Climate Project Update - Vermont Extreme Weather and Climate Trends

VELCO Operating Committee Meeting
June 18, 2020

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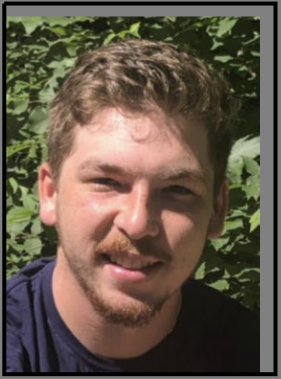
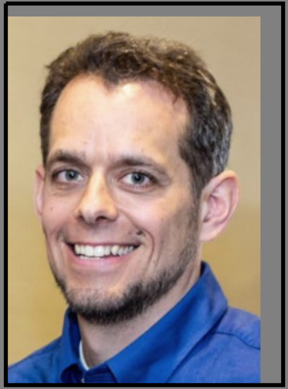
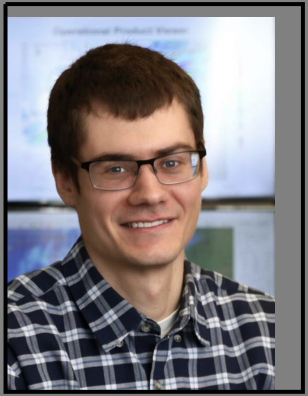
Connor Pasquale



Ryan Paulino



Jason Shafer



Kevin Cronin

Project Scope

1. Distribution outage risks
   a. Analyze historic trends in extreme weather (wet snow, ice, gradient wind)
   b. Determine climate projections and how overall risks may change for system planning
2. Extreme precipitation
   a. Analyze historic trends as they may affect flooding and hydro-power applications
   b. Determine climate projections and how overall risks may affect system assets
3. Vegetation Management
   a. Analyze growing season characteristic trends (temperature and precipitation)
   b. Determine future growing season projections and how this may affect vegetation management programs

Data and Methods

- The primary data source is the ERA5 reanalysis (hourly 1980-2019)
- ERA5 was dynamically downscaled to produce a higher resolution data (5-km)
- Higher resolution downscaling was useful for reconstructing wind events, but the native 30 km resolution was found to better for snow and ice events
- All snow and ice events are accumulated over a 48-hr period
- All results are derived on a county-level basis and aggregated across all of Vermont
- Seasons defined using meteorological standards: winter (DJF), spring (MAM), summer (JJA), fall (SON)
- A 20-year base period is used to determine changes 1980-1999 to 2000-2019

Data and Methods

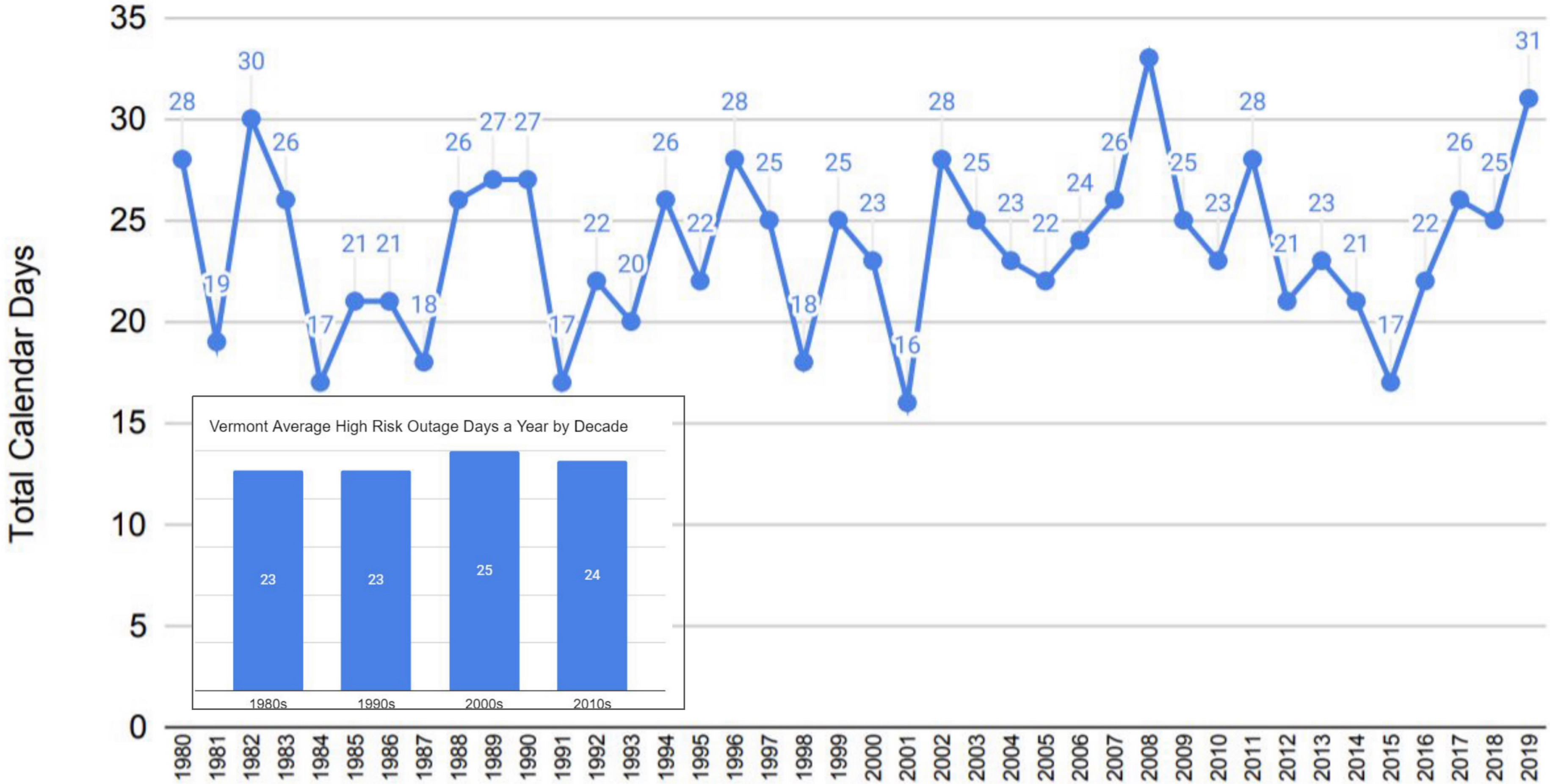
- Spatial computations are derived using spatial mean values for 14 Vermont counties and then aggregated over all of VT, we were computationally limited to make this a true asset-based analysis at the 5-km level similar to our operational products.
- Outage risk thresholds (lower values are used because of spatial averaging tending to smooth out results)
    - **Wind:** Mean wind gust values 40 mph or greater
    - **Wet Snow:** Mean wet snow accumulation of 0.30” or greater
    - **Ice:** Mean ice thickness accumulation of 0.20” or greater
- Extreme precipitation days are defined as 1.00” or greater precipitation in a 24 hr or 48 hr period
- Growing degree days are defined using a base of 50°F

