Extreme Heat Events in Vermont

Current Health Burden, Thresholds, Vulnerabilities and Future Outlook

VERMONT
DEPARTMENT OF HEALTH

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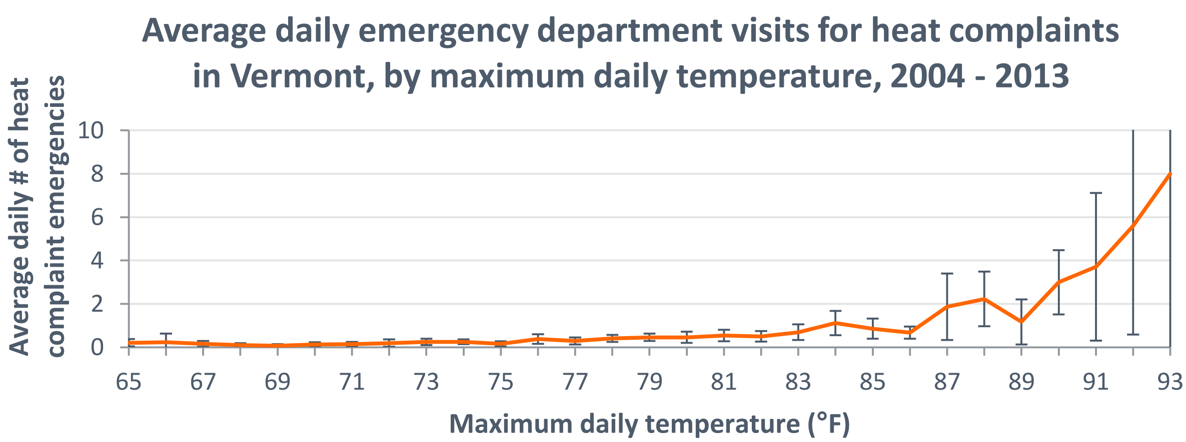
Executive Summary

A Vermont Department of Health analysis shows that Vermonters are at greater risk for serious heat-related illnesses, and even death, when the statewide average temperature reaches 87°F or hotter. Since 2000, Vermont has had an average of seven hot days per year when the temperature reached 87°F or hotter. Climate models from the Vermont State Climate Office predict 15 to 20 hot days per year by mid-century and 20 to 34 hot days per year by the end of the century. In the absence of adaptation, as the climate warms and there are more hot days, more heat-related illnesses and deaths will occur.

This summary describes how extreme heat in Vermont affects health and discusses responses and ways we can adapt and reduce these health effects.

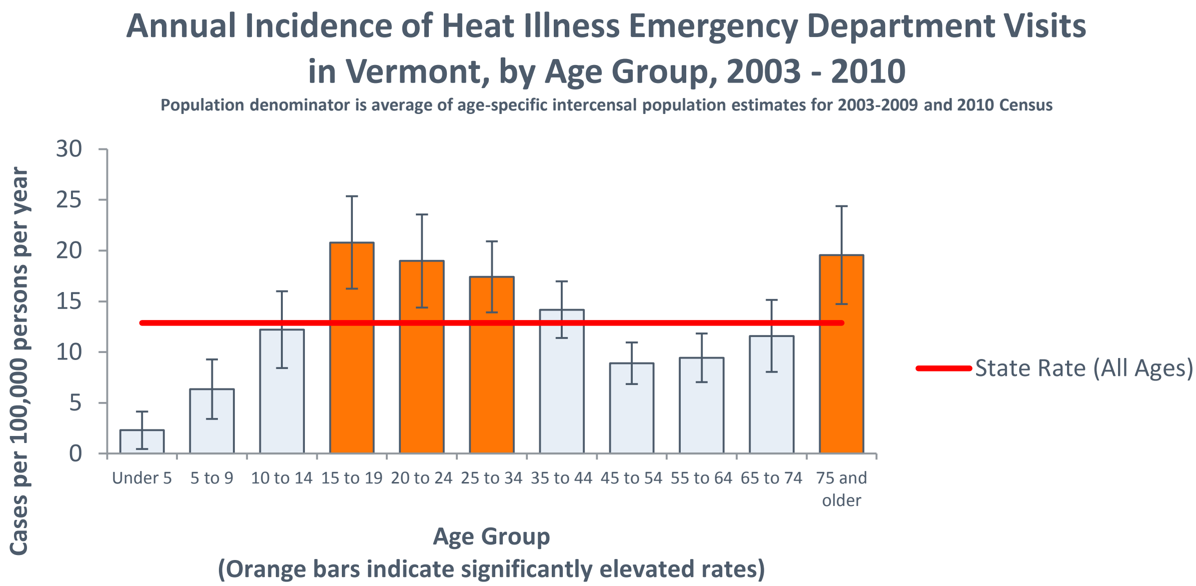
Findings

Working with the Vermont State Climate Office, the Health Department analyzed 14 years of temperature, death, and emergency department data. On days when the statewide average temperature reached at least 87°F, heat-related illnesses, such as heat exhaustion and heat stroke, occurred eight times more frequently, and there was one additional death per day among individuals age 65 and older. Heart disease, stroke, and neurological conditions were more common causes of death on these hot days. The statewide average temperature of 87°F corresponds to a range from about 85°F in cooler counties like Bennington and Essex to almost 89°F in warmer counties like Chittenden and Windham.



Data sources: temperature data - PRISM Climate Group, Oregon State University, in partnership with the Vermont State Climate Office and the National Oceanic and Atmospheric Administration's Postdocs Applying Climate Expertise Fellowship Program, University Corporation for Atmospheric Research; emergency department data - Early Aberration Reporting System (EARS).

Vermonters may be more affected by heat for two reasons: our bodies are not adapted to hot temperatures and many homes and businesses are not well designed to deal with summer heat. This may help explain why some of the highest rates of heat-related illnesses occur in cooler counties in Vermont. Adults 75 and older and people between the ages of 15 to 34 are affected most by heat-related illnesses. Adults 65 and older are at higher risk for death on hot days.



Data source: Vermont hospital discharge data

In addition to the at-risk age groups identified using Vermont data, those who work or exercise outdoors, infants and children, people who are obese, those with a long-term medical condition, and people living in more urbanized areas tend to be at greater risk. Some people will have heat-related illnesses at temperatures even lower than the mid-80s.

Responding to an extreme heat event

Care should be taken on hot days, especially by those who are at greater risk. The Health Department recommends that people:

- Stay in a cool location – either in the shade outdoors or in a cool room inside such as a basement or air conditioned room
- Draw shades while inside to keep out the sun
- Limit exercise and outdoor activity during the hottest midday hours
- Wear lightweight, light-colored, and loose-fitting clothing
- Take a cool shower or bath, or go swimming in a safe location
- Drink more water than usual—don't wait until you're thirsty to drink
- Avoid alcohol, caffeine, and drinks containing high amounts of sugar
- Rest if you feel faint or sick
- Check in on loved ones and neighbors
- Follow local weather and news reports
- Sign up to receive alerts at vtalert.gov
- Never leave children, pets, or adults with disabilities in a parked vehicle

Additionally, the Health Department encourages all Vermonters to learn how to recognize and respond to heat-related illness. Heat cramps may be the first sign; other signs may include weakness, heavy sweating, nausea, vomiting, dizziness, fainting, and confusion.

More information on heat-related illness—how to prevent it, signs to look for, and what to do—is available on the Vermont Department of Health website at: healthvermont.gov/emerg/extremeheat.aspx. Additional resources from the National Weather Service can be found here: www.nws.noaa.gov/om/heat/index.shtml.

Adaptation to a warmer future

On average each year, Vermont currently has 23 excess emergency department visits for heat complaints and five excess deaths on days when the statewide average temperature reaches or exceeds 87°F. By mid-century, we expect 54 to 72 excess emergency department visits for heat-related complaints and 12 to 16 excess deaths. By the end of the century, we expect 72 to 124 excess emergency department visits for heat-related complaints and 16 to 28 excess deaths.

Since there will likely be more hot days in the future because of climate change, it is important for people, communities, and state agencies to take proactive steps to reduce heat-related health risks. It is possible that our bodies will adapt over time to deal with the impact of warmer temperatures. However, we do not know whether these physiological changes will be sufficient to make sure that health impacts from hot temperatures do not get worse.

Some steps that can be taken to better prepare for and lessen the effects of extreme heat events include:

- **Individuals and business owners** can:
  - Modify buildings to increase fresh air flow during summer heat, improve energy efficiency, and plant trees around buildings for more shade
  - Put in air conditioners, heat pumps, or similar cooling devices
- **Communities** and community groups can:
  - Create a community response plan for extreme heat events
  - Set up local cooling centers
  - Use local aid networks to find, check-in on, and assist at-risk people
  - Create cancellation policies for workers, students, and activities on hot days
  - Plant trees and shrubs, and reduce paved surfaces in urbanized areas
  - Use energy-efficient building design, including use of cool roofs and pavements
- The **Health Department** and its partner agencies can:
  - Make people aware of the dangers of extreme heat events
  - Offer education on how to reduce the risk of heat-related illness
  - Create a public health response plan for extreme heat events
  - Identify the appropriate temperature for issuing extreme heat warnings
  - Offer extreme heat information to the public through the Vermont 2-1-1 phone line

In addition to reducing health effects related to extreme heat, many of the steps listed above help in other ways such as reducing energy usage and costs, reducing greenhouse gas emissions, reducing air pollution, improving water quality, and increasing property values.

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Introduction

Exposure to extreme natural heat contributes to substantial morbidity and premature mortality in the United States (Xu, 2012; Kovats and Hajat, 2008). Climate change is expected to lead to warmer temperatures, further increasing the impact of hot temperatures on human health (Patz et al., 2005). However, the response of health outcomes to heat exposure varies by local climate, geography and demographics (Basu and Samet, 2002). For instance, populations living at higher latitudes usually begin to experience health effects at lower temperatures than those living further south. Local analyses of the heat-health relationship are thus needed not only to estimate the health burden due to heat in a particular area, but also to determine the local meteorological conditions and population risk factors associated with these health impacts. This report summarizes the Vermont Department of Health's first comprehensive investigation into the health effects of extreme heat in the state.

This report describes the following:

1. Extreme heat impacts on health
2. Individual precautions that should be taken on hot days
3. Temperature trends and projections in Vermont
4. The impact of hot days on heat-related illness and death in Vermont
5. Projected health impacts of a warmer future
6. How individuals, communities, and the Health Department can adapt to a warmer future

Extreme heat impacts on health

Extreme heat is the leading cause of weather-related deaths in the United States (CDC, 2013). From 1999 to 2009, there were about 7,800 deaths in the United States that were directly attributable to heat. These deaths account for close to a quarter of weather-related deaths in the nation. Unfortunately, this number is likely a severe underestimate of the true death toll from extreme heat events, as it only takes into account those deaths in which heat is explicitly listed as a cause or contributing condition on the death certificate. Extreme heat events have also been associated with increased death and hospital admissions not just for specified heat-related illnesses but also for cardiovascular, kidney, and respiratory disorders (Luber et al., 2013).

