Vermont: Historic & Future Climate Change

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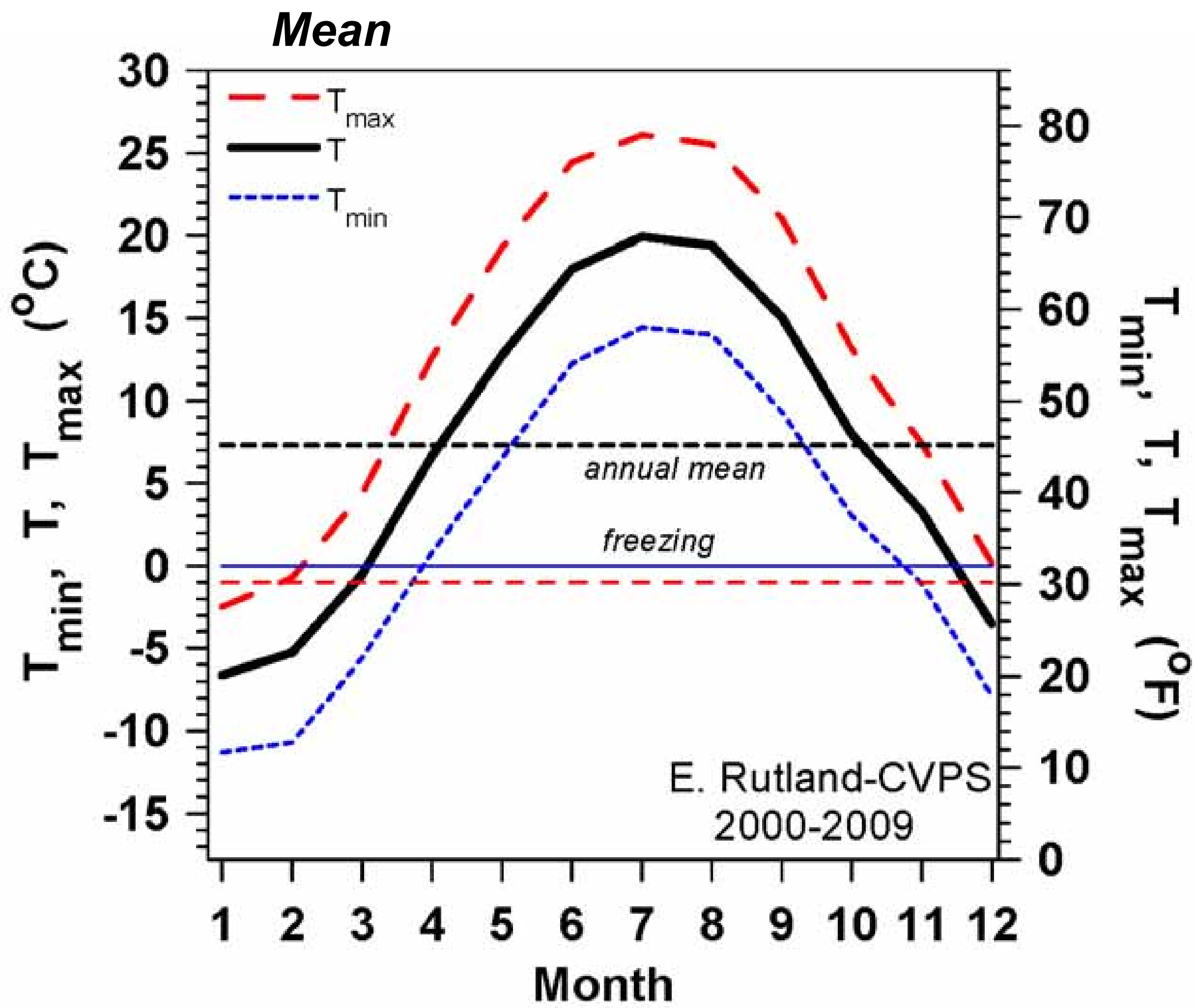
Green Mountain National Forest
Wallingford, VT

September 11, 2012

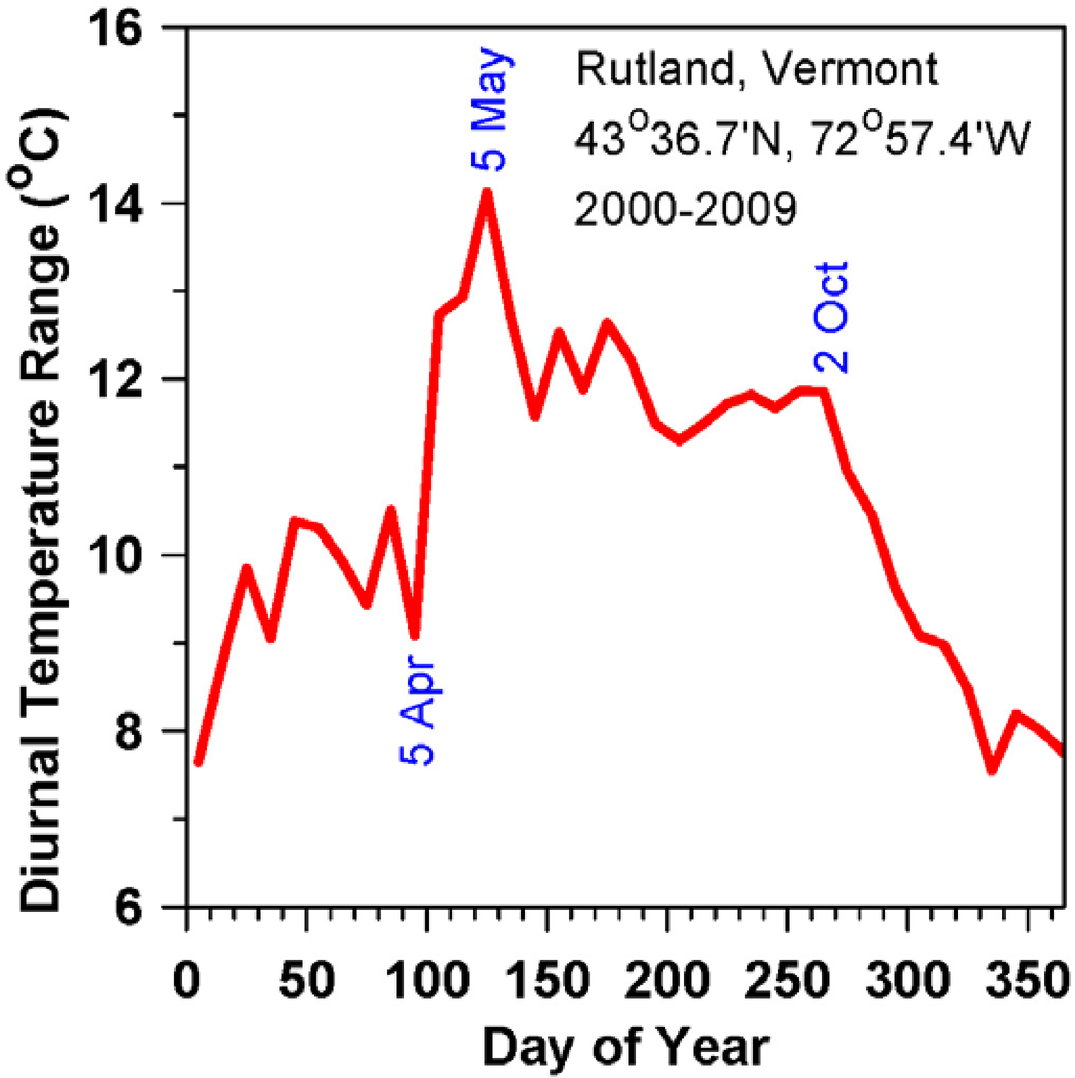
Climate of Vermont

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

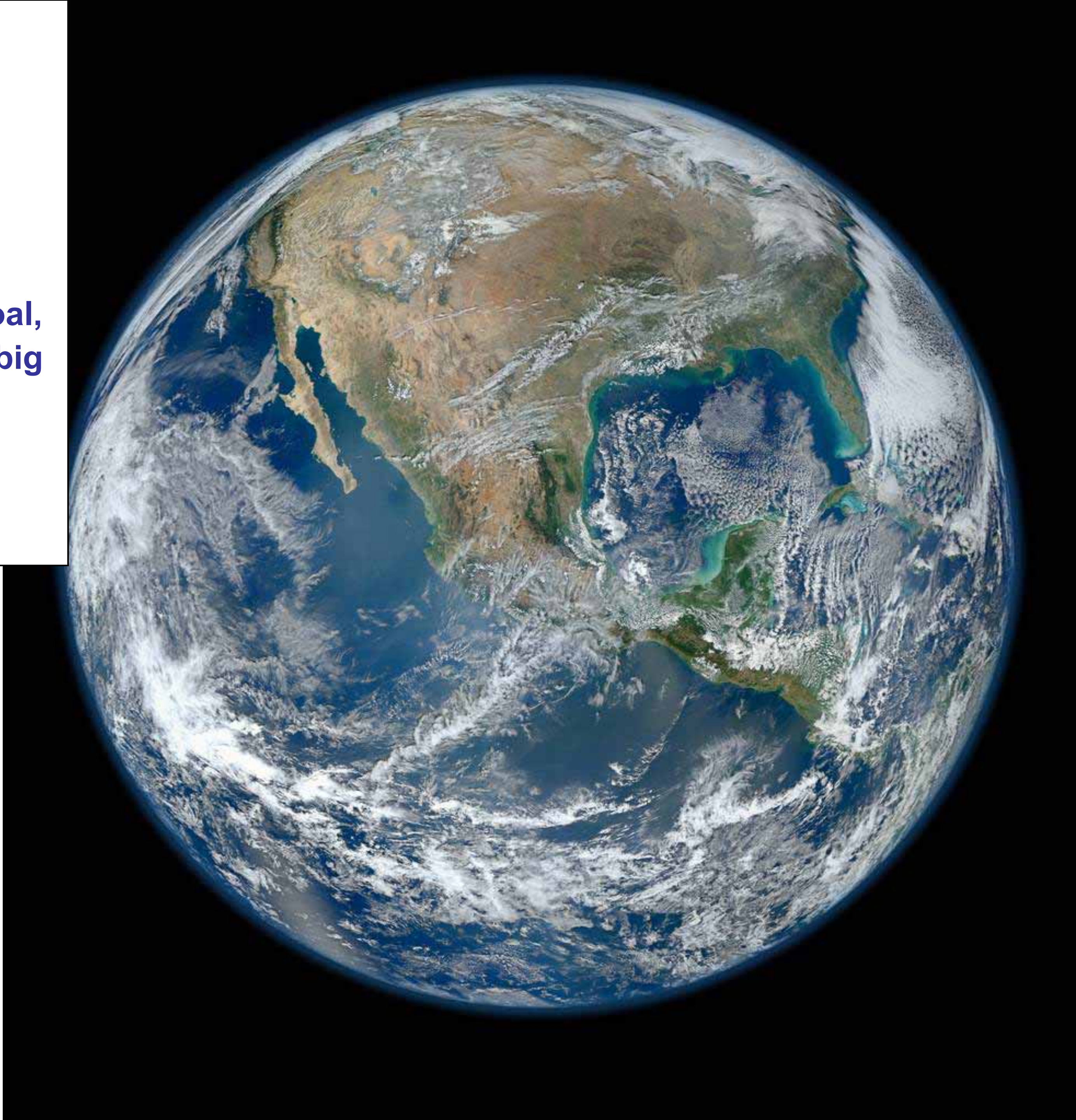


Diurnal Temperature Range

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

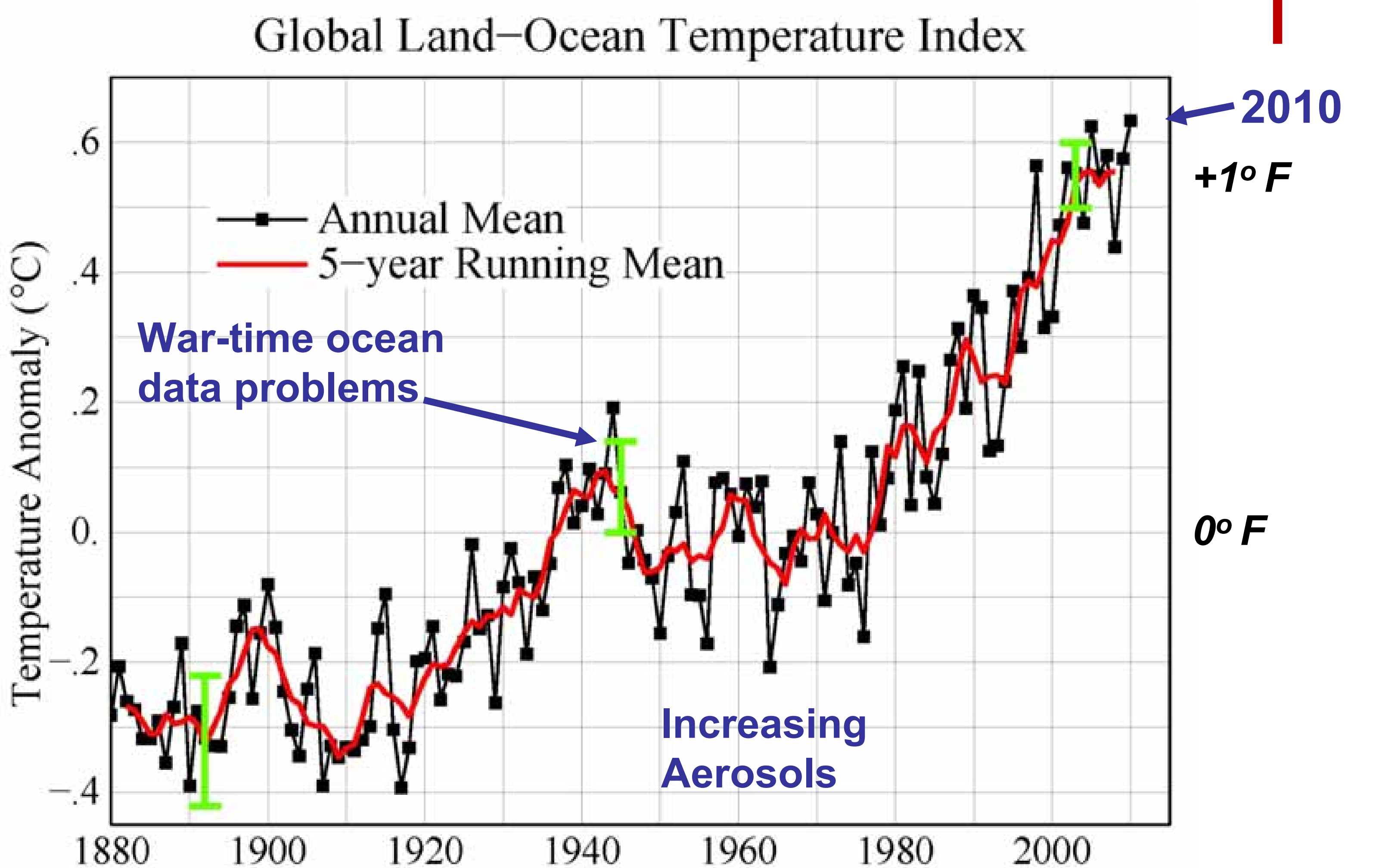


- Earth sustains life
- Weather changes fast
- Climate changes slowly
- Greenhouse gases keep Earth warm
- Burning fossil fuels – coal, oil and gas – is having a big effect on climate by increasing greenhouse gases: CO_2 and H_2O



January 2, 2012: NASA

Global Temperature Rise 1880 – Present



NASA-GISS, 2011

What Is Happening to Vermont?

