Dealing with Climate Change

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RACC High School Projects

VT EPSCoR

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RACC
Research on Adaptation to Climate Change

Vermont EPSCoR
CWDD
Center for Workforce Development & Diversity

Outline

- **Science of climate change**
  - **Global and local**
  - **What is happening to Vermont?**
  - **Why is extreme weather increasing?**

- **The transition we face**
  - **Can we stabilize the climate?**
  - **Why is it difficult?**

Discussion…

Earth sustains life

- Burning fossil fuels is increasing greenhouse gases and melting polar ice
- Climate is warming and extreme weather is increasing
- Water plays crucial role everywhere

January 2, 2012: NASA

System Issues

- Human waste streams are transforming the Earth's climate, and human and natural ecosystems
- How will this affect landscape, water supplies, food system and human health?
- What strategies and mindset are needed to mitigate, adapt and build resilience in Vermont?
  - Is this an efficient way of doing this?
  - Can we manage our waste streams better?
  - Can I deepen my connection to the Earth?

Our Present Challenge

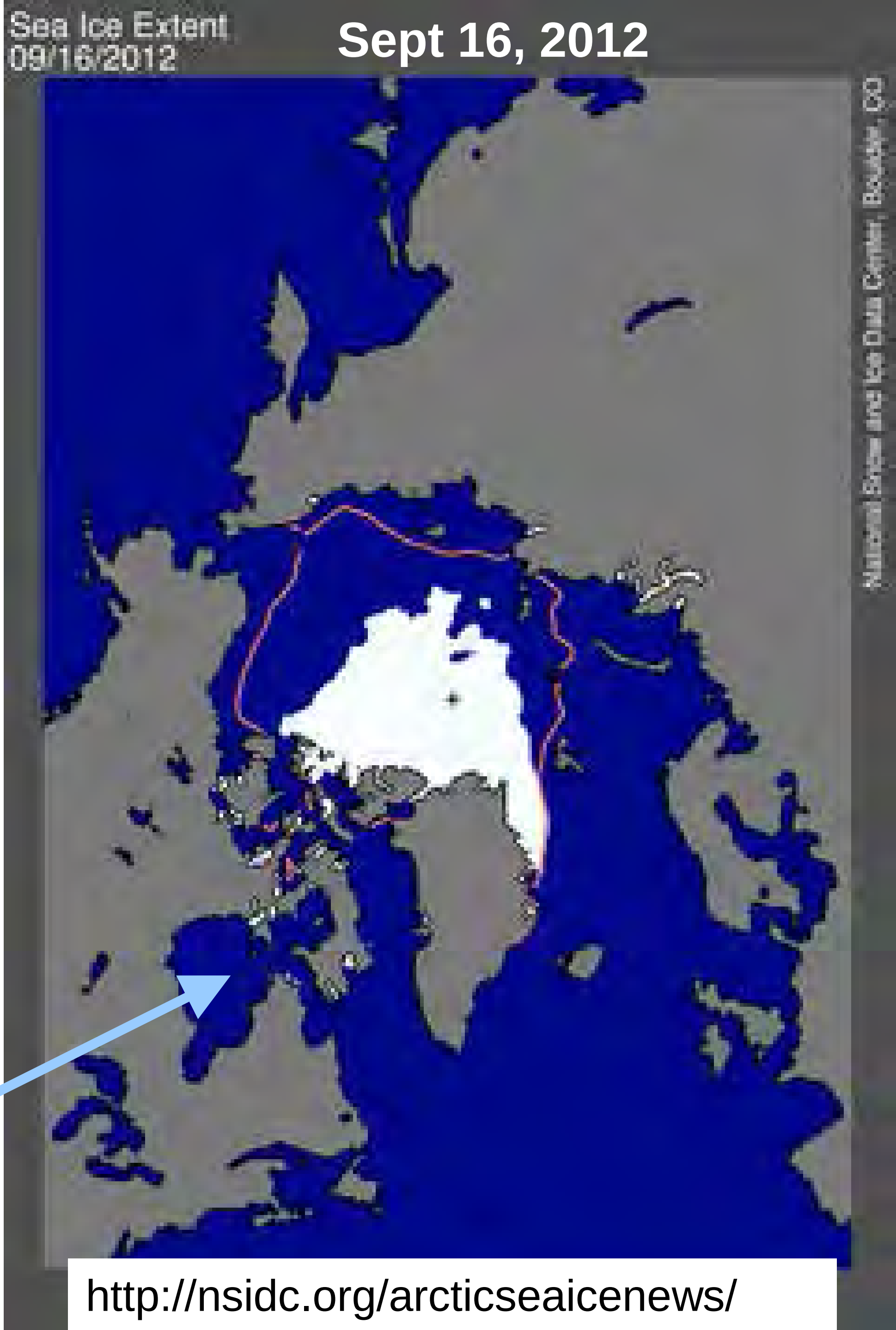
- **How to reintegrate**
  all that we know and understand

  – ***given the deep interconnectedness***
  of life & climate on Earth

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

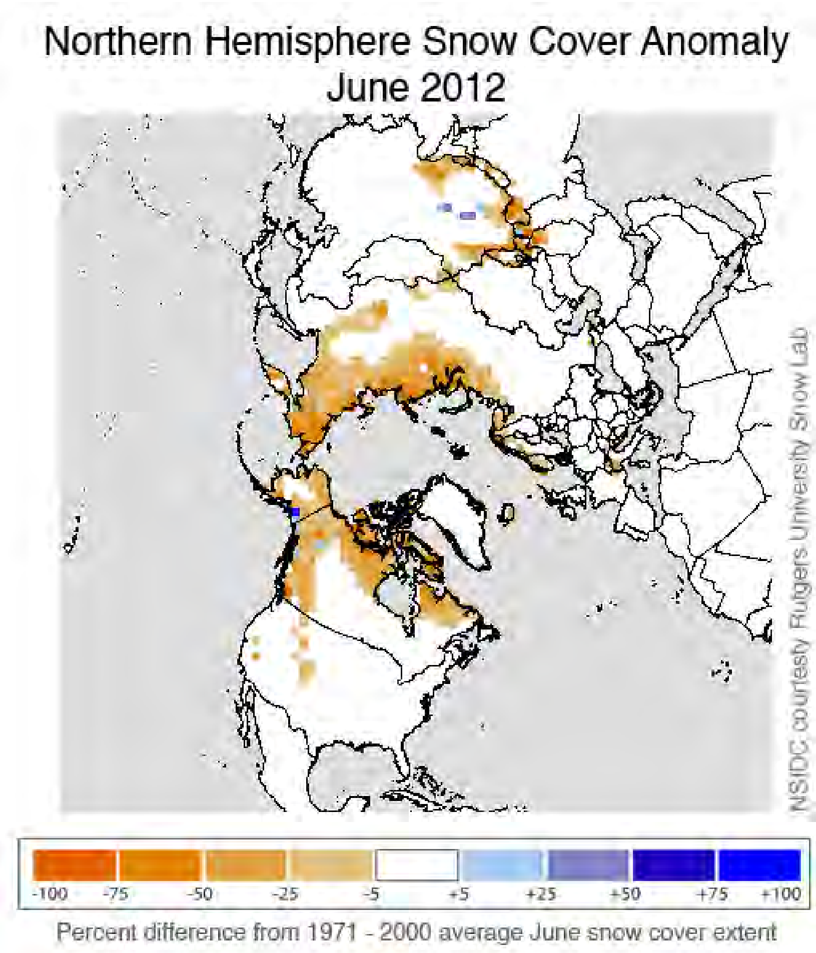
- ***Positive feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Ice thin: most 1-yr-old***

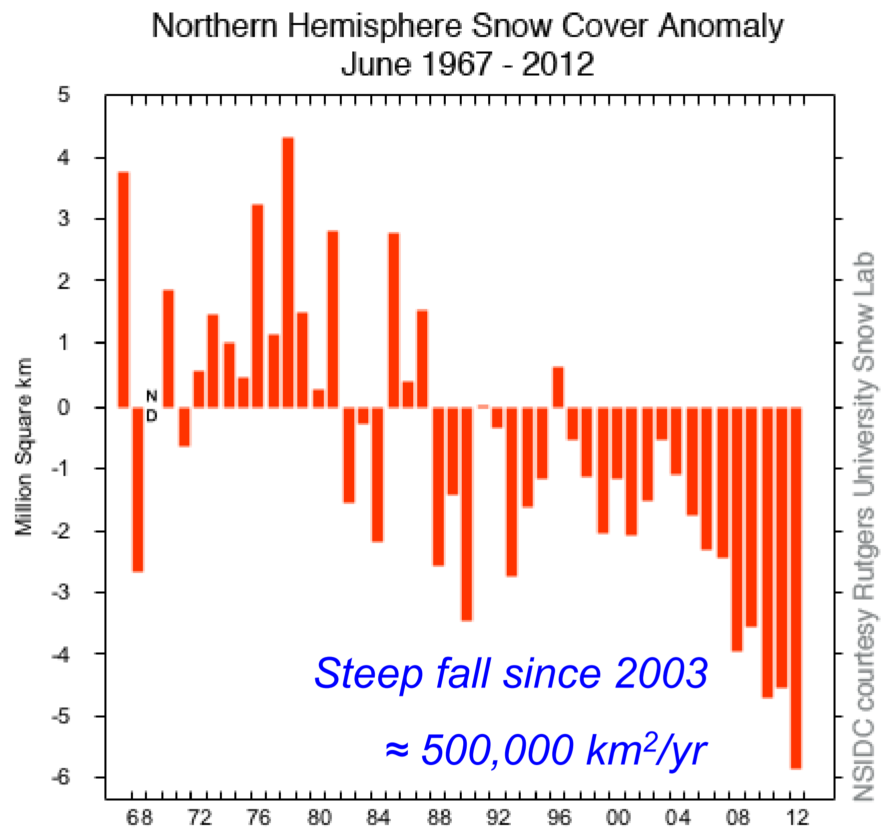
End of Nov. 2011 Hudson Bay was still nearly ice-free