When exposed to hot temperatures, the human body cools itself through two main thermoregulation processes: 1) the evaporation of sweat to help cool the skin, and 2) the redirection of blood to the skin, which can allow heat to dissipate, resulting in cooler blood returning to the rest of the body (Charkoudian, 2010). Humid conditions impair the ability for sweat to evaporate, which limits the body's capacity to cool down by sweating.

During extremely hot temperatures, blood redirected to the skin can put substantial stress on the heart, brain, lungs, muscles, and other organs, leading to reduced physical and mental function. Poor air quality, particularly related to ground-level ozone and particulate matter, can further exacerbate stress on cardiovascular and respiratory systems (Brunekreef and Holgate, 2002). Prolonged heat exposure may lead to heat cramps, heat exhaustion, heat stroke, other heat-related illnesses, and potentially death (CDC, 2013). Symptoms of heat-related illness include cramping, weakness, heavy sweating, nausea, vomiting, dizziness, fainting, and confusion.

Some populations are especially vulnerable to heat-related illnesses (CDC, 2013; Kovats and Hajat, 2008). Young children, older adults, those taking certain medications, and those with chronic health conditions or other impairments may not be able to thermoregulate effectively, resulting in increased stress on vital organs. For those with pre-existing medical conditions, thermoregulation may also put increased stress on already compromised systems. Young children can be particularly vulnerable due to their dependency on others for care, and should never be left in a motor vehicle during warm weather. Similarly, adults living alone, especially those with mobility difficulties or dependency on others for care, are at an increased risk.

Those living in urban areas can experience especially hot conditions due to the urban heat island effect, which is caused by the prevalence of impervious surfaces (e.g., pavement and rooftops) combined with the lack of open land and vegetation. Those living in top floor apartments are further affected by rising hot air being trapped below the roof. People in poverty are at an increased risk, largely because they are less likely to have air conditioning or have the financial resources to operate it. People who work outside, exercise outside, or are homeless are also at increased risk due to their high exposure.

There is no widely accepted definition of what constitutes an extreme heat event, because the temperature thresholds at which health effects begin vary by geographic region. The heat-health relationship is to some extent attenuated by physiological acclimation in populations that are accustomed to warmer climates and by adaptations in housing, air-conditioning, and lifestyle that these populations have developed over time. For instance, in New York City, analyses suggest that beyond a heat index threshold of between 95 and 100°F, excess mortality is detectable (Metzger et al., 2010). The heat index is a measure that incorporates both temperature and humidity. However, further north in Quebec, a temperature of 88°F has been associated with detectable increases in daily mortality (Health Canada, 2011). Not only do temperature thresholds differ from location-to-location, but variation also exists in whether temperature or heat index was found to be a more robust indicator.

Responding to an extreme heat event

Certain precautions should be taken on hot days, especially by those who are at greater risk. The Health Department recommends:

- Stay inside—in air conditioning if possible or cool places such as basements
- Draw shades to keep out the sun
- Seek shade when outdoors
- Limit exercise and outdoor activity during the hottest midday hours
- Wear lightweight, light-colored, and loose-fitting clothing
- Take a cool shower or bath
- Drink more water than usual—don't wait until you're thirsty to drink
- Avoid alcohol, caffeine, and drinks containing high amounts of sugar
- Rest if you feel faint or sick

- Check in on loved ones and neighbors
- Follow local weather and news reports
- Sign up to receive alerts at http://vtalert.gov
- Never leave children, pets, or adults with disabilities in a parked vehicle

Additionally, the Health Department encourages all Vermonters to learn the signs and first aid responses for heat-related illness. More information on heat-related illness—how to prevent it, signs and symptoms, and first aid responses—is available on the Vermont Department of Health website at: http://healthvermont.gov/emerg/extremeheat.aspx.

Climate change impacts on heat in Vermont

Over the last century, temperatures have warmed across the Northeast by about 0.16°F per decade (Kunkel et al., 2013). As Table 1 shows, this warming is not distributed evenly across seasons, with winter temperatures rising more than twice as quickly as summer temperatures (Kunkel et al., 2013).

Table 1. Seasonal warming trends in the Northeast over the last century (Kunkel et al. 2013).

Season	Temperature Increase °F/decade
Winter	0.24
Spring	0.14
Summer	0.11
Fall	0.12
Annual	0.16

The warming trend is sharper if calculated from 1960 onwards instead of from the beginning of the century. Figure 1 shows temperature trends for Vermont since 1960. Average temperatures in Vermont have risen by about 0.5°F per decade since 1960, with winter temperatures increasing by about 0.9°F/decade (±0.28°F) and summer temperatures by 0.4°F/decade (±0.12°F) (Betts, 2011). In other words, winter and summer temperatures are respectively about 4.5°F and 2°F higher than they were in 1960.

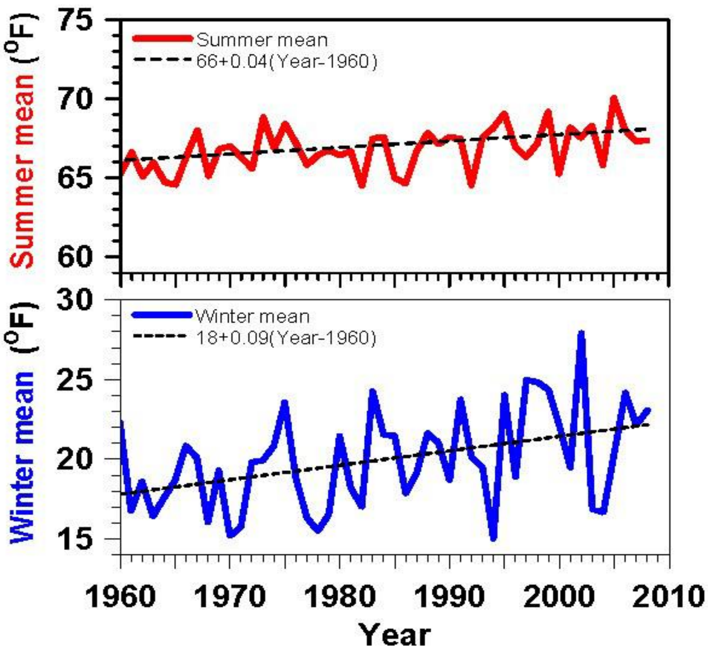


Figure 1. Trends in summer and winter temperature in Vermont (Betts 2011) Based on stations at Burlington, Cavendish, Enosburg Falls and St. Johnsbury.

Annual average temperatures are projected to continue to increase across Vermont. The Health Department partnered with Dr. Lesley-Ann Dupigny-Giroux, Vermont State Climatologist, and Dr. Evan Oswald, a Postdoctoral Fellow at the University of Vermont[1], to provide Vermont-specific projections of key climate indicators, which are described in greater detail in Appendix A. Table 2 summarizes the projected increase in average minimum and maximum daily temperatures over the year and by season for three different time periods, as compared to the 1981 – 2010 baseline. During the summer, both minimum and maximum temperatures are projected to be 3 to 7°F warmer by the end of the century depending on the amount of future greenhouse gas (GHG) emissions (the A2 scenario assumes more population growth, slower technological and economic change, and thus higher GHG emissions than the B1 scenario).

[1] National Oceanic and Atmospheric Administration's (NOAA) Postdocs Applying Climate Expertise Fellowship Program, University Corporation for Atmospheric Research

Table 2. Projected change in average maximum and minimum temperatures (°F) in Vermont compared to 1981-2010 averages (Seasons by month: Winter = DJF, Spring = MAM, Summer = JJA, Fall = SON)

Time Slice	A2 Scenario									
	Annual		Winter		Spring		Summer		Fall	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
2021 – 2050	2.1	2.3	1.8	2.9	2.4	2.2	2.1	2.0	2.2	2.0
2041 – 2070	3.7	4.2	3.5	5.7	3.7	3.7	3.8	3.7	3.7	3.7
2070 – 2099	6.6	7.4	5.9	9.5	6.7	6.7	6.7	6.7	6.8	6.6
Time Slice	**B1 Scenario**									
2021 – 2050	1.7	2.0	1.3	2.2	1.8	1.9	1.7	1.7	1.9	2.0
2041 – 2070	2.7	3.0	2.4	4.0	2.8	2.9	2.7	2.6	3.0	2.9
2070 – 2099	3.7	4.1	3.2	5.3	3.7	3.6	3.9	3.7	4.0	3.7

Weather data used in this analysis

The Health Department partnered with Dr. Lesley-Ann Dupigny-Giroux, Vermont State Climatologist, and Dr. Evan Oswald, a Postdoctoral Fellow at the University of Vermont, to develop and compile weather datasets describing historical and projected future temperatures in Vermont. Daily minimum, maximum, and mean temperatures between May and September from 1981 – 2012 were derived from the Oregon State University PRISM Climate Group's gridded dataset. The Vermont data contained 1,601 grid cells, with each grid cell measuring roughly 3.6 kilometers (km) from north to south and 4.6 km from east to west. This dataset combines recorded temperature observations at weather stations with interpolated temperatures for grid cells between weather stations. Interpolated temperatures are influenced by nearby recorded temperatures, elevation, topography, and other factors. PRISM data were combined with relative humidity data from the National Center for Environmental Protection's Climate Forecast System Reanalysis dataset to calculate heat index, though heat index was determined to be a poorer predictor of health impacts in Vermont than temperature alone.

Vermont's small population and low population density present a challenge for accurately estimating heat exposure and health impacts. Due to the State's small population, only a statewide analysis of the heat-health association was conducted (as opposed to regional or county-level analyses). To best account for the uneven distribution of both populations and temperatures across the state, daily statewide temperature was derived by first assigning each grid cell value a weight based on the amount of population living in the grid cell, then calculating a population-weighted average temperature across all 1,601 grid cells. The gridded population data were derived from U.S. Census data and are described in more detail in Owens and Gallo (2000).

More details on methods used to derive and weight temperature records in Vermont are described in Appendix B.

Emergency department visits for heat-related complaints in Vermont

Heat illnesses such as heat exhaustion, heat stroke, and heat syncope (dizziness), represent a substantial health burden in many states, including Vermont. The Environmental Public Health Tracking (EPHT) program tracks emergency department (ED) visits for heat stress occurring May through September (under the ICD-9 codes in the range of 992.0-992.9, or cause of injury code E900.0 or E900.9). Between 2003 and 2010, Vermont experienced an average of about 80 ED visits per year for heat-related complaints (equal to 12.4 heat stress ED visits per 100,000 persons per year).

While EPHT captures every heat stress related ED visit recorded in the state, there is a substantial lag between a heat event and the availability of the data corresponding to that event. In contrast, the Early Aberration Reporting System (EARS) collects and scans electronic ED records on a daily basis. EARS data are drawn from eight collaborating emergency departments, covering about 80 percent of ED visits in the state. EARS data were used to identify a total of 610 ED visits that occurred between May and September from 2004 to 2013 that listed heat among the complaints.

Based on these data, emergency department visits for heat-related complaints show a clear positive relationship with same-day statewide average maximum daily temperature. As shown in Figure 2, the average number of daily emergency department visits for heat complaints begins to increase notably at 87°F, and the number of ED visits continues increasing as temperatures rise. The statewide average temperature of 87°F corresponds to a range from about 85°F in cooler counties like Bennington and Essex to almost 89°F in warmer counties like Chittenden and Windham.