- **PAST 40/50 years (anthropogenic forcing detectible)**

- **Warming twice as fast in winter than summer**
- **Winter severity decreasing**
- **Lakes frozen less by 6.9 (±1.5) days / decade**
- **Growing season longer by 3.7 (±1.1) days / decade**
- **Spring coming earlier by 2-3 days / decade**

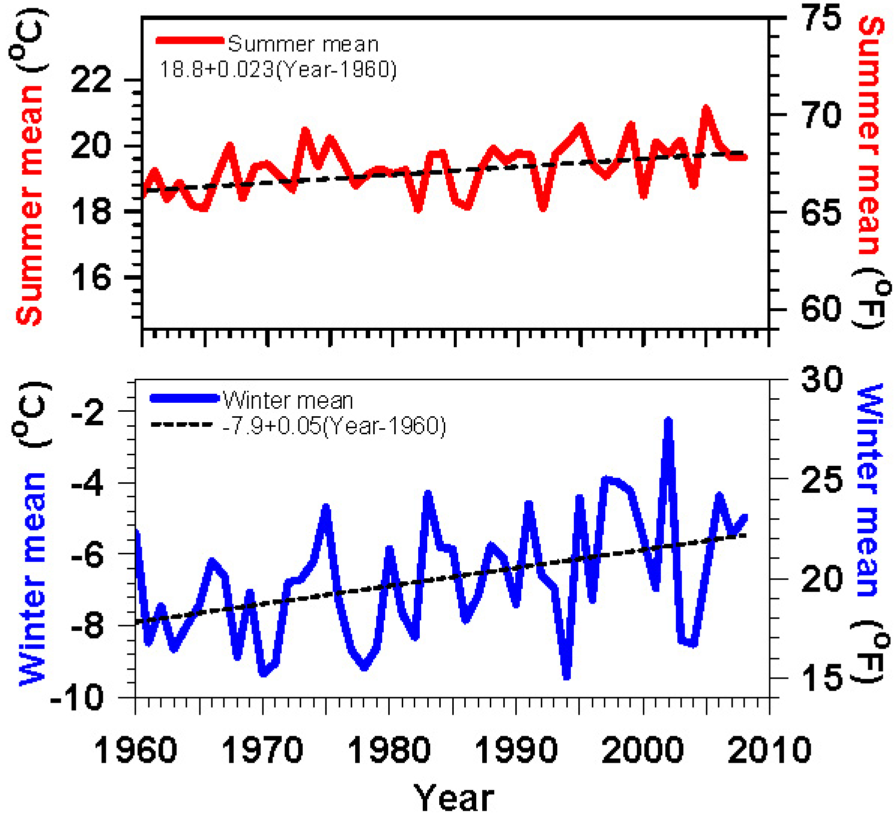
- **Extremes increasing**
- ***Evaporation increases with T***
- ***More ‘quasi-stationary weather patterns’***

Vermont Temperature Trends
1961-2008

- **Summer +0.4°F / decade**

- **Winter +0.9°F / decade**
- **Larger variability, larger trend**

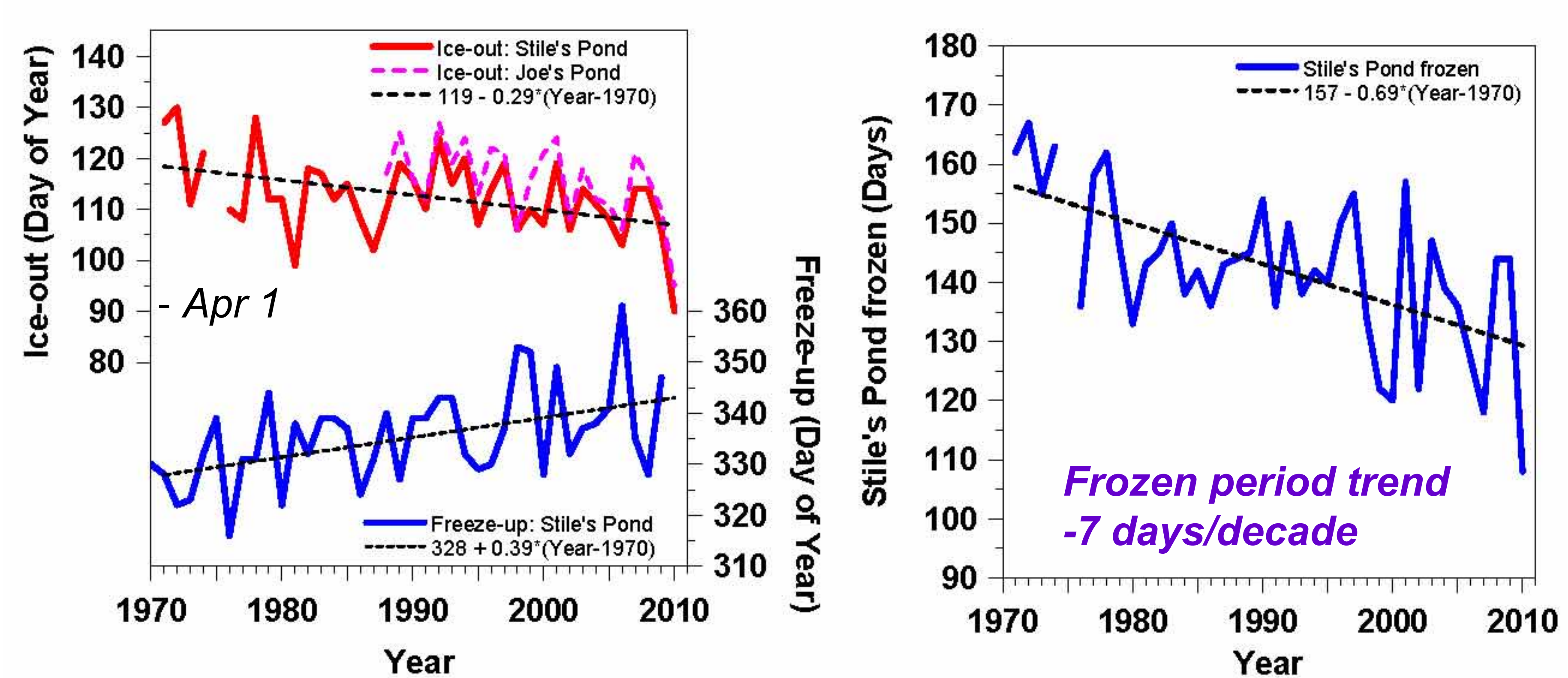
- ***Less snow (and increased water vapor) drive larger winter warming***



Note: trends since 1961: early 1950's warmer. Trends for last 4-5 decades consistent with model projections for the next few decades

Lake Freeze-up & Ice-out Changing

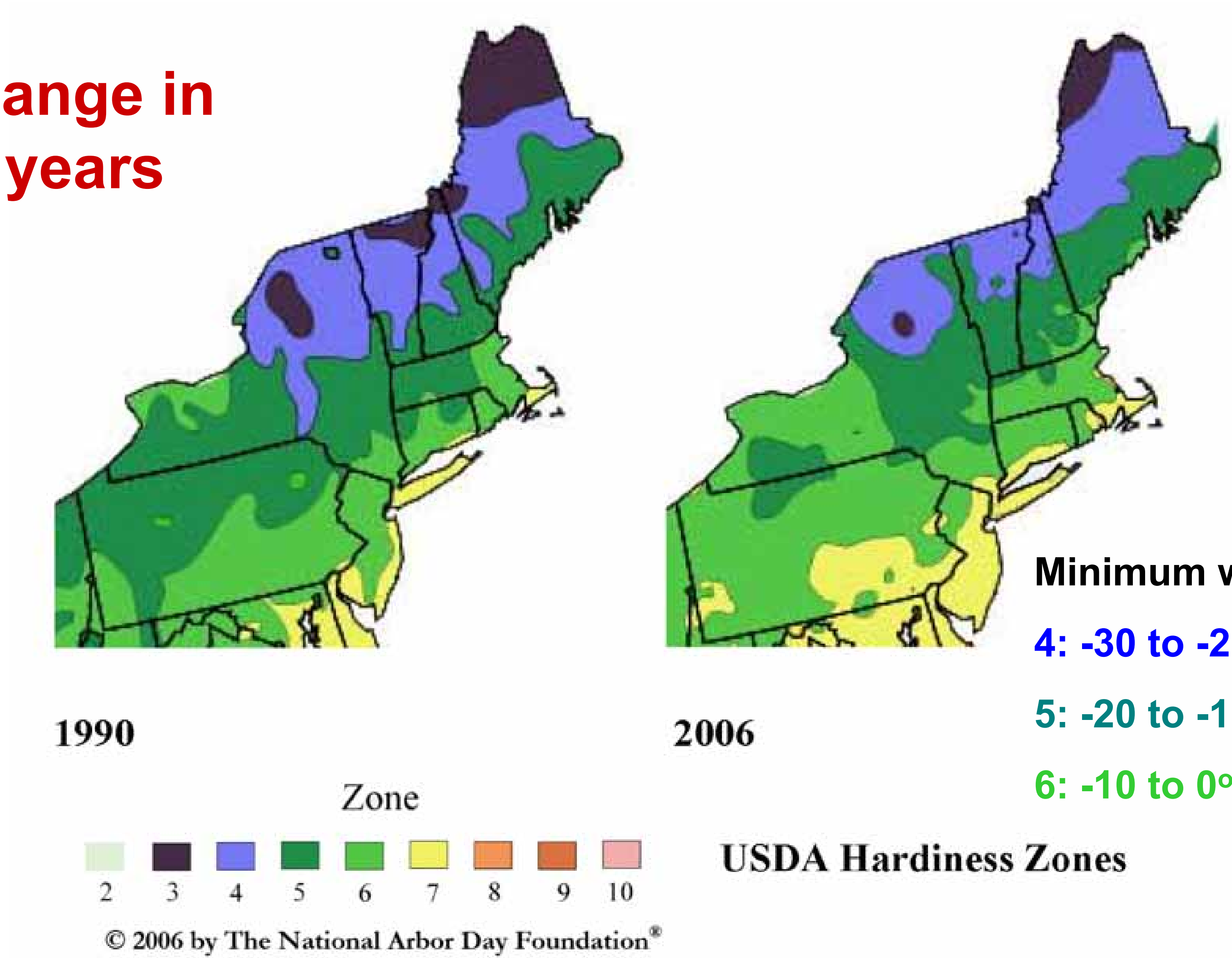
Frozen Period Shrinking Fast



- Ice-out earlier by 2.9 (±1.0) days / decade
- Freeze-up later by 3.9 (±1.1) days / decade
- *Rivers and soils similar?*

