Climate Change, Vermont and the Future

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Sustainable Development Policy

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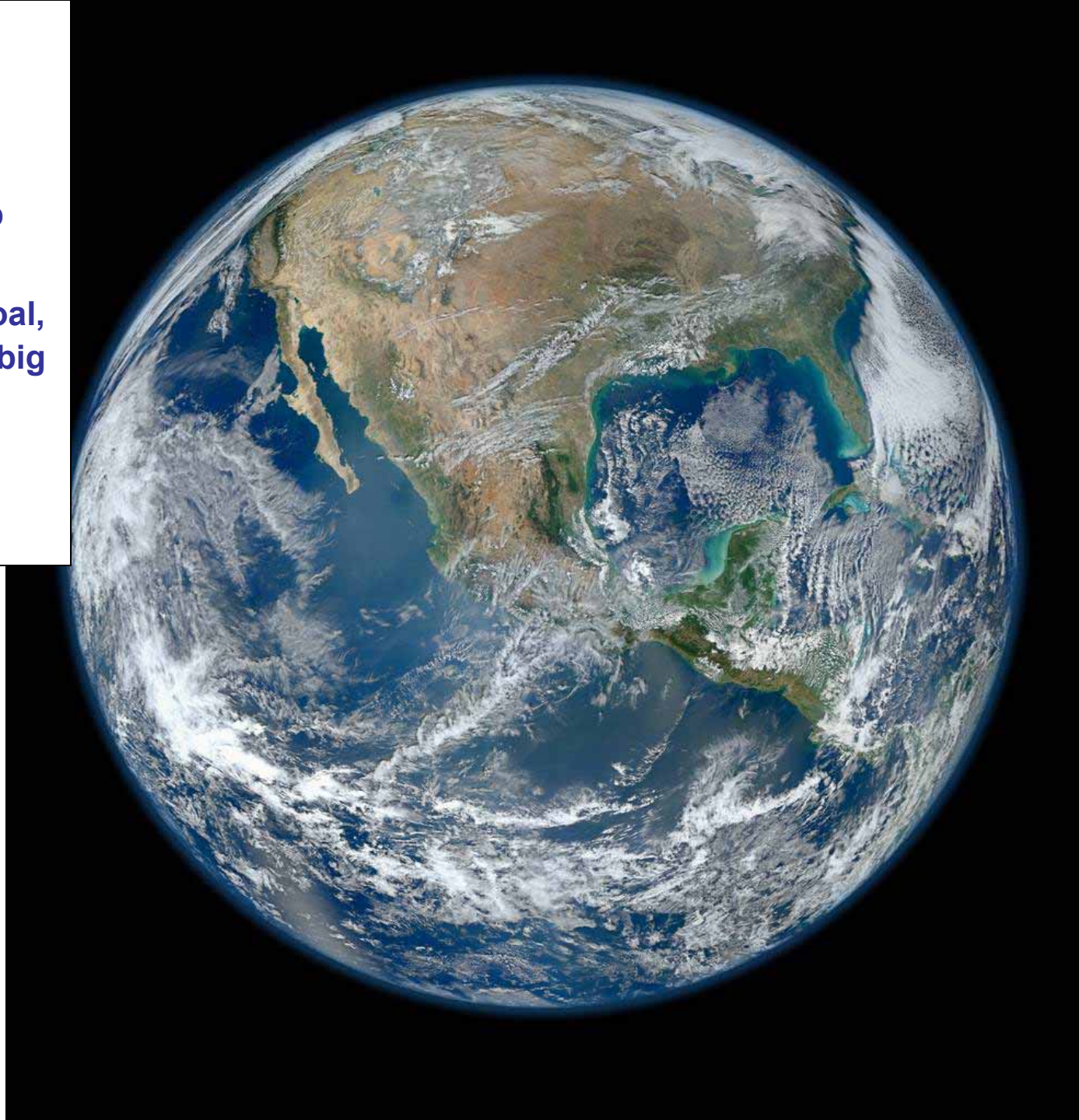
- Earth sustains life
- Weather changes fast
- Climate changes slowly
- Greenhouse gases keep Earth warm
- Burning fossil fuels – coal, oil and gas – is having a big effect on climate by increasing greenhouse gases: CO_2 and H_2O



January 2, 2012: NASA

Climate Change

- **One of the many great challenges for the 21st century - present path is unsustainable**
- **We are already decades late in taking action**

J. S. Sawyer (1972): Man-made CO_2 and the "greenhouse" effect

Charney Report (1979): Carbon dioxide and Climate

UN Framework Convention on Climate Change (1992) in Rio, Brasil

- To stop "Dangerous Climate Change"

- **It is a global issue & a local issue**
  a societal issue & a personal issue

- **Clash between Earth science**
  and economic & social values

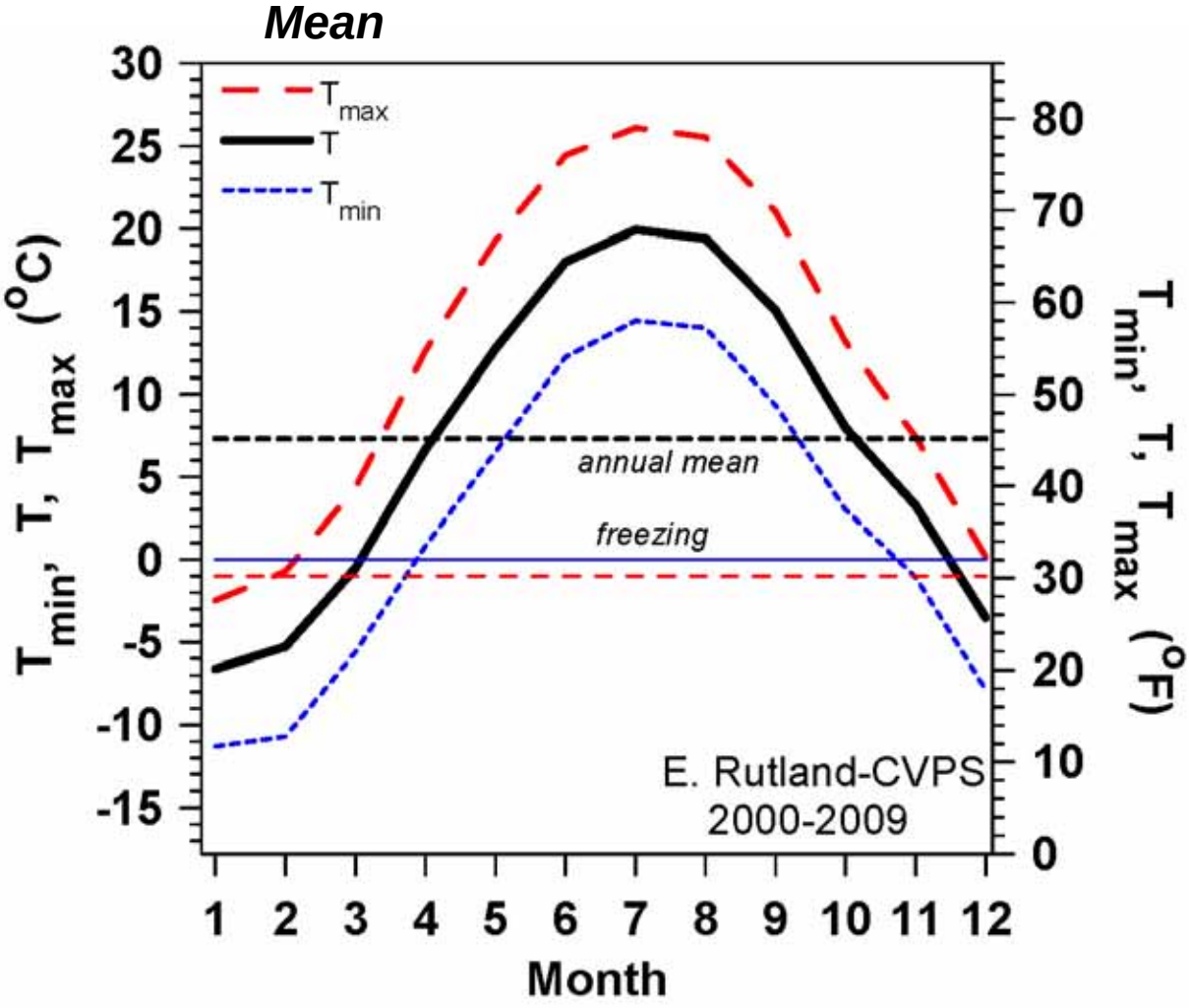
Outline

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

Discussion

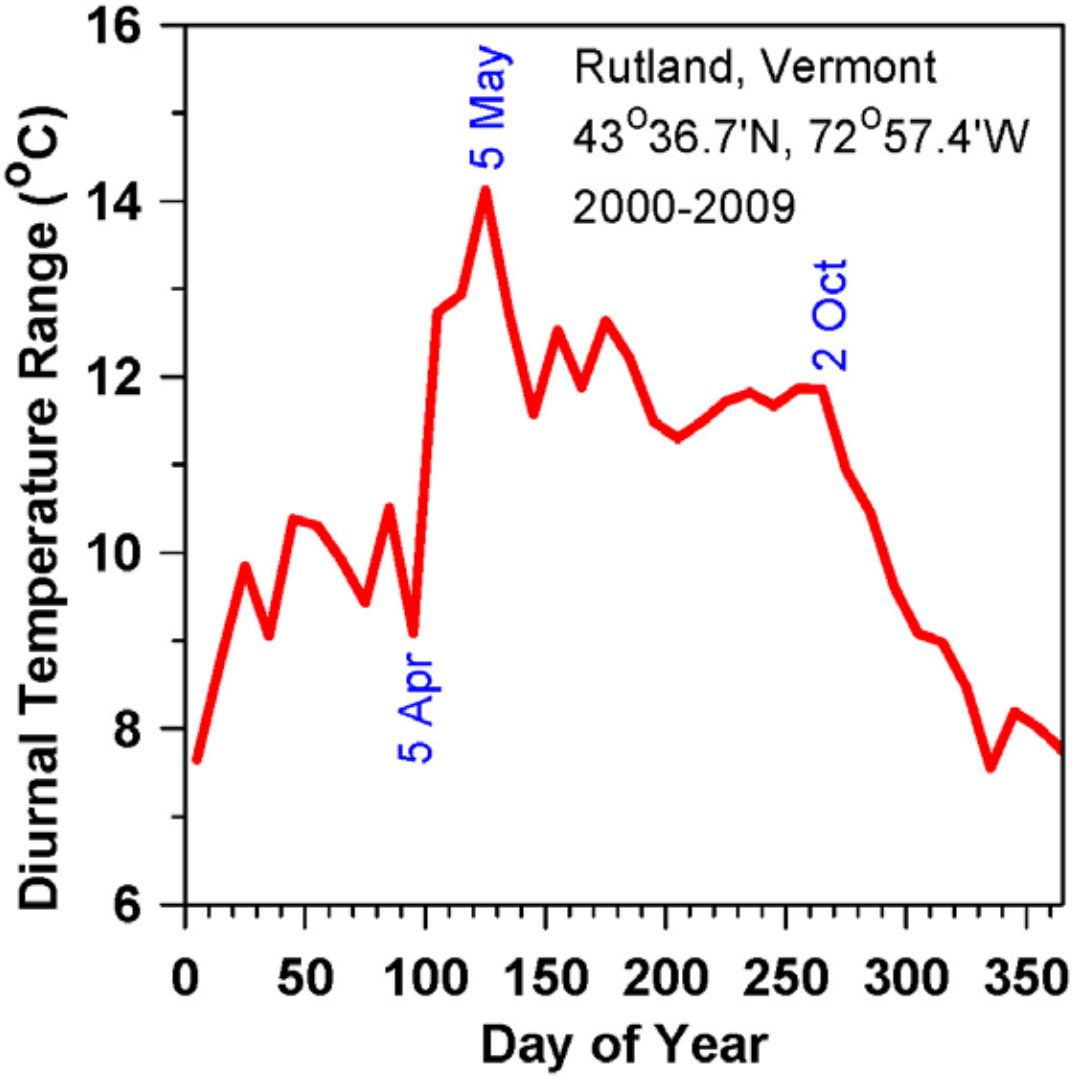
Climate of Vermont

- **Climate is a mean (10-30y)**
- **T_{max}, T, T_{min}**
- **Large seasonal range in VT**
- ***Freezing T of water critical to climate***



