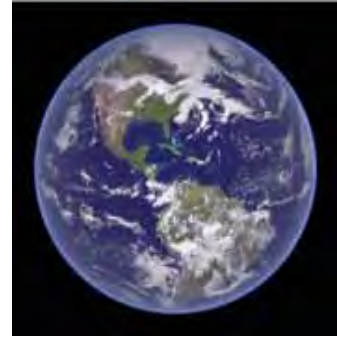




Climate Change and Vermont



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***Friends of the Winooski River,
Waterbury, Vermont***

February 7, 2012

- 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*

Climate Change

- One of the many great challenges for the 21st century - present path is unsustainable
- **We are already decades late in taking action**

J. S. Sawyer (1972): Man-made CO₂ and the “greenhouse” effect

- **It is a global issue & a local issue
a societal issue & a personal issue**
- **Clash of Earth science with social values**

Outline

- **Science of climate change**
 - **Global scale: actual and future**
 - **What is happening to Vermont**

Discussion

My Background: Peterhouse, Cambridge - UK

- **Founded 1284**
- **Medieval warm period;
Vinland colony
flourishes**



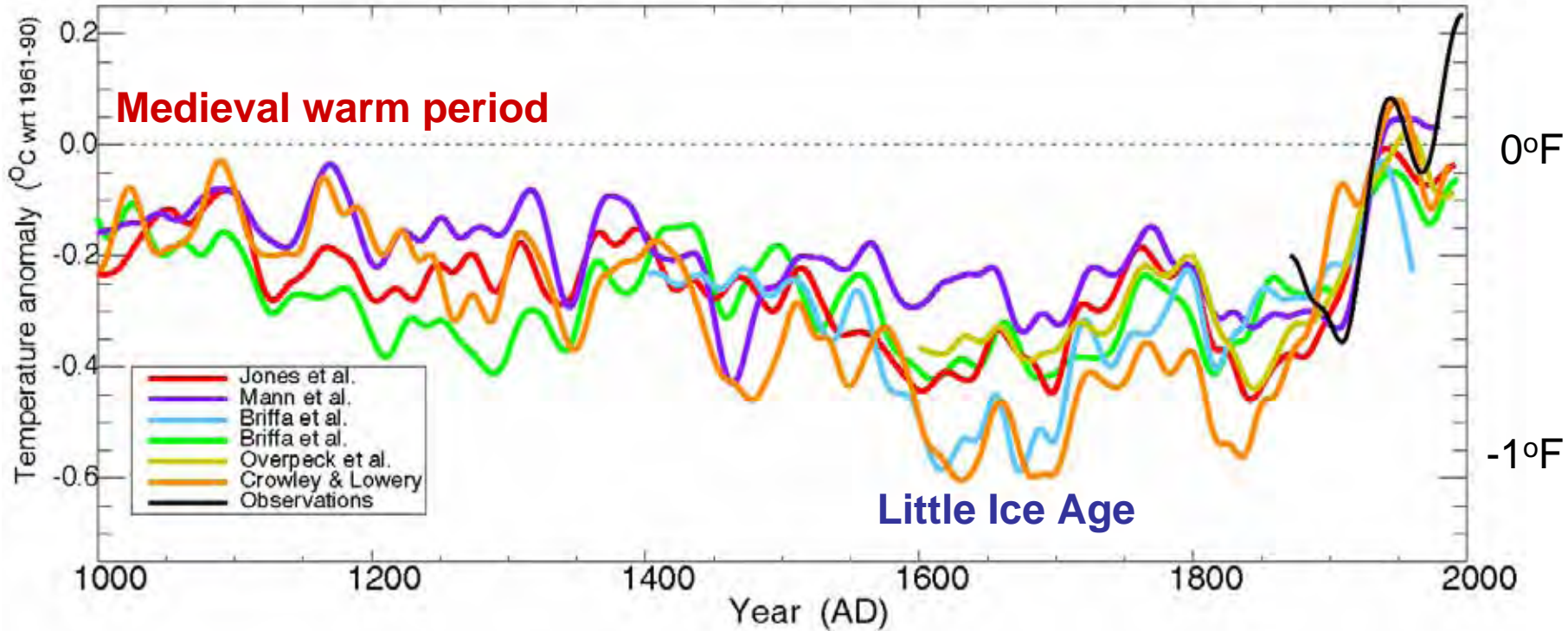
My Background: Nottingham High School

- **Founded 1513**
- **1550:**
Heading into “Little Ice Age”
- **1620:**
Pilgrim fathers face bitter winters



Millennial Temperature Record

2100: +5°F



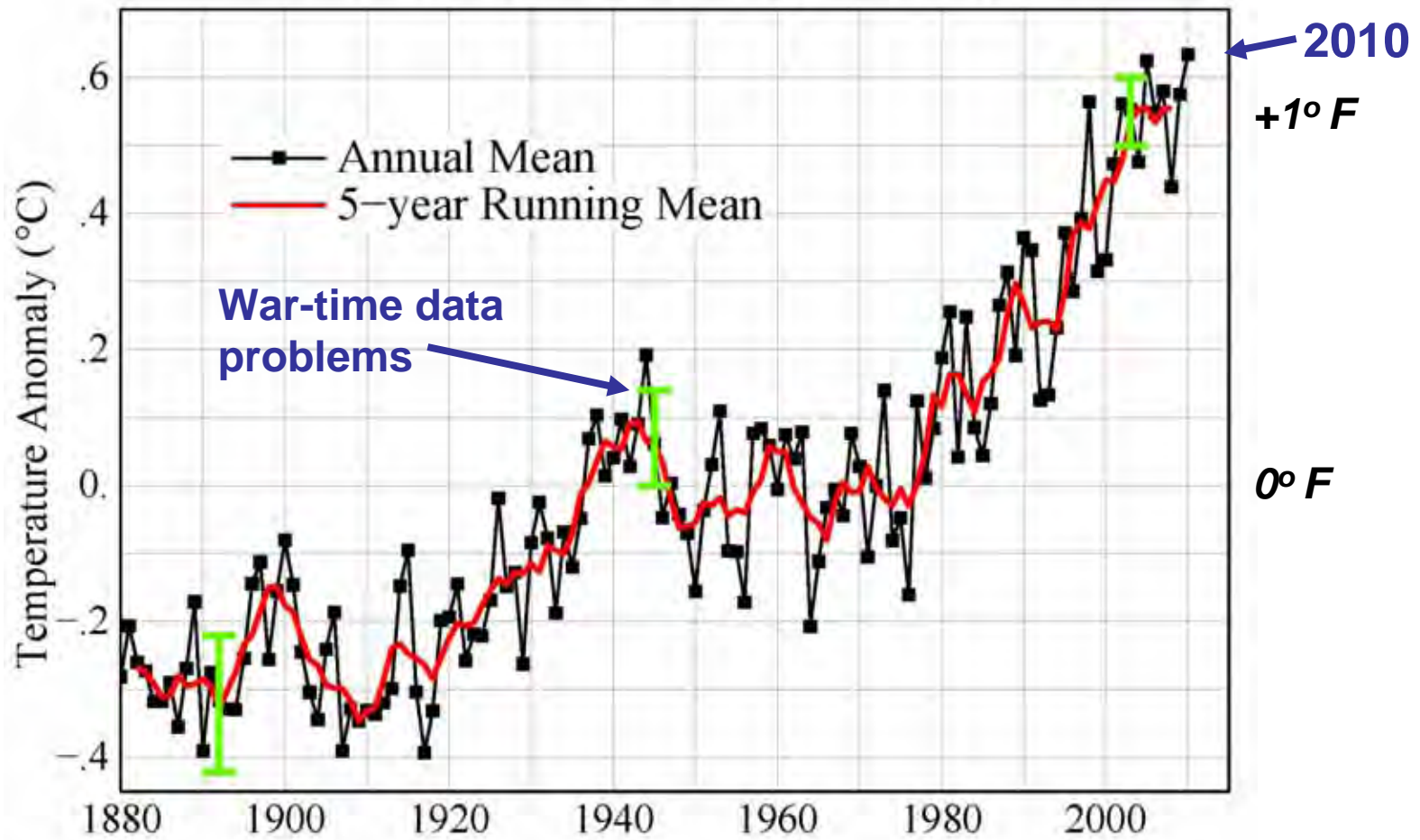
- “Proxy” records from before the time of thermometers provide uncertain data, but they’re all we have
- Black line is 150-yr instrument record