Winter Hardiness Zones - Northeast

Change in 16 years



Minimum winter T

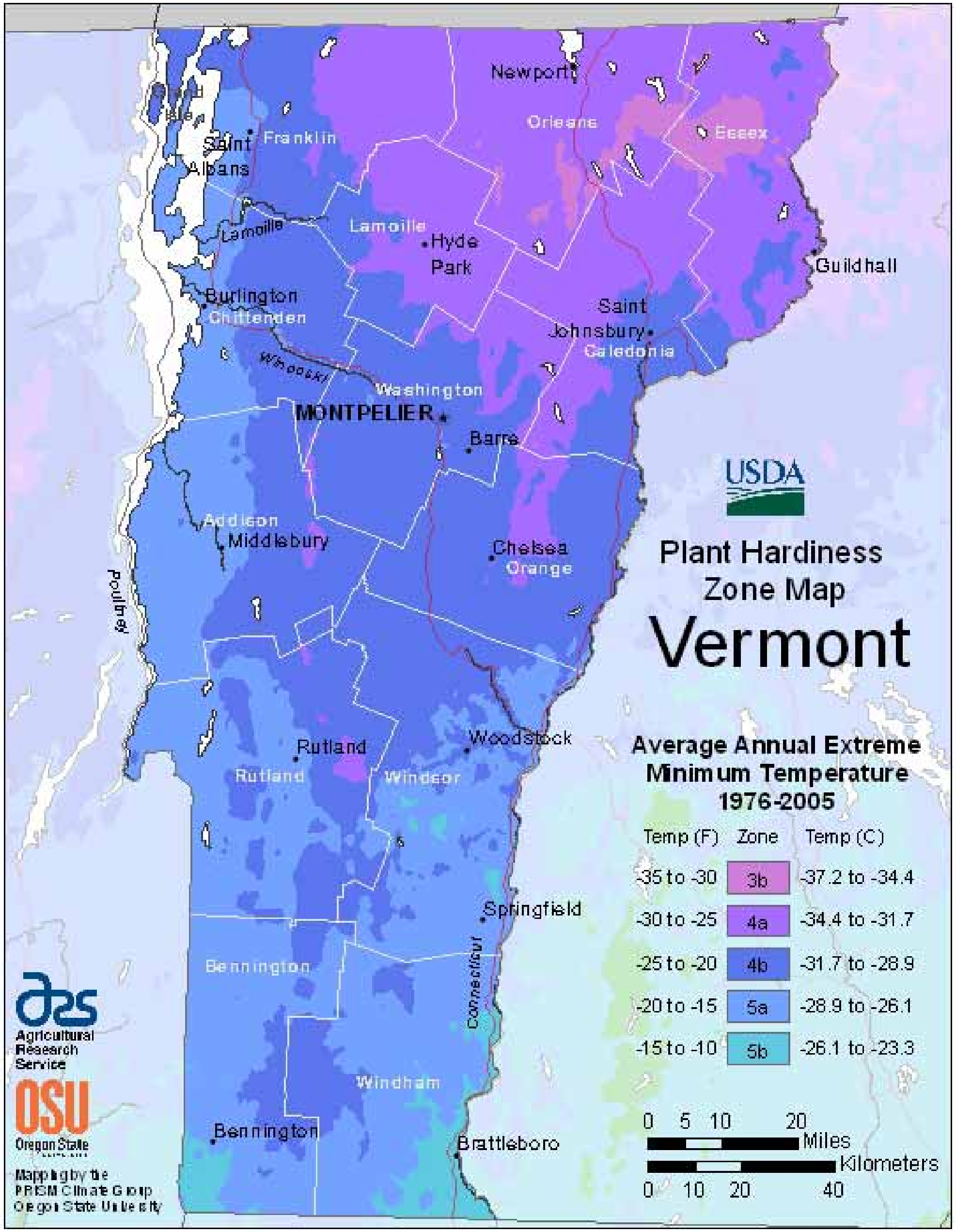
4: -30 to -20°F

5: -20 to -10°F

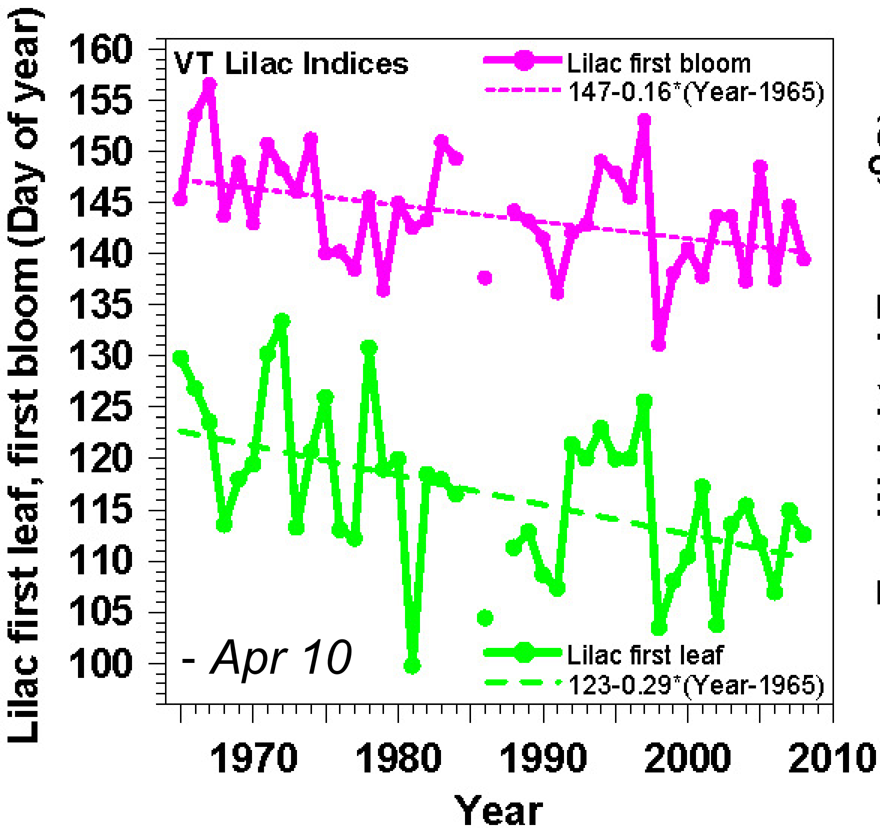
6: -10 to 0°F

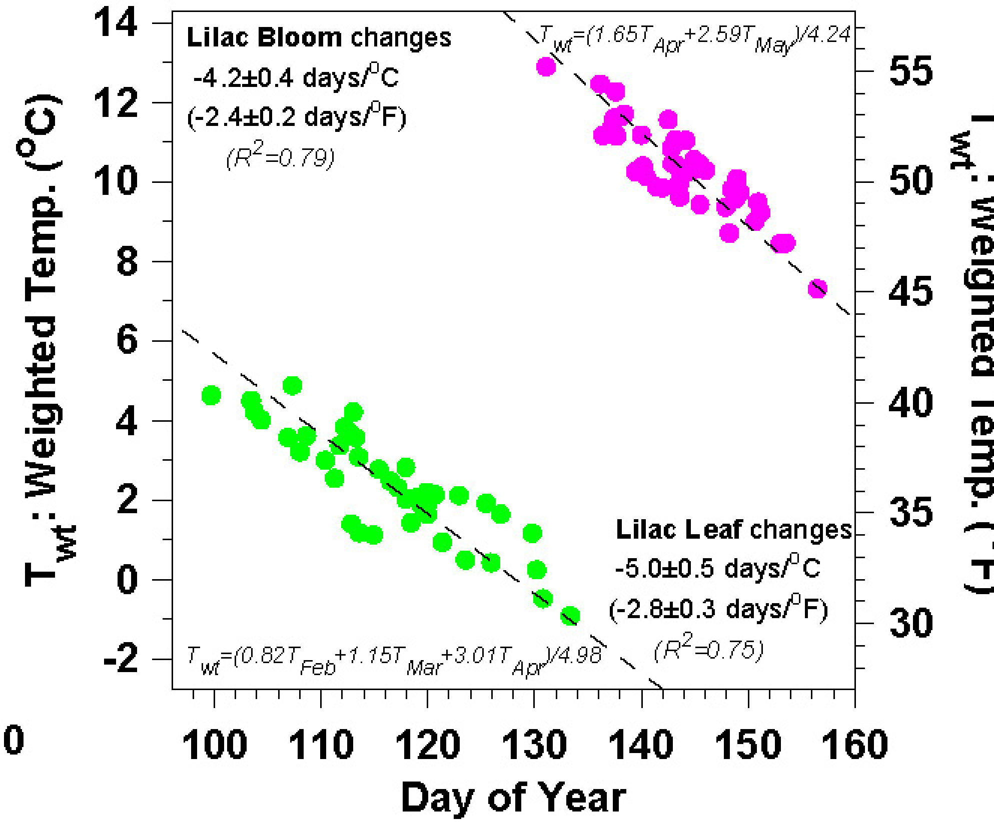
Latest detailed map

- USDA : VT Hardiness Zone Map 1976-2005 [mean 1990]
- A trend of half a zone in 16-20 years is +2.5-3.1°F/decade [triple the rise of winter mean]
- http://planthardiness.ars.usda.gov/PHZMWeb/



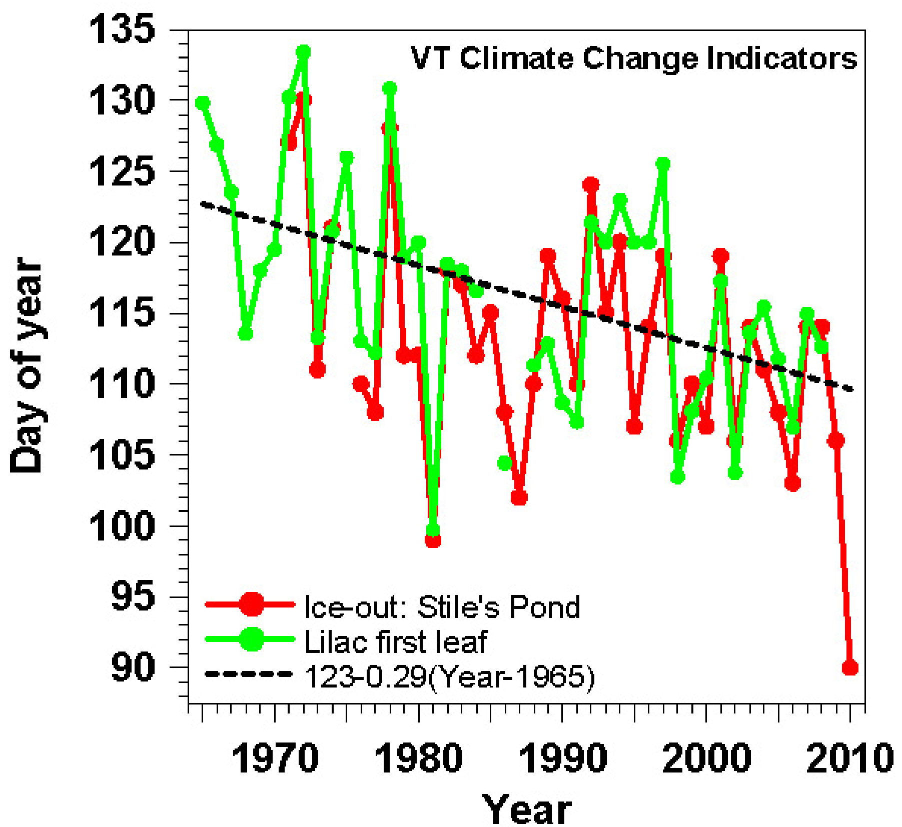
Lilac Leaf and Bloom

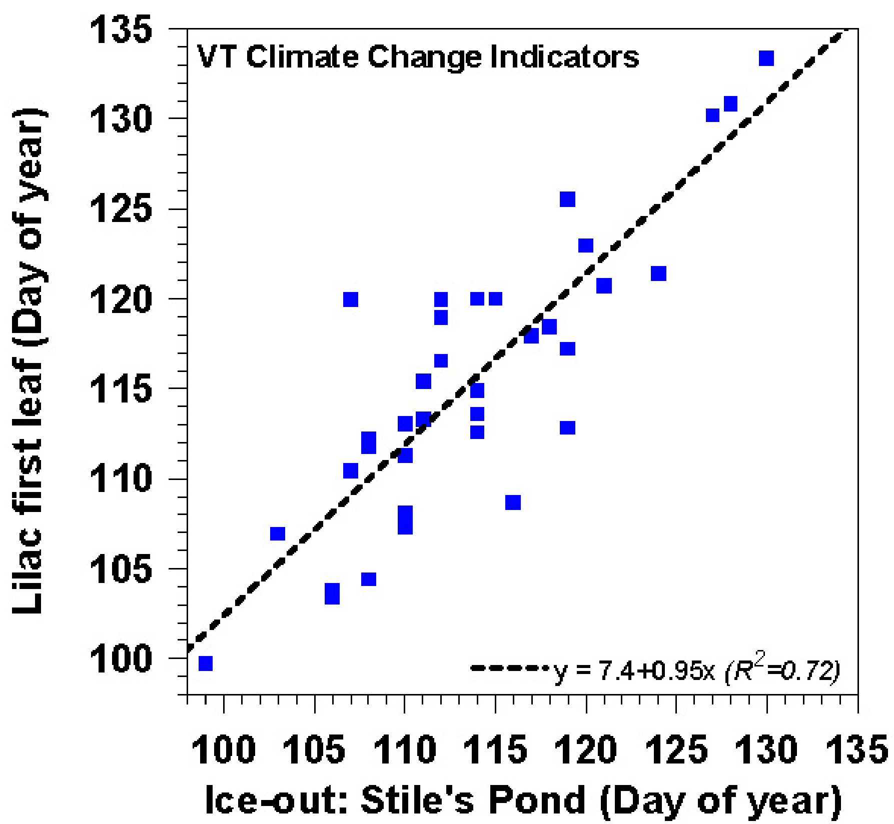




- Leaf-out -2.9 days/decade; Bloom -1.6 days/decade
- Large year-to-year variation related to temperature: 4 to 5 days/ °C

