Understanding Climate Change in Vermont

- *what are a forecaster's responsibilities?*

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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 CO_2 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**
  - **Local and global scale**
  - **What is happening to Vermont**

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

Discussion

Understanding Climate Change and Explaining it to the Public?

Blend big picture issues and local issues

Explain concepts pictorially, using seasonal climate – to build confidence

- **What is seasonal climate?**

- **Seasonal transitions**

- ***Spring, Summer, Autumn and Winter***
- ***Familiar but poorly understood***

Spring transitions

- After snowmelt, past equinox, warm dry week to ten days in Spring,
- Followed by drop of temperature of ≈3C/5F with leaf-out – wave up the eastern seaboard
- Many key climate processes:

- Seasonal lags-melt of frozen soils
- Clear-sky, large temperature range, frost
- Vegetation-evaporation coupling
- Latent heat of evaporation reduces temp.
- Evaporation-RH-cloud-WV greenhouse

Spring Climate Transitions

- **After melt & before leaf-out (mid-April)**

Little evaporation → **Dry atmosphere, low humidity**
→ **Low water vapor greenhouse**
→ **Large cooling at night**
→ **Large diurnal temp. range**
giving warm days, cool nights and frost

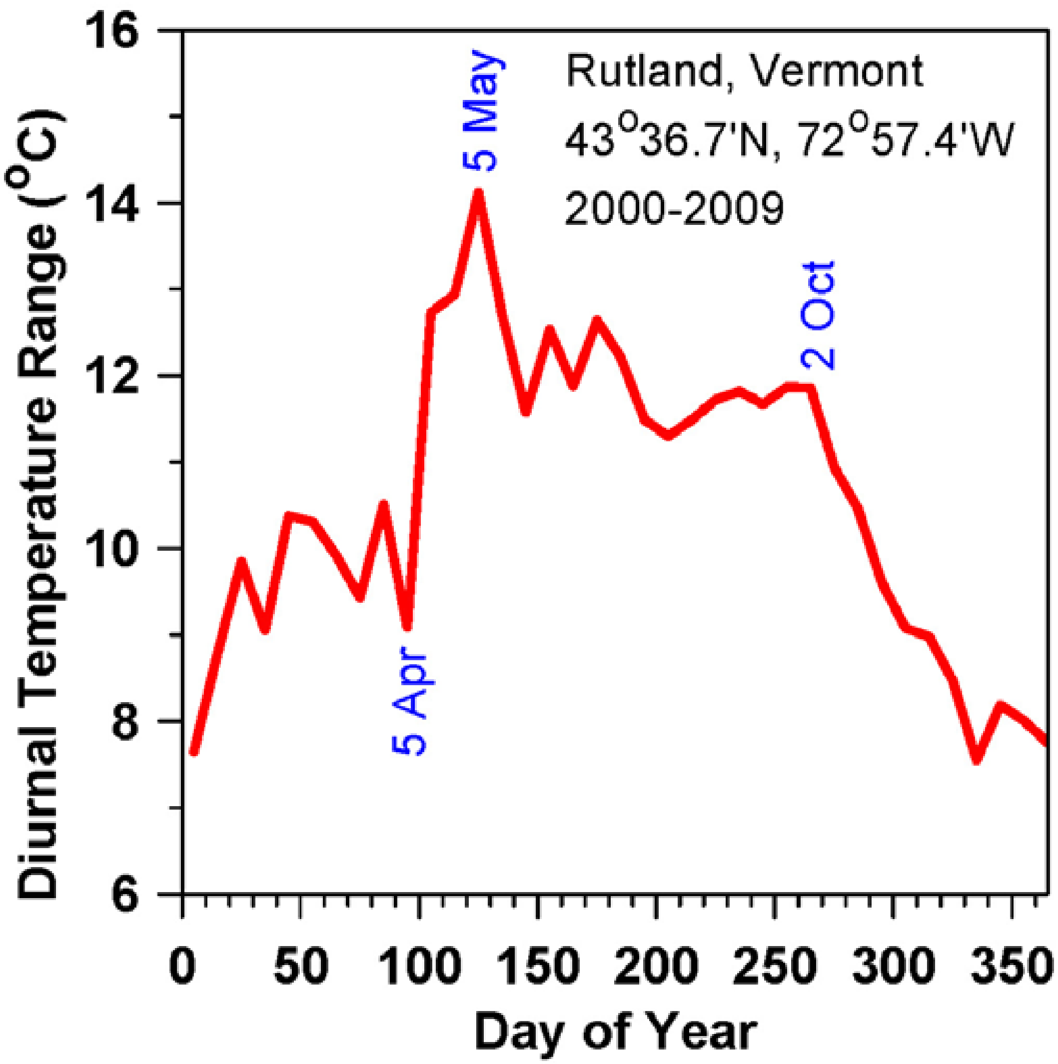
- **After leaf-out (mid-to-late-May)**

Large evaporation → **Wet atmosphere, low cloud-base**
→ **Small cooling at night**
→ **Reduced maximum temperature**
→ **Reduced chance of frost**

- ***Climate change: Spring earlier (2-3 days/decade)***

Diurnal Temperature Range

- **DTR increases sharply after 5 April, peaking at the time of forest leaf-out in the first week of May, and then falling as transpiration rapidly increases**



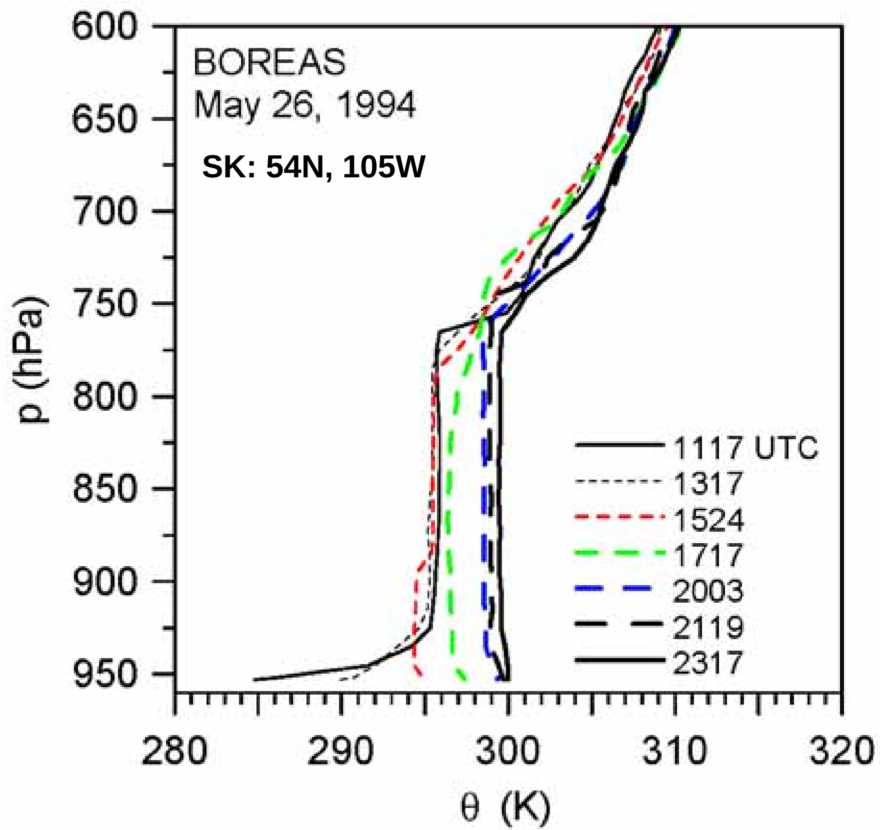
Betts, Weather 2011

More extreme at boreal latitudes

- Mid-May frozen roots; canopy at 23ºC
- Surface pools everywhere, little evaporation and afternoon RH = 27%
- Cloud-base 2000m
- A 'green desert'

