



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



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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

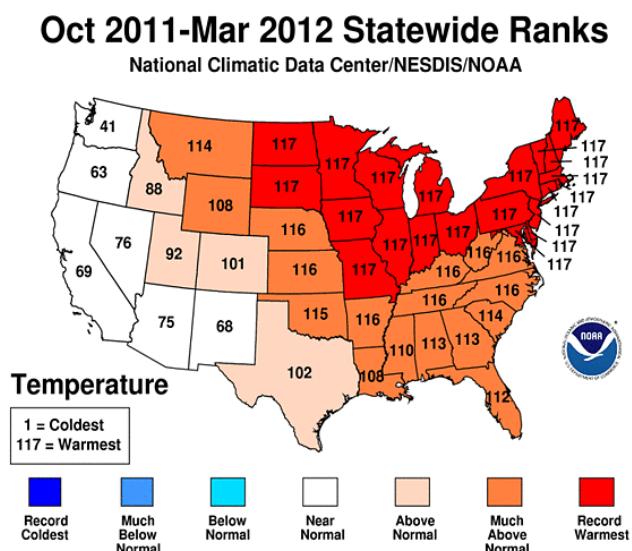


March 11, 2012



October 2011– March 2012

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



Daffodils in Bloom

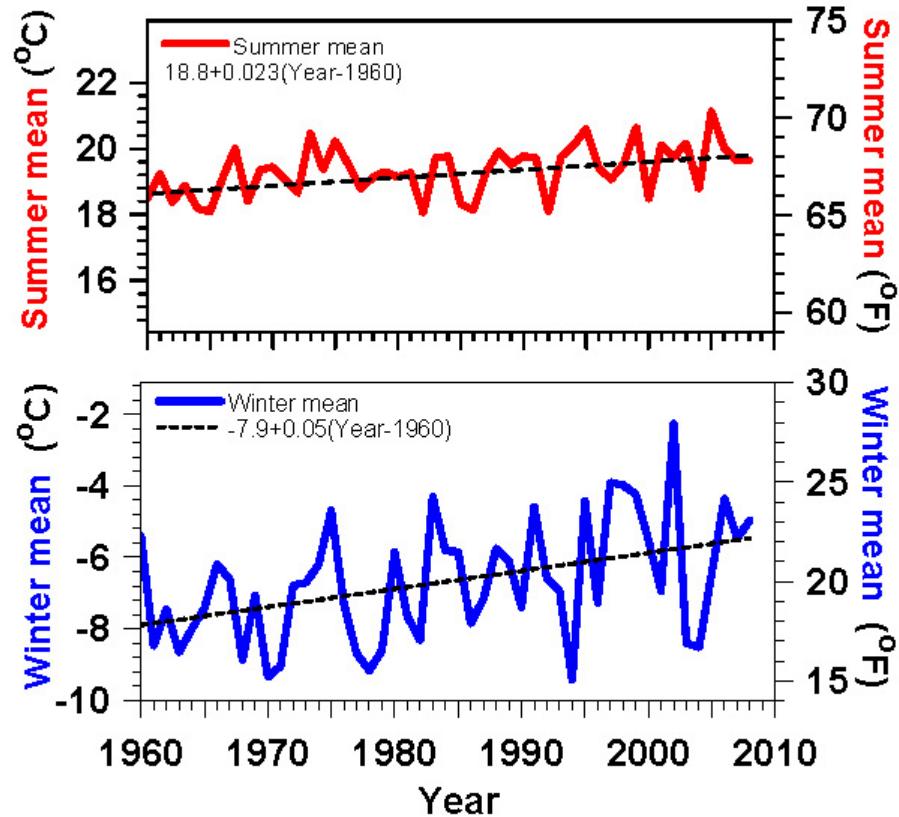
March 22 – 79°F



Pittsford
Vermont
3/22/12

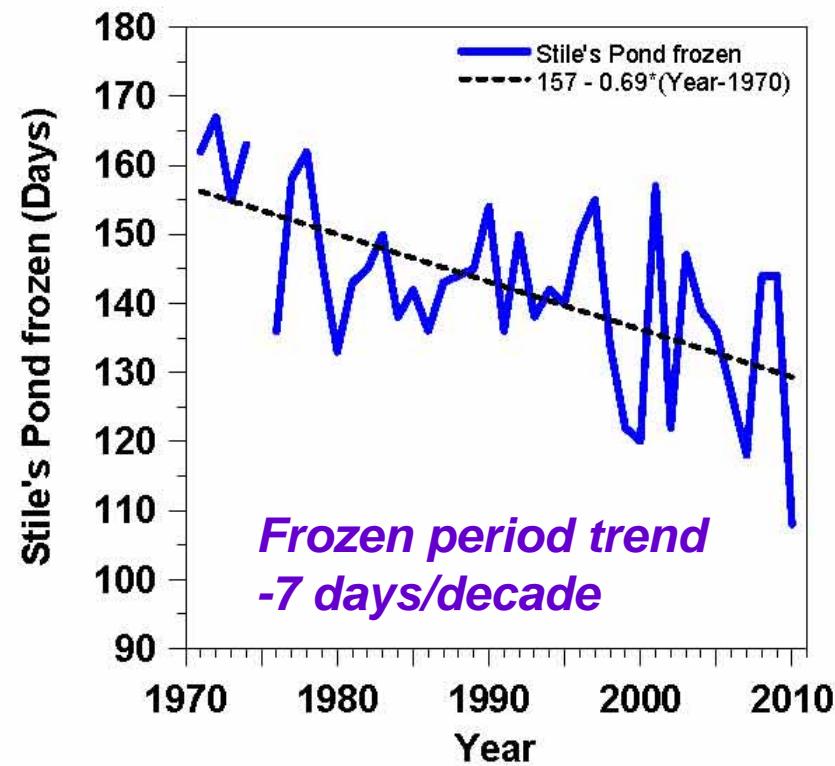
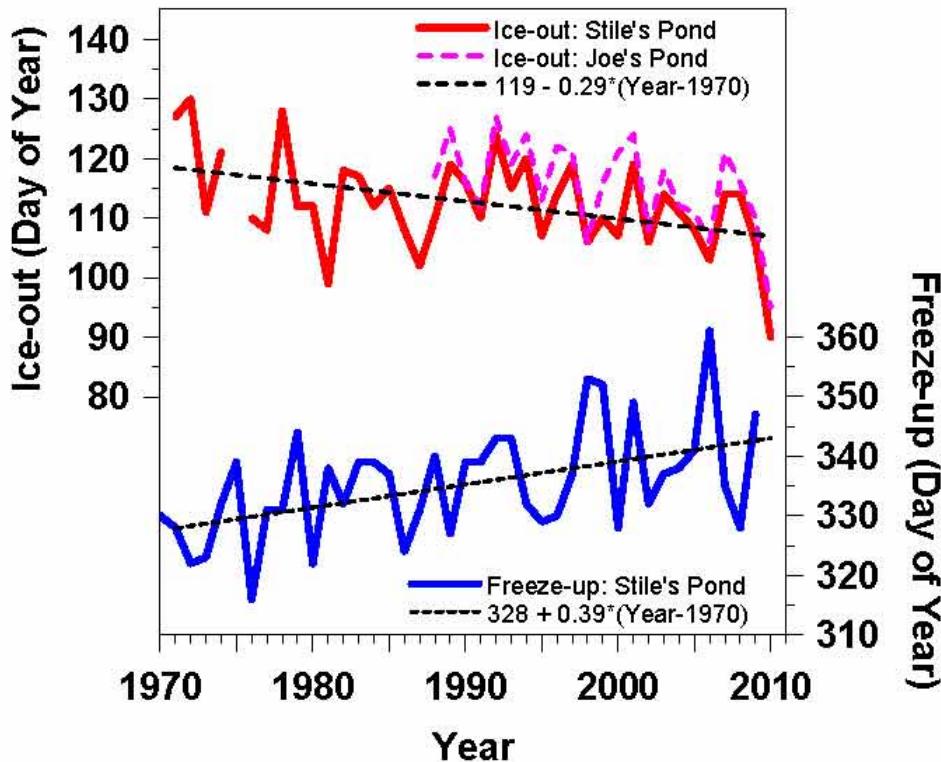
Vermont Temperature Trends

