



Adapting to Climate Change



Dr. Alan K. Betts

Atmospheric Research, Pittsford, VT 05763

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

Richford, VT



RACC

Research on Adaptation
to Climate Change

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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

January 2, 2012: NASA

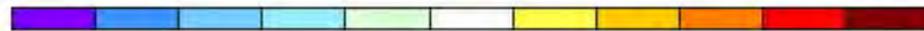
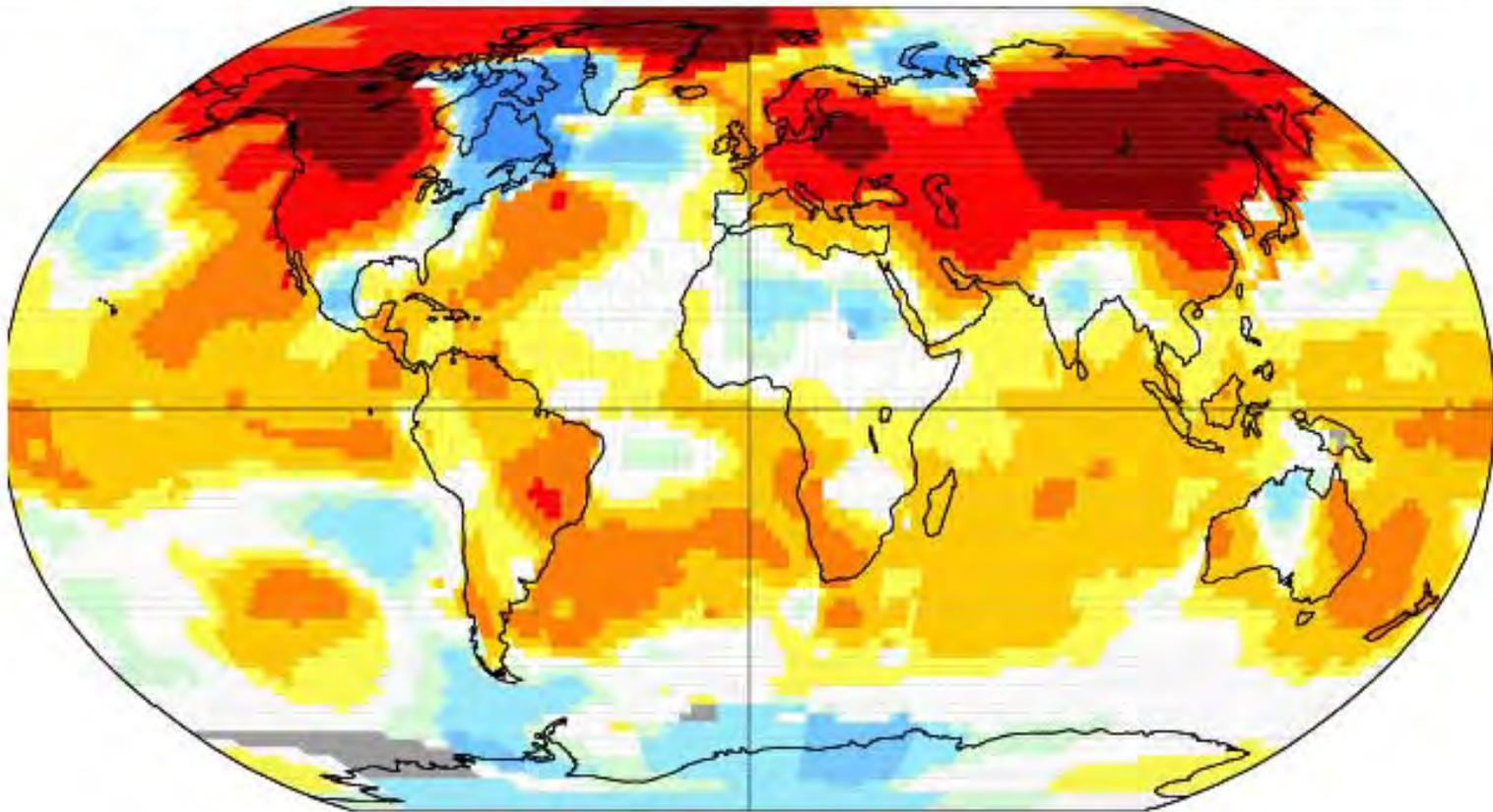
Earth's climate sustains life

- Burning fossil fuels is increasing greenhouse gases
- **Climate is warming: ice is melting, extreme weather is increasing**
- Water plays crucial amplifying role



Chilly Winter Here - Look at the Rest of the Northern Hemisphere!

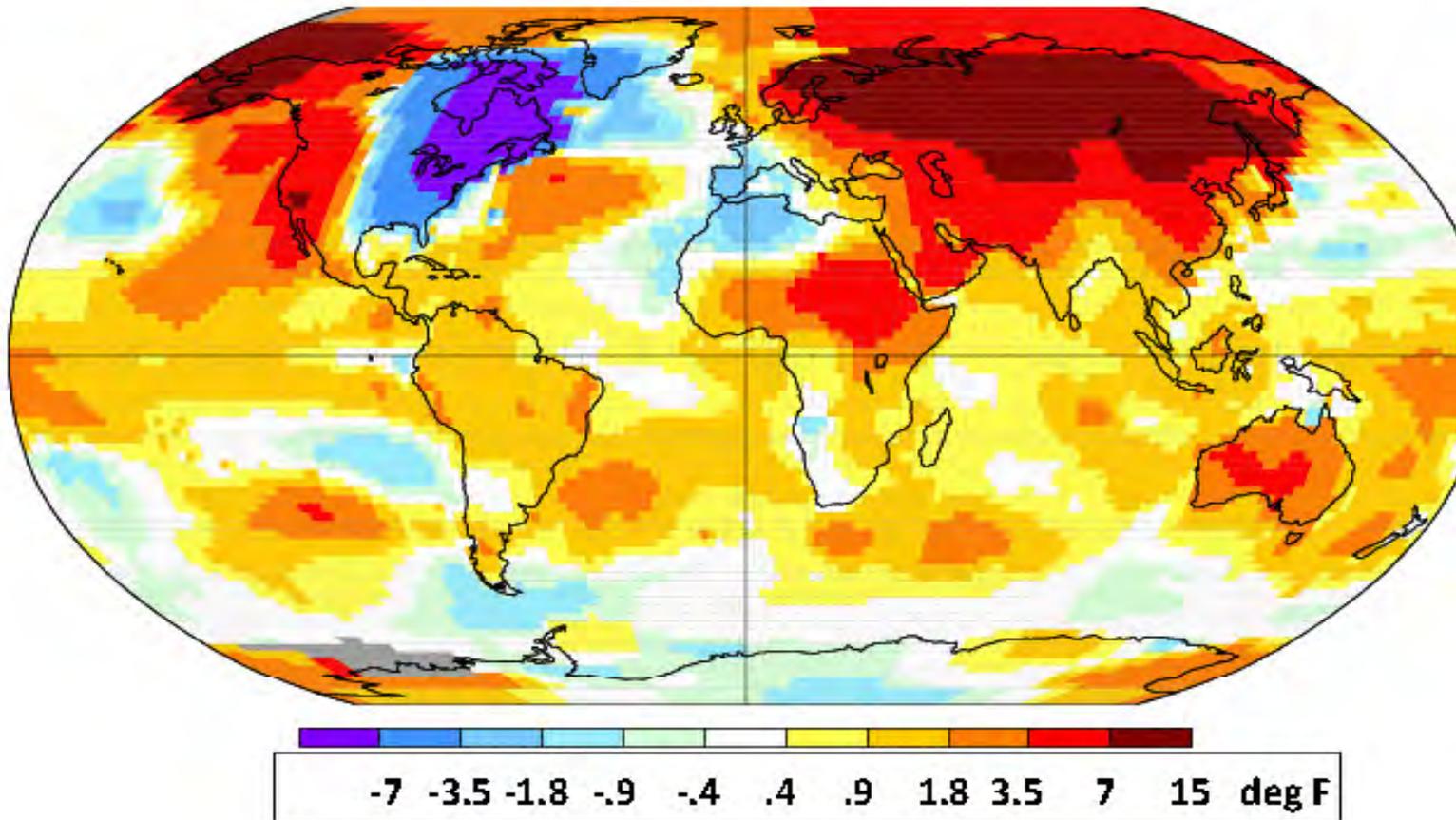
January 2015 Temperature Anomaly (deg F) from 1951-1980 (NASA)



-7 -3.5 -1.8 -.9 -.4 .4 .9 1.8 3.5 7 15 deg F

Extremes Larger in February - Pattern stationary

February 2015 Temperature Anomaly (deg F) from 1951-1980 (NASA)



