STATE OF VERMONT
PUBLIC UTILITY COMMISSION

Case No. 20-____-PET

Petition of Green Mountain Power for approval	)
of its Climate Action Plan pursuant to the Multi-	)
Year Regulation Plan proceeding May 24, 2019	)
Final Order and 30 V.S.A. § 218d	)

PREFILED DIRECT TESTIMONY OF
ROGER HILL
ON BEHALF OF GREEN MOUNTAIN POWER

January 30, 2020

Summary of Testimony

Mr. Hill presents data and analysis regarding climate change and Vermont weather, including the expectation for the more frequent severe storms Vermont has already experienced to continue, as climate change effects intensify.

TABLE OF CONTENTS

EXHIBIT LIST

PREFILED DIRECT TESTIMONY OF

ROGER HILL

ON BEHALF OF GREEN MOUNTAIN POWER

Introduction

Q1. Please state your name, address, and occupation.

A1. My name is Roger Hill. My address is 186 MacKenzie Drive, Worcester VT 05682. I am a professional operational meteorologist with a weather consulting service operating out of Worcester, Vermont. Most people know of me through the work I have done forecasting for Radio Vermont for over twenty years. I have provided professional insight to numerous clients, including Vermont newspapers the *Stowe Reporter* and *The World* in Barre. I have run my own weather forecasting and consulting business, Weathering Heights, in Vermont for over 30 years. Through that consulting business, I have contracted to provide consulting services to numerous and varying clients, such as in the ski or maple-sugaring industries, point-forecasting for outdoor events, road and infrastructure maintenance, and the state's electric utilities through VELCO.

I contract with VELCO to provide weather data consulting services to Vermont electrical utilities including Green Mountain Power. I frequently work with various towns and cities in north-central Vermont, and with emergency planners, to forecast the impacts of severe weather events, such as power outages, road conditions, and the need for snow removal. I also contract with a number of school districts to advise on weather-related school delays and closures. I lecture and present around the state about the intricacies of our weather, specifically addressing our changing climate.

While I do not have a complete meteorological degree, my out-of-the box, self-taught experience has led to insight which goes beyond schooling. My training has been mostly experiential in nature, with my expertise deriving primarily from my time in the U.S. Army, working as an Artillery Ballistic Crewman in data acquisition, followed by approximately twelve years of in-house employment with the National Oceanic and Atmospheric Administration ("NOAA") National Weather Service. During my time with the NOAA, I earned numerous certificates, including Hydro-Meteorological Technician and Pilot Weather Briefer, and worked at a number of stations in different parts of the country, including operation of a WSR-88D NEXRAD Severe Weather Radar Focal Point.

Q2. When were you first approached to provide analysis on weather trends to state utilities and how has that work developed?

A2. I originally worked with Washington Electric Coop as a Weather Hazards Forecaster in the 1990s. In 2007, this was expanded to statewide when I contracted with VELCO.

Q3. Have you previously testified before the Public Utility Commission ("Commission" or "PUC")?

A3. No.

Q4. What is the purpose of your testimony in this case?

A4. I will be providing testimony about the weather trends and hazards Vermont faces as a state, particularly in this time of significant impact from climate change, including the effects on our state's power grid. As described below, and in the material I rely upon and attach here as exhibits, our state will continue to see a nonlinear but nevertheless clearly increasing trend of storms, bringing heavier precipitation and higher winds, brought about by climate change.

Q5. How is your testimony organized?

A5. First, I note the sources where I derive the meteorological concepts included in my testimony, and upon which I rely. I then outline historical trends in weather patterns from the early 20th century forward. This outline is based primarily upon the NOAA's State Summaries – Vermont document (provided here as **Exhibit GMP-RH-1**) published in 2018, and other data sources I regularly review. Second, I discuss the verified cause-and-effect relationships behind the changing weather patterns we are experiencing in Vermont. I discuss how the rapidly warming temperatures in the Arctic have resulted in melting sea ice there, which causes an observable slowing of the jet stream. This slowing has dramatically shifted overall, long-term temperatures, which have led to notable warm season trends like stronger and more frequent thunderstorms with high winds, lightning, and flooding; and importantly, from an electric infrastructure point of view, in the cold season, more frequent and extreme storms, with stronger winds, more variable winter precipitation, and heavier, wetter snow that loads up on trees and power lines, causing widespread damage and power outages. Finally, I look ahead over the next 20 to 40 years and discuss my assessment of the outcome of these shifts.