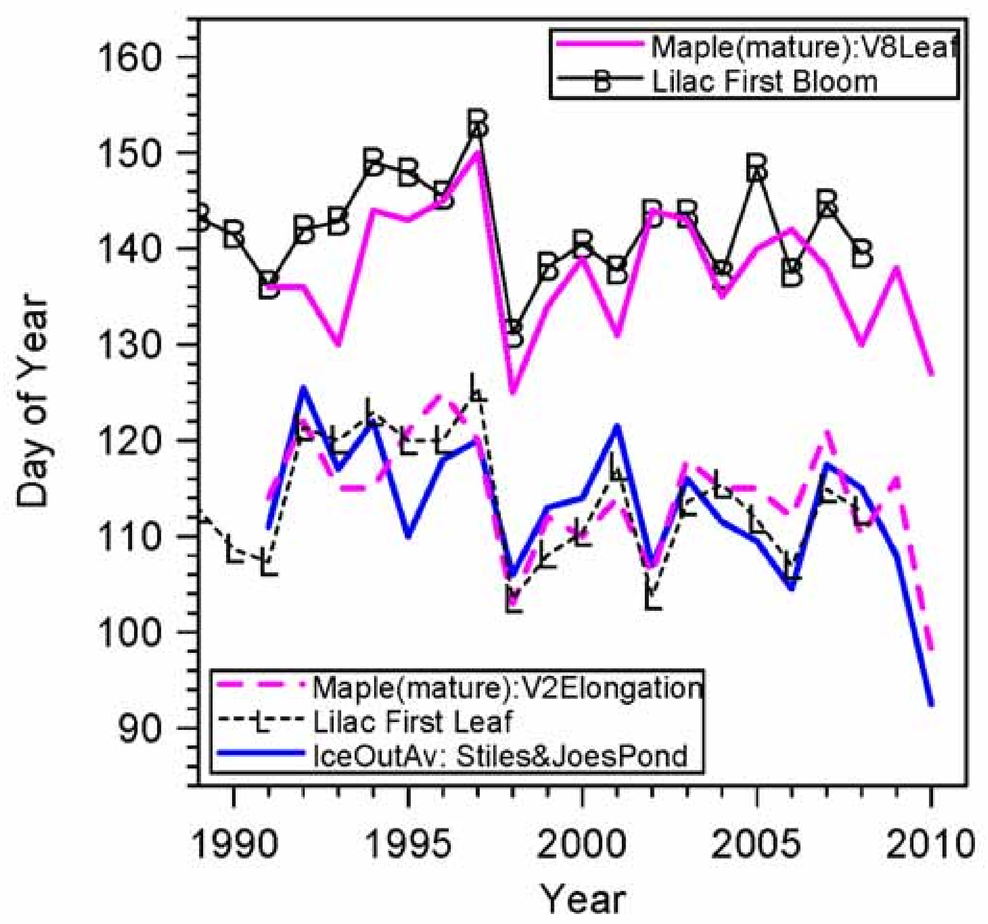
Lilac Leaf-out and Ice-out Coupled





- **Lilac leaf and lake ice-out both depend on Feb. Mar. and April temperatures**
- **Trends indicate earlier spring**

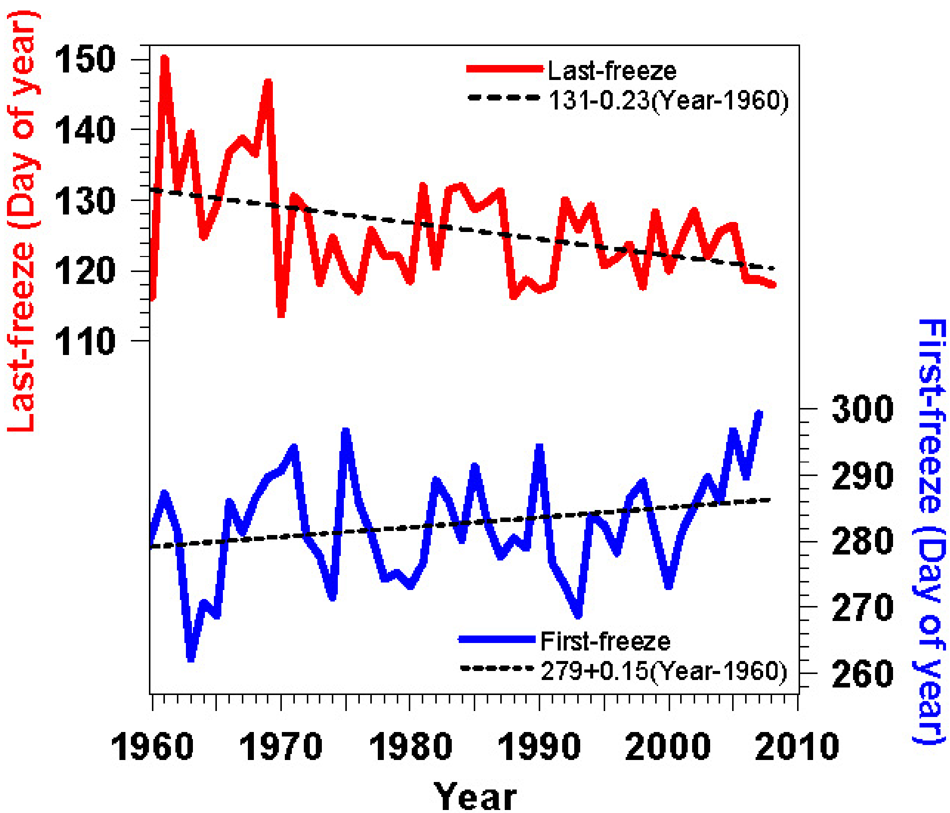
Sugar Maples in Spring

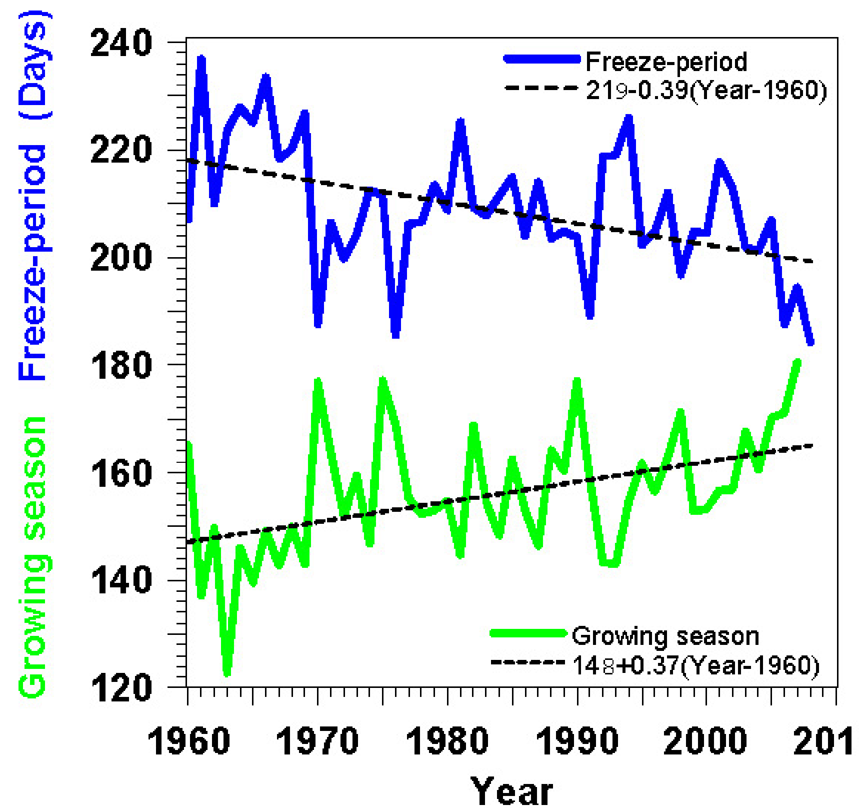


- **Ice-out, lilac leaf, maple bud elongation correlated**
- **Lilac bloom and maple leaf-out correlated**

Data: Sandy Wilmot, ANR

First and Last Frosts Changing





- **Growing season for frost-sensitive plants increasing 3.7 (±1.1) days / decade**
- **A help for growing "local food"**

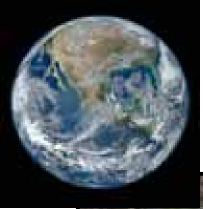
Shrinking Winter: Pittsford, VT
(Freeze-up used to be mid-November)

January 7, <u>2007</u>

December 2006:
- **Warmest on record**

January 10, <u>2008</u>

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

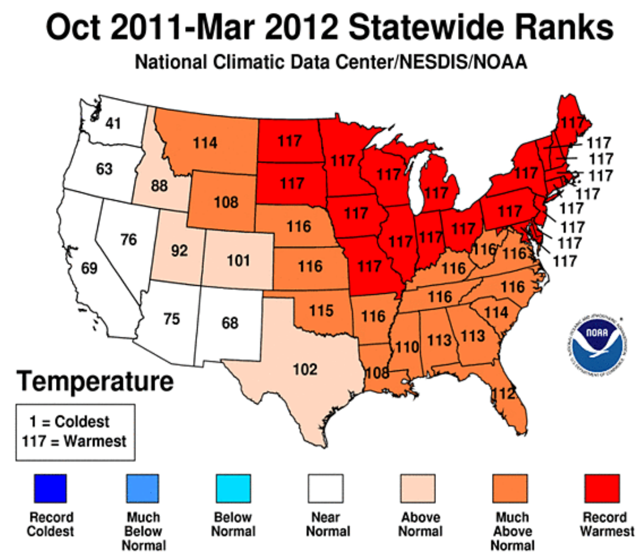


January 2, 2012

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

79°F on March 22, 2012

Pittsford Vermont

3/22/12

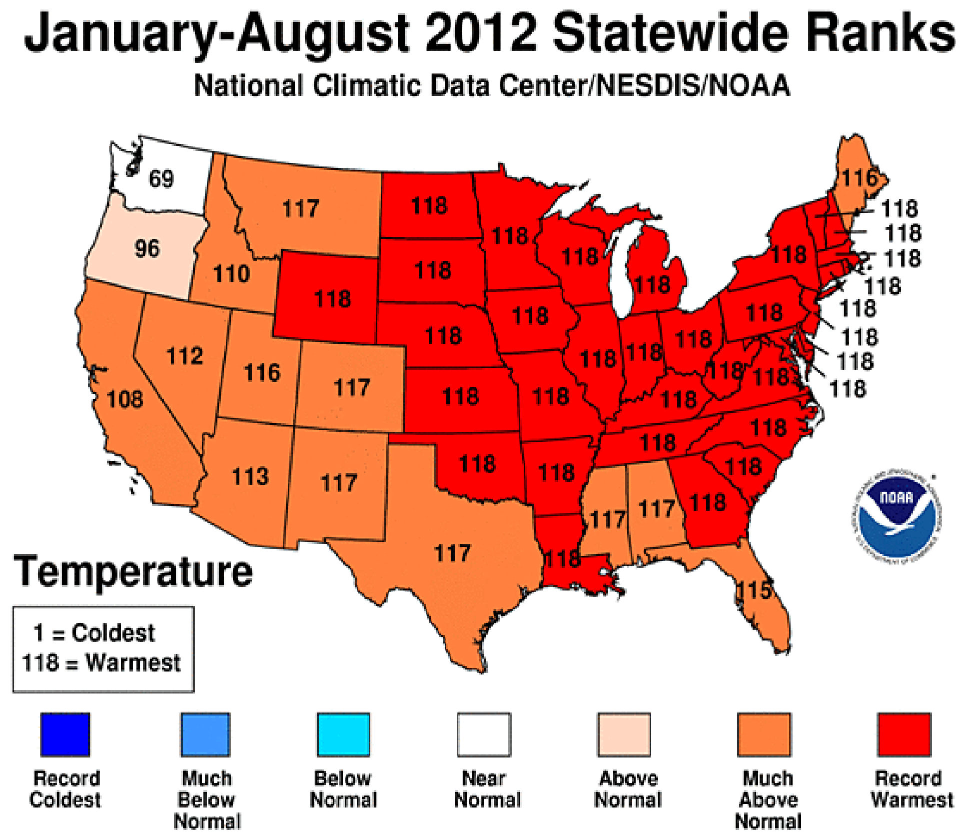
Pittsford Vermont

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

(Scott Whittier: NWS-BTV)

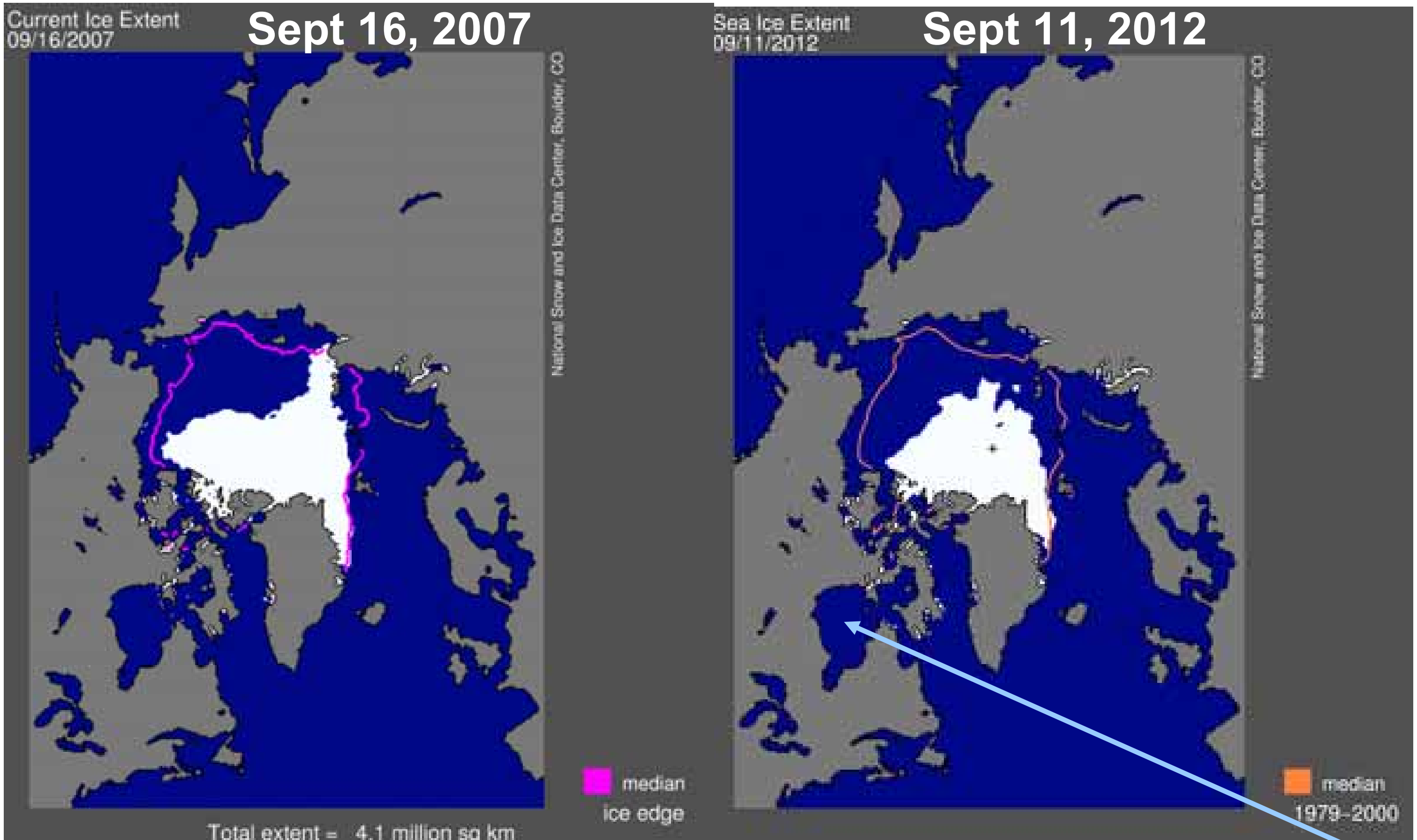


http://www.ncdc.noaa.gov/temp-and-precip/maps.php

Vermont Winter 2006

- **Sun is low; snow reflects sunlight, except where there are trees - shadows**
- **Sunlight reflected, stays cold; little evaporation, clear sky; earth cools to space**
- ***Positive feedback: Less snow, warmer winters (2012)***

