Climate Change and Vermont: an Overview

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(RACC High School Projects)

October 8, 2013

RACC
Research on Adaptation to Climate Change

Outline

- **Science of climate change**
  - **Global scale: actual and future**
  - **What is happening to Vermont**

- **The transition we face**
  - **‘Managing the earth system’**
  - **Why is it difficult?**

Discussion

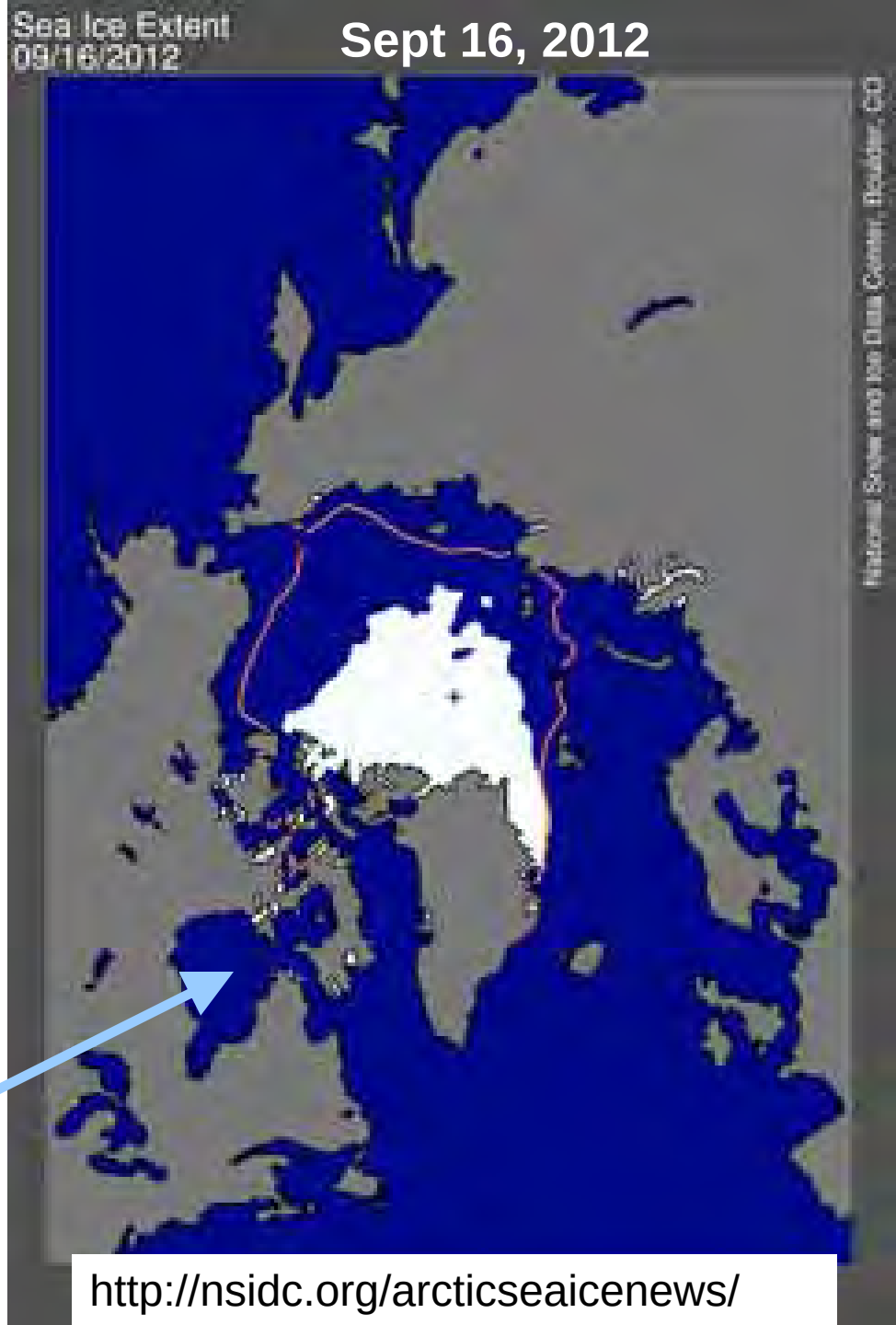
- **Earth sustains life**
- **Weather changes fast**
- **Climate changes slowly**
- **Greenhouse gases keep Earth warm**
- **Burning fossil fuels – coal, oil and gas – is having a big effect on climate by increasing greenhouse gases: CO_2 and H_2O**

January 2, 2012: NASA

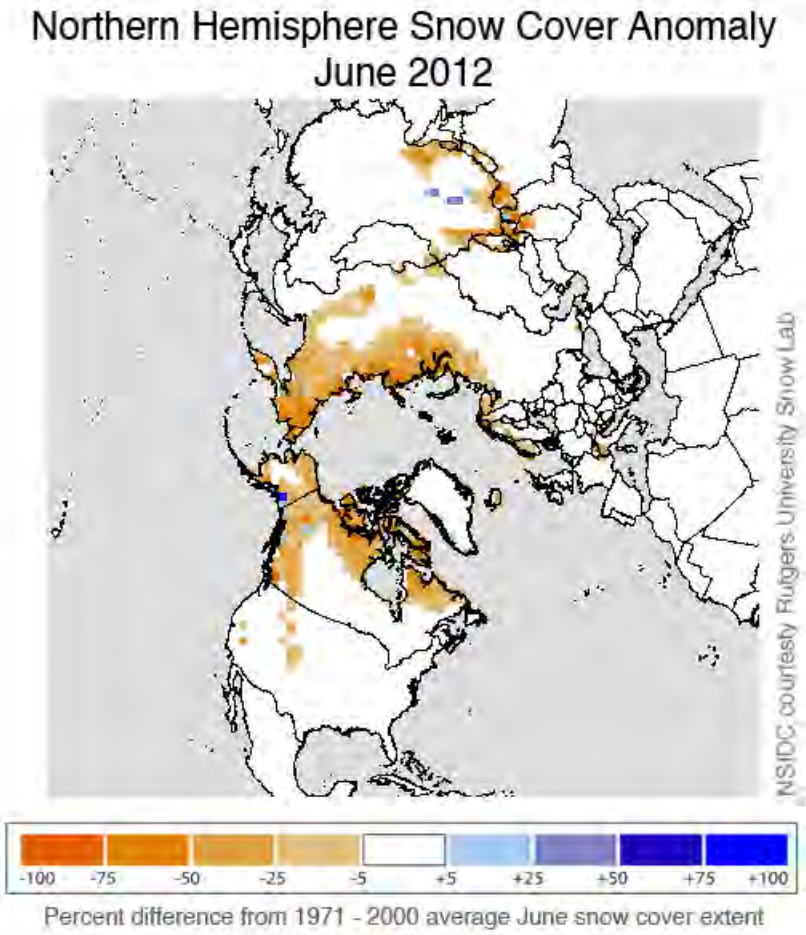
- **Half the Arctic Sea Ice Melted in 2012**
- **Open water in Oct. Nov. gives warmer Fall in Northeast**

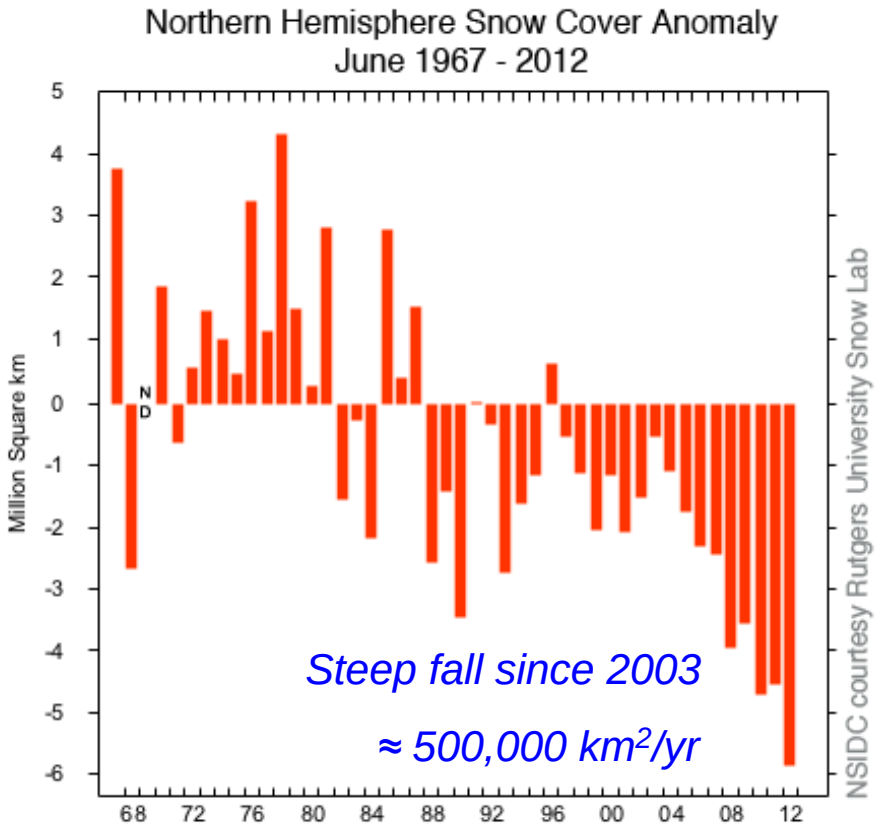
- ***Amplifying feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Ice thin: most 1-yr-old***