Warm Atlantic, Cold NE, strong coastal storms - Boston record snow

Winter Ice and Snow



Vermont Winter 2006

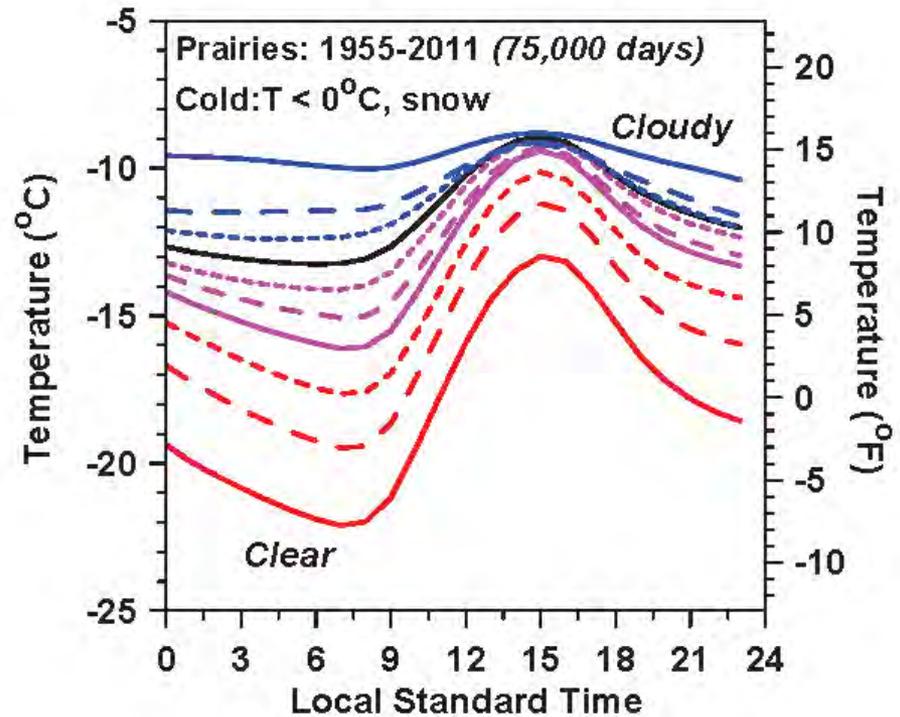
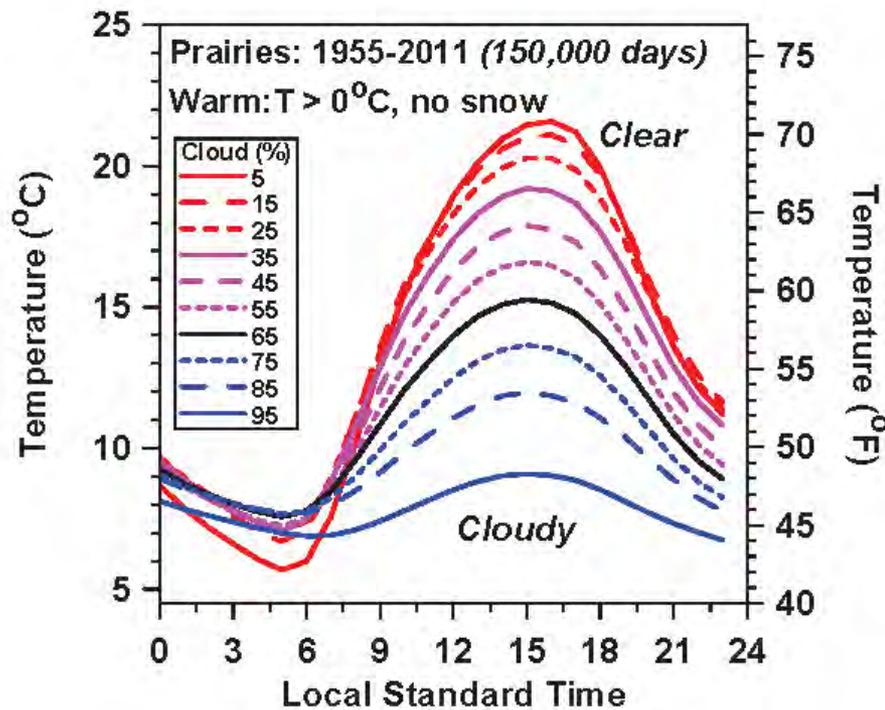


- **Snow reflects sunlight, except where trees shadow**
- **Cold; little evaporation, clear sky; earth cools to space**
- ***2011-12 warm winter, snow melts → positive feedback***
- ***2013-14 more snow and colder***

Serendipity in Science

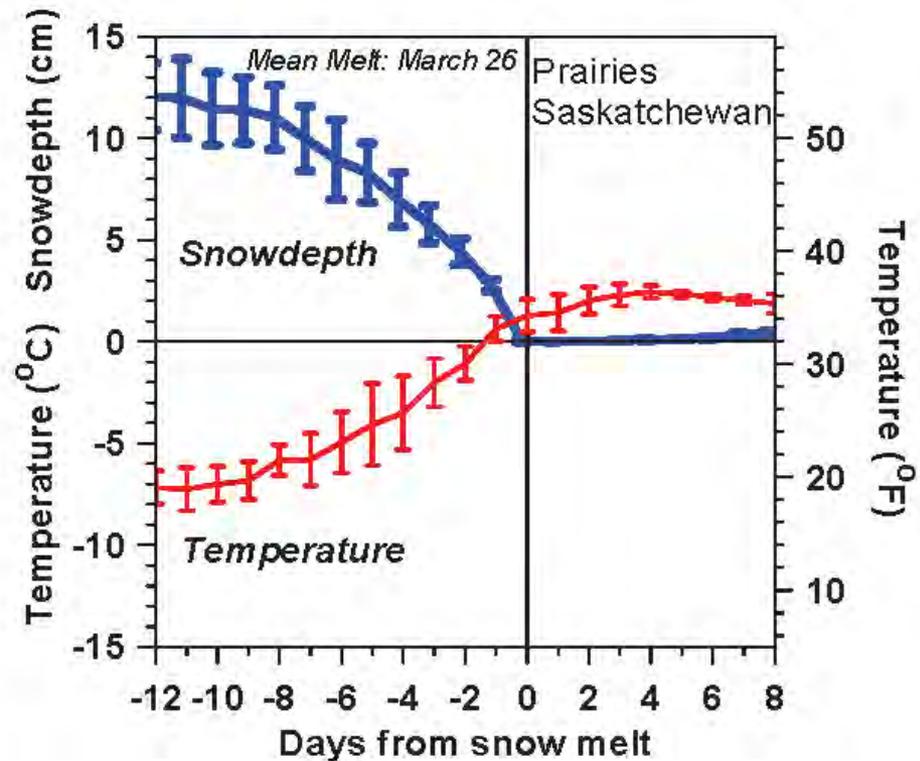
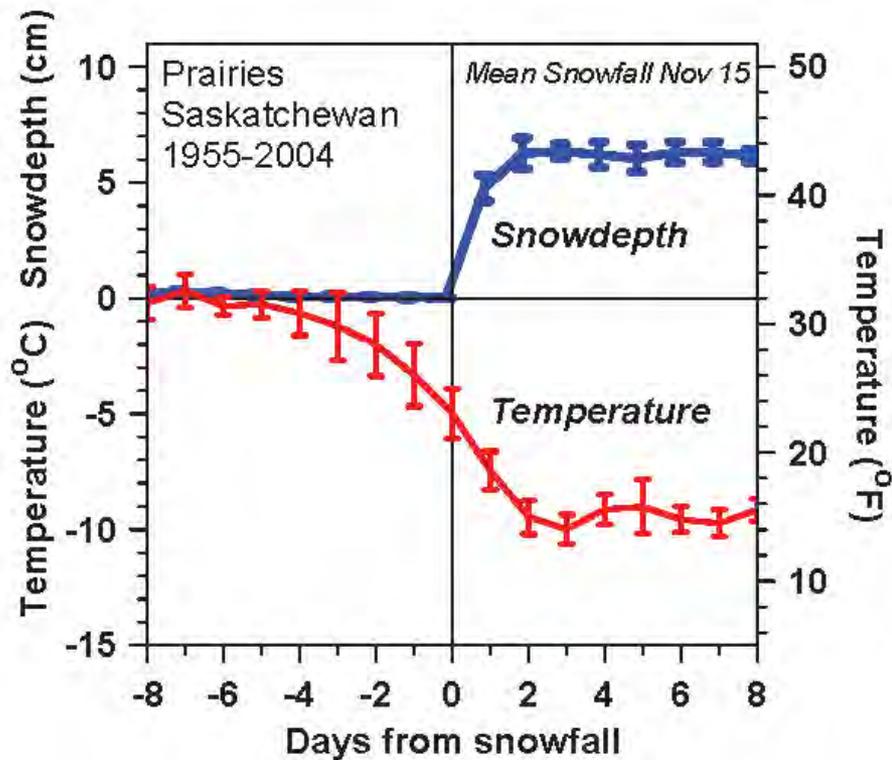
- **For years I have studied clouds and snow**
 - **And lectured on impacts (*with little data!*)**
- **August 2012 – call from Agriculture-Canada**
 - **Please help us understand changing Prairie Climate**
 - **We have hourly data from 1953**
- **Nov. 2012: data arrives – amazing gift that answers questions I have had for years**
 - **With cloud data and snow data.**

