Climate Change and Vermont

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Climate Change

- **One of the great challenges for 21st C**
- **We are already decades late in taking action**

  - *Sawyer (1972): Man-made CO_2 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

- **Perspective of Earth system scientist**

  - Managing Earth system: technical solutions

  - Choices, challenges and self-deception

My background:
Peterhouse Cambridge

- Peterhouse, Cambridge: founded 1284

- *Medieval warm period; Vinland colony flourishes*

- ***What are our colleges for?***

My background:

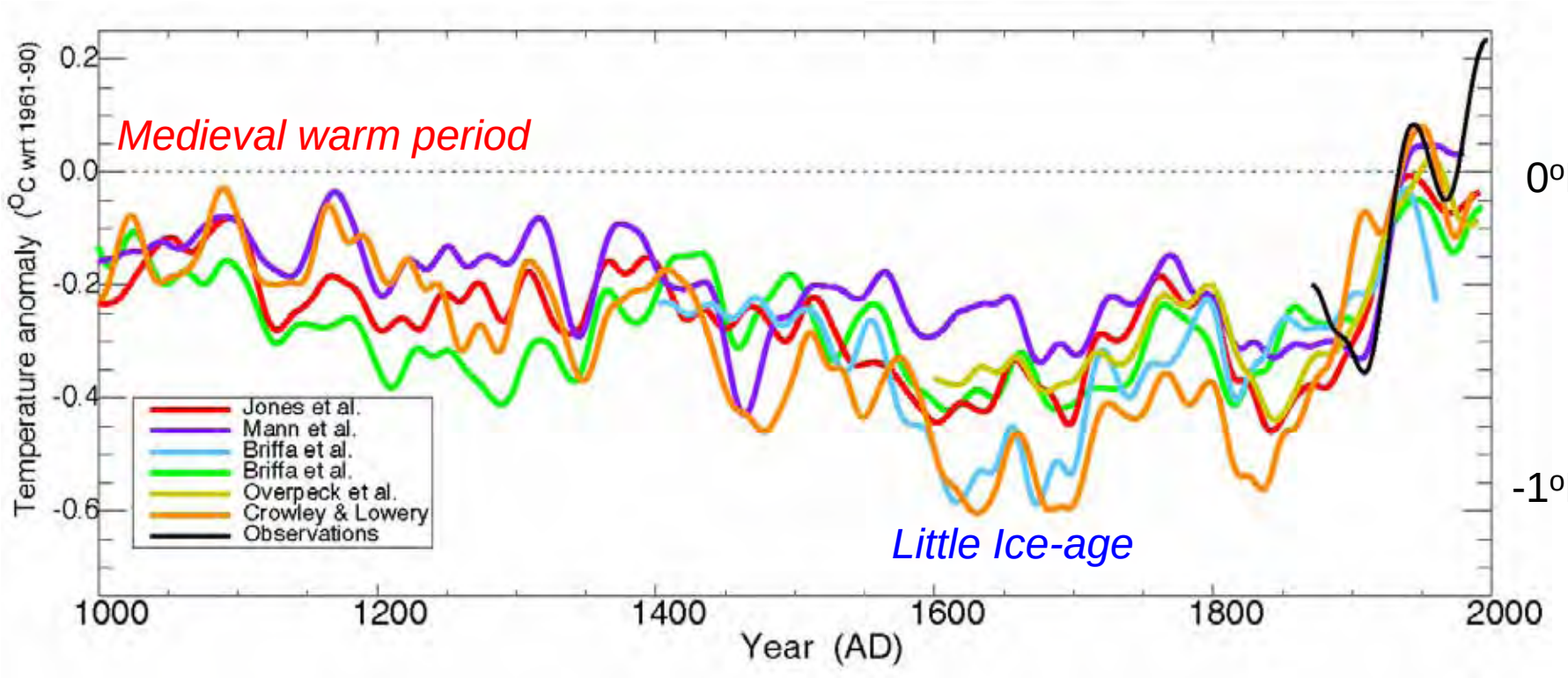
Nottingham High School

- Founded 1513

- *1550 heading into ‘little ice-age’*
- *1620 Pilgrim fathers face bitter winters*