End of Nov. 2011 Hudson Bay was still nearly ice-free



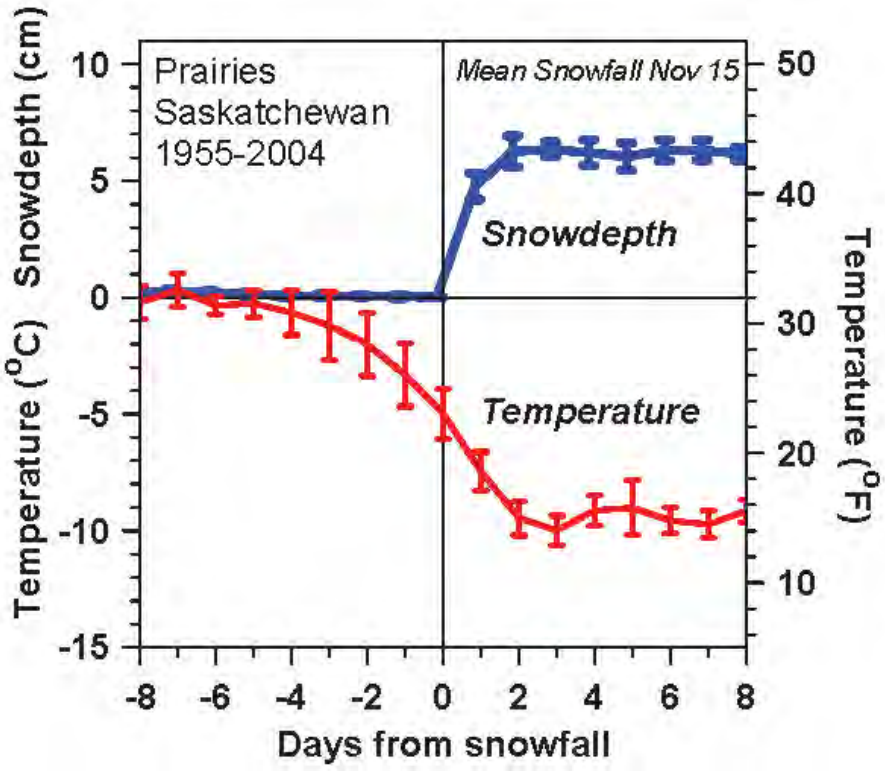
June 2012 snow cover minimum

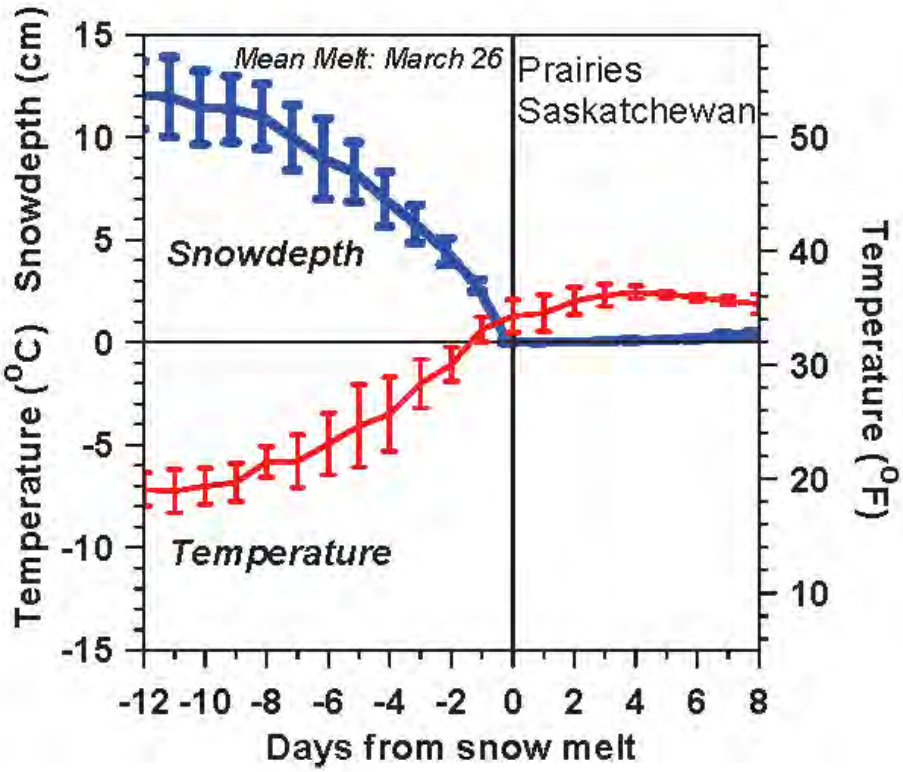




- **Arctic warming rapidly**
  - **Melting fast**
  - ***Much faster than IPCC models***
- **Northeast winters**
  - ***Same positive feedbacks***

Snowfall and Snowmelt





- **Temperature falls 16F (9C) with first snowfall**
- **Similar change with snowmelt**
- ***Snow reflects sunlight; reduces evaporation and water vapor greenhouse – changes 'local climate'***

Betts et al. 2013

What Is Happening to Vermont?

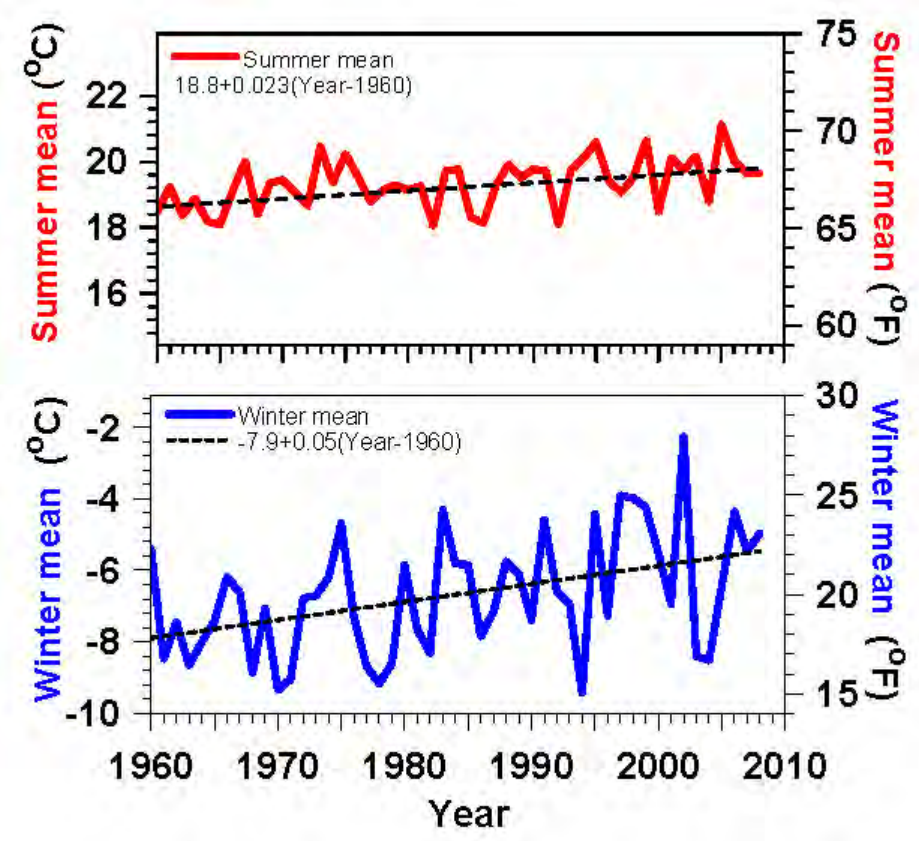
- **PAST 40/50 years** ***(global CO_2 forcing detectible)***
- **Warming twice as fast in winter than summer**
- **Winter minimums increasing even faster**
- **Lakes frozen less by 7 days / decade**
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**

(Betts, 2011)

- **Extreme weather increasing**
- ***Evaporation increases with T***
- ***More 'quasi-stationary weather patterns'***

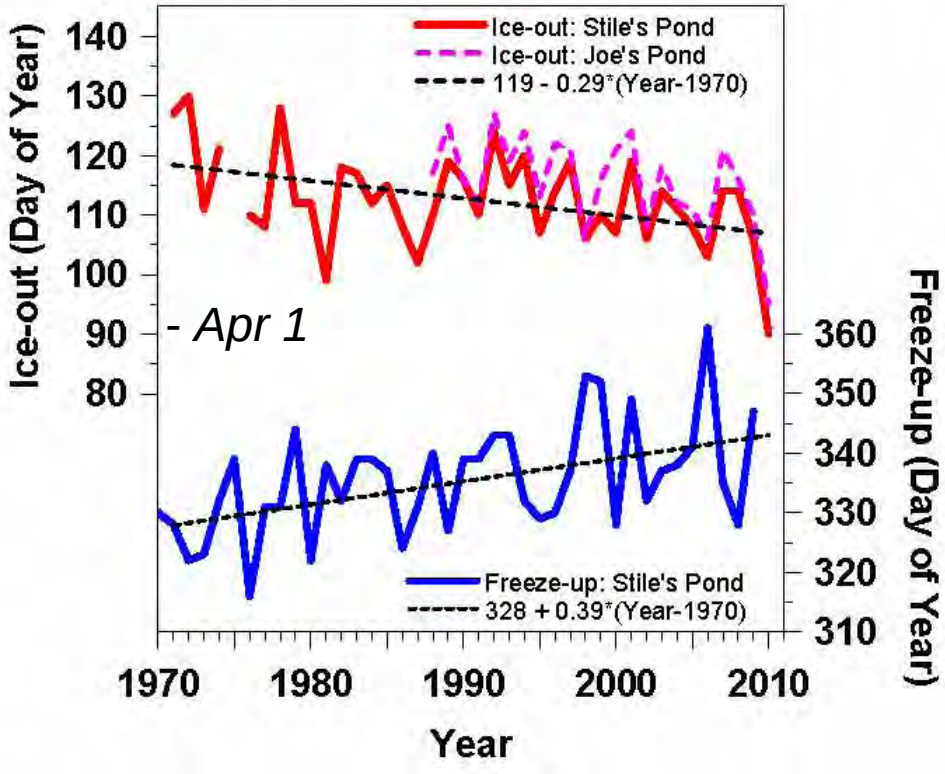
Vermont Temperature Trends 1961-2008

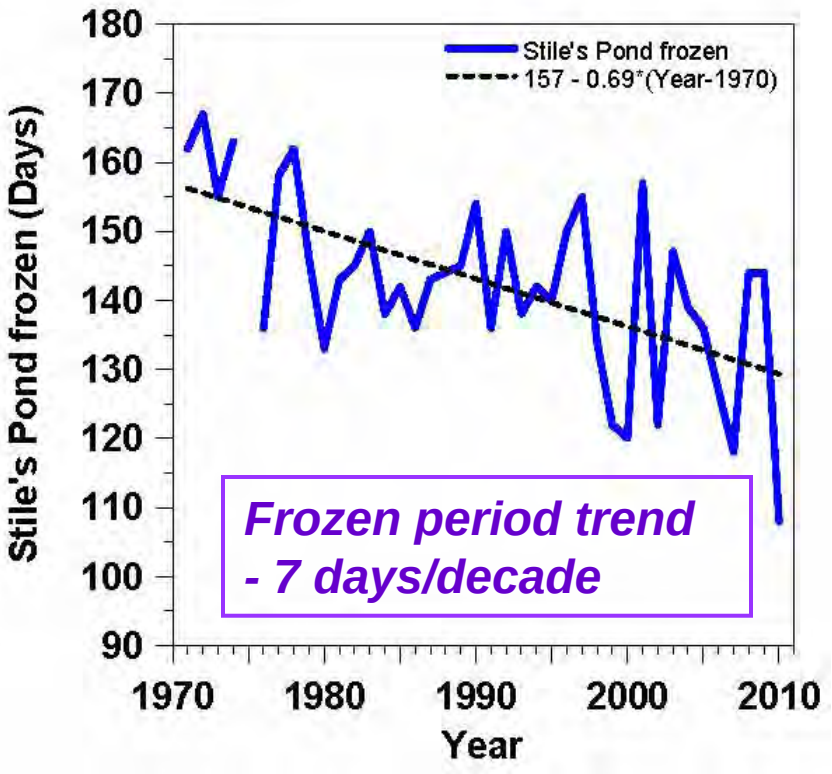
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***



Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



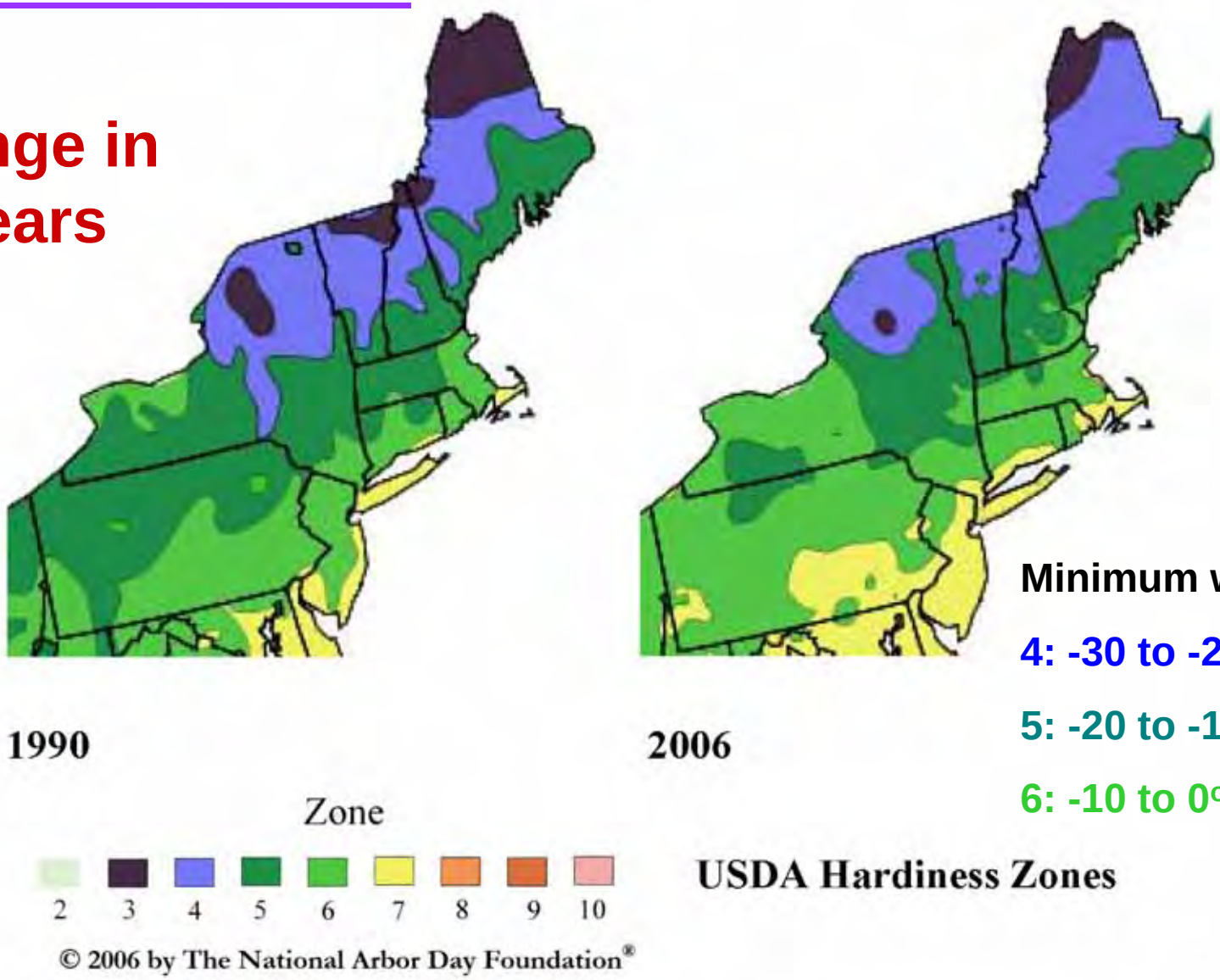


- **Ice-out earlier by 3 days / decade**
- **Freeze-up later by 4 days / decade**
- ***Soil ice probably similar***

Winter Hardiness Zones

– ***winter cold extremes***

Change in 16 years



Minimum winter T

4: -30 to -20°F

5: -20 to -10°F

6: -10 to 0°F

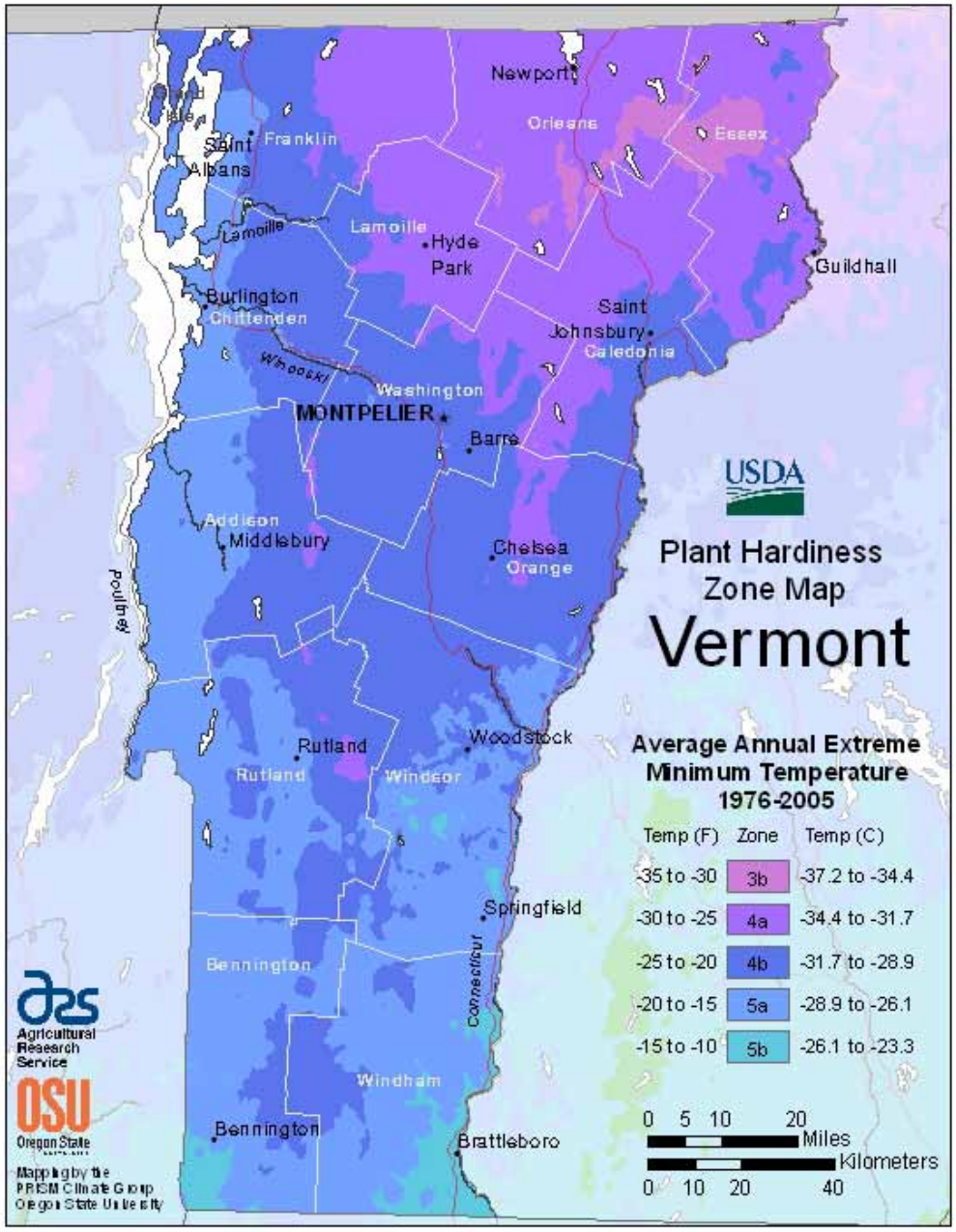
Detailed Map *(most recent)*

- **VT Hardiness Zone Map 1976-2005**
  - **mean 1990**
  - **South now zone 6**

- **Half-zone in 16 yrs = 3.1°F/ decade**
  - ***triple the rise-rate of winter mean T***
  - ***3 zones/century***

- ***http://planthardiness.ars.usda.gov/PHZMWeb/***

(Krakauer, Adv. Meteor. 2012)



