Climate Change in Vermont: What We Can Expect.

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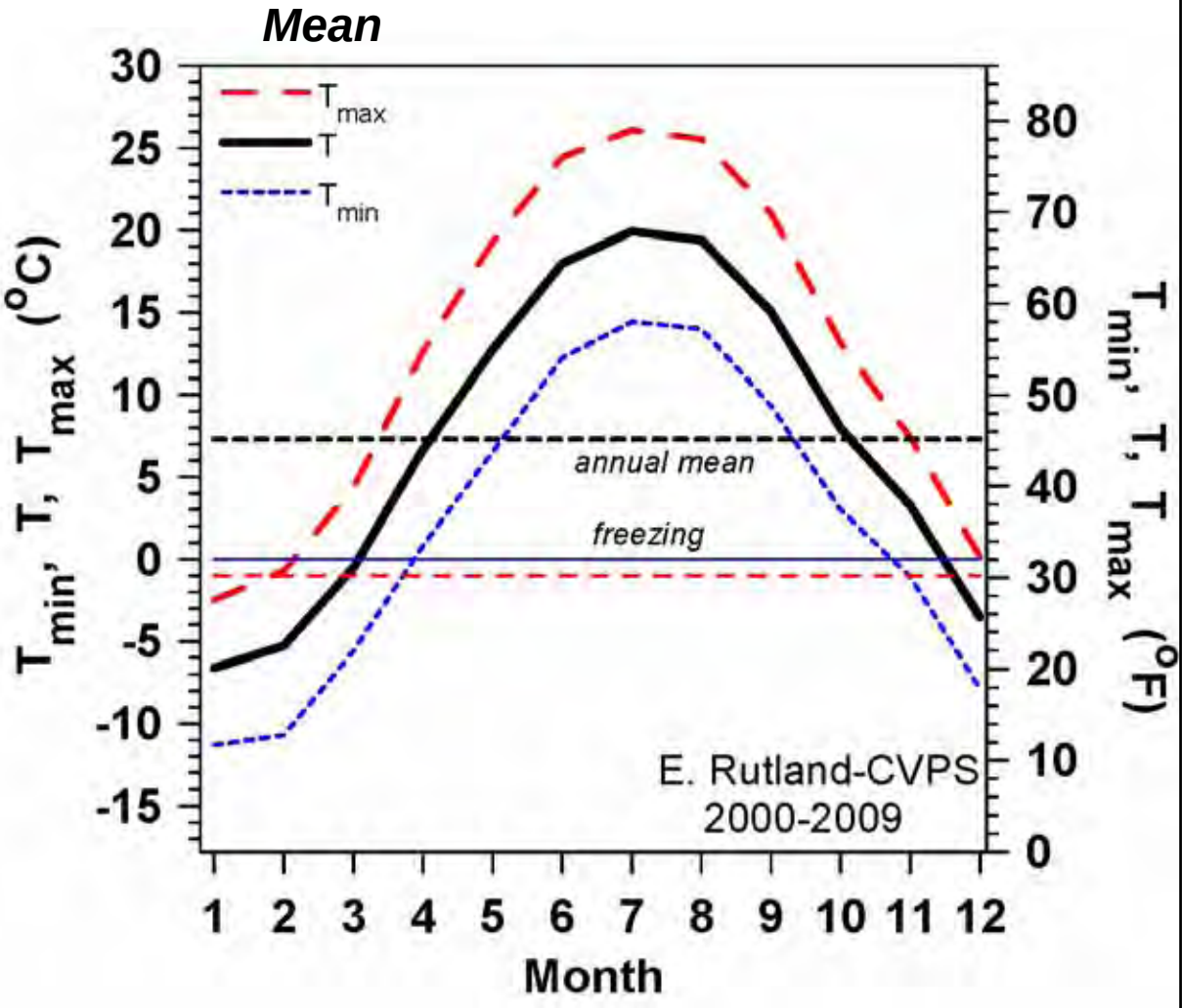
One World Conservation Center
Bennington, VT

October 18, 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**

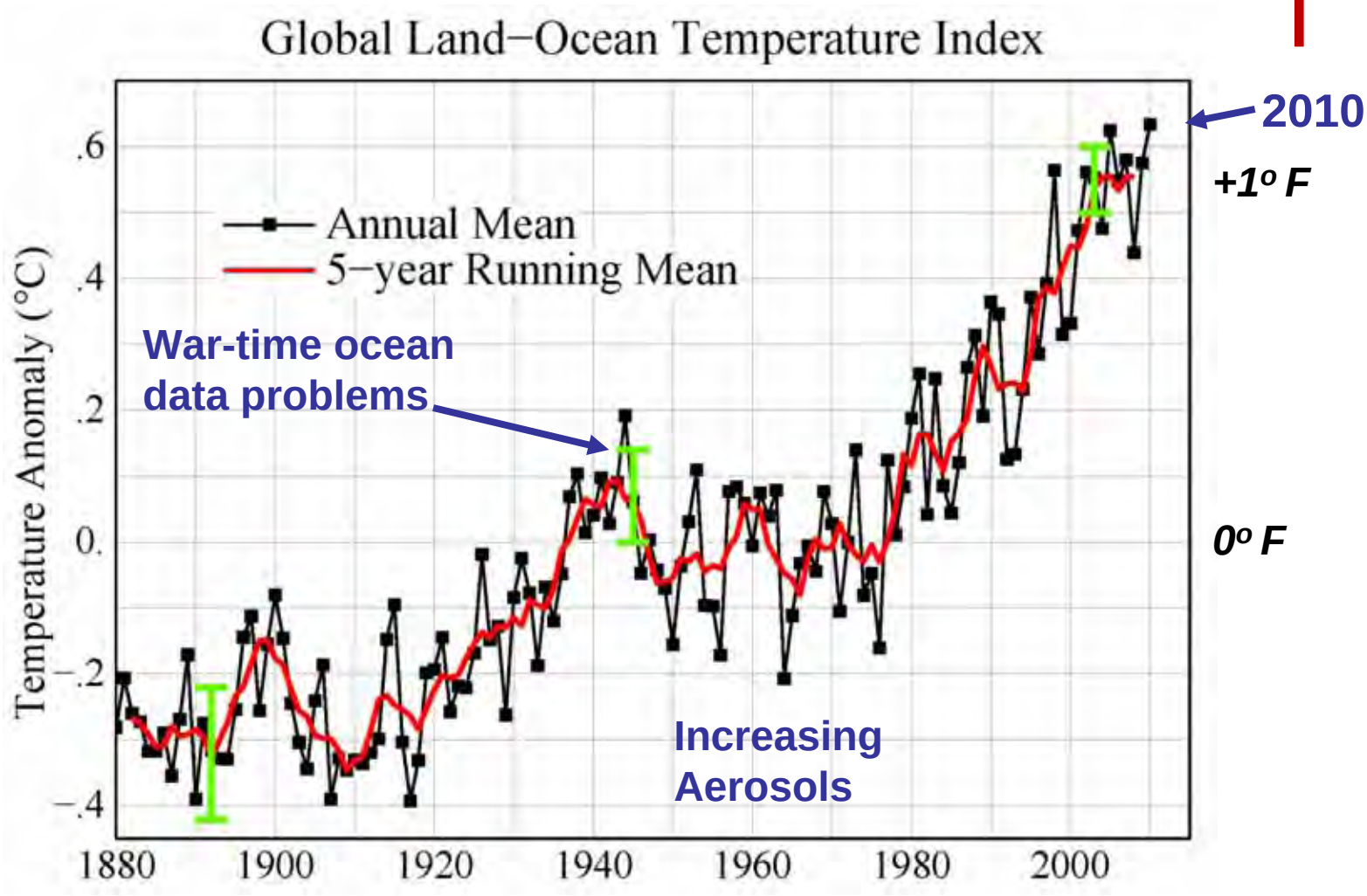
January 2, 2012: NASA

Global to Local

January 2, 2012

July 29, 2012
(Rutland storm)

Global Temperature Rise 1880 – Present



NASA-GISS, 2011

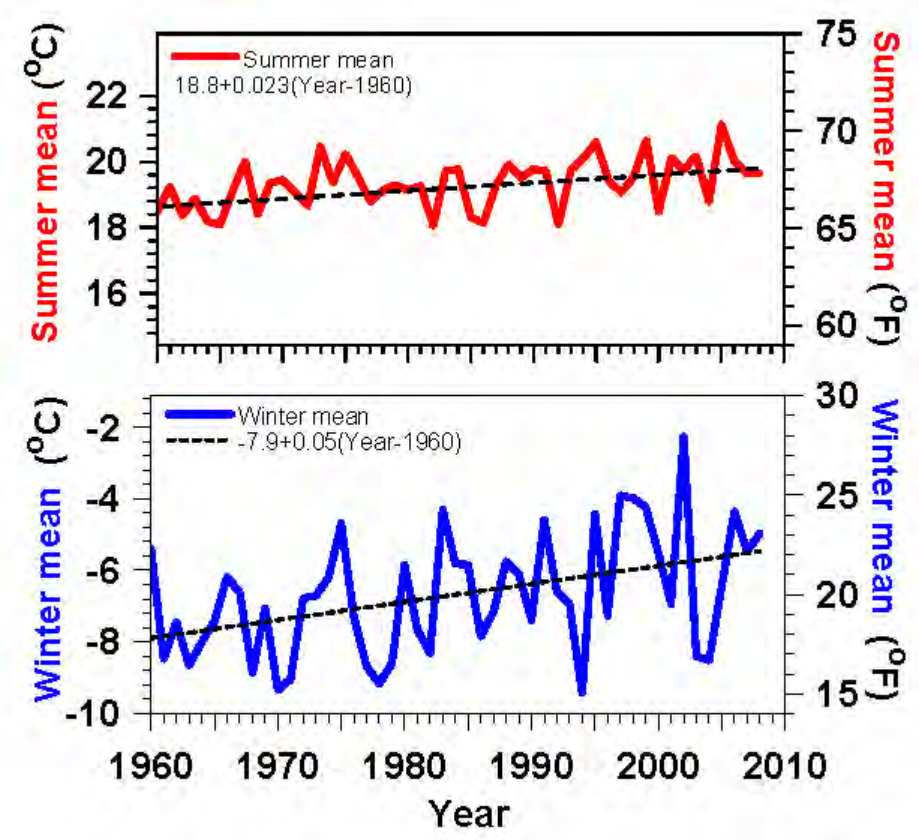
What Is Happening to Vermont?

