

## THE NEW ENGLAND REGION'S CHANGING CLIMATE



*By Barry Keim and Barrett Rock*

When people think of the climate of the New England region (the six New England states plus upstate New York), they think of crisp, clear fall days enhanced by spectacular fall foliage, hot, sunny summer days and cool summer nights, or pristine winter snowscapes with snug cabins and bustling ski slopes. While the regional weather can change on short time scales (“If you don’t like the New England weather, wait a few minutes”), we tend to think that climate is stable. Just how stable is our climate, and are we seeing evidence that our climate is changing?

New England regional weather and climate are arguably some of the most varied in the world. This climate variability holds true at time scales of days to weeks, years to decades, and thousands to millions of years. Regional variability includes extremes of both hot and cold temperatures, droughts, heavy rainfall, hurricanes, tornadoes, blizzards, and more. Such variations in the weather are influenced by many factors which relate to the region’s physical geographic setting, including its latitude and coastal orientation, its topographic variability, and its position relative to the North American continent and prevailing storm tracks.

This chapter will consider climate variations known to have characterized the region during the last two million years, the region’s physical geographic setting, and some trends suggesting what, if any, climate change may have occurred based on climate records for selected sites.

### **Primary Components of the New England Regional Climate**

The four components that dominate the modern climate of the New England region are: (1) latitude; (2) coastal orientation; (3) position within the zone of the westerlies; and (4) great changes in elevation. These factors interact to provide the New England region with its characteristic weather and climate patterns.

First, the region is located about halfway between the equator and the north pole (45°N), which is why it serves as a battleground for warmer, moist air from the south and colder, dry air from the north. The surface air mass boundaries are made up of warm, cold, and stationary fronts, which frequently traverse the region from west to east taking us from one air mass to another in rapid succession.

Second, the region is dominated by a cold ocean current along its east coast, and a warm water current along the south shore of Connecticut and Rhode Island, as well as Long Island (NY). These currents, and the corresponding water temperatures associated with them, impact summer recreation, swimming comfort, etc, and also create a notable sea breeze in spring and summer. In winter, these waters remain warm relative to land areas, thereby influencing snow-rain boundaries, which are very difficult for weather forecasters to predict.

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...the region's weather is notorious.

Third, since New England falls primarily in the zone of the westerlies, the area is dominated by drier continental airflow from various areas across North America, rather than having a prevailing flow off the Atlantic Ocean. Despite the coastal orientation of New England, it is not a maritime climate like those found on the west coast of the United States. Due to this continental airflow pattern, the New England region is downwind from much of the rest of the continent, and with that airflow comes varying degrees of air pollution from both the mid-west and from along the eastern urban corridor.

Fourth, New England has mountainous topography that also influences weather patterns. Such mountain topography enhances precipitation on the windward side of the mountain, and creates drier conditions known as rainshadows on the downwind slopes. However, the prevailing storm tracks can take storms all around the region. Hence, a south-facing slope may be in the rain shadow on one day, while the next, it could be on the windward side. Increases in elevation also lead to cooler air temperatures. The summit of Mount Washington (NH) is known for some of the most severe weather on Earth, weather so severe that hiker deaths due to exposure and hypothermia in summer months are not uncommon. Mount Marcy and the High Peaks region of the Adirondacks (NY) are also notorious for severe weather.

As a result of a combination of New England's geographical location, its continental climate, its coastal orientation, and its mountainous topography, the region's weather is notorious. It is known for its diversity over short distances and changeability in a matter of minutes.

### Temperature

New England average annual temperature is 44° F, and ranges from approximately 40° F to the north, and about 50° F along the south shore of Connecticut and Rhode Island. When we factor in elevation, temperatures are generally cooler (Mount Washington has an annual average temperature of 26° F). Absolute extreme temperatures in New England have been recorded to be as high as 107° F and as low as -50° F. The record 107° F high is hotter than the all-time high temperature recorded in Miami, Florida, and the -50° F low is colder than the record low temperatures in Anchorage, Alaska or International Falls, Minnesota (commonly the coldest location in the conterminous United States).

There has been a modest (0.7° F) regional trend toward increasing annual temperatures since 1895 (Figure 2.1). As can be seen, a good deal of year-to-year variation characterizes the regional record. The coastal zone of the region has warmed by 1.7° F over the same time period while the interior has warmed by 0.6° F.