Clouds and Climate



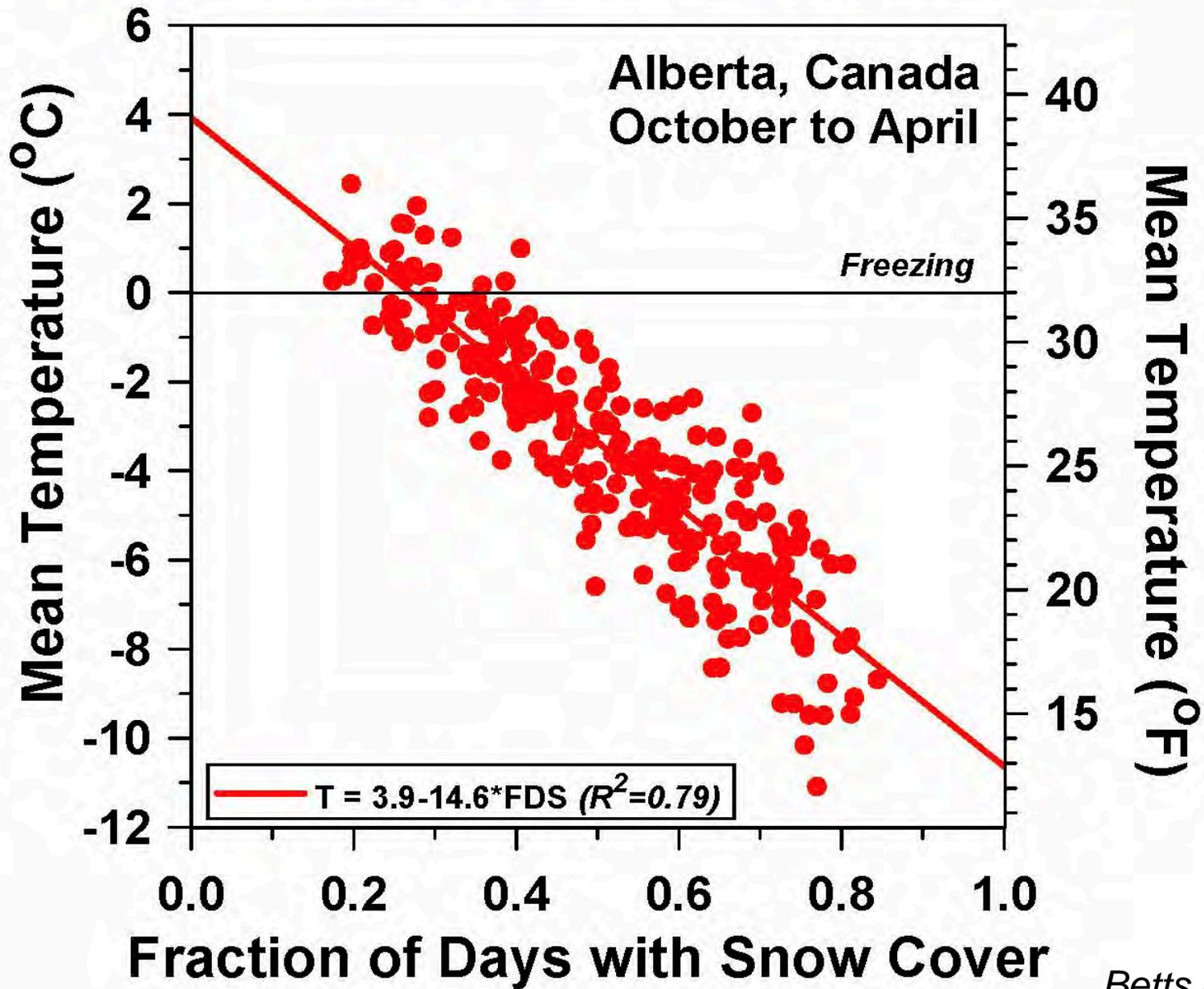
- **Above freezing: Clouds reflect sunlight**
 - Less cloud, much warmer in afternoon
- **Below freezing: Clouds are greenhouse (snow reflects sun)**
 - Less cloud, temperatures fall at night, very cold at sunrise

Snowfall and Snowmelt



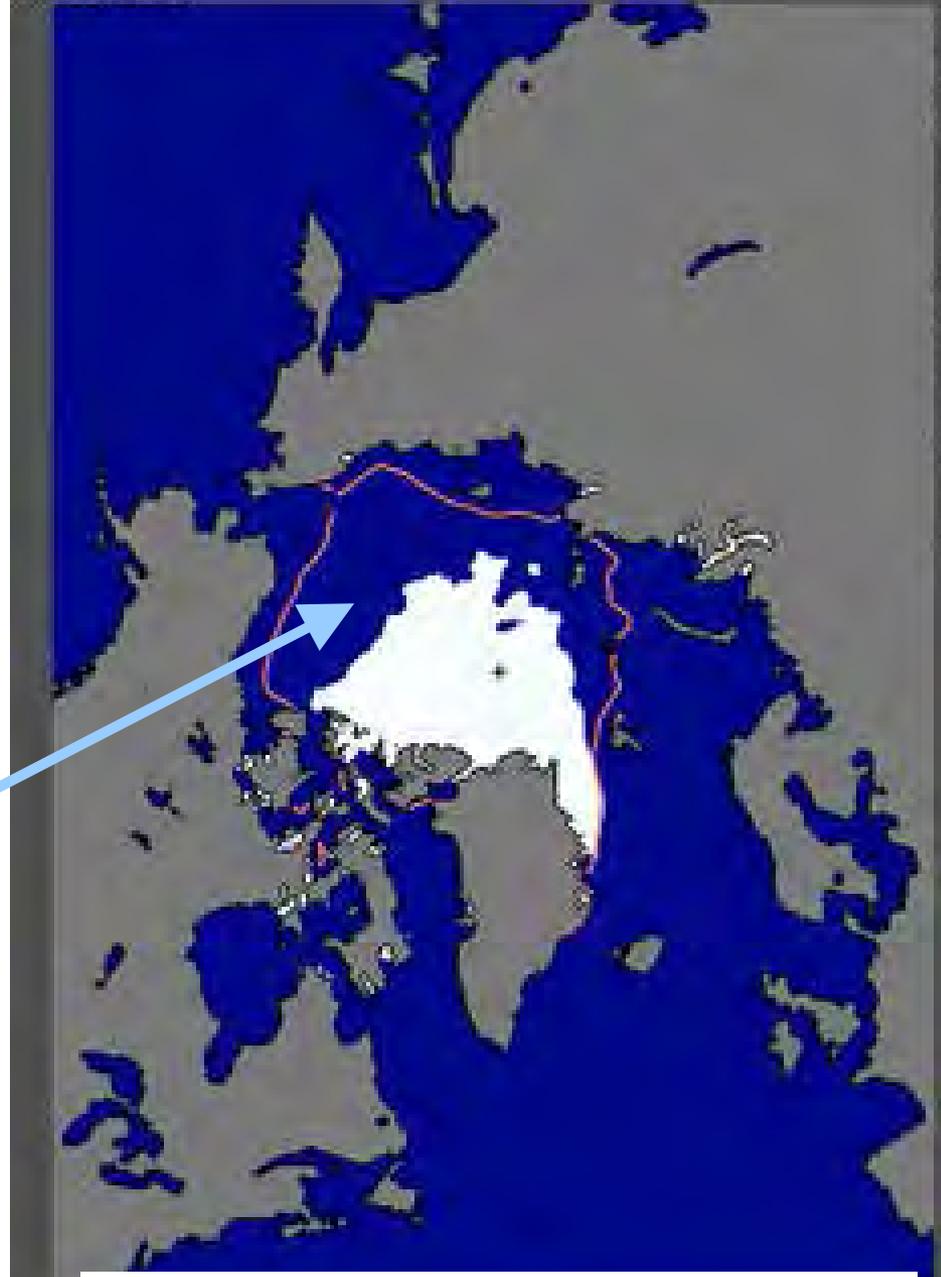
- Temperature falls 18F (10C) with first snowfall
- Reverse change with snowmelt
- *Fast transitions in 'local climate'*
 - *Snow reflects sunlight*
 - *Reduces evaporation and water vapor greenhouse*

More snow cover - Colder temperatures



- **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*
- Same feedbacks as in our winters



Rise of Greenhouse Gases (GHG) Shift Energy Balance of Planet

- The atmosphere is **transparent to light** from the sun, **but not to infrared radiation** from the earth
- **GHG:** H₂O, CO₂, CH₄, O₃, CFCs trap the infrared from the surface, giving climate suitable for life by warming planet 60°F
- Rise of CO₂ alone has only a small warming effect

BUT...



Water, Snow & Ice Give Positive Radiative Feedbacks

- As Earth warms, evaporation and water vapor increase and this is 3X amplifier on CO₂ rise
- As Earth warms, snow & ice decrease and reduced solar reflection amplifies warming in Arctic in summer and mid-latitudes in winter
- Doubling CO₂ will warm globe about 5°F (3°C)
 - Much more in the cold regions and over land, which responds faster than oceans
 - Shift climate into new states

What Is Happening to Vermont?

- Warming twice as fast in winter than summer
- Winter minimums increasing even faster
- Lakes frozen less **by 7 days / decade**

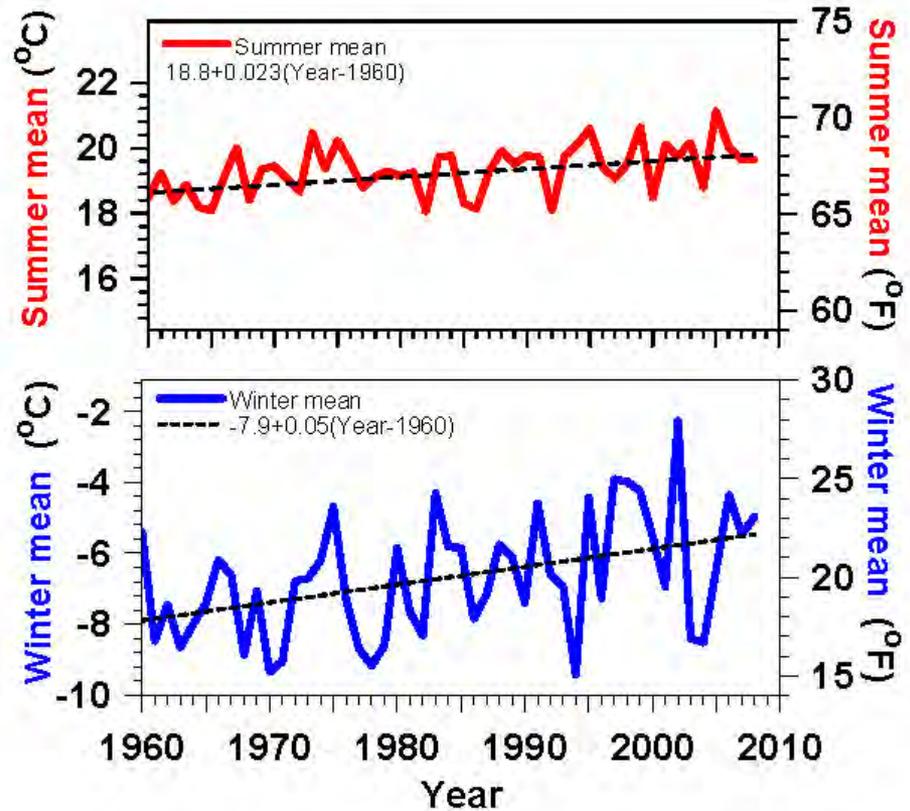
- Growing season longer **by 3-4 days / decade**
- Spring coming earlier **by 2-3 days / decade**

