Climate Change in Vermont

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1. Introduction

The climate of Vermont has changed substantially in the past fifty years. Continuing change is certain, as the Earth's climate is being driven towards a warmer mean state by the increase of greenhouse gases in the atmosphere. The primary driver is that the burning of the fossil fuels increases atmospheric CO_2, which has a centennial lifetime in the atmosphere. Since CO_2 is as a greenhouse gas, this reduces the longwave cooling of the Earth to space. The warming from the increase of CO_2 is amplified several times[1] because atmospheric water vapor, another powerful greenhouse gas, increases on monthly timescales as temperature increases. Globally some ice is melting, but the oceans are storing much of the heat that the Earth cannot radiate back to space; so the current increase in greenhouse gases will have a long-term impact lasting decades to centuries. The warming is amplified further at northern latitudes by reductions in snow and sea-ice cover[2], which means less of the sun's energy is reflected. The global atmospheric circulation is also changing in response to both the increase in greenhouse gases, and the reduction of northern sea-ice[3].

We have two complementary reference frameworks when planning for the future:

1) Regional projections from climate models
2) Climate trends in Vermont and New England in recent decades

Global model projections help us look into an uncertain future and explore humanity's options and risks. For example, we can estimate how the patterns of temperature and precipitation will change, and see how reducing greenhouse gas emissions give a smaller mean global temperature rise by the end of this century. Our models for the Earth's climate system necessarily contain simplifications, but they are continually revised as understanding improves. In 2014, the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC-AR5, 2014)[4] was completed by an international team of some 800 lead authors and 2,000 expert reviewers. This Report documented the global and regional changes in temperature and precipitation expected this century. The Third National Climate Assessment Report[5] looks at climate change impacts in the US. A new Climate Change Special Report[6] has been prepared by the US Global Change Research Program by scientists from the federal agencies, national laboratories and universities in preparation for the Fourth National Climate Assessment (NCA4). These quadrennial assessments were mandated by Congress in the Global Change Research Act of 1990. The current federal administration has recently disbanded the federal advisory committee to the National Climate Assessment as part of its efforts to suppress climate change science. However, Figures from this latest Report[6] are included in this Vermont assessment, since they have been updated through 2016, they have been thoroughly reviewed, and are scheduled for November publication.

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How does predicting climate differ from forecasting weather?

Predicting climate is very different from forecasting weather. With global models we can forecast the day-to-day weather for about a week: typically forecast skill lasts a few days longer in winter than in summer. Further into the future we can only predict the general climate.

For example, we can predict with certainty that next July will be warmer than it was in January – because the sun heats the Earth more when it is high in the sky – but we cannot forecast in spring whether it will rain on the 4th of July. Furthermore, even though the sun follows the same path in the sky every year, some summers are drier and warmer or wetter and cooler than ‘usual.’ This is because regional weather patterns vary widely, depending, for example, on the position and movement of the jet streams. Scientists say the climate system has a lot of internal variability.

Similarly as CO_2 rises in the atmosphere, we know this will push the Earth towards a warmer average climate, because CO_2 is a greenhouse gas that traps the Earth’s heat. And as the Earth warms, more water evaporates – and because water vapor is another greenhouse gas, the warming is further amplified. And as the Earth warms, ice and snow cover are reduced, so less sunlight is reflected. This amplifies the warming further. So we can predict that the Arctic (and northern winters) will warm faster as the reflective snow and sea ice decrease. In contrast, the Antarctic ice sheets are thousands of feet thick and may take decades to centuries, even millennia, to melt as the Earth warms.

We can also predict that the continents will warm faster than the oceans. As the climate warms, heat is only conducted down a short distance into the ground over land. But the oceans circulate heat down to the ocean depths, so they warm more slowly. However, the oceans store much of the heat that the Earth cannot radiate into space because of increasing greenhouse gases. Warmer oceans in the tropics and the Gulf Stream mean more powerful storms and hurricanes.

While we can predict a broad warming climate trend as atmospheric greenhouse gases rise, we cannot predict the detailed future weather. We must expect the large variability from year to year to continue; in fact variability and extremes are expected to increase.

Our ability to predict the details of future regional climate is limited, because there are strong indications that as the climate shifts globally into new warmer states and new patterns, climate extremes are increasing. So it is very helpful to examine climate trends in Vermont and New England in recent decades as a guide for understanding how the climate system is changing. These recent observational trends are familiar to local communities and can help us understand the relationship between the local climate change that we are experiencing and projected global climate changes: as one way to qualitatively assess future risks. Traditionally, climate was viewed in terms of 30-year averages; but now the climate is changing on decadal timescales, so we must update our perspective frequently. First we will outline the latest global and regional projections.

2. Projections from climate models

2.1 Temperature projections

The recent US Climate Change Special Report[6] reviews the results from the IPCC-AR5 report[4]. Figure 1 shows (right) the projected rise in global mean temperature for three of four global carbon emissions scenarios (shown left). These are labeled as representative concentration pathways (RCP) with a number that is an estimate of the radiative forcing in the year 2100, relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively). 'Radiative forcing' is the energy imbalance of the Earth, the positive difference between the incoming solar heating and the longwave cooling of the Earth to space, which is reduced as greenhouse gases increase. In simple language, RCP8.5 is a high emission scenario with a high fossil-fuel-based economy, leading to global mean temperature rises of about 8F, while RCP2.6 is a future where the shift away from fossil fuel is swift, and global temperature rises only about 3F by 2100. Neither of these futures are likely: the mid-low scenario 4.5 leads to a global temperature rise of 4.3F by 2100.

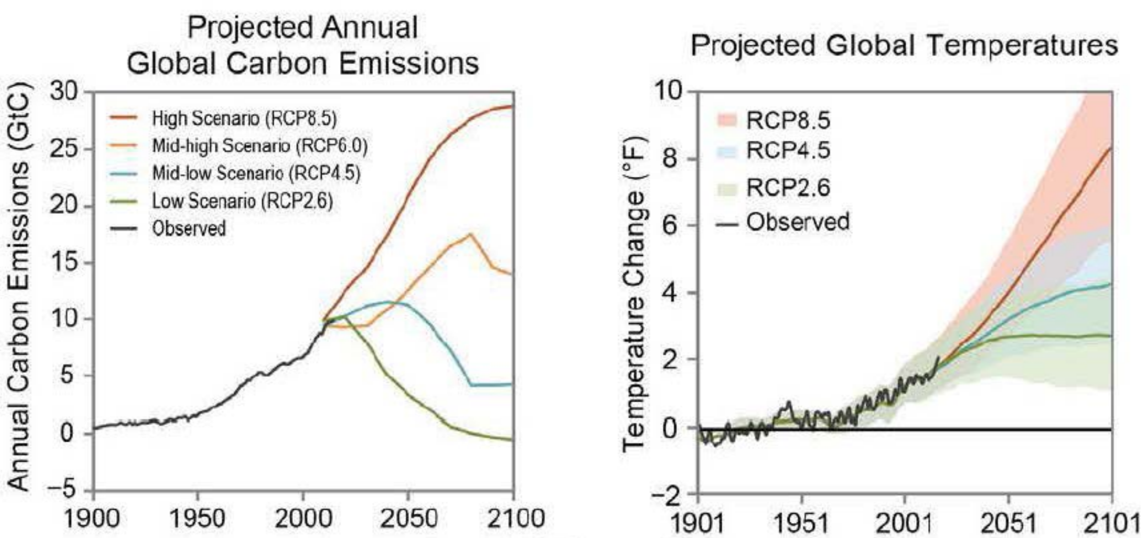

Figure 1. Greater carbon emissions lead to greater warming. (Multiply by 44/12 to convert C to CO_2 emissions)