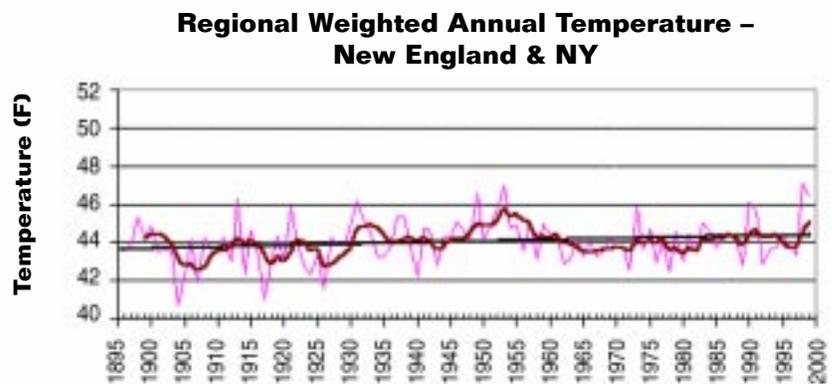


FIGURE 2.1  
Regional Weighted Annual Temperature – New England and upstate New York.  
Annual variation is seen in pink, a 5-year running mean is dark red and the overall trend as the black line. The overall regional increase is 0.7°F.

At a minimum, the 1998 ice storm has been classified as a 200-year return event, and possibly a 500-year return event.



There are two possible explanations for these differences. First, the coastal region has experienced rapid population growth over the past century and the warming could be the effects of land cover change and resulting urban heat islands. Second, there is speculation that the sea surface temperatures around New England may have warmed, thereby warming the climate of the coastal zone.

### Precipitation

The average annual precipitation for the region is approximately 40 inches per year and ranges from approximately 35 inches in the northern reaches, with higher values, to over 50 inches, along the southern coastal zone. Since elevation tends to enhance precipitation totals, Mount Washington averages approximately 99 inches of “liquid equivalent” precipitation per year.

Similar to the change-over-time patterns noted with temperature, there is a trend of slightly increasing precipitation for the entire region (a 3.7% increase - Figure 2.2), with a greater increase (16.8%) for the coastal zone over the past century, and less (2.7% increase) long-term change in the interior. In addition, there appears to be an increase in heavy rainfall events in the east coastal region, where three precipitation events with greater than 50-year return period have occurred between October 1996 (Keim, 1998) and October 1998 and a 200-year return ice storm was experienced by a large part of the region in January, 1998 (See Chapter 5). At a minimum, the 1998 ice storm has been classified as a 200-year return event, and possibly a 500-year return event.

Although the New England region is not considered to be water-limited, several periods of significant drought have occurred that were region-wide. The affect of the mid-1960s drought (covering 4-5 years) can be seen in Figure 2.2. Significant regional droughts were experienced in 1995 and 1999. As can be seen in Chapter 3, shifting patterns of high and low pressure systems over the Atlantic Ocean (the North Atlantic Oscillation or NAO) appear to correlate well with drought periods in the New England region.

**Regional Weighted Annual Precipitation –  
New England & NY**

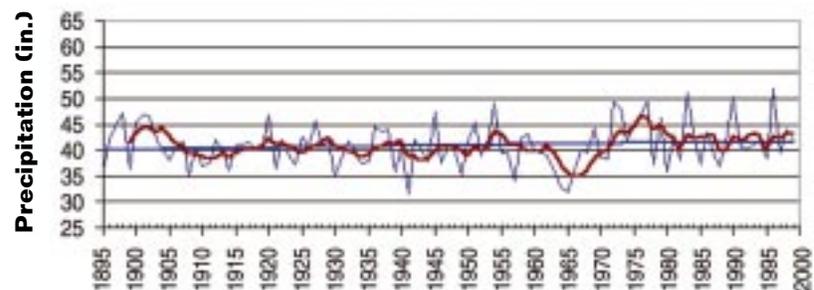


FIGURE 2.2  
Regional Weighted Annual Precipitation in upstate New England and New York shows a 3.7% increase. The affect of the mid-1960's drought is clearly seen.

## The New England Region has warmed slightly less than the nation, and approximately half of the overall global increase...