Global Temperature Rise 1880 – Present

2100: +5°F



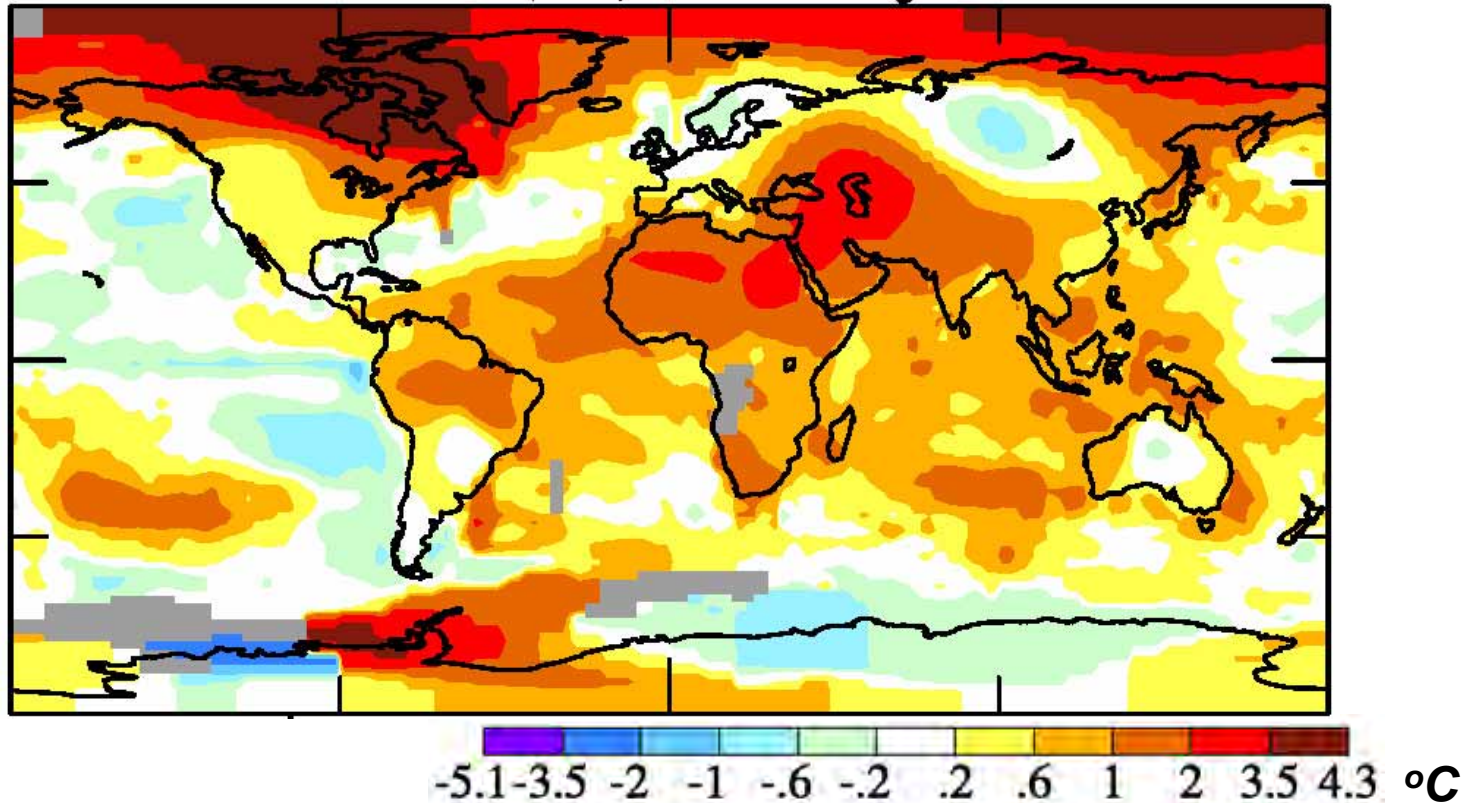
Global Land–Ocean Temperature Index



NASA-GISS, 2011

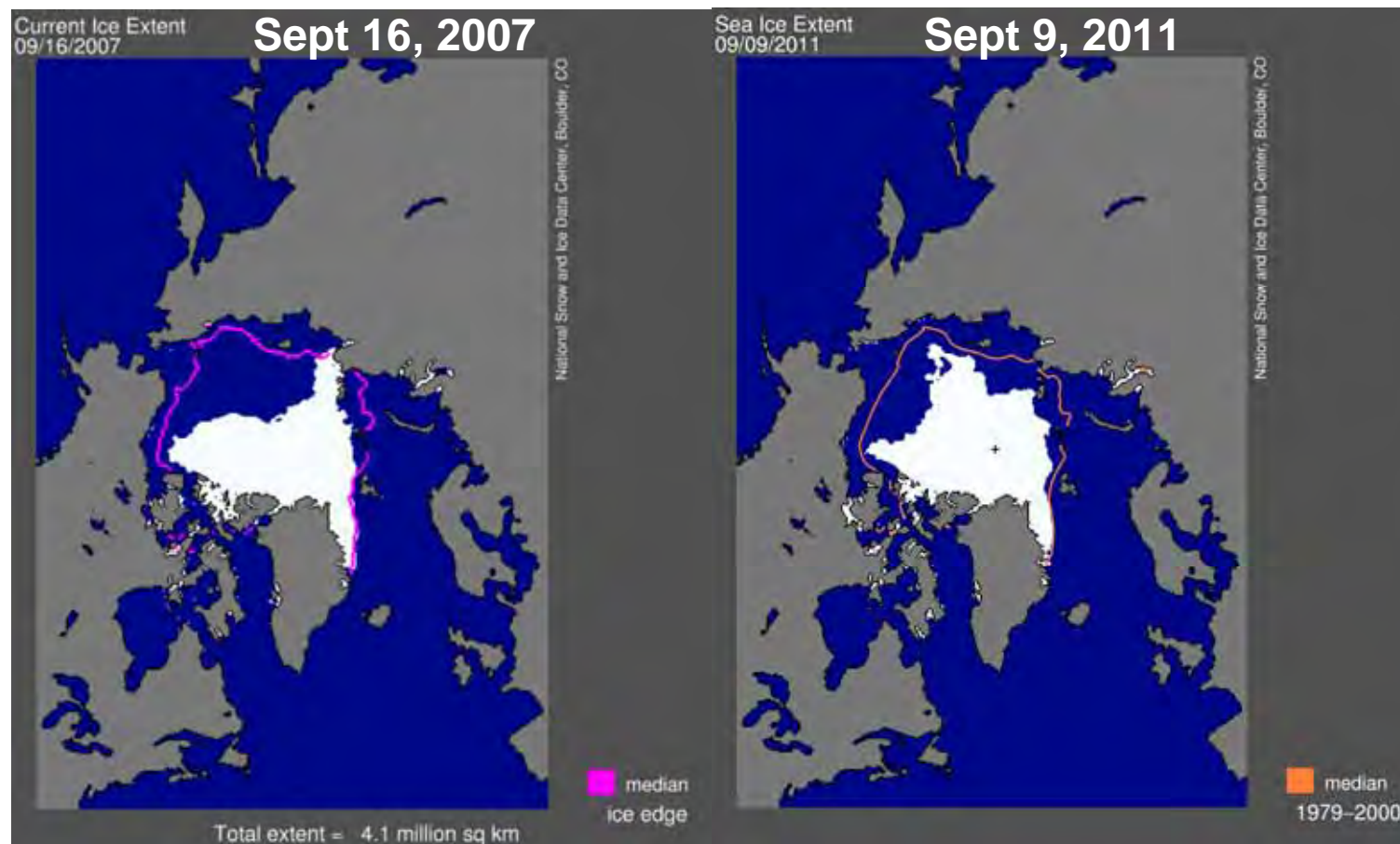
Global Picture 2010

2010, warmest (tie) of 131 years 0.63°C (1.2°F)



- **Record summer temps**
 - **Russia** (100°F) Moscow fires
 - **Pakistan** (128°F) Extreme monsoon floods

Arctic Sea Ice Loss Has Accelerated



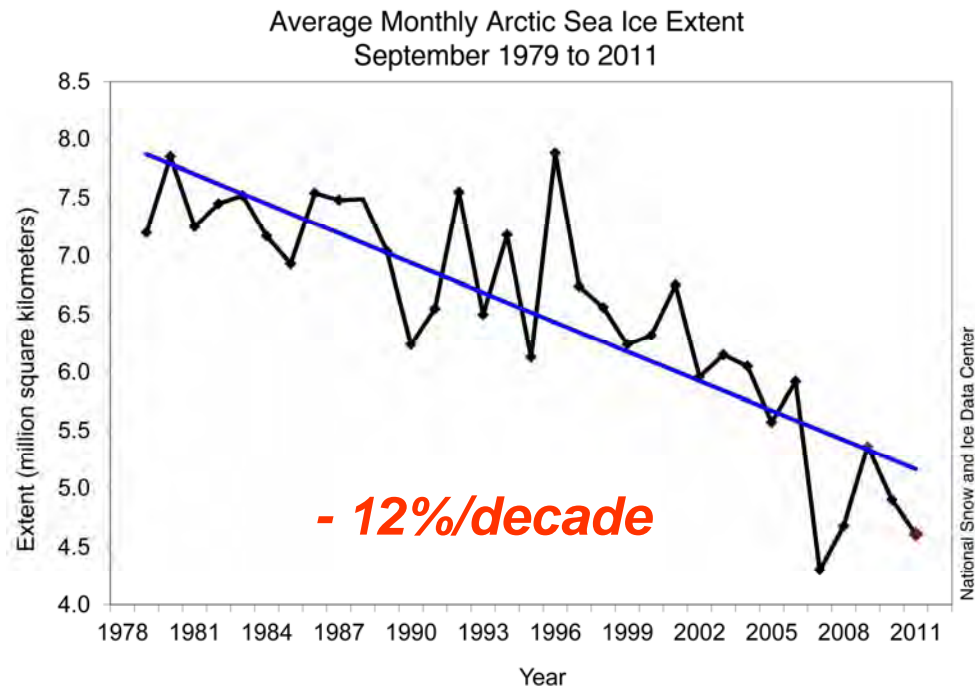
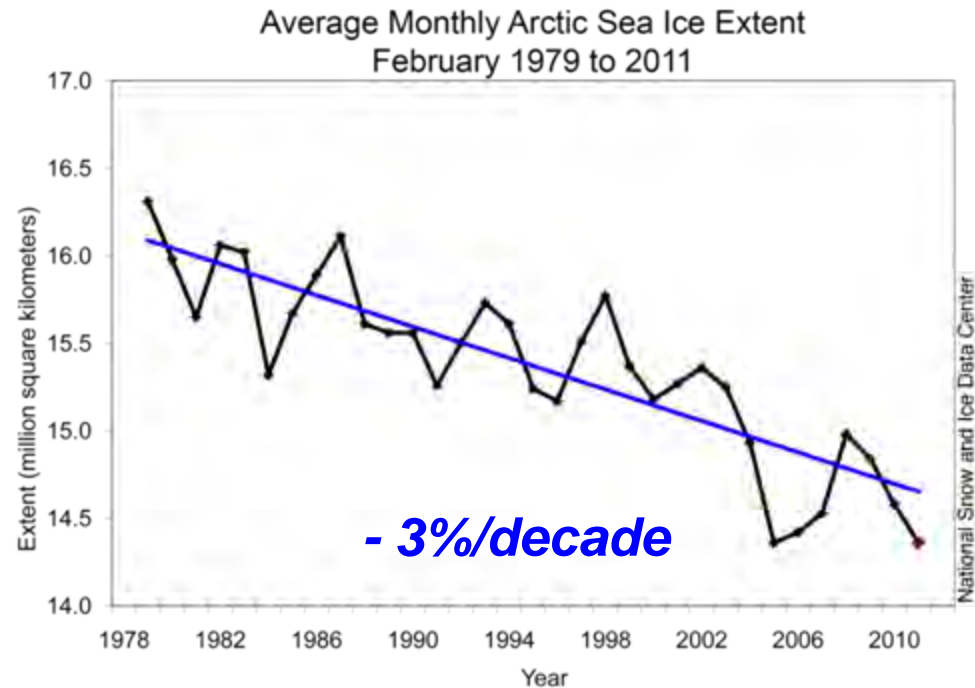
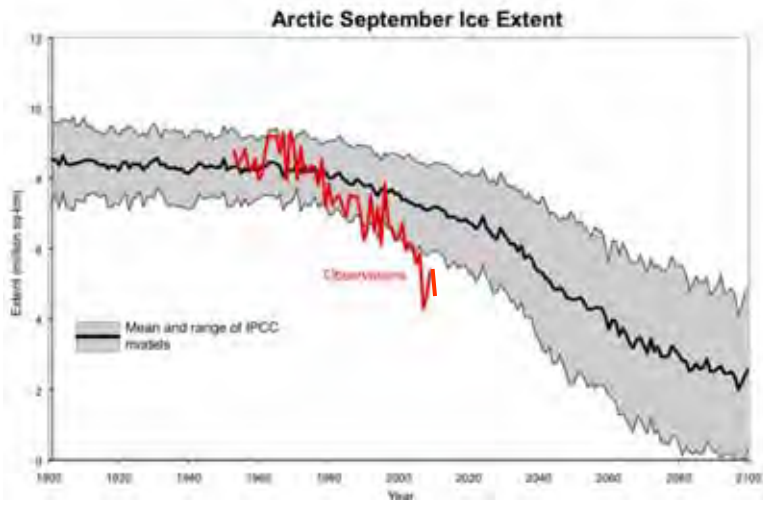
- Positive feedbacks speed melting
- Less ice, less sunlight reflected
- More evaporation, larger water vapor greenhouse effect

