Mountain Agriculture & Increased Climatic Variability

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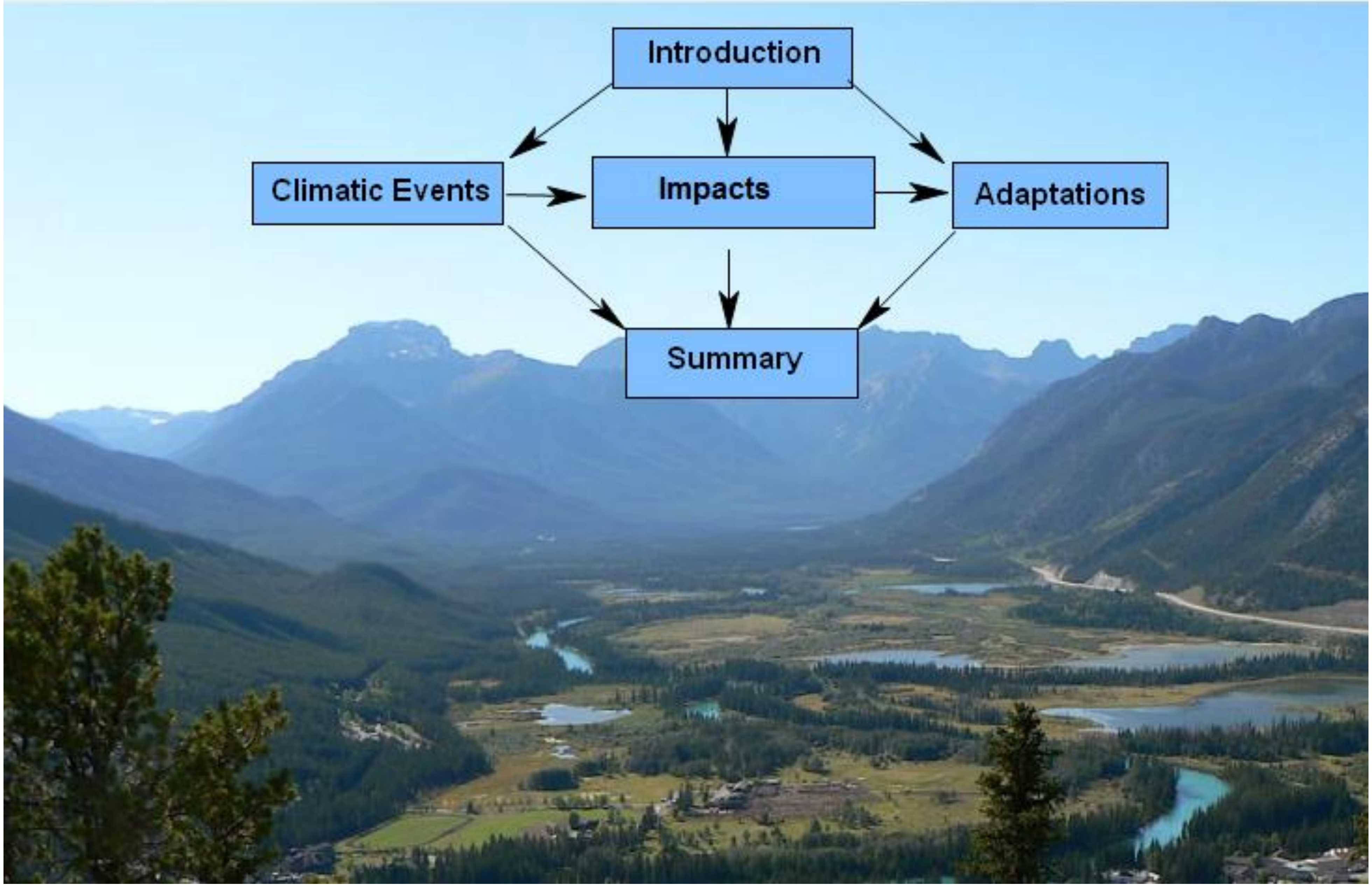
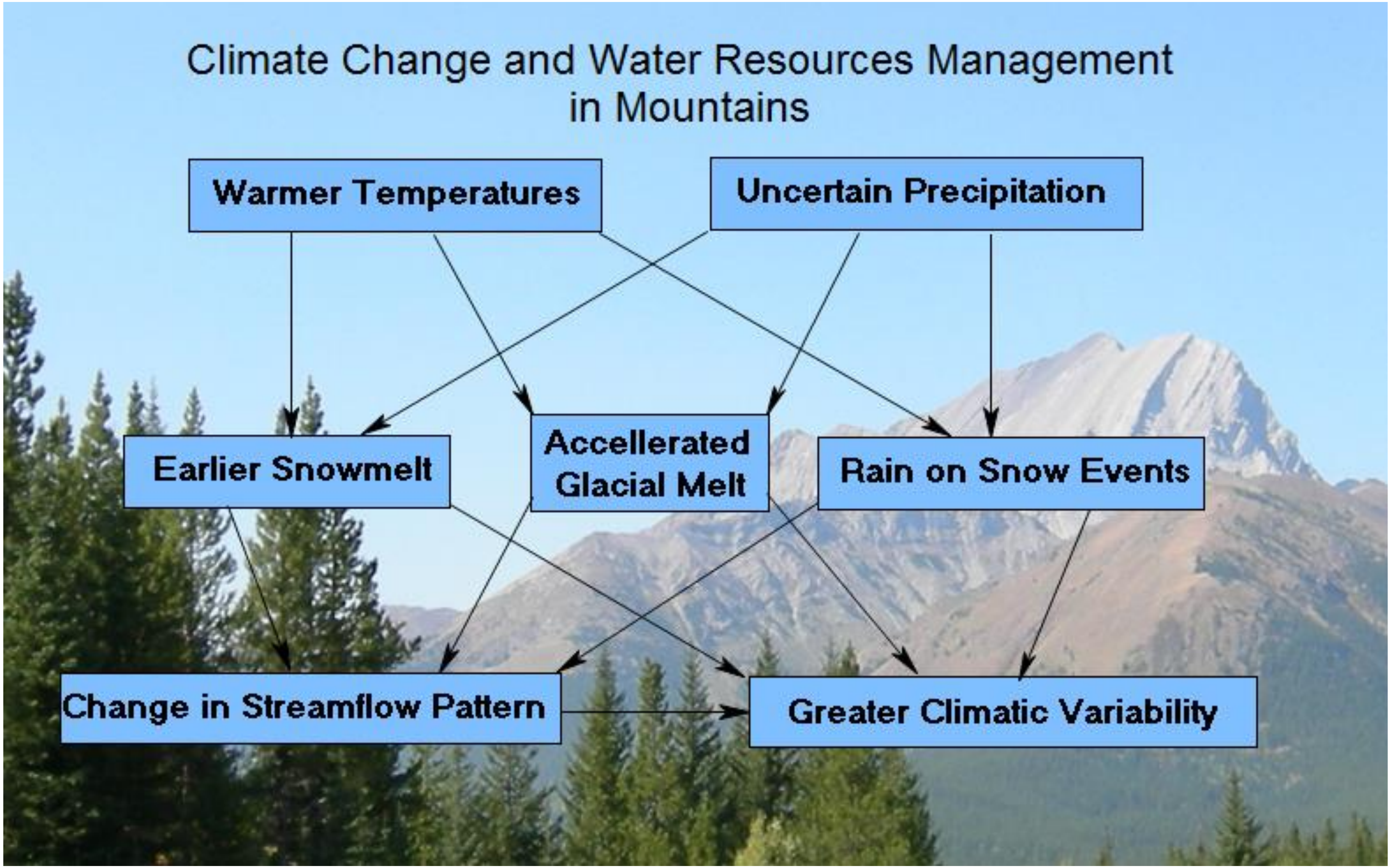
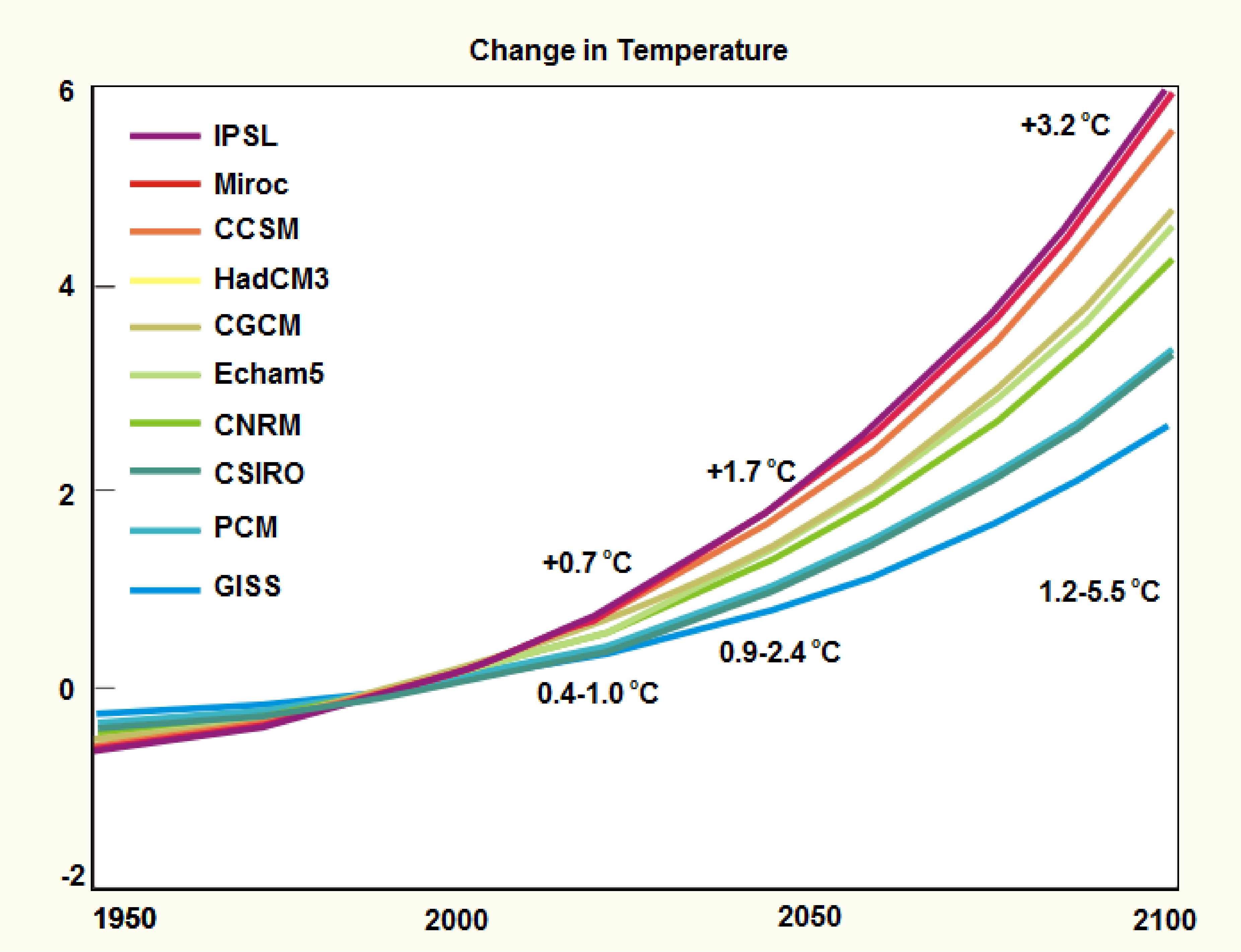
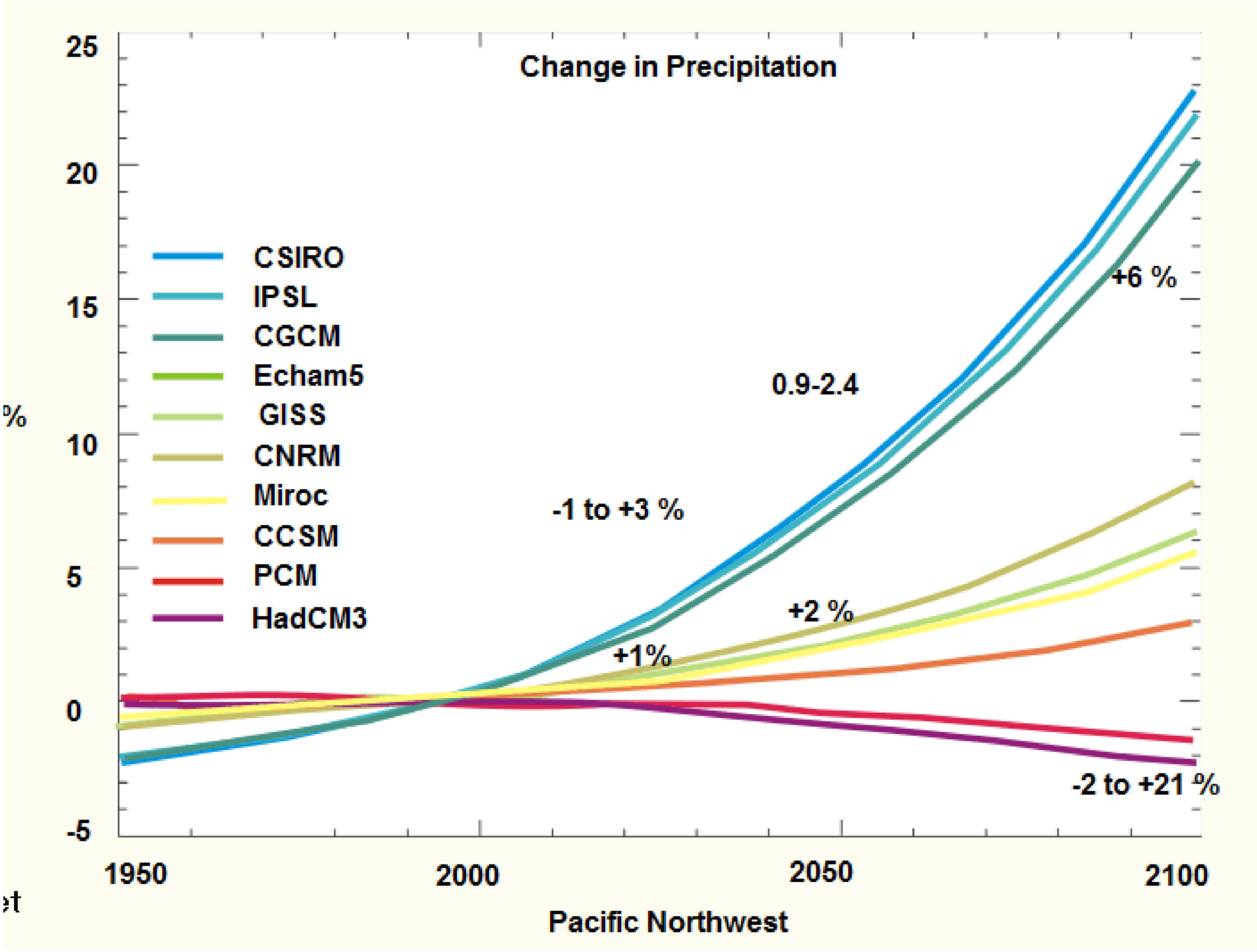
Increased Climatic Variability in Mountain Agriculture




Climate Change and Water Resources Management in Mountains
Warmer Temperatures
Uncertain Precipitation
Earlier Snowmelt
Accellerated Glacial Melt
Rain on Snow Events
Change in Streamflow Pattern
Greater Climatic Variability


Change in Temperature
6
4
2
0
-2
1950
2000
2050
2100
IPSL
Miroc
CCSM
HadCM3
CGCM
Echam5
CNRM
CSIRO
PCM
GISS
+3.2 °C
+1.7 °C
+0.7 °C
1.2-5.5 °C
0.9-2.4 °C
0.4-1.0 °C