### Annual and Spatial Temperature and Precipitation Variation within the New England Region

Annual temperatures by state and for the entire New England region (including upstate New York) have been monitored at over 300 weather stations operated by the National Climate Data Center (NCDC), as part of the Historic Climate Network (HCN - see figure 4.1). Many of these monitoring stations have been in continuous operation since 1931, and in some cases since 1895. The data provided by the NCDC/HCN constitute the most reliable long-term record of temperature and precipitation available for the region.

The 0.7° F increase in temperature since 1895 for the region is similar to the increase nationally (approximately 1.0° F). The global average temperature increase is often cited as 1.2° F. The New England Region has warmed slightly less than the nation, and approximately half of the overall global increase. The region's 4% increase in precipitation is slightly below the 5-10% average precipitation increase nationally over the 105 year period.

There is a good deal of variation within the region in both temperature and precipitation change over the past century. This heterogeneity is at both spatial (varies state to state) and temporal (seasonal) scales. As can be seen in Figure 2.3, some states have warmed more than the regional average and others less. Rhode Island has warmed the most (2.3° F), likely due to its coastal location. New Hampshire's annual temperatures have increased (1.8° F) at nearly three times the regional average (0.7° F) while Maine has exhibited a slight cooling (-0.4° F) over the same time period.

While the overall region has warmed, based on annual average temperatures, by 0.7° F, the regional wintertime months (December, January and February - Figure 2.5) have warmed by nearly 2.0° F. Summer months (June, July, and August - Figure 2.4) exhibit increases similar to the annual regional increase.

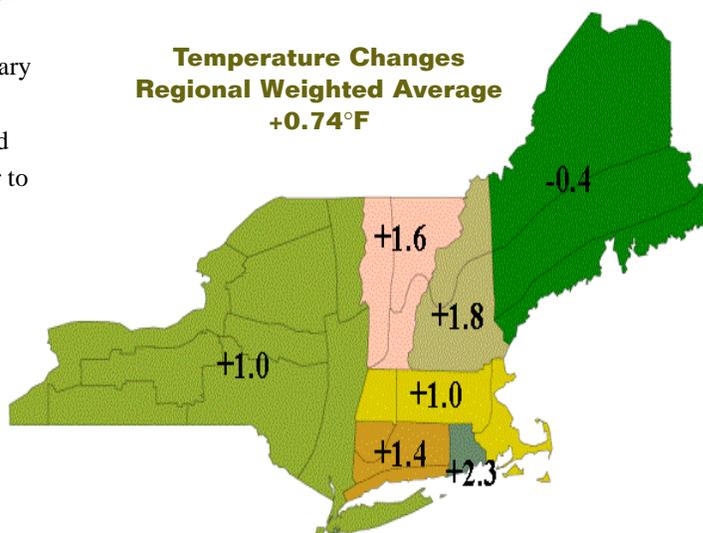


FIGURE 2.3

*New England and New York Temperature Changes (°F) Between 1895 and 1999. The faint lines within the states represent the various climate zones recognized by the National Climate Data Center.*

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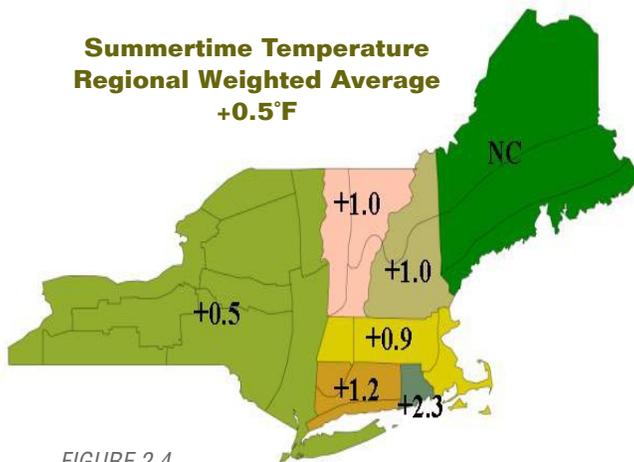


FIGURE 2.4  
New England and New York Summertime Temperature Changes (°F) Between 1895 and 1999. The faint lines within each state represent NCDC climate zones.

