



Climate Change and Vermont



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Vermont Commons School
South Burlington, VT

December 5, 2012

I went to Nottingham High School

- **Founded 1513**
- **1550**
Heading into
“Little Ice Age”
- **1620:**
Pilgrim fathers
face bitter winters



Earth sustains life

- Burning fossil fuels is increasing greenhouse gases and melting polar ice
- **Climate is warming and extreme weather is increasing**
- “Houston: we have a problem”



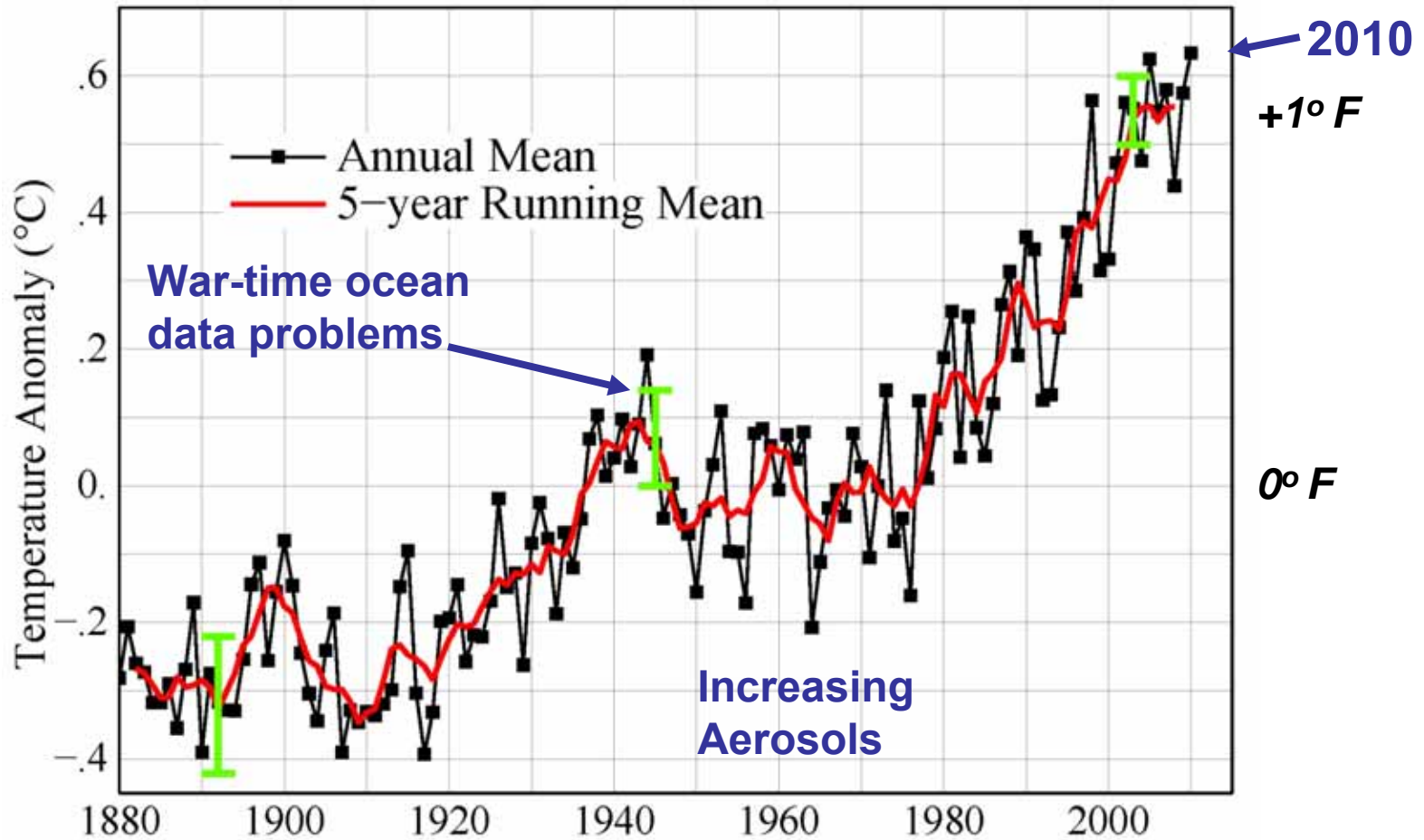
January 2, 2012: NASA

Global Temperature Rise 1880 – Present

2100: +5°F



Global Land–Ocean Temperature Index

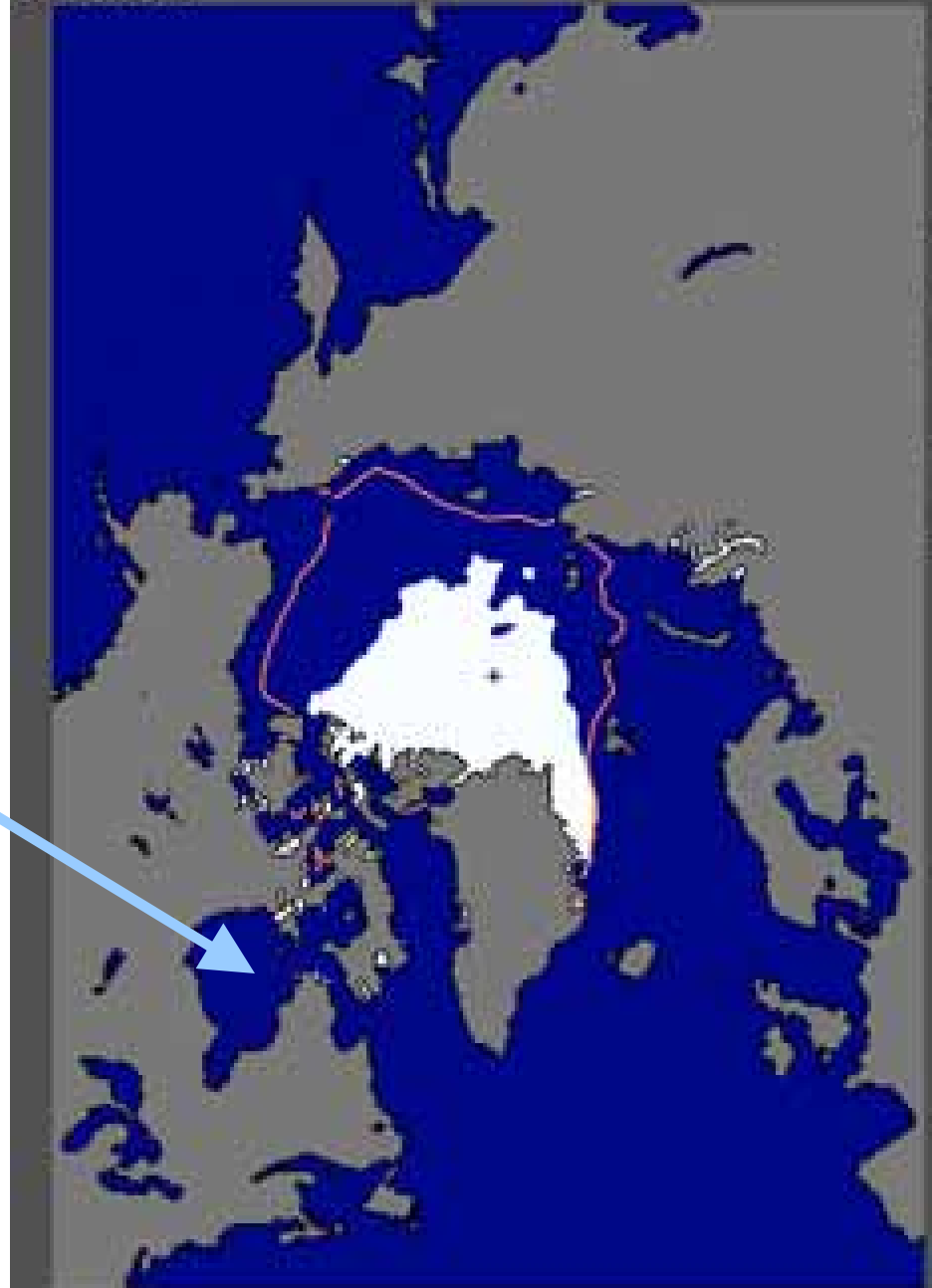


NASA-GISS, 2011

- **Half the Arctic Sea Ice Melted in 2012**
- **Open water in Oct. Nov. gives warmer Fall in Northeast**