2100: +5°F

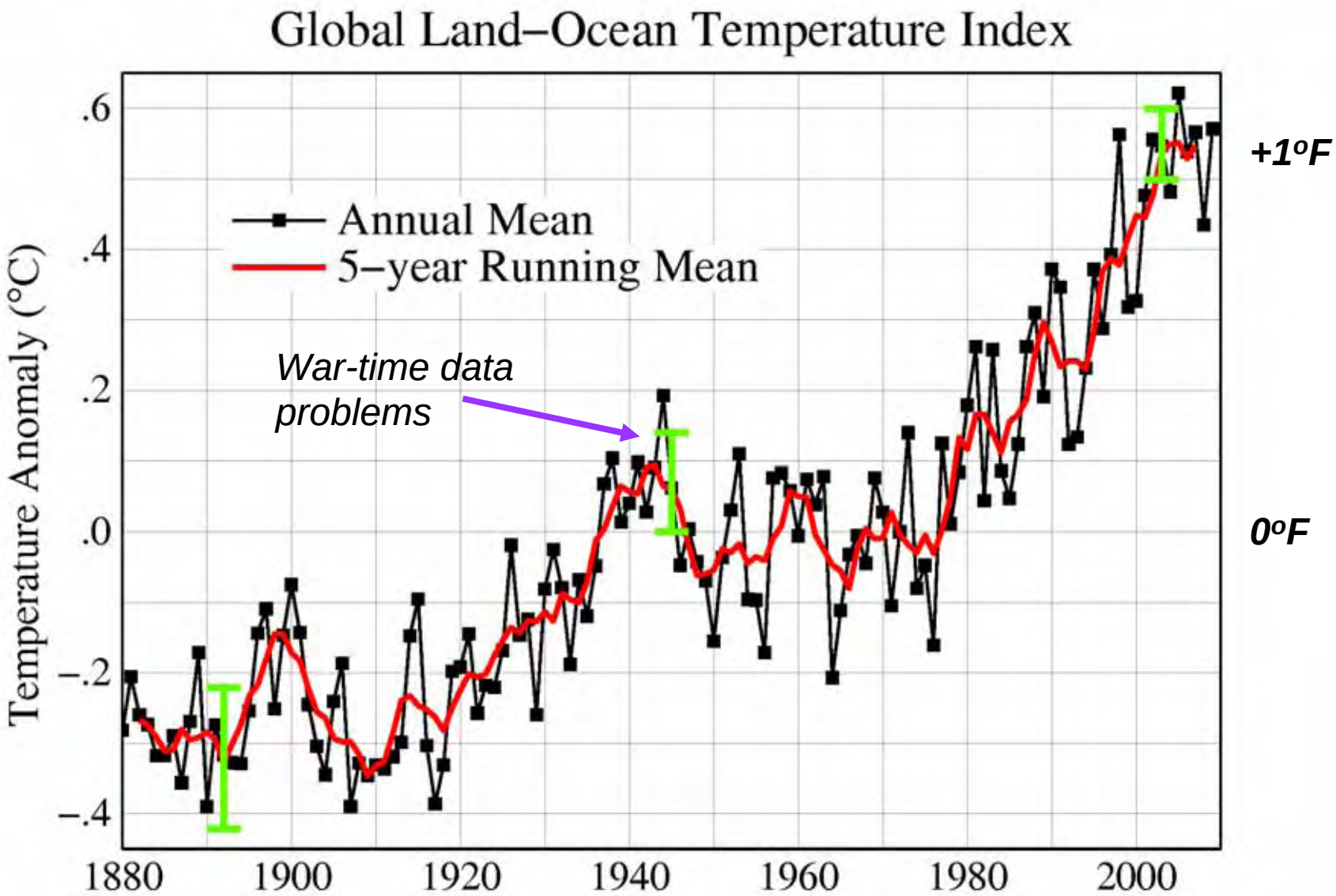
Millennial Temperature Record



- Before thermometers
  'proxy' records have large uncertainty

Global temperature rise 1880-present

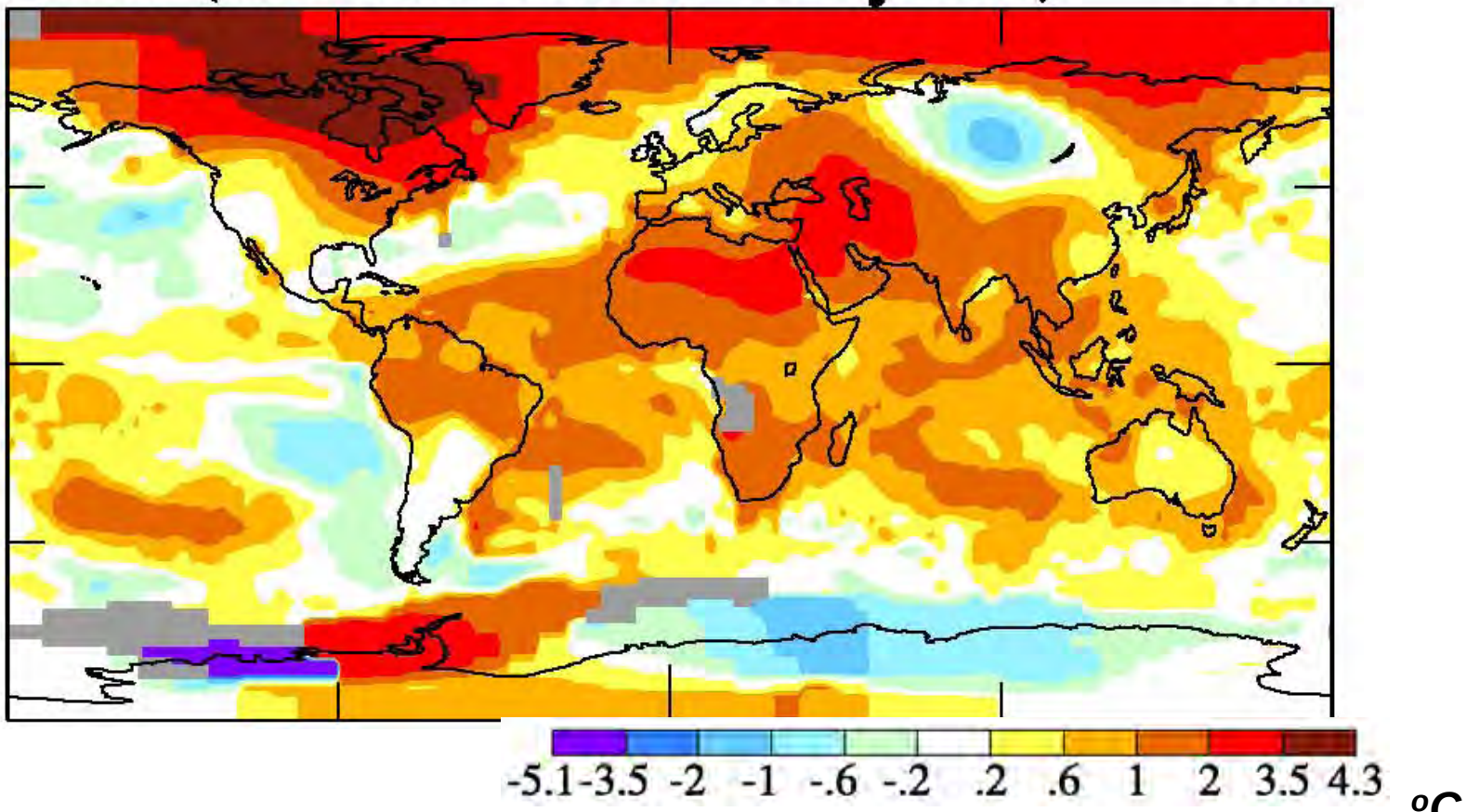
2100: +5°F



NASA-GISS, 2010

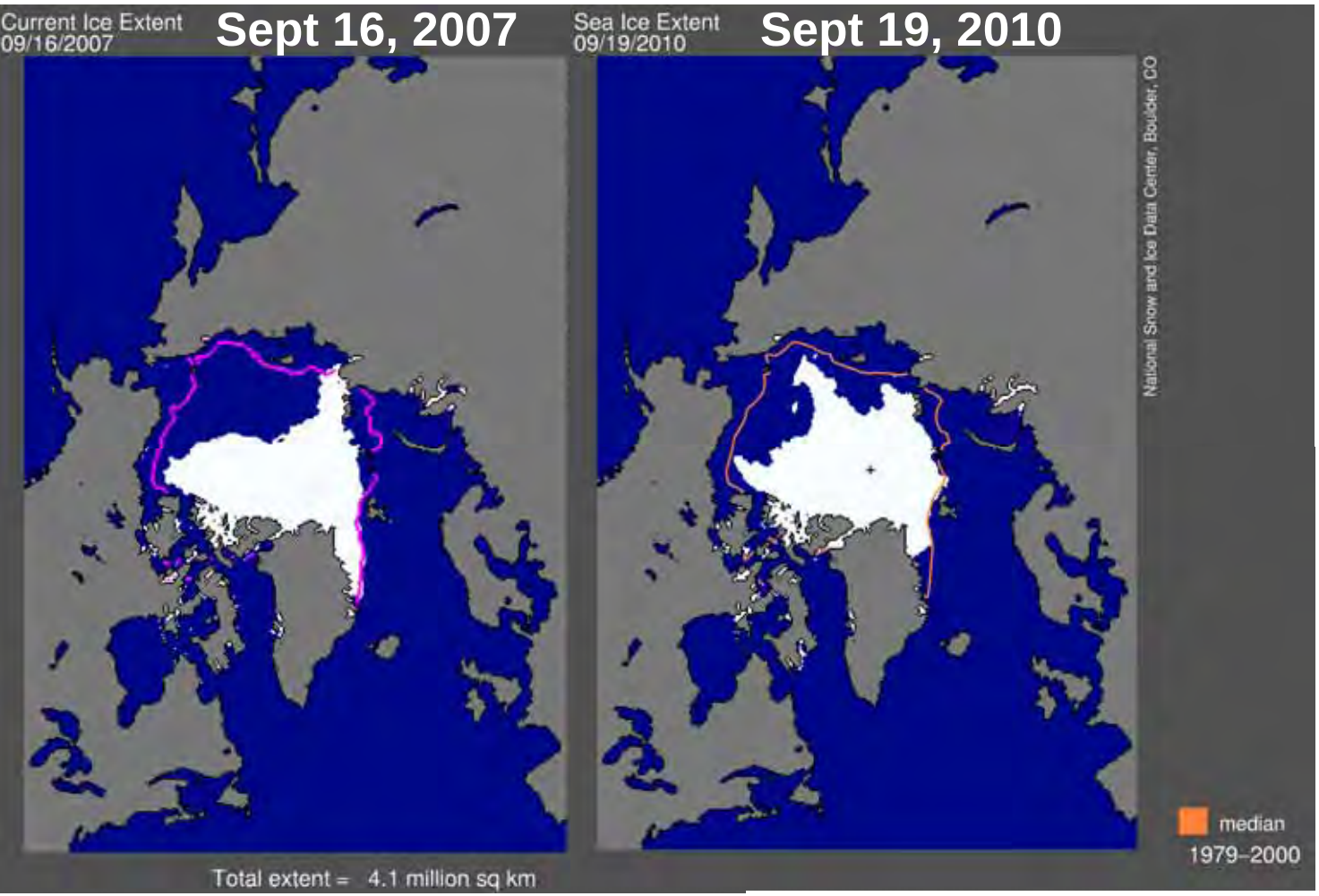
Global picture Jan-Aug 2010

2010 (the warmest of 131 years) 0.67 ºC(1.2F)