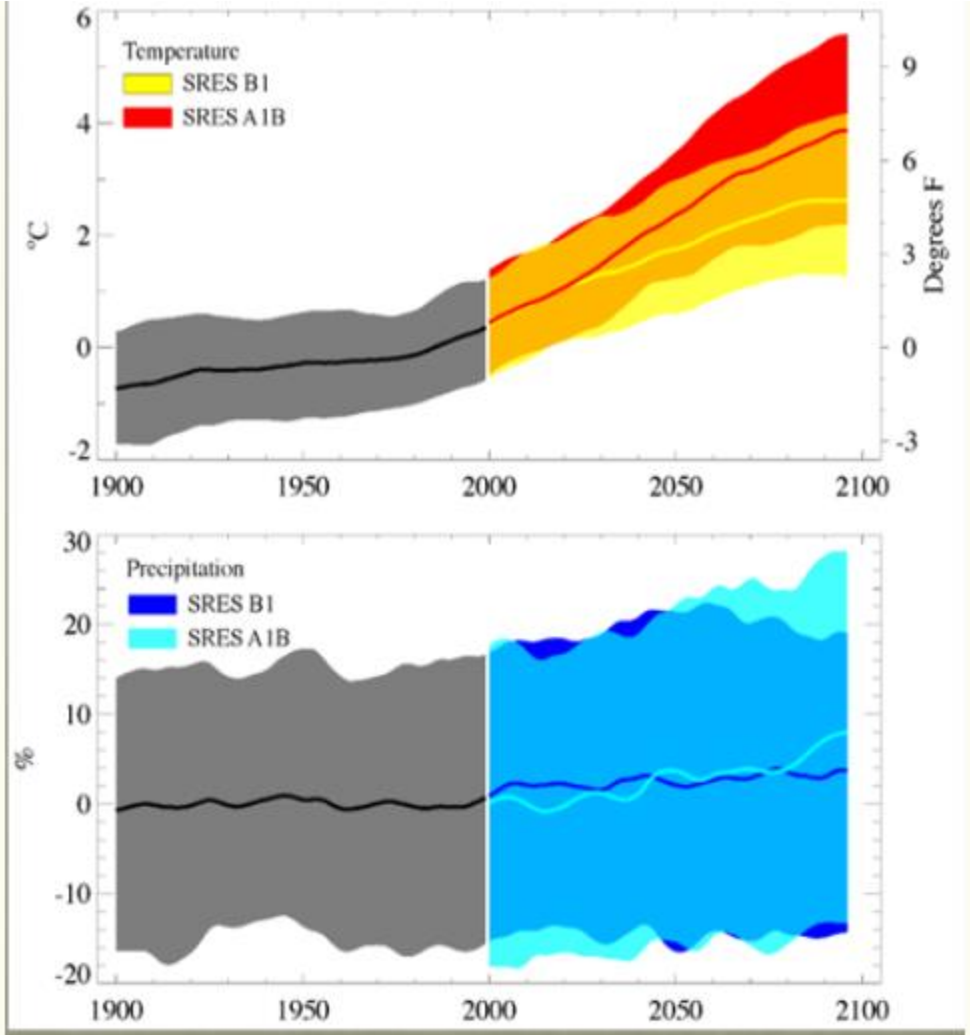


Change in Precipitation
%
25
20
15
10
5
0
-5
1950
2000
2050
2100
CSIRO
IPSL
CGCM
Echam5
GISS
CNRM
Miroc
CCSM
PCM
HadCM3
0.9-2.4
+6 %
-1 to +3 %
+2 %
+1%
-2 to +21 %
Pacific Northwest

