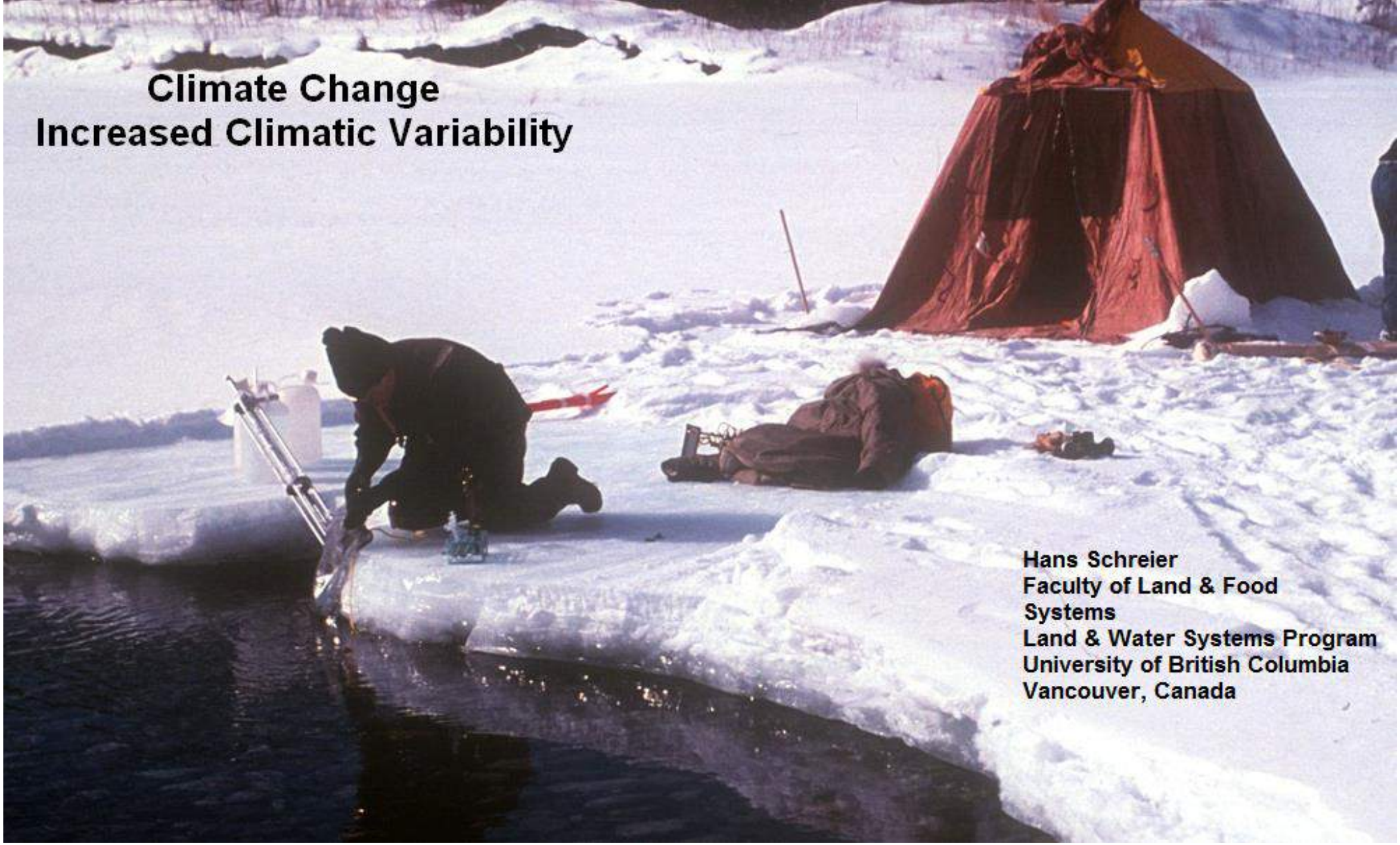

Climate Change
Increased Climatic Variability
Hans Schreier
Faculty of Land & Food Systems
Land & Water Systems Program
University of British Columbia
Vancouver, Canada

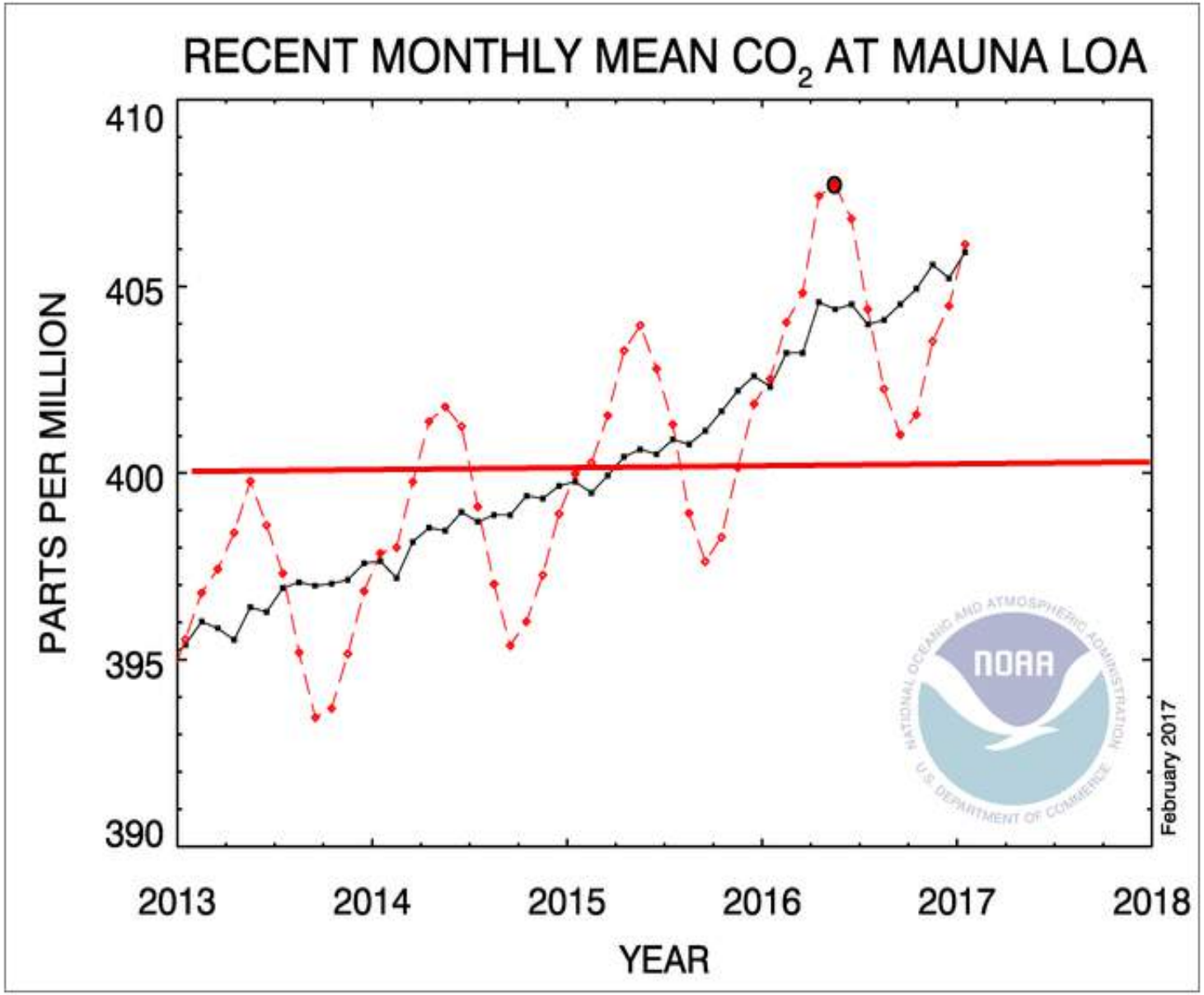
Global Overview

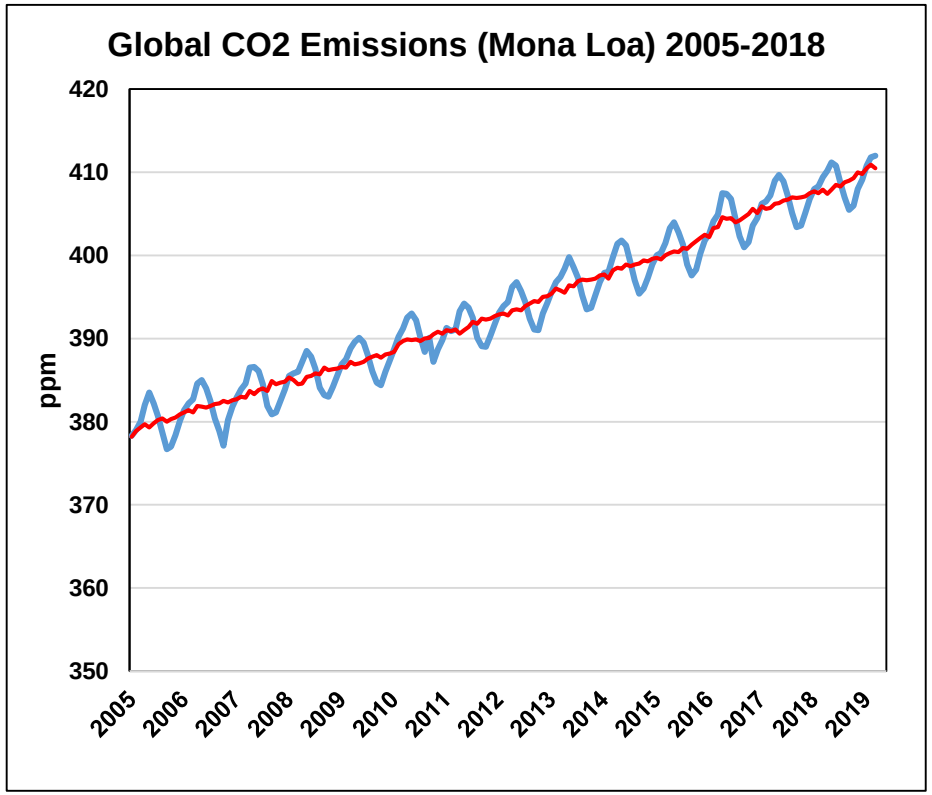
Recent Events

Implications

Summary

Trend in Global CO 2 Emissions in Hawaii



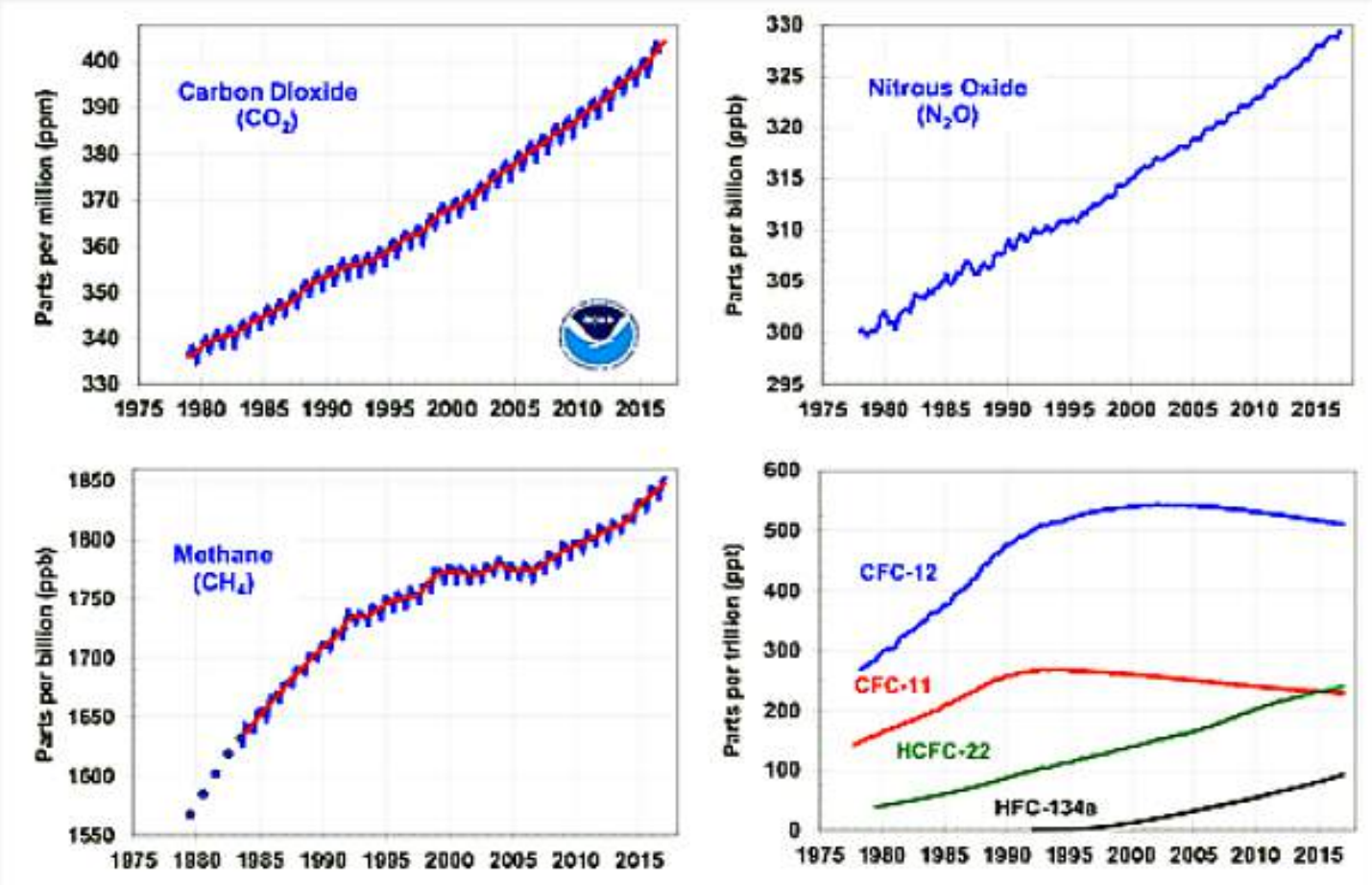


2017 Dec = 406 ppm

2019 Mar =411 ppm

Climate Change and Increased Climatic Variability

Different Greenhouse Gases



CO2 65-70% Absorbed into the Ocean over 20-200 Years

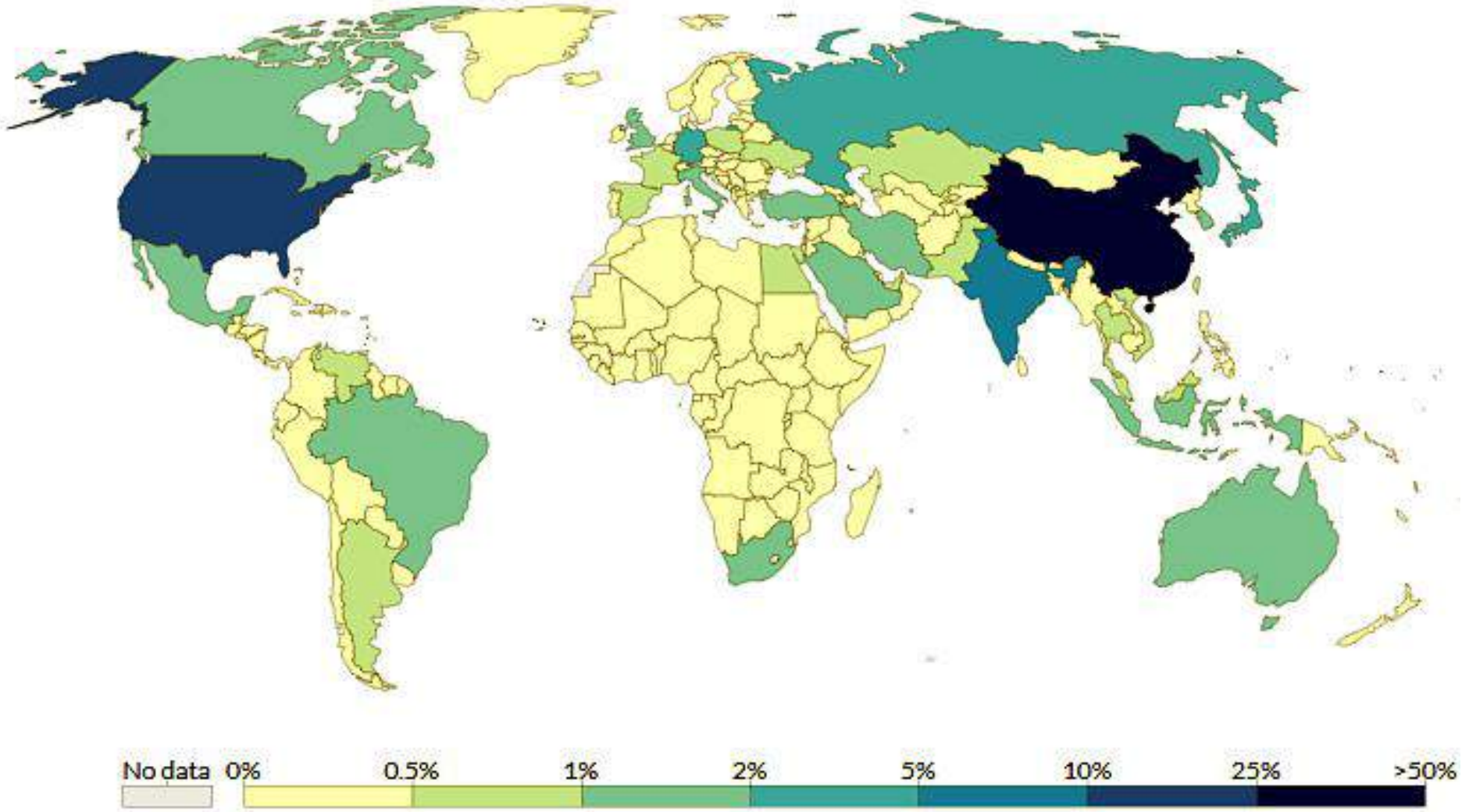
CH4 12 + Years

N2O 121 Years

CFC > 1000 Years

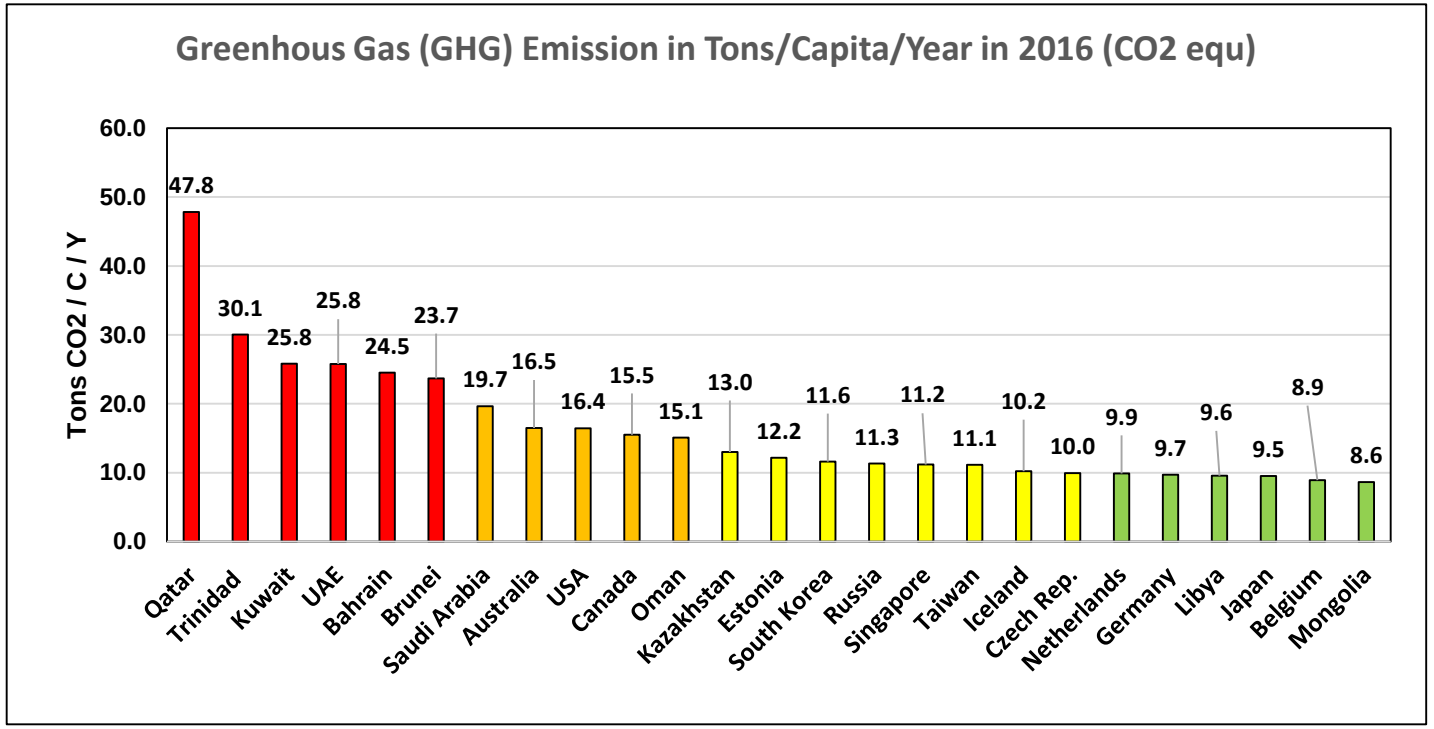
Annual share of global CO_2 emissions, 2016

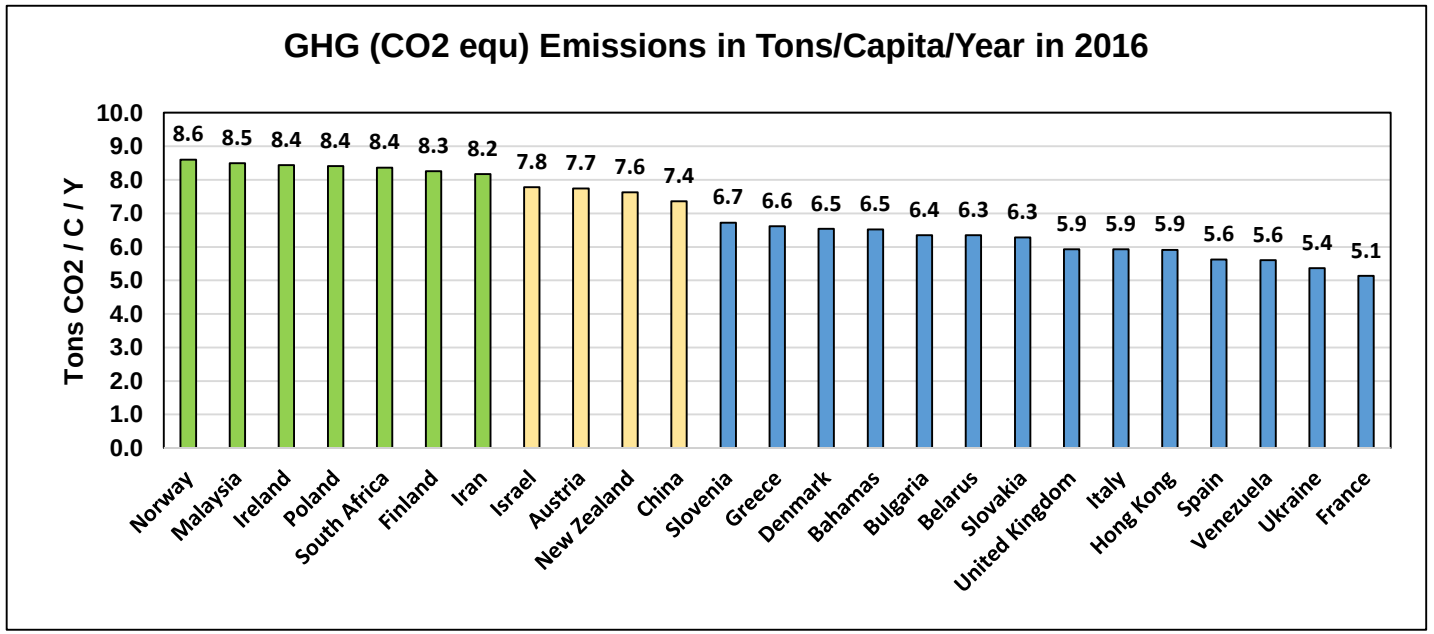
Each country's share of global carbon dioxide (CO_2) emissions. This is measured as each country's emissions divided by the sum of all countries' emissions in a given year; this does not include international aviation and shipping (known as 'bunkers') and 'statistical differences' in carbon accounts.

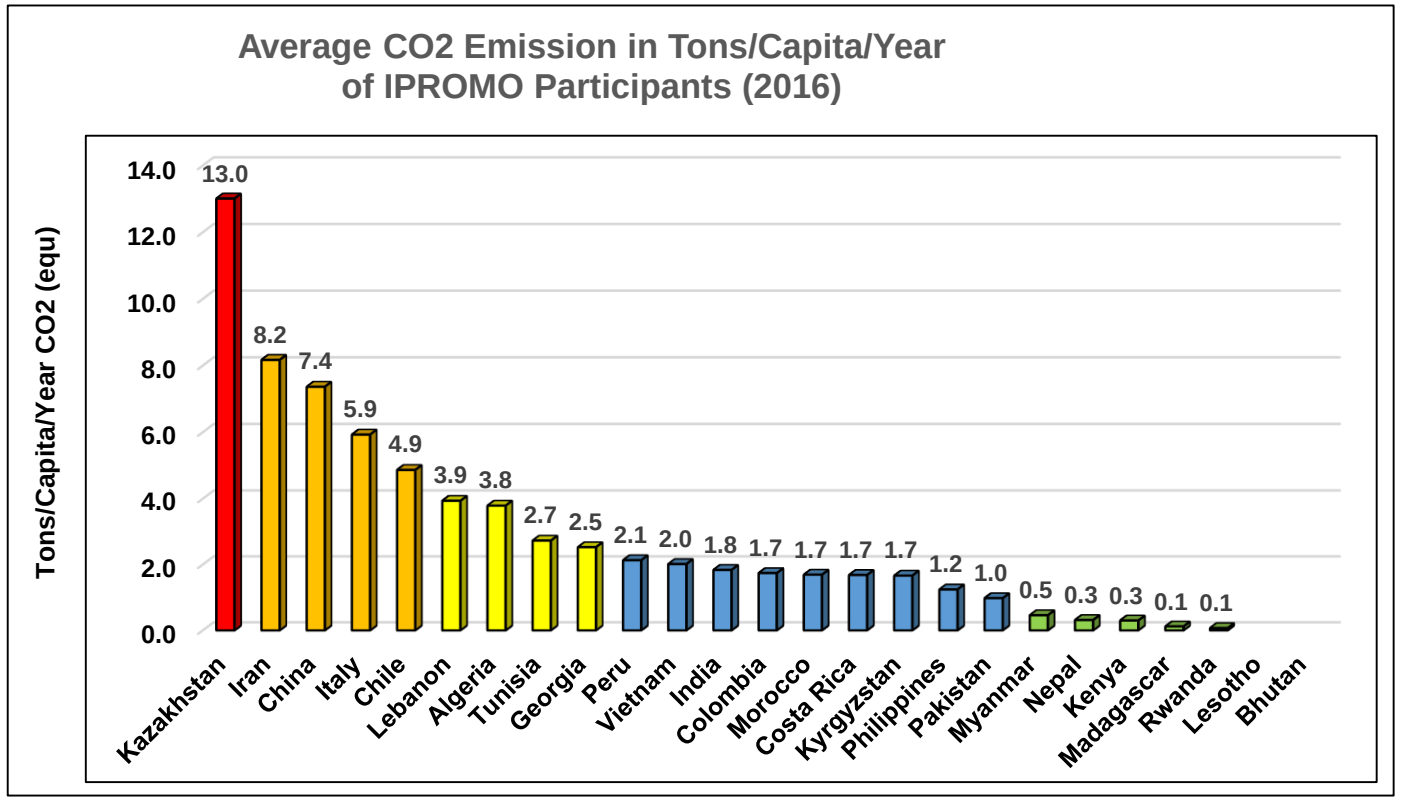


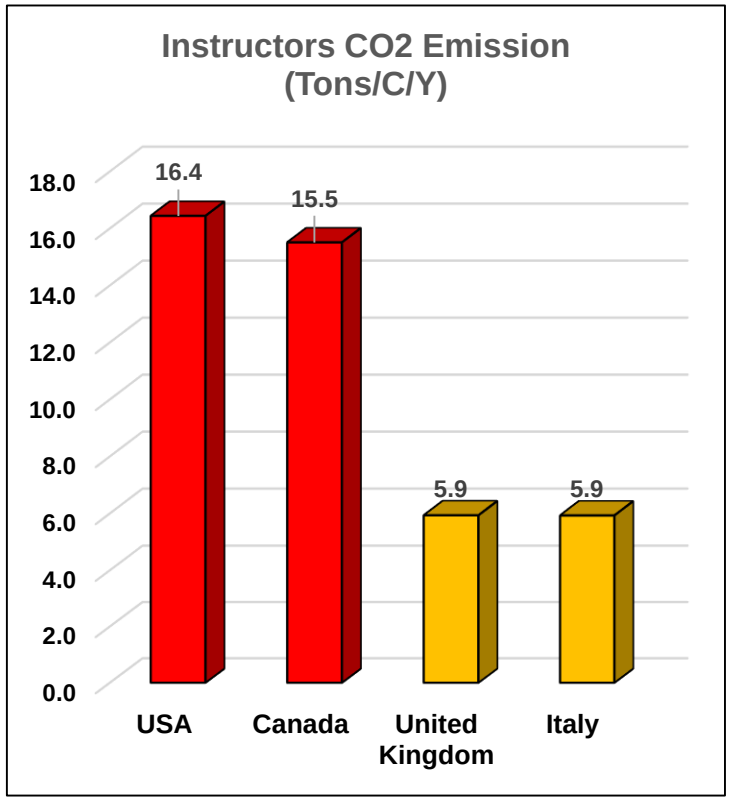
China	**28%**
USA	**15%**
EU 28	**9%**
India	**7%**
Russia	**5%**
Japan	**4%**

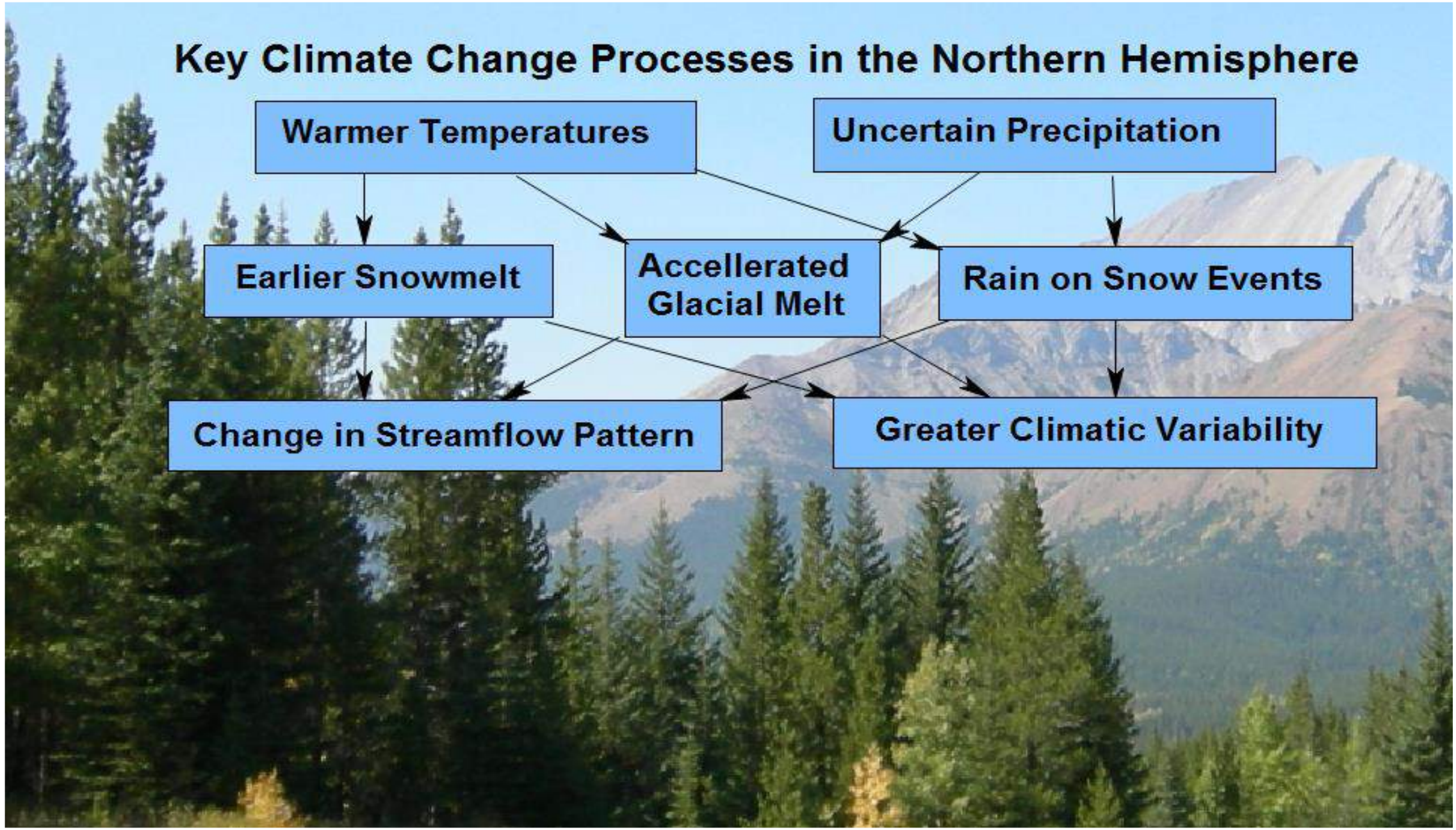
Source: Our World in Data based on Global Carbon Project (2017)


Greenhous Gas (GHG) Emission in Tons/Capita/Year in 2016 (CO2 equ)
Tons CO2 / C / Y
60.0
50.0
40.0
30.0
20.0
10.0
0.0
47.8
30.1
25.8
25.8
24.5
23.7
19.7
16.5
16.4
15.5
15.1
13.0
12.2
11.6
11.3
11.2
11.1
10.2
10.0
9.9
9.7
9.6
9.5
8.9
8.6
Qatar
Trinidad
Kuwait
UAE
Bahrain
Brunei
Saudi Arabia
Australia
USA
Canada
Oman
Kazakhstan
Estonia
South Korea
Russia
Singapore
Taiwan
Iceland
Czech Rep.
Netherlands
Germany
Libya
Japan
Belgium
Mongolia


GHG (CO2 equ) Emissions in Tons/Capita/Year in 2016
Tons CO2 / C / Y
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
8.6
8.5
8.4
8.4
8.4
8.3
8.2
7.8
7.7
7.6
7.4
6.7
6.6
6.5
6.5
6.4
6.3
6.3
5.9
5.9
5.9
5.6
5.6
5.4
5.1
Norway
Malaysia
Ireland
Poland
South Africa
Finland
Iran
Israel
Austria
New Zealand
China
Slovenia
Greece
Denmark
Bahamas
Bulgaria
Belarus
Slovakia
United Kingdom
Italy
Hong Kong
Spain
Venezuela
Ukraine
France


Average CO2 Emission in Tons/Capita/Year
of IPROMO Participants (2016)
Tons/Capita/Year CO2 (equ)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
13.0
8.2
7.4
5.9
4.9
3.9
3.8
2.7
2.5
2.1
2.0
1.8
1.7
1.7
1.7
1.7
1.2
1.0
0.5
0.3
0.3
0.1
0.1
Kazakhstan
Iran
China
Italy
Chile
Lebanon
Algeria
Tunisia
Georgia
Peru
Vietnam
India
Colombia
Morocco
Costa Rica
Kyrgyzstan
Philippines
Pakistan
Myanmar
Nepal
Kenya
Madagascar
Rwanda
Lesotho
Bhutan