- **PAST 40/50 years** **(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**

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

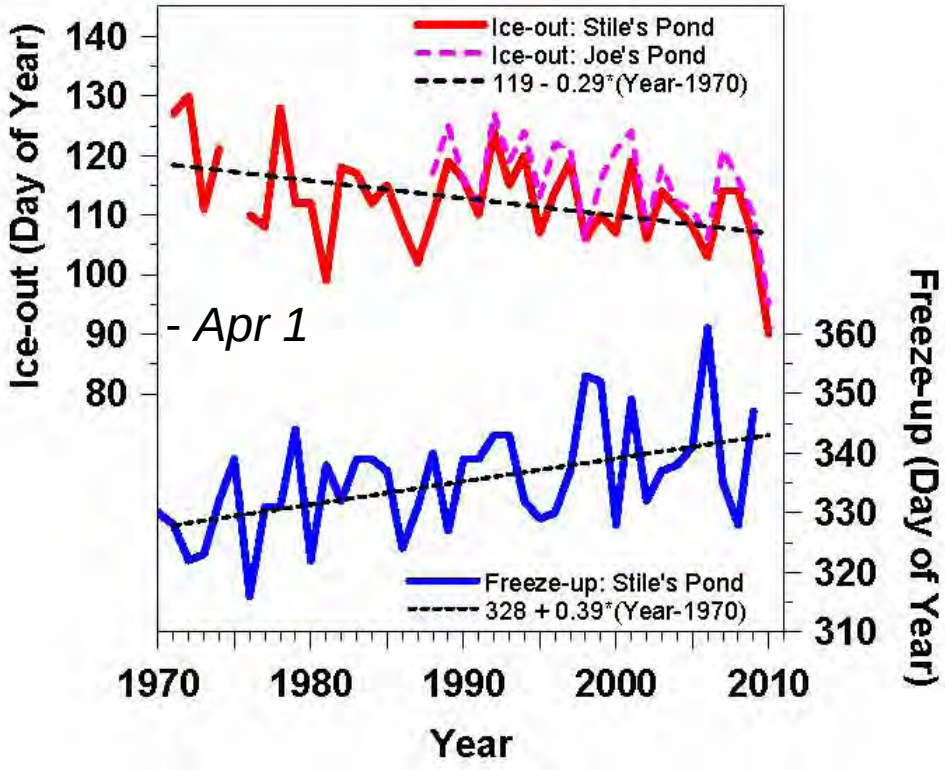
Vermont Temperature Trends
1961-2008

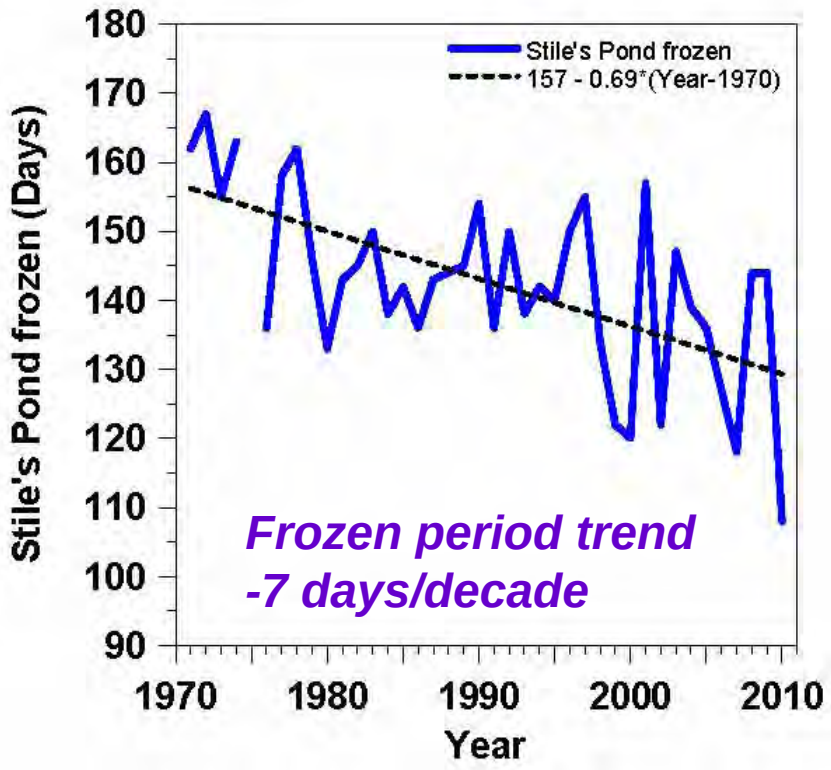
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***



Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast

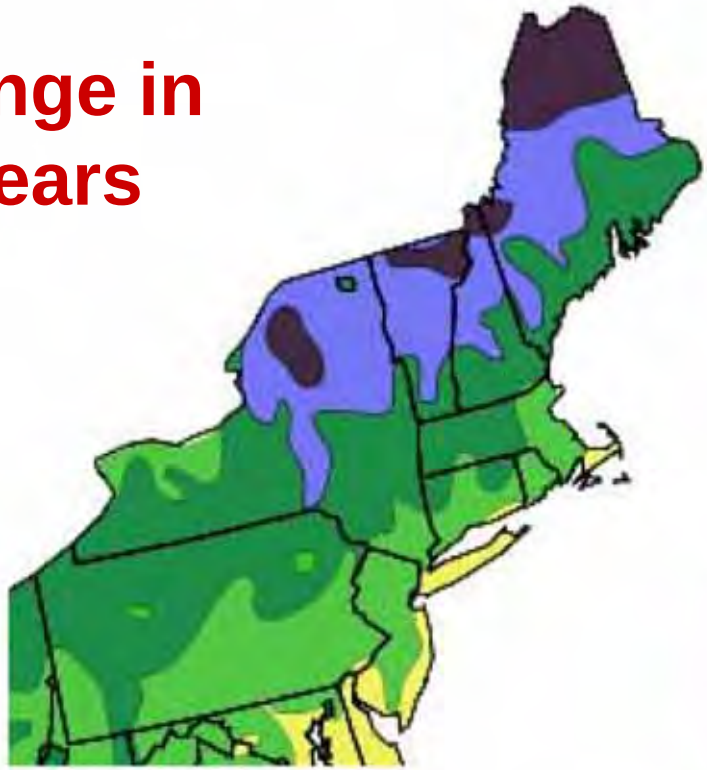




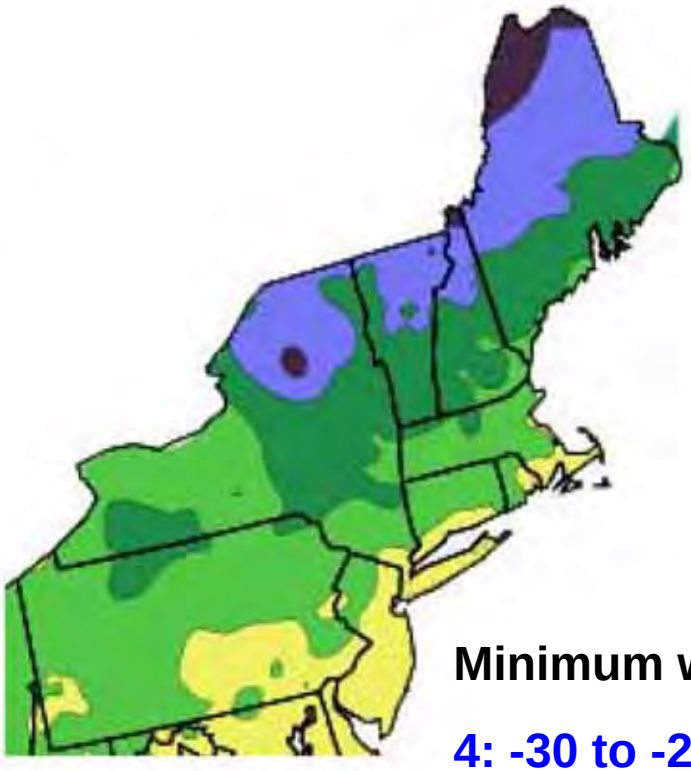
- **Ice-out earlier by 2.9 (±1.0) days / decade**
- **Freeze-up later by 3.9 (±1.1) days / decade**
- ***Rivers and soils similar?***

Winter Hardiness Zones - Northeast

Change in 16 years



1990



2006

Minimum winter T

4: -30 to -20°F

5: -20 to -10°F

6: -10 to 0°F

Zone

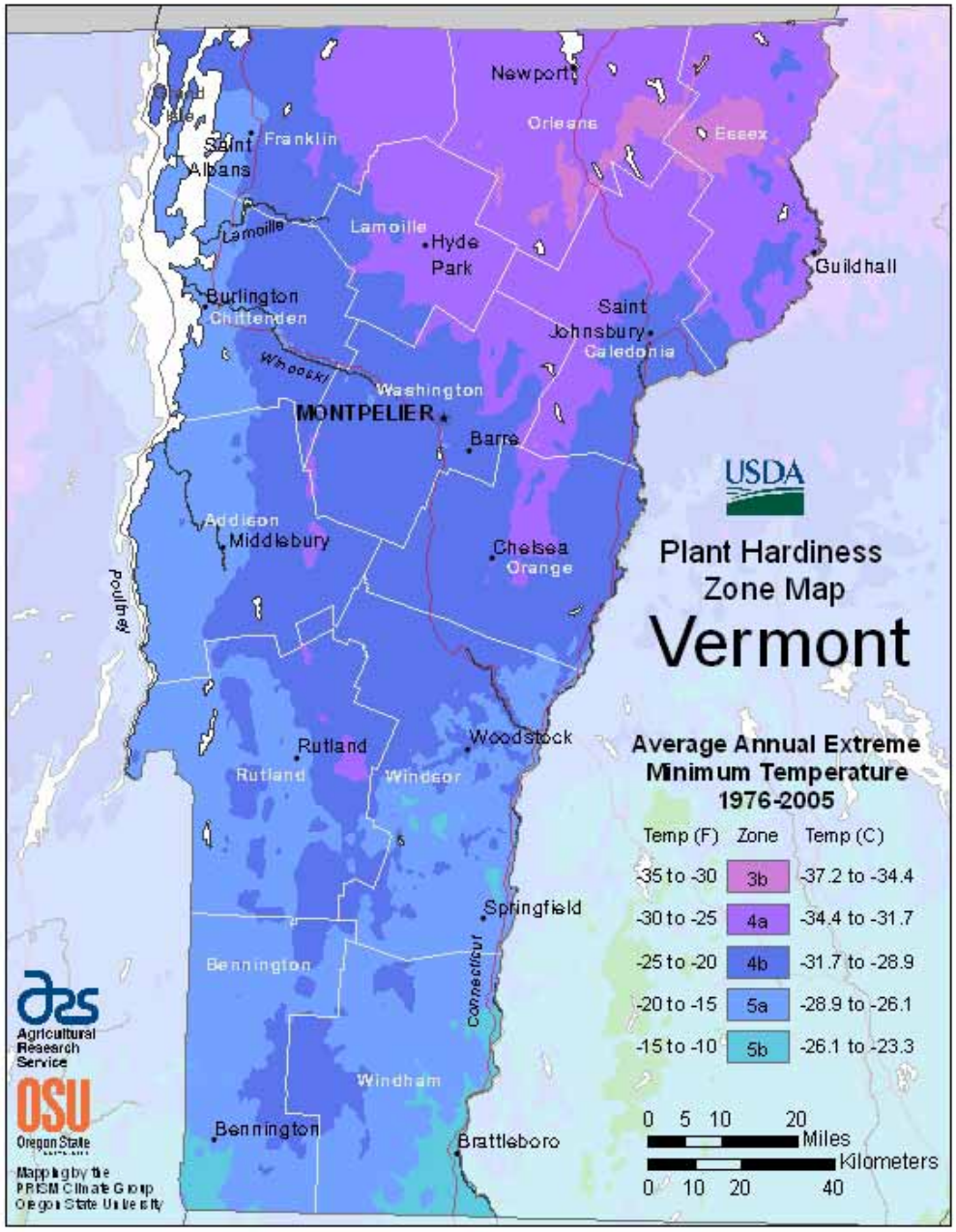
2 3 4 5 6 7 8 9 10

USDA Hardiness Zones

© 2006 by The National Arbor Day Foundation®

Latest detailed map

- **USDA : VT Hardiness Zone Map 1976-2005 [mean 1990]**
- **A trend of half a zone in 16-20 years is +2.5-3.1ºF/decade [triple the rise of winter mean]**
- **http://planthardiness.ars.usda.gov/PHZMWeb/**



