4-4: Extreme Cold

Hazard Impacts	Probability	Potential Impact					Score*:
		Infrastructure	Life	Economy	Environment	**Average:**	
Cold	3	1	3	2	2	2	6

*Score = Probability x Average Potential Impact

Extreme cold temperatures can have significant effects on human health and commercial and agricultural businesses, as well as primary and secondary effects on infrastructure (e.g. burst pipes from ice expansion and power failure). What constitutes "extreme cold" can vary across different areas of the country based on what the population is accustomed to in their respective climates. Exposure to cold temperatures can cause frostbite or hypothermia and even lead to heart attacks during physically-demanding outdoor activities like snow shoveling or winter hiking. When temperatures dip below freezing, incidents of icy conditions increase, which can lead to dangerous driving conditions and pedestrian-related slipping hazards.

A large area of low pressure and cold air surrounding the poles, known as a polar vortex, is strengthened in the winter (Figure 44). When these polar vortex winds are distorted, due to cyclical strengthening and weakening or interaction with high-amplitude jet stream patterns, they have the potential to split into two or more patterns, allowing artic air to flow southward along a jet stream[1]. As this arctic air is able to access more southerly regions, extreme cold conditions can be observed in Vermont, which also have the potential to remain over the region for extended periods.

The NOAA Wind Chill Chart identifies those temperatures and associated wind speeds that may cause frostbite if skin is exposed to the air over a certain period of time (Figure 43).

Wind Speed (mph)	Temperature (°F)																	
Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes, 10 minutes, 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T = Air Temperature (°F) and V = Wind Speed (mph)

Figure 43: Wind chill temperature index
Source: NOAA

1 http://climatechange.cornell.edu/what-is-a-polar-vortex/

In anticipation of extreme cold temperatures, the National Weather Service may issue the following watches, warnings or advisories[2], which are aimed at informing the general public as well as the agricultural industry:

- **Wind Chill Warning:** Dangerously cold wind chill values are expected or occurring
- **Wind Chill Watch:** Dangerously cold wind chill values are possible
- **Wind Chill Advisory:** Seasonably cold wind chill values but not extremely cold values are expected or occurring
- **Hard Freeze Warning:** Temperatures are expected to drop below 28°F for an extended period of time, killing most types of commercial crops and residential plants
- **Freeze Warning:** Temperatures are forecasted to go below 32°F for a long period of time, killing some types of commercial crops and residential plants
- **Freeze Watch:** Potential for significant, widespread freezing temperatures within the next 24-36 hours
- **Frost Advisory:** Areas of frost are expected or occurring, posing a threat to sensitive vegetation

In the fall, both abrupt cold snaps and record warmth can be observed, where the latter tends to be associated with southerly flow. Similarly, in winter, both extreme cold and record warm conditions occur, which can affect river flow (i.e. ice jam), snow cover, ground insulation and the agricultural industry.

