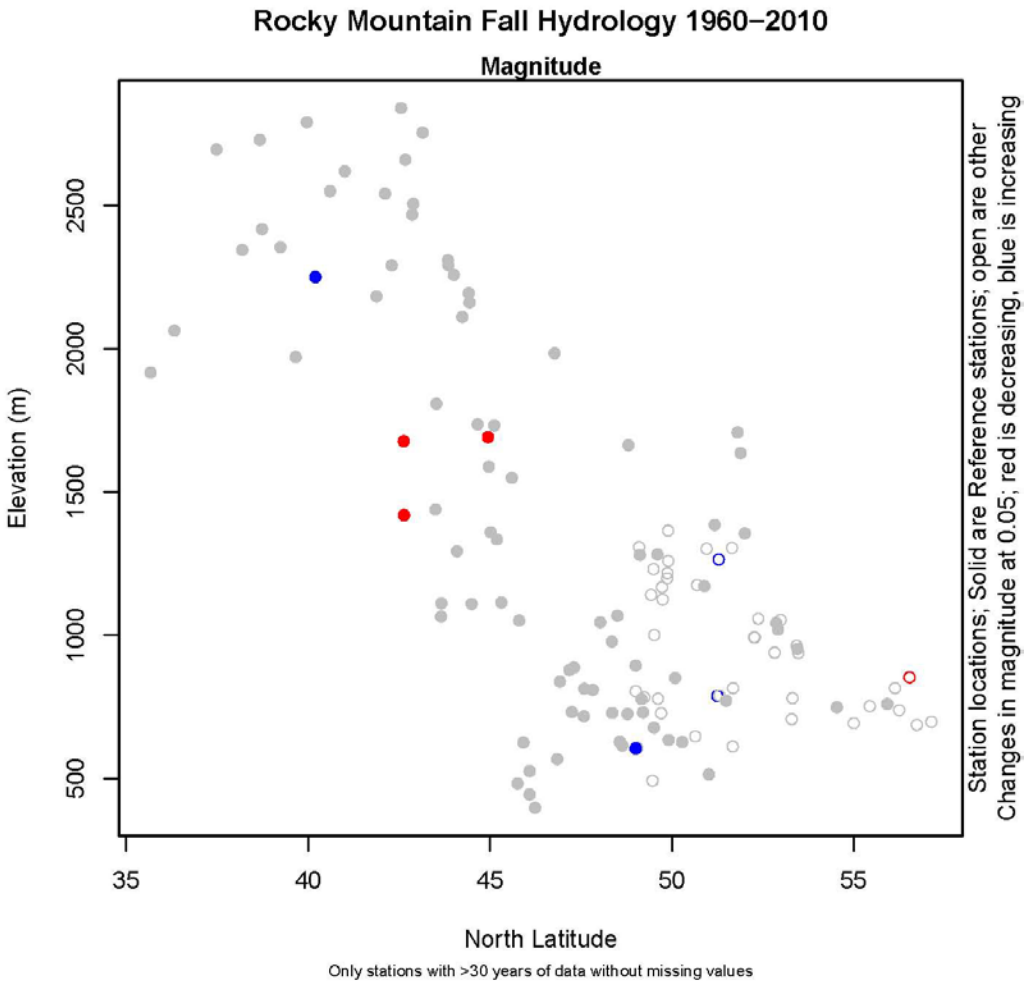


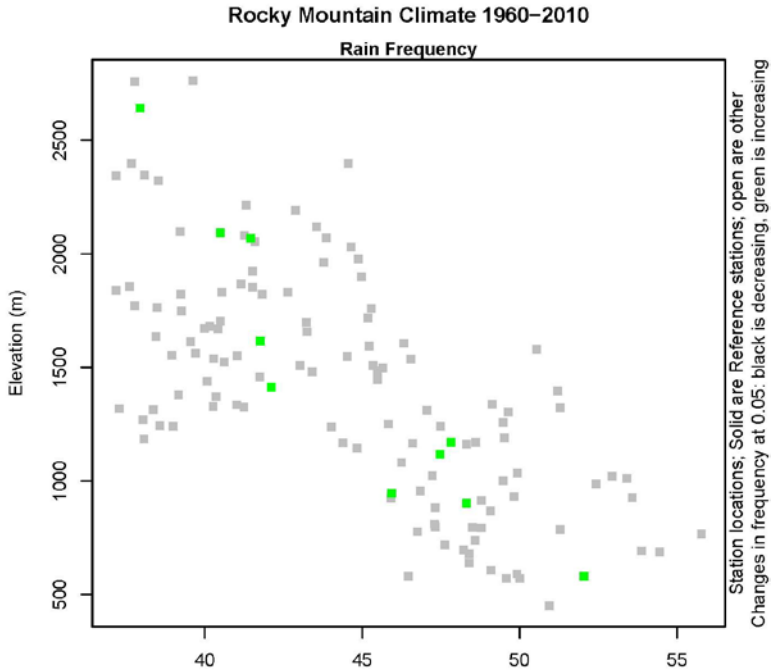
Numbers black green>expected red >2 * expected