http://nsidc.org/arcticseaicenews/

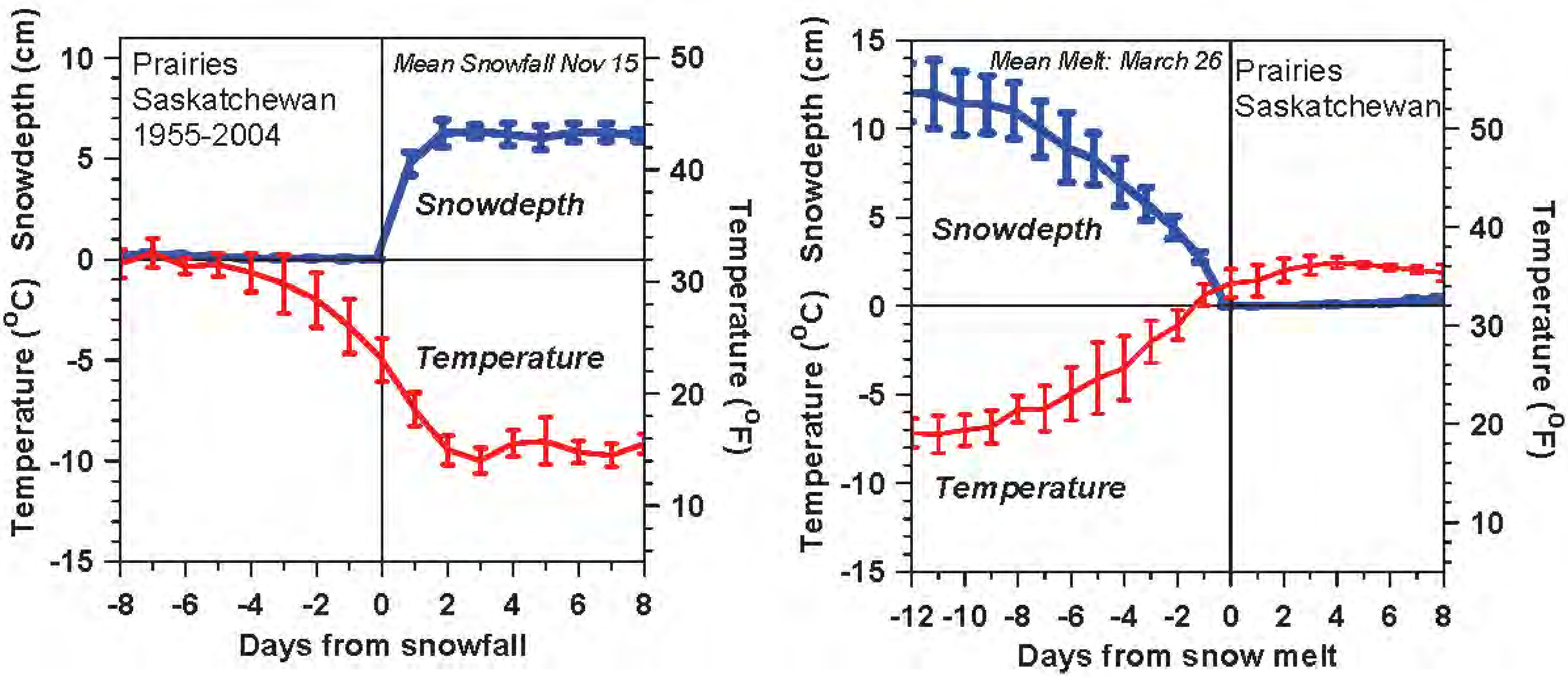
June 2012 snow cover minimum





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

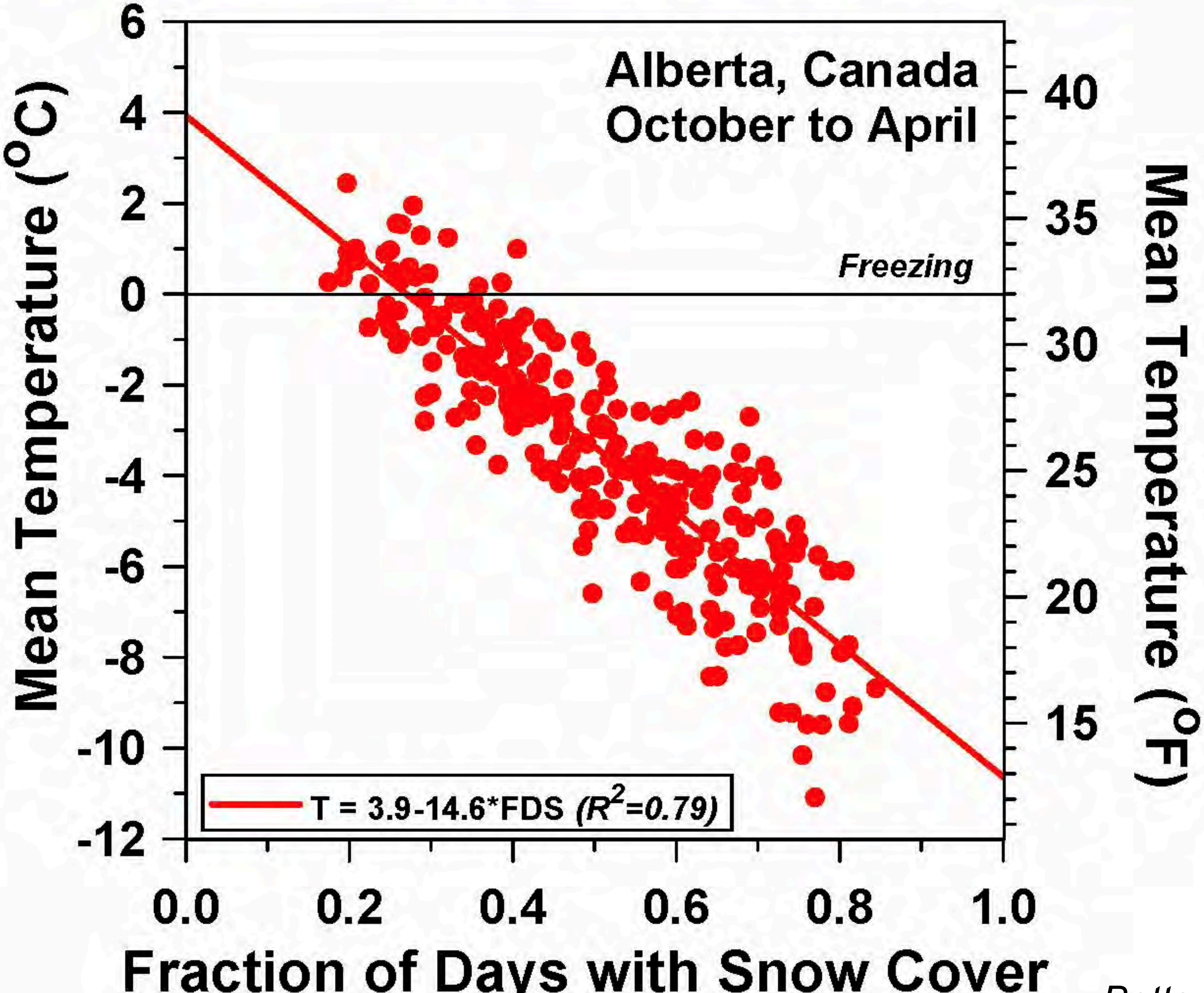
Snowfall and Snowmelt



- **Temperature falls 18F (10C) with first snowfall**
- **Similar change with snowmelt**
- ***Snow reflects sunlight; reduces evaporation and water vapor greenhouse – changes 'local climate'***

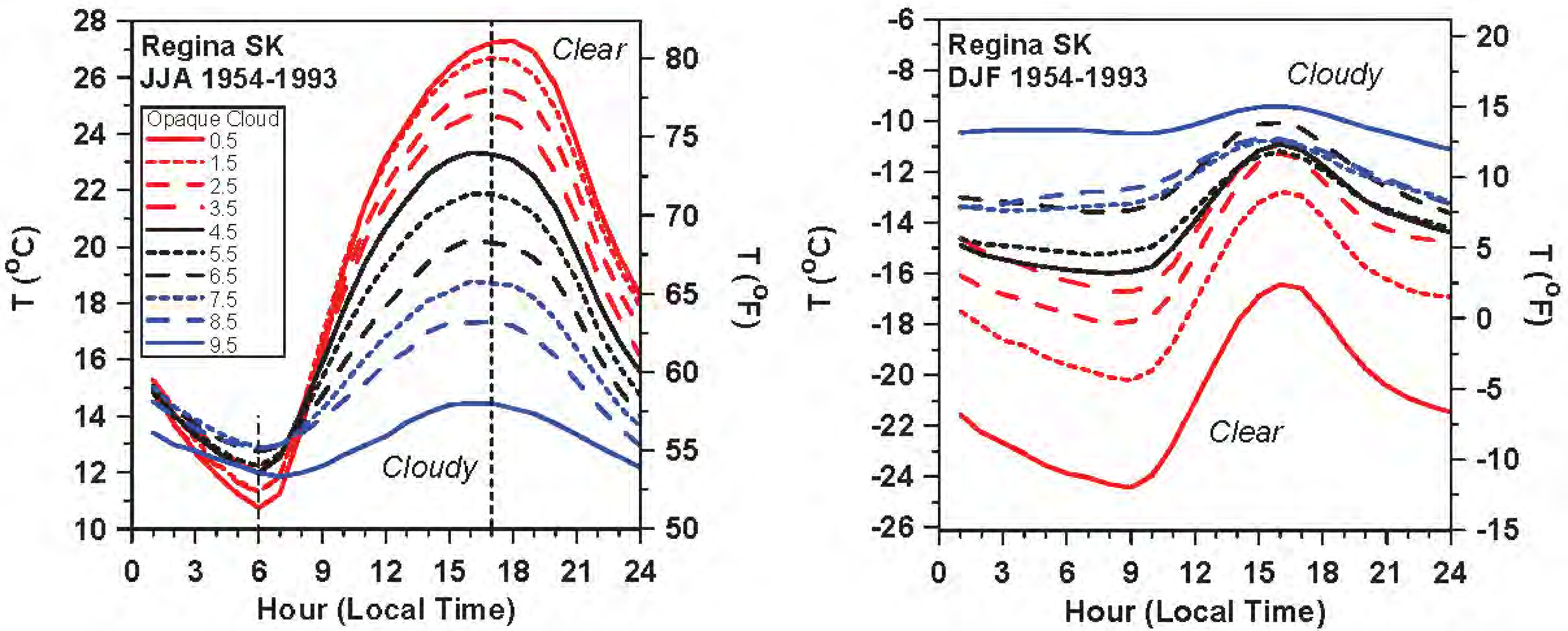
Betts et al. 2014

More snow cover - Colder temperatures



Betts et al. 2014

Clouds: Summer & Winter Climate



- **Summer:** **Clouds reflect sunlight (soil absorbs sun)**
  - **no cloud, hot days; only slightly cooler at night**
- **Winter:** **Clouds are greenhouse (snow reflects sun)**
  - **clear & dry sky, cold days and very cold nights**

Betts et al. 2013

What Is Happening to Vermont?

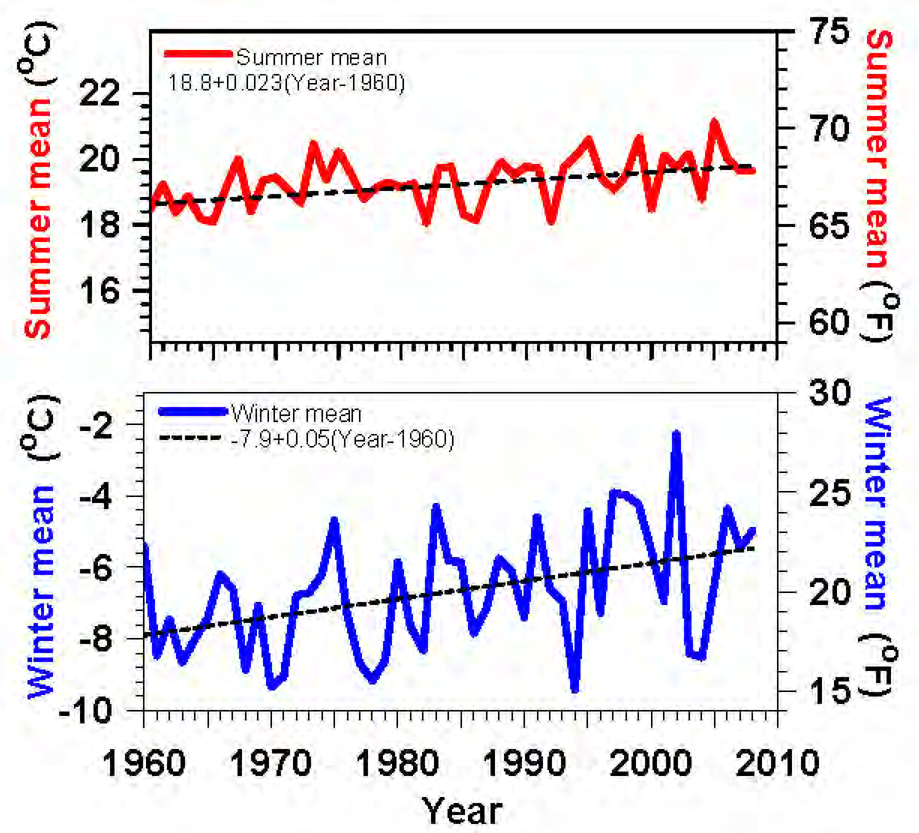
- **PAST 40/50 years** ***(global CO_2 forcing detectible)***
- **Warming twice as fast in winter than summer**
- **Winter minimums increasing even faster**
- **Lakes frozen less by 7 days / decade**
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**

