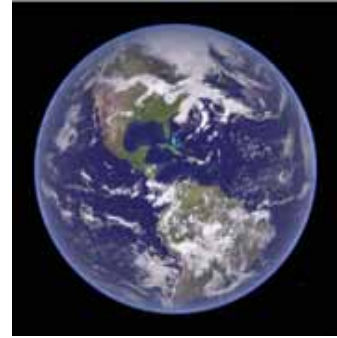




Climate Change – *What's in store for Vermont?*



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***Washington Electric Coop.
Montpelier, Vermont***

May 24, 2012

Global Climate Change

- One of the many great challenges for the 21st century - present path is unsustainable
- Known it would be a problem for 4 decades
J. S. Sawyer (1972): Man-made CO₂ and the “greenhouse” effect
- Earth science conflicts with historic values (and vested interests in fossil fuel economy)
- It is a global issue & a local issue

What Is Happening to Vermont?

- Warming twice as fast in winter than summer
- Winter severity decreasing
- Lakes frozen less **by 7 days / decade**

- Growing season longer **by 3.7 days / decade**
- Spring coming earlier **by 2-3 days / decade**

- **Extremes increasing- 'stationary weather patterns'**

January Gardening, Pittsford, VT



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



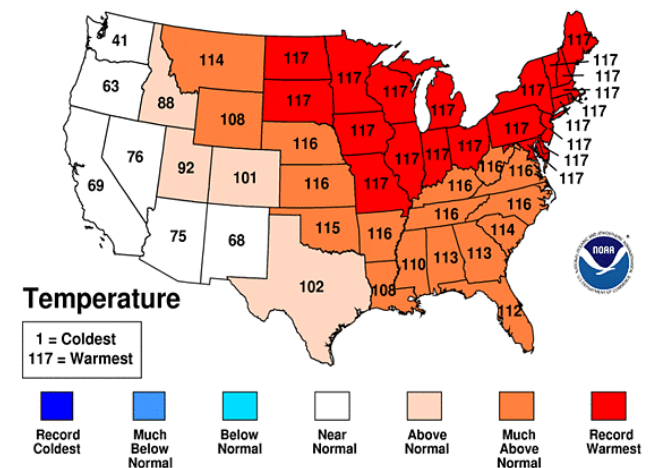
March 11, 2012



October 2011– March 2012

- **Warmest 6 months on record**
- **My garden frozen only 67 days**
- **Little snow cover**
- **Contrast snowy winter 2010-11**

