Climate Change in the Northeast

Dr. Alan K. Betts

Atmospheric Research, Pittsford, VT 05763

akbetts@aol.com
http://alanbetts.com

NNECAPA

Stowe, VT

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RACC
Research on Adaptation to Climate Change

Outline

- **Science of climate change**
  - **Global and local**
  - **Vermont as example**
  - **Why is extreme weather increasing?**
- **The transition we face**
  - **Need to reduce emissions**
  - **Need to build resilience**

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**

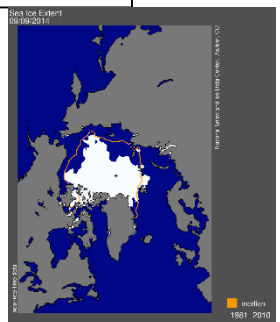
January 2, 2012: NASA

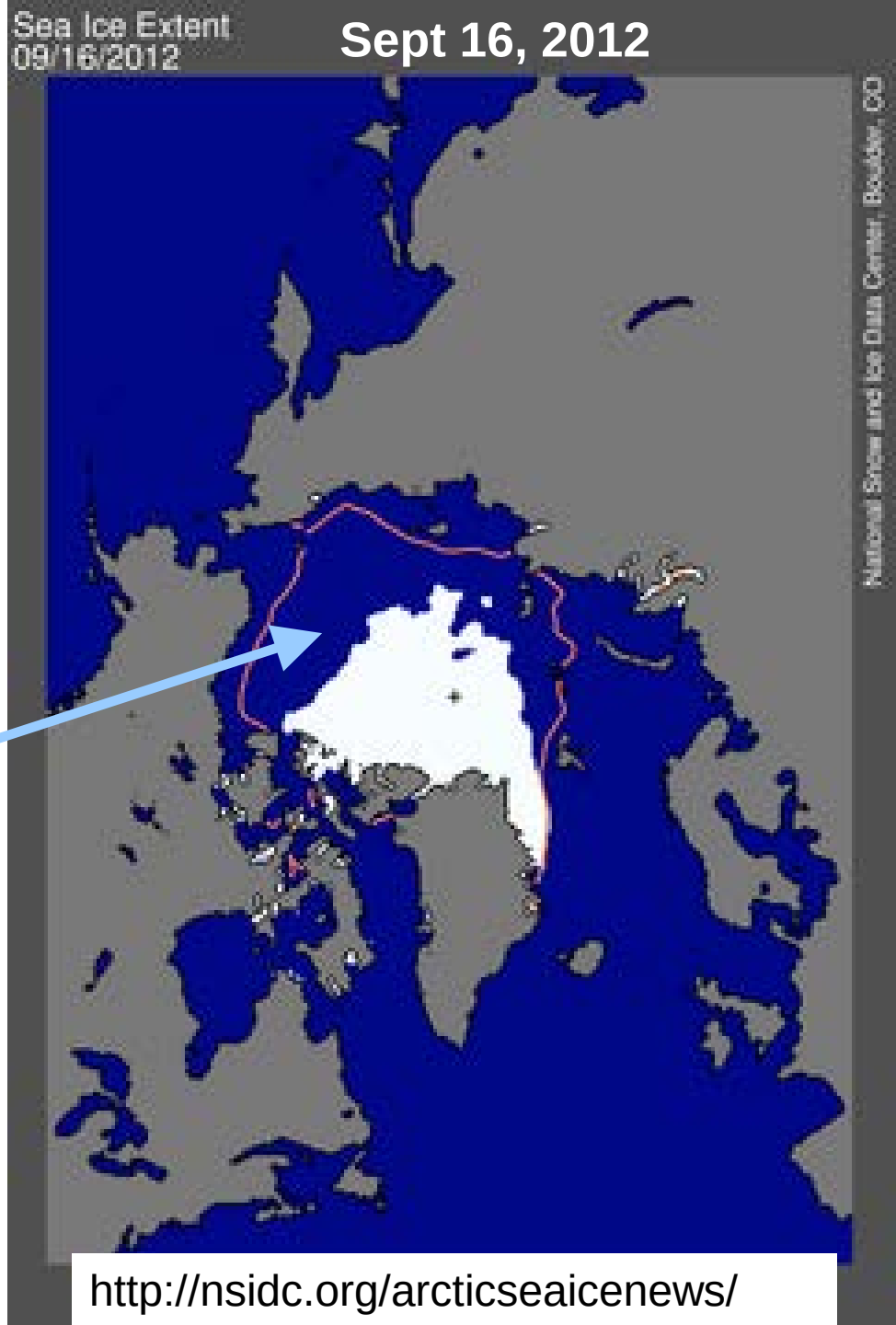
System Issues

- **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 planning strategies and mindset are needed to mitigate, adapt and build resilience in northern New England?**
  - **Is this an efficient way of doing this?**
  - **Can we manage our waste streams better?**
  - **What are long-term planning consequences?**

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

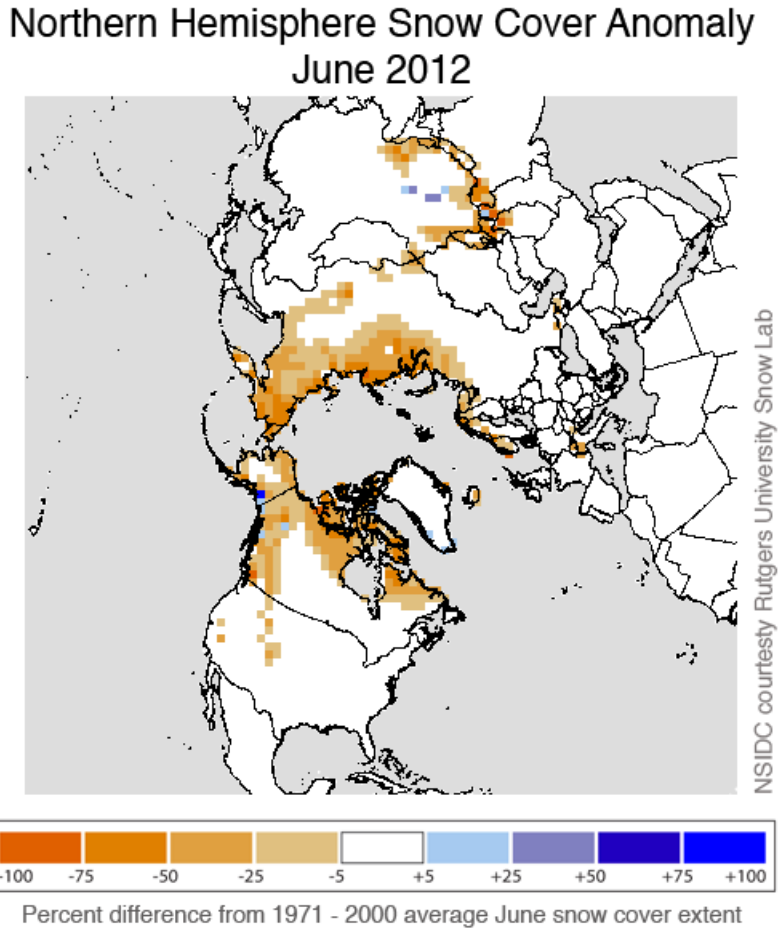
- ***Positive feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Ice thin: most 1-yr-old***