Q6. Can you share with the Commission any specific reports or presentations you have relied upon in creating this testimony?

A6. Yes. I relied upon the following sources which all relate to the phenomenon of Arctic amplification ("AA"), which is the term used for the observed doubled rate of temperature increase in the Arctic compared to the global average: first, the 2012 research paper by Francis and Vavrus, published in the Geophysical Research Letters publication,[1] which links AA to the extreme weather patterns observed in mid-latitude climates—like Vermont's. I relied upon their 2015 paper,[2] published by IOP Science, which documents metrics and evidence that support the finding of a cause-and-effect relationship between observable extreme weather events and persistent jet stream patterns linked with the recent change in Arctic temperature. I relied on Vavrus and Wang's 2015 study[3] published by the Nelson Institute Center for Climactic Research at the University of Wisconsin at Madison that tested the link between AA and extreme weather trends in mid-latitude climates. I relied on the white paper authored by the US CLIVAR Working Group on Arctic Change and Possible Influence on Mid-latitude Climate and Weather and published by NCBI[4] summarizing the findings of the 2017 workshop held in Washington D.C., which attempted to frame the relationship between AA and mid-

[1] Francis & Vavrus, *Evidence linking Arctic amplification to extreme weather in mid-latitudes* (2012). Available at https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2012GL051000.
[2] Francis & Vavrus, *Evidence for a wavier jet stream in response to rapid Arctic warming* (2015). Available at https://iopscience.iop.org/article/10.1088/1748-9326/10/1/014005/meta.
[3] Vavrus et al. *Changes in North American Atmospheric Circulation and Extreme Weather* (2017). Available at https://journals.ametsoc.org/doi/full/10.1175/JCLI-D-16-0762.1.
[4] Cohen et al. *Arctic change and possible influence on mid-latitude climate and weather* (2018). Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6800673/.

latitude weather pattern changes. I relied on the 2014 article in Nature Geoscience by Cohen et al. on the link between severe winters and AA.[5] Finally, I relied on a 2015 letter published in Nature Geoscience by Kug et al. linking the unusually harsh winter weather observed in mid-latitude climates with Arctic warming.[6] Together, each of these papers is included in **Exhibit GMP-RH-2** of my testimony. For data to confirm my observations and understanding regarding Vermont-specific weather trends, I also relied upon the NOAA's State Summaries – Vermont document, mentioned above, which contains conclusions regarding Vermont consistent with the other papers I have mentioned.

I often present information to state leaders and community groups in Vermont regarding climate change, utilizing the materials provided here in **Exhibits GMP-RH-1** and **GMP-RH-2**. For the Commission's benefit, I also attach as **Exhibit GMP-RH-3** the most recent slide deck I have used for this purpose. While it is not specific to Vermont or my testimony here, it provides some charts and other visual representations of the information I discuss below.

[5] Cohen et al. *Recent Arctic amplification and extreme mid-latitude weather* (2014). Available to purchase at https://www.nature.com/articles/ngeo2234.
[6] Kug et al. *Two distinct influences of Arctic warming on cold* (2015). Available at https://www.researchgate.net/publication/281375803_Two_distinct_influences_of_Arctic_warming_on_cold_winters_over_North_America_and_East_Asia.

I. Historical Weather Trends in Vermont

Q7. Can you describe Vermont's climate, historically, and the main influencers of its weather?

