

Climate Change in Southern New England: Past, Present, and Future

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UVAW Forum September 30, 2013





Global Climate Dashboard

▼ Climate Change

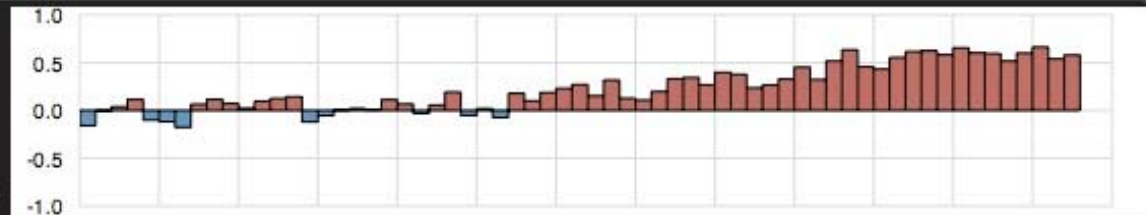
► Climate Variability

► Climate Projections

Global Average Temperature (°C)

The temperature near Earth's surface is rising: the bars show each year's average temperature compared to the 20th century average.

[Learn More >>](#)



Sun's Energy (W/m2)

The sun's energy rises and falls slightly on an 11-year cycle, with little net change over the last century.

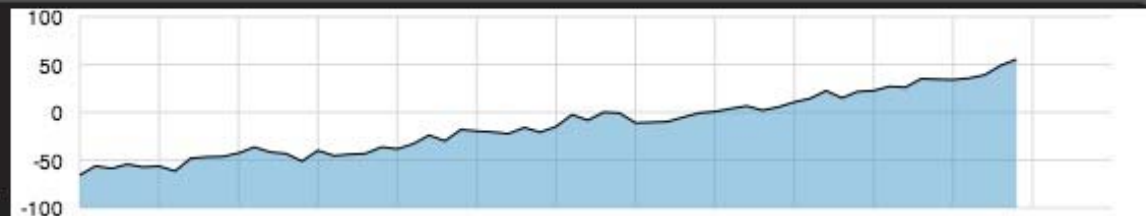
[Learn More >>](#)



Global Average Sea Level (mm)

The ocean's surface is rising: water expands as it warms, and melting of ice sheets and glaciers on land adds water to the ocean.

[Learn More >>](#)



▲ Temperature

► Carbon Dioxide

► Snow

▲ Sea Level

► Arctic Sea Ice

► Ocean Heat

▲ Sun's Energy

► Glaciers

► Heat-Trapping Gases



QUADRENNIAL DEFENSE REVIEW REPORT

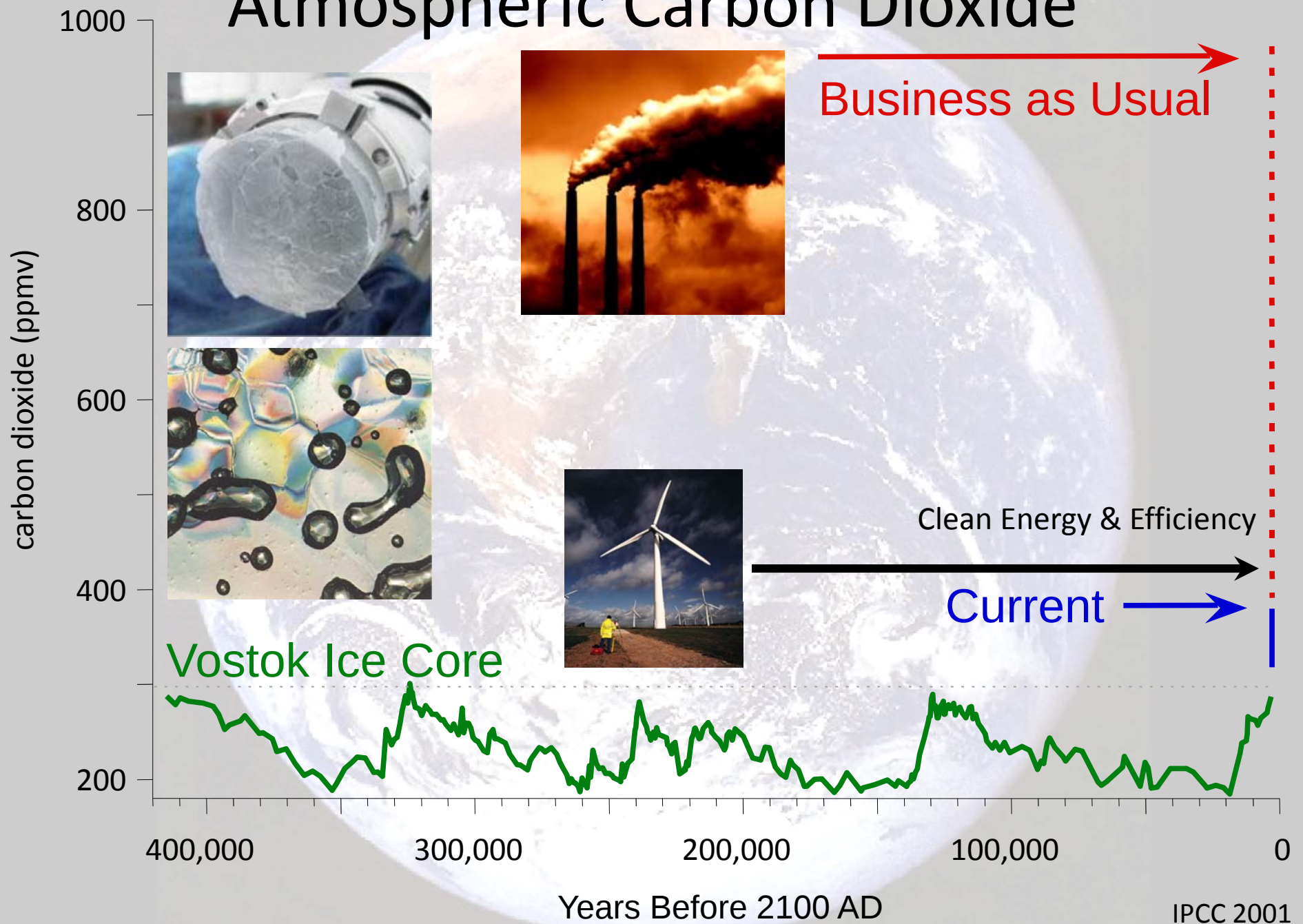
FEBRUARY 2010



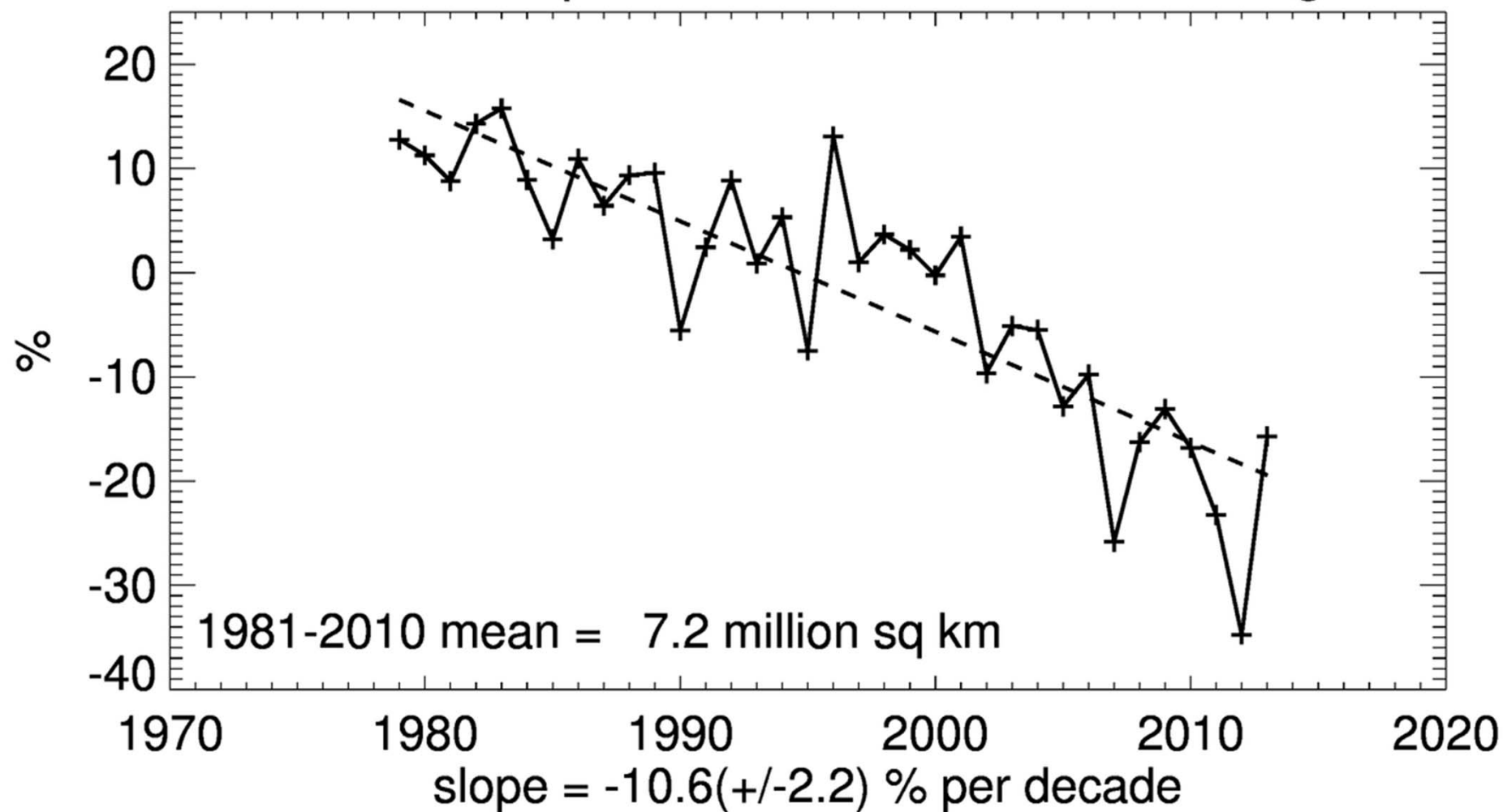
“Although they produce distinct types of challenges, climate change, energy security, and economic stability are inextricably linked”

<http://www.defense.gov/qdr/>

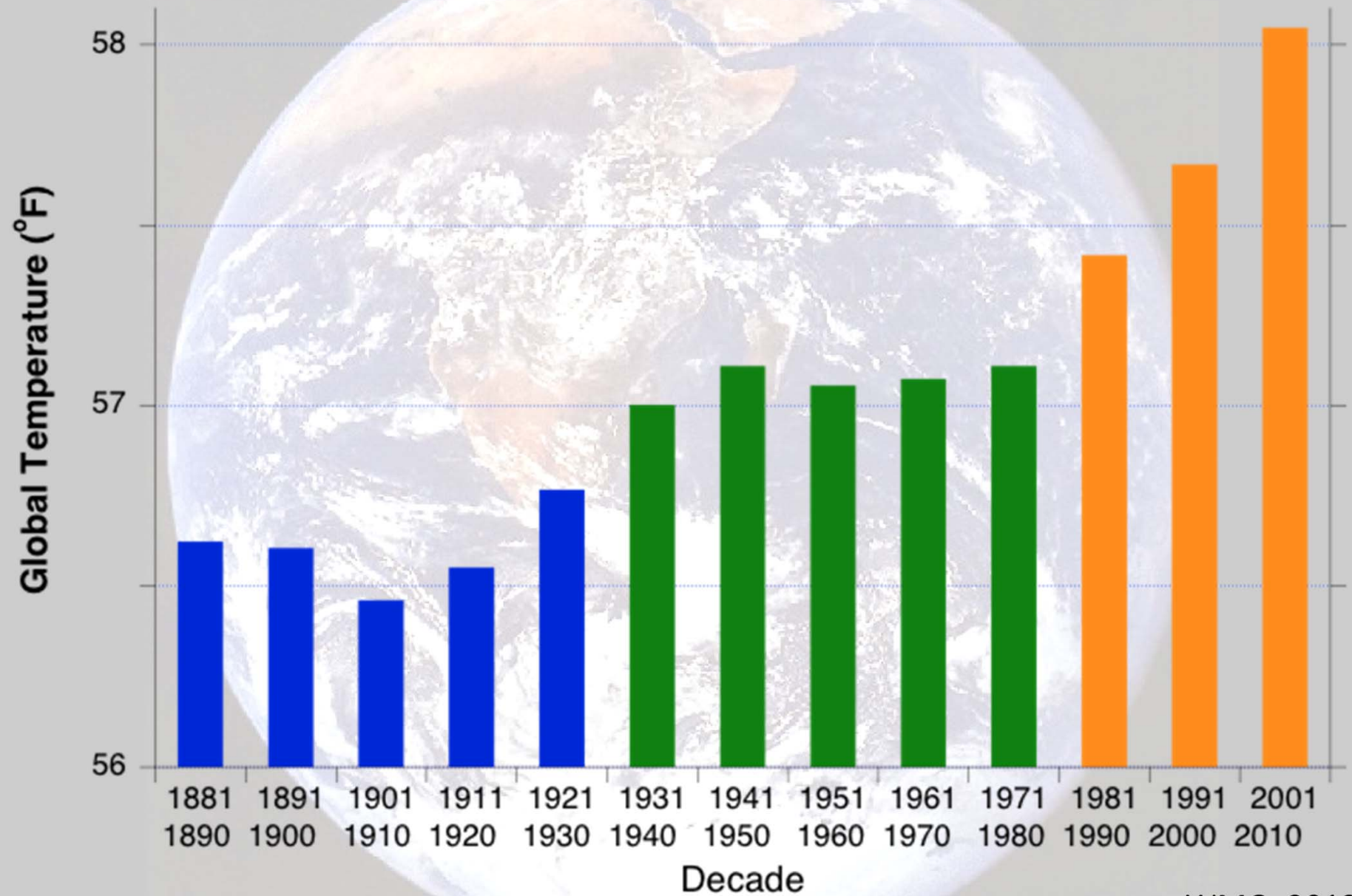
Atmospheric Carbon Dioxide



Northern Hemisphere Extent Anomalies Aug 2013

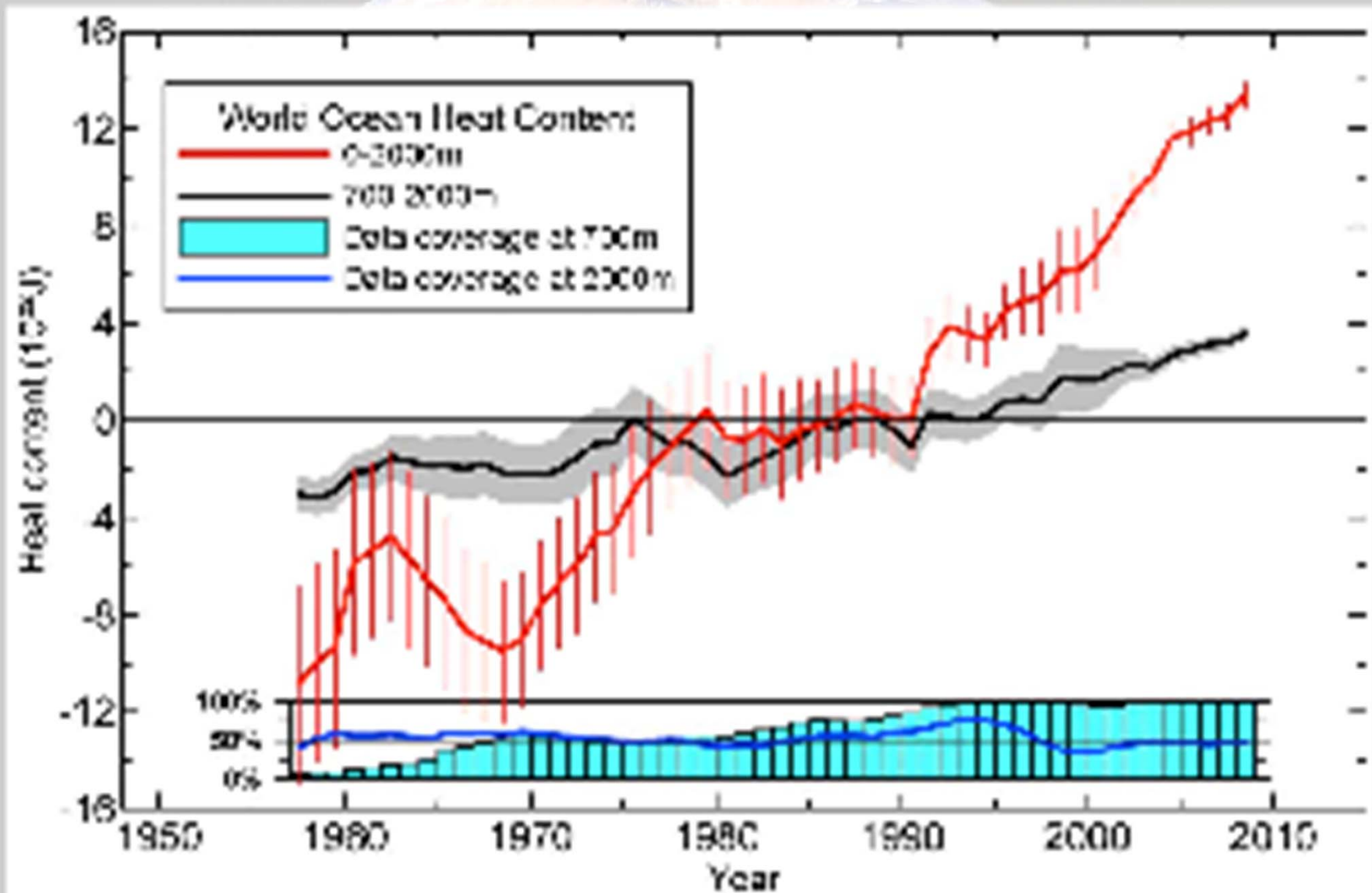


Decadal global surface-air temperature (land and SST)

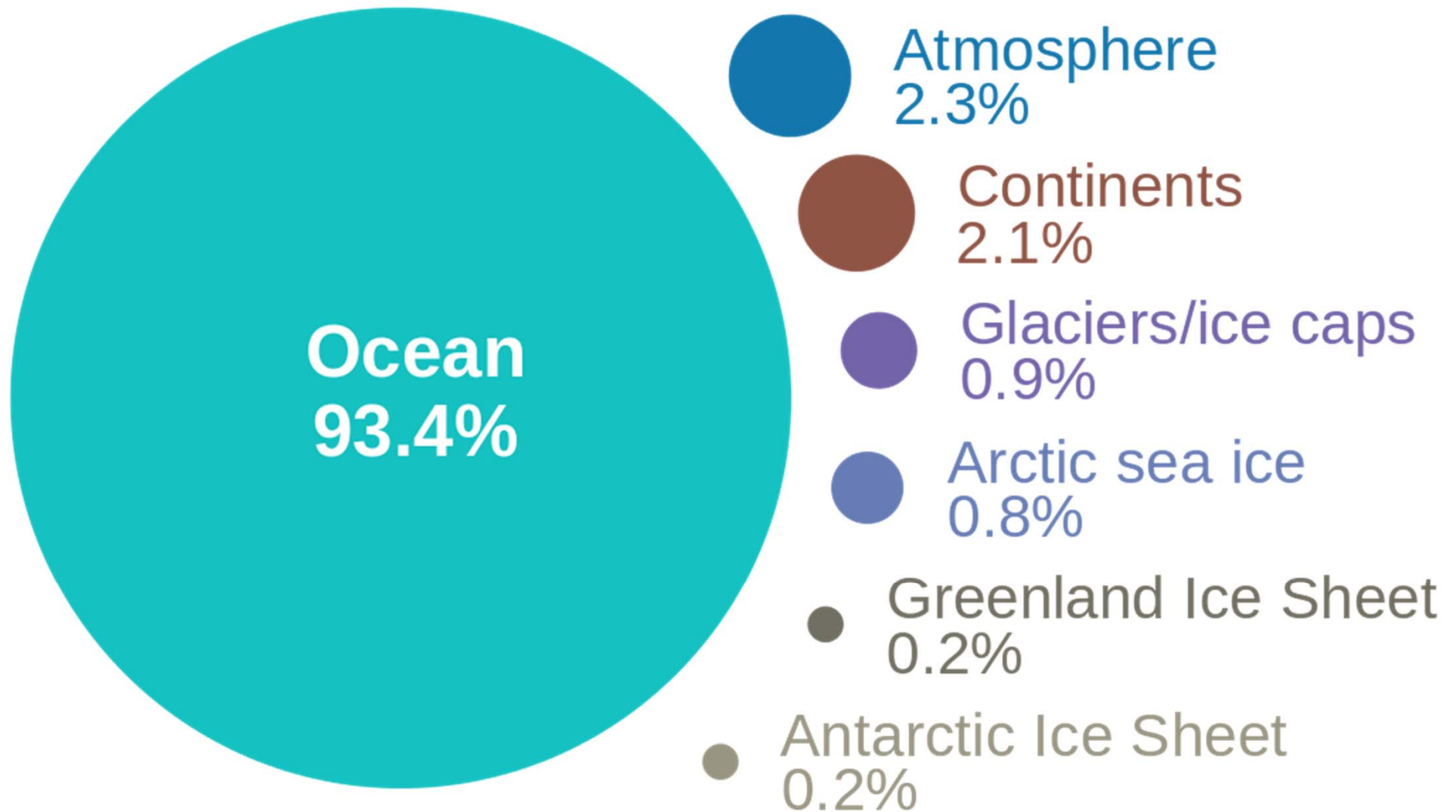


WMO 2013

World Ocean Heat Content



Where is global warming going?



IPCC Fifth Assessment Report (2013)

It is ***extremely likely*** that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together.

