



# Climate Change & the Carbon link

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*Natural Resources Conservation  
Celebration*

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# Climate Change

- **One of the great challenges for 21<sup>st</sup> C**
- **We are already decades late in taking action**
  - *Sawyer (1972): Man-made CO<sub>2</sub> and the “greenhouse” effect*
- ***Global issue & local issue;  
societal & personal issue***
- **Clash of Earth science & social values**

# Outline

- **Science of climate change**

- *Global scale: actual and future*

- *Local scale: Vermont*

- **Two critical issues**

- *What is happening to the climate?*

- *Is rising CO<sub>2</sub> responsible?*

My background:

# Peterhouse Cambridge

- Peterhouse, Cambridge:  
founded 1284
- *Medieval warm period;  
Vinland colony  
flourishes*



# My background:

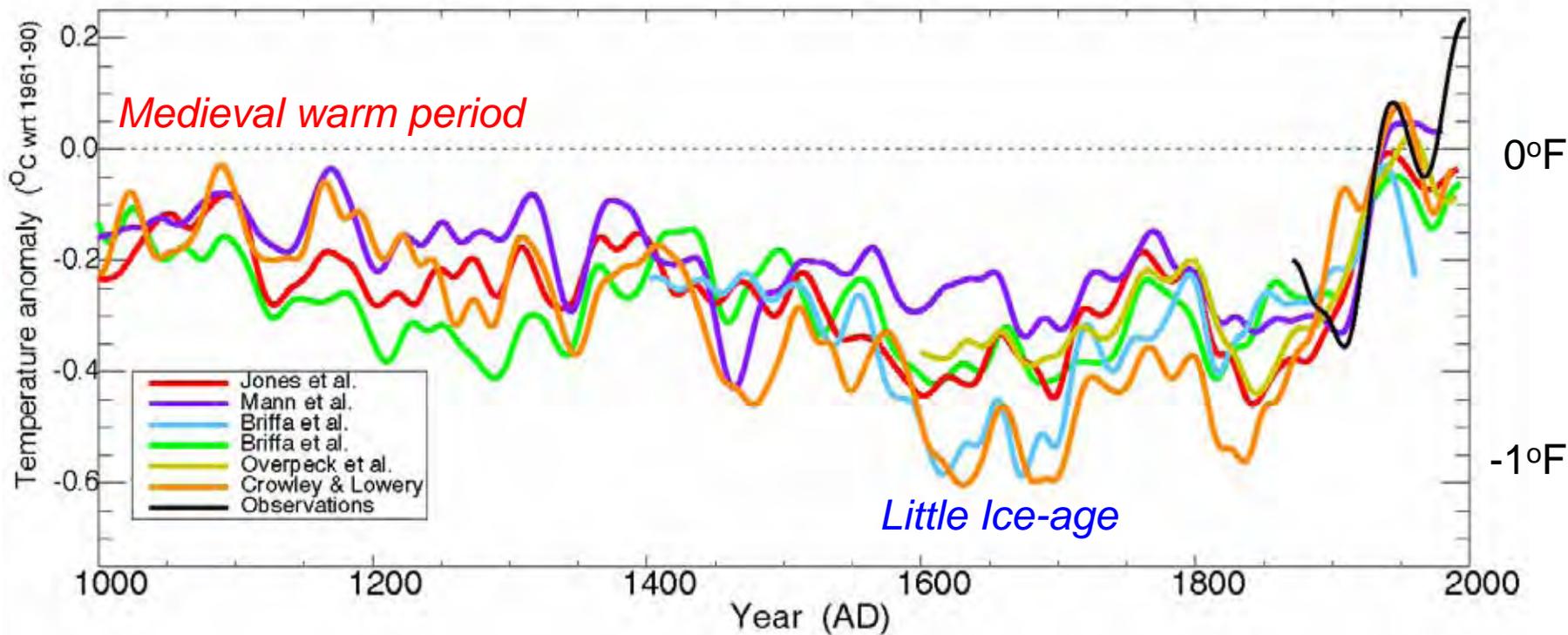
## Nottingham High School

- Founded 1513
- *1550 heading into 'little ice-age'*
- *1620 Pilgrim fathers face bitter winters*