– too cold to evaporate

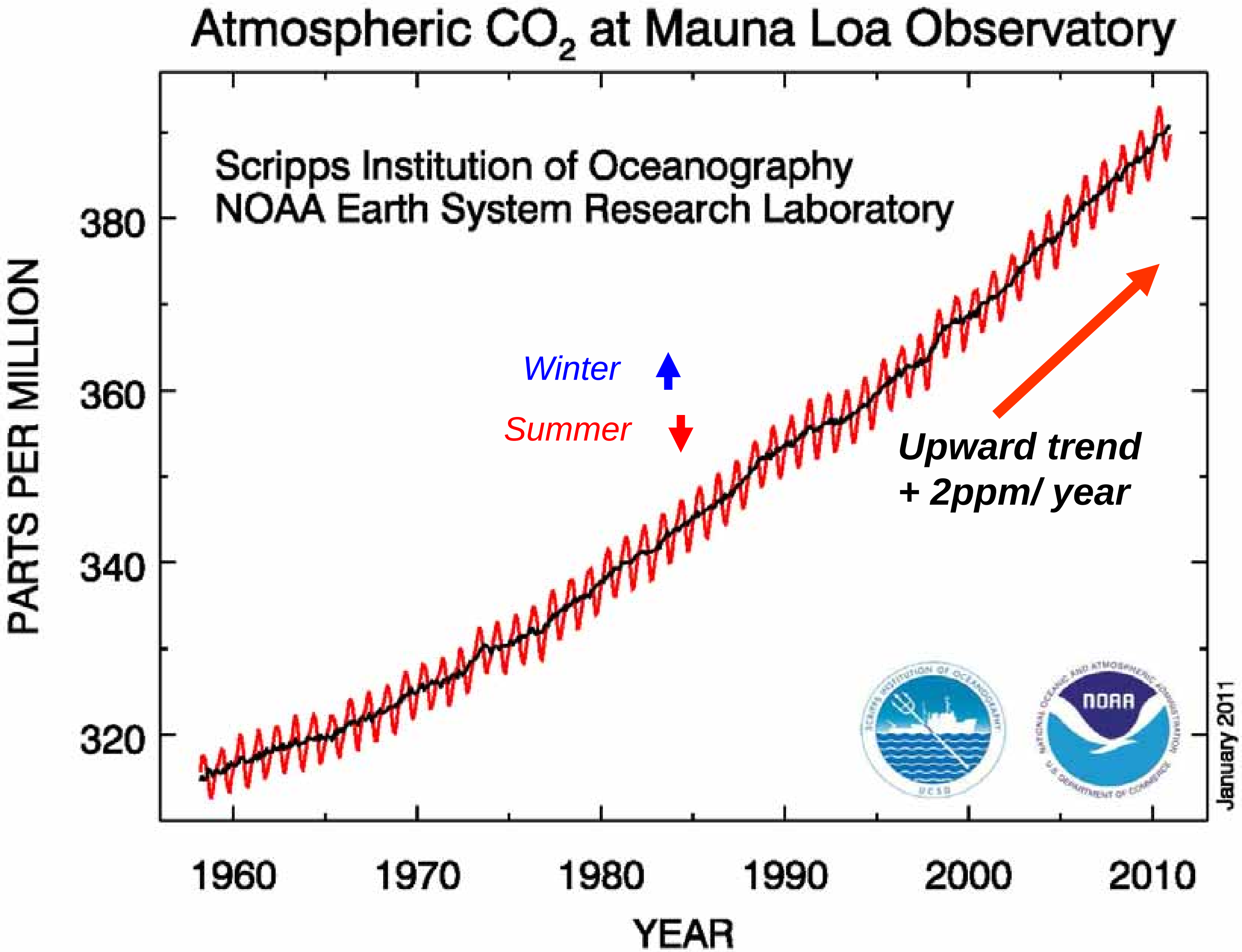
- Longer seasonal lag than New England



Spring green-photosynthesis

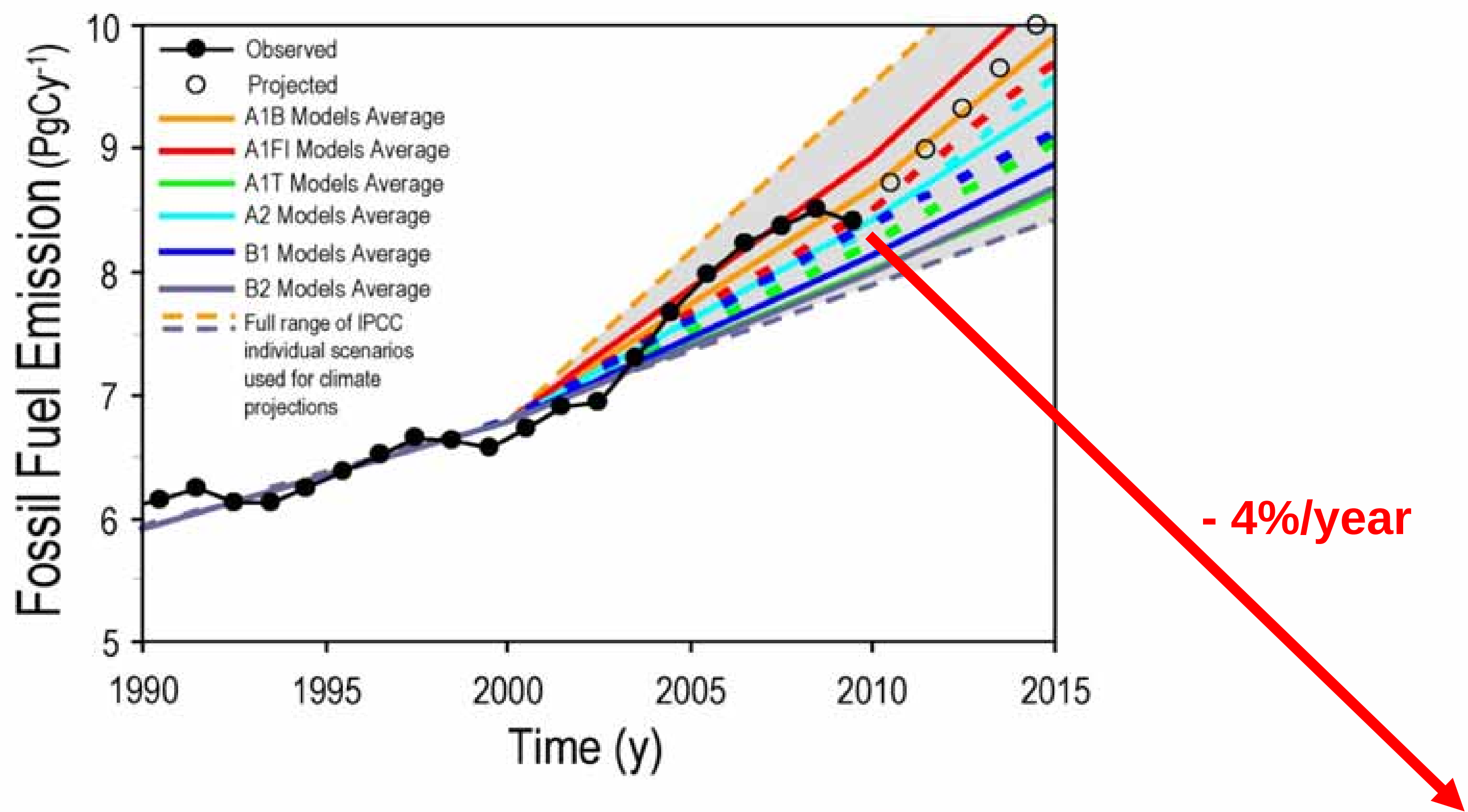
- **Leaves use red light to soak up carbon dioxide and grow. They give off oxygen.**

Carbon Dioxide Is Increasing



2009 Was “Good” for the Earth

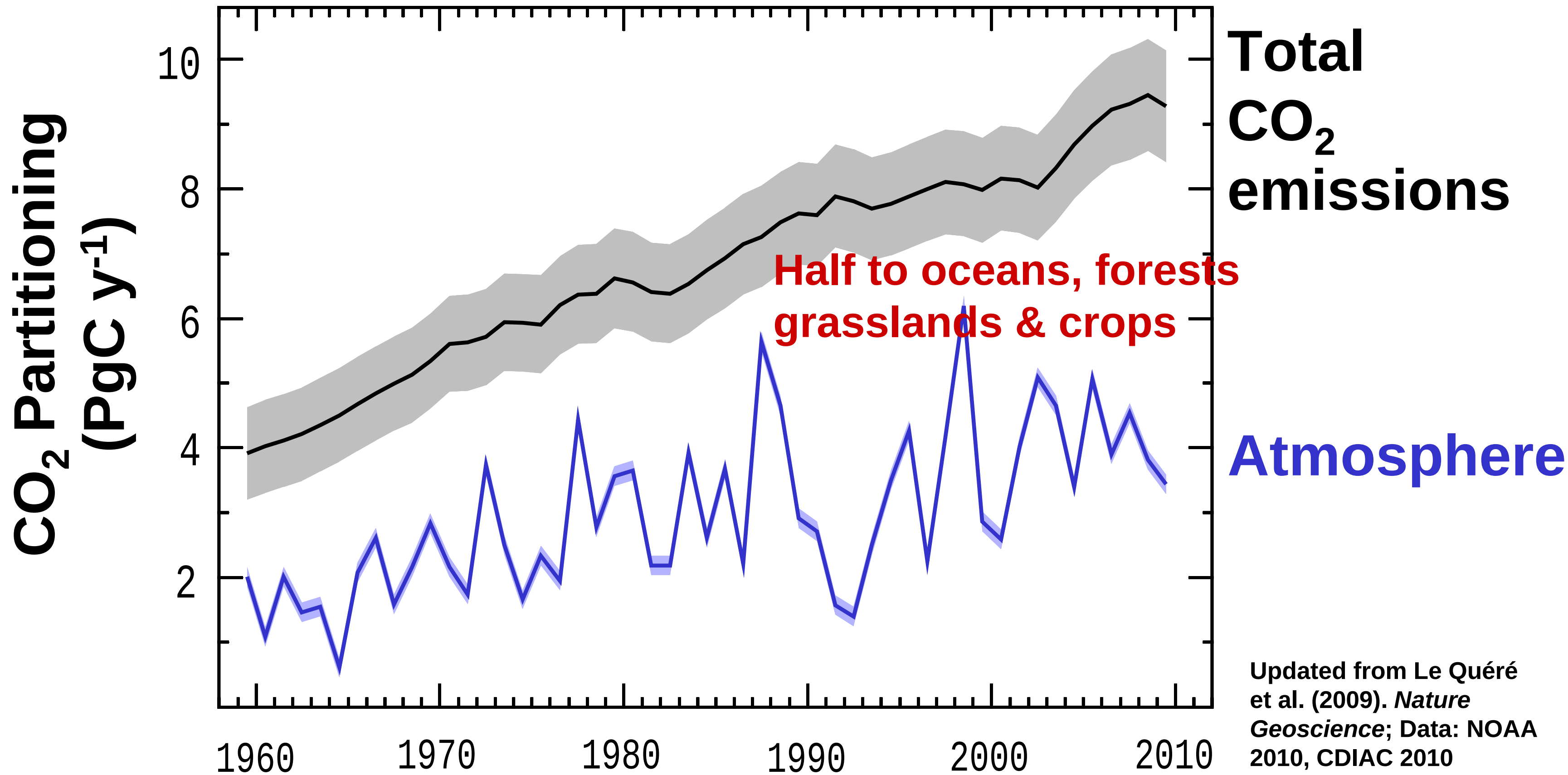
Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Updated from Raupach et al. 2007, PNAS; Data: Gregg Marland, Thomas Boden-CDIAC 2010; International Monetary Fund 2010

Key Diagnostic of the Carbon Cycle

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



Updated from Le Quéré et al. (2009). *Nature Geoscience*; Data: NOAA 2010, CDIAC 2010

It takes at least a century to remove CO_2 from the atmosphere, and many centuries to remove it from oceans

Why Is the Rise of Atmospheric CO_2 a Problem?

- The atmosphere is transparent to light from the sun, but not to infrared radiation from the earth
- Greenhouse gases: H_2O, CO_2, CH_4
  - trap the earth's heat, giving pleasant climate
- CO_2 rise alone has a small effect, BUT
- Lifetime of non-condensing gases is long – century-scale for CO_2 AND

Why Is the Rise of Atmospheric CO_2 a Problem?