(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

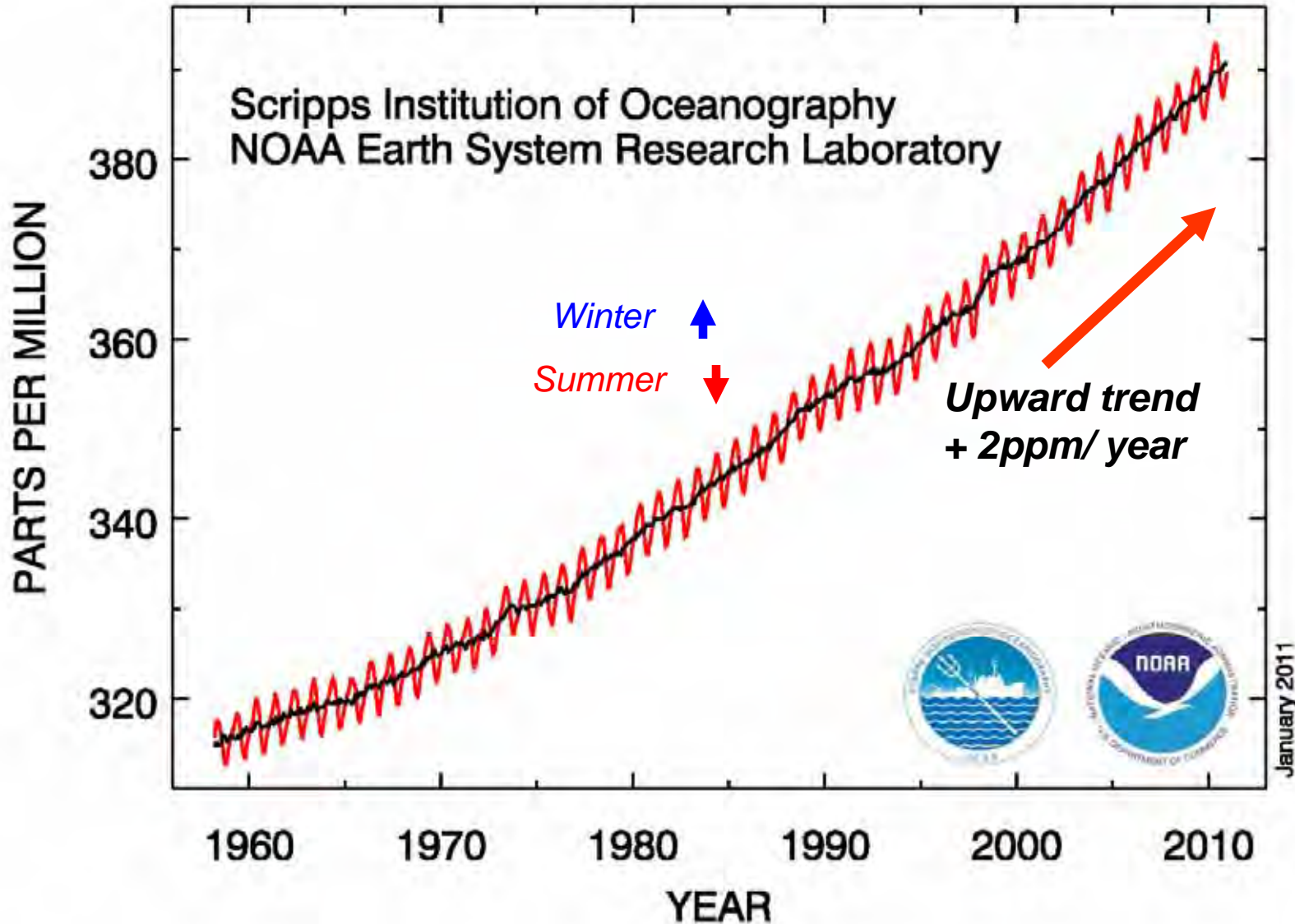
Sea Ice Trends

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



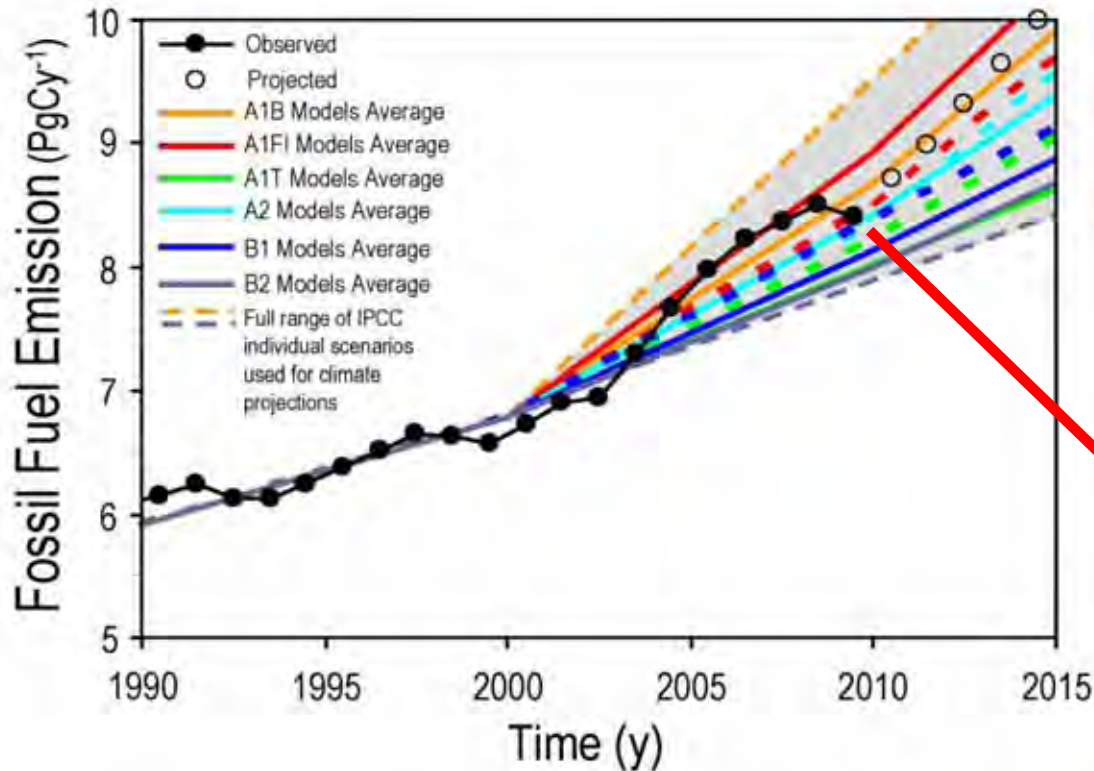
Carbon Dioxide Is Increasing

Atmospheric CO₂ at Mauna Loa Observatory



2009 Was “Good” for the Earth

Fossil Fuel Emissions: Actual vs. IPCC Scenarios

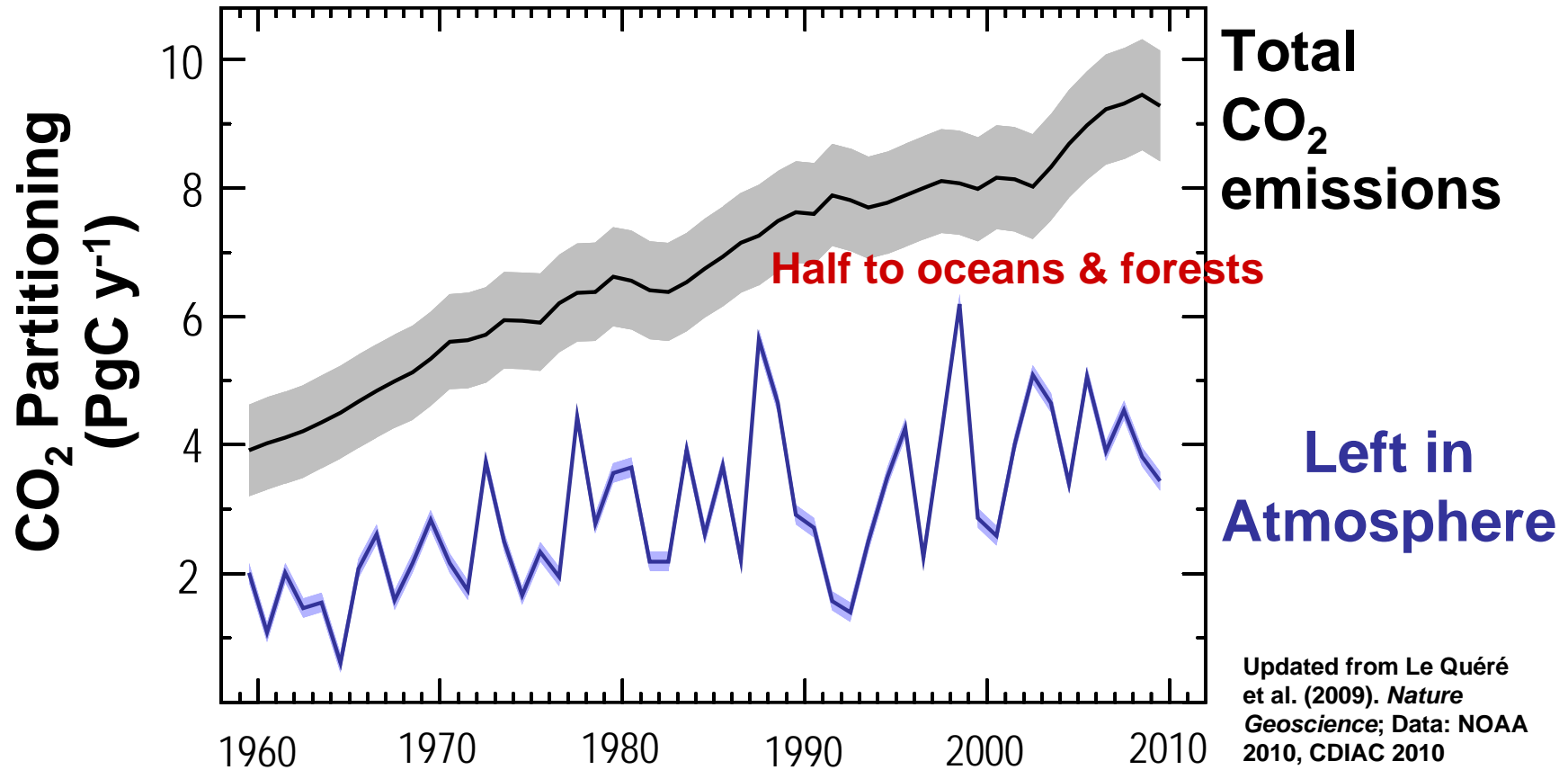


Emission
Scenarios

- 4%/year

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 CO₂ from the atmosphere, and many centuries to remove it from oceans

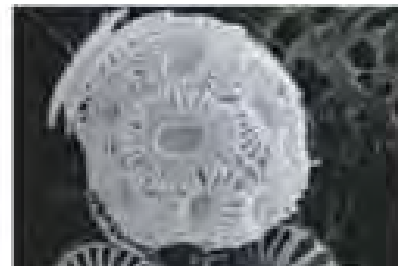
Rising Ocean Acidity Threatens Organisms



- From the Tropics to the Arctic, the seas are sucking up emissions of CO₂ — from burned fossil fuels
- When CO₂ dissolves in water, carbonic acid is produced; the oceans are becoming more acidic



