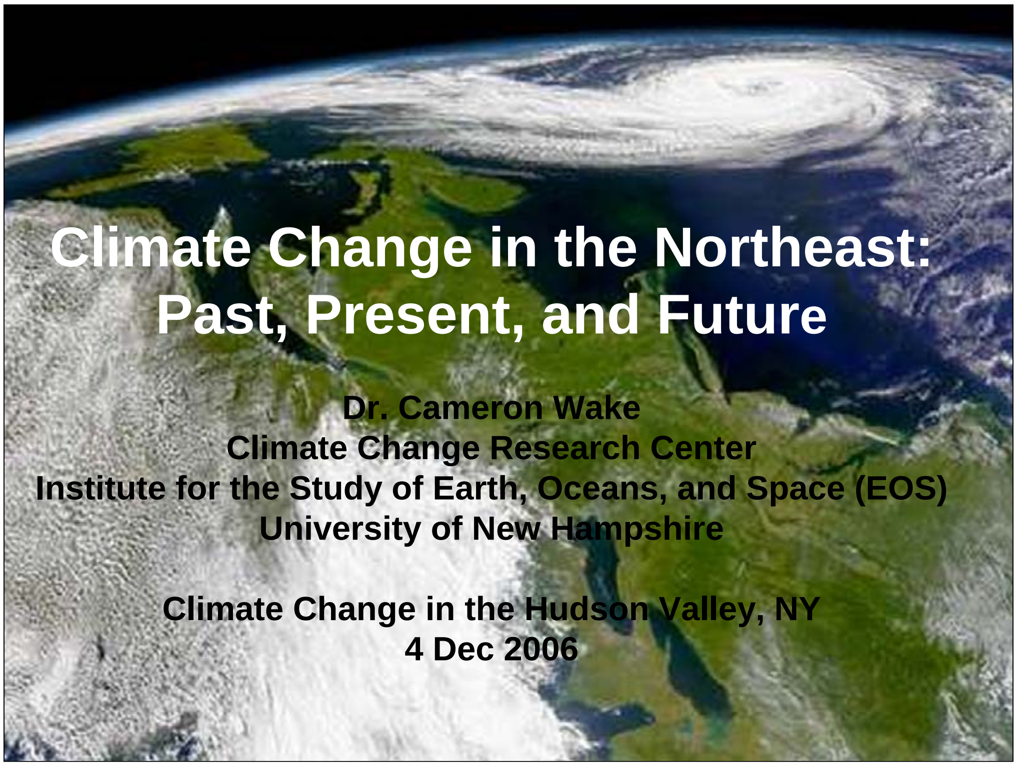
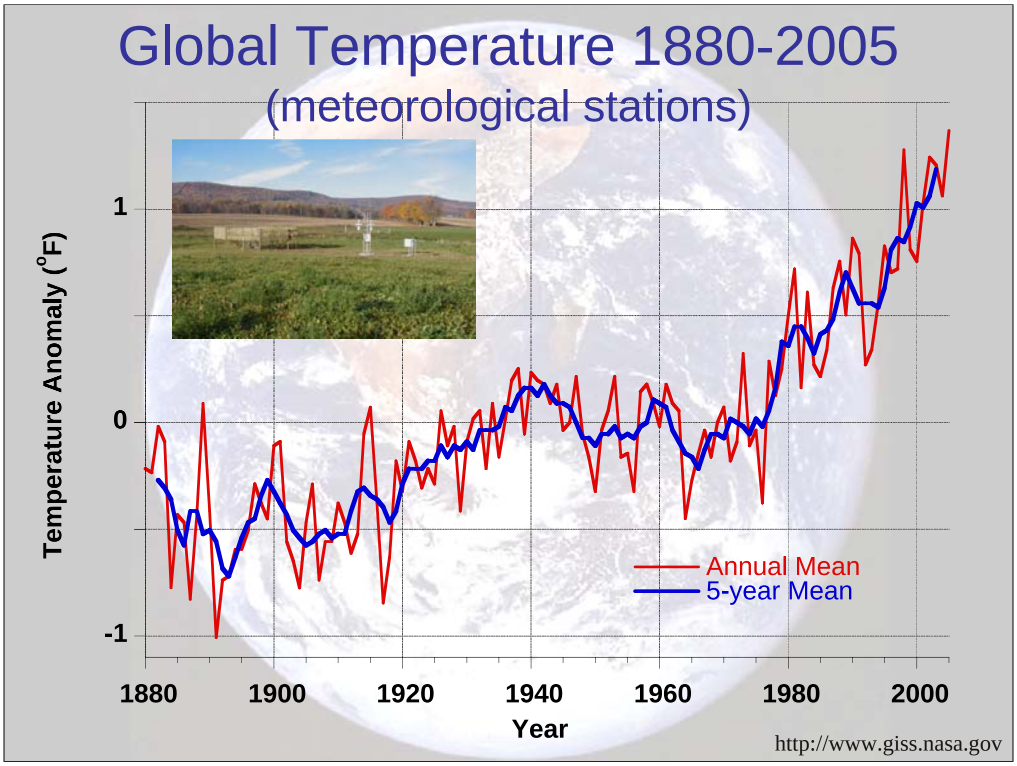


Climate Change in the Northeast: Past, Present, and Future

Dr. Cameron Wake
Climate Change Research Center
Institute for the Study of Earth, Oceans, and Space (EOS)
University of New Hampshire

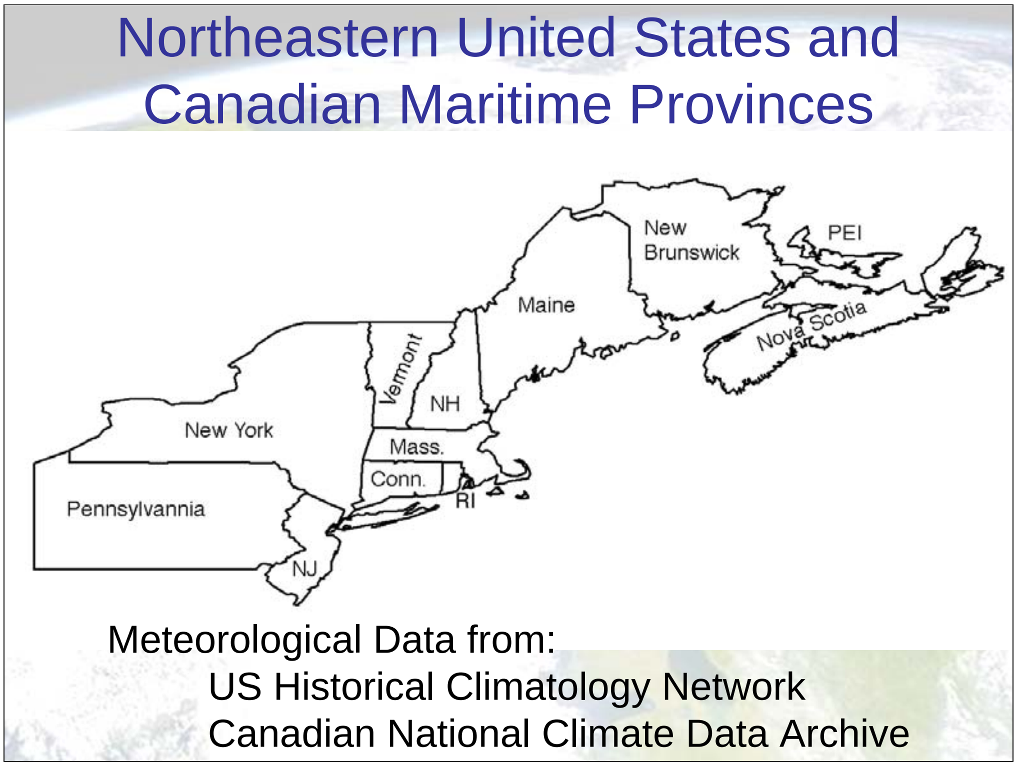
Climate Change in the Hudson Valley, NY
4 Dec 2006



Global Temperature 1880-2005

(meteorological stations)

http://www.giss.nasa.gov



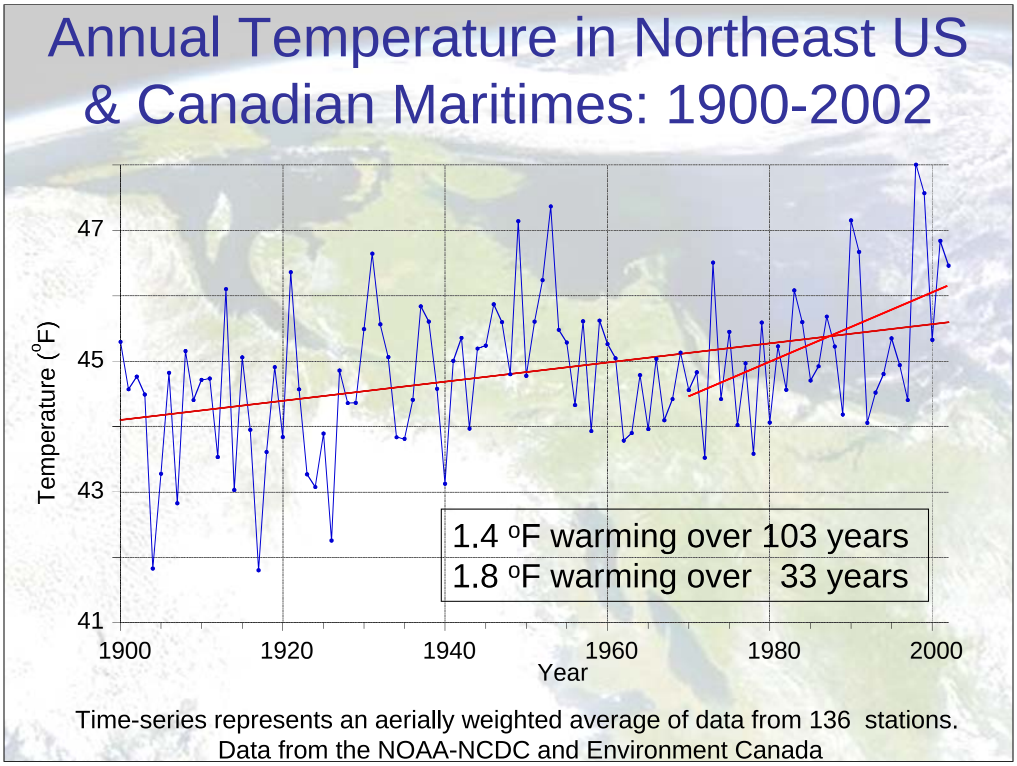
Northeastern United States and Canadian Maritime Provinces

Meteorological Data from:
US Historical Climatology Network
Canadian National Climate Data Archive

The average annual temperature for the Northeast (which we define as the six new England states, New York State, and New Jersey) was calculated by first averaging all of the annual temperature records in each climate division in each state. More information on climate divisions is available online at: http://www.cdc.noaa.gov/USclimate/map.html. The we calculated the regional average by areally weighting the temperature record from each climate division.

The record extends from 1899 to 2000.