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



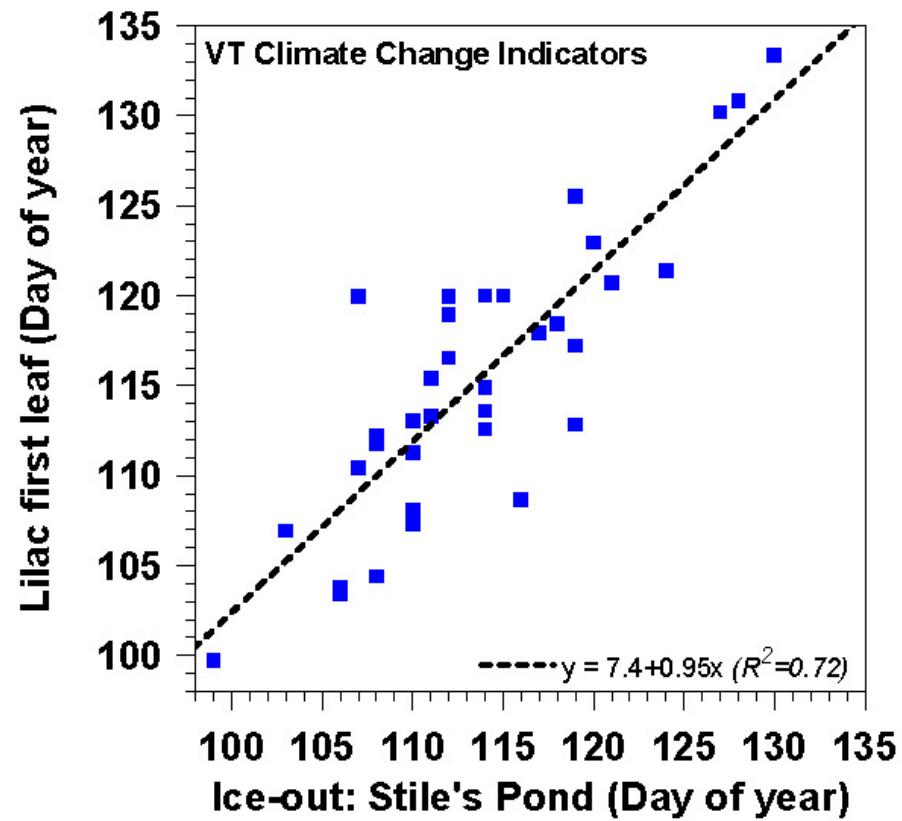
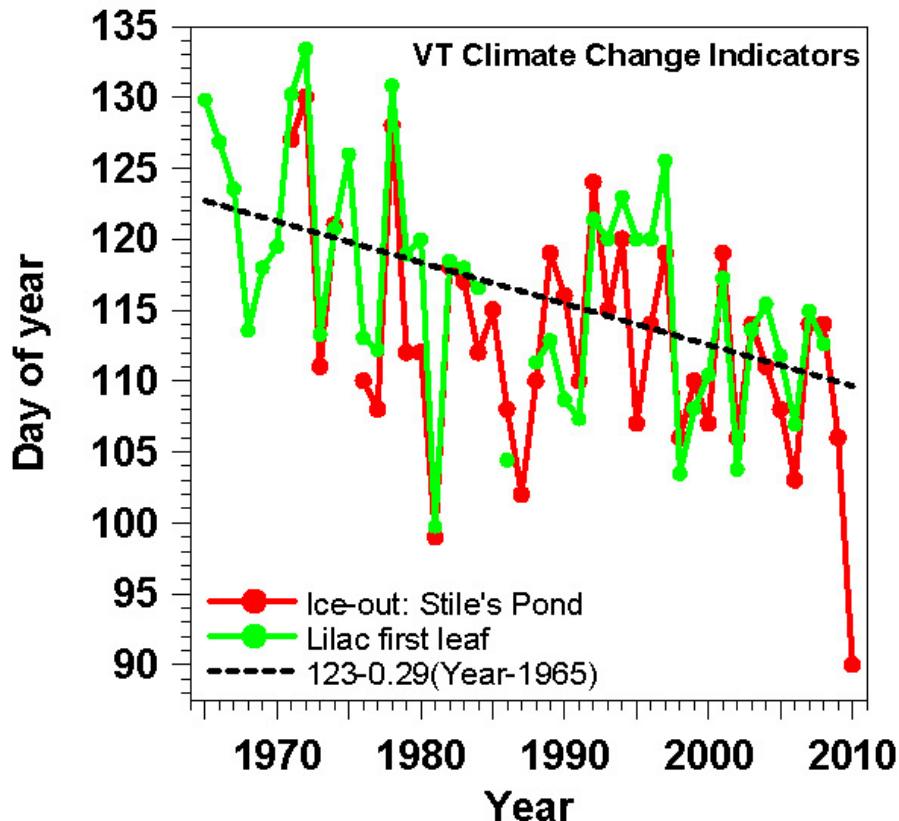
Lake Freeze-up & Ice-out Changing

