



Climate Change and Vermont



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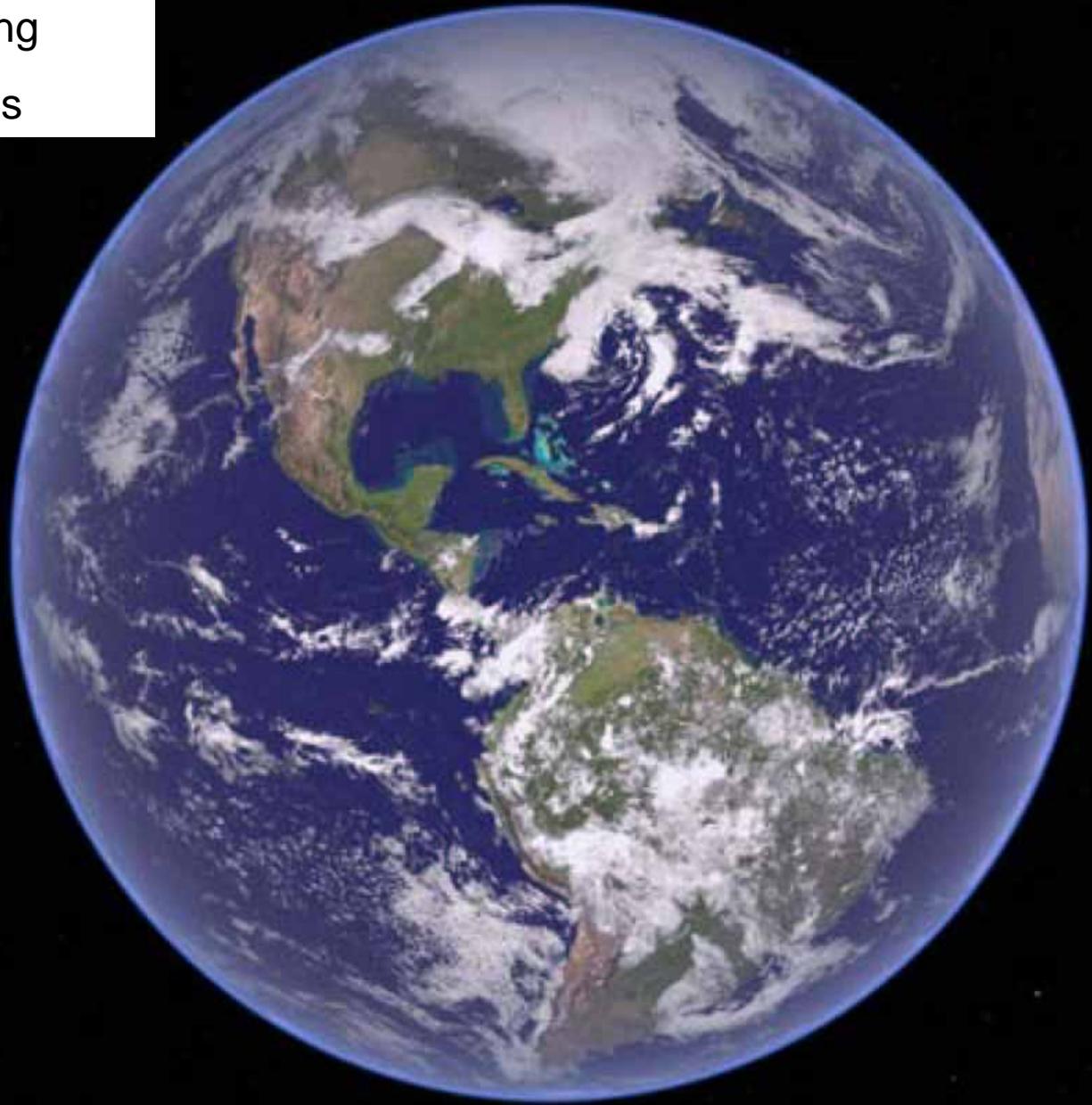
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Sustainable Development Policy

UVM, Burlington, Vermont

September 29, 2011

- Earth is a complex system
- Its timescales are long
- It runs well without us



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**
- **The transition we face**
 - **Managing the earth system**
 - **Why is it difficult?**

Discussion

My Background: Peterhouse, Cambridge - UK

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



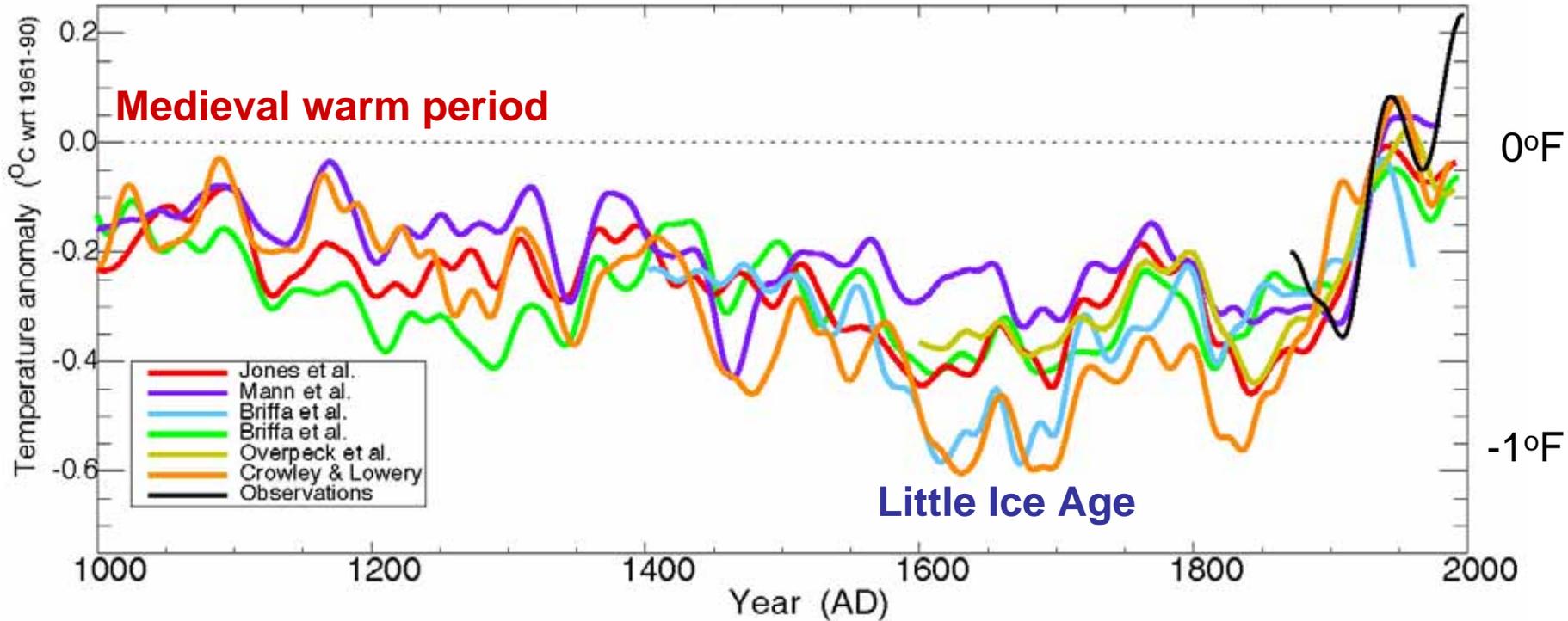
My Background: Nottingham High School

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



Millennial Temperature Record

2100: +5°F



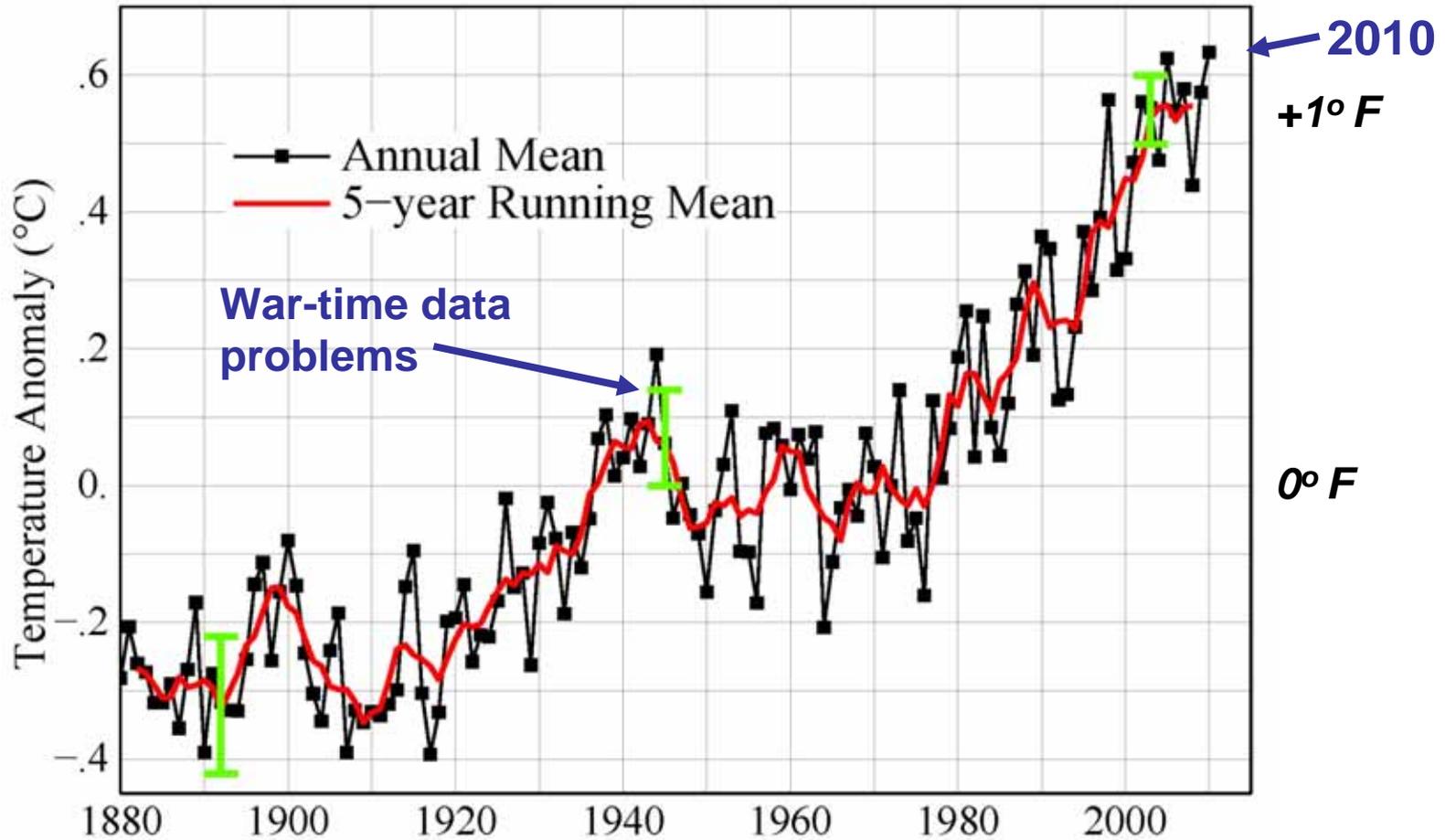
- “Proxy” records from before the time of thermometers provide uncertain data, but they’re all we have