Figure 2 shows the recent trend of global emissions[7] of CO_2. During the 2000s, global emissions increased rapidly as China industrialized by building inefficient coal-fired power plants, leading to unacceptable pollution levels in their cities. China's massive shift from coal to renewable power this decade (as well as a shift towards ultra-supercritical coal-fired power plants, and the shift away from coal by other nations) has stabilized global emissions, which have now been flat for 3 years. It is possible that global emissions are close to their peak, and RCP8.5 may have been avoided. However at 36 Gt CO_2 emissions per year (equivalent to 10 Gt of C in Figure 2), atmosphere CO_2 is rising rapidly, and this is accelerating climate change. An 80% drop in fossil fuel emissions is needed to stop the rise of CO_2 in the atmosphere. This will stabilize the climate, although this will still take decades, because so much energy is being stored in the oceans for the future.

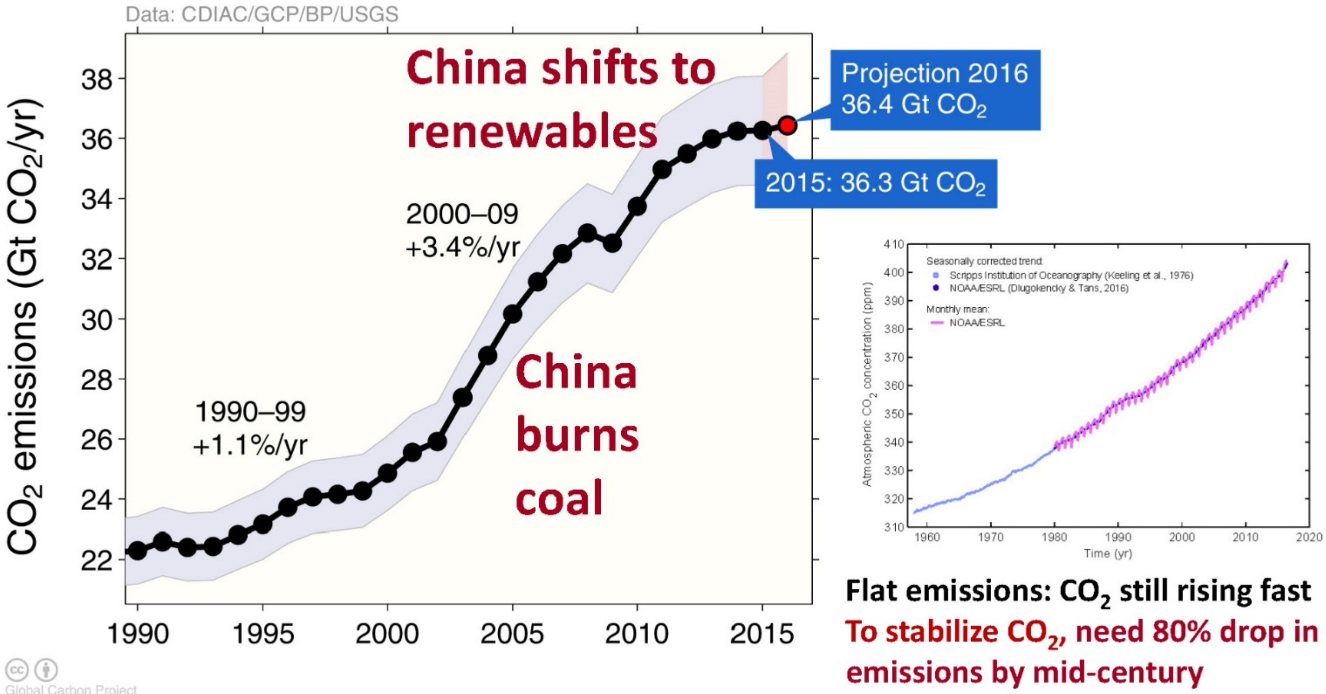

Figure 2. Annual global CO_2 emissions since 1990 (left) and (right) rise of CO_2 on Mauna Loa

Figure 3 shows the projected mean annual temperature increases for North America for mid-century and end of century for the high (RCP8.5) and mid-low (RCP4.5) emissions scenarios. For Vermont for RCP4.5, annual mean temperature will rise about 4F by mid-century and above 5F by late century. For RCP8.5 the increases are about 5F by mid-century and above 9F by late century[6]. These are annual means; winter temperature increases are likely to be higher because of reduced snow cover (see later).

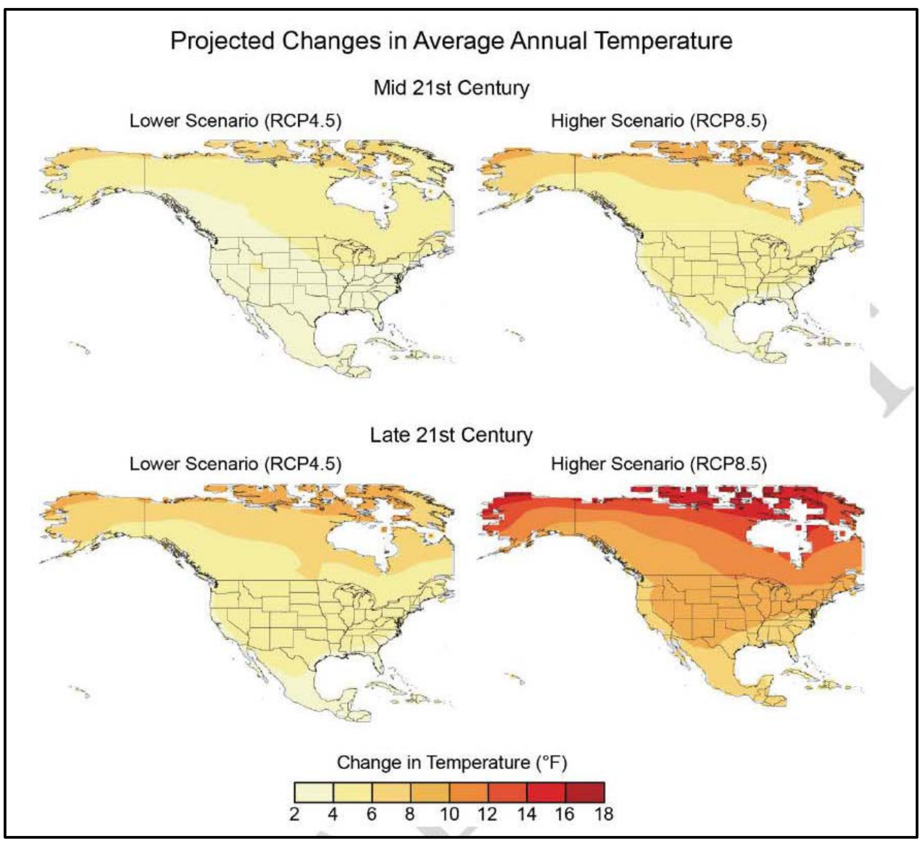

Figure 3. Significantly more warming occurs under higher greenhouse gas concentration scenarios

This schematic map from the 2007 Northeast Climate Impacts Assessment[8] gives a visualization of what summers in Vermont will feel like in terms of heat index over the course of this century with high and low greenhouse gas emissions. With high emissions, Vermont's summer climate by 2080 will feel similar to the climate of northwest Georgia for the period 1961-1990. However, with low emissions, the climate of Vermont will more closely resemble the past climate of southeastern Ohio.