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



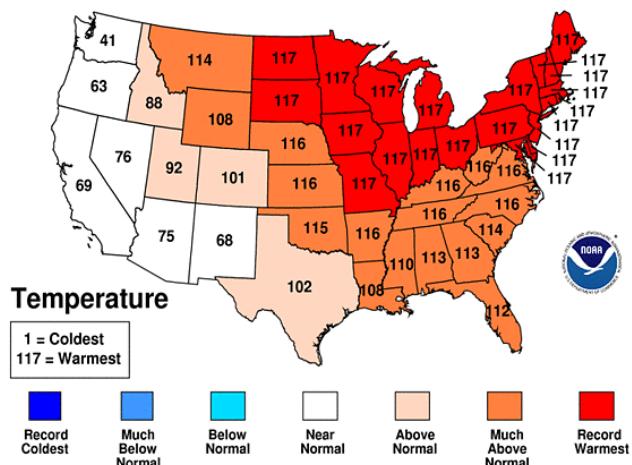
March 11, 2012



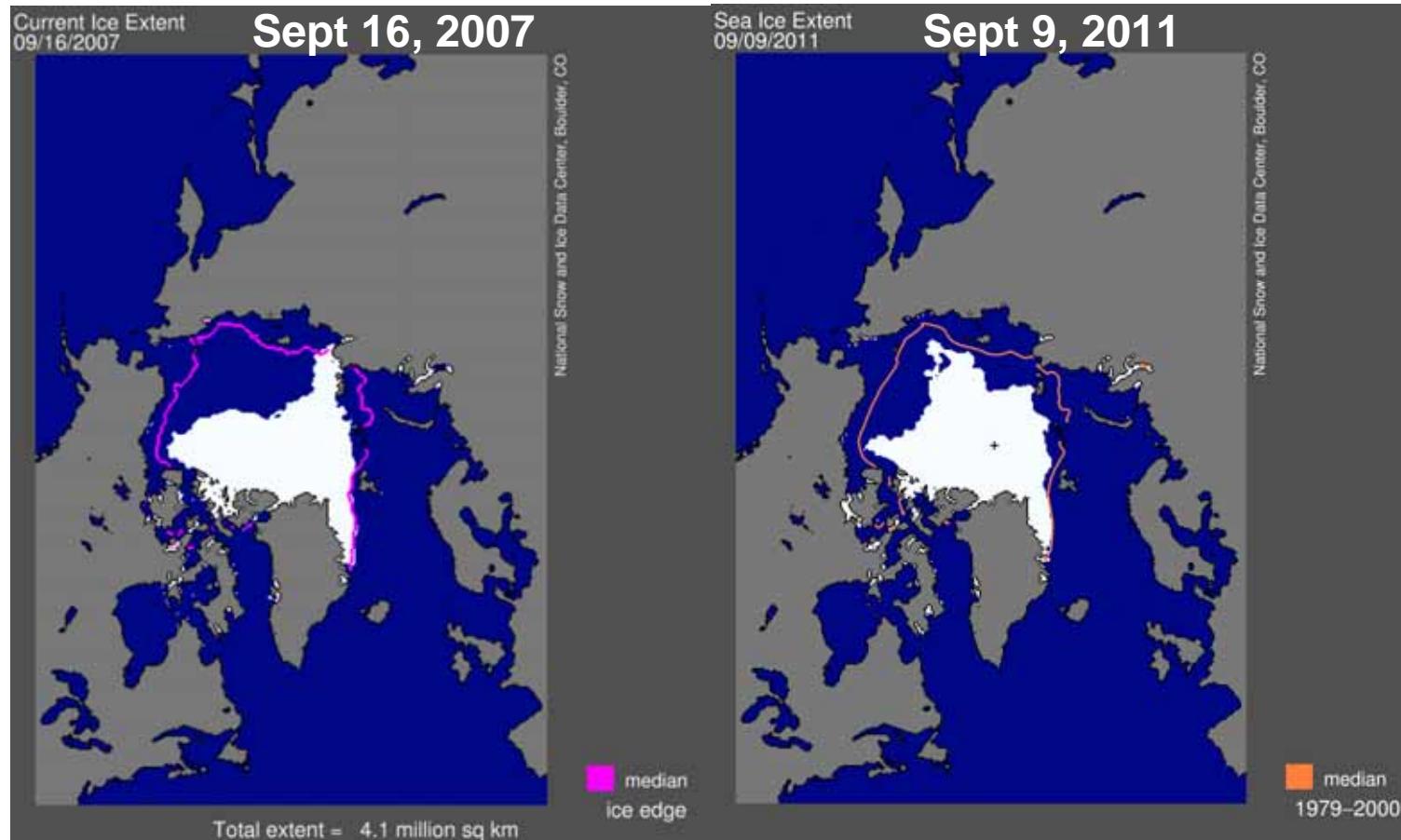
No permanent snow cover west of Green Mountains

