VERMONT CLIMATE ASSESSMENT

A report by

The Gund Institute for Ecological Economics and

The University of Vermont

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Executive Summary

The Vermont Climate Assessment (*VCA*) paints a vivid picture of a changing climate in Vermont and calls for immediate strategic planning to sustain the social, economic and environmental fabric of our state. The VCA is the first state-scale climate assessment in the country and speaks directly to the impacts of climate change as they pertain to our rural towns, cities and communities, including impacts on Vermont tourism and recreation, agriculture, natural resources and energy.

A Call for Action in Vermont

Climate change is no longer a thing of the future; it is affecting Vermont today. Extreme weather events, such as heavy downpours, have become more frequent and/or intense. Across the state, there have already been significant changes in the length of the frost-free growing season and in the warmth of nighttime temperatures. These, and other changes, are part of the pattern of global climate change, primarily driven by human activity. Vermont is a small contributor to global climate change yet must face the local consequences of climate change by building local capacity and resilience.

Many of the impacts associated with climate change affect livelihoods and ecosystems in Vermont. These impacts are the subject of this report and are significant for all communities, especially those with economic or infrastructure challenges, and for species and habitats facing other external pressures. Some impacts of climate change in Vermont are positive, but the negative impacts remain of serious concern for their economic, social and environmental consequences. Of particular significance are adverse effects to agricultural production, including dairy, fruit and maple syrup, more frequent flooding and heavy downpours, and negative influences on winter recreation industries due to reductions in snow cover. To date, Vermont has begun to pursue public policy that builds resilience within its 256 towns—the success of which is dependent upon sustained action as the memory of Tropical Storm Irene (2011), which caused serious damage in the state, begins to fade. The VCA presents information to aid in preparation for these changes in Vermont's climate (Box 1), highlighting opportunities that provide economic benefits and minimize costs over time, while noting the potential outcomes of inaction.

The VCA addresses three main goals:

1) further scientific understanding of global change trends using local, historical data;

2) develop a deeper understanding of future impacts of climate change, and

3) communicate the current state of knowledge on global change impacts in Vermont, focusing on agricultural production, forests, water resources and recreation industries.

Additionally, the VCA serves to cultivate partnerships with stakeholders while investigating priority topics for research by performing a needs assessment to understand what information is most needed for adaptation and mitigation strategies to deliver Vermont towards a more resilient future.

Box 1. Climate vs. Weather

Weather expresses the day-to-day atmospheric conditions, i.e., "What is the weather like at a specific place and point in time?" For example, weather describes short-term time frames such as rain, snow, sunshine, blizzards, flooding, ice storms, and so on.

Climate expresses patterns of weather over a longer time horizon, i.e., "What are the atmospheric conditions over a period of months, years or decades?" For example, climate describes the average long-term conditions of snowfall, rainfall, temperature, cloud cover, and so on.

"Climate is what you expect, weather is what you get."

Methods: Making the Vermont Climate Assessment

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The VCA is divided into chapters based on the sectors most important to Vermont in the face of global climate change. Each chapter concludes with confidence ratings around the impacts of climate change in Vermont for their respective key messages. "Very high" confidence rankings have strong evidence (established theory, multiple sources, consistent results, well-document methods, etc.) and high consensus. "High" confidence findings have moderate evidence (several sources, some consistency, methods vary and/or documentation is limited, etc.) and medium consensus. "Medium" confidence findings have suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.) and competing schools of thought. "Low" confidence findings have inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods that are not tested) and a disagreement or lack of opinions among experts.

