Climate Change in Vermont

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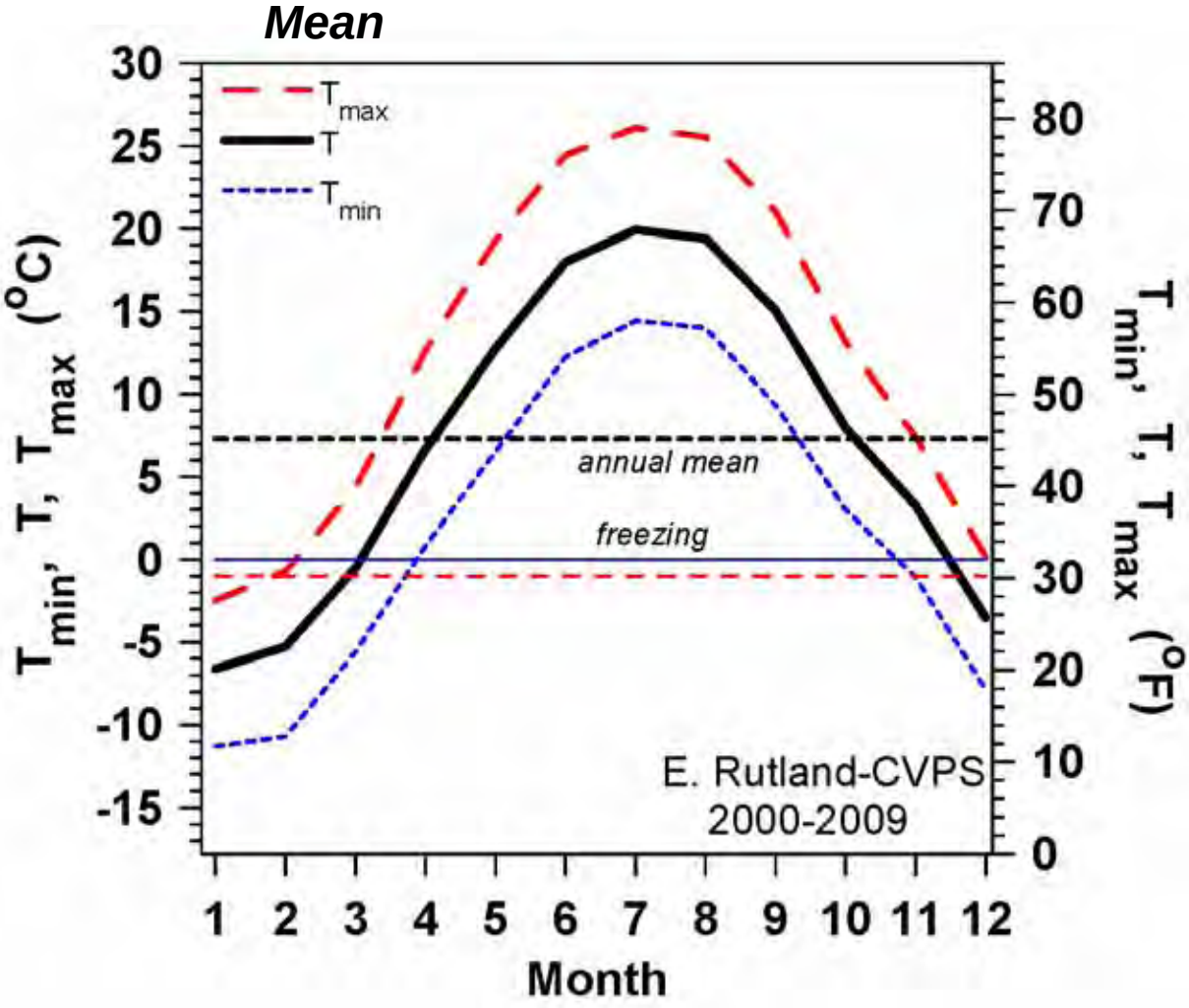
November 1, 2012

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***

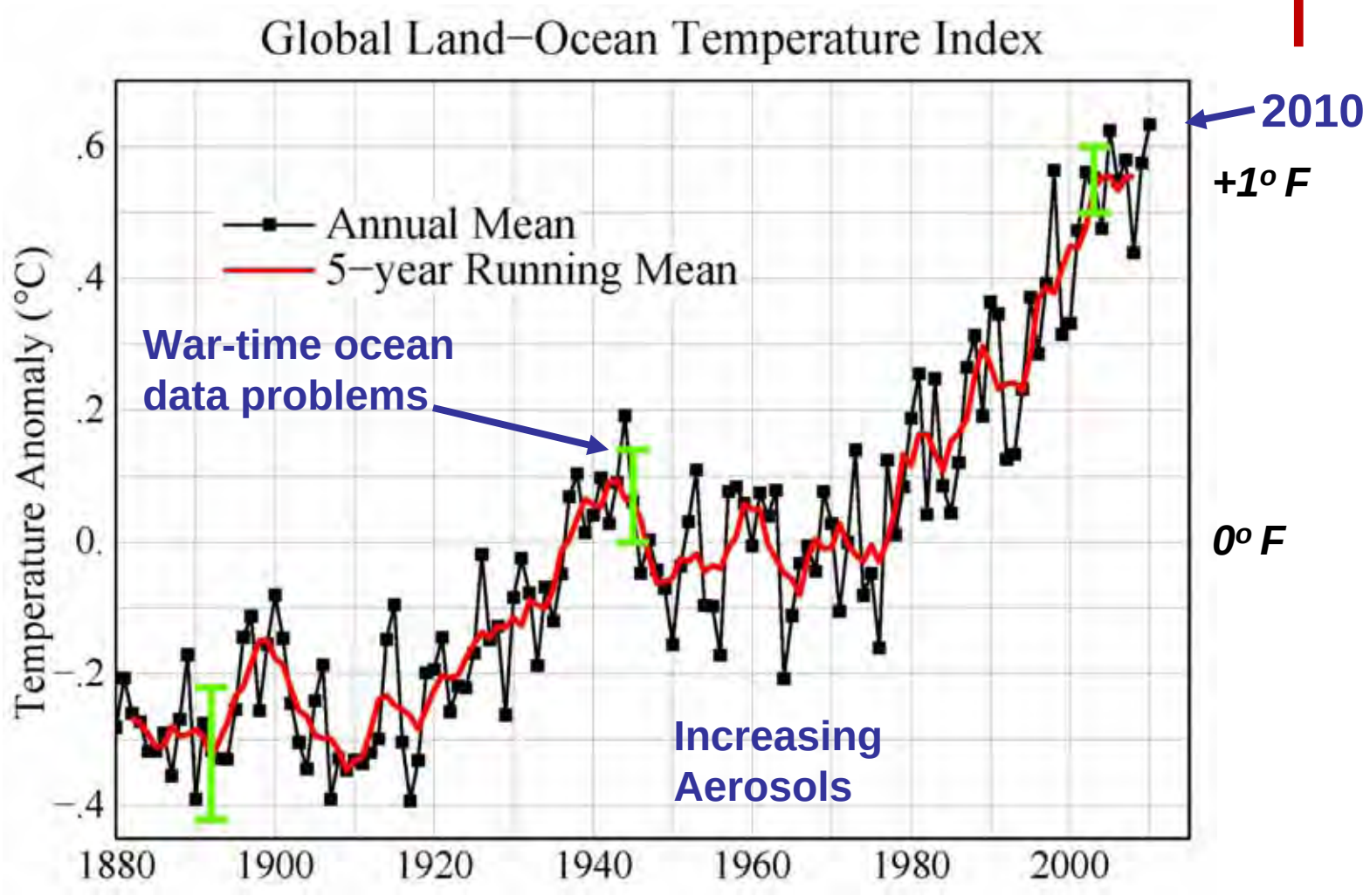


Earth sustains life

- **Burning fossil fuels is increasing greenhouse gases and melting polar ice**
- **Climate is warming and extreme weather is increasing**