Bennington & Brattleboro are becoming zone 6 *(T_{min} > -10F)*

- **Hardy peaches: 2012**
- **More pests survive winter**

- **What is this?**
  - **Oct 1, 2012**

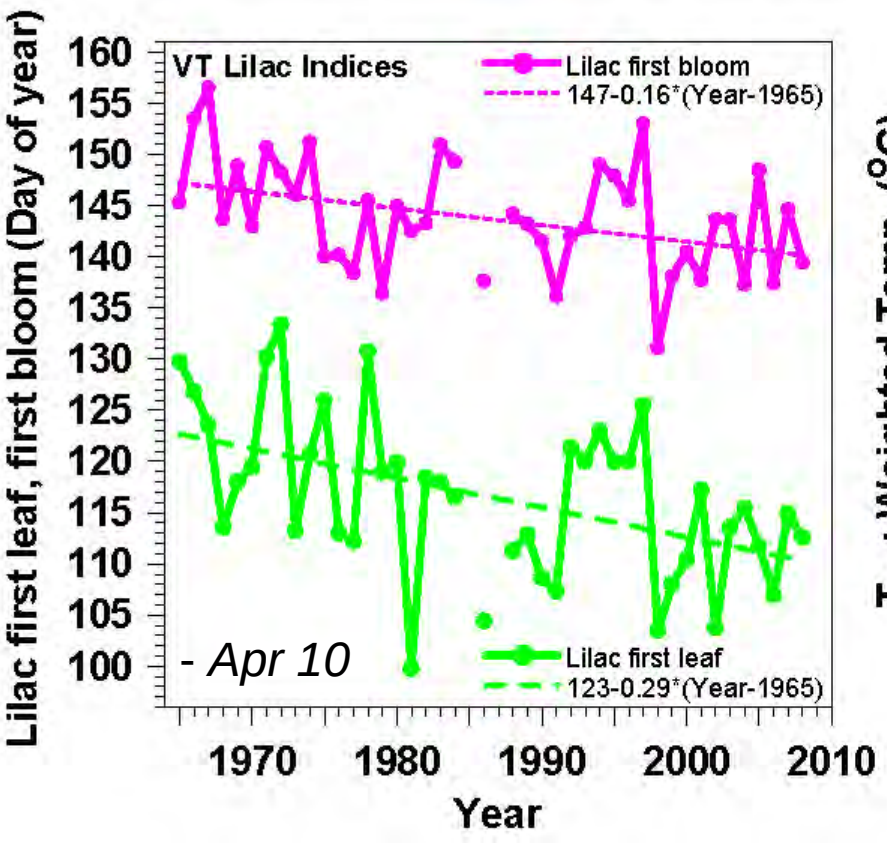
Bennington & Brattleboro are becoming zone 6

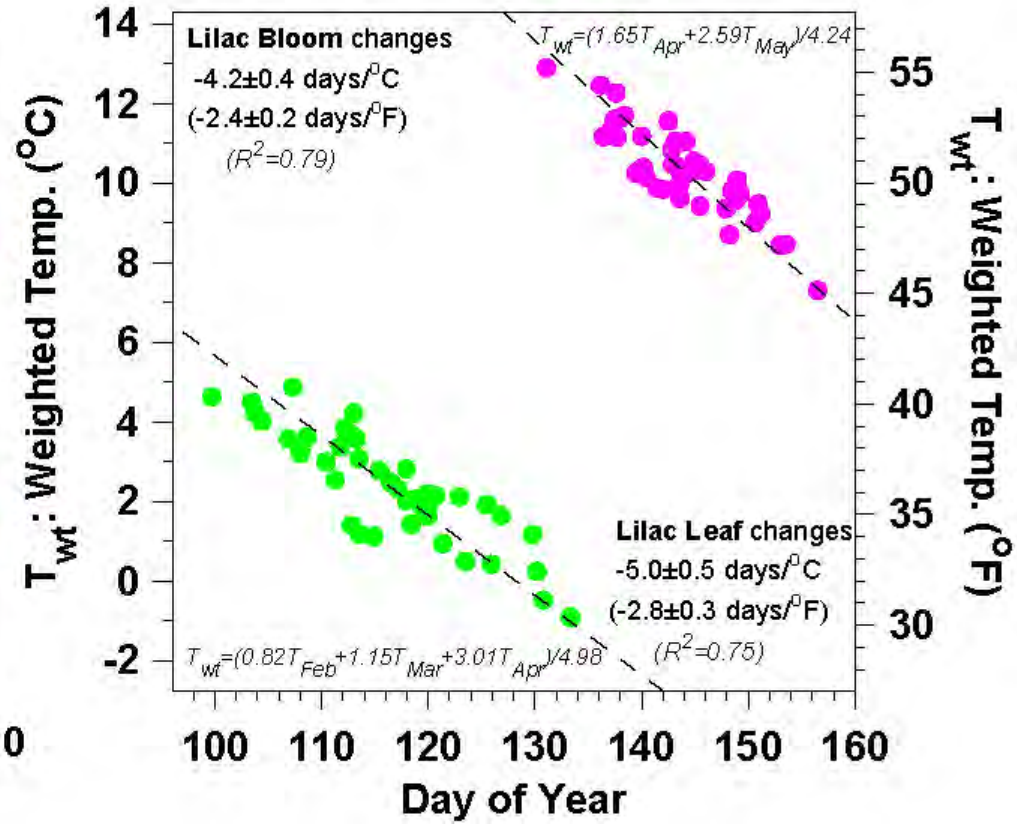
- **Hardy peaches: 2012**
- **More pests survive winter**

- **What is this?**
  - **Oct 1 2012**

- **Avocado**
  - **Didn't survive frost**
  - **2100 survive in CT**
  - **Our forests?**

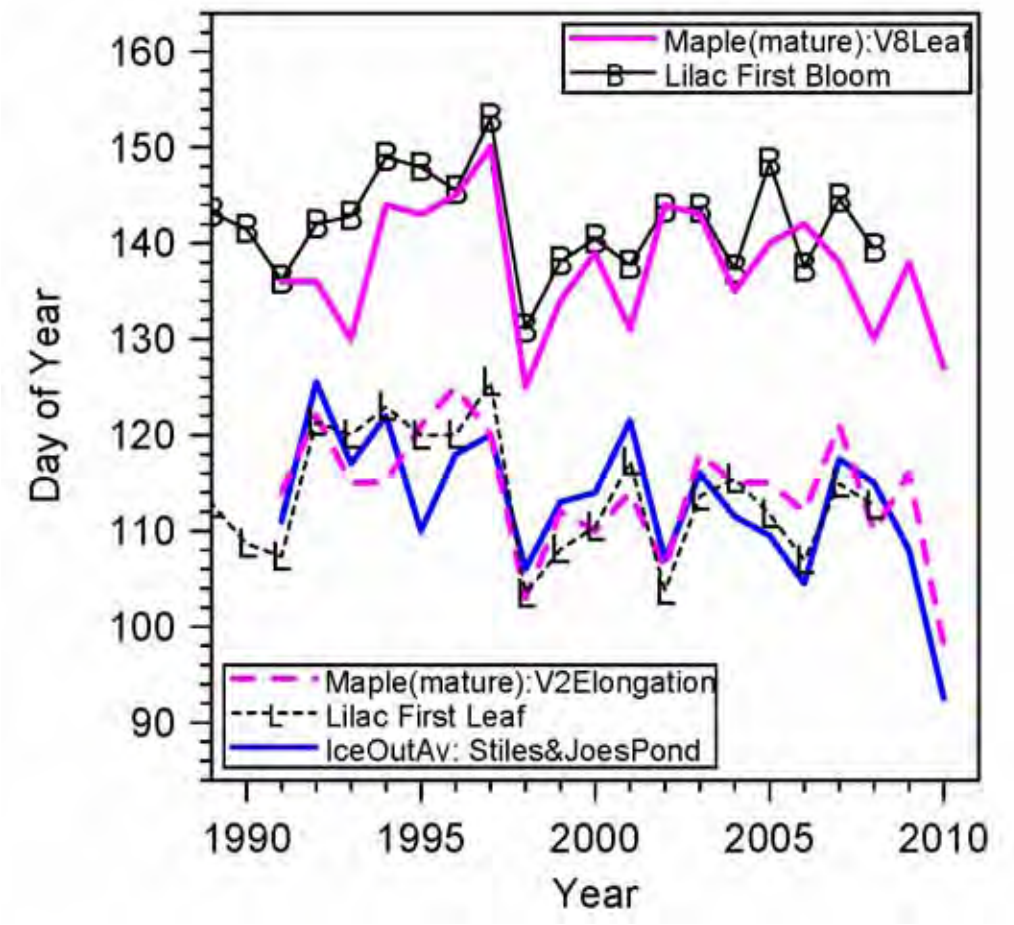
Lilac Leaf and Bloom





- **Leaf-out -2.9 days/decade; Bloom -1.6 days/decade**
- ***Large year-to-year variation related to temperature:***
  2.5 days/ °F (4.5 days/°C)

