What Climate Change means for New England

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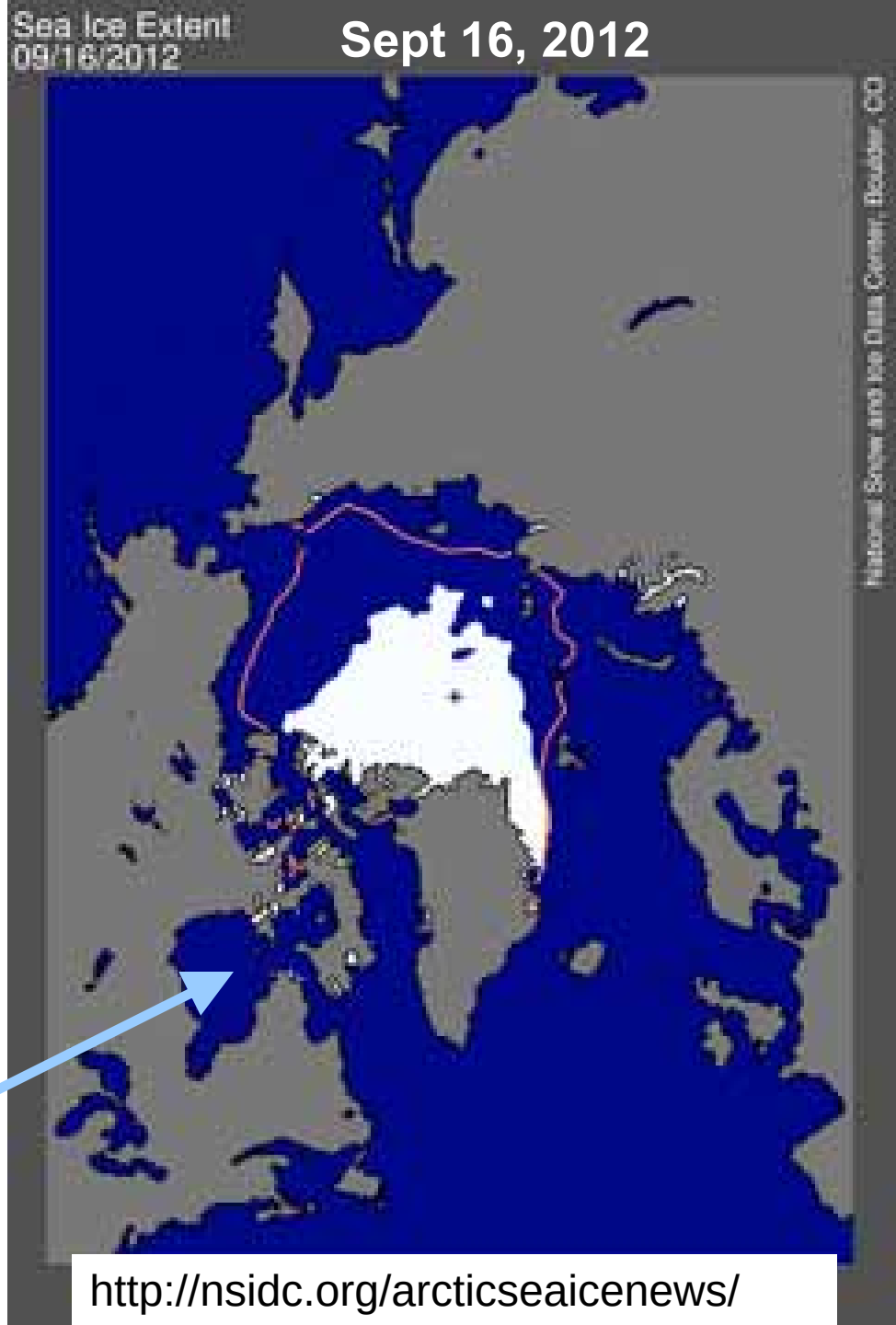
Burlington, VT

RACC
Research on Adaptation to Climate Change

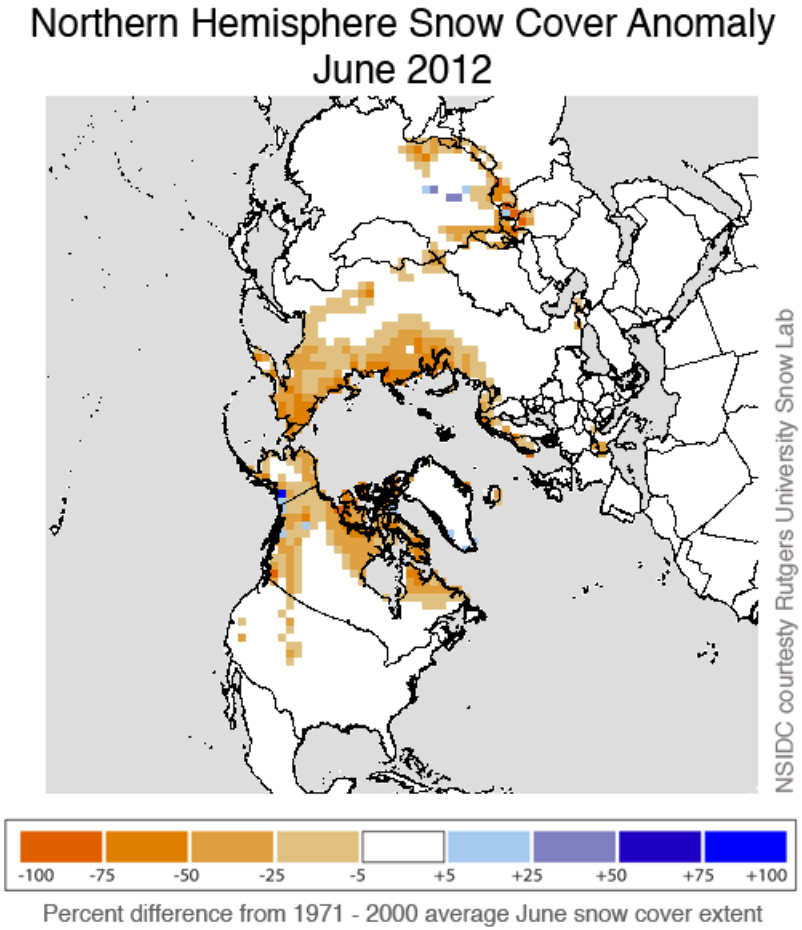
- **Half the Arctic Sea Ice Melted in 2012**
- **Open water in Oct. Nov. gives warmer Fall in Northeast**

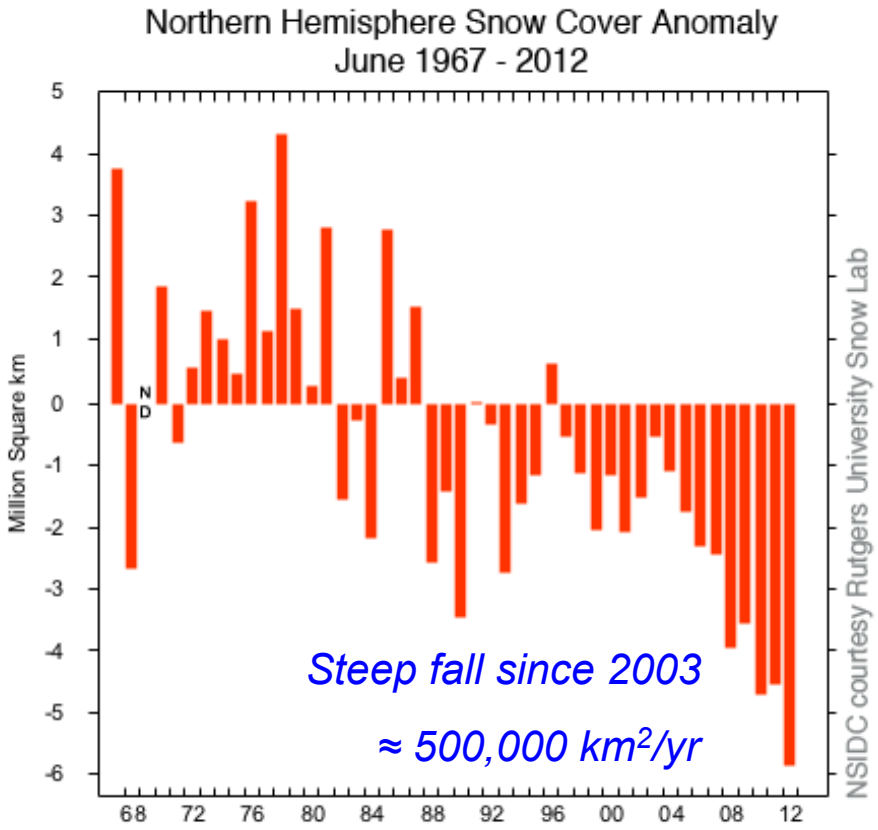
- ***Positive feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Ice thin: most 1-yr-old***

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***

Vermont Mirrors Northern NE

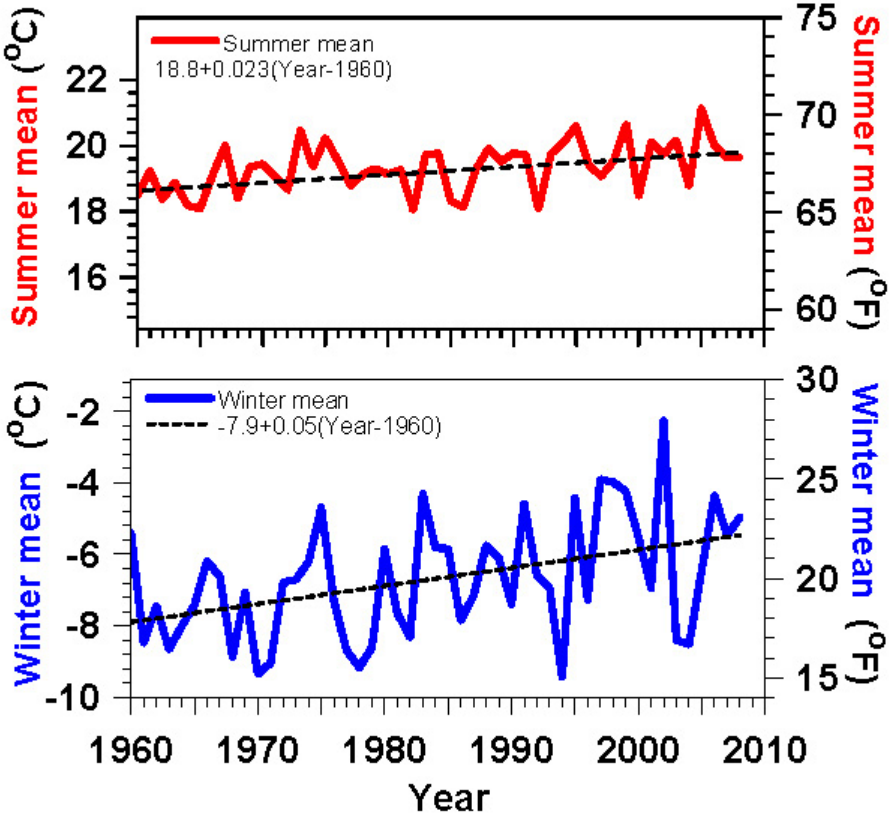
- **PAST 40/50 years** ***(global CO_2 forcing detectible)***
- **Warming twice as fast in winter than summer**
- **Winter minimums increasing even faster**
- **Lakes frozen less by 7 days / decade**
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**

