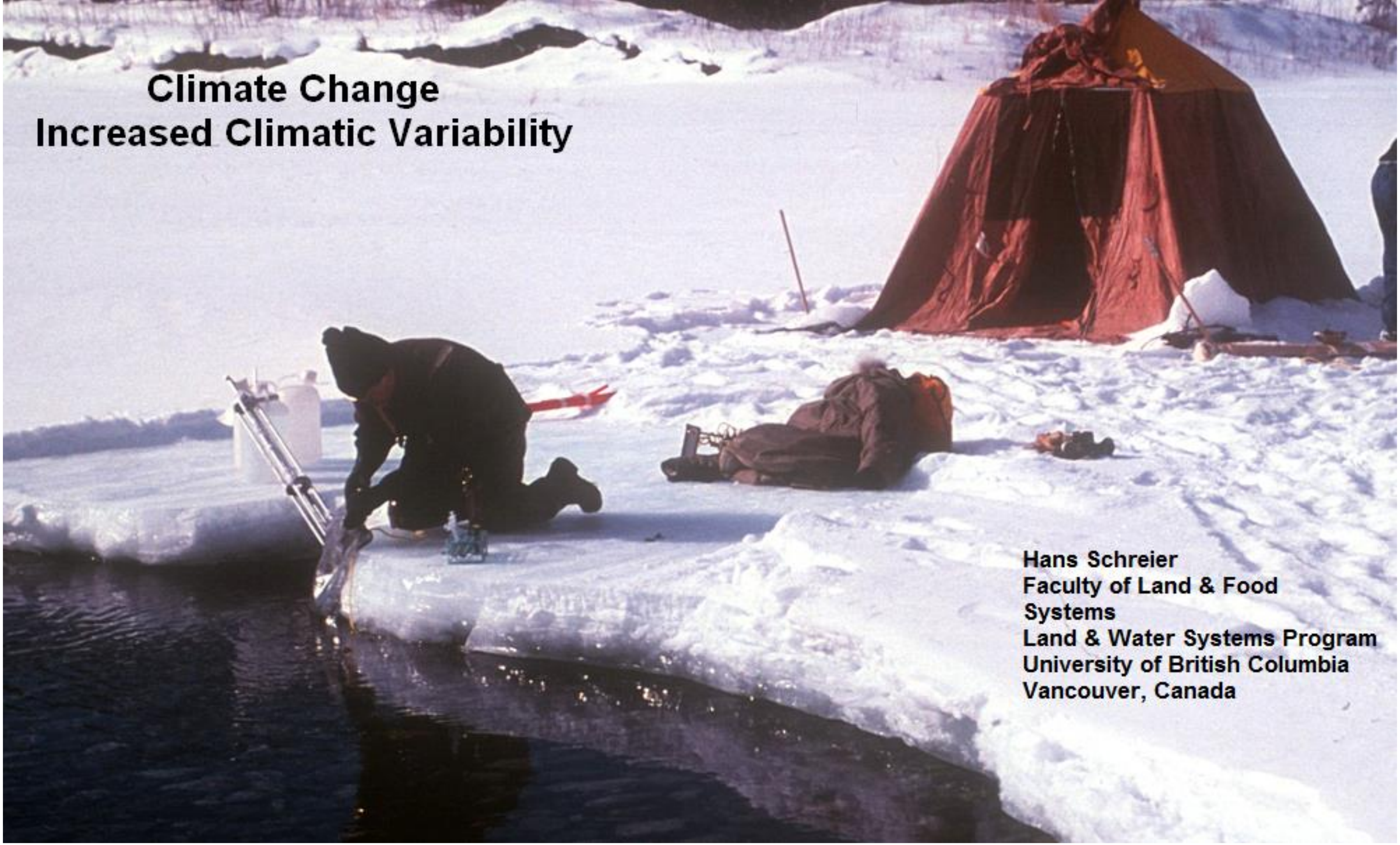
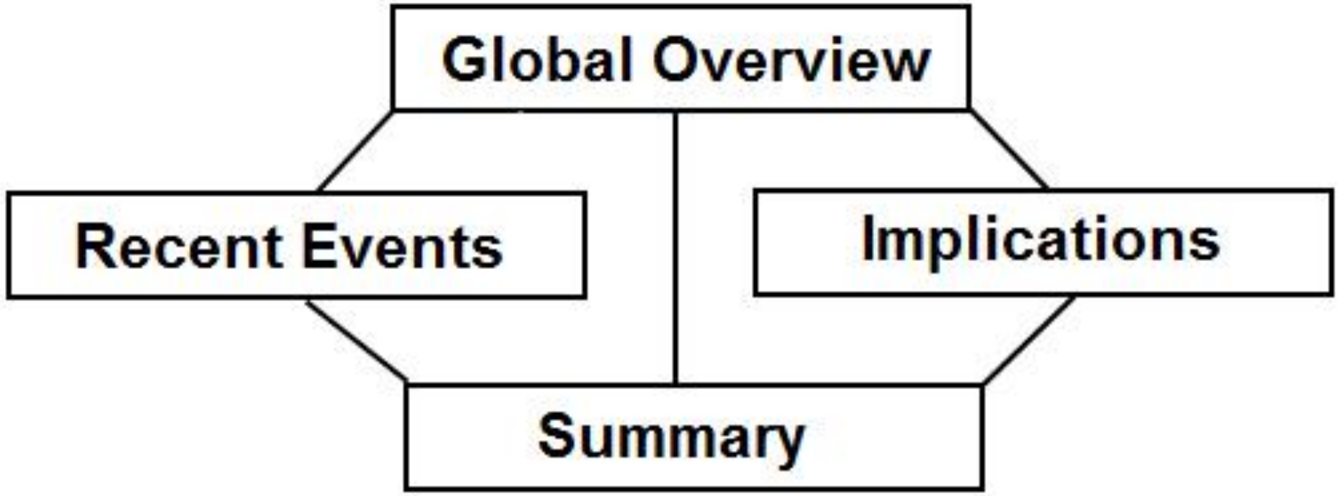
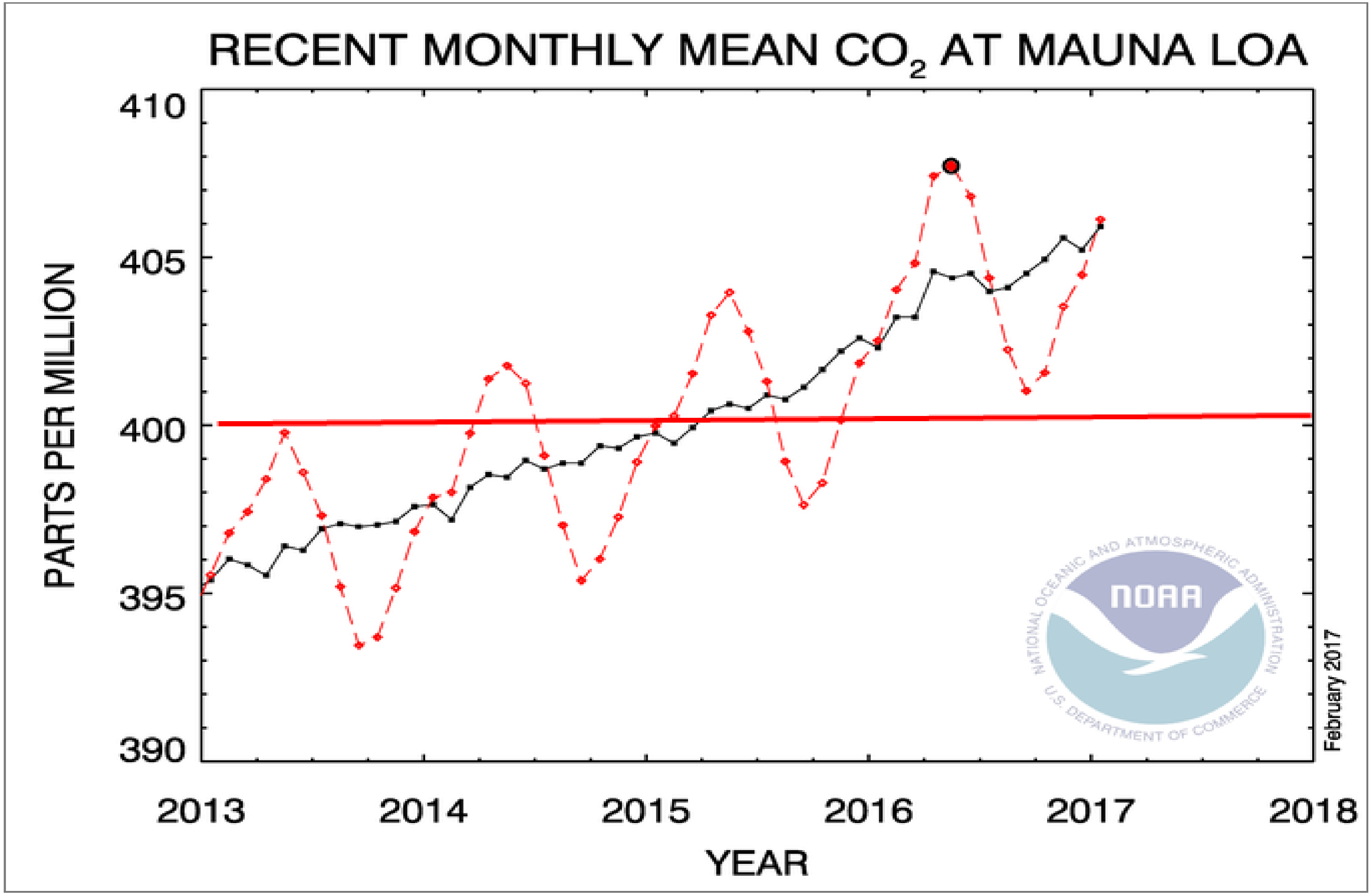

Climate Change
Increased Climatic Variability
Hans Schreier
Faculty of Land & Food
Systems
Land & Water Systems Program
University of British Columbia
Vancouver, Canada