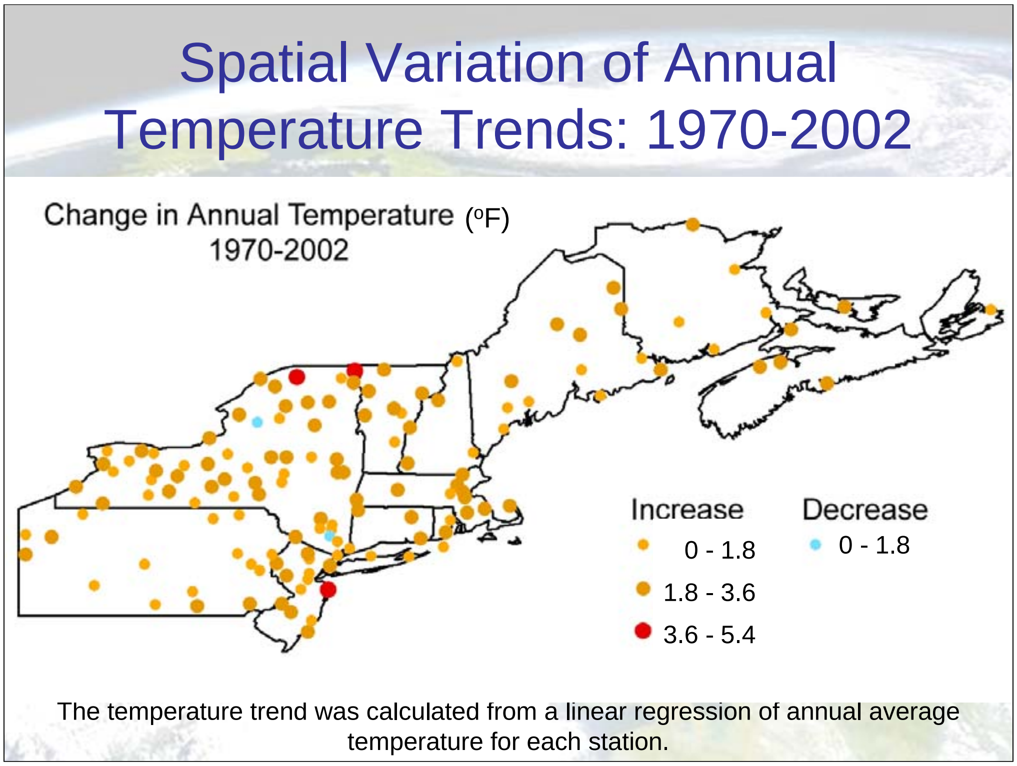
The first think to note on the graph of temperature is the significant year-to-year variability. On longer time scales (decades) there is a trend in temperature in New England that is similar to what has been observed for the entire globe. Warming from 1900 to about mid-century, then a slight cooling to about 1970, followed by a distinct warming over the last 30 years. Overall, the warming trend 1.8 ^{o}F over the last 100 years (0.18 ^{o}F per decade). Over the last 30 year, the northeast has warmed 1.4 degrees F (a rate of almost 0.5 ^{o}F per decade).



Annual Temperature in Northeast US & Canadian Maritimes: 1900-2002

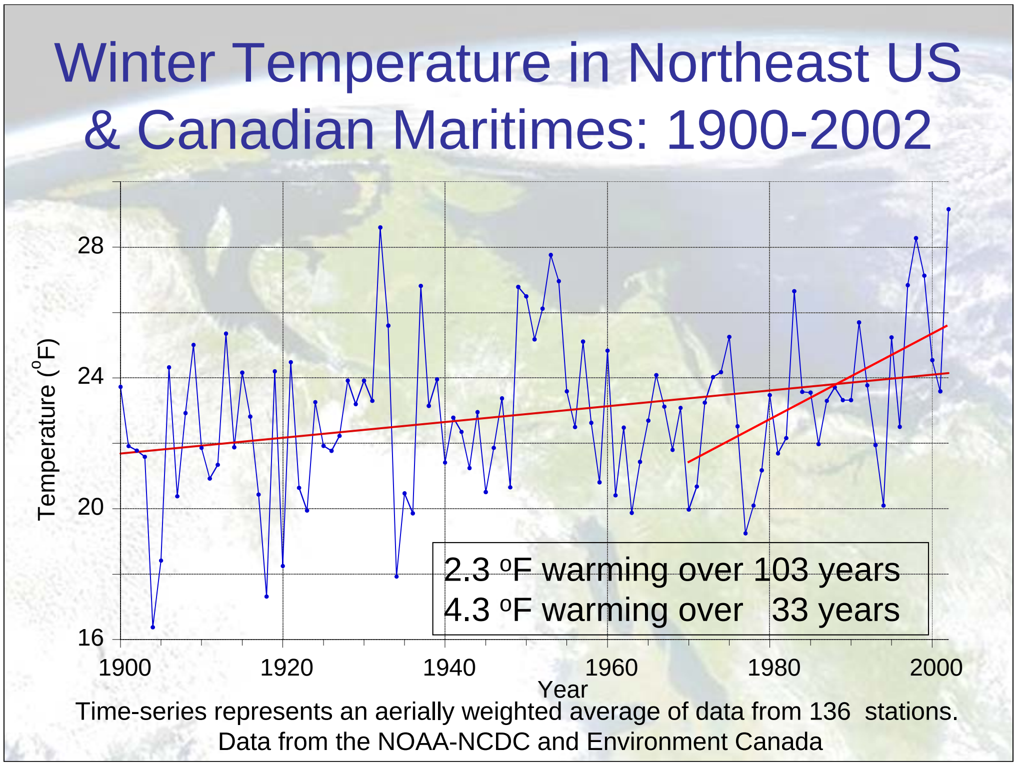
1.4 ^{o}F warming over 103 years
1.8 ^{o}F warming over 33 years

Time-series represents an aerially weighted average of data from 136 stations.
Data from the NOAA-NCDC and Environment Canada



Spatial Variation of Annual Temperature Trends: 1970-2002

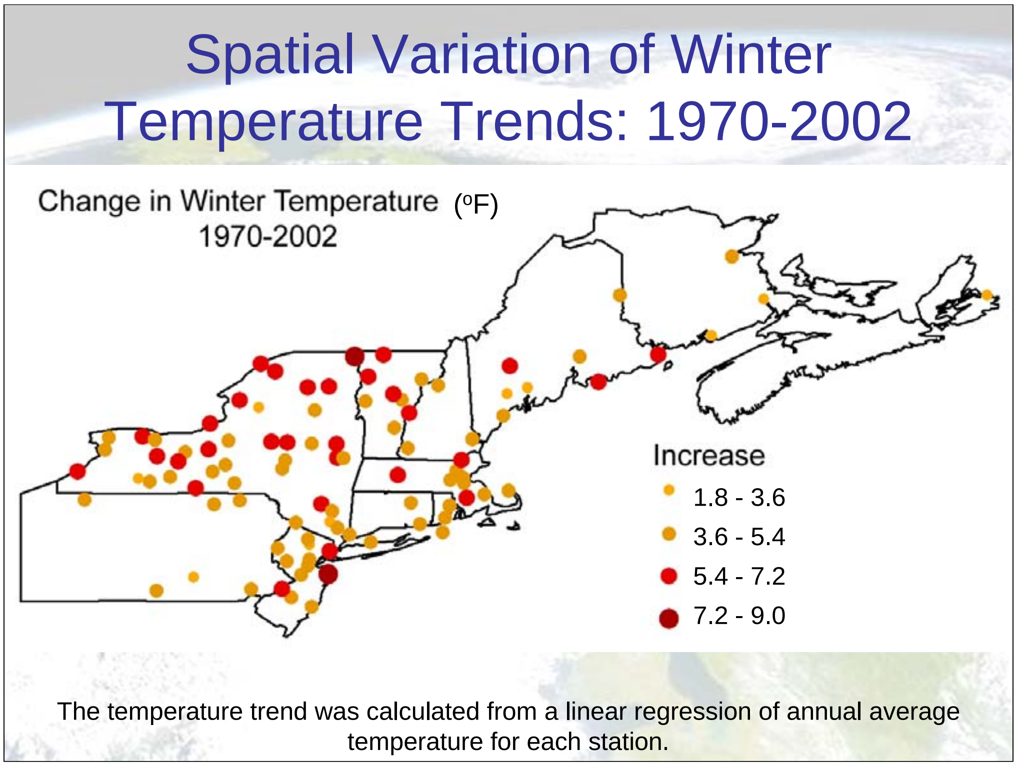
The temperature trend was calculated from a linear regression of annual average temperature for each station.



Winter Temperature in Northeast US & Canadian Maritimes: 1900-2002

2.3 ^{o}F warming over 103 years
4.3 ^{o}F warming over 33 years

Time-series represents an aerially weighted average of data from 136 stations.
Data from the NOAA-NCDC and Environment Canada

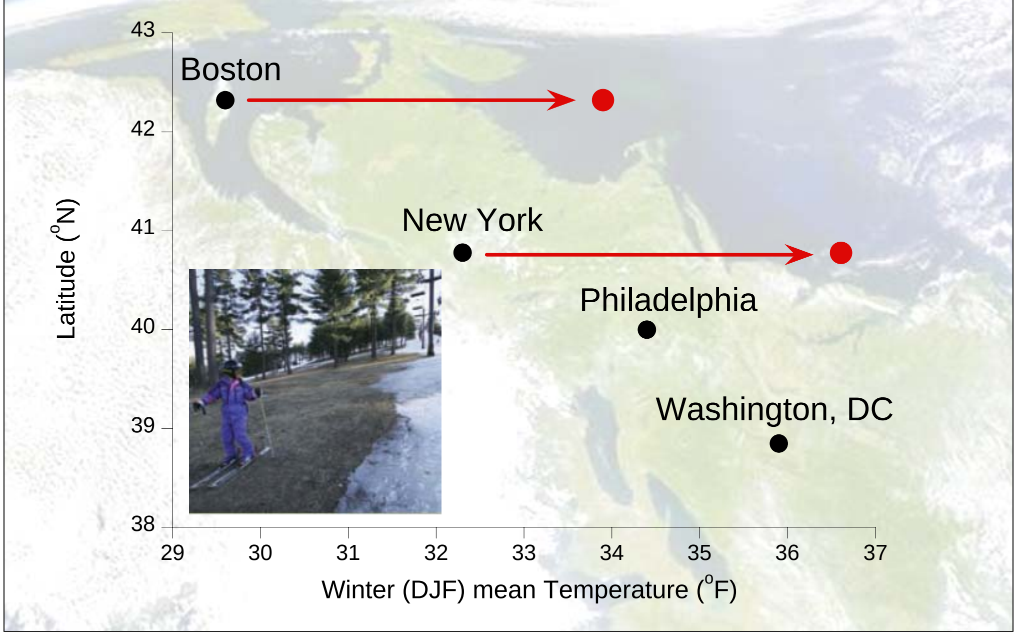


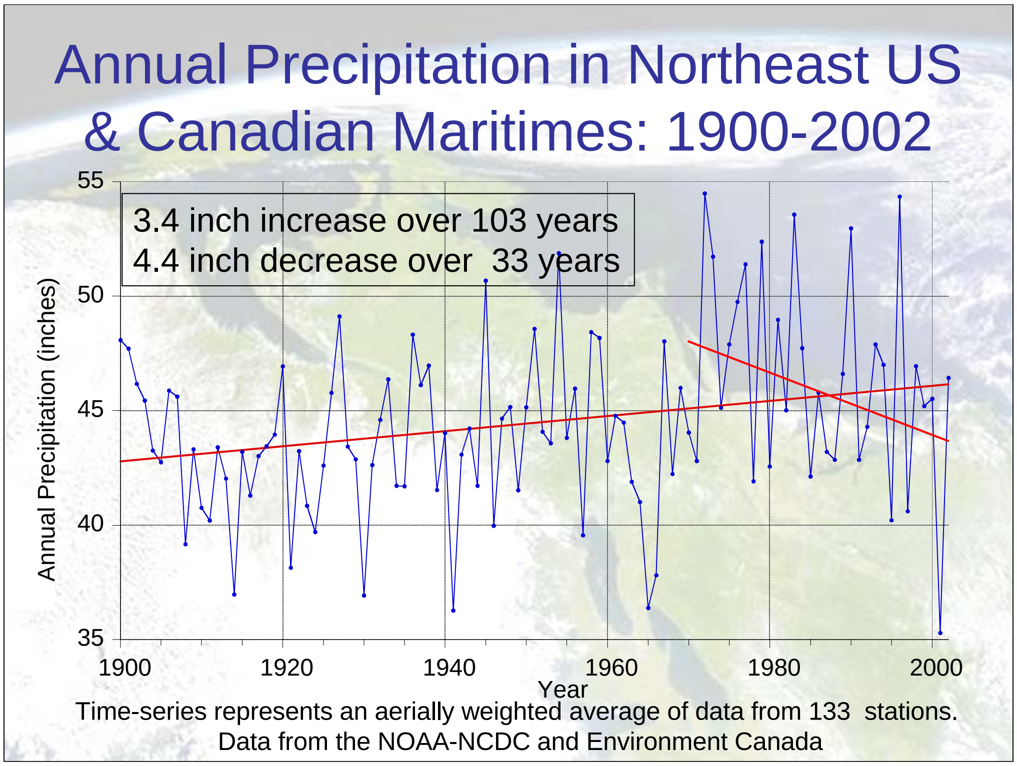
Spatial Variation of Winter Temperature Trends: 1970-2002

The temperature trend was calculated from a linear regression of annual average temperature for each station.

