# Using Data, Models and *Physics* to Plan

# *Knowns & Unknowns*

**Dr. Alan K. Betts**
**Atmospheric Research, Pittsford, VT 05763**

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

## *Regional Climate Change Scenario Development Workshop*

***Burlington, VT***

**November 13, 2012**

***Video:*** **http://www.uvm.edu/~epscor/new02/?q=node/1176**

# Overview

- ***Leslie-Ann: Weather, climate, IPCC***
- ***Brian: Initial look at down-scaling for VT***

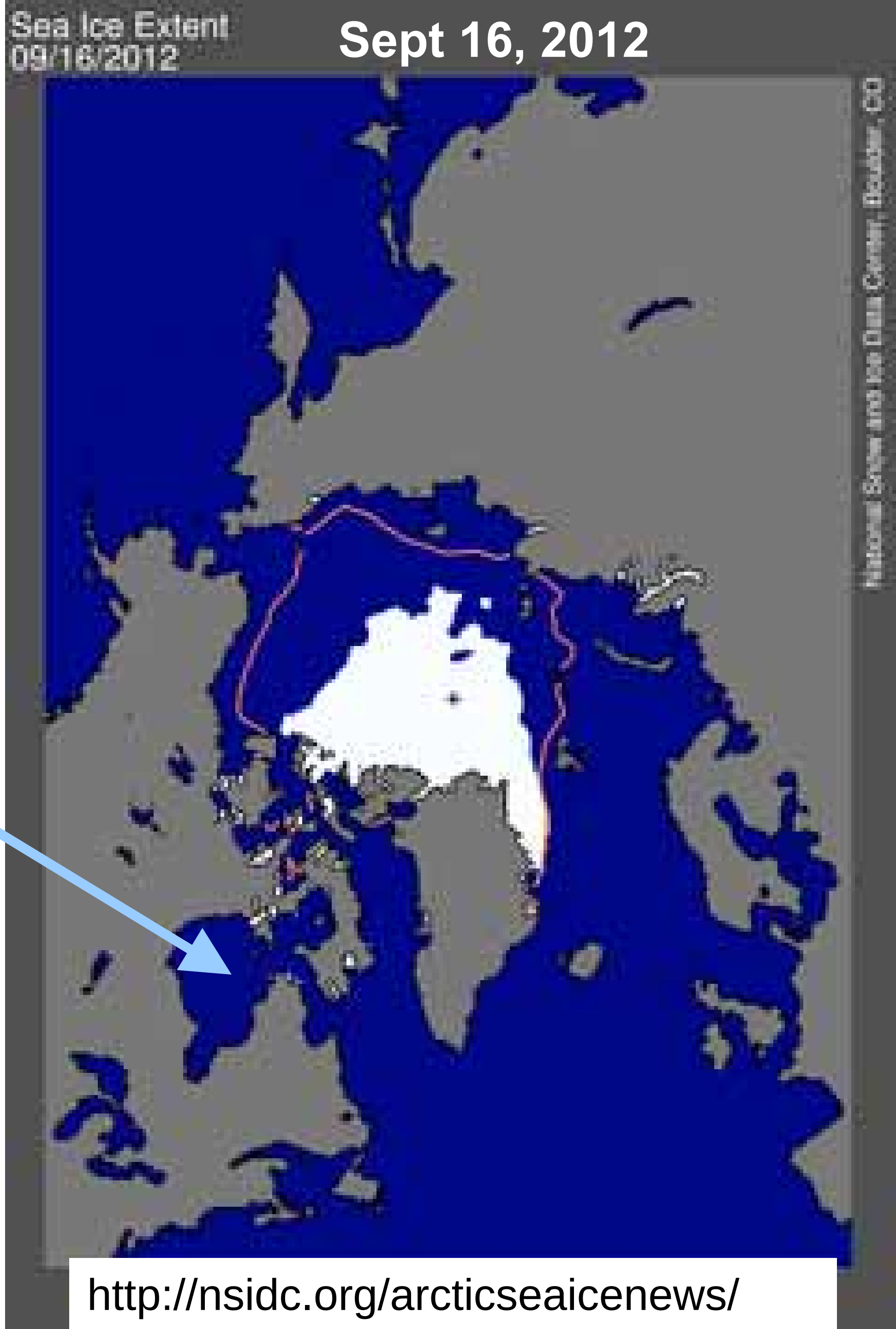
- **Broader overview: observation-centered**

- ***Beginning of an iterative process***
  - **Ask what information would help you with adaptive planning: tell us - fill out cards**
  - **Our goal is to search for answers in coming years**

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

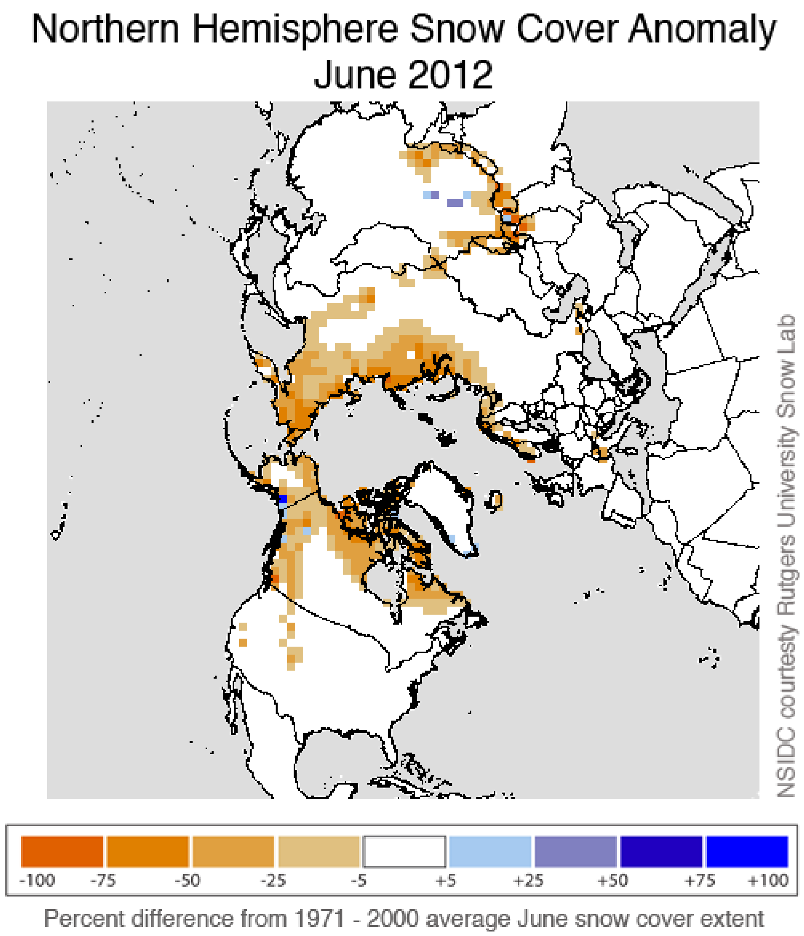
***At the end of Nov. 2011 Hudson Bay was still nearly ice-free***

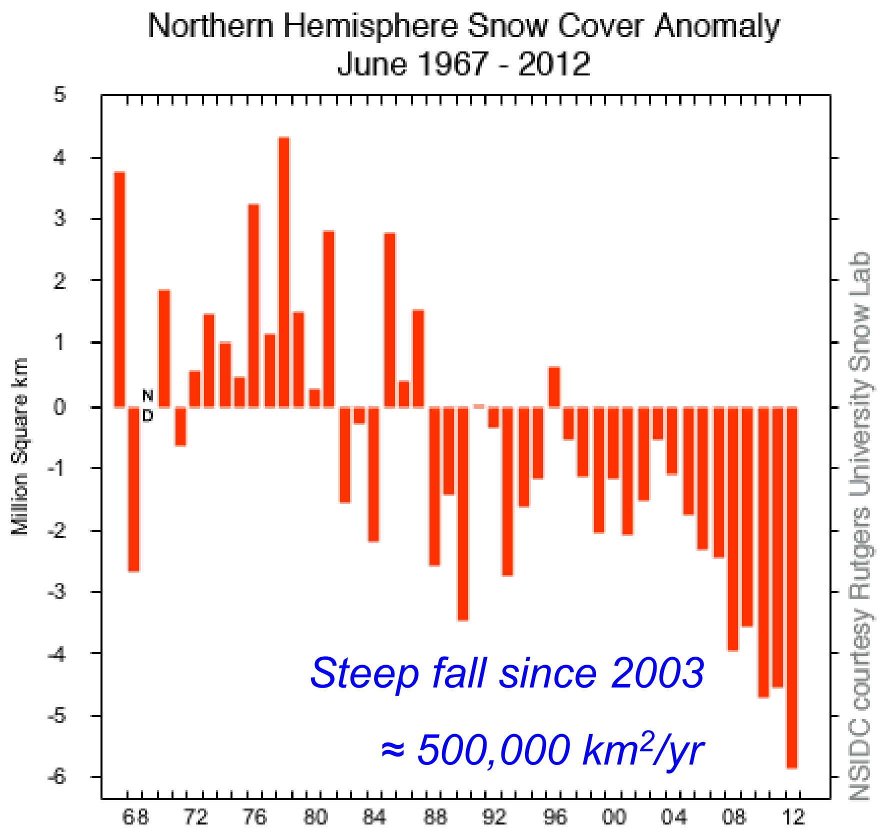
- ***Positive feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Ice thin: most 1-yr-old***




http://nsidc.org/arcticseaicenews/

# June 2012 snow cover minimum




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

# What Is Happening to Vermont?

- **PAST 40/50 years** ***(global $CO_2$ forcing detectible)***
- **Warming twice as fast in winter than summer**
- **Winter severity decreasing**
- **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)***