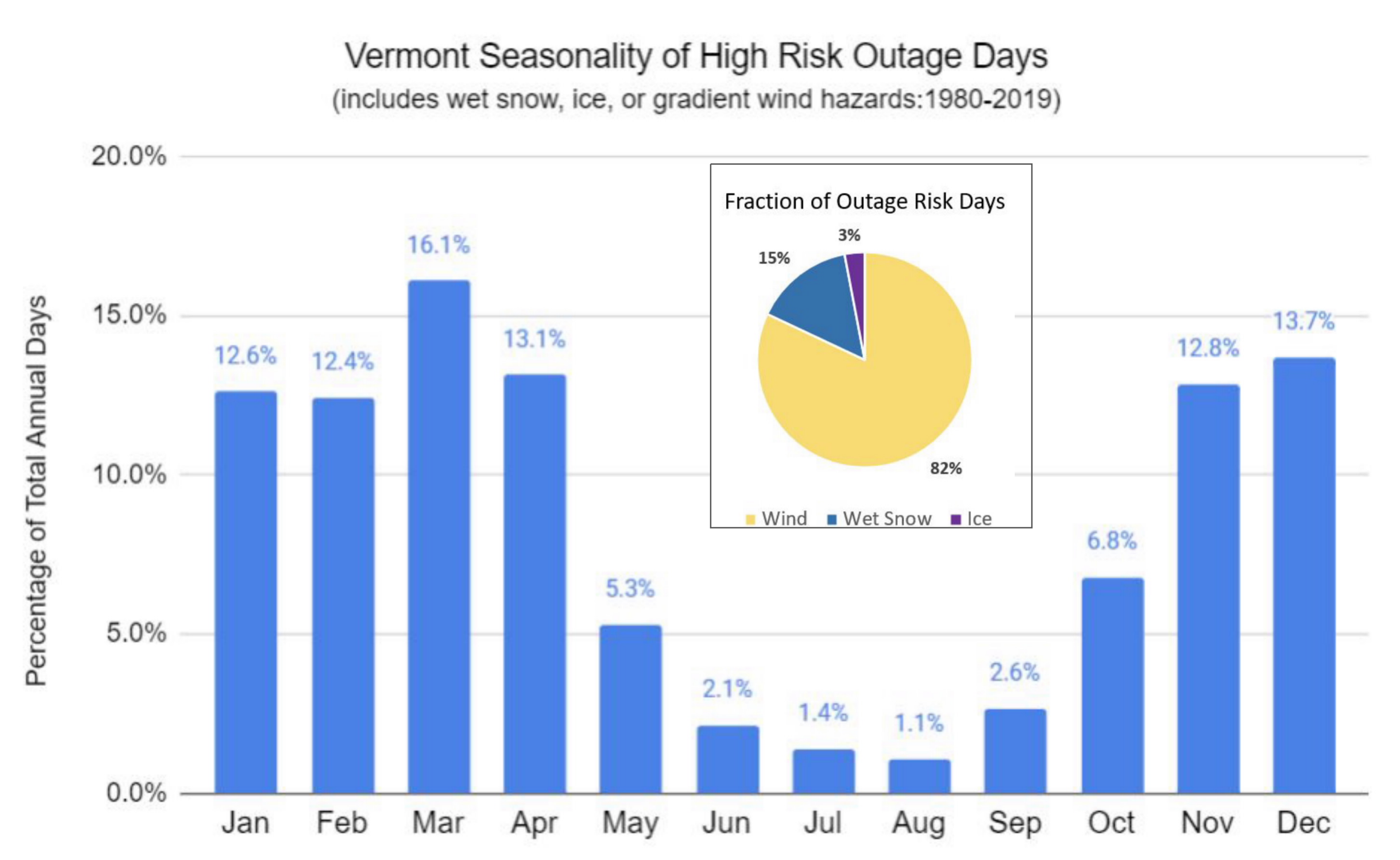
Project Management - Currently on Track

Green: Task has been completed
Red: Task has not been started or incomplete

Vermont Average High Risk Outage Days a Year

(includes wet snow, ice, or gradient wind hazards)





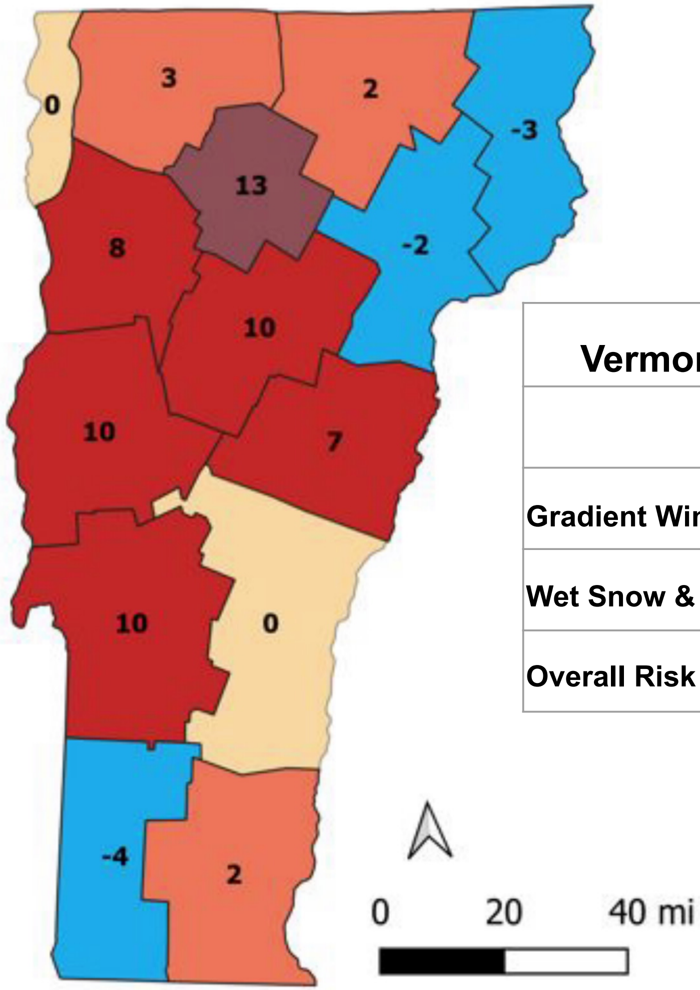
Vermont Seasonality of High Risk Outage Days
(includes wet snow, ice, or gradient wind hazards:1980-2019)
Percentage of Total Annual Days
20.0%
15.0%
10.0%
5.0%
0.0%
12.6%
12.4%
16.1%
13.1%
5.3%
2.1%
1.4%
1.1%
2.6%
6.8%
12.8%
13.7%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Fraction of Outage Risk Days
3%
15%
82%
Wind
Wet Snow
Ice

Outage risk - spatial and yearly variability

(Blue: fewer outage risk days, Red: higher outage risk days)

	Addison	Bennington	Caledonia	Chittenden	Essex	Franklin	Grand Isle	Lamoille	Orange	Orleans	Rutland	Washington	Windham	Windsor	
1980	0.7	0.6	1.6	0.7	1.7	-0.2	0.6	0.6	1.4	0.6	0.2	0.9	0.4	1.5	80
1981	-1.2	-1.3	-0.3	-1.2	-1.1	-1.2	-1.9	-1.3	-0.9	-0.9	-1.3	-0.7	0.0	0.4	81
1982	0.8	1.1	1.1	0.8	1.9	1.2	1.3	1.1	0.9	1.9	0.2	1.1	1.1	0.8	82
1983	0.3	-0.2	-0.3	0.3	0.8	1.7	0.1	-0.2	0.6	0.2	2.4	-0.2	-0.5	-0.2	83
1984	-1.5	-1.9	-1.3	-1.5	-1.3	-1.4	-1.4	-1.9	-1.1	-1.3	-0.4	-1.3	-1.4	-1.3	84
1985	-0.8	-1.3	0.0	-0.8	0.0	-0.5	-0.1	-1.3	-0.6	0.0	-0.8	-1.3	0.2	-0.2	85
1986	0.0	-0.6	-1.1	0.0	-1.1	-1.2	-0.6	-0.6	-1.4	-1.5	-0.8	-0.7	-0.4	0.2	86
1987	-0.7	-1.9	-1.3	-0.7	-1.3	-1.6	-1.0	-1.9	-1.4	-2.3	-1.3	-1.3	0.5	-1.1	87
1988	0.8	0.2	0.8	0.8	0.2	1.0	1.8	0.2	-0.9	1.1	-1.5	-0.9	-0.2	-0.8	88
1989	0.2	1.1	1.8	0.2	0.6	0.0	0.2	1.1	0.6	0.2	0.2	2.0	0.2	0.2	89
1990	1.2	0.6	1.3	1.2	0.6	1.2	0.8	0.6	-0.9	0.2	0.6	0.4	0.5	-0.2	90
1991	-0.8	-1.9	-1.3	-0.8	-0.2	-1.4	-1.4	-1.9	-2.0	-0.9	-0.4	-2.0	-2.0	-1.3	91
1992	-0.2	0.0	-0.8	-0.2	-1.1	-0.3	0.1	0.0	-1.1	-0.9	-0.8	-0.2	0.4	-1.1	92
1993	-1.0	-1.5	-0.5	-1.0	-0.8	-0.9	0.6	-1.5	-1.1	-1.3	-0.4	-0.9	-1.1	-0.6	93
1994	1.2	0.0	-0.3	1.2	0.6	0.0	1.4	0.0	-0.3	0.0	-0.2	0.0	-0.2	-0.4	94
1995	-0.3	-0.8	-0.5	-0.3	-1.3	0.5	0.5	-0.8	0.0	-0.6	-0.2	-0.7	-0.9	-0.2	95
1996	-0.2	1.7	1.6	-0.2	1.9	0.9	0.2	1.7	0.9	1.3	0.0	2.4	-1.3	-0.2	96
1997	-0.3	-0.8	0.0	-0.3	0.0	-0.9	-0.4	-0.8	0.3	1.1	0.6	0.4	2.3	1.9	97
1998	-2.2	-1.3	-0.3	-2.2	-0.4	-2.1	-1.2	-1.3	-0.9	-1.3	-1.3	-1.1	-0.7	-0.4	98
1999	0.0	-0.2	0.3	0.0	0.4	0.5	0.1	-0.2	0.3	0.9	-0.2	0.0	0.4	0.6	99
2000	0.0	0.0	0.5	0.0	-0.2	-0.5	-0.8	0.0	0.6	-0.6	-1.3	0.0	-0.5	0.2	00
2001	-1.2	-1.3	-1.6	-1.2	-1.5	-1.2	-1.7	-1.3	-1.7	-1.5	-2.1	-1.1	-2.5	-3.0	01
2002	1.0	0.8	1.3	1.0	0.8	0.5	0.8	0.8	0.3	0.9	1.9	1.5	0.0	0.0	02
2003	0.2	0.4	-0.3	0.2	0.6	0.2	0.0	0.4	0.0	-0.2	0.4	0.7	0.2	0.4	03
2004	-0.7	0.0	-0.3	-0.7	-0.4	-0.2	1.2	0.0	-0.6	0.2	-2.3	-1.1	0.2	-0.6	04
2005	0.3	-0.2	-0.5	0.3	-0.8	0.0	-0.8	-0.2	-0.6	-0.4	-0.6	-0.7	0.2	-0.6	05
2006	0.2	0.4	0.3	0.2	-0.2	0.2	-1.4	0.4	-0.3	0.0	0.4	-0.4	-0.9	0.6	06
2007	0.2	-0.2	0.8	0.2	0.6	0.2	0.6	-0.2	0.6	0.9	0.6	0.4	1.6	-0.2	07
2008	2.4	2.3	1.3	2.4	2.1	1.4	0.5	2.3	1.7	1.7	1.3	0.9	2.3	1.9	08
2009	-0.2	0.2	0.0	-0.2	0.8	0.2	-0.8	0.2	0.6	0.0	0.2	0.2	0.4	0.8	09
2010	-1.4	0.6	0.5	-1.4	0.2	-1.7	-1.1	0.6	1.4	0.2	0.9	0.7	-0.2	0.6	10
2011	1.2	0.6	0.8	1.2	-0.6	0.3	1.2	0.6	1.1	-0.6	1.1	0.7	0.9	1.5	11
2012	-0.8	-0.8	-0.8	-0.8	-0.8	-1.7	-0.7	-0.8	0.6	-0.2	-0.2	0.2	-0.7	0.0	12
2013	0.0	-0.6	-1.1	0.0	-0.8	0.2	0.2	-0.6	-0.9	0.0	0.0	-0.4	-0.2	-0.6	13
2014	0.5	-1.5	-1.6	0.5	-0.2	-0.3	0.4	-1.5	-1.4	-1.5	-0.6	-1.5	-0.7	-1.5	14
2015	-1.4	-0.8	-2.4	-1.4	-2.3	-0.9	-0.2	-0.8	-1.4	-1.9	-1.5	-1.3	-1.1	-1.9	15
2016	-1.2	-0.4	0.5	-1.2	-0.6	-0.3	-1.1	-0.4	-0.3	-0.2	-1.1	0.2	0.4	-0.2	16
2017	1.0	0.4	0.8	1.0	0.4	0.2	1.0	0.4	-0.6	0.6	0.6	-0.9	-0.2	-0.6	17
2018	0.7	0.0	0.0	0.7	0.4	-0.2	1.3	0.0	-2.0	0.4	0.0	0.0	-0.7	0.4	18
2019	2.2	1.1	0.3	2.2	0.2	2.1	1.4	1.1	1.1	1.1	0.6	1.1	1.3	0.8	19