# Millennial Temperature Record

2100: +5°F  
↑

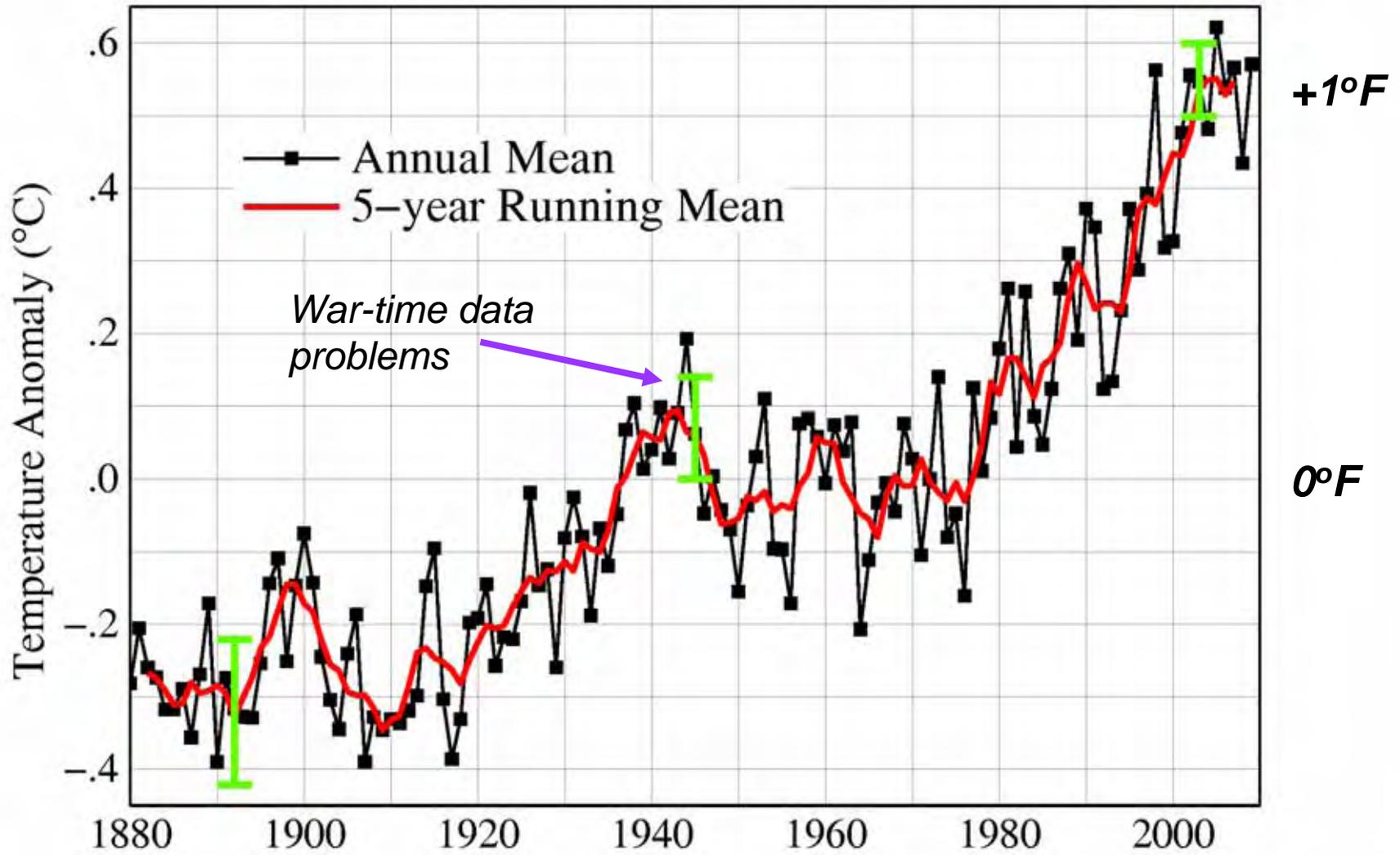


- Before thermometers  
‘proxy’ records have large uncertainty

# Global temperature rise 1880-present

2100: +5°F  
↑

## Global Land–Ocean Temperature Index

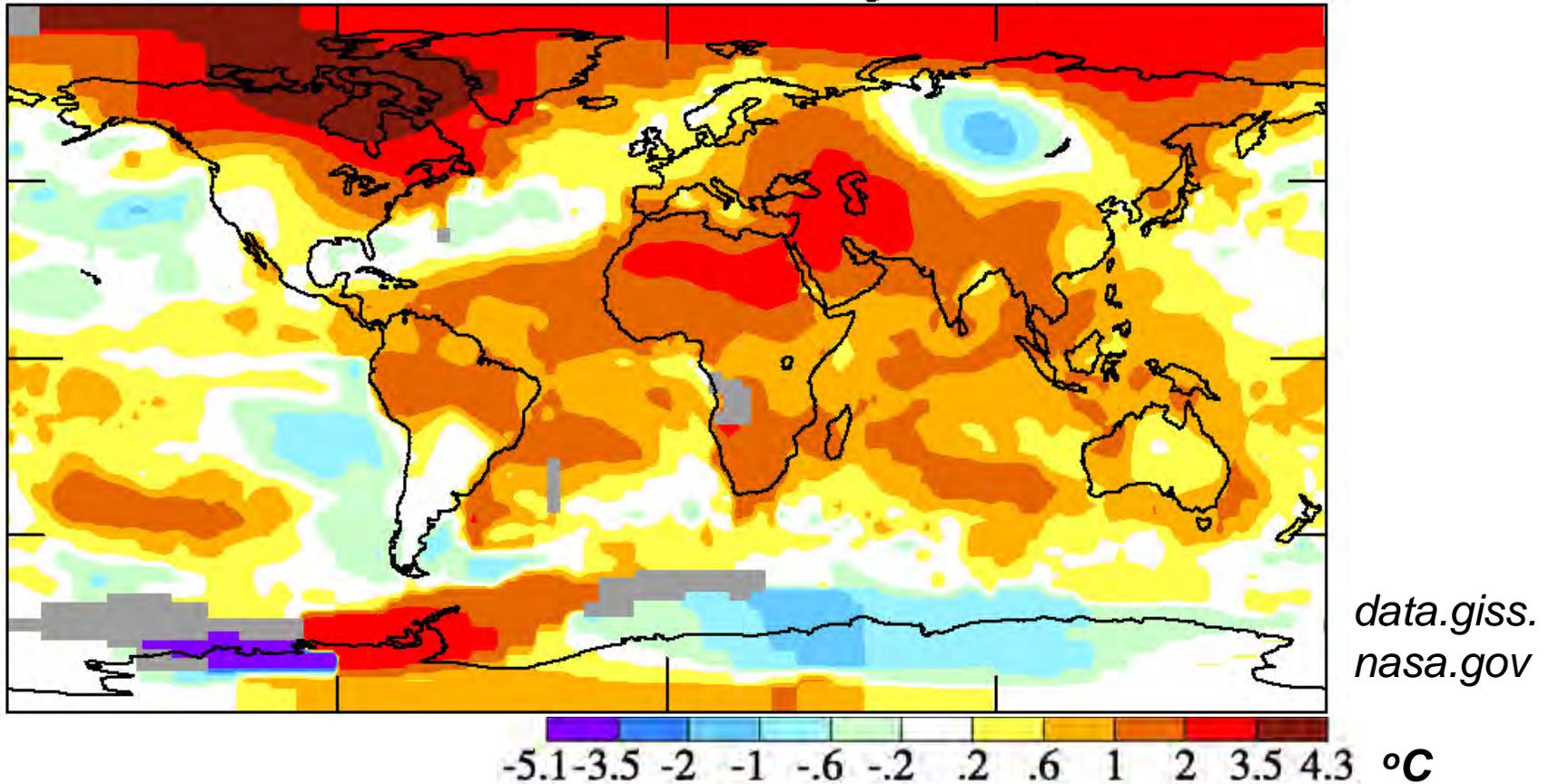


Base: 1951-1980

NASA-GISS, 2010

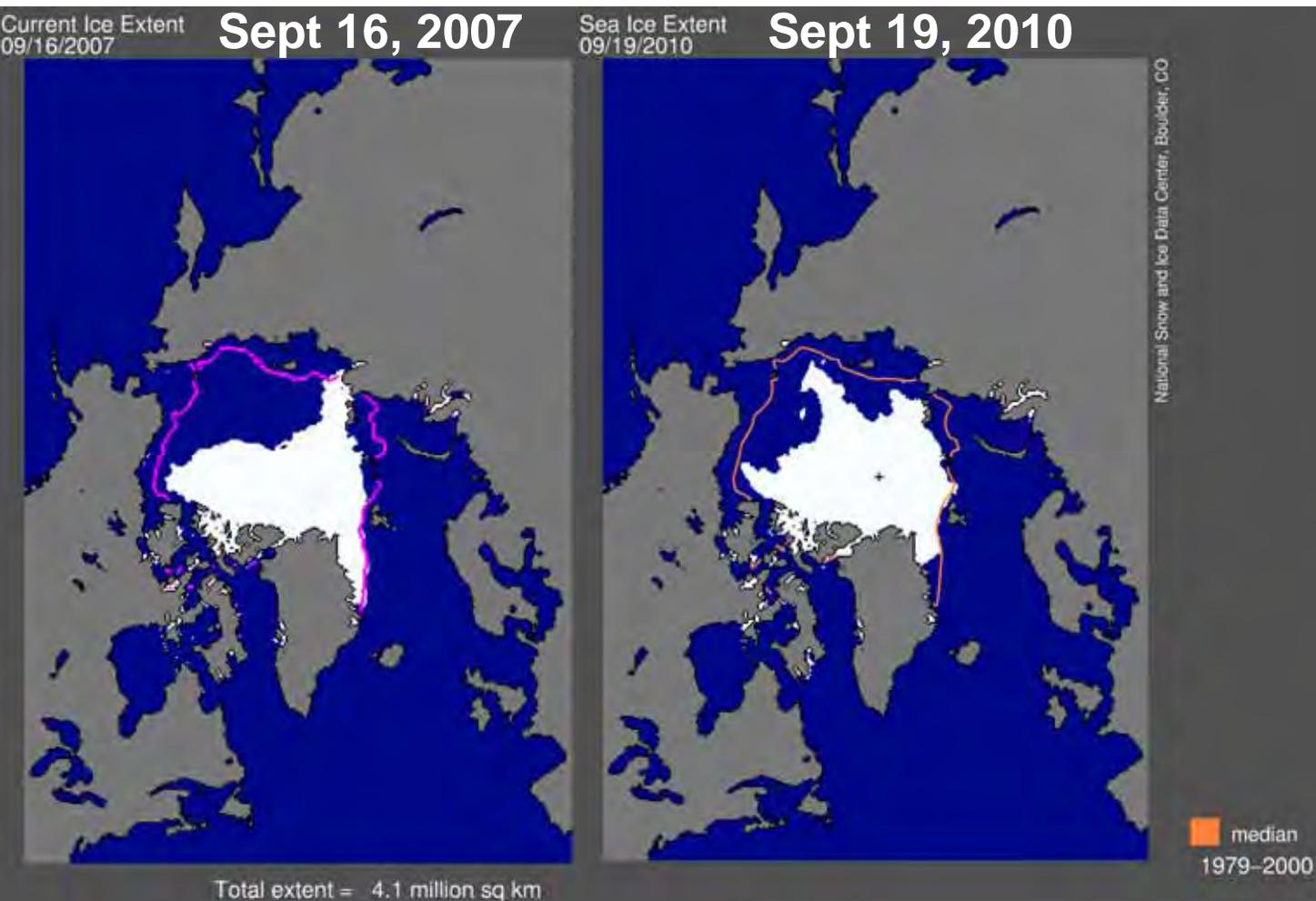
# Global picture Jan-Sep 2010

2010 (the warmest of 131 years) 0.67 °C(1.2F)



- *Record summer temps in Russia (99F) (Moscow fires) and Pakistan (128F) (extreme monsoon floods)*
- *April rain in Ellef Ringnes Islands, Nunavet, at 78°N*

# Arctic sea-ice loss has accelerated



*Feedbacks -  
speed melting*

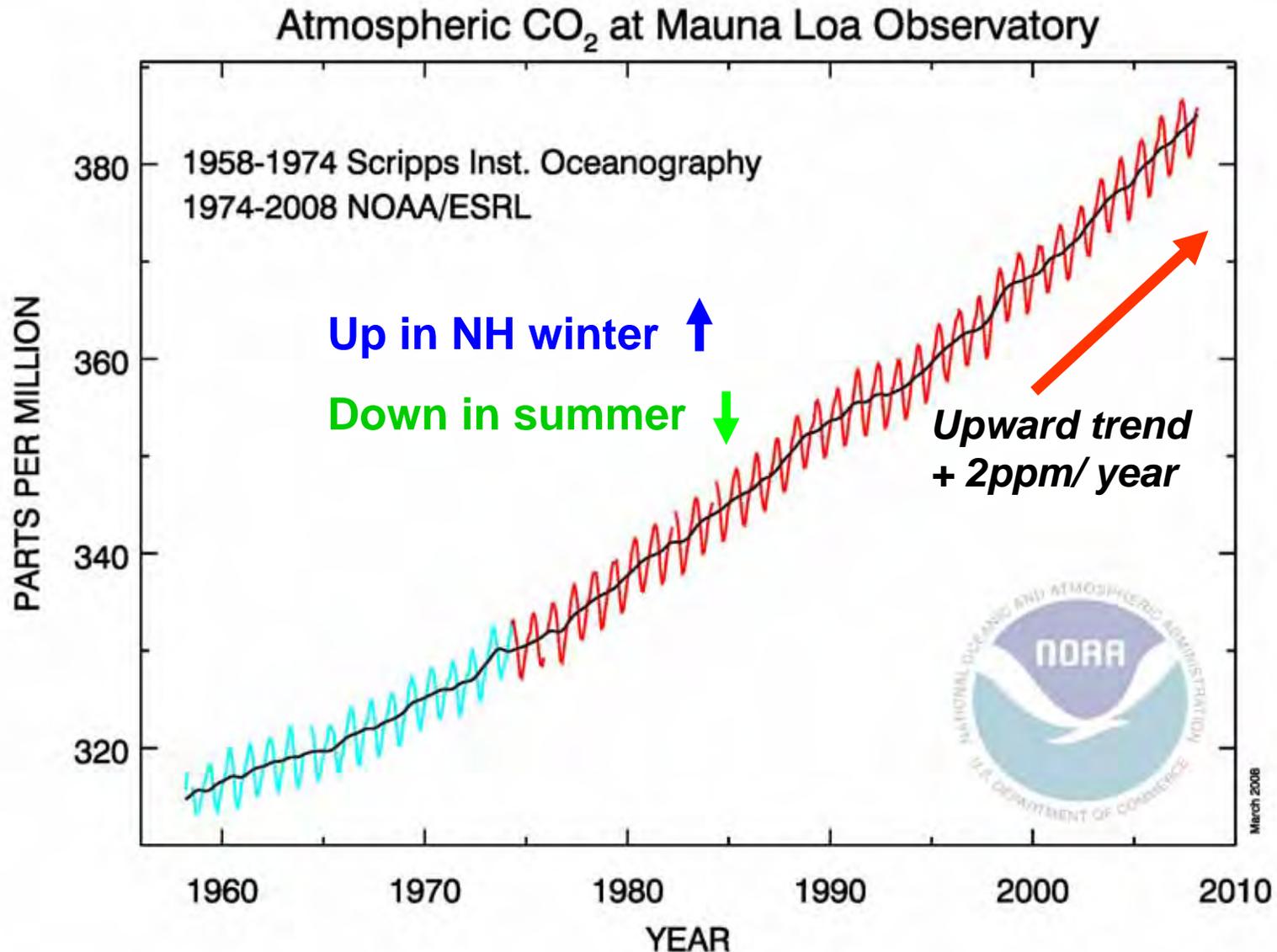
*-less ice, less  
sunlight reflected*

*-more evaporation,  
larger water vapor  
greenhouse*

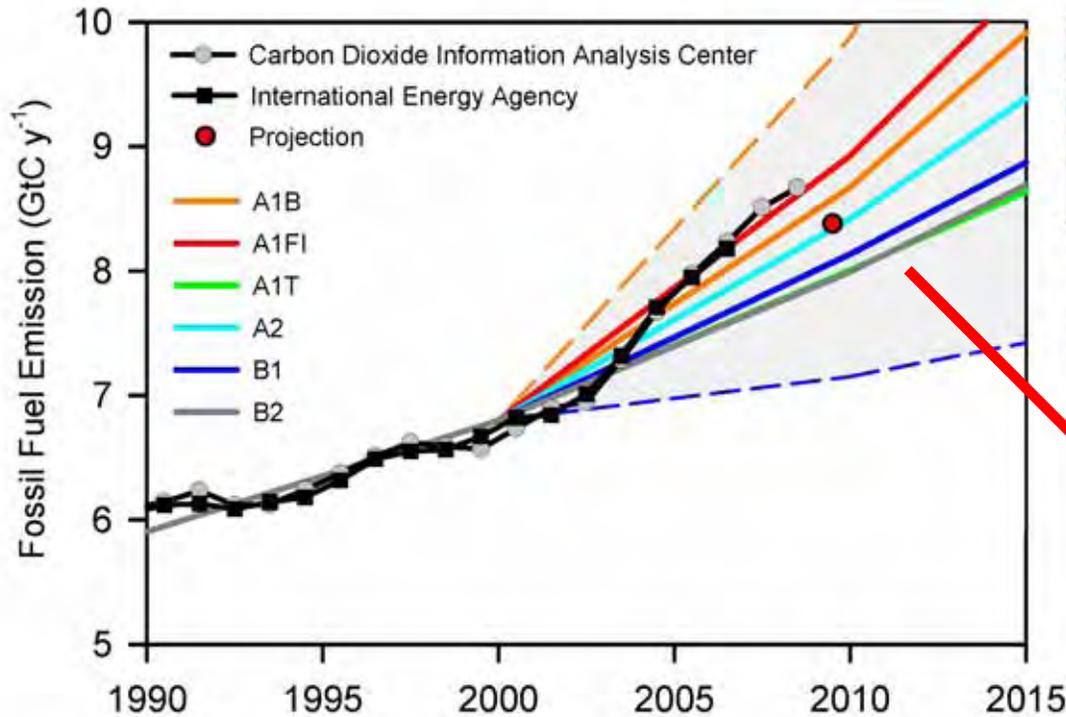
([www.nsidc.org](http://www.nsidc.org))