(Betts, 2011)

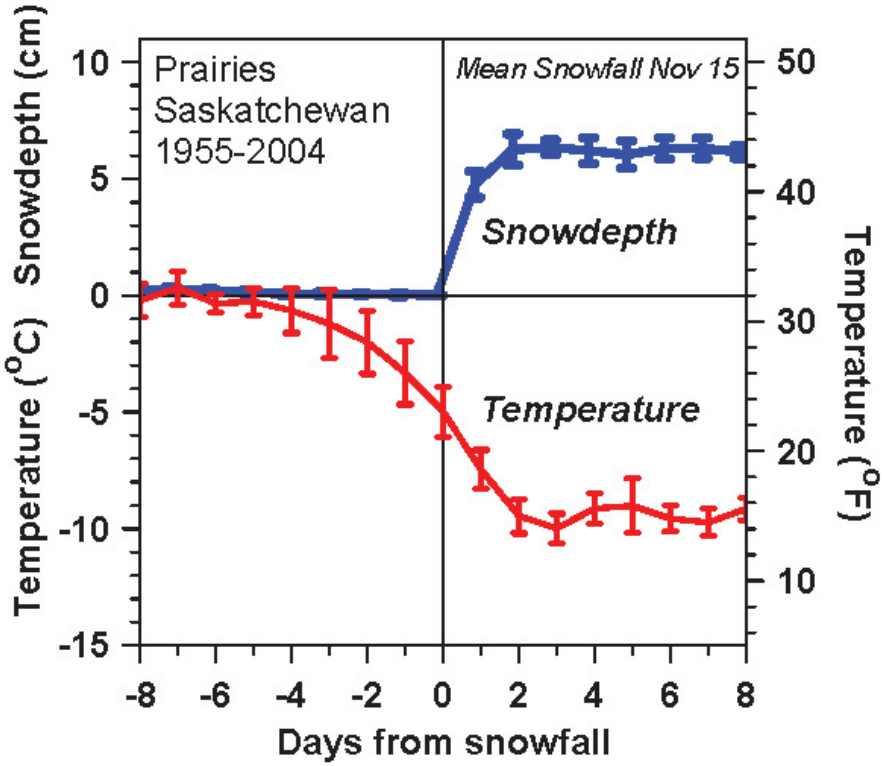
- **Extreme weather increasing**
- ***Evaporation increases with T***
- ***More 'quasi-stationary weather patterns'***

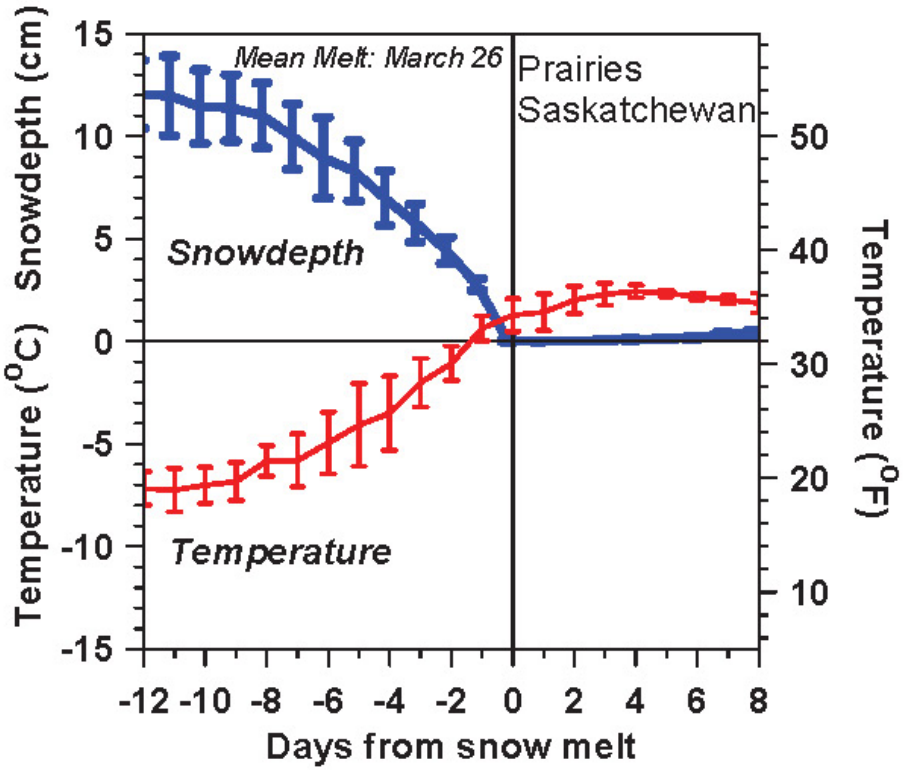
Vermont Temperature Trends 1961-2008

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



Snowfall and Snowmelt



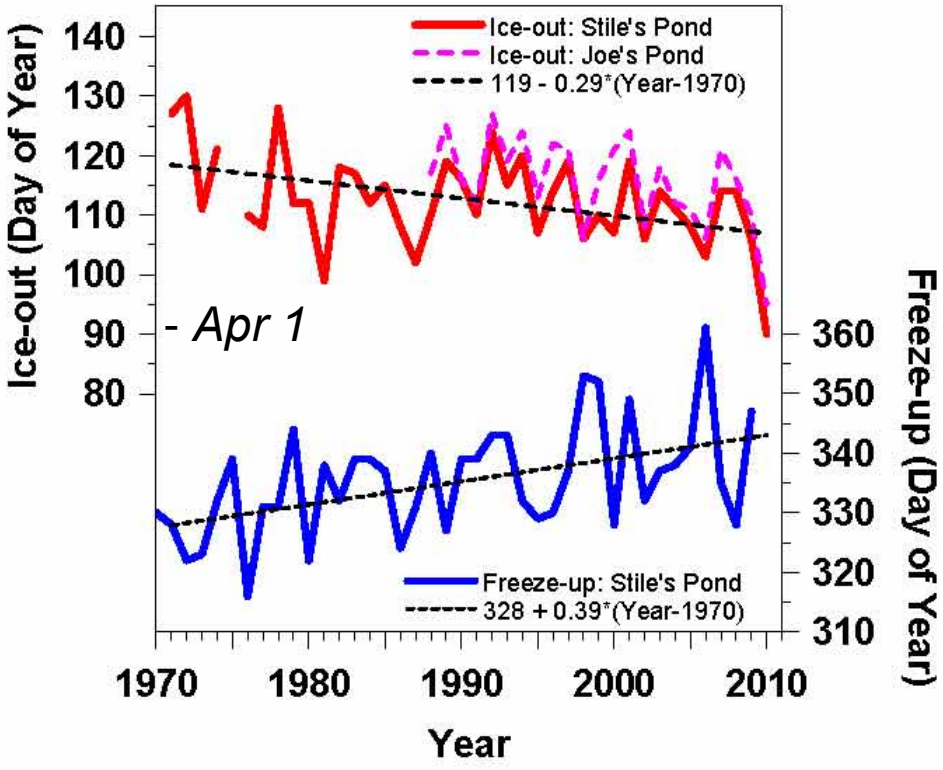


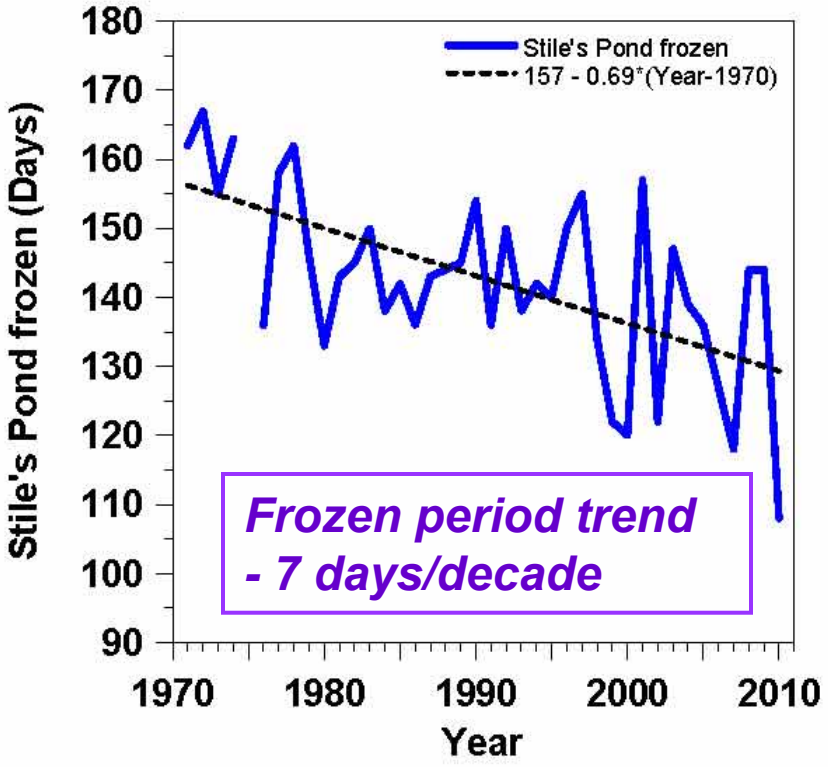
- **Temperature falls 16F (9C) with first snowfall**
- **Similar change with snowmelt**
- ***Snow reflects sunlight; reduces evaporation and water vapor greenhouse – changes 'local climate'***