- 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



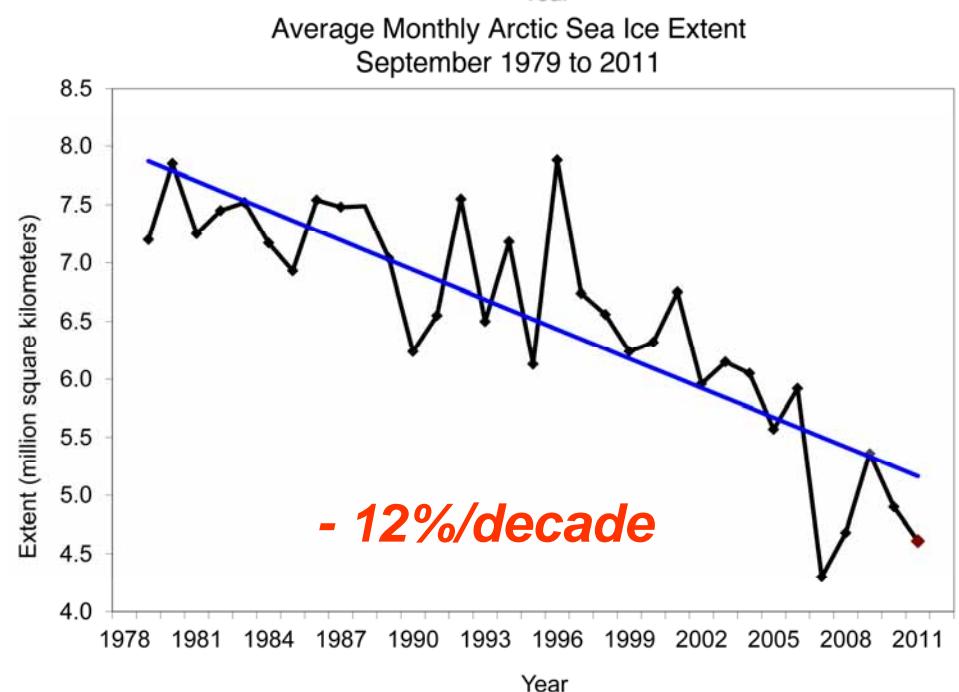
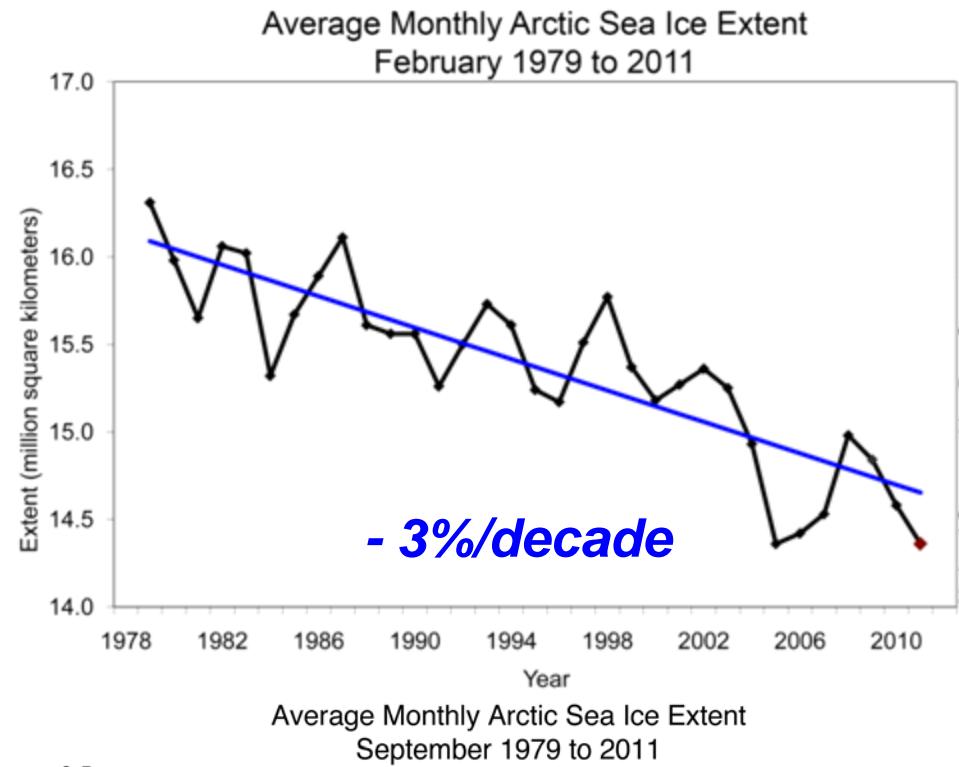
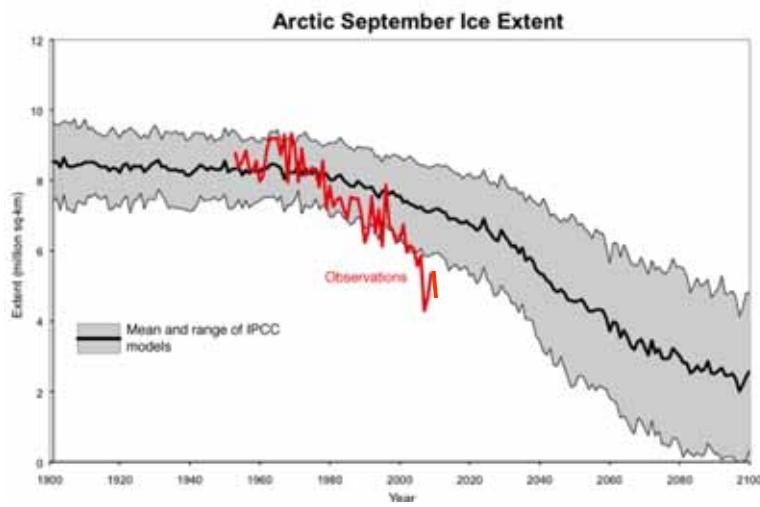
- Positive feedbacks speed melting
- Less ice, less sunlight reflected
- More evaporation, larger water vapor greenhouse effect

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

(www.nsidc.org)