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



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**

Global Warming Is Unequivocal

IPCC: Fourth Assessment, Feb., 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:

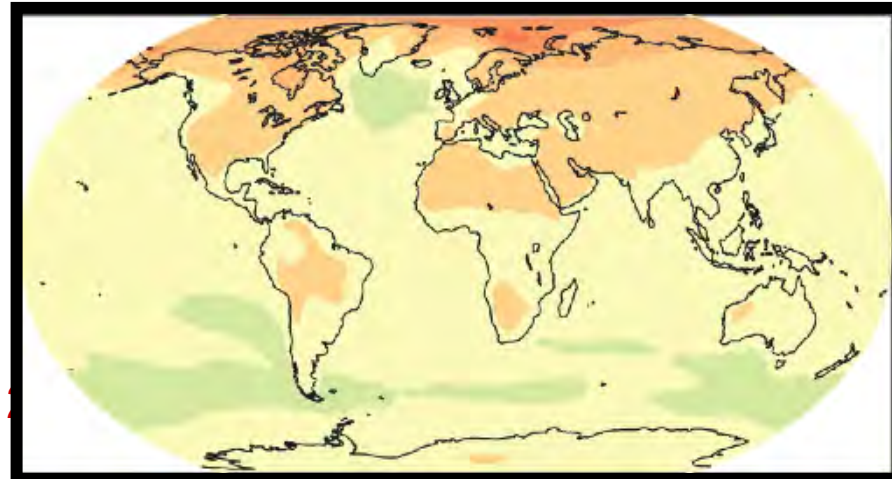
- NH snow extent
- Arctic sea ice
- Glaciers
- Ocean pH (increasing acidity)



Predicted Change in Temperature

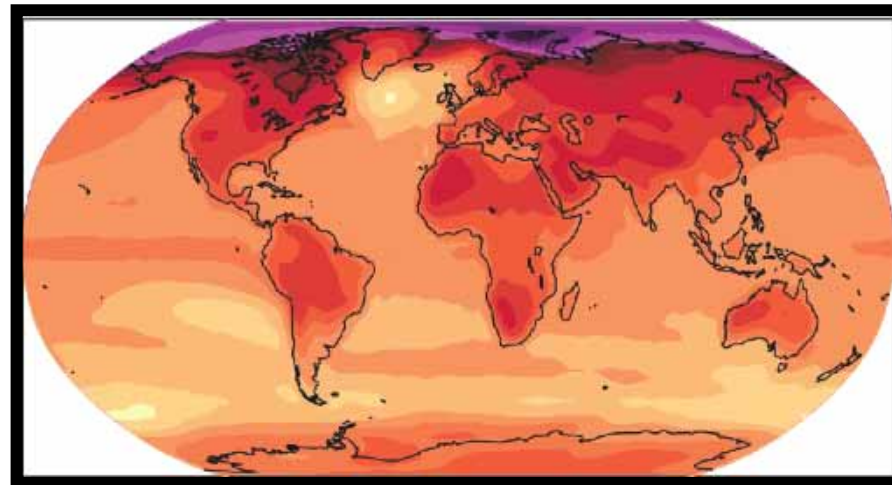
2020-2029 and 2090-2099, relative to 1980-1999 (°C)

“Committed”



(We did nothing for the last 20 years)

Still up to us!

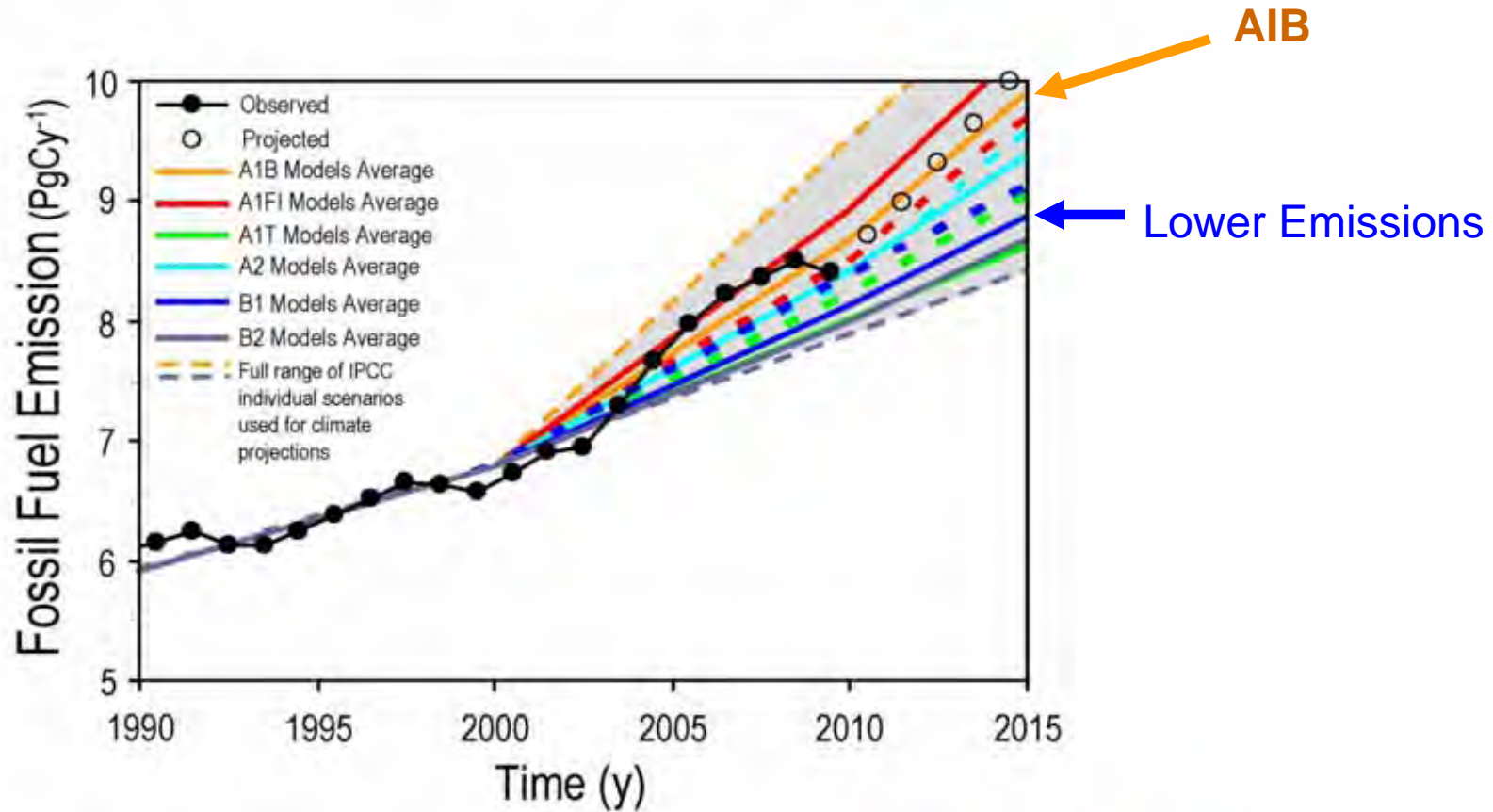


(We could halve this if we act now)



[°C]

Climate Models Run for Different Scenarios for Global Emissions



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 accelerating 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