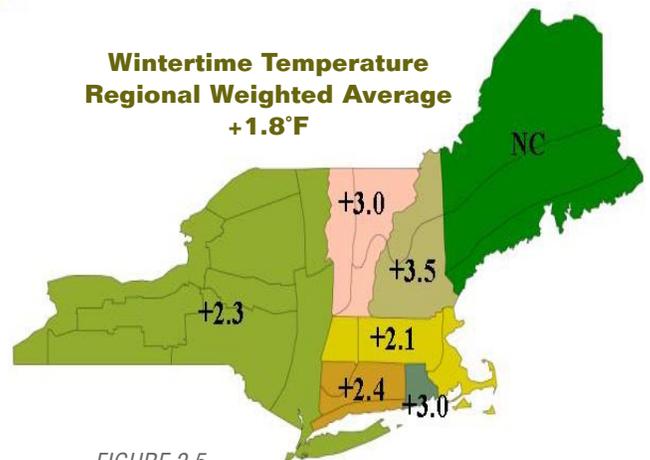


FIGURE 2.5  
New England and New York Wintertime Temperature Changes (°F) Between 1895 and 1999. The faint lines within each state represent NCDC climate zones.

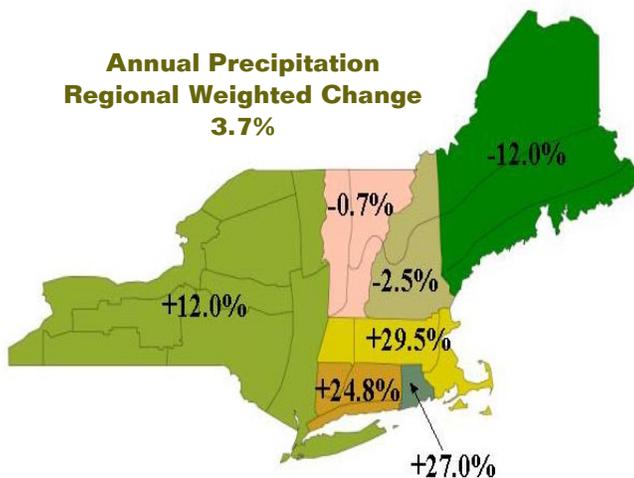


FIGURE 2.6  
New England and New York annual precipitation changes (%) between 1895 and 1999. The faint lines within each state represent NCDC climate zones.

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### Snowfall

Snowfall is highly variable in the New England region, both spatially and temporally. Southern New England receives the lowest snowfall totals on average with approximately 35 inches per year. The Northern New England region receives substantially more snowfall, with large regions in and near the White, Green, and Adirondack mountains averaging well over 100 inches per year. Due to their locations on the shore of Lake Erie and the direction of prevailing winds, Rochester and Buffalo, NY are cities known for their heavy winter “lake effect” snowstorms. Elevation enhances snowfall totals and Mount Washington averages 254 inches of snowfall per year. As seen in Figure 2.7, there has been a nearly a 15% decrease in snowfall in Maine, New Hampshire and Vermont between 1953 and 1994. Since 1996 winters have been unusually mild, resulting in lost revenues for the ski industry. The winter of 00/01, while mild, has been more typical for the region in terms of snowfall.

### Snow-on-Ground Data

Although snowfall, snowpack, and duration of snow-on-ground data have been acquired by many organizations (State Offices, the Army Corps of Engineers, etc.), only a limited number of these datasets have been analyzed. The duration of snow cover on the ground has decreased by approximately seven days over the past 50 years (Figure 2.8). As noted with temperature and precipitation data, the results are spatially varied. Snowpack has decreased significantly in some parts of the region (the northern climate zone in New Hampshire has decreased by 14.5 days) while showing no change in Maine’s northern climate zone. These variations are correlated with the heterogeneous wintertime temperature variability across the region.

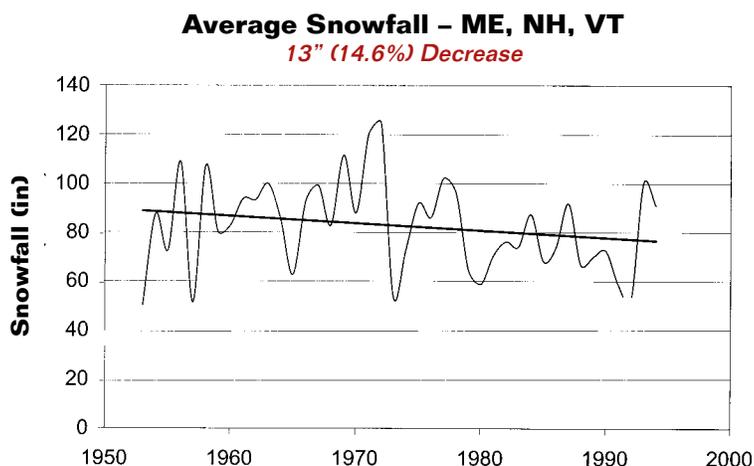


FIGURE 2.7  
Annual snowfall data for Vermont, New Hampshire and Maine between 1953 and 1994.

