Understanding Climate Change

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Eastview

Middlebury, VT

July 30, 2013

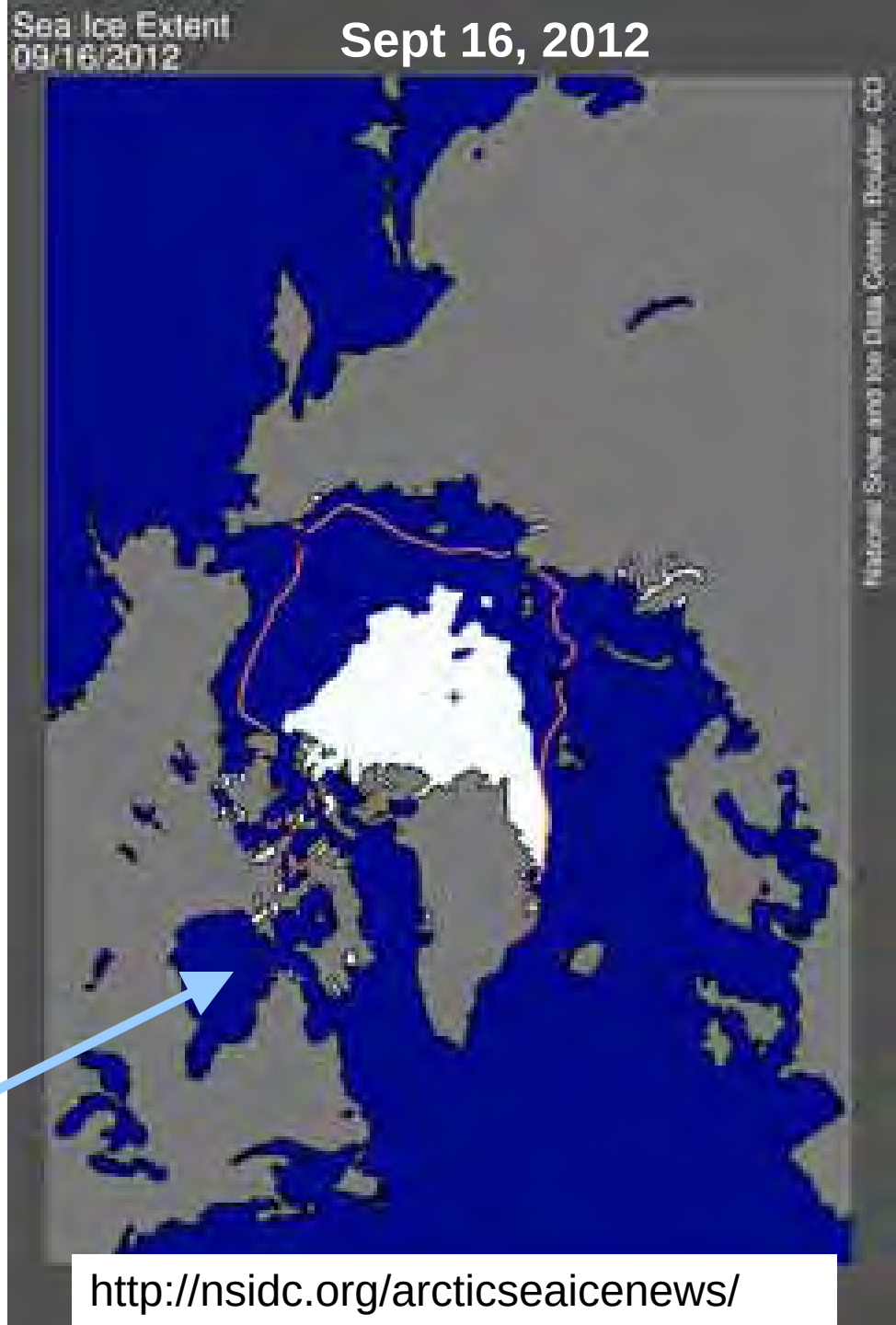
- **Earth sustains life**
- **Weather changes fast**
- **Climate changes slowly**
- **Greenhouse gases keep Earth warm**
- **Burning fossil fuels – coal, oil and gas – is having a big effect on climate by increasing greenhouse gases: CO_2 and H_2O**

January 2, 2012: NASA

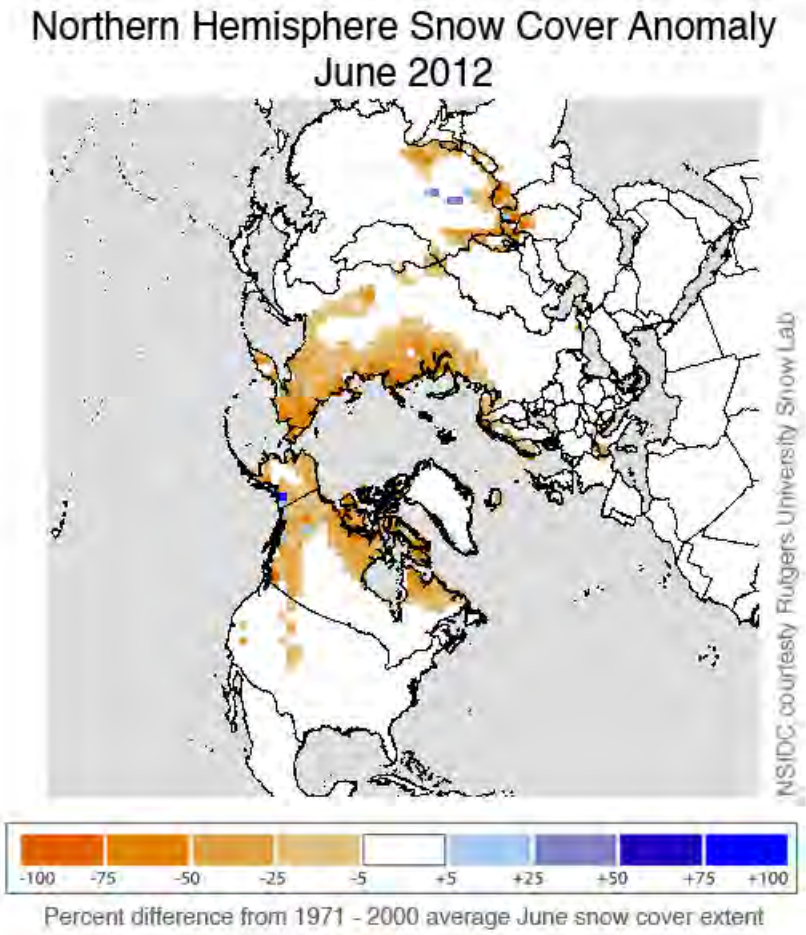
- **Half the Arctic Sea Ice Melted in 2012**
- **Open water in Oct. Nov. gives warmer Fall in Northeast**

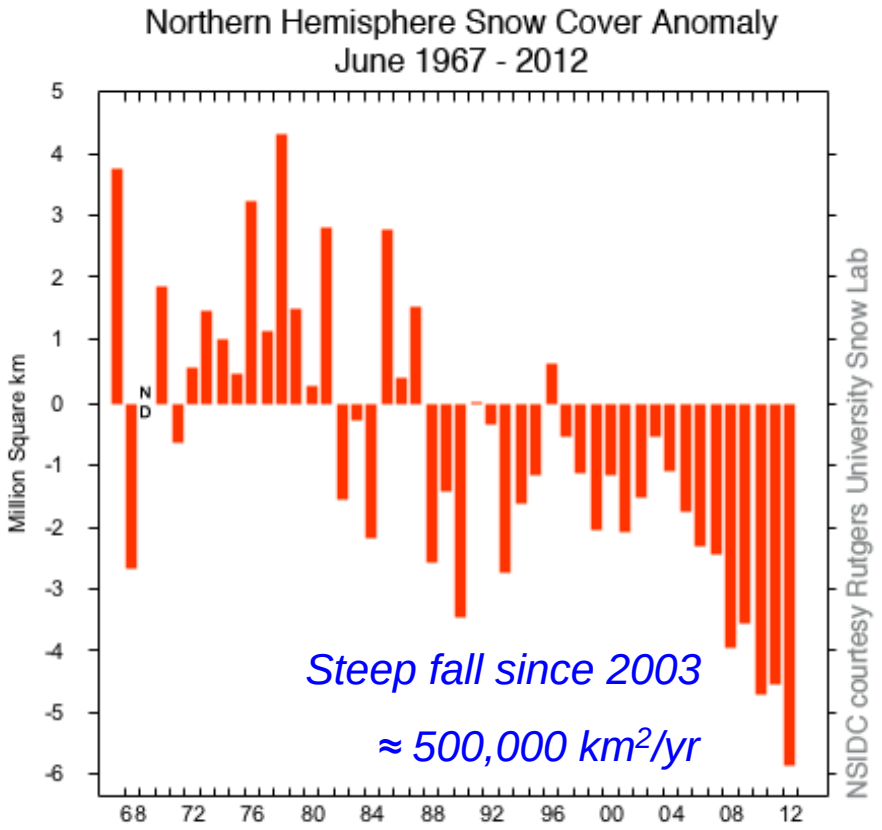
- ***Positive feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Ice thin: most 1-yr-old***

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



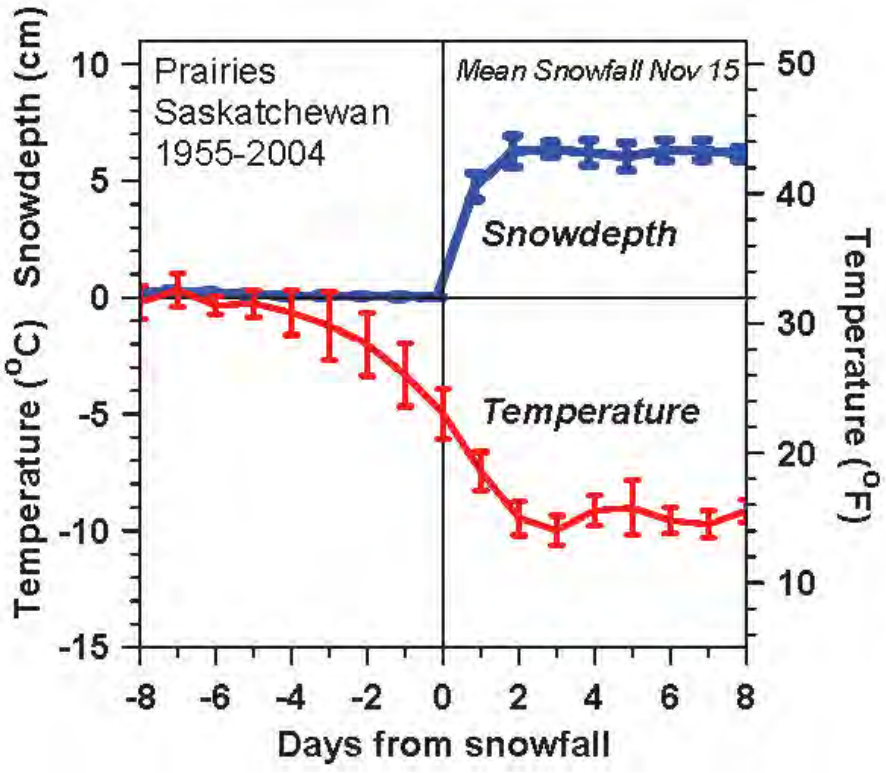
June 2012 snow cover minimum

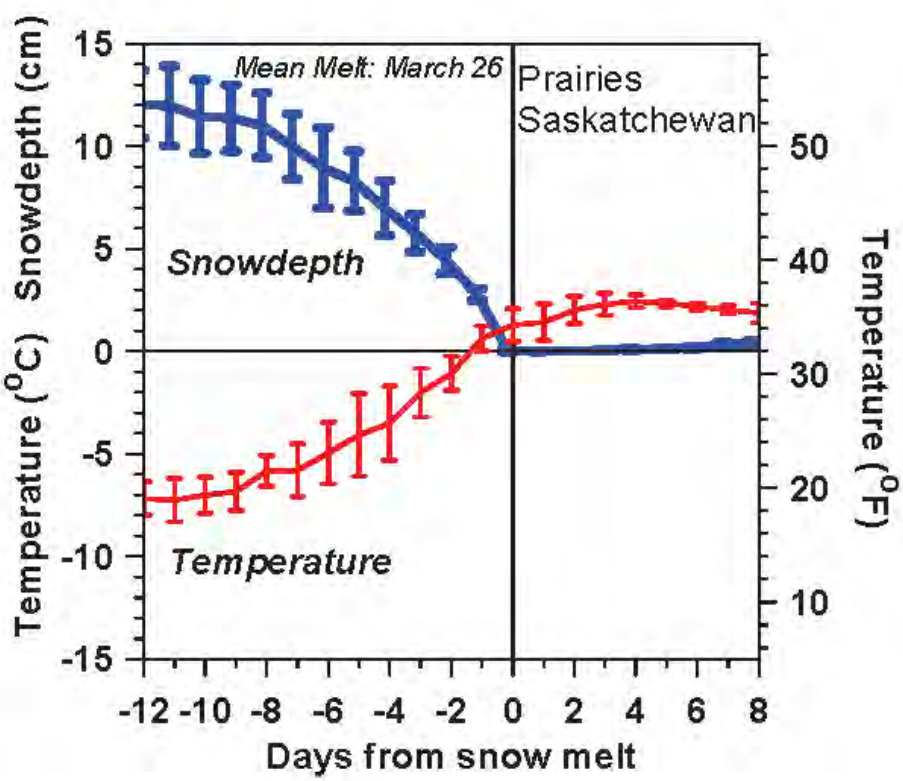




- **Arctic warming rapidly**
  - **Melting fast**
  - ***Much faster than IPCC models***
- **Northeast winters**
  - ***Same positive feedbacks***

