

The Future Climate of Vermont

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Climate Change

- One of the many great challenges for the 21st century
- **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**
- **Earth science clashes with social values**

Outline

- **Science of climate change**
 - **Global scale: actual and future**
 - **Locally: with Vermont as example**
- **The transition we face**
 - **Managing the earth system**
 - **Why is it difficult?**
 - **What do we need?**

Discussion

My Background: Peterhouse, Cambridge - UK

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



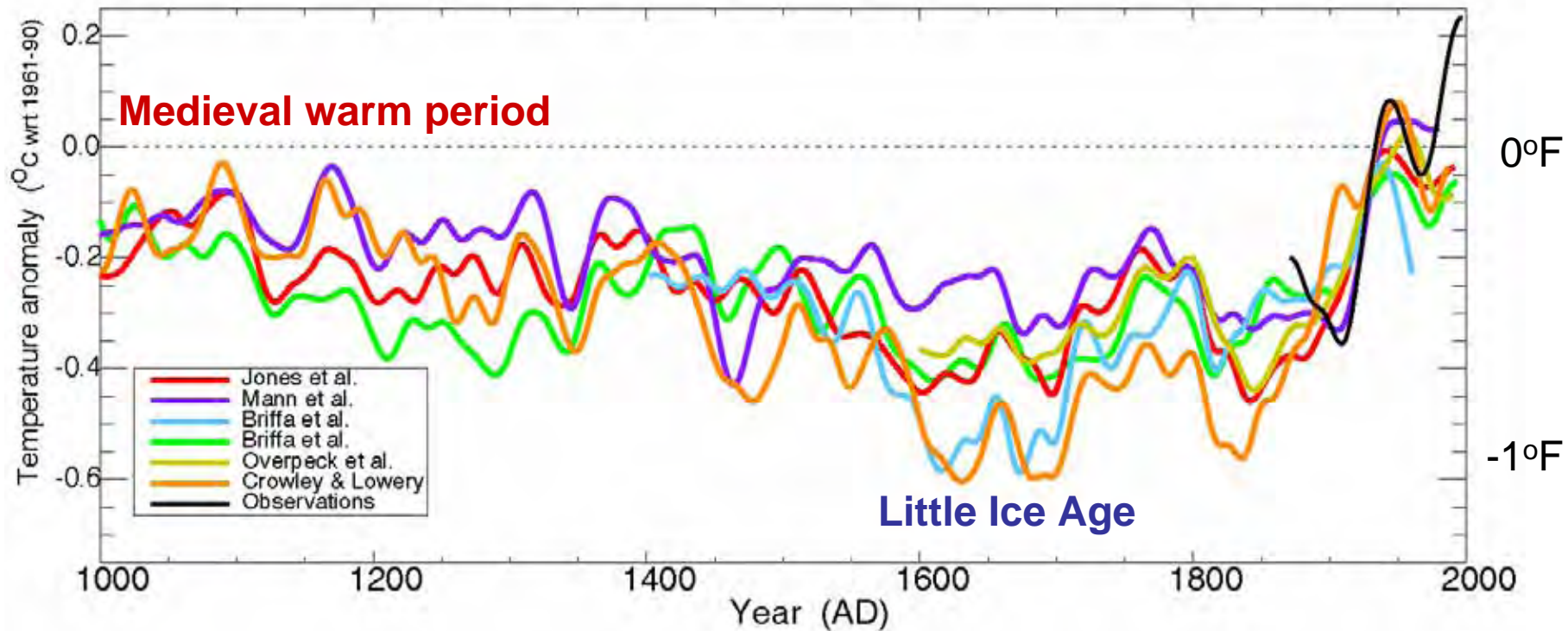
My Background: Nottingham High School

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



Millennial Temperature Record

2100: +5°F



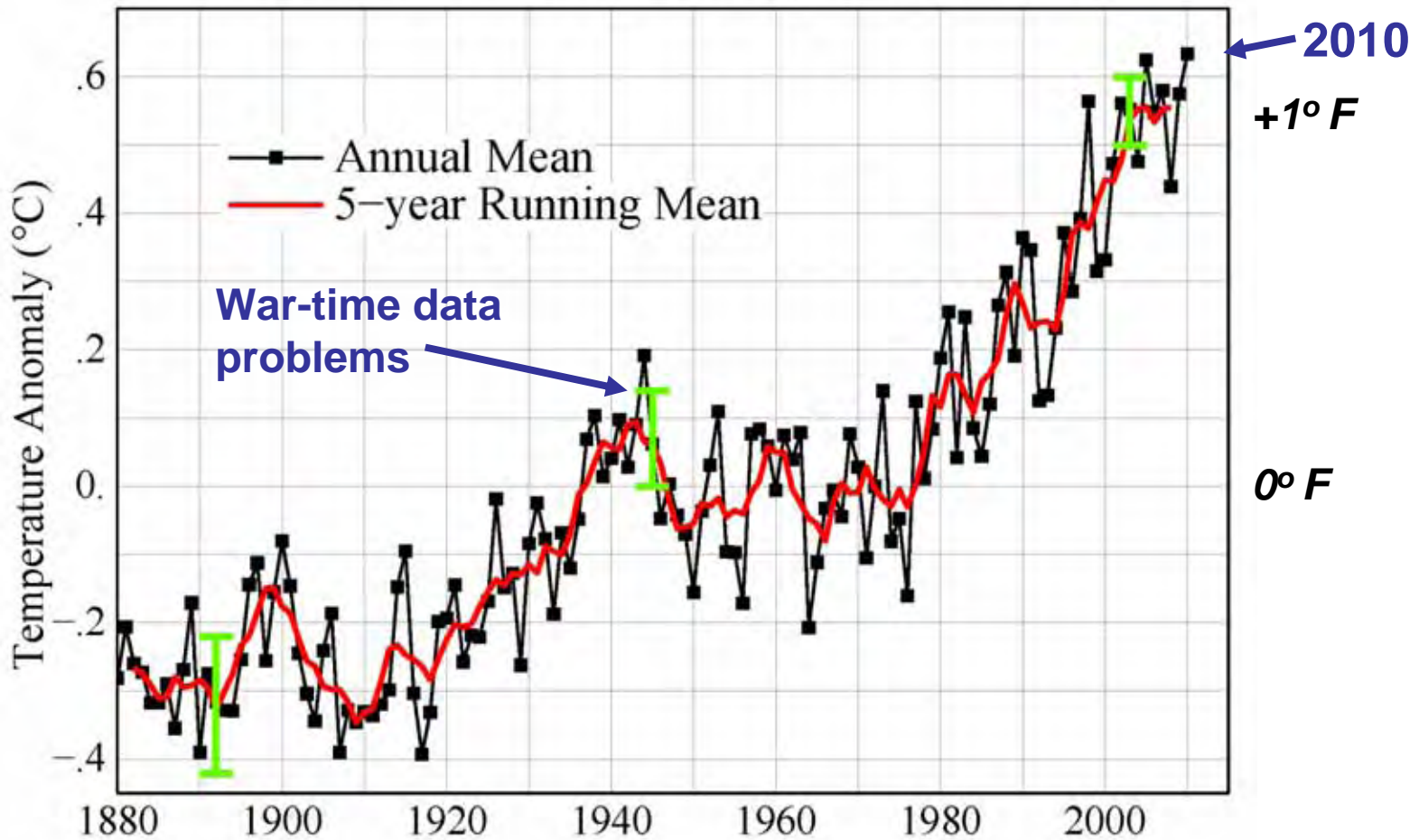
- “Proxy” records from before the time of thermometers provide uncertain data, but they’re all we have