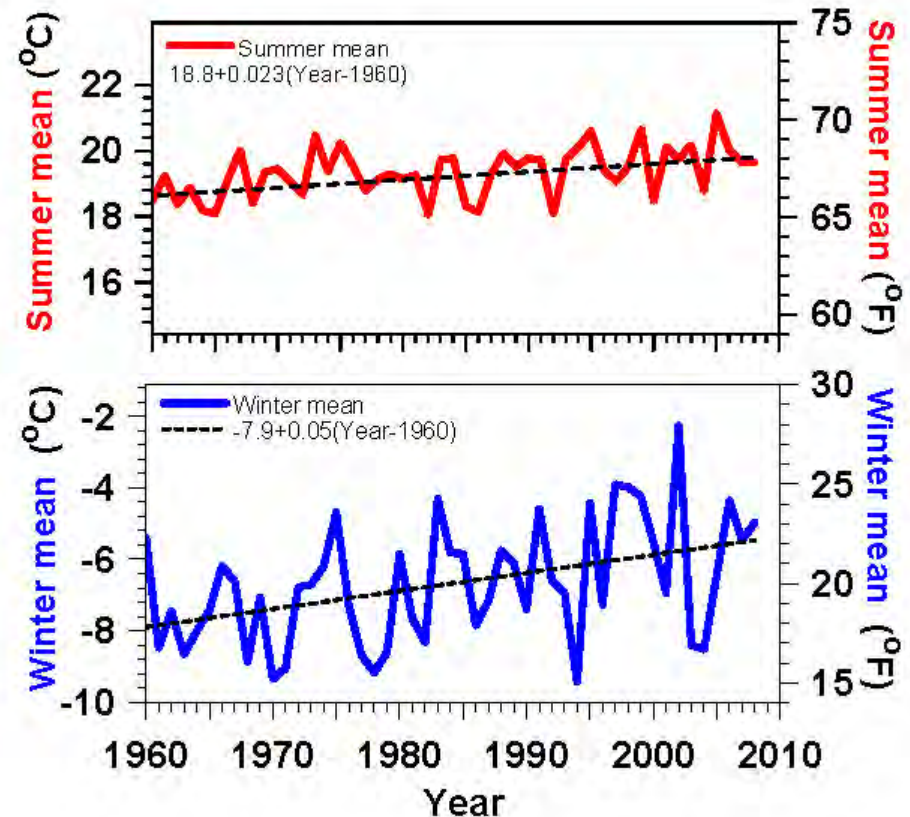
- **Extreme weather: Floods, fires, & drought**
 - **32 weather disasters >\$1B in 2011**
- **Melting Arctic and permafrost—methane release is positive feedback**
- **Ecosystem collapse, including perhaps forest and ocean ecosystems**
- **Collapse of unsustainable human population**

Local Example: What Is Happening to Vermont?

- Local climate change indicators
- Easier to grasp than global view
- 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**

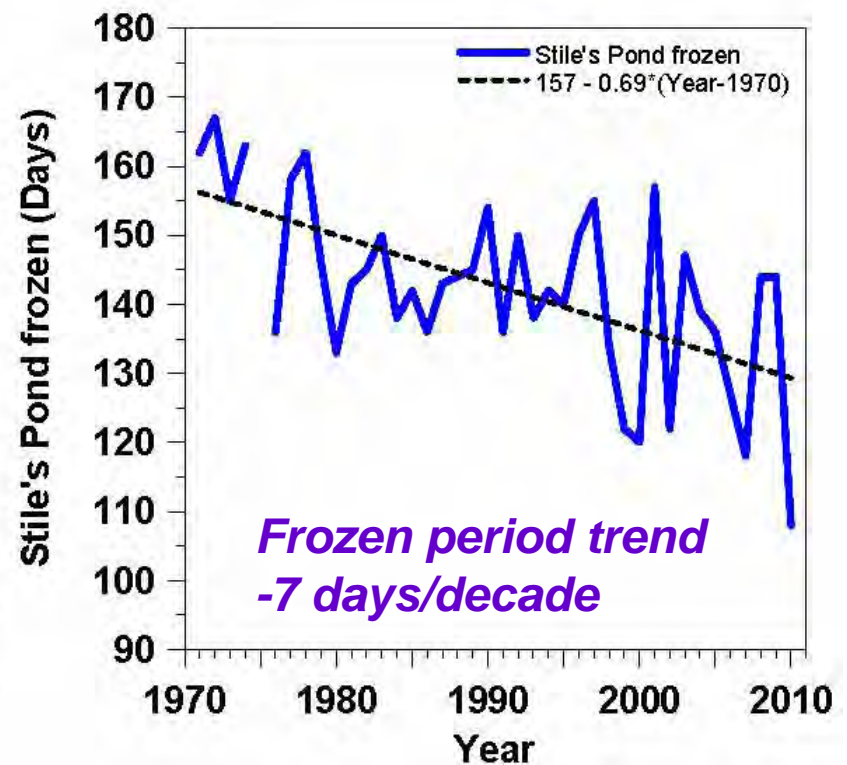
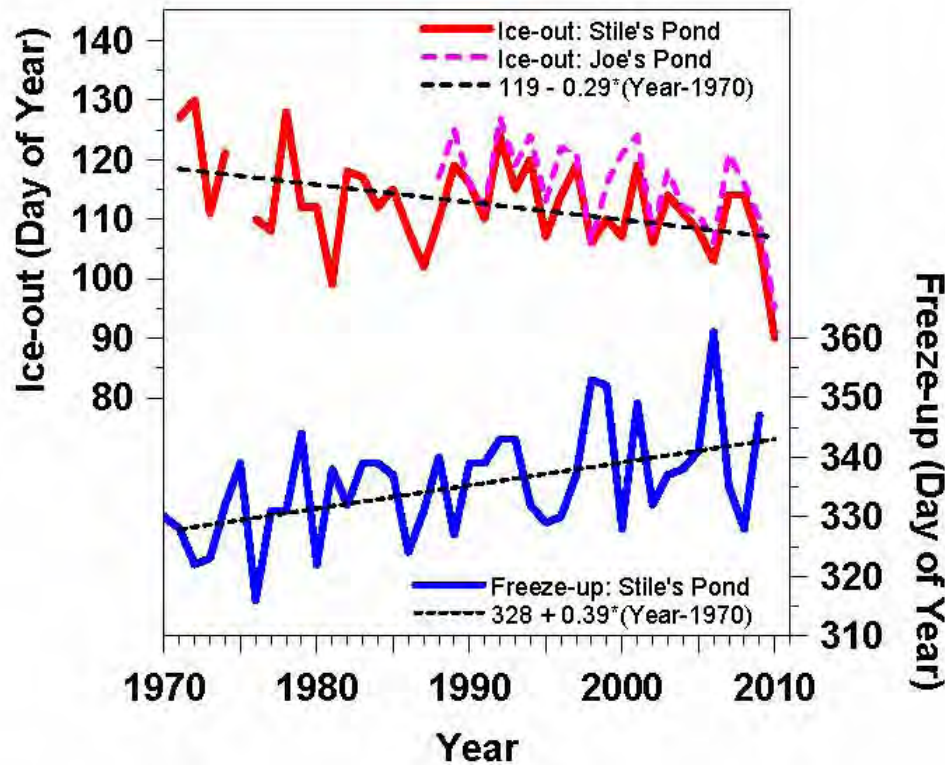
Vermont Temperature Trends

- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Less snow drives larger winter warming**



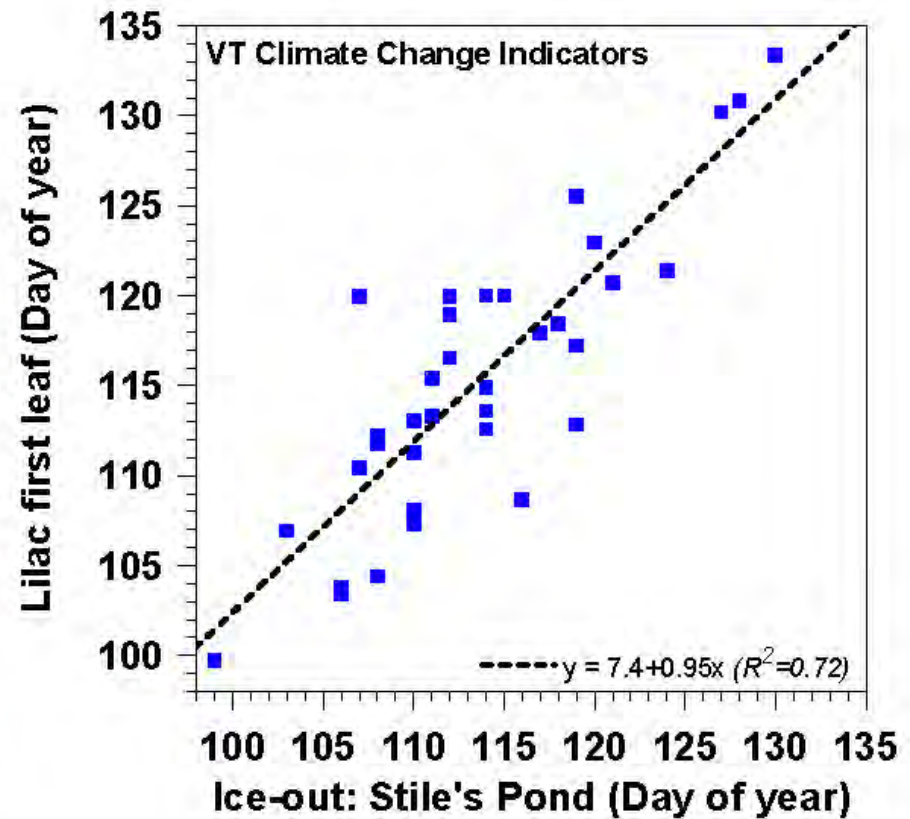
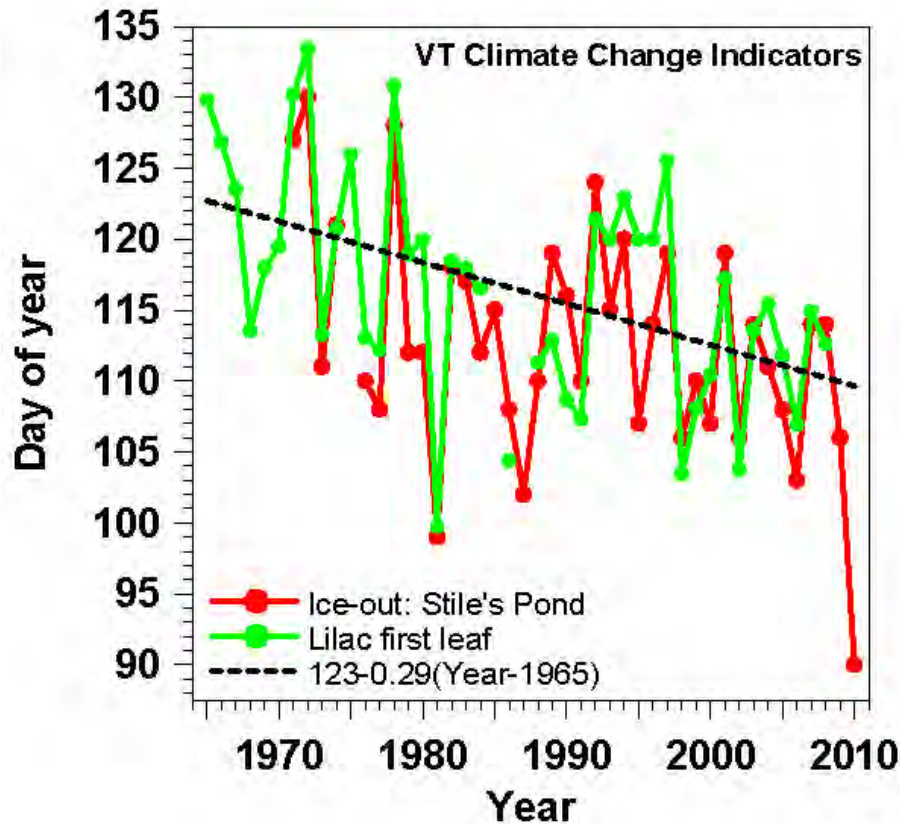
Lake Freeze-up & Ice-out Changing