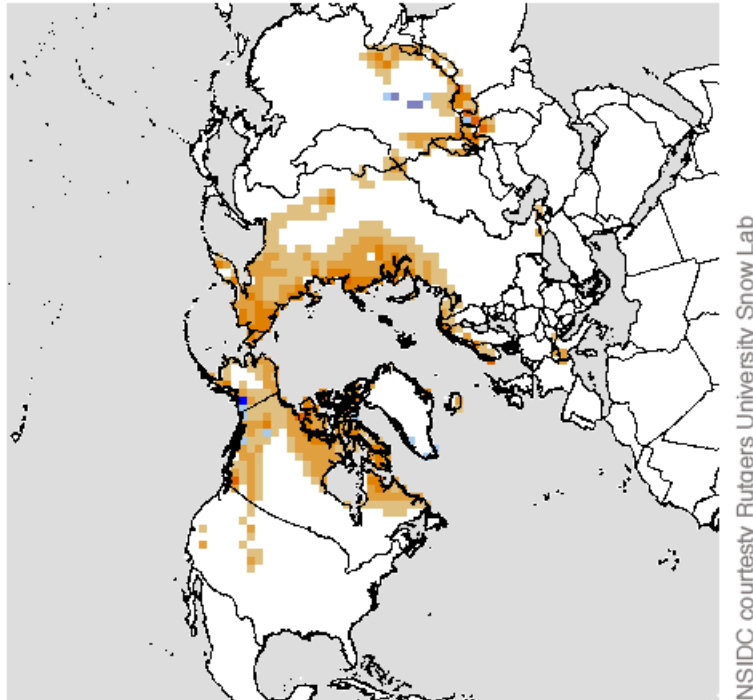
At the end of Nov. 2011 Hudson Bay was still nearly ice-free

- **Positive feedbacks:**
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Ice thin: most 1-yr-old***



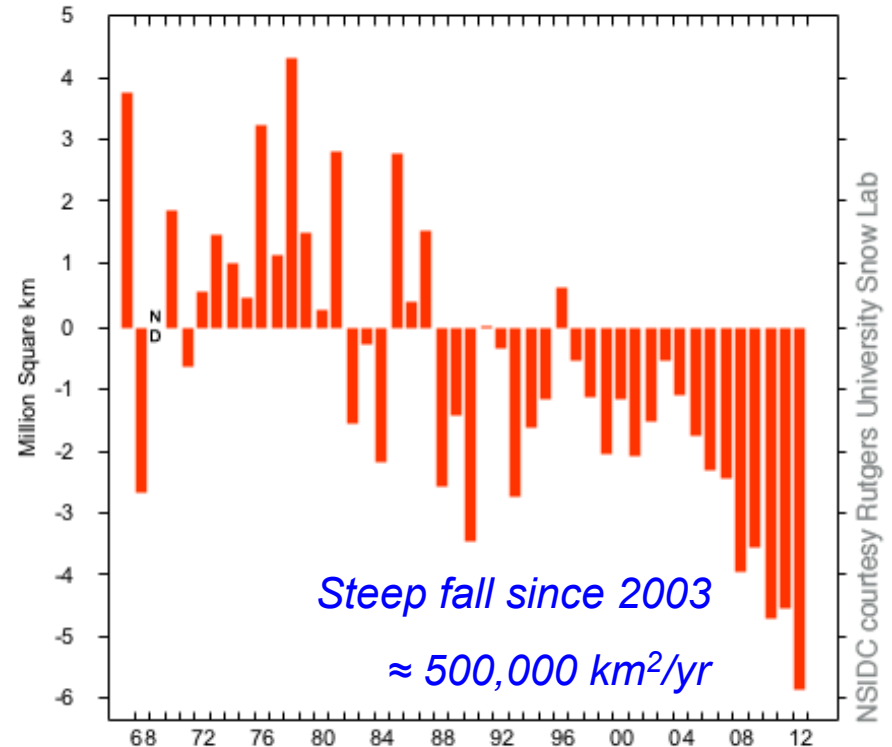
June 2012 snow cover minimum

Northern Hemisphere Snow Cover Anomaly
June 2012



Percent difference from 1971 - 2000 average June snow cover extent

Northern Hemisphere Snow Cover Anomaly
June 1967 - 2012



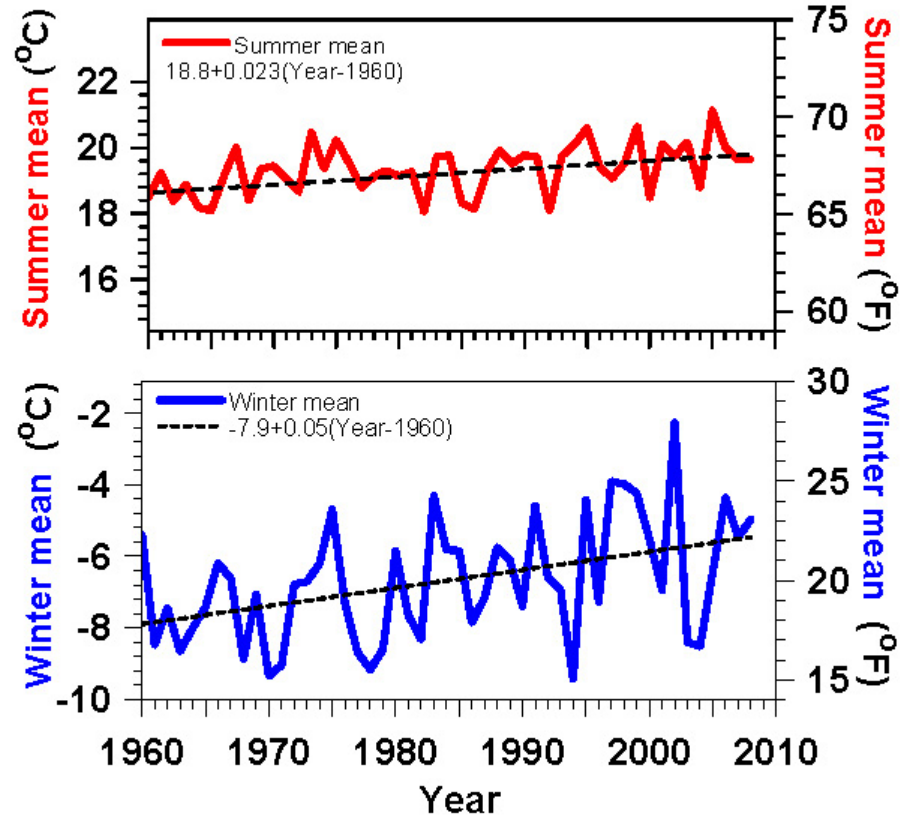
- Arctic warming rapidly
 - Melting fast
- New England winters also
 - Same positive feedbacks

What Is Happening to Vermont?

- **PAST 40/50 years** (CO₂ forcing detectible)
- **Warming twice as fast in winter than summer**
- **Winter severity decreasing**
- **Lakes frozen less by 7 days / decade**
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**
- **Weather extremes increasing**
- ***Evaporation increases with T***
- ***Weather patterns becoming more 'stationary'***