A7. Vermont is at a latitude just under the 45th parallel, and is influenced by the moderating and moistening presence of the Atlantic to its east. It is at the northern end of the mid-latitude area, from a meteorological point of view. Locally, its northwestern areas are influenced by Lake Champlain, which can moderate temperatures but also helps drive higher moisture to the western Green Mountains.

Historically, Vermont has been characterized by cold, snowy winters and warm, beautiful summers, with only relatively short bouts of high heat and humidity. Vermont has historically seen rather frequent weather pattern changes, as the warmer, wetter air from the south and west competes with the colder, drier air from the north. Vermont typically sees abundant precipitation throughout the year, and has had very few episodes of drought, though there is variability by region. All of the above is confirmed by the NOAA State Summaries – Vermont document, **Exhibit GMP-RH-1**.

But those historical patterns are changing because of the existence of human-caused global warming that is scientific and unequivocal. The dynamic nature of the global warming trend means that while Vermont, like elsewhere, will continue to see overall increases in temperature, we can expect, and are seeing now, other weather phenomena associated with this increase in temperature to directly impact us. The recently coined term called "global weirding" denotes unusual or unusually severe weather activity attributable to increasing global temperature. This includes the increase in precipitation and high wind events that Vermont has now come to expect. The increased temperatures mean that more precipitable water is present in the atmosphere and in soils, which in turn means an increase in precipitation intensity with more potential for damage.

Q8. How has Vermont's weather changed over the past several decades?

A8. Observed data shows that Vermont has gotten warmer since a century ago, following the global trend in the same direction. In fact, the NOAA State Summaries indicates that temperatures in Vermont have gone up more than 2 degrees Fahrenheit since the early 20th century. **Exhibit GMP-RH-1** at 3. This is compared to the well-documented global temperature increase of 2.4 degrees Fahrenheit since 1884. The last 25 years in Vermont have been particularly warm, with the highest winter and summer temperatures recorded and the greatest number of extreme precipitation events recorded. **Exhibit GMP-RH-1** at 2.

The same period of time has also been wetter in Vermont. Annual mean precipitation has been higher than the overall 20th century average for the last few decades, and the wettest observed period has been the period since 2005. In fact, according to the NOAA State Summaries data, average annual precipitation has increased nearly six inches since the 1960s. **Exhibit GMP-RH-1** at 3.

This wetter weather has also been more extreme. NOAA defines extreme precipitation as precipitation greater than 2 inches over 24 hours. Vermont has been above the long-term average for extreme precipitation events since 1995. *Id.* It is a principle of common physics that as temperatures warm in the atmosphere, the atmosphere holds more moisture or water and hence more water vapor, which affects the condensation-to-precipitation stage of the hydrologic cycle. As planetary temperature increases, there will be more water vapor in the atmosphere. Colder temperatures do the opposite: the atmosphere holds less water vapor. Warmer temperatures in areas without rainfall will decrease soil moisture. As a result of this, two opposite phenomena will take place in different areas across the world: there will be increasing drought in dry areas and increasing flooding and run-off in wet areas. While during certain periods of time in Vermont, a "dry feedback" of lowered soil moisture and lowered air moisture can take place, more typically in Vermont we experience the opposite: a "wet feedback" of high soil moisture and saturation with high air moisture, leading to increasing precipitation and run-off, which in turn exacerbates flooding.

Q9. What is causing the changing weather in Vermont?

A9. Without doubt, excessive planetary greenhouse gasses caused by humans are continuing to warm our world and are affecting the Green Mountain State. Vermont's weather in its upper atmosphere is controlled by the high velocity winds aloft, which is what we typically refer to as the "jet stream." This jet stream runs across the northern and southern hemispheres. It drives the weather in our lower troposphere, which is the area just above the earth's surface—where we live. The jet stream normally has large swings in its path. These swings progress eastward with troughs and ridges. When the jet stream pushes the sine wave upward geographically—that is, when it pushes north—it is referred to as a ridge of high pressure. A dip southward is called a trough of low pressure. The waves that form ridges north and troughs south track across the hemispheres without fanfare, typically traveling west to east. This is more or less normal. However, when the jet stream ridges north in an extreme way, it becomes a blocking high pressure area, and when a trough dips extremely southward, the flow can cut off the movement of low pressure systems, stalling them. Low pressure systems are associated with clouds and precipitation, while high pressure systems are associated with fair and dry weather.