Bennington almost zone 6

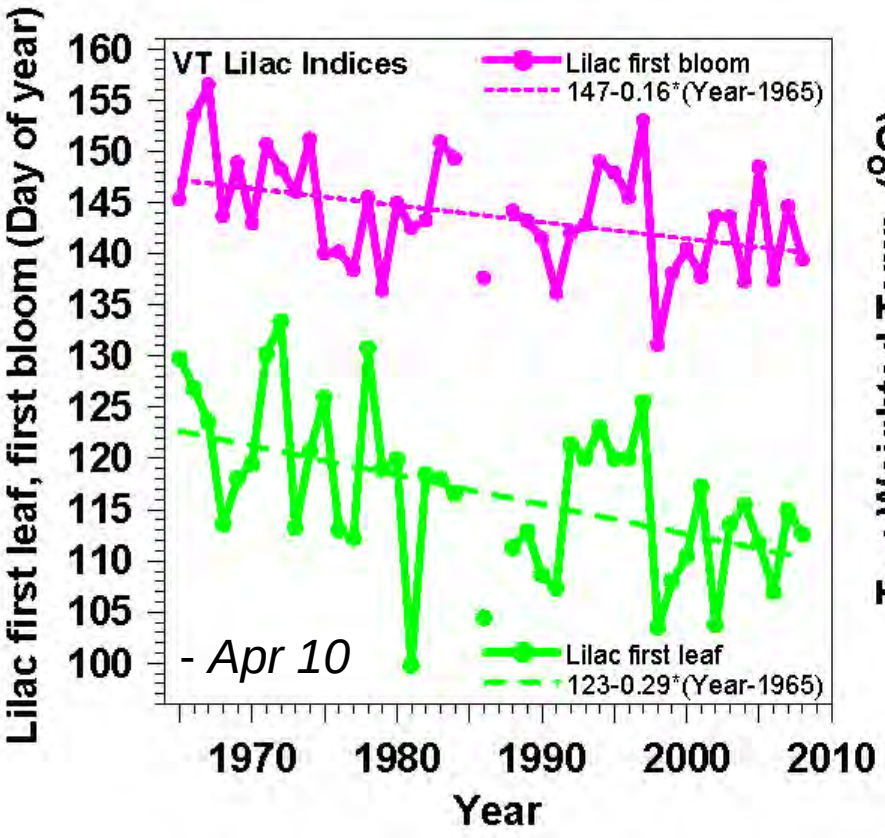
- **Hardy peaches**
  - **2012**
- **What is this?**

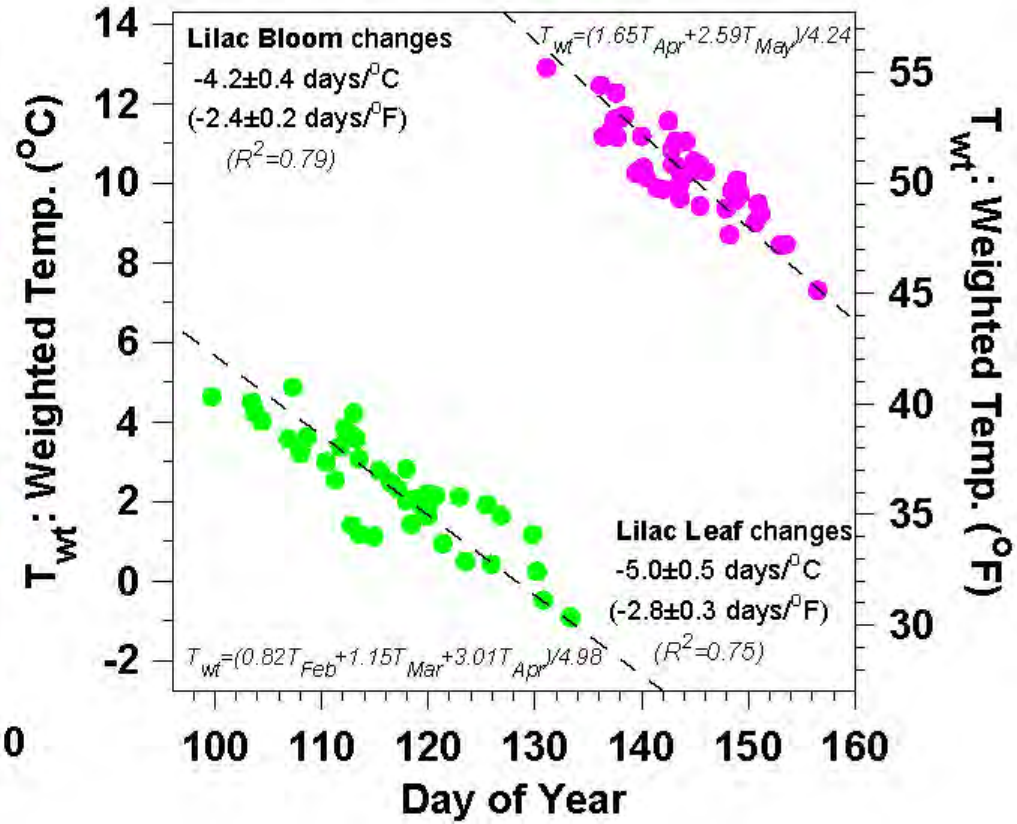
Bennington almost zone 6

- **Hardy peaches**
  - **2012**
- **What is this?**

- **Avocado**
  - **Won’t survive**
  - **Until 2100**
  - **Grand-children**

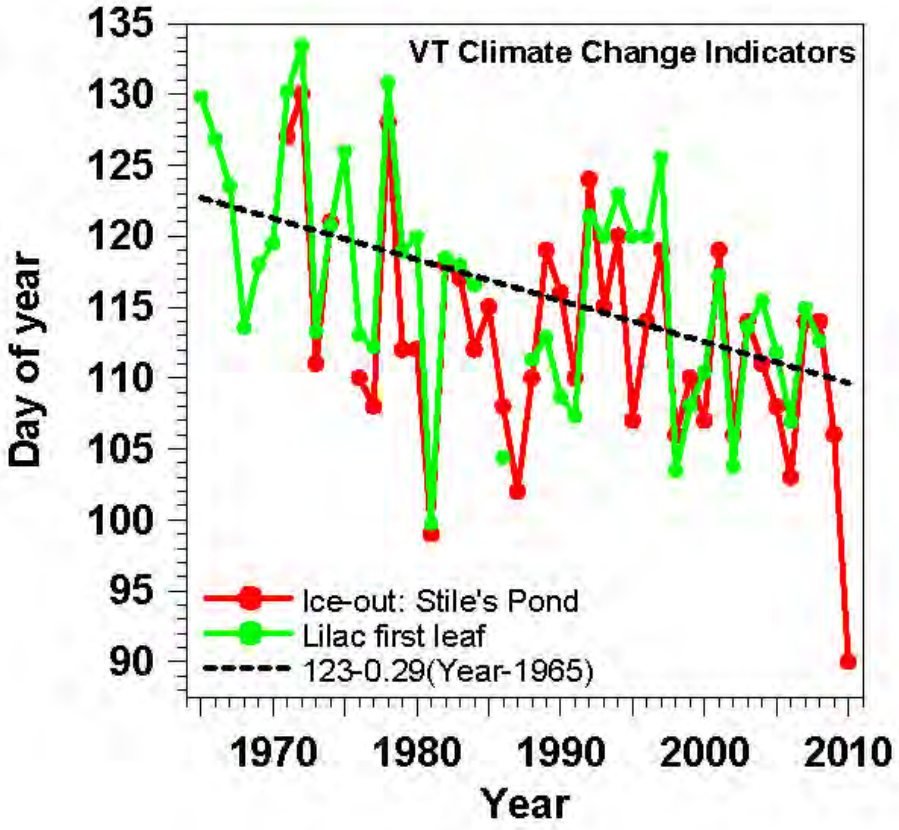
Lilac Leaf and Bloom

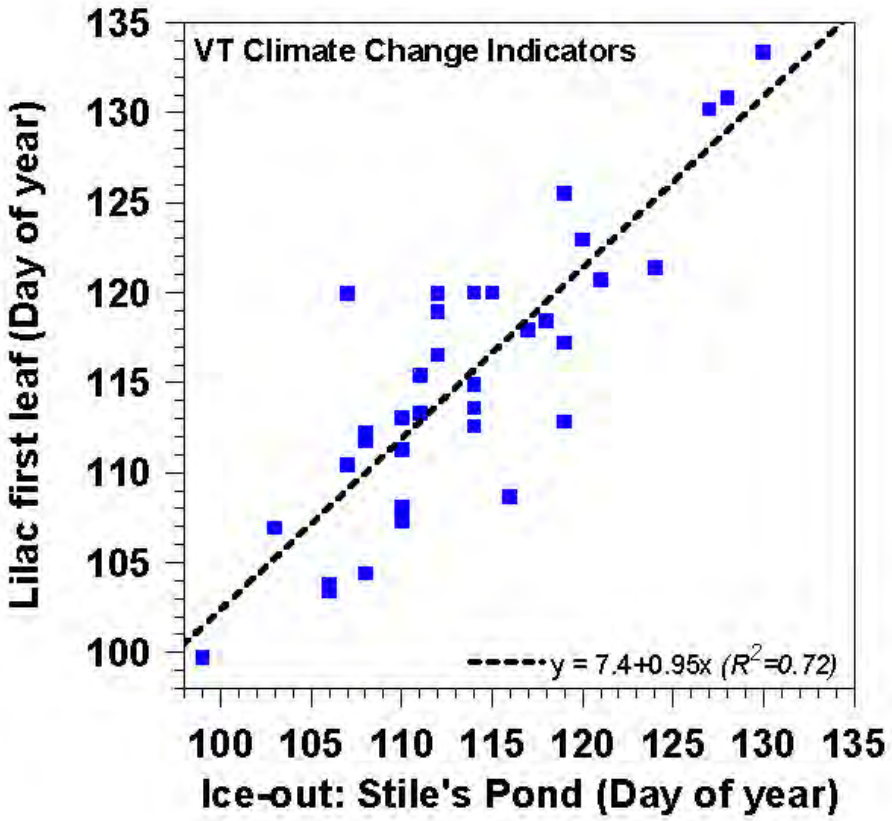




- **Leaf-out -2.9 days/decade; Bloom -1.6 days/decade**
- **Large year-to-year variation related to temperature: 2 to 3 days/ ºF**

