Adapting Agriculture to a Changing Prairie Climate
4-March-2010

The Case for Agricultural Adaptation to Rapid Climate Change on the Northern Plains:

The Transformation is Underway

Danny Blair

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Centre for Forest Interdisciplinary Research (C-FIR)
Climate Change Connection, Co-Chair

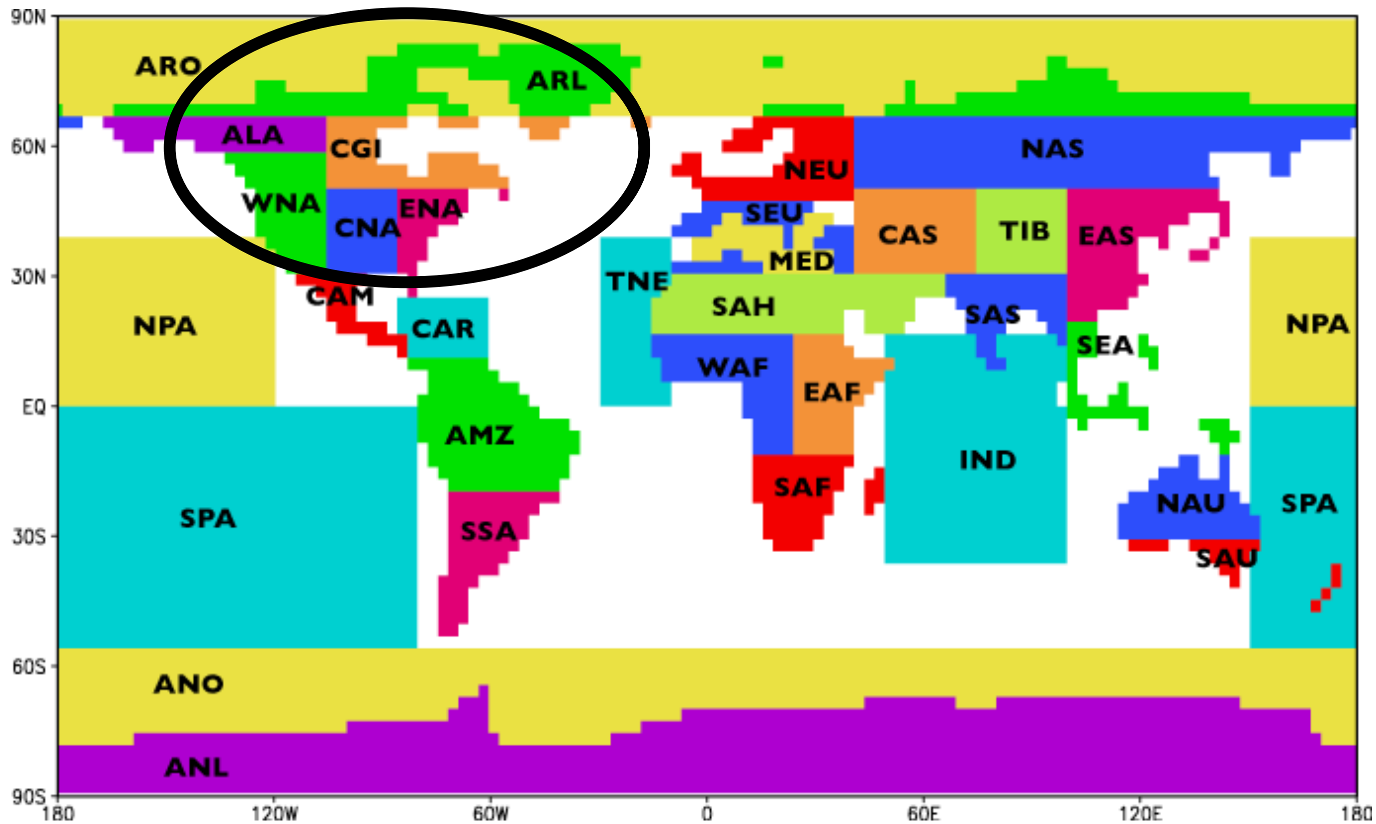
THE UNIVERSITY OF WINNIPEG

OUTLINE

Doing it backwards

- Scatterplots of temperature and precipitation projections
- Expected changes to regional thermal and hydrological conditions within the region
- Observed changes

SCATTERPLOT REGIONS



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

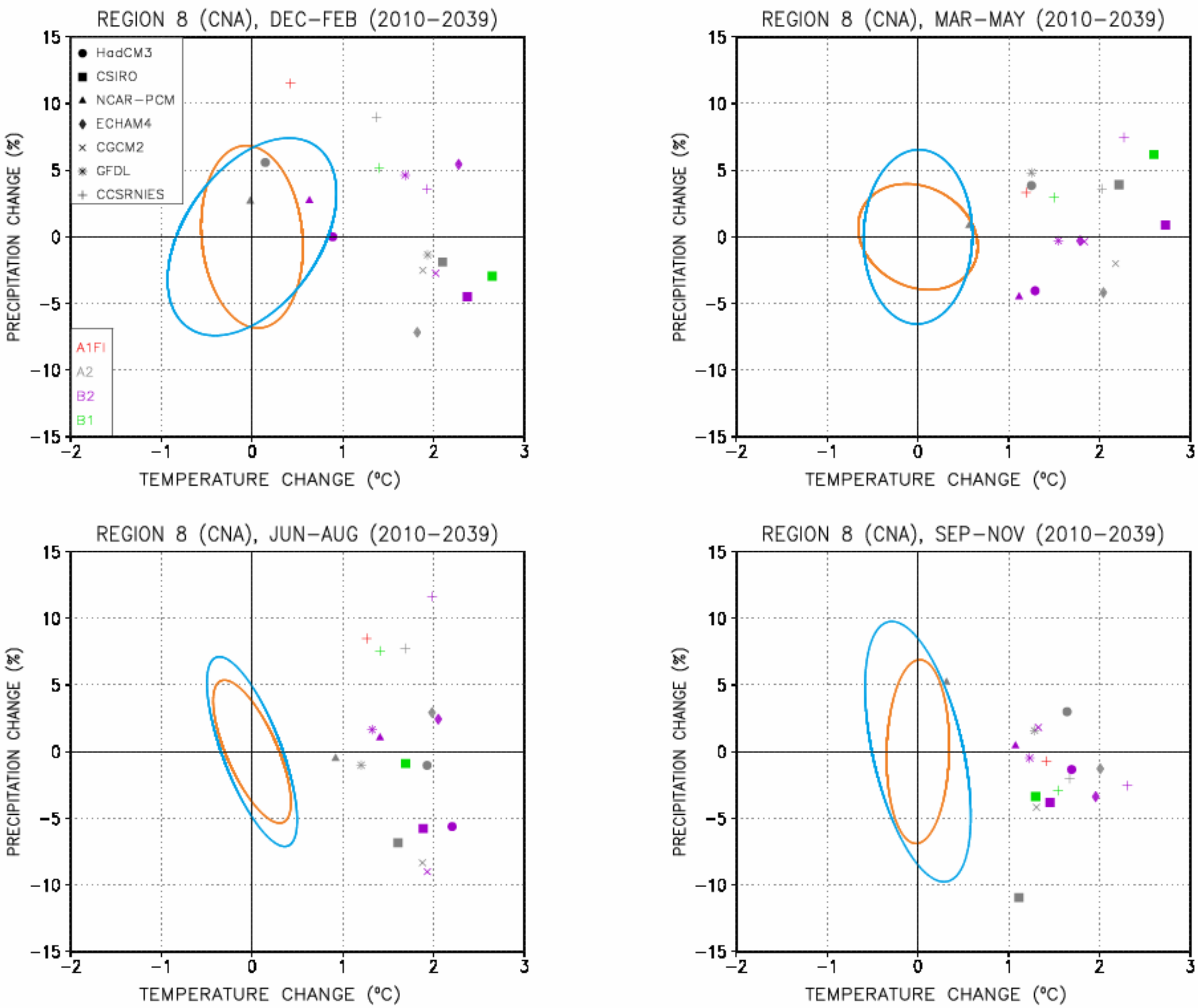
The IPCC Data Distribution Centre

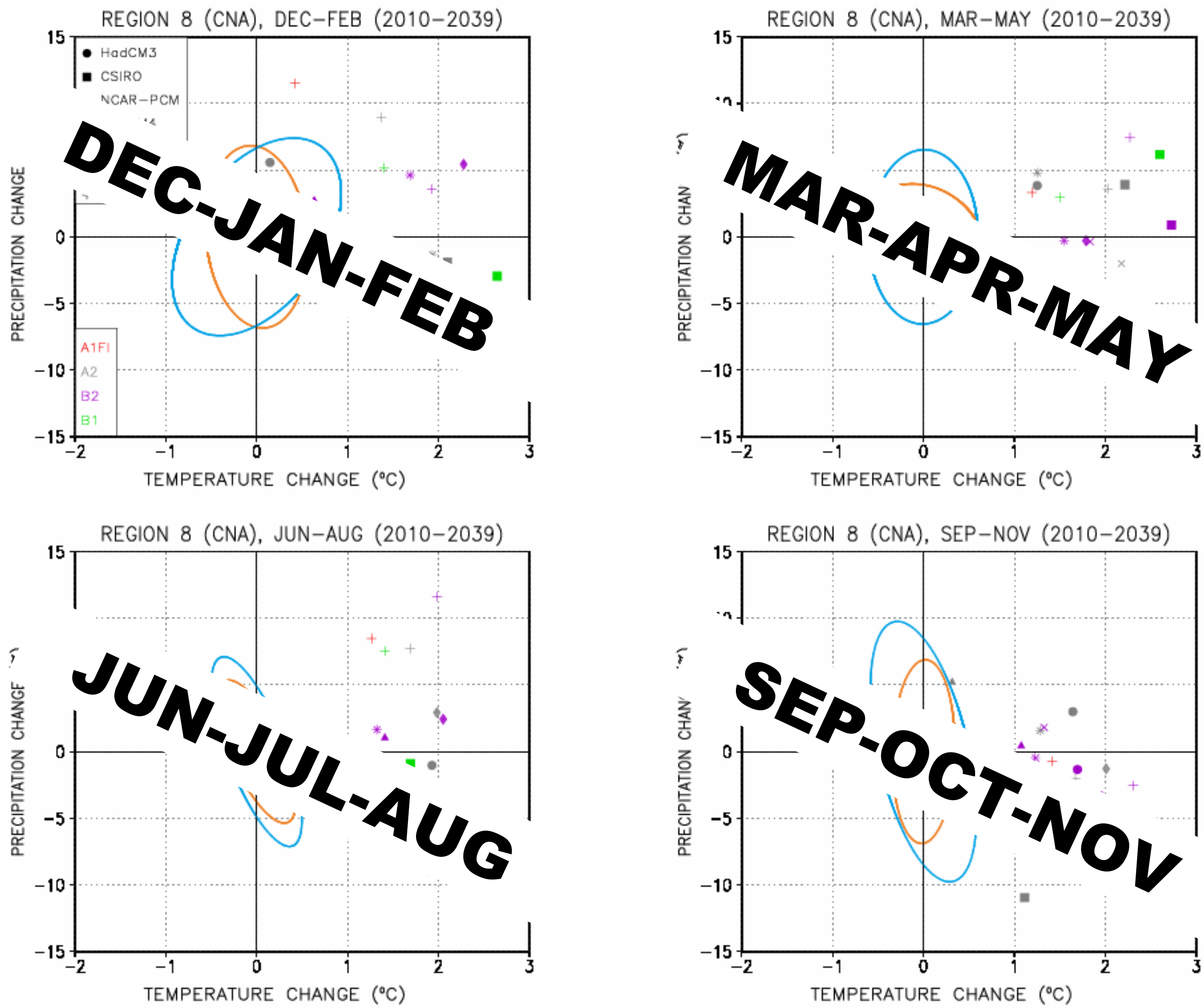
WMO

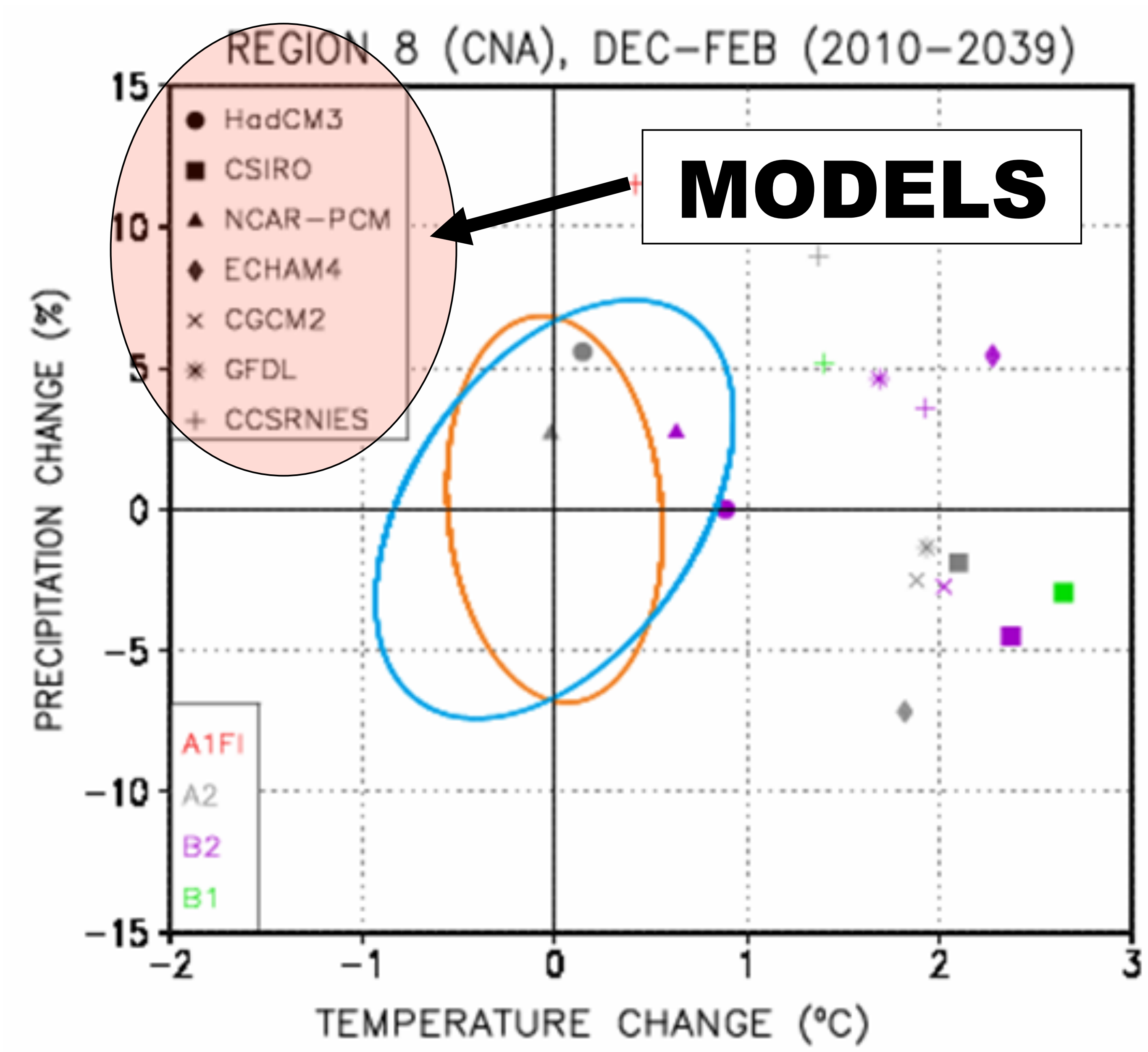
UNEP

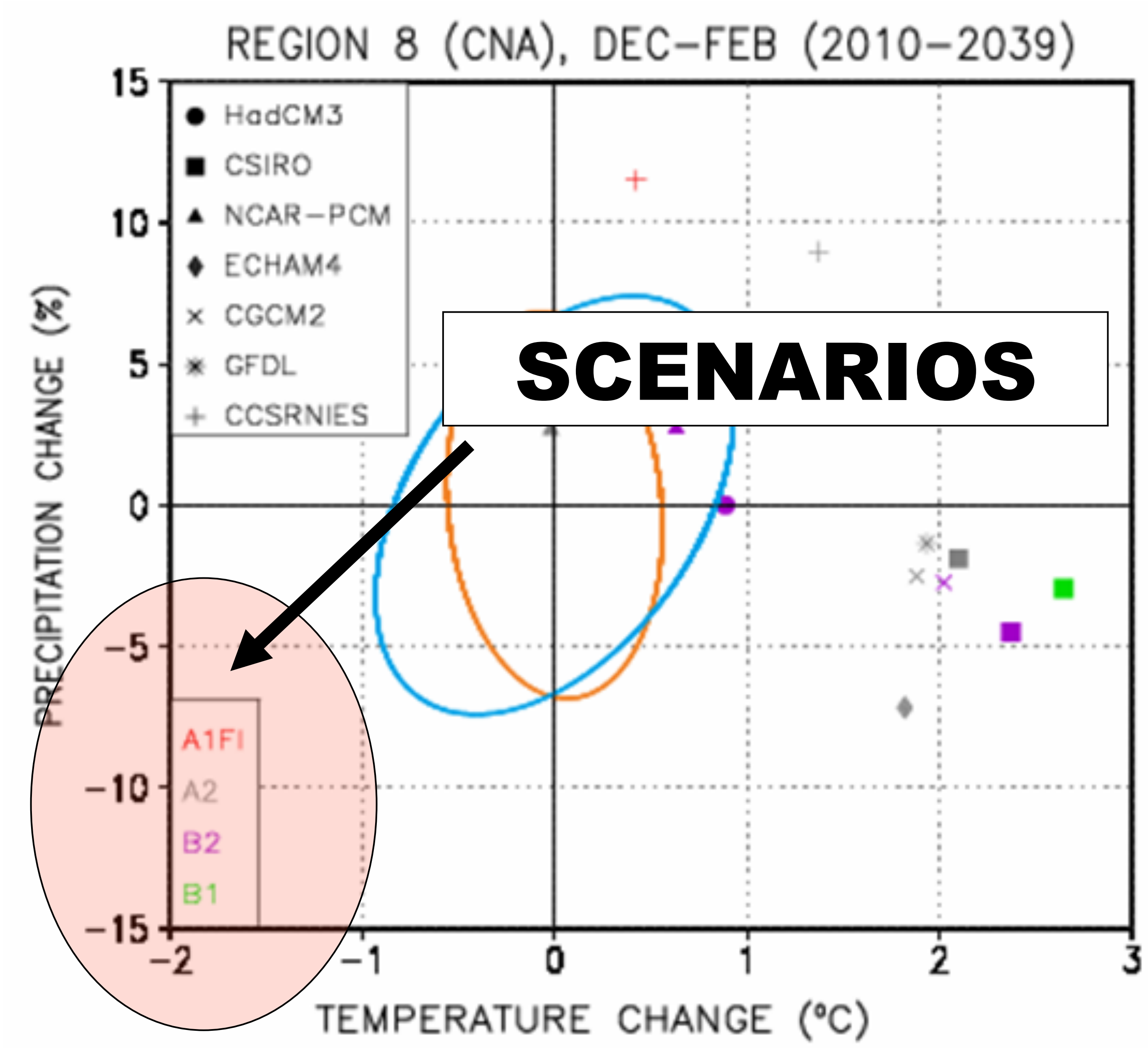
http://www.ipcc-data.org/sres/scatter_plots/scatterplots_region.html

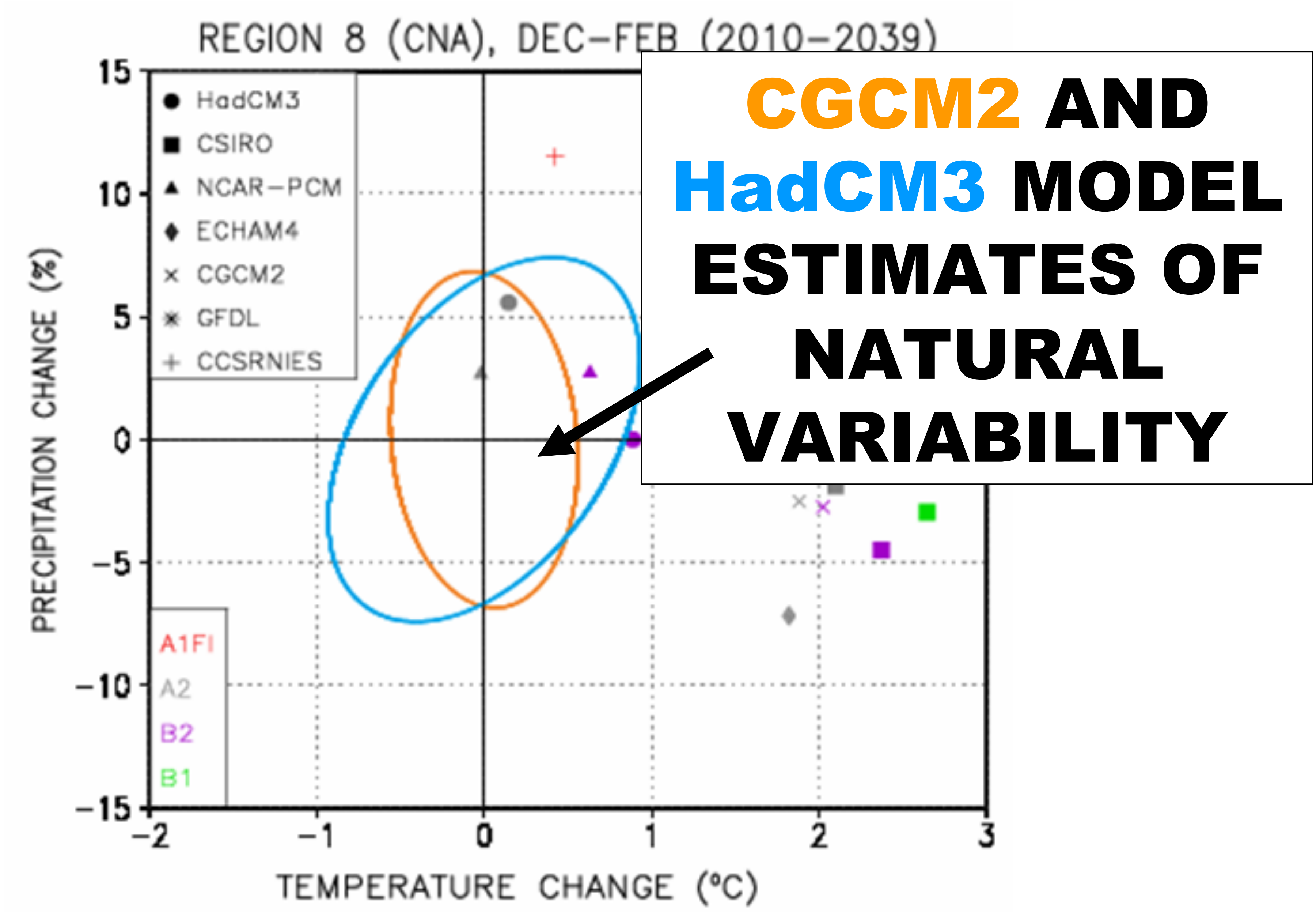
CENTRAL NORTH AMERICA 2010-2039




REGION 8 (CNA), DEC–FEB (2010–2039)
HadCM3
CSIRO
NCAR–PCM
A1FI
A2
B2
B1
DEC-JAN-FEB
REGION 8 (CNA), MAR–MAY (2010–2039)
MAR-APR-MAY
REGION 8 (CNA), JUN–AUG (2010–2039)
JUN-JUL-AUG
REGION 8 (CNA), SEP–NOV (2010–2039)
SEP-OCT-NOV
PRECIPITATION CHANGE
TEMPERATURE CHANGE (°C)


REGION 8 (CNA), DEC-FEB (2010-2039)
MODELS
HadCM3
CSIRO
NCAR-PCM
ECHAM4
CGCM2
GFDL
CCSRNIES
A1FI
A2
B2
B1
PRECIPITATION CHANGE (%)
TEMPERATURE CHANGE (°C)
15
10
5
0
−5
−10
−15
−2
−1
0
1
2
3


REGION 8 (CNA), DEC-FEB (2010-2039)
HadCM3
CSIRO
NCAR-PCM
ECHAM4
CGCM2
GFDL
CCSRNIES
SCENARIOS
A1FI
A2
B2
B1
PRECIPITATION CHANGE (%)
TEMPERATURE CHANGE (°C)


REGION 8 (CNA), DEC-FEB (2010-2039)
CGCM2 AND HadCM3 MODEL ESTIMATES OF NATURAL VARIABILITY
PRECIPITATION CHANGE (%)
TEMPERATURE CHANGE (°C)
HadCM3
CSIRO
NCAR-PCM
ECHAM4
CGCM2
GFDL
CCSRNIES
A1FI
A2
B2
B1
15
10
5
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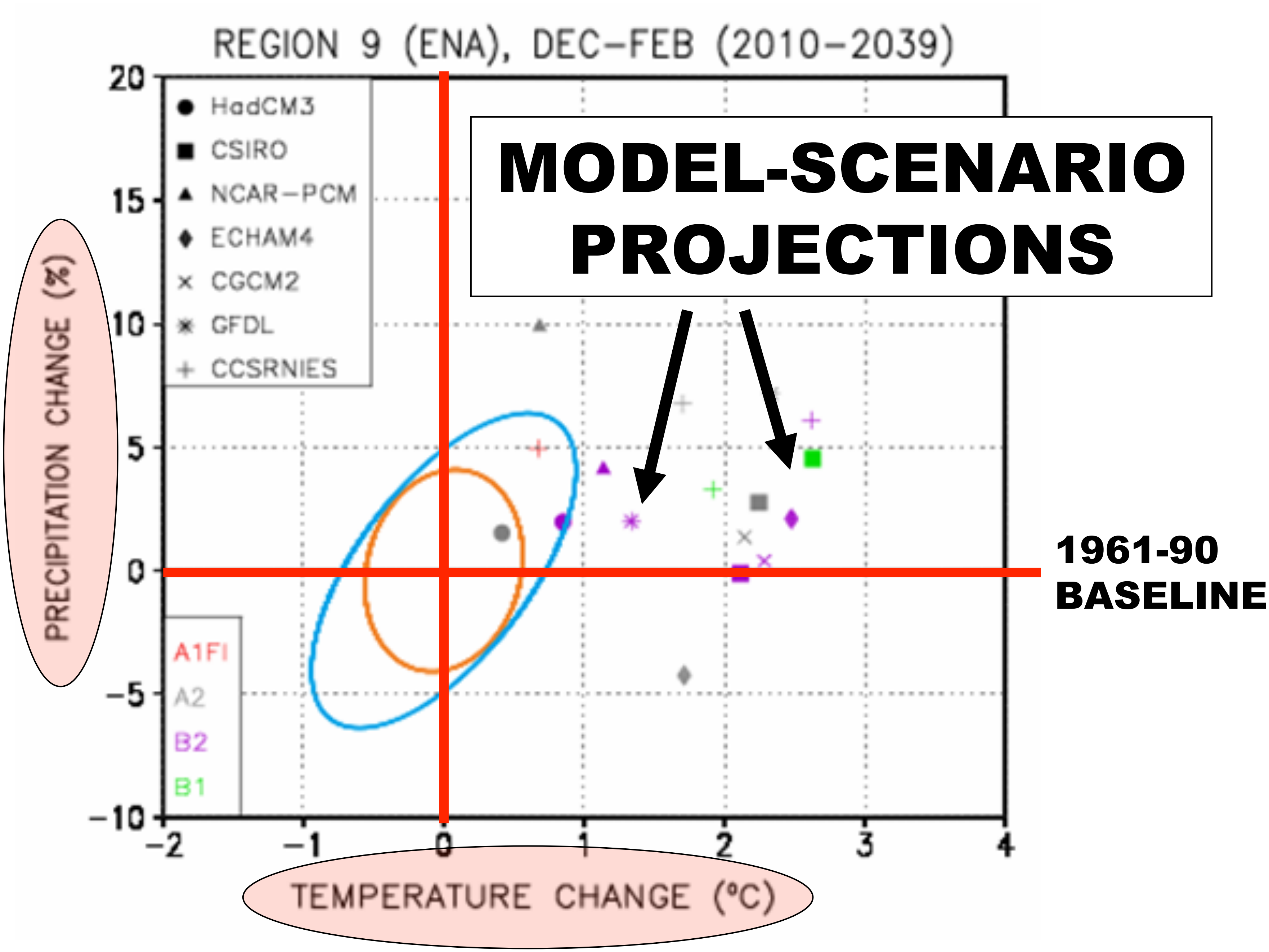
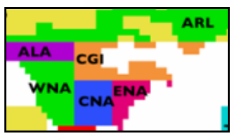
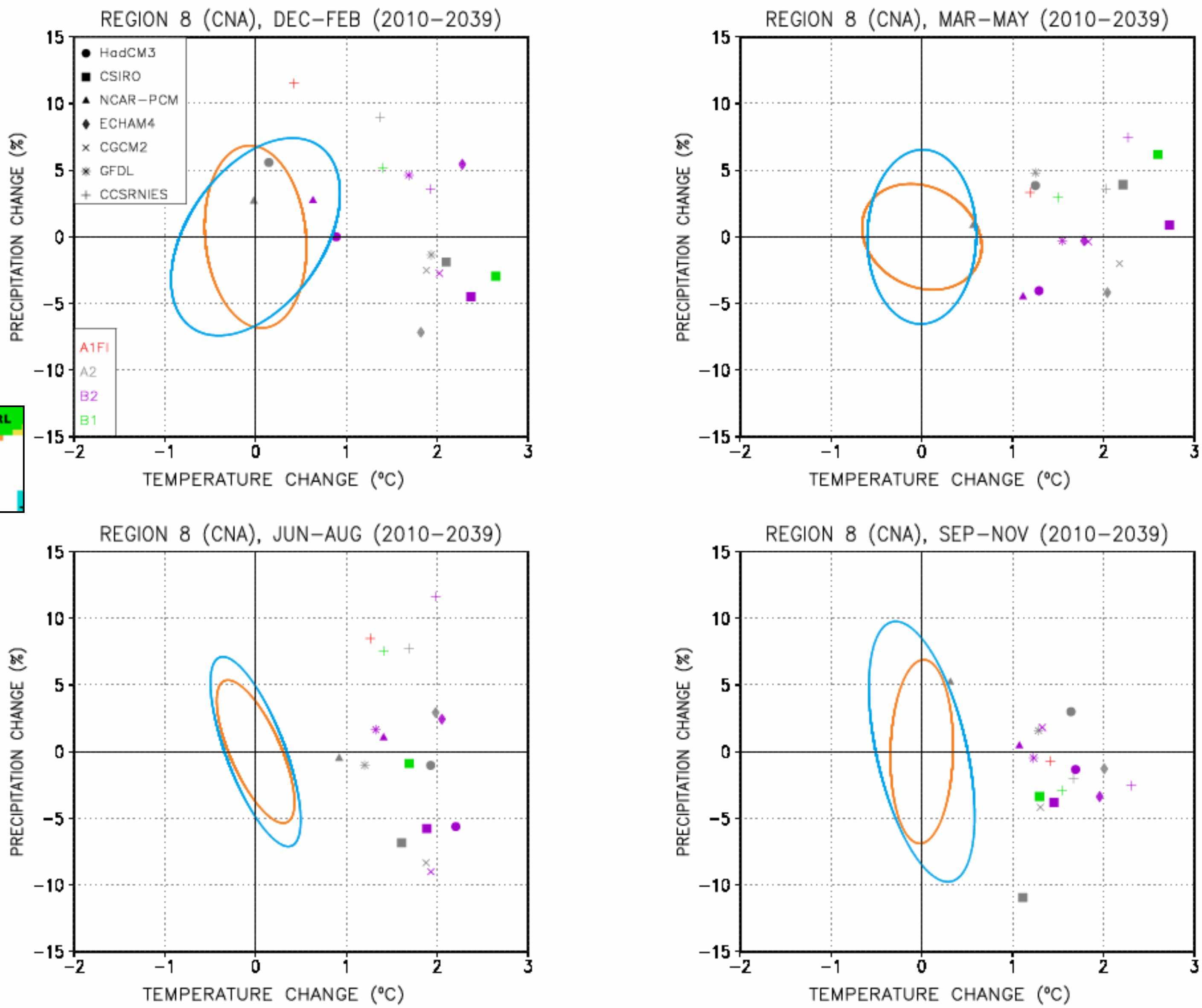
-5
-10
-15
-2
-1
0
1
2
3

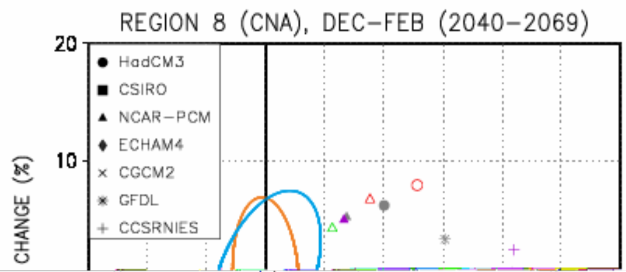

REGION 9 (ENA), DEC-FEB (2010-2039)
MODEL-SCENARIO PROJECTIONS
1961-90 BASELINE
PRECIPITATION CHANGE (%)
TEMPERATURE CHANGE (°C)
HadCM3
CSIRO
NCAR-PCM
ECHAM4
CGCM2
GFDL
CCSRNIES
A1FI
A2
B2
B1
20
15
10
5
0
-5
-10
-2
-1
0
1
2
3
4