- **As Earth warms, evaporation and water vapor increase and <u>this amplifies warming</u> a lot (3x)**
- **As Earth warms, snow and ice decrease and <u>this amplifies warming</u> in winter and northern latitudes, because less sunlight is reflected**
- **Doubling CO_2 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 mostly wet VT summers with positive evaporation-precipitation feedback

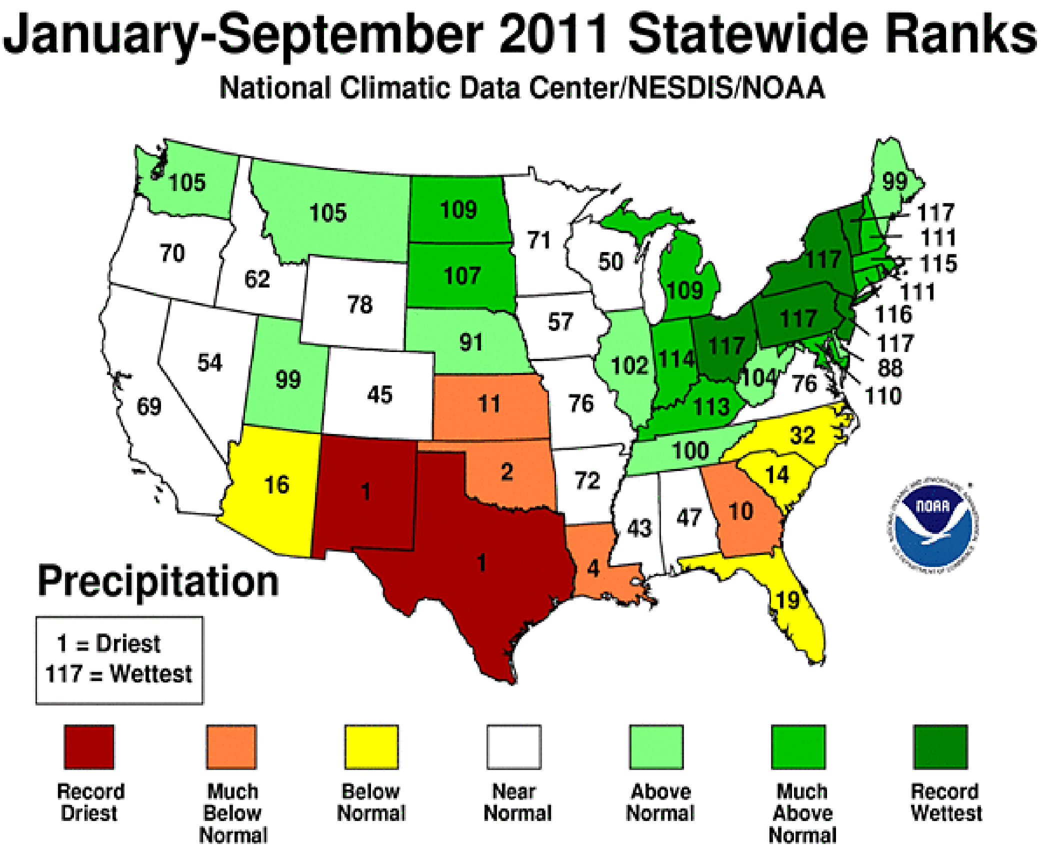
Wet summer – Dry summer

- *feedback can go either way*

- Direct fast evaporation off wet canopies & more rain
- Dry-down of soil and less evaporation & less rain
- Coupled to/broken by weather systems

Year of Irene

- **OH to VT wettest**
- **NM & TX driest**
- **'Quasi-Fixed' pattern**
- *Climate modes: La Nina/warming Arctic…*
- **Irene dumped 6 inches on saturated ground**



Fall Climate Transition

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

- **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!***

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

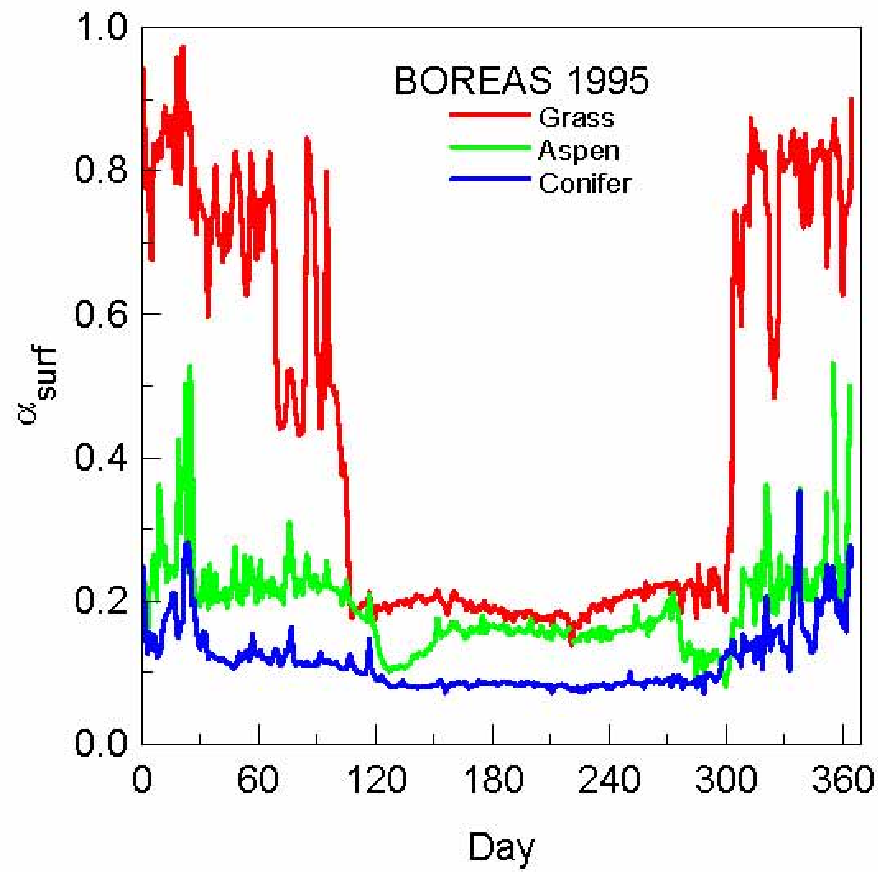
Snow Energetics

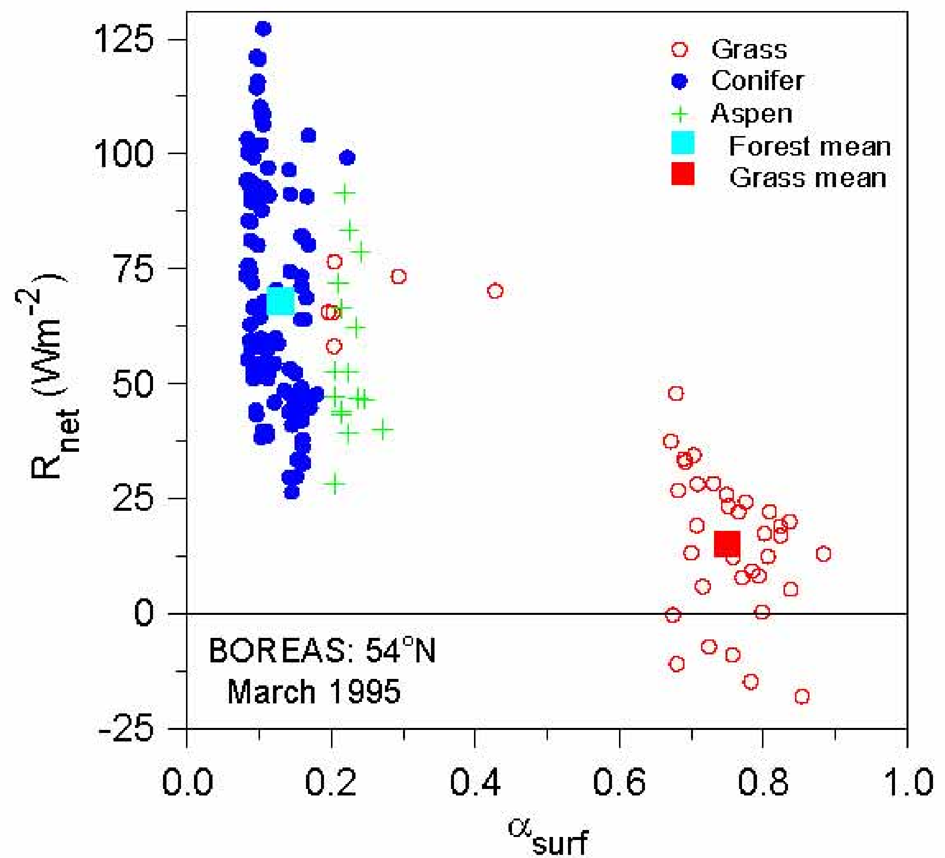
- Winter SW_{down}(clear) ≈ 130 Wm^{-2}
- 10cm fresh snow changes albedo from 0.15 to 0.75 & drops SW_{net} from 110 to 30 Wm^{-2}

- Residual 30 Wm^{-2} sublimes 1cm snow/day

- Snow loss increases as snow ages
  – snow lasts ≈ 5 days,
  – reducing solar heating to ≈ zero

Boreal forest example





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

Gardening in Pittsford, Vermont in January

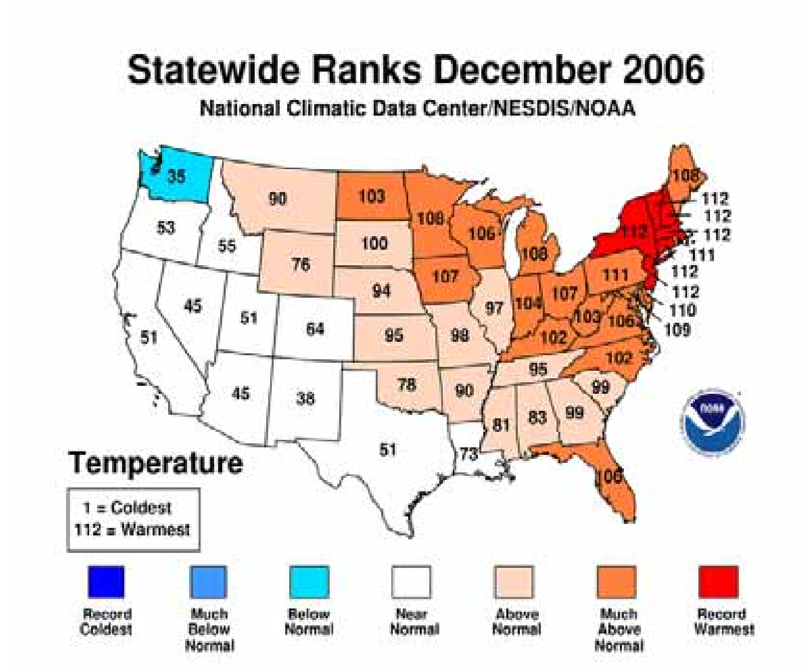
January 7, 2007

January 10, 2008

December 2006:
- Warmest on record

Warm Fall:
- Record Arctic sea-ice melt
- Snow cover in December, ground unfrozen