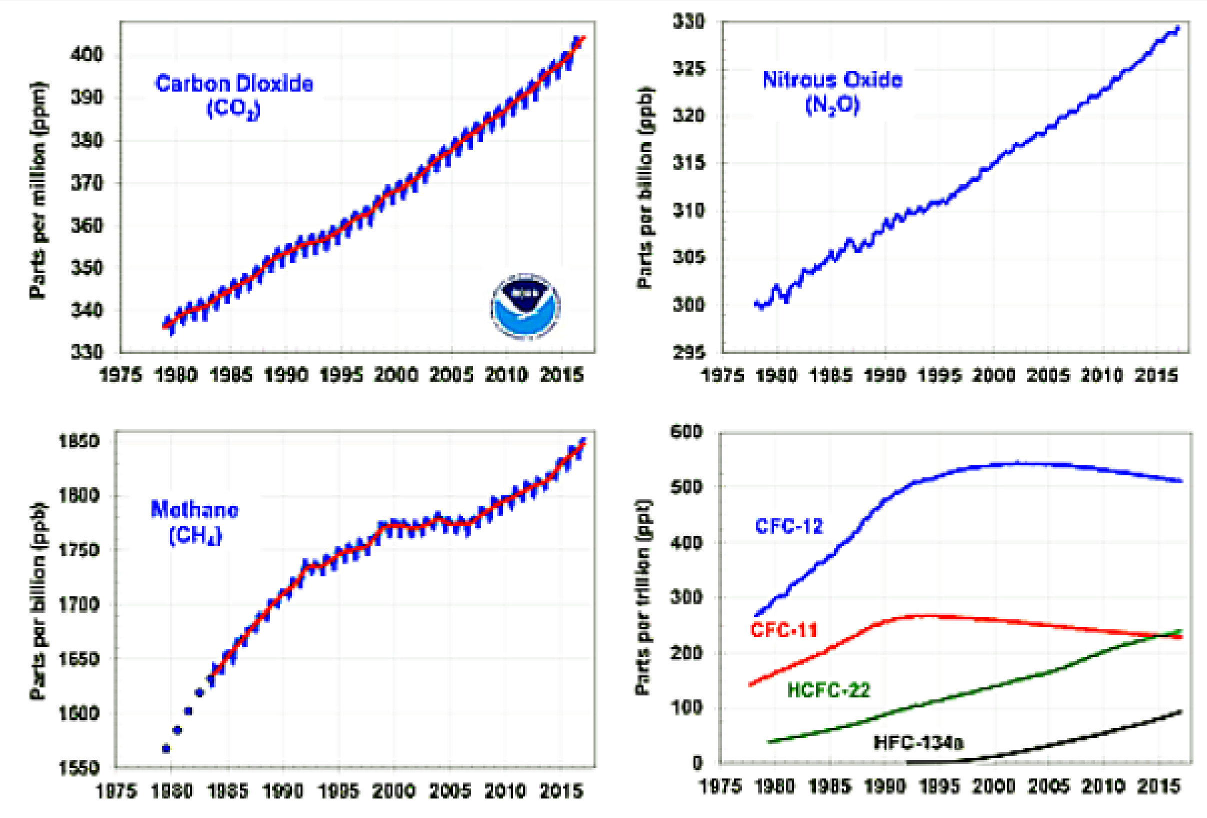

Global Overview
Recent Events
Implications
Summary

Trend in Global CO 2 Emissions in Hawaii



Climate Change and Increased Climatic Variability

Different Greenhouse Gases

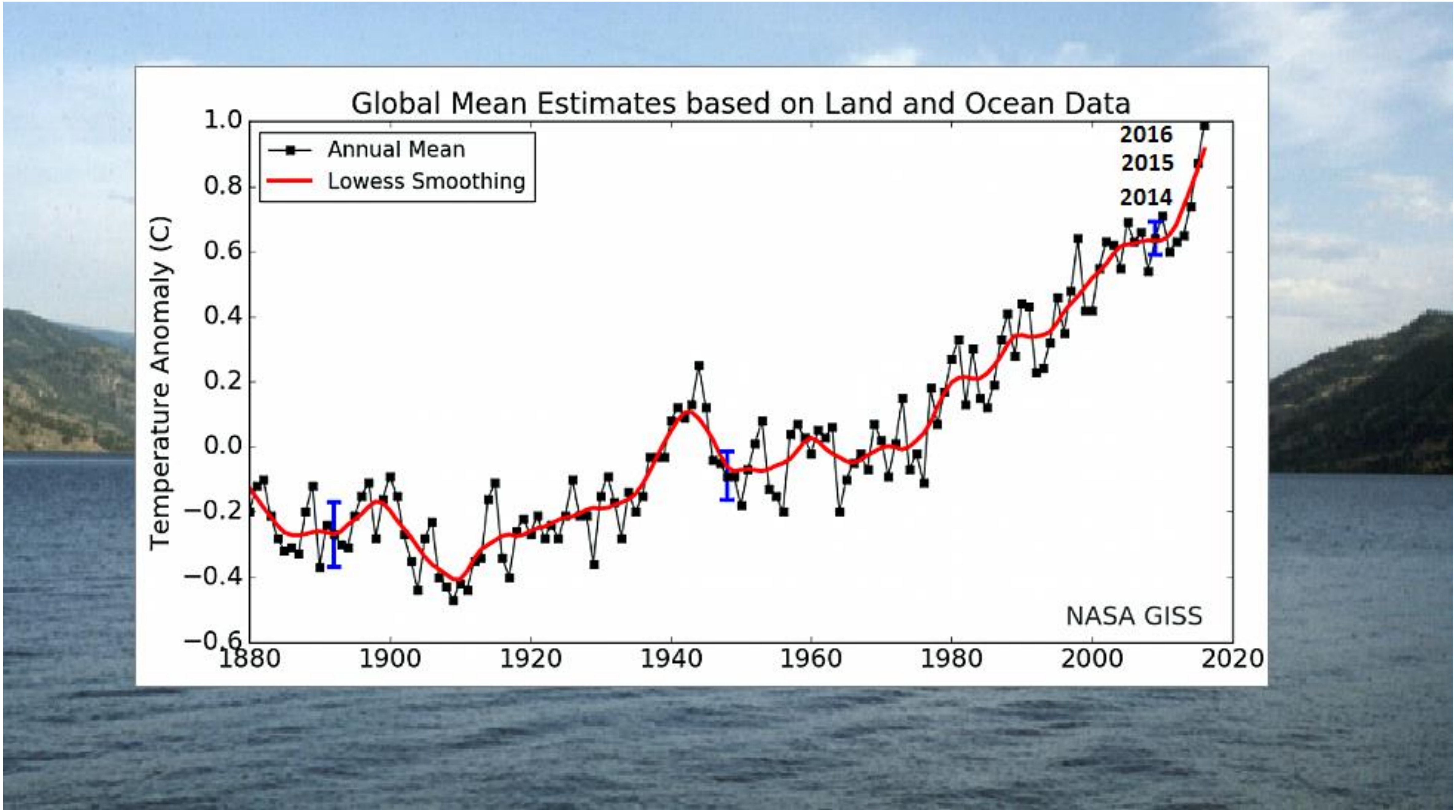


CO2 65-70% Absorbed into the Ocean over 20-200 Years

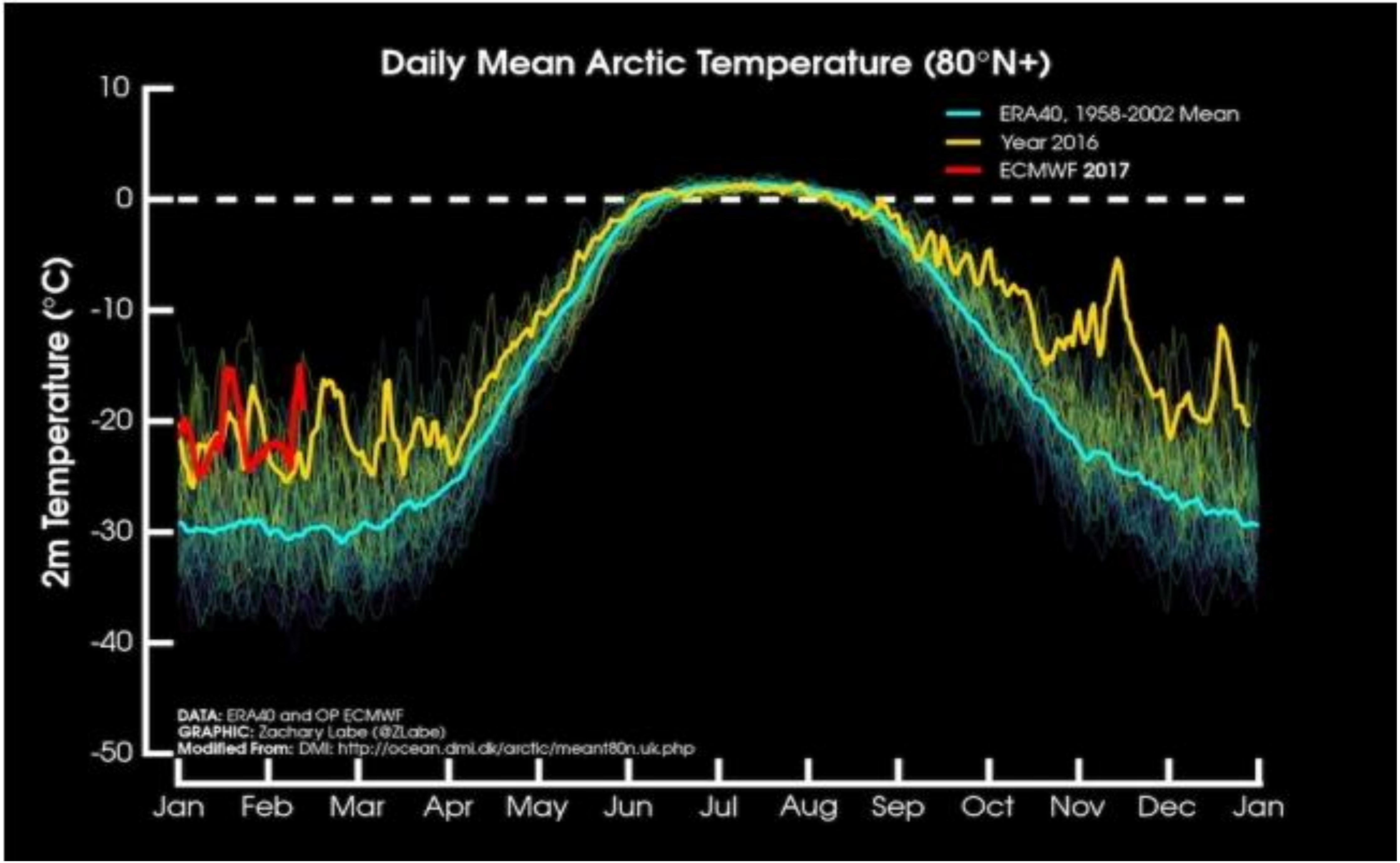
CH4 12 + Years

N2O 121 Years

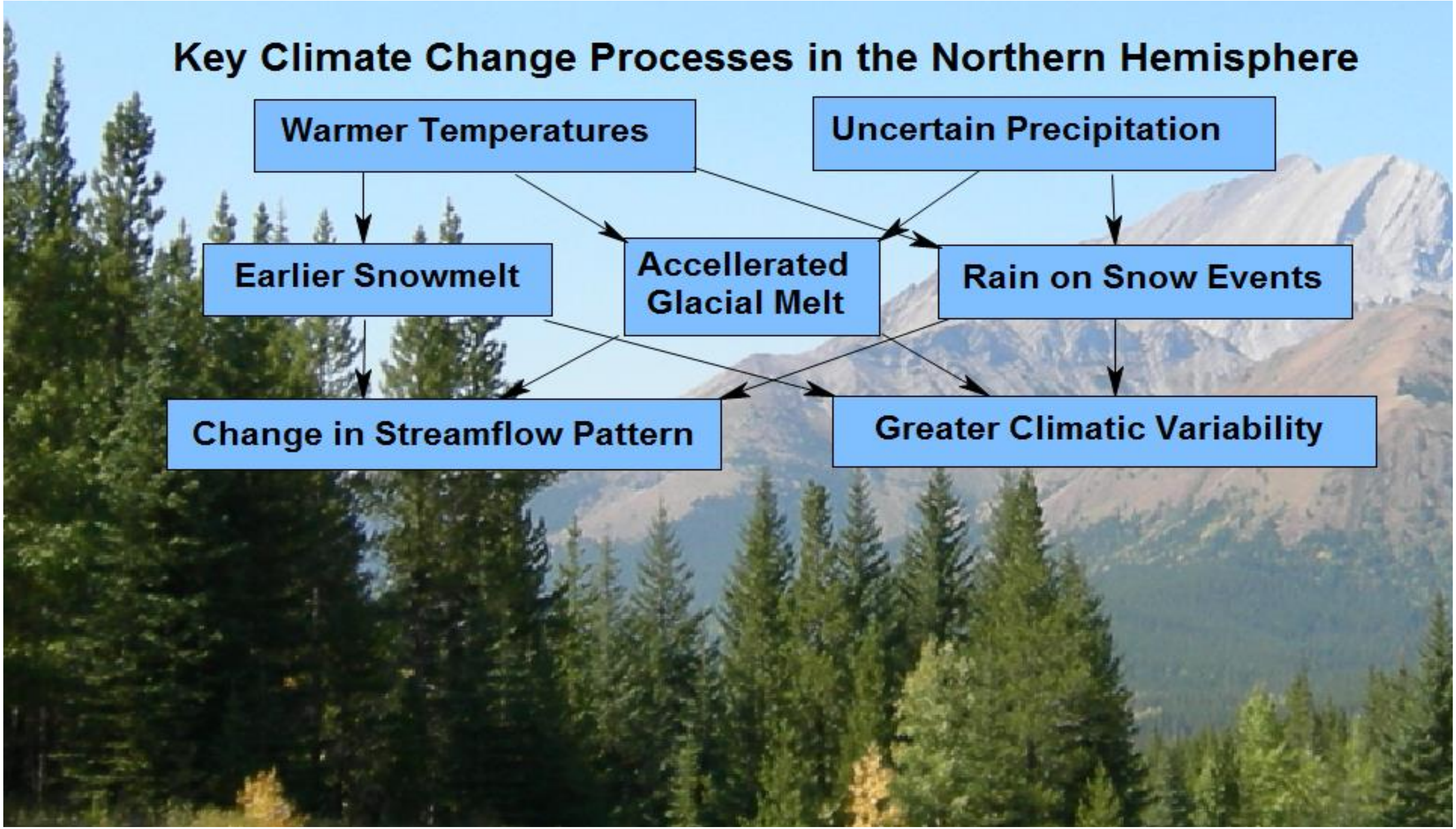
CFC > 1000 Years



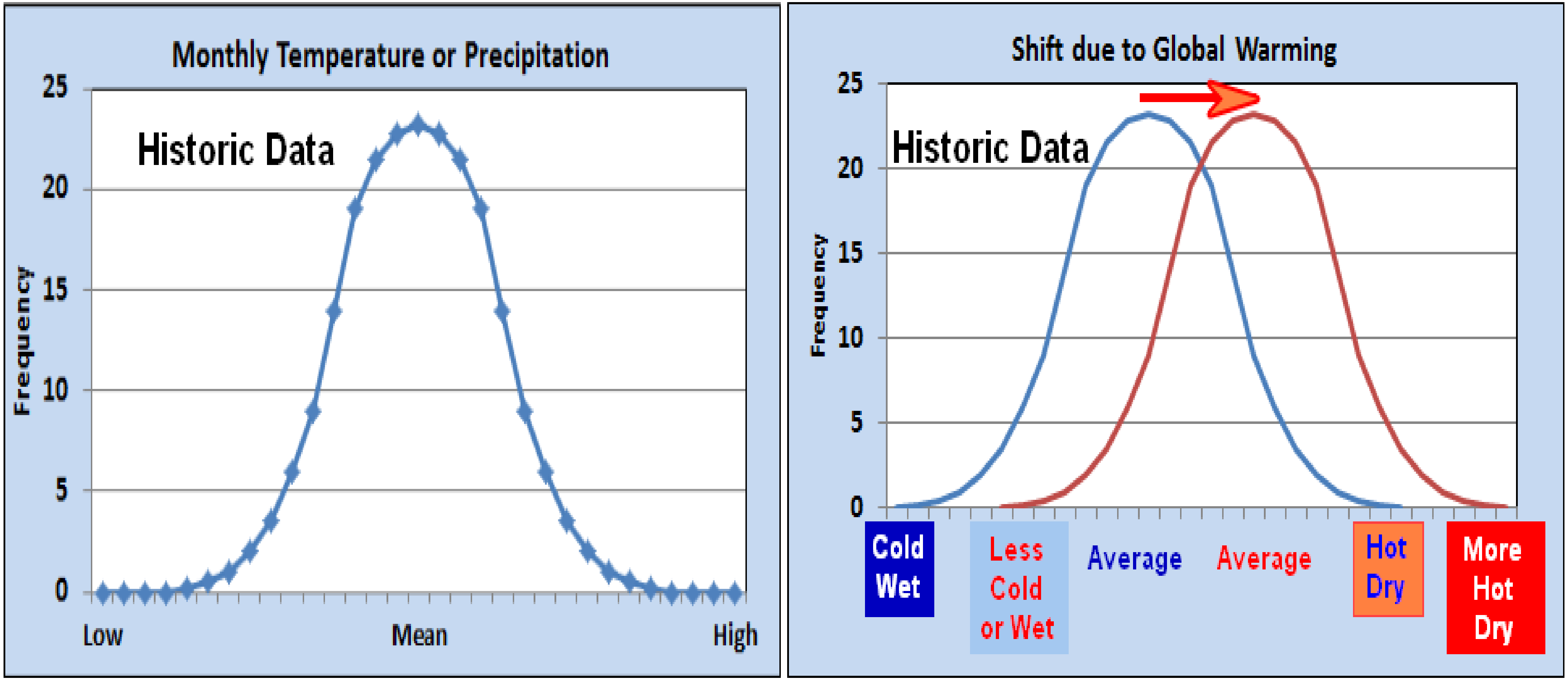
Global Mean Estimates based on Land and Ocean Data
Annual Mean
Lowess Smoothing
Temperature Anomaly (C)
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
1880
1900
1920
1940
1960
1980
2000
2020
2016
2015
2014
NASA GISS

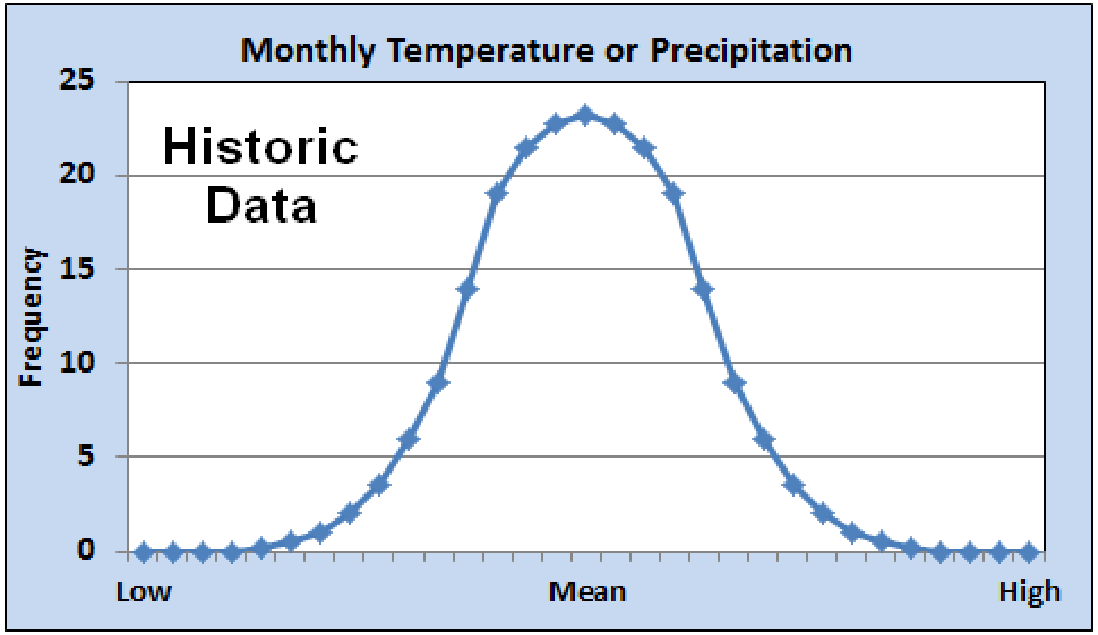


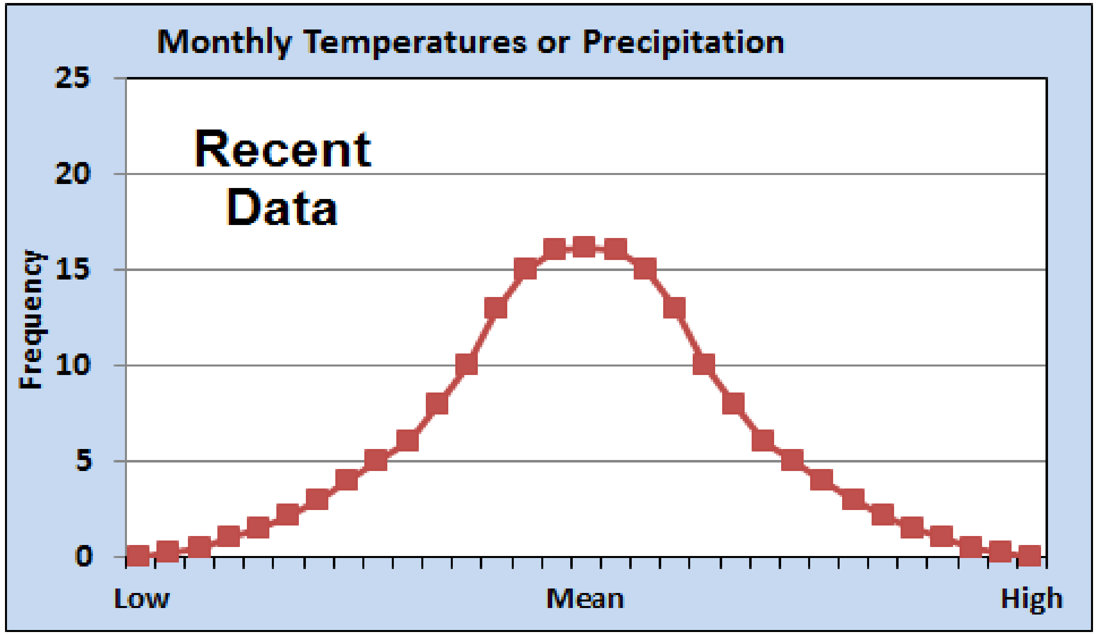
Daily Mean Arctic Temperature (80°N+)
ERA40, 1958-2002 Mean
Year 2016
ECMWF 2017
2m Temperature (°C)
10
0
-10
-20
-30
-40
-50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
DATA: ERA40 and OP ECMWF
GRAPHIC: Zachary Labe (@ZLabe)
Modified From: DMI: http://ocean.dmi.dk/arctic/meant80n.uk.php


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

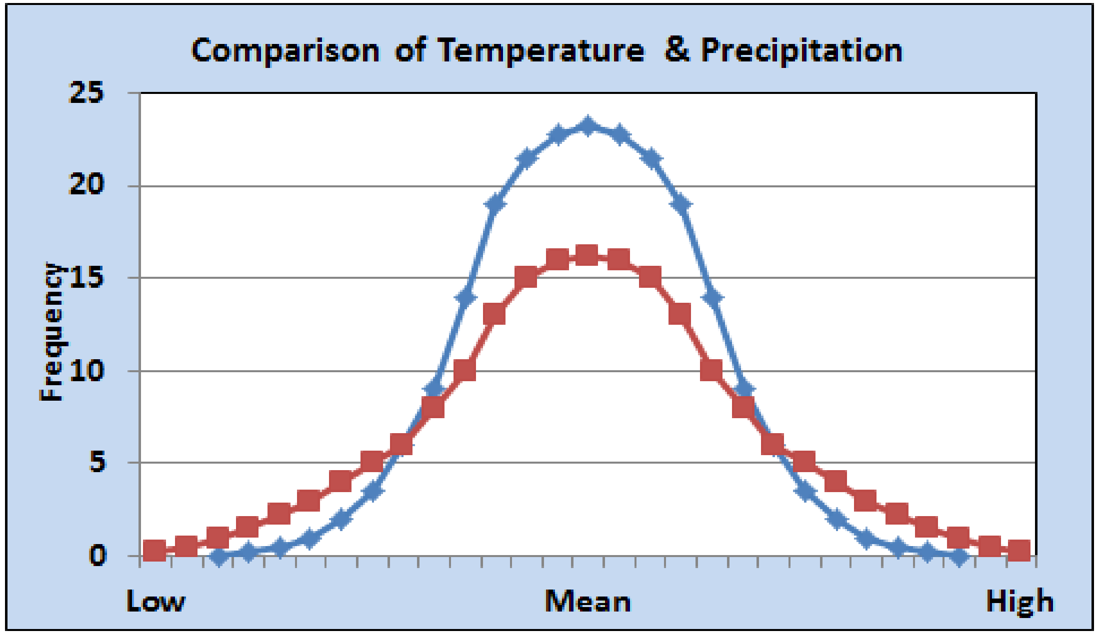
Assumption : Historic Dara Variability is Unchanged and Global Warming Increases



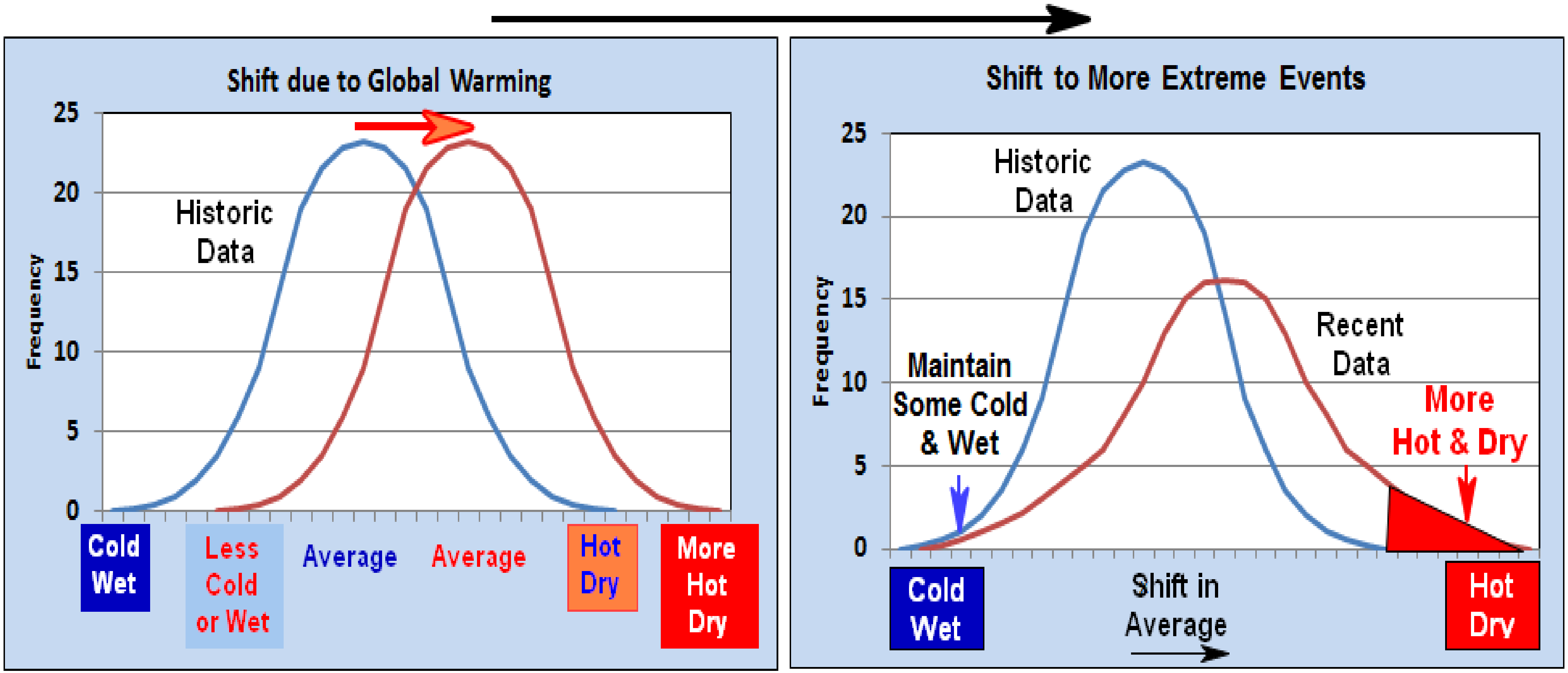




Assumption :
Shift from Historic to More Varariable Data but no Global Warming



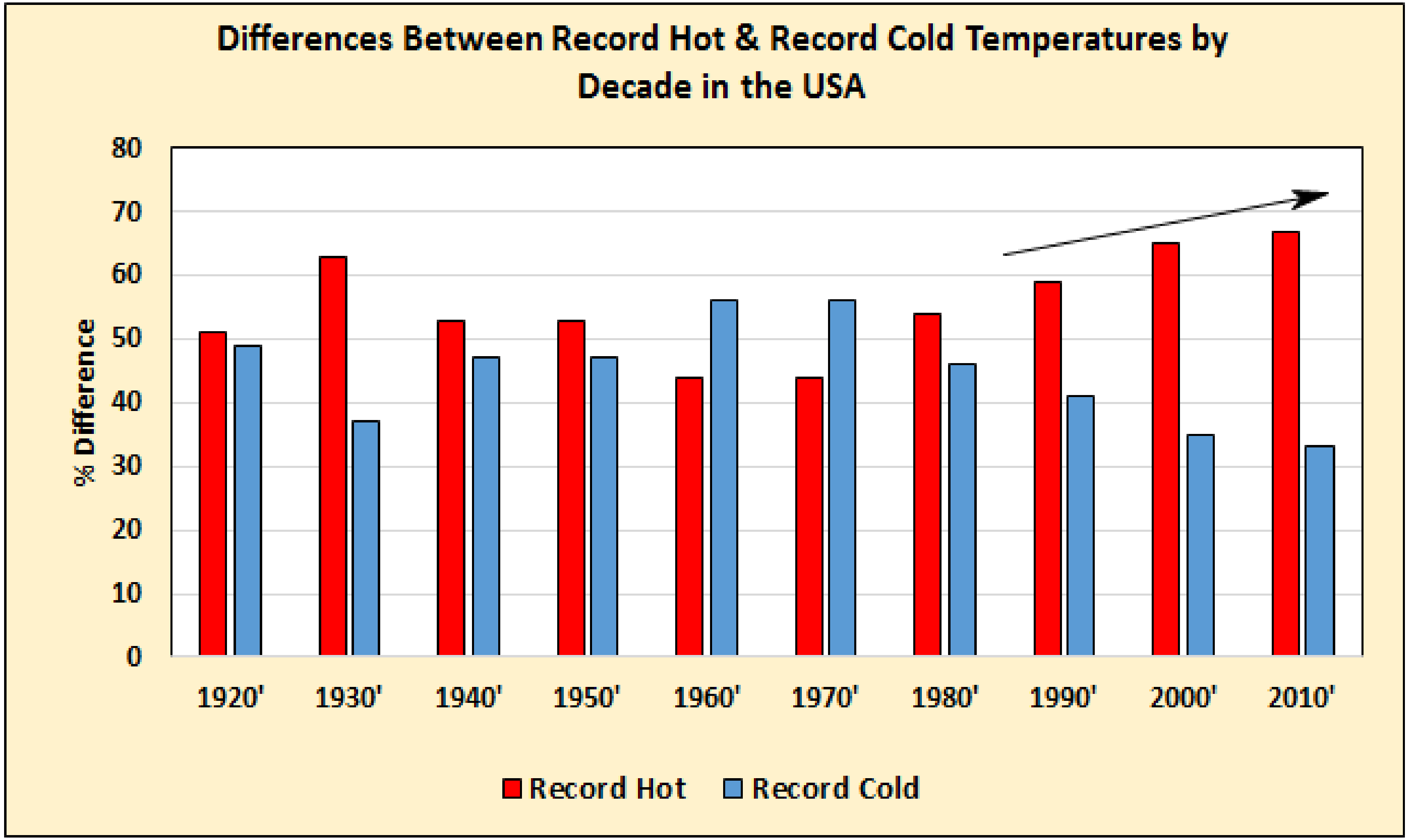
Moving from Left to Right



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

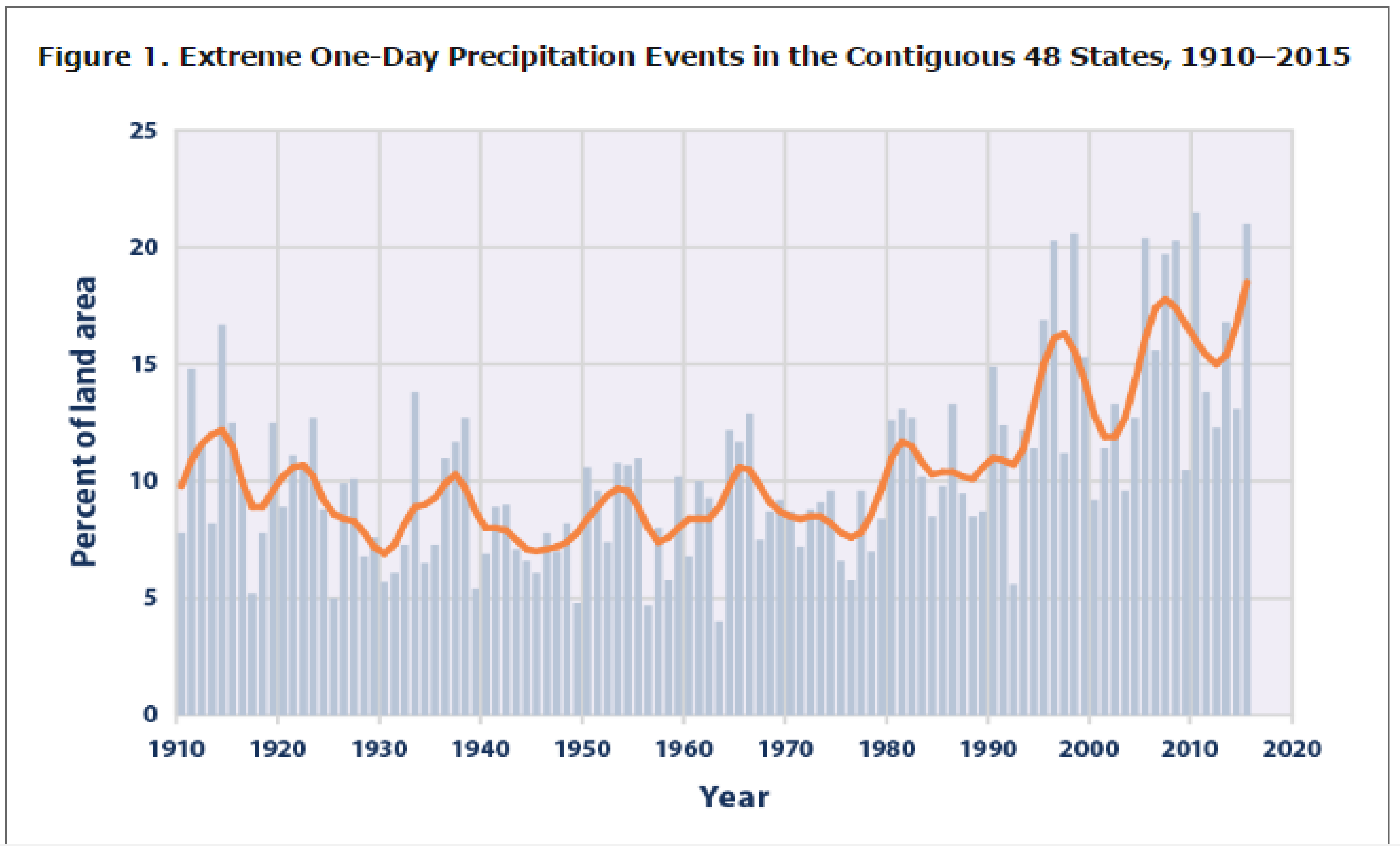


Increasing Record Hot Temperatures and Decreasing Record Low Temperatures 1980'-2010'