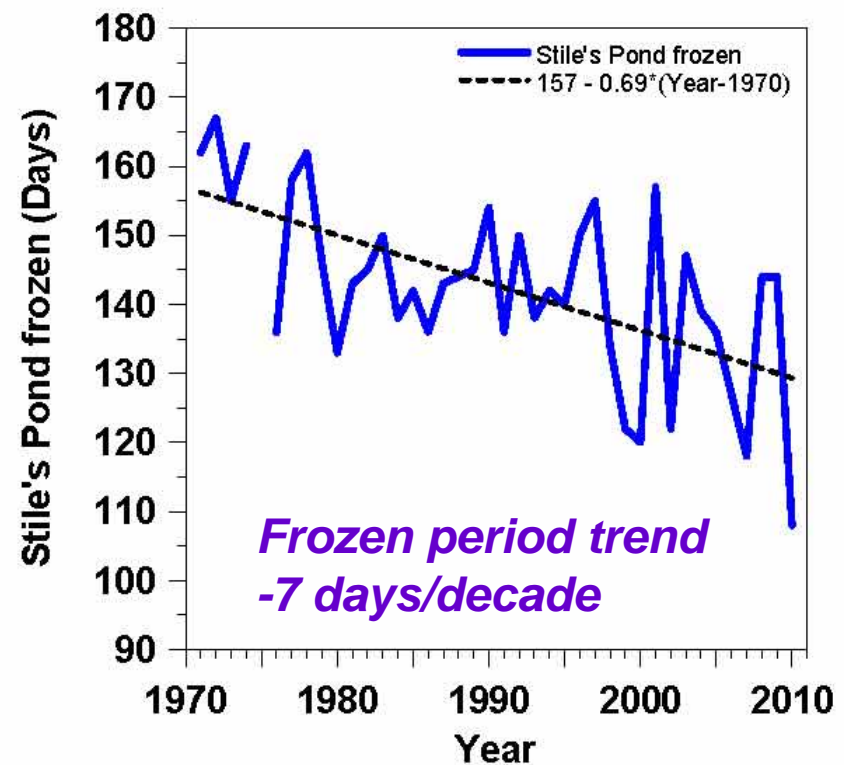
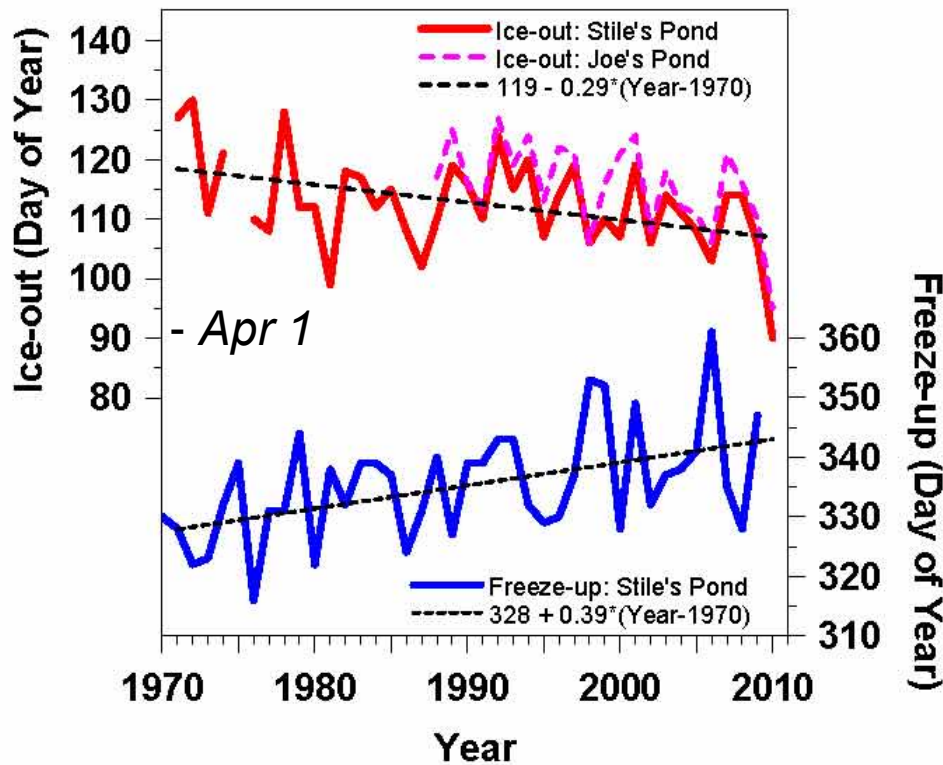
Vermont Temperature Trends 1961-2008

- **Summer $+0.4^{\circ}\text{F}$ / decade**
- **Winter $+0.9^{\circ}\text{F}$ / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***



Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast

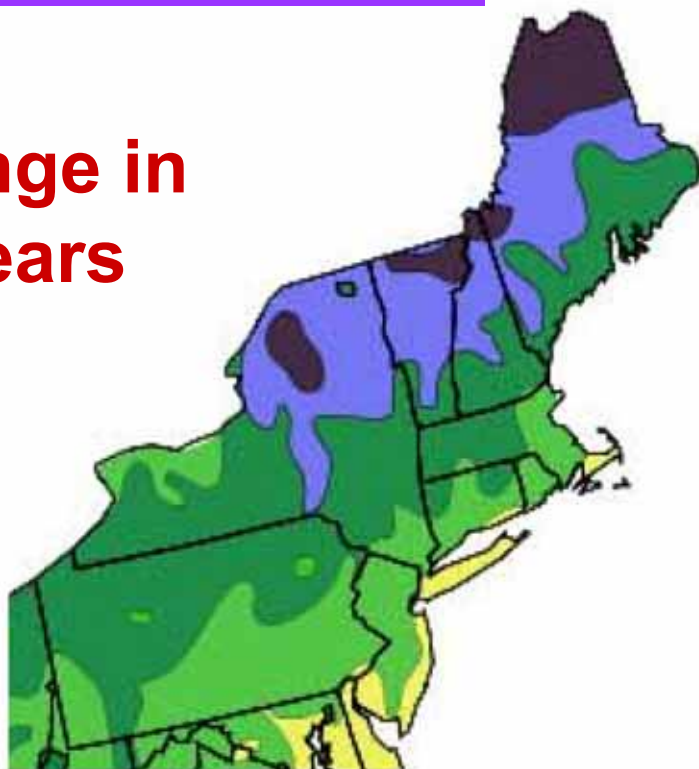


- Ice-out earlier **by 3 days / decade**
- Freeze-up later **by 4 days / decade**
- **Spring runoff peak 3 days / decade earlier**

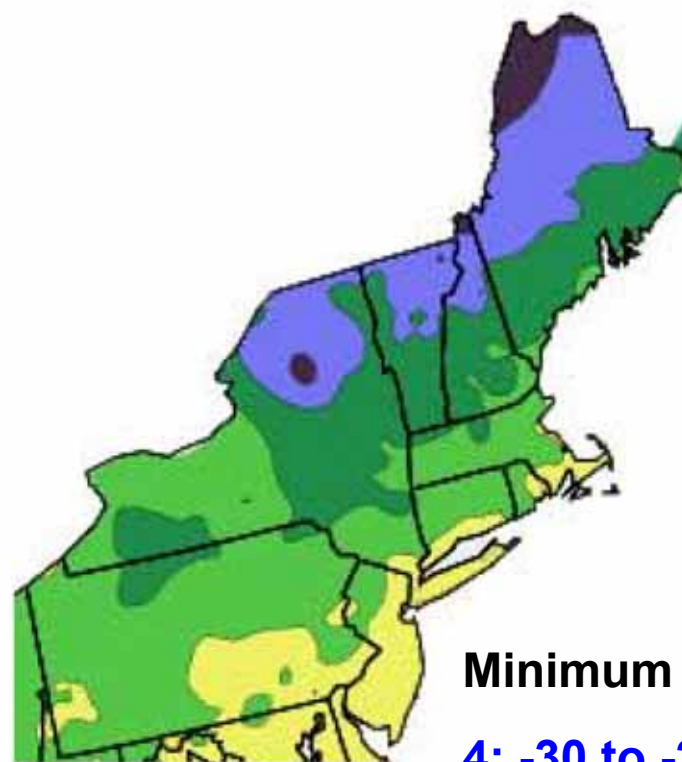
Winter Hardiness Zones

– winter cold extremes

Change in
16 years



1990



2006

Minimum winter T

4: -30 to -20°F

5: -20 to -10°F

6: -10 to 0°F

Zone



USDA Hardiness Zones

Bennington & Brattleboro are becoming 'zone 6'

- Hardy peaches: 2012
- Pests: winter survival
- What is this?