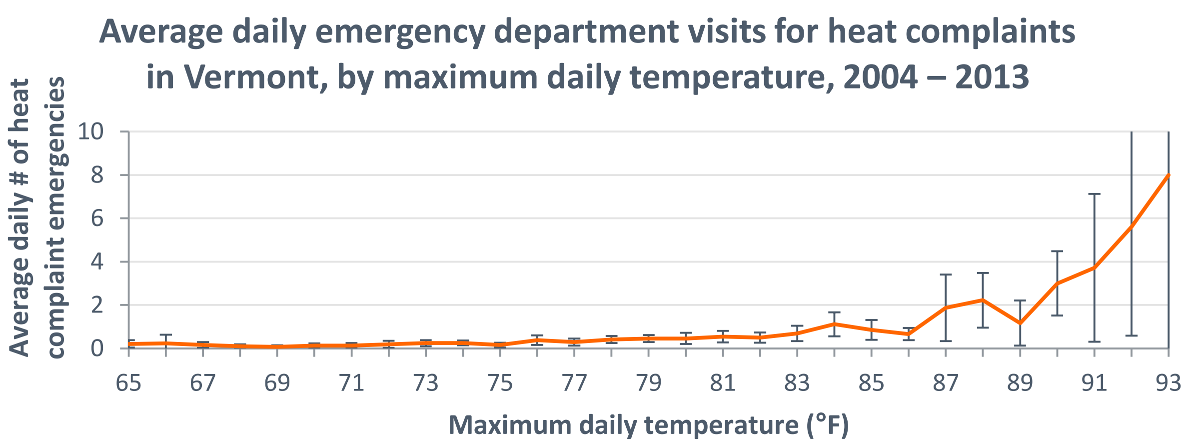
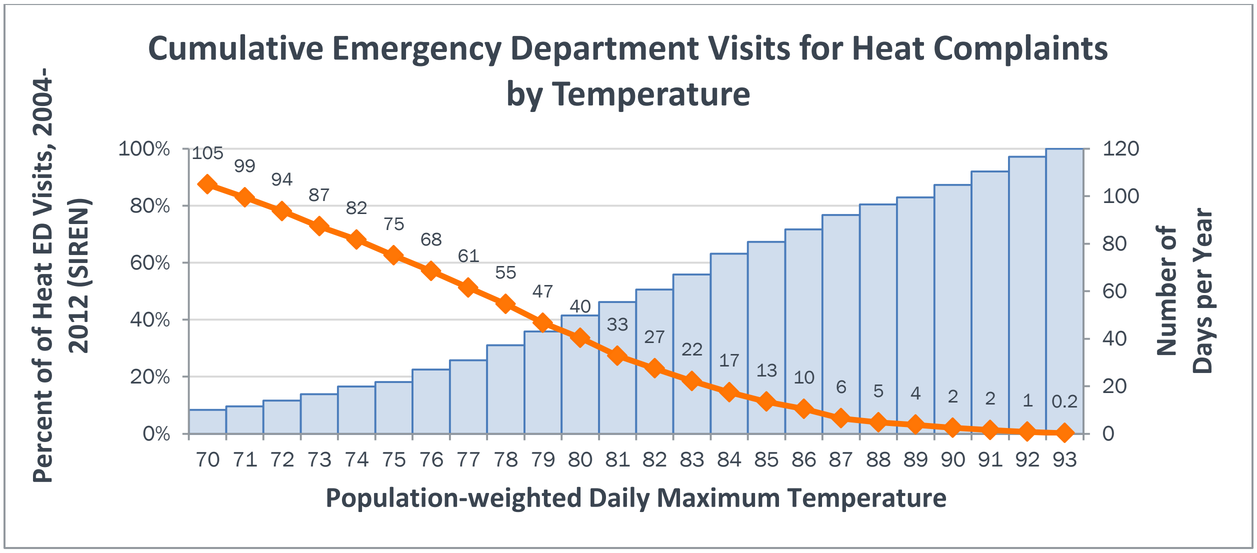


Figure 2: Average daily emergency department visits in Vermont for heat complaints by maximum daily temperature, with 95% confidence intervals.

Data sources: temperature data – PRISM Climate Group, Oregon State University, in partnership with the Vermont State Climate Office and the National Oceanic and Atmospheric Administration's Postdocs Applying Climate Expertise Fellowship Program, University Corporation for Atmospheric Research; emergency department data - Early Aberration Reporting System (EARS).

Figure 3 below displays the cumulative percentage of emergency department visits for heat complaints that occurred on days at or below the specified temperature, as well as the average number of days per year (out of a maximum of 153 days per year from May-September) reaching at least the specified temperature. For example, 72% of the emergency department visits for heat complaints occurred on 147 days per year when the high temperature was no greater than 86°F; in contrast, 28% of the emergency department visits for heat complaints occurred on only 6 days per year reaching 87°F or warmer. These data can be used to better understand the number of times health warnings or other triggered responses might occur based on different temperature thresholds, as well as an estimate of expected health impacts that may occur if no action is taken.



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Data sources: temperature data – PRISM Climate Group, Oregon State University, in partnership with the Vermont State Climate Office and the National Oceanic and Atmospheric Administration's Postdocs Applying Climate Expertise Fellowship Program, University Corporation for Atmospheric Research; emergency department data - Early Aberration Reporting System (EARS).

A statistical analysis was conducted to determine if there was a higher risk for ED visits for heat complaints on days when temperatures reached or exceeded the statewide average temperature of 87°F. Analytical methods were based on those developed by the New York City Department of Health and Mental Hygiene in its own analysis of extreme heat events (Metzger et al., 2010). A Poisson regression model (using the GENMOD procedure in SAS Enterprise Guide) was constructed to test the hypothesis that the number of ED visits for heat complaints would be higher on days when the maximum temperature reached at least 87°F.

The model output is shown in Table 3. Emergency department visits for heat-related complaints are about eight times more likely on days when temperatures reach at least 87°F in comparison to all other warm season days (between May and September). The positive coefficient for "Year" in Table 3 indicates that ED visits for heat complaints have been increasing on a yearly-basis between 2004 and 2013.

Table 3: Summary of generalized linear model of emergency department visits for heat complaints as related to days when the statewide average temperature reached at least 87°F, adjusted for year

Variable	Coefficient	p-value
Intercept	-141.77	<0.0001
Year	0.07	<0.0001
Max temperature ≥ 87°F	2.12	<0.0001

The statewide average temperature threshold of 87°F was confirmed by conducting a sensitivity test to evaluate the model fit when choosing a different threshold. The Poisson regression model was re-fit using temperature thresholds for every whole number degree value between 85°F and 91°F. Akaike's information criterion (AIC) was used to assess model fit, and was higher (indicating a worse fit) for every other model as compared to the 87°F model. For temperature thresholds below 87°F, this is likely due to the inclusion of temperatures with reduced risk for heat-related illness. For temperature thresholds above 87°F, the risk for heat-related illness increases (especially at 90°F and above), but the sample size of days at or above each threshold gets increasingly smaller. The association between temperature threshold and ED visits was statistically significant at every temperature tested.

Table 4 summarizes an application of the model for the year 2012, comparing ED visits for heat complaints on days with a statewide average maximum temperature at or above 87°F to ED visits on days below 87°F. An ED visit for a heat complaint is expected less than once every two days when the temperature is less than 87°F. In comparison, on days when temperatures reached or exceeded 87°F, this number rises to more than three heat-related complaints per day.

Table 4: Modeled effect of temperatures exceeding 87°F on daily visits to Vermont emergency departments for heat complaints in 2012, with 95% confidence interval

Indicator	ED visits / day	95% confidence interval (lower – upper)
Daily ED visits for heat complaint in 2012 when max temperature was < 87	0.4	(0.3 – 0.5)
Daily ED visits for heat complaint in 2012 when max temperature was ≥ 87°F	3.3	(2.8 – 4.0)
Excess daily ED visits for heat complaint	2.9	(2.4 – 3.5)
Relative Risk	8.3	(6.9 – 10.0)

Vulnerability in emergency department visits

EPHT data on ED visits for heat complaints were also analyzed by age strata. The findings are summarized in Figure 3. Vermonters aged 75 and older were found to be at a substantially higher risk for an ED visit for a heat complaint, which is consistent with other published findings (CDC, 2013). However, younger people aged 15 to 34 were also found to be at elevated risk, an age group not typically considered to be at elevated risk. The 15 to 19 age group in particular had nearly the same rate of ED visits for heat complaints as those aged 75 and older.

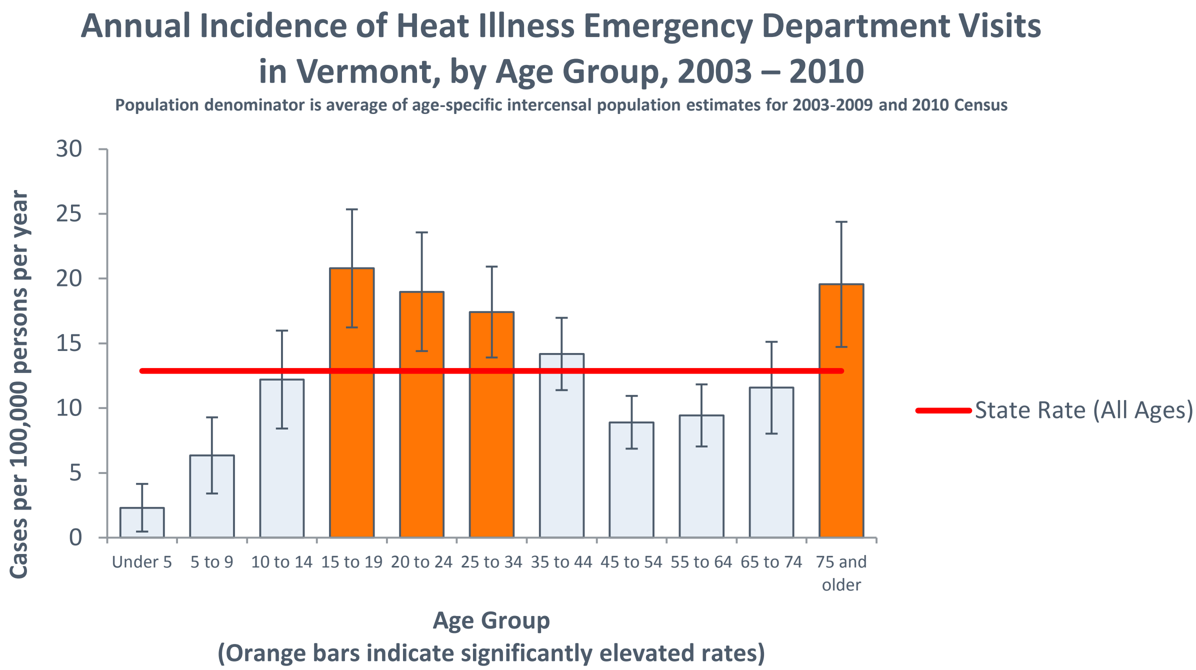

Figure 4. Age-specific annual rates of emergency department visits in Vermont. Orange bars show significantly elevated rates above the statewide average.

