



Dr. Gillian L. Galford  
Research Assistant Professor

617 MAIN STREET, BURLINGTON, VT 05405 USA  
PHONE (802) 656-2906 | FAX (802) 656-2995  
GUNDIEE@UVM.EDU | WWW.UVM.EDU/GIEE

25 March 2015

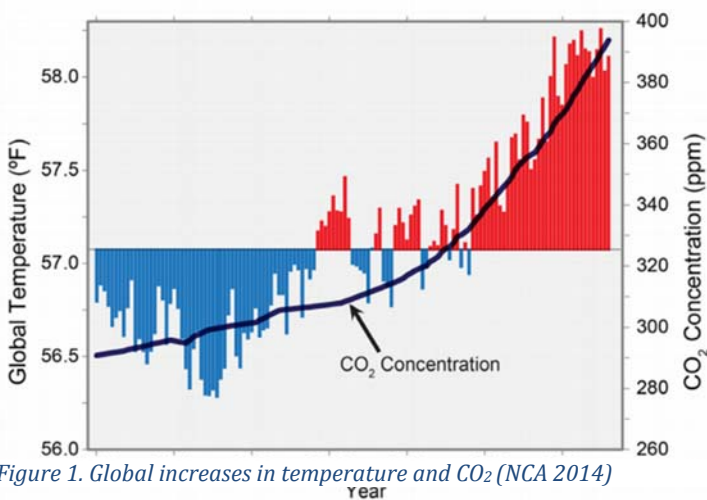
Vermont Senate Committee on Natural Resources & Energy  
115 State Street  
Montpelier, VT 05633

Dear Senators:

Thank you for having me here today to discuss the state of the science concerning climate change. I have spent the last 15 years studying, researching and experiencing the science of climate change around the world. Today I will focus on three key topics:

- 1) Disruption of climate patterns around the world,
- 2) Root causes of these disruptions, and
- 3) Actions needed to ensure a thriving Vermont

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. Since the 1960s, our global climate has been warming [Figure 1].<sup>1</sup> As the earth’s surface



temperature increases, more water enters the atmosphere as vapor. Water vapor traps more heat, creating an additional increase in air temperatures, and is a secondary source of warming. This additional water vapor means there is increased precipitation in some areas and decreased precipitation in other areas that are sources for the

<sup>1</sup> IPCC (2014) and NCA (2014). IPCC is a scientific body under the auspices of the United Nations. Thousands of sciences contribute to this global analysis of climate change and its impacts. The full report can be found online at: <http://www.ipcc.ch/>  
The National Climate Assessment is conducted by the US Global Change Research Program, a partnership of 13 federal departments and agencies. The full report can be found online at <http://nca2014.globalchange.gov/>



The University of Vermont

water vapor. Across the world we see a trend in increasing temperatures and changes in precipitation.

The initial cause of the warming, prior to the increase in water vapor, is the rise of heat trapping particles in the atmosphere. Also known as greenhouse gases, these particles absorb heat and cause temperatures in the atmosphere to increase. There are three main particles of concern: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) [Figure 2]. Today carbon dioxide in the earth's atmosphere has a concentration of 400 ppm, up from 275 ppm in 1700<sup>2</sup>. Global atmospheric temperatures have increased as carbon dioxide concentrations have increased. [Figure 1].

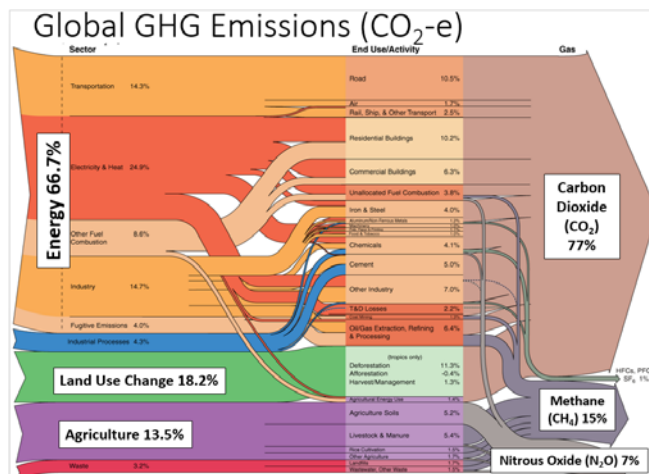


Figure 2. Human sources of greenhouse gases to the atmosphere (WRI, modified by G. Galford)

The increase in carbon dioxide comes from sources such as transportation, electricity, heat, and industry and land use change (deforestation) [Figure 2]. The combustion of fossil fuels for energy in transportation, electricity, heat, industrial processes, cement production, oil refining and more accounts for 77% of the added greenhouse gas emissions caused by humans<sup>3</sup>. The fossil fuel sources contribute 100-times as much CO<sub>2</sub> as natural point sources such as volcanic eruptions<sup>4</sup>.