Bennington & Brattleboro are becoming 'zone 6'

- Hardy peaches: 2012
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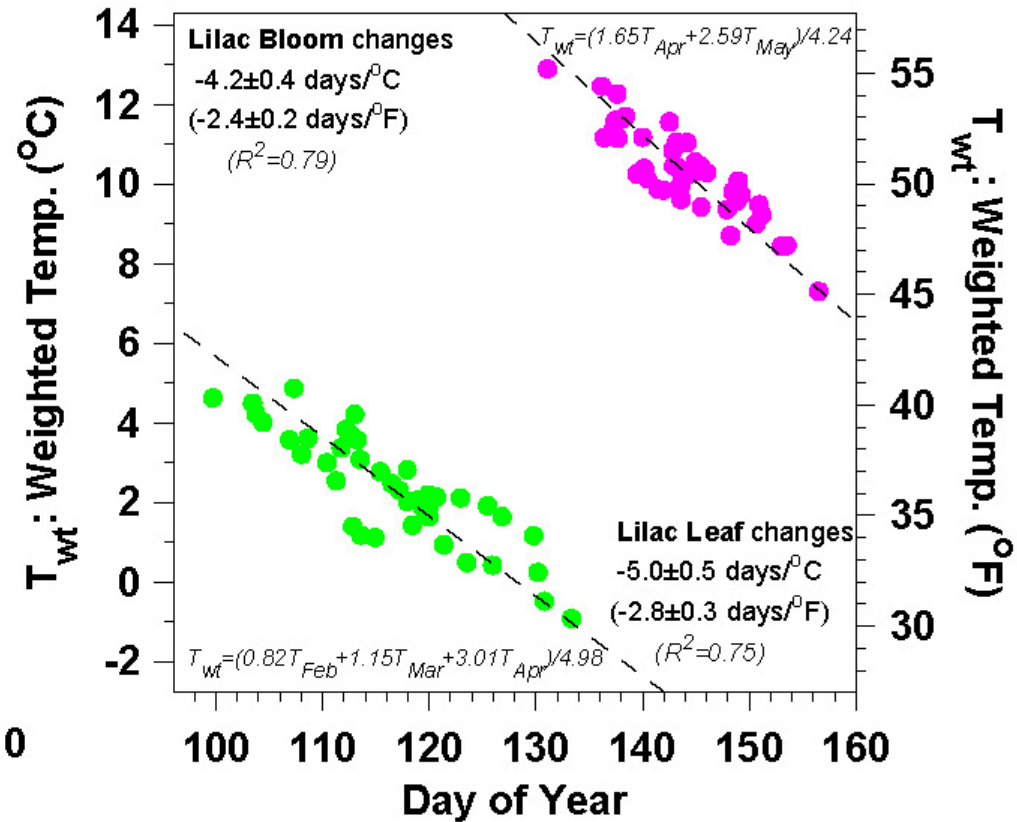
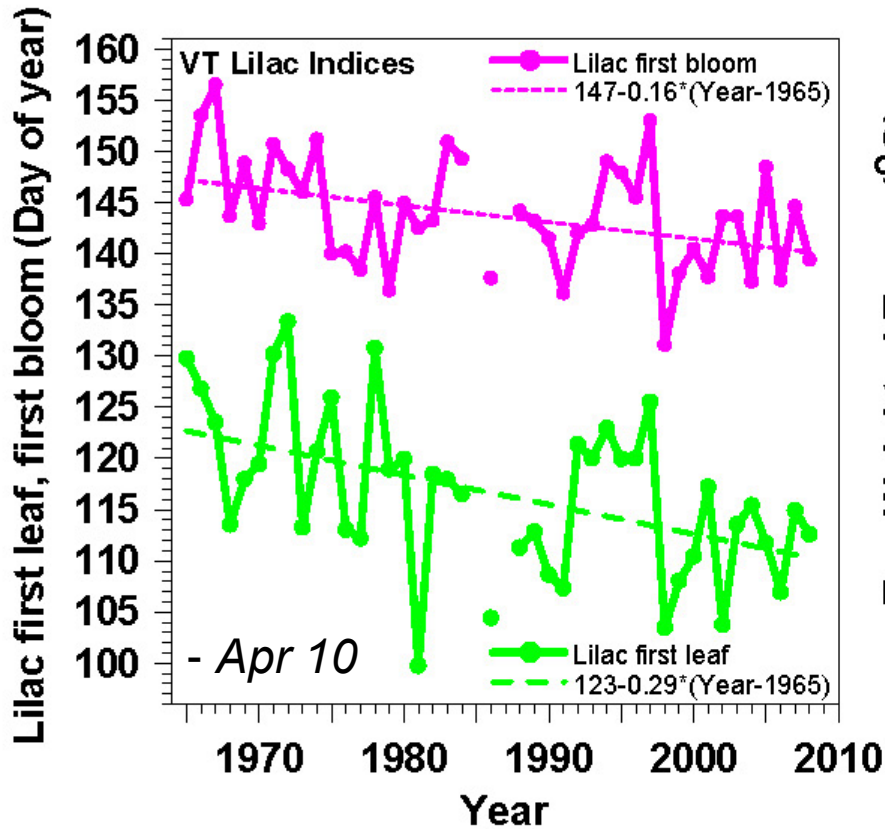
• What is this?

- **Avocado**

- Didn't survive frost
- Next century: in VT
- Our grand-children

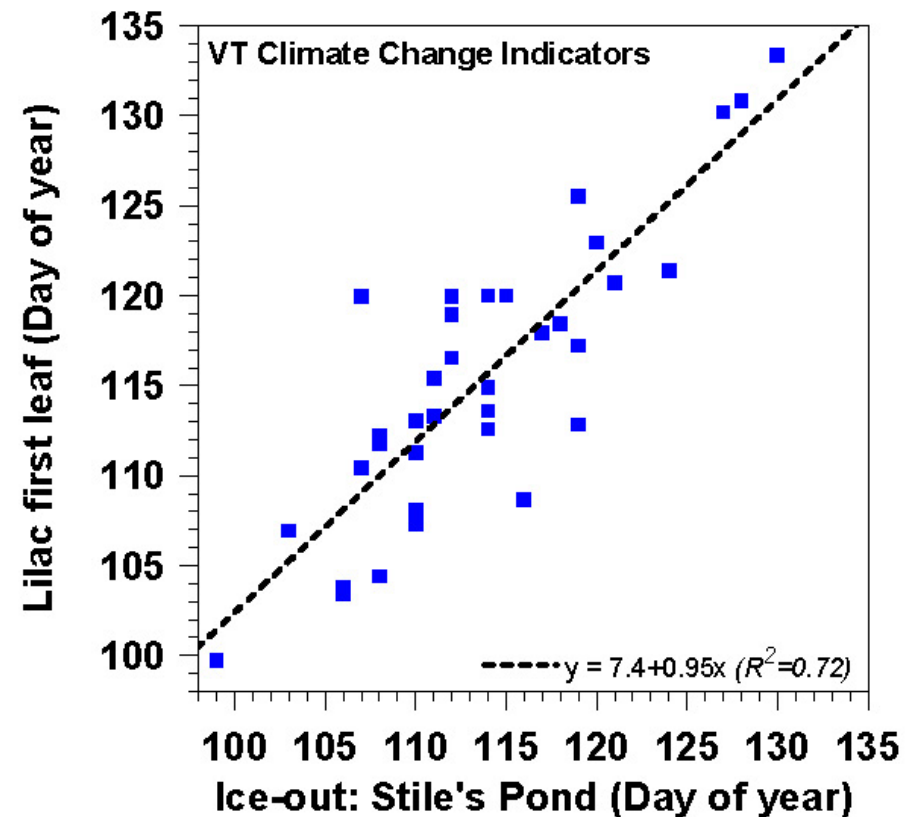
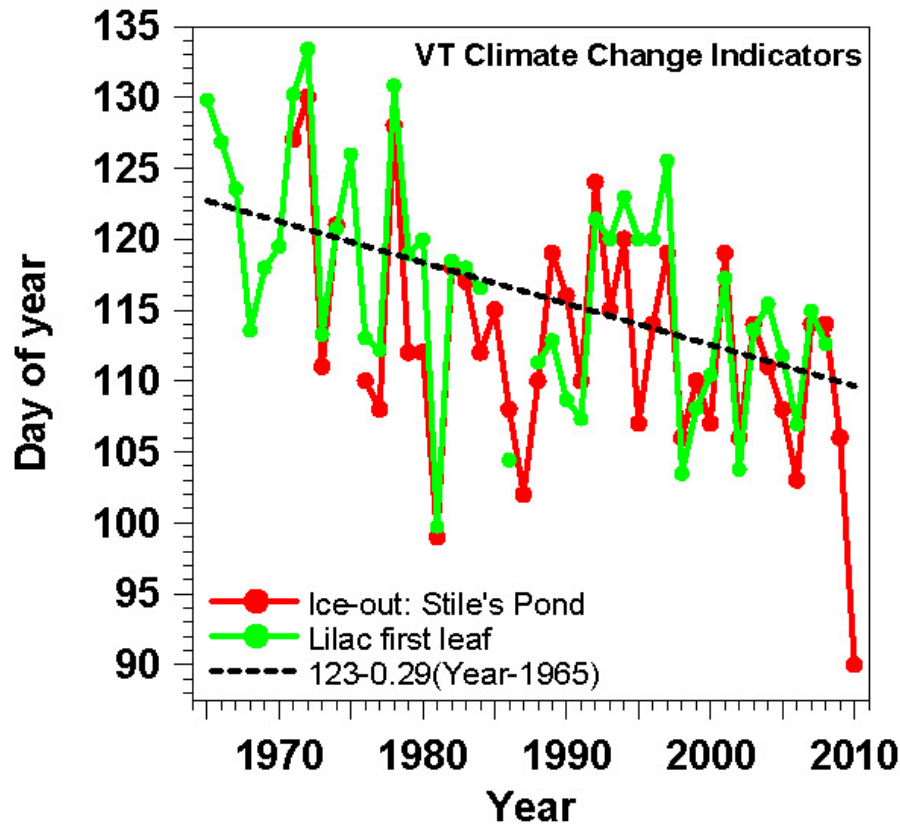