Data sources: emergency department data - Early Aberration Reporting System (EARS).

County-level variation in temperature and emergency department visits

The identification of the 87°F threshold was based on the statewide average maximum temperature. When the statewide average temperature is 87°F, the local temperature in any one location in Vermont may vary considerably. For example, between May and September from 1981 to 2014, the maximum temperature was an average of four degrees warmer in Windham County than in Essex County. During this time period, Windham County experienced an average of nine days per year when the county average temperature reached or exceeded 87°F, while Essex experienced only two such days.

Vermont data indicate that some of the highest rates of heat-related illnesses actually occur in the cooler counties. The three counties with the highest rate of age-adjusted emergency department visits for heat complaints from 2003 to 2010 were Bennington, Essex, and Orleans. These same three counties experienced the fewest days per year when temperatures reached at least 87°F. A county-level summary of emergency department visits and days per year when temperatures reached at least 87°F is shown below in Table 5.

Table 5. County-level summary of emergency department visits and days per year when temperatures reached at least 87°F.

County	Age-adjusted annual ED visits for heat complaints per 100,000 population	Rank, ED visits for heat complaints	Days/year ≥87F	Rank, days/year ≥87F
Addison	16.0	4	4.9	6
Bennington	17.5	1	2.1	14
Caledonia	9.7	12	4.5	8
Chittenden	9.5	13	9.4	2
Essex	16.9	2	2.4	13
Franklin	13.7	9	5.5	5
Grand Isle	15.4	5	9.7	1
Lamoille	8.7	14	3.7	11
Orange	14.9	7	4.7	9
Orleans	16.8	3	3.1	12
Rutland	12.9	10	4.3	10
Washington	15.4	6	4.9	6
Windham	14.3	8	9.4	2
Windsor	10.2	11	8.2	4
Vermont	**12.4**	**n/a**	**7.0**	**n/a**

The limited number of emergency department visits at the county level makes it challenging to further investigate this finding. One possible explanation is acclimation—that within Vermont, residents living in the coolest counties are the least accustomed to hot temperatures, and are therefore the most vulnerable to hot temperatures. If so, it is likely that the threshold is even lower than 87°F in the coolest counties, and higher than 87°F in the warmest counties like Grand Isle, Windham, and Chittenden.

Another possible explanation is confounding—that residents of the coolest counties are different from other Vermonters in a way that also increases their vulnerability to extreme heat events. For example, according to 2012 – 2013 Behavioral Risk Factor Surveillance Survey data, the three coolest counties also reported the three highest rates of "fair or poor health" in Vermont. Another possible confounder is air-conditioning prevalence, though there are currently no data available describing town or county level air-conditioning. Town and county-level influences on heat-related illness will be examined in further detail in the forthcoming Vermont Heat Vulnerability Assessment.

Validating EARS emergency department data with emergency response data

As mentioned earlier, the EARS emergency department data covers only 80% of the total ED visits in Vermont. To help confirm that the EARS data are representative of heat-related emergency illness in Vermont, the findings were validated with emergency medical system (EMS) response data. The Statewide Incident Reporting System (SIREN) was established in 2010 to track EMS response data. Only eight ambulance services reported data in 2010, but the number reporting climbed to 35 in 2011, 65 in 2012, and 87 in 2013. The 2013 data accounted for 85% of all ambulance services in Vermont, so the validation analysis was based only on the 2013 data. In that year, there were 83 ambulance visits for heat-related illnesses.

Similar to the EARS data, there was a marked increase in the frequency of ambulance visits on days when the temperature reached or exceeded 87^{o}F. In 2013, on days when the temperature was less than 87°F, the average frequency of heat-related incidents was about 1 incident every 5 days. In contrast, when the maximum temperature reached at least 87°F, the frequency of heat-related incidents increased to about 2 incidents per day. A second threshold was identified at 93°F, above which the frequency rose further to about 4 incidents per day. Those aged 75 years and older were found to be at almost three times the risk for EMS intervention due to heat-related conditions as compared to the average person. Older adults aged 60 – 64 and young adults aged 20 – 24 were also at an elevated risk. These findings were consistent with both the temperature threshold and the vulnerable populations identified from the EARS data.

Excess mortality related to extreme heat in Vermont

The effect of heat on mortality in Vermont was studied using death records from the months of May through September spanning the 1999 – 2012 period. Over this time period, only three records cited exposure to natural heat (ICD-10 code X30) as an underlying cause of death. All of the deceased were below the age of 65. An additional four deaths cited heat as a contributing factor in the death; three of the deceased were 65 years of age or older. Across the United States, heat was listed as an underlying or contributing cause of death in over 7,400 death certificates between 1999 to 2010 (Xu 2013). This represents more than double Vermont's death rate from heat, suggesting that heat-related mortality may not be as large a concern in Vermont as it is in other states. However, many deaths in which heat plays a contributing role are likely not identified as heat-related on the death certificate (Basu and Samet, 2002). This is because heat can trigger premature death through other causes without leaving any clear identifying signs of its contribution. This effect is detected in epidemiologic studies as peaks in daily mortality during or soon after extreme heat events (Basu and Samet, 2002). For instance, during the July 2010 heat wave in Montreal, daily deaths increased by about a third (Bustinza et al., 2013).

Heat-related excess mortality in Vermont was examined using death records from the months May through September spanning the 1999 – 2012 period. We focused on all-cause mortality in the population aged 65 and older, as this is a known vulnerable population and accounted for 77% of all deaths in Vermont during this time period.

Figure 4 shows a plot of deaths among those aged 65 and older compared to same-day statewide average maximum temperature. The red portion of the line indicates what appears to be a step-like increase at 87°F, though the trend is not as obvious as it is with emergency department visits. The confidence bars become wider on both ends of the temperature scale because there are fewer days within these temperature extremes and thus more uncertainty in their associated mortality estimates.

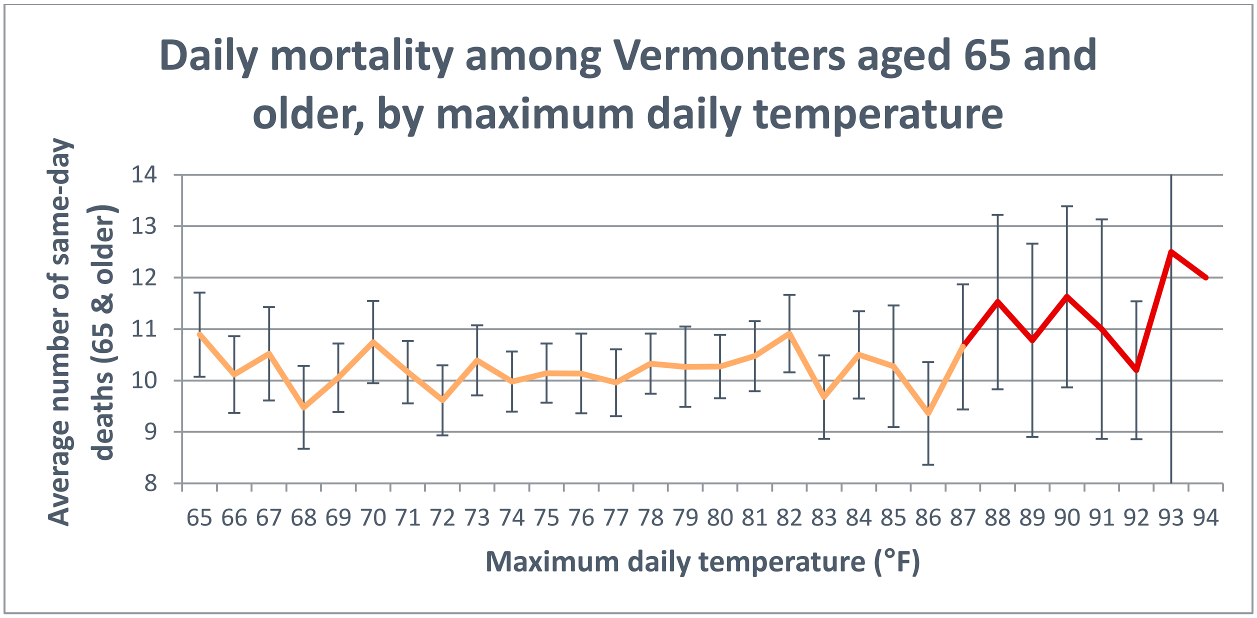

Figure 5: Average daily deaths among Vermonters aged 65 and older by statewide average maximum daily temperature, with 95% confidence intervals.

Data sources: temperature data – PRISM Climate Group, Oregon State University, in partnership with the Vermont State Climate Office and the National Oceanic and Atmospheric Administration's Postdocs Applying Climate Expertise Fellowship Program, University Corporation for Atmospheric Research; mortality data – Vermont death records.

A statistical analysis similar to that described for ED visits was conducted to determine if there was a higher risk for death in the 65 and older population on days when temperatures reached or exceeded the statewide average maximum temperature 87°F (as evaluated by Poisson regression using the GENMOD procedure in SAS Enterprise Guide). The output from the generalized linear model, adjusted for year of death, is summarized in Table 6 below. The model results show that there was a 7.8% higher risk for death on days when the maximum temperature was at least 87°F. The model also indicated that all-cause mortality for those aged 65 and older is increasing on a yearly basis, which is not surprising given that the age distribution in Vermont has been shifting towards an older population. The effect of maximum temperature on next day or later deaths was also explored, but it was determined that maximum temperature had the greatest impact on same-day deaths.

Table 6. Summary of generalized linear model output for the number of same-day deaths among those aged 65 and older, as related to temperatures exceeding 87°F, adjusted for year of death

Variable	Coefficient	p-value
Intercept	-9.2407	0.0065
Year	0.0058	0.0007
Max temperature ≥ 87°F	0.0754	0.0119

Table 7 shows model-predicted mortality for the year 2012. On average, about 0.8 extra deaths per day occurred in 2012 among Vermonters aged 65 and older when maximum temperatures reached at least 87°F, as compared to days when the temperature was less than 87°F. During the 14-year study period, there were on average 7.8 days per year when the statewide average temperature reached or exceeded

87°F, translating into more than 6 heat-related excess deaths every summer, or more than 90 excess deaths over the study period. This is 13 times greater than the number of death records in which heat was cited as an underlying or contributing cause of death, and 30 times the number of such records for decedents aged 65 and older, suggesting that under-reporting of heat-related deaths is a significant concern.