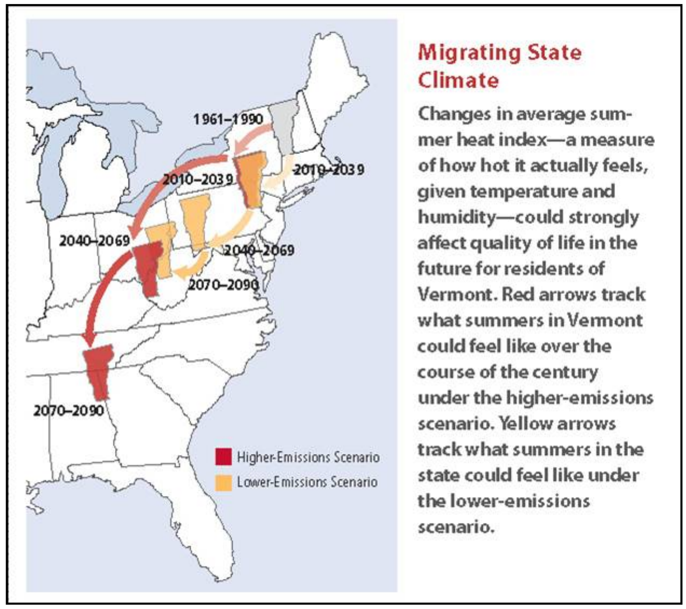

Figure 4. Schematic illustrating change of Vermont's summer climate by late-century with high and low emission scenarios

2.2 Precipitation projections

This map shows the projected seasonal changes in North American precipitation[6] by the end of the century for the RCP8.5 high emission scenario.

Precipitation is much less predictable than temperature, but these model projections reflect an increase of precipitation with warming at high northern latitudes, as well as a reduction of precipitation across the southern US. This reduction is associated with a poleward shift of the subtropical dry zones, which we are already observing [9]. Evaporation increases with temperature; therefore in regions where precipitation decreases, an increase in drought frequency is likely[10].

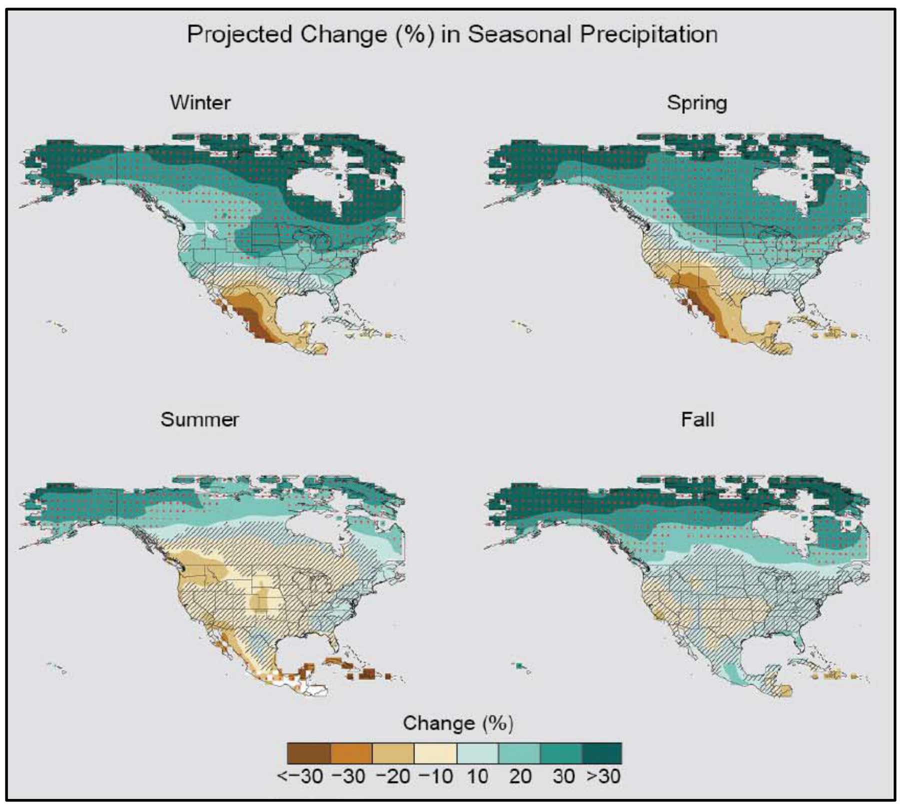

Figure 5. Projected change (%) in total seasonal precipitation from CMIP5 simulations for 2070-2099 for the RCP8.5 pathway. The values are weighted multimodel means and expressed as the percent change relative to the 1976-2005 average. Stippling/hatching indicates that changes are assessed to be large/small compared to natural variations. Data source: World Climate Research Program's (WCRP's) Coupled Model lntercomparison Project.

For Vermont the projected mean changes are increases of about 30% in winter, 25% in spring, and the changes in summer and fall are not considered statistically significant. In New England, earlier snowmelt, and more runoff from heavier summer rainfall, coupled with increased evaporation, may increase the frequency of summer droughts[11].

3. Observed continental climate changes in recent decades

Section 2 is model projections for the rest of this century for different emission scenarios. These projected changes are broadly consistent with the climate trends seen in the Northeast in recent decades[5,6,11,12,13]. This section is the most recent overview[6] of continental-scale changes.

3.1 Observed changes in temperature

Figure 6 shows the increase in annual mean temperature across the US in the past thirty years compared to the early 20th century. Temperature has increased in Vermont by more than 1.5F, with the largest warming in winter[6] (not shown).

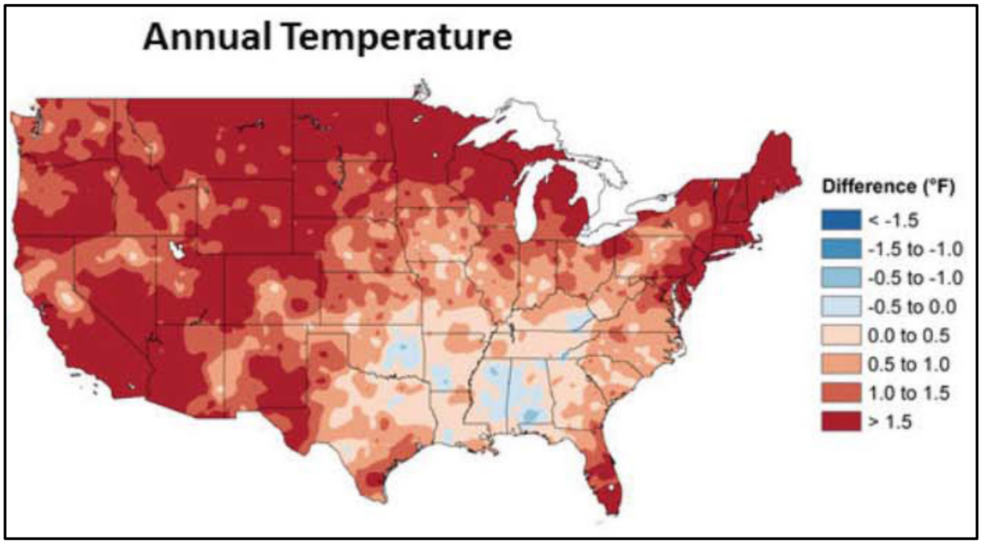

Figure 6. Change in annual temperature: present-day (1986-2015) minus the average for (1901-1960).