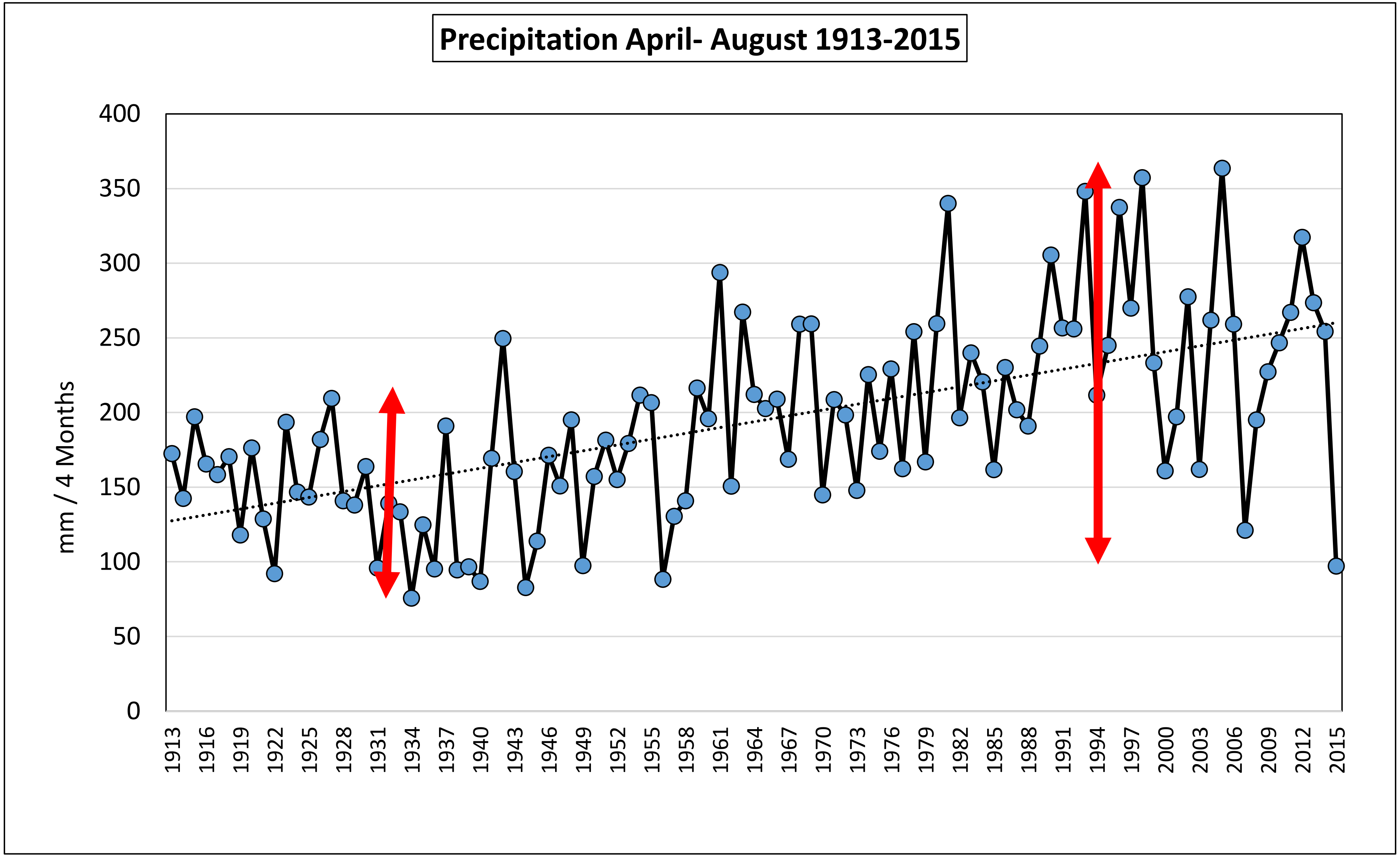
Data Source:

Climate Central 2017

Changes in Extreme One-Day Precipitation in the USA 1910-2015

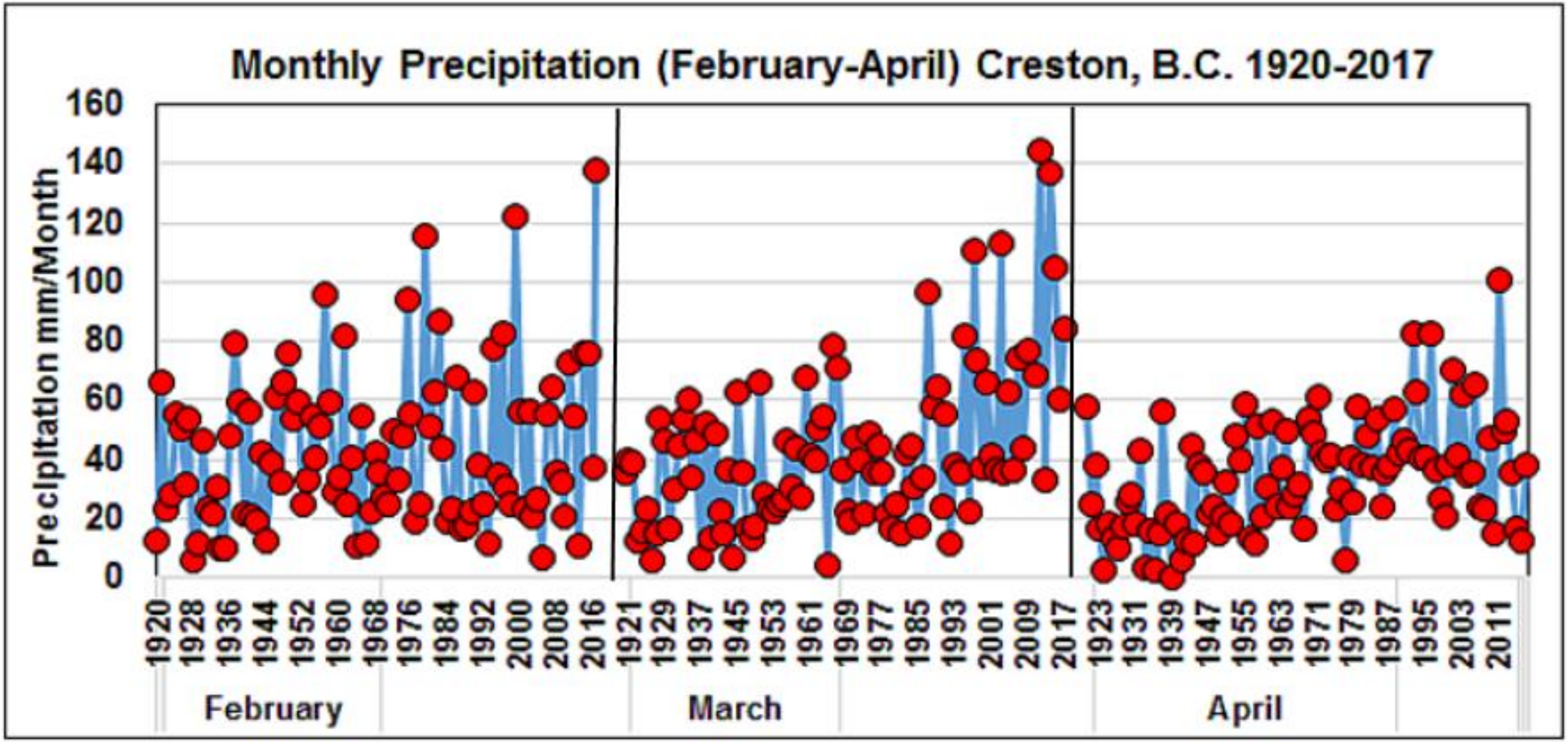


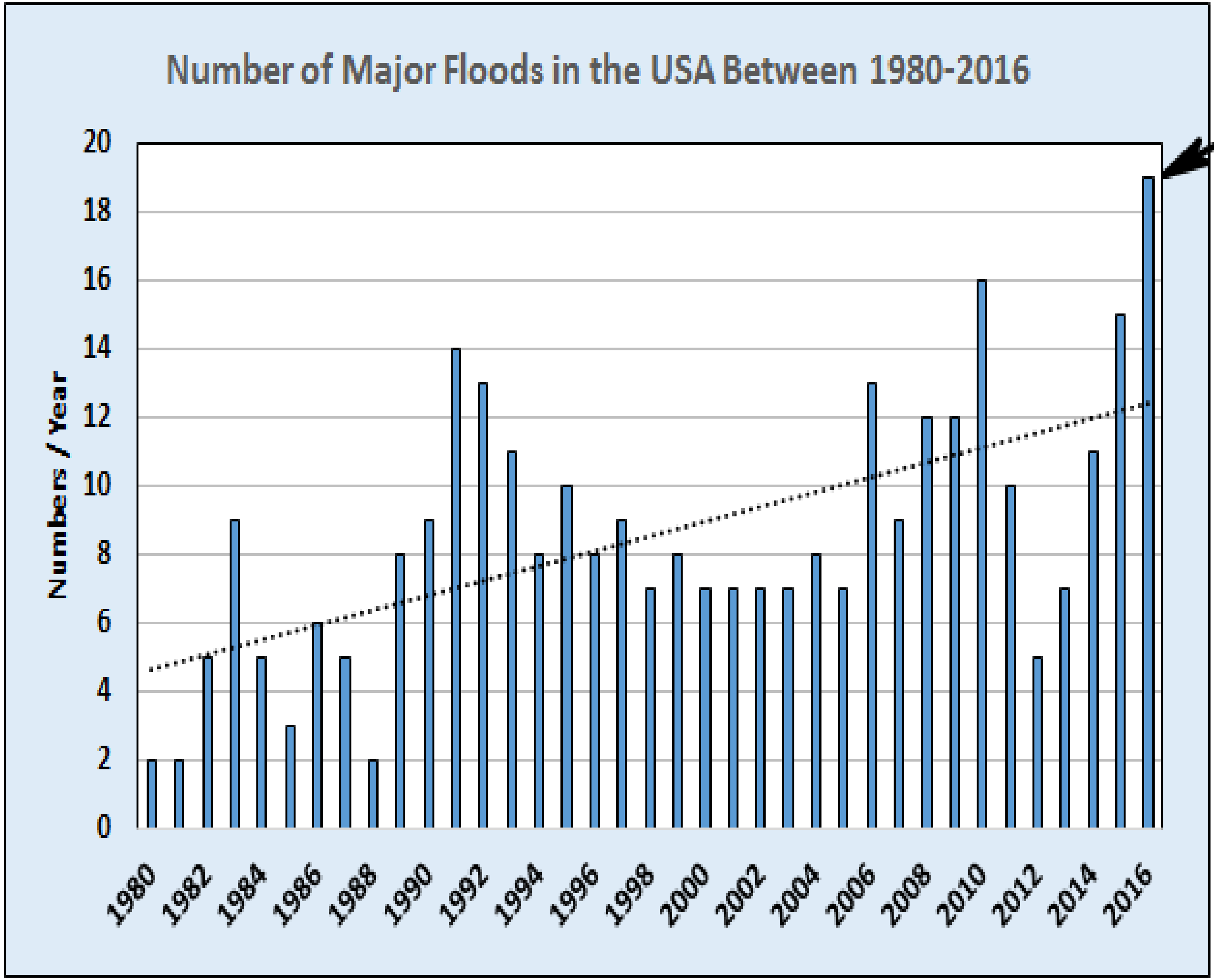
Source: US-EPS & NOAA 2016



Precipitation April- August 1913-2015
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

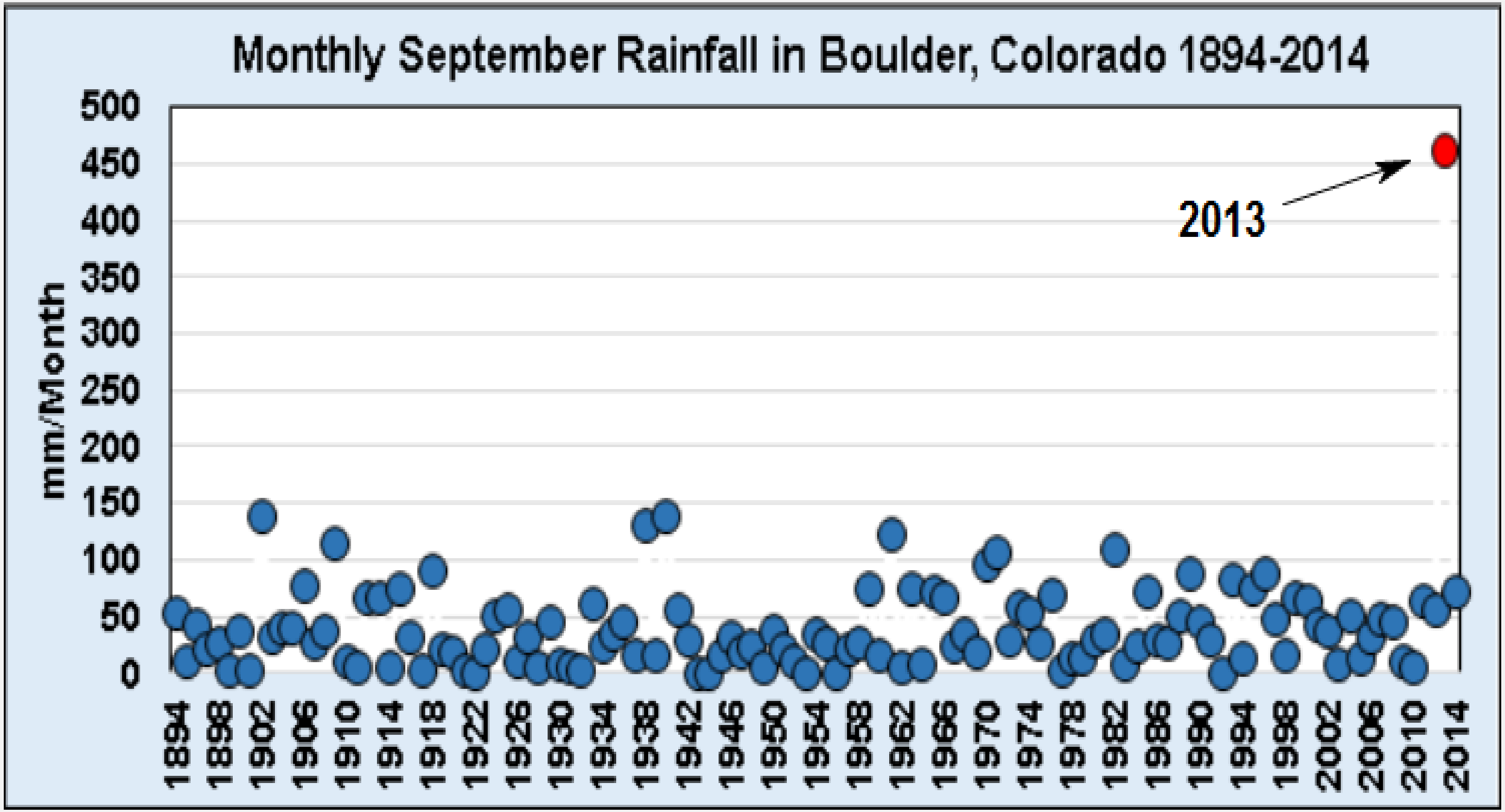




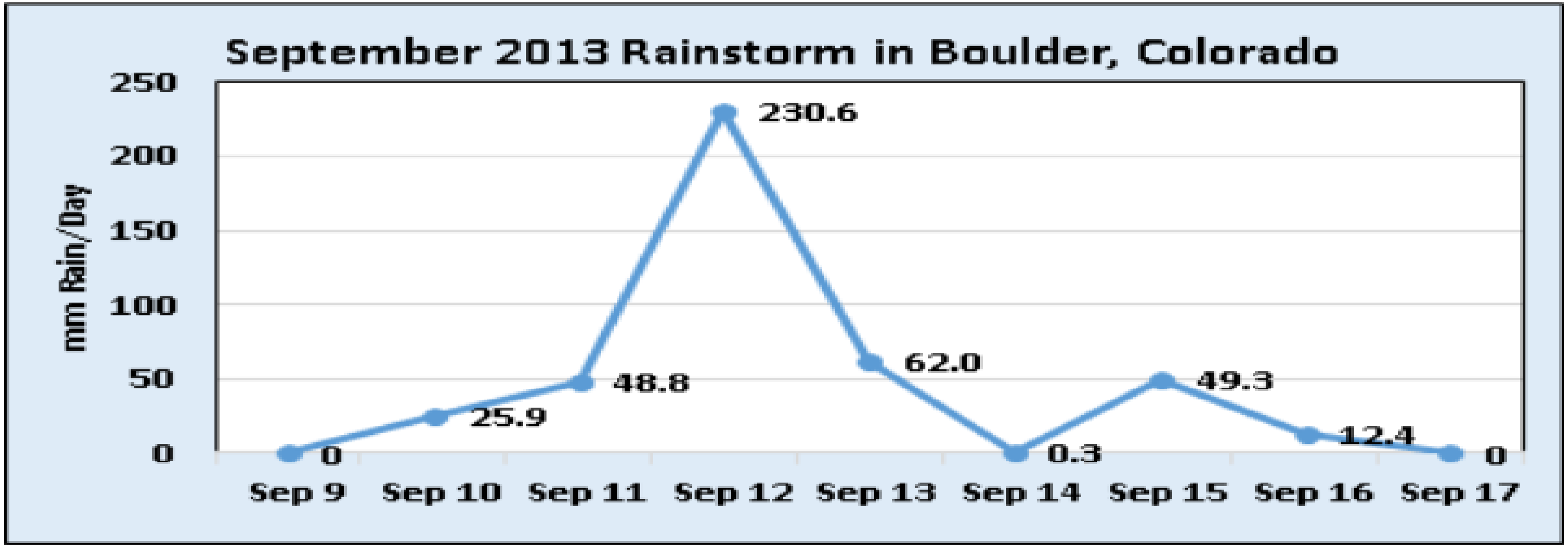
19 Major Floods in 2016

Data Source:
Munich Re-Insurance 2017

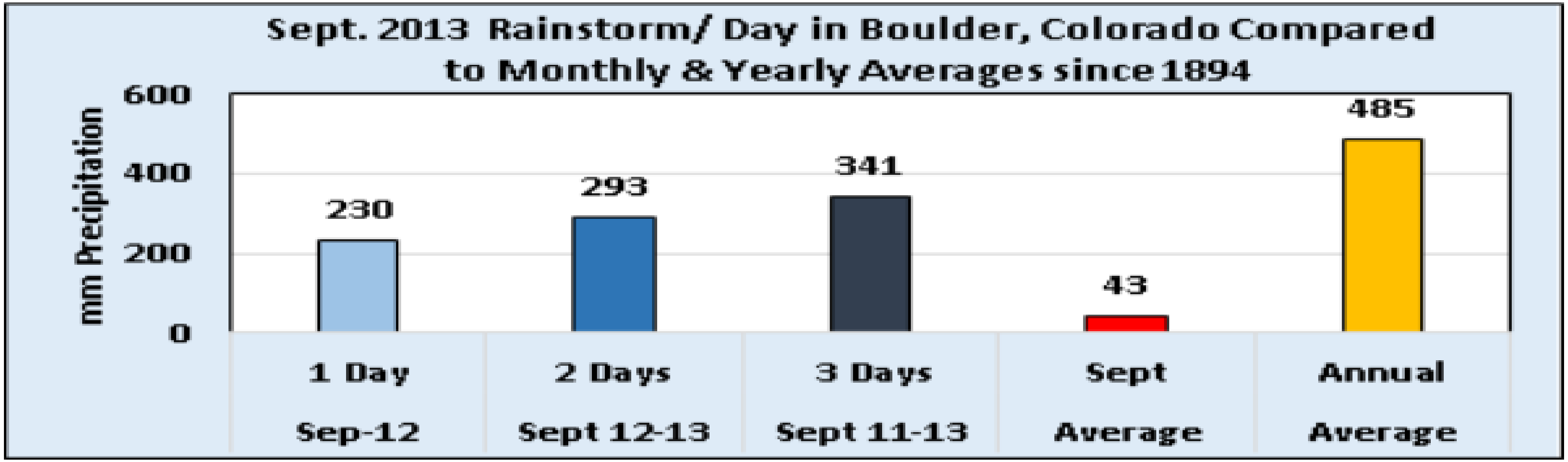
Insurance Cost $ 10 Billion



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

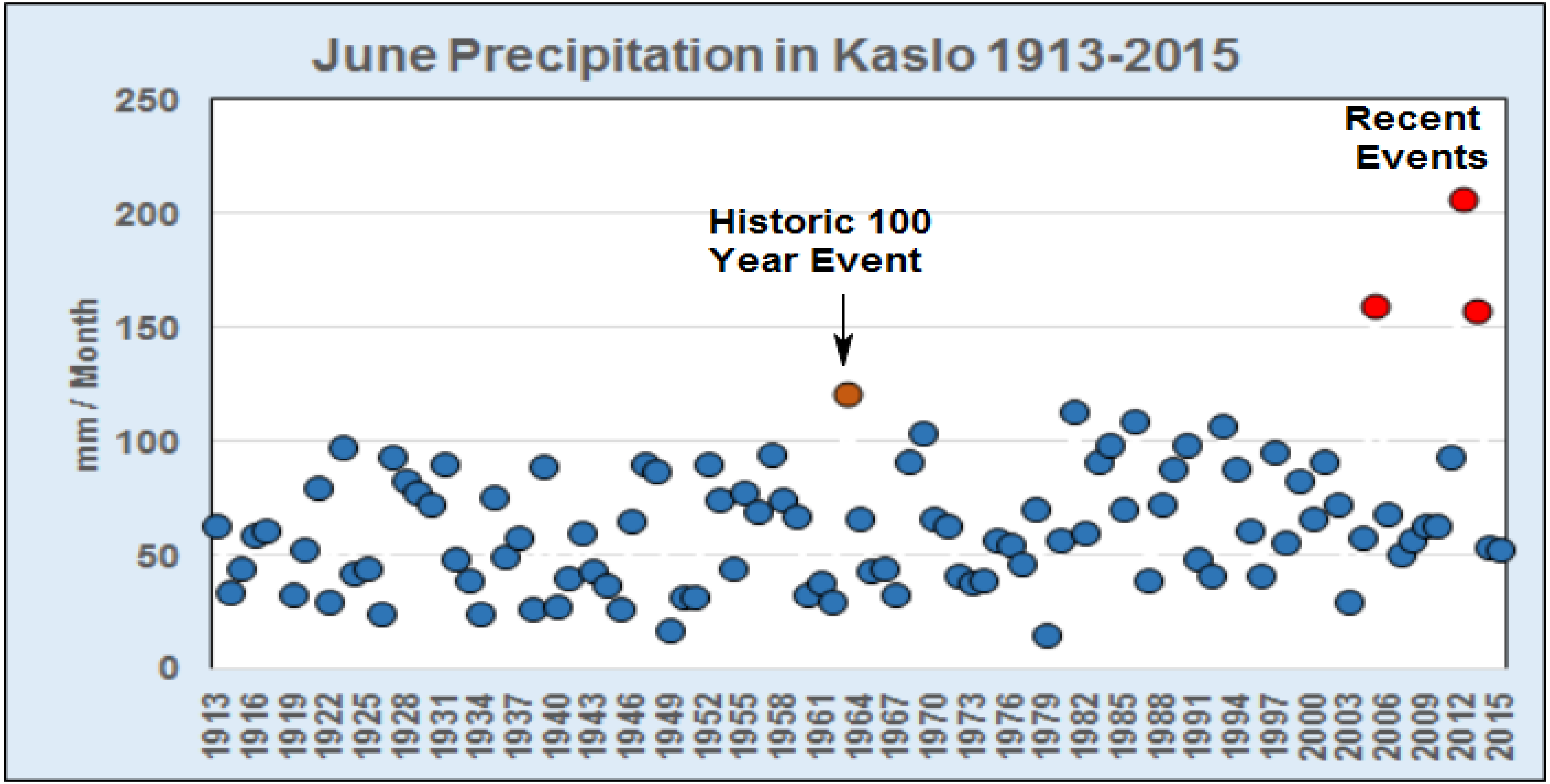


September 2013 Rainstorm in Boulder, Colorado
mm Rain/Day
250
200
150
100
50
0
0
25.9
48.8
230.6
62.0
0.3
49.3
12.4
0
Sep 9
Sep 10
Sep 11
Sep 12
Sep 13
Sep 14
Sep 15
Sep 16
Sep 17