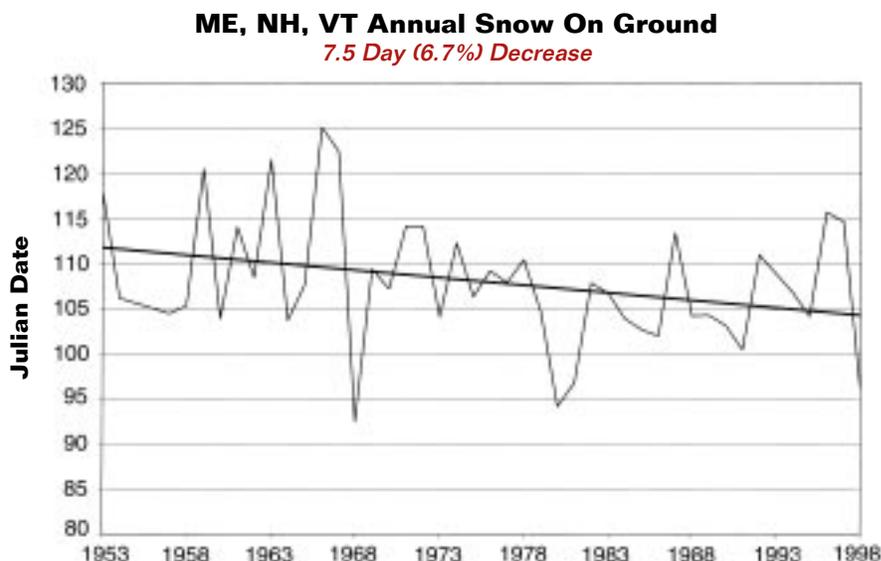


FIGURE 2.8  
Annual snow on ground data for Vermont, New Hampshire and Maine between 1953 and 1998.

...the New England region is experiencing a measurable warming trend in winter and spring that has resulted in earlier ice-out dates...

### Ice-out Dates for Regional Lakes

Accurate records of ice-out dates (the earliest date for ice-free lake surfaces) for selected New England region lakes provide evidence of a changing climate, when viewed with air temperature and precipitation records. Ice-out records have been kept for Lake Winnepesaukee (Figure 2.9), where ice is an important consideration for ferry traffic on the lake, as well as for ice fishing, snow mobiling, and cross country skiing. Ice-out data are also available for Rangeley Lake in northeastern Maine, for several New York lakes (Oneida, Otsego, Schroon and Cazenovia) and one additional Maine lake (Moosehead). Decadal averages for Lake Winnepesaukee show ice-out dates that average four days earlier, similar to those reported for the New York lakes (ice-out occurring an average 4 days earlier per 100 year period), while the data for Rangeley Lake indicate ice-out dates similar to those for Moosehead Lake (5.6 days earlier/100 year period).

Although the year-to-year ice-out dates are highly variable and somewhat cyclical patterns can be seen, the overall trends are clear. These results suggest that the New England region is experiencing a measurable warming trend in winter and spring that has resulted in earlier ice-out dates for those lakes for which long-term records exist.