Global Temperature Rise 1880 – Present

2100: +5°F



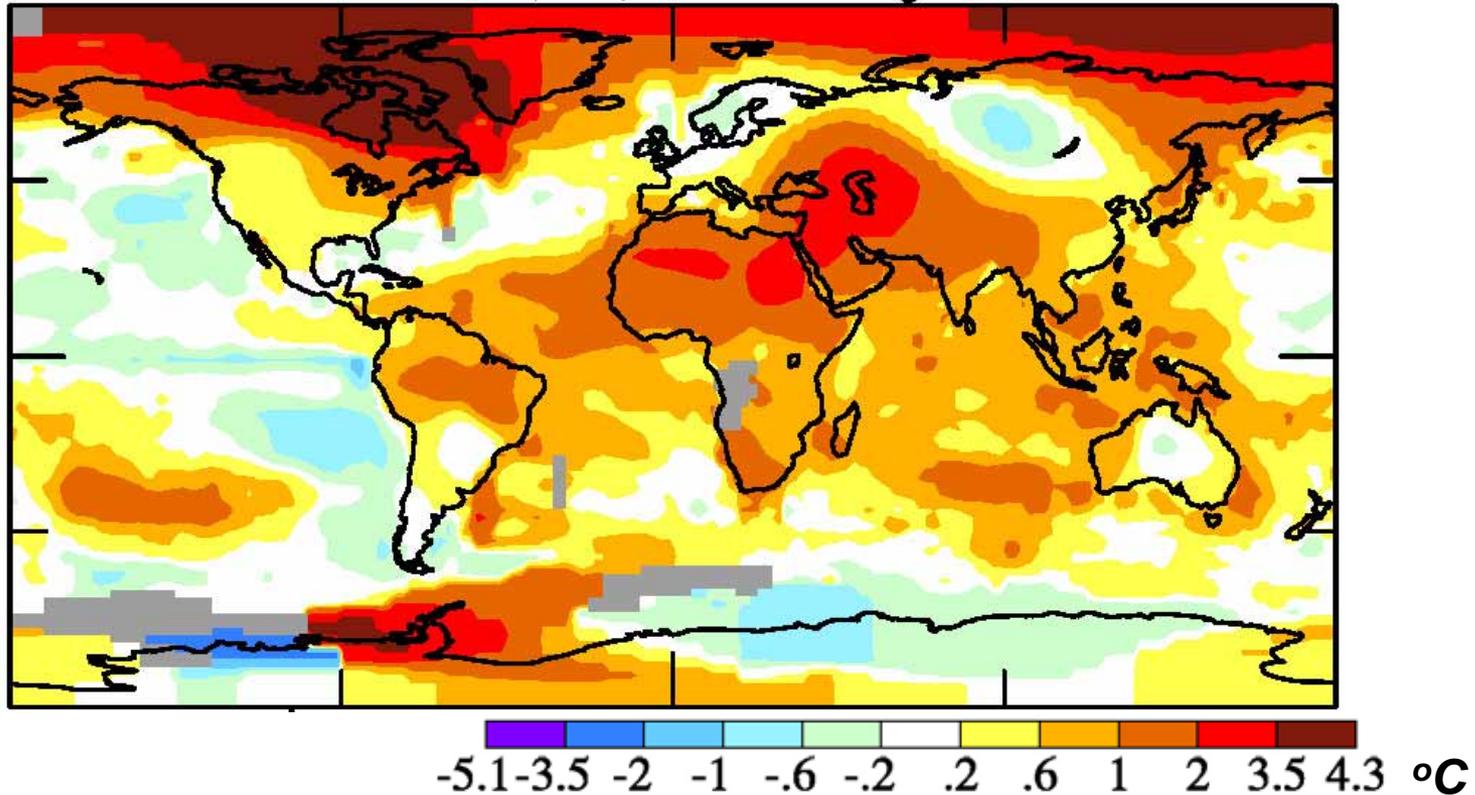
Global Land–Ocean Temperature Index



NASA-GISS, 2011

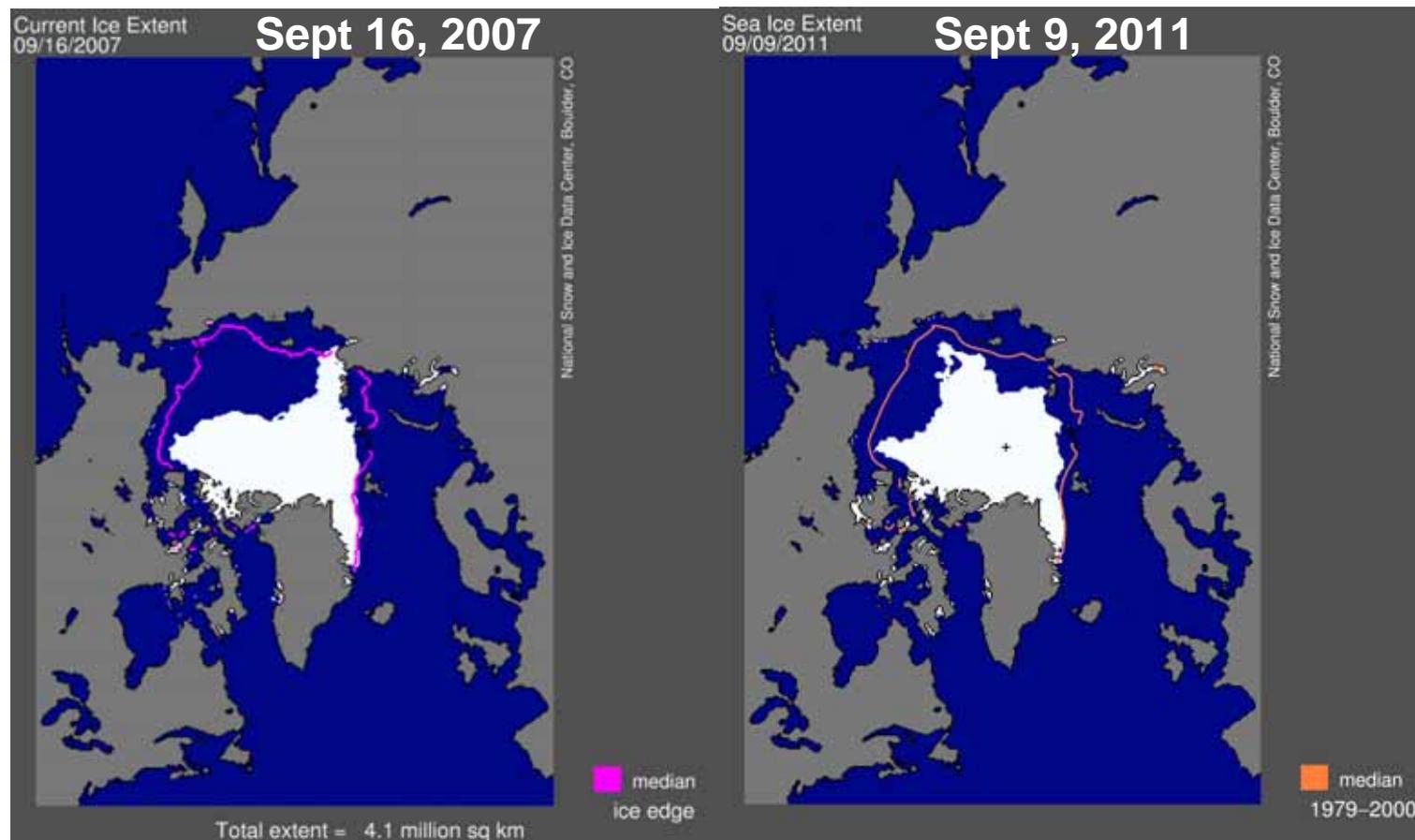
Global Picture 2010

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



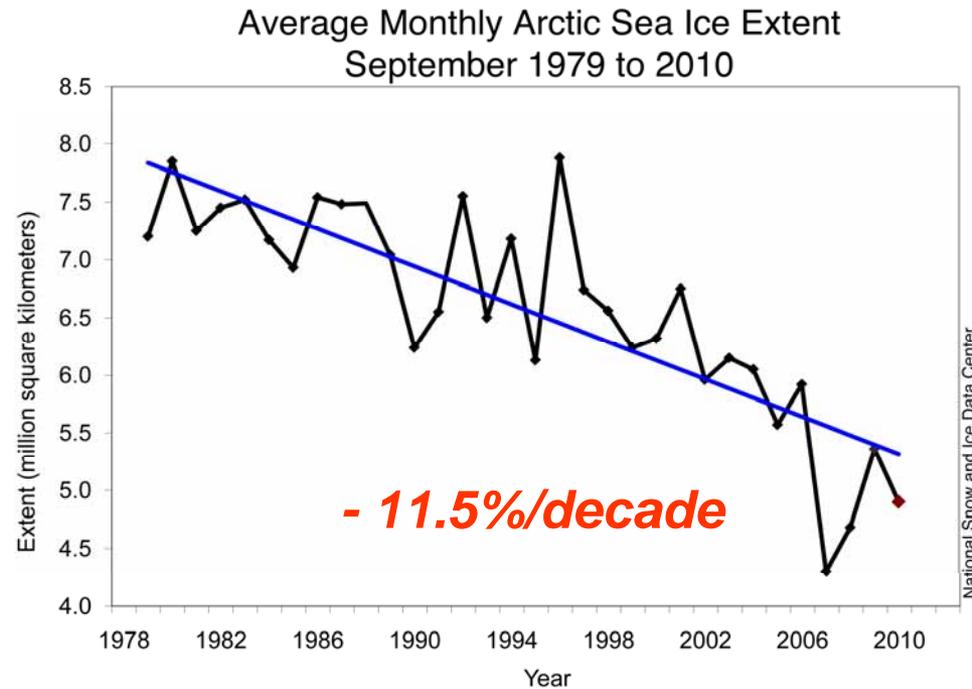
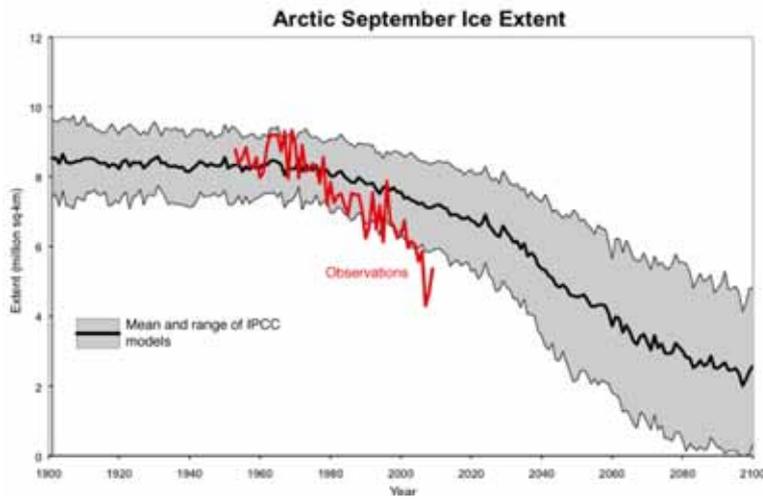
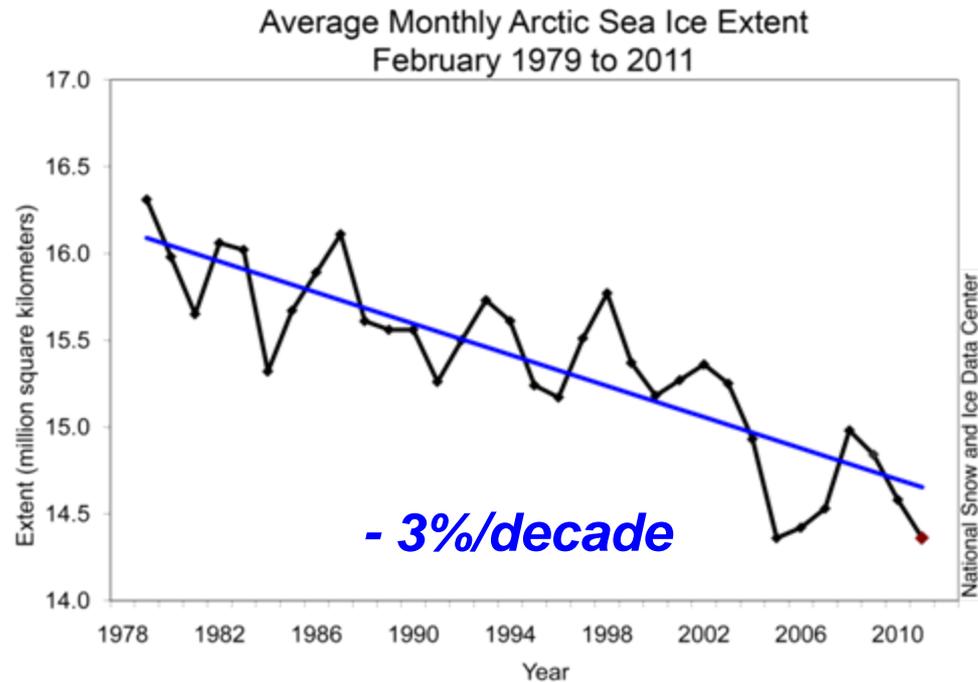
- **Feedbacks speed melting**
- **Less ice, less sunlight reflected**
- **More evaporation, larger water vapor greenhouse effect**

