



Understanding Climate Change?

- what are our responsibilities as scientists ?

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NASA/JPL

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**
- **Clash of Earth science with social values**

Outline

- **Science of climate change**
 - **Global and local scale**
 - **What is happening to Vermont**
- **The transition we face**
 - **Managing the earth system**
 - **Why is it difficult?**

Discussion

How can we explain it to Public?

Blend big picture issues and local issues

Explain concepts pictorially, using seasonal climate

- **What is seasonal climate?**
- **Seasonal transitions**
 - *Spring, Summer, Autumn and Winter*
 - *Familiar but poorly understood*

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

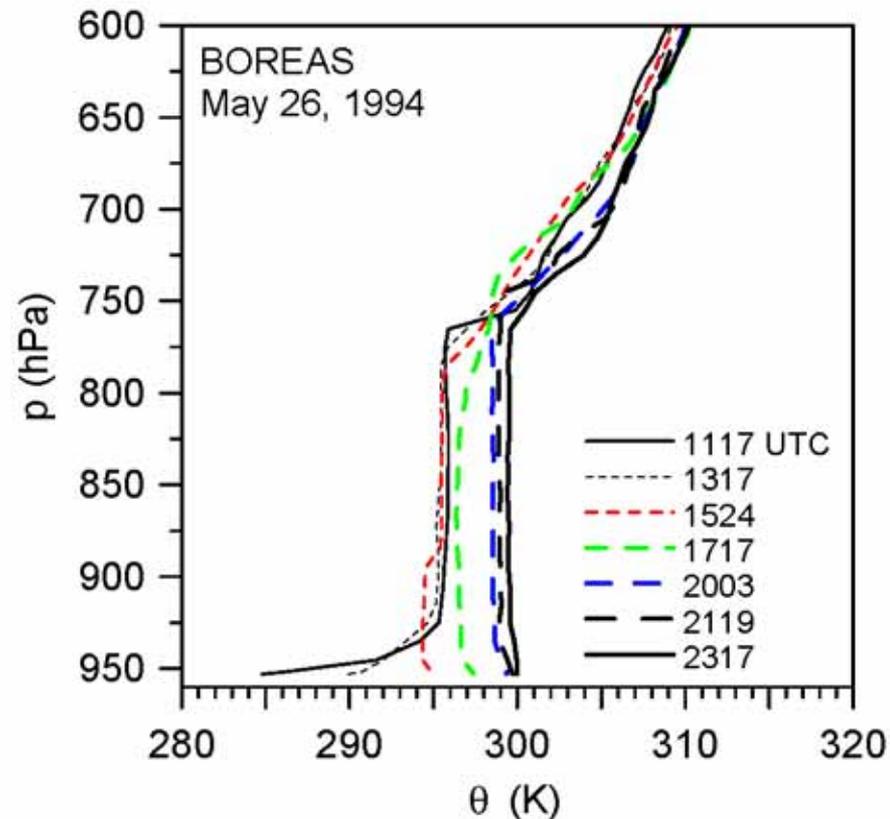
- ***Spring is coming earlier***

Spring transition

- Warm dry week to ten days in Spring, after snowmelt, past equinox
- Followed by drop of temperature of $\approx 3\text{C}/5\text{F}$ with leaf-out –wave up the eastern seaboard
- **Many key climate processes:**
 - Seasonal lags-melt of frozen soils
 - Vegetation-evaporation coupling
 - Latent heat of evaporation reduces temp.
 - Evaporation-RH-cloud-WV greenhouse
 - Clear-sky, large temperature range, frost

More extreme at boreal latitudes

- **Mid-May frozen roots; canopy at 23°C**
- **Surface pools everywhere, little evaporation and afternoon RH = 27%**
- **Cloud-base 2000m**
- **A 'green desert'**
 - **too cold to evaporate**
- **Longer seasonal lag than New England**



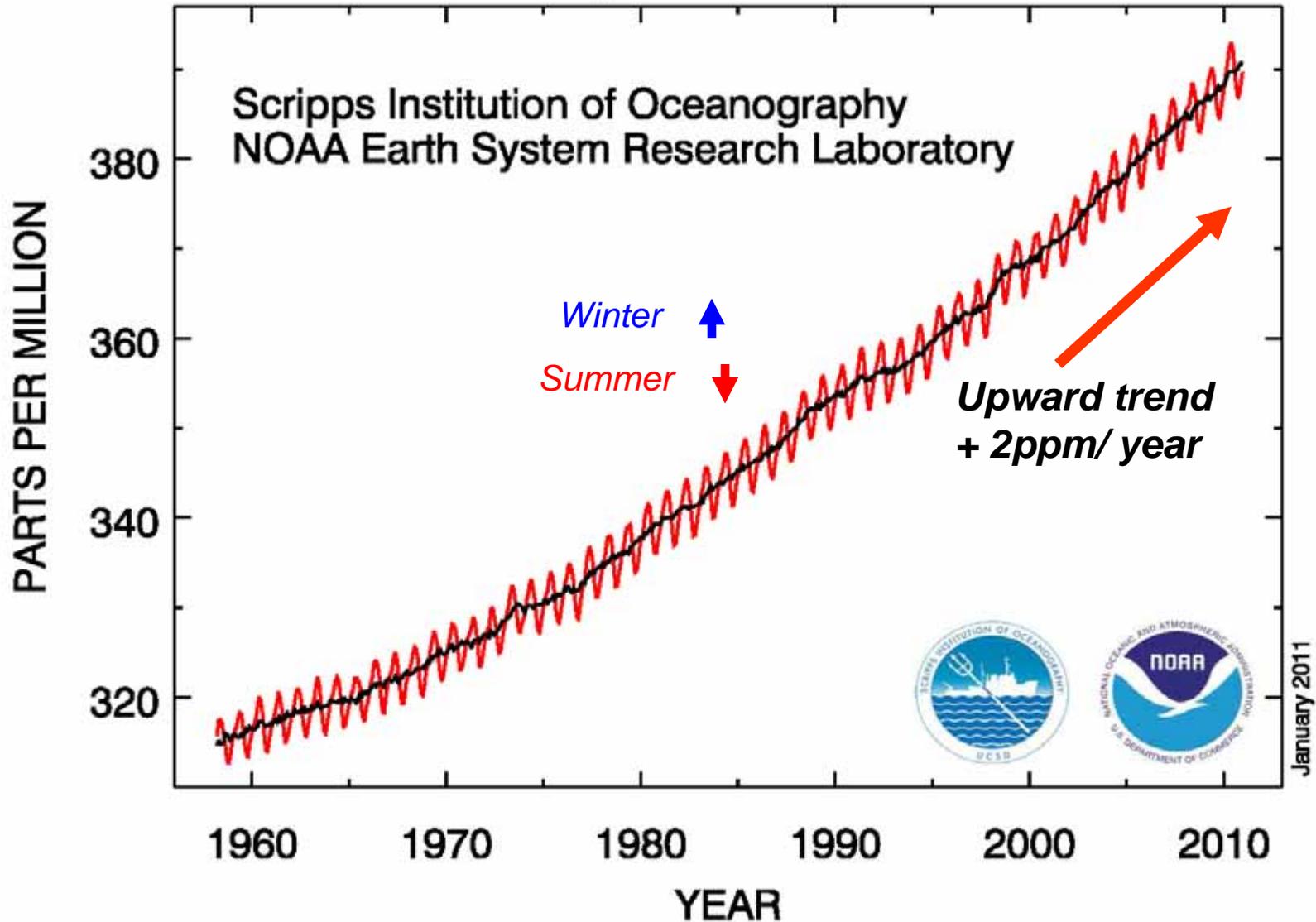
Spring green-photosynthesis



- Leaves use **red light** to soak up carbon dioxide and grow. They give off oxygen.