(Betts, 2011)

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

Vermont Temperature Trends
1961-2008

- **Summer +0.4°F / decade**

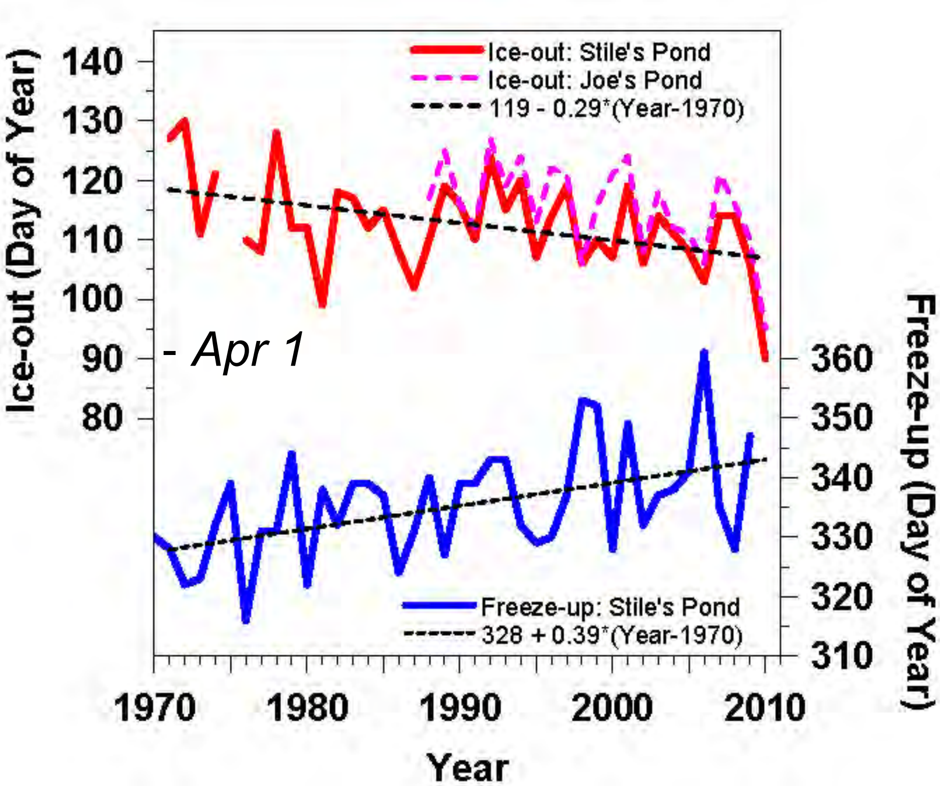


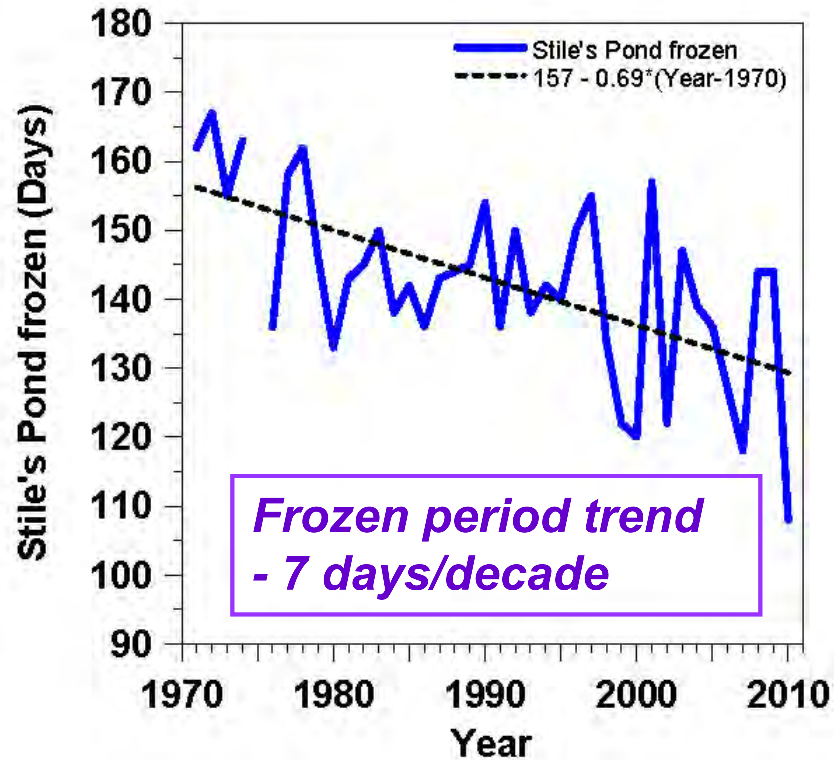
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**

- ***Less snow (and increased water vapor) drive larger winter warming***

Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast





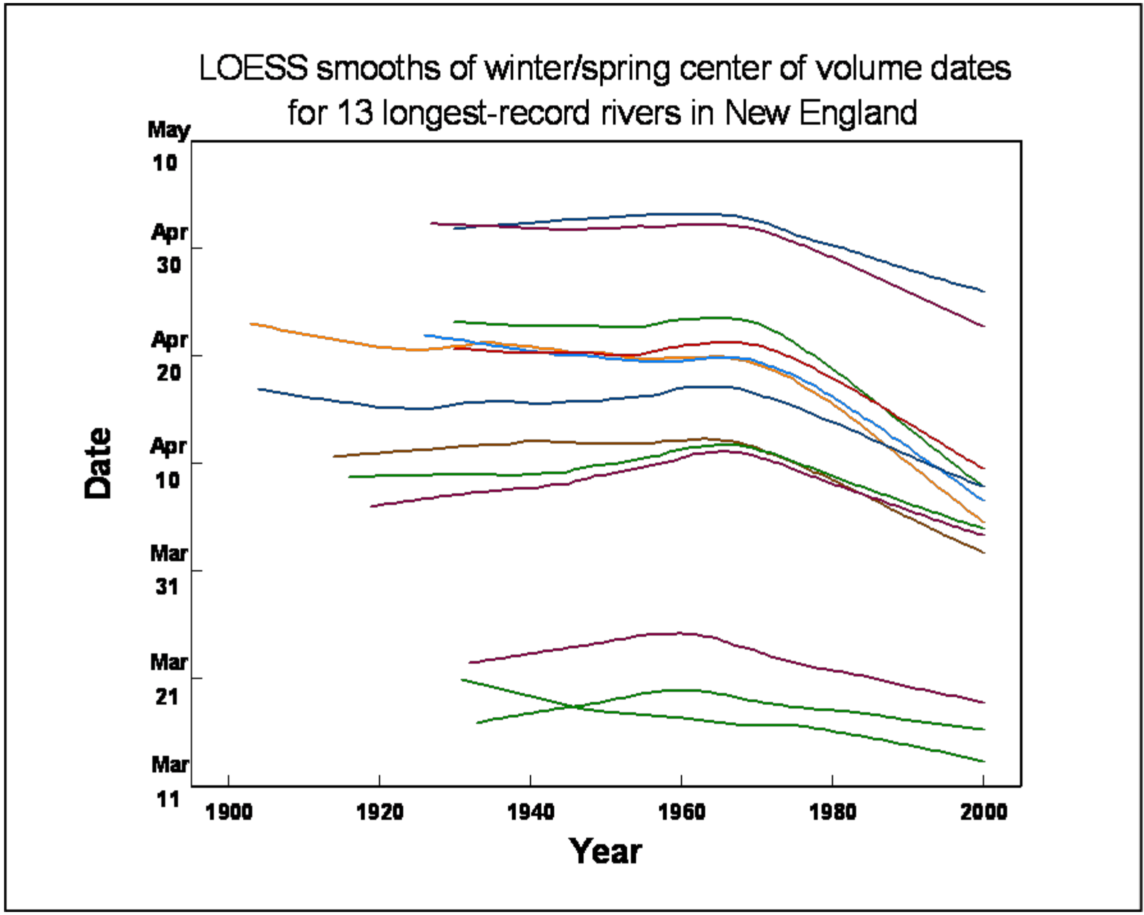
- Ice-out earlier **by 3 days / decade**
- Freeze-up later **by 4 days / decade**
- *Soil ice probably similar*

Hydrology Sensitive to Climate

Lent (2010), USGS, Me

- **Peak spring runoff**
- ***Earlier in northern New England in recent years***

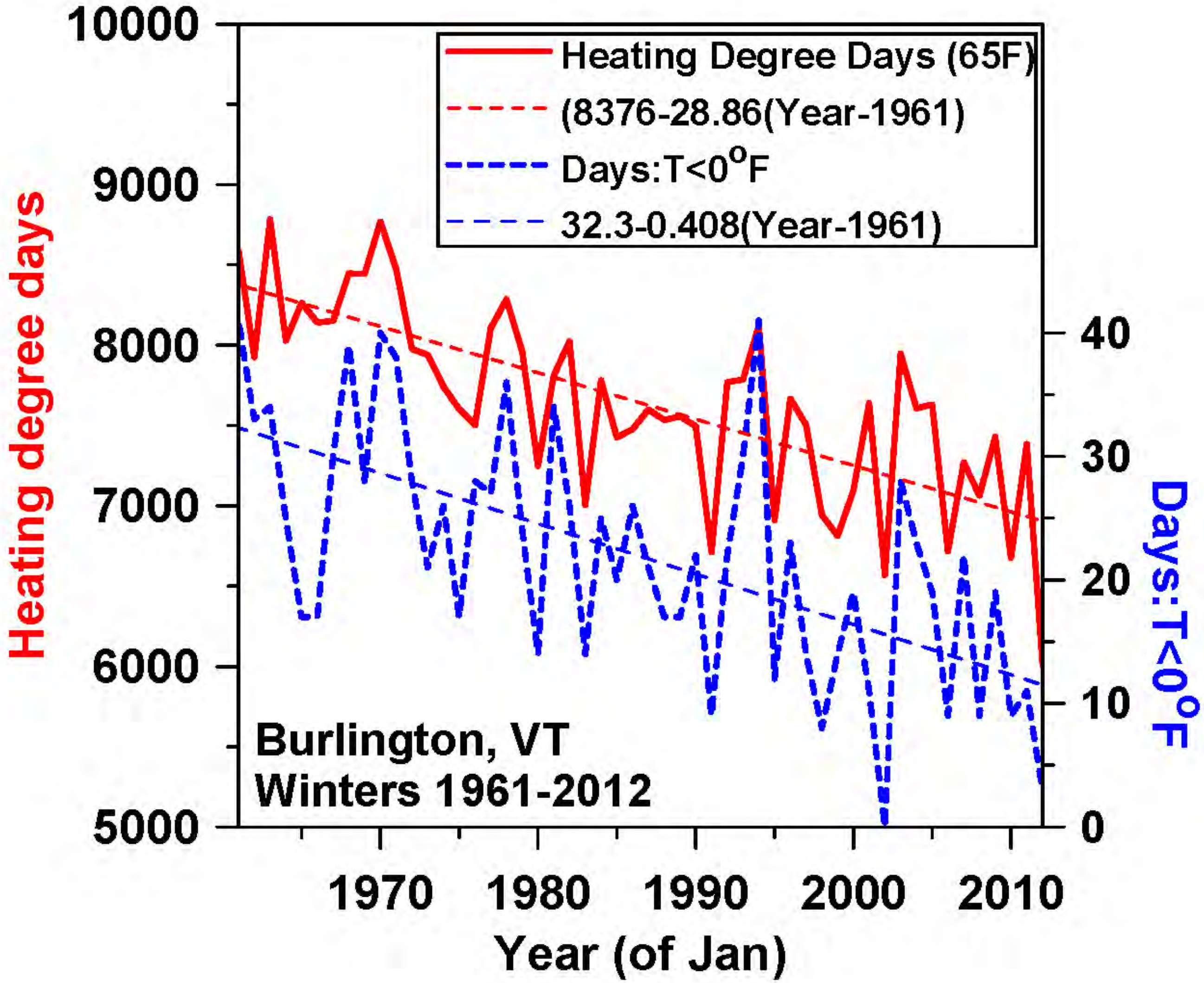
  ≈ <u>3 days/decade</u>
- ***Timing related to air temperatures in Spring***