Snowfall and Snowmelt

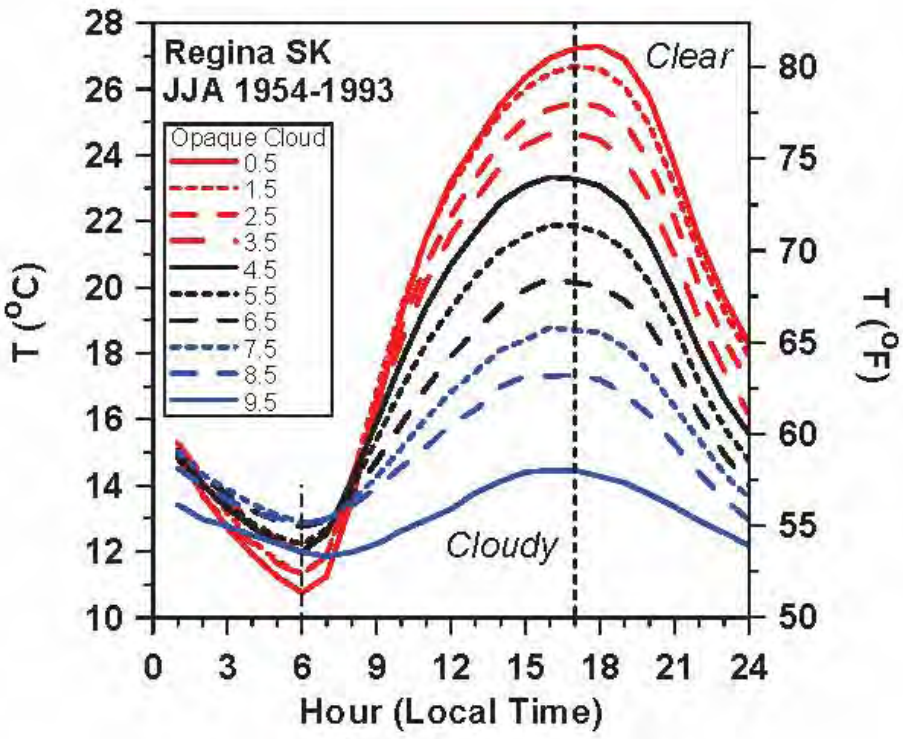


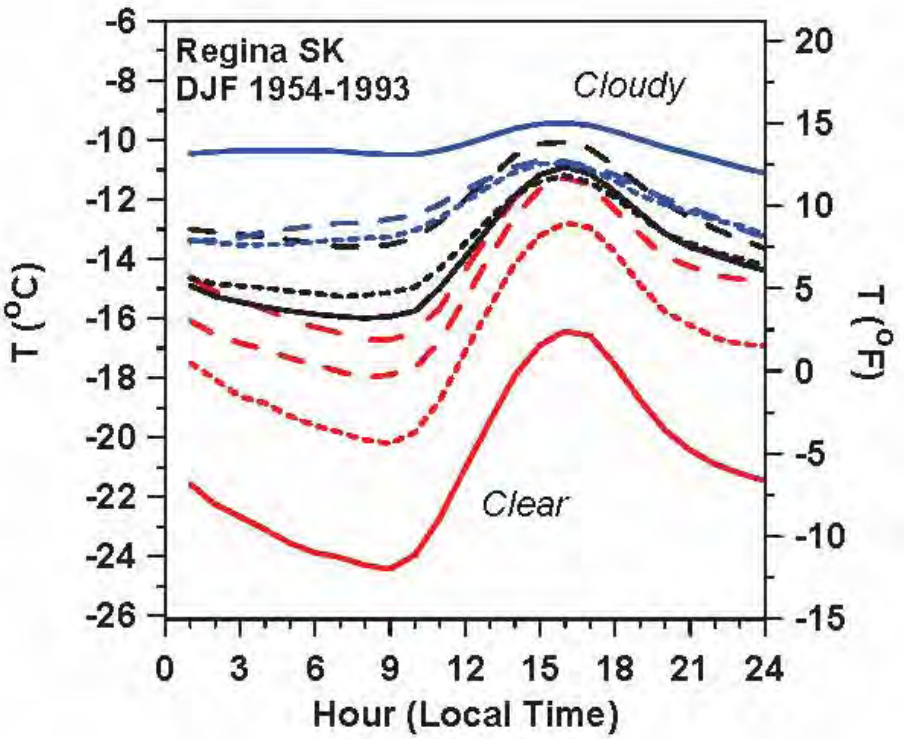


- **Temperature falls 16F (9C) with first snowfall**
- **Same rise with snowmelt**
- ***Snow reflects sunlight; reduces evaporation and water vapor greenhouse – changes 'local climate'***

Betts et al. 2013

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?

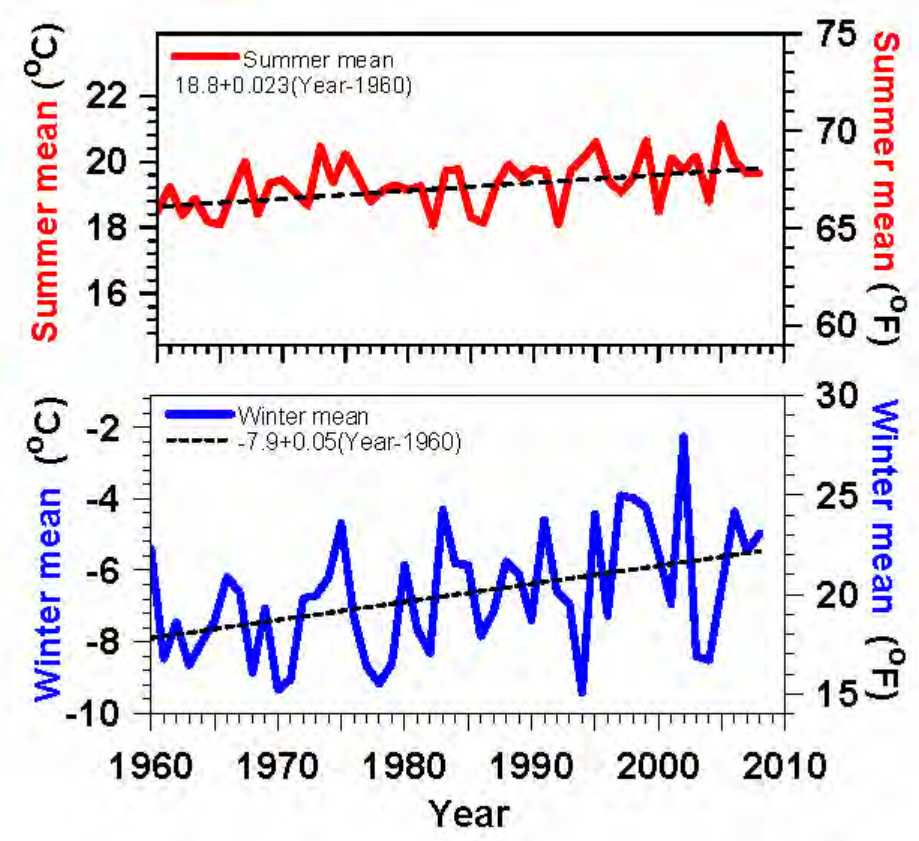
- **PAST 40/50 years** ***(global CO_2 forcing detectible)***
- **Warming twice as fast in winter than summer**
- **Winter minimums increasing even faster**
- **Lakes frozen less by 7 days / decade**
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**

(Betts, 2011)

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

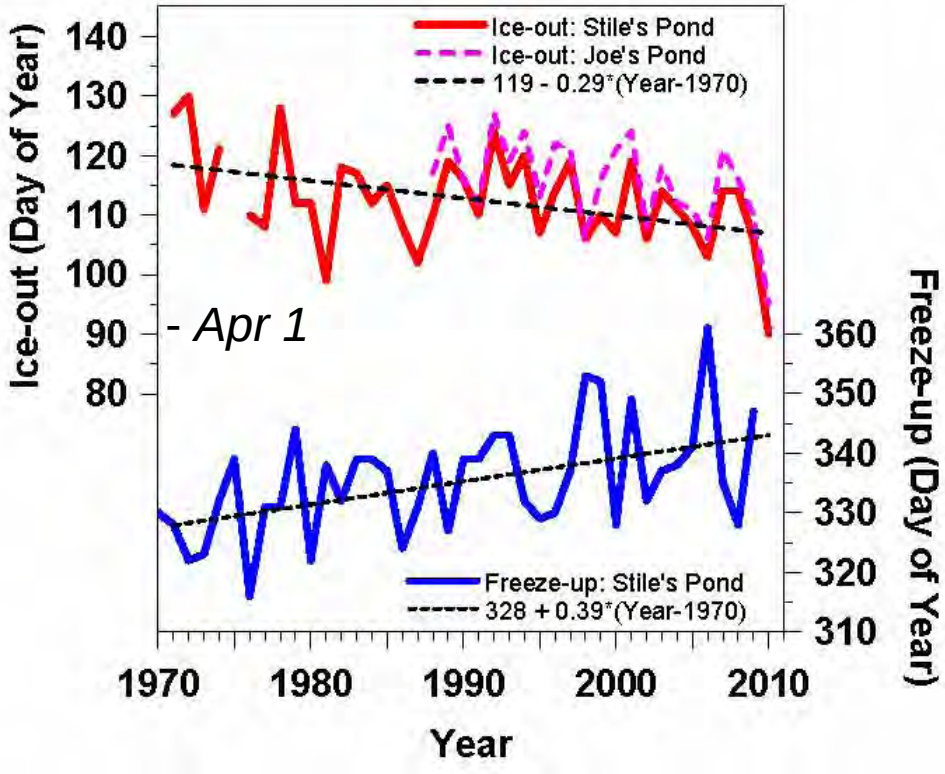
Vermont Temperature Trends 1961-2008

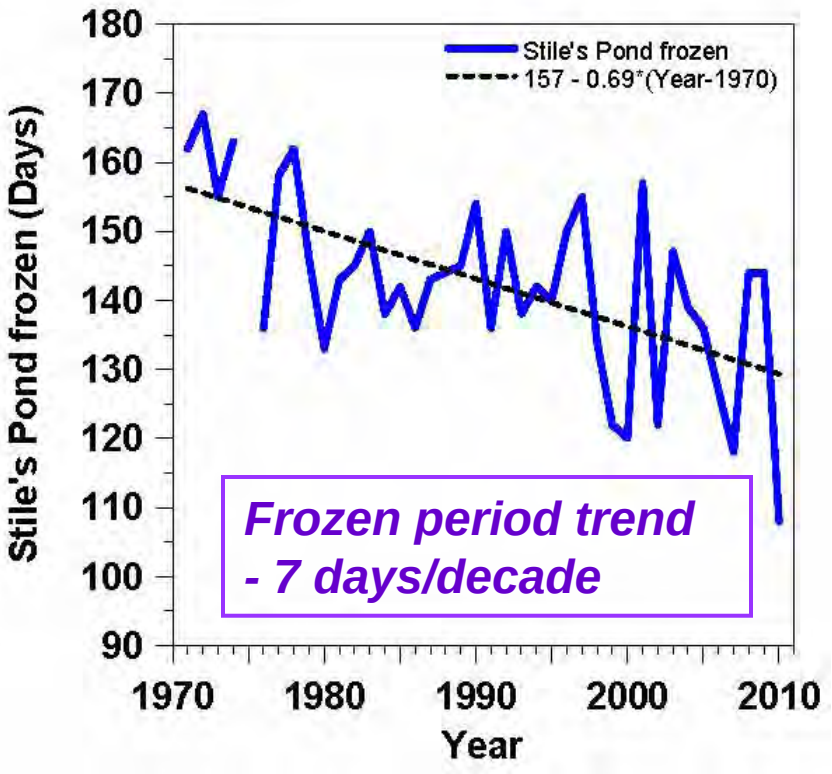
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***



Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



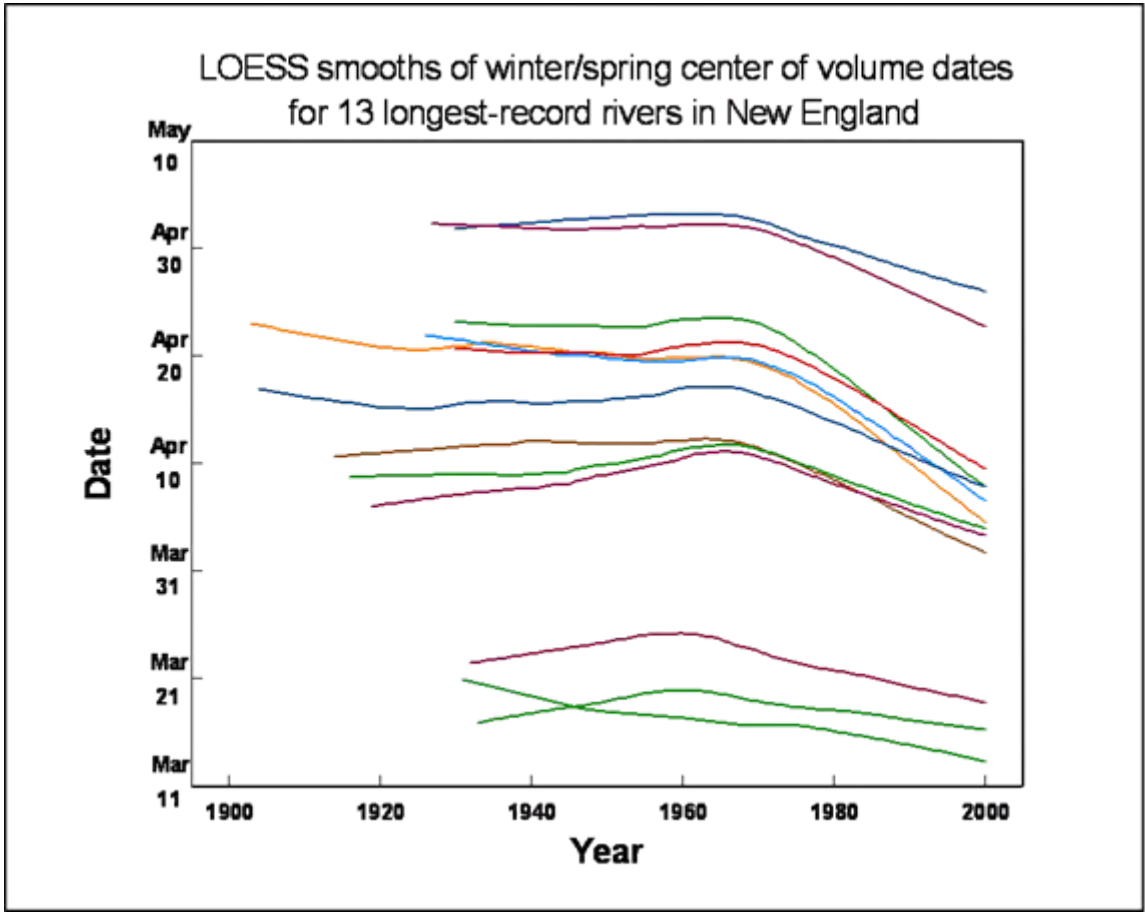


- **Ice-out earlier by 3 days / decade**
- **Freeze-up later by 4 days / decade**
- ***Soil ice probably similar***

Hydrology Sensitive to Climate

Lent (2010), USGS, Me

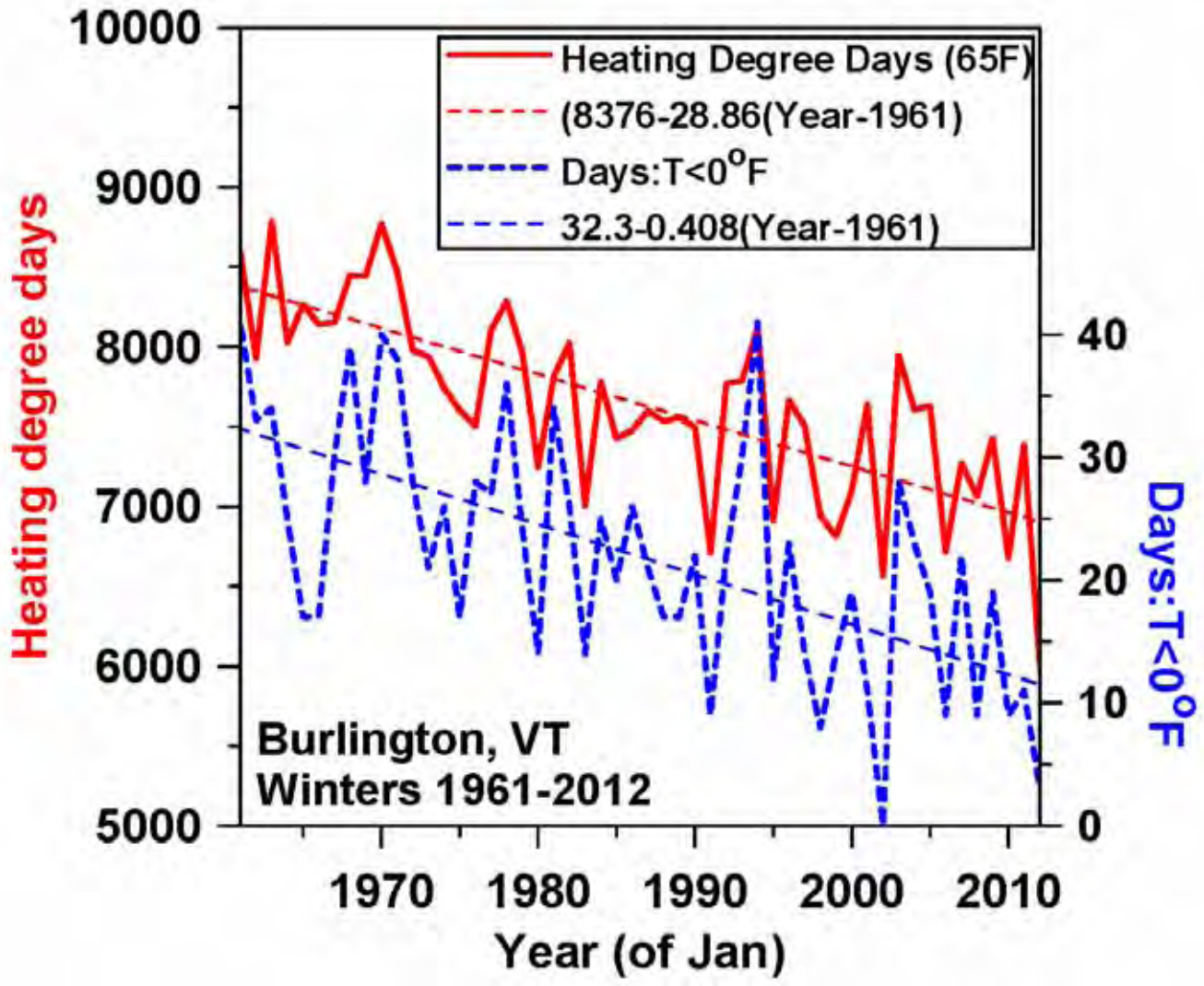
- **Peak spring runoff**
- ***Earlier in northern New England in recent years***
  ≈ 3 days/decade
- ***Timing related to air temperatures in Spring***



(Hodgkins and others, 2003)

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

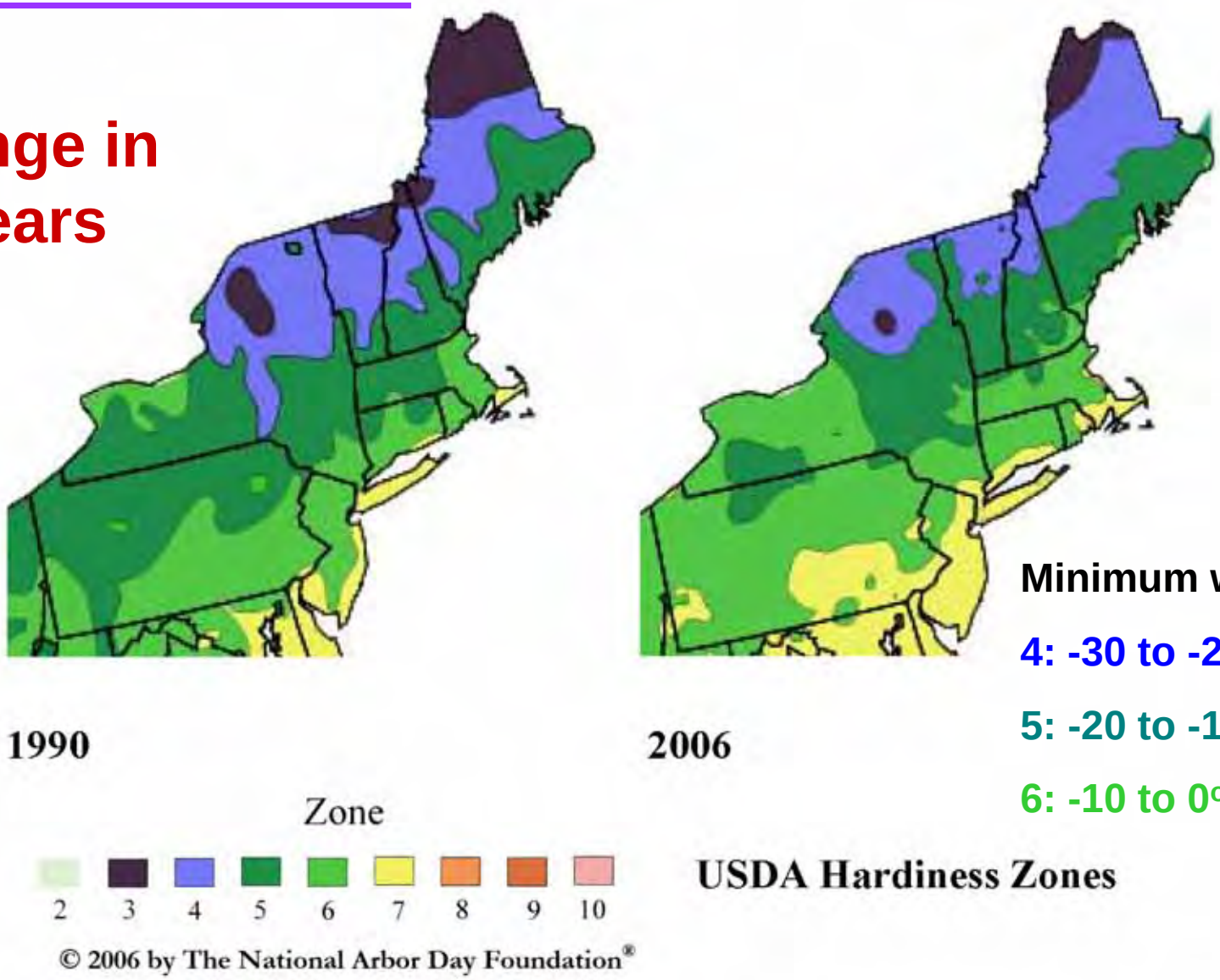
- **Heating degree days *falling 290/decade***
- **T_{min}<0°F *falling 4 days /decade***



