



Overview of Climate Change in Vermont



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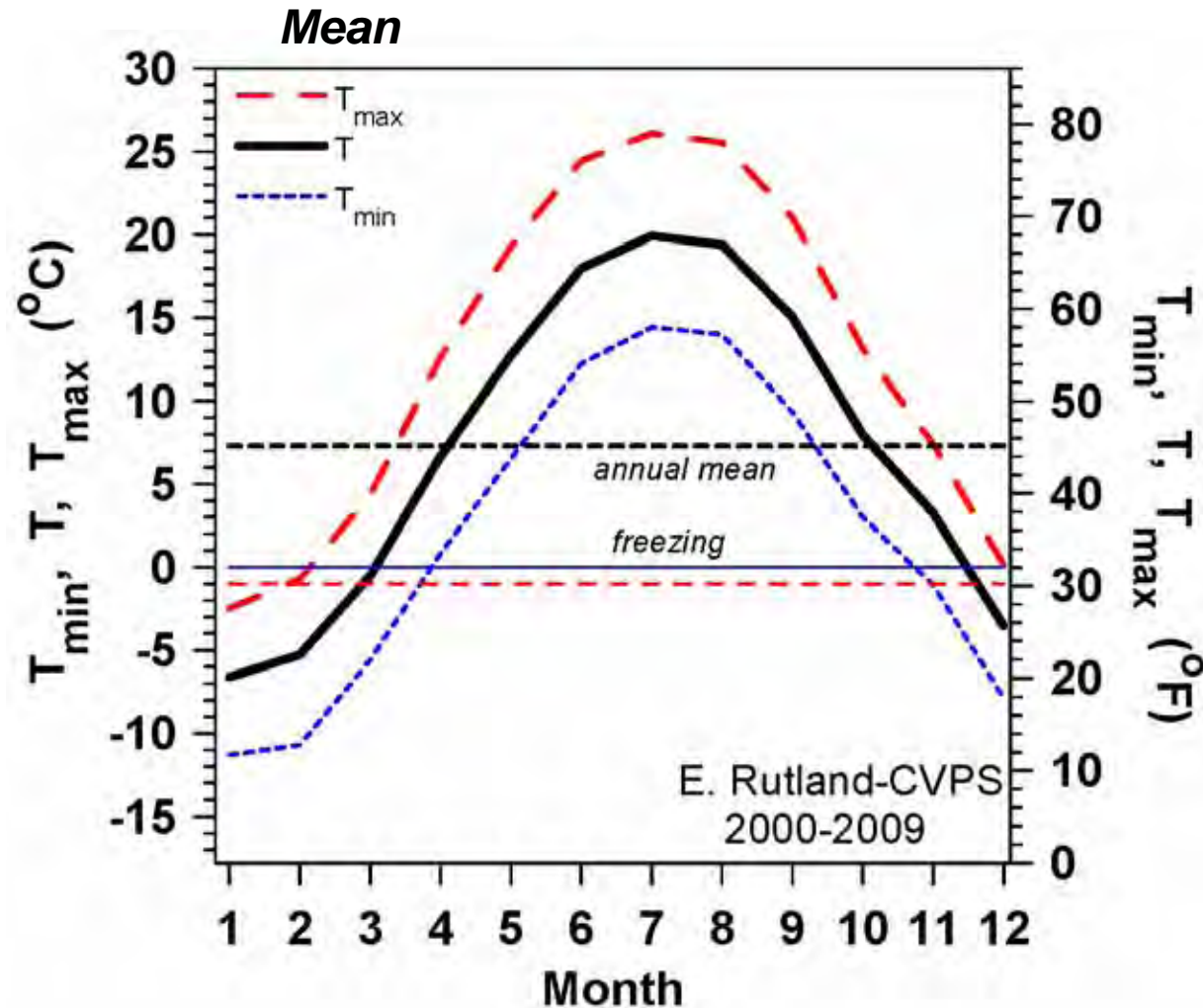
***Resource Conservation
& Development Conference***

Quechee, VT

October 26, 2012

Climate of Vermont

- Climate is a mean (10-30y)
- T_{\max} , T , T_{\min}
- Large seasonal range in VT
- *Freezing T of water critical to climate*



Earth sustains life

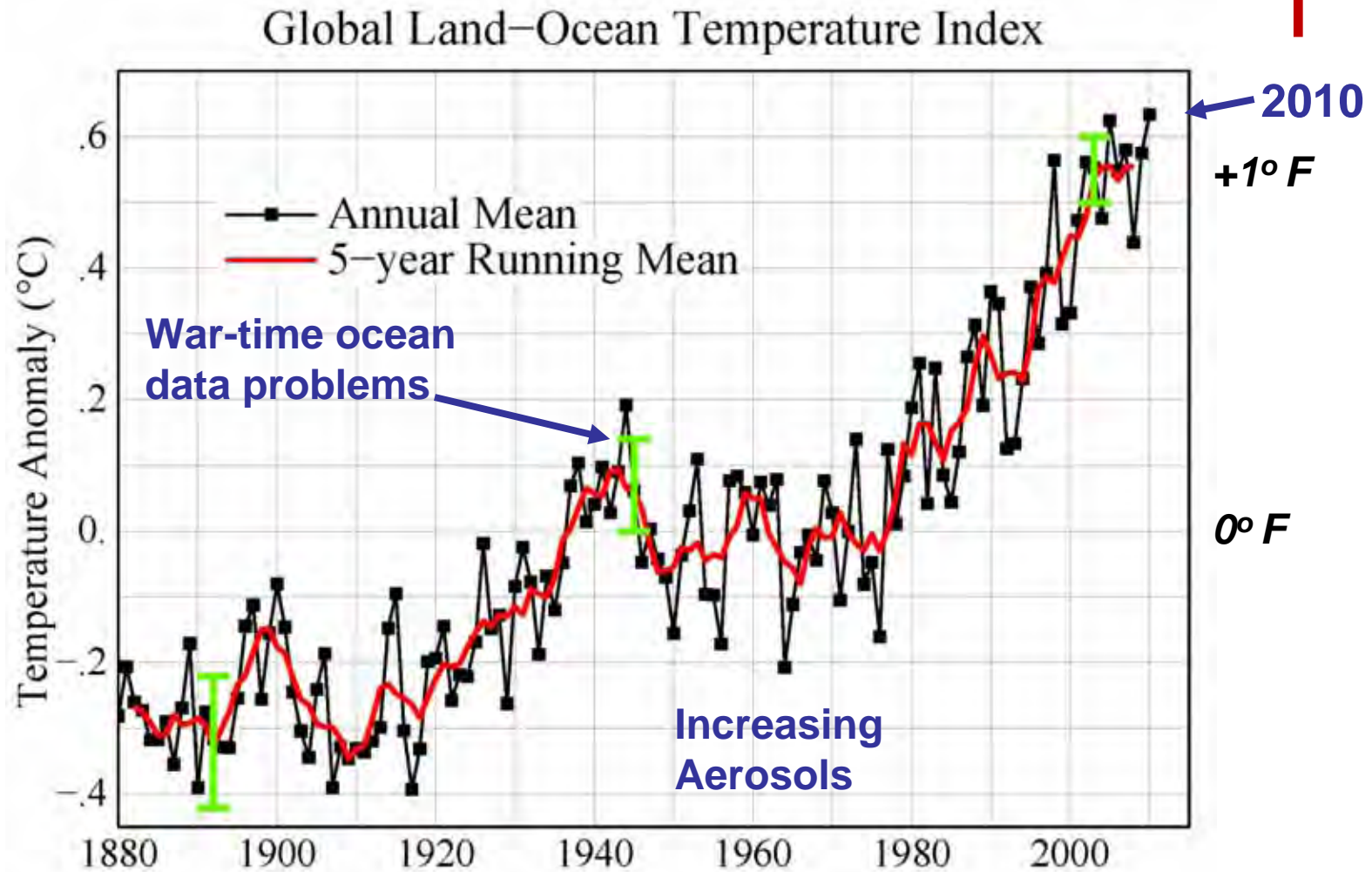
- Burning fossil fuels is increasing greenhouse gases and melting polar ice
- **Climate is warming and extreme weather is increasing**



January 2, 2012: NASA

Global Temperature Rise 1880 – Present

2100: +5°F

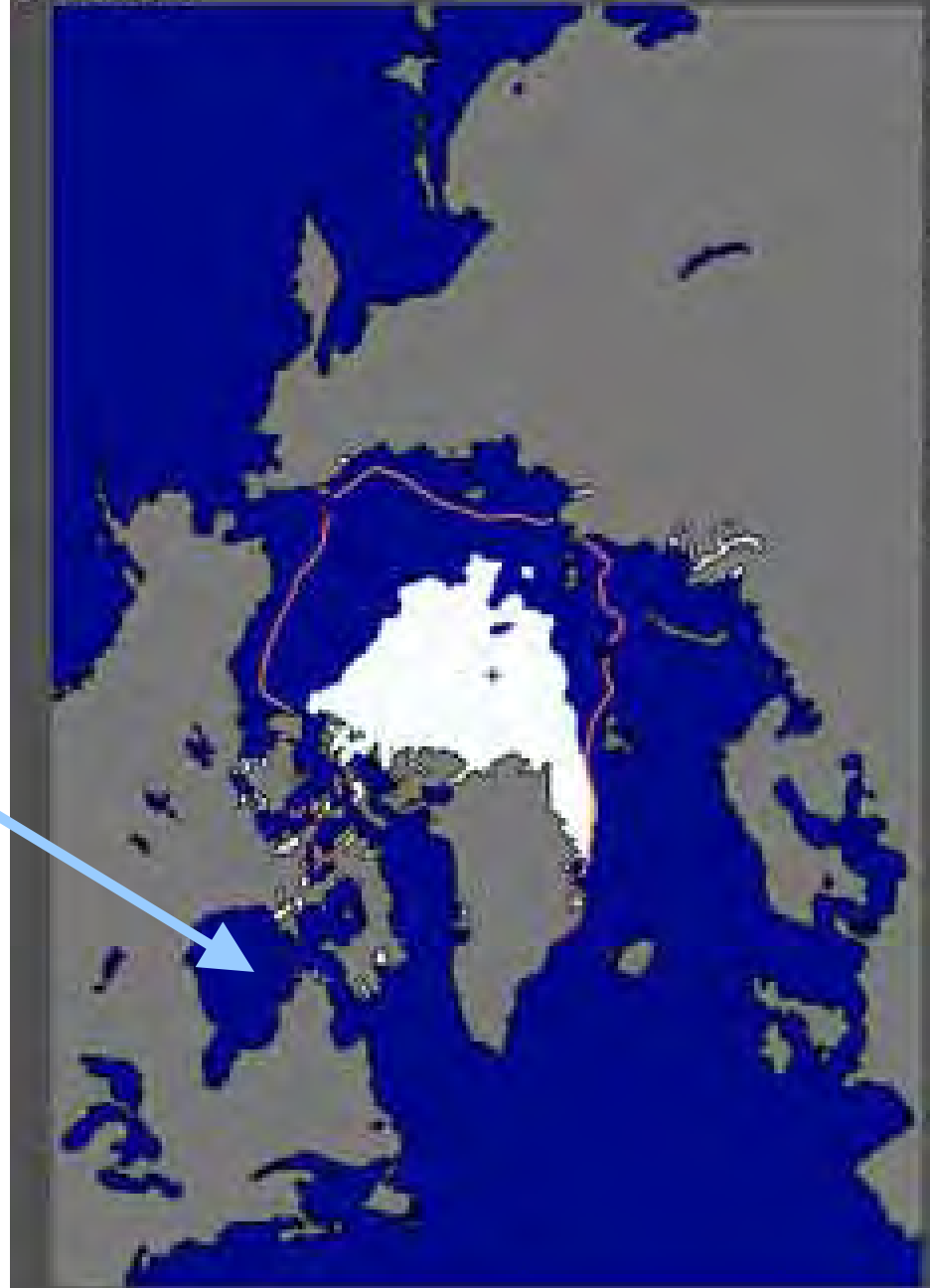


NASA-GISS, 2011

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

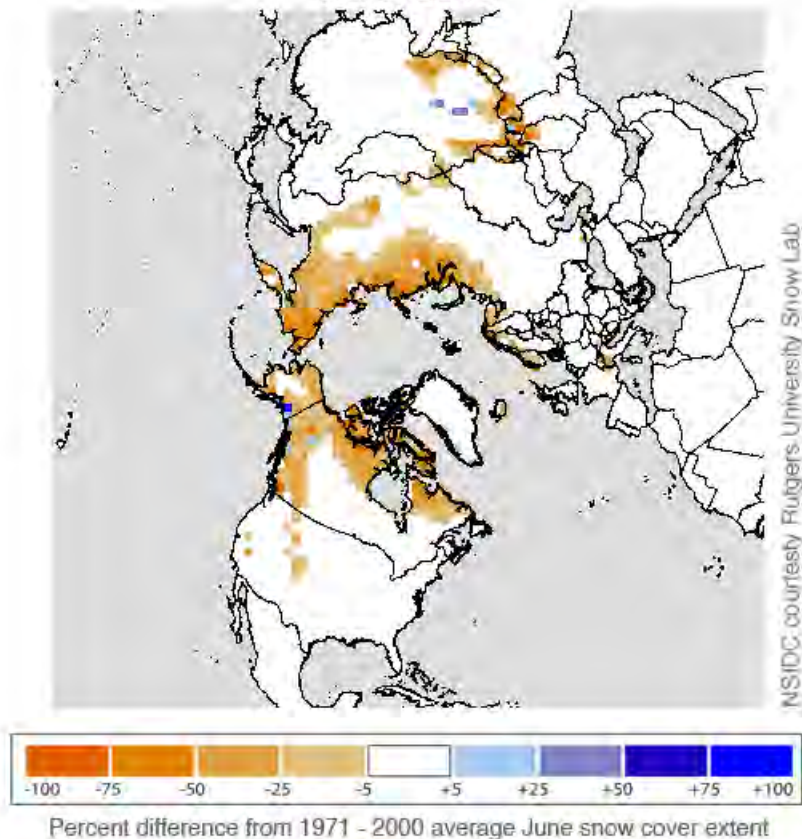
At the end of Nov. 2011 Hudson Bay was still nearly ice-free