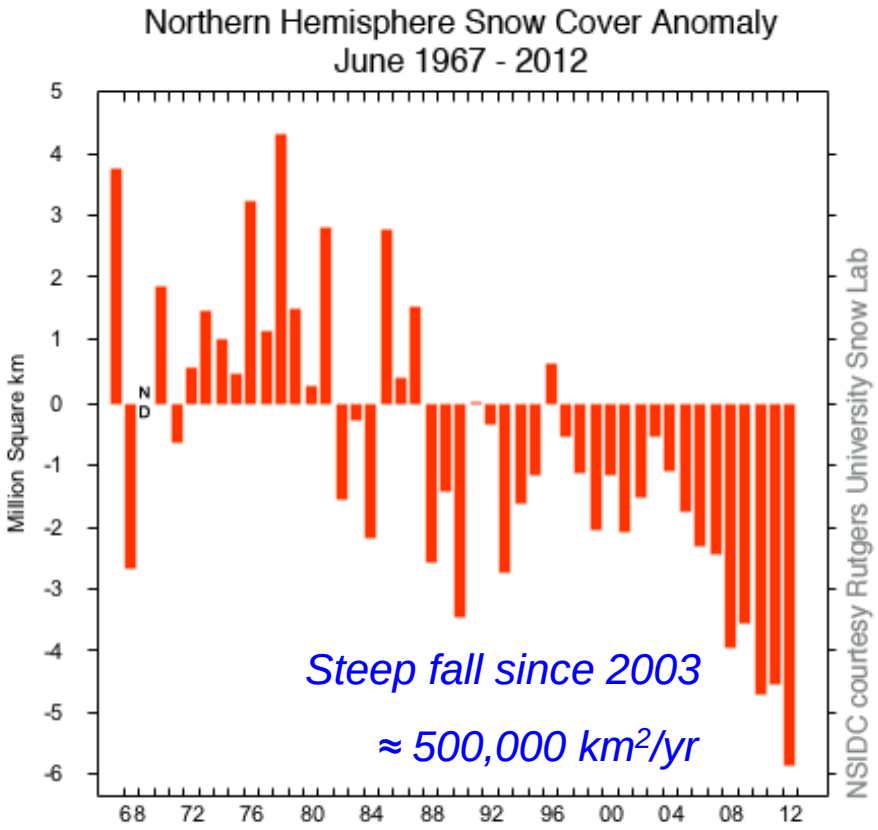




http://nsidc.org/arcticseaicenews/

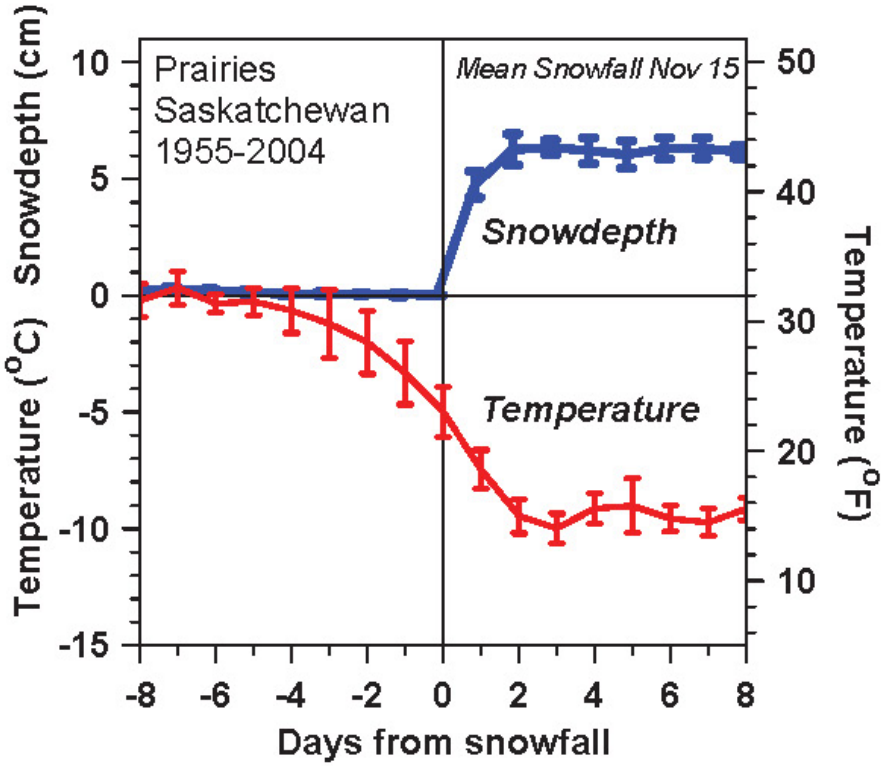
June 2012 snow cover minimum

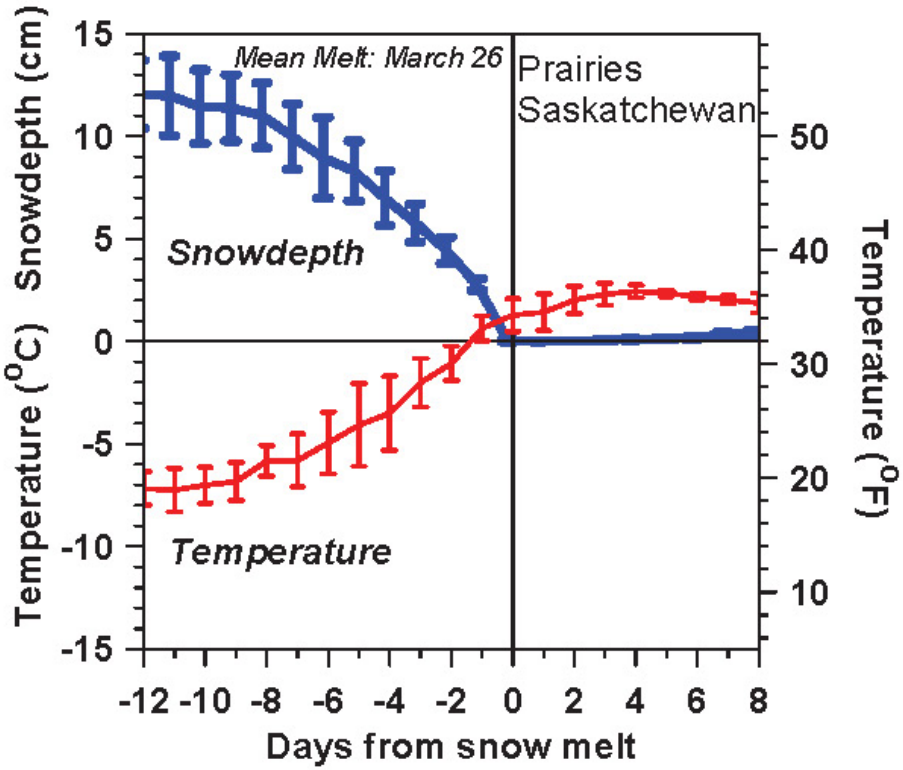




- **Arctic warming rapidly**
  - **Melting fast**
  - ***Much faster than IPCC models***
- **Northeast winters**
  - ***Same positive feedbacks***

Snowfall and Snowmelt

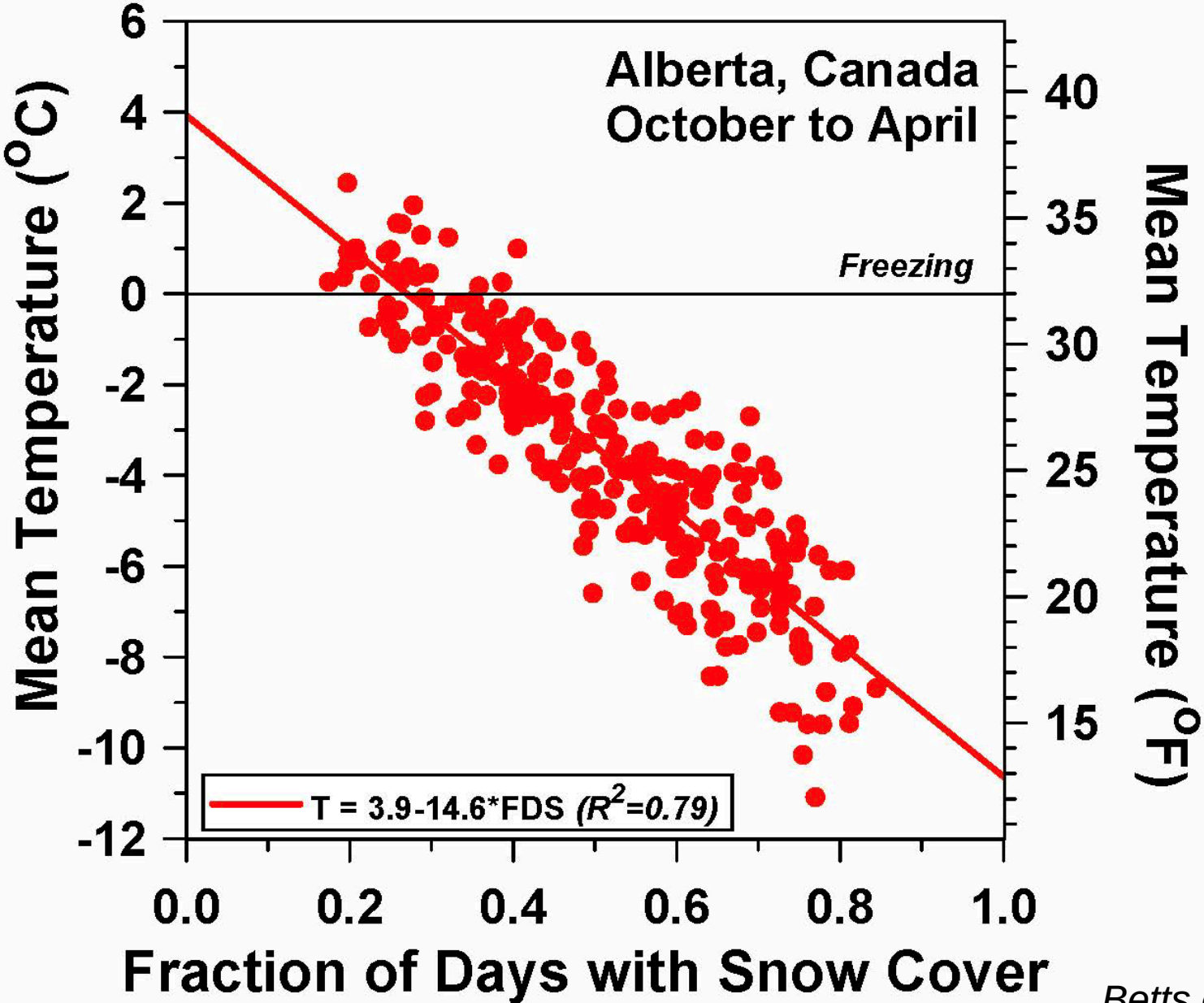




- **Temperature falls 18F (10C) with first snowfall**
- **Similar change with snowmelt**
- ***Snow reflects sunlight; reduces evaporation and water vapor greenhouse – changes 'local climate'***

