Climate Project Update - Vermont Extreme Weather and Climate Trends

VELCO Operating Committee Meeting

Jan 21, 2021

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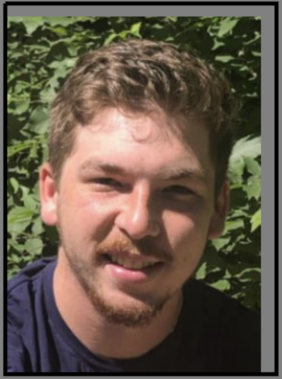
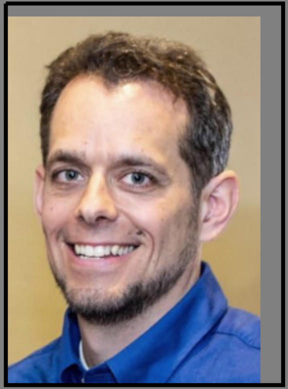
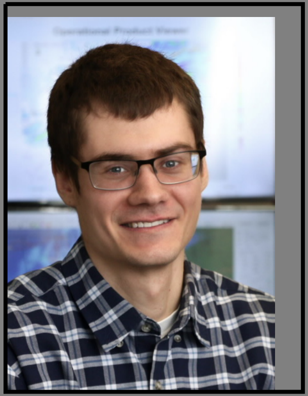
Connor Pasquale



Ryan Paulino



Jason Shafer



Kevin Cronin

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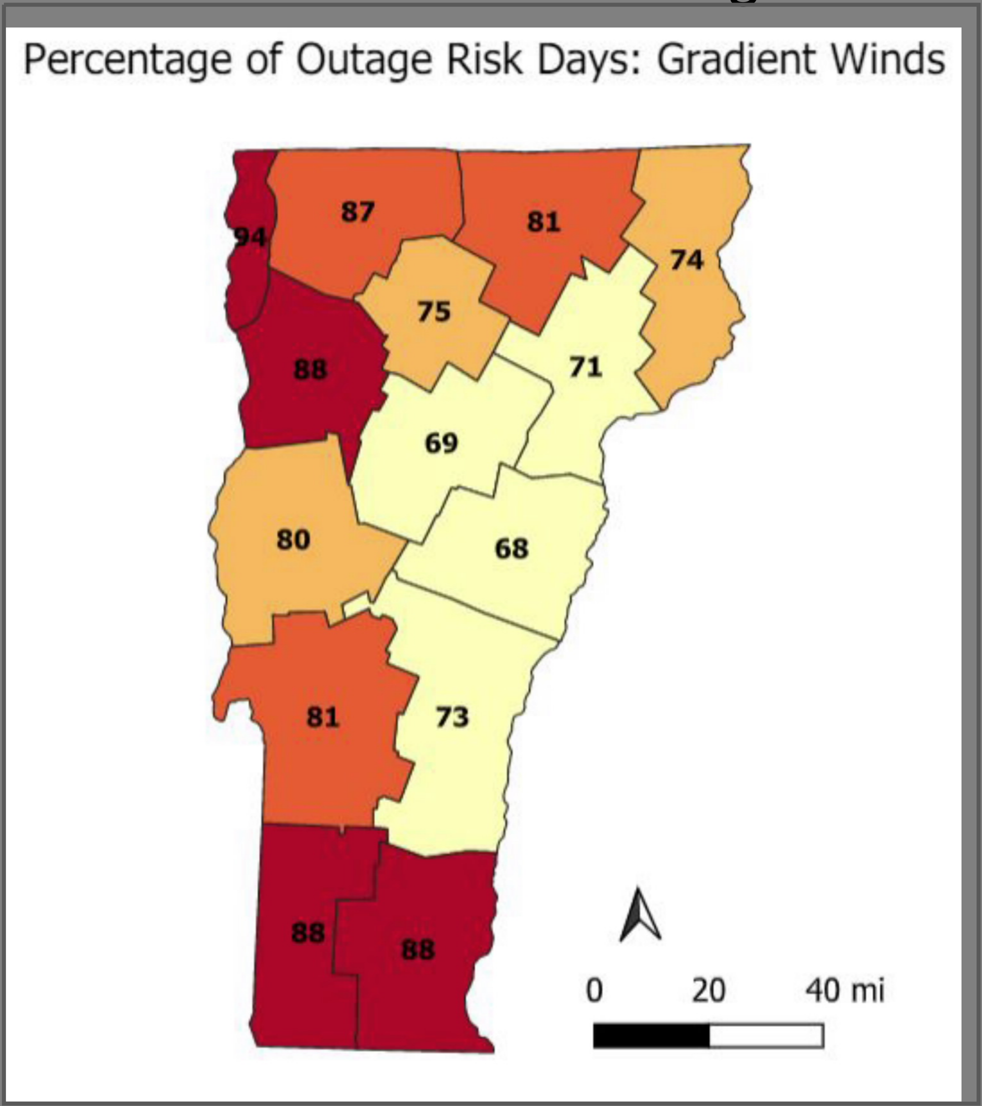
Project Tracks

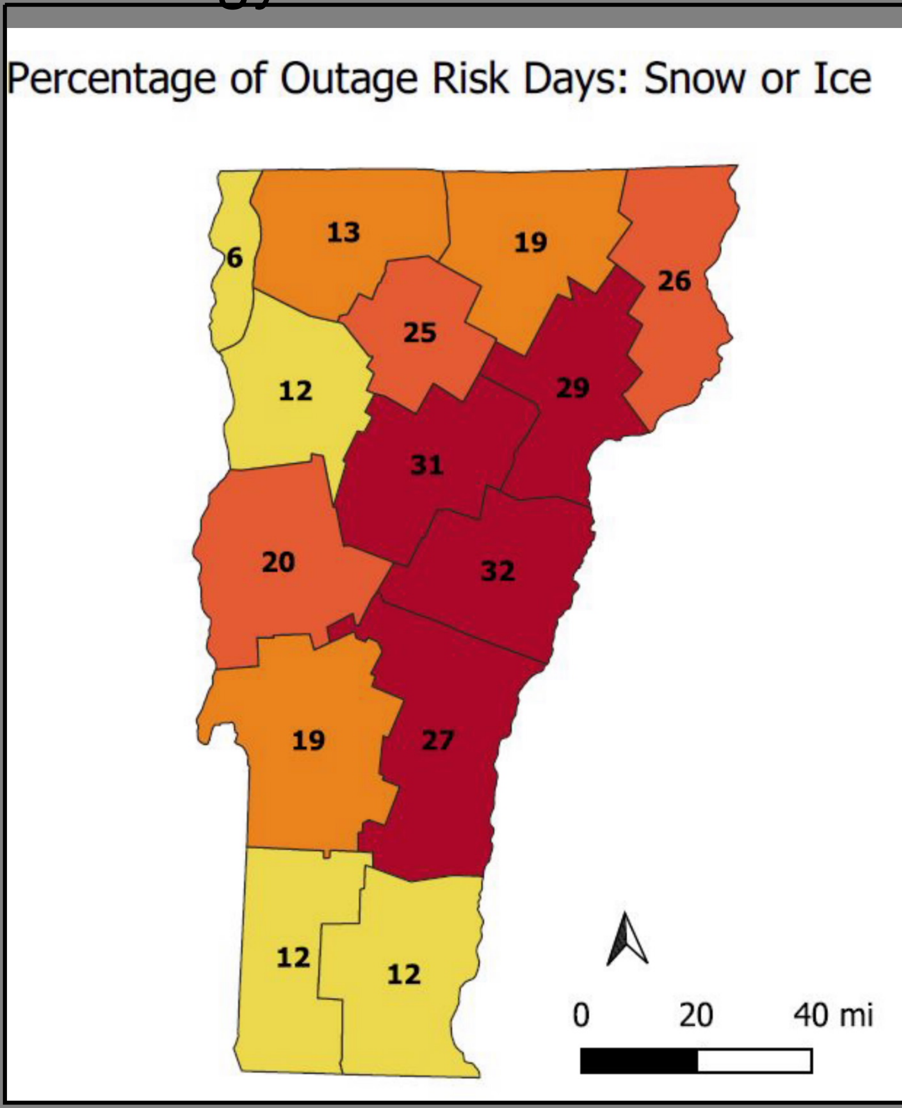
1. Distribution outage risks (GMP & VEC)
    a. Analyze historic trends in extreme weather
    b. Determine climate projections and how overall risks may change for system planning
2. Extreme precipitation (GMP)
    a. Analyze historic trends as they may affect flooding and hydro-power applications
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

Data and Methods

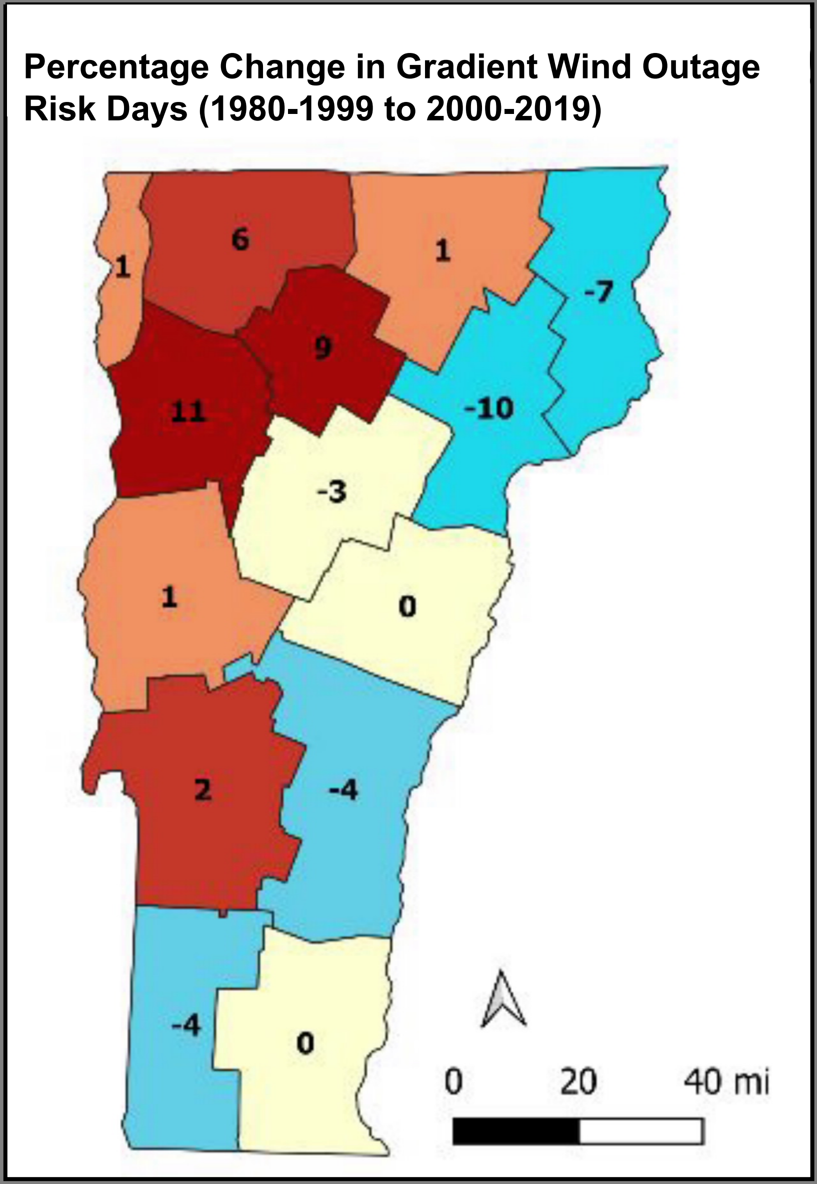
- Weather Data:
  - Primary weather data source is the ERA5 reanalysis (hourly 1980-2019)
  - Hourly power outage data was provided by GMP and VEC
  - ERA5 was dynamically downscaled to produce a higher resolution data (5-km), which was especially helpful for winds
  - Native 30 km resolution was best for precipitation events
- Distribution Power Outage Data:
  - Hourly power outage data was provided by GMP and VEC
  - Post-processed to hourly time scale and district in addition to root cause analysis
- Methods:
  - Seasons: winter (DJF), spring (MAM), summer (JJA), fall (SON)
  - A 20-year base period is used to determine most changes 1980-1999 to 2000-2019