Gardening in Pittsford, Vermont in January



January 7, <u>2007</u>

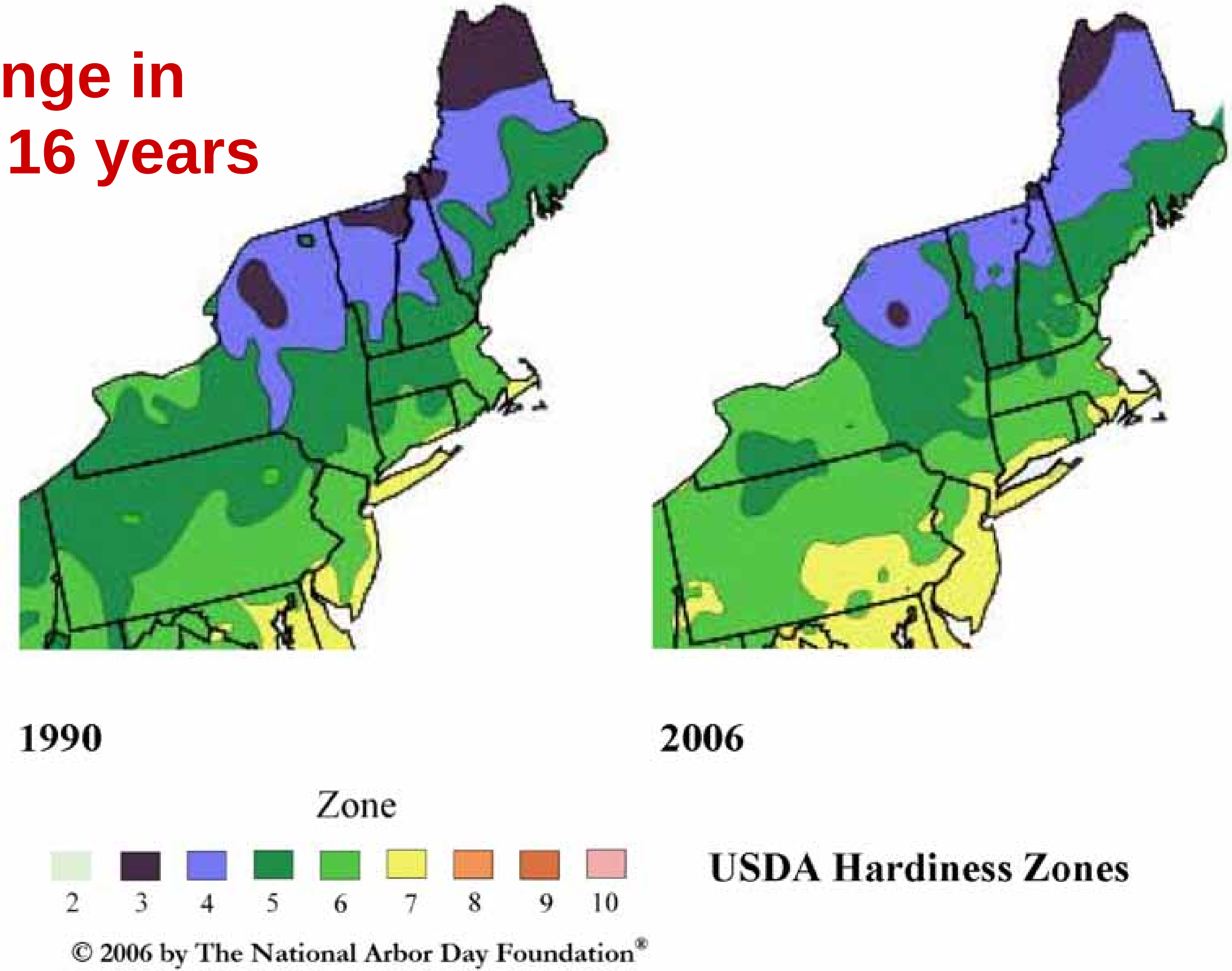
December 2006: Warmest on record in NE

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

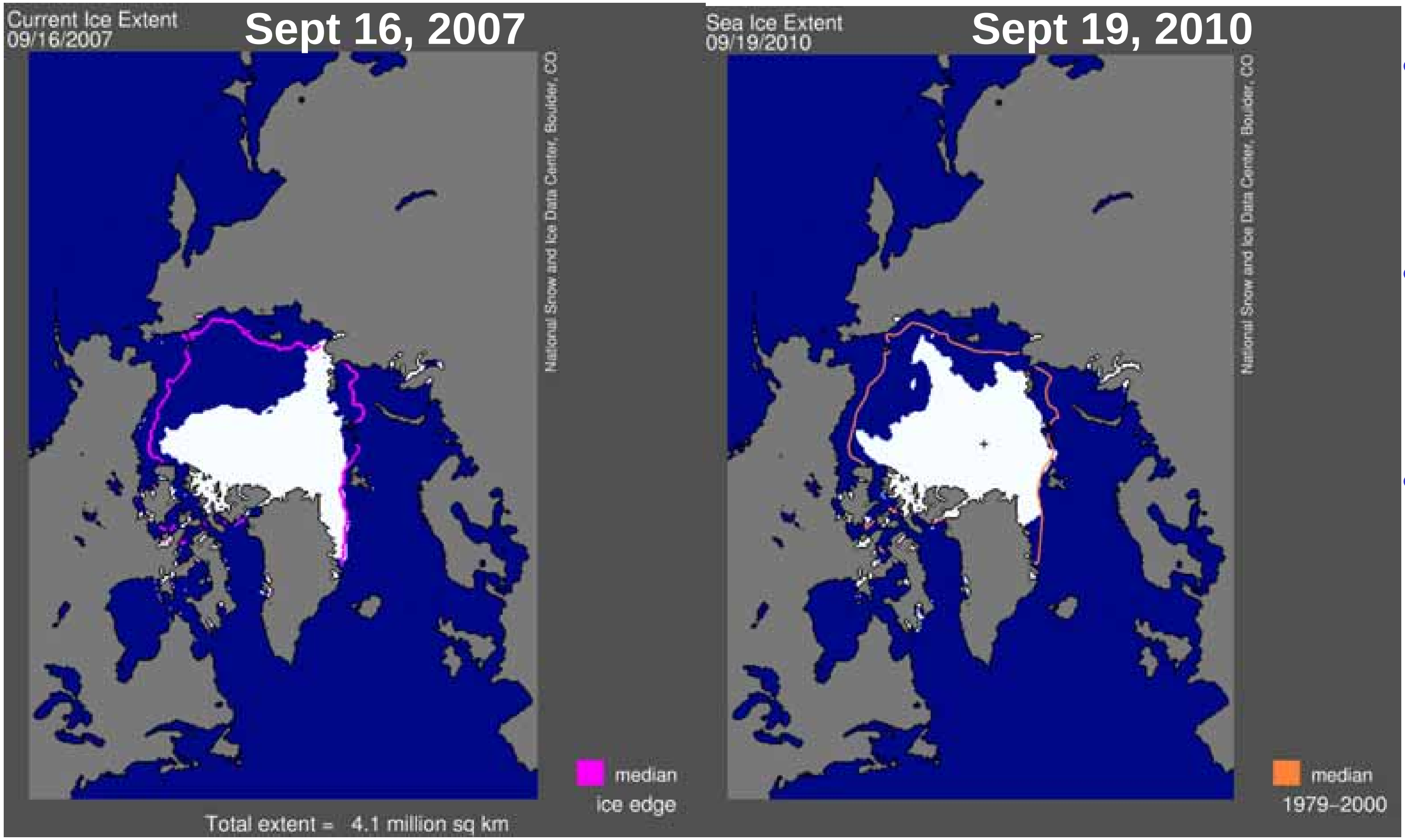
Picked February 10, 2008, Pittsford, VT

USDA Hardiness Zones - Northeast

Change in last 16 years



Arctic Sea Ice Loss Has Accelerated



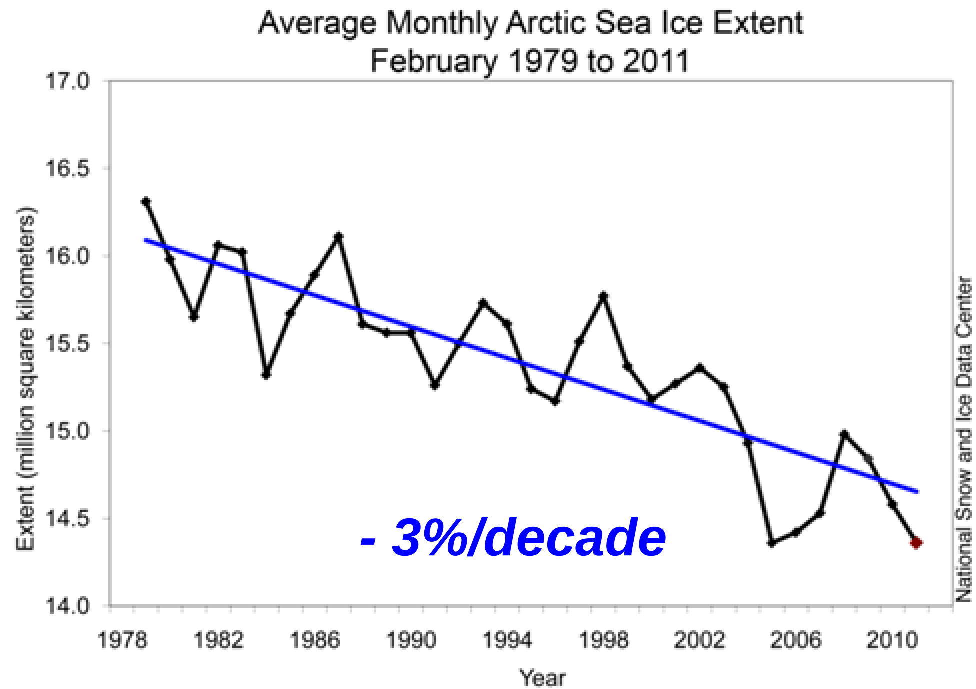
- Feedbacks speed melting
- Less ice, less sunlight reflected
- More evapor-ation, larger water vapor greenhouse effect