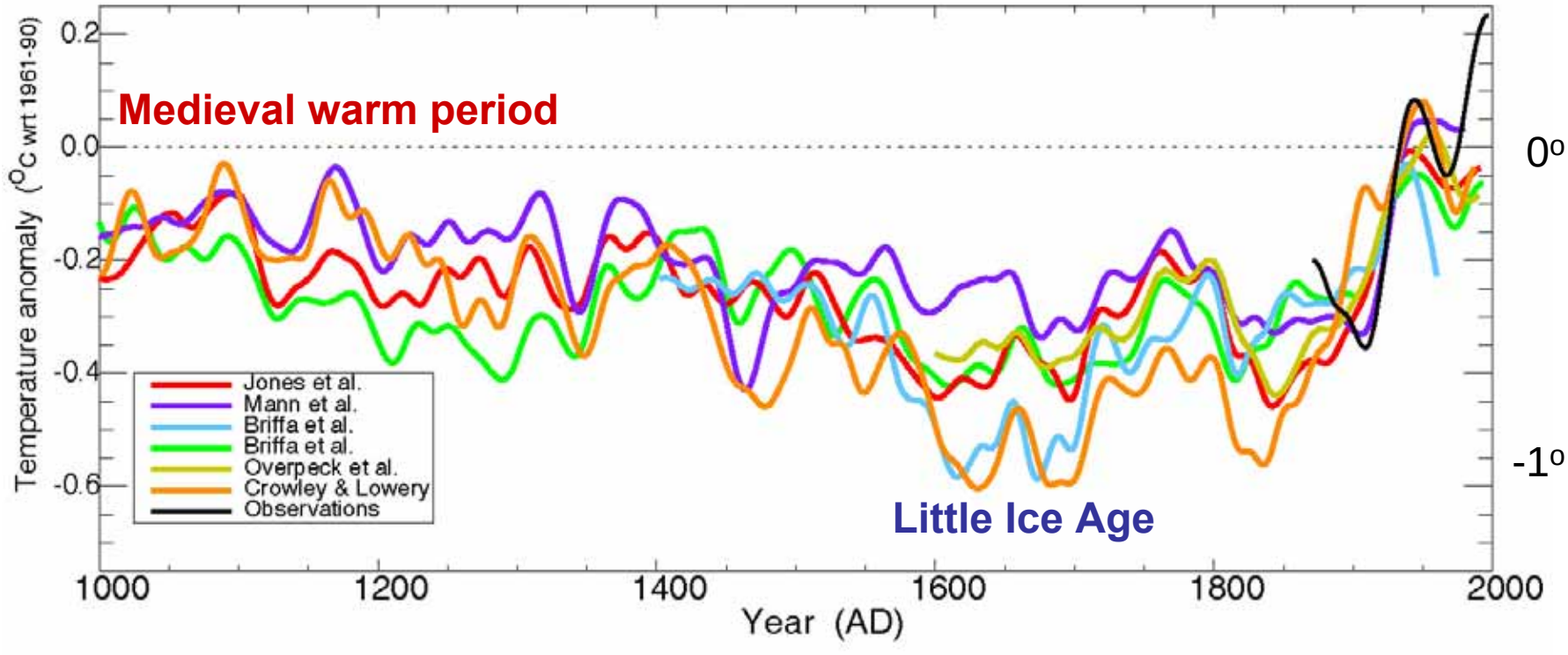
Diurnal Temperature Range

- T_{max}-T_{min}
- **Mean daily range of T varies with season**
- **Related to RH and LW_{net}**



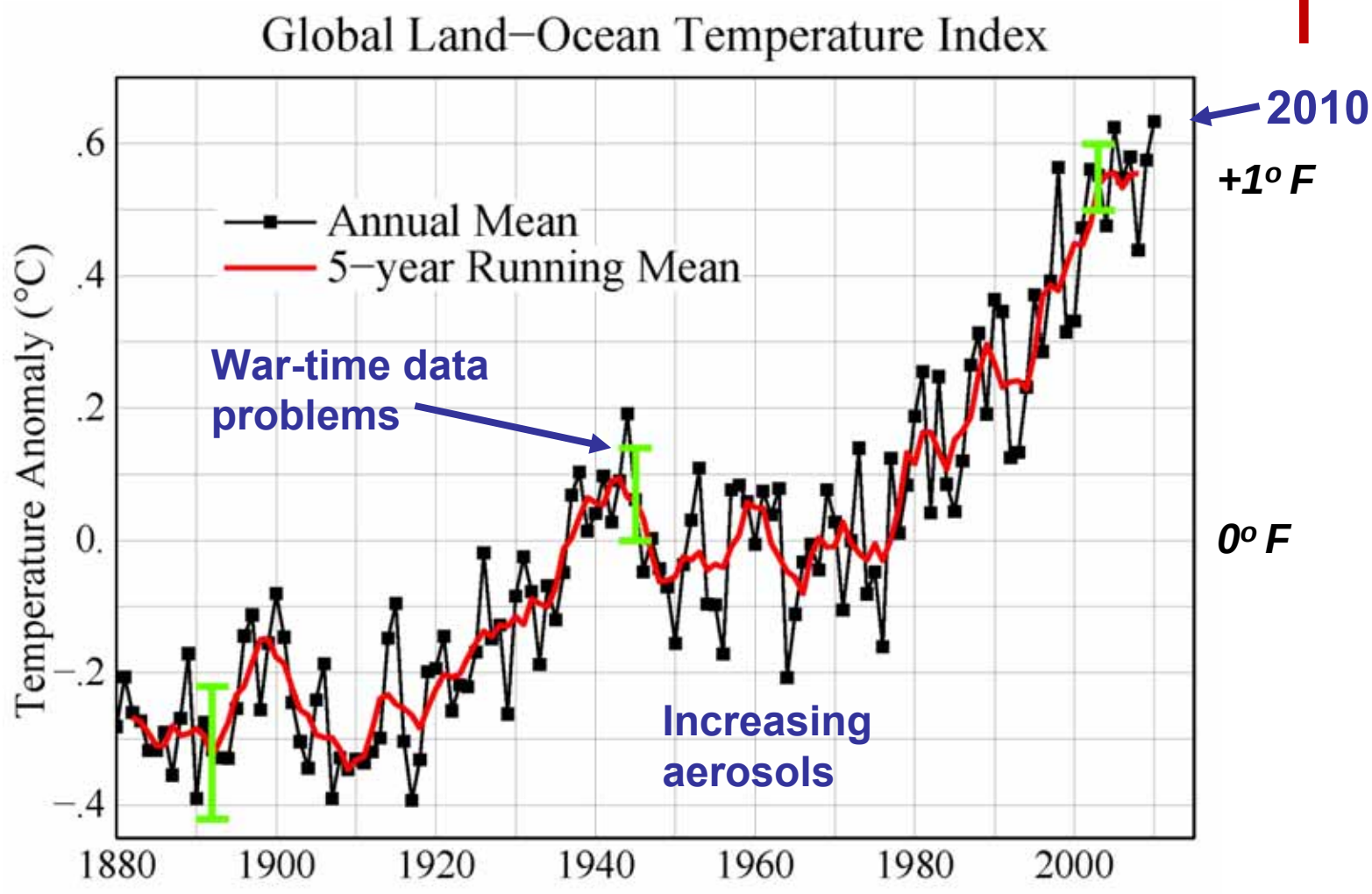
2100: +5°F

Millennial Temperature Record



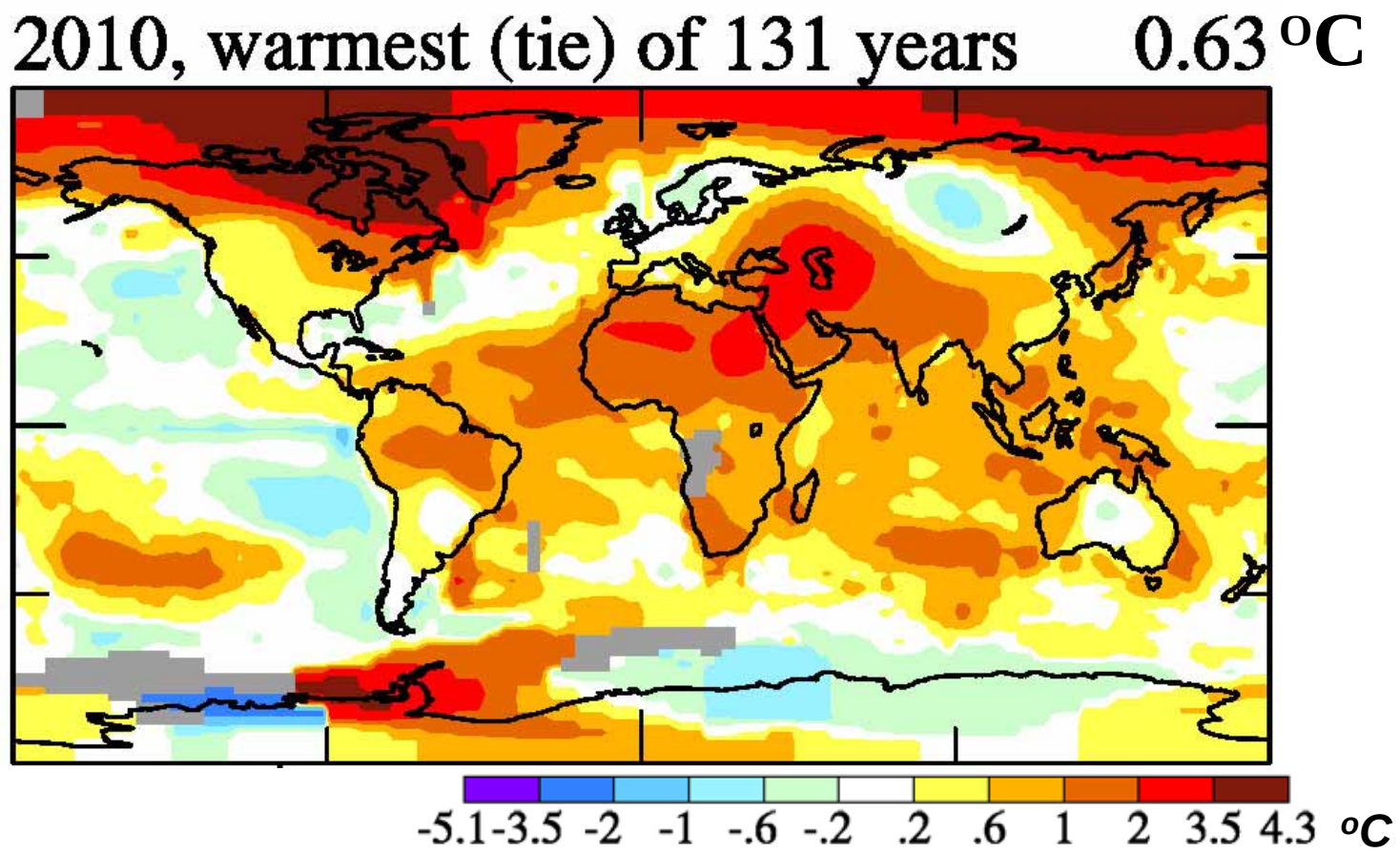
- **"Proxy" records from before the time of thermometers provide uncertain data, but they're all we have**