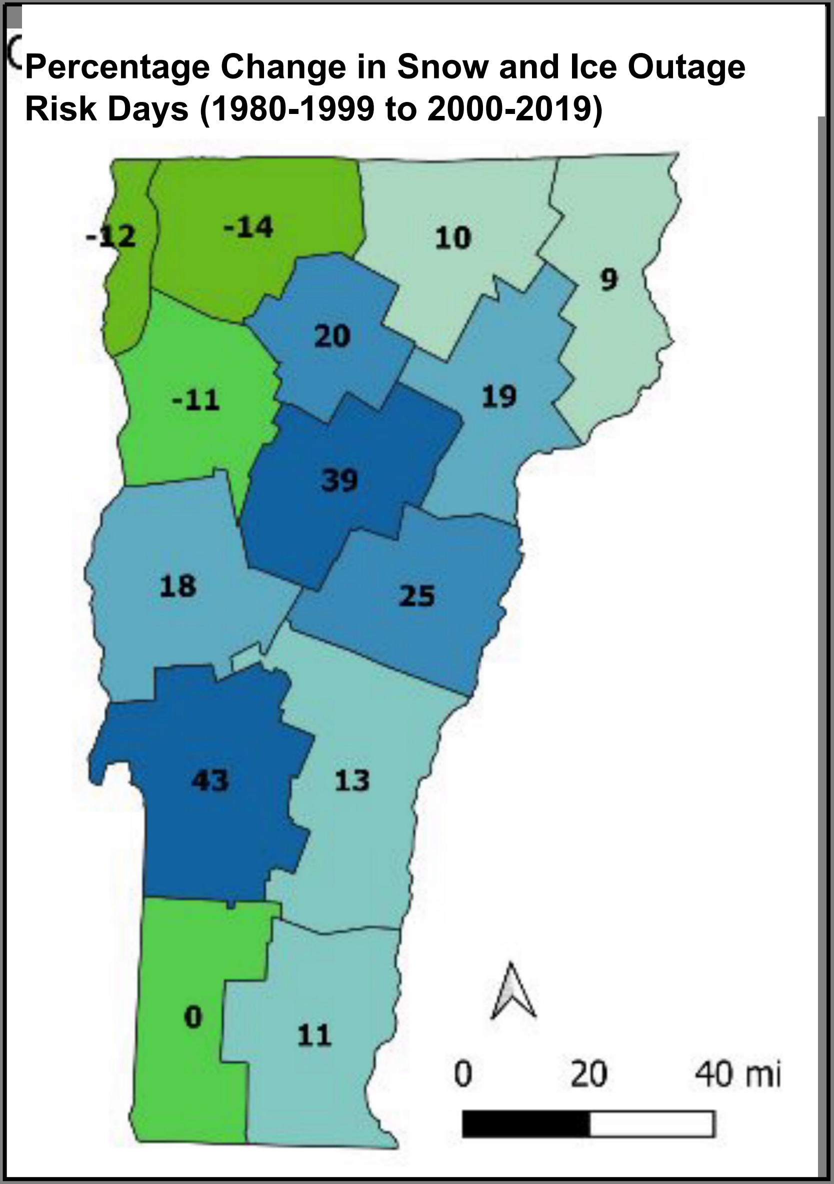
Outage Risk Climatology



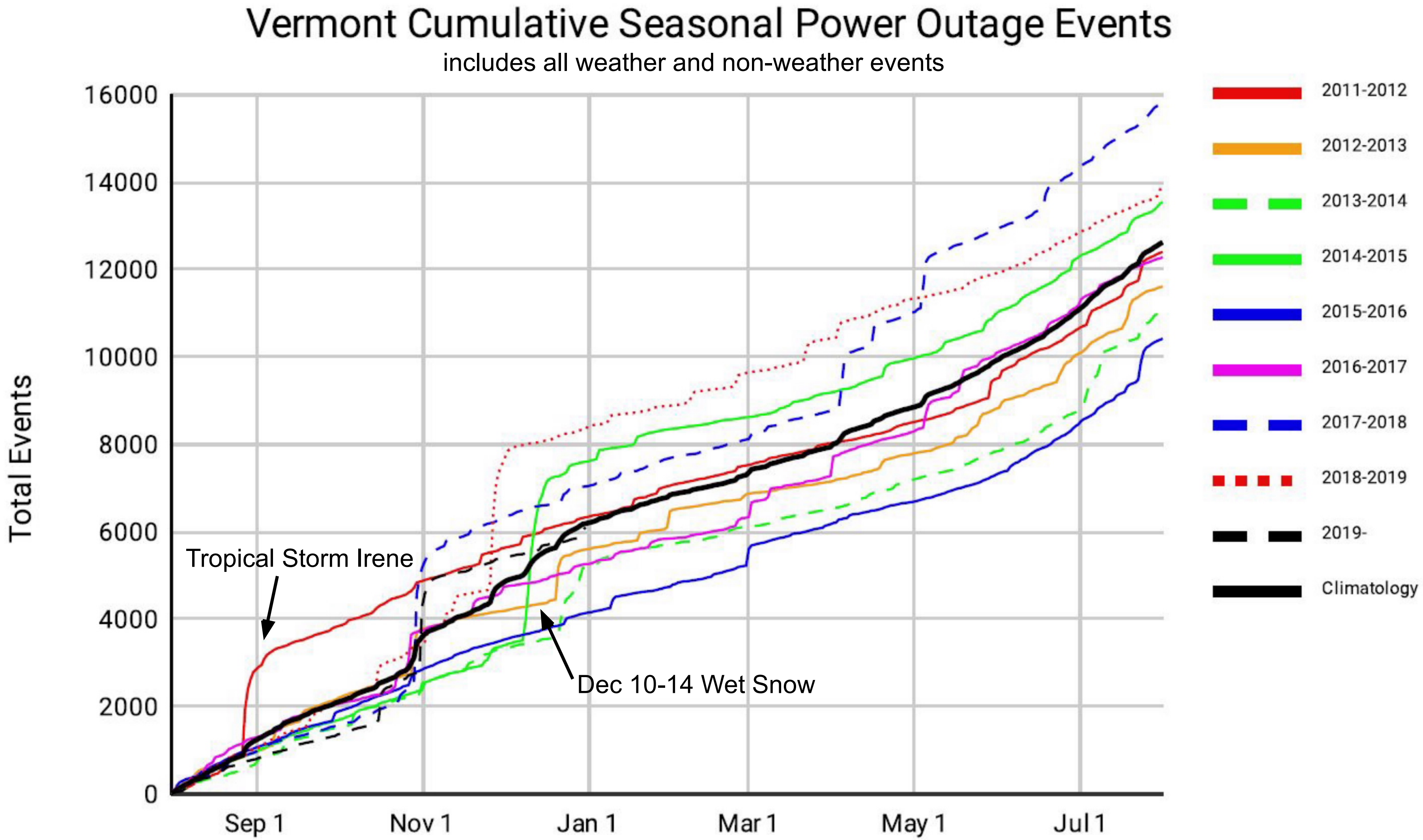


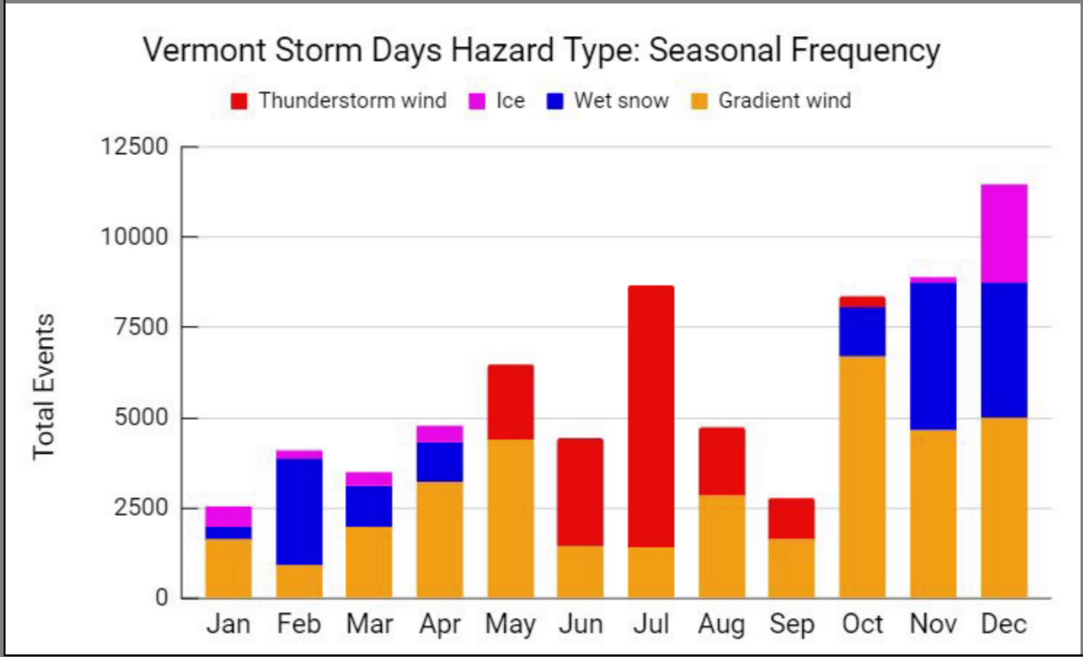
- **Wind:** Mean wind gust values 40 mph or greater
- **Wet Snow:** Mean wet snow accumulation of 0.30” or greater
- **Ice:** Mean ice thickness accumulation of 0.20” or greater

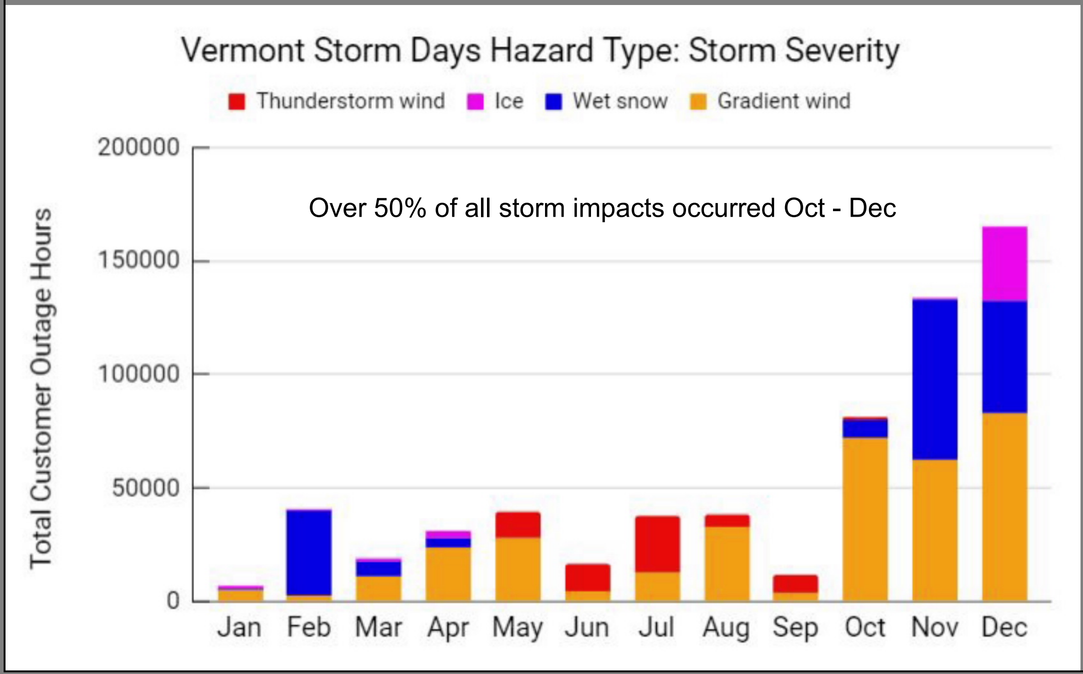




Areas prone to being windy have generally gotten windier; areas more prone to wet snow and ice have generally received more snow & ice.


