CLIMATE CHANGE IN VERMONT

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1.0 PREFACE

This section of the Climate Action Plan presents the drivers and processes of climate change in the Vermont by focusing on the natural hazards that produce effects on multiple sectors and whose overlapping stressors have a direct influence on our resilience as a state. In presenting resilience through the dual lenses of inclusion and vulnerability (of peoples, the natural environment and human infrastructure), we honor Abenaki knowledges (Figure XX) and all ways of knowing (Betts, 2021), as we seek to do no harm (Figure XX).

For consistency with other state-level Climate Action Plans, this section used data and statistical methods developed in support the Fifth National Climate Assessment (NCA5) by the National Center for Environmental Information (NCEI), the Environmental Protection Agency (EPA) and the Northeast Regional Climate Center (NRCC). One such document is the 2021 Vermont State Climate Summary which is included with permission as Appendix XX. County level climate projections of future thresholds were summarized from the NOAA Climate Explorer and included in Appendix XX. Sectoral impacts of climate change across Vermont can be found in the 2021 Vermont Climate Assessment. Existing tools for monitoring and quantifying vulnerabilities will be woven throughout this section.

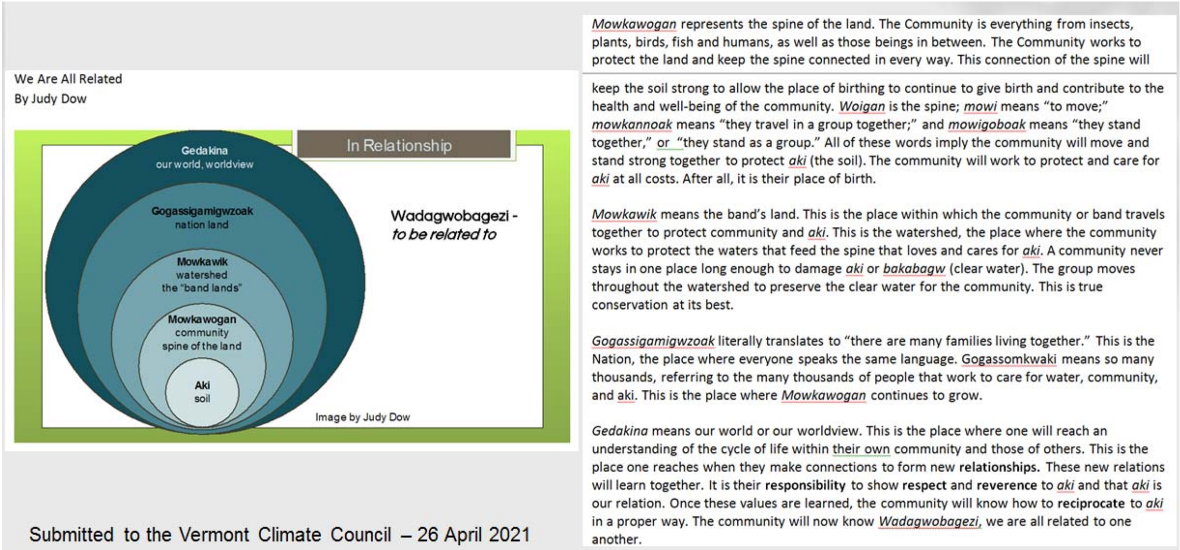
2.0 BACKGROUND

Across Vermont, natural hazards of varying intensity, duration and frequency occur. These include severe storms, winter storms, drought, flooding, wildfires, air pollution, ground-level ozone, temperature extremes, localized winds and biotic elements (insects and disease) (Dupigny-Giroux, 2002). Some of these hazards are ubiquitous, while others tend to occur at specific locations across the Green Mountain State, posing differing exposure or risk and therefore, vulnerability. As climate change continues to be observed in Vermont, the characteristics of these hazards are also changing and this sets up cultural, socioeconomic and policy implications for Vermonters as individuals, municipalities, communities and indigenous peoples, as well as for the built and natural environments. In addition to increasing vulnerabilities at the human and landscape scales, climate change related impacts on our economic sectors are of central importance in this Climate Action Plan, as we lay out the inaugural framework for mitigating against and adapting to climate change, while building our resilience as a State.

2.1 **Geographies of vulnerability** (human, landscape, infrastructure)

The topography or physical geography of Vermont is one of the most important factors in the incidence of natural hazards, the affected populations and the capacity to increase resilience. The north-south spine of the Green Mountains, along with the complex east-west valleys and the north-south ridges of the Taconic Mountains (Dale, 1905) affect the movement of localized winds and incidence of freezing rain and cold air damming conditions; produces enhanced orographic precipitation and the associated flooding events; controls the incidence of pollution and stagnation events, as well as variations in freeze and frost dates <https://www.weather.gov/btv/climoFreeze>.

a)



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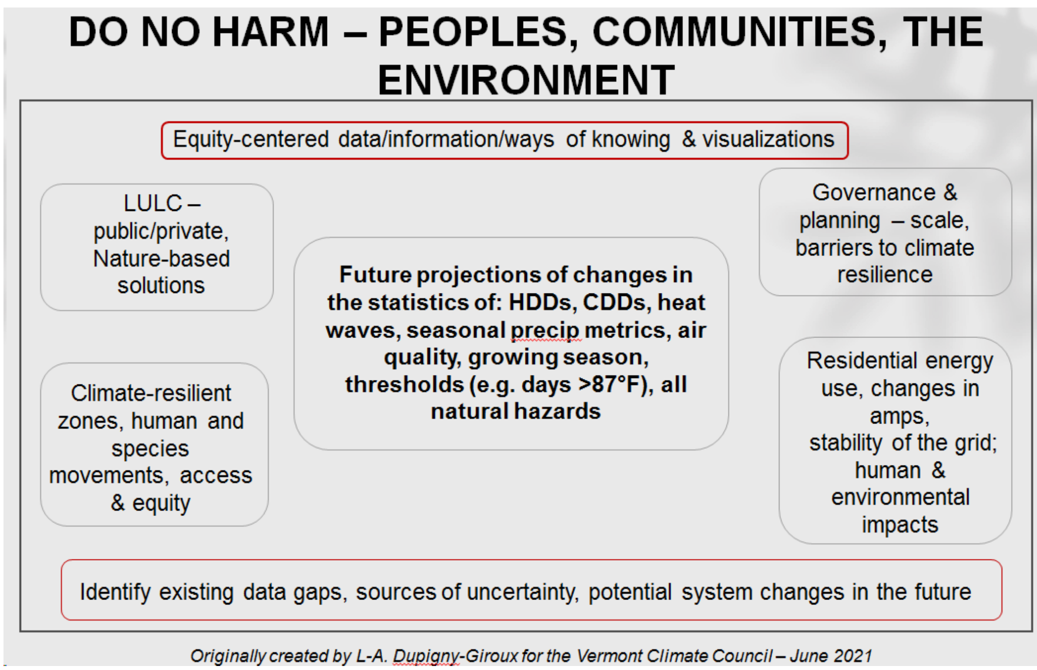


FIGURE XX. Diagrams submitted to the Vermont Climate Council as frameworks to guide discussions and understanding. We are all related was created by Abenaki scholar and educator Judy Dow (a) and Do no harm- Peoples, Communities, the Environment by Lesley-Ann Dupigny-Giroux, in consultation with Abenaki elders and scholars.

3.0 COMPONENTS OF CLIMATE & CLIMATE CHANGE IN VERMONT

3.1 Wind and snowfall climatologies

The occurrence of high winds in Vermont shows a strong correlation with elevation. This is simply due to the wind increasing in speed with elevation climatologically in midlatitudes. Unique meteorological conditions are generally required to get winds aloft to mix or transport down to the surface within valleys during storms.

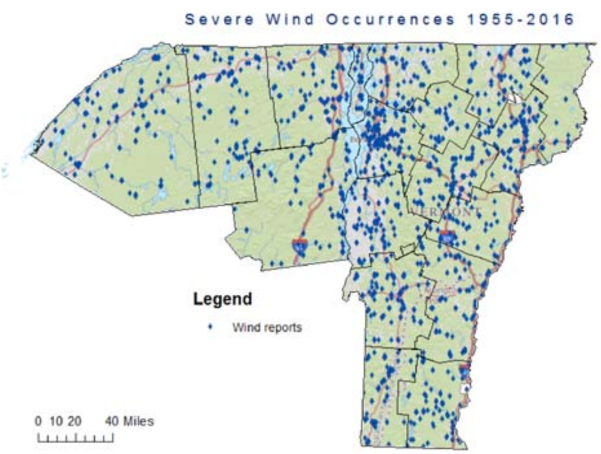
Vermont's distribution of snowfall follows a strong correlation with elevation. This is due colder temperatures at higher elevations, and the influence of the mountains producing upslope flow that produces localized clouds and enhances winter precipitation. Total snowfall ranges from around 70" a year in the deeper valleys to over 200" in the highest Green Mountains. Winter temperatures and precipitation are increasing, which will likely result in a greater number of winter storms featuring elevation-sensitive rain or snow accumulations. A comparison by the National Weather Service Burlington Forecast Office (NWSFO-BTV) of the average monthly snowfall received during the 1980-2010 vs. 1990-2020 overlapping 30-year periods <https://www.weather.gov/btv/climoSnowfall>, revealed that with the exception of January and April, total snowfall received at long-term stations across the North Country, decreased for the months of November, December (FIGURE XX), February and March (Banacos, 2011).