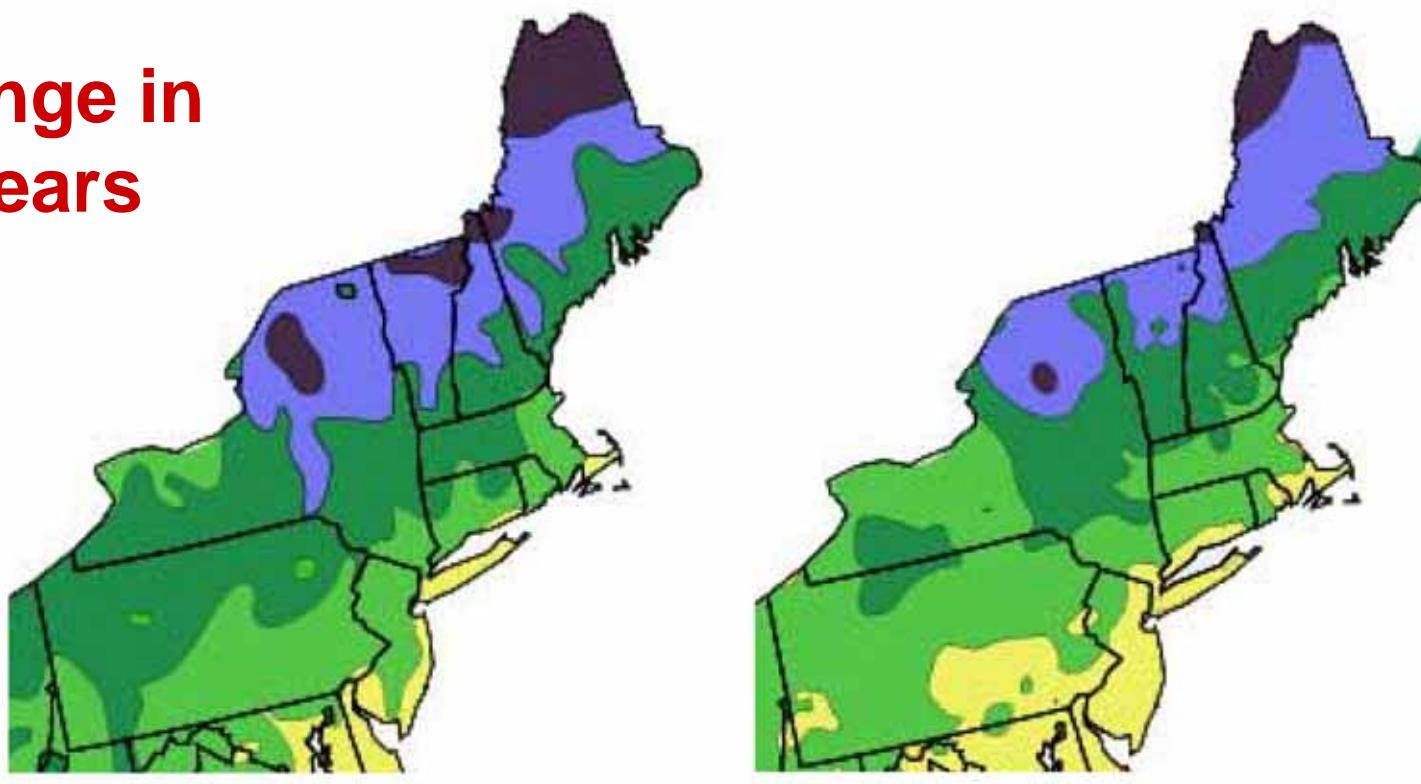
Sea Ice Trends

- 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

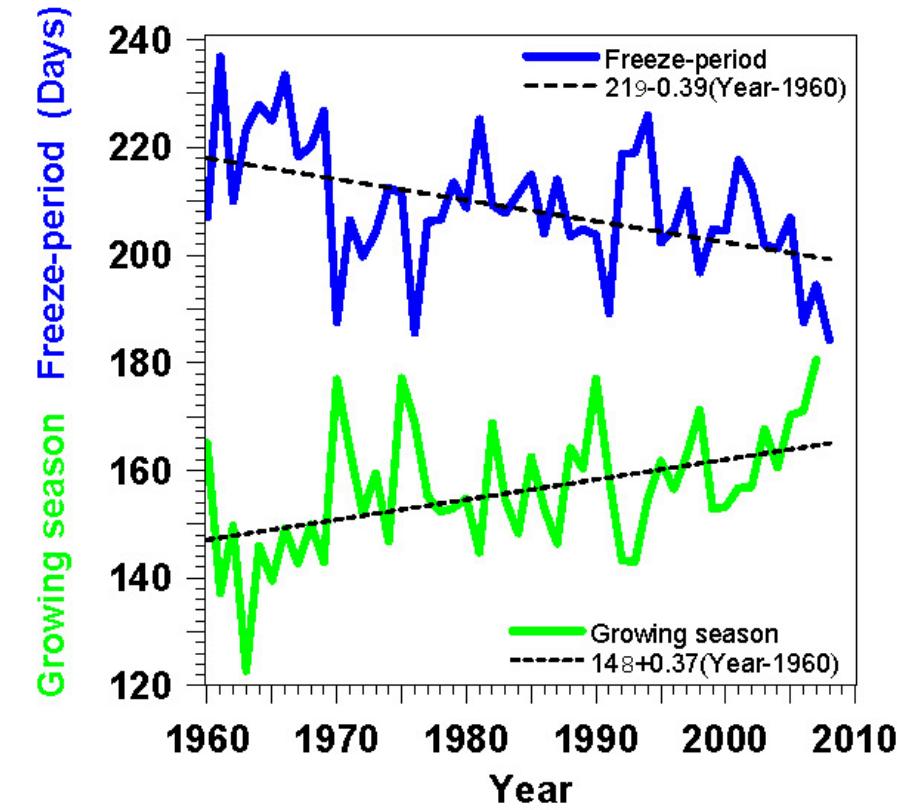
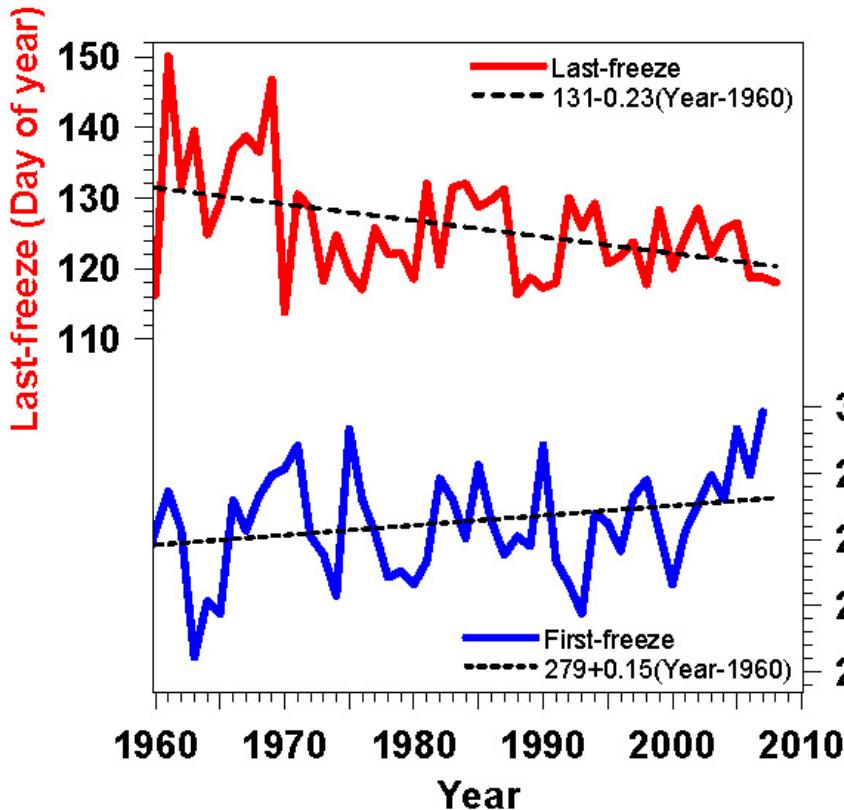
2006

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!*



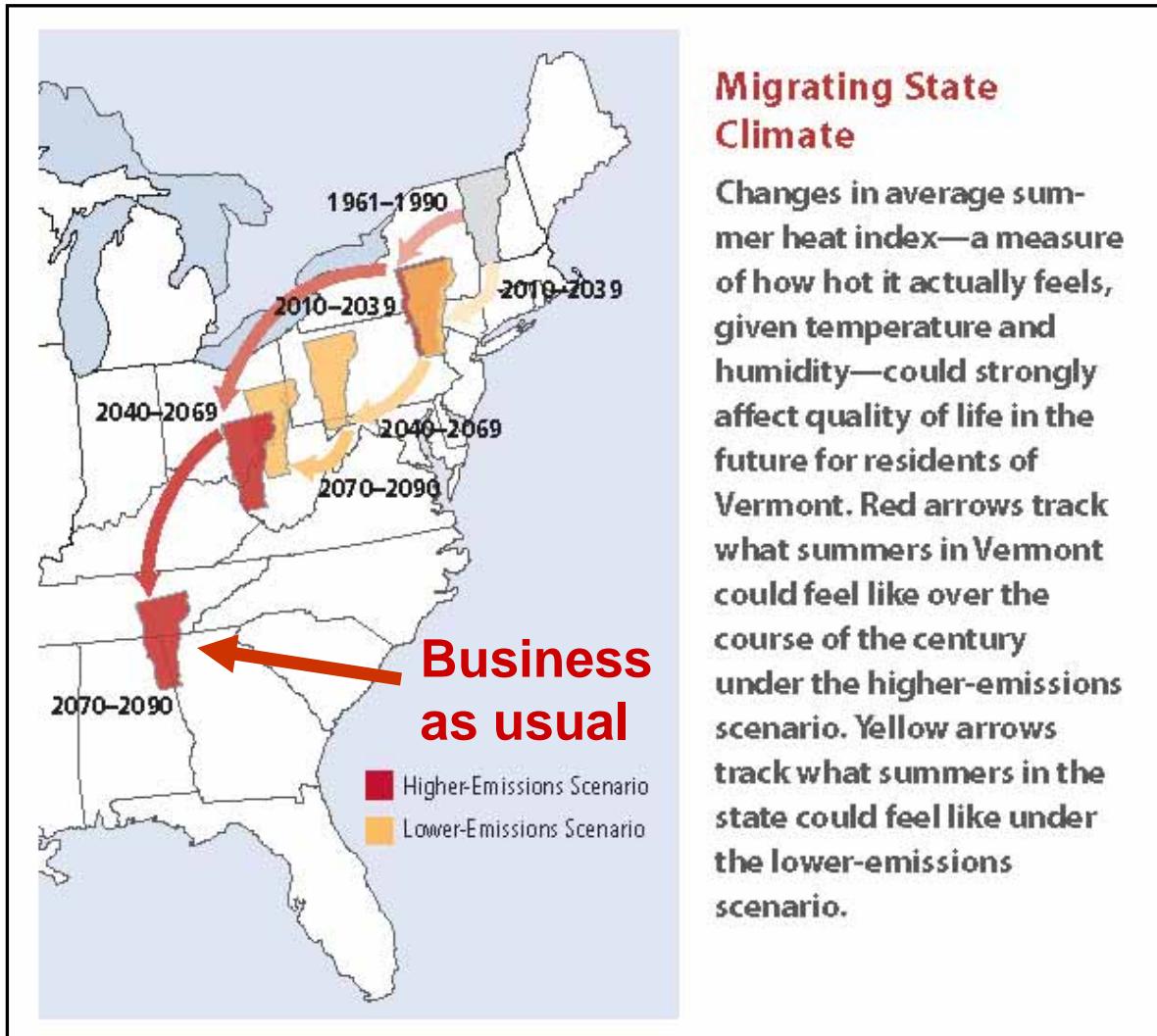
Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