Advanced chemistry methods can “fingerprint” the sources of the increasing carbon dioxide in the earth's atmosphere. Radioisotopes of carbon were initially identified by Dr. Hans Suess in 1955 as a method to trace the source of carbon dioxide. The atmospheric concentration of CO<sub>2</sub> was once rich in <sup>14</sup>CO<sub>2</sub> (carbon dioxide with the carbon-14 isotope, <sup>14</sup>C) and has been diluted with CO<sub>2</sub> that does not contain <sup>14</sup>CO<sub>2</sub>. The only source of CO<sub>2</sub> that is not rich in <sup>14</sup>C is fossil fuels so this is “proof positive” that the source of increasing CO<sub>2</sub> in the earth's atmosphere is from fossil fuel combustion.<sup>5</sup>

There is no debate among the scientific community that a) our global climate is changing and b) that the causes are from human activities. A peer-reviewed article in a leading scientific journal,

<sup>2</sup> Scripps Institution of Oceanography (2015). The Keeling Curve: Carbon dioxide concentration at Mauna Loa Observatory. <https://scripps.ucsd.edu/programs/keelingcurve/> accessed online March 25, 2015.

<sup>3</sup> Baumert, KA, T Herzog, J Pershing (2005). Navigating the Numbers: Greenhouse Gas Data and International Climate Policy. World Resources Institute, Washington, DC. 122p.

<sup>4</sup> Gerlach, TM (2011). Volcanic versus anthropogenic carbon dioxide. EOS, Transactions American Geophysical Union, vol. 92, issue 24, pp. 201-202. DOI: 10.1029/2011EO24001

<sup>5</sup> Tans, PP, AFM de Jong, MG Mook (1979). Natural atmospheric <sup>14</sup>C variation and the Suess effect. Nature, vol. 280, 826 – 828. doi:10.1038/280826a0



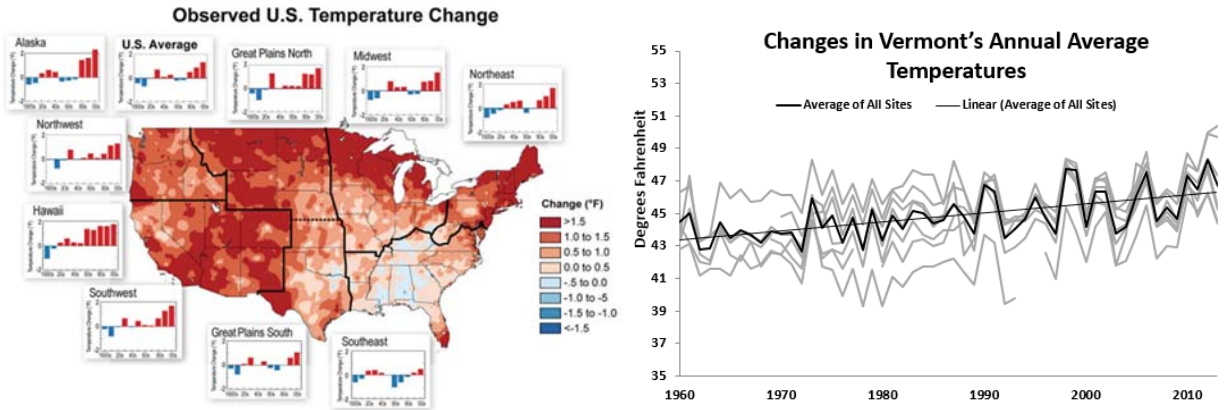


Figure 3. Changes in temperature for the US (left, NCA 2014) and for Vermont (right). Vermont data includes NOAA/NWS stations in lowland areas (VCA 2014)

*Environmental Research Letters*, found 97% agreement that climate change is happening and is due to human actions by examining all peer-reviewed journal articles on the topic published from 1991-2011 (n=11,944)<sup>6</sup>. Scientific bodies such as the Intergovernmental Panel on Climate Change (IPCC)<sup>7</sup> and the United States' National Climate Assessment (NCA)<sup>8</sup> found that climate change is real and the effects are already being felt. On a local level, climate change has real impacts. For example, Commissioner Kristin Jacobs of Broward County, FL has testified that sea level rise and flooding have already begun to affect her constituents, requiring expensive changes to storm water infrastructure<sup>9</sup>.