Global Temperature Rise 1880 – Present



NASA-GISS, 2011

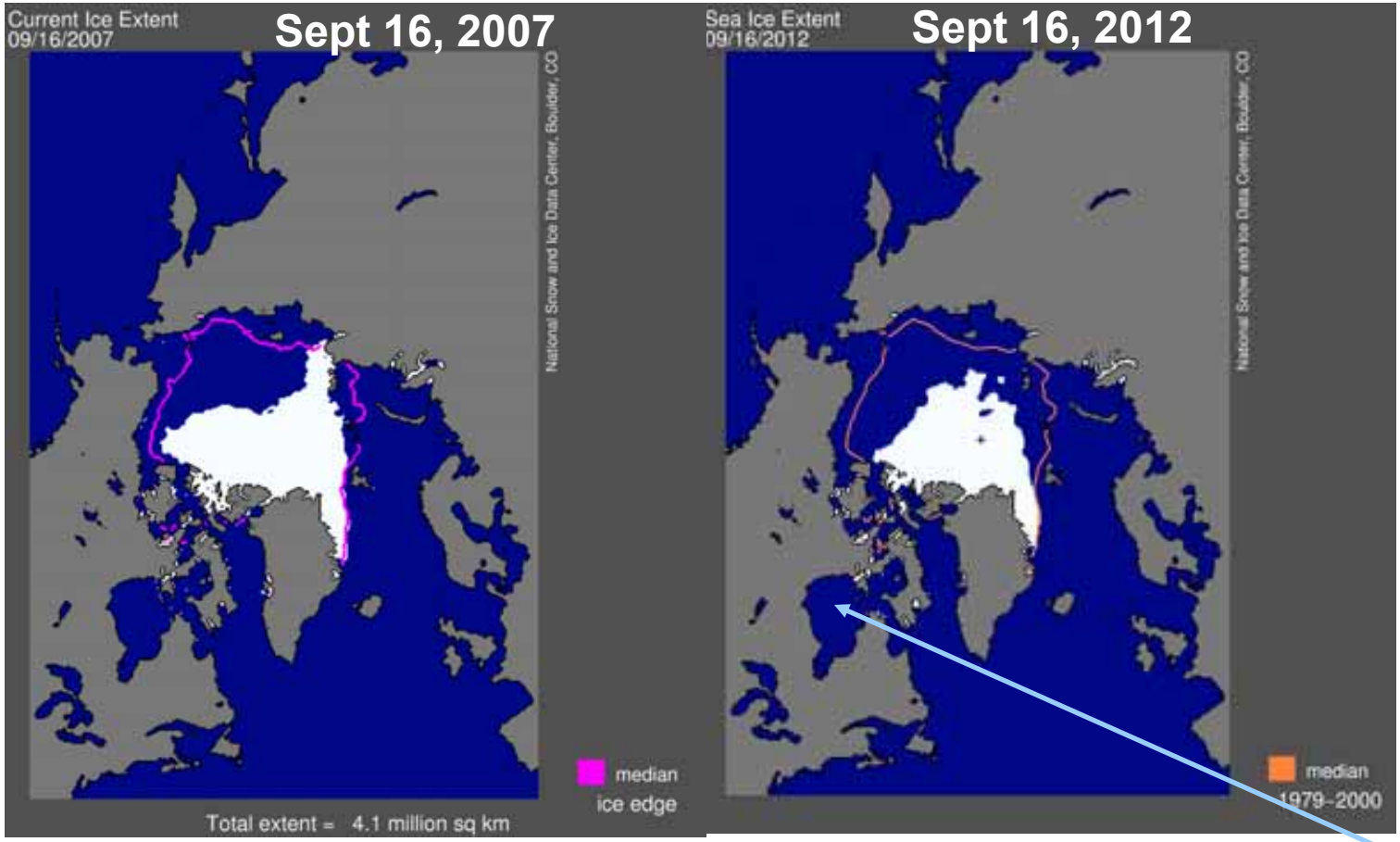
Global Picture 2010



- **Record summer temps**
  - **Russia (100°F) Moscow fires**
  - **Pakistan (128°F) Extreme monsoon floods**

Arctic Sea Ice Loss Has Accelerated

Climate Indicator: Integrates Over Years



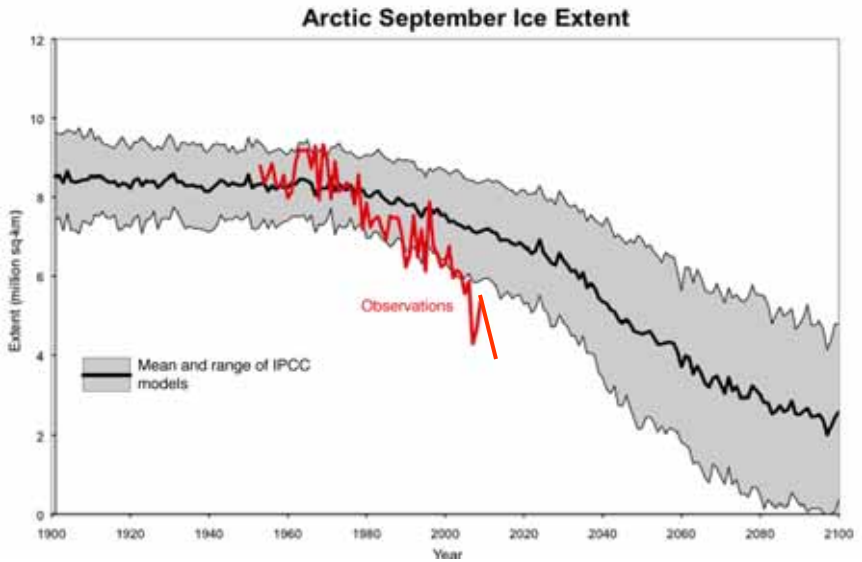
- **Positive feedbacks speed melting**
- **Less ice, less sunlight reflected**
- **More evapor-ation, larger water vapor greenhouse effect**

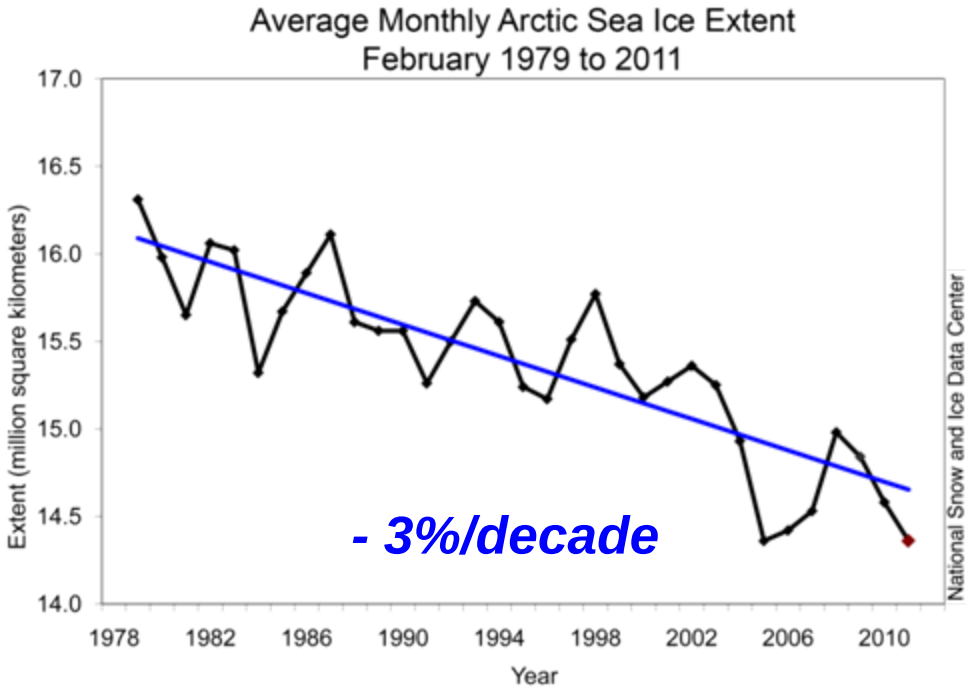
- **New Record Ice-loss: 2012** ***(www.nsidc.org)***
  - **most ice now thin (3-4ft) and only 1-year-old**
- **Open water in Oct. Nov. favors warmer Fall**

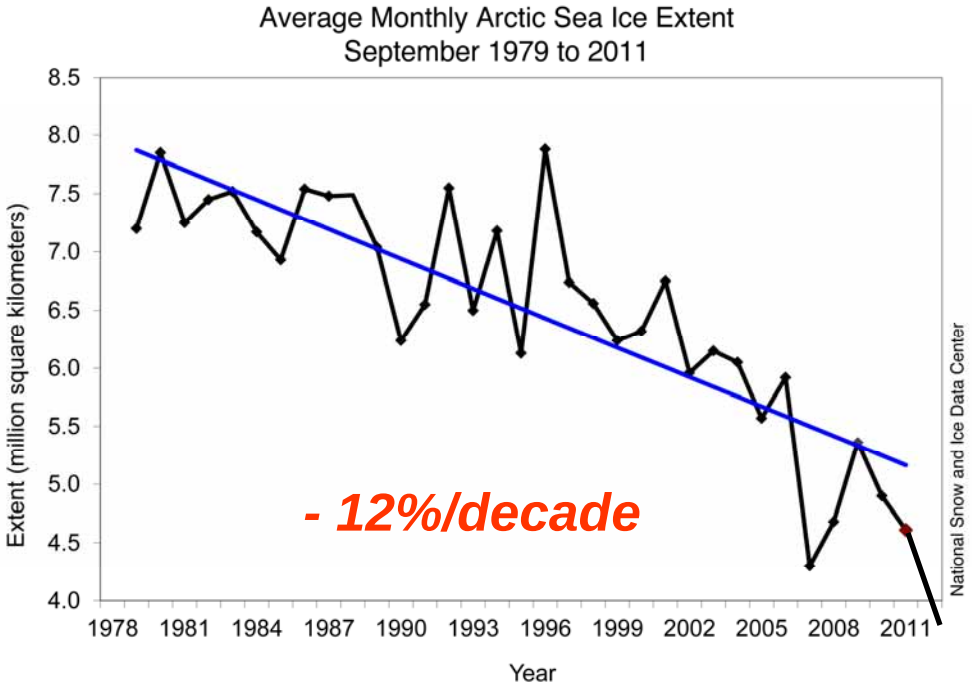
At the end of Nov. 2011 Hudson Bay was still nearly ice-free.

Sea Ice Trends

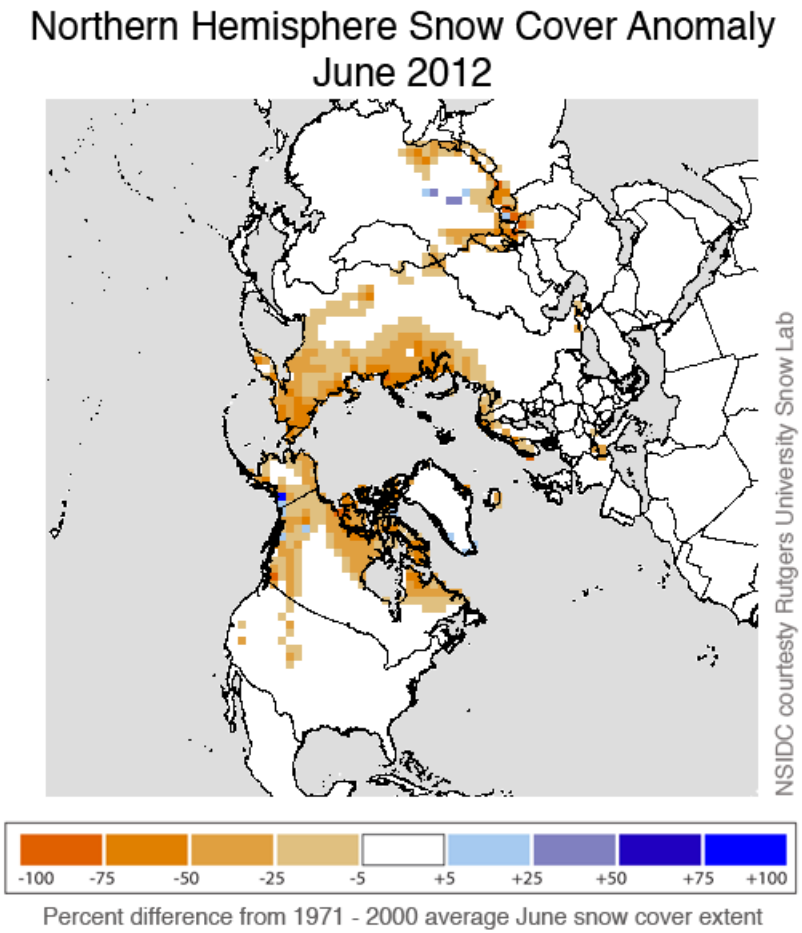
- Sea ice is thinning rapidly
- Observed September decline appears to be faster than IPCC-AR4 climate model projections
- *[AR5 projections should be faster]*