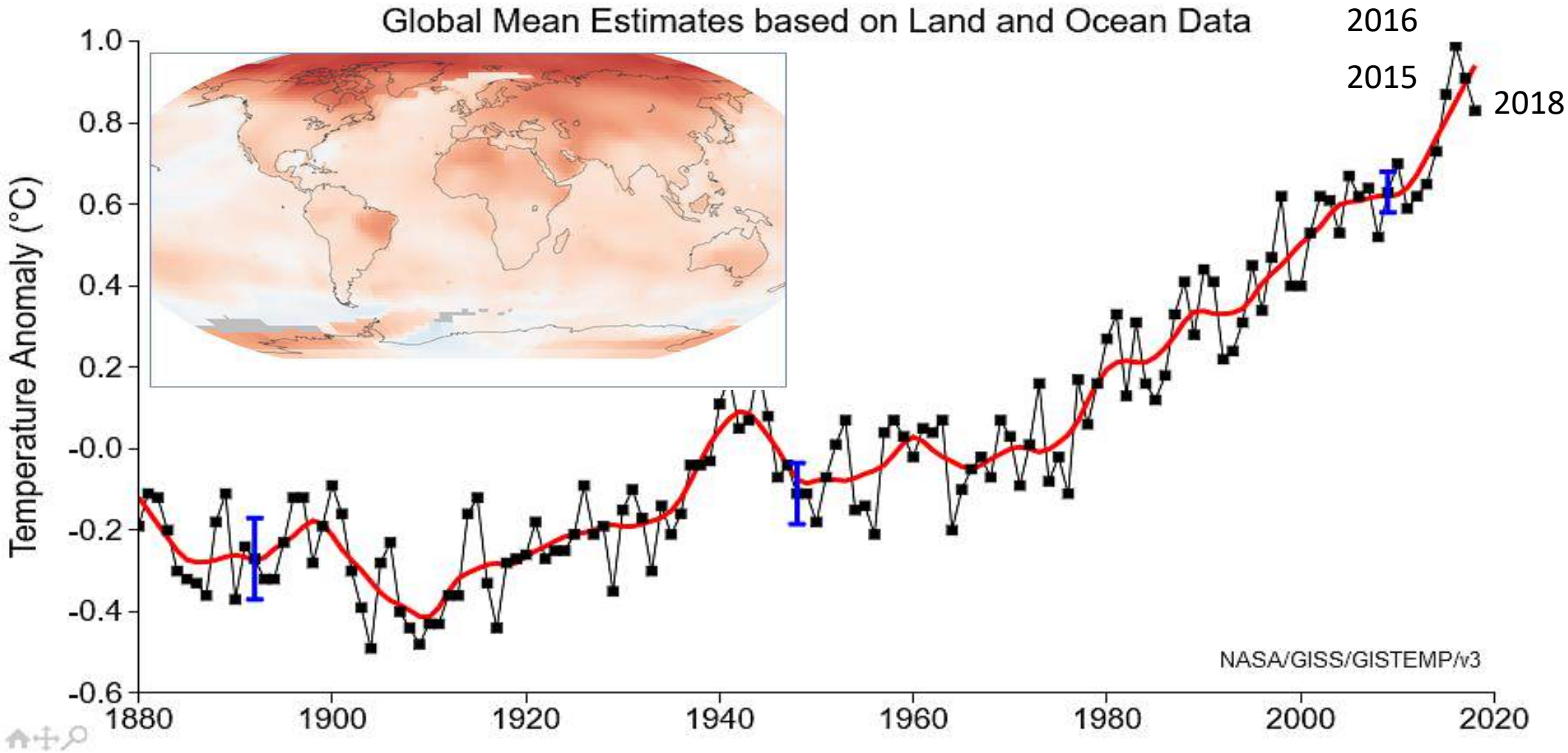

Instructors CO2 Emission
(Tons/C/Y)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
16.4
15.5
5.9
5.9
USA
Canada
United
Kingdom
Italy


Key Climate Change Processes in the Northern Hemisphere
Warmer Temperatures
Uncertain Precipitation
Earlier Snowmelt
Accellerated Glacial Melt
Rain on Snow Events
Change in Streamflow Pattern
Greater Climatic Variability

Climate Questions:

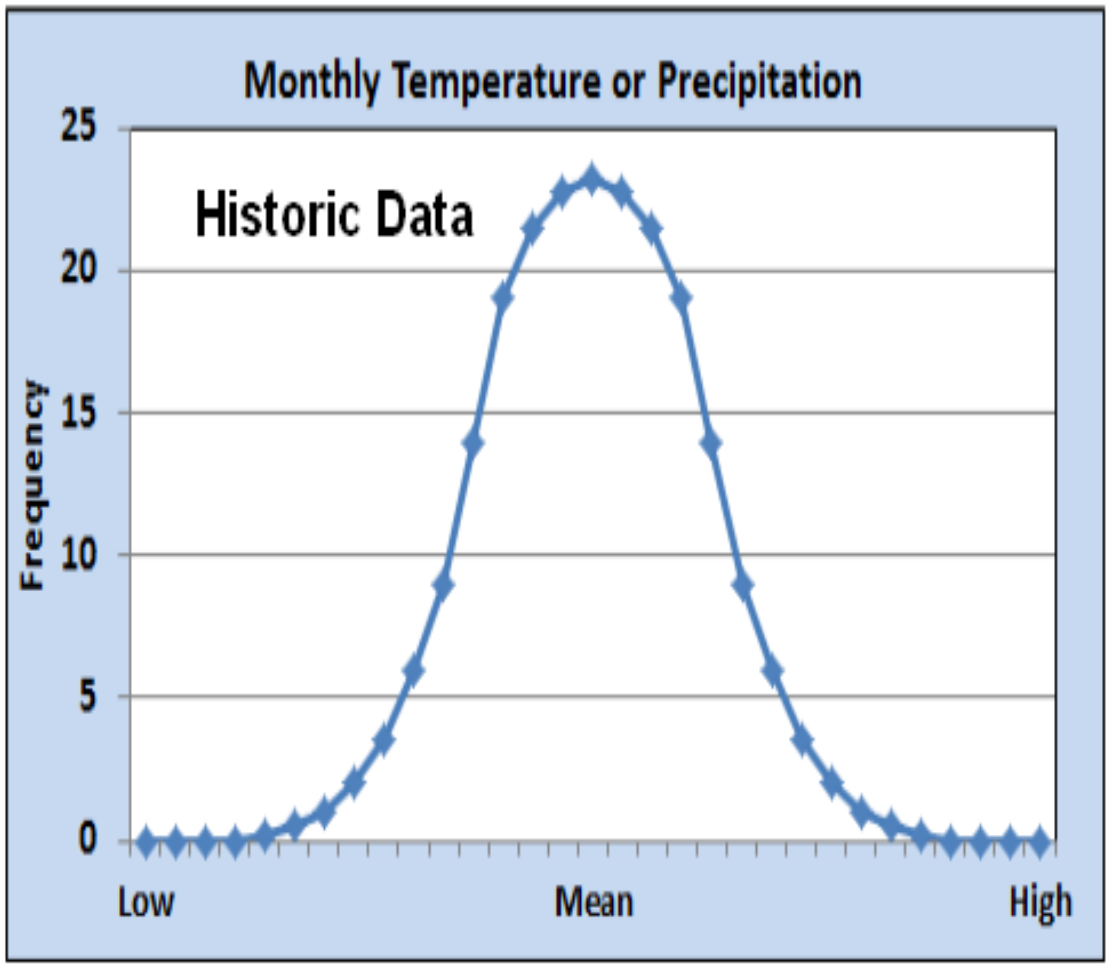
- How have Extreme Hot and Cold Temperature Changed ?
- Evidence of Record Hot Temperatures ?
- Is Rainfall Intensity, Duration & Frequency Increasing?
- Combined Temperature & Precipitation Interactions ?
- How does Topography Impact Rainfall & Runoff?

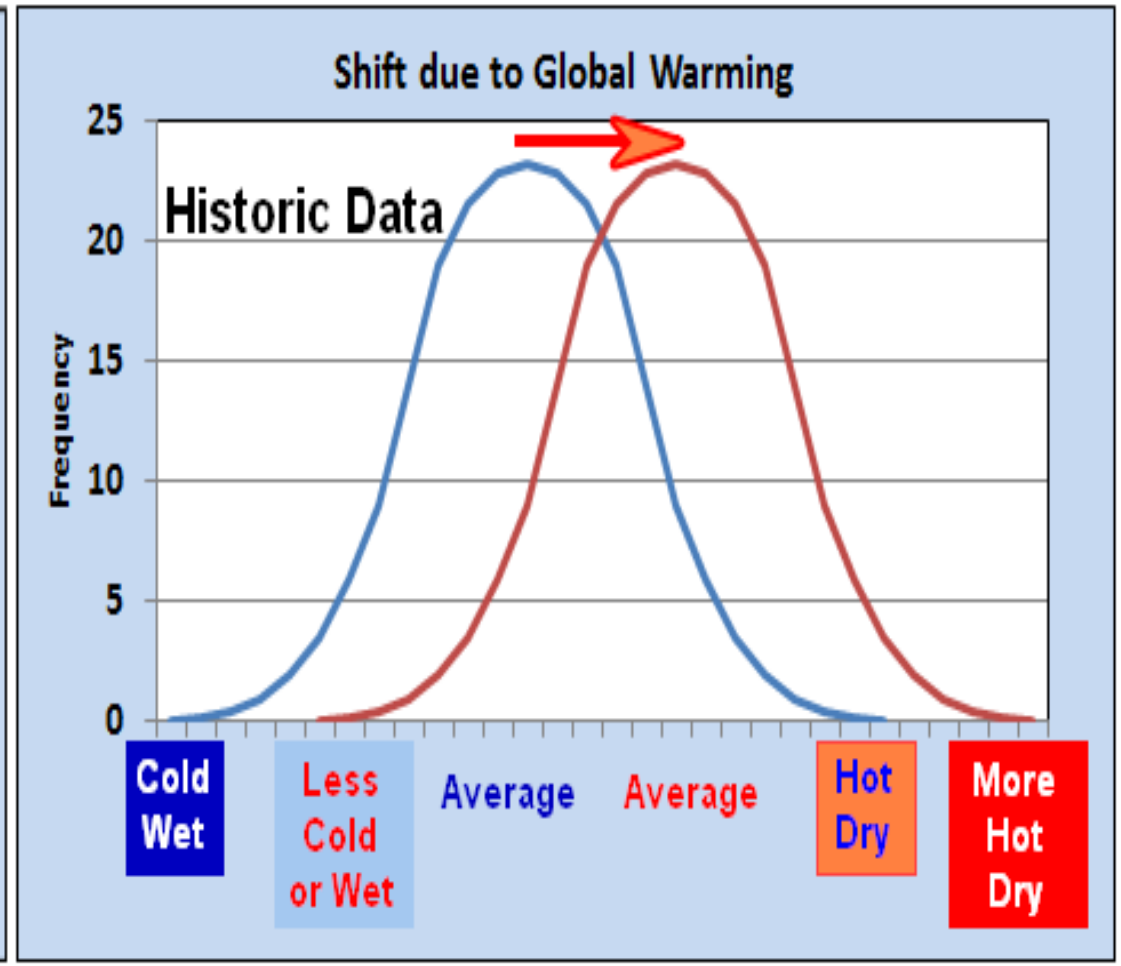


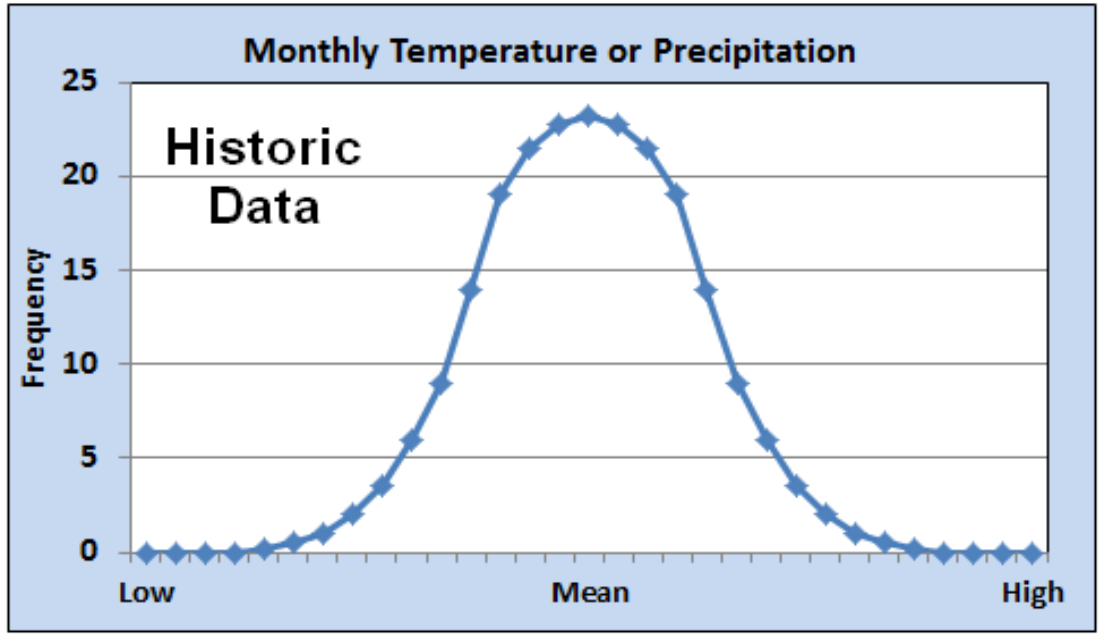


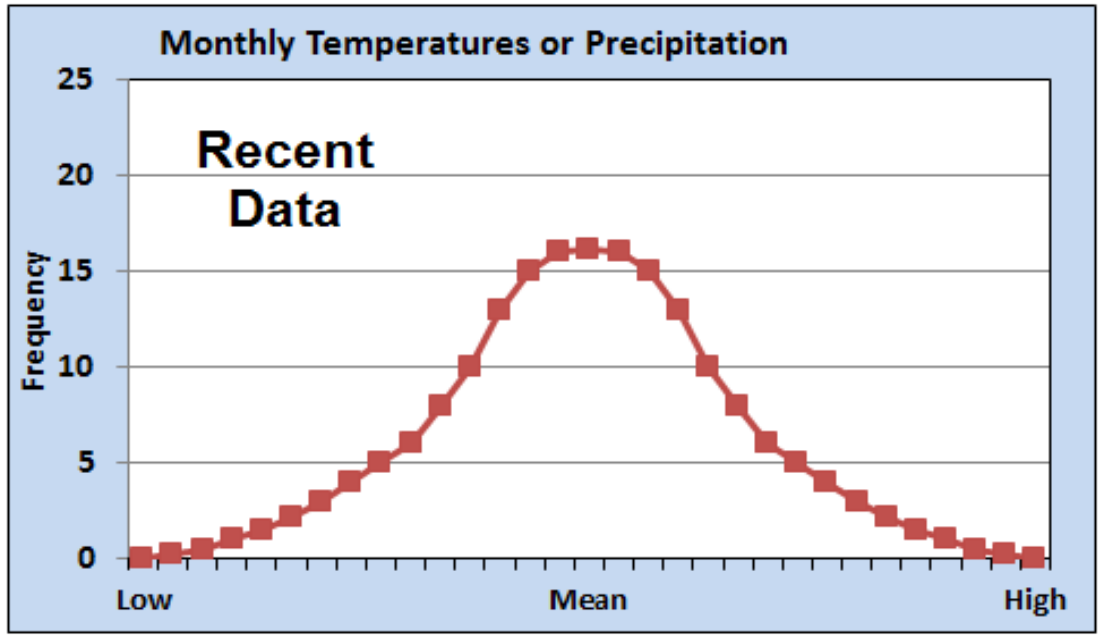
Land-ocean temperature index, 1880 to present, with base period 1951-1980. The solid black line is the global annual mean and the solid red line is the five-year lowess smooth. The blue uncertainty bars (95% confidence limit) account only for incomplete spatial sampling. [This is an update of Fig. 9a in Hansen et al. (2010).]

Assumption : Historic Dara Variability is Unchanged and Global Warming Increases

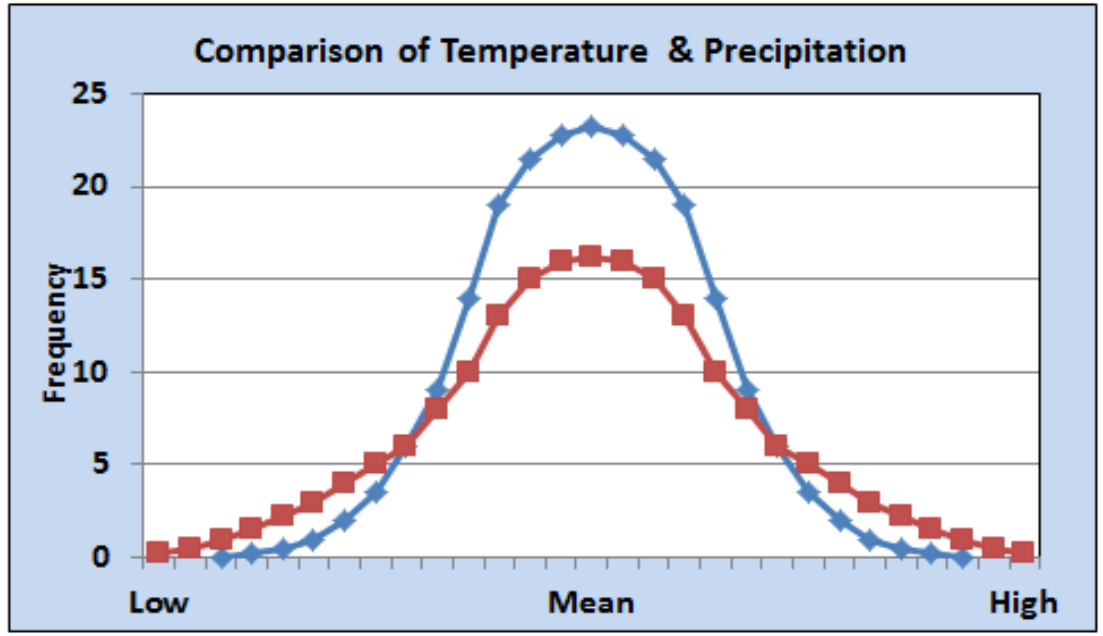




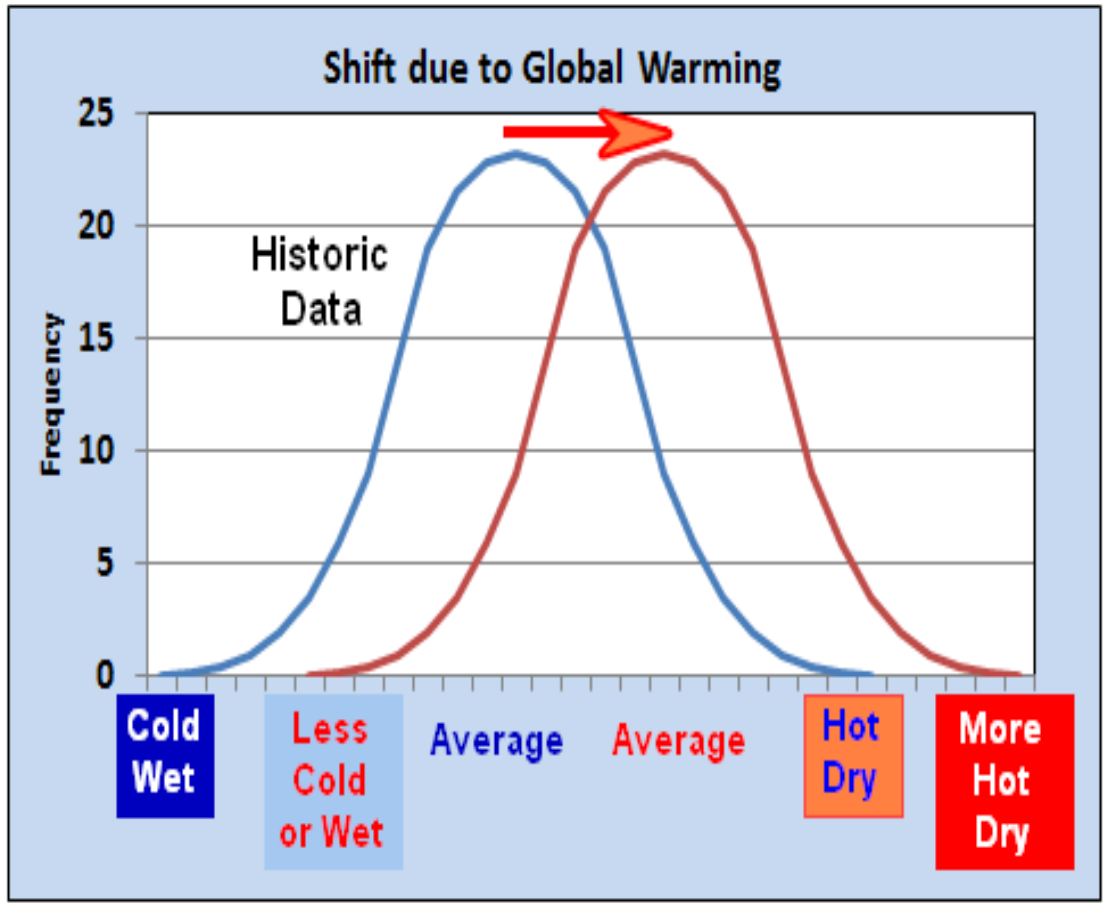


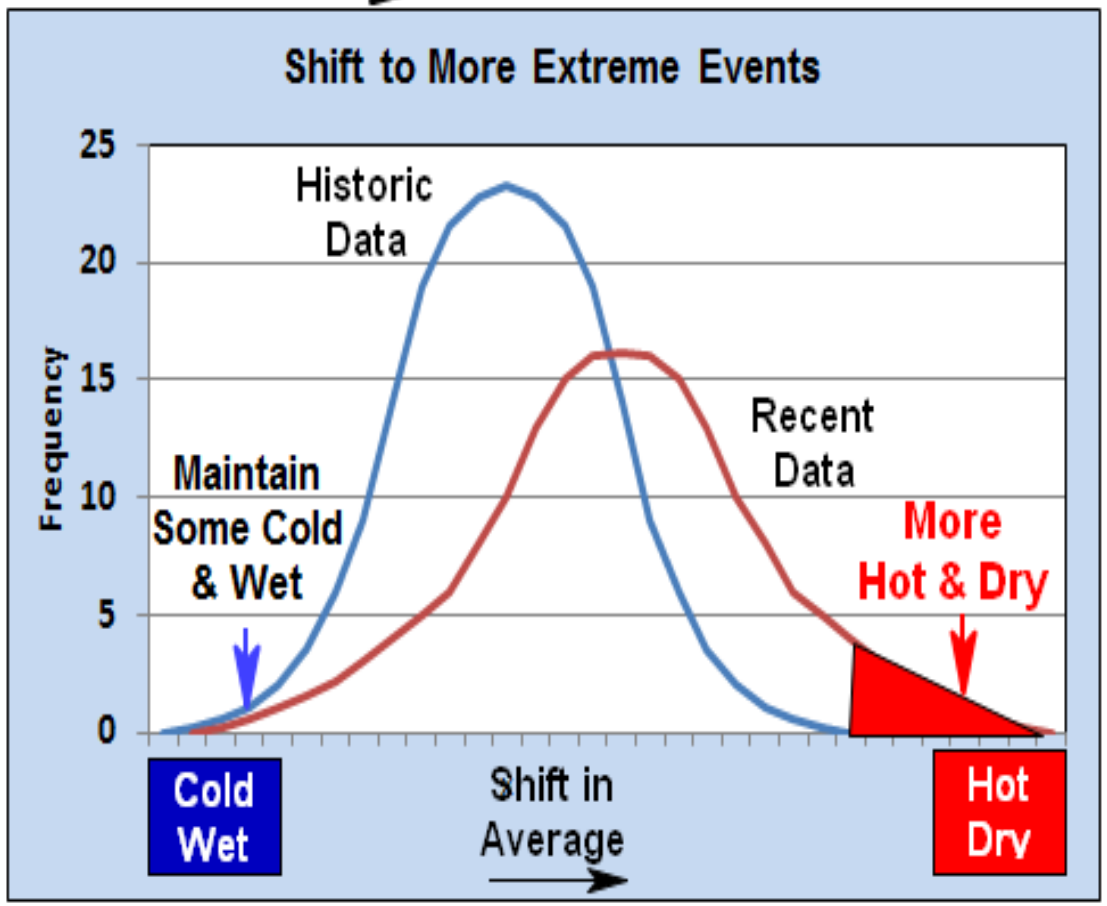


Assumption :
Shift from Historic to More Vararіable Data but no Global Warming



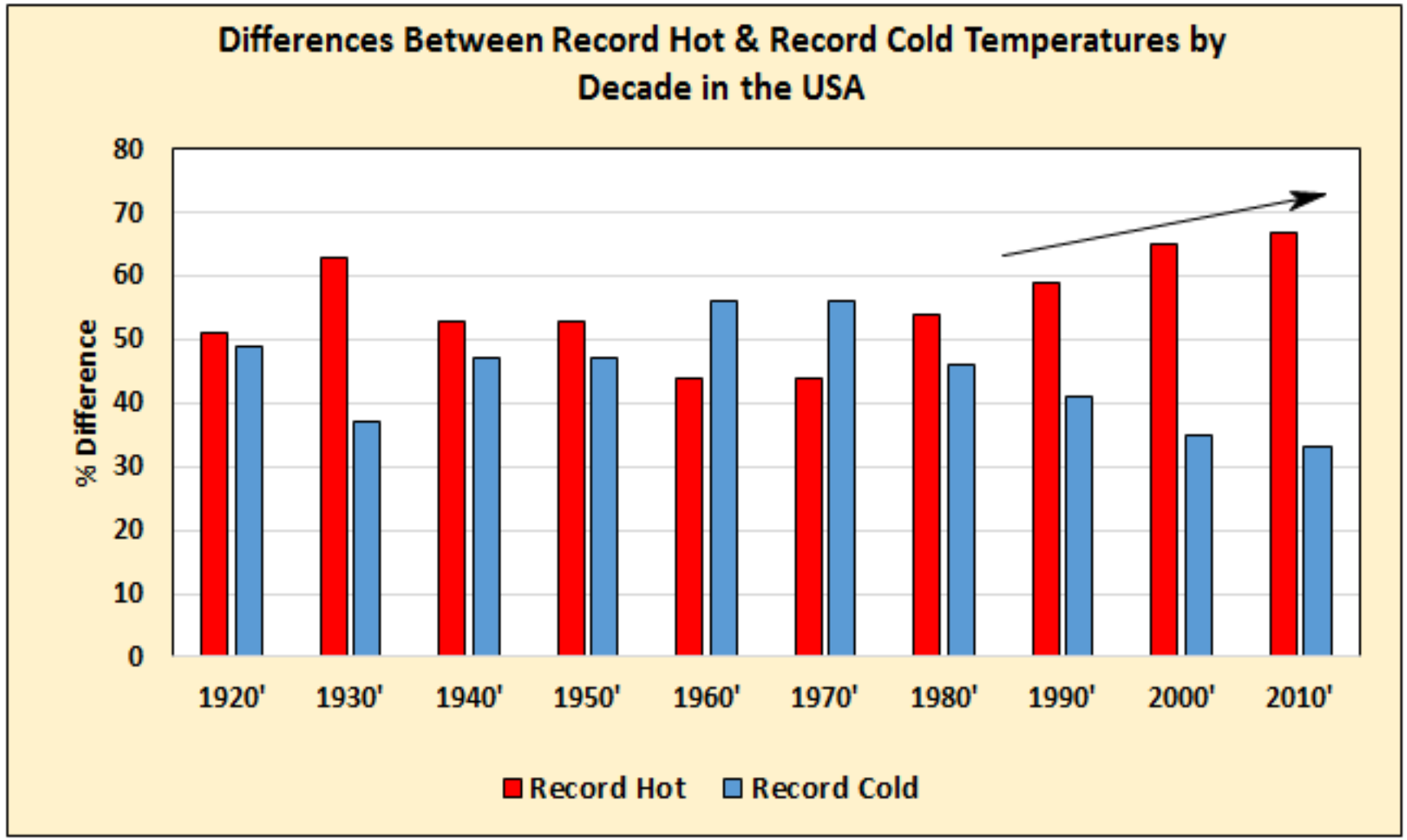
Moving from Left to Right





Results: We will have more extreme event
Less frequent cold & wet more frequent hot and dry conditions

Differences Between Record Low and High Temperatures by Decades in the USA

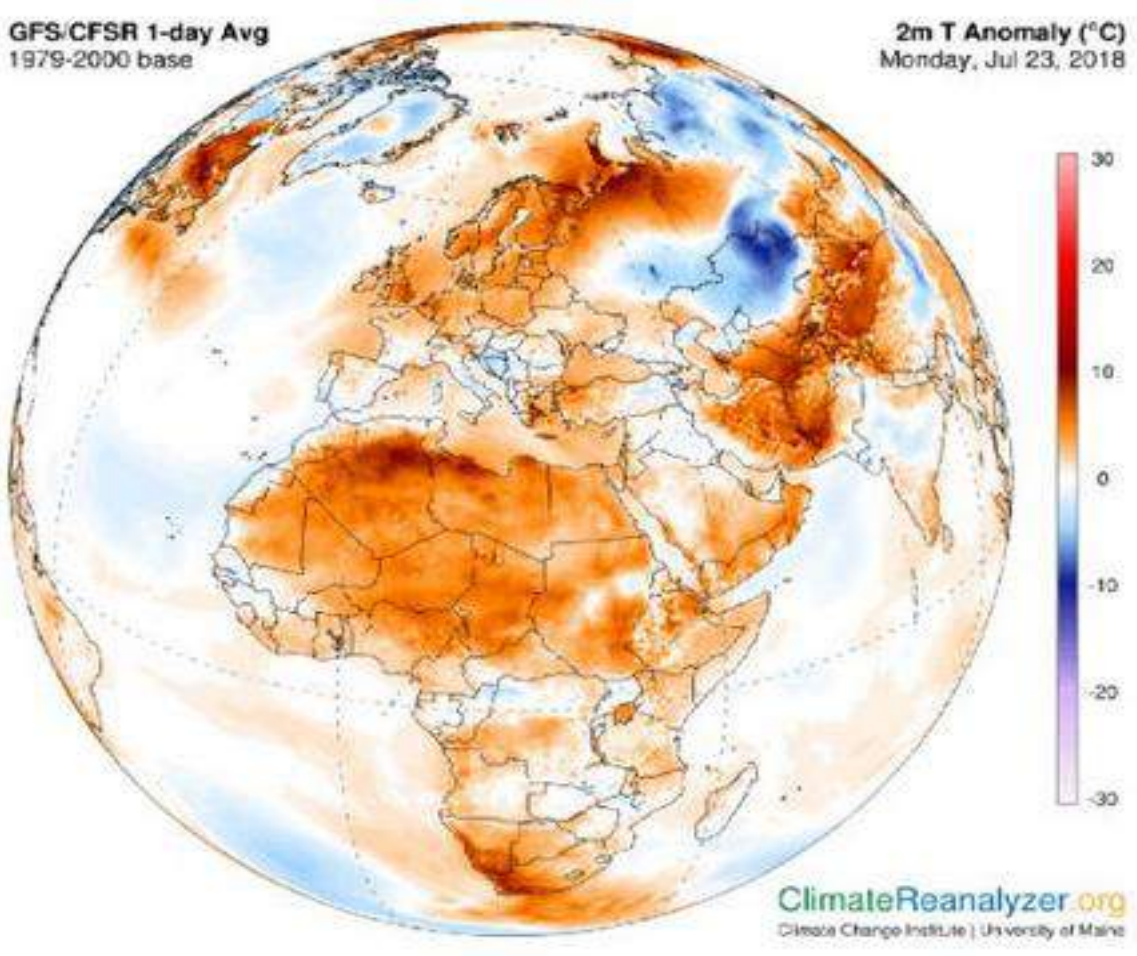


Increasing Record Hot Temperatures and Decreasing Record Low Temperatures 1980'-2010'

Data Source:

Climate Central 2017

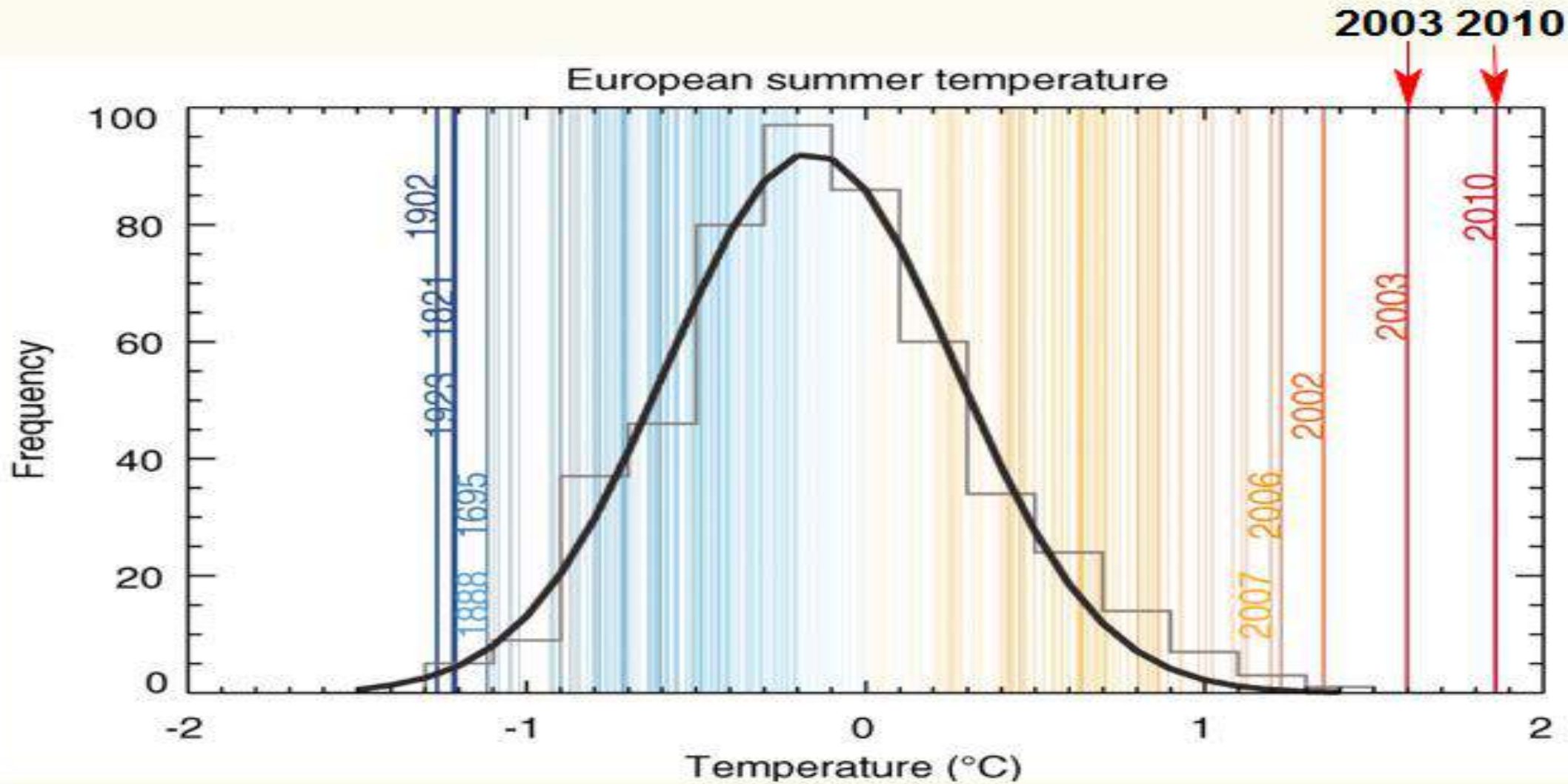
According to NOAA 3220 Record High Temperature Were Broken in June & July 2018