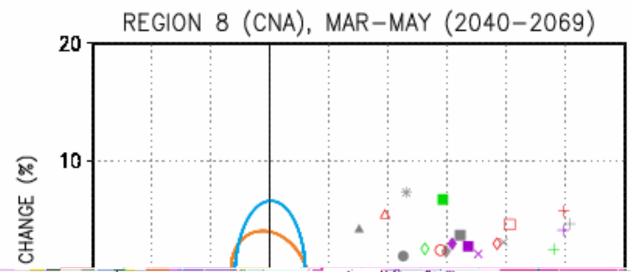
CENTRAL NORTH AMERICA 2010-2039

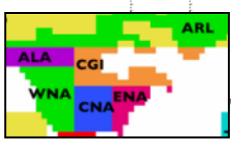




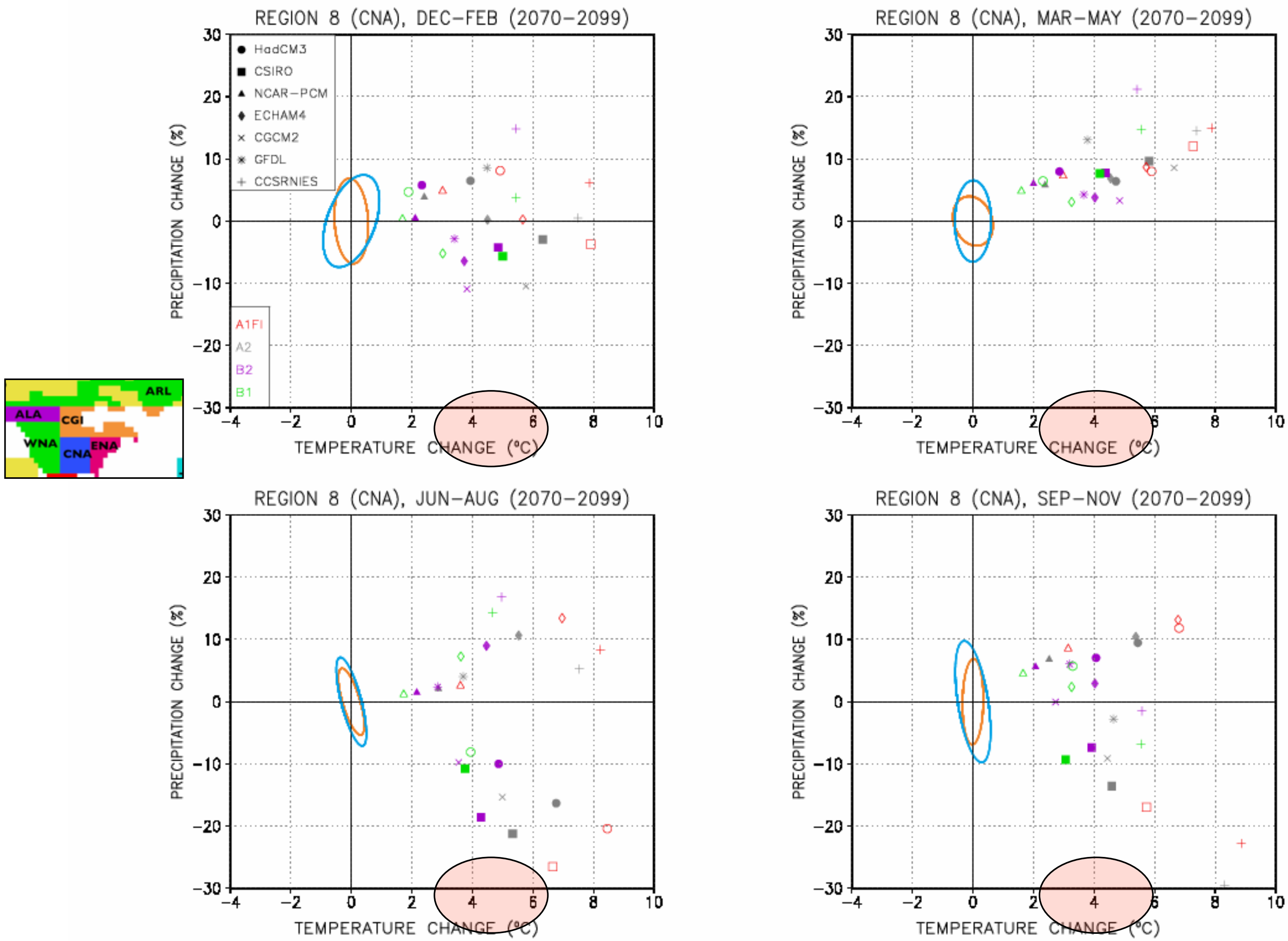
CENTRAL NORTH AMERICA 2040-2069







CENTRAL NORTH AMERICA 2070-2099



CHAPTER 7
Prairies

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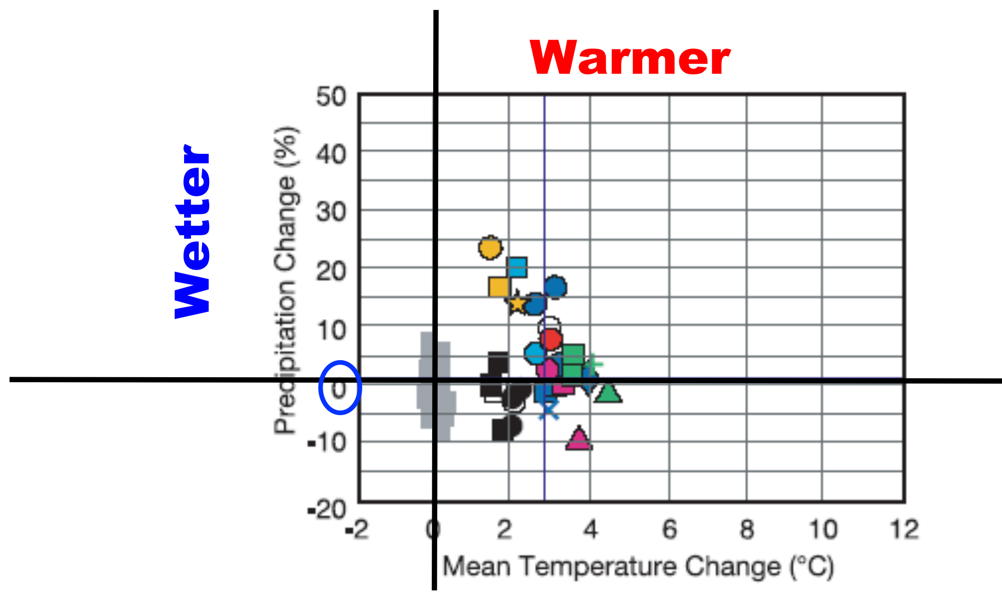
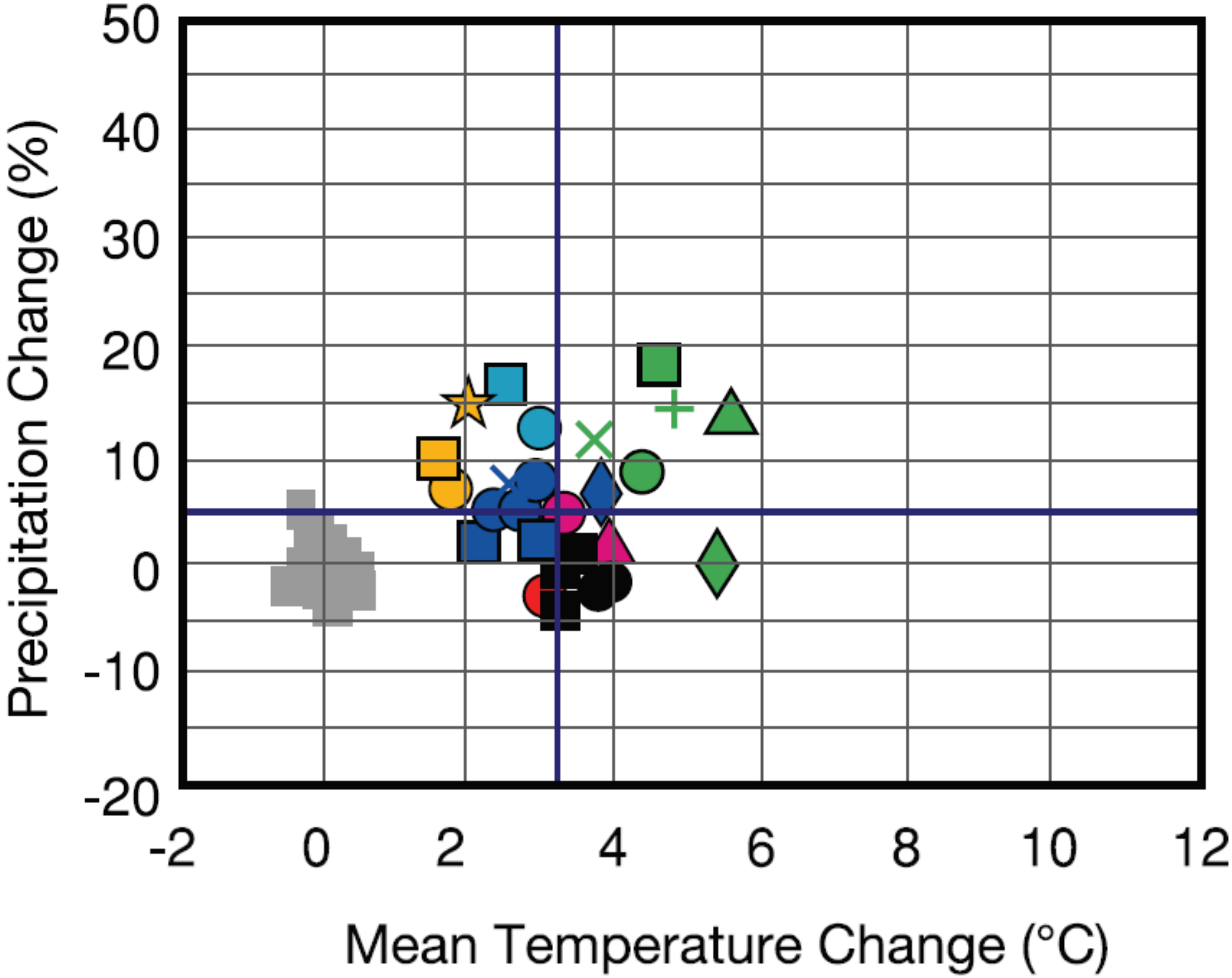
Legend

Global Climate Model		Emissions Scenario
CGCM2	■	Natural climate variability
CGCM2	◆	A1FI
HadCM3	+	A1T
CCSRNIES	▲	A1
CSIROMk2	★	A1B
ECHAM4	●	A2
NCARPCM	×	B1
GFDL-R30	■	B2

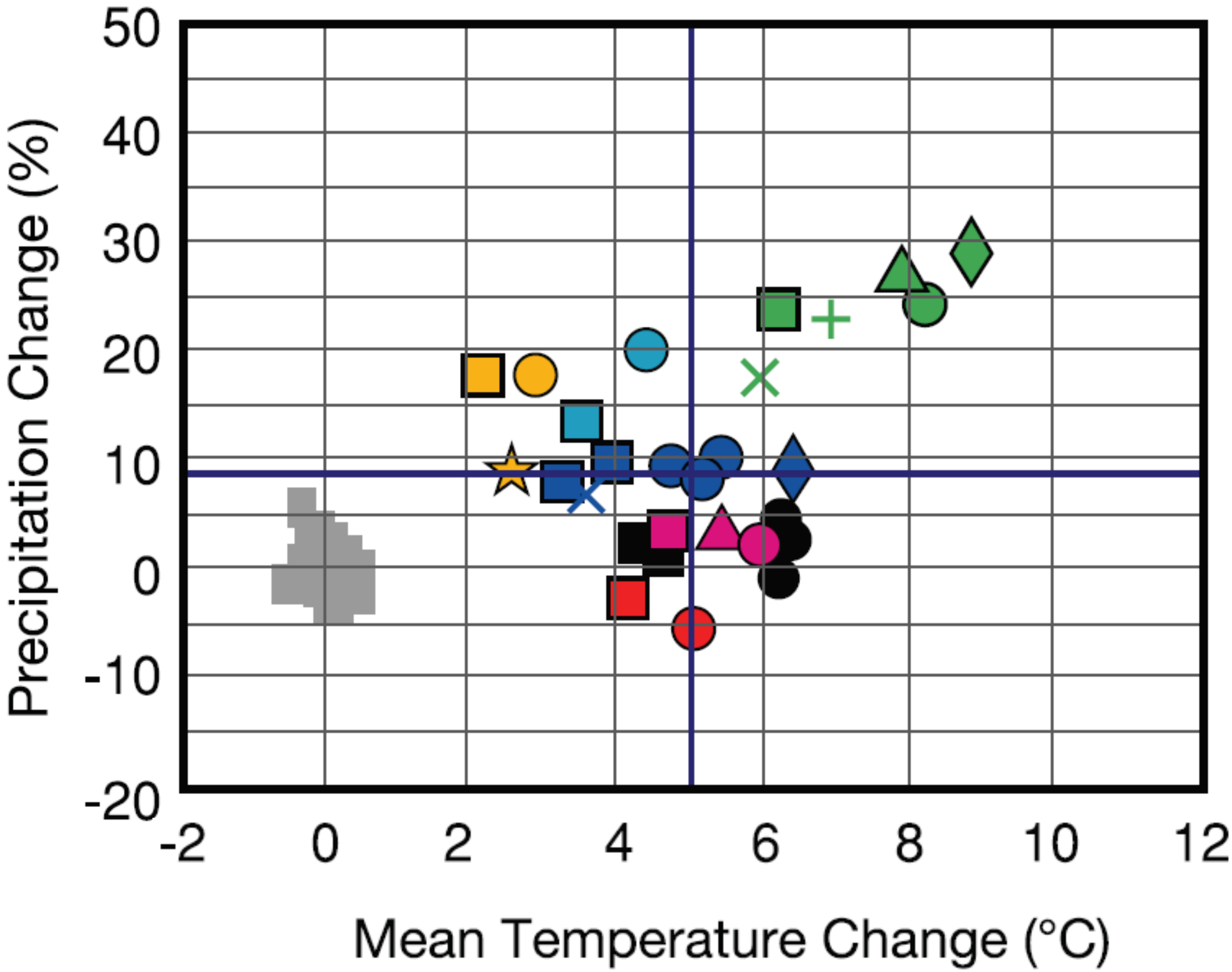
Projected Temperature and Precipitation Scatterplots



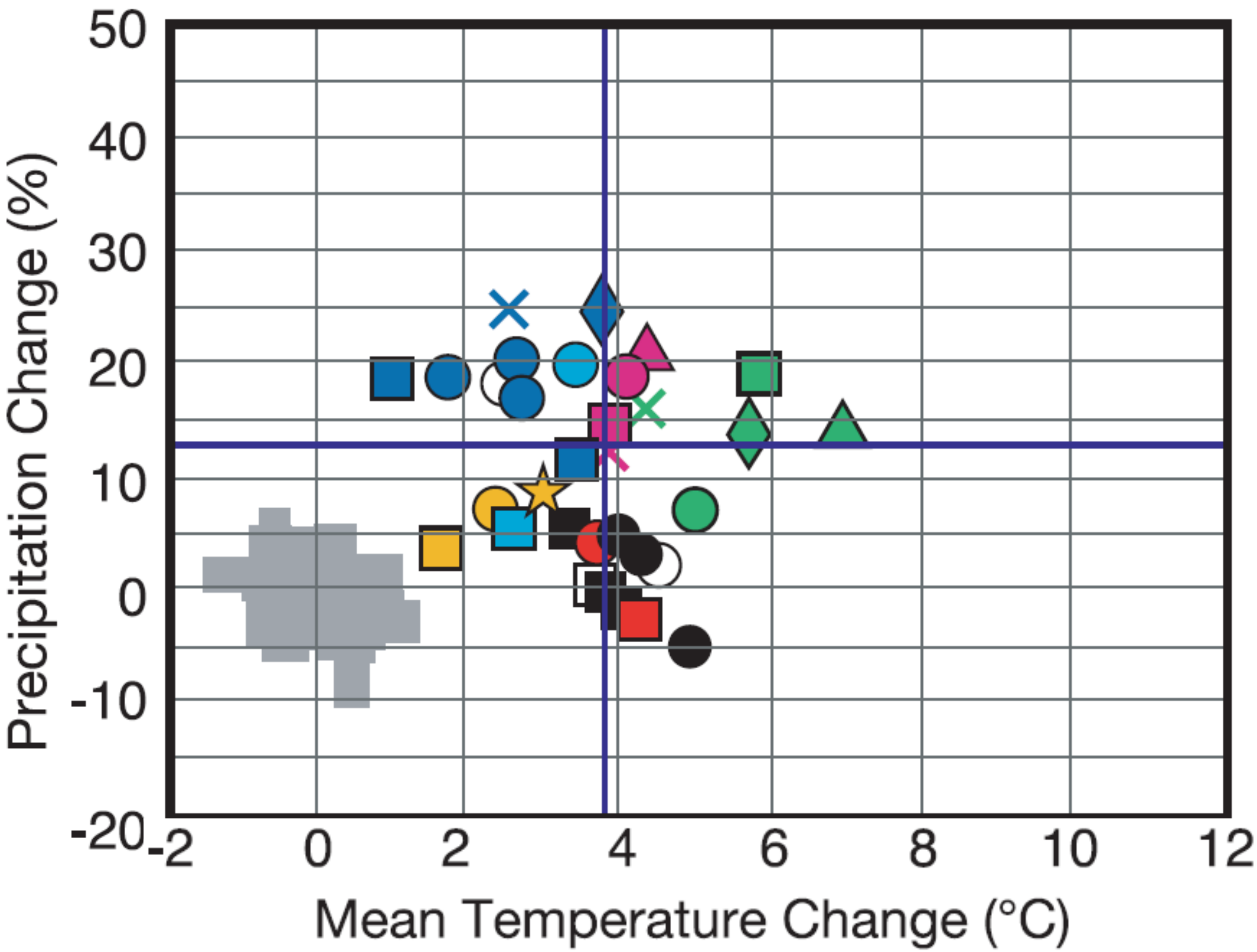
Prairie Grassland Region: 2050s



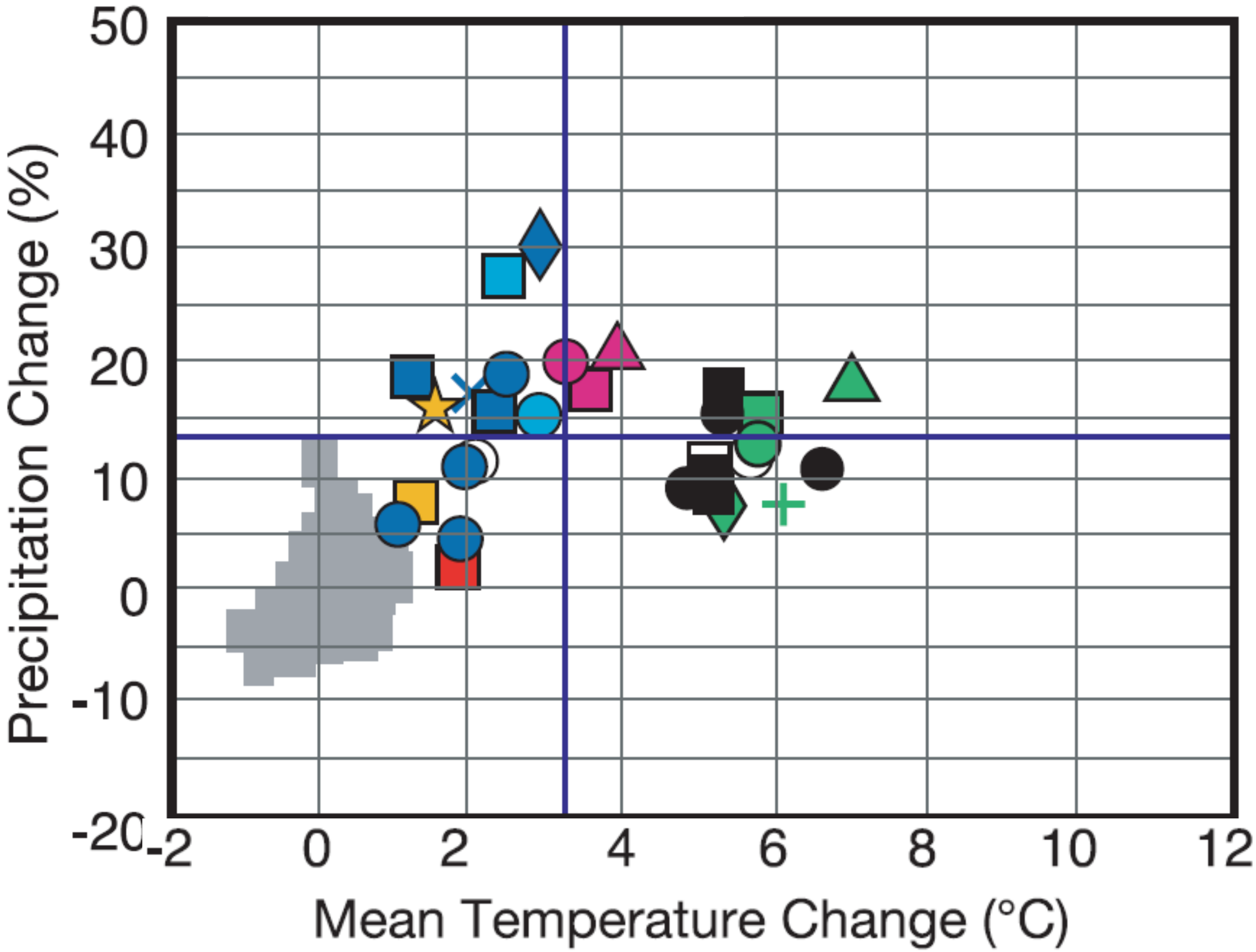
Prairie Grassland Region: 2080s



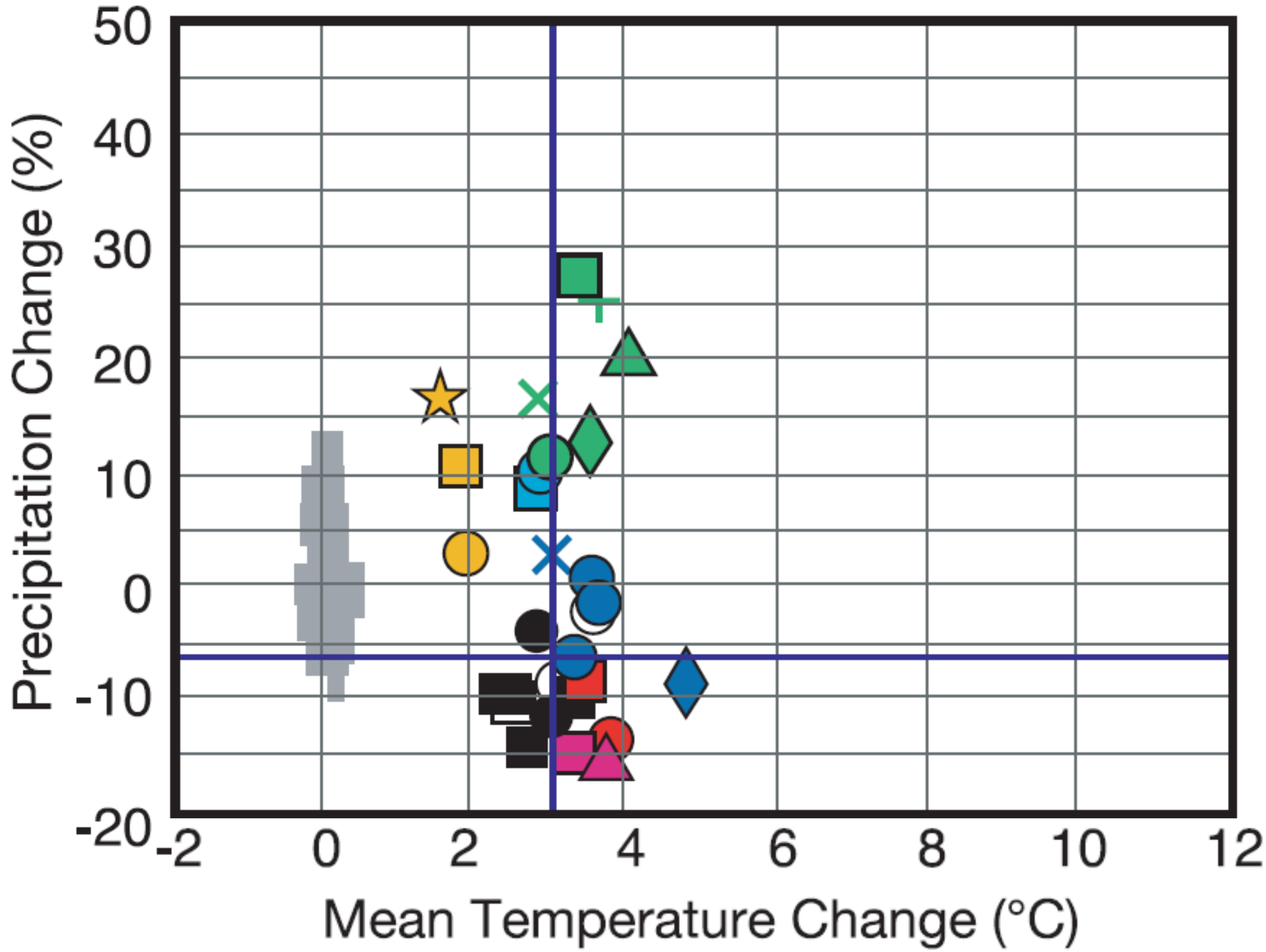
Prairie Grassland Region: 2050s Winter



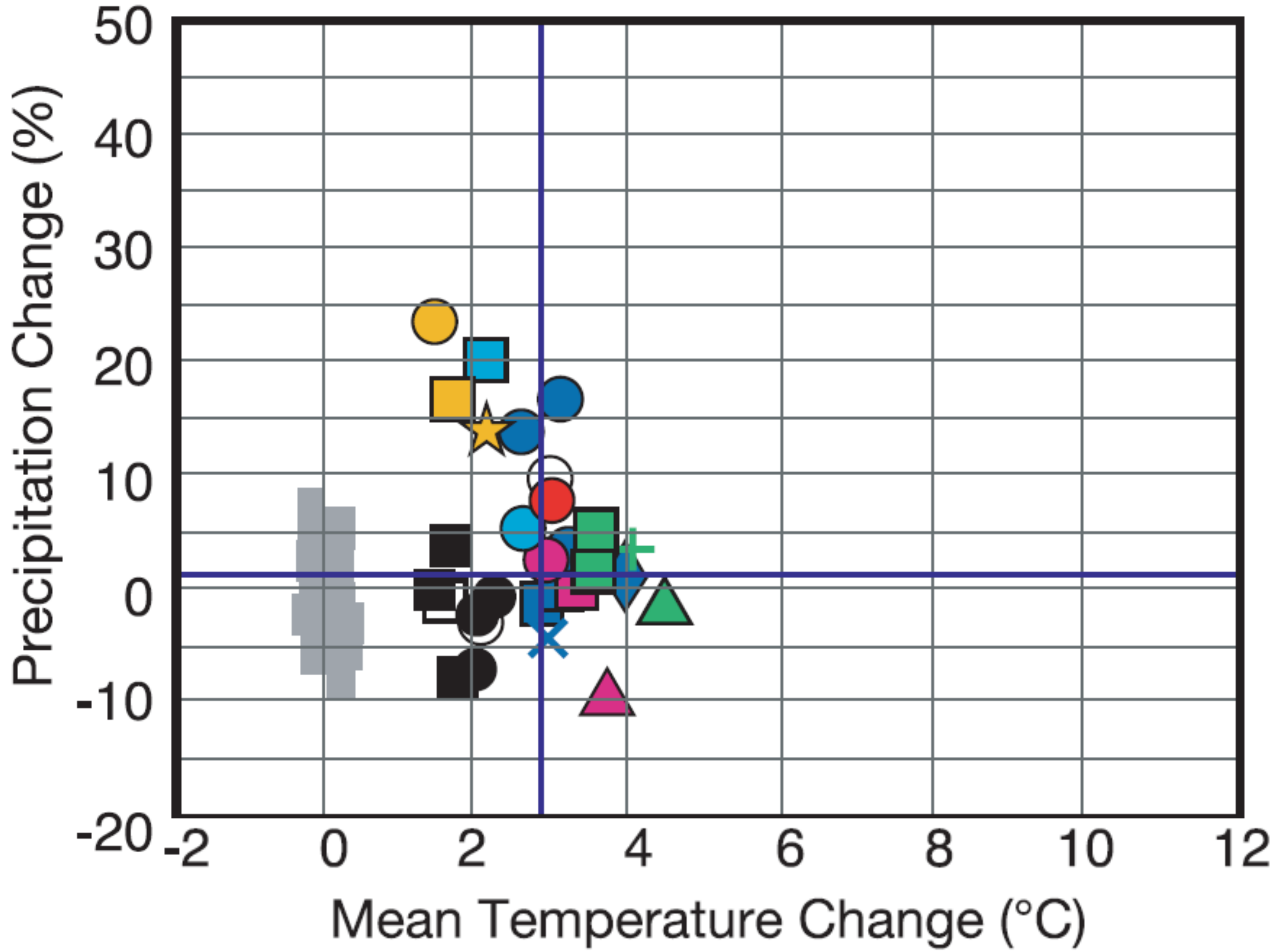
Prairie Grassland Region: 2050s Spring



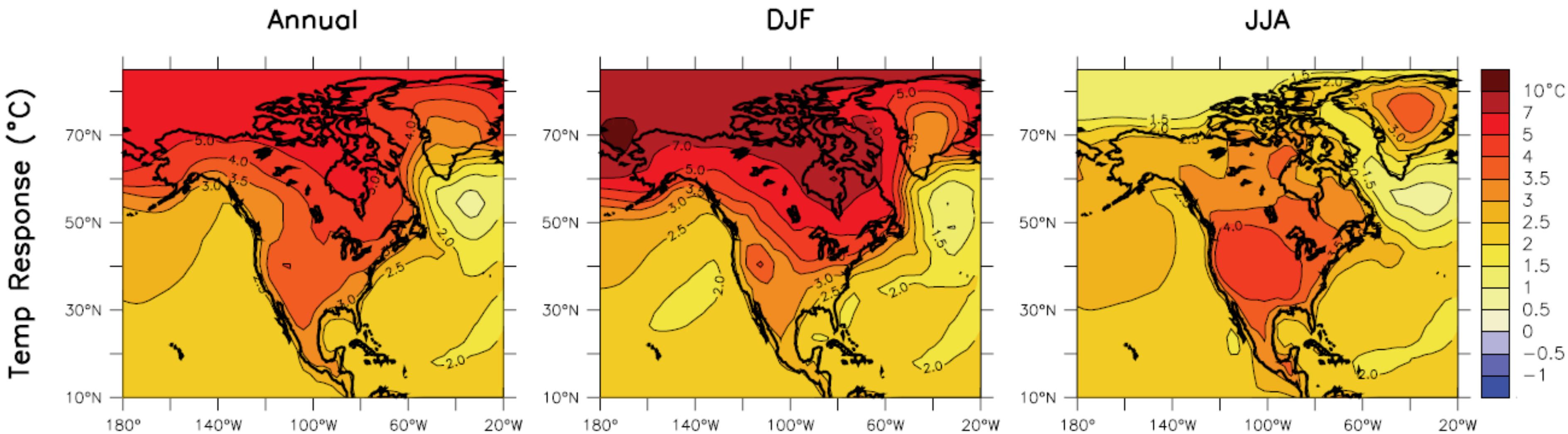
Prairie Grassland Region: 2050s Summer



Prairie Grassland Region: 2050s Fall

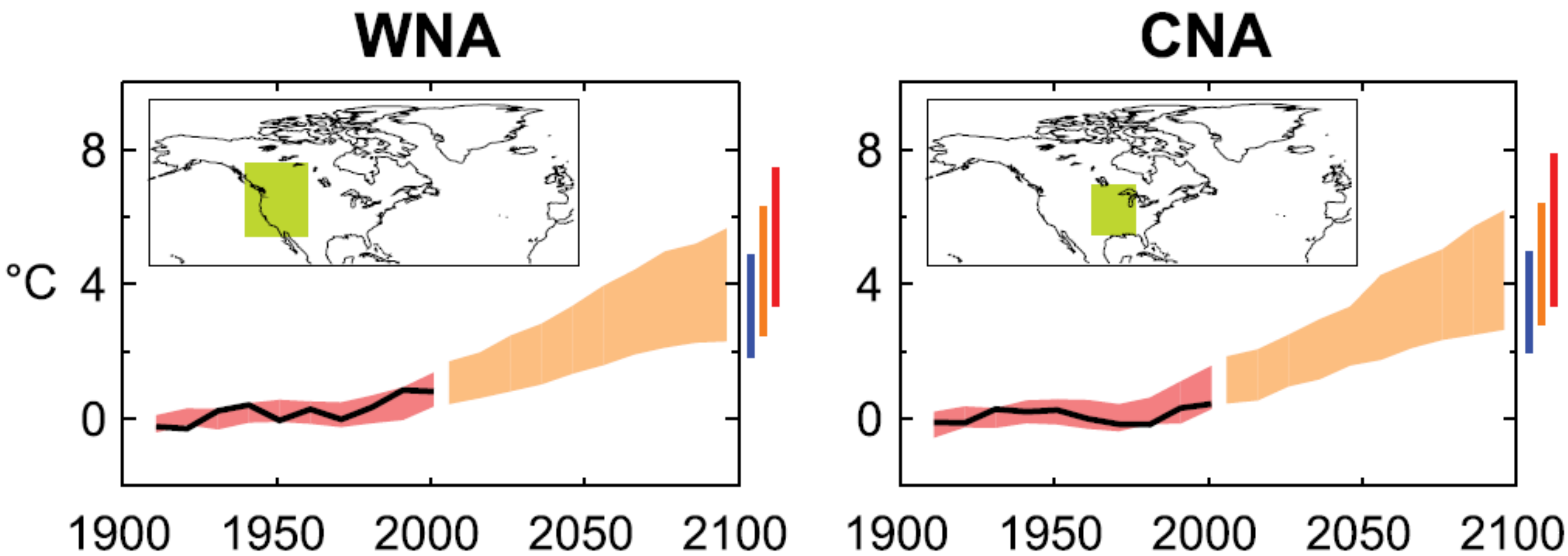


Temperature Changes from the MMD-A1B Simulations



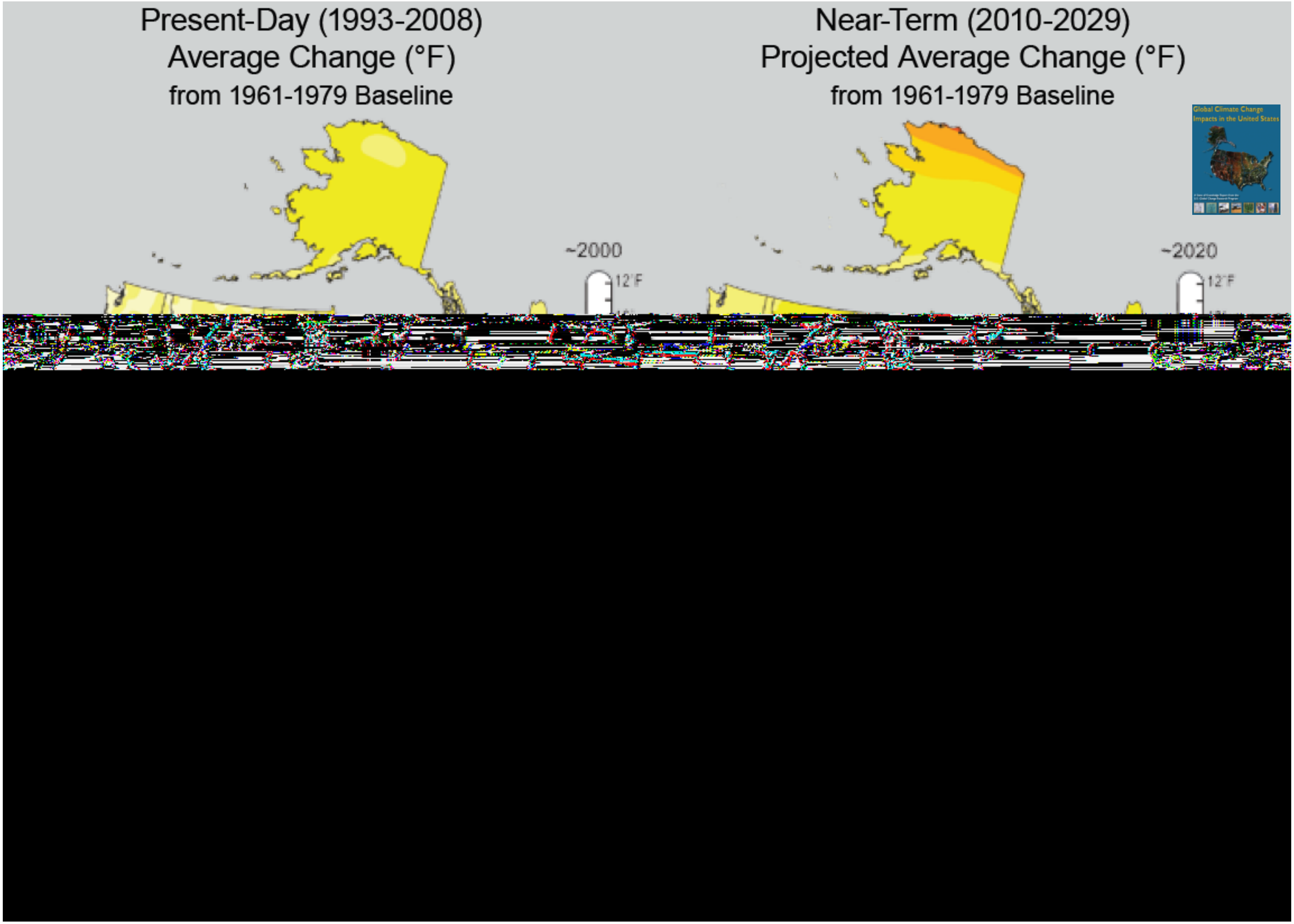
IPCC 2007

Western/Central North American Observed, Simulated and A1B Projected Temperature Anomalies