January 2, 2012: NASA

Global Temperature Rise 1880 – Present

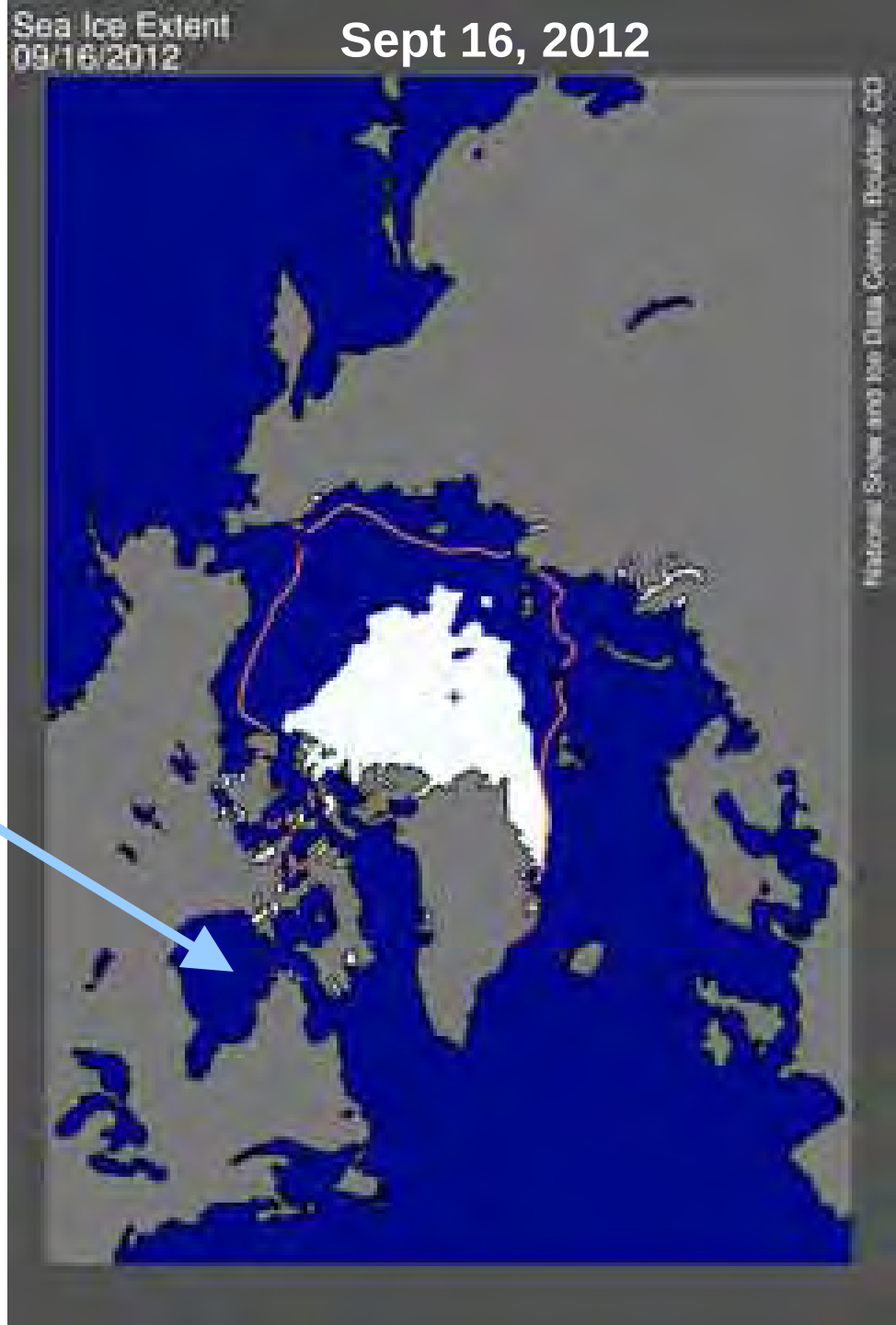


NASA-GISS, 2011

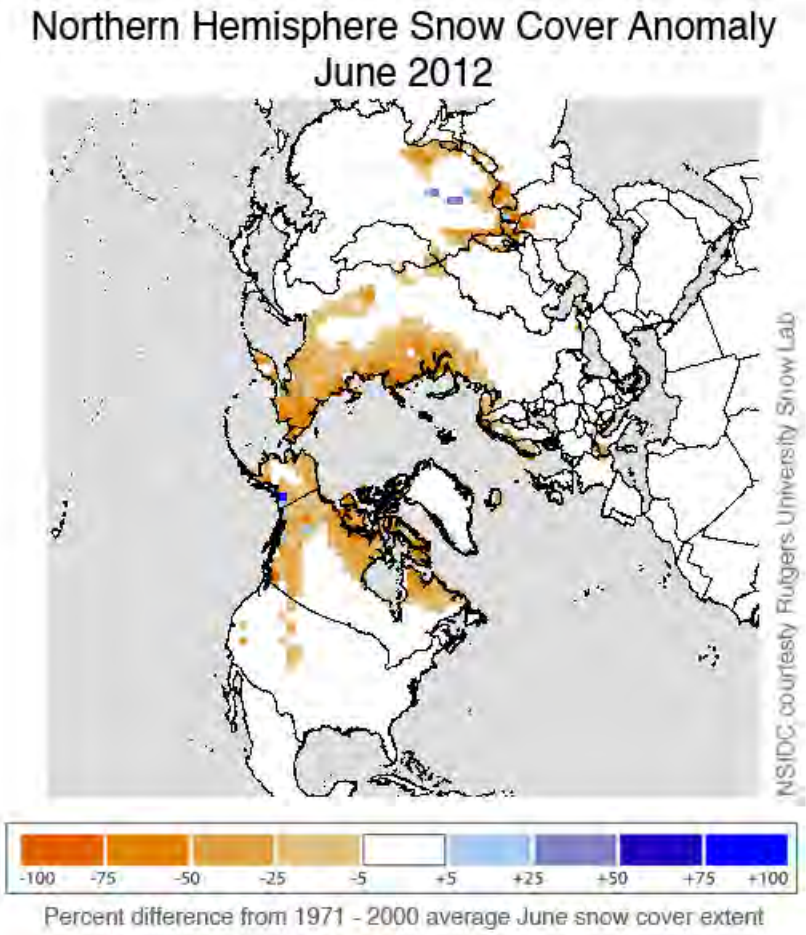
- **Half the Arctic Sea Ice Melted in 2012**
- **Open water in Oct. Nov. gives warmer Fall in Northeast**

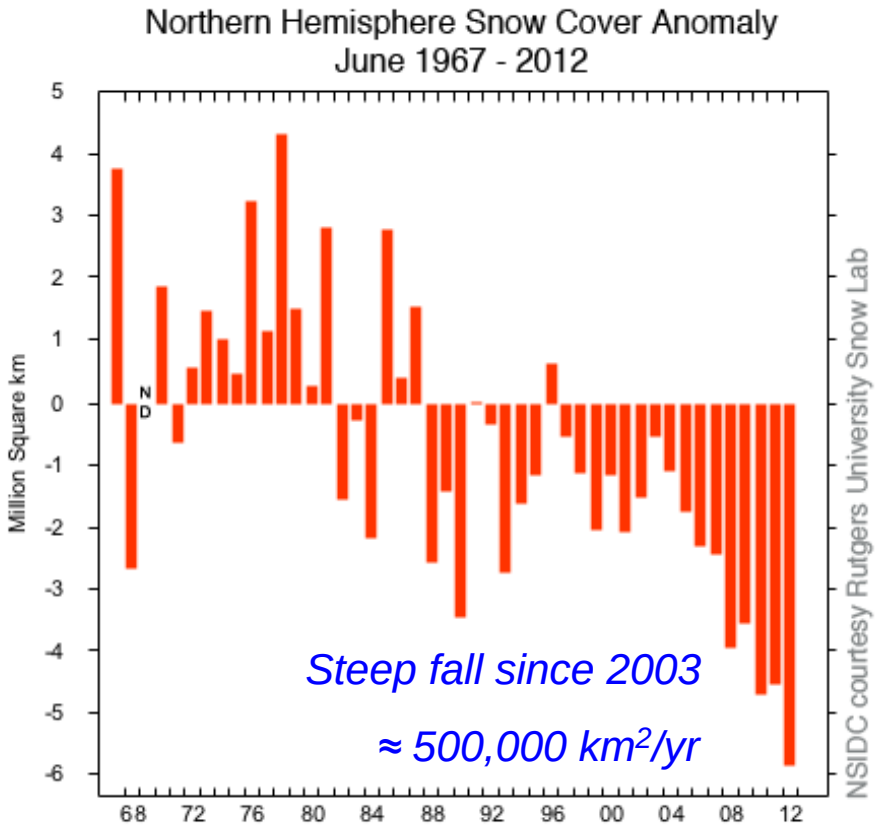
At the end of Nov. 2011 Hudson Bay was still nearly ice-free

- ***Positive feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Ice thin: most 1-yr-old***



June 2012 snow cover minimum





- **Arctic warming rapidly**
  - **Melting fast**
- **New England winters also**
  - **Same positive feedbacks**