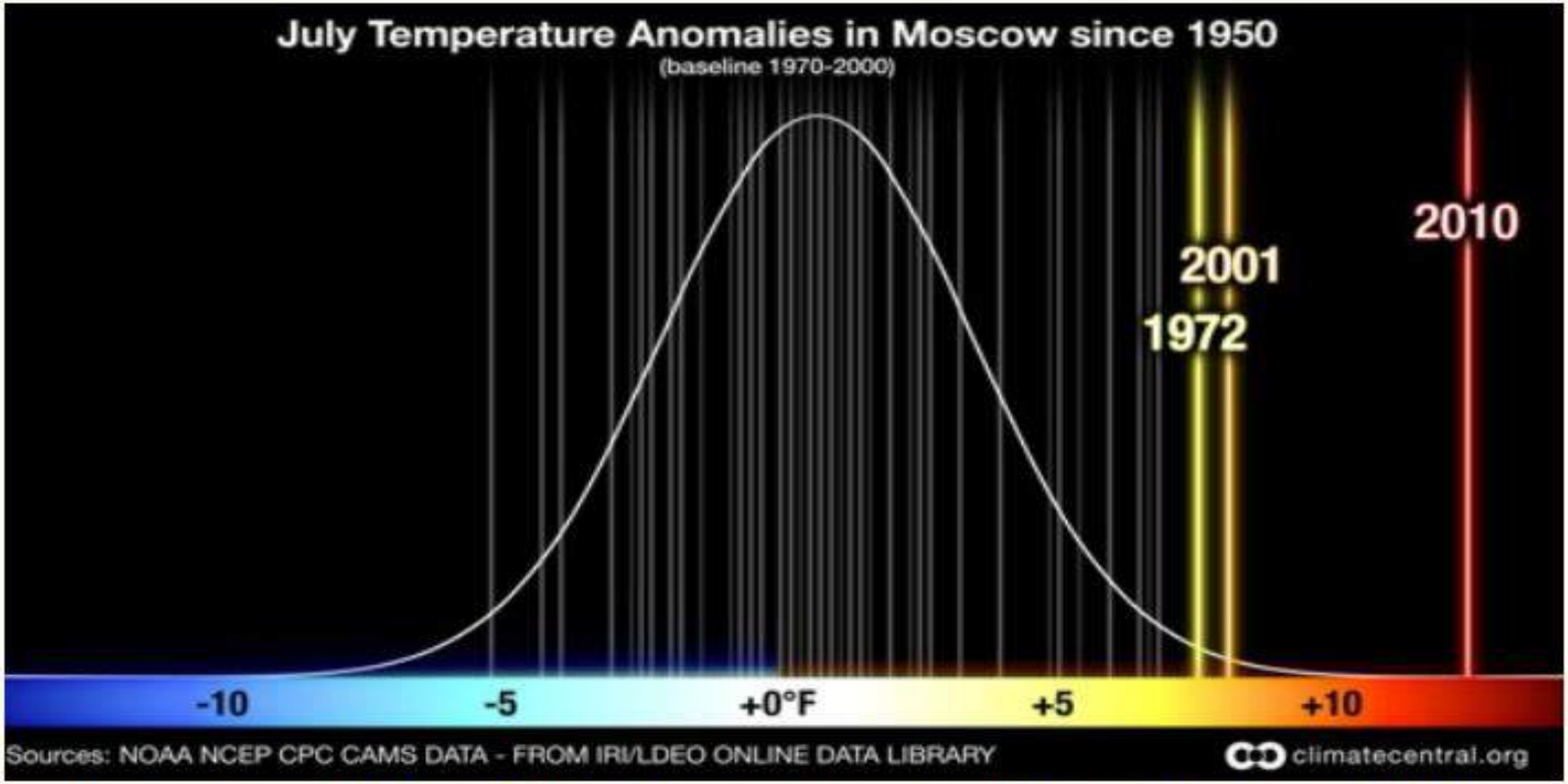
Worst Case Scenario for a Drought

High Temperatures
Low Precipitation
Low Moisture Holding Capacity in Soil
Over Extended Time Period

Maintain Mean Warming below 2 Degrees ==== Challenge: Worry about Extremes Events

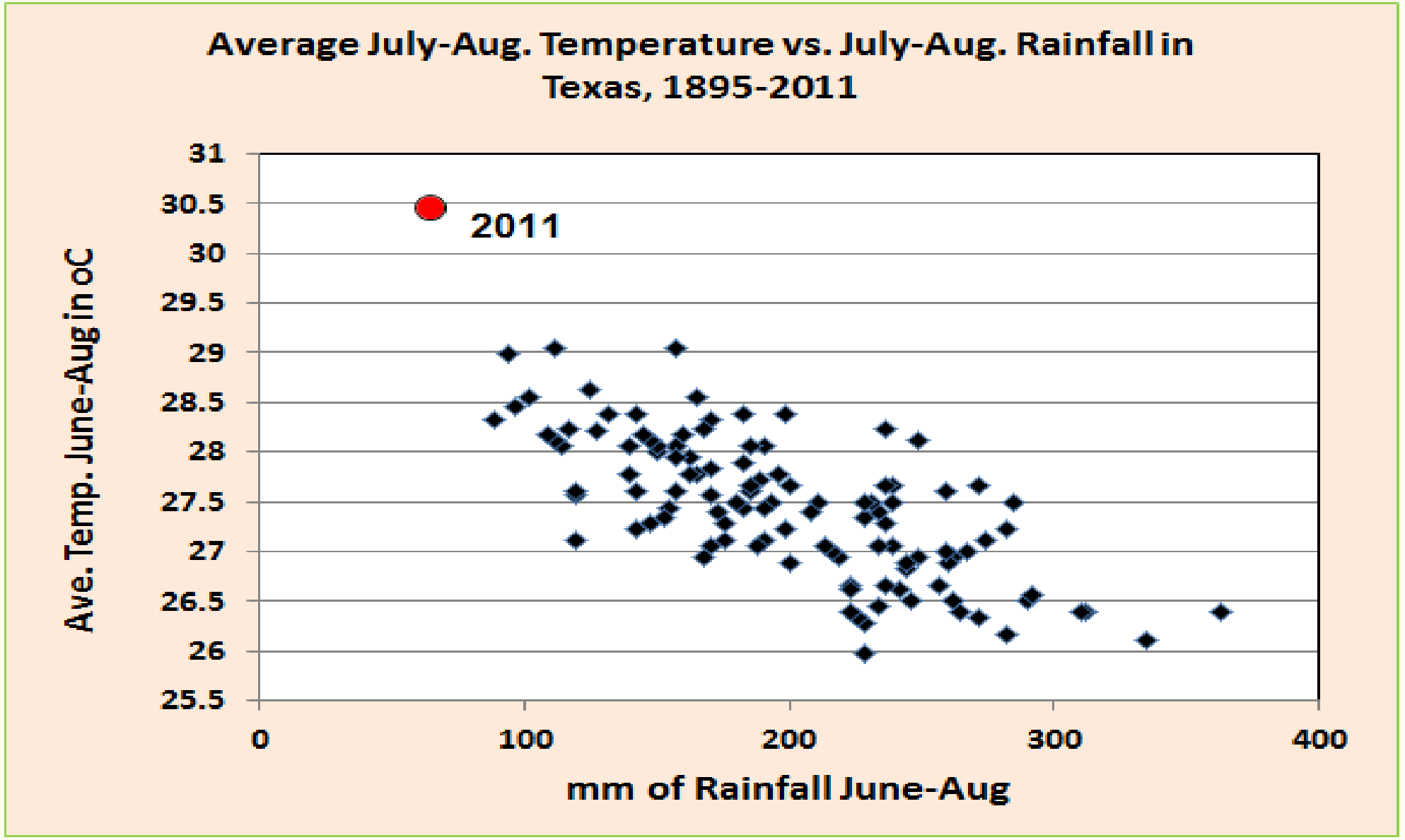


Data Source: Barriopedro et al. 2011. The hot summer of 2010. Redrawing the temperature record Map of Europe. Science: 332(6026):220-224



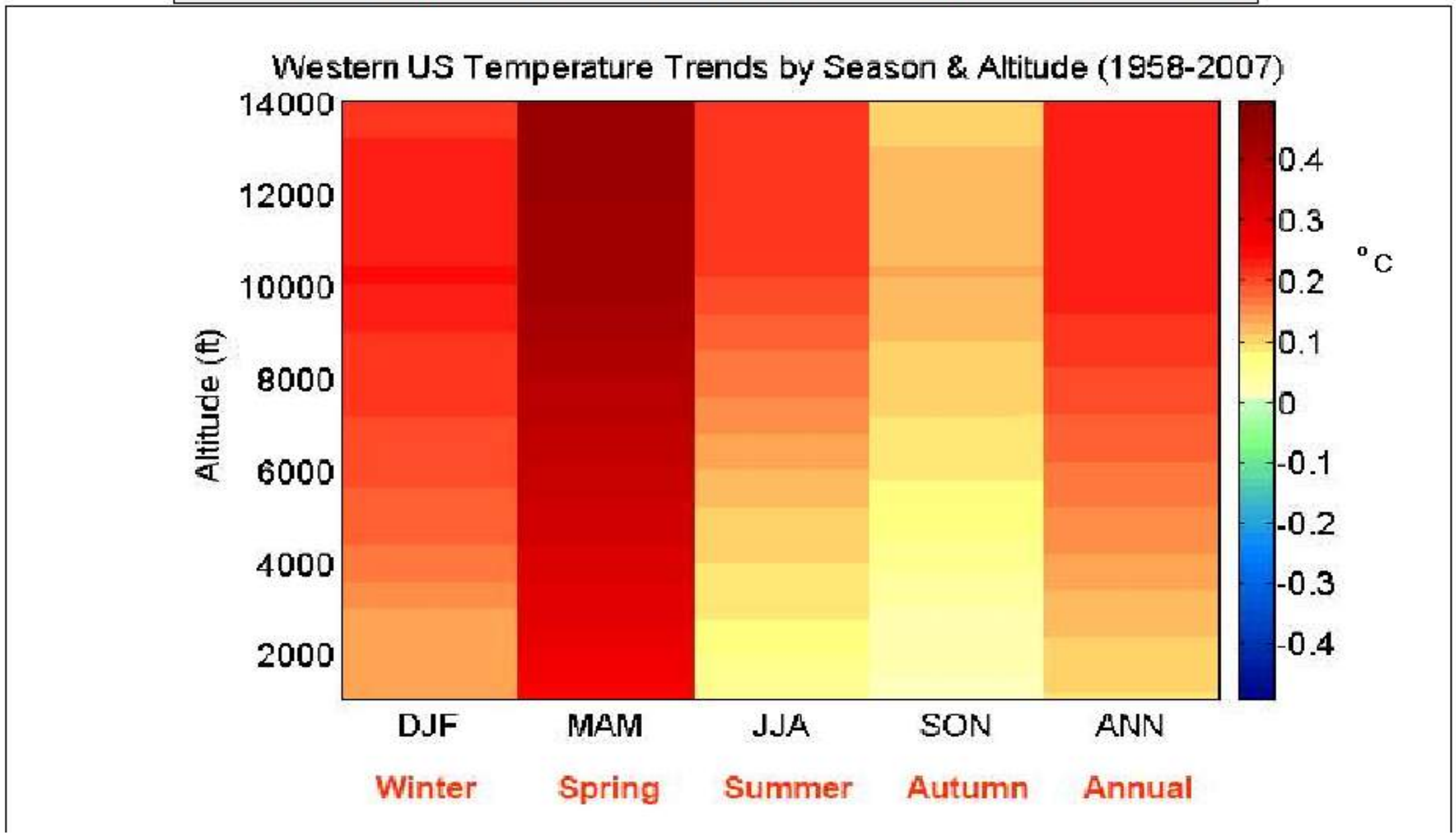
Anomaly of July 2010 Temperature in Moscow since 1950
Source: NOAA, Climate Central and Tebaldi & Ziemlinksi, 2010
(with permission)

The 2011 Drought in Texas



Data Source: J.Nielsen-Gammon, 2011

More Temperature Increases at Higher Elevations



Canada is warming up the fastest in the World

Increases in Mean Temperatures in Degree C 1948-2016					
	Winter	Spring	Summer	Fall	Annual
Canada	3.3	1.7	1.5	1.7	1.7
B.C.	3.7	1.9	1.4	0.7	1.9
Arctic	4.3	2.0	1.6	2.3	2.3
% Changes in Mean Precipitation Between 1948-2016					
	Winter	Spring	Summer	Fall	Annual
Canada	20	25	13	19	18
B.C.	-9	18	8	12	5
Arctic	54	42	18	32	33

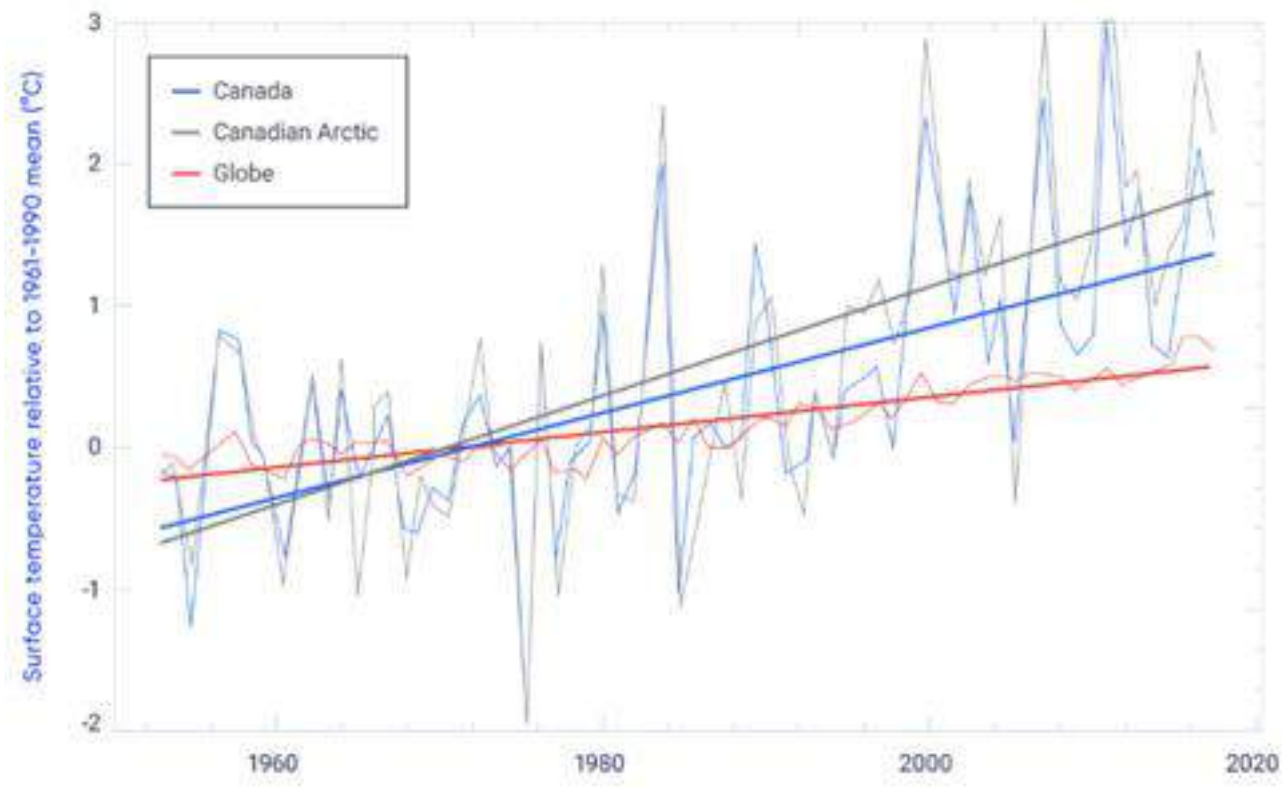
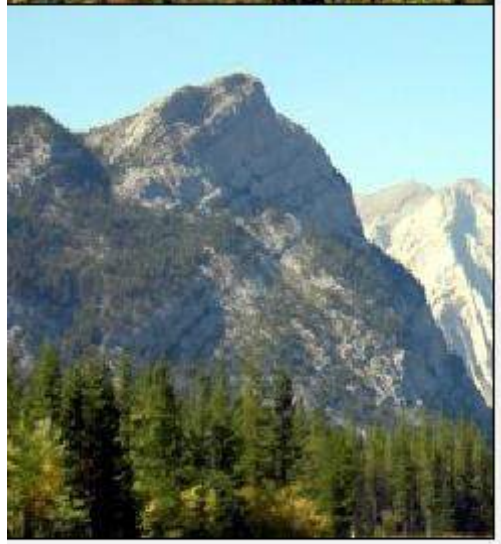
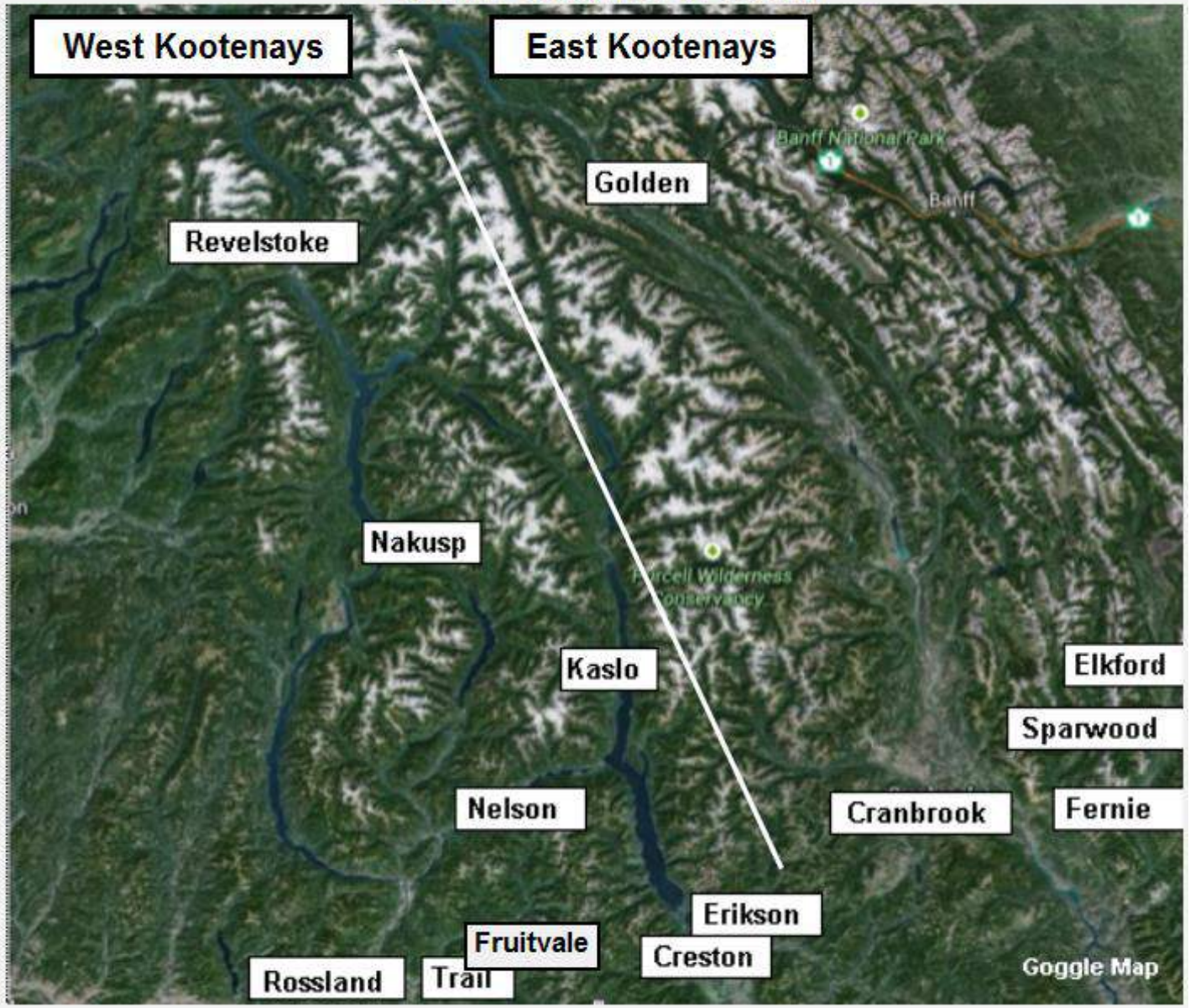


Figure 3.3: Rates of warming for Canada, the Canadian Arctic and the world

Climate Data for 14 Communities in The Canadian Portion of the Columbia Basin

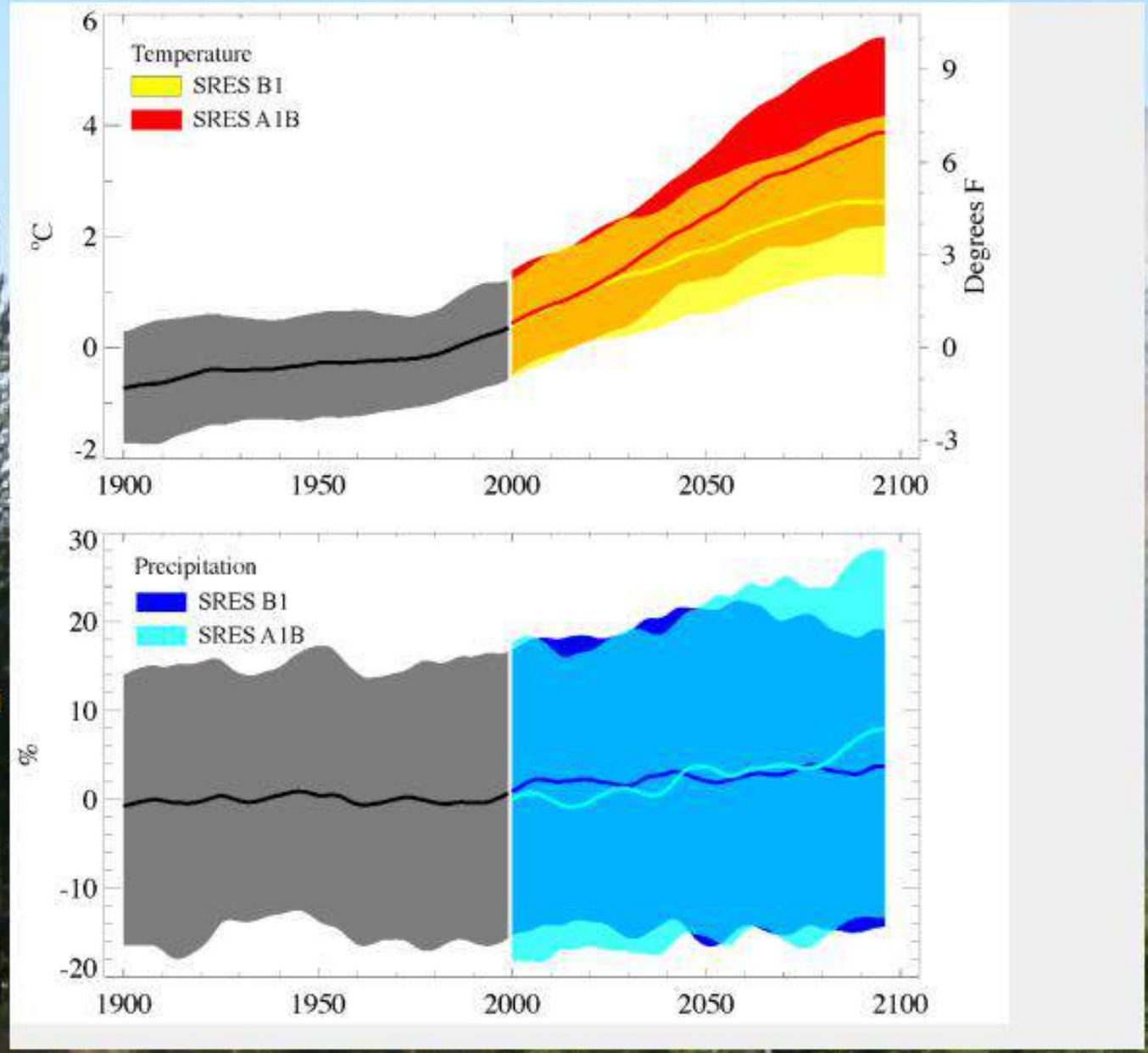




Climate Projections for the Pacific North-West

Temperature

Precipitation



Dates of Record Breaking Monthly Mean Maximum & Mean Minimum Temperatures in the Columbia Basin in Canada (Based on 1920-2017 Climate Record)

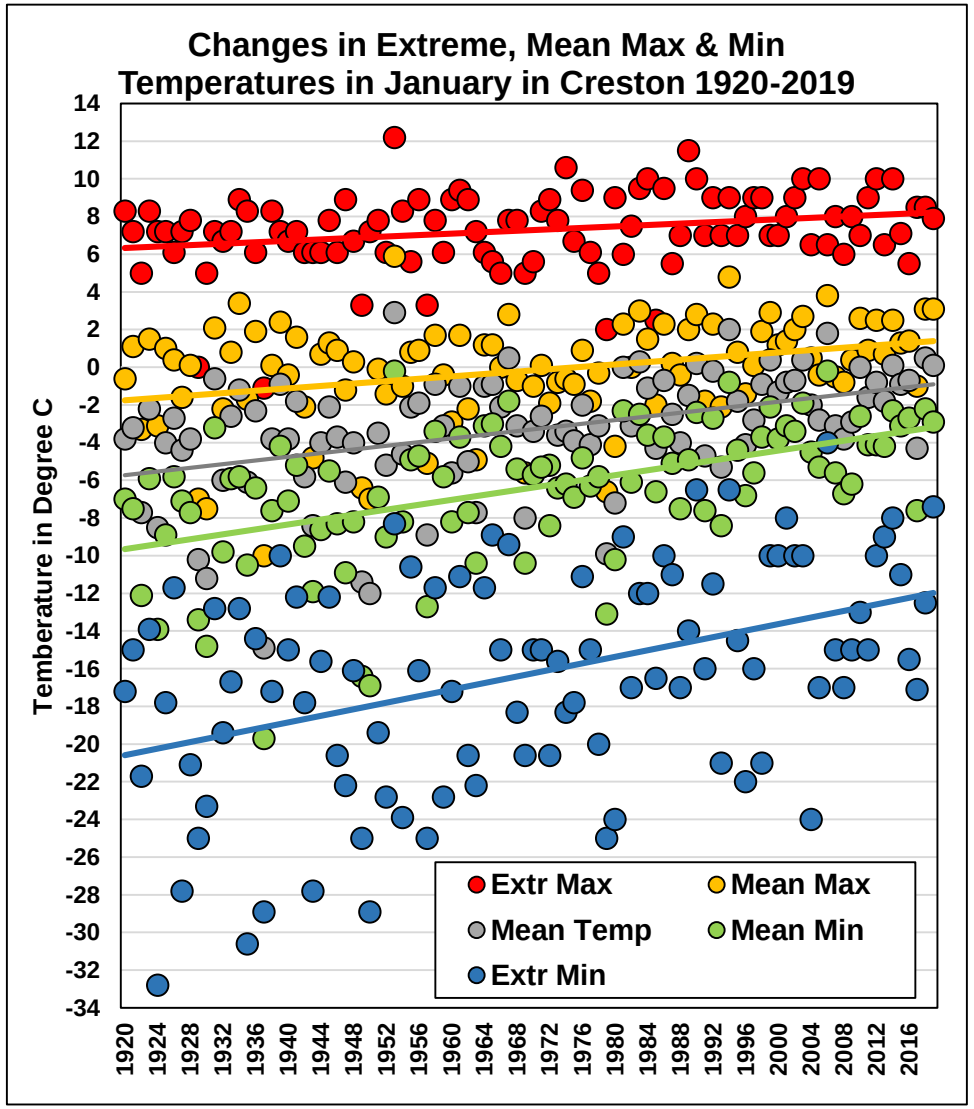
			Year of Record of Mean Maximum Monthly Temperatures between 1920-2017										
Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Creston		2015		2016	2015	2015	2006	2017			2016		
Warfield		2015		2016		2015	2017				2016		
Nelson		2015		2016					2011				
Kaslo	2006					2015	2015			2015			
Revelstoke	2006		2016	2016									
Golden	2006			2016				2017					
Cranbrook				2016			2017				2012		

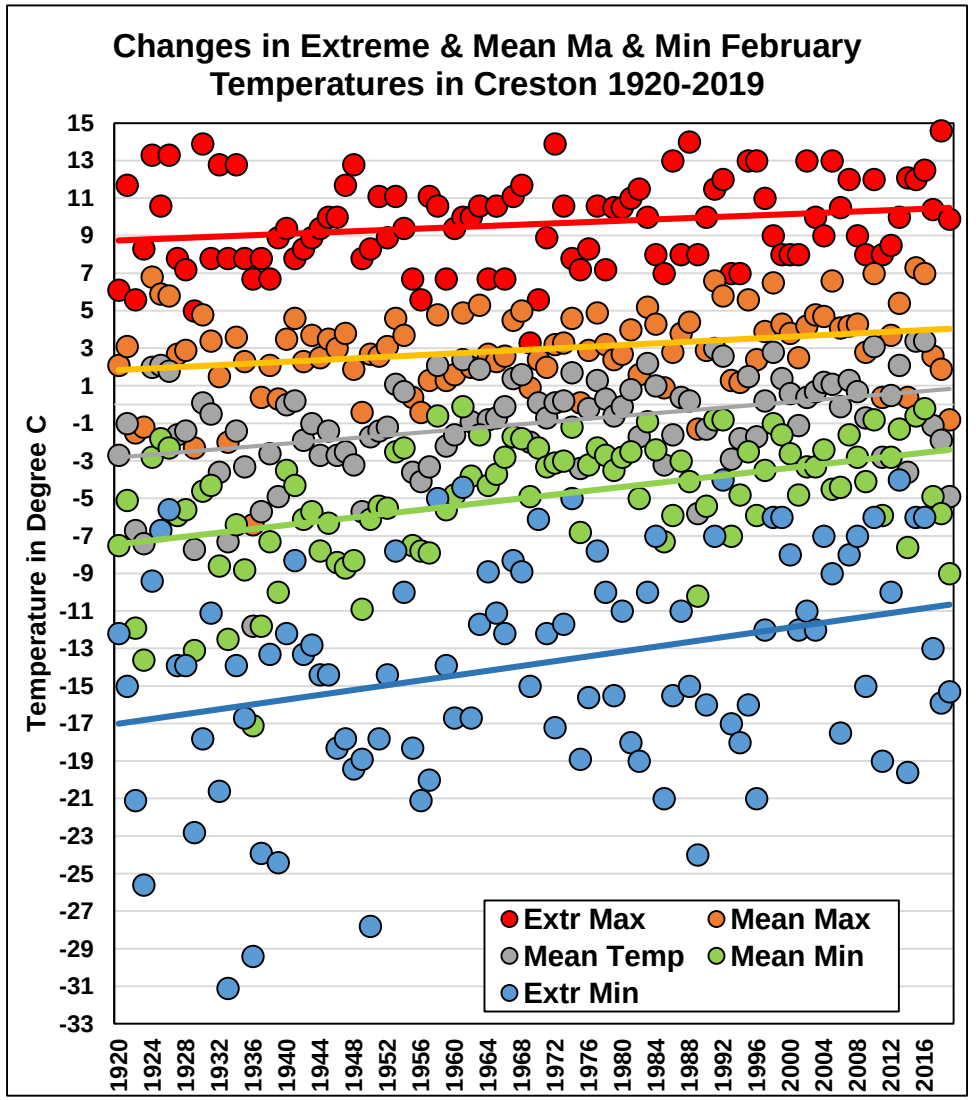
Legend
2017
2016
2015
2013
2012
2011
2005-07

			Year of Record of Mean Minimum Monthly Temperatures between 1920-2017										
Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Creston				2016	2015	2015	2017	2017		2013	2016		
Warfield				2016							2016		
Nelson	2006			2016		2015					2016		
Kaslo		2015	2015	2016		2015	2015		2013	2015			
Revelstoke	2006		2016	2016						2014	2016		
Golden	2006		2015	2016		2015				2015			
Cranbrook	2006			2016			2007				2012		

Legend
2017
2016
2015
2014
2013
2012
2011
2005-07

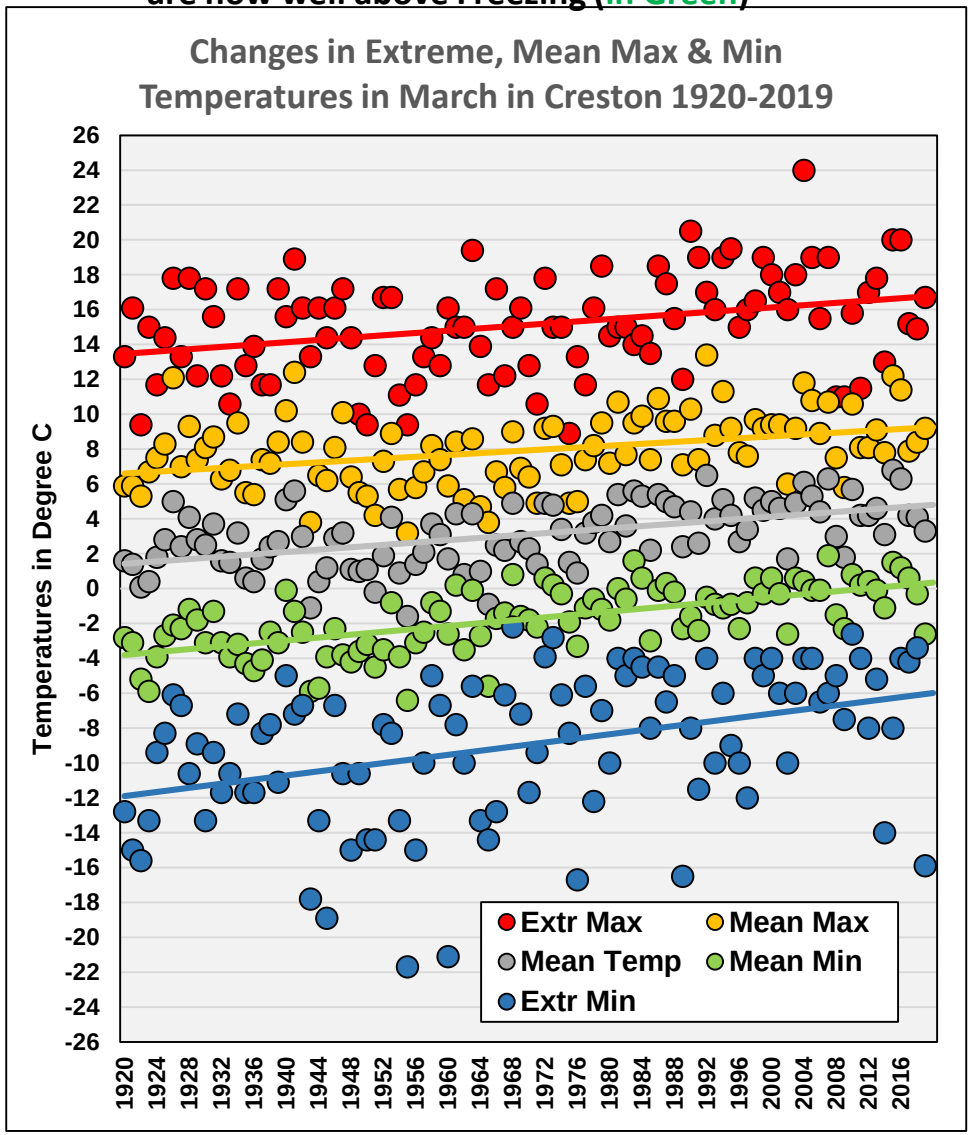
January and February Data : The Extreme Minimum & Mean Minimum Temperatures are Warming up Faster than the Maximum Temperatures