(Betts, 2011)

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

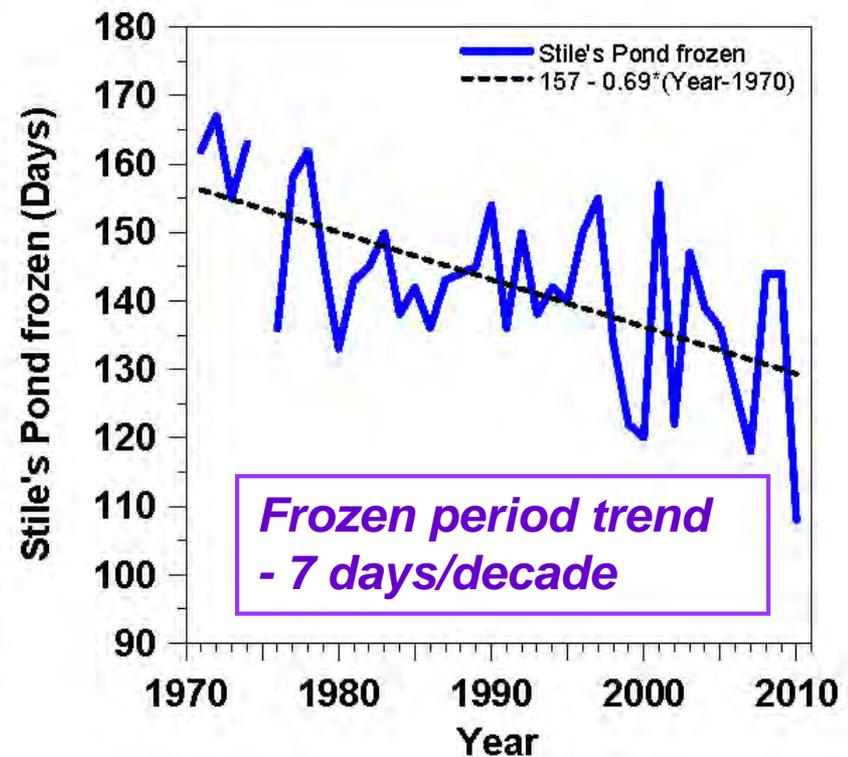
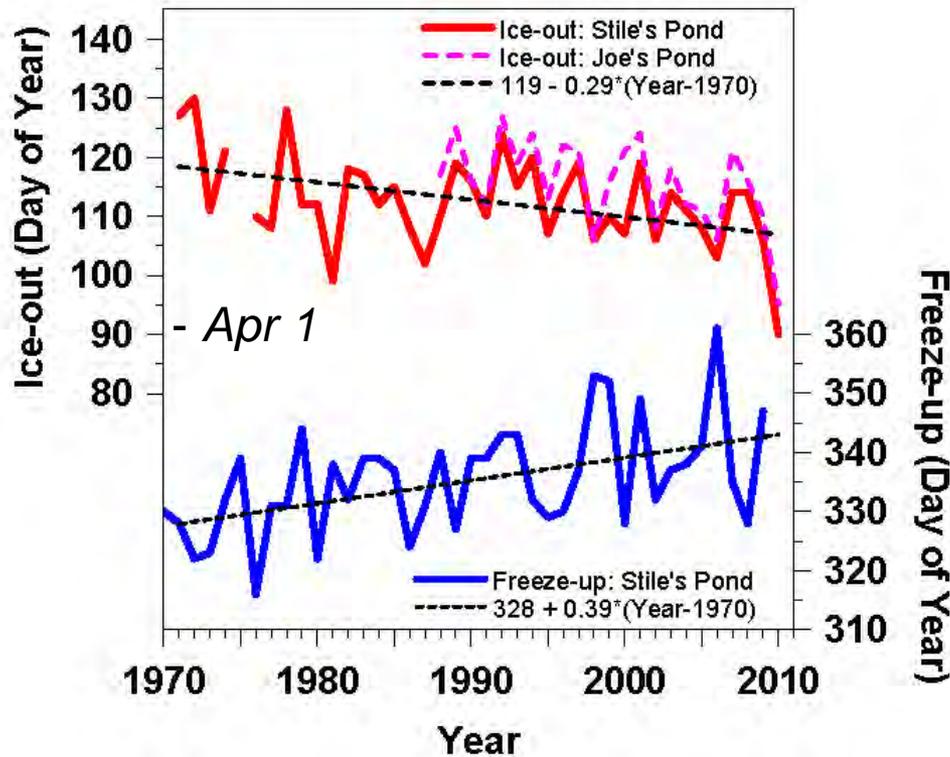
Vermont Temperature Trends 1961-2008

- **Summer $+0.4^{\circ}\text{F}$ / decade**
- **Winter $+0.9^{\circ}\text{F}$ / 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

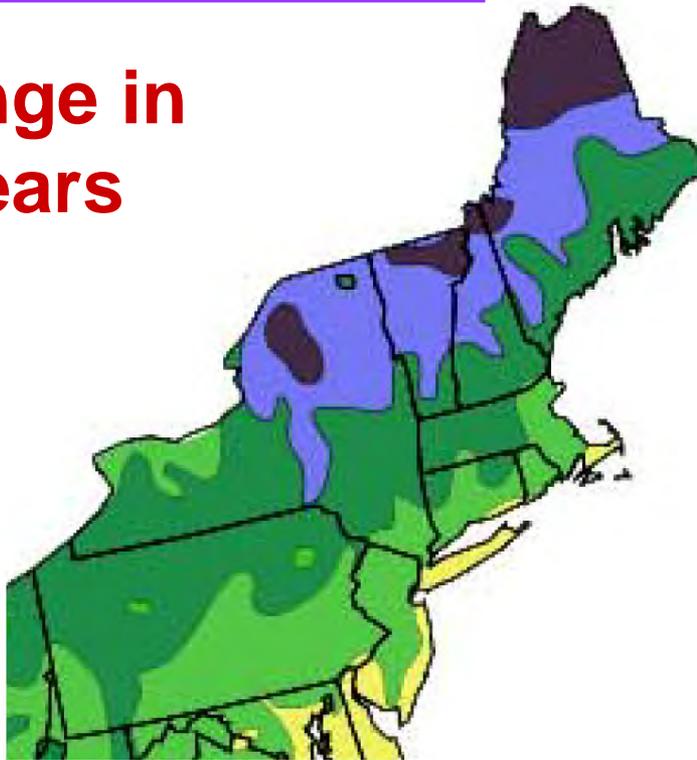


- Ice-out earlier **by 3 days / decade**
- Freeze-up later **by 4 days / decade**
- *Soil ice probably similar*