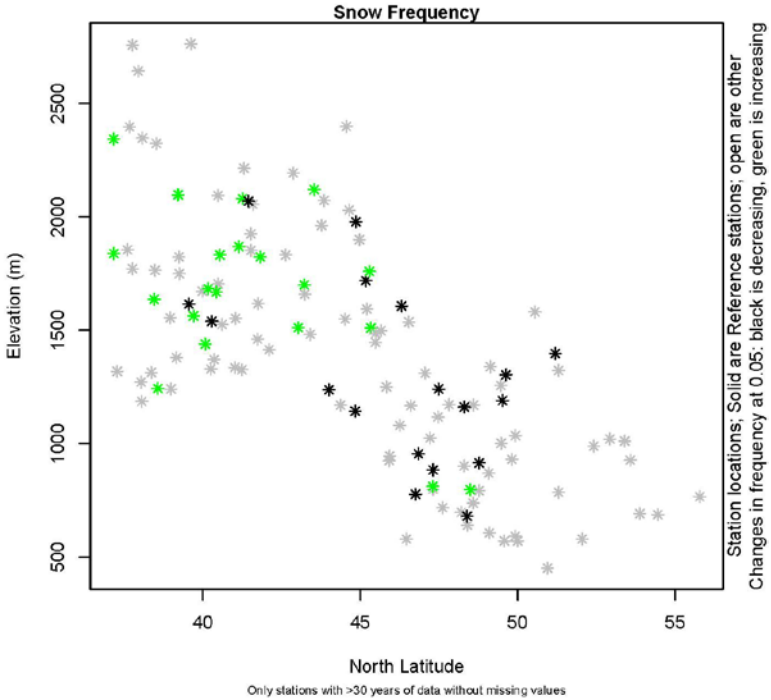
- Interaction between Latitude and elevation?