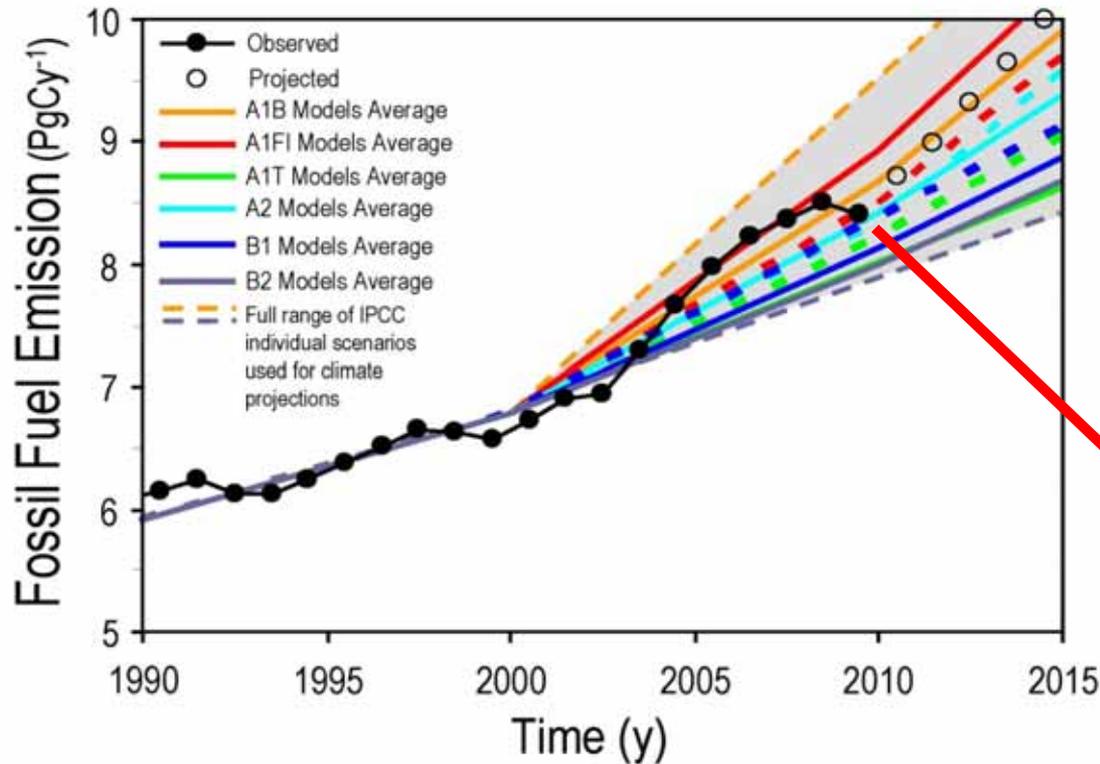
Carbon Dioxide Is Increasing

Atmospheric CO₂ at Mauna Loa Observatory



2009 Was “Good” for the Earth

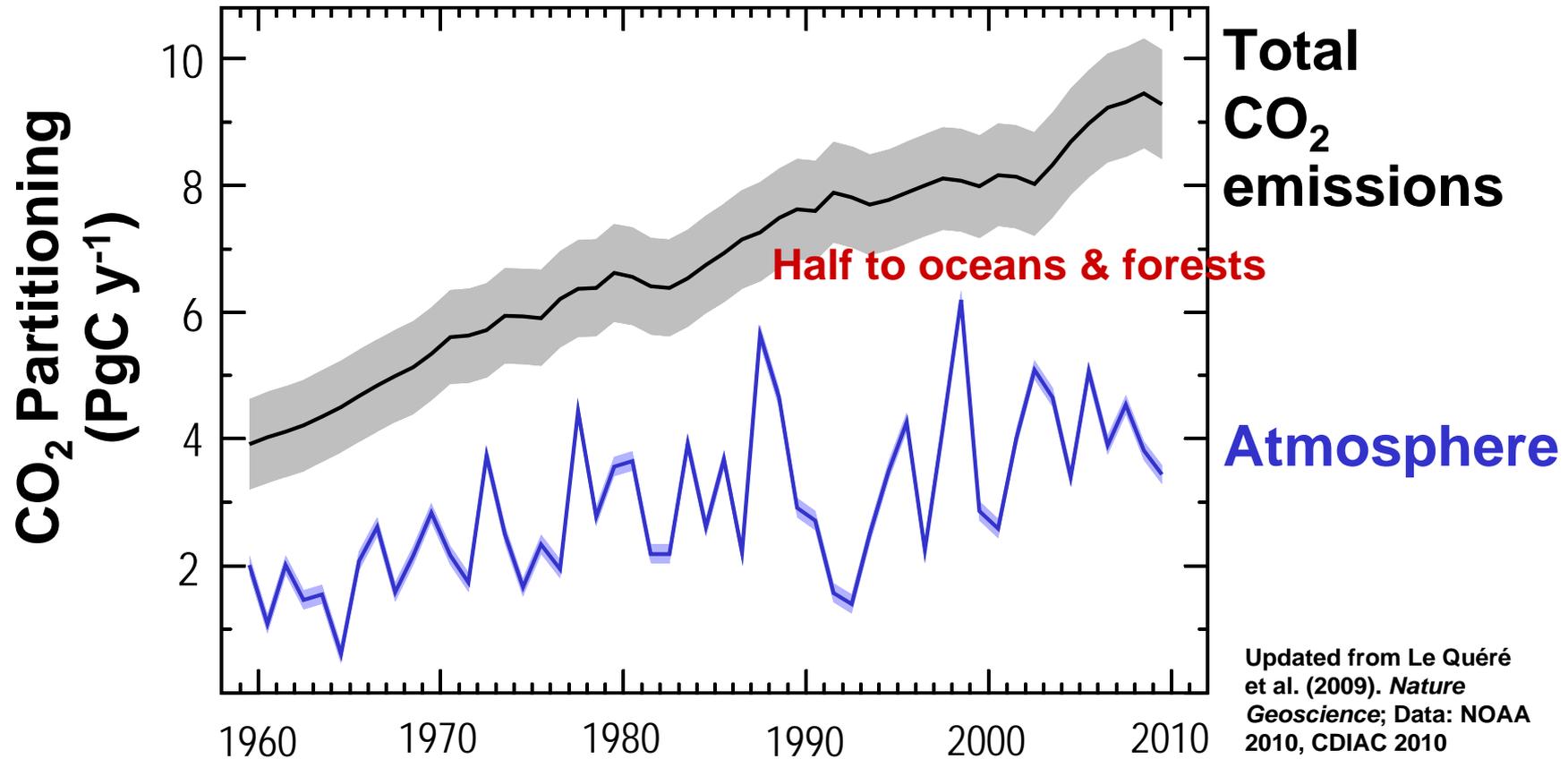
Fossil Fuel Emissions: Actual vs. IPCC Scenarios



- 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

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**

Summer transition

- **Summer dry-down; soil moisture falls, evaporation falls, BL drier, no precipitation**
- **May lock into a dry spell, a 'drought' till upset by strong weather system**
- **But it can go either way...**
- **2008, 2009, 2011, we had wet VT summers with + evaporation-precipitation feedback**

Wet summer – Dry summer

- *feedback can go either way*

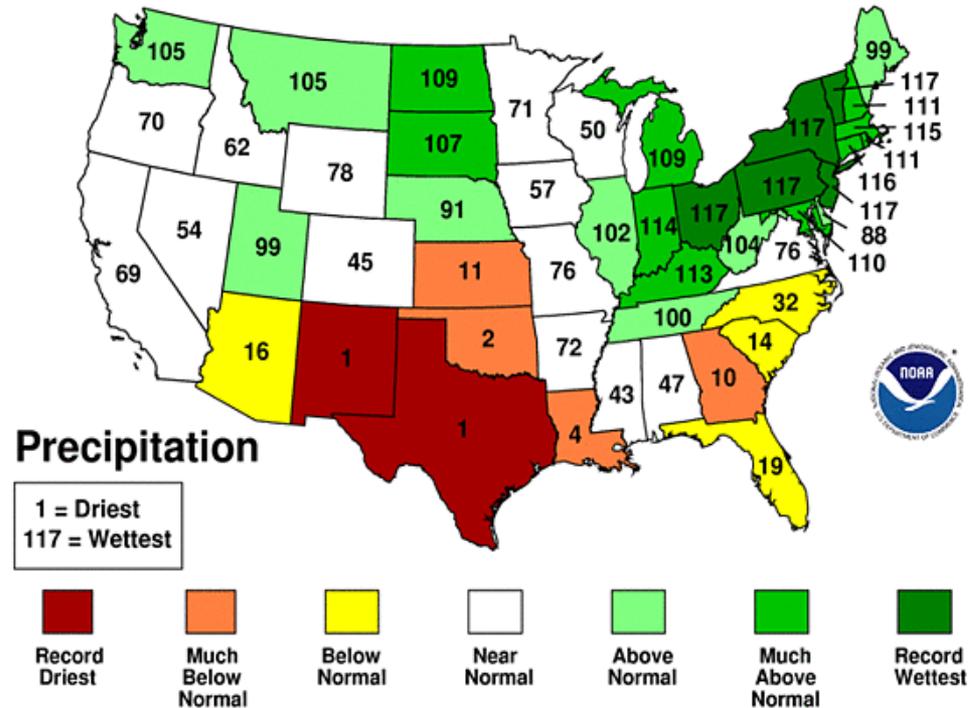


- **Direct fast evaporation off wet canopies & more rain**
- **Dry-down of soil and less evaporation & less rain**
- **Depends on weather systems**