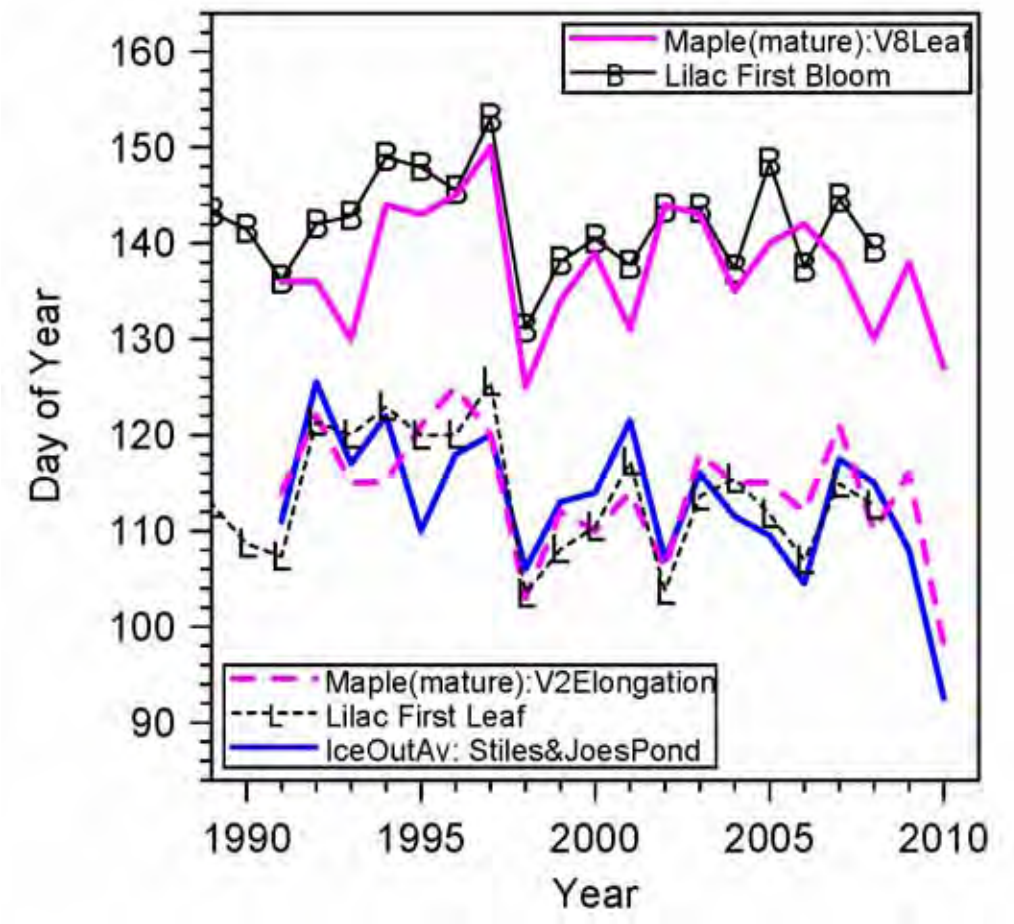
Lilac Leaf-out and Ice-out Coupled





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

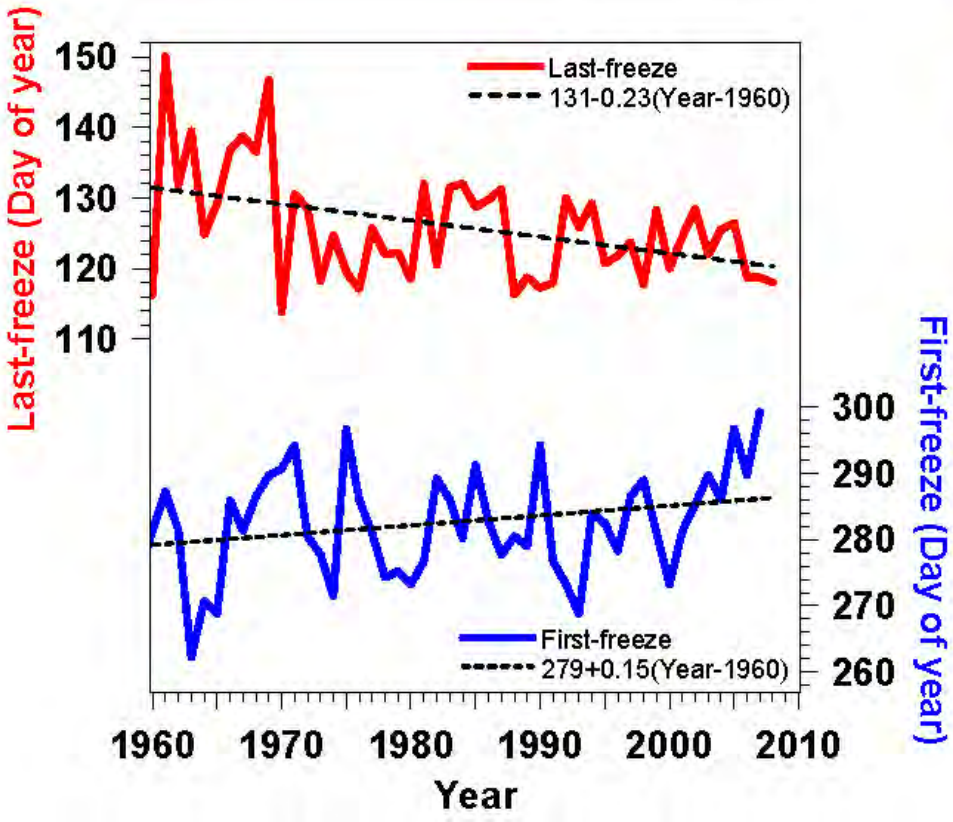
Sugar Maples in Spring

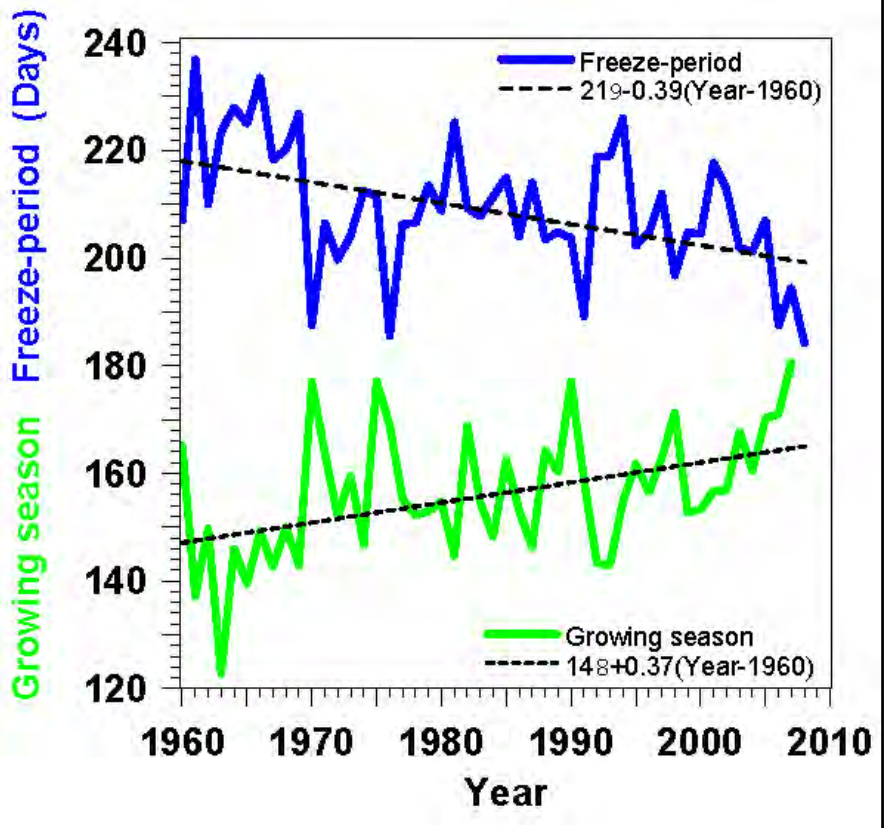


- **Ice-out, lilac leaf, maple bud elongation correlated**
- **Lilac bloom and maple leaf-out correlated**

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

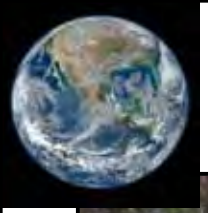
December 2006:

- **Warmest on record**

January 10, 2008

Warm Fall:

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

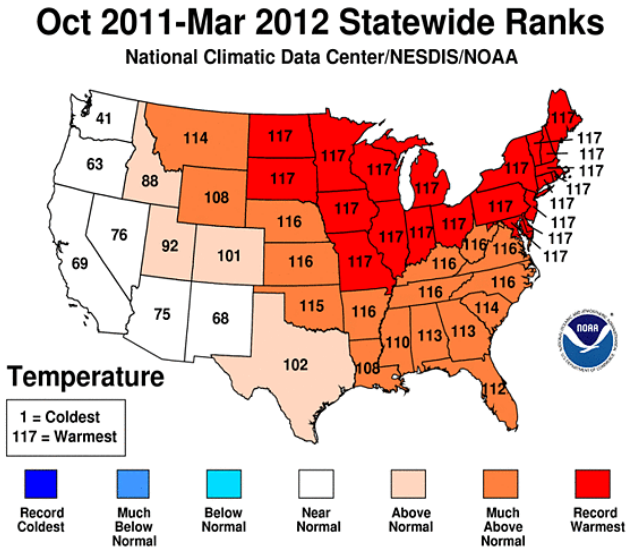


January 2, 2012

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**



Early Spring: Daffodils, Forsythia

79ºF on March 22, 2012

Pittsford Vermont

3/22/12

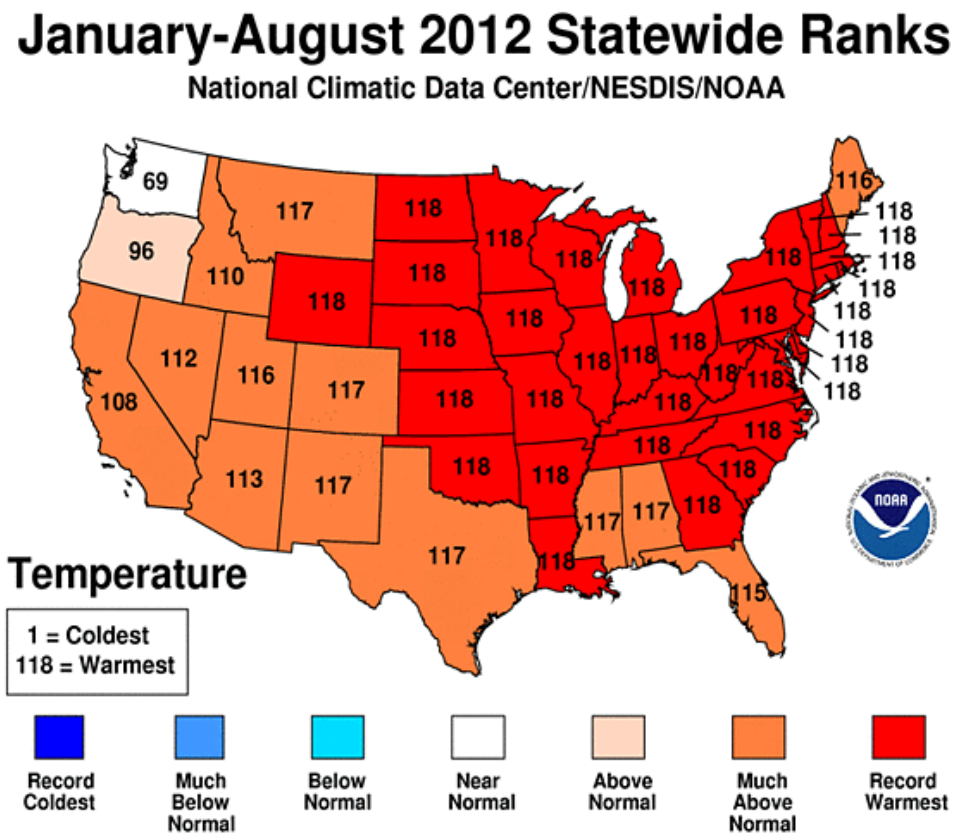
Pittsford Vermont

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)