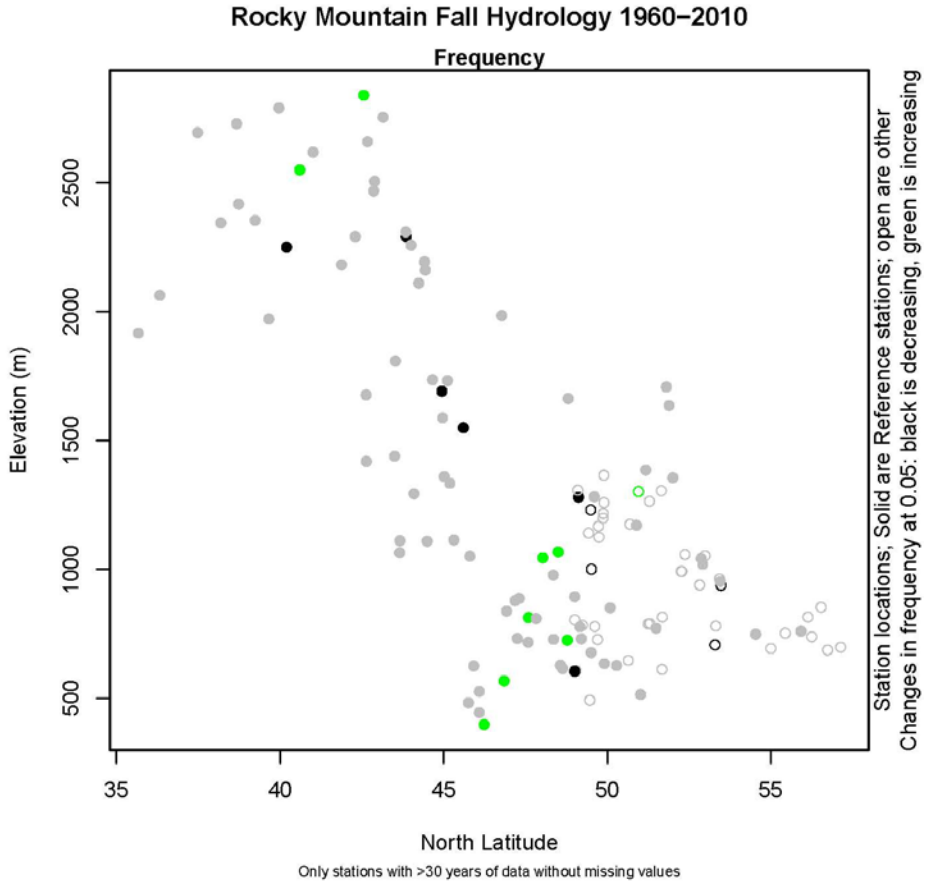

Rocky Mountain Climate 1960–2010
Rain Magnitude
Elevation (m)
500
1000
1500
2000
2500
40
45
50
55

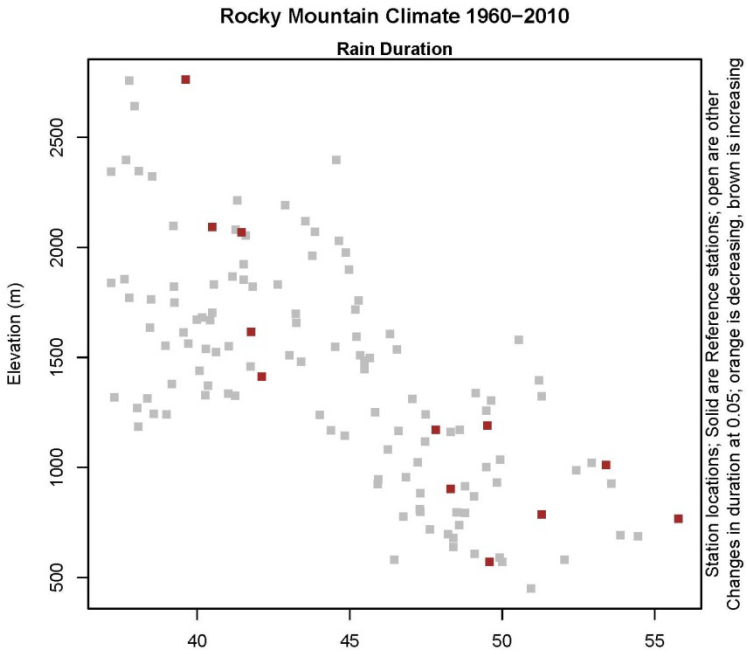

Snow Magnitude
Elevation (m)
500
1000
1500
2000
2500
40
45
50
55
North Latitude

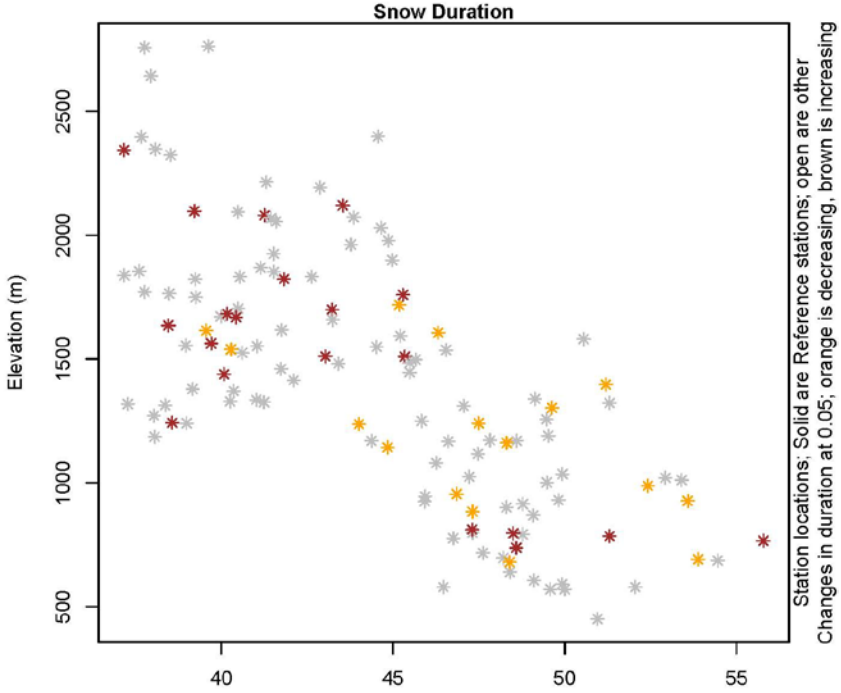

Rocky Mountain Fall Hydrology 1960–2010
Magnitude
Elevation (m)
500
1000
1500
2000
2500
35
40
45
50
55
North Latitude
Only stations with >30 years of data without missing values
Station locations; Solid are Reference stations; open are other
Changes in magnitude at 0.05; red is decreasing, blue is increasing