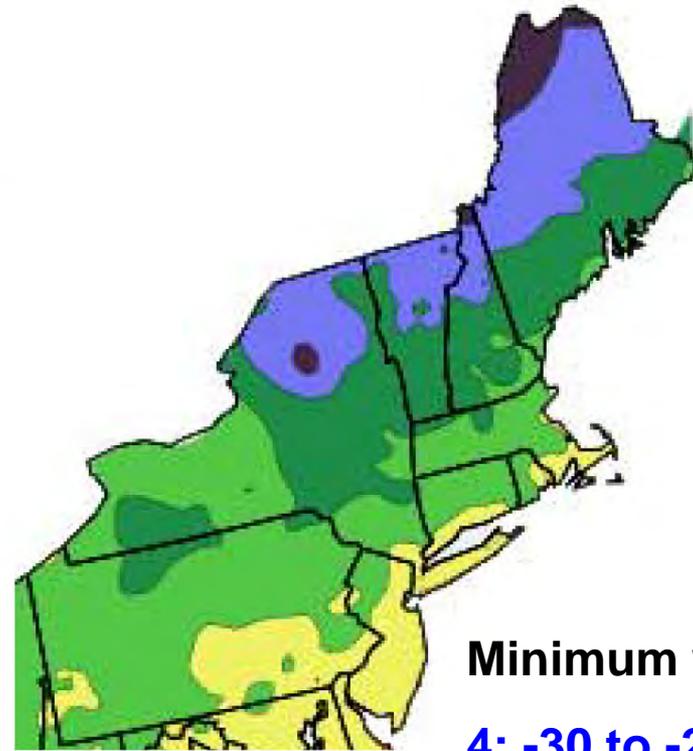
Winter Hardiness Zones

– winter cold extremes

**Change in
16 years**



1990



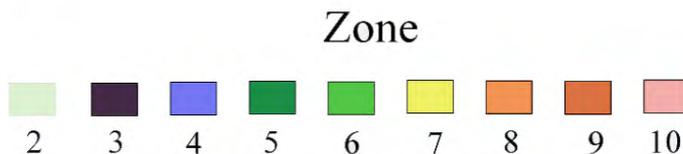
2006

Minimum winter T

4: -30 to -20°F

5: -20 to -10°F

6: -10 to 0°F

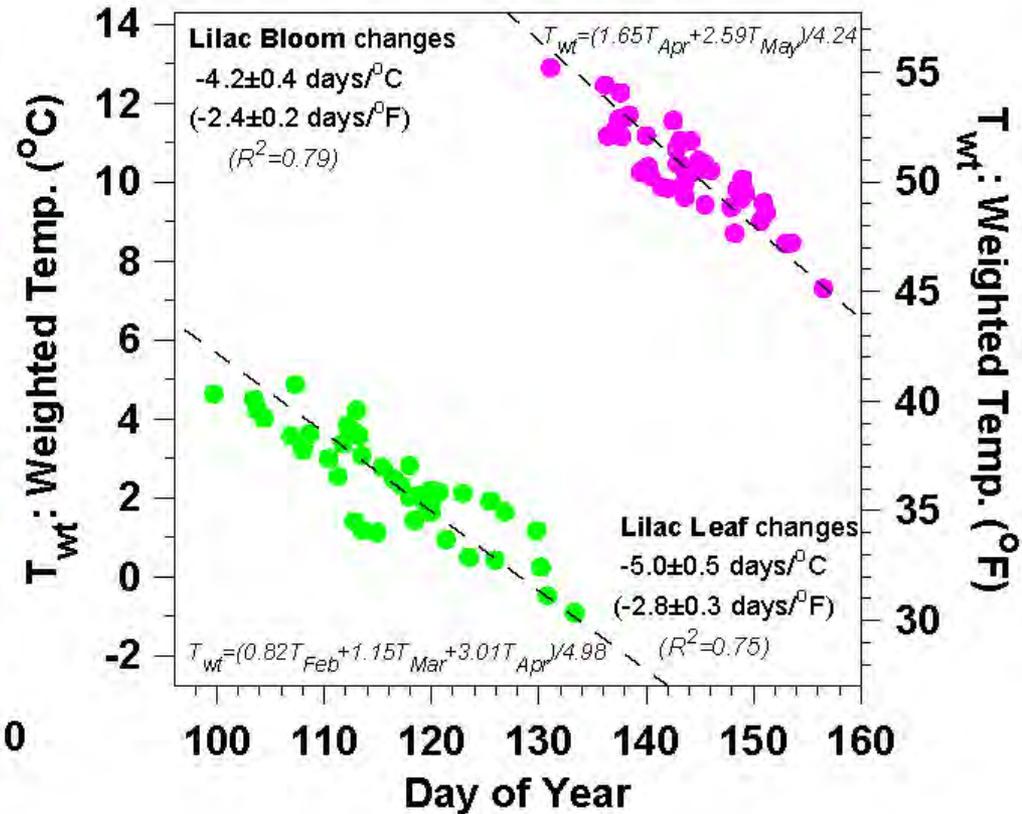
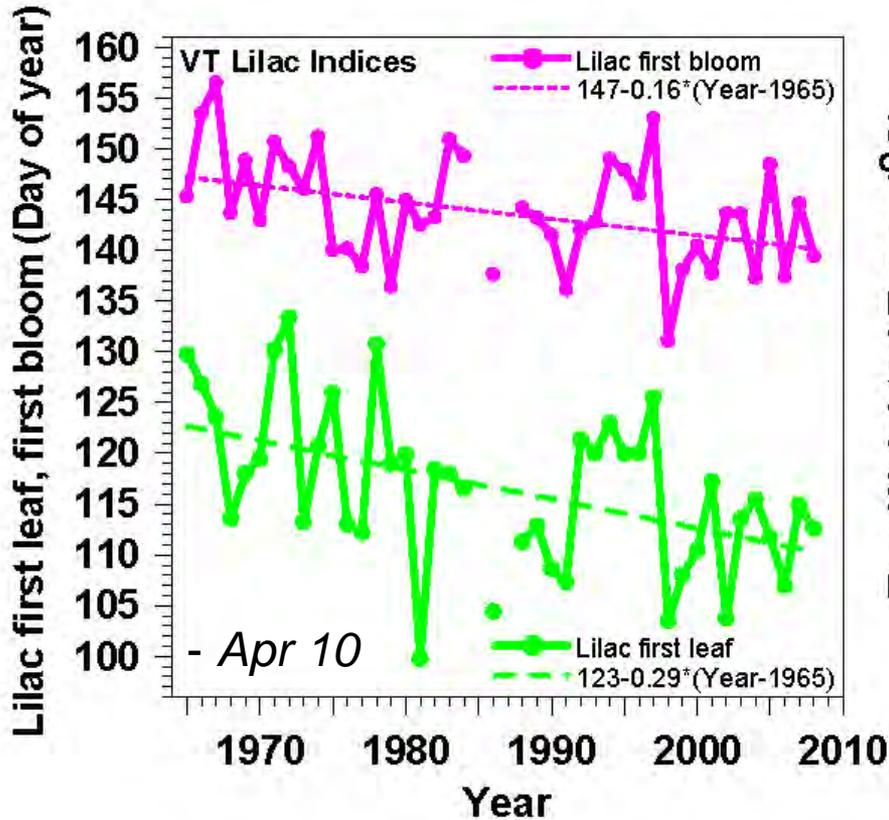


USDA Hardiness Zones

© 2006 by The National Arbor Day Foundation®

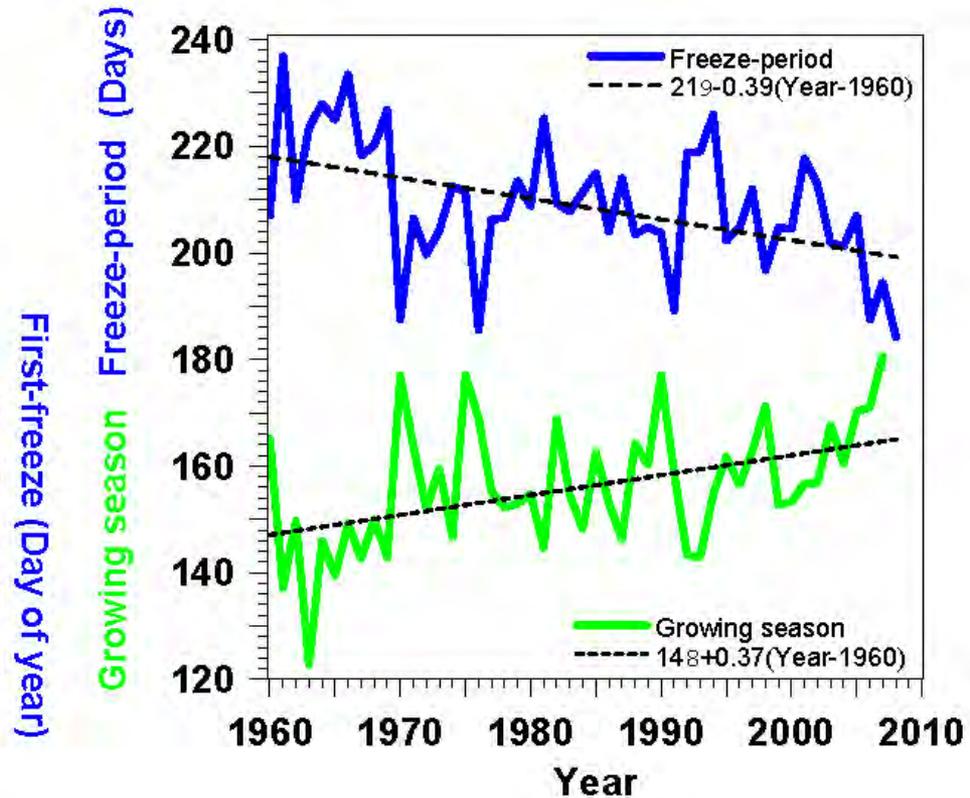
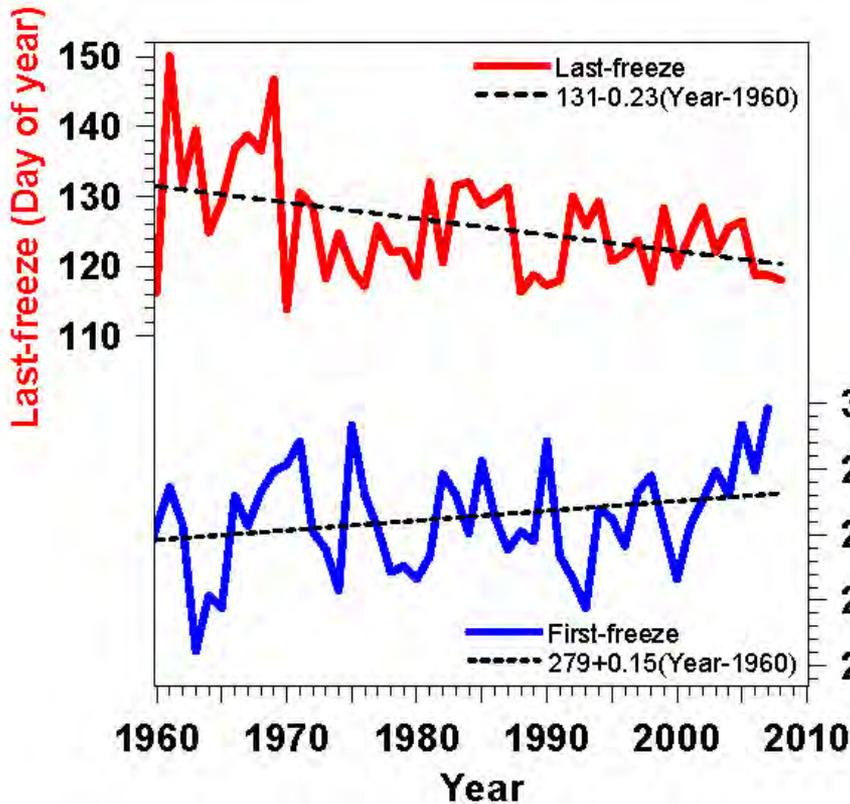
But winter variability getting larger