Betts et al. 2013

Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



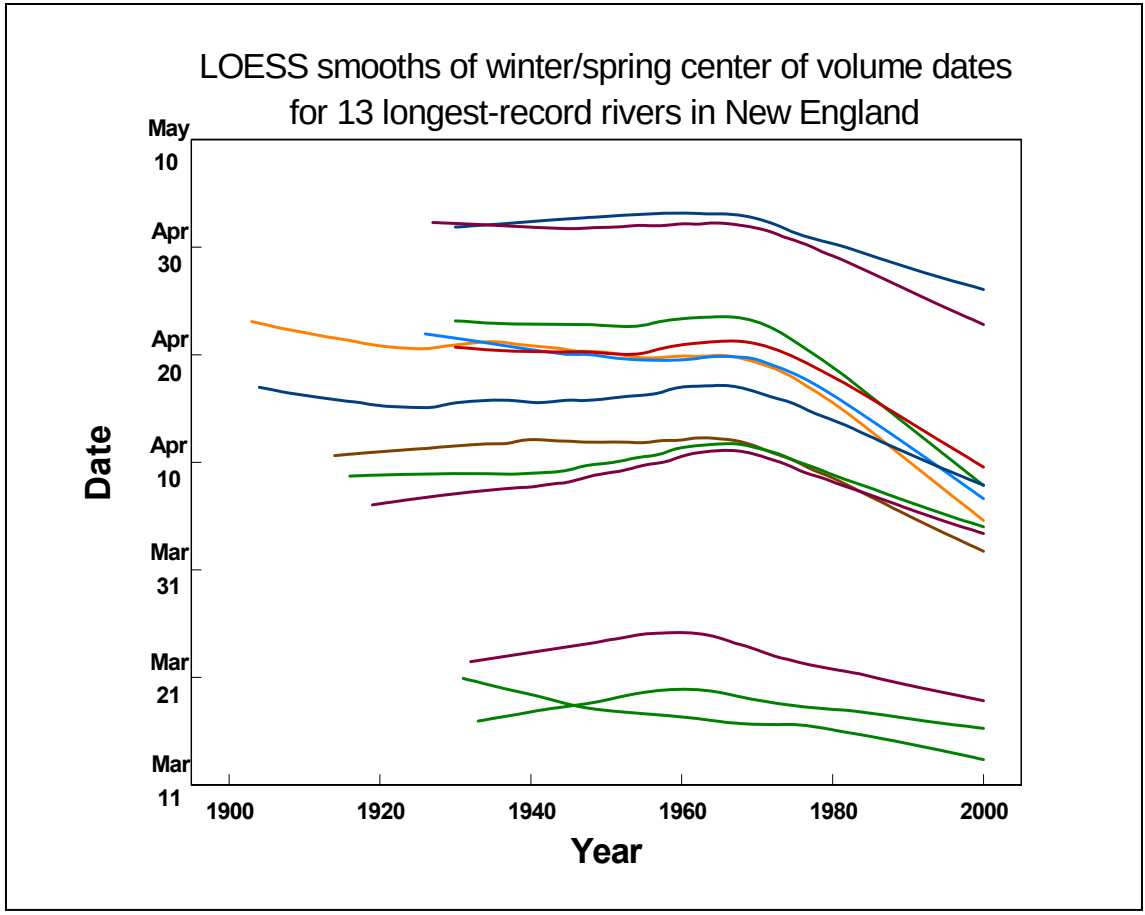


- Ice-out earlier by 3 days / decade
- Freeze-up later by 4 days / decade
- *Soil ice probably similar*

Hydrology Sensitive to Climate

Lent (2010), USGS, Me

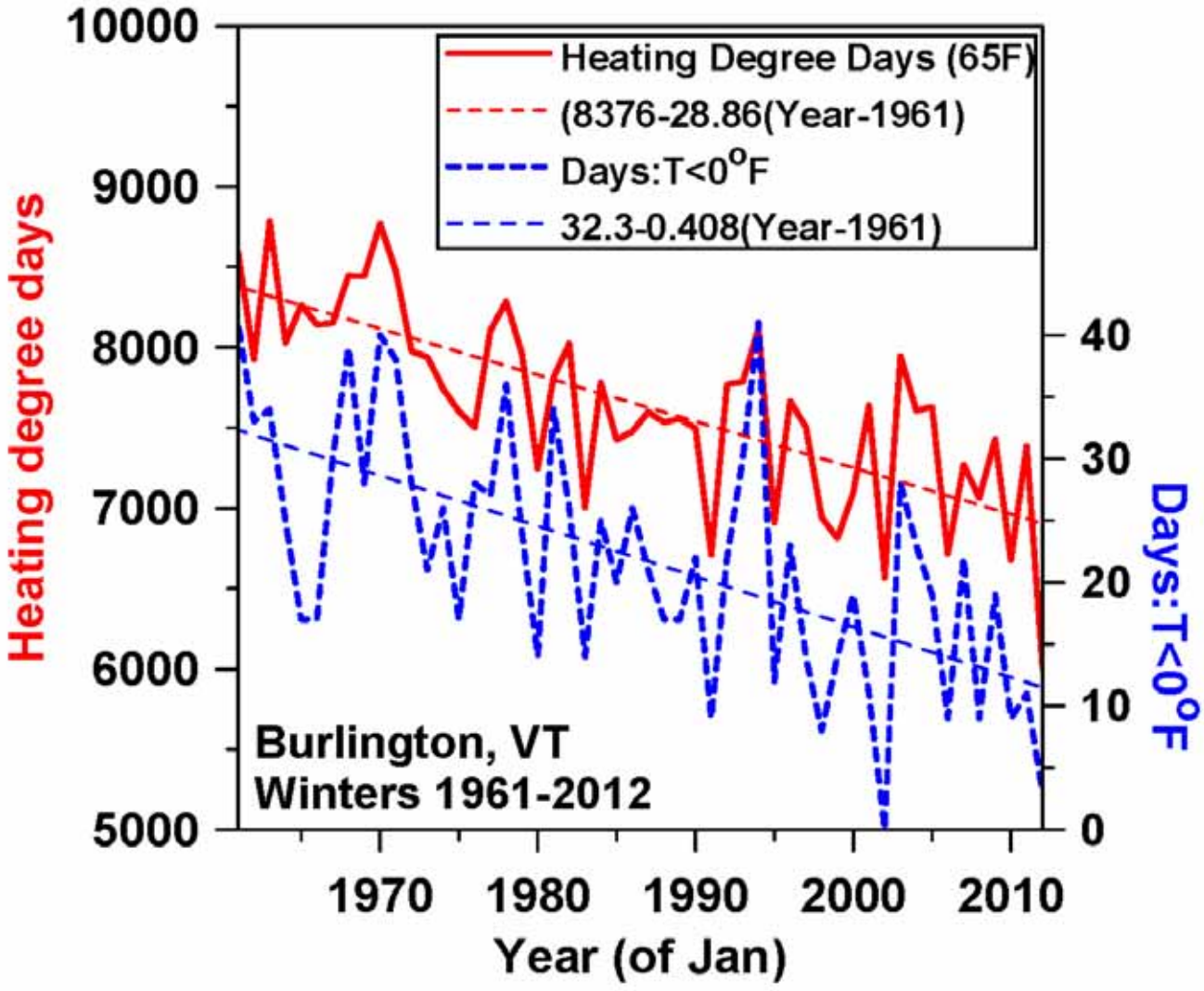
- **Peak spring runoff**
- ***Earlier in northern New England in recent years***
  ≈ 3 days/decade
- ***Timing related to air temperatures in Spring***



(Hodgkins and others, 2003)

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

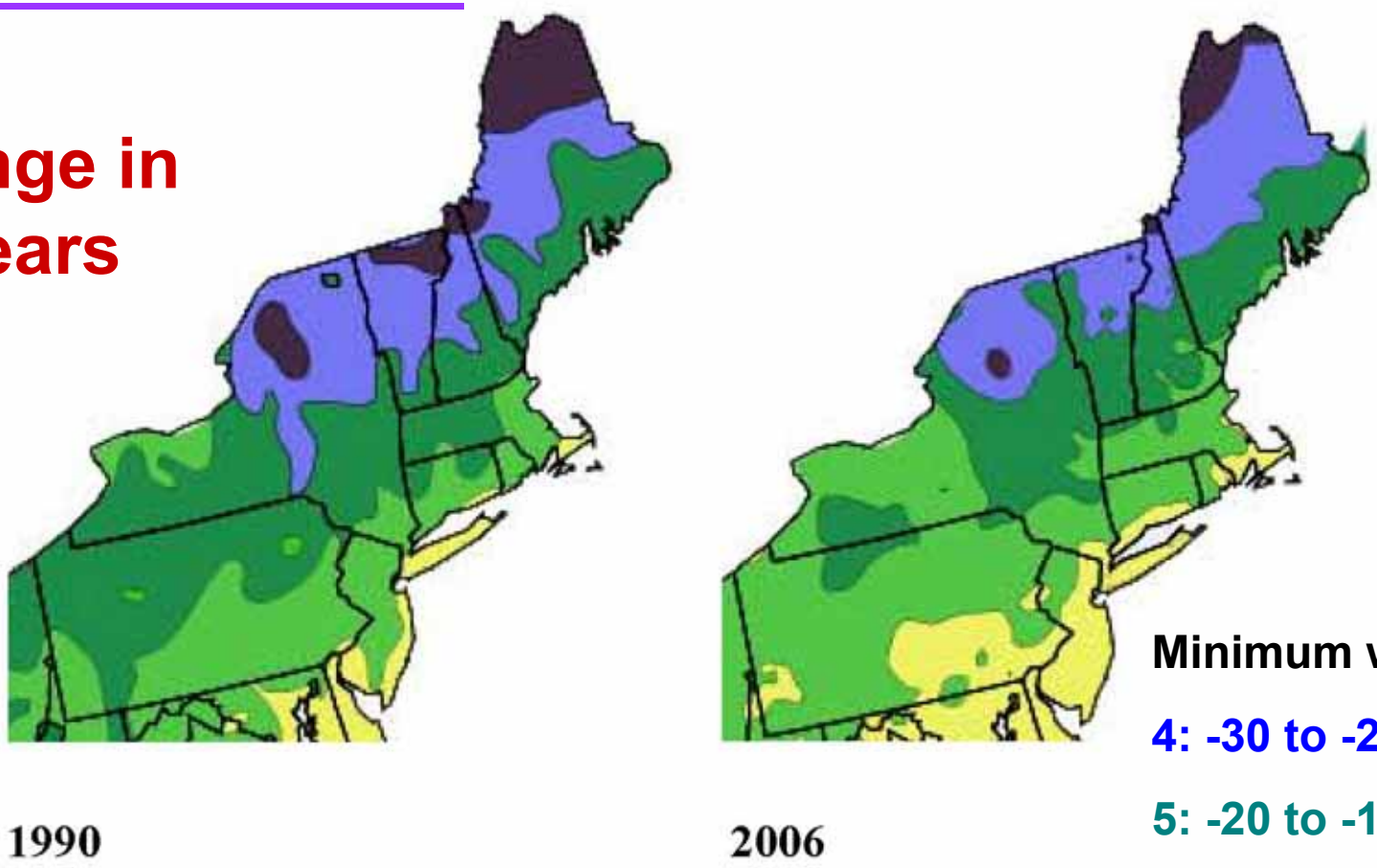
- **Heating degree days *falling 290/decade***
- **T_{min}<0°F *falling 4 days /decade***