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

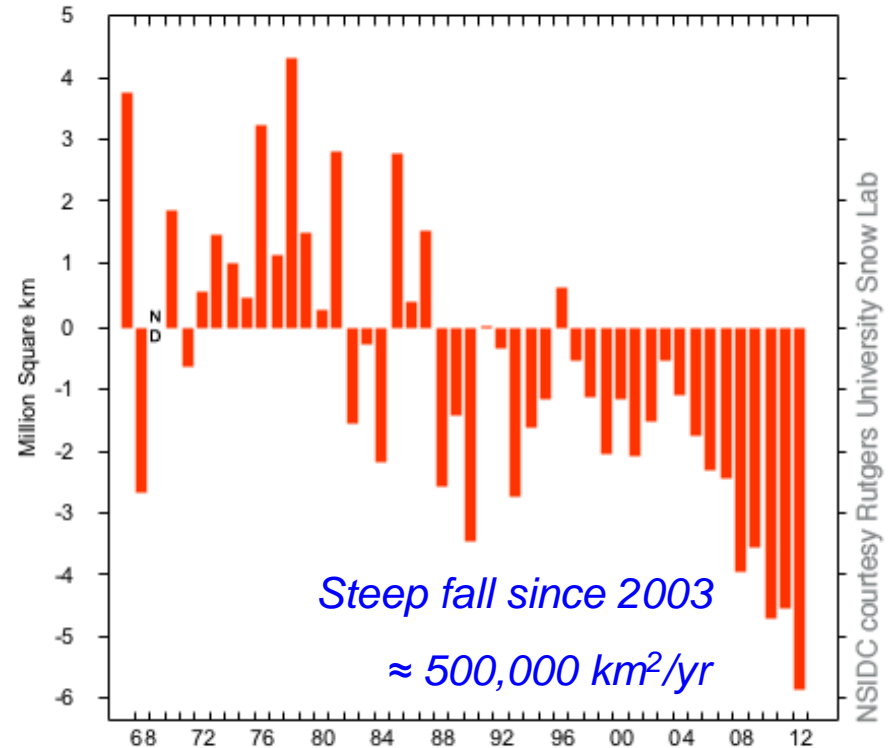


June 2012 snow cover minimum

Northern Hemisphere Snow Cover Anomaly
June 2012



Northern Hemisphere Snow Cover Anomaly
June 1967 - 2012



- Arctic warming rapidly
 - Melting fast
- New England winters also
 - Same positive feedbacks

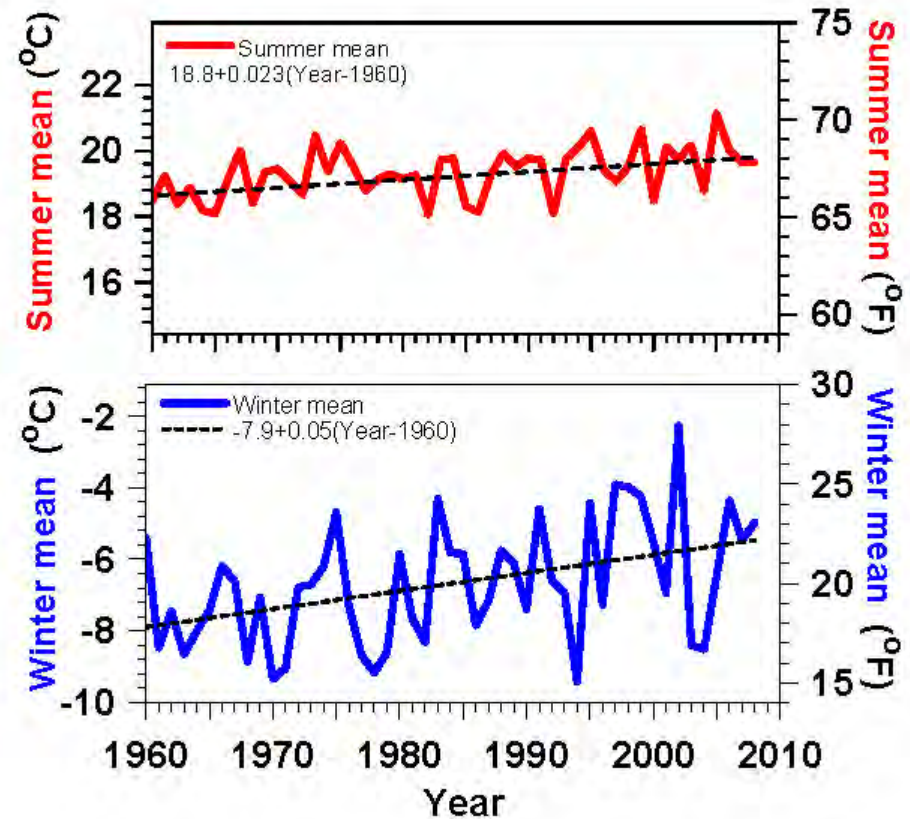
What Is Happening to Vermont?

- **PAST 40/50 years** (CO₂ 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**

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

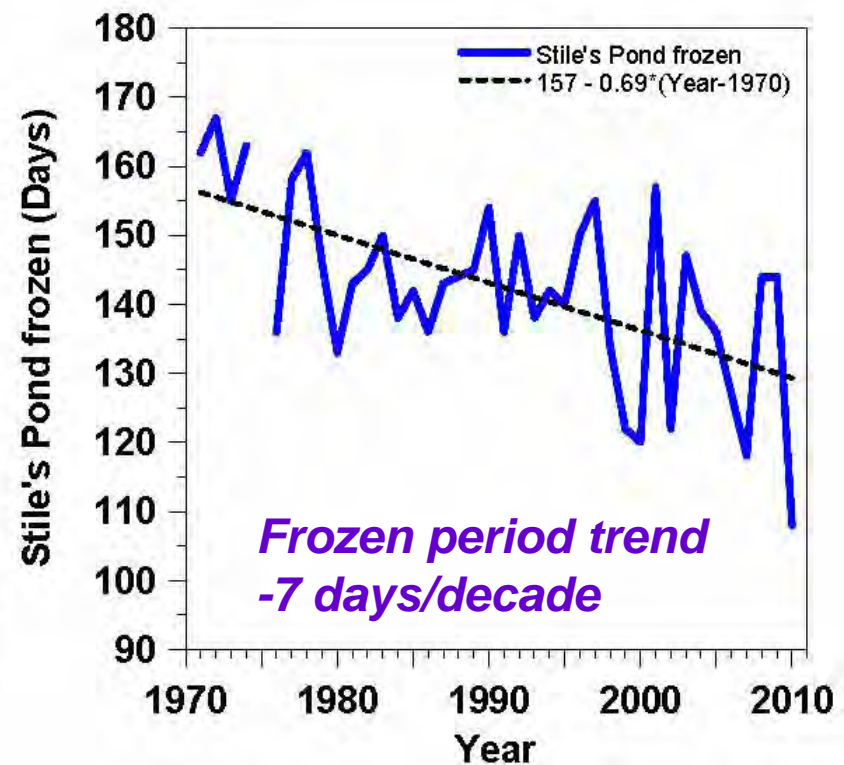
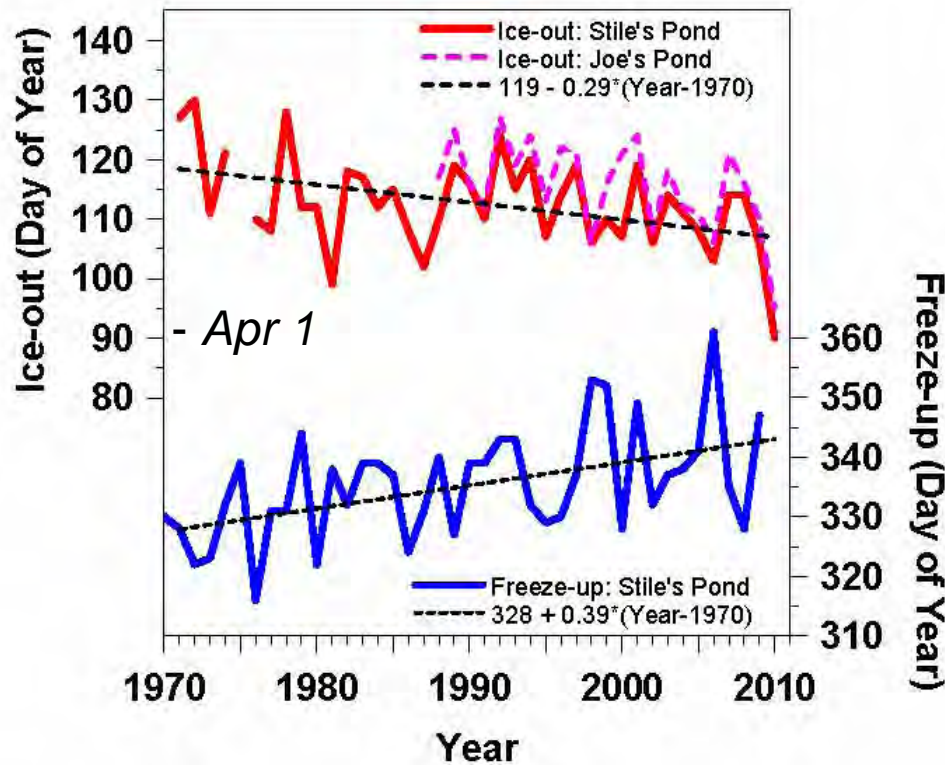
Vermont Temperature Trends 1961-2008

- **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

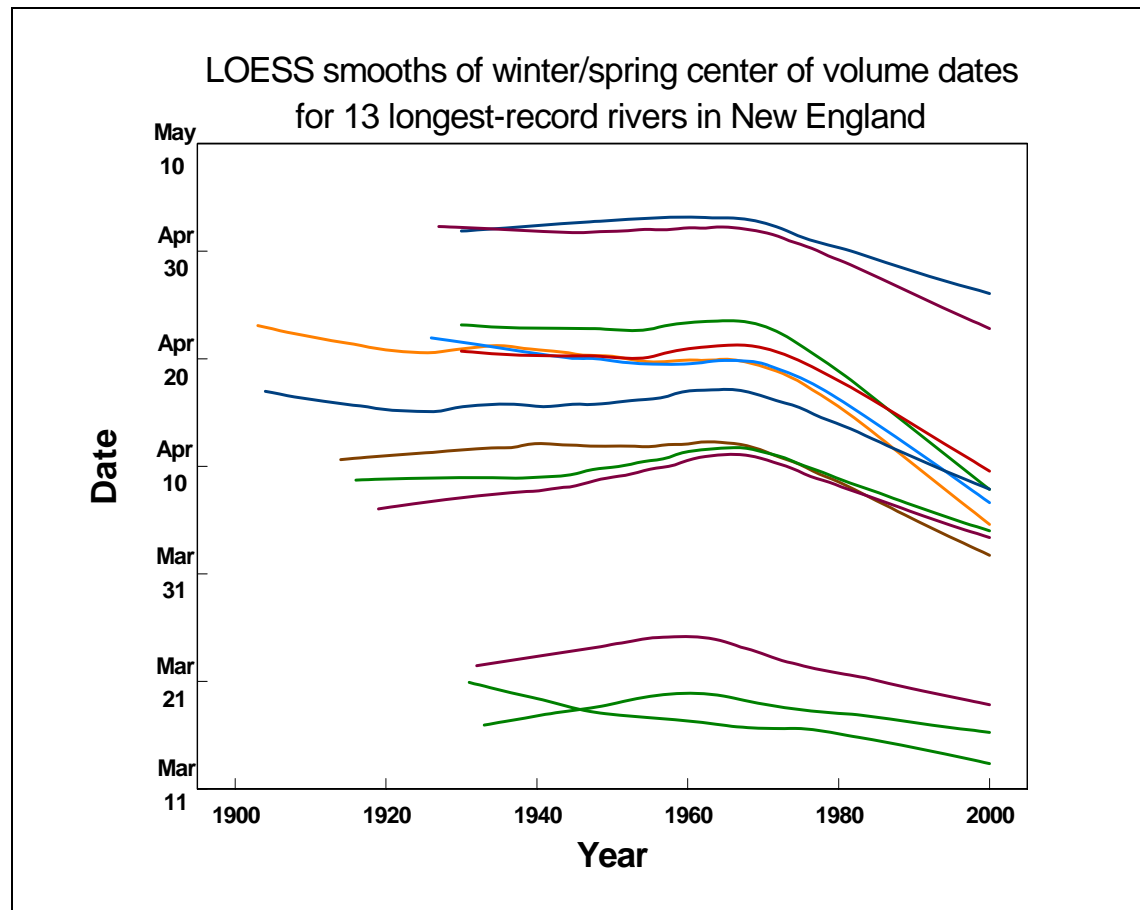


- Ice-out earlier by 2.9 (± 1.0) days / decade
- Freeze-up later by 3.9 (± 1.1) days / decade
- Rivers and soils similar?