Vermont Cumulative Seasonal Power Outage Events
includes all weather and non-weather events
Total Events
16000
14000
12000
10000
8000
6000
4000
2000
0
Sep 1
Nov 1
Jan 1
Mar 1
May 1
Jul 1
Tropical Storm Irene
Dec 10-14 Wet Snow
2011-2012
2012-2013
2013-2014
2014-2015
2015-2016
2016-2017
2017-2018
2018-2019
2019-
Climatology

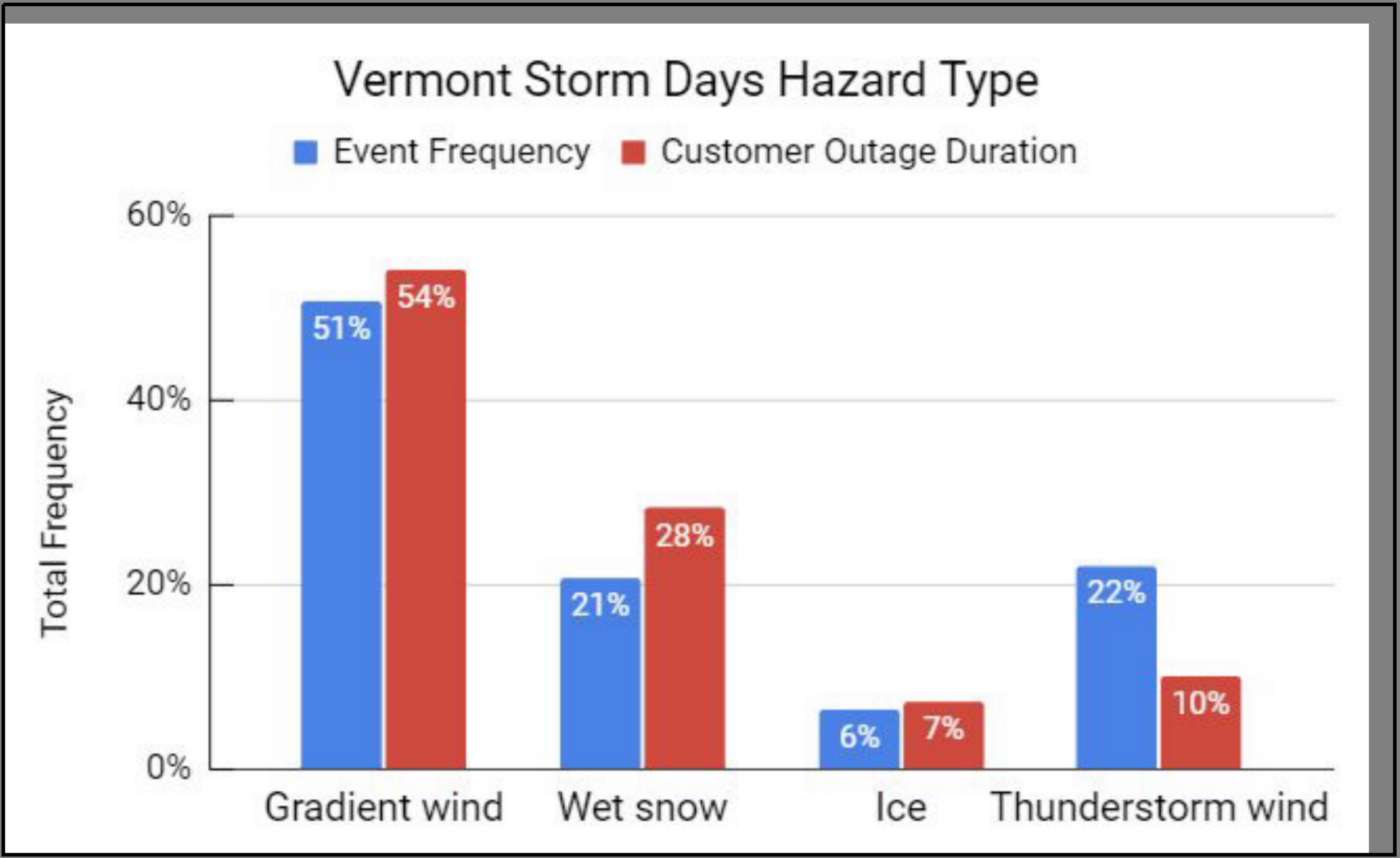




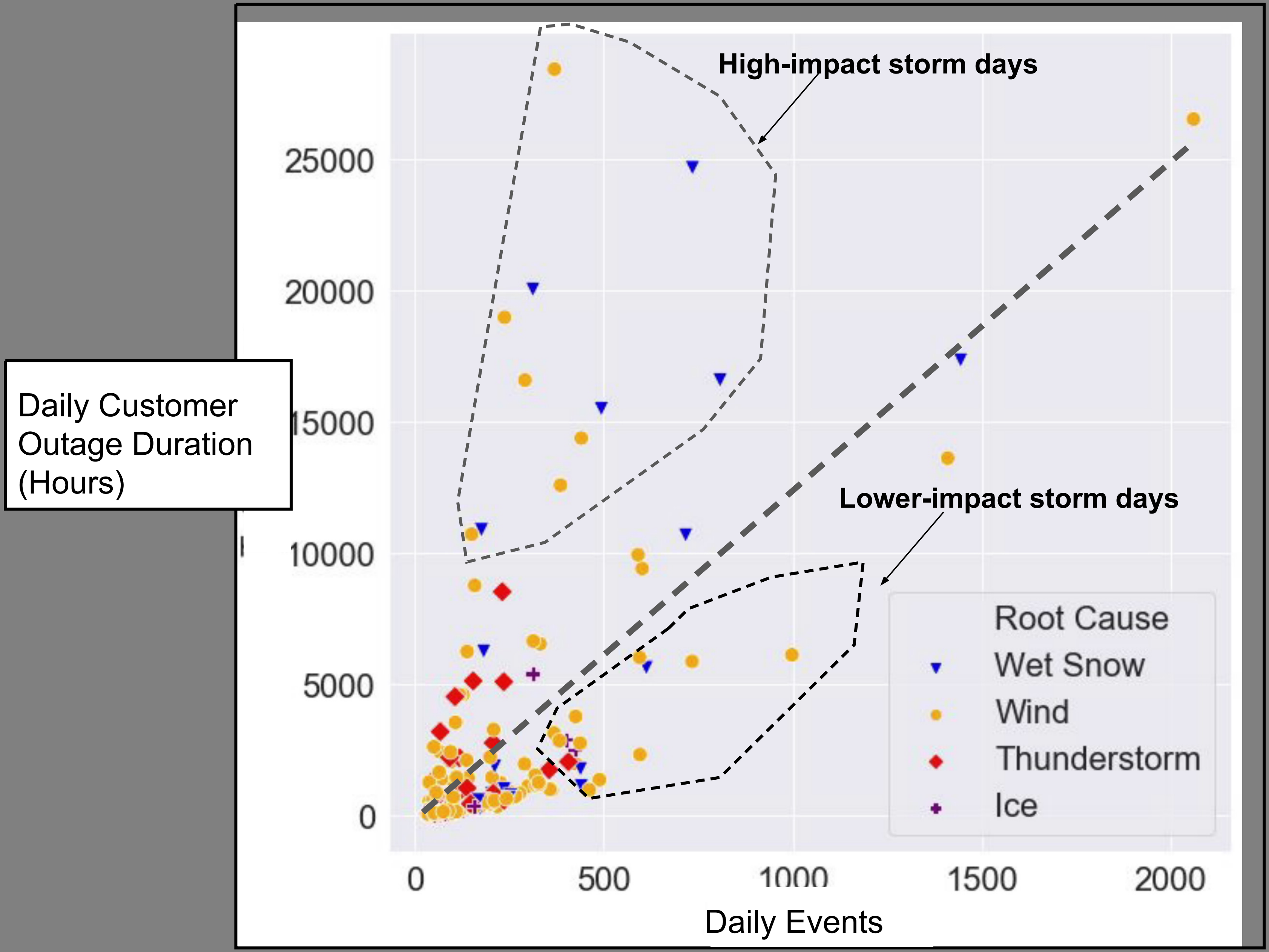
Combines this data:

GMP: 2008-2019 (50 or more events on a day)

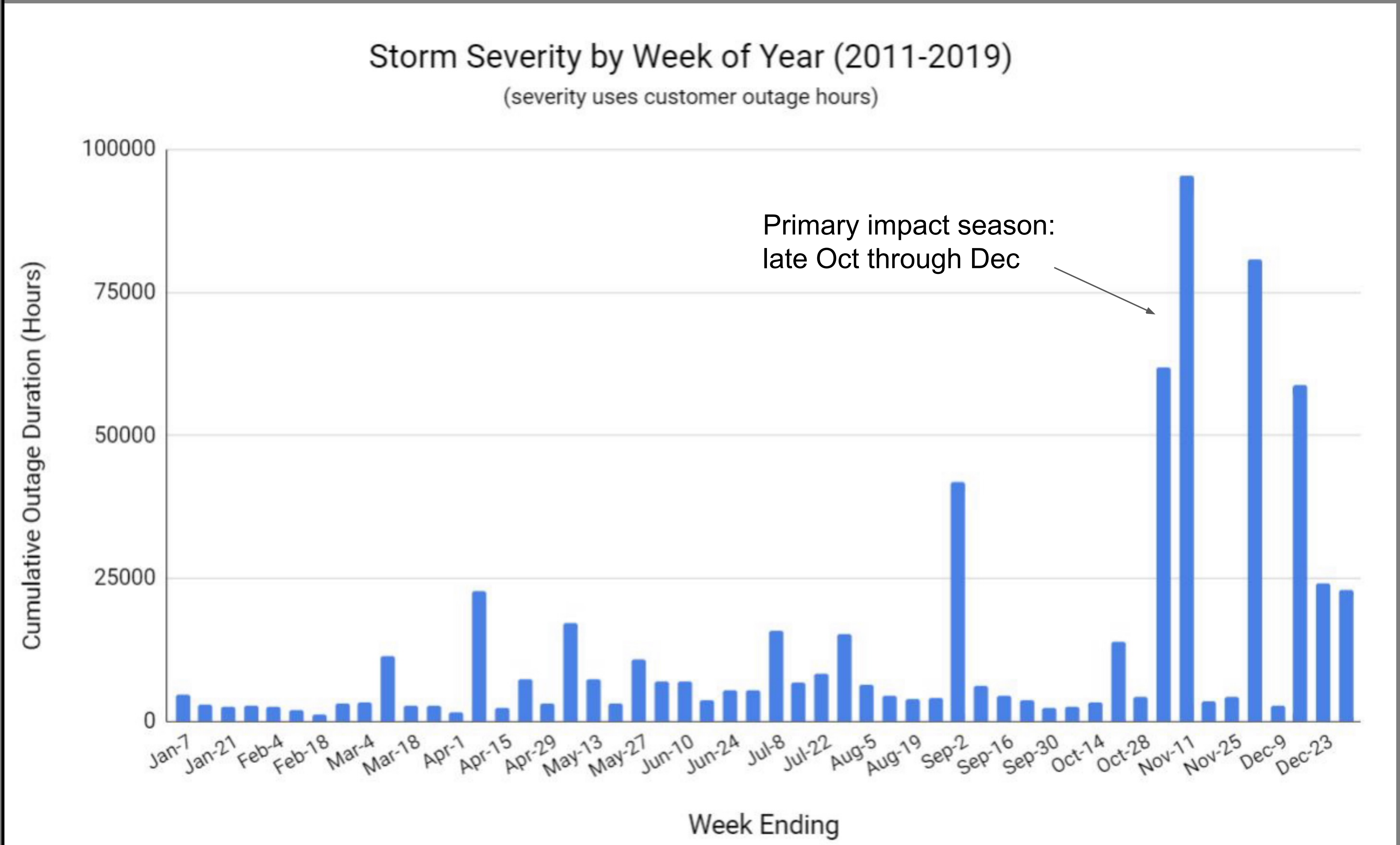
VEC: 2011-2019 (10 or more events on a day)