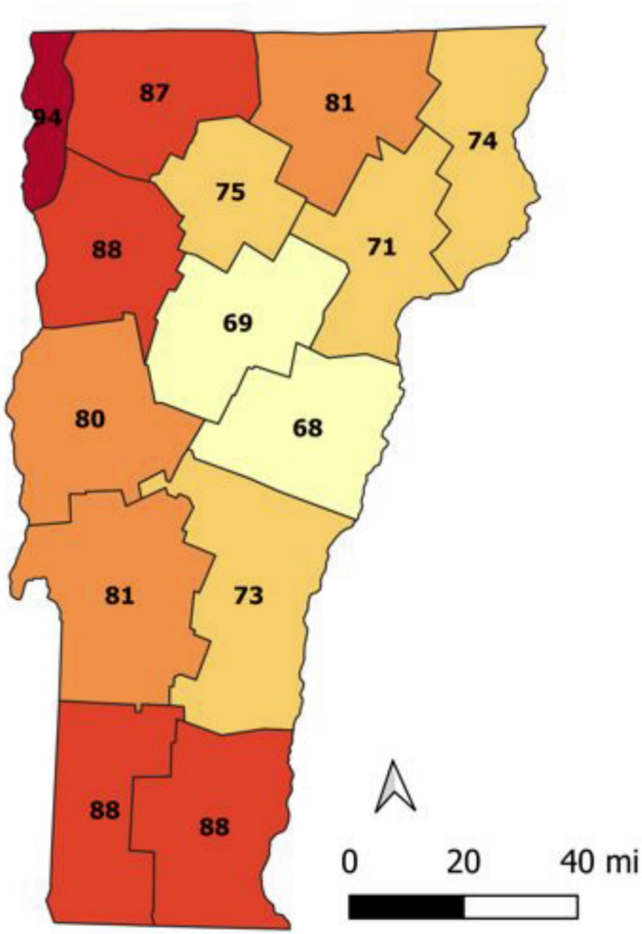
Percent Change In Outage Risk Days (1980-1999 to 2000-2019)



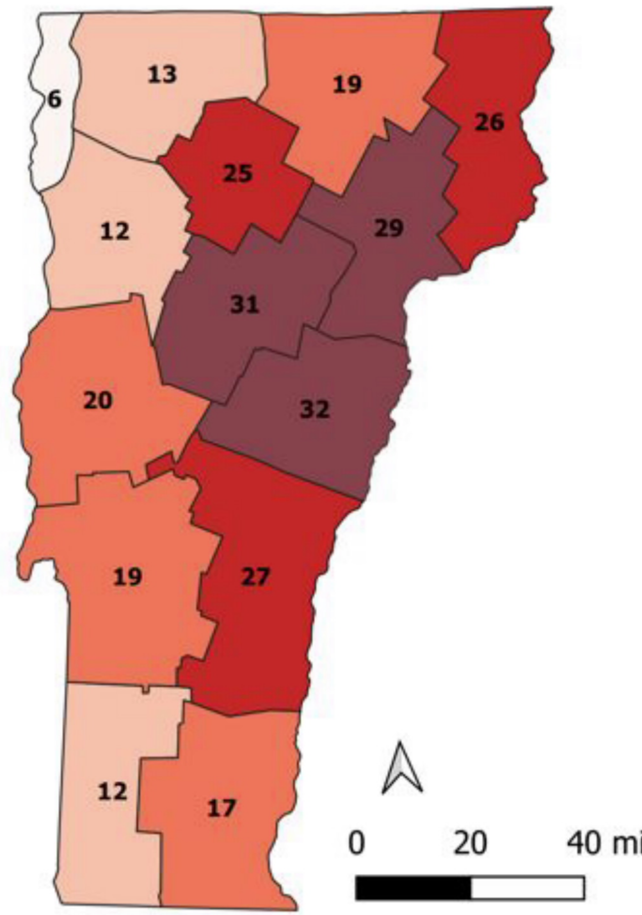
Vermont Aggregated Trends	
	Percentage Change
Gradient Wind	+1%
Wet Snow & Ice	+13%
Overall Risk	+3%

Outage Risk Climatology: Wind vs Snow & Ice Frequency

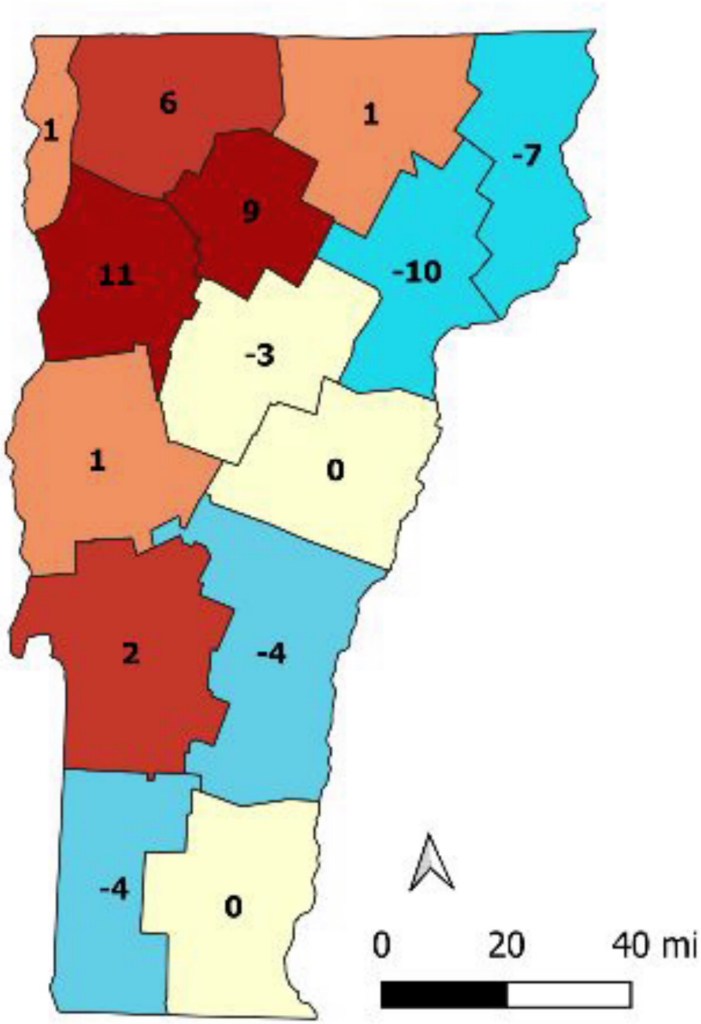
Percentage of Outage Risk Days: Gradient Winds