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

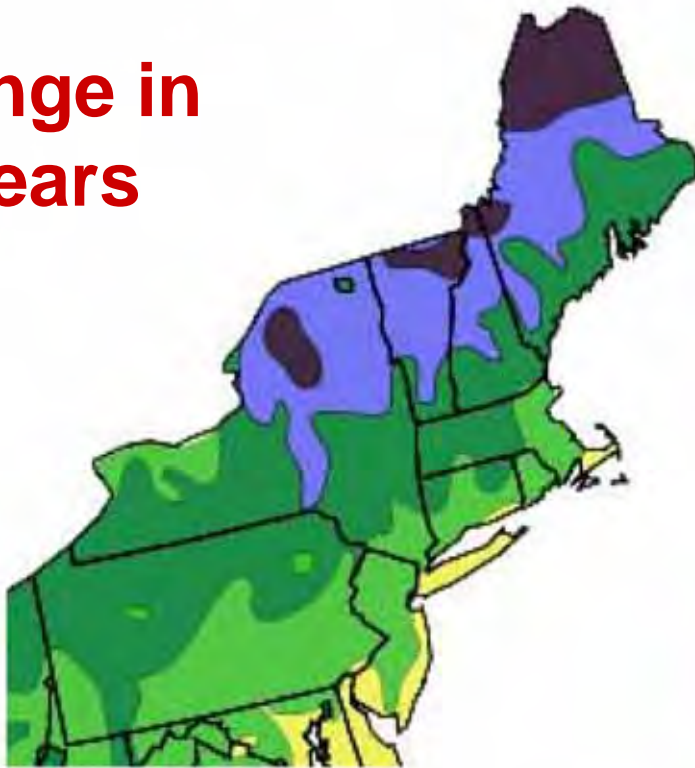
Vermont Winter 2006



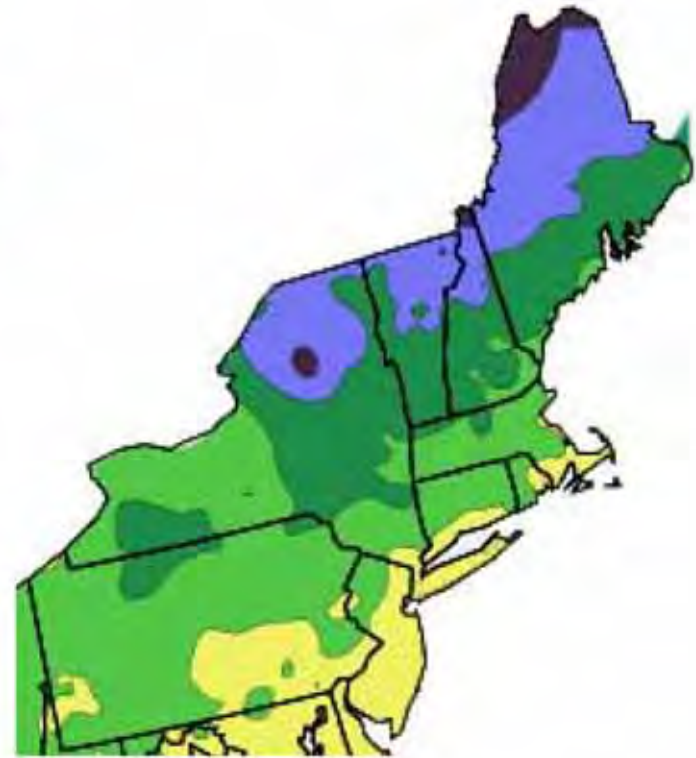
- **Sun is low; and snow reflects sunlight, except where there are trees!**
- **Sunlight reflected, stays cold; little evaporation, clear sky; earth cools to space**

USDA Hardiness Zones - Northeast

**Change in
16 years**



1990



2006

Zone



USDA Hardiness Zones

Gardening in Pittsford, Vermont in January



January 7, 2007

December 2006:

- **Warmest on record**



January 10, 2008

Warm Fall:

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

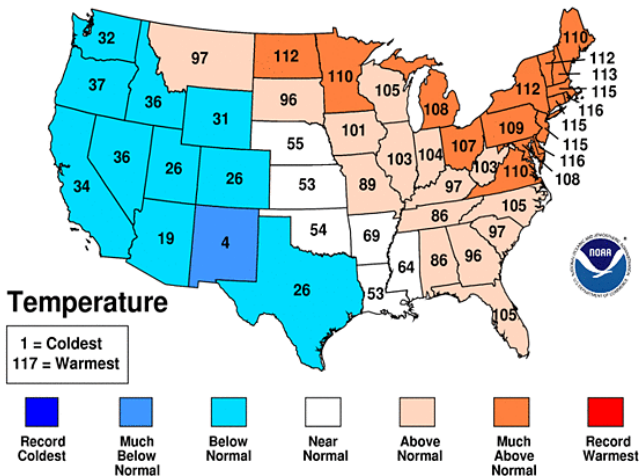
December 20, 2011



January 2, 2012



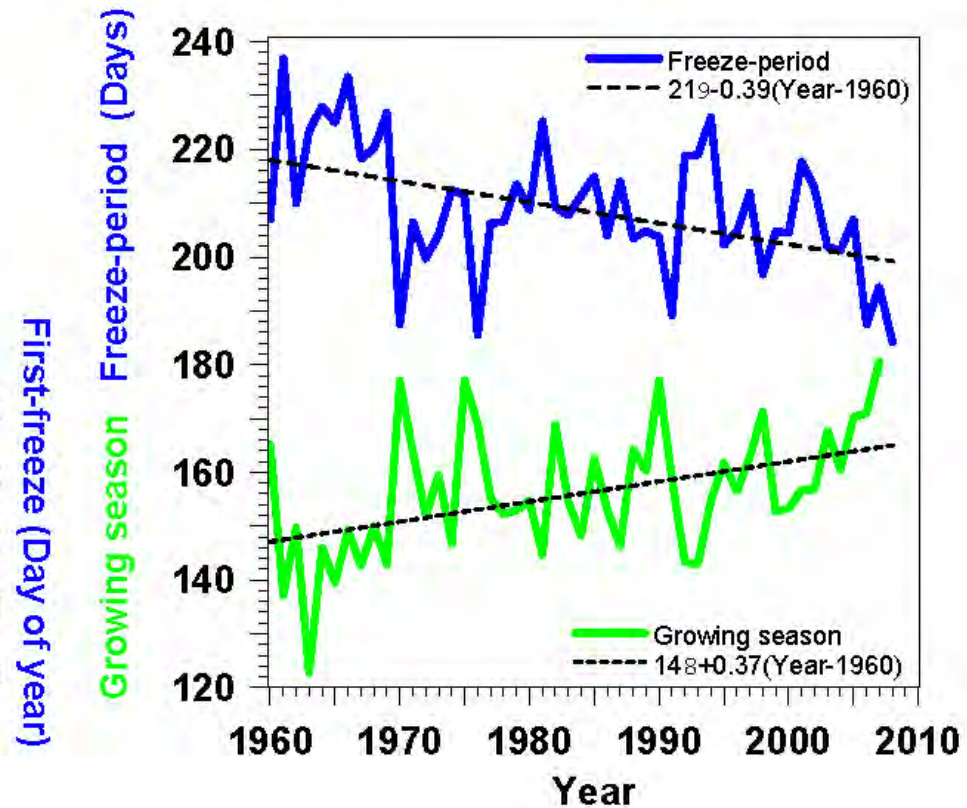
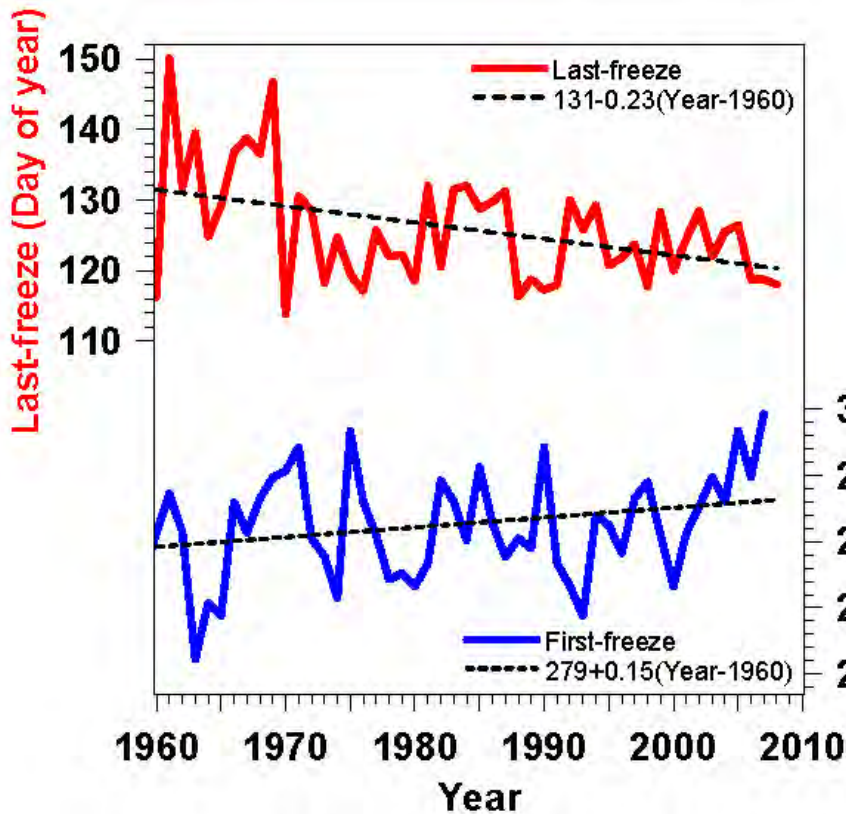
December 2011 Statewide Ranks
National Climatic Data Center/NESDIS/NOAA