- 2007 saw record ice-loss: most ice now only 1-2yrs old
- Open water in October contributes to warmer Fall

# Carbon dioxide is increasing



# Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Projection 2009  
 Emissions: -2.8%  
 GDP: -1.1%  
 C intensity: -1.7%

- 4%/year

Need 80%  
 drop by 2050

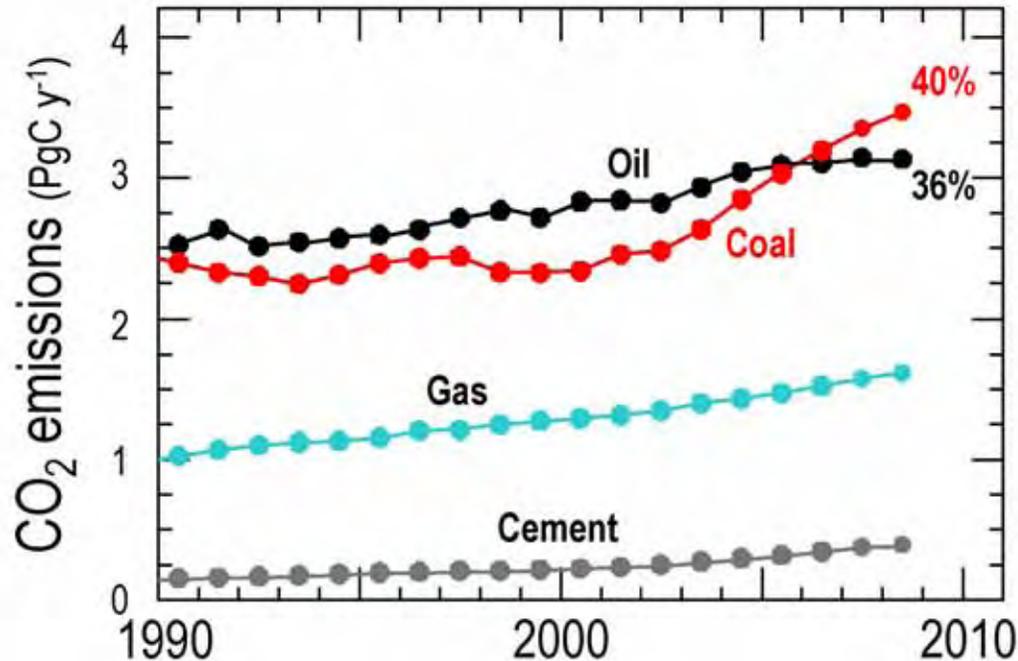
- 2009 was 'good' for the Earth



Raupach et al. 2007, PNAS, updated; Le Quéré et al. 2009, Nature Geoscience; International Monetary Fund 2009



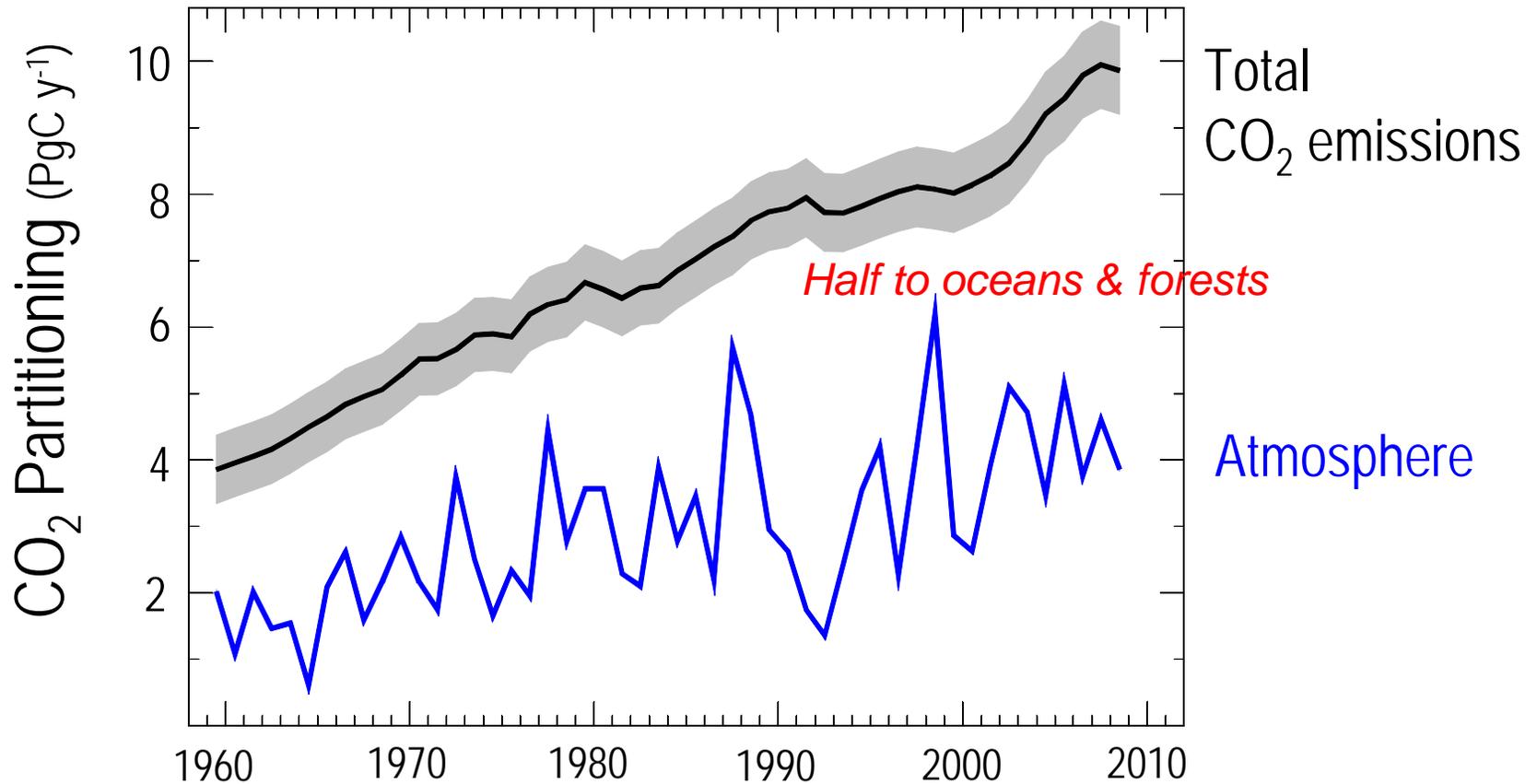
# Components of FF Emissions



- Steep rise is from coal - China & India

# Key Diagnostic of the Carbon Cycle

Evolution of the fraction of total emissions that remain in the atmosphere



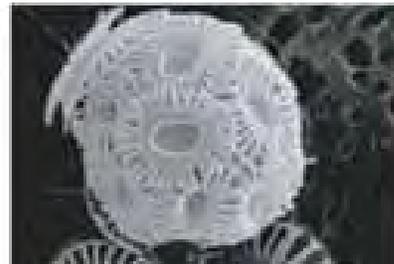
*It takes a century or more to remove CO<sub>2</sub> from  
atmos., and many centuries from the oceans*

# Rising ocean acidity threatens organisms

- From the tropics to the Arctic, the seas are sucking up emissions of carbon dioxide —from fossil-fuel burning.
- When carbon dioxide dissolves in water, carbonic acid is produced, so the oceans are becoming more acidic.



*[Ruttiman, Nature, 31 Aug., 2006]*



# *Why is rise of atmospheric CO<sub>2</sub> a problem?*

- Atmosphere is transparent to 'light' from sun but not to 'infrared' radiation from earth
- Greenhouse gases: H<sub>2</sub>O, CO<sub>2</sub>, CH<sub>4</sub>, HCFCs...  
- trap the earth's heat
- CO<sub>2</sub> alone has a small effect, BUT
- As Earth warms, evaporation and water vapor increase, clouds decrease; **amplifies warming 4x**
- As Earth warms, snow and ice decrease and this **amplifies warming** in winter and northern high lats, because less sunlight is reflected
- **Doubling CO<sub>2</sub> will warm Earth about 3C (5F)**