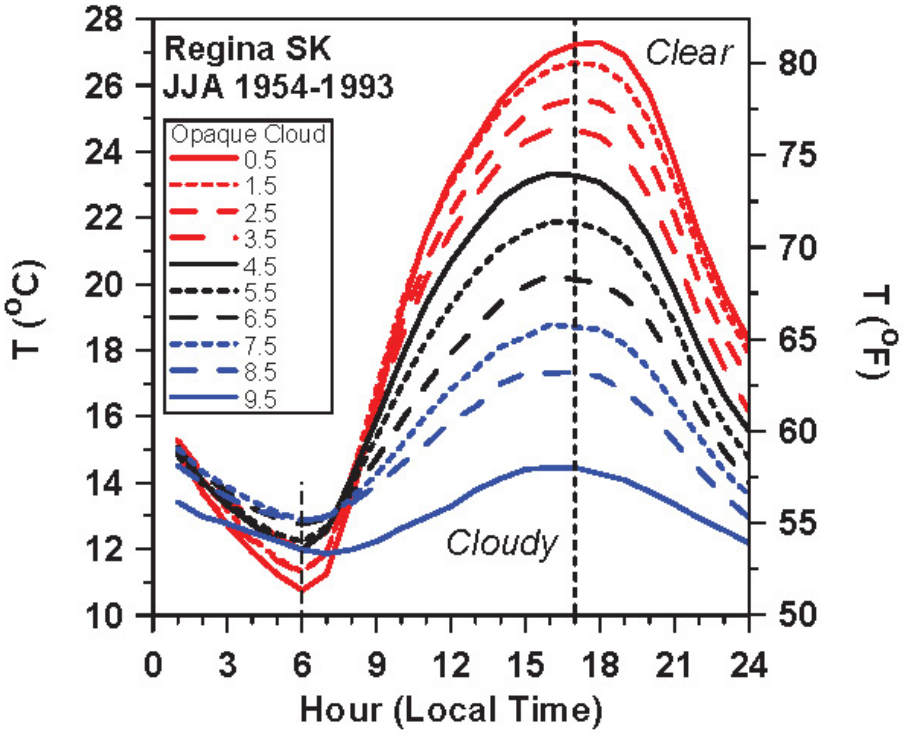
Betts et al. 2014

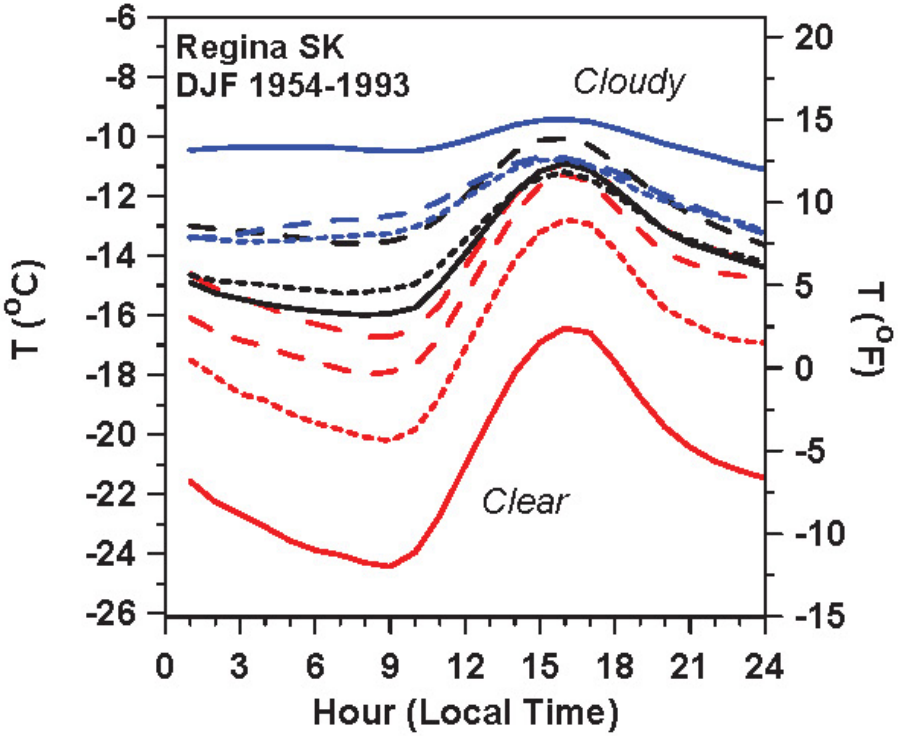
More snow cover - Colder temperatures



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?

(Representative of Northern NE)

- **PAST 40/50 years** ***(global CO_2 forcing detectible)***

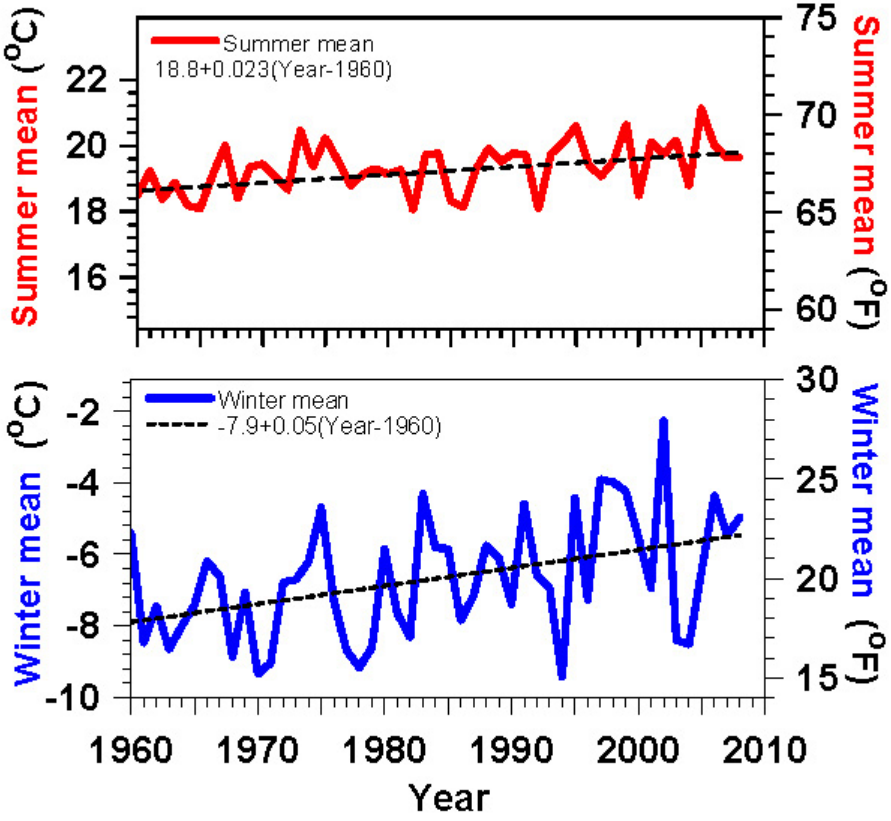
- **Warming twice as fast in winter than summer**
- **Winter minimums increasing even faster**
- **Lakes frozen less by 7 days / decade**
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**

(Betts, 2011)

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

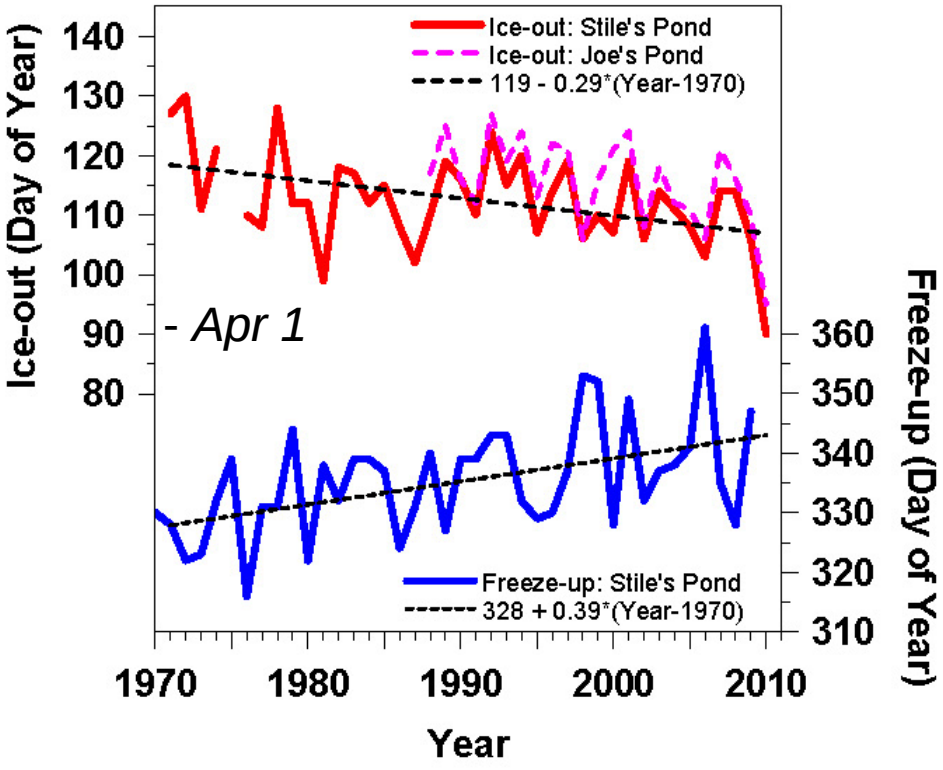
Vermont Temperature Trends 1961-2008

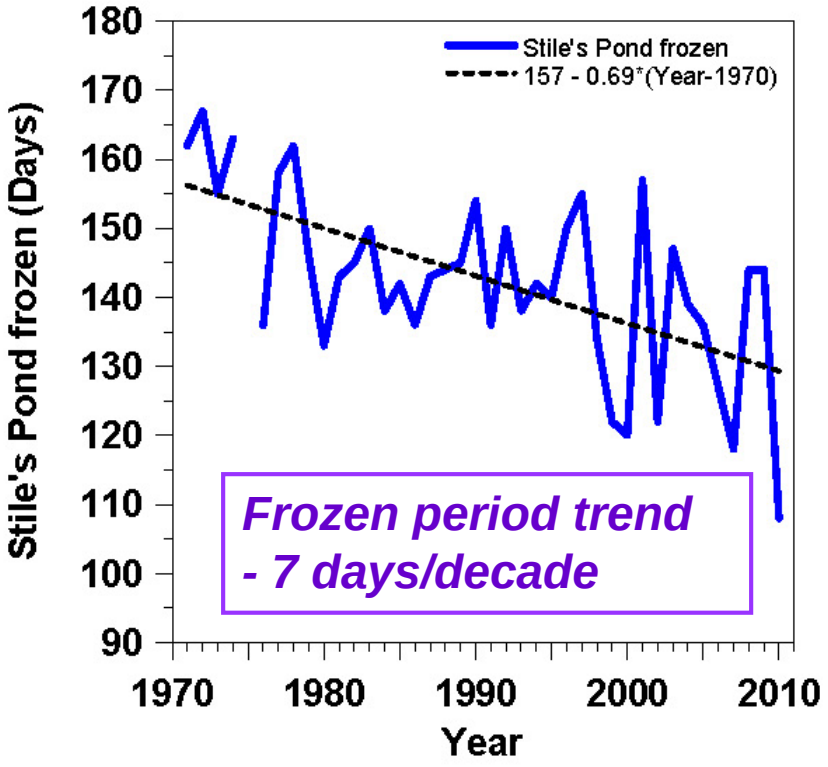
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***



Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



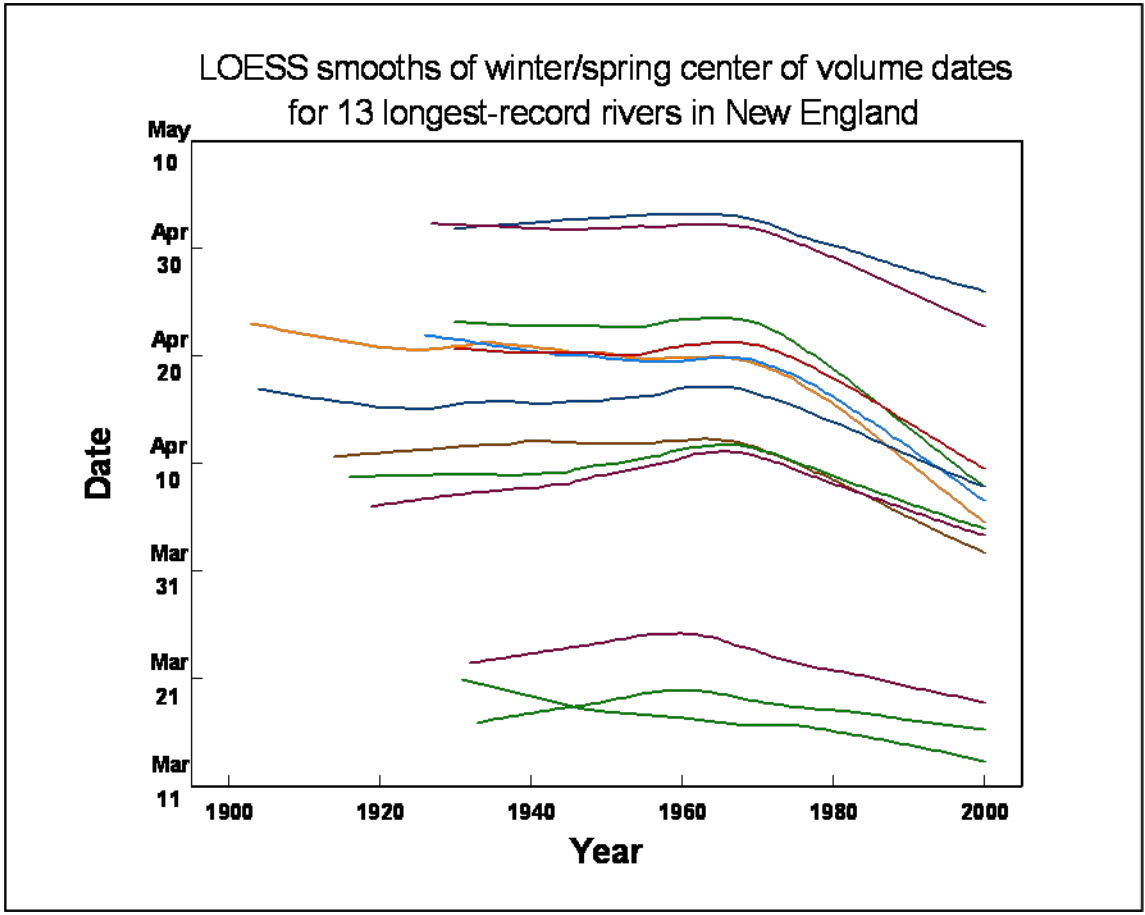


- **Ice-out earlier by 3 days / decade**
- **Freeze-up later by 4 days / decade**
- ***Soil ice probably similar***

Hydrology Sensitive to Climate

Lent (2010), USGS, Me

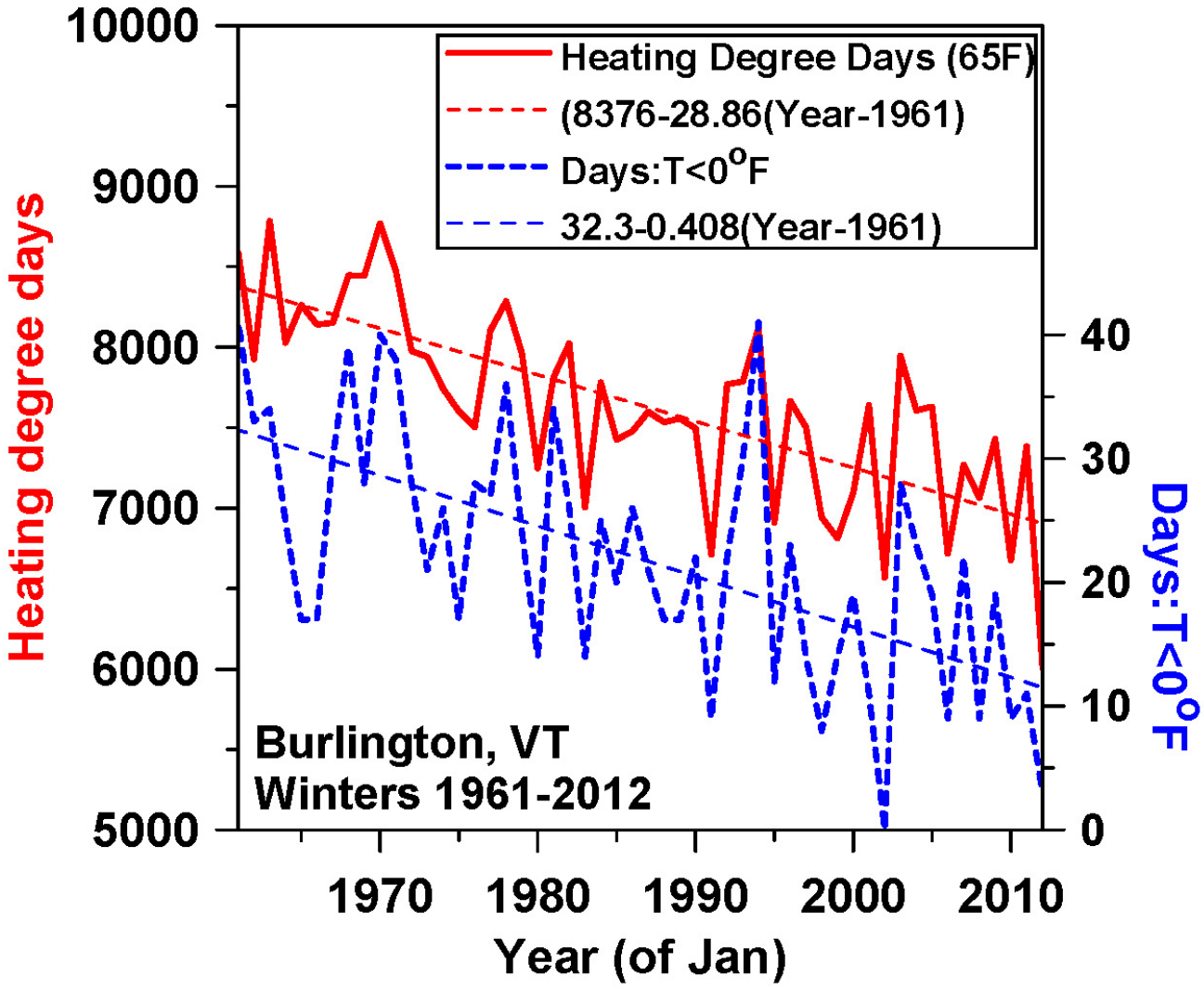
- **Peak spring runoff**
- ***Earlier in northern New England in recent years***
  ≈ 3 days/decade
- ***Timing related to air temperatures in Spring***



(Hodgkins and others, 2003)

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

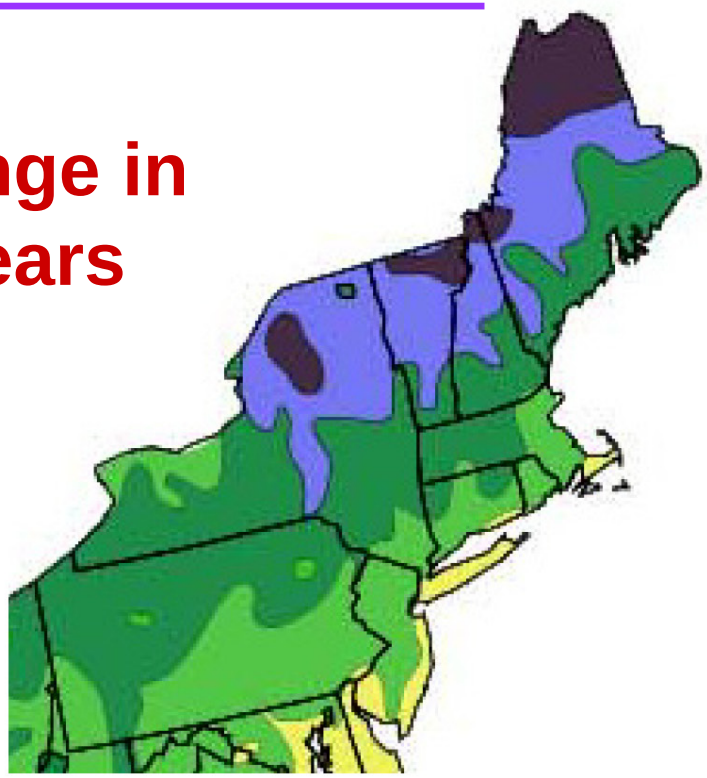
- **Heating degree days *falling 290/decade***
- **T_{min}<0°F *falling 4 days /decade***