Anomaly Baseline: 1901 to 1050

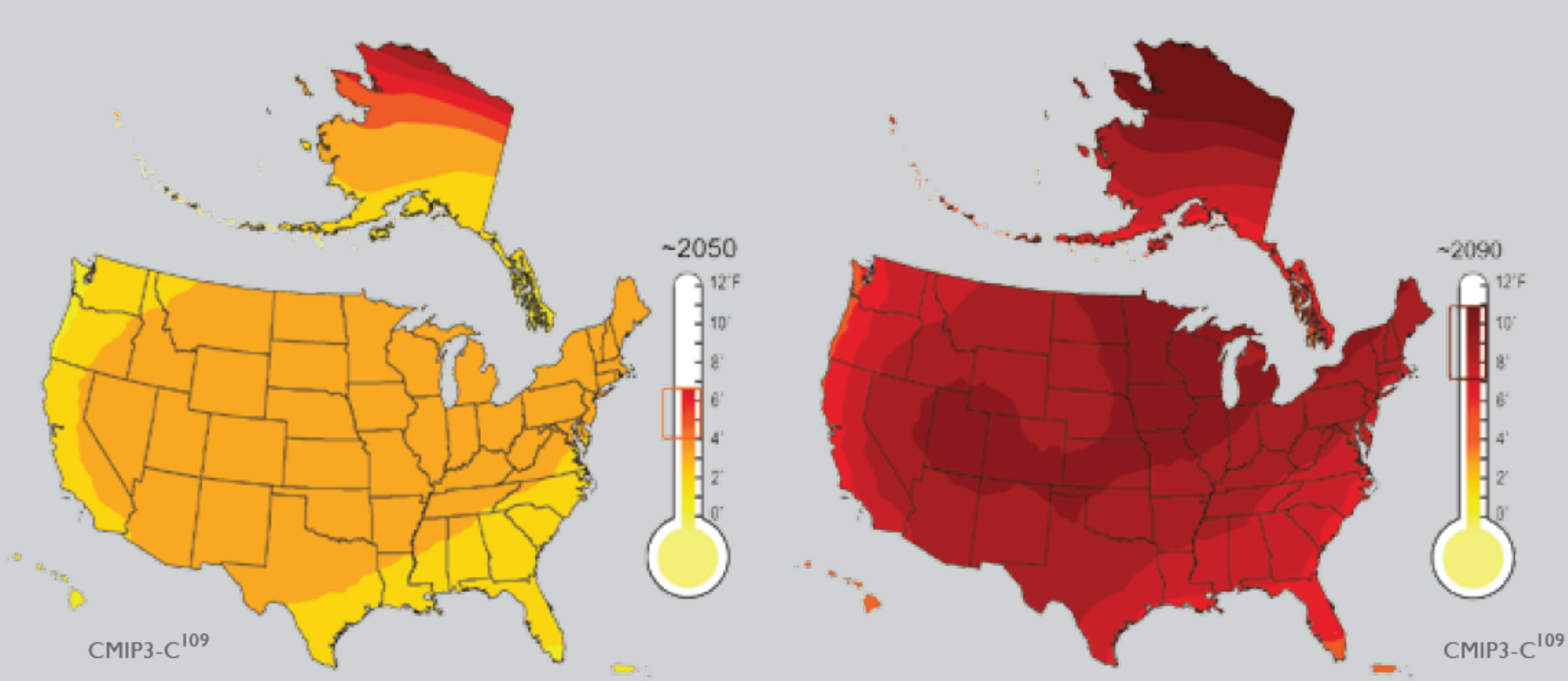
IPCC 2007



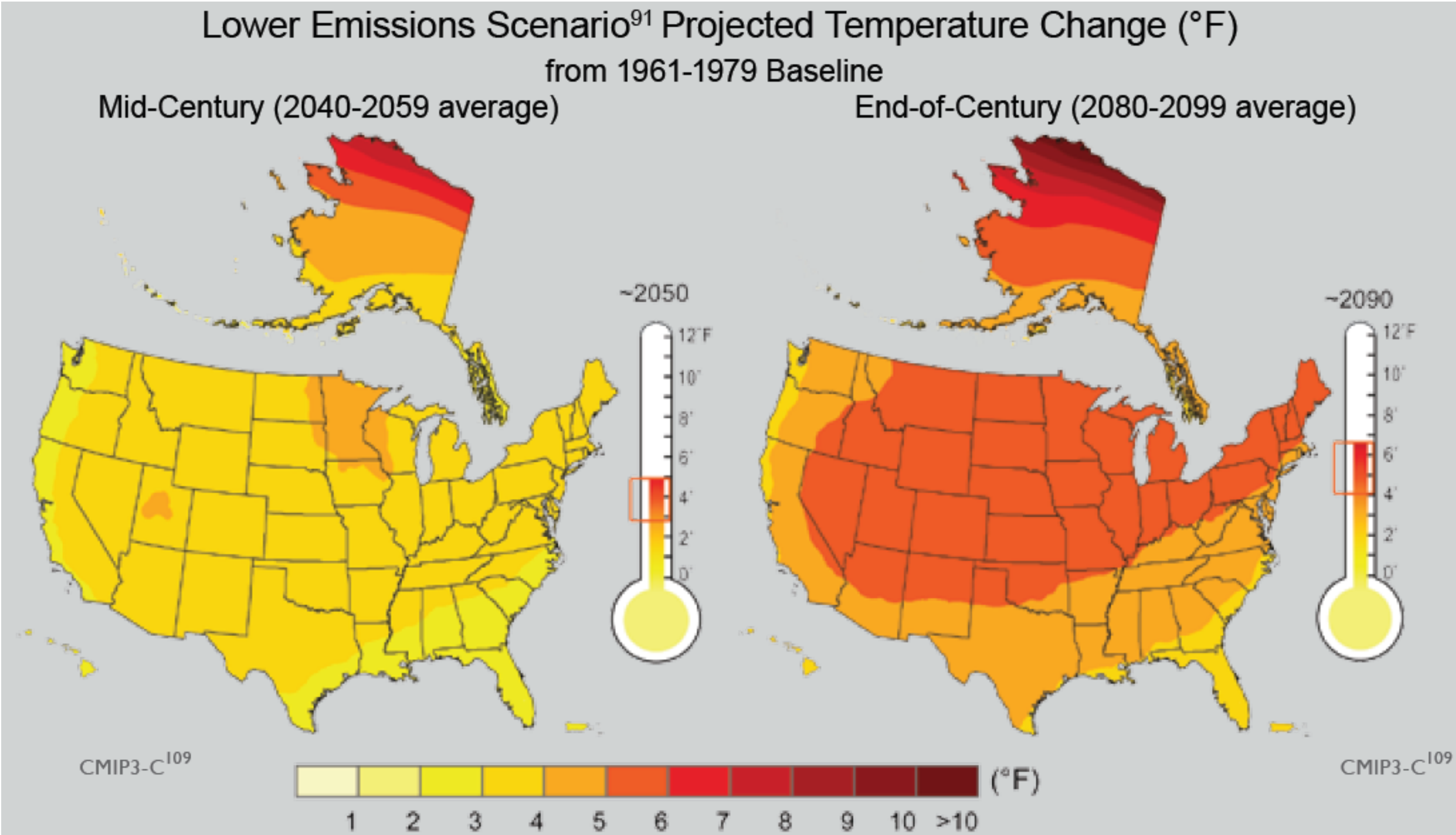
Present-Day (1993-2008)
Average Change (°F)
from 1961-1979 Baseline
~2000
12°F
Near-Term (2010-2029)
Projected Average Change (°F)
from 1961-1979 Baseline
~2020
12°F
Global Climate Change
Impacts in the United States

Higher Emissions Scenario[91] Projected Temperature Change (°F)
from 1961-1979 Baseline

Mid-Century (2040-2059 average) | End-of-Century (2080-2099 average)



The maps on this page and the previous page are based on projections of future temperature by 16 of the Coupled Model Intercomparison Project Three (CMIP3) climate models using two emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC), *Special Report on Emission Scenarios* (SRES).[91] The "lower" scenario here is B1, while the "higher" is A2.[91] The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. Additional information on these scenarios is on pages 22 and 23 in the previous section, *Global Climate Change*. These maps, and others in this report, show projections at national, regional, and sub-regional scales, using well-established techniques.[110]



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Seasonal Change in Temperature by the 2050s (°C)

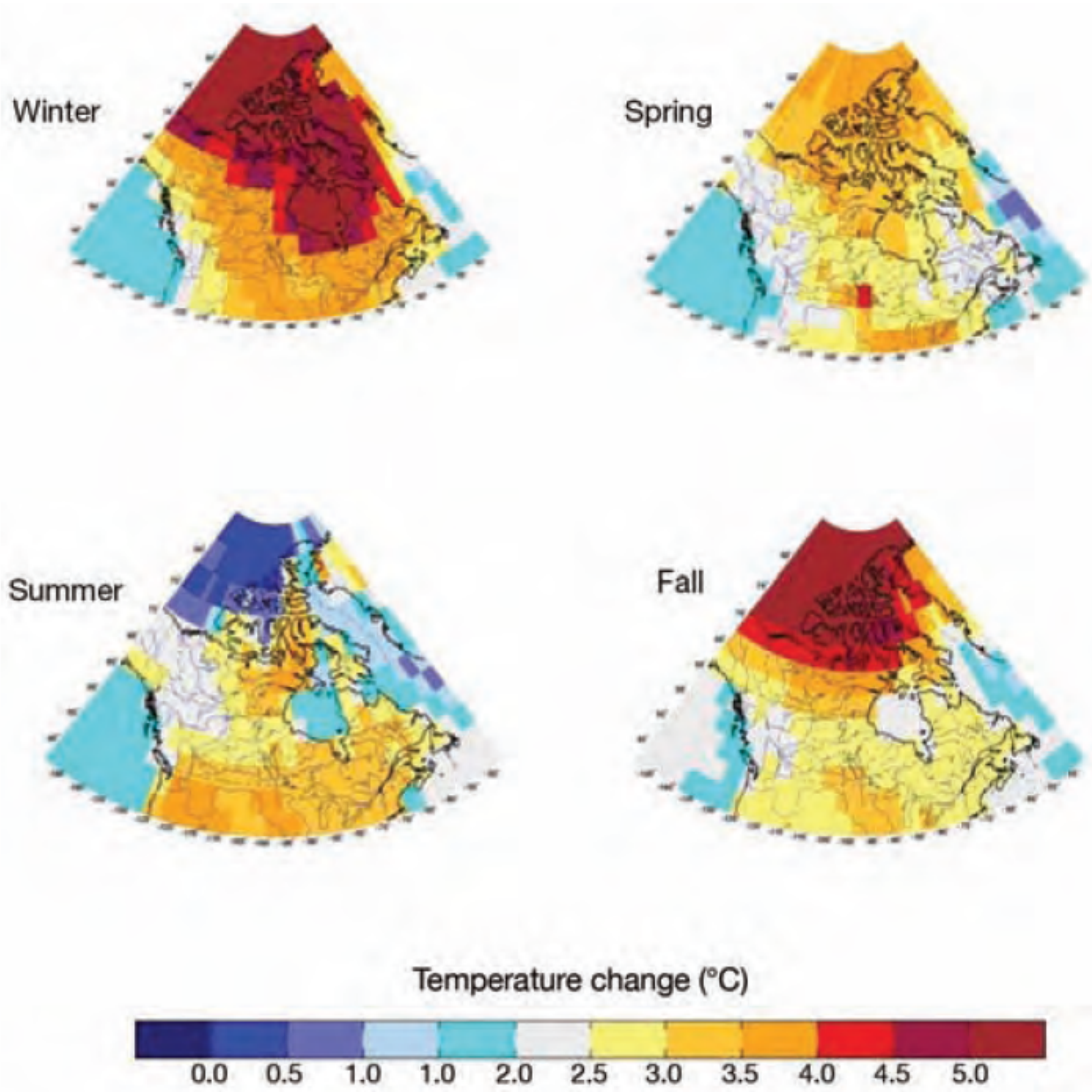
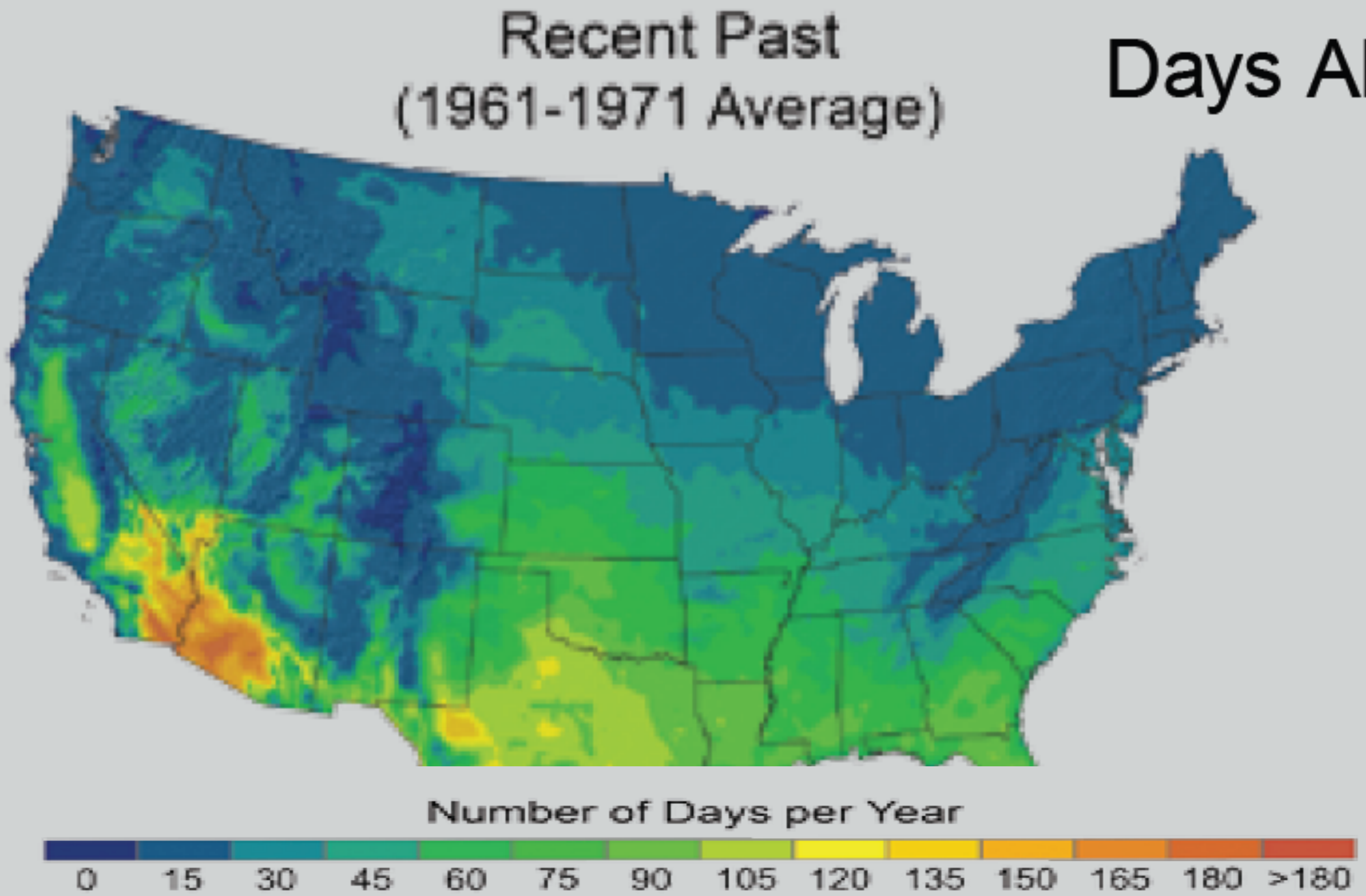
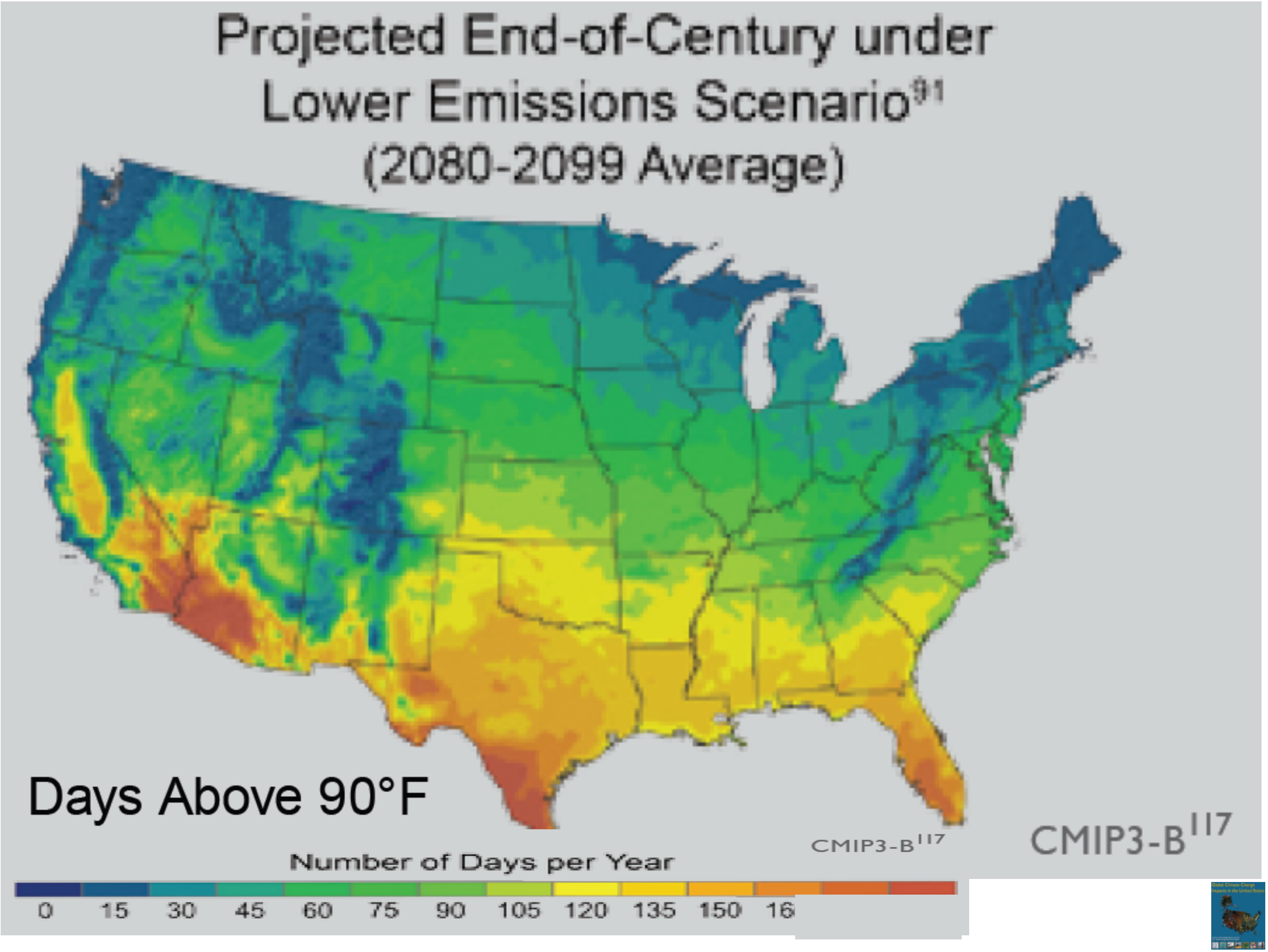


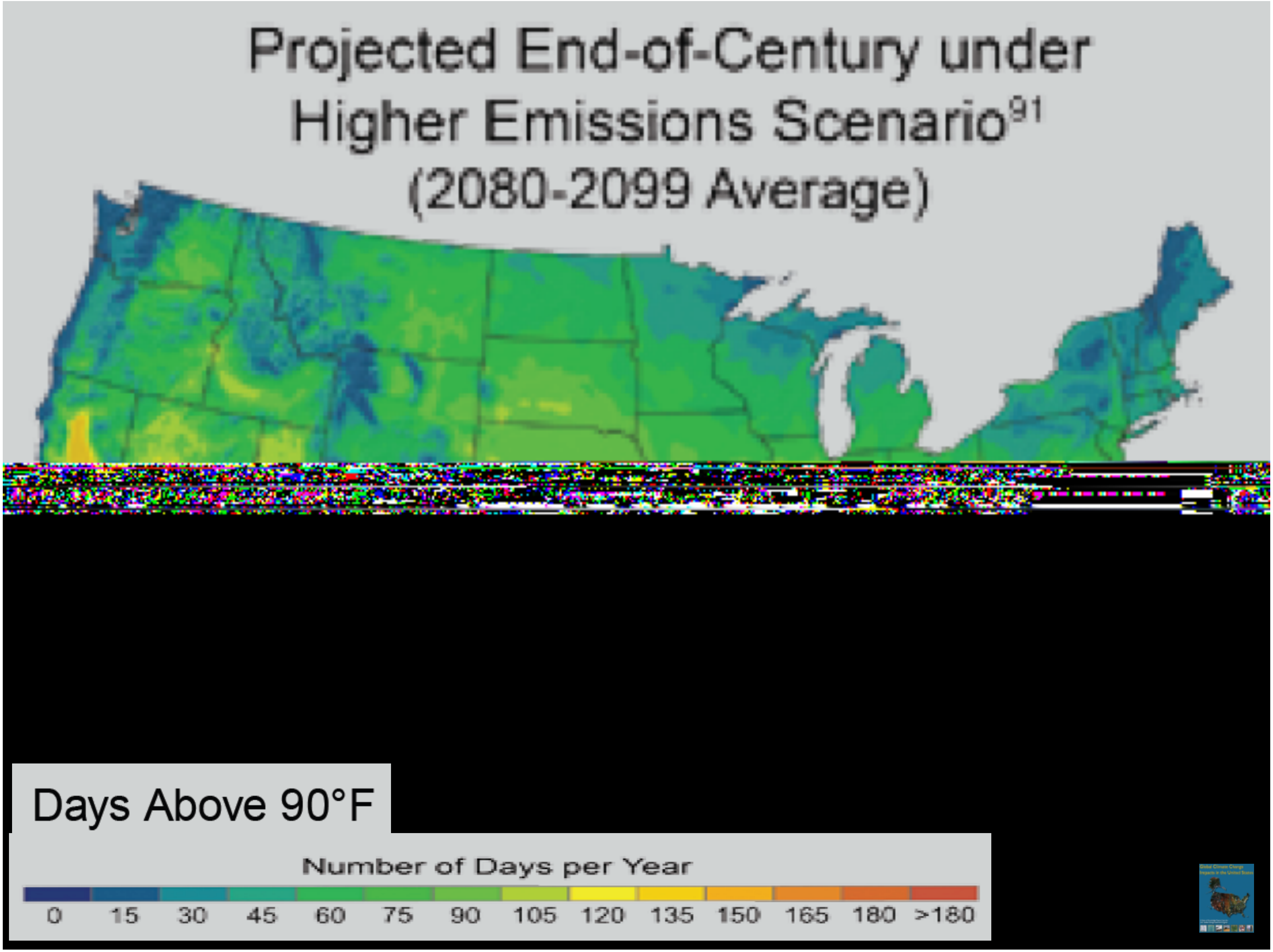
FIGURE 16: Seasonal change in temperature across Canada by 2050 (relative to 1961–1990), based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

Days Above 90°F

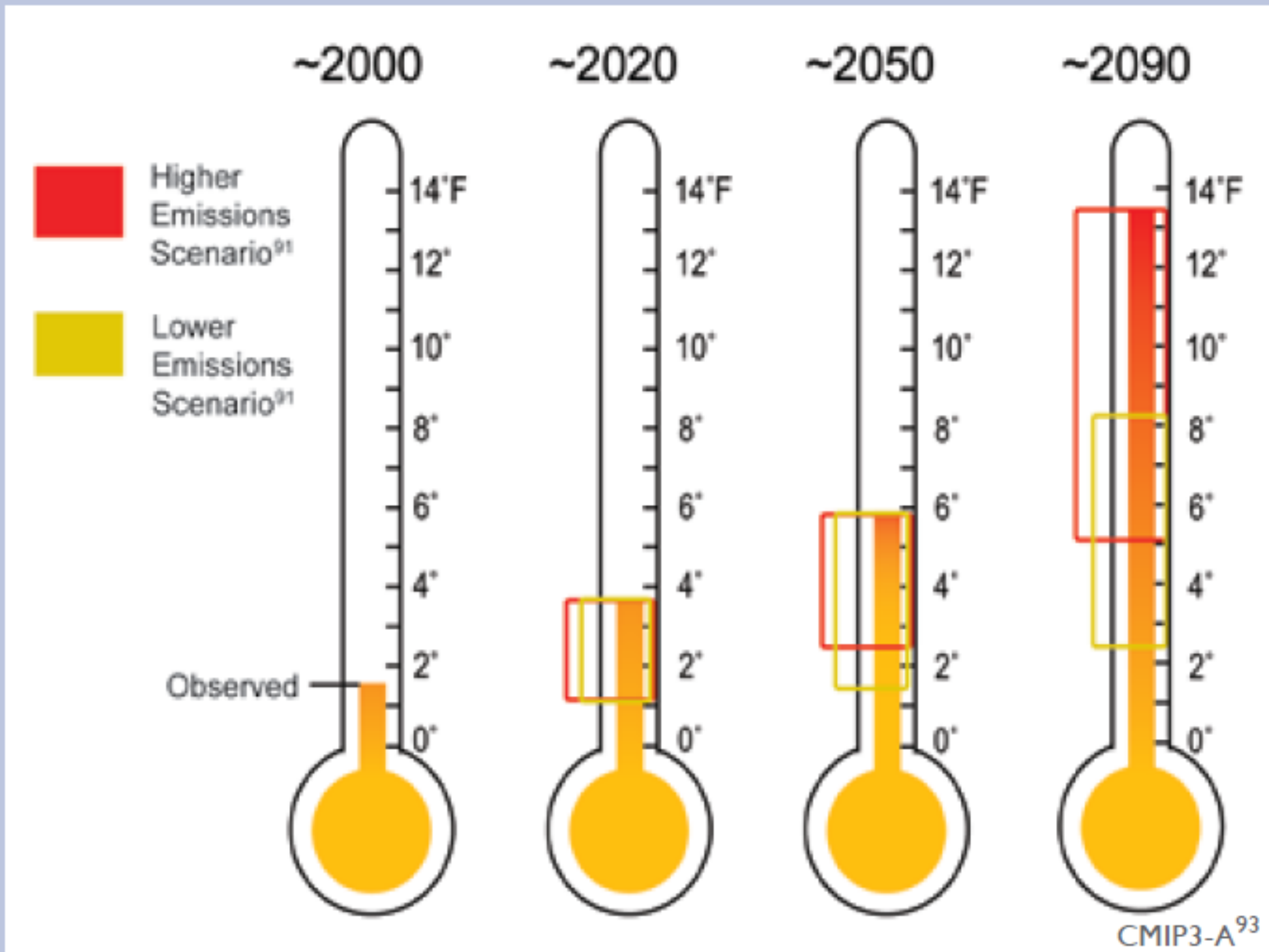


The average number of days per year when the maximum temperature exceeded 90°F from 1961-1979 (top) and the projected number of days per year above 90°F by the 2080s and 2090s for lower emissions (middle) and higher emissions (bottom).[91] Much of the southern United States is projected to have more than twice as many days per year above 90°F by the end of this century.