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

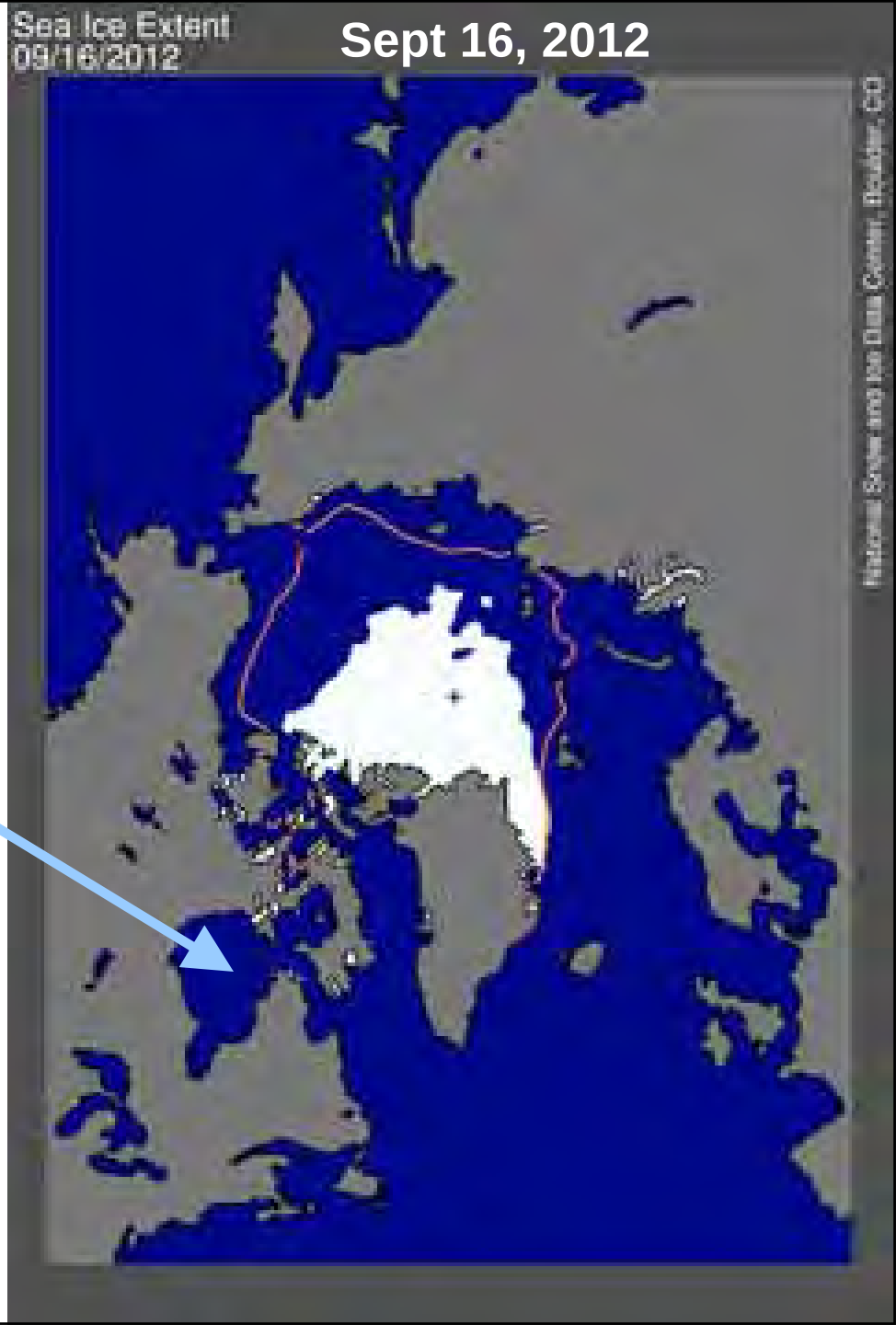
Vermont Winter 2006

- **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)***

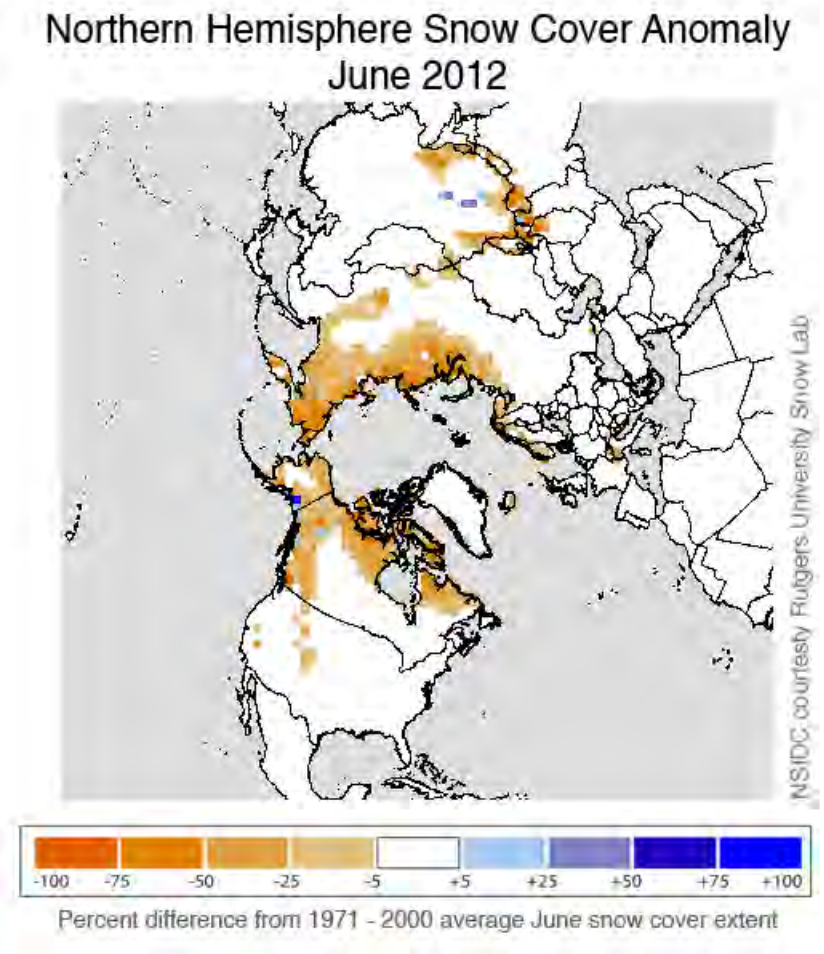
- **Half the Arctic Sea Ice Melted in 2012**
- **Open water in Oct. Nov. gives warmer Fall in Northeast**

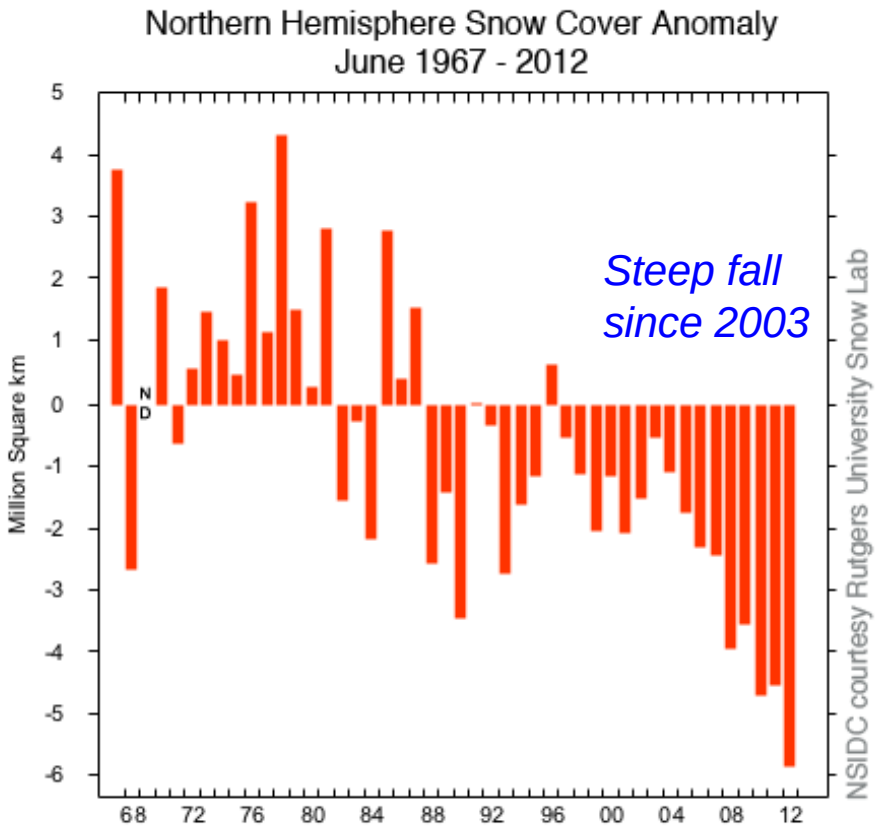
At the end of Nov. 2011 Hudson Bay was still nearly ice-free