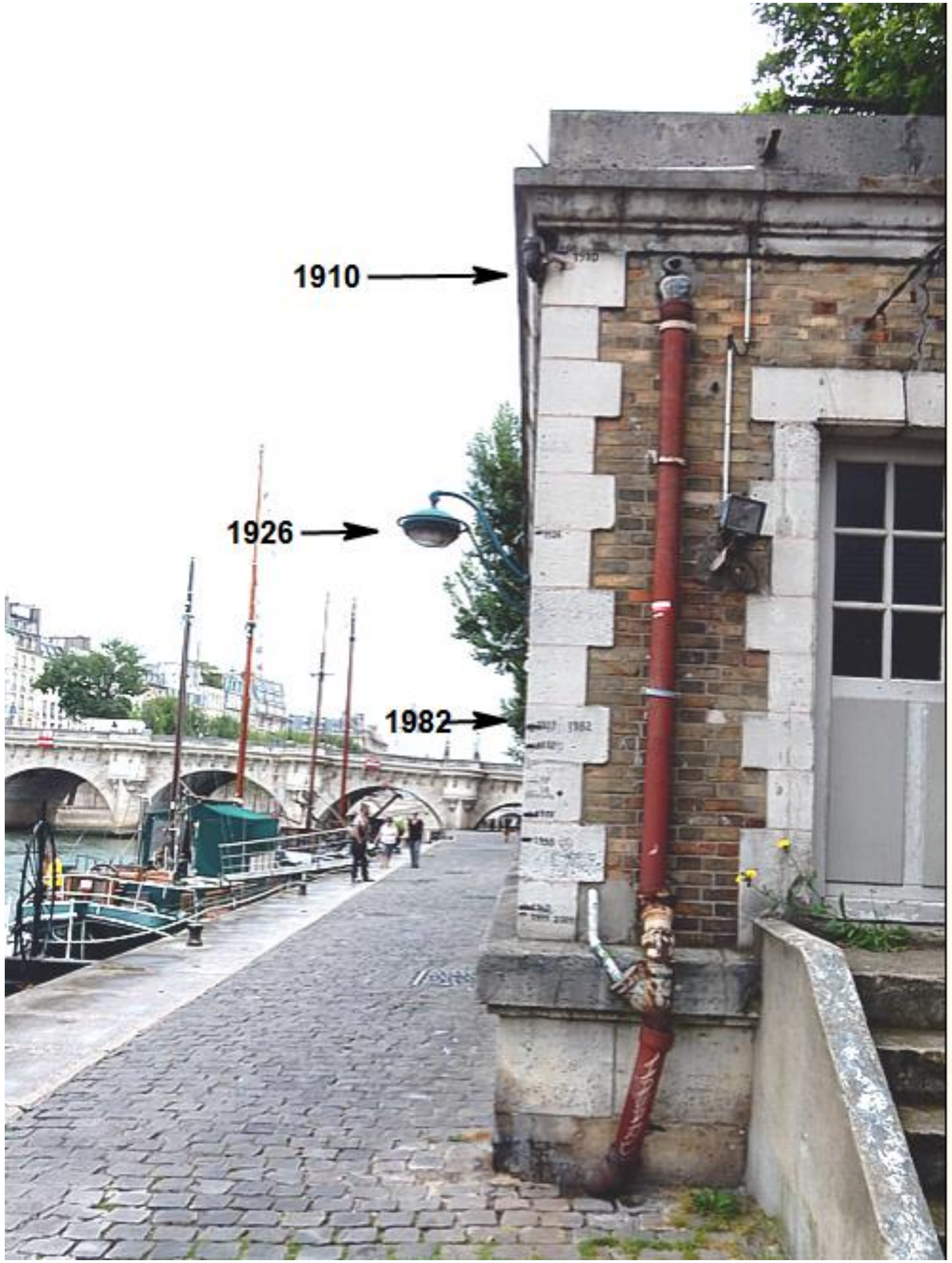


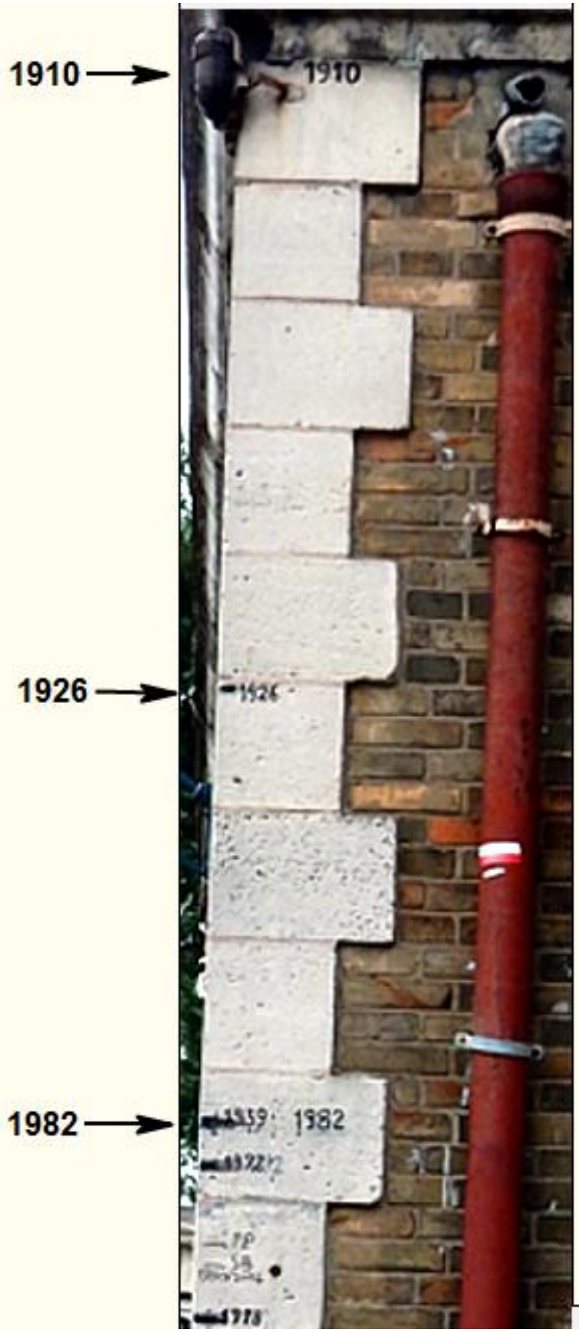
Sept. 2013 Rainstorm/ Day in Boulder, Colorado Compared to Monthly & Yearly Averages since 1894
mm Precipitation
600
400
200
0
230
293
341
43
485
1 Day Sep-12
2 Days Sept 12-13
3 Days Sept 11-13
Sept Average
Annual Average

Increased Variability in Precipitation and Increasing Extremes



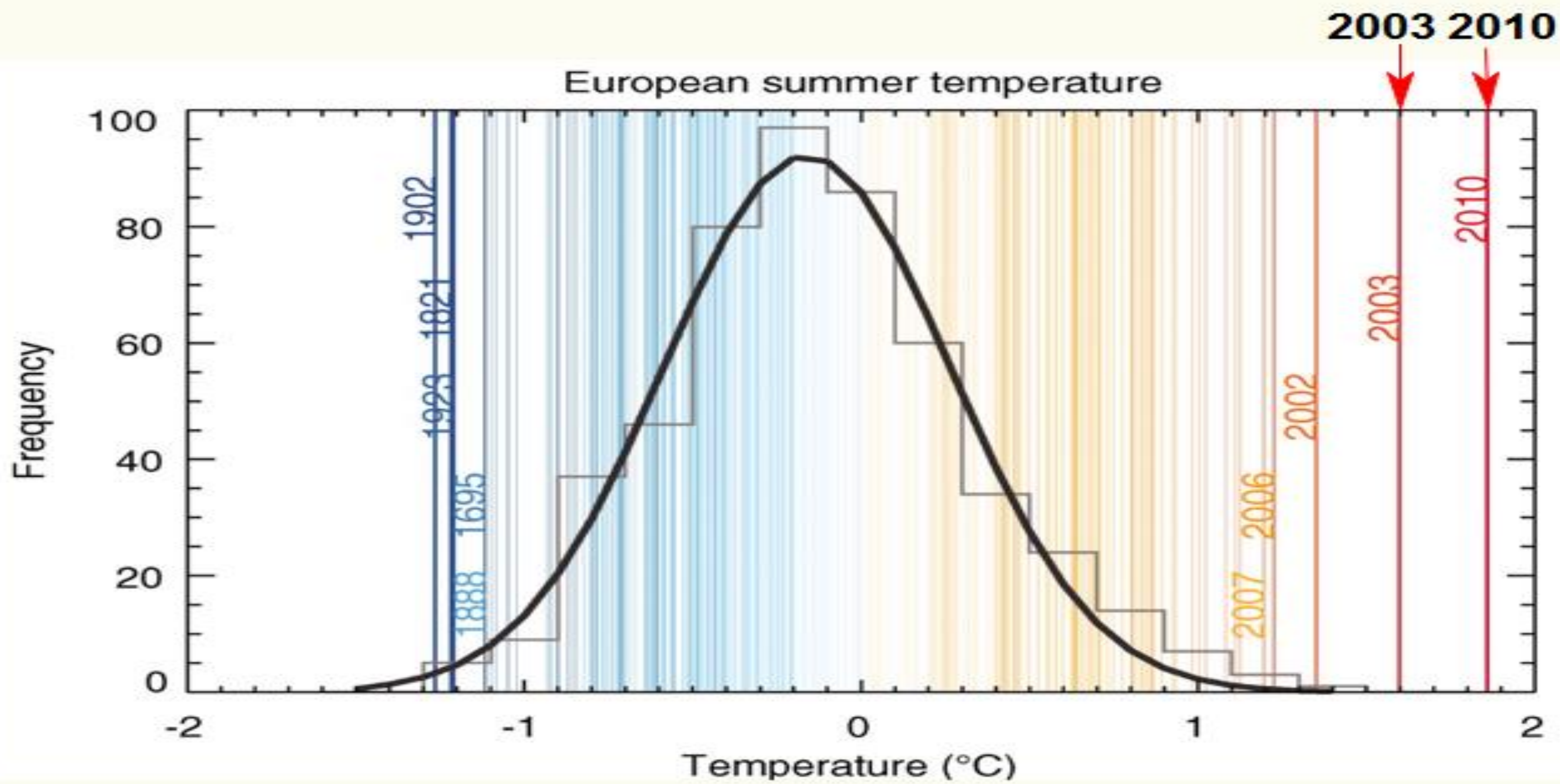
The Precipitation in June in 2005, 2012 and 2013 produced 30-70% more rain than in any other June since records stated in 1913.



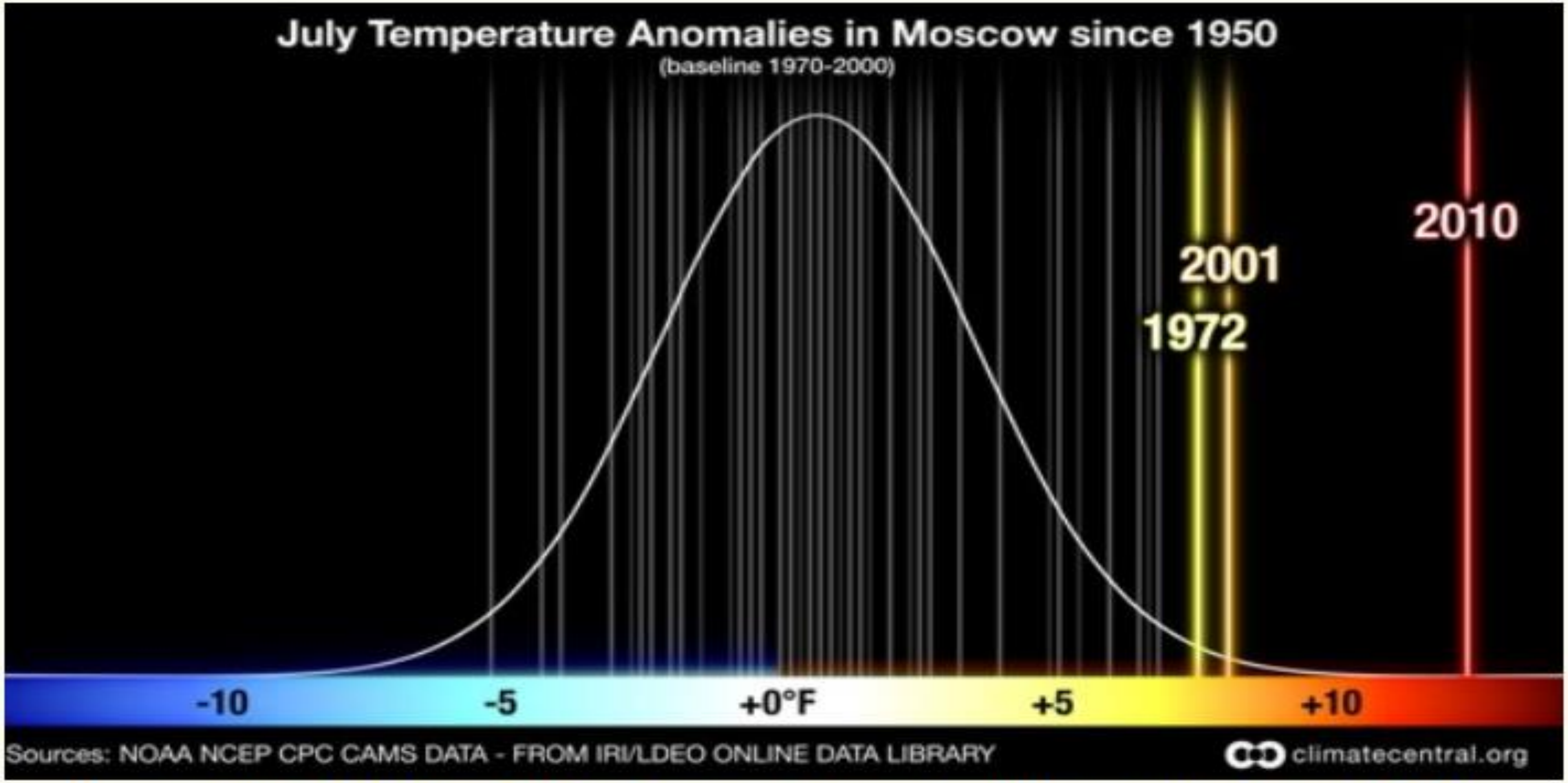


Historic Flood Record in Paris, France

Highest Temperature on Record	Death Valley CA	56.7 °C July 10, 1913
Records	Basra, Iraq Kuwait Rajasthan, India Delhoran. Iran	53.9 °C July, 21,2016 54 °C July, 21,2016 51 °C May, 19,2016 53 °C July, 22,2016
	Vancouver, B.C. Rangiora, NZ	33.8 °C July,29, 2009 42.4 °C Feb, 7, 1973
	Canada, Saskachewan	45°C July, 5, 1937
Blood	Temperature	37 °C

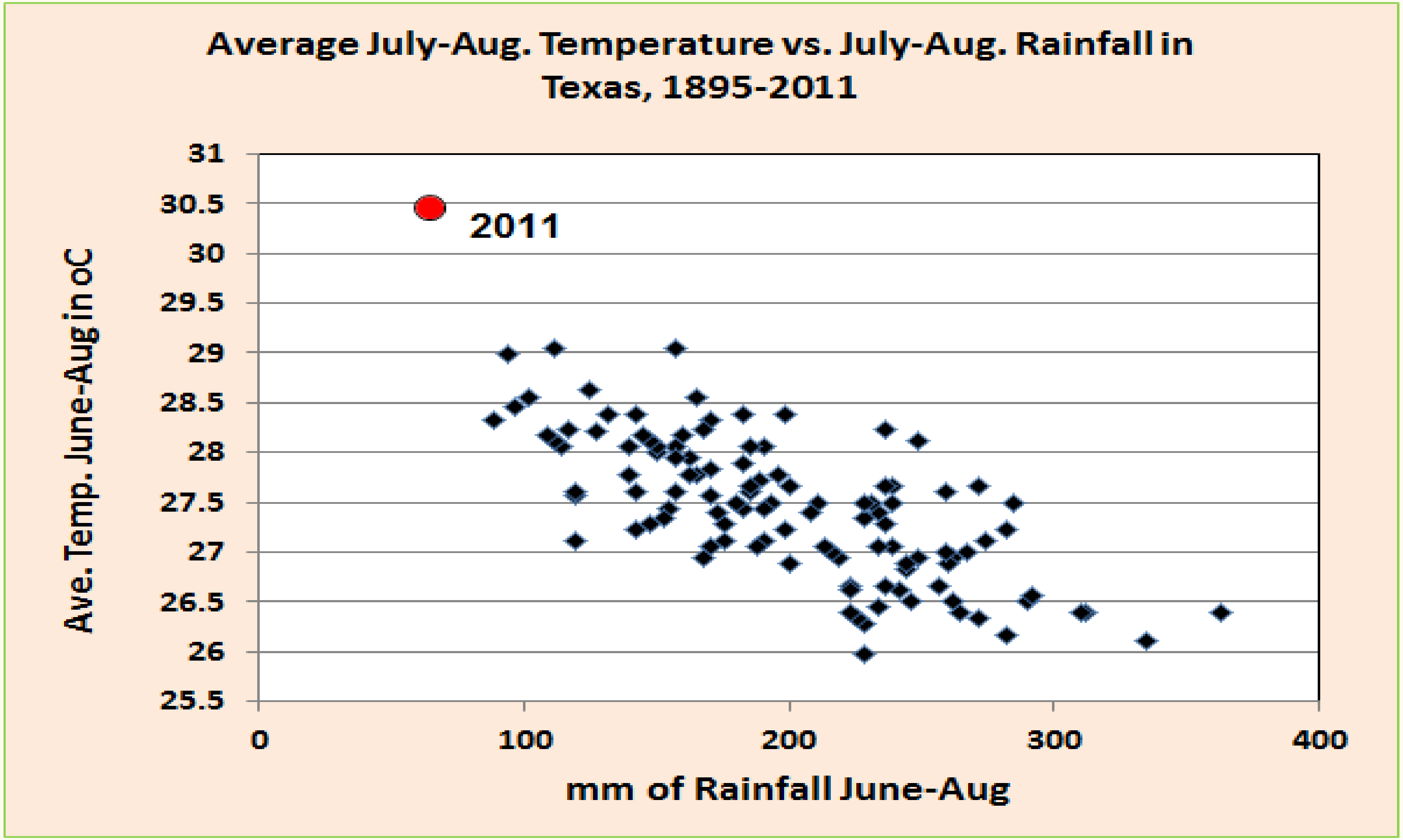


Data Source: Barriopedro et al. 2011. The hot summer of 2010. Redrawing the temperature record Map of Europe. Science: 332(6026):220-224