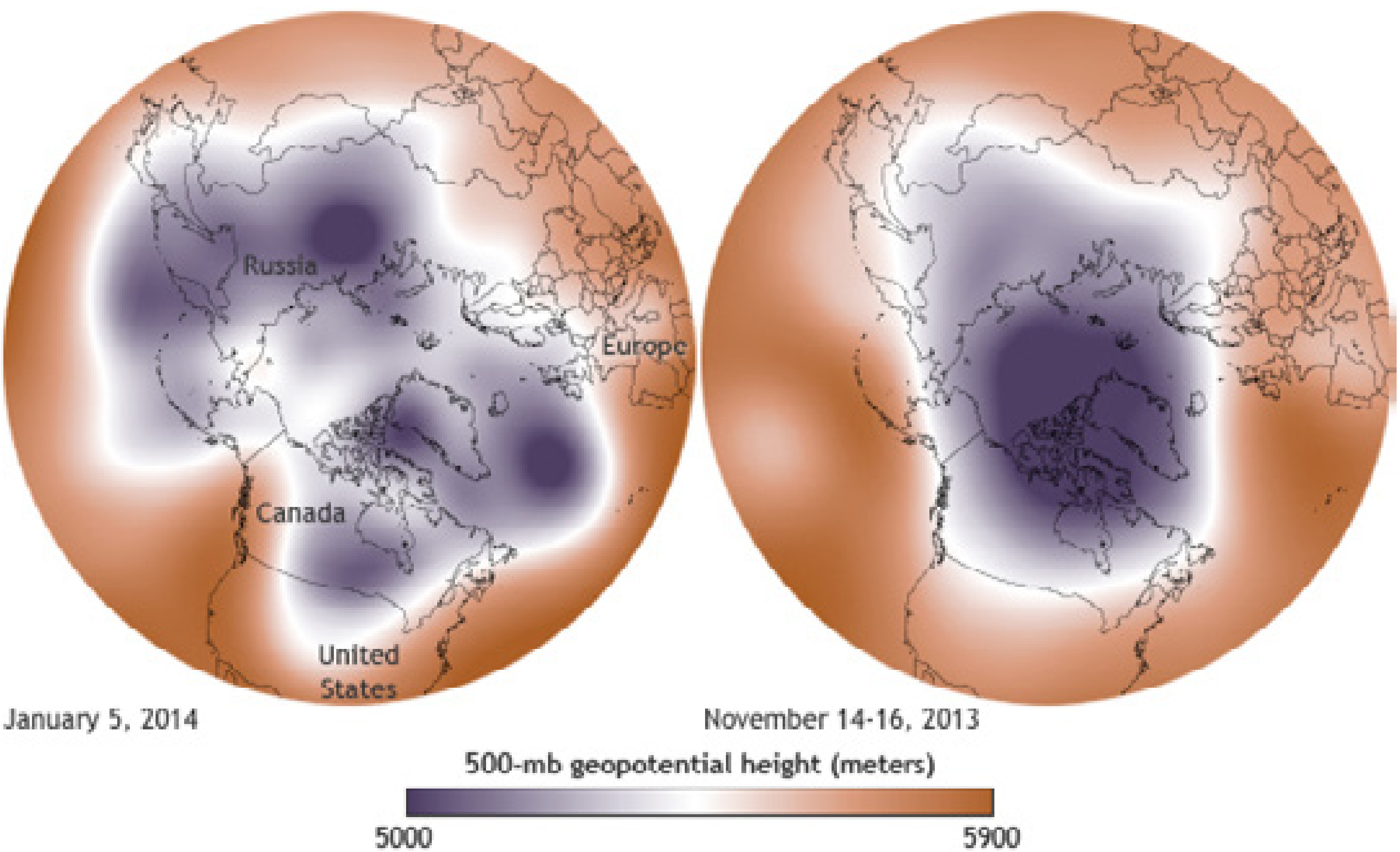

Figure 44: Wavy polar vortex configuration (left) versus more typical, compact configuration (right)
Source: https://www.climate.gov/news-features/event-tracker/wobbly-polar-vortex-triggers-extreme-cold-air-outbreak

2 https://www.weather.gov/safety/cold-wind-chill-warning

Extreme Cold History

The winter of 1933–1934 was particularly cold, and the lowest temperature ever recorded for the State (-50°F) occurred at Bloomfield on December 30, 1933. Prior to this, extreme cold temperatures were widespread on January 4 and December 18, 1835, with -40°F at Montpelier and White River, -38°F at Bradford, -30°F at Rutland and -26°F at Burlington. Following the winter of 1933–1934, more than 20% of the apple trees in Vermont were eliminated, although this figure was less than 2% for the Macintosh variety. Temperature is a very important variable in promoting apple growth. The dwarf trees introduced in the 1860s lacked the winter hardiness needed to be truly viable in Vermont. The severe winter of 1917–1918 destroyed almost all of the Baldwin and other strains. Only the Macintosh variety survived, and it remains the dominant strain grown today. In 2001, temperature fluctuations in the spring produced a different loss. Daily maximum temperatures of at least 90°F followed by minimum temperatures near 20°F accelerated the flowering of the apple blossoms, which were then killed by the low nighttime temperatures.

One of the most prolonged cold episodes lasted from January 18 to February 3, 1969. Maximum temperatures were below 0°F. Water mains and other connections froze and burst in record numbers across the State. Since then, extreme cold has been recorded in February 1993 and again on January 19, 1997. In both cases, cold dense air moving out from an Arctic high-pressure system caused temperatures to plummet. Daytime highs in 1993 were 10°F, while the minimums were -5°F. The winter of 1997 holds the record for longest streak of consecutive days below freezing, without a thaw, at 51 days.

More recently, the winter of 2015 maintained below freezing temperatures for 27 days, while the period between December 24, 2017 and January 8, 2018 (or 16 consecutive days) did not exceed 32°F.

Between the winters of 2000 and 2018, the number of recorded days per year with a daily temperature low of less than or equal to 0°F peaked during the 2015 winter at 31 days in Burlington, 44 days in Montpelier, 55 days in Island Pond and 32 days in Bennington.