Changes to climate are a tangible reality. **Vermont's climate has already begun to change**<sup>10</sup>:

- **Rising Temperatures [Figure 3]:** The evidence of changing climate is clear for Vermont. Since 1960, average temperature has increased 1.6° F, and since 1990, average temperatures increased 0.9° F. The last decade was the warmest on record, with average temperatures increasing by 0.4° F. All regions within Vermont are experiencing warming, although the changes in temperature are not uniform. Vermont is likely to see greater temperature increases in winter than in summer and in nighttime than in daytime.<sup>11</sup>

<sup>6</sup> Cook, J. et al. (2013). Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environmental Research Letters*, vol. 8, no. 2. [doi:10.1088/1748-9326/8/2/024024](https://doi.org/10.1088/1748-9326/8/2/024024)

<sup>7</sup> IPCC (2014)

<sup>8</sup> National Climate Assessment (2014)

<sup>9</sup> Jacobs, Kristin. Written Testimony of Kristin Jacobs, Commissioner, Broward County, FL to the US Senate Environment and Public Works Clean Air and Nuclear Safety Subcommittee. July 29, 2014. [http://www.epw.senate.gov/public/index.cfm?FuseAction=Files.View&FileStore\\_id=d54a8c4f-81b4-45d9-87e1-b5513196cd26](http://www.epw.senate.gov/public/index.cfm?FuseAction=Files.View&FileStore_id=d54a8c4f-81b4-45d9-87e1-b5513196cd26) accessed online March 25, 2015

<sup>10</sup> Vermont Climate Assessment (2014). [www.VTclimate.org](http://www.VTclimate.org) accessed online March 25, 2015. All data provided by NOAA/NWS, Burlington, VT.

<sup>11</sup> Ibid, Chapter 1.



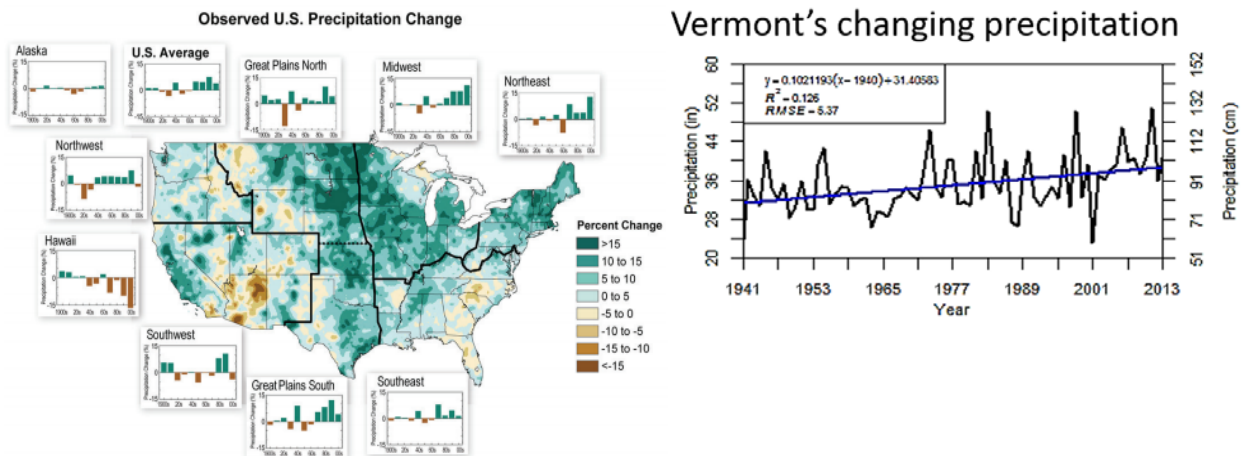
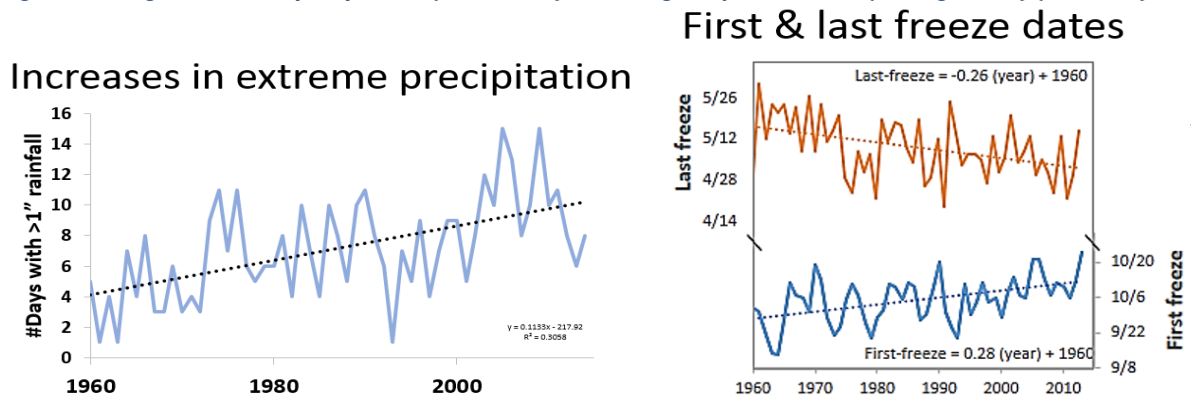