Later frost: Growing season getting longer

Vermont's Future with High and Low GHG Emissions

What
about
skiing?

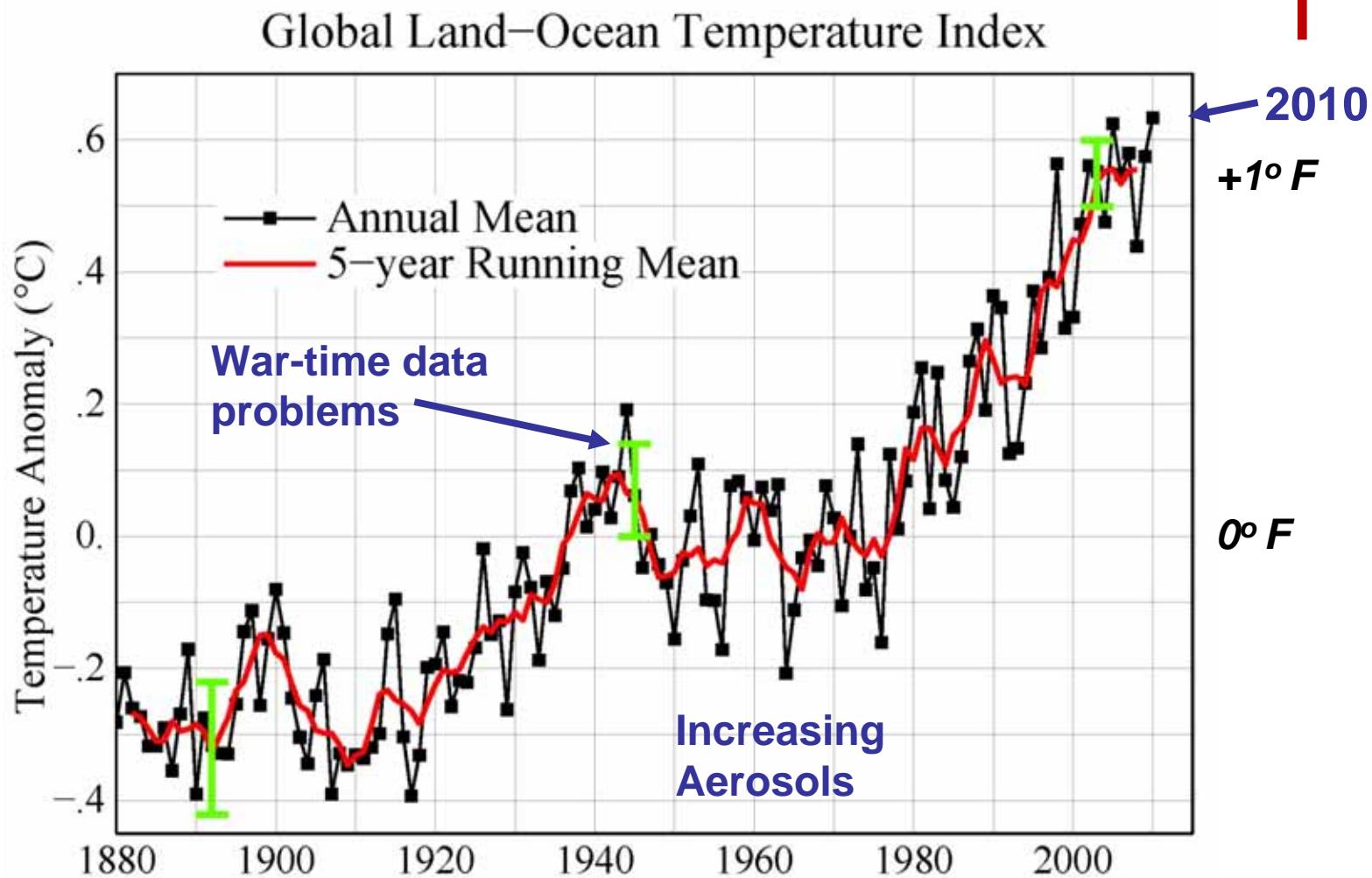
What
about
tropics?