NOAA storm event history for Vermont includes several extreme cold/wind chill events since 2000, none of which included any deaths, injuries, or recorded damages:

- **January 17, 2000:** A northwest wind averaging between 15-30 mph across southern Vermont, impacting Bennington and Windham Counties, with the addition of temperatures between 0°F to -10°F, produced dangerously low wind chill values of -50°F to -60°F.
- **January 25, 2007:** An arctic cold front moved across Vermont on January 24, delivering very cold temperatures of 0°F to -25°F by the following morning. A secondary cold front accounted for the combination of brisk northwest winds of 10-15 mph and temperatures -5°F to -20°F with wind chill readings of -25°F to -40°F across the State. Another arctic front pushed across the area on January 29 and brought early morning low temperatures of -10°F to -30°F.
- **March 6-9, 2007:** An arctic cold front swept across the State March 5 causing temperatures to plummet to -5°F to -20°F by dawn March 6. These frigid temperatures, accompanied by winds of 15-30 mph created dangerously cold wind chills of -20°F to -40°F. Brisk winds with temperatures around 0°F continued through the day. The winds subsided after sunset but it remained extremely cold through the morning of March 7. Arctic high pressure settled across New England March 9 with morning lows of -10°F to -34°F across Vermont.
- **January 14, 2009:** An arctic cold front moved across Vermont which delivered some of the coldest temperatures across the region in several years as temperatures dropped over 20°F within several hours, averaging 20°F to 25°F below normal values, which were already at climatological winter minimums.

Nighttime minimums were -10°F to -30°F across Vermont with isolated readings colder than -40°F. These extremely cold temperatures led to numerous cold weather related problems including numerous dead vehicle batteries and broken home/business water pipes.

- **January 23, 2011:** Bitterly cold air settled into the region and temperatures plummeted to -10°F to -25°F below zero across southern Vermont in Bennington and Windham Counties. Brisk westerly winds diminished during the evening, becoming light and variable to calm after midnight, resulting in wind chill readings of -25°F to -35°F.
- **January 8, 2015:** Wind chills colder than -25°F to -40°F were observed overnight January 7, with morning lows of -15°F to -35°F across Vermont, with the coldest temperatures within the southern Green Mountains and observed wind chills in the mountains from -40°F to -70°F. These dangerously cold wind chills lead to delayed school openings of 2 hours or cancelled classes on the morning of January 8.
- **February 15, 2015:** An extremely frigid Arctic air mass pour into the region from the north, beginning during the late morning hours and a strong pressure gradient allowed for very strong winds. Northwest winds frequently gusted over 30 mph, with some gusts as high as 39 mph through the evening. Temperatures fell quickly through the day and dropped below zero for Sunday night into the morning of February 16. Some temperatures were as cold as -20°F with chill values of -20°F to -45°F, predominately in Bennington and Windham Counties. Many towns had warming shelters open and there were reports of bursts water mains and pipes due to the frigid temperatures.
- **February 13, 2016:** Behind an Arctic cold front, very cold temperatures poured into the region upon brisk northwesterly winds, reaching lows of -12°F to -28°F along with winds gusting 20 to 40 mph, wind chill values reached -25°F to -45°F in Bennington and Windham Counties.
- **December 27, 2017-January 1, 2018:** A frigid Arctic air mass poured into the region December 27 with gusty northwesterly winds. Low temperatures fell to as low as -5°F to -14°F with wind chill values as low as -37°F in Bennington and Windham Counties. Temperatures plummeted from -10°F in Windham County to -18°F Bennington County with wind chills ranging from -11°F to -31°F during the early morning hours of New Year's day and dropping to -15°F to -35°F throughout the morning.
- **January 5-7, 2018:** A brutally cold Arctic air rushed southward into Vermont, resulting in an extended period of extremely cold conditions. The coldest wind chills occurred during the mornings of January 6 and 7, when frigid air combined with westerly winds gusting to 30 to 40 mph resulted in widespread wind chills as low as -20°F to -40°F. High temperatures on January 6 were mainly in the single digits above and below zero. Many warming shelters were opened across the Vermont as a result of the cold weather.

Extreme Cold Trends & Vulnerability

The Steering Committee considered the probability of a plausibly significant extreme cold event to be Likely, with the most significant impacts felt by people, followed then by the direct and indirect impacts to the environment and the economy.