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

Arctic sea-ice loss has accelerated



Feedbacks - speed melting

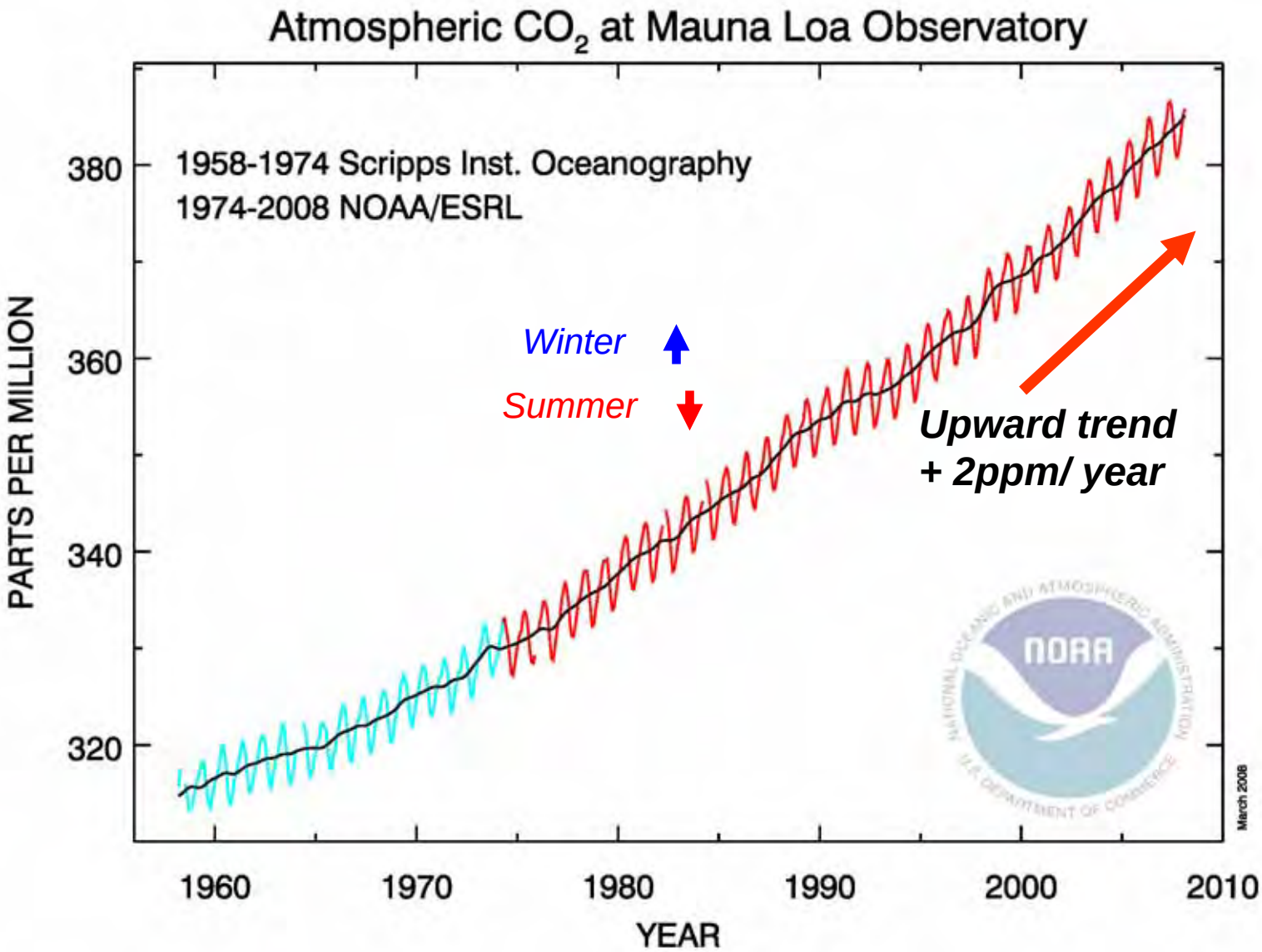
-less ice, less sunlight reflected

-more evaporation, larger water vapor greenhouse

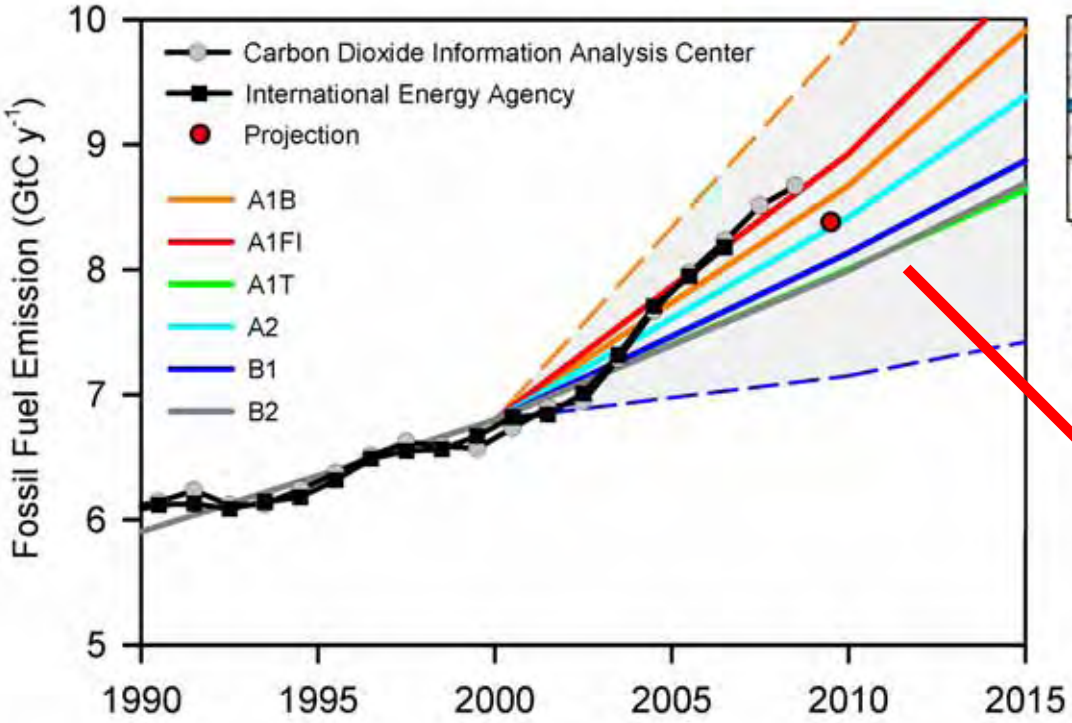
(www.nsidc.org)

- 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

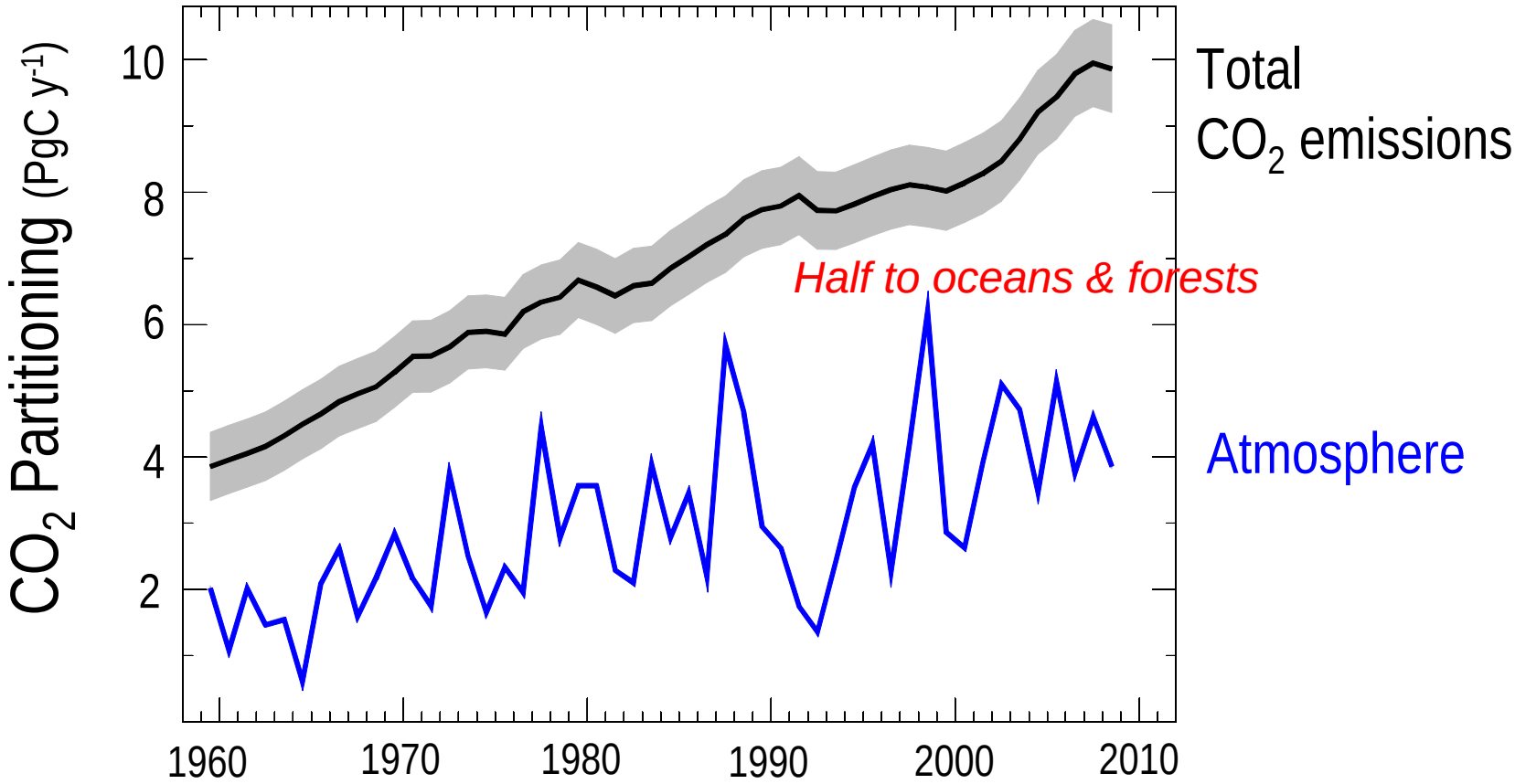
Raupach et al. 2007, PNAS, updated; Le Quéré et al. 2009, Nature Geoscience; International Monetary Fund 2009

Need 80% drop by 2050

- 2009 was 'good' for the Earth

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_2 from atmos., and many centuries from the oceans

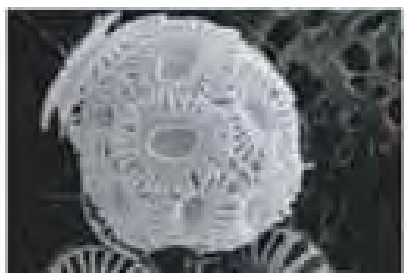
Data: NOAA, CDIAC; Le Quéré et al. 2009, Nature Geoscience

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_2 a problem?

- **Atmosphere is transparent to 'light' from sun but not to 'infrared' radiation from earth**
- Greenhouse gases: H_2O, CO_2, CH_4, HCFCs…
  - trap the earth's heat
- **CO_2 alone has a small effect, BUT**
- 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 high lats, because less sunlight is reflected

- **Doubling CO_2 will warm Earth about 3C (5F)**

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

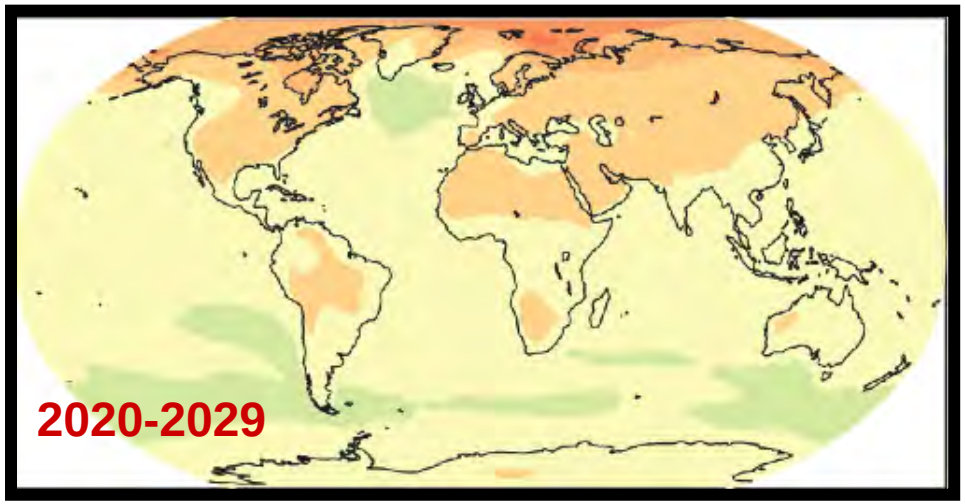
[www.ipcc.ch]

Decrease in:

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

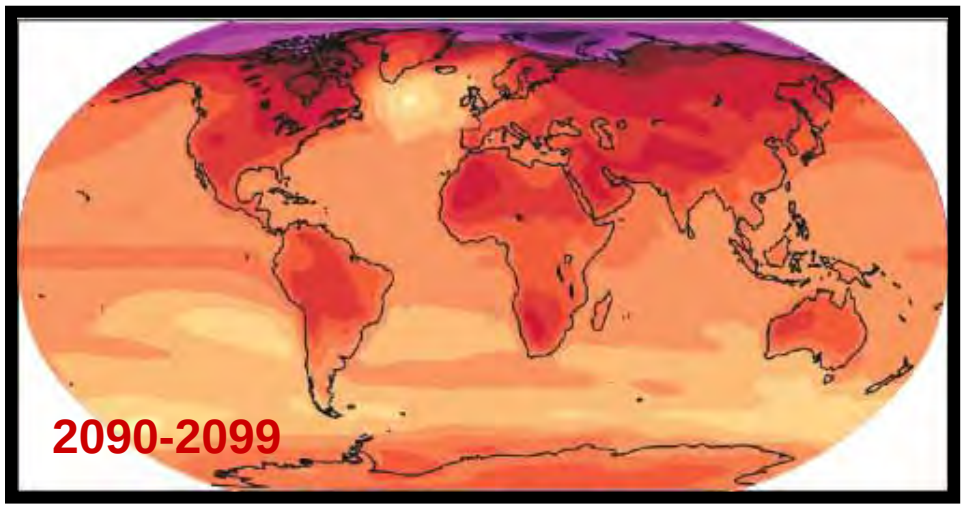
Multi-model Predicted Percent Change in Temperature (2020-2029 and 2090-2090 relative to 1980-1999) [^{o}C]

‘Committed’

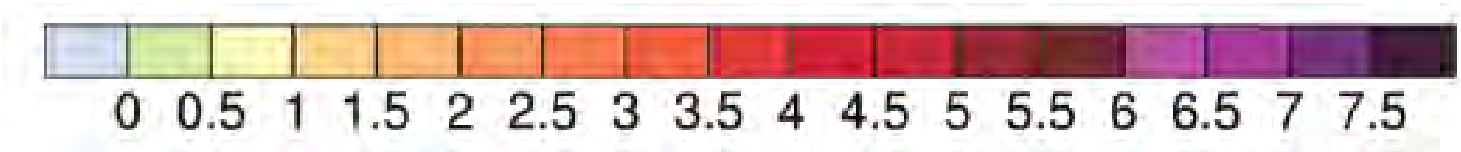


(We did nothing for the last 20 years)

Still up to us!