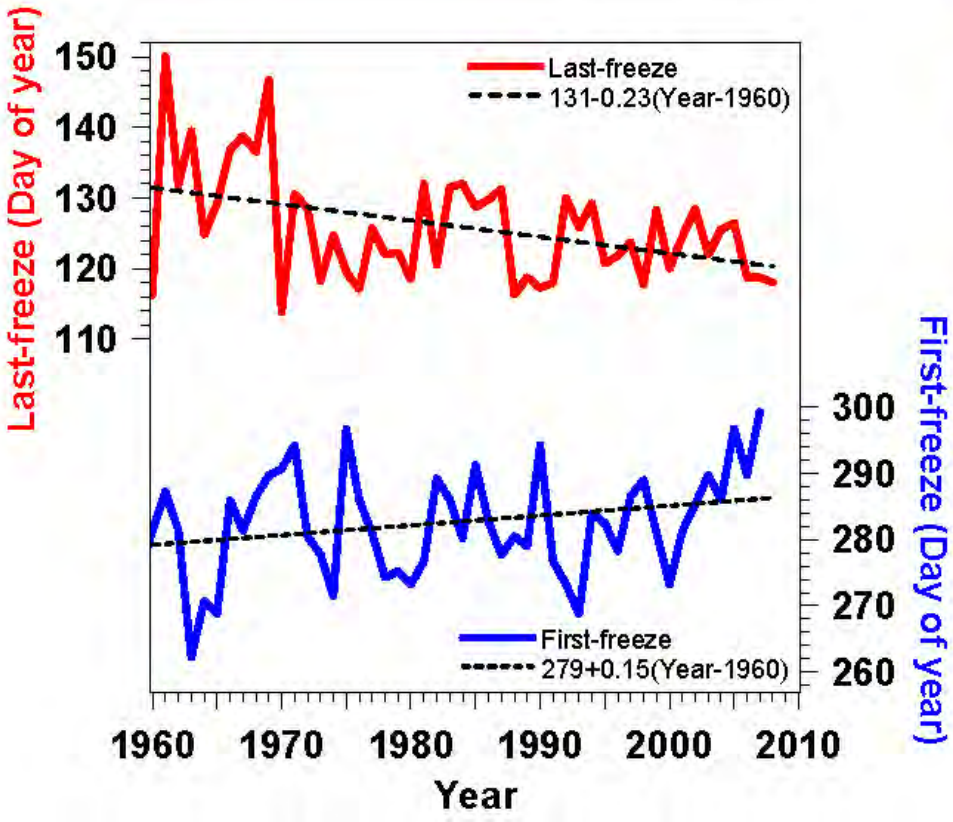
Sugar Maples in Spring

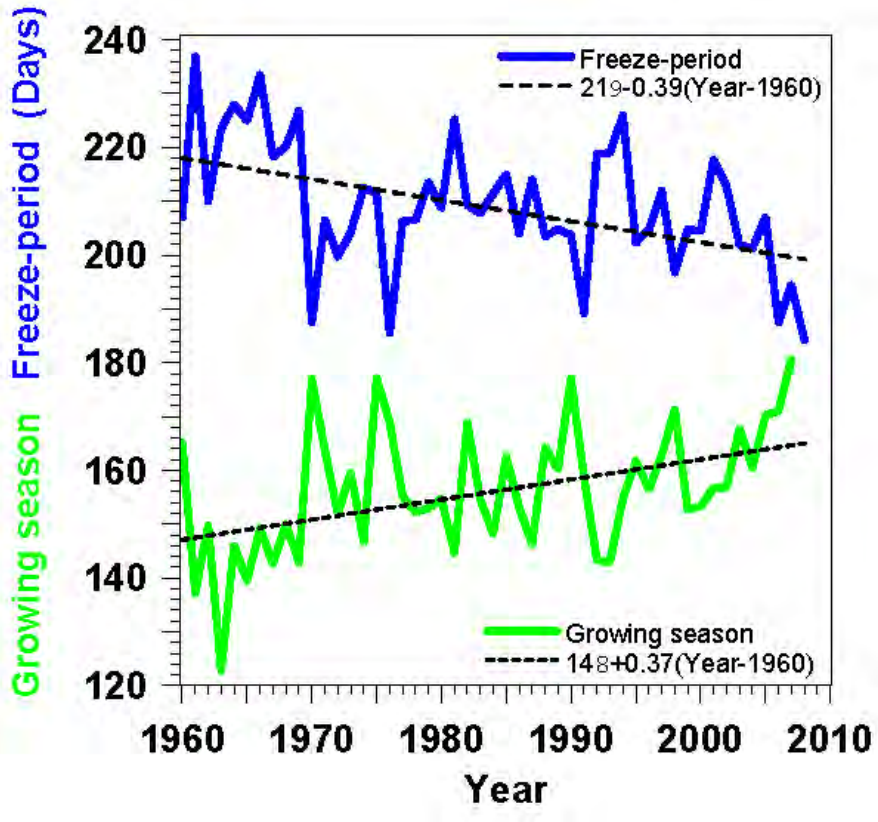


- **Ice-out, lilac leaf, maple bud elongation correlated**
- **Lilac bloom and maple leaf-out correlated**

Data: Sandy Wilmot, ANR

First and Last Frosts Changing





- **Growing season for frost-sensitive plants increasing 3.7 days / decade**
- ***Important for agriculture; local food supply***

January 2, 2012

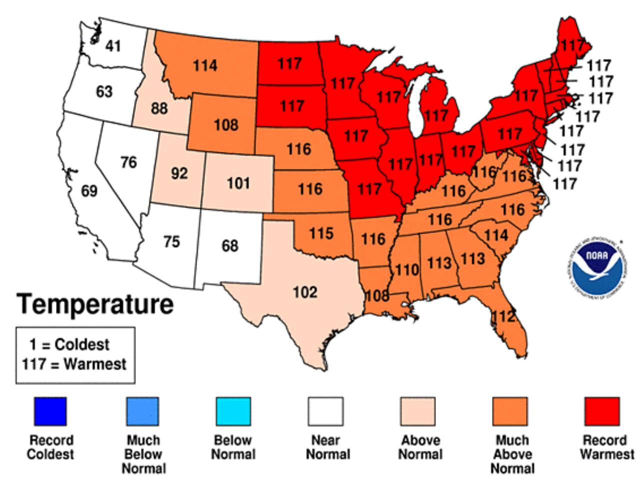
March 11, 2012

October 2011– March 2012

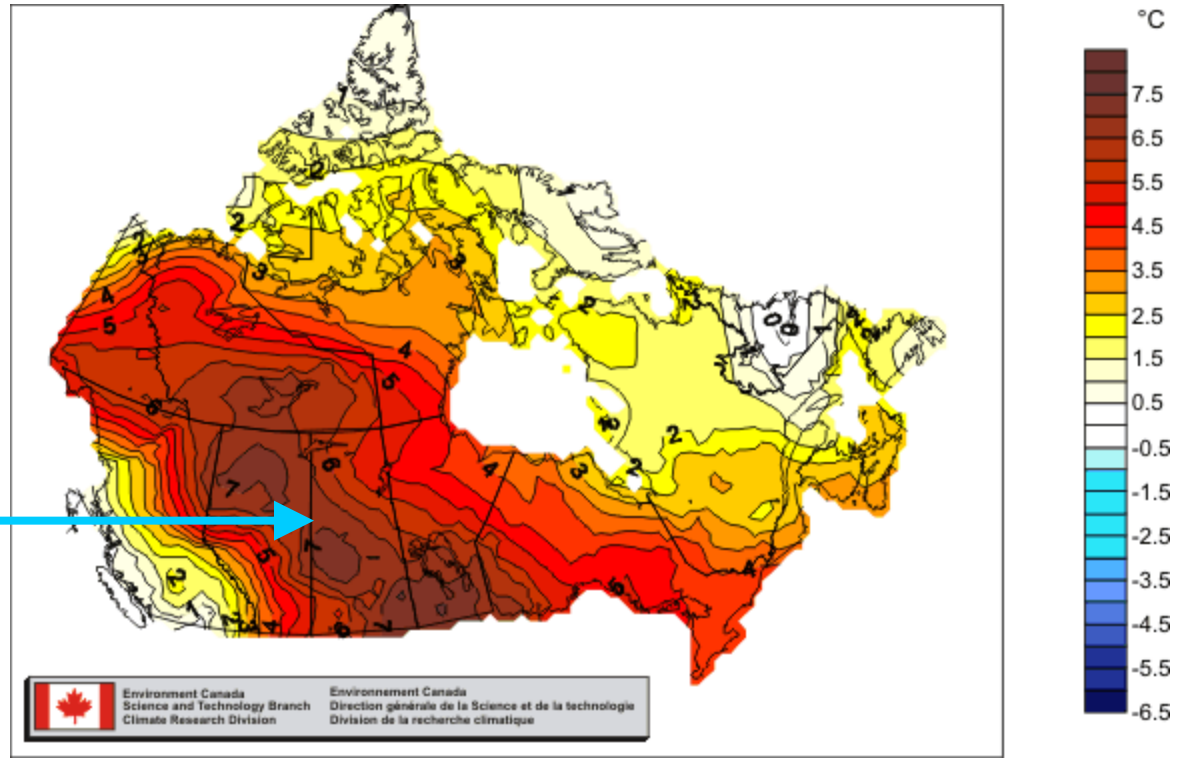
- **Warmest 6 months on record**
- **My garden frozen only 67 days**
- **No permanent snow cover west of Green Mountains**
- **Contrast snowy winter 2010-11**

Oct 2011-Mar 2012 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



Across the border: Canada



+12ºF

- **Winter 2011-12: Far above "normal"**
  - **Canada's winters also warming 0.9ºF/decade**
- ***Climate doesn't see the border!***

Early Spring: Daffodils, Forsythia

79ºF on March 22, 2012

Pittsford Vermont

3/22/12

Pittsford Vermont

3/24/12

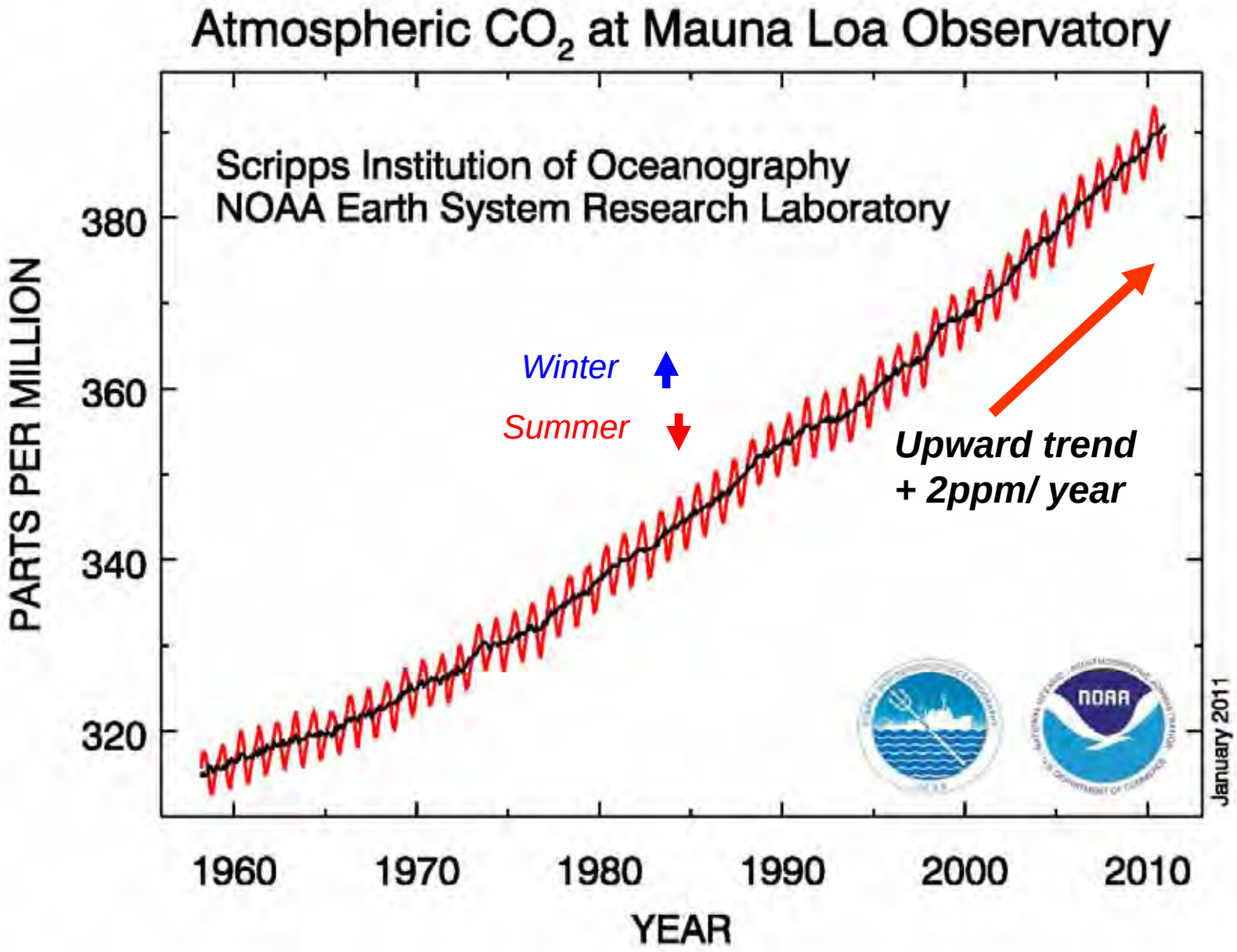
December 21, 2012

January 15, 2013

Past Winter

- Dec 25: Ground froze hard
- Dec 27-28: Foot of snow
  - Air temperatures plunged but ground thawed under snow
- Jan 12-14: 45-50F: Snow melted
- Jan 15: Time to dig again..
- Followed by freeze-up.. Melt
- Final Melt - March 11

Carbon Dioxide Is Increasing



Why Is More Carbon Dioxide in the Air a Problem?