Temperature fluctuations are a result of several meteorological processes[3]. Due to the tilt of Earth's axis, regions of the globe receive varying levels of solar radiation. The delta between these levels produces circulation patterns at the global level, which drive air and storm system movement via air masses. Air masses, as defined by NOAA, are thousands of feet thick and extend across large areas of the earth. Air masses that form over tropical ocean regions will become exceptionally hot and humid, while those masses above high latitude continents will become cool and dry. When these air masses meet, a front is created; fronts can either be cold or warm. In addition to these air mass and front-related impacts humans feel at ground level, movement of narrow bands of strong wind high in the atmosphere, known as jet streams, maneuver weather

3 http://www.noaa.gov/resource-collections/weather-systems-patterns

systems below and transfer heat and moisture across the globe. The speed and intensity of the jet stream will affect the duration and temperature associated with a cold or warm front.

According to NOAA Climate Center[4], annual average temperatures for the contiguous United States from 1895-2016 are increasing at a rate of 1.45°F per century (Figure 45). Coupled with EPA data that suggest that both the number of days colder than the 5th percentile and the percent of daily record lows are decreasing in the northeastern United States between 1948 and 2015[5], the probability of extreme cold temperatures in Vermont is decreasing.

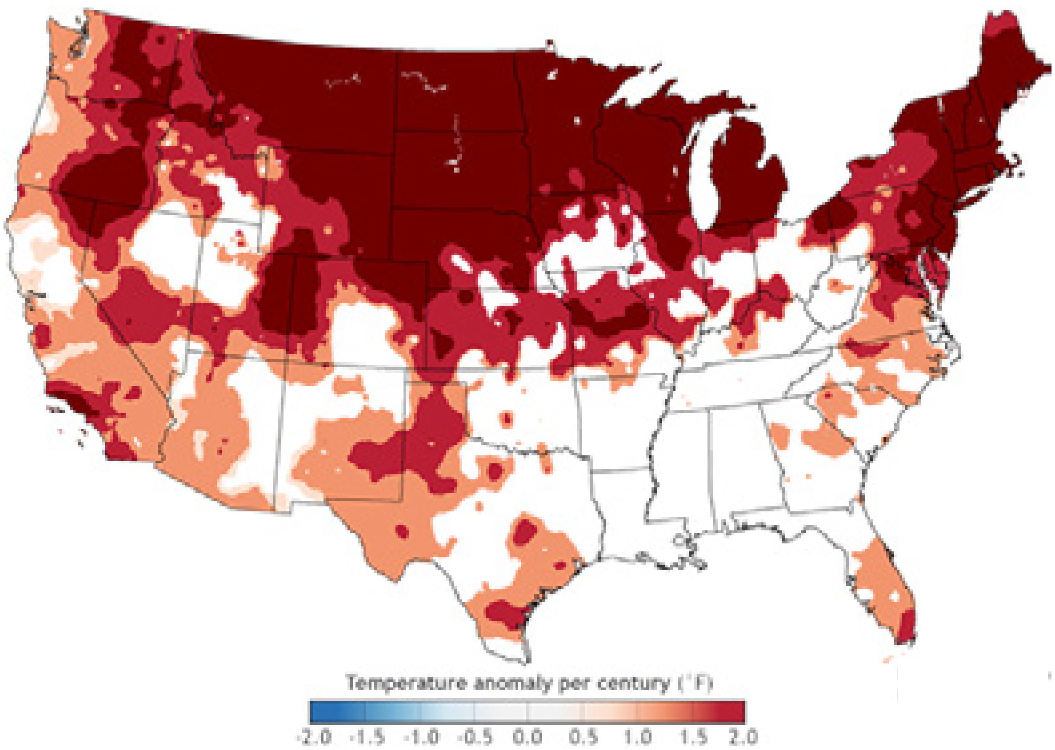

Figure 45: Average mean temperature trends in the U.S. map, February 1895-2016 (95% confidence interval)
Source: NOAA

However, Vermont remains vulnerable to extreme cold temperatures and periods of prolonged cold temperatures, especially in the northeastern portion of the State. This region, colloquially referred to as the Northeast Kingdom, can see temperatures as low as -35°F. Because this area also receives the most snowfall, is the most rural region in the State, and has the oldest average resident age, it is considered to be the most vulnerable to impacts related to extreme cold temperature.

According to the Vermont Department of Health, the average number of cold-related deaths (i.e. deaths caused by exposure to cold air or water temperatures) between 2008 and 2015 was 2.75 persons annually. This number does not take into consideration deaths by drowning following falls through ice or those deaths related to trauma experienced from slipping on ice. This number also does not consider those deaths resulting from ice-related traffic events.