3.2 Observed changes in precipitation

Figure 7 shows the increase in precipitation in the past thirty years compared to the early 20th century. Precipitation has increased in Vermont by 10-15% in the past thirty years[6], with increasing trends throughout much of the year.

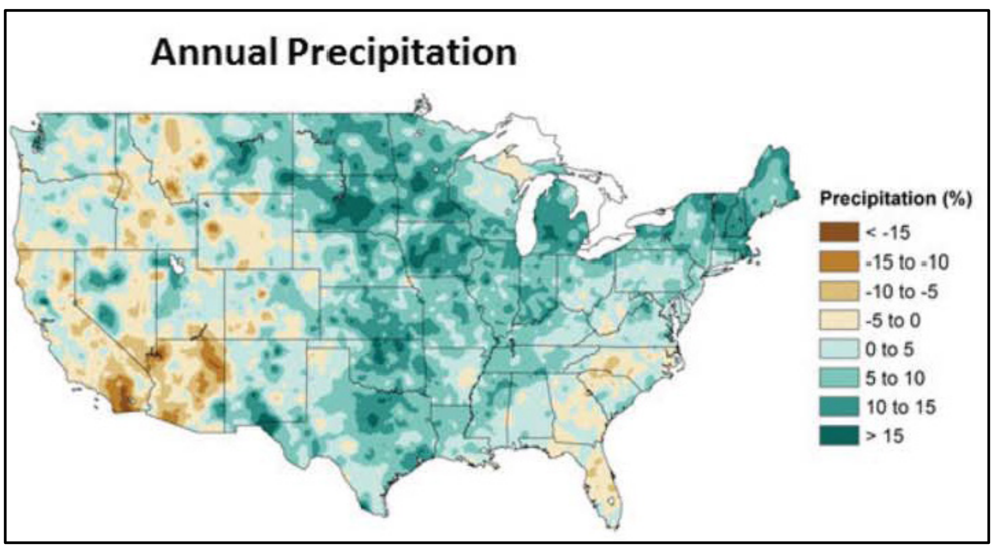

Figure 7. Percent change in annual precipitation: present-day (1986-2015) minus the average for (1901-1960).

Figure 8 shows several measures of the observed change in heavy precipitation[6] with 1901-2016 (left) and 1958-2016 (right). The circled numbers are regional averages, and the largest increases in heavy rain episodes are for the northeast region.

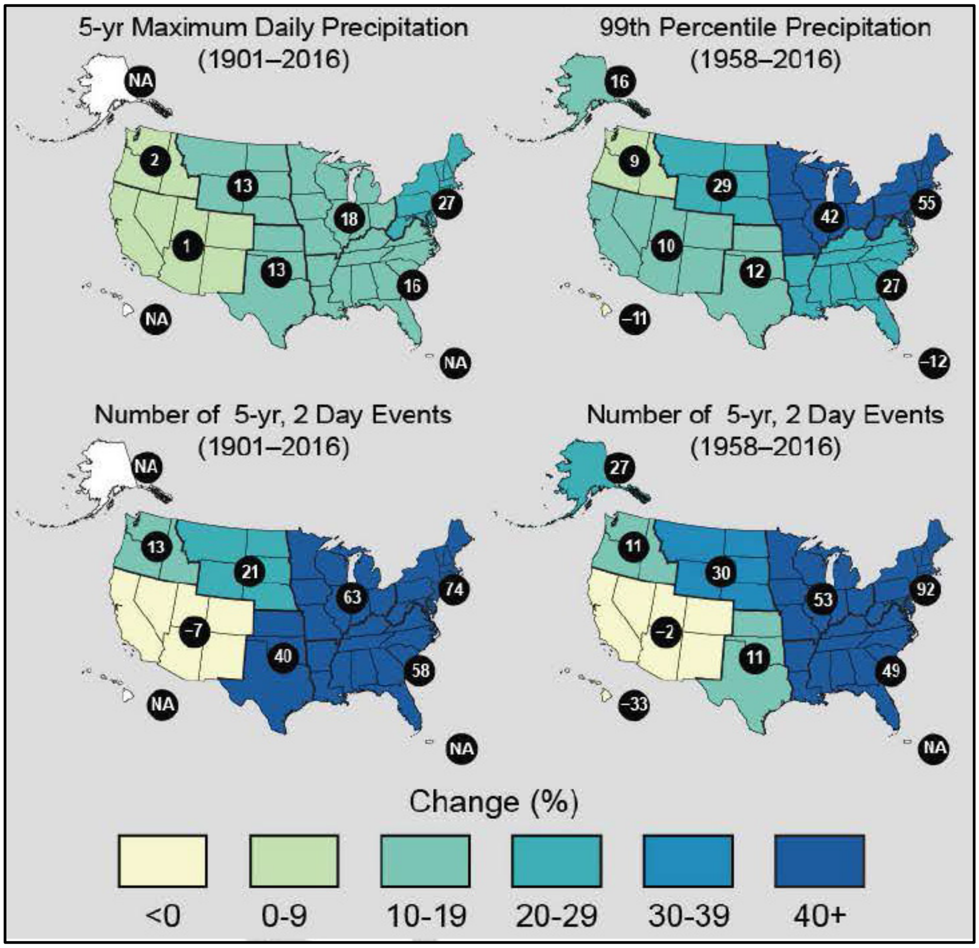

Figure 8. These maps show the change in several metrics of extreme precipitation by NCA4 region, including (upper left) the maximum daily precipitation in consecutive 5-year blocks, (upper right) the amount of precipitation falling in daily events that exceed the 99th percentile of all non-zero precipitation days , (lower left) the number of 2-day events with a precipitation total exceeding the largest 2-day amount that is expected to occur, on average, only once every 5 years, as calculated over 1901-2016, and (lower right) the number of 2-day events with a precipitation total exceeding the largest 2-day amount that is expected to occur, on average, only once every 5 years, as calculated over 1958-2016.

A recent detailed study[14] has suggested that the large increase in extreme precipitation in the northeast in recent decades came after an abrupt upward shift in 1996.

This increase in heavy precipitation increases the risks of flooding. Water management has traditionally been based on historical precipitation statistics, but this assumption is no longer valid. [15]

USGS has recently developed a framework for a hydrologic climate-response program in New England.[16] This shows that the warming since 1970 has led to earlier spring flow consistent with earlier ice-melt of lakes.

4. Seasonal climate trends in Vermont

This section will review Vermont temperature trends, trends in frost dates and the frozen period for the reference lake Stiles Pond. We will also show the continental-scale change in the USDA plant hardiness zones since 1990.

4.1 Summer and winter temperature trends since 1960

Figure 9 shows the mean trends in Vermont summer temperatures and winter temperatures since 1960 from an average of four Vermont climate stations in Burlington, Cavendish, Enosburg Falls and St. Johnsbury[17]. From 1960-2016:

- Summer temperature trend is 0.34 (±0.09)°F per decade
- Winter temperature trend is 1.00 (±0.24)°F per decade (includes the 2016-17 winter)

The upward trend in winter temperature is about three times as large as in summer. Note that the variability from year to year in winter is more than twice as large as in summer. In 55 years, mean winter temperatures in Vermont have risen about 5.5 °F; while in summer, mean temperatures have risen almost 2 °F.