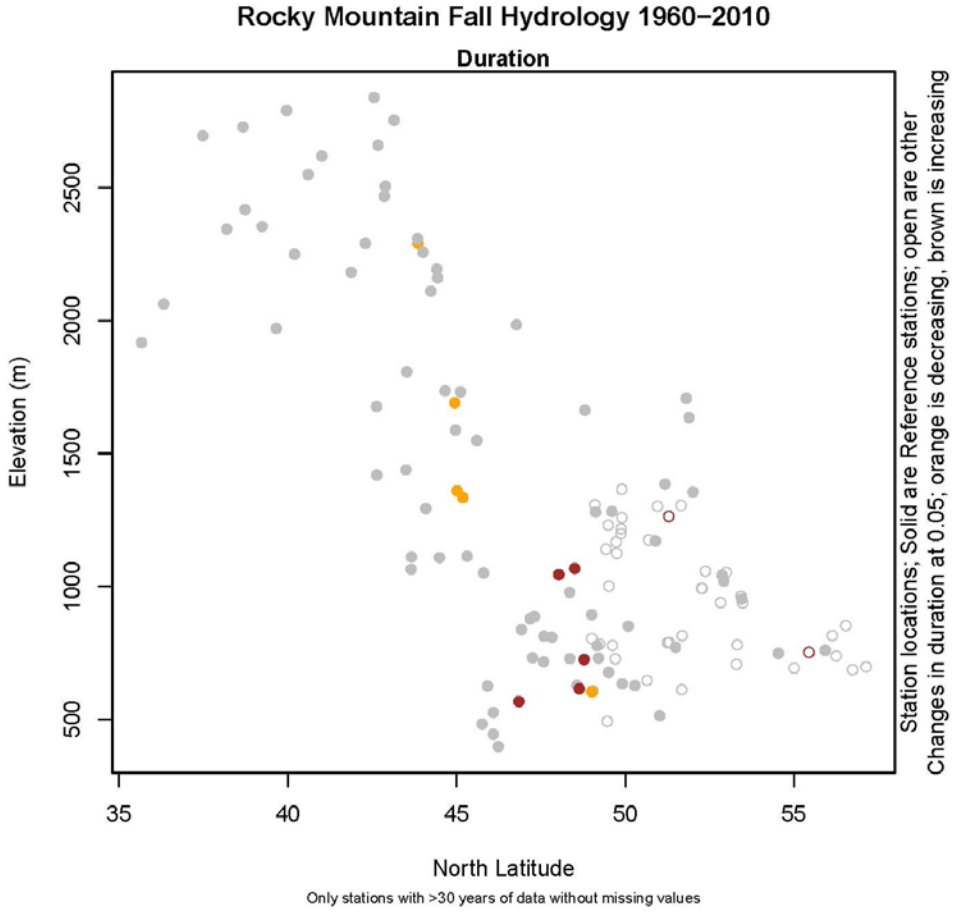

Rocky Mountain Climate 1960–2010
Rain Frequency
Elevation (m)
500
1000
1500
2000
2500
40
45
50
55
Station locations; Solid are Reference stations; open are other
Changes in frequency at 0.05: black is decreasing, green is increasing


Snow Frequency
Elevation (m)
500
1000
1500
2000
2500
40
45
50
55
North Latitude
Only stations with >30 years of data without missing values
Station locations; Solid are Reference stations; open are other
Changes in frequency at 0.05: black is decreasing, green is increasing


Rocky Mountain Fall Hydrology 1960–2010
Frequency
Elevation (m)
500
1000
1500
2000
2500
35
40
45
50
55
North Latitude
Only stations with >30 years of data without missing values
Station locations; Solid are Reference stations; open are other
Changes in frequency at 0.05: black is decreasing, green is increasing


Rocky Mountain Climate 1960–2010
Rain Duration
Elevation (m)
500
1000
1500
2000
2500
40
45
50
55
Station locations; Solid are Reference stations; open are other
Changes in duration at 0.05; orange is decreasing, brown is increasing