Projected End-of-Century under
Lower Emissions Scenario[91]
(2080-2099 Average)
Days Above 90°F
Number of Days per Year
0 15 30 45 60 75 90 105 120 135 150 16
CMIP3-B[117]
CMIP3-B[117]

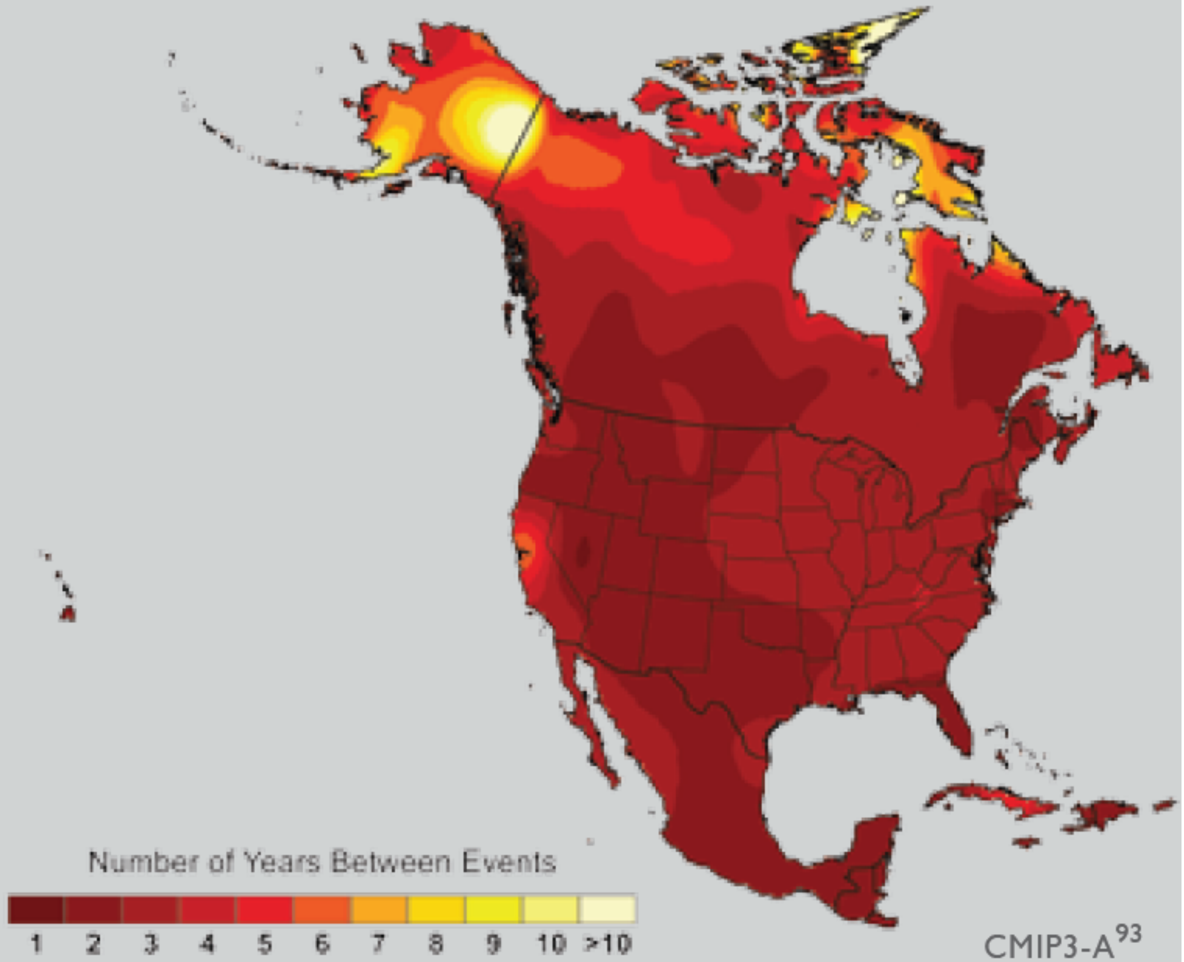

Projected End-of-Century under
Higher Emissions Scenario[91]
(2080-2099 Average)
Days Above 90°F
Number of Days per Year
0 15 30 45 60 75 90 105 120 135 150 165 180 >180

Observed and Projected Temperature Rise



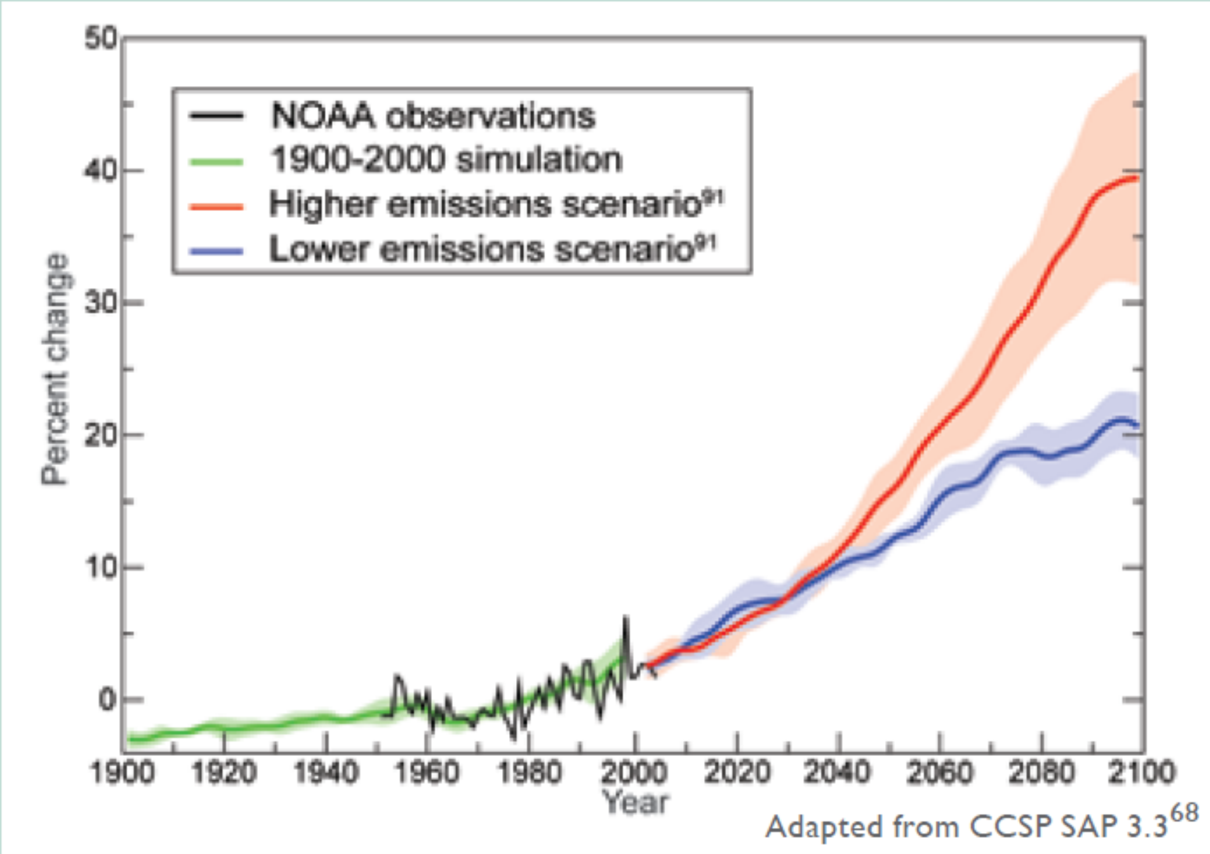
The average temperature in the Great Plains already has increased roughly 1.5°F relative to a 1960s and 1970s baseline. By the end of the century, temperatures are projected to continue to increase by 2.5°F to more than 13°F compared with the 1960 to 1979 baseline, depending on future emissions of heat-trapping gases. The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible.

Projected Frequency of Extreme Heat
(2080-2099 Average)



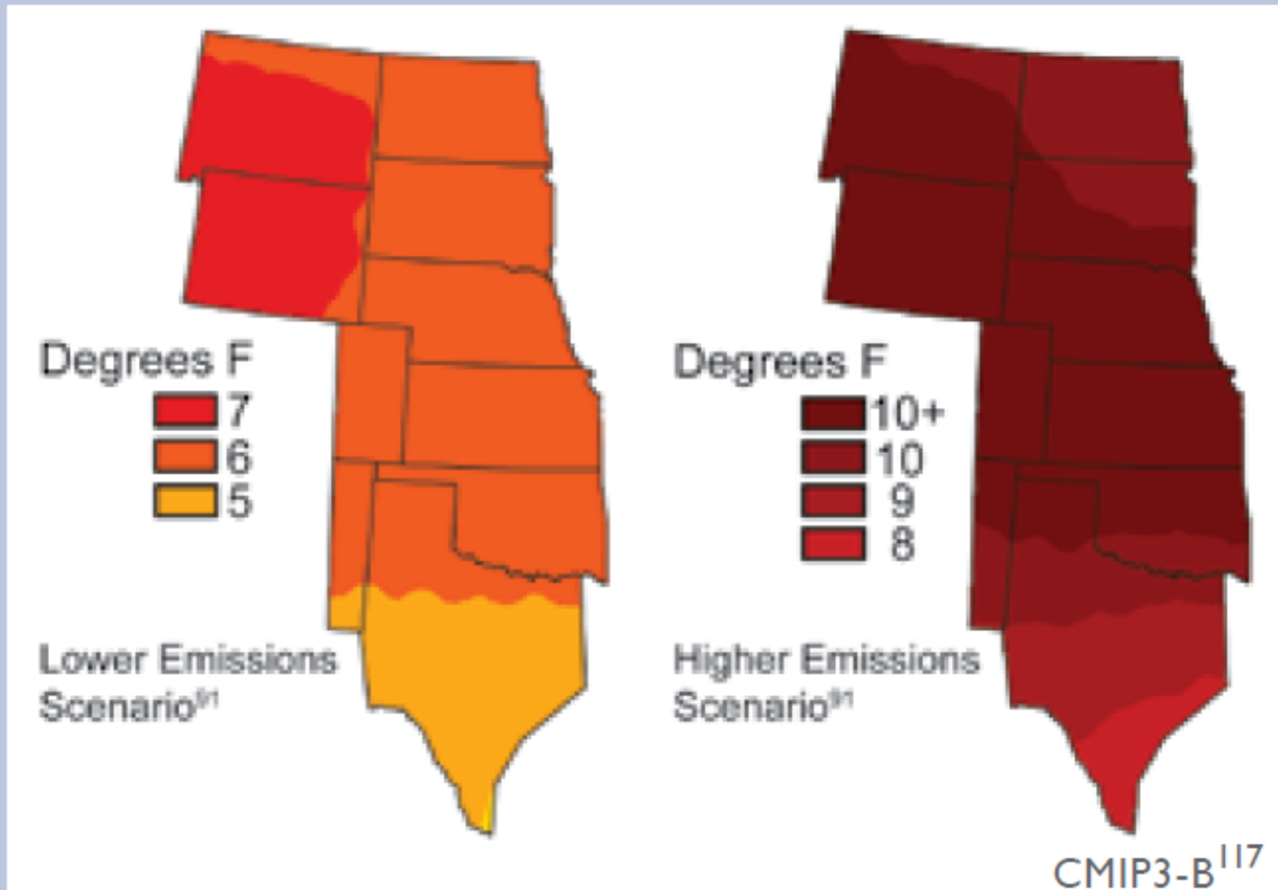
Simulations for 2080-2099 indicate how currently rare extremes (a 1-in-20-year event) are projected to become more commonplace. A day so hot that it is currently experienced once every 20 years would occur every other year or more frequently by the end of the century under the higher emissions scenario.[91]

Increase in Percent of Very Warm Nights



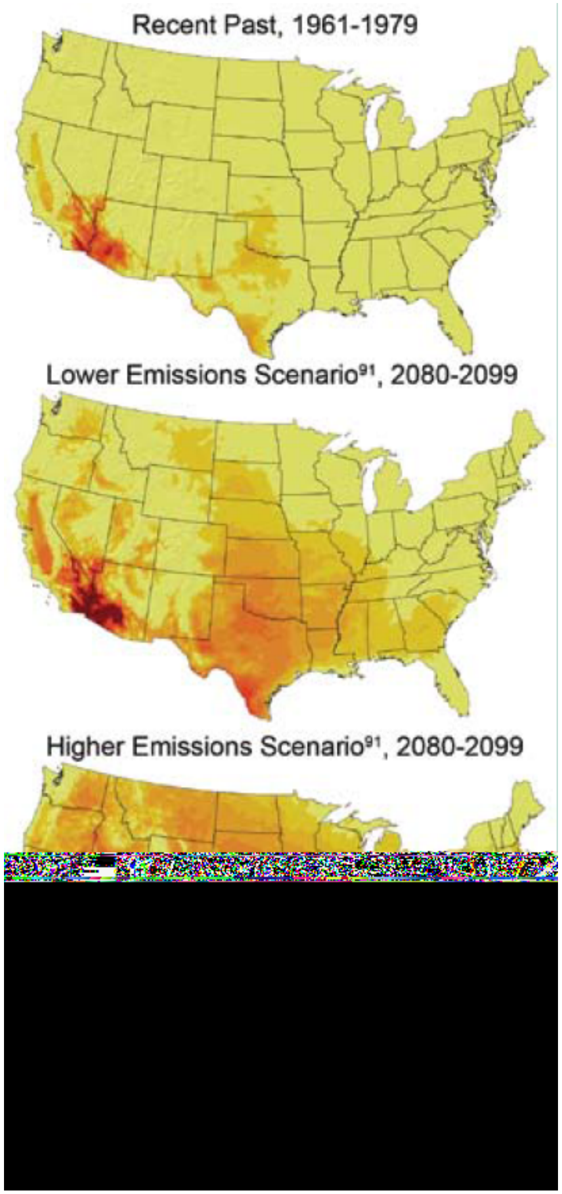
The graph shows the observed and projected change in percent of very warm nights from the 1950-1990 average in the United States. Under the lower emissions scenario,[91] the percentage of very warm nights is projected to increase about 20 percent by 2100. Under the higher emissions scenario,[91] it is projected to increase by about 40 percent.[68] The shaded areas show the likely ranges while the lines show the central projections from a set of climate models. The projections appear smooth because they show the calculated average of many models.

Summer Temperature Change by 2080-2099

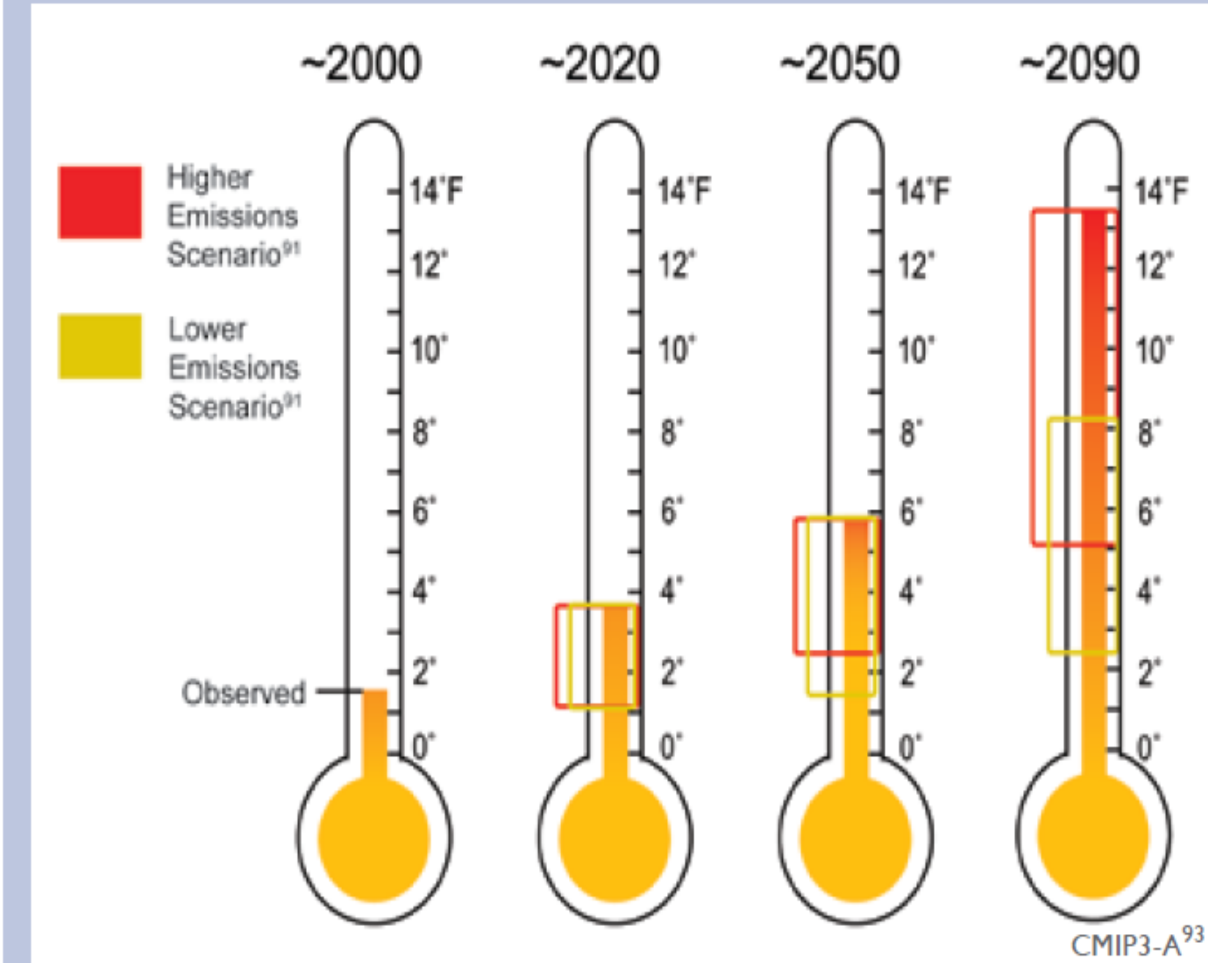


Temperatures in the Great Plains are projected to increase significantly by the end of this century, with the northern part of the region experiencing the greatest projected increase in temperature.

Number of Days Over 100°F

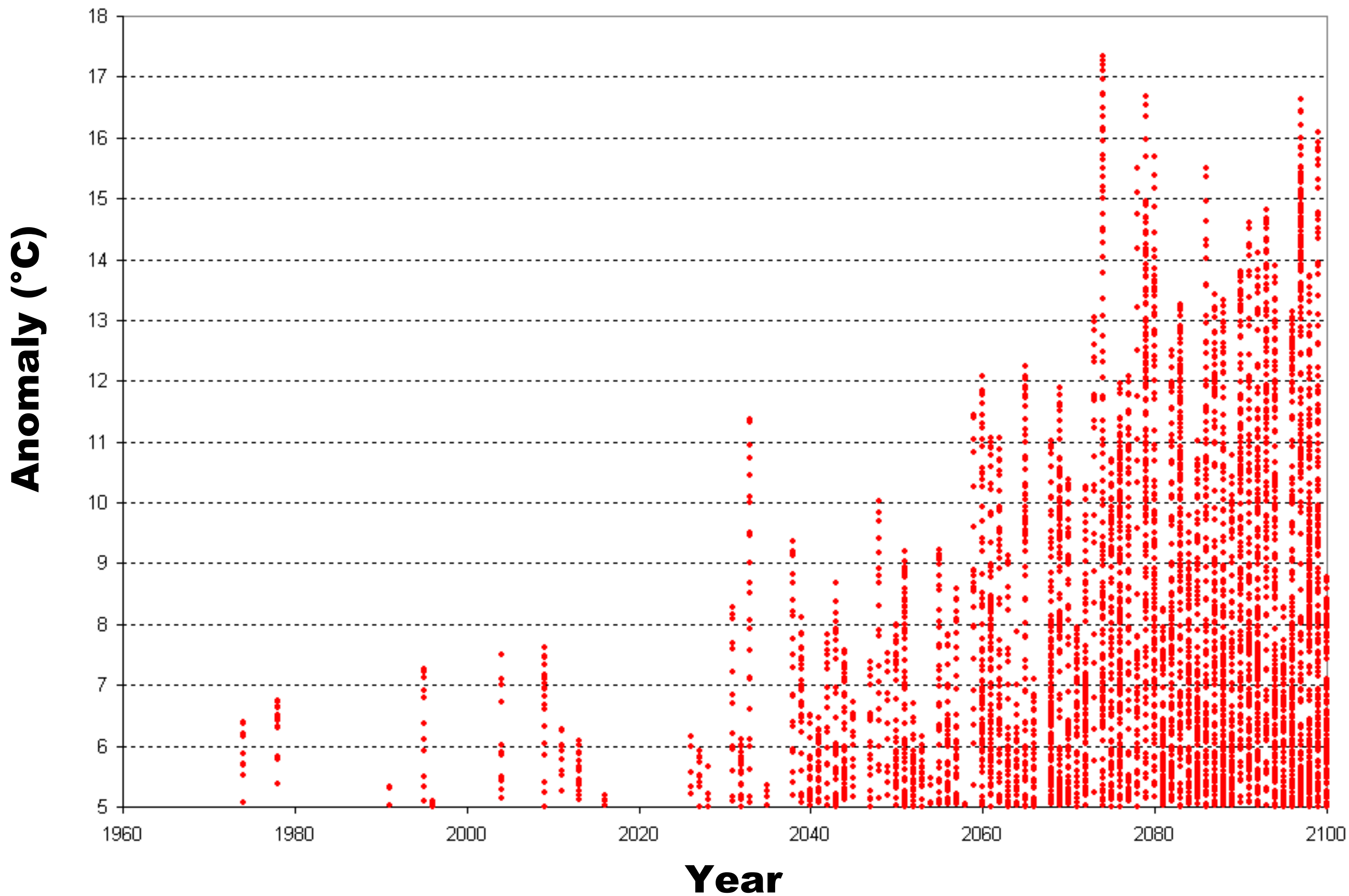


Observed and Projected Temperature Rise

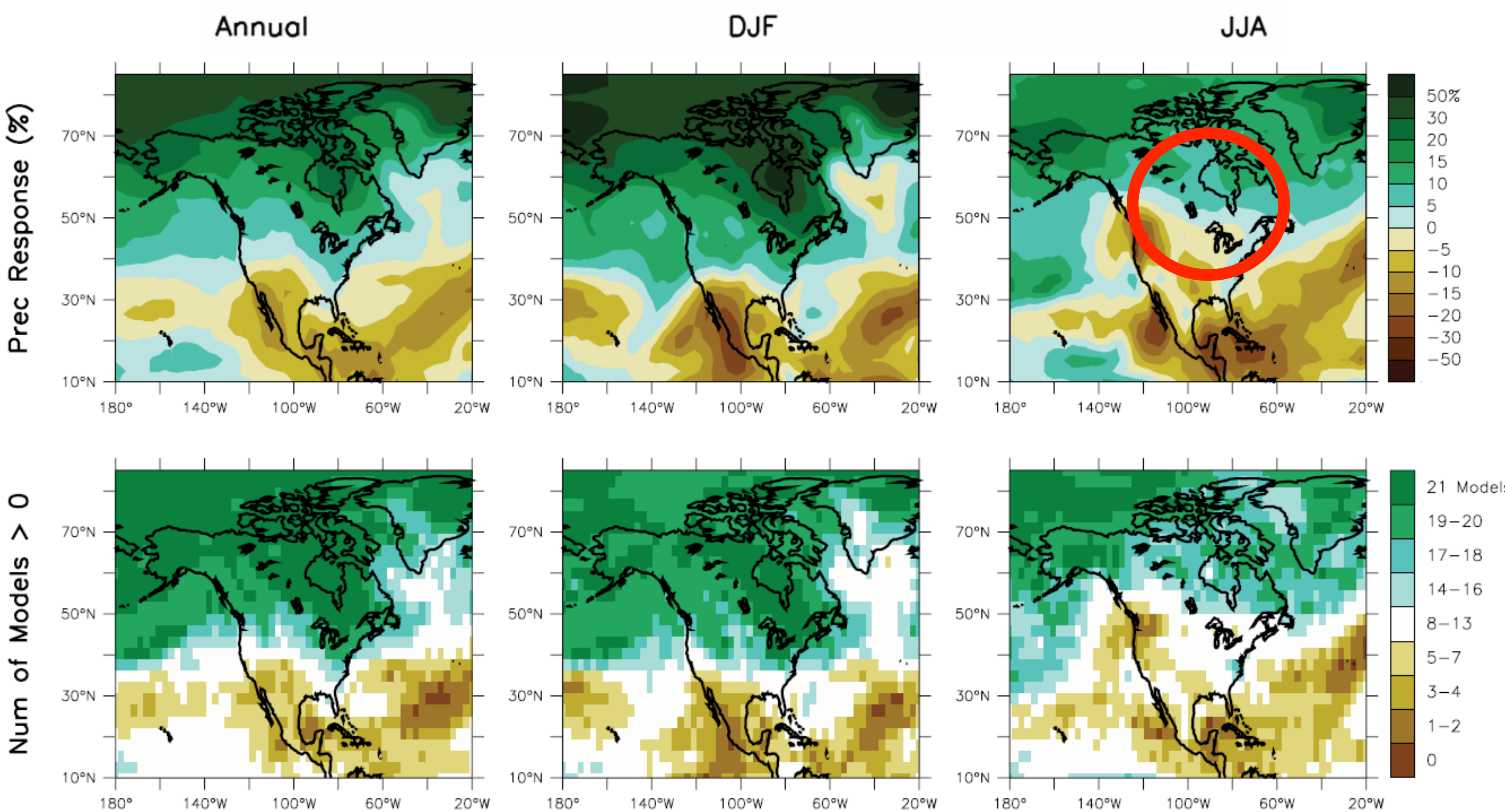


The average temperature in the Great Plains already has increased roughly 1.5°F relative to a 1960s and 1970s baseline. By the end of the century, temperatures are projected to continue to increase by 2.5°F to more than 13°F compared with the 1960 to 1979 baseline, depending on future emissions of heat-trapping gases. The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible.

Scatterplot of Annul 21-day Warm Spells (>5°C above normal), 1961-2100 (CGCM2 A2 Model)

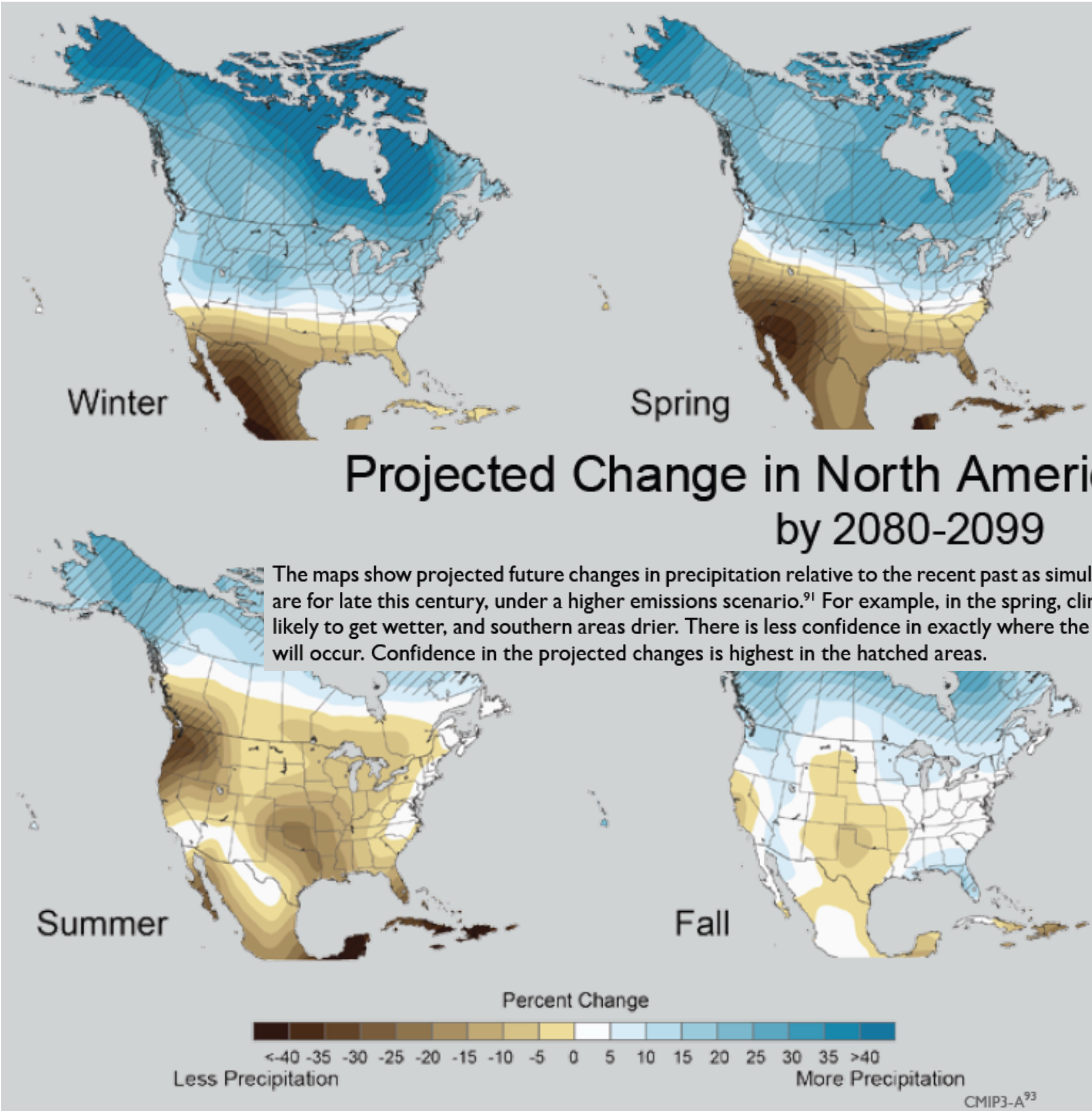


Precipitation Changes from the A1B Simulations, 2080s



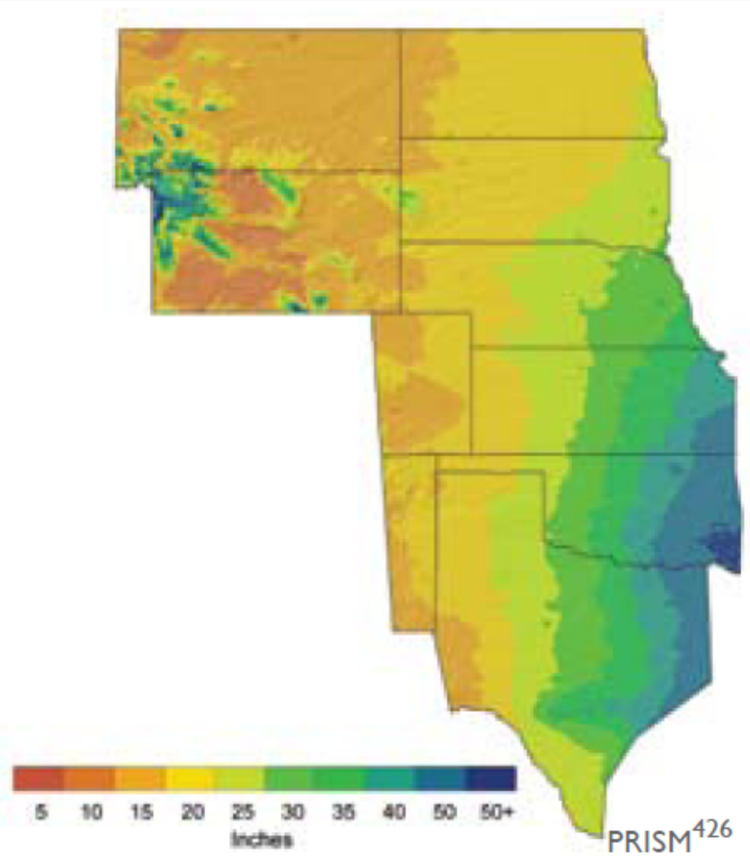
IPCC 2007

Projected Change in North American Precipitation by 2080-2099



The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario.[91] For example, in the spring, climate models agree that northern areas are likely to get wetter, and southern areas drier. There is less confidence in exactly where the transition between wetter and drier areas will occur. Confidence in the projected changes is highest in the hatched areas.

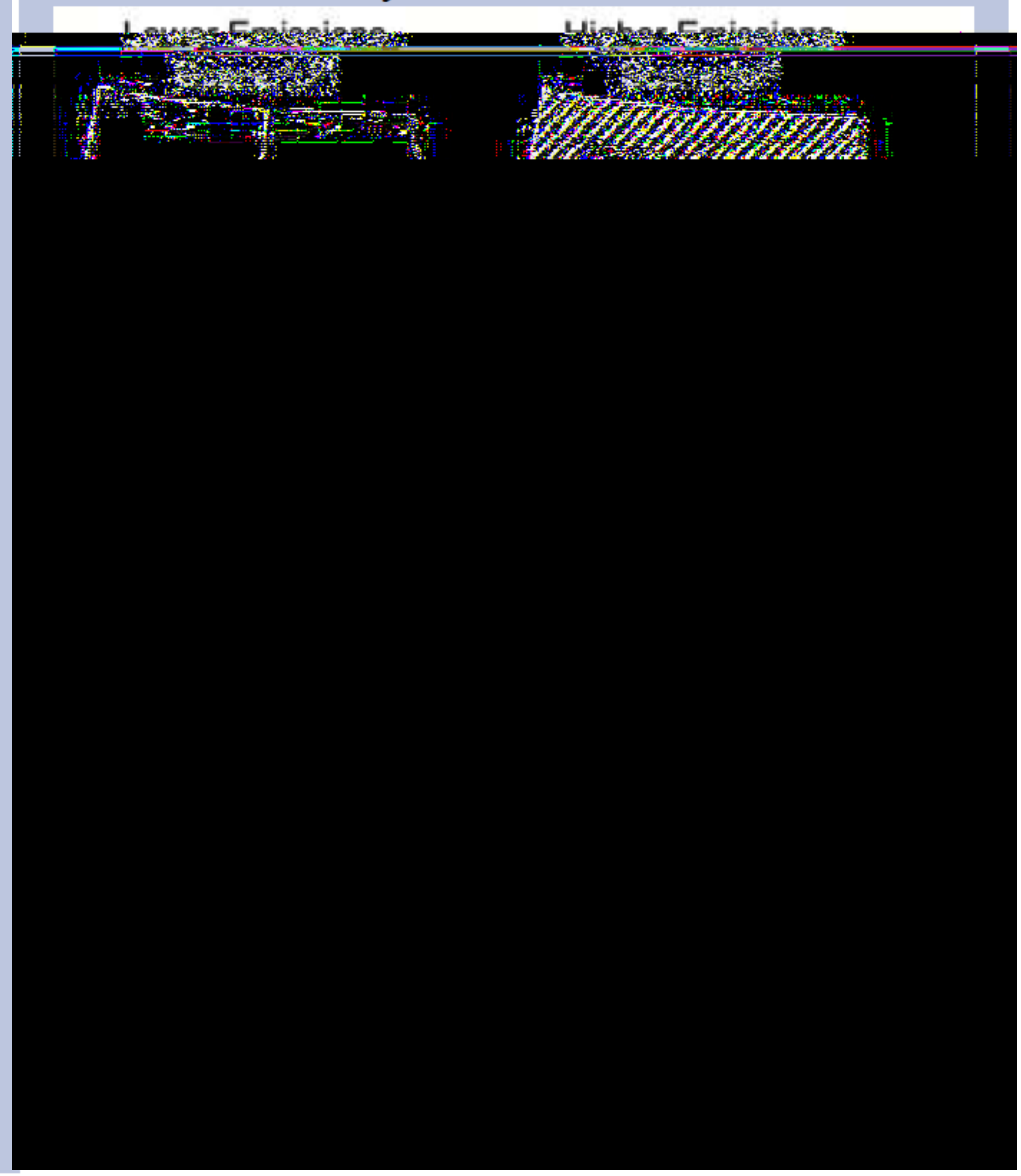
Average Annual Observed Precipitation
1971-2000



PRISM[426]

The Great Plains currently experiences a sharp precipitation gradient from east to west, from more than 50 inches of precipitation per year in eastern Oklahoma and Texas to less than 10 inches in some of the western parts of the region.