- ***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





- **New minimum by 10^6 km^2 (1971-2000 ref)**

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***

Recently Many Wet Summers in Vermont

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

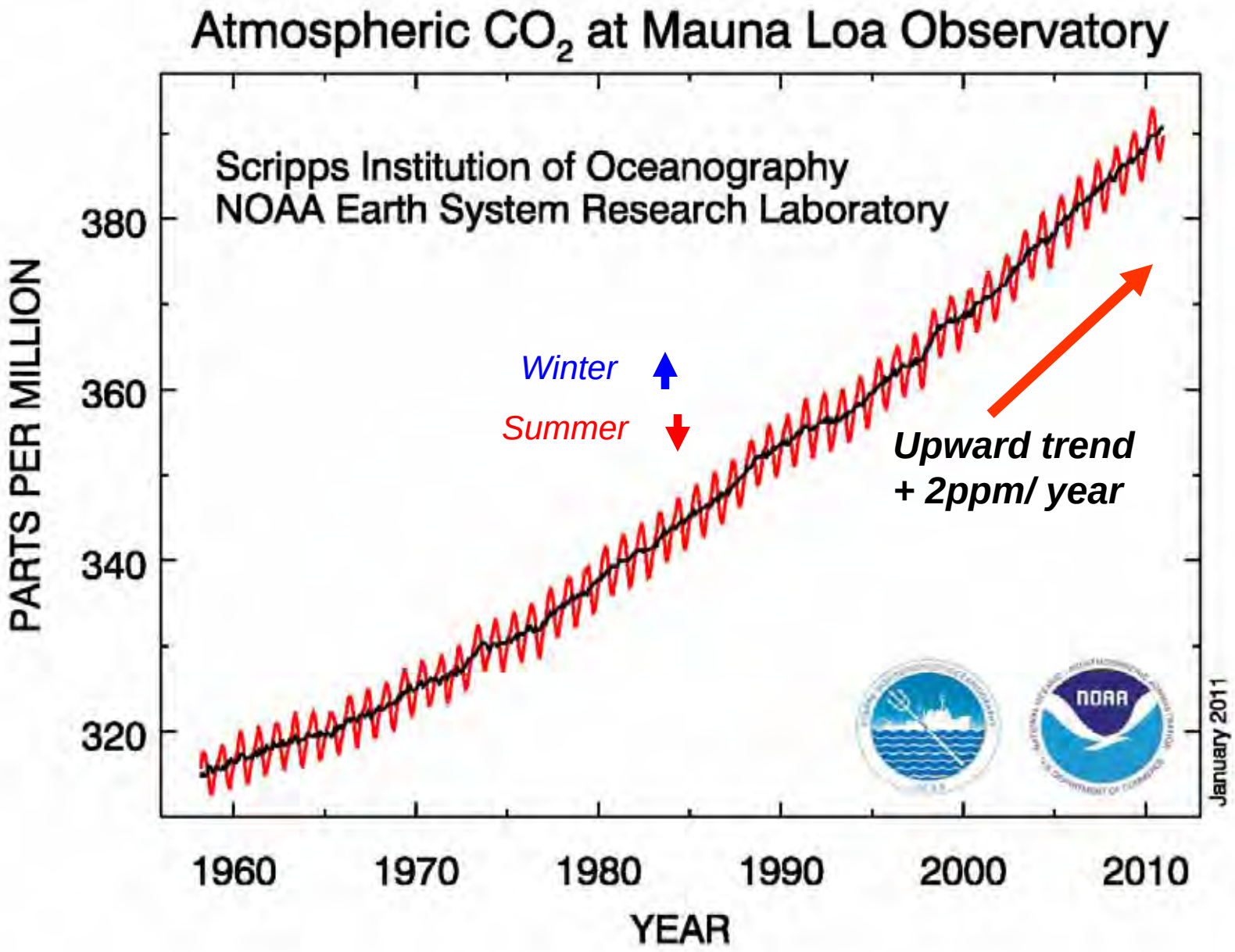
Fall Climate Transition

- **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

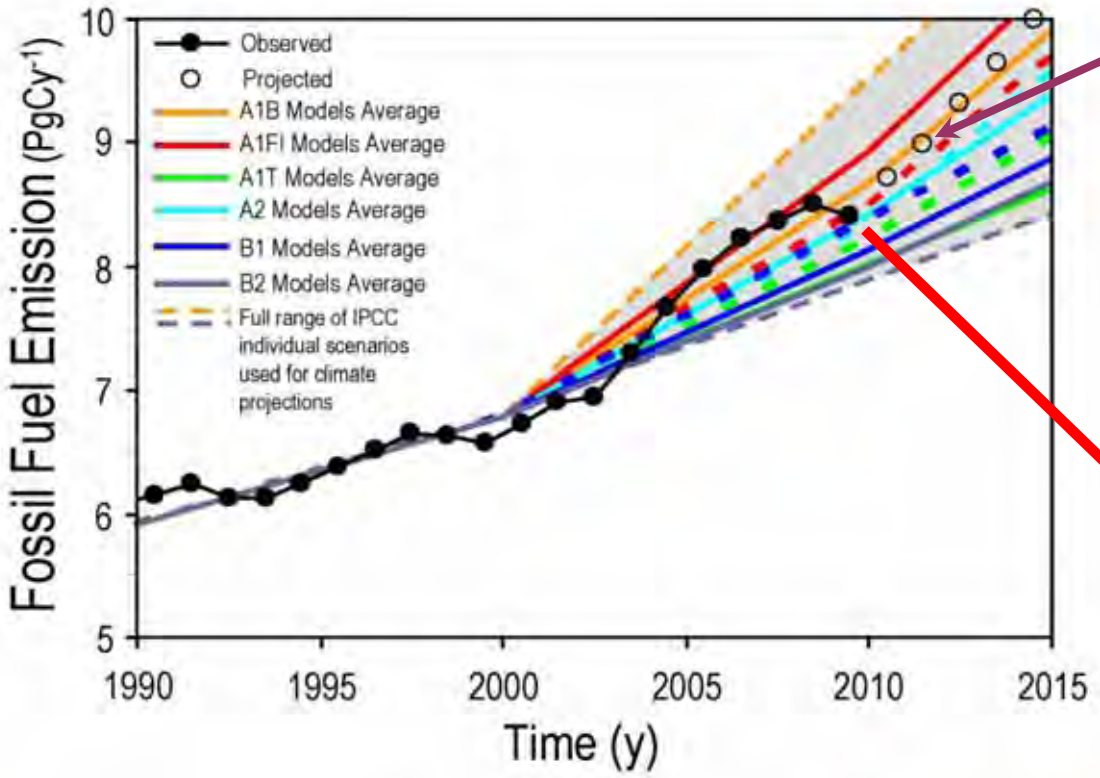
Later frost: Growing season getting longer

Carbon Dioxide Is Increasing



2009 Was “Good” for the Earth

Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Back on growth: 2010, 2011

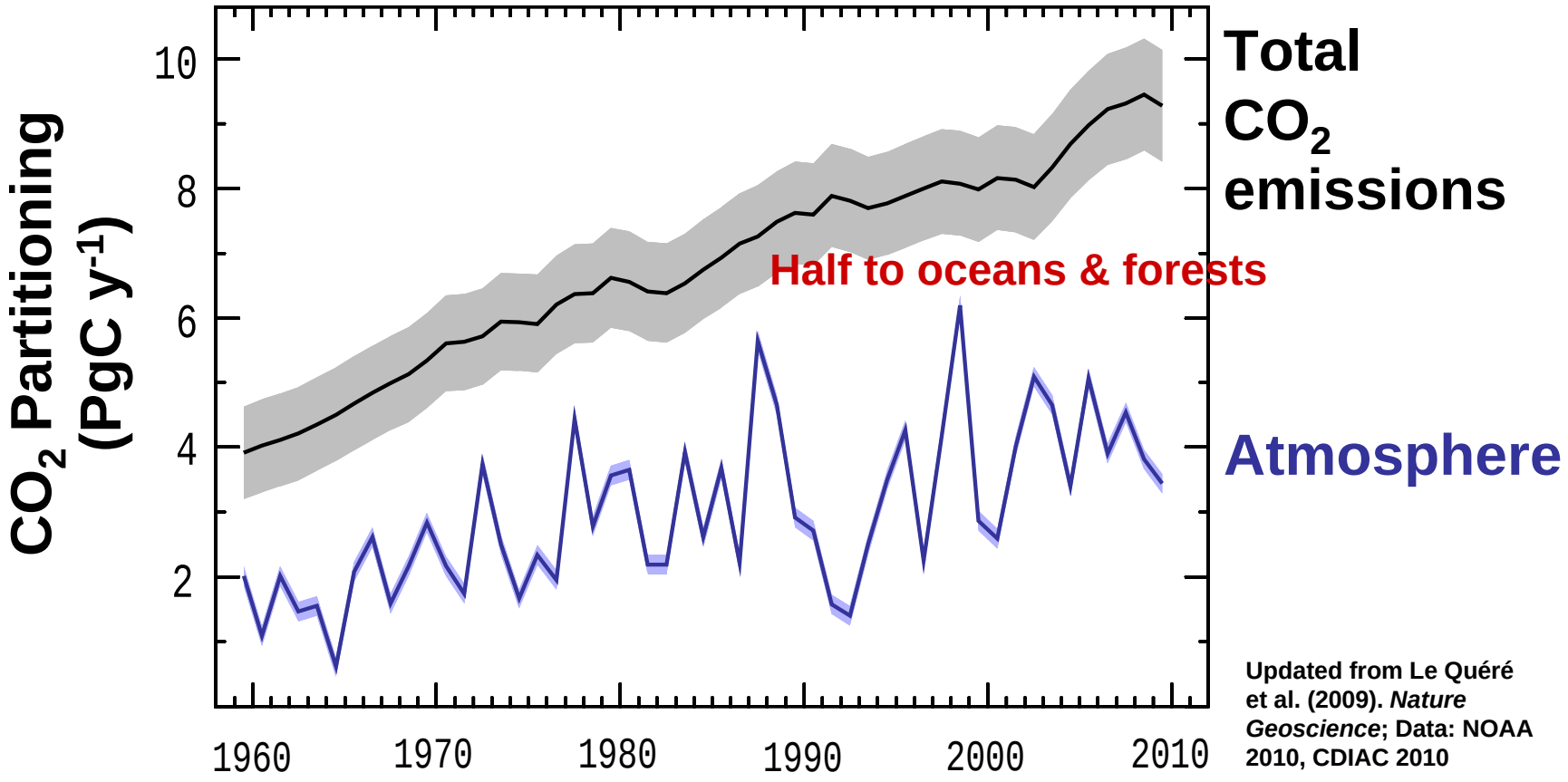
Emission Scenarios

- 4%/year

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

Key Diagnostic of the Carbon Cycle

Evolution of the fraction of total emissions that remain in the atmosphere

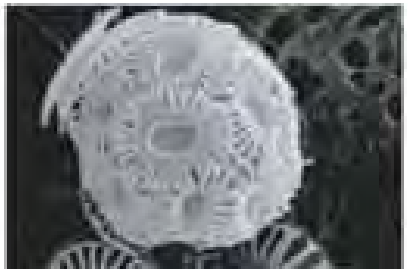


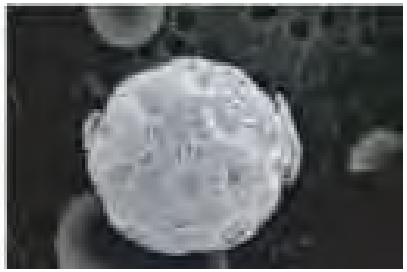
It takes at least a century to remove CO_2 from the atmosphere, and many centuries to remove it from oceans

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 absorb and reradiate IR from the surface, giving climate suitable for life by warming planet 30^oC**
- **CO_2 rise alone has 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 3°C (5°F)
  - Much more in the North 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:

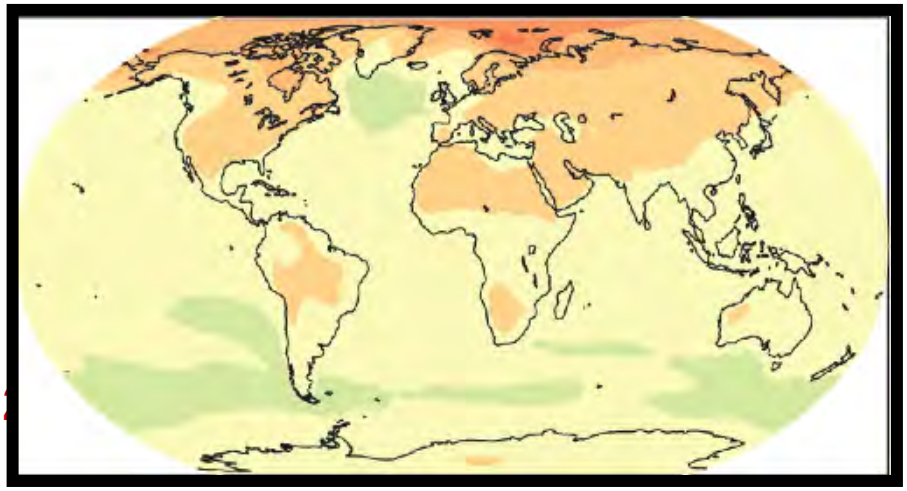
- NH snow extent
- Arctic sea ice
- Glaciers
- Ocean pH (increasing acidity)