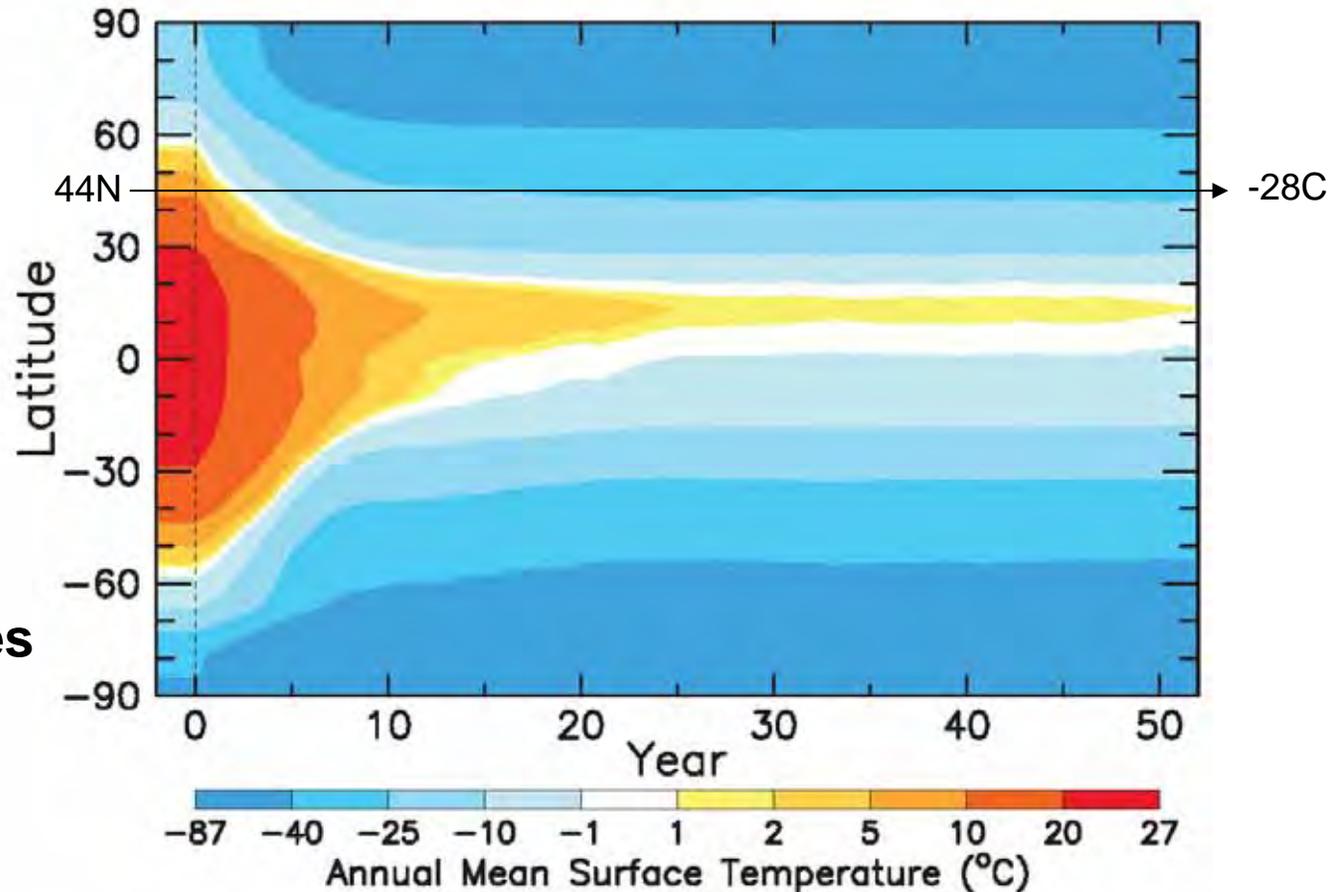
# CO<sub>2</sub> is the primary control knob in the climate system

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

(Lacis et al., Science, 2010)

**Remove CO<sub>2</sub> and other 'non-condensing' GHG from climate model**

**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%

# *IPCC, Feb 2, 2007*

## **Global Warming is *unequivocal***

Since 1970, rise in:

- Global surface temperatures
- 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:

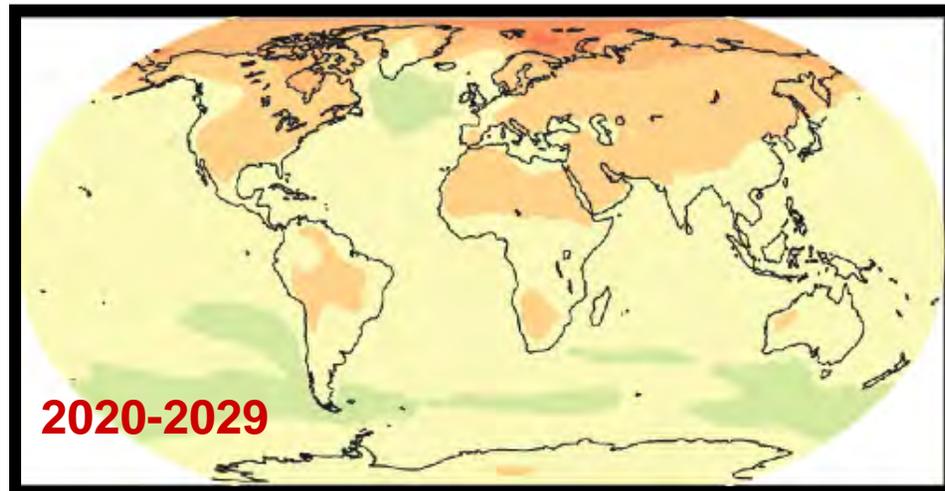
- NH Snow extent
- Arctic sea ice
- Glaciers
- Ocean pH [increasing acidity]

[\[www.ipcc.ch\]](http://www.ipcc.ch)



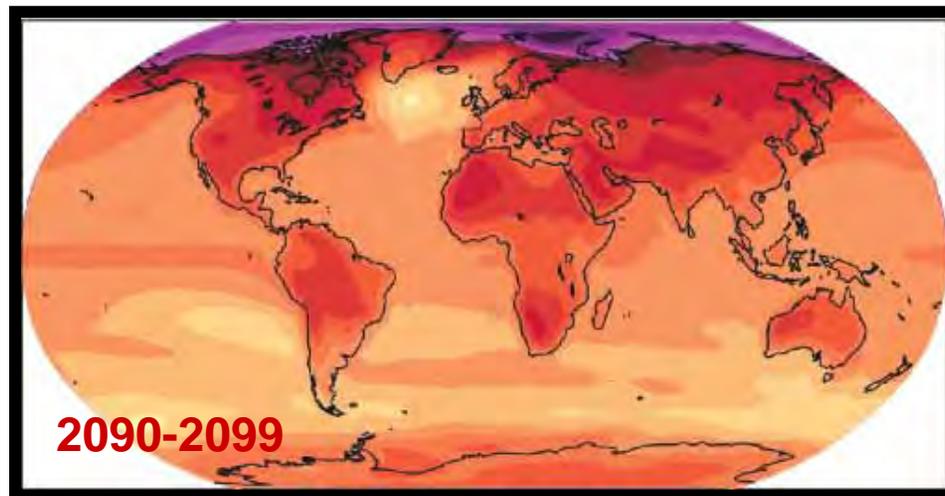
# Multi-model Predicted Percent Change in Temperature (2020-2029 and 2090-2090 relative to 1980-1999) [ $^{\circ}\text{C}$ ]

**'Committed'**



**(We did nothing for the last 20 years)**

**Still up to us!**



**(We could halve this if we act now)**



**[ $^{\circ}\text{C}$ ]**

# Sea-level rise will flood coastal cities

- Late 20thC sea-level rise 1ft/century
- 21stC -likely to triple to 3-4 ft/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!*

# And much more..

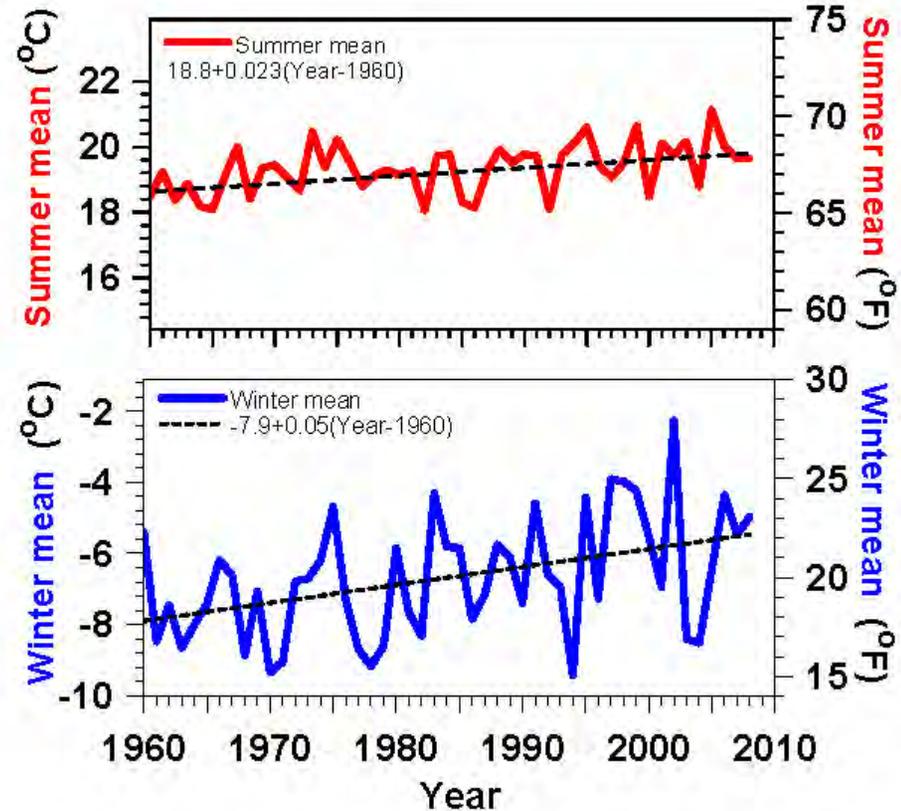
- Melting Arctic and permafrost – methane release?
- Extreme weather: floods, fires & drought
- Collapse of many ecosystems, including perhaps forest and ocean ecosystems
- Collapse of unsustainable human population

# What is happening to New England? – *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 3.7 days/decade*
- *Spring earlier by 2-3 days per decade*

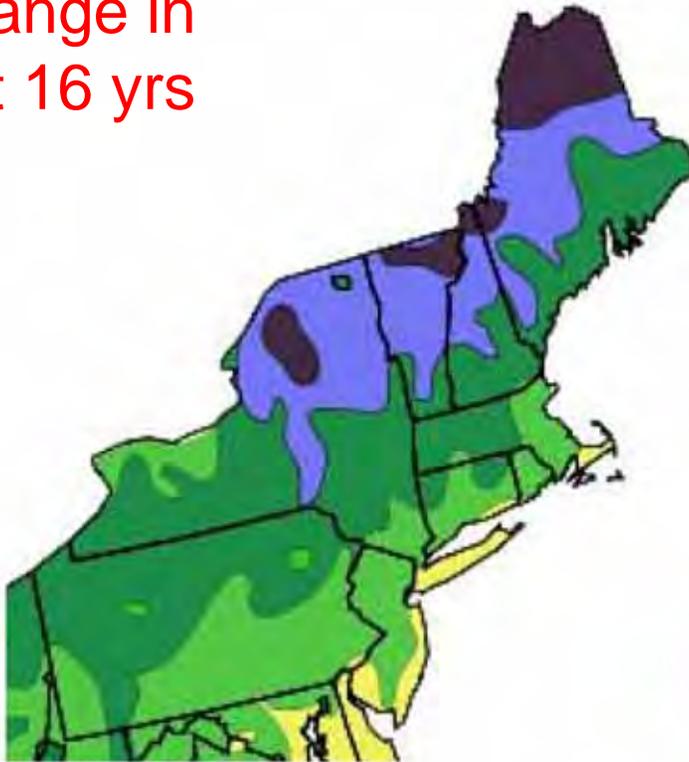
# Vermont temperature trends

- summer +0.4F/decade
- winter +0.9F/decade
- Less snow drives larger winter warming