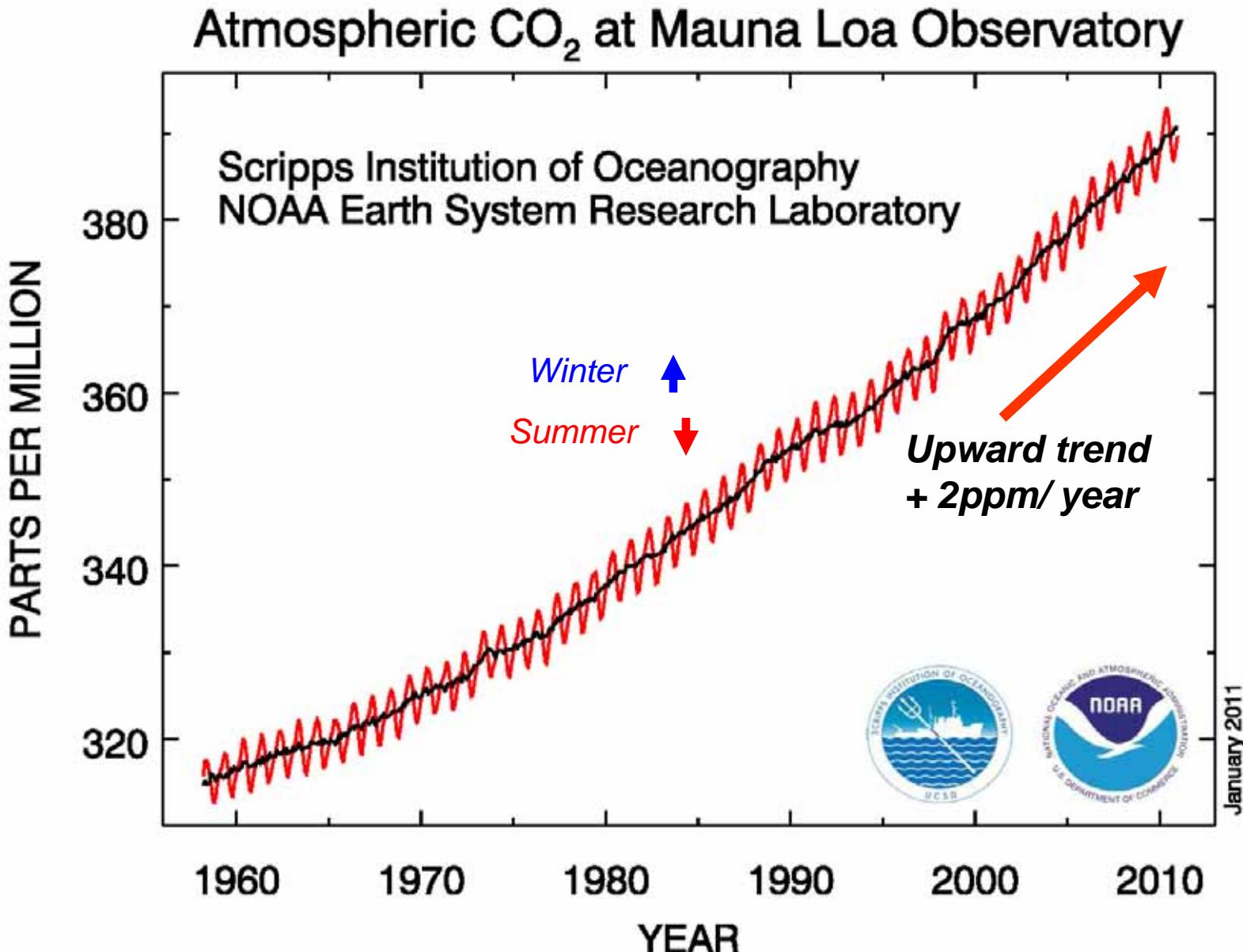
NECIA,
2007

Global Temperature Rise 1880 – Present

2100: +5°F

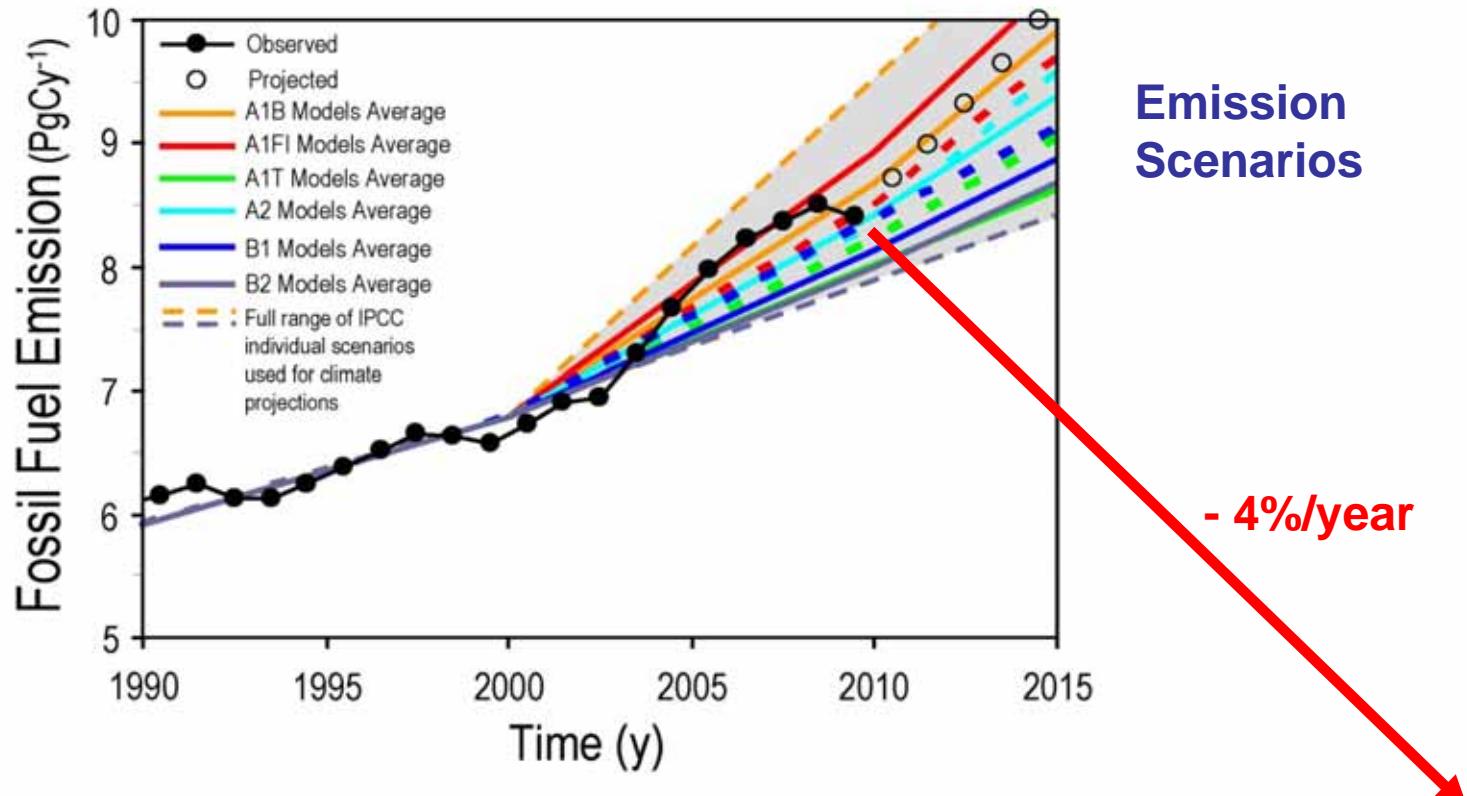


Carbon Dioxide Is Increasing



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



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...