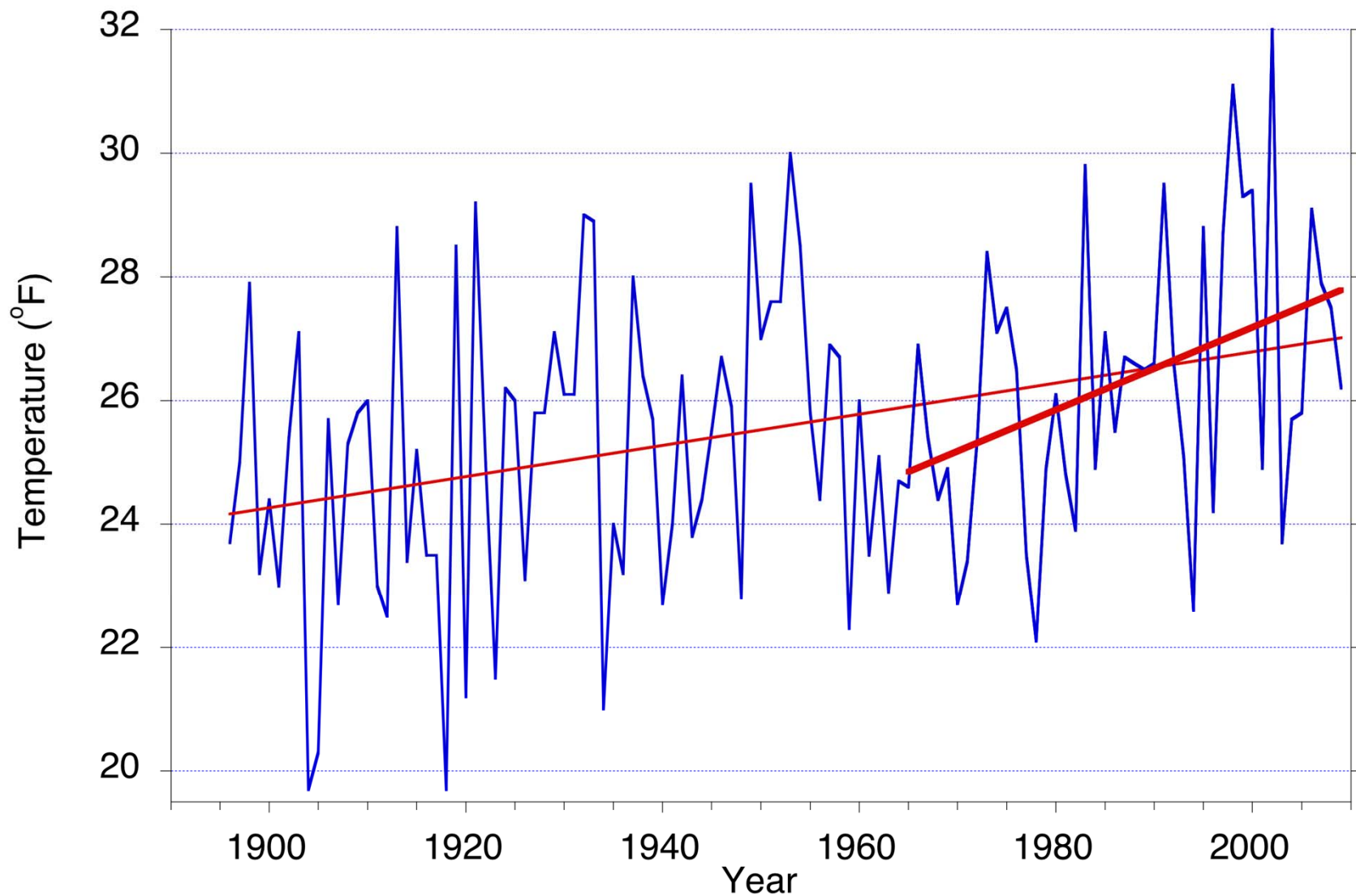


2007: Most of the observed increase in global average temperatures since the mid-20th century is ***very likely*** due to the observed increase in anthropogenic greenhouse gas concentrations.

2001: most of the observed warming over the last 50 years is ***likely*** to have been due to the increase in greenhouse gas concentrations

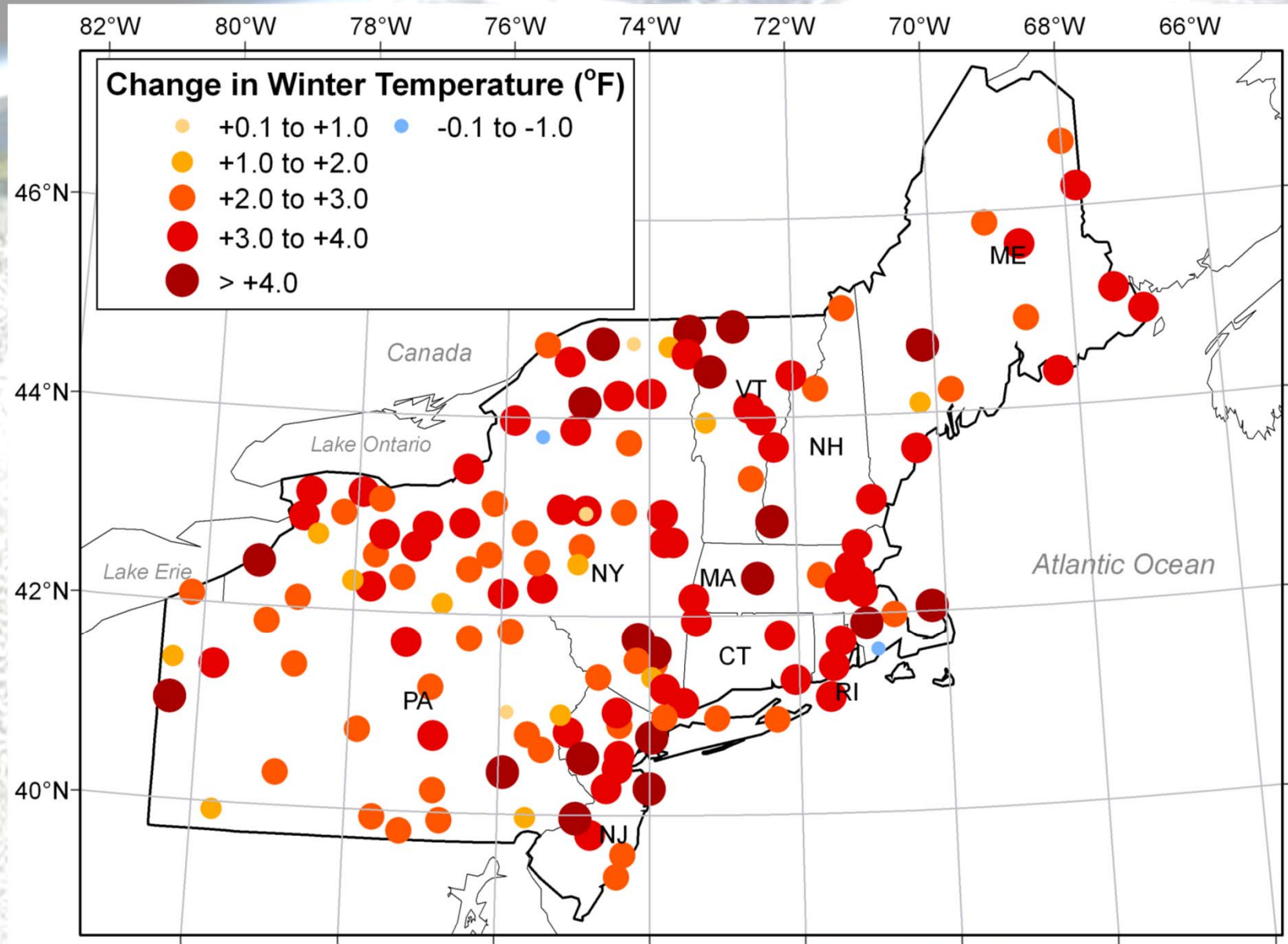
1996: ***More convincing*** recent evidence for the attribution of a human effect on climate is emerging from pattern-based studies

Northeast Winter Temperature Trends 1895-2008



Burakowski et al., 2008, JGR

Northeast Winter Temperature Trends 1965-2008



Burakowski et al., 2008, JGR

New Hampshire's Climate: PAST AND FUTURE CHANGES



Climate has varied throughout the Earth's history, and will continue to change. However, a recent climate assessment from the University of New Hampshire shows that the rate of change in New Hampshire has increased significantly over the last four decades, with the state getting warmer and wetter.

TEMPERATURES

WHAT HAVE WE SEEN SINCE 1970?

- Average maximum temperatures have warmed by 2.0°F (annual) and 2.9°F (winter)
- Average minimum temperatures have warmed by 3.2°F (annual) and 6.1°F (winter)

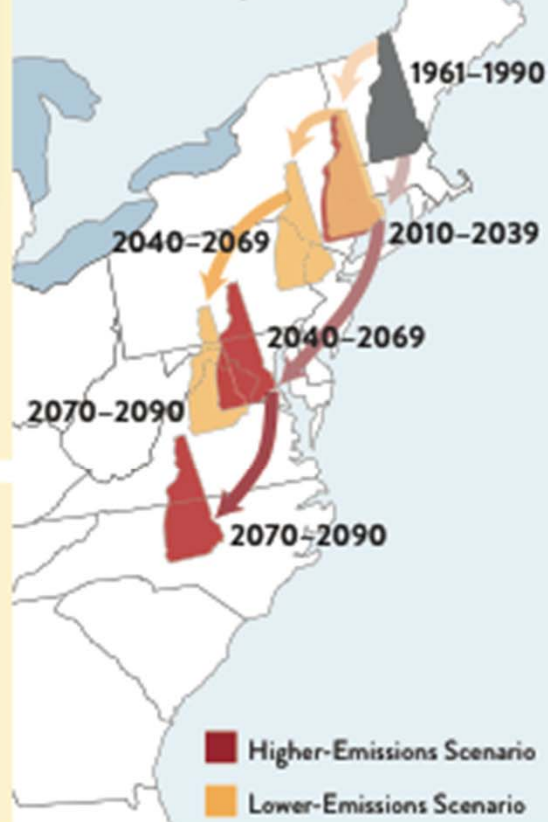
WHAT CAN WE EXPECT?

- Warmer winters: 20-45 fewer days below 32°F
- Hotter summers:
10-35 days above 90°F for northern NH (compared to 3 currently);
16-47 days above 90°F for southern NH (compared to 7 currently)



CLIMATE ON THE MOVE

Changing Summers
in New Hampshire

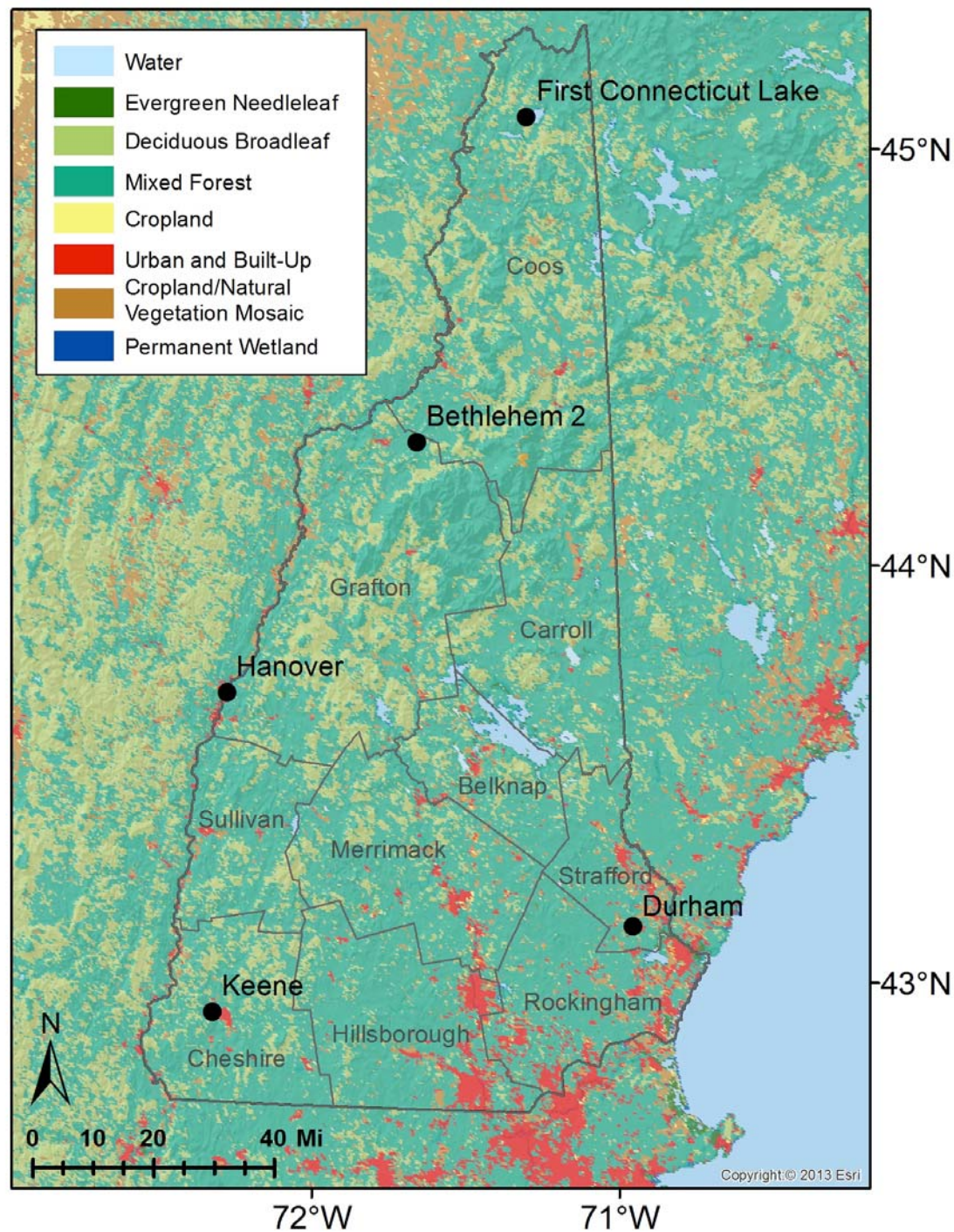


RAINFALL AND FLOODING

WHAT HAVE WE SEEN SINCE 1970?

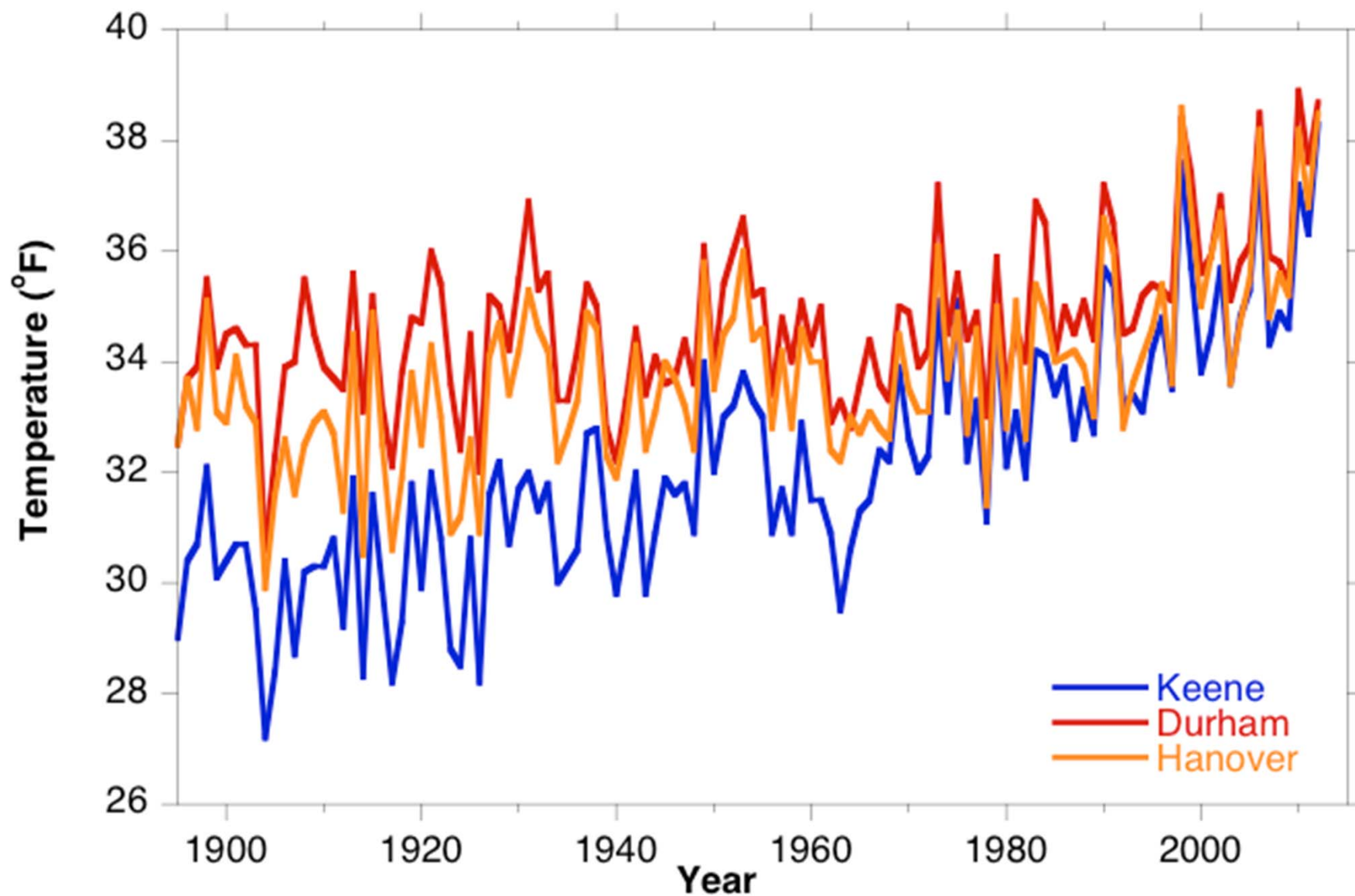
- Annual precipitation has increased 8-22%
- Both the frequency and magnitude of extreme precipitation events has increased

WHAT CAN WE EXPECT?