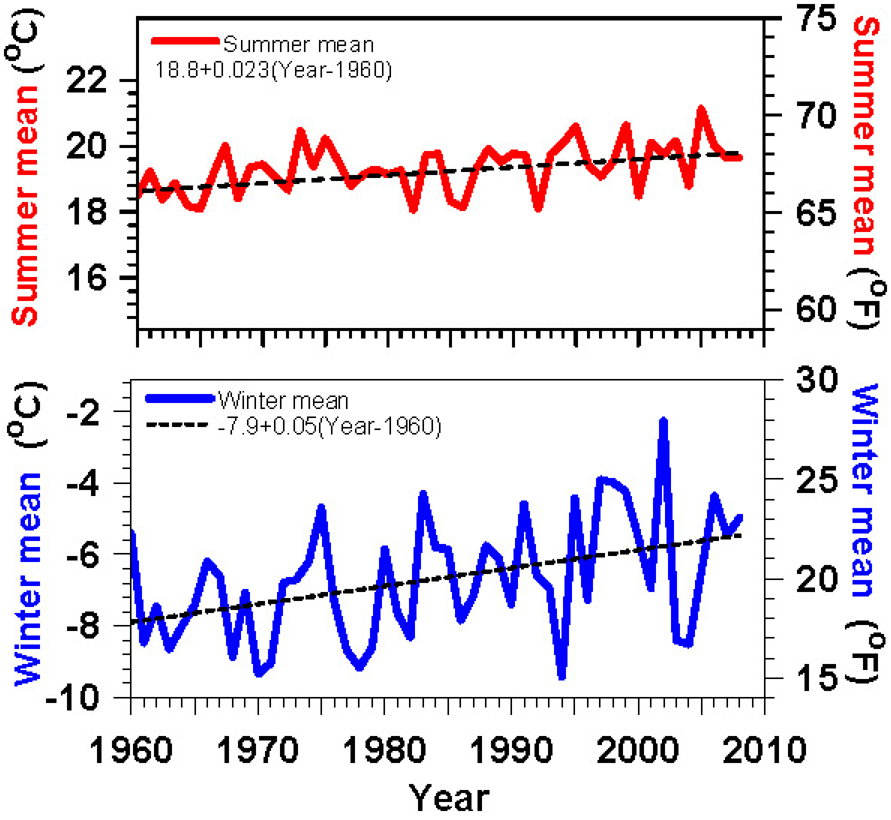
- **Extremes increasing**
- ***Evaporation increases with T***
- ***More 'quasi-stationary weather patterns'***

# Vermont Temperature Trends 1961-2008

- **Summer +0.4°F / decade**

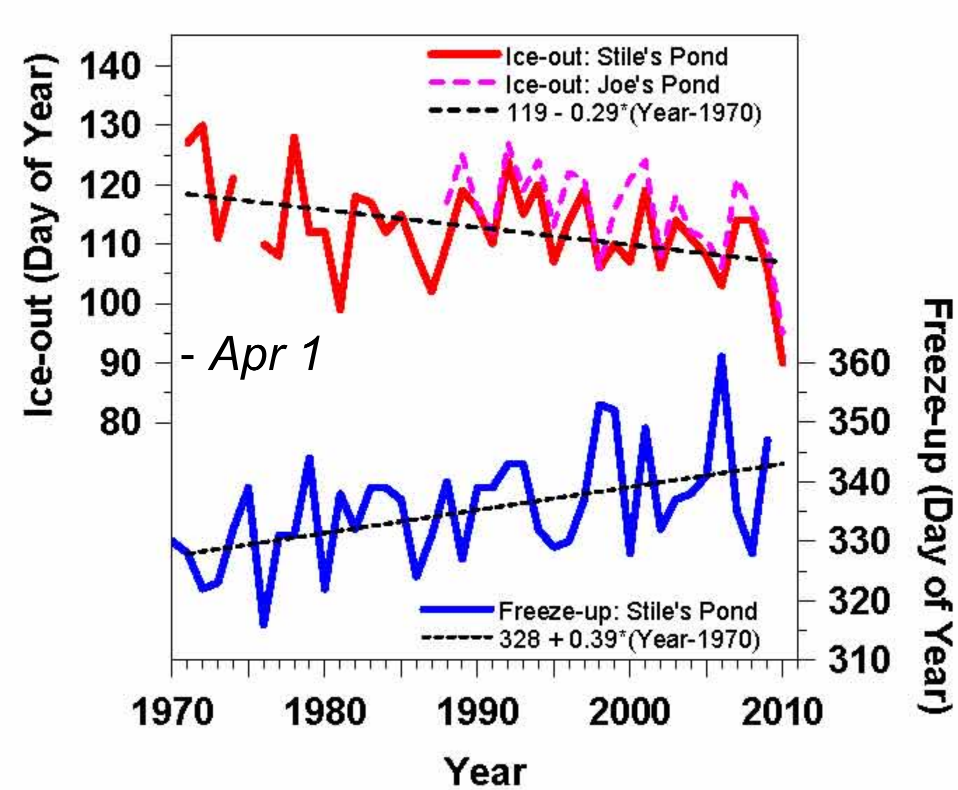
- **Winter +0.9°F / decade**
  - ***Larger variability, larger trend***

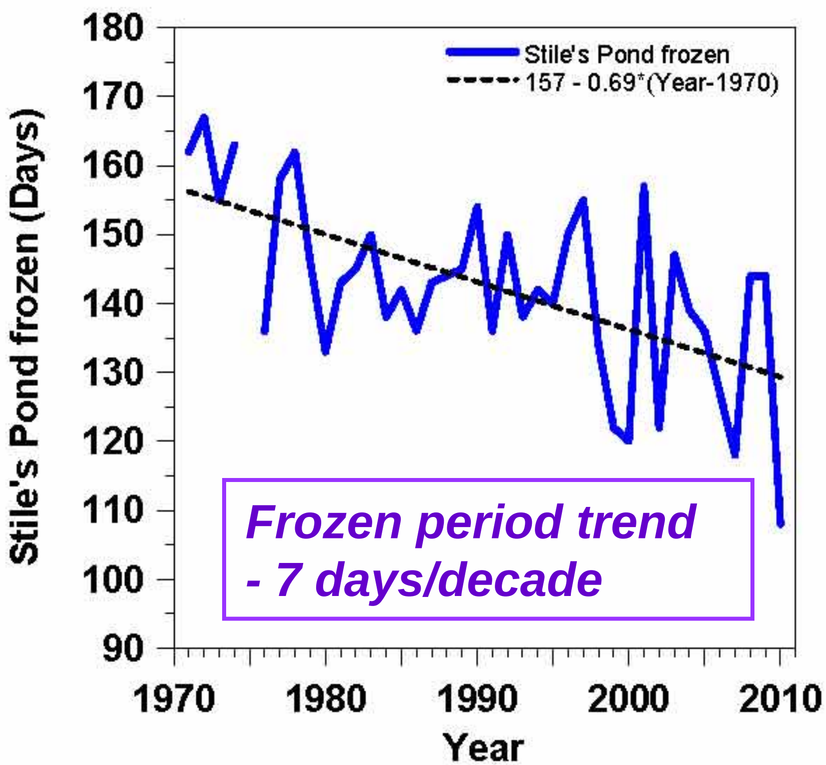
- ***Less snow (and increased water vapor) drive larger winter warming***



