Adapting to Climate Change

Dr. Alan K. Betts

Atmospheric Research, Pittsford, VT 05763

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

Osher, Rutland, VT

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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?**

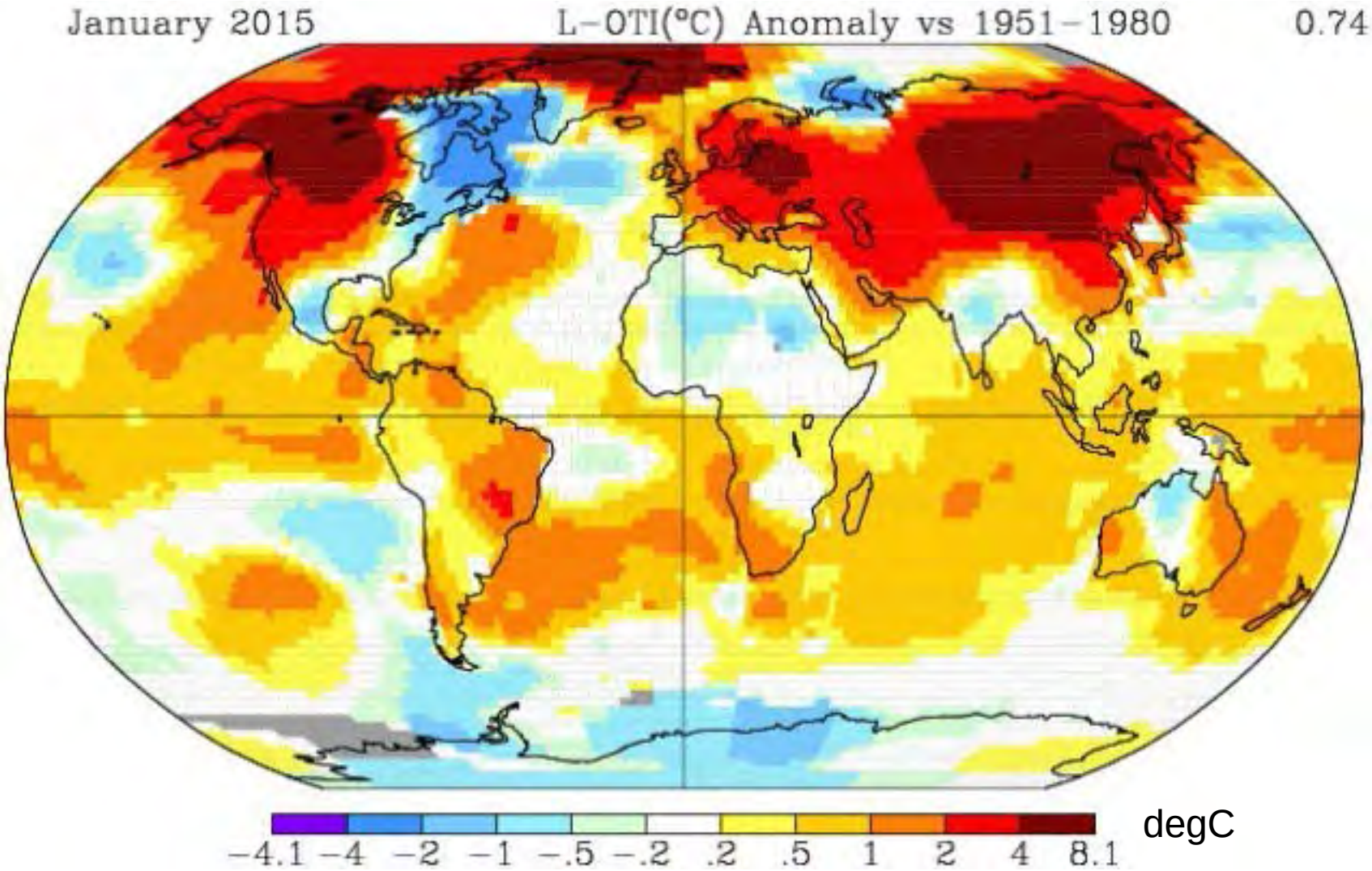
Discussion

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**

January 2, 2012: NASA

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



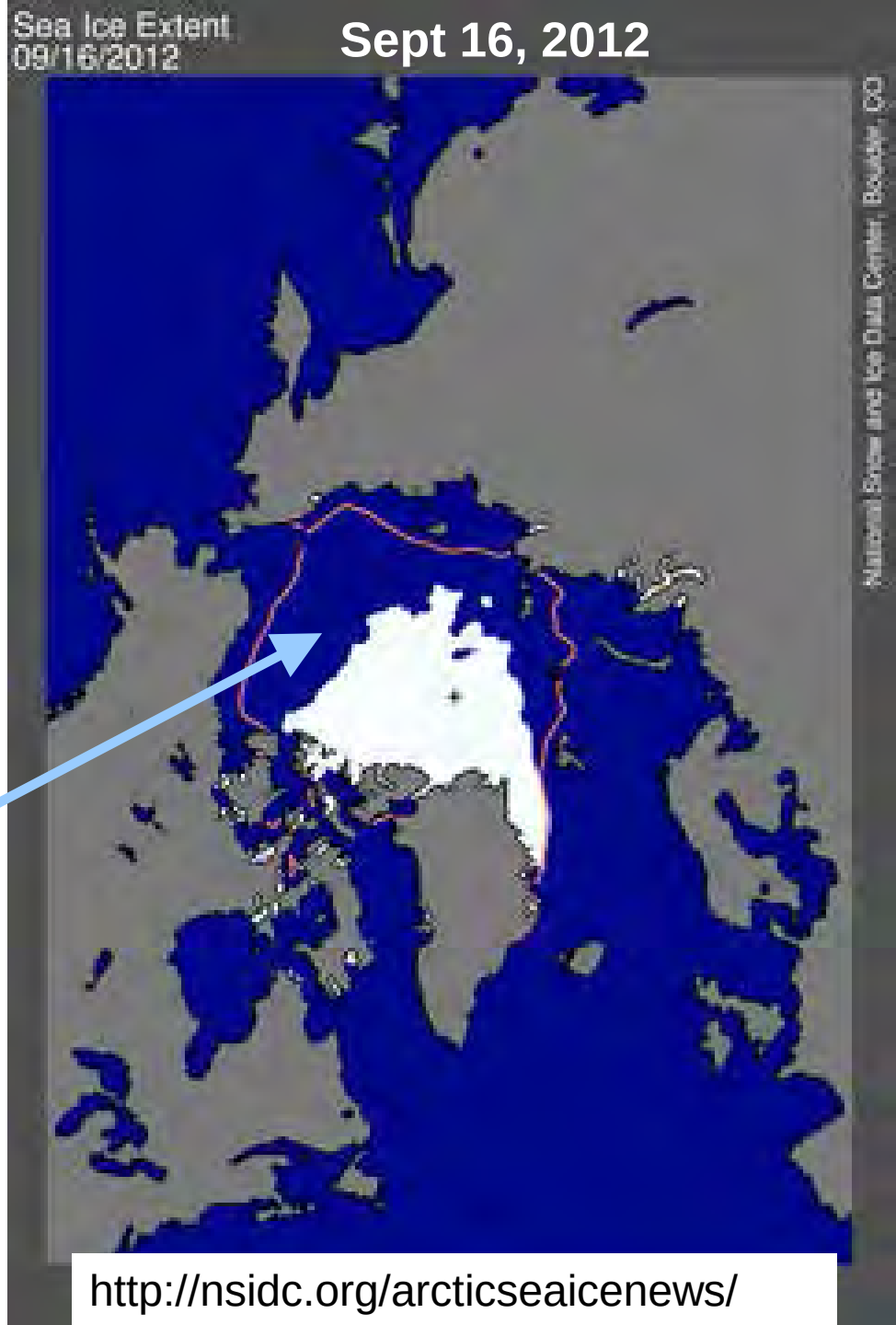
Winter Ice and Snow

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***

- **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***