The works cited above and included in **Exhibit GMP-RH-2**, particularly the 2012 Francis & Vavrus paper, have shown a relationship between much stronger global heating in the Arctic, where the rate of warming is 2 to 3 times the rate further south in the mid-latitudes, and much bigger swinging north and south in the jet stream. (This is what they refer to as Arctic amplification, or AA, as described earlier.) The ocean warms, which causes the sea ice to melt, which creates warmer sea surface temperatures, which causes wider swings—or amplification—in the jet stream. These wider swings have caused the jet stream and subsequent storm track to occasionally slow down and even get stuck. When this takes place, the geographical area located under a trough or a ridge is essentially receiving too much of one thing—either fair, dry weather or too much precipitation, such as the Boston region in 2015. The extended fair, dry weather often leads to drought, as in parts of the western U.S. In areas that experience too much precipitation, storm systems form and can get stuck or can repeat, creating a series of synoptic storm systems over the same geographical area, with run-off and flooding. In Vermont, we have experienced an increase in extreme precipitation events, with heaviest rainfall generated by these large storm systems.

Another effect of these highly amplified jet stream scenarios is the more frequent generation of large air masses featuring extreme heat or extreme cold. Meteorologically speaking, when a significantly cold air mass is close to its warm opposite, strong systems of low barometric pressure—or storms—develop. The deeper the barometric pressure associated with these lows, the tighter the pressure gradient and the higher the wind velocity. These are the gusts which can take down tree limbs, trees, and power lines, and they have been more frequent in the last decade or two.

These high wind events are causing the tree damage and power outages, and combined with the heavier precipitation events, have been taking their toll on Vermont's utility infrastructure. These events and the damage they cause correspond with the higher amplitude of toughs and ridges in the jet stream I just explained. The more waviness or amplitude of the jet stream, the slower these large undulating waves (called "Rossby waves" in the literature I cite in **Exhibit GMP-RH-2**) move. The slowing down of these waves increases the likelihood of blocking, which causes weather patterns to get stuck, so to speak, meaning they do not change over long periods of time. Stuck jet stream patterns mean more persistent extreme weather conditions like cold spells, flooding, and prolonged snowfall.

Q10. What effects have these weather shifts had in Vermont?

A10. There have been several. First, the warmer temperatures over the past century have markedly changed the overall growing season, with the time between first frost in Fall and last frost in Spring decreasing. The data in the NOAA State Summaries indicates that Vermont's growing season has lengthened by four days in each of the last four decades—about half a month longer than it was in the mid-20th century. **Exhibit GMP-RH-1**. From a utility perspective, longer growing seasons mean more vegetation—i.e. more tree canopy growth.

Second, warmer air tends to support greater moisture, and we have indeed seen increased precipitation in Vermont, without extended drought. Vermonters nowadays often think of Tropical Storm Irene as the clearest example of extreme weather to hit the state in recent years. In 2011, Tropical Storm Irene hit the state with torrential rain, with areas experiencing 3 to 7 inches of rain in less than 18 hours. This caused the most damaging flooding in Vermont since 1927. Many rivers reached stages that were at their highest recorded level or second to only the 1927 Great Flood. The damage was estimated at $733 million across the state, with loss of life and livelihood resulting from the swift storm. **Exhibit GMP-RH-1** at 3.

There is evidence that a warming climate enhanced Tropical Storm Irene. Sea surface temperatures off the New England coast had warmed some 2 to 7 degrees Fahrenheit above average ahead of that storm. When tropical cyclones, which feed off latent heat of the ocean's surface, develop into mature Atlantic hurricanes, the hurricane's intensity may not lose as much energy while traveling north of the relatively warm waters of the Gulf Stream. Thus, stronger winds and lower pressure within the storm structure, and more moisture, contribute to a more devastating hurricane, such as Irene.