Hydrology is Sensitive to Climate

Lent (2010), USGS, Me


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



Hodgkins and others, 2003

- winter cold extremes

Change in
years



Minimum winter temperatures

4: -30 to -25

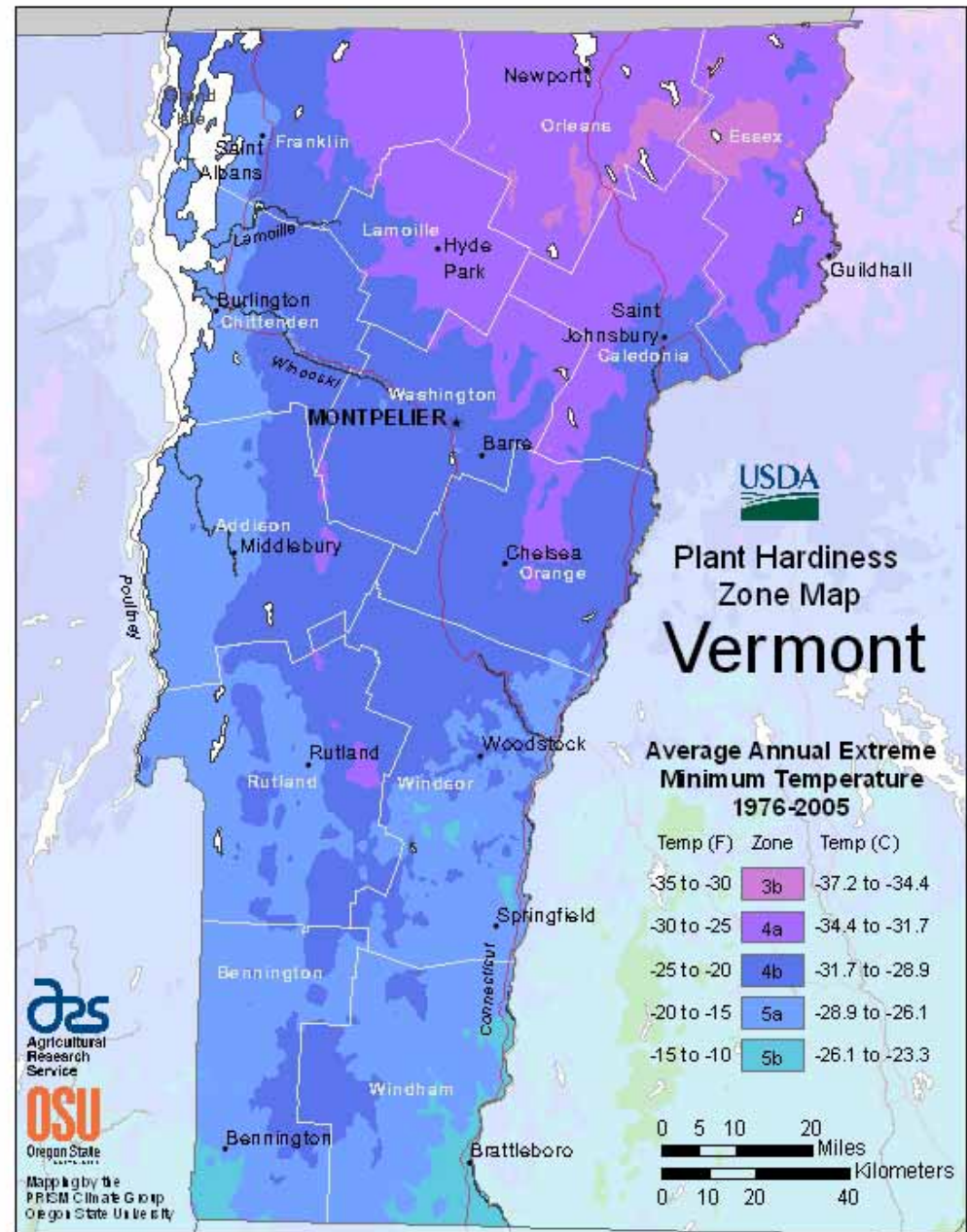
6: -10 to 0°F

2 3 4 5 6 7 8 9 10

© 2006 by The National Arbor Day Foundation®

Detailed Map (most recent)

- USDA : VT
Hardiness Zone
Map 1976-2005
 - mean 1990
 - South into zone 6
- Half-zone in 16 yrs
= 3.1°F/ decade
 - triple the rise-rate
of winter mean T
- <http://planthardiness.ars.usda.gov/PHZMWeb/>



Bennington & Brattleboro are almost zone 6

- Hardy peaches: 2012
- Pests: winter survival
- What is this?



Bennington & Brattleboro are almost zone 6

- Hardy peaches
 - 2012

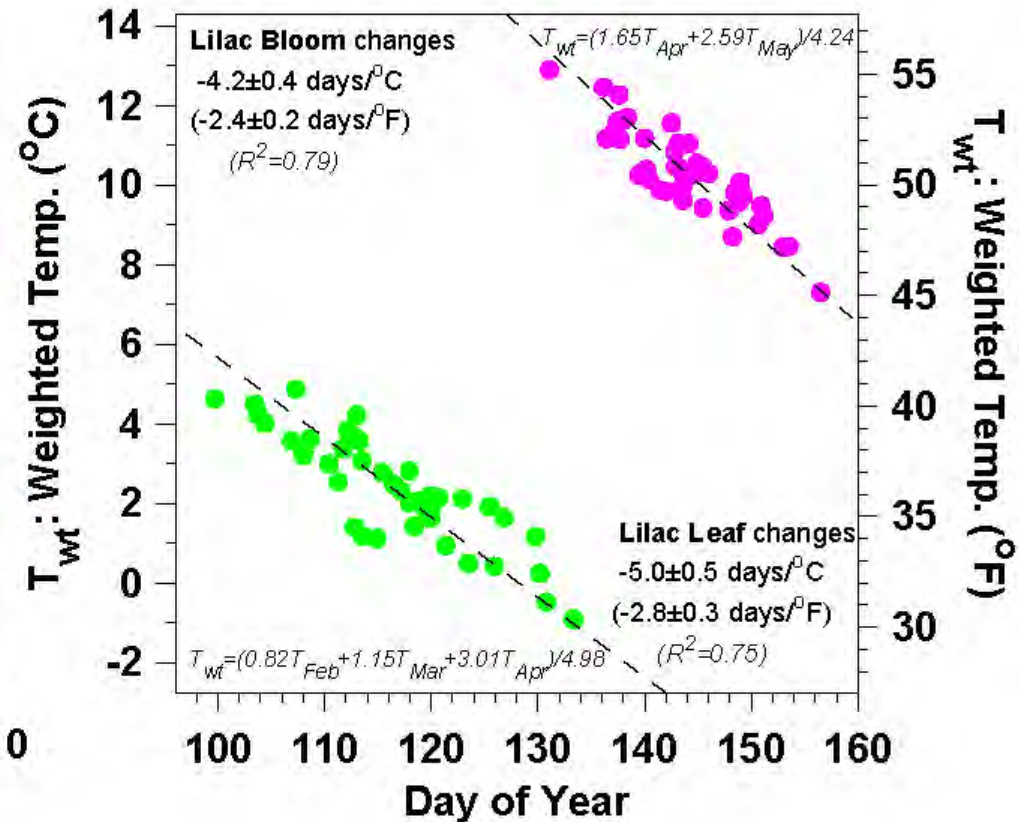
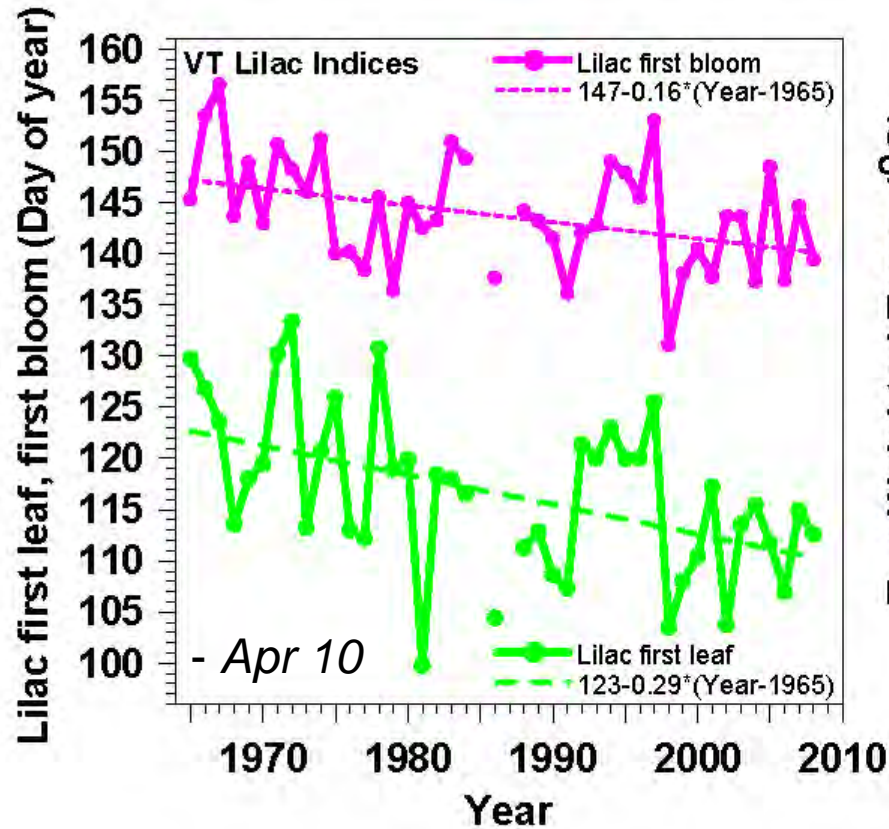
- What is this?