(Hodgkins and others, 2003)

Heating Degree Days and Days below 0°F (Burlington)

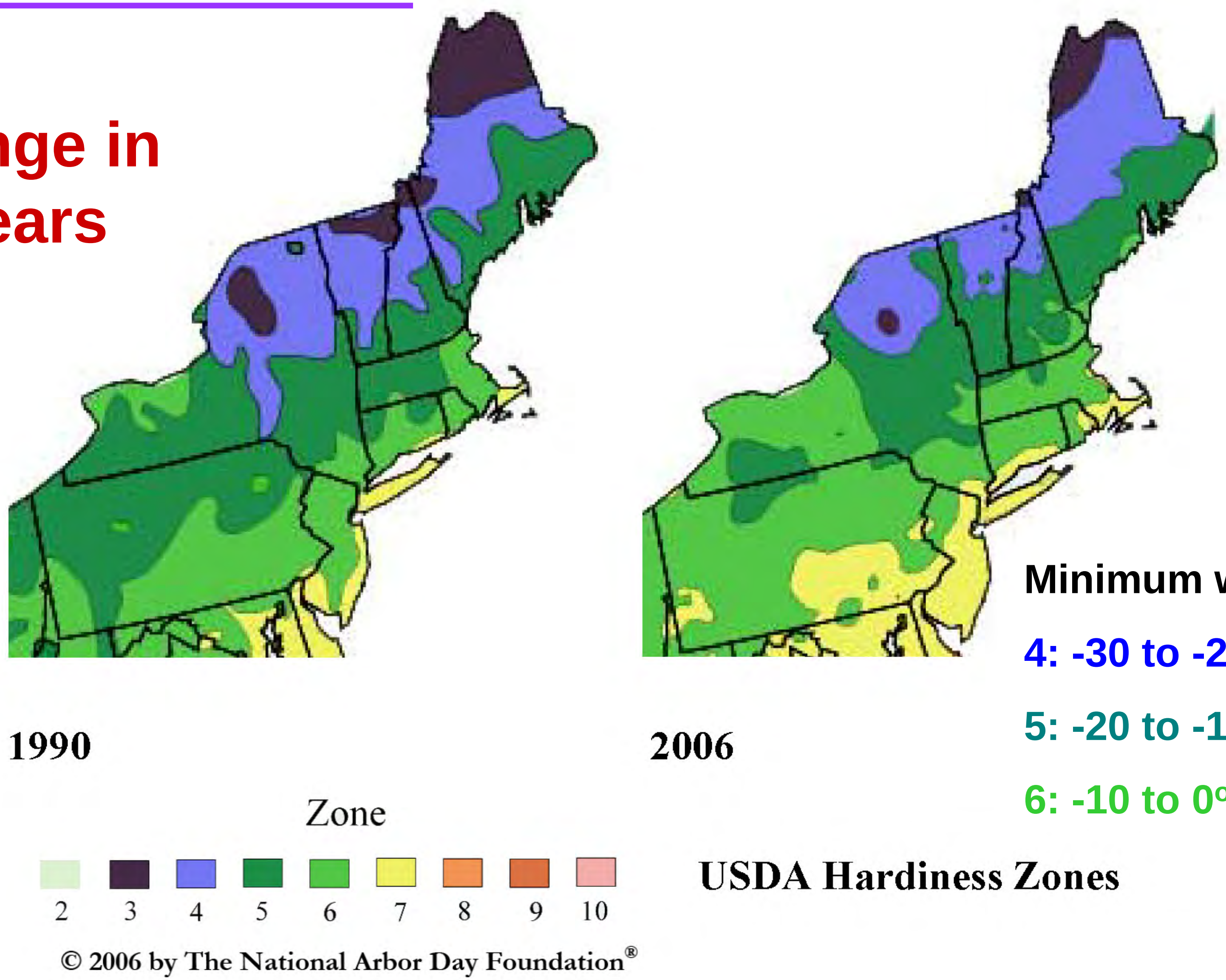
- **Heating degree days *falling 290/decade***
- **T_{min}<0°F *falling 4 days /decade***



Winter Hardiness Zones

– *winter cold extremes*

Change in 16 years



Minimum winter T

4: -30 to -20^{o}F

5: -20 to -10^{o}F

6: -10 to 0^{o}F

USDA Hardiness Zones

Detailed Map
(most recent)

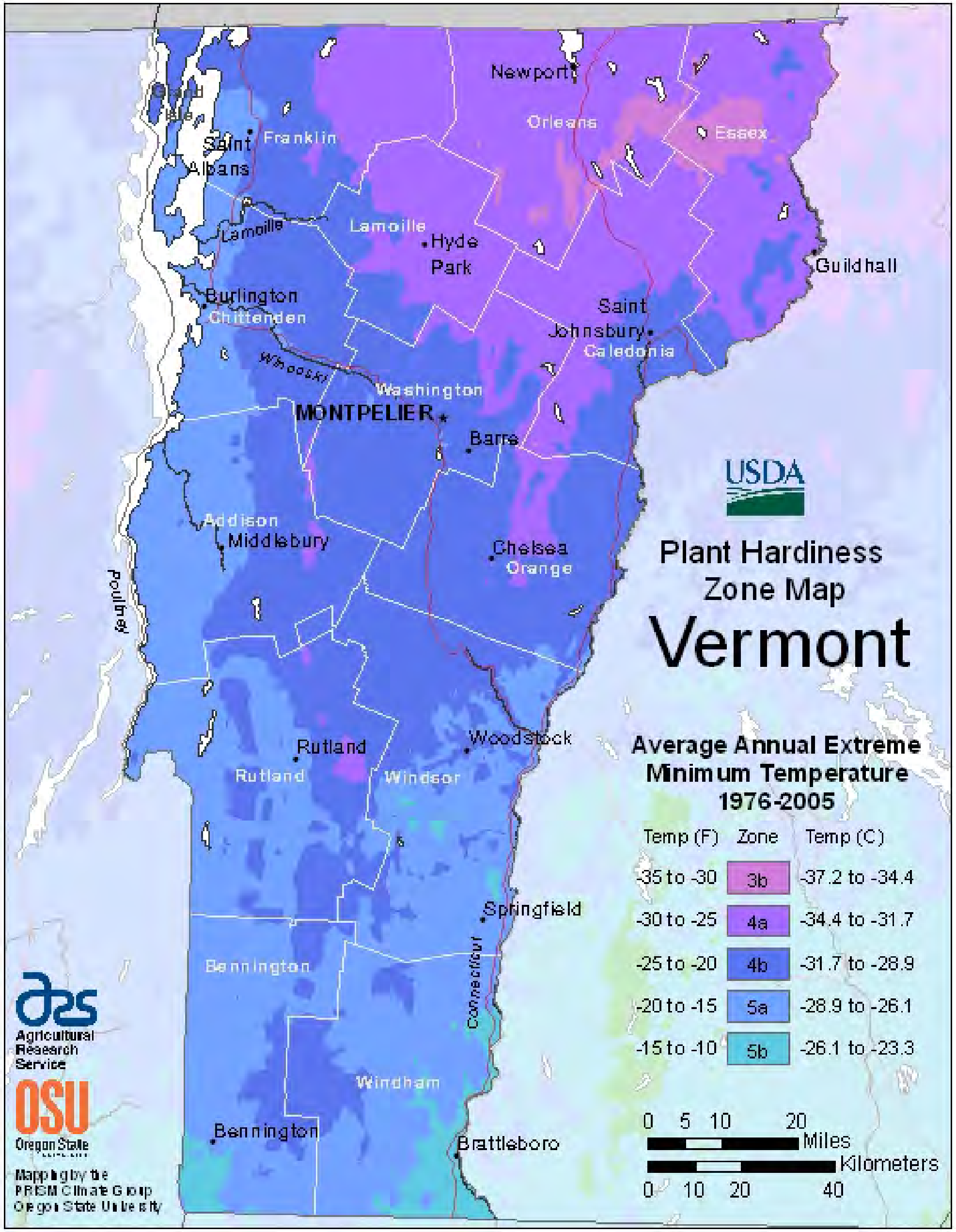
- **VT Hardiness Zone Map 1976-2005**
  - **<u>mean 1990</u>**
  - **South now zone 6**

- **Half-zone in 16 yrs = 3.1ºF/ decade**
  - ***<u>triple the rise-rate of winter mean T</u>***

  - ***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**

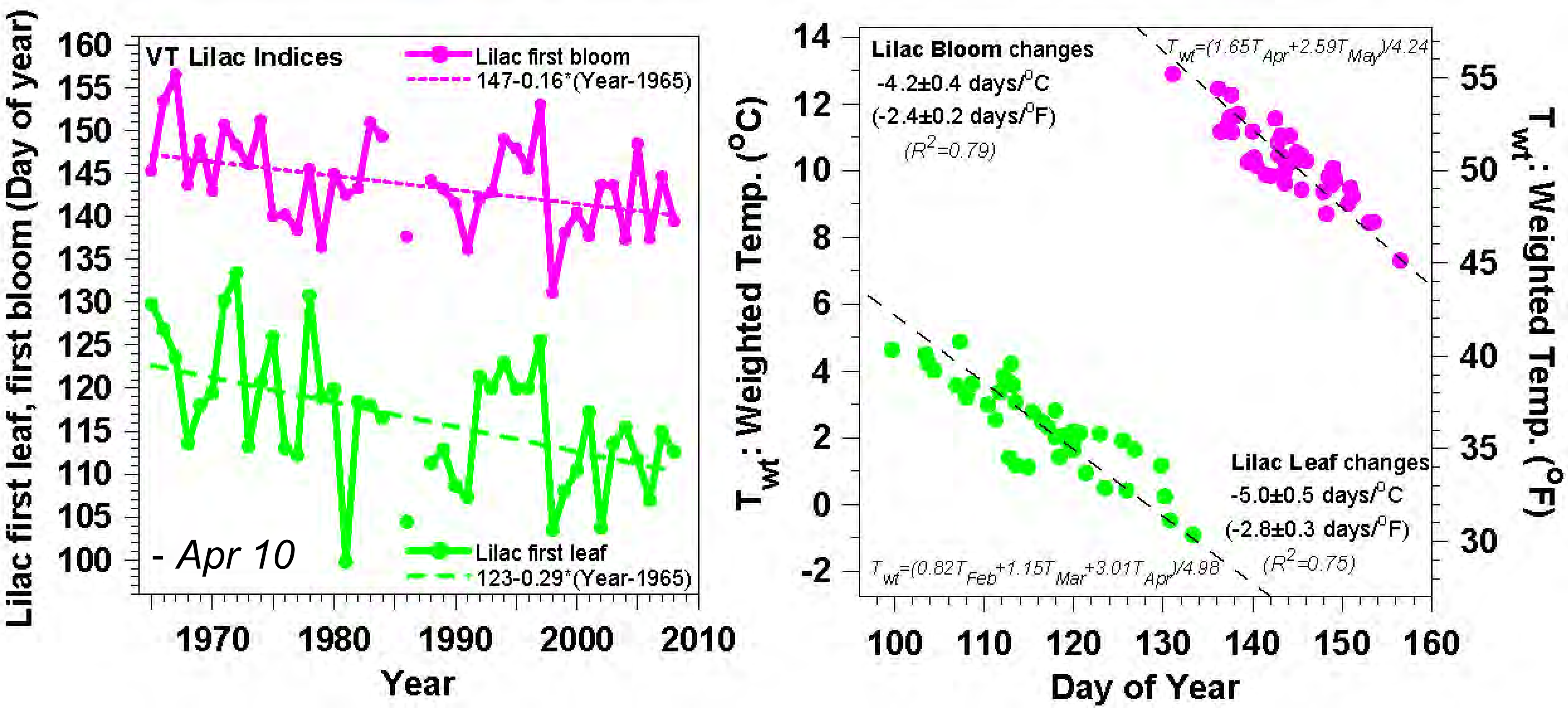
Bennington & Brattleboro are becoming zone 6