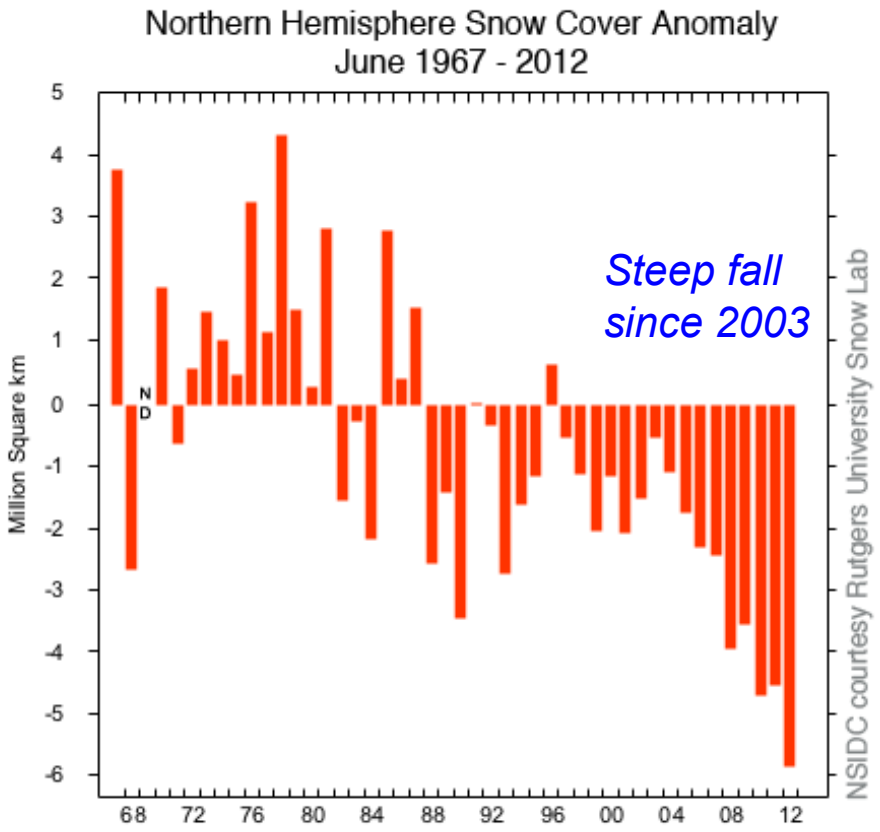






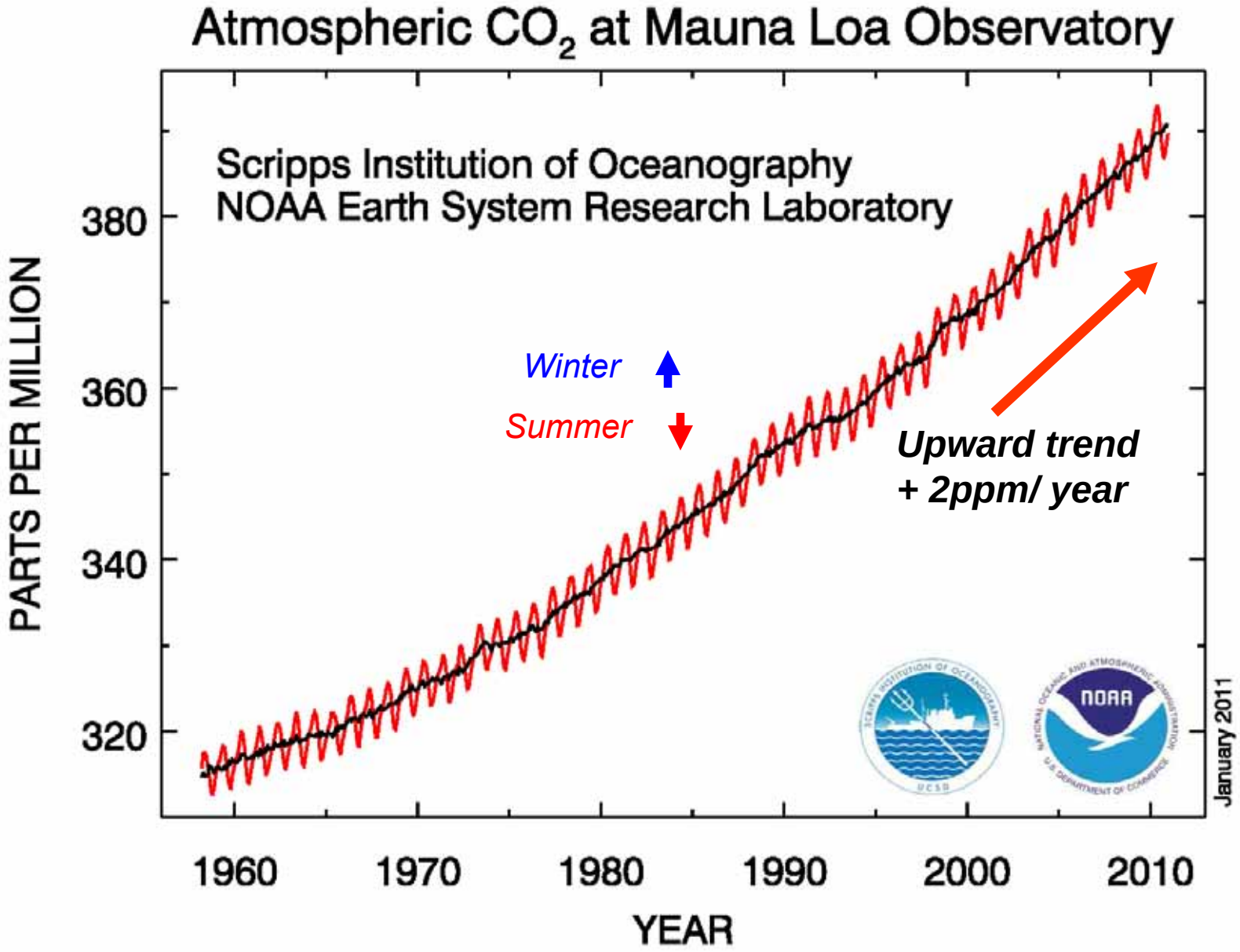
June 2012 snow cover minimum





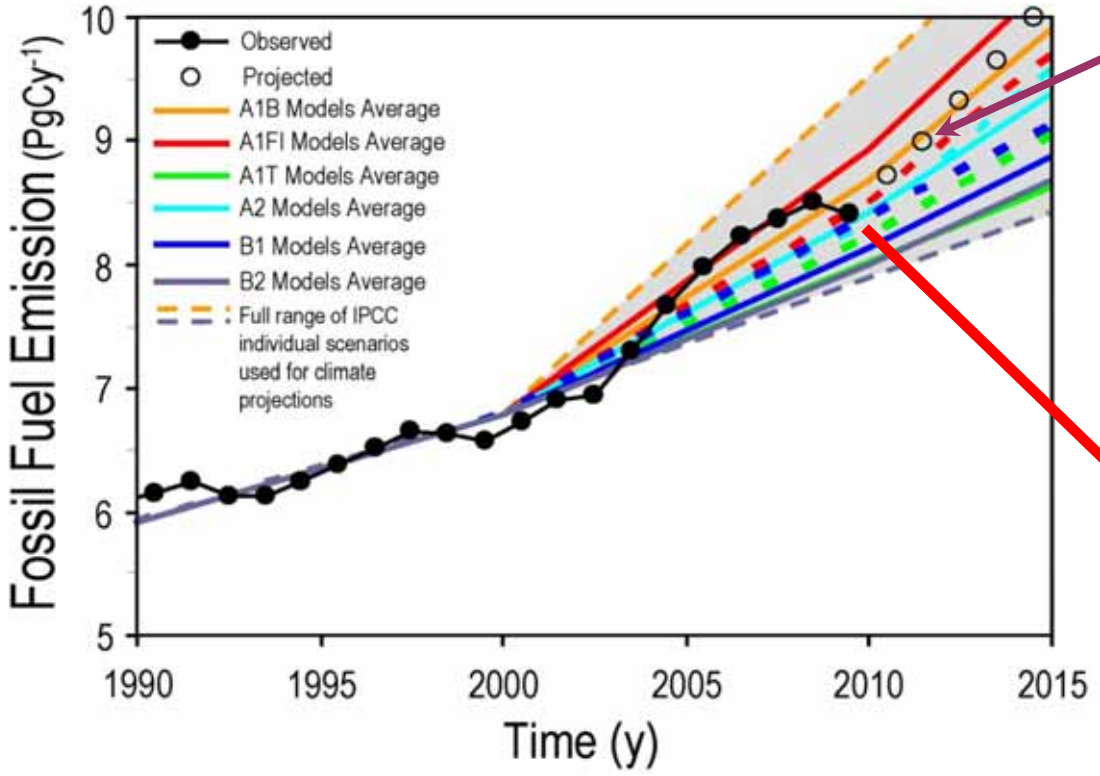
- **New minimum by 10^6 km^2 (1971-2000 ref)**

Carbon Dioxide Is Increasing



2009 Was "Good" for the Earth

Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Back on growth: 2010, 2011

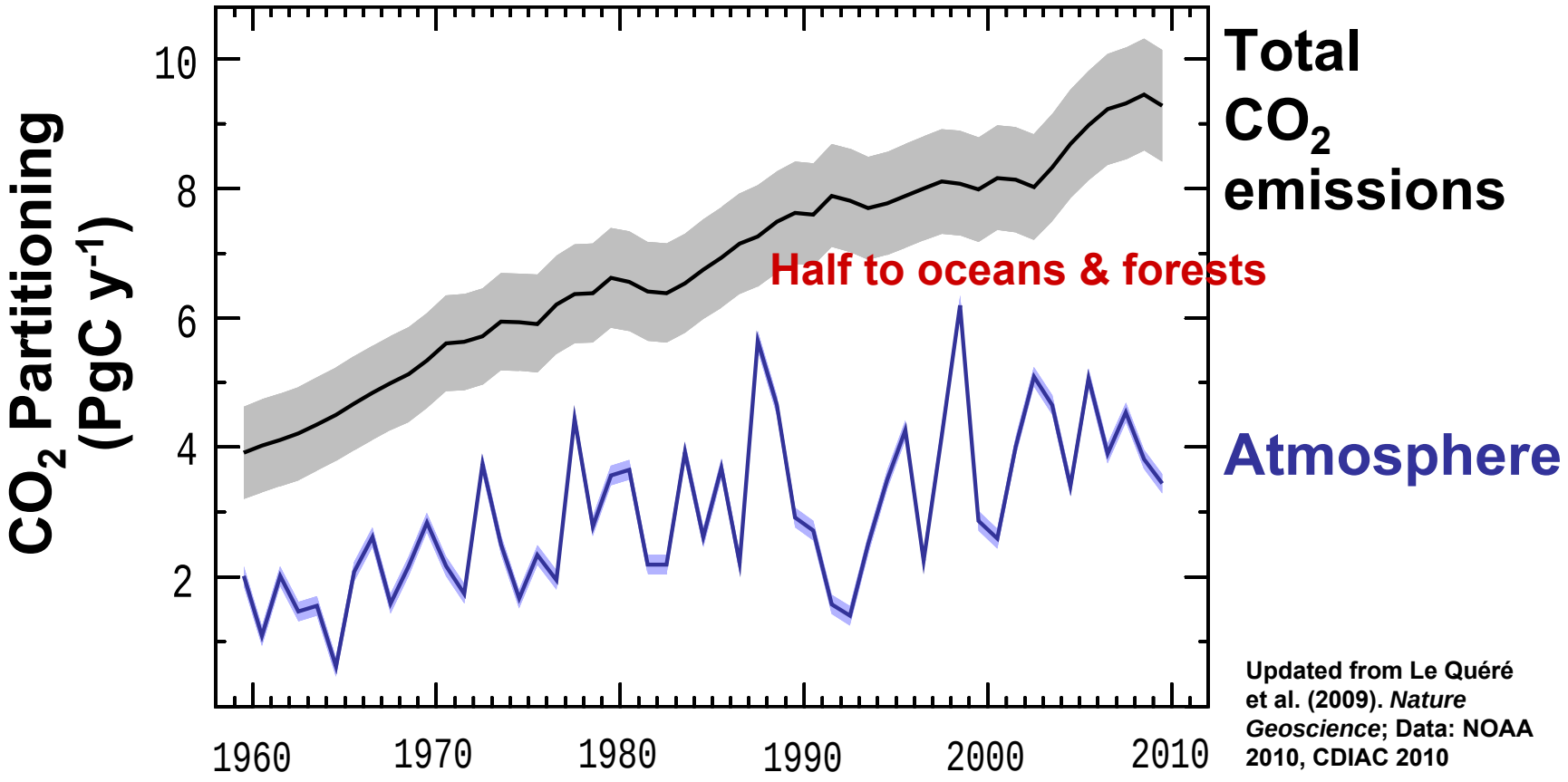
Emission Scenarios

- 4%/year

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

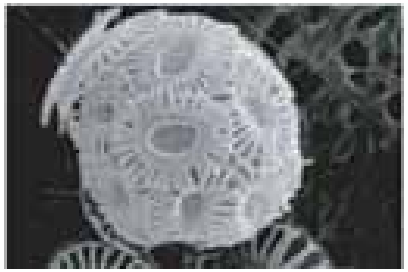


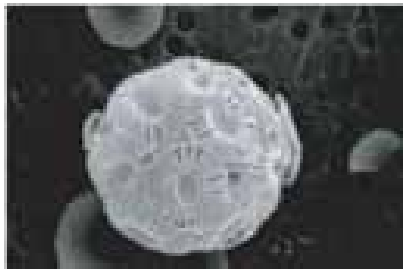
It takes at least a century to remove CO_2 from the atmosphere, and many centuries to remove it from oceans

Rising Ocean Acidity Threatens Organisms

- **From the Tropics to the Arctic, the seas are sucking up emissions of CO_2 — from burned fossil fuels**
- **When CO_2 dissolves in water, carbonic acid is produced; the oceans are becoming more acidic**

(Ruttiman, *Nature,* 31 Aug. 2006)