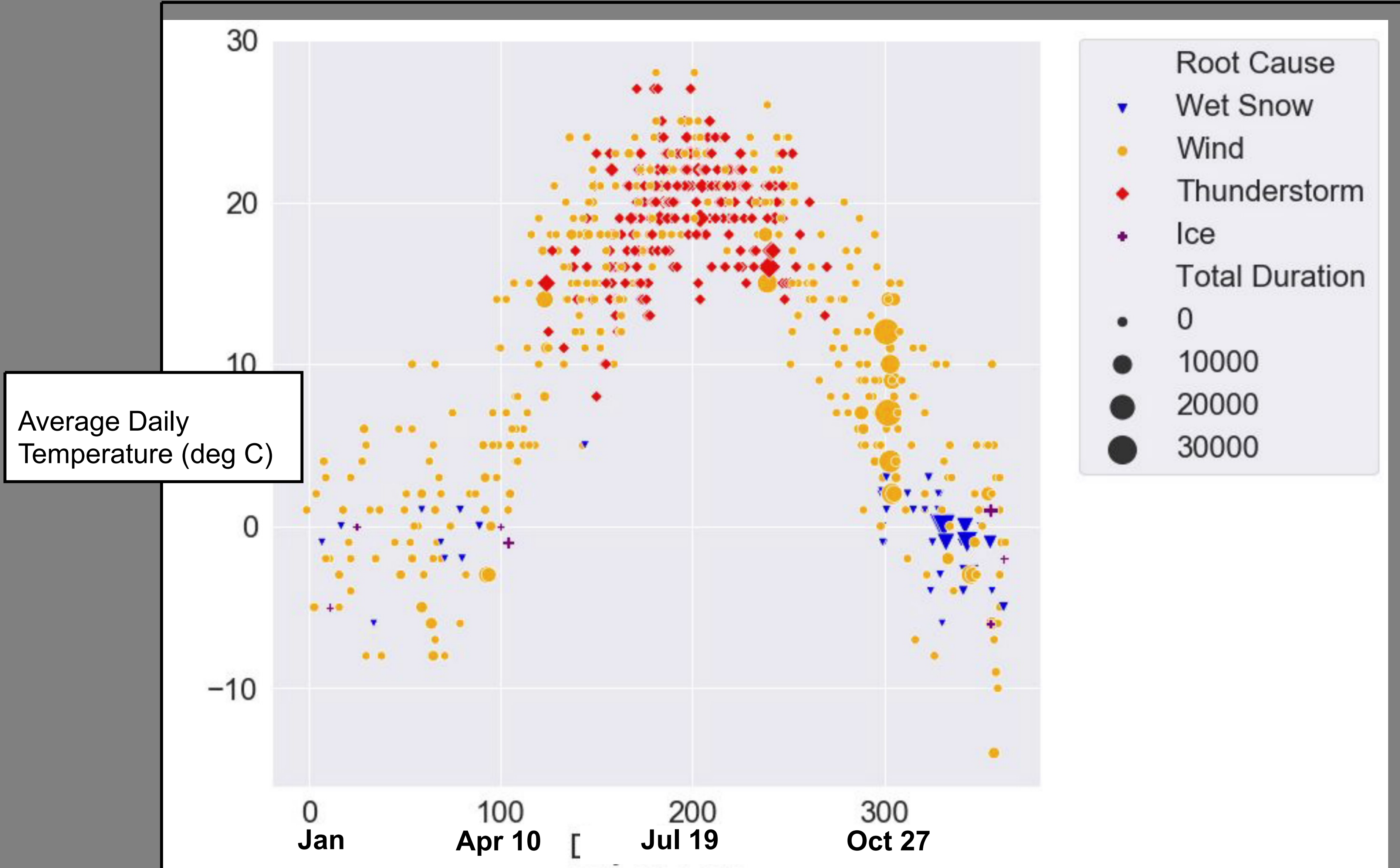
Vermont Storm Days Hazard Type
Event Frequency
Customer Outage Duration
Total Frequency
60%
40%
20%
0%
51%
54%
21%
28%
6%
7%
22%
10%
Gradient wind
Wet snow
Ice
Thunderstorm wind



High-impact storm days
Lower-impact storm days
Daily Customer Outage Duration (Hours)
25000
20000
15000
10000
5000
0
0
500
1000
1500
2000
Daily Events
Root Cause
Wet Snow
Wind
Thunderstorm
Ice

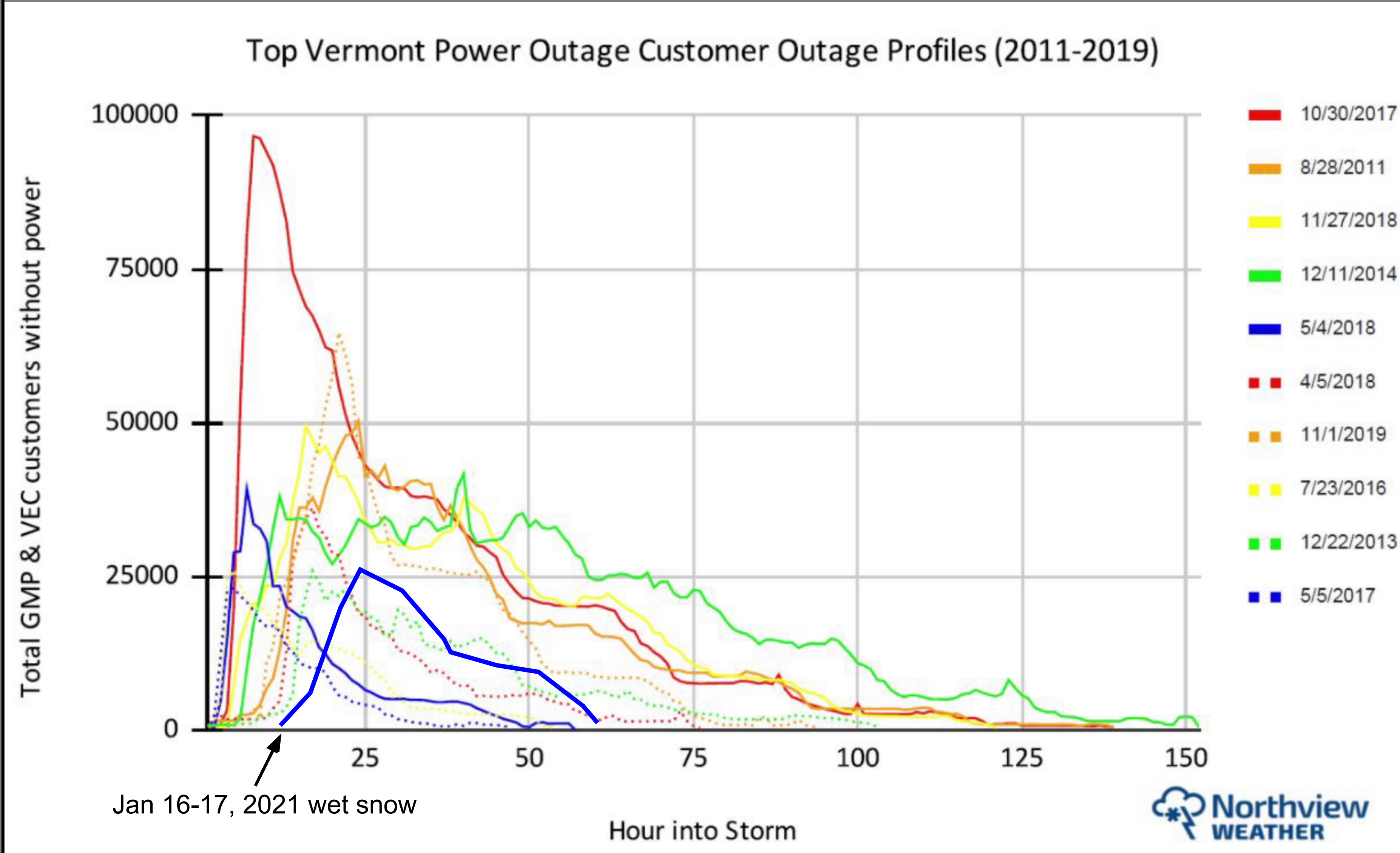


Storm Severity by Week of Year (2011-2019)
(severity uses customer outage hours)
Primary impact season:
late Oct through Dec
Cumulative Outage Duration (Hours)
100000
75000
50000
25000
0
Jan-7
Jan-21
Feb-4
Feb-18
Mar-4
Mar-18
Apr-1
Apr-15
Apr-29
May-13
May-27
Jun-10
Jun-24
Jul-8
Jul-22
Aug-5
Aug-19
Sep-2
Sep-16
Sep-30
Oct-14
Oct-28
Nov-11
Nov-25
Dec-9
Dec-23
Week Ending


Average Daily Temperature (deg C)
30
20
10
0
−10
0
Jan
100
Apr 10
200
Jul 19
300
Oct 27
Root Cause
Wet Snow
Wind
Thunderstorm
Ice
Total Duration
0
10000
20000
30000

Severe Storm Trends

Photo: GMP


Top Vermont Power Outage Customer Outage Profiles (2011-2019)
Total GMP & VEC customers without power
100000
75000
50000
25000
0
25
50
75
100
125
150
Hour into Storm
10/30/2017
8/28/2011
11/27/2018
12/11/2014
5/4/2018
4/5/2018
11/1/2019
7/23/2016
12/22/2013
5/5/2017
Jan 16-17, 2021 wet snow
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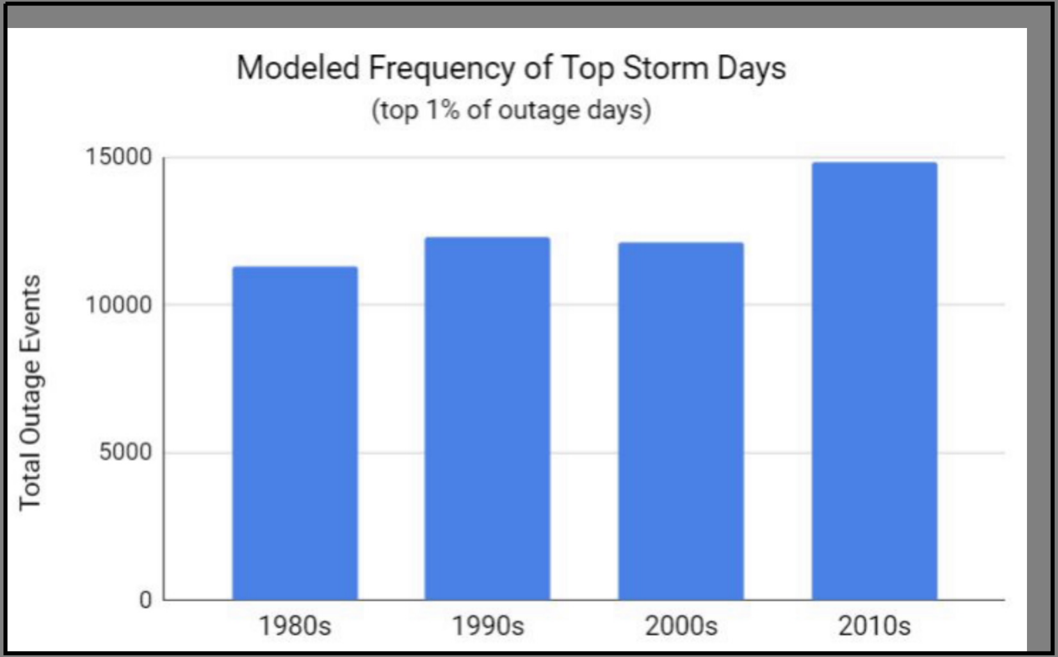
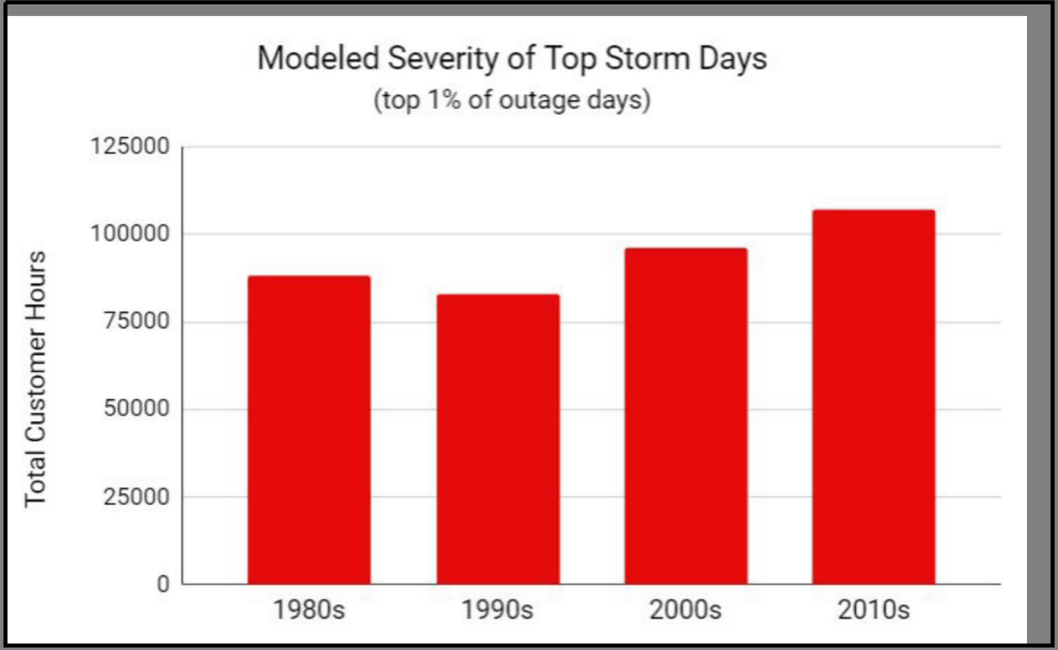
Methods: Deep Learning Model