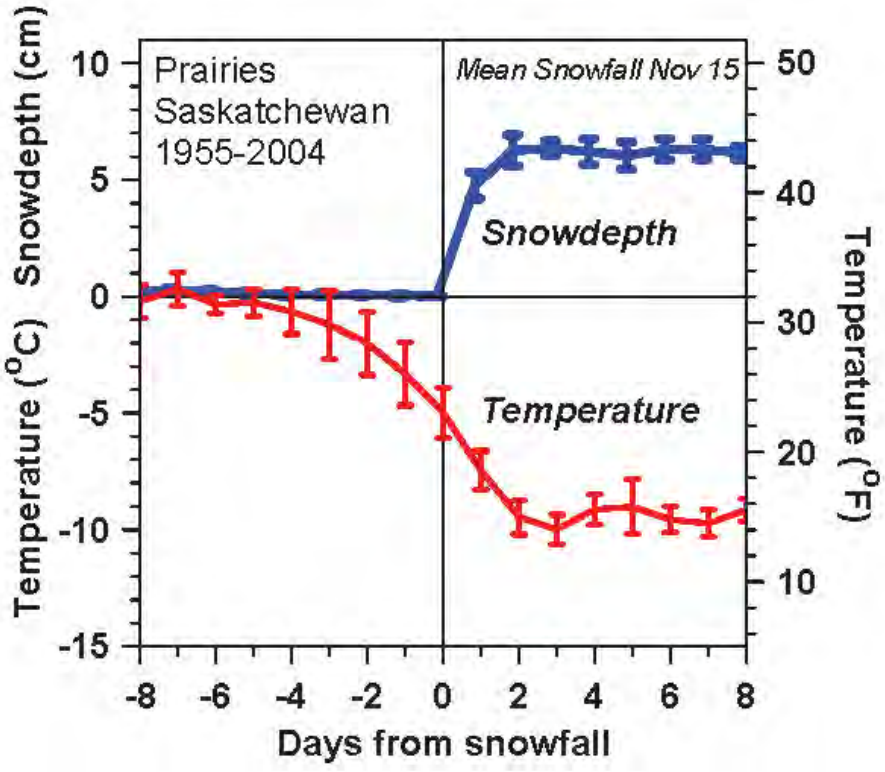
Serendipity in Science

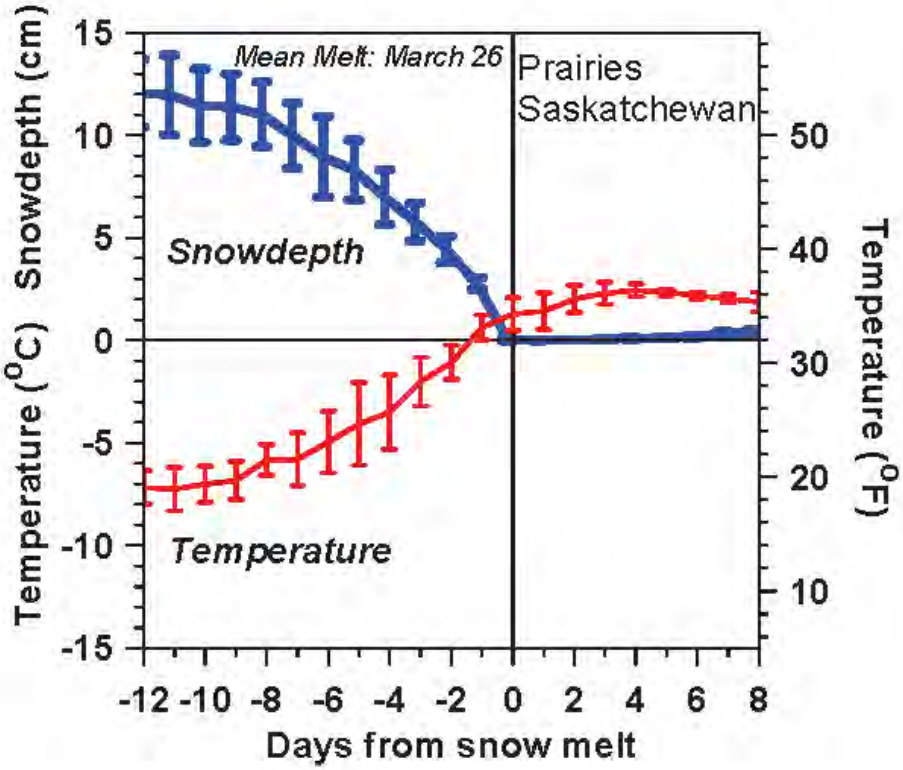
- **For years I have studied clouds and snow**
  - **And lectured on impacts *(with little data!)***

- **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.**

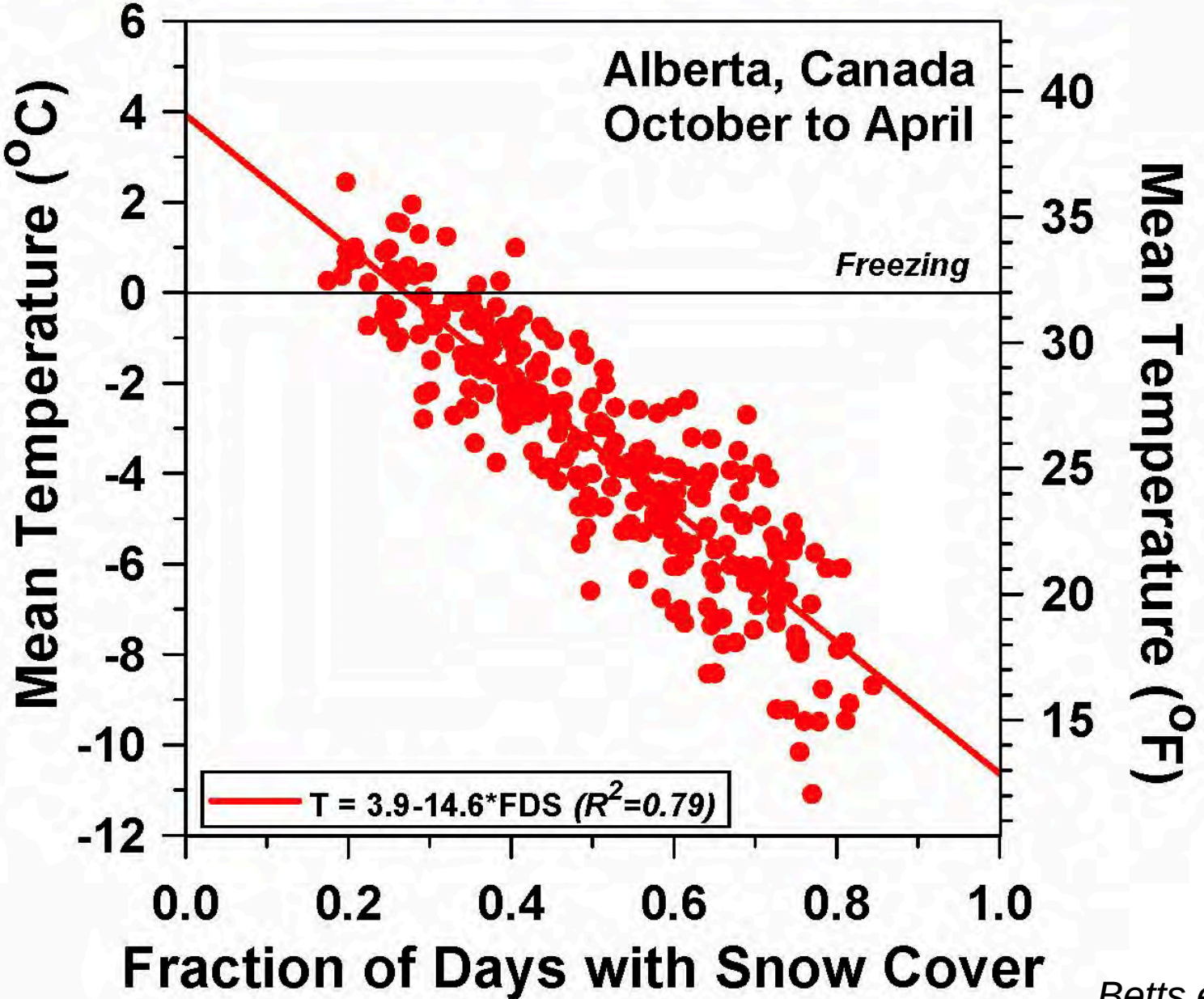
Snowfall and Snowmelt





- **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



Betts et al. 2014

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**

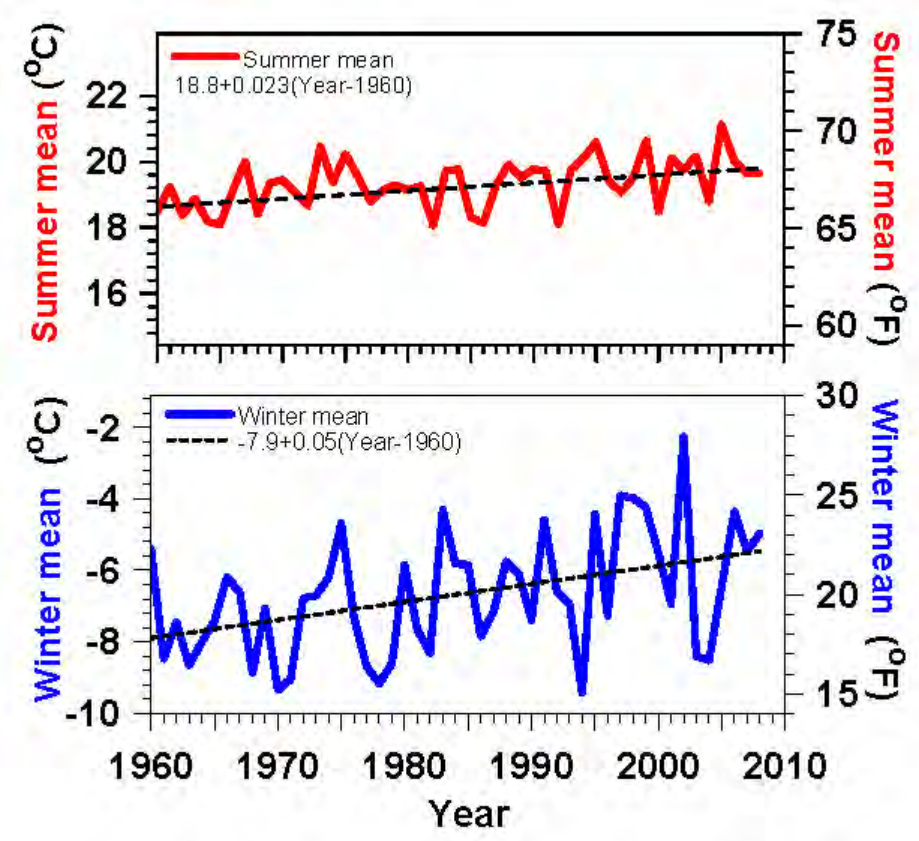
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**

(Betts, 2011)