It cannot be fully connected yet, but research also shows an increase toward much heavier precipitation, slower forward-speed of the storm (meaning more hours of heavier rainfall) and thus more devastation—e.g. Hurricane Harvey and Hurricane Maria. In the years ahead, future tropical-related cyclones that come north up the eastern seaboard may have a longer track over relatively warm sea surfaces of the Atlantic Ocean that will keep those tropical cyclones more intense, with more devastation as they drive inland into Vermont.

Since Tropical Storm Irene, we have actually seen even more precipitation in some areas of the state, particularly in the recent October 2019 storm that caused flooding in areas north of those areas hardest hit by Tropical Storm Irene. In fact, the Missisquoi and Lamoille Rivers reached flood stages higher than they had during Tropical Storm Irene. This is linked to a slowing jet stream creating a slower, more powerful storm system with intense rainfall.

Third, again due to the increased temperatures, this increased precipitation has more often been in the form of rain, wetter snow, or ice, rather than the drier snow that can occur in colder conditions and was more common in prior decades. The 1998 ice storm comes to mind as an example of what can happen when warmer temperatures aloft cause winter precipitation to fall as rain and produce ice rather than snow. We had a much less impactful example of this during the recent January 2020 thaw.

Finally, the more active weather has brought with it increased winds as the barometric pressure changes between systems become more pronounced. When a well-developed trough of low pressure and a well-developed dome of high pressure forms, it produces a strong flow of air that interacts with Vermont terrain, causing these gradient winds to occur. These have been more frequent, causing more tree damage—and thus the increase in power outages related to high wind events. Using wind-related power outages as a proxy, gradient wind events have been notably increasing.

Of course, all of the above can interact together to increase damage: higher vegetation growth means taller trees; more precipitation means higher soil moisture (which weakens the ground's ability to hold roots); and higher winds mean more loading on tree branches and canopy—all of which combine to mean more downed trees.

Q11. Are these trends of overall warmer weather, more precipitation, and higher winds expected to continue?

A11. Unfortunately, yes, and they are expected to worsen over time, though not linearly. According to the NOAA State Summaries, "[a]verage annual precipitation is projected to increase in Vermont over the 21st century, particularly during winter and spring…. Corresponding increases in temperature will increase the proportion of precipitation falling as rain rather than snow. In addition, extreme precipitation is projected to increase, likely increasing the frequency and intensity of floods." **Exhibit GMP-RH-**1 at 4. Here is the corresponding graphic that follows this excerpt in the NOAA State Summaries exhibit:

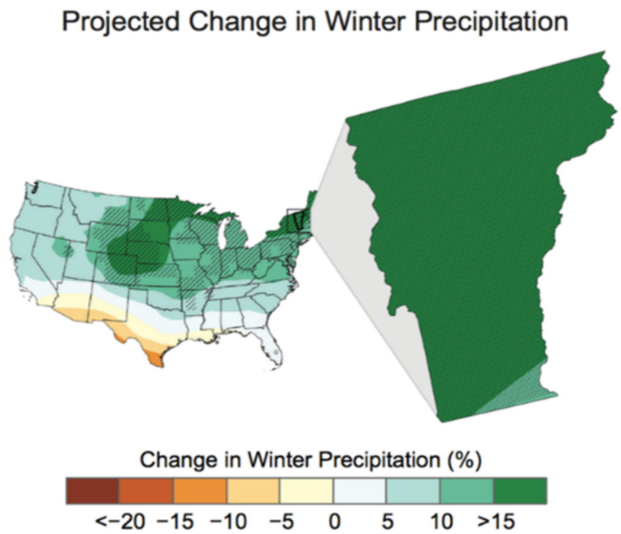

Figure 5: Projected change in winter precipitation (%) by the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Vermont is part of a large area of the Northeast that is expected to experience increases in winter precipitation. Source: CICS-NC and NOAA NCEI.