Winter time temperature increases are more uniform than annual temperature increases. The entire region is experiencing significant winter warming.

4.3°F Winter Temperature Increase

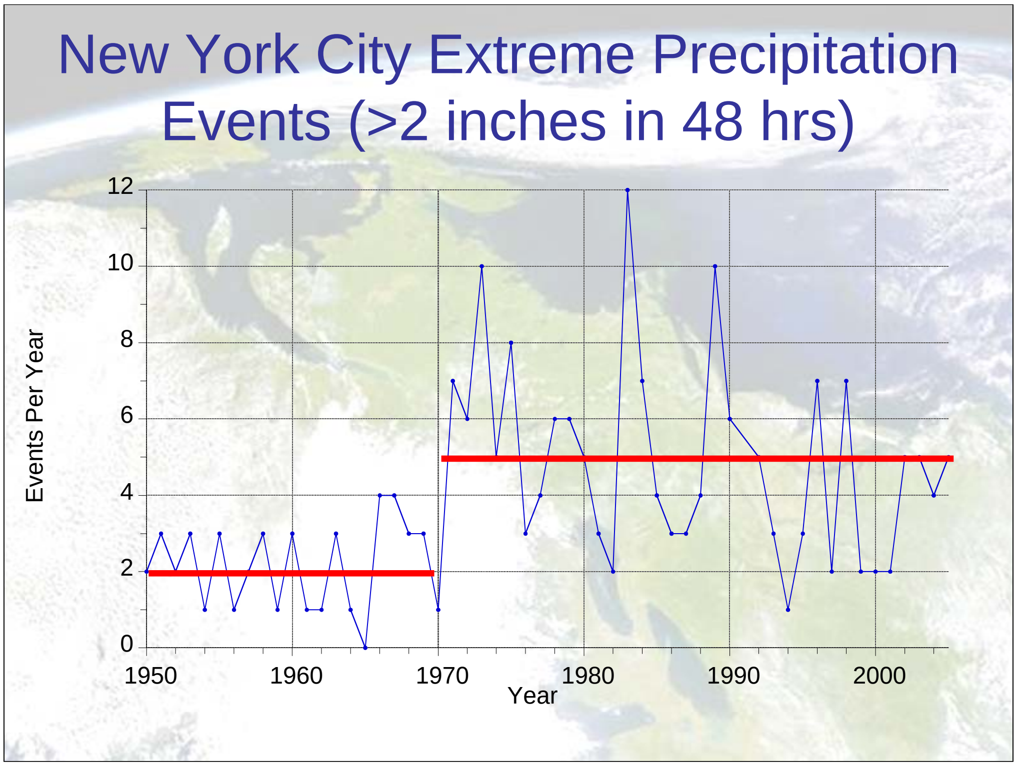




Annual Precipitation in Northeast US & Canadian Maritimes: 1900-2002

3.4 inch increase over 103 years
4.4 inch decrease over 33 years

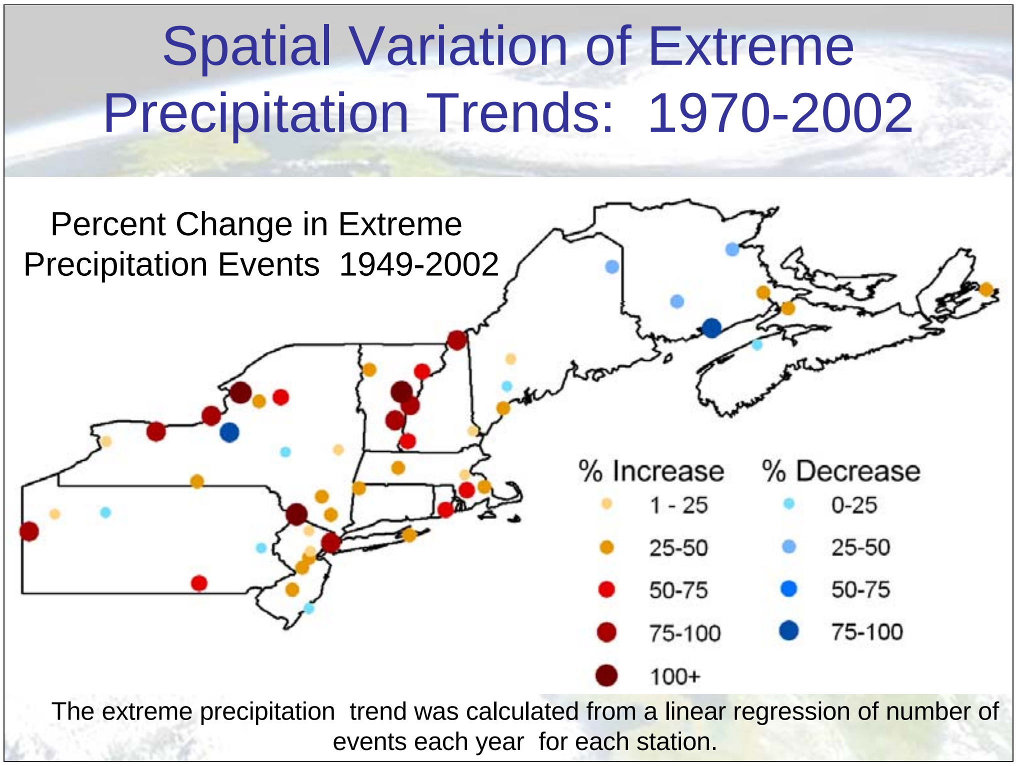
Time-series represents an aerially weighted average of data from 133 stations.
Data from the NOAA-NCDC and Environment Canada



New York City Extreme Precipitation Events (>2 inches in 48 hrs)

1950 to 1970 average 2 events per year

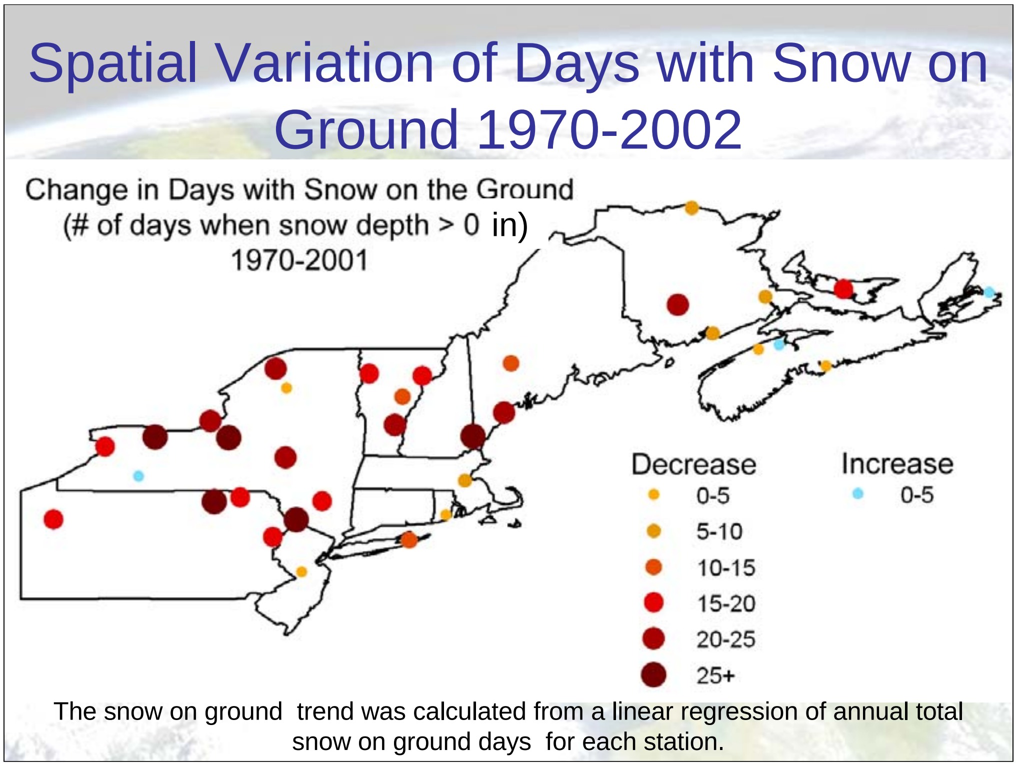
1971 to 2005 average 5 events per year



Spatial Variation of Extreme Precipitation Trends: 1970-2002

Percent Change in Extreme Precipitation Events 1949-2002

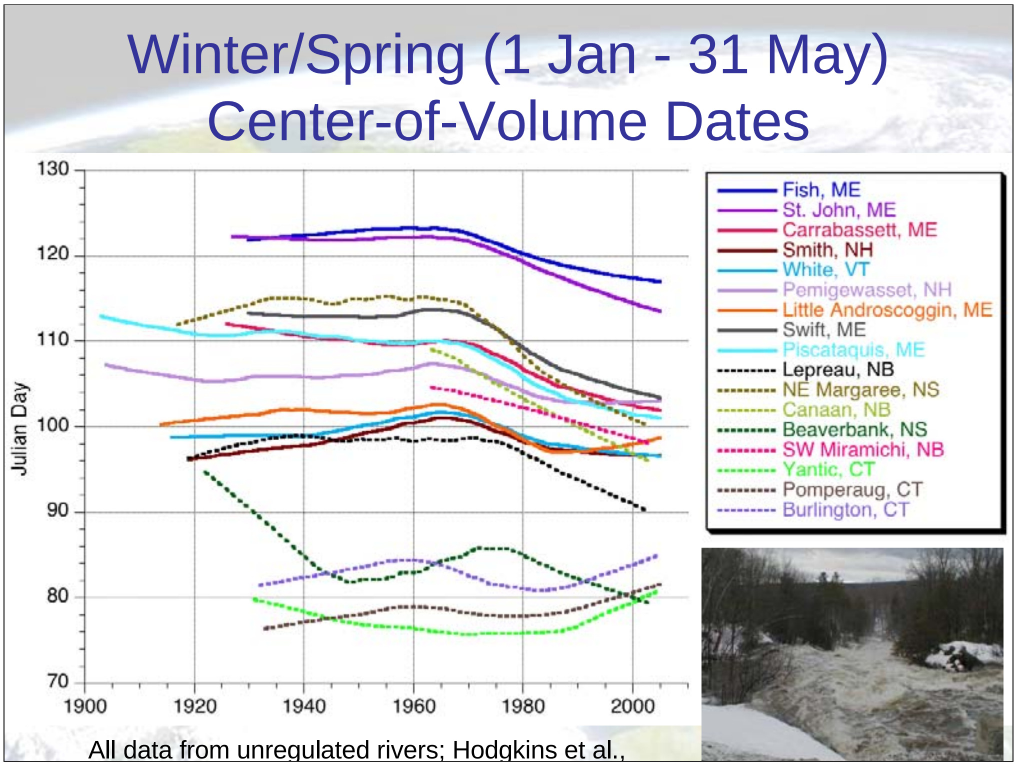
The extreme precipitation trend was calculated from a linear regression of number of events each year for each station.