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

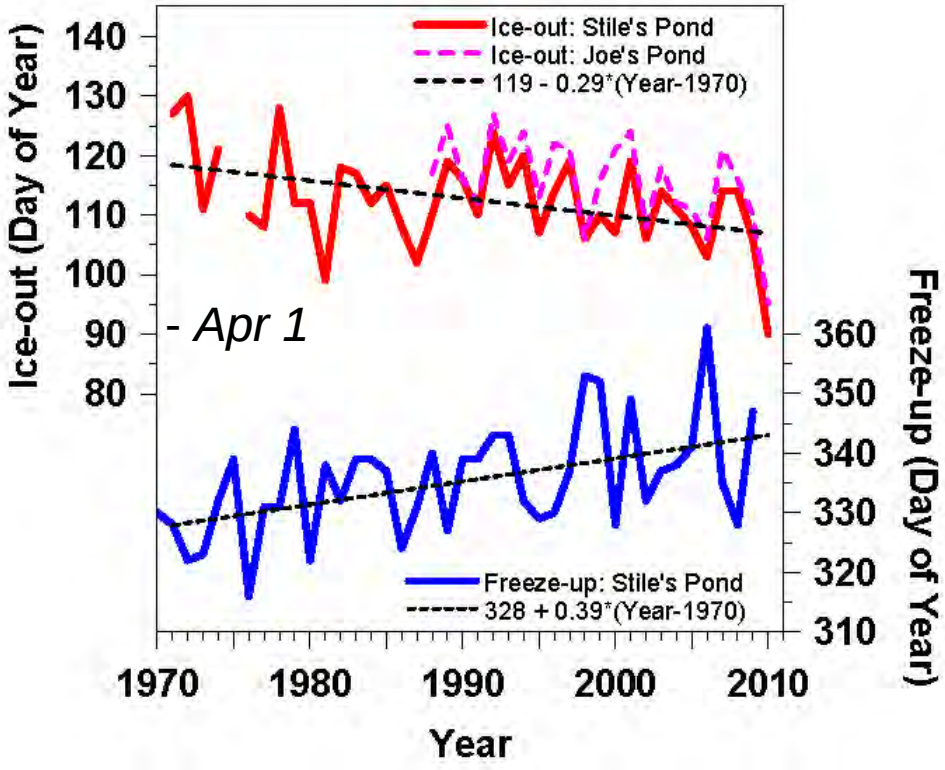
Vermont Temperature Trends 1961-2008

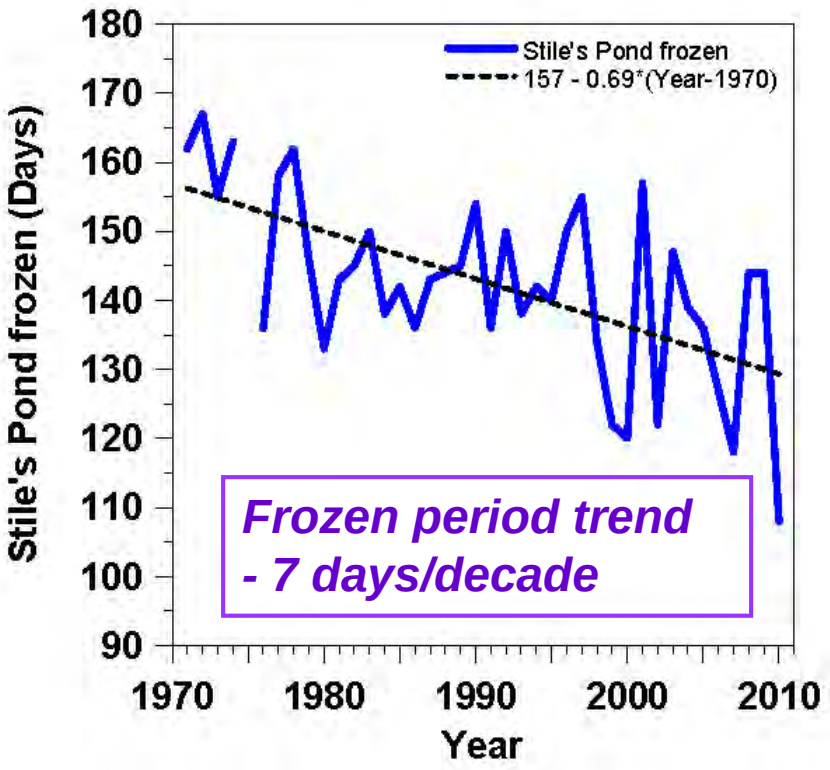
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***



Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



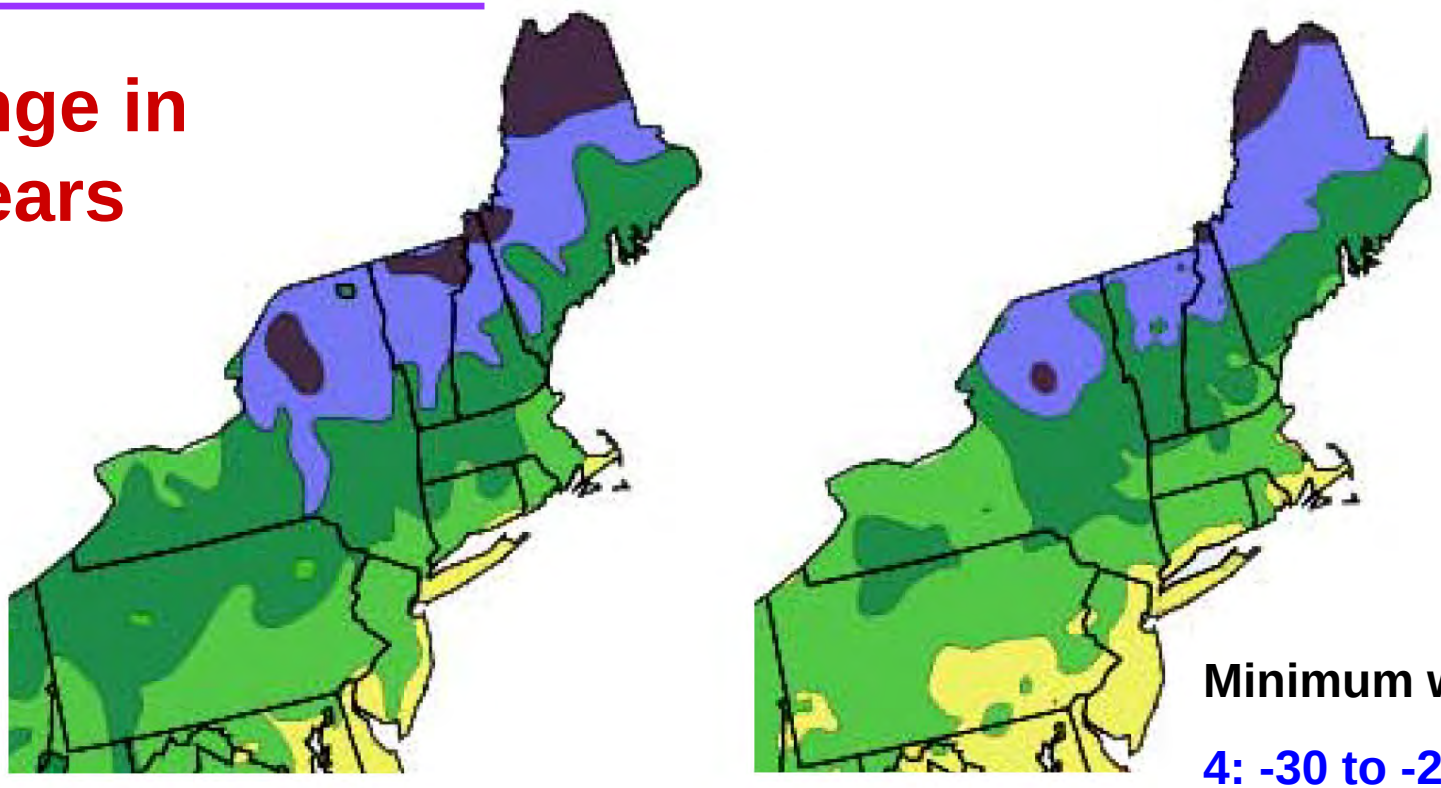


- **Ice-out earlier by 3 days / decade**
- **Freeze-up later by 4 days / decade**
- ***Soil ice probably similar***