Lilac Leaf and Bloom



- Leaf-out -2.9 days/decade; Bloom -1.6 days/decade
- Large year-to-year variation related to temperature: 2 to 3 days/°F

First and Last Frosts Changing



- Growing season for frost-sensitive plants increasing **3.7 days / decade**
- A help for growing “local food”



January 2, 2012



March 11, 2012



October 2011– March 2012

- **Warmest 6 months on record**
- **My garden frozen only 67 days**

- **January 15, 2013** →
- **but 2014, 2015 frozen!**



Warm winter with little snow

Early Spring: *79°F on March 22, 2012*



Pittsford Vermont

3/22/12



Pittsford Vermont

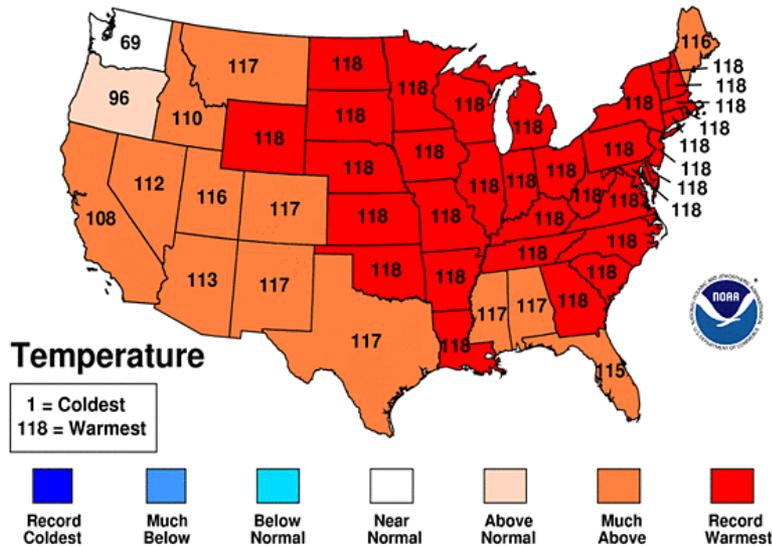
3/24/12

Daffodils, Forsythia in bloom

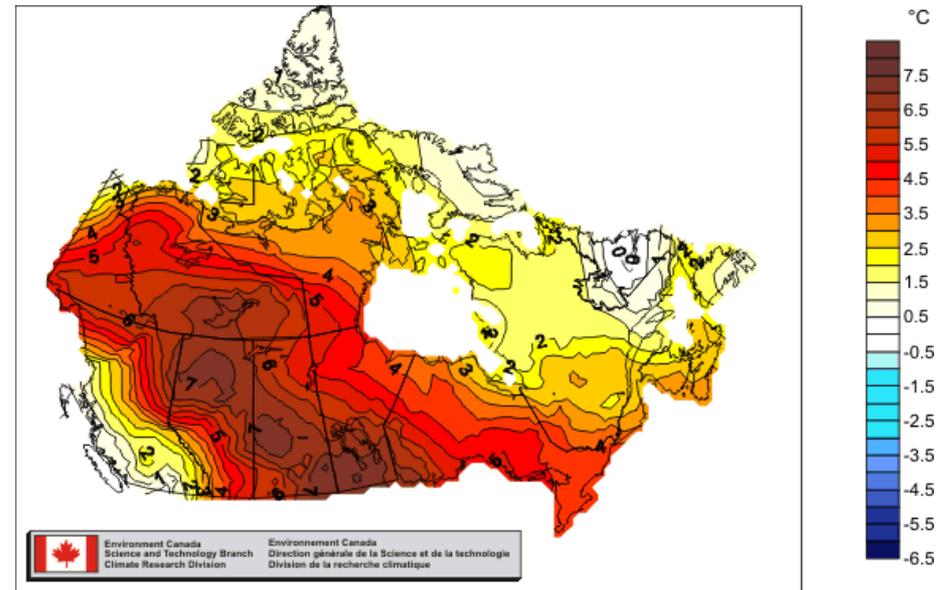
2012 Exceptionally Warm

January-August 2012 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



2011-2012 Winter in Canada



Little snow in Vermont winter 2011-12 – very warm
Record temperatures Jan-Aug 2012
Record Arctic ice melt

Spring transition-1

4/15/2008

- ***Weather***

Sunny, dry week

- ***Climate***

- After snowmelt
before leaf-out
- Little evaporation
- Warm & dry
- Large daily temp. range

- **Frost likely**

- ***Trend earlier***



Pittsford, Vermont

Spring transition-2

5/15/2010

- ***Weather***

Cooler, humid,
cloudy week

- ***Climate***

- After leaf-out,
large evaporation
- Temp. falls 3-5°C
- Low cloud-base
- Smaller daily
temp. range

- **Frost unlikely**

- ***Trend earlier***



Pittsford, Vermont

Summer dry-down

- **Wet in spring**
- **Soil moisture falls:
summer dry-down**
- **Low humidity &
little rain**
- *Can lock-in drought in
central US: as 2012*



Many Wet Summers in Vermont – in last decade



- 2004, 2006, 2008, 2009, (2010), 2011, 2013, (2014) wet
- **Direct fast evaporation off wet canopies**
 - *Evaporation-precipitation feedback increases rain*

Fall Climate Transition

- **Vegetation delays first killing frost**
- **While deciduous trees still evaporating: moister air with clouds**
- **Water vapor & cloud greenhouse reduces cooling at night and prevents frost**
- **Till one night, dry air advection from north gives first hard frost.**
- **Vegetation dies, skies become clearer and frosts become frequent**

- *The opposite of what happens in Spring with leaf-out!*



Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

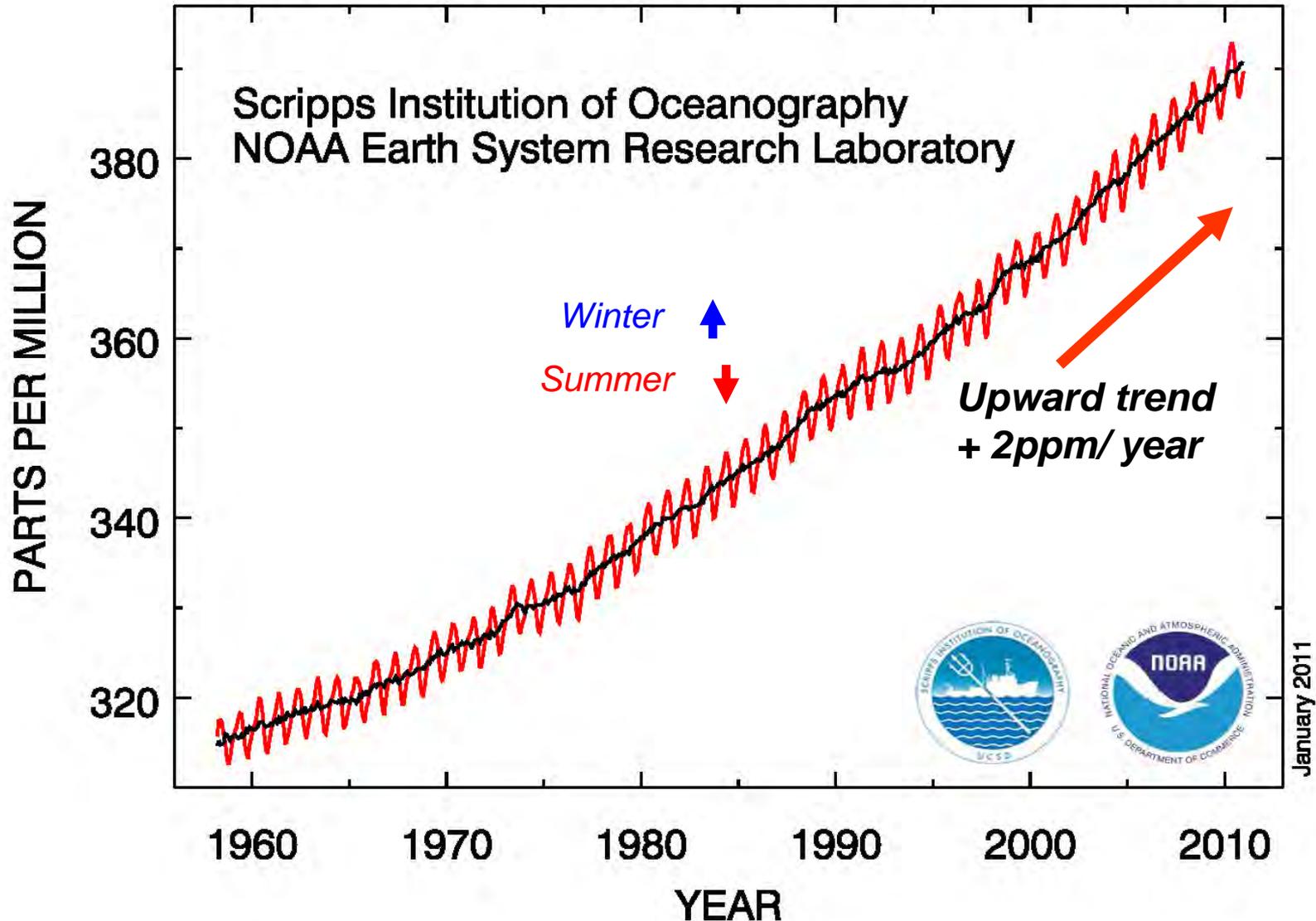
Later frost: Growing season getting longer