Projected Spring Precipitation Change by 2080s-2090s



Seasonal Change in Precipitation by the 2050s (%)

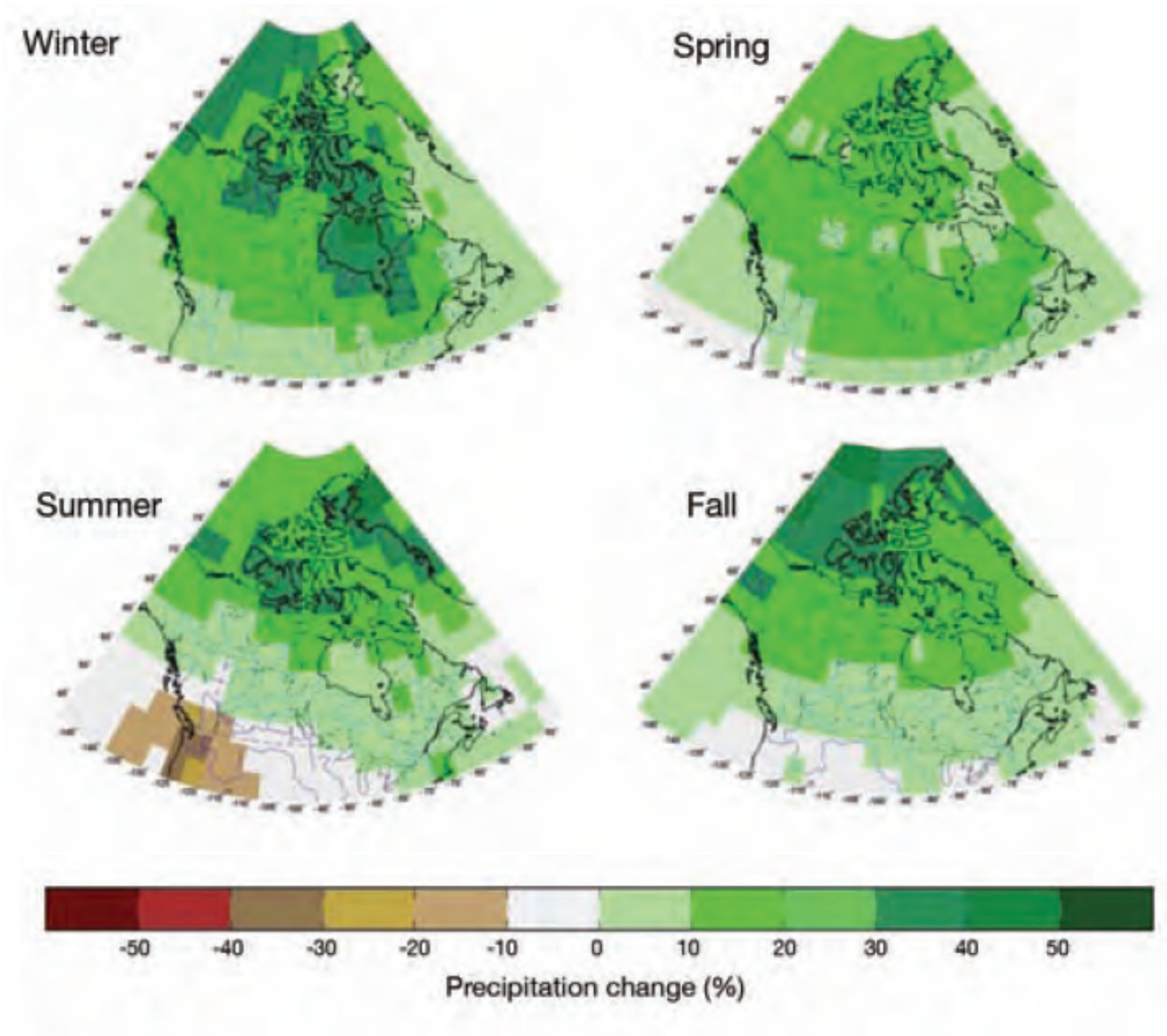
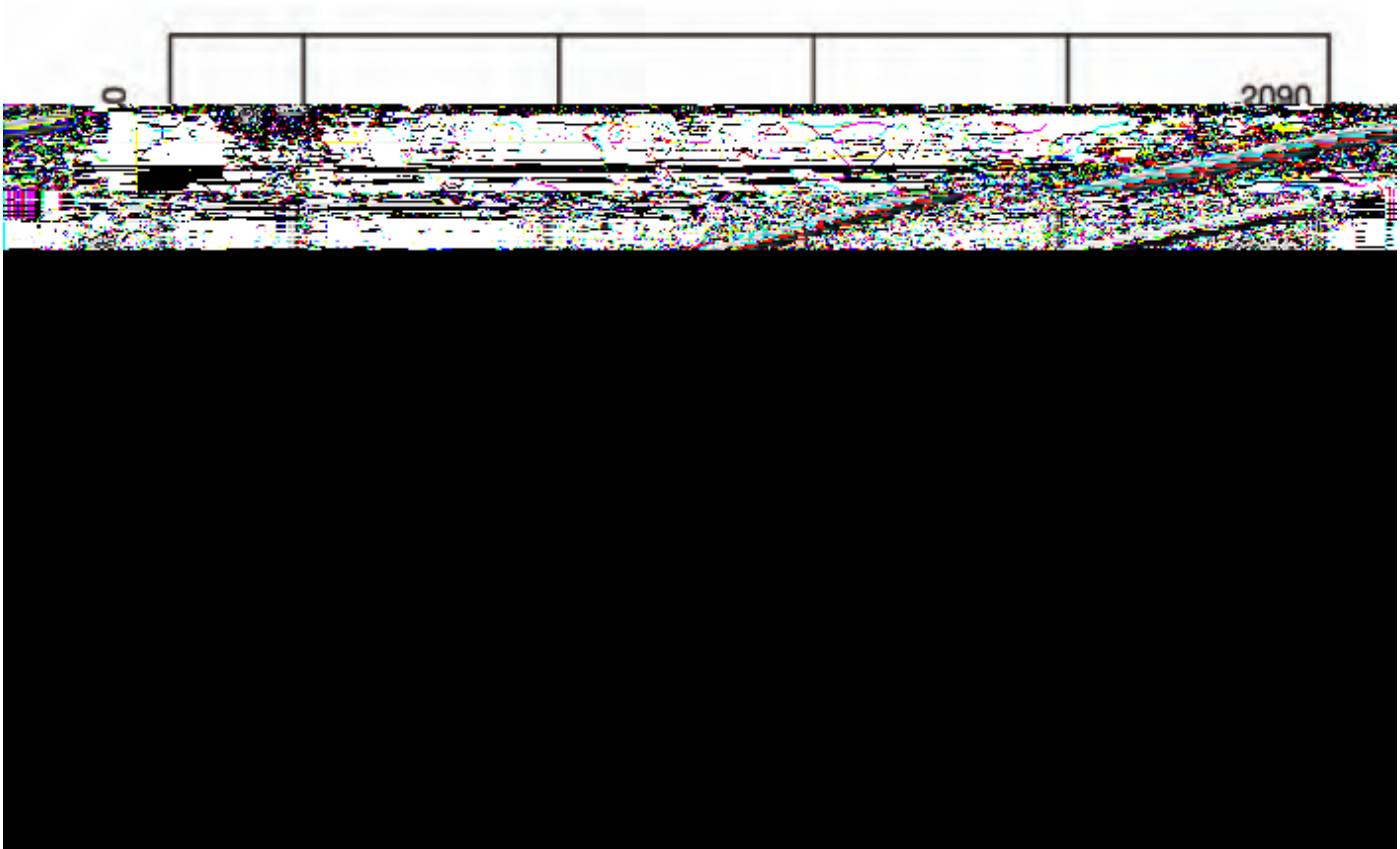
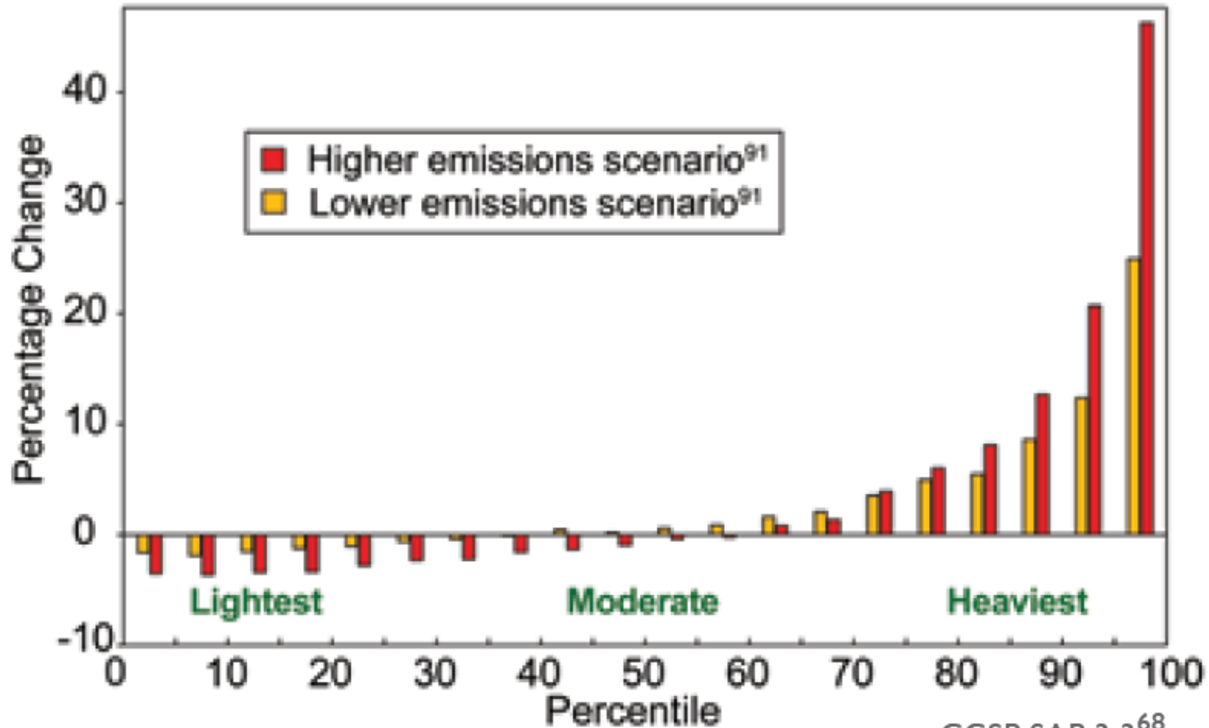


FIGURE 14: Seasonal change in precipitation by the 2050s (relative to 1961–1990), based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).



Projected changes in extreme 24-hour precipitation events, North America, between 25°N and 65°N

Projected Changes in Light, Moderate, and Heavy Precipitation (by 2090s)

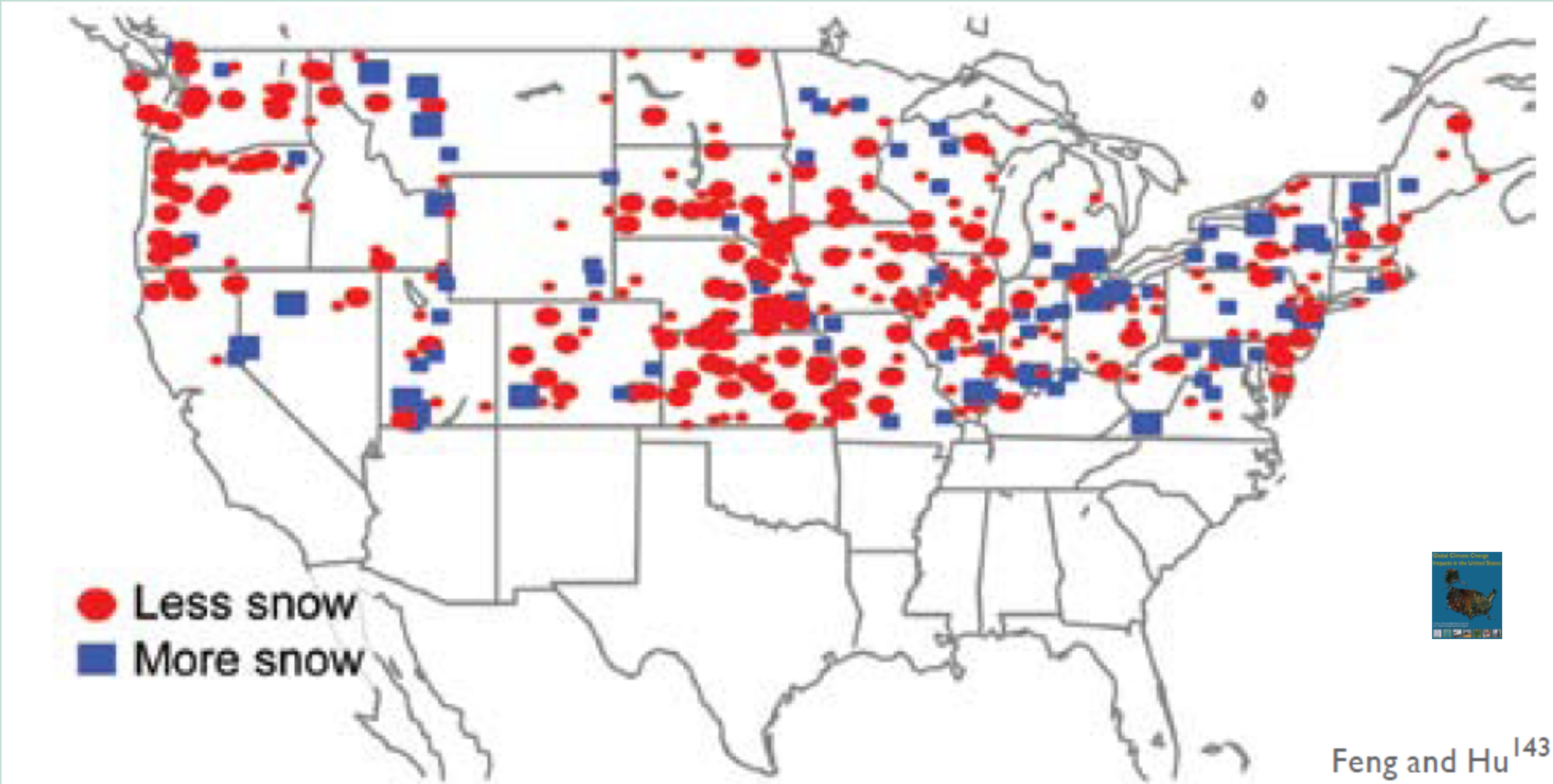


CCSP SAP 3.3[68]

The figure shows projected changes from the 1990s average to the 2090s average in the amount of precipitation falling in light, moderate, and heavy events in North America. Projected changes are displayed in 5 percent increments from the lightest drizzles to the heaviest downpours. As shown here, the lightest precipitation is projected to decrease, while the heaviest will increase, continuing the observed trend. The higher emission scenario[91] yields larger changes. Projections are based on the models used in the IPCC 2007 Fourth Assessment Report.

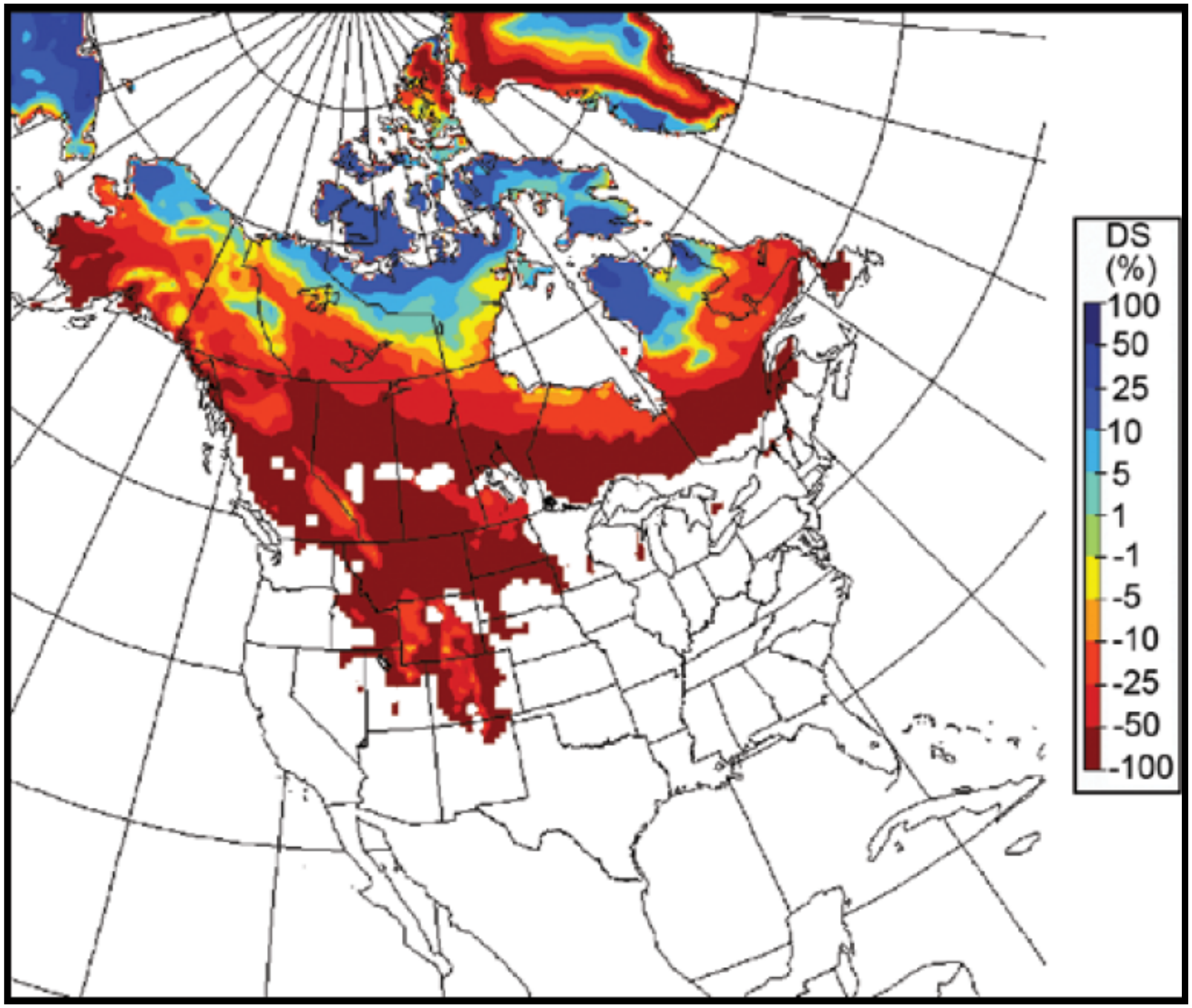
Changes in Snowfall Contributions to Wintertime Precipitation

1949 to 2005



Trends in winter snow-to-total precipitation ratio from 1949 to 2005. Red circles indicate less snow, while blue squares indicate more snow. Large circles and squares indicate the most significant trends.[143] Areas south of 37°N latitude were excluded from the analysis because most of that area receives little snowfall. White areas above that line have inadequate data for this analysis.

Percent Snow Depth Change in March for 2041 to 2070



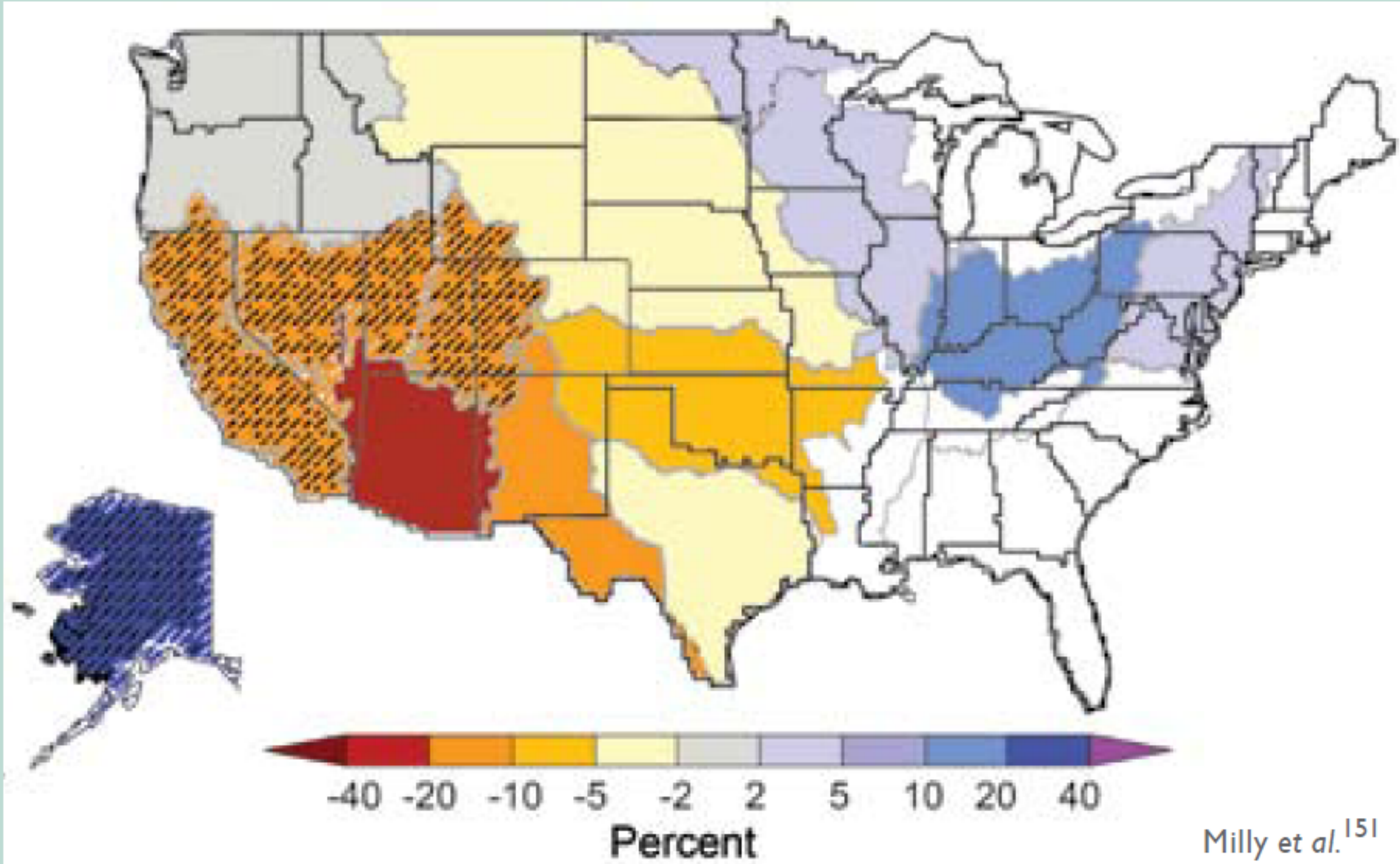
Model: CGCM

Scenario: SRES A2

Only calculated where snow is > 5 mm water

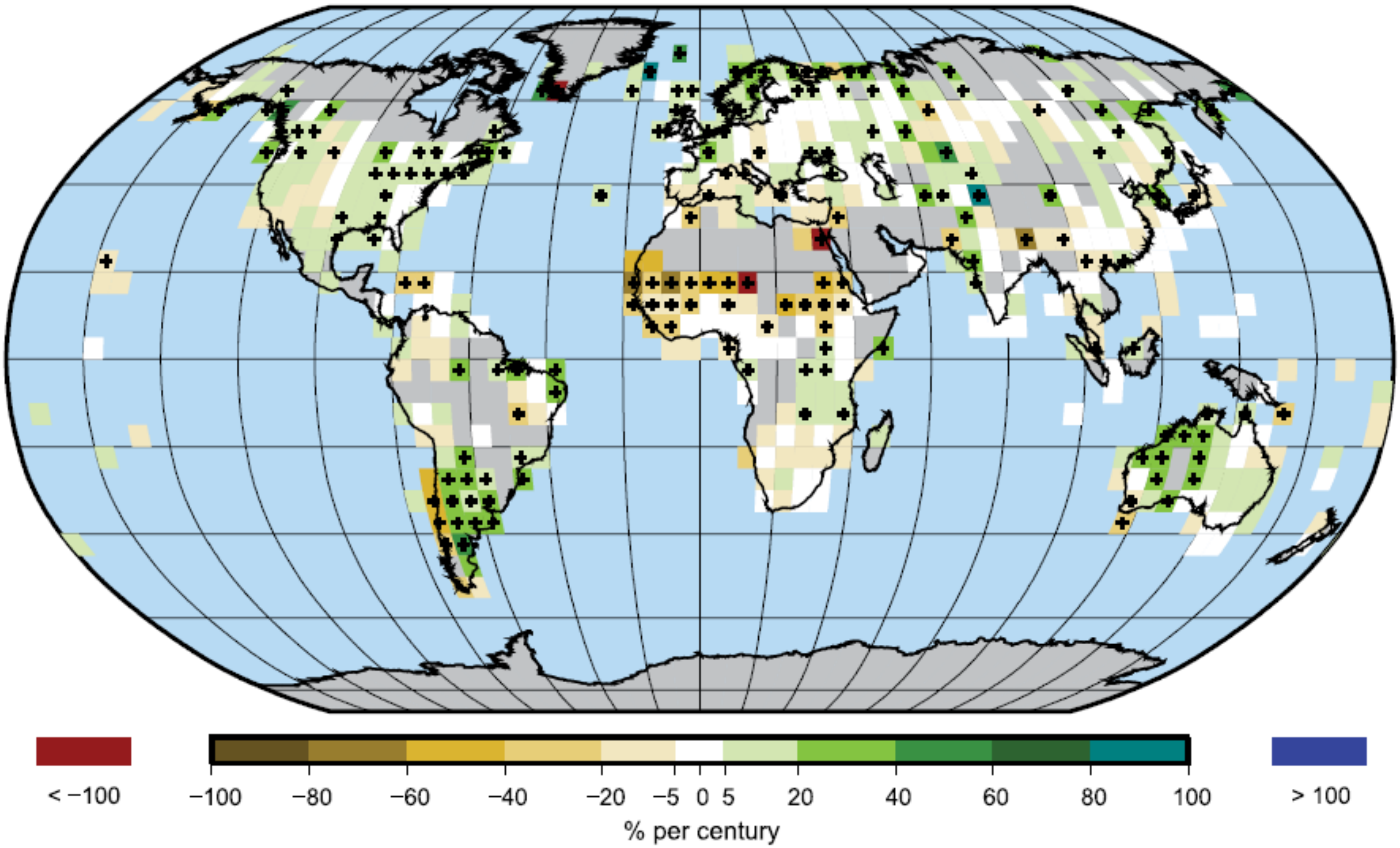
IPCC 2007

Projected Changes in Annual Runoff



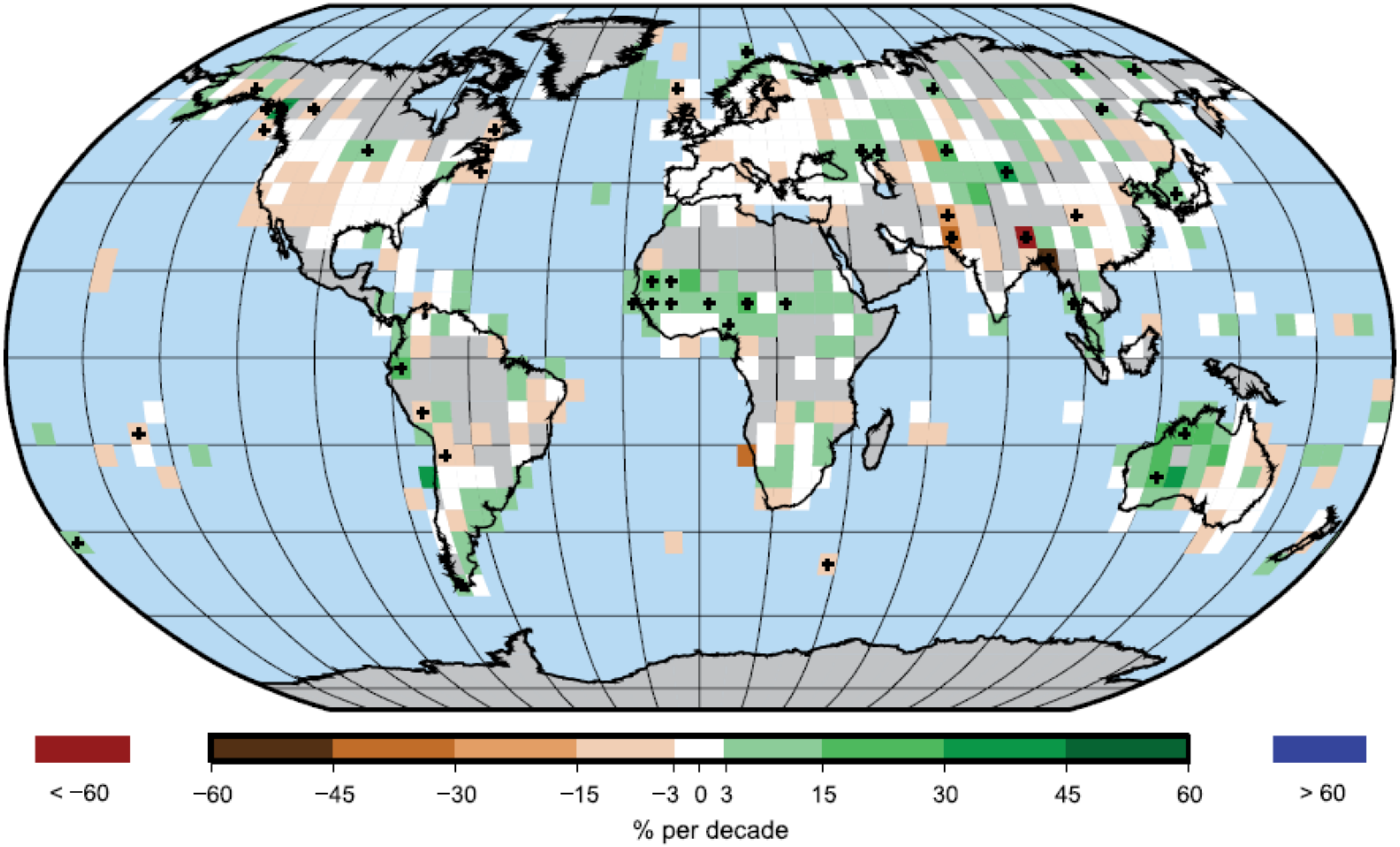
Projected changes in median runoff for 2041-2060, relative to a 1901-1970 baseline, are mapped by water-resource region. Colors indicate percentage changes in runoff. Hatched areas indicate greater confidence due to strong agreement among model projections. White areas indicate divergence among model projections. Results are based on emissions in between the lower and higher emissions scenarios.[91]