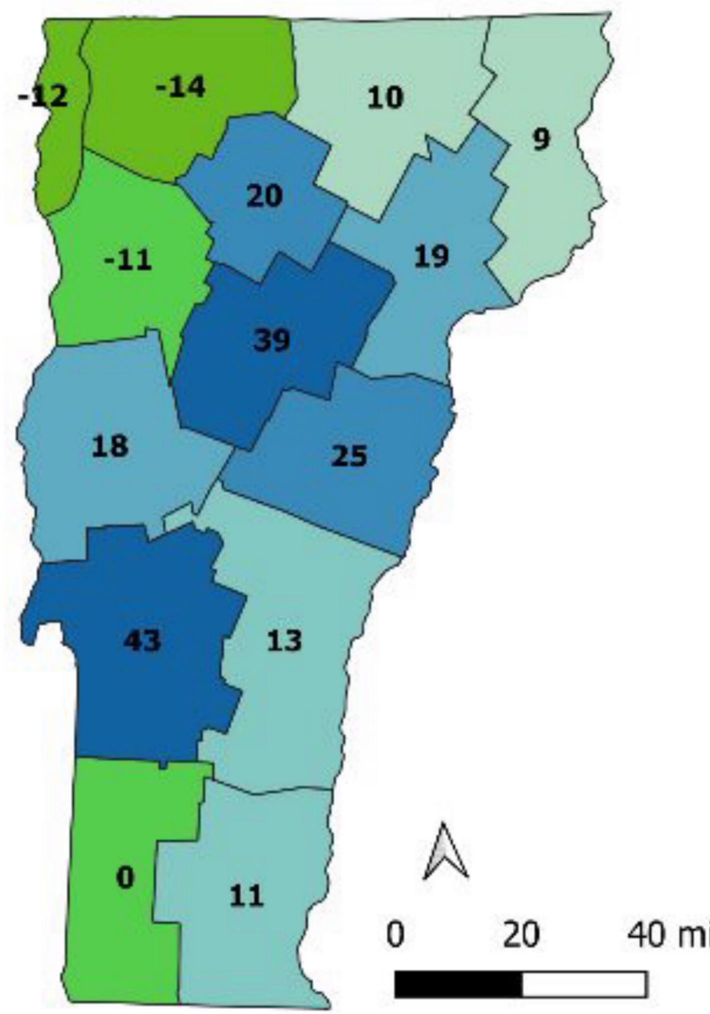
Percentage of Outage Risk Days: Snow or Ice



Percentage Change in Gradient Wind Outage Risk Days (1980-1999 to 2000-2019)



Percentage Change in Snow and Ice Outage Risk Days (1980-1999 to 2000-2019)