Winter Hardiness Zones

– ***winter cold extremes***

Change in 16 years



Minimum winter T

4: -30 to -20ºF

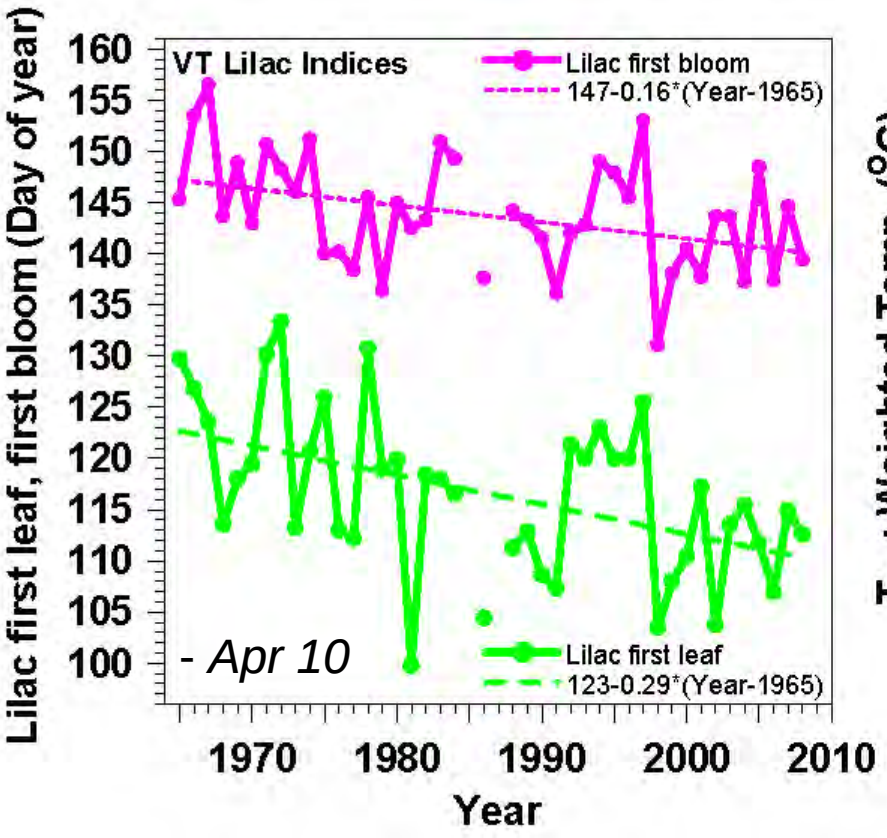
5: -20 to -10ºF

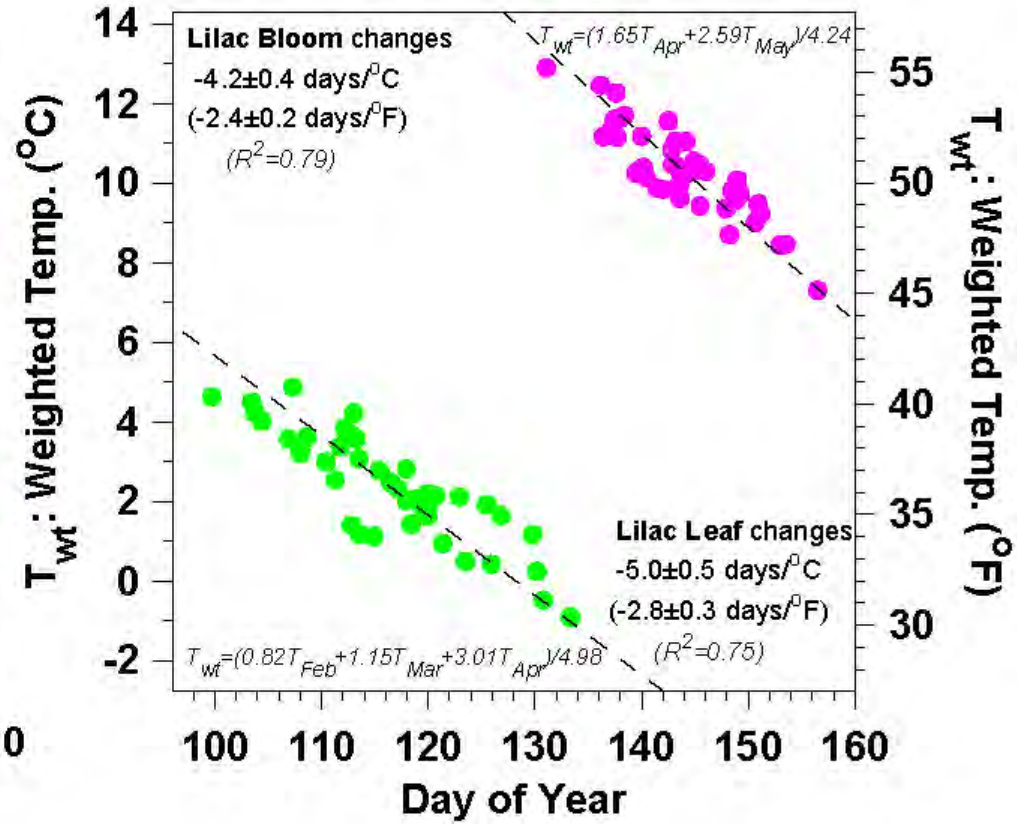
6: -10 to 0ºF

USDA Hardiness Zones

But winter variability getting larger

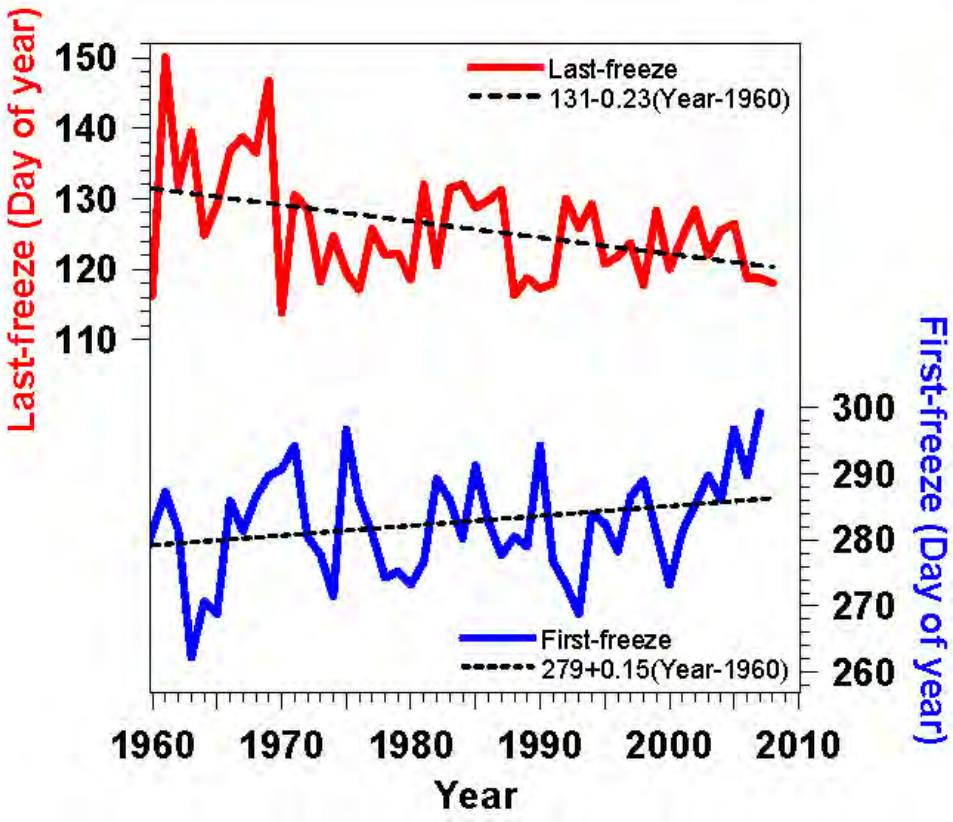
Lilac Leaf and Bloom

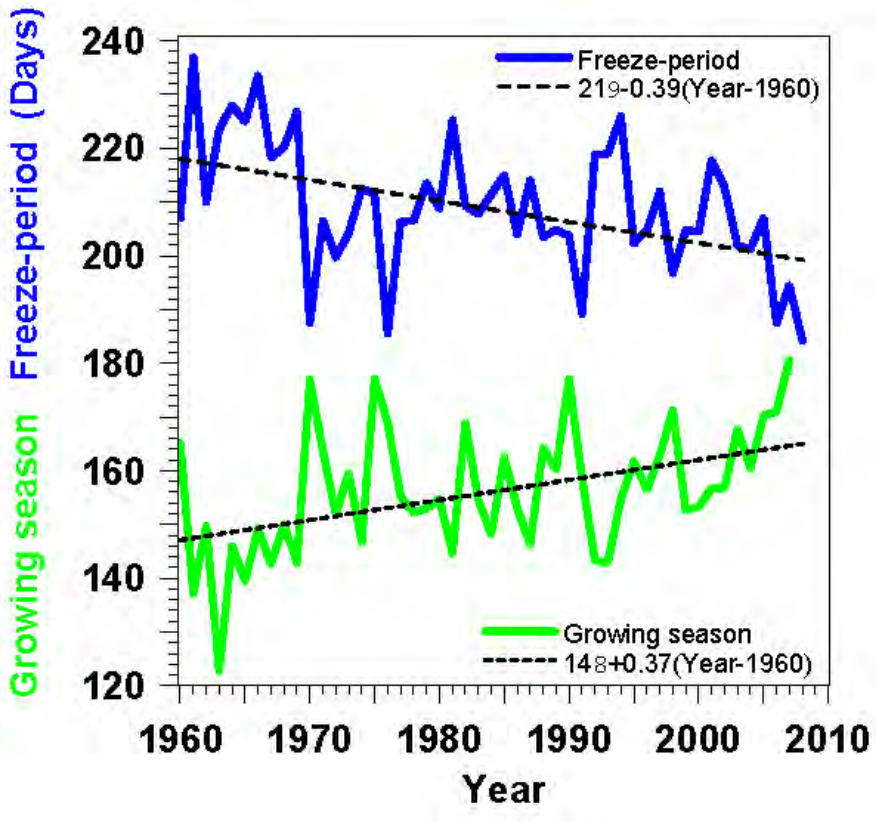




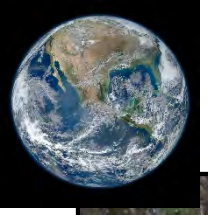
- **Leaf-out -2.9 days/decade; Bloom -1.6 days/decade**
- **Large year-to-year variation related to temperature: 2 to 3 days/ ºF**