Winter Hardiness Zones

– ***winter cold extremes***

Change in 16 years



Minimum winter T

4: -30 to -20°F

5: -20 to -10°F

6: -10 to 0°F

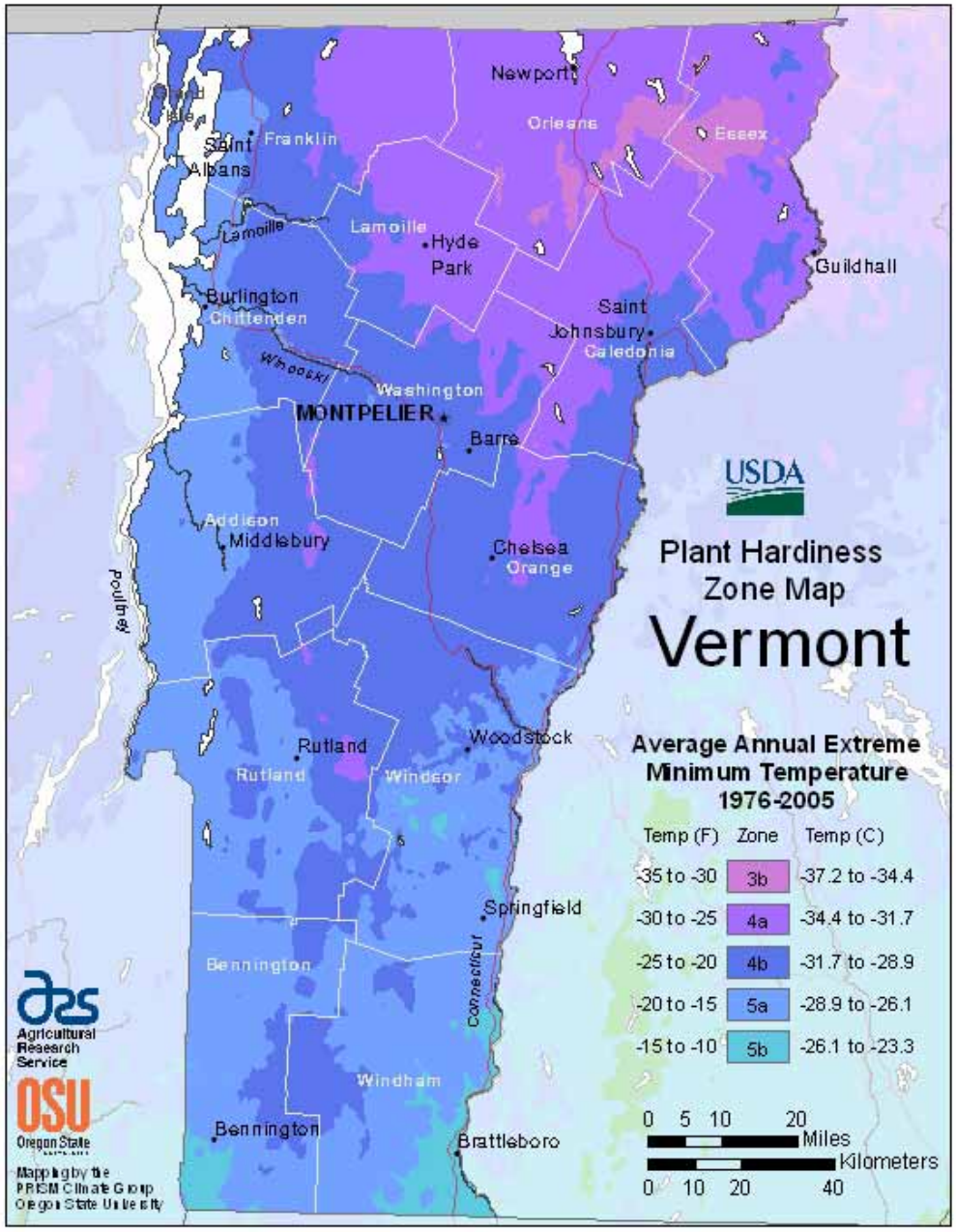
Detailed Map *(most recent)*

- **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**

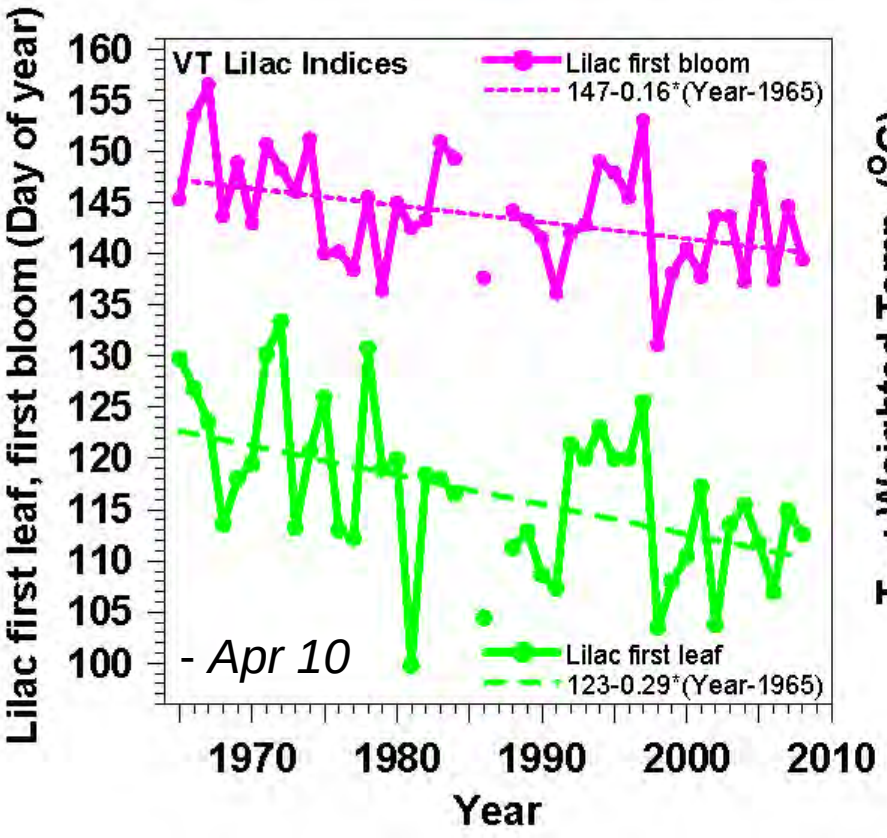
Bennington & Brattleboro are becoming zone 6

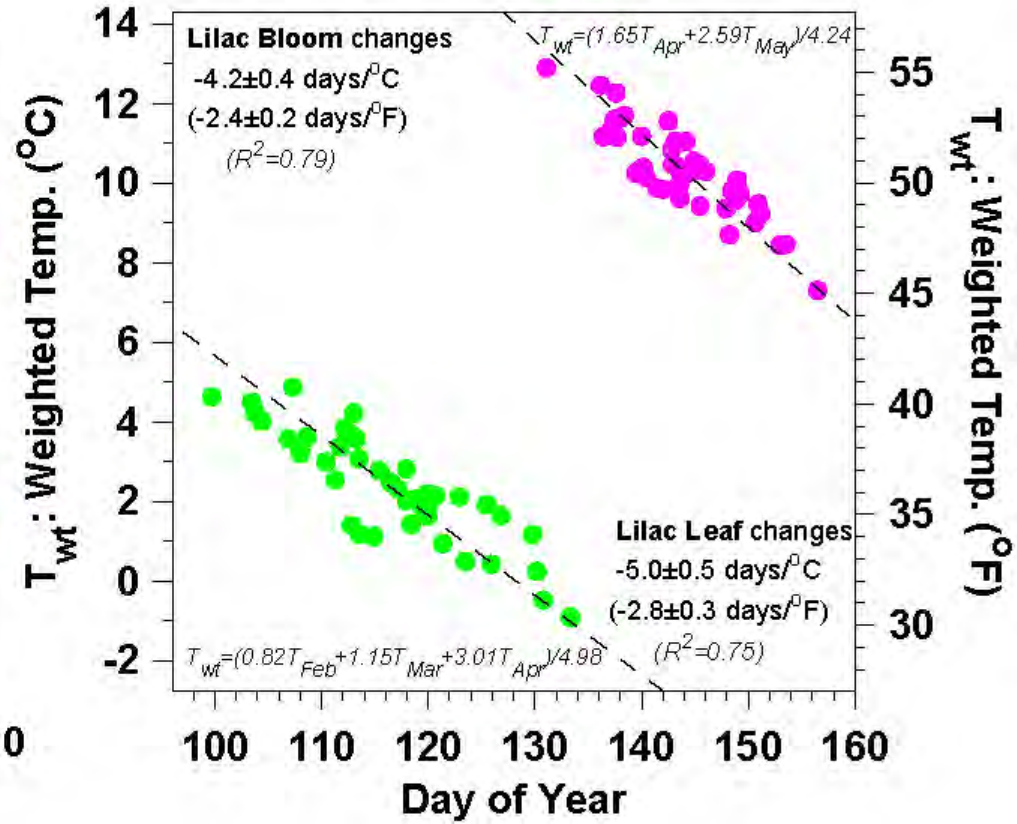
- **Hardy peaches: 2012**
- **More pests survive winter**

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

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

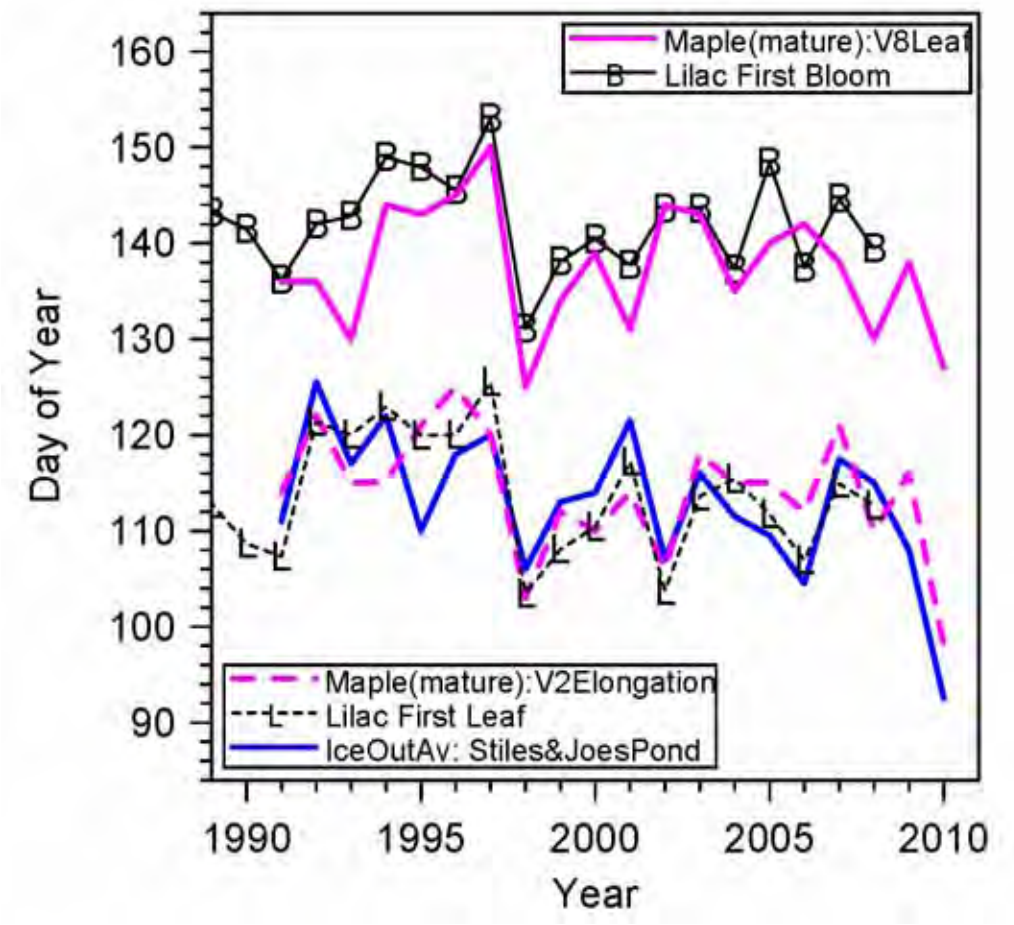
Lilac Leaf and Bloom





- **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)