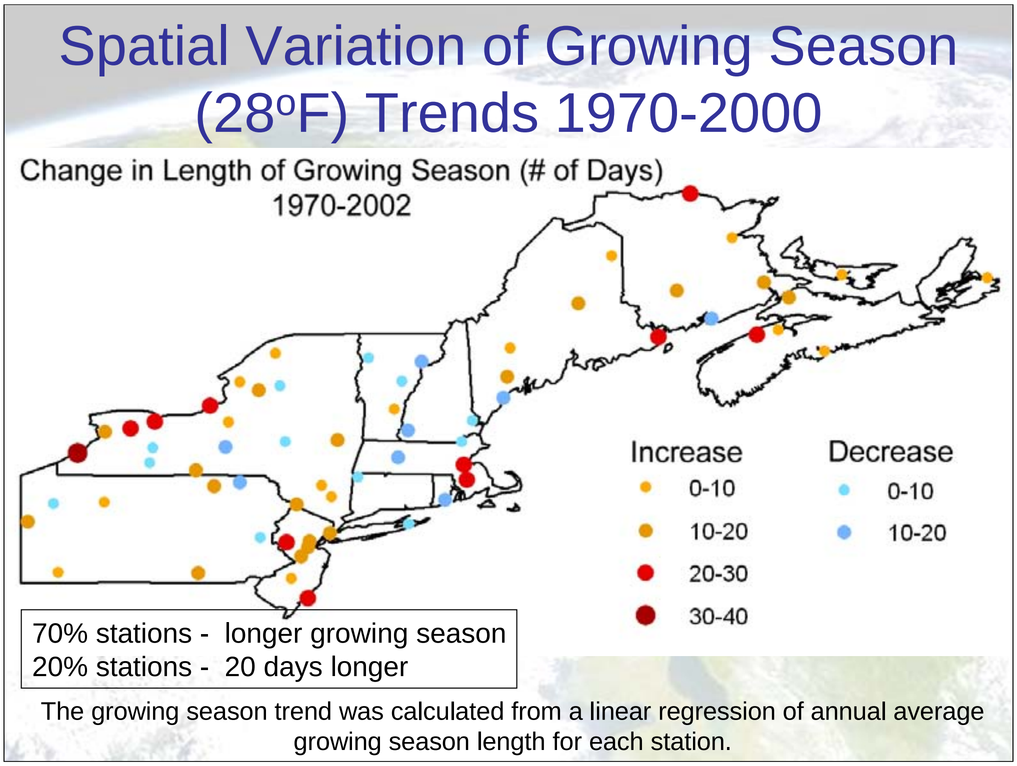
Spatial Variation of Days with Snow on Ground 1970-2002

The snow on ground trend was calculated from a linear regression of annual total snow on ground days for each station.

Winter/Spring (1 Jan - 31 May) Center-of-Volume Dates



All data from unregulated rivers; Hodgkins et al.,



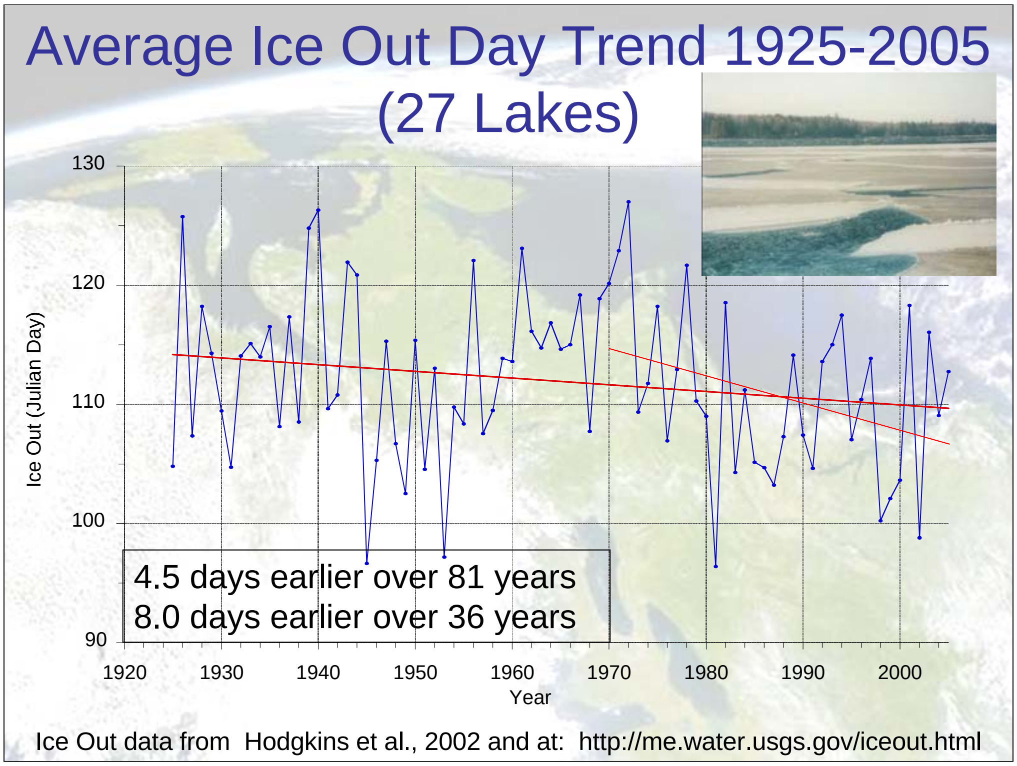
Spatial Variation of Growing Season (28^{o}F) Trends 1970-2000

70% stations - longer growing season
20% stations - 20 days longer

The growing season trend was calculated from a linear regression of annual average growing season length for each station.

70% (49 stations) show longer growing season; 20% (12 stations) more than 20 days longer

30 % (20 stations) show a decrease in growing season; 12 stations less than 10 days longer



Average Ice Out Day Trend 1925-2005 (27 Lakes)

4.5 days earlier over 81 years
8.0 days earlier over 36 years

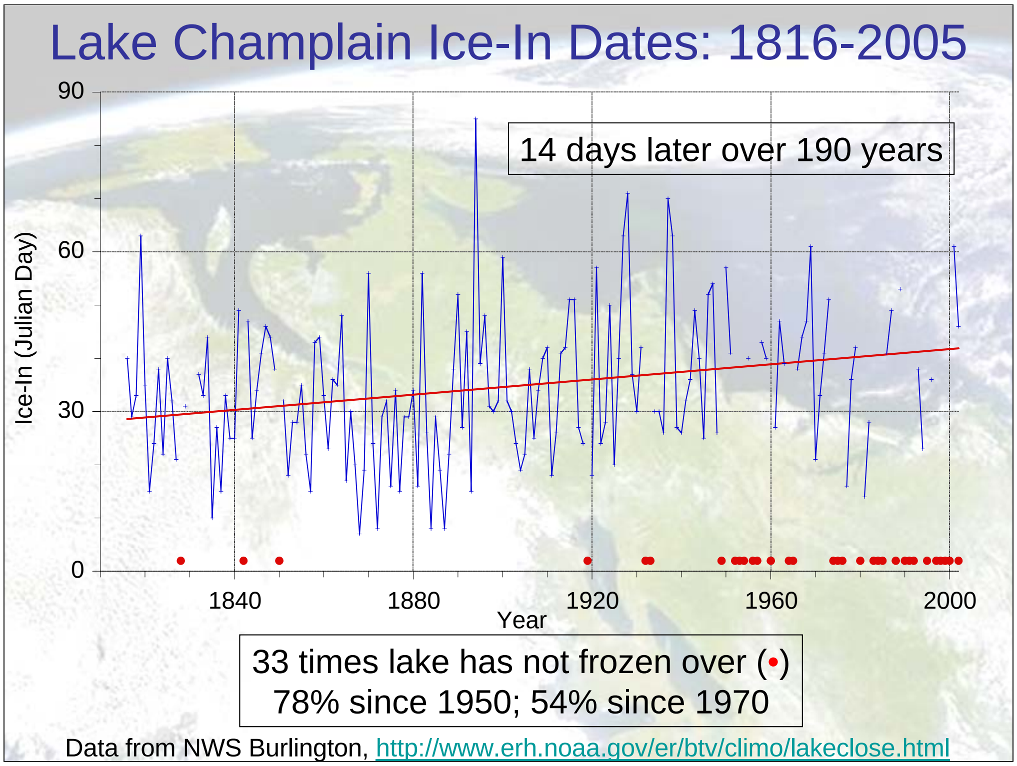
Ice Out data from Hodgkins et al., 2002 and at: http://me.water.usgs.gov/iceout.html

Ice out days have been collected by scientists at the USGS in Maine for the northern parts of New England. The criteria used for ice out changes from lake to lake, depending on the observer and the purpose for collecgin the record. For exampl, on Lake Winepasauke in NH, the ice out date is defined as the day the passenger boat the *Mt. Washington* can get into all of the harbors on the lake. Other records are defined by when a boat can be rowed across a particular section of a lake. So wile the criteria are different among lakes, for the purpose of the longer term records that have been collected, the criteria for each particular lake has remained the same.

The data shows over the past 75 years that ice out dates on lakes occur about 6 days earlier, while over the last 30 years the ice out dates occur 13 days earlier.

REFERENCE:

Hodgkins, Glenn A., Ivan C. James II, and Thomas G. Huntington, 2002: Historical changes in lake ice-out dates as indicators of climate change in New England, 1850-2000. *Int. J. Climatol.*, 22 (15), 1819-1827.