Rise of Greenhouse Gases (GHG) Shift Energy Balance of Planet

- **The atmosphere is transparent to light from the sun, but not to infrared radiation from the earth**
- **GHG: H_2O, CO_2, CH_4, O_3, CFCs absorb and reradiate IR from the surface, giving climate suitable for life by warming planet 30^oC**
- **CO_2 rise alone has a small warming effect**

  BUT…

Water, Snow & Ice Give Positive Radiative Feedbacks

- As Earth warms, evaporation and water vapor increase and this is 3X amplifier on CO_2 rise
- As Earth warms, snow & ice decrease and reduced SW reflection amplifies warming in Arctic in summer and mid-latitudes in winter
- Doubling CO_2 will warm globe about 3°C (5°F)
  - Much more in the North and over land, which responds faster than oceans

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

(www.ipcc.ch)

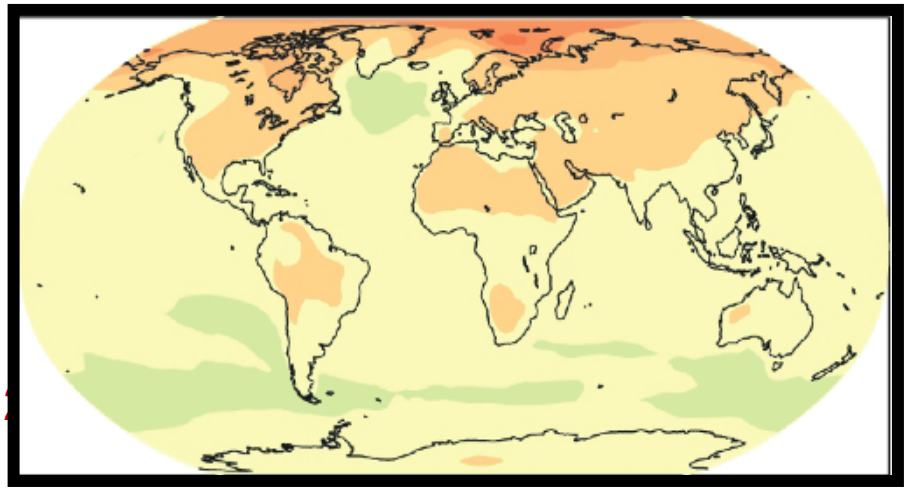
Decrease in:

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

Predicted Change in Temperature

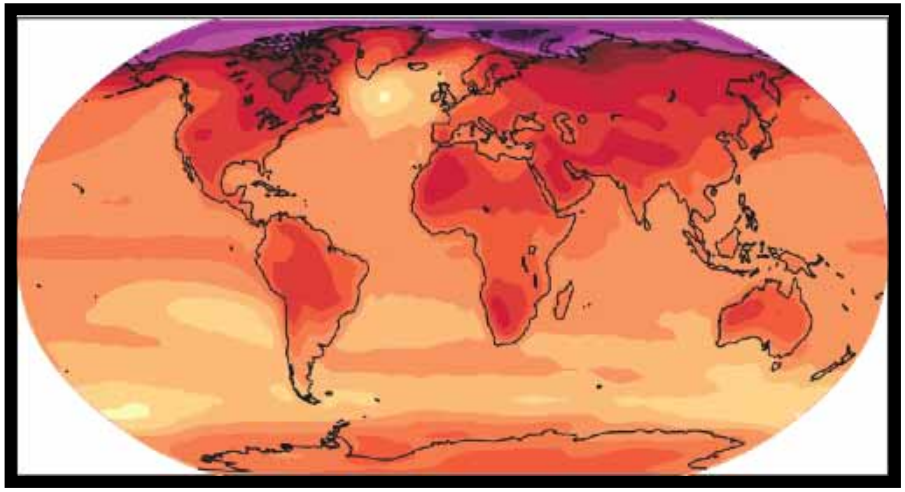
2020-2029 and 2090-2099, relative to 1980-1999 (°C)

"Committed"

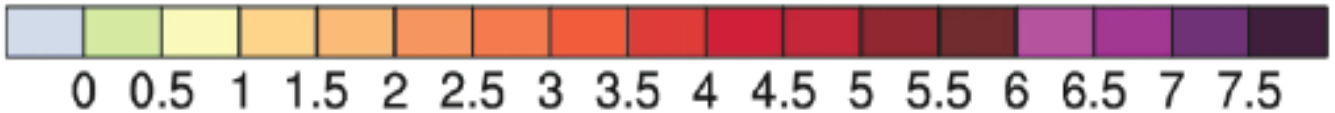


(We did nothing for the last 20 years)

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 for centuries (accelerating for business as usual)**

- ***http://www.nature.com/news/us-northeast-coast-is-hotspot-for-rising-sea-levels-1.10880***

Many Challenges Face Us

- **Extreme weather:** Floods, fires, & drought

  - 32 weather disasters >$1B in 2011

- **Melting** Arctic and permafrost—
  methane release is positive feedback
- **Ecosystem collapse,** including perhaps forest and ocean ecosystems
- **Collapse of unsustainable human population**

What Is Happening to Vermont?

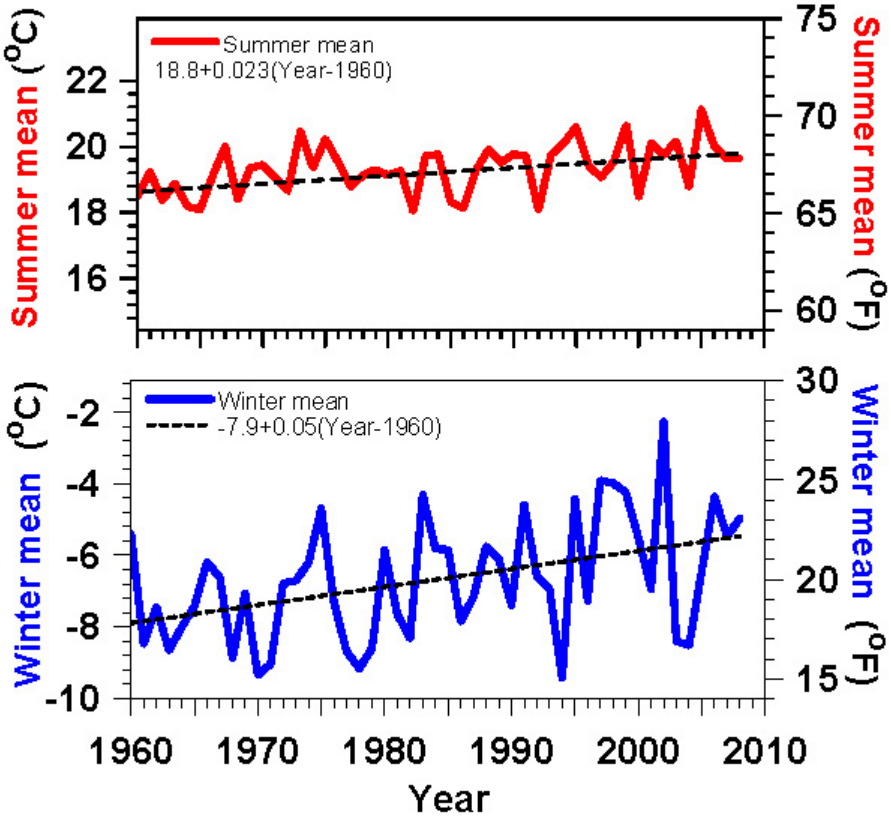
- **Local climate change indicators past 40/50 years**

- **Warming twice as fast in winter than summer**
- **Winter severity decreasing even faster**
- **Lakes frozen less by 7 days / decade**
- **Growing season longer by 3.7 days / decade**
- **Spring coming earlier by 2-3 days / decade**

- **Extremes increasing**
- ***Evaporation increases with T***
- ***More 'quasi-stationary weather patterns'***

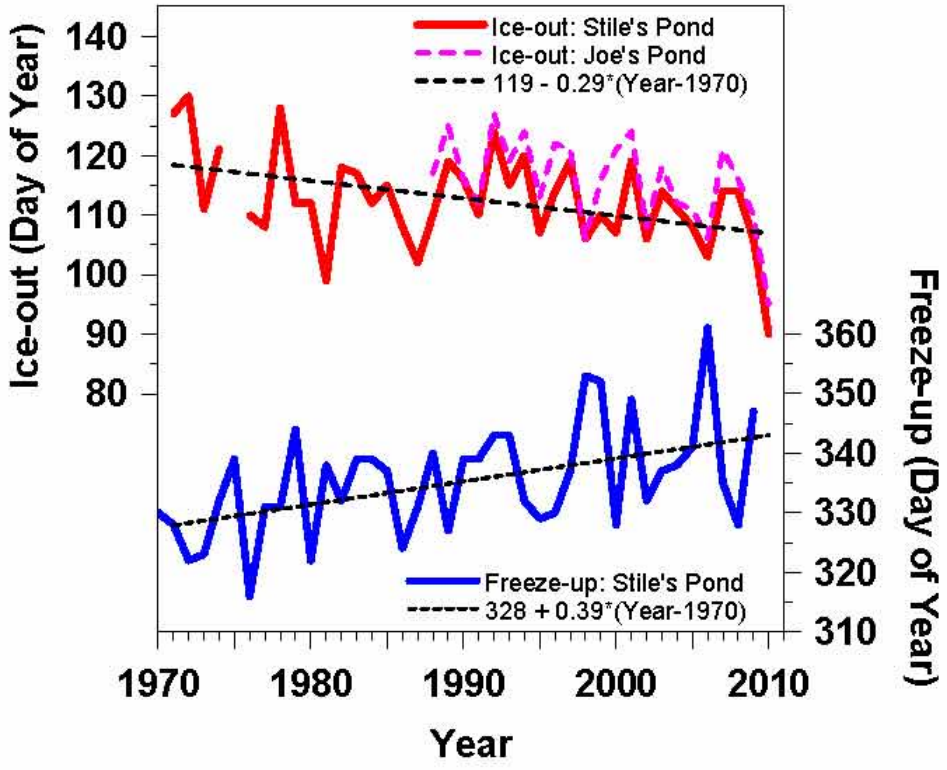
Vermont Temperature Trends
1961-2008

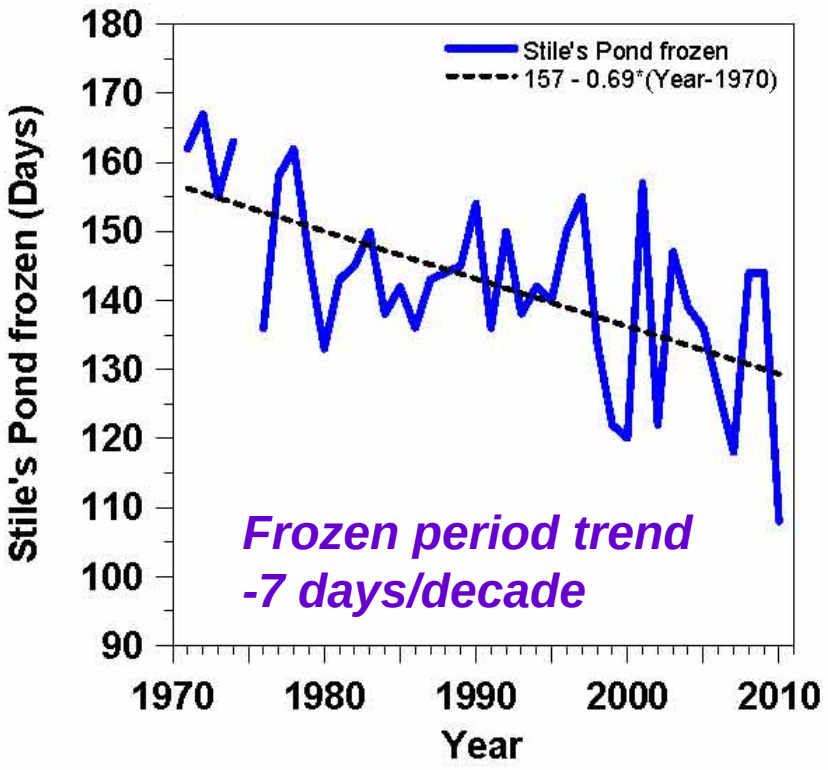
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***