- Simulates historic outages back to 1980 based on observed outage data
- Training period was 2008-2019 (GMP) and 2011-2019 (VEC)
- Separate models where done for event frequency and outage duration (severity)
- Leveraged ERA5 data as synchronous training features:
  - **Time:** Month, Day of Year
  - **Weather (ERA5 dataset):** Precipitation 24hr, Snow 24hr, Snow 48hr, Ice 24hr, Ice 48hr, Wet Snow 24hr, Wet Snow 48hr, Rain 24hr, Rain 48hr, Avg Temp 24hr, Dew Point 24hr, Wind Gust 24hr
  - **Leaf Area Index:** Climatological values for Vermont derived from MODIS sensor on NASA's Terra and Aqua satellites (2003-2018)
- Temporal aggregation: daily
- Spatial aggregation: district-level (21 districts with GMP & VEC)
- Does not incorporate asset information such as overhead line mileage, asset health, conductor type (assumes static system configuration)
- Does not physically represent thunderstorm wind variability

Top storm events include approximately 212 events or greater statewide and accounted for approximately 11% of all outages in the modeled dataset; however based on outage observations we estimate these storms contribute to 24% of all outages and 33% of all weather-caused outages



14% increase over 40 years



19% increase over 40 years

Outage Risk Trends (1980 to 2019 - 20 Year Trend)		
	Storm Frequency	**Storm Severity**
Machine Learning Model	+1.7%	+3.6%
Reanalysis Dataset	+3%	NA

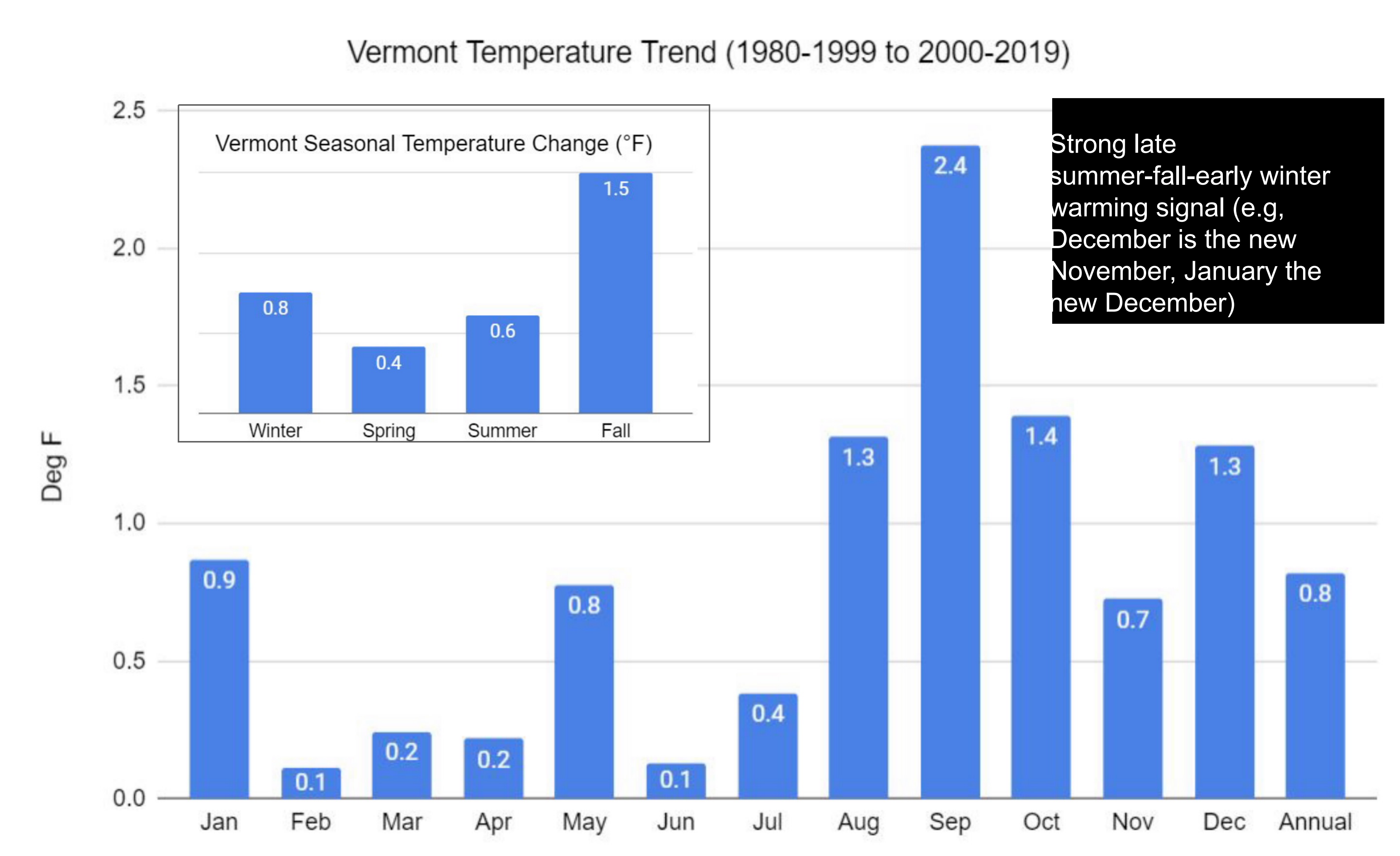
80% due to wet snow increases

20% due to gradient wind increases

Top 1% of Modeled Outage Days - Most Severe Storms		
	Total Events	**Outage Duration (Hours)**
1980-1999 Average	23597	171128
2000-2019 Average	26993	203077
20-Year Trend	+14%	+19%

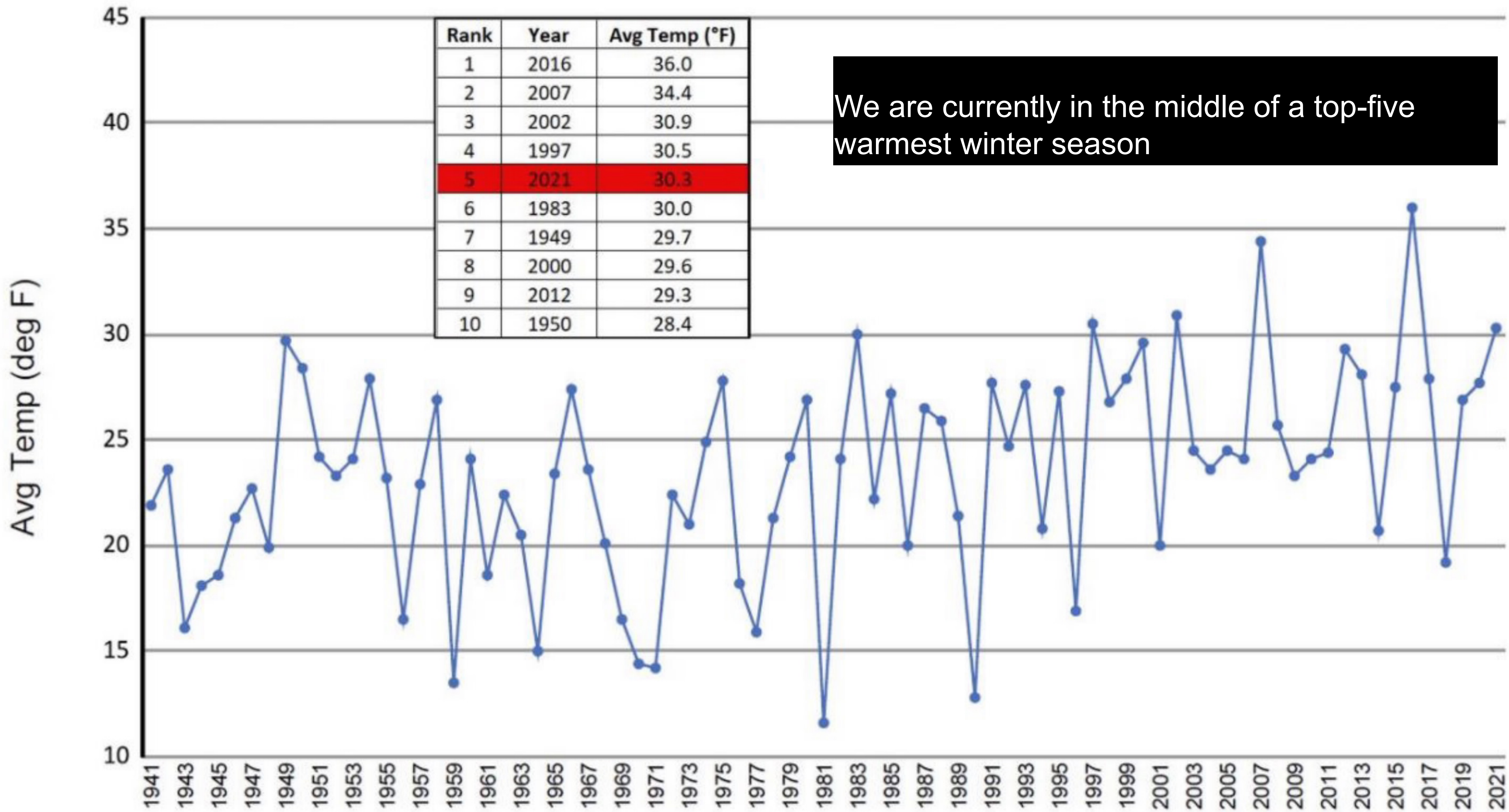
Key Takeaway: Overall outage risks have increased both due to the frequency and intensity increases of severe storms. Storms appear to be getting more severe with impacts. Frequency increases likely come from seasonal changes lengthening grid risk exposures (longer storm seasons with a warming climate).