Wet snowfall occurs when partially melted snowflakes have water on their edges, making them sticky. Freezing rain occurs when rain falls into a shallow subfreezing layer of air and then freezes on contact to surfaces. These processes are more frequent at higher elevations, principally due to colder temperatures and higher precipitation accumulations. The greatest risks from wet snow and freezing rain icing (from a frequency perspective) show a strong correlation with elevation across Vermont. Thus, wet snow and freezing rain hazards are more likely to produce power outages at higher elevations. However, intense storms can still occur in valleys, especially in deeper northern valleys near the international border when shallow cold air can recharge itself from Canadian source regions (FIGURE XXe).

3.2 Temperature variability

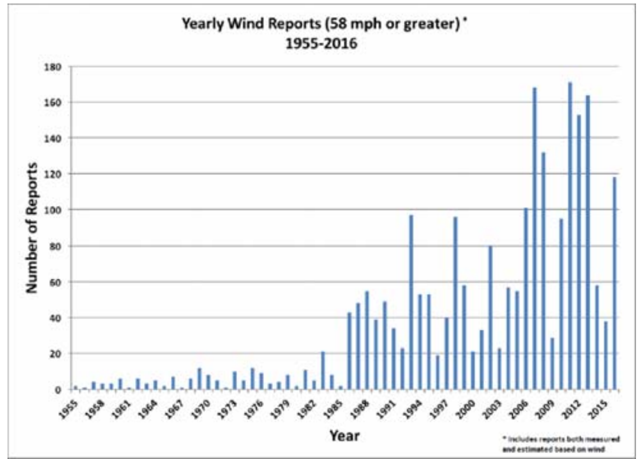
Across Vermont, the 2010-2020 11-year period has been the warmest since records began in 1895, with the warmest winter and summer seasons occurring in the 2000-2020 period (Runkle et al., 2021). Vermont's average annual temperature has increased over 2°F from the 1970s to 2010s and over 3°F from the end of the last century (Figure XX). The rate of warming has increased through the last 120 years, and is currently around +0.5°F a decade. While this rate of warming may seem relatively small compared to perceptions of daily temperature changes, the overall warming is having a number of notable effects. Some of these include a lengthening of the growing season, less reliable winter snow cover, and shifting peak energy usage to the summertime. Seasonal temperature trends show the winter season warming nearly twice as fast, increasing over 4°F from the 1960s to the 2010s. Other observed seasonal shifts include an expanding warm season causing longer falls and winter to have more false starts, and increased intra-seasonal and inter-seasonal temperature variability (more fluctuation within seasons). Backward or false springs (during with snow and freezing rain can occur in April-June after the normal progression of warming temperatures (Dupigny-Giroux, 2009) continue to be observed, even with the observation that freeze-free seasons are longer (Runkle et al., 2021).

a)



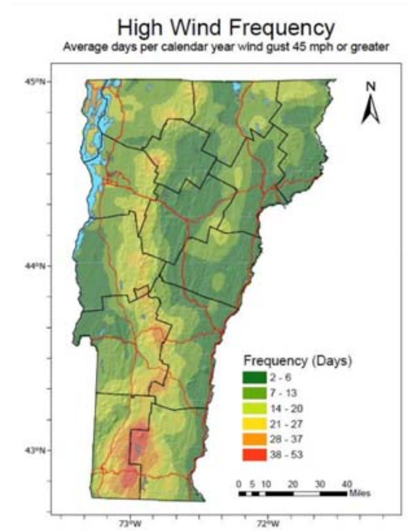
Severe Wind Occurrences 1955-2016
Legend
Wind reports
0 10 20 40 Miles

b)



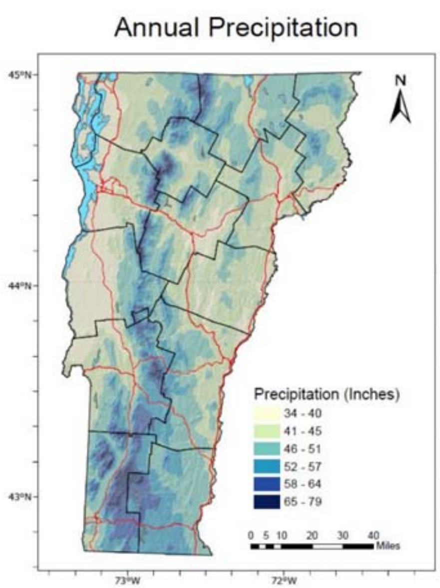
Yearly Wind Reports (58 mph or greater)*
1955-2016
Number of Reports
Year
* Includes reports both measured and estimated based on wind

c)



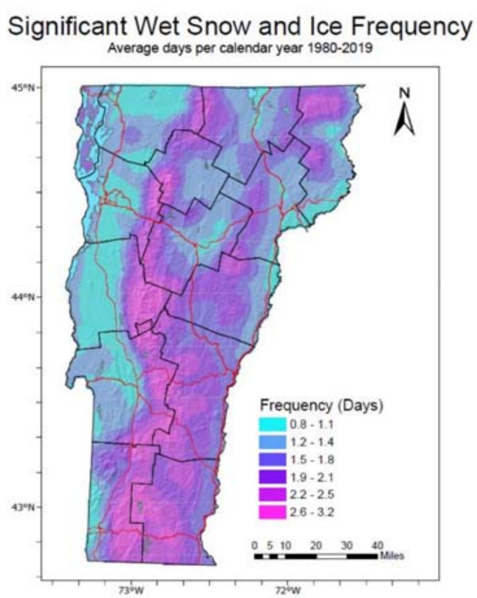
High Wind Frequency
Average days per calendar year wind gust 45 mph or greater
Frequency (Days)
2 - 6
7 - 13
14 - 20
21 - 27
28 - 37
38 - 53
0 5 10 20 30 40 Miles
45°N
44°N
43°N
73°W
72°W
N

d)



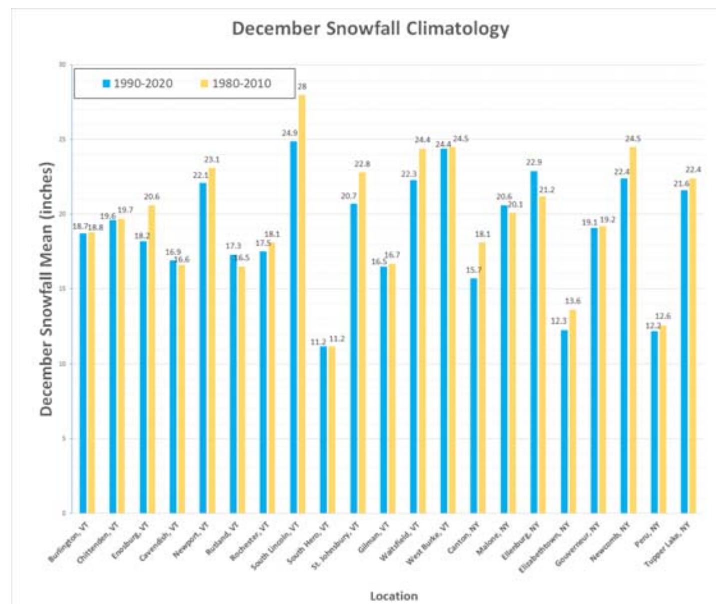
Annual Precipitation
Precipitation (Inches)
34 - 40
41 - 45
46 - 51
52 - 57
58 - 64
65 - 79
0 5 10 20 30 40 Miles
45°N
44°N
43°N
73°W
72°W
N

e)



Significant Wet Snow and Ice Frequency
Average days per calendar year 1980-2019
Frequency (Days)
0.8 - 1.1
1.2 - 1.4
1.5 - 1.8
1.9 - 2.1
2.2 - 2.5
2.6 - 3.2
0 5 10 20 30 40 Miles
45°N
44°N
43°N
73°W
72°W
N

f)