Winter Hardiness Zones

– ***winter cold extremes***

Change in 16 years



Minimum winter T

4: -30 to -20°F

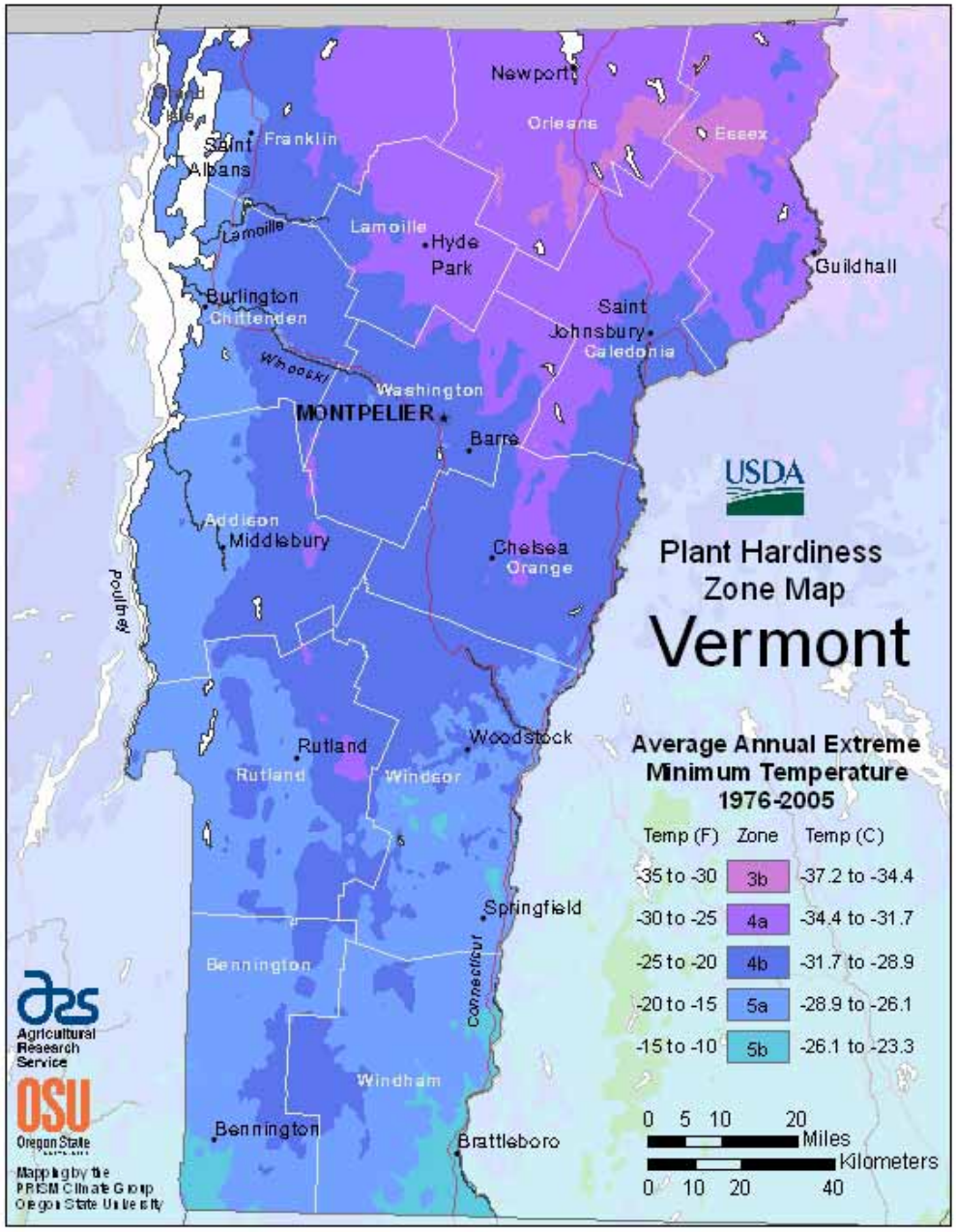
5: -20 to -10°F

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)*

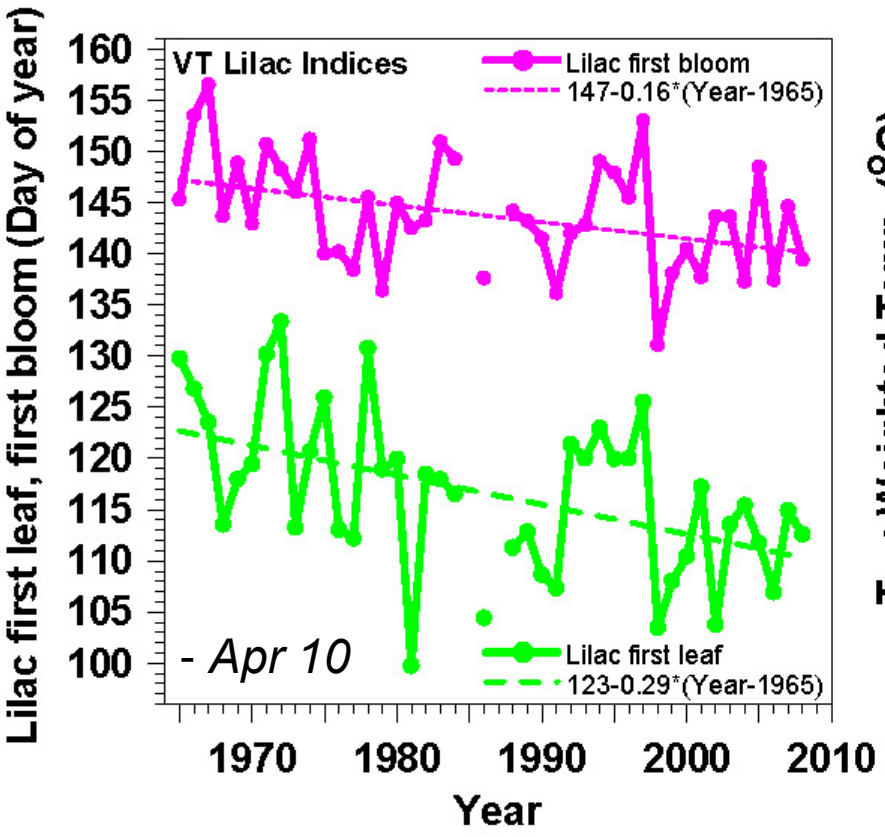
- **Hardy peaches: 2012**
- **More pests survive winter**
- **What is this?**

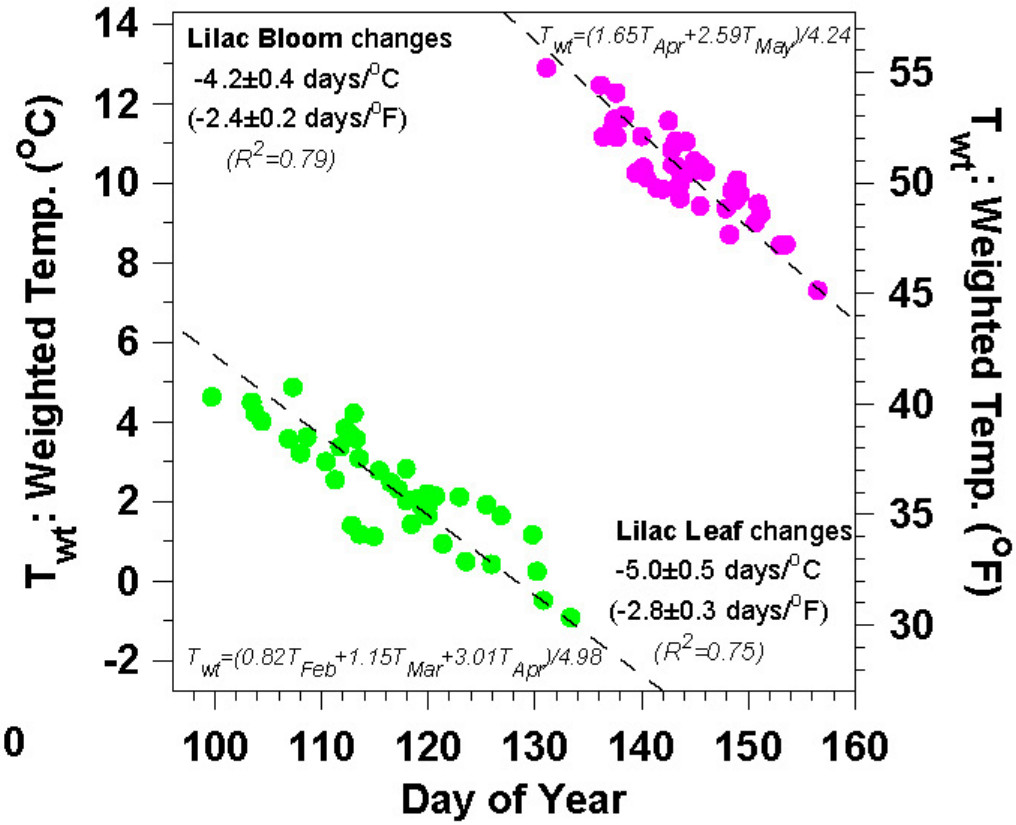
Bennington & Brattleboro are becoming zone 6

- Hardy peaches: 2012
- More pests survive winter
- What is this?