- **Avocado**

- Didn't survive frost
 - Late century: CT
 - Our grand-children

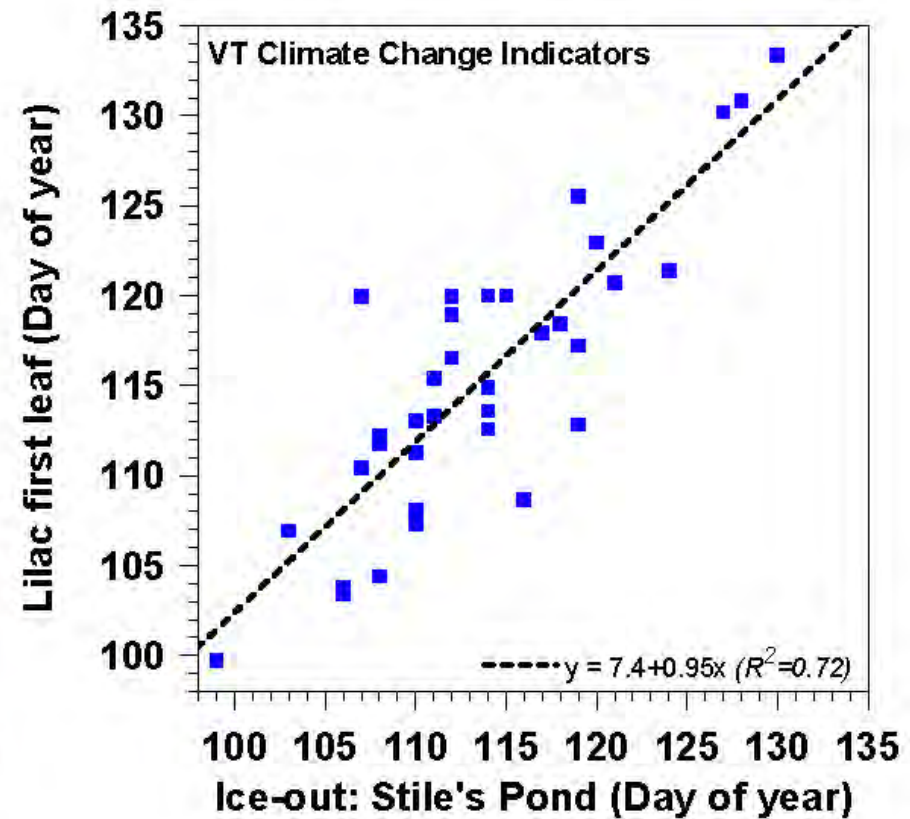
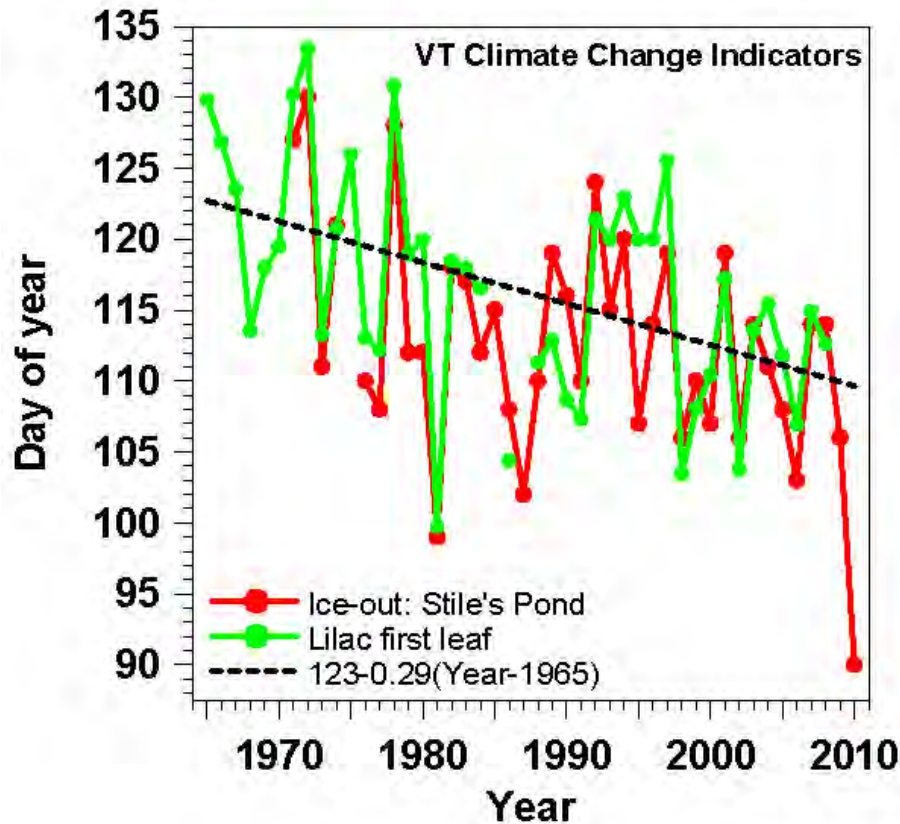


Lilac Leaf and Bloom



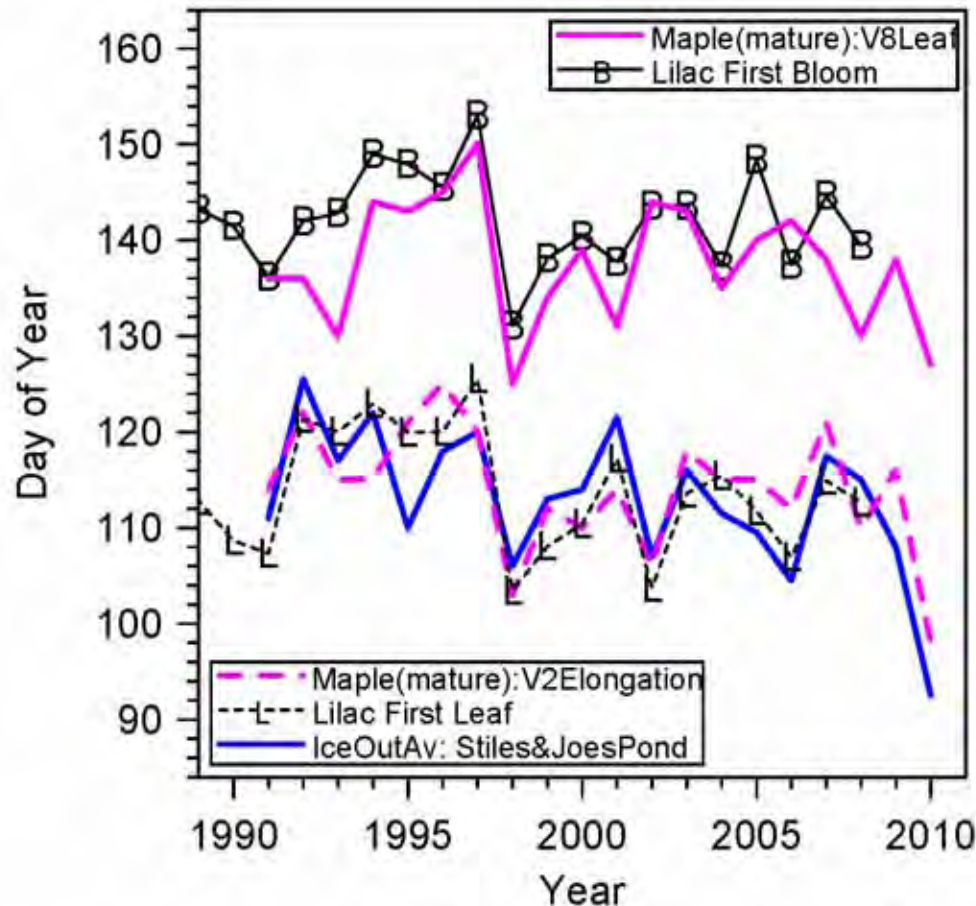
- Leaf-out -2.9 days/decade; Bloom -1.6 days/decade
- Large year-to-year variation related to temperature:
2 to 3 days/ $^{\circ}\text{F}$

Lilac Leaf-out and Ice-out Coupled



- Lilac leaf and lake ice-out both depend on Feb. Mar. and April temperatures
- Trends indicate earlier spring

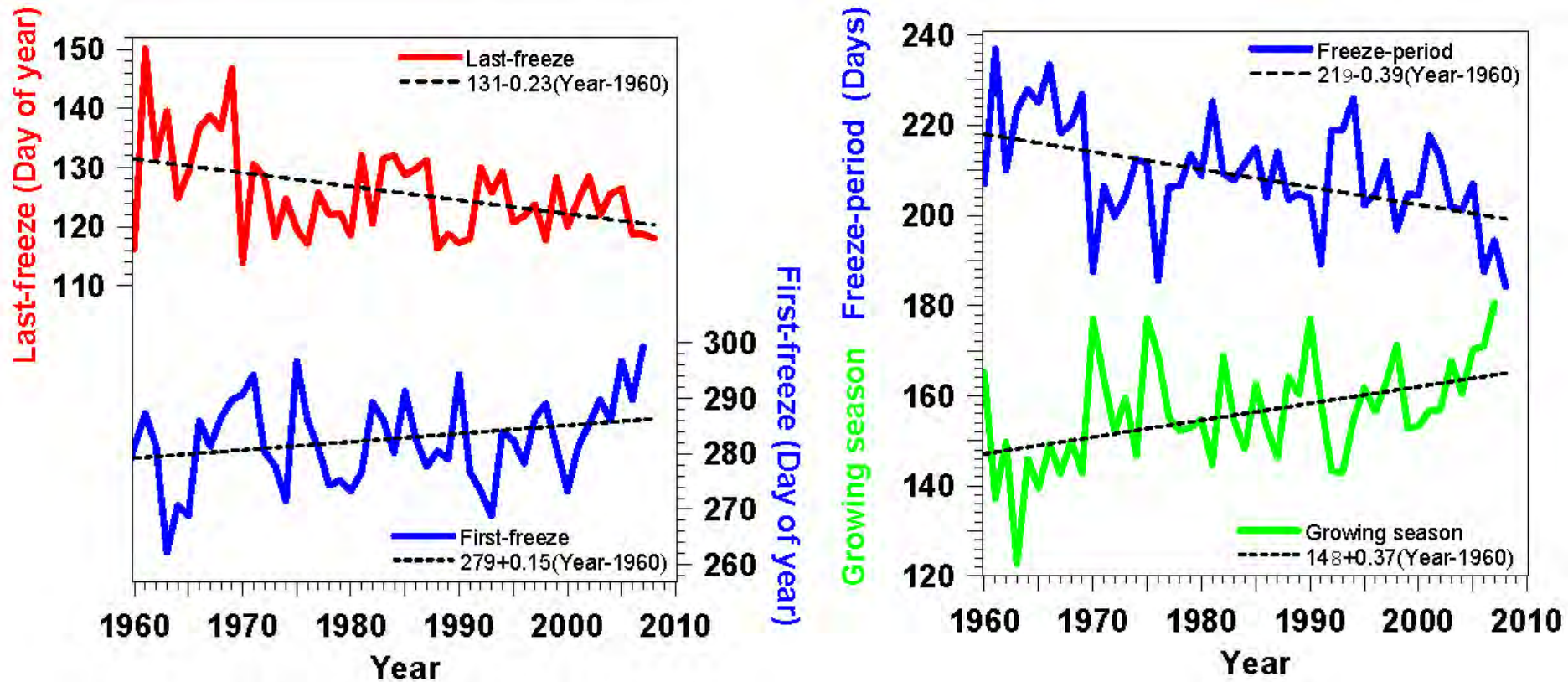
Sugar Maples in Spring



- Ice-out, lilac leaf, maple bud elongation correlated
- Lilac bloom and maple leaf-out correlated

Data: Sandy Wilmot, ANR

First and Last Frosts Changing



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

Shrinking Winter: Pittsford, VT

(Freeze-up used to be mid-November)



January 7, 2007

December 2006:

- Warmest on record



January 10, 2008

Warm Fall:

- Record Arctic sea-ice melt
- Snow cover in December, ground unfrozen



January 2, 2012



March 11, 2012

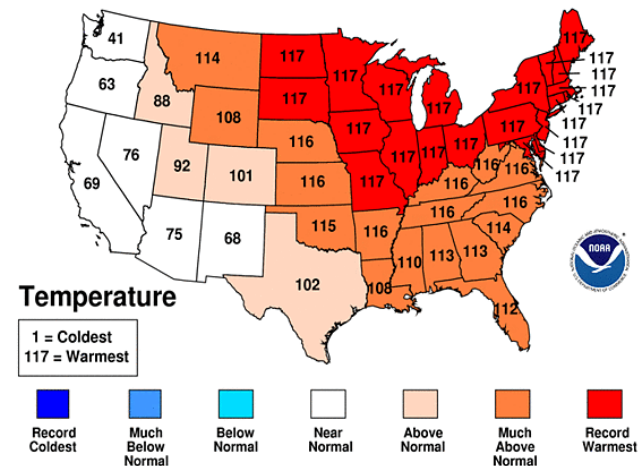


October 2011– March 2012

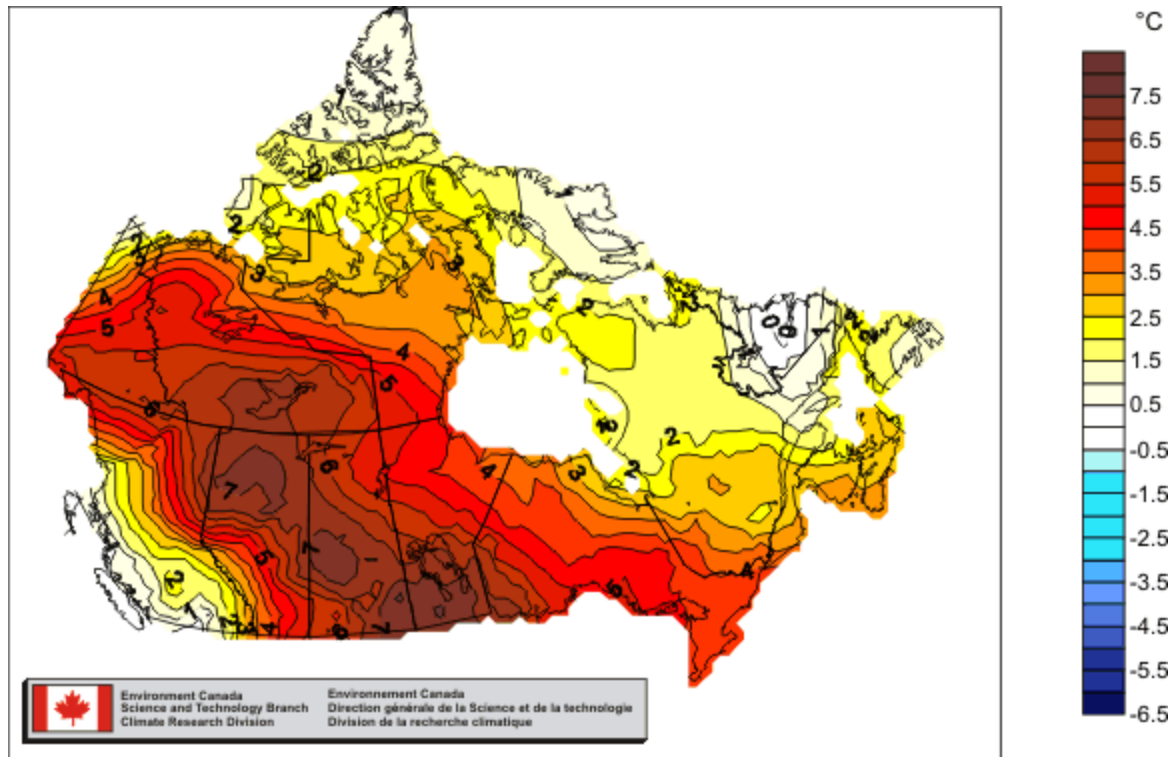
- **Warmest 6 months on record**
- **My garden frozen only 67 days**
- **No permanent snow cover west of Green Mountains**
- **Contrast snowy winter 2010-11**

Oct 2011-Mar 2012 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



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!