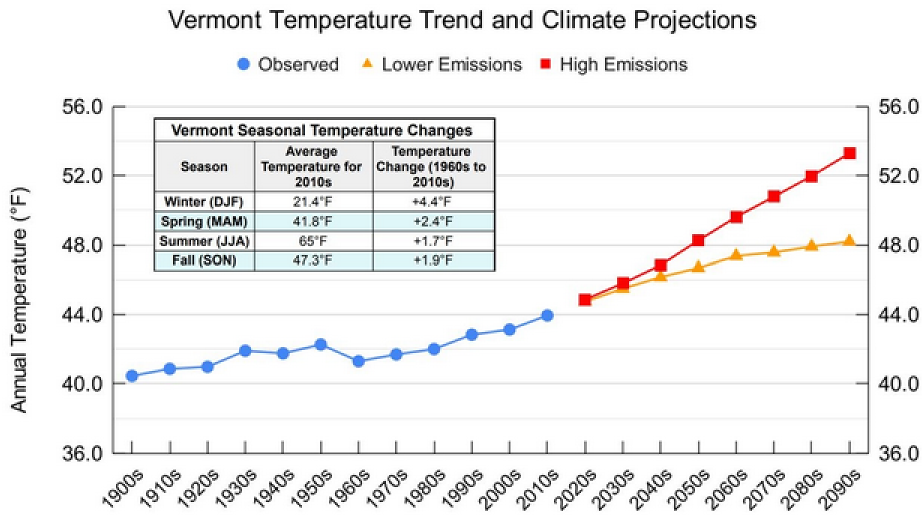


December Snowfall Climatology
1990-2020
1980-2010
December Snowfall Mean (inches)
Location
Burlington, VT
Chittenden, VT
Enosburg, VT
Cavendish, VT
Newport, VT
Rutland, VT
Rochester, VT
South Lincoln, VT
South Hero, VT
St. Johnsbury, VT
Gilman, VT
Waitsfield, VT
West Burke, VT
Canton, NY
Malone, NY
Ellenburg, NY
Elizabethtown, NY
Gouverneur, NY
Newcomb, NY
Peru, NY
Tupper Lake, NY

Figure XX.

a) Vermont observed temperatures and climate projections. Low emissions scenario is the RCP4.5 (moderate global emissions mitigation), and the high emissions scenario is RCP8.5 (emissions continuing on current trends as usual). Inset table based on data from NOAA's National Centers for Environmental Information. b) Average cumulative seasonal growing degree days (using a 50°F base). Based on a 5-km downscaled dataset from 1990-2019 following Shafer and Cronin (2021)[2].

a)



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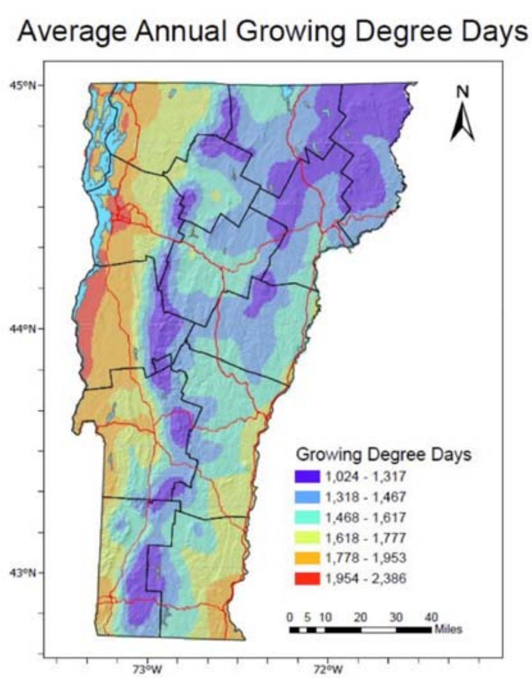


Growing degree days are a general proxy for warm season growing potential for various crops; this is basically a measure of growing potential energy available to plants. Growing degree days are highest in the warmest areas of Vermont (primarily west of the Green Mountains and in southern valleys), and lowest in the Northeast Kingdom and highest elevations. Growing degree days have increased by approximately 5 to 10% over the last 40 years (Figure XX).

As Vermont's climate warms there has been an observable shift in temperature extremes. Heat waves are becoming more likely while cold waves are decreasing. Evidence for this from Burlington shows a steady decline in cold waves peaking around nearly 6 per year in the 1970s to less than 2 per year in the 2010s. Heat waves have generally increased from around 3 to 4 per year in the 1960s/1970s to over 7 per year in the 2010s. These changes will cause a shift in peak energy demand to more likely occur during the summer season, and increase heat exposure health risks to vulnerable populations.

Since the mid-2000s, a below average number of very cold nights has also been observed in winter, with a near to above average annual number of warm nights in the 2000-2020 period (Runkle et al., 2021; see Appendix XX). The Vermont Department of Health <https://www.healthvermont.gov/sites/default/files/documents/pdf/ENV_CH_WhitePaper.pdf> has documented the combined influence of warmer winters and longer warm seasons as contributing to both a more hospitable environment for blacklegged ticks, as well as their hosts, white-footed mice. Figure XX captures the exponential increase in probable Lyme disease cases between 1990 and 2016, with Vermont and Maine being the states with the highest increases in actual reported case rates since 1991 (EPA Change Indicators, 2021 <https://www.epa.gov/climate-indicators/climate-change-indicators-lyme-disease>) (Figure XX). The Department's climate and health pages <https://www.healthvermont.gov/environment/climate> offer a rich resource of the climate impacts on health, considerations for vulnerable populations <https://www.healthvermont.gov/health-environment/climate-health/vulnerable-populations>, potential impacts (e.g. on pollen, allergies, mold in buildings, waterborne and foodborne diseases) and the health benefits to be derived from climate change adaptation and mitigation. The Vermont Heat Vulnerability Index Mapping Tool can be found at <https://ahs-vt.maps.arcgis.com/apps/MapSeries/index.html?appid=5bfd71bdeff242d4a8f0d2780369807a> and the Vermont Social Vulnerability Mapping Tool at <https://ahs-vt.maps.arcgis.com/apps/MapSeries/index.html?appid=ffea40ec90e94093b009d0ddb4a8b5c8>.

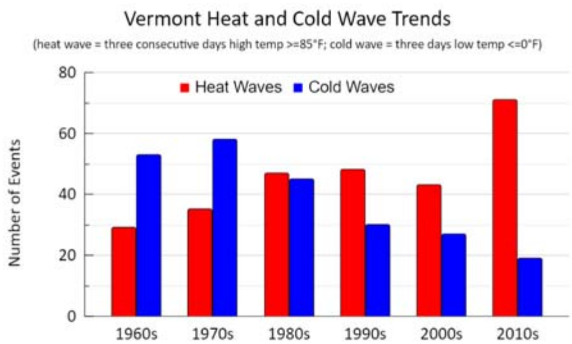
3.3 Moisture variability

As Vermont's climate warms, the overall amount of precipitation is also increasing. Warmer temperatures produce increased evaporation of water vapor from nearby bodies of water, resulting in a greater potential for weather systems to produce higher amounts of precipitation. The decadal correlation between annual precipitation and temperature shows a statistically significant relationship (not shown). Increases in annual changes are relatively small, on the order of +0.5" to +1.0" a decade. The winter season has shown the greatest increases to precipitation (not shown).