Global Temperature Rise 1880 – Present

2100: +5°F



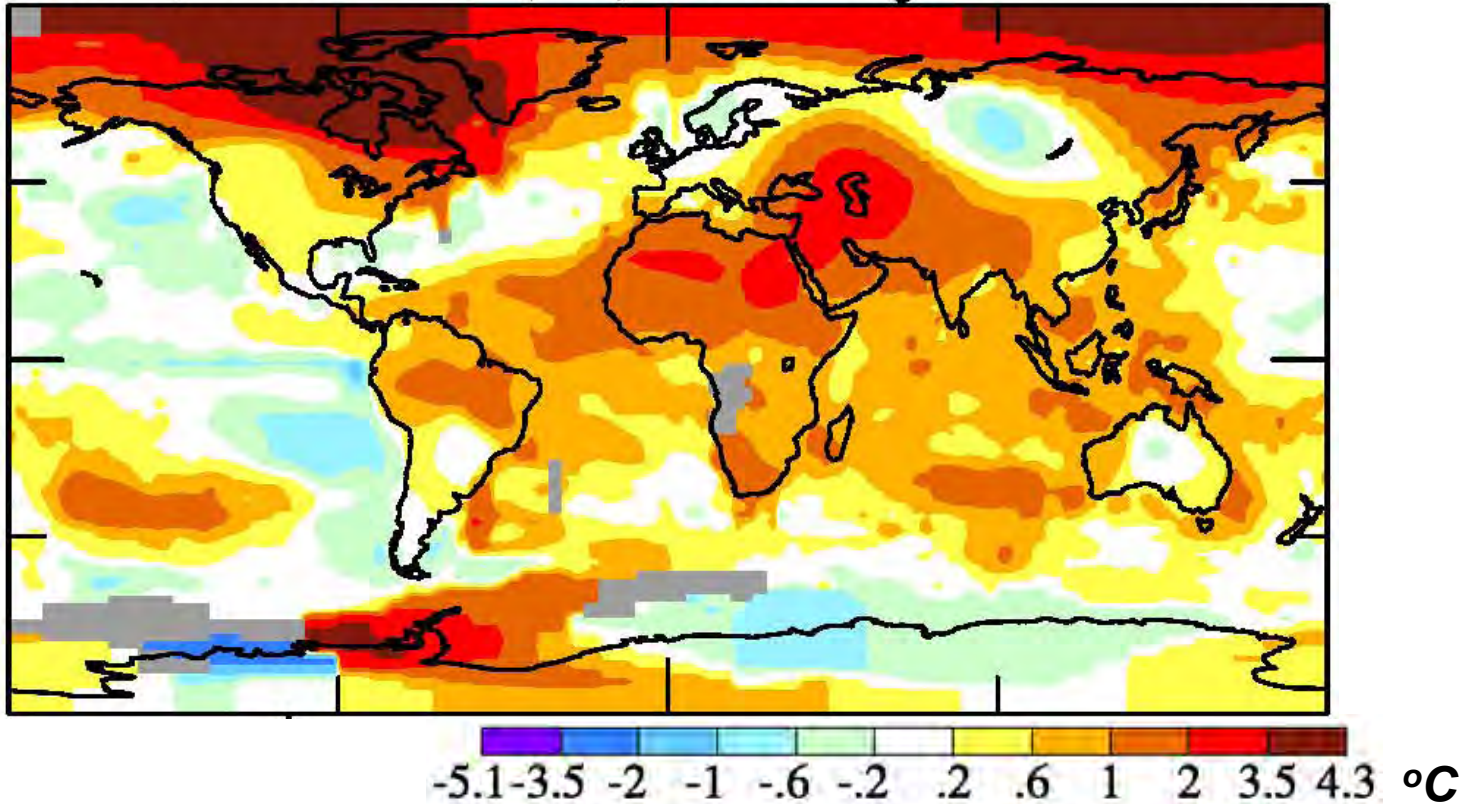
Global Land–Ocean Temperature Index



NASA-GISS, 2011

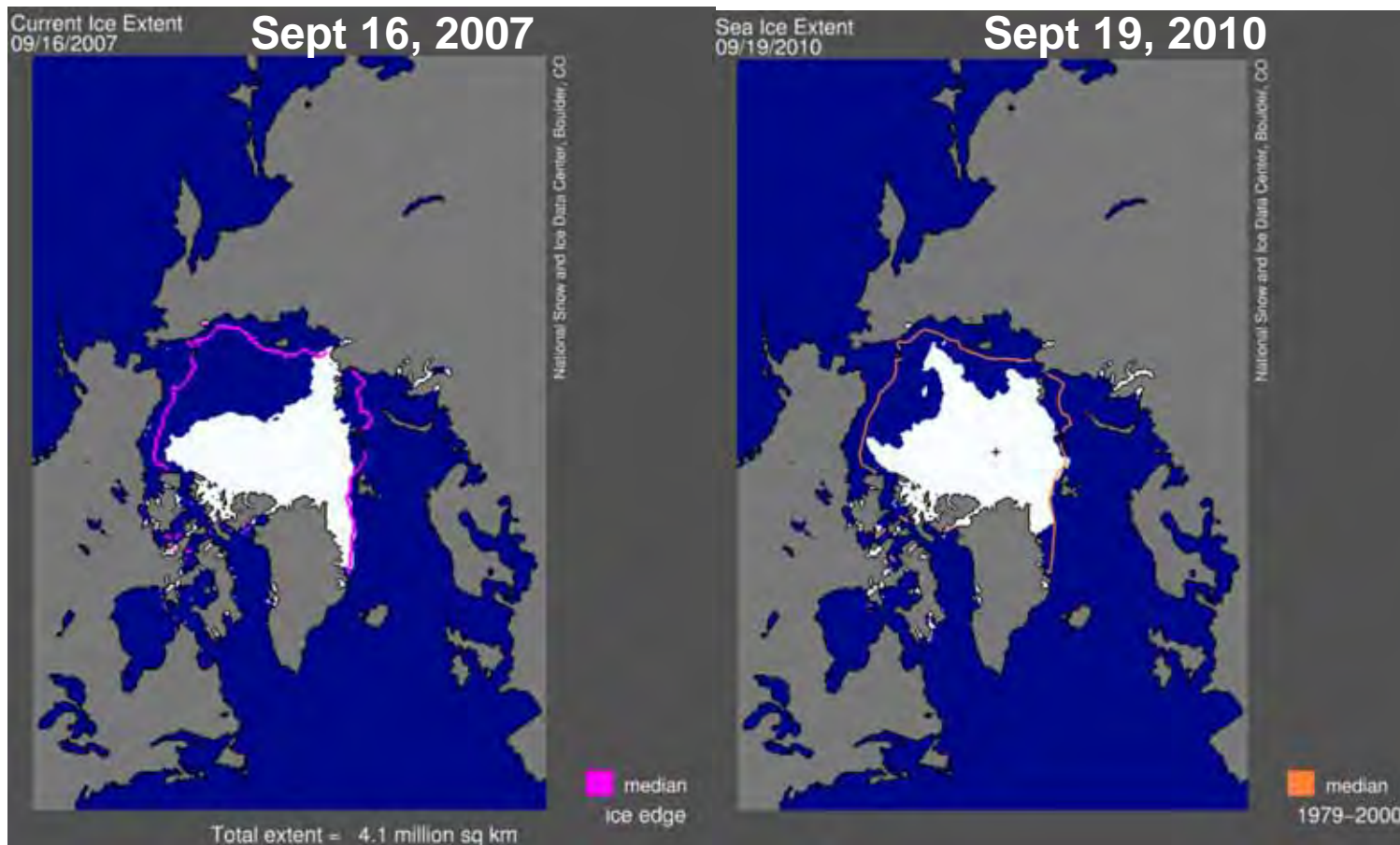
Global Picture 2010

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