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**

Warm winter with little snow
Early Spring: *79ºF on March 22, 2012*

Pittsford Vermont

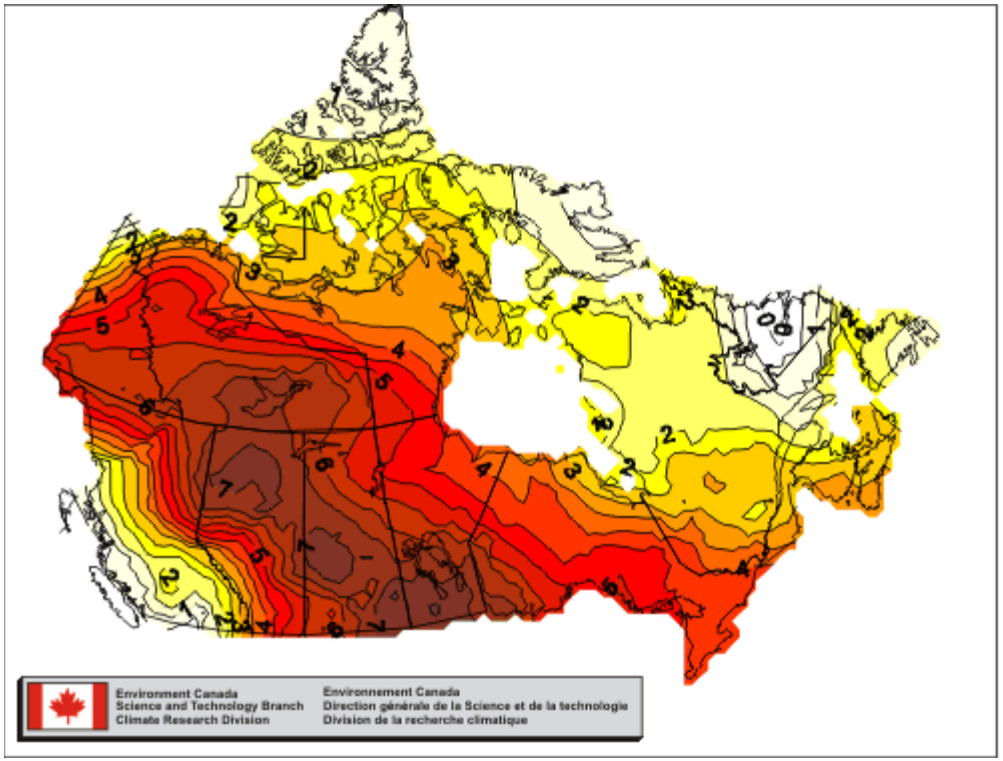
3/22/12

Pittsford Vermont

3/24/12

Daffodils, Forsythia in bloom

Across the border: Canada



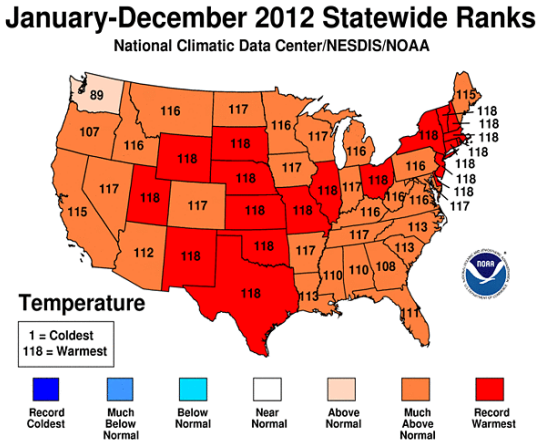
13ºF

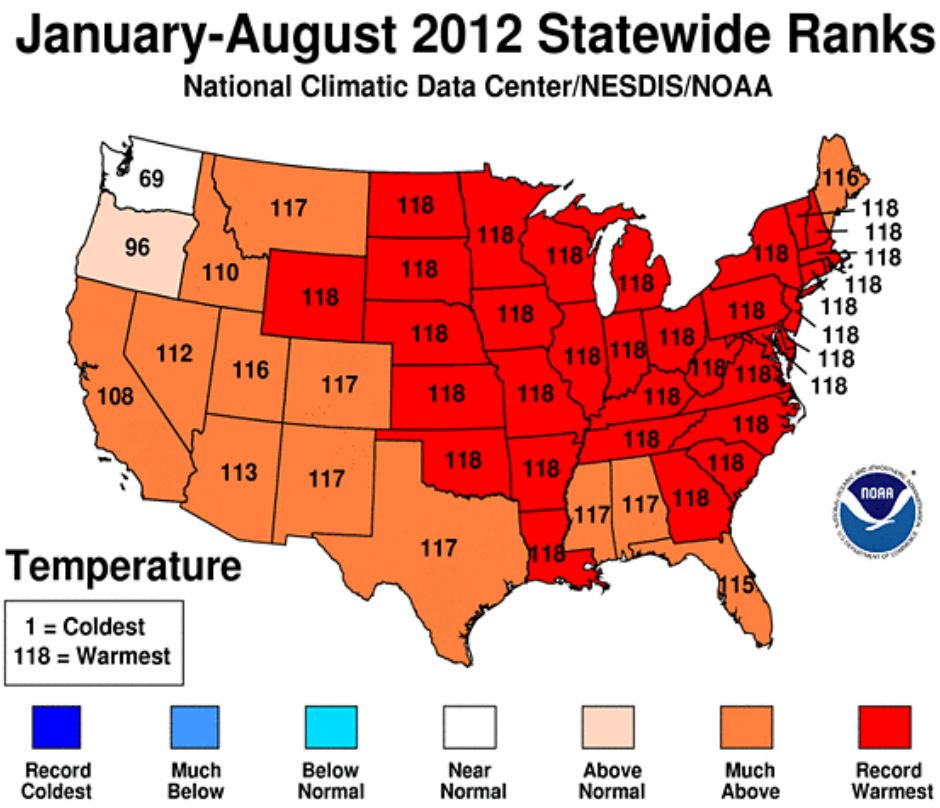
- **Winter 2011-12: 3.6ºC (6.5ºF) above ‘normal’**
  - **Canada’s winters also warming 0.9ºF/decade**
- **Climate doesn’t see the border!**

2012 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

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^{o}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

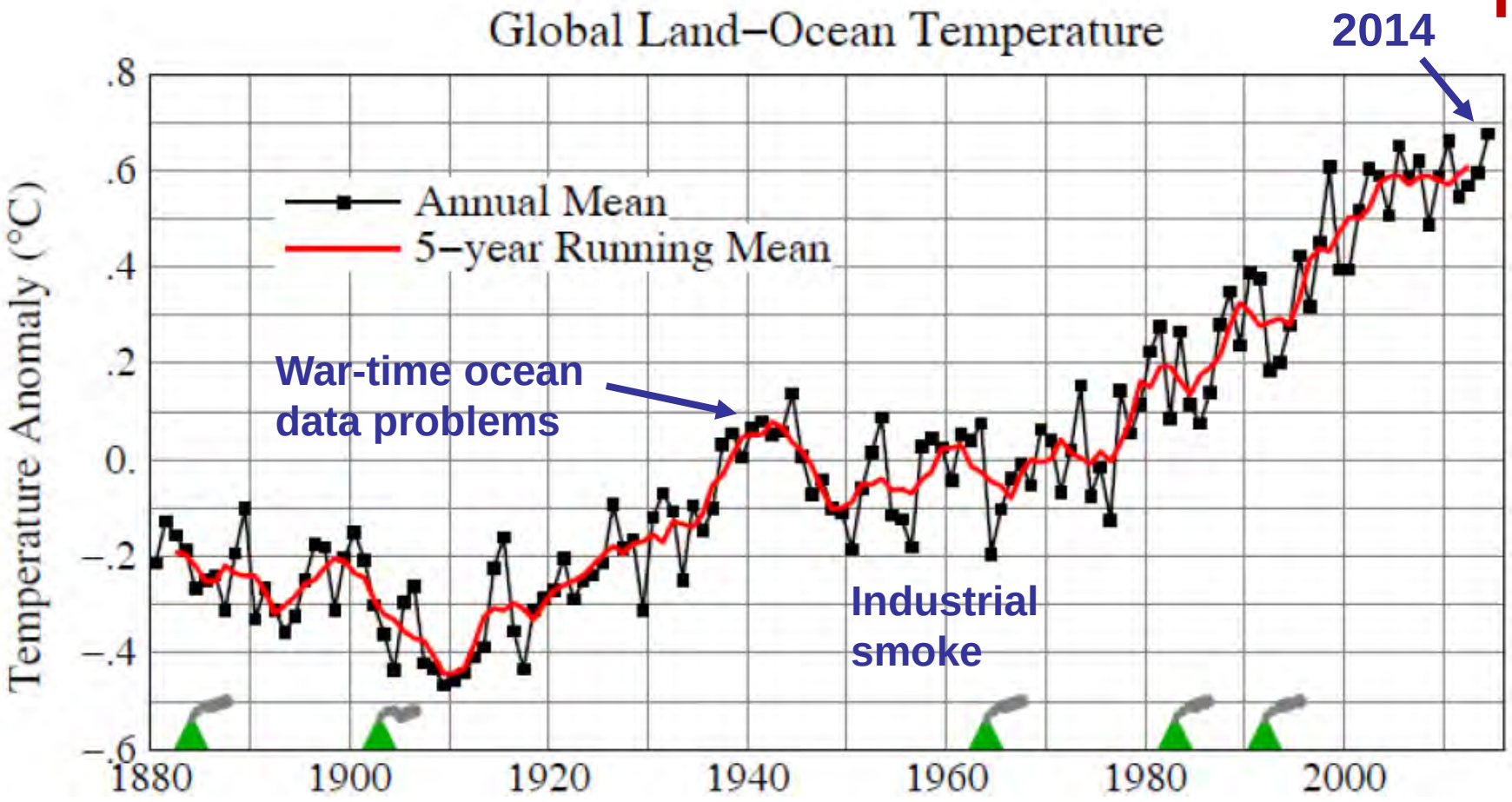
Later frost: Growing season getting longer