Temperature Trends

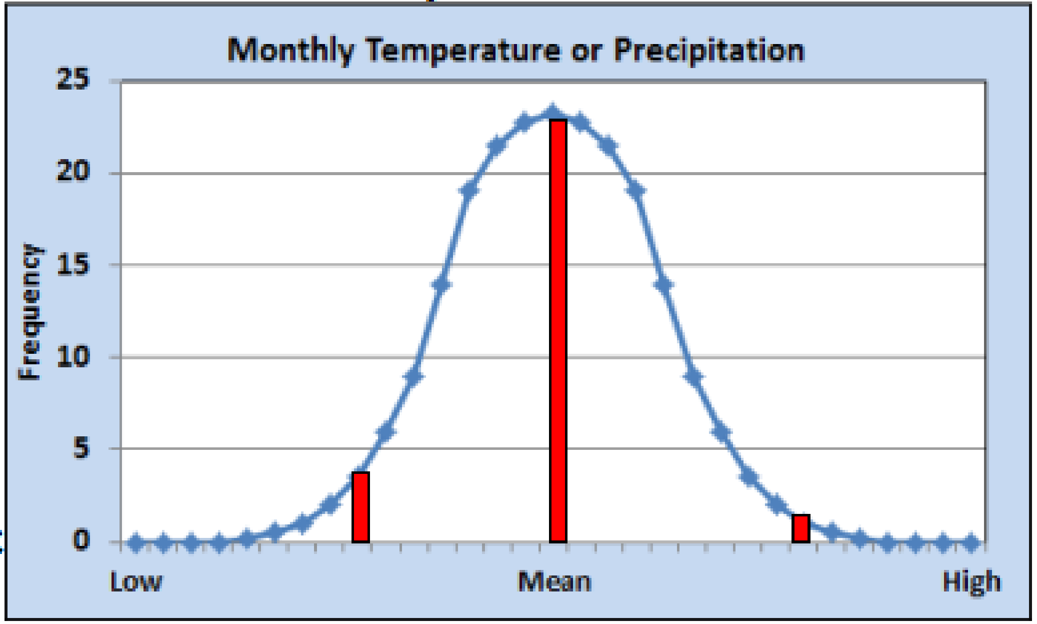
Precipitation Trends

Source: Hamlet et al. 2006

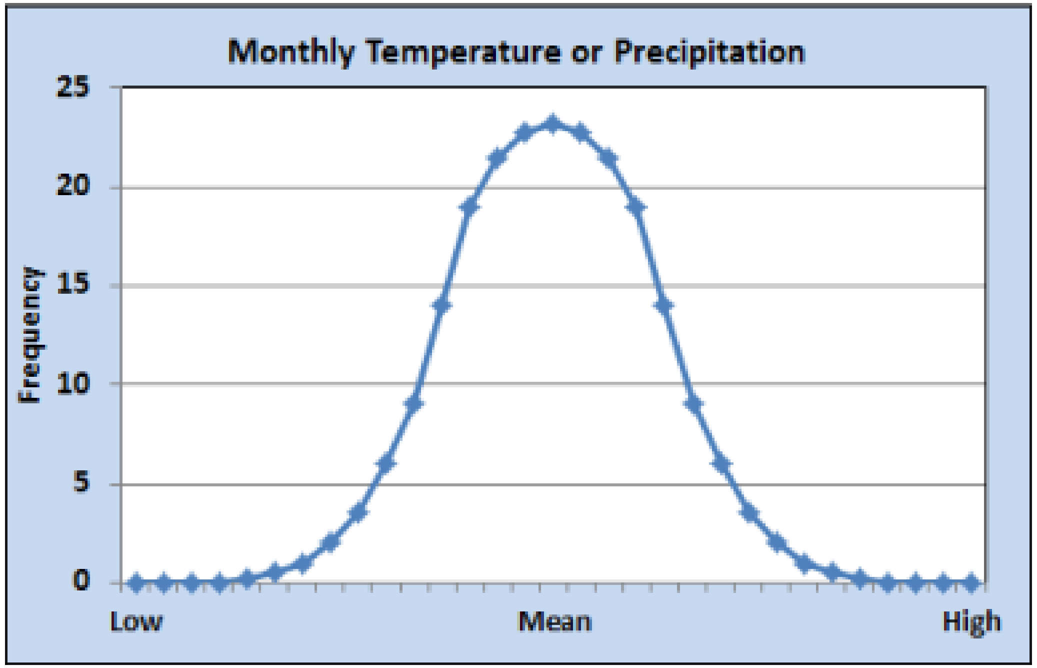


Source: Hamlet, A. 2012, With Permission

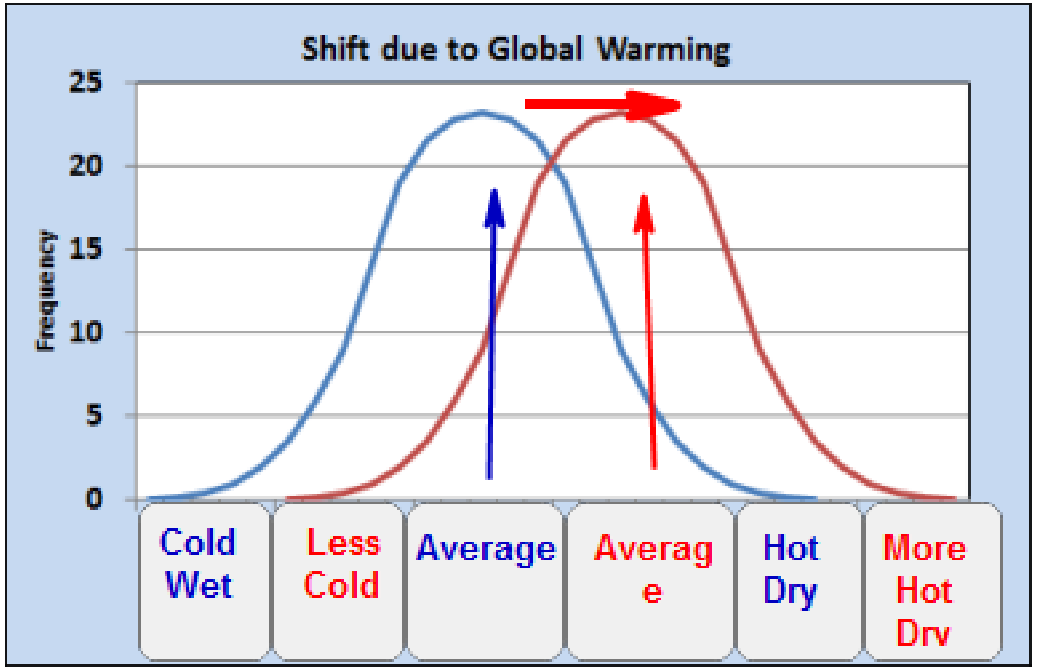
Historic Temperature Distribution



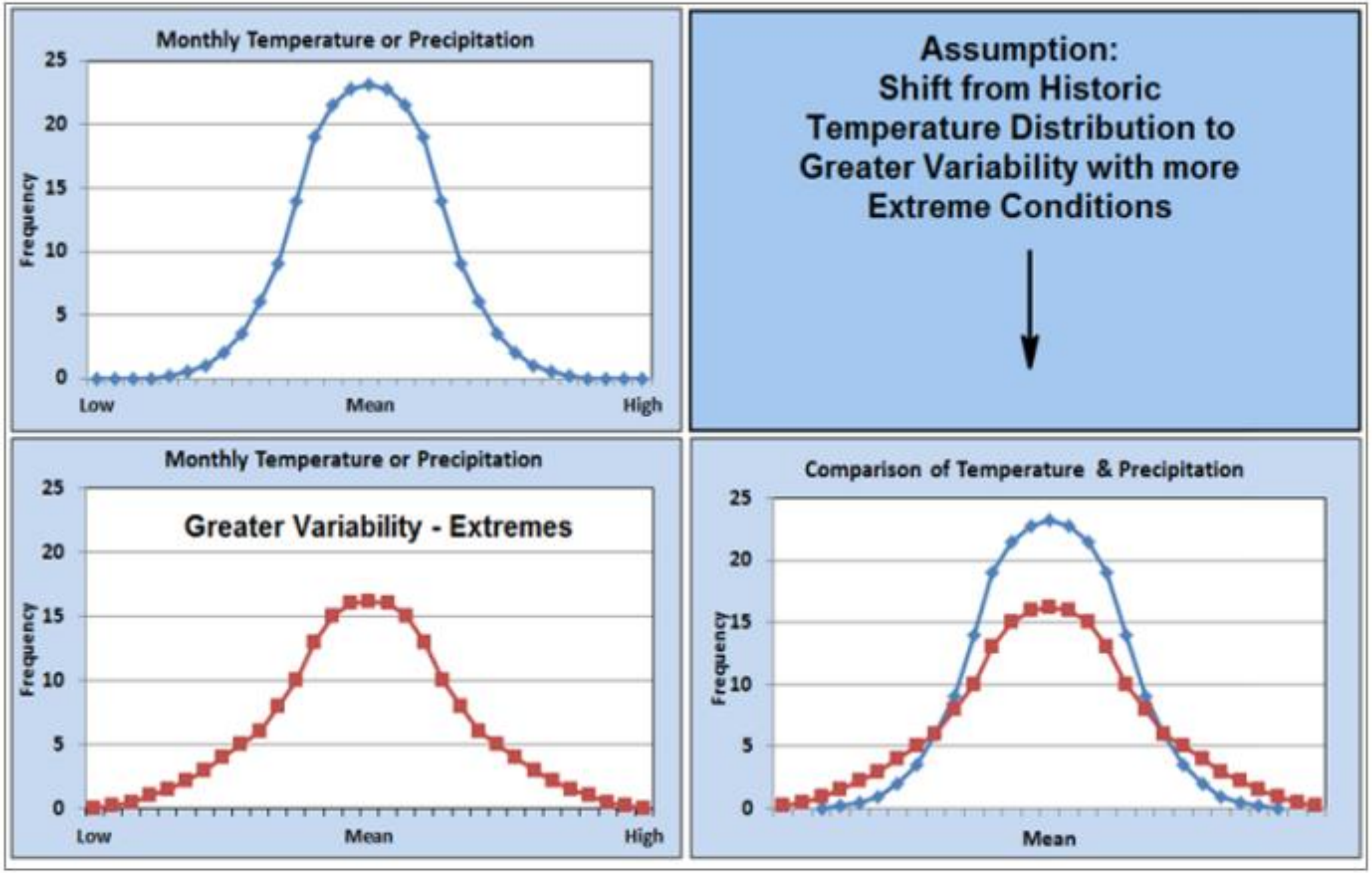
Frequency of Historic Temperature Data



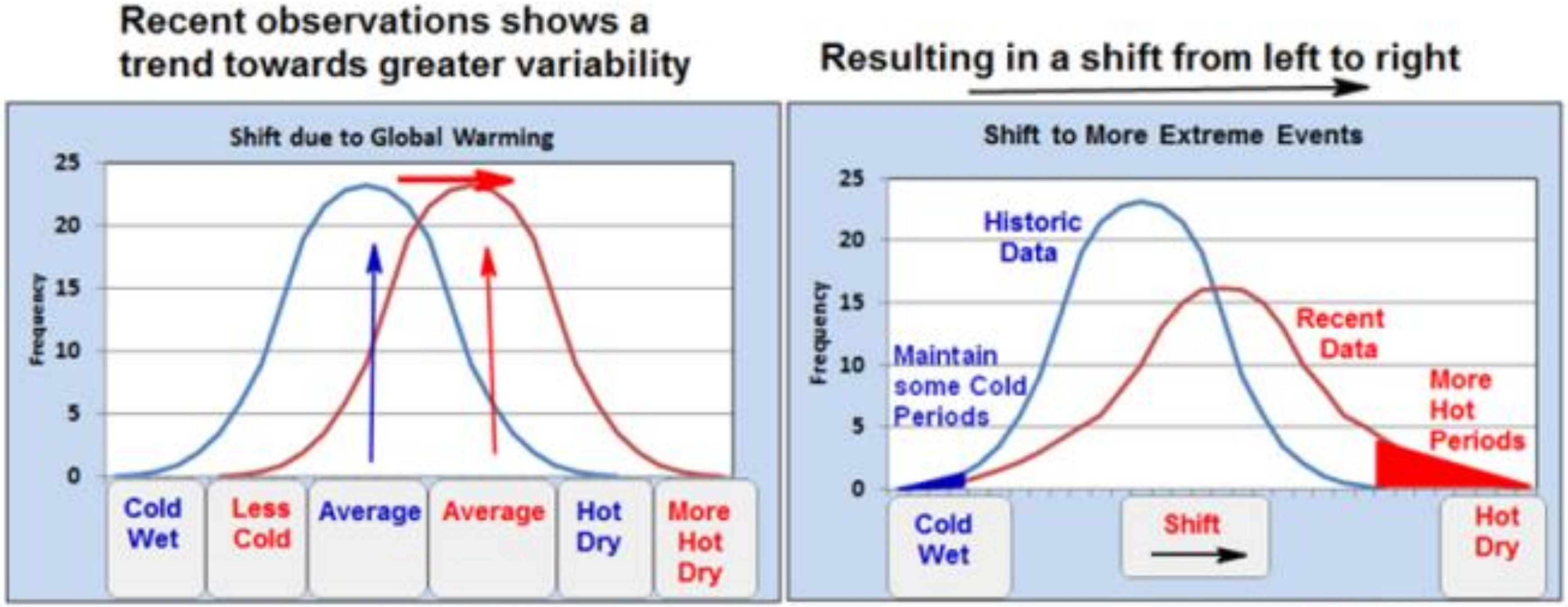
Shift due to Global Warming



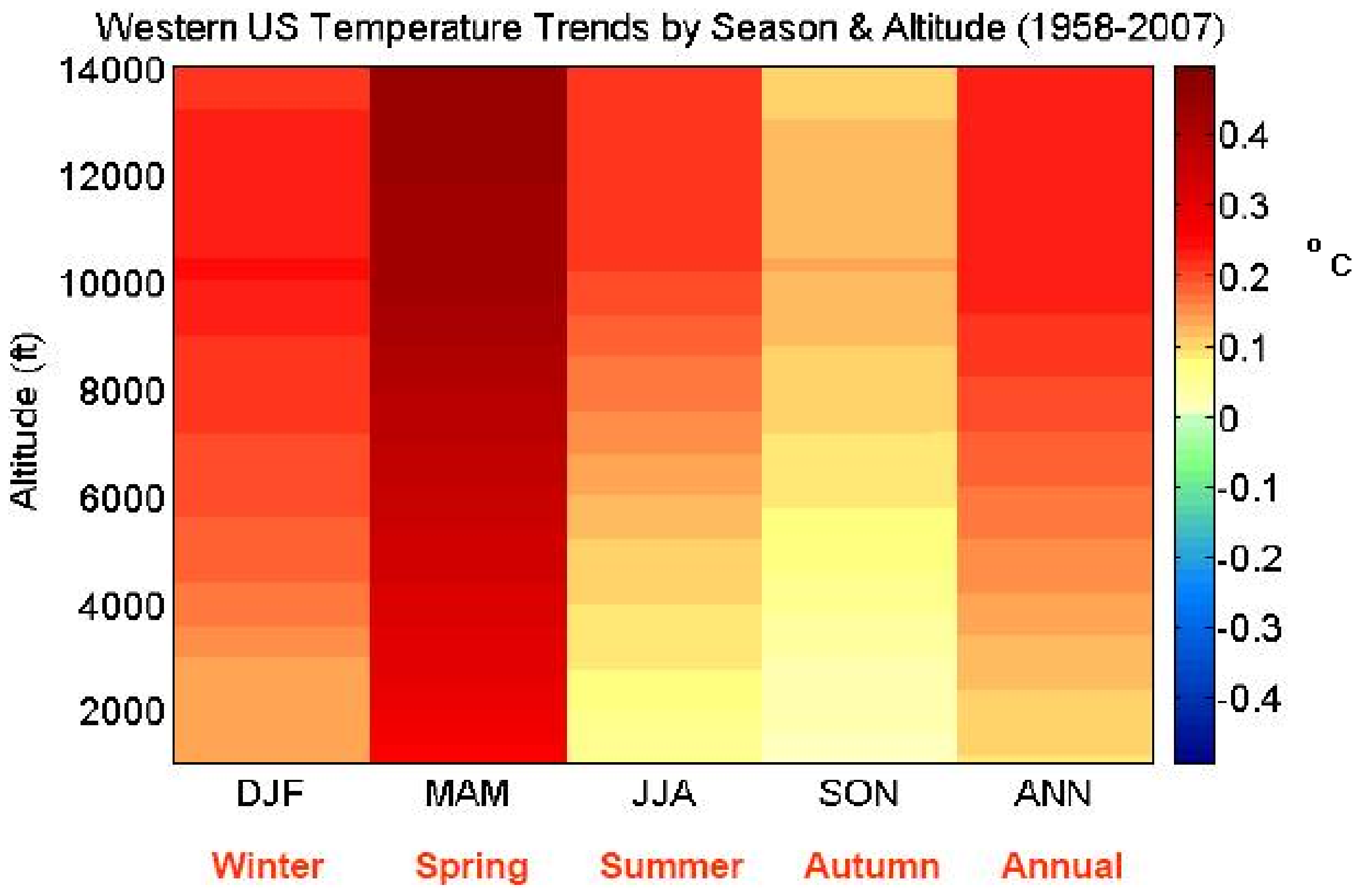
Different in Frequency Distribution Between Historic and Recent Temperature and Precipitation Data



Shift in Extreme Events - Greater Variability

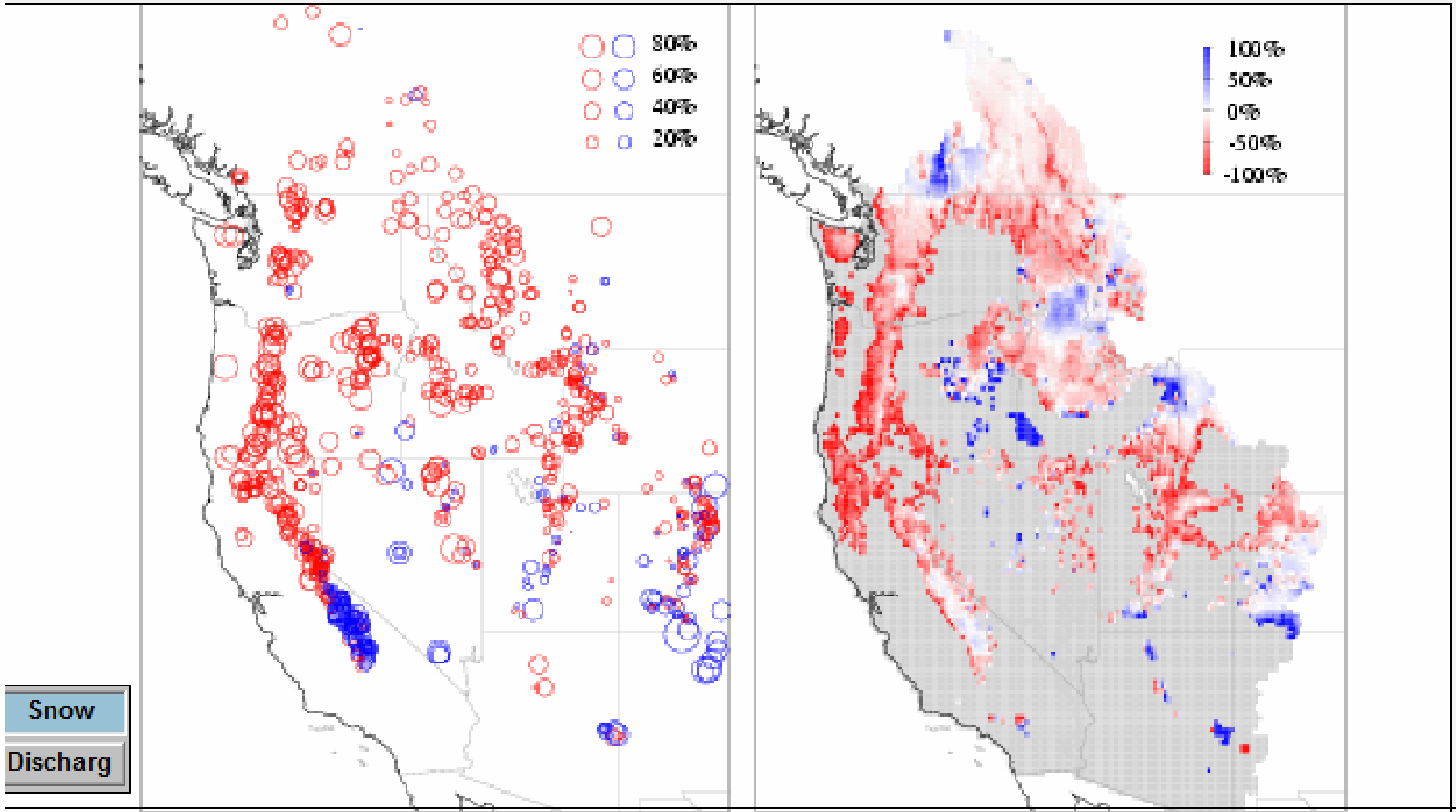


Results: We will have more extreme events but less frequent cold periods but more frequent hot and dry conditions

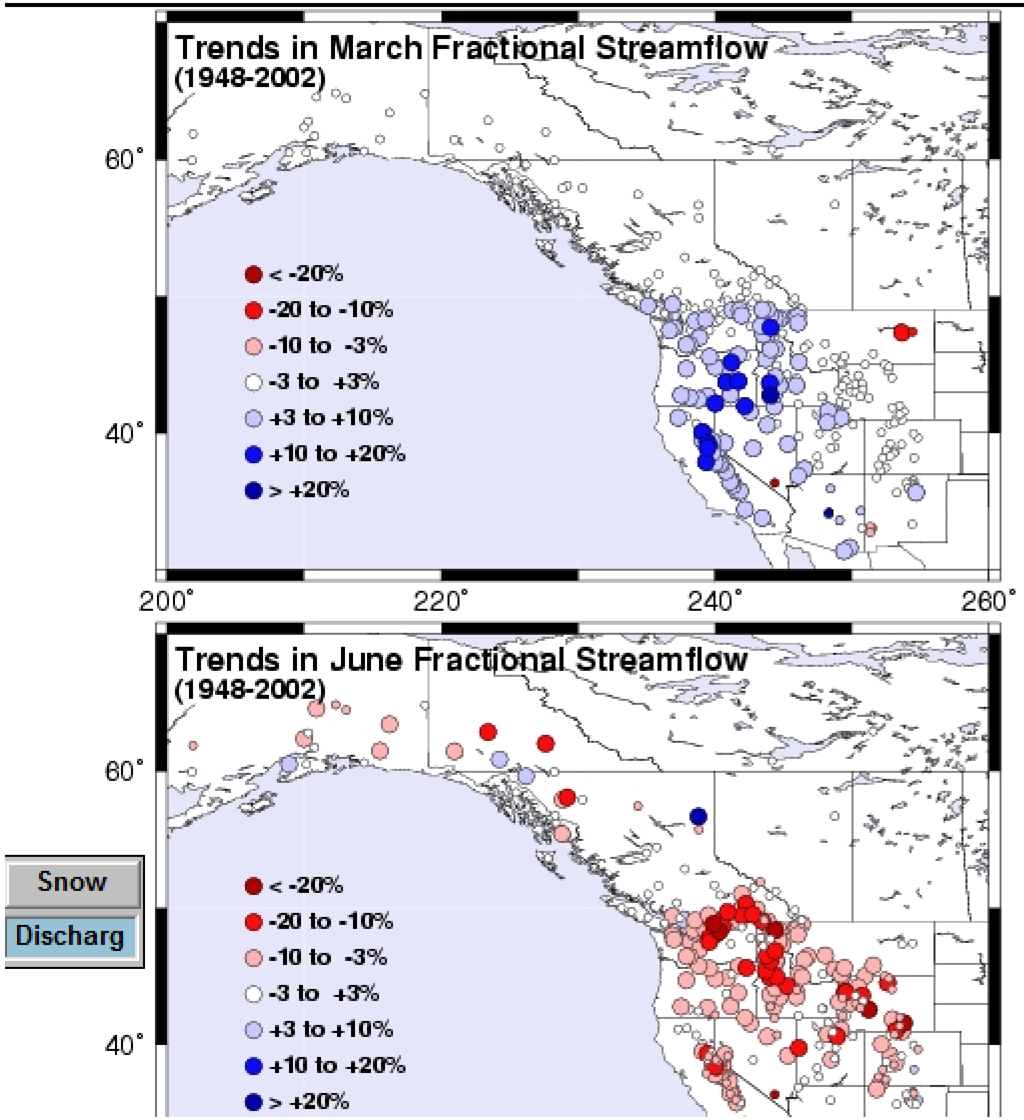


Redmond, K. and J. Abatzoglou. 2007. Recent accellerated warming in Western US Mountains. AGU, San Francisco, Desert Research Institute, Western Regional Climate Centre, Reno, Nevada

Trends in April 1 SWE 1950-1997



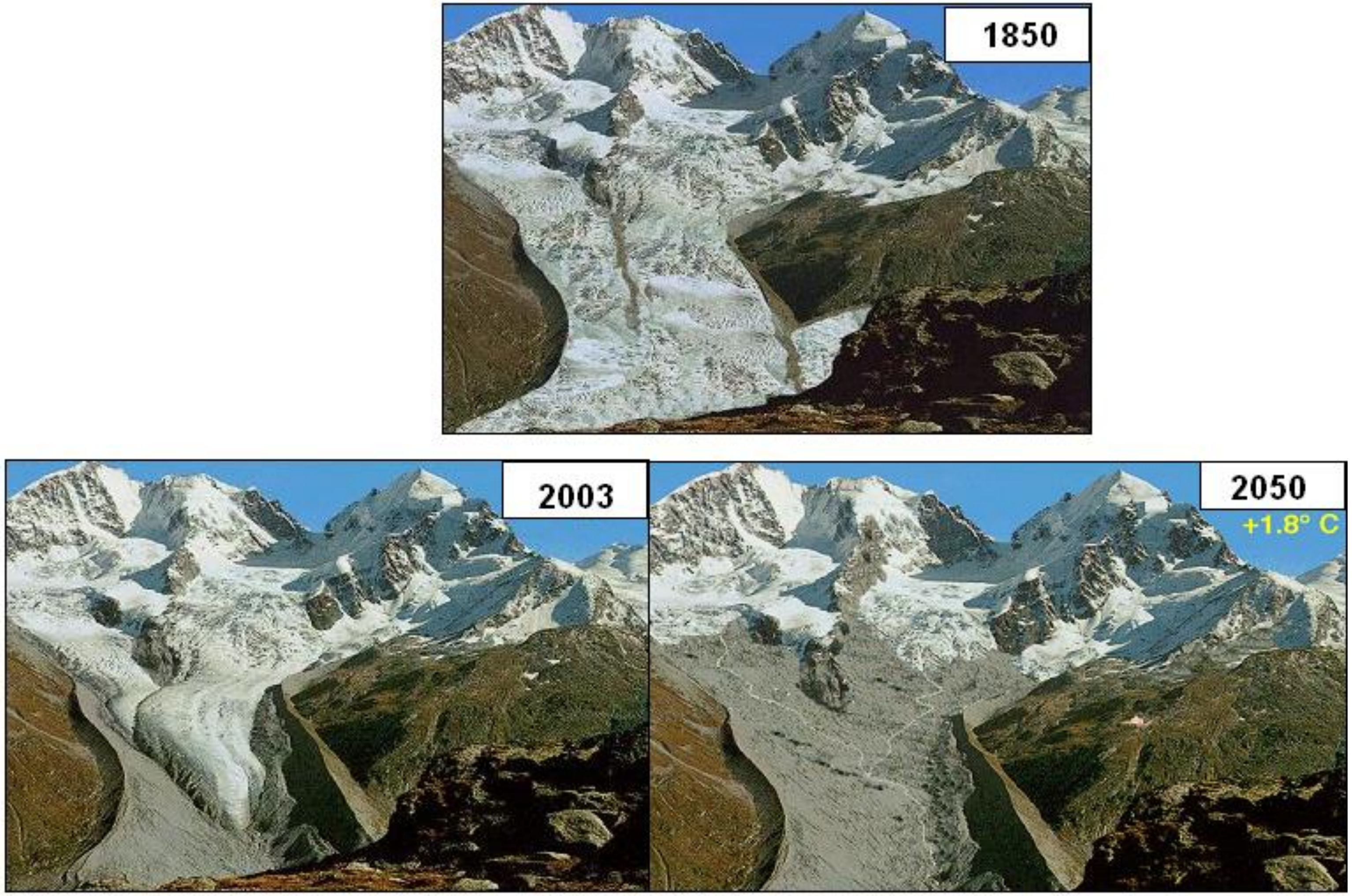
Mote P.W.,Hamlet A.F., Clark M.P., Lettenmaier D.P., 2005, Declining mountain snowpack in western North America, BAMS, 86 (1): 39-49