Table 7: Modeled effect of temperatures exceeding 87°F on daily mortality among Vermonters aged 65 and older in 2012

Indicator	Deaths / Day	95% confidence interval (lower – upper)
Daily mortality in 2012 when max temperature was < 87°F	10.6	(10.4 – 10.9)
Daily mortality in 2012 when max temperature was ≥ 87°F	11.5	(10.8 – 12.2)
Excess daily heat-related deaths	0.8	(0.4 – 1.3)
Percent increase attributable to heat	7.8%	(1.7% – 14.4%)

The 87°F statewide average temperature threshold was confirmed by conducting a sensitivity test to evaluate the model fit when choosing a different threshold. The Poisson regression model was re-fit using temperature thresholds between 84°F and 91°F. AIC was used to assess model fit, and was higher (indicating a worse fit) for every other model as compared to the 87°F model. For temperature thresholds below 87°F, this is likely due to the inclusion of temperatures with reduced risk for death. For some of the temperature thresholds above 87°F, the risk for death is slightly higher (at 88°F and 90°F), but the sample size of days at or above each threshold gets increasingly smaller. The association between temperature threshold and death was only statistically significant at 87°F and 88°F.

It should be noted that daily deaths in Vermont are highly variable, as would be expected in a relatively small population. While average summer daily mortality among those aged 65 and older is about 10, daily deaths ranged from 1 to 21 per day in the available data. It is thus difficult to detect heat-related increases with high levels of certainty. This is why the 95% confidence interval of the modeled increase in mortality is fairly wide, ranging from as low as 1.7% and as high as 14.0%. Nevertheless, even the lower bound estimate is 7 times greater than the number of death certificates among those aged 65 and older that cite heat as an underlying or contributing cause of death.

All-cause mortality across all ages showed a similar albeit less robust relationship with maximum daily temperature exceeding 87°F (results from this analysis are not shown). Heat index was a weaker predictor of mortality than was temperature. Temperature on the one to four days preceding death and consecutive hot days did not have a strong relationship with mortality. This lack of relationship could be solely due to the small sample size, as extended heat waves are relatively rare in Vermont.

Several additional variables were tested in the regression models but ultimately not used in the final model described above. Day of heat season (where May 5 of a given year is day 1, and September 30 is day 149) had a statistically significant effect, with deaths decreasing slightly throughout the season (suggesting that older adults acclimate to hot temperatures during the heat season), but the magnitude of the effect was very small and resulted in poorer model fit (as assessed by AIC). Mortality on weekends and holidays did not significantly differ from that of weekdays in our models. Ground level ozone levels were expressed as the maximum daily 8-hour average based on measurements at Bennington and Underhill. Fine particulate ($PM_{2.5}$) concentrations were expressed as 24-hour averages based on measurements at Bennington, Burlington and Rutland. Since $PM_{2.5}$ measurements are taken once every 3 days, intervening days were interpolated. There was no significant association between ground level ozone and particulate matter concentrations and daily mortality in our data, although days with ground level ozone exceeding a threshold of 60 parts per billion (ppb) and $PM_{2.5}$ exceeding a threshold of 35 micrograms per cubic meter ($\mu g/m^3$) were both associated with a slight, but non-significant increase in mortality. Both ozone and $PM_{2.5}$ were positively correlated with temperature.

Excess mortality vulnerabilities

The generalized linear model described above detected a statistically significant rise in the number of all-cause deaths on hot days among those aged 65 and older. The same model was run with all-cause deaths replaced by natural, accidental, circulatory, and respiratory causes of death respectively, as well as fatal falls and motor vehicle crashes. None of these sub-analyses yielded statistically significant results. This is not surprising given the small number of daily deaths, which becomes still smaller when subdivided by more specific causes of death.

However, an examination of the respective contributions of various causes of death to the statistically significant rise in mortality can help identify Vermont's heat-vulnerable populations. ICD-10 codes were used to classify death records of those 65 and older into 19 categories of underlying causes of death. The number of deaths occurring in each category on days at or above the statewide average temperature of 87°F was compared to the number of deaths from those same causes on days below 87°F. Contributions to the total increase in death are shown in Figure 5. The leading contributors included cardiovascular, cerebrovascular, and nervous system conditions.

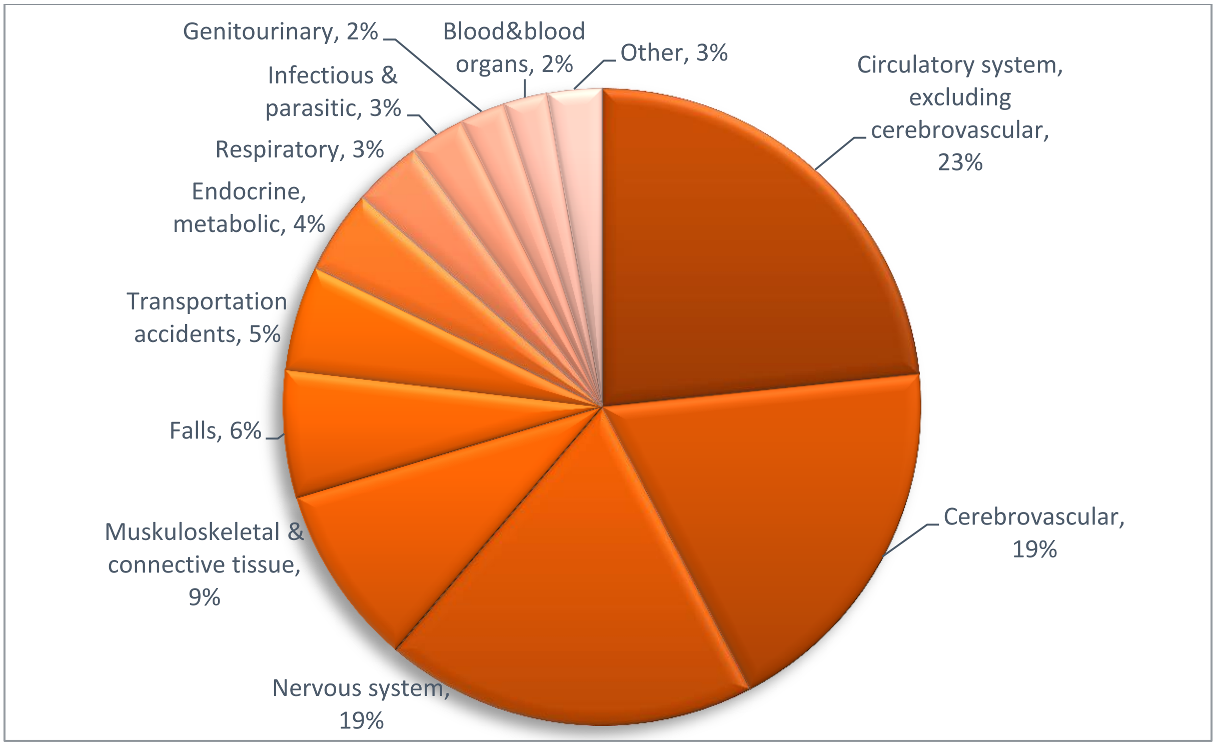

Figure 6: Contribution of cause-of-death categories to the increase in daily deaths among those 65 and older on days when temperatures exceed 87°F. Only those categories contributing at least 2% to the excess mortality burden are shown.

Data sources: emergency department data - Early Aberration Reporting System (EARS).

The cause-of-death categories which seem to be driving the rise in daily mortality on hot days are generally consistent with published heat-related causes of death. Among more recent studies, a Spanish investigation found that increases in death on days exceeding the 95th percentile of temperatures over the 1983 – 2006 period was driven by deaths from cardiovascular and respiratory diseases, mental and nervous system disorders, infectious and digestive system diseases, diabetes, and some external causes, including suicide (Basagna et al., 2011). Another study of an intense heat wave in Belgrade found increased deaths from diabetes, chronic kidney, respiratory, nervous and cardiovascular diseases, and malignant neoplasms (Bogdanović et al., 2013). A study of the effects of heat on mortality in nine European cities found increases in cardiovascular, cerebrovascular and respiratory disease (D'Ippoliti et al., 2010). Among those aged 65 to 74 and over 85 respectively, cardiovascular deaths increased by 6.3% and 10.6%, cerebrovascular deaths by 6.3% and 17.8% and respiratory deaths by 16.8% and 12.1%. Zanobetti et al. (2013) found an 8% and 6% increase in daily mortality associated with extreme heat among those with Alzheimer's disease and dementia respectively. Page et al. (2007) documented an increase in suicides in England and Wales. Wilson et al. (2013) found odds ratios of 1.14 and 1.22 for respiratory and diabetes-related deaths respectively on hot days.

The contributions of rare musculoskeletal causes of death and of fatal falls and motor vehicle accidents do not appear to be documented in the literature and it is possible that some or all of these observed effects in Vermont may be spurious given the small numbers involved. However, the contribution of these diseases to heat-related excess mortality does seem plausible. For instance, of the 22 records in the study period listing osteoporosis as the underlying cause of death, 14 had a respiratory or circulatory contributing cause and these in turn could be related to heat. Of the 4 deaths due to Wegener's Granulmatosis over the 14-year study period, 2 occurred on consecutive days at the end of a string of days exceeding 87˚F. Wegener's Granulomatosis is a rare disorder that restricts blood flow to various organs and is a risk factor for respiratory tract, kidney and heart damage (MedlinePlus, 2015); additional stress created by the body's attempt to regulate its temperature during an extended heat episode could thus have contributed to premature death. As for the increase in fatal falls and car accidents among those aged 65 and older, it is possible that reduced coordination on hot days could have contributed to these accidents. However, while these proposed mechanisms may be plausible, it is not possible to verify their validity in a statistically significant way.

Urban heat islands

Areas with high amounts of asphalt, concrete, rooftops, and other impervious surfaces can trap heat, leading to an "urban heat island effect" with higher localized temperatures than the surrounding countryside, especially in larger cities (CDC, 2013). Although Vermont is primarily considered to be a rural state, about 40% of the population lives in areas classified by the U.S. Census as "urban" based on population density, impervious surface, and other factors.

For every emergency department visit, the patient's town of residence is recorded. To investigate the impact of the heat island effect in Vermont, towns and cities were classified into two categories: 1) "urban," those that had 50% or more of their population classified as living in an "urban" area, as designated by the 2010 U.S. Census, and 2) "rural," those that had less than 50% of their population classified as living in an "urban" area. Out of concern for potential address misclassification in the emergency department data, the four cities in Vermont that share the same name as an adjacent town were grouped together (i.e., Barre City/Town, Newport City/Town, Rutland City/Town, St. Albans City/Town). All four of these paired communities had an overall population that was more than 50% urban. In all, 30 Vermont towns were classified into the "urban" category, and 225 were classified into the "rural" category.

Age-adjusted annual incidence of emergency department visits was calculated and compared, as derived from Vermont hospital discharge data from 2003 to 2010 using the EPHT definition for heat-related illness cases[2] (any diagnosis or emergency ICD-9 code in the range of 992.0-992.9, or cause of injury code E900.0 or E900.9, and not E900.1). On average, towns classified in the "urban" category experienced nearly three more emergency department visits per 100,000 persons per year for heat-related illness than those in the "rural" category, and the difference was statistically significant (see Table 8 below).

[2] *Note:* Due to a lack of availability of date in the hospital discharge dataset, we were unable to limit cases to only the months May through September, as is specified in the EPHT definition. Instead, cases were taken from all months.