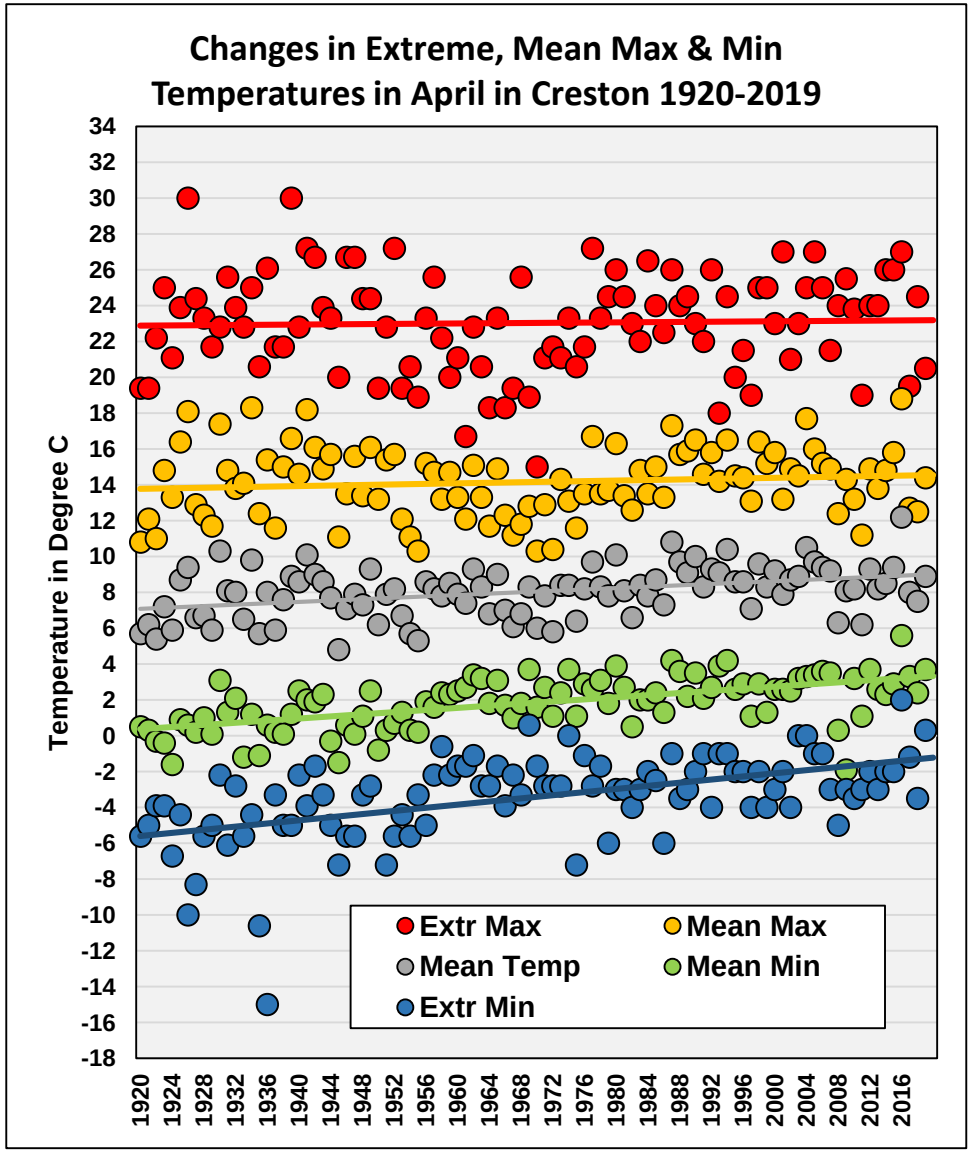




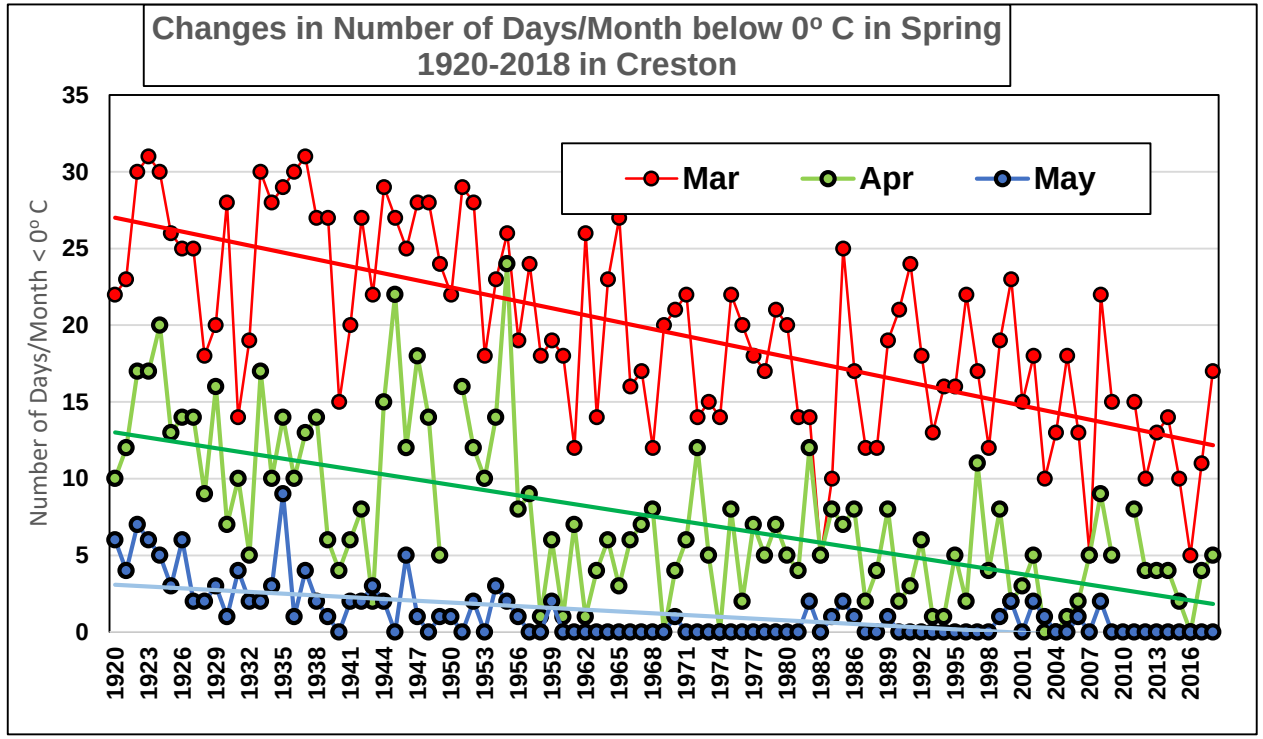
Temperature Changes in March & April in Creston Between 1920-2019

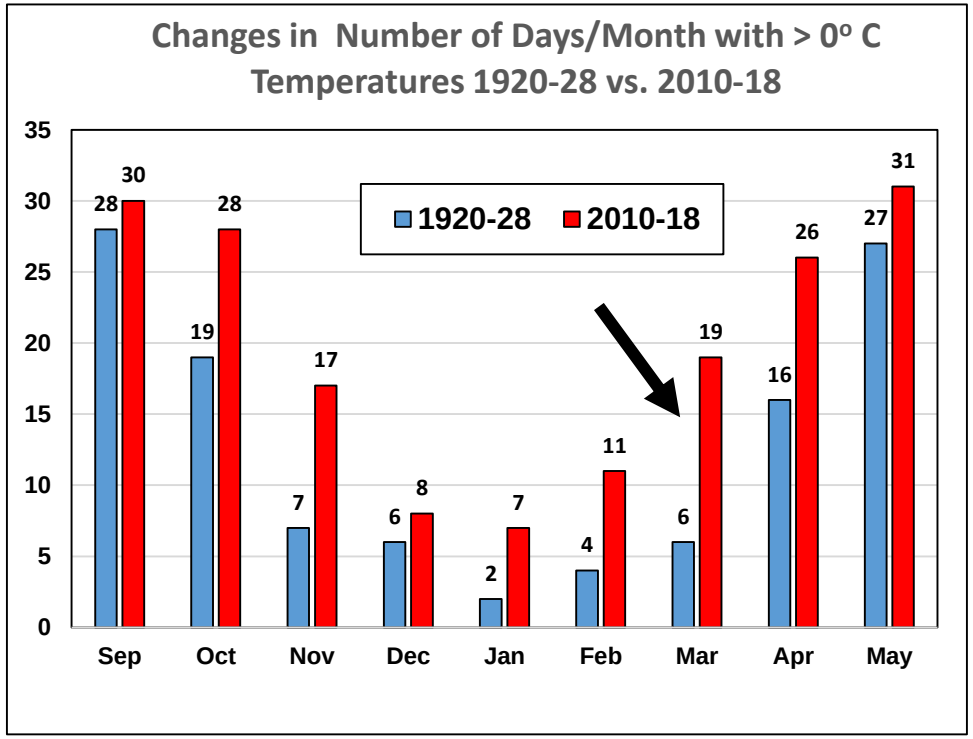
Note: Mean Minimum Monthly Temperatures are now well above Freezing (in Green)





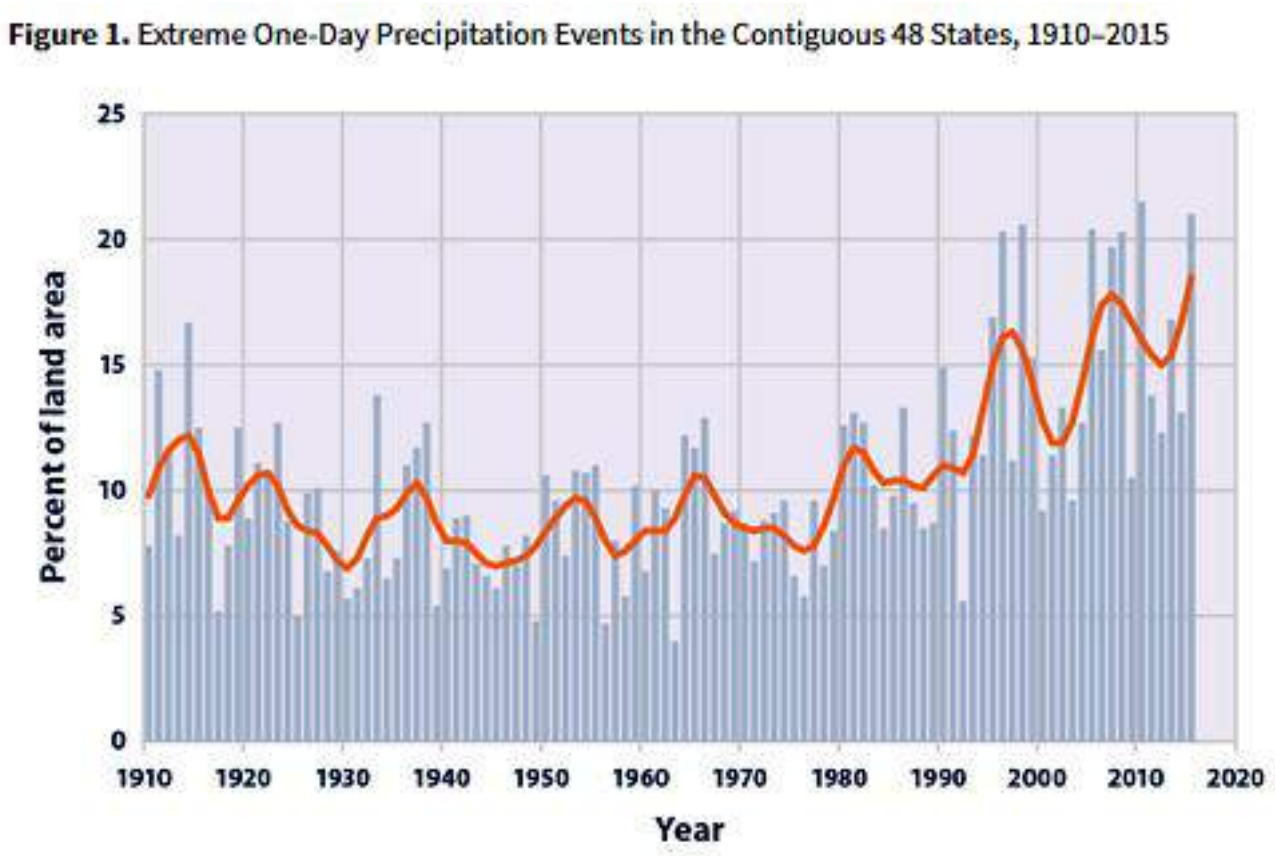
Freeze – Thaw Temperatures Shift During Spring



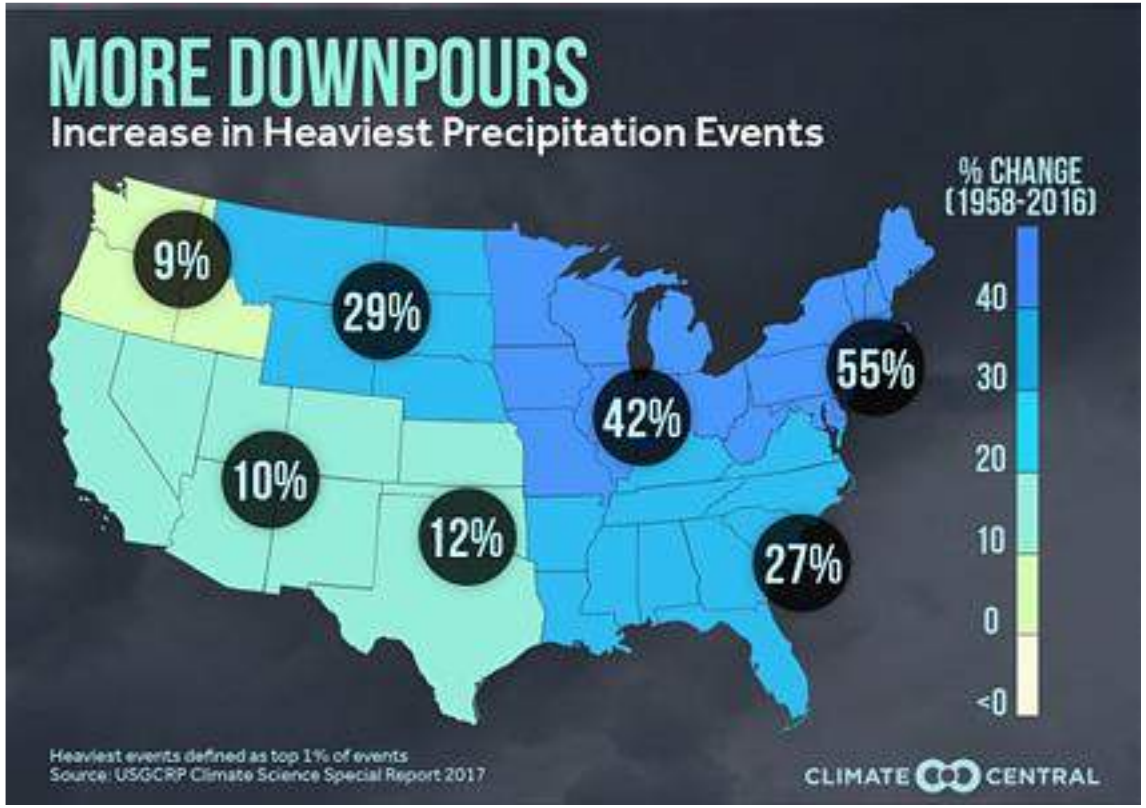


Earlier & More Rapid Snow-Melt
March - April

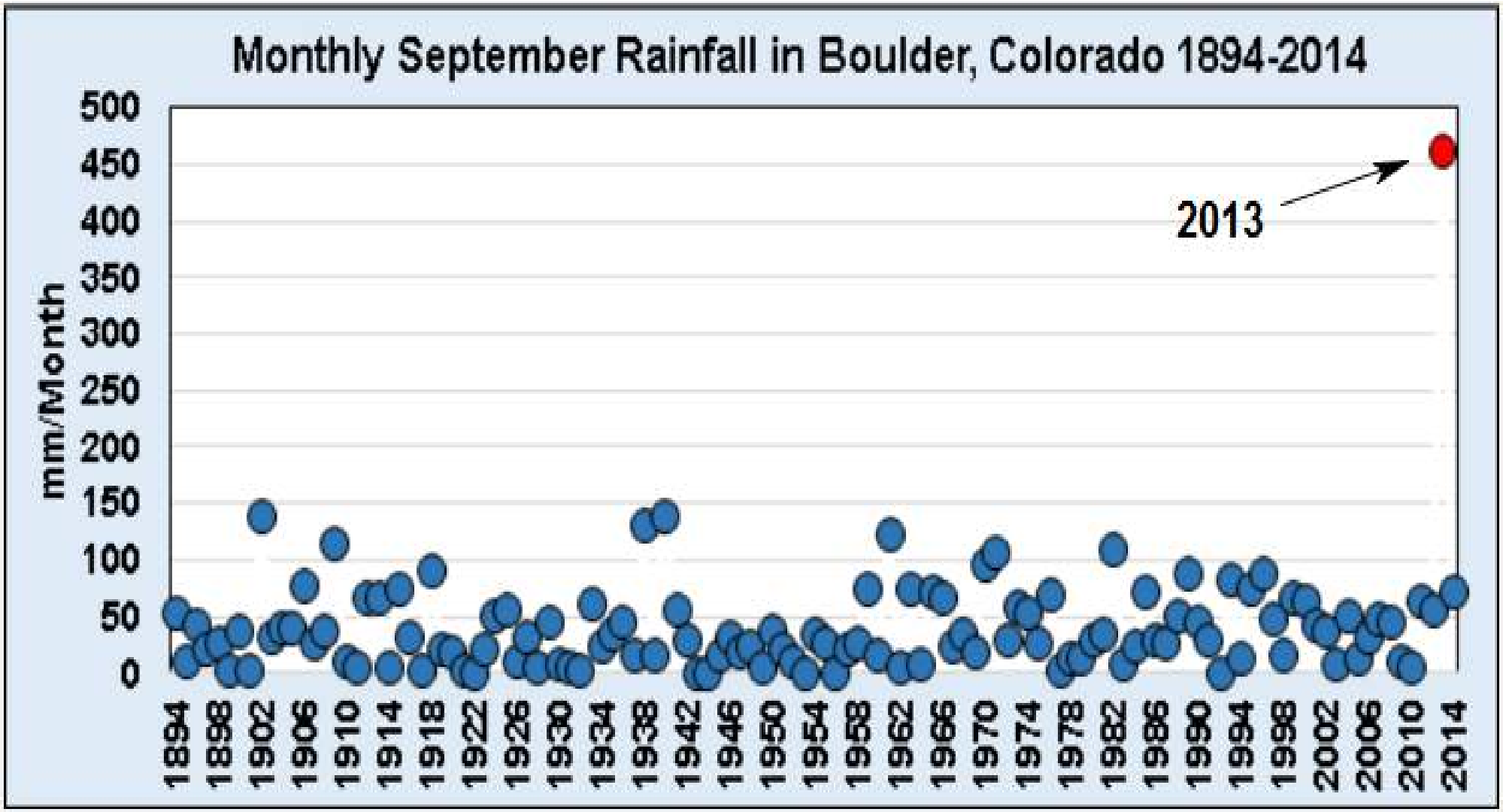
Is Rainfall Intensity, Duration and Frequency Increasing?

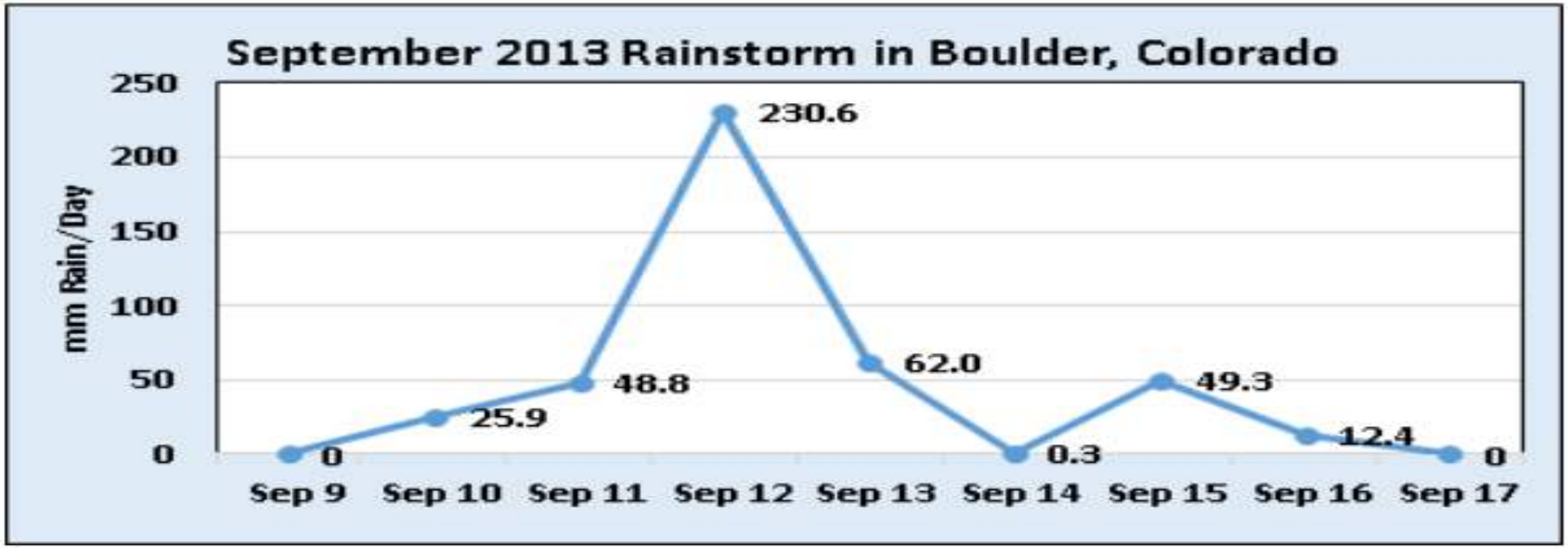


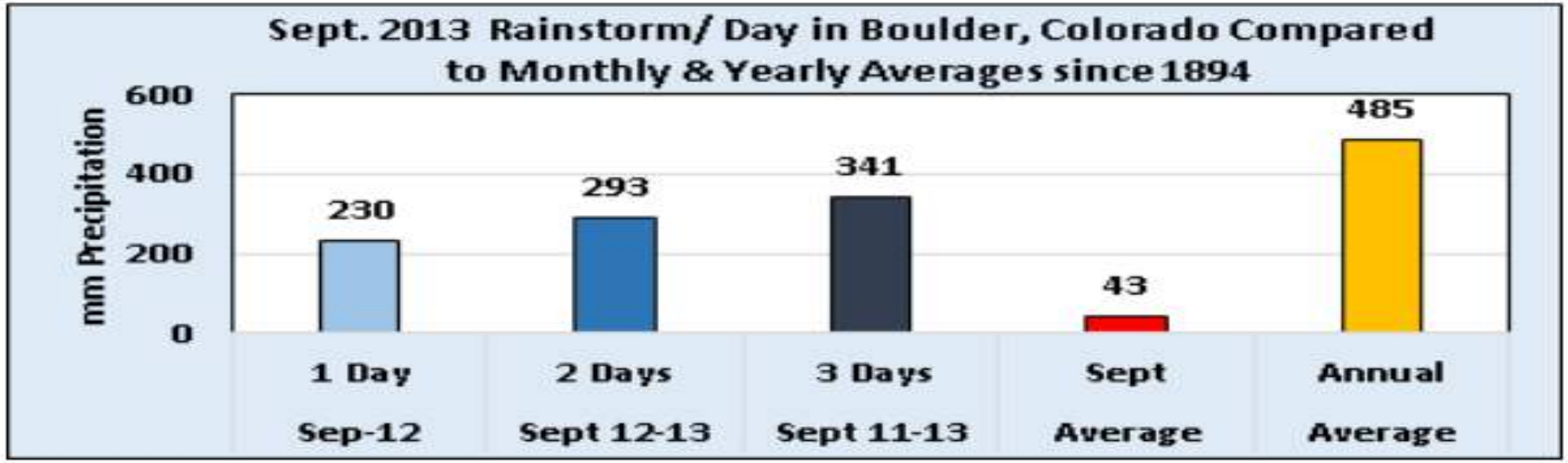
Data Source: US-EPA & NOAA 2016



Data Source: Climate Central 2016


Monthly September Rainfall in Boulder, Colorado 1894-2014
mm/Month
500
450
400
350
300
250
200
150
100
50
0
2013
1894
1898
1902
1906
1910
1914
1918
1922
1926
1930
1934
1938
1942
1946
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006
2010
2014

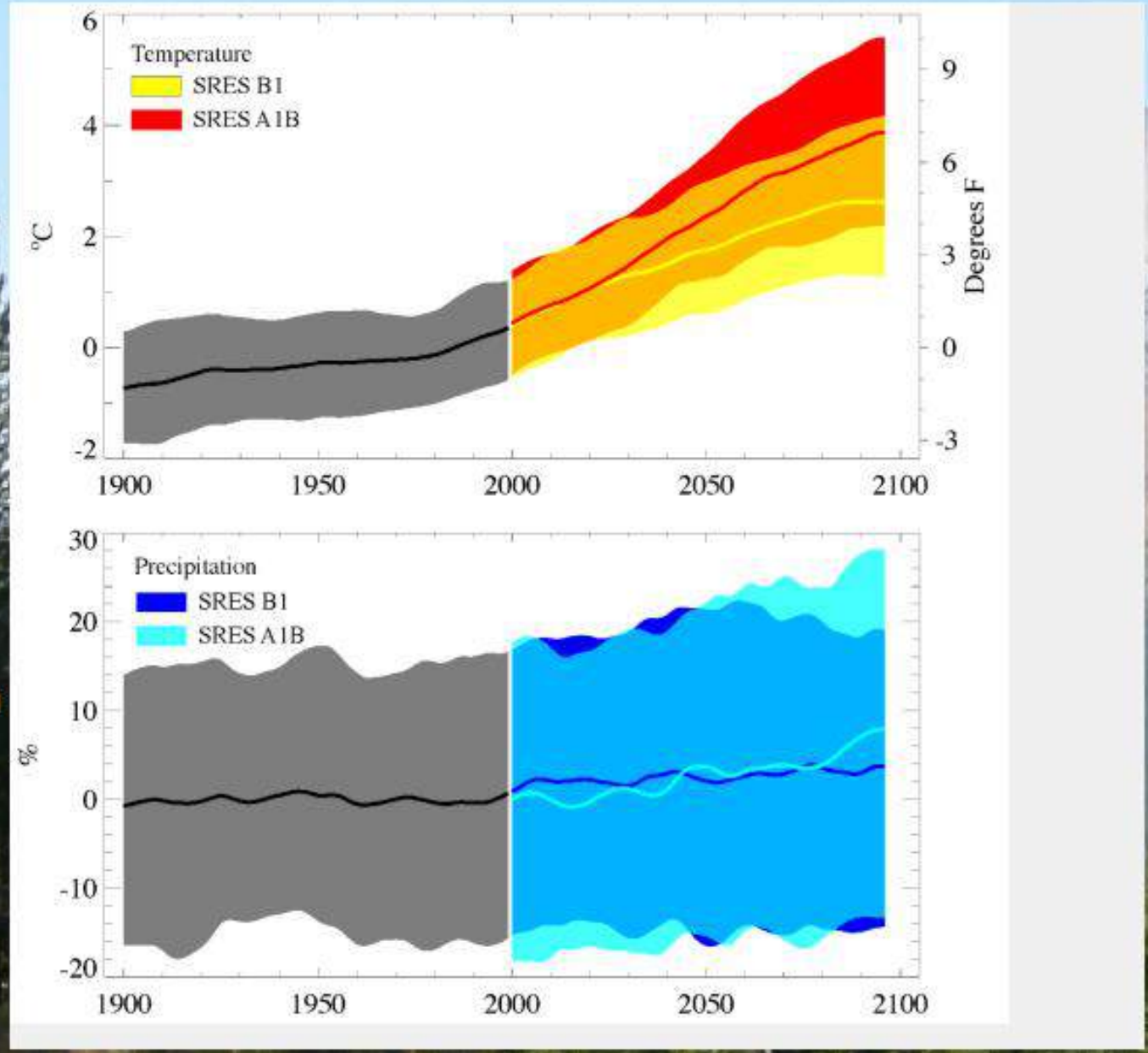

September 2013 Rainstorm in Boulder, Colorado
mm Rain/Day
250
200
150
100
50
0
0
25.9
48.8
230.6
62.0
0.3
49.3
12.4
0
Sep 9
Sep 10
Sep 11
Sep 12
Sep 13
Sep 14
Sep 15
Sep 16
Sep 17

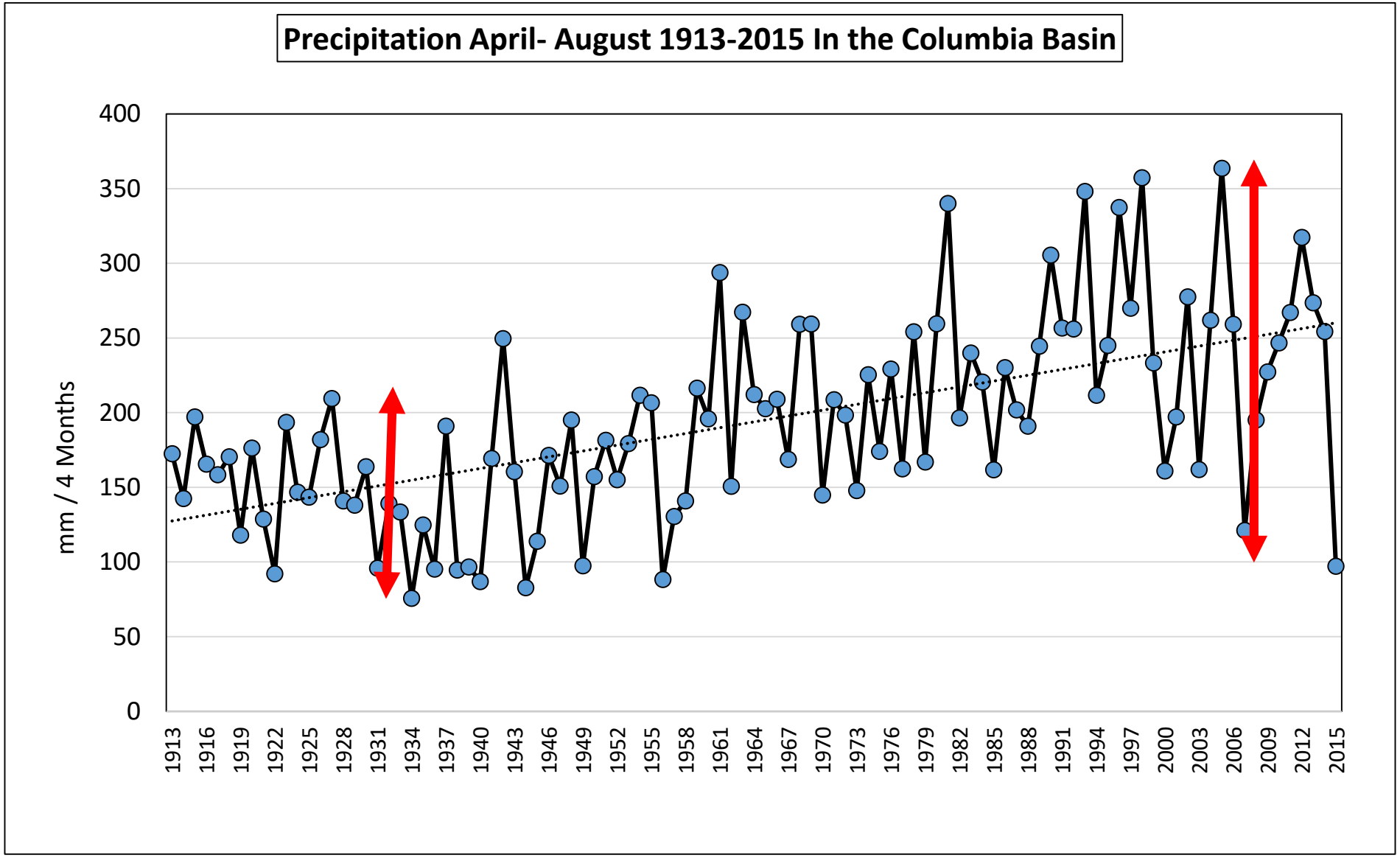

Sept. 2013 Rainstorm/ Day in Boulder, Colorado Compared to Monthly & Yearly Averages since 1894
mm Precipitation
600
400
200
0
230
293
341
43
485
1 Day
Sep-12
2 Days
Sept 12-13
3 Days
Sept 11-13
Sept
Average
Annual
Average

Climate Projections for the Pacific North-West

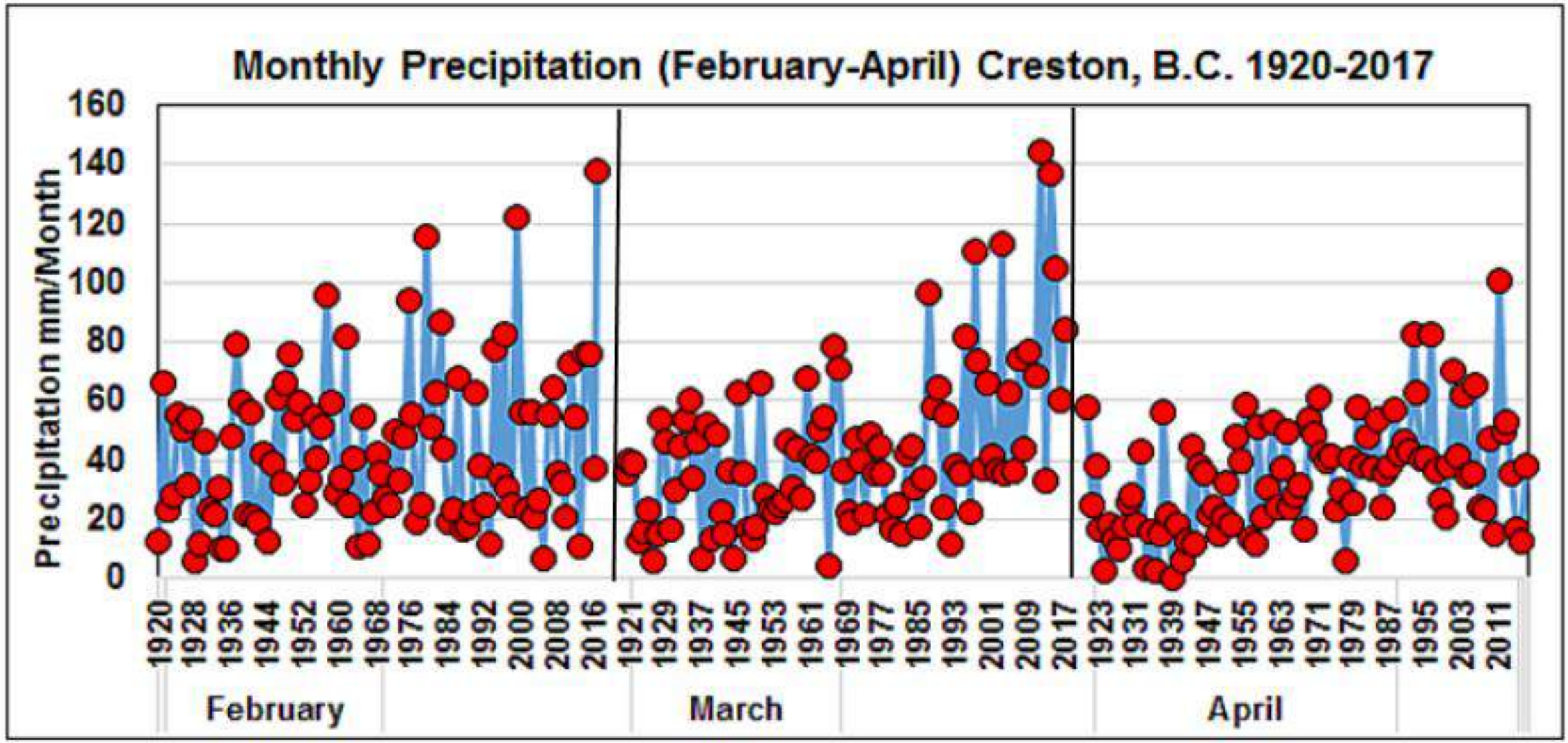
Temperature

Precipitation

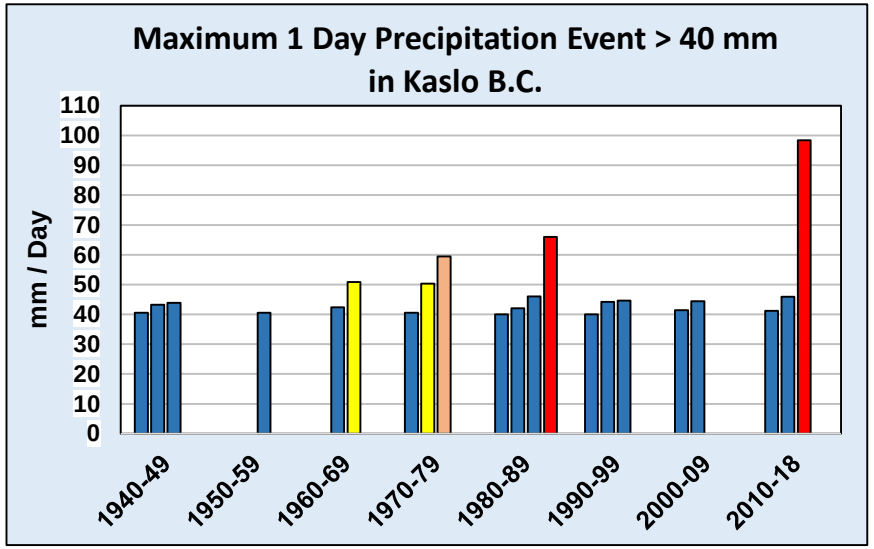


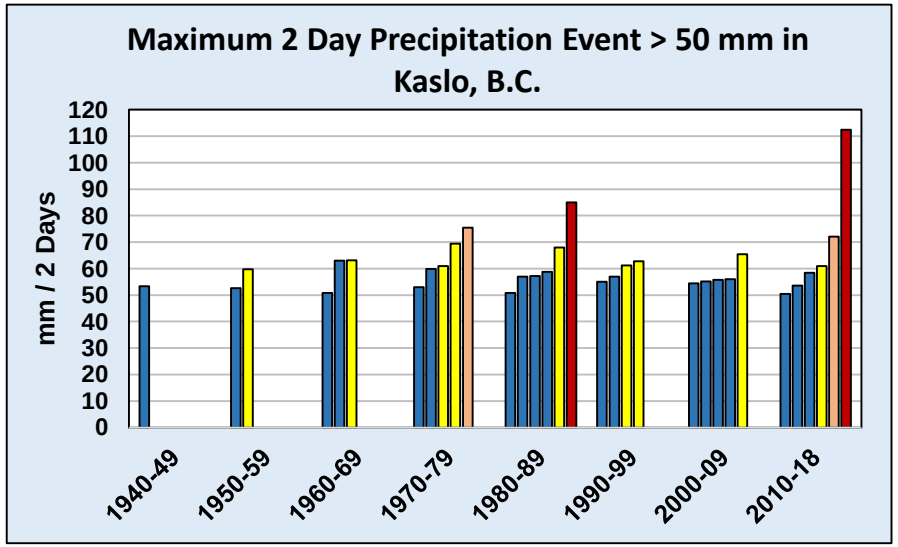

Precipitation April- August 1913-2015 In the Columbia Basin
mm / 4 Months
400
350
300
250
200
150
100
50
0
1913
1916
1919
1922
1925
1928
1931
1934
1937
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2015