Early Spring: Daffodils, Forsythia

79°F on March 22, 2012



Pittsford Vermont

3/22/12



Pittsford Vermont

3/24/12

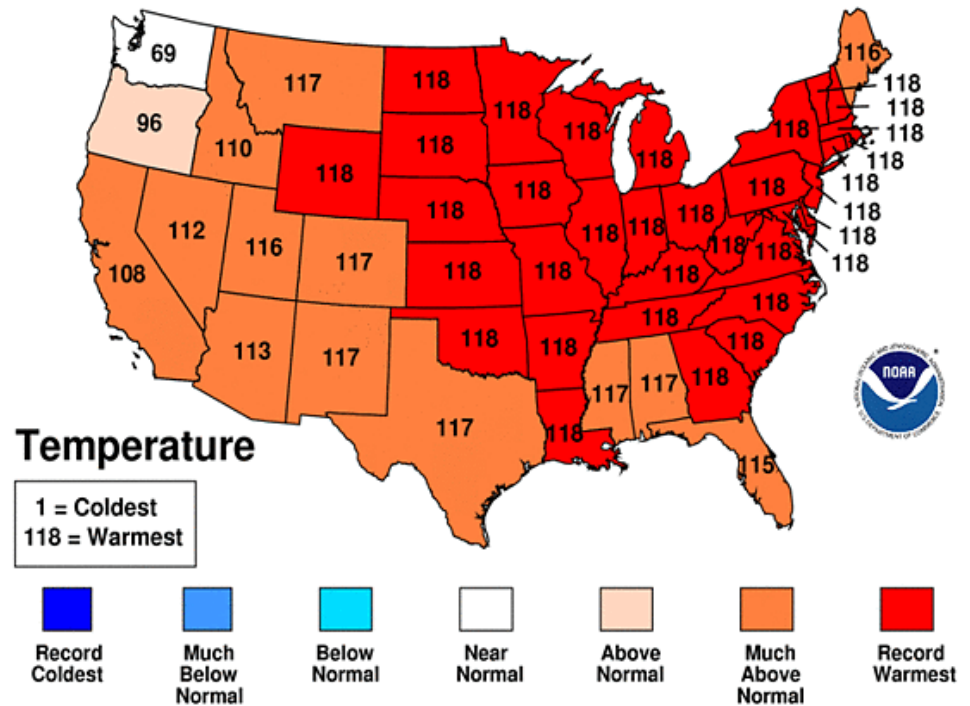
This Year Exceptionally Warm

- 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)

January-August 2012 Statewide Ranks

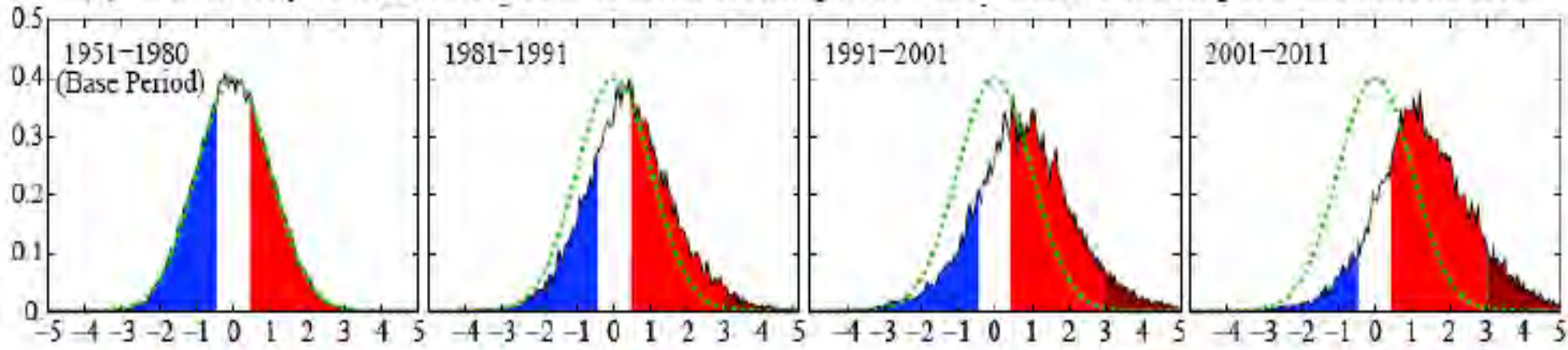
National Climatic Data Center/NESDIS/NOAA



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

Increasing Temperature Extremes is “Global Warming”

(a) Probability Distribution of Northern Hemisphere Land Summer Temperature Anomalies



(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 $> +3\sigma$ is global warming**
 - Increased from baseline 0.15% to 10% in 45 years

Vermont Winter 2006



- Sun is low; snow reflects sunlight, except where there are trees - shadows
- Sunlight reflected, stays cold; little evaporation, clear sky; earth cools to space
- *Positive feedback: Less snow, warmer winters (2012)*

Spring Climate Transition



- **Before leaf-out**

Little evaporation → Dry atmosphere, low humidity
→ Low water vapor greenhouse
→ Large cooling at night
→ Large diurnal temp. range
giving warm days, cool nights and frost

- **After leaf-out**

Large evaporation → Wet atmosphere, low cloudbase
→ Small cooling at night
→ Reduced maximum temperature
→ Reduced chance of frost

- ***Spring is coming earlier: 2012 was extreme***

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 – 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*