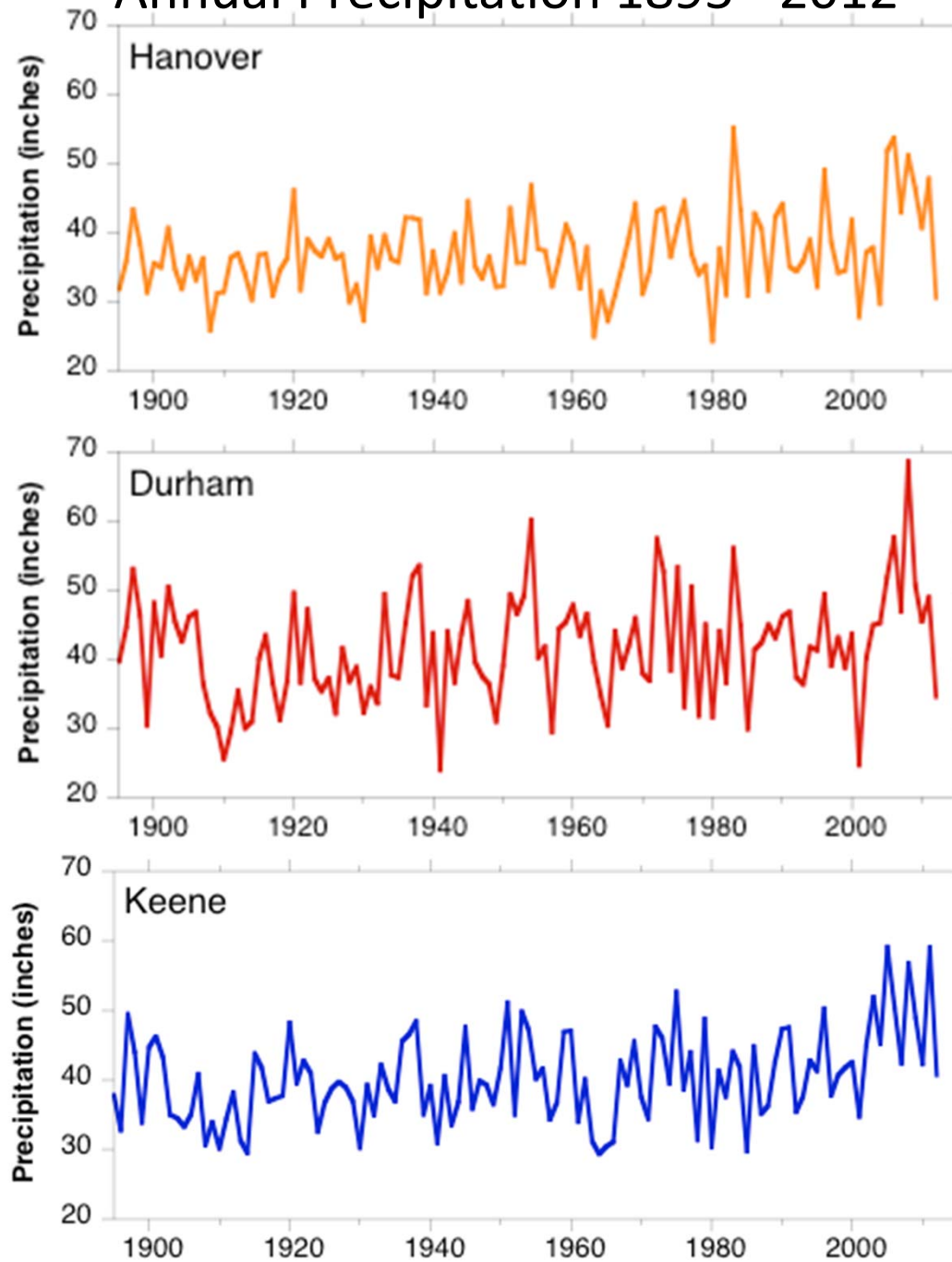


NH USHCN Meteorological Stations (•) Temperature & Precipitation

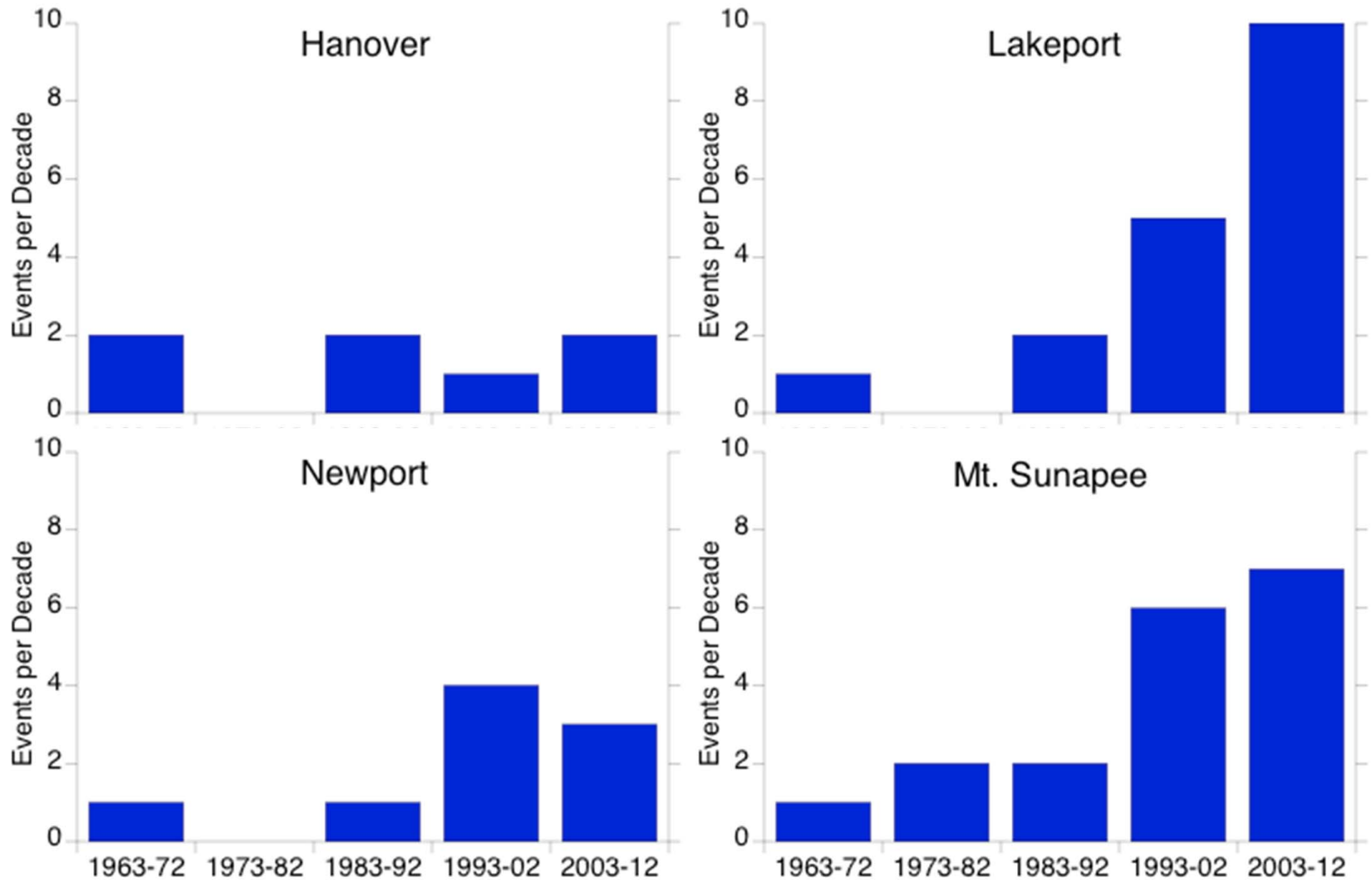
Annual TMIN 1895 - 2012



Annual Precipitation 1895 - 2012



Precipitation Events >4" in 48 hrs - per Decade



Precipitation Events >4" in 48 hrs - per Decade

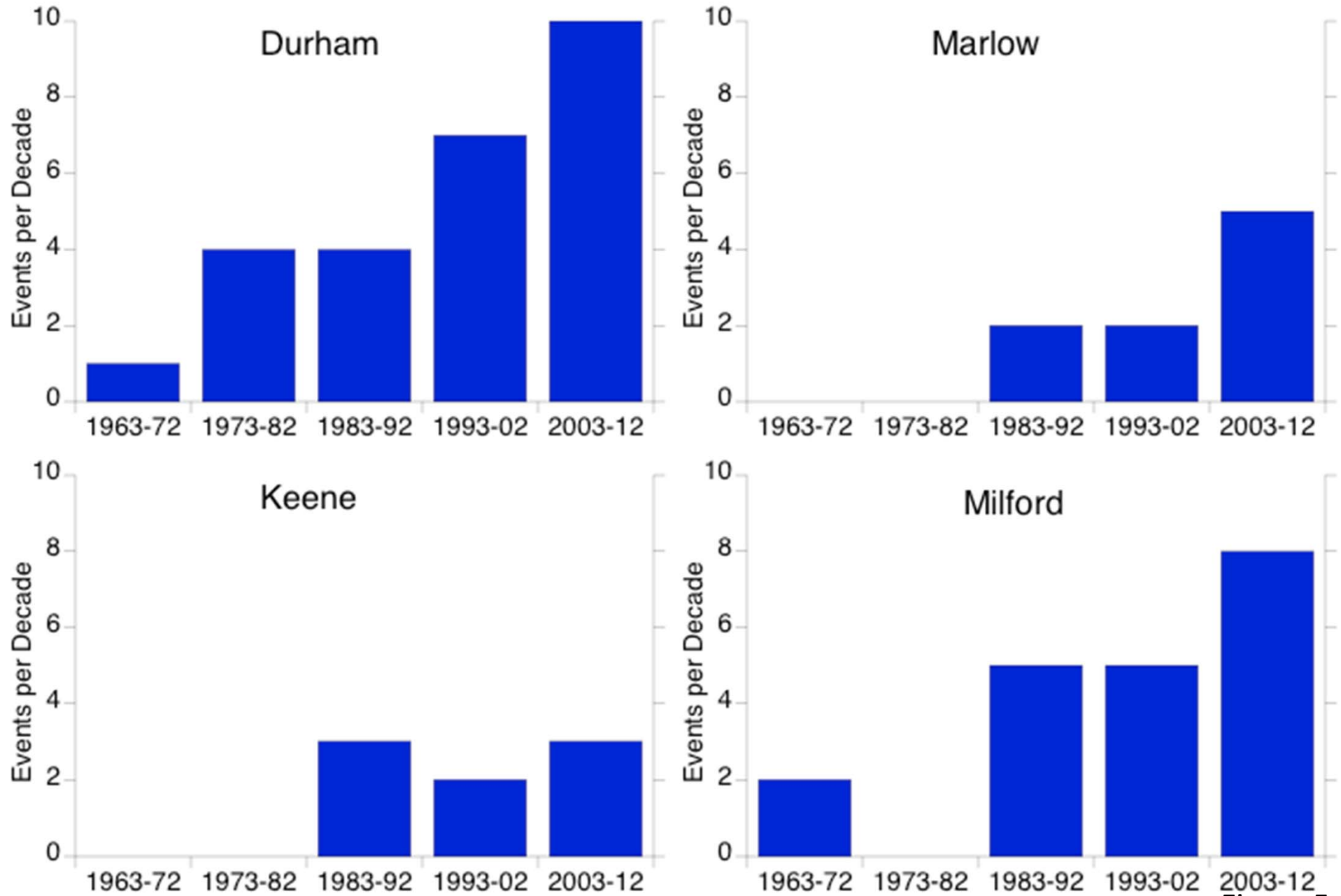
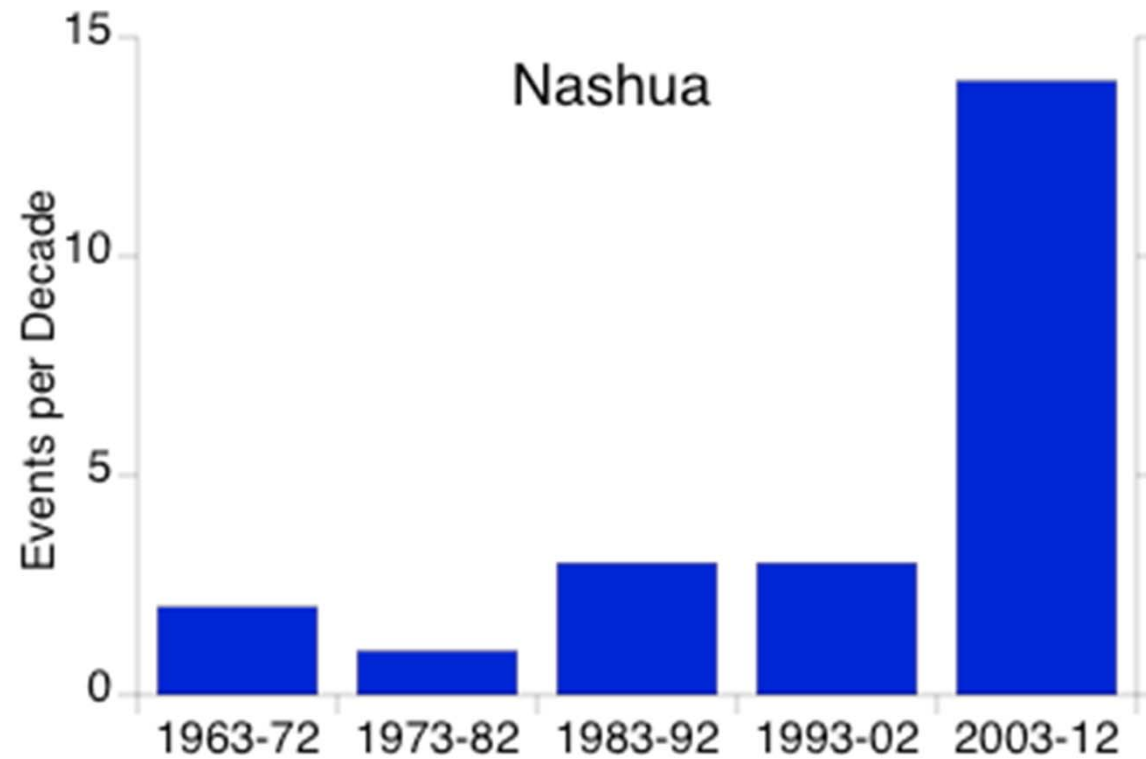
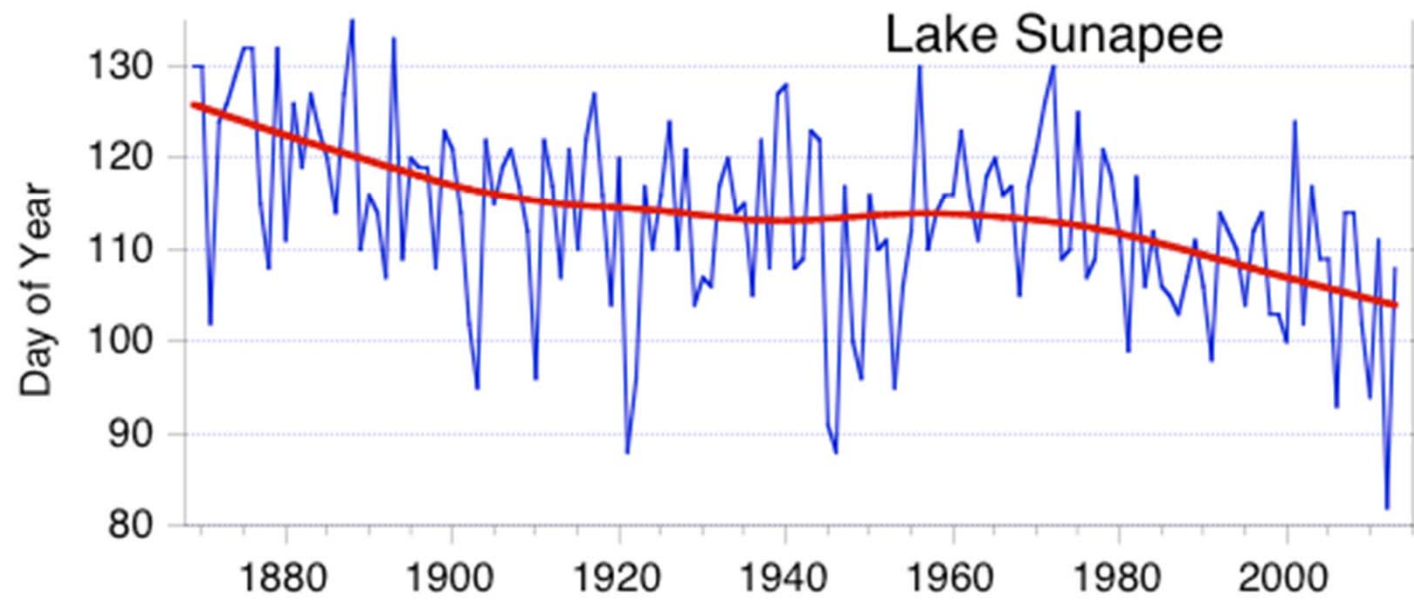
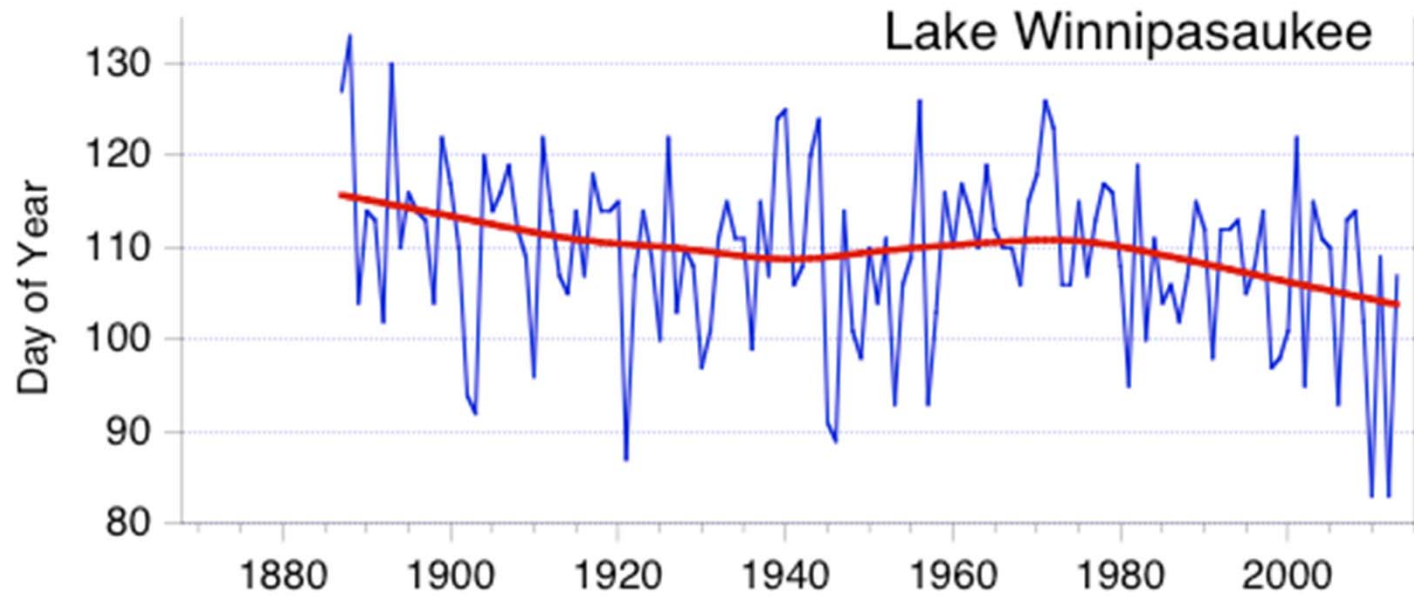


Figure 5

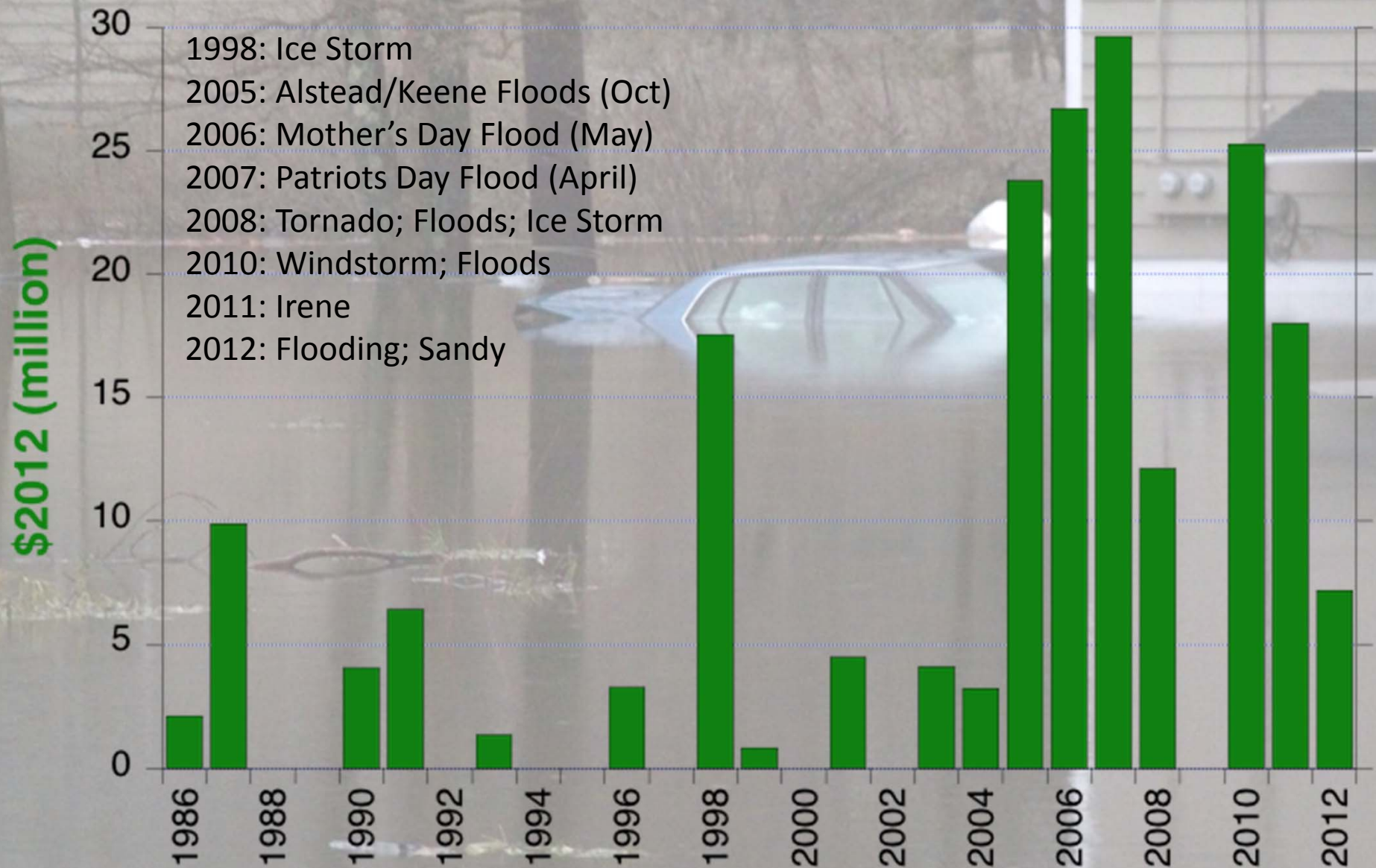
Precipitation Events >4" in 48 hrs - per Decade



Ice-Out Dates

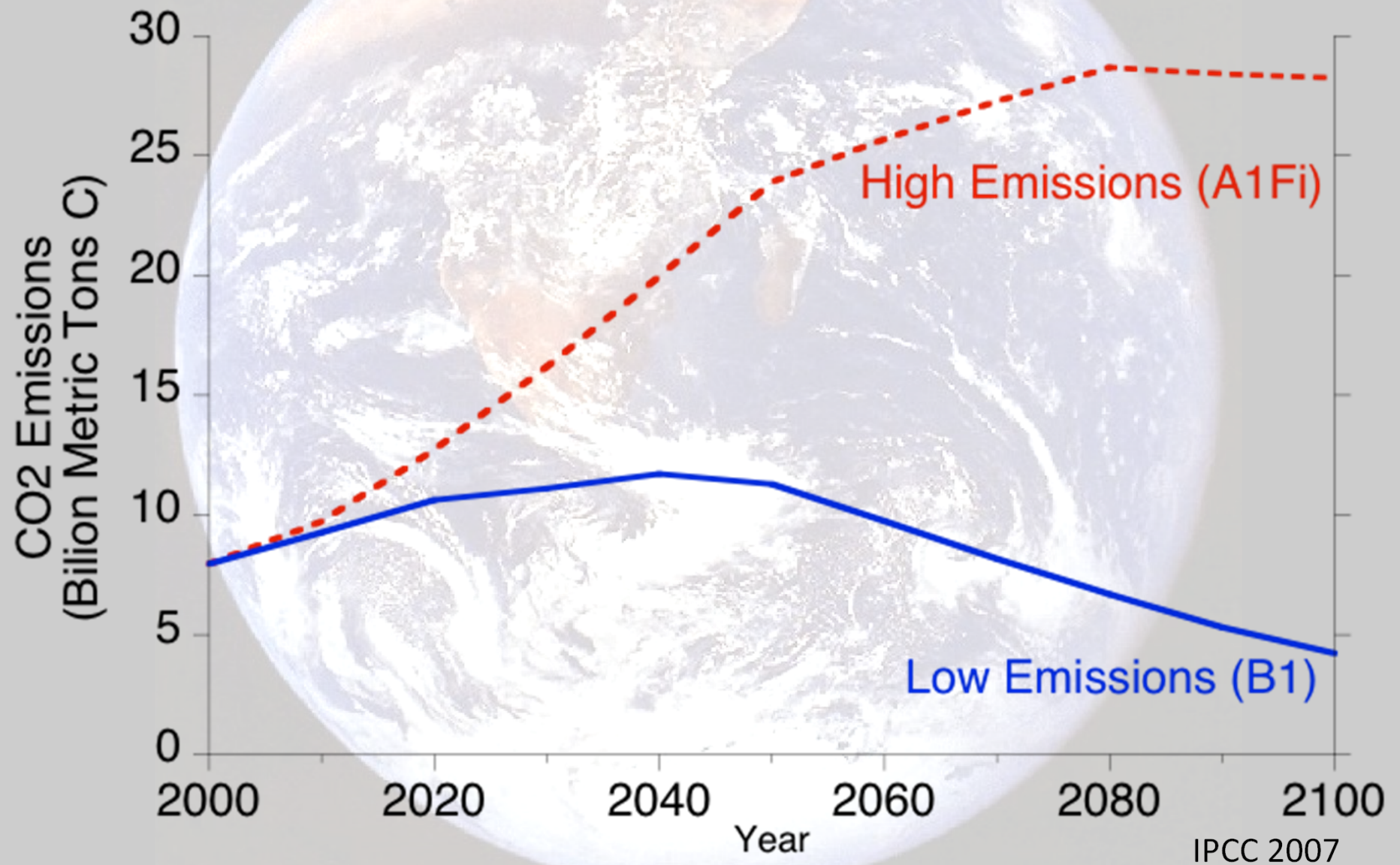


Federal Expenditures on Presidentially Declared Disasters And Emergency Declarations in NH