Year of Irene

- OH-VT wettest
- NM & TX driest
- ‘Fixed’ pattern all year
- Irene dumped 6 inches on saturated ground

January-September 2011 Statewide Ranks
National Climatic Data Center/NESDIS/NOAA



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. In 2011, my first frost Oct. 28th with snowfall.

Winter transition

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

Vermont Winter 2006

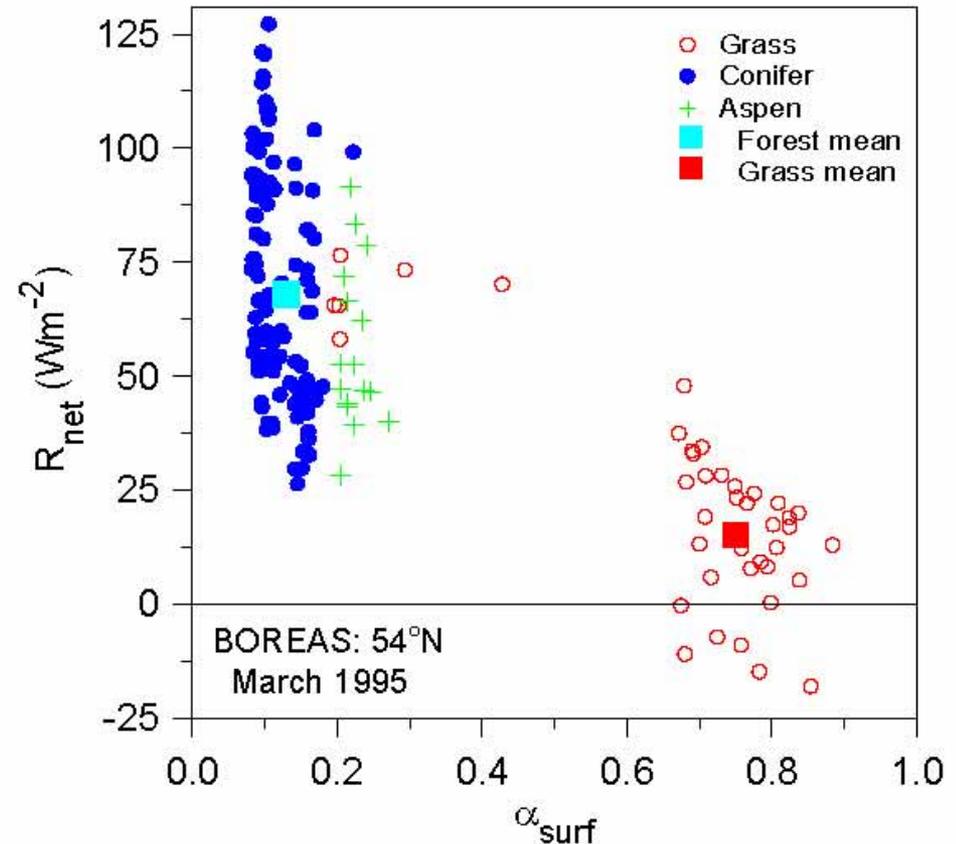
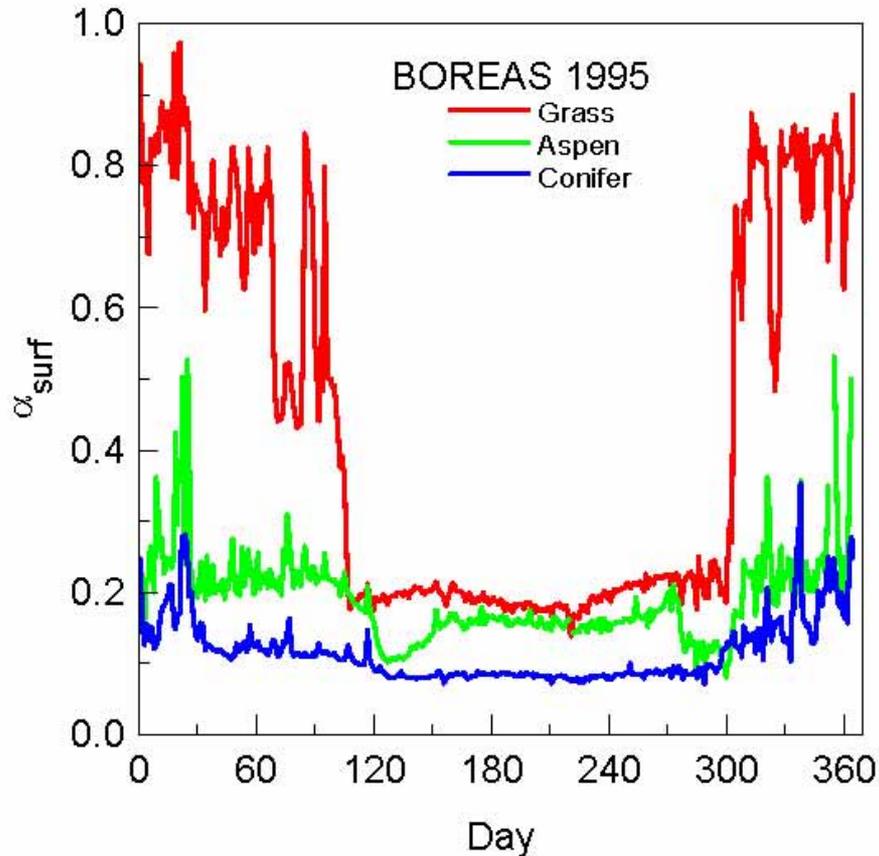


- **Sun is low; and snow reflects sunlight, except where there are trees!**
- **Sunlight reflected, stays cold; little evaporation, clear sky; earth cools to space**

Snow Energetics

- **Winter $SW_{\text{down}}(\text{clear}) \approx 130 \text{ Wm}^{-2}$**
- **10cm fresh snow changes albedo from 0.15 to 0.75 & drops SW_{net} from 110 to 30 Wm^{-2}**
- **Residual 30 Wm^{-2} sublimates 1cm snow/day**
- **Snow loss increases as snow ages**
 - snow lasts ≈ 5 days,
 - reducing solar heating to \approx zero

Boreal forest example



- High albedo in March: $R_{\text{net}} \approx \text{zero}$
- Difference between snow on grass and under trees is huge: **snow-albedo feedback** gives cold surface temperature