Lilac Leaf and Bloom



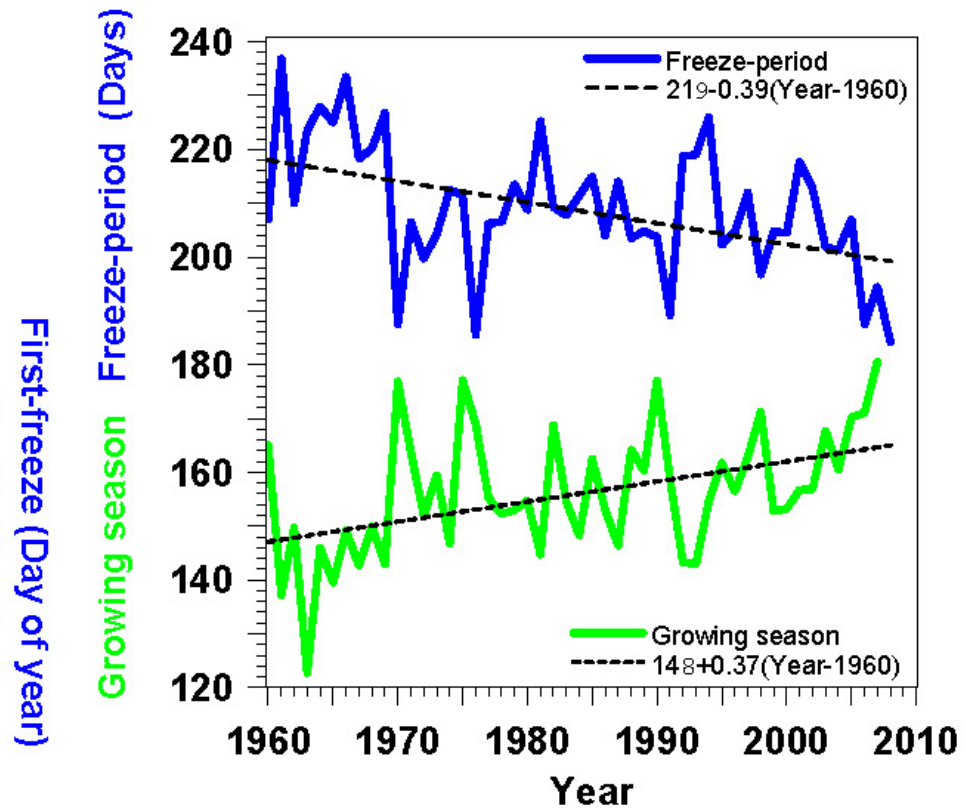
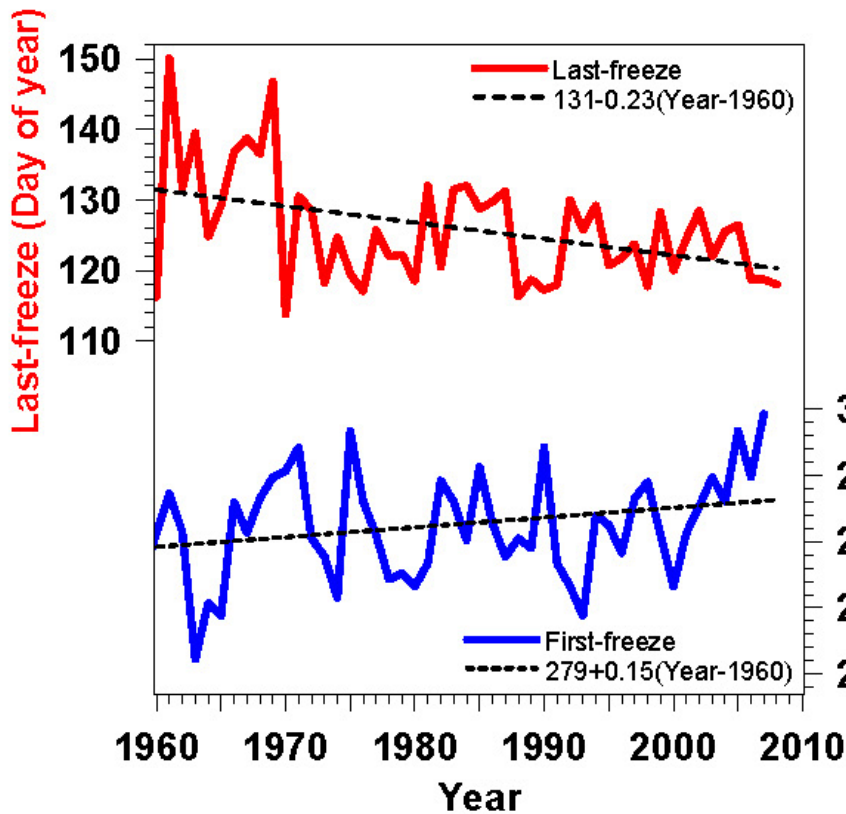
- Leaf-out -2.9 days/decade; Bloom -1.6 days/decade
- Large year-to-year variation related to temperature: 2 to 3 days/ °F

Lilac Leaf-out and Ice-out Coupled



- Lilac leaf and lake ice-out both depend on Feb. Mar. and April temperatures
- Trends indicate earlier spring

First and Last Frosts Changing



- Growing season for frost-sensitive plants increasing **3.7 days / decade**
- A help for growing “local food”



January 2, 2012



March 11, 2012

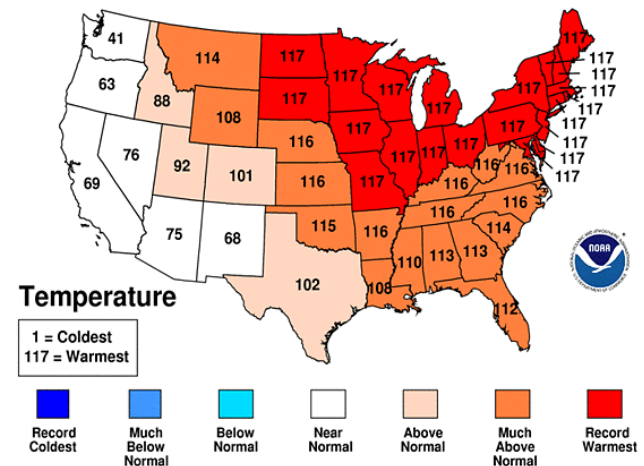


October 2011– March 2012

- **Warmest 6 months on record**
- **My garden frozen only 67 days**
- **No permanent snow cover west of Green Mountains**
- **Contrast snowy winter 2010-11**

Oct 2011-Mar 2012 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



Early Spring: Daffodils, Forsythia

79°F on March 22, 2012



Pittsford Vermont

3/22/12



Pittsford Vermont

3/24/12

Vermont Winter 2006



- **Snow reflects sunlight, unless shadowed by trees**
- **Stays cold; little evaporation, clear sky; earth cools to space**
- ***Positive feedback: Less snow, warmer winters (2012)***

Spring Climate Transitions



- **Before leaf-out**

- **Little evaporation** → Dry atmosphere, low humidity
 - Low water vapor greenhouse
 - Large cooling at night
 - Warm days, cool nights and frost

- **After leaf-out**

- **Large evaporation** → Wet atmosphere, low cloud-base
 - Small cooling at night
 - Reduced maximum temperature
 - Reduced chance of frost

- ***Spring is coming earlier: 2012 was extreme***

Summer dry-down

- **Wet in spring**
- **Soil moisture falls:
summer dry-down**
- **Low humidity &
little rain**
- *Can lock-in drought in
central US: as in 2012*



Many Wet Summers in Vermont – till 2012



- 2004, 2006, 2008, 2009, (2010), 2011 all wet
- **Fast evaporation off wet canopies**
- *Positive evaporation-precipitation feedback*