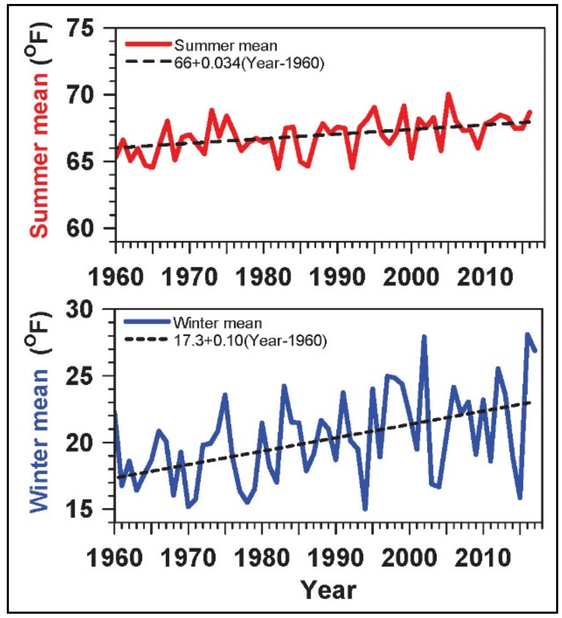

Figure 9. Summer and winter temperature trends since 1960.

The annual mean trend for Vermont is the same as for New England, about 0.5 °F per decade. If we extrapolate the observed mean annual warming trend for Vermont of 0.5°F per decade from 1970 out to 2050, we get a 4°F warming, which is comparable with the model annual projections shown in section 2 for the period 1990-2050.

4.2 Length of Vermont's growing season

These warming trends are affecting the timing and nature of the Vermont seasons[17,18,19]. Figure 10 shows how the first and last freeze dates have been changing, and the length of the growing season is increasing. There is large variability from year to year, as first and last frosts are single night events, but the trend lines show that on average:

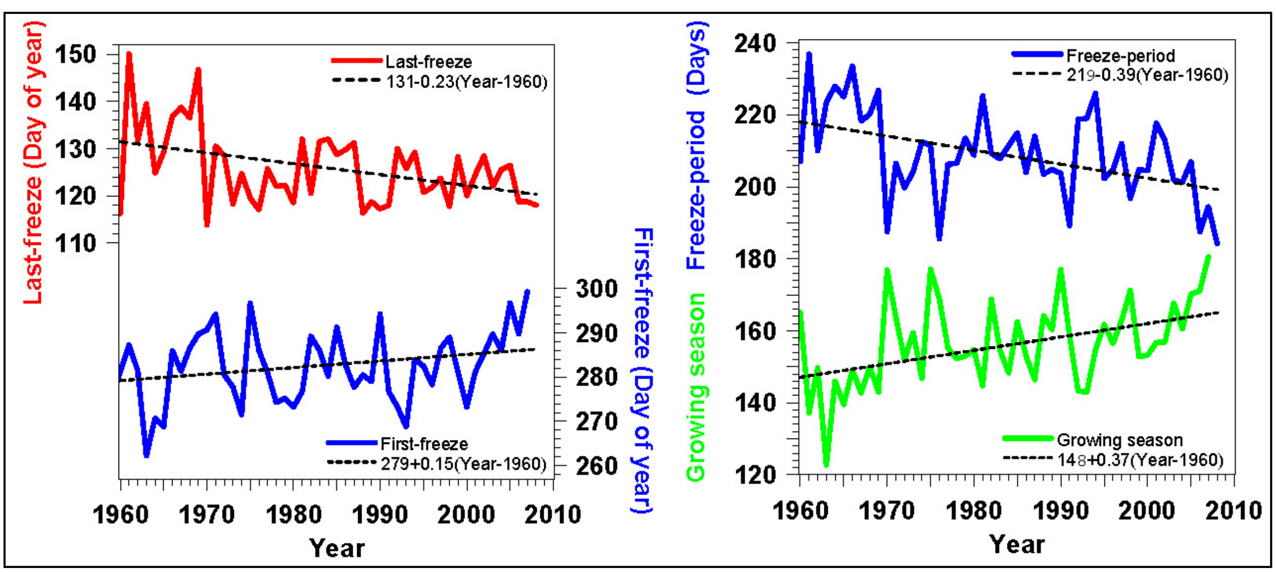

Figure 10. (left) Last spring freeze and first autumn frost and (right) length of freeze period and growing season. Data from [18], not updated to present.

- Last spring freeze has come earlier by 2.3 (±0.7) days per decade
- First autumn freeze has come later by 1.5 (±0.8) days per decade
- Freeze-period has decreased 3.9 (±1.1) days per decade
- Growing season has increased 3.7 (±1.1) days per decade

These trends show that in the past forty years, the growing season for frost-sensitive plants has increased by about 2 weeks.

4.3 Freeze-up, ice-out and frozen duration for a Vermont reference lake

The freeze and ice-out dates for small lakes are good integrated climate indicators for the length and severity of the cold season in Vermont[17]. The date of freeze-up depends on lake and air temperatures over many weeks in the fall; ice thickness depends on the severity of the winter; and the date of spring melt/ice-out depends on ice thickness and air temperatures in spring. These dates are important for the ecology of the lakes; and the frozen period and ice thickness matter to the public for winter recreation, including ice fishing.

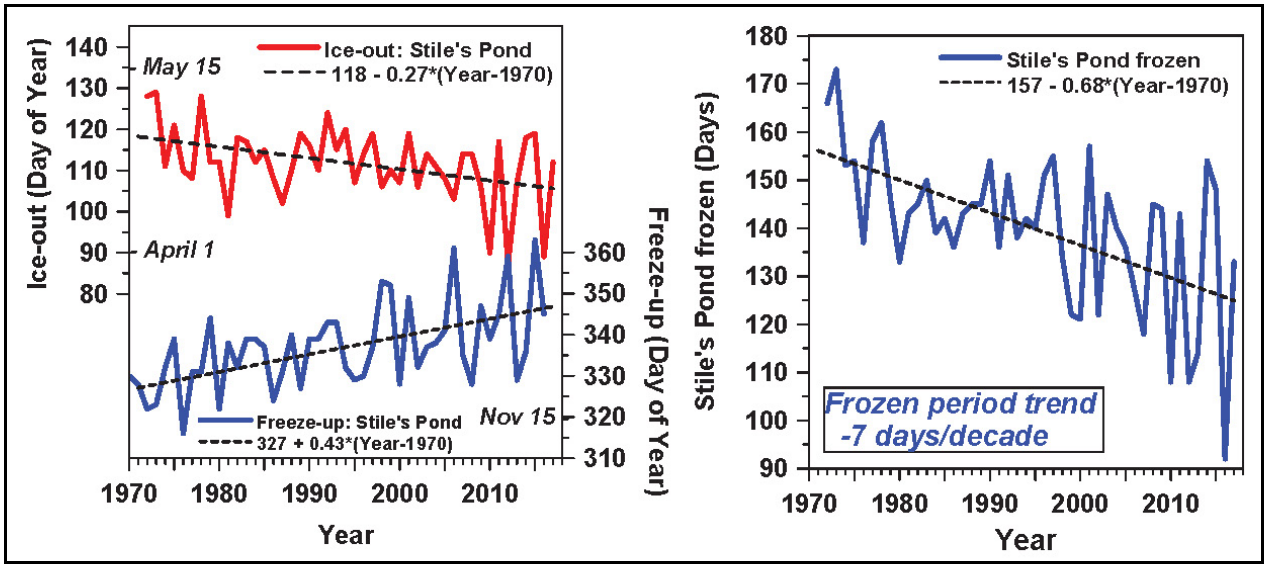

Figure 11. Freeze-up and ice-out days for Stile's Pond (left) and (right) winter frozen period for Stile's Pond.