The majority of findings in the VCA have a very high to high confidence level. The confidence ranking tables for each chapter's key messages provides 1) documentation of the process the authors used to come to the conclusions in their key messages; 2) additional information to reviewers about the quality of the information used; and 3) allows traceability to data and resources.). Direct references to the data and literature source of the findings can be found in these tables as well as throughout the text. Historical climate data was supplied by NOAA/National Weather Service with assistance from the Burlington office and Andy Nash, Meterologist-in-Charge (NOAA/NWS). Projections of future climate change are supplied by the Intergovernmental Panel on Climate Change and refer to model ensembles from the Couple Model Intercomparison Project Phase 5 (CMIP5) and represent low to high global emission scenarios and representative concentration pathways.[1]

National Coordination on Climate Change

The VCA is partnered with the National Climate Assessment (NCA) to engage producers and users of assessment information across the United States. The VCA is the first state-level climate assessment modeled after the NCA. The NCA is mandated by the US Global Change Research Act of 1990 and now serves as a broad communication tool on climate change and its impacts around the United States. The third National Climate Assessment (NCA) was officially released on May 6, 2014.[2] The VCA mirrors the NCA structure but is tailored toward the sectors most applicable to Vermont environmentally, socially and economically.

While the NCA contains a wealth of information, it provides only high-level summaries. The Northeast regional report does not address the breadth and depth of impacts on economic, social and environmental impacts specific to Vermont. To date, Vermont has had no comprehensive assessment of economic impacts of historical climate variability or analysis of regions or sectors that may be challenged under future climate change scenarios. In fact, no single state in the US has completed a state-level climate assessment providing data similar to the NCA until the VCA.

Climate Change in Vermont: Historical Trends

Rising Temperatures: The evidence of changing climate is clear for Vermont. The state's average temperature has increased by 1.3°F since 1960; 45% of this increase has occurred since 1990. The most recent decade was Vermont's hottest on record. All regions within Vermont are

[1] Christensen et al. (2013). Climate Phenomena and their Relevance for Future Regional Climate Change. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker et al., Eds. Cambridge and New York, Cambridge University Press.

[2] US Global Change Research Program (2014). US National Climate Assessment: Climate Change Impacts in the United States. Washington, DC, US GCRP**:** 841.

experiencing warming, although the changes in temperature are not uniform. Vermont is likely to see larger temperature increases in winter than in summer.

Increasing Precipitation: In general, precipitation has and will continue to increase, particularly in winter months. Through observations taken since the 1940's, we see that rainfall has increased across Vermont with the greatest increases occurring in the mountainous regions. Average annual precipitation across the state has increased by 5.9 inches since 1960; 48% of this increase has occurred since 1990. Rainfall records show that heavy rainfall events are becoming more common and pose threats of flooding. In August 2011, heavy rainfall saturated the ground and, as a result, flooding was widespread when additional rains fell with the arrival of Tropical Storm Irene.

Freeze-Thaw Cycles: Warmer seasonal temperatures are resulting in later "first-fall freeze" and earlier "last-spring freeze". The result is a change in growing season days, with freeze period decreasing by 3.9 days per decade and growing seasons increasing by 3.7 days per decade over the past forty years. This also affects the freeze up and thaw out dates of small lakes and ponds.

Flooding: Impacts of flooding on water quality continues to be a concern in agricultural areas where the historical legacy of fertilizer use decades ago is resulting in high levels of nutrient run-off into rivers and lakes. Large pulses of nutrients are stripped from soils and transported through waterways during large precipitation events. Records across Vermont show that flashy flows are increasingly common in our rivers. These large pulses of water in small river valleys may threaten development located in floodplains. Particularly vulnerable to the effects of floods are mobile home parks, and their low-income residents. These parks are often located in floodplains and can be catastrophically destroyed by just one to two feet of flood water.

Box 2. Projected vs. Predicted

Projected vs. Predicted: We use the term 'projected' rather than 'predicted', as predict implies a certainty that we do not have for future climate conditions. Projections for future conditions carry levels of uncertainty. Located at the end of each chapter are confidence tables that express the likelihood of our key findings on a scale from low to very high.

Forecasts are based on assumptions that reflect the conditions that are expected to exist. For example, a weather forecast is produced by applying existing knowledge to *project* the state of the atmosphere for a given location.