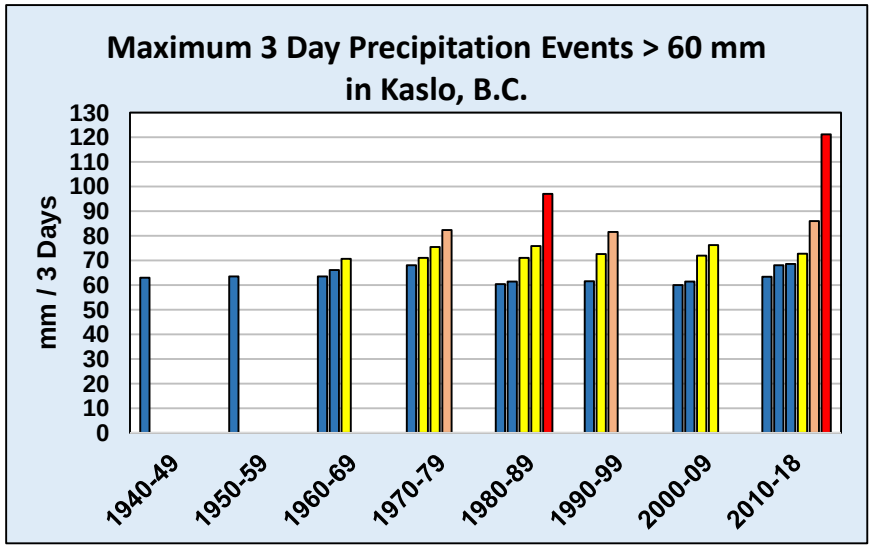
Evidence of Increased Variability in Monthly Precipitation in the Columbia Basin (Creston, B.C,) Between 1920 and 2017



Changes in 1, 2 & 3 Day Precipitation Events / Decade in the Columbia Basin



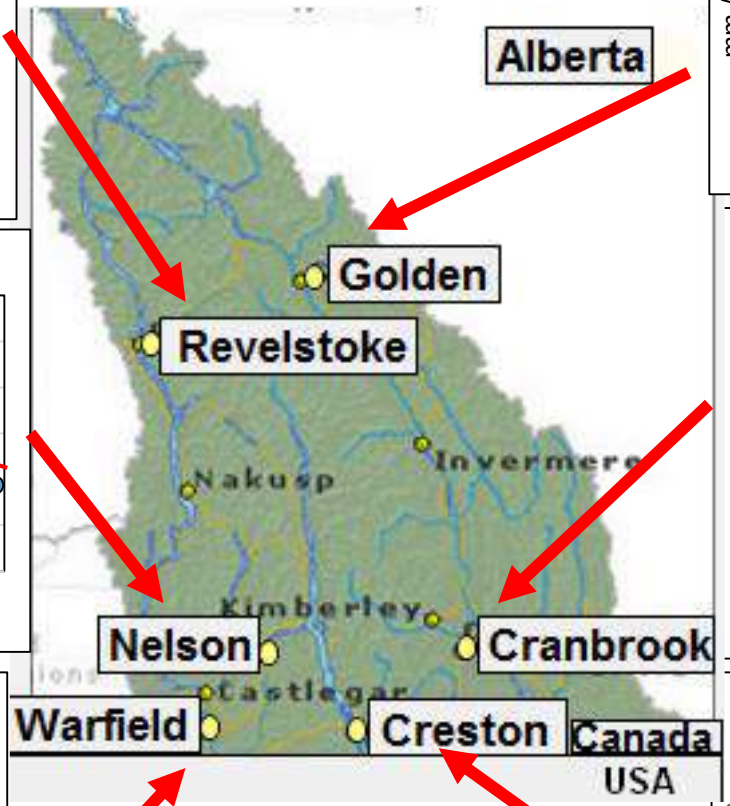


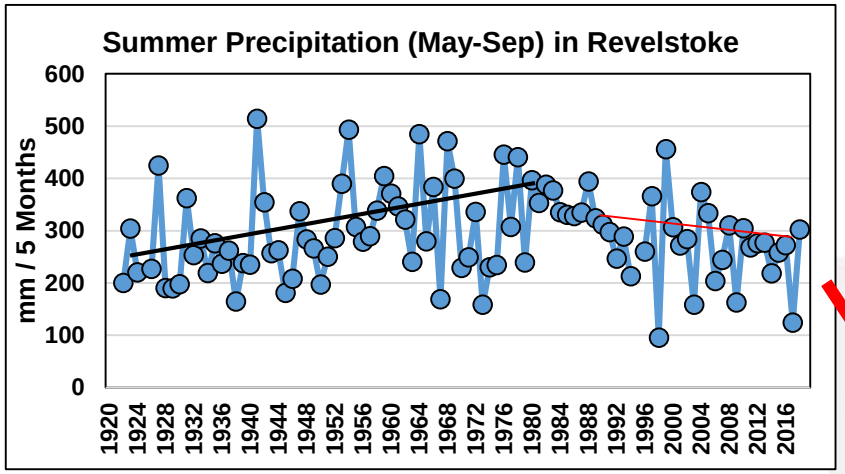


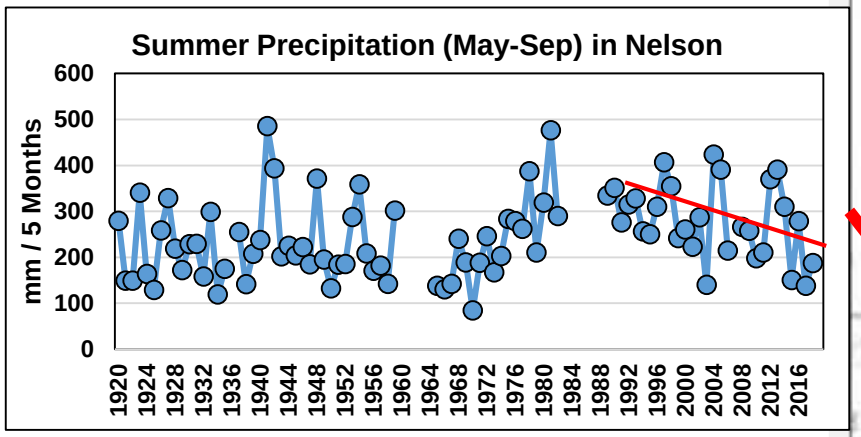
Dates of Record Breaking Monthly Precipitation Events in the Columbia Basin in Canada Between 1930 and 2017

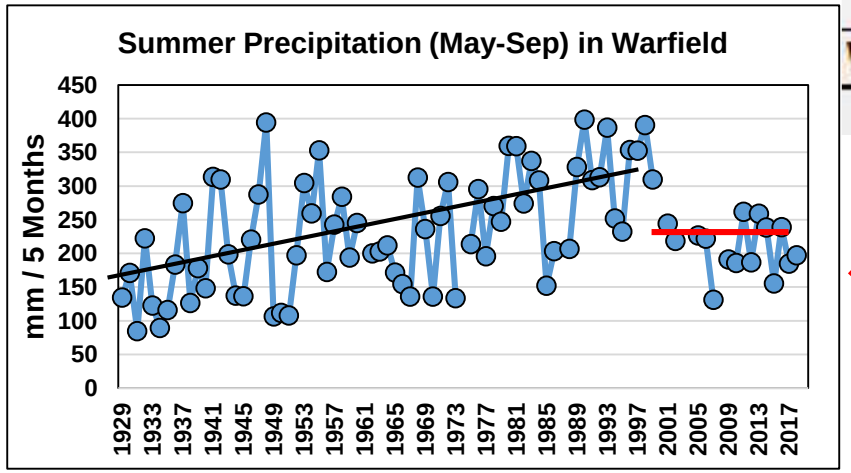
			Year of Record High Maximum Monthly Precipitation between 1920-2017										
Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Legend
Creston		2017		2011	2012	2005			2013	2016			2017
Warfield										2016			2016
Nelson		2016	2017			2012				2016	2006		2015
Kaslo			2017			2012					2006		2013
Revelstoke			2007			2012	2017				2006		2012
Golden						2005		2017			2006		2011
Cranbrook			2012							2016	2006		2005-07

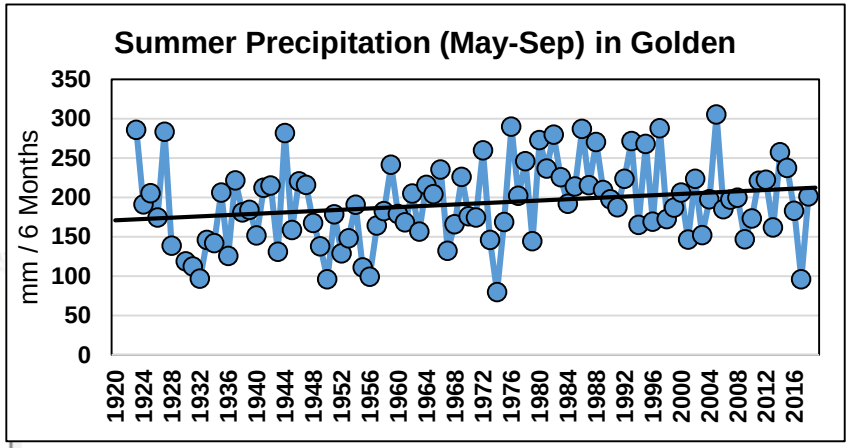
Columbia Basin in Canada
Summer Precipitation Trends
May – Sep 1920-2019

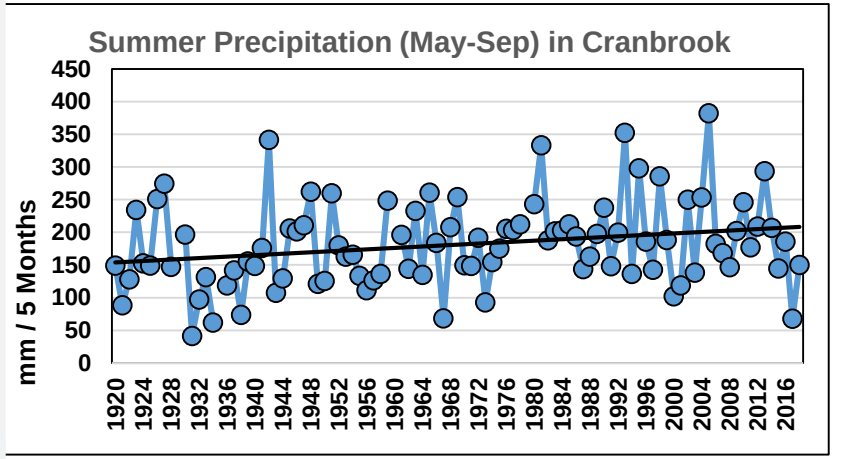


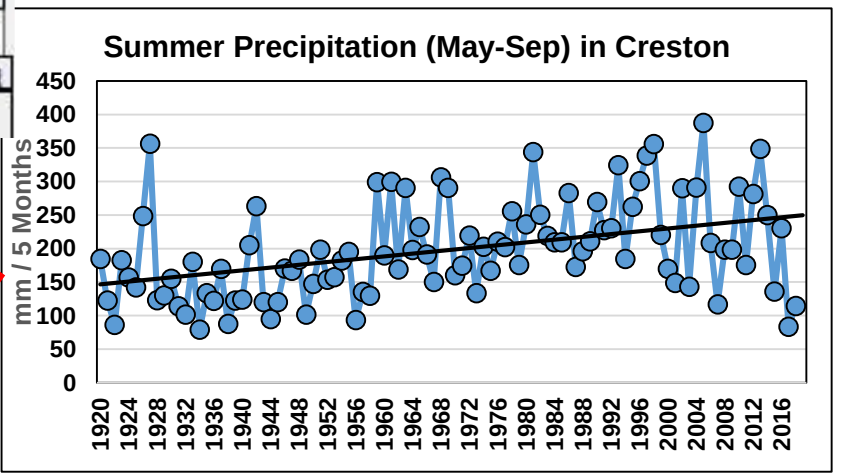




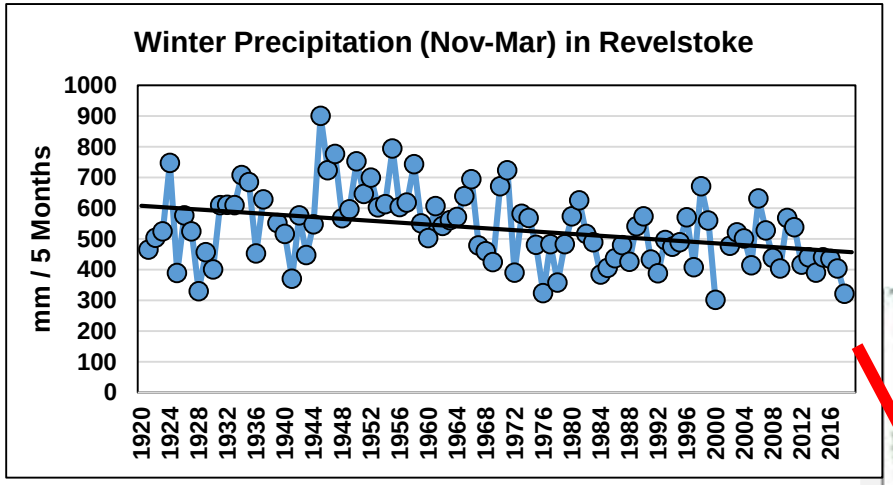


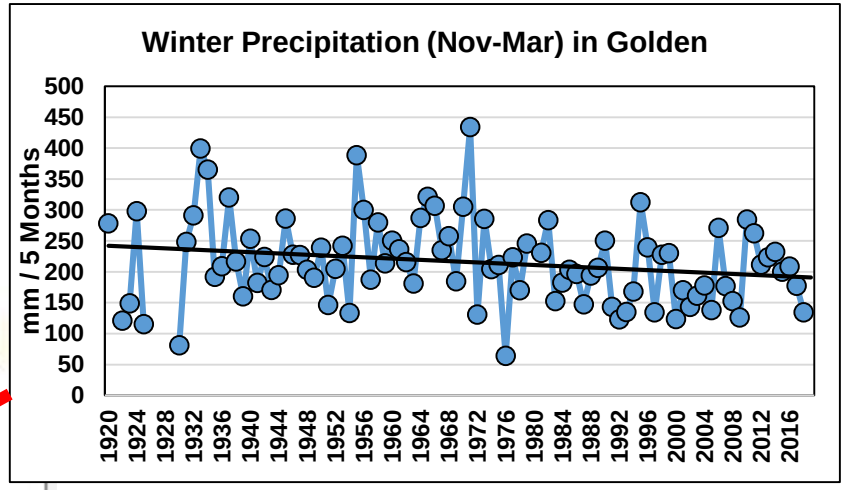


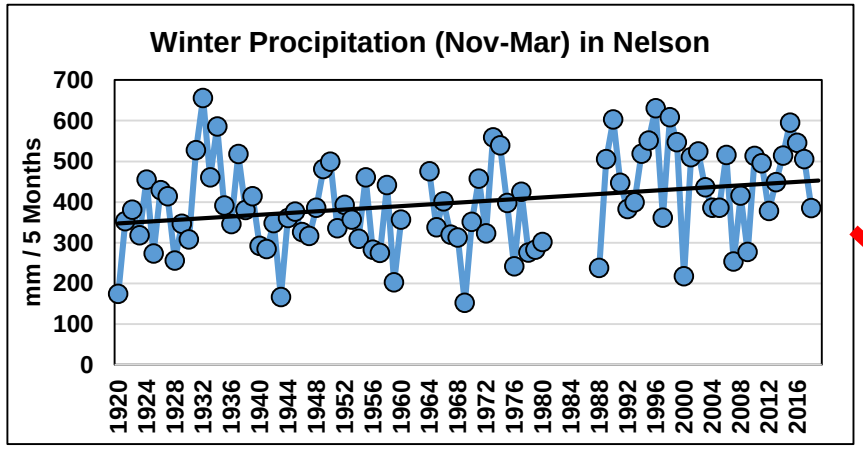


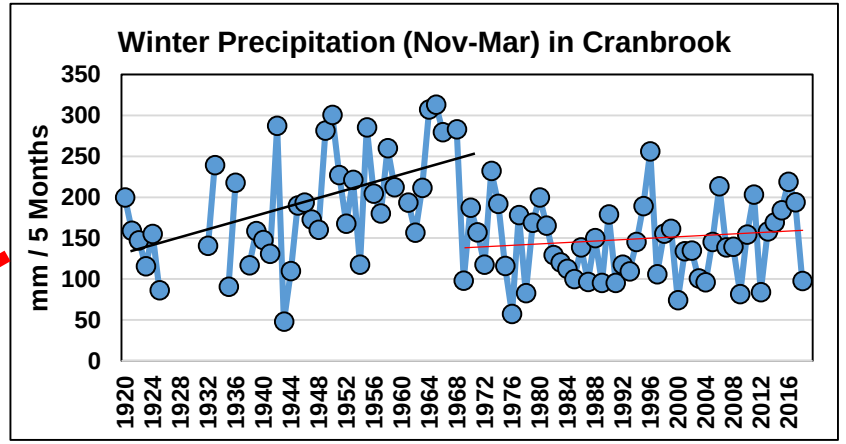


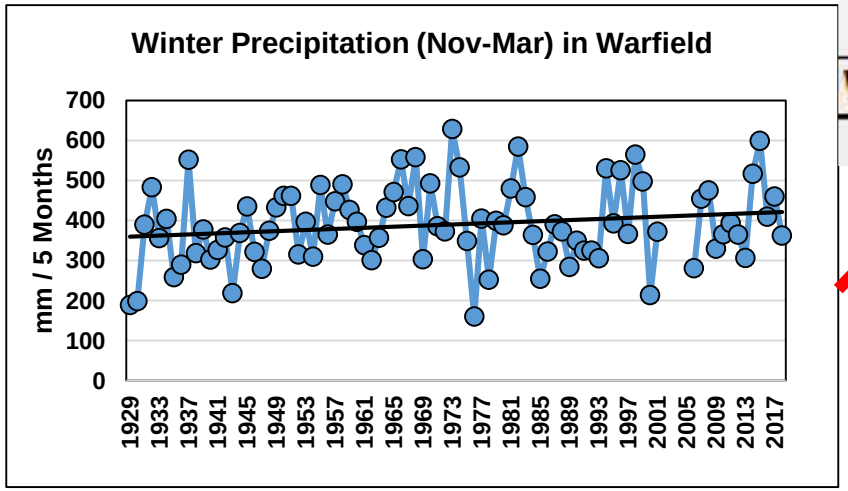
Columbia Basin Canada
Winter Precipitation Trends
Nov-Mar 1920-2019

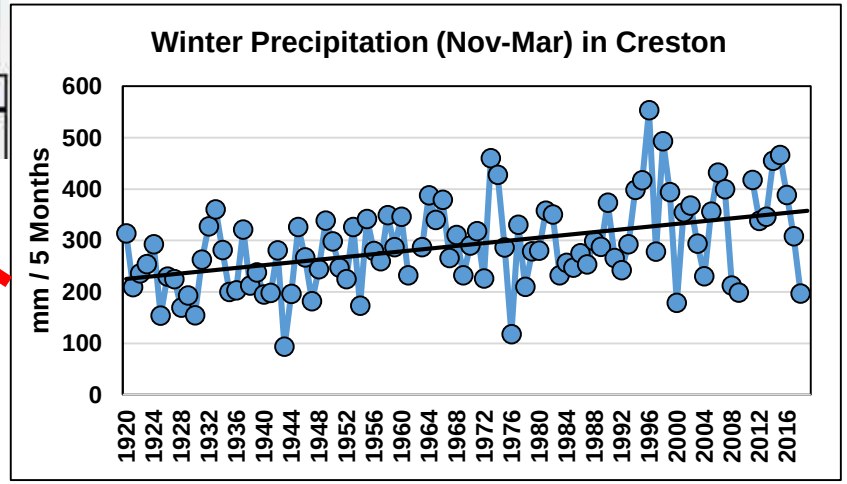


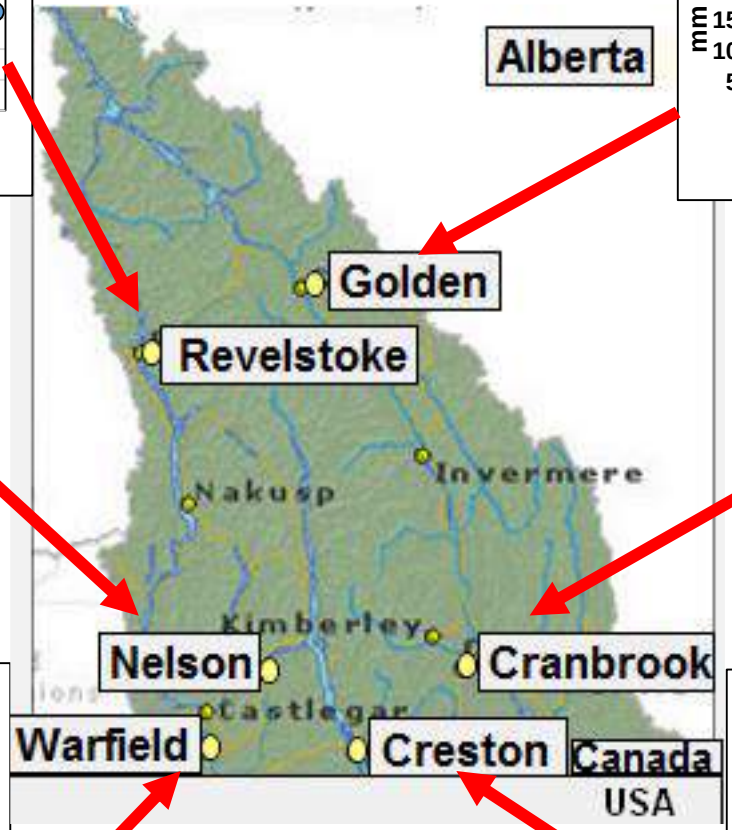




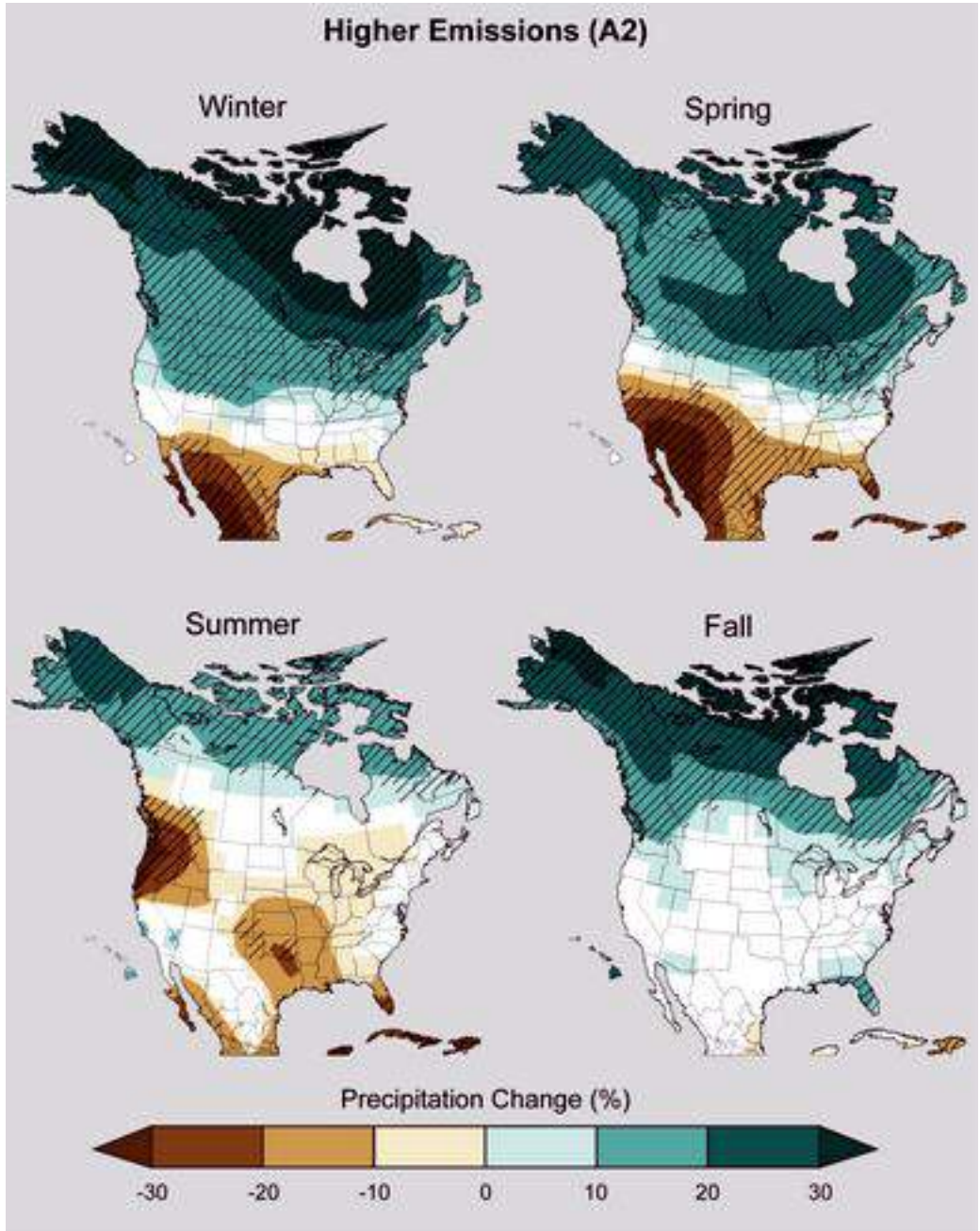








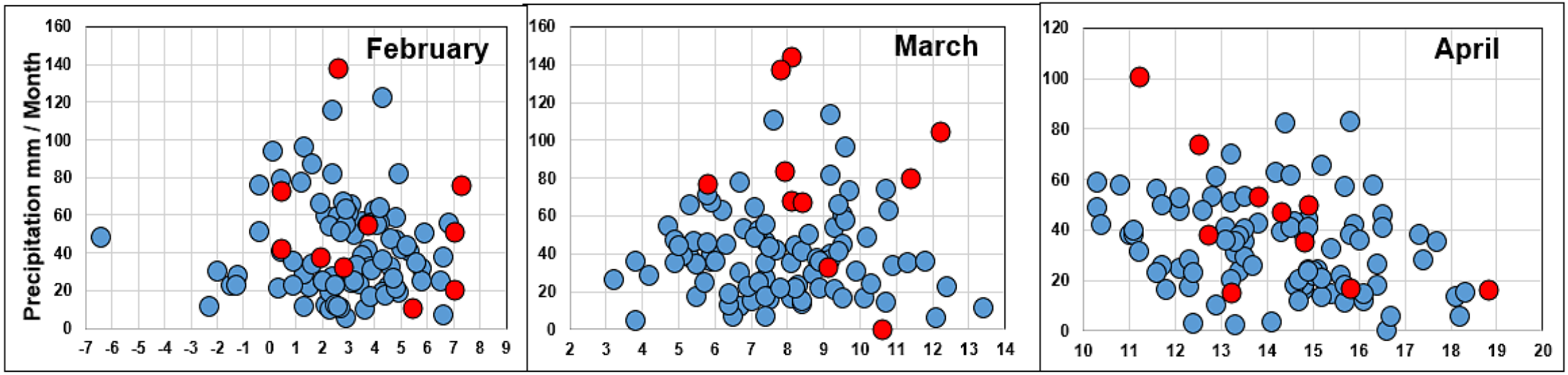
Projected Seasonal Changes in Precipitation