Figure 11 shows the freeze-up and ice-out dates for Stile's Pond in Waterford, Vermont (44^{o}25'N, 71^{o}56.4W, elevation 880ft), which have been recorded since 1972 by the Fairbanks Museum in St. Johnsbury. Despite the large variability from year to year, trends are clear.
For Stile's Pond over the past forty winters:

- Freeze-up has occurred later by 4.3 (±1.0) days per decade.
- Ice-out has come earlier by 2.7 (±0.9) days per decade.
- Lake frozen duration has decreased by 6.8 (±1.5) days per decade.

These results show that as our northern climate has warmed substantially in fall, winter and spring, Stile's Pond is frozen for 4 weeks less on average than forty years ago. However it is clear from Figure 11 that the interannual variability in the last few years has been huge: we will review the difference between the 2015 and 2016 winters in section 5 below.

4.4 Change in winter hardiness zones

The USDA winter hardiness zones are determined by average minimum winter temperatures in 10°F ranges. They tell us what plants, shrubs and trees are likely to survive a typical winter. Figure 12 shows that the winter minimum temperatures have climbed across most of the US. Vermont has changed[20] from mostly Zone 4 to mostly zone 5 between 1990 and 2015; Massachusetts has become almost all Zone 6, and parts of southern Connecticut and New York have become Zone 7. In Vermont, this rise of the winter minimum temperatures has greatly benefitted local food production, because more vegetables can now be overwintered, or planted in February in unheated high tunnels with row covers as needed.

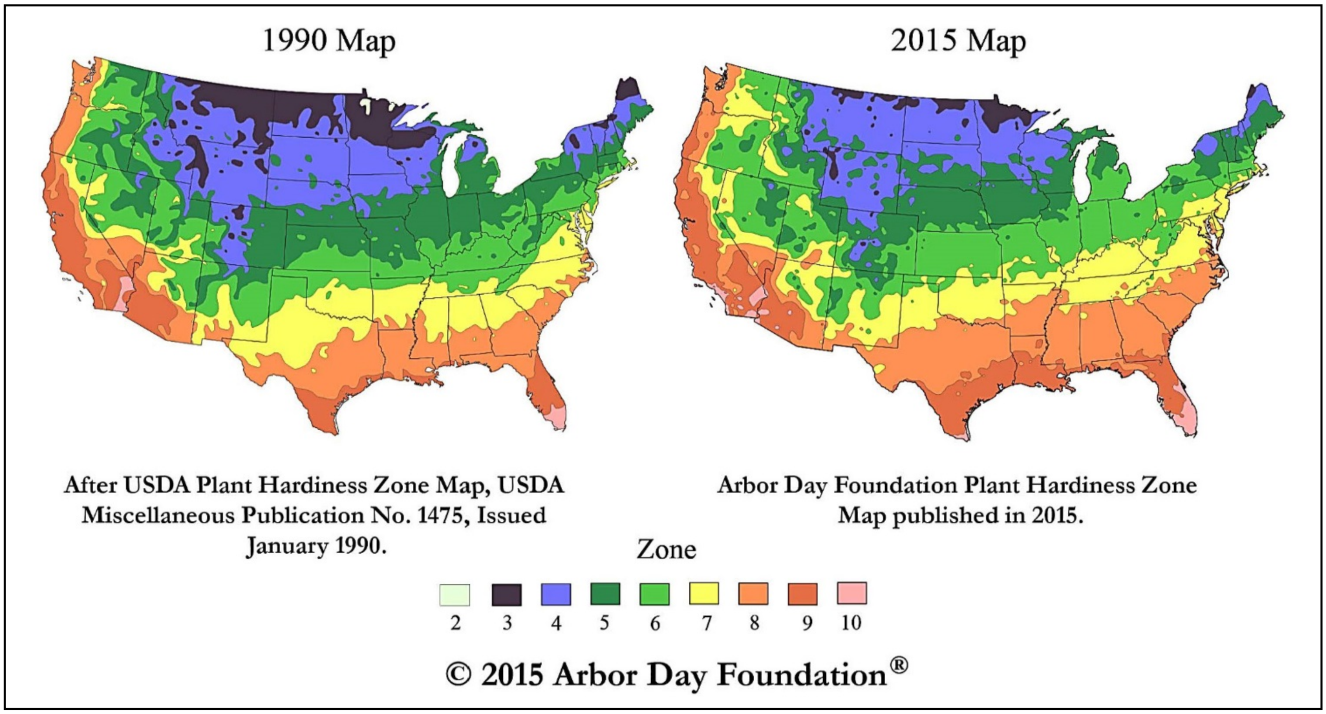

Figure 12. Change in plant hardiness zones across US between 1990 and 2015

5. Understanding increasing extremes

There are many signs that severe weather is increasing globally with simultaneous droughts, fires and floods. However, our understanding is still very incomplete, because the whole global climate system, oceans, land, ice and atmosphere are fully coupled, and the climate is moving into new states that have been rare in the past. Some aspects we do understand. As greenhouse gases increase in the atmosphere, this reduces the cooling on the Earth to space, and the Earth warms. Much of the heat is stored in the oceans, which are getting warmer. Evaporation increases steeply as ocean temperatures increase. This lead to more water vapor in the atmosphere and heavier precipitation rates. More atmospheric water vapor warms the planet more because water vapor is a powerful greenhouse gas; and the latent heat release from heavier precipitation drives stronger storms.

The 2017 hurricane season is illustrative. Surface temperatures are high in the Atlantic, Caribbean and Gulf of Mexico; and hurricanes Harvey, Irma, Jose and Maria all grew rapidly to category 4 or 5 storms over the warm water in conditions of low vertical wind shear. Harvey had a heavy rain rate, typical of a strong hurricane, of around 12in per day. But it became a flooding disaster for Houston, because stationary blocking high pressure patterns to the north prevented it from moving north and inland as most hurricanes do. So it stayed over the southern Texas coast for 3-4 days, drawing water from the warm ocean, and total rain amounts reached 3-4 feet. We can forecast the strength and motion of the hurricane from the large scale weather patterns, but we cannot yet forecast the nearly stationary large-scale patterns far ahead. Stationary high pressure systems across the western US in summer 2017 have also led to record temperatures and low rainfall, leading to major fires. The following hurricane Irma became the strongest category 5 storm recorded in the Atlantic with 180 mph winds; and heavily damaged many islands, as well as Florida. Hurricane Maria followed and strengthened to Category 5 with severe damage to more Caribbean islands. Its passage across Puerto Rico heavily damaged the island's basic infrastructure.