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!*

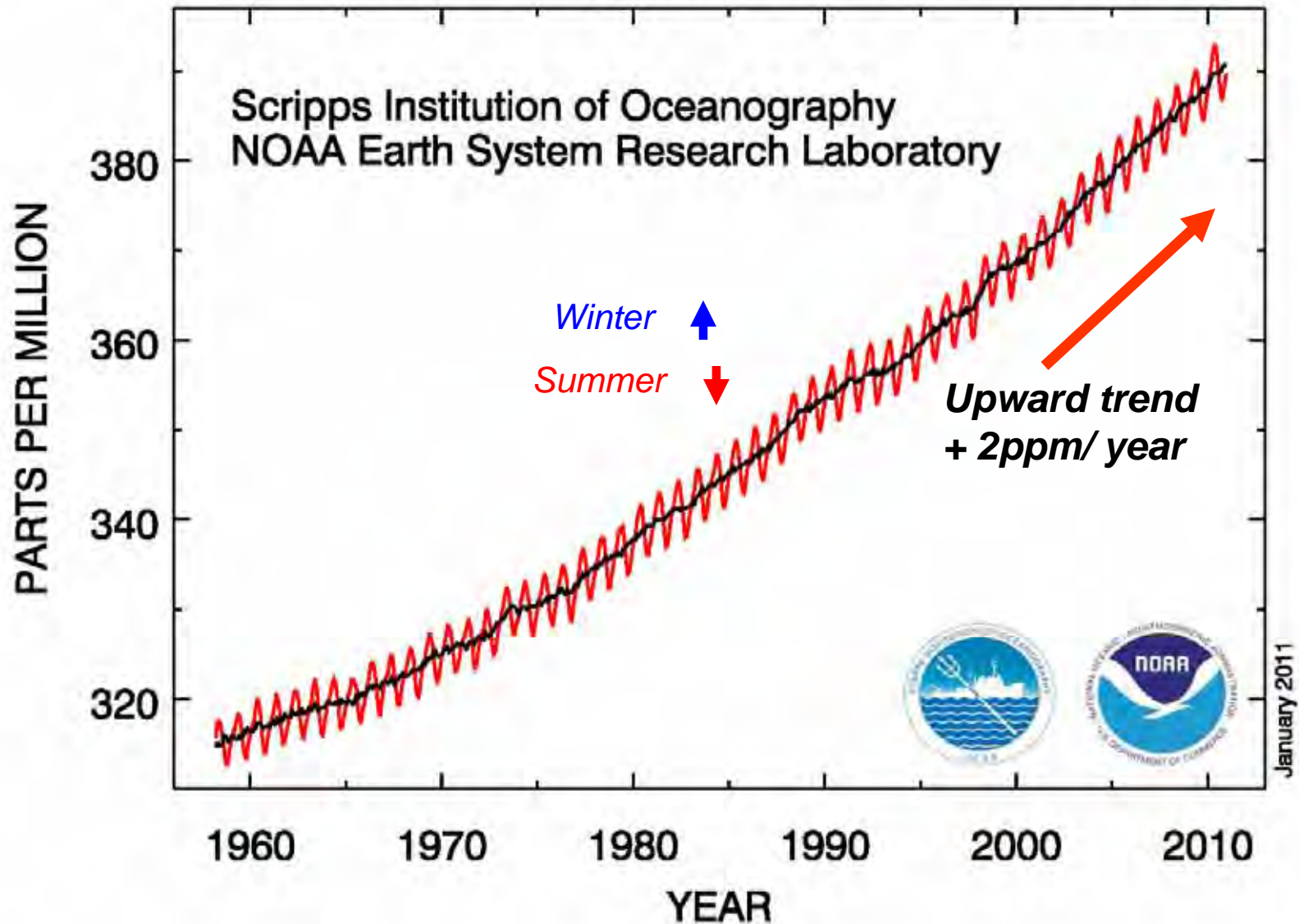


Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

Later frost: Growing season getting longer

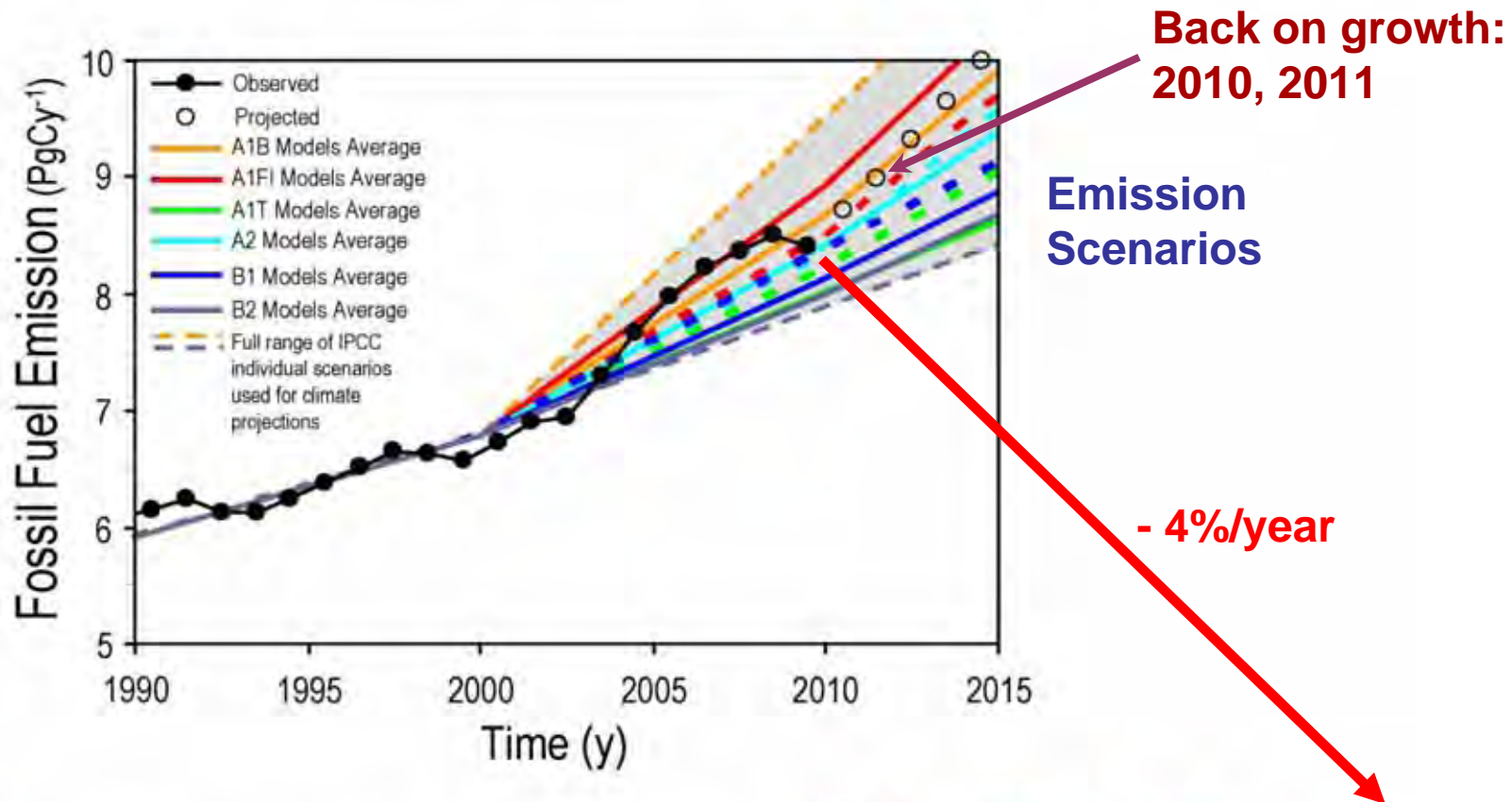
Carbon Dioxide Is Increasing

Atmospheric CO₂ at Mauna Loa Observatory



2009 Was “Good” for the Earth

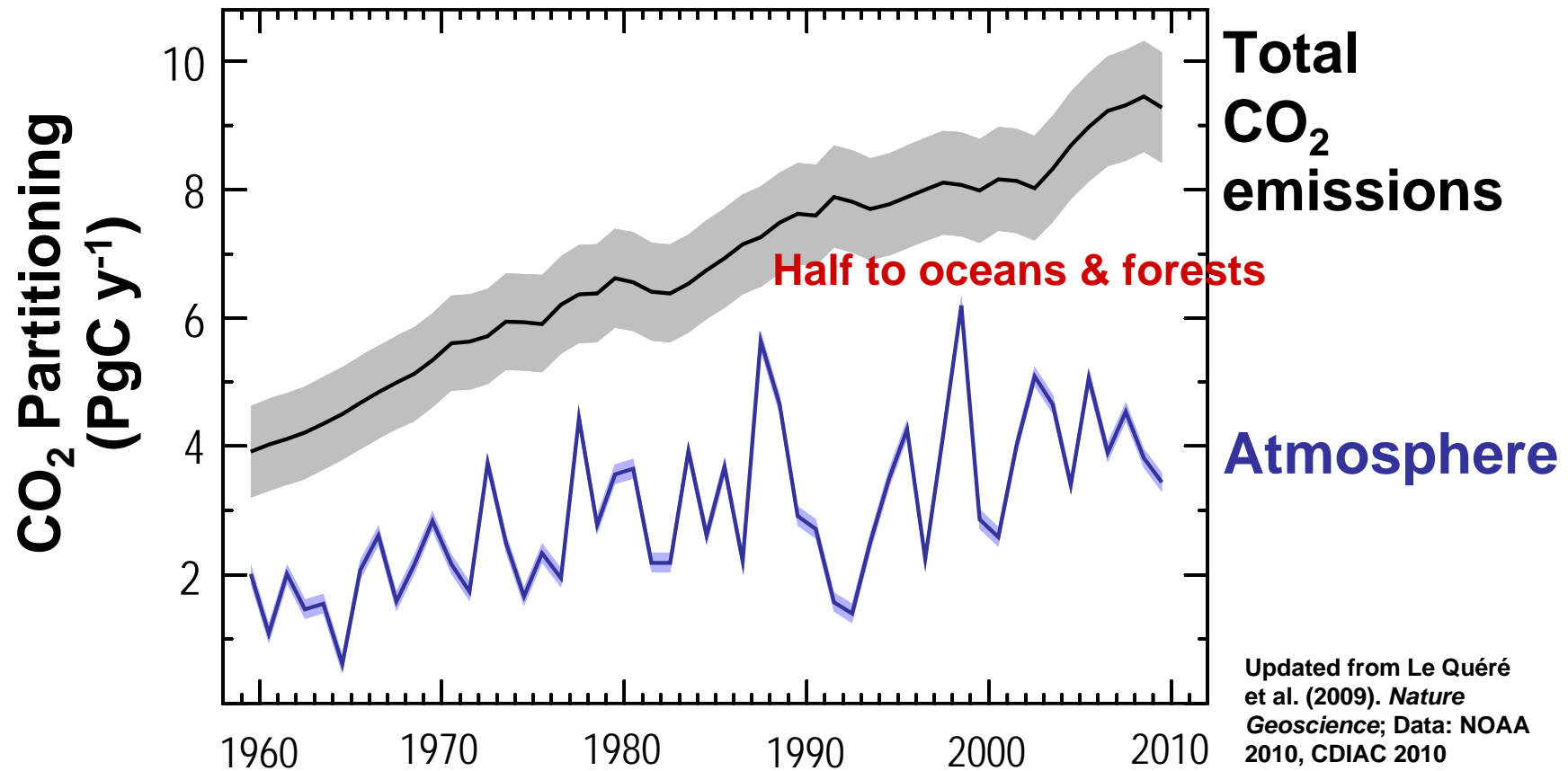
Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Updated from Raupach et al. 2007, PNAS; Data: Gregg Marland, Thomas Boden-CDIAC 2010; International Monetary Fund 2010



Only Half of Total CO₂ Emissions Remain in the Atmosphere



It takes at least a century to remove CO₂ from the atmosphere, and many centuries to remove it from oceans

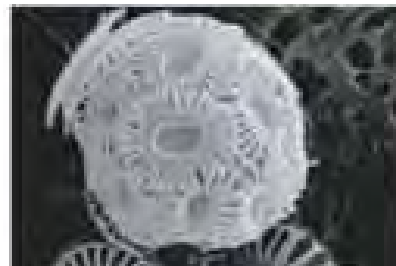
Rising Ocean Acidity Threatens Organisms



- 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 CO₂ rise
- As Earth warms, snow & ice decrease and reduced SW 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

Global Warming Is Unequivocal

IPCC: February 2, 2007

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

Decrease in:

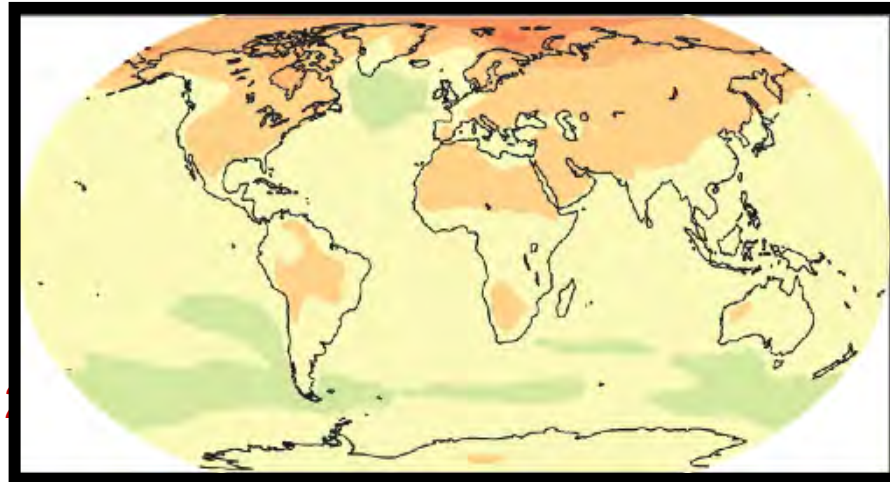
- NH snow extent
- Arctic sea ice
- Glaciers
- Ocean pH (increasing acidity)



Predicted Change in Temperature

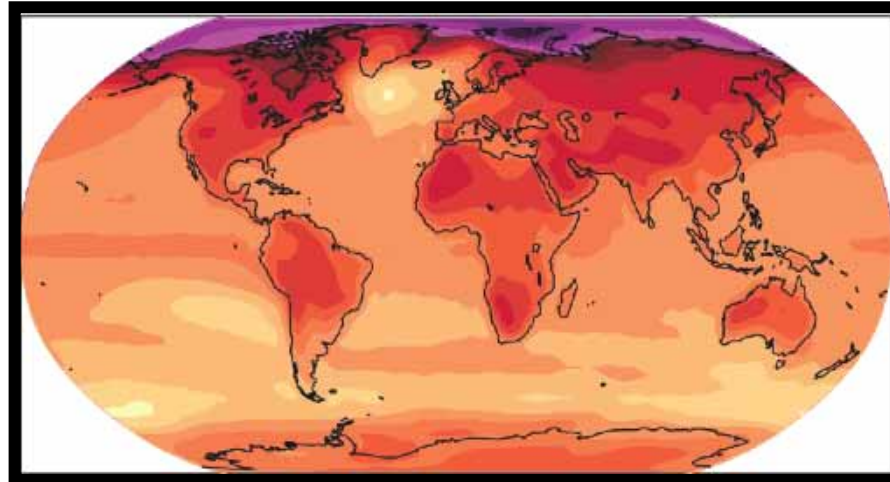
2020-2029 and 2090-2099, relative to 1980-1999 (°C)

“Committed”



**(We did
nothing for
the last 20
years)**

Still up to us!



**(We could
halve this if
we act now)**

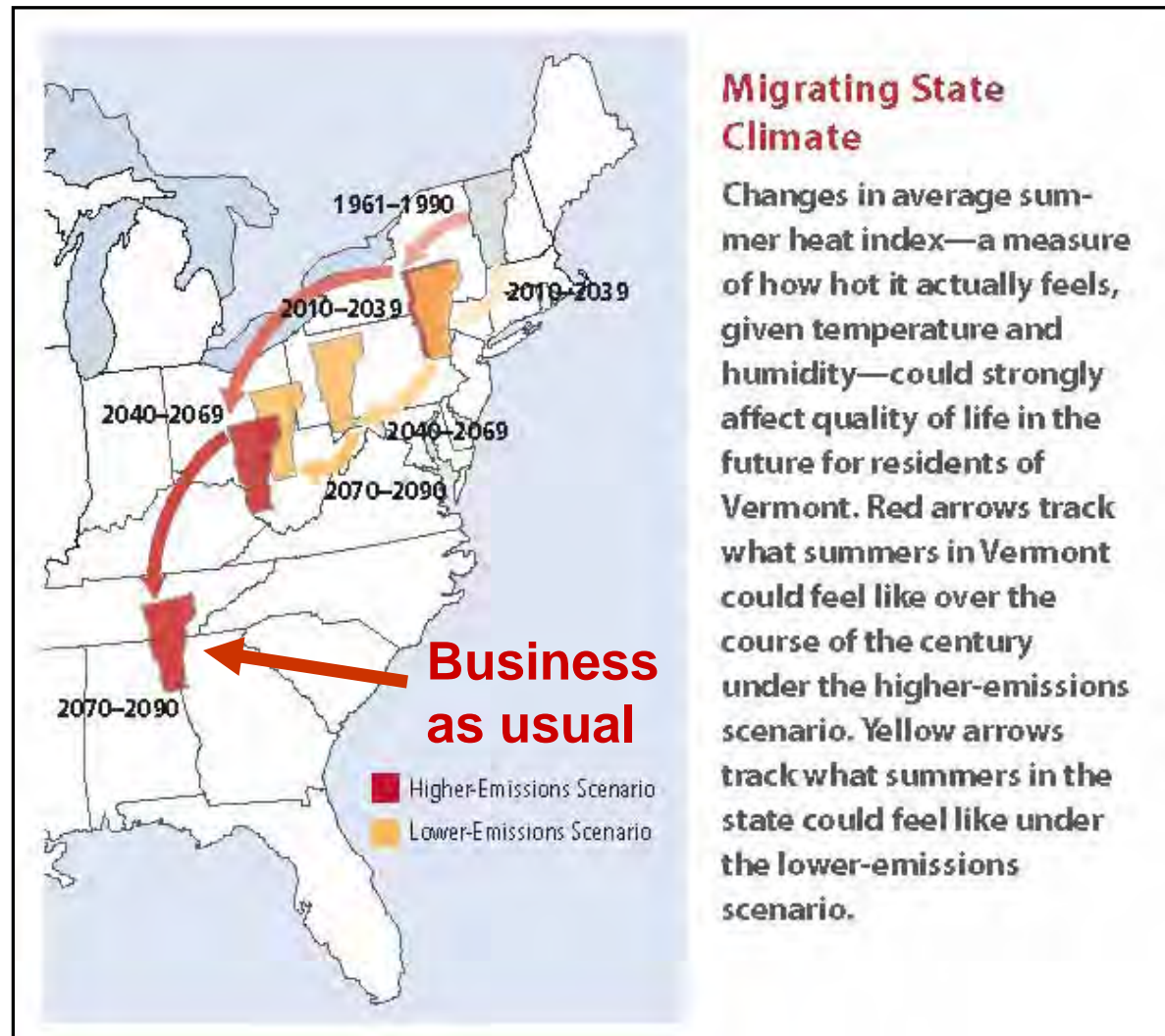


[°C]

Vermont's Future with High and Low GHG Emissions

What
about
skiing?