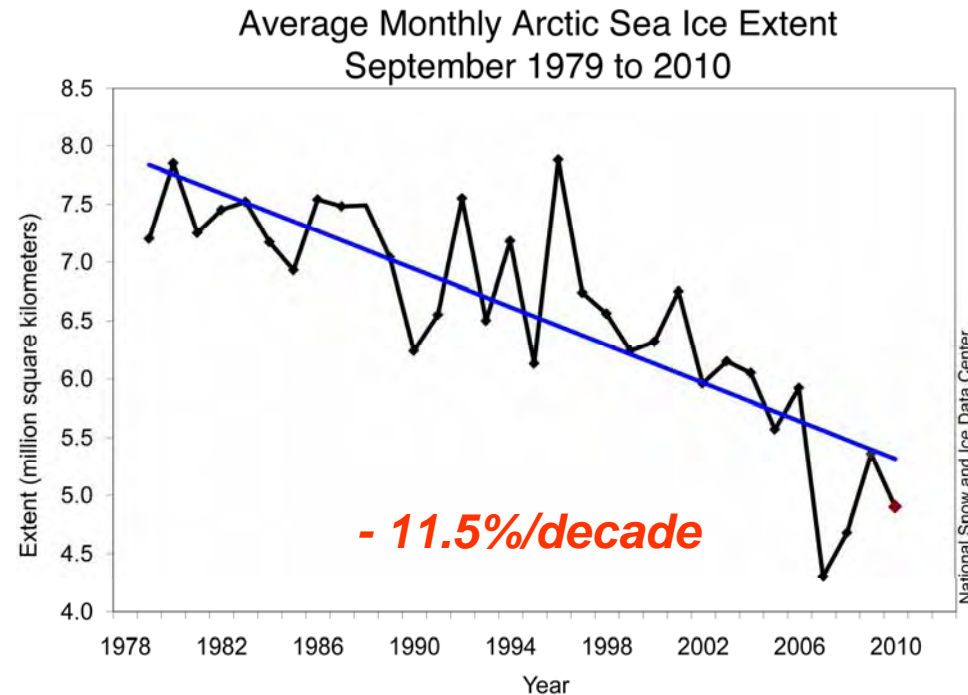
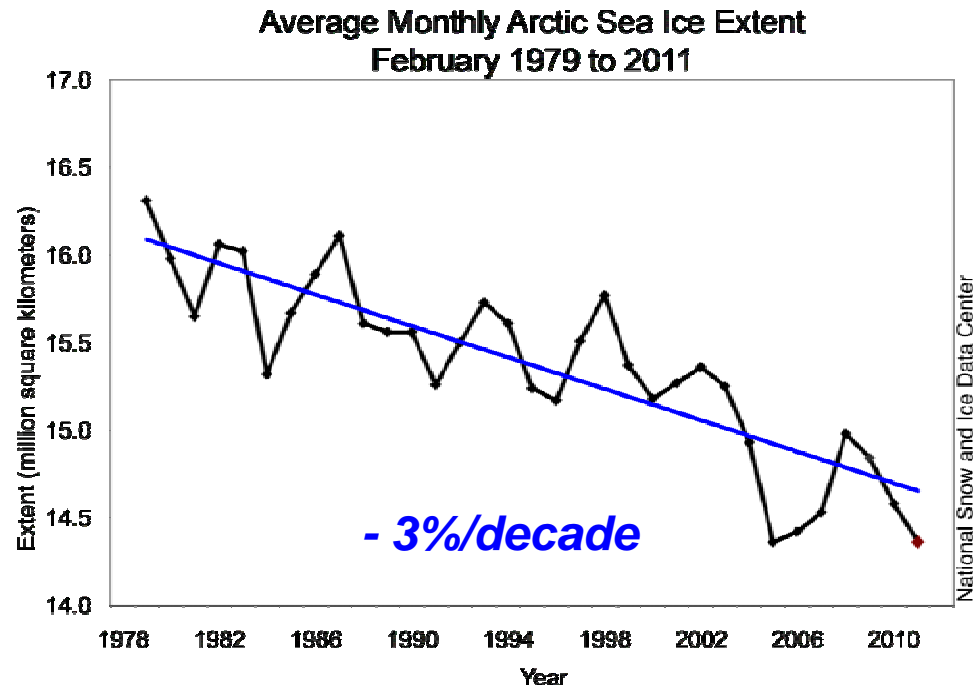
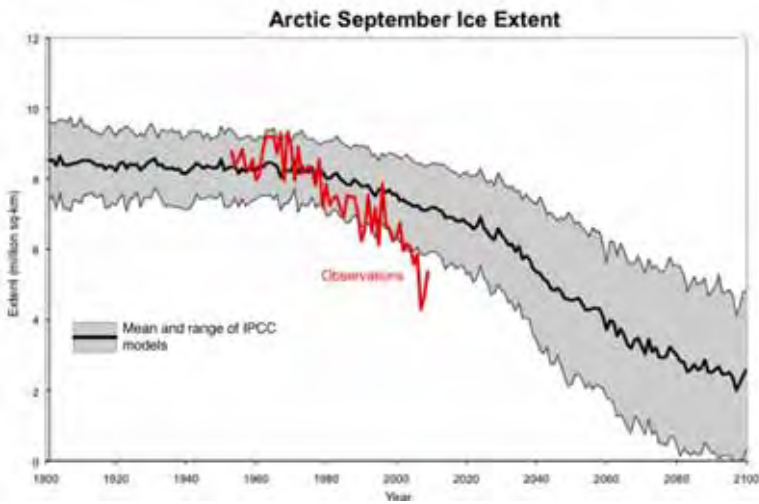
- **Feedbacks speed melting**
- **Less ice, less sunlight reflected**
- **More evaporation, larger water vapor greenhouse effect**

(www.nsidc.org)