Extreme Precipitation and Vegetation Tracks

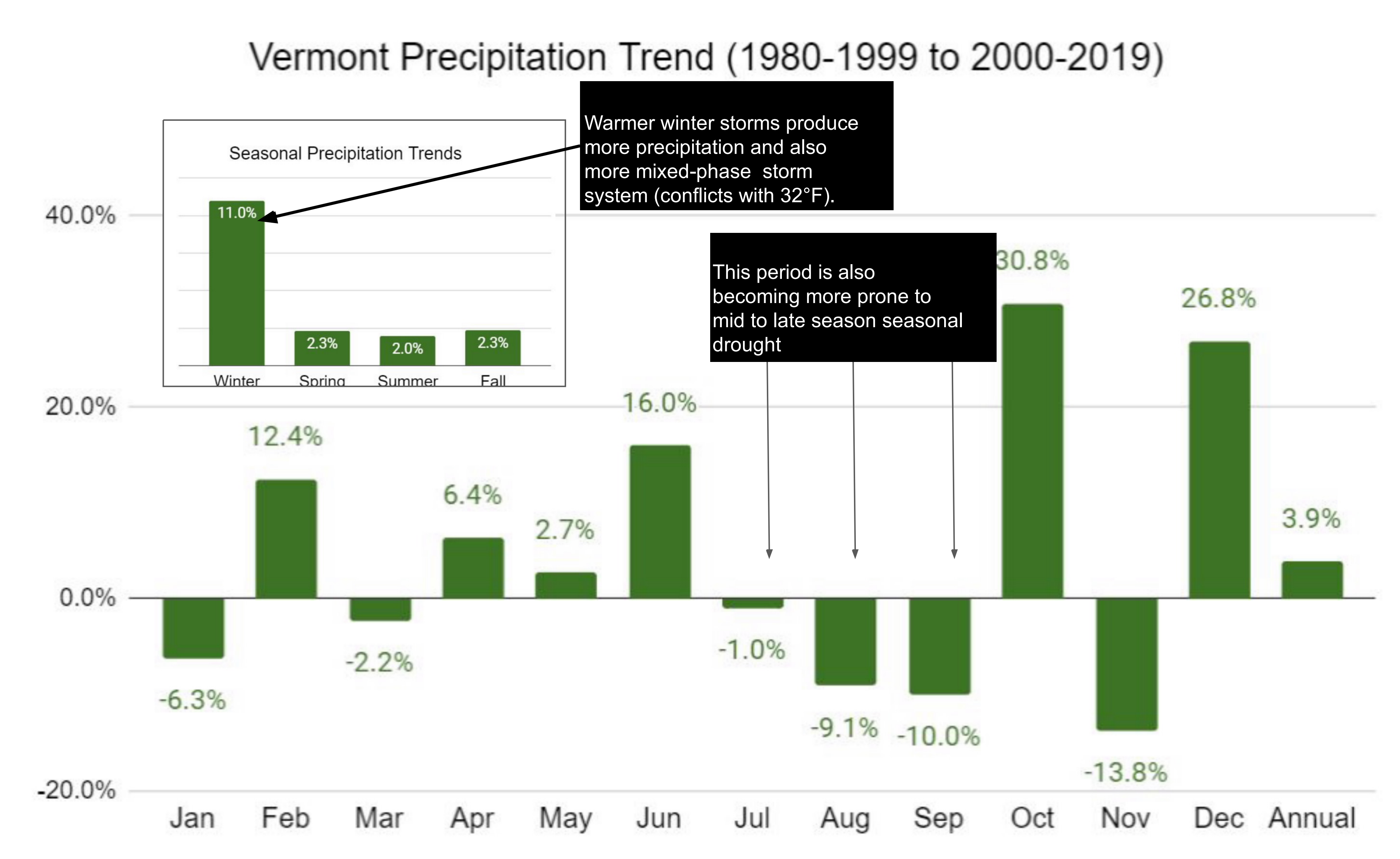

Vermont Temperature Trend (1980-1999 to 2000-2019)
Deg F
2.5
2.0
1.5
1.0
0.5
0.0
Vermont Seasonal Temperature Change (°F)
0.8
0.4
0.6
1.5
Winter
Spring
Summer
Fall
0.9
0.1
0.2
0.2
0.8
0.1
0.4
1.3
2.4
1.4
0.7
1.3
0.8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Annual
Strong late summer-fall-early winter warming signal (e.g, December is the new November, January the new December)

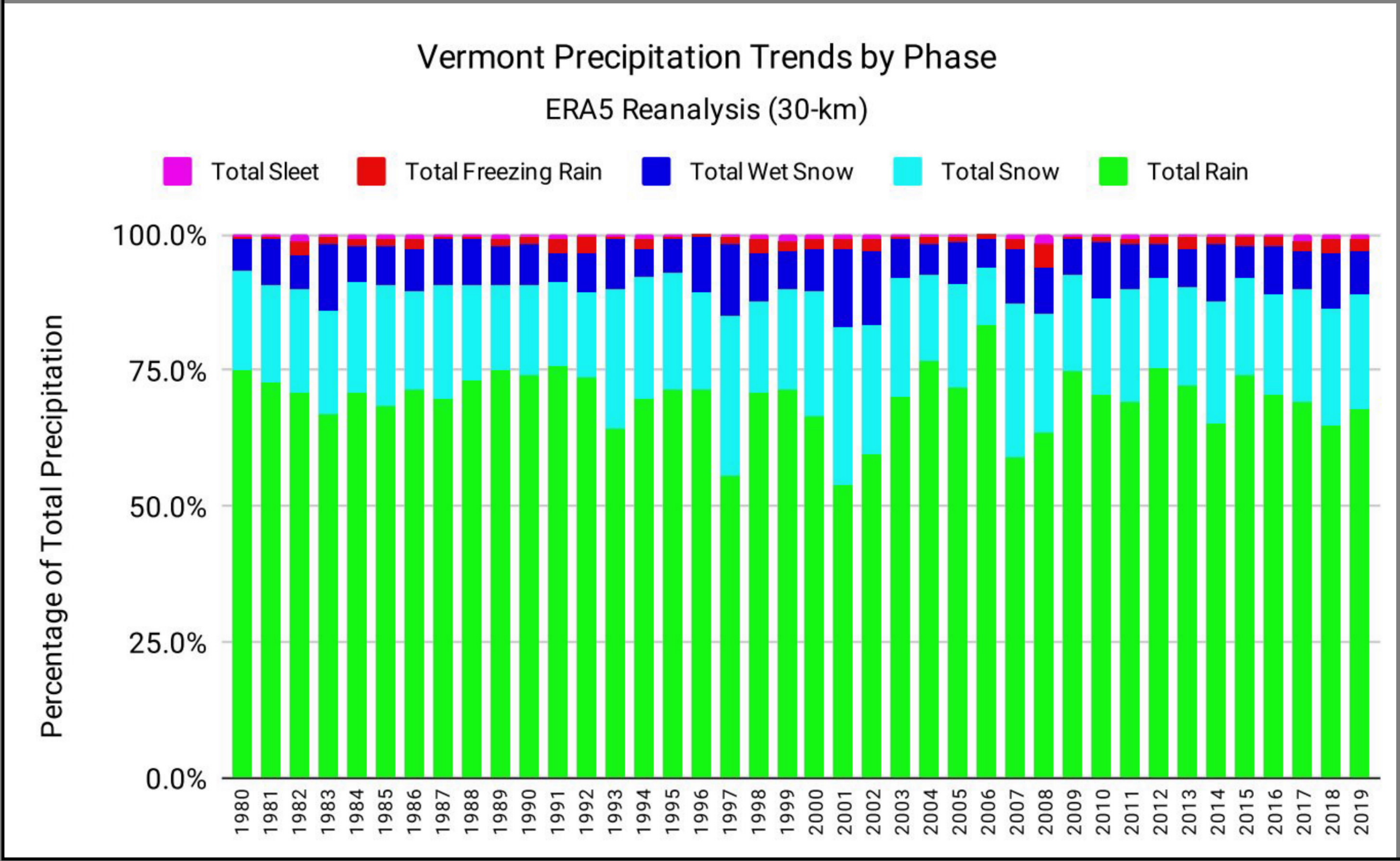
Burlington, VT Dec 1-Jan 9 Average Temperature

We are currently in the middle of a top-five warmest winter season



Rank	Year	Avg Temp (°F)
1	2016	36.0
2	2007	34.4
3	2002	30.9
4	1997	30.5
5	2021	30.3
6	1983	30.0
7	1949	29.7
8	2000	29.6
9	2012	29.3
10	1950	28.4


Vermont Precipitation Trend (1980-1999 to 2000-2019)
Seasonal Precipitation Trends
11.0%
2.3%
2.0%
2.3%
Winter
Spring
Summer
Fall
Warmer winter storms produce more precipitation and also more mixed-phase storm system (conflicts with 32°F).
This period is also becoming more prone to mid to late season seasonal drought
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


Vermont Precipitation Trends by Phase
ERA5 Reanalysis (30-km)
Total Sleet
Total Freezing Rain
Total Wet Snow
Total Snow
Total Rain
Percentage of Total Precipitation
100.0%
75.0%
50.0%
25.0%
0.0%
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
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2007
2008
2009
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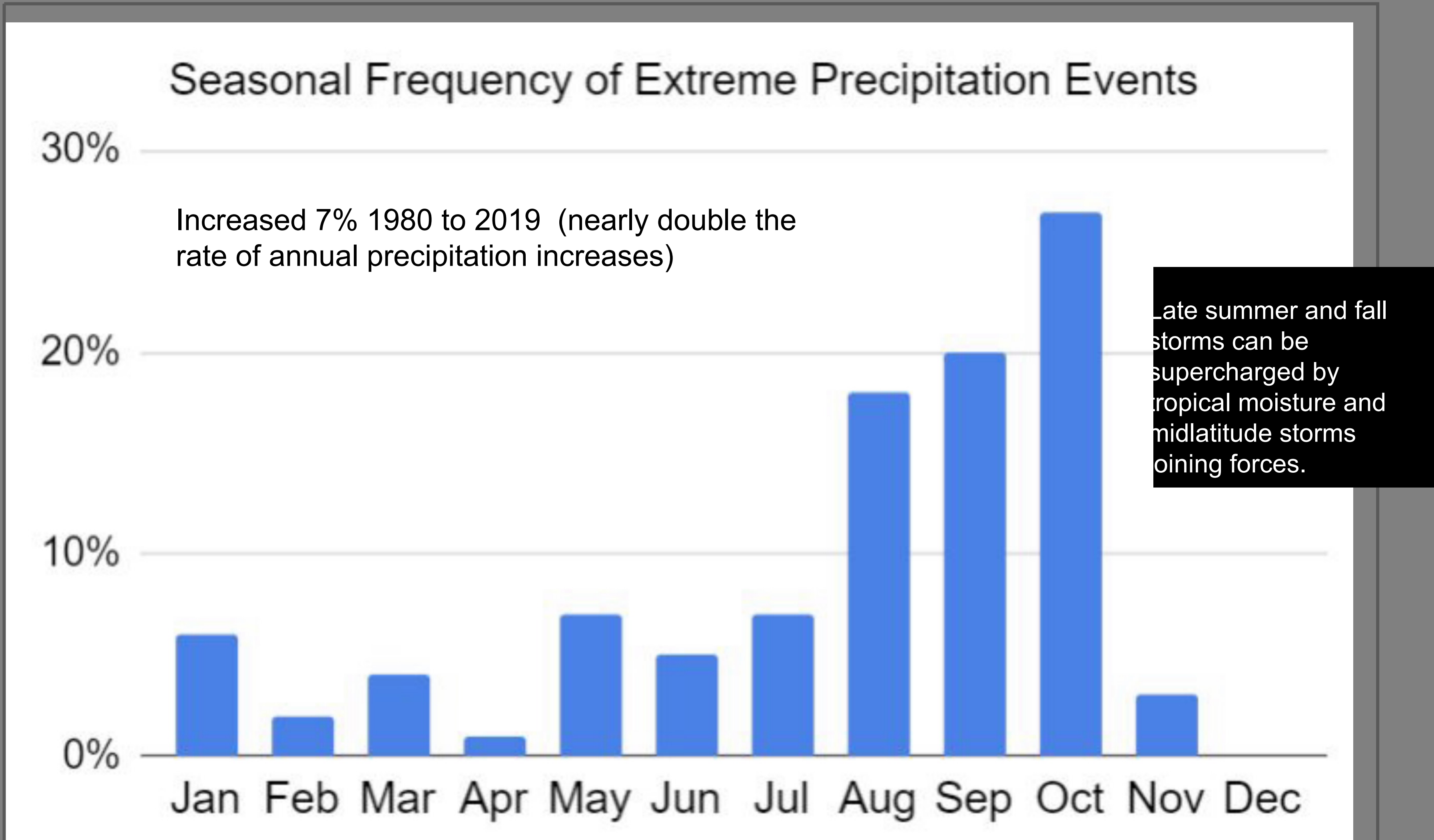
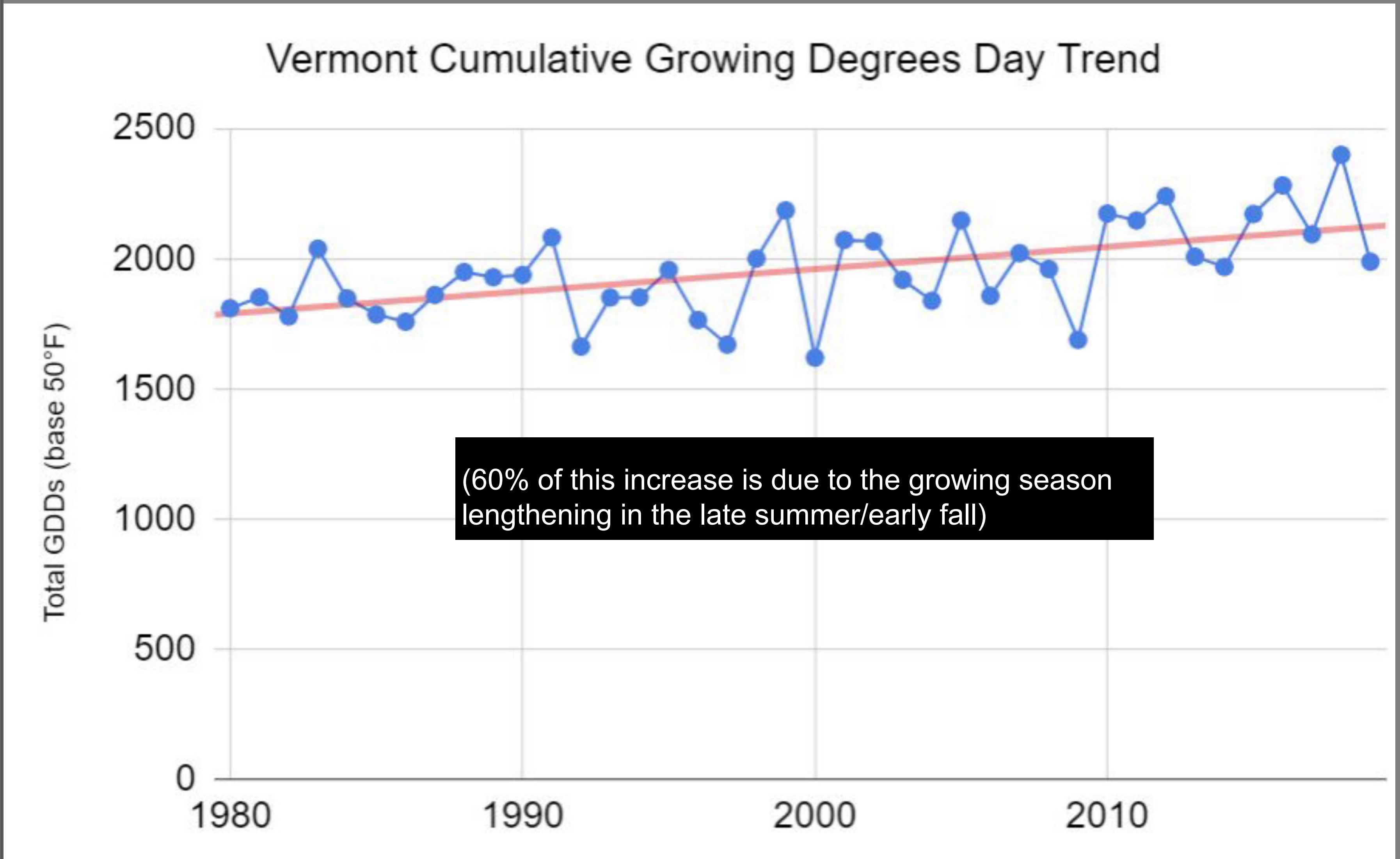
2011
2012
2013
2014
2015
2016
2017
2018
2019