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**

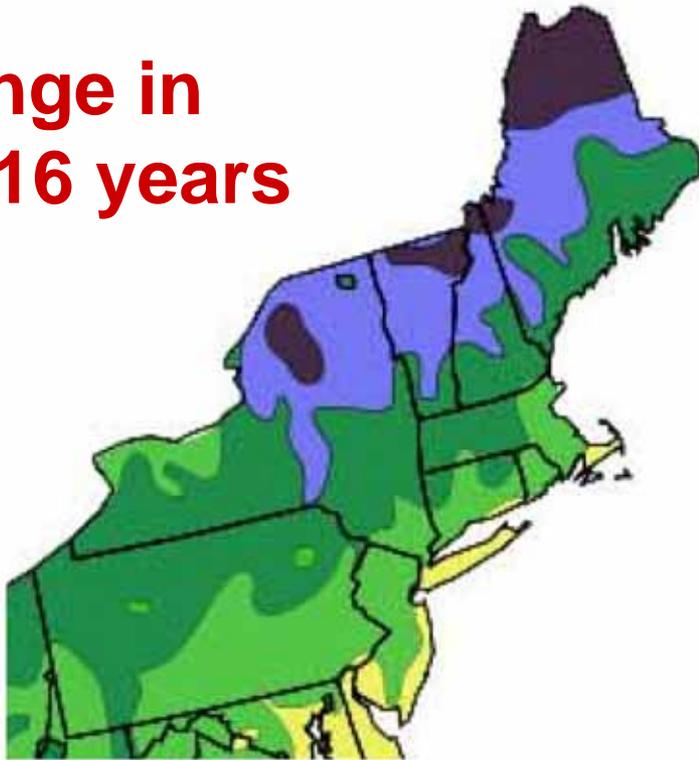
Brussel sprouts can now survive VT winter [protected by leaves & snow]