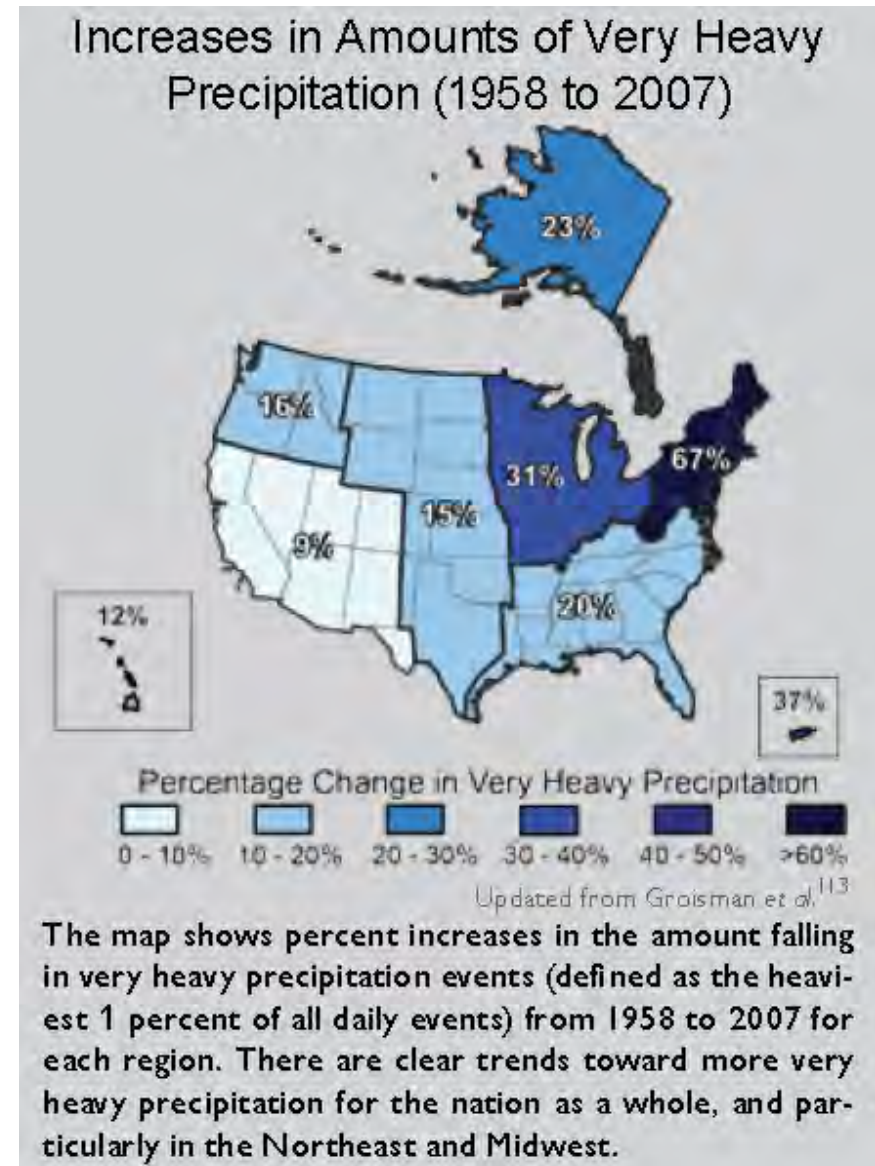
What
about
tropics?



**NECIA,
2007**

Very Heavy Precipitation Is Increasing

- **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**
- Little change or a decrease in the frequency of light and moderate precipitation
- **NE stormflow increasing**
(Lent, USGS, 2010)



**Summer
stormflow
increases
20-50%**

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

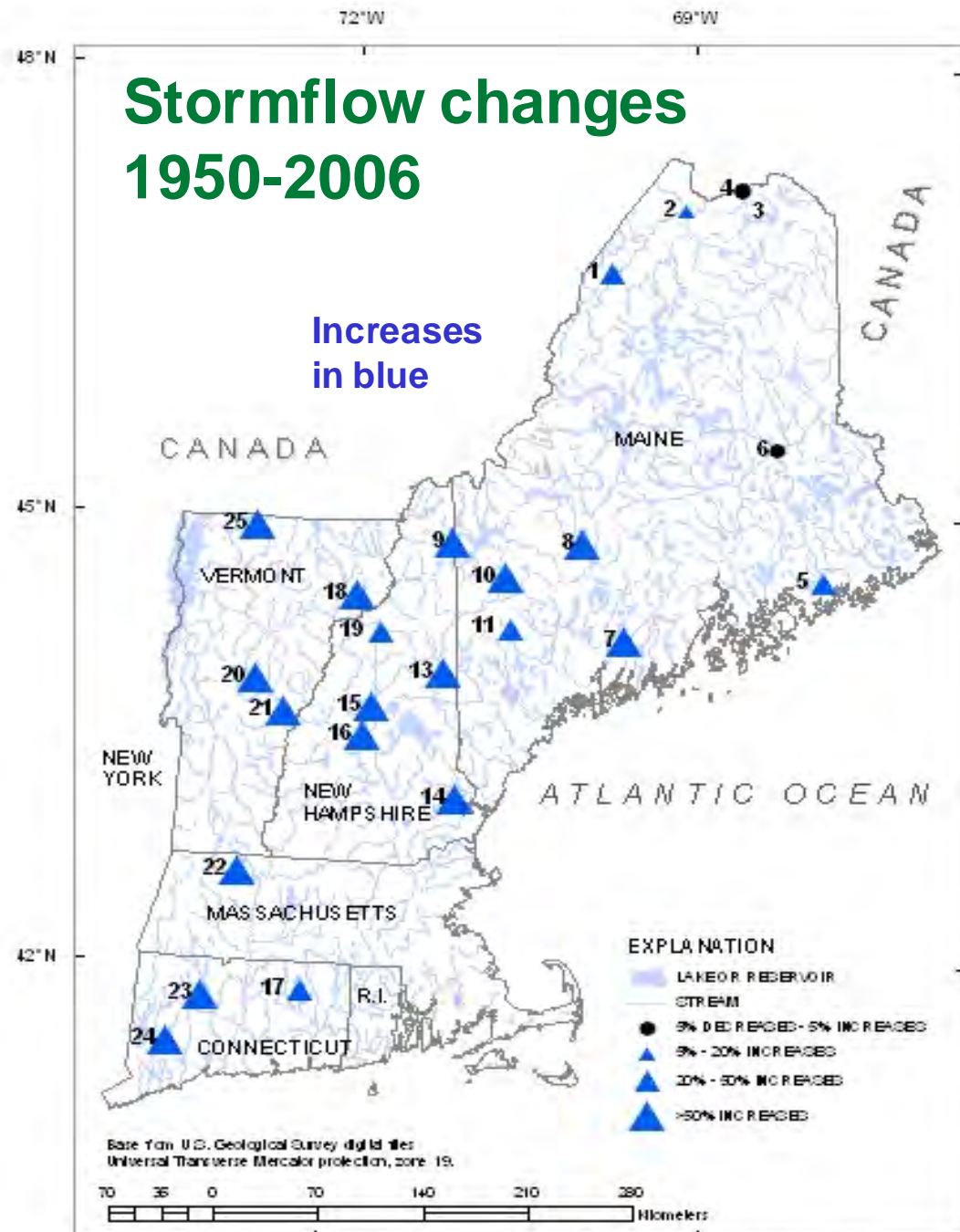
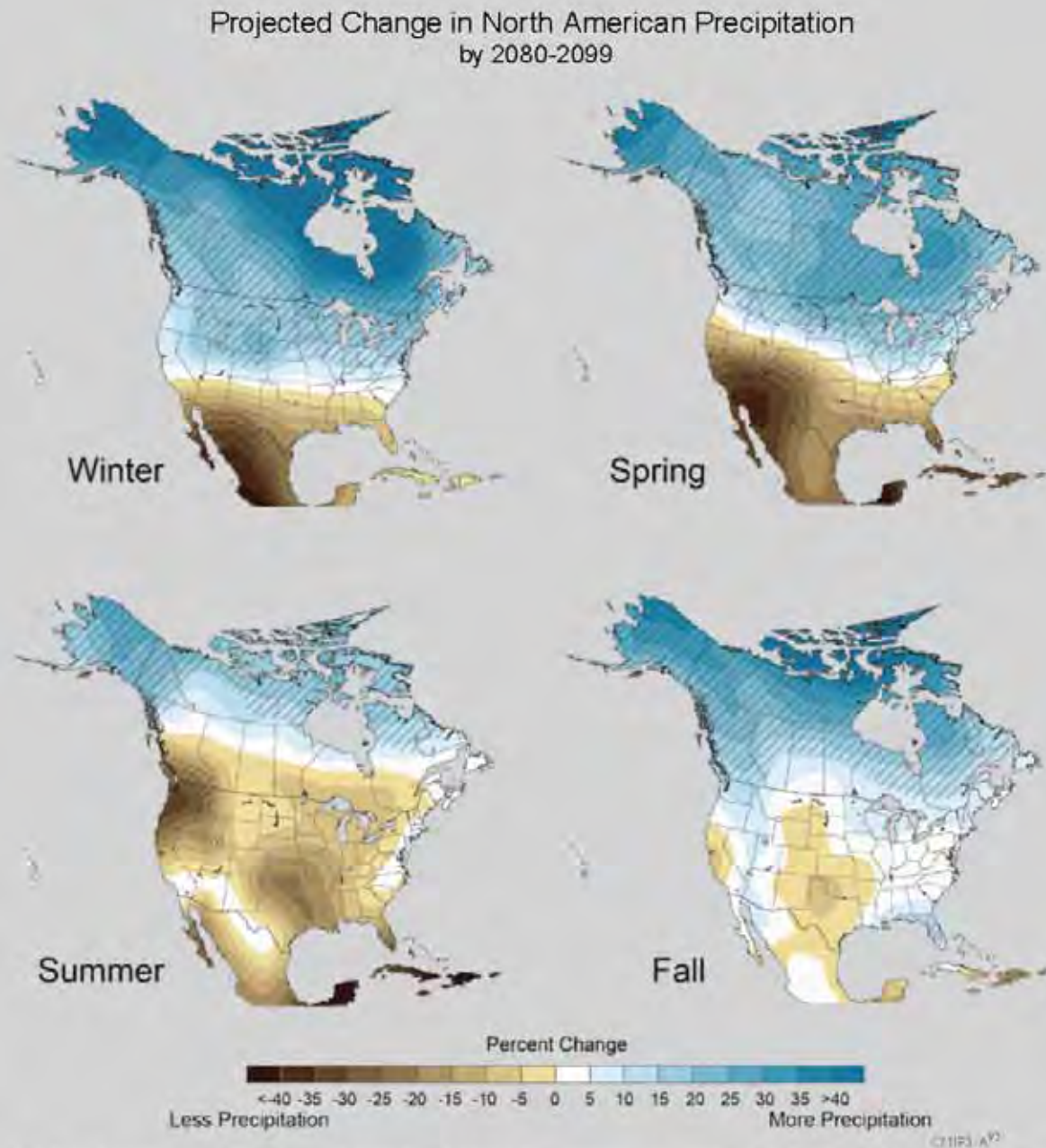


Figure 4. Geographic distribution of summer stormflow trends, 1950-2006.

Projected Mean Precipitation Increase by 2090

- **Wetter - North**
- **Drier - South**
- **For NE**
 - +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.²¹ 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.

Extreme Weather (precip.)