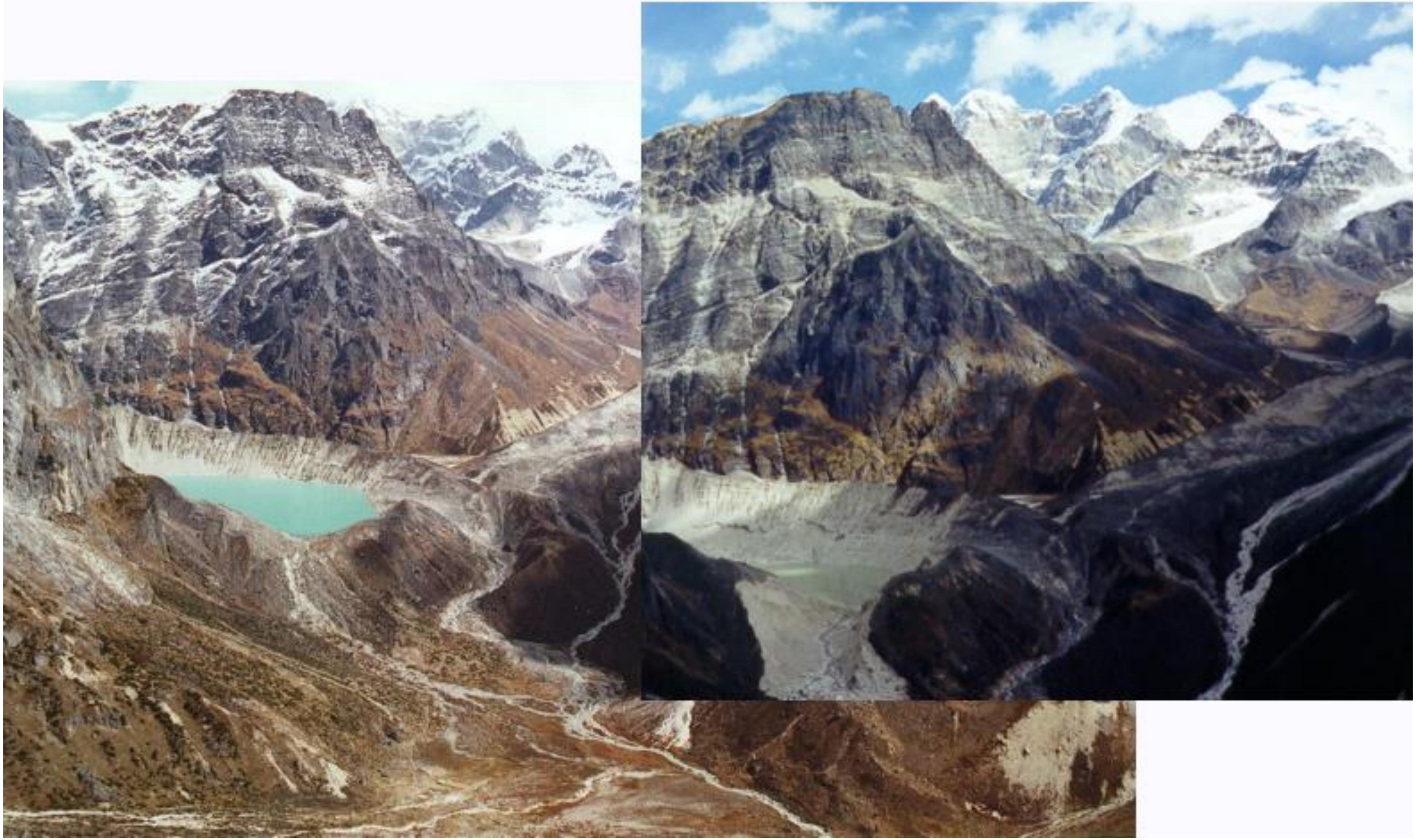
As the West warms, spring flows rise and summer flows drop

Stewart IT, Cayan DR, Dettinger MD, 2005: Changes toward earlier streamflow timing across western North America, J. Climate, 18 (8): 1136-115

Glacier Recession and Climate Change



Tam Pokhari Glacial Lake Outburst Flood

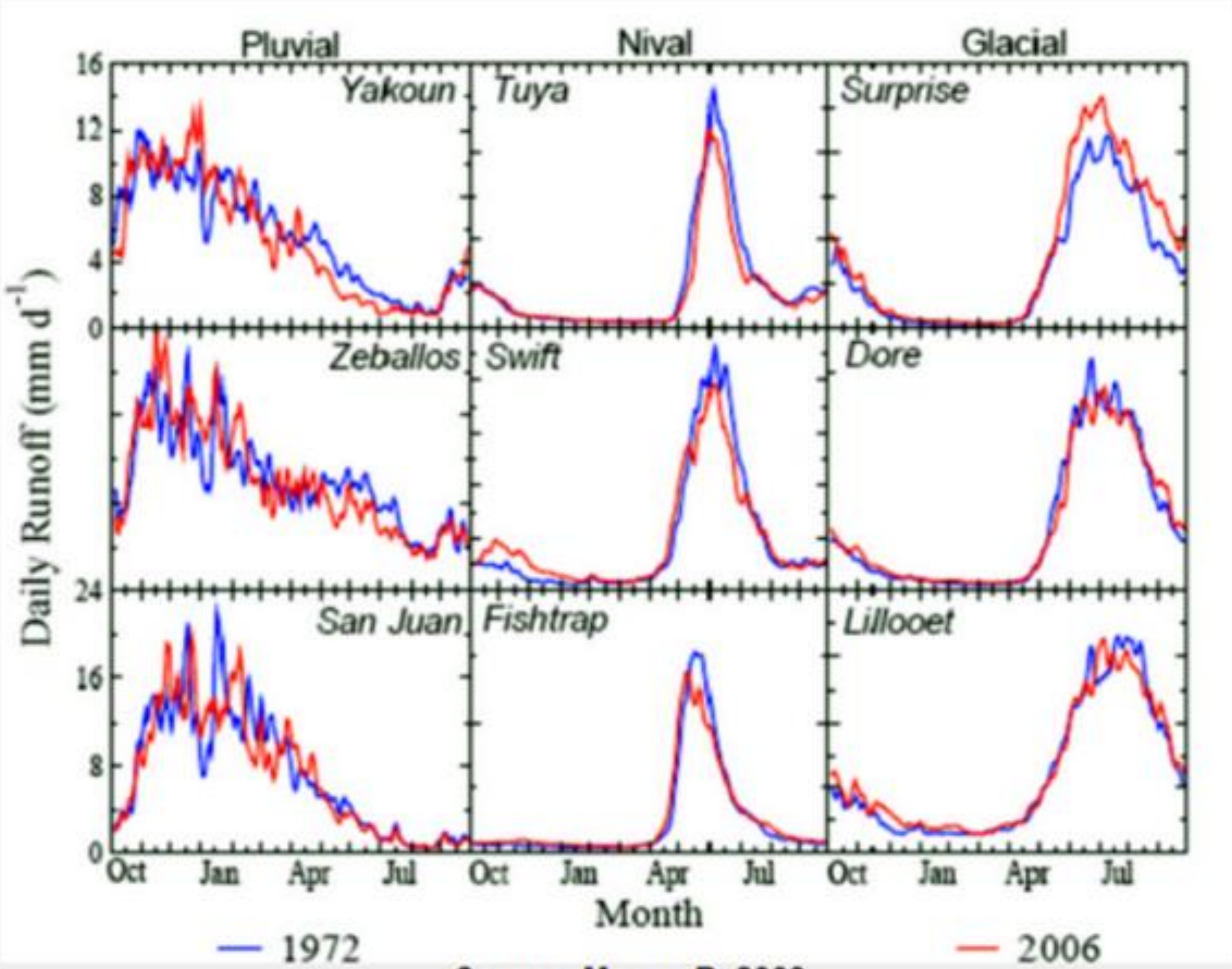


Tam Pokhari GLOF

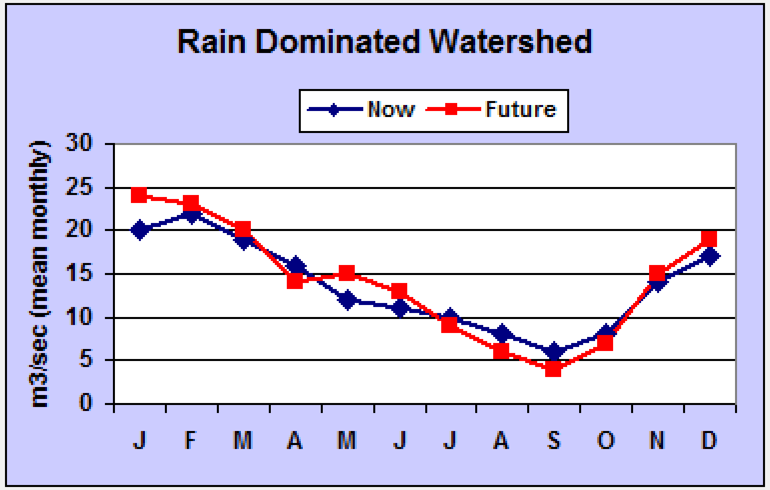
The GLOF seen from Thagnak (photo by: Lapka Goeljen Sherpa)

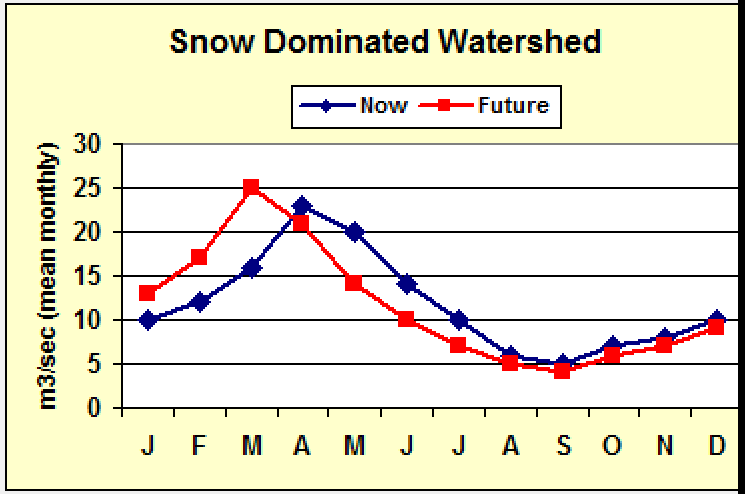

Inkhu Valley
before 1998
Inkhu Valley
After 1998

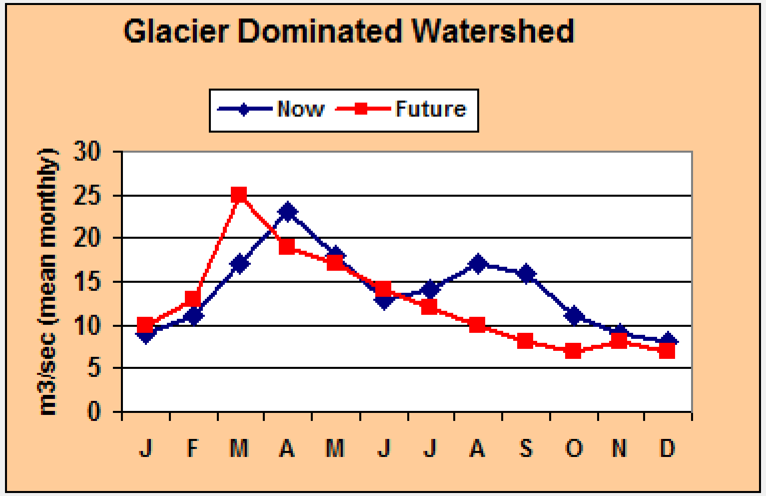
Differences Between Rain Snow and Glacier Dominated Streamflow



Source: Moore, D. 2009







Anticipated Hydrological Changes:

Greatest changes in glacier dominated watersheds

Major shift in peak and low flow in snow dominated watershed

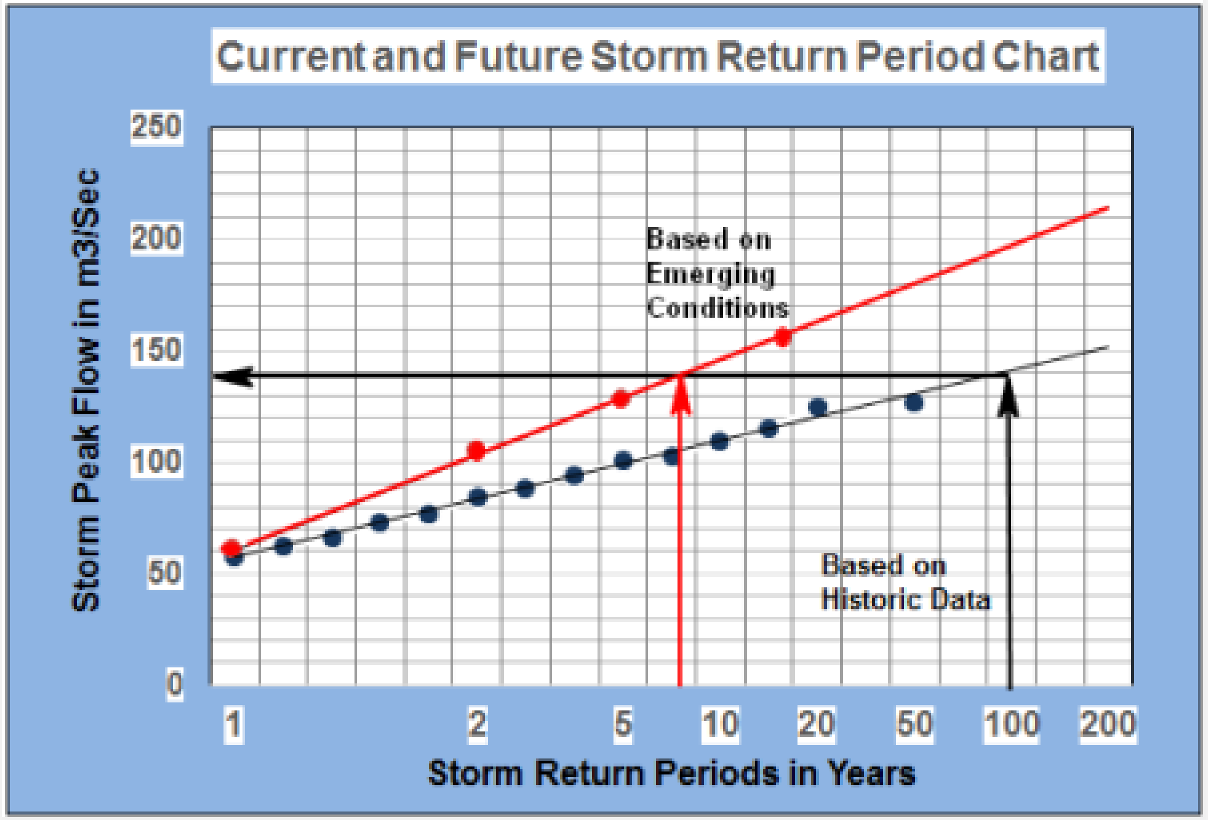
More variability in rain dominated watershed

3

Flooding

Fluvial Flooding: River Overtopping

Pluvial Flooding: Intensive Rain - Overland Flow

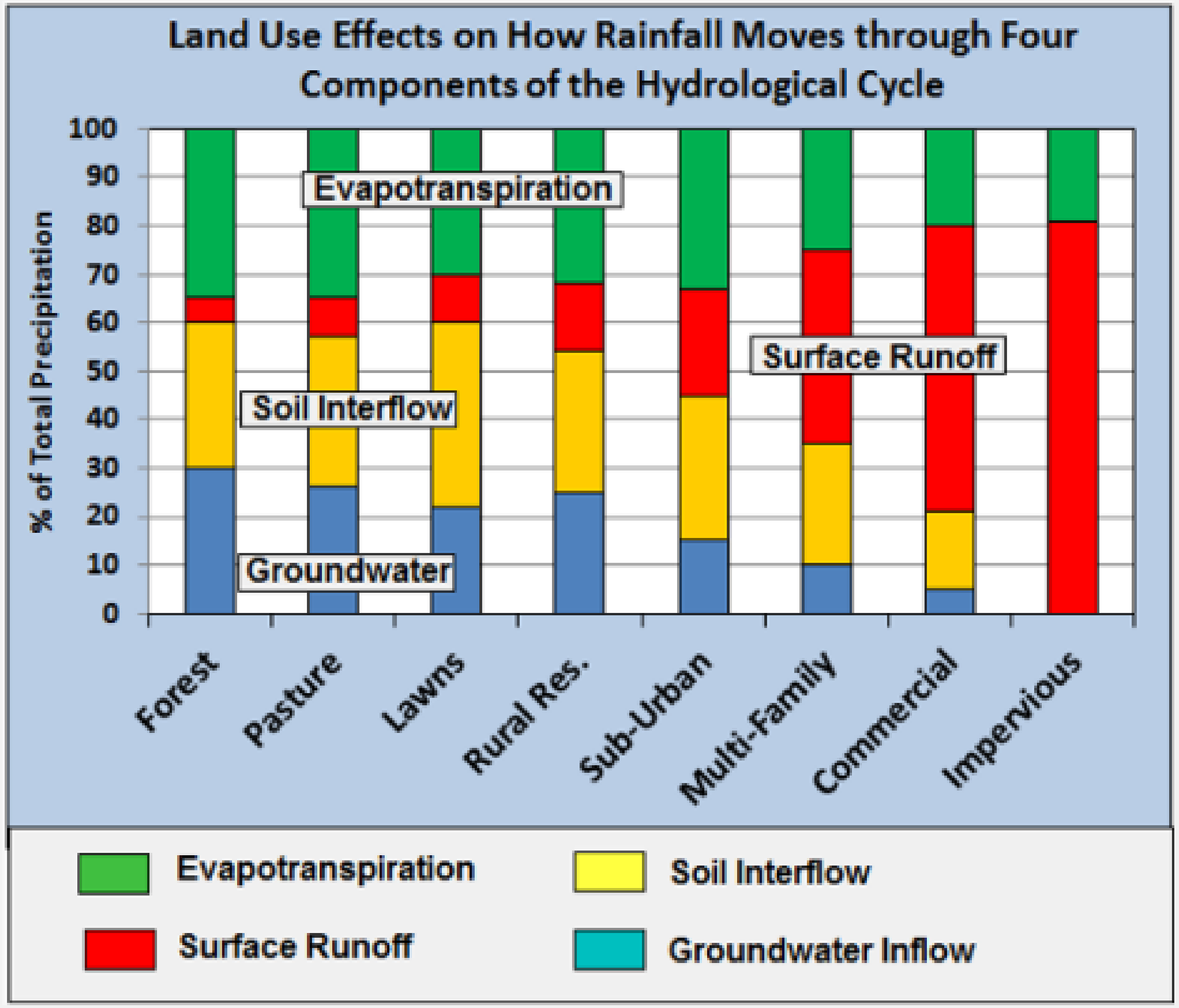


Storm Return Period Usually Based on Historic Precipitation Record (e.g. highest 100 Year event .
(IDF Curve + Intensity, Duration, Frequency of Rain)