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

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

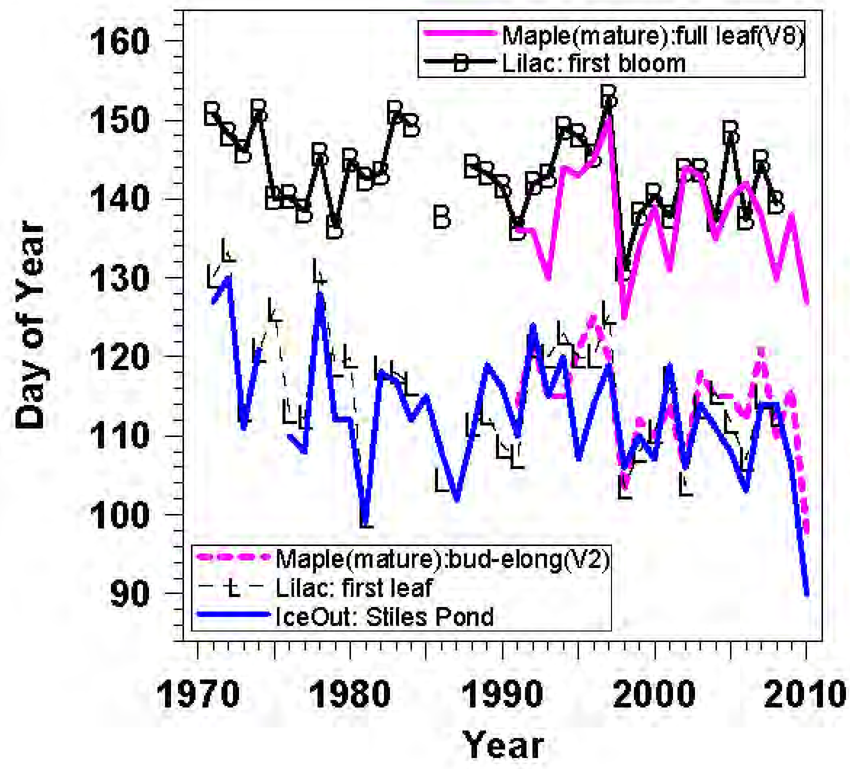
- **Avocado**
  - **Didn't survive frost**
  - **2100 survive in CT**
  - **Our forests?**

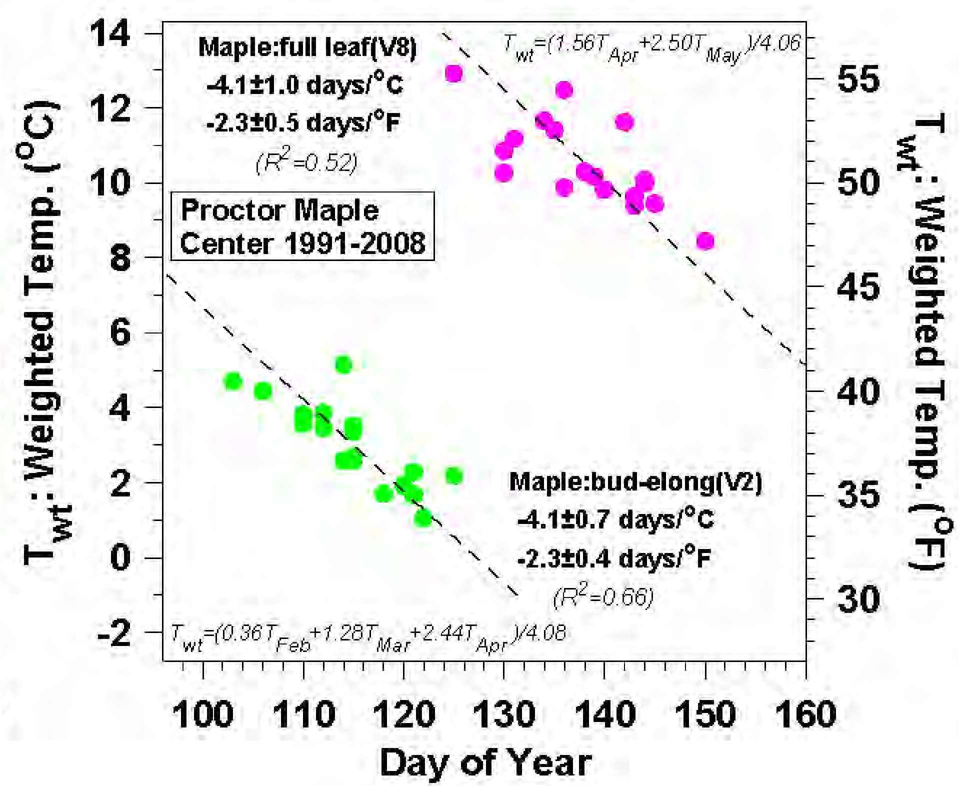
Lilac Leaf and Bloom



- **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)***

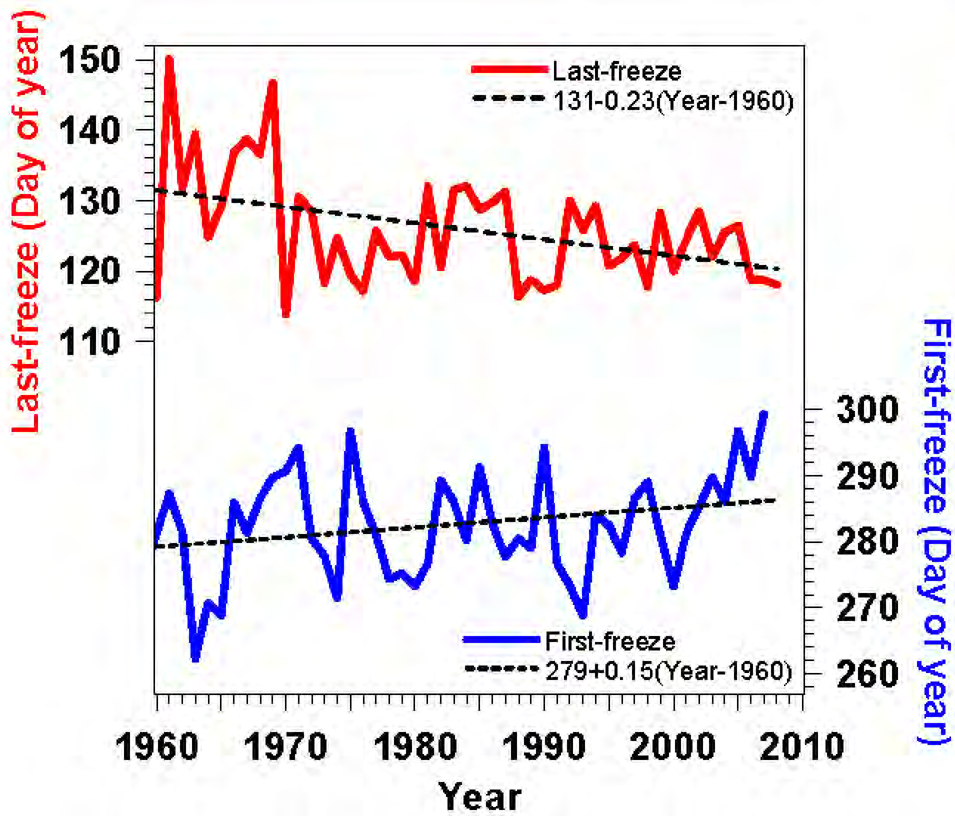
Maples and Lilacs in spring

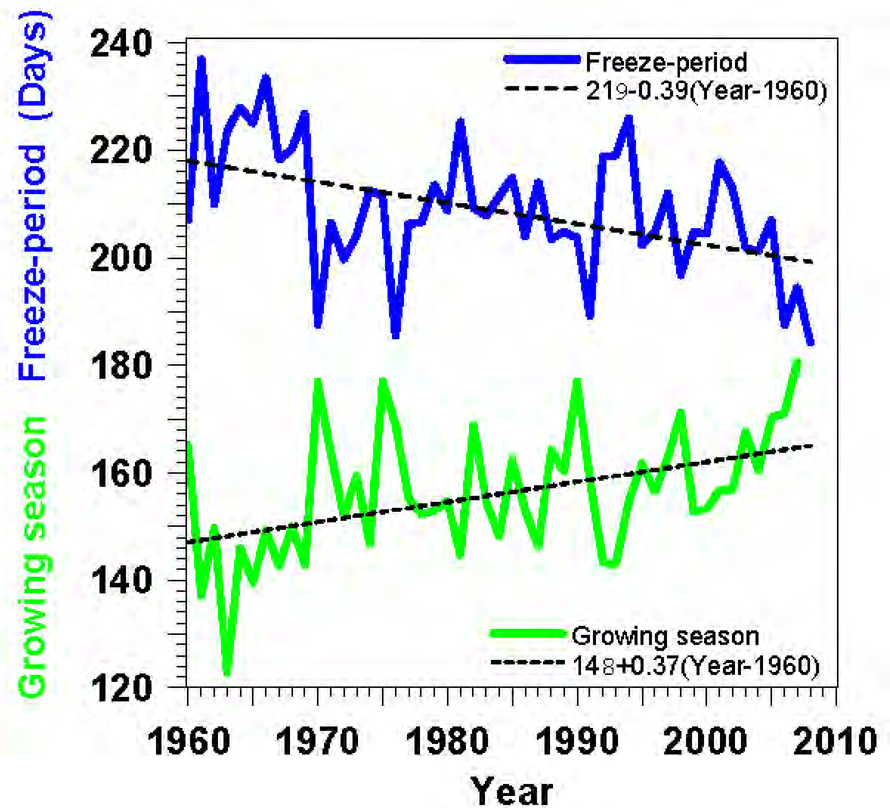




- Maple bud elongation mirrors lilac leaf
- Maple leaf-out mirrors lilac bloom

First and Last Frosts Changing



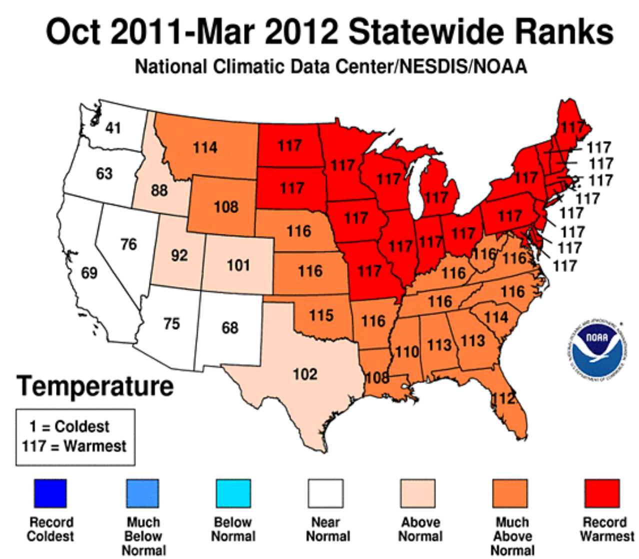


- **Growing season for frost-sensitive plants increasing 3.7 days / decade**
- ***Important for agriculture; local food supply***