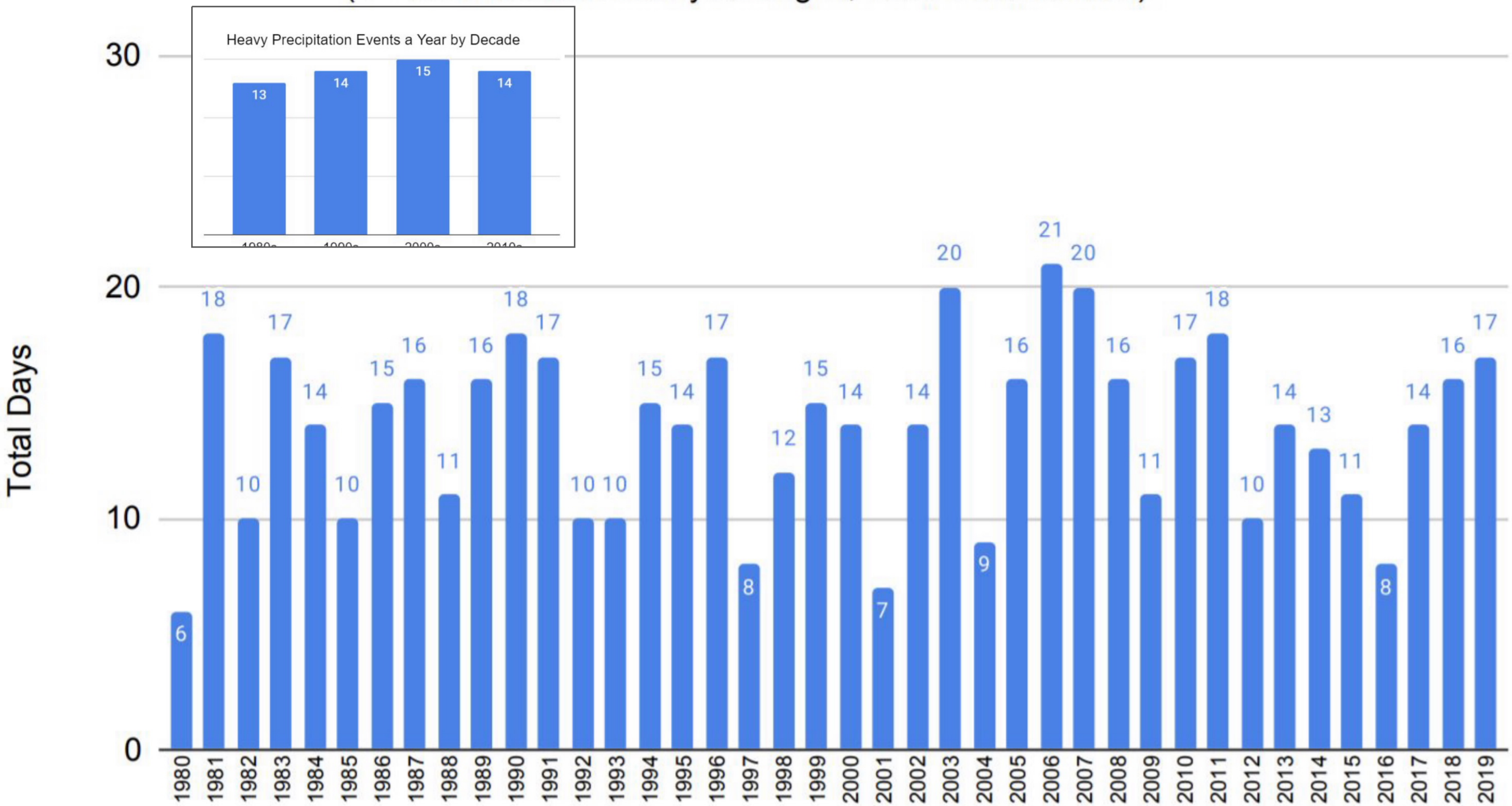


Extreme Precipitation Trends

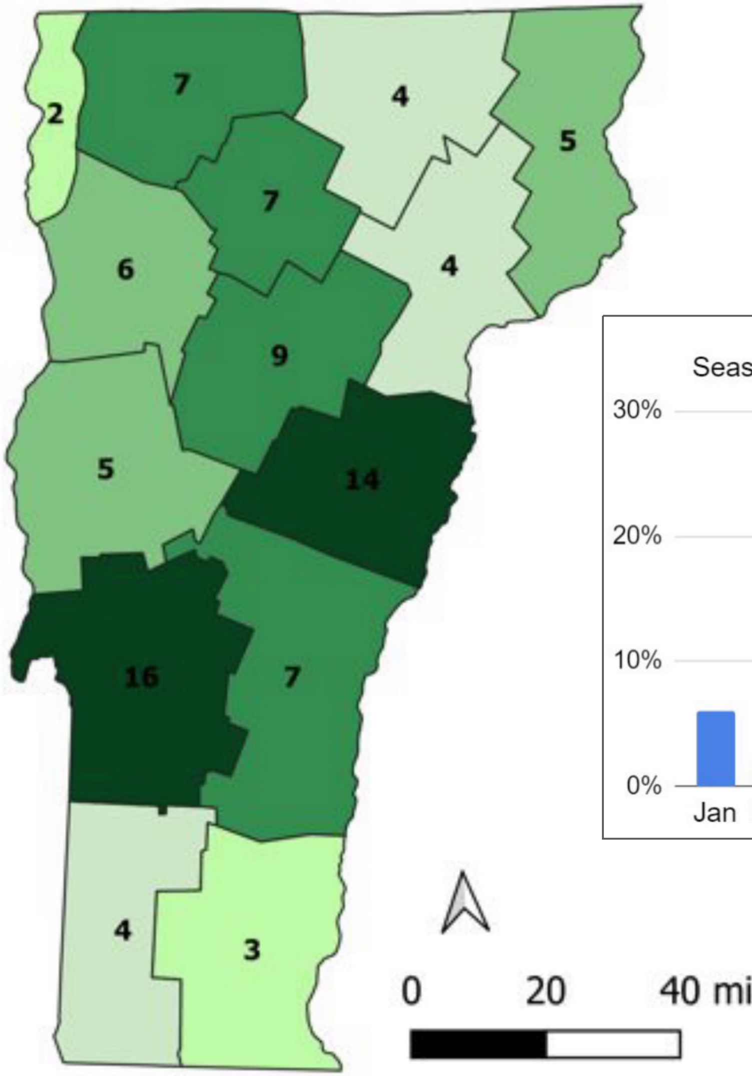
Vermont Aggregated Precipitation Phase Trends	
	Percentage Change (1980-1999 to 2000-2019)
Extreme Precipitation Events	+7%
Total Annual Precipitation	+4%
Total Annual Snowfall	+9%
Total Annual Wet Snowfall	+10%
Total Annual Freezing Rain	+25%

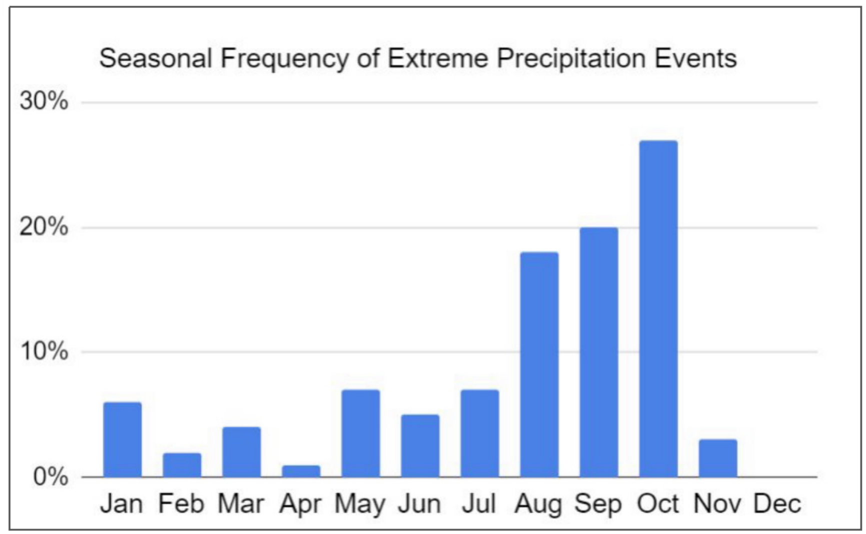
Vermont Heavy Precipitation Event Trend

(1"+ accumulation county averaged, 48 hr accumulation)