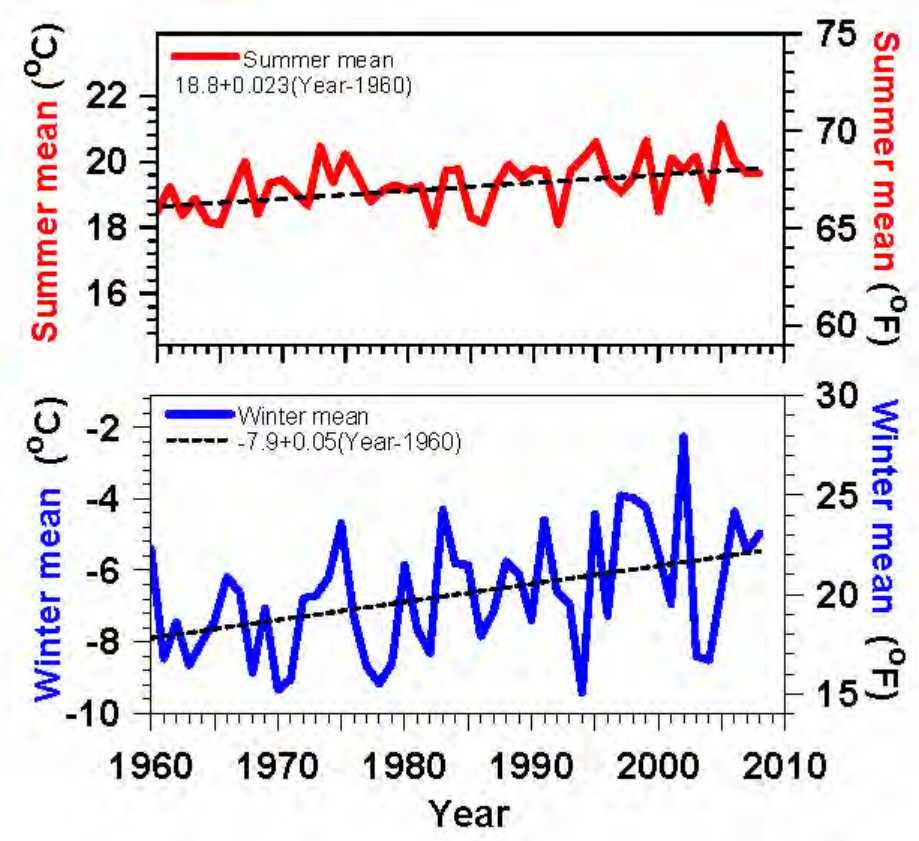
What Is Happening to Vermont?

- **PAST 40/50 years** **(CO_2 forcing detectible)**
- **Warming twice as fast in winter than summer**
- **Winter severity decreasing**
- **Lakes frozen less by 7 days / decade**
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**

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

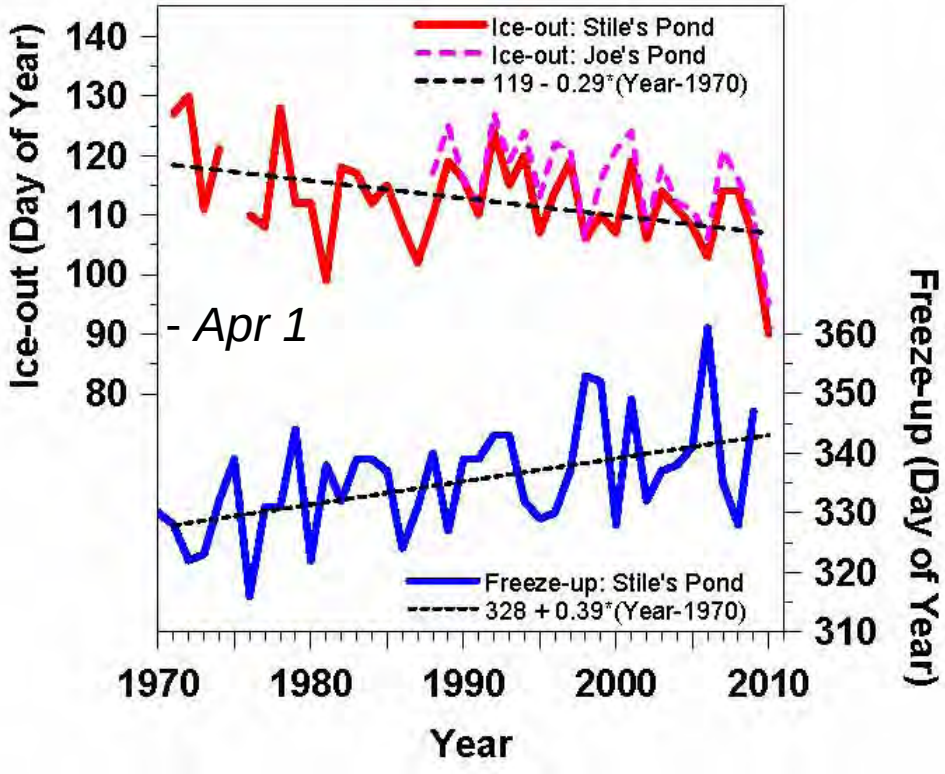
Vermont Temperature Trends 1961-2008

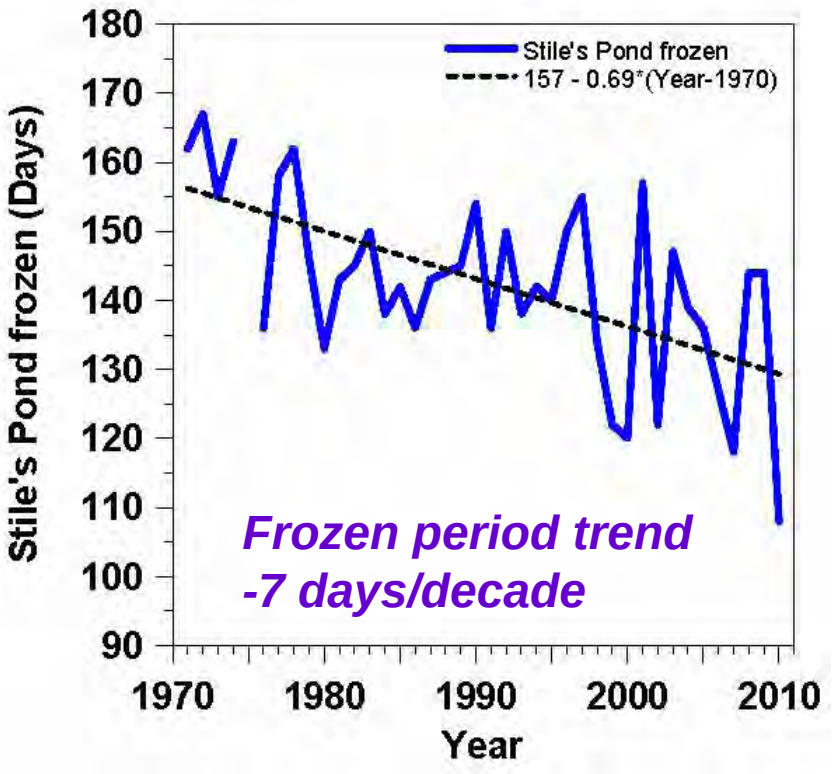
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***



Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



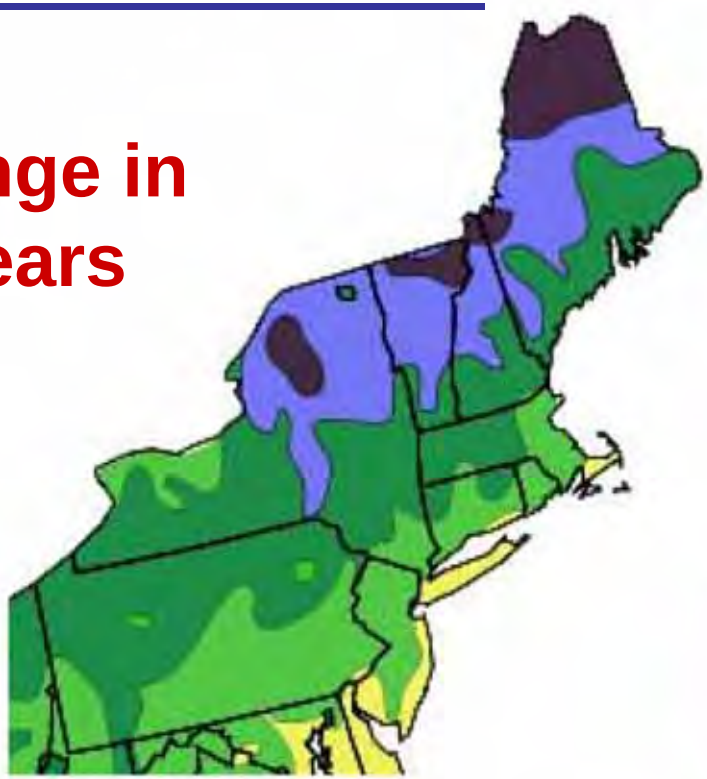


- **Ice-out earlier by 3 days / decade**
- **Freeze-up later by 4 days / decade**
- ***Spring runoff peak 3 days / decade earlier***