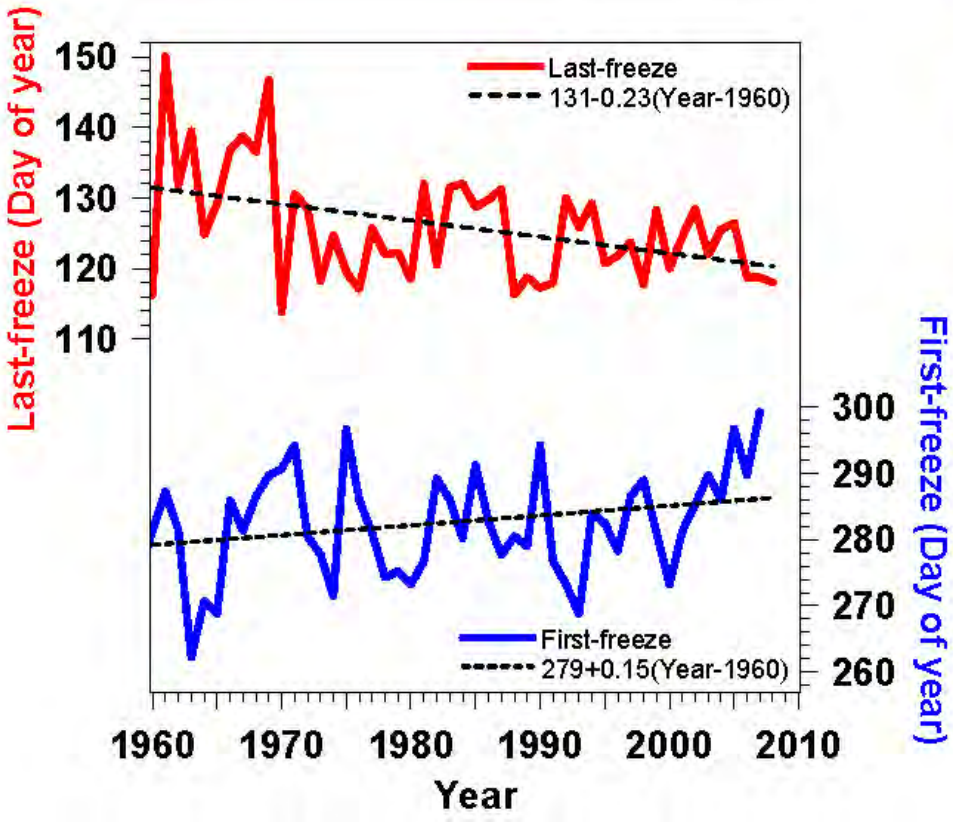
Sugar Maples in Spring

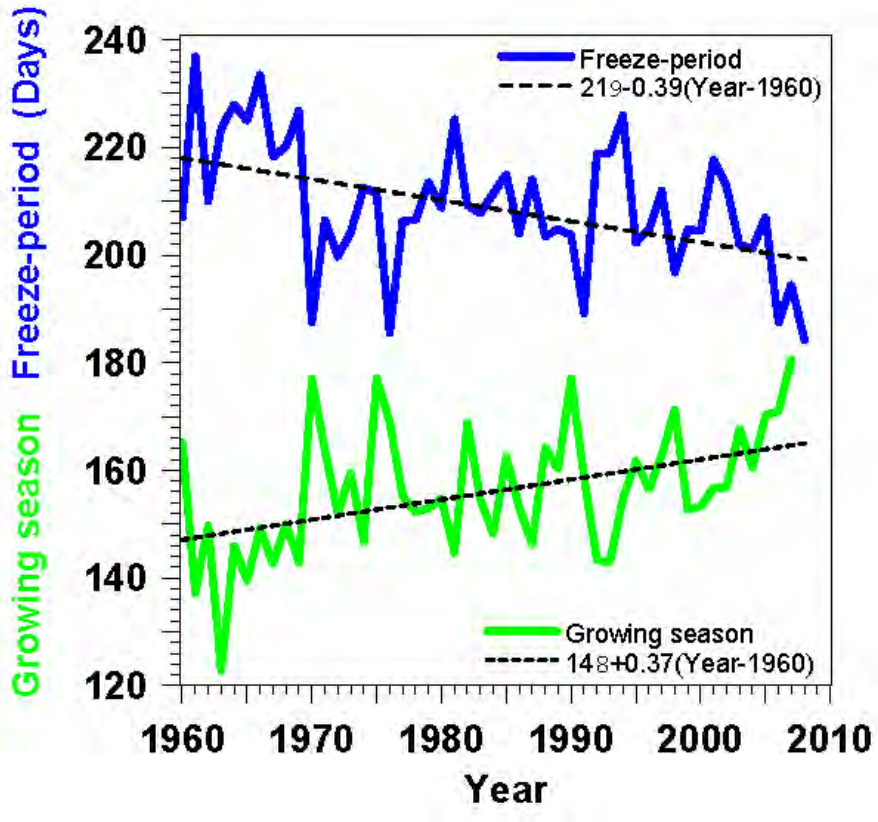


- **Ice-out, lilac leaf, maple bud elongation correlated**
- **Lilac bloom and maple leaf-out correlated**

Data: Sandy Wilmot, ANR

First and Last Frosts Changing





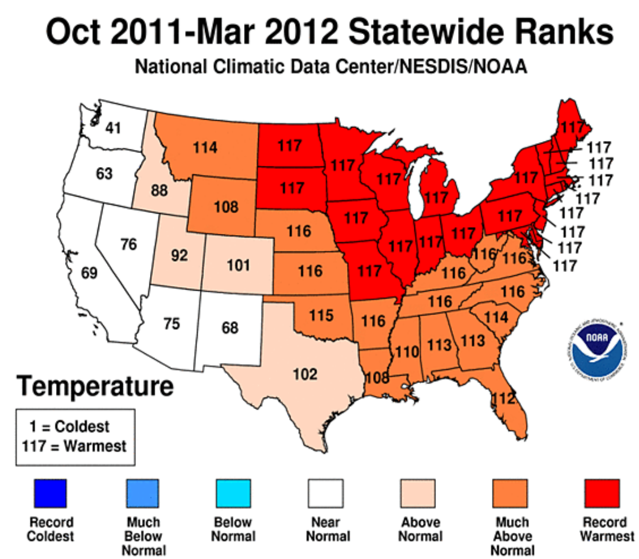
- **Growing season for frost-sensitive plants increasing 3.7 days / decade**
- ***Important for agriculture; local food supply***

January 2, 2012

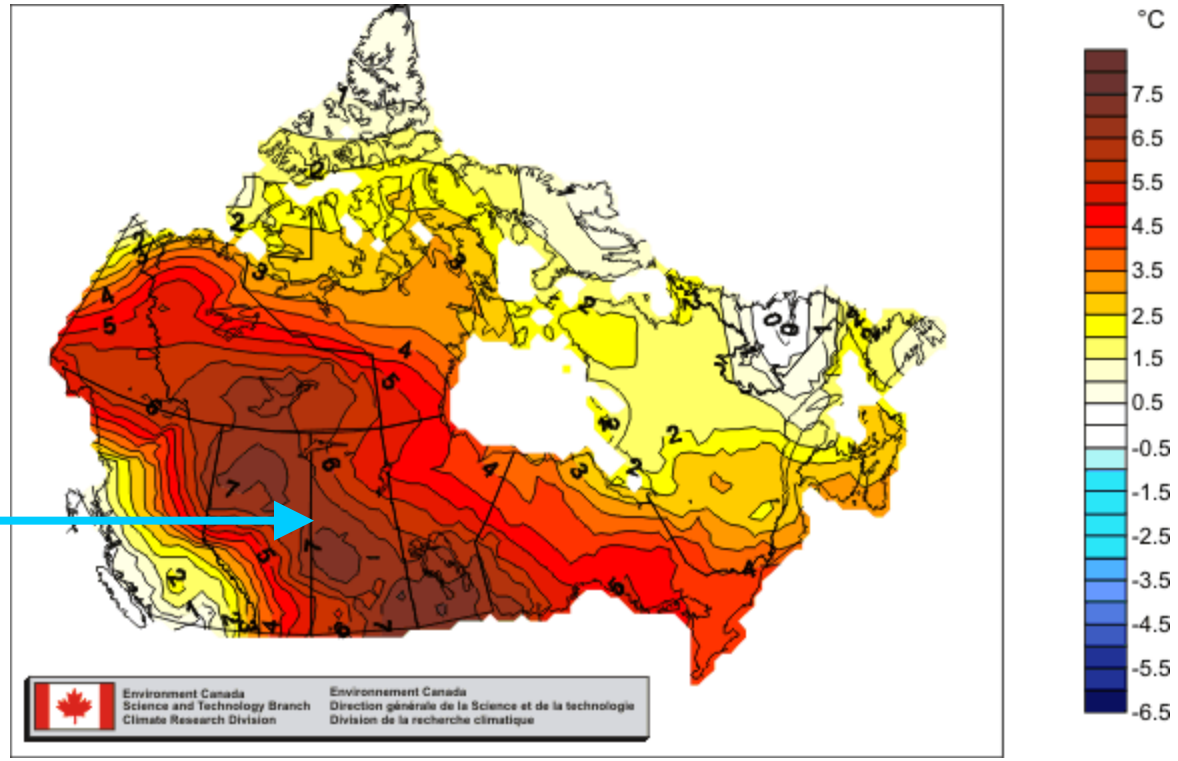
March 11, 2012

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**



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

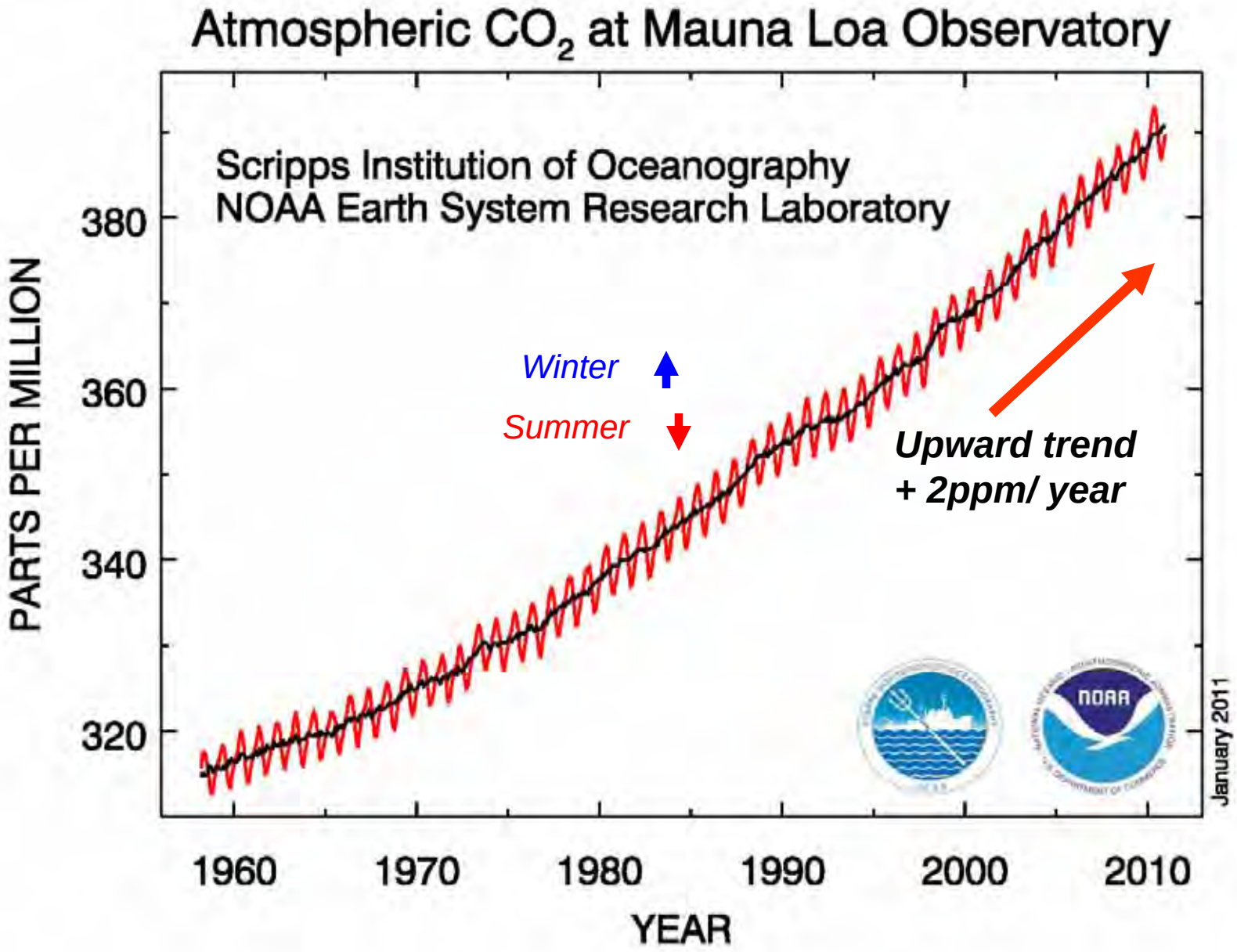
Past Winter

Dec 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**
- **Very wet: mid-May to mid-July**

Carbon Dioxide Is Increasing



Why Is the Rise of Atmospheric CO_2 a Problem?