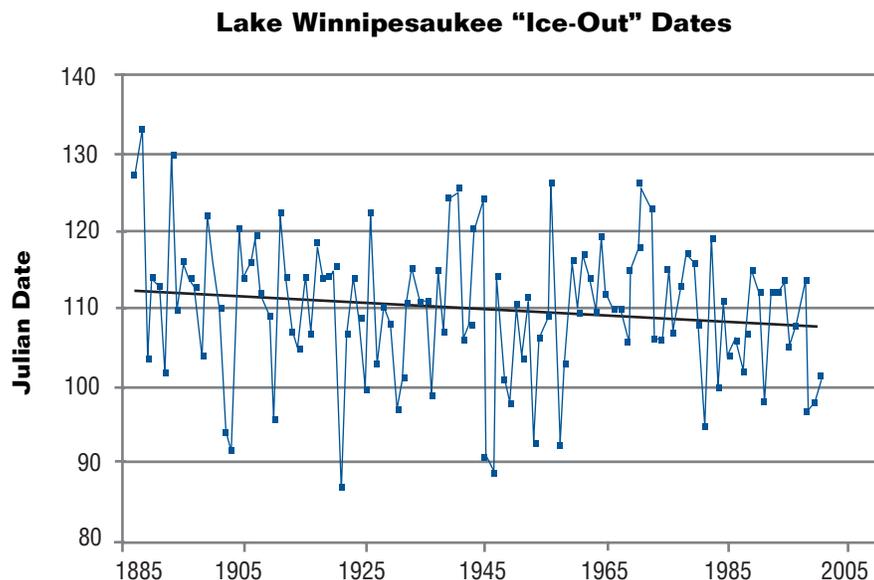


FIGURE 2.9

*Ice-out dates occur an average of four days earlier than in 1886 for Lake Winnepesaukee, NH. Note that interannual variability is high.*

...it is clear that the decade of the 1990s has been characterized by an unusual number of extreme events.

### Extreme Events

In recent years, extreme events may have become more common in the United States, particularly in the Northeast. Note the following extremes in the region, occurring since 1996.

- Region-wide blizzard with storm snowfall totals in excess of 30 inches (January, 1996)
- Coastal New England Rainstorm producing over 19 inches of rainfall (October, 1996)
- Warmest single-day February temperature record in Seacoast of New Hampshire (1997)
- Boston's 24-hour snowfall record broken (April 1997)
- Severe Ice storm strikes northern New England, New York, and southeastern Canada (January, 1998)
- Warmest single-day March temperature ever recorded in New Hampshire (1998)
- Longest snow-free period ever recorded at Boston's Logan Airport (304 days – 1999/2000)
- The 1999/2000 winter was the mildest on record (replacing the 1998/1999 winter as the previous record, which in turn replaced 1997/1998)
- One of the hottest and driest summers on record in southern and western New England (1999)
- One of the coolest and wettest summers on record for southern New England (2000)
- One of the heaviest snowfall winters on record across the region (2000/01)

Evidence of increases in extreme events is also provided in the form of increasing trends in weather-related insurance claims. Using insurance claims to document an increase in storm severity may not be related so much to weather extremes, as to the fact that human population in the US is increasing, and more people are building more expensive homes in weather-sensitive areas (coastal property susceptible to hurricanes, and floodplains vulnerable to flooding). Research does suggest that the proportion of annual rainfall contributed by 1-day extremes has increased in the US over the past century.

While the "Top Ten Most Memorable Weather Events for the New England Region" (see next page) span the 20<sup>th</sup> Century, from the infamous 1927 flood in Vermont to the 1998 ice storm across much of New York, Vermont, New Hampshire and Maine, two of these "Top Ten" events occurred in the 1990s. While it is difficult to say with certainty that extreme events are on the increase in the New England region, it is clear that the decade of the 1990s has been characterized by an unusual number of extreme events.

Predicting future extreme events in a dynamic region such as New England has proven to be a difficult task. Most of what is known about future climates is derived from general circulation models (GCMs). The various GCMs [e.g. the Canadian Global Coupled Model (CGCM) and the Hadley model from the United Kingdom Meteorological Office] generally agree that global temperature and precipitation should increase as concentrations of atmospheric greenhouse gases increase, but regional impacts remain unclear. Furthermore, most extreme events (e.g. intense precipitation events, tornadoes, hurricanes, high winds, etc.) are too small in scale for GCM recognition and therefore the GCMs are of limited value in predicting extremes.