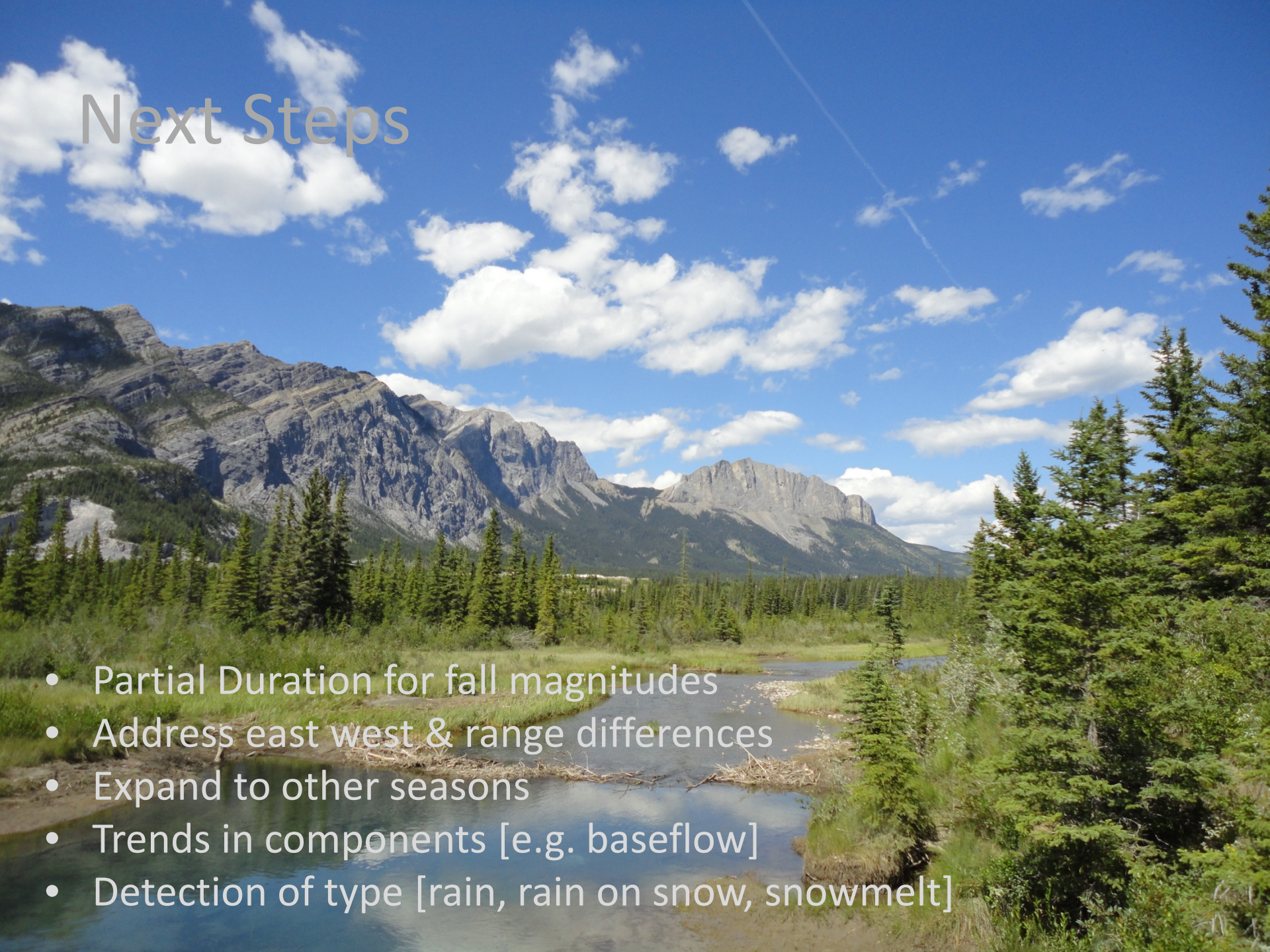

Snow Duration
Elevation (m)
500
1000
1500
2000
2500
40
45
50
55
Station locations; Solid are Reference stations; open are other
Changes in duration at 0.05; orange is decreasing, brown is increasing


Rocky Mountain Fall Hydrology 1960–2010
Duration
Elevation (m)
500
1000
1500
2000
2500
35
40
45
50
55
North Latitude
Only stations with >30 years of data without missing values
Station locations; Solid are Reference stations; open are other
Changes in duration at 0.05; orange is decreasing, brown is increasing

Summary

- More significant cases than expected
- Uneven
  - snow >> flow > rain 99 39 32
  - Frequency > duration >> magnitude 67 60 43
- Spatial pattern
  - Differences between south and north
  - Interaction with elevation
  - Gradients?

Next Steps



- Partial Duration for fall magnitudes
- Address east west & range differences
- Expand to other seasons
- Trends in components [e.g. baseflow]
- Detection of type [rain, rain on snow, snowmelt]