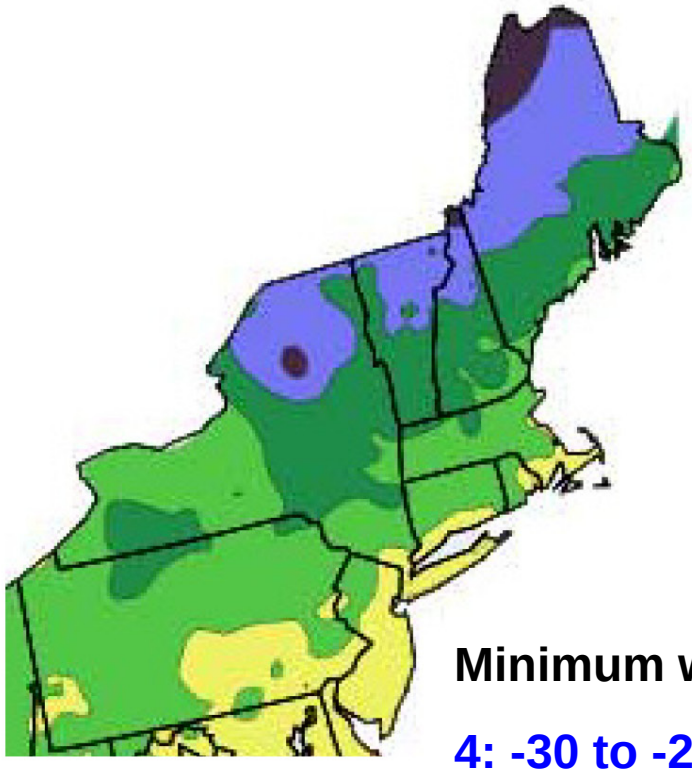
Winter Hardiness Zones

– *winter cold extremes*

Change in 16 years

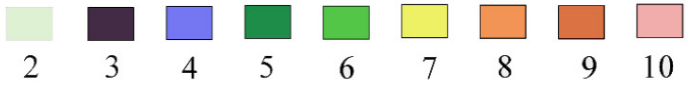


1990



2006

Zone



Minimum winter T

4: -30 to -20ºF

5: -20 to -10ºF

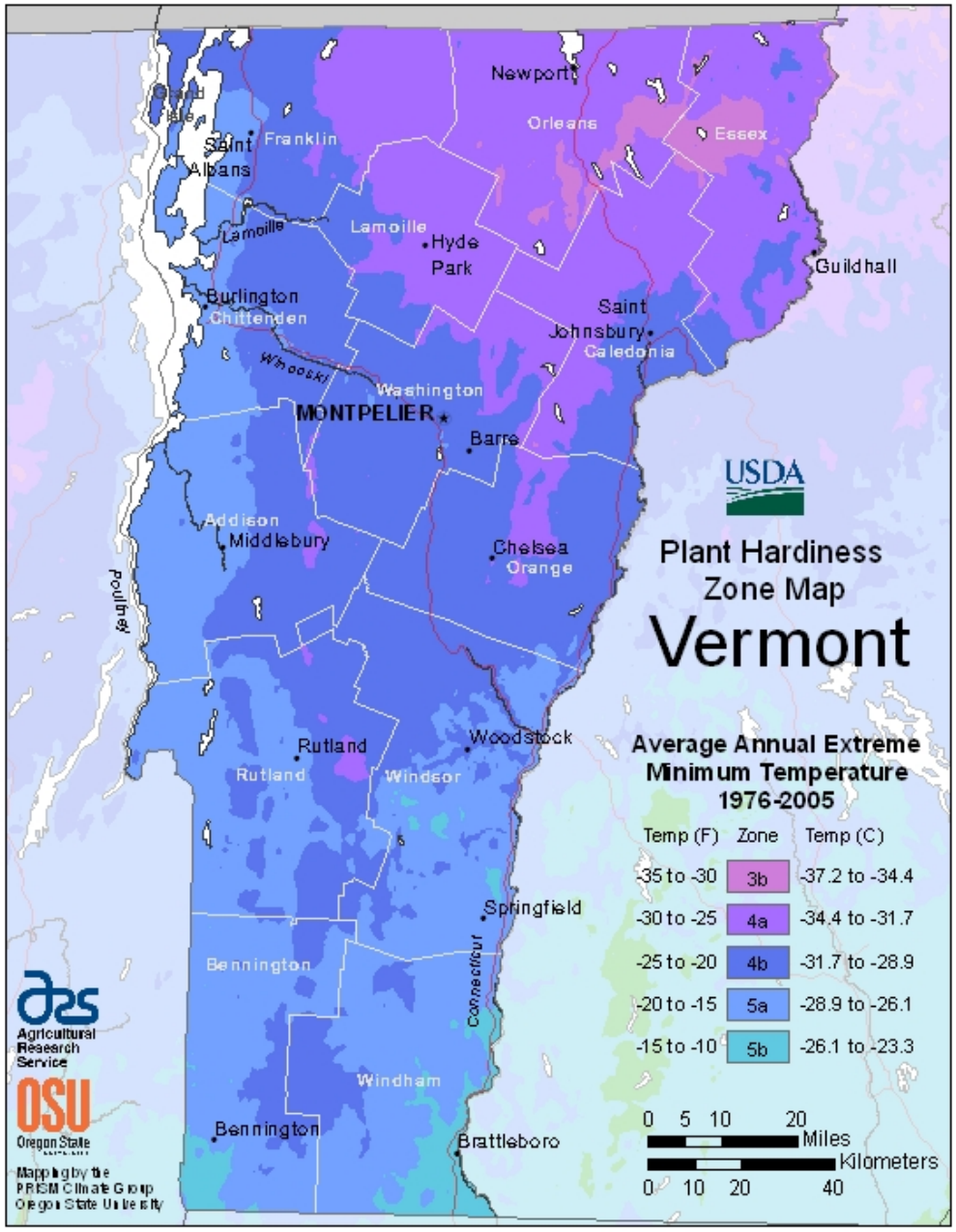
6: -10 to 0ºF

USDA Hardiness Zones

Detailed Map *(most recent)*

- **VT Hardiness Zone Map 1976-2005**
  - **mean 1990**
  - **South now zone 6**
- **Half-zone in 16 yrs = 3.1ºF/ 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**

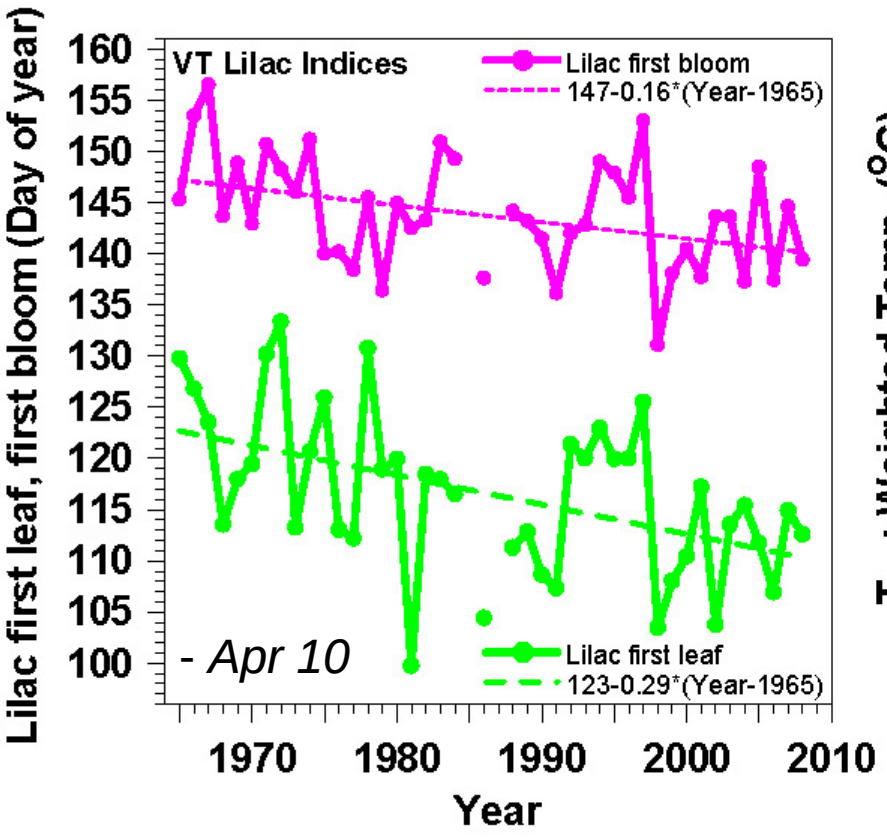
Bennington & Brattleboro are becoming zone 6

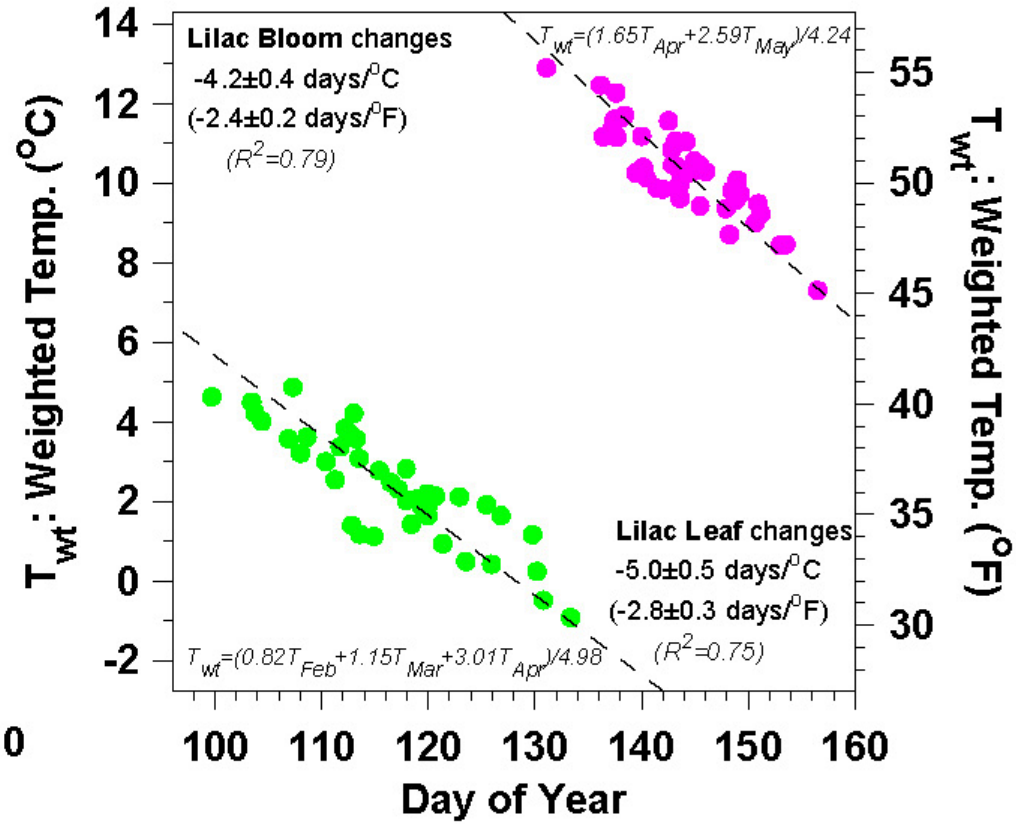
- **Hardy peaches: 2012**
- **More pests survive winter**