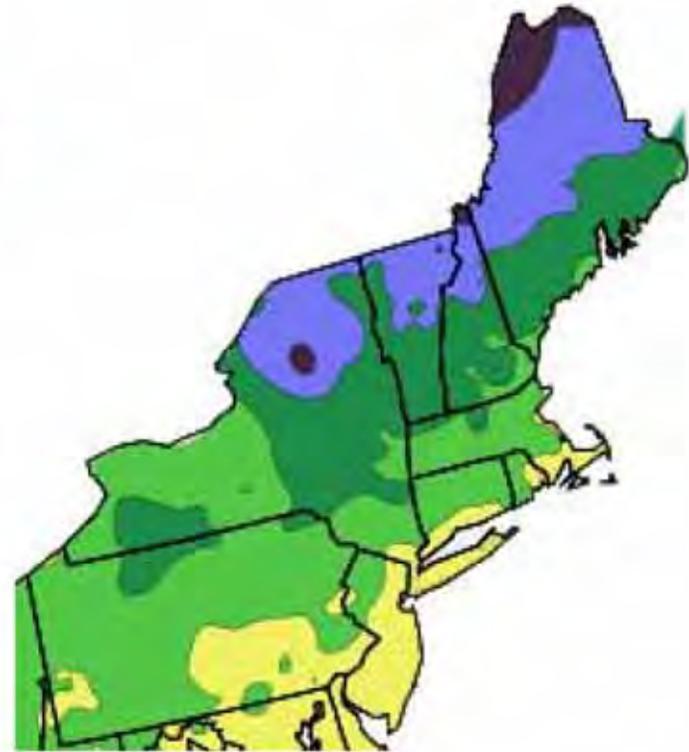


# USDA Hardiness Zones - Northeast

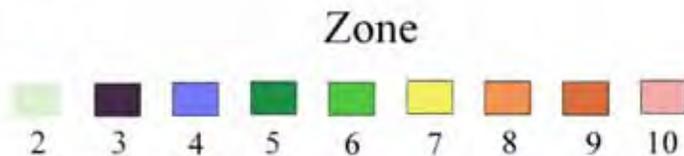
Change in  
last 16 yrs



1990



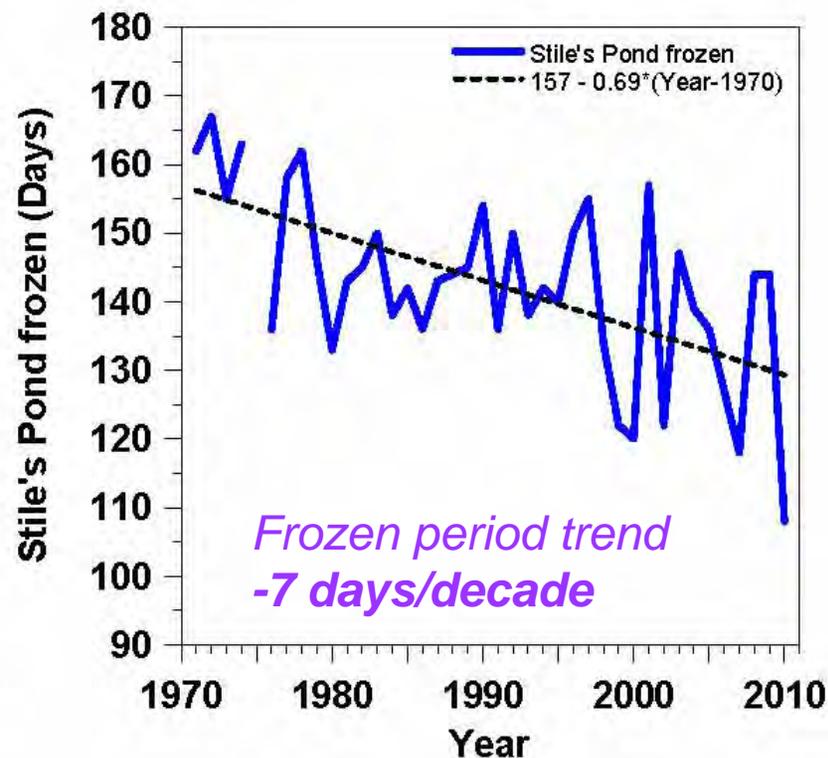
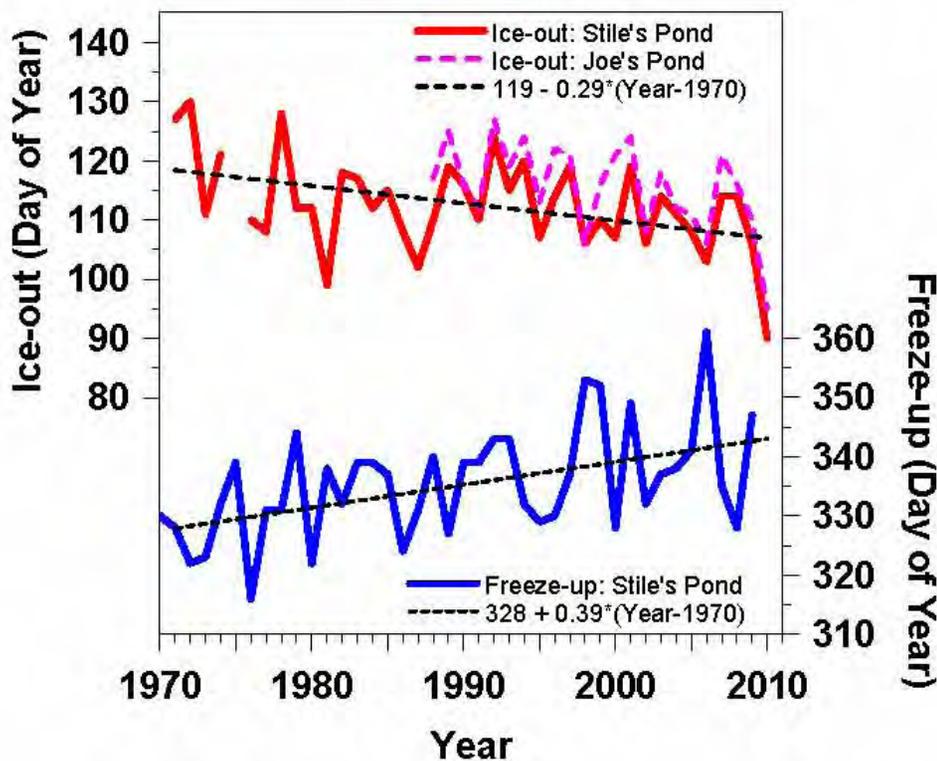
2006



USDA Hardiness Zones

# Lake freeze-up & Ice-out changing

– *frozen period shrinking fast*



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

# Vermont winter, 2006



- Sun is low; and snow reflects sunlight, except where trees!
- Sunlight reflected, stays colder; little evaporation, clear sky

# Gardening in Pittsford, VT in January



Jan 7, 2007

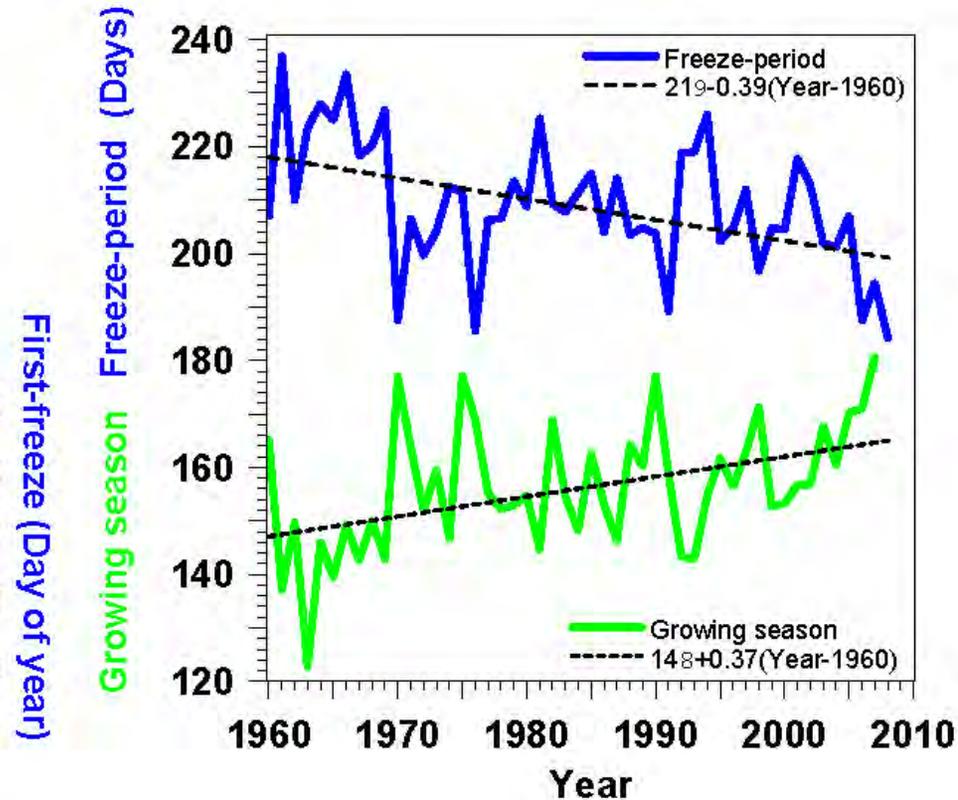
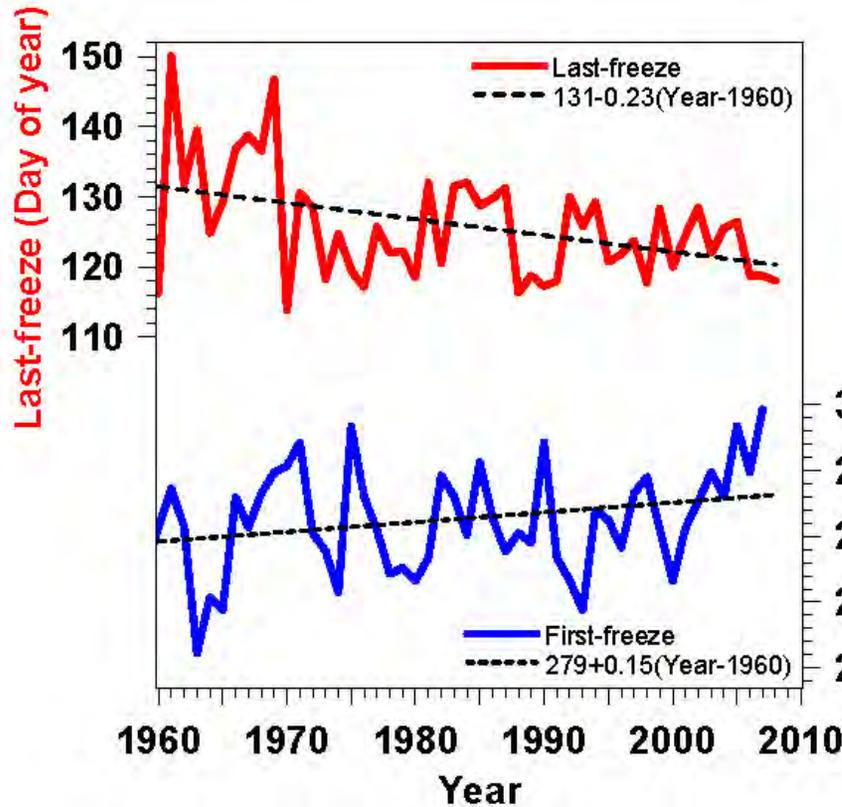
December, 2006, *warmest on record*  
[since 1894]