As climate data confirm that the contiguous United State is warming at a rate 50% greater than the global average, with the most significant warming observed in New England in the winter months[6], Vermont is also experiencing a decline in the level of snow cover (Figure 46). During these more frequent, warmer winters, snow, which acts as a protective, insulating layer between the cold air and the ground, is more likely to

4 https://www.climate.gov/news-features/blogs/beyond-data/mapping-us-climate-trends
5 https://www.epa.gov/climate-indicators/climate-change-indicators-high-and-low-temperatures
6 https://www.climate.gov/news-features/blogs/beyond-data/mapping-us-climate-trends

melt. When seasonable, cold air moves back into the region after prolonged exposure to above-freezing temperatures that have melted much of the snow coverage, the exposed ground experiences deeper soil frost, which can negatively impact road infrastructure (i.e. frost heaves), water lines (i.e. burst pipes from water-ice expansion) and perennial crops that rely on the snow for protection from cold temperatures and winds.

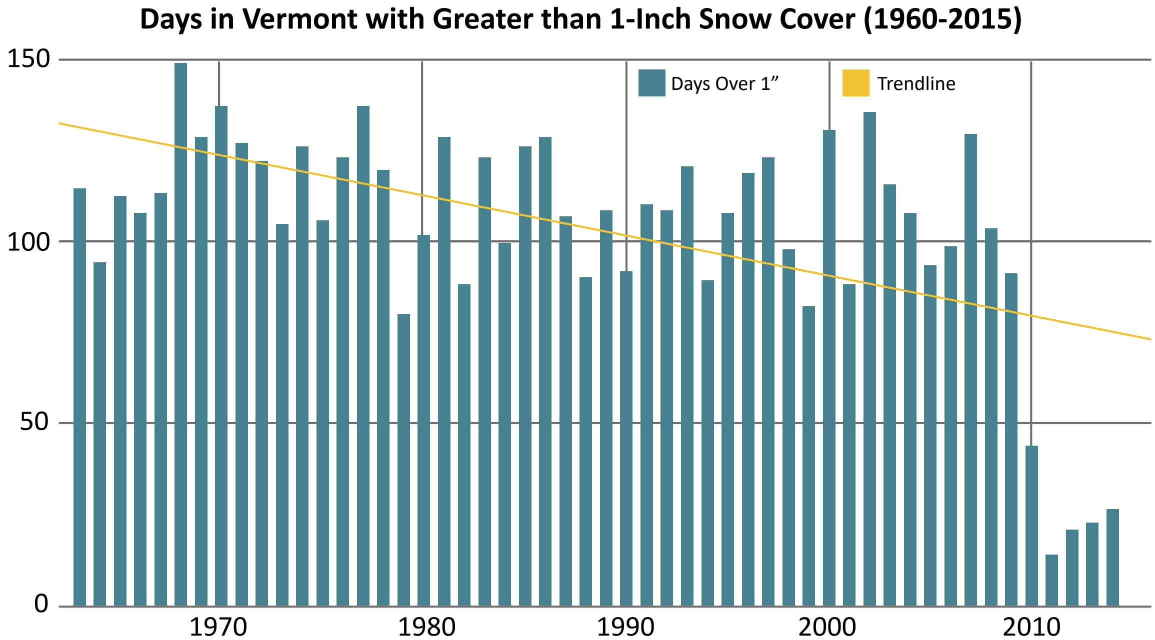

Figure 46: Number of days in Vermont with greater than 1-Inch snow cover (1960-2015)
Data Source: http://climatechange.vermont.gov

In addition to exposed soil, Vermont's rivers and lakes are also impacted from fluctuating periods of warmth and extreme cold. The continued freeze-melt-freeze cycle on rivers leads to increased ice accumulation, which can then be broken into large sheets of mobile ice during the next period of warming. This phenomenon is called ice jamming, which often results in flooding (see: Inundation Flooding & Fluvial Erosion).

Extreme Cold Mitigation

In 2014, Vermont Emergency Management submitted a Statewide Generator Project application under DR-4022 for several emergency shelters and critical facilities to reduce statewide vulnerability to residents experiencing power outage as a result of various hazard events. Because extreme cold temperatures often occur in tandem with winter storms (see: Snow Storm & Ice Storm) or lead to ice jam flooding (see: Inundation Flooding & Fluvial Erosion), residents who lose power during Vermont's coldest months need warm shelters where they can be protected from harsh conditions and reduce the potential for health-related impacts of exposure to cold temperatures, such as hypothermia or frostbite.

This Plan has also identified a mitigation strategy to develop resilient design and construction standards (see: Mitigation Strategy) in the form of auditing existing building codes, which would include standards for cold insulation. Additionally, several strategies aimed at increasing public knowledge about hazards and mitigation, supporting vulnerable populations and coordinating hazard mitigation mapping must consider extreme cold and exposure to prolonged cold weather events during implementation.