Fall Climate Transition

- **Vegetation delays first killing frost**
- **Forest evaporation gives moister air, clouds, less cooling at night**
- **Till one night, north wind brings cold dry air, giving first hard frost**
- **Vegetation dies, skies become clearer and frosts become frequent**
- *Opposite of what happens in Spring with leaf-out*

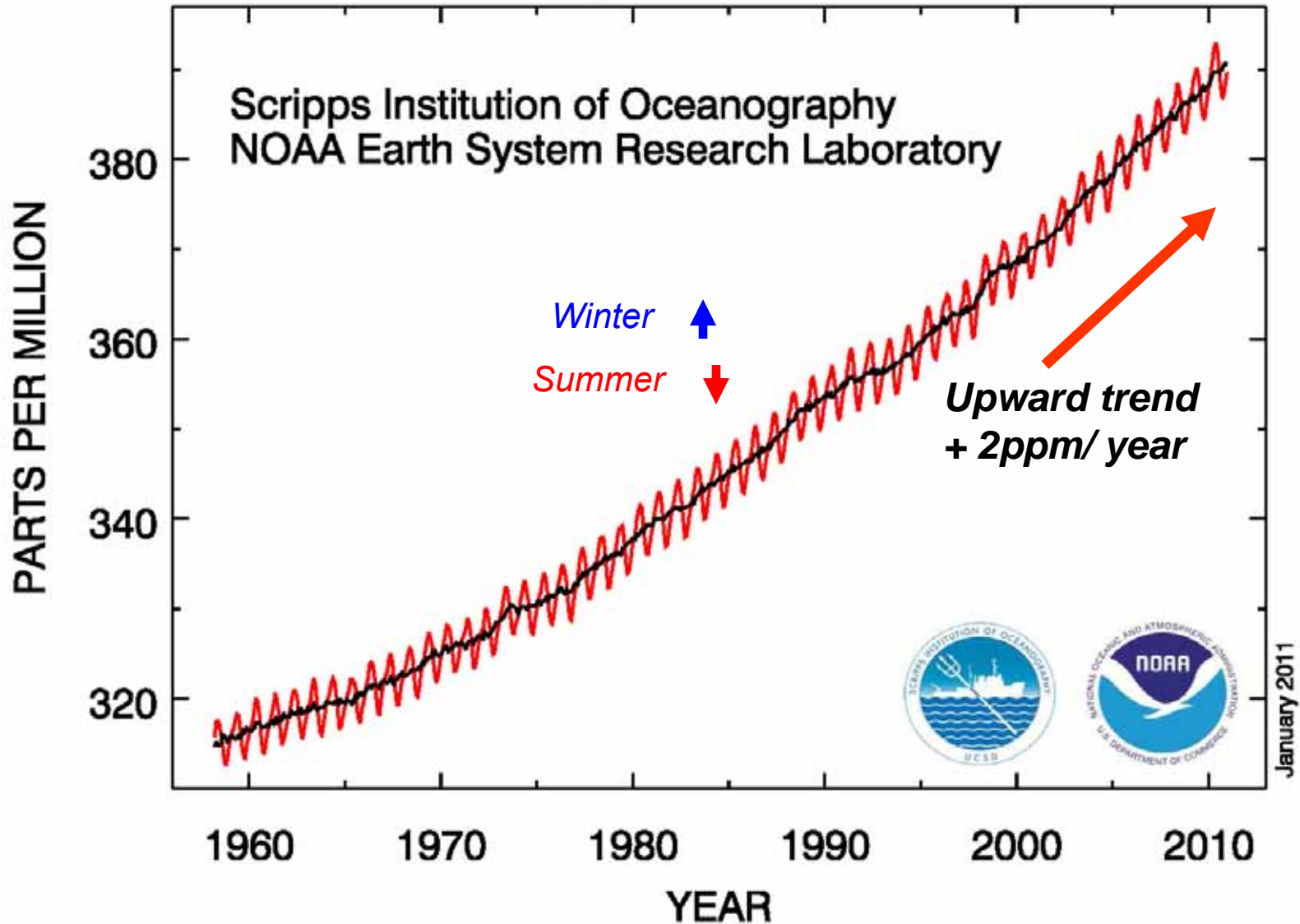
Later frost: Growing season getting longer



Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

Carbon Dioxide Is Increasing

Atmospheric CO₂ at Mauna Loa Observatory



Rise of Greenhouse Gases (GHG) Changes Earth's Energy Balance

- The atmosphere is **transparent to light** from the sun, **but not to infrared radiation** from the earth
- **GHG:** H₂O, CO₂, CH₄, O₃, CFCs trap the infrared from the surface, giving climate suitable for life *by warming planet 60°F*
- Rise of CO₂ alone has only a small warming effect

BUT...



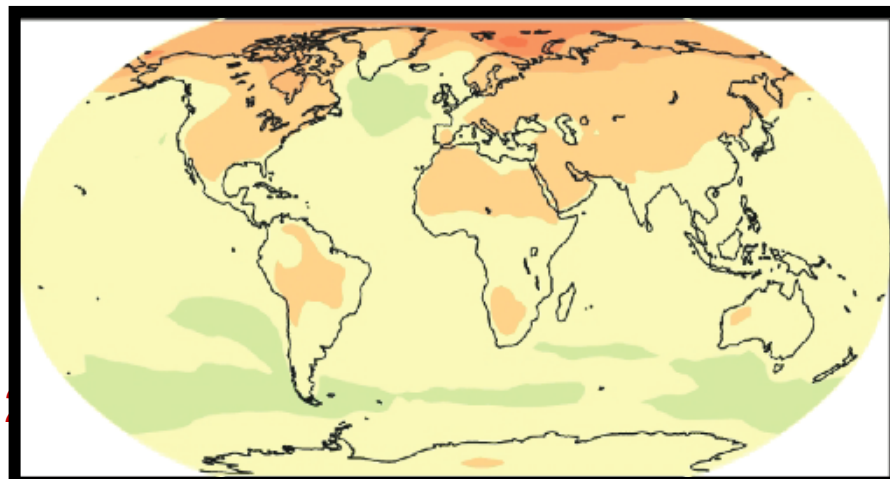
Water, Snow & Ice Give Positive Radiative Feedbacks

- As Earth warms, evaporation and water vapor increase and **this is 3X amplifier** on CO₂ rise
- As Earth warms, snow & ice decrease, so less sunlight is reflected - **this amplifies warming** in Arctic in summer and mid-latitudes in winter
- Doubling CO₂ will warm globe about 5°F (3°C)
 - **Much more in the cold regions and over land, which responds faster than oceans**

Predicted Change in Temperature

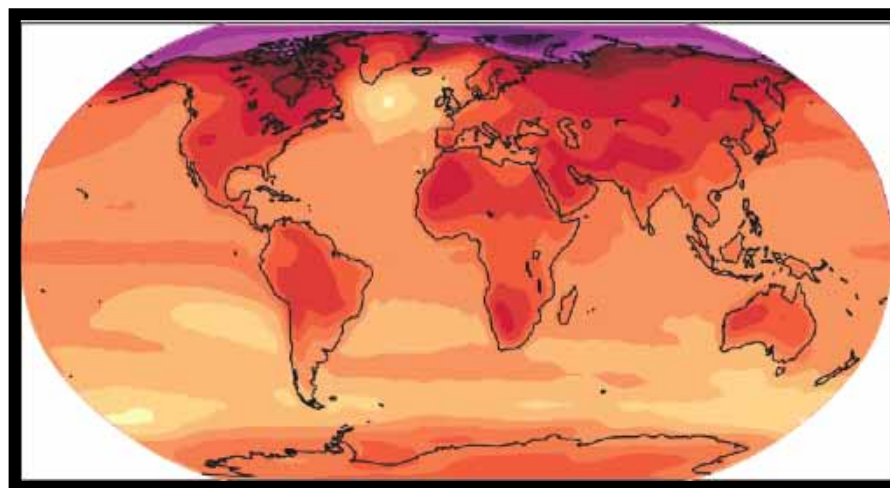
2020-2029 and 2090-2099, relative to 1980-1999 (°C)

“Committed”

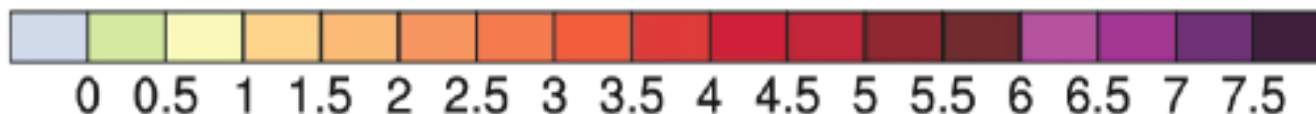


(We did nothing for the last 20 years)

Still up to us!