Oct 2011-Mar 2012 Statewide Ranks
National Climatic Data Center/NESDIS/NOAA



Daffodils in Bloom

March 22 – 79°F



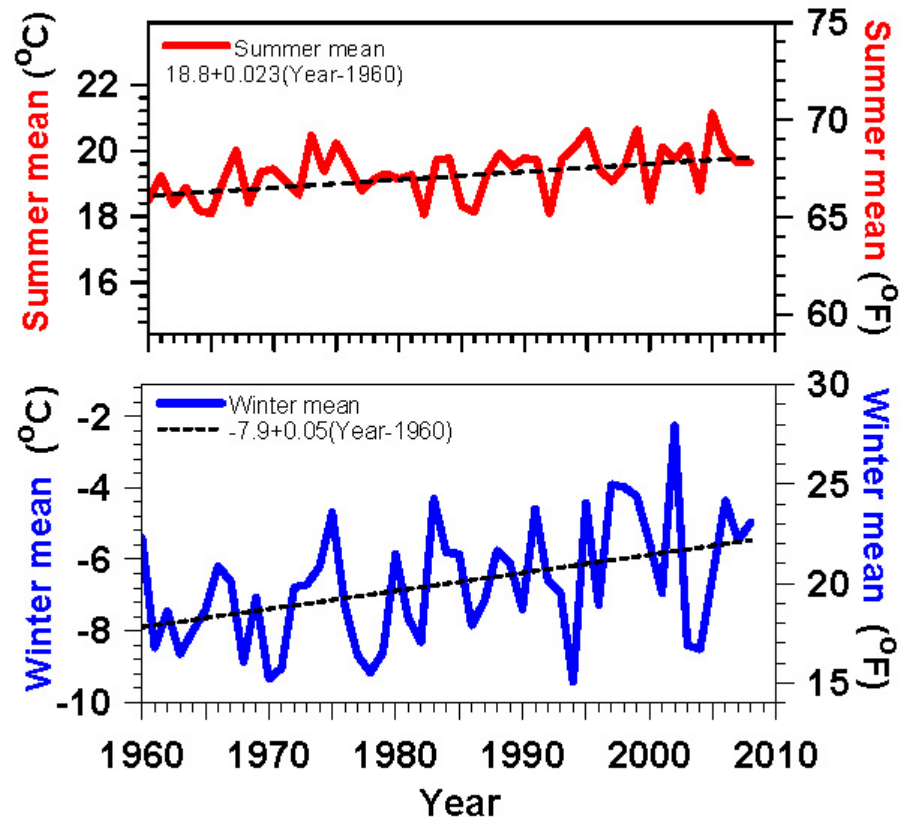
Pittsford

Vermont

3/22/12

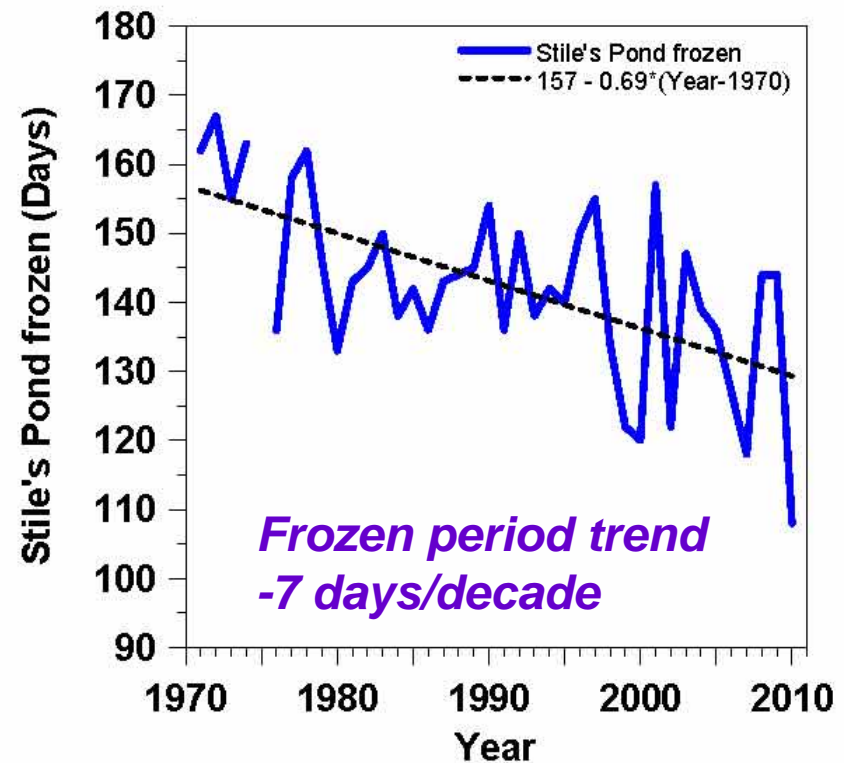
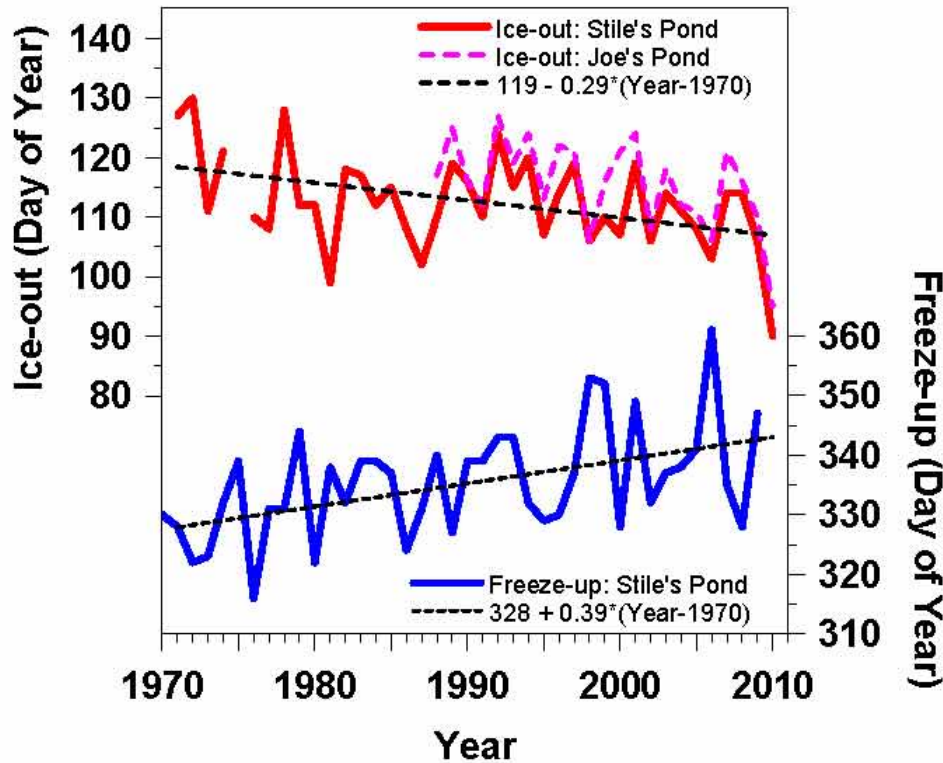
Vermont Temperature Trends

- **Summer $+0.4^{\circ}\text{F}$ / decade**
- **Winter $+0.9^{\circ}\text{F}$ / decade**
- ***Less snow (and increased water vapor) drive larger winter warming***



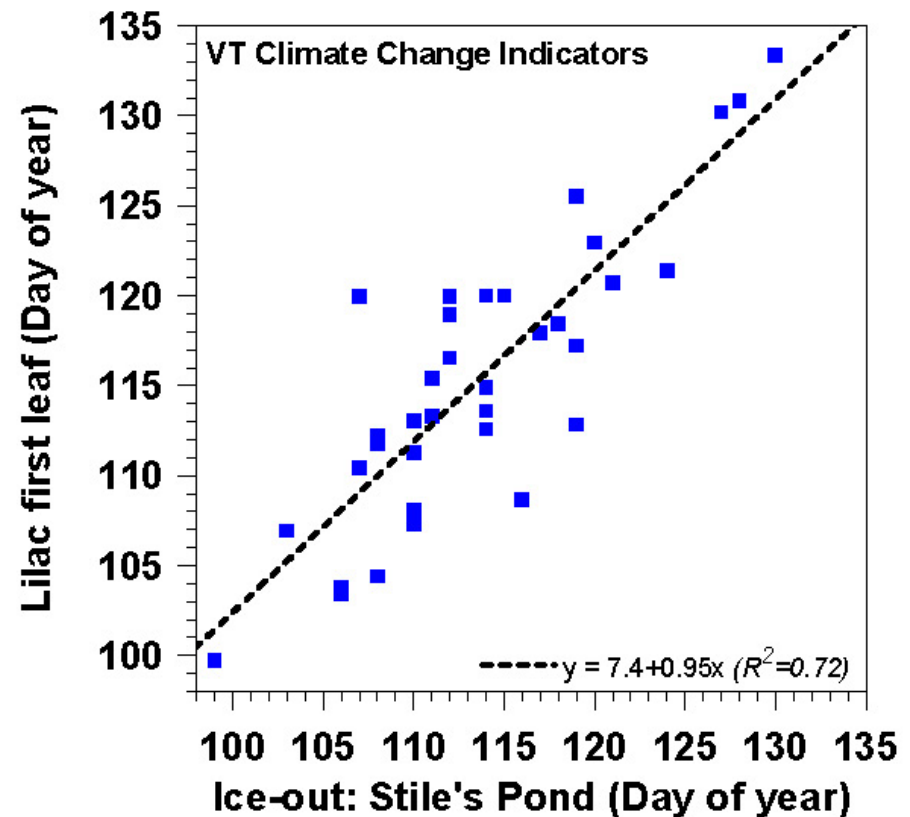
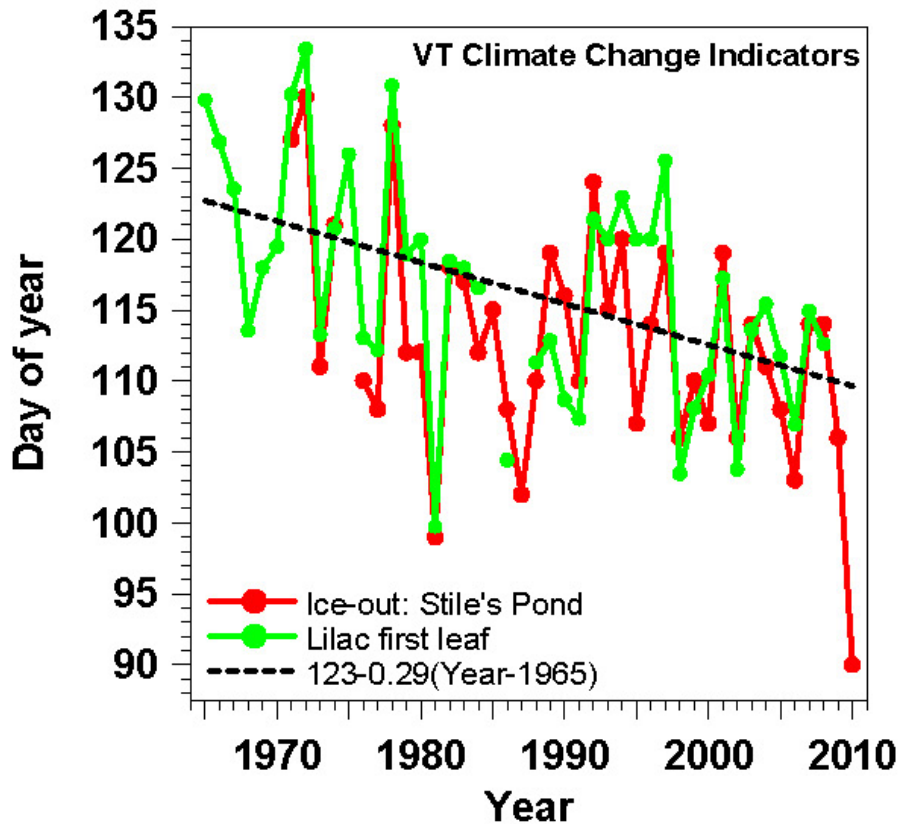
Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