- **The air is transparent to sunlight, which warms the Earth**
- **But some gases in the air trap the Earth's heat , reradiate down, and keep the Earth warm (30^{o}C)**
- **These are "Greenhouse gases"- water vapor, carbon dioxide, ozone, methane (H_2O, CO_2, O_3, CH_4, CFCs..)**
- **CO_2 is rising fast: by itself only a small effect**

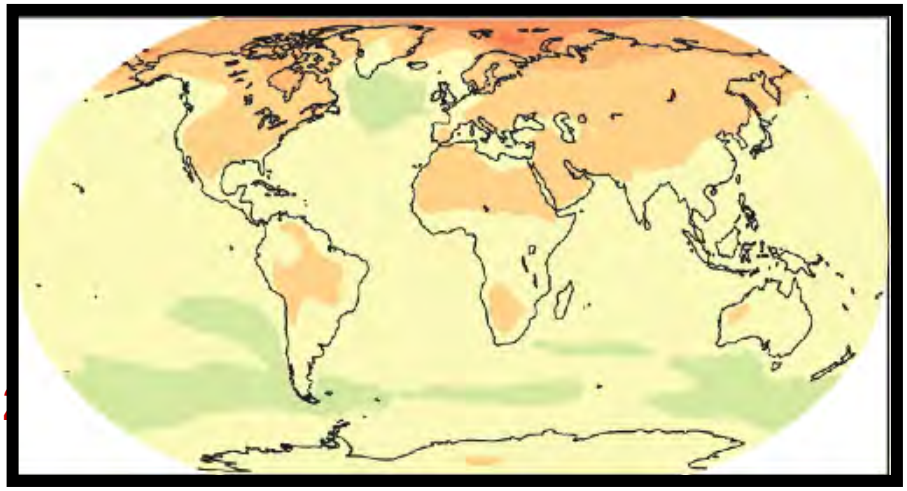
But as CO_2 Increases, Strong Water Cycle Feedbacks

- **Earth warms, and evaporation and water vapor in the air increases and this triples the warming**
- **As Earth warms, snow and ice decrease, so less sunlight is reflected, so winters and the Arctic are warming faster**
- **Doubling CO_2 will warm Earth about 5°F**
  - **Much more in the North, over land, in winter**
  - **Climate change we are seeing in Vermont will continue**

Predicted Change in Temperature

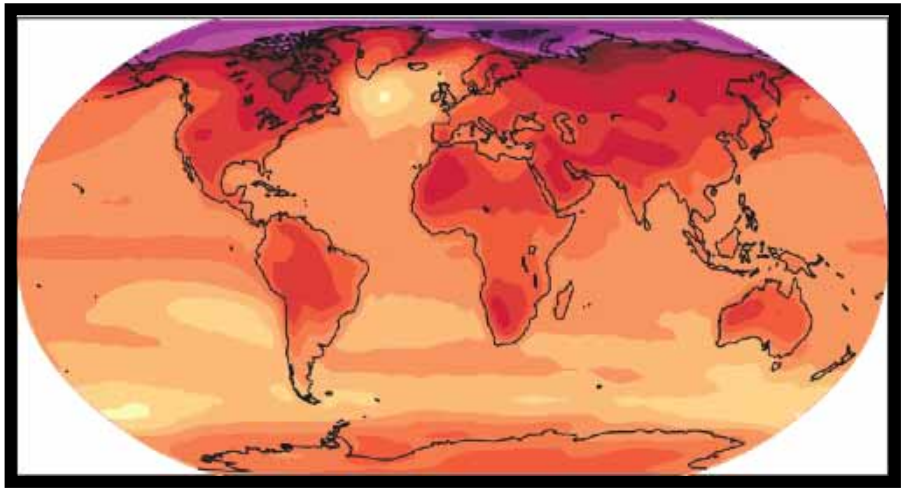
2020-2029 and 2090-2099, relative to 1980-1999 (ºC)

“Committed”

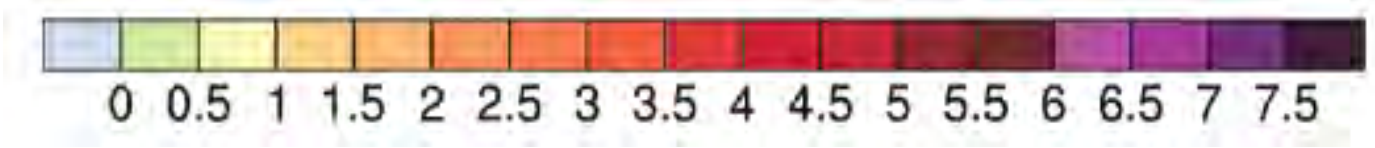


(We did nothing for the last 20 years)

Still up to us!



(We could halve this if we act now)

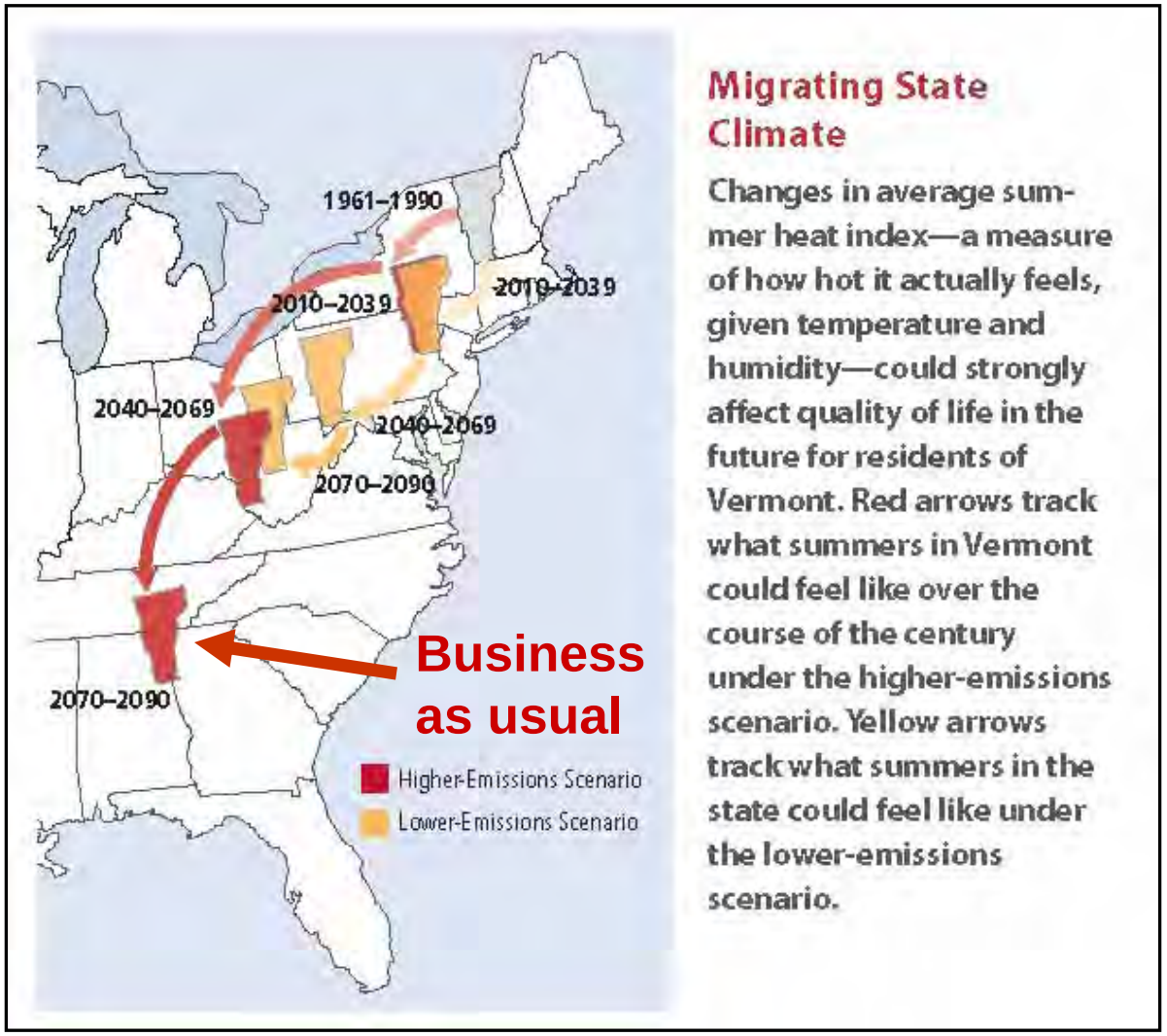


[ºC]