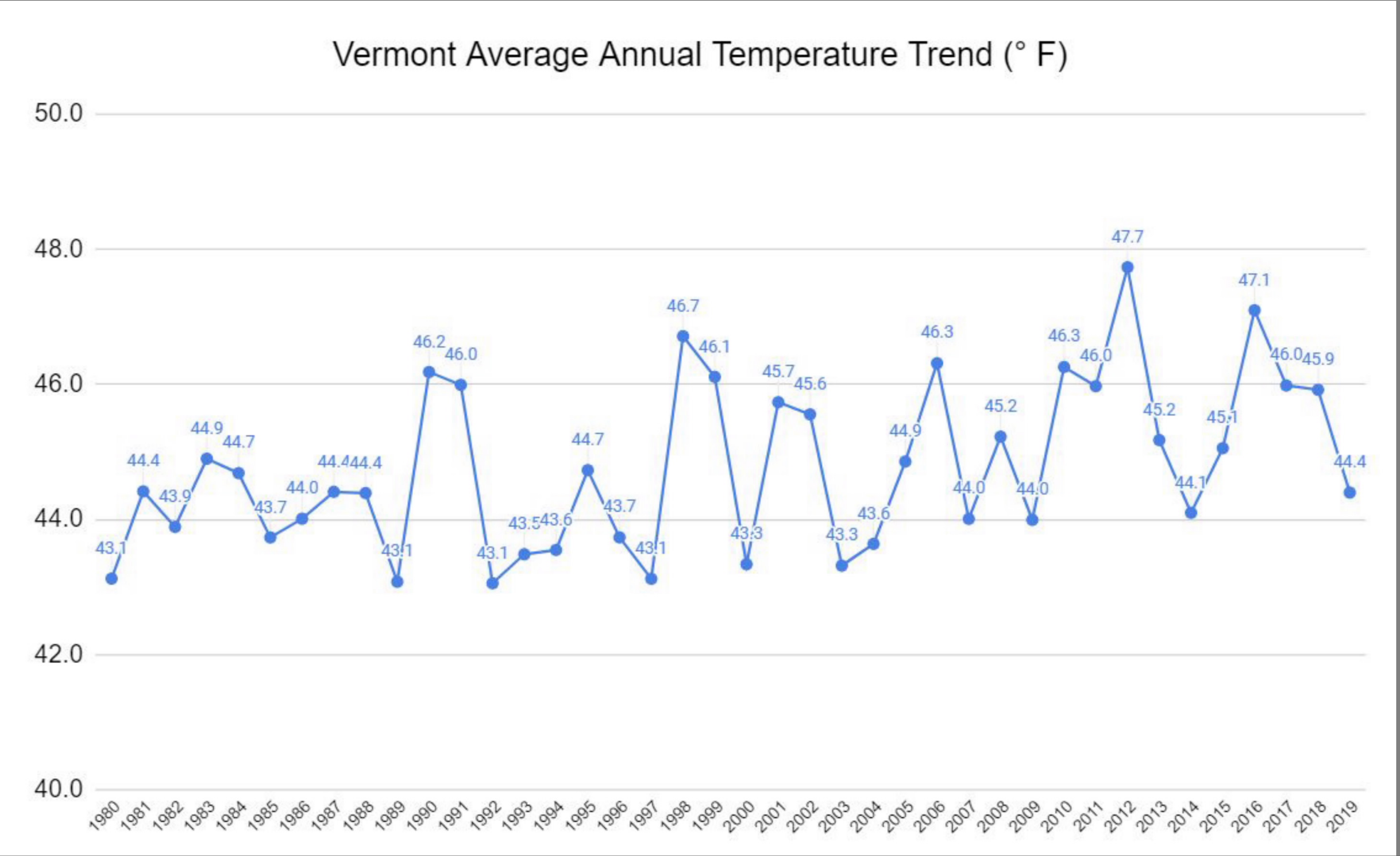


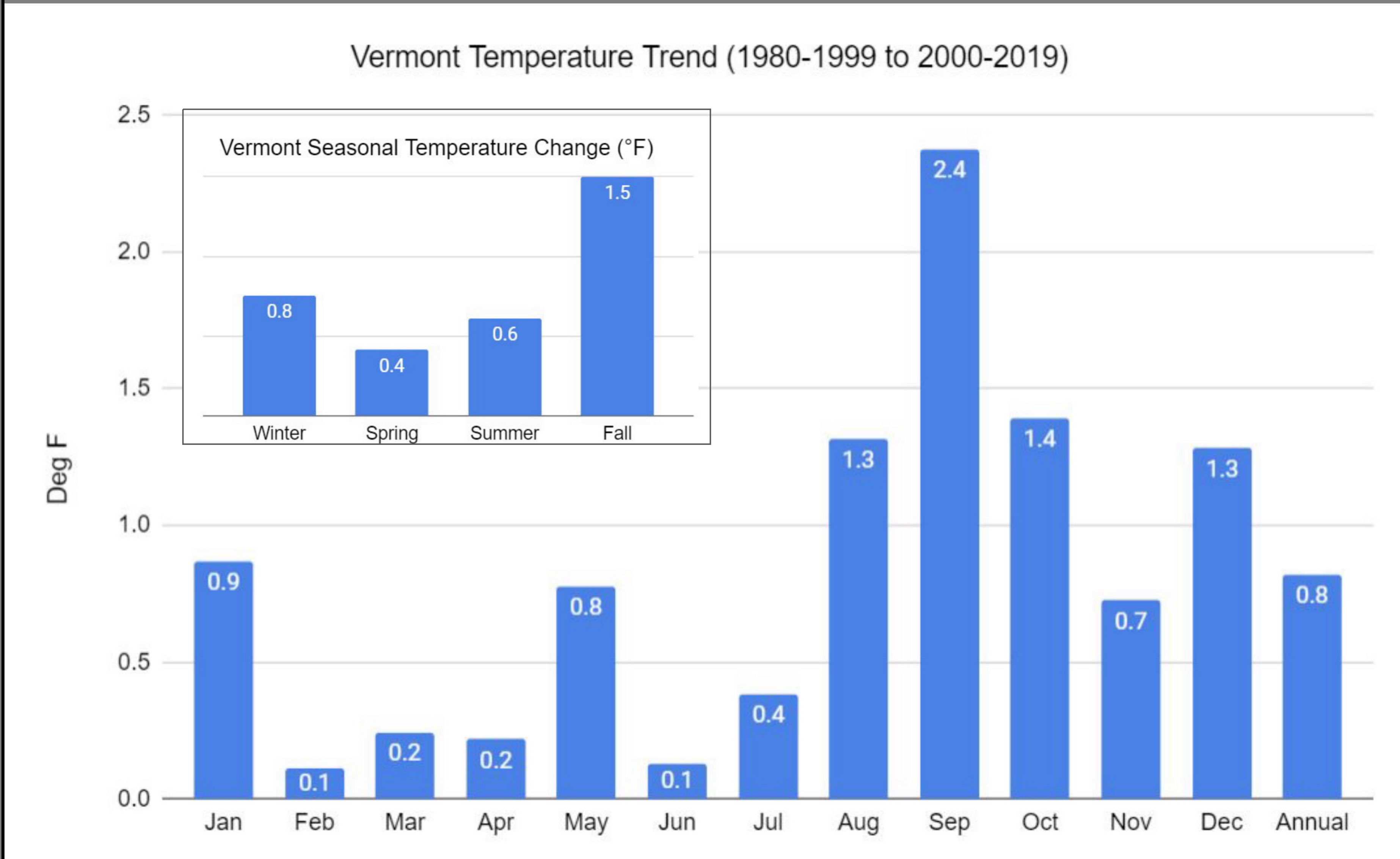
Percent Increase In Heavy Precipitation Days 1980-1999 vs 2000-2019



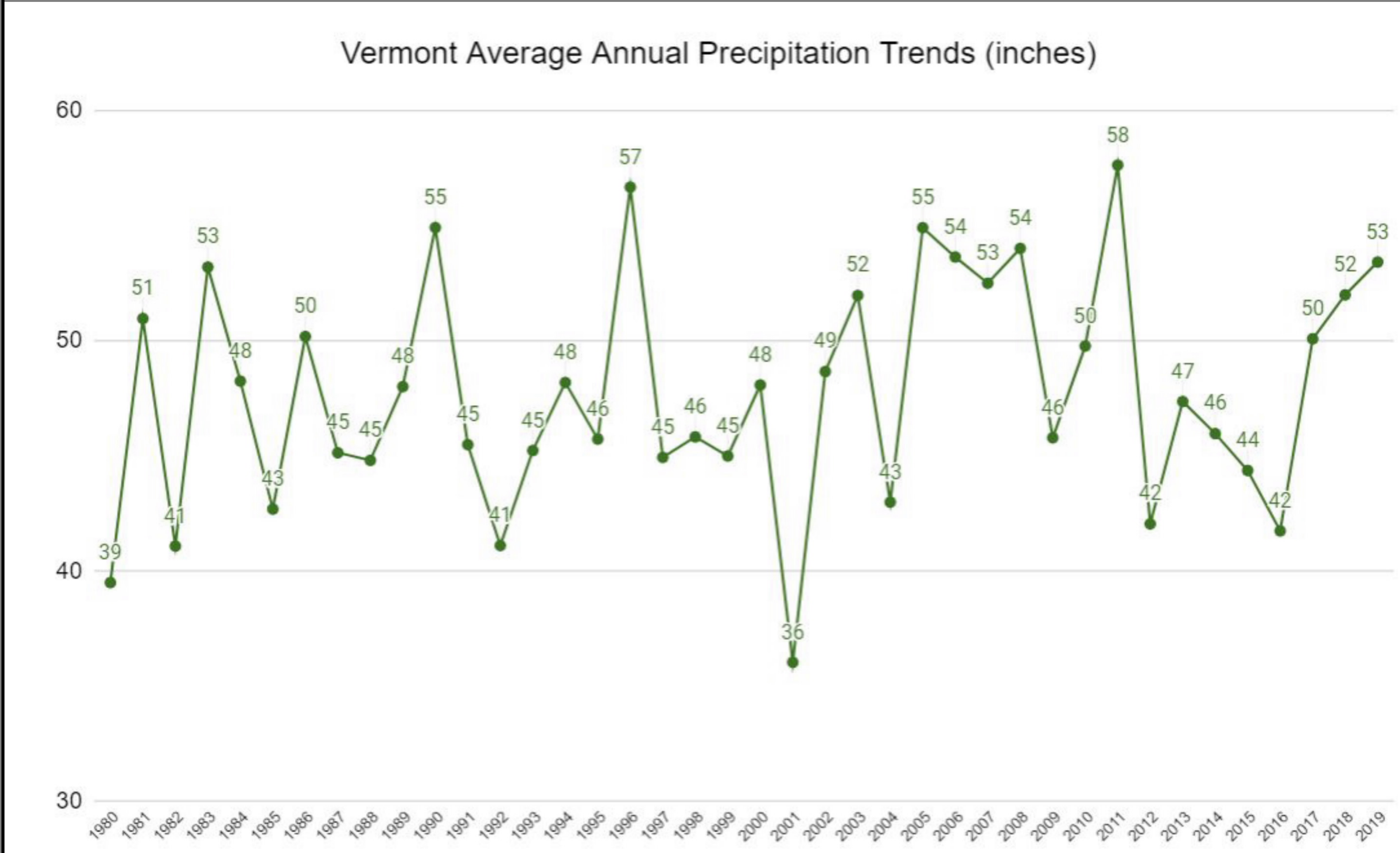


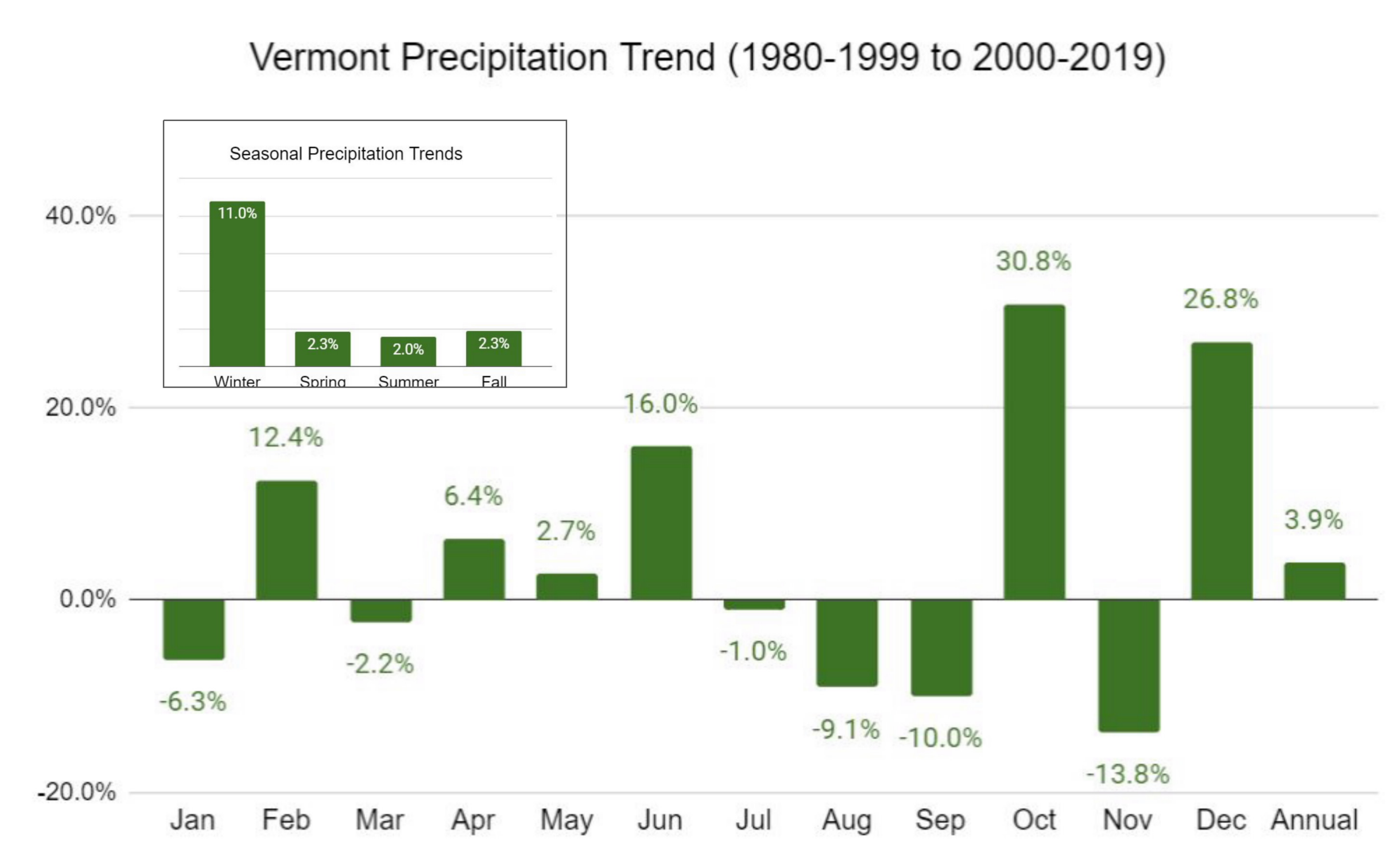
Vegetation Management - General Seasonal Trends