- Ice-out earlier **by 3 days / decade**
- Freeze-up later **by 4 days / decade**

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

Vermont Winter 2006



- **Sun is low; and snow reflects sunlight, except where there are trees!**
- **Sunlight reflected, stays cold; little evaporation, clear sky; earth cools to space**

January 2, 2012



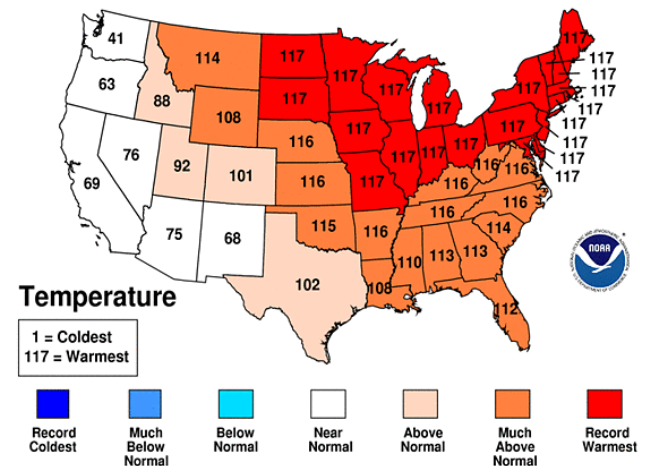
March 11, 2012



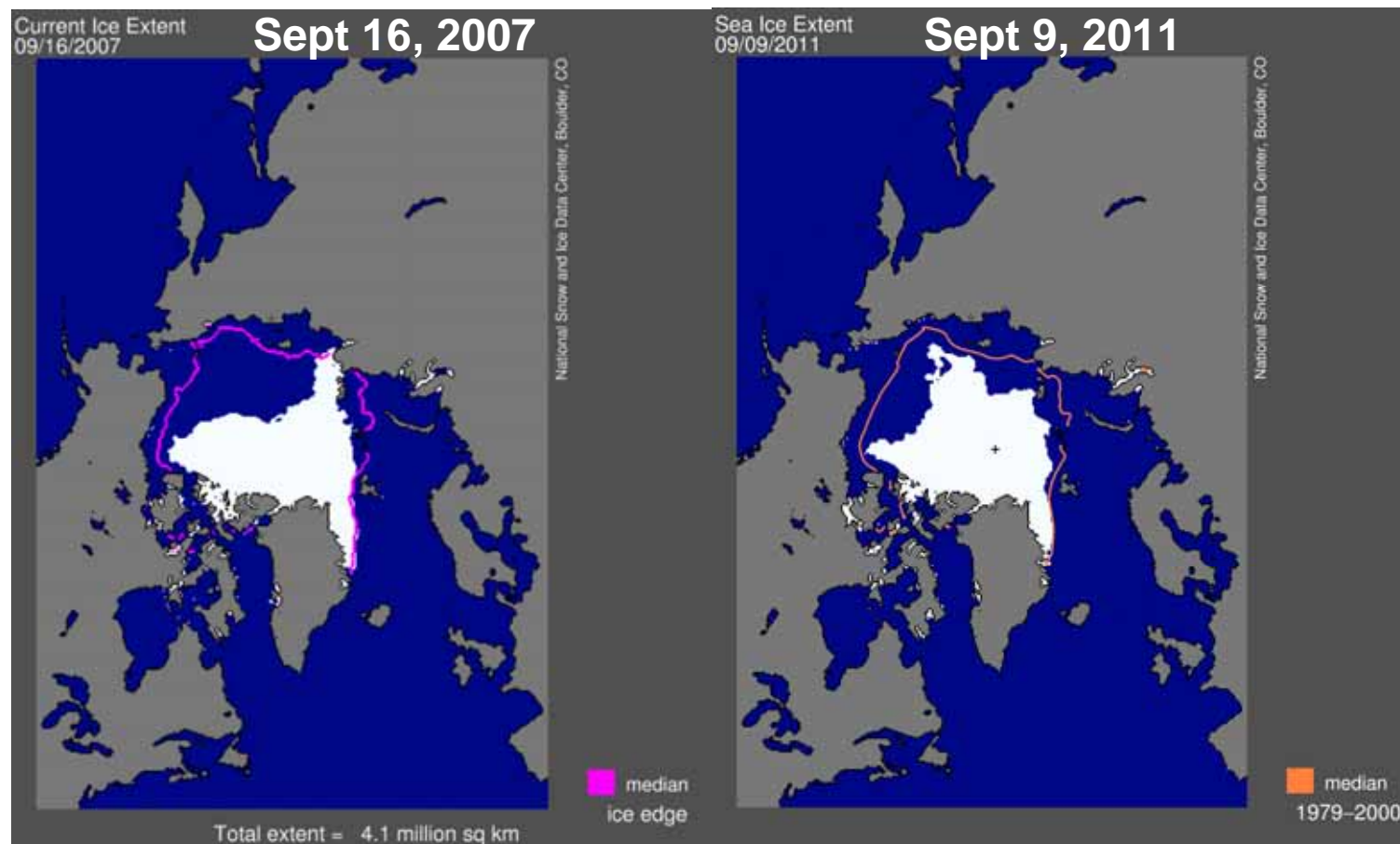
No permanent snow cover west of Green Mountains

- Warmest 6 months on record
- Dry winter, little snow
- Less reflection → Warmer, so snow melts faster