Vermont's Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US



NECIA, 2007

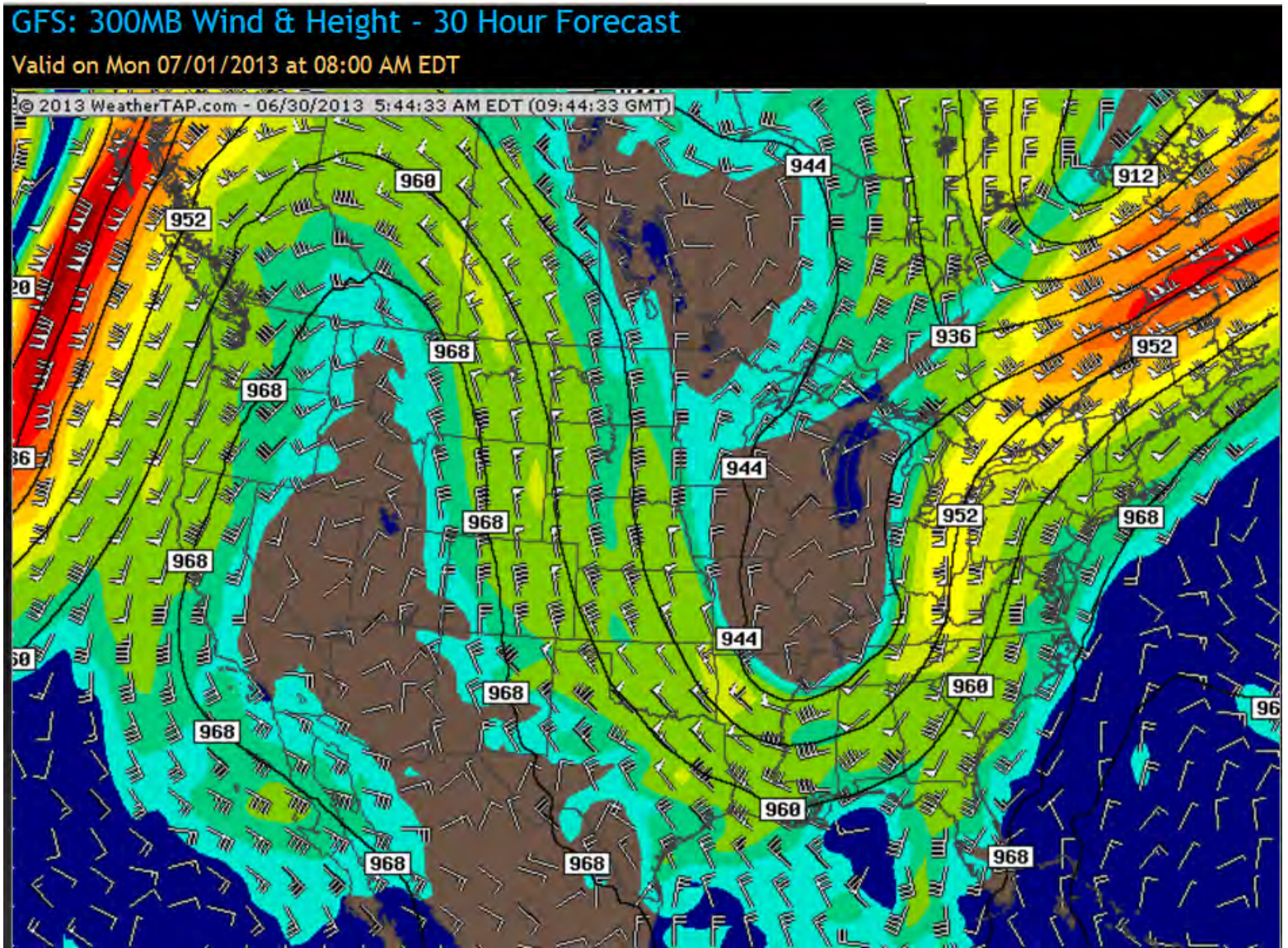
Extreme Weather (precip.)

- **Precip. is condensation of atmospheric water vapor - larger latent heat release drives storms**
- ***Saturation vapor pressure at cloud-base increases steeply with temperature (4%/ºF)***

- **Quasi-stationary large-scale flow means longer rain events in low-pressure convergent regions, and longer droughts in high-pressure divergent regions**
- ***As climate changes, quasi-stationary large-scale modes appear to be more frequent***
  - ***Cause may be Arctic warming: needs more study***

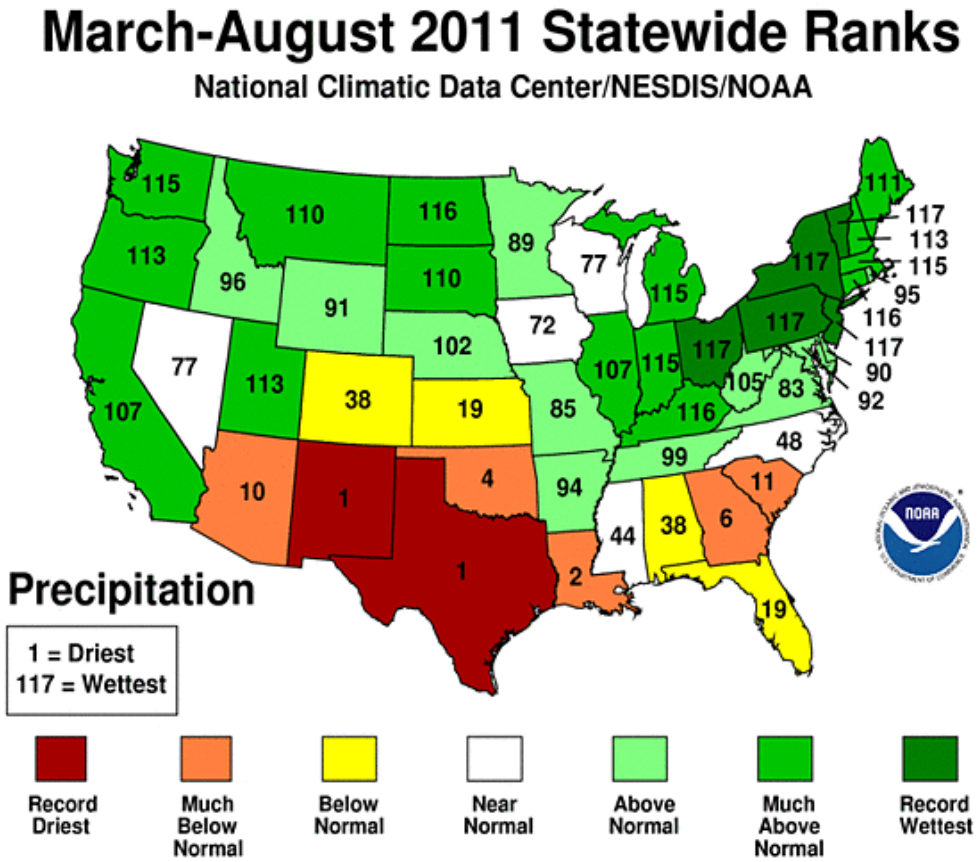
Jet Stream Patterns Slowing Down and Amplifying, Giving More Extreme Weather

(Francis and Vavrus, 2012)



2011 Floods: VT and NY

- **Record spring flood: Lake Champlain**
- **Record flood with tropical storm Irene**



March-August, 2011

- **Record wet : OH to VT**
- **Record drought: TX & NM**
- **'Quasi-stationary' pattern**

2011 Classic Flood Situations

- **Spring flood: heavy rain and warm weather, melting large snowpack from 2010 winter**
  - **70F (Apr. 11) and 80F (May 27) + heavy rain**
  - **record April, May rainfall: 3X at BTV**
  - **Severe floods on Winooski and Adirondack rivers**
  - **Lake Champlain record flood stage of 103ft**
- **Irene flood: tropical storm moved up east of Green Mountains and Catskills**
  - **dumped 6-8 ins rain on wet soils**
  - **Extreme flooding**
  - **(Floyd on 9/17/1999 had similar rain - but with dry soils there was less flooding)**

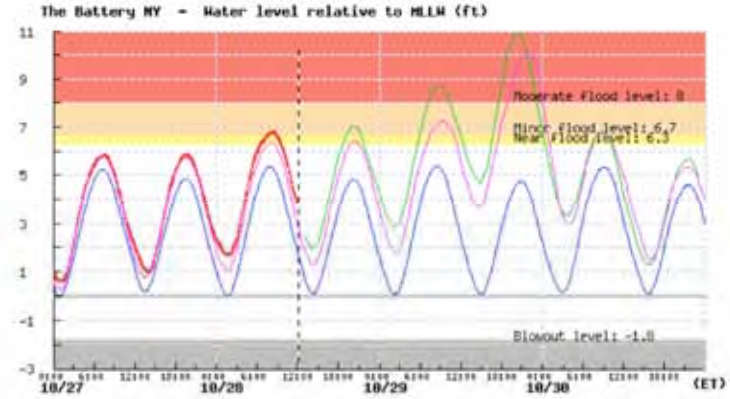
Three Successive Years of East-Coast Tropical Storm Disasters

- **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; 8 million lose power**

Disasters Happen in Strong Storms

- **Hurricane Sandy hits NYC and floods subway tunnels: Oct 29 2012**

- **Extreme weather event + climate change = disaster**
  - **≈ 1ft rise in mean sea-level**
  - **Gulfstream warm + 5ºF**
  - **Blocking high: NE Canada**
  - **13 ft storm surge**



Blocking Pattern - Unique track

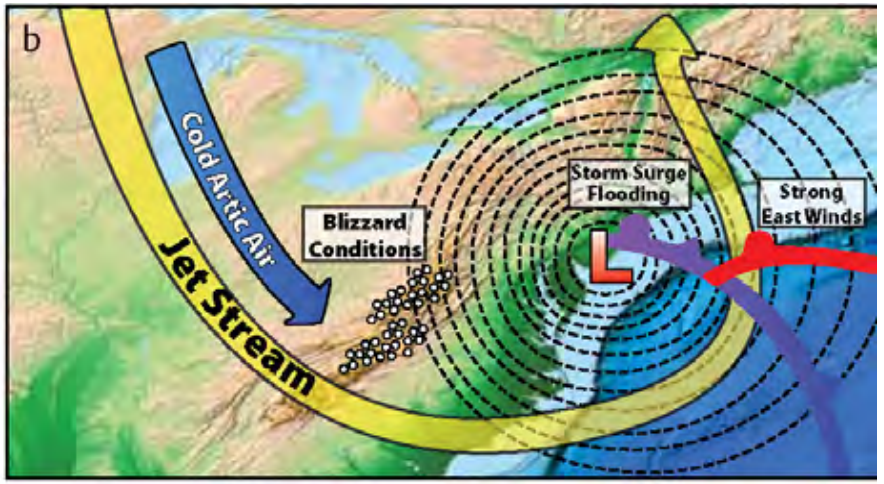


Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical and extra-tropical storm systems, the hybrid Superstorm Sandy made landfall in New Jersey and New York, bringing strong winds, storm surge, and flooding to areas near the coast and blizzard conditions to Appalachia.