I also think it is important for us to consider newer research which I believe worsens the picture for Vermont as we look ahead to increased climate change risk. With Arctic sea ice loss, there is apparently a bit of a curve ball to our otherwise linear warming during late fall and winter, as new research has shown. Work done by Dr. Judah Cohen of Verisk Atmospheric and Environmental Research and MIT uncovered a relationship—a positive feedback loop effect, to be specific—between ice loss in the Arctic and cold and snowy conditions across the mid-latitudes and in Vermont. As sea ice loss will continue to expand in an increasingly warming world, typically during the months of August, September, and October, the open sea allows energy from latent heat at these high latitudes to develop blocking ridges of higher pressure. Recent scientific studies have established a vertical flux in the troposphere (where we live) into the stratosphere above us, causing sudden warming in the stratosphere which “disrupts” the stratospheric polar vortex. The weakening of the polar vortex in the stratosphere boomerangs, so to speak, vertically downward into the troposphere, disrupting the tropospheric polar vortex, meaning driving the cold air down onto us.[7] This mechanism is well-documented in the recent decade. *See also* Kug et al. (2015) in **Exhibit GMP-RH-2**. The mechanism allows severely cold Arctic air to spill southward into lower latitudes during winter resulting in a sudden increase in hazardous winter weather, often times not well modeled in the short, medium, and longer-range forecasts. This vertical energy affecting and disrupting the polar vortex is responsible for stronger storms in the mid-latitudes—roughly near 45 N latitude—including Vermont. The energy transfer process takes place over a couple of weeks to a month and can set the stage for "extreme winter weather" in the mid-latitudes. *See* Cohen et al. (2014) in **Exhibit GMP-RH-2.**

This research is new as the loss of the northern polar ice cap is also relatively new (roughly since about 1990); therefore, the research data sets are shorter and not yet part of the widely accepted consensus. Climatologists typically work in 30-year data set baselines; for the phenomenon I am discussing here, the markers of it have been the strongest since about 2005, and when the polar vortex has become disrupted this has indeed coincided with extreme weather conditions in Vermont. Extreme cold has been the result as recently as November 2019, and this polar vortex disruption also was

[7] For a visual of the disruption of the polar vortex by the phenomenon of Arctic amplification, and its effects on the mid-latitudes, see Verisk's Atmospheric and Environmental Research's video at https://www.youtube.com/watch?v=EMeI4N5dui4&feature=youtu.be.

responsible for our colder fall recently, and colder spring and extended winter of 2018 last year.

While the technical explanation of the vertical flux that causes this phenomenon can be esoteric, essentially it causes Arctic air to be displaced southward more frequently and for greater lengths of time into eastern North America and parts of Eurasia. While it seems contradictory, these colder winters are due to planetary warming because of manmade greenhouse gases warming the oceans, melting the sea ice, and then causing reconfigurations of the jet stream flow. This displaces Arctic air more frequently into Vermont. This is a relatively new discovery with much more research on the way.

There is also emerging concern in the meteorological community that this projection of colder and snowier weather in Vermont could escalate over the next several years with sea ice melt into something called "Blue Ocean Events." Blue Ocean Events are when large patches of sea ice disappear altogether due to warmer surface temperatures and warmer ocean. So, as we think of human-caused global warming, we should also understand that future conditions during portions of each winter may become extreme. Thus, with the advent of sea ice loss driving these patterns at the North Pole, we should expect highly variable, nonlinear winters, including more episodes of extreme cold, in Vermont's future.

Q12. Are there regions of Vermont that will be hit particularly hard by the heavier precipitation we expect to continue?