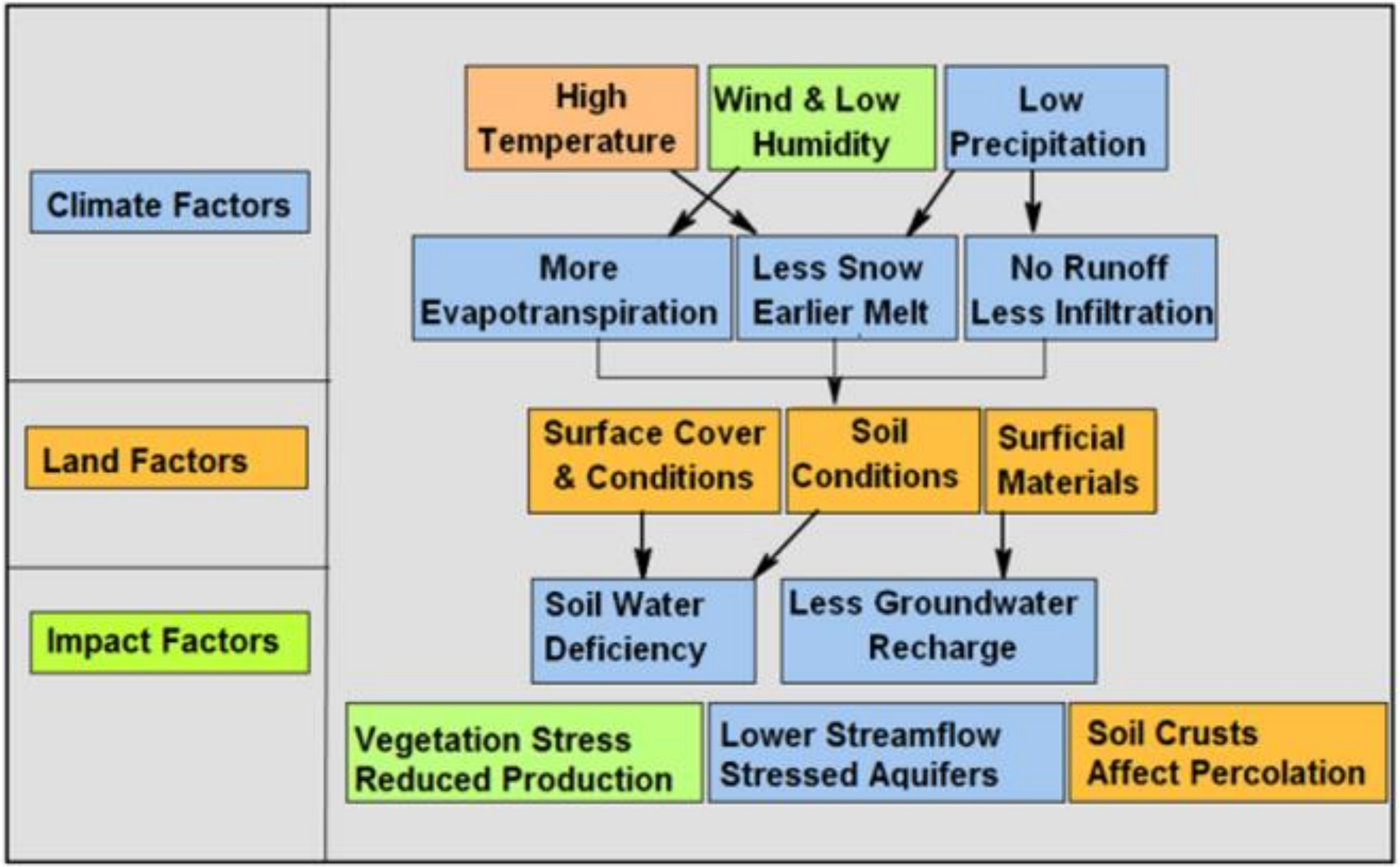
Problem: Runoff is a function of precipitation and land surface conditions.

Rainfall Redistribution by Land Use

Note: Change in Surface Runoff as a result of land use changes (in Red)



Drought Processes



Different Types of Drought

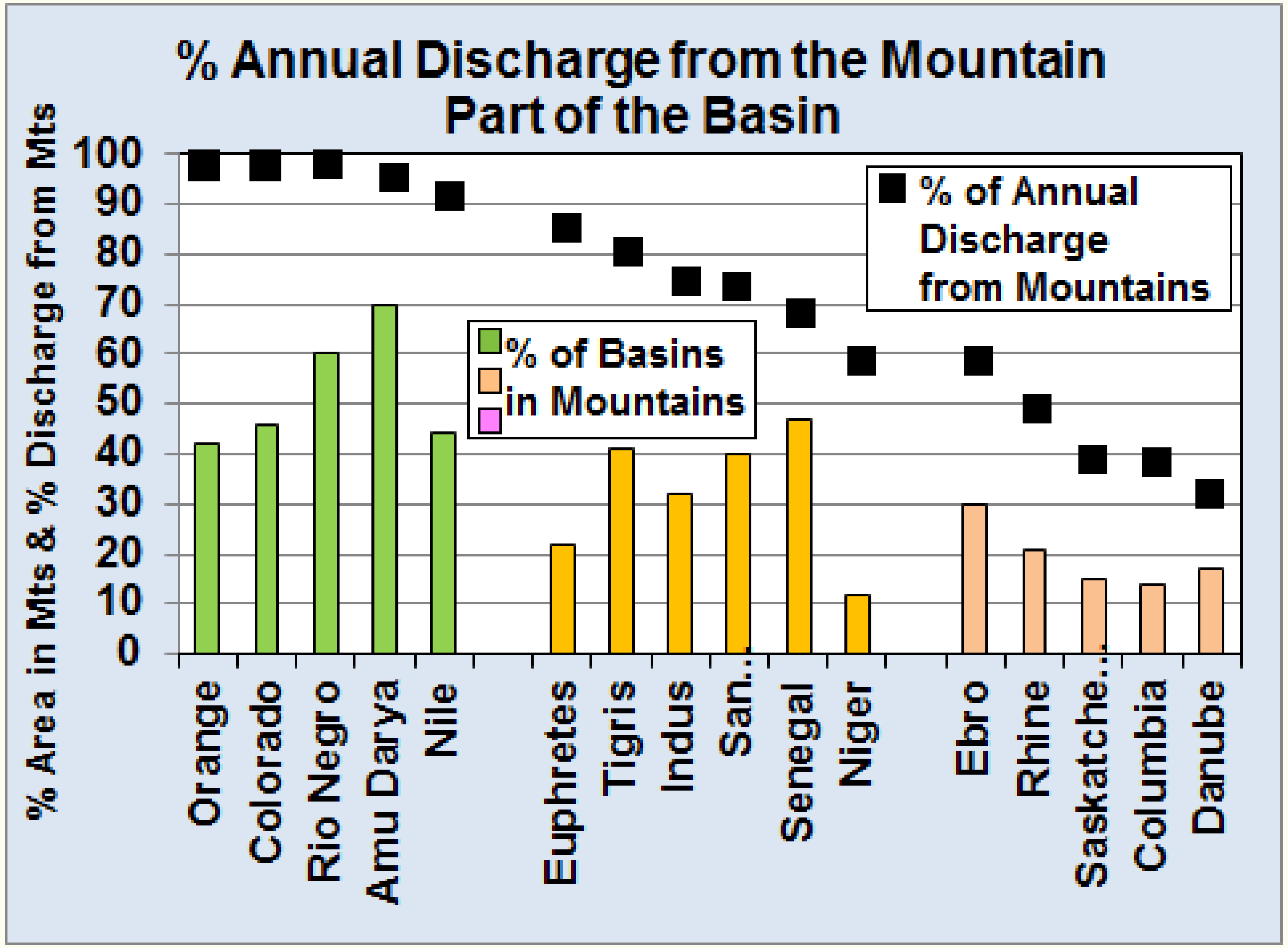
Meteorological Drought	A significant deviation from the long-term mean precipitation
Hydrological Drought	A major deficit in the supply & availability of groundwater and surface
Soil Moisture Drought	A major deficit in soil mosture as a result of Climate & Hydrology deficits

Groundwater Drought

Using Groundwater during a meteorolgical drought is often a good adaptation method but this will lead to aquifer depletion particularly during extended periods of droughts.

Impact Differences

Flood Impacts	Droughts Impacts
Flood impacts occur in individual watersheds Floodplains are the main impacted areas	Droughts cover very large areas The impact can be over large watersheds
The source of the flood water usually is long distance away from the flood impact	The impact is regional and not specific to floodplains
The impact is over relatively short time periods (Days-Weeks)	The impact is over longer periods (Months- Years)



% Annual Discharge from the Mountain Part of the Basin
% Area in Mts & % Discharge from Mts
100
90
80
70
60
50
40
30
20
10
0
% of Annual Discharge from Mountains
% of Basins in Mountains
Orange
Colorado
Rio Negro
Amu Darya
Nile
Euphretes
Tigris
Indus
San...
Senegal
Niger
Ebro
Rhine
Saskatche...
Columbia
Danube

Increasing Extreme Events

Accellerated Glacial Melt
Earlier Season Melting of Snowpack
Increased Variability in Snowfall
Requirement for Snow Making
Seasonal Advance of Peak Streamflow

Temperature Variability is Increasing
Increased Extreme Rainfall Events
Increased Windstorm Damage
Increased Flooding Events
Extended Low Flow Periods

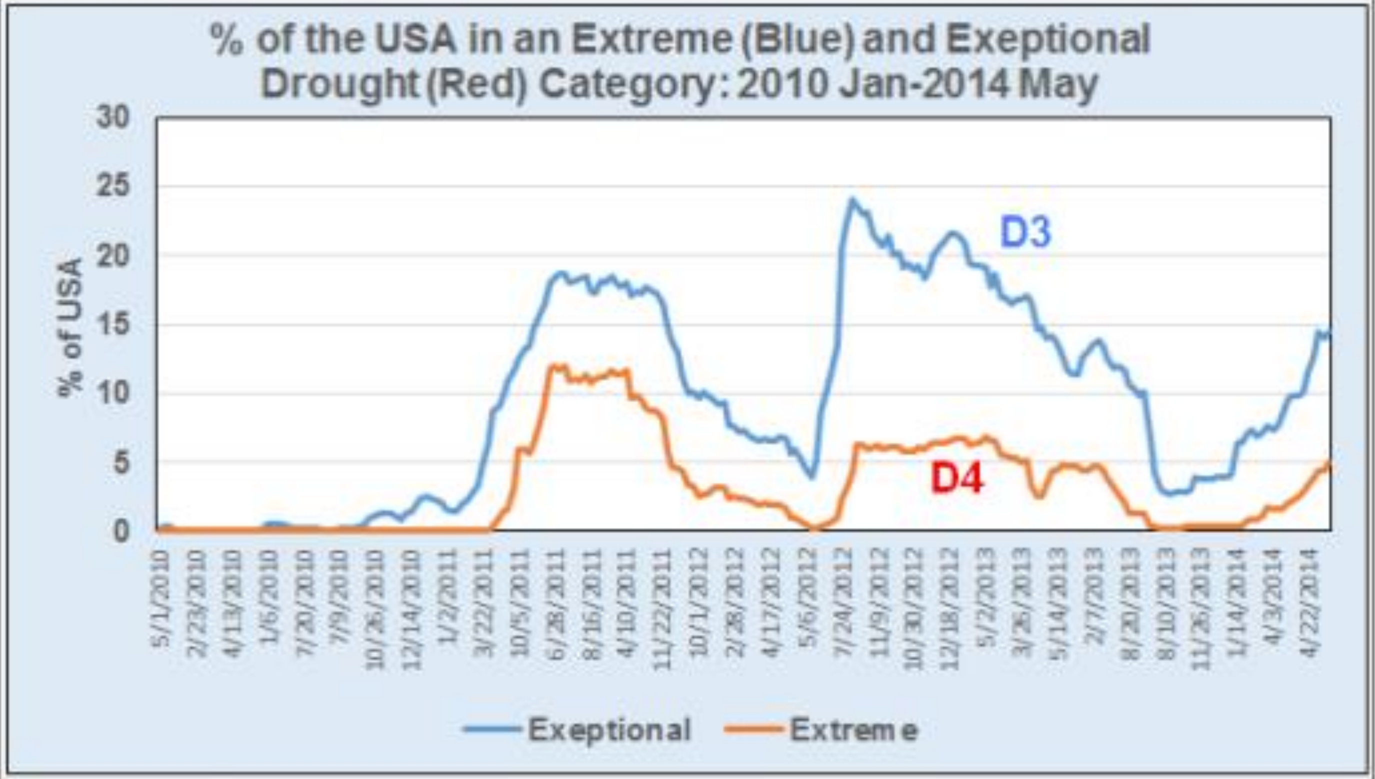
Important Consideration:
Increased Climatic Variability and Land Use Change Have a Profound Impact on the Hydrological Cycle

Separating the two factors is almost impossible !