Lake Freeze-up & Ice-out Changing

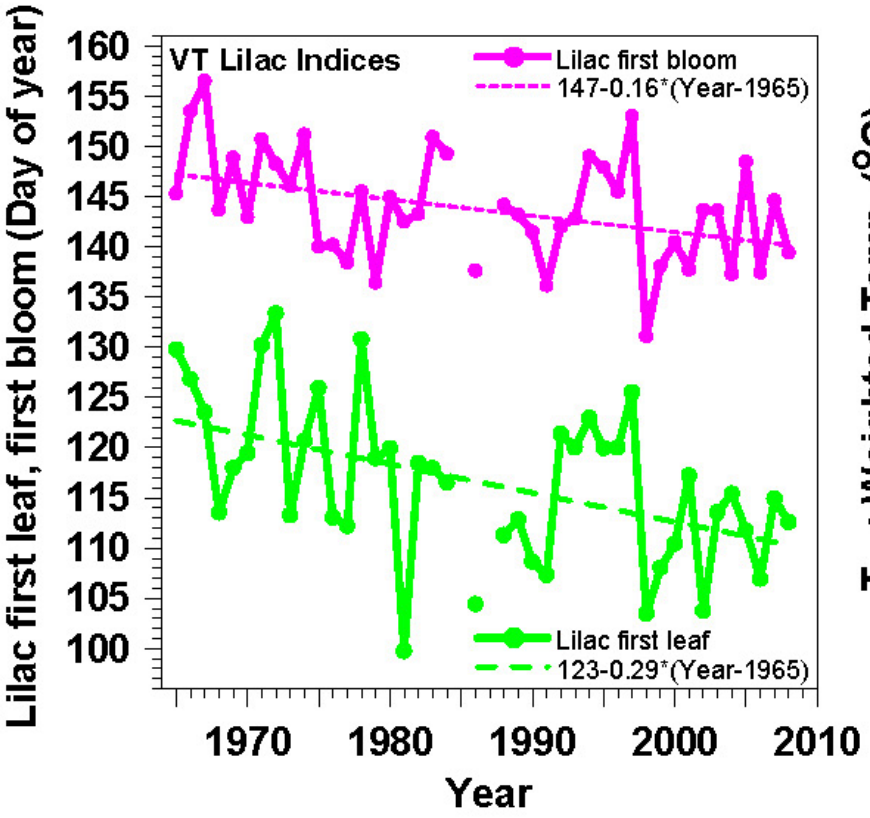
Frozen Period Shrinking Fast

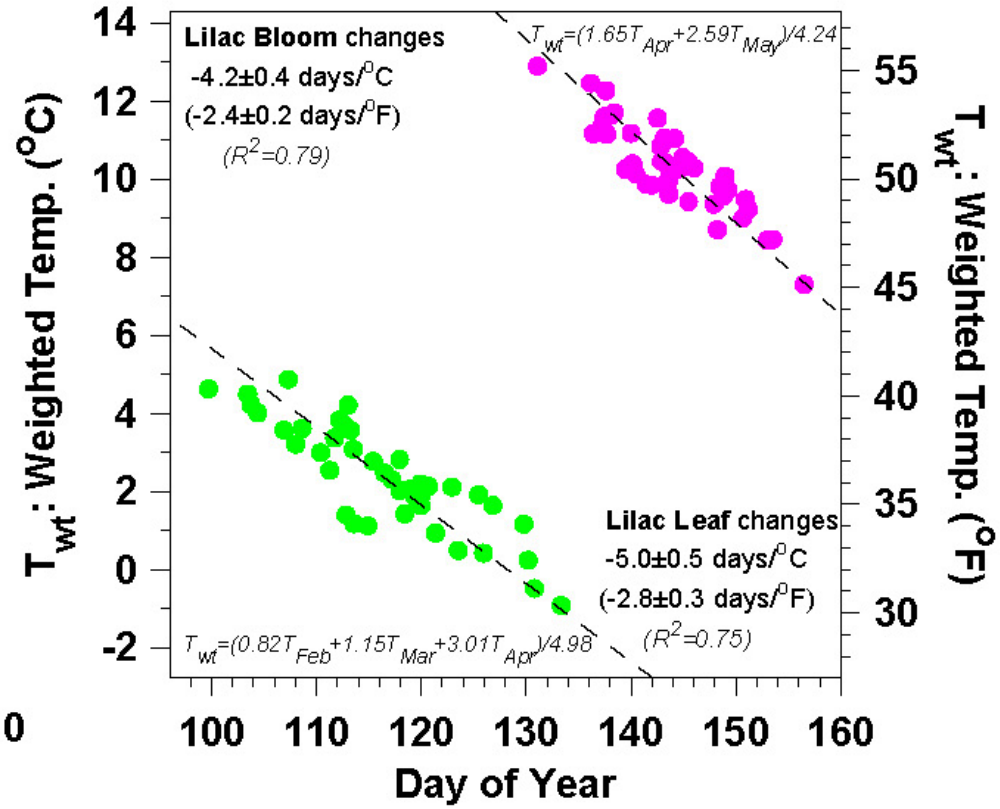




- Ice-out earlier by 3 days / decade
- Freeze-up later by 4 days / decade

Lilac Leaf and Bloom in Spring





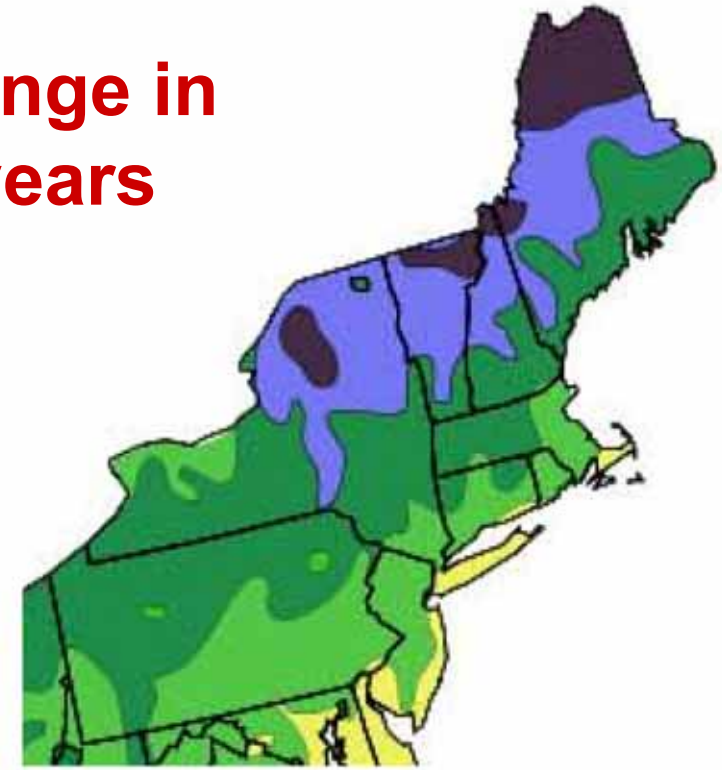
- Leaf-out earlier by 3 days/decade (tracks ice-out)
- Bloom earlier by 1.5 days/decade
- Leaf & bloom change 2.5 days/°F (4.5 days/°C)

Vermont Winter 2006

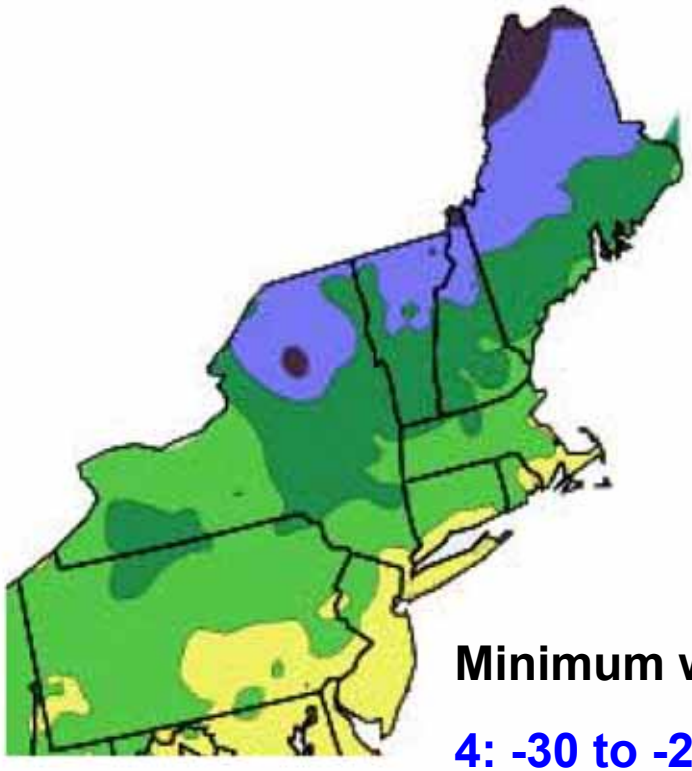
- **Snow reflects sunlight, except where trees shadow**
- **Cold; little evaporation, clear sky; earth cools to space**
- ***2012 warm winter, snow melts → positive feedback***

Winter Hardiness Zones - Northeast

Change in 16 years



1990



2006

Minimum winter T

4: -30 to -20°F

5: -20 to -10°F

6: -10 to 0°F

Zone

2 3 4 5 6 7 8 9 10

USDA Hardiness Zones

Shrinking Winter: Pittsford, VT
(Freeze-up used to be mid-November)

January 7, 2007

December 2006:

- **Warmest on record**

January 10, 2008

Warm Fall:

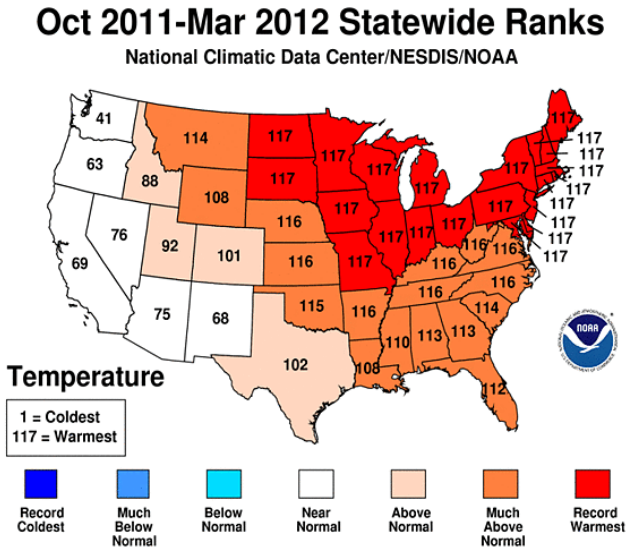
- **Record Arctic sea-ice melt**
- **Snow cover in December, ground unfrozen**

January 2, 2012

March 11, 2012

October 2011– March 2012

- **Warmest 6 months on record**
- **My garden frozen only 67 days**
- **No permanent snow cover west of Green Mntns**
- **Contrast snowy winter 2010-11**