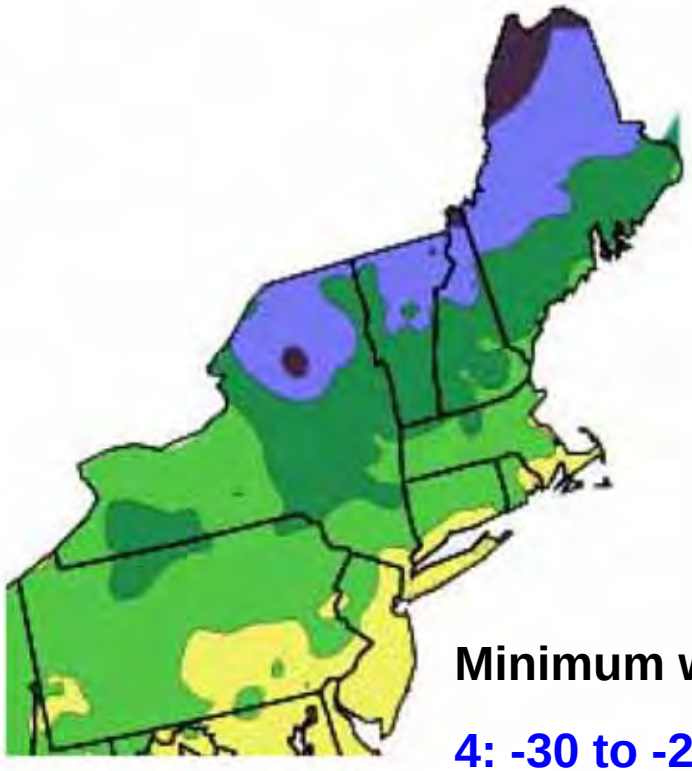
Winter Hardiness Zones

– winter cold extremes

Change in 16 years



1990



2006

Zone

2 3 4 5 6 7 8 9 10

USDA Hardiness Zones

Minimum winter T

4: -30 to -20°F

5: -20 to -10°F

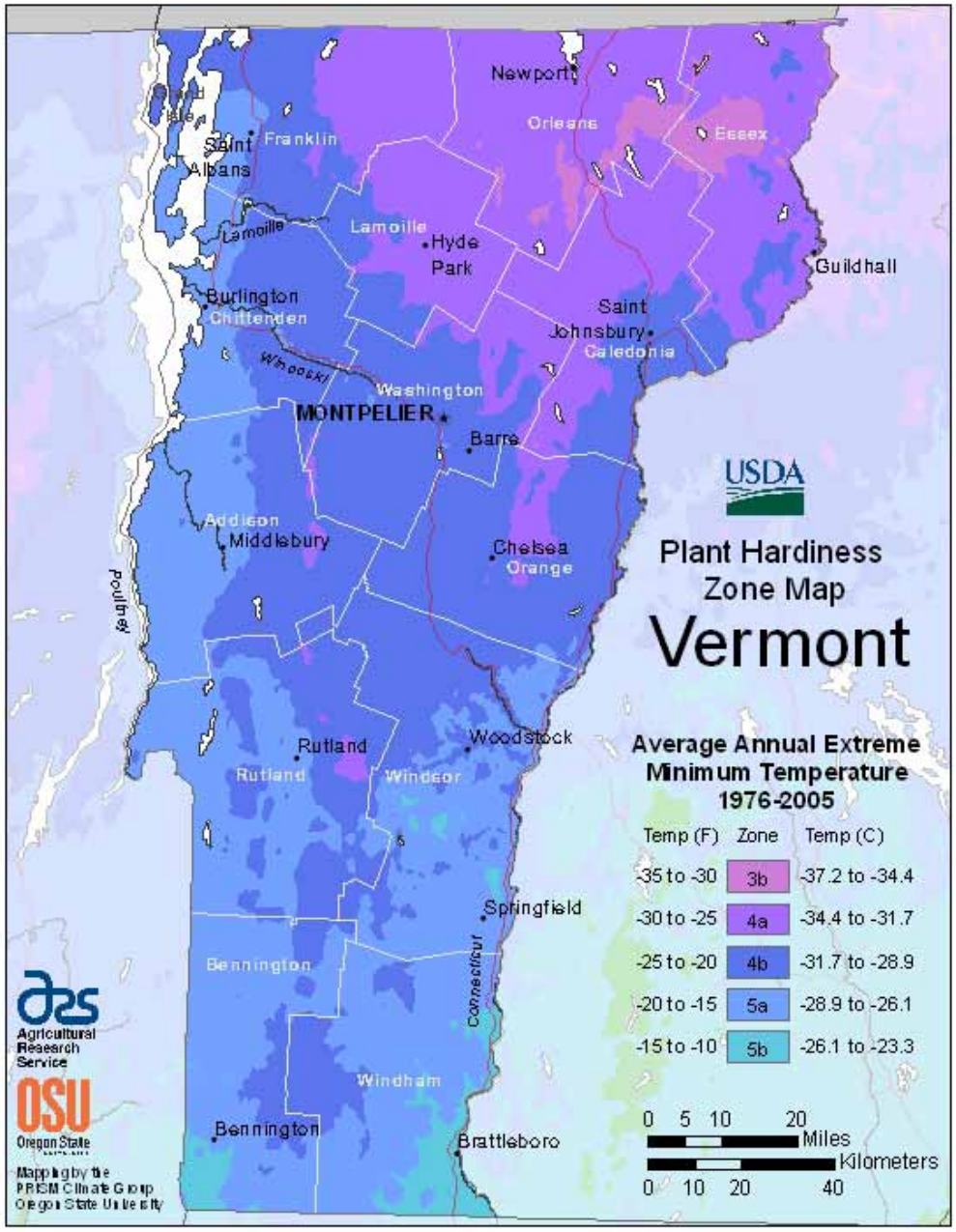
6: -10 to 0°F

Detailed Map *(most recent)*

- **USDA : VT Hardiness Zone Map 1976-2005**
  - **mean 1990**
  - **South into zone 6**

- **Half-zone in 16 yrs = 3.1°F/ decade**
  - **triple the rise-rate of winter mean T**

- ***http://planthardiness.ars.usda.gov/PHZMWeb/***



Bennington & Brattleboro are becoming zone 6

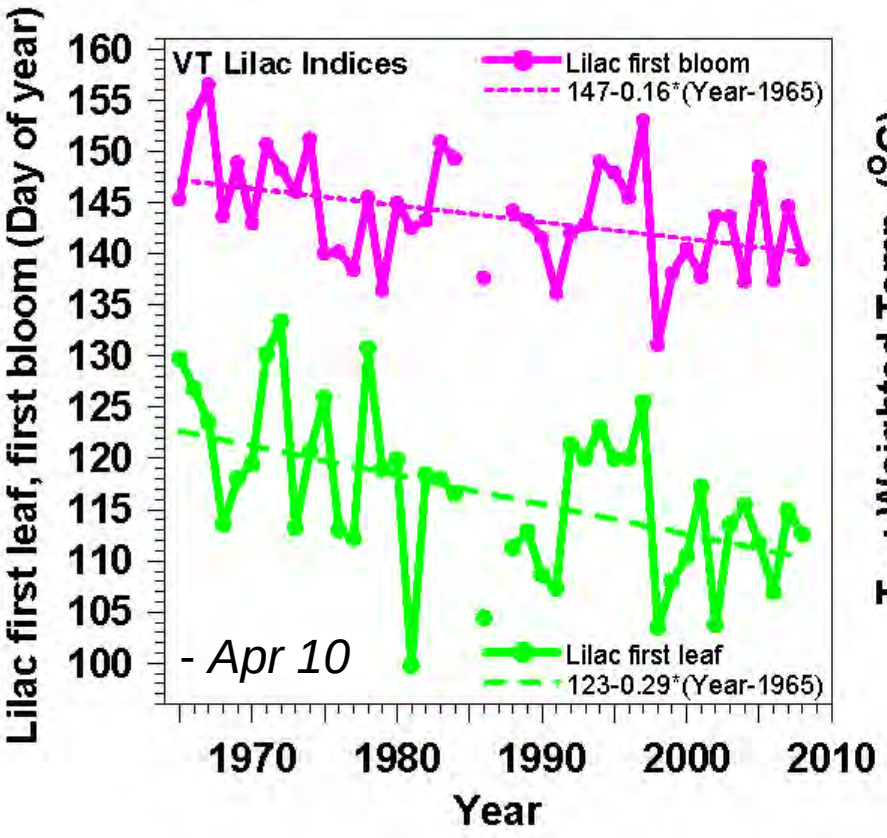
- **Hardy peaches: 2012**
- **Pests: winter survival**
- **What is this?**