Vermont's distribution of precipitation follows a strong correlation with elevation with nearly a doubling factor in the deeper valleys which receive less than 40"/year while, the highest

Figure XX. Observed changes in severe heat and cold. Heat waves are defined as three consecutive days reaching 85°F or warmer. Cold waves are defined as three consecutive days falling to 0°F or colder. Based on observations at Burlington International Airport (KBTV (a).Climatology of days >= 87°F as issued by the National Weather Service Burlington, in collaboration with the Department of Health (b). Vermont Department of Health's quantification of the sources of human health vulnerability to heat by age (c); exposure and/or life status (d).

a)



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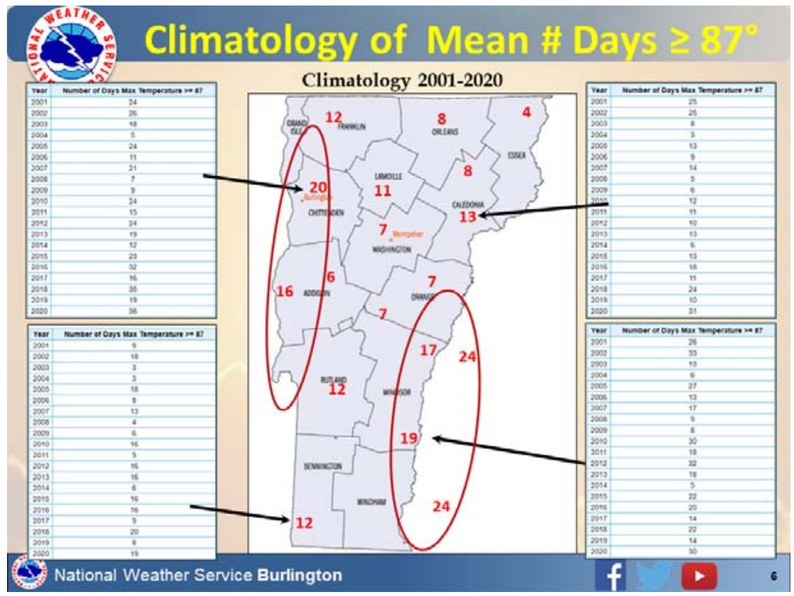

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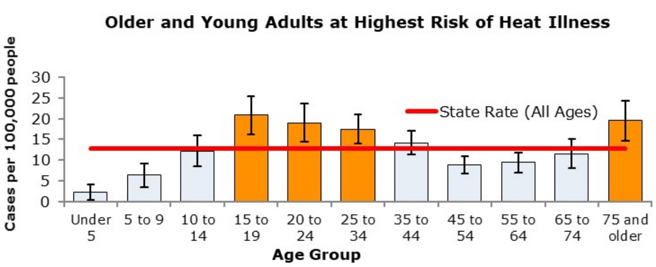

d)

	Vulnerability Type	Health Impact Area: Extreme Heat	Extreme Weather	Water/ Foodborne Diseases	Vector-Borne Diseases	Cyano-bacteria	Asthma, Allergies & Air Quality
Target Populations	Older adults	X	X	X	X		X
	Children and teenagers	X	X	X	X	X	X
	People with chronic health conditions	X	X	X	X		X
	New Vermonters (refugee and other foreign-born)	X	X	X	X		X
	People with limited socioeconomic resources	X	X				X
	People living alone	X	X				
	People who are homeless or housing-insecure	X	X		X		X
	Users of private wells and small water systems			X			
	Outdoor workers	X	X		X		X
	Outdoor recreationalists	X		X	X	X	X
Target Locations	Mobile home communities	X	X	X			
	Urban areas (more impervious surfaces, less tree canopy)	X	X				
	Remote areas with long drive times to hospitals	X	X				
	Flood plains		X	X	X		
	Mountain valleys prone to temperature inversions						X
	Locations near recreational waters			X		X	
	Forest/field edges and trails where ticks thrive				X		
	Areas near stagnant water				X		

Table 1. People and places that are at elevated risk for particular climate hazards are indicated by an "X".

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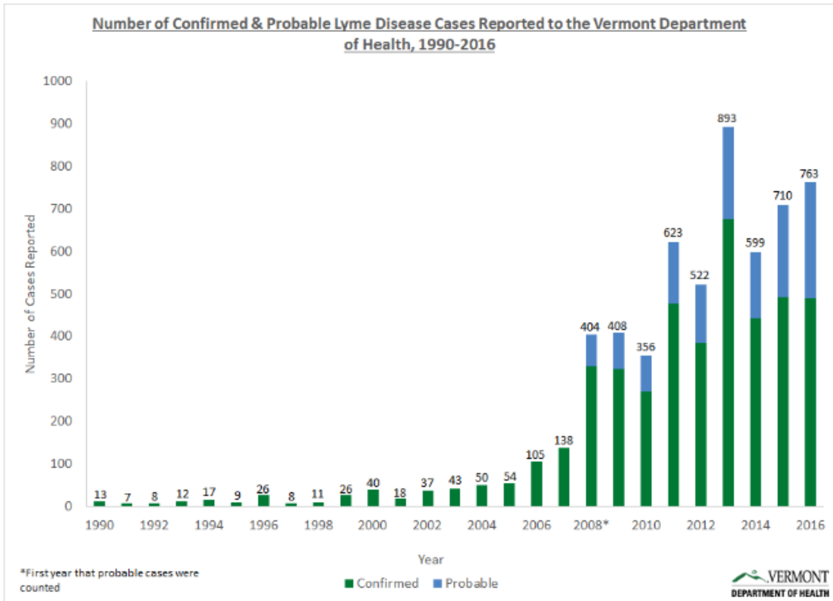
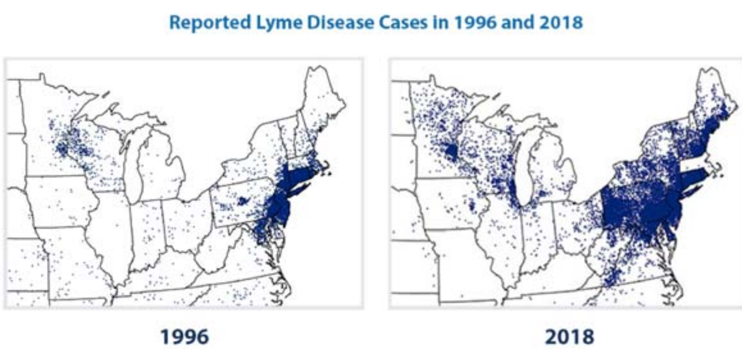


Figure 5: Number of confirmed and probable Lyme disease cases reported to Vermont Department of Health, 1990 to 2016

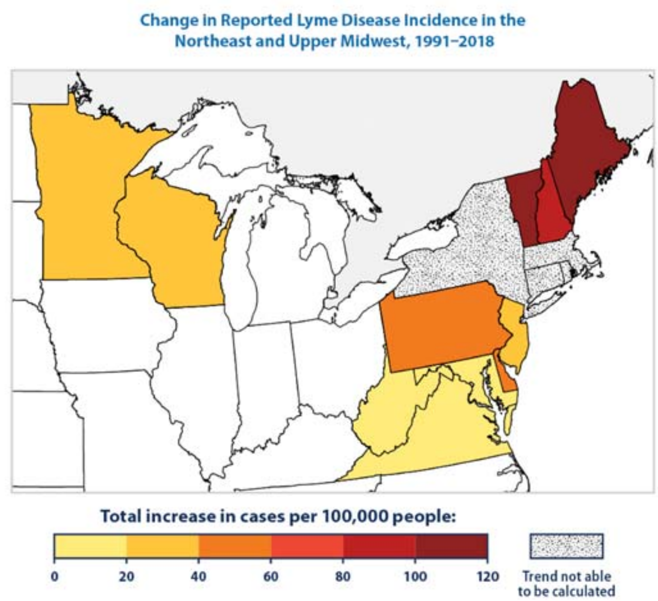
b)



Data source: CDC (Centers for Disease Control and Prevention). 2019. Lyme disease maps: Historical data. Updated November 22, 2019. Accessed January 2021. www.cdc.gov/lyme/stats/maps.html.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

c)



Data source: CDC (Centers for Disease Control and Prevention). 2019. Lyme disease data tables: Historical data. Updated November 22, 2019. Accessed January 2021. www.cdc.gov/lyme/stats/tables.html.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

FIGURE XX. Confirmed and probable cases of Lyme disease 1990-2016, Vermont Department of Health (a). Comparison of the reported cases of Lyme disease in 1996 and 2018 for the Northeast and Upper Midwest, Centers for Disease Control and Prevention, EPA Climate Change Indicators (b). Change in the reported cases of Lyme disease 1991- 2018 for the Northeast and Upper Midwest, Centers for Disease Control and Prevention, EPA Climate Change Indicators (c).

peaks nearly reach 80”/year (FIGURE XX). Terrain produces local areas of precipitation enhancement in upslope areas and precipitation suppression in downslope areas. The Champlain Valley, for example, rests in the climatological rain shadow from the Adirondack Mountains of New York. As westerly airflow reaches the Green Mountains, and if sufficient moisture and cloud growth processes exist, additional precipitation is produced as air reaches the Green Mountain crest and other downstream sub-ranges.

As noted in Runkle et al. 2021 (and shown in the Standardized Precipitation Index values on Figure XXa), the year 1970 marked a shift towards annual average precipitation trending above the long term average, increasing by almost 6" since the drought decade of the 1960s. The wettest period since 1895 was observed in 2005-2014. Extreme precipitation (defined as greater than 2") has also trended above the long-term average since 1995. These trends are reflected in the increases in stormflow between 1950-2006 (Figure XX b; Hodgkins and Dudley, 2011), as well as the increasing magnitudes of the 1% (100-year return interval) storms across timescales from 1 hour (Figure XXc) to 1 day(Figure XXd). Such changes in recurrence intervals and other precipitation statistics should be factored into infrastructure planning, hydraulic studies and floodplain management in order to mitigate against ongoing loss, failure or disruption.