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

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

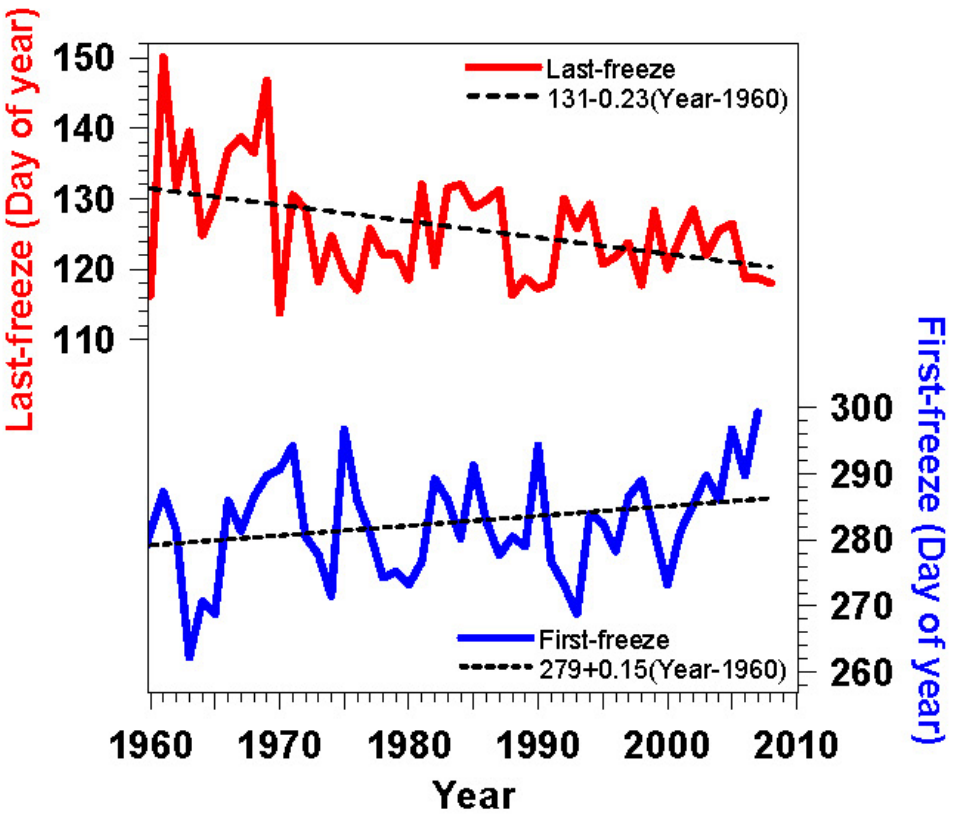
Lilac Leaf and Bloom

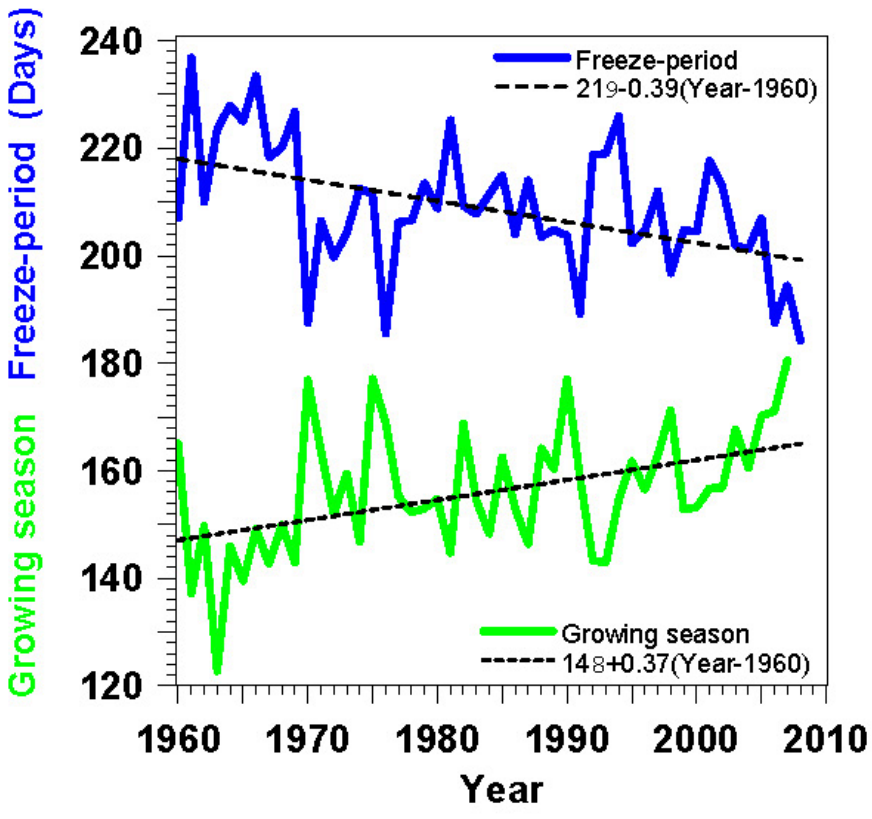




- **Leaf-out -2.9 days/decade; Bloom -1.6 days/decade**
- ***Large year-to-year variation related to temperature:***
  2.5 days/ °F (4.5 days/°C)