Trend in Annual Precipitation, 1901-2005

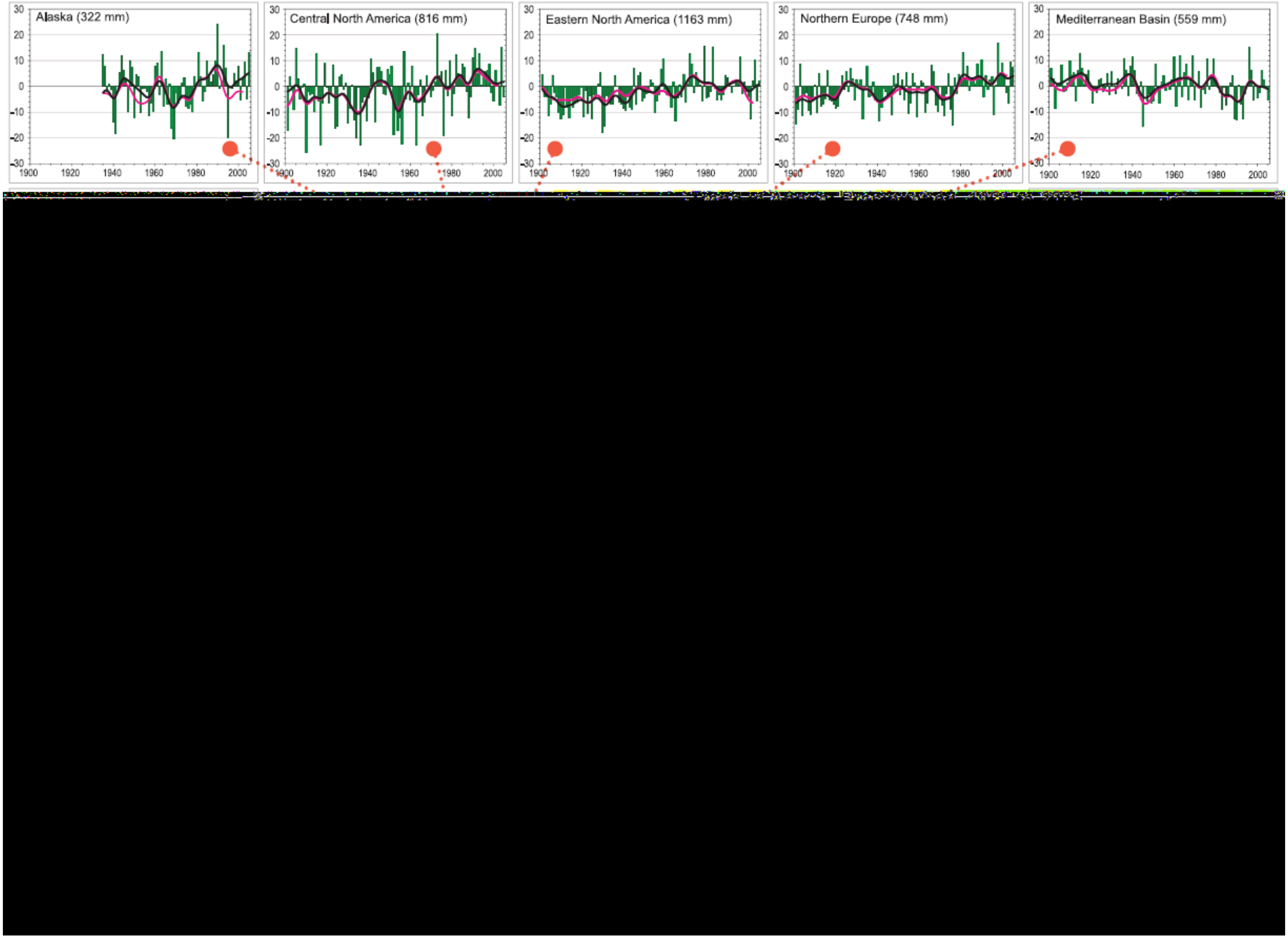


IPCC 2007

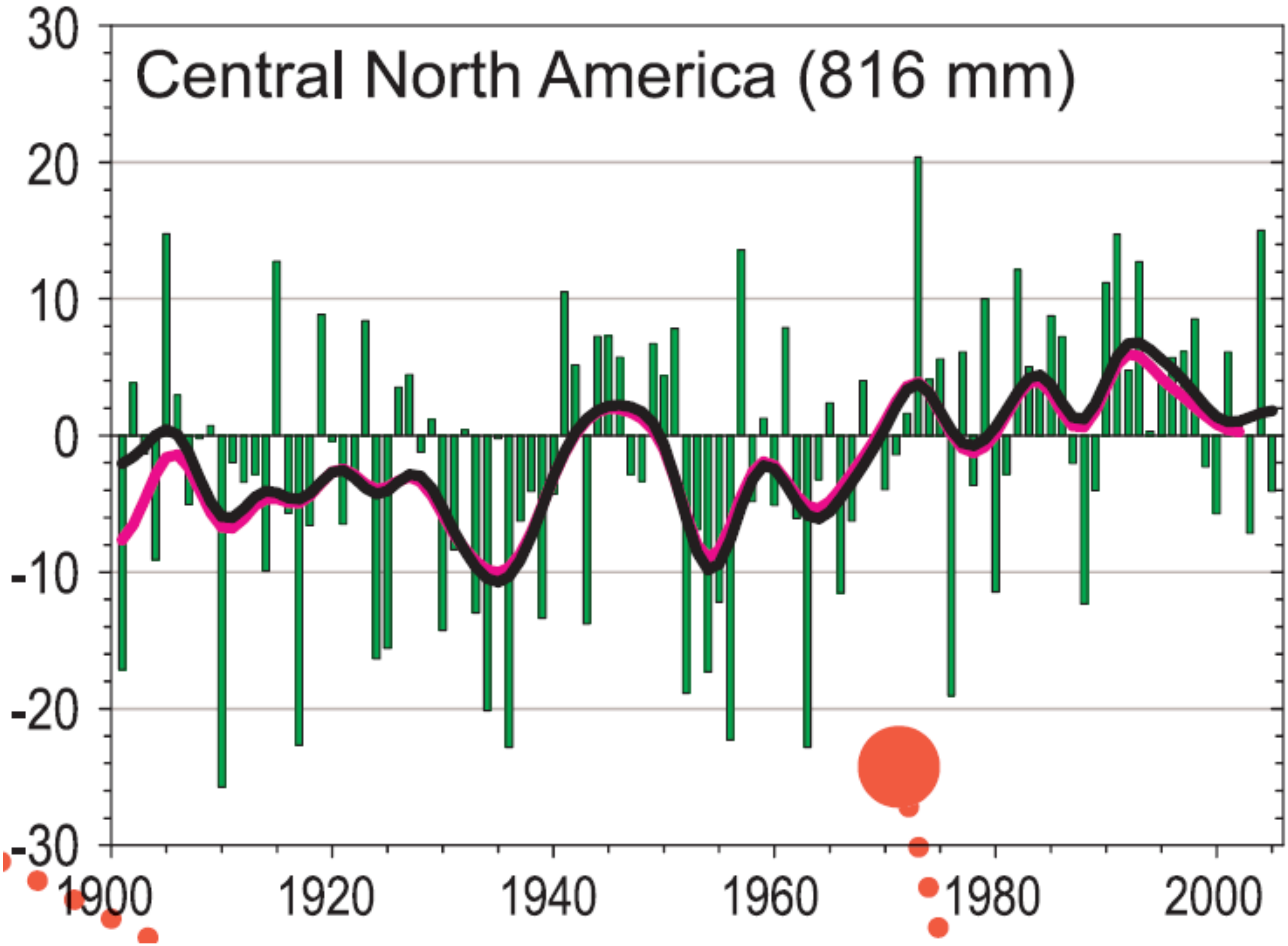
Trend in Annual Precipitation, 1979-2005



IPCC 2007


Alaska (322 mm)
Central North America (816 mm)
Eastern North America (1163 mm)
Northern Europe (748 mm)
Mediterranean Basin (559 mm)
30
20
10
0
-10
-20
-30
1900
1920
1940
1960
1980
2000

IPCC 2007

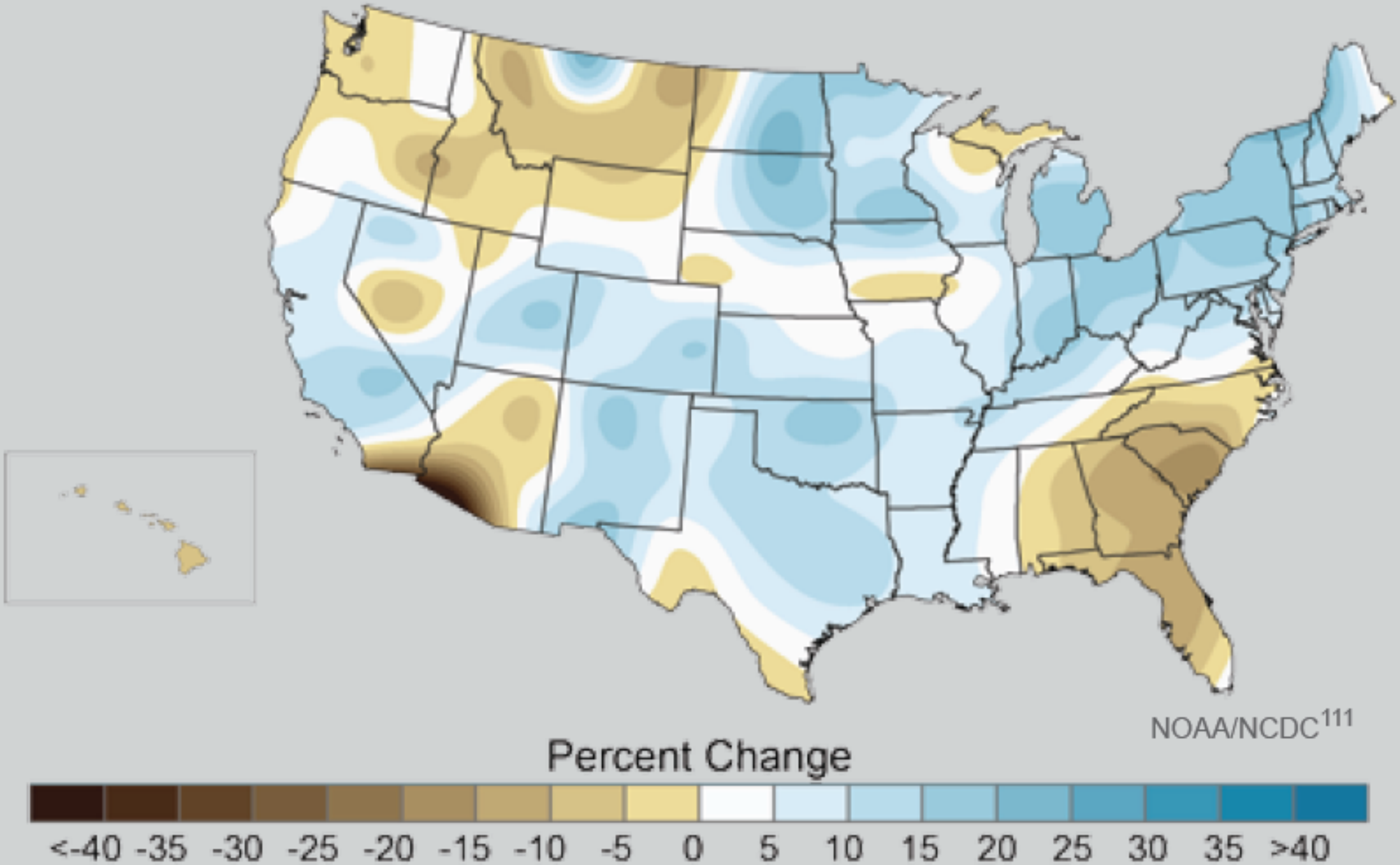


Central North America (816 mm)
30
20
10
0
-10
-20
-30
1900
1920
1940
1960
1980
2000

IPCC 2007

Observed Change in Annual Average Precipitation

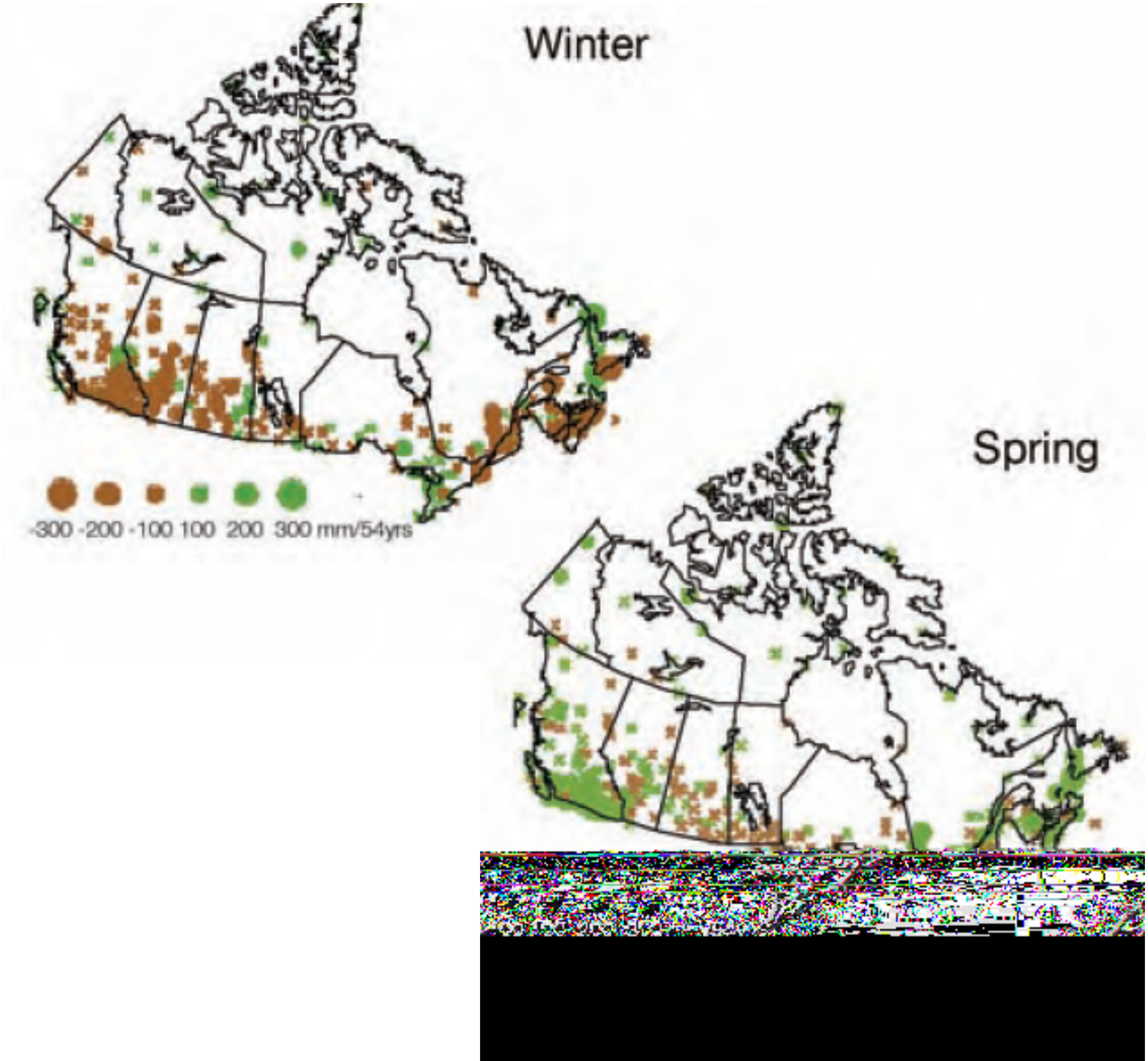
1958 to 2008

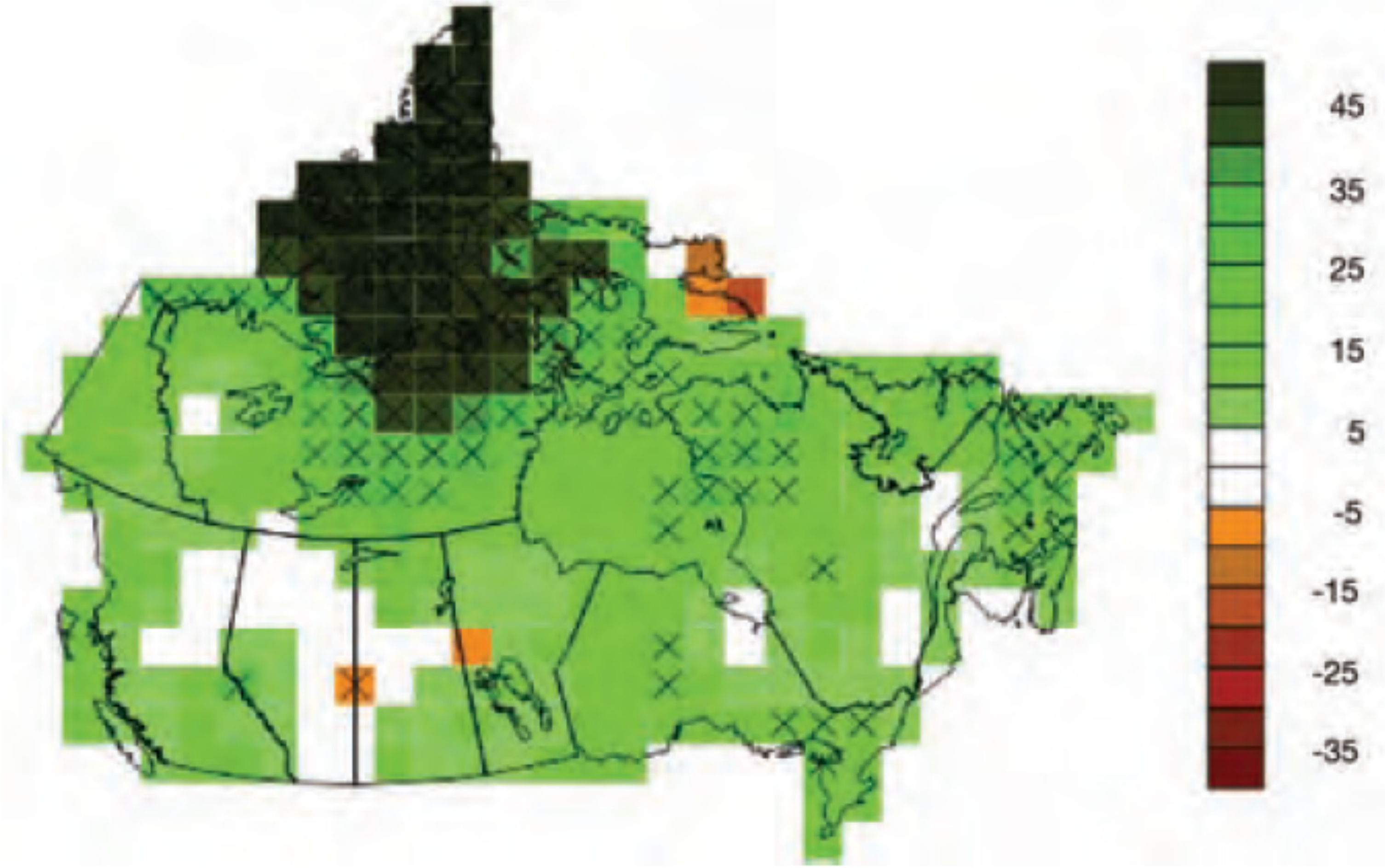


While U.S. annual average precipitation has increased about 5 percent over the past 50 years, there have been important regional differences as shown above.

Change in Precipitation, 1950-2003 (mm)

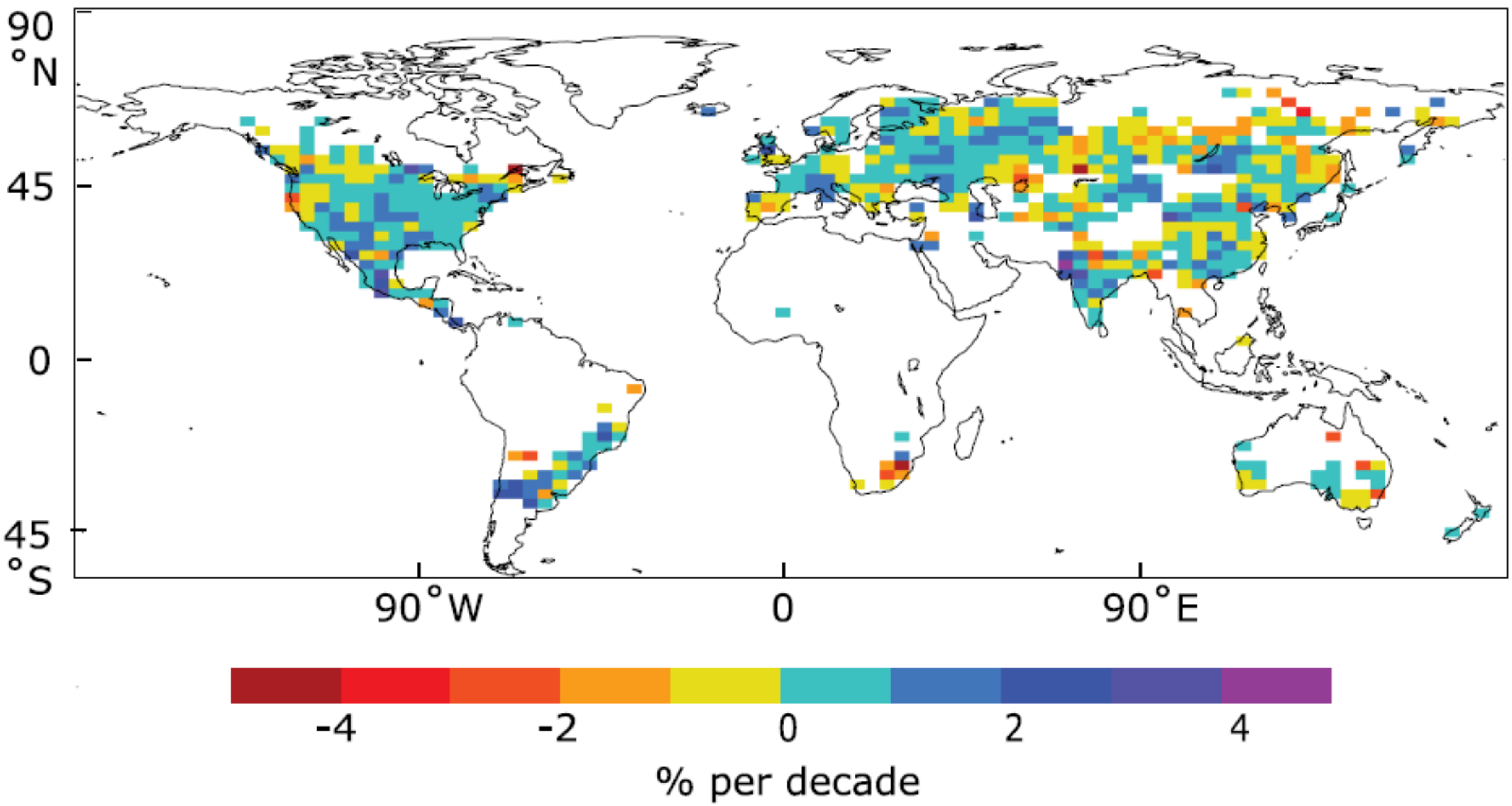
Change in Precipitation, 1950-2003 (mm)





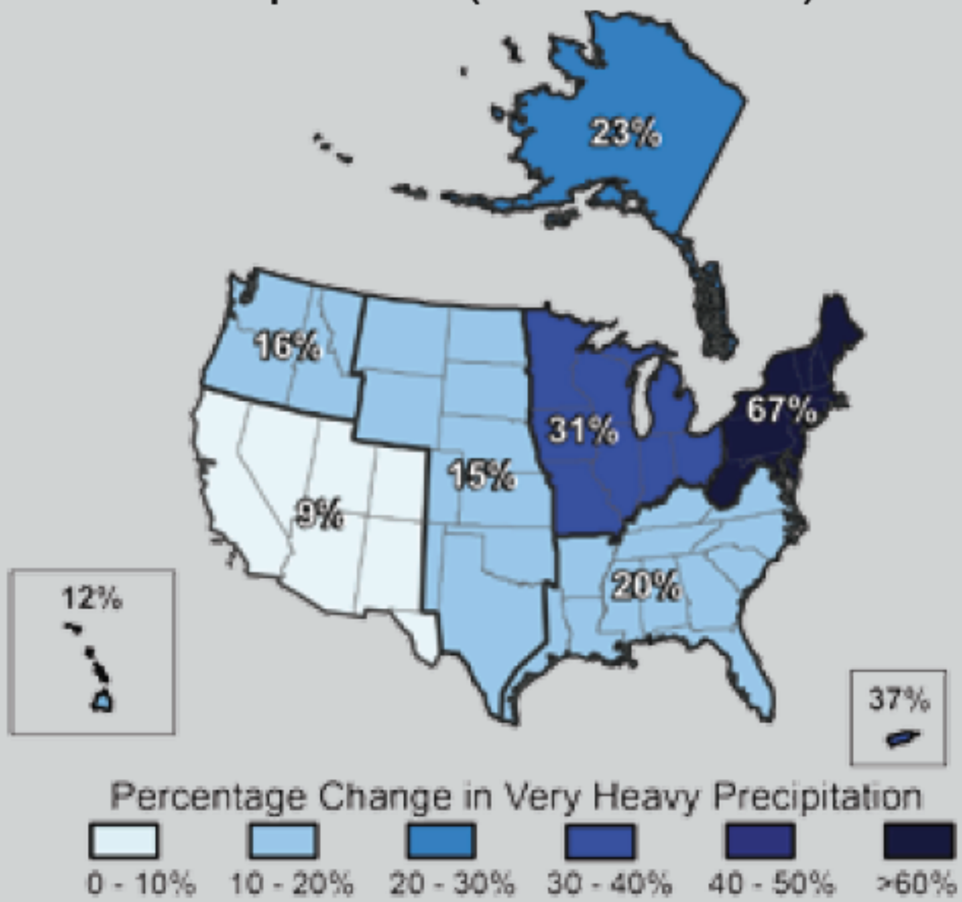
Annual Precipitation Trends between 1948 and 2003 (% Change)

Trend in Contribution from Very Wet Days, 1951-2003



IPCC 2007

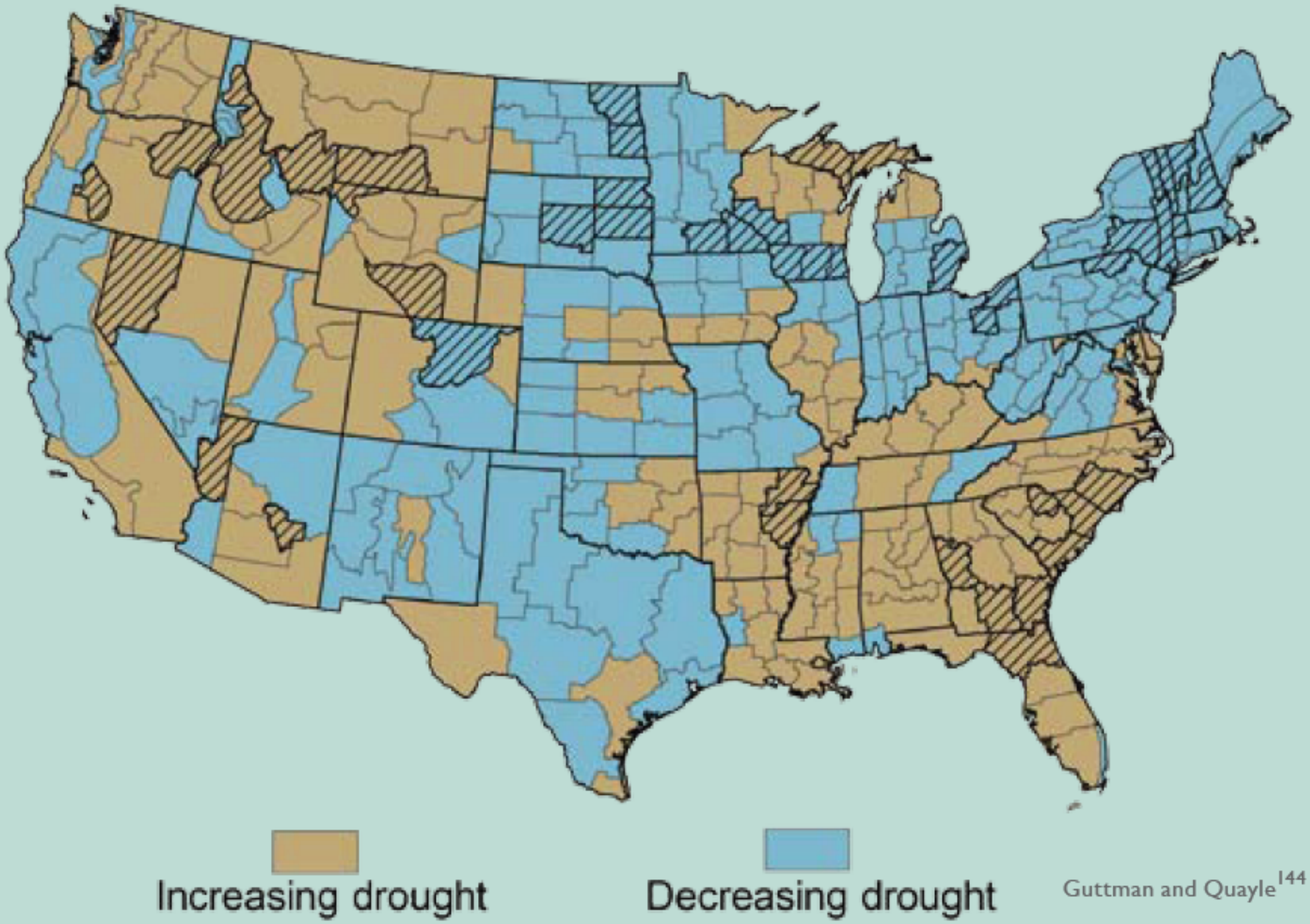
Increases in Amounts of Very Heavy Precipitation (1958 to 2007)



Updated from Groisman *et al.*[113]

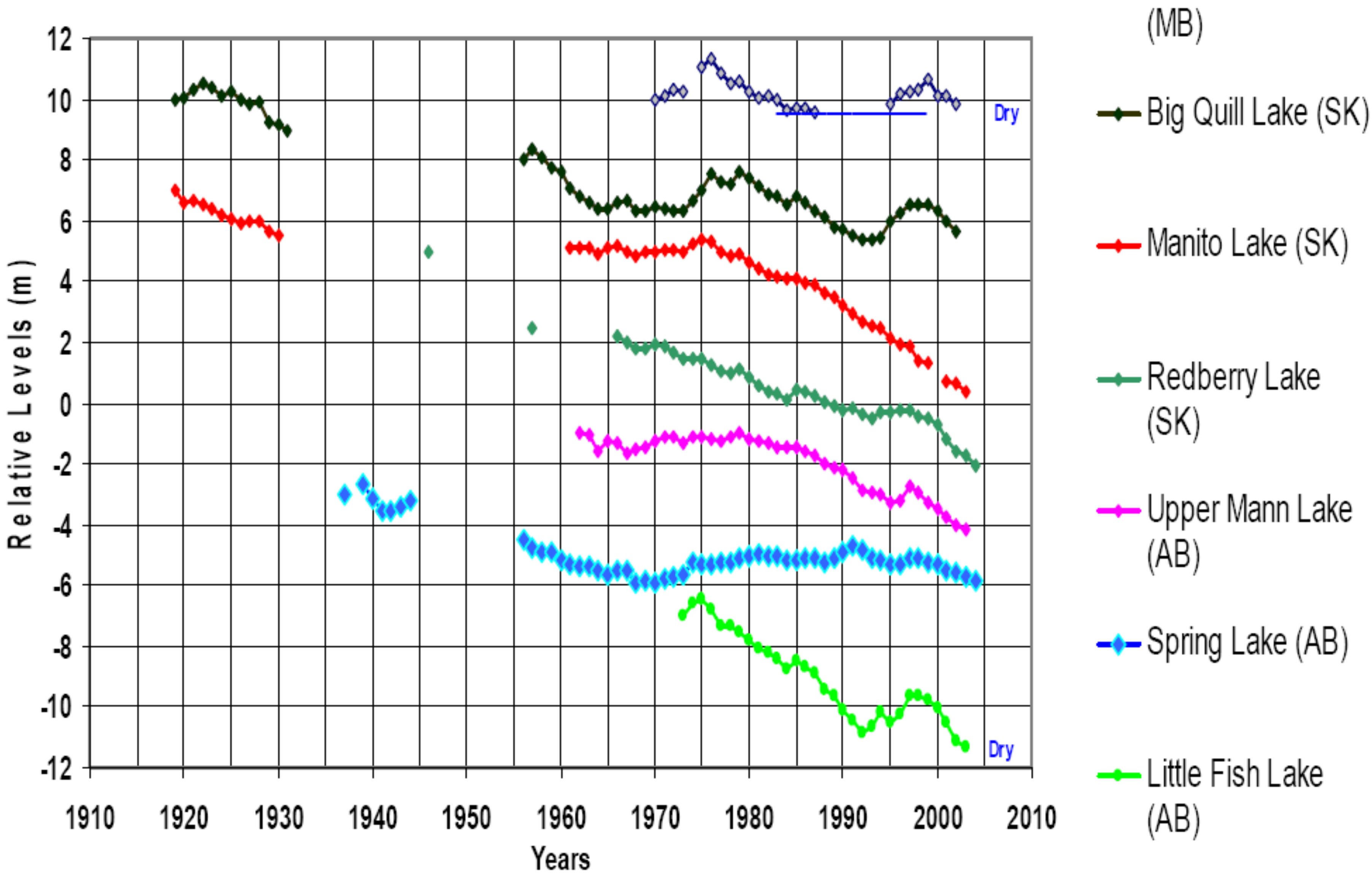
The map shows percent increases in the amount falling in very heavy precipitation events (defined as the heaviest 1 percent of all daily events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

Observed Drought Trends 1958 to 2007



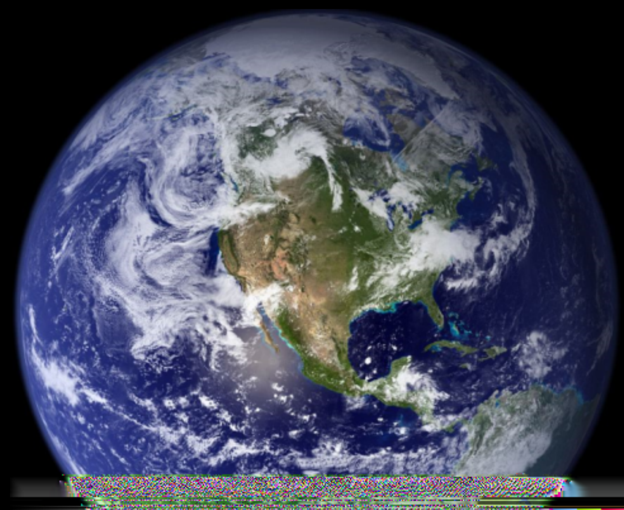
Trends in end-of-summer drought as measured by the Palmer Drought Severity Index from 1958 to 2007 in each of 344 U.S. climate divisions.[144] Hatching indicates significant trends.