Debris Flow in Switzerland. 2005

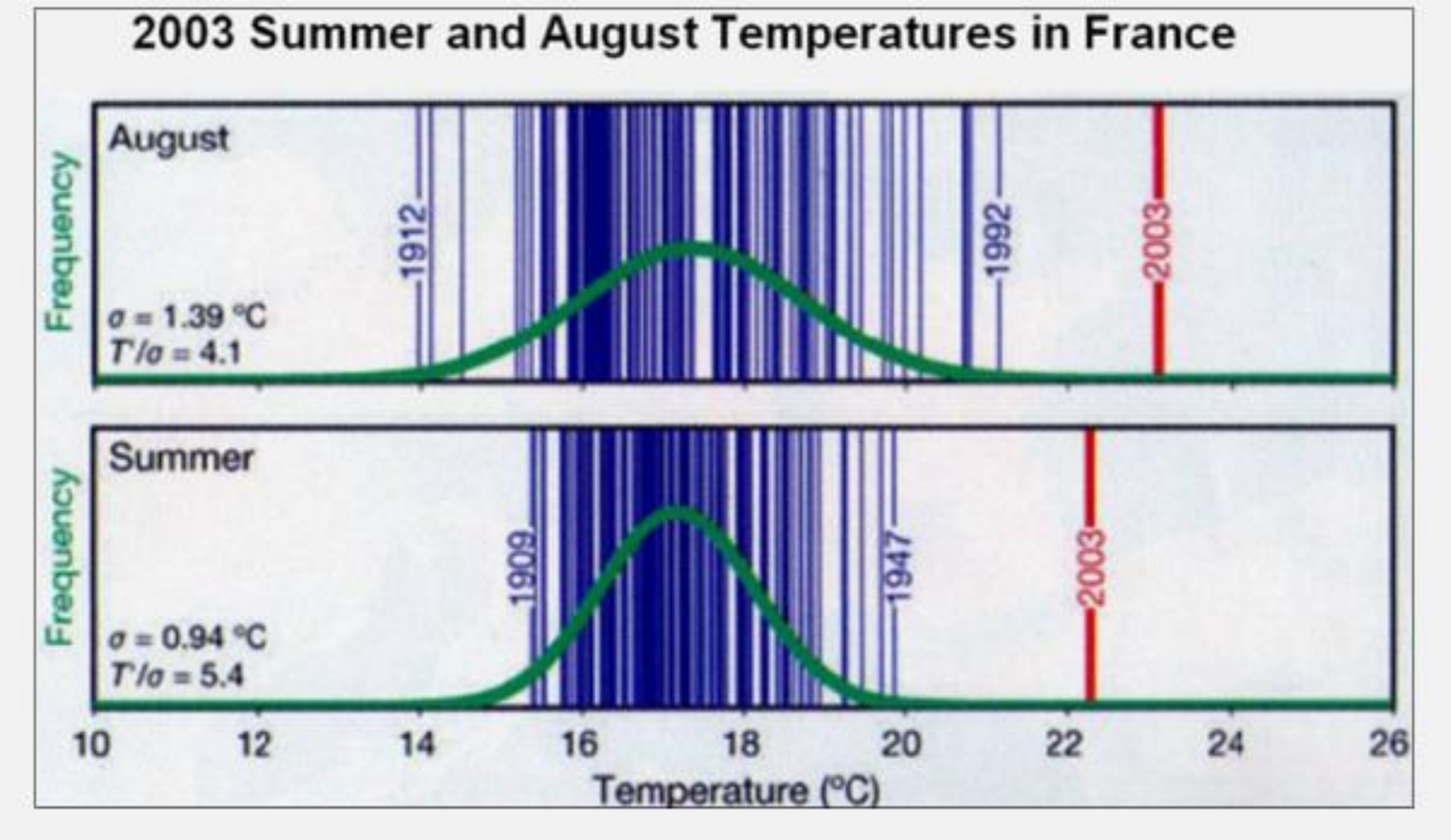
US Drought 2011-12

Recent Drought History in the USA 2010-2014

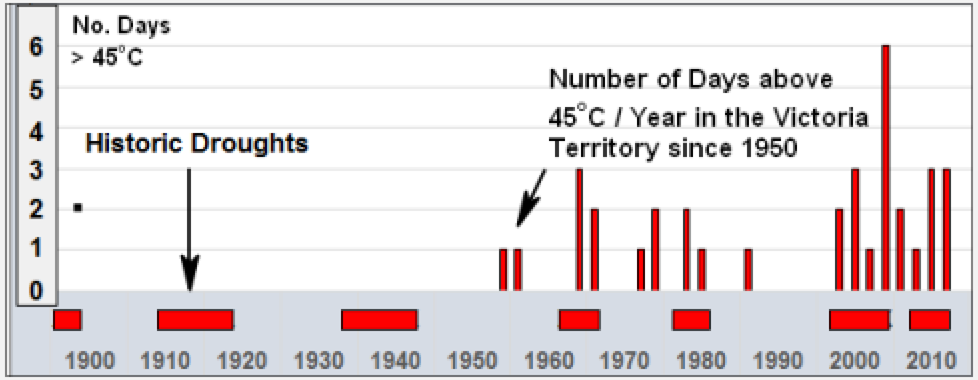


Drought Category	Description	Palmer Drought Index	CPC Soil Moisture %	USGS Weekly Streamflow %	Precipitation Index SPI
DO	Abnormally Dry	-1 to -1.9	21-30	21-30	-0.5 to -0.7
D1	Moderate Drought	-2 to -2.9	11-20	11-20	-0.8 to -1.2
D2	Severe Drought	-3 to -3.9	6-10	6-10	-1.3 to -1.5
D3	Extreme Drought	-4 to -4.9	3 - 5	3 - 5	-1.6 to -1.9
D4	Exceptional Drought	-5 or <	0 - 2	0 - 2	- 2 or <

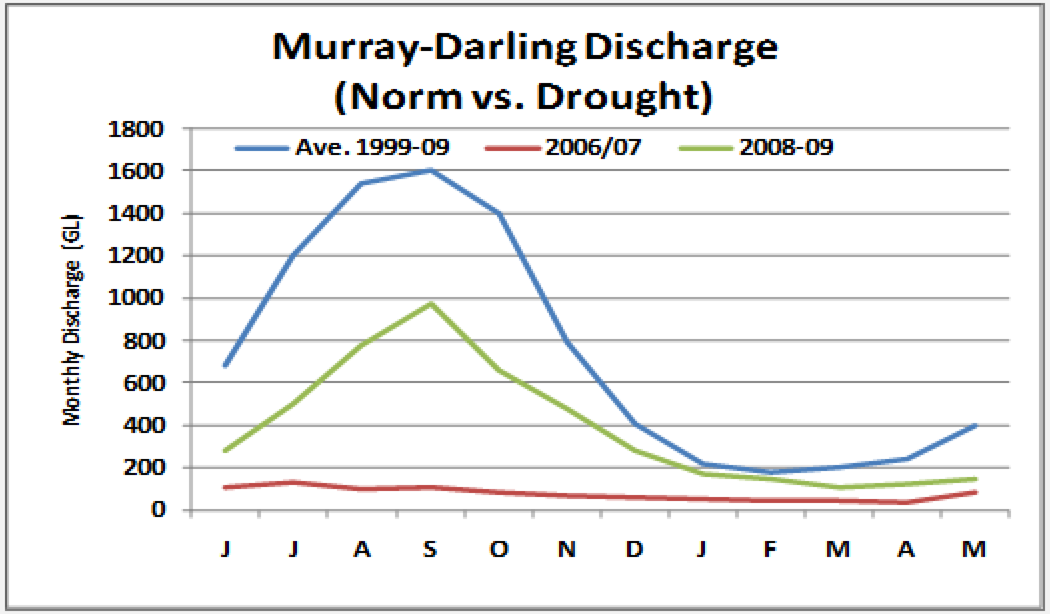
Data Source: USDA- US Drought Monitor 2014


2003 Summer and August Temperatures in France
August
Summer
Frequency
1912
1992
2003
1909
1947
σ = 1.39 °C
T'/σ = 4.1
σ = 0.94 °C
T'/σ = 5.4
10
12
14
16
18
20
22
24
26
Temperature (°C)

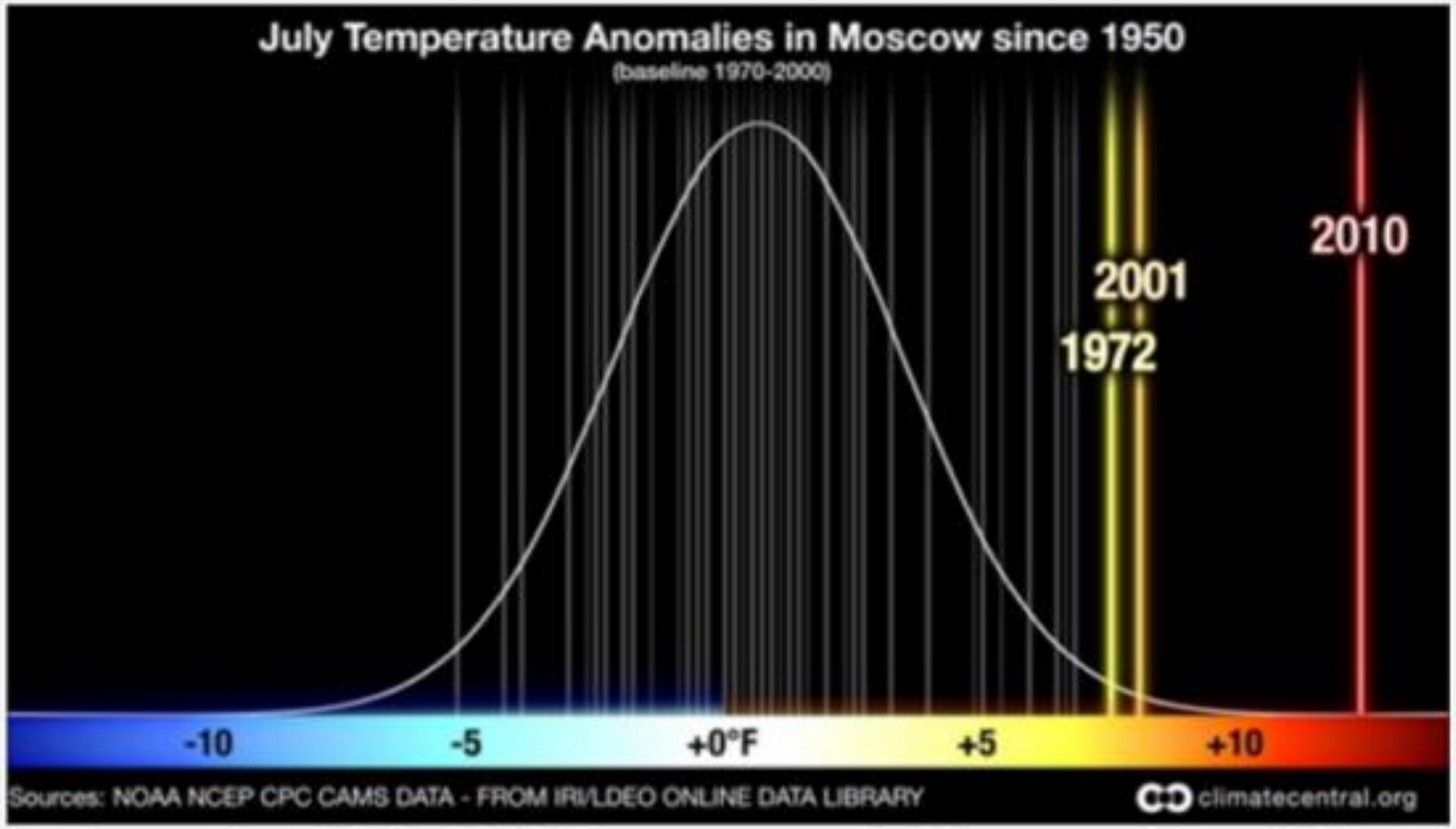
Australian Drought History and Days with Extreme Temperatures > 45°C



Changes in Discharge in the Murray Darling Watershed in Australia; Average Discharge before, during Peak of Drought 2006-07

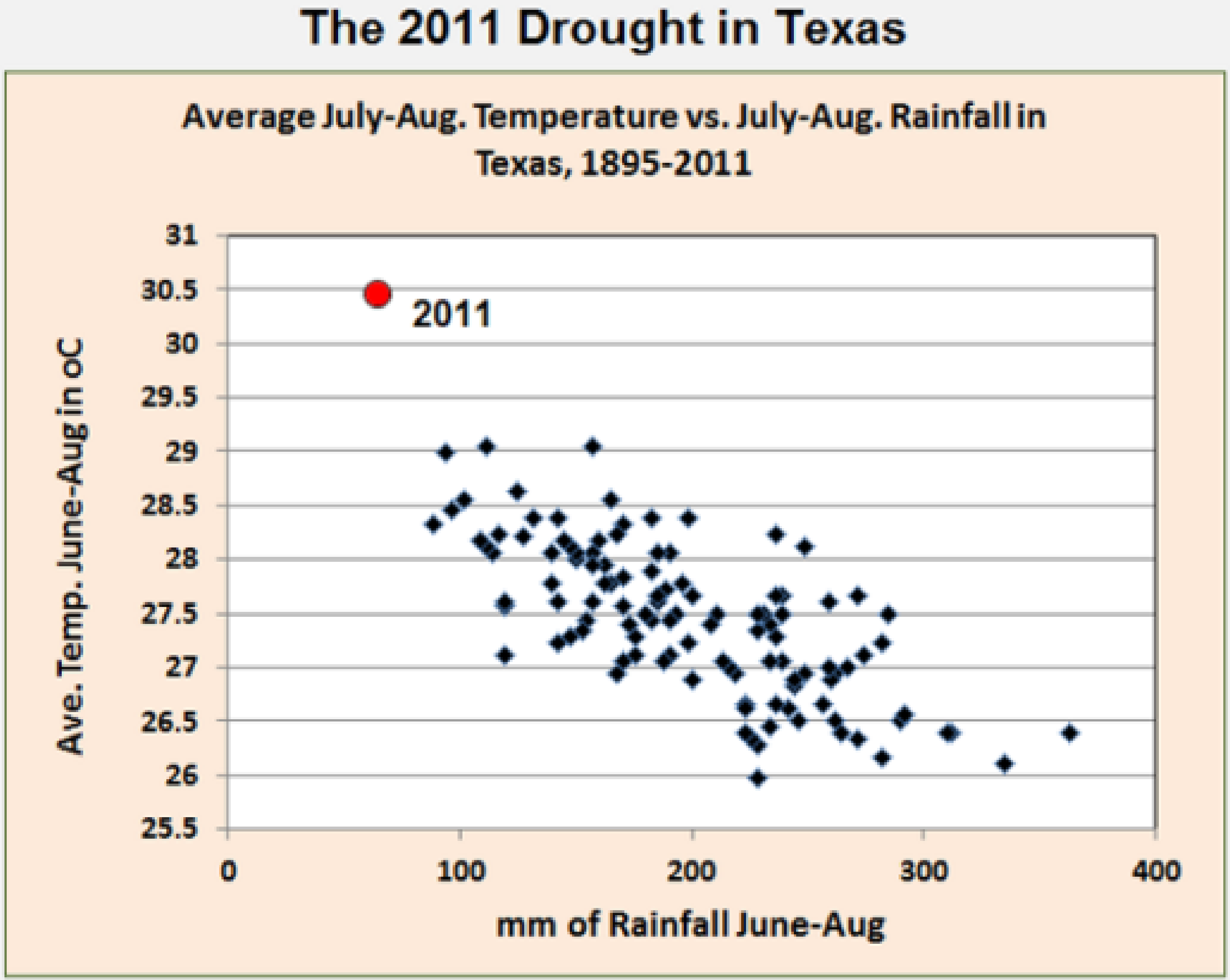


Extreme Temperatures in Russia in the Summer of 2010



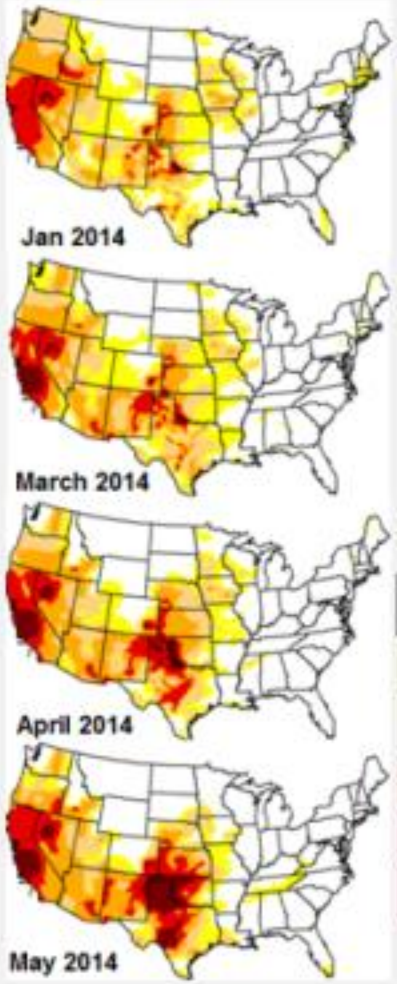
Anomaly of July 2010 Temperature in Moscow since 1950
Source: NOAA, Climate Central and Tebaldi & Ziemlinksi, 2010
(with permission)