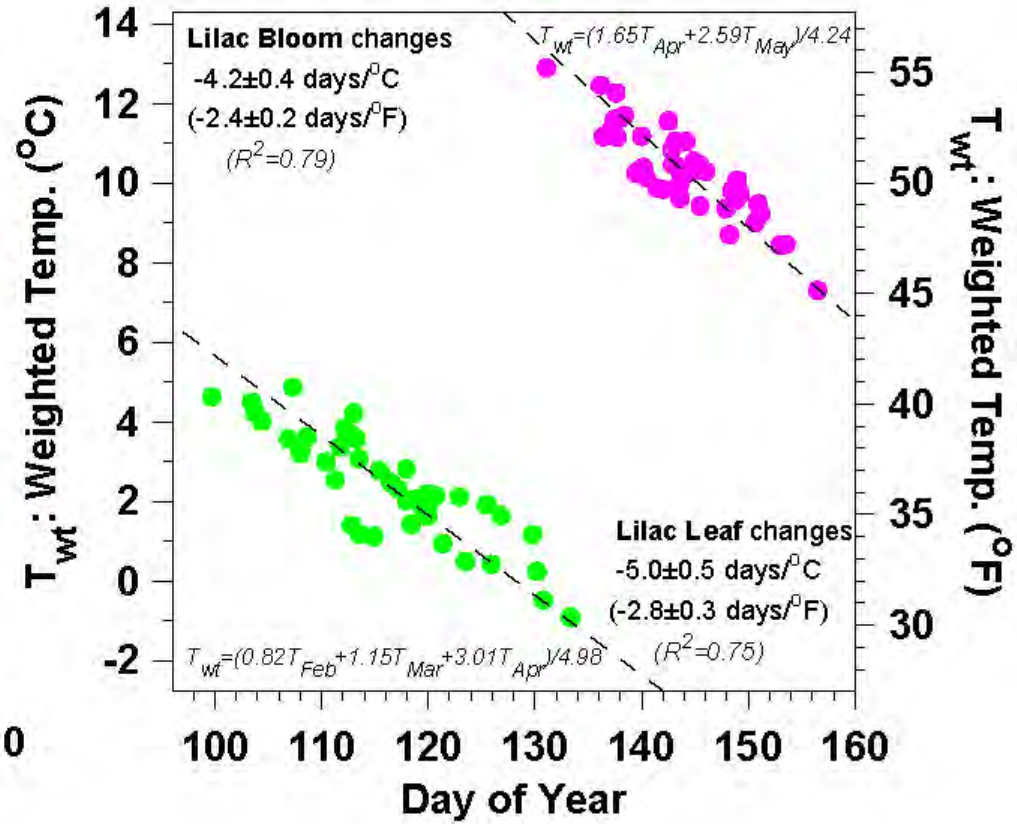
Bennington & Brattleboro are becoming zone 6

- **Hardy peaches: 2012**
- **Pests: winter survival**
- **What is this?**

- **Avocado**
  - **Didn’t survive frost**
  - **Late century: in CT**
  - **Our grand-children**

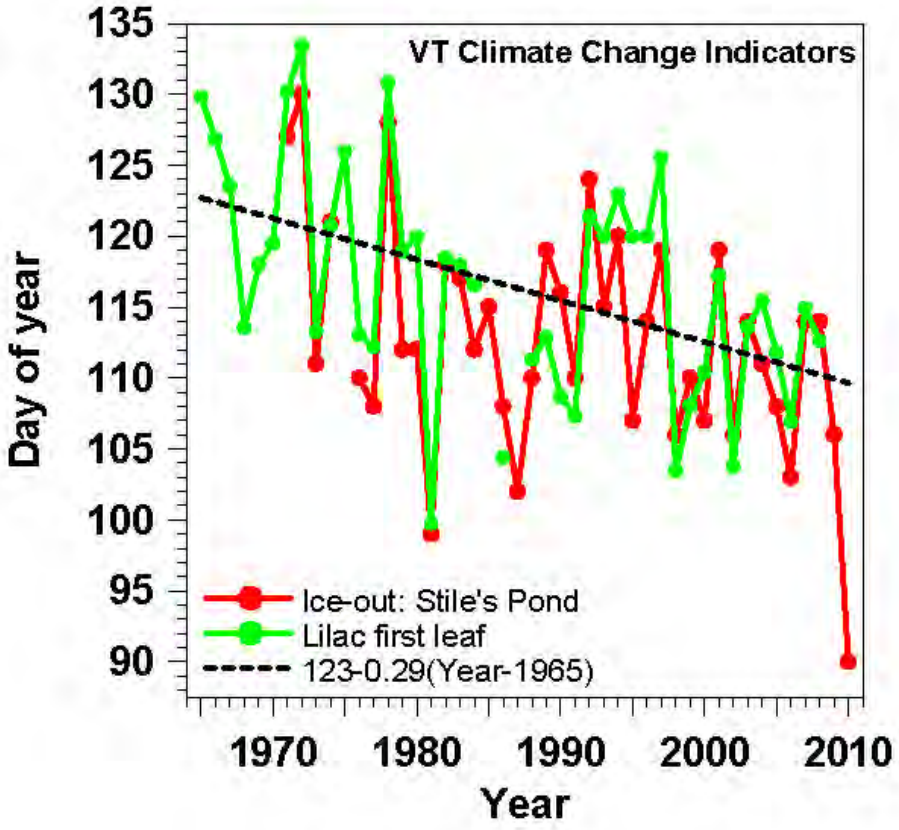
Lilac Leaf and Bloom

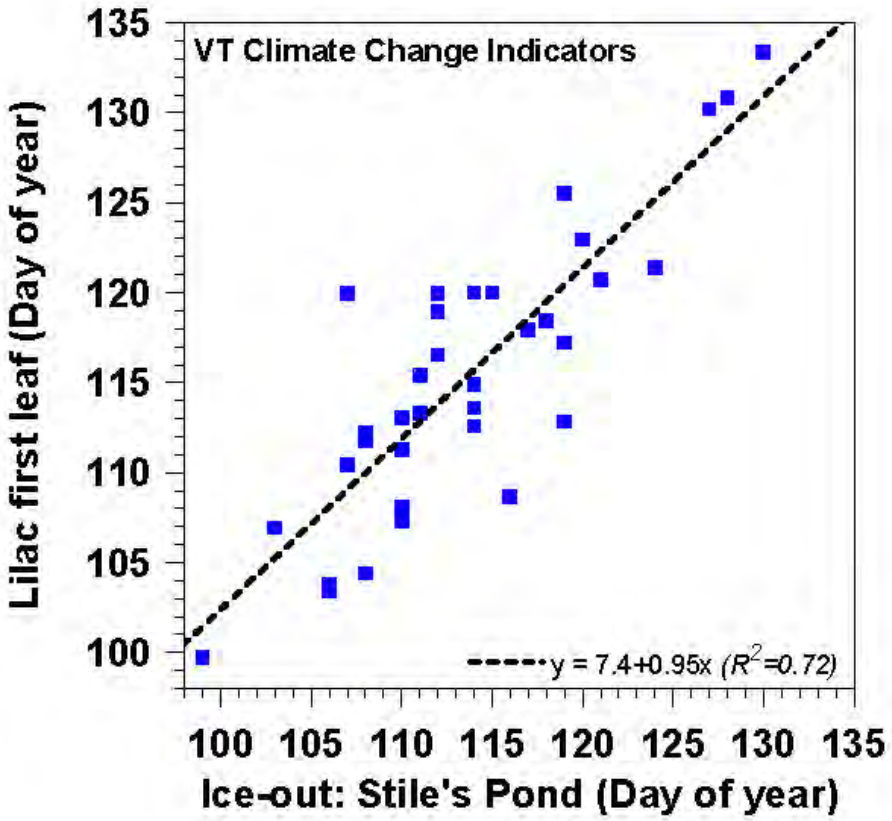




- **Leaf-out -2.9 days/decade; Bloom -1.6 days/decade**
- **Large year-to-year variation related to temperature: 2 to 3 days/ ºF**