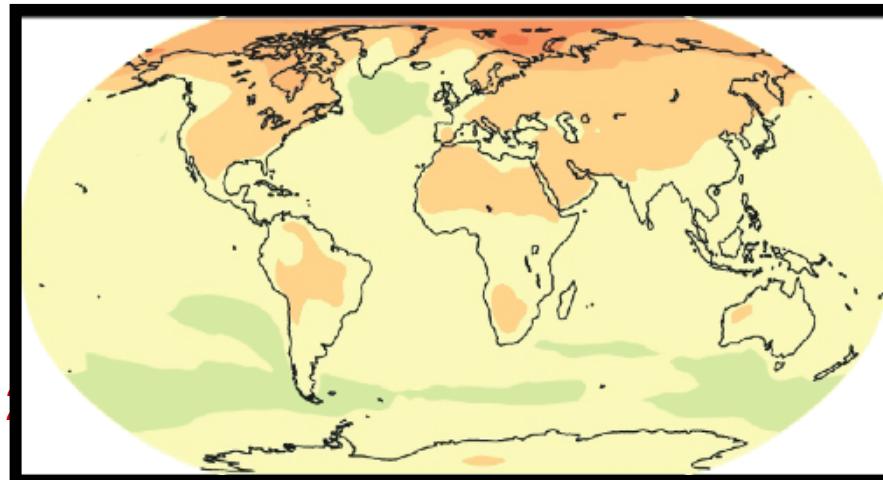
Why Is the Rise of Atmospheric CO₂ a Problem?

- 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

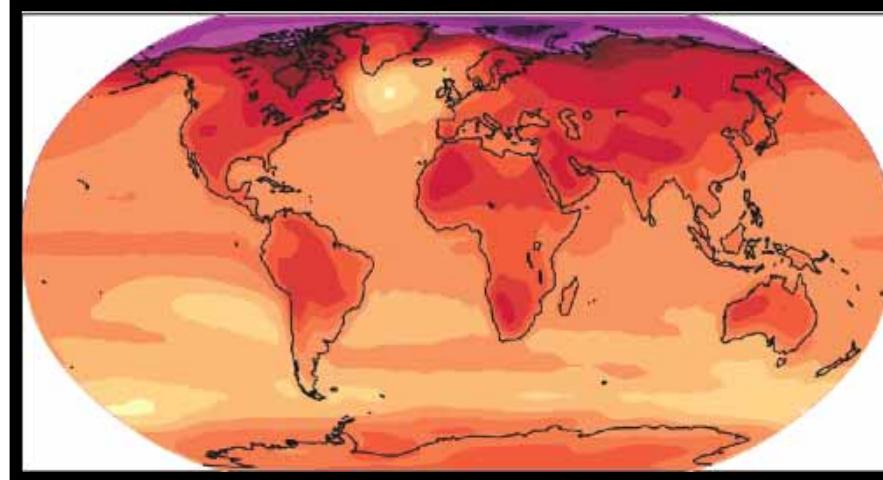
2020-2029 and 2090-2099, relative to 1980-1999 ($^{\circ}\text{C}$)

“Committed”

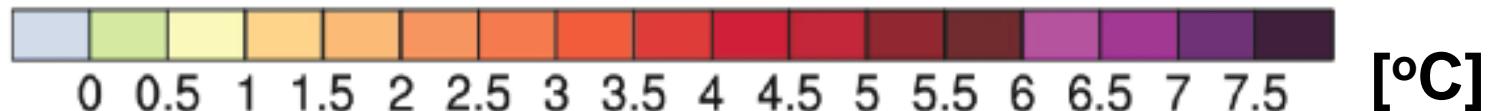


(We did
nothing for
the last 20
years)

Still up to us!



(We could
halve this if
we act now)



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

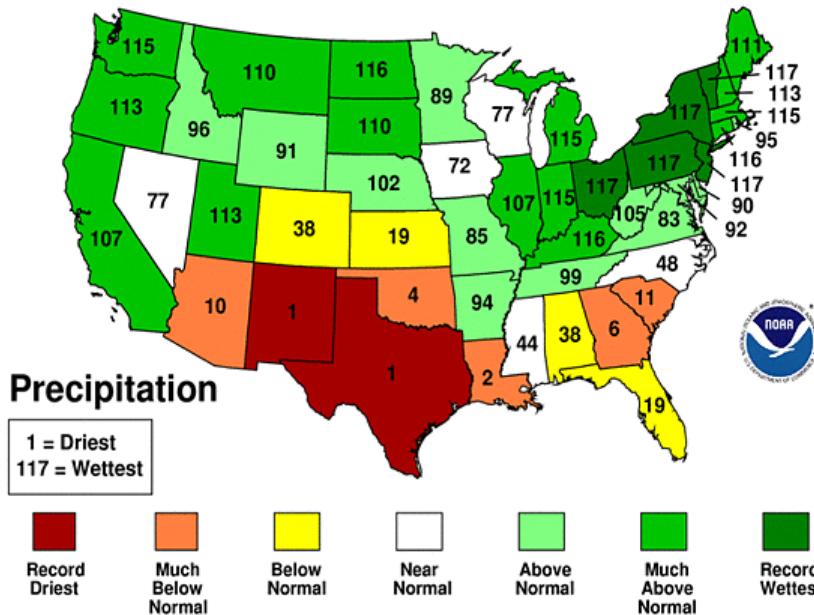
- Extreme weather: Floods, fires, & drought
 - 32 weather disasters >\$1B in 2011
- Melting Arctic and permafrost—methane release is positive feedback
- Ecosystem collapse, including perhaps forest and ocean ecosystems
- Collapse of unsustainable human population

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)

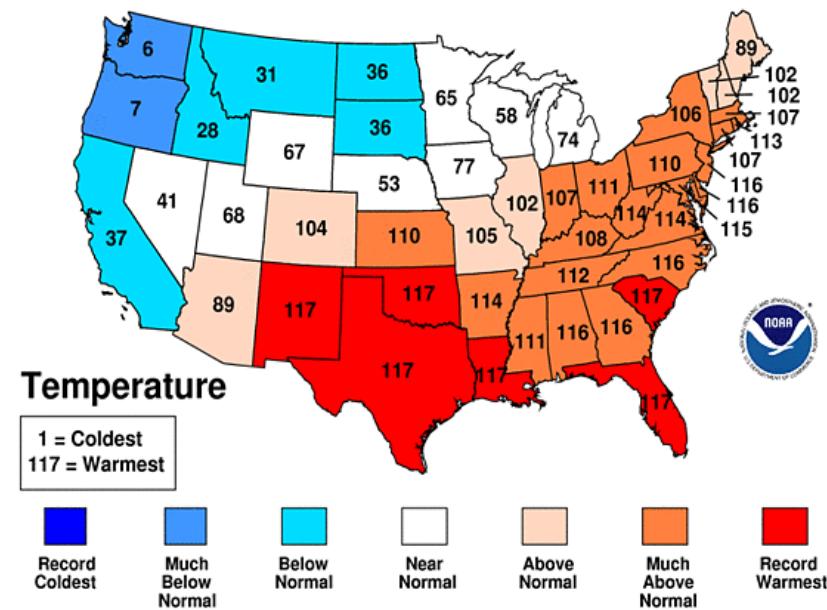
March-August 2011 Statewide Ranks

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