Oct 2011-Mar 2012 Statewide Ranks
National Climatic Data Center/NESDIS/NOAA



Arctic Sea Ice Loss Has Accelerated



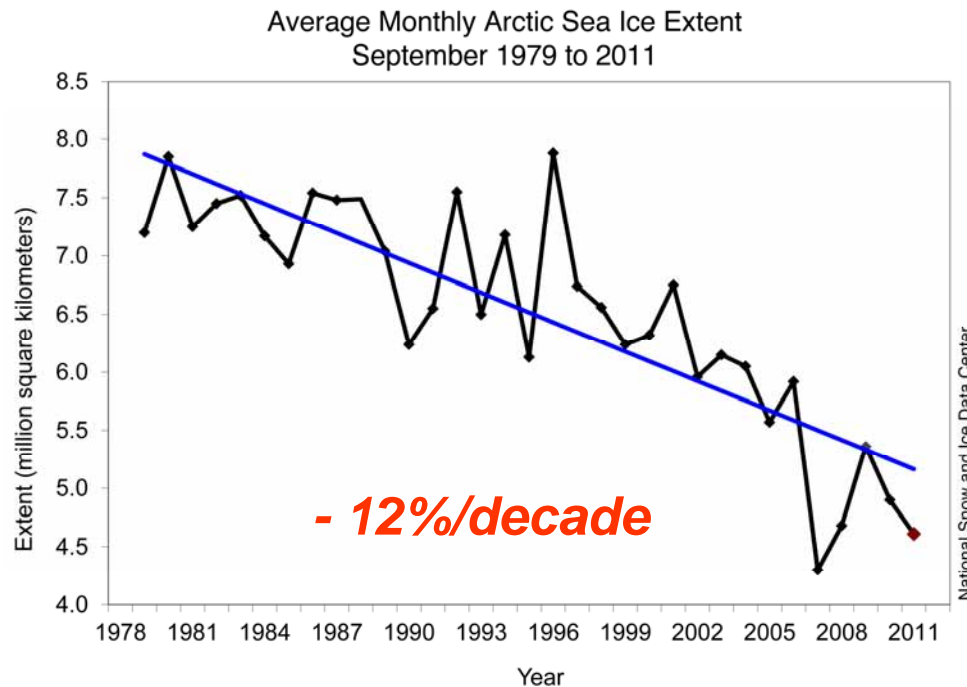
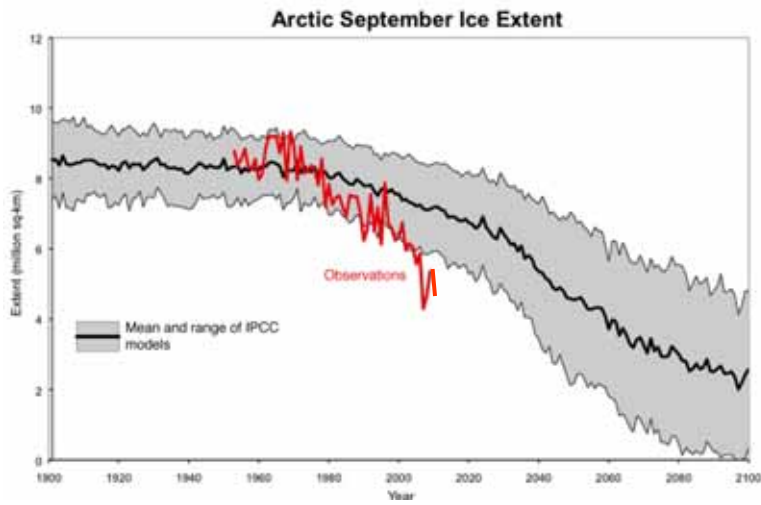
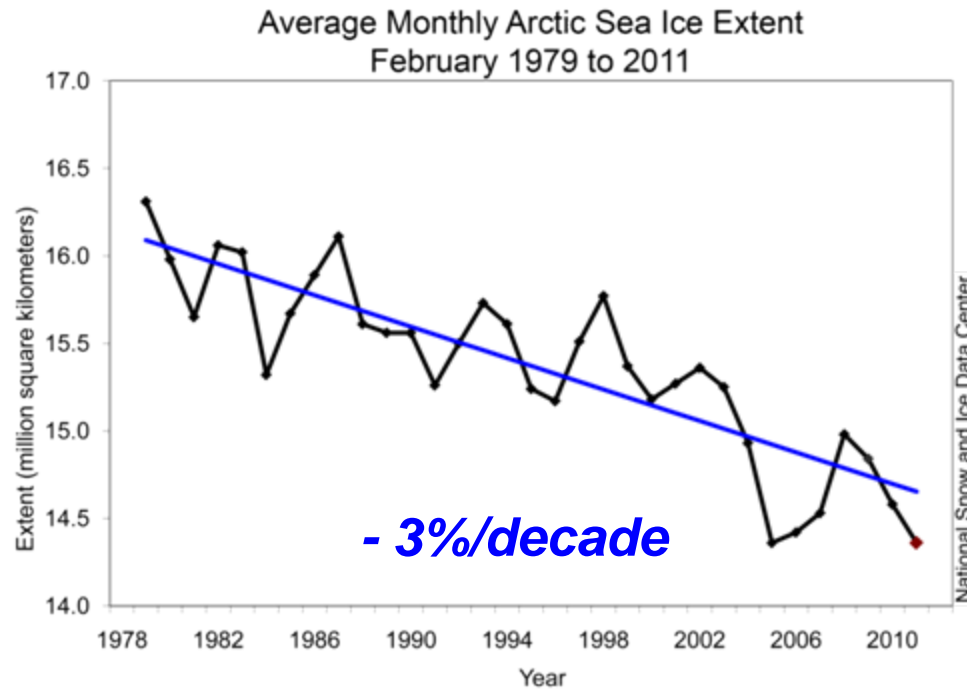
- **Positive feedbacks speed melting**
- **Less ice, less sunlight reflected**
- **More evaporation, larger water vapor greenhouse effect**

(www.nsidc.org)

- **Record ice loss in 2007**
 - most ice now thin and only 1-2 years old
- **Open water in October contributes to warmer Fall**

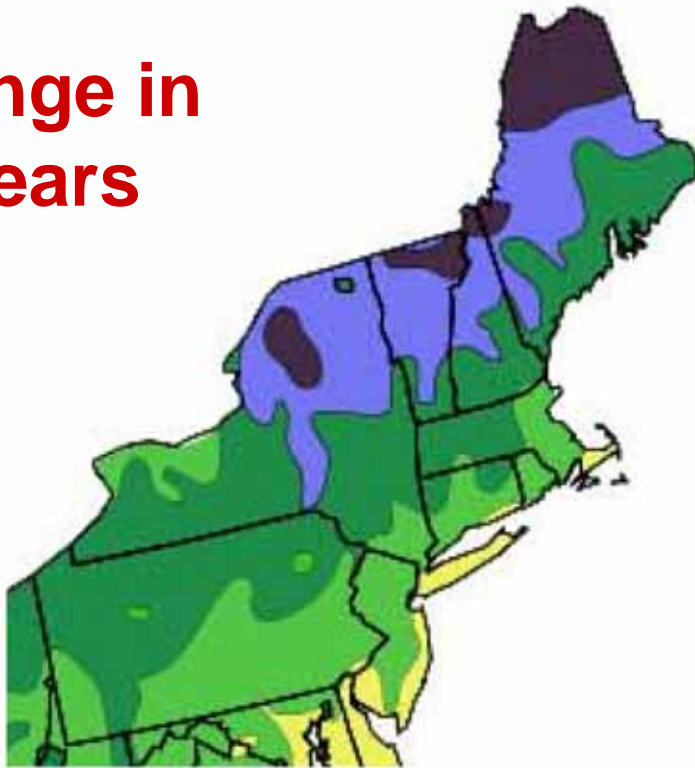
Sea Ice Trends

- Sea ice is thinning rapidly
- Observed September decline appears to be faster than IPCC-AR4 climate model projections