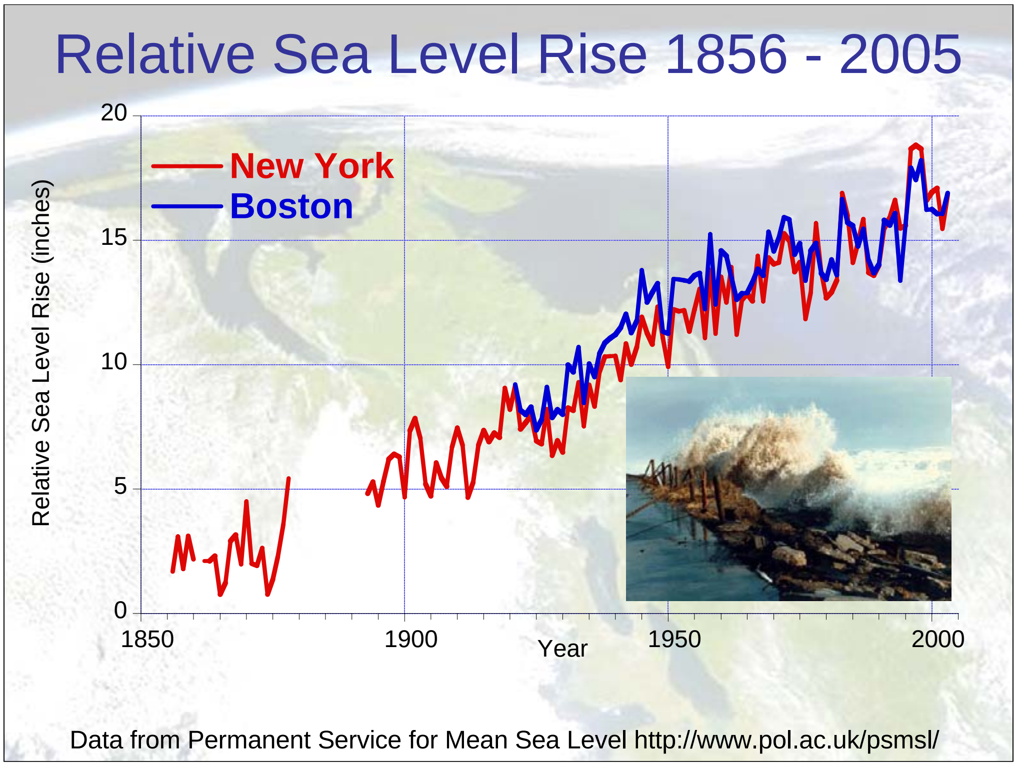
Lake Champlain Ice-In Dates: 1816-2005

14 days later over 190 years

33 times lake has not frozen over (●)
78% since 1950; 54% since 1970

Data from NWS Burlington, http://www.erh.noaa.gov/er/btv/climo/lakeclose.html

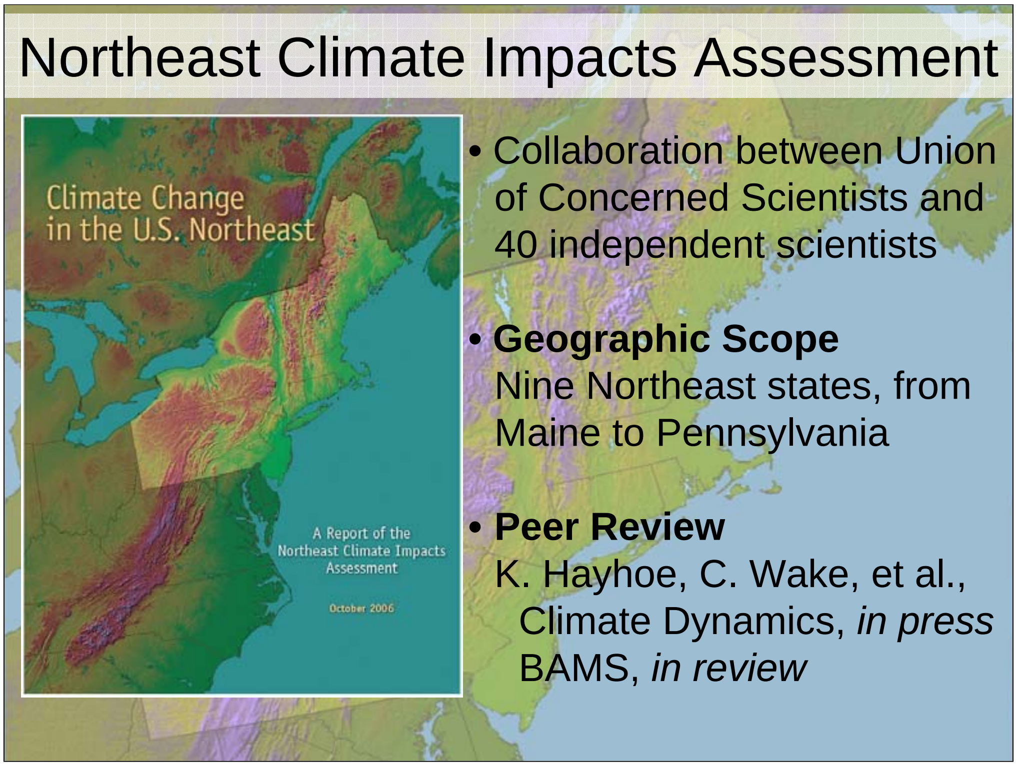
A particularly interesting lake ice record comes from Lake Champlain where they record the ice in date. This is of obvious importance to the ice fisherman in the region. Over the past 180 years, the ice in date has - on average - occurred 11 days later. Of more significance is the fact that the ice has not frozen in the area of observation in 16 of the past 30 years (marked by the red diamonds on the bottom of the graph). This represents a key “threshold response” of the climate system. While the warming has bee gradual, we have apparently moved into a mode where the lake does not freeze more often than not.



Relative Sea Level Rise 1856 - 2005

Data from Permanent Service for Mean Sea Level http://www.pol.ac.uk/psmsl/

Relative sea level rise measure in Boston and New York measured with tidal gauges. Sea level has risen about 15 inches over the last 150 years. This is a result of both increasing volume of ocean water (due to the fact the water is getting warmer and therefore occupies more volume, and because glaciers around the world are melting, contributing more water to the ocean) and because the New England coast continues to subside in response to the retreat of the large ice sheet that was here 18,000 years ago.



Northeast Climate Impacts Assessment

Climate Change
in the U.S. Northeast

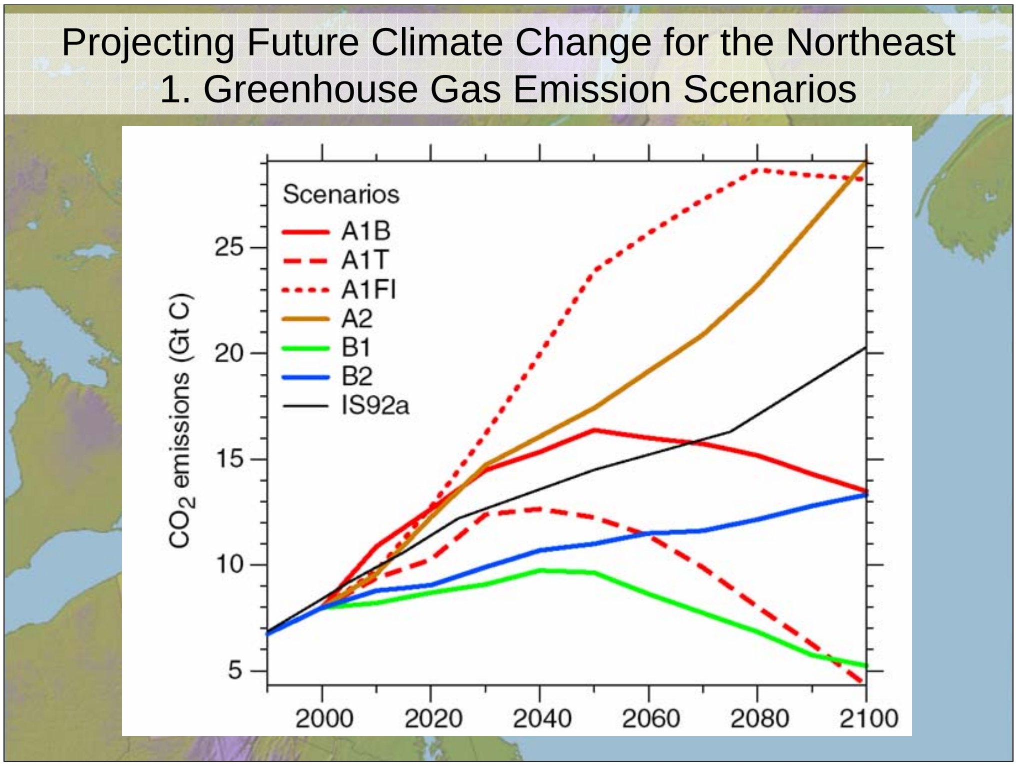
A Report of the
Northeast Climate Impacts
Assessment

October 2006

- Collaboration between Union of Concerned Scientists and 40 independent scientists

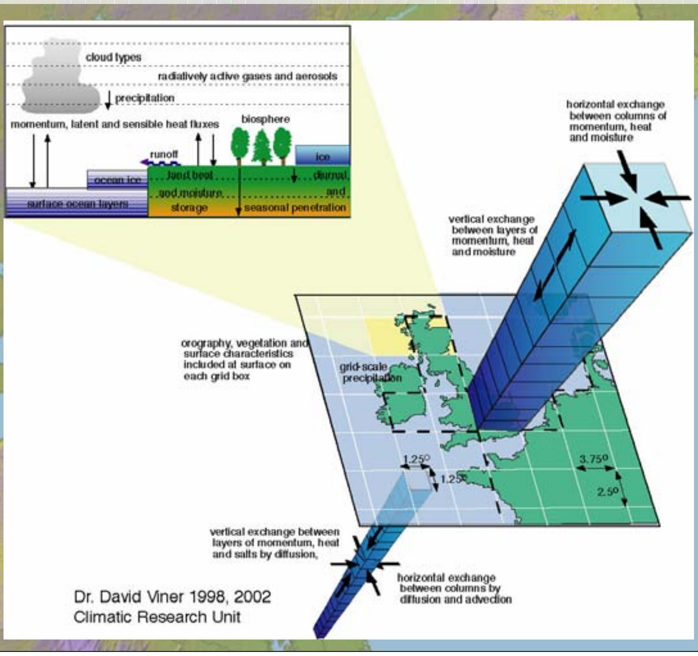
- **Geographic Scope**
  Nine Northeast states, from Maine to Pennsylvania

- **Peer Review**
  K. Hayhoe, C. Wake, et al.,
    Climate Dynamics, *in press*
    BAMS, *in review*

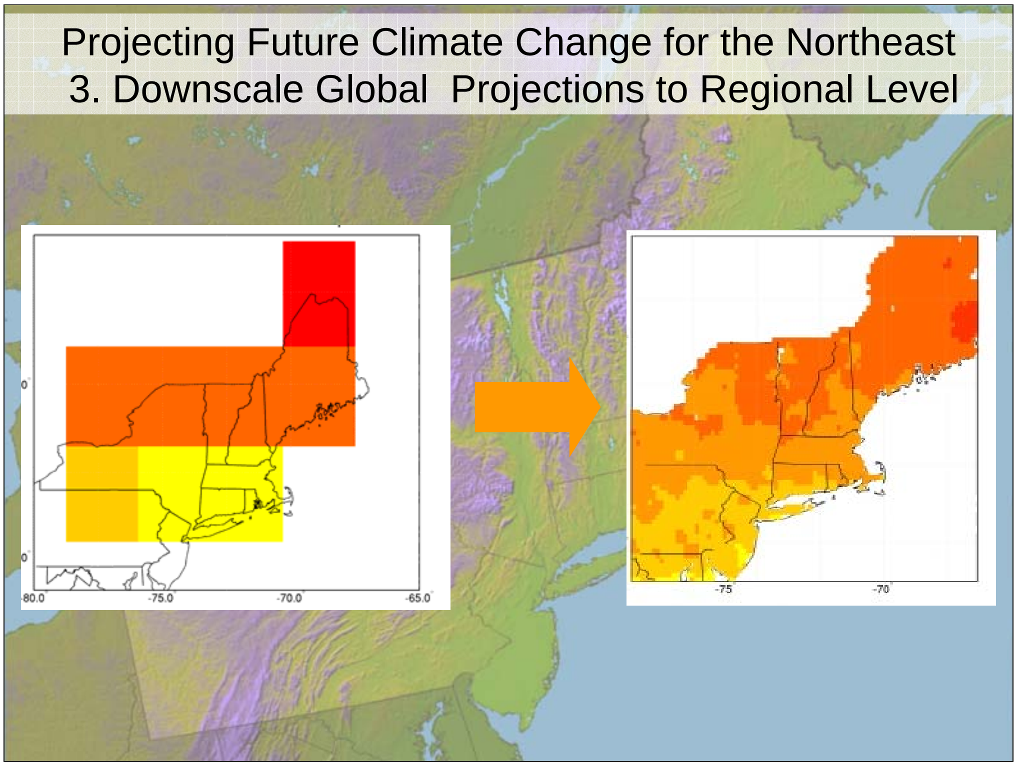


Projecting Future Climate Change for the Northeast
1. Greenhouse Gas Emission Scenarios