# Lake Freeze-up & Ice-out Changing

## Frozen Period Shrinking Fast



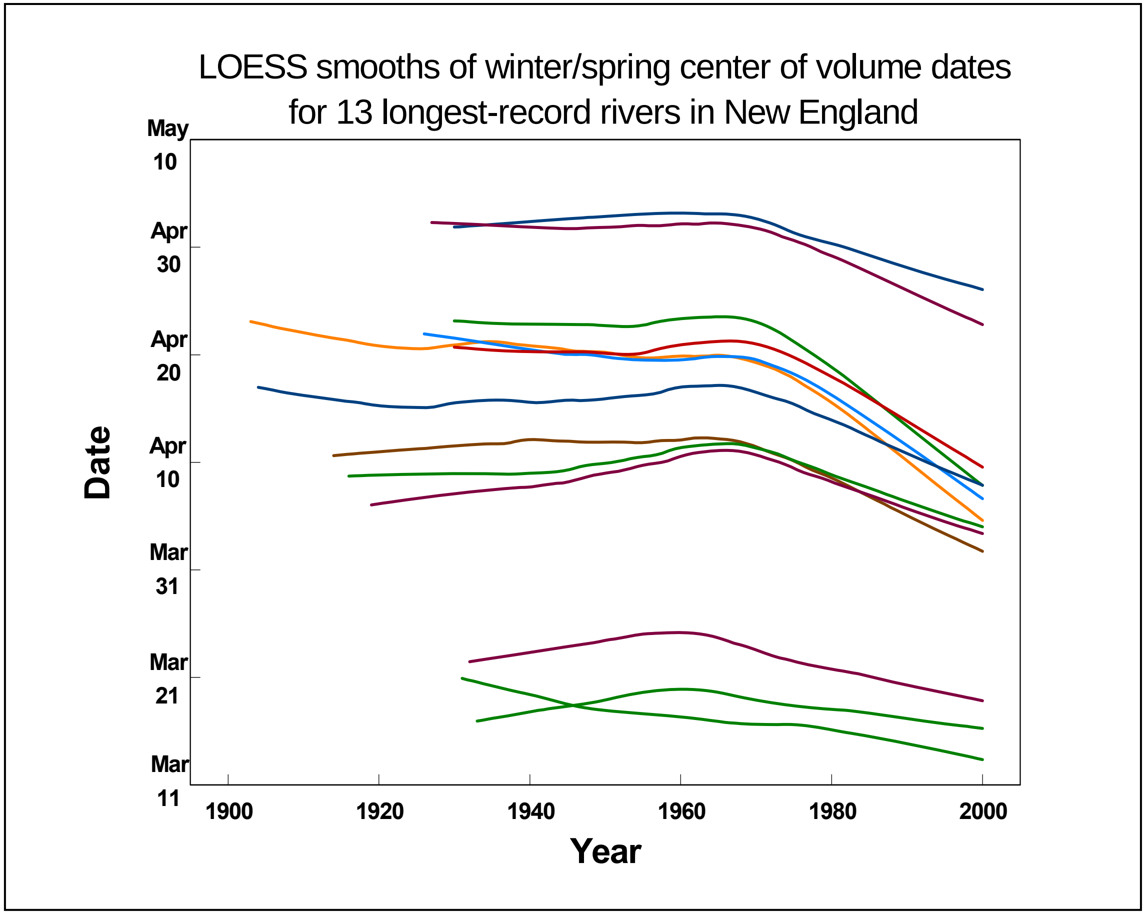




- **Ice-out earlier by 2.9 (±1.0) days / decade**
- **Freeze-up later by 3.9 (±1.1) days / decade**
- ***River and soil ice probably similar***

# Hydrology Sensitive to Climate

*Lent (2010), USGS, Me*

- **Spring runoff dominates the annual hydrograph**
- ***Significantly earlier in northern New England in recent years***
  - ***-3 days/decade***
- ***Timing related to air temperatures in Spring***