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**

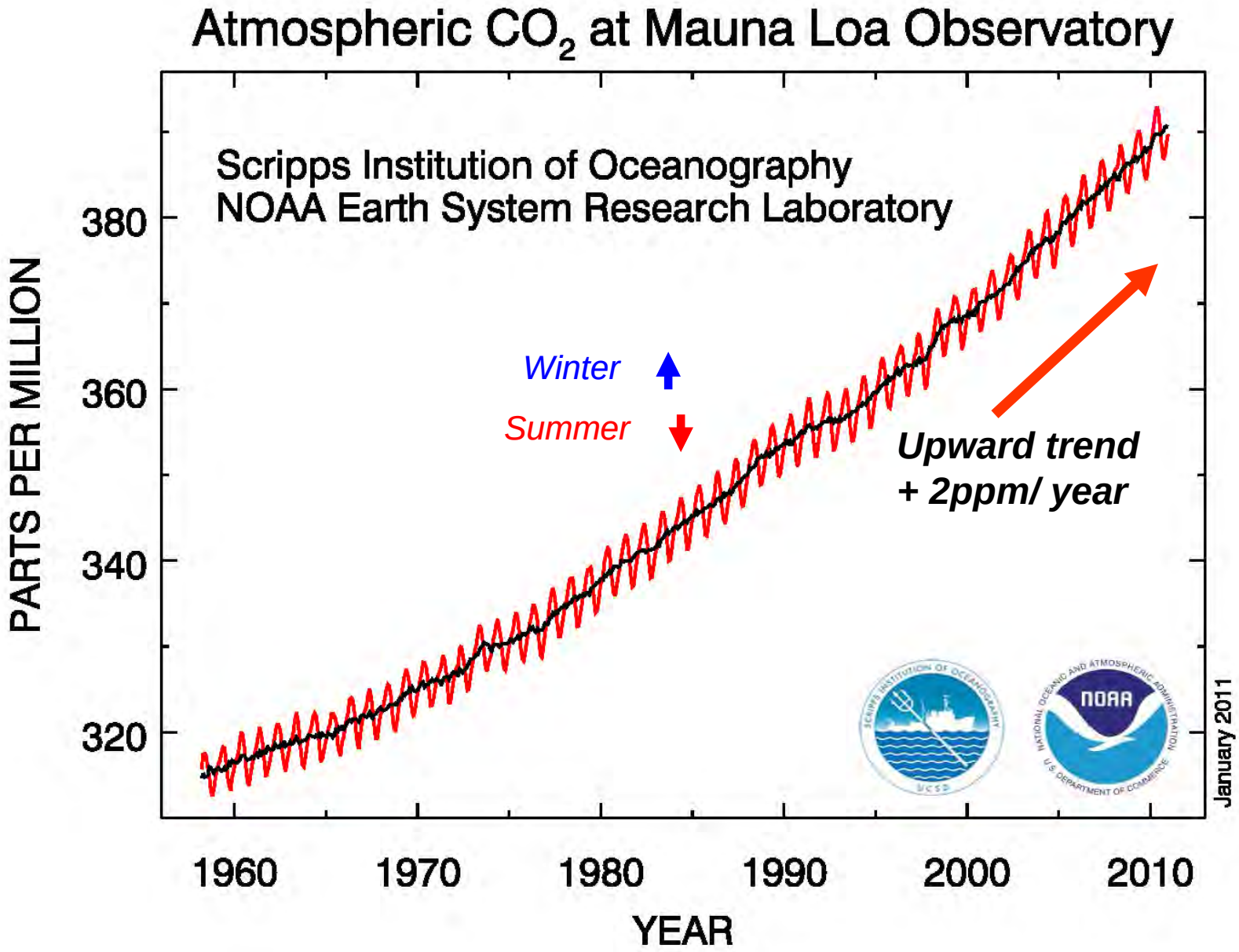
Global Temperature Rise
1880 – Present

2100: +5ºF

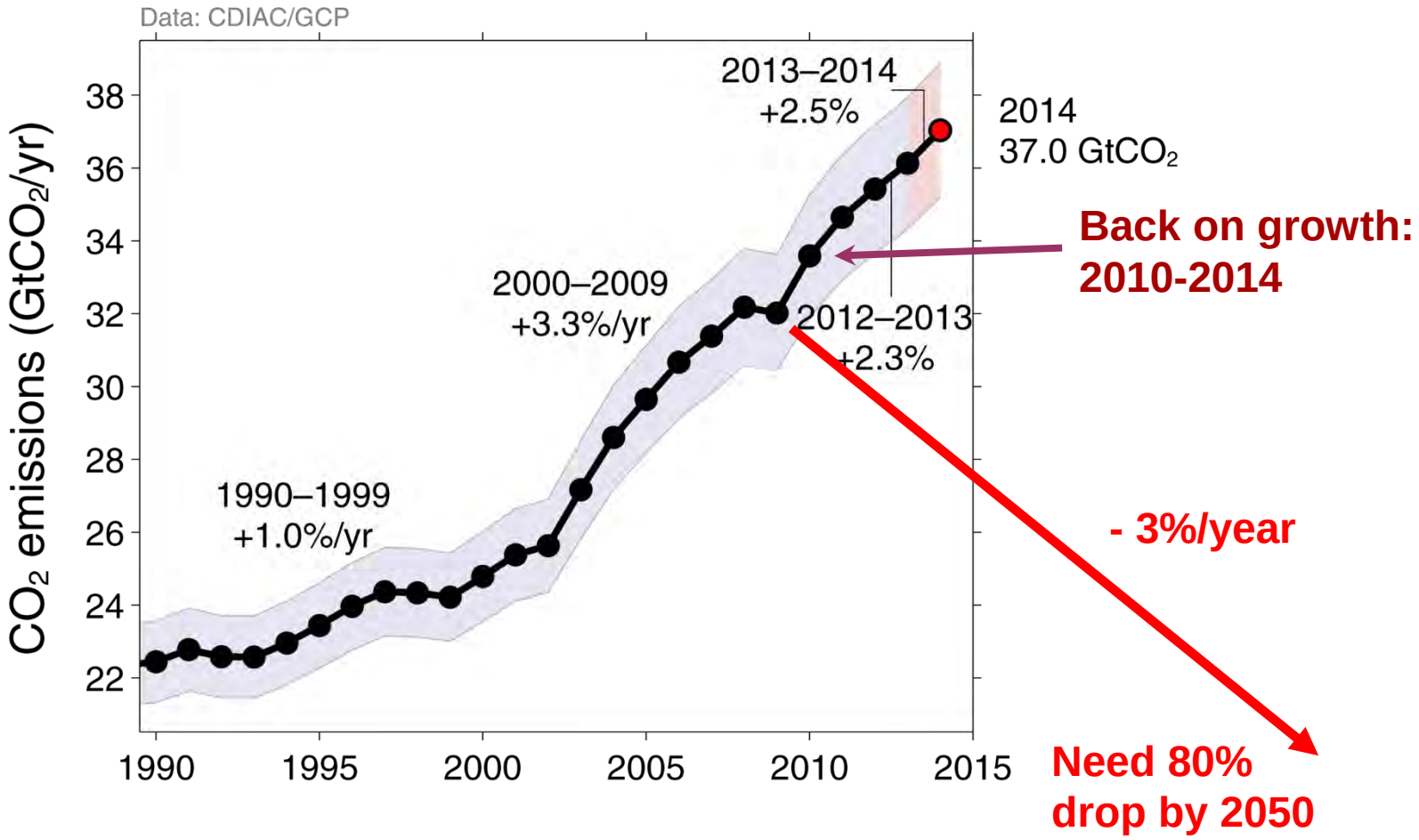


NASA-GISS, 2015

Carbon Dioxide Is Increasing



Growth of CO_2 Emissions Continues



Fate of Anthropogenic CO_2 Emissions (2004-2013 average)

32.4 ± 1.6 $GtCO_2/yr$ 91%

3.3 ± 1.8 $GtCO_2/yr$ 9%

+

15.8 ± 0.4 $GtCO_2/yr$
44%

10.6 ± 2.9 $GtCO_2/yr$
29%

Calculated as the residual of all other flux components

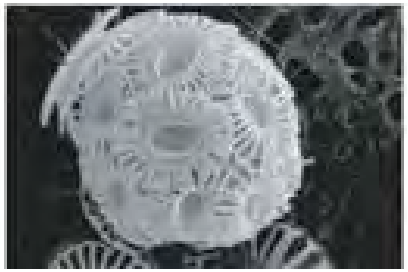
9.4 ± 1.8 $GtCO_2/yr$
26%

Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2014; Global Carbon Budget 2014

Rising Ocean Acidity Threatens Organisms

- **From the Tropics to the Arctic, the seas are sucking up emissions of CO_2 — from burned fossil fuels**
- **When CO_2 dissolves in water, carbonic acid is produced; the oceans are becoming more acidic**

(Ruttiman, *Nature,* 31 Aug. 2006)



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: H_2O, CO_2, CH_4, O_3, CFCs trap the infrared from the surface, giving climate suitable for life by warming planet 60°F**
- **Rise of CO_2 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 CO_2 rise**
- **As Earth warms, snow & ice decrease and reduced SW reflection amplifies warming in Arctic in summer and mid-latitudes in winter**
- **Doubling CO_2 will warm globe about 5°F (3°C)**
  - **Much more in the cold regions and over land, which responds faster than oceans**

Global Warming Is Unequivocal
IPCC: 2007, 2013

Since 1970, a rise in:

- Global surface temperature
- Lower atmosphere temperatures
- Global sea-surface temperatures
- Global sea level
- Ocean heat content
- Water vapor
- Rainfall intensity
- Extratropical precipitation
- Hurricane intensity
- Drought
- Extreme high temperatures
- Heat waves

(www.ipcc.ch)

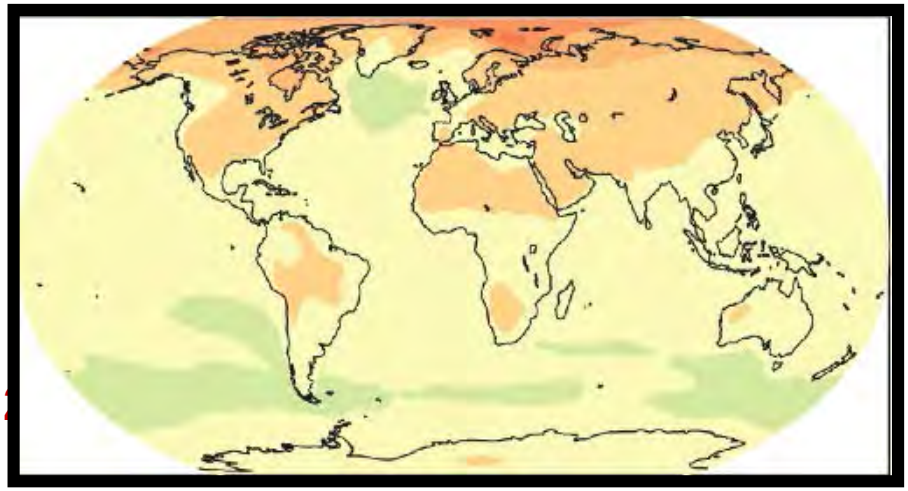
Decrease in:

- NH snow extent
- Arctic sea ice
- Glaciers
- Ocean pH (increasing acidity)

Predicted Change in Temperature

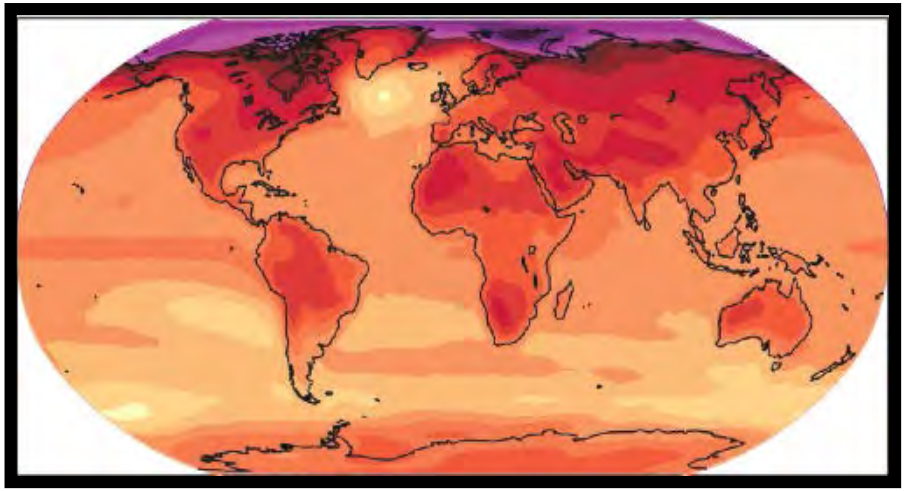
2020-2029 and 2090-2099, relative to 1980-1999 (ºC)

“Committed”



(We did nothing for the last 20 years)

Still up to us!