Vermont is marked by tremendous hydrologic variability over time and space. Temporally, fluctuations of importance can occur over very short time frames (e.g. in the transportation sector, heavy precipitation on the order of minutes to hours is of critical interest) up to weeks, months and years (which are important to the agricultural sector where moisture availability during key phenological stages of the planting, growing and harvesting seasons is paramount). Moisture extremes (droughts and floods) can and have occurred simultaneously across the state (e.g. flooding in Southern Vermont in 2021, while the northern reaches were in moderate drought). In fact, Southern Vermont just experienced its wettest four summer months (June through September 2021) on record, with major localized flooding throughout the month of July and its most widespread major flooding event occurring on July 29, 2021 since Tropical Storm Irene, nearly 10 years earlier. The region was fortunate to experience only glancing blows from tropical systems Fred, Henri, and Ida thereafter. Both the flooding that did occur, and the catastrophic flooding that could have occurred but did not had the paths of major systems, confirm the need for climate adaptation and resilience even as the production of greenhouse gases must be reduced.

Apart from heavy precipitation, especially from slow-moving or stalled storms, flood-producing conditions include the presence of deep snow cover, frozen ground and ice-covered rivers (primarily in the cool season), with saturated soil, existing bankfull conditions, full reservoirs and complex topography

Droughts followed by flooding in the same year is also a characteristic of Vermont, a pattern which has not changed over the last 100 years. For example, this flip-flop was observed in 1927 (where the November floods remain the flood of record for Northern Vermont) and more recently in August 2011 (where the flooding due to Tropical Storm Irene stands as the flood of record for Southern Vermont). The August 2011 drought was an example of a new type of drought called a flash drought, which is now observed more frequently in Vermont. Flash droughts (Otkin et al., 2019), as their name suggests, develop very quickly (weeks), typically in the spring/summer months, where the lack of precipitation and decreased soil moisture is often exacerbated by high daytime temperatures and low relative humidities in the air.

Apart from the newer flash droughts, traditional droughts tend to fall into staggered categories with meteorological (precipitation deficit) occurring first, followed by agricultural

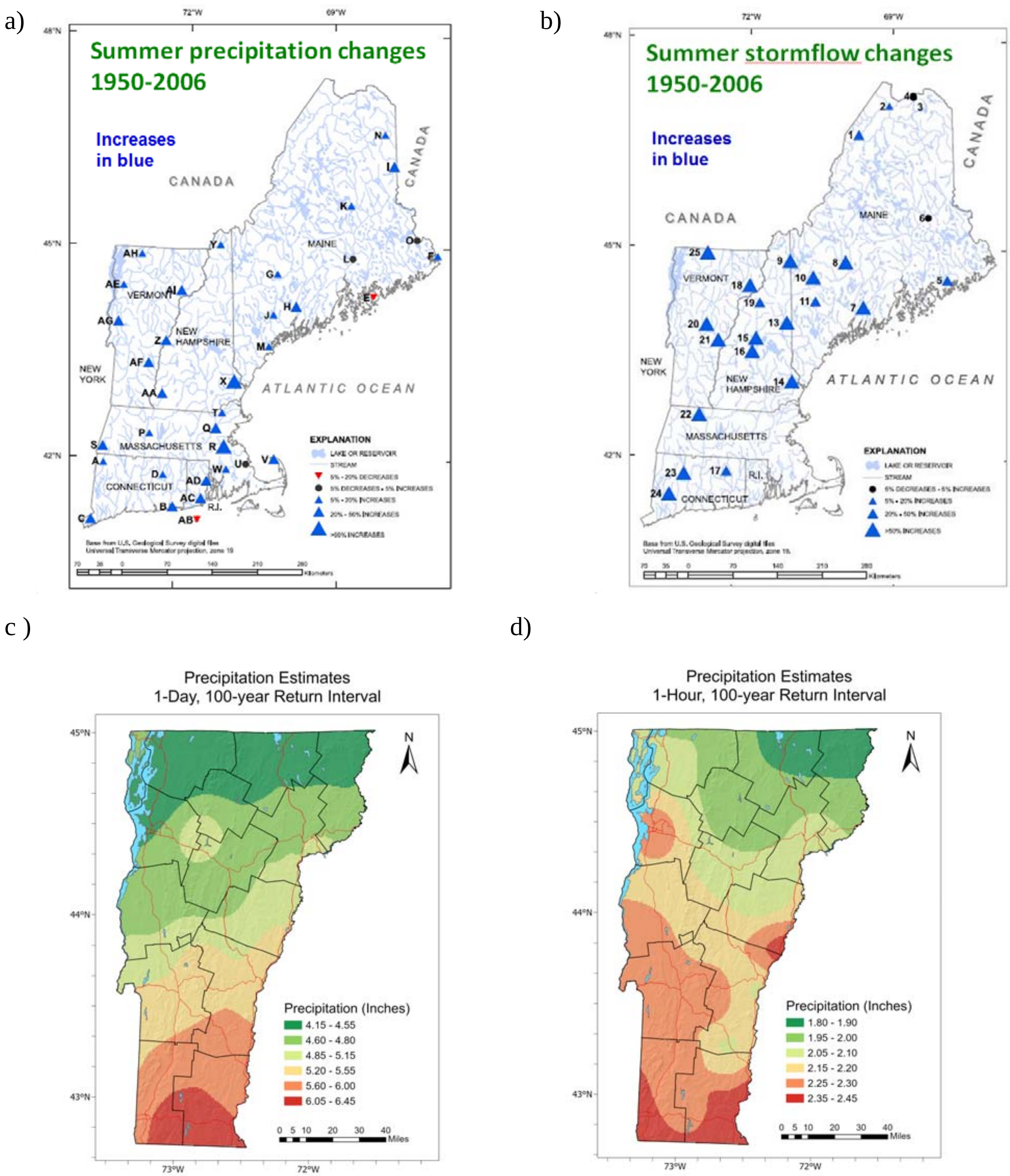


FIGURE XX. Increases in summer precipitation (a) and stormflow (b) for the 1950-2006 period (Hodgkins and Dudley, 2011). Estimated precipitation amounts for the 1-day, 100-year return interval (c) and 1-hour, 100-year return interval (d) for Vermont, as derived from the Extreme Precipitation in New York and New England tool <http://precip.eas.cornell.edu/>.

droughts (soil moisture deficit) and then hydrologic ones (when surface waters, lakes, groundwater and wells are affected over the course of months to years). As Figure XX shows, it is possible to be in a meteorological drought (e.g. 1910s, 1930s), but not a longer term hydrologic drought. Recent droughts in Vermont and across New England suggest that this traditional sequence is changing. The year 2020 was a marker year when short term flash droughts over the summer were followed by record-setting streamflow and groundwater droughts in the fall (Lombard et al., 2020). This was significant because some of these records that were set or tied occurred on streams with 71, 89 and 90 years of records, dating back to the droughts of the 1930s. Across Vermont, evidence of this severe 2020-2021 hydrologic drought included the number and depth of new wells being drilled, and the fact the well drillers were still managing homeowner requests into the fall of 2021.

Hydropower generation is also subject to fluctuations in water levels. The Connecticut River is a heavily-managed river due to the presence of hydropower facilities at Wilder, Bellows Falls, Vernon, and Northfield, Massachusetts (which affects the flow of the river and erosion in Vernon, Vermont). It is also falls within the jurisdiction of both the states of Vermont and New Hampshire, with the river at and below the low-water mark on the western shore falling within the jurisdiction of the latter. To the extent climate change forecasts suggest intensification of the hydrologic cycle, this has implications for Connecticut River water quality and quantity that will require greater coordination between the states of Vermont and New Hampshire, greater management of competing uses, and which could have significant downstream implications including the Long Island Sound Total Maximum Daily Load for nitrogen. This coordination could create new purpose for the Connecticut River Joint Commissions (see 10 V.S.A. § 1193). Drought impacts on drinking water supplies as well as adequate water availability for key Vermont sectors such as hydropower, agriculture, forestry and other water-based recreation and tourism activities, represent a pressing need for building resilience to moisture extremes.

4.0 Economic impacts of climate change in Vermont

Due to the small geographic extent of Vermont as a state relative to the global economy, it is difficult to provide absolute attribution to the gradual, but certain climate changes that are occurring. Similarly, it is also difficult to tease out all of the specific economic impacts directly attributed to climate change. However, there are three categories of economic damage where the impacts are clear. These are structural damage, human health impacts and the disruption to production and supply chain within the business sector.