Climate Change in Vermont: Projected Trends

Warming Temperatures: Temperatures will continue to rise, with the next few decades projected (Box 2) to see another 3° F by 2050 and 5° F (1.7° and 2.8° C, respectively) of warming by late century in most areas at the low emissions scenario. According to the IPCC, the amount of warming by the end of this century is projected to be roughly 2° F to 5.2° F (1.1° C to 2.9° C) under a lower emissions scenario involving substantial reductions in emissions after 2050 ("B1 scenario") or 3.6° F to 9.7° F (2.0° to 5.4° C) for a higher emissions scenario assuming continued increases in emissions ("A2 scenario") (Christensen et al. 2013). Across the state, historical weather data show that temperatures have been warming twice as fast in winter than in summer. As a result of warmer winters, the time that Vermont's rivers and lakes are frozen each winter is decreasing by 7 days per decade. Spring has started 2 to 3 days earlier per decade which has increased the growing season by 3.7 days per decade. Due to warmer temperatures and longer growing seasons, Vermont has already transitioned from hardiness zone 4 to zone 5 from 1990 to 2006.

Increasing Precipitation: Precipitation will continue to increase over the next century in Vermont, with the largest increases occurring in mountainous regions. In the near-term of the next 25 years, much of this precipitation will fall as snow. As temperatures continue to increase, winter precipitation will shift to rainfall in the next 50 years and beyond.

Weather Extremes: The chances of record-breaking high temperature extremes will continue to increase as the climate continues to change. High nighttime temperatures are increasingly common and have widespread impacts on humans, recreation and energy demand. In winter months, warmer nighttime temperatures threaten snow and ice cover for winter recreation. In summer months, this causes increased demand for cooling. An increase in high-energy electric (lighting) storms is projected to continue particularly threatening infrastructure and transportation systems.

The Jet Stream: Vermont's location allows the jet stream, which varies season by season, to deliver much of its short-term weather systems. Recent "blocking" or quasi-stationary patterns in the jet stream have led to prolonged periods of intense rainfall (e.g., June 2013) or dry spells (e.g., August 2012). Scientists believe reductions in ice cover in the Arctic have changed global temperature gradients, which increases the likelihood of blocking patterns and unseasonably high or low temperatures and/or precipitation.

Economic Impacts of Climate Change in Vermont

Policy: Vermont can play a role in demonstrating systemic change for decreasing greenhouse gas emissions. The Vermont State Government has been taking action towards emissions reduction programs since the beginning of the century. A constituent base that values climate change action across the state generally supports current legislation to advance the state goals of a 50% reduction in greenhouse gas emissions by 2028 and 90% of energy obtained from renewable sources by 2050.

Community Development: As average annual rainfall has increased in recent decades, average annual flows in Vermont rivers have increased. Rural and urban communities around Vermont are at risk from these impacts. Many communities have already been highly impacted and are engaged in processes to respond to climate change related transitions through formal planning. Community infrastructure systems are highly vulnerable to climate change. This vulnerability is exacerbated by the state's mountainous, rural geography and small rural communities with limitations existing in transportation routes and communication systems.

Energy: The temperature rise in summer and the increased use of air conditioning will outweigh the reduction in energy demand for heating in the winter. Increased risk of major storm events in Vermont will threaten energy infrastructure. In June and July of 2013 alone, 70,000 separate energy outages occurred in Vermont. In Vermont, forecasts to 2030 anticipate peak energy load increasing 0.7% annually due to increased demand for air conditioning. Adaptation through the use of renewable, local energy sources will be critically important as extreme weather events increase and threaten fossil fuel-based energy supplies. Energy efficiency and conservation are key components of Vermont's goal of obtaining 90% renewable energy sources by 2050. Energy policy attempts to leverage behavior change to accomplish energy efficiency goals.

Water resources: Warmer temperatures are leading to earlier thaw dates on Vermont's rivers, lakes and ponds and snowpack in the mountains. Average annual stream flows are shifting and, overall, are expected to continue increasing in coming decades. High flows are already occurring more frequently. Under assumptions of high green-house-gas emissions scenarios, up to an 80% increase in the probability of high stream flows is projected by end of the century. Climate models project more frequent high flow events (and flooding), particularly in the winter months as a greater fraction of winter precipitation will fall as rain or freezing rain rather than snow. While Vermont rivers have sustained higher levels of base flow over recent decades in summer months in contrast to other New England states, climate projections show increased potential for short-term dry spells. Too much and too little water pose threats to agriculture, forests, infrastructure, health, and homes.