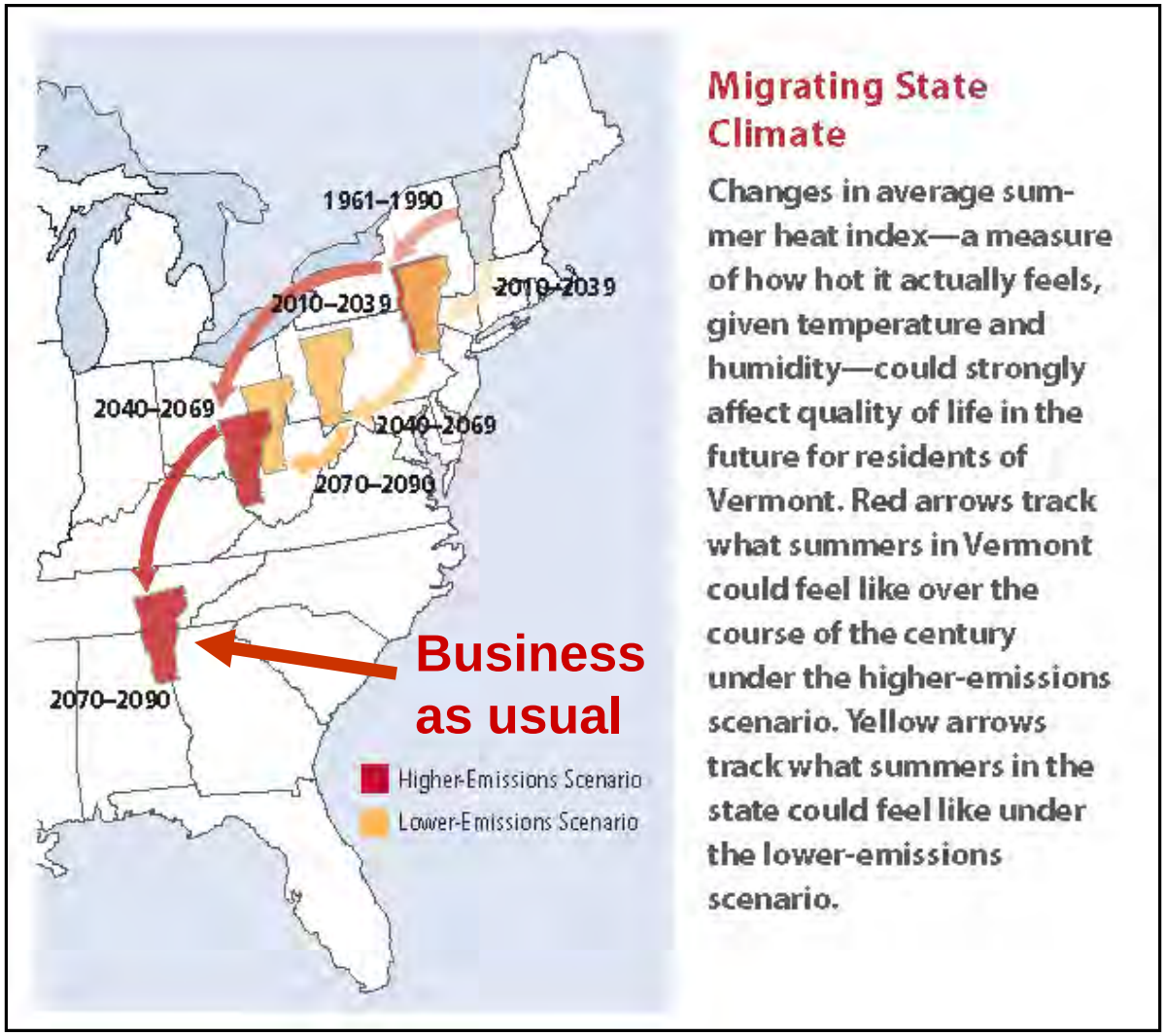
(We could halve this if we act now)

[ºC]

Vermont's Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US

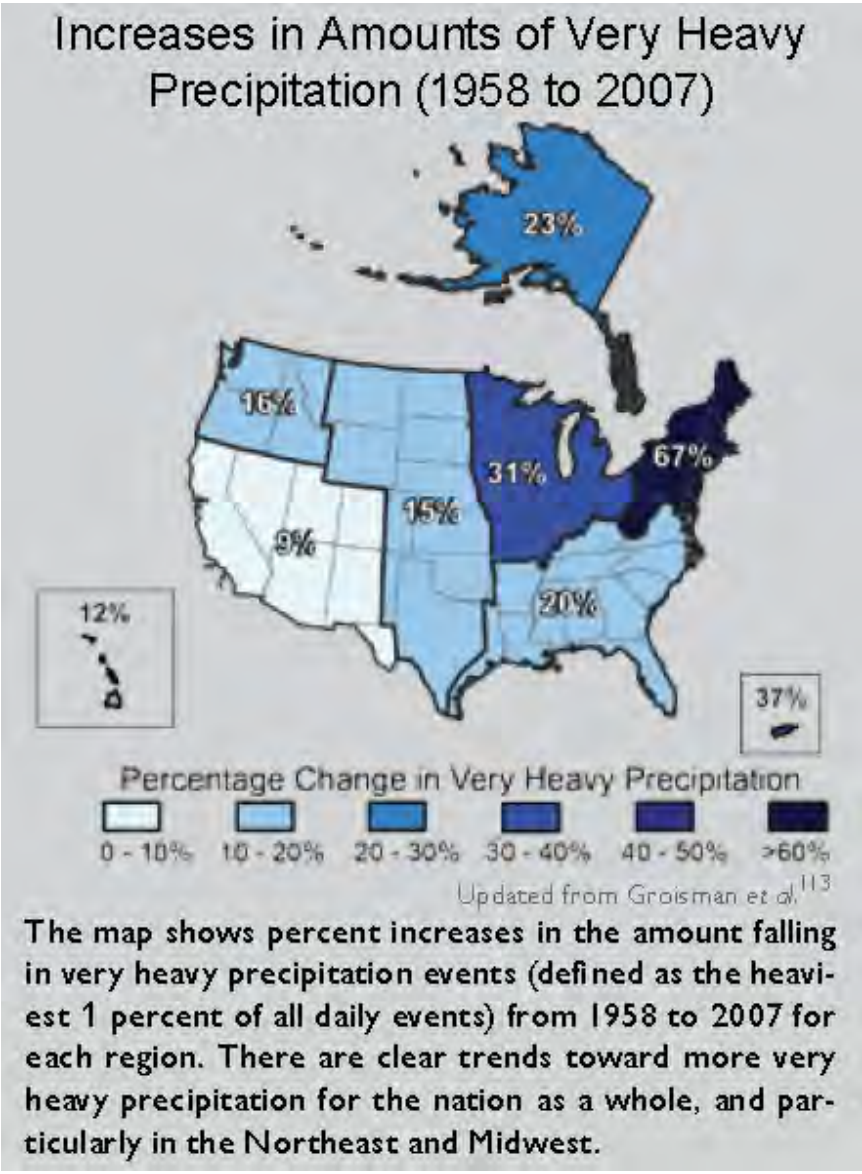


NECIA, 2007

Very Heavy Precipitation Is Increasing

(USGCRP, 2009)

- **Precipitation Extremes**
- **Most of the observed precipitation increase during the last 50 years has come from the increasing frequency and intensity of heavy downpours.**
- **67% increase in Northeast**



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.

Extreme Weather (precip.)

- **Precip. is condensation of atmospheric water vapor - large latent heat release drives storms**
- ***Saturation vapor pressure at cloud-base increases steeply with temperature (7%/^{o}C)***

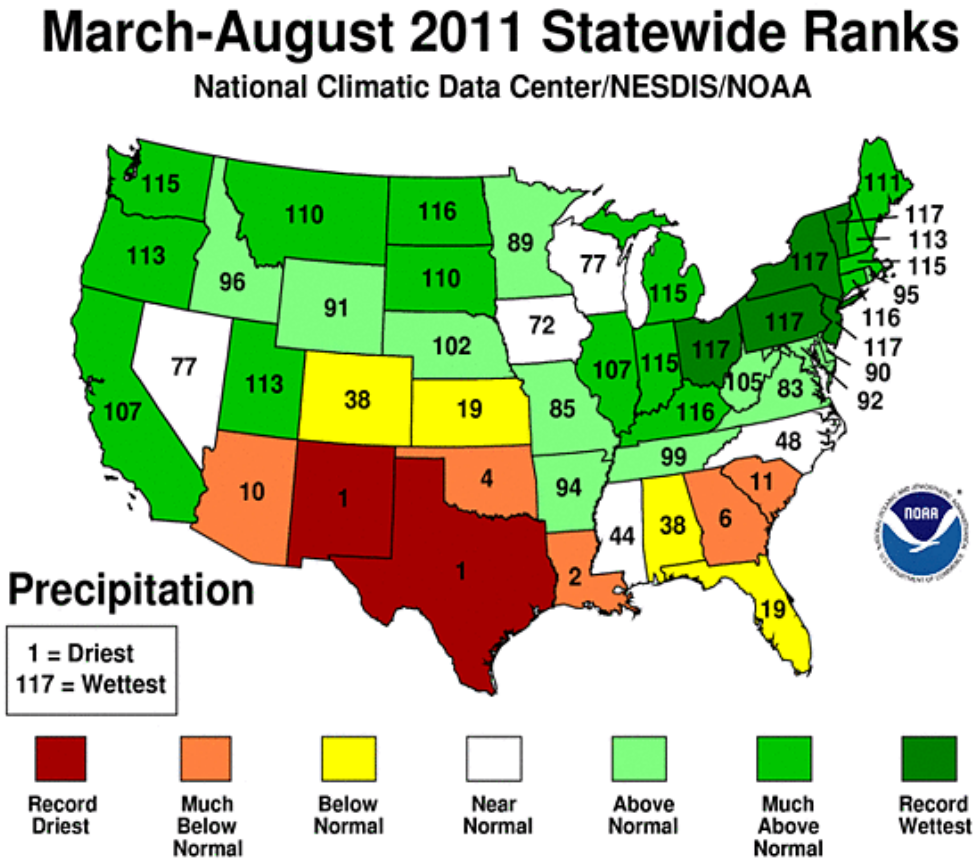
- **Quasi-stationary large-scale flow means longer rain events in low-pressure convergent regions, and longer droughts in high-pressure divergent regions**
- ***As climate changes, quasi-stationary large-scale modes appear to be more frequent***
  - ***Cause may be Arctic warming - needs more study***