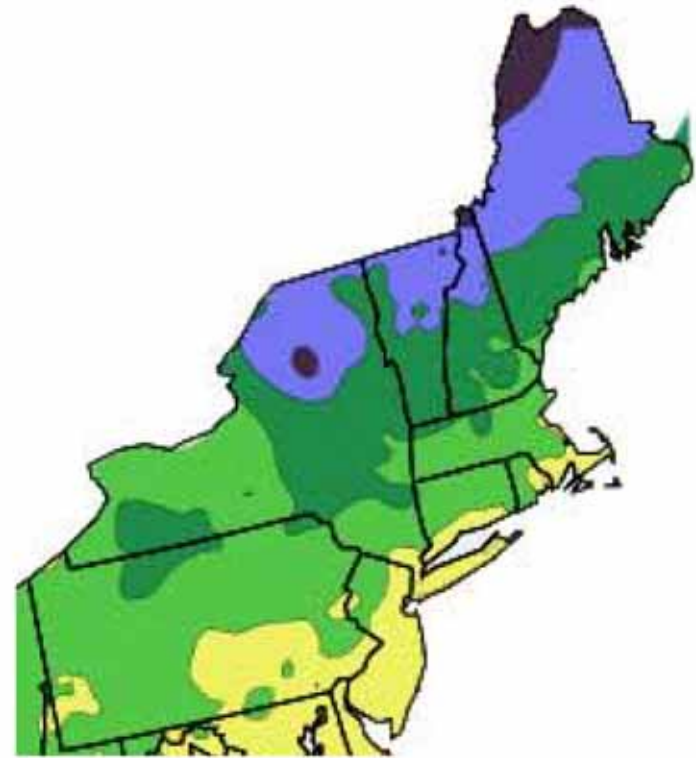


USDA Hardiness Zones - Northeast

**Change in
16 years**

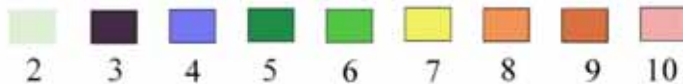


1990



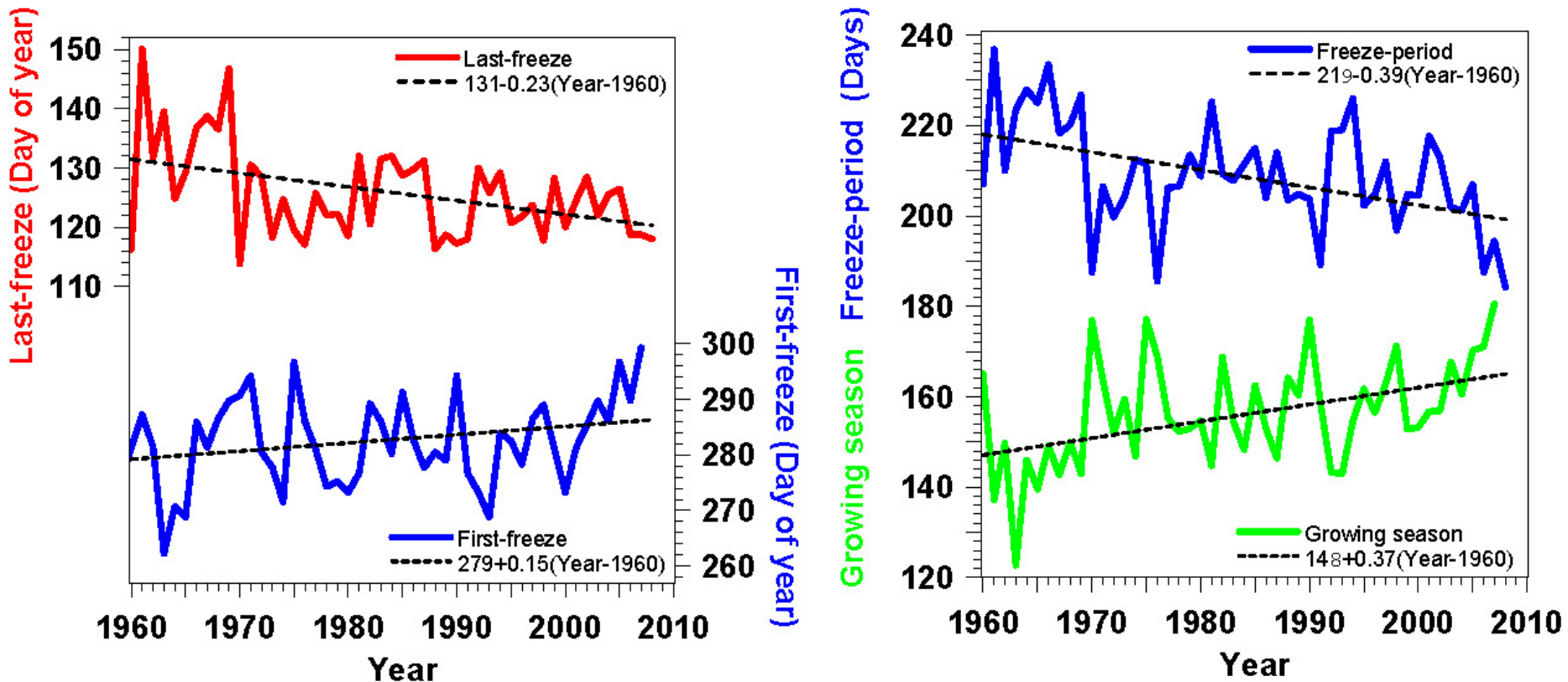
2006

Zone



USDA Hardiness Zones

First and Last Frosts Changing



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

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***

Fall Climate Transition

- **Vegetation postpones first killing frost**
- **Deciduous trees still evaporating: moist 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 shuts down, leaves turn, skies become clearer and frosts become frequent**

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



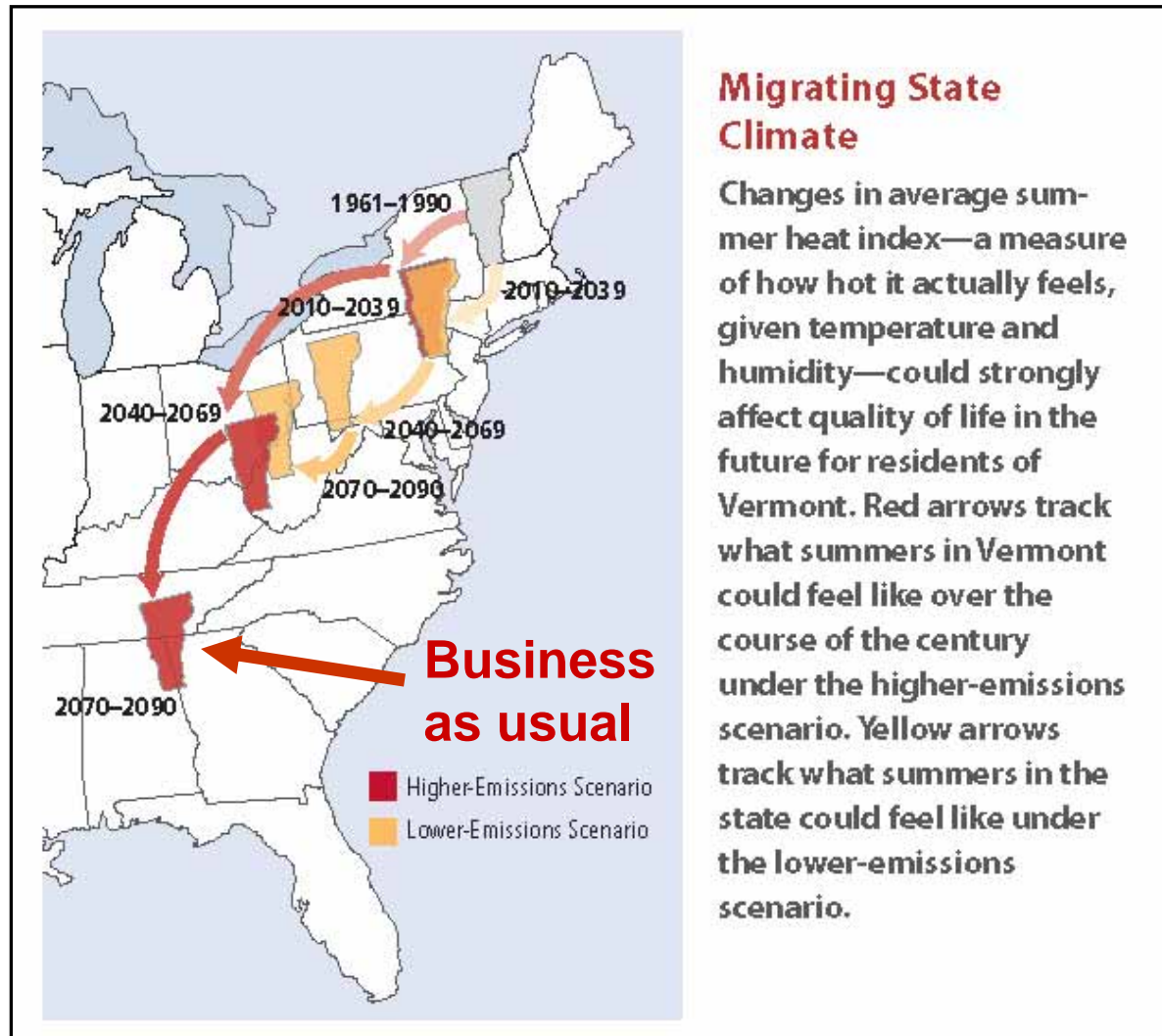
Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