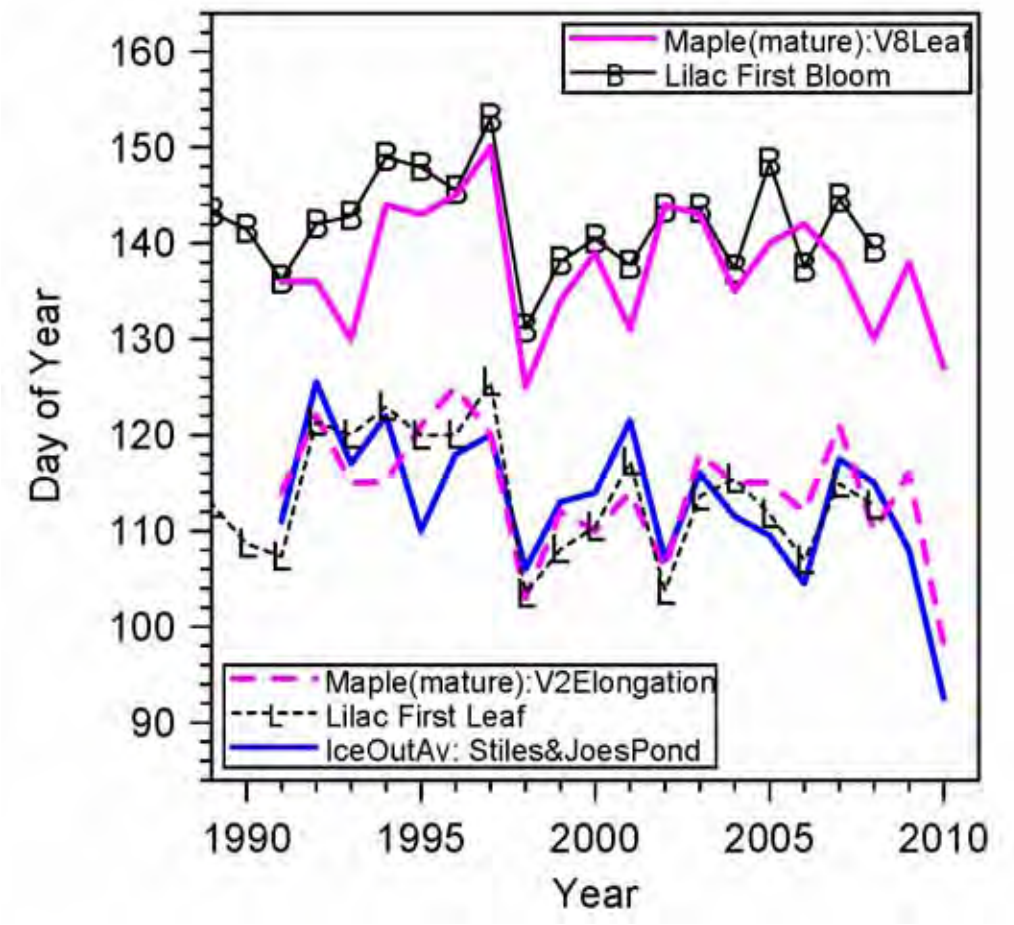
Lilac Leaf-out and Ice-out Coupled





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

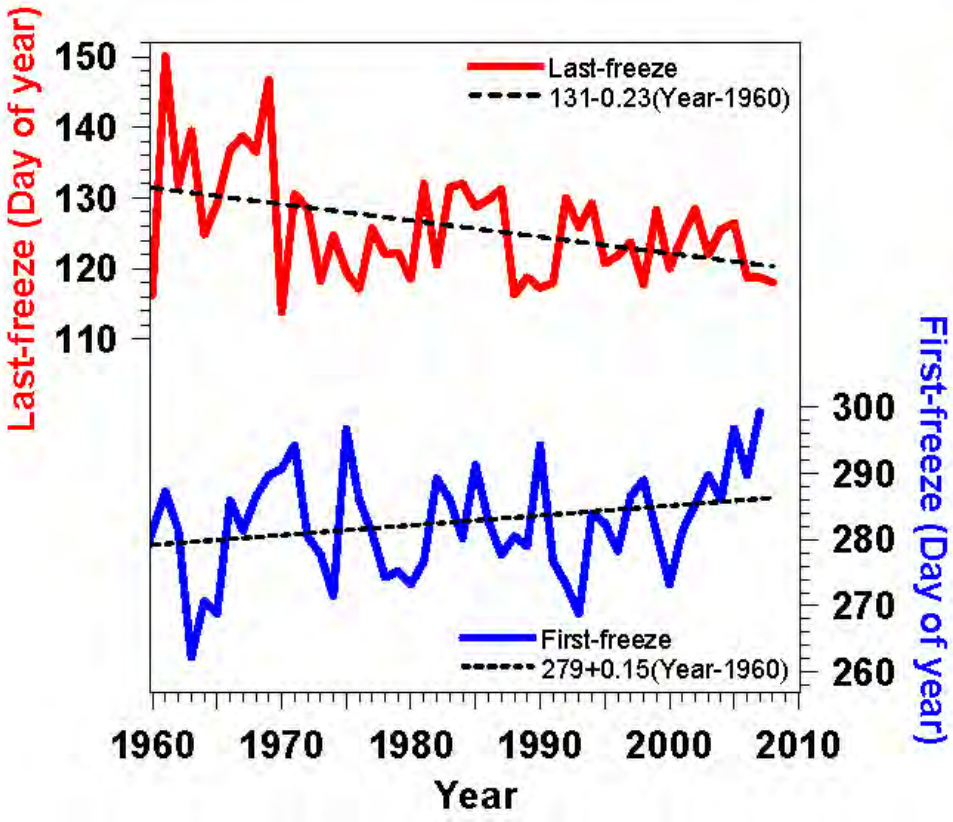
Sugar Maples in Spring

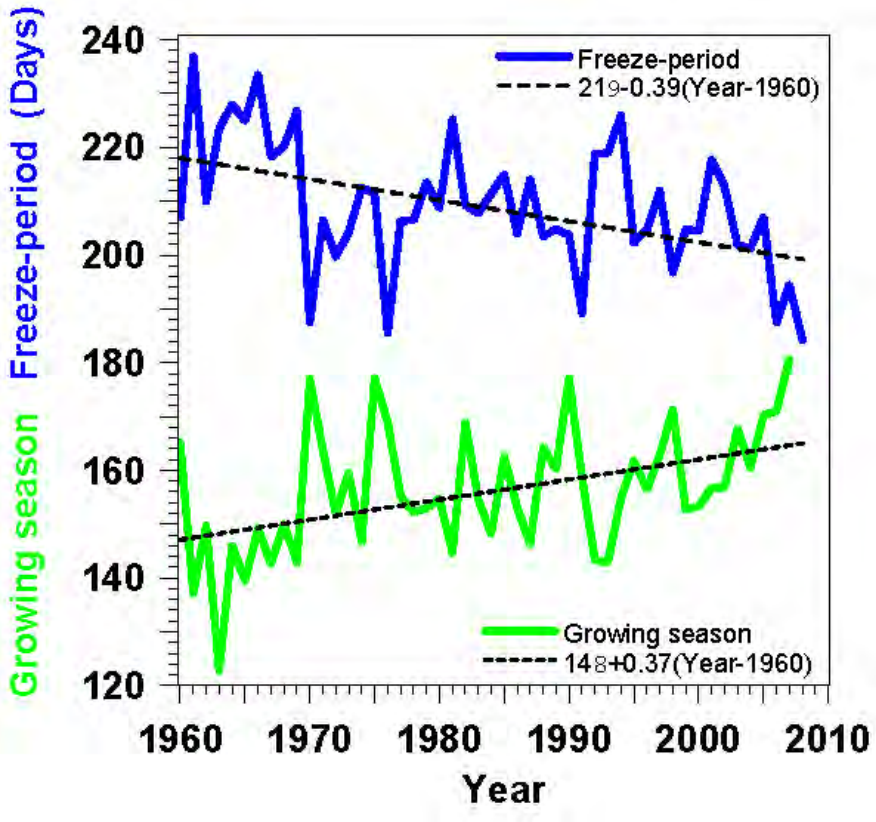


- **Ice-out, lilac leaf, maple bud elongation correlated**
- **Lilac bloom and maple leaf-out correlated**

Data: Sandy Wilmot, ANR

First and Last Frosts Changing





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

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

January 7, 2007

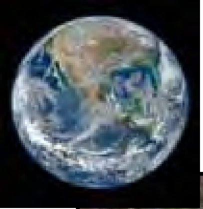
December 2006:

- **Warmest on record**

January 10, 2008

Warm Fall:

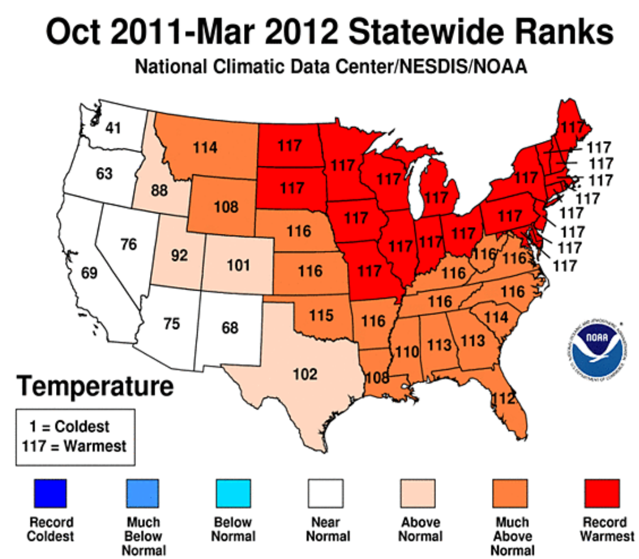
- **Record Arctic sea-ice melt**
- **Snow cover in December, ground unfrozen**