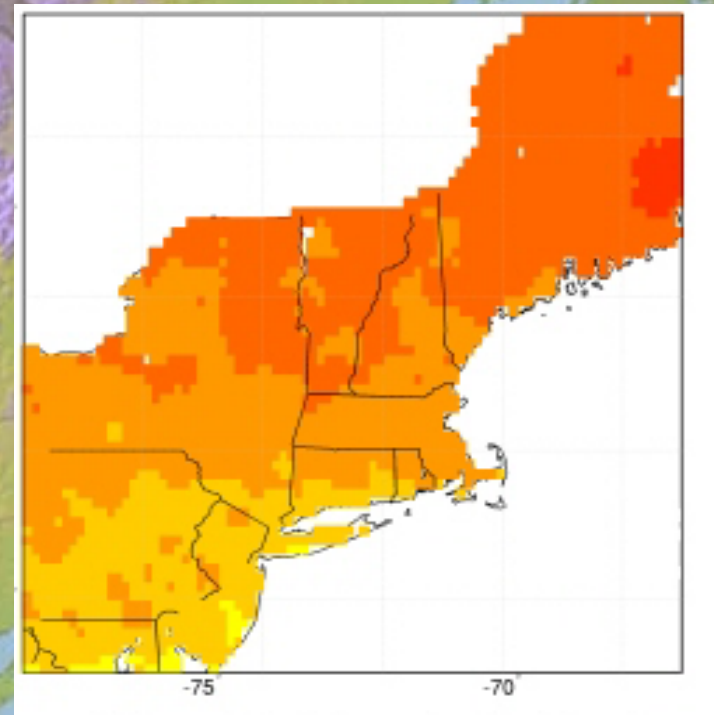
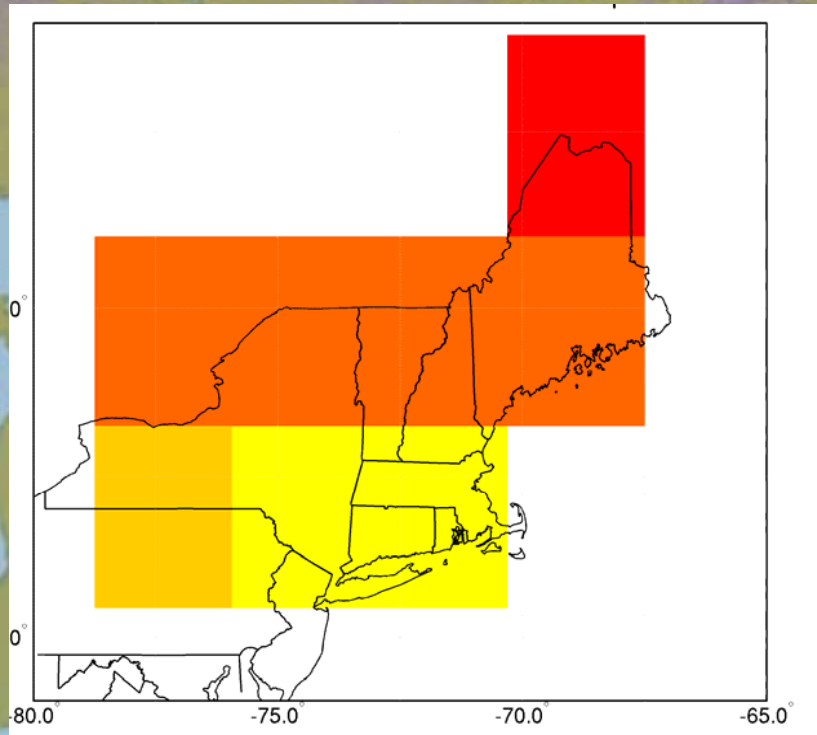


Global Greenhouse Gas Emission Scenarios

Key Input for GCM projections of future climate change



Projecting Future Climate Change for the Northeast: Downscale Global Projections to Regional Level



Projections from 3 or 4 different climate models:

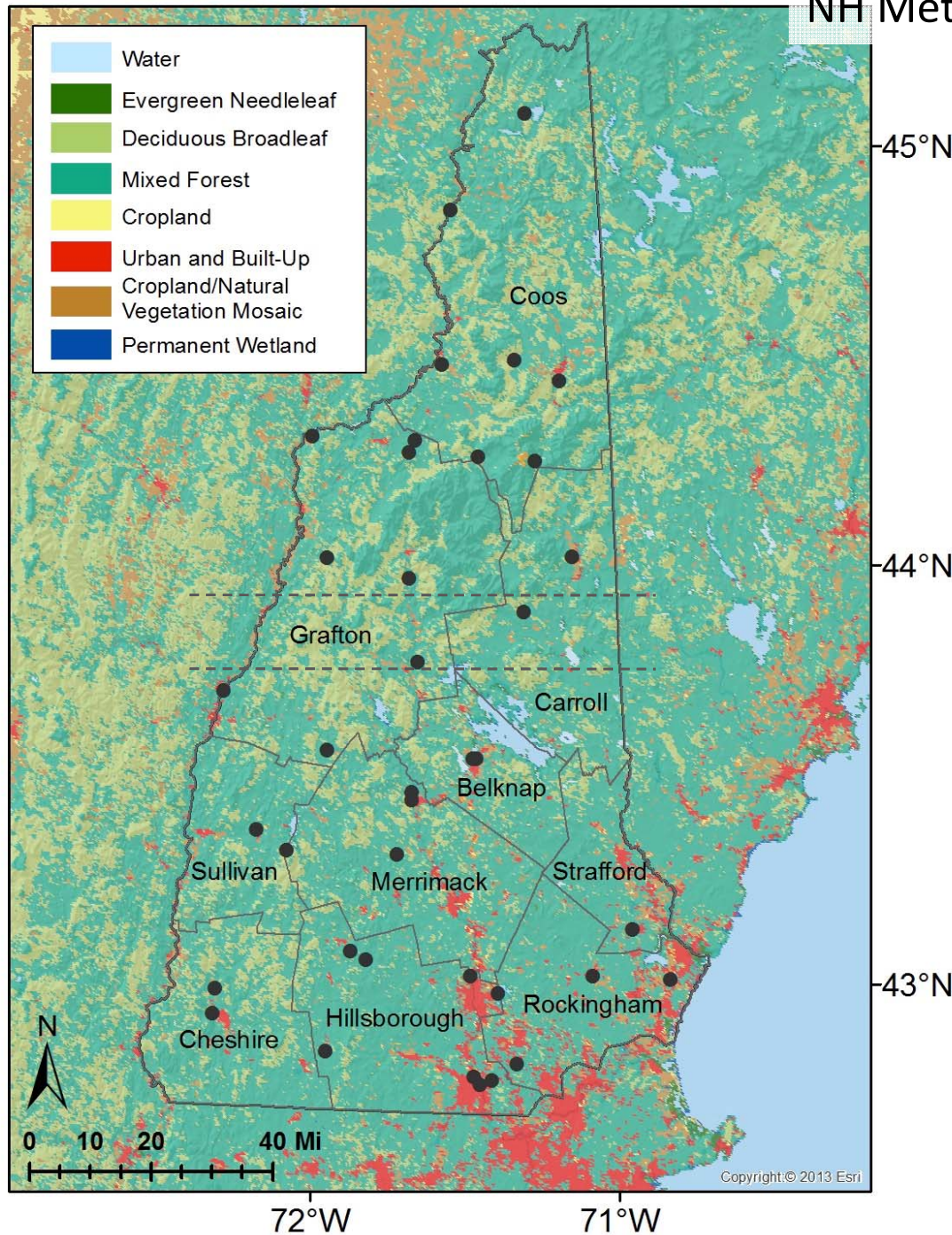
NOAA – GFDL

UKMO – HadCM3

NCAR – PCM

NCAR – CCSM3

NH Meteorological Stations (•) Temperature



Station Name	Lat.	Long.	Elev (ft)
First Connecticut Lake	45.1	71.3	506
Colebrook	44.9	71.5	341
York Pond	44.5	71.3	466
Lancaster	44.5	71.6	262
Berlin	44.4	71.2	284
Monroe	44.3	72.0	201
Bethlehem	44.3	71.7	360
Bethlehem	44.3	71.7	421
Fabyan	44.3	71.5	494
Pinkham Notch	44.3	71.3	613
Benton	44.0	71.9	366
North Conway	44.0	71.1	166
Woodstock	44.0	71.7	220
Tamworth	43.9	71.3	241
Plymouth	43.8	71.7	201
Hanover	43.7	72.3	178
Grafton	43.6	72.0	253
Lakeport	43.6	71.5	171
Lakeport	43.5	71.5	152
Franklin Falls	43.5	71.7	131
Franklin	43.5	71.7	119
Newport	43.4	72.2	235
Mt. Sunapee	43.3	72.1	387
Blackwater Dam	43.3	71.7	183
Durham	43.1	71.0	23
Deering	43.1	71.9	325
East Deering	43.1	71.8	241
Manchester	43.0	71.5	64
Epping	43.0	71.1	49
Greenland	43.0	70.8	26
Surry Mtn	43.0	72.3	171
Massabesic Lake	43.0	71.4	77
Keene	42.9	72.3	156
Peterboro	42.9	72.0	311
Windham	42.8	71.3	67
Nashua	42.8	71.5	41
Hudson	42.8	71.4	56
Nashua	42.8	71.5	27

Annual Maximum Temperature, Southern NH (25 stations)

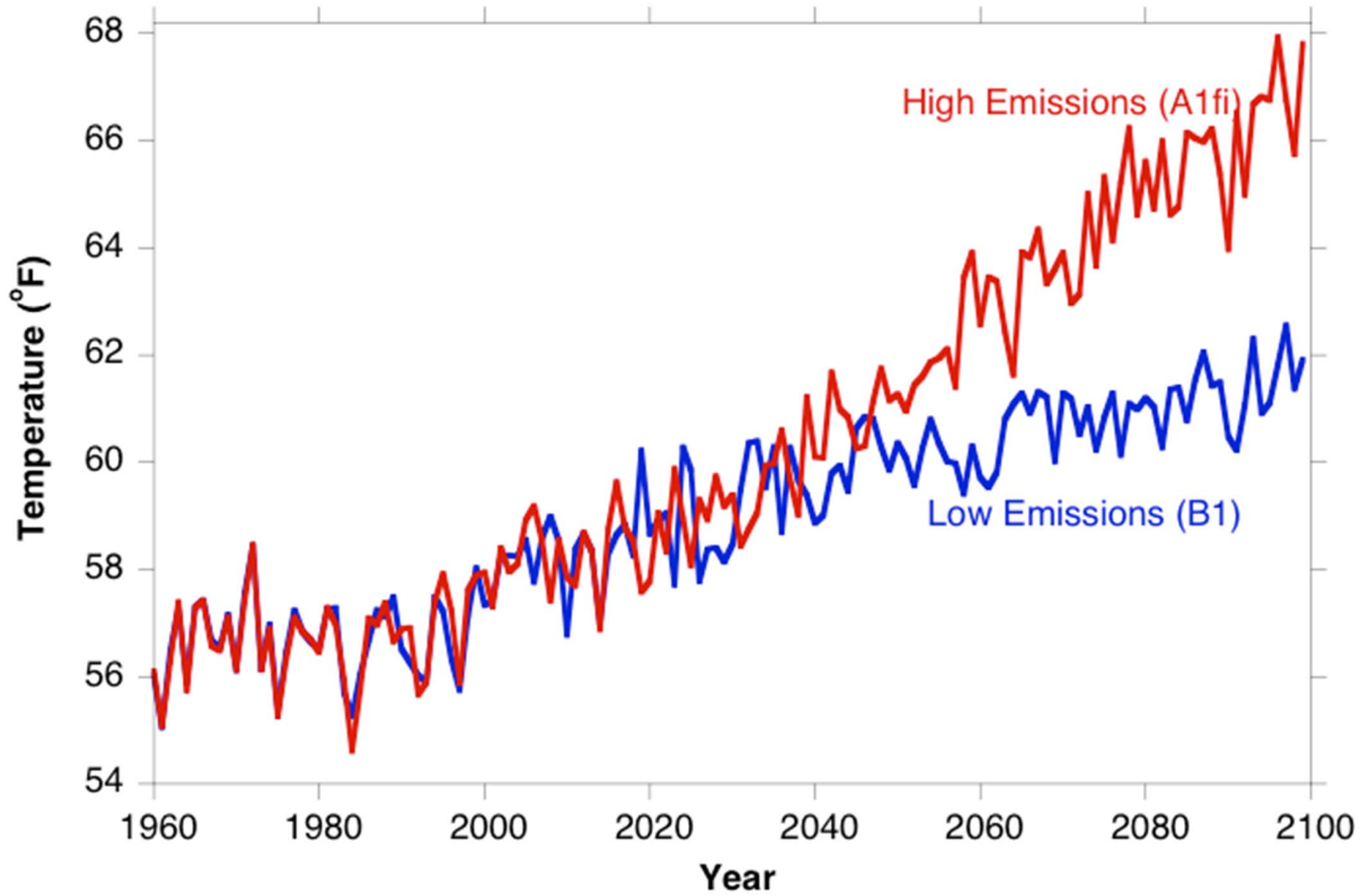


Figure 12a

Annual Minimum Temperature, Southern NH (25 stations)