January 2, 2012	March 11, 2012
	

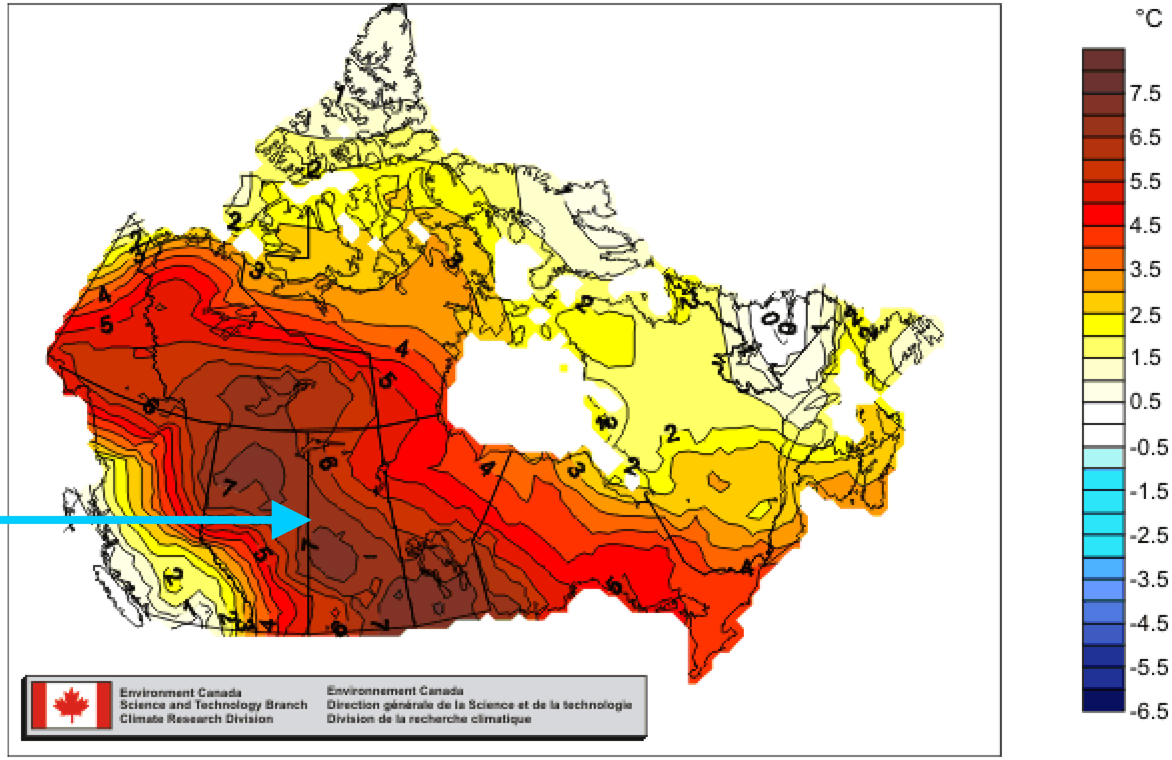
October 2011– March 2012

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



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!***

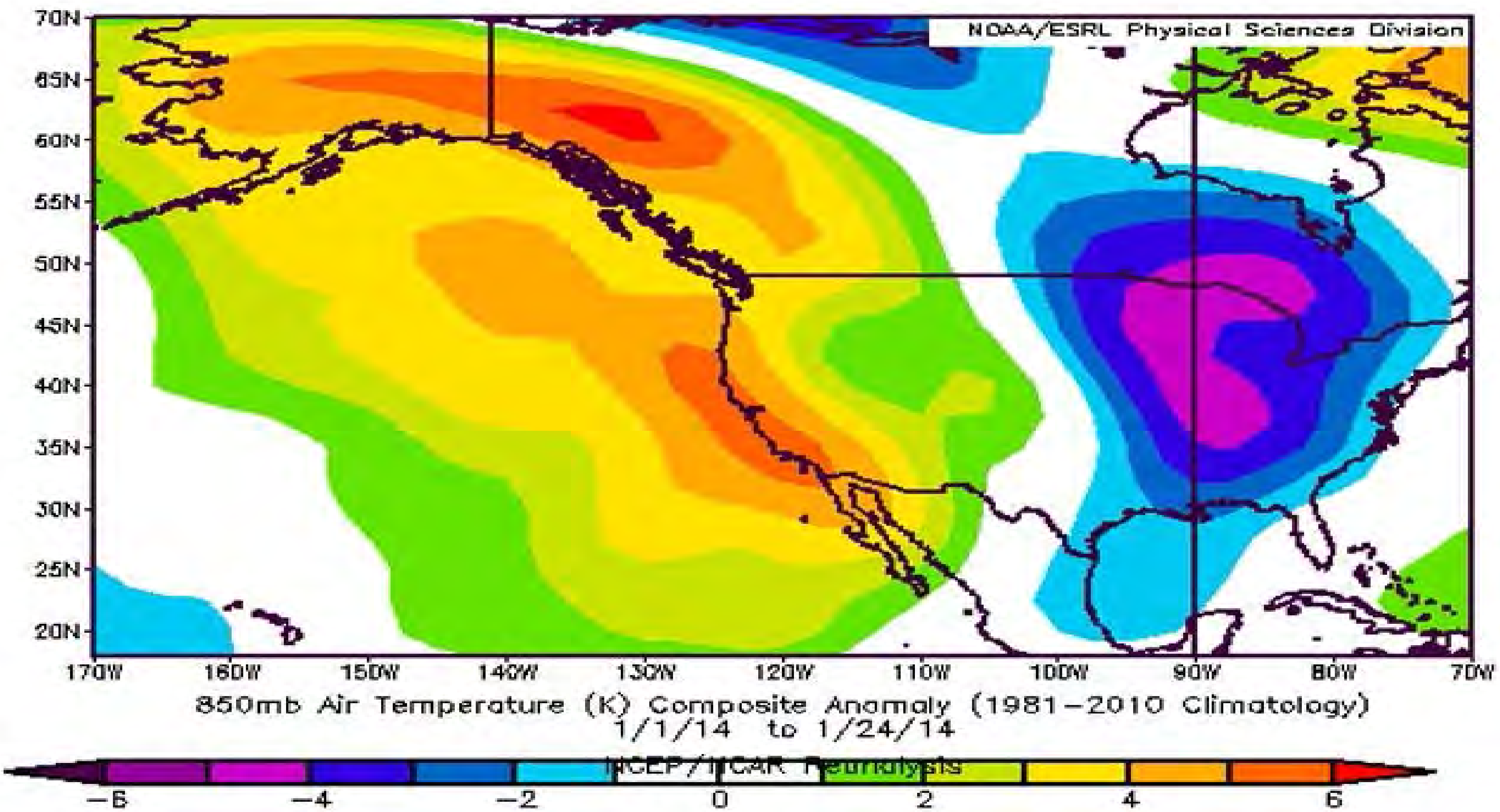
December 21, 2012

January 15, 2013

Past Winter

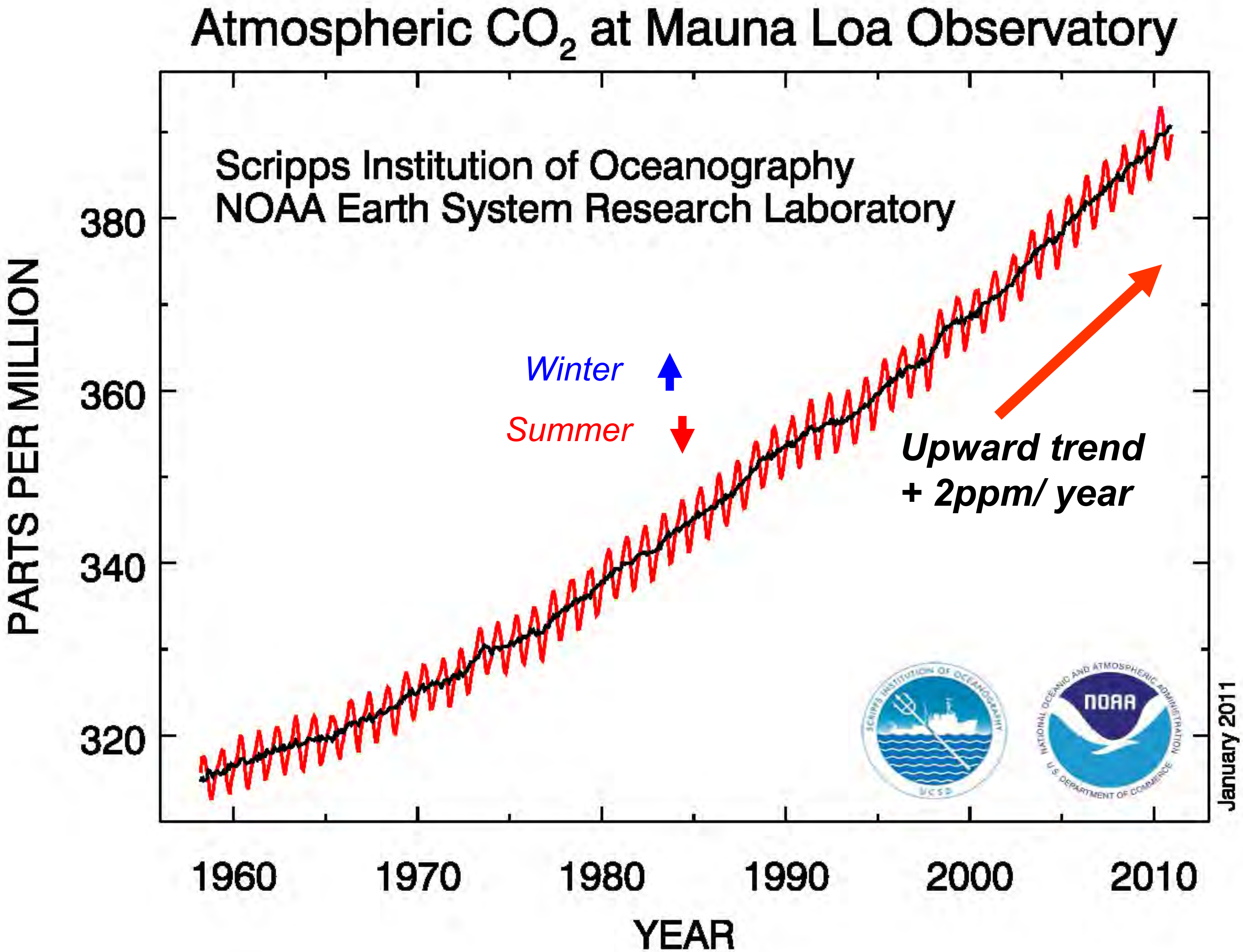
- **Dec 25:** **Ground froze hard**
- **Dec 27-28:** **Foot of snow**
  - **Air temperatures plunged but ground thawed under snow**
- **Jan 12-14:** **45-50F:** **Snow melted**
- **Jan 15:** **Time to dig again..**
- **Followed by freeze-up.. Melt**
- **Final Melt - March 11**