Historical Closed-Basin Water Levels

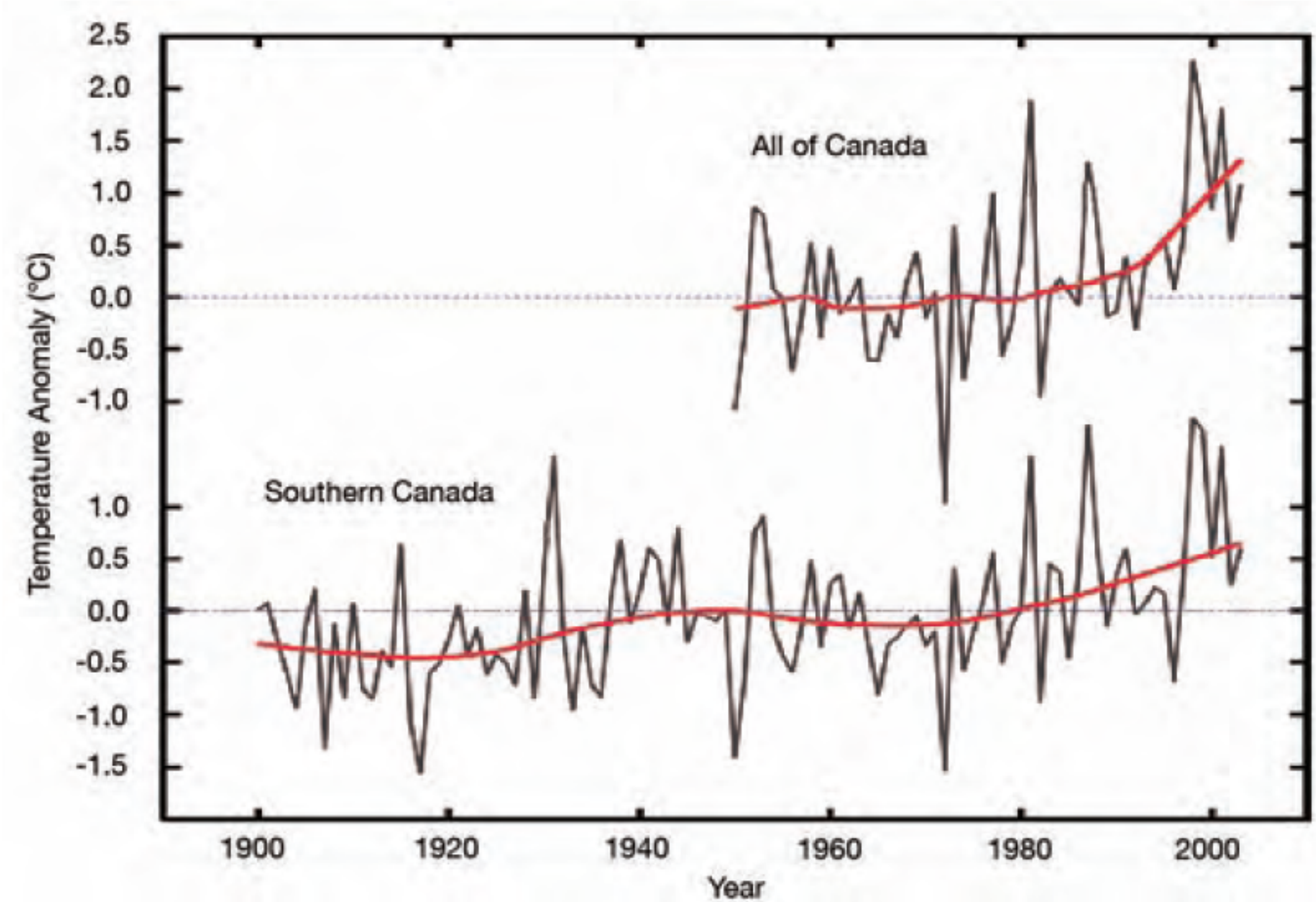


van der Kamp et al. 2006; van der Kamp & Keir 2005

The 100-year (1906-2005) linear warming trend was 0.74°C per century.



The trend over the last 50 years was 0.13°C per decade, nearly twice that for the last 100 years.



Annual National Temperature Trend

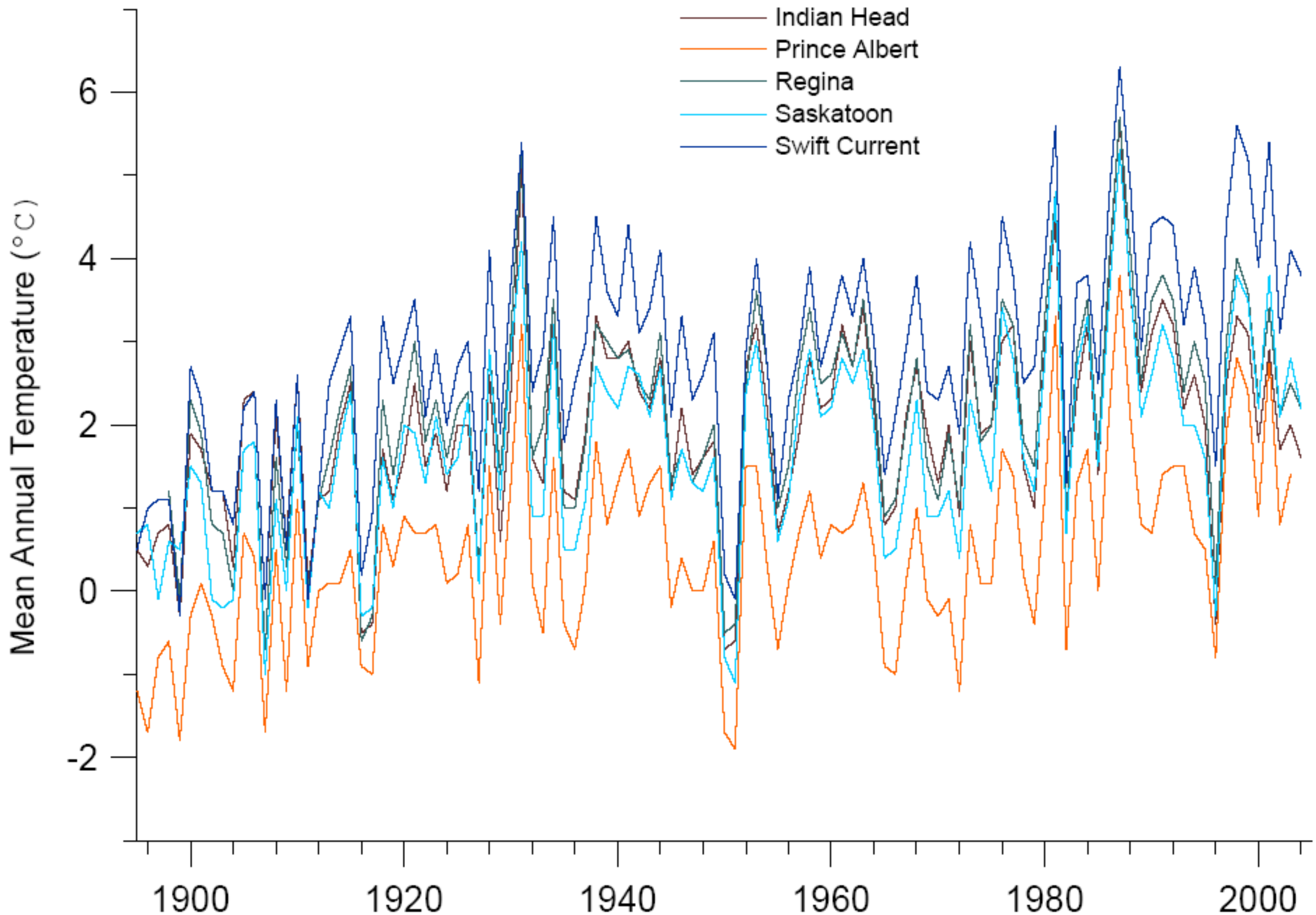
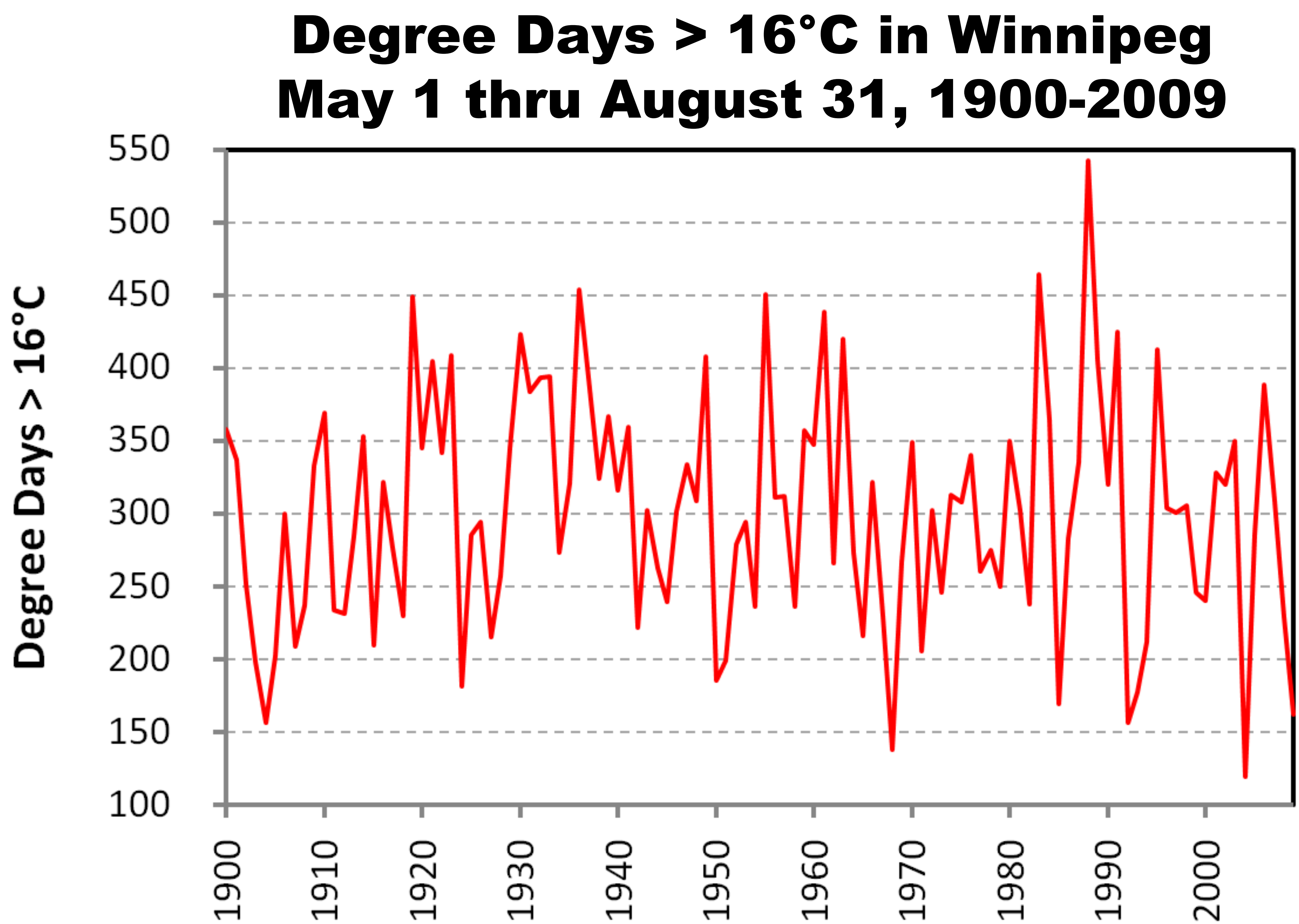
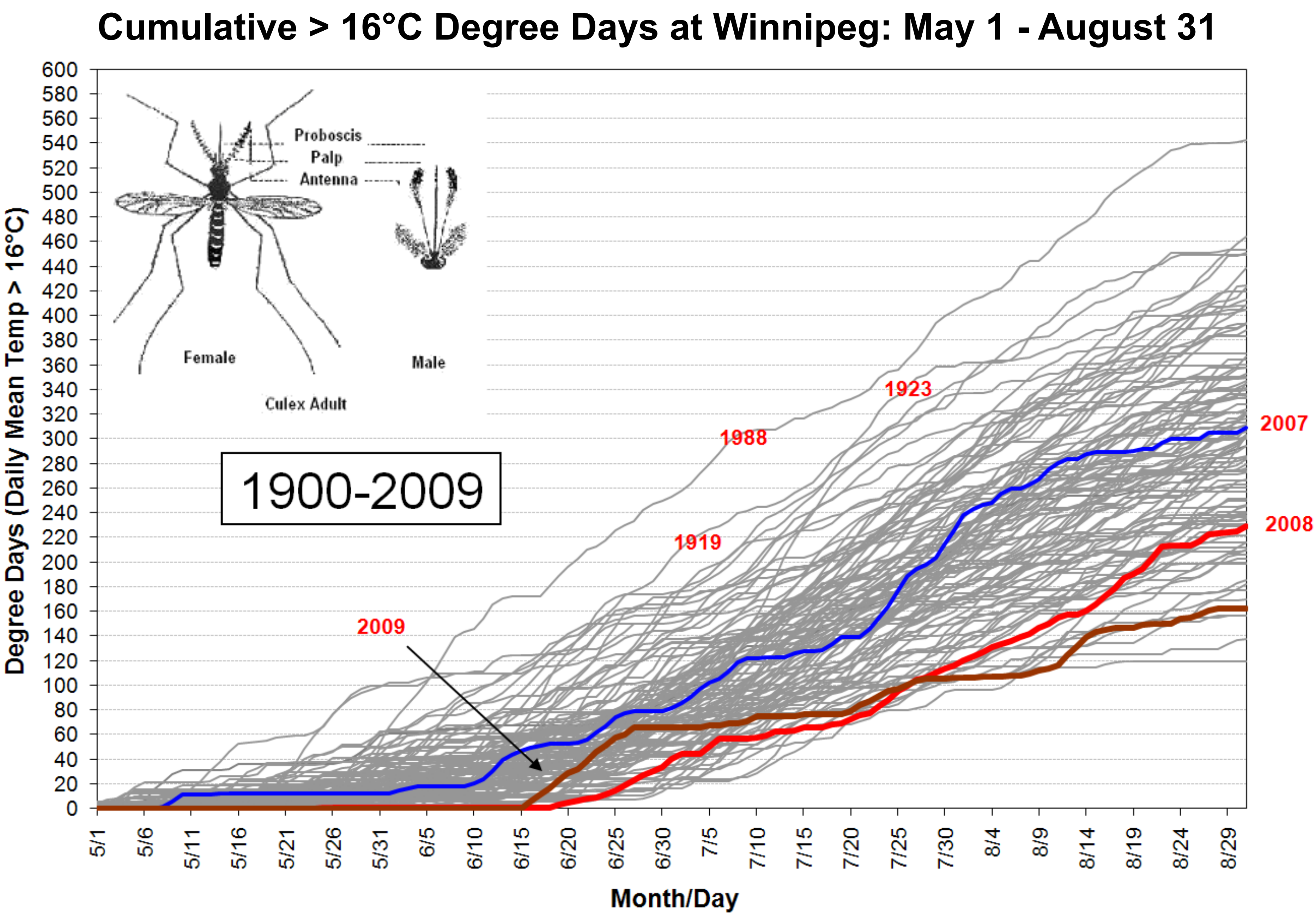


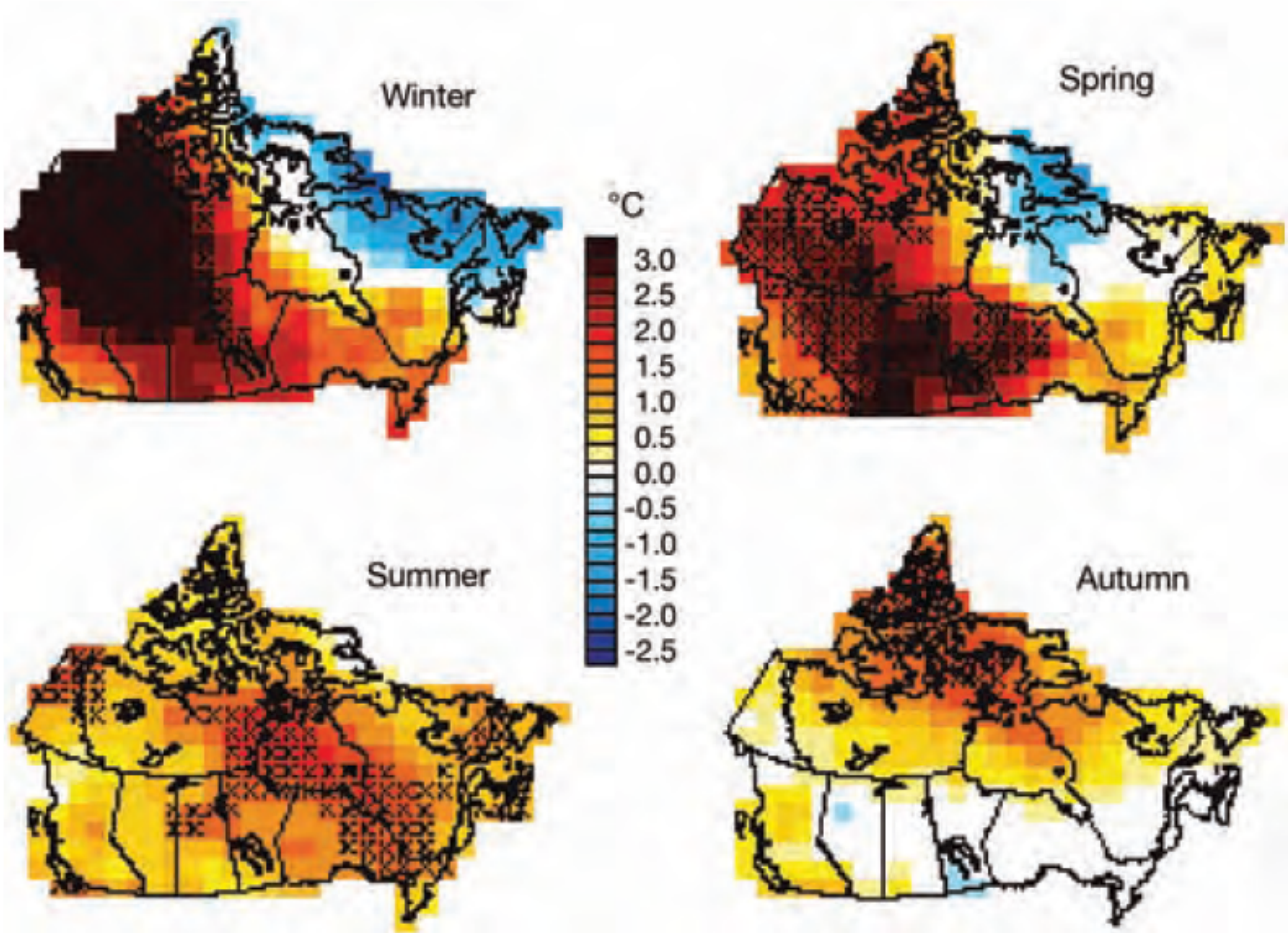
Figure 4. Mean annual temperature records for five Saskatchewan communities.



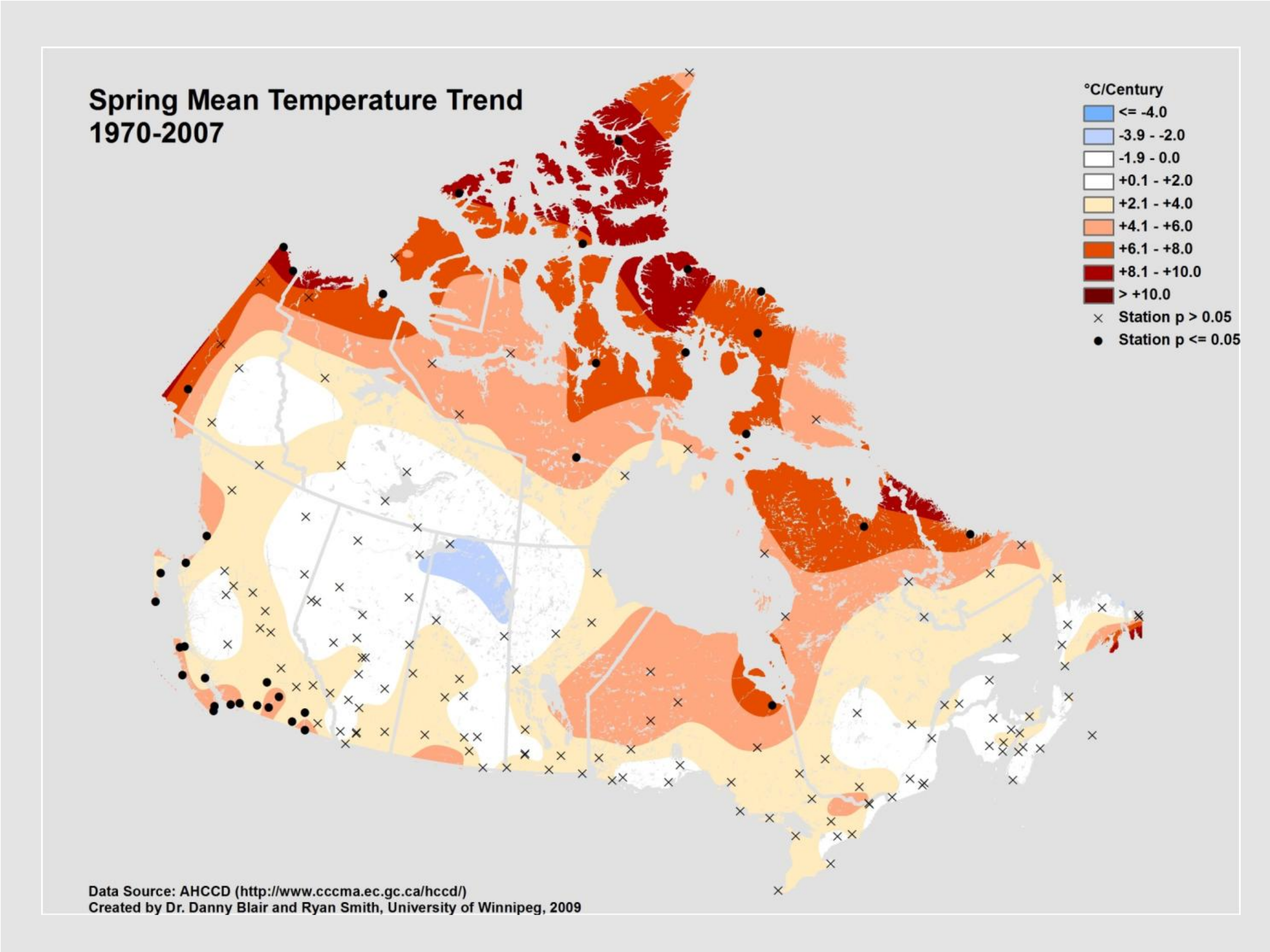
Degree Days > 16°C in Winnipeg
May 1 thru August 31, 1900-2009
Degree Days > 16°C
550
500
450
400
350
300
250
200
150
100
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

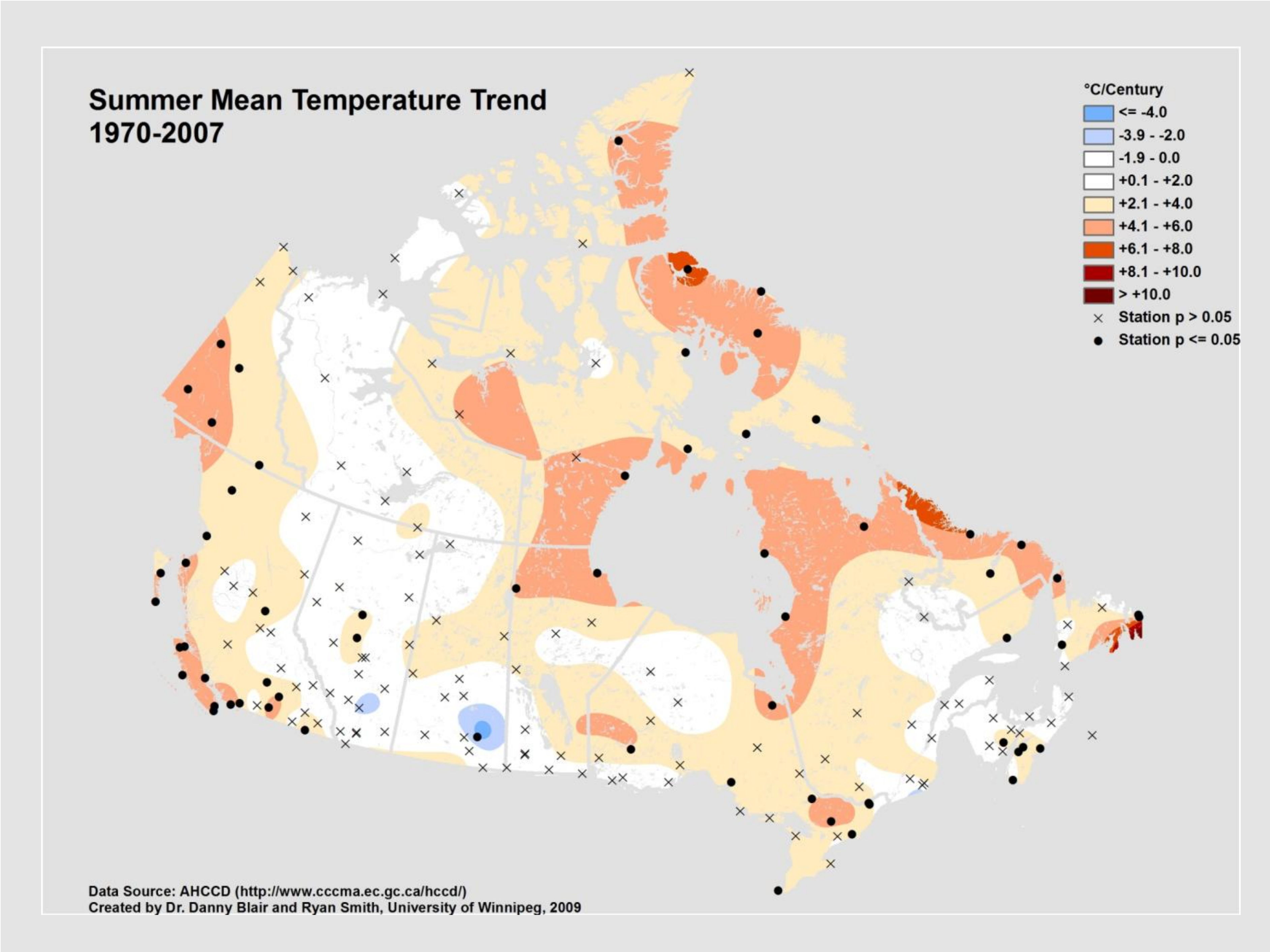


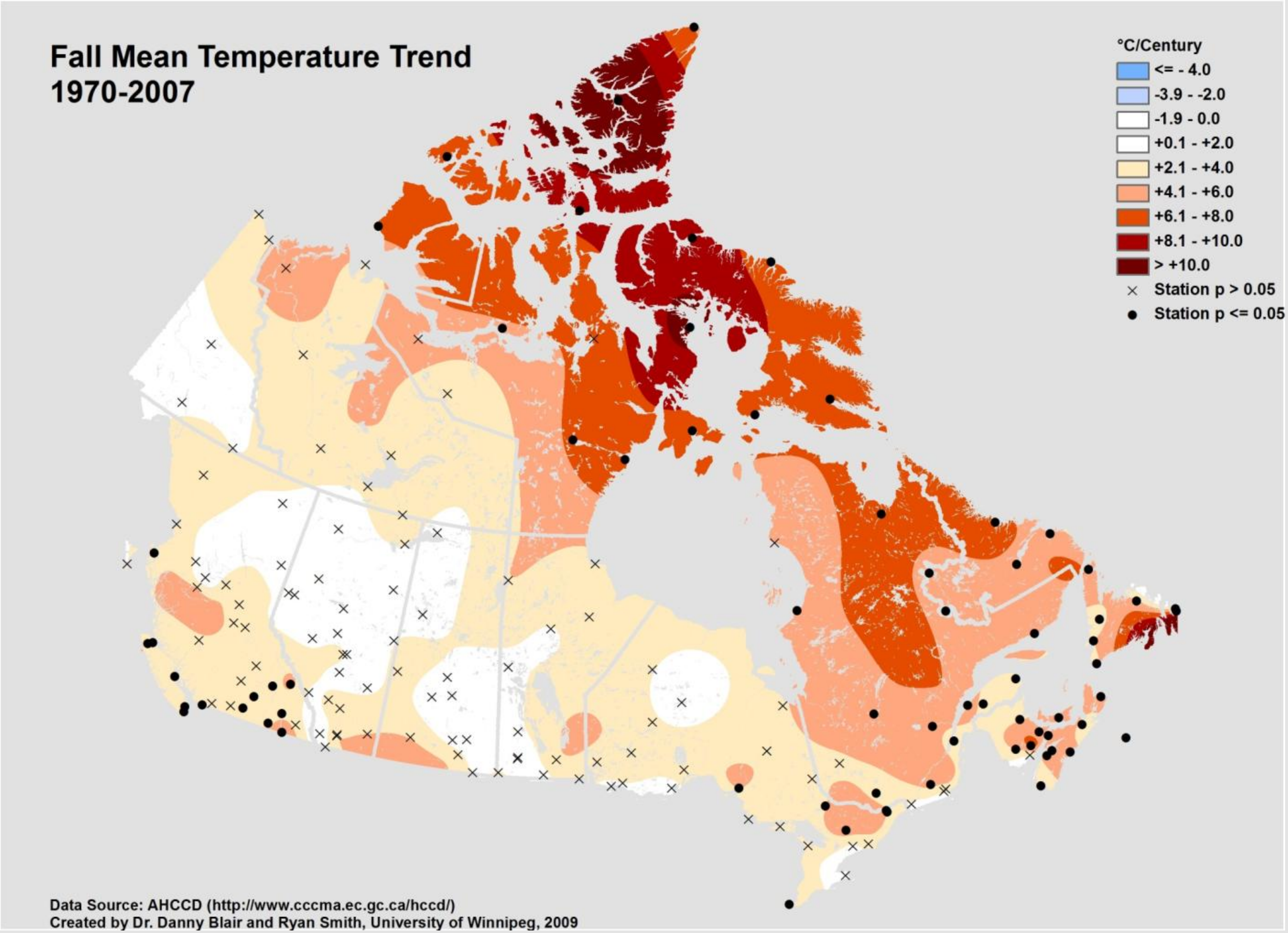
Cumulative > 16°C Degree Days at Winnipeg: May 1 - August 31
Degree Days (Daily Mean Temp > 16°C)
Month/Day
Proboscis
Palp
Antenna
Female
Male
Culex Adult
1900-2009
1923
1988
1919
2009
2007
2008



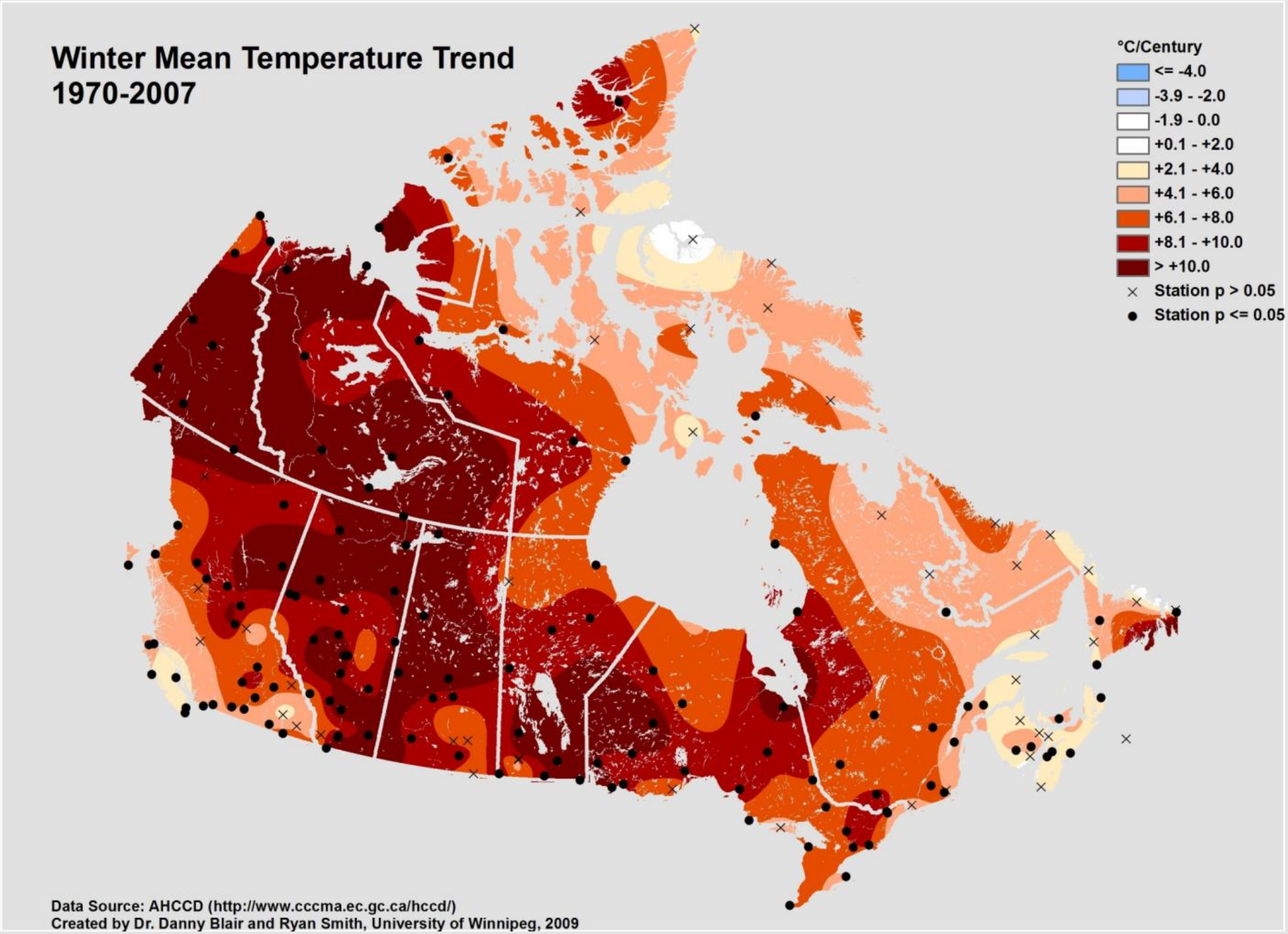
Seasonal Linear Temperature Trends between 1948 and 2003 (°C)