(www.ipcc.ch)

Predicted Change in Temperature

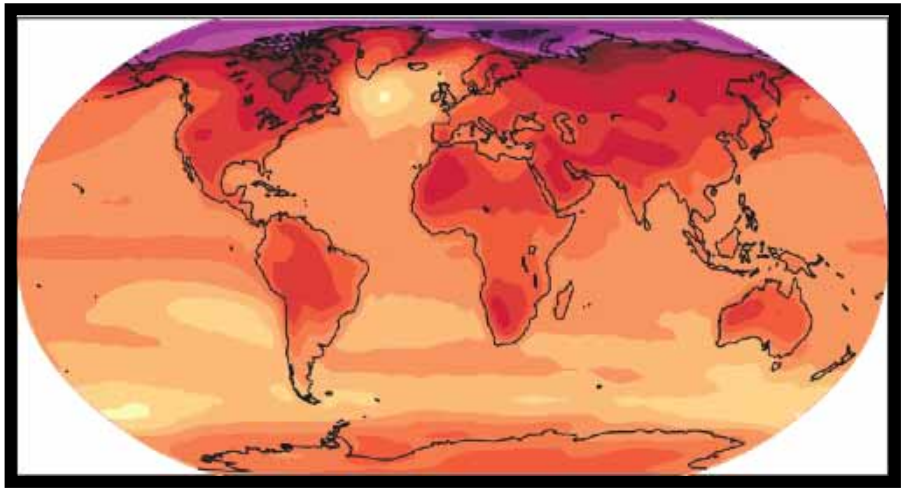
2020-2029 and 2090-2099, relative to 1980-1999 (ºC)

“Committed”

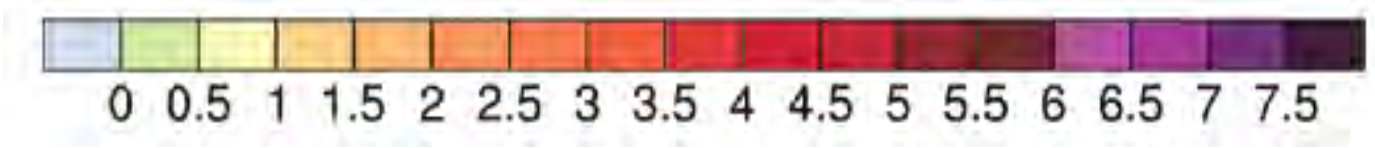


(We did nothing for the last 20 years)

Still up to us!



(We could halve this if we act now)

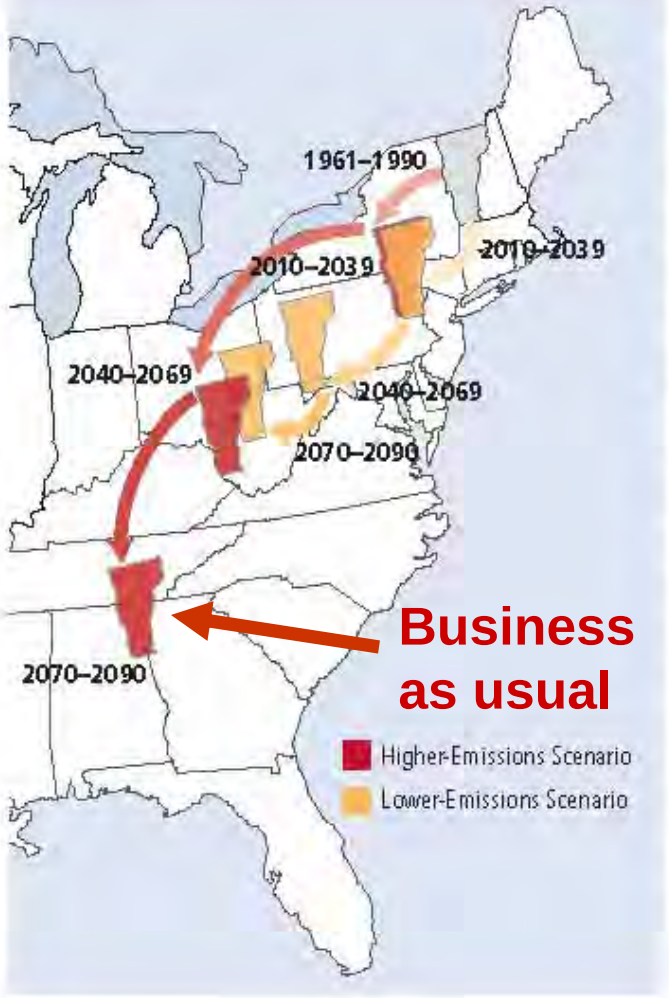


[ºC]

Vermont's Future with High and Low GHG Emissions

What about skiing?

What about tropics?



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

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

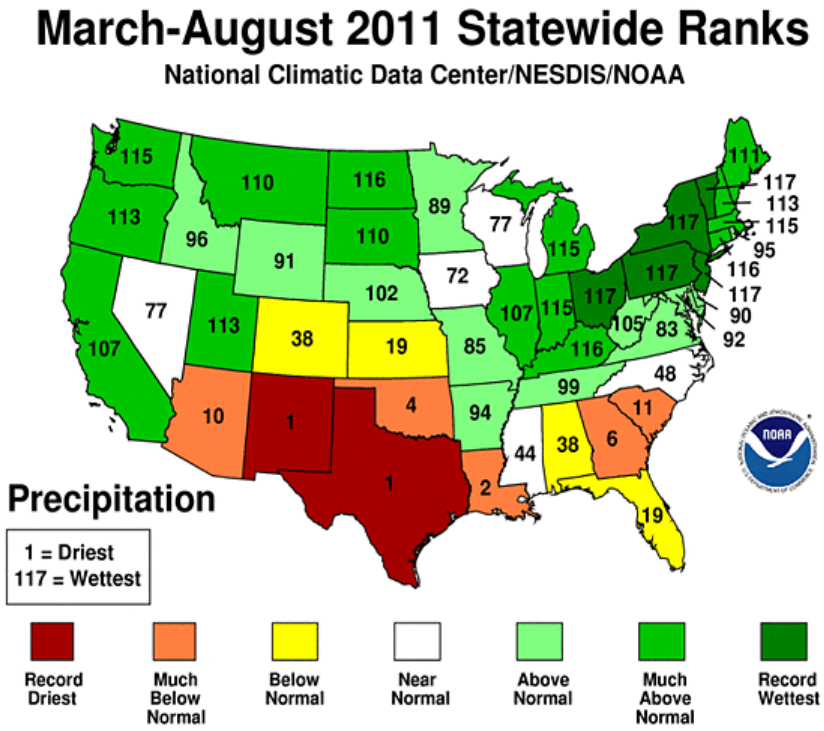
- **Melting Arctic and permafrost—methane release is positive feedback**
- **Ecosystem collapse, including perhaps forest and ocean ecosystems**
- **Collapse of unsustainable human population**

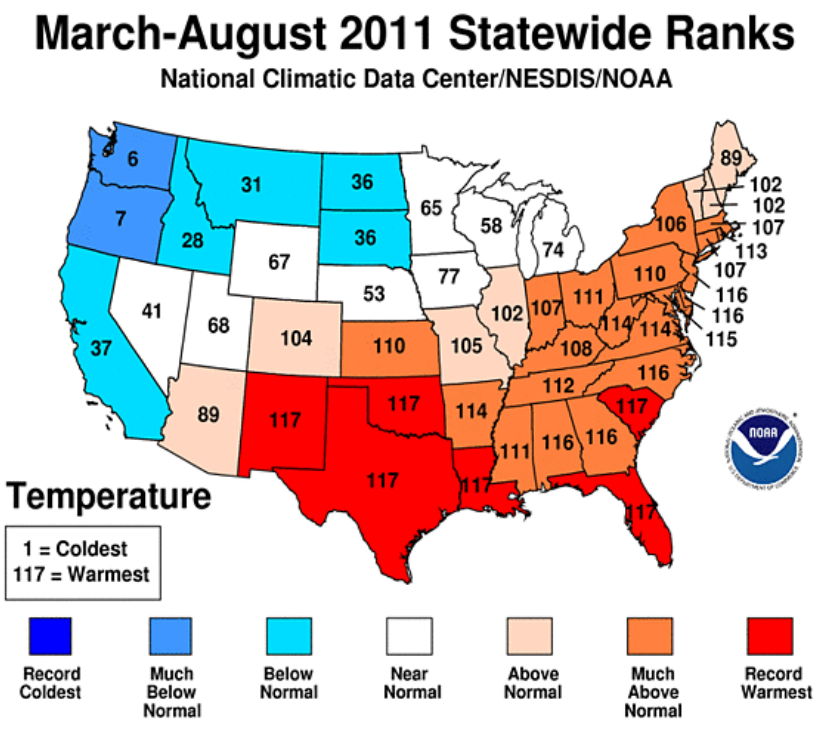
Extreme Weather (precip.)

- ***Precip. is condensation of atmospheric water vapor (large latent heat release)***
- ***Saturation vapor pressure at cloud-base increases steeply with temperature (6%/^{o}C)***
- ***More latent heat organizes storms, increasing convergence of vapor***
- ***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***
- ***Wet surface: more evaporation and runoff***

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***





Winooski River 2011

- **Two classic VT flood situations**
- **Spring flood: heavy rain and warm weather, melting large snowpack**

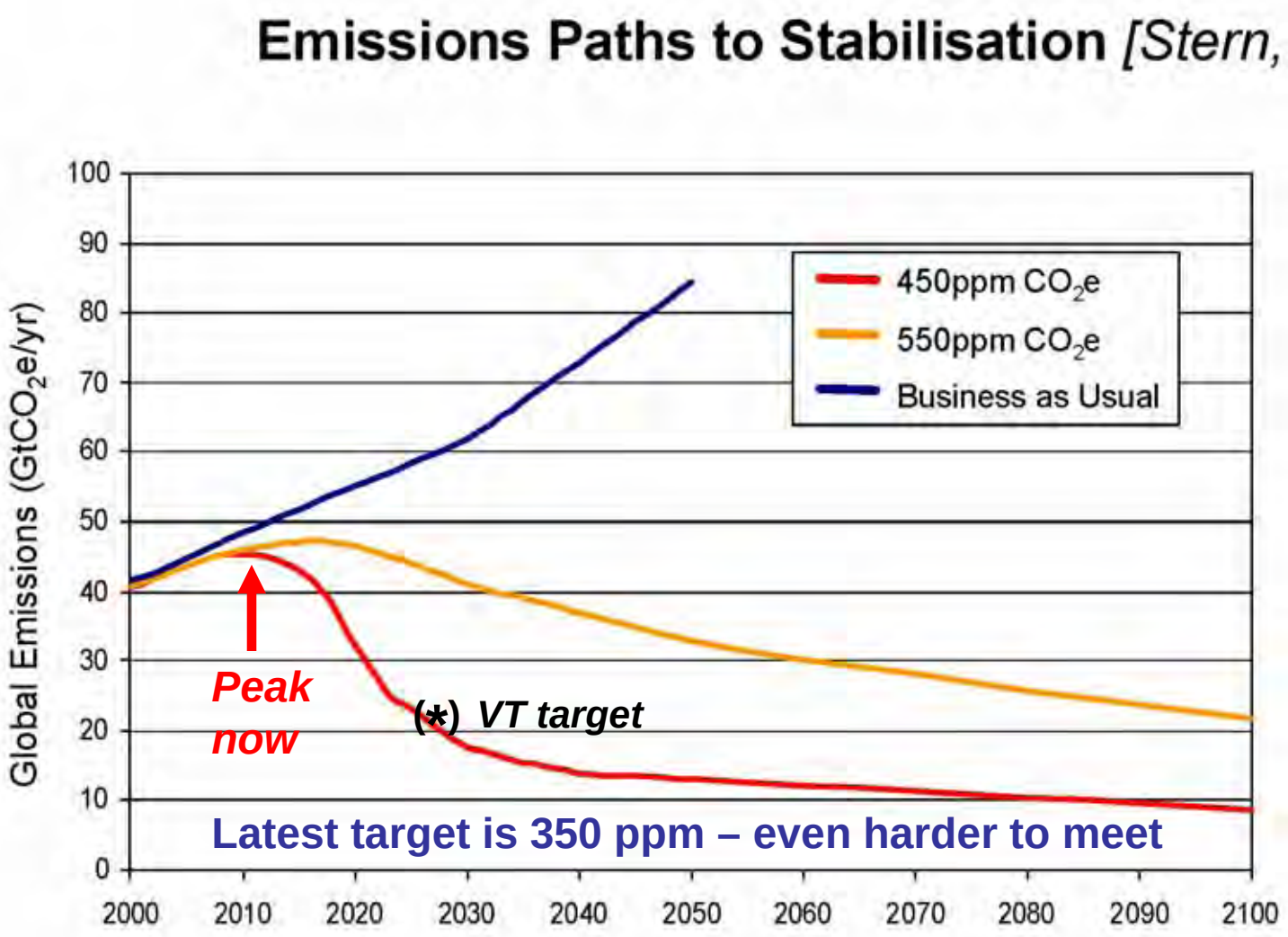
  - 70F (4/11) and 80F(5/27) + heavy rain