Extreme precipitation events are defined as 1.00” or greater precipitation in a 24 hr or 48 hr period across most of Vermont.



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.

Vegetation Growth Factors

- Seasonal Drought
- Invasive Species
- Pathogens
- Species Dependency
- Seasonal Timing of Climate Changes
- Extreme Storm Damage
- Water availability
- Species Migration
- Solar Radiation
- Forest Age

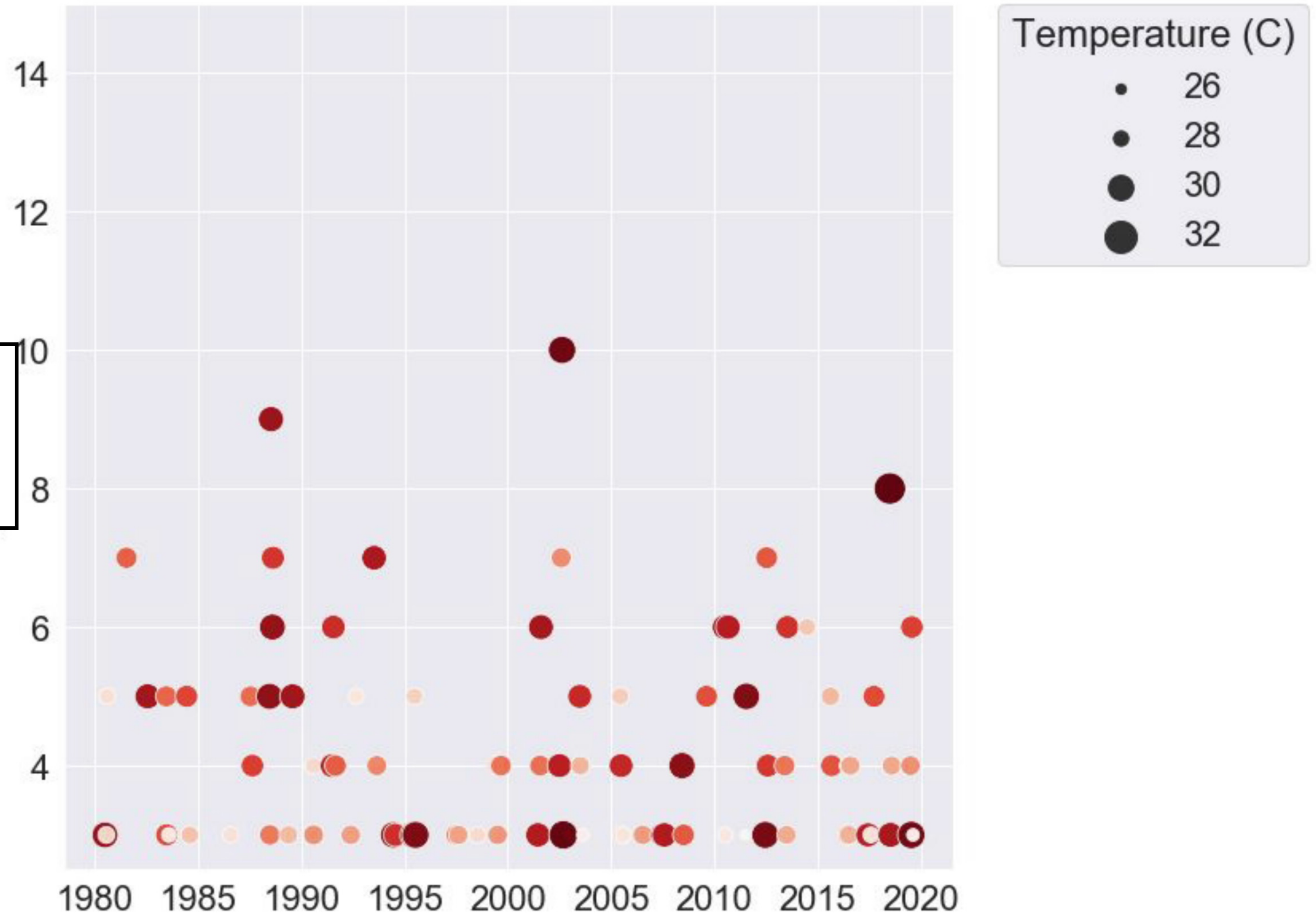

Photo: VELCO

Vegetation Growth Conclusions

- Growing seasons generally appear favorable in a fairly stable climate regime with warming seasons and adequate precipitation
- Water availability (soil moisture/evapotranspiration rates) will be primary limiting weather-climate factor
  - Early season drought reduces growth more significantly than late season drought
  - Deciduous trees follow strong seasonal growth patterns and other asynchronous influences and may not respond to lengthening growing seasons in the late summer/early fall
  - Coniferous softwoods may respond more rapidly to growing seasons getting longer with year-round photosynthesis
- Species migration is a slow process, similar species makeup likely next 30 years
- Seasonal drought appears more likely mid to late in growing seasons

Extreme Temperature and Peak Load Applications

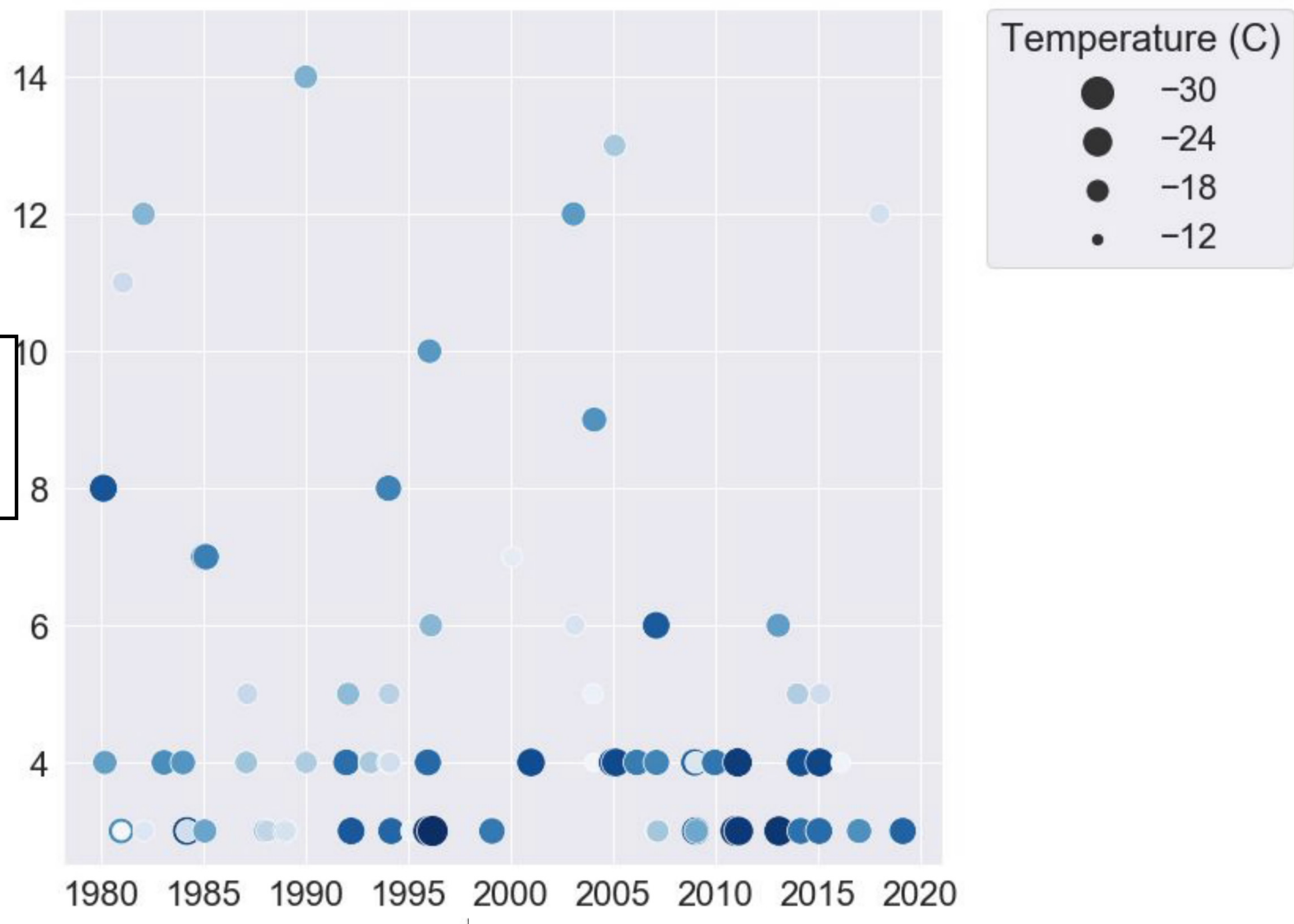
Heat Wave Trends



Heat Wave Duration (days)