One partial measure of structural damage resulting from the increasing strength and frequency of storms is represented by FEMA-designated disaster declarations and the resulting payments. A review of FEMA designations between 2010 and 2019, shows that Vermont receives on average $9-30 million in assistance support. The range is based on either including or not including Irene-related damages that influence the ten year average significantly. However, FEMA only addresses short term catastrophic impacts and not the less destructive but still significant issues associated with increased precipitation and storms resulting in wet basements and tree damage. To get a handle on the size of these smaller scale impacts, it is instructive to review consumer expenditures as reported by the Census Bureau Consumer Expenditure Survey (CES). The CES includes a category for home maintenance, repair and insurance. For the northeastern states (Vermont specific data are not robust enough for reporting), the proportion of household income attributed to home maintenance, repair and

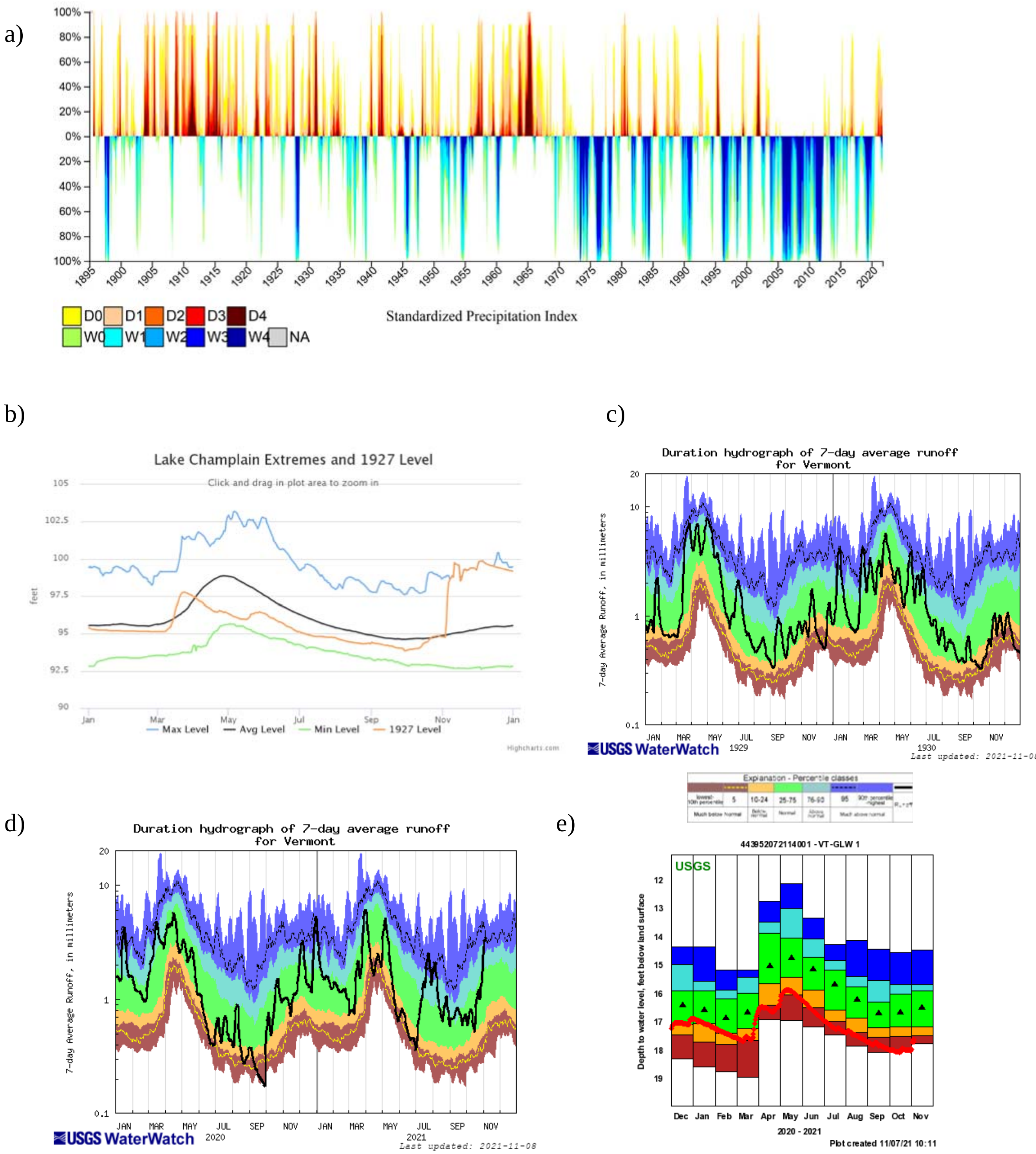


FIGURE XX. Monthly Standardized Precipitation Index (SPI) values showing meteorological droughts and wet periods from 1895-2021 (a) <https://www.drought.gov/states/vermont>. Lake Champlain heights in 1927 relative to the extremes and median observation as of November 2021 (b) <https://www.weather.gov/btv/lakeLevel?year=1927>. USGS hydrographs showing the 7-day average runoff for 1929-1930 (c) and 2020-2021 (d). USGS height of the groundwater well at Glover, Vermont for December 2020-November 2021 highlighting the record low observations (e) <https://groundwaterwatch.usgs.gov/AWLSites.asp?mt=g&S=443952072114001&ncd=awl>.

insurance has increased from 1.88% to 2.15% between the 2003-4 and 2019-20 reports. This amounts to an average increase of $250 per household and for Vermont adds up to an additional $66 million in economic costs per year. It should be noted that, applying a similar approach to southern states in the US, with higher incidences of storm related damage due to hurricanes, tornadoes and tropical storms, yields an annual increase in maintenance, repair and insurance of $576 per household when comparing the 2003-4 data with 2019-20.

The impacts on residential properties parallel damage to commercial properties. In Vermont, the Grand list value Commercial and Industrial properties is about 12% of that of residential properties. If Commercial and Industrial properties suffer the same proportion of damage increases as do residential properties, the damage estimate increases by $8 million to a total property damage estimate of almost $75 million per year.

There are several examples of human health that are affected by climate change. While the human suffering associated with these human health impacts is important, it is still possible to assign dollar amounts to the increased health care services that result. In terms of the aforementioned exponential increase in probable and actual reported cases of Lyme disease and other tickborne illness, the Tick Borne Disease Working Group at the federal level estimates the dollar costs for Lyme disease at about $1.3 billion and because Vermont represents 1.5-2% of national cases, the dollar costs are $20-25 million per year. This value is in addition to the dramatic increases in anaplasmosis observed across the state. Prior to 2008, case of anaplasmosis were close to zero and that number increased to more than 200 in 2016. Finally, in terms of mosquito-borne diseases have been observed in Vermont for decades and include the West Nile Virus and Eastern Equine Encephalitis. A website focusing on mosquito-borne diseases puts national level economic damages in the billions of dollars.

Apart from vector-borne ailments, increasing temperatures pose economic effects due to water contamination impacts and those related to heat waves. In terms of the former, beach closures in Vermont are the result of a combination of increased water temperatures and increased nutrient loads. There is no dollar estimate that specifically informs the climate change component, but Vermont spends tens of millions of dollars each year to address water quality contaminants in our large lakes. Finally, in terms of heat waves, periods of extreme heat result in increases to the emergency room. Using the aforementioned threshold of 87°F as an extreme heat day since 2016, it should be noted that, prior to the year 2000, extreme heat days averaged about 6 per year resulting in dozens of emergency room visits. Models show these numbers increasing significantly with a resulting increase in emergency room visits. Perhaps more economically important than acute health events is the trend towards adding air conditioning to Vermont homes. One of the drivers behind an increase in the installation of heat pumps is the ability of a heat pump to also provide air conditioning services. The dollar cost for heat pump installation from 2019 to 2021 is estimated in this report to be $84 million or $27 million per year.

4.1 Vulnerabilities exposed by the COVID-19 pandemic

The ongoing SARS-CoV-2 (COVID-19) pandemic has acted as a compound stressor or threat multiplier on communities and activities that were already vulnerable to natural hazards, climate change impacts and socioeconomic disruptions. In particular, 2020-2021 has been marked by climate migration and business disruptions.