Early Spring: Daffodils, Forsythia

79ºF on March 22, 2012

Pittsford Vermont

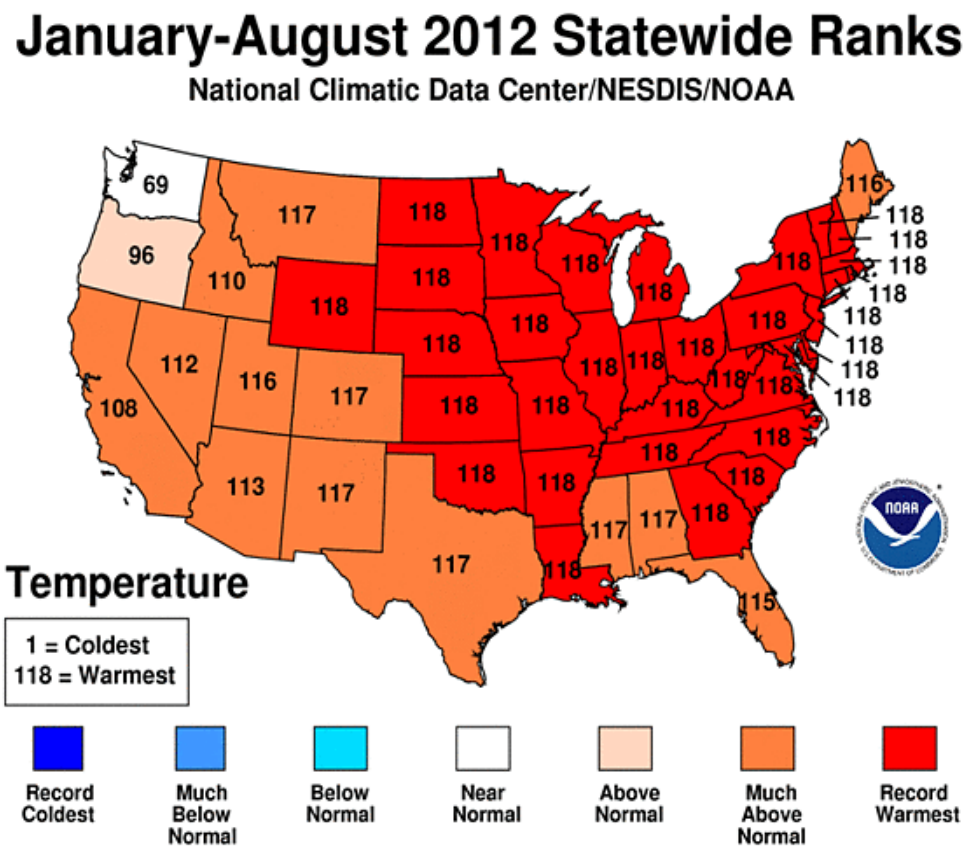
3/22/12

Pittsford Vermont

3/24/12

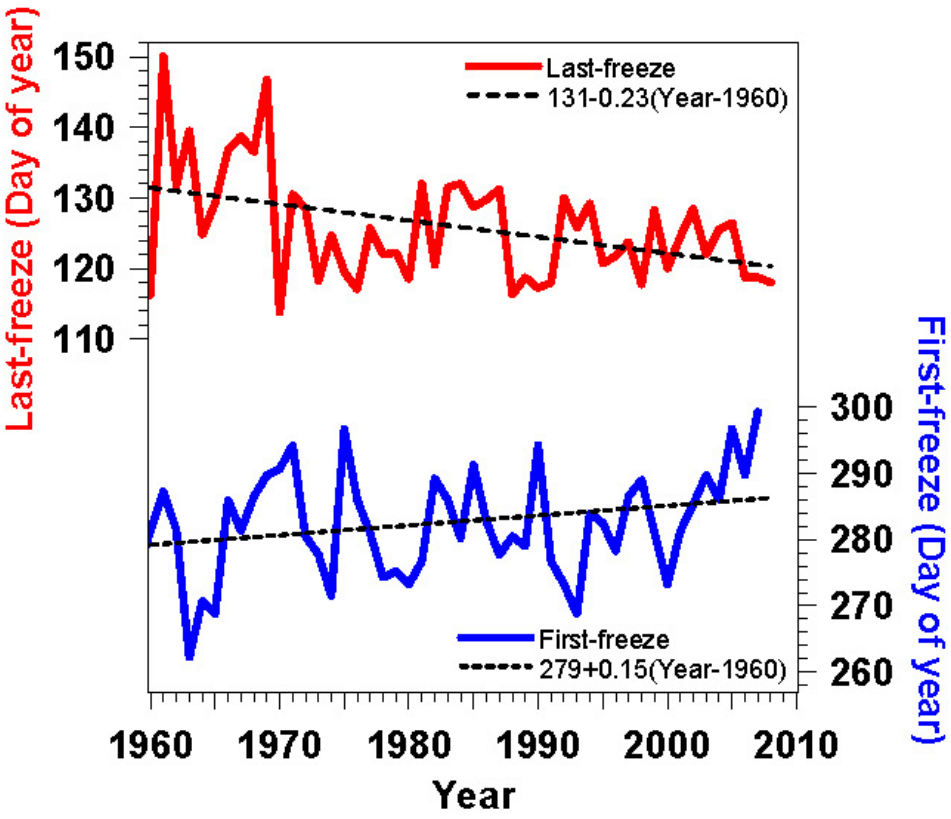
This Year Exceptionally Warm

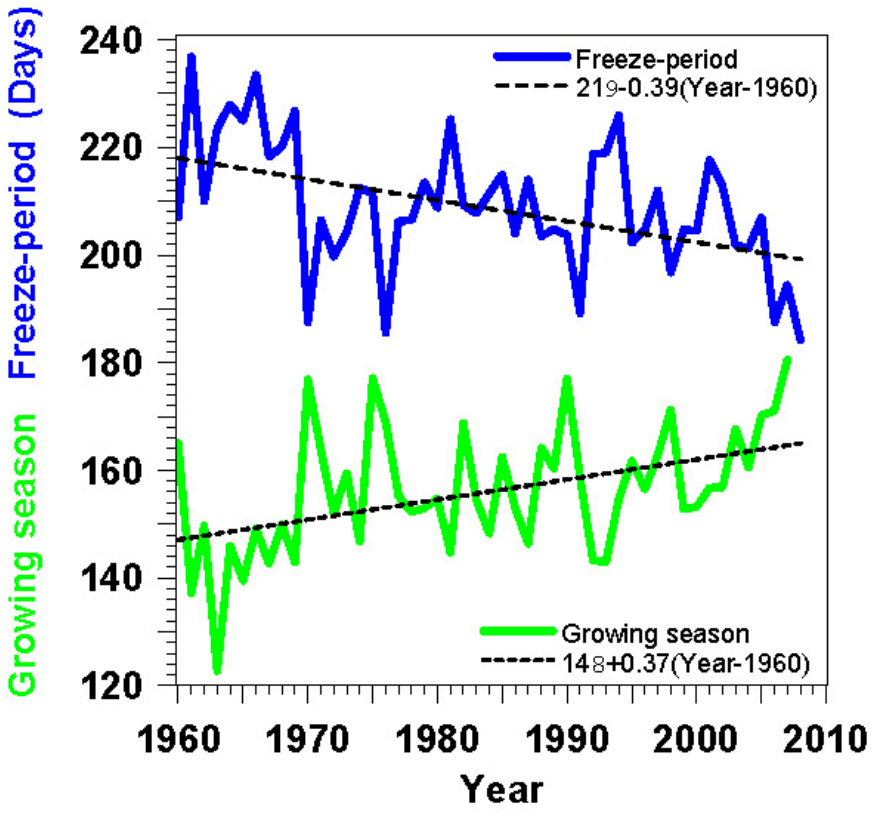
- Burlington Area Extremes
- Highest Average Temperature degrees F
- Days: 9/1/2011 - 8/31/2012
- Length of period: 365 days
- Years: 1850-2012
- Rank Value Ending Date
- **1 50.4 8/31/2012**
- 2 48.4 8/31/2002, 8/31/1949
- 4 48.2 8/31/2010
- 5 48.0 8/31/1999
- 6 47.9 8/31/2006
- 7 47.8 8/31/1991, 8/31/1995
- 9 47.6 8/31/1899, 8/31/1903



http://www.ncdc.noaa.gov/temp-and-precip/maps.php

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 humidity**
→ **Low water vapor greenhouse**
→ **Large cooling at night**
→ **Large diurnal temp. range**
giving 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***

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!***

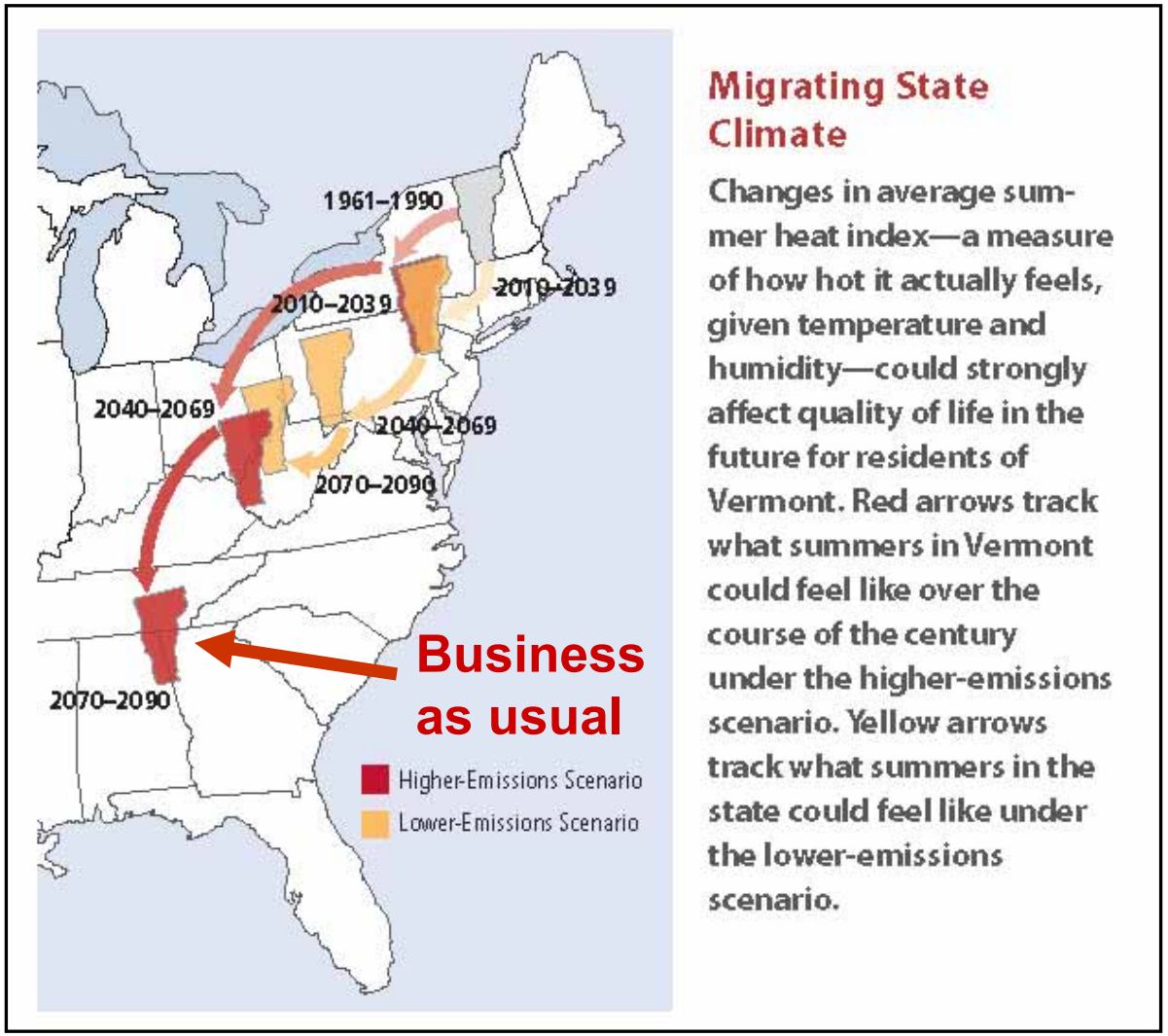
Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

Later frost: Growing season getting longer

Vermont's Future with High and Low GHG Emissions

What about skiing?

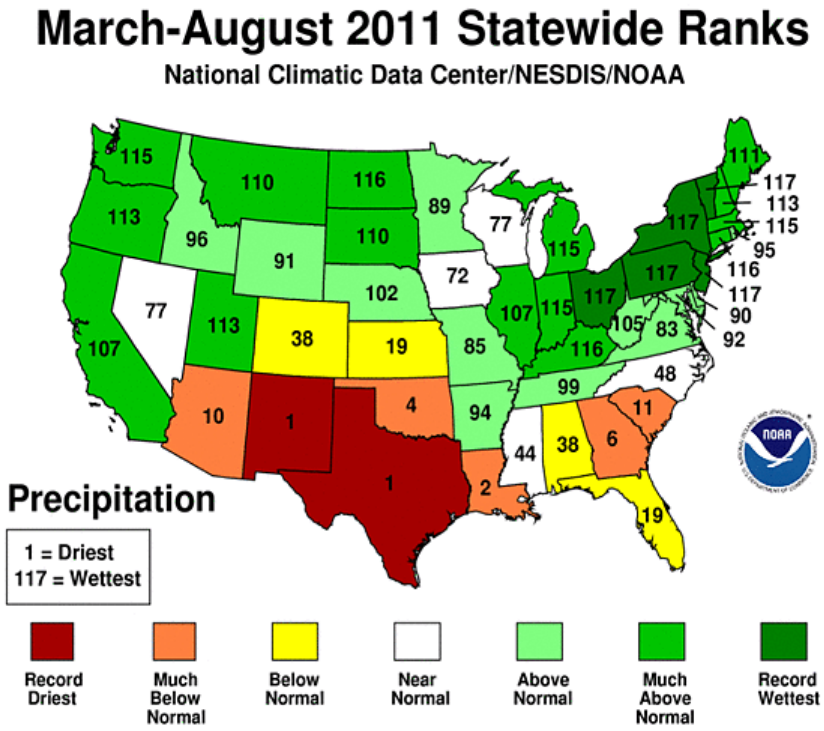
What about tropics?