Table 8: Comparison of heat illness incidence rates in urban and rural Vermont towns

Area Type	Population Estimate (2010 Census)	Age-adjusted Incidence Rate, per 100k persons per year	95% confidence interval (lower – upper)
Urban	285,904	14.1	(12.6 - 15.6)
Rural	339,837	11.2	(9.9 - 12.5)

Three potential sources of error or bias in this analysis were: 1) the potential for residents in rural areas to have a mailing address (used for geocoding emergency department visits) in an urban area, 2) the possibility that residents living closer to hospitals are more likely to go to the hospital for any purpose out of greater convenience, and 3) the potential that residents spend much of their time in a town other than their town of residence. However, the analysis indicated that the burden of heat stress illness may be slightly higher in more urbanized towns in Vermont, although when evaluated individually, no specific urbanized towns had significantly increased rates of heat stress illness visits. If migration from rural to urban areas continues in the future, the urban heat island effect is likely to become a larger factor in a warmer future.

Heat surveillance for emergency response

The excess mortality analysis was based on the record period 1999 – 2012. It is however likely that Vermont will experience, or already has experienced, extreme heat events of a greater magnitude than those captured in this 14-year period. If an exceptional heat wave, similar to historic heat waves such as those occurring in Chicago in 1995 or Europe in 2003, were to strike Vermont, public health officials would need to decide whether to initiate a stepped-up response. While the National Weather Service provides information on extreme meteorological conditions, it would be useful to know whether public health is being affected by these conditions before taking further action.

Since it can take weeks to months for mortality data to become available, excess deaths are not a useful "real-time" indicator for emergency response decision-making. However, emergency department visit information is compiled and analyzed daily and could serve as a gauge of the health effects of a heat event as it unfolds. Over the 2004 – 2012 period, the highest number of emergency department visits for a heat complaint in a single day was 8. A threshold value, for instance 150% of the maximum recorded daily emergency department visits, or 12 per day, could potentially be used to trigger a stepped-up response. The Center for Disease Control and Prevention's National Syndromic Surveillance Program BioSense Platform could be used for this purpose.[3]

A hotter future: the impact of climate change

As the global climate system warms, Vermont is projected to experience an increase in the number of days on which the statewide average temperature exceeds 87°F. The Health Department partnered with Dr. Lesley-Ann Dupigny-Giroux, Vermont State Climatologist, and Dr. Evan Oswald, a Postdoctoral Fellow

[3] http://www.cdc.gov/nssp/biosense/

at the University of Vermont, to extract Vermont-specific data from global climate models (GCMs) from a dataset used in the 2014 National Climate Assessment. The dataset is based on the output of six global climate models (GCMs):

1) National Center for Atmospheric Research's Parallel Climate Model (PCM)
2) Canadian Centre for Climate Modeling and Analysis's CGCM3.1-T47 model
3) Canadian Centre for Climate Modeling and Analysis's CGCM3.1-T63 model
4) Centre National de Recherches Meteorologiques's CNRM-CM3 model
5) Max Planck Institute for Meteorology's ECHAM5/MPI model
6) NOAA Geophysical Fluid Dynamics Laboratory's GFDL CM2.1 model

The coarse GCM output was downscaled to a smaller grid spacing using a method developed by Dr. Katherine Hayhoe (Hayhoe, 2013). Multi-model means for the six models were calculated by researchers at the National Oceanic and Atmospheric Administration (NOAA). Climate indicators were projected for both lower (B1) and higher (A2) GHG scenarios. The projected annual occurrence of days when the statewide average maximum temperature will reach at least 87°F is summarized in Figure 6. Between 1981 and 2010, Vermonters experienced an average of seven days per year when the maximum temperature reached or exceeded 87°F. Under the low-emissions scenario, the number of days at or above this threshold is expected to increase to 15 by mid-century and 20 by the end of the century. For the high emissions scenario, the increase in hot days is expected to be much more drastic. Twenty days with maximum temperatures of at least 87°F are expected by mid-century and 34 by the end of the century.

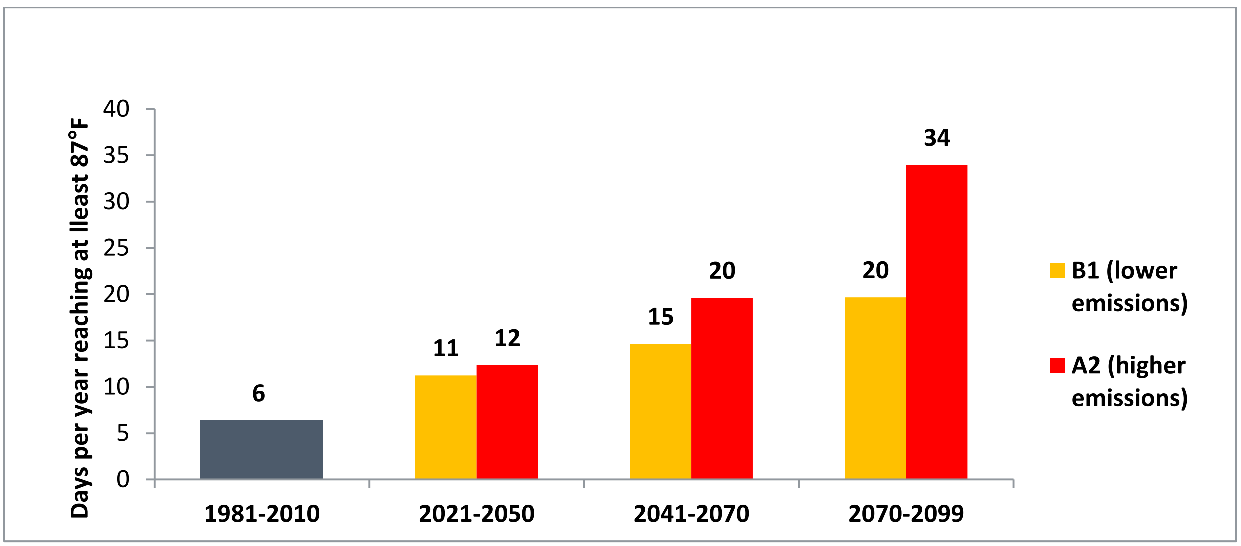

Figure 7: Projected number of days 87°F or warmer, by lower (B1) and higher (A2) emissions scenarios

Table 9 shows the expected health burden in 2012 (baseline) based on applying the ED visit and mortality models described earlier, compared to the projected health burden for three future time periods. According to the baseline model for 2012, Vermont currently experiences about 23 excess emergency department visits per year for heat complaints and 5 deaths per year attributable to hot days when the statewide average temperature reaches or exceeds 87°F. By mid-century, we expect the number of annual excess emergency department visits related to heat complaints to increase to 54 – 72 while the number of annual excess deaths increases to 9 – 10. By the end of the century, we expect the number of annual excess emergency department visits related to heat complaints to further increase to 72 – 124 while the number of annual excess deaths increases to 16 – 28.

Table 9. Baseline and projected yearly excess emergency department visits for heat complaints and deaths attributable to hot days reaching at least 87°F

Time period	Days/year with max temp ≥ 87°F (B1 – A2 range)	Excess emergency department visits/year for heat complaints	Excess deaths/year attributable to heat
Baseline (2012)	6	23	5
2021 – 2050	11 – 12	41 – 45	9 – 10
2041 – 2070	15 – 20	54 – 72	12 – 16
2070 – 2099	20 – 34	72 – 124	16 – 28

Assumptions: For the baseline year, we assumed there to be 6.37 days when the statewide average maximum temperature reached or exceeded 87°F, which was the average number of days that were at least 87°F during the 1981 – 2010 period. For future years, we assumed a range for the number days when the maximum temperature reached or exceeded 87°F, based on the projected annual average number of days when the maximum temperature reached or exceeded 87°F for the low (B1) and high (A2) GHG emissions scenarios during each 30-year time period. For the baseline and future time periods, we multiplied each day reaching at least 87°F by 2.93 excess emergency department visits (based on Table 4) and 0.83 excess deaths (based on Table 7) attributable to heat. Projected excess emergency visits were inflated by 25% to account for the fact that the EARS database used to fit the regression model included only about 80% of all emergency department visits occurring in Vermont. For ease of comparison to the baseline, the population in future years is assumed to be identical to 2012 in terms of both age and geographical distribution. All numbers in the table were rounded to the nearest whole number.

Additionally, we expect an increase in the number of consecutive hot days in the future, which may further exacerbate the health effects that extreme heat episodes have on Vermonters. Consecutive hot days, especially when nighttime low temperatures do not drop enough to provide relief, have been associated with increased health impacts (Basu and Samet, 2002).

It is possible that physiological acclimation and progressive adaption (for instance, greater use of air conditioning) may over time raise the temperature threshold at which health effects are seen and to some extent lessen the impact of warmer temperatures. However, little is currently known about how quickly Vermont's population will adjust and whether the rate of adaptation will match the rate of temperature change. In addition to individual adaptation, public health interventions will likely be necessary to prevent a worsening of the already substantial health burden related to extreme heat.

Adaptation to a warmer future

Because the number of hot days is expected to increase in the future as a result of climate change, it is important for individuals, communities, and state agencies to take proactive steps to reduce heat-related health impacts. Some steps that can be taken to better prepare for and mitigate the impacts of extreme heat events include:

- **Individuals and business owners** can:
    - Modify buildings to increase fresh air flow during summer heat, improve energy efficiency, and plant trees around buildings for more shade
    - Put in air conditioners, heat pumps, or similar cooling devices
- **Communities** and community groups can:

  - Create a community response plan for extreme heat events
  - Set up local cooling centers
  - Use local aid networks to find, check-in on, and assist at-risk people
  - Create cancellation policies for workers, students, and activities on hot days
  - Plant trees and shrubs, and reduce paved surfaces in urbanized areas
  - Use energy-efficient building design, including use of cool roofs and pavements
- The **Health Department** and its partner agencies can:
  - Make people aware of the dangers of extreme heat events
  - Offer education on how to reduce the risk of heat-related illness
  - Create a public health response plan for extreme heat events
  - Identify the appropriate temperature for issuing extreme heat warnings
  - Offer extreme heat information to the public through the Vermont 2-1-1 phone line

In addition to reducing health impacts related to extreme heat, many of the above adaptation strategies provide additional benefits such as reducing energy usage and costs, reducing greenhouse gas emissions, reducing air pollution, improving water quality, and increasing property values.

A table containing additional details on potential intervention strategies is included in Appendix C, including additional resources providing further information about or examples of the strategies, published evidence on the effectiveness of each intervention (where available), and potential co-benefits for certain strategies in addition to reducing heat-related illness and death.