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

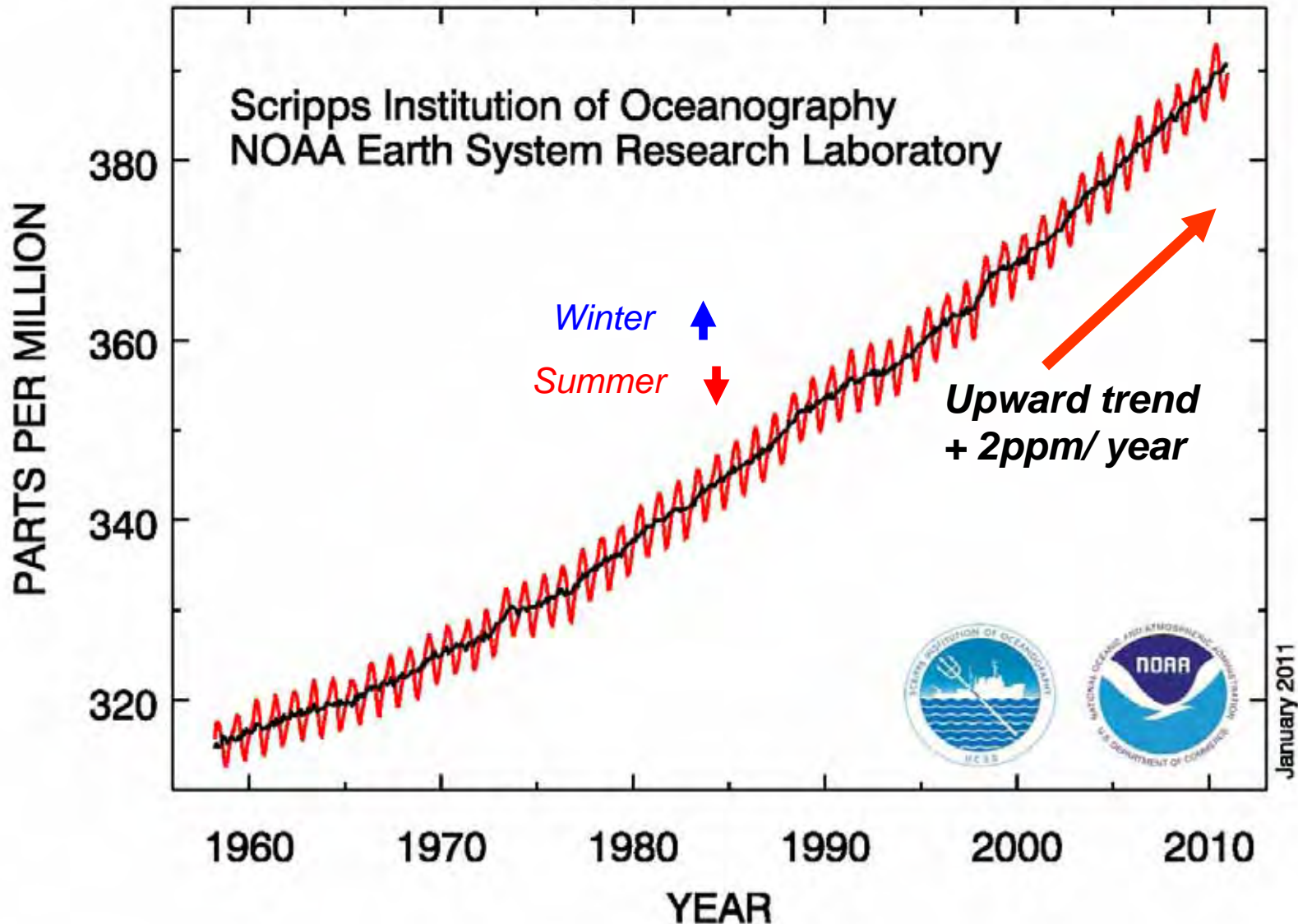
Sea Ice Trends

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



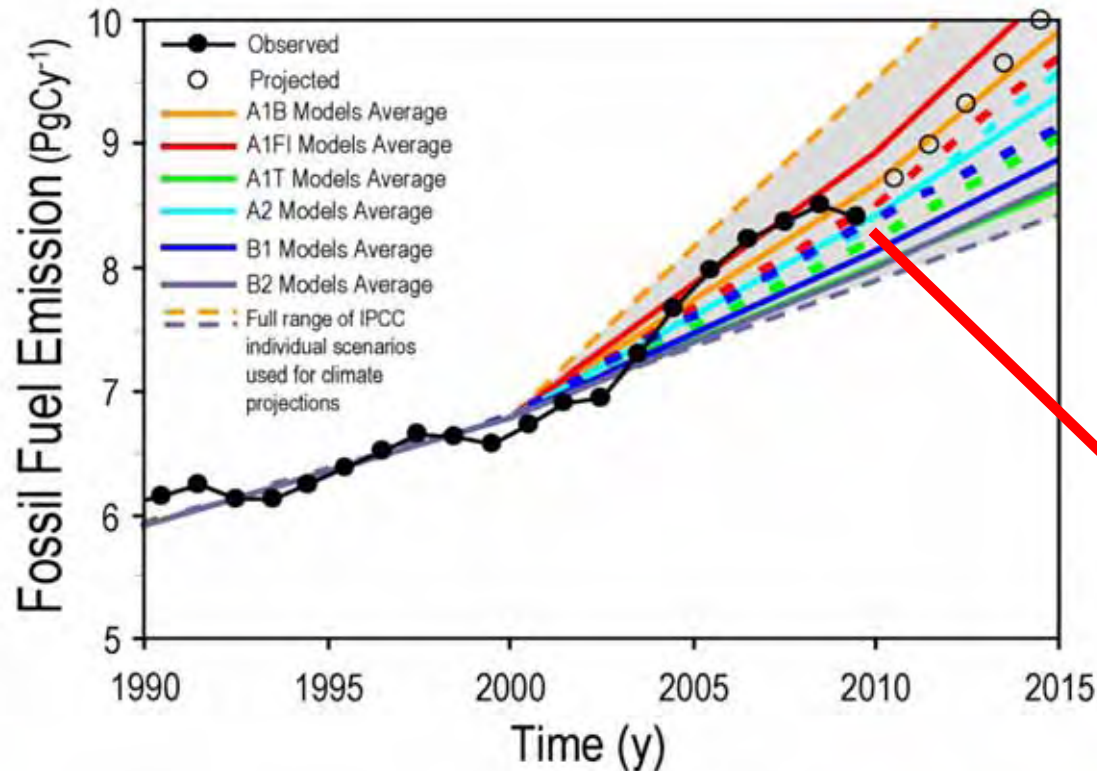
Carbon Dioxide Is Increasing

Atmospheric CO₂ at Mauna Loa Observatory



2009 Was “Good” for the Earth

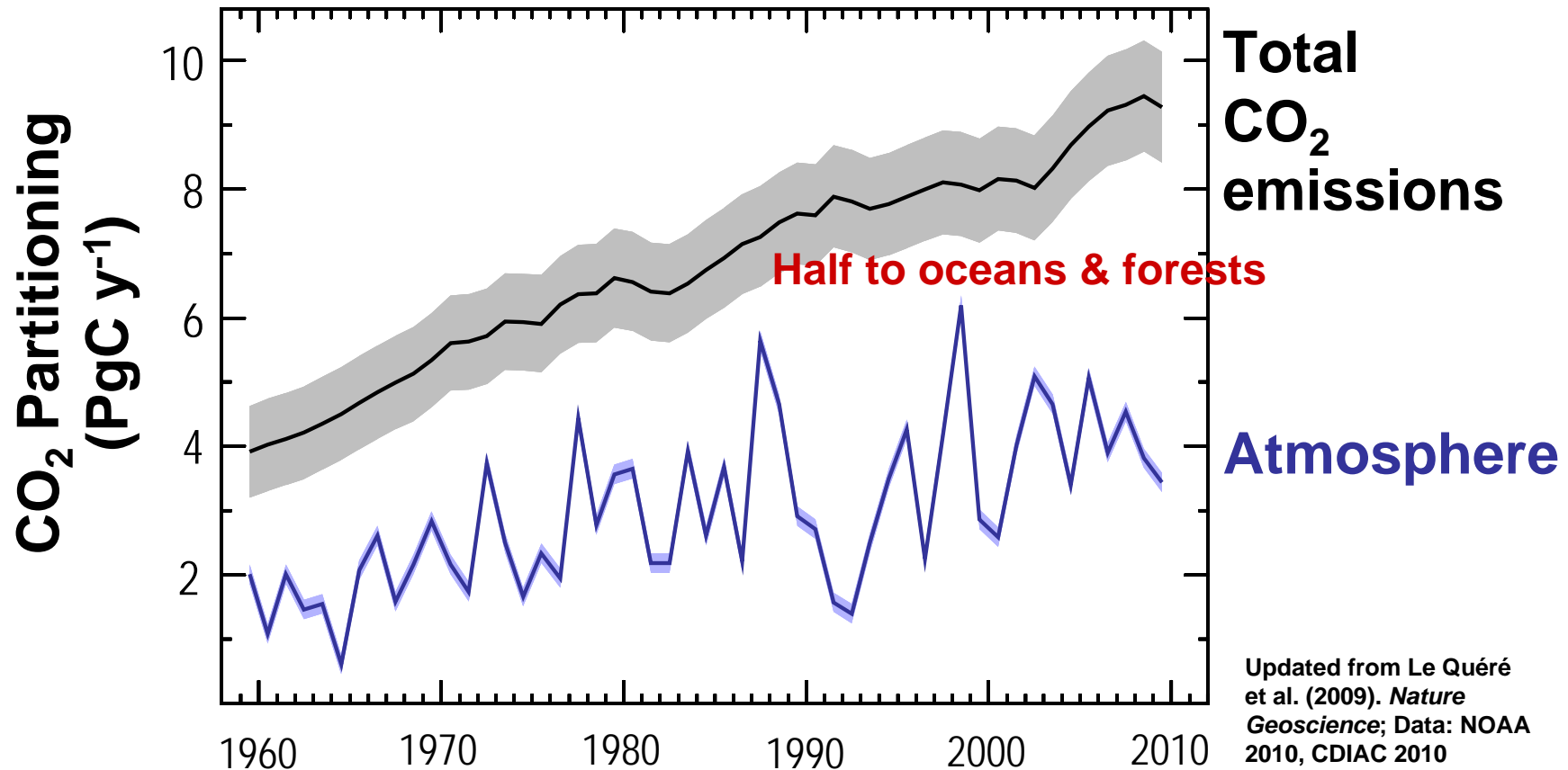
Fossil Fuel Emissions: Actual vs. IPCC Scenarios



- 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

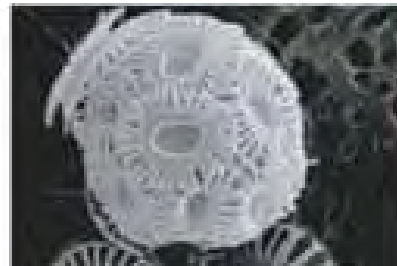
Rising Ocean Acidity Threatens Organisms



- 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
- 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:

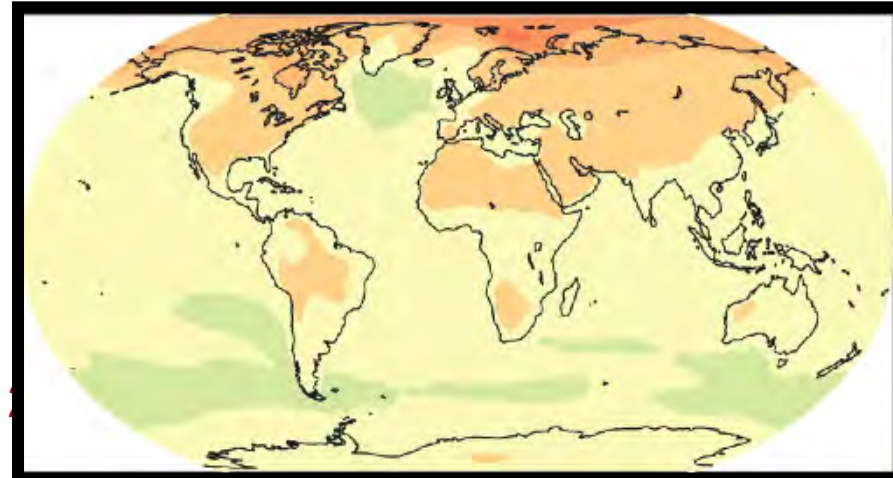
- NH snow extent
- Arctic sea ice
- Glaciers
- Ocean pH (increasing acidity)