(We could halve this if we act now)



[^{o}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 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

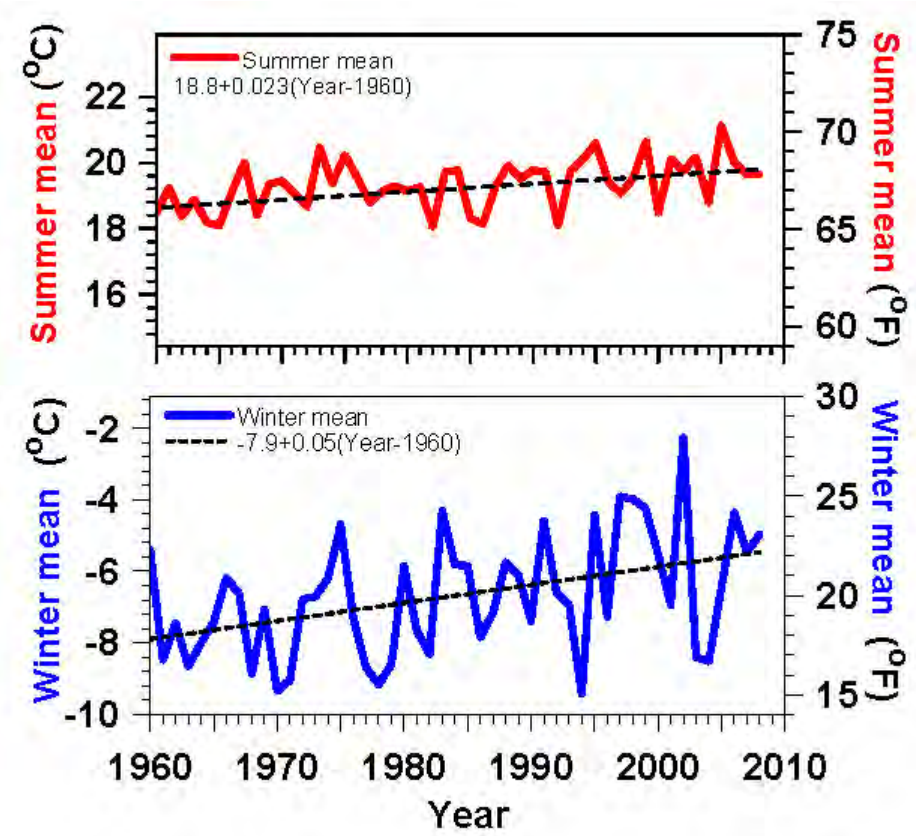
What is happening to Vermont?