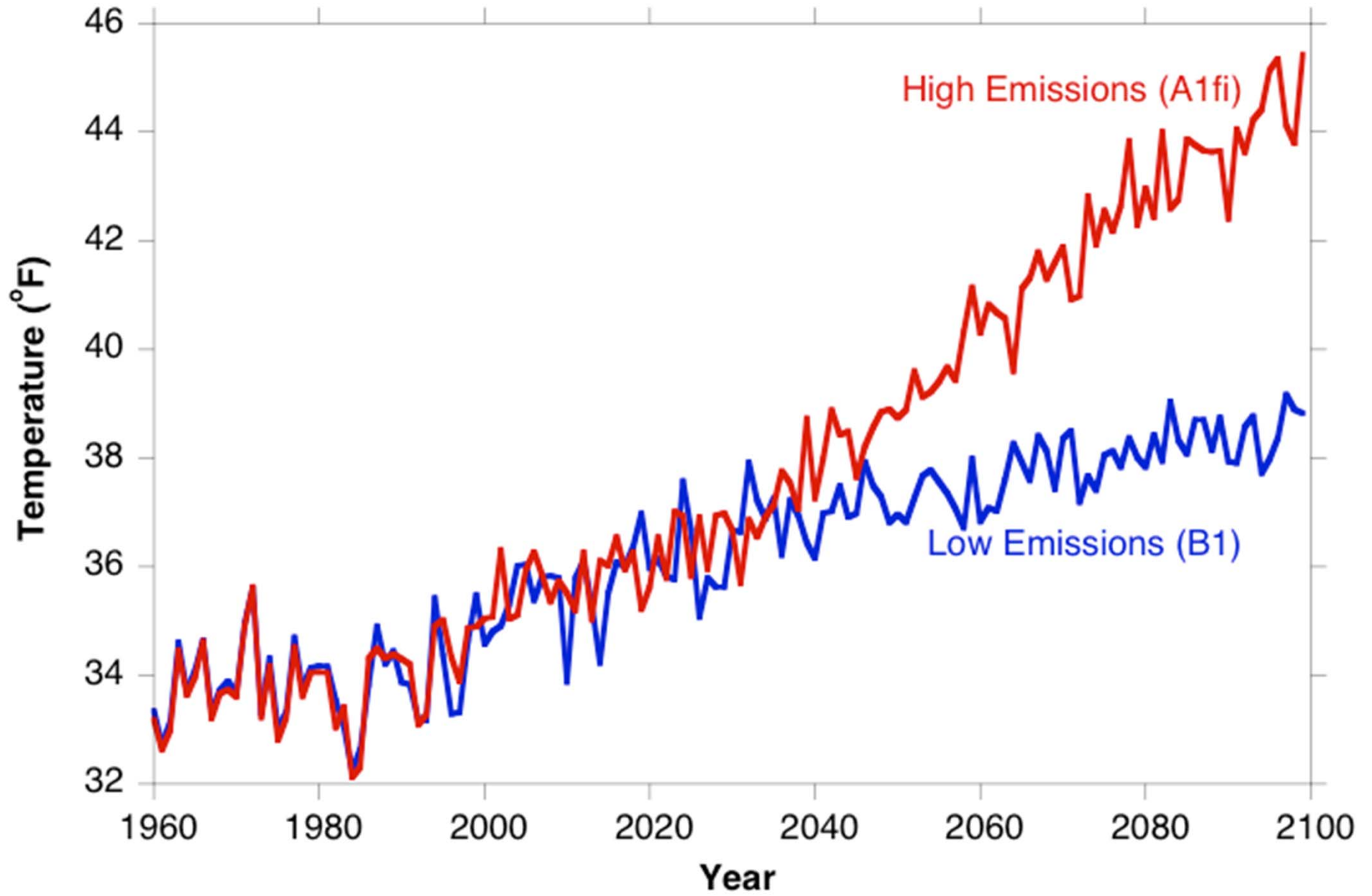
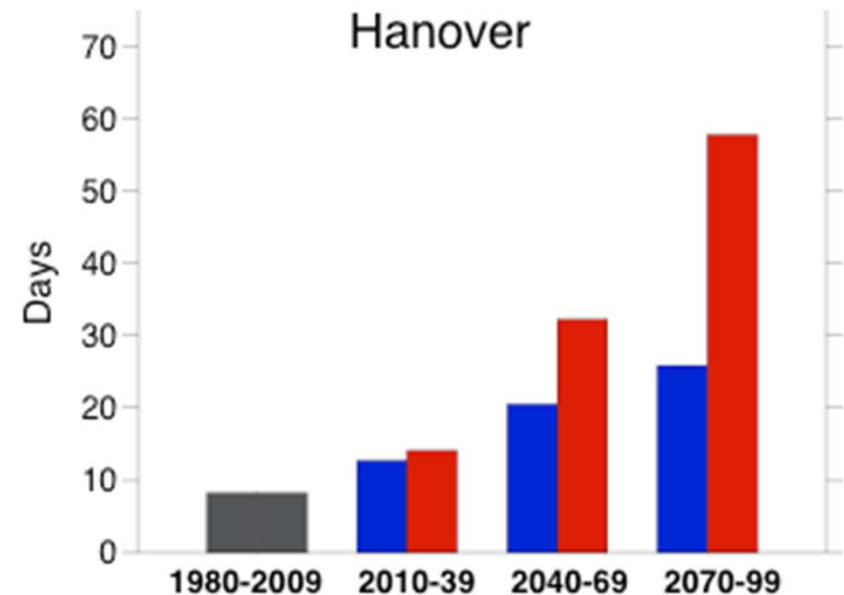
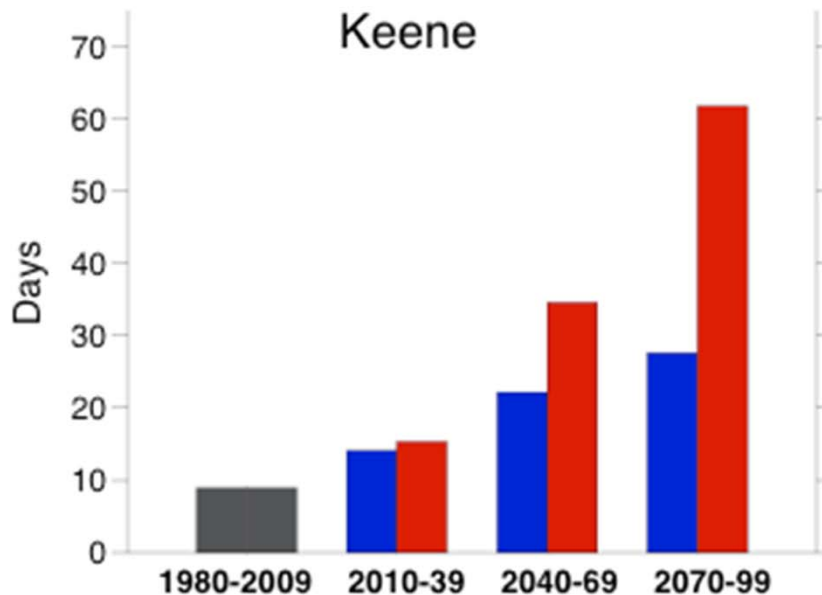
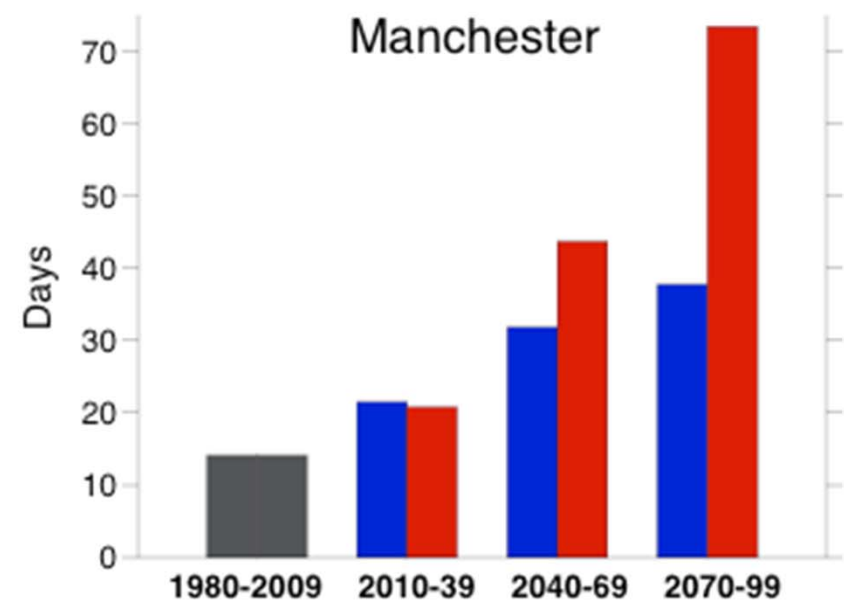
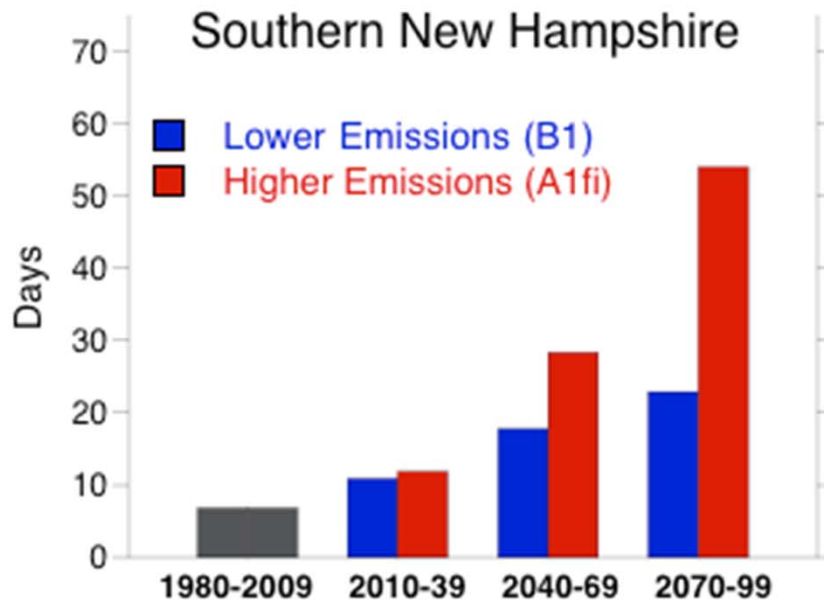
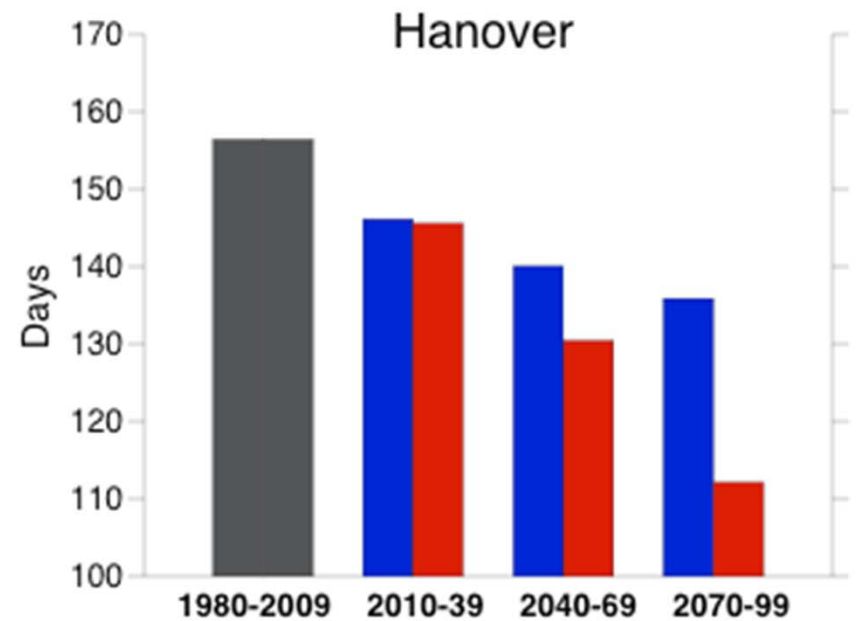
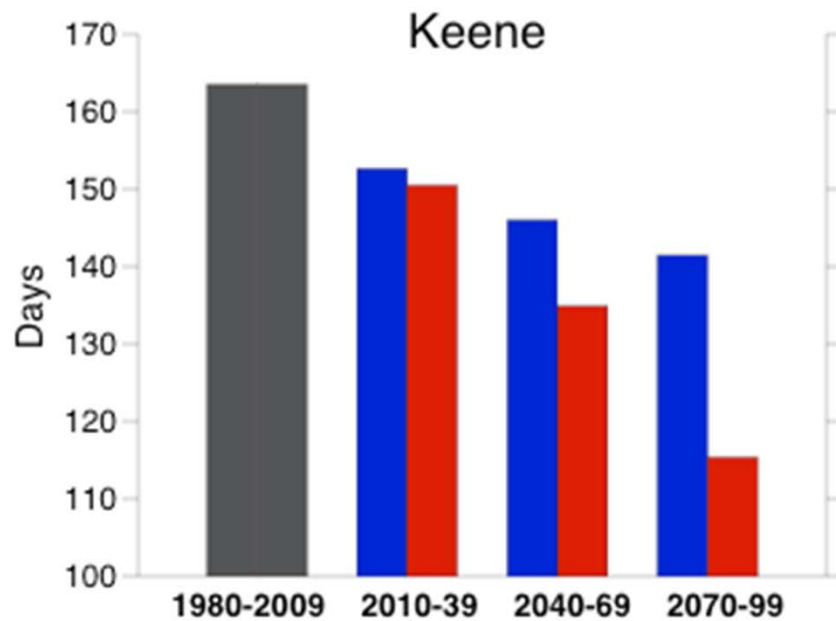
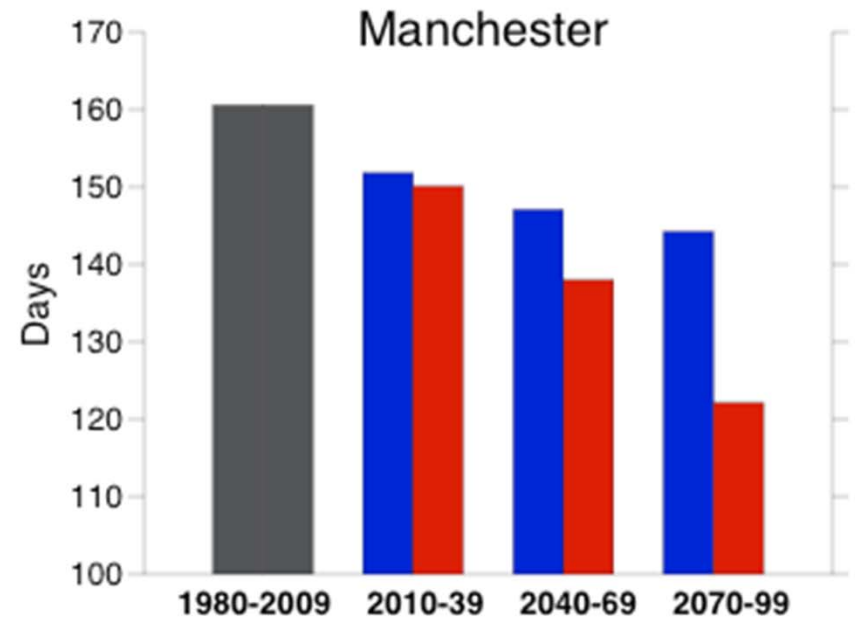
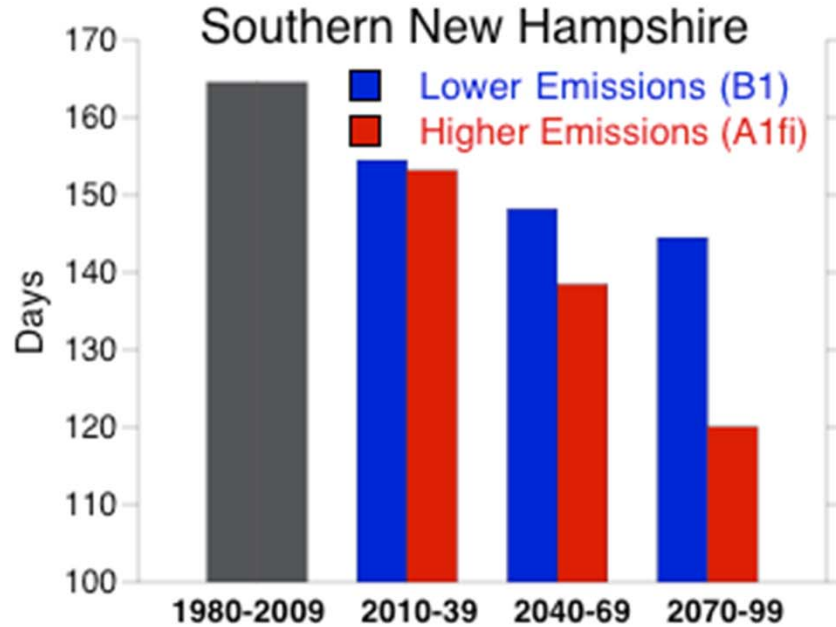


Figure 13a

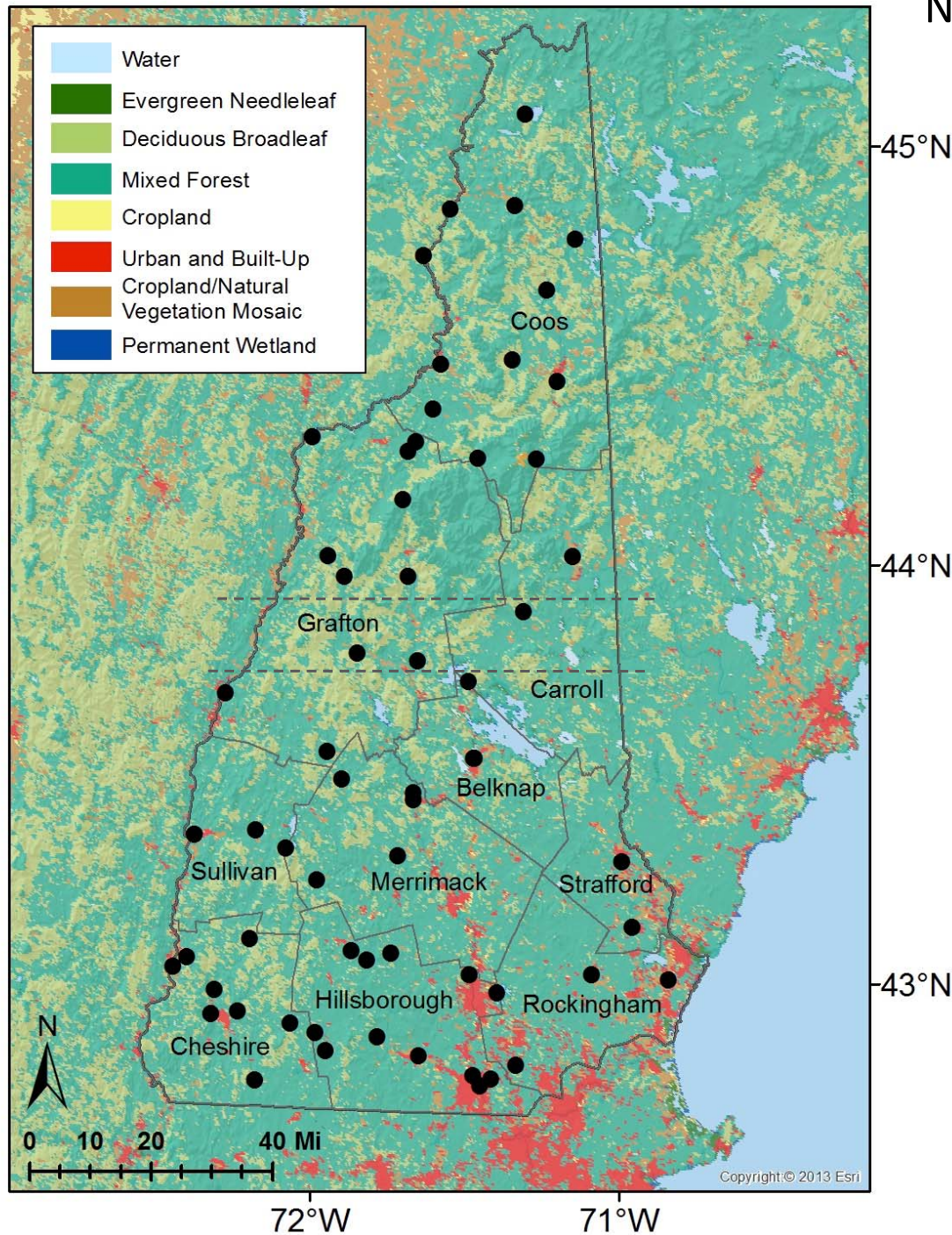
Number of Days Hotter than 90° (30 year averages)



Number of Days Cooler than 32°F (30 yr averages)



NH Meteorological Stations (●) Precip.



Station Name	Lat	Lon	Elev
First Connecticut Lake	45.09	-71.29	506.0
Dixville Notch	44.87	-71.32	515.1
Colebrook	44.86	-71.54	341.4
Errol	44.79	-71.12	390.1
North Stratford	44.75	-71.63	277.4
Milan	44.67	-71.22	360.0
York Pond	44.50	-71.33	466.3
Lancaster	44.49	-71.57	262.1
Berlin	44.45	-71.18	283.5
Whitefield	44.38	-71.60	331.9
Monroe	44.32	-72.00	201.2
Bethlehem	44.31	-71.66	359.7
Bethlehem	44.28	-71.68	420.6
Fabyan	44.27	-71.45	494.1
Pinkham Notch	44.26	-71.26	612.6
Cannon Mtn	44.17	-71.70	1220.1
Benton	44.03	-71.95	365.8
North Conway	44.03	-71.14	165.8
Glenciff	43.98	-71.89	329.2
Woodstock	43.98	-71.68	220.1
Tamworth	43.90	-71.30	240.8
West Rumney	43.80	-71.85	170.7
Plymouth	43.78	-71.65	201.2
Moultonboro	43.73	-71.48	182.9
Hanover	43.71	-72.29	178.0
Grafton	43.57	-71.95	253.0
Lakeport	43.55	-71.47	170.7
Lakeport2	43.55	-71.46	152.4
South Danbury	43.50	-71.90	284.1
Franklin Falls Dam	43.47	-71.67	131.1
Franklin	43.45	-71.67	118.9
Newport	43.38	-72.18	234.7
Claremont Junction	43.37	-72.38	131.1
Mt. Sunapee	43.33	-72.08	387.1
Blackwater Dam	43.32	-71.72	182.9
Rochester	43.30	-70.98	70.1
Bradford	43.26	-71.98	286.5
Durham	43.14	-70.95	22.9
Marlow	43.12	-72.20	359.7
Deering	43.09	-71.87	325.2
Weare	43.08	-71.74	219.5
East Deering	43.07	-71.82	241.1
Walpole3	43.07	-72.41	283.5
Walpole	43.05	-72.45	92.0
Epping	43.03	-71.08	48.8
Manchester	43.03	-71.48	64.0
Greenland	43.02	-70.83	25.9
Surry Mtn. Lake	43.00	-72.31	170.7
Massabesic Lake	42.99	-71.39	77.1
Otter Brook lake	42.95	-72.24	207.3
Keene	42.94	-72.32	155.8
Dublin	42.92	-72.07	454.2
Edward Macdowell Lake	42.89	-71.98	295.7
South Lyndeboro	42.88	-71.78	198.1
Peterboro	42.85	-71.95	310.9
Milford	42.84	-71.65	97.5
Windham	42.82	-71.33	67.1
Nashua2	42.79	-71.47	41.1
Nashua	42.77	-71.45	26.5
Fitzwilliam	42.78	-72.18	362.7
Hudson	42.78	-71.41	56.4

Annual Precipitation, Southern NH (41 stations)

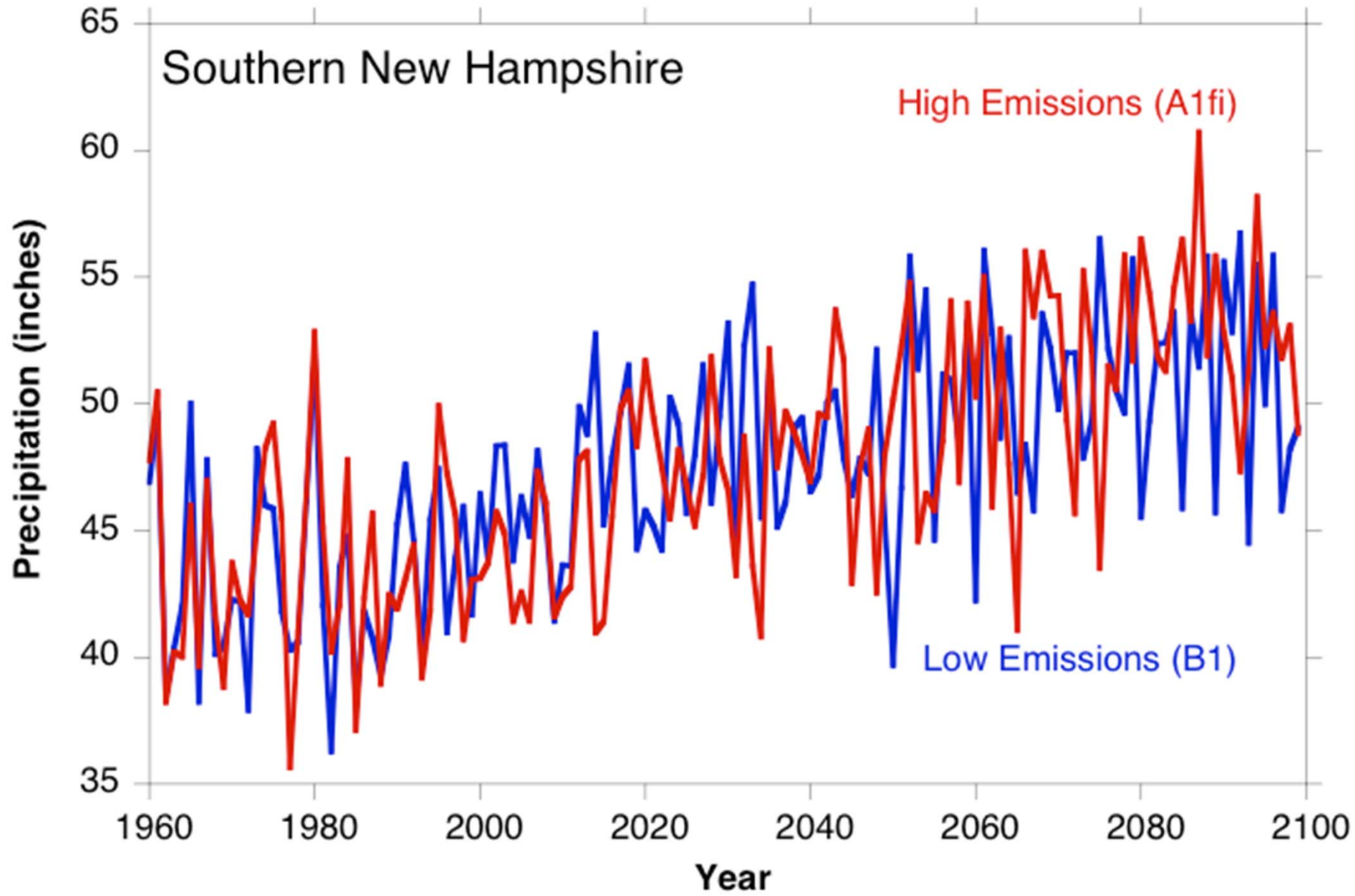


Figure 16a

Seasonal Precipitation, Southern NH (41 stations)