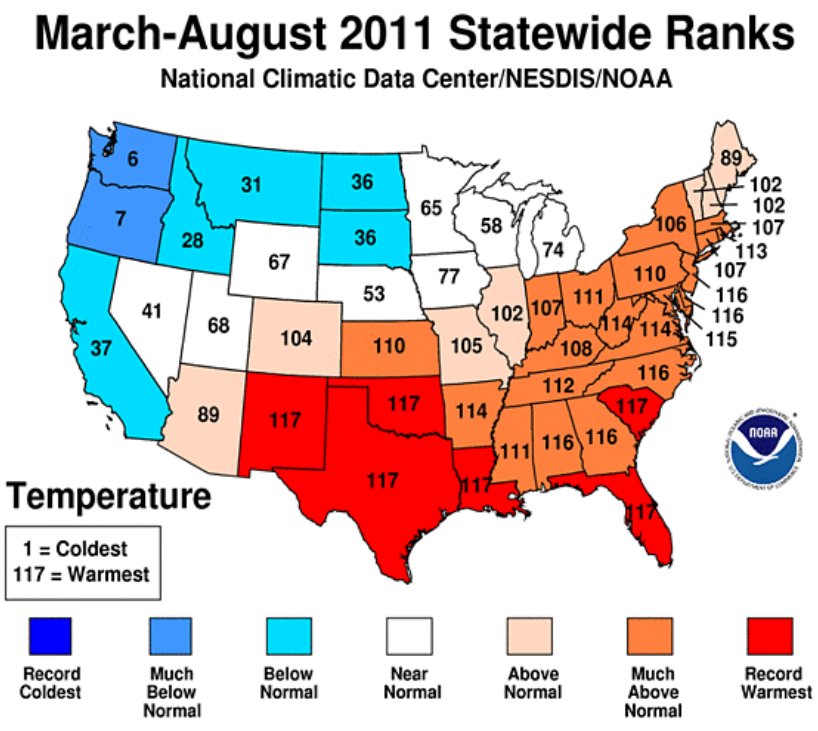


NECIA, 2007

2011 Vermont Floods

- **Record spring flood on Lake Champlain**
- **Record floods following TS Irene**
- **Record wet in NE March-August, 2011 (but TX, NM record drought)**





Outline

- Science of climate change
  - Global scale: actual and future
  - What is happening to Vermont

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

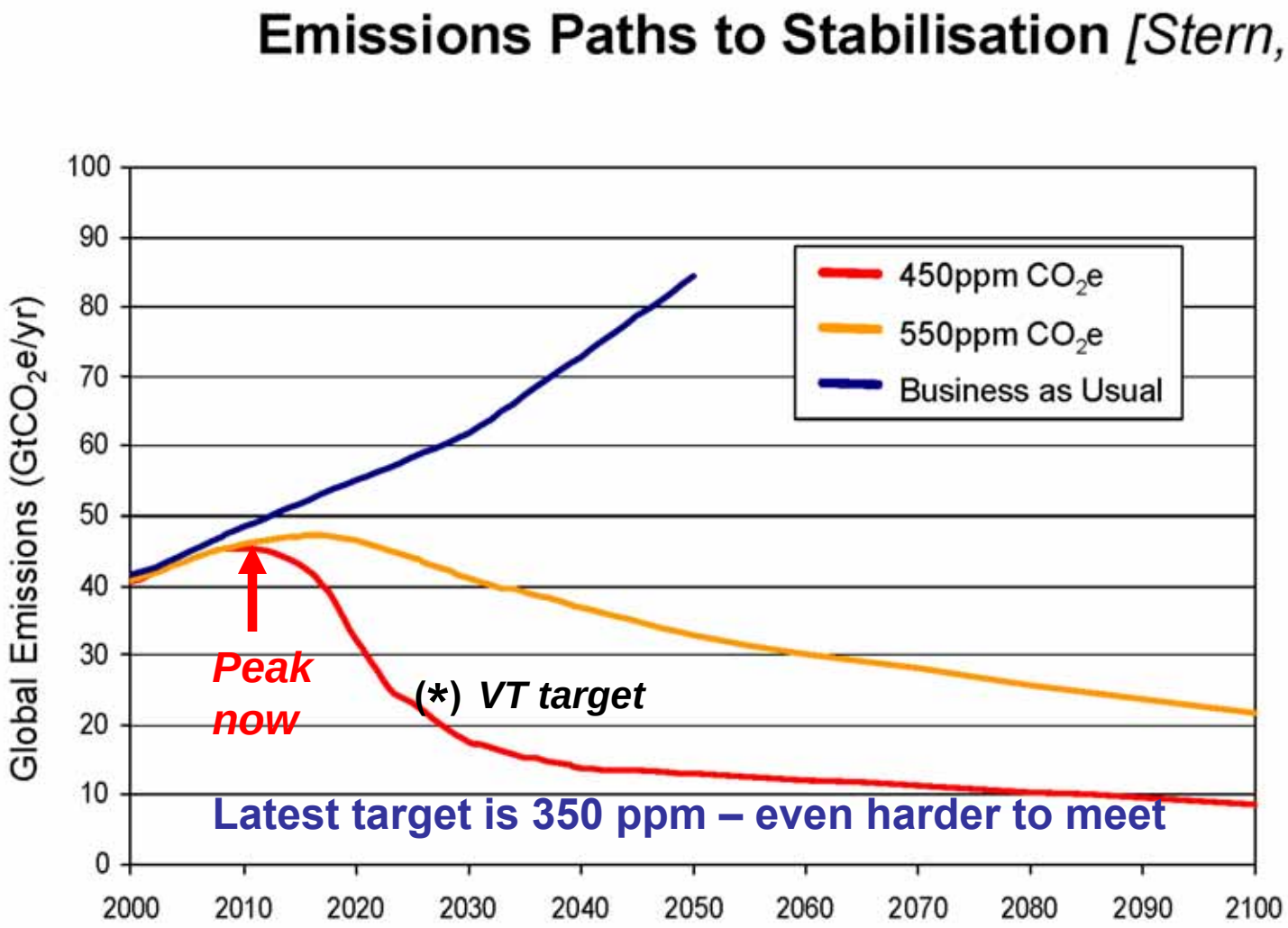
Discussion

Can We Stop "Dangerous Climate Change"?

(UNFCCC 1992)

- **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 fuels**

How Do We Avoid "Dangerous Climate Change"?



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**

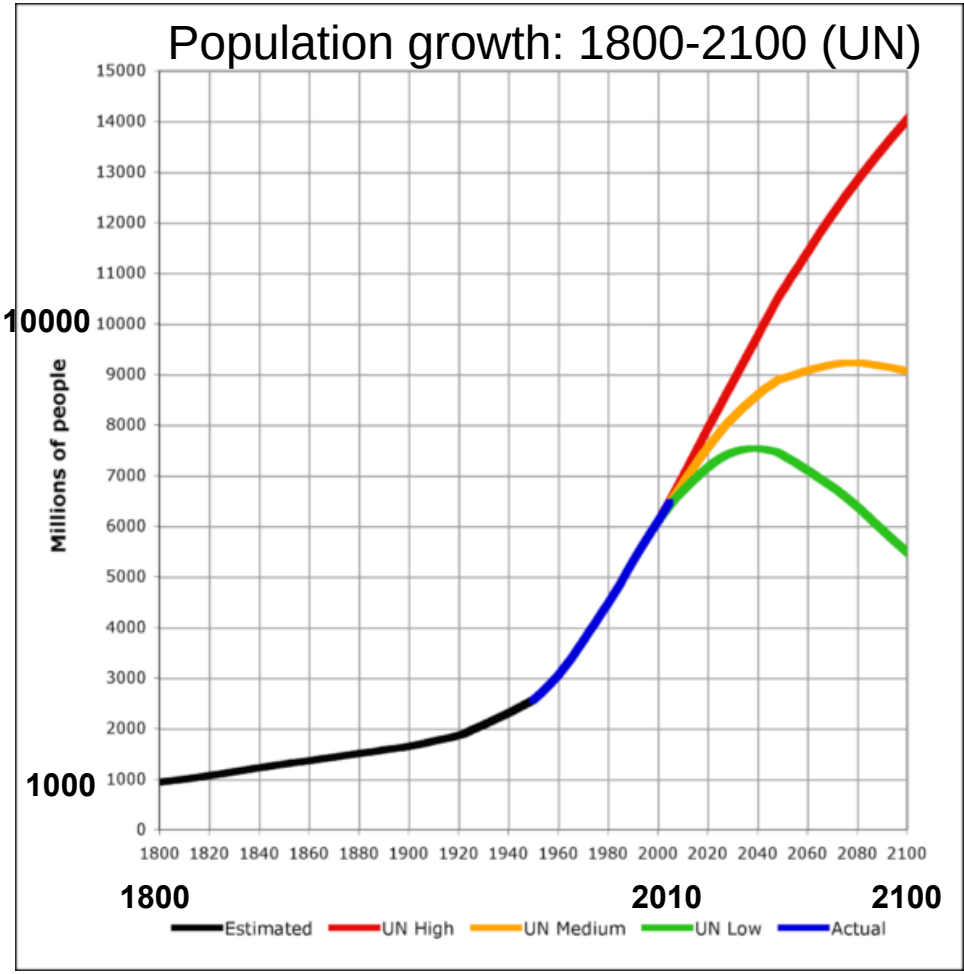
Why Is It Difficult for Us?

- **Fossil fuels reserves are worth $20-30T**
- **Regulating emissions of CO_2 is an "unfair cost" to the "free market"**

- **Real Earth system issues being ignored**
- **Our politics are facing collapse – becoming a fantasy disconnected from the real world**

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**

Surely Technology Can Save Us?

- **Now our world of technology is having a global impact on the natural world, so technology must be carefully managed — particularly our waste-streams — because we are dependent on the natural world**
  - **But this is incompatible with our ideology**

Technology can be 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**

Can't Avoid the Big Issues!

- **Regulation is good – Reagan, G.H. Bush and Riley (EPA) pushed through the Montreal Protocol and the Clean Air Act Amendments over business opposition and saved the Earth from an ozone catastrophe**
- **Technology must be managed to minimize human impacts on the Earth**
- **Impacts have to be <u>fully</u> costed**
- **People need a vote, so they need to be informed**

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
  - That deal with society's fears

The Future Is Not Our Past

- **Collectively, we create the future, so we need to plan for a transition to a sustainable society**

- **Efficient society**
- **Renewable technologies to replace fossil fuels**

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**

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**

- **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

  - articles at http://alanbetts.com/writings

  - papers at http://alanbetts.com/research

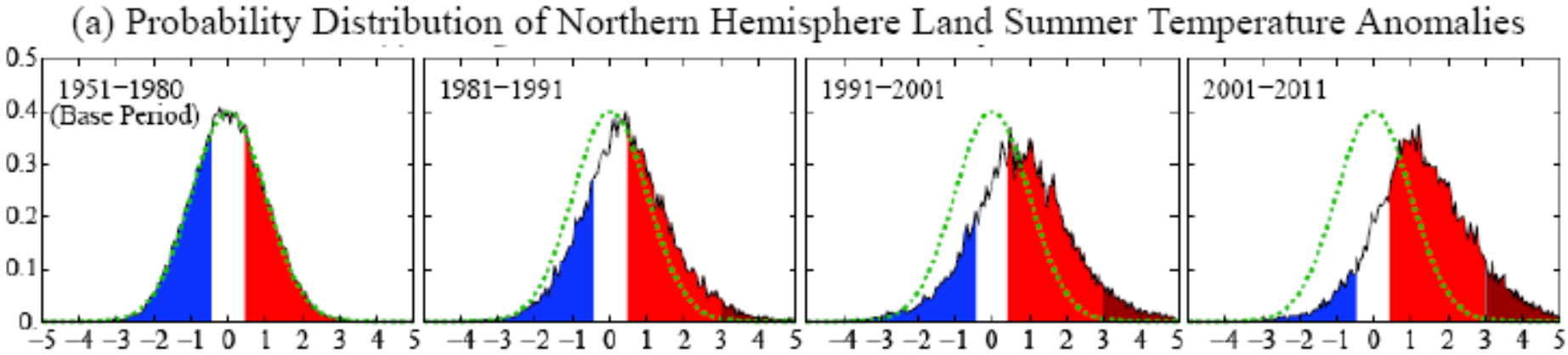
- ***Vermont Climate Change Indicators***
- ***Seasonal Climate Transitions in New England***

Media Resources

- **Sunday Environment page in Rutland Herald/Montpelier Times Argus:**
  2008-2012 – 50 articles
  http://alanbetts.com/writings
- ***Environmental Journalism Revisited***

- **Media Commentaries: VPR/PEG-TV**
  http://alanbetts.com/talks

Are Temperature Extremes a Sign of Global Warming?



(Hansen, 2012)

- **Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies for Northern Hemisphere land in units of local standard deviation (horizontal axis). The normal (gaussian) distribution bell curve is shown in green.**

- **Large increase in anomalies > +3σ is global warming**

(± 3σ includes 99.7% of data in 1951-1980 base period)

Western Forest Fires: 2000s

- 1,000 acre fires: twice as many as 1970s
- 10,000 acre fires: seven times as many as 1970s
- 100,000 acre wildfires do not appear in records before the late 1980s.
- Burn season 2.5 months longer than 1970s
- Early snowmelt; warmer, drier spring & summer and forest management practice
- Each 1^{o}C warming quadruples area burned