Figure 4. Changes in precipitation for the US (left, NCA 2014) and for Vermont (Burlington NWS station, VCA 2014)

- **Increasing Precipitation [Figures 4, 5]:** Precipitation has and will continue to increase, particularly in winter months. Through observations taken since the 1940's, 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 [Figure 4]; 48% of this increase has occurred since 1990. Rainfall records show that heavy rainfall events are becoming more common and pose threats of flooding [Figure 5]. 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 [Figure 5]:** 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

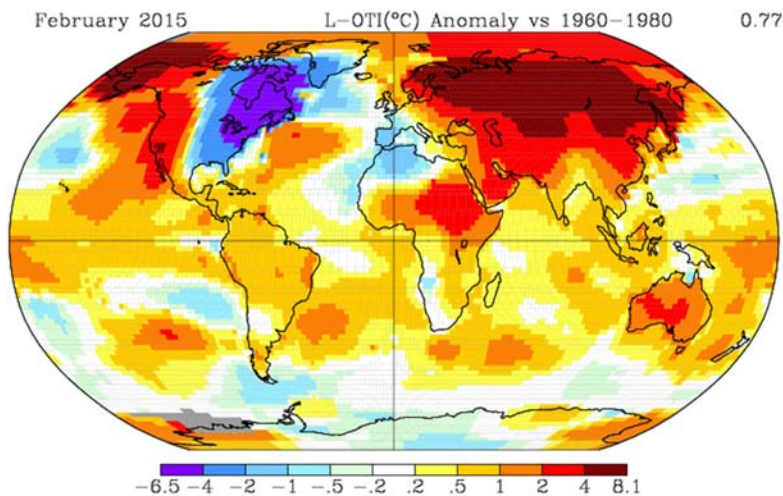
Figure 5. Changes in extreme precipitation (Rutland, VT) and changes in frozen season (Burlington, VT) (VCA 2014)



and thaw out dates of small lakes and ponds. While this presents new opportunities it also poses risks and expenses to farmers to deal with more unstable conditions.<sup>12</sup>

- **Flooding:** 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 residents. These parks are often located in floodplains and can be catastrophically destroyed by just one to two feet of flood water.<sup>13</sup>
- **The Jet Stream:** Vermont's location allows the North American jet stream to deliver much of its short-term weather systems. In the winter it brings much cold weather and in the summer it brings warm, moist weather. 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.<sup>14</sup> Note that winter 2014-2015 was abnormally cold compared to the proceeding decade but it would have been average thirty years ago. Although Vermont was locked in cold Arctic air for most of the winter, the global average of this winter was much above average [Figure 6].<sup>15</sup>

Figure 6. Global temperatures in February 2015 were well above average, although colder than average in the Northeast



Meteorological stations run by NOAA/NWS are not the only records of climate. Ray Allan of South Hero has recorded daily weather for the past 45 years. Spring is coming 5-6 day earlier than when he took over the farm in 1968 [Figure 7]. The early blooming of his trees requires additionally management to avoid fungal infections from the warm wet conditions.

<sup>12</sup> VCA (2014). Chapter 1.

<sup>13</sup> VCA (2014). Water Resources, pp. 94-131.

<sup>14</sup> VCA (2014). Chapter 1.

<sup>15</sup> NASA Goddard Institute for Space Studies. Surface Temperature Analysis. February 2015 anomaly from 1960-1980 reference period in degrees Celsius. [http://data.giss.nasa.gov/cgi-bin/gistemp/nmaps.cgi?sat=4&sst=3&type=anoms&mean\\_gen=02&year1=2015&year2=2015&base1=1960&base2=1980&radius=1200&pol=rob](http://data.giss.nasa.gov/cgi-bin/gistemp/nmaps.cgi?sat=4&sst=3&type=anoms&mean_gen=02&year1=2015&year2=2015&base1=1960&base2=1980&radius=1200&pol=rob) accessed online March 25, 2015.