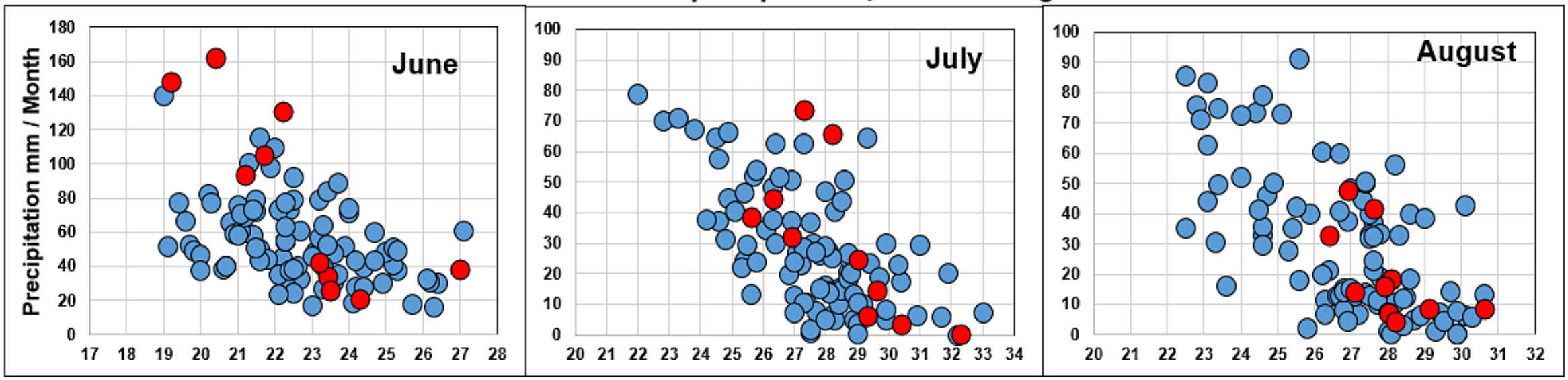


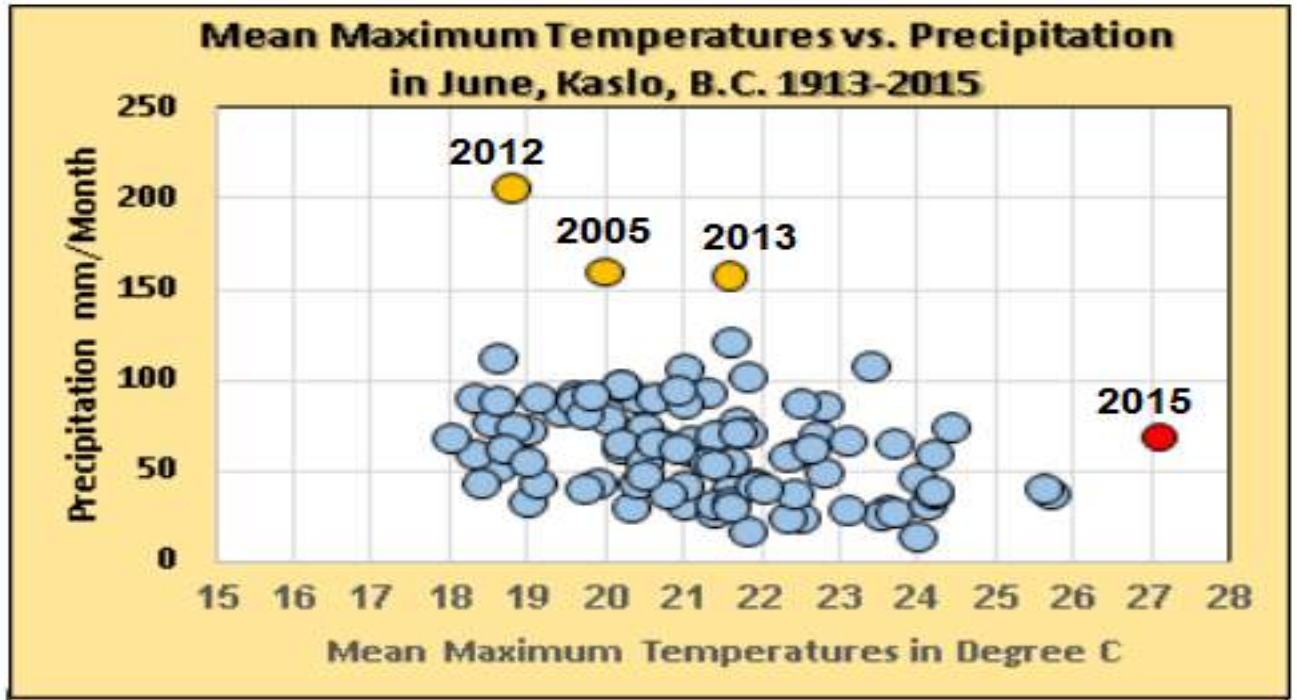
US Global Change Research Program 2018

Mean Maximum Temperature vs. Precipitation in Creston 1913-2018

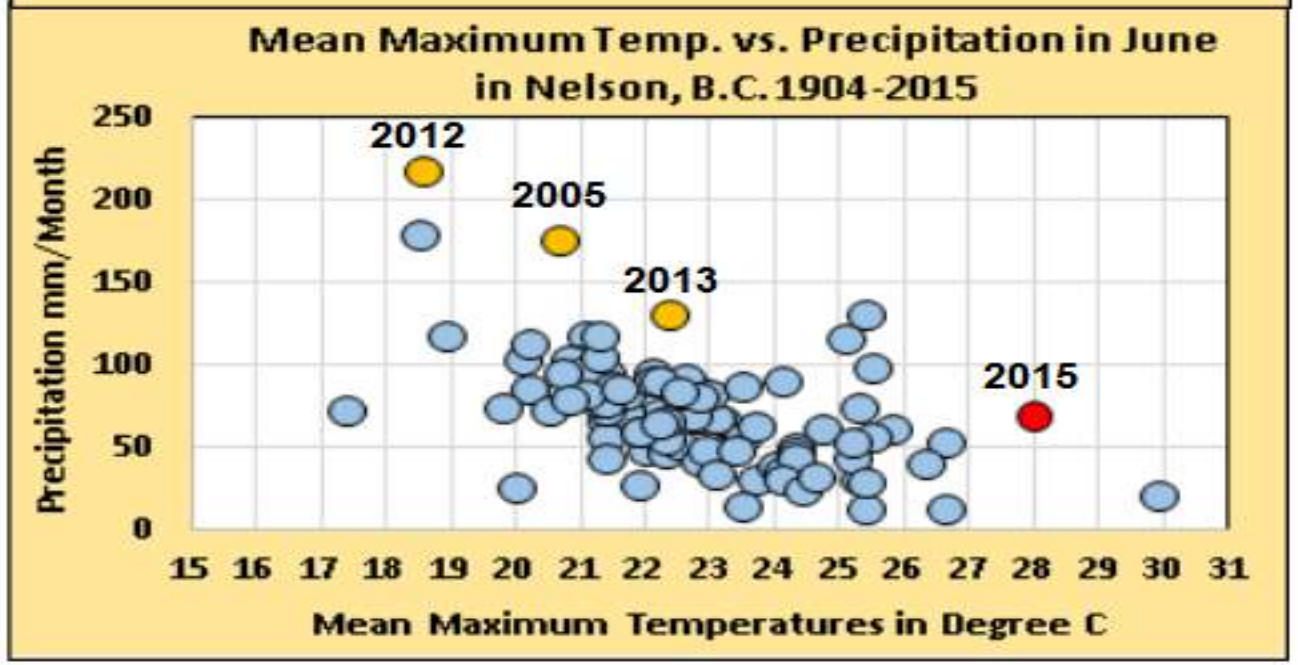
2009-2018
1920-2008





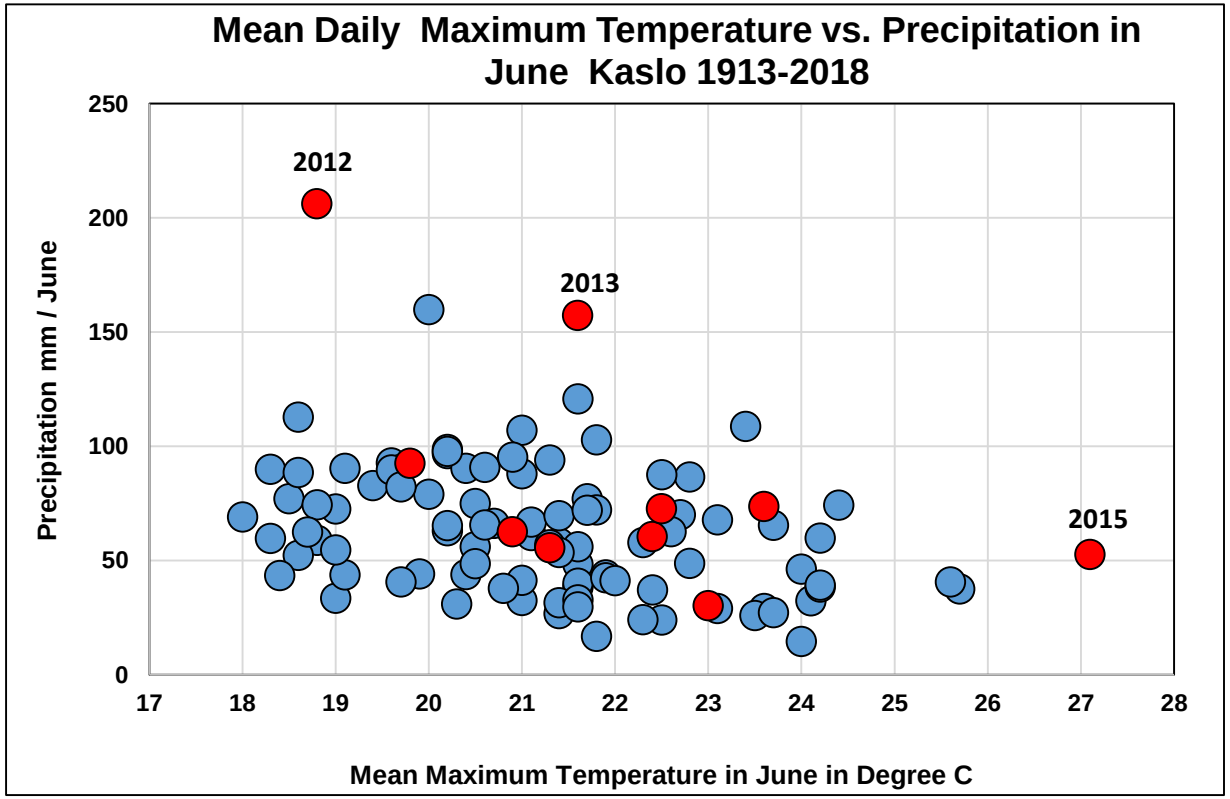


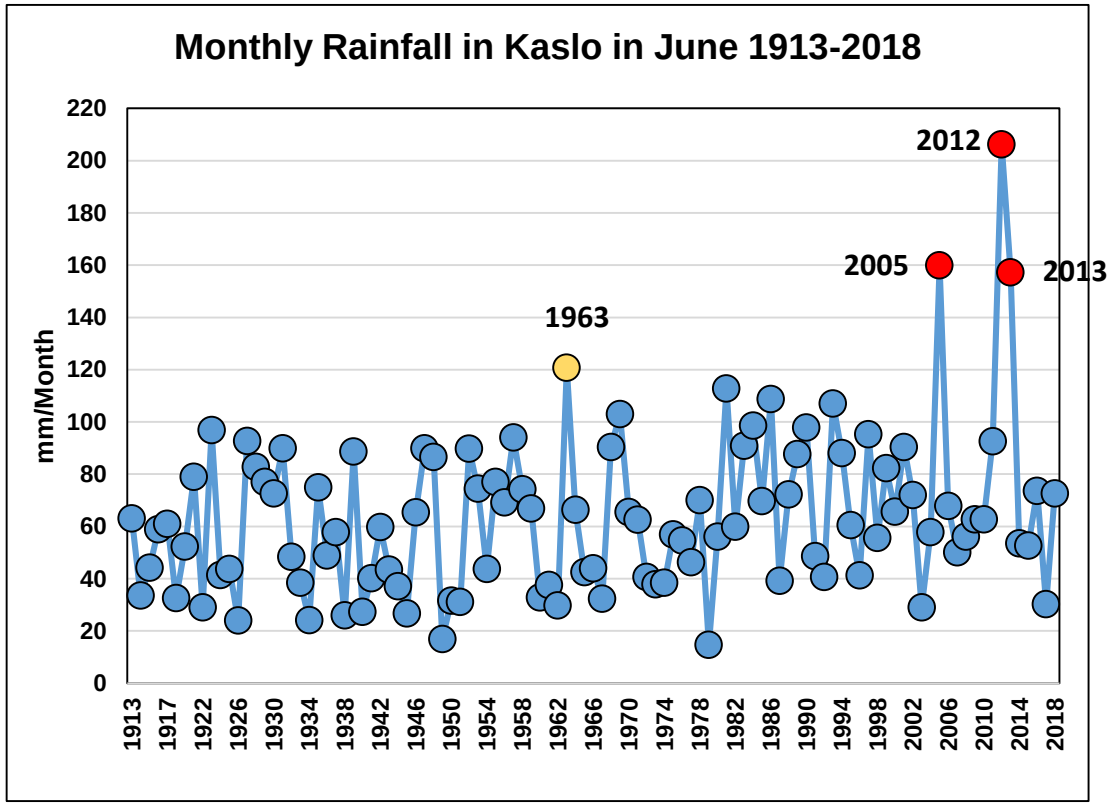
Data Record: 102 Years
Wettest June : 2012- 206 mm
Warmest June: 2015- 27.1°C



Data Record: 111 Years
Wettest June : 2012- 216.2 mm
Warmest June: 2015- 28°C

June Temperatures and Precipitation in Kaslo, B.C. 1913-3018





1913-2008

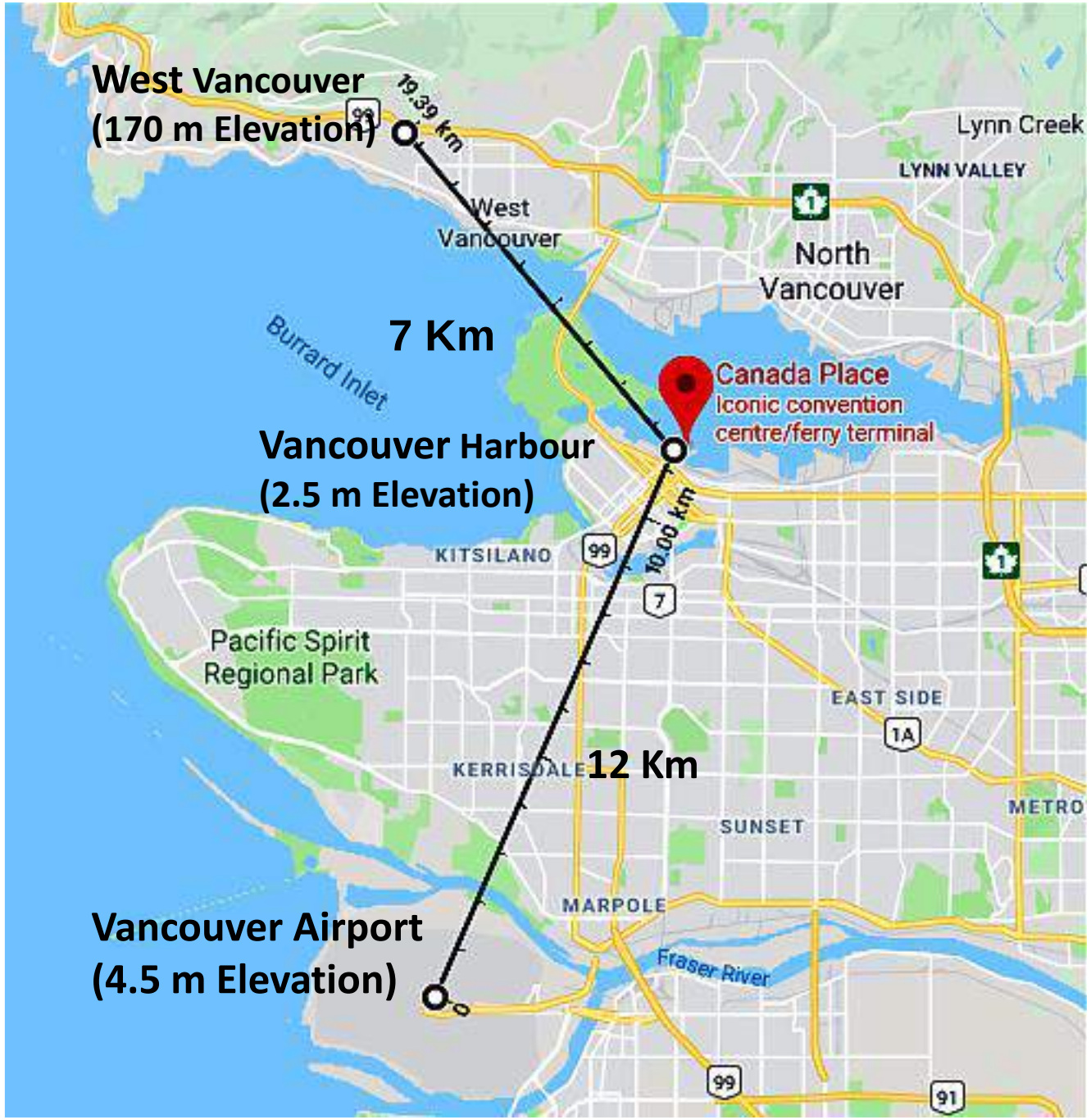
2009-2018

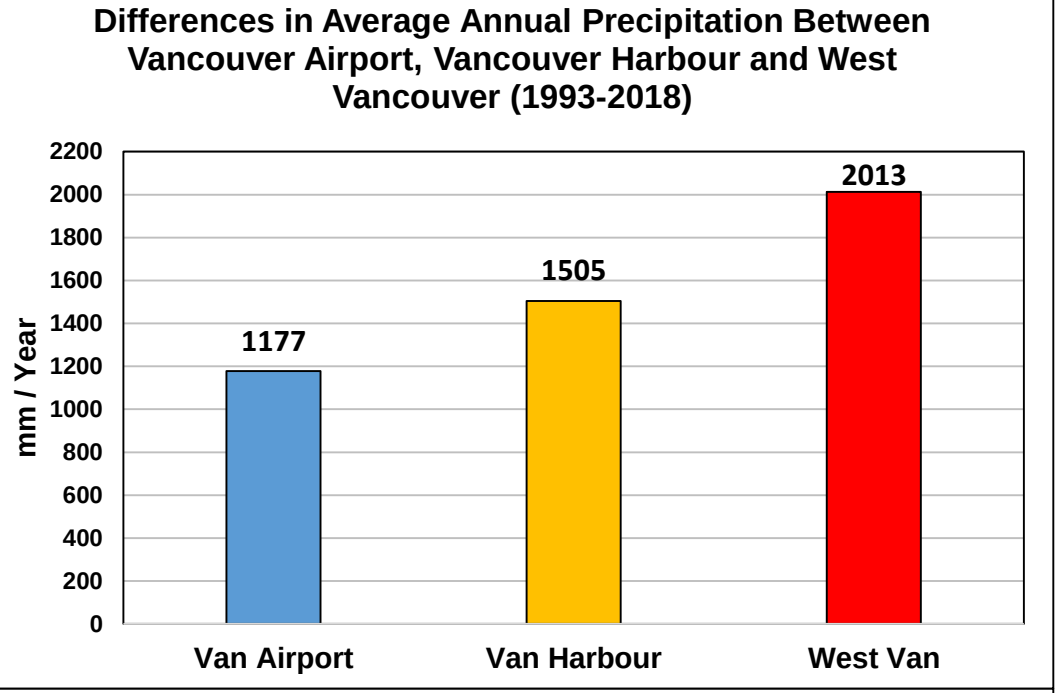
June Rainfall: 1963 highest historic rainfall

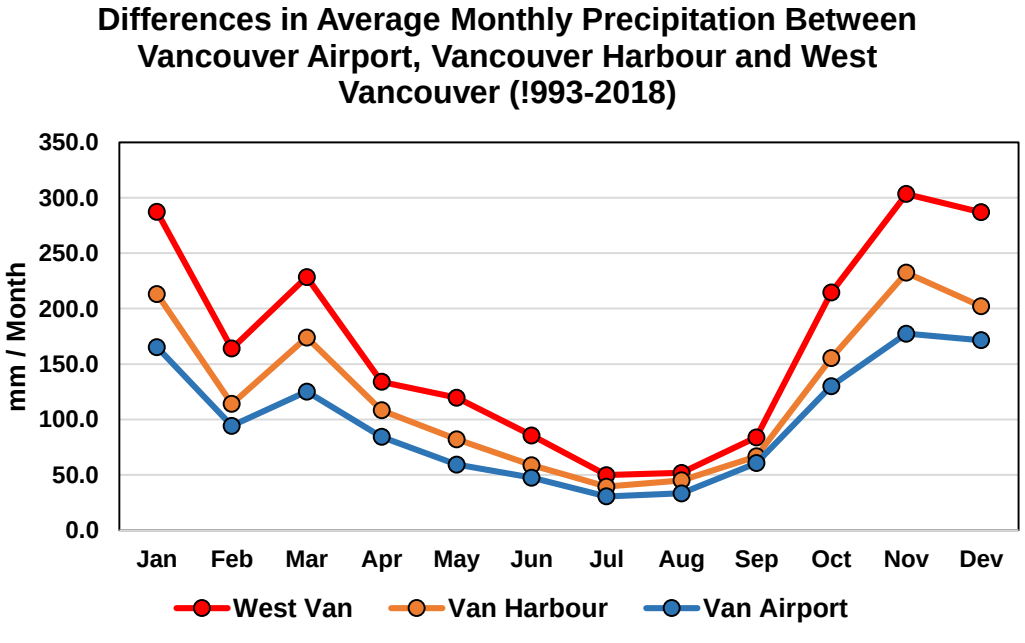
2005, 2012, 2013 had 30-70% more rain in June than over the historic record

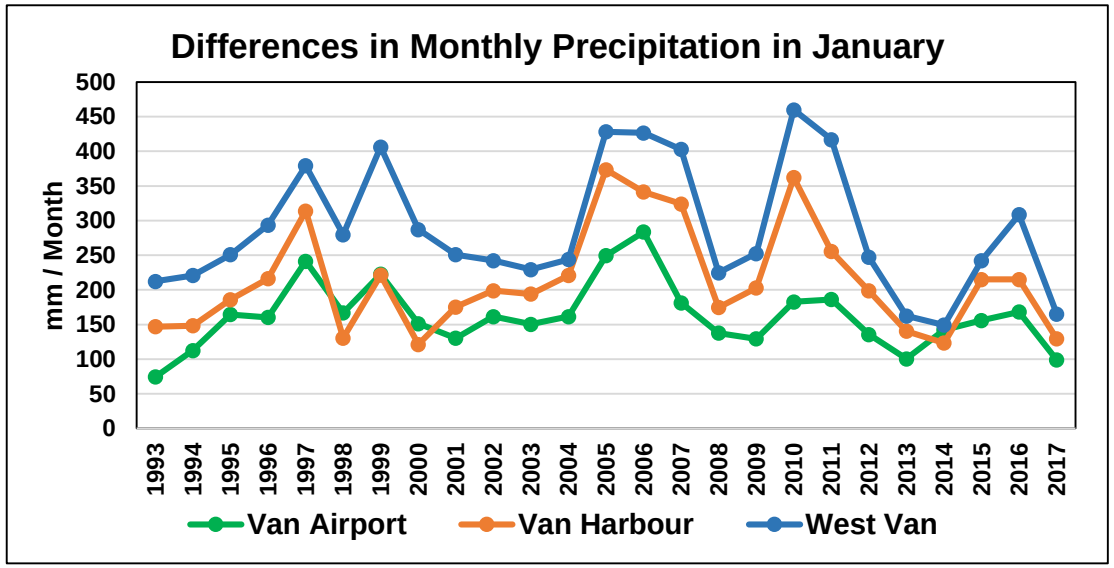
2012 Flood Event in Nelson B.C.

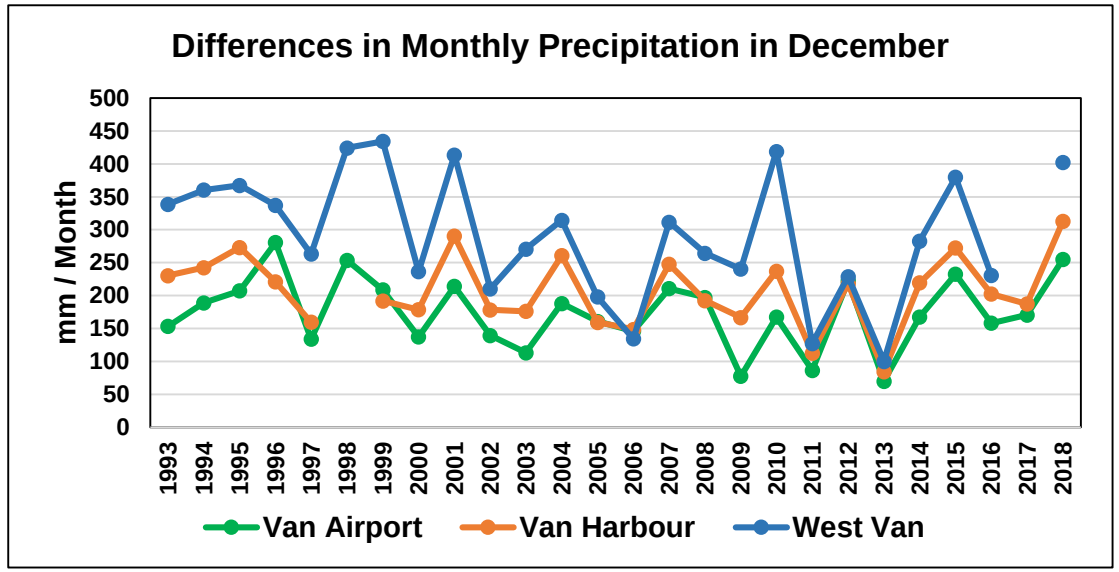
How does Topography Impact Rainfall & Runoff?


West Vancouver
(170 m Elevation)
19.39 km
Lynn Creek
LYNN VALLEY
West Vancouver
North Vancouver
7 Km
Burrard Inlet
Canada Place
Iconic convention centre/ferry terminal
Vancouver Harbour
(2.5 m Elevation)
10.00 km
KITSILANO
99
7
Pacific Spirit Regional Park
EAST SIDE
1A
KERRISDALE
12 Km
METRO
SUNSET
MARPOLE
Fraser River
Vancouver Airport
(4.5 m Elevation)
99
91


Differences in Average Annual Precipitation Between Vancouver Airport, Vancouver Harbour and West Vancouver (1993-2018)
mm / Year
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1177
1505
2013
Van Airport
Van Harbour
West Van


Differences in Average Monthly Precipitation Between Vancouver Airport, Vancouver Harbour and West Vancouver (!993-2018)
mm / Month
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dev
West Van
Van Harbour
Van Airport



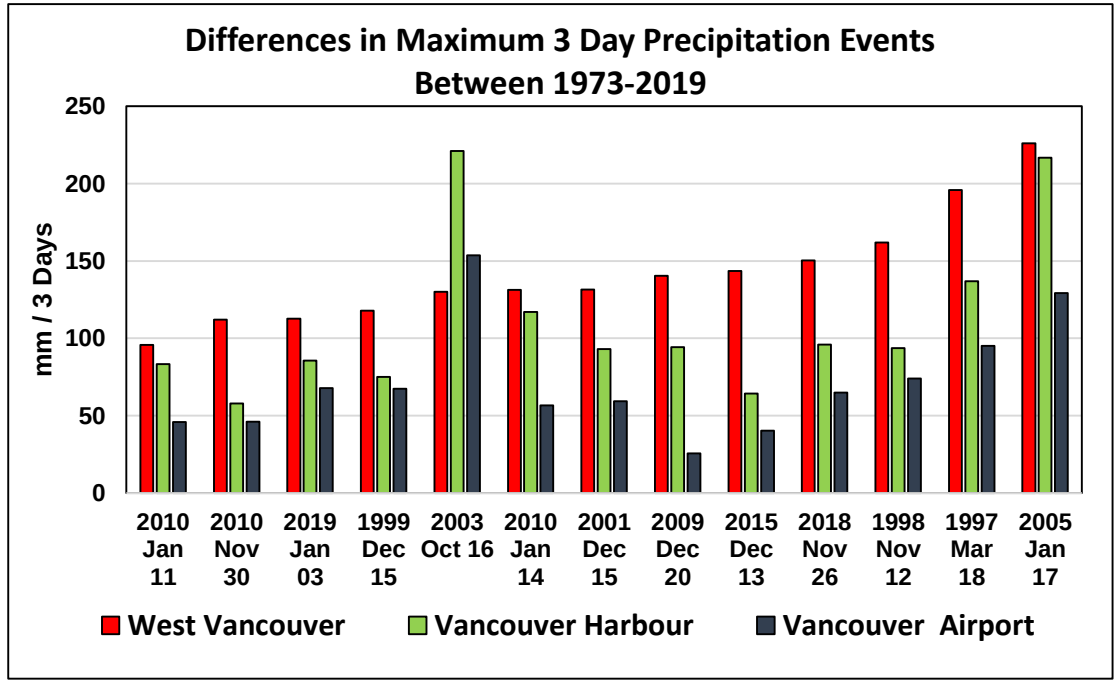


Elevation Difference: 170 m

Differences in Precipitation between West Vancouver & Van Airport

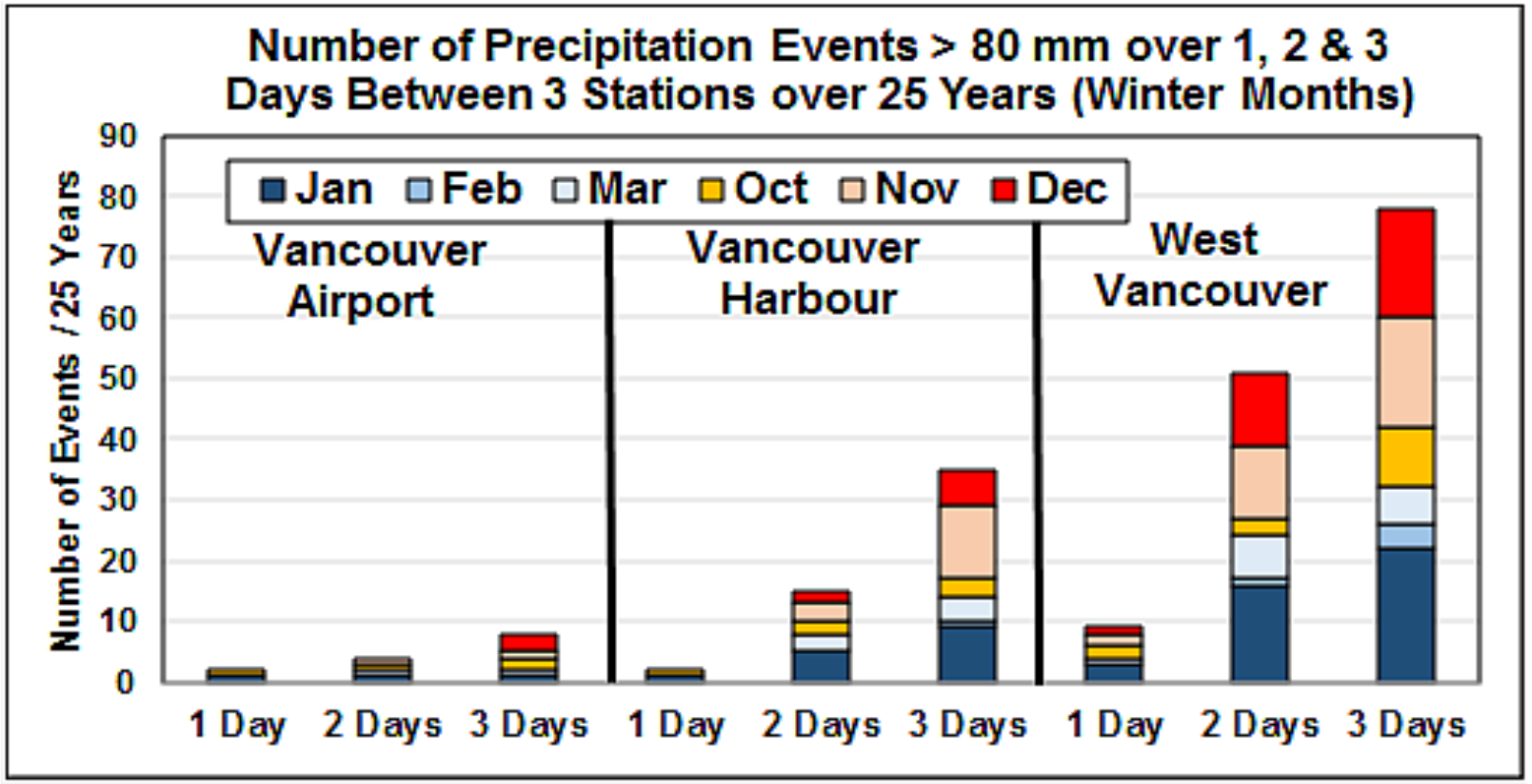
Annually > 70%
Monthly or Daily 2-3 times more

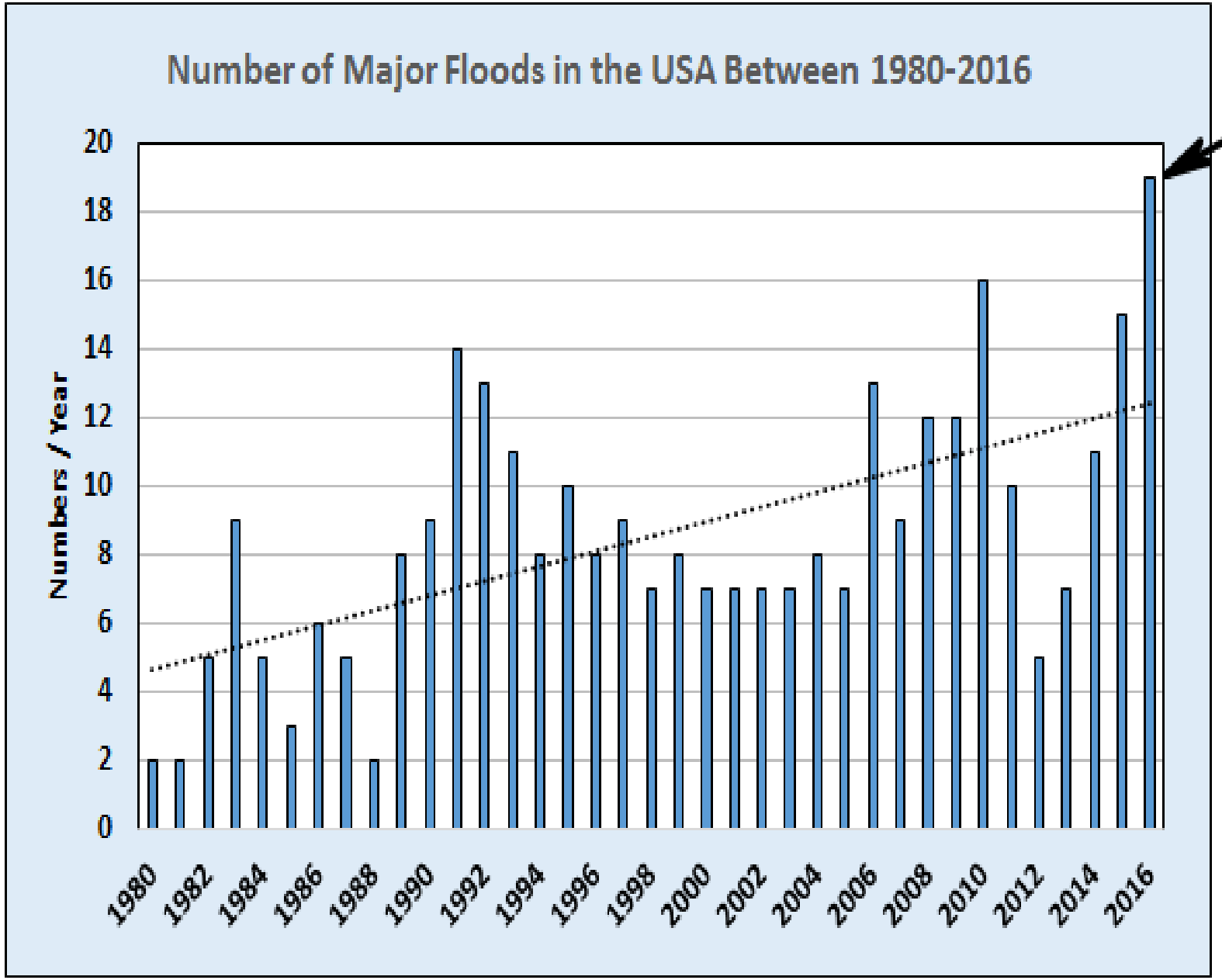
Largest 3 Day Precipitation Events



No. of Precipitation Events > 80 mm over 25 Years (1993-2018)			
	Vancouver Airport	Vancouver Harbour	West Vancouver
1 Day	2	2	10
2 Days	4	15	60
3 Days	10	38	102

No. of Precipitation Events > 100 mm over 25 Years (1993-2018)			
	Vancouver Airport	Vancouver Harbour	West Vancouver
1 Day	0	2	1
2 Days	2	15	21
3 Days	3	38	49