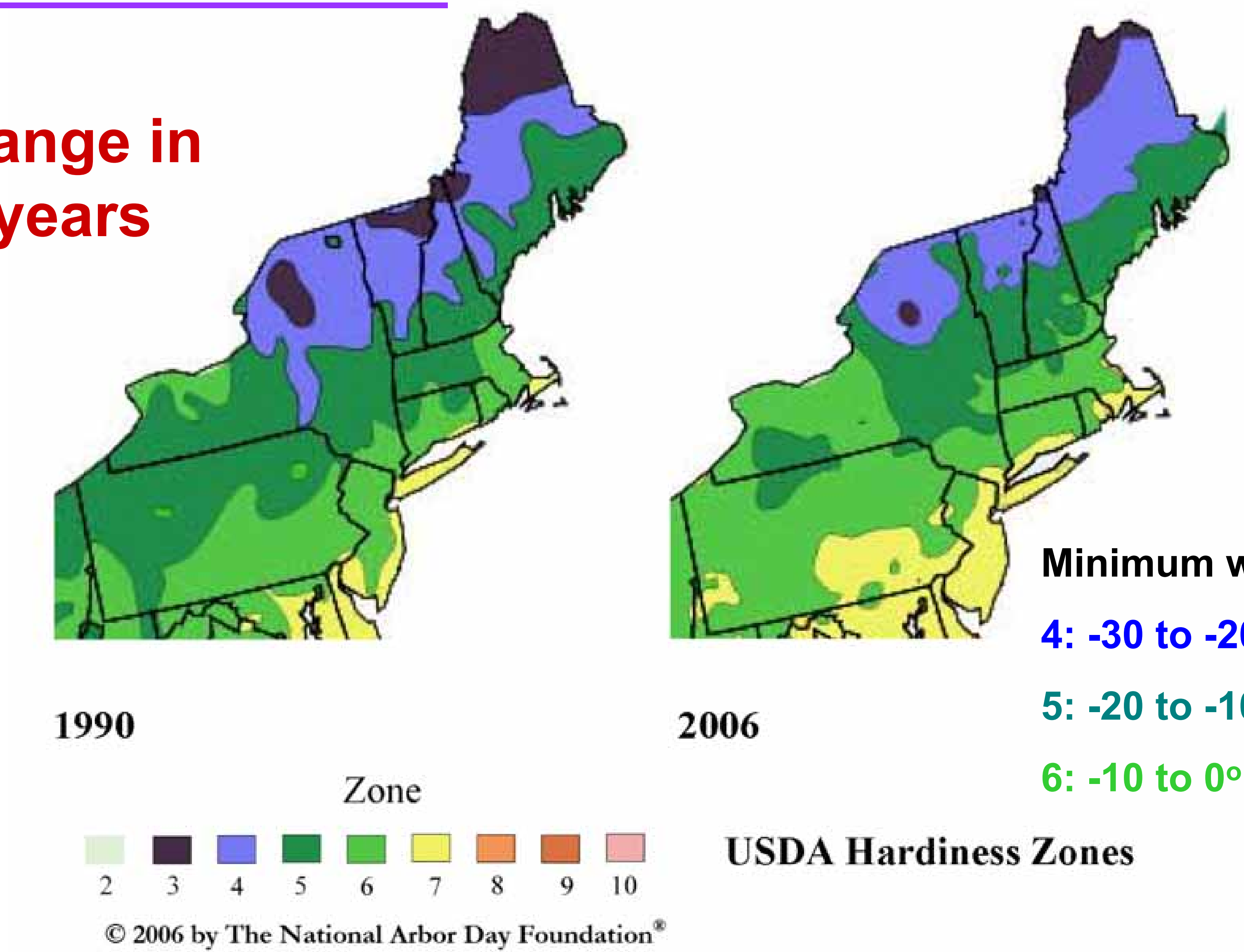



*(Hodgkins and others, 2003)*

# Winter Hardiness Zones

– *winter cold extremes*

Change in 16 years




Minimum winter T

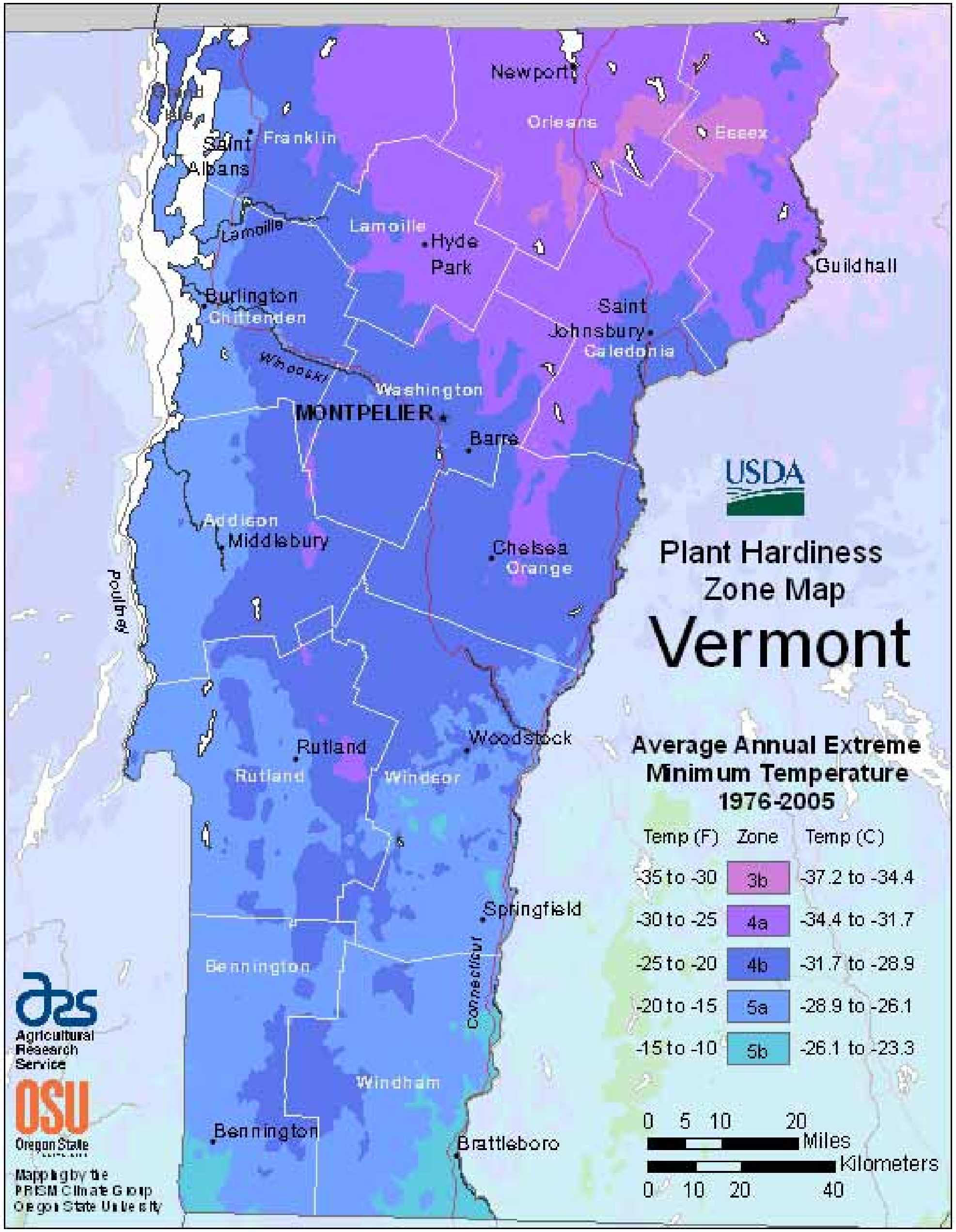
4: -30 to -20°F

5: -20 to -10°F

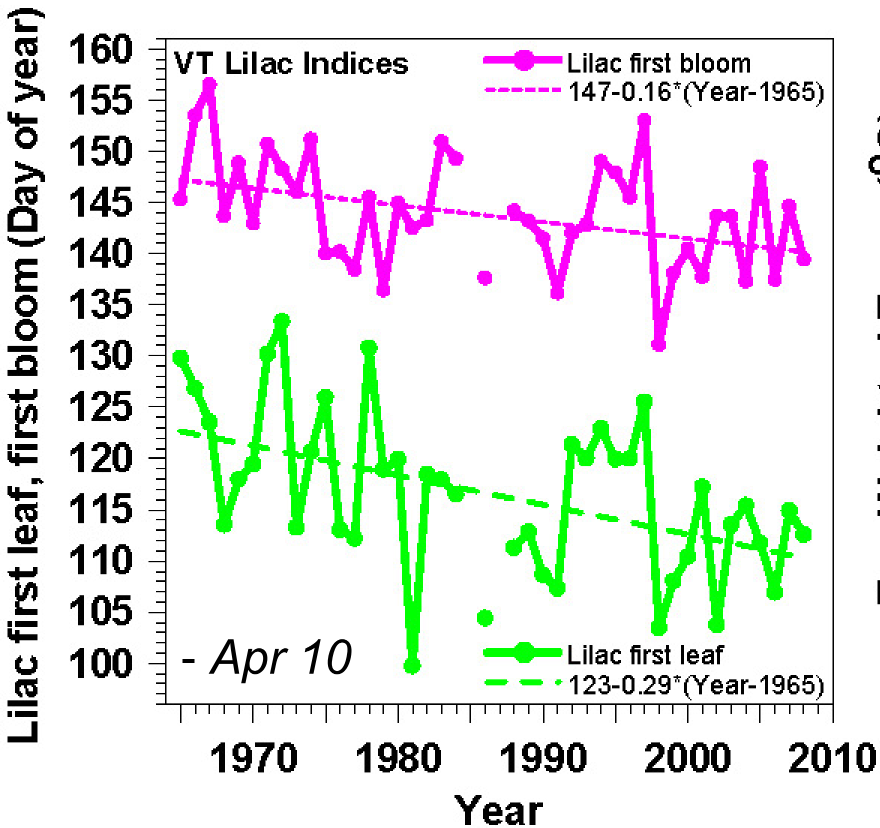
6: -10 to 0°F

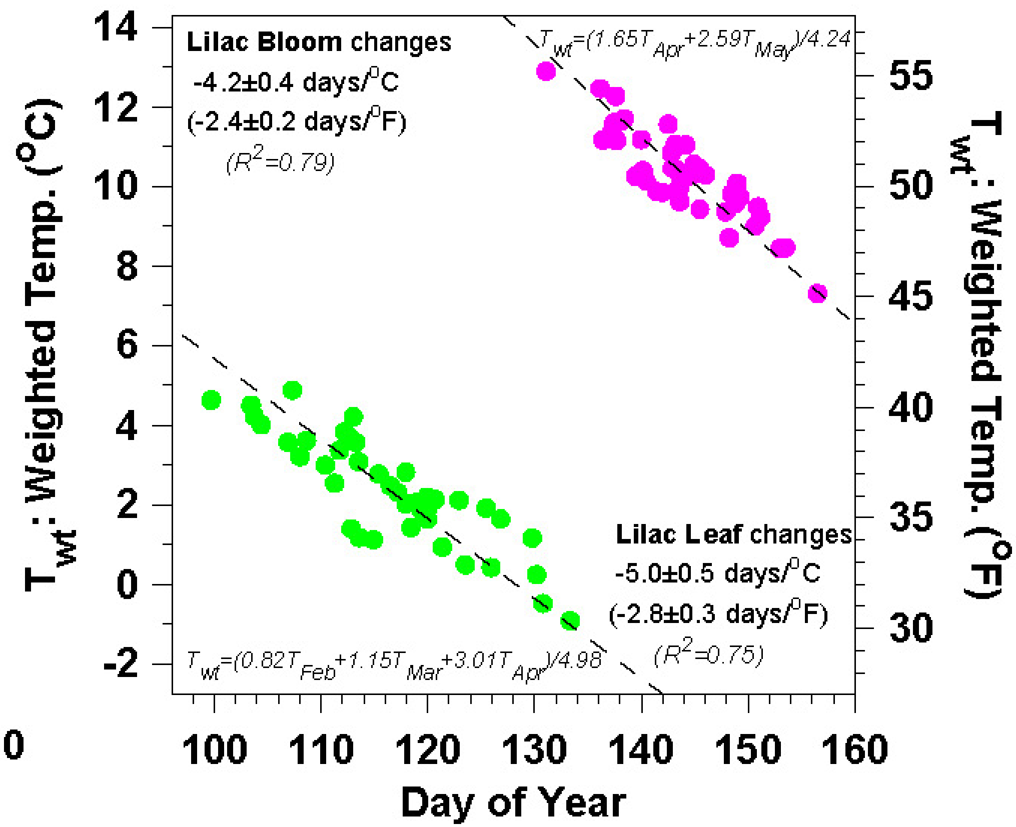
# Detailed Map *(most recent)*

- 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/*



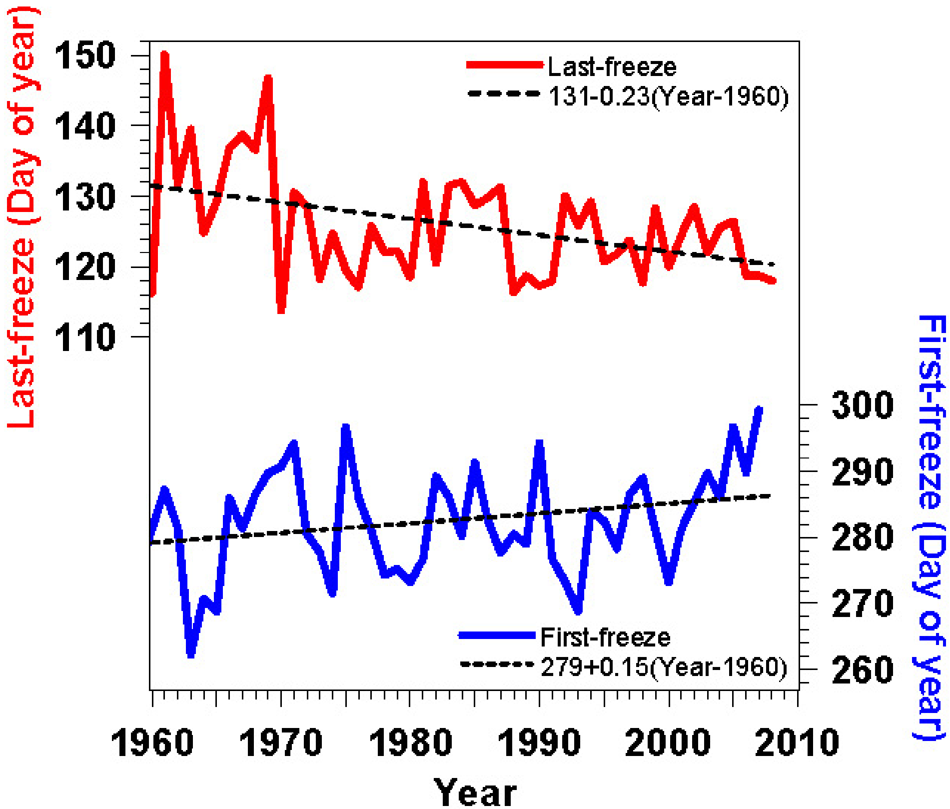
# Lilac Leaf and Bloom

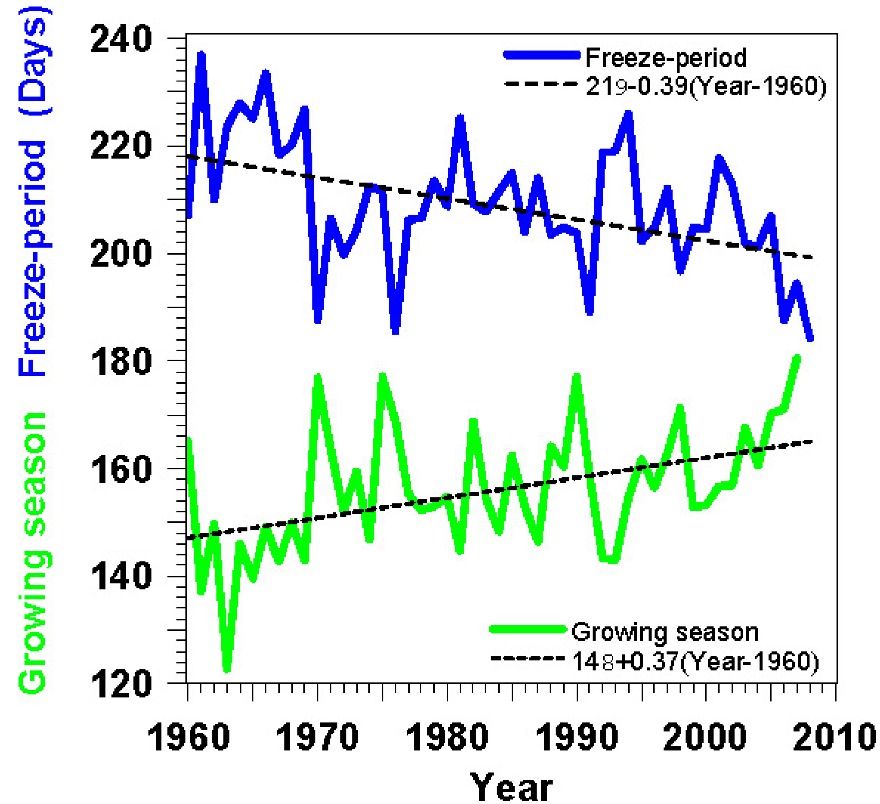


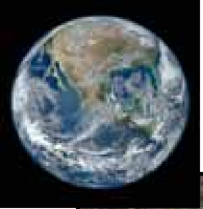

- **Leaf-out -2.9 days/decade; Bloom -1.6 days/decade**
- ***Large year-to-year variation related to temperature: 2.5 days/ °F or 4.5 days/ °C***