Extreme Temperatures in Texas in the Summer of 2011

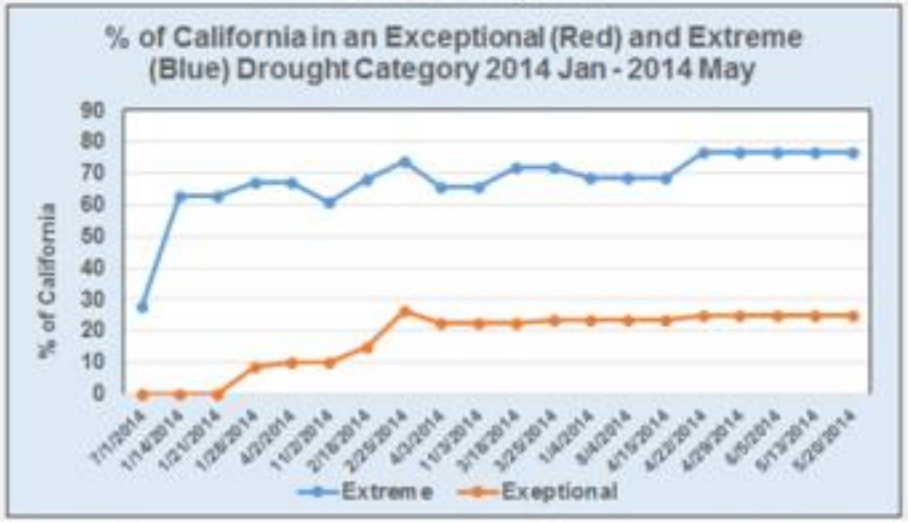


Data Source: J.Nielsen-Gammon, 2011

California Drought in 2014



California Drought 2014



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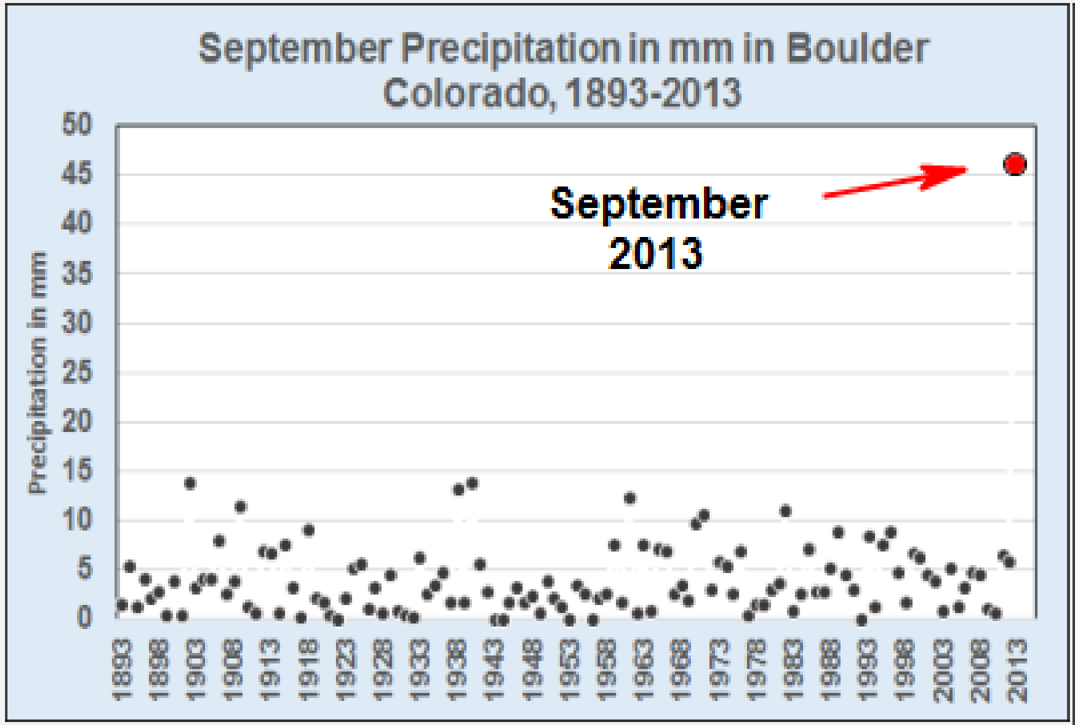
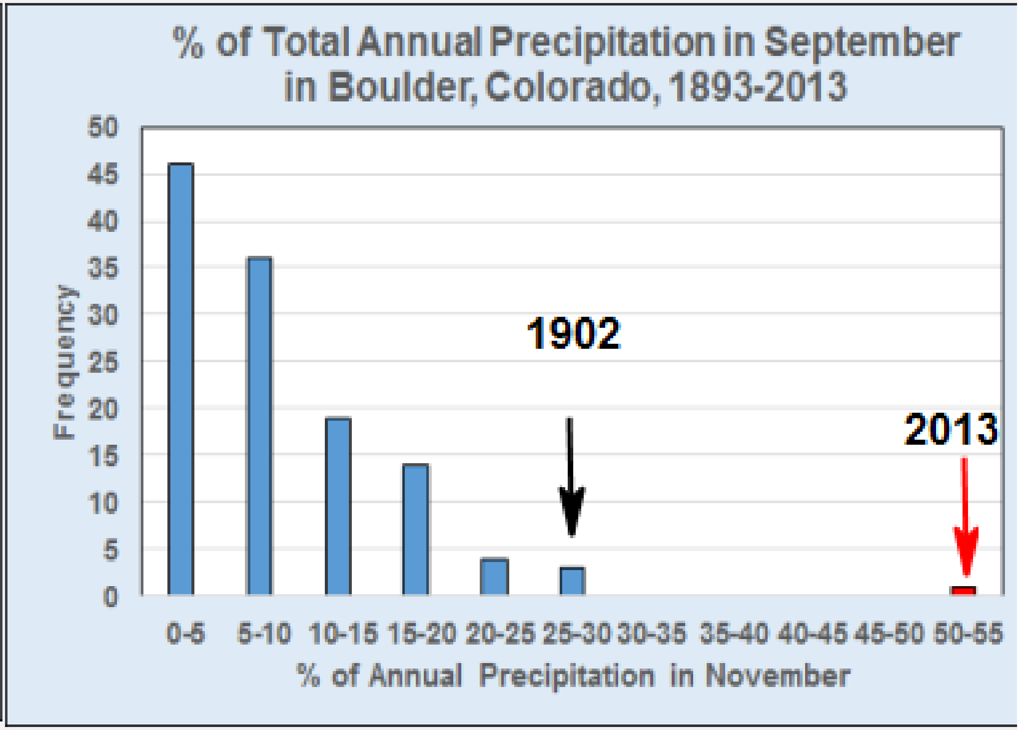
Data Source: USDA- US Drought Monitor 2014

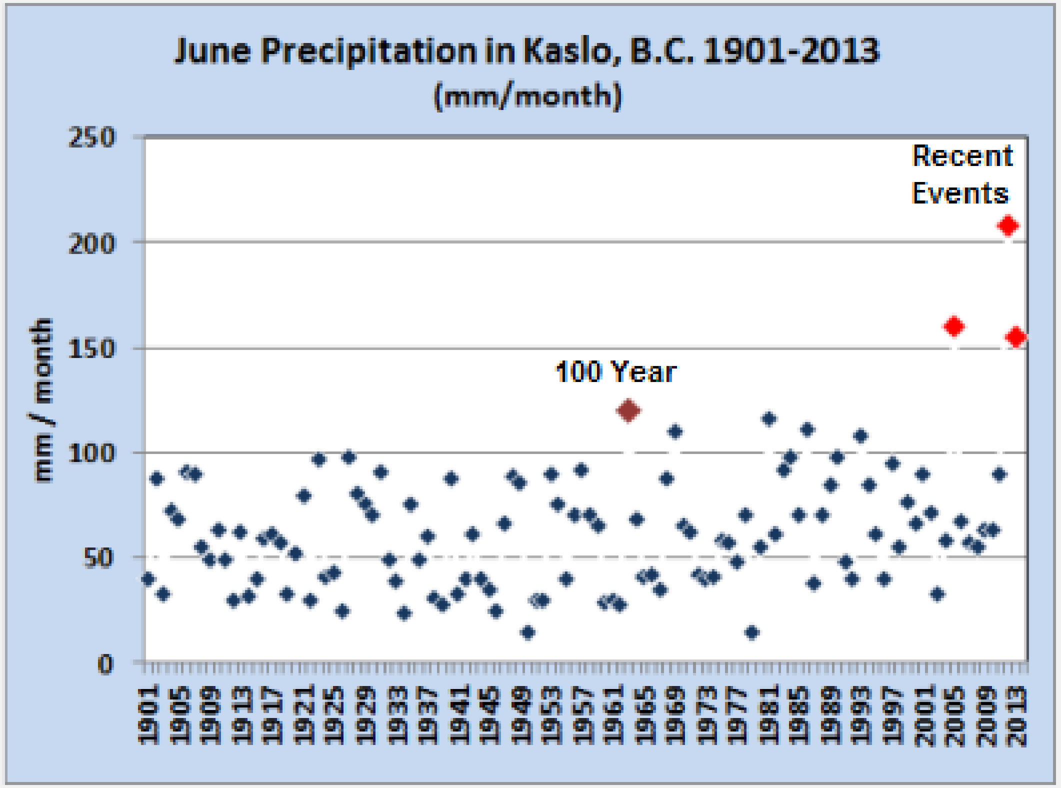
Extreme Precipitation Event in Boulder Colorado in Spetember

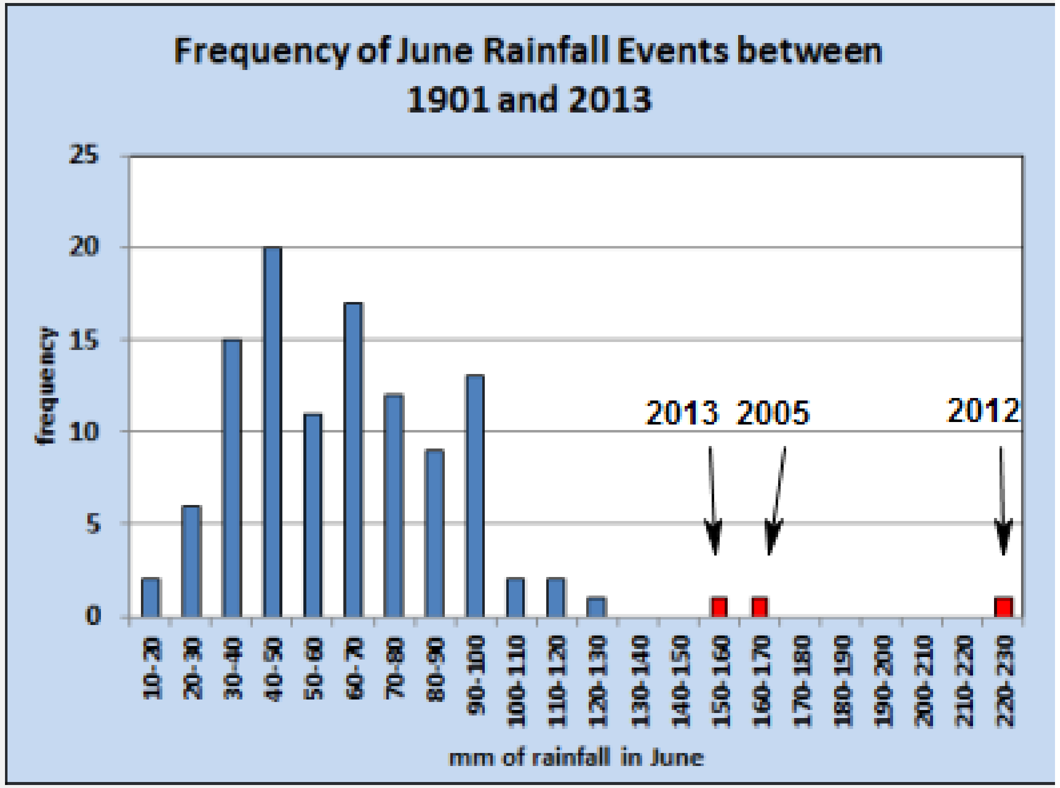




Over the 120 Year Historic Record the Average September Precipitation in Boulder, Colorado was 8.5% of the annual total.
In September 2013 it reached 53% of the annual total and the next highest were in 1902 and 1940 with 29% and 27% respectively.

Extreme Precipitation Events in (Kaslo, B.C.)



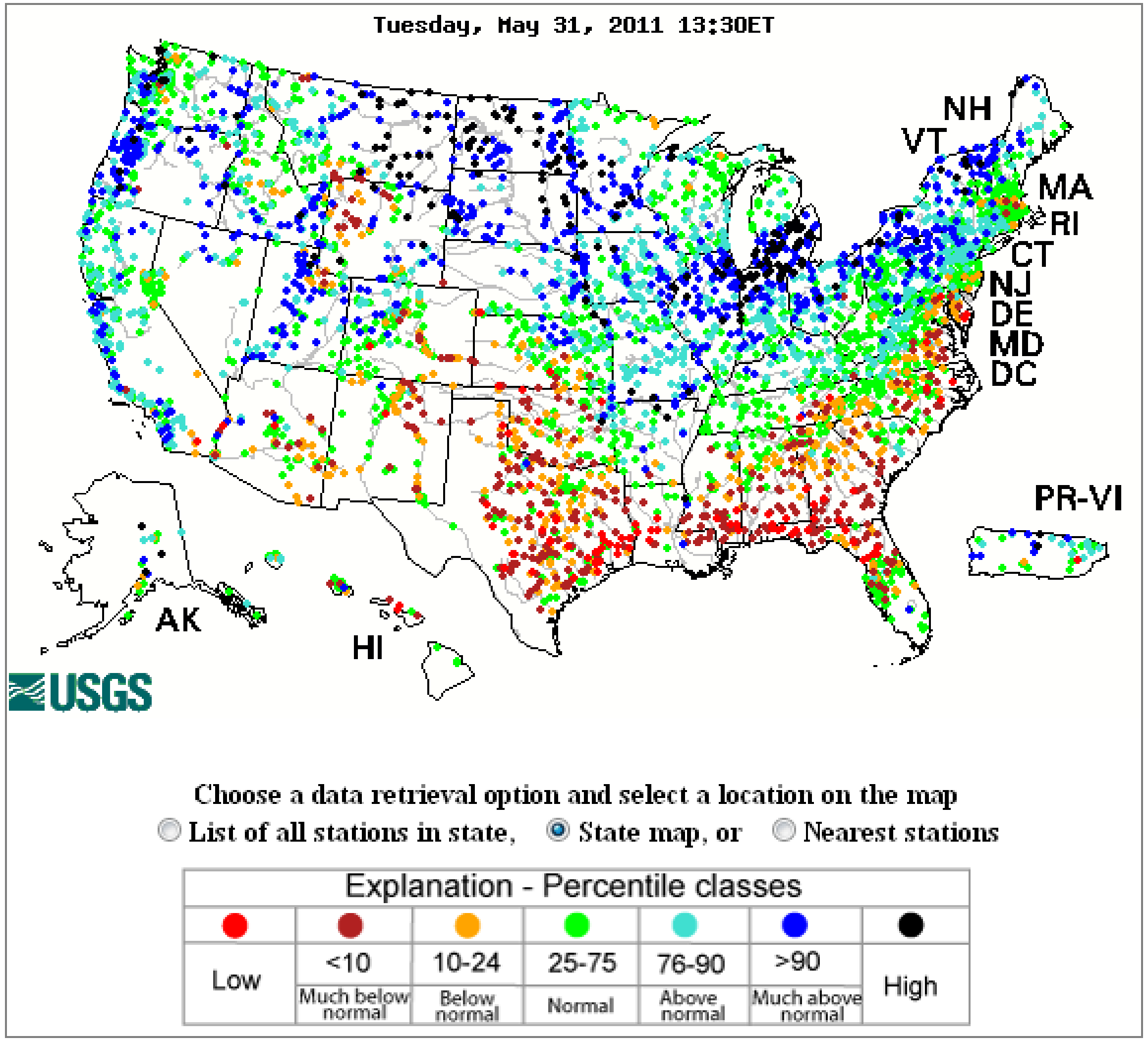


Stormwater Management and Design in usually based on the highest Historic Rainfall Event that occured over the past 100 Years. Kaslo's Design was based on the 1963 event that reached 125mm. Three recent events far exceeded this value and in 2013 is almost reached double the value obtained in 1963.