Heat waves remaining steady

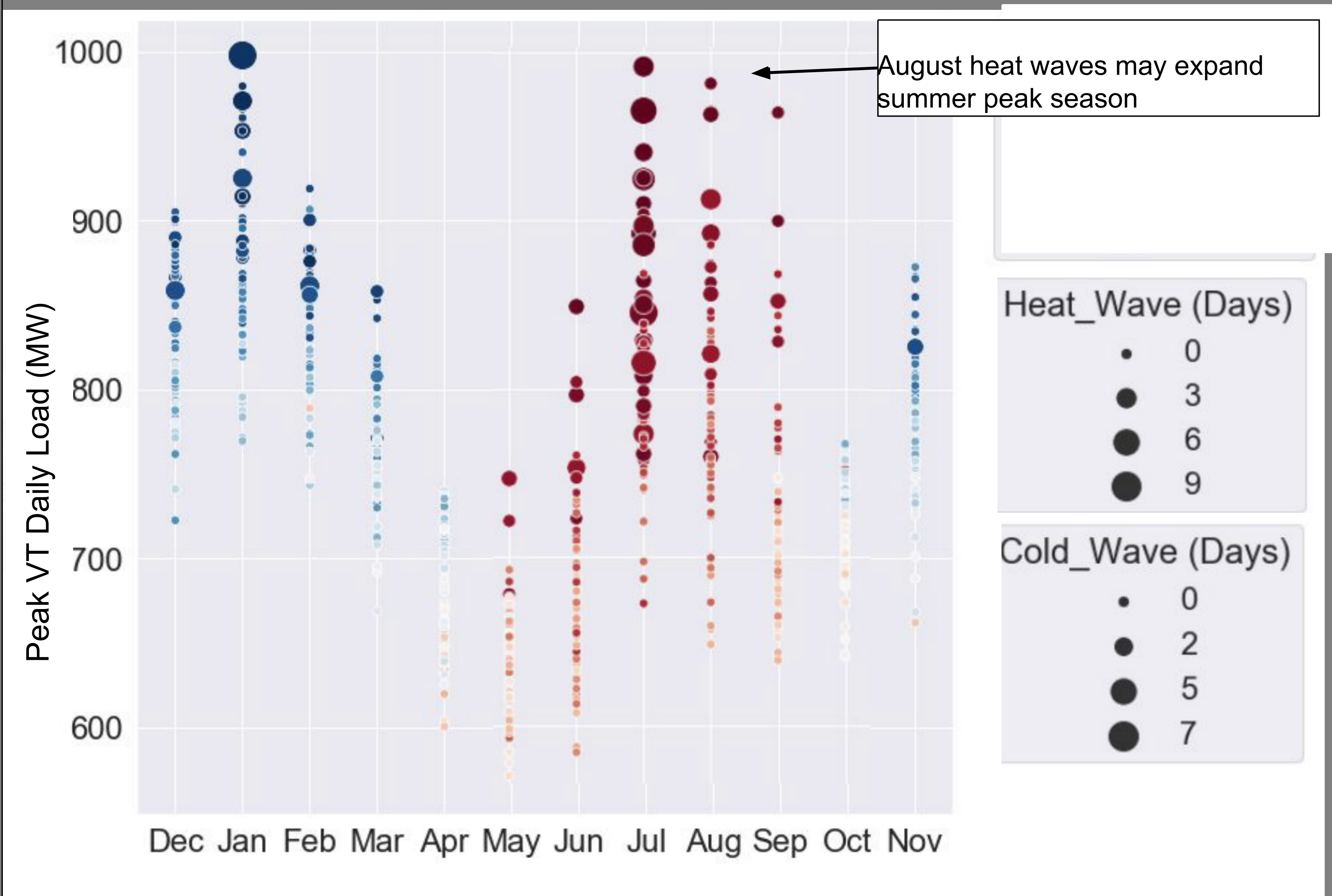
Cold Wave Trends



Cold Wave Duration (days)

General decline in duration of cold waves

Daily Peak Loads vs Temperature



uses three years of hourly load data (2018-2020)

Climate Projections:
What about the next 30 years?

Forecast Formula

Historic Trends

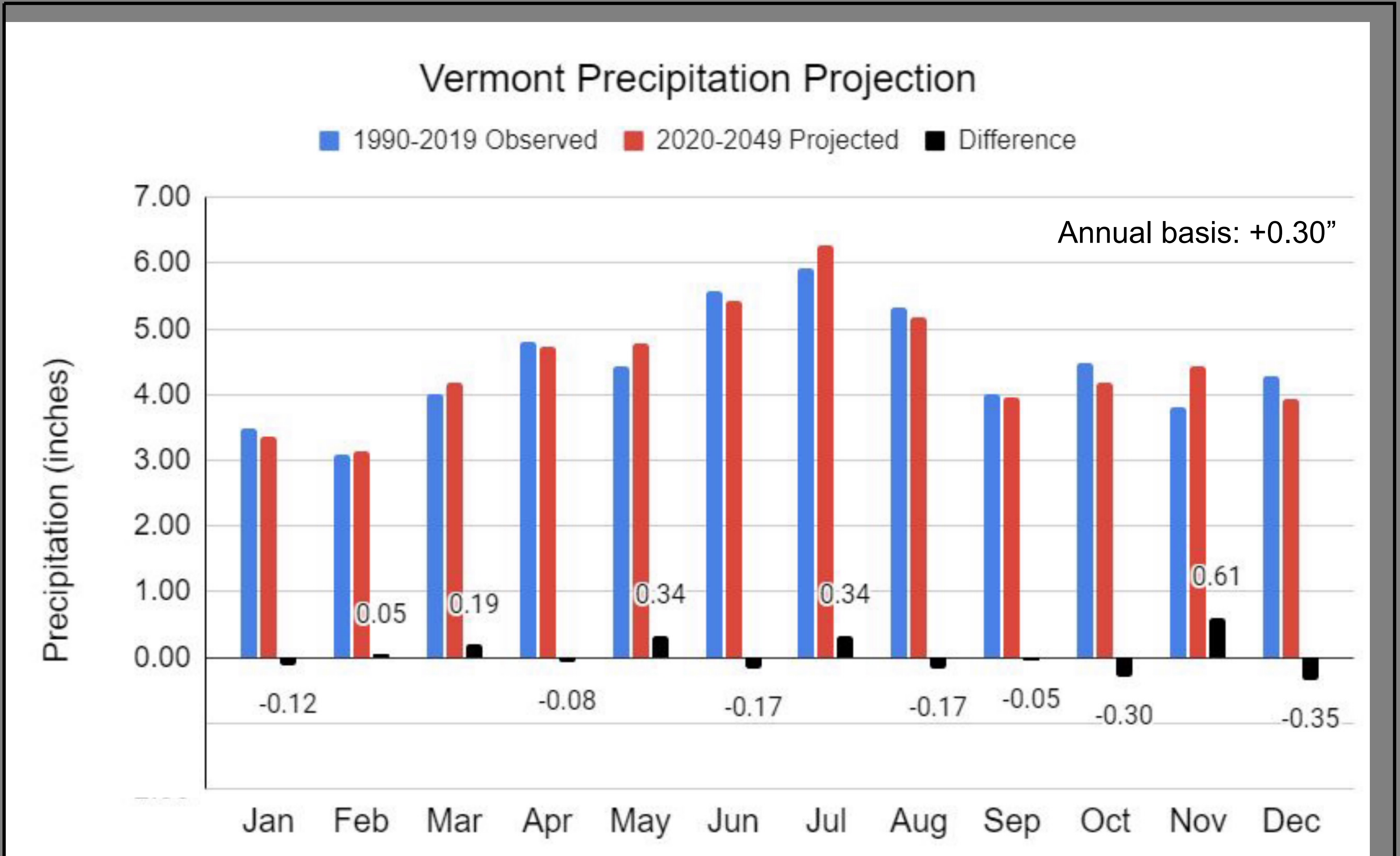
These will be weighted the most, current trends likely point in the future direction given strong climate change signals in play.

Literature

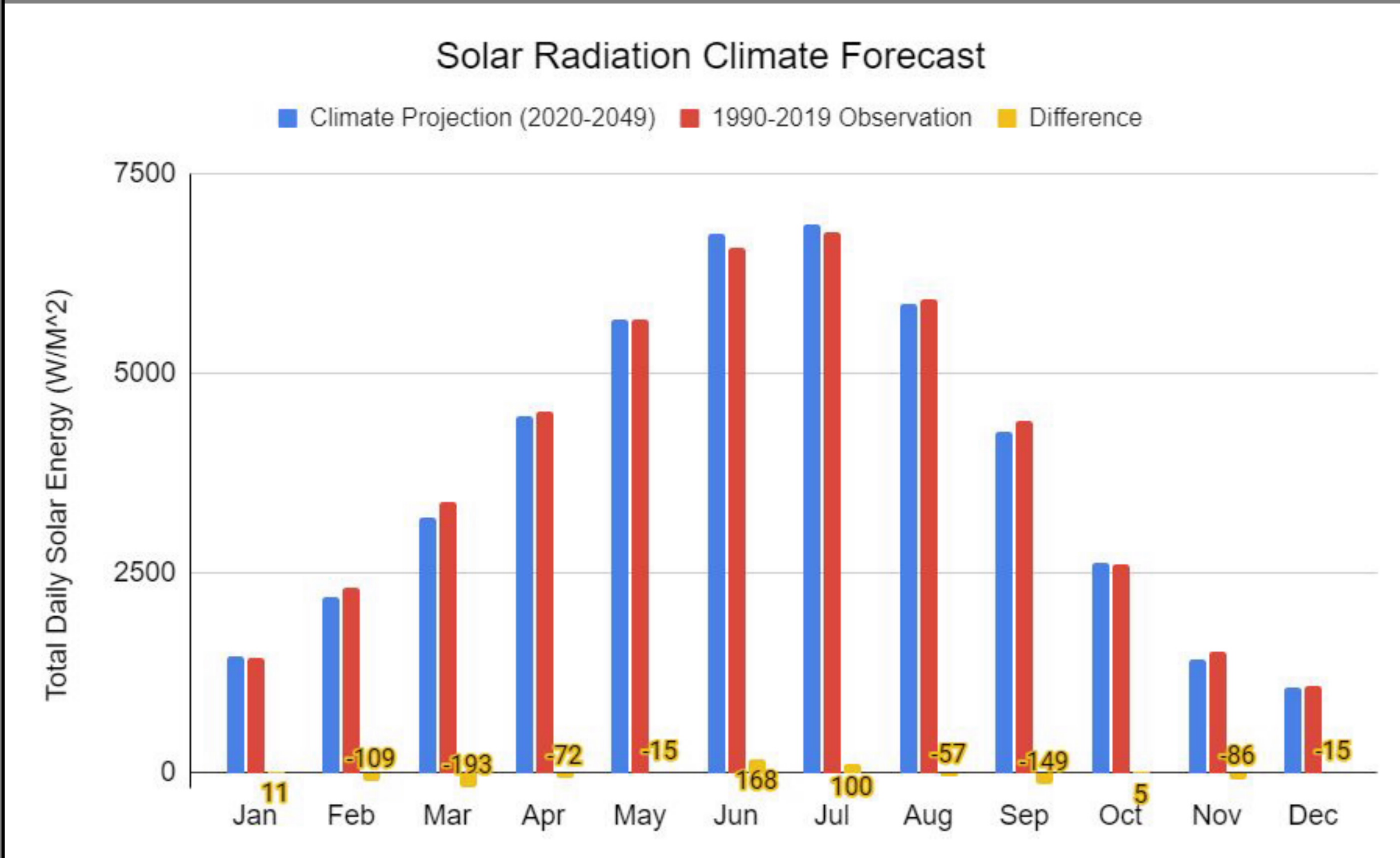
Where possible, results from the literature will be incorporated and cross-referenced to provide additional information and confidence in these results.

Climate Simulations

We conducted two climate simulation models; these simulations will help provide more specific details. However, the quality of these simulations suggest an inability to capture extreme storms (a known problem), so these will instead be used for broader seasonal signals.



Vermont Precipitation Projection
1990-2019 Observed
2020-2049 Projected
Difference
Precipitation (inches)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Annual basis: +0.30"
-0.12
0.05
0.19
-0.08
0.34
-0.17
0.34
-0.17
-0.05
-0.30
0.61
-0.35
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Solar Radiation Climate Forecast
Climate Projection (2020-2049)
1990-2019 Observation
Difference
Total Daily Solar Energy (W/M^2)
7500
5000
2500
0
11
-109
-193
-72
-15
168
100
-57
-149
5
-86
-15
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Conclusions

- Climate is getting warmer and wetter, warming fastest in late summer to fall, and getting wetter fastest in the winter
- Outage power outage risks have increased 3-6% 1980 to 2019, driven largely by major storm events becoming more frequent and more intense
- Fall and early winter season will continue to feature most powerful storm systems (tropical and midlatitude storm merges)
- Overall power outage risk will continue to increase with widening of warm season (especially late fall to early winter)
- Vegetation growth unclear with competing influences (e.g., seasonal drought) and a complex set of tree health factors
- Last decade likely best indicator of the next three decades - general seasonal trends are likely to continue

Next Steps...

- Incorporate climate simulations with trends for a forecast through 2049
- Feedback welcome
  - Extreme precipitation and hydropower applications
  - Vegetation management applications
- Tie this analysis into 8760 planning applications (e.g., peak load) simulating a broad set of weather situations

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