# First and Last Frosts Changing



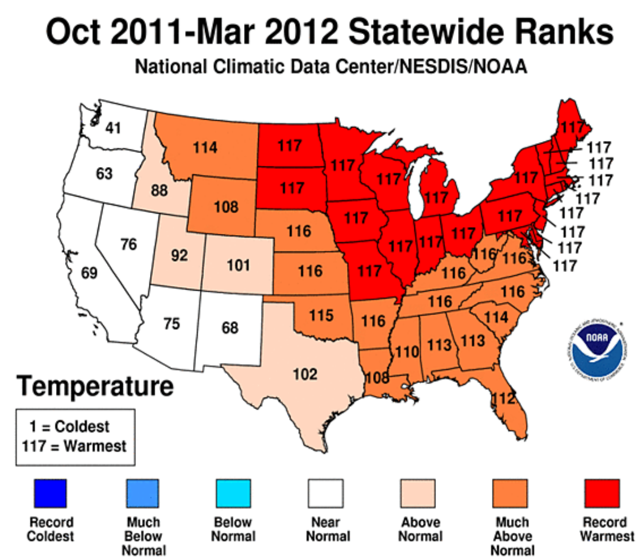

- **Growing season for frost-sensitive plants increasing 3.7 days / decade**
- ***Important for agriculture; local food supply***



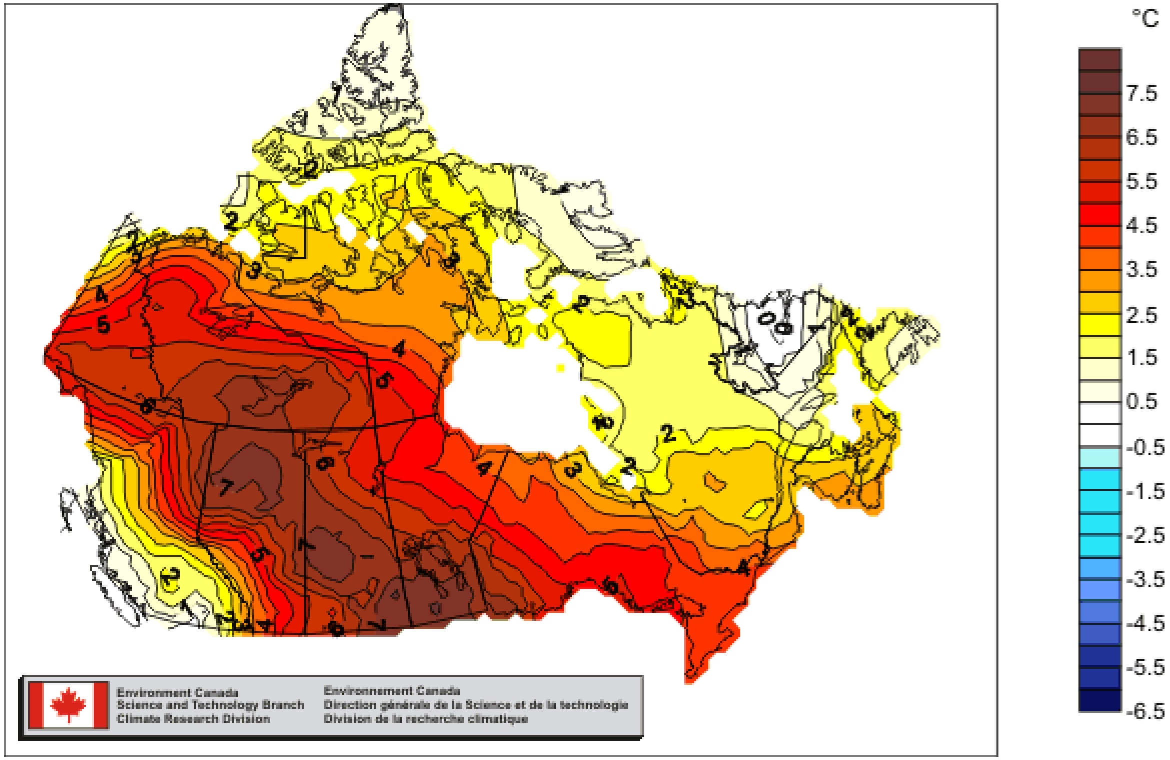
# January 2, 2012 — March 11, 2012

### *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

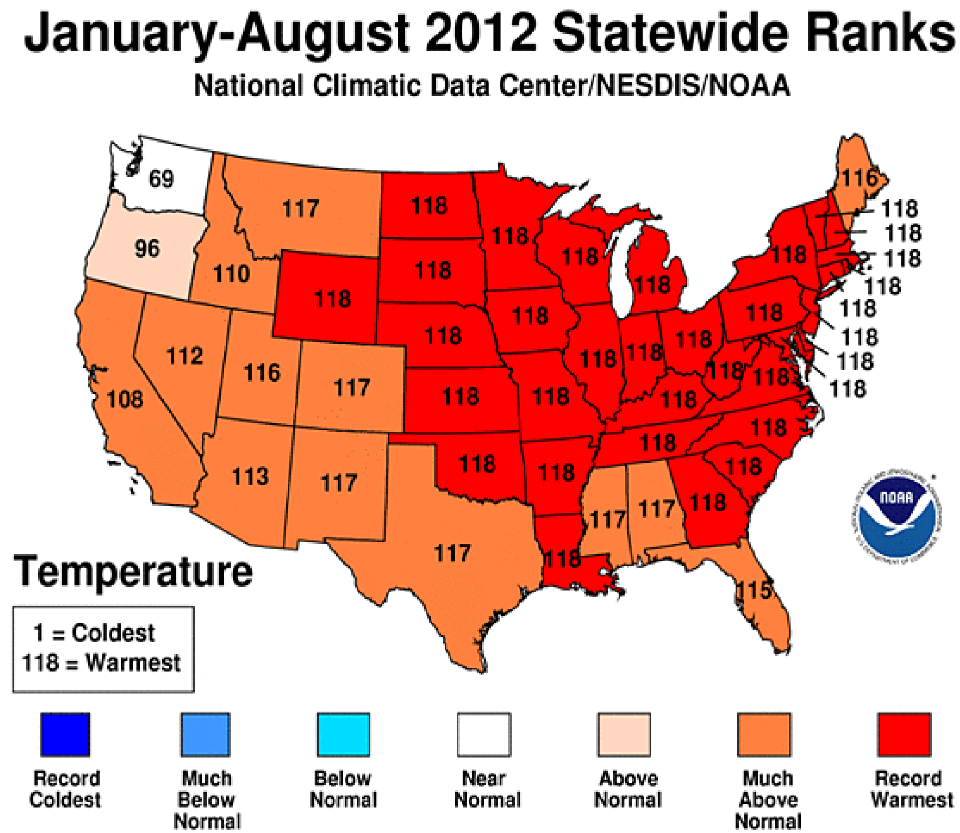



- **Winter 2011-12: 3.6°C (6.5°F) above normal**
  - **Canada's winters also warming 0.9°F/decade**
- ***Climate doesn't see the border!***