2011 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 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)**

2011 Floods: VT and NY

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

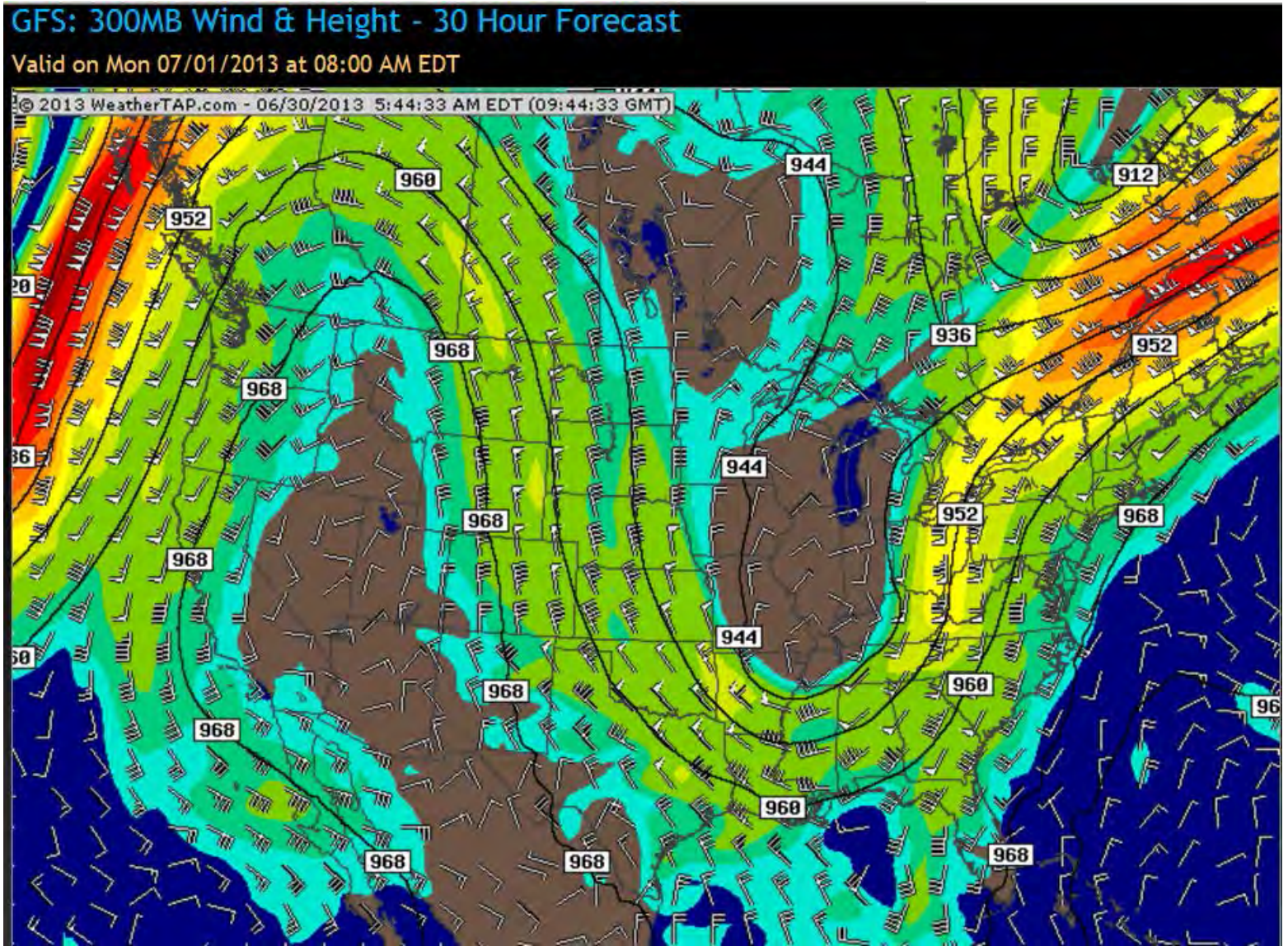


March-August, 2011

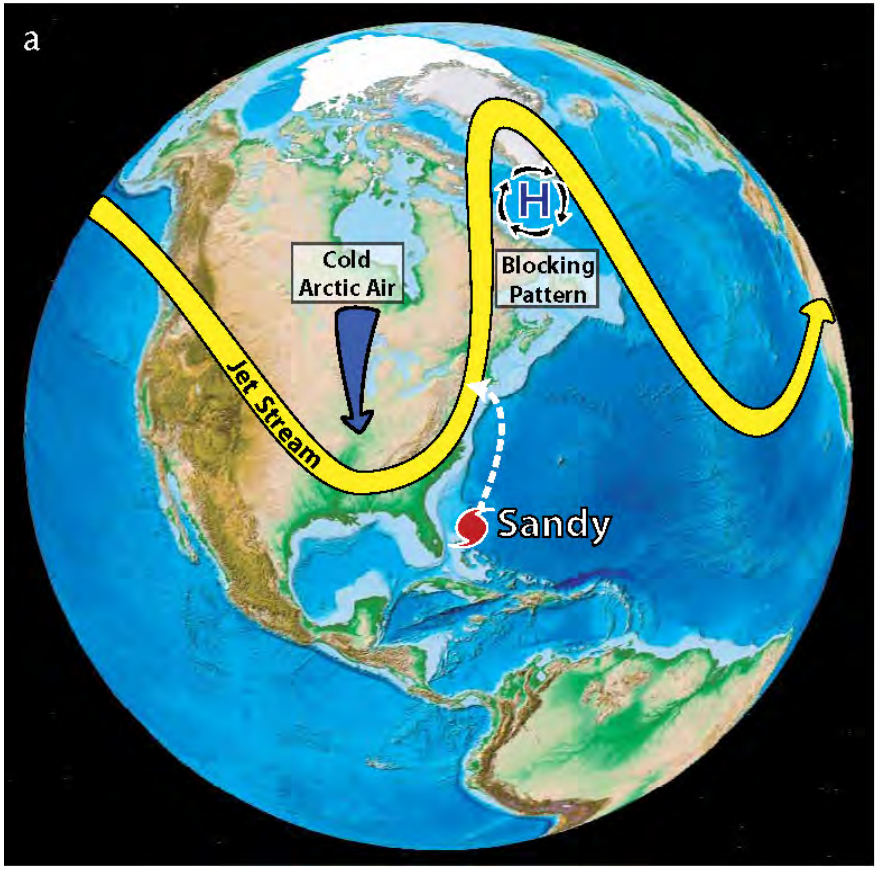
- **Record wet : OH to VT**
- **Record drought: TX & NM**
- **'Quasi-stationary' pattern**

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

(Francis and Vavrus, 2012)



Blocking Pattern - Unique track



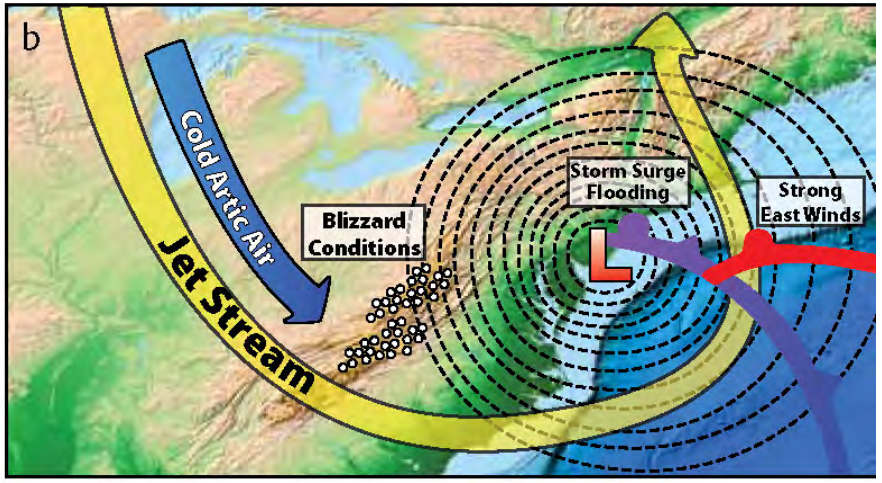


Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical 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 CO_2**
- **This means an 80% drop in CO_2 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 CO_2 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 CO_2 is an "unfair cost" to the "free market"**
  - **Carbon tax needed to change economics**
- **Politics lost in fantasy and deceipt**
  - **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**

Why Is It Difficult for Us?

- **The "American dream" is crumbling**
  - **"Economic growth" based on fossil fuels, debt, and consumerism is unsustainable**
  - **Global market capitalism is disaster for the planet**
- **Individual "rights" and the needs of humanity must be balanced against the needs of the earth's ecosystem**
- **We don't know how to guide and manage technology —so the result is tremendous successes and catastrophic failures**

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**

How Do We Manage the Earth?
(When there is so much we don't know)

- **Need a long time horizon:**
  - **Generational to century *(Forest timescale)***
- **We need some new rules / guidelines !**
  - **Our numbers are so great**
  - **Our industrial impact is too large**
  - **Maximizing profit as a guide has failed us**
- **We must manage our society better!**

Broad Guidelines or Rules to Minimize Impacts

- **Minimize the lifetime of human 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**

Is Better Technology Enough?

“The difficulty is that with the rise of the modern sciences we began to think of the universe as a collection of objects rather than a communion of subjects”

The Great Work: Our Way into the Future
Thomas Berry, 1999

Change of Attitude Needed?

- **Do we just exploit the Earth's wealth**
  - **For greater 'economic growth'**
  - **For a wealthy few**
  - **What is left for our children?**
  - **What happens to the ecosystems we depend on?**
- **Moral Issue**
  - **Don't we need to co-operate with the Earth?**
  - **Shift in understanding and mind-set needed**

What Do We Need?

- So we need honest, truthful, smart pathways forward
  - That will not frighten people into paralysis
  - That will spread hope, not anger or despair
  - That sidestep ideological barriers with new language
  - That develop adaptive governance
    - The US Constitution gives no rights to the Earth
  - That respect Earth system limits
  - That accept our moral responsibilities

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***

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***