Jan. 1-24, 2014
850mb Temperature Anomaly



Extremes increasing across whole hemisphere: stationary patterns

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: <u>by itself only a small effect</u>**

But as CO_2 Increases, Strong Water Cycle Feedbacks

- **Earth warms, and evaporation and water vapor in the air increases and <u>this triples the warming</u>**
- **As Earth warms, snow and ice decrease, so less sunlight is reflected, so winters and the Arctic are <u>warming faster</u>**
- **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**

Increasing CO_2 is long-lived driver

Water: *Strong Feed-backs Amplify*

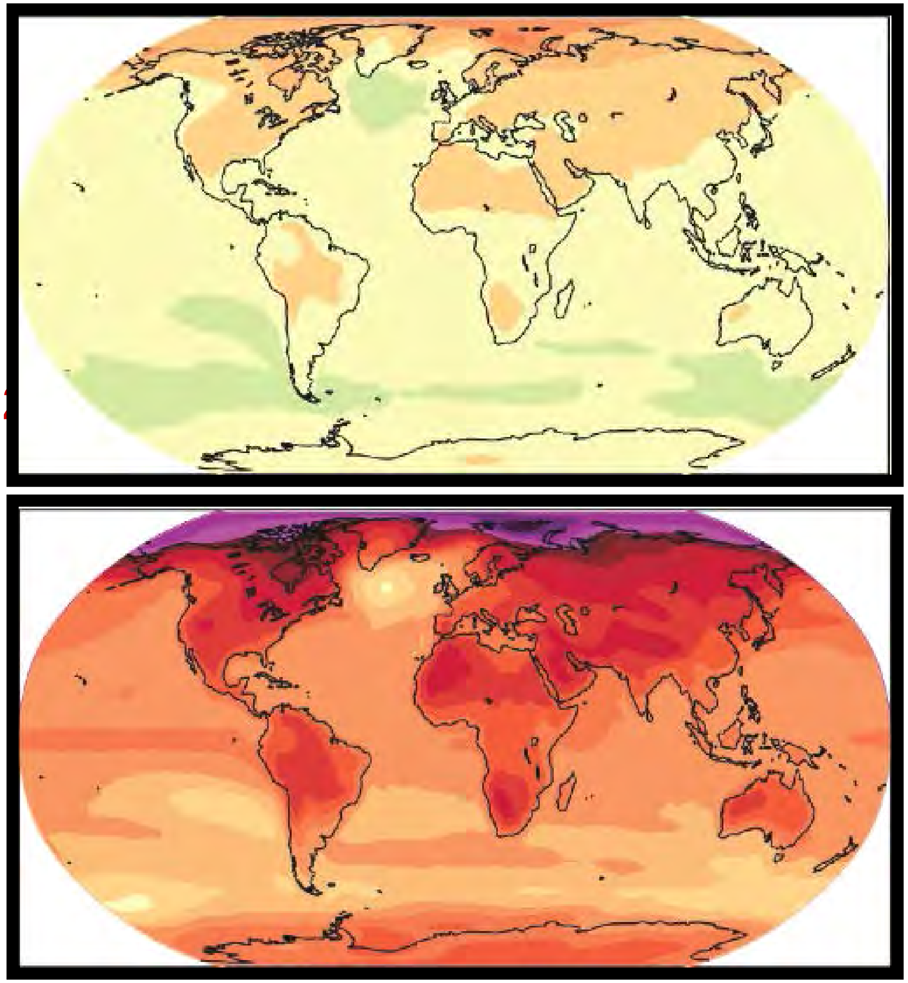
- GHGs up → Oceans, land warmer → Evaporation up
- Water Vapor up
  - WV infrared greenhouse up
    - Approx triples climate warming of planet
    - Locally reduces night-time cooling
      - Winter T_{min} increase: less severe winters
      - Longer growing season between frosts
  - Latent heat release 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

Predicted Change in Temperature

2020-2029 and 2090-2099, relative to 1980-1999 (^{o}C)

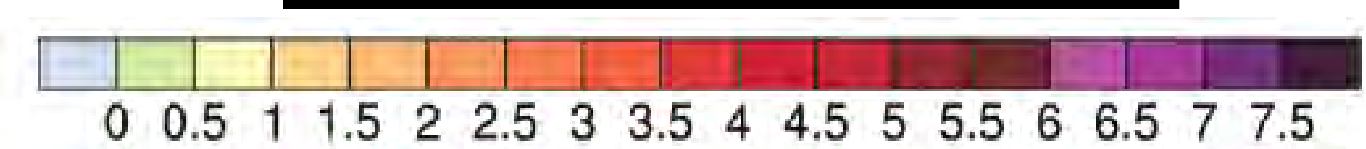
“Committed”

(We did nothing for the last 20 years)



Still up to us!

(We could halve this if we act now)

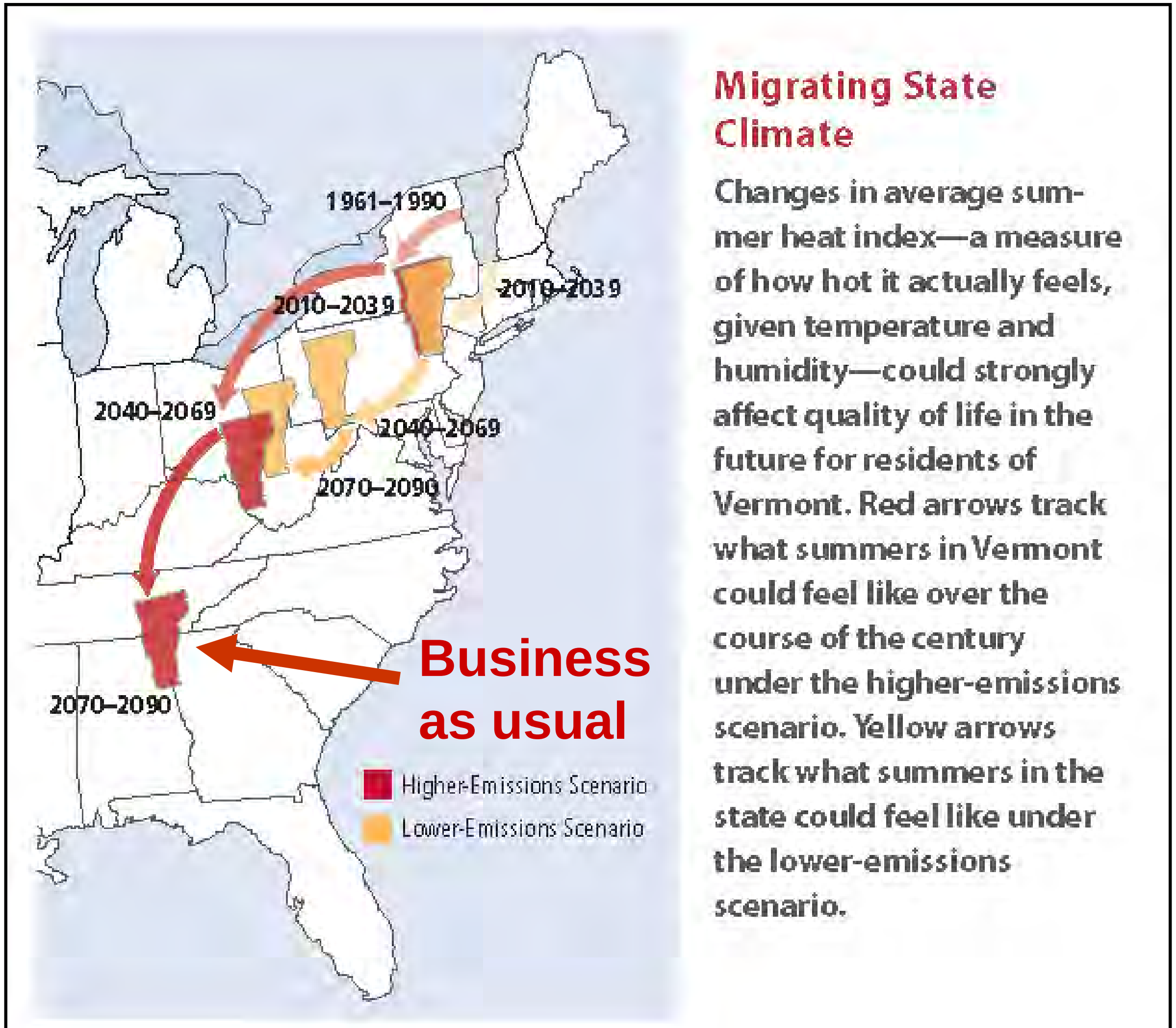


[^{o}C]

Vermont's Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US

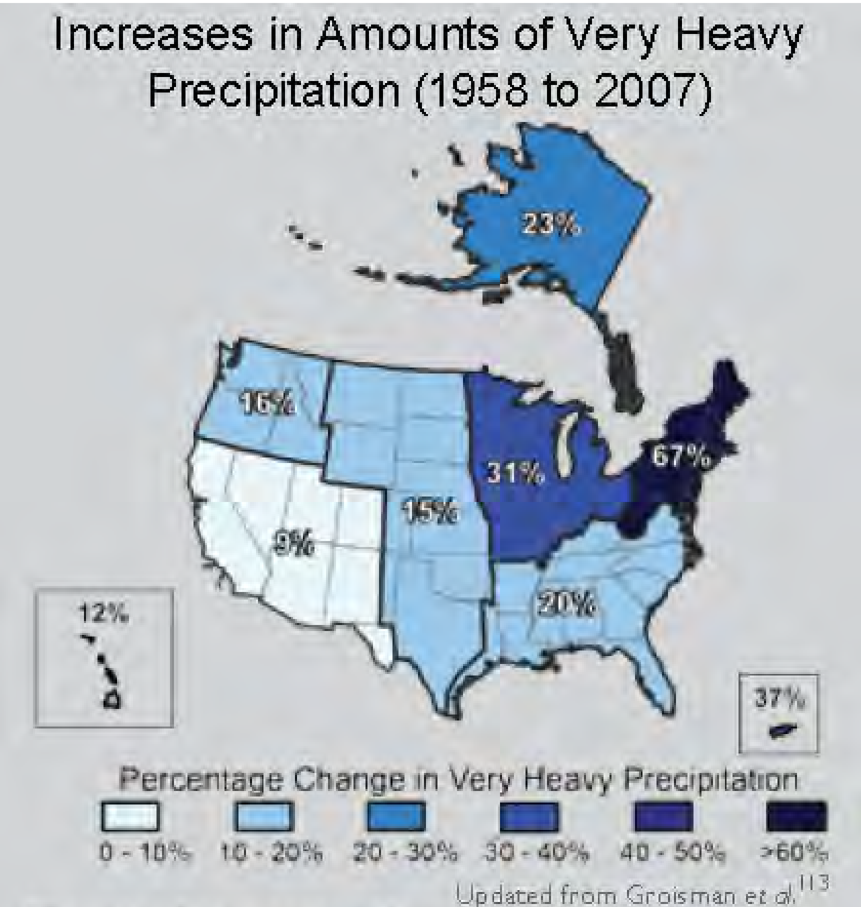


NECIA, 2007

Very Heavy Precipitation Is Increasing

(USGCRP, 2009)

- <u>**Precipitation Extremes**</u>
- **Most of the observed increase in precipitation during the <u>last 50 years</u> has come from the increasing frequency and intensity of heavy downpours.**
- **67% increase in Northeast**
- ***Nine out of ten recent summers have been 'wet'***



The map shows percent increases in the amount falling in very heavy precipitation events (defined as the heaviest 1 percent of all daily events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