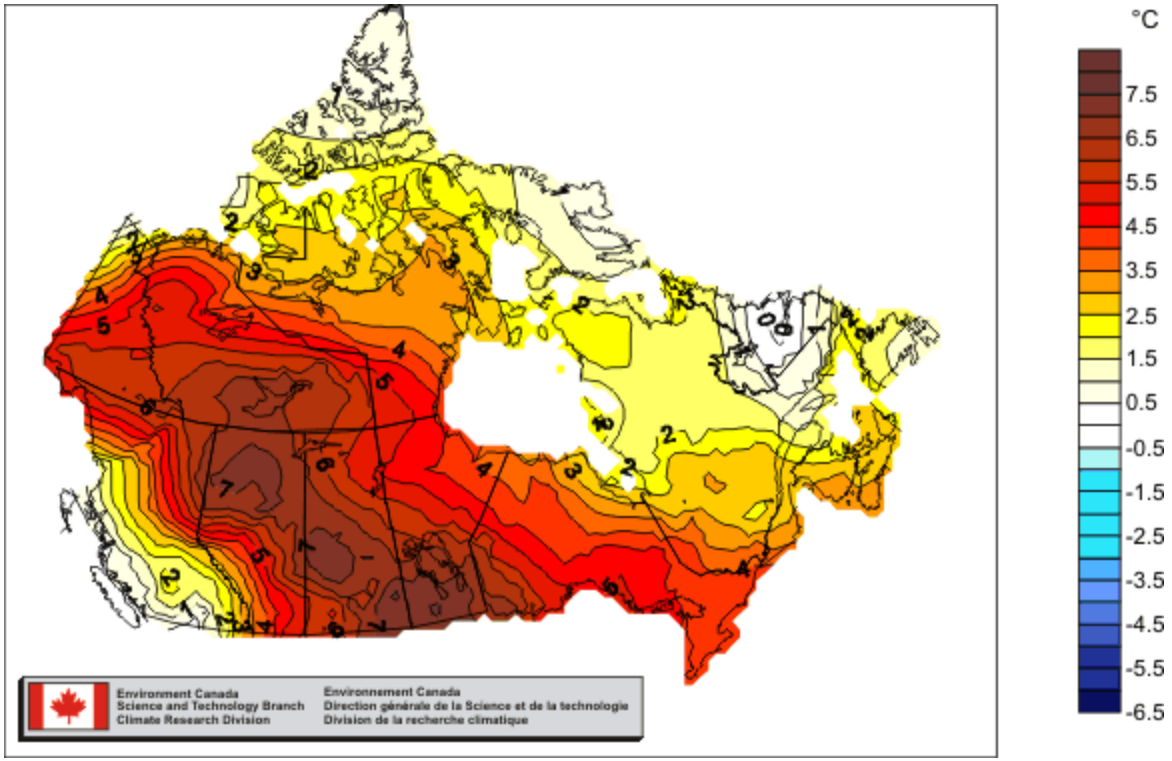
January 2, 2012   March 11, 2012

October 2011– March 2012

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



Across the border: Canada



- **Winter 2011-12: 3.6°C (6.5°F) above normal**
  - **Canada's winters also warming 0.9°F/decade**
- **Climate doesn't see the border!**

Early Spring: Daffodils, Forsythia

79ºF on March 22, 2012

Pittsford Vermont

3/22/12

Pittsford Vermont

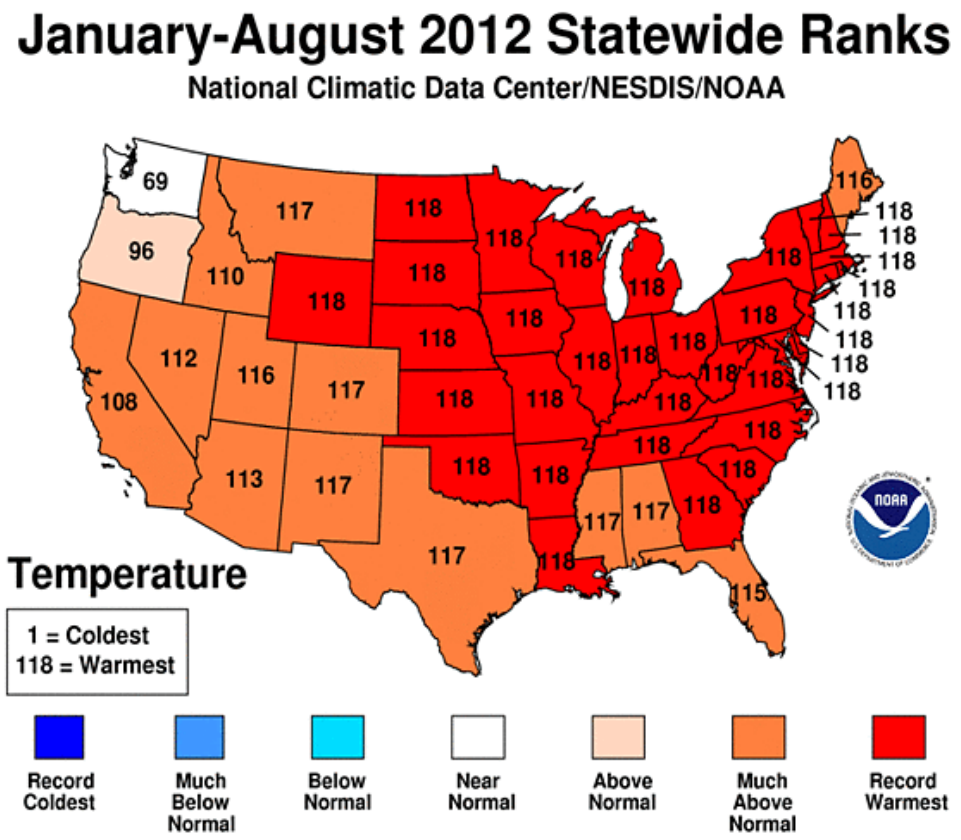
3/24/12

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

(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)***

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***

Many Wet Summers in Vermont – till 2012

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

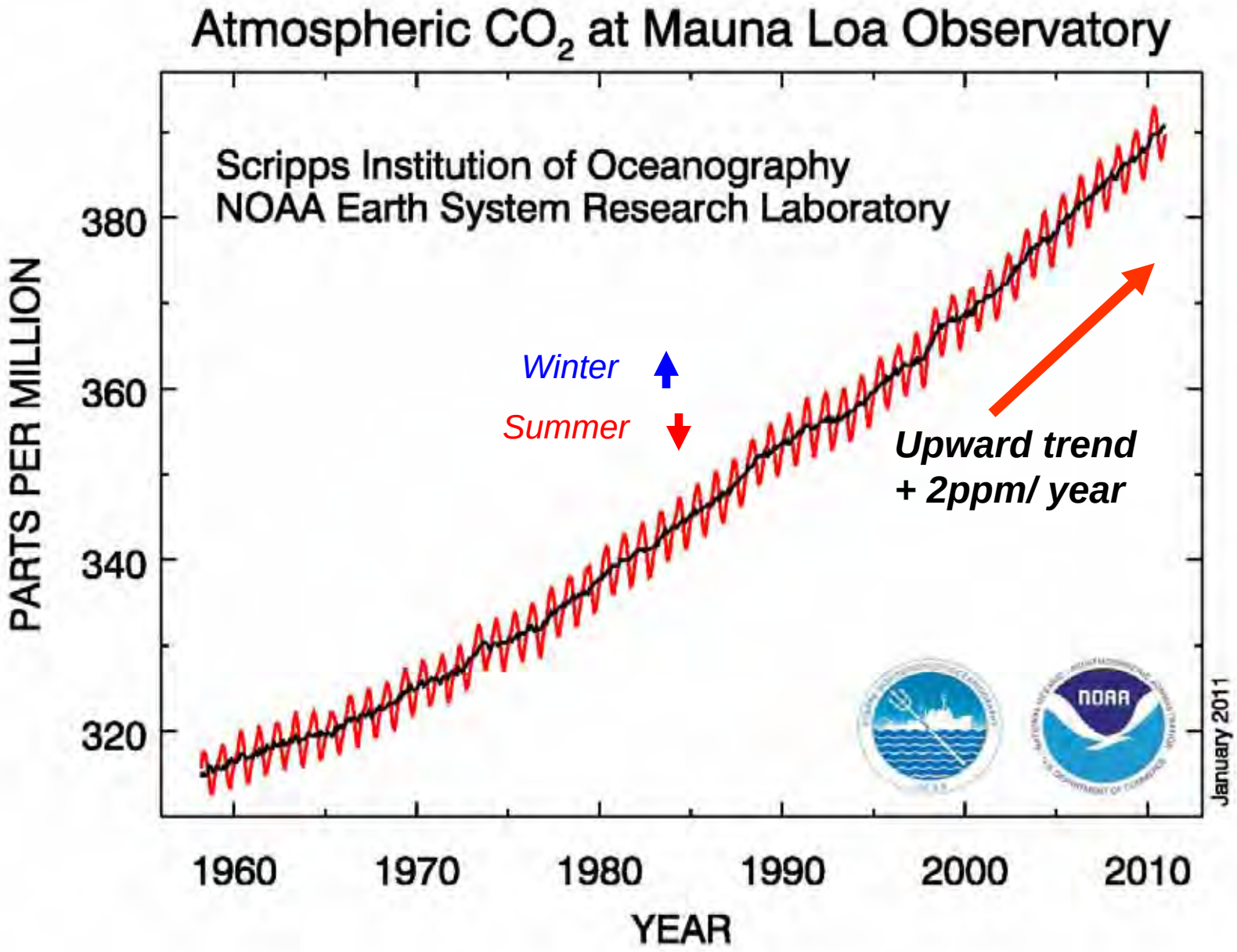
Fall Climate Transition

- **Vegetation delays first killing frost**
- **While deciduous trees still evaporating: moister 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 dies, 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