# This Year Exceptionally Warm

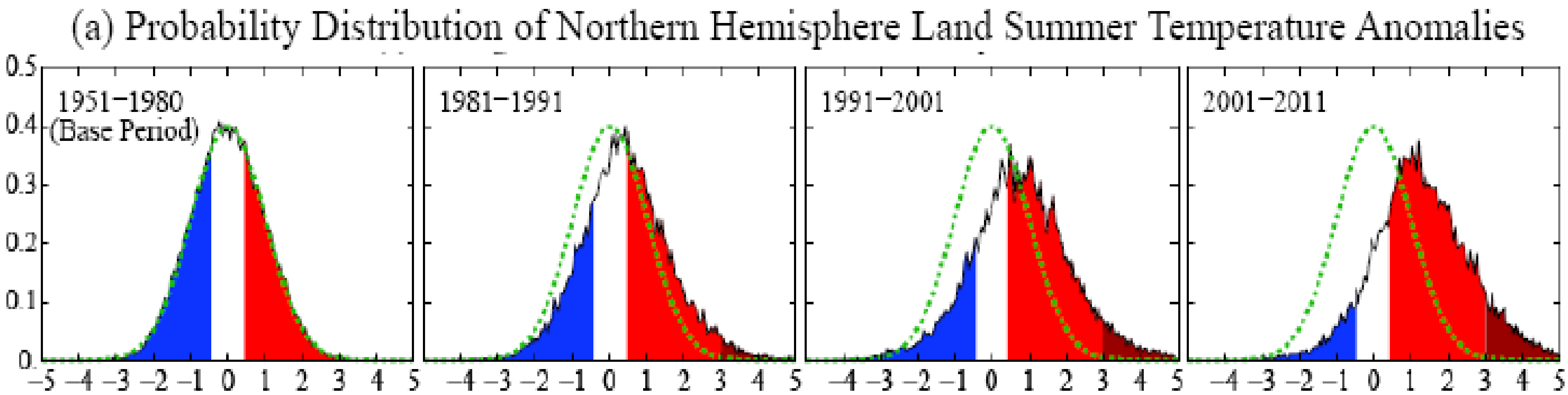
- Burlington Area Extremes
- Highest Average Temperature degrees F
- Days: 9/1/2011 - 8/31/2012
- Length of period: 365 days
- Years: 1850-2012
- Rank Value Ending Date
- **1 50.4 8/31/2012**
- 2 48.4 8/31/2002, 8/31/1949
- 4 48.2 8/31/2010
- 5 48.0 8/31/1999
- 6 47.9 8/31/2006
- 7 47.8 8/31/1991, 8/31/1995
- 9 47.6 8/31/1899, 8/31/1903

*(Scott Whittier: NWS-BTV)*




http://www.ncdc.noaa.gov/temp-and-precip/maps.php

# Increasing Temperature Extremes is "Global Warming"




*(Hansen, 2012)*

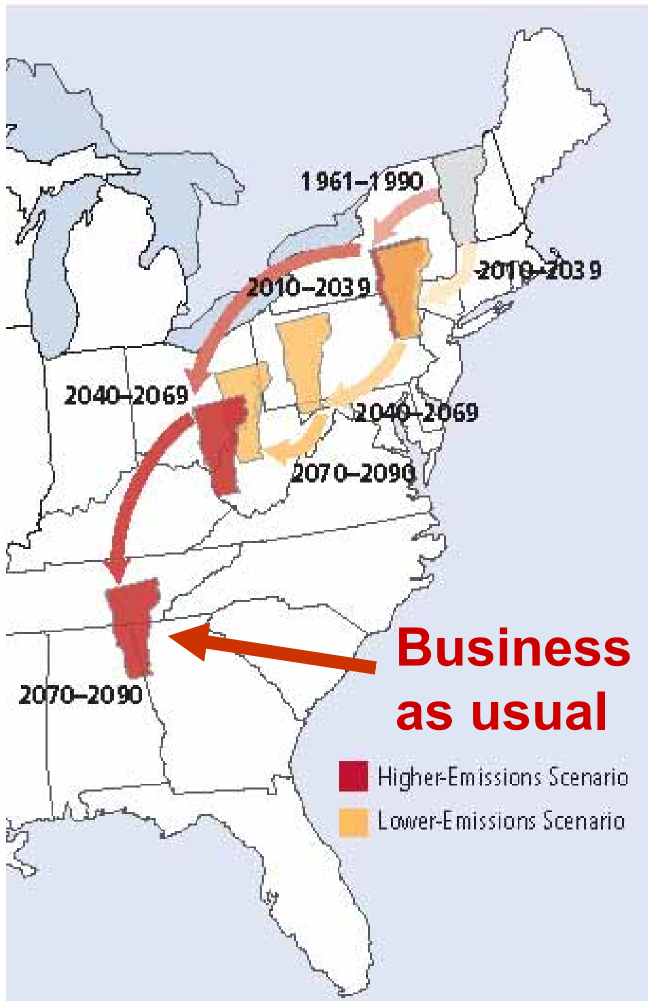
- **Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies for Northern Hemisphere land in units of local standard deviation (horizontal axis). The normal (gaussian) distribution bell curve is shown in green.**

- **Large increase in anomalies > +3σ *is* global warming**
  - ***Baseline 0.15% has increased to 10% in 45 years***

# 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.

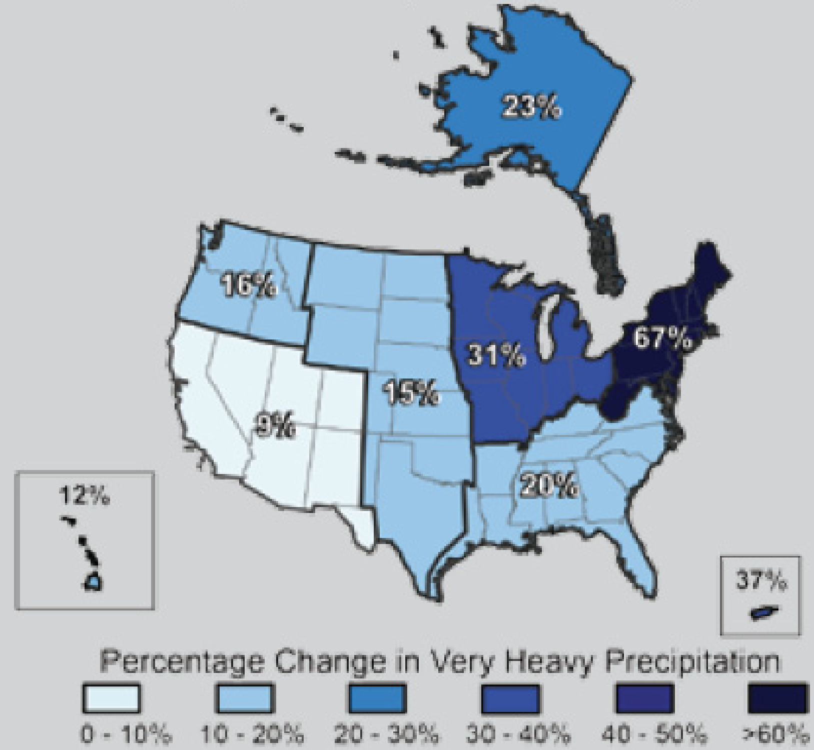
*NECIA, 2007*

# Very Heavy Precipitation Is Increasing

*(USGCRP, 2009)*

- <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**
- **Little change or a decrease in the frequency of light and moderate precipitation**
- **Vermont streamflow is increasing**

Increases in Amounts of Very Heavy Precipitation (1958 to 2007)




Updated from Groisman et al.[113]