Historically many broad features of the global climate could be linked to ocean temperatures, but now the Arctic is also changing rapidly and affecting mid-latitude climate. It has been suggested that the warming of the Arctic has changed the jet-stream patterns, but issues remain unresolved[21,22]. Recent research[23] reported in *Nature* shows the link between anthropogenic climate change, planetary wave resonance (that is nearly stationary jet-stream patterns) and extreme weather events.

Here we will illustrate this issue with three examples of extremes of the Vermont climate in the past decade.

5.1 Two contrasting winters: 2015 and 2016

The variability between warm and cold winters, as illustrated by the frozen period of Stile's pond in Figure 11, has become extremely large in recent years. This is linked with much larger scale nearly-stationary patterns. Figure 13 contrasts the different global mean temperature anomalies[24] for the January–February–March periods in 2015 and 2016. In 2016, there are strong warm anomalies (red and brown) across the northern continents that lasted all 3 months. In contrast in 2015, there was a strong cold anomaly over eastern North America that lasted all 3 months, with 3 months of snow cover in northern New England and eastern Canada. The strong temperature contrast between the cold land and the warm ocean produced a series of powerful coastal storms that gave Boston a record 9 feet (2.7 meters) of snow. In 2016, this same region was very warm for three months, with very little snow cover. Snow cover acts as a climate switch[25]: with little snow cover, winter temperatures were about

10°F warmer in 2015 than in 2016 (see Figure 9). Stationary patterns like this that last for months produce climate extremes, and they appear to be coming more frequent. Unfortunately we are unable as yet to forecast them a season ahead.

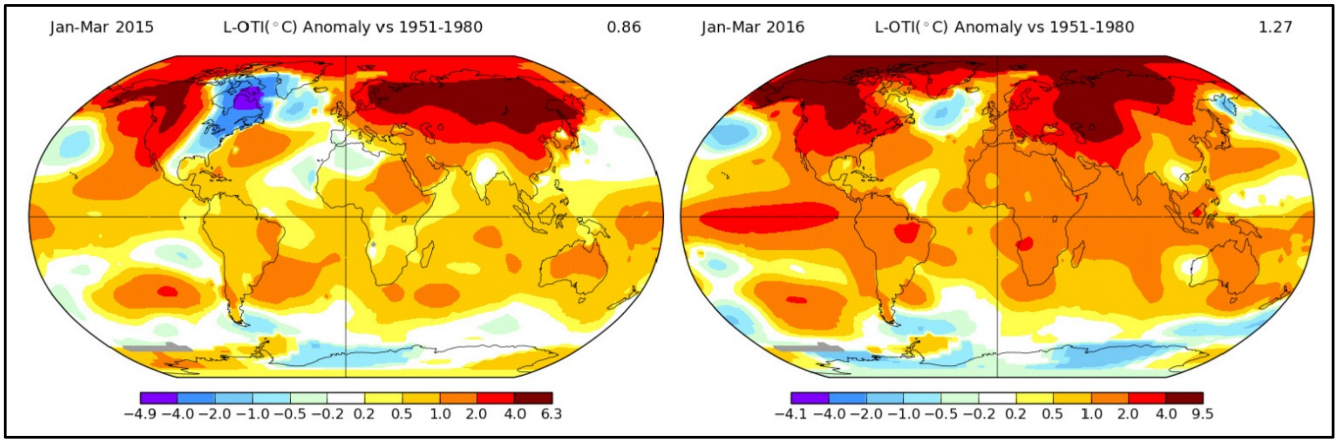

Figure 13. Contrasting global anomalies of temperature (in °C) for Jan-Feb-Mar 2015 and 2016 (Data are from NASA Goddard Institute for Space Studies)

5.2 Stationary patterns and severe flooding: the 2011 Vermont floods

The conditions that produce severe flooding are particularly important as Vermont develops plans for future river management. Vermont experienced two severe floods in 2011of different types, and these provide some insight. In the spring there was a very severe flood on the Winooski River and the Adirondack rivers. This was related to the rapid melt of a substantial winter snowpack with heavy rain and high temperatures in April. Lake Champlain rose to a new record of 103ft above sea level and stayed above flood stage (100ft ASL) for a record 2 months.

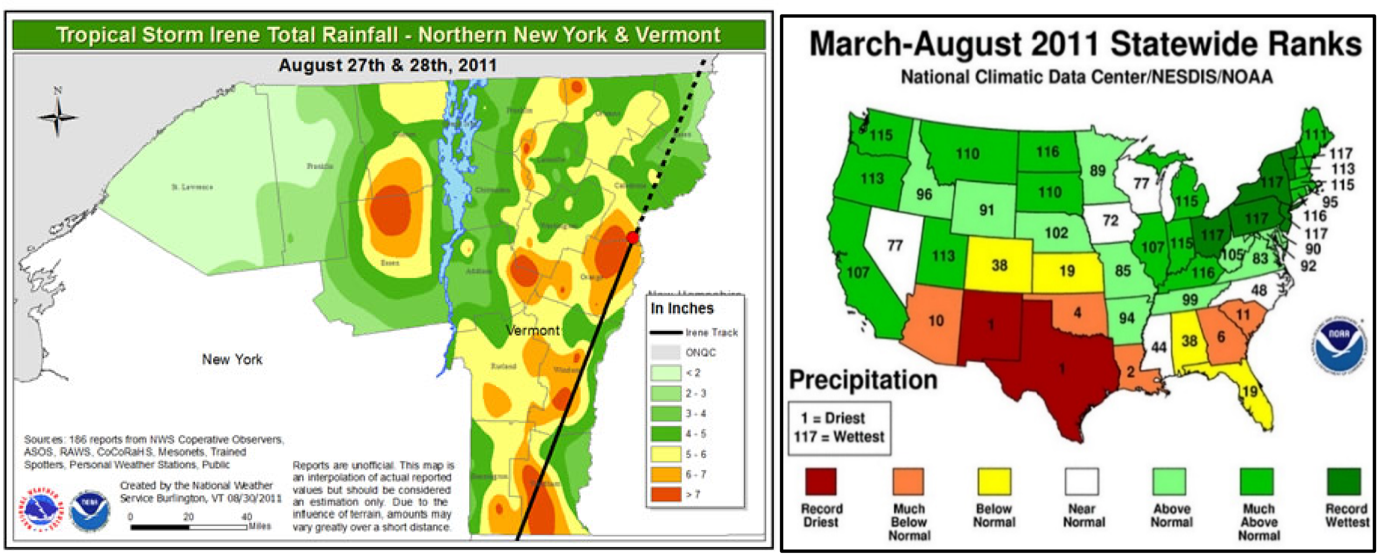

Figure 14. Track and rainfall totals for tropical storm Irene (left) and (right) statewide ranks of 6-monthly rainfall for March-August, 2011

The March-August 2011 precipitation set a new record for Vermont (see Figure 14). As a result, Vermont soils were unusually wet when tropical storm Irene moved up the Connecticut River valley in late August. The 6-8 inches of rain that fell on wet soils on the hilly Vermont landscape produced severe flooding, destroying bridges and roads and cutting off 19 Vermont towns.

Figure 14 (left panel) shows the track and precipitation totals for Irene as is crossed Vermont, produced by the National Weather Service Office in Burlington, VT. Figure 14 (right panel) shows the March-August 2011 ranking of state precipitation totals in terms of the 117-year precipitation record[26]. The states from Ohio to Vermont (labelled 117 in dark green) had the wettest 6-months on record, while Texas and New Mexico (labelled 1 in brown) had the driest 6-months on record. So for an extended period of 6 months, the storm tracks went north of Texas, and preferentially crossed the northeastern US.