- 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***

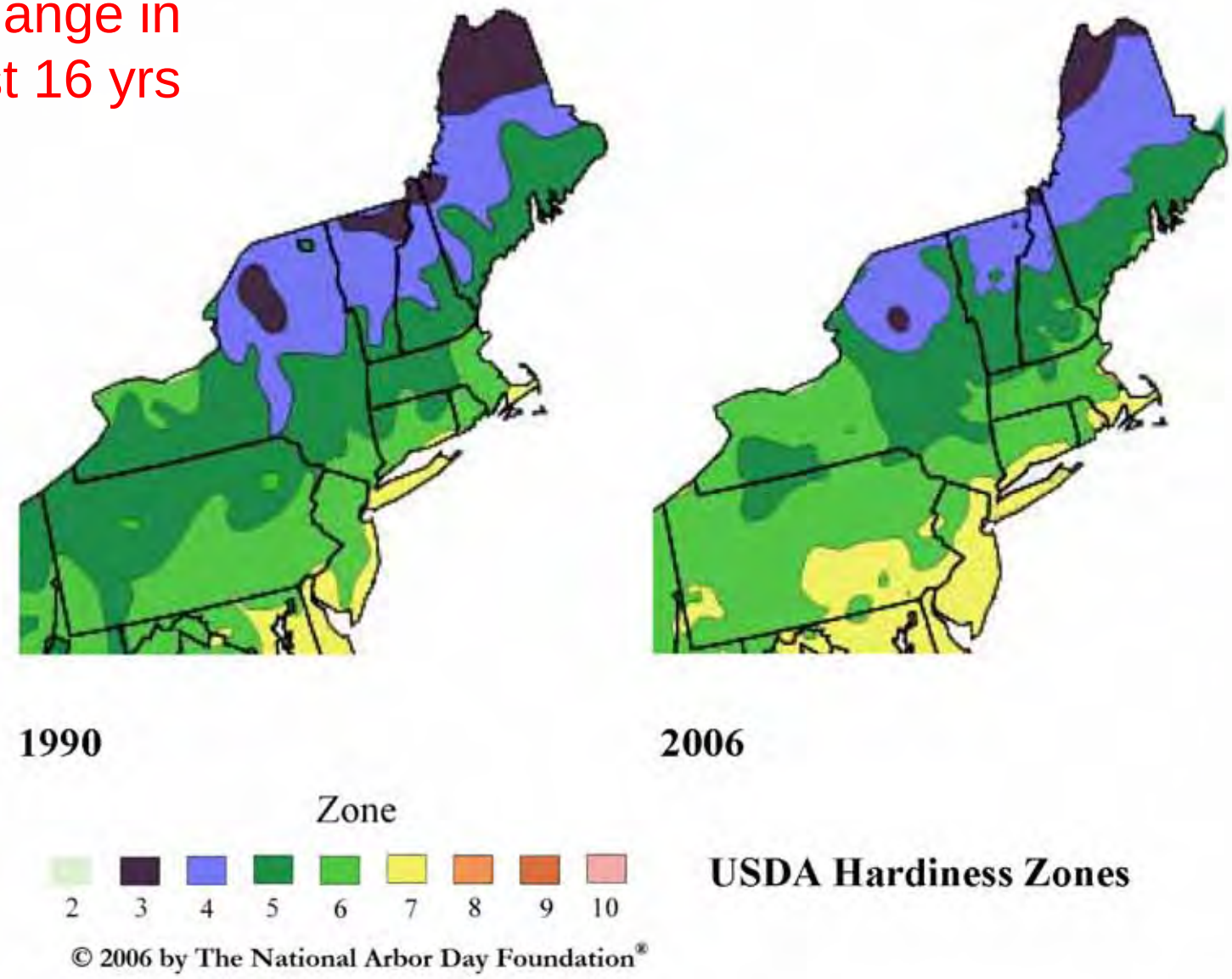
Vermont temperature trends

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

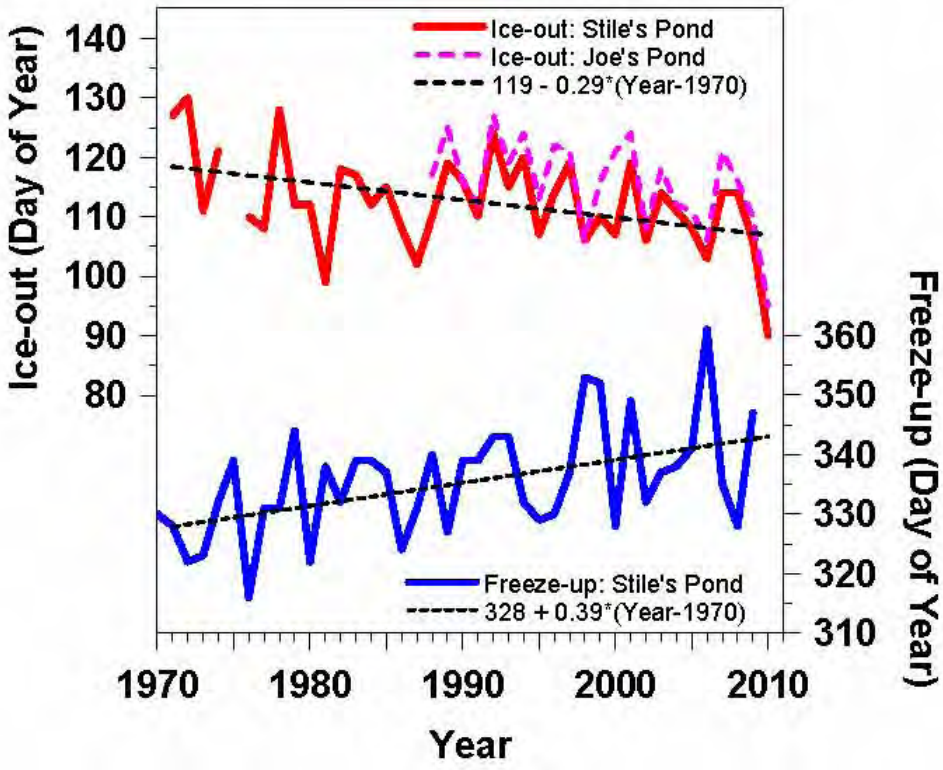


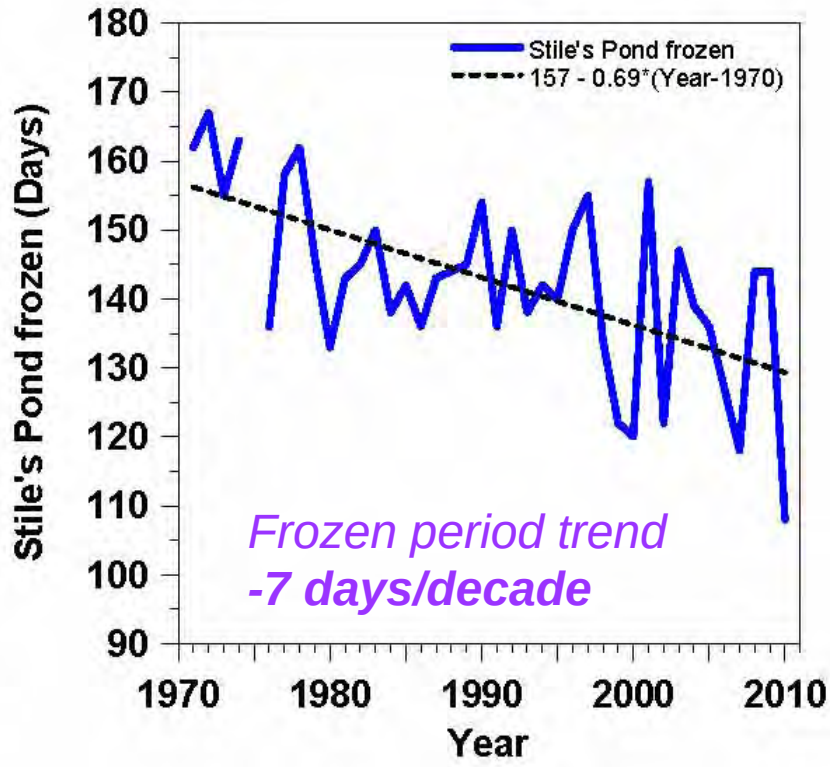
USDA Hardiness Zones - Northeast

Change in
last 16 yrs



Lake freeze-up & Ice-out changing
– *frozen period shrinking fast*





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

Gardening in Pittsford, VT in January

Jan 7, 2007

December, 2006, *warmest on record*

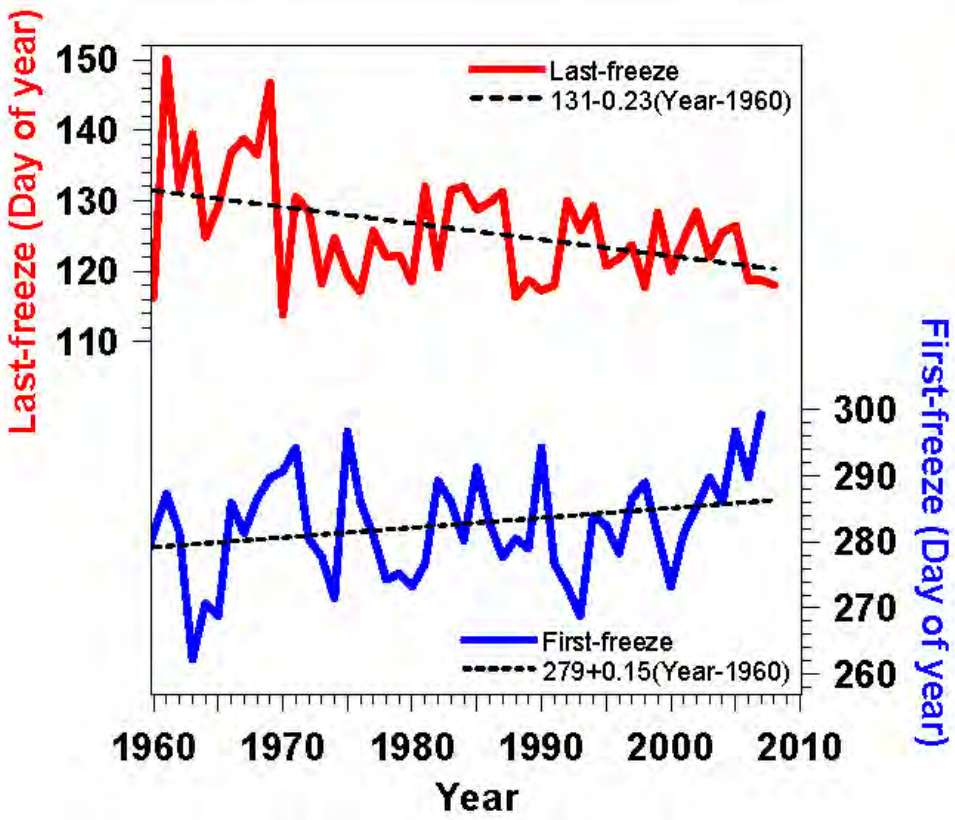
[since 1894]