Predicted Change in Temperature

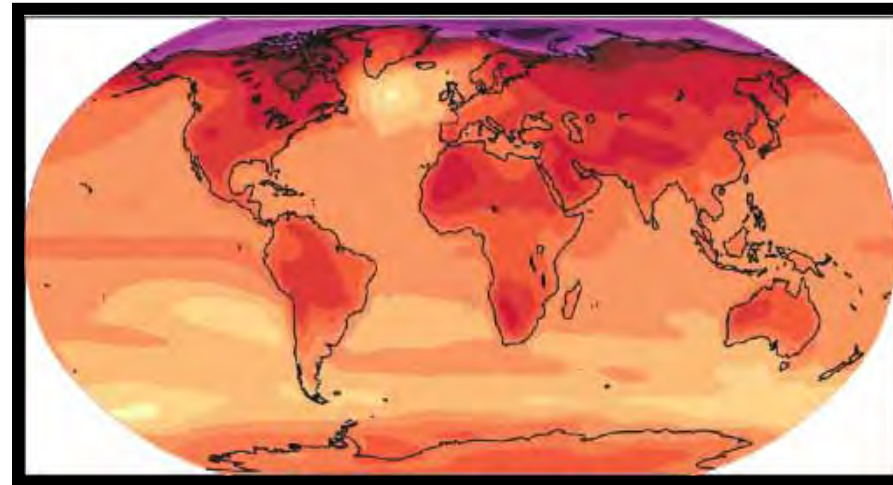
2020-2029 and 2090-2099, relative to 1980-1999 (°C)

“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

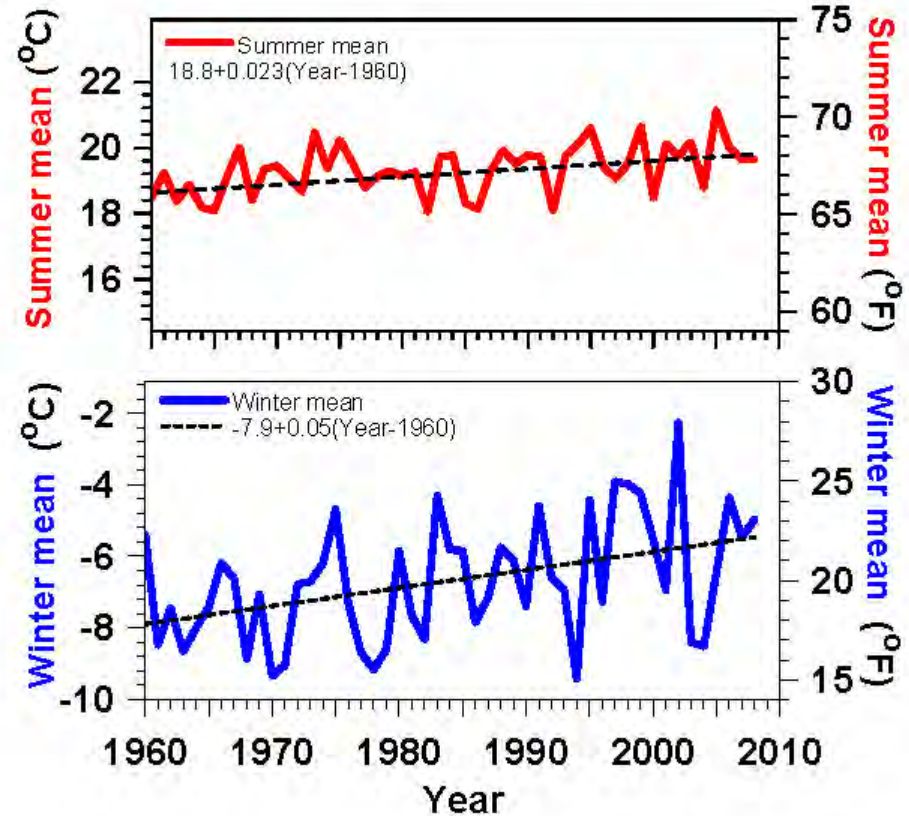
- **Extreme weather: Floods, fires, & drought**
- **Melting Arctic and permafrost—methane release?**
- **Ecosystem collapse, including perhaps forest and ocean ecosystems**
- **Collapse of unsustainable human population**

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**

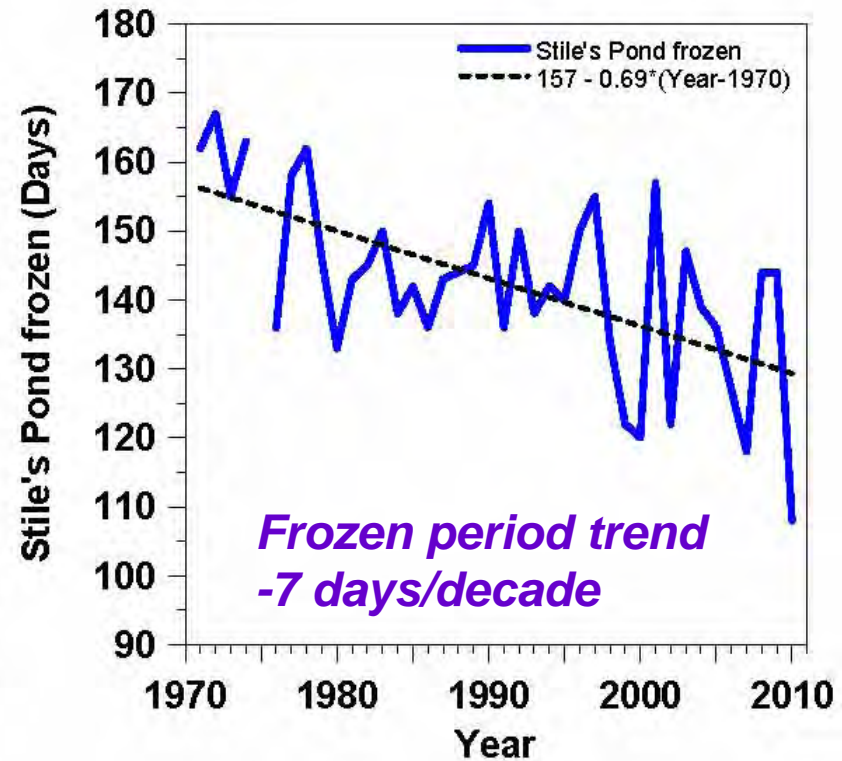
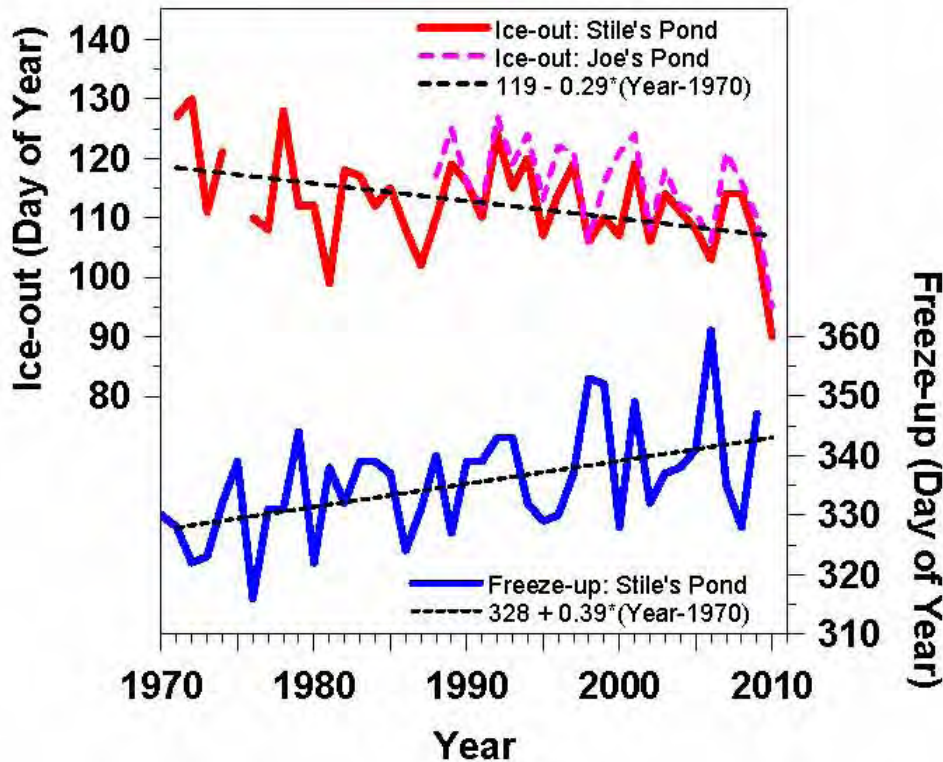
Vermont Temperature Trends