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

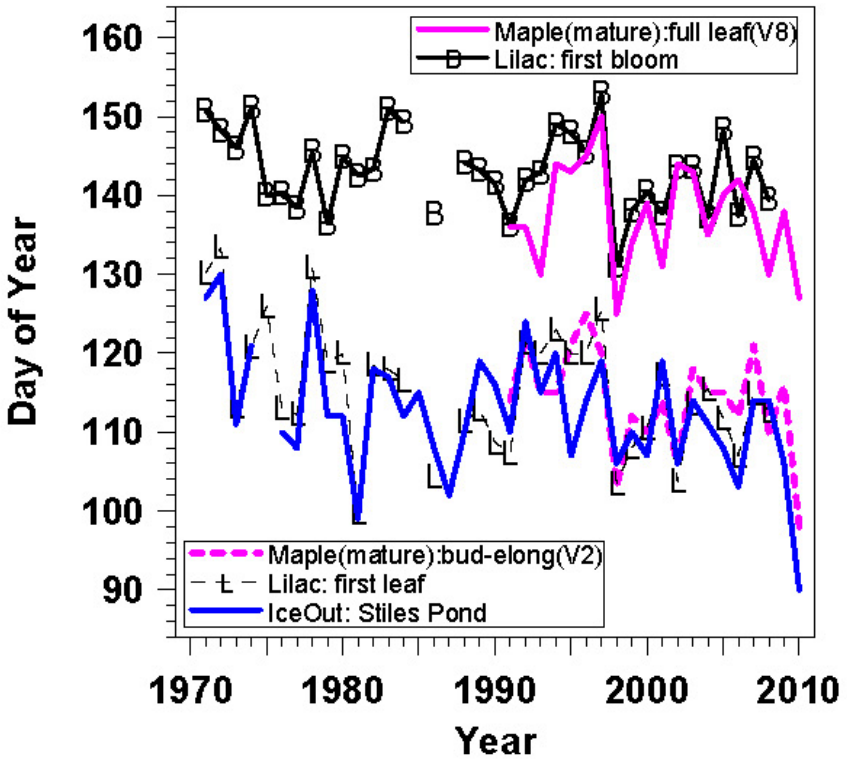
Lilac Leaf and Bloom

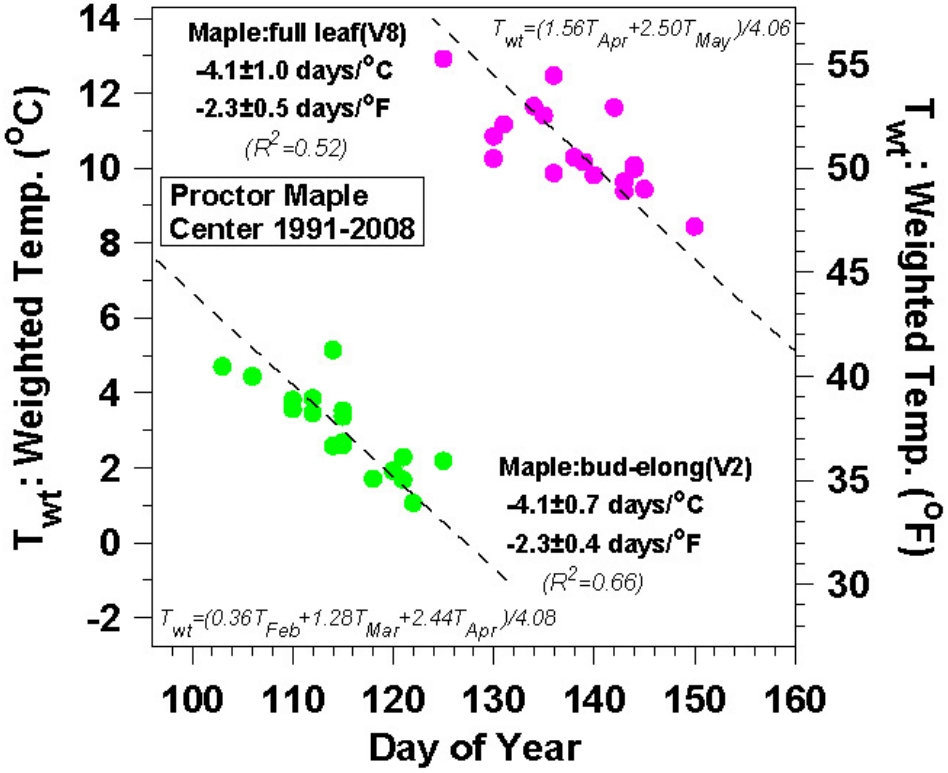




- **Leaf-out -2.9 days/decade; Bloom -1.6 days/decade**
- ***Large year-to-year variation related to temperature: 2.5 days/ °F***

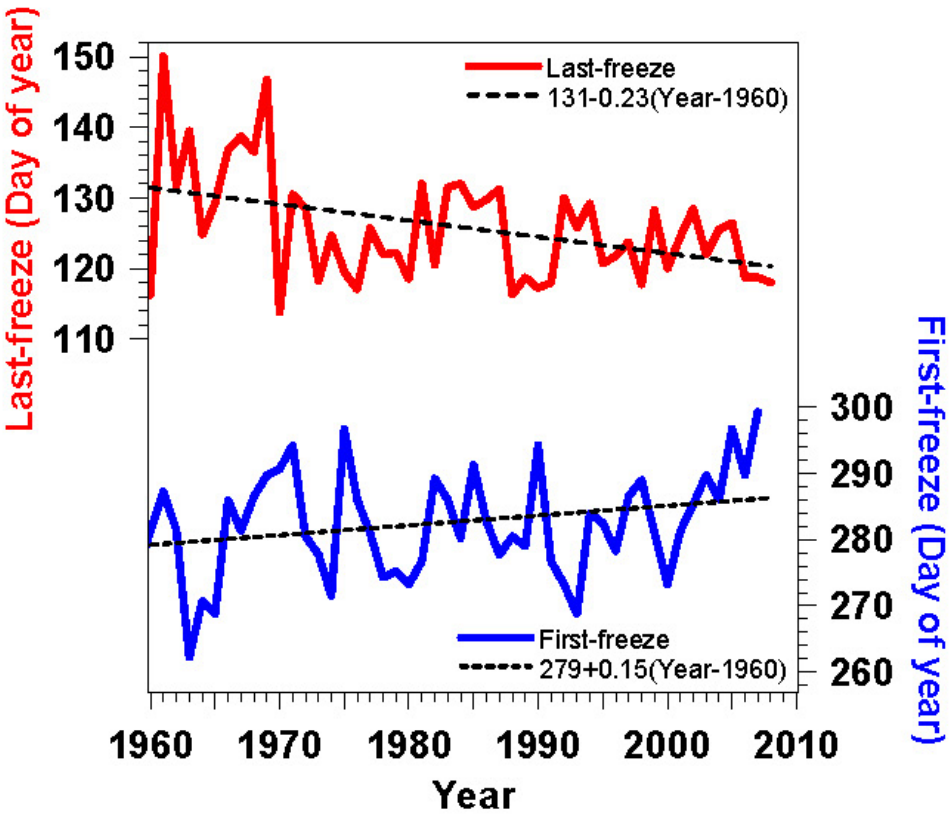
Maples and Lilacs in spring

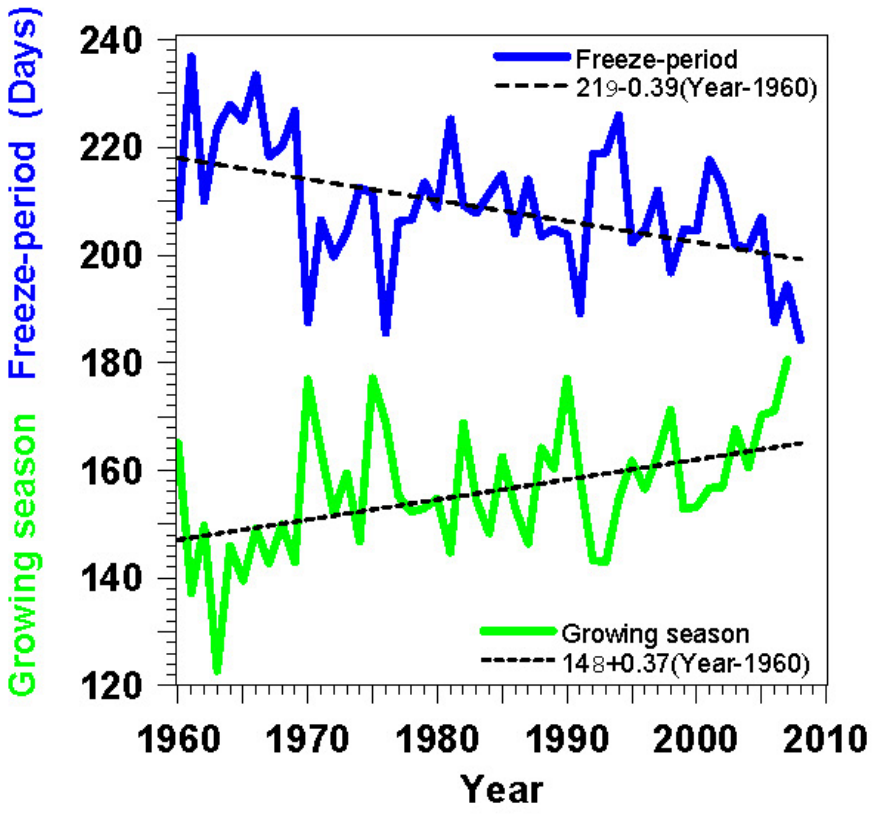




- **Maple bud elongation mirrors lilac leaf**
- **Maple leaf-out mirrors lilac bloom**

First and Last Frosts Changing





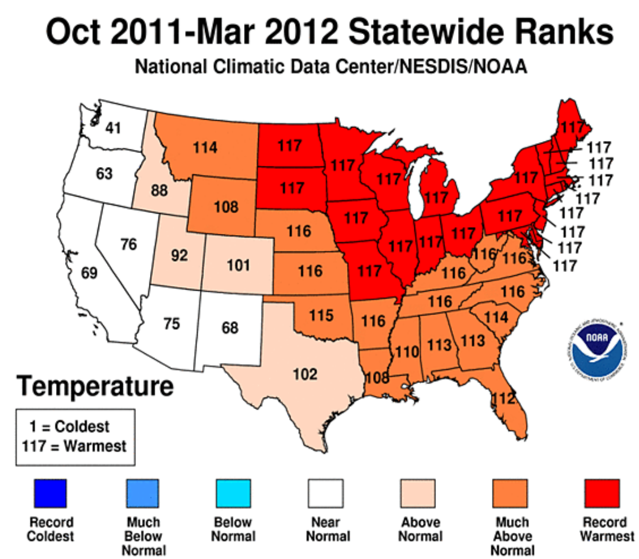
- **Growing season for frost-sensitive plants increasing 3.7 days / decade**
- ***Important for agriculture; local food supply***