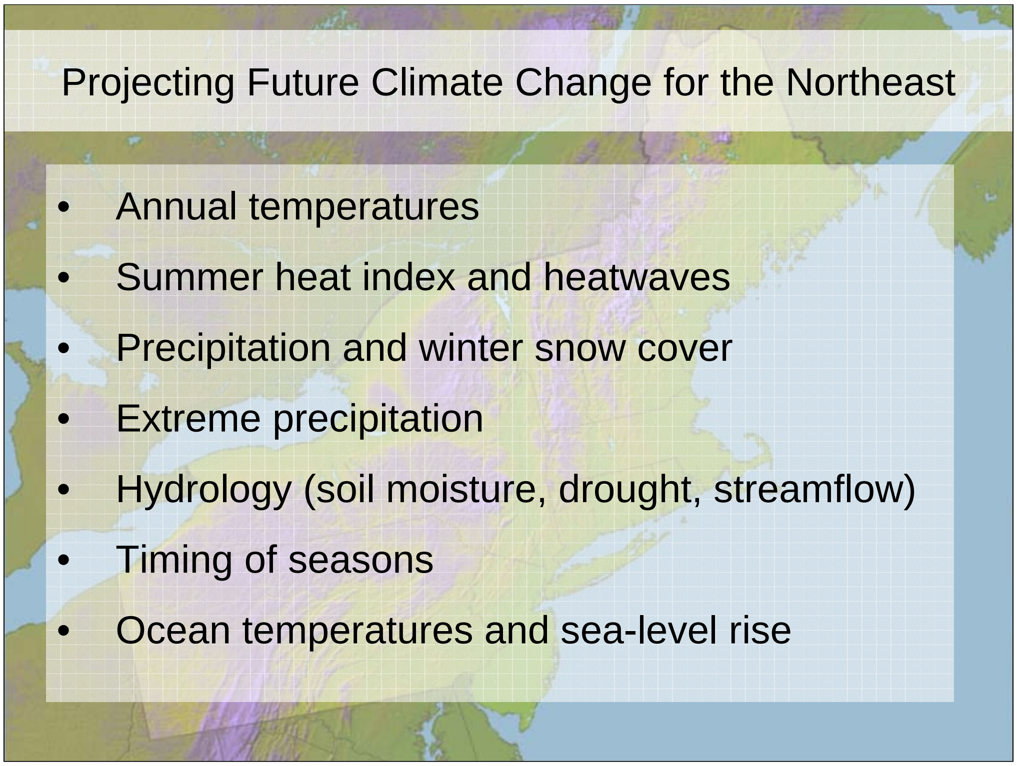
Projecting Future Climate Change for the Northeast
2. Use Scenarios as Input to Global Circulation Models



Dr. David Viner 1998, 2002
Climatic Research Unit



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



Projecting Future Climate Change for the Northeast

- Annual temperatures
- Summer heat index and heatwaves
- Precipitation and winter snow cover
- Extreme precipitation
- Hydrology (soil moisture, drought, streamflow)
- Timing of seasons
- Ocean temperatures and sea-level rise

The outputs of this research include projected changes in each of the following climate variables:

Seasonal and annual temperatures

Summer heat index -- how hot a future summer will “feel”

Heatwaves and temperature extremes

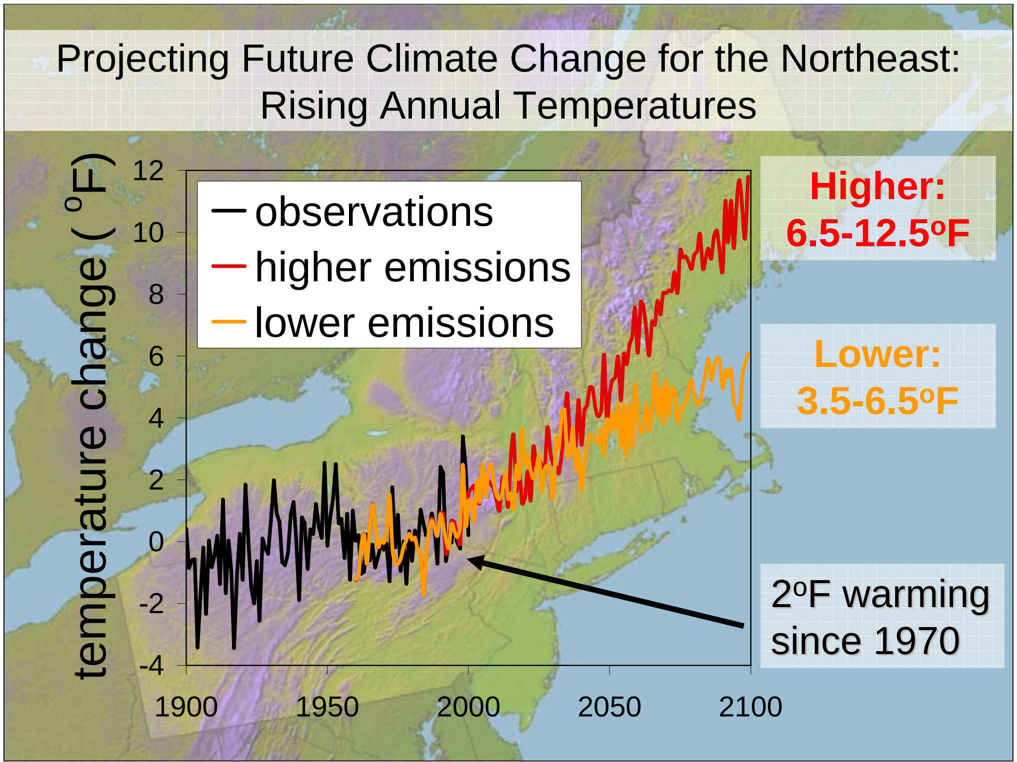
Precipitation and winter snow

Extreme precipitation and storms

Hydrology (soil moisture, drought, streamflow, water supply)

Timing of seasons

Ocean temperatures and sea-level rise



Annual temperatures across the Northeast have risen more than 1.5oF since 1970.

Winters have been warming fastest, at 1.3oF per decade since 1970.

Under the lower-emissions scenario, annual temperatures are projected to increase 3.5 to 6.5oF by 2100, and 6.5 to 12.5oF under the higher-emissions scenario.

Figure 3. *Observed and model-based changes in annual average temperature for the Northeast (in oF) relative to 1961-1990 average temperature. Modeled historic and future temperatures represent the average of the GFDL, HadCM3, and PCM models.*

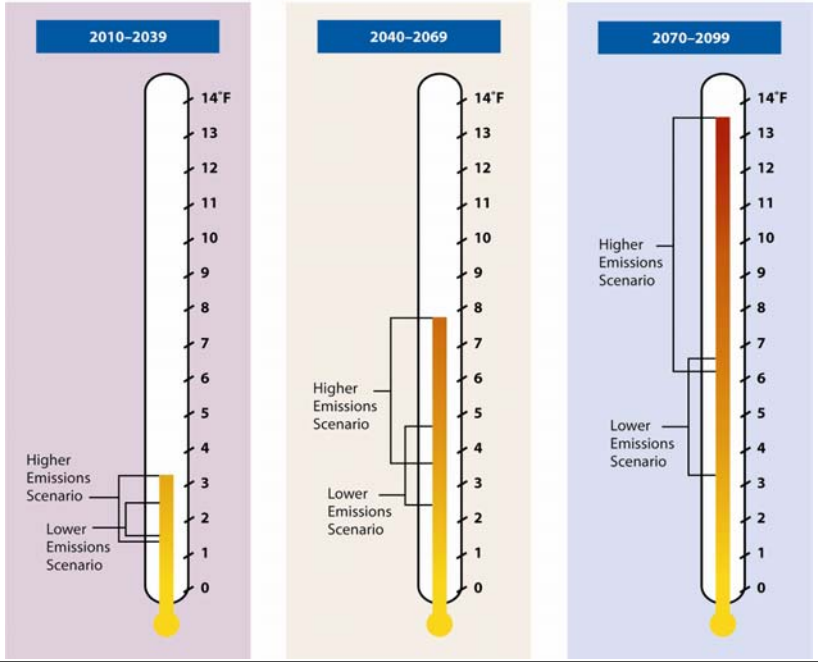
The Northeast is a temperate region, with highly distinct seasons and a wide range in annual temperatures. Currently, annual average temperatures range from 40oF in the northern part of the region up to 50oF in the southern part. Across a single year, temperatures can range from well below freezing in winter to over 100oF in summer.

Given the day-to-day and year-to-year variability experienced in the Northeast, one year might be relatively warm and the following year could be colder than average. However, analysis of average annual and seasonal temperatures over longer periods of time shows a distinct upward trend. This is particularly true over the last few decades.

Since 1900, annual temperatures across the Northeast have risen an average of 0.14oF per decade. From 1970 to 2002, however, the region has been warming at an average rate of 0.5oF per decade. This corresponds to an overall warming for the entire region during that time of 1.75oF on average—although of course any given year can still be warmer or cooler than average. The upward trend in winter temperatures is even greater, rising an average 1.3oF per decade since 1970.

Over the next century, temperatures across the Northeast are projected to continue rising (Figure 3). In the next few decades (2010 to 2039), changes are similar under the lower- and higher-emissions scenarios, but by mid-century, temperature differences between the scenarios begin to appear. By the latter part of the century (2070 to 2099), the difference between the higher- and lower-emissions scenarios is a dramatic 4.5oF.

Rising Summer Temperatures

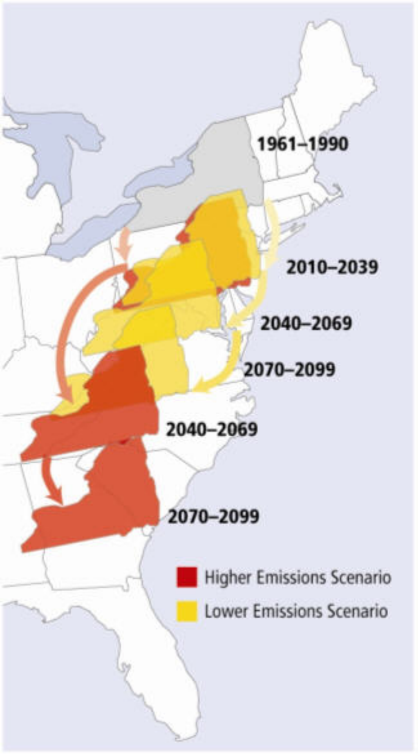


Model-based changes in average summer temperature for the Northeast (in oF) relative to 1961-1990 average temperature. Modeled historic and future temperatures represent the average of the GFDL, HadCM3, and PCM models.