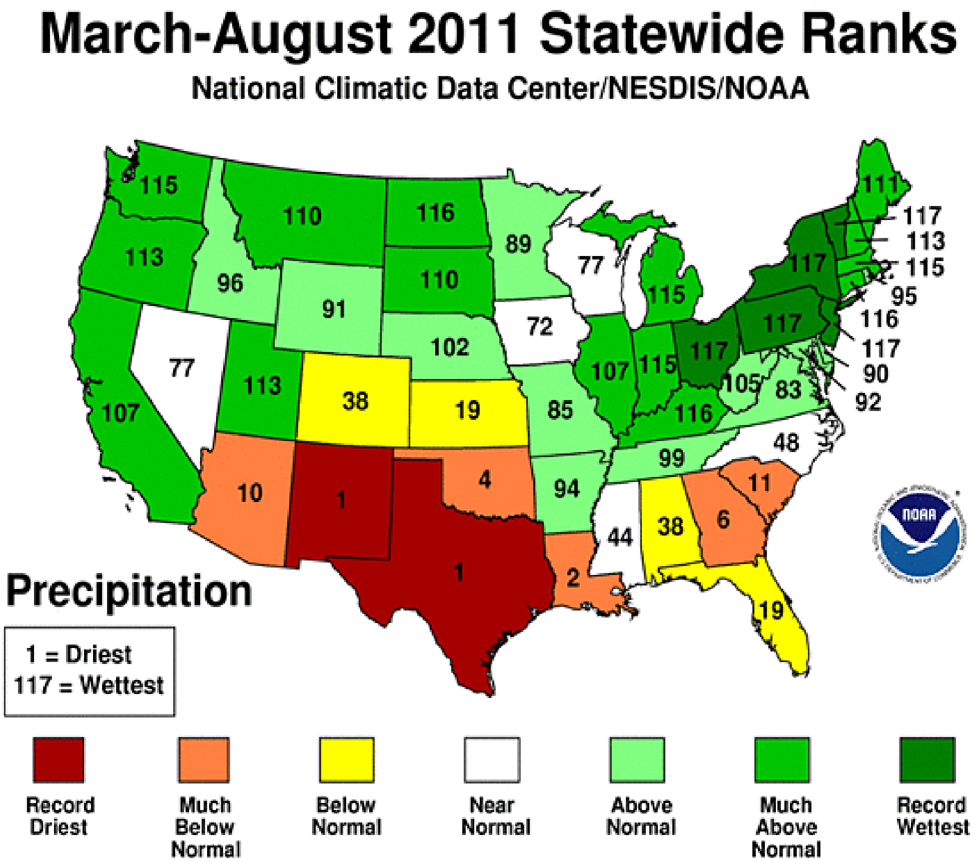
Extreme Weather (precip.)

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

- **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, or W. Pacific warming: needs more study***

2011 Floods: VT and NY

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



March-August, 2011

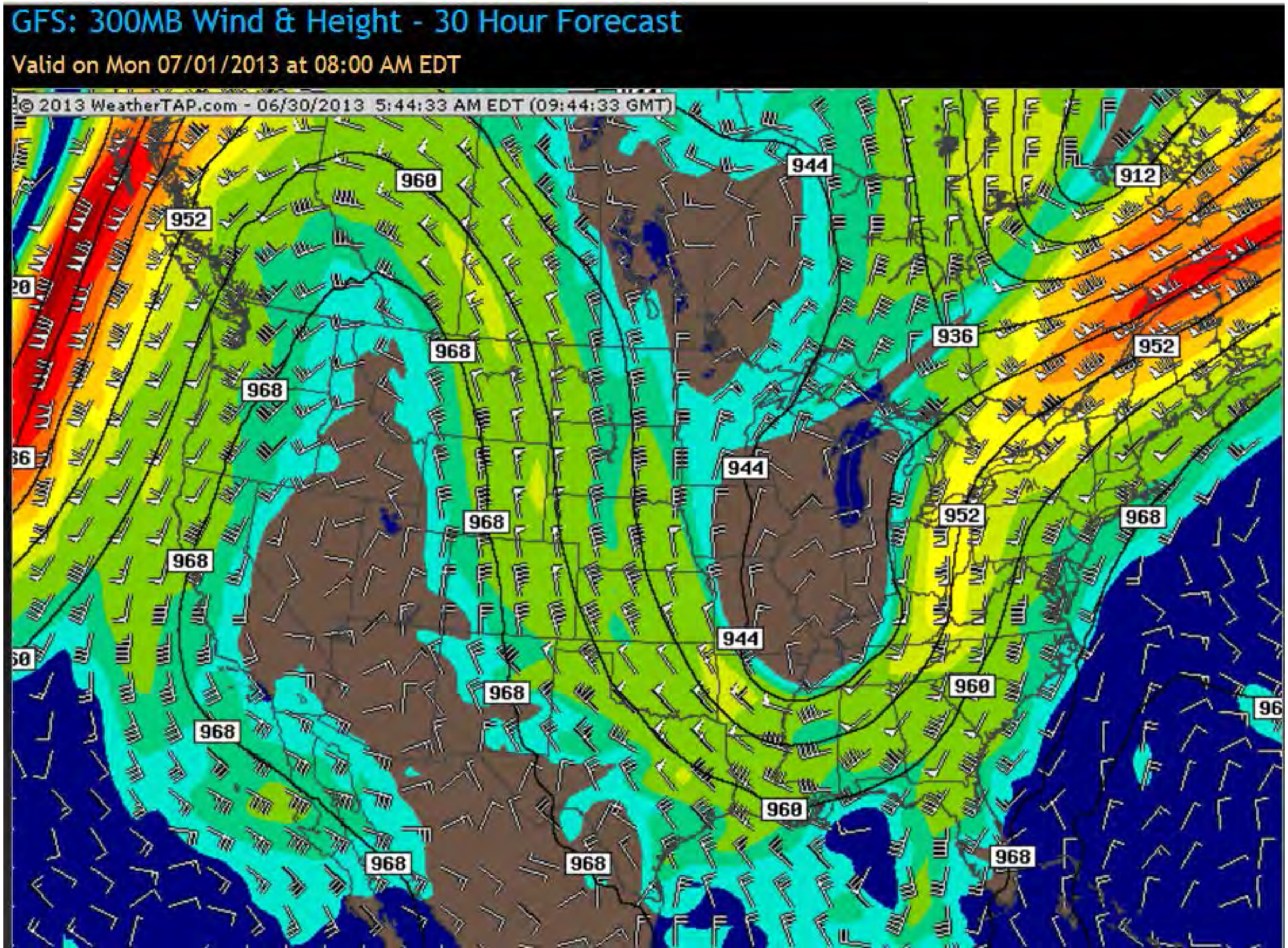
- Record wet : OH to VT
- Record drought: TX & NM
- ‘Quasi-stationary’ pattern

2011 Classic Flood Situations

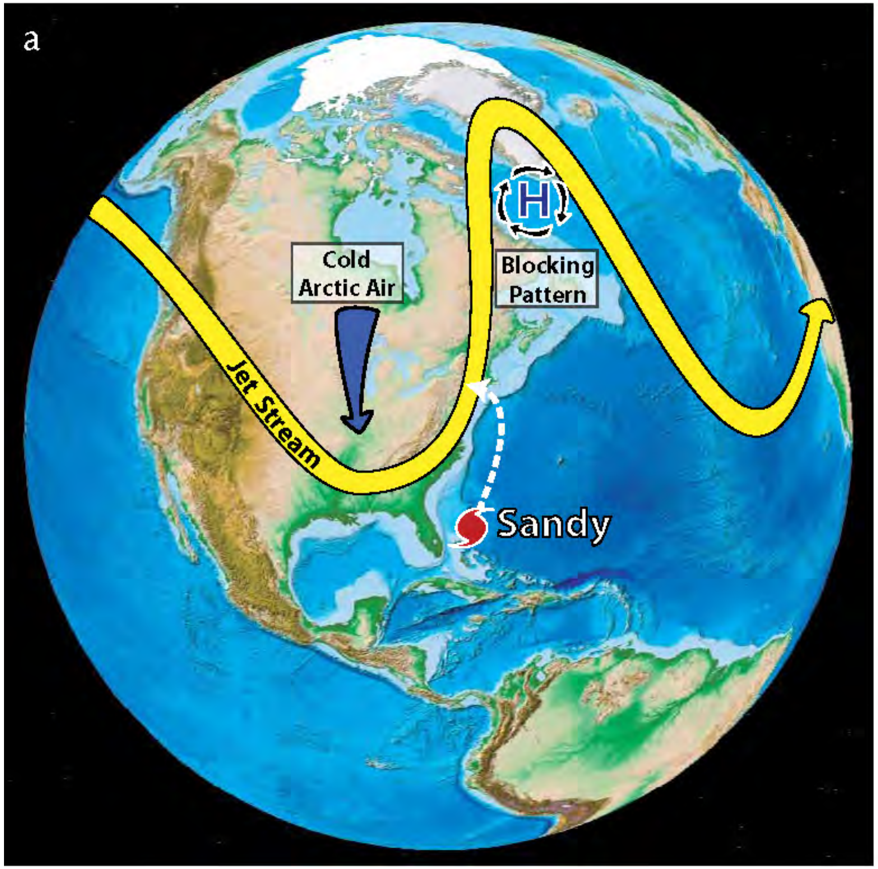
- Spring flood: heavy rain and warm weather, melting large snowpack from 2010 winter
  - 70F (4/11) and 80F(5/27) + heavy rain
  - record April, May rainfall: 3X at BTV
  - Severe floods on Winooski and Adirondack rivers
  - Lake Champlain record flood stage of 103ft
- Irene flood: tropical storm moved 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)

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

(Francis and Vavrus, 2012)



Blocking Pattern - Unique track



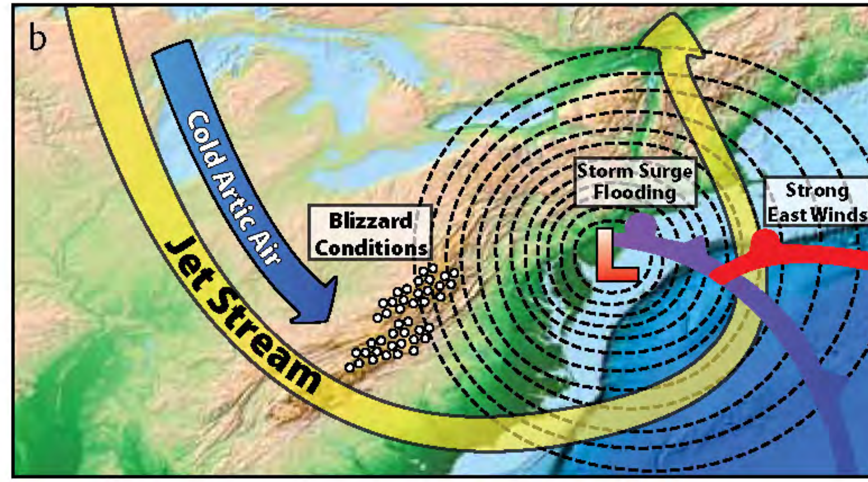


Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical 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]

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

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**

Guidelines to Minimize Impacts

- *Planning a trajectory for sustainability*
- Minimize waste streams
  - Especially those 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

Will Attitudes Change?

- Irene changed Vermont’s attitude
- Changing climate and extreme weather will raise awareness (sea level rise will be too slow)
- ‘Managing’ Lake Champlain basin is a microcosm for ‘managing’ the Earth

As Climate Changes….

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

- You have specific tasks in a large project
- But keep your eyes open to the big picture and draw connections
- Record more than the project lists/protocols
- Keep asking us for guidance

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