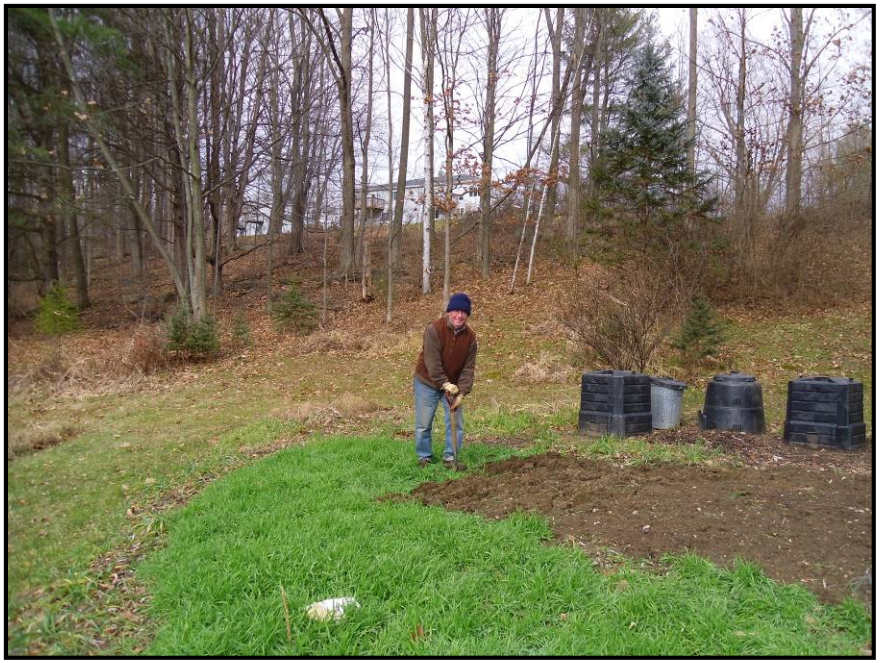
First and Last Frosts Changing





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

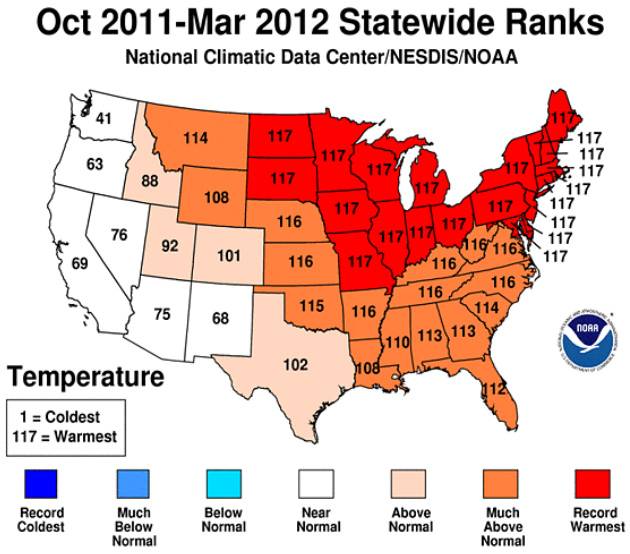
January 2, 2012



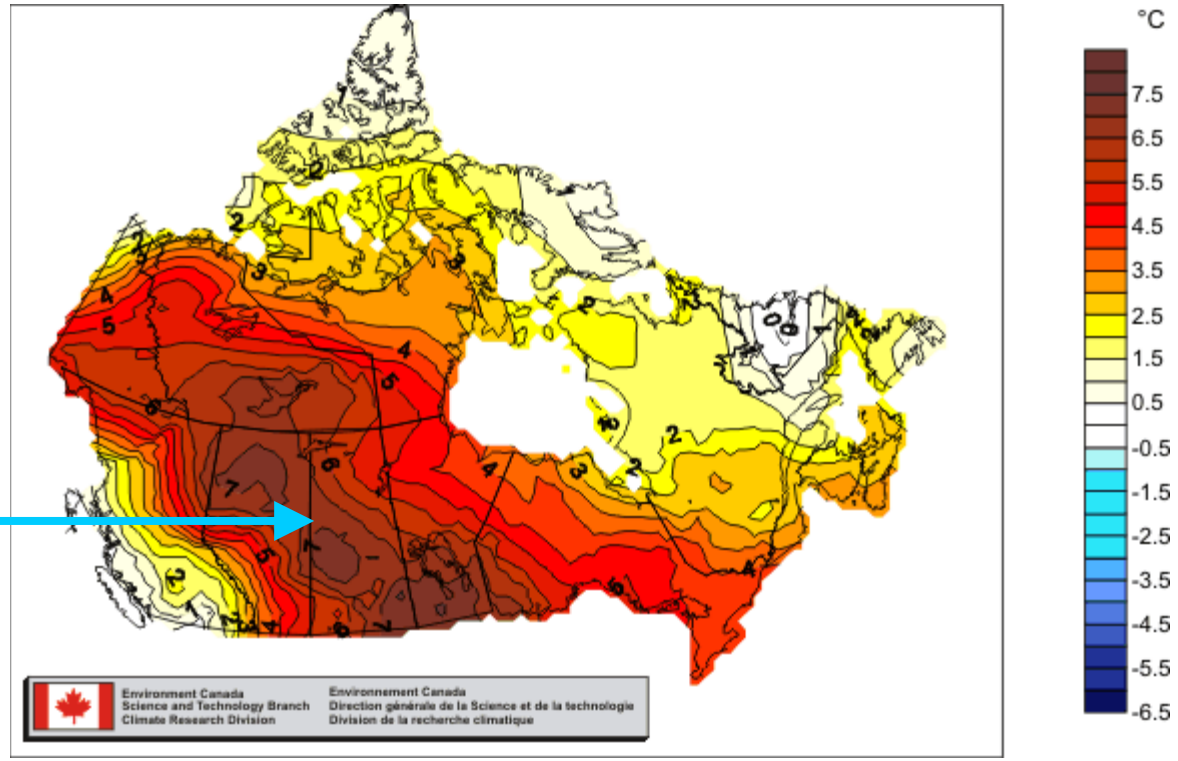
March 11, 2012

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**



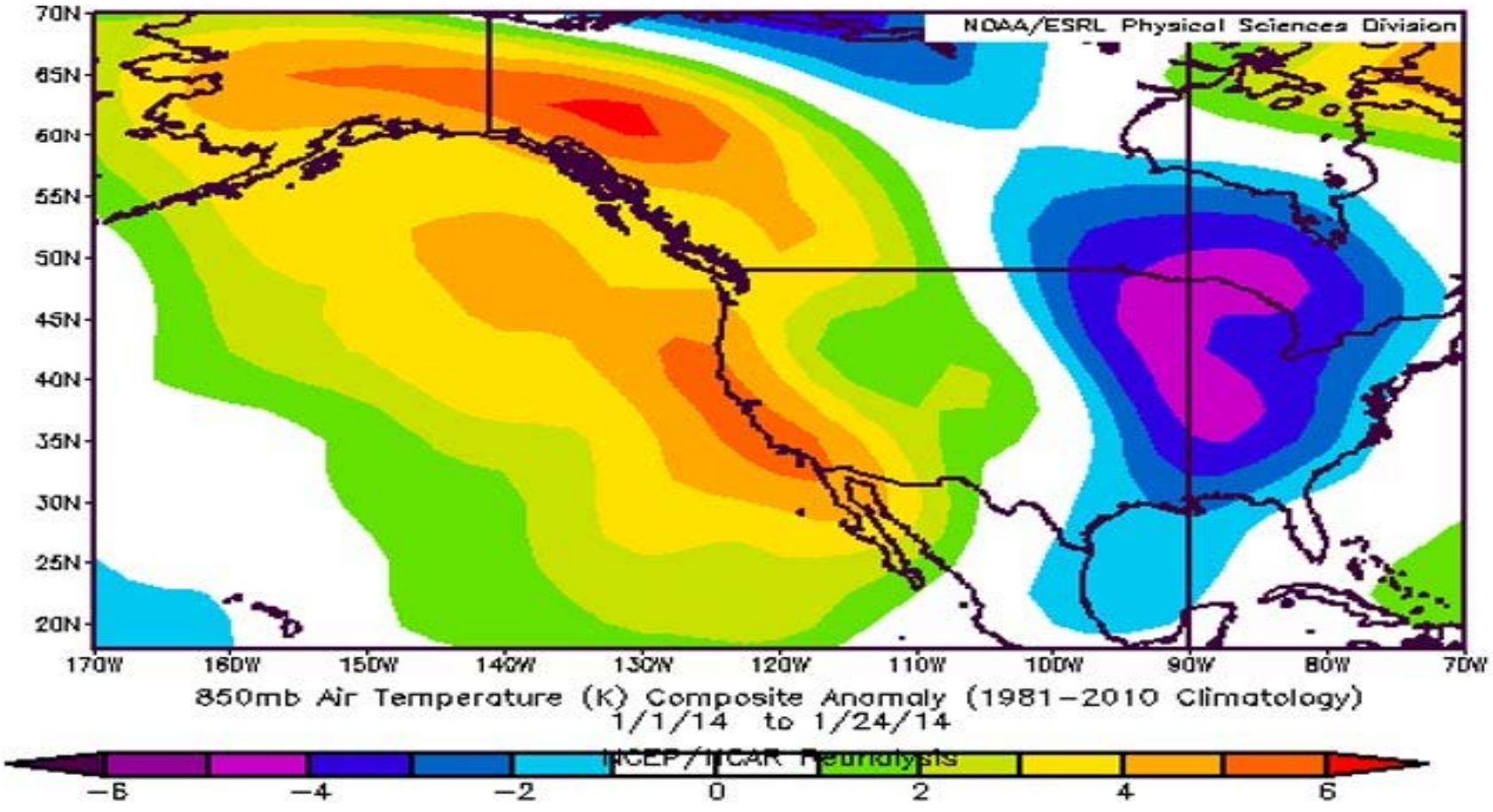
Across the border: Canada



+12ºF

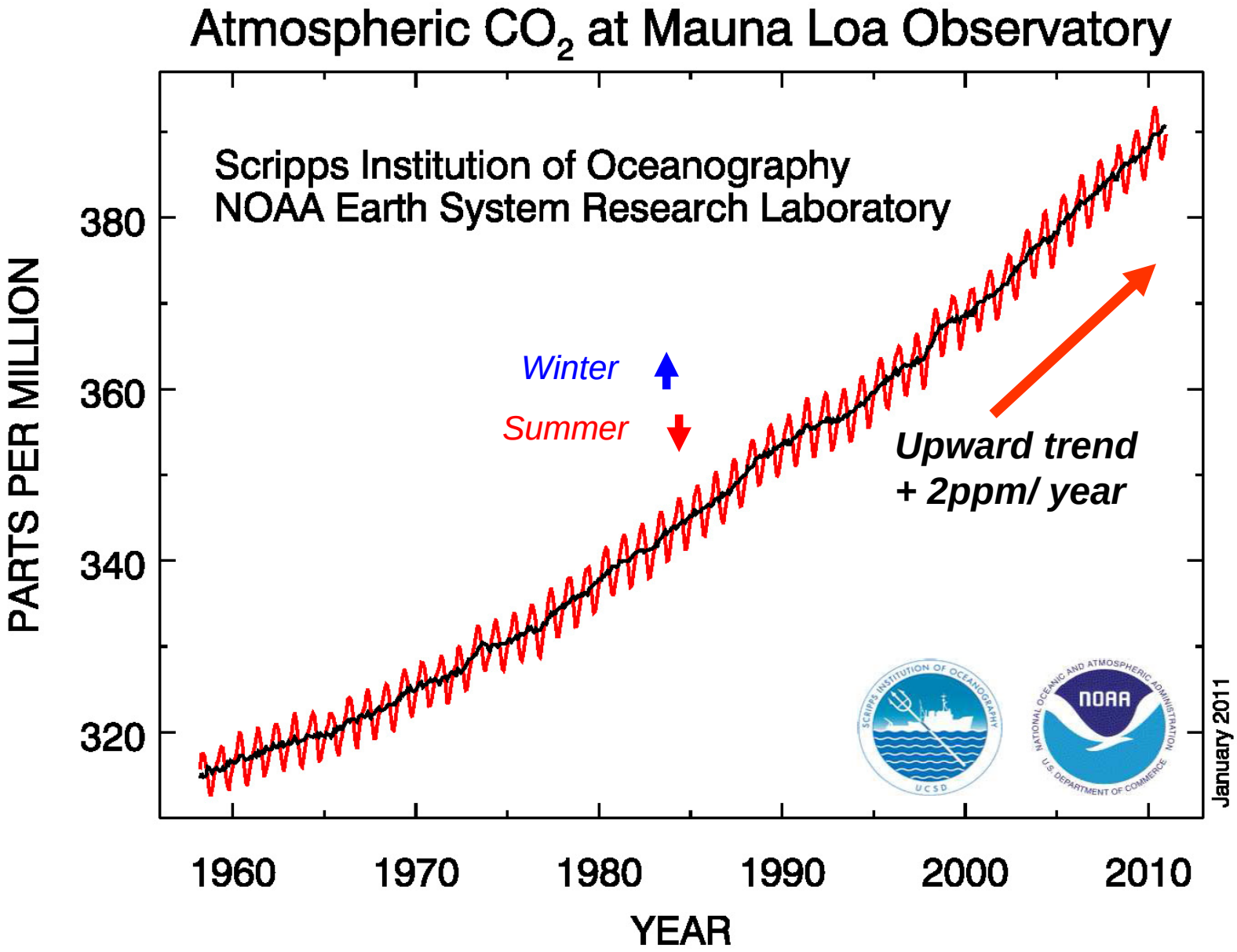
- **Winter 2011-12: Far above "normal"**
  - **Canada's winters also warming 0.9ºF/decade**
- ***Climate doesn't see the border!***

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: 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**

Increasing CO_2 is long-lived driver

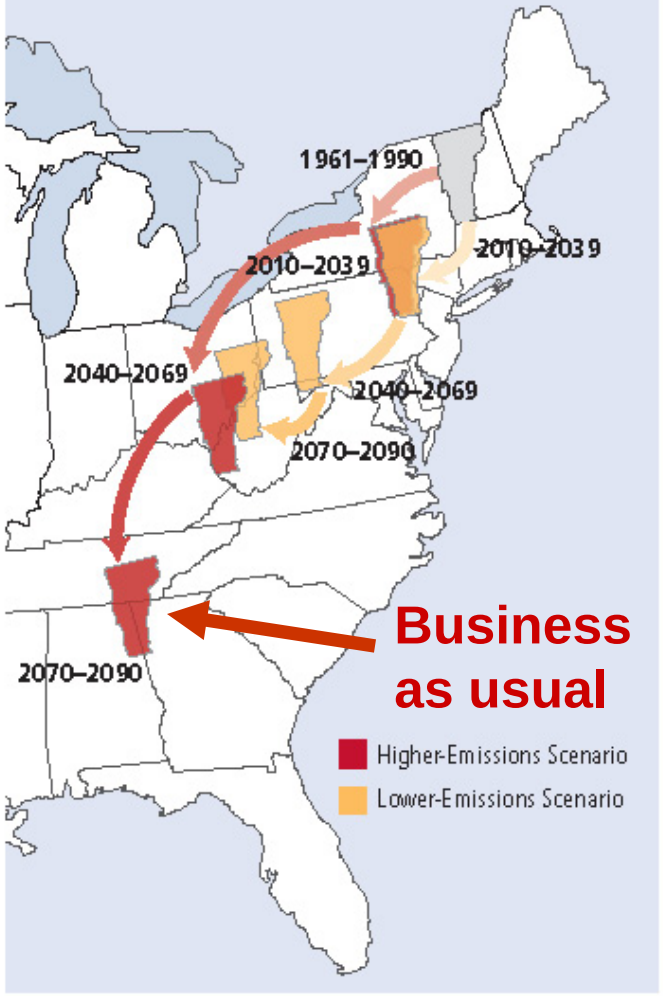
Water: *Strong Feed-backs Amplify*

- **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**

Vermont's Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US



Migrating State Climate

Changes in average summer heat index—a measure of how hot it actually feels, given temperature and humidity—could strongly affect quality of life in the future for residents of Vermont. Red arrows track what summers in Vermont could feel like over the course of the century under the higher-emissions scenario. Yellow arrows track what summers in the state could feel like under the lower-emissions scenario.