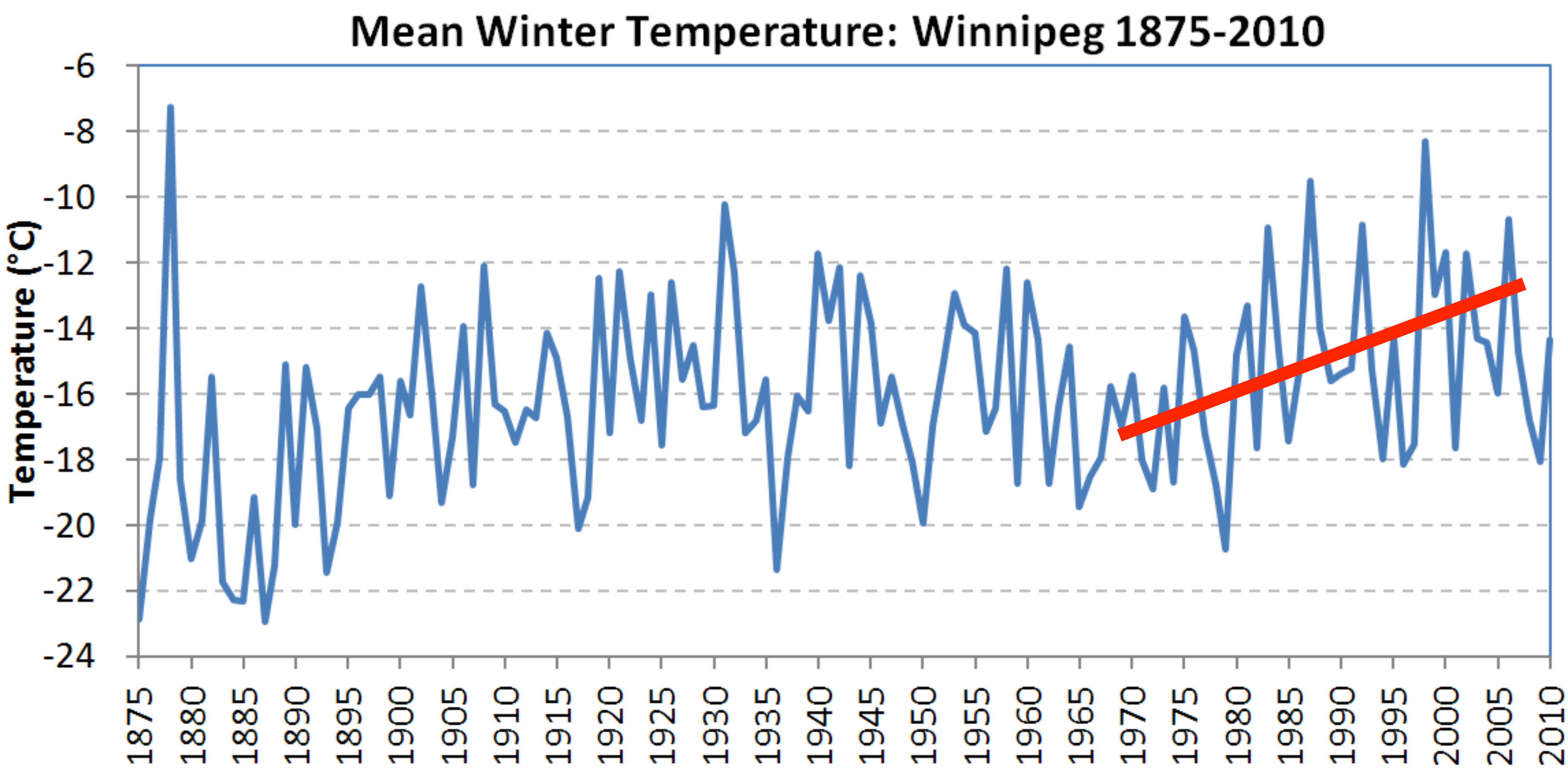

Spring Mean Temperature Trend
1970-2007
°C/Century
<= -4.0
-3.9 - -2.0
-1.9 - 0.0
+0.1 - +2.0
+2.1 - +4.0
+4.1 - +6.0
+6.1 - +8.0
+8.1 - +10.0
> +10.0
Station p > 0.05
Station p <= 0.05
Data Source: AHCCD (http://www.cccma.ec.gc.ca/hccd/)
Created by Dr. Danny Blair and Ryan Smith, University of Winnipeg, 2009


Summer Mean Temperature Trend
1970-2007
°C/Century
<= -4.0
-3.9 - -2.0
-1.9 - 0.0
+0.1 - +2.0
+2.1 - +4.0
+4.1 - +6.0
+6.1 - +8.0
+8.1 - +10.0
> +10.0
Station p > 0.05
Station p <= 0.05
Data Source: AHCCD (http://www.cccma.ec.gc.ca/hccd/)
Created by Dr. Danny Blair and Ryan Smith, University of Winnipeg, 2009



Fall Mean Temperature Trend
1970-2007
°C/Century
<= - 4.0
-3.9 - -2.0
-1.9 - 0.0
+0.1 - +2.0
+2.1 - +4.0
+4.1 - +6.0
+6.1 - +8.0
+8.1 - +10.0
> +10.0
Station p > 0.05
Station p <= 0.05
Data Source: AHCCD (http://www.cccma.ec.gc.ca/hccd/)
Created by Dr. Danny Blair and Ryan Smith, University of Winnipeg, 2009


Winter Mean Temperature Trend
1970-2007
°C/Century
<= -4.0
-3.9 - -2.0
-1.9 - 0.0
+0.1 - +2.0
+2.1 - +4.0
+4.1 - +6.0
+6.1 - +8.0
+8.1 - +10.0
> +10.0
Station p > 0.05
Station p <= 0.05
Data Source: AHCCD (http://www.cccma.ec.gc.ca/hccd/)
Created by Dr. Danny Blair and Ryan Smith, University of Winnipeg, 2009

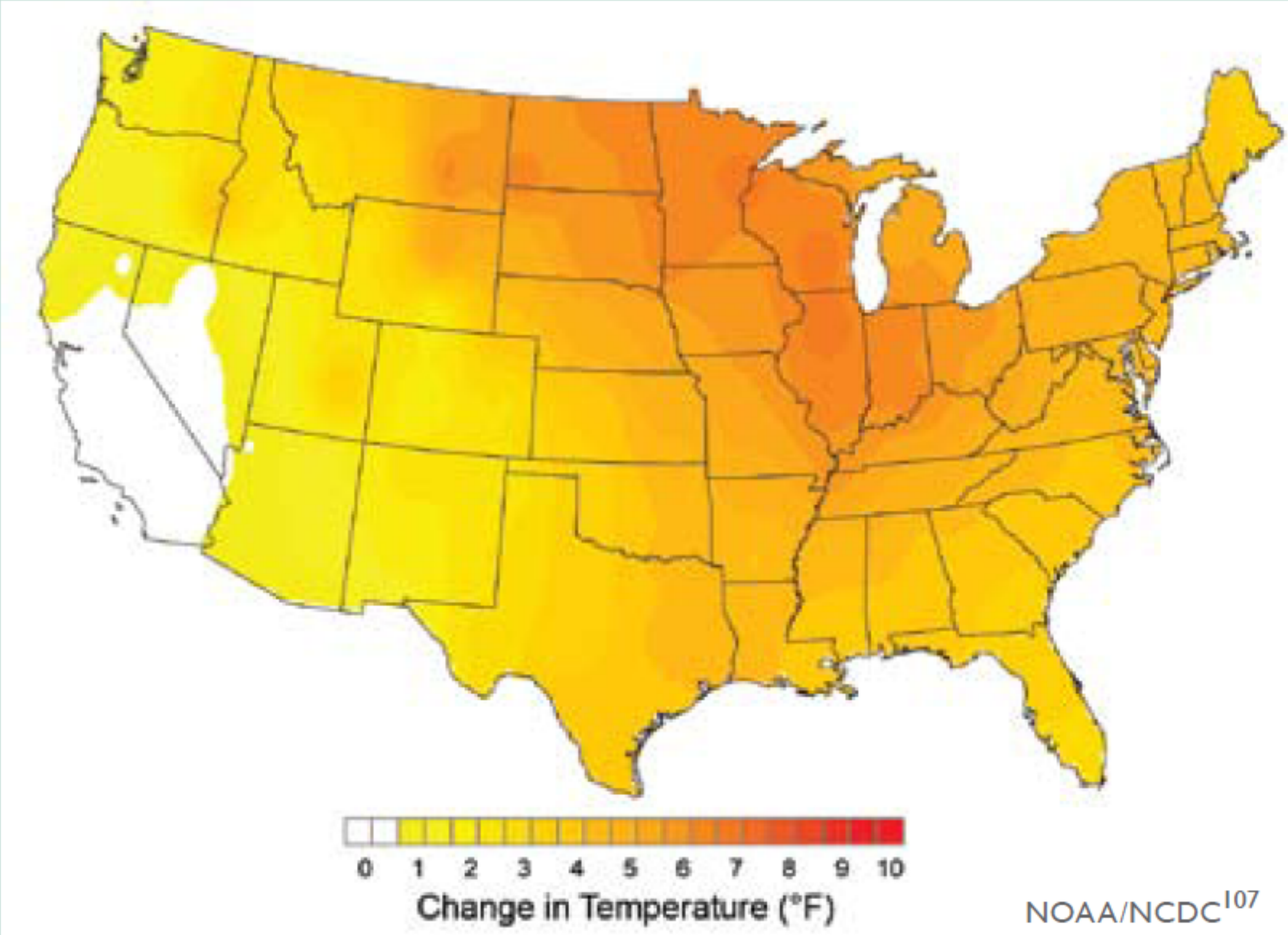


1970-2007

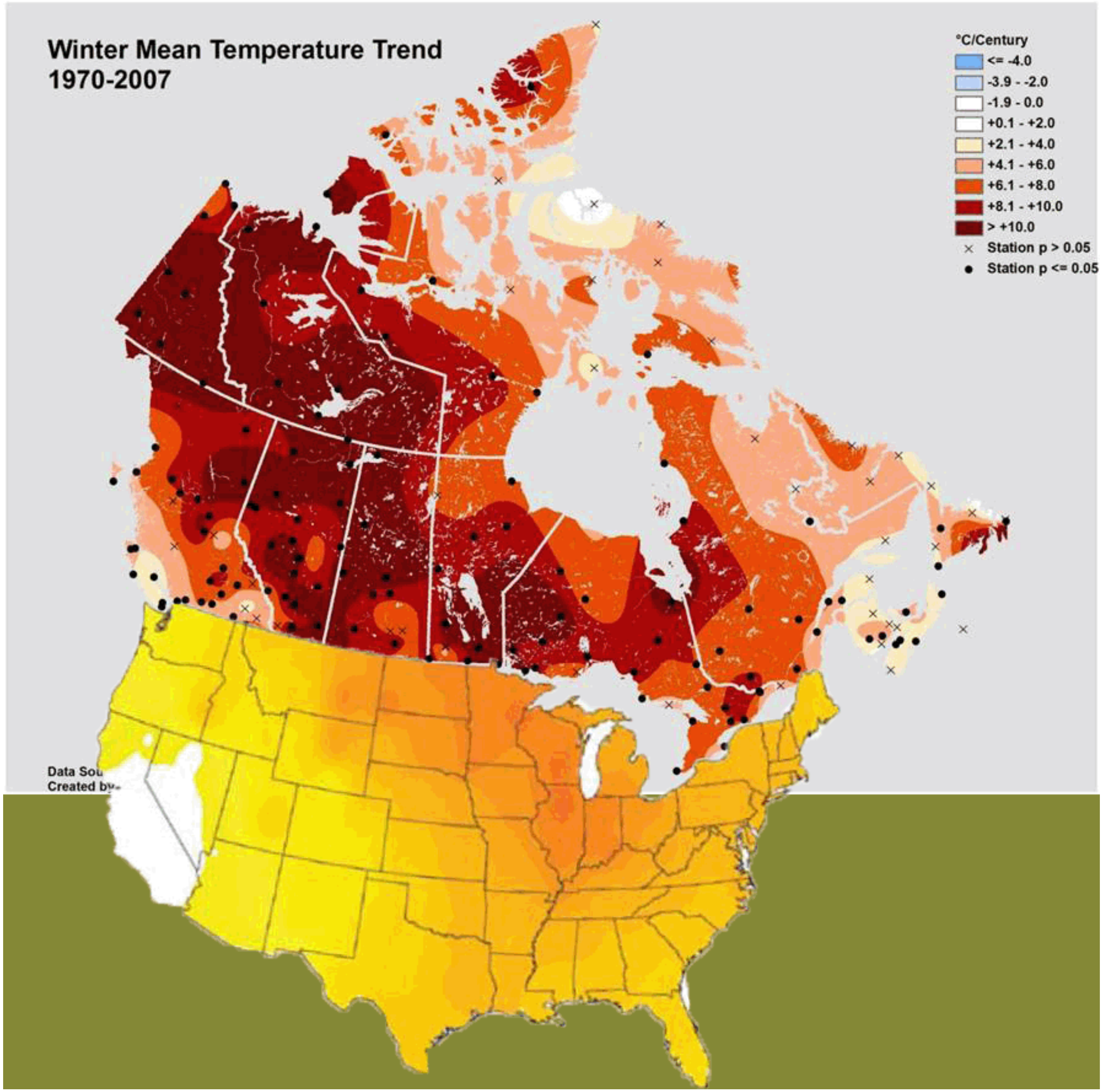
Slope = 10.9°C per century

p = 0.009

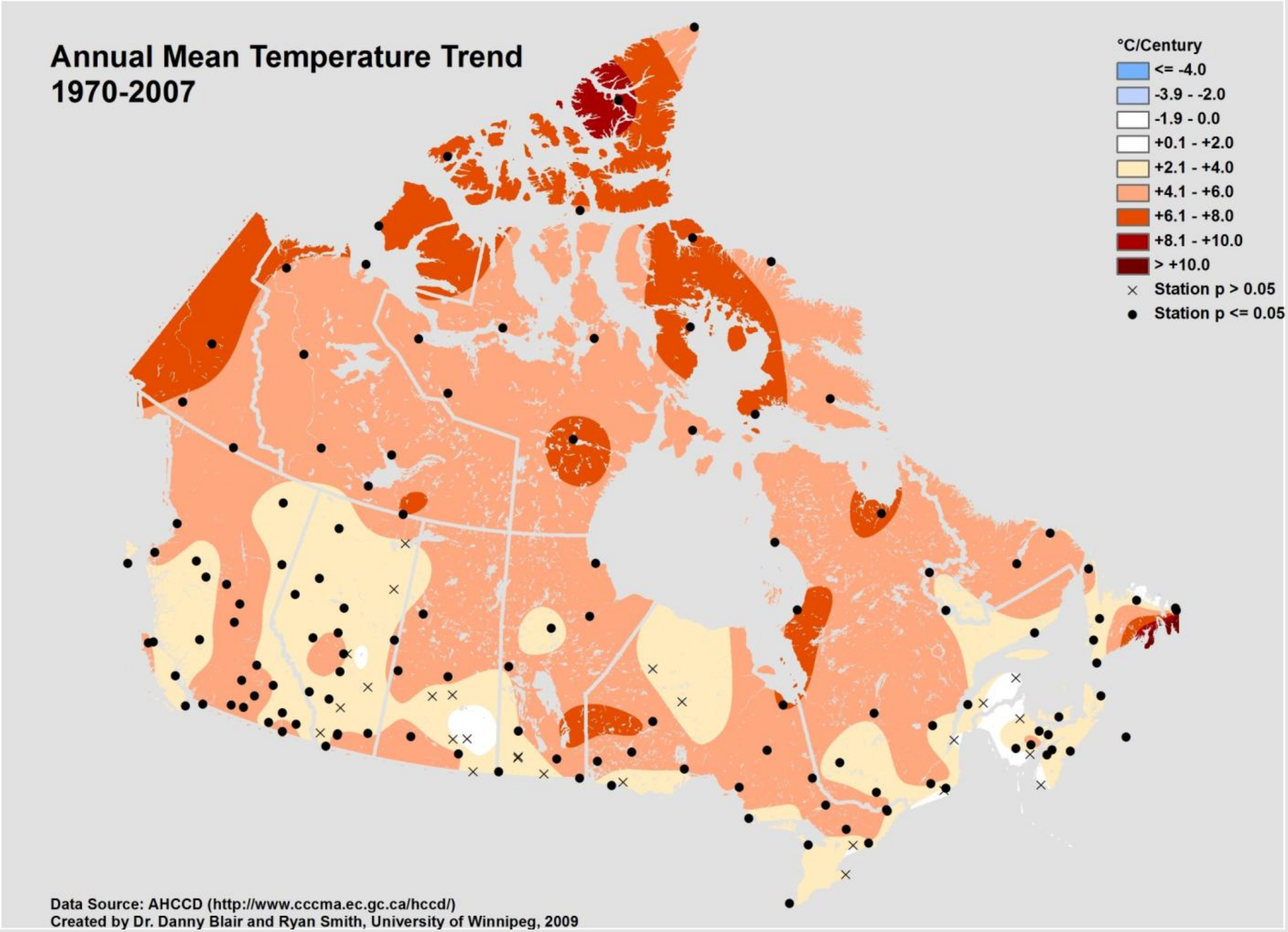
Winter Temperature Trends, 1975 to 2007

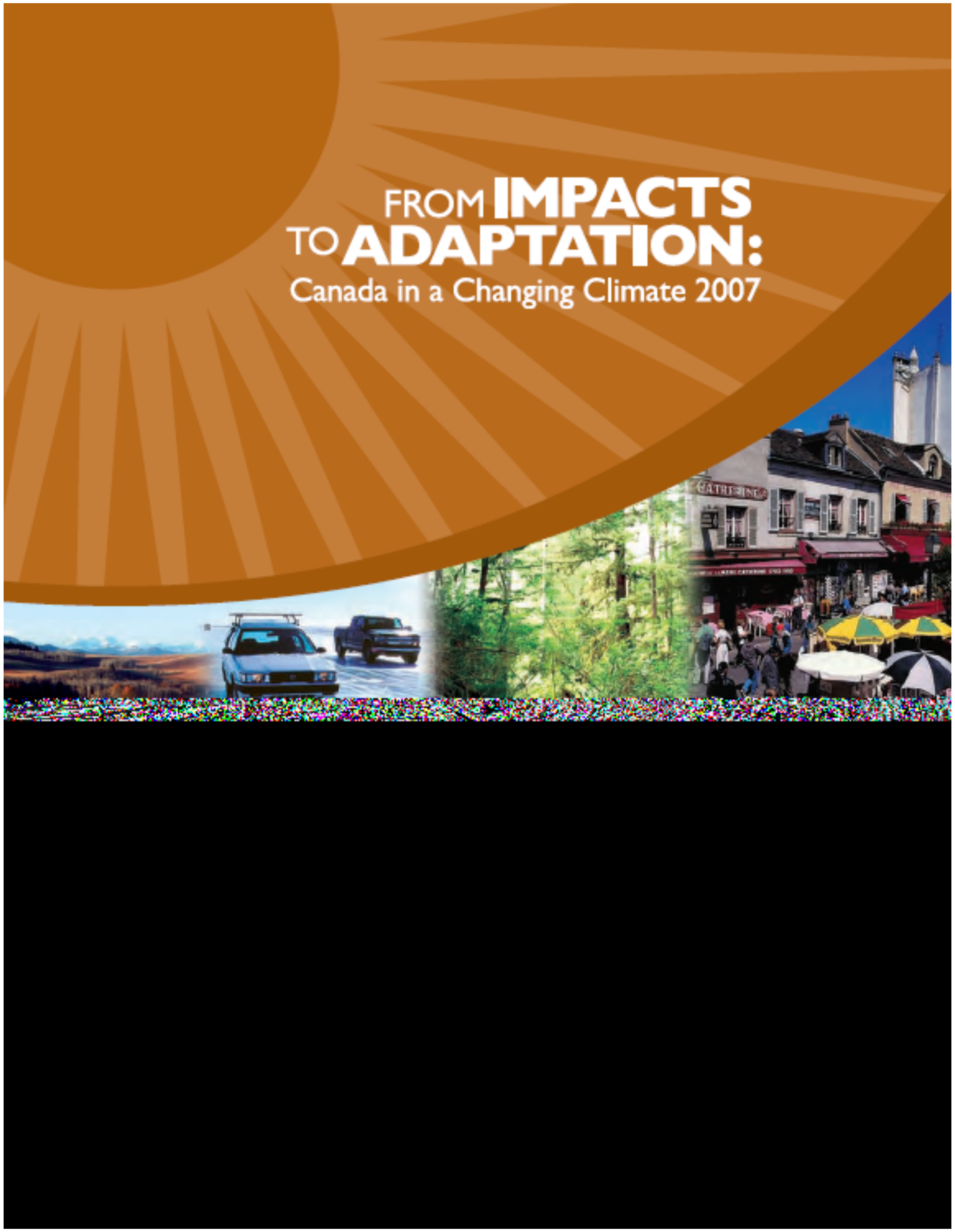


Temperatures are rising faster in winter than in any other season, especially in many key agricultural regions. This allows many insect pests and crop diseases to expand and thrive, creating increasing challenges for agriculture. As indicated by the map, the Midwest and northern Great Plains have experienced increases of more than 7°F in average winter temperatures over the past 30 years.



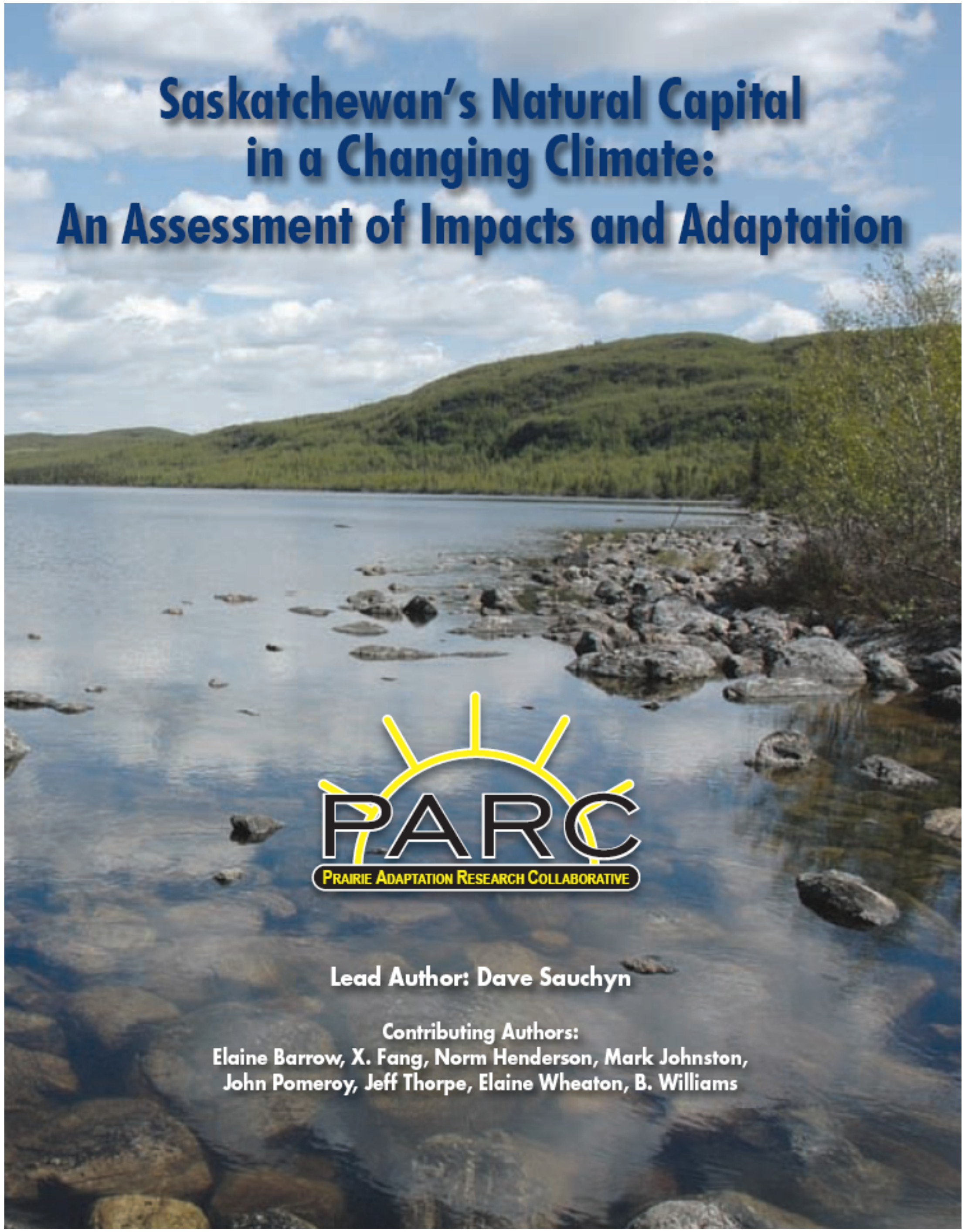
Winter Mean Temperature Trend
1970-2007
°C/Century
<= -4.0
-3.9 - -2.0
-1.9 - 0.0
+0.1 - +2.0
+2.1 - +4.0
+4.1 - +6.0
+6.1 - +8.0
+8.1 - +10.0
> +10.0
Station p > 0.05
Station p <= 0.05
Data Sou
Created by


Annual Mean Temperature Trend
1970-2007
°C/Century
<= -4.0
-3.9 - -2.0
-1.9 - 0.0
+0.1 - +2.0
+2.1 - +4.0
+4.1 - +6.0
+6.1 - +8.0
+8.1 - +10.0
> +10.0
Station p > 0.05
Station p <= 0.05
Data Source: AHCCD (http://www.cccma.ec.gc.ca/hccd/)
Created by Dr. Danny Blair and Ryan Smith, University of Winnipeg, 2009



Canada's latest assessment of climate change impacts and adaptation, region by region.


Global Climate Change
Impacts in the United States
2009
A State of Knowledge Report from the
U.S. Global Change Research Program



Saskatchewan's Natural Capital in a Changing Climate: An Assessment of Impacts and Adaptation

PARC
PRAIRIE ADAPTATION RESEARCH COLLABORATIVE

Lead Author: Dave Sauchyn

Contributing Authors:
Elaine Barrow, X. Fang, Norm Henderson, Mark Johnston,
John Pomeroy, Jeff Thorpe, Elaine Wheaton, B. Williams

Observed Water-Related Changes During the Last Century[142]		
Observed Change	**Direction of Change**	**Region Affected**
One to four week earlier peak streamflow due to earlier warming-driven snowmelt	Earlier	West and Northeast
Proportion of precipitation falling as snow	Decreasing	West and Northeast
Duration and extent of snow cover	Decreasing	Most of the United States
Mountain snow water equivalent	Decreasing	West
Annual precipitation	Increasing	Most of the United States
Annual precipitation	Decreasing	Southwest
Frequency of heavy precipitation events	Increasing	Most of the United States
Runoff and streamflow	Decreasing	Colorado and Columbia River Basins
Streamflow	Increasing	Most of East
Amount of ice in mountain glaciers	Decreasing	U.S. western mountains, Alaska
Water temperature of lakes and streams	Increasing	Most of the United States
Ice cover on lakes and rivers	Decreasing	Great Lakes and Northeast
Periods of drought	Increasing	Parts of West and East
Salinization of surface waters	Increasing	Florida, Louisiana
Widespread thawing of permafrost	Increasing	Alaska

TABLE 9: Future possible changes in agri-climates for the agricultural region of the Prairies, and examples of possible advantages and disadvanages for agriculture.

Index	Changes (relative to 1961-1990 unless noted)	Climate model and emission scenario	Period and spatial pattern	Reference	Possible advantages for agriculture[1]	Possible disadvantages for agri-culture[1]
Thermal indices:						
Growing degree-days	25 to 40% 42 to 45%	CSIROMk2b B2, greater changes with the other models CGCM1 GA1	2050s; greater changes in the north 2050s for Lethbridge and Yorkton	Thorpe et al. (2004) CCIS[2] (2002)	More crop options; more crops per year; improved crop quality; shifts to earlier spring and later fall growth	Accelerated maturation rates and lower yields; increased insect activity; changed herbicide and pesticide efficacy
Heating degree-days	–23%	CGCM1 GA1	2050s for Lethbridge and Yorkton	CCIS[2] (2002)	Decreased heating costs	
Cooling degree-days	146 to 218%	CGCM1 GA1	2050s for Lethbridge and Yorkton	CCIS[2] (2002)		Increased ventilation for barns, more cooling shelters and air conditioning
Hot spells: 20-year return period of maximum temperature	1 to 2°C increase	CGCM2 A2	2050	Kharin and Zwiers (2005)		Heat stress to plants and animals; increased transpiration rates can reduce yields; increased need for water for cooling and drinking

Cold spells: 20-year return period of minimum temperature	2 to >4°C increase from 2000	CGCM2 A2	2050	Kharin and Zwiers (2005)	Decreased heat stress to animals	Increased pests and diseases; increased winterkill potential
Moisture indices:						
Soil moisture capacity (fraction), annual	>0 to <–0.2; mostly drying	CGCM2 A2 ensemble mean	2050s; greatest decreases in south to southeast	Barrow et al.(2004)		Increased moisture stress to crops; decreased water availability
Palmer Drought Severity Index	Severe droughts twice as frequent	Goddard Institute for Space Studies	Doubled CO_2 for southern Saskatchewan	Williams et al. (1988)		Increased damages and losses from droughts; increased costs of adaptation, etc.
Moisture deficit: annual precipitation minus potential evapo-transpiration (P-PET)	–60 to –140 mm (i.e. increased deficit of 0 to –75mm	CGCM1 and HadCM3	2050s	Gameda et al. (2005)	As for droughts	As for droughts
		CGCM1 GA1	2050s	Nyirfa and Harron (2001)	As above	As above
Aridity Index (AI): ratio of annual precipitation and potential evapotranspiration (P/PET)	Area of AI <0.65 increases by 50%	CGCM2 B2	2050s	Sauchyn et al. (2005)	As above	As above

Index	Changes (relative to 1961-1990 unless noted)	Climate model and emission scenario	Period and spatial pattern	Reference	Possible advantages for agriculture[1]	Possible disadvantages for agriculture[1]
Number of dry days: time between 2 consecutive rain days (>1 mm)	Modest and insignificant changes	CGCM2 A2	2080 to 2100	Kharin and Zwiers (2000)		
Number of rain days	Modest and insignificant changes	CGCM2 A2	2080 to 2100	Kharin and Zwiers (2000)		
Precipitation extremes: 20-year return period of annual extremes	Increase of 5 to 10 mm and return period decreases by about a factor of 2	CGCM2 A2	2050	Kharin and Zwiers (2005)		More flooding and erosion concerns; more difficult planning for extremes
Snow cover	Widespread reductions	CGCM2 IS92a	Next 50 to 100 years	Brown (2006)	Decreased snow ploughing; increased grazing season	Decreased quantity and quality of water supplies

Wind speed, annual	<5 to >10%	CGCM2 A2 ensemble mean	2050s	Barrow et al. (2004)	Greater dispersion of air pollution	Greater soil erosion of exposed soils; damage to plants and animals
Wind erosion of soil	16%	Manabe and Stouffer	Doubled CO_2	Williams and Wheaton (1998)		
	–15%	Goddard Institute for Space Studies	Doubled CO_2			
Incident solar radiation	<–2 to <–6 W/m^2	CGCM2 A2 ensemble mean	2050s; greatest decreases in central north	Barrow et al. (2004)	Decreased radiation may partially offset heat stress	Reduced plant growth if thresholds are exceeded
Climate Severity Index[3]	–3 to –9	CGCM1 IS92a	2050s; greatest improvements in Alberta and Manitoba	Barrow et al. (2004)		Less severe climates for outside work; more suitable for animals
Carbon dioxide	Various emission scenarios used (e.g., 1% per year)	IS92a		Leggett et al. (1992)	Increased plant productivity, depending on other limits	Possible reduced quality of yield