The influx of out of state residents to Vermont during the COVID-19 pandemic, and others transitioning second homes into primary homes, provides a glimpse into what could be the leading edge of climate influenced, if not driven, migration to Vermont and the northeast. This has resulted in housing demand outstripping supply, leading to increased housing prices, decreased housing availability, and the exacerbation of housing fairness, equity and justice issues. Lack of infrastructure (chiefly community wastewater and water systems) makes compact settlement a challenge, thereby causing housing development to follow the path of least resistance, which is dispersed single-family home development on large lots along rural roads. This de facto development pattern will only exacerbate energy use patterns that will make achievement of many of the goals and objectives of the GWSA a challenge, and underscore the need to create an effective land use planning and regulation rubric that can achieve housing development and accessibility, compact settlement, smart growth, and just transitions policy imperatives.

News headlines in 2021 also report disruptions to the supply chain due to the COVID-19 pandemic. Prior to 2020 and continuing through the pandemic are transportation disruptions due to coastal storms. One of the most apparent sectors affected by climate change induced storms is for oil and gas production. Gulf of Mexico drilling platforms and coastal refineries are closed with increased frequency, each time causing a spike in petroleum and natural gas prices. Droughts cause a disruption in hydroelectricity generation requiring electric utilities to purchase alternative, higher priced generation (and often with greater greenhouse gas emissions). Agriculture is probably most susceptible to climate change. While Vermont may see longer growing seasons, most of our food comes from other parts of the world, many of which are subject to water restrictions due to drought. Shipping food on barges is often delayed during flooding events on the major river corridors.

5.0 Projections of future climate change

A warming and wetter climate has varying effects on different weather and climate hazards (Figure XX). Projected changes in temperature through 2050 show a high degree of confidence in temperatures increasing, resulting in a higher frequency of warmer temperatures and heat waves. On the other hand, the most extreme cold temperatures will likely decline in magnitude slightly as arctic warming tends to diminish the strength of wintertime arctic air masses. Overall annual precipitation will likely increase, although at a slower rate than temperature (moderate confidence). Extreme precipitation events, such as those with 2” or greater precipitation in a 24-hour period, will likely increase in frequency (moderate confidence); these precipitation systems may come from a variety of weather systems, as a warmer and wetter climate simply has the capacity to produce higher amounts of precipitation.

Annual snowfall variability will likely remain high, as some winter seasons with more precipitation may actually produce higher than average snowfall, as the climate remains cold enough to continue to support snowfall. However, the general trend will be for more winter rain and reduced annual snowfall, especially in lower elevations. Risks from power outages related to wet snowfall are expected to increase, as more winter storms will likely be closer to freezing where snowfall is wet or sticky in nature (moderate confidence).

Wind storms are expected to increase in intensity, but these will likely be related to unique meteorological storm types. Tropical Storms or Hurricanes, if they make landfall and move inland, will likely be able to maintain strength at higher latitudes from warming ocean temperatures, therefore increasing the risk for low-frequency but catastrophic storm impacts. On the other hand, as the jet stream generally migrates further to the north, gradient wind events from midlatitude storm systems across Canada or nor'easters may decline in frequency.

The projected frequency of ice storms and thunderstorms remain low confidence as the current science is incomplete and there are competing meteorological risk factors for each. Low-end icing events with minor ice accretion from freezing rain are expected to increase, as warmer winter temperatures produce more winter storms with mixed precipitation types.

Overall risks to the power distribution grid have been shown to be increasing, more due to storm systems becoming more intense. A combination of weighing current trends, literature, and two climate simulations shows that overall power outage risks are projected to increase by approximately 5-10% through 2050, due to more frequent wet snowfall, and potentially stronger wind storms (Shafer and Cronin 20212)

Vermont's annual precipitation is projected to increase 1" to 2" through 2050 (Figure XXa). These rates of increase track closely to current precipitation rate changes over the last 30 to 40 years. Through 2100, the lower emissions scenario predicts approximately 4" greater precipitation whereas the high emissions scenario predicts 9" greater annual precipitation. The spatial distribution precipitation change is relatively equal across Vermont counties. Extreme precipitation events will increase as annual precipitation increases, likely following current ratios of extreme events to annual precipitation rate changes.

Vermont's annual temperatures are projected to increase over 2°F through 2050 on either the lower emission or high emissions scenarios (Figure XXb). These scenarios differ significantly through 2100, with the lower emissions scenario predicts 4°F of warming whereas the high emissions scenario predicts 9°F of warming. The spatial distribution of warming is relatively equal across Vermont counties. With a warming climate comes a greater likelihood of higher temperatures. Extreme temperatures (as defined by a high temperature >= 90°F) are projected to double in frequency by 2050 through either the lower emission or high emissions scenario (Figure XXc). Vermont-wide average days above 90°F go from 4 days a year to 9 days a year by 2050. By 2100, however, there is significant variability, with the lower emissions scenario reaching 15 days a year, and the high emissions scenario projecting 45 days a year.

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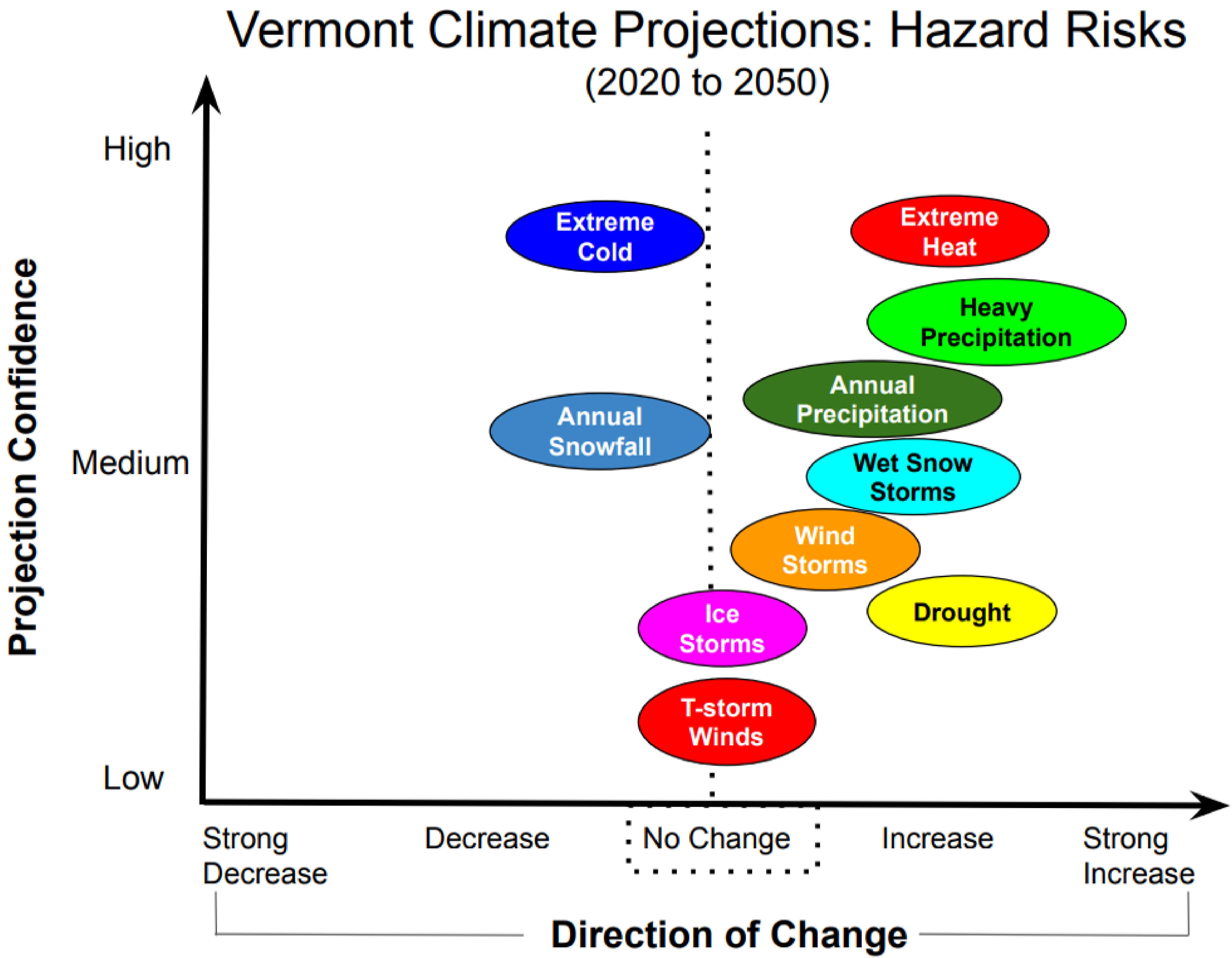
Vermont Climate Projections: Hazard Risks
(2020 to 2050)
Projection Confidence
High
Medium
Low
Extreme Cold
Annual Snowfall
Ice Storms
T-storm Winds
Extreme Heat
Heavy Precipitation
Annual Precipitation
Wet Snow Storms
Wind Storms
Drought
Strong Decrease
Decrease
No Change
Increase
Strong Increase
Direction of Change

a)