January 2, 2012

March 11, 2012

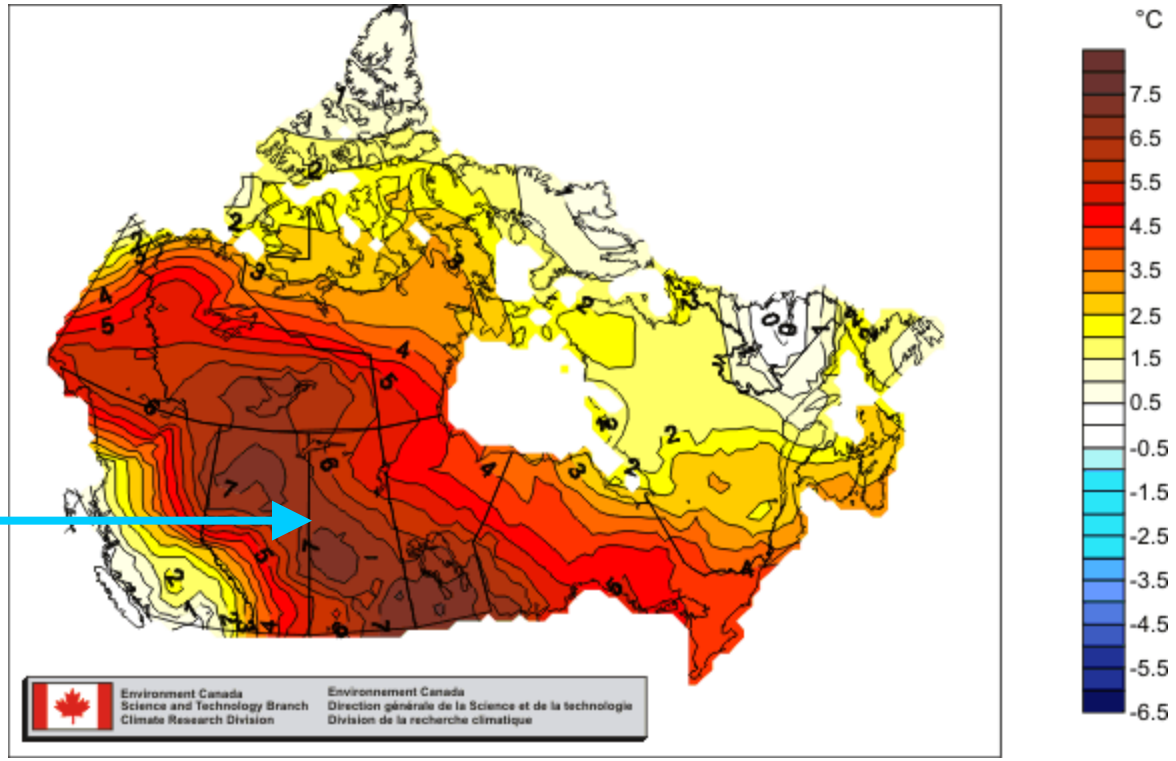
October 2011– March 2012

- **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

+12°F



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

December 21, 2012

January 15, 2013

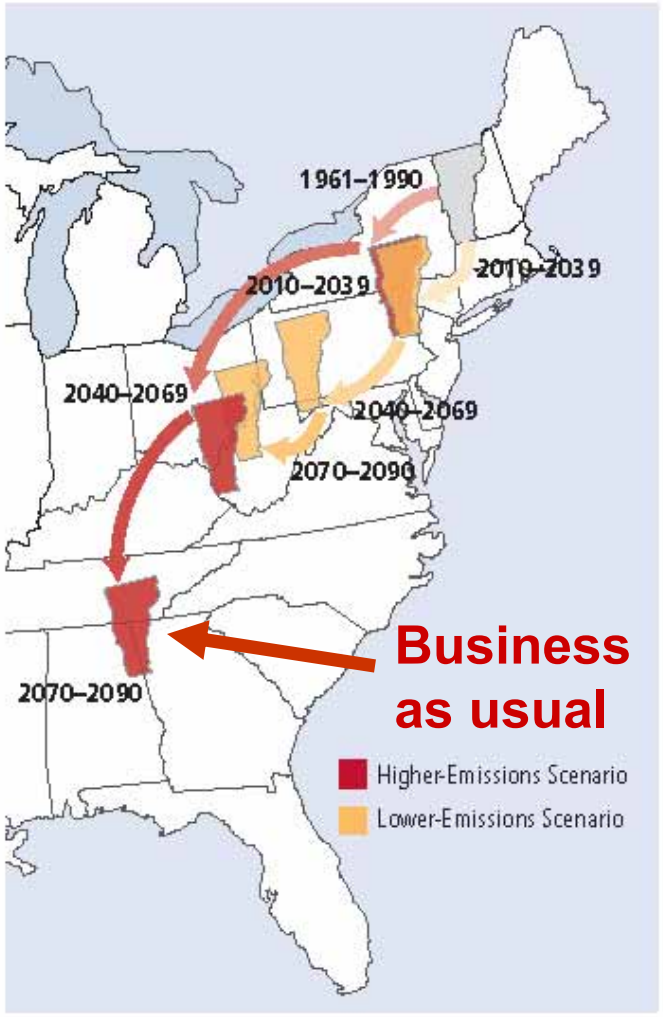
Past Winter

- 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

Vermont's Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US



Migrating State Climate

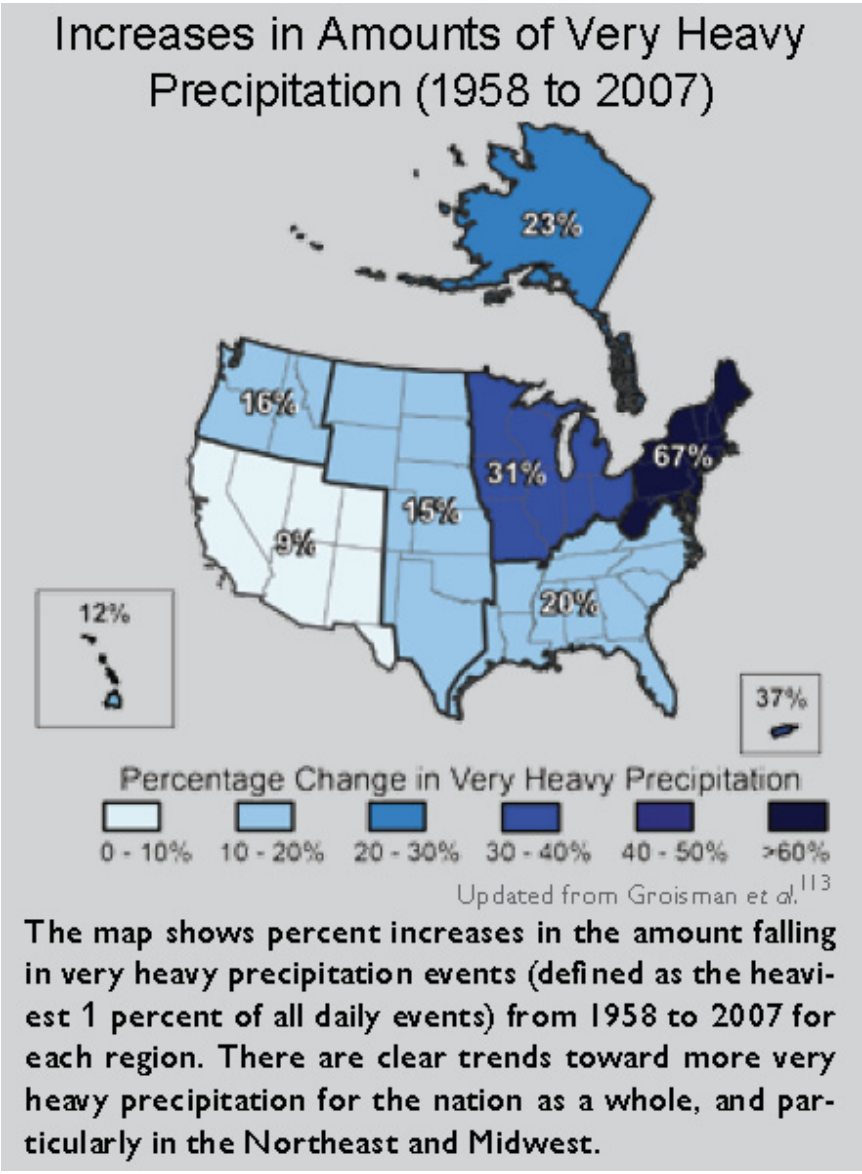
Changes in average summer heat index—a measure of how hot it actually feels, given temperature and humidity—could strongly affect quality of life in the future for residents of Vermont. Red arrows track what summers in Vermont could feel like over the course of the century under the higher-emissions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

NECIA, 2007

Very Heavy Precipitation Is Increasing

(USGCRP, 2009)

- **Precipitation Extremes**
- **Most of the observed increase in precipitation during the last 50 years 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.