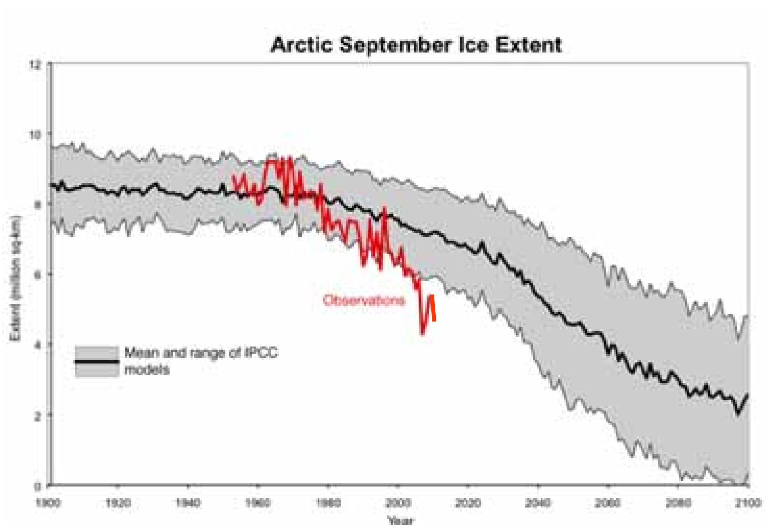
(www.nsidc.org)

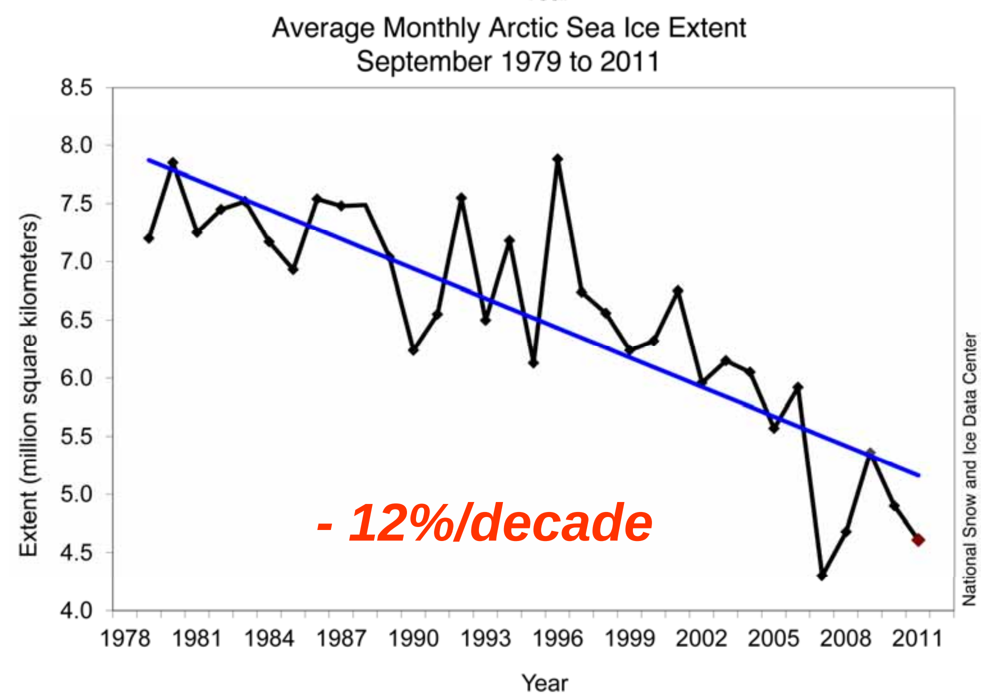
- Record ice loss in 2007
  - most ice now only 1-2 years old
- Open water in October contributes to warmer Fall

Sea Ice Trends

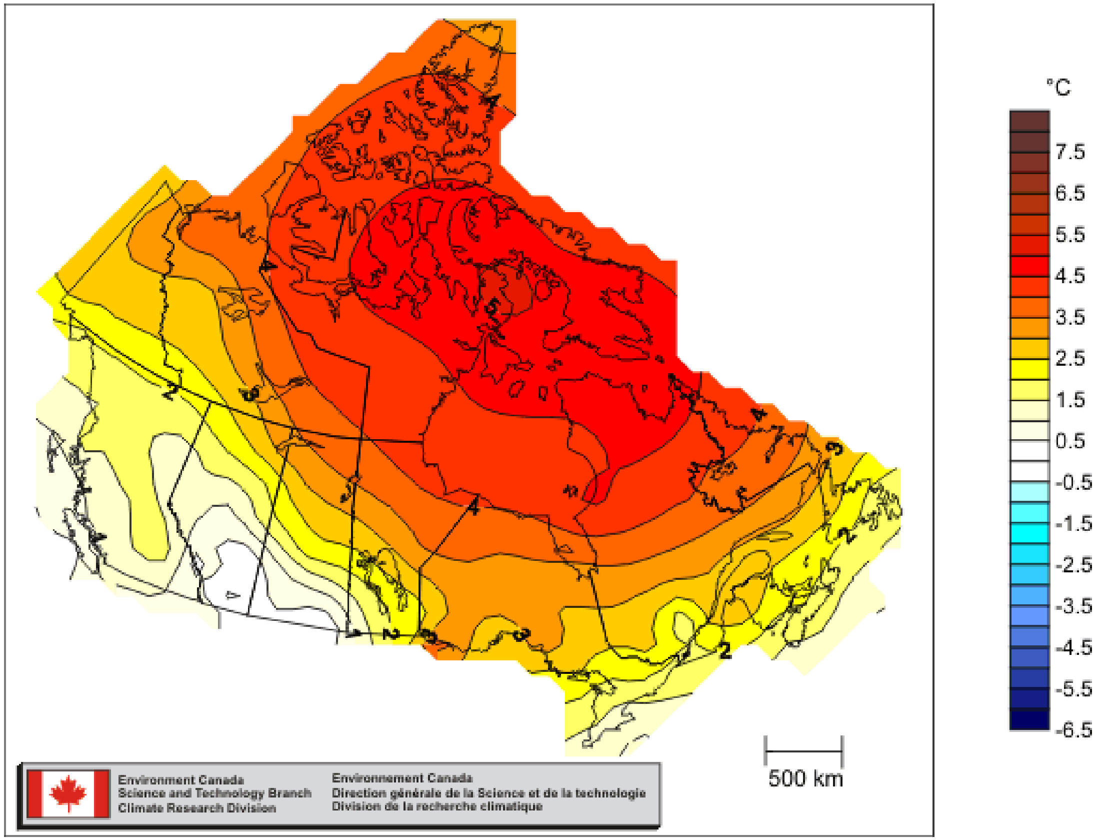
- **Sea ice is thinning rapidly**
- **Observed September decline appears to be faster than IPCC climate model projections**



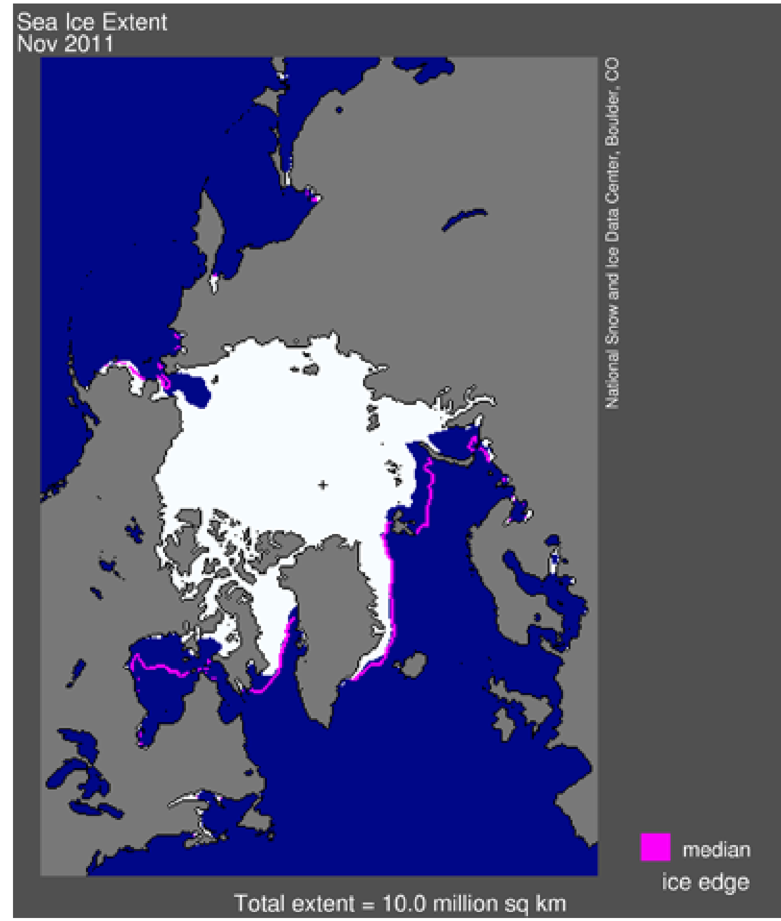




Watch Canada, Hudson’s Bay?