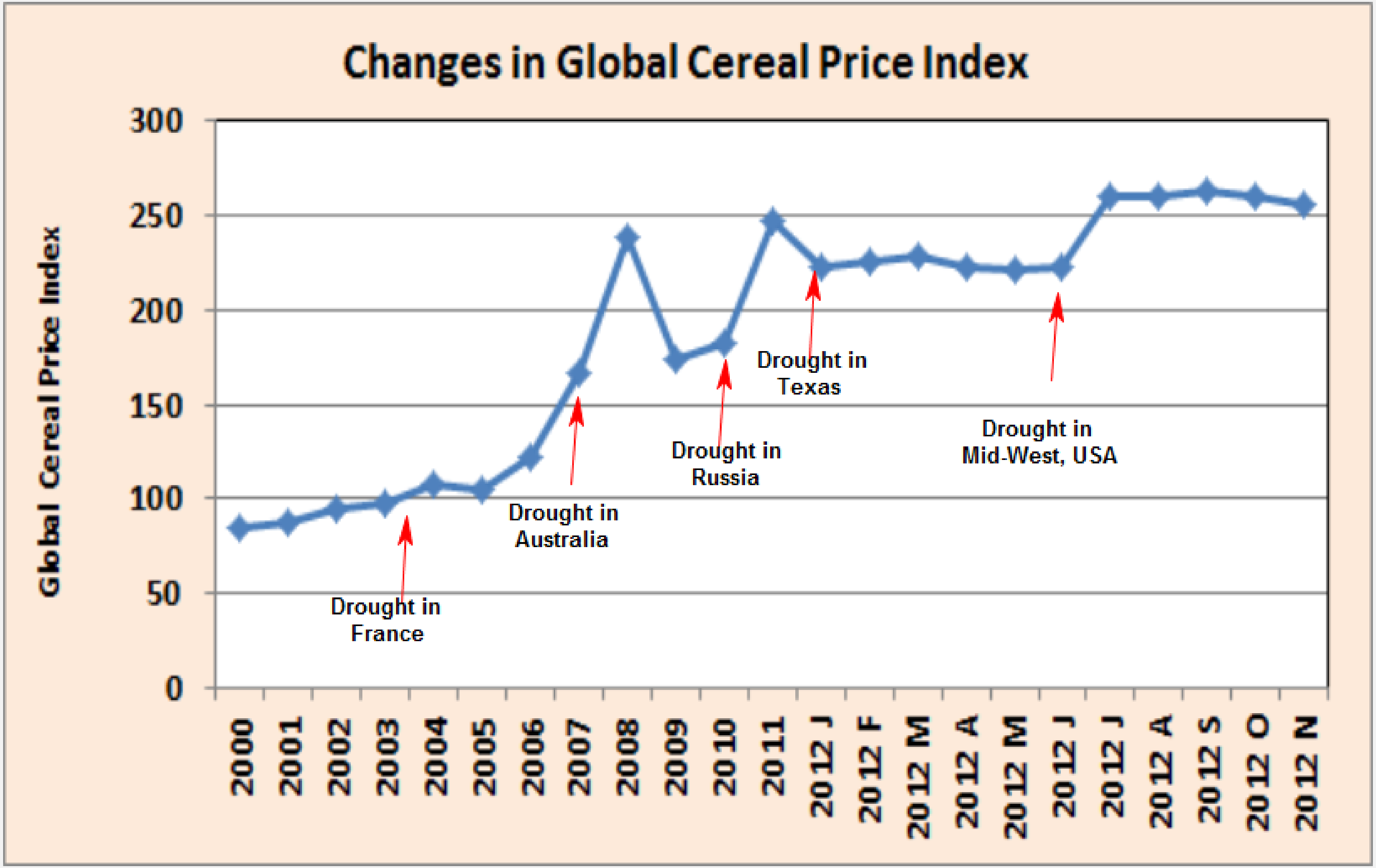


Anomaly of July 2010 Temperature in Moscow since 1950
Source: NOAA, Climate Central and Tebaldi & Ziemlinksi, 2010
(with permission)

The 2011 Drought in Texas



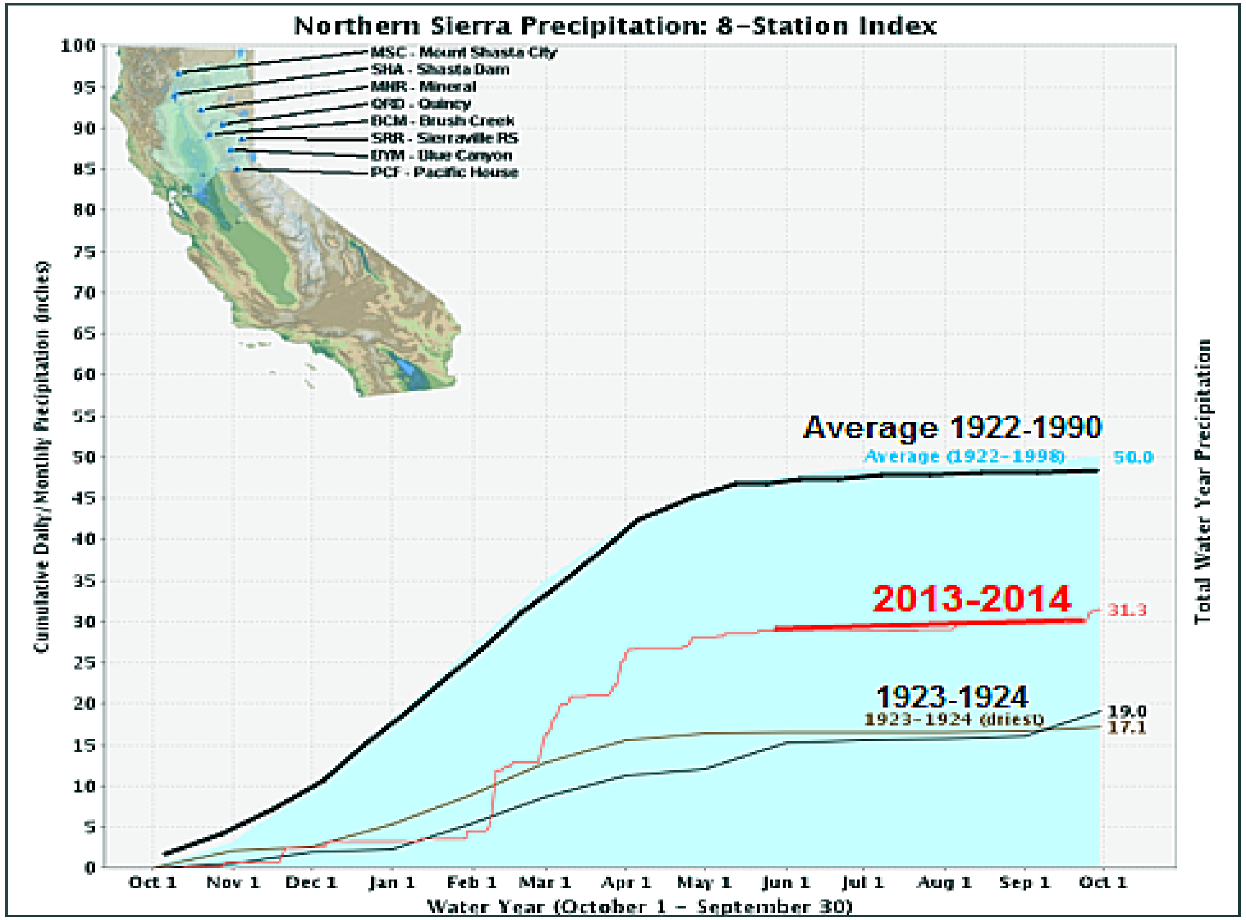
Data Source: J.Nielsen-Gammon, 2011



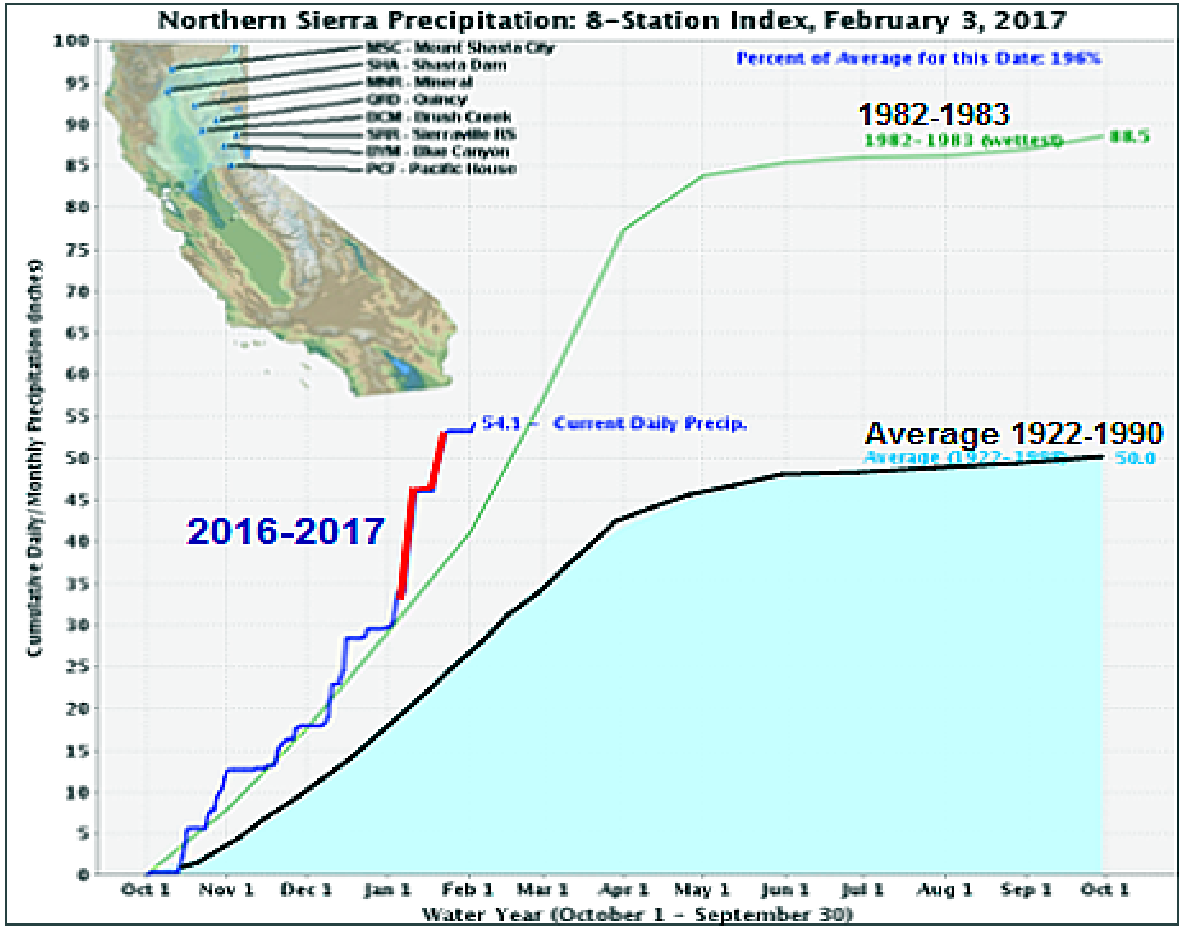
Changes in Global Cereal Price Index
Global Cereal Price Index
300
250
200
150
100
50
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012 J
2012 F
2012 M
2012 A
2012 M
2012 J
2012 J
2012 A
2012 S
2012 O
2012 N
Drought in France
Drought in Australia
Drought in Russia
Drought in Texas
Drought in Mid-West, USA

Temperature Changes in Mountains

2013-2014 Drought in California



2016-2017 Wet Winter in California



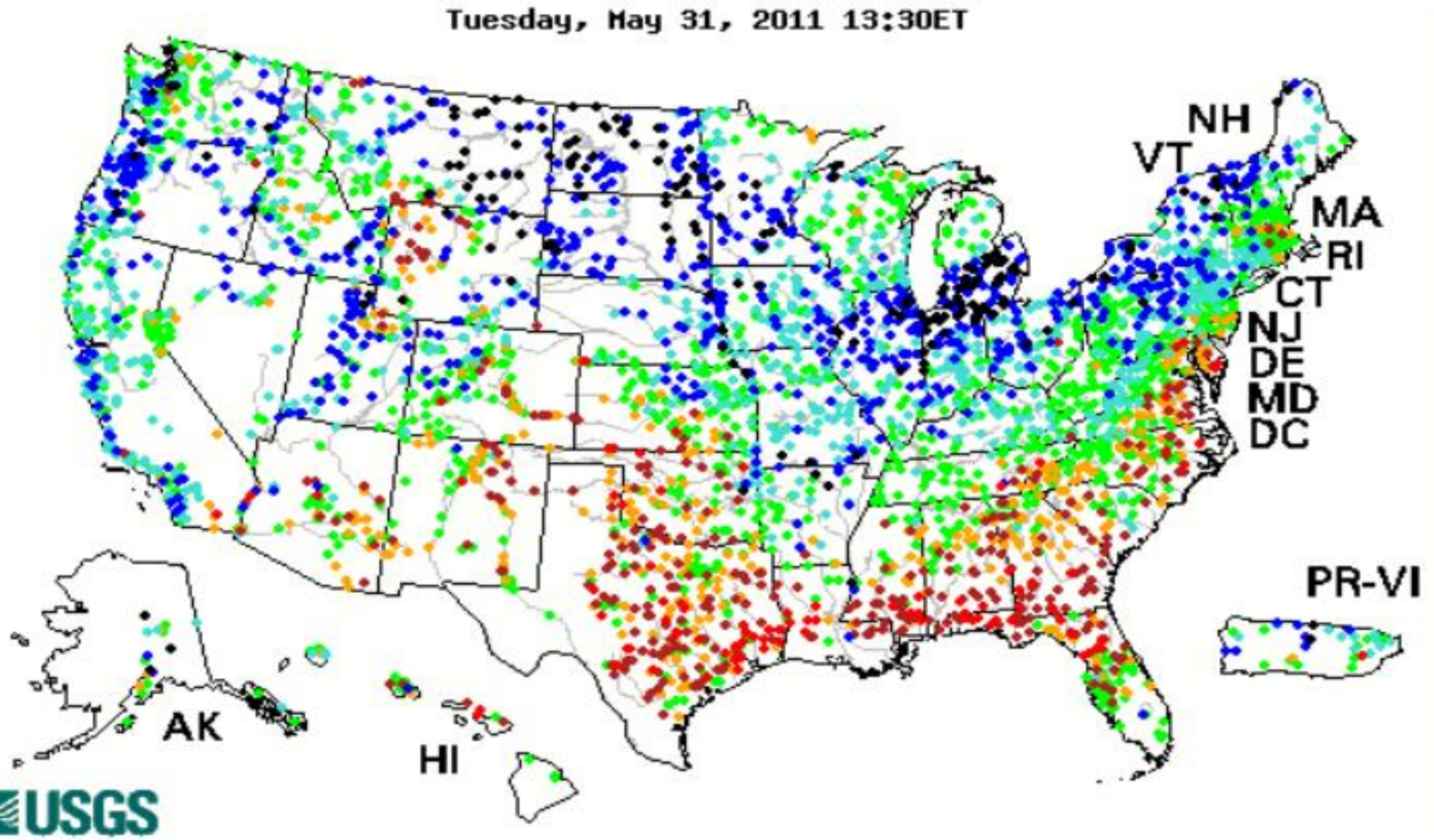
Extreme Minimum and Average Annual Precipitation in Northern California Since 1922

Extreme Maximum and Average Annual Precipitation in Northern California Since 1922

Source: California Department of Water Resources 2017

Hydrometic Data: USGS

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

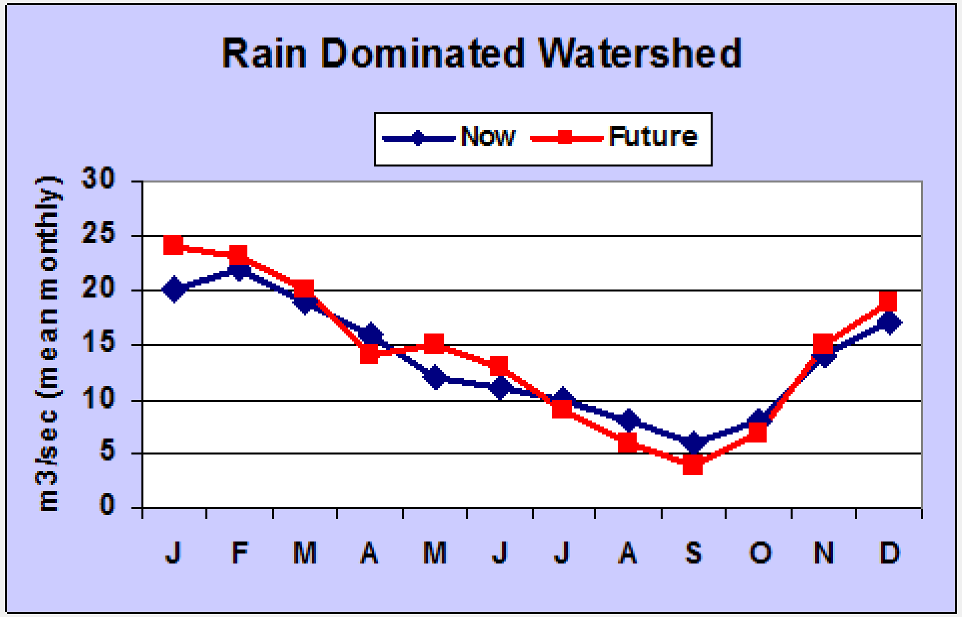


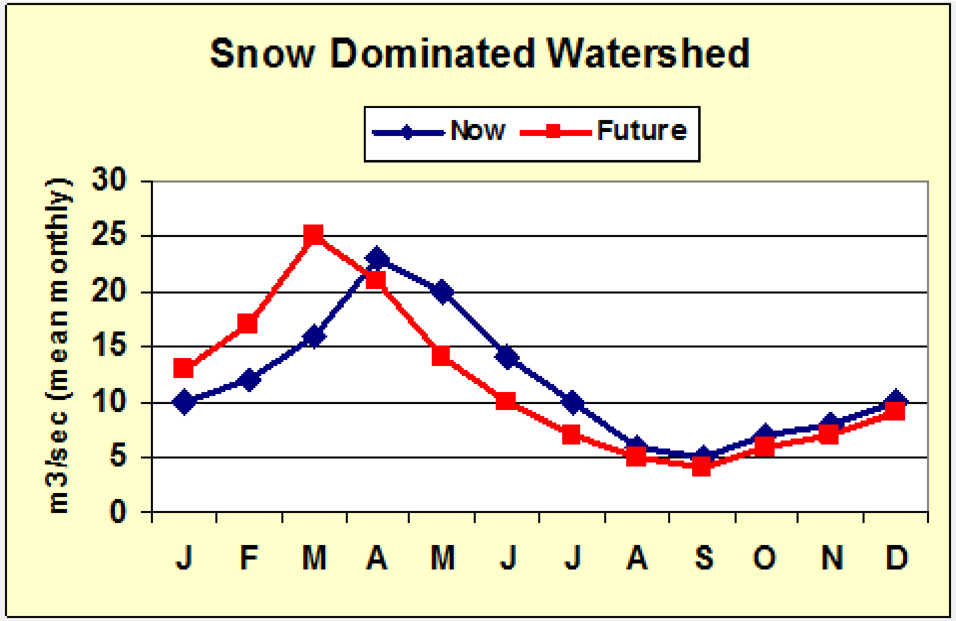
USGS

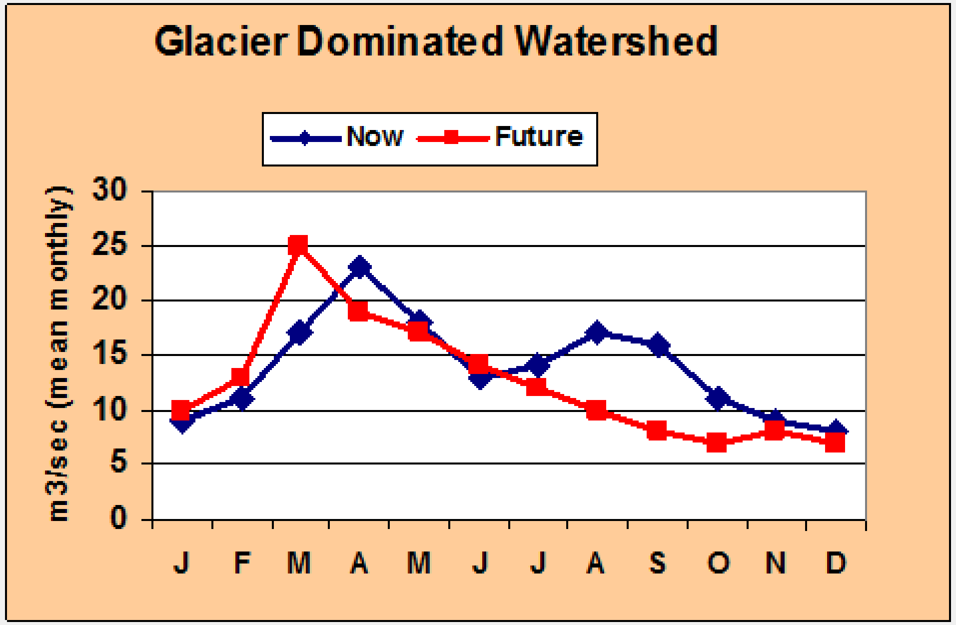
Choose a data retrieval option and select a location on the map
List of all stations in state, State map, or Nearest stations

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

	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.
Preparedeness	Advanced Notice, Some Time to Respond to Fast Moving Event	Little Advanced Notice, Requires Adaptive Response. Slow Progressive Event





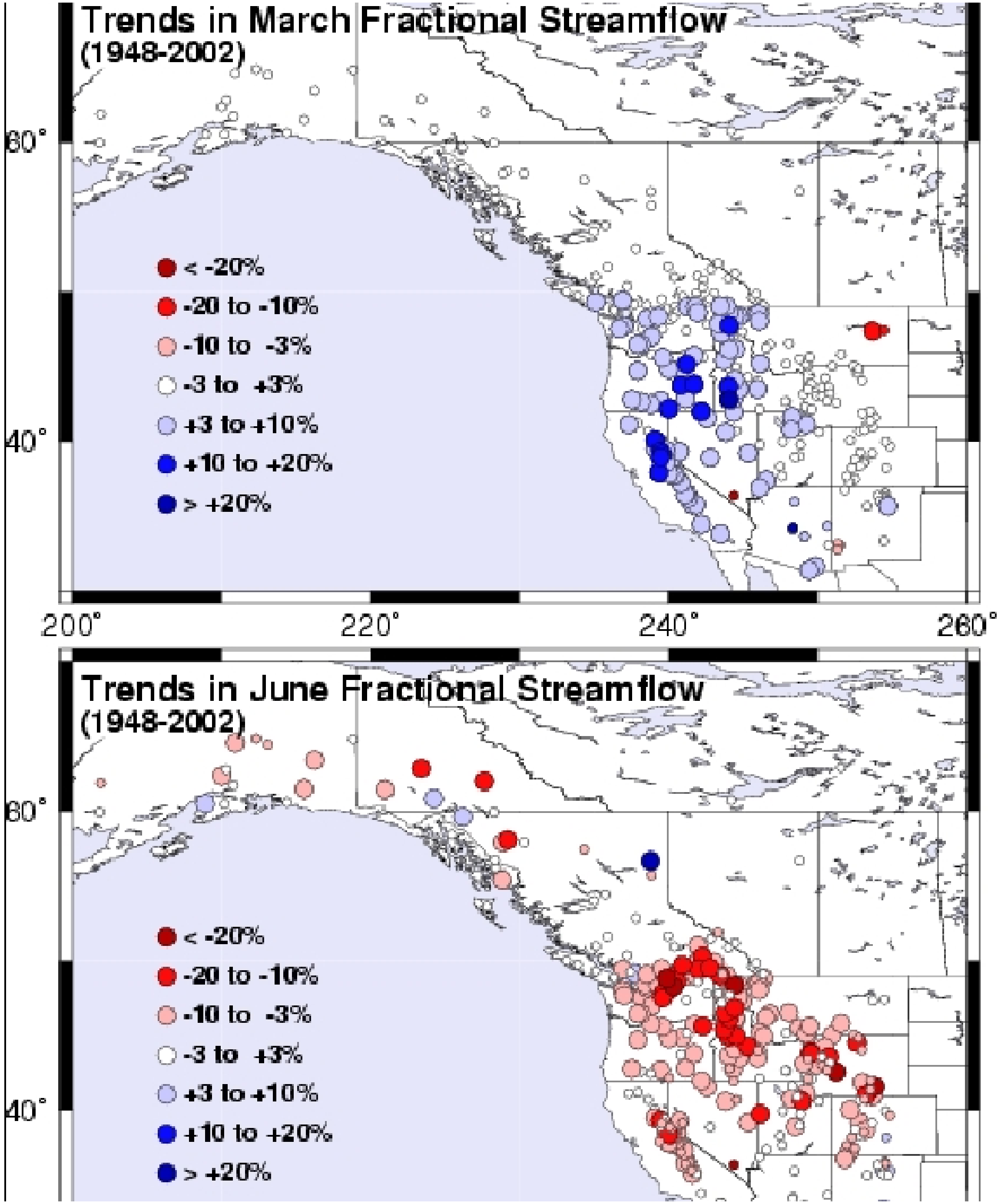


Anticipated Hydrological Changes:

Greatest changes in glacier dominated watersheds

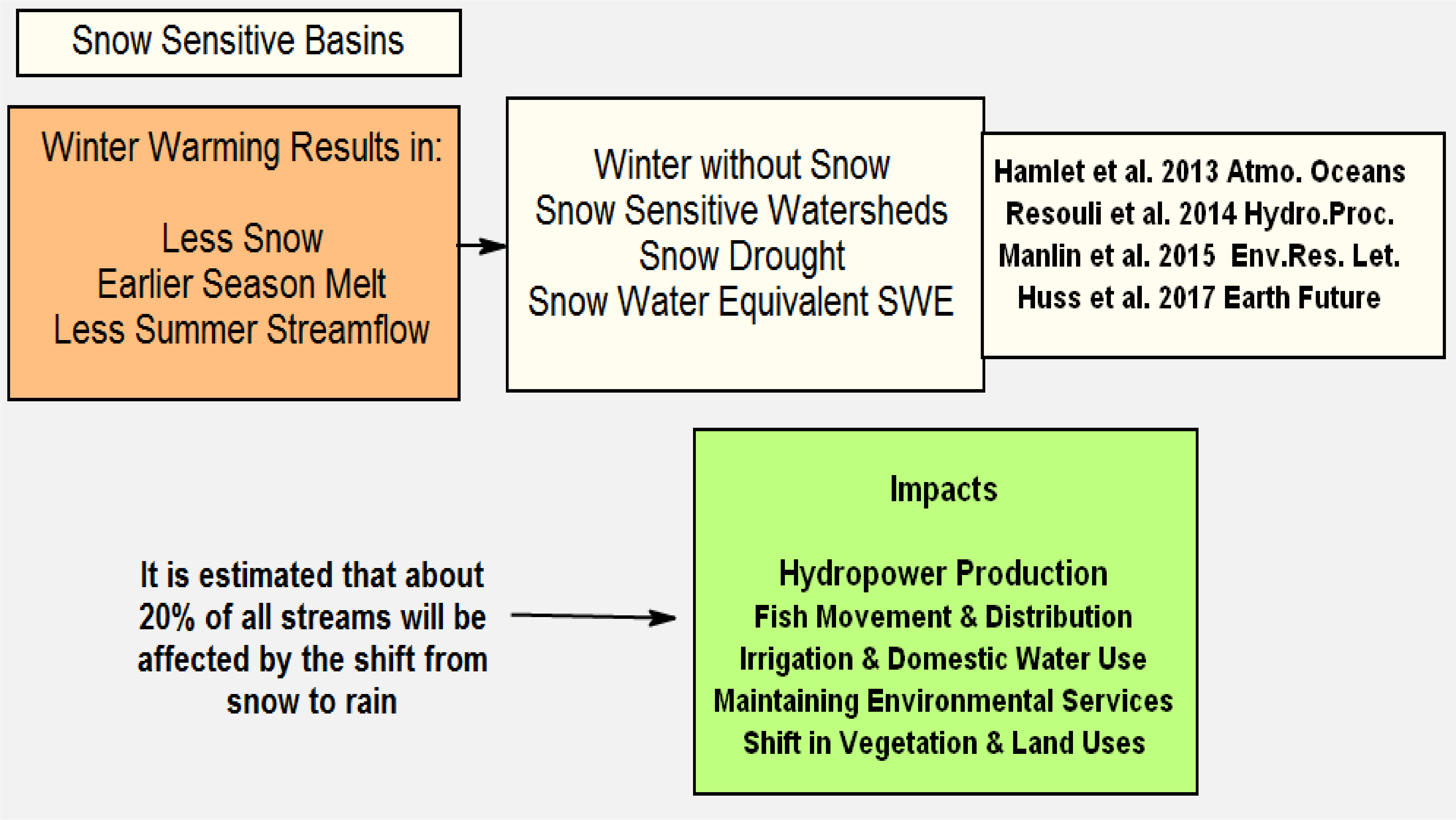
Major shift in peak and low flow in snow dominated watershed

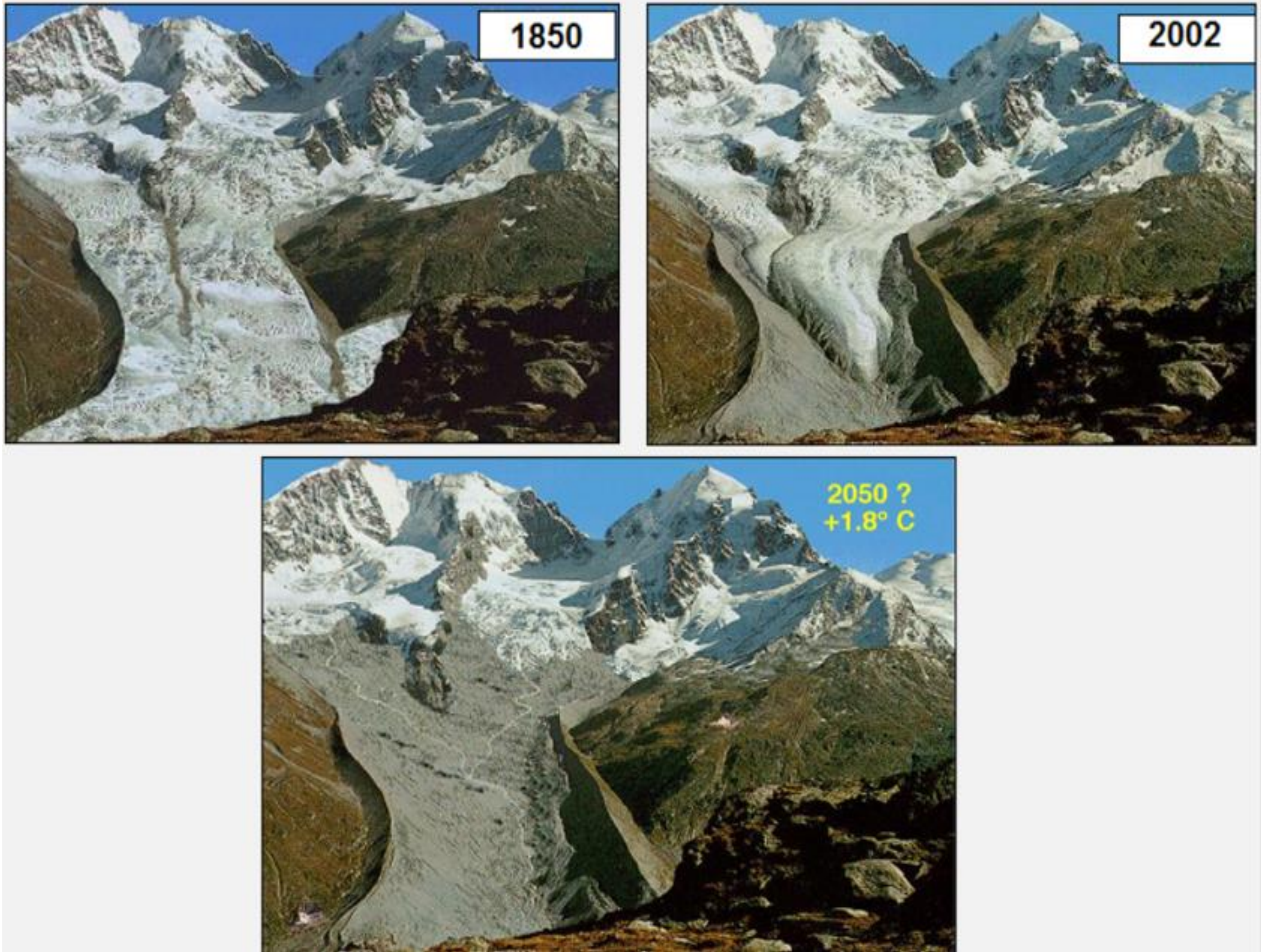
More variability in rain dominated watershed



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


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


1850
2002
2050 ?
+1.8° C

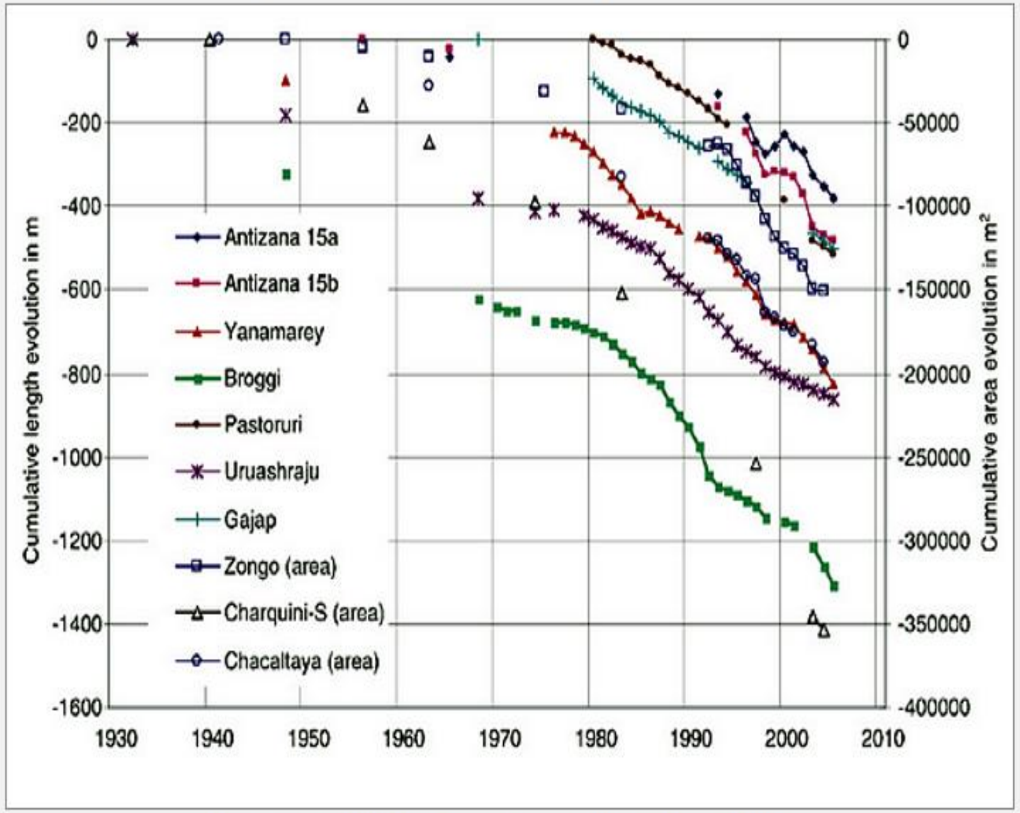
Shepard Glacier

W. C. Alden/ USGS photo. 1913

W. C. Alden/ USGS photo. 1913

B. Reardon/ USGS photo 2005

Changes in Length and Volume of Tropical Glaciers in the Andes



Data Source: Vuille et al. 2008, Earth Sci. Rev. 89:74-90

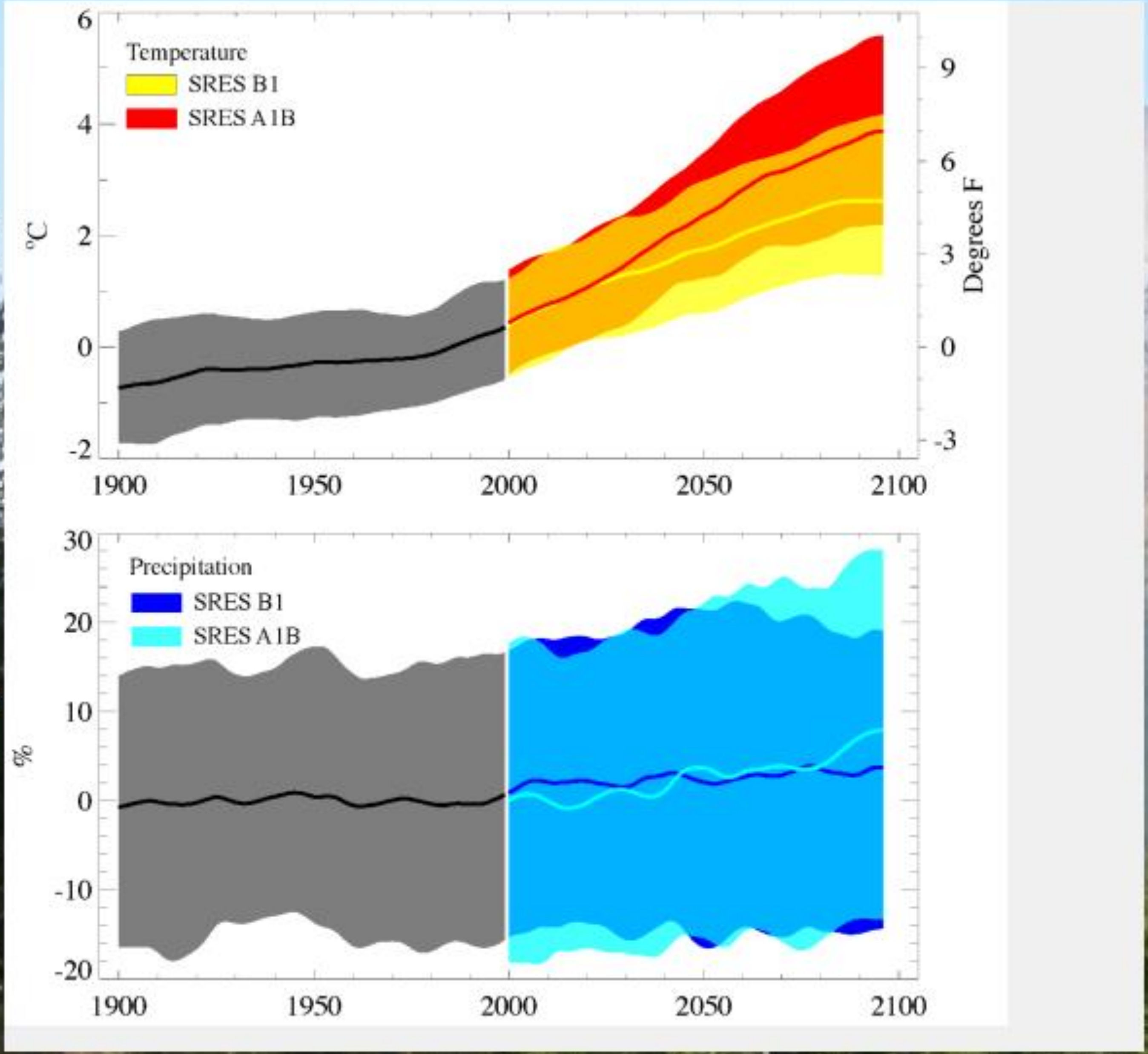


Inkhu Valley
before 1998
Inkhu Valley
After 1998

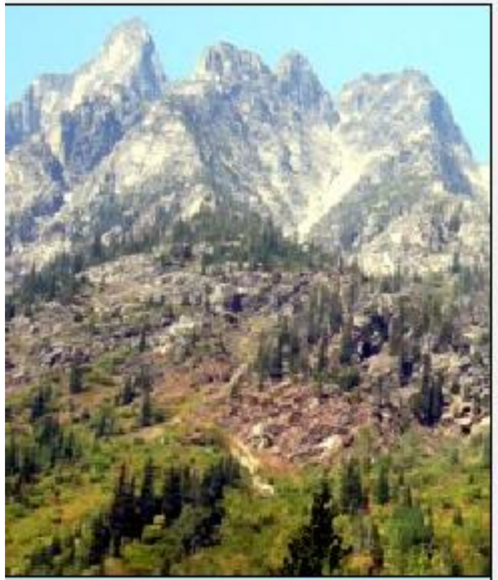
Climate Projections for the Pacific North-West