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 increases 20-50%

***Lent (2010) USGS, Me***

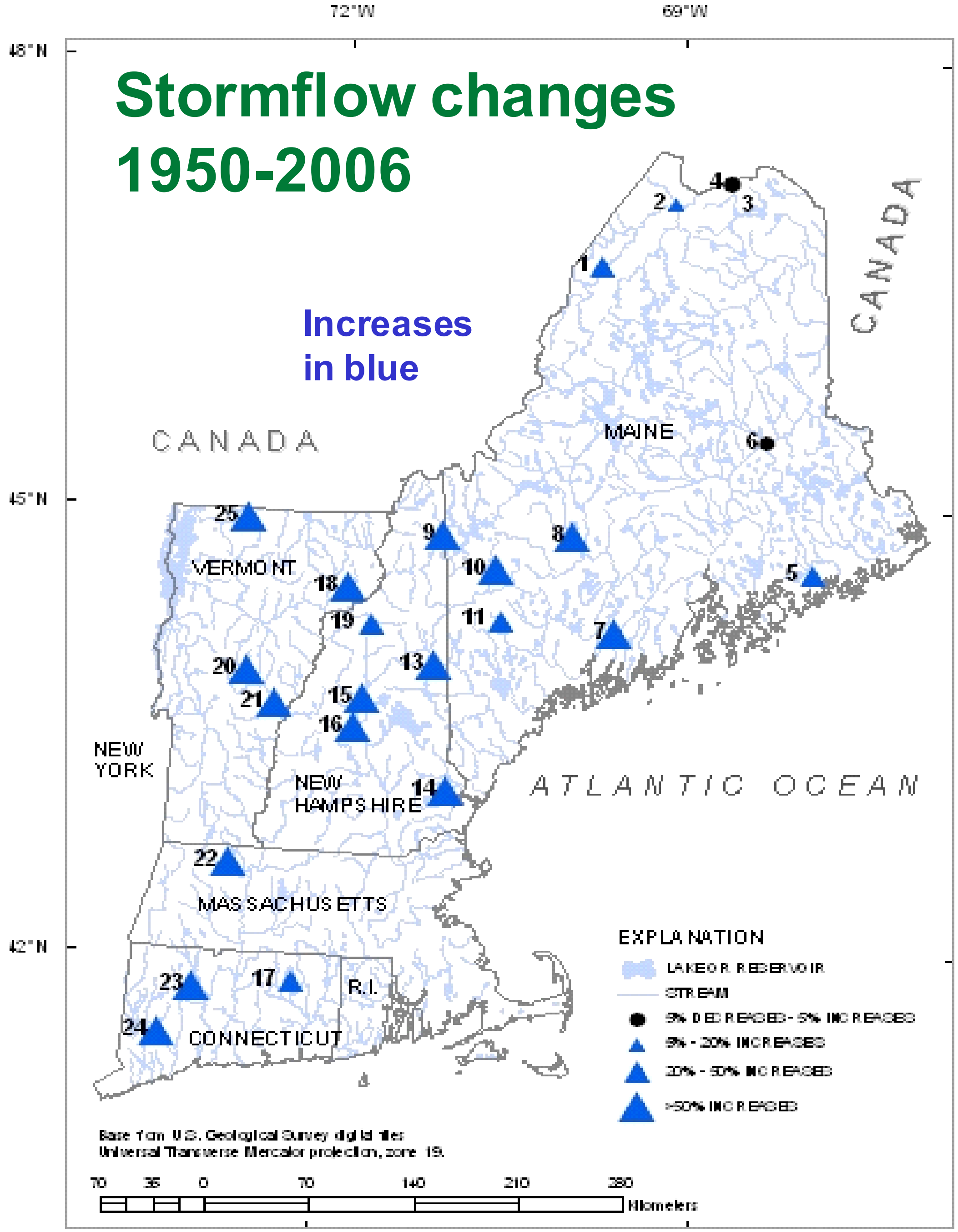
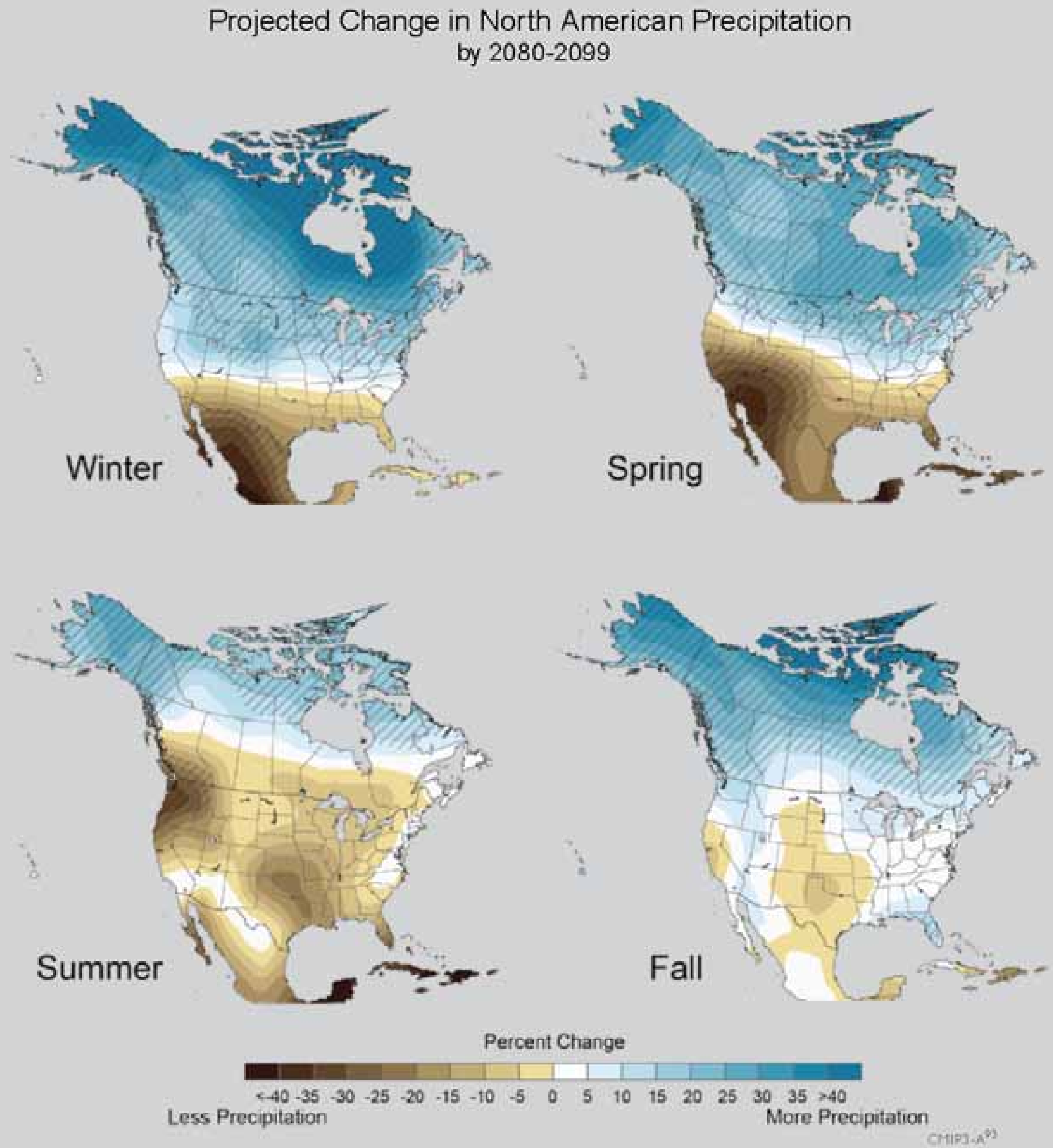



Figure 4. Geographic distribution of summer stormflow trends, 1950-2006.

# Projected <u>Mean</u> Precipitation Increase by 2090

- ***Wetter - North***
- ***Drier - South***
- ***For Vermont***
  - **+15% in winter**
  - **+10% in spring**
  - **+5% in fall**
  - **No change summer**
  - **But heavier rain & more drought**
- **(Unshaded**
  - **less confident)**




The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario.[11] For example, in the spring, climate models agree that northern areas are likely to get wetter, and southern areas drier. There is less confidence in exactly where the transition between wetter and drier areas will occur. Confidence in the projected changes is highest in the hatched areas.

# Many Wet Summers in Vermont – till 2012


- **2004, 2006, 2008, 2009, (2010), 2011 all wet**
- **Direct fast evaporation off wet canopies**
- ***Positive evaporation-precipitation feedback, coupled to synoptic system frequency***

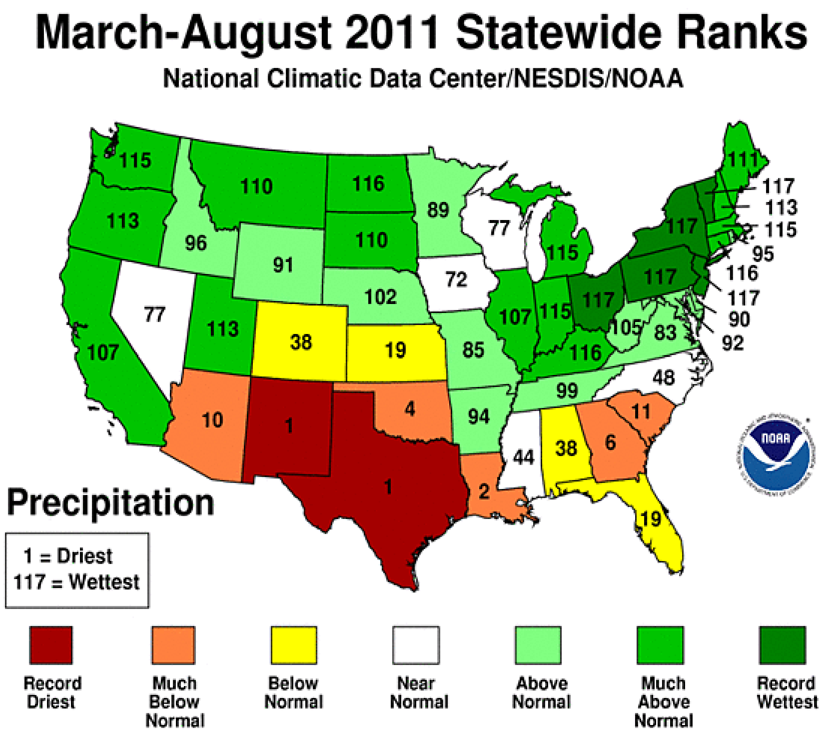
# Extreme Weather (precip.)

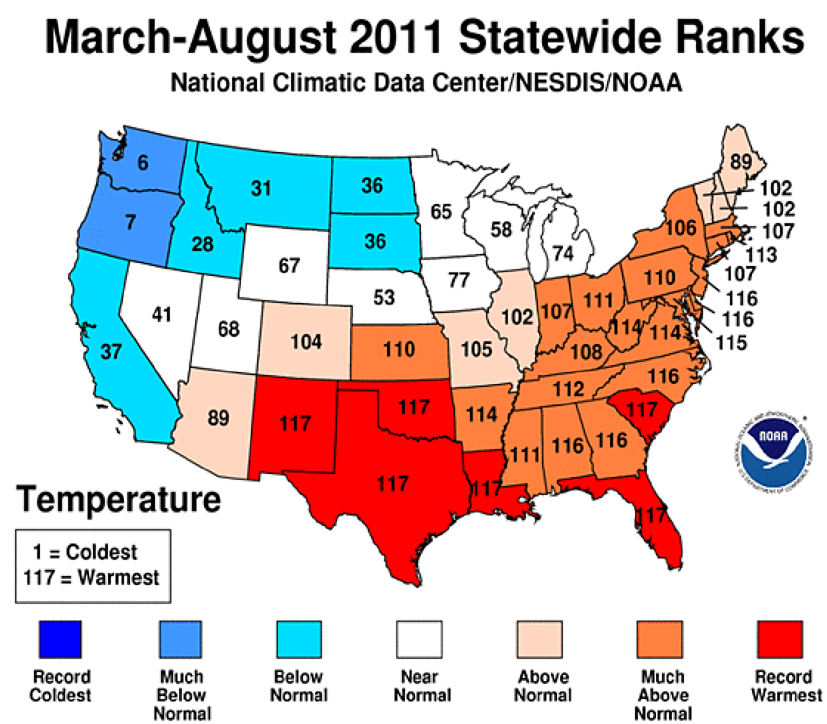
- **Precip. is condensation of atmospheric water vapor - larger latent heat release drives storms**
- ***Saturation vapor pressure at cloud-base increases steeply with temperature (6%/$^o$C)***