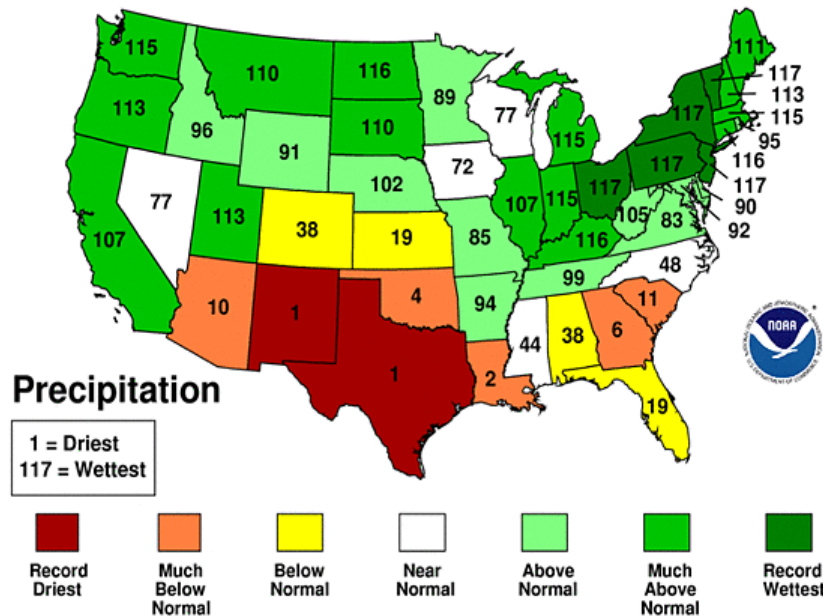
- Precip. is condensation of atmospheric water vapor - large latent heat release drives storms
- *Saturation vapor pressure at cloud-base increases steeply with temperature (6%/°C)*
- Quasi-stationary large-scale flow means longer rain events in low-pressure convergent regions, and longer droughts in high-pressure divergent regions
- *As climate changes, quasi-stationary large-scale modes appear to be more frequent*
 - *Cause may be Arctic warming*

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

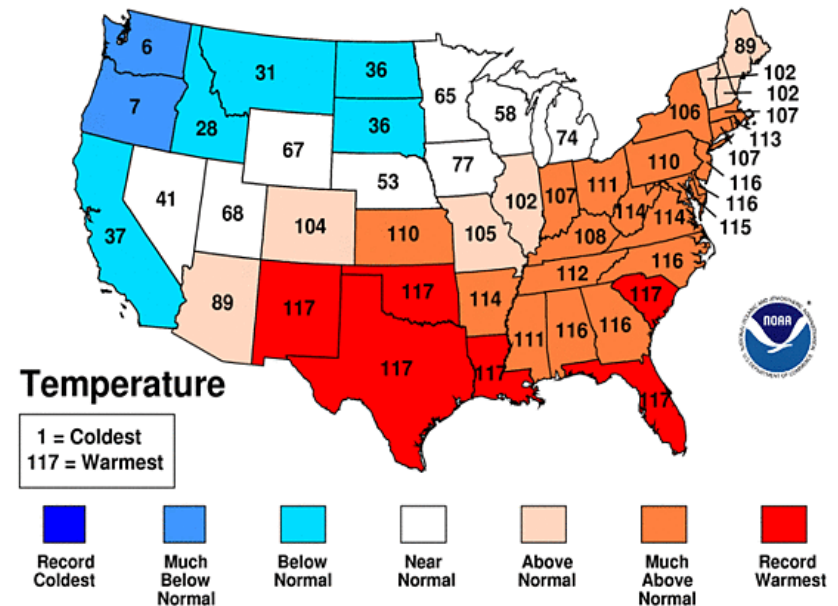
March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



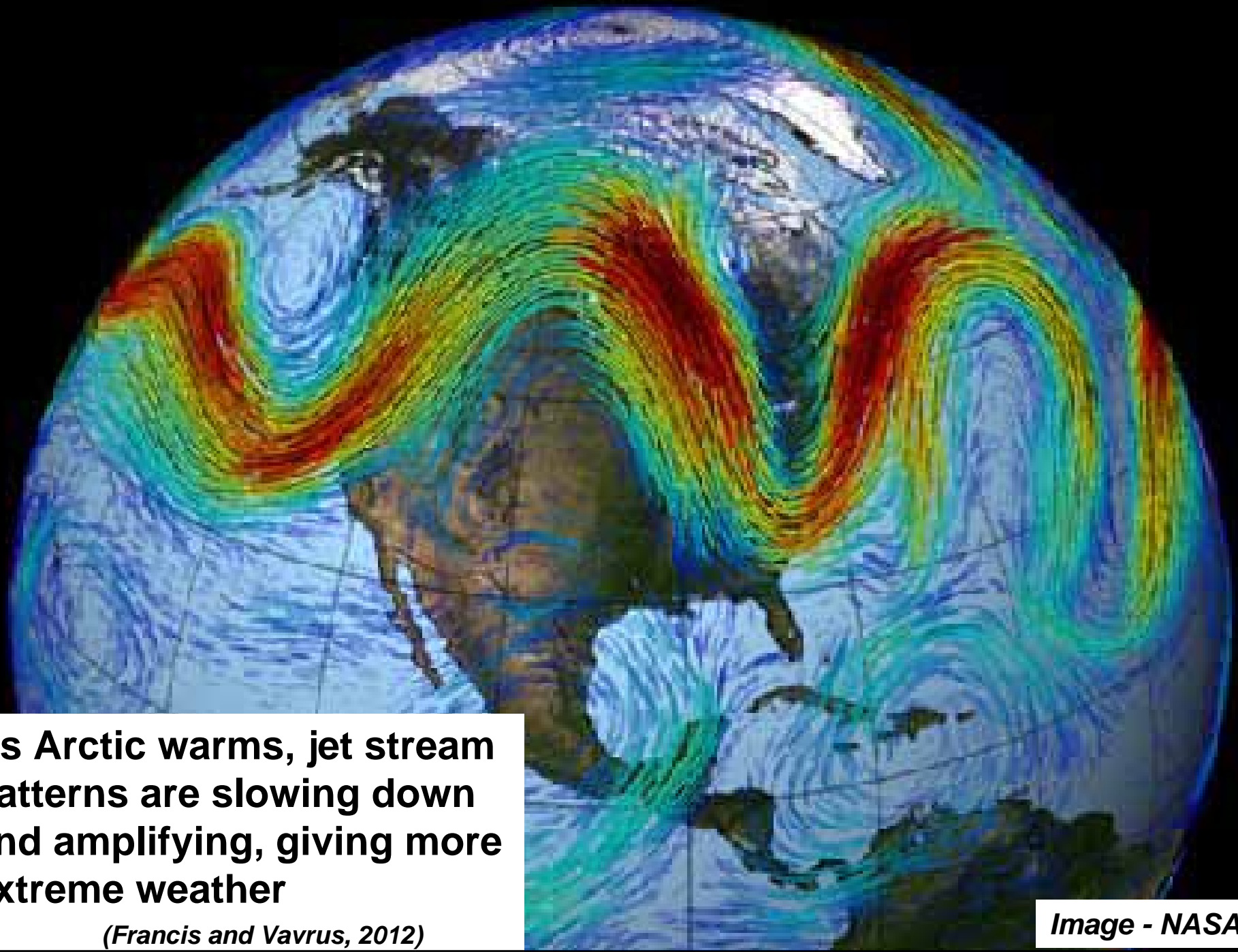
March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



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)



As Arctic warms, jet stream patterns are slowing down and amplifying, giving more extreme weather

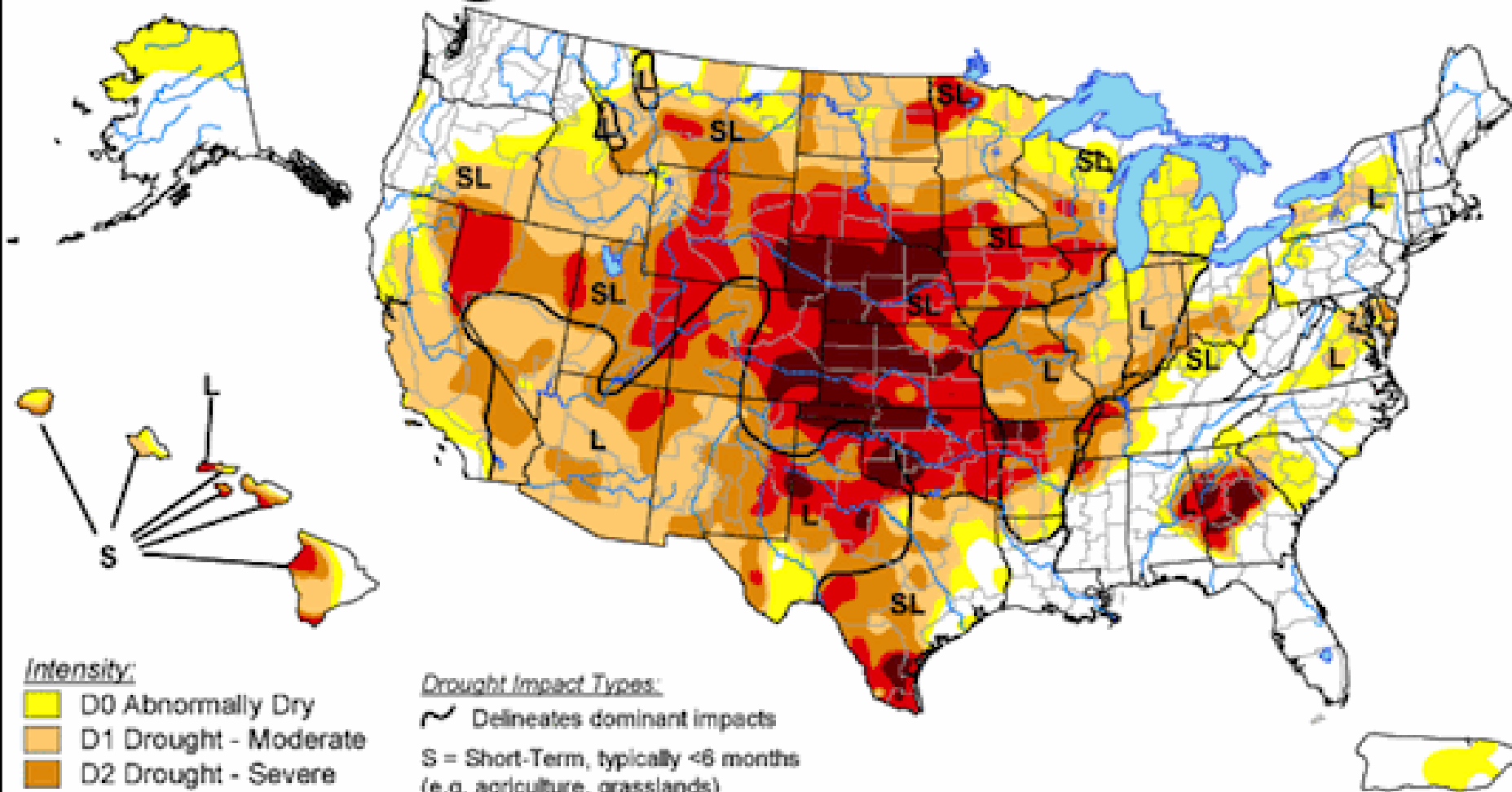
(Francis and Vavrus, 2012)

Image - NASA

U.S. Drought Monitor

September 25, 2012

Valid 7 a.m. EDT



Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

- ~ Delineates dominant impacts
- S = Short-Term, typically <6 months
(e.g. agriculture, grasslands)
- L = Long-Term, typically >6 months
(e.g. hydrology, ecology)

The Drought Monitor focuses on broad-scale conditions.
Local conditions may vary. See accompanying text summary
for forecast statements.

<http://droughtmonitor.unl.edu/>



Released Thursday, September 27, 2012

Author: Anthony Artusa, NOAA/NWS/NCEP/CPC

Sea-level Rise Will Eventually Flood Coastal Cities

- Late 20th-century sea-level rise: 1 foot / century
- 21st century: Likely to triple to 3 - 4 feet / century
 - And continue for centuries (accelerating for business as usual)
- *<http://www.nature.com/news/us-northeast-coast-is-hotspot-for-rising-sea-levels-1.10880>*

Many Challenges Face Us

- **Extreme weather: Floods, fires, & drought**
 - **32 weather disasters >\$1B in 2011**
- **Melting Arctic and permafrost—methane release is positive feedback**
- **Ecosystem collapse, including perhaps forest and ocean ecosystems**
- **Collapse of unsustainable human population**

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**
 - **Can we “sequester” CO₂ (put it back in the earth)?**

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”
 - Yet we are still subsidizing fossil fuels
- **Politics lost in fantasy**
 - Ignoring Earth system and climate issues

Why Is It Difficult for Us?

- The “American dream” is crumbling
 - “Economic growth” based on **fossil fuels, debt, and consumerism is unsustainable** — and a 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 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 processes & limits**

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*