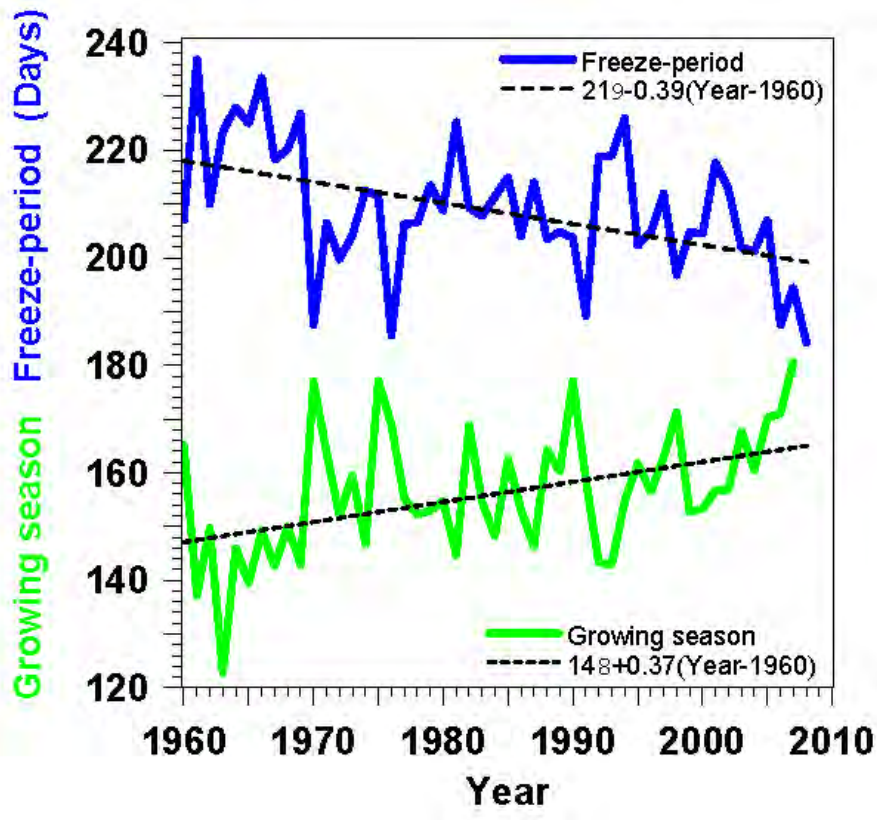
Jan 10, 2008

Warm Fall, *record Arctic sea-ice melt*

Snow cover in December, ground unfrozen

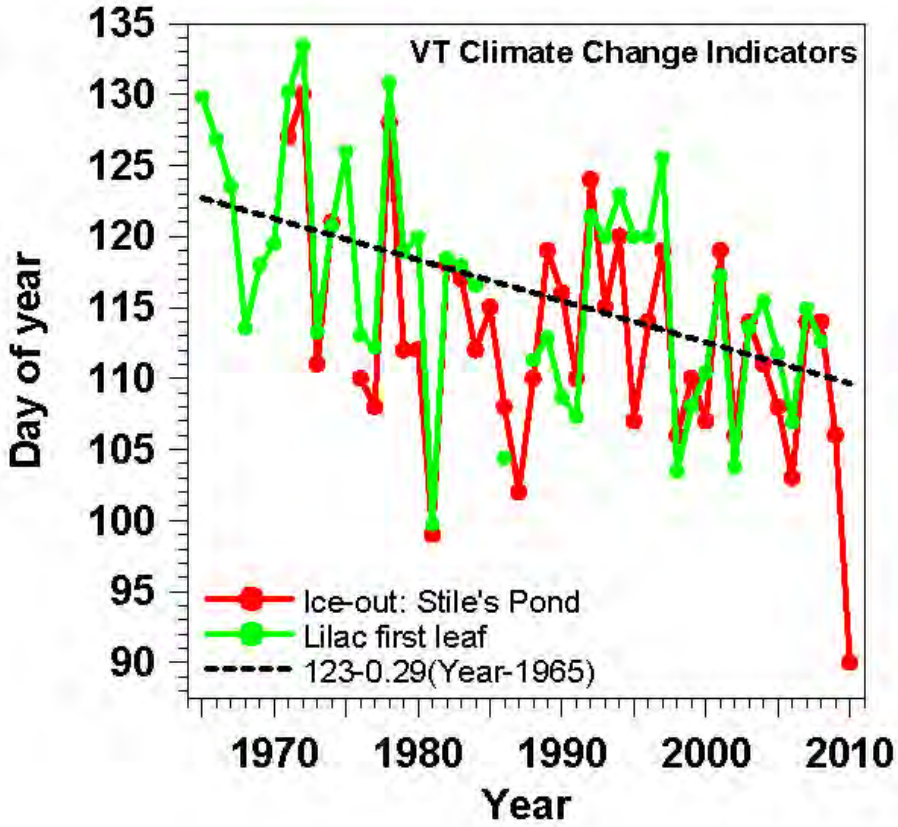
First & last frosts changing

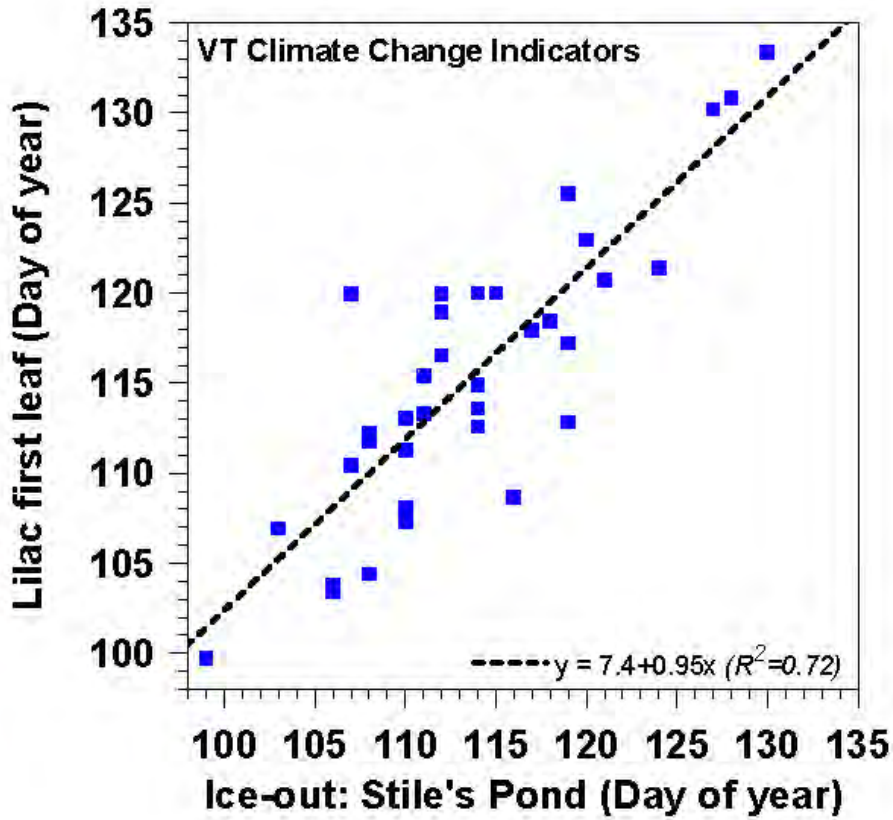




- *Growing season for frost sensitive plants increasing 3.7 days/decade*

Lilac leaf-out and Ice-out coupled





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

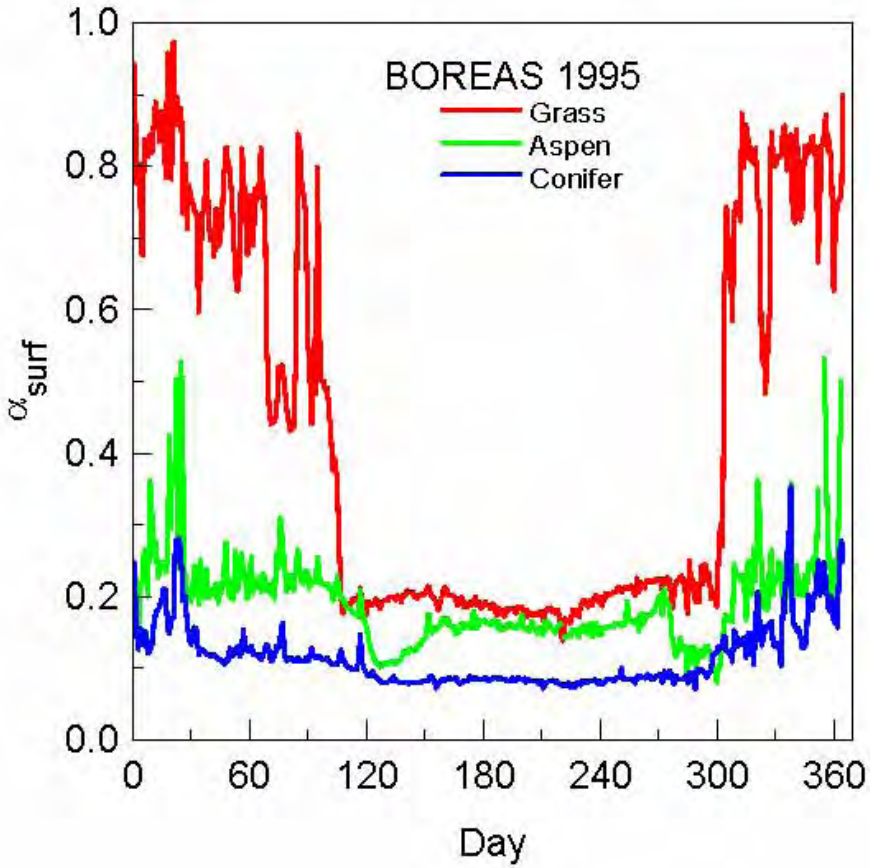
Climate transitions - Winter

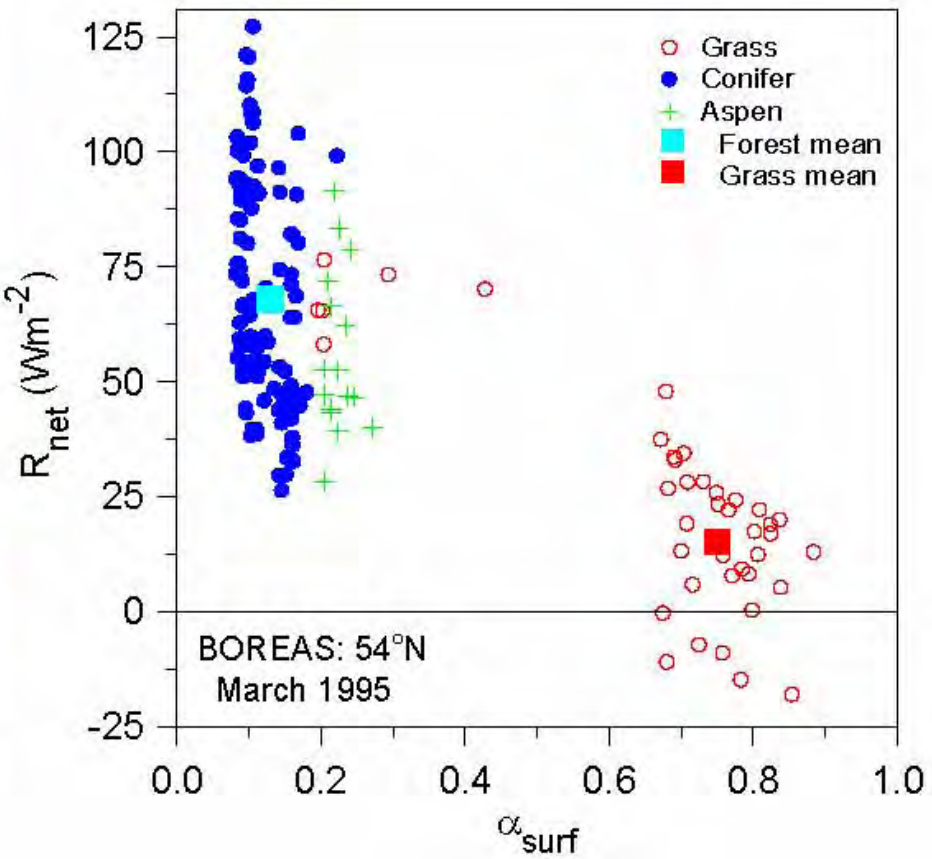
- First heavy snow brings plunge of Temp. because reflection of sunlight drops net radiation below zero –
- Related to **snow/ice-albedo feedback** in climate system

- *Sublimation of snow by residual SW_{net} reduces surface solar heating to zero [& evaporation is reduced]*

- **Coupled to water vapor greenhouse feedback:** *evaporation falls with frozen temperatures & cloud decreases. Clear sky outgoing LW_{net} increases and locks in colder temperatures*

Boreal forest example





- High albedo in March: $R_{net} \approx$ zero

Vermont winter, 2006

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

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 (DTR)
giving warm days, cool nights and frost

- **After leaf-out**

Large evaporation → Wet atmosphere, low cloudbase
→ Small outgoing LW_{net}
→ Reduced DTR, reduced T_{max}
→ Reduced chance of frost

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!

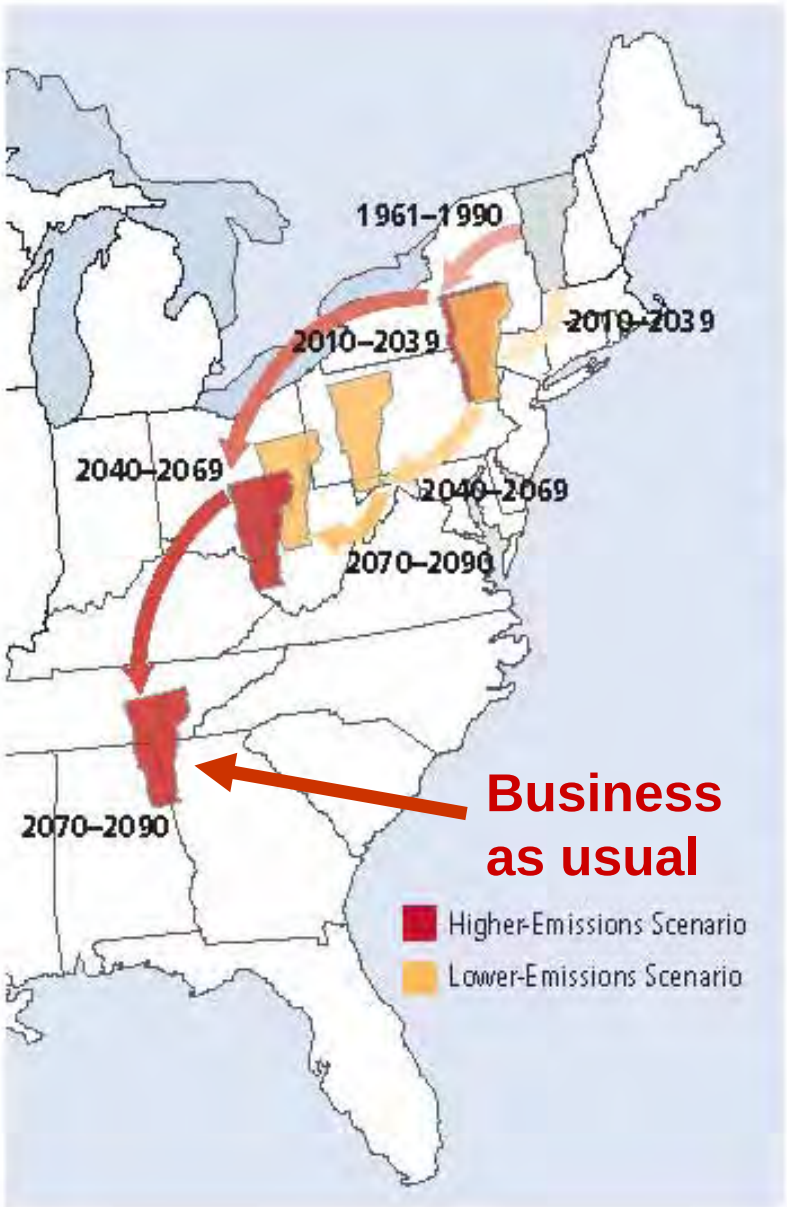
Clear dry blue sky after frost. Forest evaporation has ended and water vapor greenhouse is reduced so Earth cools fast to space at night

Growing season getting longer

Vermont's future with high and low GHG emissions

What about Skiing?