Arctic Sea Ice Loss Has Accelerated



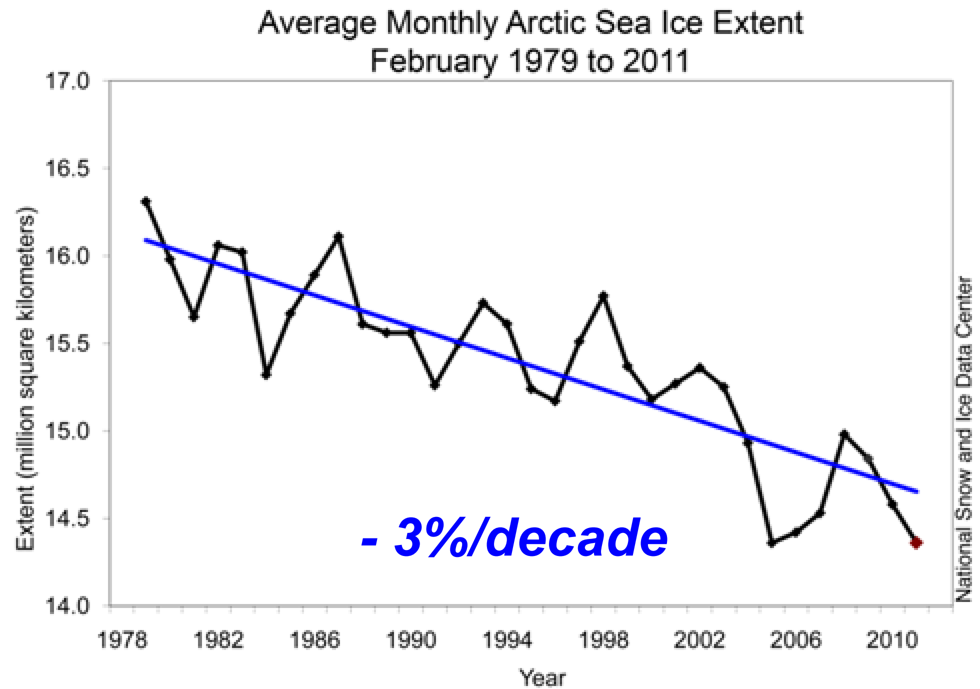
- Positive feedbacks speed melting
- Less ice, less sunlight reflected
- More evapor-ation, larger water vapor greenhouse effect

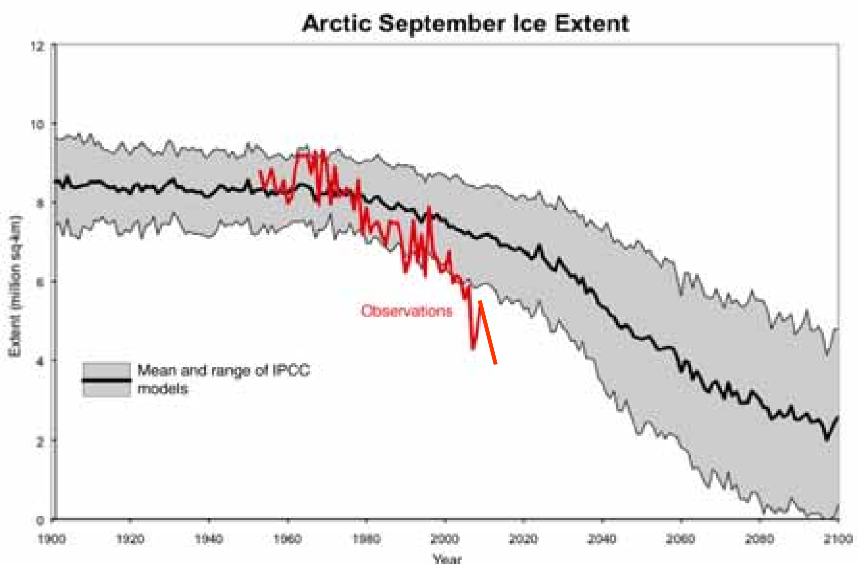
At the end of Nov. 2011 Hudson Bay was still nearly ice-free.

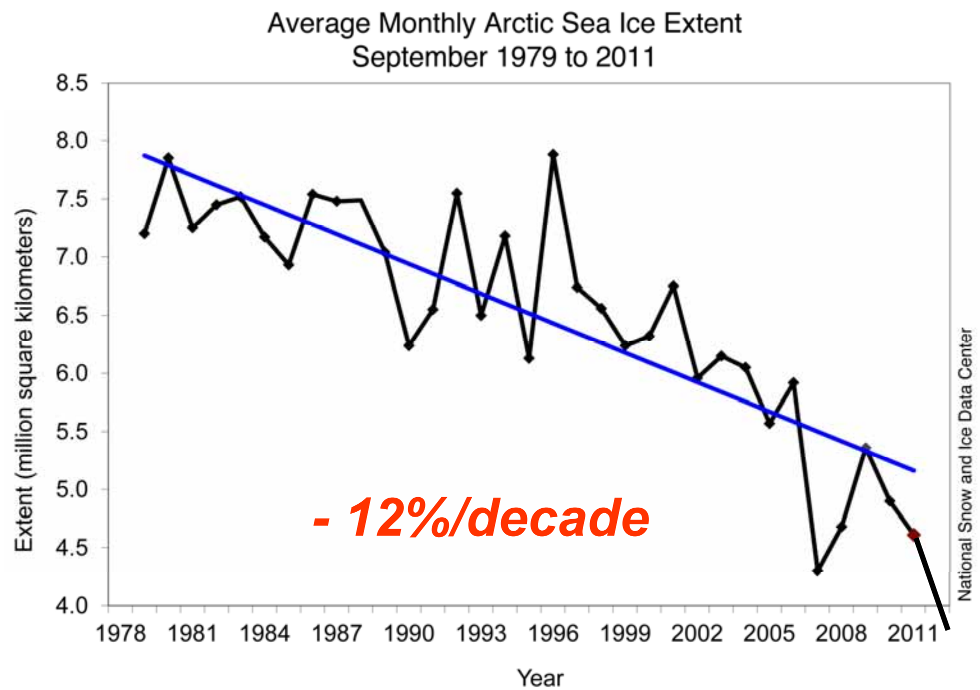
- New Record Ice-loss: 2012 *(www.nsidc.org)*
  - most ice now thin (3-4ft) and only 1-year-old
- Open water in Oct. Nov. favors warmer Fall

Sea Ice Trends

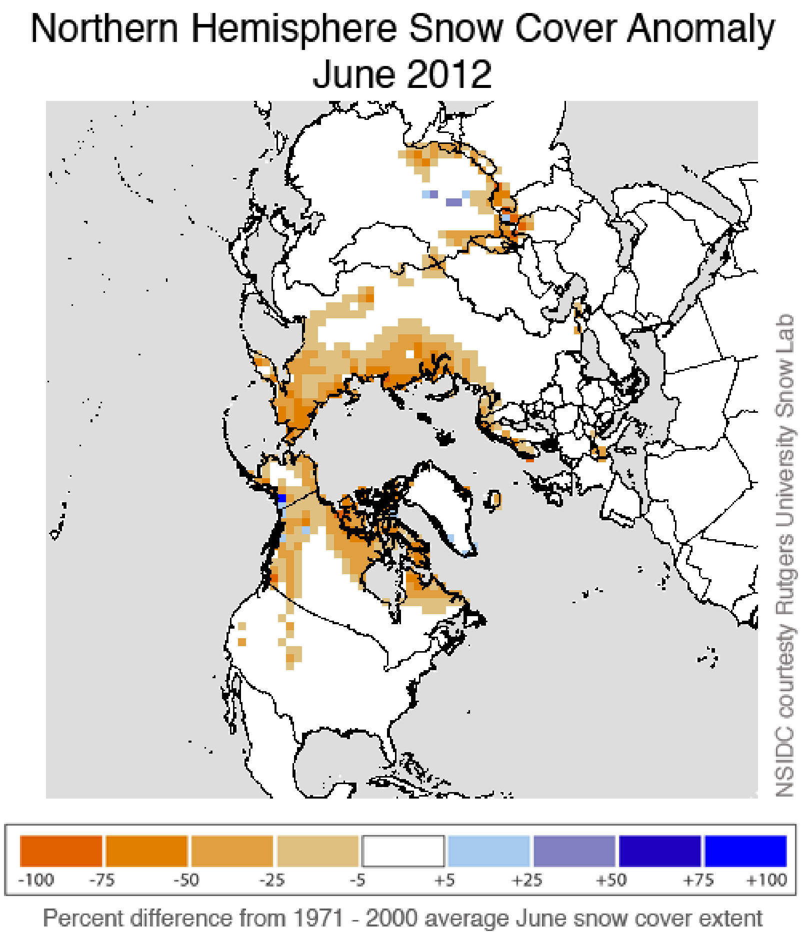
- **Sea ice is thinning rapidly**
- **Observed September decline appears to be faster than IPCC-AR4 climate model projections**
- ***AR5 projections should be faster!***