Summary heat index:

How hot summers will "feel" in

Upstate New York

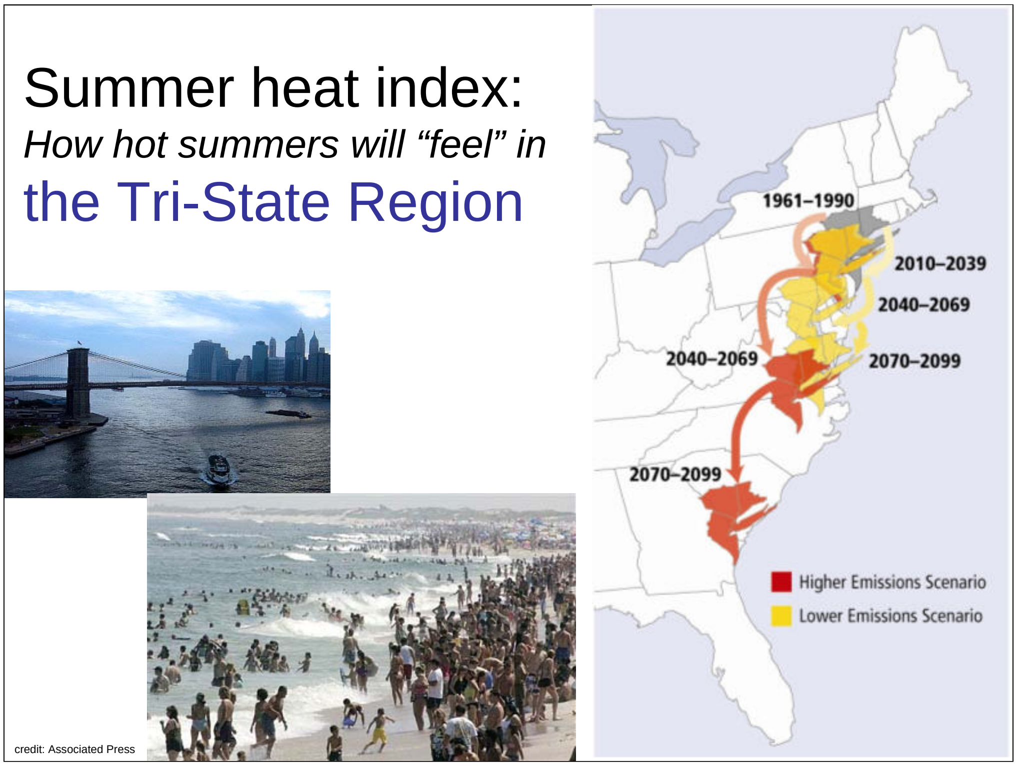


The "heat index" provides a measure of how hot it *feels.*

Taking into account humidity, future temperature increases are likely to feel nearly twice what they actually are.

The impact of changes in summer heat and humidity can be best illustrated by comparing the types of future conditions expected in Northeast states with other states along the southeastern coast of the U.S. For example, based on present-day average heat index values, by mid-century the state of Massachusetts is projected to resemble New Jersey under the lower emissions scenario, and Maryland under the higher emissions scenario. Under the lower emissions scenario, Eastern Pennsylvania could feel more like Virginia does today, while under the higher one it could feel more like North Carolina.

Even greater changes are expected by the end of the century. Under higher emissions, the typical Northeast summer day is projected to feel 12 to 16o F warmer than it did on average between 1961-1990, the historical reference period used in this study. An average Massachusetts summer could resemble those of South Carolina today under the higher emissions scenario, and Maryland under the lower one. Summers in New Hampshire and Upstate New York are projected to feel more like current summers in North Carolina and Georgia, respectively, under the higher emissions scenario, and Virginia under the lower emissions scenario.



Summer heat index:

How hot summers will "feel" in

the Tri-State Region

credit: Associated Press

The "heat index" provides a measure of how hot it *feels.*

Taking into account humidity, future temperature increases are likely to feel nearly twice what they actually are.

The impact of changes in summer heat and humidity can be best illustrated by comparing the types of future conditions expected in Northeast states with other states along the southeastern coast of the U.S. [Figure 4]. For example, based on present-day average heat index values, by mid-century the state of Massachusetts is projected to resemble New Jersey under the lower emissions scenario, and Maryland under the higher emissions scenario. Under the lower emissions scenario, Eastern Pennsylvania could feel more like Virginia does today, while under the higher one it could feel more like North Carolina.

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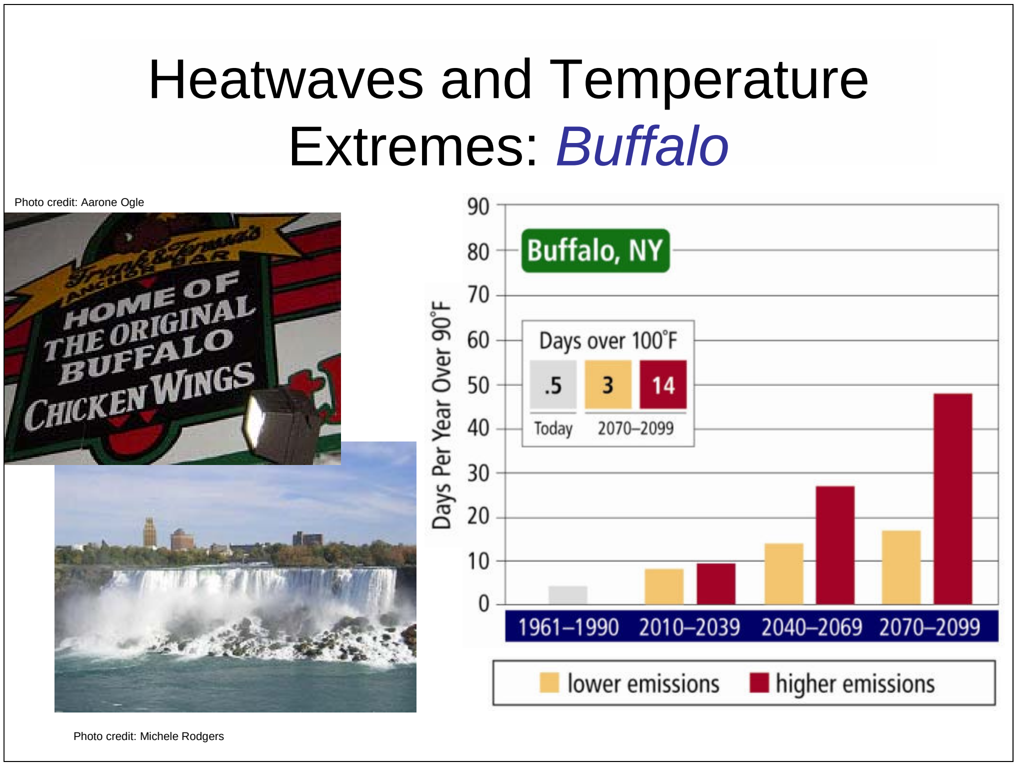


Heatwaves and Temperature Extremes: *Buffalo*

Photo credit: Aarone Ogle

Photo credit: Michele Rodgers

The number of very hot days is increasing across the Northeast.

By the end of the century, many northeastern cities can expect 30 or more days over 90oF under the lower-emissions scenario, and 60 or more days per year under the higher-emissions scenario.

Currently, northeastern cities experience one or two days per summer over 100oF. This number could increase by late century to between three and nine days under lower emissions and between 14 and 28 days under higher emissions.

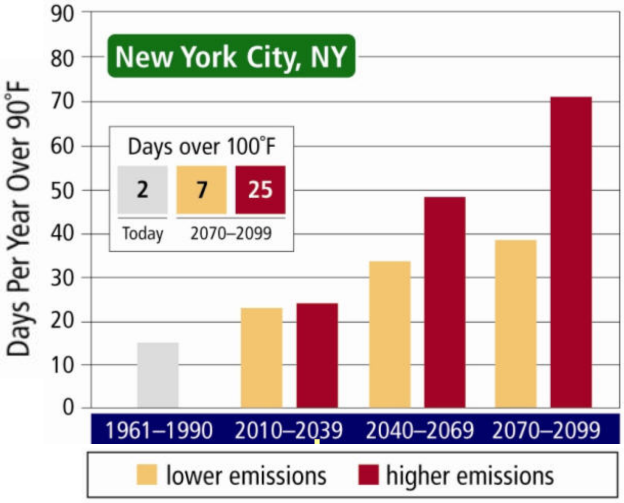
Global warming is projected to increase these numbers dramatically. By 2010-2039, the number of days per summer that exceed 90oF could double relative to the 1961-1990 average. By mid-century, models project an additional 30-60 days per year (one to two months) over 90oF under the higher emissions scenario and 20-30 days per year (almost a full month) over 90oF under the lower scenario.

Under the higher emissions scenario, most cities are projected to experience more than 60 days each year with temperatures over 90oF by the end of the century. The smallest changes are expected for more northern cities such as Buffalo, with just over 40 days per year, while Philadelphia is projected to experience an average of 82 days over 90oF per year. The number of days per year over 100oF is likely to be at least 20 and closer to 30 in more southern cities such as Philadelphia and New York [Figure 5].

Under the lower emissions scenario, increases in extreme heat are less than those projected under the higher emissions scenario, but are still much greater than today. By the end of the century, most cities are projected to have at least 30 days per year over 90oF. Projected increases in the number of days over 100oF range from three in more northern cities up to nine days per year in more southern cities.