- **2010 anomaly (ºC)**



Hudson’s Bay unfrozen, Nov. 2011
http://nsidc.org/arcticseaicenews/

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**

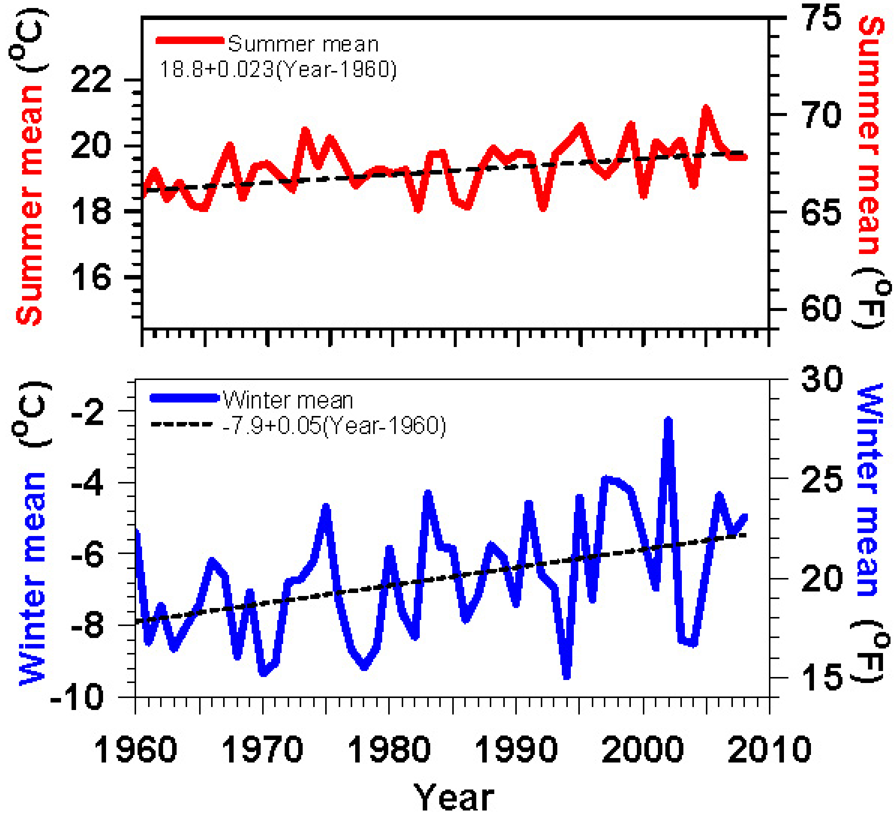
Betts, WCAS, 2011

Vermont Temperature Trends

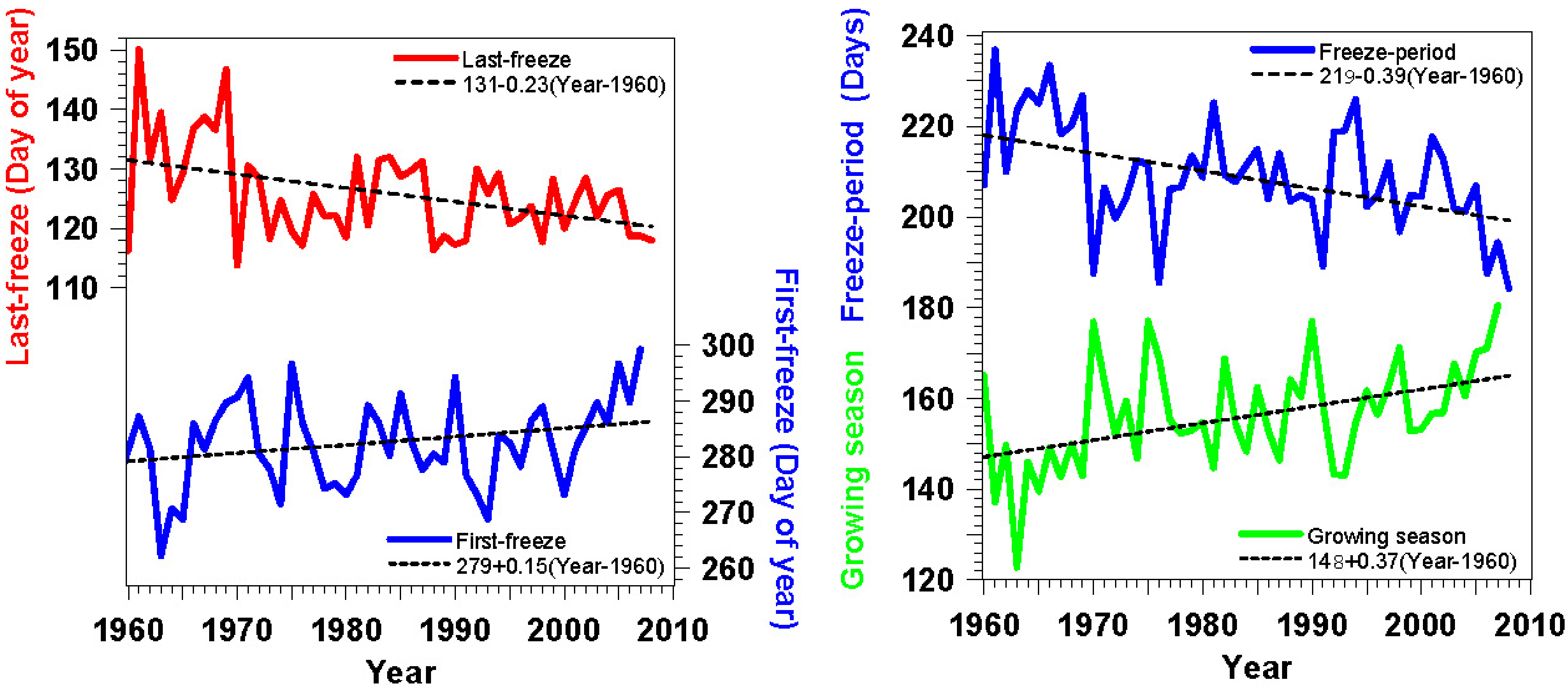
- **Summer +0.4°F / decade**

- **Winter +0.9°F / decade**

- **Less snow drives larger winter warming**



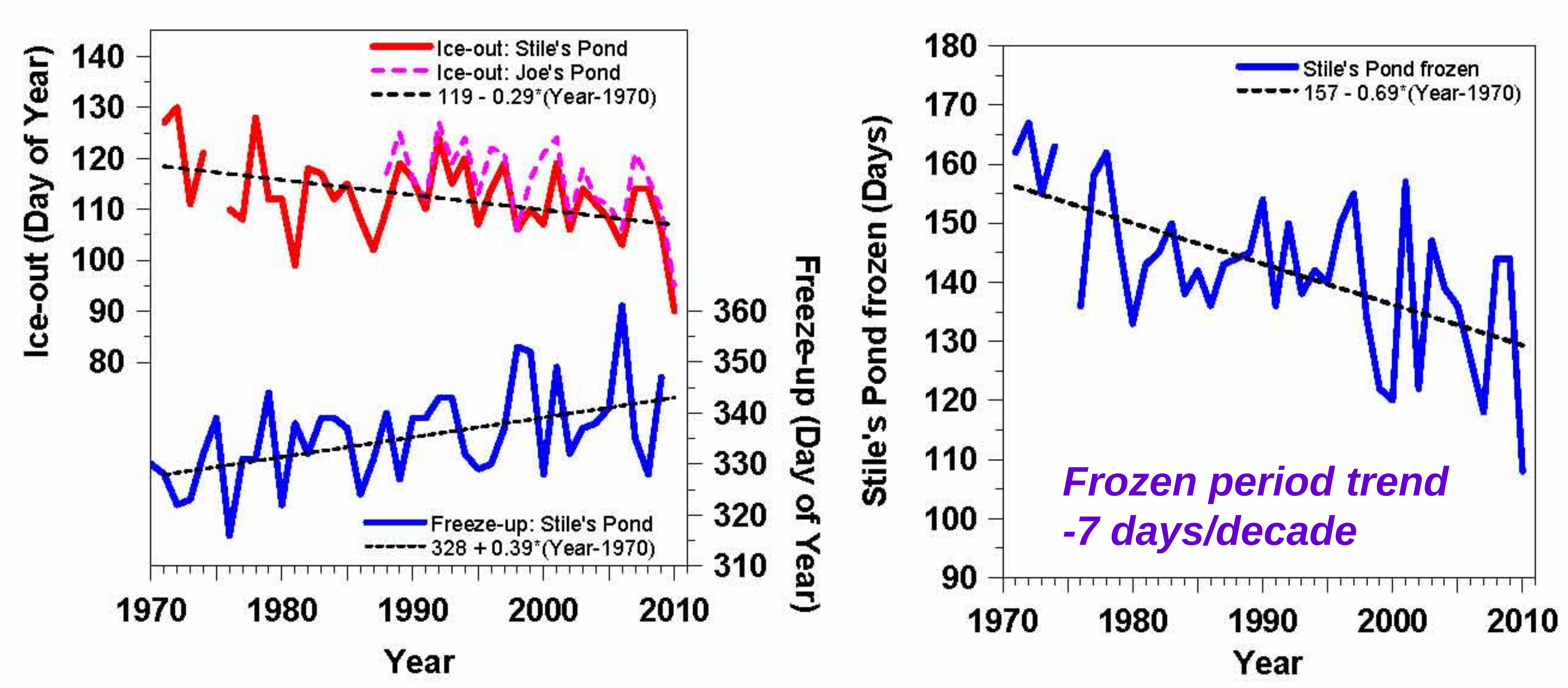
First and Last Frosts Changing



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