Joe's Pond Association's Annual Ice Out contest has recorded the date of ice out with incredible precision since the 1988. In West Danville, winter average temperatures have increased. Ice out comes seven days earlier than in the late 1980s [Figure 8].

The data is clear that climate is changing—globally, nationally and here in Vermont—and that is it caused by human activities. Scientists clearly have consensus. Today you will hear testimony on the implications for security, morality of action, and accountability. Please note that there is incredible expertise within our state academics, engineers and others in evaluating and designing mitigation measures. This is a point of hope for slowing and eventually reversing climate change.

I will leave you with a quote from the Global Commission on the Economy and Climate— as an independent initiative to report to the international community,

*“Low-carbon and climate resilient growth is possible. The capital for necessary investments is available, and the potential for innovation is vast. [...] the world can reduce the risks of climate change and achieve high-quality, resilience, and inclusive economic growth.”<sup>16</sup>*

Thank you again for the opportunity to speak to you today.

Figure 7. Changes in spring as observed by the blooming of apple trees (South Hero, VT) (VCA 2014)

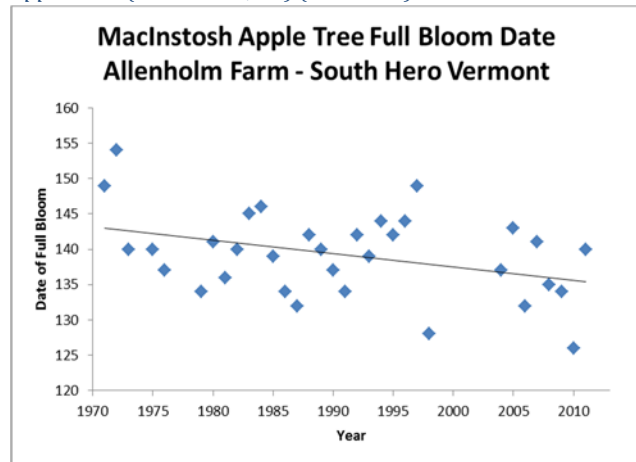
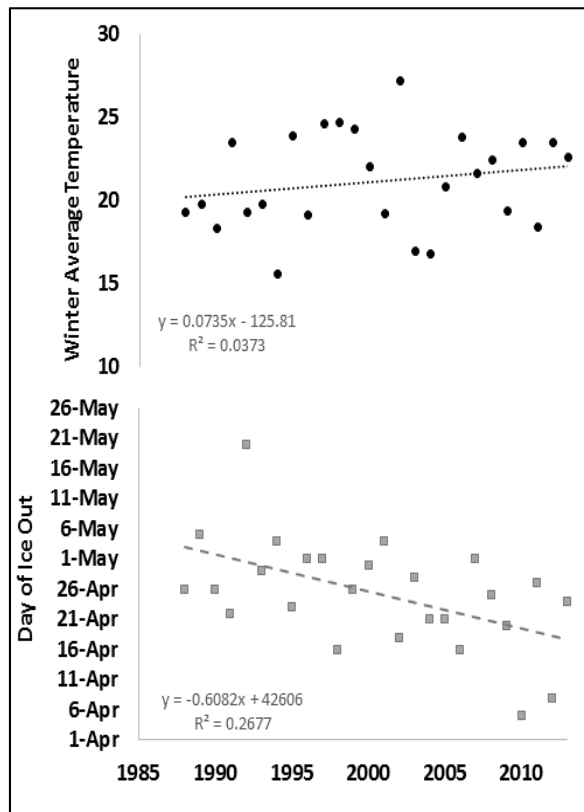


Figure 8. Changes in winter temperature and Ice Out at Joe's Pond are significantly correlated (VCA 2014)



<sup>16</sup> The New Climate Economy Report. <http://newclimateeconomy.report/overview/> accessed online March 25, 2015. Publication of joint efforts by the World Bank and regional development banks, the International Monetary Fund, International Energy Agency, Organisation for Economic Co-operation and Development, United Nations agencies and a variety of other research institutes around the world. Led by Helen Mountford and reviewed by an Advisory Panel of globally-recognized economists (Chair: Lord Nicholas Stern). Commissioned by seven countries – Colombia, Ethiopia, Indonesia, Norway, South Korea, Sweden and the United Kingdom