Conclusions

Exposure to high summer temperatures already poses a serious public health threat to Vermonters, and that threat is expected to grow in the future as a result of climate change. The Health Department's investigation into the effects of extreme heat on Vermonters revealed the following:

1. **The statewide average temperature of 87°F marks an important threshold in Vermont, at and above, which Vermonters increasingly experience serious health impacts related to heat, and even death for adults 65 and older.** Heat-related illnesses, such as heat exhaustion and heat stroke, were eight times more likely on days when statewide average maximum temperatures reached at least 87°F. Data also showed that there was one additional death per day among individuals aged 65 and older when maximum temperatures reached at least 87°F. Both of these findings were statistically significant. These findings are consistent with a similar analysis conducted in Quebec in 2010, which identified a threshold of 87.8°F, above which a significant increase in heat-related mortality is expected (Health Canada, 2011).
2. **Adults aged 75 and older and those aged 15 to 34 experience the highest rates of heat-related illnesses. Adults 65 and older are at higher risk for death on such hot days.** In addition to the at-risk age groups identified using Vermont data, published evidence also suggests that those who work or exercise outdoors, infants and children, the homeless and impoverished, adults living alone, people taking certain medications, people with a chronic medical condition, and people living in more urbanized areas are also typically at greater risk. Some people may even suffer heat-related illnesses at temperatures lower than the mid-80s.
3. **Vermont counties with lower average temperatures experience higher rates of heat-related illness than warmer counties.** It is possible that physiological acclimation and progressive adaption (e.g., greater use of air conditioning) help to reduce heat-related illness in warmer counties. Over time, acclimation and adaptation will raise the temperature threshold throughout Vermont at which health effects are seen and to some extent attenuate the impact of warmer temperatures. However, little is currently known about how quickly Vermont's population will adjust and whether the rate of adaptation will match the rate of temperature change. In addition to individual adaptation, public health interventions will likely be necessary to prevent a worsening of the already substantial health burden related to extreme heat.
4. **The Early Aberration Reporting System (EARS) appears to provide a valid representation of heat-related illness in Vermont.** Although EARS data represent only about 80% of emergency department visits in Vermont, the distribution of cases by age is similar between EARS and Environmental Public Health Tracking (EPHT) data, and the relationship between heat and emergency visits is similar between EARS and ambulance service data. EARS provides a benefit over EPHT data and death records in that it is available nearly in real-time, which may be of benefit for surveillance and response purposes.
5. **The health impact of heat events is expected to increase in the future as a result of climate change.** On average each year, Vermont currently experiences about 25 excess emergency department visits for heat complaints and 6 deaths attributable to hot days when statewide average temperatures reach or exceed 87°F. By mid-century, we expect the number of excess

emergency department visits related to heat complaints to increase to 54 – 72 while the number of excess deaths increases to 11 – 12. By the end of the century, we expect the number of excess emergency department visits related to heat complaints to further increase to 72 – 123 while the number of excess deaths increases to 18 – 30.

6. **Vermont can respond and adapt to extreme heat events through a combination of individual, communal, and state efforts.** Individual precautions should be taken on hot days to minimize potential health impacts, such as staying in a cool place, keeping well hydrated, and limiting outdoor activity during the hottest parts of the day. Adaptation actions can be taken at all levels to improve warnings, messaging, and actions to take during heat events as well as to modify buildings, landscape, and community design to reduce heat impacts.

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Appendix A: Methods used to develop climate change forecasts

Introduction to Projections

The Health Department partnered with Dr. Lesley-Ann Dupigny-Giroux, Vermont State Climatologist, and Dr. Evan Oswald, a Postdoctoral Fellow at the University of Vermont to provide Vermont-specific projections of key climate indicators. These indicators were extracted from a dataset created for the National Climate Assessment's Northeast Region section by Dr. Katherine Hayhoe. The original dataset was based on the output of 11 climate models known alternately as Global Climate Models or General Circulation Models (GCM). GCMs are complex simulations of our planet's climate system. The Coupled Model Intercomparison Project (CMIP) sets guidelines for climate modelers to facilitate the comparison of output from different models. Since each GCM is built somewhat differently, each produces different projections. By taking the average of a large number of models, a realistic estimate of the real future climate is more likely to be obtained. The output of GCMs is spatially course, covering grid points of several hundred miles. The dataset created by Dr. Hayhoe consists of this coarse GCM output that has been statistically correlated to local weather data in a process known as "downscaling." This downscaling yields projections for a higher-resolution, 1/8 degree (8 x 6 mile) grid. The original 11 GCMs used were drawn from the CMIP3 round of simulations, which was compiled mostly between 2005 and 2006. Six of the original 11 GCMs were used for the Vermont indicators.

Emissions Scenarios

Estimates of future GHG emissions are a critical component of climate models. But how will these emissions change over the coming century? The Intergovernmental Panel on Climate Change (IPCC) examined possible emissions trajectories in its Special Report on Emissions Scenarios (IPCC, 2000). The report describes four families of emissions scenarios, each considered to have an equal probability of occurring (IPCC, 2000). The four families of scenario (A1, A2, B1, B2) are shown in Figure 7. The two scenario families used in this report are the A2 and B1. These scenarios are described below. Neither scenario assumes GHG emissions reduction efforts, such as reduction treaties, to be implemented per se, though the B1 scenario assumes a more sustainable pattern of development that does in turn result in decreased emissions.

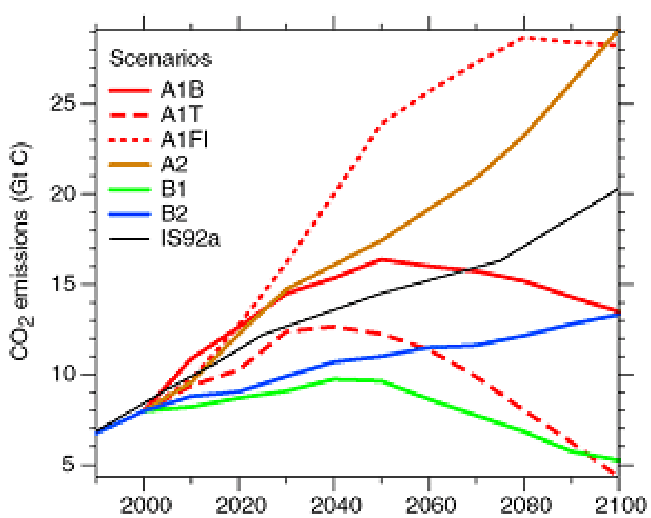

Figure 8: SRES scenarios. The graph includes the 3 sub-groups of the A1 family, as well as the IS92a scenario, which was an earlier modeling scenario and not part of the SRES. A2 and B1 are used in this report. (Graph from Nakicenovic et al. 2000)

The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change is more fragmented and slower than in other storylines (IPCC, 2000).

The B1 scenario describes a convergent world with a global population that peaks in midcentury and declines thereafter, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives (IPCC, 2000).

Time Slices

GCMs are by definition climate models and *not* weather models. Climate is generally understood as the average weather over a given period. GCMs do not thus project the weather over a specific future year, but rather the average weather over a future 30-year period, known as a time slice. This report presents results for three time slices: 2021 to 2050, 2041 to 2070, and 2070 to 2099. These projections are compared to a baseline climate representing the 1981 – 2010 period. The more distant a projection is, the more uncertain it becomes. GCM projections beyond a 100-year timeframe are not currently practicable.

Appendix B: Methods used to develop 1981 – 2014 weather data for Vermont

Report accompanying the 1981 – 2014 daily meteorological data given to the Vermont Department of Health by the Vermont State Climatology Office

Written by: Dr. Evan M Oswald, 05/12/15

Overview

Public health scientists from within the Vermont Department of Health are interested in revisiting the establishment of relationships between meteorology and public health. In particular the relationship between precipitation and/or air temperature and health statistics, vector-borne diseases and water quality. The health statistics needs spatial aggregating to the state and county levels because it better matches the health data. This document briefly explains the origins, processing and printing out of spatially aggregated, daily meteorological data.

Acquisition and preprocessing

The climate data product that ultimately supports these data is the AN81d dataset, provided by the PRISM Climate Group out of the University of Oregon[4]. On that group's website the document linked through the "PRISM datasets" link describes the different PRISM datasets, and can provide details to the creation of this dataset.[5] This data was downloaded from the part of the website titled "Recent Years". This data extends the January 1981 through October 2014 time period on an approximate 4 km resolution regular rectangular grid, and consists of daily maximum and minimum air temperatures as well as the daily precipitation totals. Temperature is natively provided in degrees Celsius and precipitation in millimeters, but was recalculated in units of degrees Fahrenheit and inches. For illustrative purposes, below is a map of the 1981 – 2012 May 1 -– September 30 mean daily minimum temperatures.

[4] http://www.prism.oregonstate.edu

[5] http://www.prism.oregonstate.edu/documents/PRISM_datasets.pdf

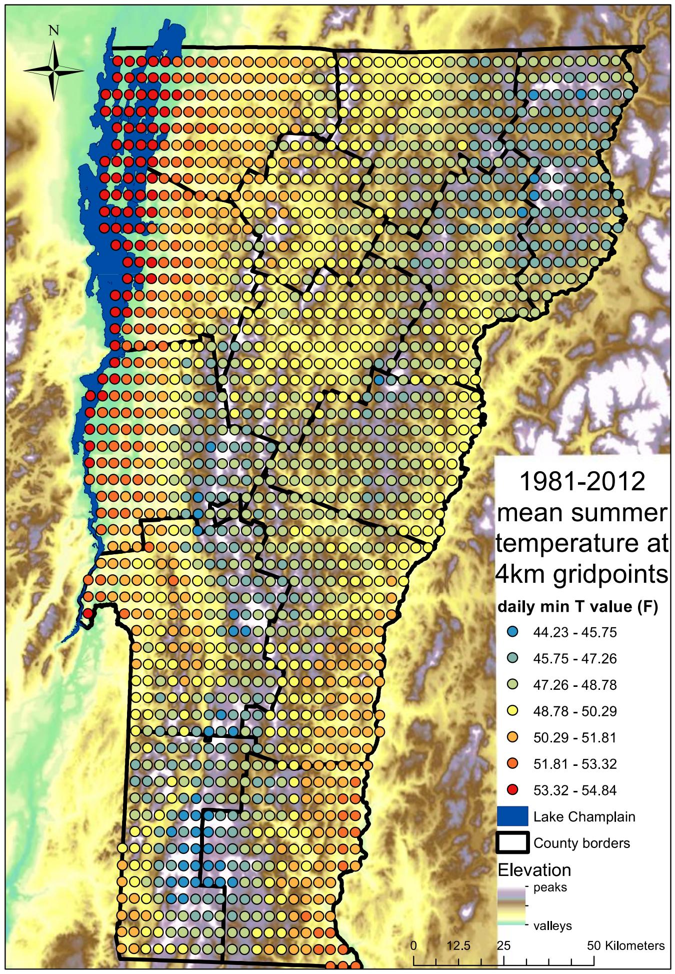

Figure 9. 1981 – 2012 mean summer temperature (°F) in Vermont at 4 km grid point resolution.

While these data can be freely downloaded, they are provided as single-day files (i.e., each file is a map of a particular day). This requires an automated procedure that opens each file, and stores the desired (here, Vermont) grid cells in a three-dimensional matrix (the third being *time*). Then this matrix of grid cells, dates and meteorological variables is saved and stored (at the Vermont State Climate Office (VSCO)) in a MatFile format (easily opened by Matlab software). This matrix can be used (with an interpolation method) to extract time series at any point within Vermont, if needed.