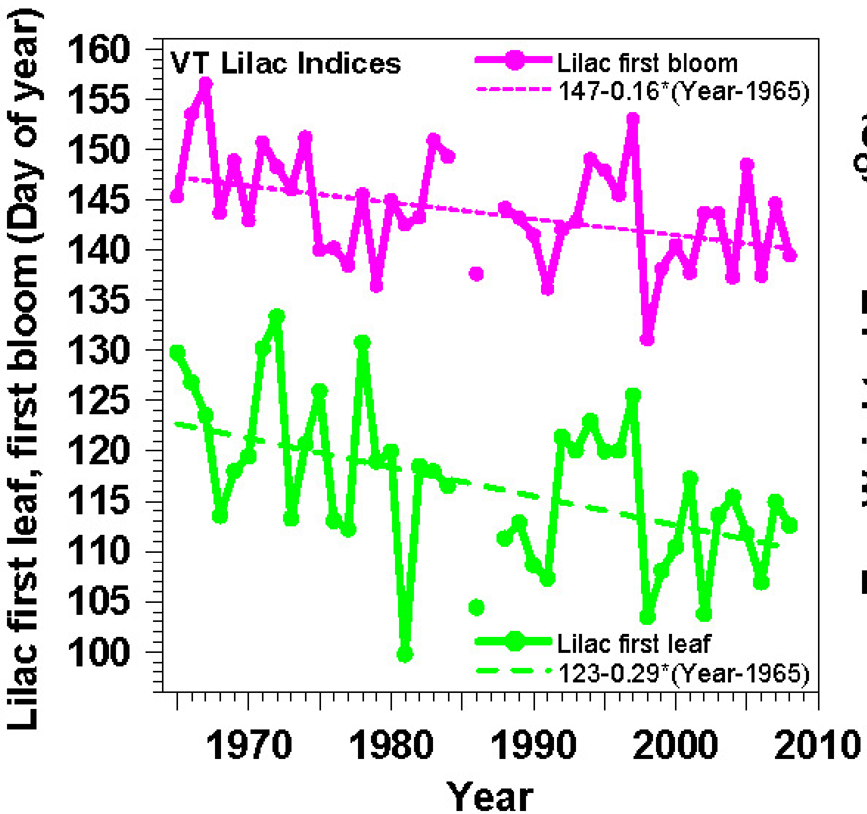
Lake Freeze-up & Ice-out Changing

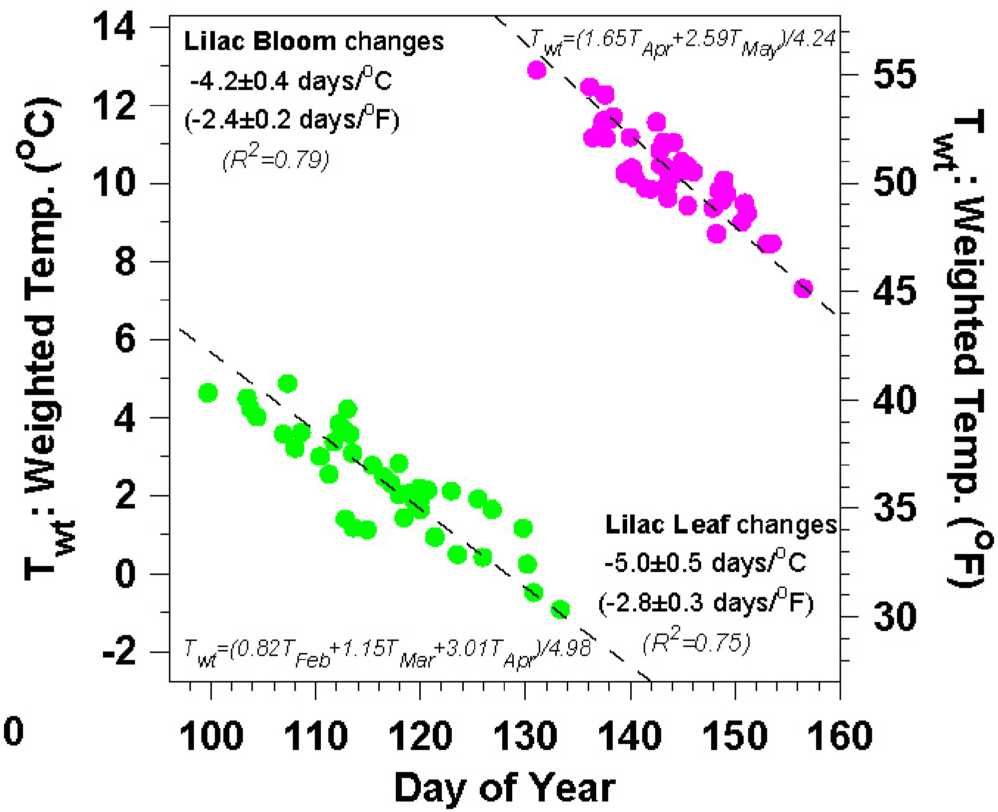
Frozen Period Shrinking Fast



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

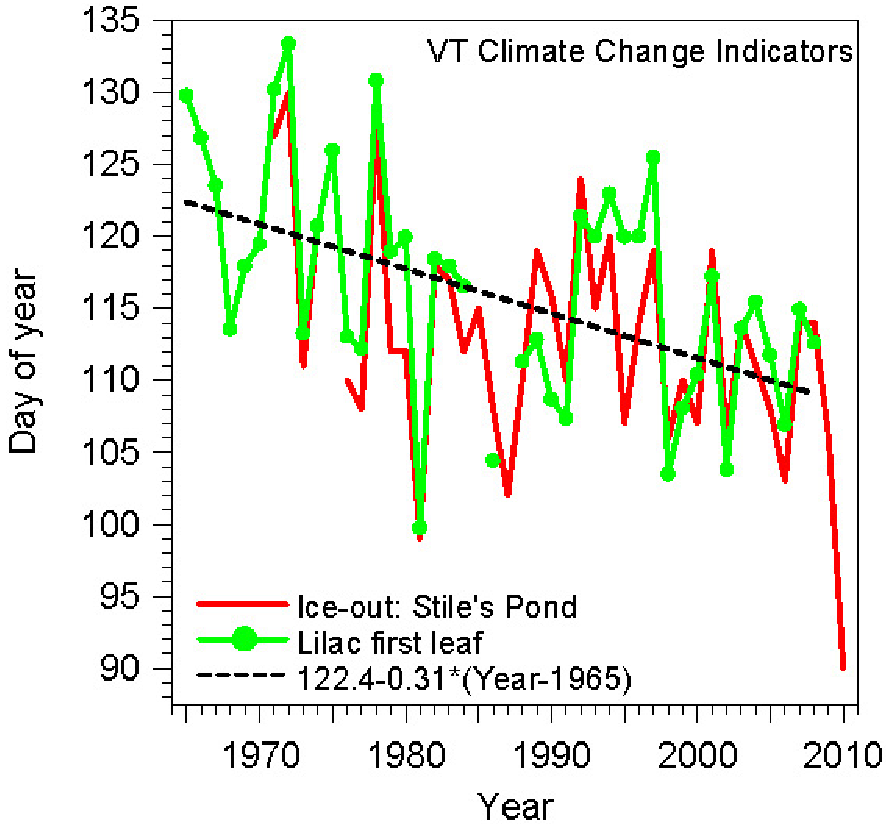
Lilac Leaf and Bloom in Spring

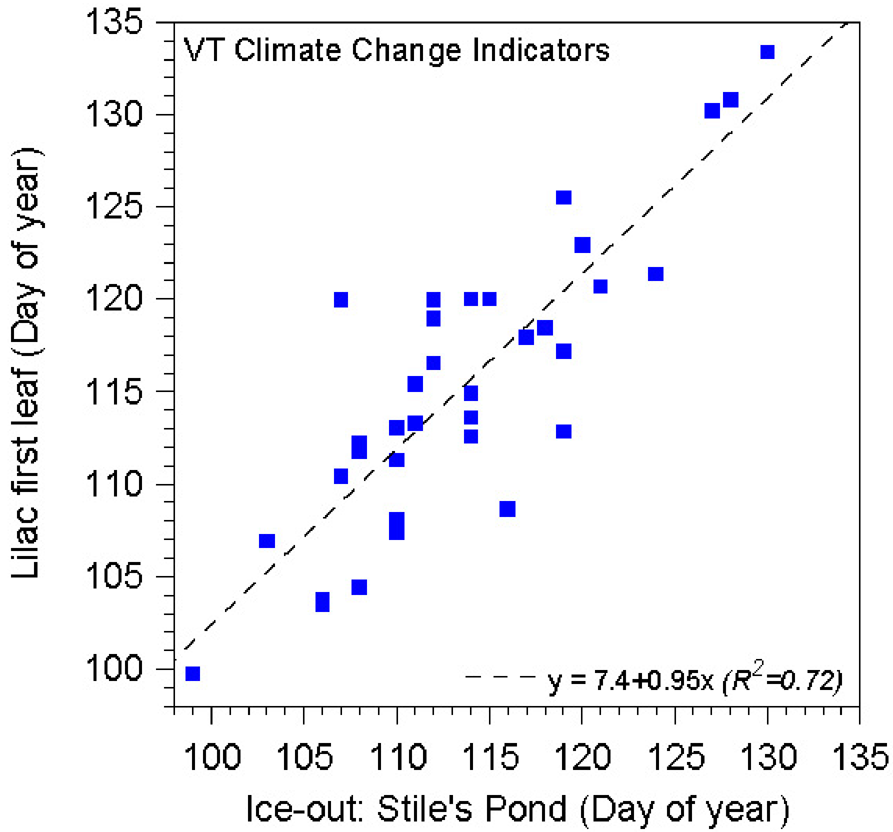




- **Leaf-out earlier by 3 days/decade (tracks ice-out)**
- **Bloom earlier by 1.5 days/decade**
- **Leaf & bloom change 2.5 days/°F (4.5 days/°C)**

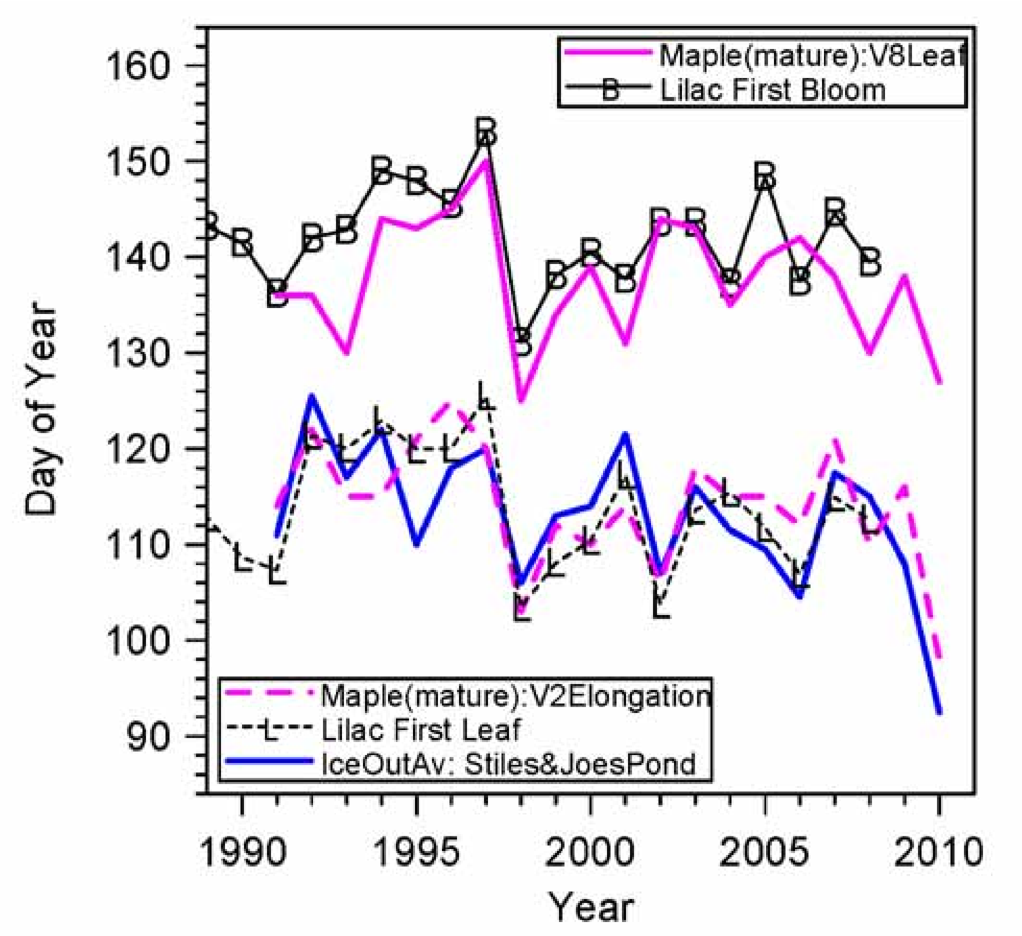
Lilac first leaf matches ice-out!