Jan 10, 2008

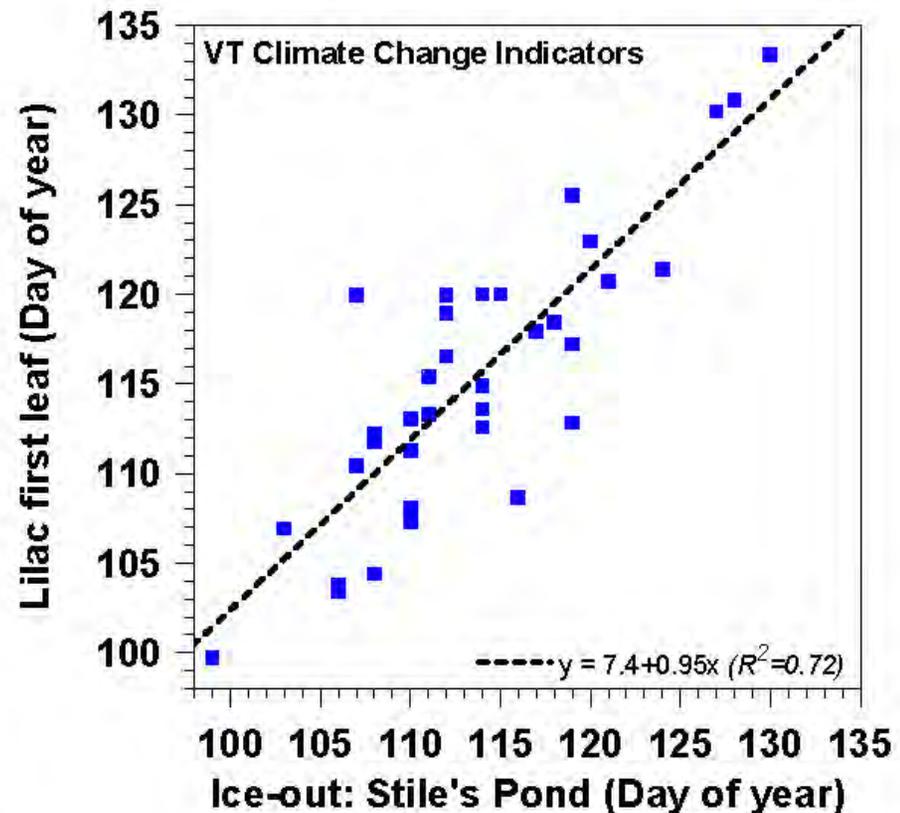
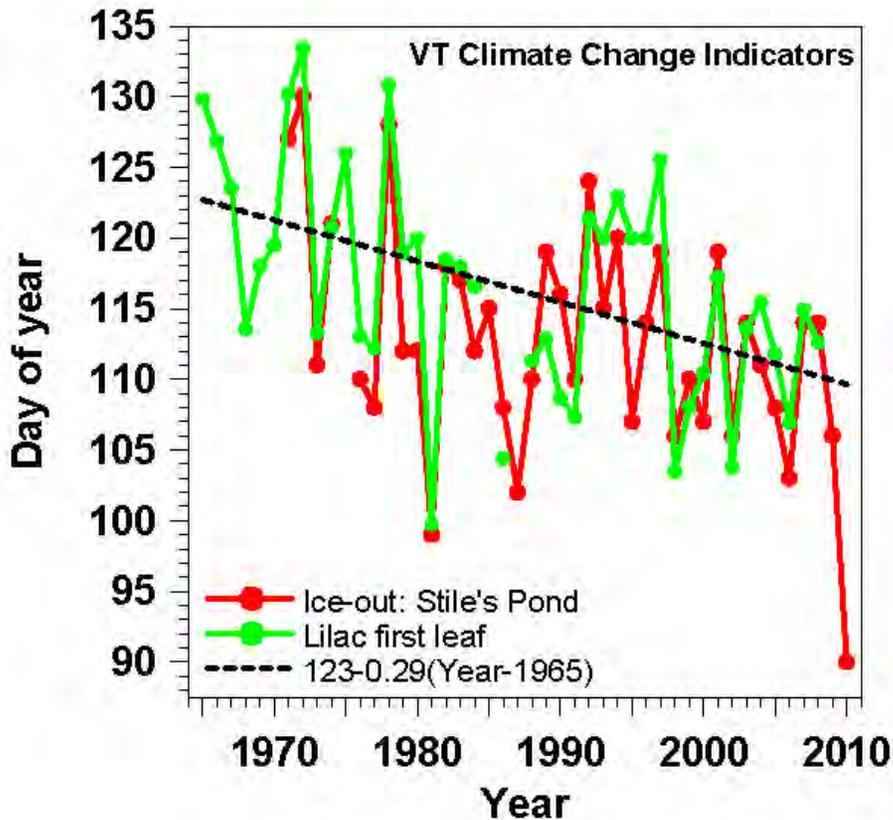
Warm Fall, *record Arctic sea-ice melt*  
Snow cover in December, ground unfrozen

# First & last frosts changing



- *Growing season for frost sensitive plants increasing 3.7 days/decade*

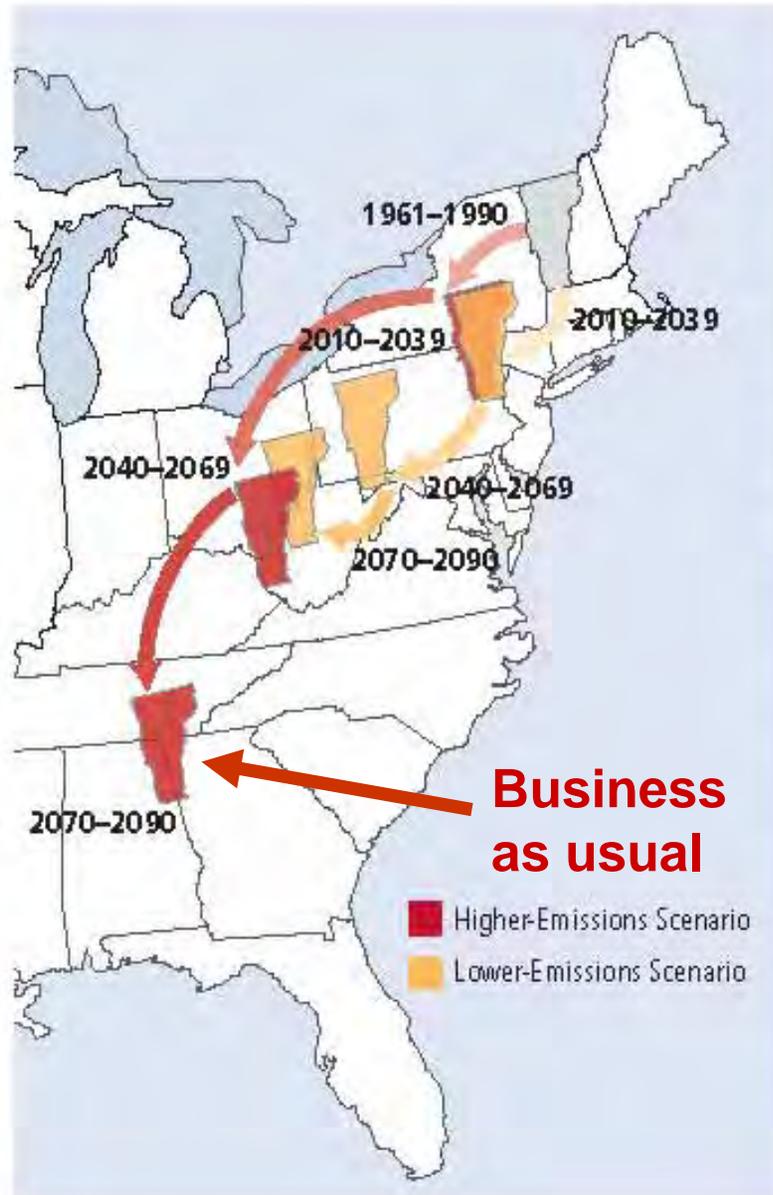
# Lilac leaf-out and Ice-out coupled



- *Lilac leaf and lake ice-out depend on same Feb. Mar. and April temperatures*
- *Earlier spring*