- **The atmosphere is transparent to light from the sun, but not to infrared radiation from the earth**
- **Greenhouse gases: H_2O, CO_2, CH_4**
  - **trap the earth's heat, giving pleasant climate**
- **CO_2 rise alone has a small warming effect**

BUT…

Why Is the Rise of Atmospheric CO_2 a Problem?

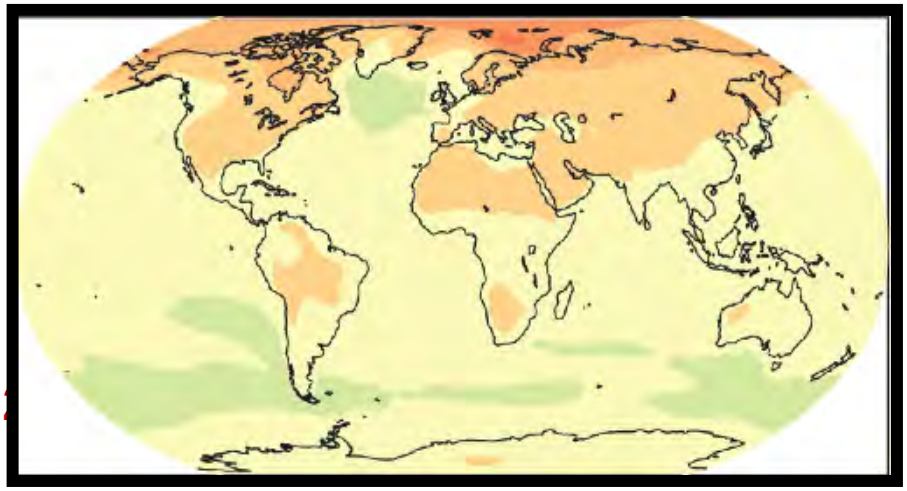
- **As Earth warms, evaporation and water vapor increase and this amplifies warming a lot (3X)**
- **As Earth warms, snow and ice decrease and this amplifies warming in winter and northern latitudes, because less sunlight is reflected**

- **Doubling CO_2 will warm Earth about 5°F (3°C)**
  - **much more in the North and over land**

Predicted Change in Temperature

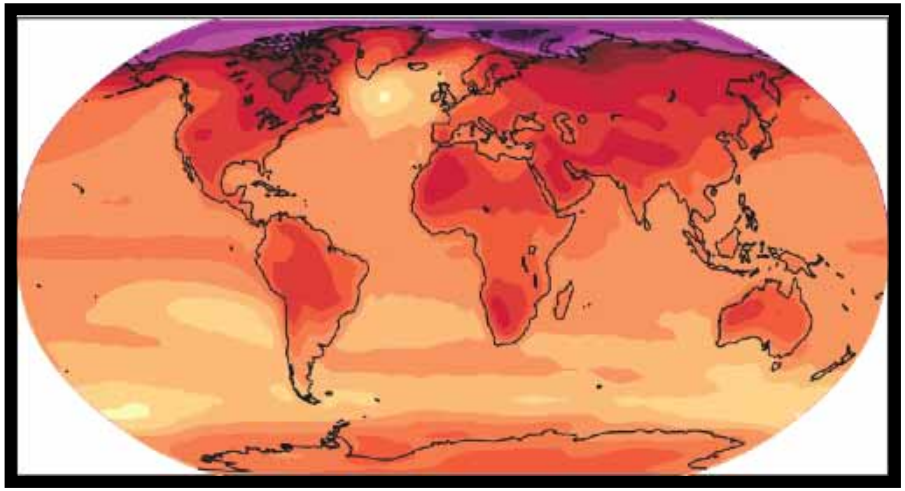
2020-2029 and 2090-2099, relative to 1980-1999 (ºC)

“Committed”

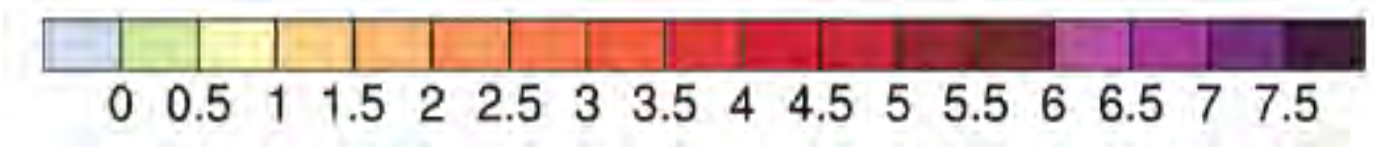


(We did nothing for the last 20 years)

Still up to us!



(We could halve this if we act now)

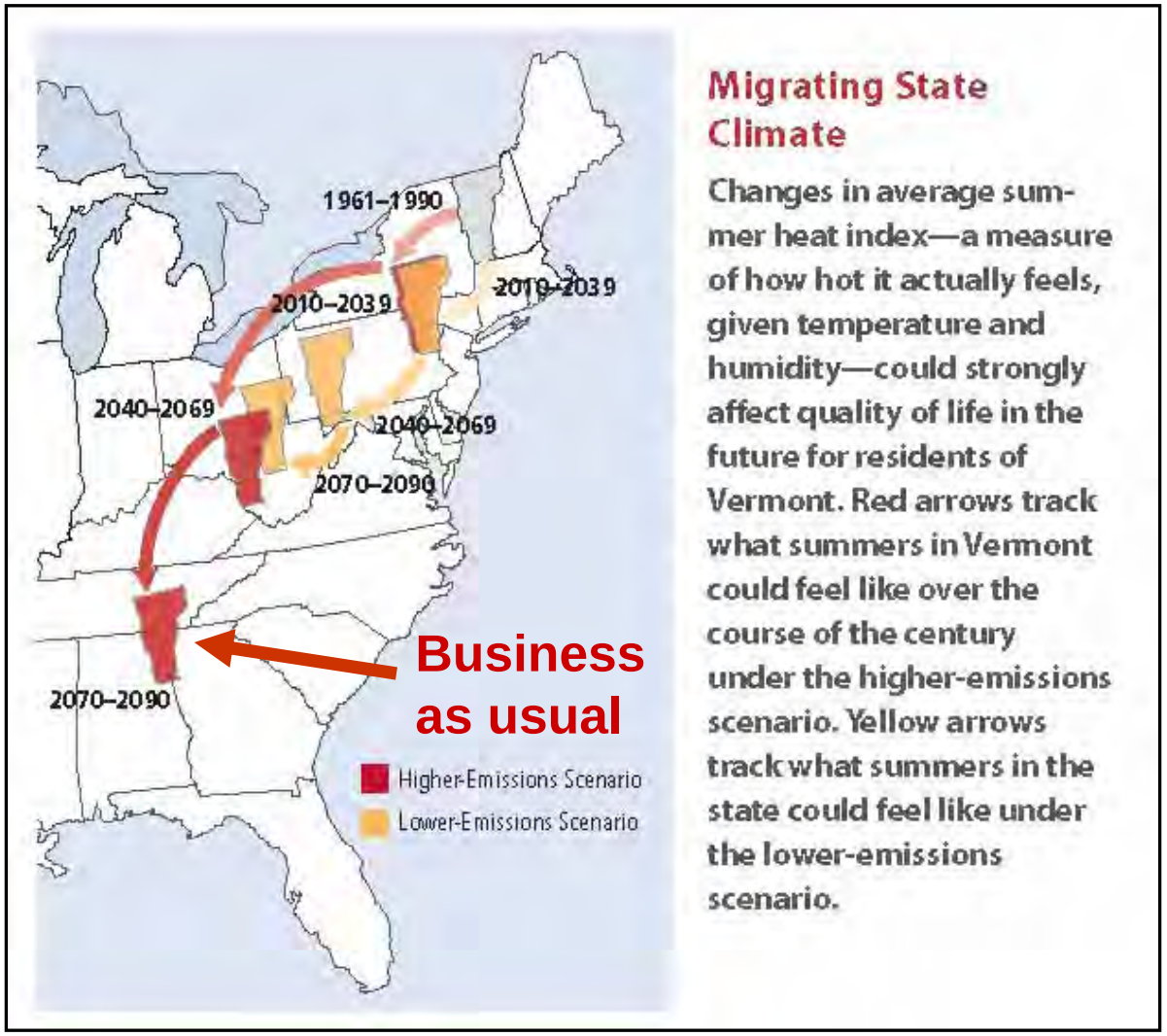


[ºC]