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



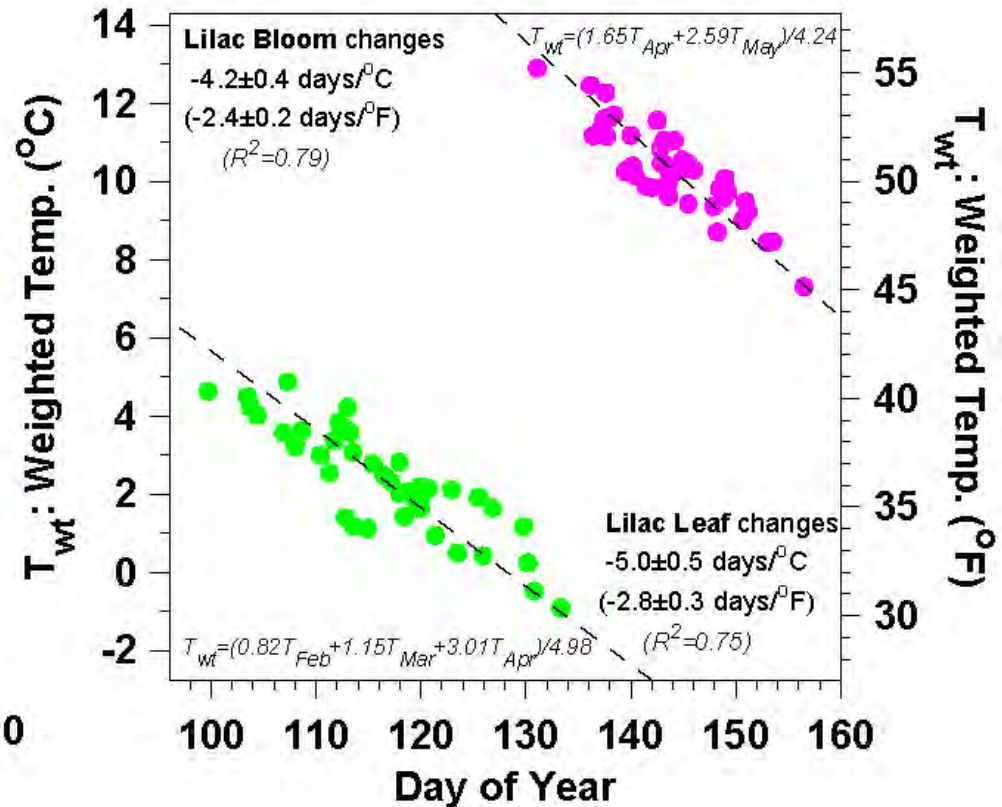
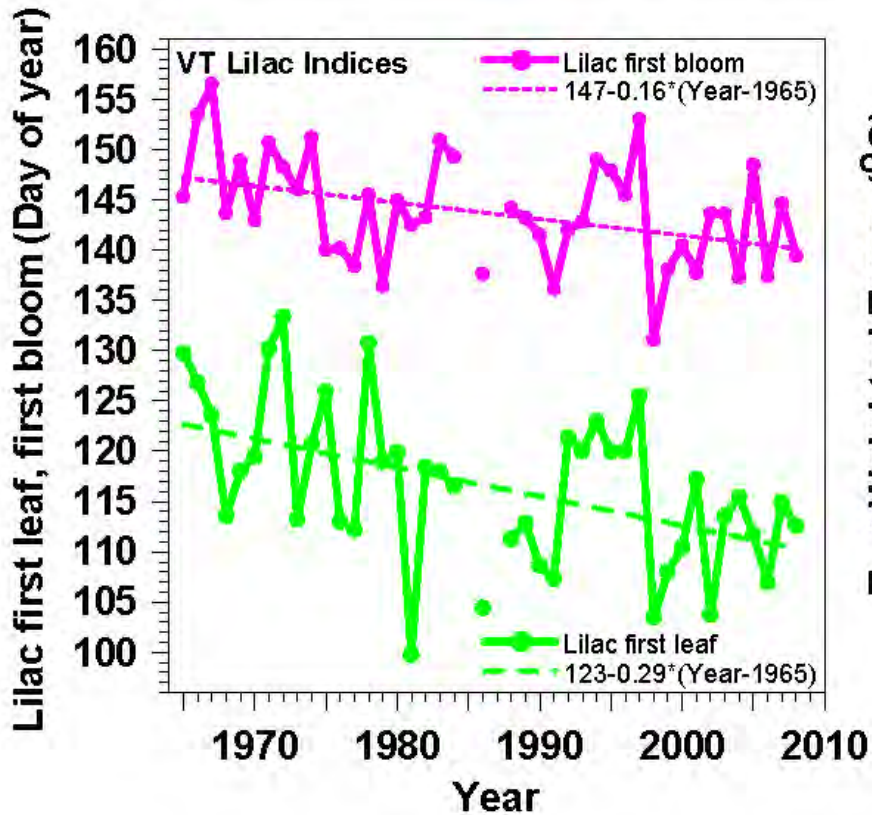
Lake Freeze-up & Ice-out Changing

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)

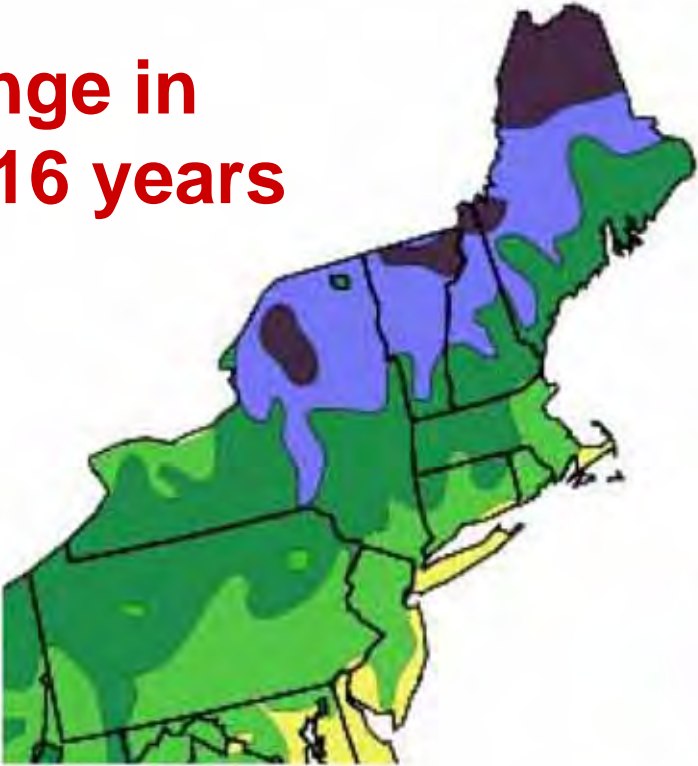
Vermont Winter 2006



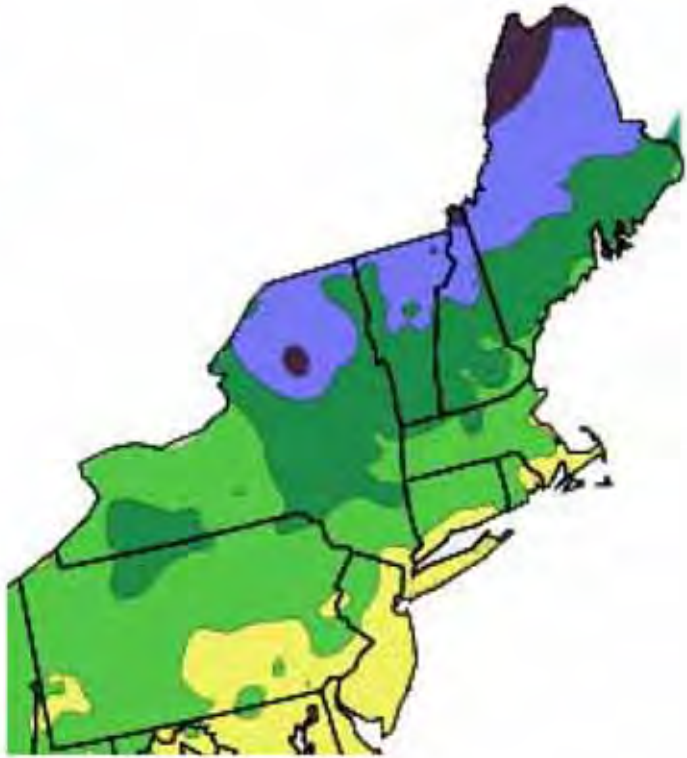
- **Sun is low; and snow reflects sunlight, except where there are trees!**
- **Sunlight reflected, stays cold; little evaporation, clear sky; earth cools to space**

USDA Hardiness Zones - Northeast

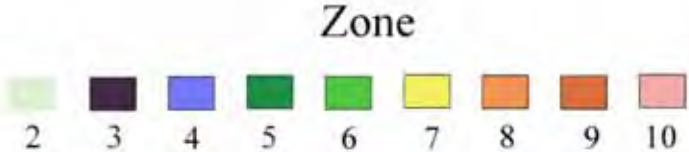
Change in
last 16 years



1990



2006



USDA Hardiness Zones

Gardening in Pittsford, Vermont in January



January 7, 2007

December 2006:

- **Warmest on record**

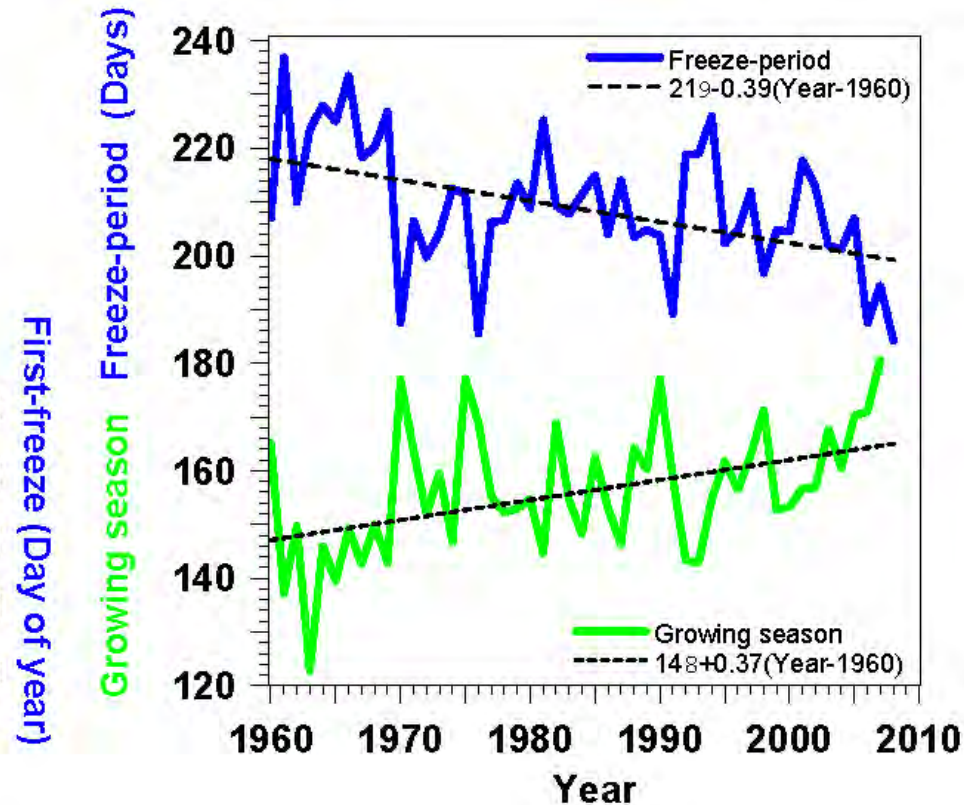
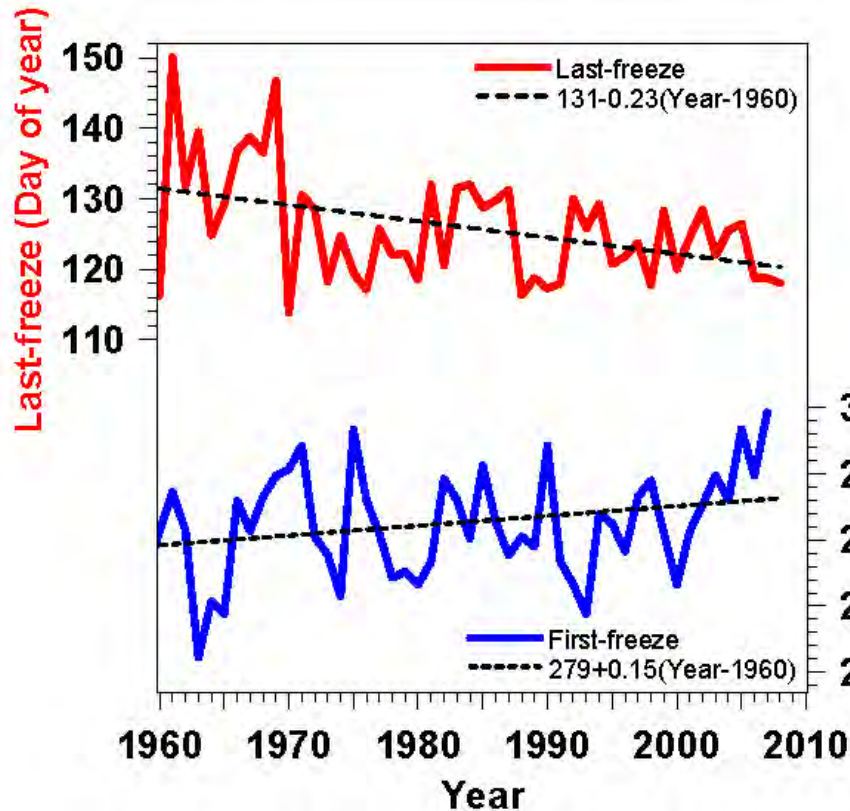


January 10, 2008

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 RH

→ Deep dry BL

→ Large outgoing LW_{net}

*Low water vapor
greenhouse*

→ Large diurnal temp. range

giving warm days, cool nights and frost

- **After leaf-out**

Large evaporation → Wet atmosphere, low cloudbase

→ Small outgoing LW_{net}

→ Reduced T_{max}

→ Reduced chance of frost

- ***Spring is coming earlier***

Fall climate transition - *first frost*

- Vegetation tries to postpone first killing frost in fall
- Deciduous trees still evaporating: moist air with clouds
- Water vapor & cloud greenhouse reduces 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!



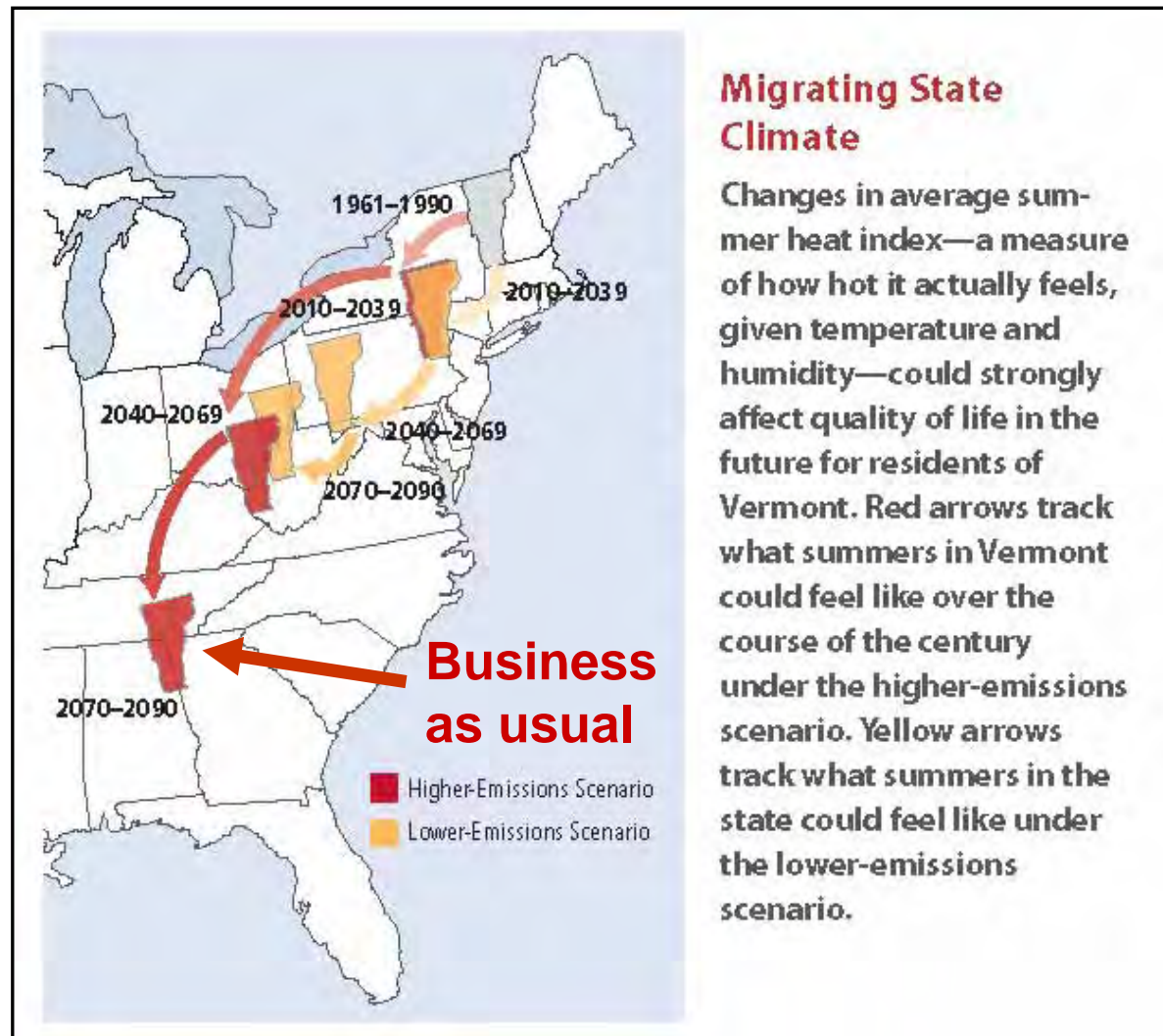
Clear dry blue sky after frost. Forest evaporation has ended and water vapor greenhouse is reduced so Earth cools fast to space at night

Later frost: Growing season getting longer

Vermont's Future with High and Low GHG Emissions

What
about
skiing?