Freeze-up was January 3

- December 2011:
 - 6th Warmest on record

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. rangegiving 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!*



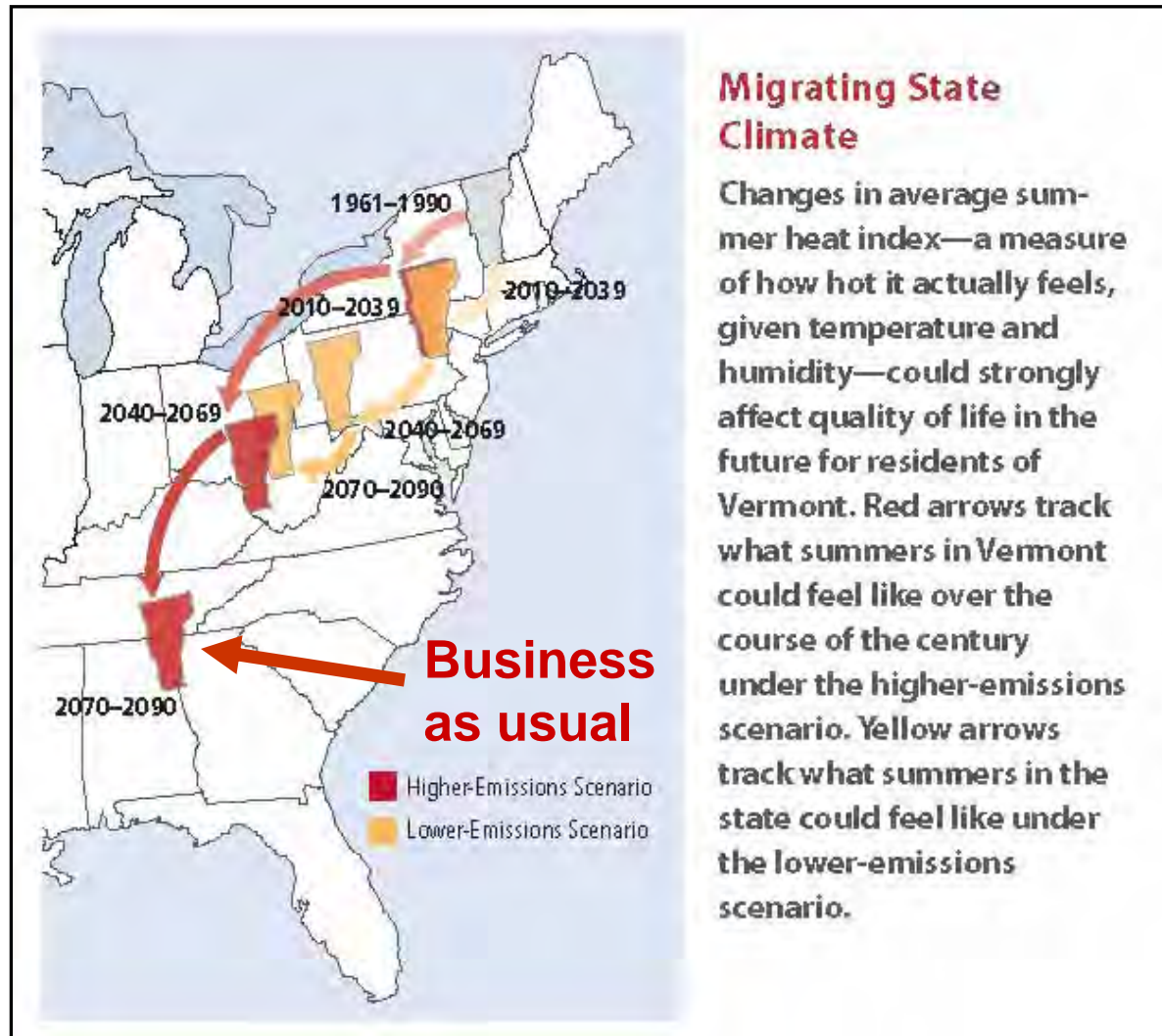
Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

Later frost: Growing season getting longer

Vermont's Future with High and Low GHG Emissions

What
about
skiing?

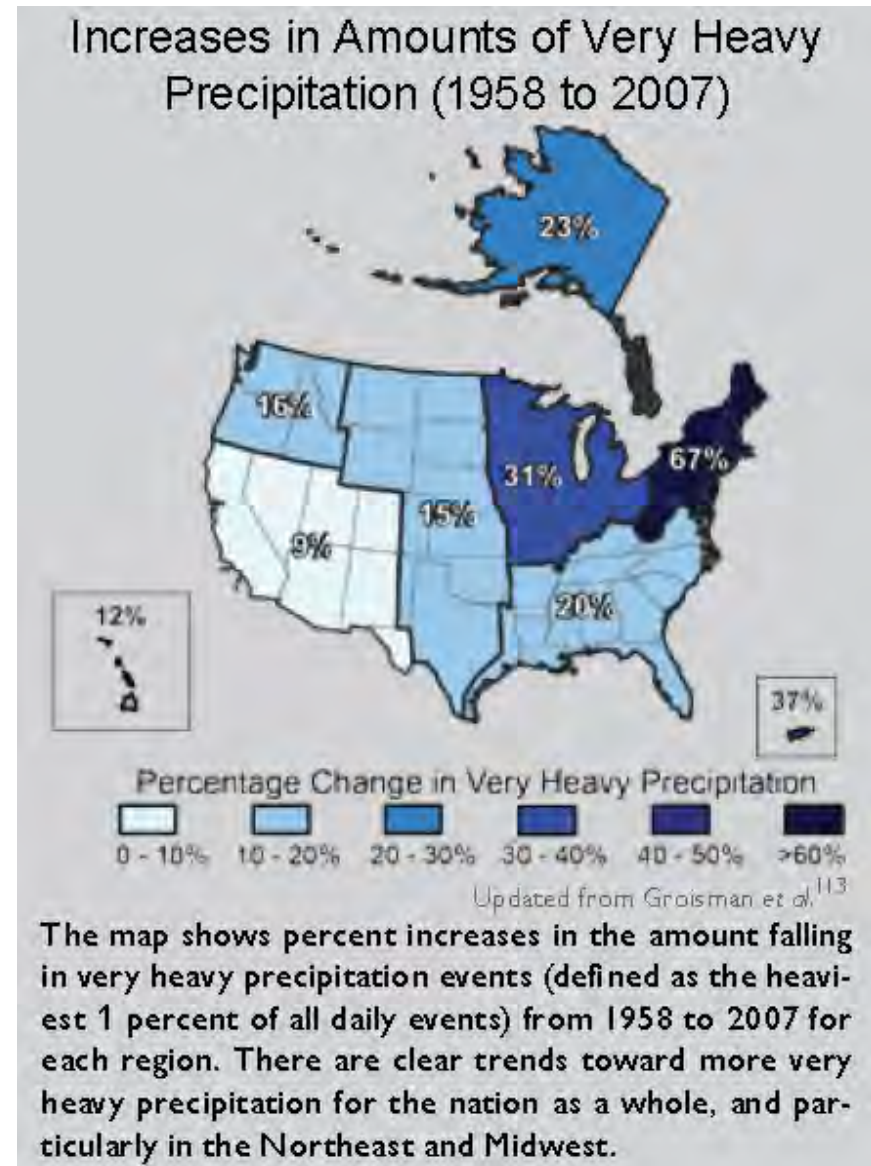
What
about
tropics?



NECIA,
2007

Very Heavy Precipitation Is Increasing

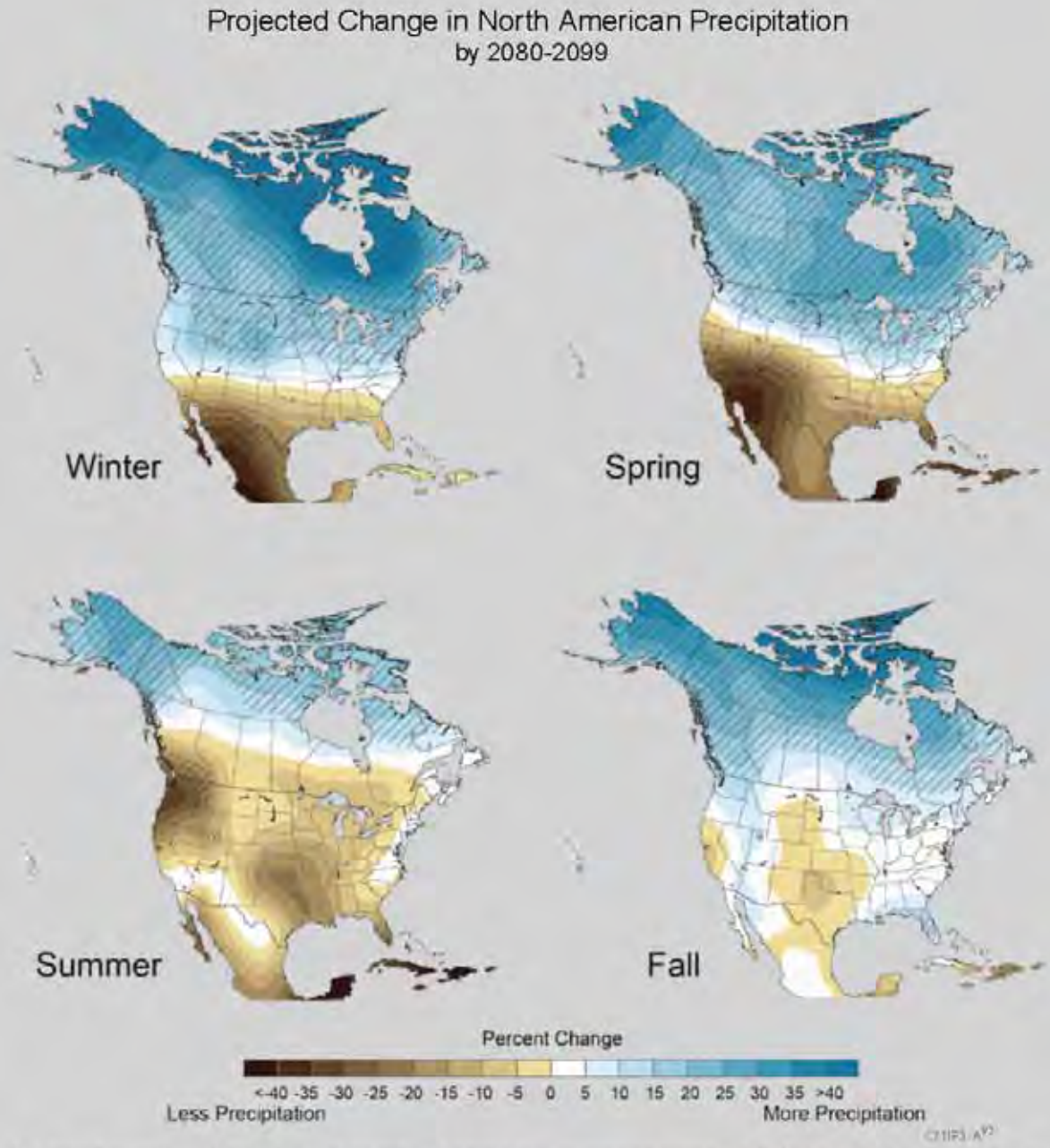
- **Most of the observed increase in precipitation during the last 50 years has come from the increasing frequency and intensity of heavy downpours.**
- **67% increase in Northeast**
- **Little change or a decrease in the frequency of light and moderate precipitation**
- **Vermont streamflow is increasing**