Vermont's Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US

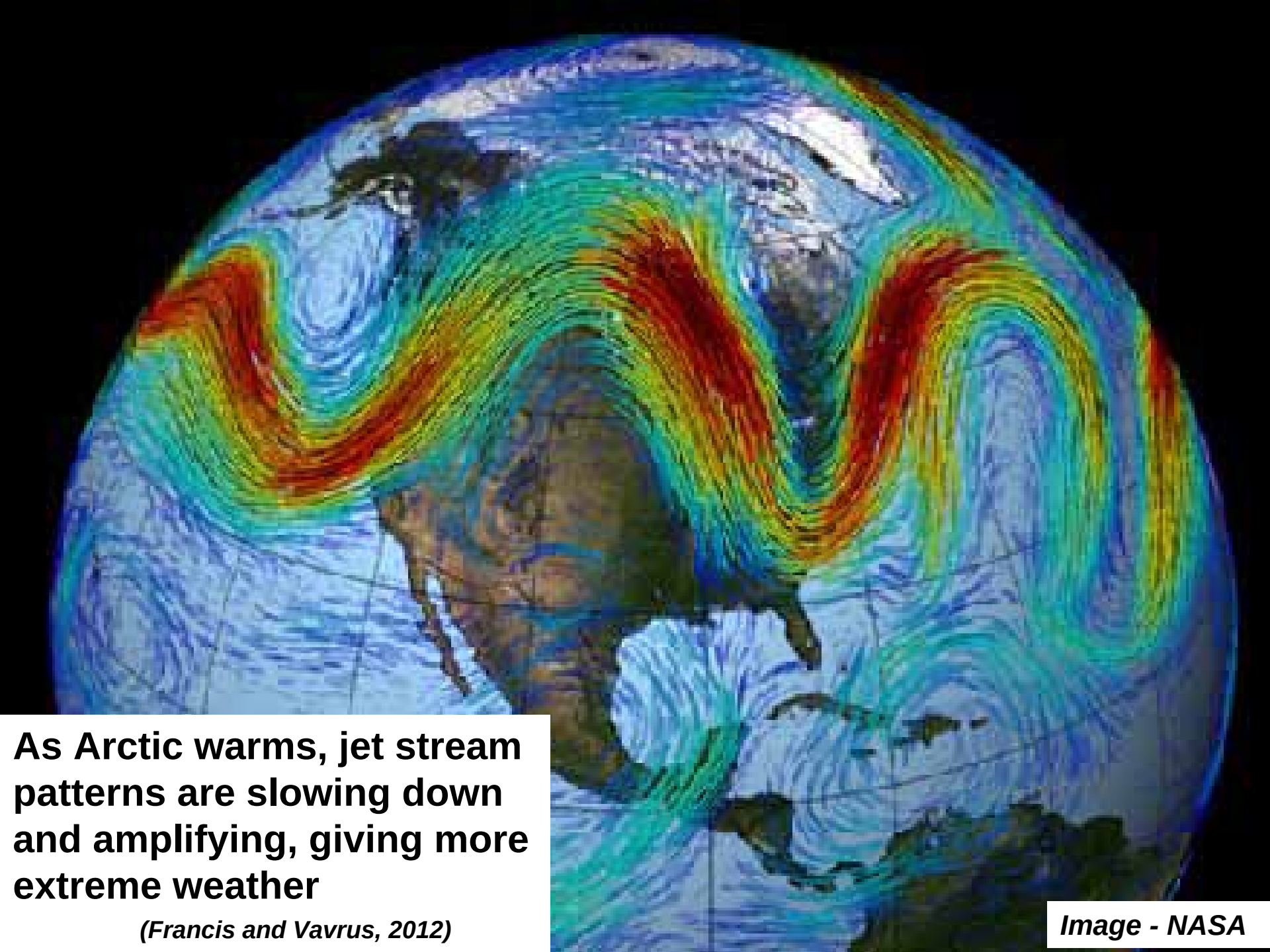


NECIA, 2007

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***



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

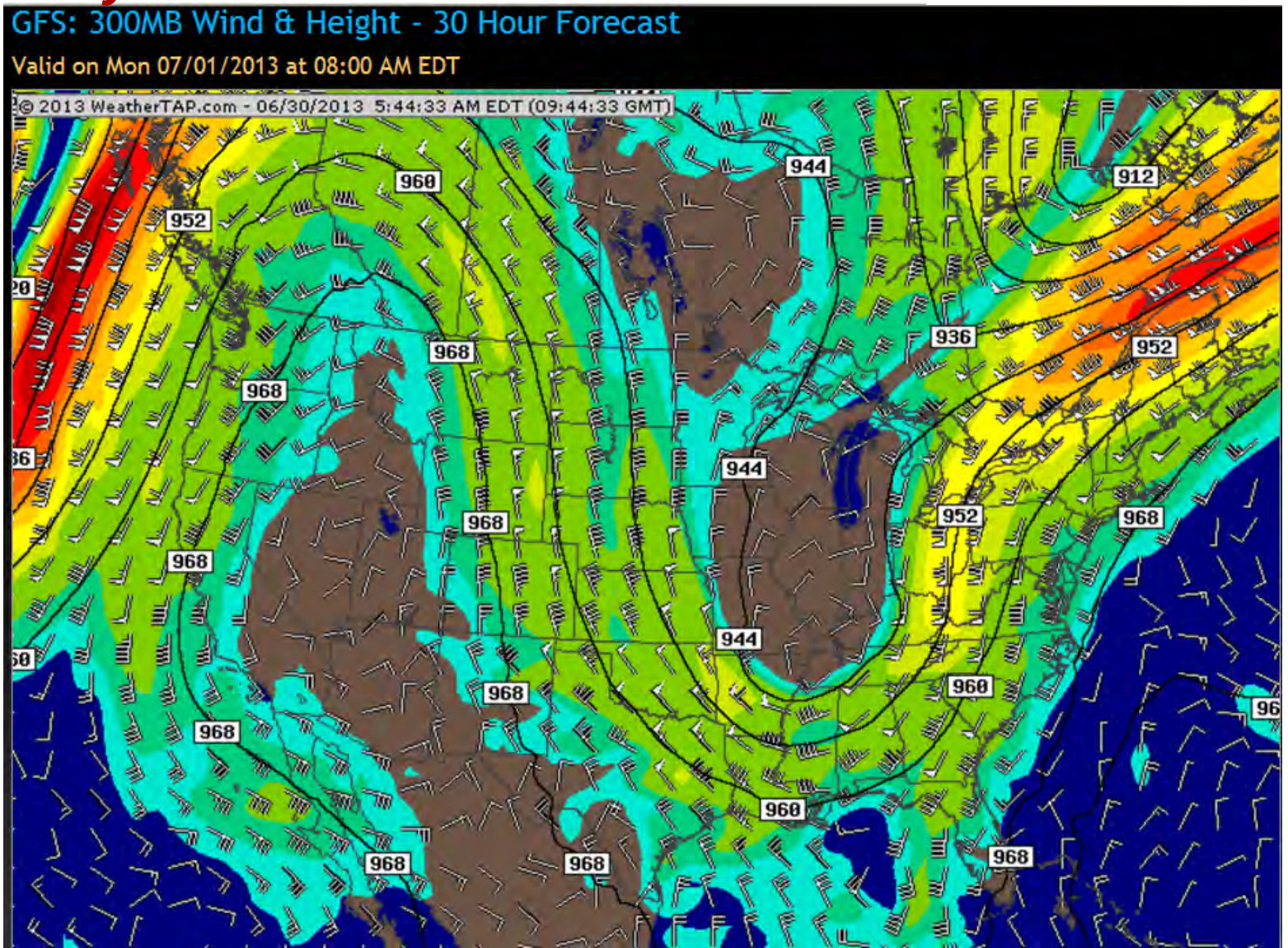
(Francis and Vavrus, 2012)

Image - NASA

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

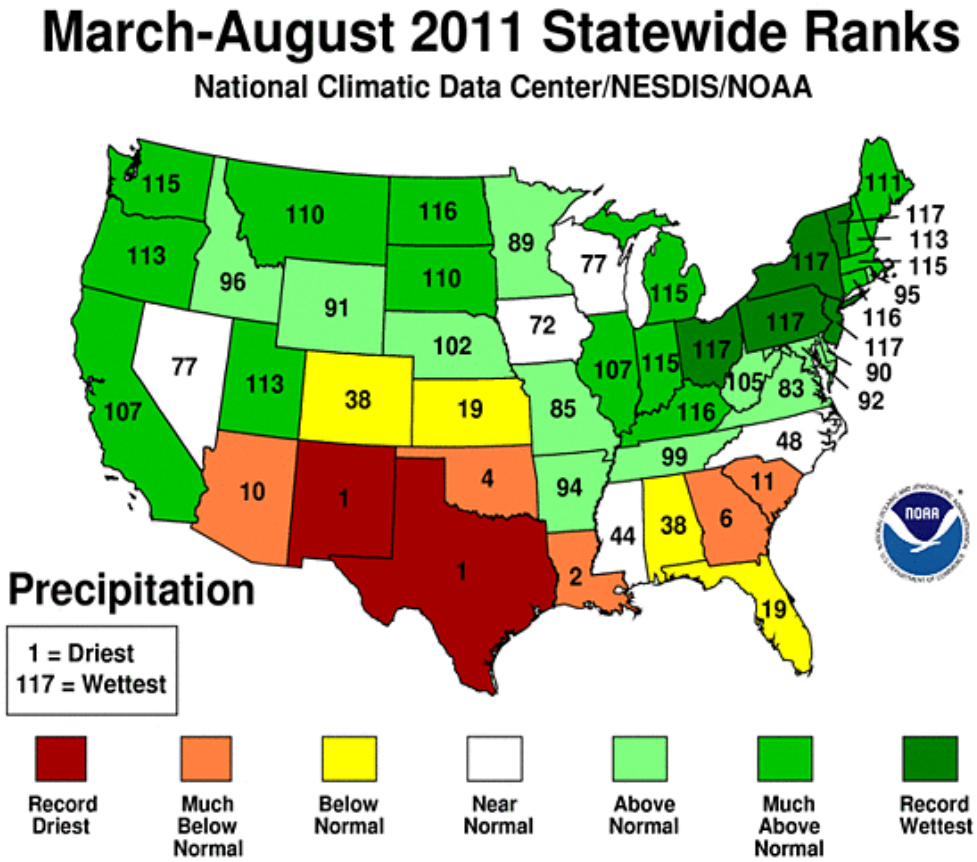
Very wet June in VT

(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 (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)**

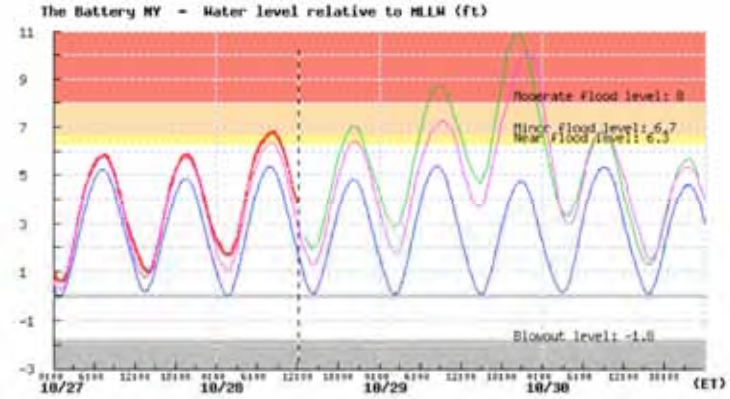
Three Successive Years of East-Coast Tropical Storm Disasters

- **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

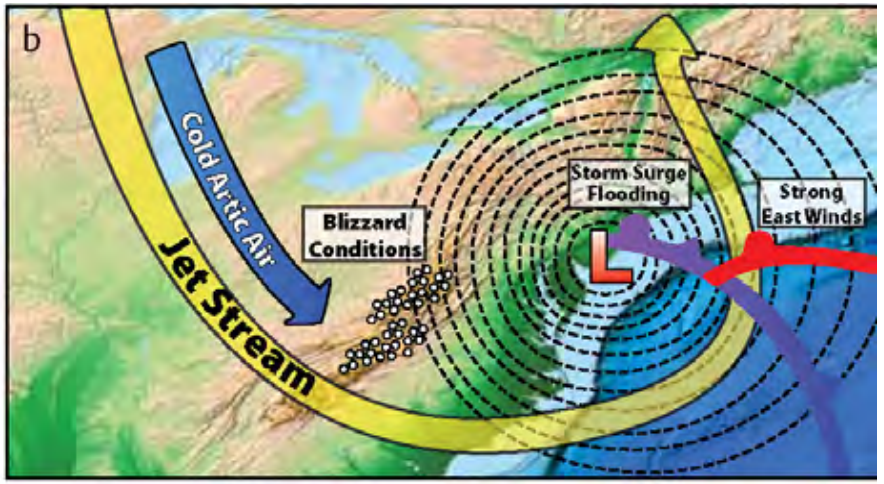
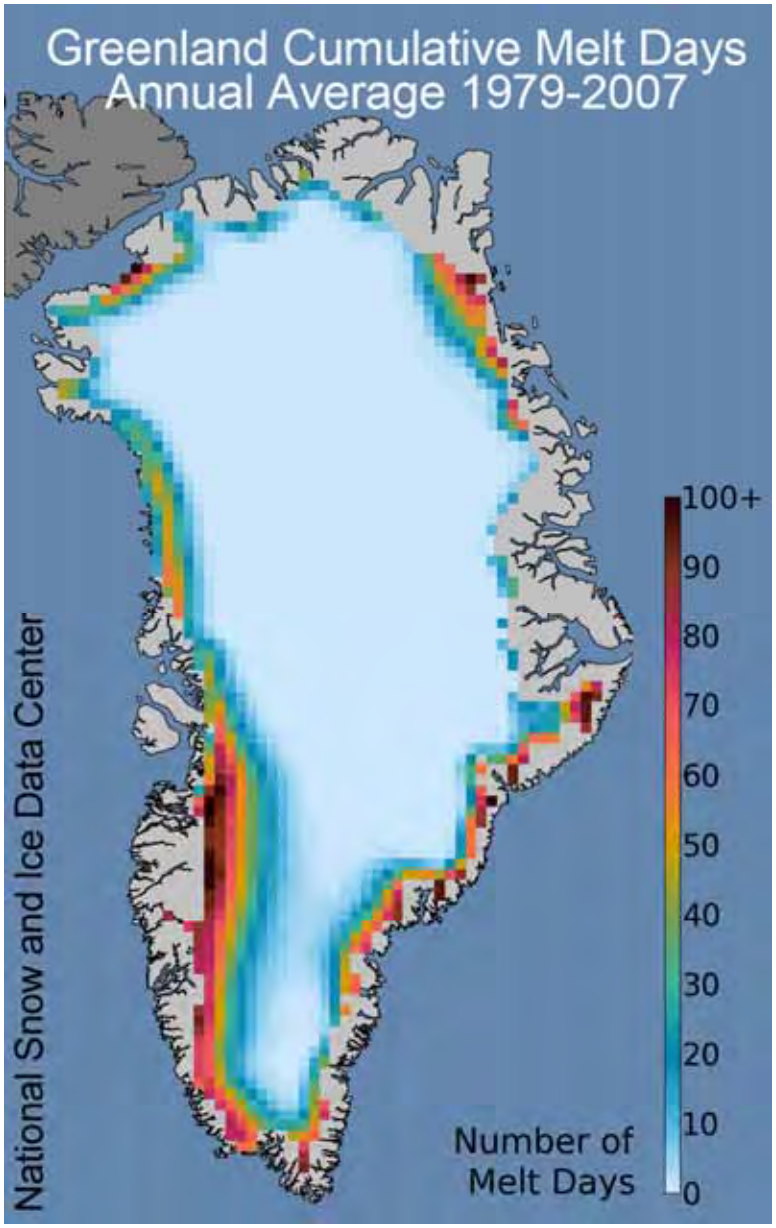