Later frost: Growing season getting longer

Vermont's Future with High and Low GHG Emissions

What
about
skiing?

What
about
tropics?



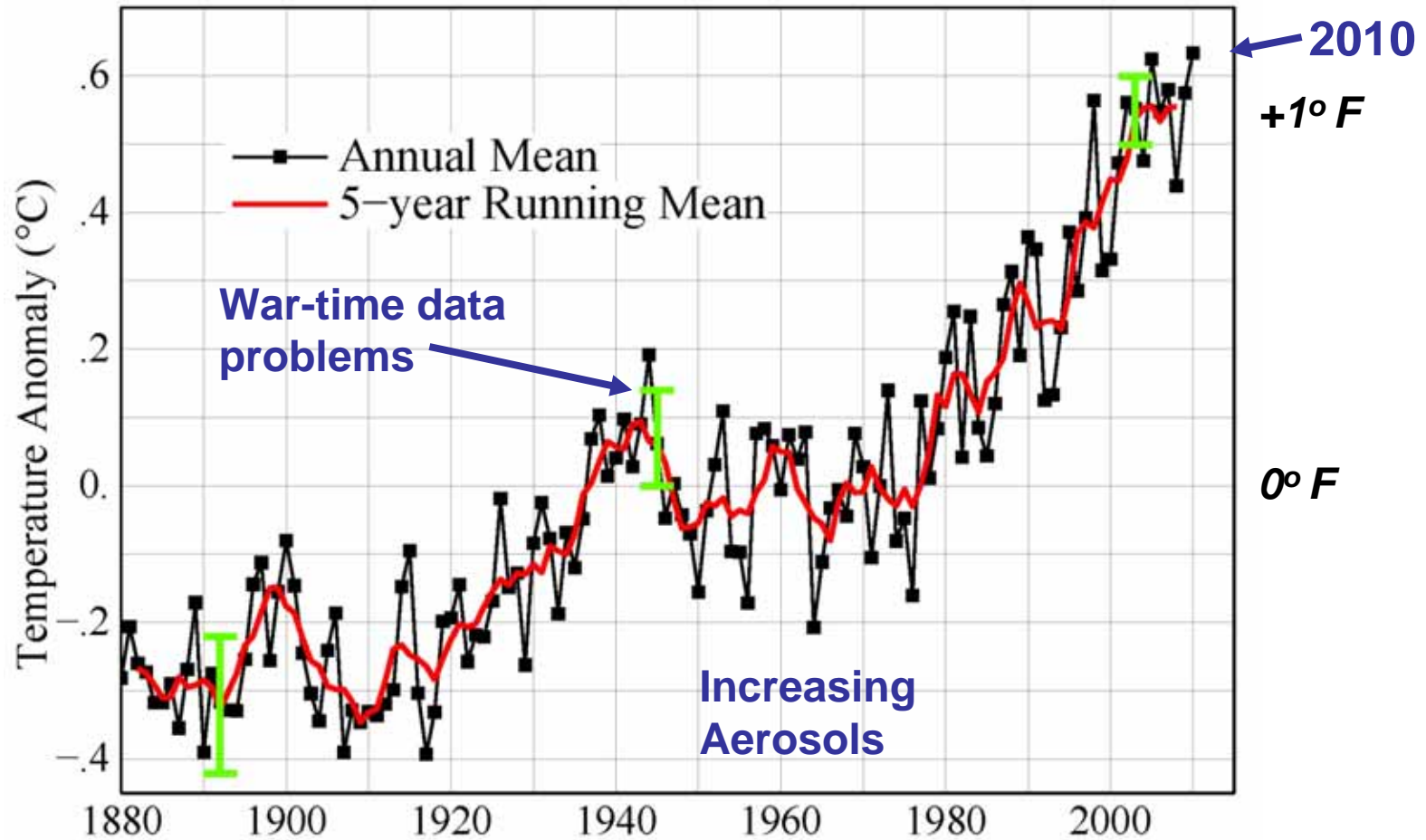
NECIA,
2007

Global Temperature Rise 1880 – Present

2100: +5°F



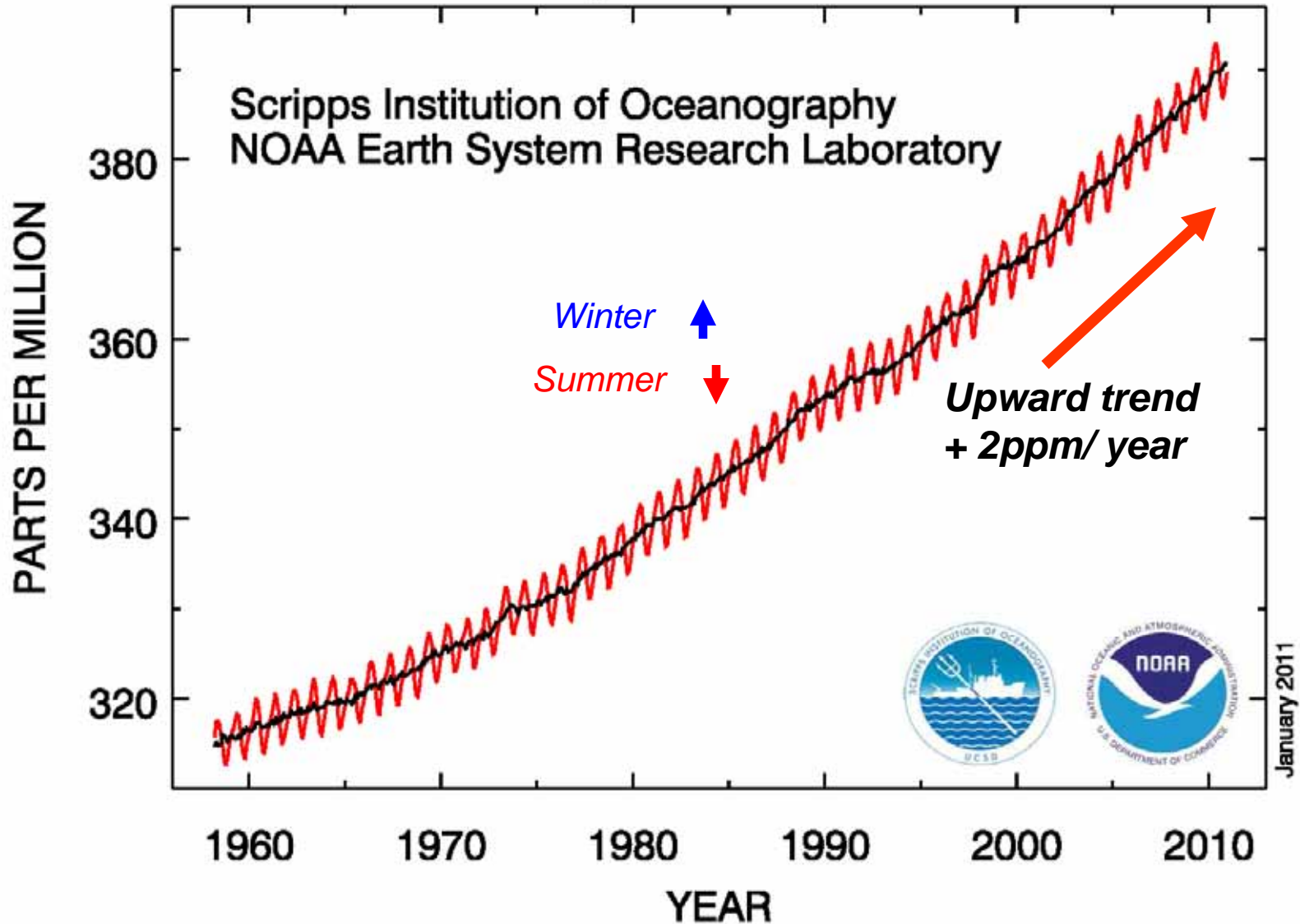
Global Land–Ocean Temperature Index



NASA-GISS, 2011

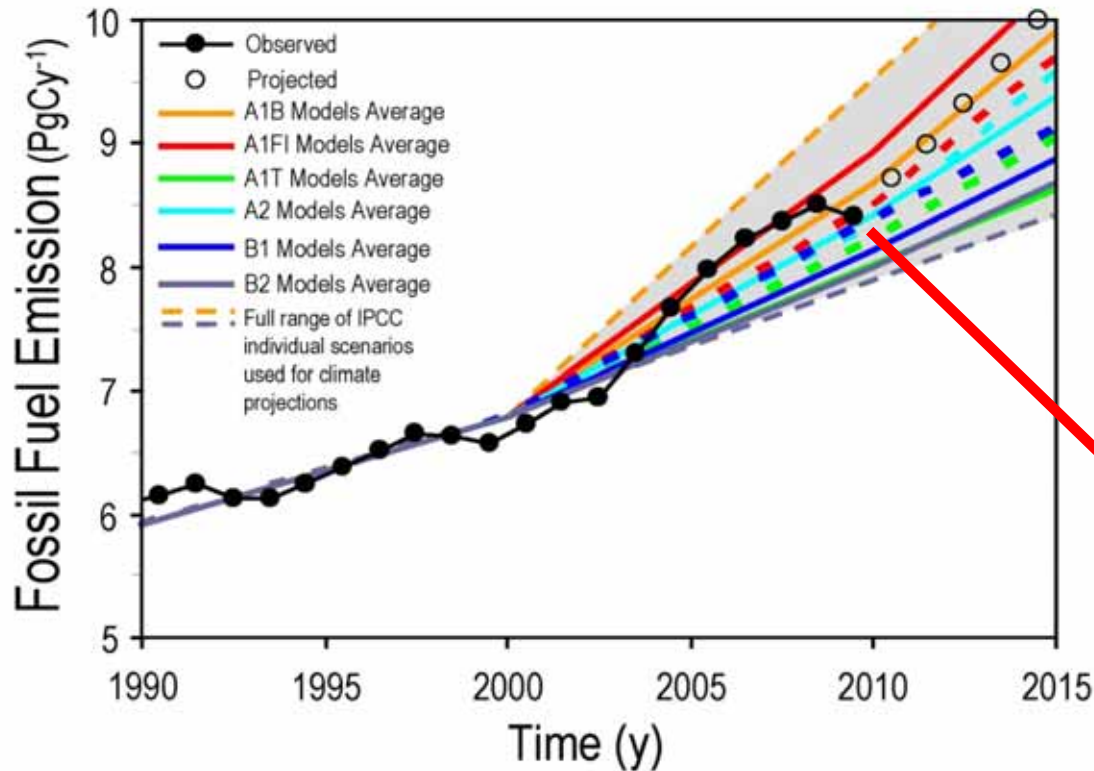
Carbon Dioxide Is Increasing

Atmospheric CO₂ at Mauna Loa Observatory