## **“Top Ten” Most Memorable Weather Events for the New England Region**

*Compiled by Barry Keim*

- 1.** The Hurricane of 1938 - September 21, 1938. A hurricane, named appropriately as the "Hurricane of 1938," made landfall in southern Connecticut and given the storm's path and power, impacted the entire region. Over 600 deaths are attributed to this storm, which was caused primarily by the 17 foot storm surge along the Connecticut and Rhode Island Coasts. However, high winds and rain caused large stands of trees to be blown down all the way up into the White Mountains and flash flooding was problematic in MA, VT, and NH.
- 2.** The Blizzard of 1978 - February 5-7, 1978. The Blizzard of '78 was caused by an intense coastal nor'easter that produced winds in excess of hurricane force and very high snow totals. Northern Rhode Island received over 50 inches of snow, with most of southeastern New England buried beneath 3 or more feet. The region was paralyzed for over a week.
- 3.** Hurricane Diane - August 17-19, 1955. Hurricane Diane produced a 24-hour rainfall total of 18.15 inches (the New England record) and a storm total of 19.75 inches rainfall. These impressive totals caused massive flooding as they fell on saturated grounds — Hurricane Connie visited the area only days prior to Hurricane Diane to soak the area.
- 4.** The “All New England Flood” - Mid-March 1936. Two heavy rain events fell on greater than normal snowpack to produce the "All-New England Flood" which led to the most serious widespread flooding ever experienced in New England. Hookset, NH had 18-20 feet of water flowing down mainstreet and the Amoskeag Mills were badly damaged with record flood crests on the Merrimack River and beyond.
- 5.** The 1998 Ice Storm - January 5-9, 1998. Northern New England experienced the worst ice storm (see Ice Storm Case Studies; Chapter 6) in recorded history with loss of life, widespread power outages that took months to fully restore and damage to forests that may require decades to recover.
- 6.** The Worcester Tornado - June 9, 1953. The Worcester Tornado touched down as a F4 tornado, with wind speeds between 200-260 mph. It carved a path of 46 miles from Petersham, MA to Southboro, MA, while persisting for 1 hour and 20 minutes, killing 90 people. That same day, tornadoes also touched down in Exeter, NH and Sutton, MA.
- 7.** Highest Recorded Windspeed on Earth - April 12, 1934. Mt Washington, NH measures a windspeed of 231 mph, which still stands as the highest windspeed ever recorded in the world.
- 8.** Record Rainfall in Maine and New Hampshire - October 20-21, 1996. A persistent rainstorm produced the all-time state rainfall records for both Maine and New Hampshire. A storm total of 19.2 inches was produced in Camp Ellis, Maine which ranks as the second largest rain event in New England recorded history — estimated to be a 500-year rainfall event for the Maine-NH coastal area. New Hampshire also broke its all-time 24-hour rainfall total with 10.8 inches measured at Mt. Washington.
- 9.** The Nor'easter of '69 - February 22-28, 1969. A noreaster produced over 3 feet or more of snow across large portions of ME, NH, MA, and RI, with totals of 98 and 77 inches recorded at Mt Washington and Pinkham Notch, respectively. These values are unprecedented snowfall totals for any single storm event in this region. This storm was also preceded by yet another impressive snowstorm on February 8-10 which produced between 1 and 2 feet across most of New England. The combination led to incredibly high "snow on ground" totals and large snow drifts.
- 10.** The Flood of '27 - November 3-4, 1927. A frontal system was assisted by tropical moisture to produce rainfall totals near 10 inches across central VT, leading to massive river-basin flooding. Eighty-four Vermonters perished and to this day, this storm is still considered the worst weather catastrophe in the state.

## Overall, the climate of the New England region has changed over the past 100 years...

### Summary

The weather and climate of New England has proven to be highly variable over long and short time scales and across short distances. Much of this variability can be attributed to the region's unique geographic location. In a given year, the region can experience hurricanes, blizzards, drought, and more. Over the past century, the historic record indicates that regional temperatures are warming (0.7° F), especially in the coastal zone (1.7° F) and for selected states (RI 2.3° F, NH 1.8° F). The same record shows that Maine has actually cooled by 0.4° F. Clearly, more warming has occurred during winter months (1.8° F for the region; 3.5° F for NH), and snowfall, snow on ground, and ice-out dates for regional lakes suggest the seasonal warming has had an effect. The limited data available indicate that regional snowfall and snowpack have decreased over the past 50 years although this varies by state and climate zone. Ice-out dates are occurring from four to six days earlier when compared with 100 years ago. Little overall change in precipitation has occurred over the past century (4% increase), but this too has been highly variable.

There is limited evidence that extreme events may be on the rise, but a more thorough analysis is needed. At the national level evidence supports the view that extreme rainfall events are on the increase. Overall, the climate of the New England region has changed over the past 100 years, exhibiting a modest warming trend along with a slight increase in annual precipitation, with a high degree of variability by state. The reason for the spatial variability is not known.