What
about
tropics?



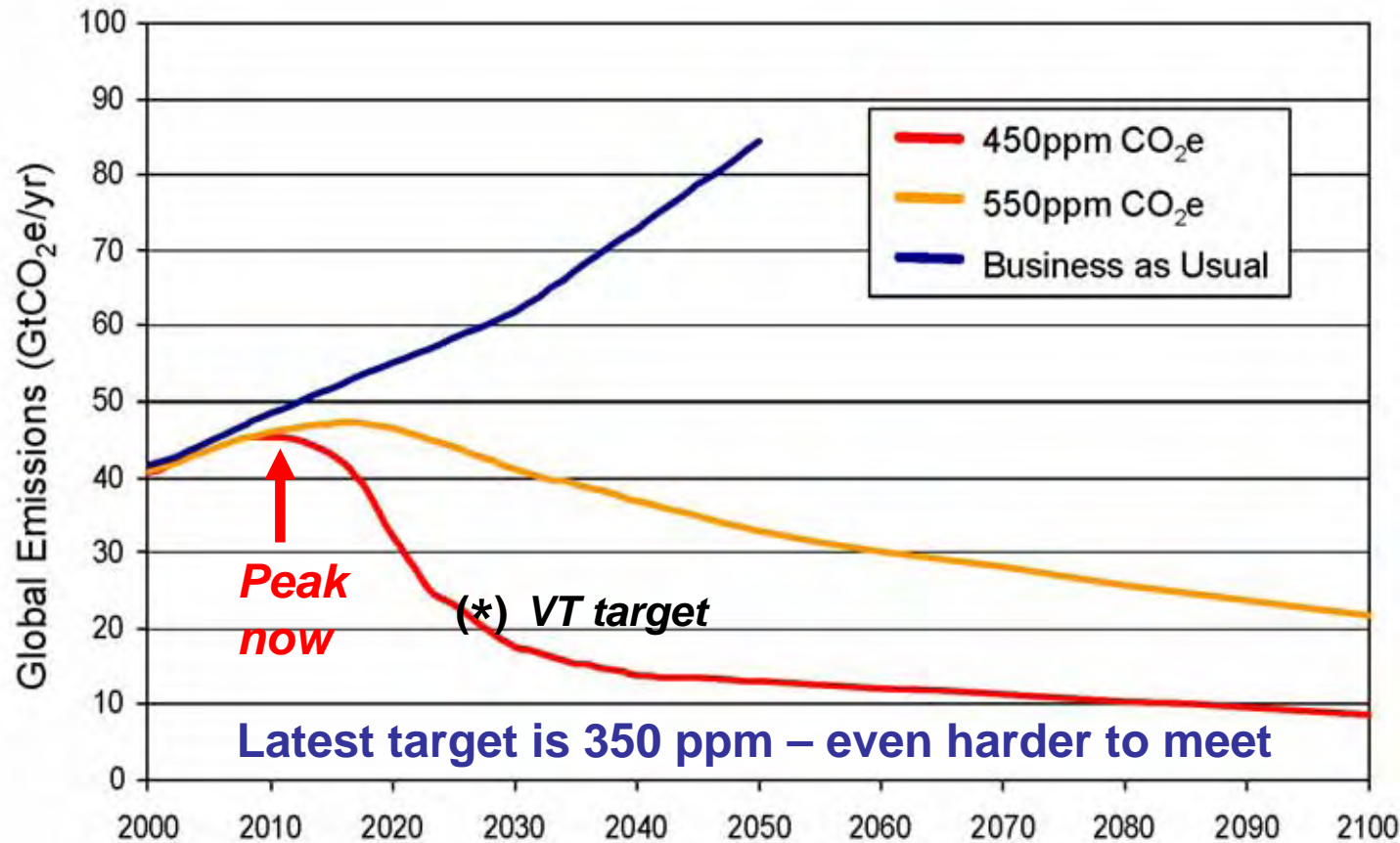
NECIA,
2007

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 fuel**

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**
- **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** – radioactive – 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)?**

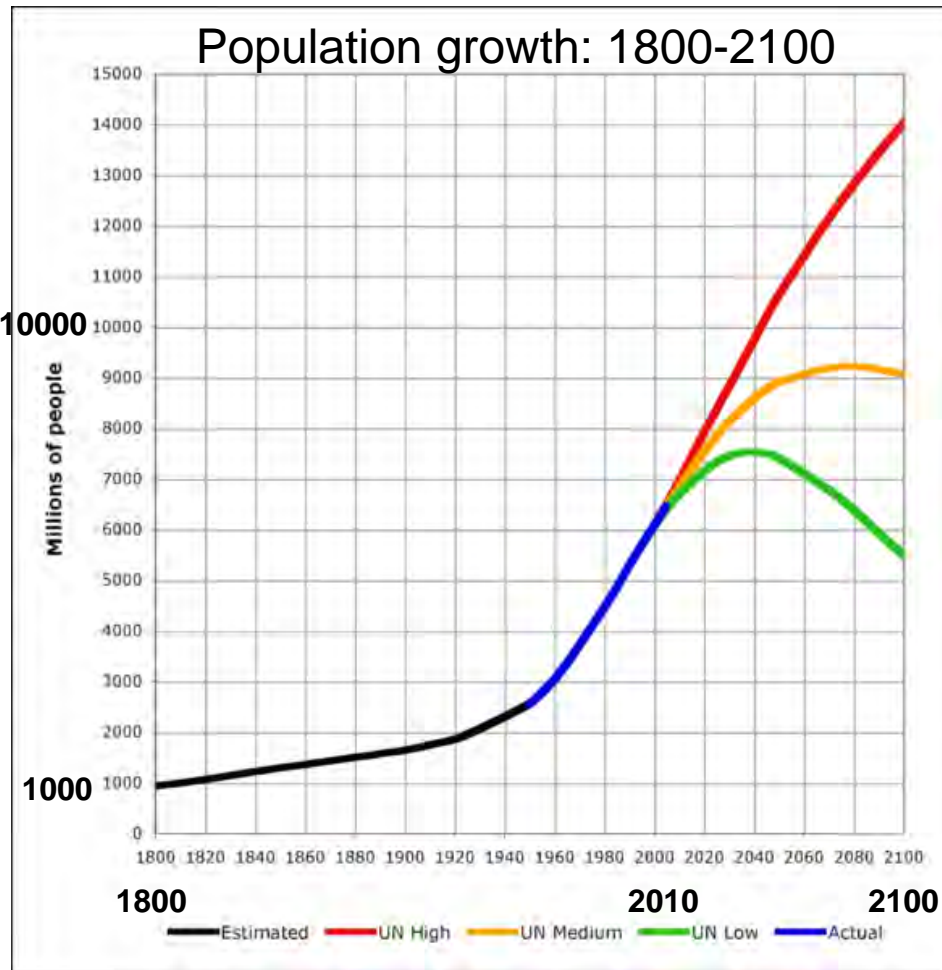
Why Is It Difficult for Us?

- 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 have no workable paradigm 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**
 - **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**
 - 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 plan for a transition to a sustainable society**
- **Communities are one key:**
 - www.transitiontowns.org

What do we need to do?

- Plan for transition to a sustainable society
- *Recognize this will take decades and that it needs a community effort*

- **Food:** local agriculture & gardens
- **Energy:** Double energy efficiency
 - home heating – district heating + cogen
 - renewable electricity mix
 - efficient transportation system
- **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**
- **Local food; local power; community solutions**
- **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>
 - papers at <http://alanbetts.com/research>
- *Vermont Climate Change Indicators*
- *Seasonal Climate Transitions in New England*

What are scientists' responsibilities?

- **Climate science is under attack because it is politically and economically relevant**
- *Traditionally scientists “stuck to science”*
- **How do we proactively defend the science and maintain trust and integrity of science?**
- **Needs deeper ethical/historical understanding**
- **Needs greater public engagement by scientists**