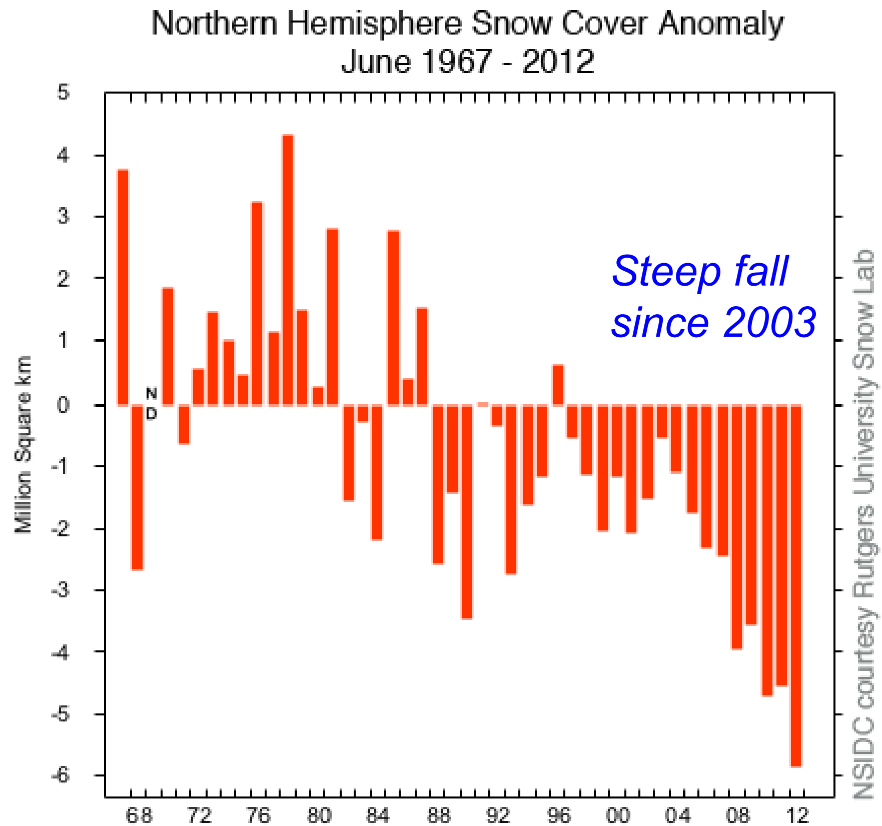






June 2012 snow cover minimum

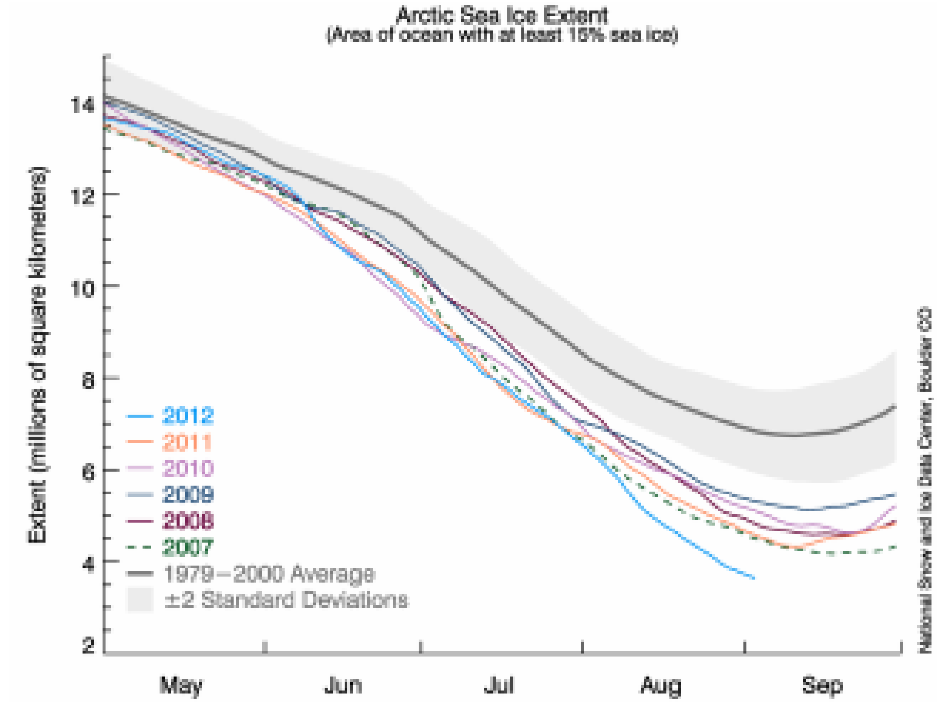




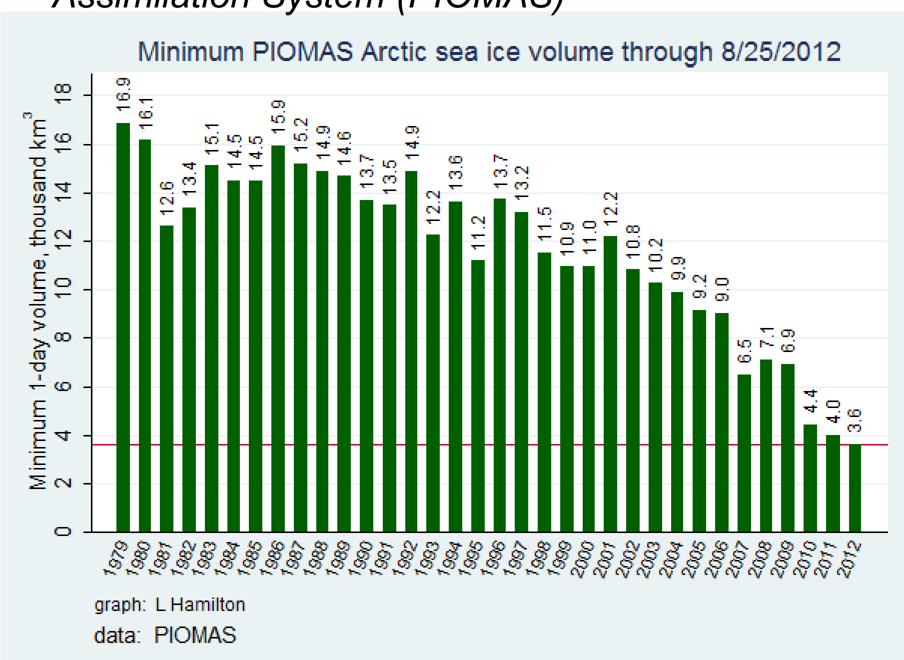
- **New minimum by 10^6 km^2 (1971-2000 ref)**

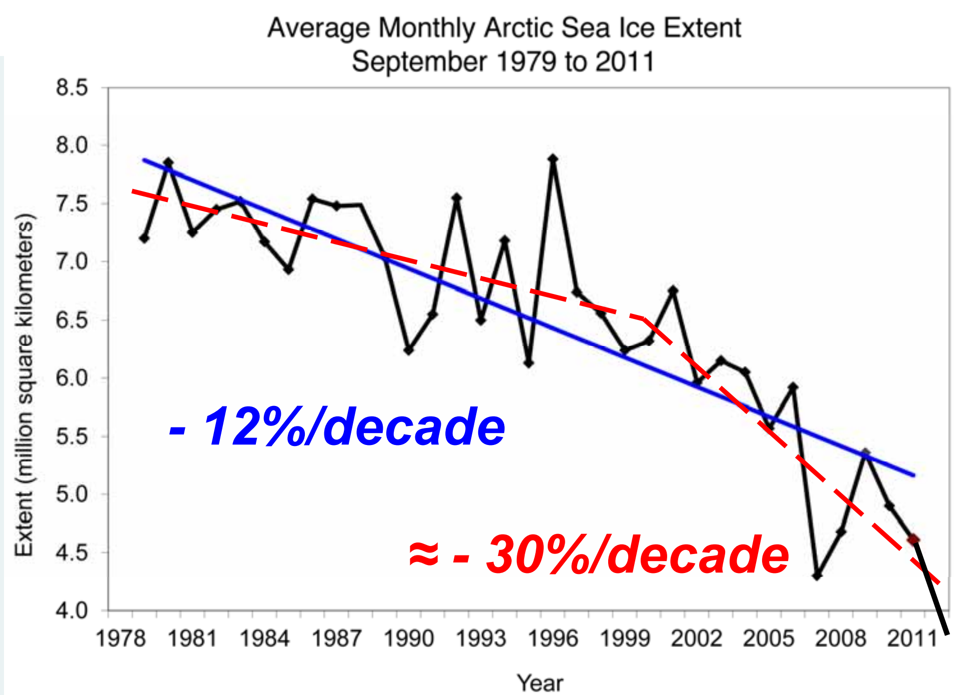
Sea Ice Trends

- Sea ice is **thinning rapidly**
- Now mostly 1-year-old ice
- Observed September decline appears to be **steeper in last decade**



Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS)





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: 2012 was extreme***

Summer dry-down

- Wet in spring
- Soil moisture falls: summer dry-down
- Low humidity & little rain

- *Can lock-in drought in central US: as 2012*

Recently Many Wet Summers in Vermont


- **2004, 2006, 2008, 2009, (2010), 2011 all wet**
- **Direct fast evaporation off wet canopies**
- ***Positive evaporation-precipitation feedback, coupled to synoptic system frequency***

Fall Climate Transition

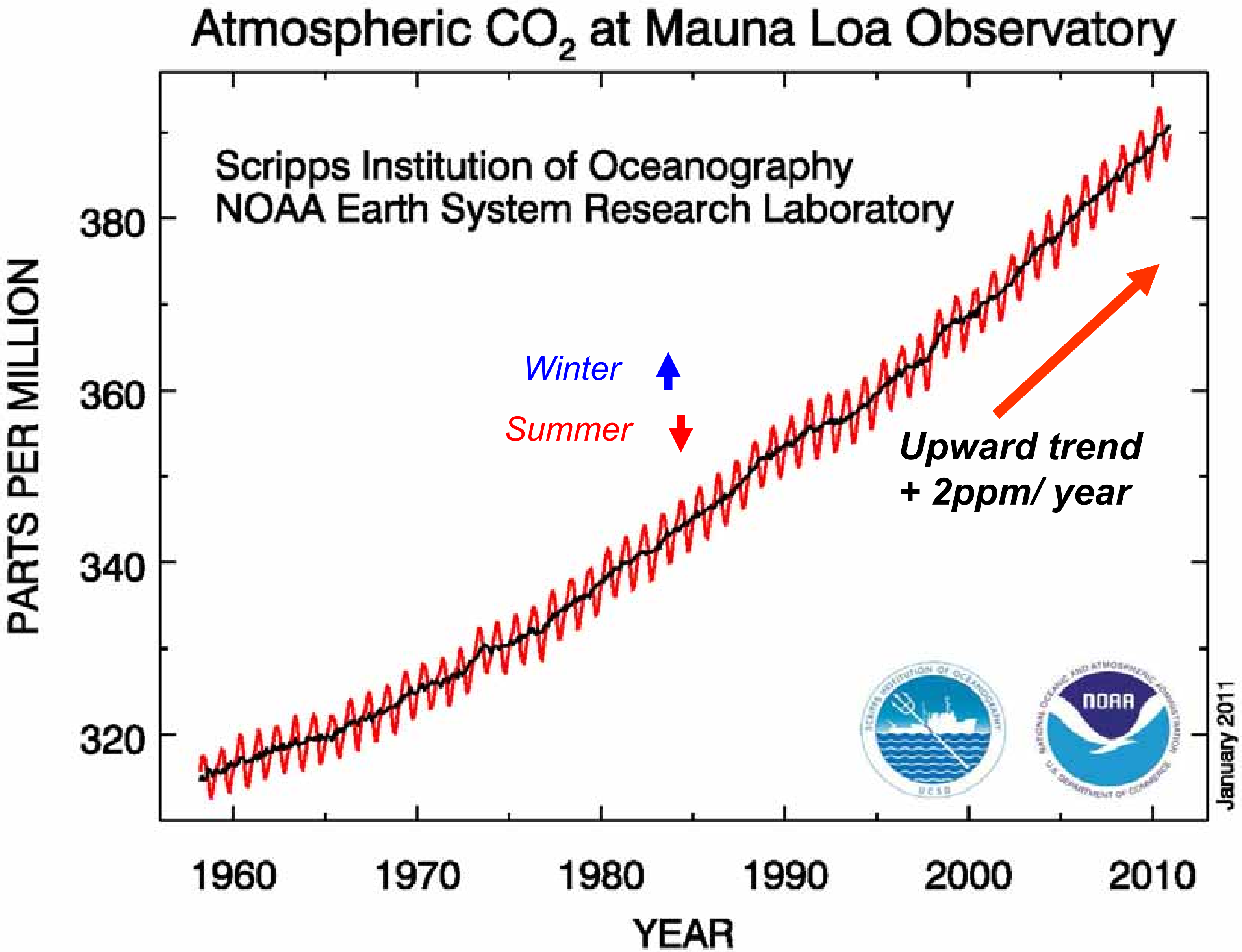
Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

- **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**

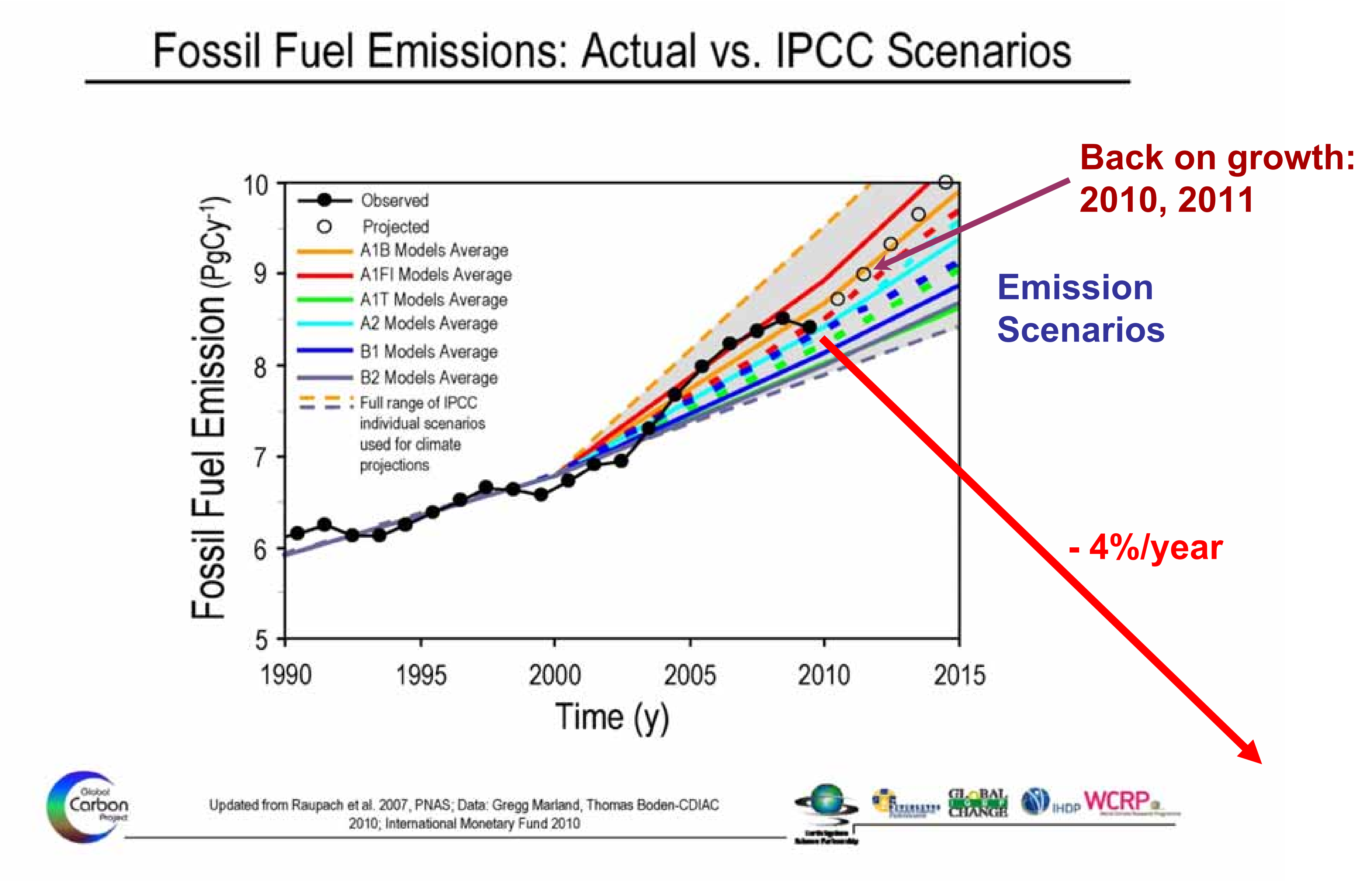
- ***The opposite of what happens in Spring with leaf-out!***