Projected Precip. Increase by 2090

- *For Vermont*
- 15% in winter,
- 10% in spring
- 5% in fall

- No change, summer
- Heavier rain and more drought



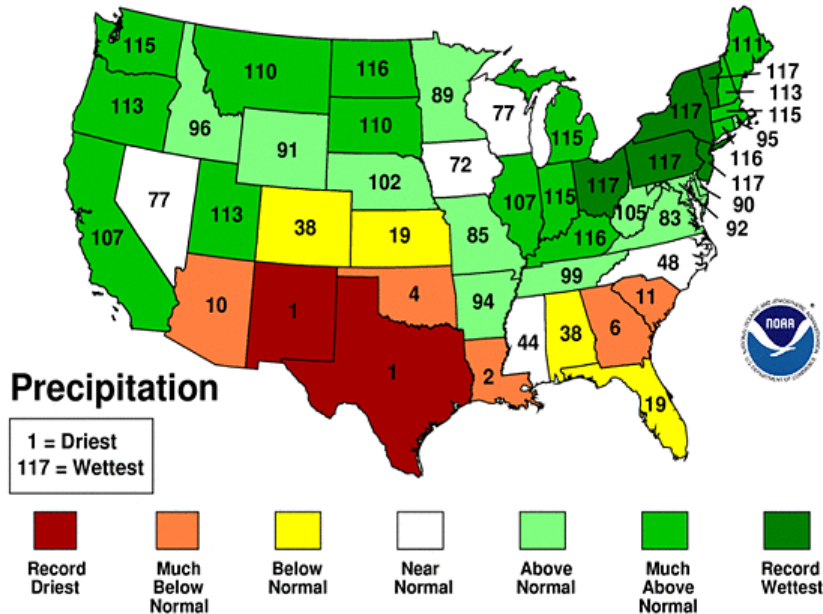
The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario.⁷¹ For example, in the spring, climate models agree that northern areas are likely to get wetter, and southern 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.

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)

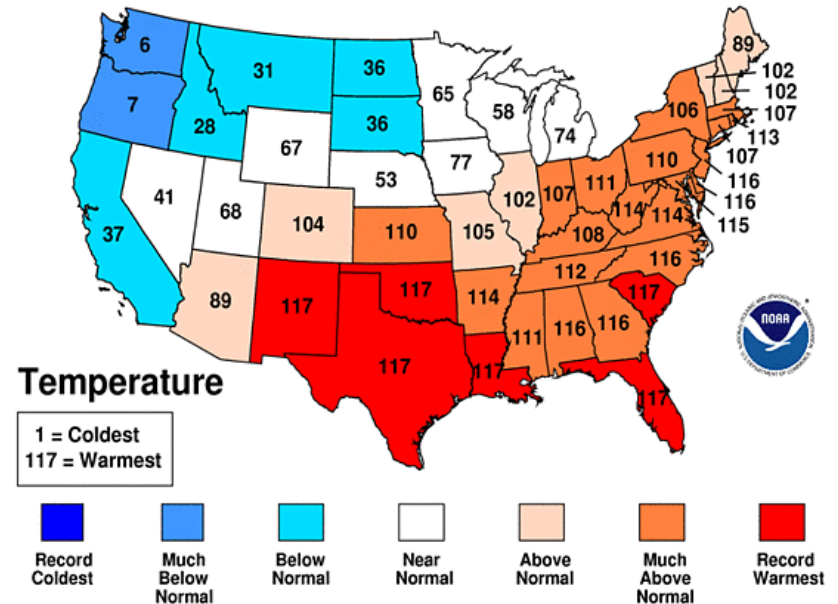
March-August 2011 Statewide Ranks

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(4/27) + heavy rain**
 - **record April, May rainfall (BTV) 3X**
- **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>
 - papers at <http://alanbetts.com/research>
- *Vermont Climate Change Indicators*
- *Seasonal Climate Transitions in New England*

Other Resources

- **Sunday Environment page in Rutland Herald/Montpelier Times Argus:
*2008-2012 – 43 articles***

<http://alanbetts.com/writings>

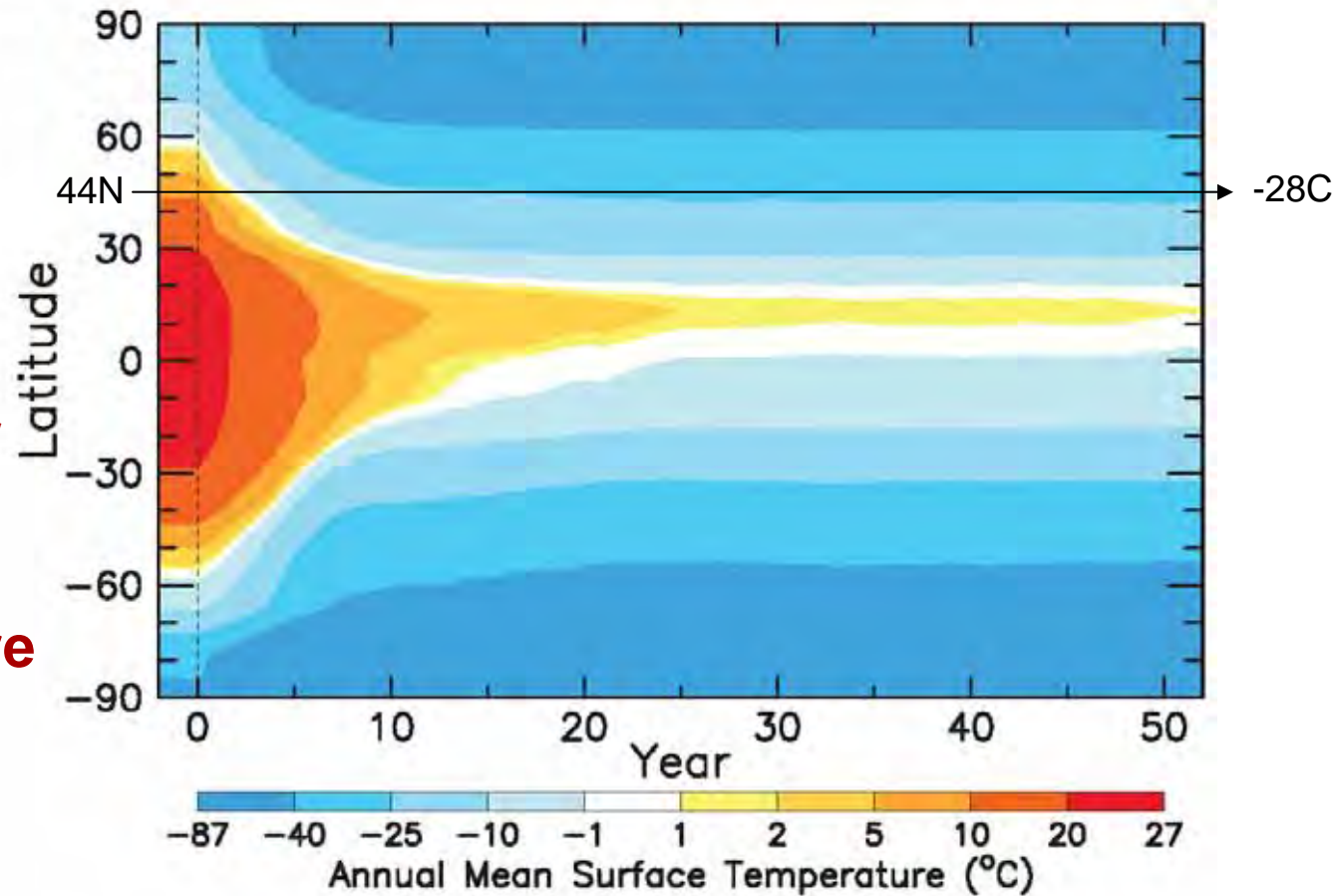
- ***Yearly summary articles***

CO₂ is the Primary Control Knob in the Climate System

Fig. 3. Zonally averaged annual mean surface temperature change after the zeroing out of noncondensing GHGs.

(Lacis et al., *Science*, 2010)

Remove CO₂ and other 'non-condensing' GHG from climate model & Global Temperature plunges



- Falls 5°C in 1 year; 35°C in 50 years
- Water vapor falls 90%; cloud-cover goes to 75%; sea-ice to 50%

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?**

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 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
- **CO₂ 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 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 do we know from past?

- **Reconstruct past climate**
- Ice core history: T, CO₂, CH₄ through many ice-ages - nearly a million years
- Ocean sediments
- Tree rings – a few thousand years

Ice-core history!



Last four ice-age cycles