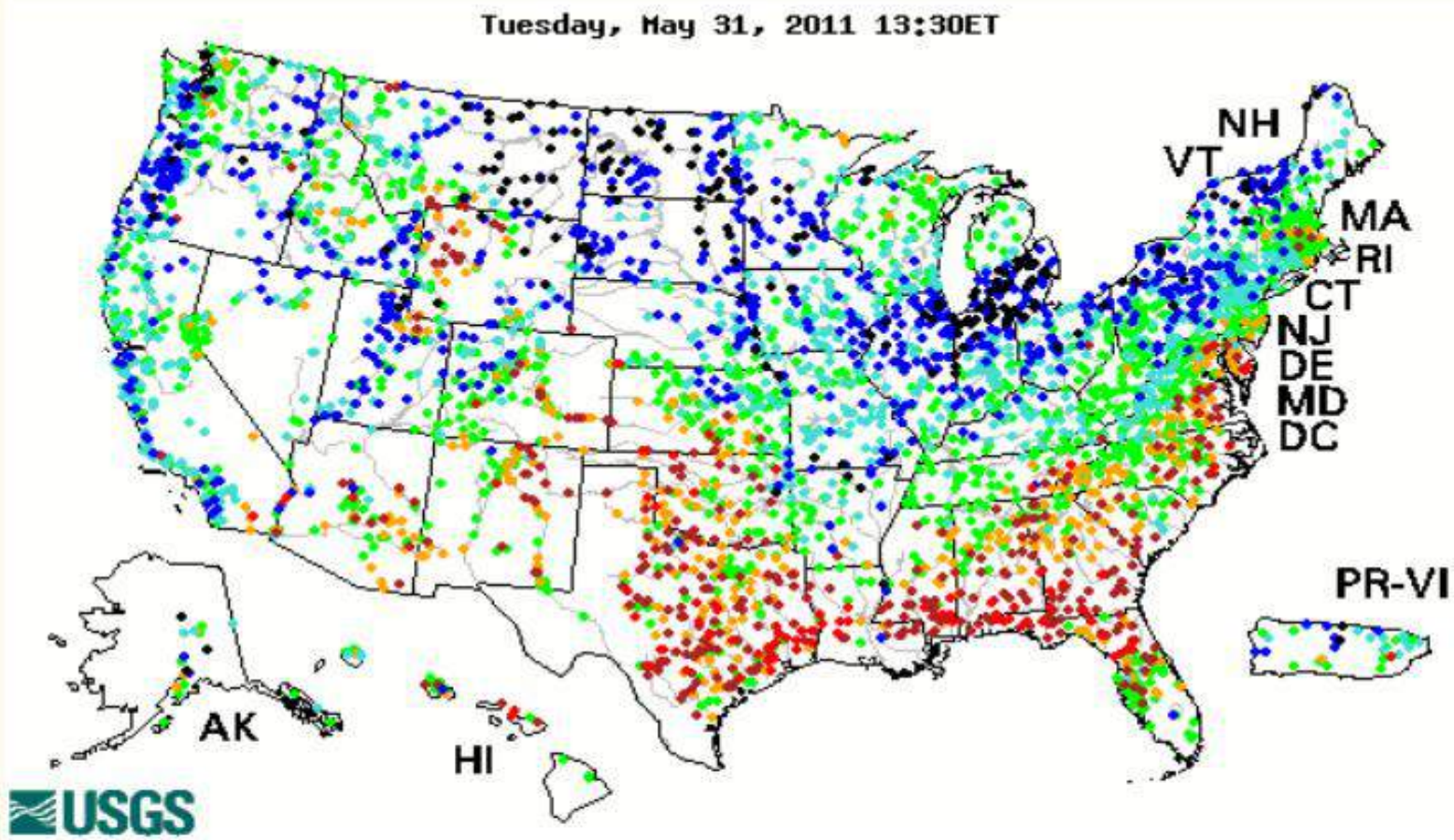
19 Major Floods in 2016

Data Source:
Munich Re-Insurance 2017

Insurance Cost $ 10 Billion

Hydrometic Data: USGS

28 Day Average Streamflow compared to Historic Streamflow for this time of the Year

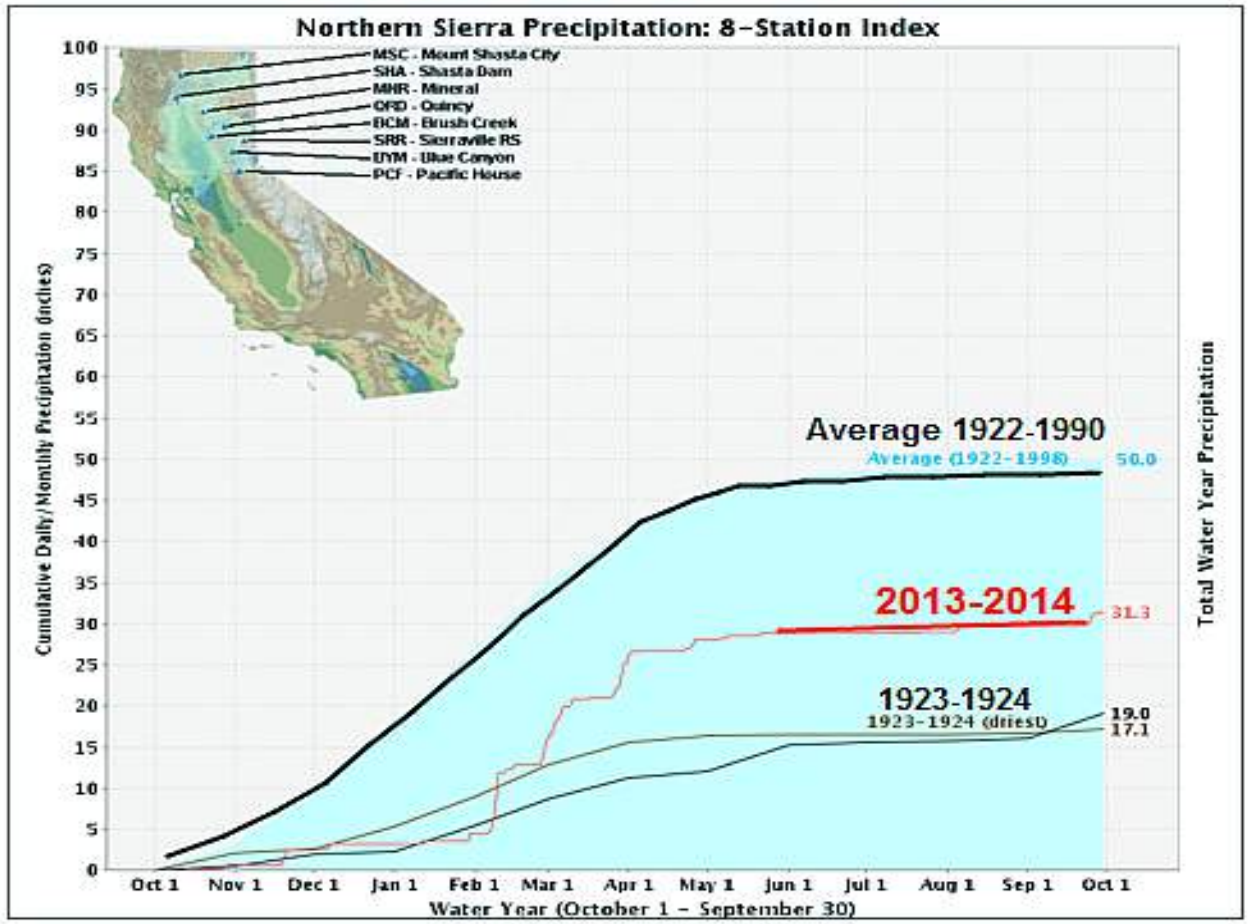


Choose a data retrieval option and select a location on the map

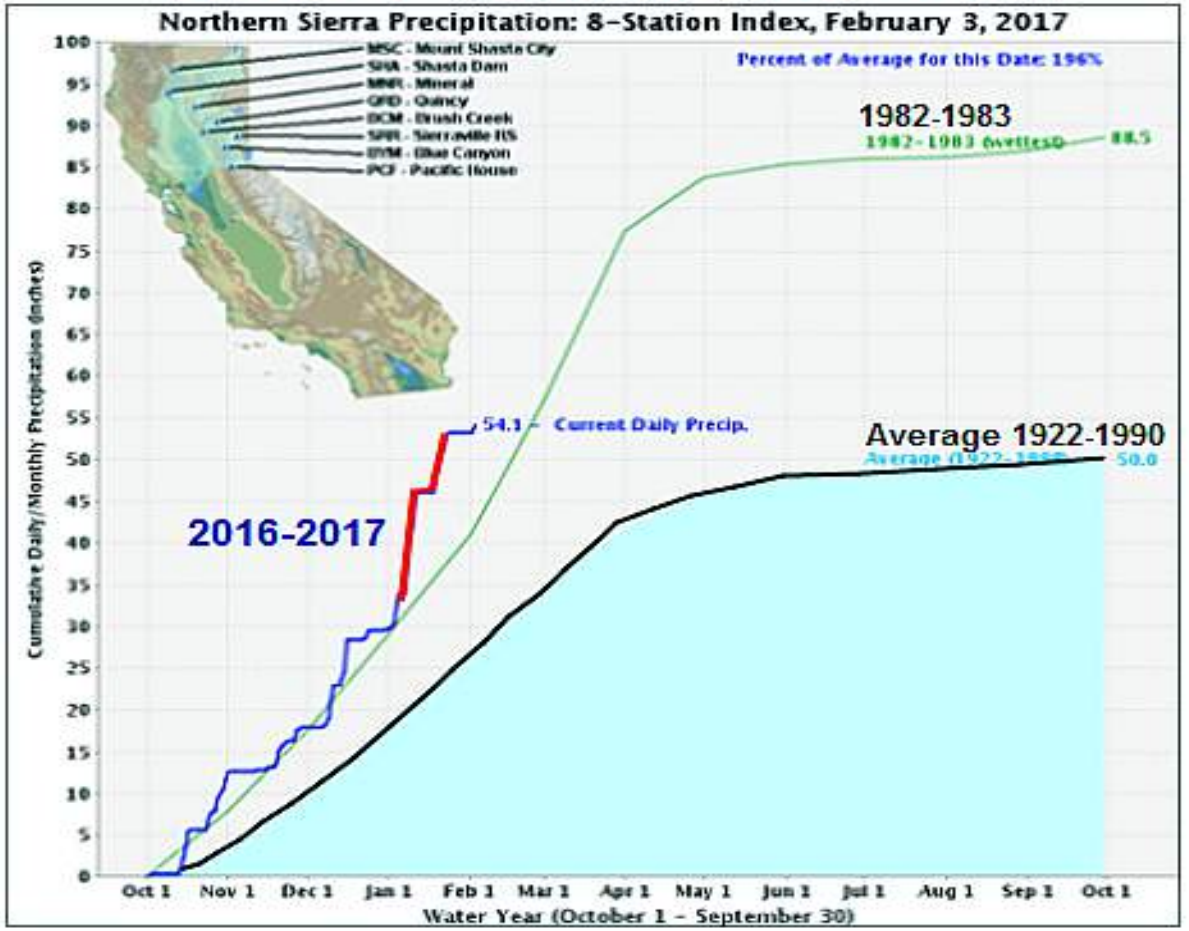
List of all stations in state, State map, or Nearest stations

Explanation - Percentile classes						
Low	<10	10-24	25-75	76-90	>90	High
	Much below normal	Below normal	Normal	Above normal	Much above normal	

2013-2014 Drought in California



2016-2017 Wet Winter in California

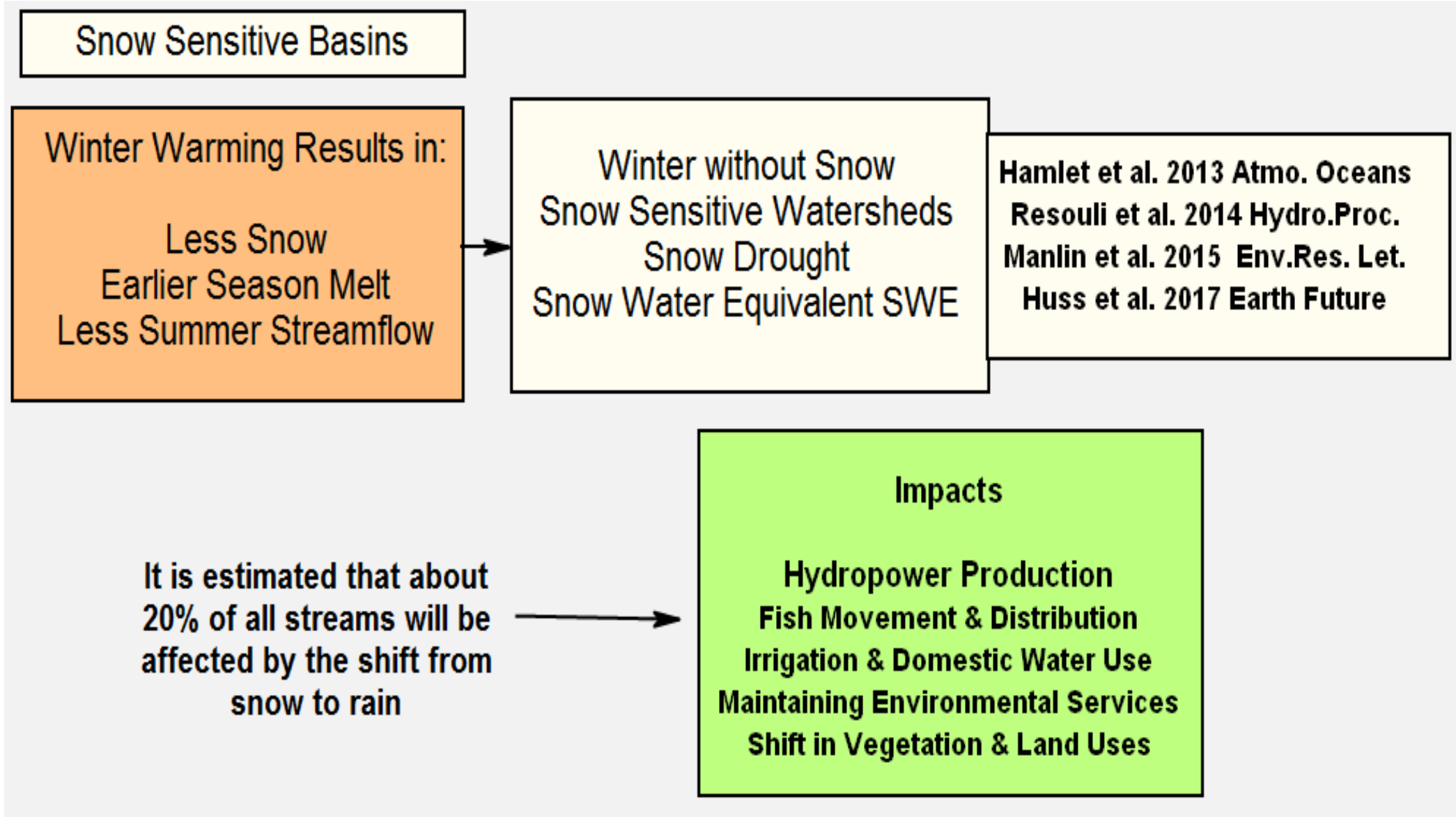


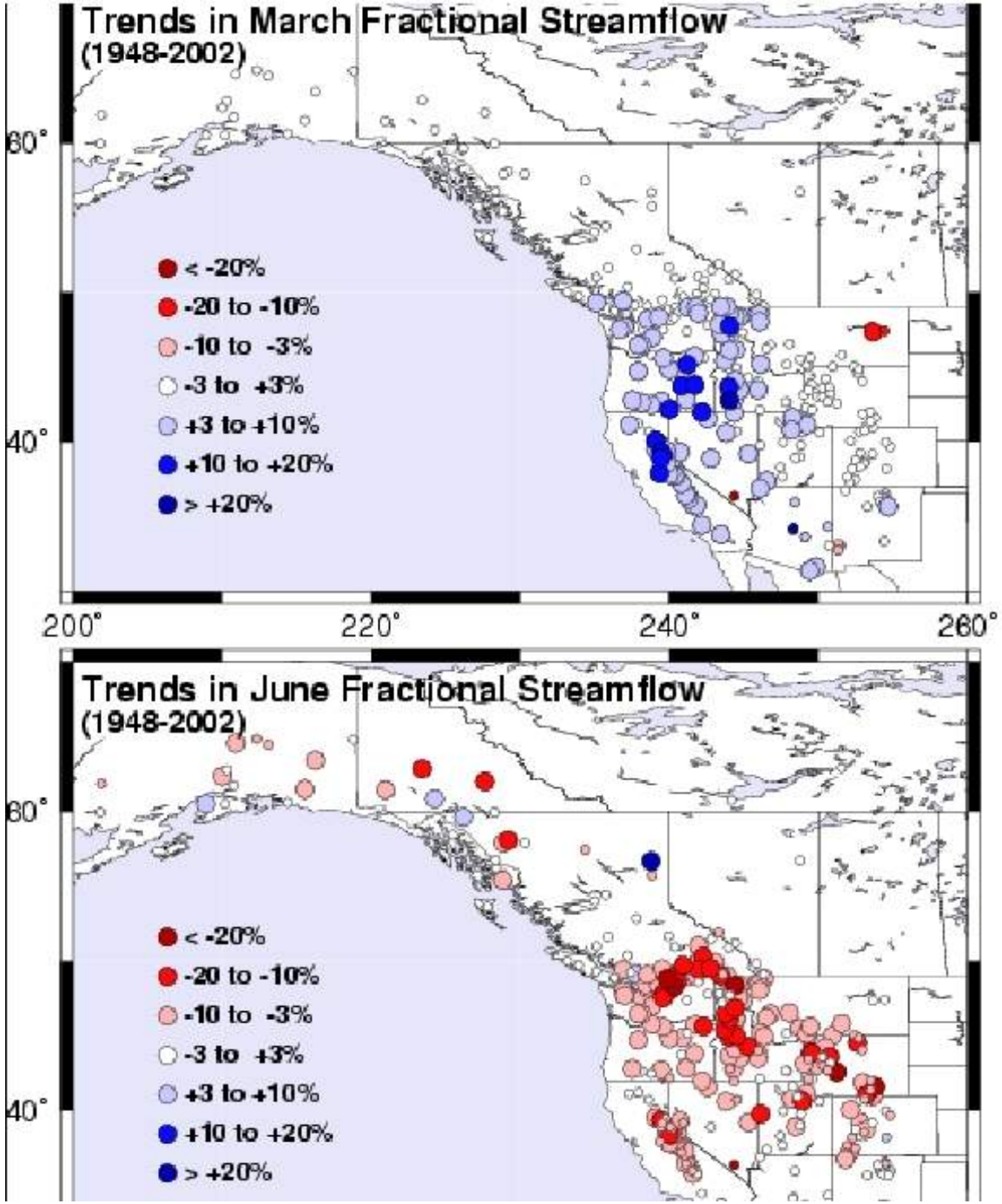
Extreme Minimum and Average Annual Precipitation in Northern California Since 1922

Extreme Maximum and Average Annual Precipitation in Northern California Since 1922

Source: California Department of Water Resources 2017

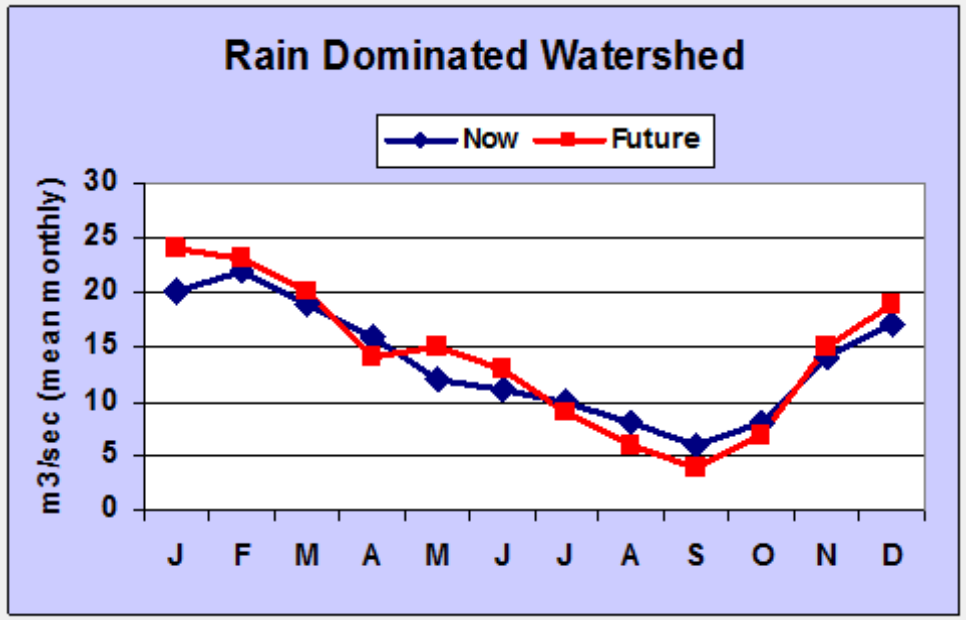
	Floods	Droughts
Key Factors	Climate & Land Use	Primarily Climate
Predictability	Somewhat	Difficult
	Start and Size is Predictable Timing is more difficult	Start, Size and Length of Drought is difficult to Predict
Reasons	Based on Rainfall, Snow Cover, Snow Water Equivalent (SWE) Land Use, Imperviouness, Antecedent Soil Moisture, lag-time between Rainfall & Runoff, Historic Streamflow Record	Depends on Climate factors (Temperatures & Precipitation). Minor information soil moisture conditions at start can help. Historic Record is not Particularly Useful.
Prepardeness	Advanced Notice, Some Time to Respond to Fast Moving Event	Little Advanced Notice, Requires Adaptive Response. Slow Progressive Event

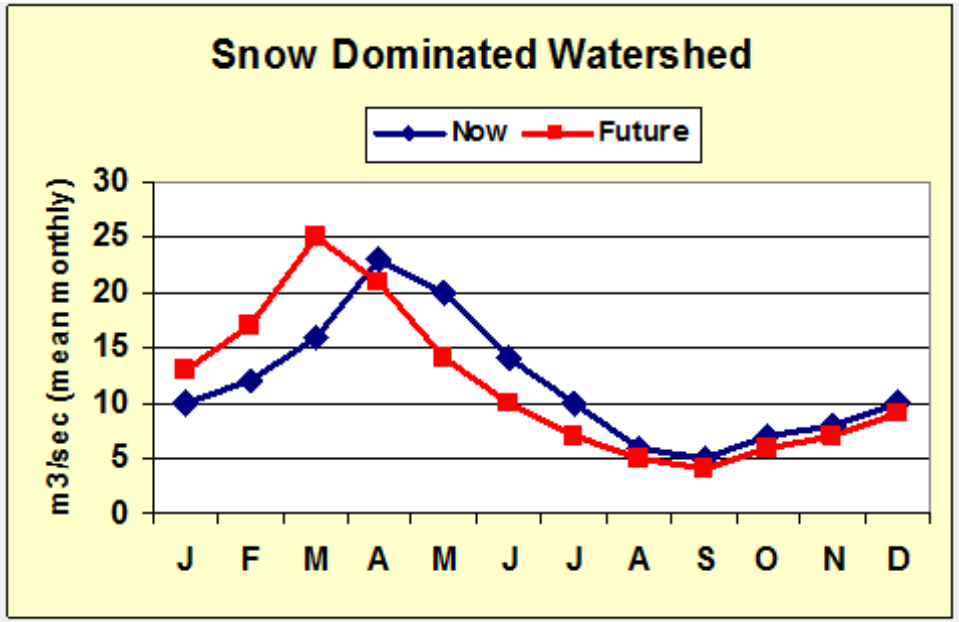

Snow Sensitive Basins
Winter Warming Results in:
Less Snow
Earlier Season Melt
Less Summer Streamflow
Winter without Snow
Snow Sensitive Watersheds
Snow Drought
Snow Water Equivalent SWE
Hamlet et al. 2013 Atmo. Oceans
Resouli et al. 2014 Hydro.Proc.
Manlin et al. 2015 Env.Res. Let.
Huss et al. 2017 Earth Future
It is estimated that about 20% of all streams will be affected by the shift from snow to rain
Impacts
Hydropower Production
Fish Movement & Distribution
Irrigation & Domestic Water Use
Maintaining Environmental Services
Shift in Vegetation & Land Uses

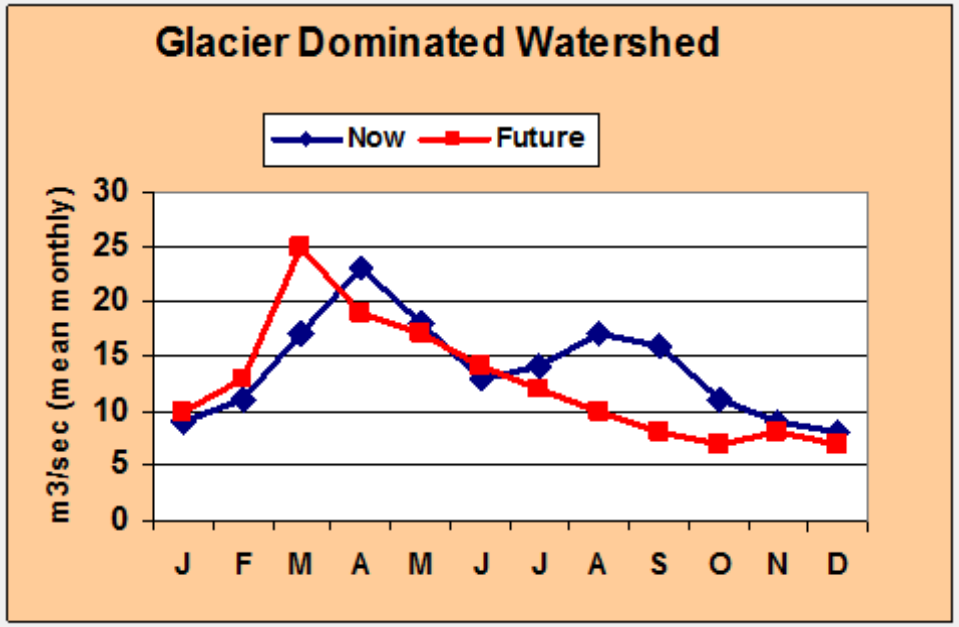


As the West warms, spring flows rise and summer flows drop

Stewart IT, Cayan DR, Dettinger MD, 2005: Changes toward earlier streamflow timing across western North America, J. Climate, 18 (8): 1136-1155





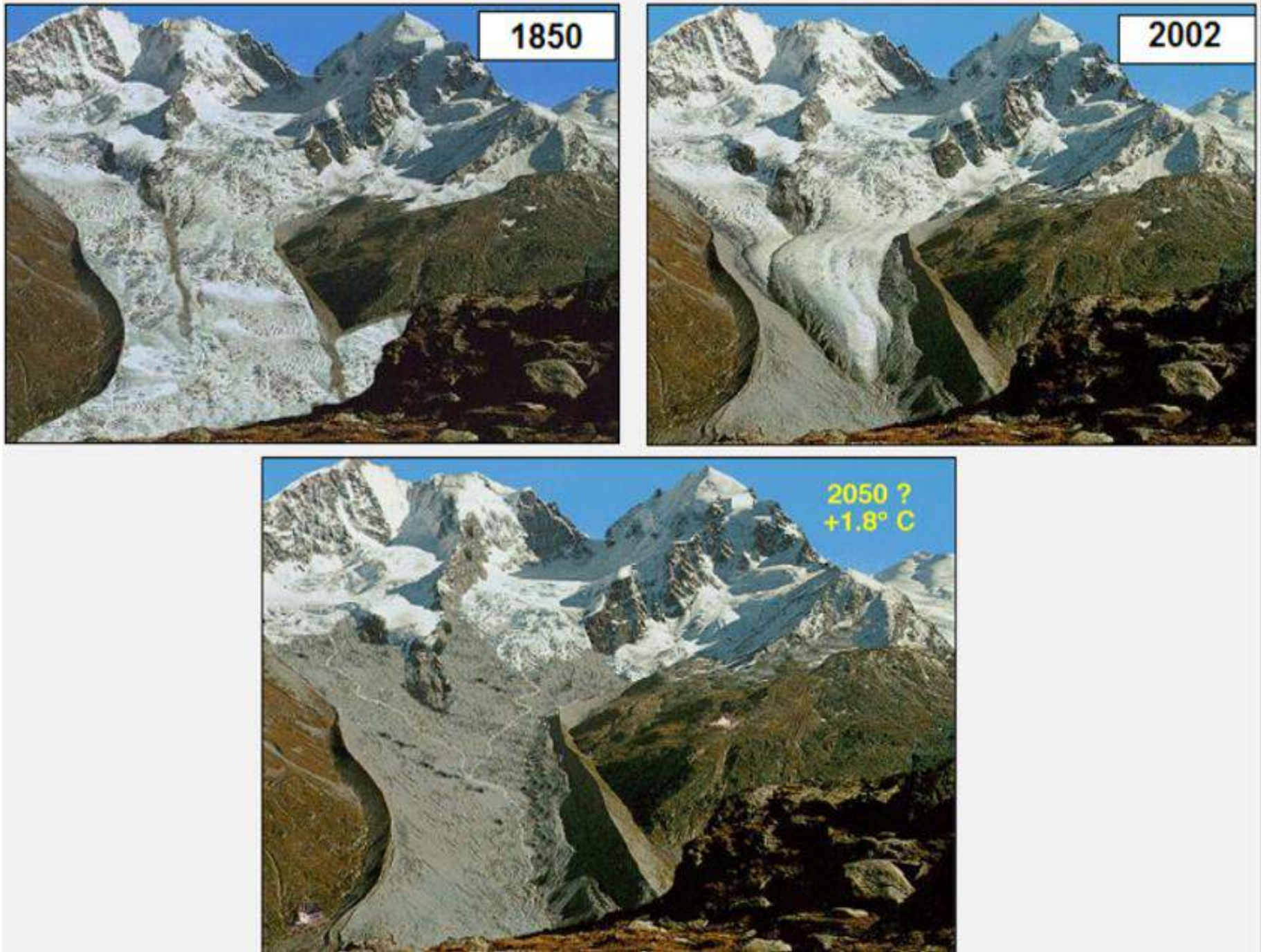


Anticipated Hydrological Changes:

Greatest changes in glacier dominated watersheds

Major shift in peak and low flow in snow dominated watershed

More variability in rain dominated watershed


1850
2002
2050 ?
+1.8° C

Shepard Glacier

W. C. Alden/ USGS photo. **1913**

W. C. Alden/ USGS photo. **1913**

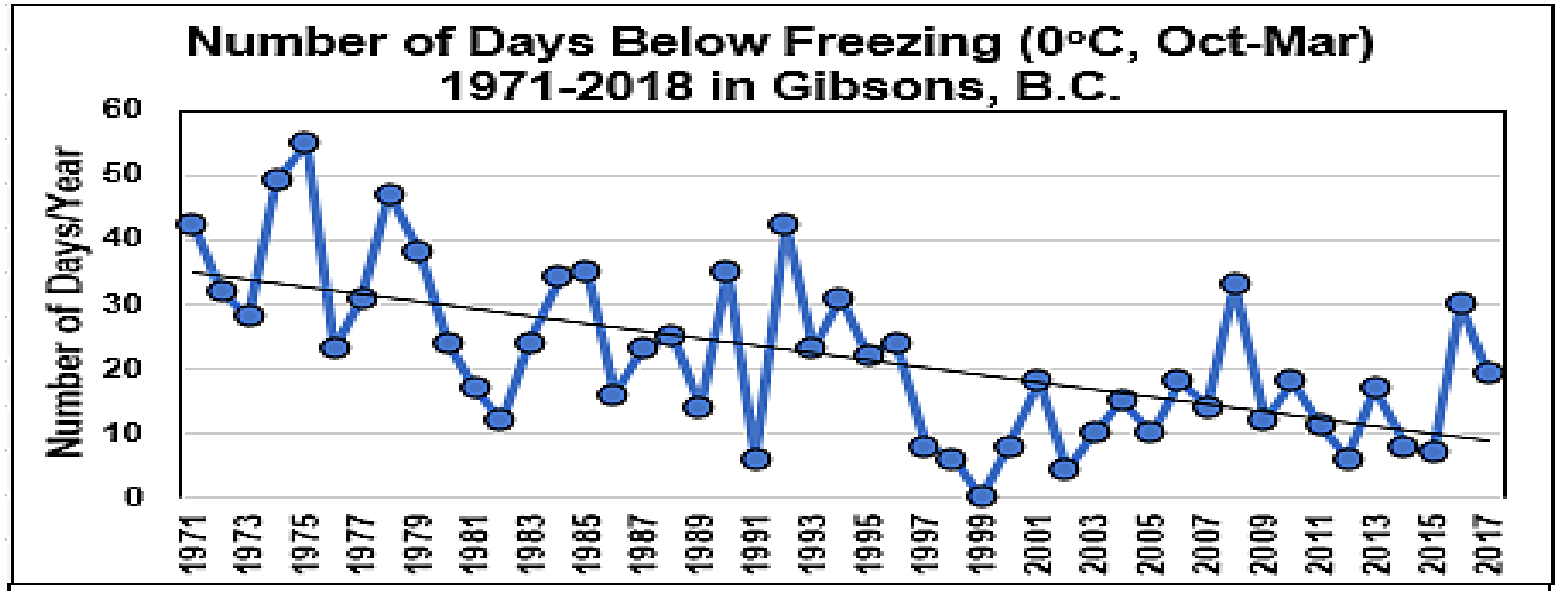
B. Reardon/ USGS photo **2005**

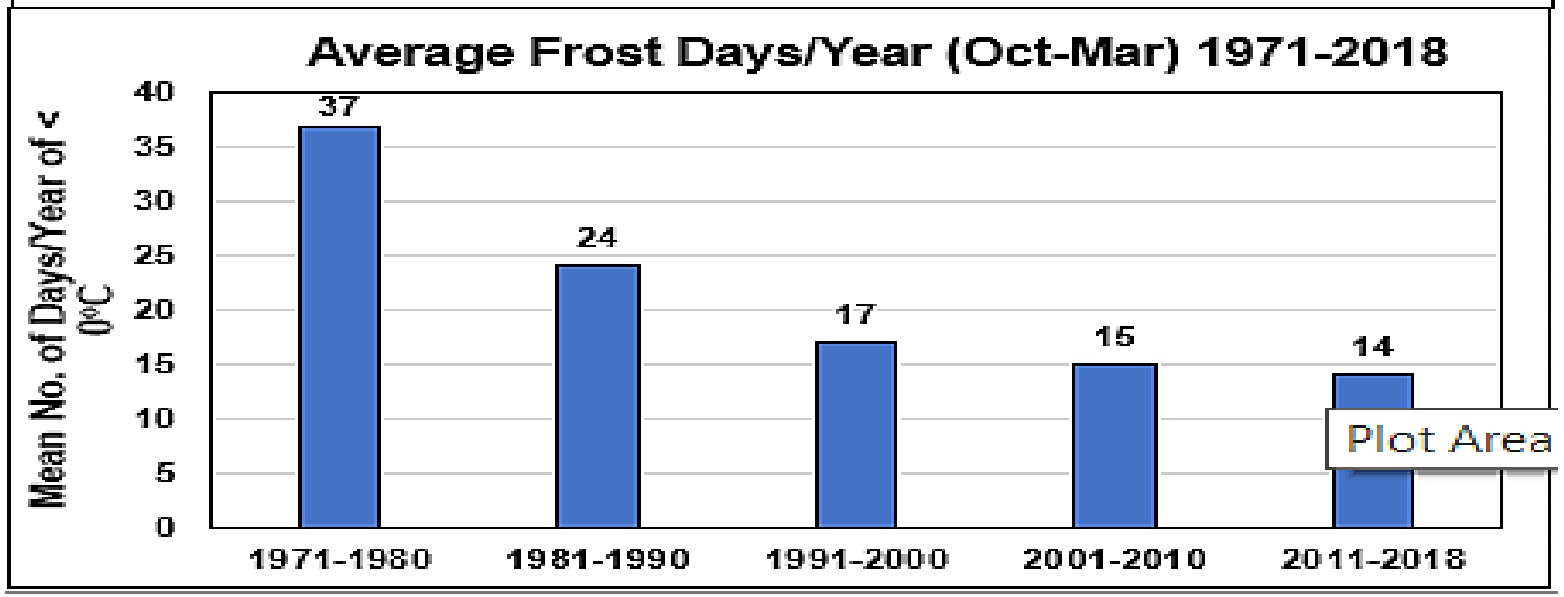
Nevado del Ruiz, Colombia
Ice cover at Equator

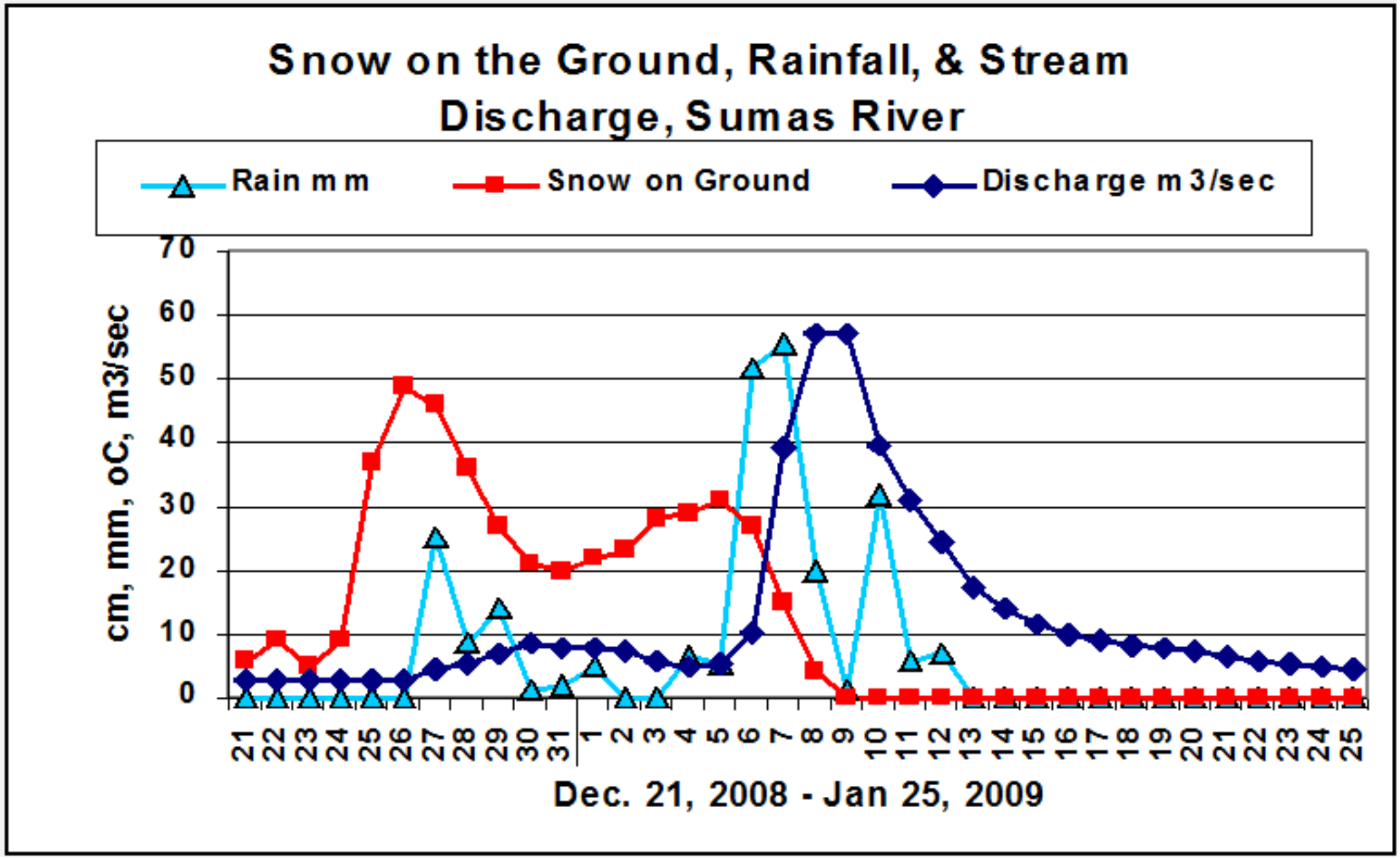
1900 = 100 km2
1959 = 34 km2
1985 = 20 km2
2003 = 10 km2