Global Climate Change

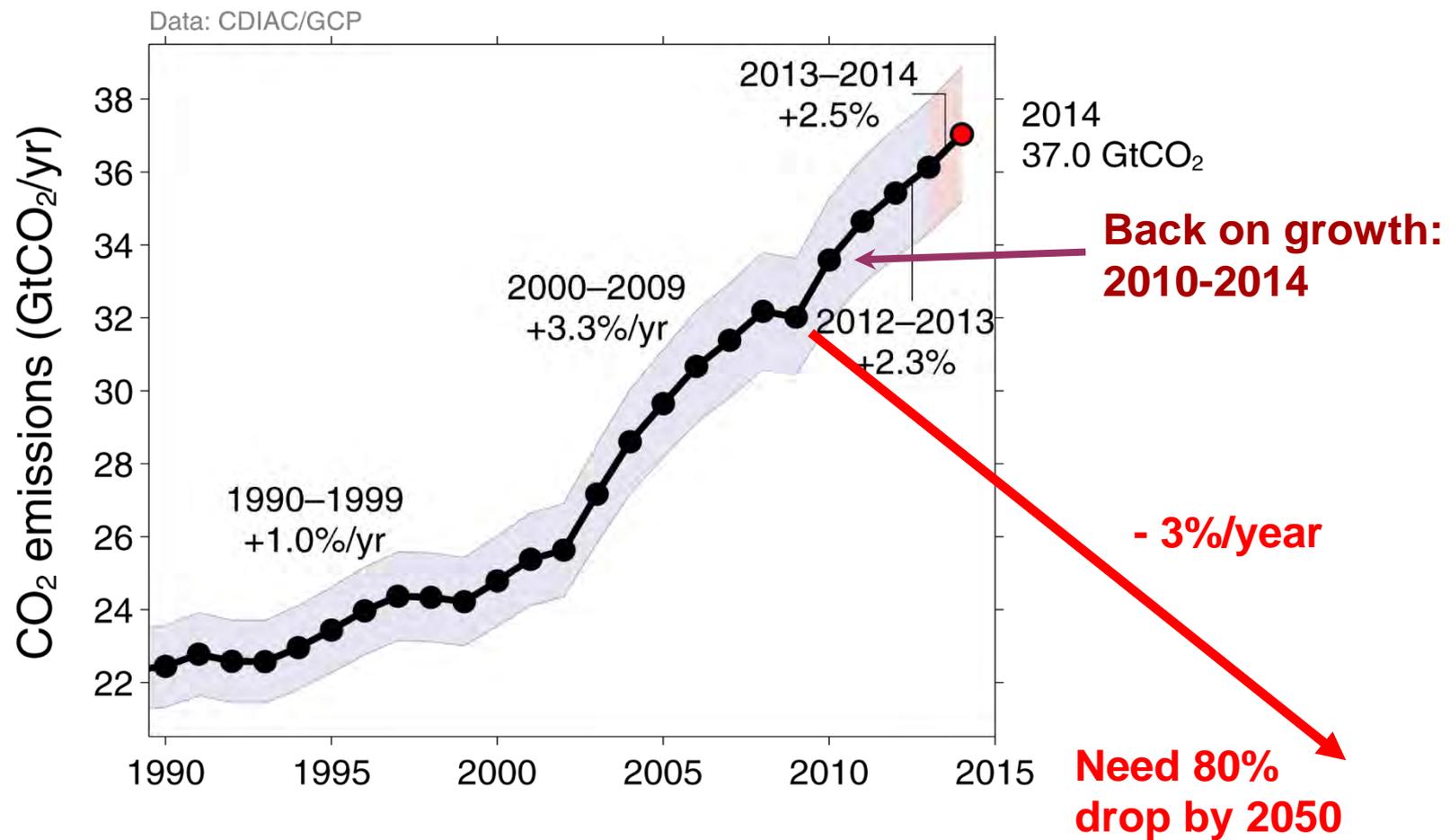
- **One of the many great challenges for the 21st century - present path is unsustainable**
- **Known about it for 35 years:**
 - *First National Academy of Science Report in 1979*
- **Earth science conflicts with political values (and vested interests in fossil fuel economy)**
- **It is a global issue and local issue**

Carbon Dioxide Is Increasing

Atmospheric CO₂ at Mauna Loa Observatory



Growth of CO₂ Emissions Continues

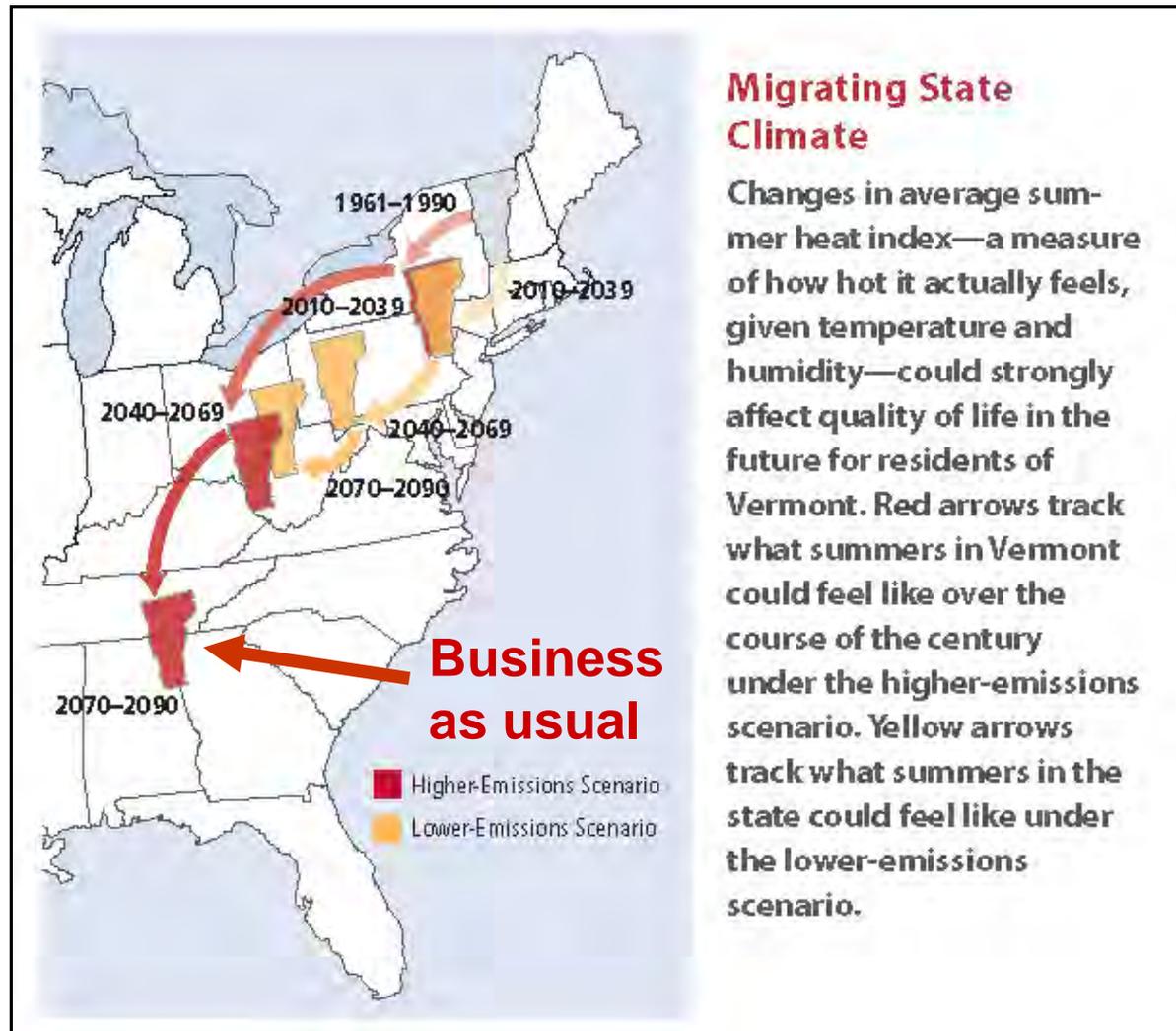


2014 emissions flat – shift from coal in China

Vermont's Future with High and Low GHG Emissions

What
about VT
forests?

Sub-tropical
drought areas
moving into
southern US



*NECIA,
2007*

2011 Classic VT Flood Situations

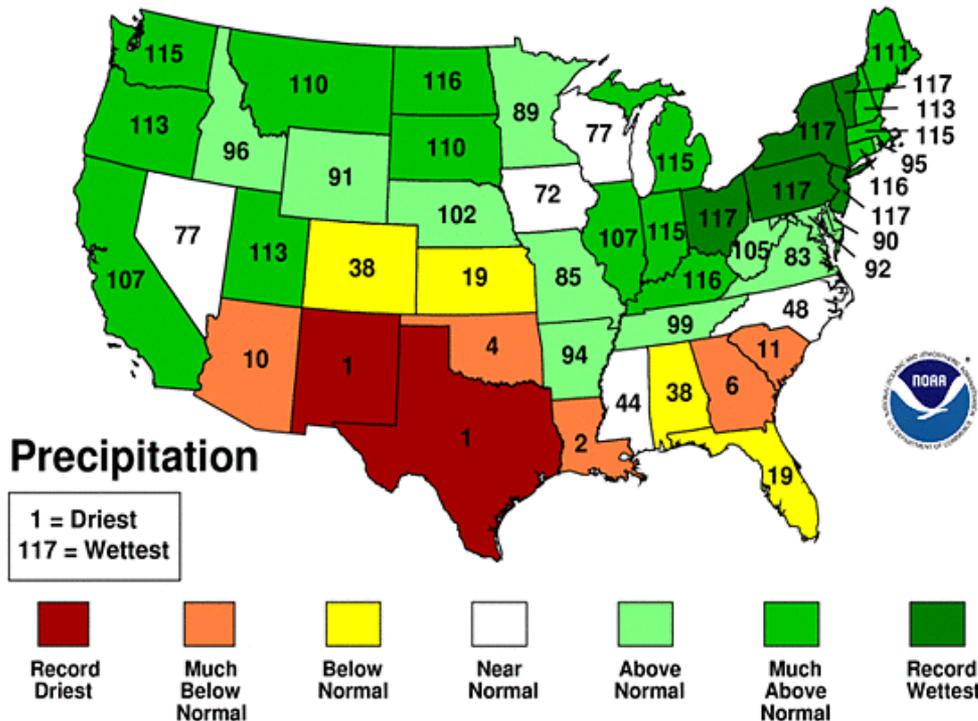
- **Spring flood:** heavy rain and warm weather, melting large snowpack from 2010-11 winter
 - 70F (4/11) and 80F(5/27) + heavy rain
 - record April, May rainfall: 3X at Burlington
 - Severe Winooski flood
 - Lake Champlain record flood stage of 103ft
- **Irene flood: tropical storm** moved up east of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