Heatwaves and Temperature Extremes: *New York City*

Photo credit: Associated Press



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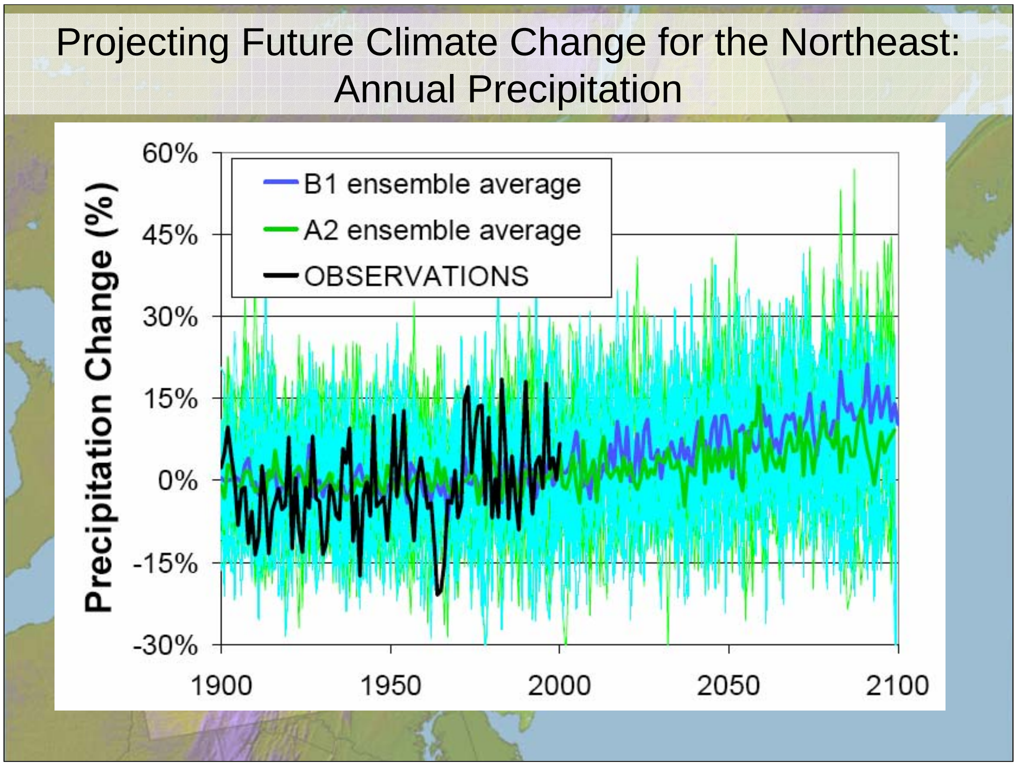
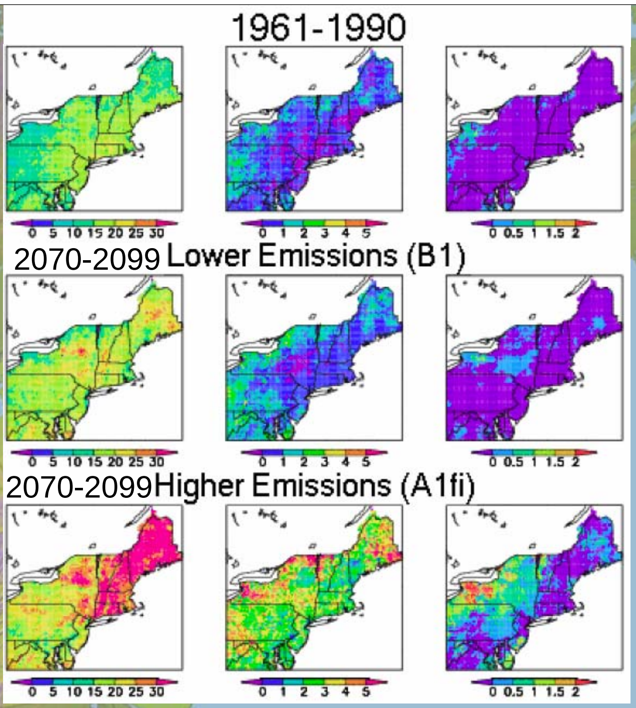


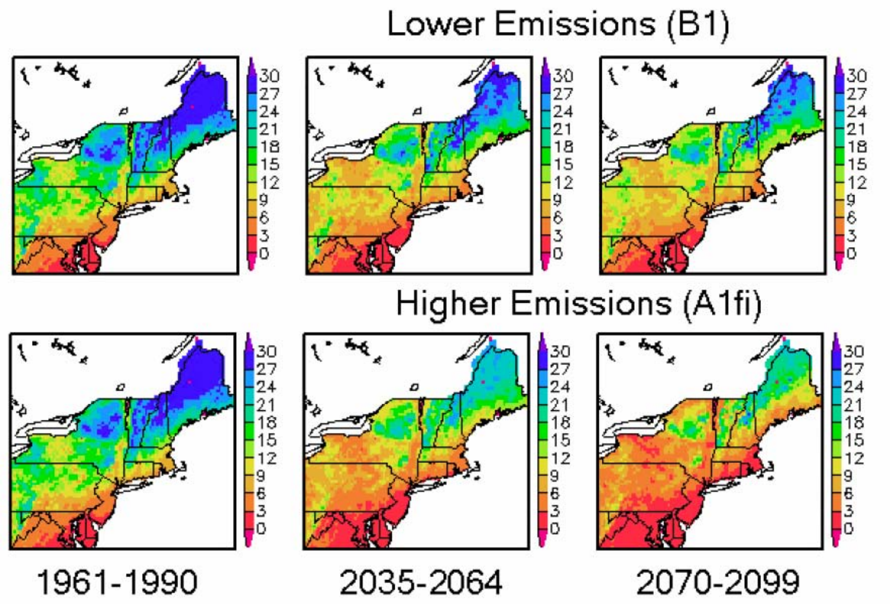
Projecting Future Climate Change for the Northeast: Annual Precipitation

Drought



SHORT MEDIUM LONG

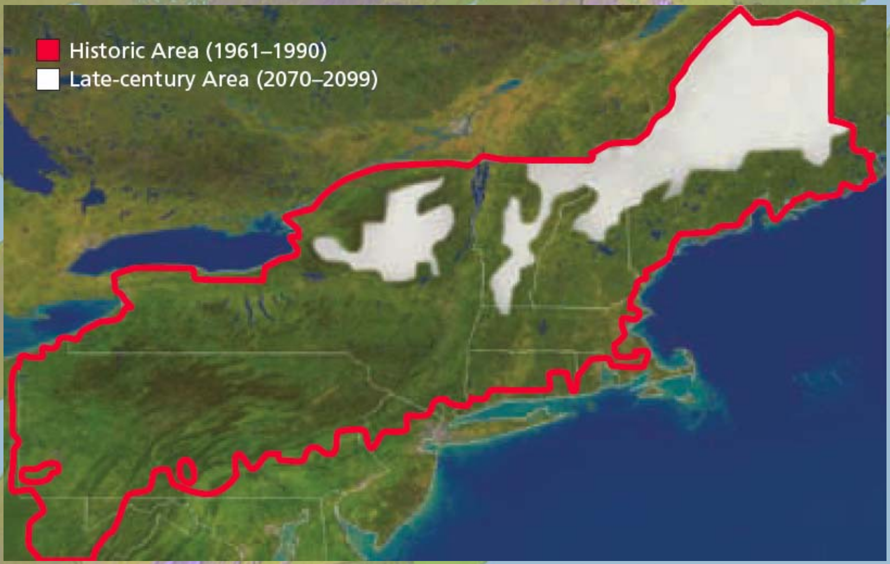
Reduced Snow on Ground Days



Days per month with snow on the ground

Reduction in Snow Cover

(Area with greater than 30 days of snow on ground)



Higher emissions: 50% reduction in snow-covered days (shown here)

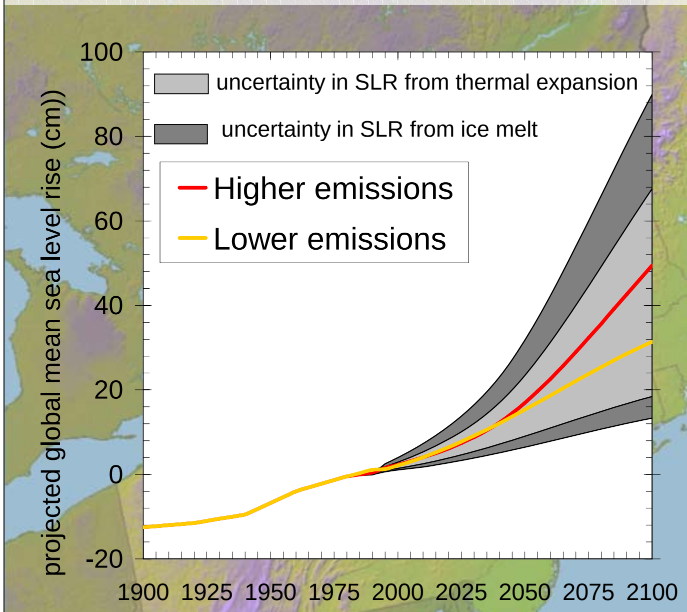
Lower emissions: 25% reduction in snow-covered days

Extreme Precipitation

- Heavy rainfall events are becoming more frequent across the Northeast
- Under both emissions scenarios
  - – rainfall expected to become more intense
  - – periods of heavy rainfall are expected to become more frequent.

credit: Associated Press

Sea Level Rise



Higher: 8-33 inches

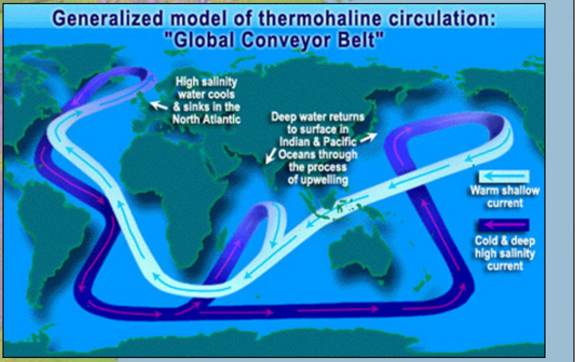
Lower: 4-21 inches

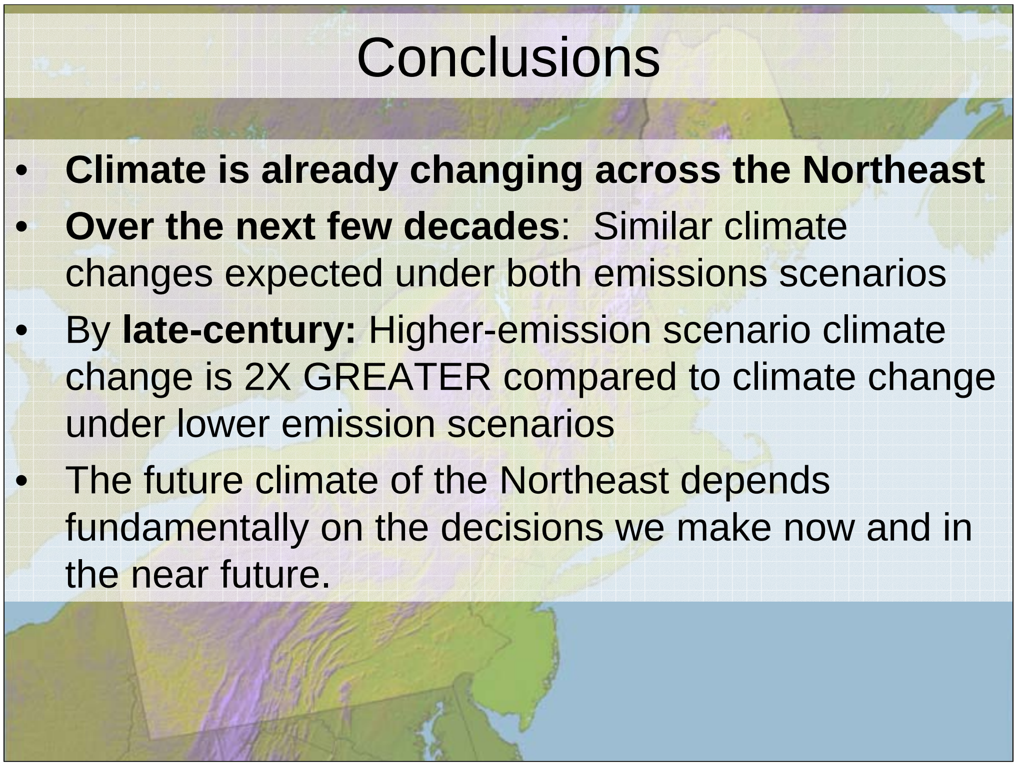
These estimates do not include the potential for additional increases due to more rapid melting of major polar ice sheets.

Abrupt Climate Change?

Greenland Ice Sheet Melting?

Changes in the Gulf Stream?





Conclusions

- **Climate is already changing across the Northeast**
- **Over the next few decades**: Similar climate changes expected under both emissions scenarios
- By **late-century:** Higher-emission scenario climate change is 2X GREATER compared to climate change under lower emission scenarios
- The future climate of the Northeast depends fundamentally on the decisions we make now and in the near future.

More Info

For basic information on the NECIA:
http://www.northeastclimateimpacts.org

For copies of the reports and more information visit:
http://www.climatechoices.org