Vermont Average Annual Temperature Trend (° F)
50.0
48.0
46.0
44.0
42.0
40.0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
43.1 44.4 43.9 44.9 44.7 43.7 44.0 44.4 44.4 43.1 46.2 46.0 43.1 43.5 43.6 44.7 43.7 43.1 46.7 46.1 43.3 45.7 45.6 43.3 43.6 44.9 46.3 44.0 45.2 44.0 46.3 46.0 47.7 45.2 44.1 45.1 47.1 46.0 45.9 44.4

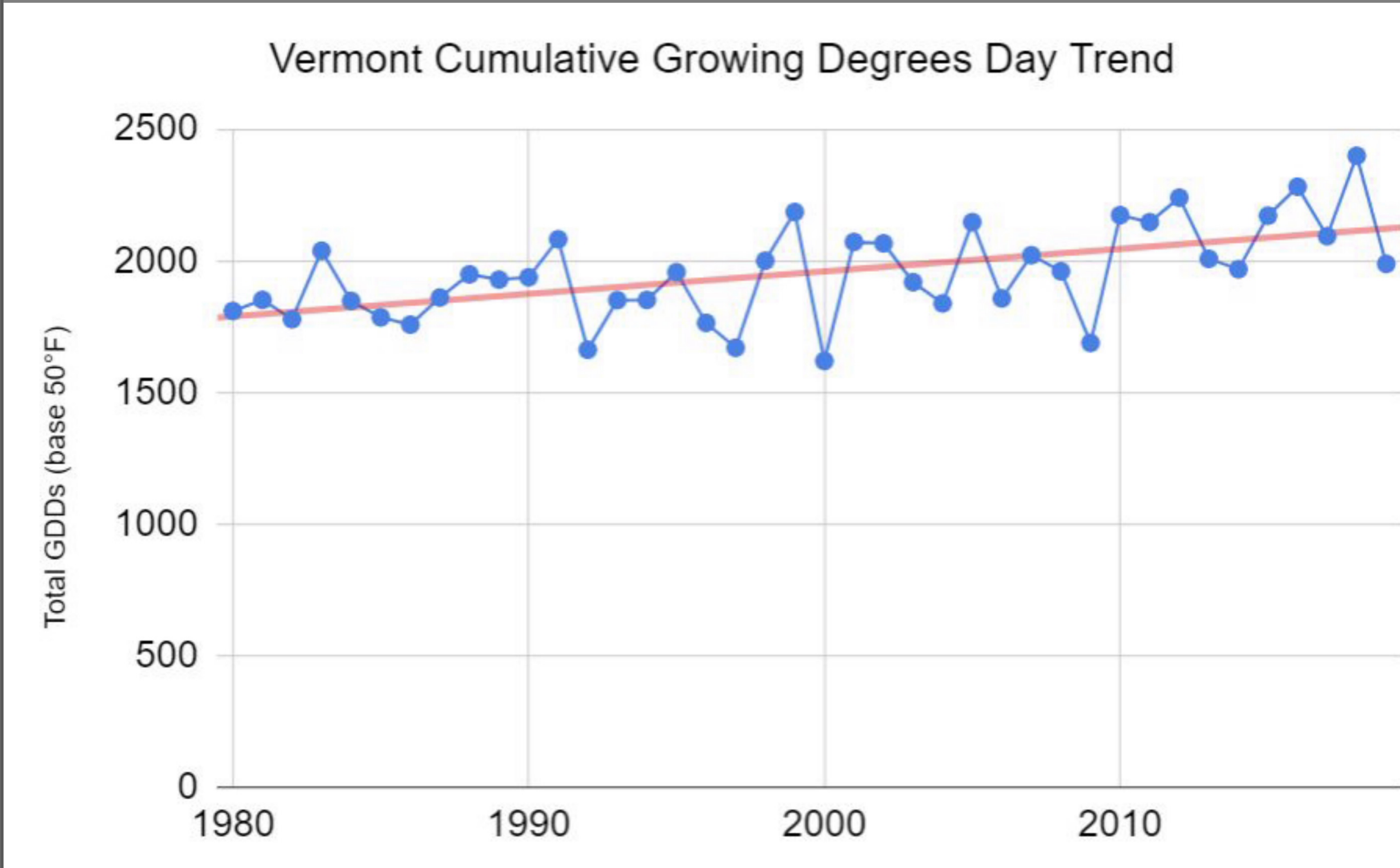


Vermont Temperature Trend (1980-1999 to 2000-2019)
Deg F
2.5
2.0
1.5
1.0
0.5
0.0
Vermont Seasonal Temperature Change (°F)
0.8
0.4
0.6
1.5
Winter
Spring
Summer
Fall
0.9
0.1
0.2
0.2
0.8
0.1
0.4
1.3
2.4
1.4
0.7
1.3
0.8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Annual