2009 Was “Good” for the Earth

Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Emission Scenarios

- 4%/year

Why Is the Rise of Atmospheric CO₂ a Problem?

- The atmosphere is transparent to light from the sun, but not to infrared radiation from the earth
- Greenhouse gases: H₂O, CO₂, CH₄
 - trap the earth's heat, giving pleasant climate
- CO₂ rise alone has a small effect, BUT...

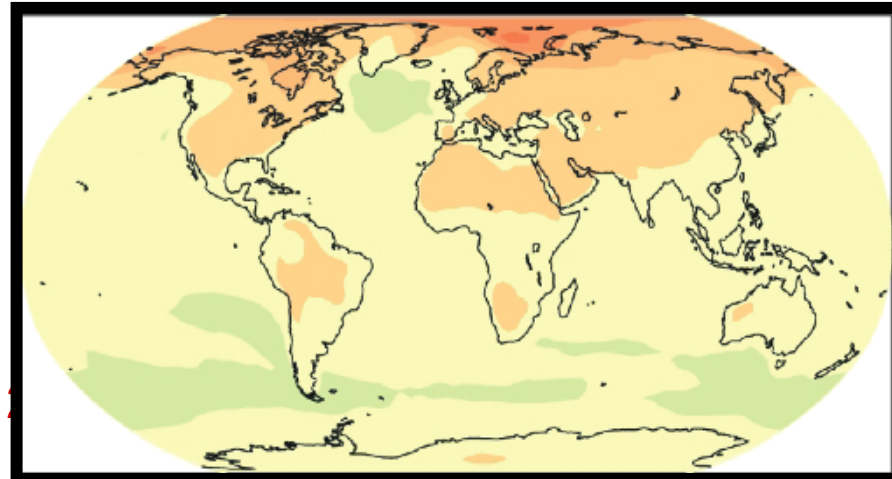
Why Is the Rise of Atmospheric CO₂ a Problem?