Summer "stormflow" increasing

Most >50%

Lent (2010) USGS, Me

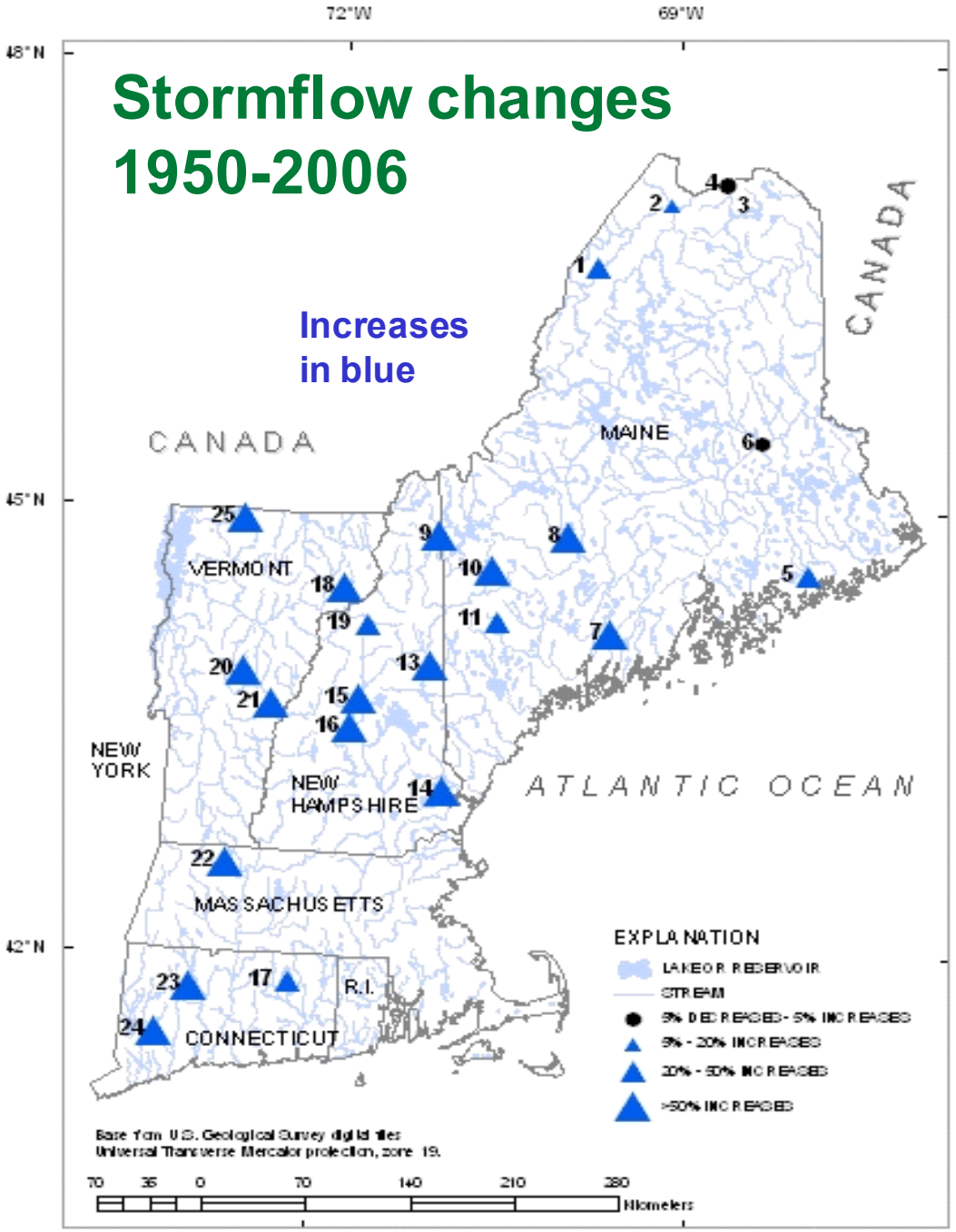


Figure 4. Geographic distribution of summer stormflow trends, 1950-2006.

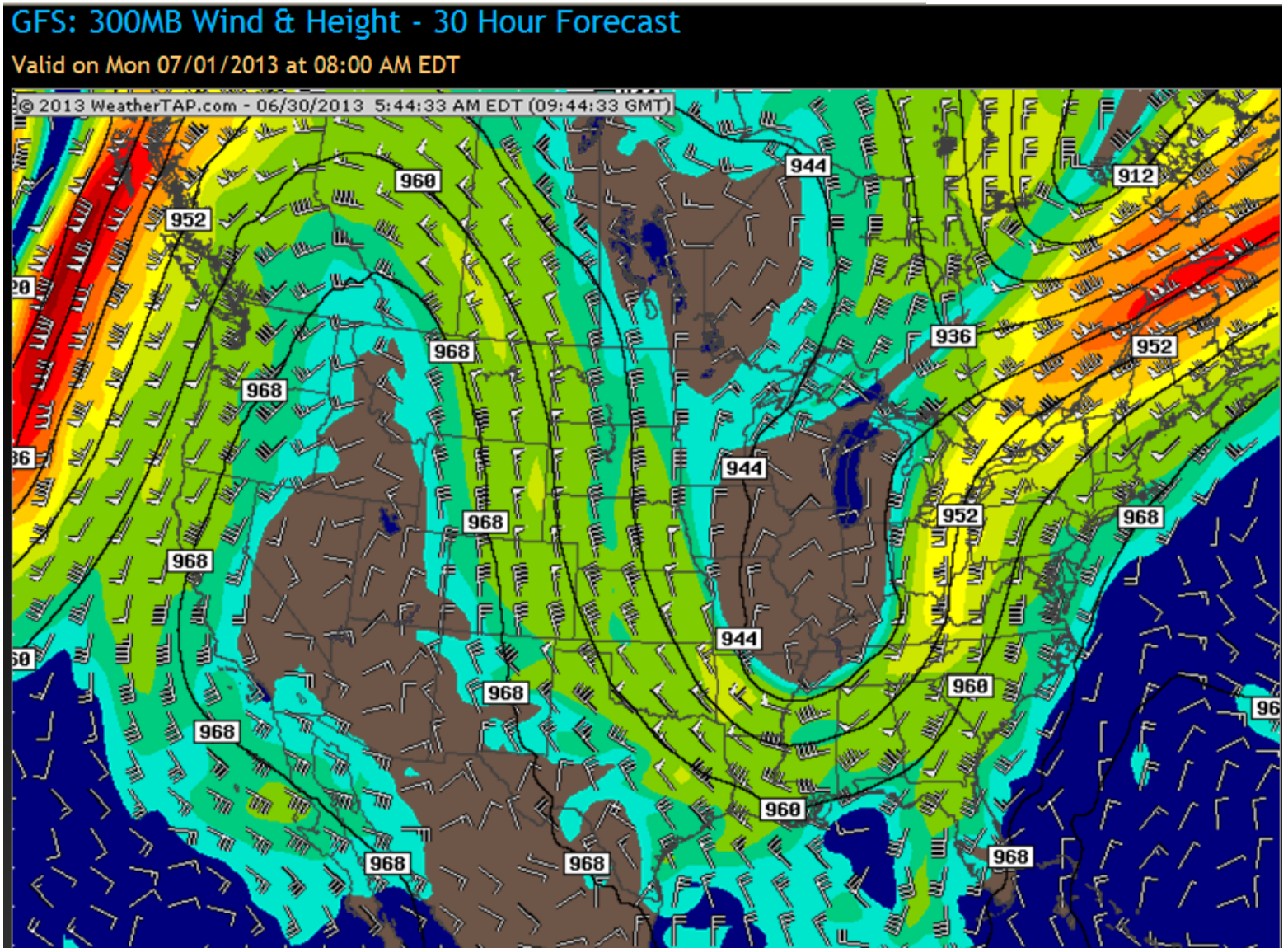
Extreme Weather (precip.)

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

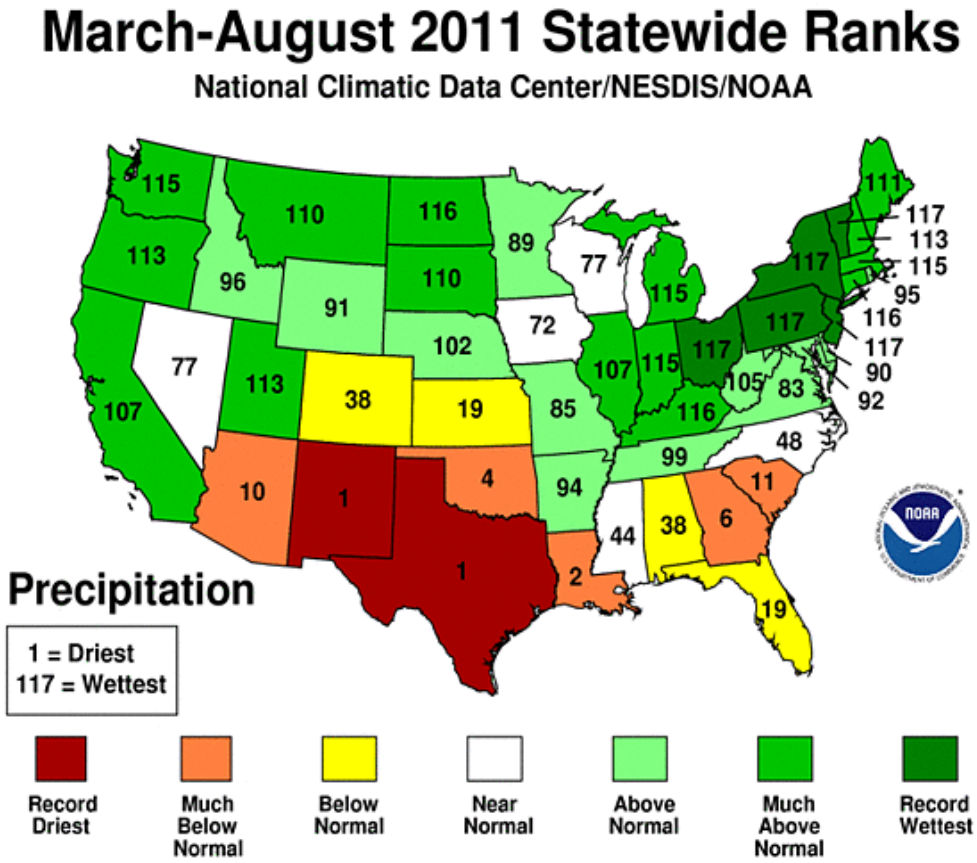
Jet Stream Patterns Slowing Down and Amplifying, Giving More Extreme Weather

(Francis and Vavrus, 2012)