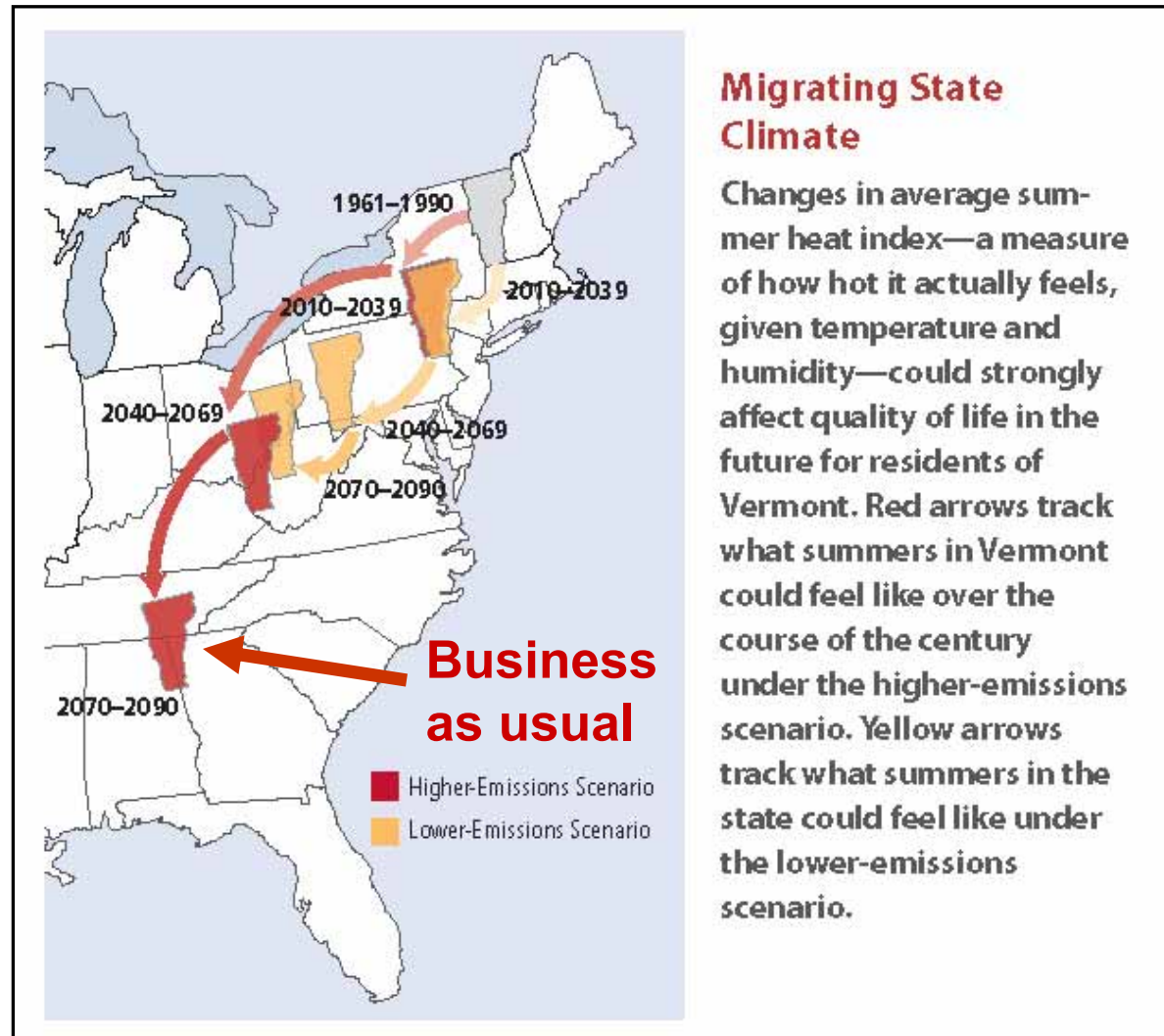
(We could halve this if we act now)



Vermont's Future with High and Low GHG Emissions

What
about
skiing?

What
about
tropics?



Extreme Weather Increasing

- **Precipitation - condensation of water vapor - large heat release - drives powerful storms**
- ***Water vapor at cloud-base increases steeply with temperature (6% per °C)***
- **Slow-moving global patterns mean longer rain events in low-pressure regions, and longer droughts in high-pressure regions**
- ***As climate changes, slower-moving weather systems becoming more frequent***
 - ***We think cause may be Arctic warming***



As Arctic warms, jet stream patterns are slowing down and amplifying, giving more extreme weather

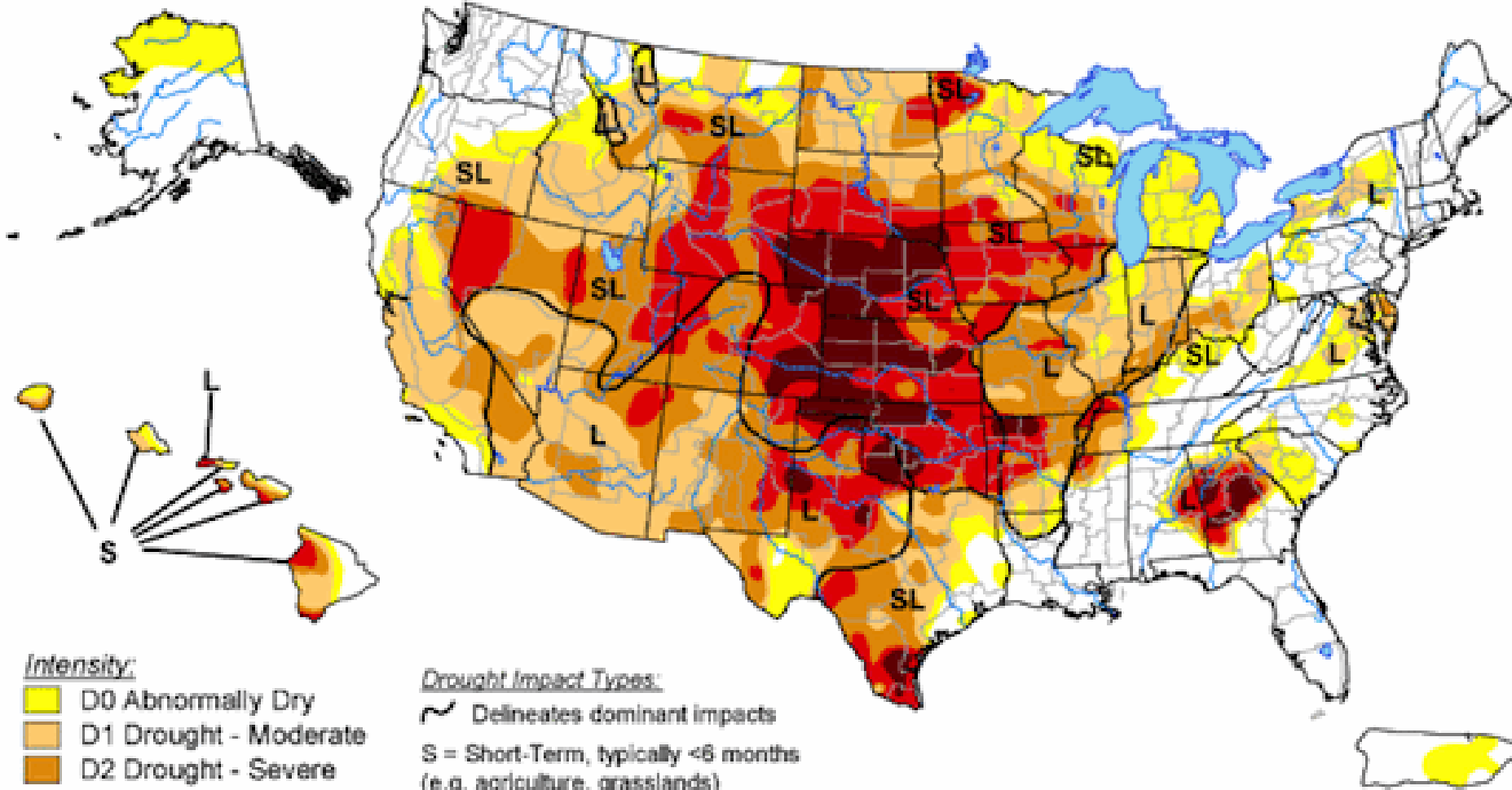
(Francis and Vavrus, 2012)