What about tropics?



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

Outline

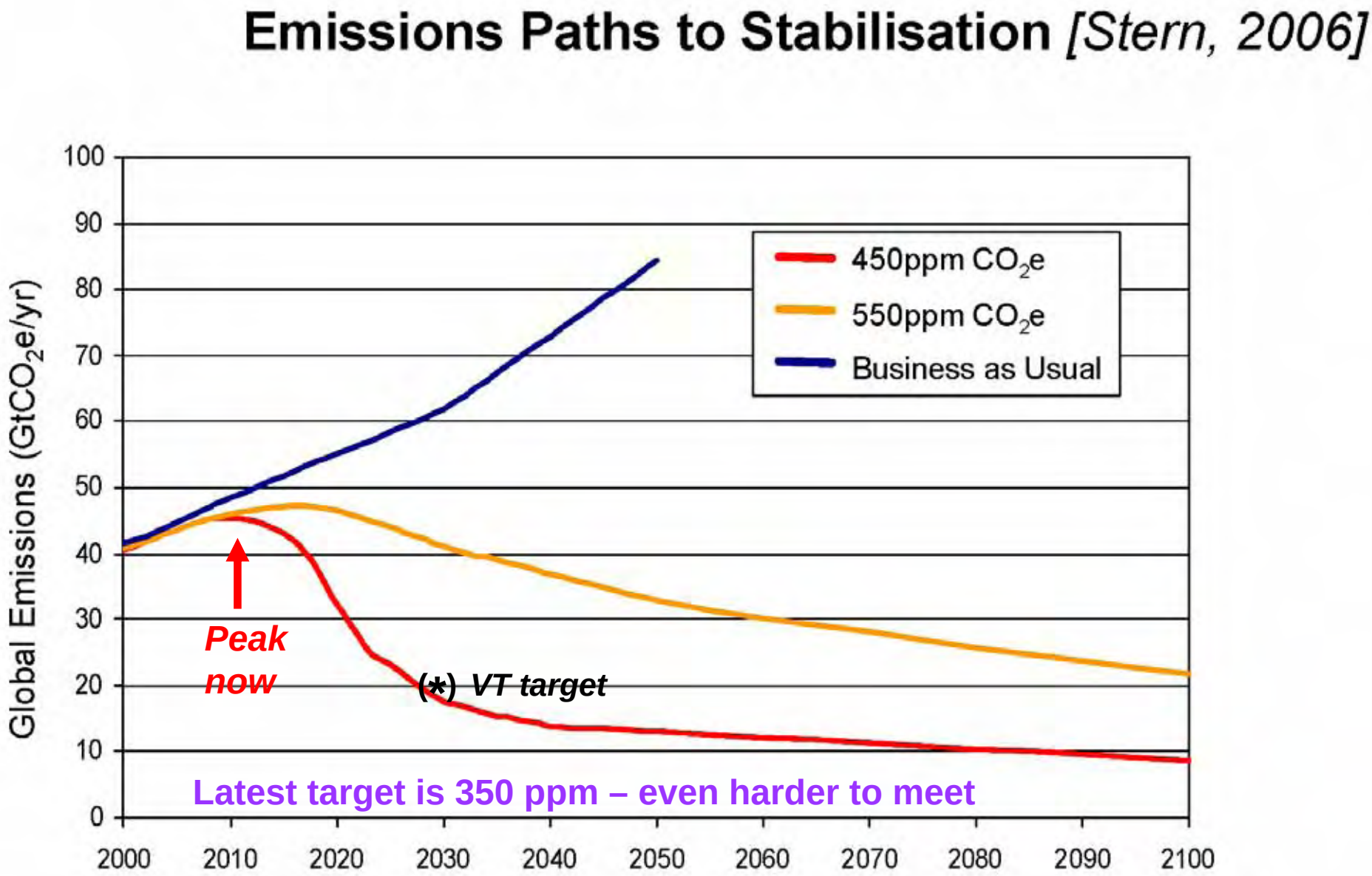
- **Science of climate change**
  - *Global scale: actual and future*
  - *Local scale*

- **Perspective of Earth system scientist**
  - *Technical solutions: managing Earth system*
  - *Choices, challenges and self-deception*

Can we stop dangerous climate change?

- Yes – Quickly stabilize atmospheric CO_2
- This means 80% drop in CO_2 emissions!

How do we avoid 'Dangerous Climate Change"?



How do we manage the Earth?

(When there is so much we don't know)

- ***Long time horizon*: generational to century**

- All *waste products* must have short lifetime in biosphere [think CFCs, CO_2, Pu-239]
- Minimize use of raw materials by *remanufacturing*
- Maximize efficiency of use of *energy and water*

- *Relocalize* to regain control/responsibility and minimize transport

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
- CO_2 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**

We live in a dream world, but..

- ***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

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

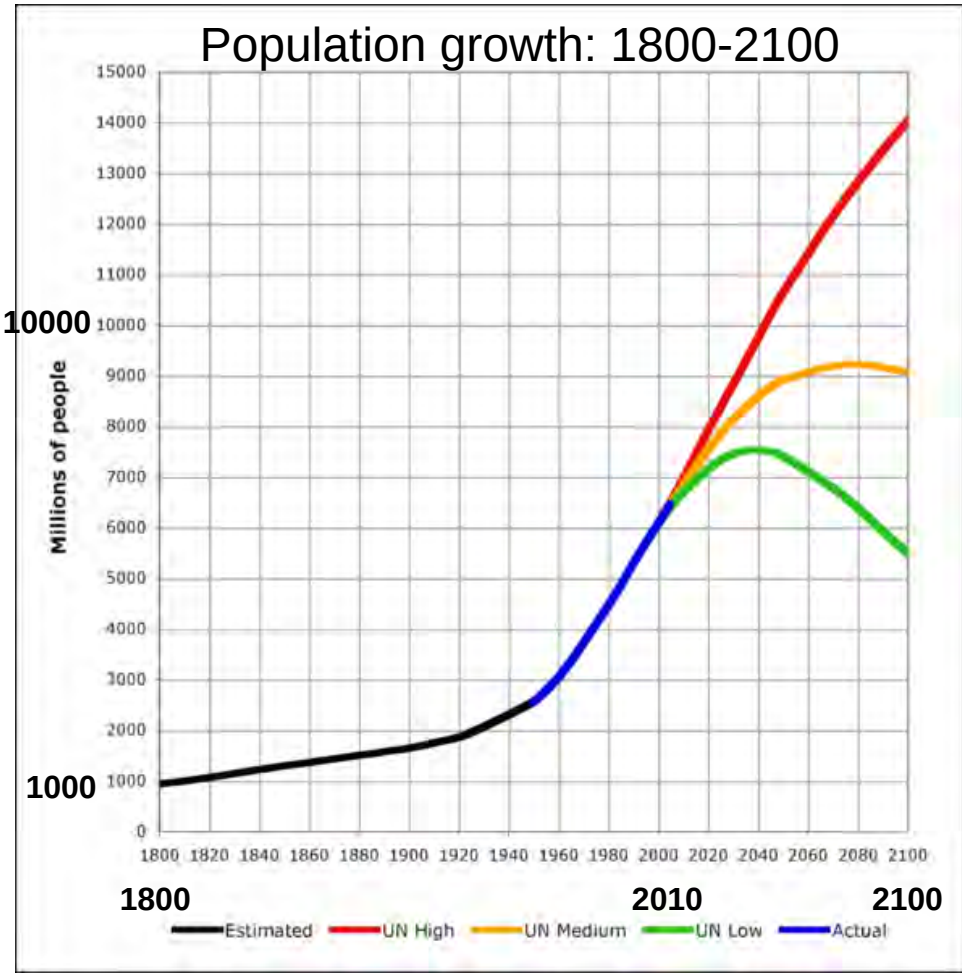
- **The problem with "Growth"**

- **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***



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.***

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.**

Climate Change is a huge challenge for humanity

- **We haven't integrated our science/technology and our moral responsibility for the earth**
- **We have a large investment in a fossil fuel infrastructure, that must be replaced**
- **We have major political problems finding consensus**
- ***We are already decades late in taking action and the lags in the earth system are long***

So what do we do?

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**

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**

Three broad guide-lines or ‘rules’

Minimize 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.**

Gadgets can help!

What is this?

Gadgets can help!

30 mph Danish electric tricycle

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_2 to 1000ppm *[and in time melt ice-caps]*. Can we "sequester" CO_2 [put it back in the earth]?**

Faced with..