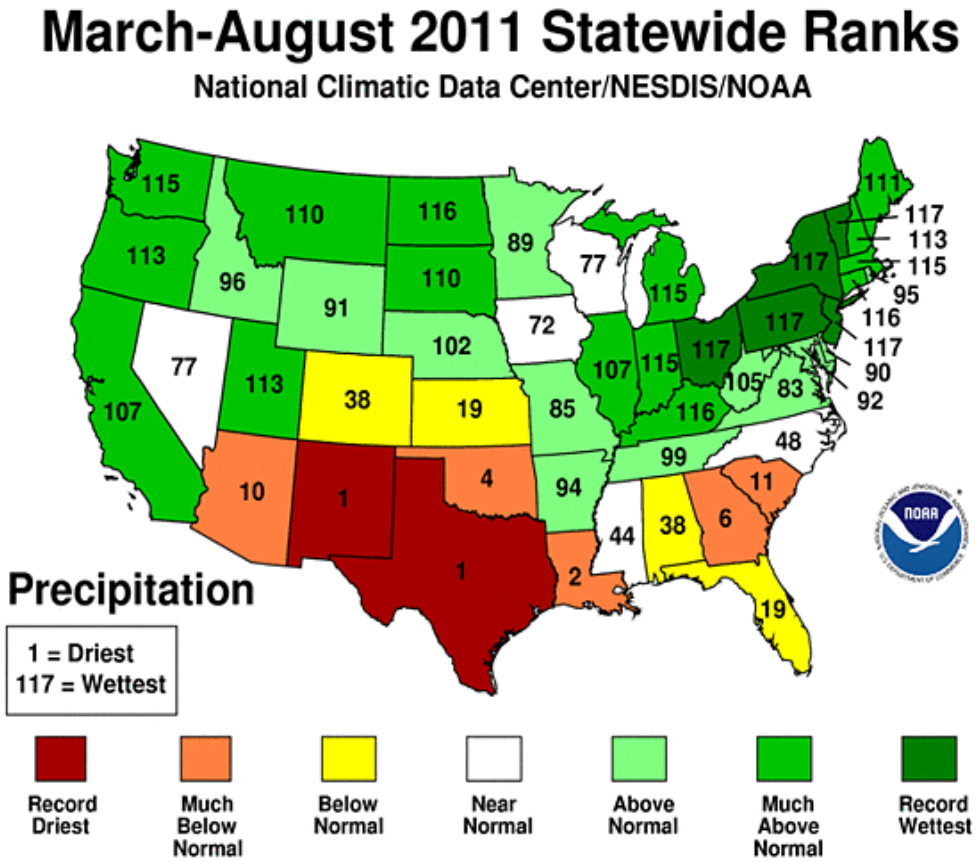
NECIA, 2007

Extreme Weather (precip.)

- **Precipitation - condensation of water vapor - larger heat release – increases with temperature**
  - ***Saturation vapor pressure at cloud-base increases steeply with temperature (4%/ºF)***
  - ***Gives heavier rain-rates and stronger storms***
- **Quasi-stationary large-scale flow patterns give**
  - **longer rain events in low-pressure regions**
  - **longer droughts in high-pressure 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

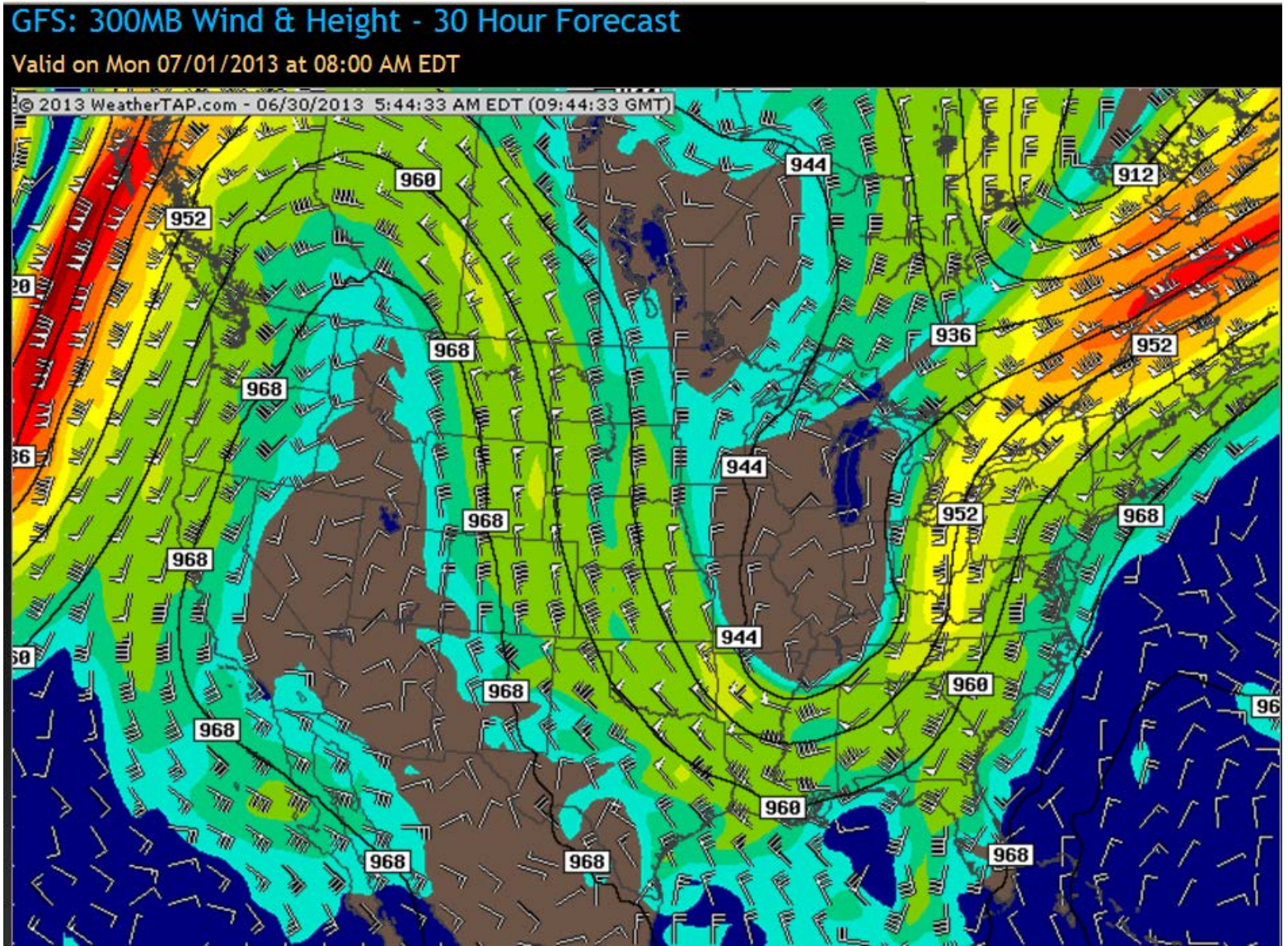
- **Record wet : OH to VT**
- **Record drought: TX & NM**
- **'Quasi-stationary' pattern**

2011 Classic Flood Situations

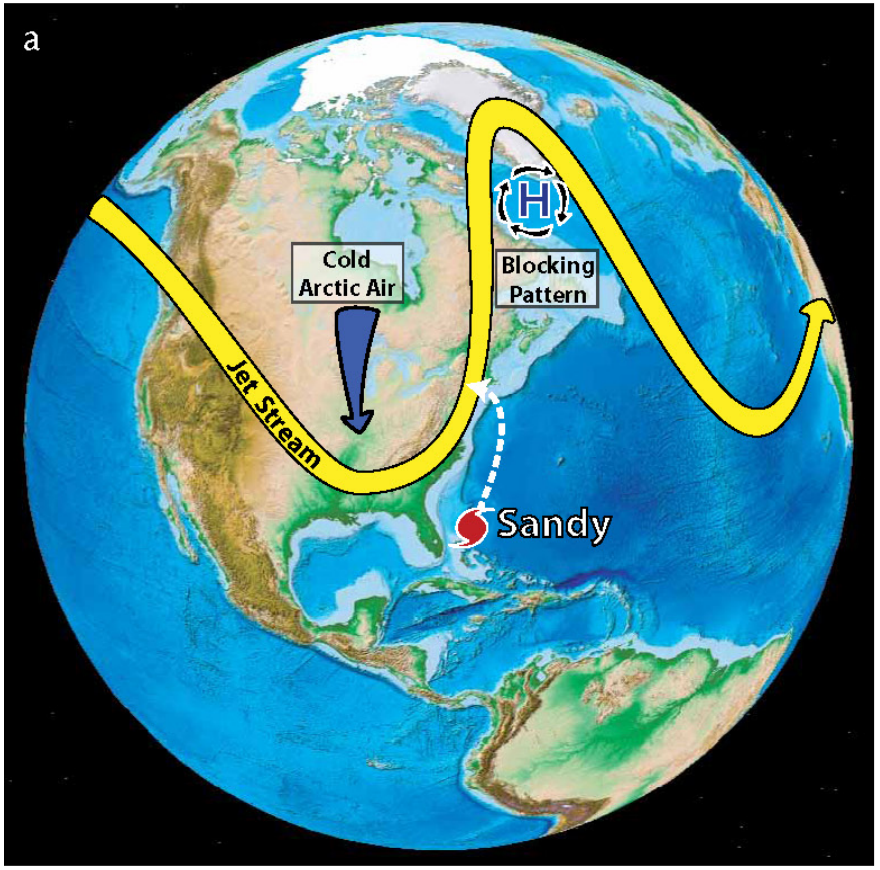
- **Spring flood: heavy rain and warm weather, melting large snowpack from 2010 winter**
  - **70F (4/11) and 80F(5/27) + heavy rain**
  - **record April, May rainfall: 3X at BTV**
  - **Severe floods on Winooski and Adirondack rivers**
  - **Lake Champlain record flood stage of 103ft**
- **Irene flood: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



Hurricane Sandy - Unique track



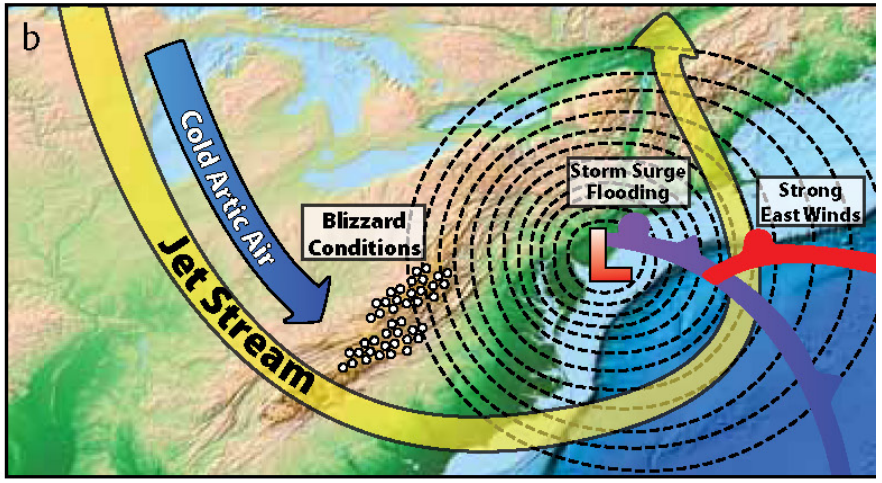


Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical 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 and unaffordable**
  - **long term costs now exceed $1000 trillion**
  - **mitigation costs about 2%**
- ***Will need fossil carbon tax or fee***
  - ***to shift economy away from fossil fuels***
  - ***pay for the long-term costs***

Guidelines to Minimize Impacts

- ***Plan 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**

Discussion

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