Forests: Increased temperatures will lengthen growing seasons and increase suitable range for certain Vermont tree species like oak, hickory, and red maple, but decrease suitable range for cold-tolerant species like spruce and fir. Changes in precipitation cycles (wetter winters and extended dry spells in summers) will place more stress on important tree species such as sugar maple and red spruce, which have already experienced periods of decline in Vermont. Certain models project that by the end of the century, the northeast could be dominated by an oak-hickory forest, with spruce-fir forests being virtually non-existent and maple-beech-birch forests being driven north to Maine. Warmer temperatures will result in earlier bud burst and flowering periods for certain species, making them more susceptible to pests and pathogens. Warming temperatures may threaten plant and animal species in our forests by changing growing conditions that are unfavorable or that encourage invasive species. Forests currently offset almost all of Vermont's greenhouse gas emissions so their shifts or losses will feedback to climate change as well as having economic impacts on recreation and tourism, forestry, and maple industries.

Agriculture: Increasingly variable levels of summer precipitation and/or extreme temperatures may heighten challenges in the agricultural sector. Warmer seasonal temperatures will result in later "first-fall freeze" and earlier "last-spring freeze". This extended growing season can increase overall crop productivity and create new crop opportunities. The potential negative effects include increased stress from weed growth, disease outbreaks and pest infestations. Higher CO_2 in the atmosphere promotes photosynthesis and can potentially fuel the growth of many Vermont plant varietals. For Vermont livestock operations, summer heat stress could lead to slight decreases in livestock productivity. More pronounced climate change impacts come from pasture productivity and other production inputs such as feed costs and energy costs. Variations in seasonal precipitation combined with the increased frequency of high-energy storms could lead to extreme year-to-year weather variations with implications on farm business viability.

Recreation and Tourism: In the short term, increasing precipitation will increase snowfall and preserve Vermont's winter recreation industry. In the long term, as snow cover recedes, there are opportunities for increasing summer tourism earnings that could compensate for winter losses as snowfall turns to rain later this century. Within 30-40 years, average winter temperatures are expected to increase to the point that most winter precipitation will fall as rain, which will result in shorter-lasting snowpack and snowfall, reducing the winter tourism and recreation seasons. However, over the next 25 years, snowfall in mountainous areas may increase with increasing winter precipitation (a climate change "sweet spot"), which would have a positive impact on winter-related recreation and tourism industries. The summer tourism and recreation seasons will lengthen, and increased temperatures combined with higher humidity further south are expected to drive more tourists to Vermont. Increased temperatures will encourage expansion of pest species, reducing the quality of the recreation experience and requiring increased monitoring and treatment. Fall recreational opportunities and tourism will lengthen with the warmer temperatures, creating expanded economic opportunities.

Public Health: Climate change may intensify existing health threats, and new health threats will emerge. Potential public health threats include: heat-related illnesses, intensified air pollution, injury associated with flooding events, increase in freshwater-borne disease, and viral diseases carried by ticks and mosquitoes. The elderly, children, the poor, and the sick may be more vulnerable to the range of climate change-related health impacts. Pollen counts are increasing with increased temperatures and precipitation, which will increase the burden of allergens and asthma. Due to flood risk, residents living in floodplains and narrow mountain valleys have increased risk and vulnerability. Just as some choices can make us more vulnerable, other choices can make us more resilient. Maintaining a robust public health infrastructure will be critical to managing the potential health impacts of climate change.

Transportation and Housing: Climate change and other human modifications of ecosystems and landscapes often increase vulnerability to damage from extreme events and reduce natural capacity to modulate the impacts of such events. Floodplain wetlands in Vermont absorb floodwaters and reduce the effects of high flows on river-margin lands. Maintaining intact floodplains will mitigate the chance of disastrous flooding in our communities. High- energy storms can bring tornados or cause large windthrows that damage our transportation infrastructure.