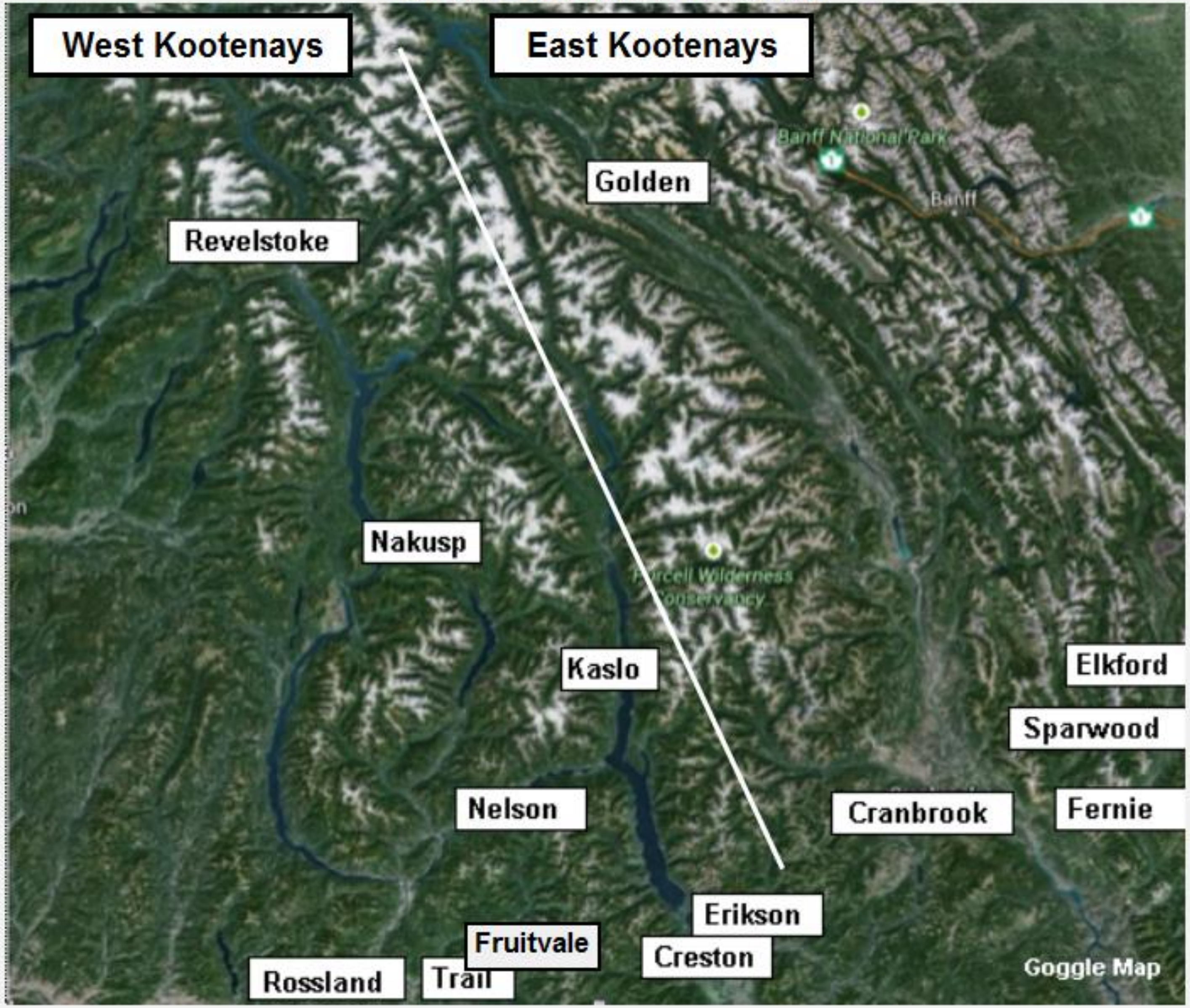
Temperature

Precipitation

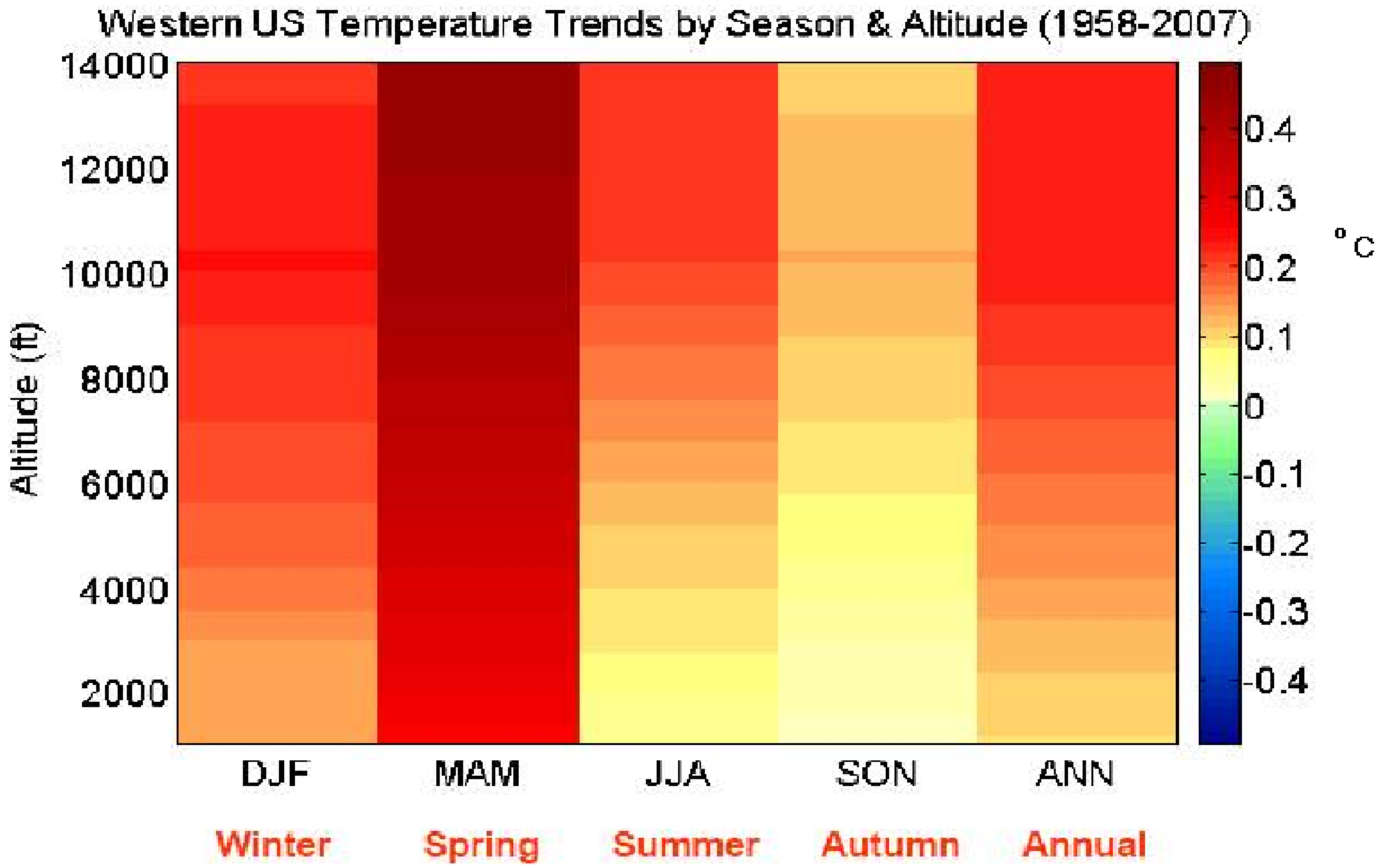


Climate Data for 14 Communities in The Canadian Portion of the Columbia Basin

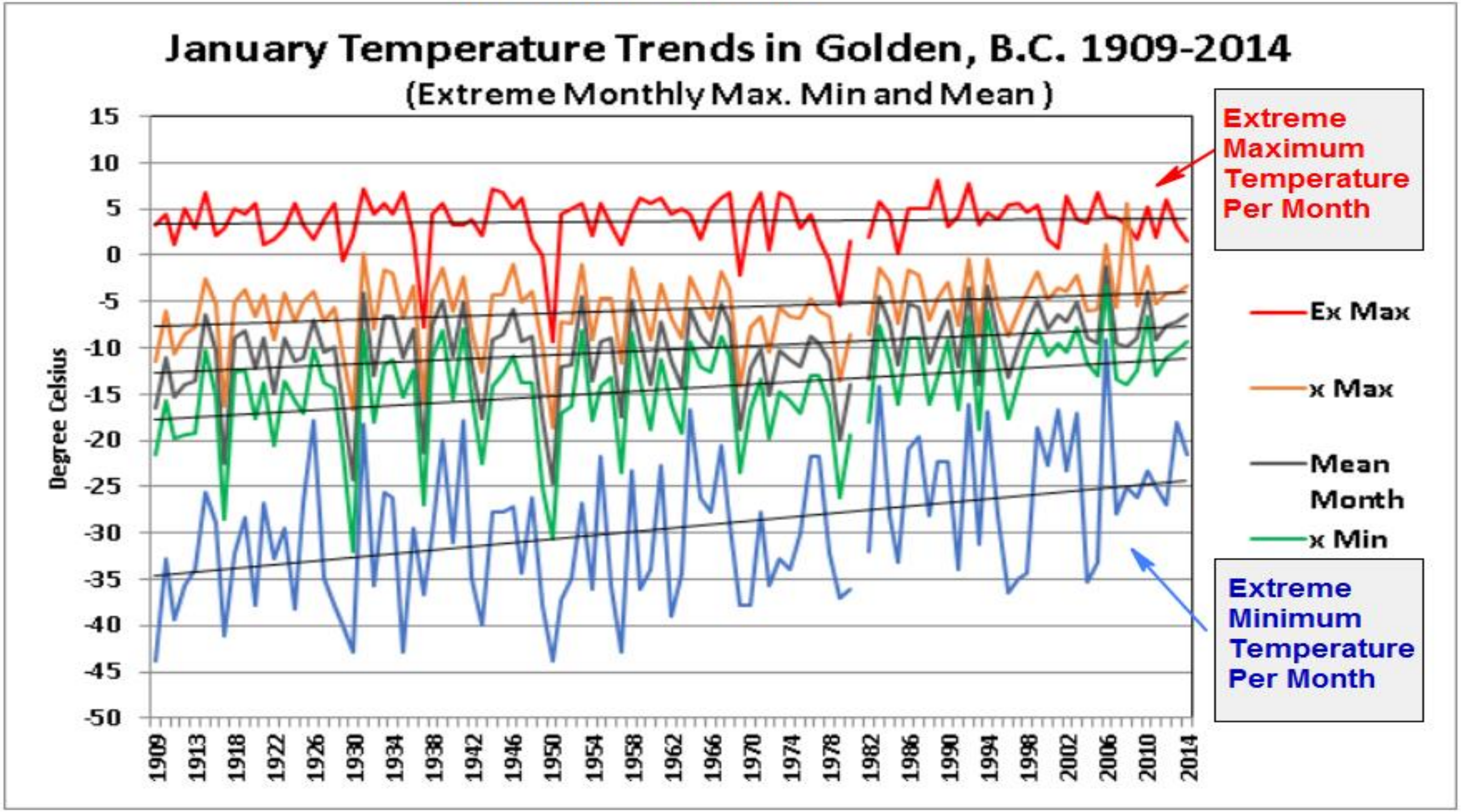




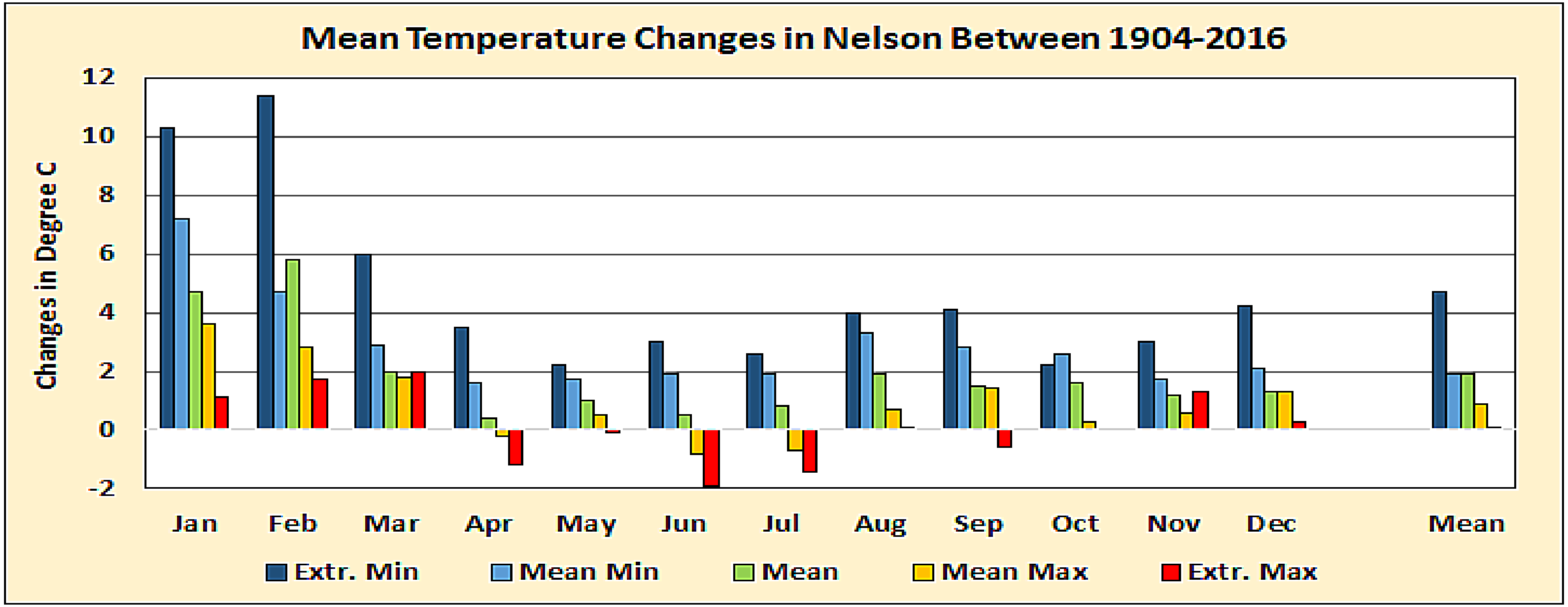
More Temperature Increases at Higher Elevations



Minimum Temperatures are increasing more rapidly in Winter & Summer



Average Monthly Temperature Changes Between 1904-2016 in Nelson, B.C.



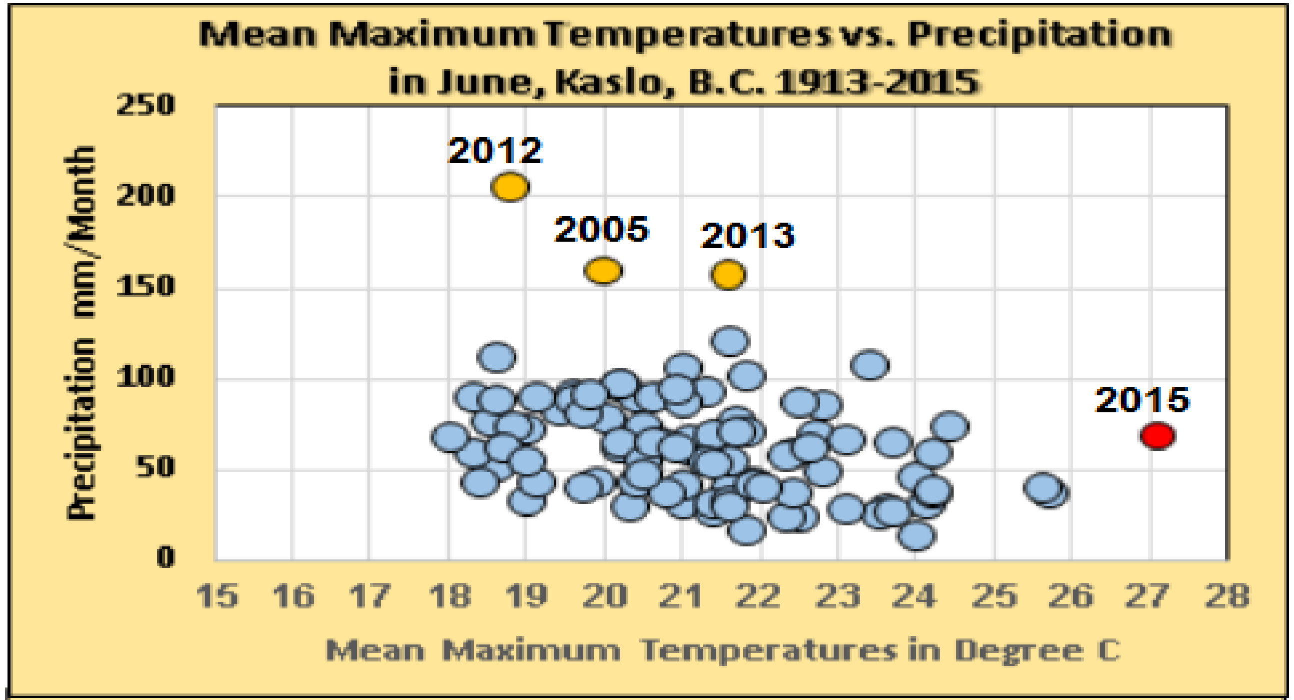
Extreme Minimum Monthly Temperature

Mean Minimum Monthly Temperature

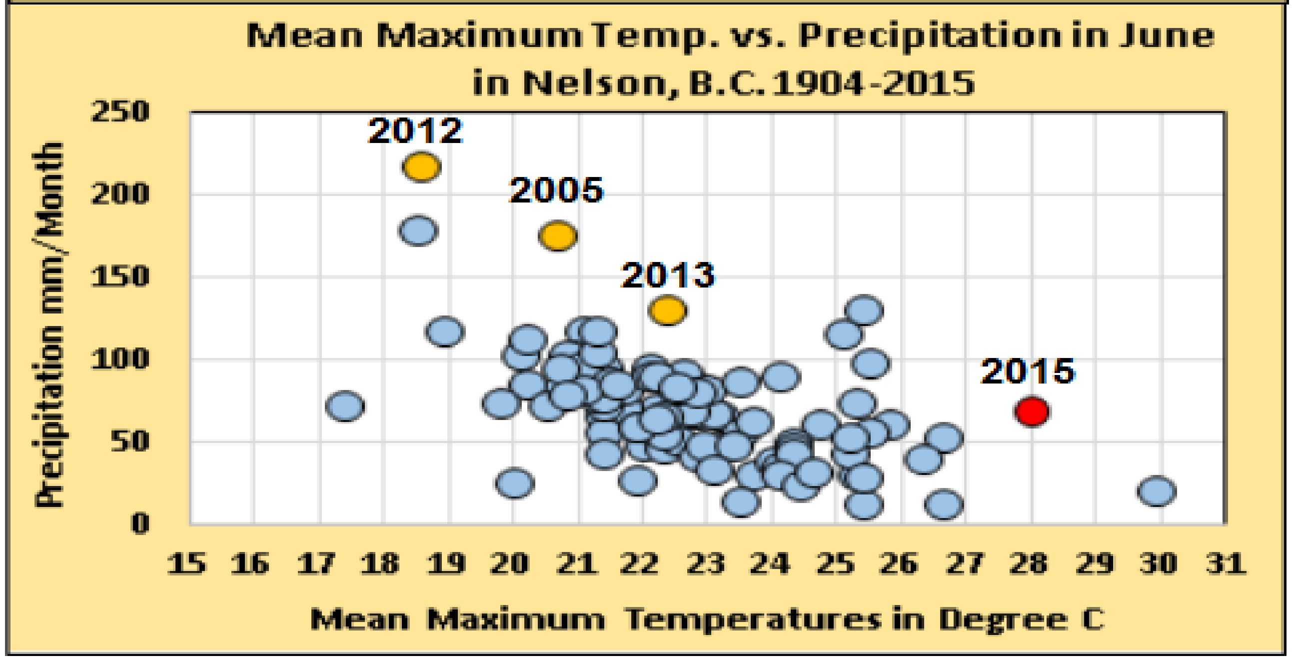
Mean Monthly Temperature

Extreme Maximum Monthly Temperature

Mean Maximum Monthly Temperature



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

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
Creston		2017		2011	2012	2005			2013	2016		
Warfield										2016		
Nelson		2016	2017			2012				2016	2006	
Kaslo			2017			2012					2006	
Revelstoke			2007			2012	2017				2006	
Golden						2005		2017			2006	
Cranbrook			2012							2016	2006	

Legend
2017
2016
2015
2013
2012
2011
2005-07

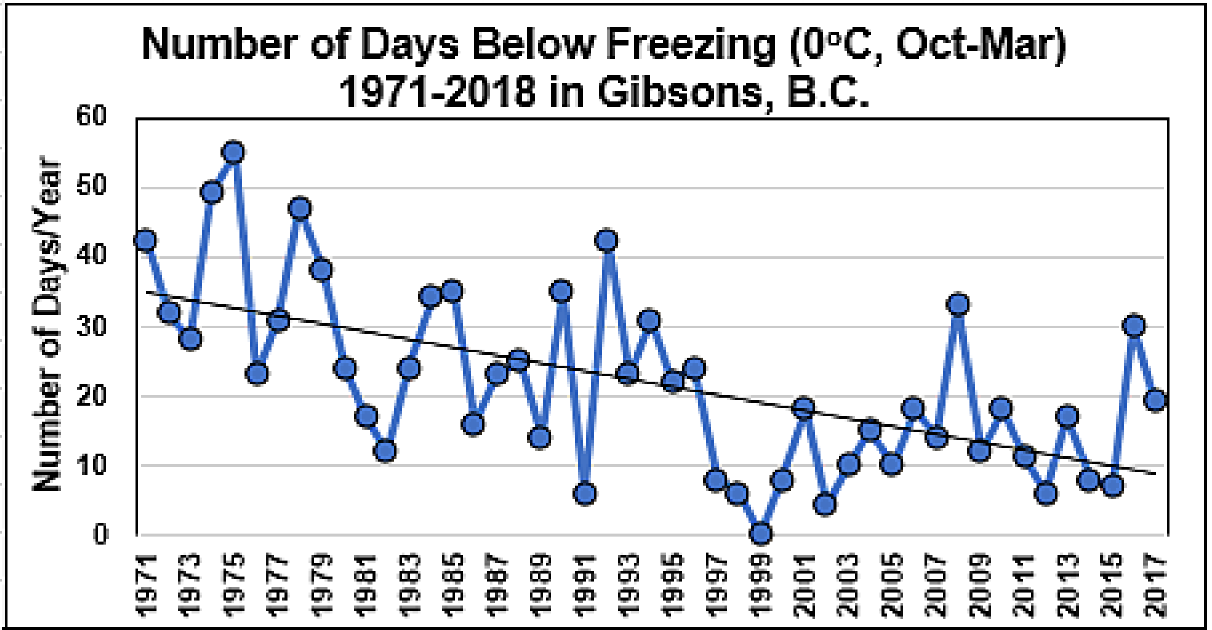
Dates of Record Breaking Monthly Mean Maximum & Mean Minimum Temperatures in the Columbia Basin in Canada (Based on 1920-2017 Climate Record)

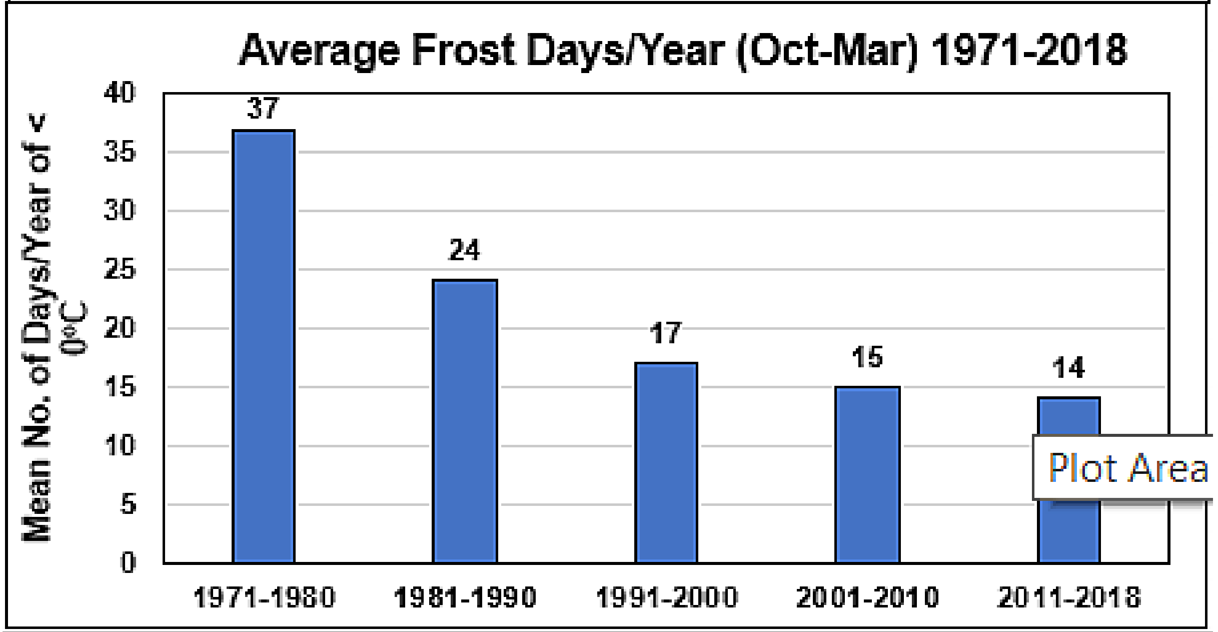
			Year of Record of Mean Maximum Monthly Temperatures between 1920-2017									
Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Creston		2015		2016	2015	2015	2006	2017			2016	
Warfield		2015		2016		2015	2017				2016	
Nelson		2015		2016					2011			
Kaslo	2006					2015	2015			2015		
Revelstoke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