(www.nsidc.org)

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

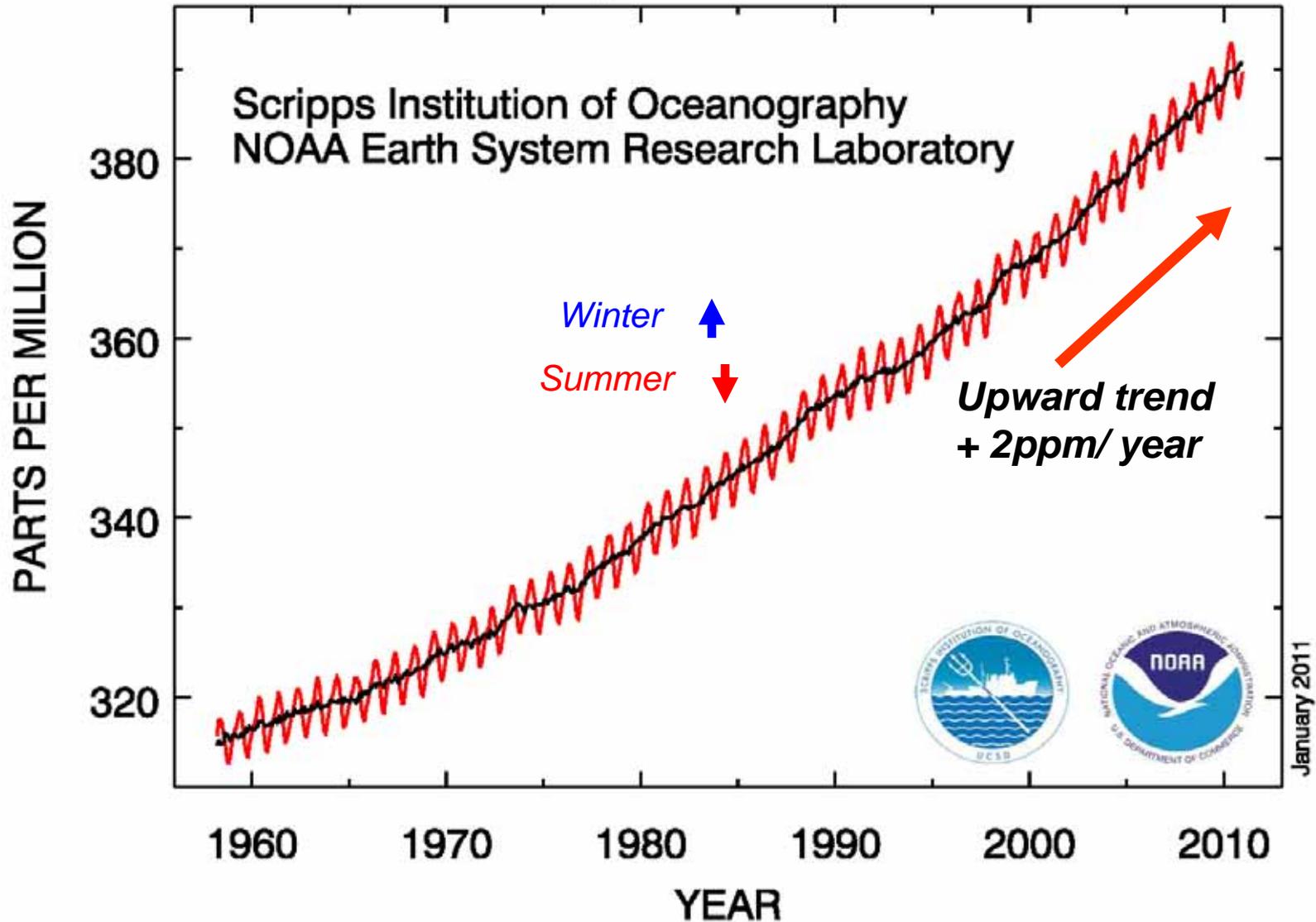
Sea Ice Trends

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



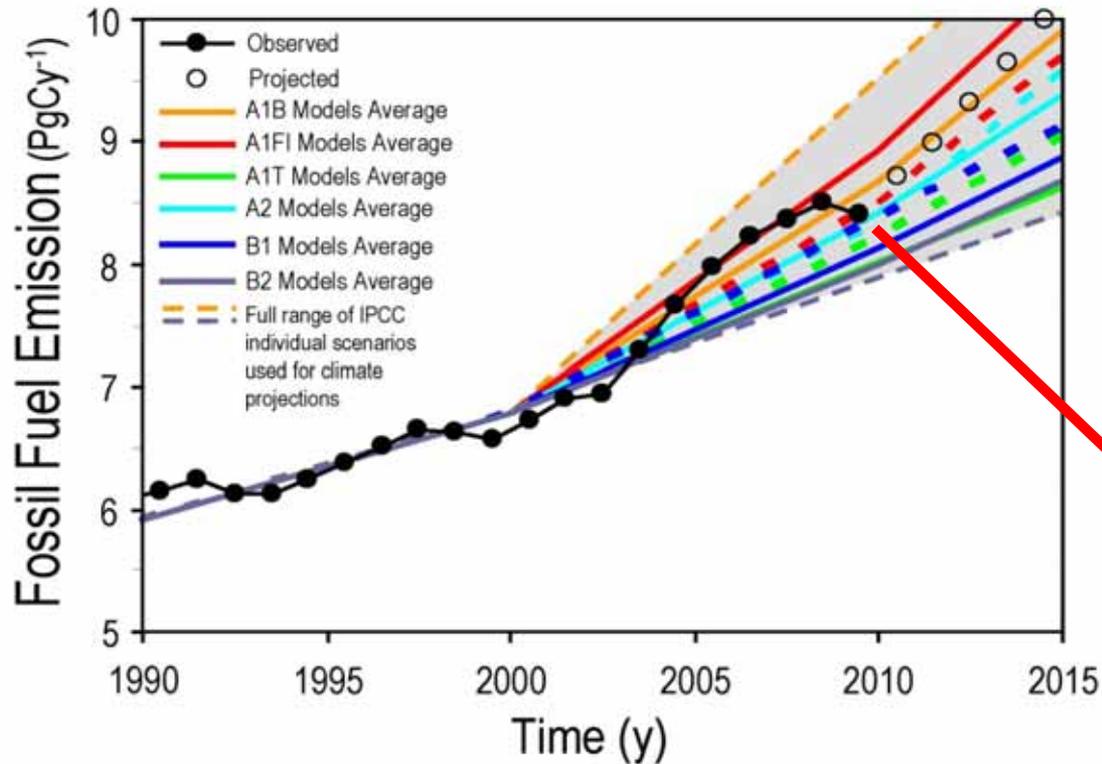
Carbon Dioxide Is Increasing

Atmospheric CO₂ at Mauna Loa Observatory



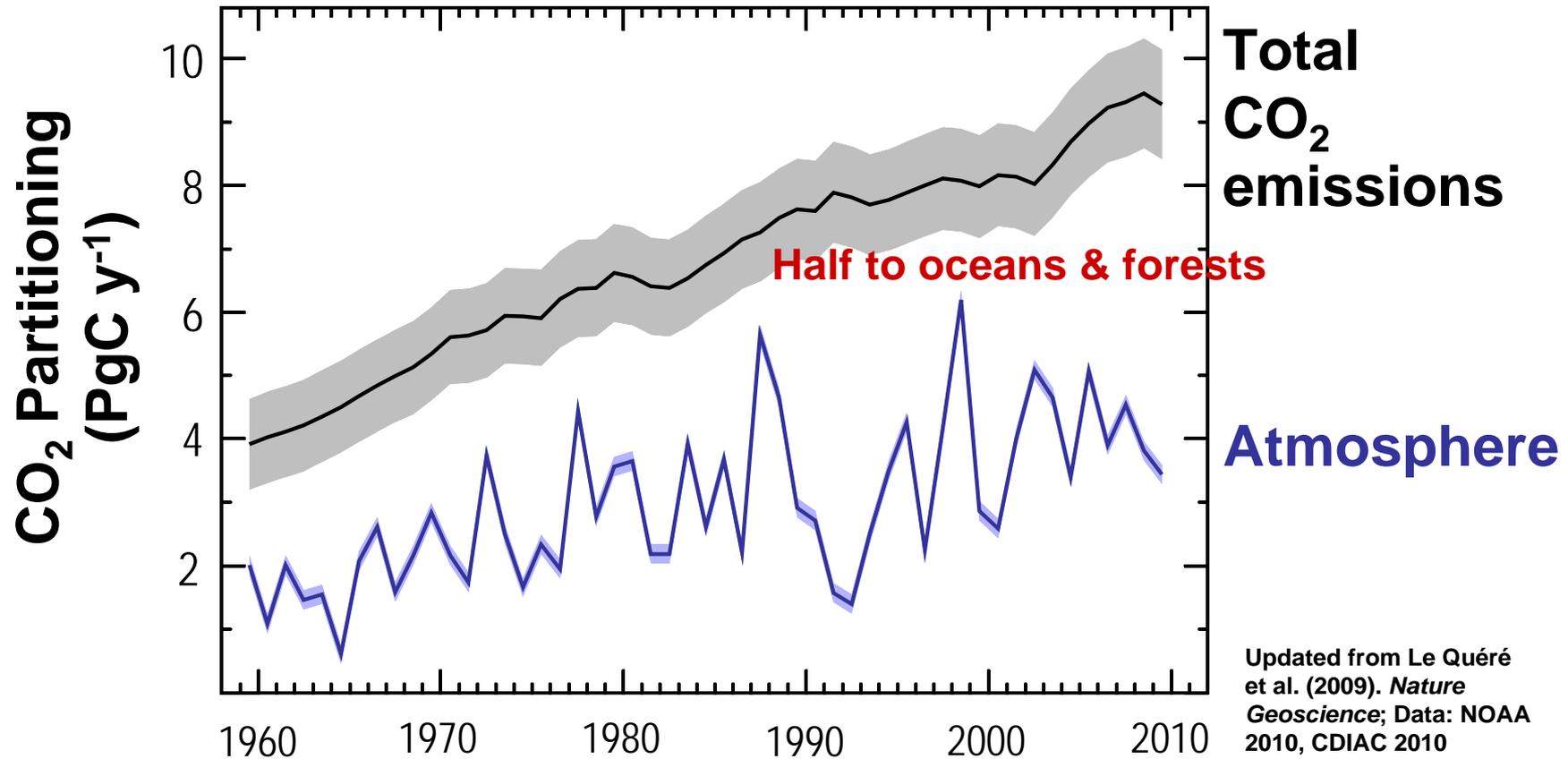
2009 Was “Good” for the Earth

Fossil Fuel Emissions: Actual vs. IPCC Scenarios



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

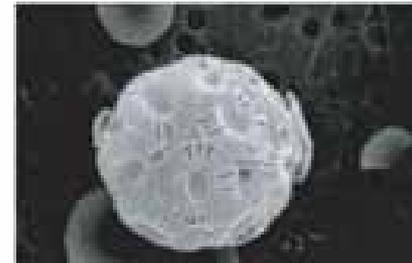
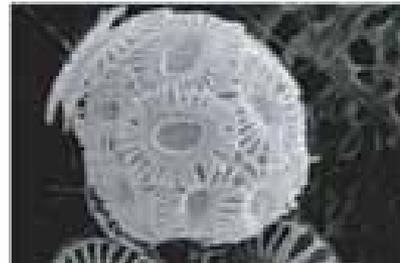
Rising Ocean Acidity Threatens Organisms