Image - NASA

U.S. Drought Monitor

September 25, 2012

Valid 7 a.m. EDT



Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

- Delineates dominant impacts
- S = Short-Term, typically <6 months (e.g. agriculture, grasslands)
- L = Long-Term, typically >6 months (e.g. hydrology, ecology)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

<http://droughtmonitor.unl.edu/>



Released Thursday, September 27, 2012

Author: Anthony Artusa, NOAA/NWS/NCEP/CPC

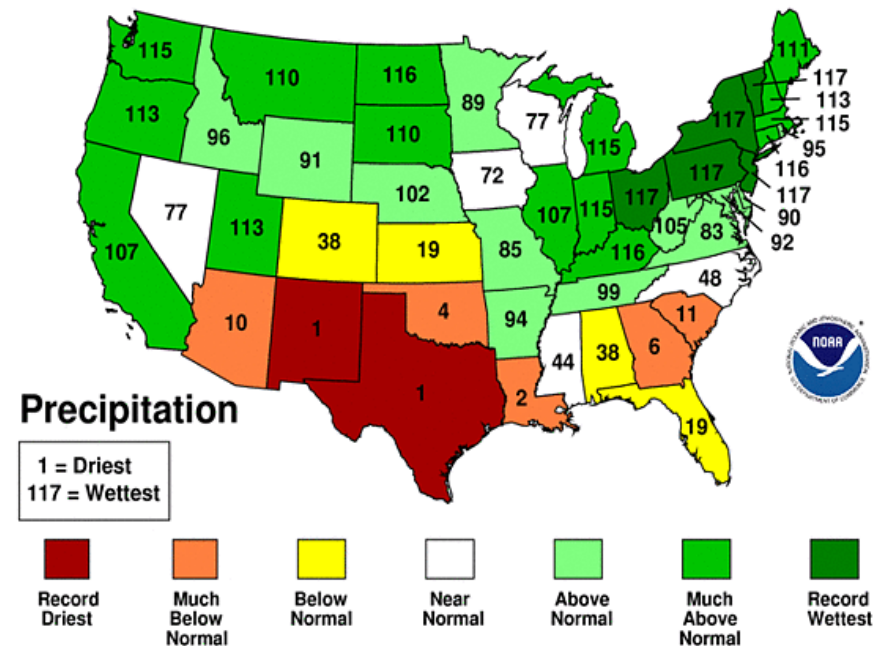
2011 Vermont Floods

- **Spring flood:** heavy rain and warm weather, melting large snowpack from 2010 winter
 - Lake Champlain record flood stage of 103ft
- **Irene flood: tropical storm** moved up east of Green Mountains
 - dumped 6-8 ins rain on wet soils: extreme flooding

- *For 6 months in 2011 US rainfall pattern nearly stationary*

- Record wet: OH to VT
- Record drought: TX & NM)

March-August 2011 Statewide Ranks
National Climatic Data Center/NESDIS/NOAA

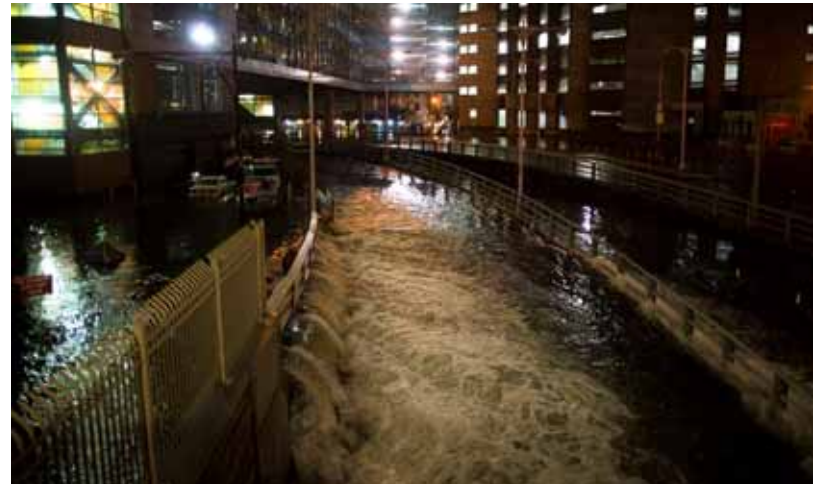


Three Successive Years of East-Coast Tropical Storm Disasters

- **September 21, 2010: Hurricane Igor with winds and record rainfall devastates eastern Newfoundland, isolating 150 communities as swollen rivers washed away the only roads into town and all connecting bridges. The worst storm ever in a province known for its storms.**
- **August 28, 2011: Tropical Storm Irene devastates Vermont, as heavy rain washes out roads and bridges, cutting off 20 towns**
- **October 29, 2012: Hurricane Sandy devastates New Jersey and New York City with winds and record storm surge flooding the subway tunnels, airports and shorelines**

Disasters Happen in Strong Storms

- Hurricane Sandy hits NYC and floods subway tunnels: Oct 29 2012
- **Extreme weather event + climate change = disaster**
 - \approx 1ft rise of mean sea-level
 - Gulfstream warm + 5°F
 - Blocking high: NE Canada
 - \approx 2ft extra storm surge
 - **Extra 3ft = disaster**



Many Challenges Face Us

- **Extreme weather: Floods, fires, & drought**
 - **32 weather disasters >\$1B in 2011**
- **Sea-level rise: 3 - 5 feet per century likely**
- **Melting Arctic and permafrost — methane release is positive feedback**
- **Ecosystem collapse possible**
 - perhaps forest and ocean ecosystems

The 1992 UN Framework Convention on Climate Change Agreed to Stop “Dangerous Climate Change”

- *Signed by 194 countries, including US*
- **Can we do this?**
 - **Yes:** Quickly stabilize atmospheric CO₂
 - This means an 80% drop in CO₂ emissions!
- **But it is very difficult for human society**
 - Fossil fuels have driven our industrial growth and population growth for 200 years
 - Our “lifestyle” has become dependent on fossil fuels

Increased Energy Efficiency is Critical

- **We need to double or triple our energy efficiency because...**
 - We cannot replace current fossil fuel use with biofuels & renewable energy
- **Oil and gas reserves are limited, but...**
 - Coal, shale-oil & shale-gas reserves are sufficient to push CO₂ to 1,000 ppm—and in time melt icecaps, and raise sea-level 180ft
 - Can we “sequester” CO₂ (put it back in the earth)?

Why Is It Difficult for Us?

- **Fossil fuels reserves are worth \$20-30T**
 - Regulating or taxing emissions of CO₂ considered an “unfair cost” to the “free market”
 - Yet in reality we are still subsidizing fossil fuels
- **Politics lost in fantasy**
 - Ignoring Earth system, climate issues
 - Ignoring moral issues
 - Ignoring risks, future costs
 - With Irene, Manhattan came within 1-ft of flooding
 - Did they put waterproof doors on tunnels? No!

Why Is It Difficult for Us?

- The “American dream” is crumbling
 - “Economic growth” based on **fossil fuels, debt, and consumerism is unsustainable** — and a disaster for the planet
- Individual “rights” and the needs of humanity must be **balanced** against the needs of the earth’s ecosystem
- We don’t know how to **guide and manage technology**
 - Result is tremendous successes and catastrophic failures
- Growing impacts lie in the future
 - **Your lifetime and your children’s**

Will Attitudes Change?

- **Irene changed attitudes in VT**
- **Sandy changed attitudes in NY and NJ**
- **Central US droughts may affect attitudes**
 - Increasing extreme weather will raise awareness
 - But time is running short (decades)
 - Sea level rise will be too slow (Century)
- **Everything is interconnected**
 - Human society and waste streams
 - People's choices and actions
 - Precipitation, seasons, streams, and forests; habitat and wildlife

What Do We Need?

- We need **honest, truthful, smart** paths forward
 - That will **not frighten people** into paralysis
 - That will **spread hope, not anger or despair**
 - That **sidestep ideological barriers with new language**
 - That **develop adaptive governance**
 - The US Constitution gives no rights to the Earth
- **That respect Earth system limits**

Discussion

- This talk <http://alanbetts.com/talks>
- Rutland Herald articles at <http://alanbetts.com/writings>
- Interesting papers at <http://alanbetts.com/research>
 - *Vermont Climate Change Indicators*
 - *Seasonal Climate Transitions in New England*