Later frost: Growing season getting longer

Carbon Dioxide Is Increasing



2009 Was "Good" for the Earth



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^{o}C
- 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 <u>this is 3X amplifier</u> on CO_2 rise**
- **As Earth warms, snow & ice decrease and reduced SW reflection <u>amplifies warming</u> 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**

Climate Change Projections

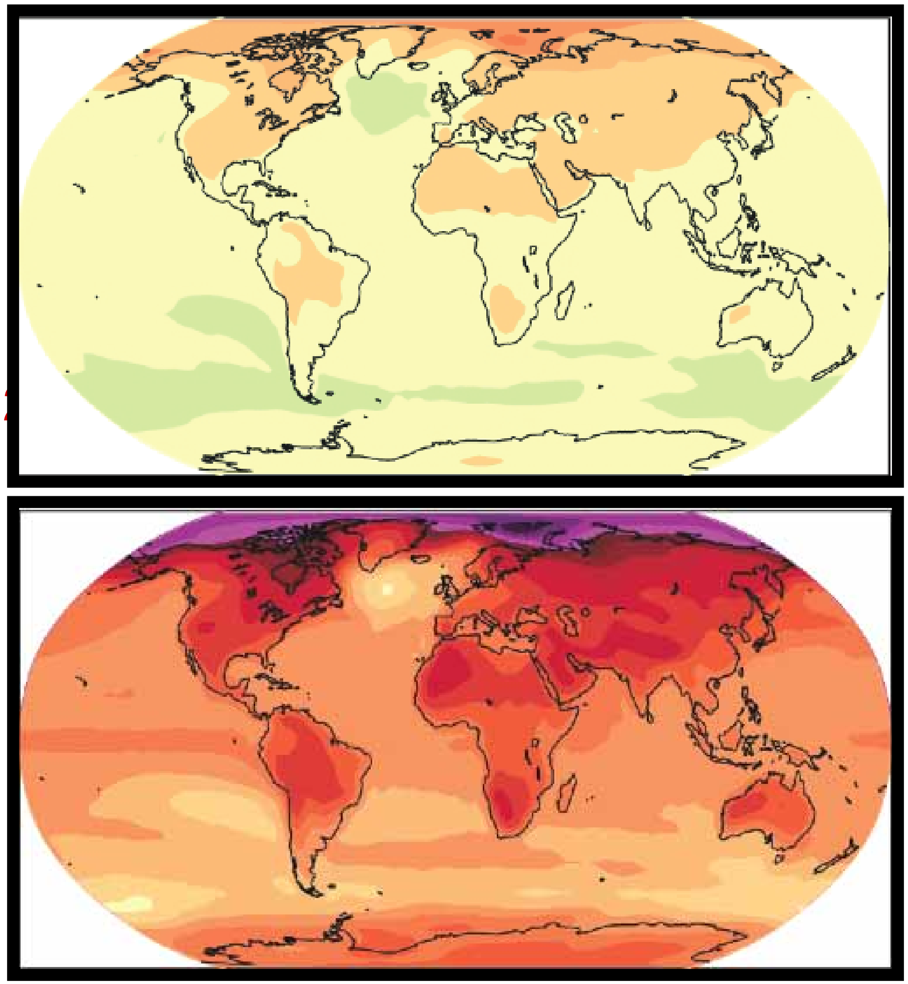
- **IPCC 2007 (Fourth Assessment - AR4)**

- ***AR5 in progress with improved models –expect no large change***
- **Higher resolution: Improved aerosols, sea-ice & carbon cycle (probably slightly increased climate sensitivity and wider range between models)**

Predicted Change in Temperature

2020-2029 and 2090-2099, relative to 1980-1999 (^oC)

"Committed"



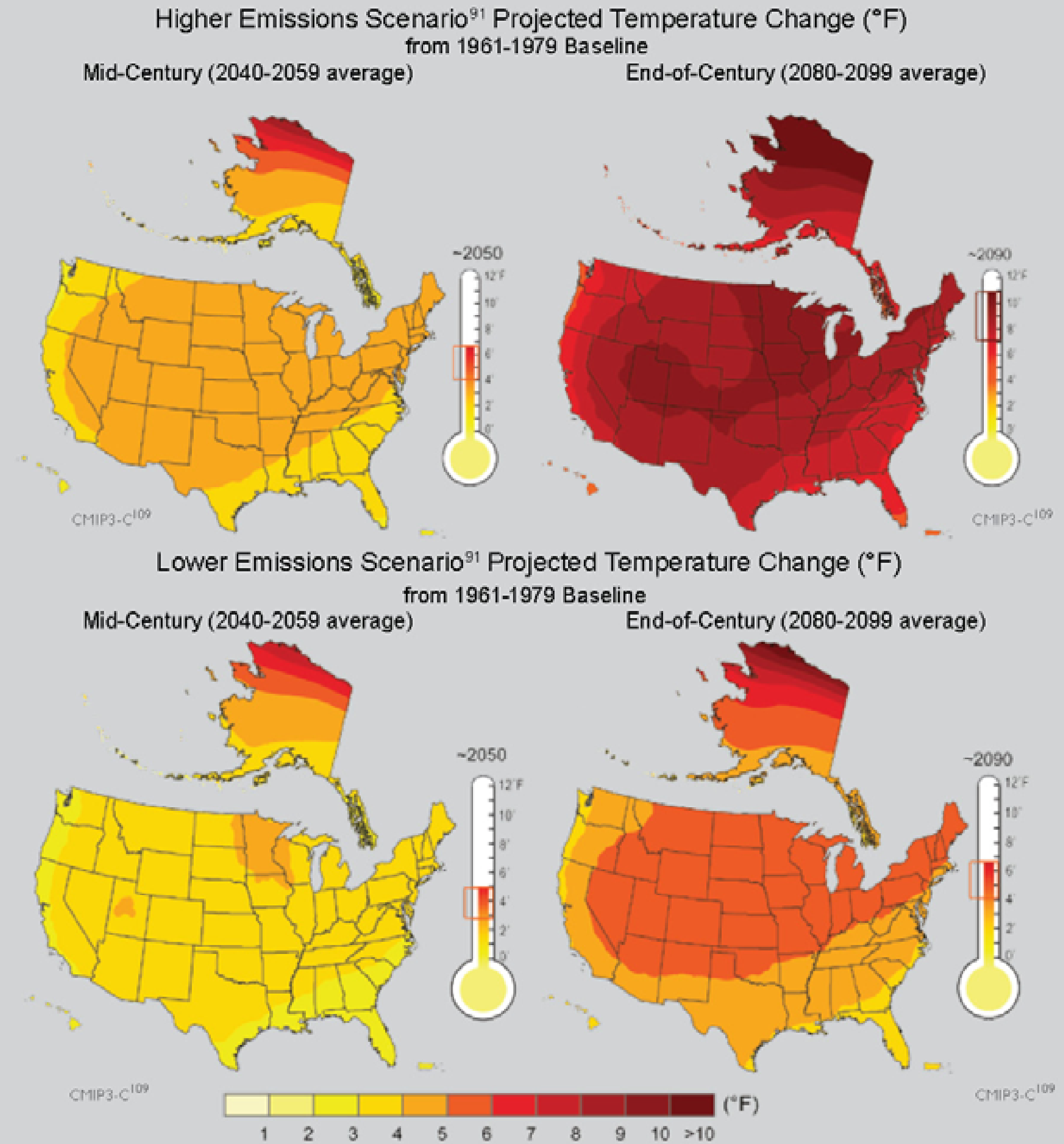
(We did nothing for the last 20 years)

Still up to us!

(We could halve this if we act now)

USGCRP (2009) - p29

- Mean of 16 CMIP3 models

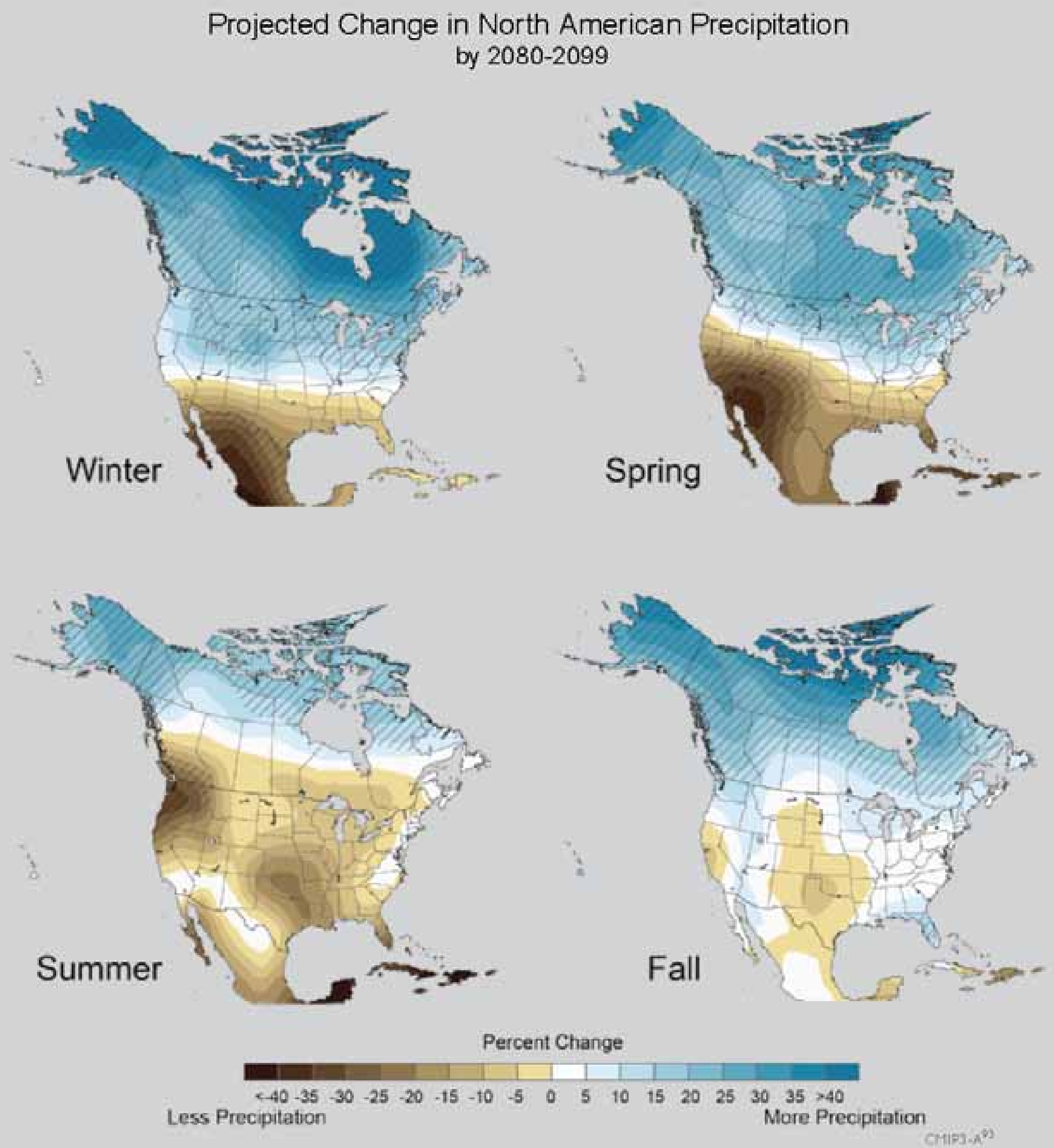


The maps on this page and the previous page are based on projections of future temperature by 16 of the Coupled Model Intercomparison Project Three (CMIP3) climate models using two emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC), *Special Report on Emission Scenarios* (SRES).[91] The "lower" scenario here is B1, while the "higher" is A2.[91] The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. Additional information on these scenarios is on pages 22 and 23 in the previous section, *Global Climate Change*. These maps, and others in this report, show projections at national, regional, and sub-regional scales, using well-established techniques.[110]

USGCRP (2009) - pp 29

USGCRP (2009) – p31

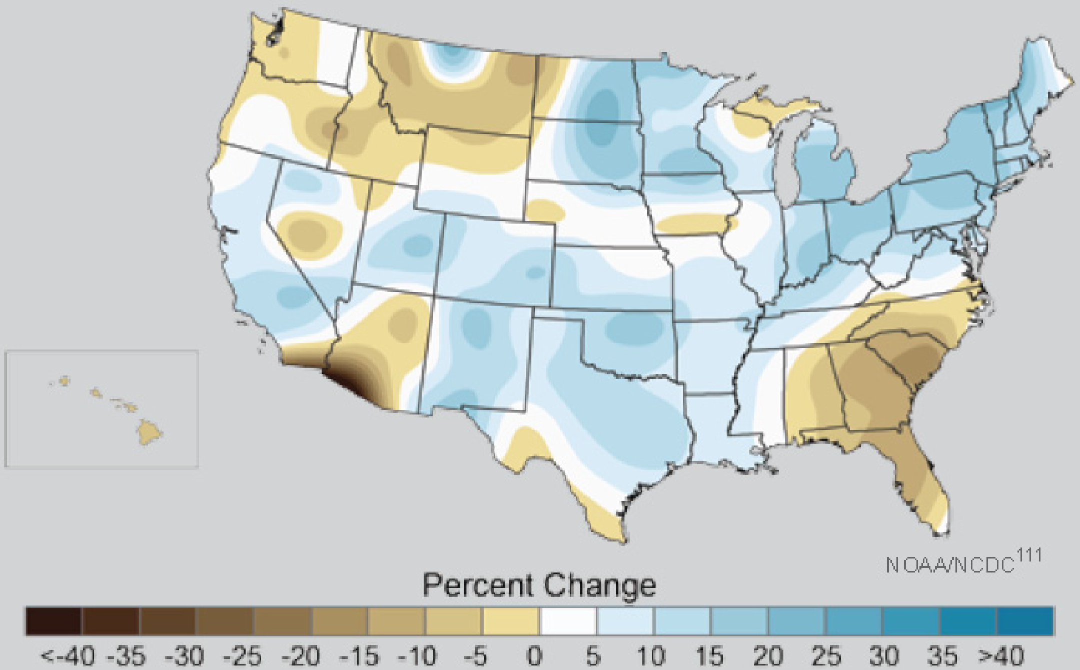
- **More confidence where shaded**
- **Northern areas wetter**



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.[91] 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.