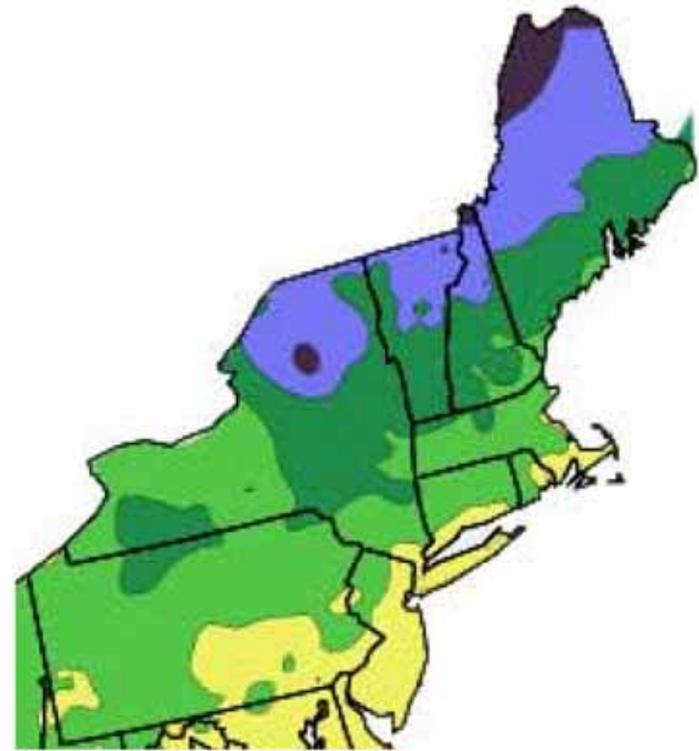
Picked February 10, 2008, Pittsford, VT

USDA Hardiness Zones - Northeast

Change in
last 16 years



1990

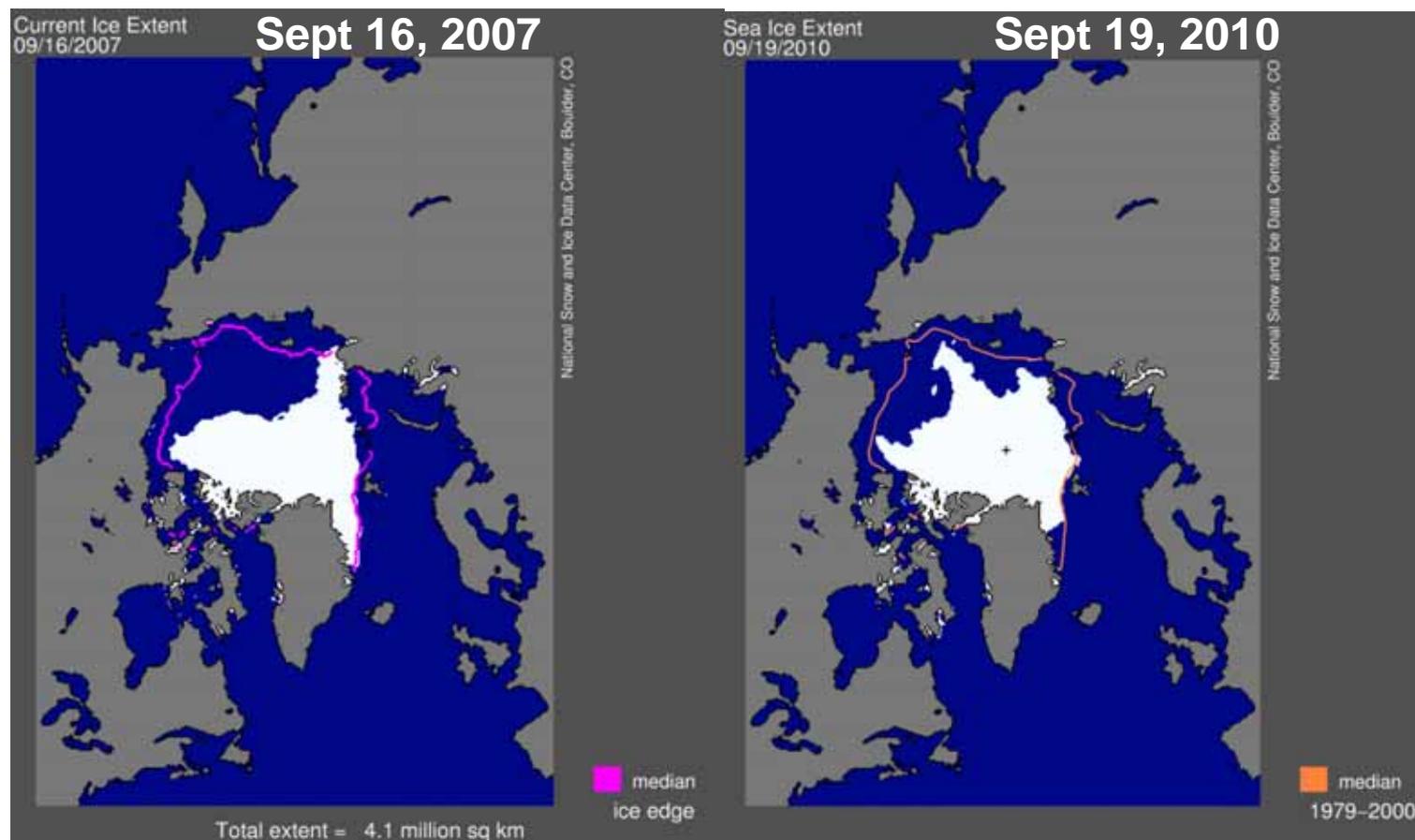


2006



USDA Hardiness Zones

Arctic Sea Ice Loss Has Accelerated



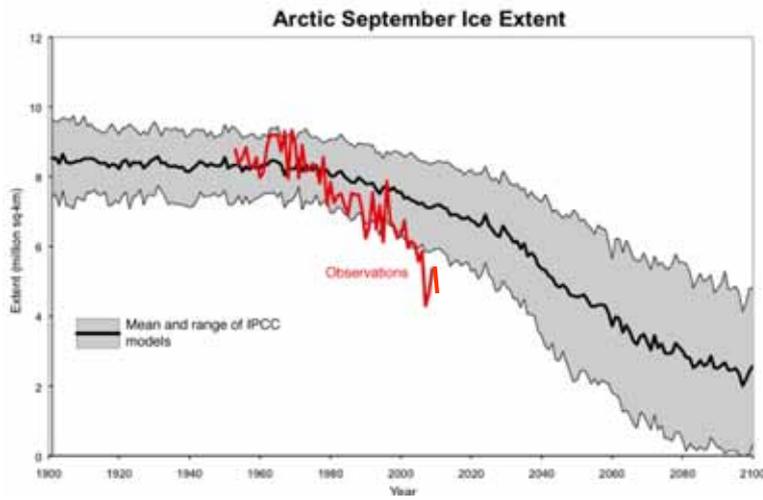
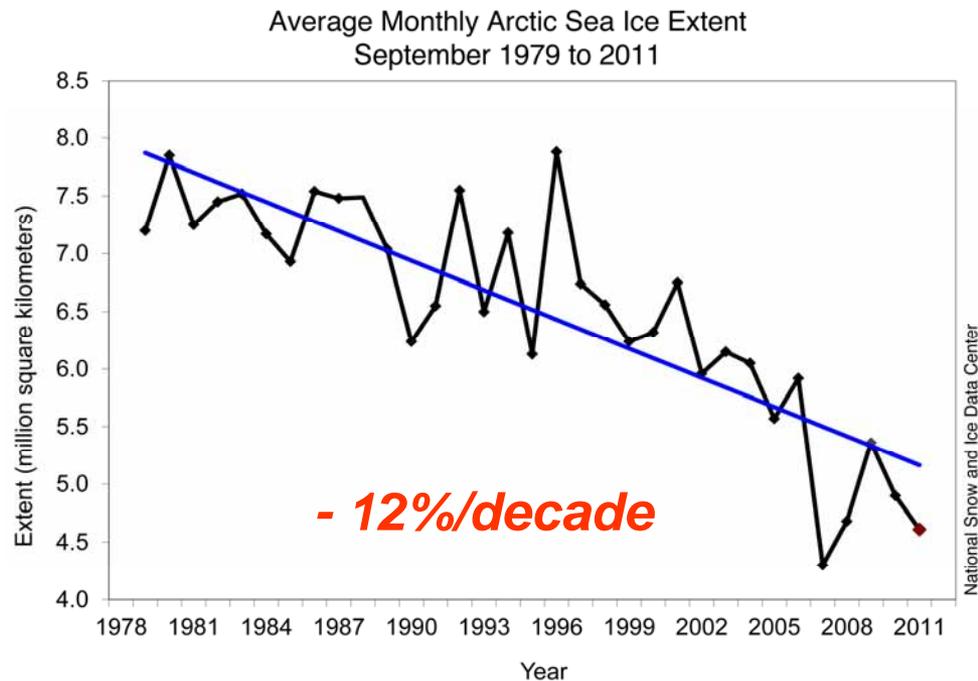
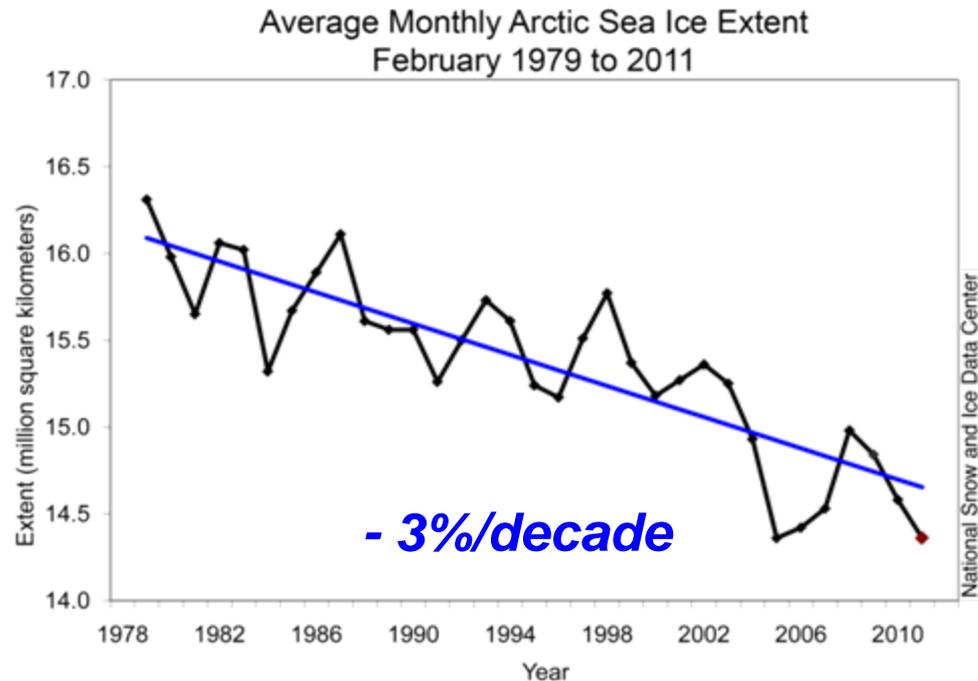
- **Feedbacks speed melting**
- **Less ice, less sunlight reflected**
- **More evaporation, larger water vapor greenhouse effect**

(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

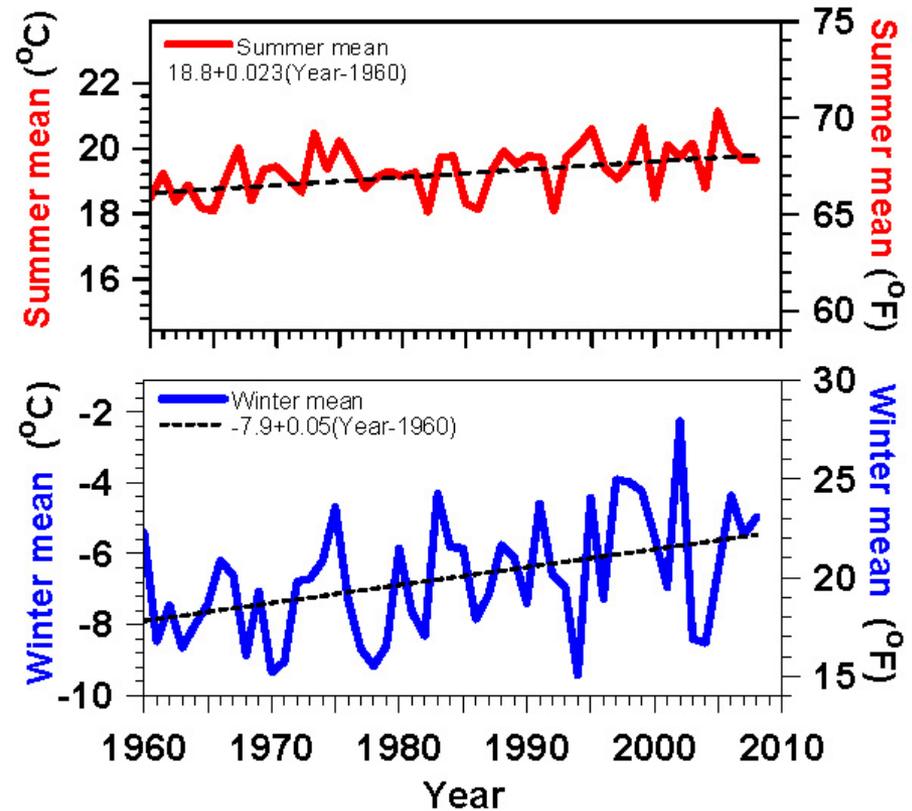


Local Example: What Is Happening to Vermont?