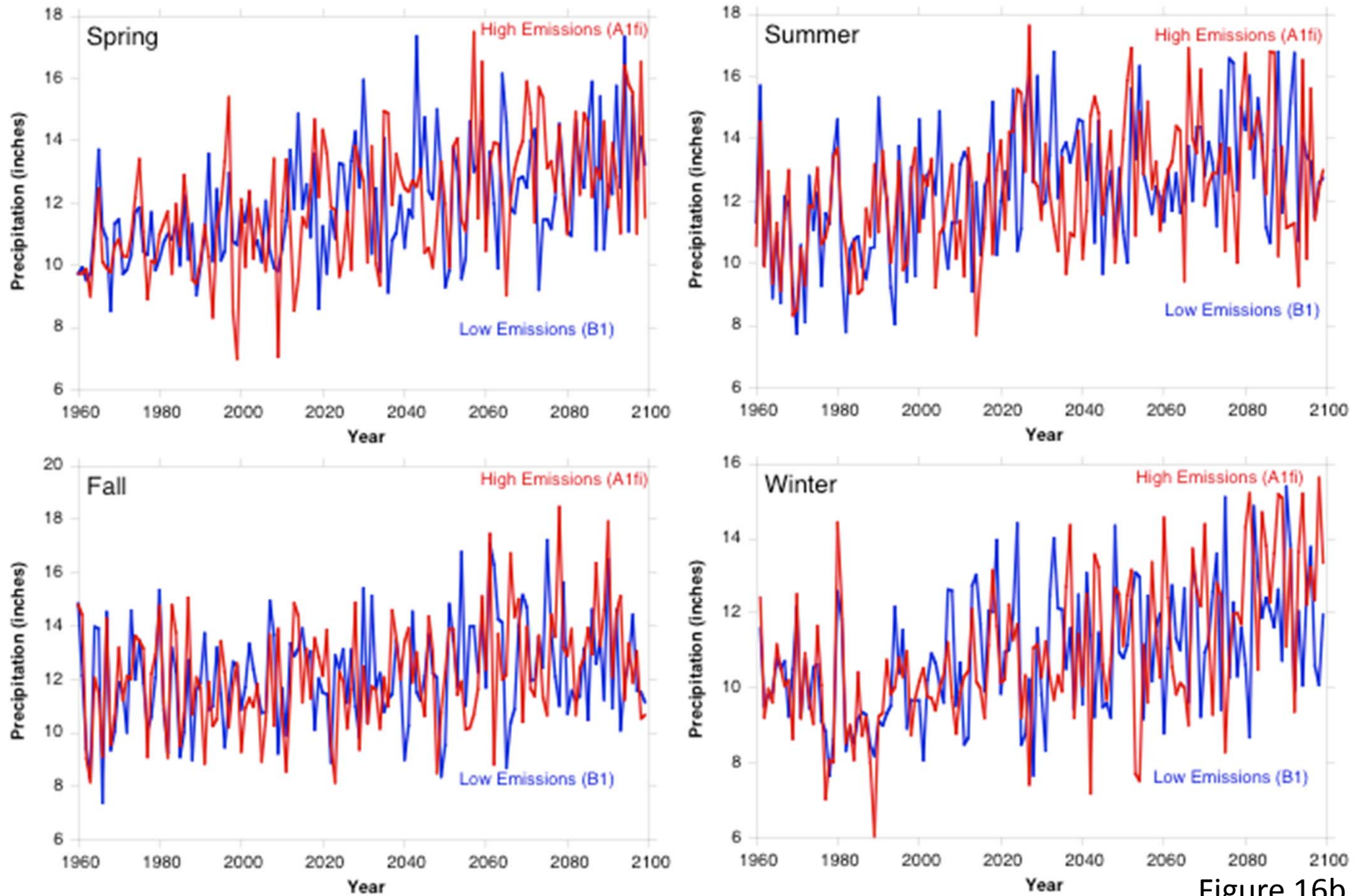
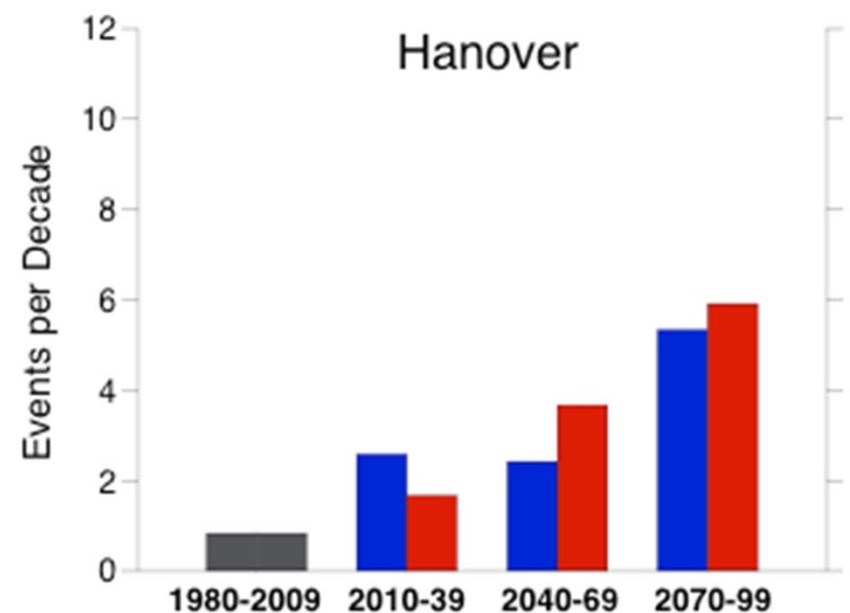
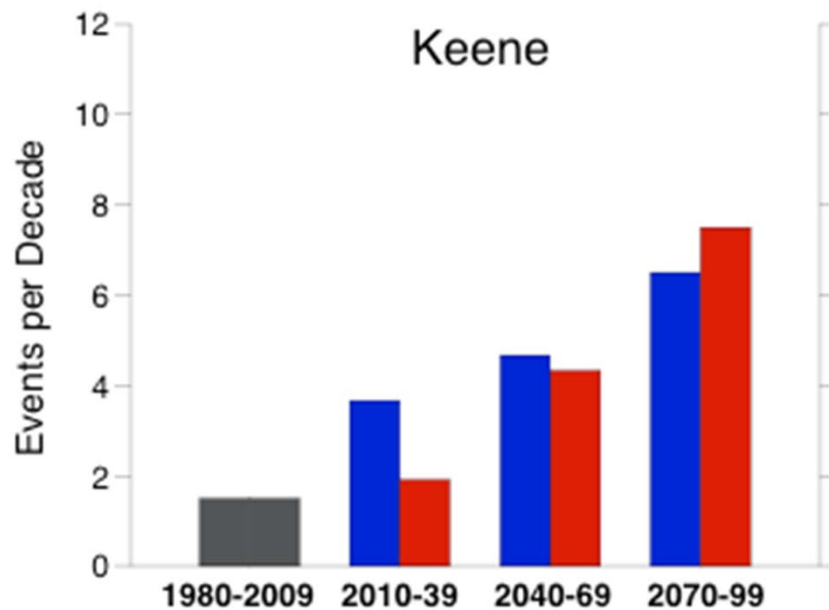
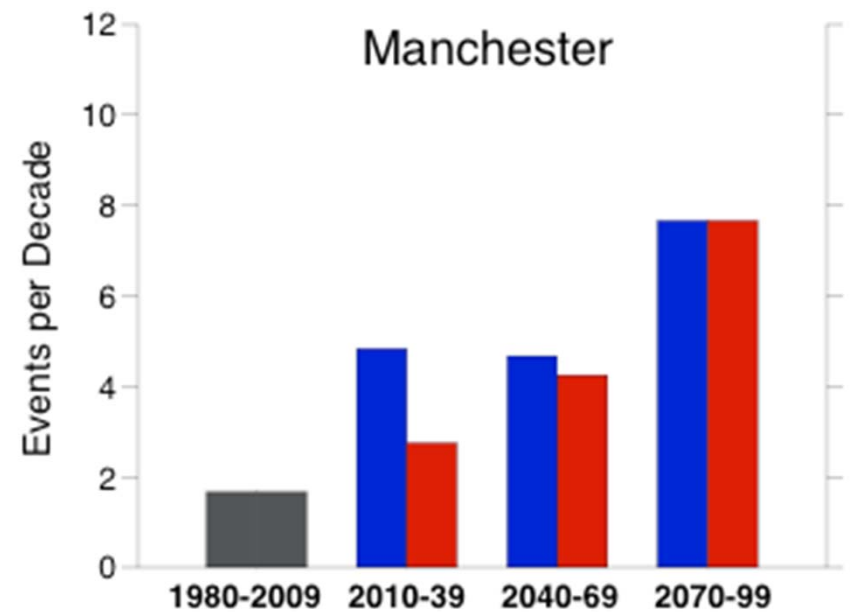
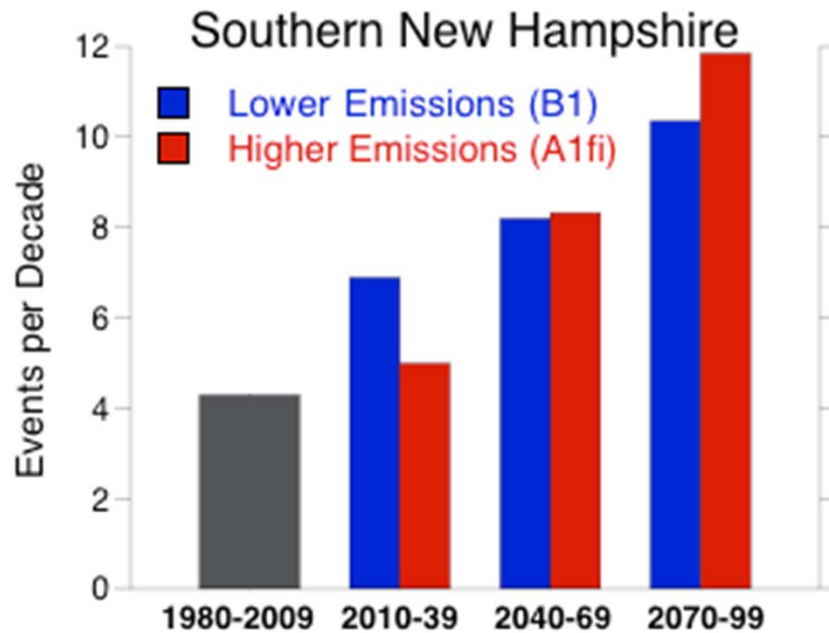
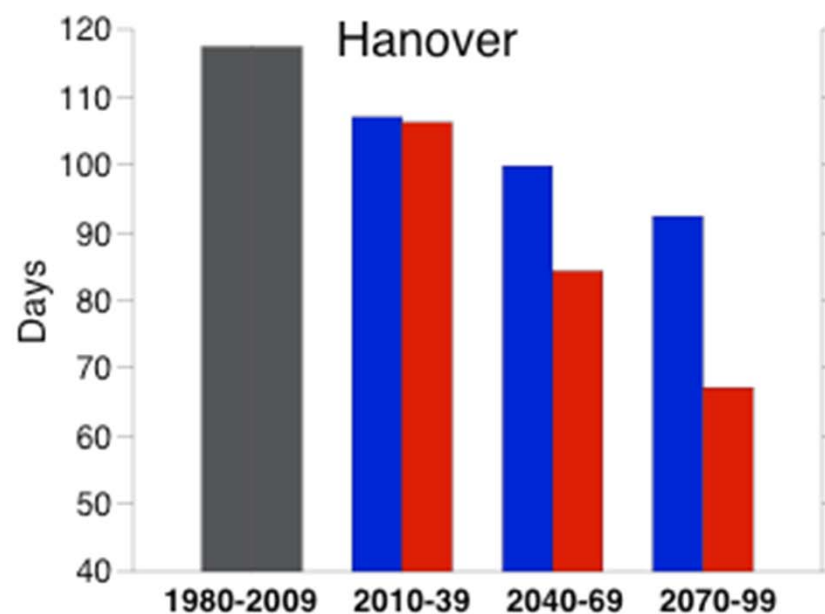
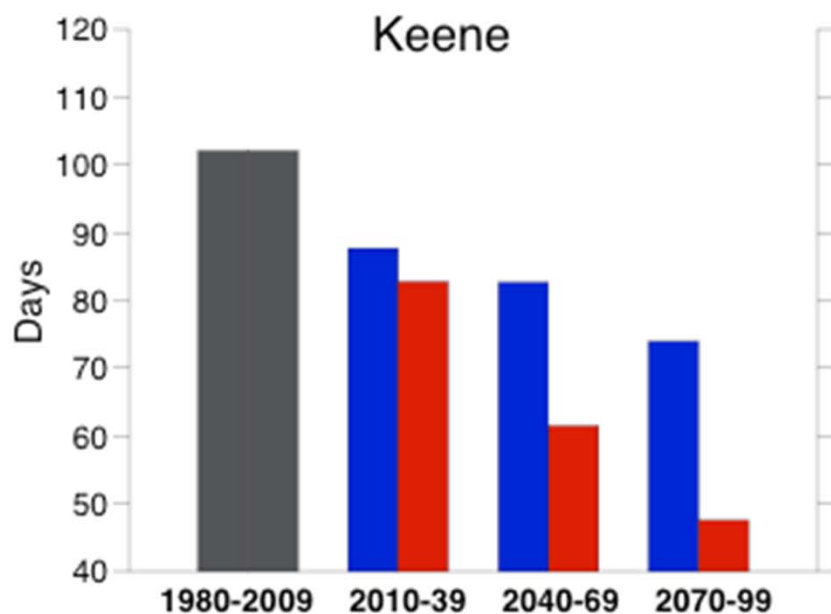
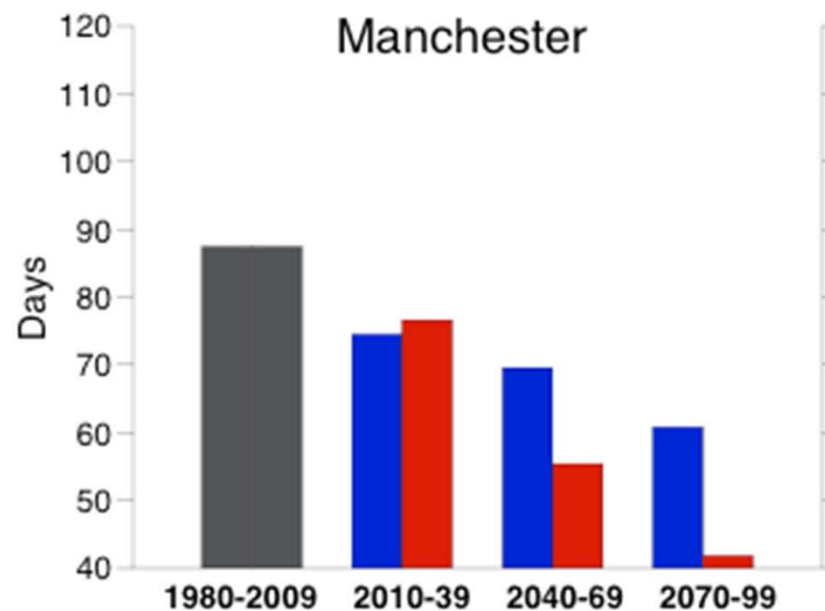
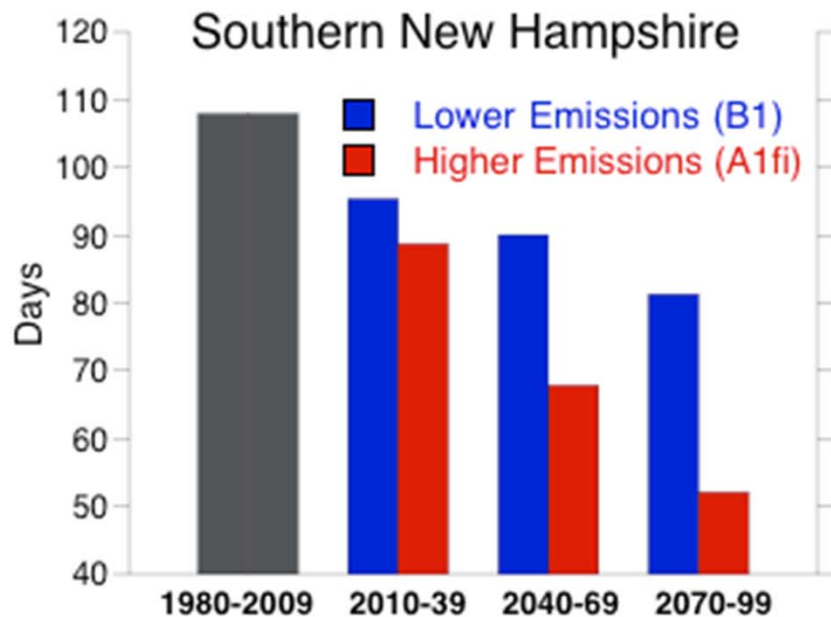


Figure 16b

4" in 48 hrs per Decade (30 year averages)



Snow Covered Days (30 yr averages)