5.3 Flooding in central Vermont on July 1, 2017

On July 1, central Vermont experienced severe flooding, as bands of slow moving storms moved across the state from 10 am to midnight EDT. Figure 15 (left) shows that the National Weather Service 24-hr precipitation totals were only in the range 2 to 3 in. However the right panel shows that this followed three months, when the Vermont precipitation was the 4th highest on record, and soils were already wet. The good local news from this event was that the carefully engineered and recently completed flood diversion culvert under route 7, built to protect Brandon after Irene, saved the town from another disastrous flood.

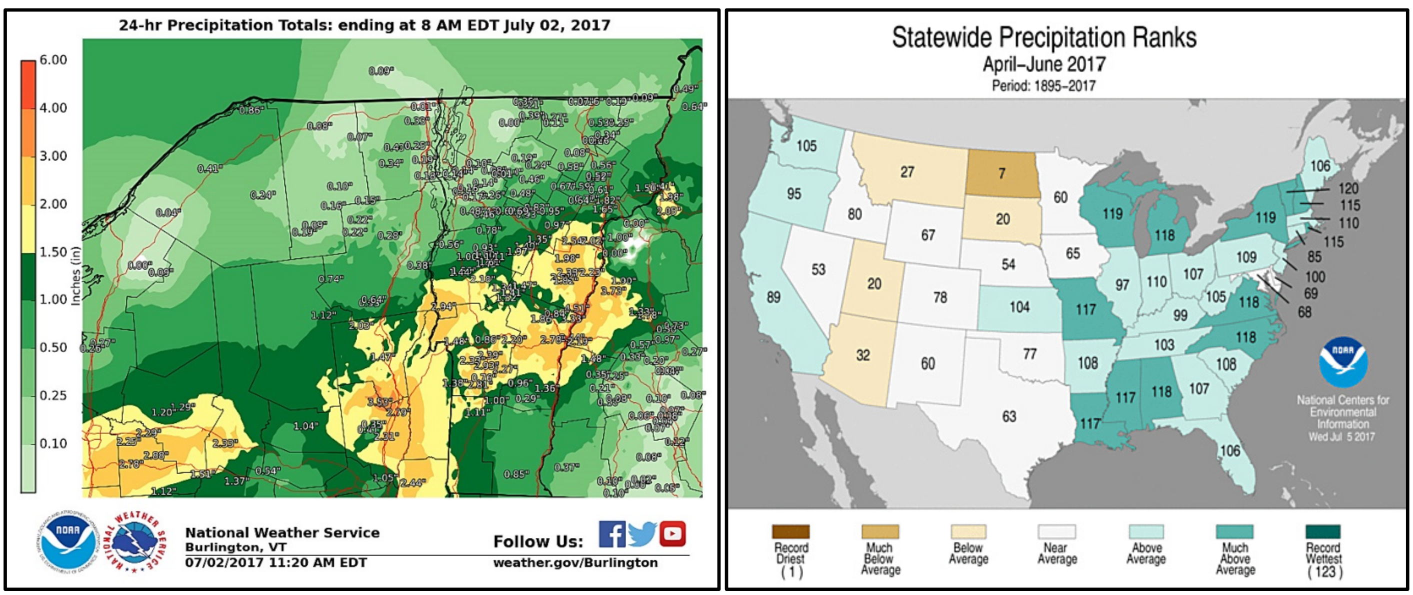

Figure 15 Precipitation totals for July 1, 2017 (left) and (right) statewide precipitation ranks for 3-monthly rainfall, April-June 2017. ***(Note layout and color scheme have changed since 2011)***

6. Summary of expected changes in the climate of Vermont

Broadly speaking, the changes projected by models for the next few decades, shown in section 2, are consistent with the climate trends seen in the Northeast and in Vermont in recent decades[5,6,11,12,13]. Since 1970 the annual average temperature in the Northeast has increased by 2°F, and average winter temperatures have risen nearly 5°F. Extreme winter minimum temperatures that determine the survival of plants, shrubs and trees as well as some pests, have risen about 10°F since 1990. However interannual variability, especially in winter, has also been increasing. This presents a challenge for adaptation planning.

Warmer temperatures result in some clear shifts of climate:

• Earlier arrival of spring and later arrival of winter
• A longer frost-free growing season and winter survival of protected crops
• Increased heavy precipitation extremes, bring more frequent flooding
• In many winters: reduced snowpack as some winter precipitation shifts from snow to rain
• And earlier snowmelt and breakup of winter ice on lakes and rivers, giving earlier peak river flows

However the increased winter variability, linked to very different stationary weather patterns, has given us some cold winters with extended snow cover, similar to those of decades ago. This variability is linked to global scale changes in weather patterns in mid-latitudes, and it is unclear whether these are well represented by model climate simulations for the future. Models predict a significant increase precipitation in winter and spring, but not in summer and fall. As a result, models also predict more frequent summer days with temperatures above 90°F. However, Vermont has not seen this yet, because 13 out of the past 15 summers have had above average precipitation, so that increased evaporation has reduced warm temperature extremes.

On a larger scale, rising sea surface temperatures and rising Great Lake temperatures can affect Vermont. Lake effect snow storms are increasing, as lakes freeze less frequently. The warming Gulf Stream powers stronger winter coastal storms: the winter of 2015 was the most recent example when 9 ft of snow fell on Boston, and substantial snow fell on Vermont.

Although we cannot predict in detail the changes in weather patterns resulting from climate change, we can summarize the seasonal changes we are likely to see in Vermont in the coming decades:

In winter:

- Later arrival of winter
- Warmer winters: continuing upward shift of USDA climate zones
- More overwintering of pests
- Increased winter precipitation
- More wet snow and freezing rain
- Multiple melt events in the winter with possible flooding
- Shortened ski, snowmobile, ice-fishing, and snowshoeing season
- Increased variability between winters, linked to fraction of days with snow cover

In spring:

- Sugaring season shifts earlier and ends earlier; possibly reduced productivity of sugar maples
- Earlier ice-out of lakes and ponds

- Earlier spring melt and run-off; larger stream flows and possible flooding if substantial snowpack
- Earlier arrival of spring for daffodils and forsythia
- Earlier last spring frost (on average)
- Earlier bloom dates for many plant species; but more false springs, when early blooms are damaged by a late frost

In summer:

- Longer growing season
- Hotter summers, unless rainfall is above average
- Reduced productivity of cold-weather crops
- Reduced productivity of dairy cows
- More heavy rain events
- More frequent floods and associated flood damage
- Greater frequency of 1-2 month droughts
- Increased warm-weather pest species, such as mosquitoes, ticks, and algae in lakes
- Increased threats to cold-water fish and wildlife species
- Increased hazards to human health, including heat waves and the spread of disease
- Increased hazards to human safety, such as landslides, flooding, and violent storm events
- Increased threat to infrastructure, such as roads and bridges near streams and rivers
- Worsening air quality in some areas

In fall:

- Warmer fall temperatures
- Later first fall frost
- Possibly increased fall precipitation and stream flow
- Later fall color: possibly reduced fall color

More broadly, Vermont will need to study further how its iconic landscape and forest species will be impacted, as the climate is now changing on decadal timescales. In fact we need ongoing detailed decadal statistics on both seasonal climate and increasing severe weather, so that we can update our perspective frequently.

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