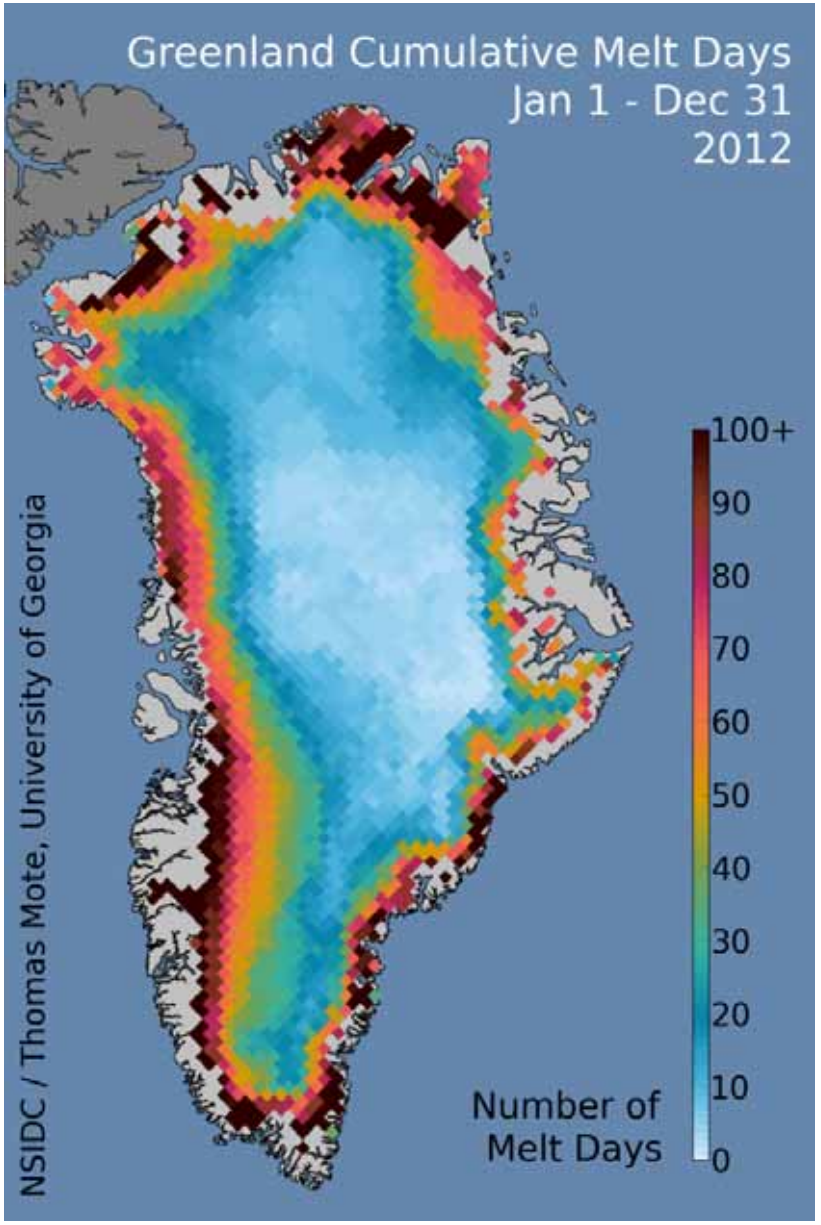
Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical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

Greenland ice-cap melting rapidly





Melting water cascades down a crevasse to the base of the Greenland ice sheet in summer

Softens ice

Glaciers speeding up: when will ice-sheet become unstable?

Sea-level: 20 ft rise if ice-cap melts

Expect 3ft rise this century

Picture: Roger Braithwaite, University of Manchester (UK)

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 estimated at $1000 trillion**
- ***Will need fossil carbon tax (a "waste" tax) to incentivize mitigation and pay for the long-term costs***

Discussion

Background papers:

http://alanbetts.com/

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

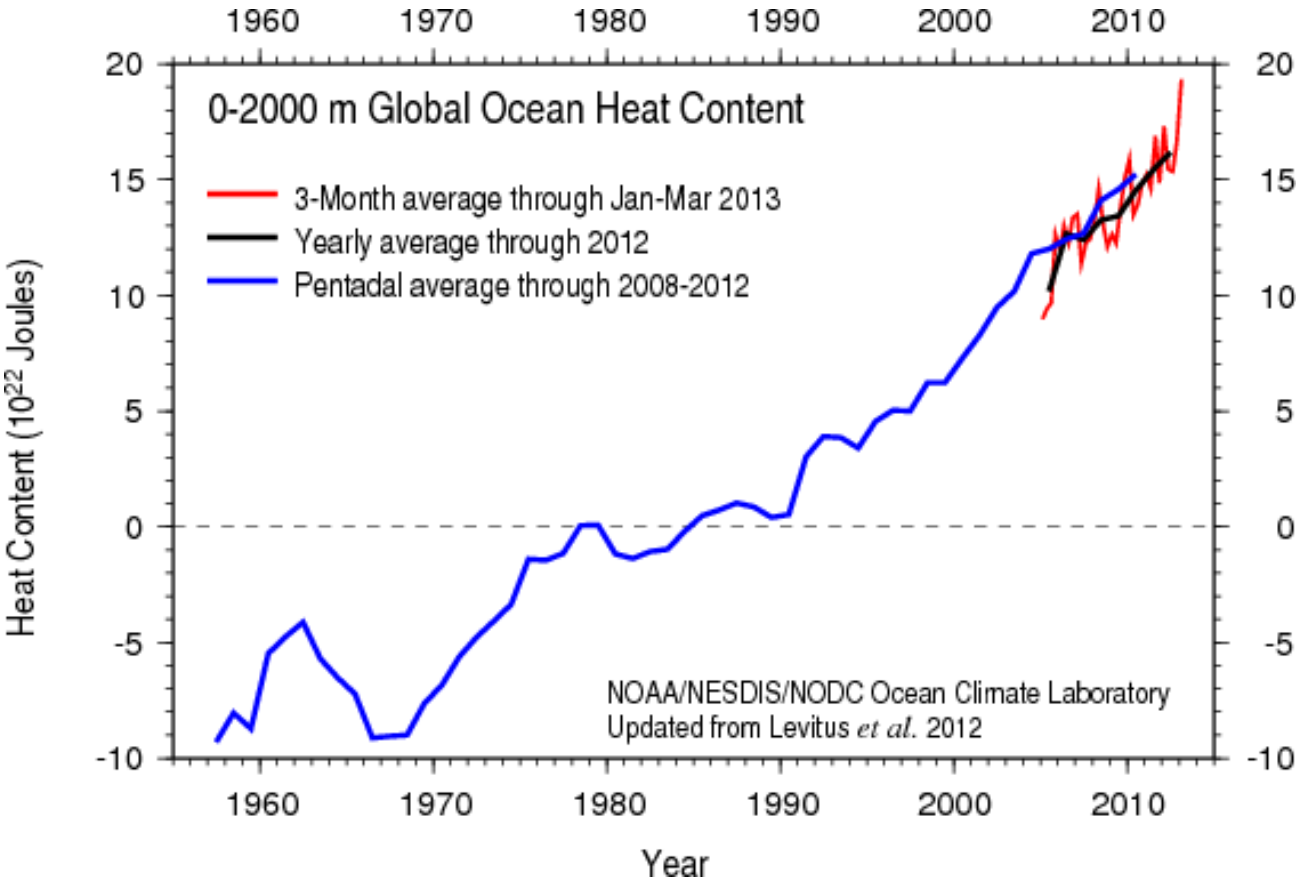
August 27: The Great Transition
- Mitigation & adaptation
- Efficiency and renewable energy

Oceans circulations have long timescales

- **Equatorial Pacific : El Nino**
  - **Warm phase: warmer global climate**
  - **Last strong El Nino was 1998**
- **Pacific ‘decadal oscillation’**
  - **N. Pacific now in cold phase**
  - **Cooler NH**
  - **Mixing heat downward into deep ocean**

Where Does Heating Go?

- ≈ 1 W/m^2
- Warms surface
- Melts ice
- Stored in Ocean



China Industrializing

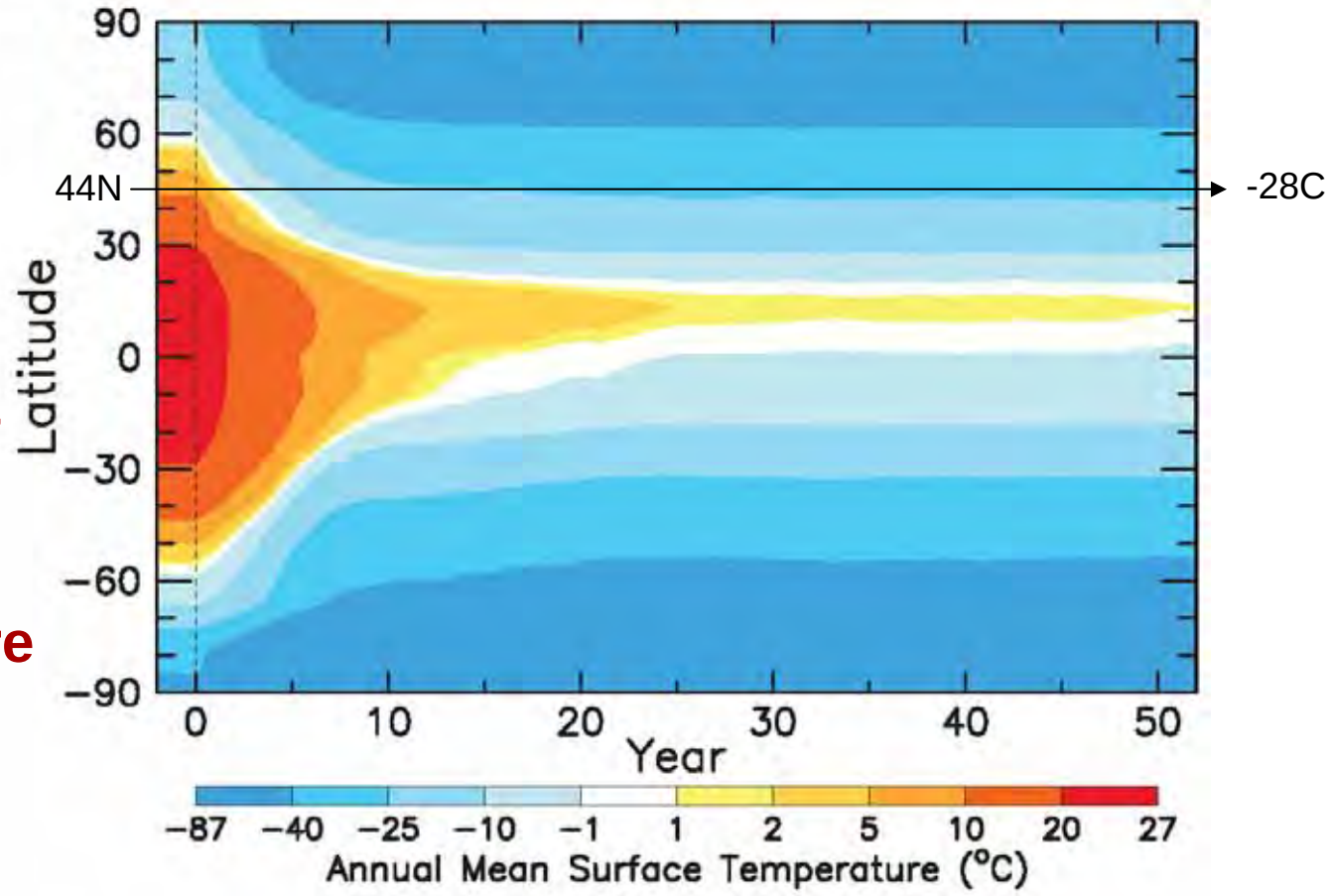
- **Rapid industrial growth in 2000's**
- **Based on coal**
- **Extreme air pollution**

- **Limited global measurements of atmospheric aerosols**

CO_2 is the Primary Control Knob in the Climate System

Fig. 3. Zonally averaged annual mean surface temperature change after the zeroing out of noncondensing GHGs.

(Lacis et al., Science, 2010)



Remove CO_2 and other 'non-condensing' GHG from climate model &

Global Temperature plunges

- **Falls 5°C in 1 year; 35°C in 50 years**
- **Water vapor falls 90%; cloud-cover goes to 75%; sea-ice to 50%**

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**