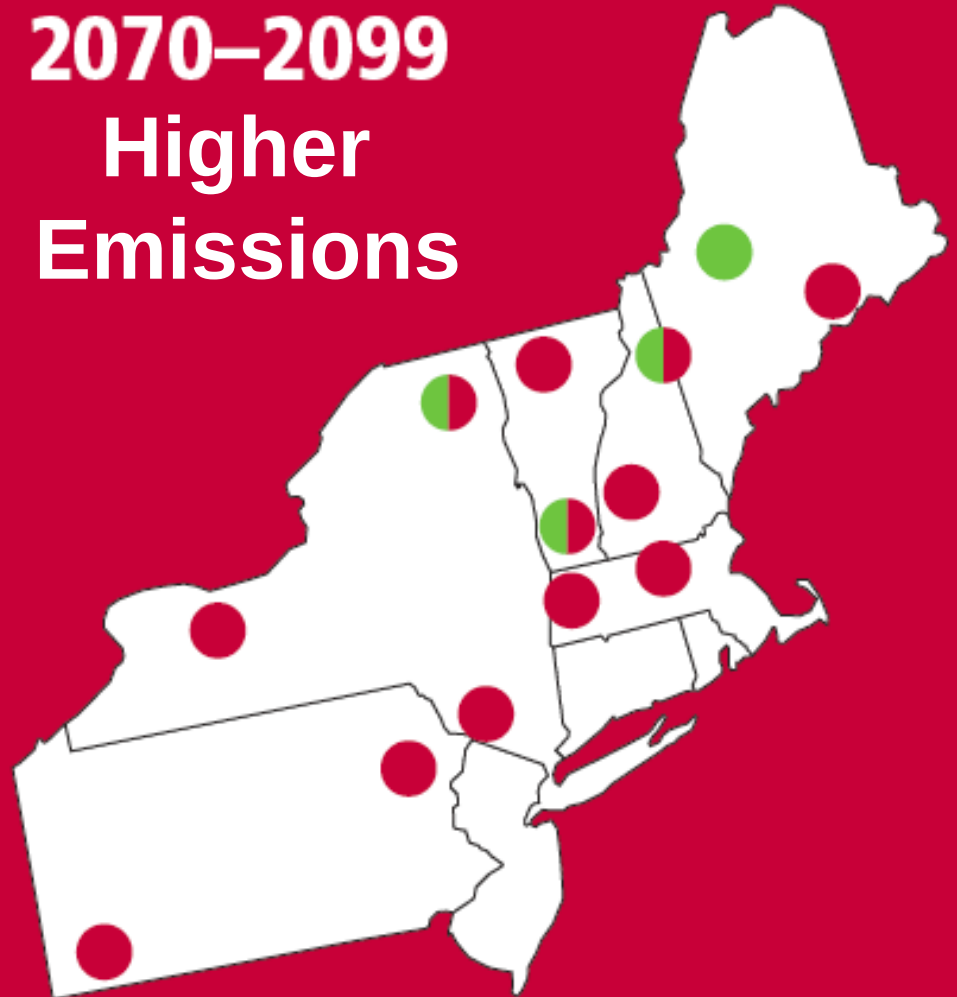


Vulnerability of Ski Resorts to Climate Change

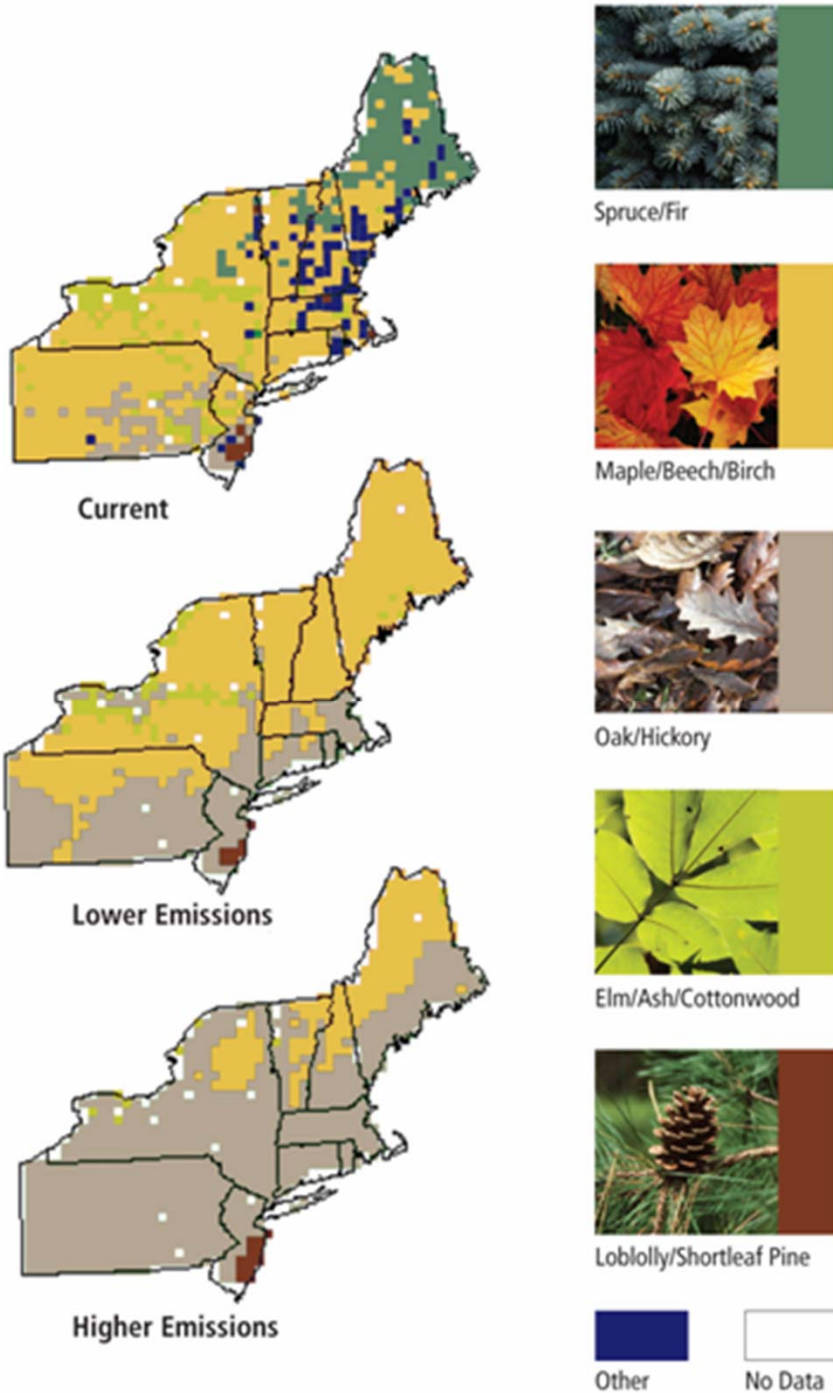


- highly vulnerable
- vulnerable
- viable

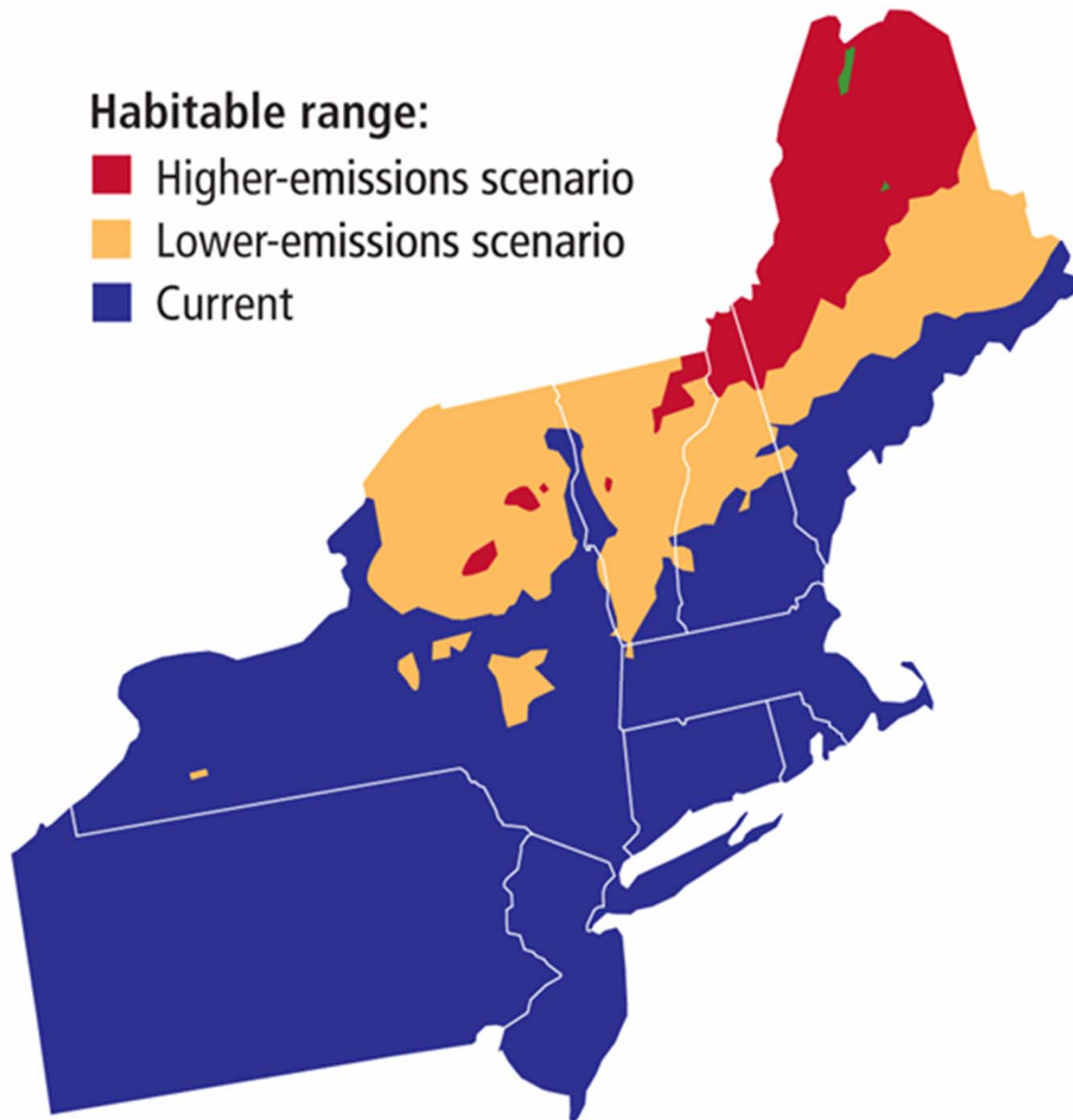
**2070–2099
Higher
Emissions**



Changes in Habitat Suitability for Different Forest Types



Late-Century Range of Hemlock Woolly Adelgid



Indicators		Historical* 1980-2009		Change from Historical (+ or -)					
				Short Term 2010-2039		Medium Term 2040-2069		Long Term 2070-2099	
				Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
Temperature Anomaly (°F)									
	Annual TMIN	35.2		1.8	2.0	2.9	5.1	3.9	8.8
	Winter TMIN	12.3		2.5	2.9	4.0	6.2	5.5	10.3
	Spring TMIN	32.9		3.0	1.6	4.7	4.4	5.9	7.7
	Summer TMIN	56.2		1.5	2.0	2.6	5.2	3.2	9.0
	Fall TMIN	38.9		0.2	1.6	0.5	4.9	1.0	8.1
	Annual TMAX	56.7		1.8	1.8	3.1	4.9	4.0	8.3
	Winter TMAX	31.5		1.8	1.7	2.7	3.6	3.9	6.3
	Spring TMAX	56.0		2.5	1.6	4.9	4.8	6.6	8.7
	Summer TMAX	80.3		1.8	2.1	3.3	5.8	4.2	9.6
	Fall TMAX	58.7		0.9	1.6	1.3	5.3	1.5	8.5
Temperature Extreme (days per year)									
	<32°F	156		-10	-10	-16	-26	-20	-44
	<0°F	18		-5	-5	-9	-12	-10	-16
	>90°F	8		5	6	13	24	18	50
	>95°F	1		1	2	4	10	6	27
	TMAX on hottest day of the year	94.2		1.8	1.3	2.9	4.6	4.0	8.3
	TMIN on coldest day of the year	-18.0		4.0	4.4	6.1	10.7	8.1	18.6

Hanover, NH										
Indicators			Historical* 1980-2009		Change from Historical (+ or -)					
					Short Term 2010-2039		Medium Term 2040-2069		Long Term 2070-2099	
					Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
Precipitation (in.)										
	Annual mean	38.5		3.7	2.9	4.5	6.2	6.4	9.1	
	Winter mean	8.2		0.9	0.6	0.9	1.1	1.5	2.2	
	Spring mean	9.3		0.8	1.0	1.6	1.7	1.7	3.0	
	Summer mean	10.7		1.4	0.7	0.9	1.9	2.1	1.4	
	Fall mean									
Extreme Precipitation (events per year)										
	1" in 24 hrs	8.2		1.6	1.6	2.1	2.8	3.0	4.9	
	2" in 48 hours	3.1		1.2	0.8	1.1	2.2	2.2	3.5	
Extreme Precipitation (events per decade)										
	4" in 48 hours	1.0		1.6	0.7	1.4	2.7	4.3	4.9	
Snow Covered Days			117		-10	-11	-17	-33	-25	-50
Growing Season (days)			168		14	14	20	31	23	51

What path will we take to the future?



Two roads diverged in a wood, and I -
I took the one less traveled by,
And that has made all the difference.

Robert Frost

NH Climate Action Plan

- One of the largest, most diverse collections of leading NH citizens
- Promotes growth of new jobs and renewable energy development
- Reduces energy costs
- Identifies 67 recommended actions
 - buildings
 - electricity generation,
 - transportation & land use
 - natural resources
 - government action
 - adaptation**
- Reduce greenhouse gas emissions
 - 44% below 2005 levels by 2025
 - 86% below 2005 levels by 2050

New Hampshire Climate Change Policy Task Force

The New Hampshire Climate Action Plan

A Plan for New Hampshire's Energy, Environmental
and Economic Development Future



Prepared by NH Department of Environmental Services
March 2009

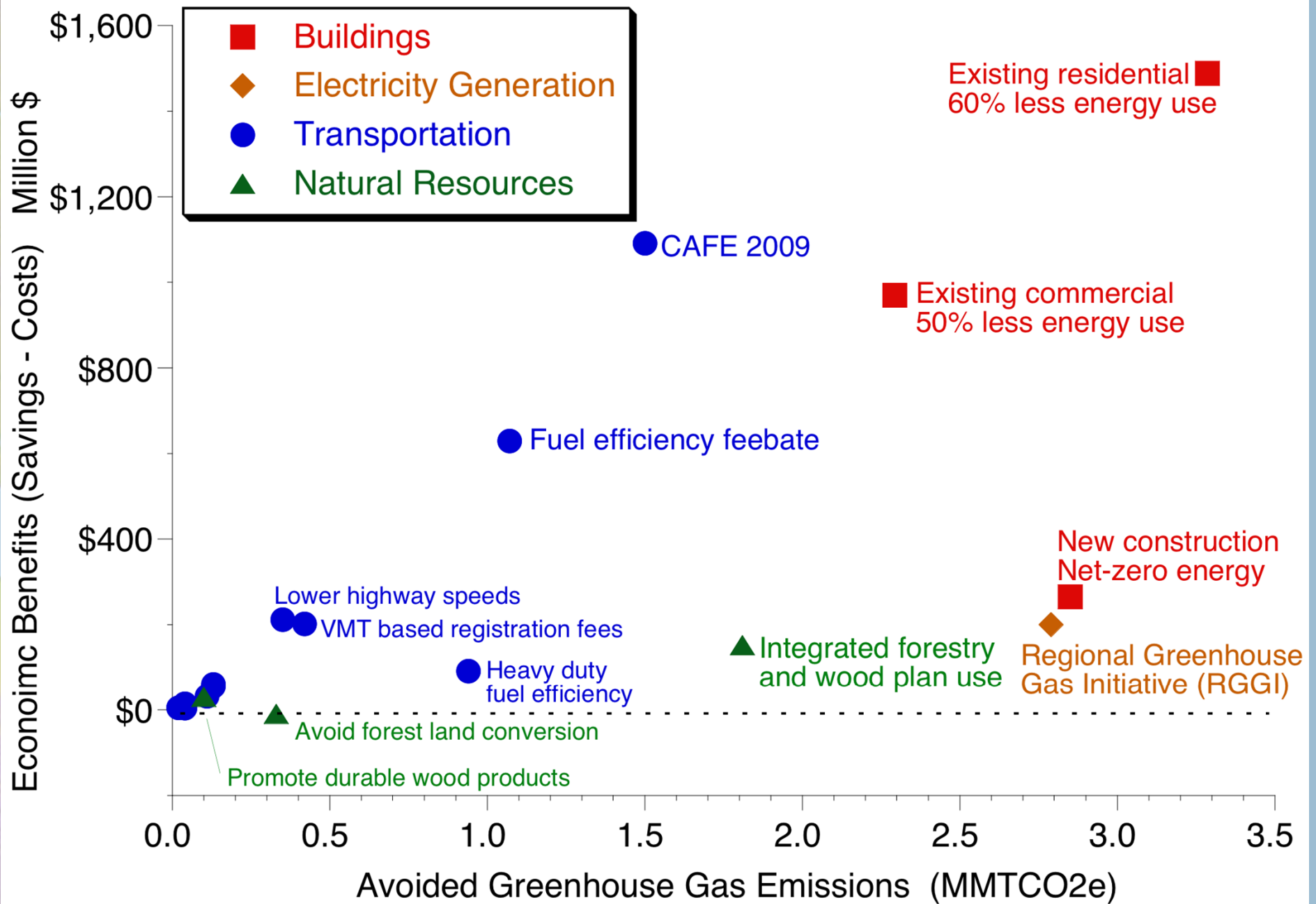
More info at:

<http://CarbonSolutionsNE.org>

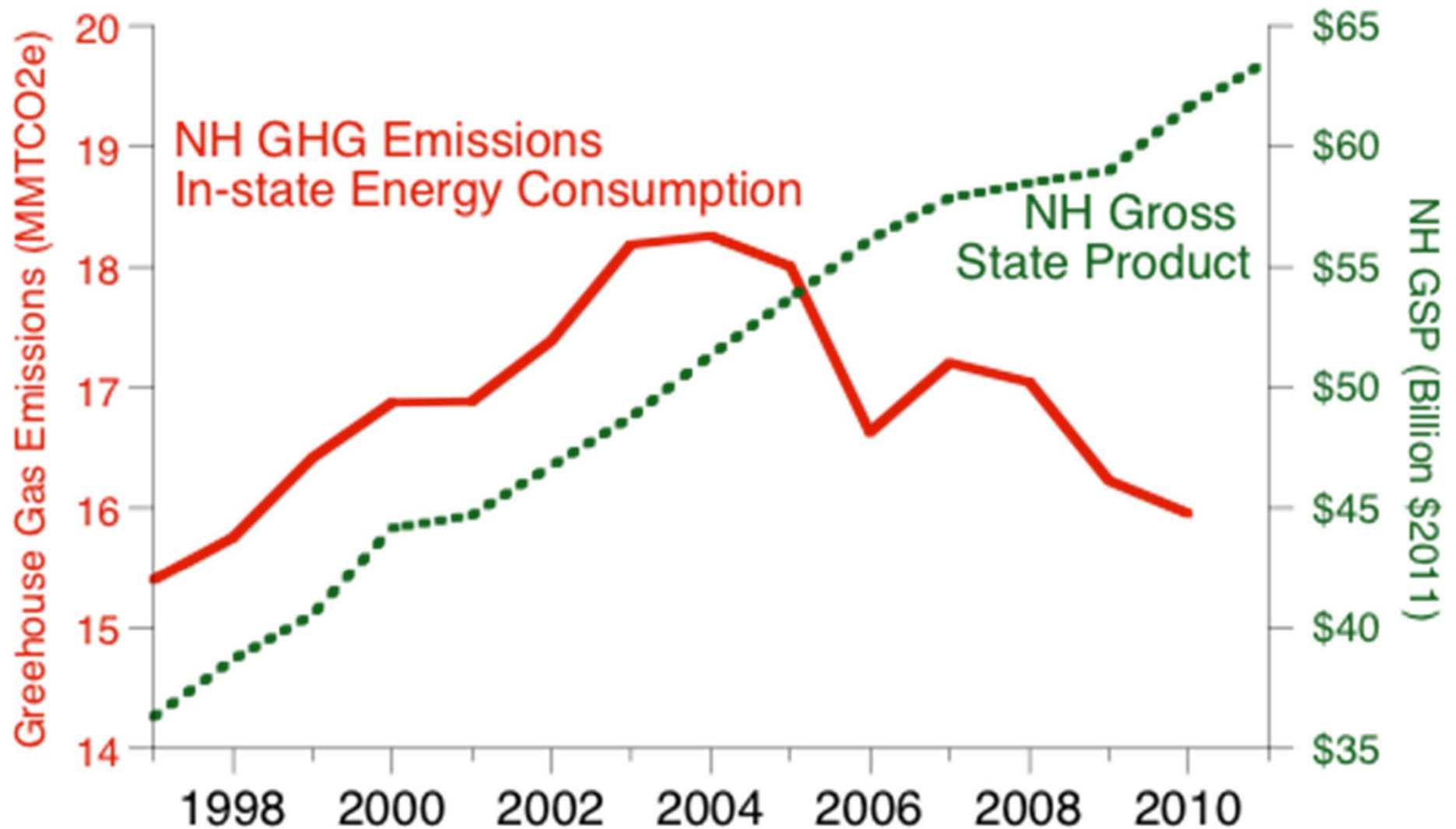
Overarching Strategies to Achieve Goals

1. Maximize energy efficiency in buildings & transportation
2. Increase renewable & low-emitting heat & electric power sources
3. Protect our natural resources to enhance the amount of carbon sequestration
4. Develop an integrated education, outreach and workforce training program
5. Develop plans to adapt to existing and potential climate change

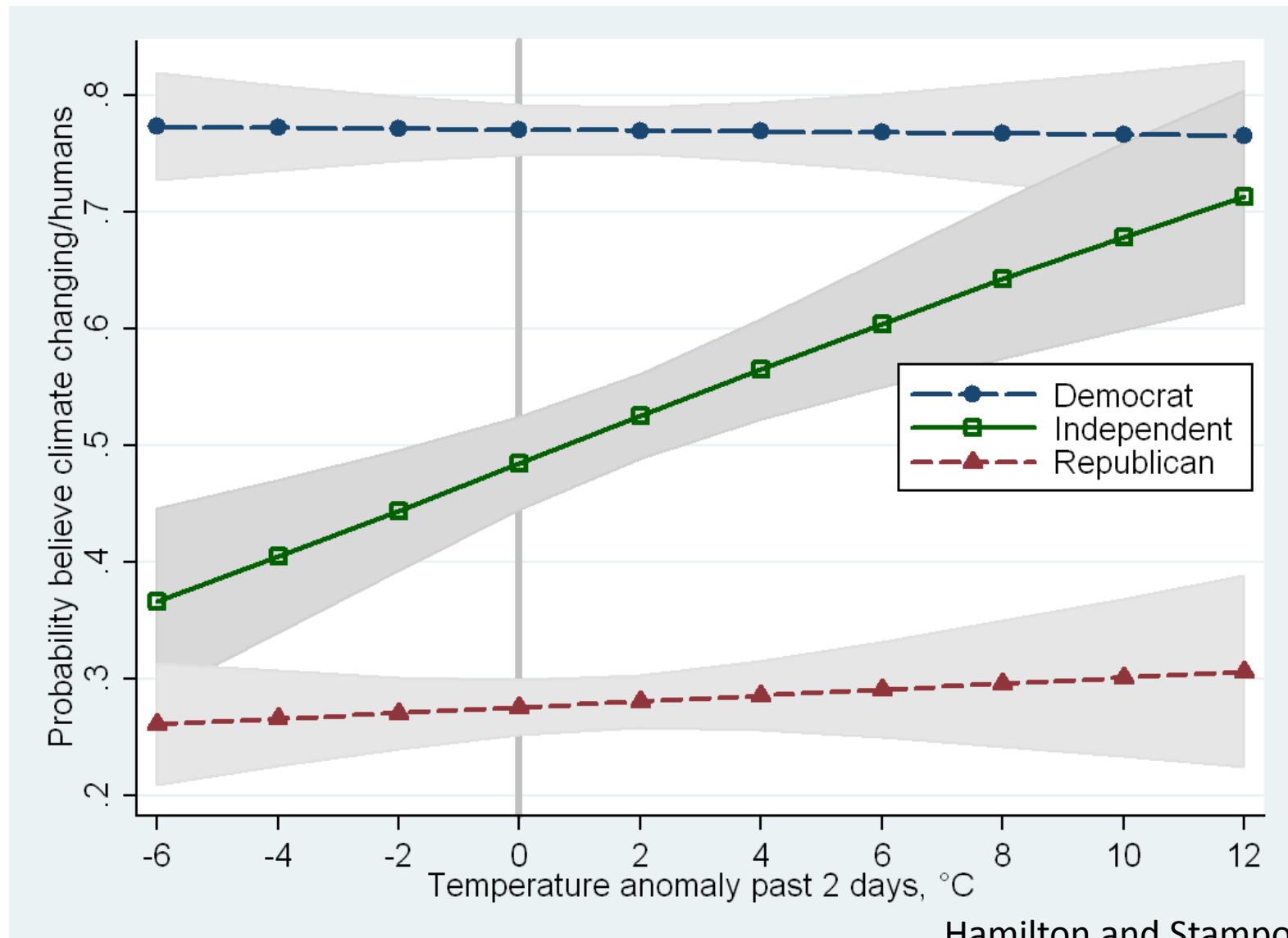
New Hampshire Economic Benefits vs Avoided CO2e Emissions in 2025



Gross State Product & Greenhouse Gas Emissions



Predicted probability of “climate change is happening now, caused mainly by human activities” response as a function of temperature and political party, adjusted for background variables.