- **High amplitude jet-stream + blocking pattern + strong cyclone + hurricane winds + full moon high tide = record storm surge + disaster**

[Greene et al., Oceanography, 2013]

Outline

- Science of climate change
  - Global scale: actual and future
  - What is happening to Vermont

- The transition we face
  - Managing the earth system
  - Why is it difficult?

Discussion

What Lies Ahead?

- **Accelerating change, increasing extremes**
- **Increasing adaptation and rebuilding costs**
- **Environmental damage that will transform or destroy ecosystems- locally and globally**
- **Freely dumping waste streams from society into atmosphere, streams, lakes and oceans is unsustainable – long term costs now exceed $1000 trillion**
- ***Will need fossil carbon tax (a "waste" tax) to incentivize mitigation and pay for the long-term costs***

Can We Stop "Dangerous Climate Change"?

(UNFCCC 1992)

- **Yes: Quickly stabilize atmospheric CO_2**
- **This means an 80% drop in CO_2 emissions!**
- **This is very difficult**
  - **Fossil fuels have driven our industrial growth and population growth for 200 years**
  - **Our "lifestyle" has become dependent on fossil fuels**

‘Managing’ Our Relation to the Earth System

- **Our technology and our waste-streams are having large local and global impacts on the natural world and must be carefully managed — *because we are dependent on the natural ecosystems***
- **We need new ‘rules’ because**
  - **Our numbers and industrial output are so large**
  - **Maximizing consumption and profit have led to present predicament**

A Path Towards ‘Sustainability’

- ***Necessary to***
- **Minimize the lifetime of human waste products in the Earth system and eliminate waste with critical biosphere interactions**
- **Maximize recycling and re-manufacturing to minimize waste-streams and the use of non-renewable raw materials**
- **Maximize the efficiency with which our society uses energy and fresh water**
- **Maximize the use of renewable resources**

Efficiency Comes First

- **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 & oil shale reserves are enough to push CO_2 to 1,000 ppm—and in time melt icecaps**
    - **Can we "sequester" CO_2 (put it back in the earth)?**

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 —so the result is tremendous successes and catastrophic failures**

Why Is It Difficult for Us?

- **Fossil fuels reserves are worth $20-30T**
- **Regulating emissions of CO_2 is an "unfair cost" to the "free market"**

- **Real Earth system issues being ignored**
- ***Our politics are facing collapse – becoming a fantasy disconnected from the real world***

Will Attitudes Change?

- **Irene changed Vermont's attitude**

- **State moving in right direction**
- **Local community solutions essential**

- **We need to push for Federal and global strategies**

As Climate Changes….

- **Everything is interconnected**

- **Human society and waste streams: people's choices and actions**
- **Precipitation, seasons, streams, and forests; habitat and wildlife**

- **Keep your eyes open to the big picture and draw connections**
- **Talk to your neighbors and ask what you can do**
- **Stay connected to Vermont's natural environment**

What Do We Need?

- **So we need honest, truthful, smart pathways 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 processes & limits**
  - **That deal with society's fears**

The Future Is Not Our Past

- **Collectively, we create the future, so we need to plan for a transition to a sustainable society that isn't powered by fossil fuels**
- **Energy efficient society**
  - **Housing: button-up; build better**
  - **Electricity use: efficient appliances, off if not in-use**
  - **Transportation: efficient vehicles**
- **Renewable technologies to replace fossil fuels**

Discussion

Background papers:

http://alanbetts.com/

- ***Vermont Climate Change Indicators***
- ***Seasonal Climate Transitions in New England***
- ***Extreme Weather and Climate Change***

http://www.anr.state.vt.us/anr/climatechange/Adaptation.html

Climate and Resilience

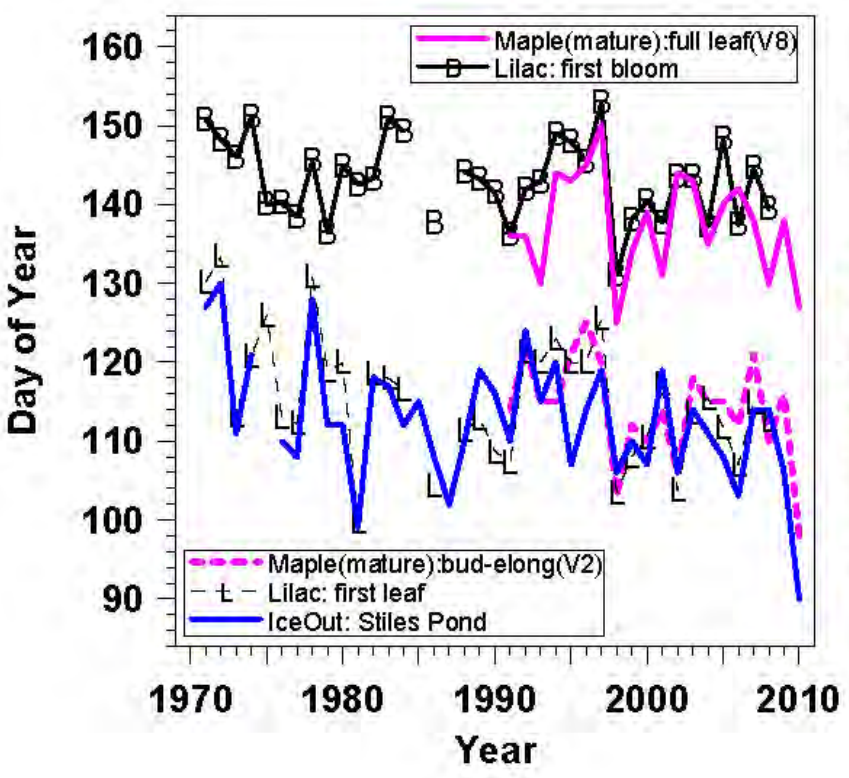
- **Trend to milder winters; longer growing season; earlier spring – variability large**
- **Trend to more precipitation in cool season; more wet snow and mixed in winter**
- **Warmer summers; heavier rain in summer; periods of drought – increase infiltration and water storage – *forests stabilize climate***
- **Agriculture issues**
  - **Build soil carbon and organic matter for water storage and fertility**
  - **Recycle nutrients and phosphorus**

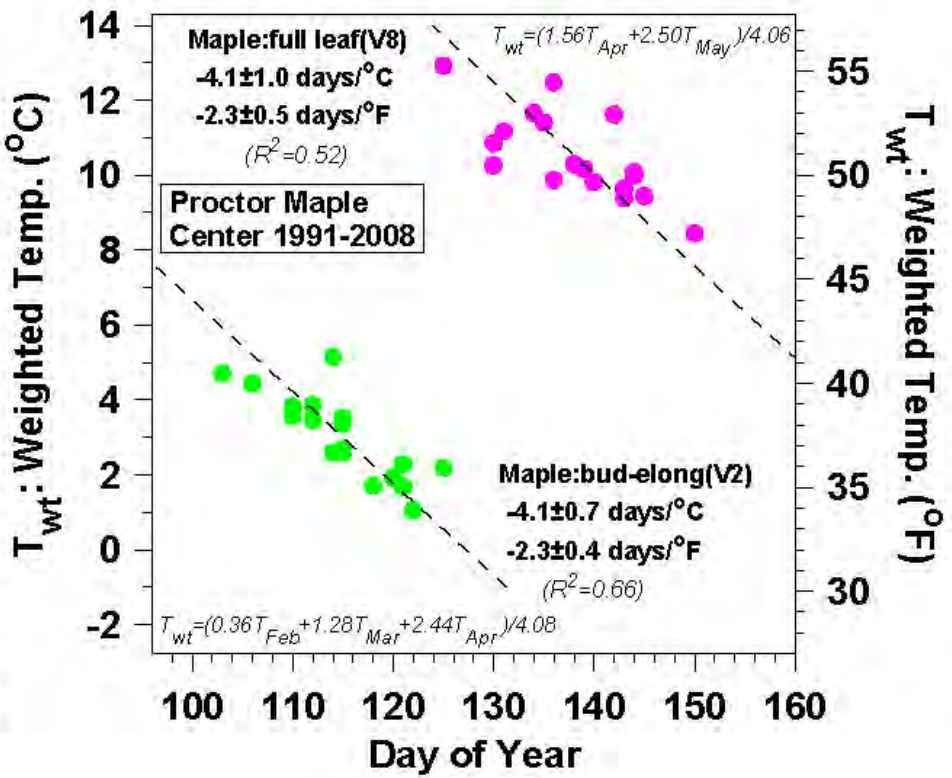
Increasing CO_2 is long-lived driver

Water: *Strong Positive Feed-backs*

- **GHGs up → Oceans, land warmer → Evaporation up**
- **Water Vapor up**
  - **WV infrared greenhouse up**
    - **Approx triples climate warming of planet**
    - **Locally reduces night-time cooling**
      - **Winter T_{min} increase: less severe winters**
      - **Longer growing season between frosts**
  - **Latent heat release in storms up**
    - **Increases precipitation rates**
      - **Increases precipitation extremes**
    - **Increases wind-speeds and storm damage**
    - **Increases snowfall from coastal storms in winter**
- **Snow and ice down, less sunlight reflected**
    - **Warmer Arctic in summer**
    - **Warmer northern winters**
  - **Less ice-cover: more evaporation**
  - **More lake-effect snowstorms**

Maples and Lilacs in spring





- **Maple bud elongation mirrors lilac leaf**
- **Maple leaf-out mirrors lilac bloom**

Fall Climate Transition

- **Vegetation postpones first killing frost**
- **Deciduous trees still evaporating: moist air with clouds**
- **Water vapor & cloud greenhouse reduces cooling at night and prevents frost**
- **Till one night, dry air advection from north gives first hard frost.**
- **Vegetation shuts down, leaves turn, skies become clearer and frosts become frequent**
- ***The opposite of what happens in Spring with leaf-out!***

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

Later frost: Growing season getting longer