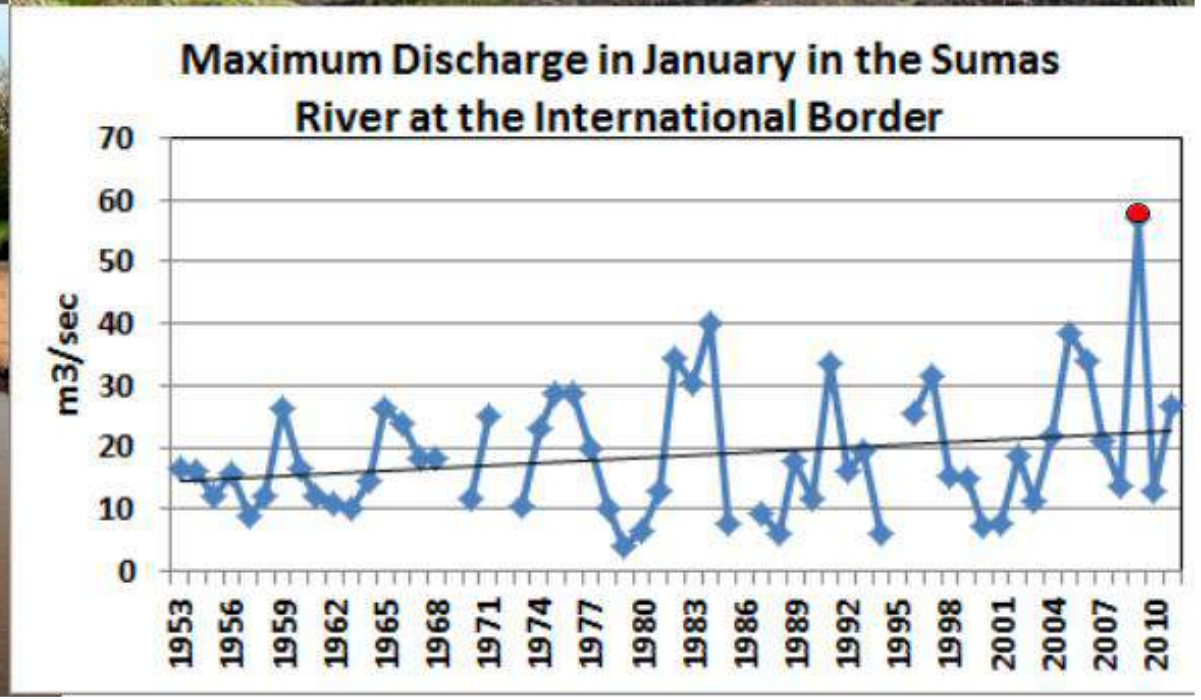
Volcanic Eruption 1985
impacted Albedo

Winter Temperature Fluctuation Affecting Snow Security





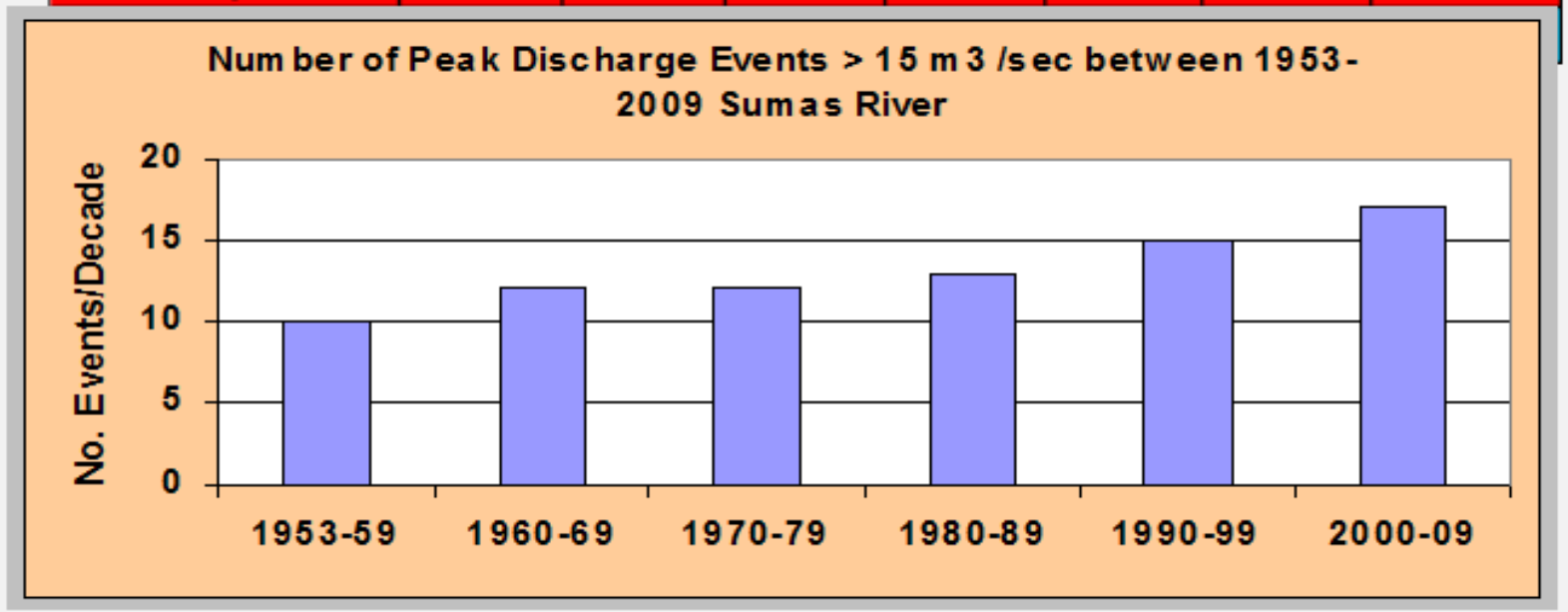

Snow on the Ground, Rainfall, & Stream Discharge, Sumas River
Rain mm
Snow on Ground
Discharge m3/sec
cm, mm, oC, m3/sec
70
60
50
40
30
20
10
0
21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Dec. 21, 2008 - Jan 25, 2009


Maximum Discharge in January in the Sumas River at the International Border
m3/sec
70
60
50
40
30
20
10
0
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010

Increases in Storm Runoff Events (1950'-2010) Combined effect of increased climatic variability and land use intensification

Storm Events 1953-2009 - Sumas River, B.C.

	1953-59	1960-69	1970-79	1980-89	1990-99	2000-09	# Events
15-19.9 m3 /sec	8	6	2	5	5	5	31
20-24.9 m3 /sec	1	4	2	1	2	5	15
25-29.9 m3 /sec	1	1	4	1	2	1	10
30-34.9 m3 /sec	0	1	2	2	5	3	13
35-57 m3 /sec	0	0	2	4	1	3	10

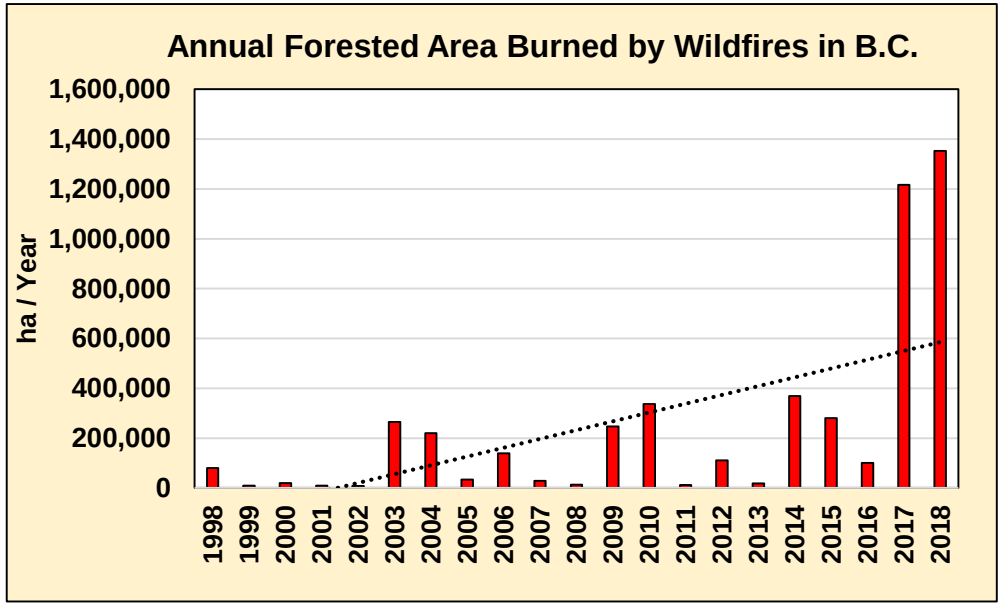


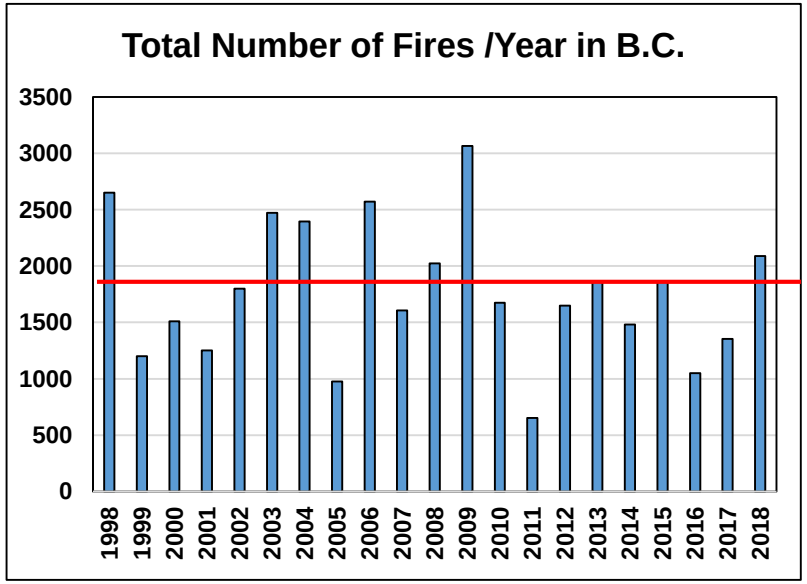

Inkhu Valley
before 1998
Inkhu Valley
After 1998

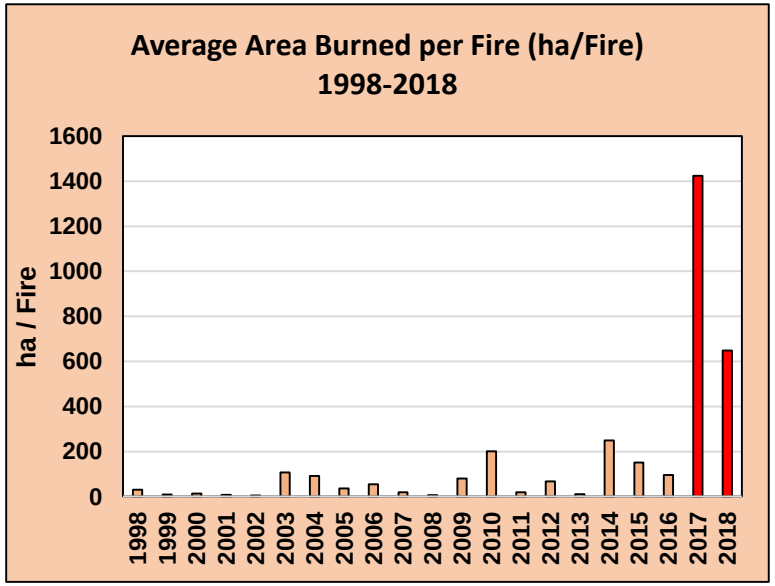
Forest Fires

64% of Land Area in B.C.
is Covered in Forests

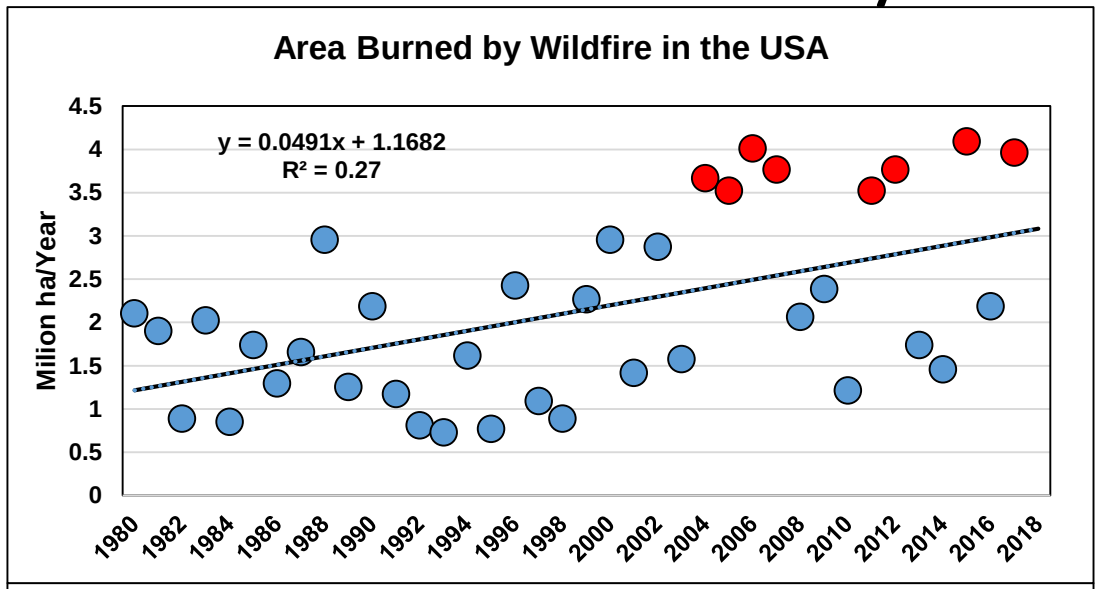
60 Million ha of Forests

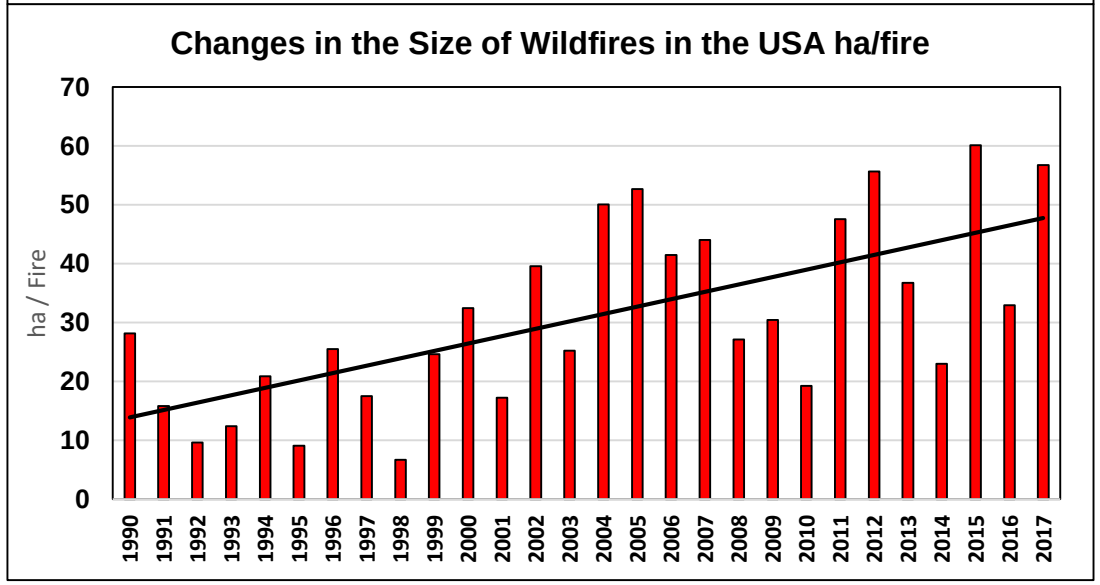






Wildfire History in the USA 1990-2017





Reasons for Change in fires

1. **Higher Temperature (stressing trees)**
2. **Mono-Culture (Same Species Even Age)**
3. **Increase in Disease (Changing Climate)**
4. **Air-pollution stressing trees**
5. **Neglected Fuel-loads**
6. **More Access Roads – Careless People**

Pine Beetles and Fire

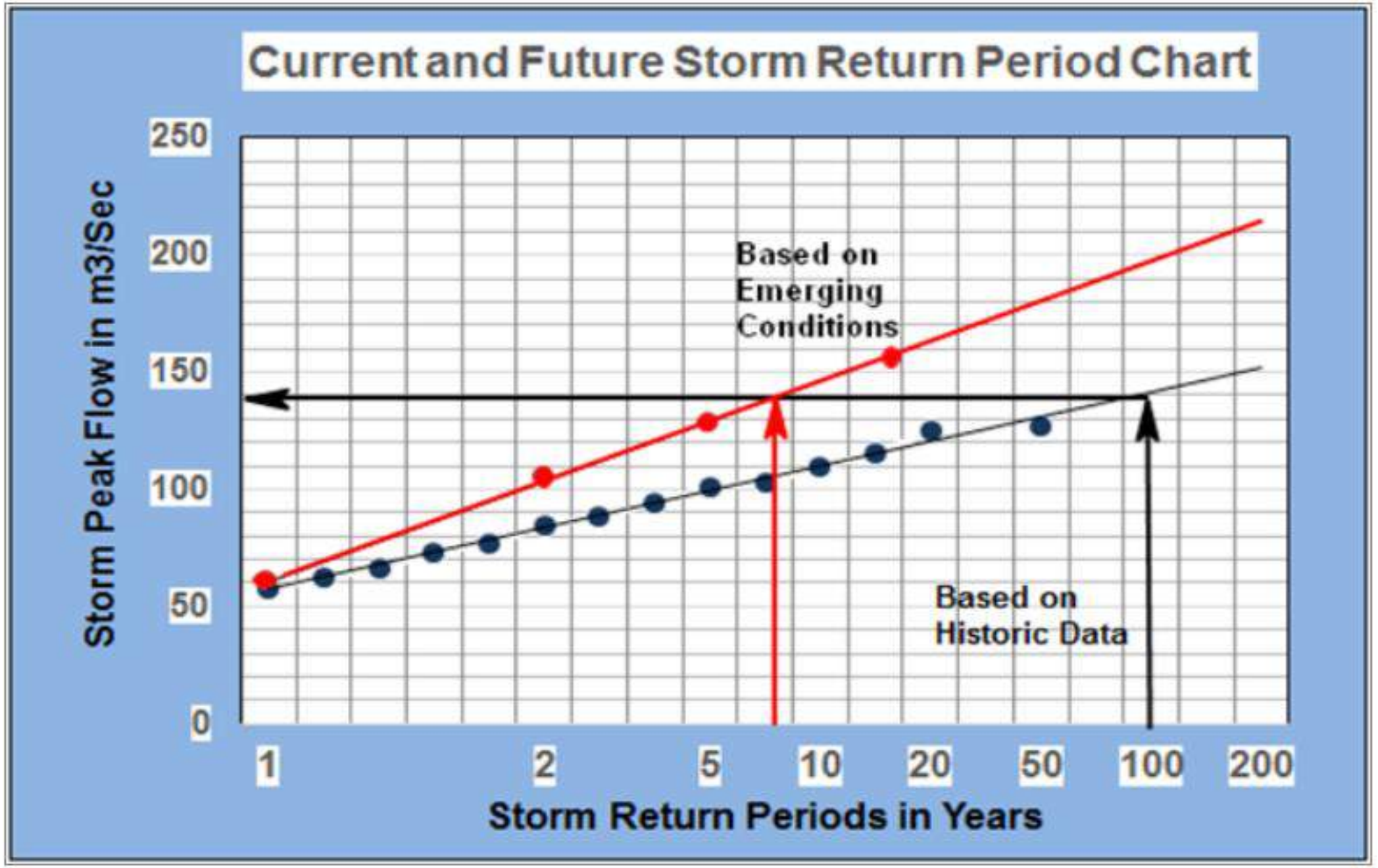
Estimated Area Affected in between 1999 and 2014: 18 Million ha (2 times the size of Austria)

Impact since 1999: 800 Mio m^3 of timber

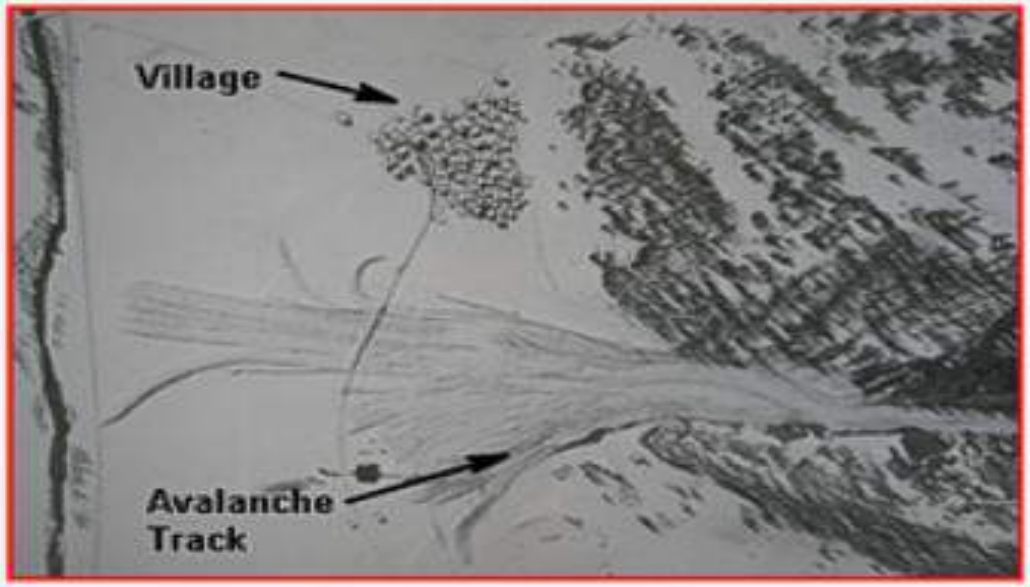
Dilemma:

If harvested within 2-3 years the wood can still be used
If left standing it creates a forest fire hazard
In both cases it is a problem for Carbon Balance
The impact on the hydrological cycle is uncertain

Implications



Natural Hazards and its Impact Downstream



Summary

Focus on Increased climatic Variability

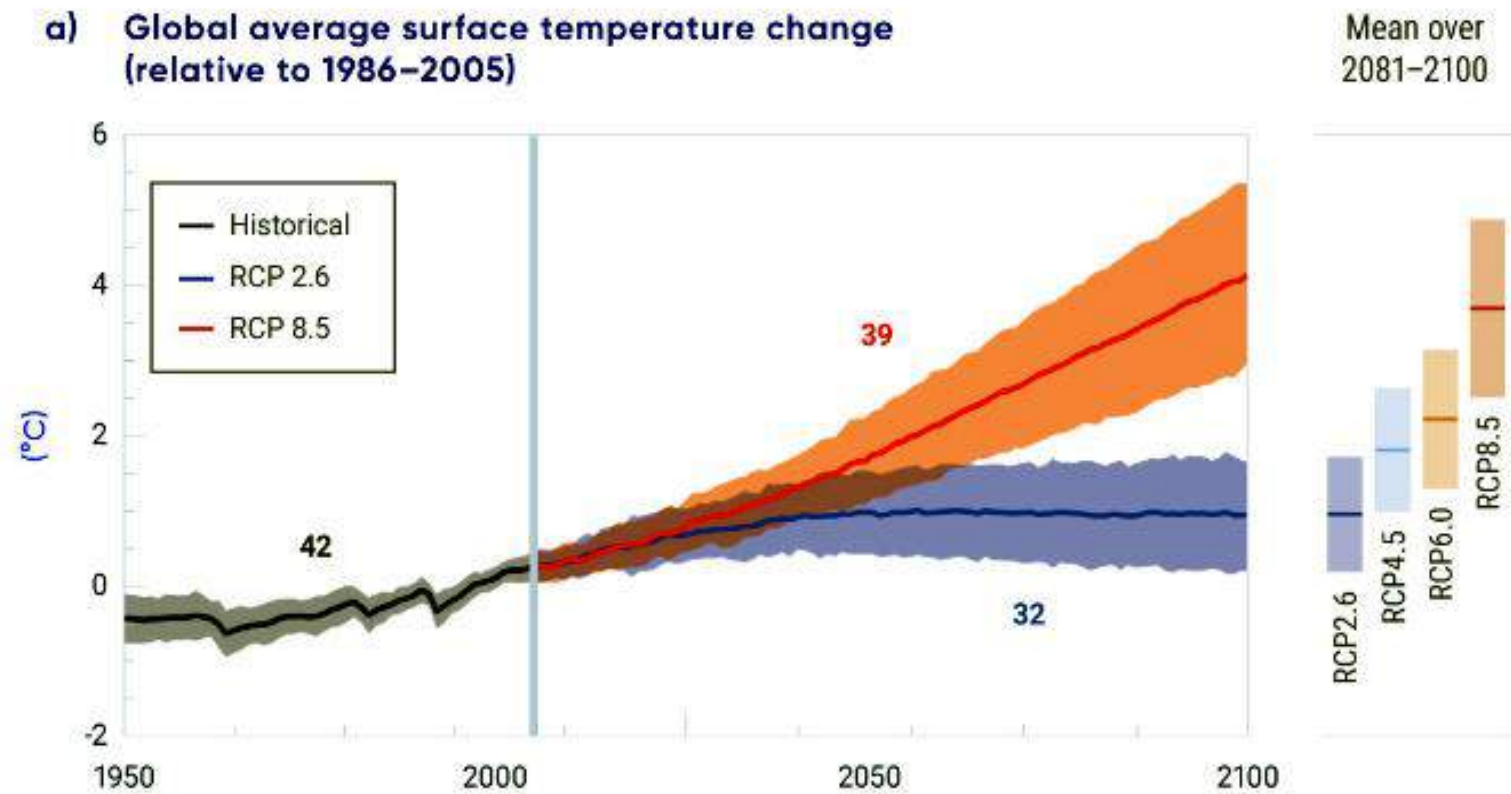
Increased Windstorms
Increased Extreme Rainfall Events
Less Snow and Earlier Snowmelt
More Freeze and Thaw Event
More Rain on Snow Events
Accellerated Glacial Melt
Reduced Summer Flow after Glacier Melt
Shift in Timing of Peakflow
More peakflow, Less Summer Baseflow

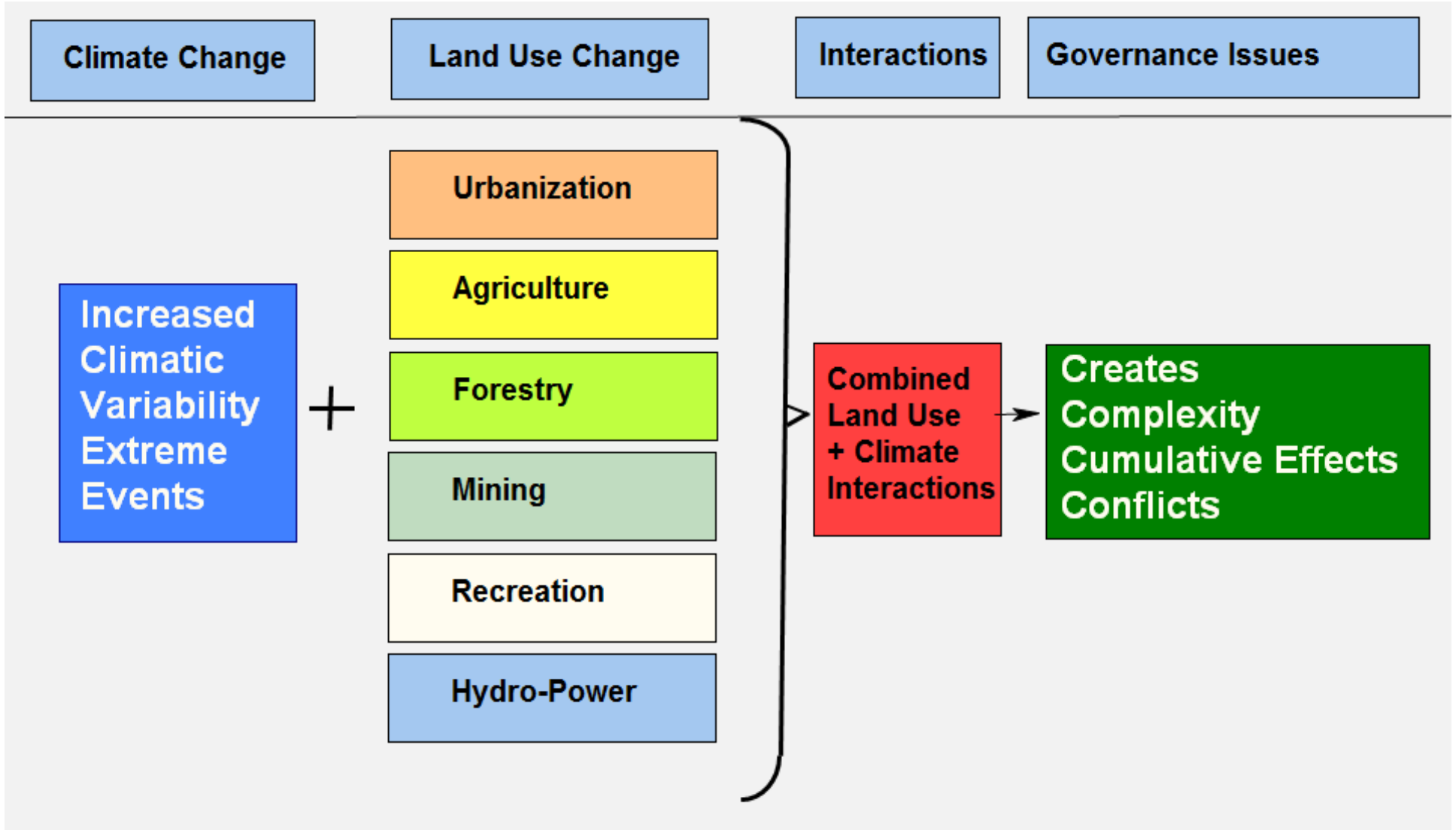
Focus on Adaptations:

More Water Infiltration into Soil
Green Water Storage
Recharge of Aquifers
Water Harvesting
Water Detention during Peakflow
Water Conservation
Wetland Storage
Innovative Flood Control
Demand Management

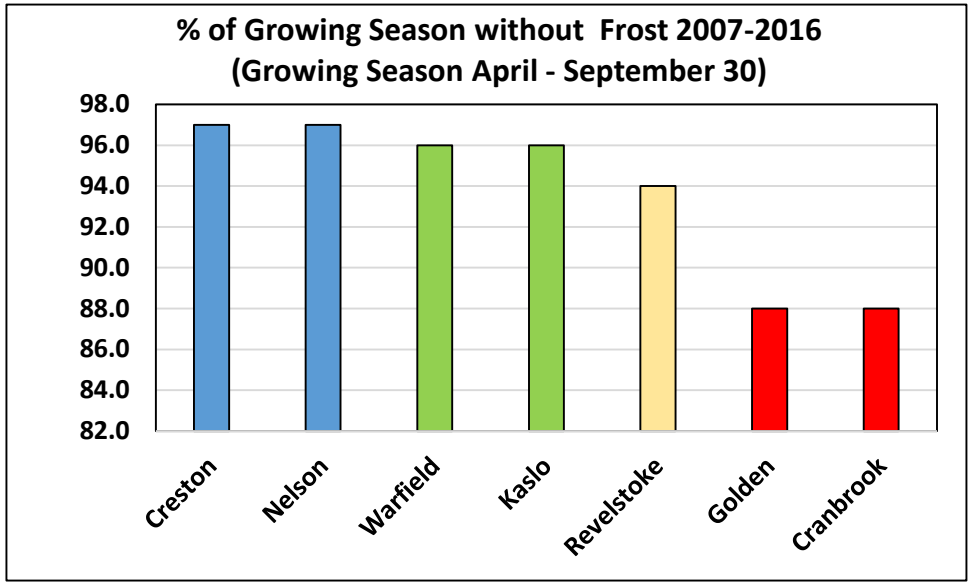
1. Decrease CO_2 Emissions
2. Adaptation Measures

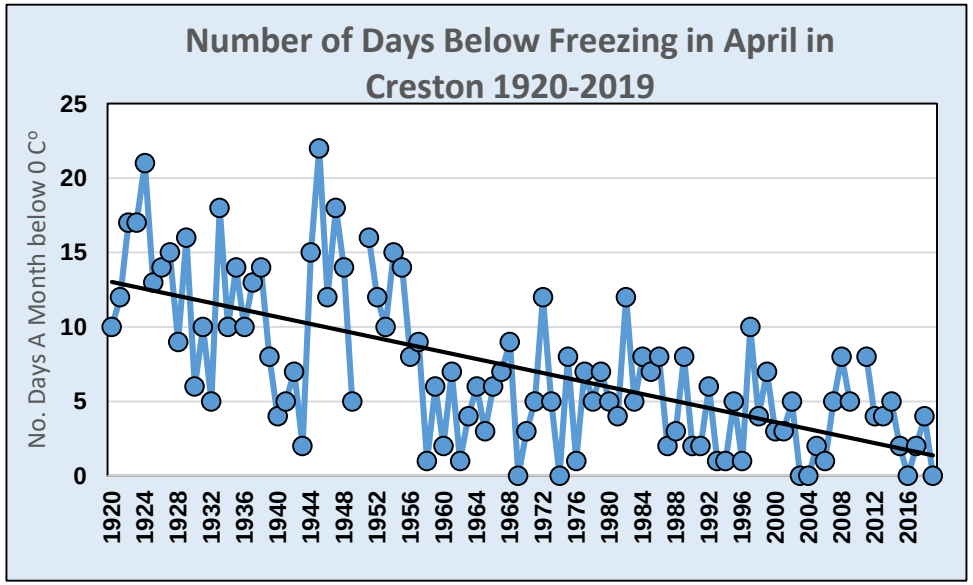
- Who needs to Adapt?
- What are the best Adaptation options?
- What adaptation measures will be most effective?
- What are the most likely adaptations to be implemented?
- Who will pay for it?


a) Global average surface temperature change
(relative to 1986–2005)
Mean over
2081–2100
6
4
2
0
-2
(°C)
Historical
RCP 2.6
RCP 8.5
42
39
32
1950
2000
2050
2100
RCP2.6
RCP4.5
RCP6.0
RCP8.5


Climate Change
Land Use Change
Interactions
Governance Issues
Increased Climatic Variability Extreme Events
+
Urbanization
Agriculture
Forestry
Mining
Recreation
Hydro-Power
Combined Land Use + Climate Interactions
Creates Complexity Cumulative Effects Conflicts

Land Use Activities	Water Demand & Use	Surface Runoff	Water Pollution
Urbanization	Increasing Demand Summer Peak Use	Increased Surface Runoff & Floods	NPS & Wastewater Discharge
Agriculture	More Irrigation	More Runoff due to Soil Compaction	Nutrient, Sediments Pathogen Leaching
Forestry	Water for Fire Fighting	Road and after Fire Runoff	Sediments
Mining	Fracking Water & Processing	Runoff from Tailing Failures	Metals & Organics Hg and Cyanide
Recreation	Water for Snow Increasing Peak Use	Changes in Sesonal Runoff	Pathogens & Sediments
Hydro-Power	More Reservoirs Pump Storage	Release during Peak Demand	Flushing during Summer
Combined Land Use	Cumulative Effect on Water Use, Runoff & Pollution		


% of Growing Season without Frost 2007-2016
(Growing Season April - September 30)
98.0
96.0
94.0
92.0
90.0
88.0
86.0
84.0
82.0
Creston
Nelson
Warfield
Kaslo
Revelstoke
Golden
Cranbrook


Number of Days Below Freezing in April in Creston 1920-2019
No. Days A Month below 0 C°
25
20
15
10
5
0
1920
1924
1928
1932
1936
1940
1944
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016