- **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***

# 2011 Vermont Floods

- **Record spring flood on Lake Champlain**
- **Record floods following TS Irene**
- **Record wet March-August, 2011: OH to VT**
  **(but record drought in TX & NM)**
- ***Quasi-stationary pattern for 6 mos***



# 2011 Classic VT Flood Situations

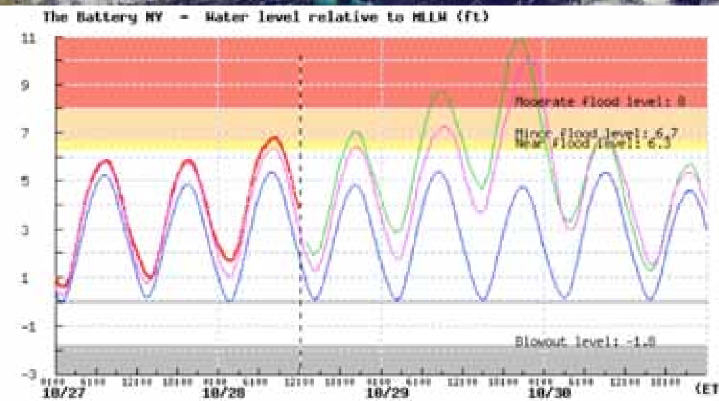
- **Spring flood**: heavy rain and warm weather, melting large snowpack from 2010 winter
  - 70F (4/11) and 80F(5/27) + heavy rain
  - record April, May rainfall: 3X at BTV
  - Severe Winooski flood
  - Lake Champlain record flood stage of 103ft
- **Irene flood: tropical storm** moved up east of Green Mountains
  - 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 + 5$^{o}$F
  - Blocking high: NE Canada
  - 13 ft (4m) storm surge

# Increasing Extreme Weather

- ***The answer to the oft-asked question of whether an (extreme) event is caused by climate change is that <u>it is the wrong question.</u>***

- ***<u>All weather events are affected by climate change</u> because the environment in which they occur is warmer and moister than it used to be.*** ***(Trenberth: Climatic Change 2012)***

# 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
- Snow and ice down
  - Less sunlight reflected
    - Warmer Arctic in summer
    - Warmer northern winters
  - Less ice-cover: more evaporation

# Models Strengths and Weaknesses

- **Weather: Sandy landfall forecast at 7-days lead-time**
- **Climate: Mean state changes**
- **Temperature mean trends and statistics**
  - Depend on model sensitivity to clouds/ice-melt
  - Cloud field changes uncertain, Arctic ice-melt too slow
  - Bias of model Temps. *from freezing* critical

- **Large-scale mean precipitation trends**
  - Circulation mode changes less certain
  - Precipitation extremes less certain
- **Diurnal cycle trends poorly forecast**
- **Arctic melt-rate under-forecast**
  - Appears to be changing circulation modes
- **Biogeochemical feedbacks uncertain**
  - Methane release, $CO_2$ fertilization

# Winter snowfall *(USGCRP 2009)*

- Trends since 1970
  - Winter temps rising 1°F/decade
  - Less winter precipitation falling as snow and more as rain
  - Reduced snowpack
  - Earlier breakup of winter ice on lakes and rivers
  - Earlier spring snowmelt resulting in earlier peak river flows

- Projections to late century
  - Winters in the Northeast are projected to be much shorter with fewer cold days and more precipitation
  - The length of the winter snow season would be cut in half across northern New York, Vermont, New Hampshire, and Maine, and reduced to a week or two in southern parts of the region

# Current Reality

- **Northern winters may be shrinking faster than model projections**
  - **Model ice-coupled feedbacks too weak?**
  - **Winter extremes increasing: eg 2010, 2011**
- **Our limited seasonal forecast skill is related to Pacific and Atlantic ocean temperatures**
  - **Now Arctic warming is major factor**
  - **Changing NH circulation: blocking patterns**
  - **Limited understanding: *less than decade of data***

# Agricultural planning

- **Frozen ground and lakes: -7d/decade**
- **Earlier melt, earlier spring leaf-out: - 3d/decade**
- **Frost-free growing season: +4d/decade**
  - **Greenhouse, row cover seasonal extenders**
- **Winter extremes increasing with variable snow**
  - **$T_{min}$ extremes increasing +3°F/decade**

- **More winter precipitation**
  - **Wetter snow; more mixed phase; more frequent melt**
- **Variable summer precipitation**
  - **Heavier rain-rates, longer storms, longer droughts**
  - **Maximize soil water infiltration; water storage**
  - **Manage to reduce soil erosion**
  - **Design infrastructure to handle larger runoff**

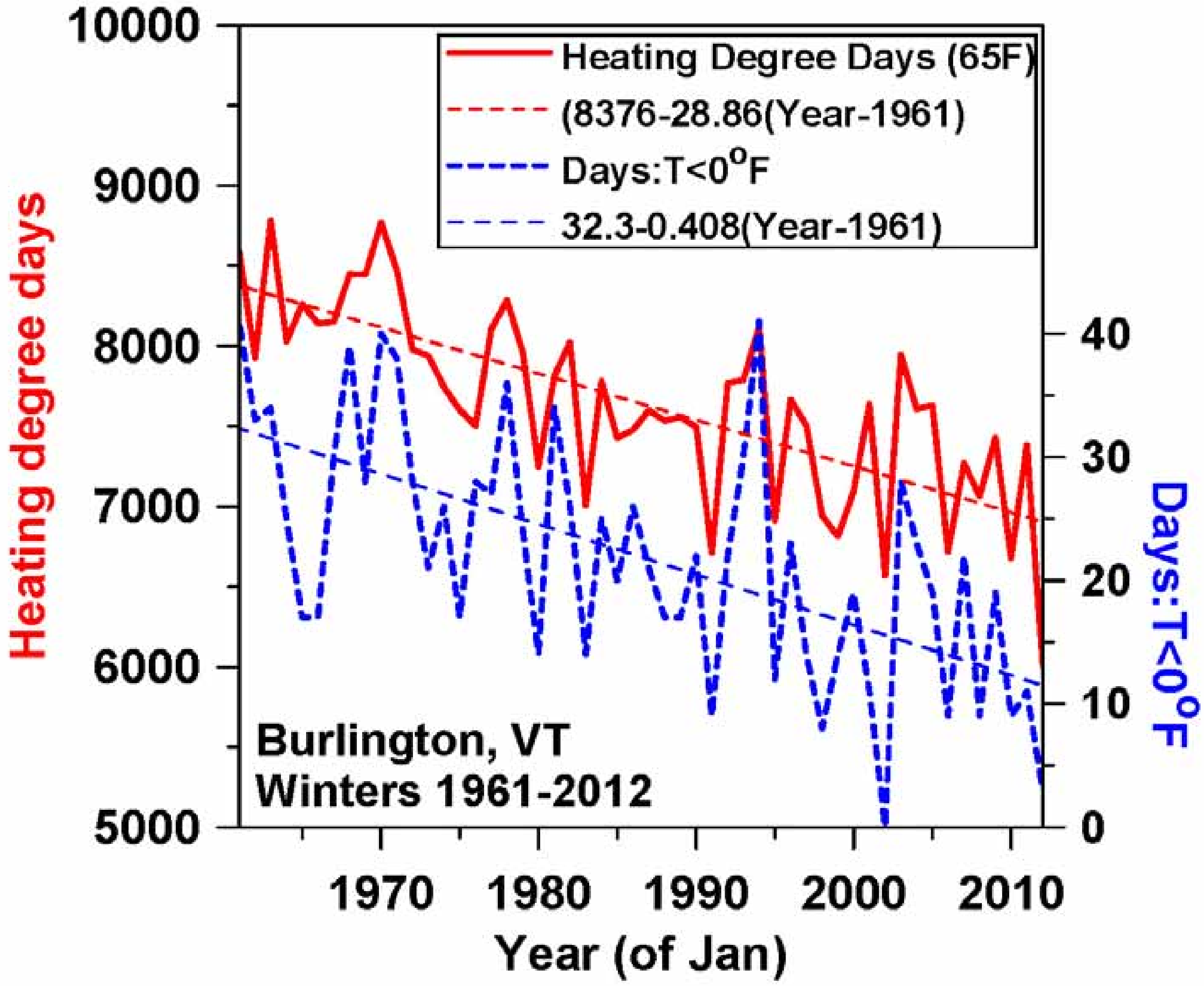
# Discussion

- ***This is an iterative process***
  - **What information would help with adaptive planning? Tell us - fill out cards**
  - **Our goal is to search for answers in coming years**

- **Background papers: http://alanbetts.com/**
  - ***Vermont Climate Change Indicators***
  - ***Seasonal Climate Transitions in New England***
  - ***Extreme Weather and Climate Change***

# Heating Degree Days and Days below 0°F *(-17.8°C)* (Burlington)

- **HDD trend 289 (±37) /decade**
- **$T_{min}$<0°F 4.1 (±0.7) days /decade**



# Cooling Degree Days and Days $T_{max}$ > 90°F

- **CDD trend 37 (±11) /decade**
- **$T_{max}$>90°F no trend *(2004-2011 were wet)***