Hamilton and Stampone, 2012





THE CHRISTIAN SCIENCE MONITOR

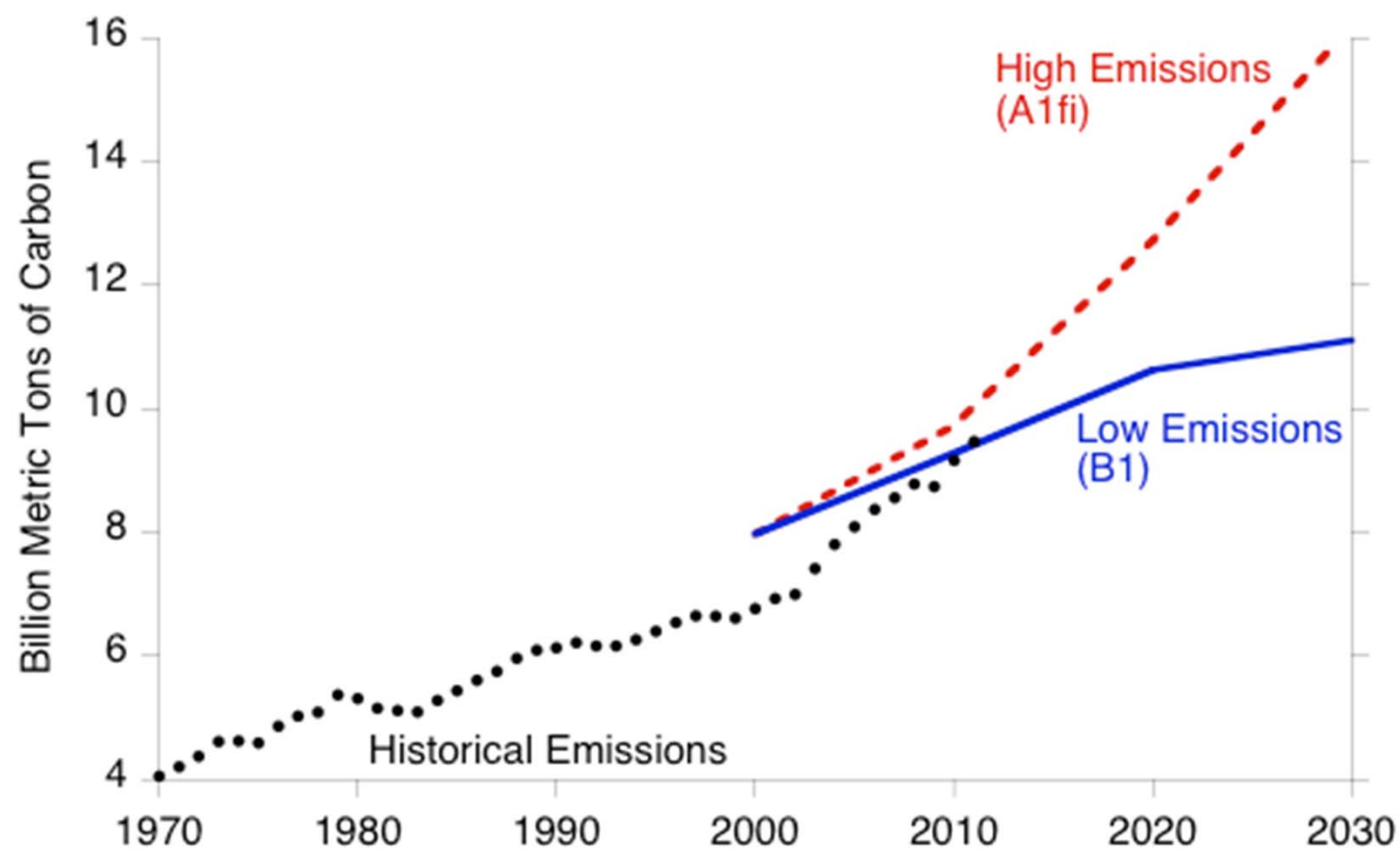


Figure 9

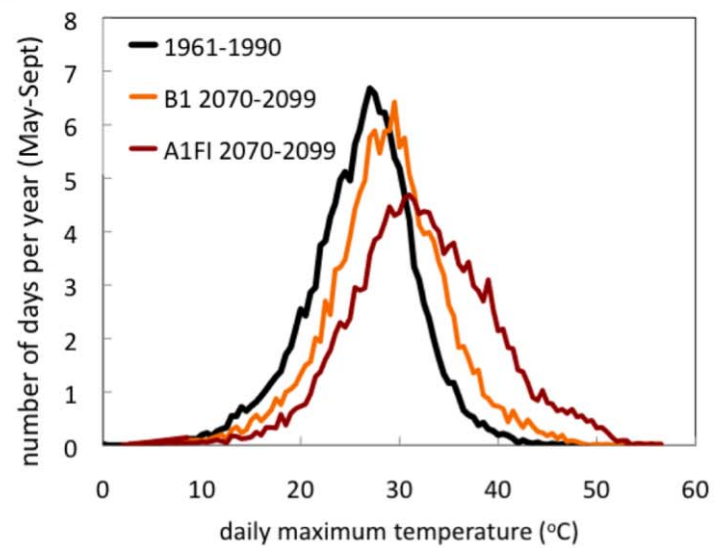
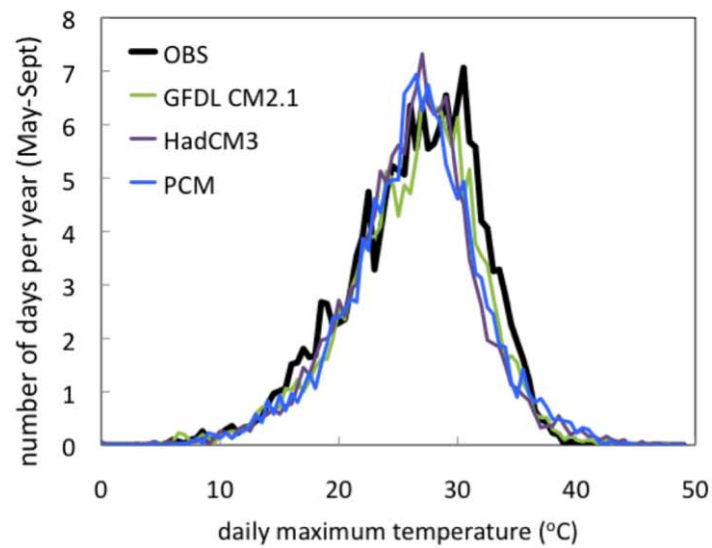


Figure 2.

Figure 10

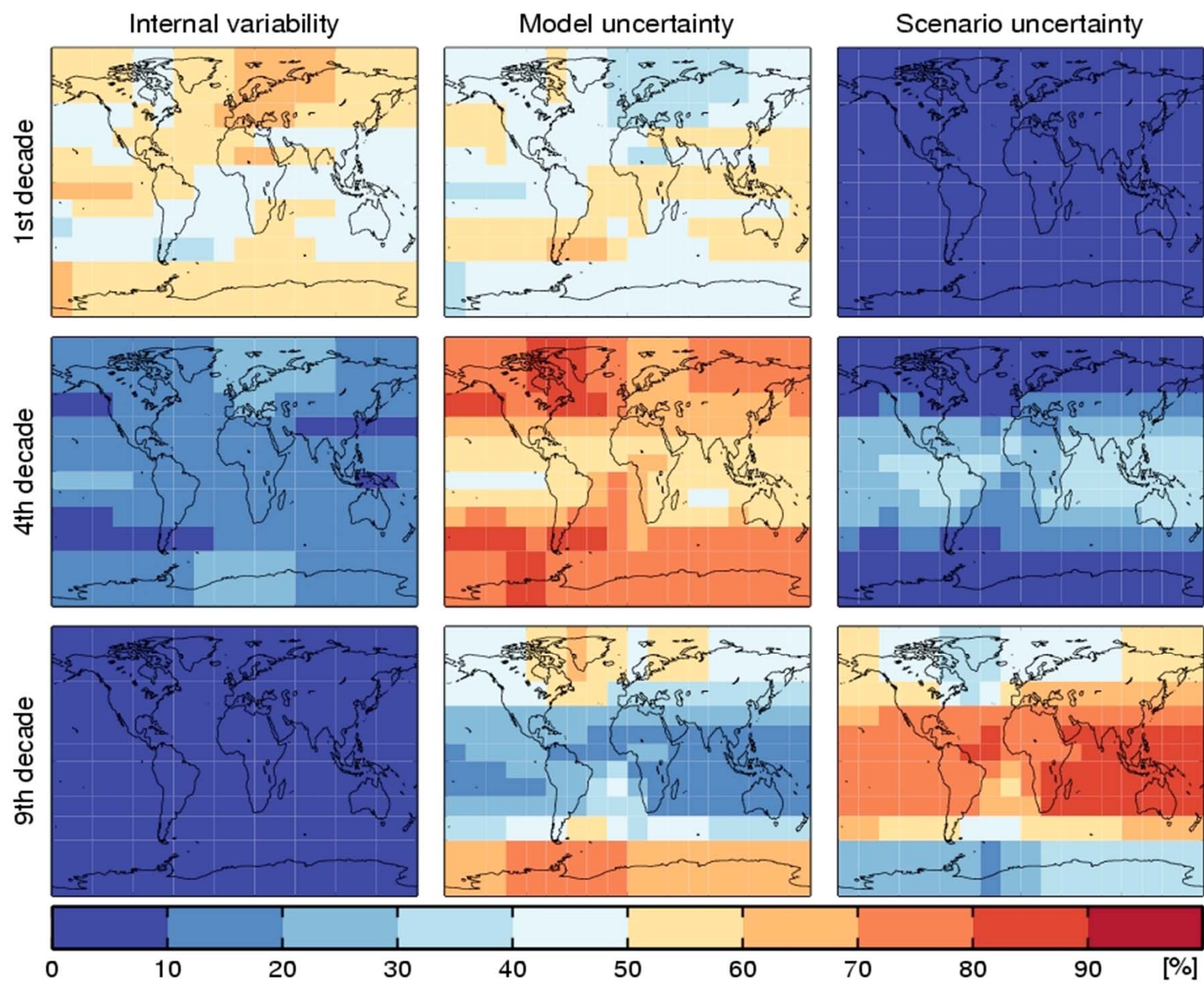
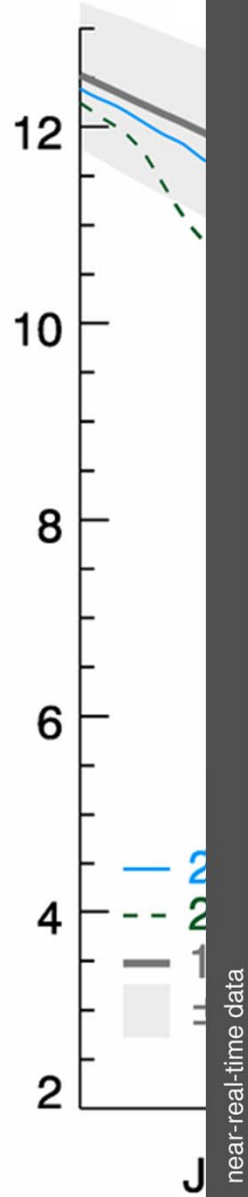
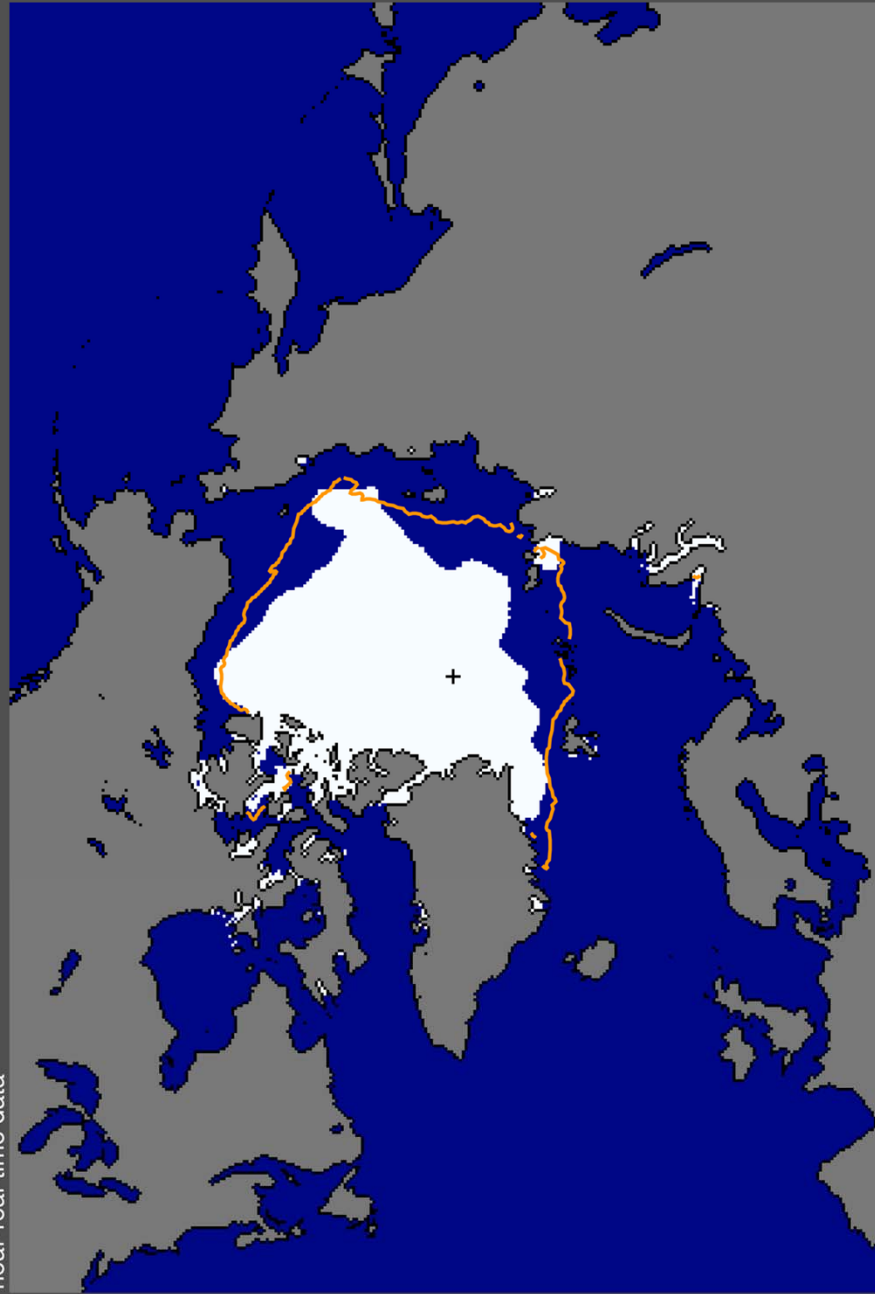


Figure 11

Extent (millions of square kilometers)



Sea Ice Extent
09/13/2013



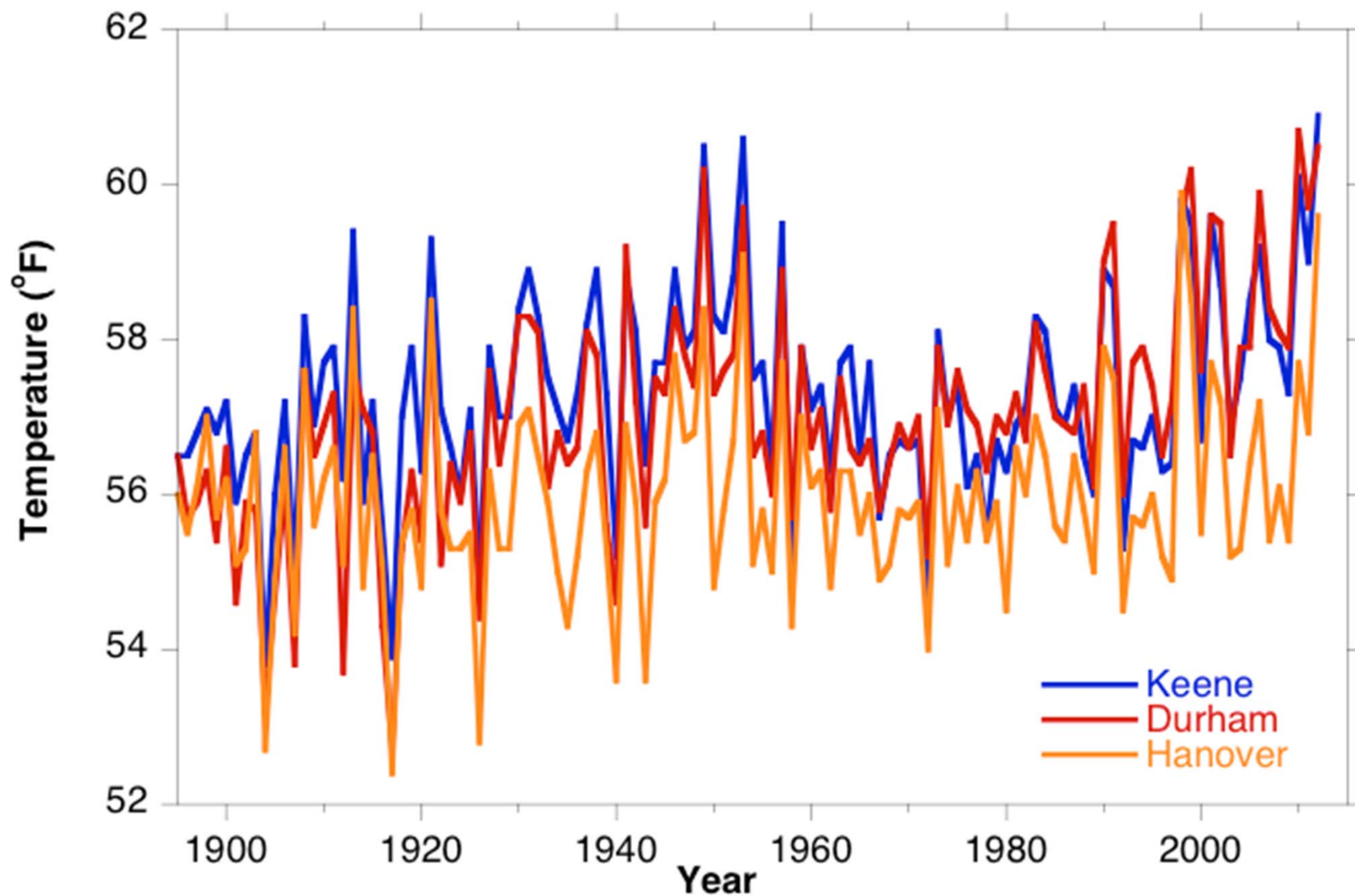
National Snow and Ice Data Center, Boulder, CO

median
1981–2010

Sep 2013

National Snow and Ice Data Center, Boulder CO

Annual TMAX 1895 - 2012



Snowfall & Snow Covered Days (SCD) 1970-2012

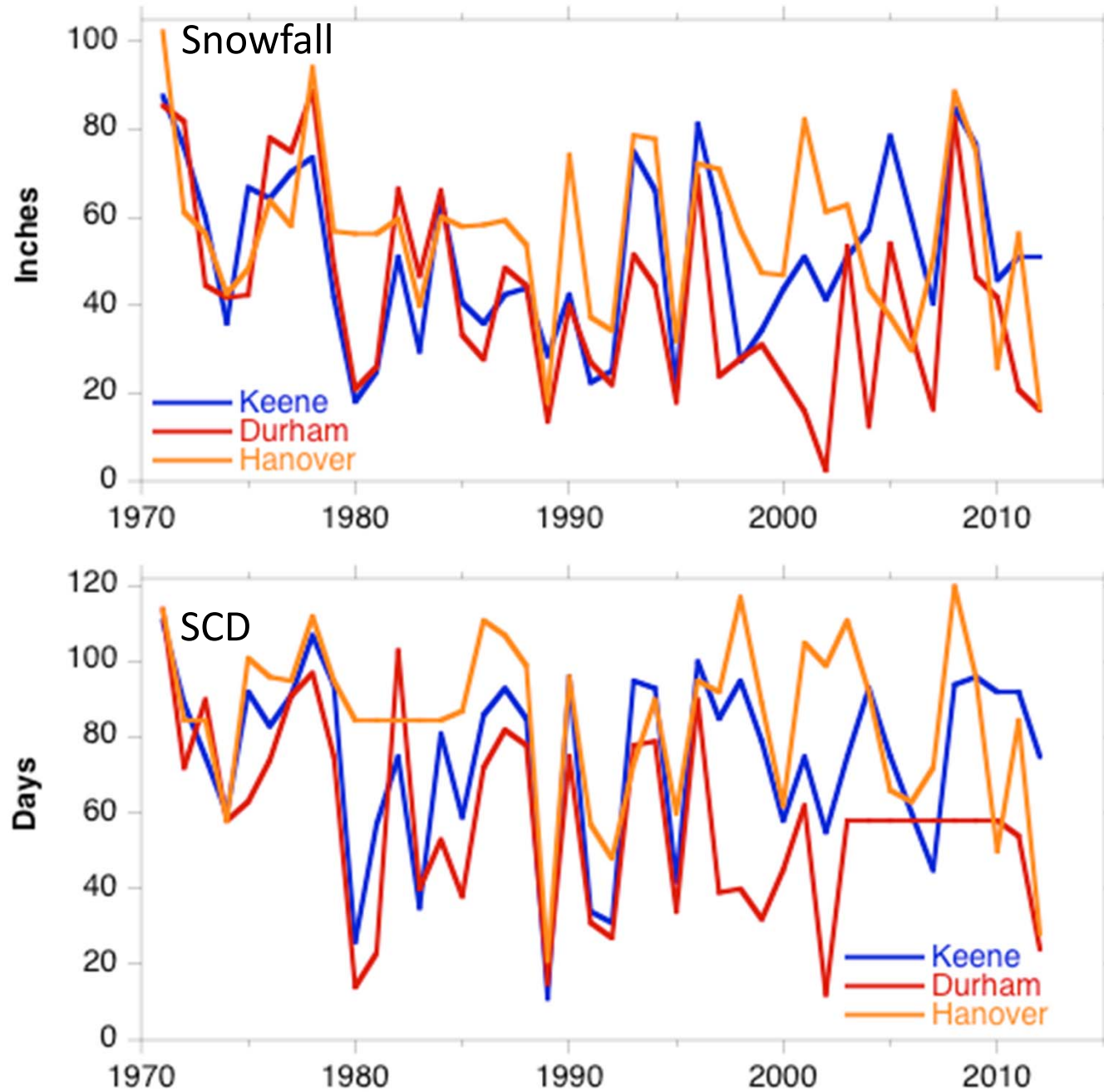


Figure 6

Trends

Parameter	Durham		Keene		Hanover	
	1895-2012	1970-2012	1895-2012	1970-2012	1895-2012	1970-2012
TMAX (°F per decade)						
Annual	<u>0.21</u>	<u>0.55</u>	<u>0.09</u>	<u>0.61</u>	0.05	0.25
Winter	<u>0.20</u>	<u>0.80</u>	0.10	<u>0.71</u>	0.08	0.37
Spring	<u>0.32</u>	<u>0.72</u>	0.10	0.58	<u>0.15</u>	0.29
Summer	<u>0.27</u>	<u>0.47</u>	<u>0.12</u>	0.35	0.08	-0.05
Fall	<u>0.11</u>	<u>0.48</u>	0.04	<u>0.68</u>	-0.05	<u>0.60</u>
TMIN (°F per decade)						
Annual	<u>0.20</u>	<u>0.58</u>	<u>0.50</u>	<u>0.82</u>	<u>0.25</u>	<u>0.74</u>
Winter	<u>0.28</u>	<u>0.93</u>	<u>0.58</u>	<u>1.70</u>	<u>0.36</u>	<u>1.45</u>
Spring	<u>0.18</u>	0.24	<u>0.45</u>	0.31	<u>0.23</u>	<u>0.60</u>
Summer	<u>0.25</u>	<u>0.71</u>	<u>0.49</u>	<u>0.47</u>	<u>0.27</u>	<u>0.60</u>
Fall	<u>0.14</u>	<u>0.83</u>	<u>0.50</u>	<u>1.11</u>	<u>0.22</u>	<u>0.61</u>
Precipitation (inches per decade)						
Annual	<u>0.56</u>	1.63	0.32	2.02	0.26	1.16
Winter	-0.03	-0.61	0.45	0.16	0.37	-0.11
Spring	0.08	0.20	0.21	0.14	0.20	0.22
Summer	0.14	<u>0.93</u>	0.31	0.57	0.27	0.55
Fall	<u>0.27</u>	0.26	0.32	1.12	0.24	0.19
Snowfall	NA	<u>-9.14</u>	NA	0.34	NA	-3.44
Snow Covered Days (days per decade)						
Winter	NA	<u>-6.6</u>	NA	0.0	NA	-2.9

An Asynchronous Regional Regression Model for Statistical Downscaling of Daily Climate Variables

Stoner, Hayhoe, Yang and Wuebbles (2012) International Journal of Climatology