  - record April, May rainfall: 3X at BTV
- **Irene flood: tropical storm moved up east of Green Mountains - dumping 6ins rain on wet soils (Floyd on 9/17/1999 had similar rain - but with dry soils there was less flooding)**

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**

How Do We Avoid "Dangerous Climate Change"?



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

- **We must manage our society better!**
- **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 guiding rule has failed us**
- **Re-localize to regain control / responsibility and minimize transport**

Broad Guidelines or Rules to Minimize Impacts

- **Minimize the lifetime of human waste 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**

Examples of Long-Lived ‘Waste’

- **CFCs – refrigerants – very stable – lifetime centuries - broken down by sunlight in stratosphere – catalyze ozone destruction, which protects earth from UV**
- **CO_2 from fossil fuels – lifetime centuries – a greenhouse gas that traps earth’s heat radiation – pushing earth to warmer climate**
- **Nuclear waste – plutonium-239: half-life 24000 years – nuclear weapons**

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 & oil shale reserves are sufficient to push CO_2 to 1,000 ppm—and in time melt icecaps**
    - **Can we "sequester" CO_2 (put it back in the earth)?**

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**

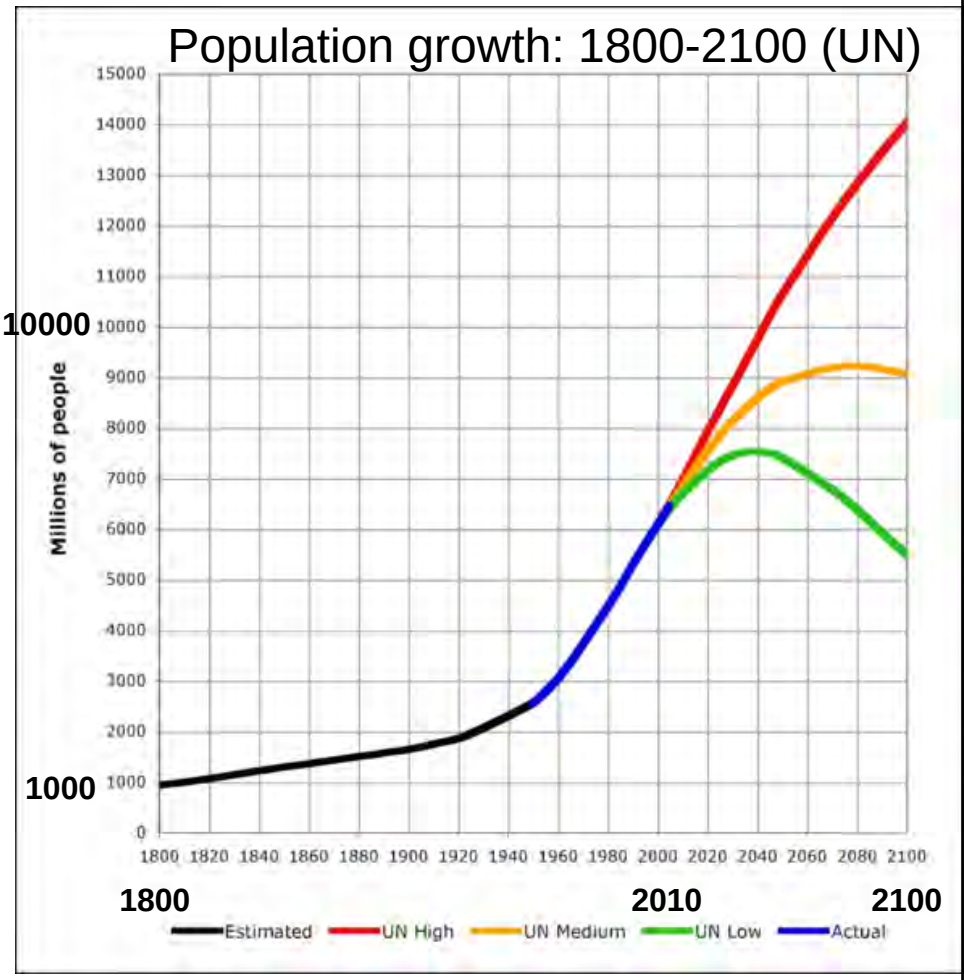
Why Is It Difficult for Us?

- **Fossil fuels reserves are worth $20-30T**
- **Regulating emissions of CO_2 is an "unfair cost" to the "free market"**

- **Real Earth system issues being ignored**
- **Our politics are facing collapse – becoming fantasy disconnected from the real world**

We Passed the Carrying Capacity of the Earth in the 1980s (?)

- **Population is still rising**
- **Consumption still rising**
- **Fossil fuel use still rising**
- ***We still 'believe' in Growth***
- ***Global poverty & suffering are growing: the future looks bleak for billions***
- ***In a finite world, growth leads to overshoot & collapse***



But If Growth Can't Save Us, Surely Technology Can?

- **We have lost sight of the critical distinction between the human-made world and the natural world**
- **We understand the human-made world, the world of computers & technology—because we made it—it is predictable and controllable, except when we are careless (& earthquakes)**

  [E. F. Schumacher (1977). *A Guide for the Perplexed*]
- **The same is not true of the natural world – which is far more complex and alive. Our understanding is limited; prediction & control are not possible**

But If Growth Can't Save Us, Surely Technology Can?

- **Now our world of technology is having a global impact on the natural world and it must be carefully managed — because we are dependent on the natural world**
  - **But this is incompatible with our ideology**

Technology can be Useful

30 mph Danish electric tricycle:

with 150 mile range

Our Choices Are Bounded

- ***Whether we use technical, social or religious language***
- **Humanity is an integral part of the earth system and dependent on its stability**
- **We do not have the freedom to do what we wish, whatever our economic or theological doctrine**
- **The response of the Earth system to our human-centered arrogance will be sufficiently large this century that we will rethink our doctrine**
- **We would be wise to rethink sooner rather than later**

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

The Future Is Not Our Past

- **Collectively, we create the future, so we need to plan for a transition to a sustainable society**

- **Efficient society**
- **Renewable technologies to replace fossil fuels**

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**

What Will This Mean For You?

- **Society needs to rethink its relationship to the natural environment and its ecosystems in less than one generation**
- **Our 'lifestyle' is disconnected from what the earth can sustain and the large inertia of the earth system is masking the extent of the crisis we face**
- **Individual can rethink priorities but societal changes are needed: from towns to global**

- **Ask**
  - **Is this an efficient and sustainable way of doing this?**
  - **Do I have a deep understanding and connection to Earth?**

Discussion

- **This talk http://alanbetts.com/talks**
- **Rutland Herald articles at**

  http://alanbetts.com/writings
- **Interesting papers at**

  http://alanbetts.com/research

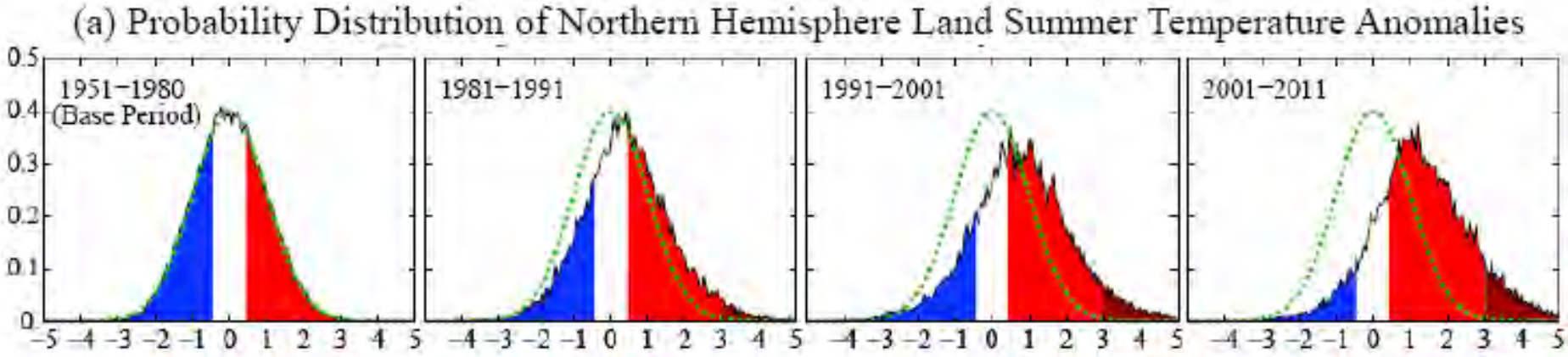
  – ***Vermont Climate Change Indicators***

  – ***Seasonal Climate Transitions in New England***

‘Anti-global warming’ tactics [*delay, confuse and deny*]

- **Fabricate ‘data’ or cherry-pick the science for unsolved issues and ignore the big picture. ‘This disproves global warming’ *or* ‘Science isn’t resolved; we need more science.’**
- **Models can’t predict the future with certainty, so the models are ‘unreliable’, ‘can’t be trusted’. Given this uncertainty, *we cannot be held responsible for the future*.**
- **If climate change were real, it would require collective government regulation of the ‘free market’, which we are opposed to; so *climate change must be a ‘hoax/conspiracy’***
- **It is too costly to make structural changes to our society, and it would affect profit margins.**
- **[We will wait till China and India take action]**
- **[The poor in Africa need energy]**

Are Temperature Extremes a Sign of 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**

(± 3σ includes 99.7% of data in 1951-1980 base period)

Ice-core history!

Last four ice-age cycles