Vermont Average Annual Precipitation Projections					
County	2010s Average Annual Precipitation (inches)	2010s-2040s Projected Change (inches)		2010s-2090s Projected Change (inches)	
		RCP4.5 (Low Emissions)	RCP8.5 (High Emissions)	RCP4.5 (Low Emissions)	RCP8.5 (High Emissions)
Addison	39.7	+0.8	+1.6	+1.8	+4.0
Bennington	54.6	+1.0	+1.9	+2.3	+5.0
Caledonia	43.3	+0.8	+1.6	+1.7	+4.2
Chittenden	39.8	+0.8	+1.5	+1.6	+4.2
Essex	45.1	+0.8	+1.6	+1.6	+4.2
Franklin	43.5	+0.9	+1.5	+1.5	+3.8
Grand Isle	35.8	+0.9	+1.7	+1.6	+4.0
Lamoille	44.5	+0.8	+1.4	+1.3	+3.4
Orange	41.0	+0.8	+1.8	+1.9	+4.4
Orleans	45.1	+0.9	+1.6	+1.6	+4.1
Rutland	46.9	+0.9	+1.7	+2.1	+4.6
Washington	42.6	+0.8	+1.9	+1.8	+4.8
Windham	51.3	+1.0	+1.9	+2.5	+5.4
Windsor	45.6	+0.9	+1.9	+2.2	+5.1
Statewide Average	44.2"	+0.9"	+1.7"	+1.8"	+4.4"

b)

Vermont Average Annual Temperature Projections					
County	2010s Average Annual Temp (°F)	2010s-2040s Projected Change (°F)		2010s-2090s Projected Change (°F)	
		RCP4.5 (Low Emissions)	RCP8.5 (High Emissions)	RCP4.5 (Low Emissions)	RCP8.5 (High Emissions)
Addison	45.8	+2.2	+2.8	+4.2	+9.3
Bennington	43.9	+2.1	+2.9	+4.2	+9.3
Caledonia	42.4	+2.0	+2.7	+4.1	+9.1
Chittenden	46.3	+2.3	+3.0	+4.5	+9.7
Essex	41.2	+2.2	+2.9	+4.3	+9.6
Franklin	45.4	+2.3	+3.0	+4.5	+9.8
Grand Isle	47.5	+2.2	+2.7	+4.1	+9.2
Lamoille	44.0	+2.3	+3.0	+4.5	+9.7
Orange	43.1	+2.1	+2.8	+4.1	+9.2
Orleans	42.5	+2.3	+3.0	+4.4	+9.6
Rutland	45.4	+2.1	+2.7	+4.0	+9.1
Washington	43.5	+2.2	+2.9	+4.2	+9.4
Windham	44.5	+2.0	+2.7	+4.0	+8.8
Windsor	44.1	+2.1	+2.8	+4.1	+9.0
Statewide Average	44.2°F	+2.2°F	+2.9°F	+4.2°F	+9.3°F

c)

Projected Change in Number of Days with High Temperature >= 90°F					
County	Average number of days per year >= 90°F in 2010s	2010s-2040s Projected Change (days)		2010s-2090s Projected Change (days)	
		RCP4.5 (Low Emissions)	RCP8.5 (High Emissions)	RCP4.5 (Low Emissions)	RCP8.5 (High Emissions)
Addison	7	+6	+8	+14	+46
Bennington	3	+4	+5	+9	+36
Caledonia	3	+4	+5	+9	+36
Chittenden	6	+6	+8	+14	+46
Essex	2	+3	+4	+7	+32
Franklin	4	+5	+6	+12	+42
Grand Isle	8	+7	+9	+16	+49
Lamoille	2	+3	+4	+8	+34
Orange	3	+4	+6	+10	+40
Orleans	2	+4	+5	+9	+35
Rutland	5	+6	+8	+13	+45
Washington	3	+4	+5	+10	+38
Windham	5	+6	+8	+13	+43
Windsor	5	+6	+8	+13	+44
Statewide Average	4	+5	+6	+11	+41

FIGURE XX.
Vermont projected average annual (a) precipitation changes (b) temperature changes and (c) days with temperatures ≥ 90°F through the 2040s and 2090s based on lower emissions (RCP4.5) and high emission (RCP8.5) scenarios). Based on data from the US Climate Resilience Toolkit Climate Explorer.

APPENDIX XX

Vermont State Climate Summary (provided with NCEI permission)
Runkle, J., K.E. Kunkel, S. Champion, L.-A. Dupigny-Giroux, and J. Spaccio, 2017 (2021 revision): Vermont State Climate Summary, Supplemental Figures. NOAA Technical Report NESDIS 149-VT. NOAA/NESDIS, Silver Spring, MD, 26 pp.

VERMONT

Key Messages

Temperatures in Vermont have risen about 3°F since the beginning of the 20th century. The last 11-year period (2010–2020) was the warmest 11-year period on record. Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century. The intensity of extreme winter cold is projected to decrease.

Annual average precipitation has increased nearly 6 inches since the 1960s (a decade marked by prolonged, multiyear droughts and cold temperatures), with the largest increases occurring in mountainous regions of the state. Winter and spring precipitation is projected to increase throughout this century, and warming will increase the proportion of that precipitation that will fall as rain.

Extreme weather events, particularly floods and severe storms, are having a stronger impact on Vermont. At the same time, multiyear meteorological and hydrological droughts continue to pose challenges for water-dependent sectors. Extreme rainfall events are projected to become more frequent and intense in the future.

Vermont's northerly latitude and geographic location on the eastern edge of the North American continent expose it to the moderating and moistening influence of the Atlantic Ocean and the effects of the hot and cold air masses from the interior of the continent. Its climate is characterized by cold, snowy winters and pleasantly warm summers. The jet stream that is often located near the state gives it highly variable weather patterns, widely ranging daily and annual temperatures, and generally abundant precipitation throughout the year. Changes in Vermont's elevation, terrain, and its proximity to Lake Champlain and the Atlantic Ocean all contribute to variations in climate across the state. The western part of the state is moderated by the lake and experiences higher temperatures and a longer growing season than the more mountainous northeastern region (also referred to as the Northeast Kingdom). Southeastern Vermont, with its lower elevation and landlocked location, tends to be warmer and more drought-prone than the rest of the state.

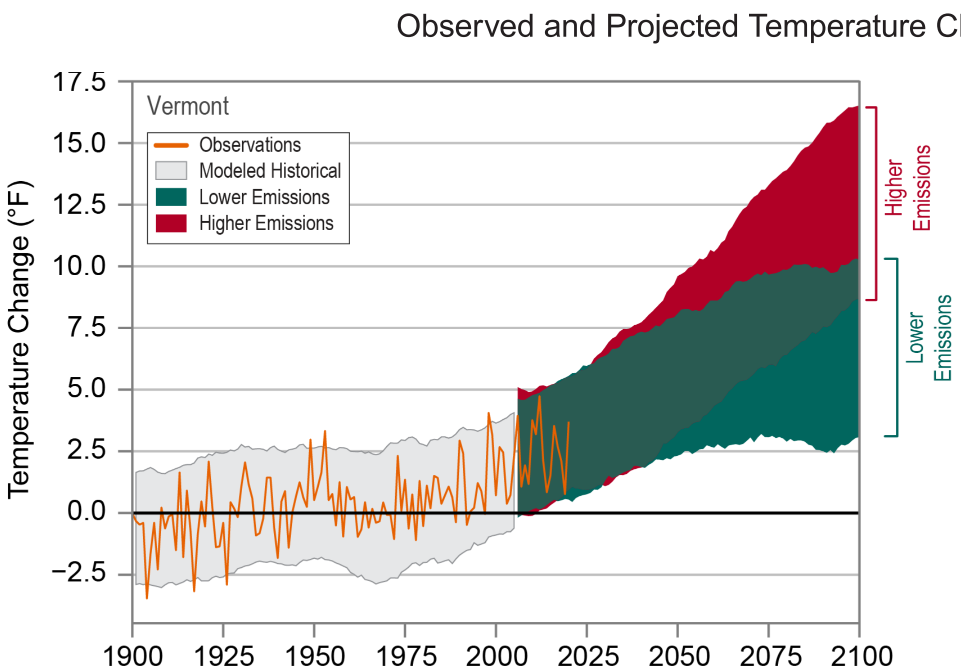

Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Vermont. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Vermont (orange line) have risen about 3°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (grey shading). Historically unprecedented warming is projected to continue through this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 3°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.