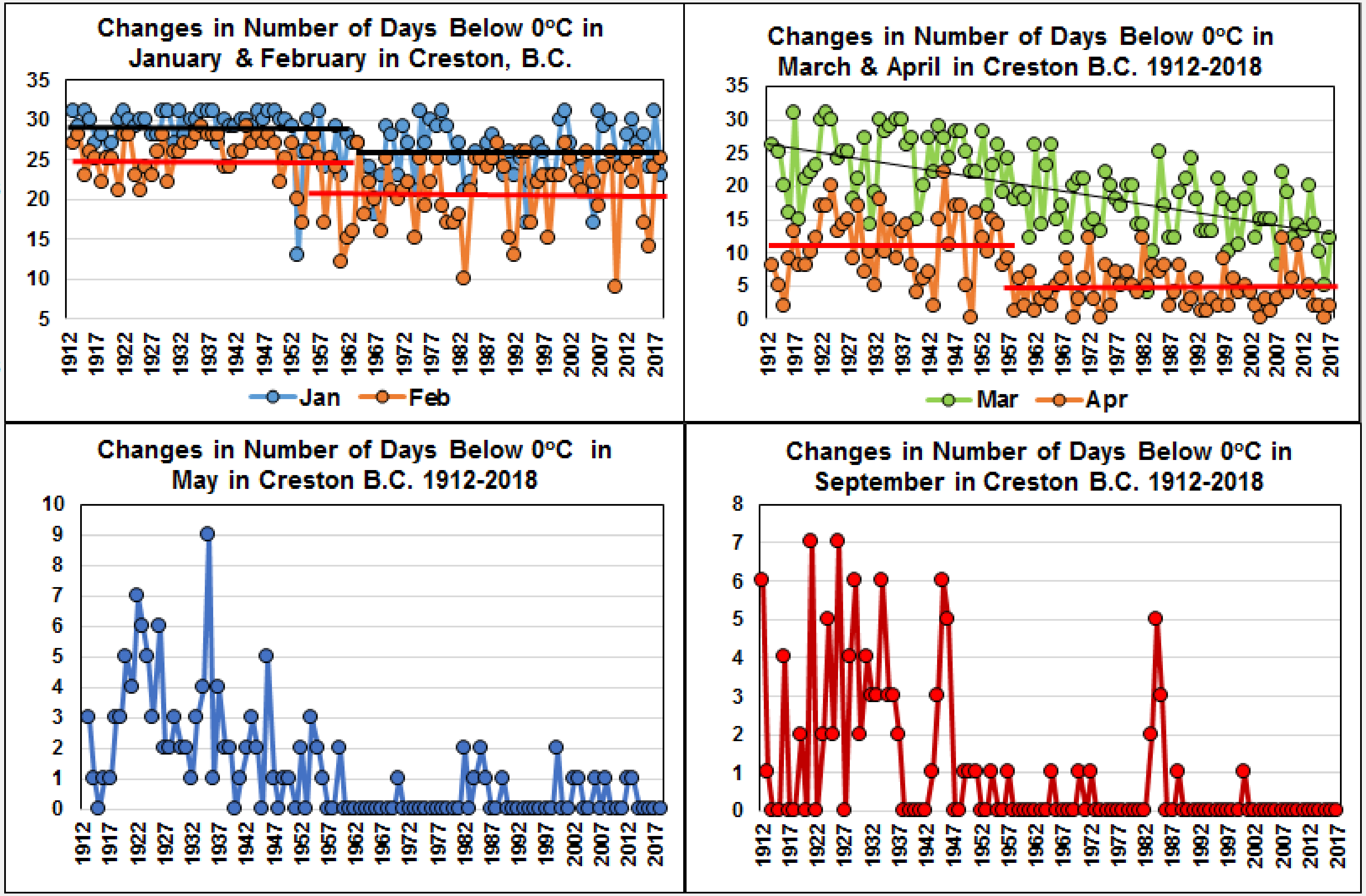

Number of Days Below Freezing (0°C, Oct-Mar)
1971-2018 in Gibsons, B.C.
Number of Days/Year
60
50
40
30
20
10
0
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017


Average Frost Days/Year (Oct-Mar) 1971-2018
Mean No. of Days/Year of < 0°C
40
35
30
25
20
15
10
5
0
37
24
17
15
14
1971-1980
1981-1990
1991-2000
2001-2010
2011-2018
Plot Area

Changes in the Number of Days Below Freezing in Jan-Sept in Creston 1912-2017

January Step Change 29-26 Days

February Step Change 25-21 Days

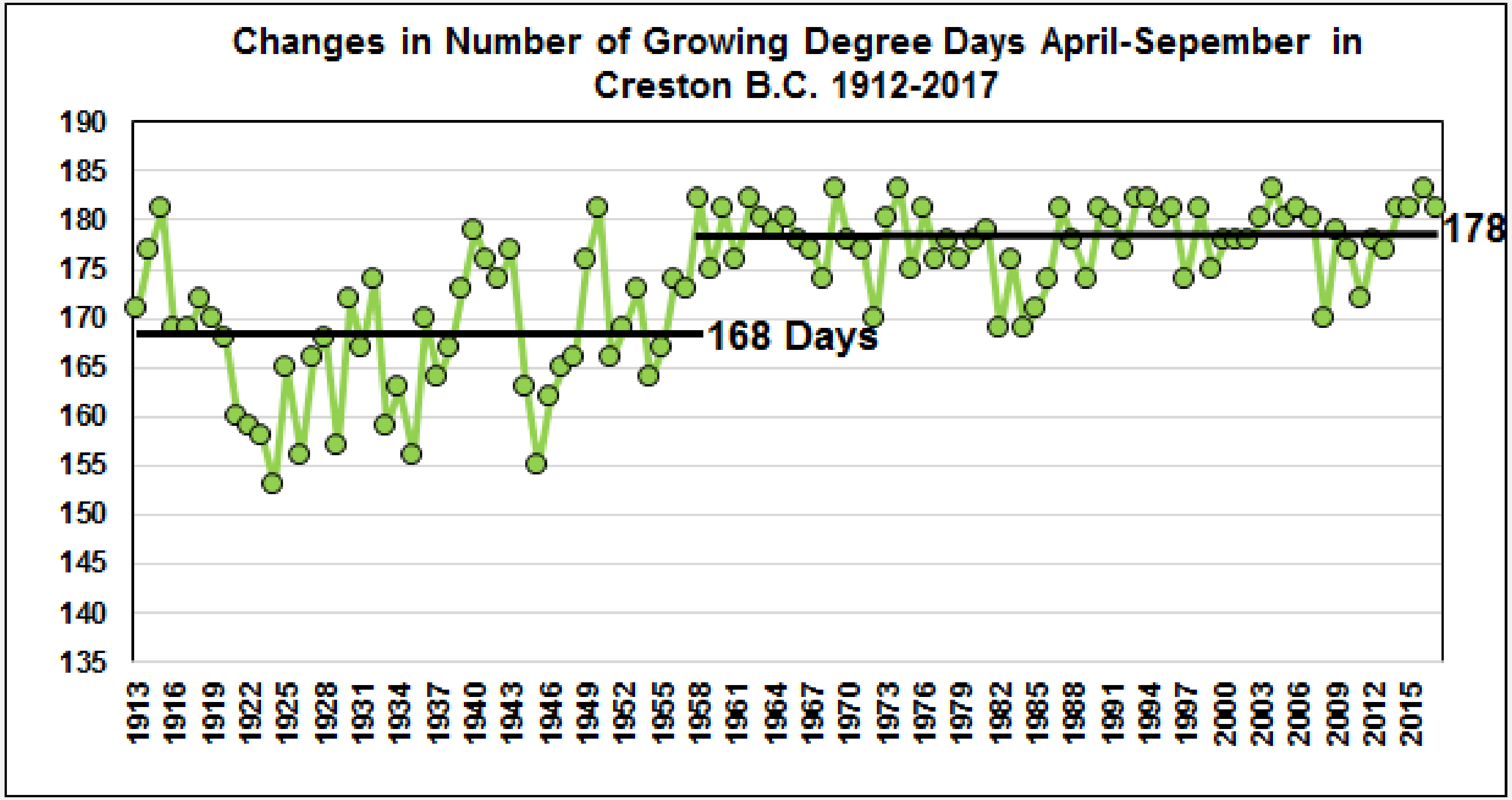


March Change 11-5 Days

April Step Change 11-5 Days

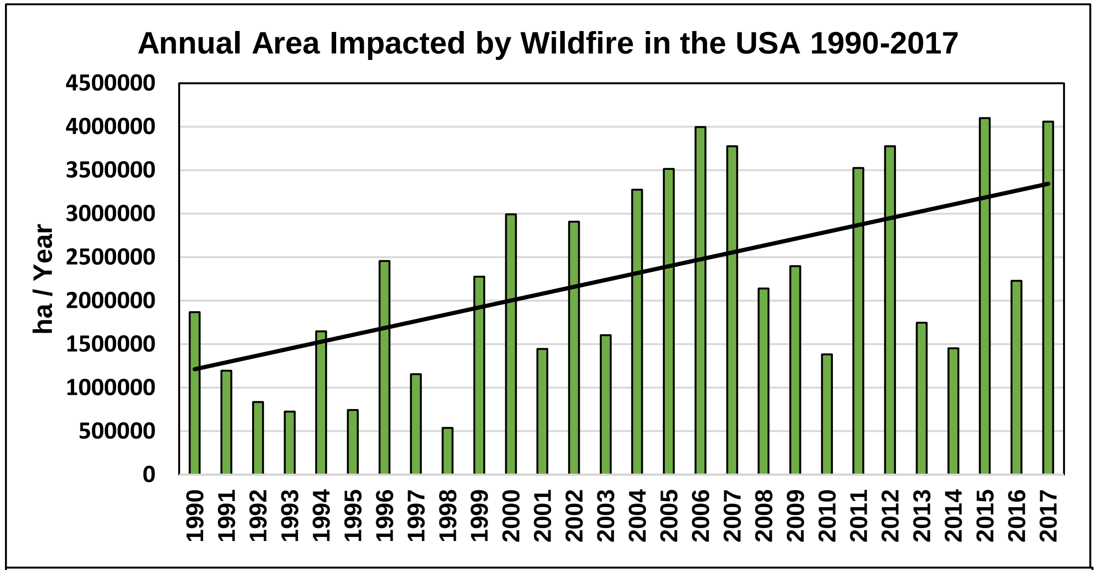
Note: Winter Variability in January & February is Increasing. Variability in Early Spring (May) and Early Fall (Sept) is Decreasing.

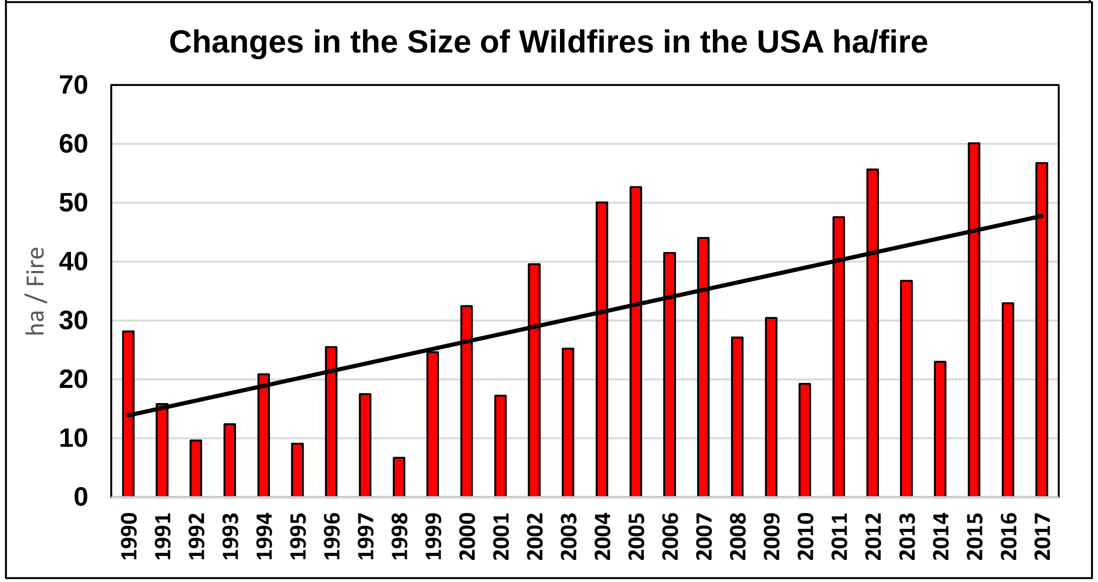
Changes in the Number of Growing Degree Days in A Mountain Community In Canada



Note Step Change around 1958 from 168 Days below freezing to 178 Days between 1960-2017

Wildfire History in the USA 1990-2017

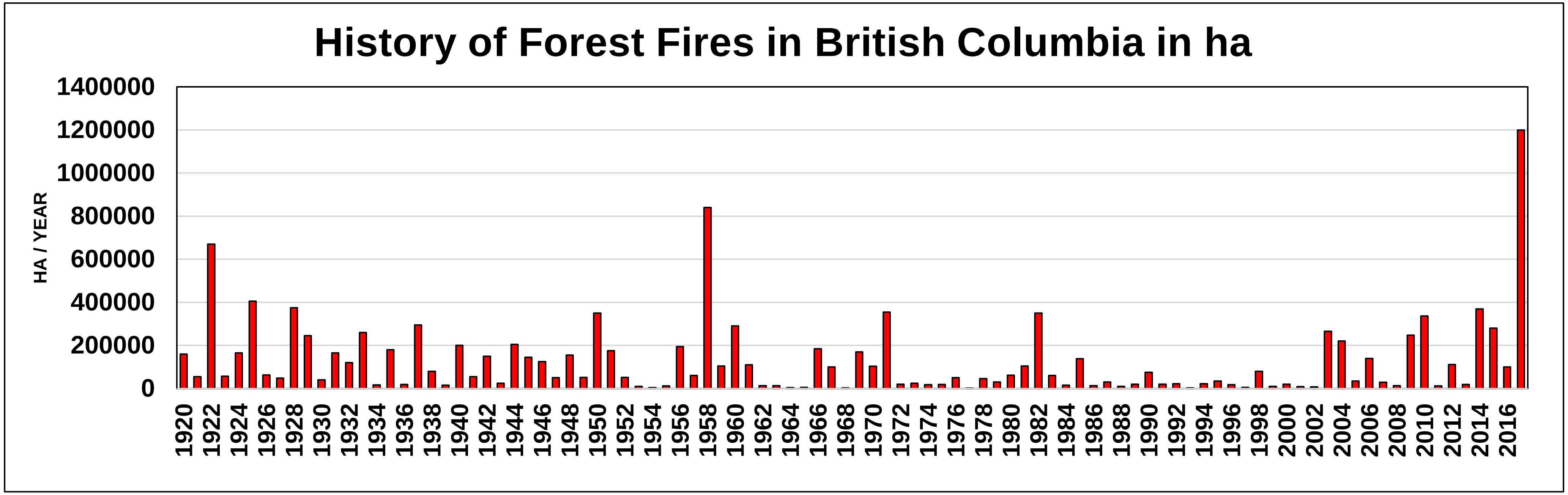




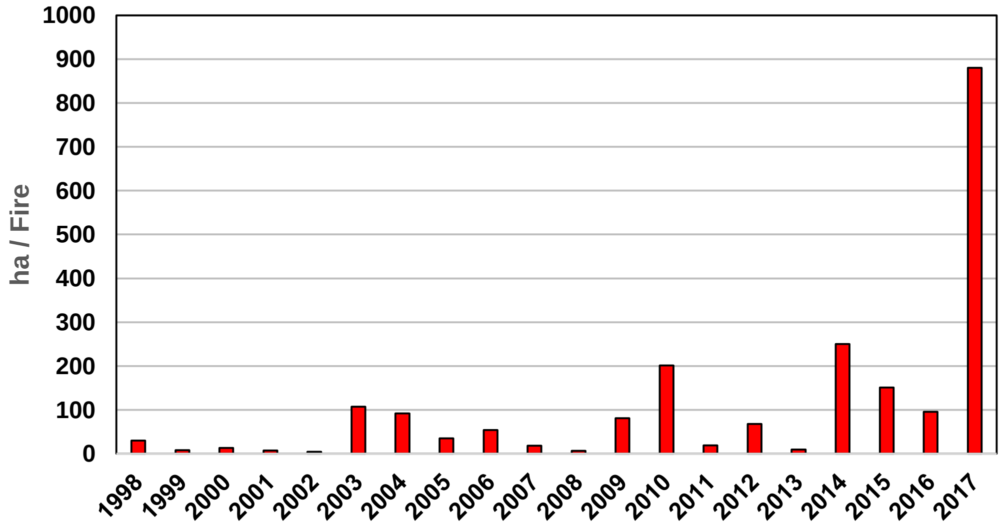
Reasons for Change in fires

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

Wildfire History in B.C. Canada 1920-2017 (ha / Year)



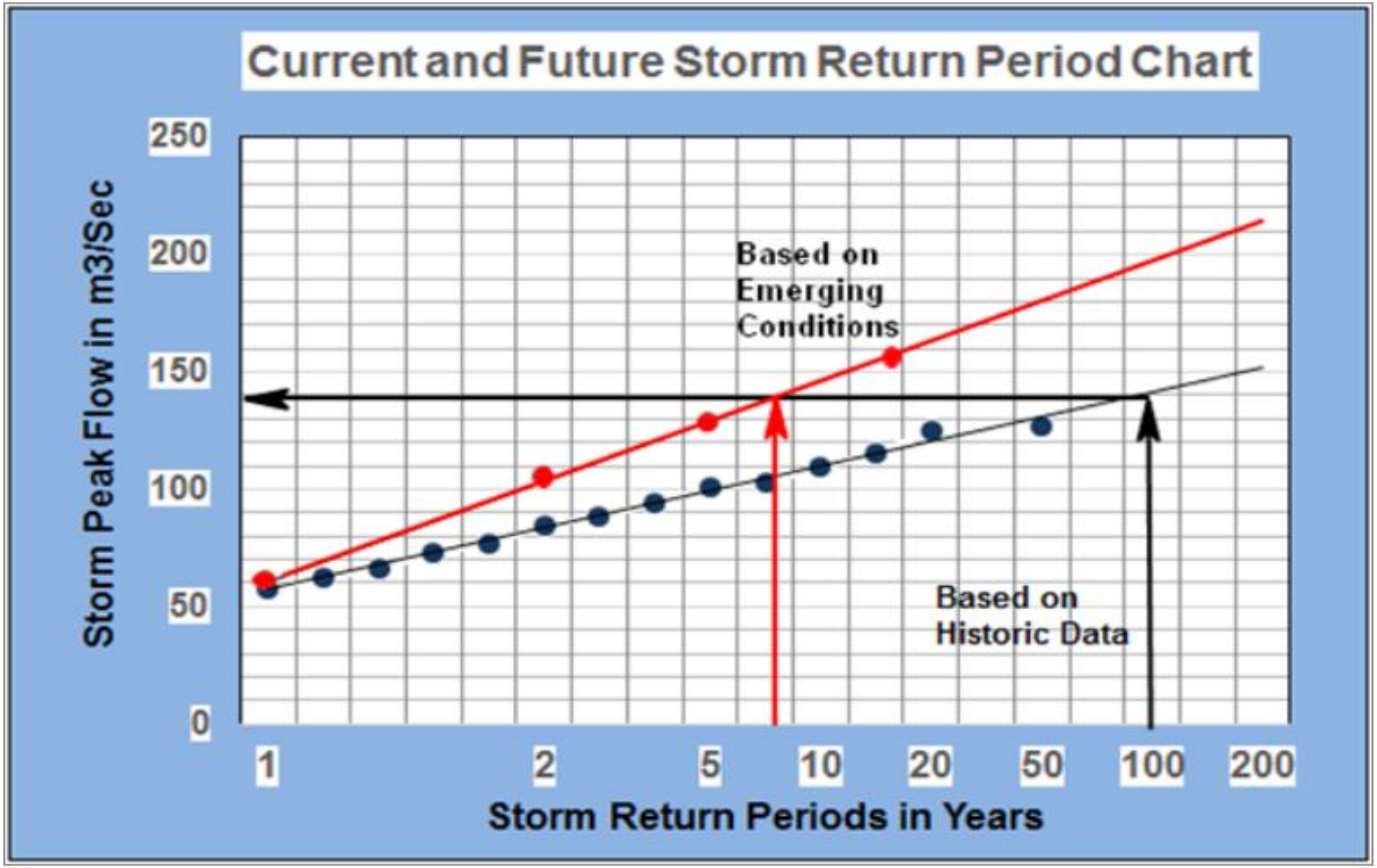
Changes in Size of Wildfire in Fire in B.C. (ha/Fire)



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?

Implications



Summary

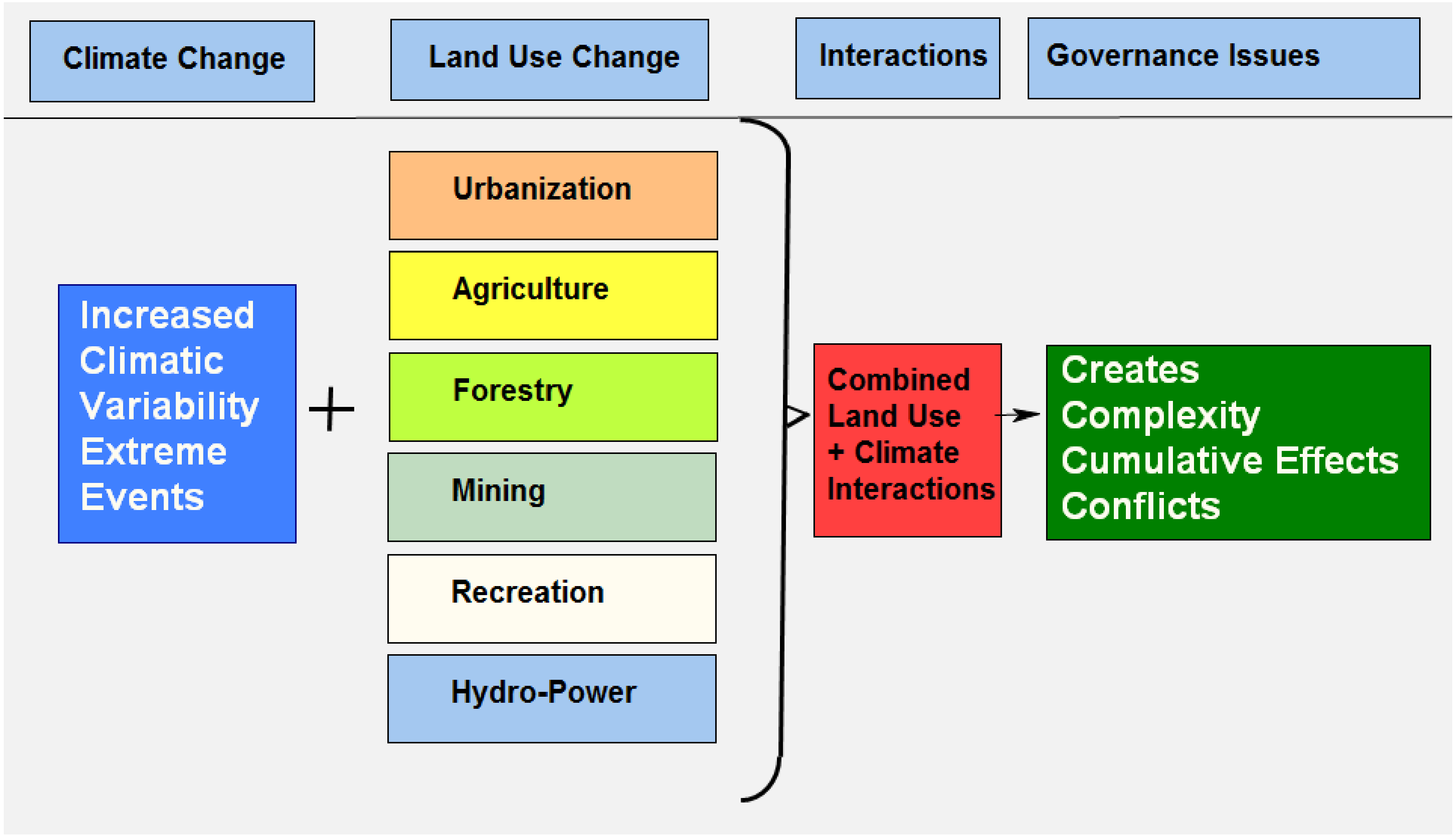
Focus on Increased climatic Variability

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

Natural Hazards and its Impact Downstream



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		