2011 Floods: VT and NY

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

March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA

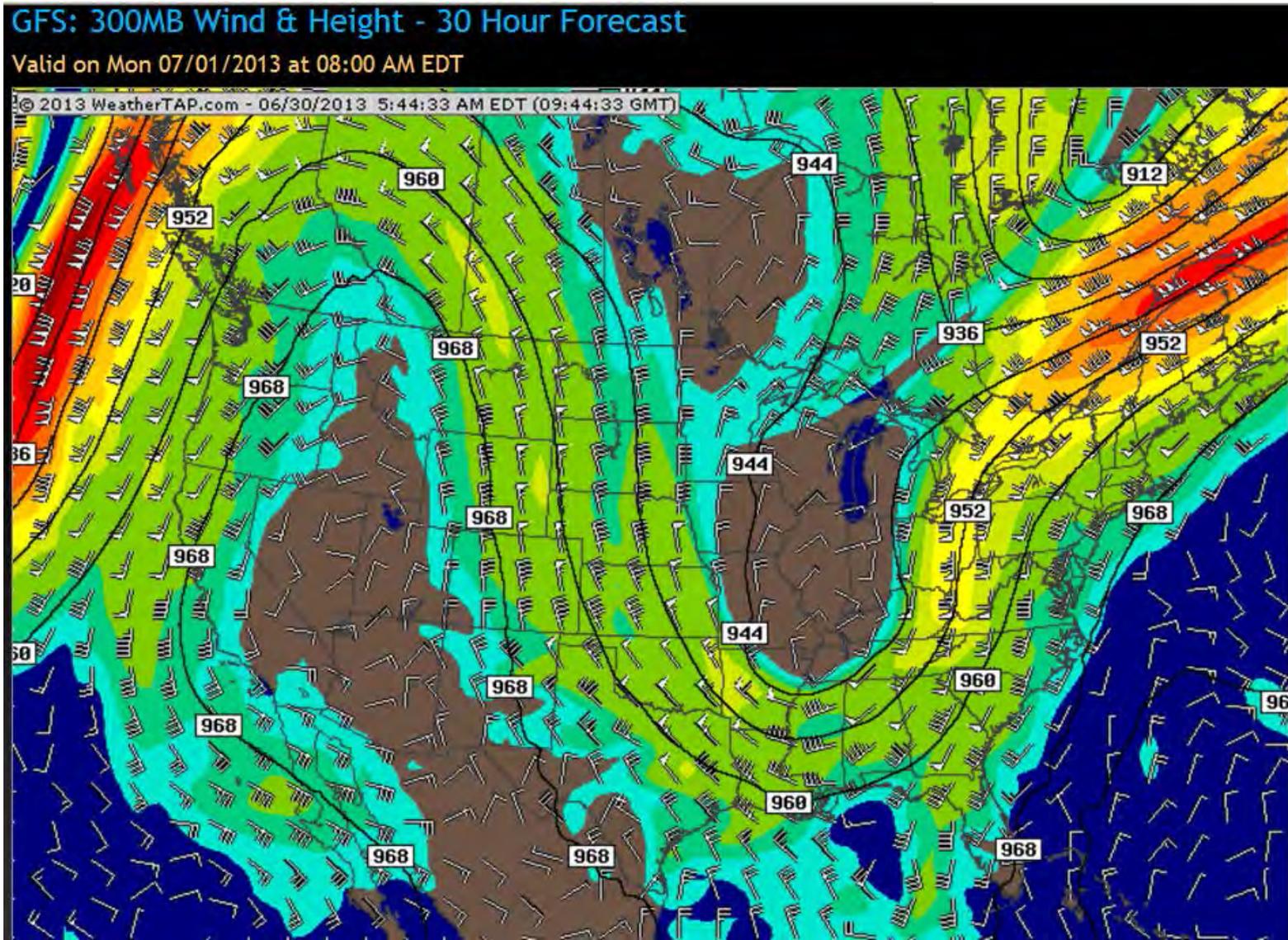


March-August, 2011

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

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

(Francis and Vavrus, 2012)



Blocking Pattern - Unique track

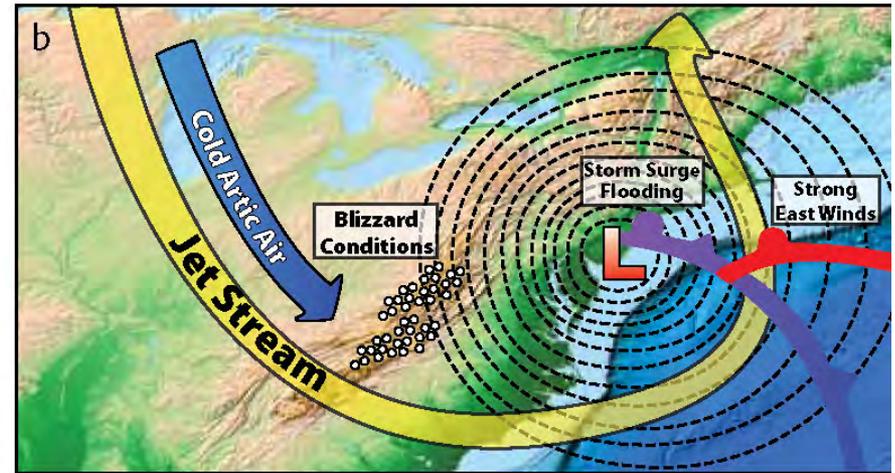


Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical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

Can We Stop “Dangerous Climate Change”?

- **Yes: Quickly stabilize atmospheric CO₂**
- **This means an 80% drop in CO₂ emissions!**
- **This is very difficult**
 - **Fossil fuels have driven our industrial growth and population growth for 200 years**
 - **Our “lifestyle” has become dependent on fossil fuels**

Efficiency Comes First

- **We need to double or triple our energy efficiency because...**
 - **We cannot replace current fossil fuel use with biofuels & renewable energy**
 - **Oil and gas reserves are limited, but coal, shale-gas & shale-oil reserves are sufficient to push CO₂ to 1,000 ppm—and in time melt icecaps**
 - **Need to leave 1/3 oil; 1/2 gas; 4/5 coal in ground**

Why Is It Difficult for Us?

- **Fossil fuels reserves are worth \$20-30T**
 - Regulating emissions of CO₂ is an “unfair cost” to the “free market”
 - Carbon tax needed to change economics
- **Politics lost in fantasy and deceit**
 - Ignoring Earth system and climate issues
 - Ignoring future costs
 - Manhattan within 1-ft of flooding with Irene
 - Did they put waterproof doors on tunnels? No

What Lies Ahead?

- **Humanity's impact is now global**
- **Climate extremes increasing**
- **Environmental damage that will transform or destroy ecosystems**
- **Dumping waste streams into atmosphere, streams, lakes and oceans is unsustainable – long term costs likely to exceed \$1000 trillion**
- **Will need fossil carbon tax to incentivize mitigation and pay for the long-term costs**

Guidelines to Minimize Impacts

- **Minimize the lifetime of waste products** in the Earth system and eliminate waste with critical biosphere interactions
- **Minimize the use of non-renewable raw materials, and**
- **Maximize recycling and re-manufacturing**
- **Maximize the efficiency** with which our society uses energy and fresh water, and
- **Maximize the use of renewable resources**

Change of Attitude Needed?

- **Do we just exploit the Earth's wealth**
 - For greater 'economic growth'
 - For a wealthy few
 - What will be left for our children?
 - What happens to the ecosystems we depend on?
 - How do we pay for the damage we are doing?
- **Moral Issue**
 - We need to care for and co-operate with the Earth
 - Shift in understanding and mind-set needed

The Future Is Not Our Past

- **Collectively, we create the future, so we need to plan for a transition to a sustainable society**
- **In the face of a powerful economic and financial system driven by short-term profit**
- **Needs deep community discussion**
 - *New values that respect the Earth*

2015 is Transition Year

- **Climate meeting in Paris in November**
 - Nations making commitments
 - 33 countries have submitted plans so far
- **Pope Francis will issue the first Papal Encyclical on the environment, climate change and our responsibilities to the Earth**
 - Will shift the position of the Catholic church
 - Protestant traditions will follow his lead
 - Shift from short-term profit as primary motive
- *New values that respect the Earth*

Discussion

- This talk <http://alanbetts.com/talks>
- Rutland Herald articles at <http://alanbetts.com/writings>
- Interesting papers at <http://alanbetts.com/research>
 - *Vermont Climate Change Indicators*
 - *Seasonal Climate Transitions in New England*

What Do We Need To Do?

- **The transition to a sustainable society will take decades and a community effort**
- **Food:** local agriculture & gardens
- **Energy:** Double energy efficiency
 - home heating – district heating + cogen
 - renewable electricity mix
 - efficient transportation system
 - **careful forest management**
- **Finance:** relocalization in real world

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 +2-3°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
 - Increase soil organic matter