# Vermont's future with **high** and **low** GHG emissions

*Summer  
Change*



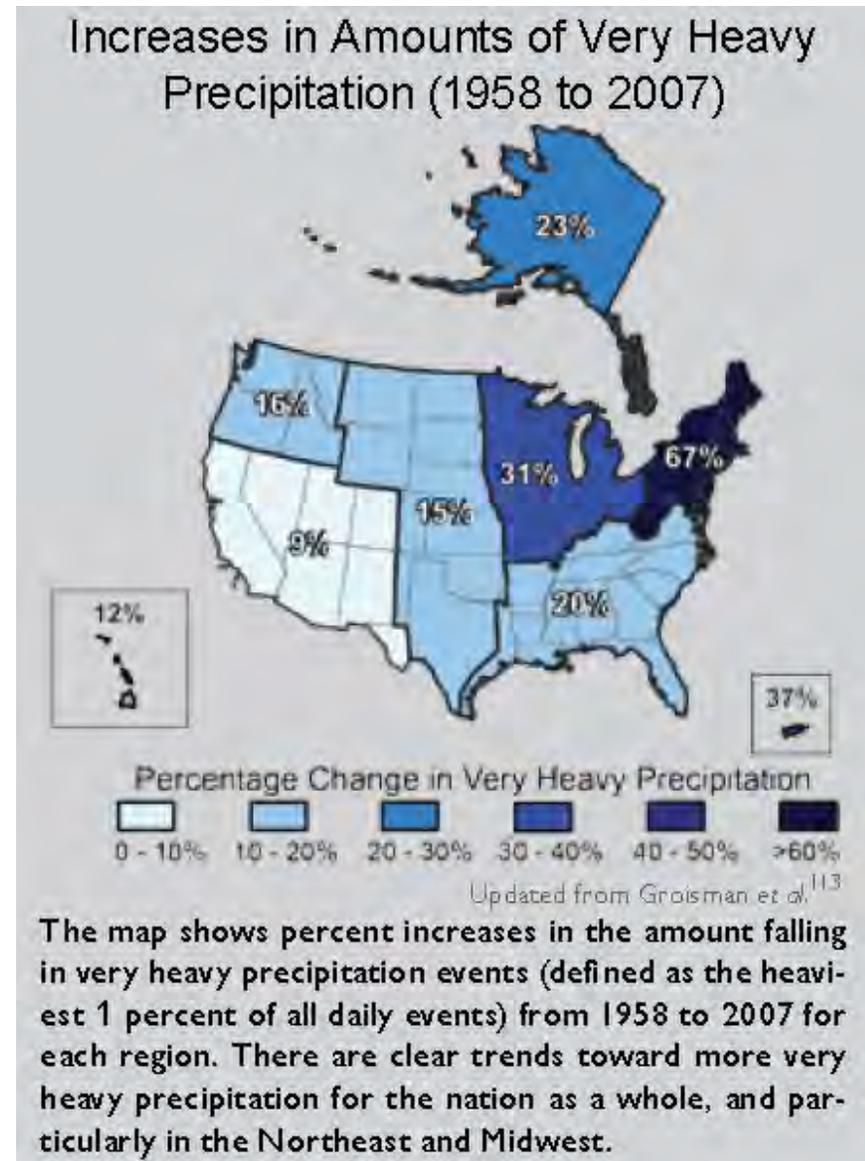
## Migrating State Climate

Changes in average summer heat index—a measure of how hot it actually feels, given temperature and humidity—could strongly affect quality of life in the future for residents of Vermont. Red arrows track what summers in Vermont could feel like over the course of the century under the higher-emissions scenario. Yellow arrows track what summers in the state could feel like under the lower-emissions scenario.

*NECIA, 2007*

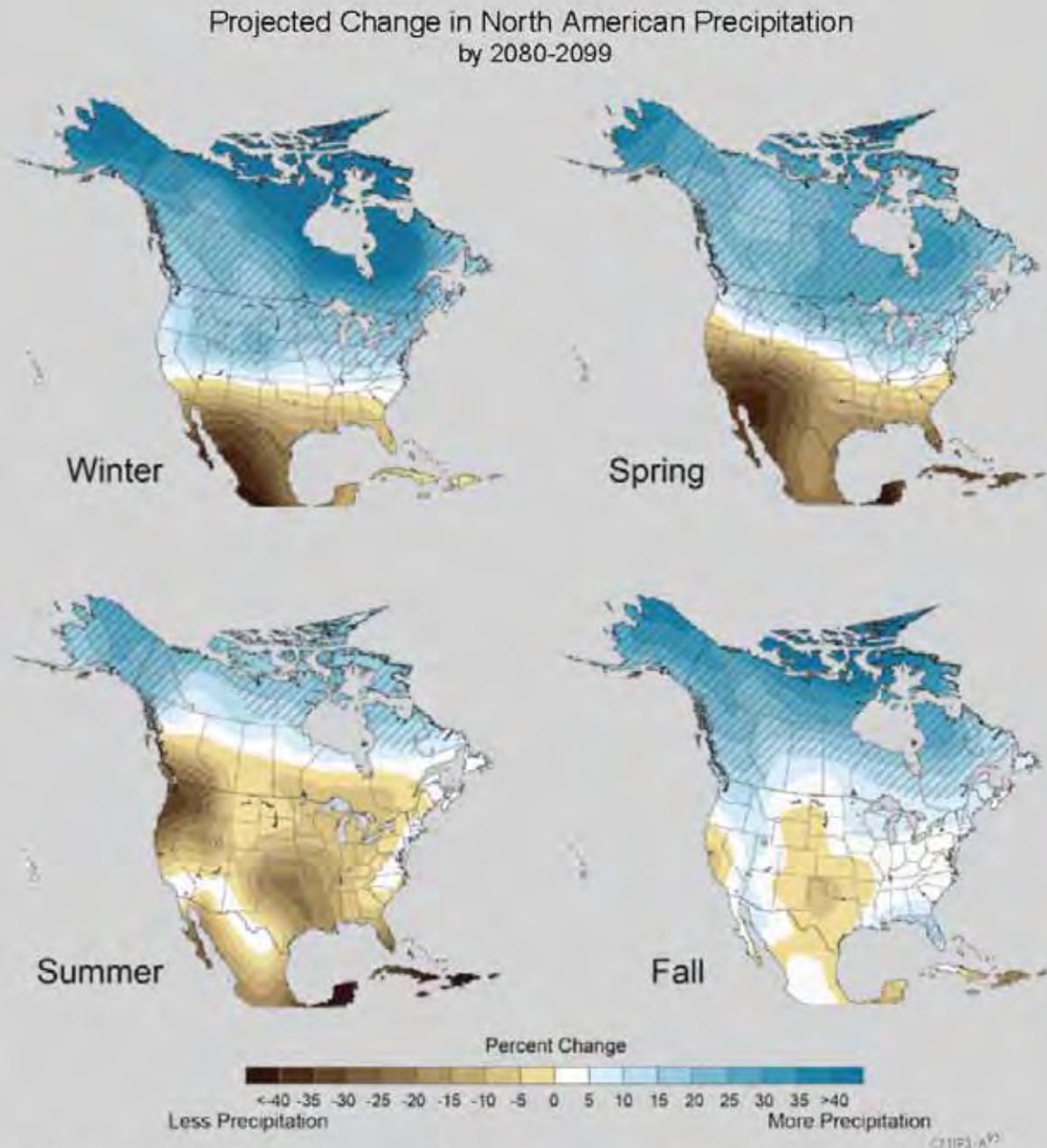
# Very heavy precipitation is increasing

- 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

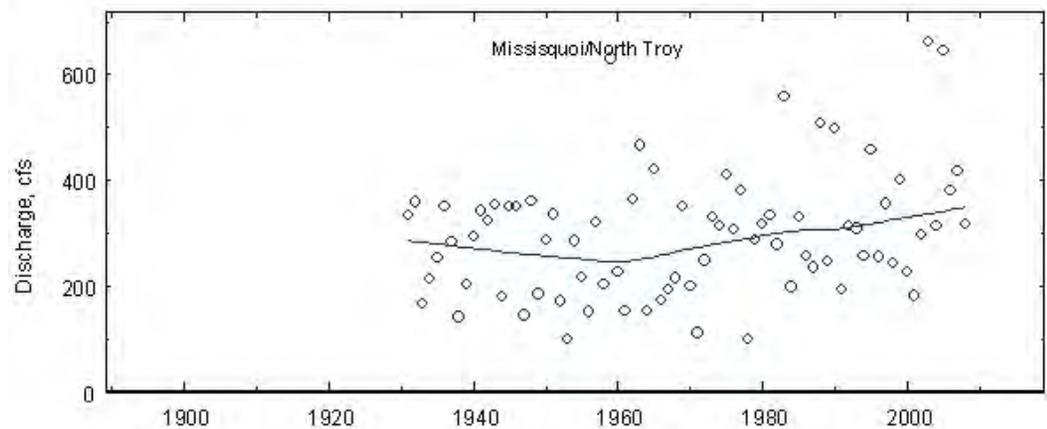
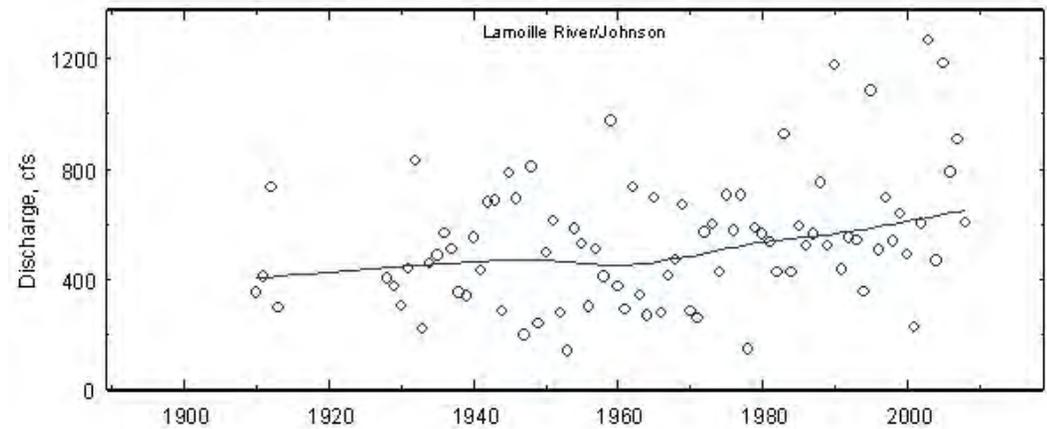
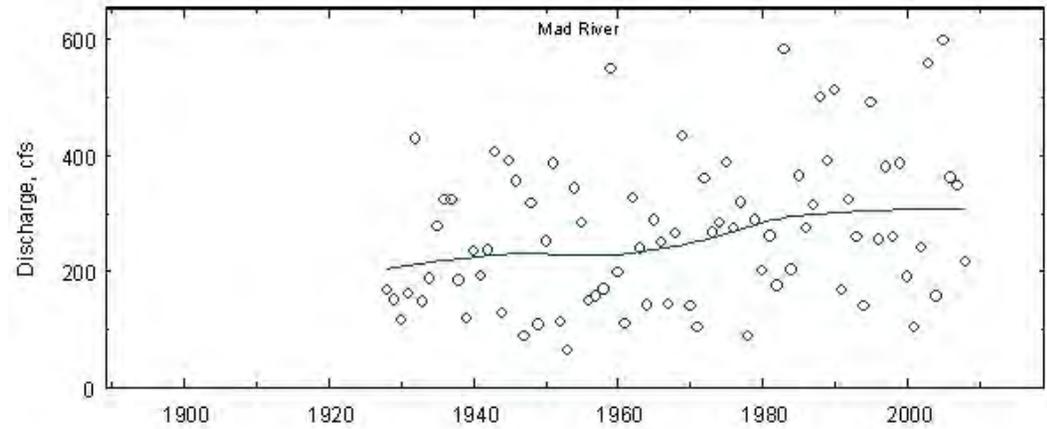
- *For Vermont*
- 15% in winter,
- 10% in spring
- 5% in fall
- no change, summer
  
- Heavier rain and more drought



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.<sup>11</sup> 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.