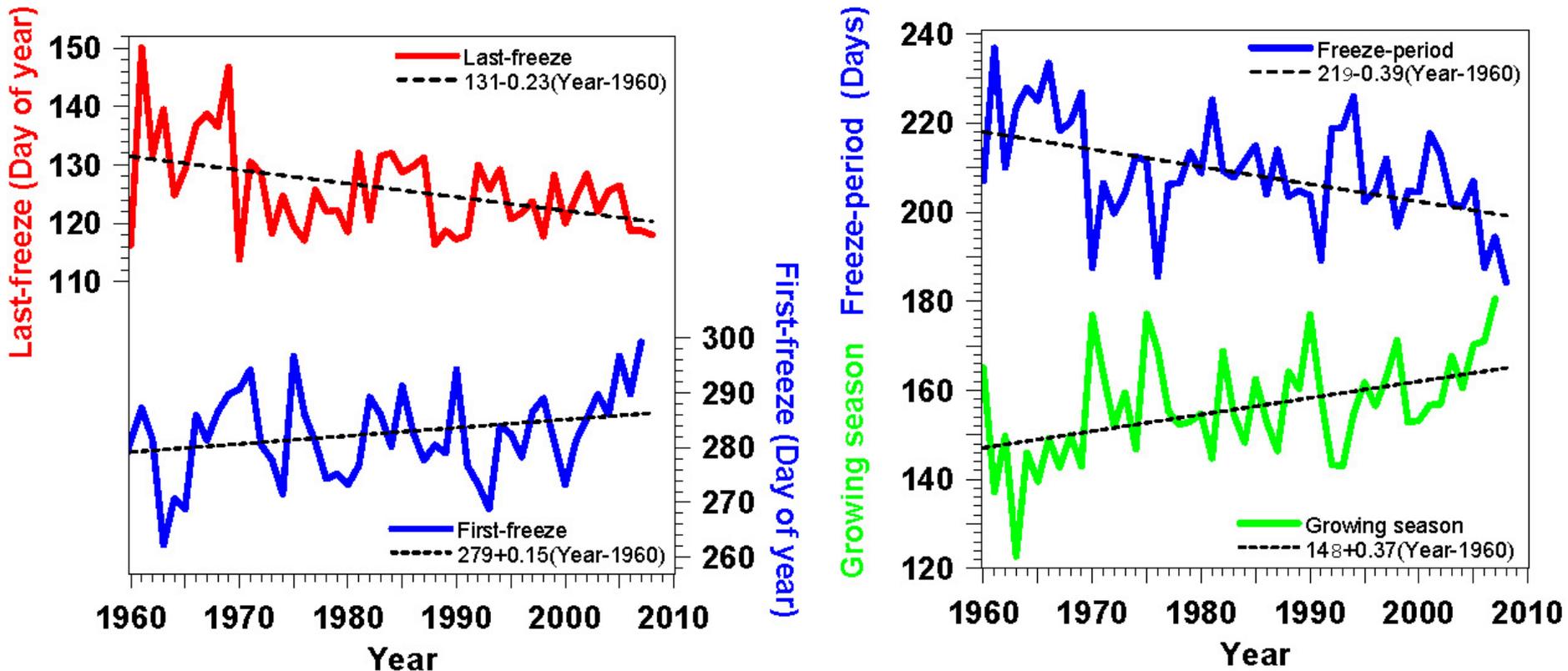
- Local climate change indicators
- Easier to grasp than global view
- Warming twice as fast in winter than summer
- Winter severity decreasing
- Lakes frozen less **by 7 days / decade**
- Growing season longer **by 3.7 days / decade**
- Spring coming earlier **by 2-3 days / decade**

Vermont Temperature Trends

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



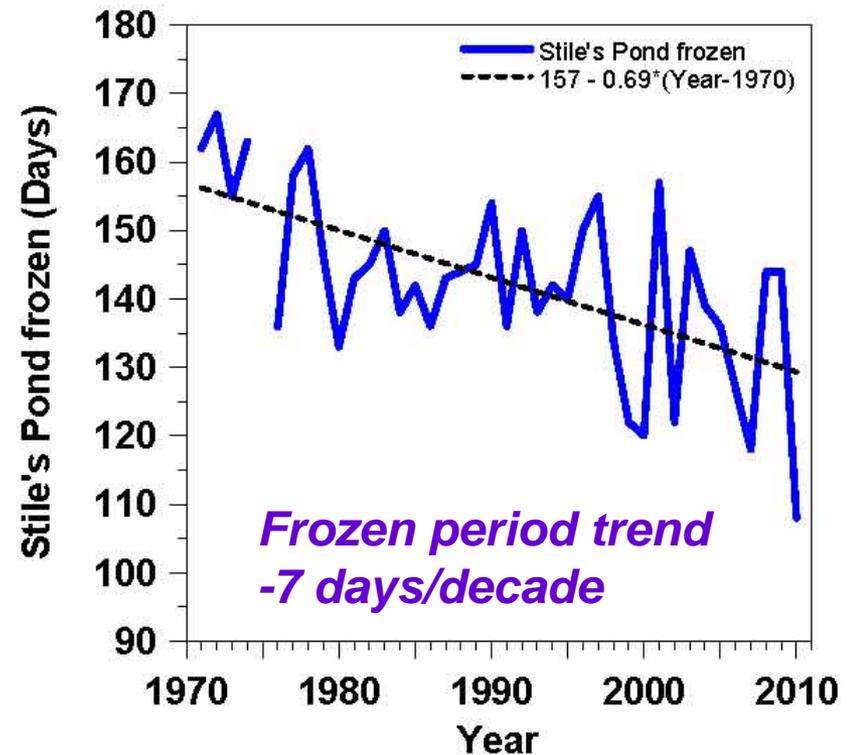
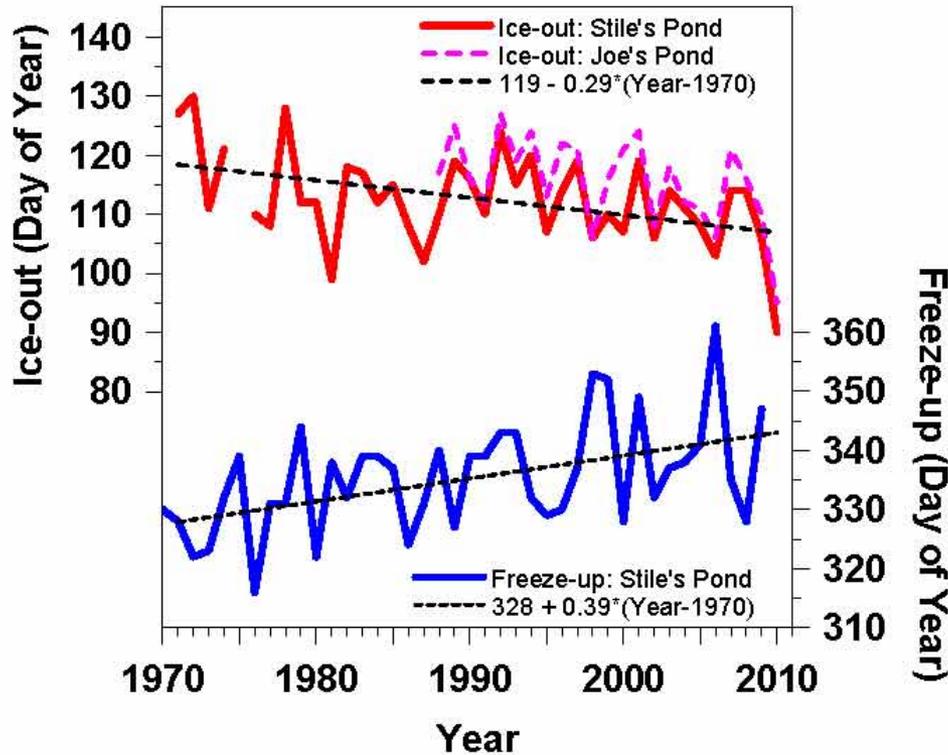
First and Last Frosts Changing



- Growing season for frost-sensitive plants increasing **3.7 days / decade**
- A help for growing “local food”