- From the Tropics to the Arctic, the seas are sucking up emissions of 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)



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: 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:

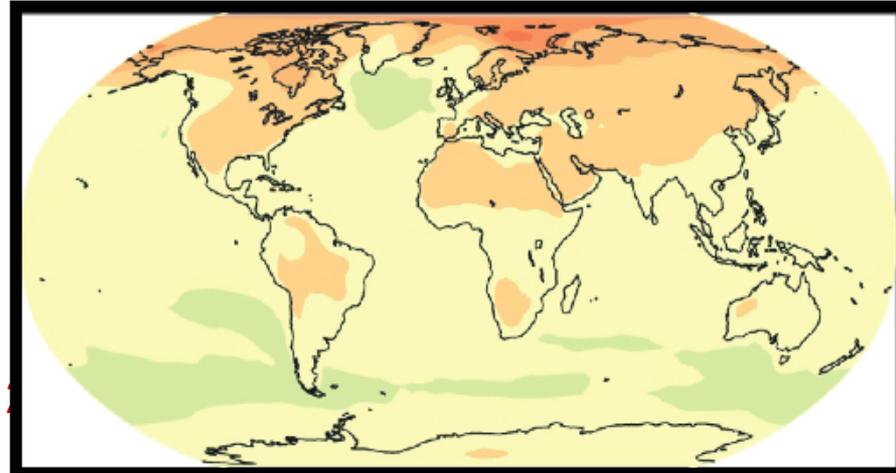
- NH snow extent
- Arctic sea ice
- Glaciers
- Ocean pH (increasing acidity)



Predicted Change in Temperature

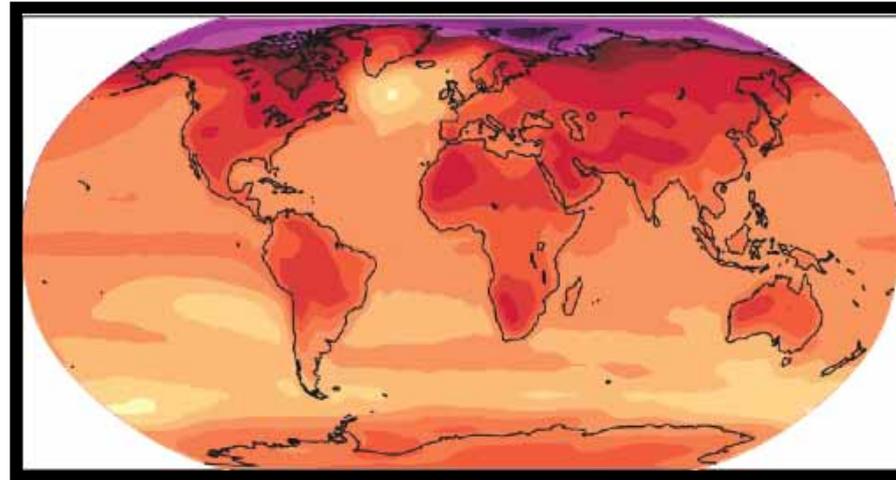
2020-2029 and 2090-2099, relative to 1980-1999 (°C)

“Committed”

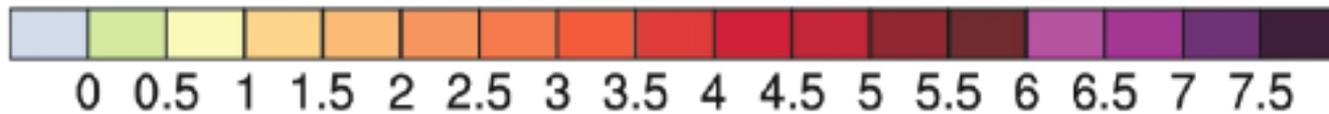


(We did nothing for the last 20 years)

Still up to us!



(We could halve this if we act now)



[°C]

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 at this rate 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

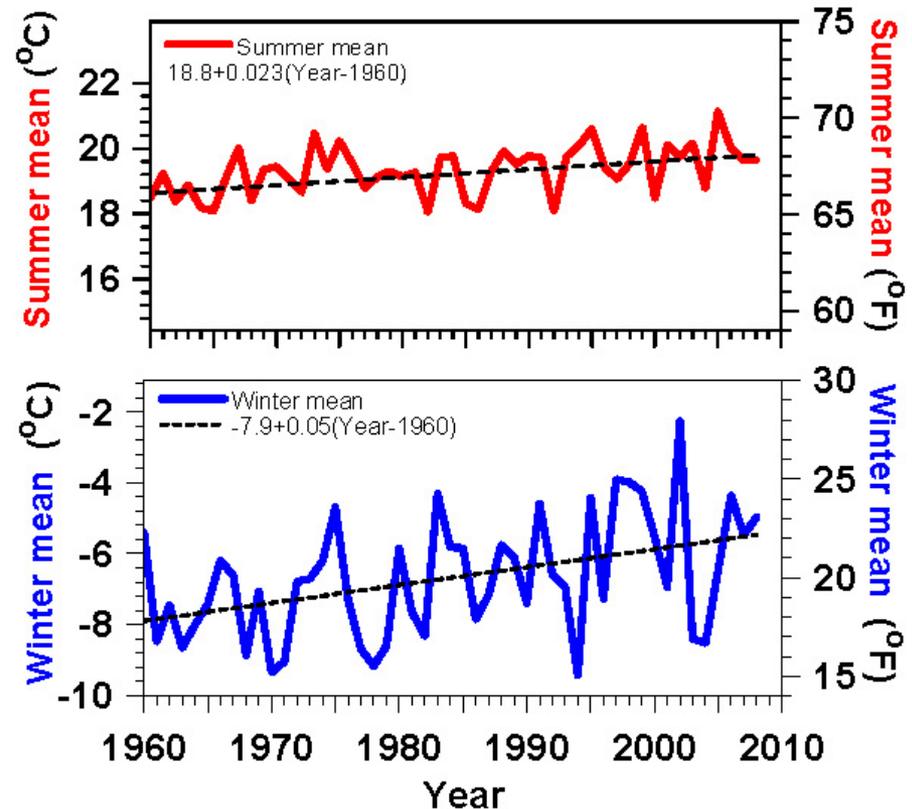
- **Extreme weather: Floods, fires, & drought**
- **Melting Arctic and permafrost—methane release?**
- **Ecosystem collapse, including perhaps forest and ocean ecosystems**
- **Collapse of unsustainable human population**

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**

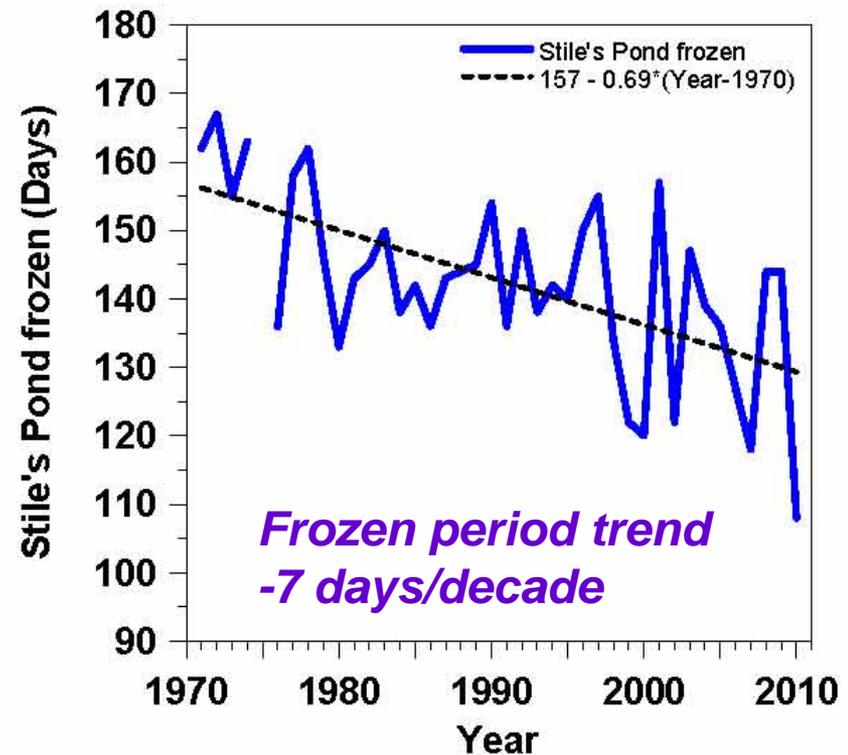
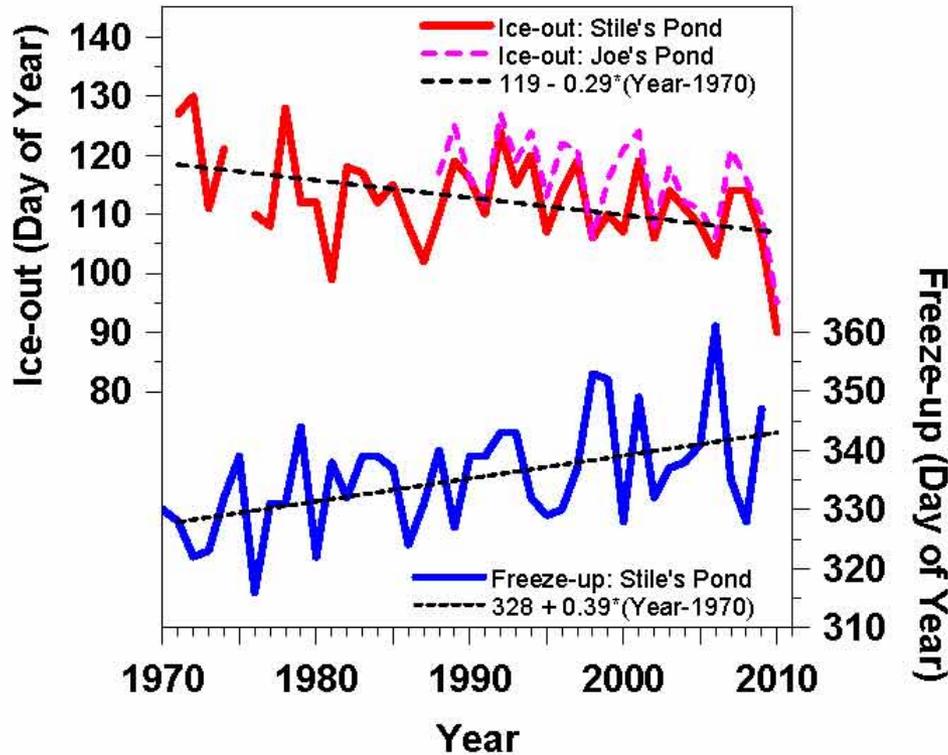
Vermont Temperature Trends