Floods and Droughts in the Same Basin at the Same Time

Hydrometic Data: USGS

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



Recent Flood Events

	$ 2 Billion Damage	$ 850 Million	$ 2 Billion Damage	Largest Nat. Disaster	Both Coasts	Largest Cyclone
Where	Austria Germany Poland	Toronto	Calgary	Colorado	Mexico Both Coasts	Taiwan Philipinnes China
When	June	July	July	Sept	Sept	Sept

2013 -2014

Recent Droughts

	Hottest Summer	7 Year Drought Hottest Temp	Hottest Aug Temp	Largest Drought since 1890	Drought US Mid-West	Drought California
Where	Europe France	Australia	Moscow	Texas	USA	USA
When	2003	2003-07	2010	2011	2012	2013-14

2003 - 2014

Impacts on Agriculture

Possible Impacts of Climate Change on Agriculture

Positive Impacts:	Negative Impacts:
▪ Extended growing season in higher latitudes and altitudes due to higher temperatures, smaller diurnal temperature ranges, and less frequent frost has the potential to grow more food and to introduce new crops ▪ Increased productivity due to enhanced CO_2 concentrations ▪ Accelerated maturation rates for crops Reduced moisture stress in some areas where precipitation is increasing ▪ Less crop damage due to less frost and snow and higher minimum temperature	▪ Greater problem with insect infestation due to higher temp. milder winters and longer season ▪ Crop stress due to extreme heat events and higher raters of evapotranspiration ▪ More extreme events can disrupt production (floods and droughts) ▪ Soil moisture stress in extended summers and higher temperatures ▪ Greater demand for irrigation water due to higher temperatures ▪ Heat stress on livestock & pathogens affect health Regional shift in crops & rotations might be needed ▪ Increased erosion and degradation due to increased variability and unusual events ▪ Elevated CO_2 levels and higher temperatures will increase weed growth, virus survival and can change distribution and frequency of pest problems ▪ May create a greater need for water conservation in agriculture and reduce irrigation in some areas

Possible Impacts of Climate Change on Water Resources

Positive Impacts:

- Some glacial fed rivers will have increasing annual runoff which can (for some times) result in expansion of irrigation downstream.
- In areas where stream discharge is increasing, pollution concentrations will likely decrease
- In areas with higher precipitation and higher temperature agricultural productivity can potentially be increased

Negative Impacts:

- Stream discharge is likely to decrease in many semi-arid areas due to increased evaporation and increasing demands for water (irrigation, urban)
- In snow dominated watersheds, the peak discharge will shift into late winter and will result in extended low flow periods in late summer
- Peakflow periods are expected to increase leading to more severe flooding
- The frequency and magnitude of storms is expected to increase, leading to flooding hazards
- Droughts are expected to become more frequent in already dry areas and will affect water supplies, groundwater recharge, fish survival.
- Streamflows reduction due to increased temp. will increase pollution concentrations in late fall
- Stream channel modification & changes in sediment transport are expected due to increased variability in discharge
- Storm management systems based on past hydrological events will need to be changed Increases demand & decreases water supplies

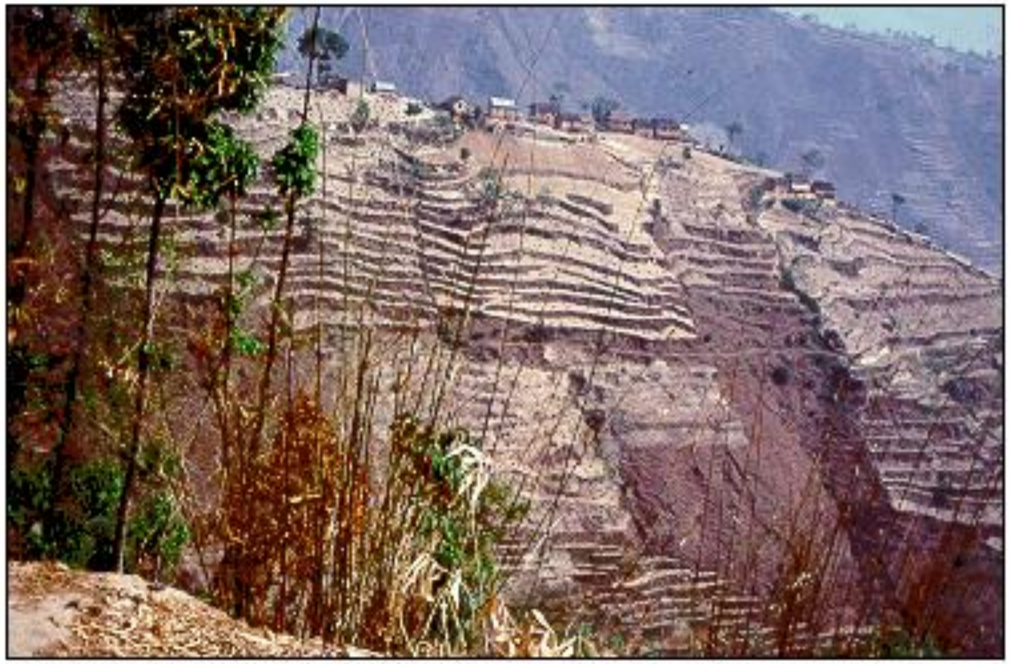
Issues to be addressed

	Intensive agriculture	Extensive agriculture
Importance of water		
Competing demands		
Impacts of agriculture on water		
Cumulative impacts		

The Risks of Expanding Agriculture onto Marginal Land:

Slope Failure
Soil Erosion & Sedimentation
Nutrient Losses

Typical Erosion Rates:
10-15 tons / ha / year



The Risks of Intensifying Agriculture in Mountains

Access to Inputs & Markets
Maintaining Soil Fertility
Irrigation Availability & Maintenance
Water Contamination (Eutrophication)
Increased Climatic Variability
High Labour Requirements

Downstream Impacts

Problem: Events in the Mountains have large Impacts Downstream

Adaptation

	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

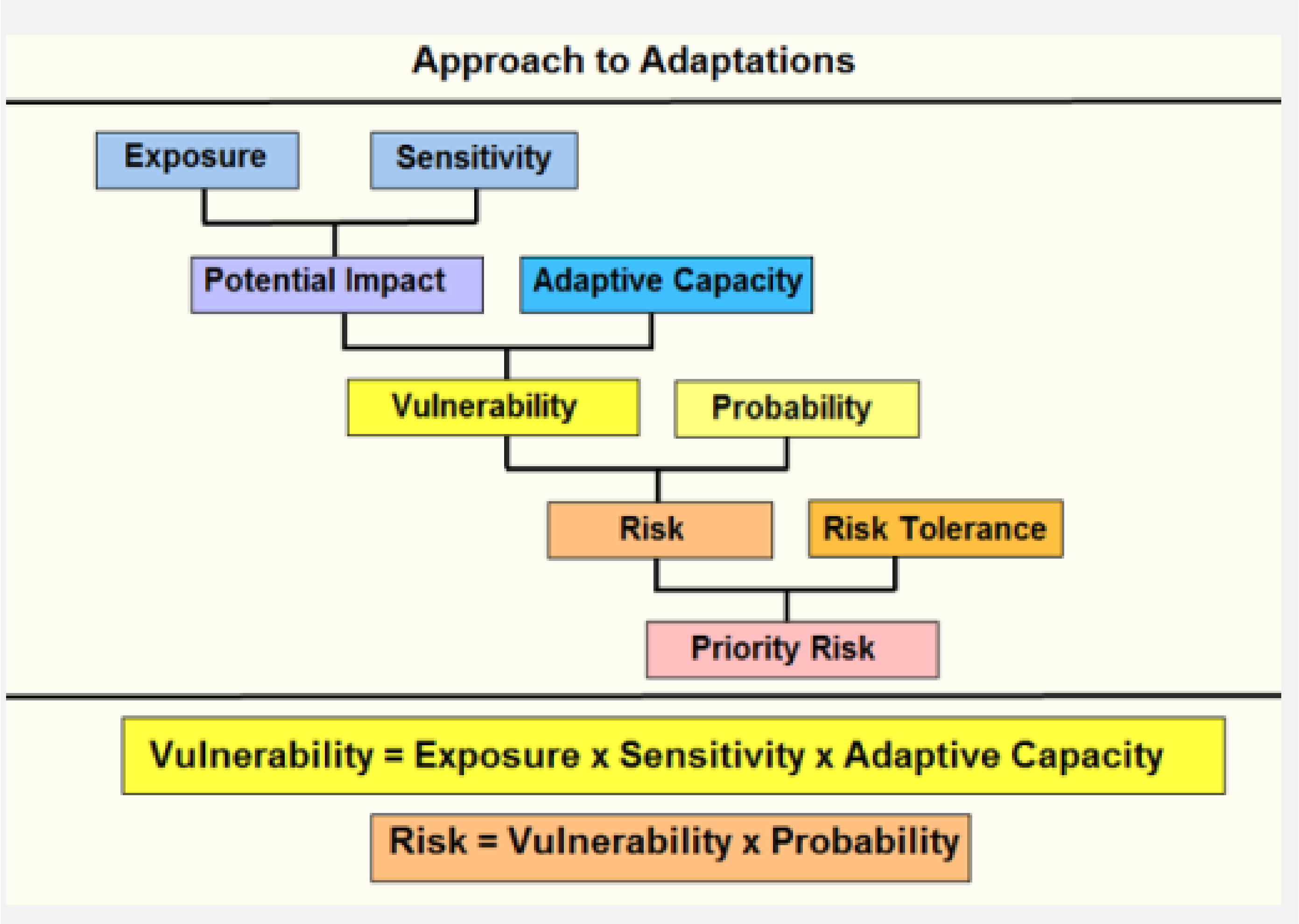
Adaptations

Increased Temperature	Agricultural Adaptations to Higher Temperatures
Crops	Heat tolerant crops, crop diversification, changes in crop rotation, select crops with lower rates of evapotranspiration
Irrigation	Improve use of irrigation water (sprinklers, drip), lined and covered channels, irrigate at night or early morning when evaporation is low
Soils	Minimum or conservation tillage to conserve moisture, summer fallow, maintain organic matter & infiltration rates
Grassland	Select drought resistant grasses, diversify species to prevent expansion of diseases
Livestock	Heat tolerant species, provide shading and shelter belts

Increased Precipitation	Agricultural Adaptations to Higher Precipitation
Crops	Expansion of rotation, shift in crops, introduce crops that suit new conditions, improve pest management,
Soils	Drainage improvements, avoid soil compaction, maintain soil structure & porosity
Livestock	Shift in grazing areas, modify feeding practices

Less Snow & Ice	Agricultural Adaptations to less Snow and Ice
Grass & Crops	Allows expansion into new areas (expanded grazing) Expansion of rotation, shift in crops, introduce crops that suit new conditions,
Irrigation	Water supply patterns will shift and provision need to be made for water storage for late summer irrigation
Long term Issues	Initial runoff will be higher and consistent but will decline as glaciers shrink

Extreme Events	Agricultural Adaptations to Increased Extreme Events
Crop Protection	Wind shelters, dykes, water detention ponds, designate designed flooding areas, buffer zones
Flooding	Increased flood risk may require shift in production, type of cultivation and soil protection
Soils	Increased erosion problems require conservation practices Requires improved sediment management


Approach to Adaptations
Exposure
Sensitivity
Potential Impact
Adaptive Capacity
Vulnerability
Probability
Risk
Risk Tolerance
Priority Risk
Vulnerability = Exposure x Sensitivity x Adaptive Capacity
Risk = Vulnerability x Probability

Priority Issues Identified by the Different Communities

Communities	Water Availability	Wildfire	Flooding Stormwater	Food Security	Infra-Structure	Tourism (Snow)	Energy
Elkford	3	1	2				
Kimberley	1	2			3	4	
Kaslo	1			2			
Rossland	1		3	4			2
Castlegar	1		3	2			

1	Highest Priority
2	2nd Priority
3	3rd Priority
4	4th Priority
	Minor Concern

Flooding Risk Assessment Summary

Vulnerability	**Very high** *(High sensitivity, low adaptive capacity AC)*	• Flooding of buildings and land • Damage to bridge		Damage to bridge	Flooding of buildings and land		
	High (High sensitivity, moderate AC or Moderate sensitivity low AC)	• Pumphouse floods and compromises water supply		Pumphouse flooding			
	Moderate *(Moderate sensitivity and adaptive capacity)*						
	Low *(low sensitivity moderate AC or moderate sensitivity high AC)*	•Stormwater management stress •Death/ injury to river users		Death/injury to river users	Stormwater management stress		
	Very Low *(Low sensitivity, high adaptive capacity)*						
			Unlikely to occur	**May occur once**	**Likely to occur at least once**	**Likely to occur several times**	**Occurs frequently**

Reasons for Climate Change Adaptation

Increased Climatic Variability

Higher Extremes
Floods & Droughts

Increasing Demand:

Urban Domestic Use
Agricultural Use

Limited New Uncontaminated Freshwater Sources
Water Contamination & Treatment Costs

Traditional Versus New Approach to Floodwater Management

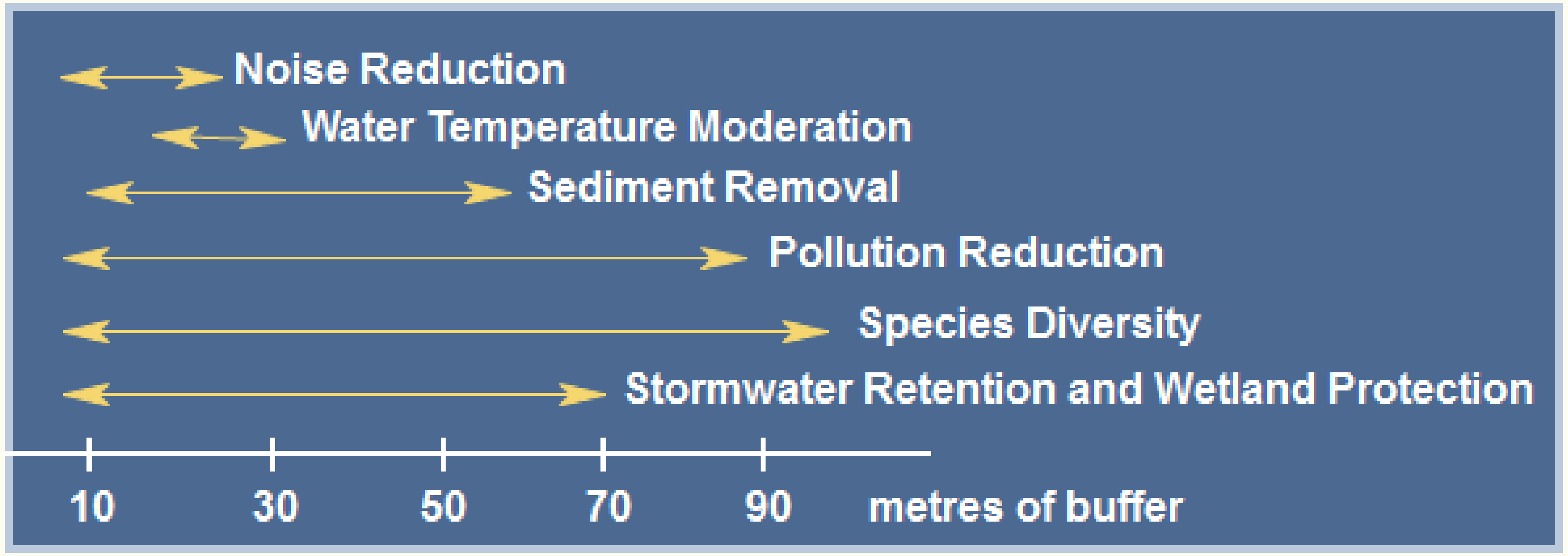
Traditional Approach	New Ecological Approach
Engineering, Structural	Natural, Ecological
Get water off the land as quickly as possible by conveyance using pipes, structural channels & build protective structures in lowlands	Spread & retain water on site by infiltration & detention to slow down & accommodate runoff. Mimic nature. Use soils, wetlands, buffers
Control Peak Flow ↔	Accept Peak Flow
Resist Disturbance ↔	Absorb Disturbance
Improve Prediction Capacity ↔	Unpredictable
Rigid Structural Boundaries ↔	Flexible Boundaries
Seek Stability ↔	No Equilibrium, Unstable

Floodwater Management Practices

Traditional Approach	New Ecological Approach
Engineering, Structural	Natural, Ecological
Upstream Quick flow & Conveyance Push high water downstream Stormwater Pipes Streightening Channels Armoring Channels	**Upsteam** Spread & retain water Infiltration and slow release Raingardens, Pervious Pavement Temporary Storage Ponds, Swales Wetlands, Wide Buffers
In Floodplain Structural Engineering Dykes, Levees, Dams Protection Systems Flood Proofing Non-structural: Zoning	**In Floodplain** Recreate Natural Channels Wide Riparian Zone with Wetlands Create Side Channels Designate areas for Temporary Water Storage, Zoning,

Stream Buffer Zones

Buffer Zone Width is usually a compromise between political & public acceptability



Dependent on:
- functional value of resource
- intensity of adjacent use
- buffer zone characteristics
- specific buffer requirements
- size of stream

General guidelines:
5 - 10 m buffer is too little
15 - 30 m buffer is a minimum
30 - 100 m is a realistic compromise

Stream Buffer Zones

Effective Use of Buffer Zones

- Effective Use
- Protecting Streams
- Multi-purpose Use
- Detention
- Conservation

Not Effective

Innovations

Buffer zones should be of variable size depending on site conditions, surficial materials, bedrock conditions and filter capacity of the soils. However, enforcing the variable sizes of buffer zones concept in cities is very difficult.

Effective

Adaptation Res. Priorities	Specific Concerns	Impacts and Challenges
Public education challenges	Understanding physical processes, linkages, effects & consequences	Strategies for changing behaviours, and consumption patterns, short & long term
Trade and global market response to climate change	Security, scarcity, crisis, subsidies, protection strategies	Human adaptation and rate of change due to different policies & incentives
Adaptation and decision making	Who decides, what, when & where How to chose adaption strategy?	Conflict resolution & multi-stakeholder processes, consensus building
Comparison of effectiveness of adaptation strategies	What is realistic, how to measure and compare different strategies	Single vs. multiple actions, limited tests options due to long term response
Risk assessment and risk quantification	Thresholds, comparison of risk, trade-off analysis	Evaluating short vs. long term risk & effectiveness of risk reduction
Choice of Best Management Practices (BMPs)	Economic & social considerations Long term vs. short term	Evaluation criteria for choosing BMP's ? Different social & economic conditions

Summary: Increased Climatic Variability

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