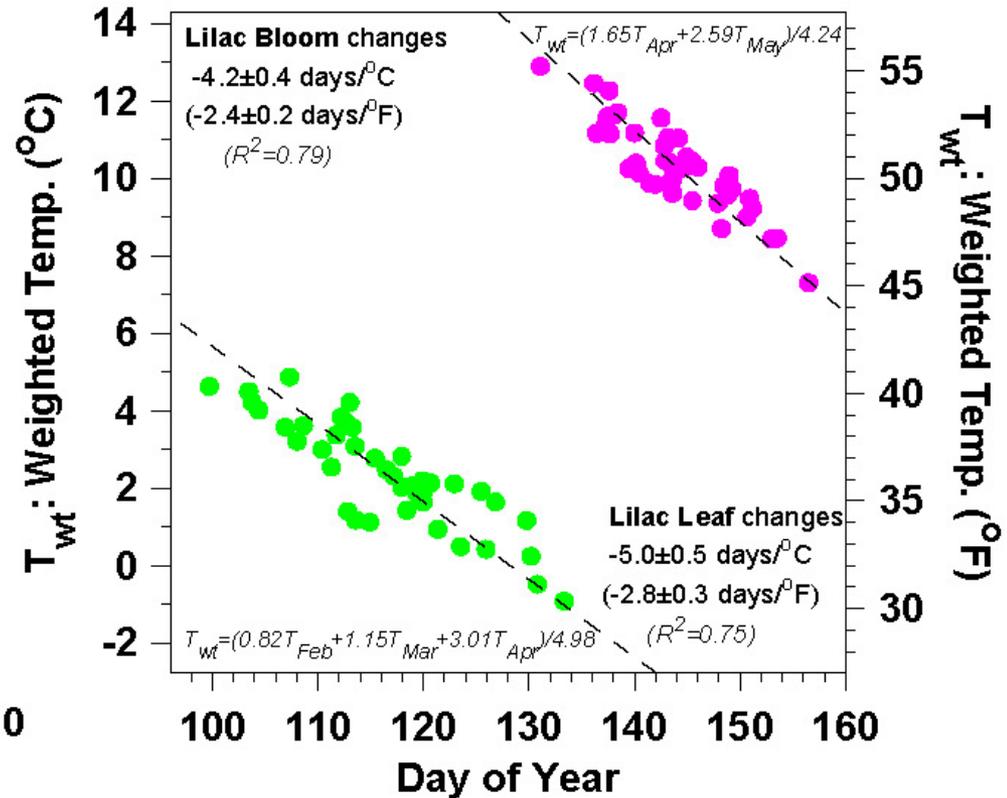
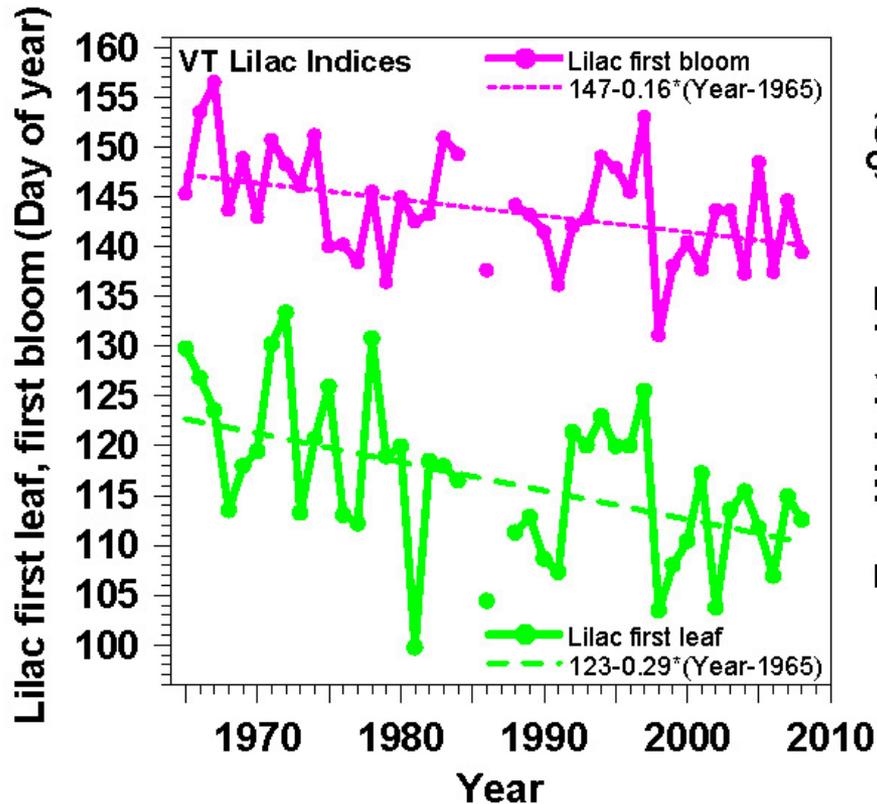
Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



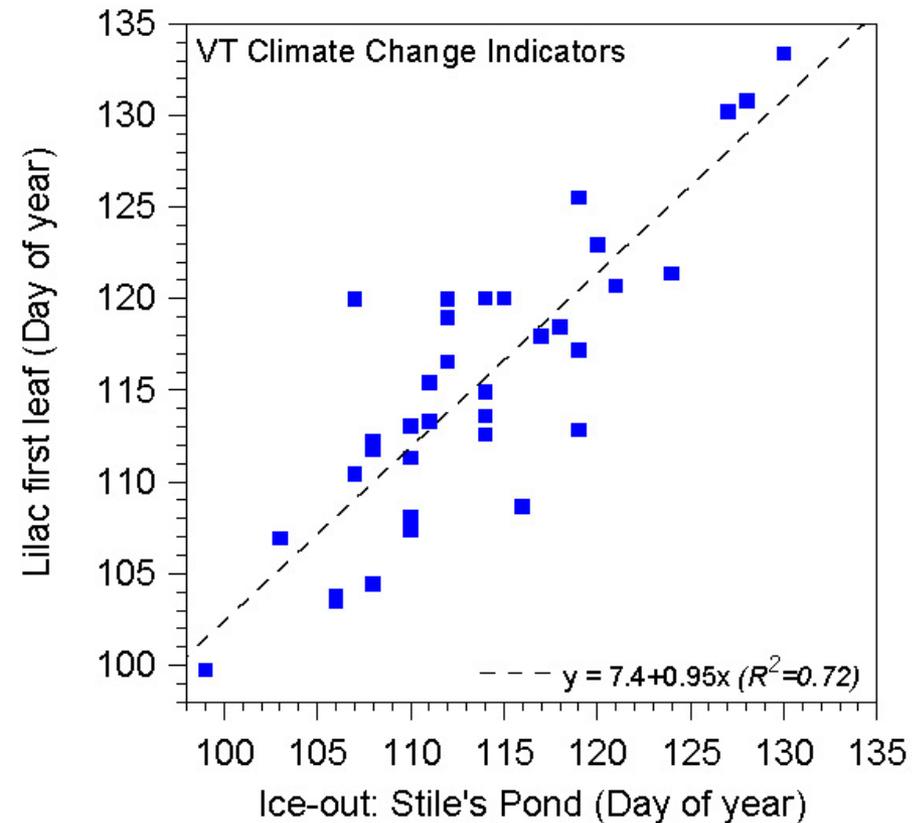
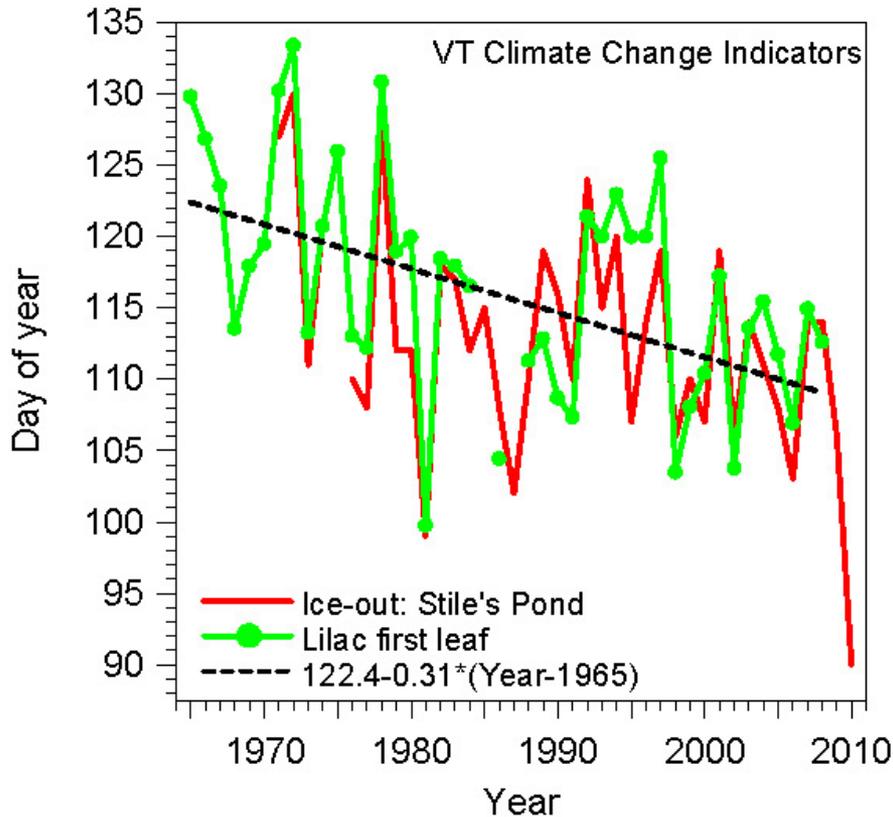
- Ice-out earlier **by 3 days / decade**
- Freeze-up later **by 4 days / decade**