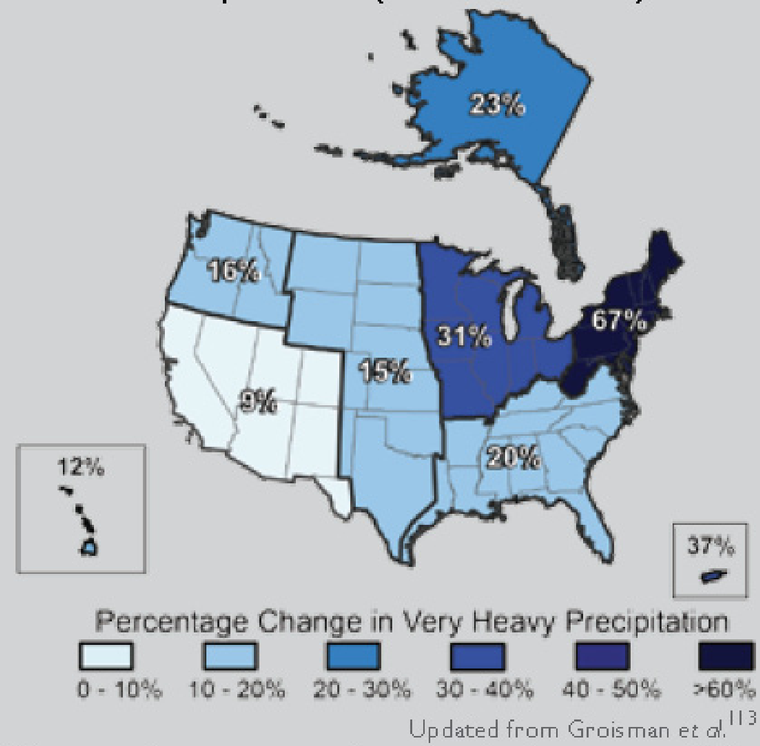
Observed Changes: Total Precip and Heavy Precip. (upper 1%)

Observed Change in Annual Average Precipitation
1958 to 2008



While U.S. annual average precipitation has increased about 5 percent over the past 50 years, there have been important regional differences as shown above.

Increases in Amounts of Very Heavy Precipitation (1958 to 2007)

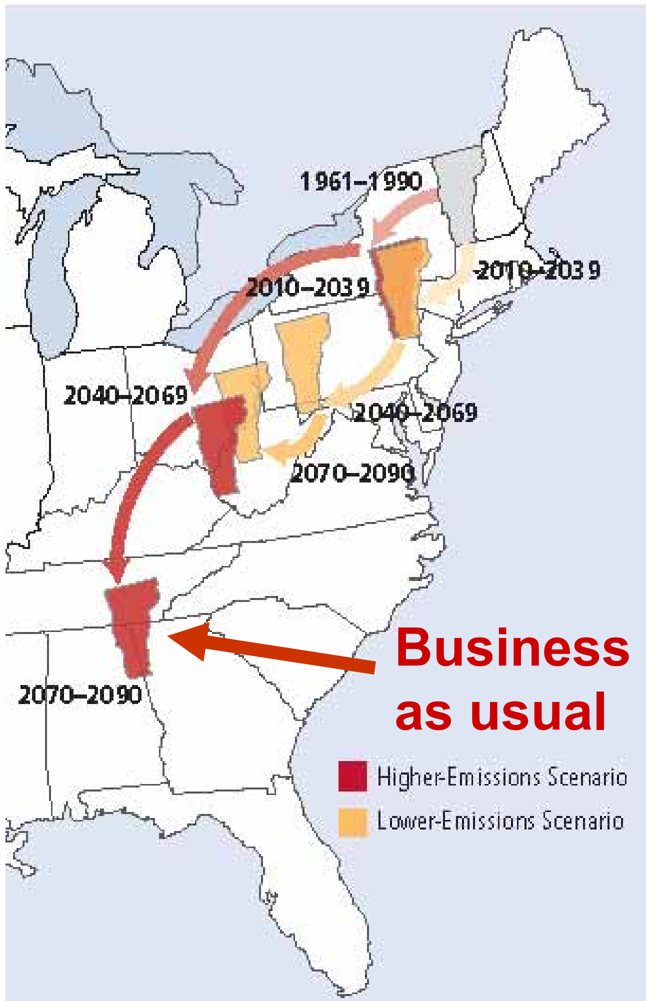


The map shows percent increases in the amount falling in very heavy precipitation events (defined as the heaviest 1 percent of all daily events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

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

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

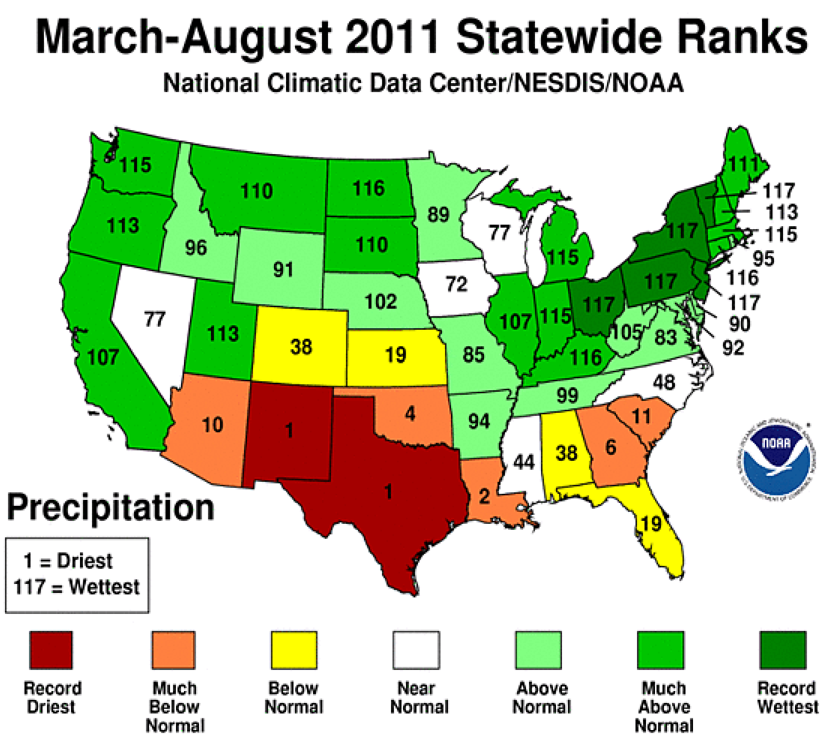
  - 32 weather disasters >$1B in 2011
- Melting Arctic and permafrost—
  methane release is positive feedback
- Ecosystem collapse, including perhaps forest and ocean ecosystems
- Collapse of unsustainable human population

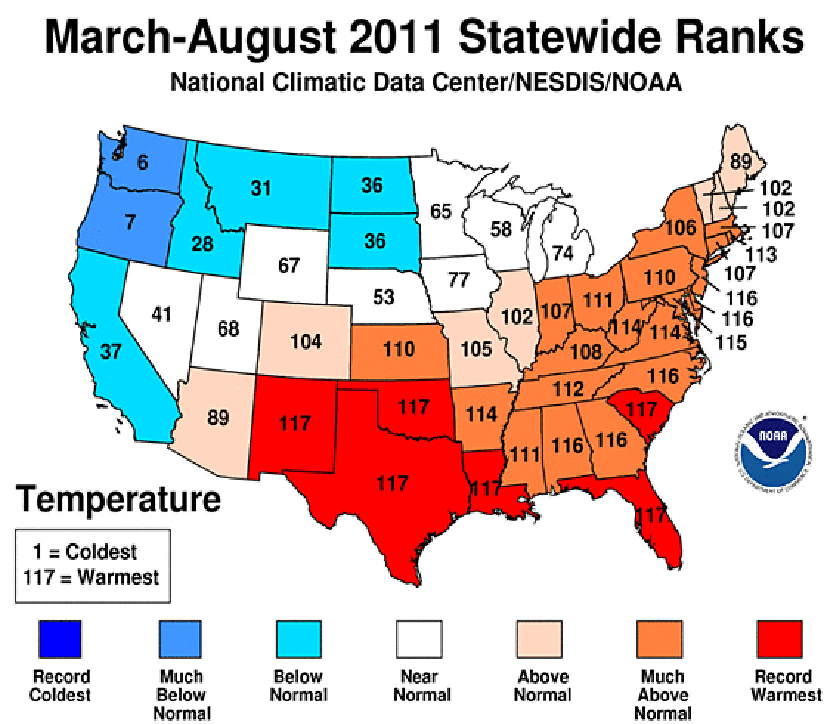
Extreme Weather (precip.)

- *Precip. is condensation of atmospheric water vapor (large latent heat release)*
- *Saturation vapor pressure at cloud-base increases steeply with temperature (6%/^{o}C)*
- *More latent heat organizes storms, increasing convergence of vapor*
- *Quasi-stationary large-scale flow means longer rain events in low-pressure convergent regions, and longer droughts in high-pressure divergent regions*
- *As climate changes, quasi-stationary large-scale modes appear to be more frequent*
- *Wet surface: more evaporation and runoff*

2011 Vermont Floods

- **Record spring flood on Lake Champlain**
- **Record floods following TS Irene**
- **Record wet March-August, 2011: OH to VT**
  (but record drought in TX & NM)
- ***Quasi-stationary pattern for 6 mos***





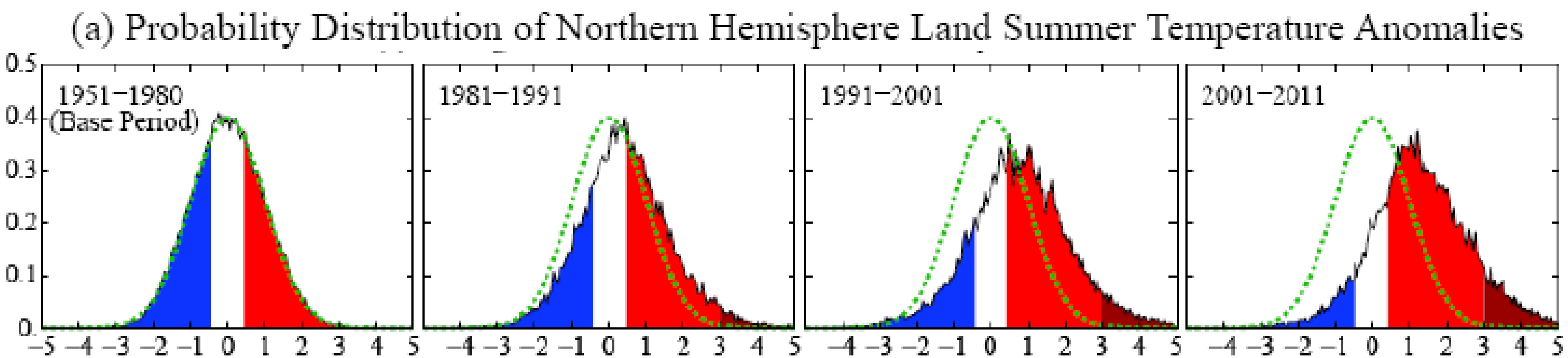
Winooski River 2011

- Two classic VT flood situations
- Spring flood: heavy rain and warm weather, melting large snowpack
  - 70F (4/11) and 80F(5/27) + heavy rain
  - record April, May rainfall: 3X at BTV
- Irene flood: tropical storm moved up east of Green Mountains - dumping 6ins rain on wet soils (Floyd on 9/17/1999 had similar rain - but with dry soils there was less flooding)

Discussion

- **This talk http://alanbetts.com/research**
- **VTCCAdaptClimateChangeVTBetts10-29.pdf http://www.anr.state.vt.us/anr/climatechange/Adaptation.html**
- ***Vermont Climate Change Indicators***
- ***Seasonal Climate Transitions in New England***

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)

USGCRP Northeast.pdf (2009)

- **Since 1970, the annual average temperature in the Northeast has increased by 2°F, with winter temperatures rising twice this much**
- **Warming has resulted in many other climate-related changes including:**

- **More frequent days with temperatures above 90°F**
- **A longer growing season**
- **Increased heavy precipitation**
- **Less winter precipitation falling as snow and more as rain**
- **Reduced snowpack**
- **Earlier breakup of winter ice on lakes and rivers**
- **Earlier spring snowmelt resulting in earlier peak river flows**
- **Rising sea surface temperatures and sea level**

http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/northeast

USGCRP Northeast.pdf (2009)

- Over the next several decades, temperatures in the Northeast are projected to rise an additional 2.5 to 4°F in winter and 1.5 to 3.5°F in summer.
- By mid-century and beyond, however, today's emissions choices would generate starkly different climate futures; the lower the emissions, the smaller the climatic changes and resulting impacts.

- By late this century, under a higher emissions scenario:

- Winters in the Northeast are projected to be much shorter with fewer cold days and more precipitation.
- The length of the winter snow season would be cut in half across northern New York, Vermont, New Hampshire, and Maine, and reduced to a week or two in southern parts of the region.
- Cities that today experience few days above 100°F each summer would average 20 such days per summer, while certain cities, such as Hartford and Philadelphia, would average nearly 30 days over 100°F.
- Short-term (one- to three-month) droughts are projected to occur as frequently as once each summer in the Catskill and Adirondack Mountains, and across the New England states.
- Hot summer conditions would arrive three weeks earlier and last three weeks longer into the fall.
- Sea level in this region is projected to rise more than the global average

Climate Model Predictions