- **Over-population, over-consumption, amazing waste, and climate change we have to change direction because**

- **The Earth is unstoppable, though it reacts slowly**
- **Humanity will lose unless we smarten up and minimize our impacts on the Earth system**

- **We have no choice - so find the bright side!**

The future is not our past

- **We create the future**

- **Communities are one key**
  [transitiontowns.org]

- **Need adaptive governance**

- *US government paralyzed by ideology*
- *US constitution gives no rights to Earth*

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**

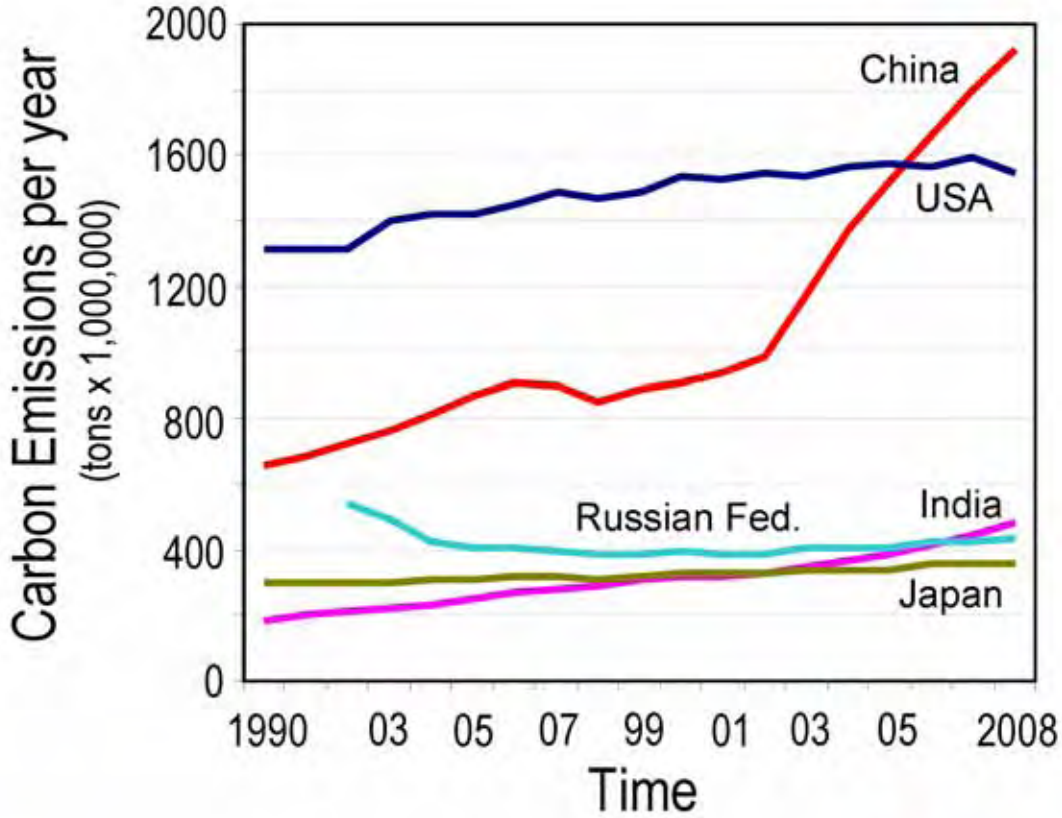
- **Ask: Is this an efficient and sustainable way of doing this?**
- **Do I have a deep understanding and connection to Earth?**

Conclusions

- **The issues humanity faces are deep**
- We are all part of the problem/solution
- *We have the tools & knowledge*
  - so lets seek the wisdom!
- Look beyond traditional ideas and accept our individual and collective responsibilities

- **We create the future – it is not a given!**

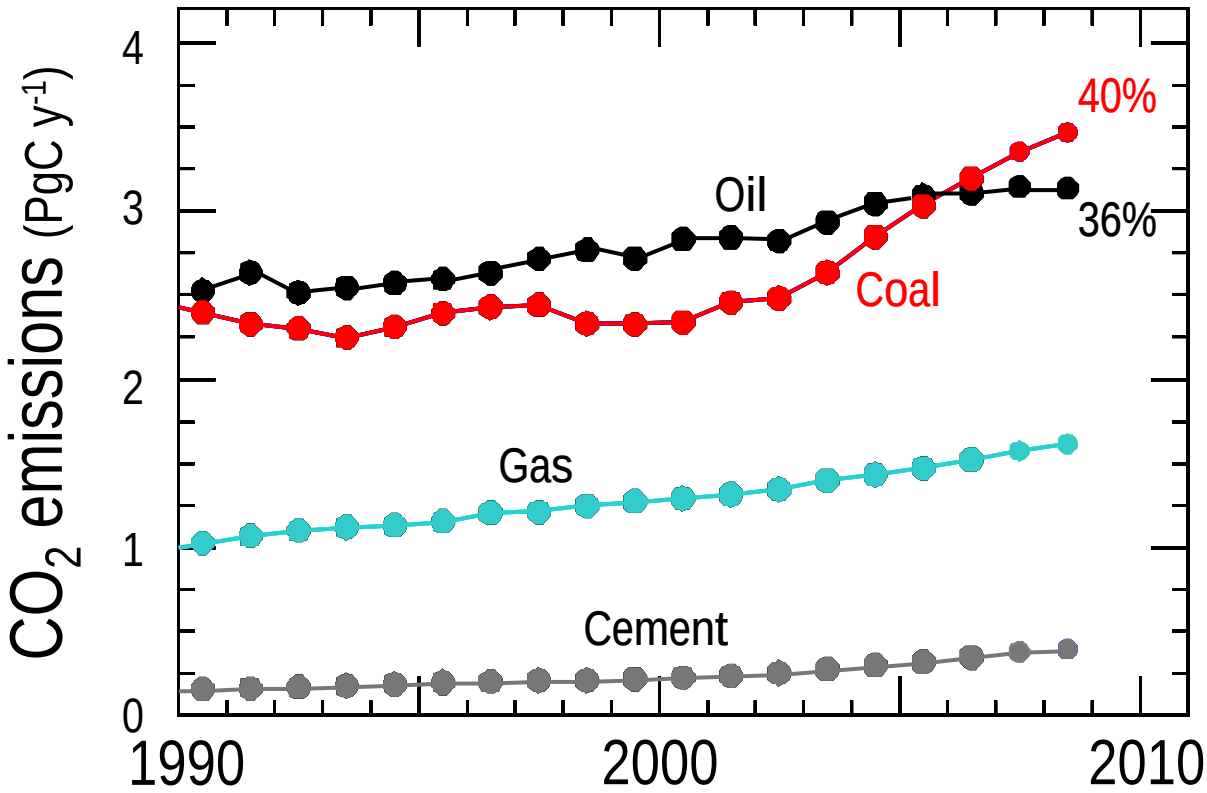
Fossil Fuel Emissions: Top Emitters (>4% of Total)



Global Carbon Project 2009; Data: Gregg Marland, CDIAC 2009

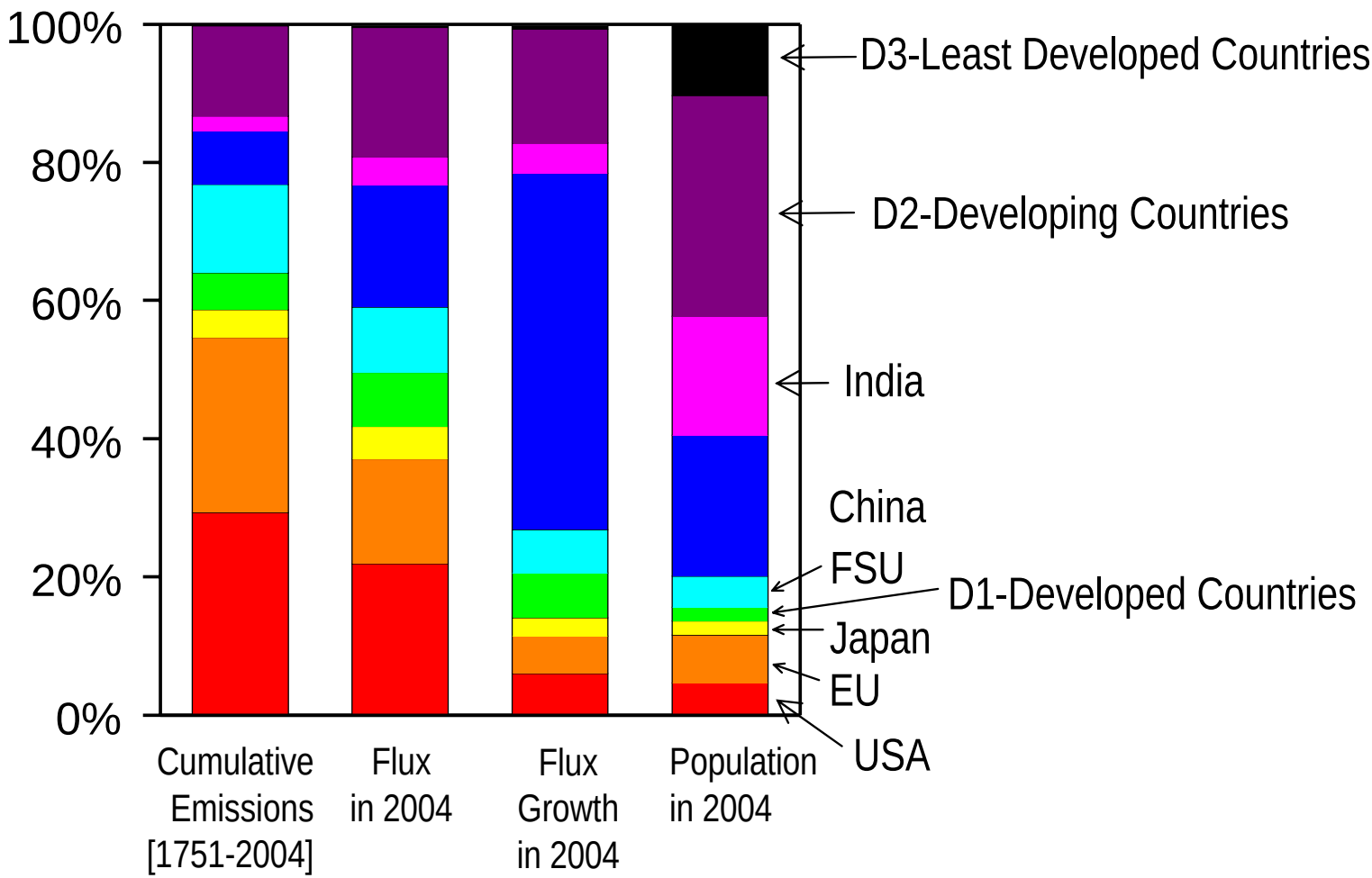
- China has overtaken the US [4 X population]

Components of FF Emissions



Le Quéré et al. 2009, Nature Geoscience

Regional Share of Fossil Fuel Emissions



Developed countries produced 75% of cumulative emissions

- Others will suffer the most from climate change

Raupach et al. 2007, PNAS