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



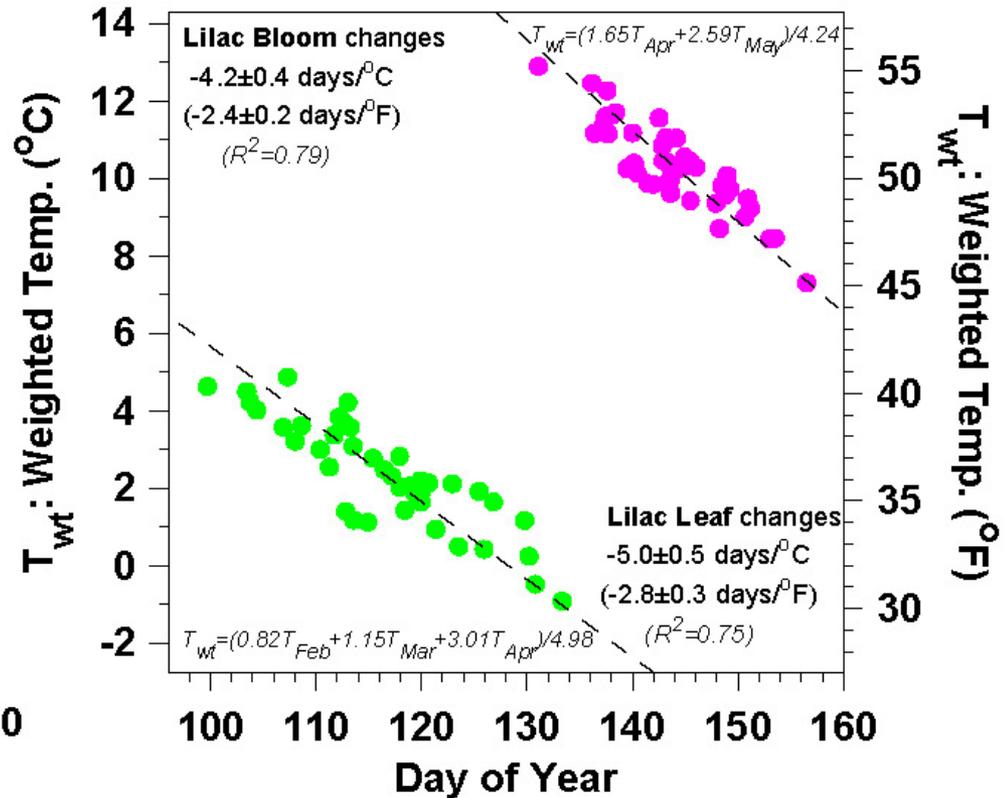
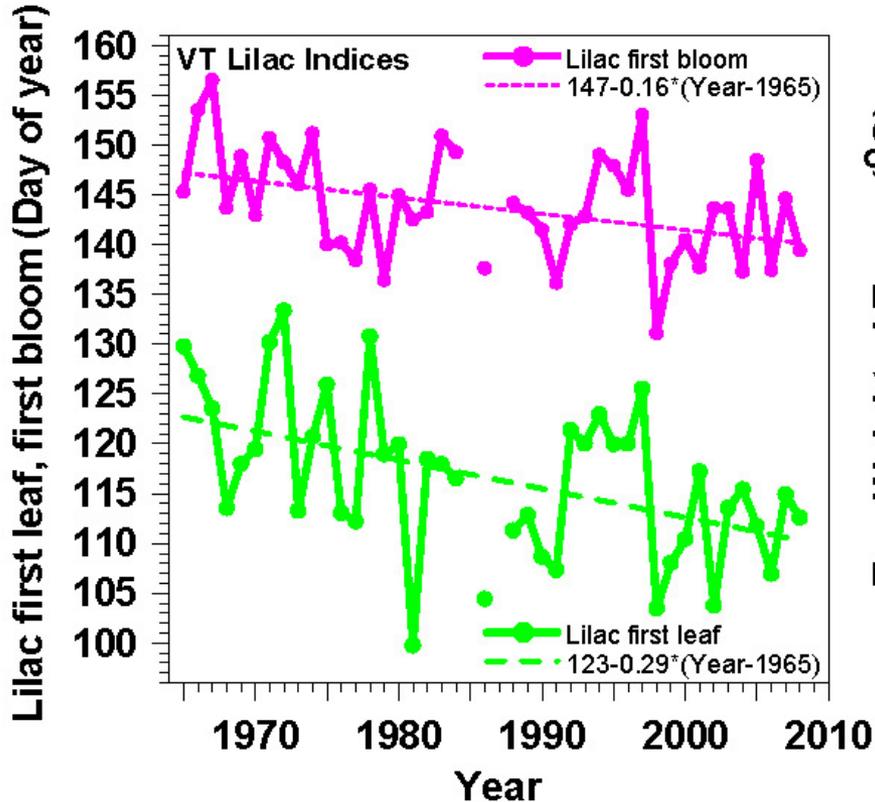
Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



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

Lilac Leaf and Bloom in Spring



- Leaf-out earlier by **3 days/decade** (tracks ice-out)
- Bloom earlier by **1.5 days/decade**
- Leaf & bloom change **2.5 days/°F** (4.5 days/°C)

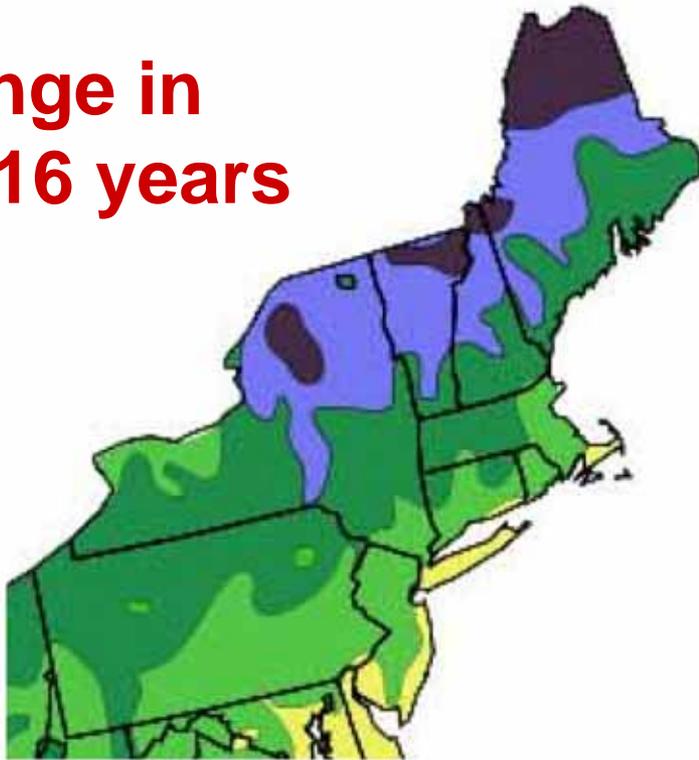
Vermont Winter 2006



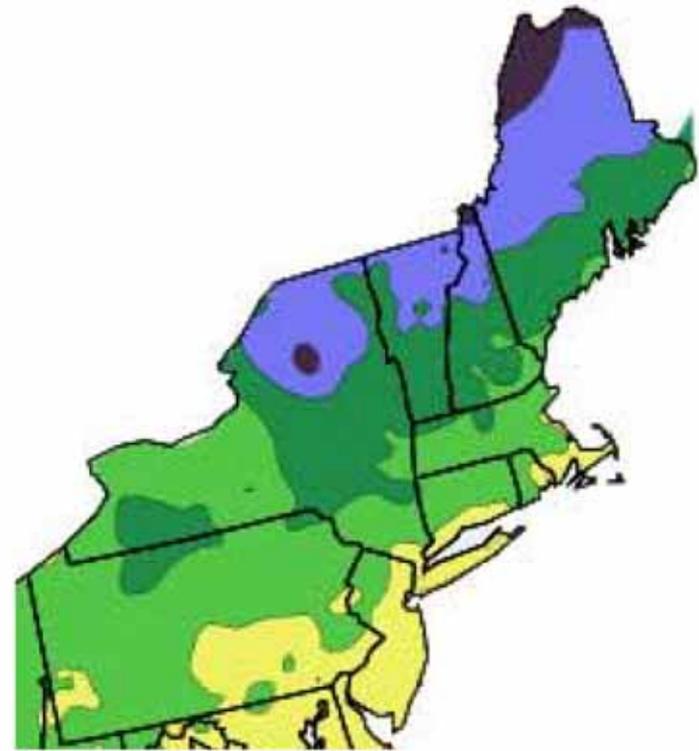
- **Sun is low; and snow reflects sunlight, except where there are trees!**
- **Sunlight reflected, stays cold; little evaporation, clear sky; earth cools to space**

USDA Hardiness Zones - Northeast

Change in
last 16 years

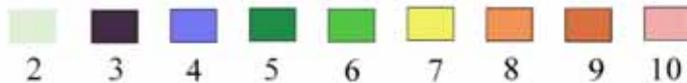


1990



2006

Zone



USDA Hardiness Zones

Gardening in Pittsford, Vermont in January



January 7, 2007

December 2006:

- **Warmest on record**

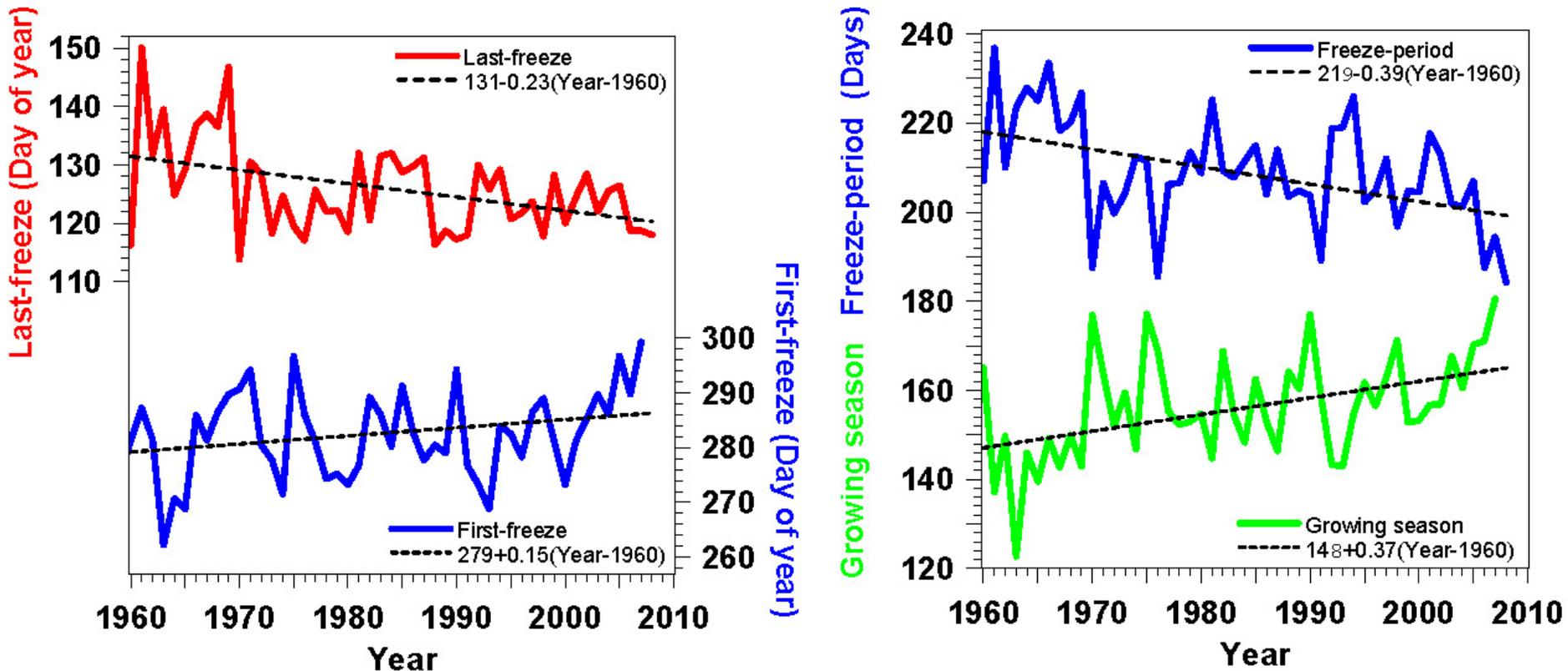


January 10, 2008

Warm Fall:

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

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!*



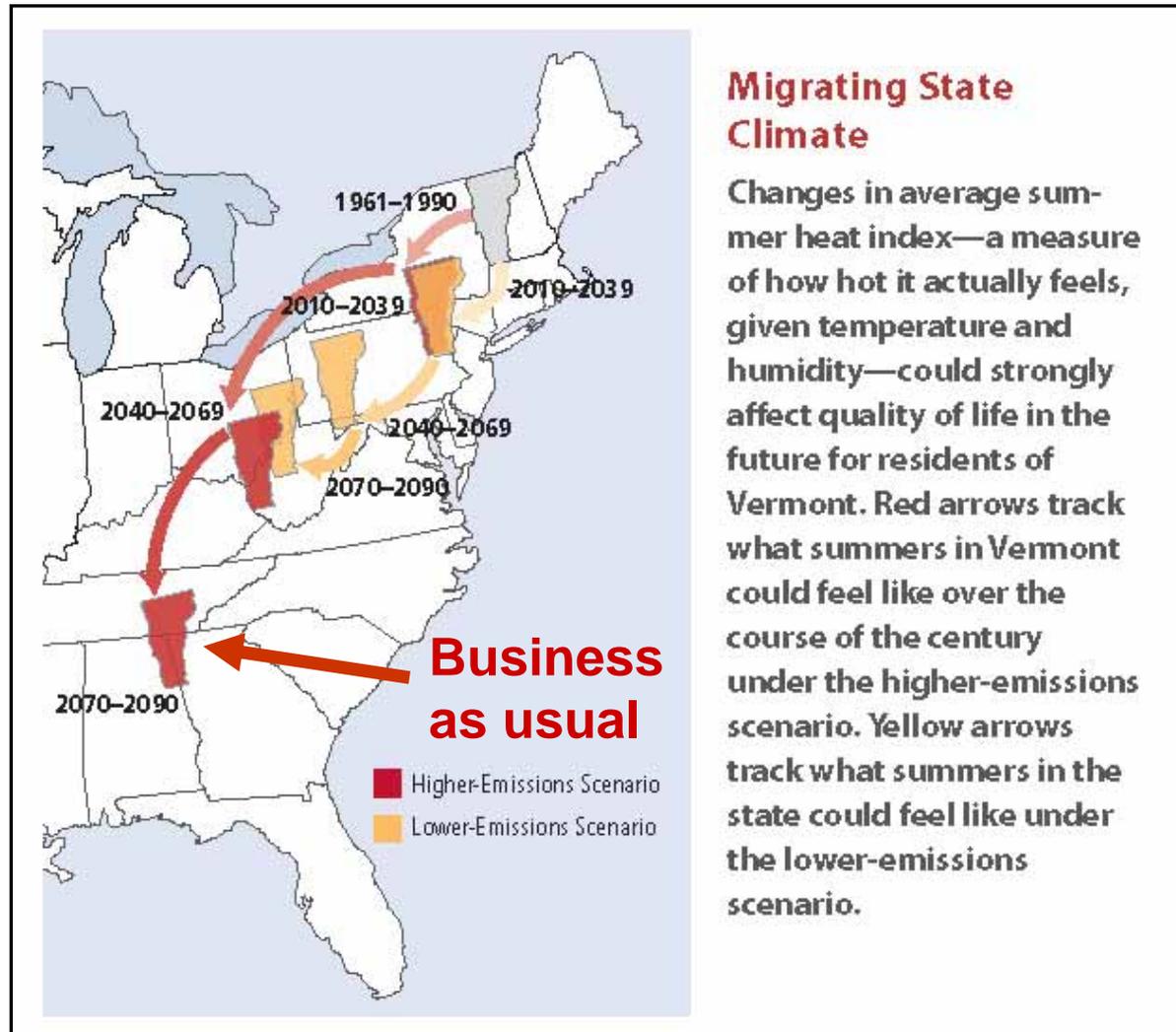
Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

Later frost: Growing season getting longer

Vermont's Future with High and Low GHG Emissions

What
about
skiing?

What
about
tropics?



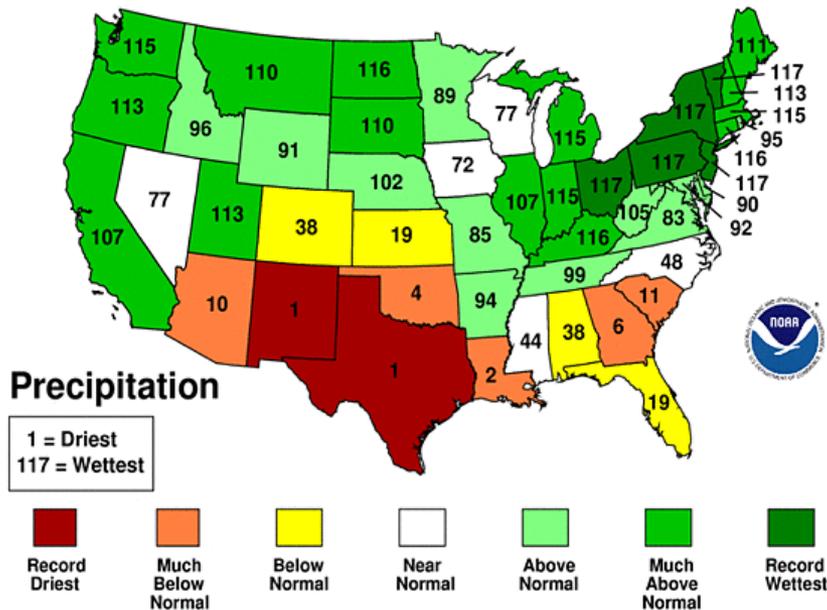
NECIA,
2007

2011 Vermont Floods

- Record spring flood on Lake Champlain
- Record floods following TS Irene
- Record wet in NE March-August, 2011
(but TX, NM record drought)

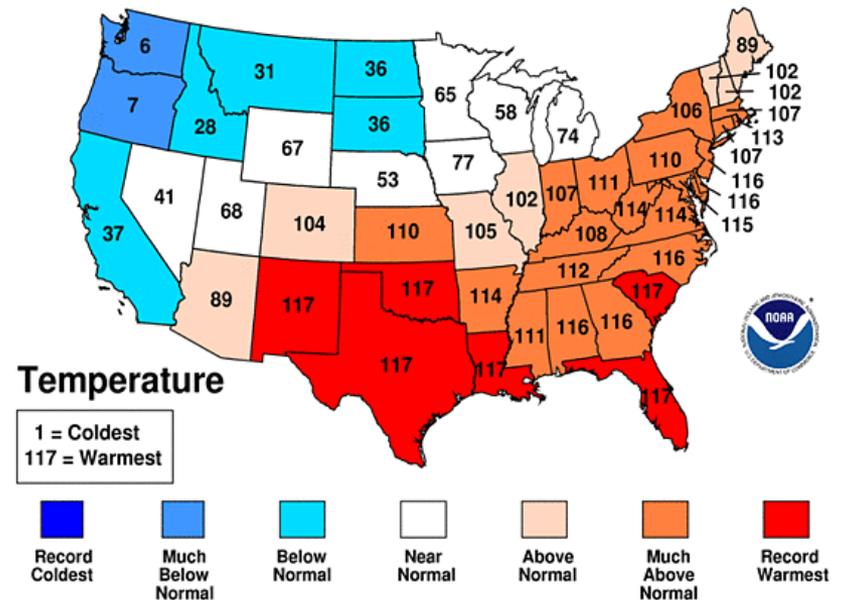
March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



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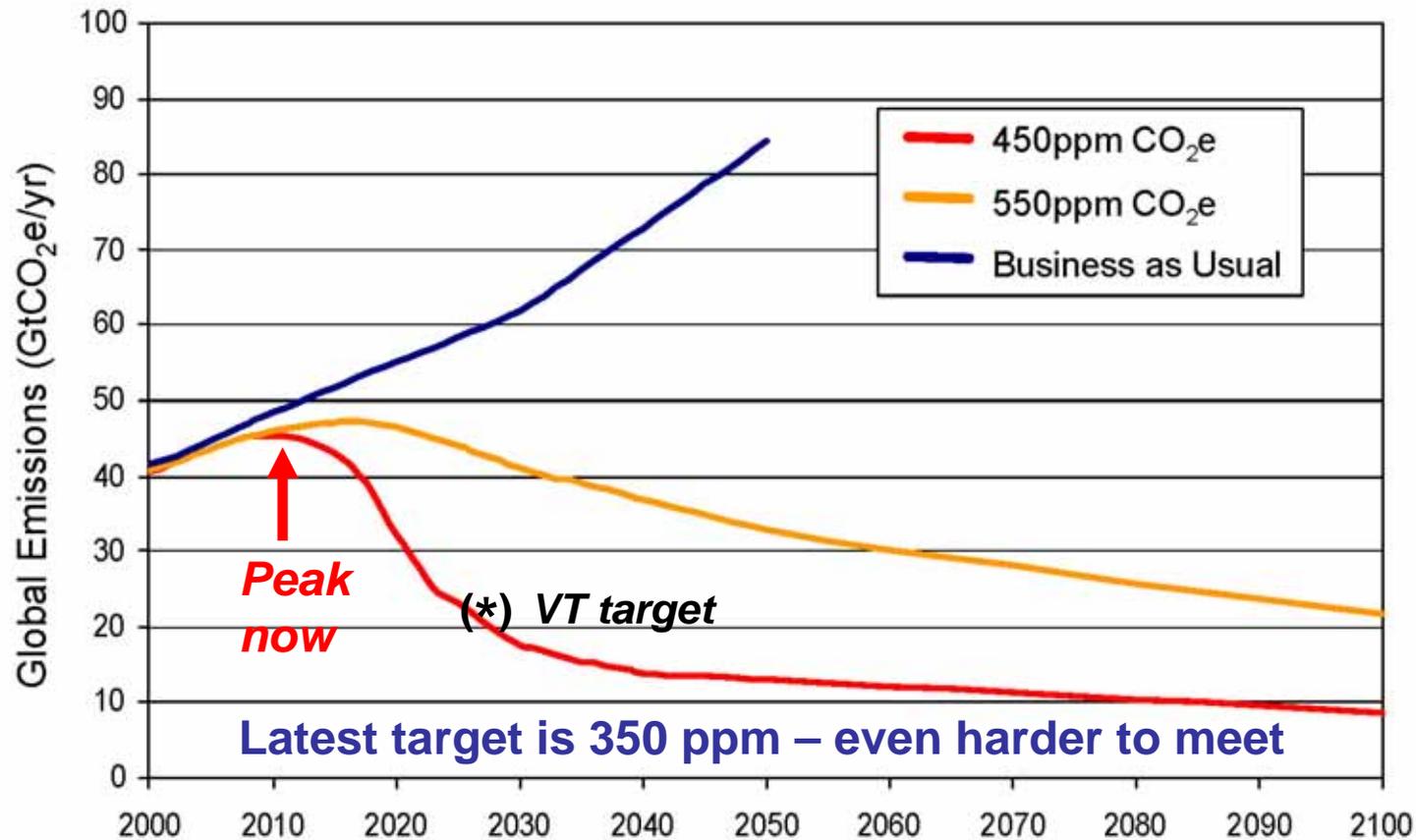
Discussion

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**

How Do We Avoid “Dangerous Climate Change”?