- As Earth warms, **evaporation and water vapor increase** and **this amplifies warming a lot (3X)**
- As Earth warms, **snow and ice decrease** and **this amplifies warming in winter and northern latitudes, because less sunlight is reflected**
- **Doubling CO₂ will warm Earth about 5°F (3°C)**
 - **much more in the North and over land**

Predicted Change in Temperature

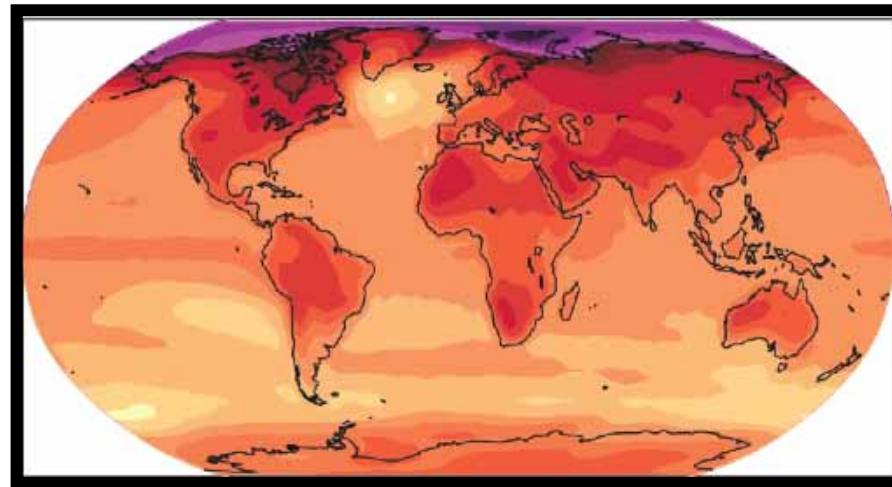
2020-2029 and 2090-2099, relative to 1980-1999 (°C)

“Committed”

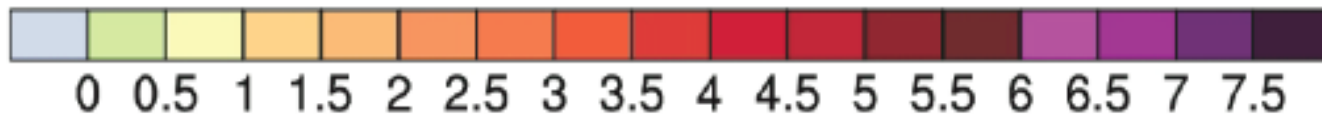


(We did nothing for the last 20 years)

Still up to us!



(We could halve this if we act now)



[°C]

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**
- Unless we drastically **reduce burning of fossil fuels** by 80% by 2050
- Sea-level rise will get our attention
 - **But it will be too late!**

Many Challenges Face Us

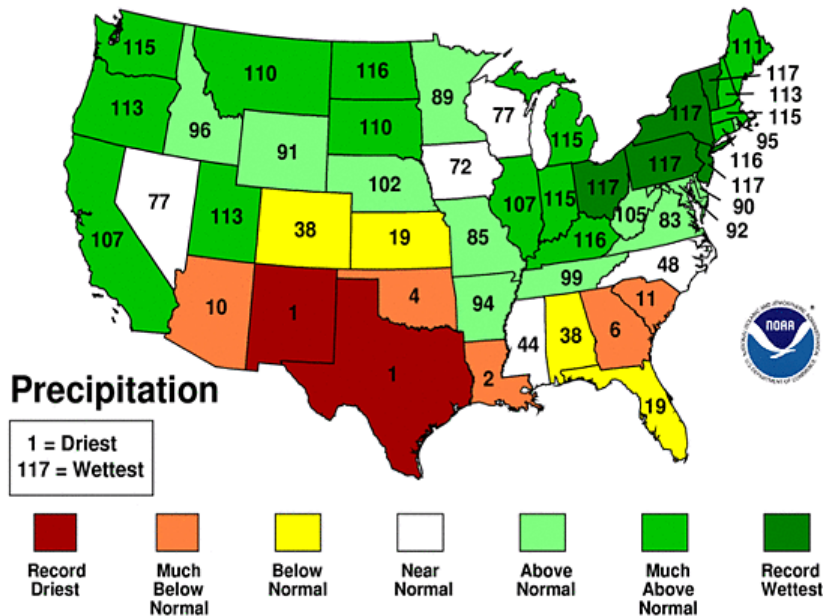
- **Extreme weather: Floods, fires, & drought**
 - **32 weather disasters >\$1B in 2011**
- **Melting Arctic and permafrost—methane release is positive feedback**
- **Ecosystem collapse, including perhaps forest and ocean ecosystems**
- **Collapse of unsustainable human population**

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)

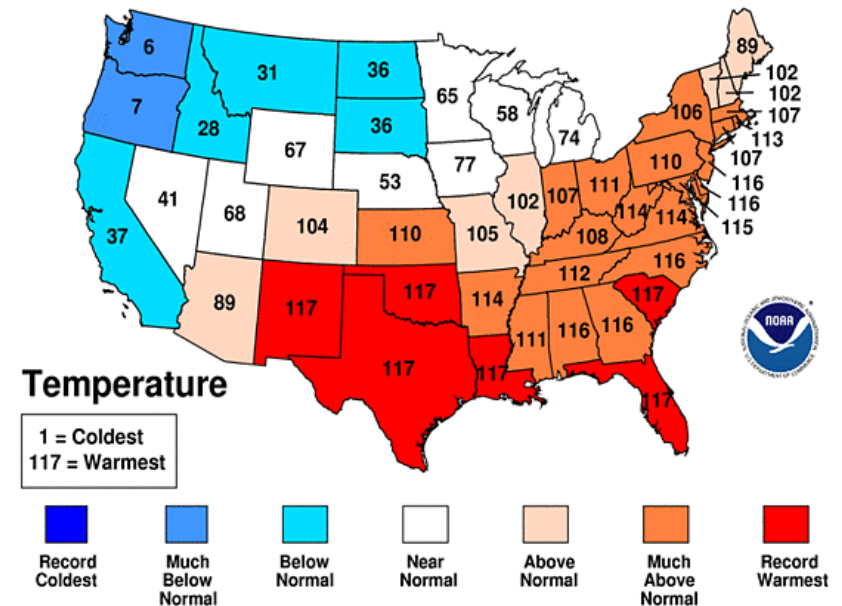
March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



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**

Discussion

- <http://alanbetts.com>
 - this talk <http://alanbetts.com/talks>
 - articles at <http://alanbetts.com/writings>
 - **Sunday Environment page in Herald/
Times Argus: 2008-2012**
- *Vermont Climate Change Indicators*
- *Seasonal Climate Transitions in New England*

Extra Slides Follow

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**

Broad Guidelines 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**

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 CO₂ to 1,000 ppm—and in time melt icecaps**
 - **Can we “sequester” CO₂ (put it back in the earth)?**

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?**

- Earth is a complex system
- Its timescales are long
 - It runs well without us
 - but Earth's climate is unstable (ice-ages)
- Humanity - big perturbation



*January 2, 2012: NASA
NPP VIIRS composite*