A12. Streams and rivers in our mountainous areas are likely to be most impacted. With more and more heavy precipitation, the interaction of weather with local terrain comes into play. Typically, air masses with water vapor interact with our north-south axis mountain ranges, releasing moisture as the air rises over the mountain. As the Green Mountains are our tallest range, they breed the wettest weather. A moist flow of air will push across valleys only to confront the local hills and mountains. The moisture is lifted with more condensation and precipitation falling across the mountains, most typically heaviest on the front side of prevailing flow. This mountain barrier lifting mechanism occurs in all seasons and its why there much more snow in the mountains than the valleys. This same mechanism will continue to operate as we experience increased precipitation. Geographically, many of our main roads and towns and cities are near or on flood plains, meant to take up extra water. Infrastructures will be most affected by flooding in these locations versus slightly elevated away from river and stream flows.

Of course, some of the worst flooding takes place in spring where a combined melting snow pack raises stream and river levels with an incoming stalled weather system providing excessive rainfall. The combined effects can create perilous flooding on our water ways. But intense rain events can cause flooding risk throughout the year—even in winter, as seen in some areas this month. The change in annual precipitation between 1941 and 2013 (from Burlington, Vermont climate data) shows that the trend of days with more than one inch of rainfall includes some variability but is clearly increasing over time. Run-off caused by more saturated ground was projected for the Mad River as an example, with 10 more days per year of high flow expected. **Exhibit GMP-RH-3** at 34–35. With Vermont's development pattern of towns in valleys along streams and rivers, our infrastructure continues to be at risk.

Q13. What can soil moisture tell us about predicting precipitation events and the damage they can cause?

A13. During excessive rainfall events, or rainfall over a larger time scale, ground saturation that is too high—too much moisture in the soil, in other words—plays a huge role in determining how much damage occurs. Even if the precipitating rainfall event is more moderate, saturated soil leads to flooding more quickly. If the rainfall is excessive, then rivers, streams, and lakes become even higher, the damage more abundant, and displacement and mitigation efforts necessary become more extreme. This may lead to a number of other negative impacts on agriculture, tourism, travel, and infrastructure maintenance. High soil-moisture also leads to uprooting of trees during wind gust events, since wet soil has a weaker hold on the roots than dry soil. Indeed, wet soil in effect lowers the wind velocity thresholds that uproot trees, causing yet more power outages.

Q14. Is there reason to believe Vermont might face other weather trends once limited to other areas further south and west on the continent?

A14. Yes, unfortunately. Springfield, Massachusetts saw a tornado signature weather pattern in early June 2011, which remained on the ground an estimated 33 miles. In general, due to warming we should expect that, at warmer and wetter times of the year, our weather increasingly looks more like what we have seen to our south and west. And, as described above, at other times of the year, our weather may look more like what we typically think of farther north, as colder air dips down. In general, what this leads to is more extreme weather in Vermont year-round, compared to what we considered normal in past decades.

I should mention that there is also reason to anticipate periods of drought, in addition to periods of increased precipitation. While this is not the immediately prevailing weather phenomenon we can expect, when it occurs, just like the higher precipitation, it may be more extreme and may cause significant forest fires. As documented across the globe, oscillations in precipitation will occasionally allow for droughts even here in the otherwise wetter temperate rain forest of Northeast U.S. and adjacent Canada. Just as blocking highs set up cold weather incoming from the Arctic in winter, large blocking high pressure systems work off the heat waves they produce, and can reinforce more heat and dry weather or a dry feedback loop. Northern boreal fires have been increasing during the summer months from Siberia to Alaska through Canada and even recently along the scant forests of Greenland, where excessively dry weather can produce those conditions that cause wildfires. However, due to bodies of water from the Great Lakes to the adjacent Atlantic Ocean, it is much more likely that the threat from wildfires would be rare over the next two to four decades, but at some time a tipping point might be passed that causes a drying out here much like what we expect will prevail for the interior sections of North America.

Q15. What are the documented correlations between power outages and weather?