Emissions Paths to Stabilisation [*Stern, 2006*]



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)?**

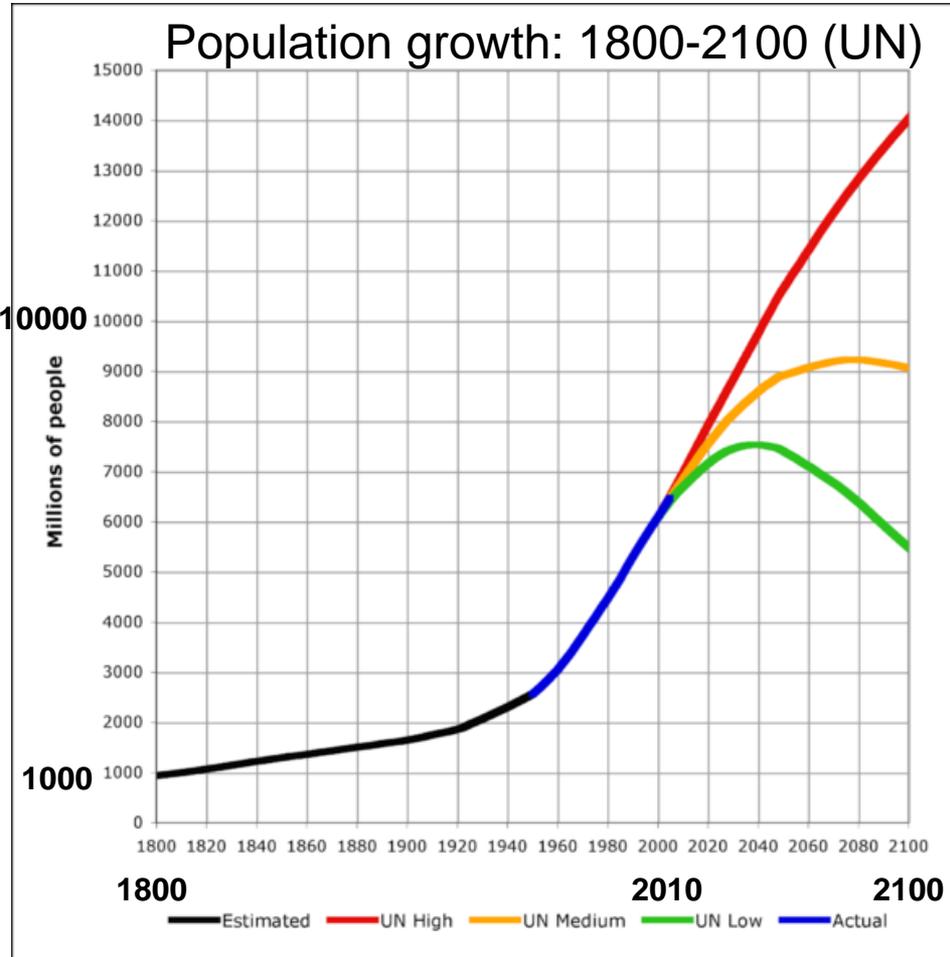
Why Is It Difficult for Us?

- 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

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**

Some Technology Is 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

- <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***

Media Resources

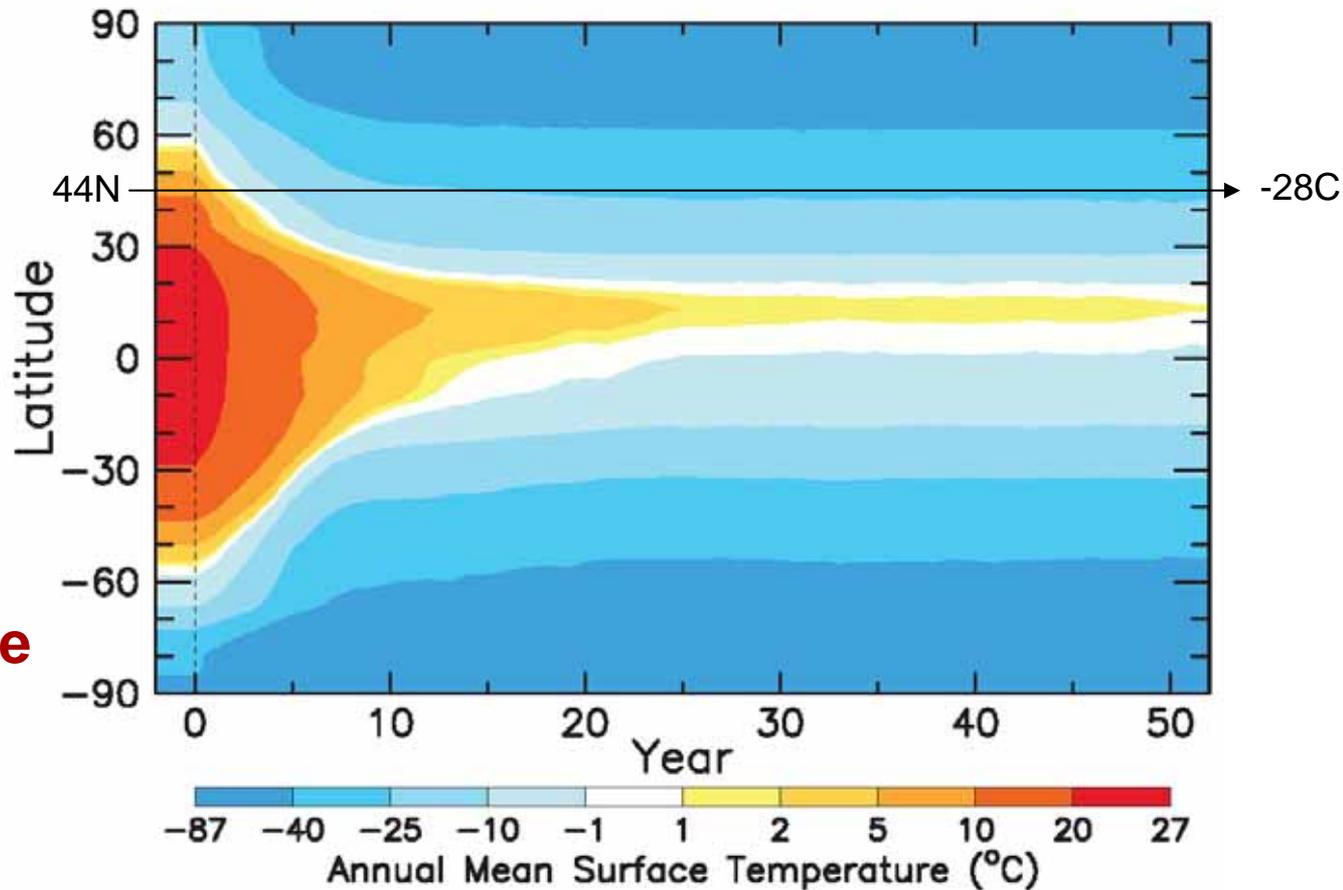
- **Sunday Environment page in Rutland Herald/Montpelier Times Argus:
2008-2011 – see handout: 34 articles
<http://alanbetts.com/writings>**
- **VPR Commentaries: vpr.net or
<http://alanbetts.com/talks>**

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

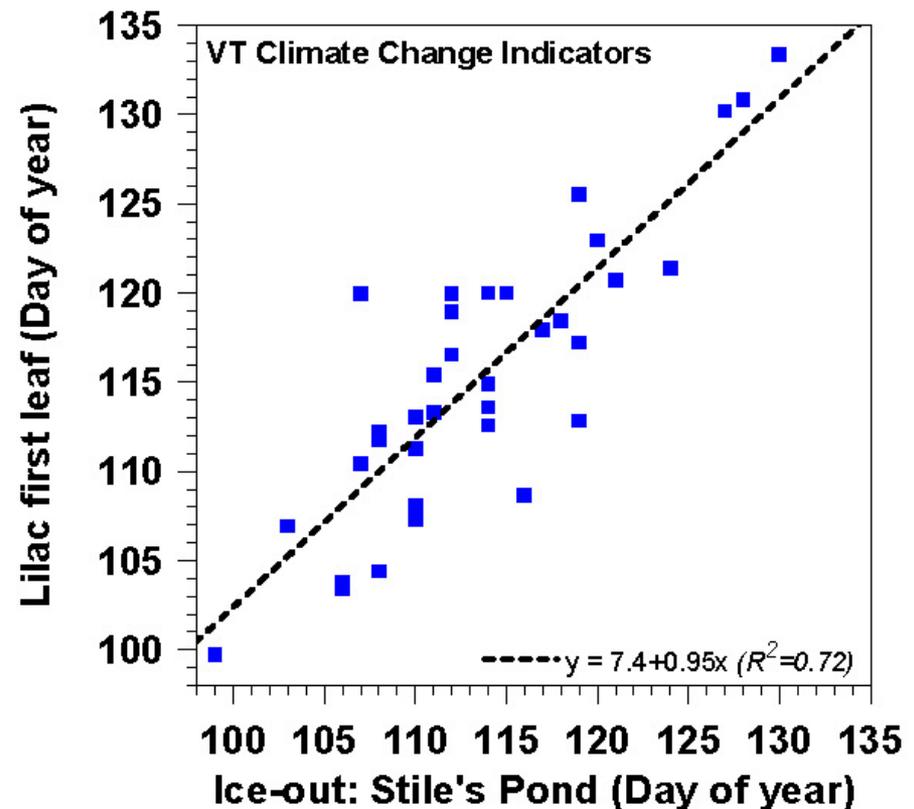
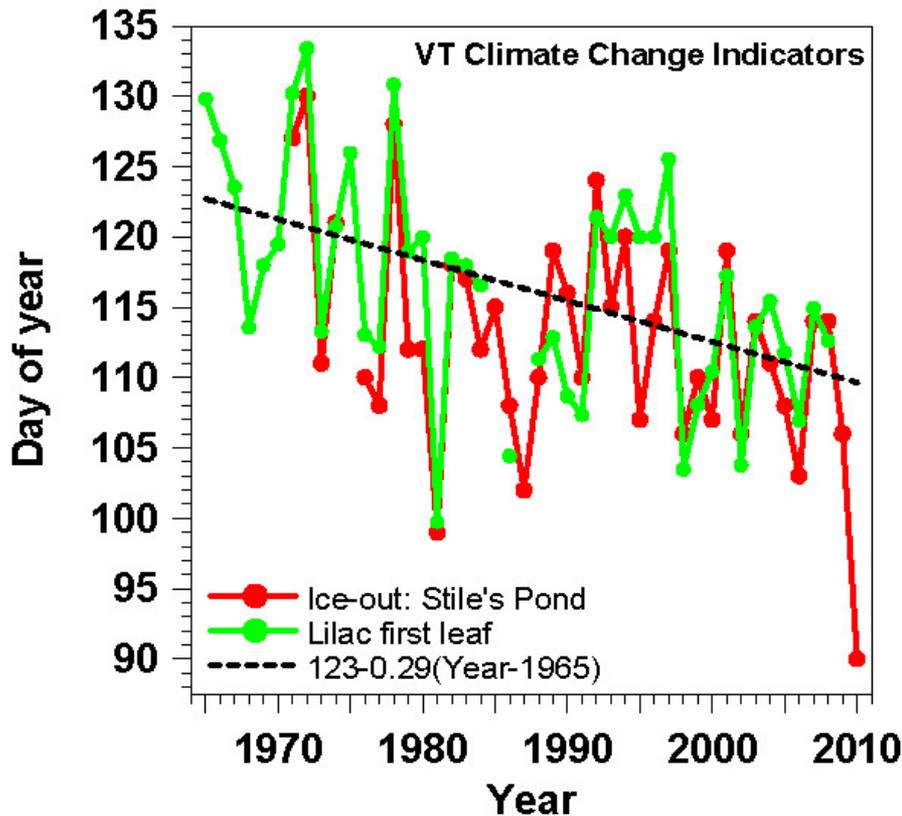