2011 Floods: VT and NY

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



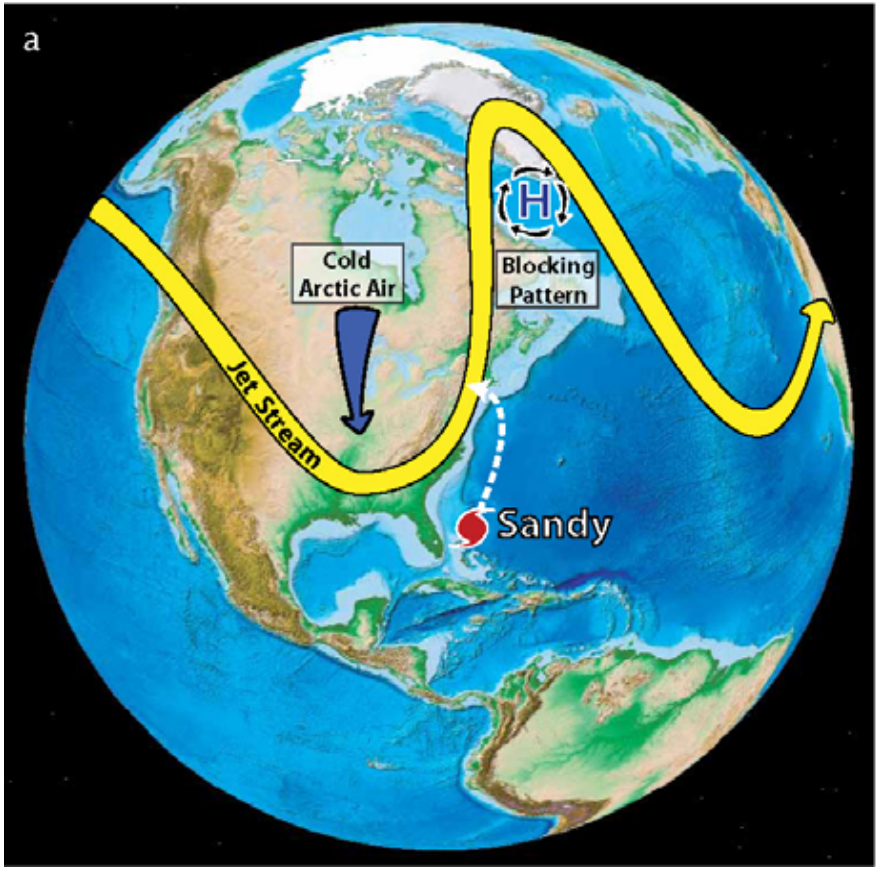
March-August, 2011

- **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 (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)

Blocking Pattern - Unique track



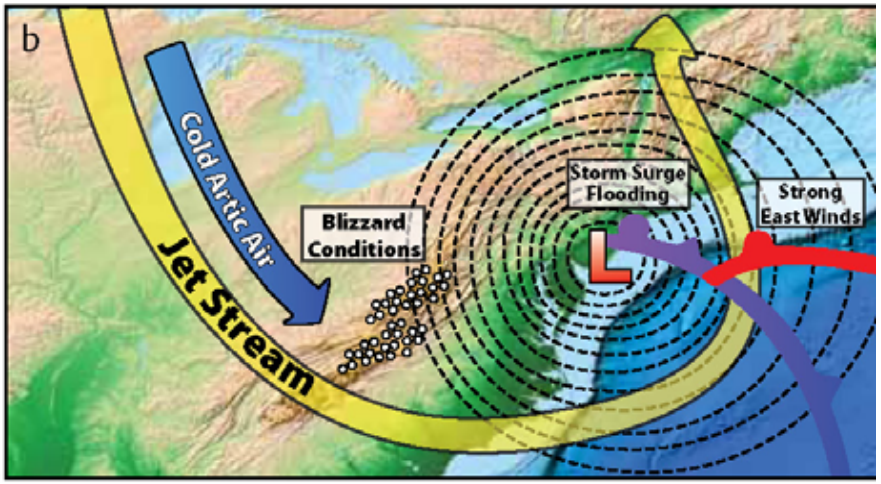
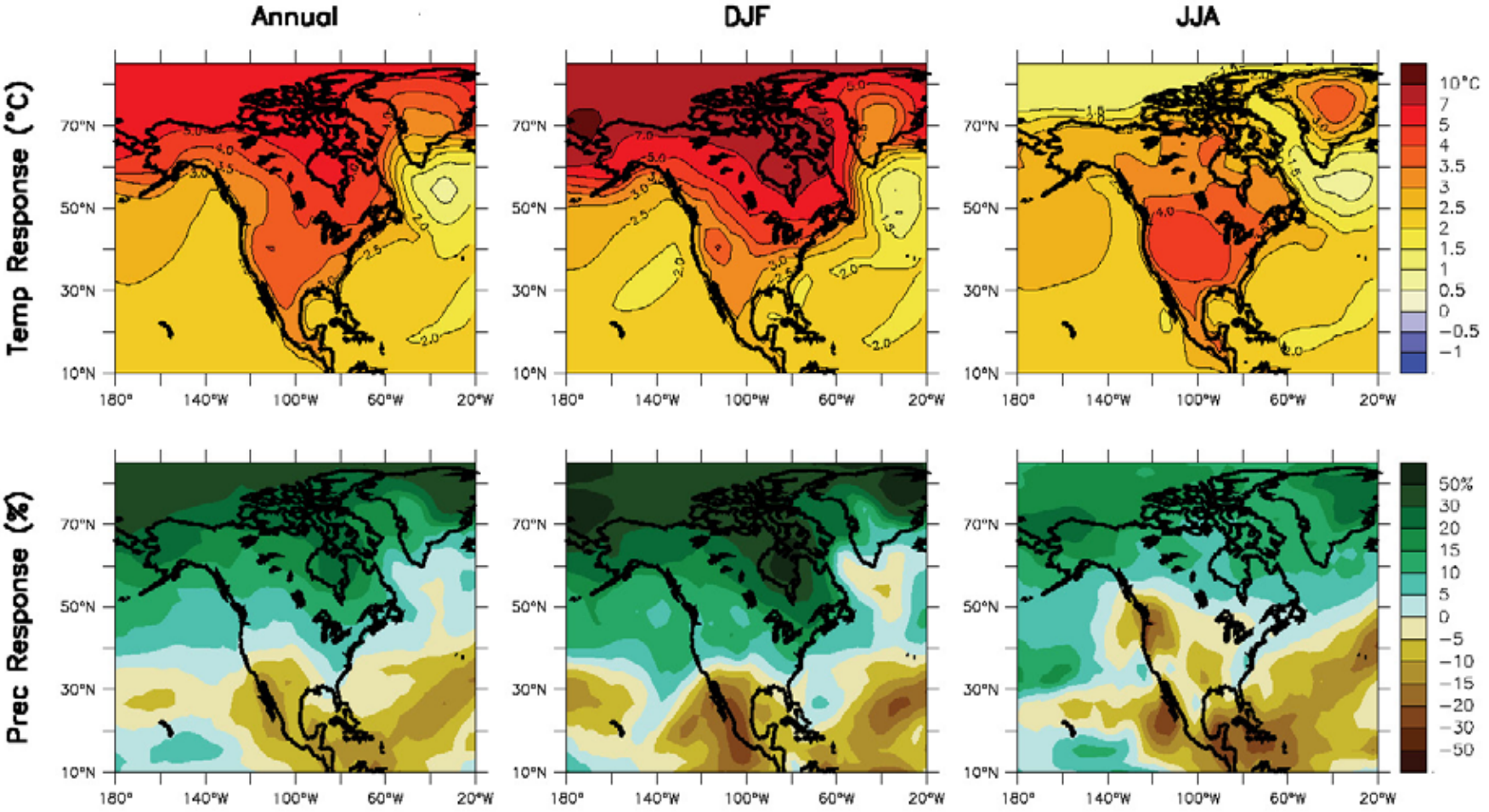


Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical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

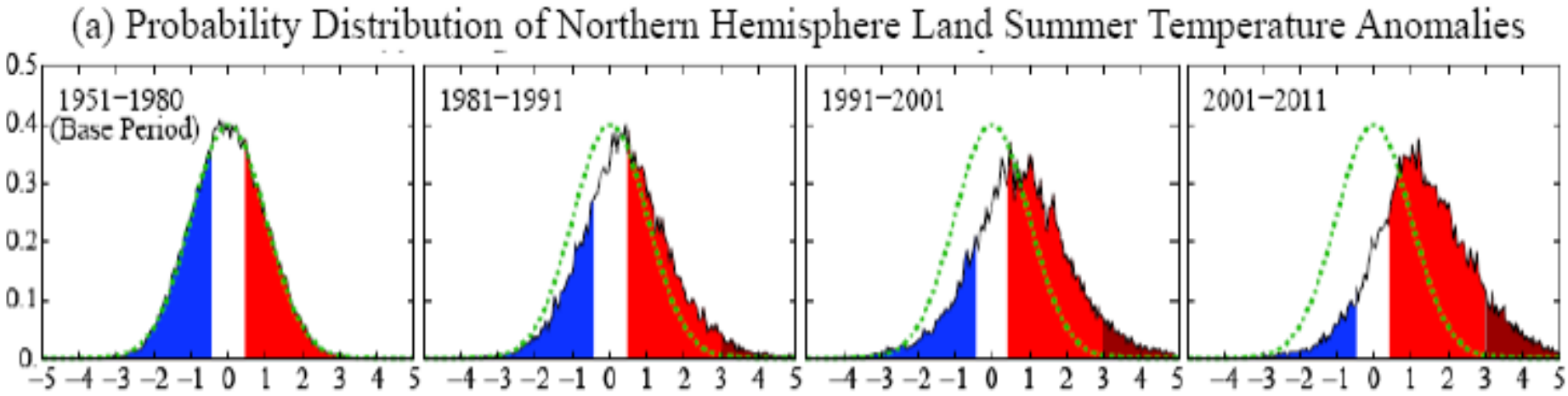
[Greene et al., Oceanography, 2013]

North American Changes: T, Precip.



- Temperature and precipitation changes over North America from an average of 21 AOGCM projections for A1B (high emission) scenarios.
- Top row: Annual mean, winter (DJF) and summer (JJA) temperature change between 1980 to 1999 and 2080 to 2099. **[NE winter: +4.5C, +8F]**
- Bottom row: for fractional change in precipitation. **[NE winter: +25%]**

Increasing Positive Temperature Extremes is "Global Warming"



(Hansen, 2012)

- **Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies for Northern Hemisphere land in units of local standard deviation (horizontal axis). The normal (gaussian) distribution bell curve is shown in green.**
- **Large increase in anomalies > +3σ *is* global warming**
  - ***Baseline 0.15% has increased to 10% in 45 years***

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 adaptation and health costs***

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**

What are Key Issues for Health?

- **Higher temperature extremes**
  - **Offset by wet summers in NE**
- **Winter survival of pests**
  - **Blacklegged Tick (Deer Tick):** A warming climate, combined with the spread of the invasive shrub Barberry, has allowed this pest to expand its range to the entirety of Vermont. This invasive is responsible for the spread of Lyme disease throughout New England.
- **Mosquito-borne diseases – EEE/West Nile**
  - **Increased summer breeding:** ***nine out of ten recent summers have had well-above average rainfall*** **– NOAA** ***data currently unavailable***

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

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**