A15. If you look at utility outage data, it pretty clearly shows that storms cause the damage that in turn causes power outages, by resulting chiefly in fallen trees and tree limbs, ice which coats powerlines, floods which undermine utility infrastructure, and high winds which directly damage poles and wires. We also know that there is a particular correlation between power outages and the temperature when precipitation falls. Wet snow and ice accretion during somewhat warmer winter events is a major culprit. When snow falls with temperatures close to the freezing mark (32 degrees Fahrenheit), it is a wetter snowfall. Wet snow sticks to twigs, branches, and power lines like velcro. These wet snows load up, developing extreme weight and causing tree limbs to sag or break, taking out lines and power poles. Snow level increases have been more conservative than precipitation rates, but we do know that mean winter temperatures are rising. A "powder storm" with no power outage is becoming rarer these days. In just the last five years there has been a notable uptick in heavy wet snowstorms associated with snow loading. Recent data show that these conditions have caused the most power outages—from wet snow even more than from wind, though the effects can combine as previously described. As our snowstorms become wetter, this has been and will continue to be hugely problematic for damage, safety, and outages. While at some point rising temperatures may mean more rain than snow, lessening these snow-loading effects, that will not be our situation for some time. As described earlier, with the advent of Arctic air displacement into eastern North America, there's a new signal for highly variable and potentially colder snowy winters which may lead to more of these events.

II. <u>Assessment of Impacts from Extreme Weather in Years Ahead</u>

Q16. As you look at the weather data and the research regarding climate change, how do you assess the impacts Vermont will experience from extreme weather in the years ahead?

A16. The heavier precipitation in more frequent events, plus increased wind and the increased threat of heavier snow and/or ice in the winter, all mean greater risk of infrastructure damage generally, including the utility system. The trends for infrastructure damage will be increasing over time nonlinearly. Because the science is still young, exact predictions are tricky, but I don't think we can ignore that the weather enemy to infrastructure is very likely to be heavier precipitation events in both warm and cold season, and more frequent high wind events as seen in the climatological trend.

Q17. You have several years of experience working with the state's utilities to forecast and assess weather. What have you observed about the effects of weather on utility infrastructure over your career?

A17. As a Weather Hazards Forecaster, it is my duty to forecast with some lead time conditions that will damage utility infrastructure, so that utilities can plan response. We have a saying in the weather business: *the trend is your friend*. Though in this case the trends are not positive—climatology data and utility outage data already show the effects of more extreme weather. In the years ahead, the effects from a warming world and the related unforeseen "curve balls" that affect utility infrastructure will only increase, notably not every year but nevertheless it will become harder in the future to keep the power on, with increased frequency of damaging storms.

On a personal note, my job to forecast these challenging storms has become harder over time as weather parameters that cause power outages have red flagged more frequently, with many of the incoming storm situations "on the fence" causing more intensive work to determine whether utility infrastructure is likely to be affected. This Increased difficulty of weather hazards forecasting with day-to-day meteorological analysis and prediction systems have been notable, and I have experienced increased stress levels and have seen the effects of more frequent and less predictable storms on my colleagues too.

Increased extreme weather events due to a changing climate and its effects on our infrastructure and daily lives is already harming us, and that will only continue. We have already started paying for it here in Vermont, and we cannot act as if we can continue business as usual, magically, without ramifications. The planet's atmospheric system is reacting and will continue to react in ways very costly to our infrastructure, not to mention our wellbeing and health. Even though we have seen this coming for at least a couple decades now, we still do not have the policy changes in place necessary to mitigate our fossil fuel emissions. It is as if, as a planet, we are driving with our eyes closed and the pedal floored. While I highlight in this testimony the weather affecting specifically utilities in Vermont through the damage to our infrastructure and other key systems, I cannot conclude this testimony without making clear that climate change will also affect our health and welfare, our food supply, our water (including through significant loss of clean fresh water through glacier melt), our natural environment worldwide, including extinction of animals and loss of biodiversity on land and in the oceans, and our geopolitical stability. It is, in my view, a global emergency and we are way behind in addressing it.

Q18. Does this conclude your testimony at this time?

A18. Yes, it does.