- 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

- 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

Can We Stop “Dangerous Climate Change”?

- **Yes:** **Quickly stabilize atmospheric CO_2**
- **This means an 80% drop in CO_2 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
- **CO_2 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 CO_2 to 1,000 ppm—and in time melt icecaps
    - Can we “sequester” CO_2 (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**

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?

Conclusions -2

- ***We have the tools & knowledge - but not the wisdom!***

- **We need to look beyond our traditional silos and accept our individual and collective responsibilities**

- **We create the future – it is not a given!**
  - **Is this an efficient, sustainable way of doing this?**
  - **Do I have a deep understanding of the Earth?**

What can the Weather Service do?

- **Climate science is under attack because it is politically and economically relevant**
- ***Yet the public wants to know and understand what is happening!***
- **Explain links between weather and climate. Discuss extreme weather.**
- **Push for more research to explain what is happening to mid-latitude climate as the Arctic melts**

Forecasting challenges

- Non-stationary system: climate changing; climate mode frequency changing
- Severe weather increasing: stationary mode frequency increasing & temperature increasing
- Historic teleconnection indices (NAO, AO, PNA, ENSO, MJO, etc.) for extended range forecasting?
- Big new signals are warming Arctic, warming northern winters (albedo/LW greenhouse)
- How do these affect synoptic patterns; 500 hPa wave modes; blocking?

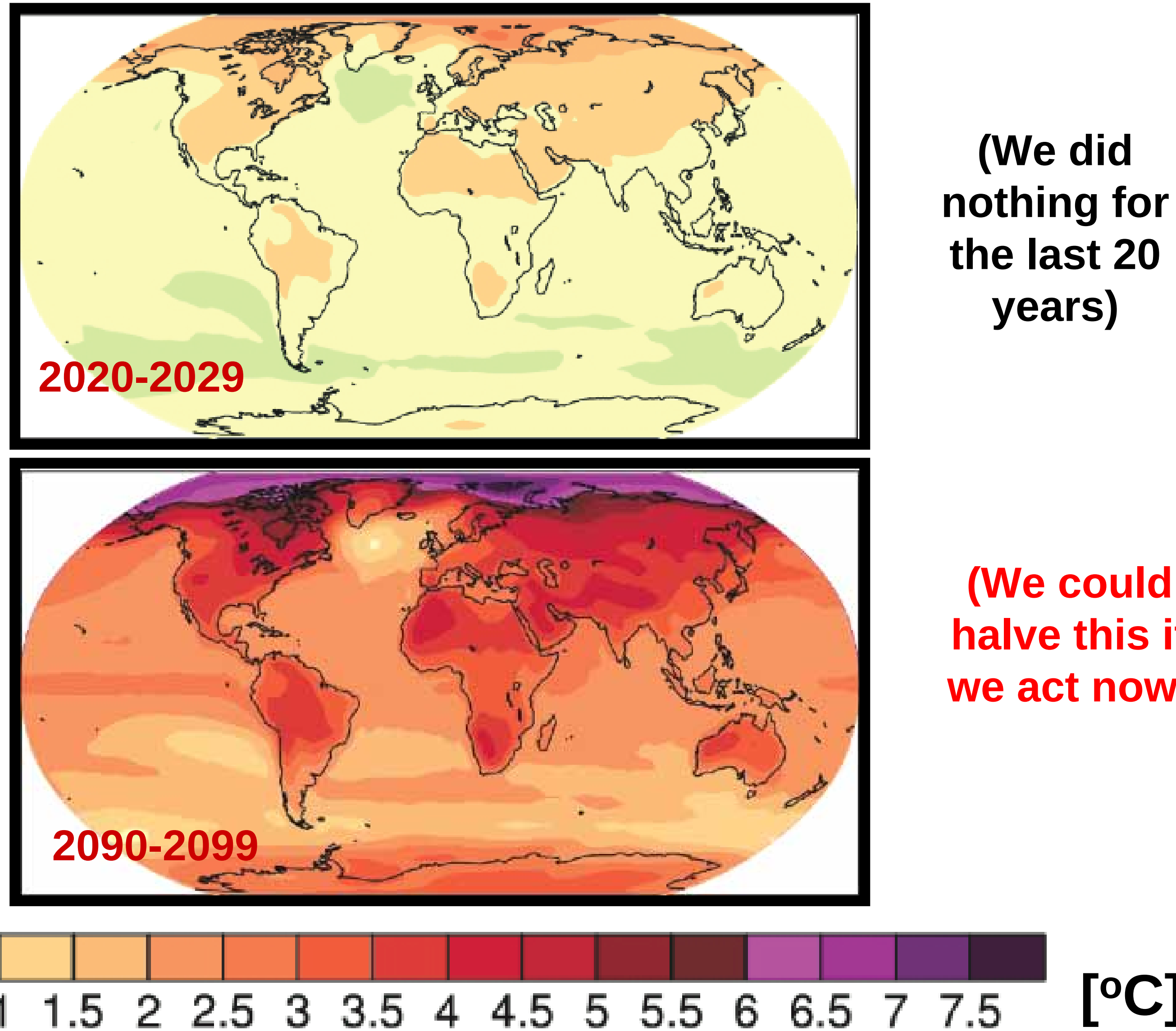
Multi-model Predicted Percent Change in Temperature (2020-2029 and 2090-2090 relative to 1980-1999) [°C]

‘Committed’

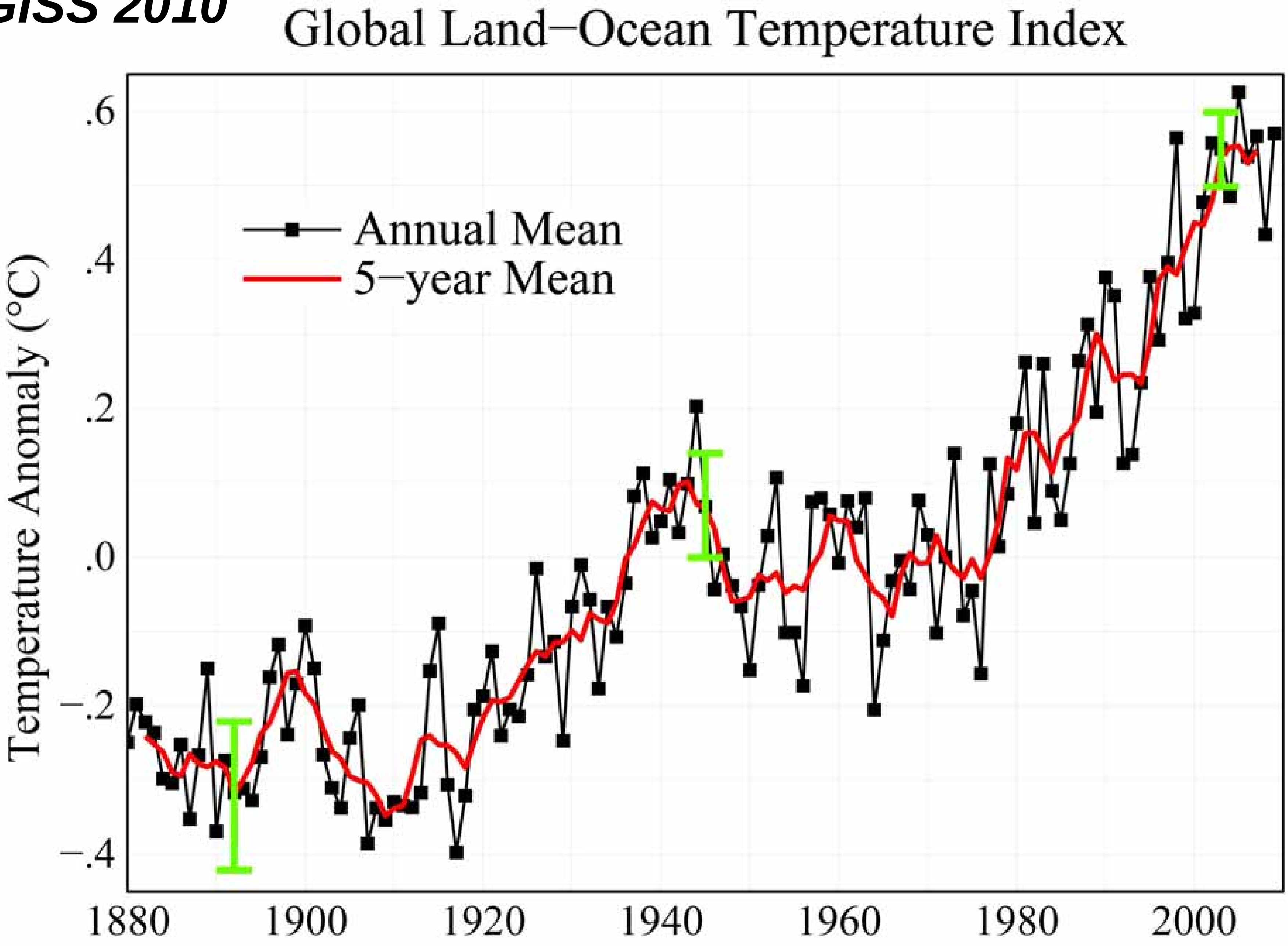
(We did nothing for the last 20 years)

Still up to us!

(We could halve this if we act now)



GISS 2010



Global Land−Ocean Temperature Index
Annual Mean
5−year Mean
Temperature Anomaly (°C)
.6
.4
.2
.0
−.2
−.4
1880
1900
1920
1940
1960
1980
2000