Lilac Leaf and Bloom in Spring



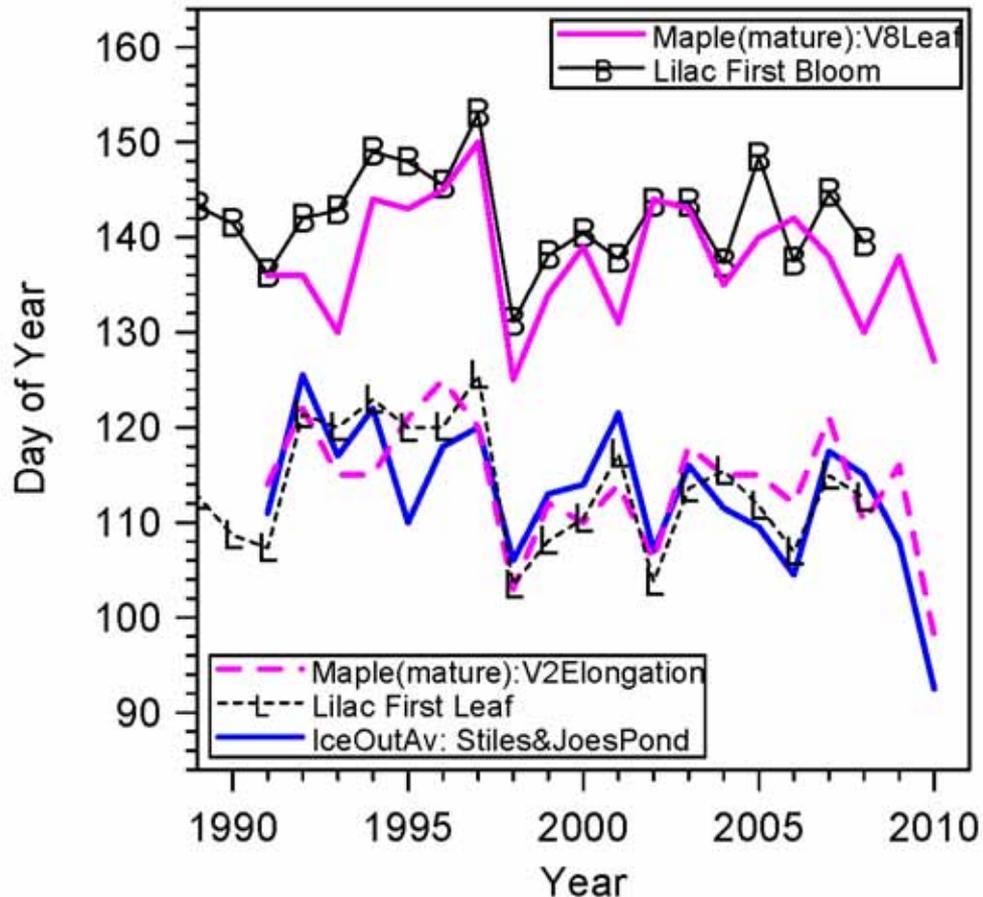
- Leaf-out earlier by **3 days/decade** (tracks ice-out)
- Bloom earlier by **1.5 days/decade**
- Leaf & bloom change **2.5 days/°F** (**4.5 days/°C**)

Lilac first leaf matches ice-out!



- Lilac first leaf correlated with spring ice-out
- Trend for both is **-3 days/decade**
- Frost-hardy plants are following ice-out trend

What about the sugar maples?



- Ice-out, lilac leaf, maple bud elongation correlated
- Lilac bloom and maple leaf-out correlated



Conclusions -1



- **Understanding seasonal climate transitions helps us understand key climate processes & grasp the local and global nature of what is happening to the Earth**
- **Local climate change indicators provide a clear framework for communities – for understanding, acceptance and adaptation planning**

Outline

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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 fuel**

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

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 understanding of our responsibility to society**

Climate Neutrality?



- **We know what we need**
 - **Energy-efficient society**
 - **Energy sources renewable: not fossil**
- **What are the obstacles?**
- **Why are we taking such a huge risk for this planet?**

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**

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

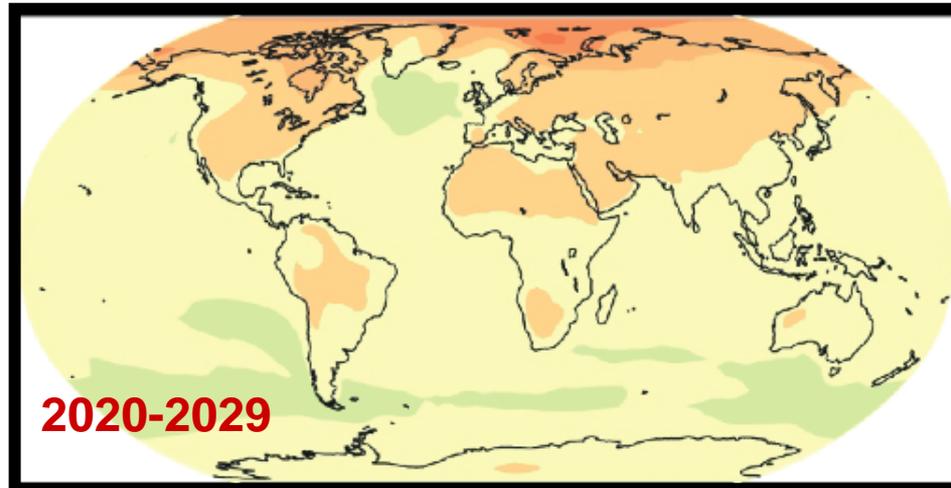
Conclusions -2



- ***We have the tools & knowledge
- but not the wisdom!***
- **We need to look beyond our traditional silos and creatively accept our individual and collective responsibilities**
- **We create the future – it is not a given!**
 - **Is this an efficient and sustainable way of doing this?**
 - **Do I have a deep understanding and connection to Earth?**

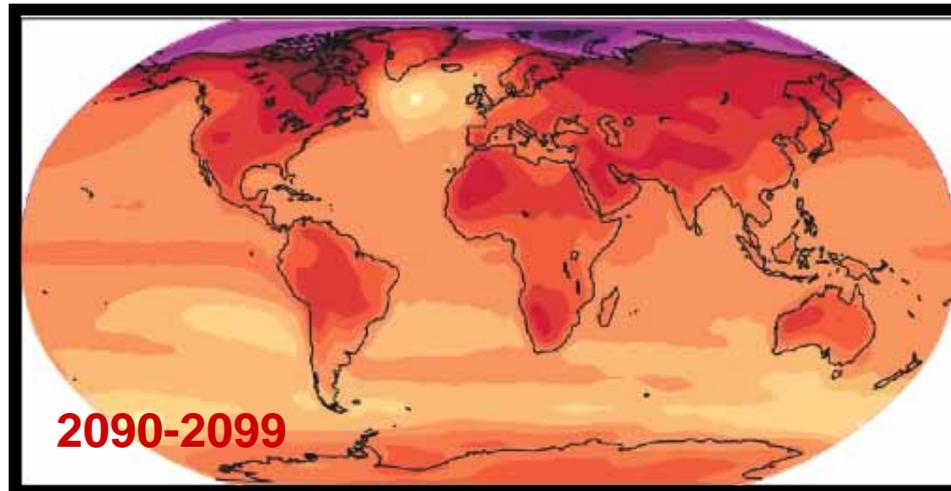
Multi-model Predicted Percent Change in Temperature (2020-2029 and 2090-2090 relative to 1980-1999) [°C]

'Committed'

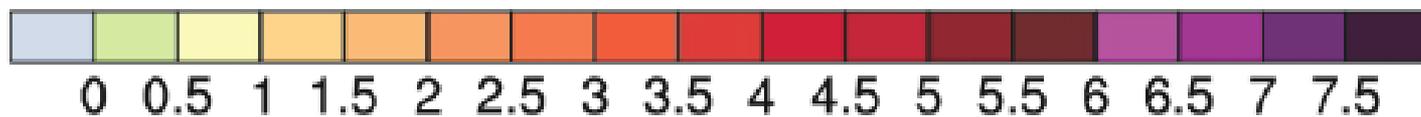


(We did nothing for the last 20 years)

Still up to us!



(We could halve this if we act now)



[°C]