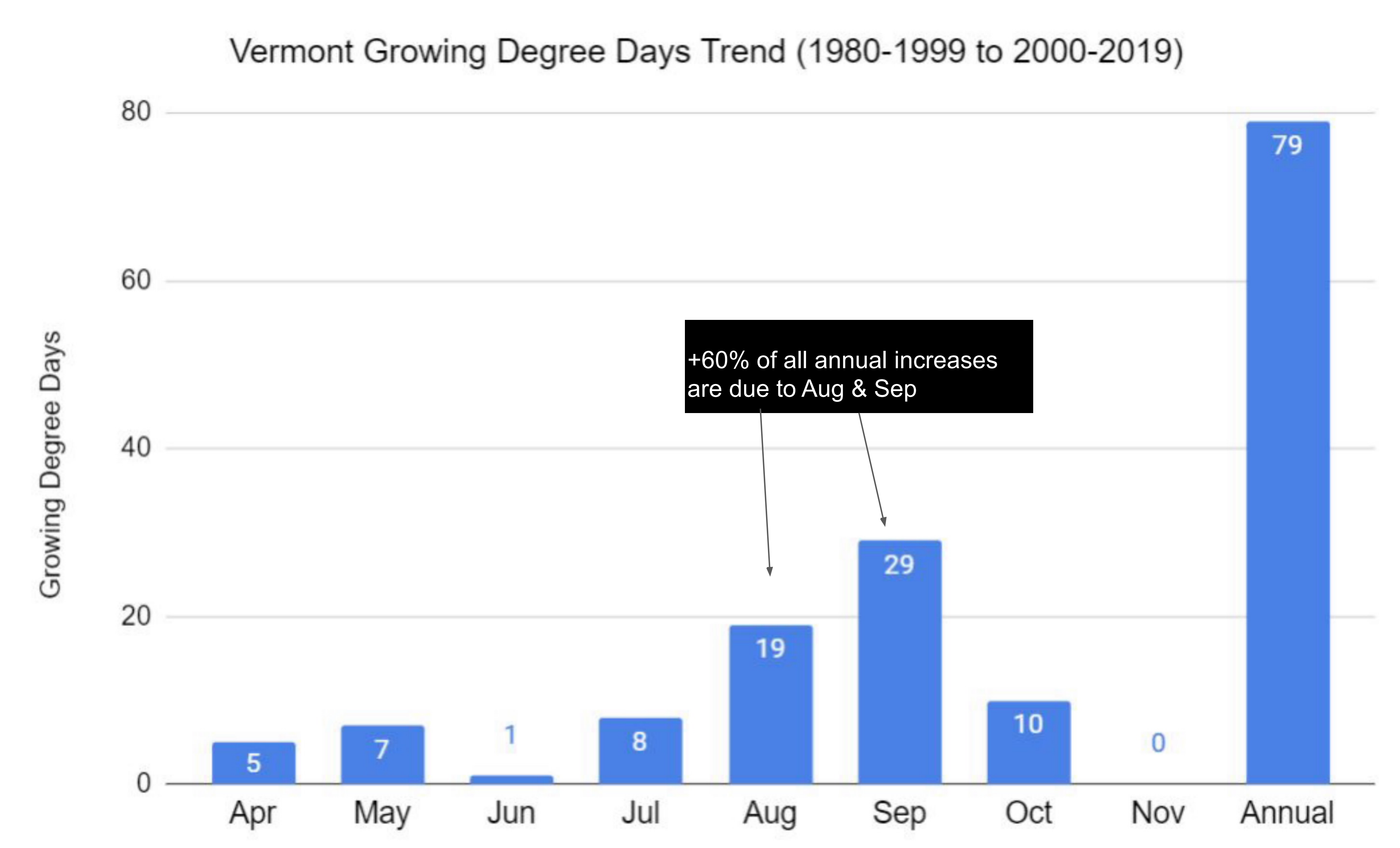

Vermont Average Annual Precipitation Trends (inches)
60
50
40
30
39
51
41
53
48
43
50
45
45
48
55
45
41
45
48
46
57
45
46
45
48
36
49
52
43
55
54
53
54
46
50
58
42
47
46
44
42
50
52
53
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019



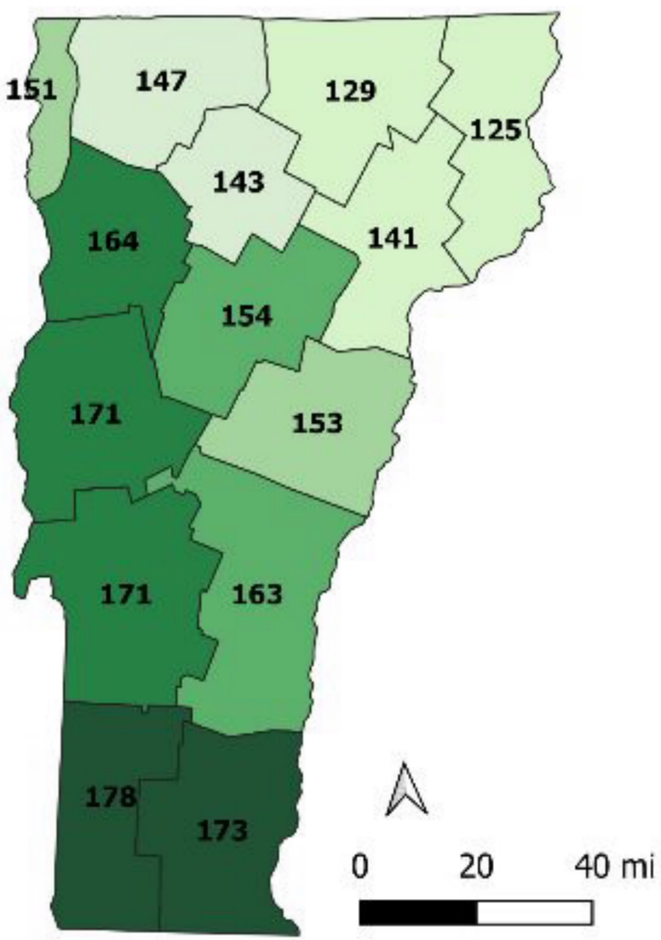
Vermont Precipitation Trend (1980-1999 to 2000-2019)
Seasonal Precipitation Trends
11.0%
2.3%
2.0%
2.3%
Winter
Spring
Summer
Fall
40.0%
20.0%
0.0%
-20.0%
-6.3%
12.4%
-2.2%
6.4%
2.7%
16.0%
-1.0%
-9.1%
-10.0%
30.8%
-13.8%
26.8%
3.9%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Annual



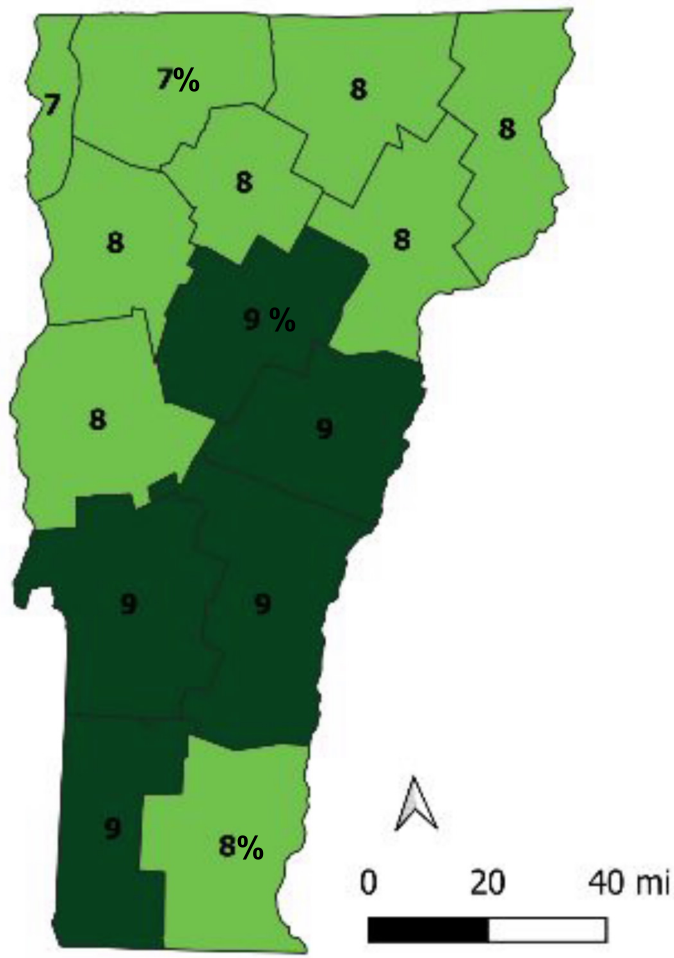
Growing degree days (GDD) are defined using the mean daily temperature (average of the high and low temperature) minus a base of 50°F (in this work). If the mean daily temperature is below 50°F, there are no growing degree days. For example, if the high temperature was 70°F and the low temperature was 50°F, the mean daily temperature would be 60°F. GDD = 60°F - 50°F = 10. There would be ten growing degree days with this example. GDDs are accumulated through the year in this time series graph.


Vermont Growing Degree Days Trend (1980-1999 to 2000-2019)
Growing Degree Days
80
60
40
20
0
+60% of all annual increases are due to Aug & Sep
5
7
1
8
19
29
10
0
79
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Annual

Change in Annual Growing Degree Days (1980-1999 to 2000-2019)



Percent Change in Annual Growing Degree Days (1980-1999 to 2000-2019)



Summary

- Overall statewide mean annual temperature has increased by approximately 0.8°F from 1980-2019, with the largest increases during fall.
- Overall statewide mean annual precipitation has increased by approximately 2” or 4% from 1980-2019, with the largest increases during winter.
- Extreme precipitation events increased nearly twice as fast as the annual precipitation base state.
- Overall statewide distribution outage risks have increased by approximately 3% 1980-2019, with much of that increase due to increases in wet snow and ice events.
- Areas more climatologically prone to stronger gradient winds have had larger increase in high wind days. Areas more climatologically prone to wet snow and ice have had larger increases in wet snow and ice events
- Outage risk changes are likely a function of vegetation growth changes with longer growing seasons (more vegetation ingrowth).
- Growing season is becoming longer primarily due to an expansion into the late summer and fall, with nearly a 10% magnitude increase.
- Precipitation does not appear to be a major limiting factor on growing season quality.
- These results are consistent with the literature.

Continuing Work...

- Customize this historic analysis to VEC and GMP service areas.
- Cross validate identification of outage risk days to outage data (GMP outage data is still needed).
- Develop better ways to quantify growing season changes to vegetation growth. We can use some feedback.
- Conduct analysis of climate projections to assess if these trends are anticipated to continue through the next 30 years.