The data available for the 1981 – 2012 time period are provided free of missing grid-dates, and the data for the 2013 – 2014 period are currently not. These missing values were in the daily maximum and minimum air temperatures (213 and 304 grid-dates, respectively) and during the cold months only. Visual inspection showed all missing grid-dates were temporally isolated (i.e., non-consecutive) and fairly spatially isolated (only 1 – 11 grid cells in Vermont (1601 grid cells), per date with missing grids, and most are not direct neighbors).

Estimates of these missing values require the following values to be calculated: the state average temperature (maximum or minimum) for the date of the missing value and the dates directly prior and afterward, and the individual grid cell's value on the dates directly prior and afterward. Using these values, the difference between the missing date's state average temperature and the state average temperature average of the proceeding and preceding dates, is applied to the target grid cell state average temperature average of the proceeding and preceding dates. The equation below describes this mathematical relationship.

$$T_J = [(T_{J+1} + T_{J-1})/2] + [\overline{T}_J - ((\overline{T}_{J+1} + \overline{T}_{J-1})/2)]$$

Where **J** being the date of missing the missing value, $\overline{T}$ being the statewide average temperature and **T** being the grid cell temperature. It is assumed the state average calculations are not significantly compromised by missing between 1 and 11 grid values (out of 1601)

Aggregating

Aggregations at the state, climate division, and county levels from the individual grid cells were through two general methods: geographic and population-density based. The geographic weighting uses the cosine of the latitude degrees to assign a weight to each grid cell. This is the precise way to take a spatial average using PRISM grid cells because the grid cells at high latitudes contain less spatial area per grid cell. The importance of this weighting over a small region like Vermont is debatable. The second type of weighting is based on population density. This weighting method uses the mean 1980 – 2010 population density at each grid cell, compared to the area being averaged, to determine the weight in the averaging process. Clearly this weighting focuses on potential relationships between health statistics and human exposure. This is accomplished in two ways, once at the native (to the population data grid) 1 km resolution and another after the population dataset was aggregated to the same resolution of the PRISM grid (4 km). The number of grid cells per county, climate division, and state are provided in the readme file accompanying the data provided to the Vermont Department of Health and at the Vermont State Climate Office.

The gridded population dataset (Owens and Gallo 2000) was previously acquired (in 2012) at the National Climatic Data Center (NCDC) and is based on census data. The dataset spans 1930 – 2000 at the decadal temporal resolution with a spatial resolution of 1 km. This dataset has previously been used to diagnose locations as either rural or urban from the surrounding areas (e.g., Hausfather et al. 2013).

Exporting

Once the daily time series for each meteorological parameter were aggregated to the various spatial scales, they are printed out to several text files that were passed along to the Department of Health. These files are in table format with the rows corresponding to different dates, and the columns corresponding to various variables (including year, month, and day of the month). These variables usually include the sum of the daily precipitation for an area, precipitation average for an area, and geographically and population weighted average daily maximum or minimum air temperatures. These files have commas that separate the various values, and there should be no missing values.

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Appendix C: Catalog of potential intervention strategies

Ongoing messaging & education

Intervention	**Resources/notes**	**Other Supporting Evidence in Scientific Literature**	**Co-benefits**
General messaging/education at beginning and throughout heat season, focusing on: • Temperature threshold for health impacts • Health dangers of high heat • Vulnerable populations at higher risk • How to protect yourself, neighbors, and family Potential venues for messaging: radio, TV, newspaper, internet, social media, brochures, posters	• CDC Climate Change and Extreme Heat Events Guidebook • CDC Extreme Heat and Your Health information	A public education campaign related to health risks of heat waves was found to reach 66% of the target population. Electronic media, especially television, was found to be the most effective venue. Exposure to messaging was associated with adoption of protective behaviors, and a dose-response relationship was noted. (Gosselin et al., 2010)	None identified

Emergency event warnings & messaging

Intervention	**Resources/notes**	**Other Supporting Evidence in Scientific Literature**	**Co-benefits**
Implement public warning/messaging system	• CDC Climate Change and Extreme Heat Events Guidebook • CDC Extreme Heat and Your Health information • Health Canada: Extreme Heat Events • Health Canada: Heat Alert and Response Systems to Protect Health, Best Practices Guidebook • EPA Excessive Heat Events Guidebook	• A systematic review found reduced deaths in locations with heat warning systems across six studies; perceived threat of heat danger was important for heeding warning; costs (e.g., A/C costs) were a barrier to taking action (Toloo et al., 2013) • Some evidence of reduced risk for those ≥75 years old after	None identified
Develop messaging related to personal cooling strategies (cool clothes, drinking cool beverages, limit activity, wide-brimmed hat, stay in shade, extra cool showers/baths, etc.)			
Develop messaging related to home cooling strategies (air conditioning, fans, close windows/curtains/blinds—			

especially for sun-facing windows, don't use stove/oven)	• Heatwave Early Warning Systems and Adaptation Advice to Reduce Human Health Consequences of Heatwaves • WHO: Heatwaves and Health: Guidance on Warning-System Development	implementation of warning system (Morabito et al., 2012) • Significant decrease in mortality after implementation of warning system (Delaroziere and Sanmarco, 2004) • Non-significant increases in ischemic heart disease and stroke mortality without using a heat warning system (Chau et al., 2009) • Reduced mortality and mortality-related cost savings were attributable to heat warning system (Ebi et al., 2004) • Significant reduction in heat-related mortality after implementation of warning system (Fouillet et al., 2008)	
Coordinate with National Weather Service to identify thresholds for extreme heat event warning and "how to stay cool" messaging to broadcast during extreme heat events.			
When hot temperatures are forecast, transmit warnings and "how to stay cool" messaging through VT Alert, Health Department, Vermont 211, news/radio stations, schools, other state/local partners, automated phone alerts, etc.			

Public health and community response during an emergency event

Intervention	Resources/notes	Other Supporting Evidence in Scientific Literature	Co-benefits
Develop action plan for extreme heat event public health & community response • Planning mechanisms: Hazard Mitigation Plans, Emergency Operations Plans, other state/regional/local plans • Partners: Department of Health, Town Health Officers, Medical Reserve Corps, Community Emergency Response Teams, local hospital/health facilities, local community/resilience groups	• CDC Climate Change and Extreme Heat Events Guidebook • Health Canada: Heat Alert and Response Systems to Protect Health, Best Practices Guidebook • Heatwave Early Warning Systems and Adaptation Advice to Reduce Human Health Consequences of Heatwaves • WHO: Improving Public Health Responses to Extreme Weather/Heat Waves	See evidence above for emergency event warnings & messaging, which are typically components of a larger extreme heat response plan	None identified
Use Vermont 2-1-1 or similar service to provide individual support during heat	NCCEH - Evidence on Effectiveness of Interventions During Heat Episodes	• No evidence on effectiveness identified, though phone hotlines are often a	None identified

events		component of a larger extreme heat response plan • Phone hotlines were identified as a useful source of real-time information regarding heat wave severity (WHO, 2009)	
Establish local cooling centers	CDC Climate Change and Extreme Heat Events Guidebook	From a meta-analysis, there was a significant reduction in heat wave deaths (OR=0.34) for visiting cool environment (Bouchama et al., 2007)	None identified
Operationalize local social/aid networks to check-in on vulnerable individuals, hard to reach populations (e.g., homeless), provide transport to cooling centers, etc.	CDC Climate Change and Extreme Heat Events Guidebook	From a meta-analysis, there was a significant reduction in heat wave deaths (OR=0.4) for increased social contact (Bouchama et al., 2007)	None identified
Enact cancellation policies for workers, students, activities affected by extreme heat	CDC Climate Change and Extreme Heat Events Guidebook	• No evidence on effectiveness identified, though cancellation policies are often a component of a larger extreme heat response plan	None identified

Long-term adaptation strategies

Intervention	Resources/notes	Other Supporting Evidence in Scientific Literature	Co-benefits
Increase installation of air conditioning, heat pumps, fans, and other cooling devices in residences, workplaces, senior centers, schools, etc.	NCCEH - Evidence on Effectiveness of Interventions During Heat Episodes Note: Increasing air conditioning usage may be counterproductive at reducing energy usage and greenhouse gas emissions; more efficient technologies like heat pumps can help to offset this impact, though typically at a higher up-front cost than conventional air conditioning: Energy.gov: Heat Pump Systems	• Significant reductions in respiratory disease, cardiovascular disease, and heat stroke hospitalizations associated with having air conditioning (Ostro et al., 2010) • Significant reduction in mortality for central air compared to no air, but not for room air versus no air (Rogot et al., 1992) • From a meta-analysis, there was a significant reduction in heat wave deaths (OR=0.23) for home air	Reduced home cooling costs
Coordinate w/ local utilities to ensure	CDC Climate Change and Extreme Heat		

adequate power supply during extreme heat events	Events Guidebook	conditioning, and a non-significant reduction (OR=0.6) for having a fan (Bouchama et al., 2007)	
Provide subsidies to assist households with air conditioning or heat pump installation and operating costs	None identified		
Retrofit homes for improved cooling • Shade trees/plants • Install awnings or other shade cover over windows • Install light-colored, thermal blocking curtains/shades	Passive cooling strategies in North Carolina	Building-scale passive cooling strategies can reduce indoor temperatures through heat control, storage, and dissipation (Santamouris and Kolokotsa, 2013)	Reduced energy usage and cost, reduced greenhouse gas emissions
Develop/expand urban greening programs, with focus on trees, vegetation, green space, green roofs, and limiting impervious surface	• EPA - Reducing Urban Heat Islands: Compendium of Strategies • NCCEH - Evidence on Effectiveness of Interventions During Heat Episodes • Adapting Cities for Climate Change: The Role of the Green Infrastructure	• Data from a variety of cities show that temperatures within urban parks are on average about 2°F lower than surrounding areas, but can be as much as 13°F lower depending on amount of tree canopy and impervious surface, park size, and other characteristics (Nowak and Heisler, 2010, Bowler et al., 2010) • Summer building surface temperatures in Toronto were significantly lower when measured in a tree-shaded versus a non-shaded location. The largest effects were for west-facing walls, late afternoon temperatures, large mature trees within 5 meters of the building. Vines were as effective as trees, and isolated trees as effective as clusters of trees. (Millward et al., 2014)	Beautification, increased wildlife habitat, increased food production, reduced air pollution, reduced energy usage and cost, reduced GHG emissions
Increase use of high reflectivity/emittance materials in roofs, buildings, paving, etc.	• Cool Roof Rating Council • EPA - Reducing Urban Heat Islands: Compendium of Strategies - Cool Pavements • Preparing California for Extreme Heat	• The use of cool paving materials was associated with a reduction in over 3°F in ambient temperature (Santamouris et al., 2012) • Cool roofs may be more effective for heat mitigation, though green roofs	Reduced energy usage and cost, reduced GHG emissions
Adopt cool building/site construction standards			

	• California Green Building Standards	(especially when irrigated) can be effective while also providing other benefits (Santamouris, 2014, Coutts et al., 2013)	

Surveillance

Intervention	Resources/notes	Evidence	Co-benefits
Record and publicly report heat-related emergency visits & mortality	• Preparing California for Extreme Heat • WHO: Improving Public Health Responses to Extreme Weather/Heat Waves	None identified	None identified