- Falls 5°C in 1 year; 35°C in 50 years
- Water vapor falls 90%; cloud-cover goes to 75%; sea-ice to 50%

Climate and Resilience

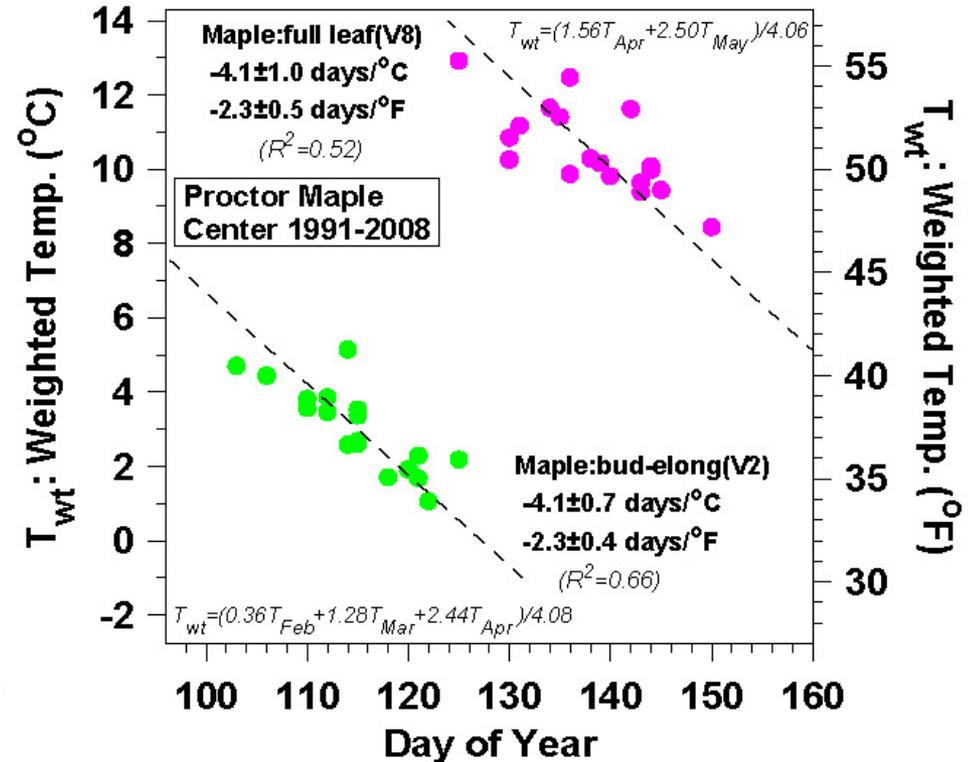
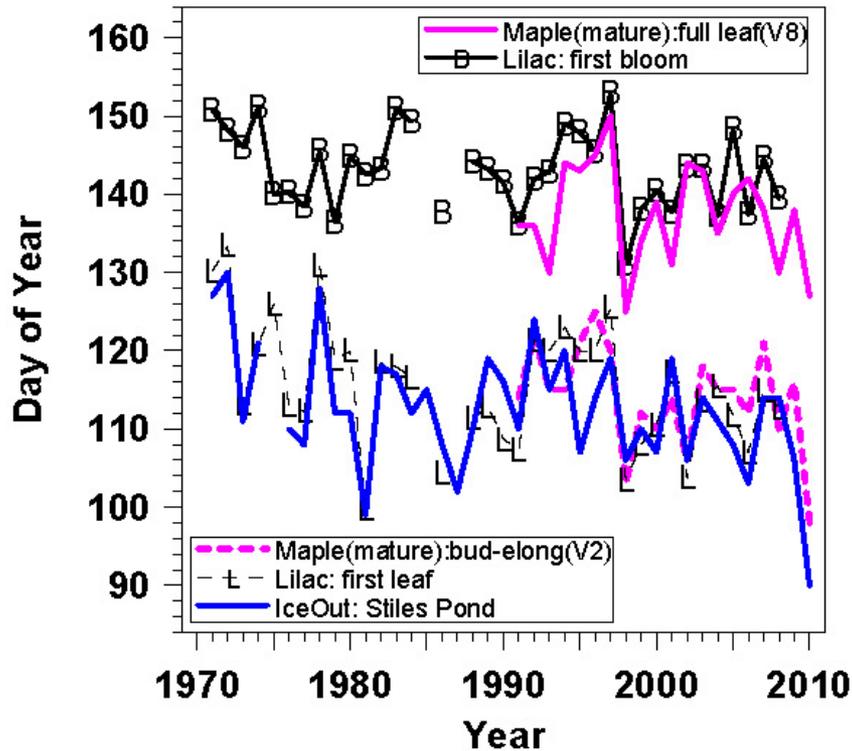
- Trend to **milder winters**; longer growing season; earlier spring – variability large
- Trend to **more precipitation in cool season**; more wet snow and mixed in winter
- **Warmer summers**; **heavier rain** in summer; periods of drought – increase infiltration and water storage – ***forests stabilize climate***
- **Agriculture issues**
 - Build soil carbon and organic matter for water storage and fertility
 - Recycle nutrients and **phosphorus**

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**

Maples and Lilacs in spring

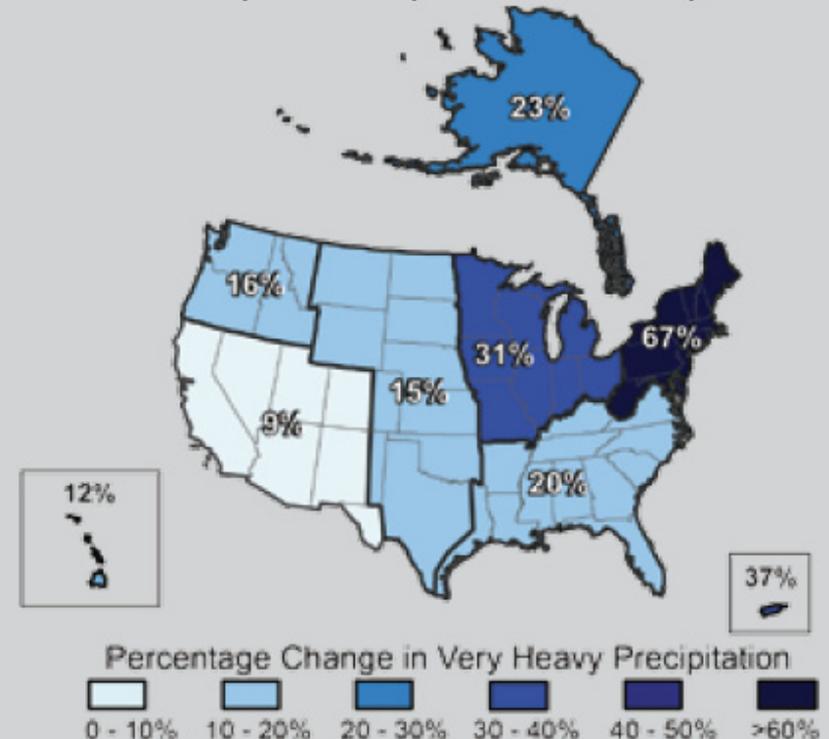


- Maple bud elongation mirrors lilac leaf
- Maple leaf-out mirrors lilac bloom

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**

Increases in Amounts of Very Heavy Precipitation (1958 to 2007)



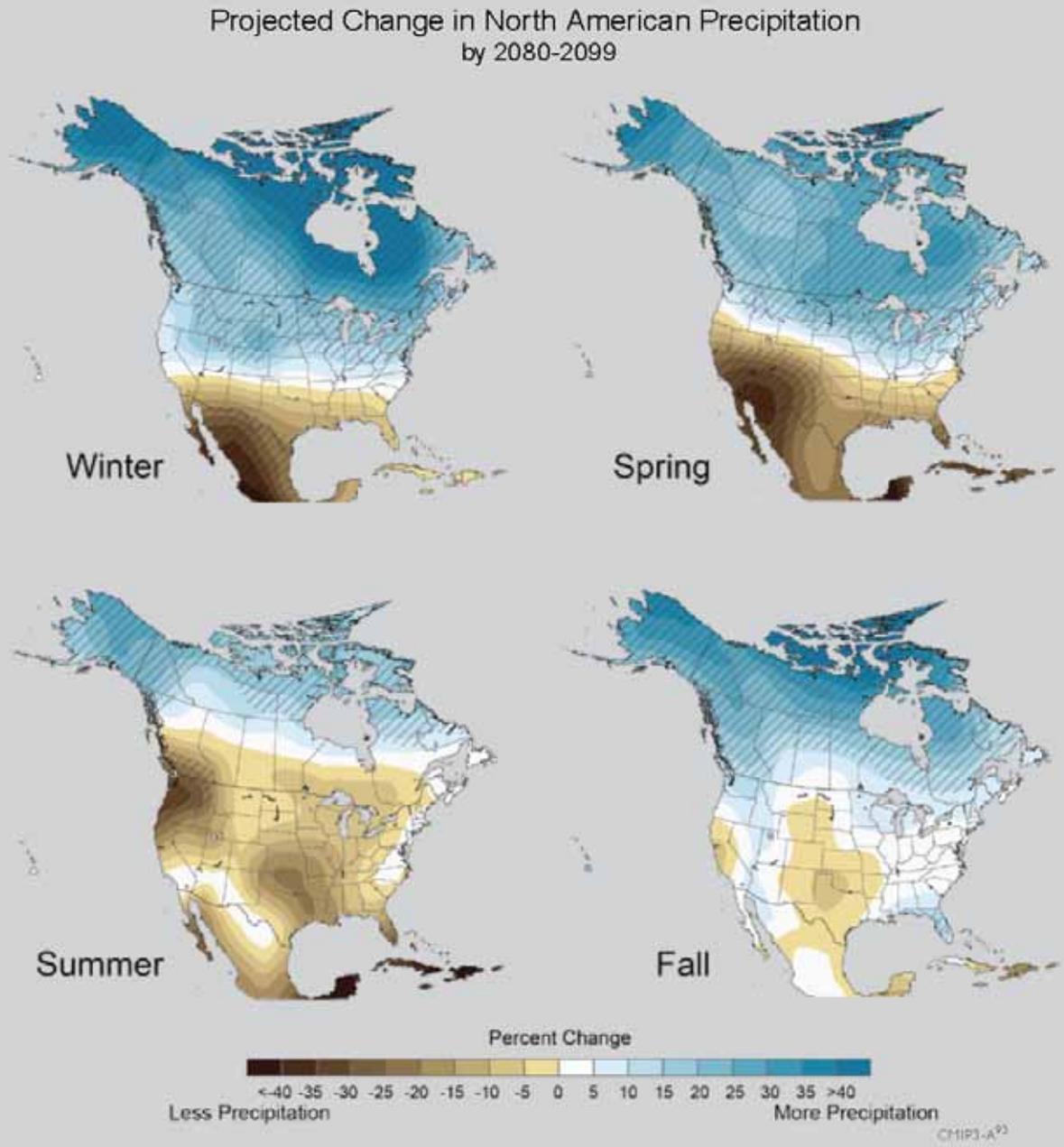
Updated from Groisman et al.¹¹³

The map shows percent increases in the amount falling in very heavy precipitation events (defined as the heaviest 1 percent of all daily events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

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.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.