# VT streamflow

- *Mad, Lamoille and Missisquoi*
- 35-40% increase in November streamflow since 1960



# Can we stop dangerous climate change?

- Yes – Quickly stabilize atmospheric CO<sub>2</sub>
- This means 80% drop in CO<sub>2</sub> emissions!
- Sequester Carbon: forests/soil uptake

# **Broad guide-lines for managing Earth**

## *Minimize human impacts*

- **Minimize lifetime of human waste in the Earth system and eliminate waste with critical biosphere interactions**
- **Minimize the use of non-renewable raw materials; maximize recycling and remanufacturing**
- **Maximize the efficiency with which our society uses energy and water, and maximize the use of renewable resources.**

# Efficiency comes first

- **Need to double or triple our energy efficiency because..**
- **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 CO<sub>2</sub> to 1000ppm [*and in time melt ice-caps*]. Can we “sequester” CO<sub>2</sub> [put it back in the earth]?**

# 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**  
*[US constitution gives no rights to the Earth]*
- **That respect Earth system processes & limits**

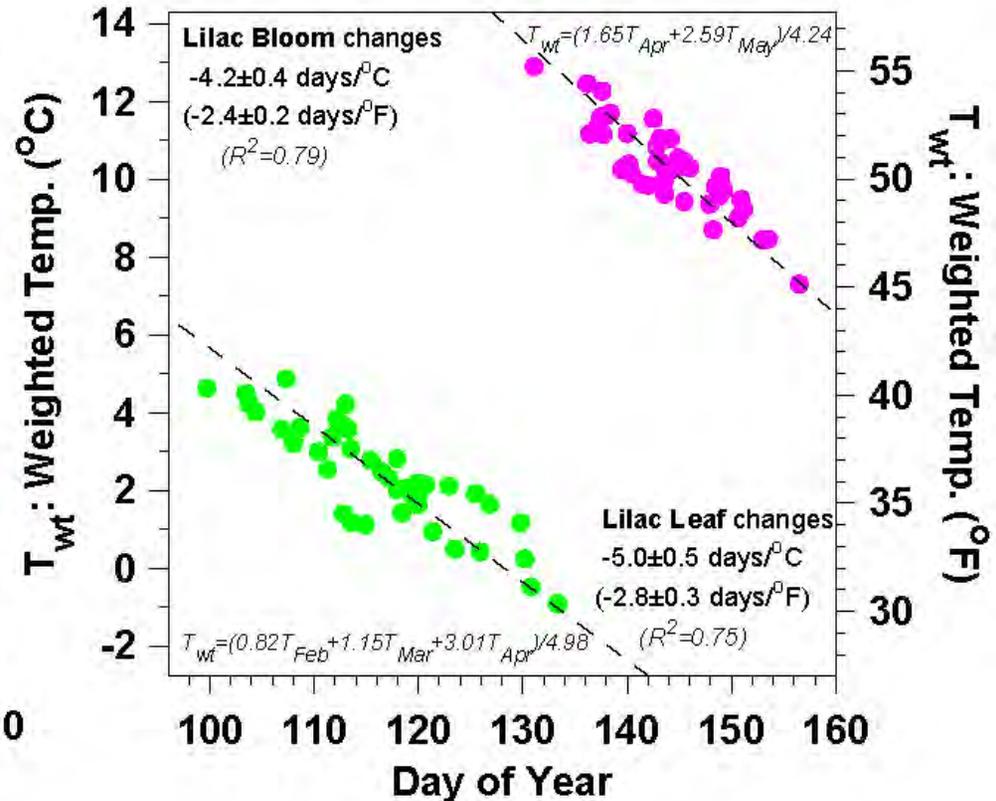
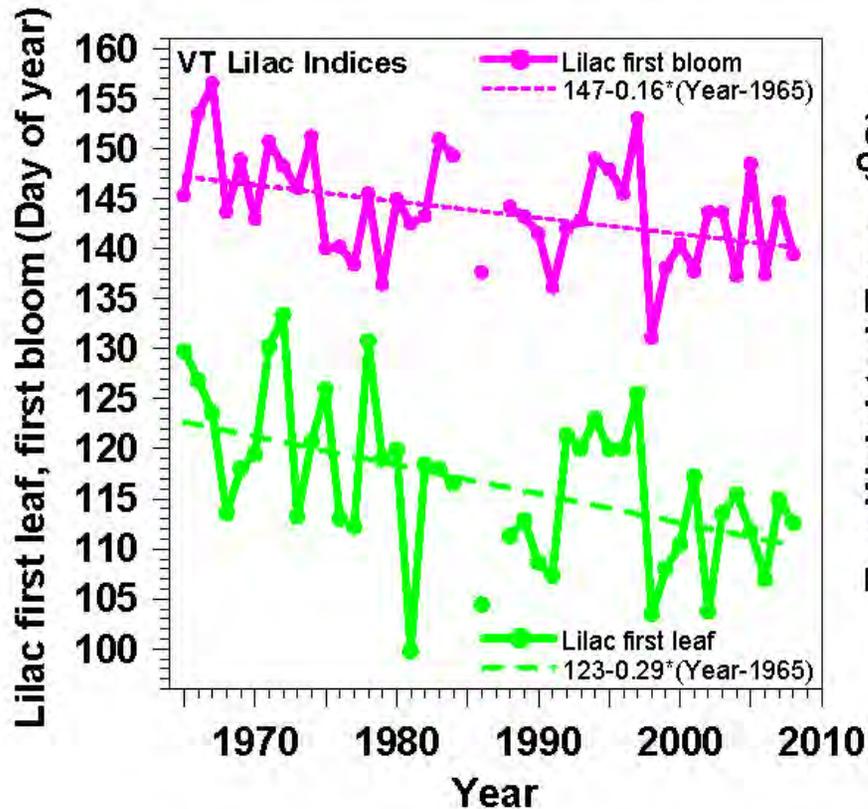
# Why is it difficult for us?

- *Three pillars of American dream are crumbling*
- “Economic growth” based on **fossil fuels, debt and consumerism** is **unsustainable**
  - and a disaster for the planet!
- **Individual “rights”** & 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 result is tremendous successes and catastrophic failures

# 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, controllable, except when we are careless.*
- 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* *[E. F. Schumacher, 1977]*
- *Now our world of technology is having a global impact on the natural world and it must be heavily managed – but this is incompatible with our ideology.*

# Lilac leaf and bloom in spring

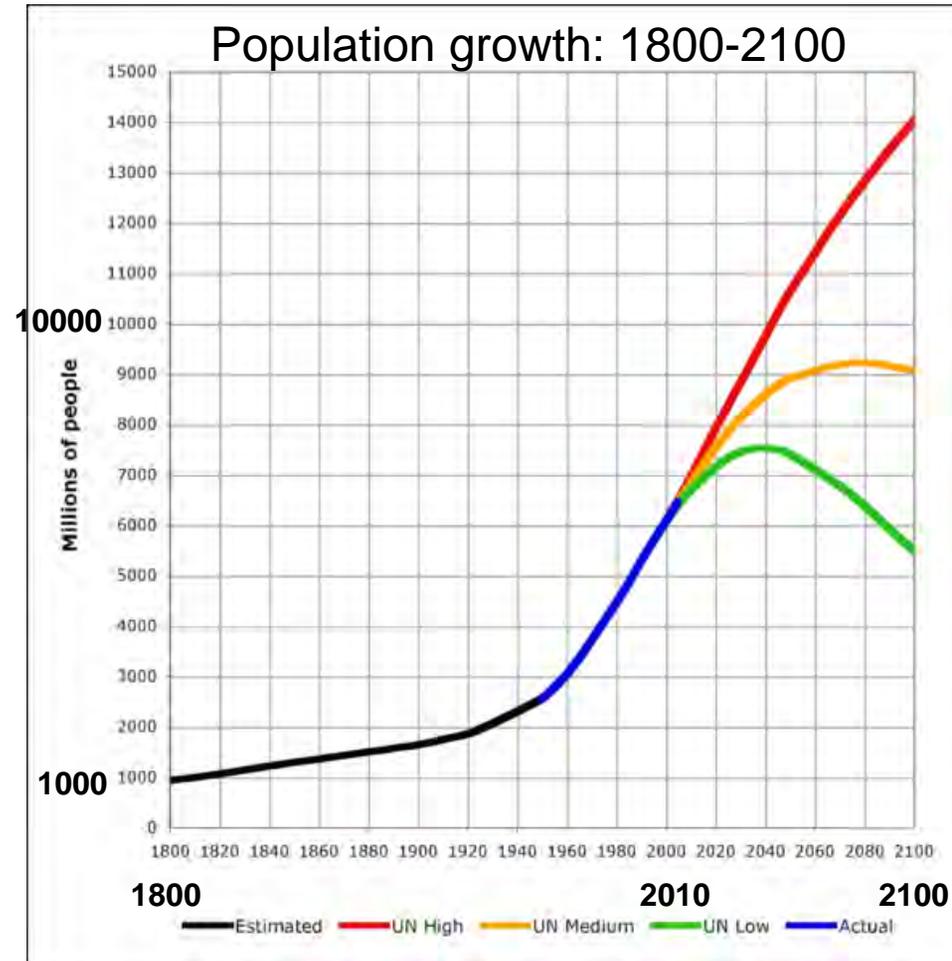


- Leaf-out trend: 3 days/decade
- Bloom trend: 1.5 days/decade
- Leaf & bloom date: 2-3 days/degF

# We passed the carrying capacity of the Earth in the 1980s



- **The problem with “Growth”**
- **Population is still rising**
- **Consumption is still rising**
- **Fossil fuel use is still rising**
- *We still ‘believe’ in Growth*
- *Global poverty & suffering are still growing: the future looks bleak for billions*
- *In a finite world, growth leads to overshoot & collapse*



# How do we avoid 'Dangerous Climate Change'?

## Emissions Paths to Stabilisation [Stern, 2006]