Education: The use of education and outreach is needed to help Vermonters avoid negative and costly climate change impacts through changes in our behavior (e.g., energy usage, infrastructure investments, consumer behavior, etc.). Over the past 15 years the Vermont State Government, and in particular the current Governor's Office, has taken a lead role in promoting education and outreach with respect to climate change. Vermont's institutions of higher education are also very active in conducting research and disseminating knowledge to both the scientific community and the public at large. The study of climate change is only partially, but increasingly, incorporated into K-12 education. Student knowledge of earth science lags behind that of biological and physical science. Combining climate change educational activities with appeals to Vermonters' values, changes in material incentives through policy reforms, and strengthened social norms could induce more pro-environmental behavior and improve economic outcomes in light of climate change.

Cross-Cutting Themes

Turning Vulnerability to Resiliency: Taking action through Adaptation and Mitigation

This report defines ***resiliency*** as the capability of social and or natural systems to respond to and recover from climate change events (Box 3).

Adaptation is the process of adjustments that social ecological systems make in response to changing situations to reduce vulnerability from climate change impacts.

Meanwhile, ***mitigation*** refers to a proactive process that moderates climate change disruption through reducing our overall contribution to emissions.

These terms and their definitions appear in every chapter. The key messages in all chapters are chiefly summarizations of the vulnerability of a given sector, agriculture, for instance, to projected climate impacts. Adaptation is often assessed and summarized as well. For example, in the case of the agriculture sector, there are serious vulnerabilities regarding changing growing seasons, but altering specific farm practices or timing of certain operations are adaptation strategies to address this vulnerability. These actions contribute to the resiliency of a farm.

Adaptation presents new opportunities by taking advantage of specific changes in climate, such as growing new crop varieties due to a longer growing season. Mitigation and adaptation are linked, in that effective mitigation reduces the need for adaptation. Vermont has embraced "resilience" as a way to incorporate adaptation and mitigation in policy, lifestyles, and more. This is an empowering stance on climate change and is an essential part of a comprehensive response strategy.

Box 3. Action in Vermont

Adaptation: In Vermont, adaptation activities include town-level planning for flood resilience.
Mitigation: Investments in the state's renewable energy portfolio mitigate our emissions that contribute to the acceleration of climate change impacts.
Resilience: Examples of resilience include designing new bridges to allow for meandering of rivers, such that during flood stage the rivers can jump their bank without damage to transportation infrastructure.

Weather and Climate Extremes

"Extremes" refers to weather and climate events like hot spells, heavy rains, periods of drought and flooding, and severe storms (Box 4). Impacts expected to have the greatest consequences will be characterized by changes in the frequency, intensity, timing, duration, and spatial extent of extremes particularly arriving as unprecedented events. Most of the scientific literature on extremes uses definitions that fall roughly into two categories (IPCC 2012): those related to the probability of occurrence of a certain type of event, and those related to exceeding a particular threshold.

Box 4. Classifying an Extreme

Extremes might be determined by the number, percentage, or fraction of days in a month, season, or year with maximum (or minimum) temperature above the 90th, 95th, or 99th percentile compared to a reference time period, such as the last four decades. Alternatively, how often a threshold temperature, for example 32°F or 90°F, is exceeded during a given decade. Extremes are also measured based on the average frequency of a given event that exceeds a specific magnitude. Extremes is a broad term and refers to a variety of events that vary in timescale.

Future Steps

As climate change and its impacts are becoming more prevalent, Vermonters face choices.

As a result of past emissions of heat-trapping gases, additional climate change with its related impacts is now unavoidable. This is due to the long-lived nature of many of these gases, the amount of heat absorbed and retained by the oceans, and other responses within the climate system. However, beyond the next few decades, the amount of climate change will still largely be determined by choices society makes about emissions. While Vermont does not have a remotely significant effect on global greenhouse emissions, it is in a position to demonstrate the effectiveness of various systemic changes in reducing overall greenhouse gas emissions. Vermont's progressive climate policies, particularly regarding energy and transportation, are largely discussed in the climate policy chapter, the energy chapter, and the brief transportation chapter. Both top-down policies and bottom-up management and decision making will ensure our communities thrive as our climate changes.

A system that is truly resilient to climate change will be one that embraces and adopts both mitigation and adaptation strategies—this is the future of Vermont.