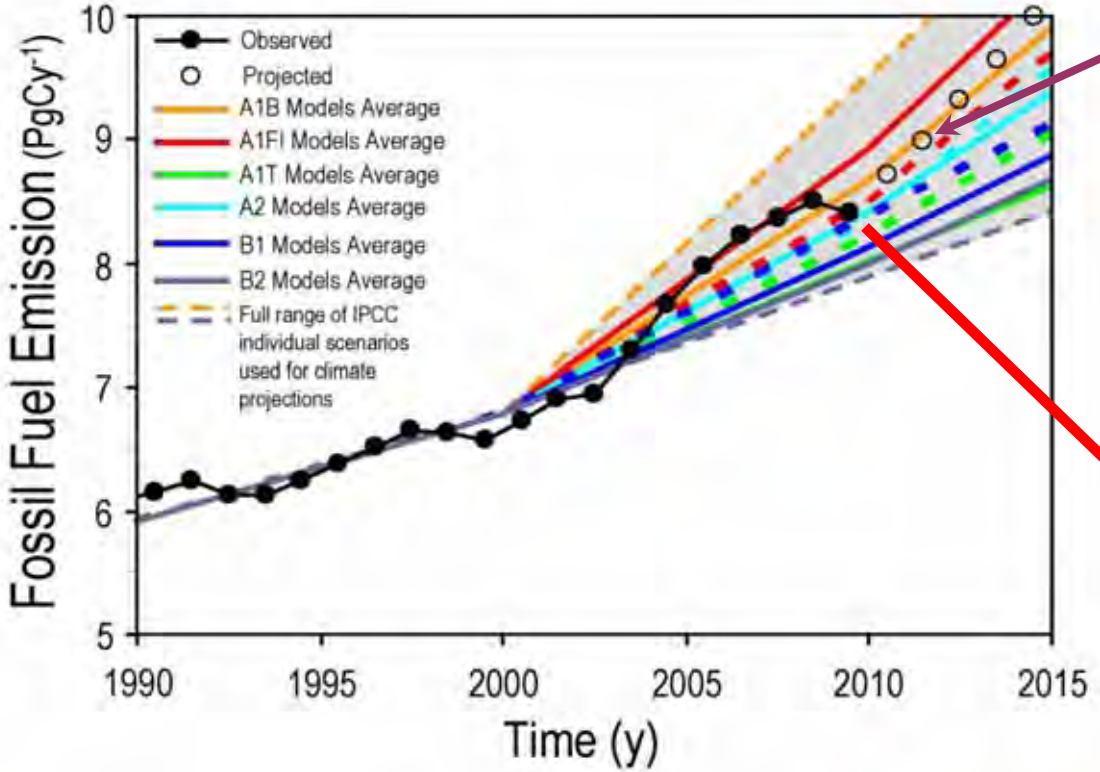
Later frost: Growing season getting longer

Carbon Dioxide Is Increasing



2009 Was "Good" for the Earth

Fossil Fuel Emissions: Actual vs. IPCC Scenarios



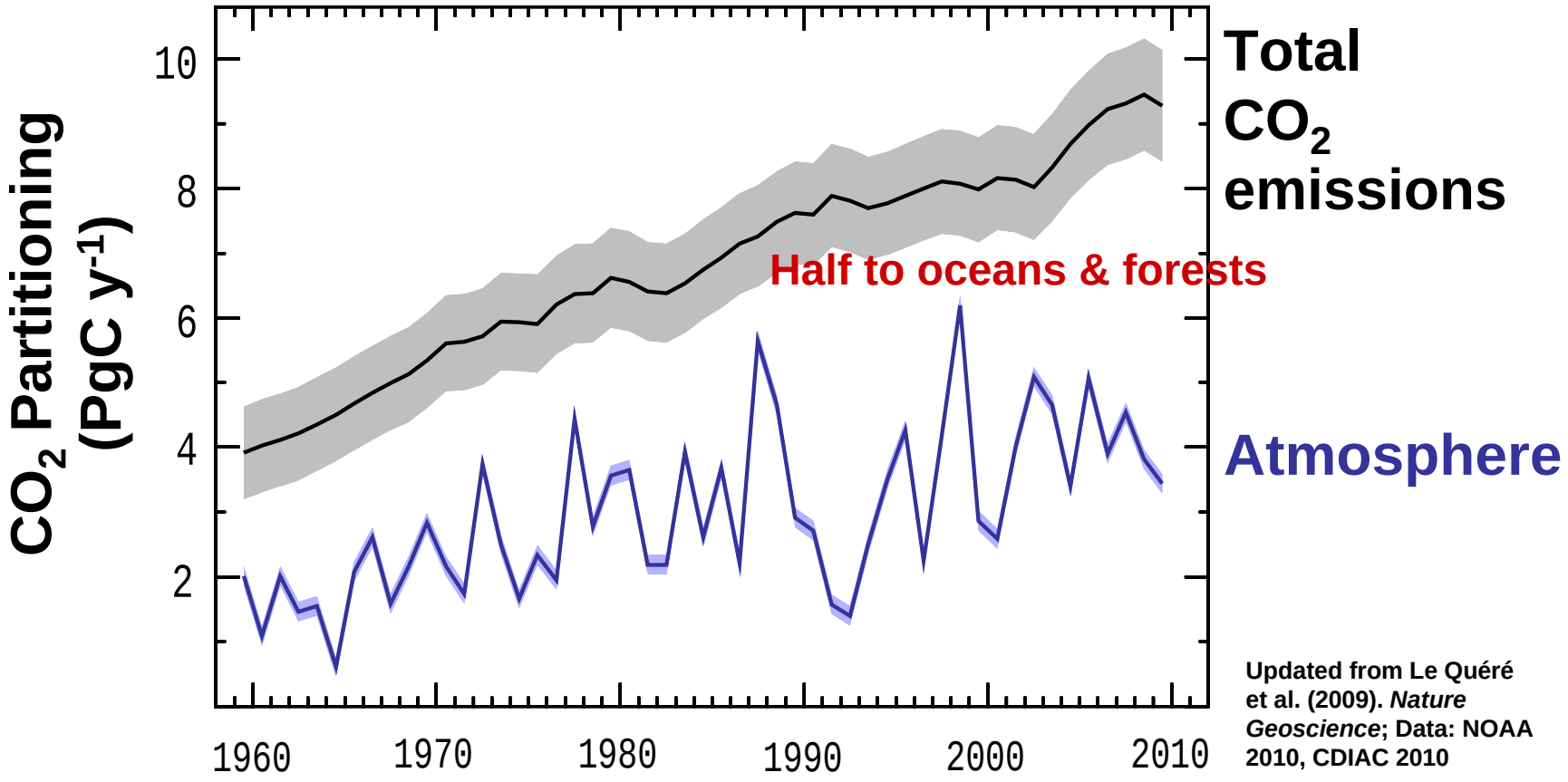
Back on growth: 2010, 2011

Emission Scenarios

- 4%/year

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

Only Half of Total CO_2 Emissions Remain in the Atmosphere

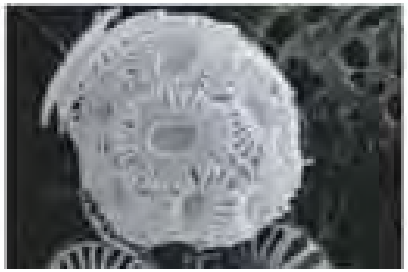


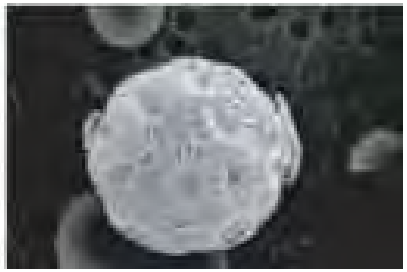
It takes at least a century to remove CO_2 from the atmosphere, and many centuries to remove it from oceans

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 trap the infrared from the surface, giving climate suitable for life by warming planet 60^oF**
- **Rise of CO_2 alone has only 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 5°F (3°C)**
  - **Much more in the cold regions 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)

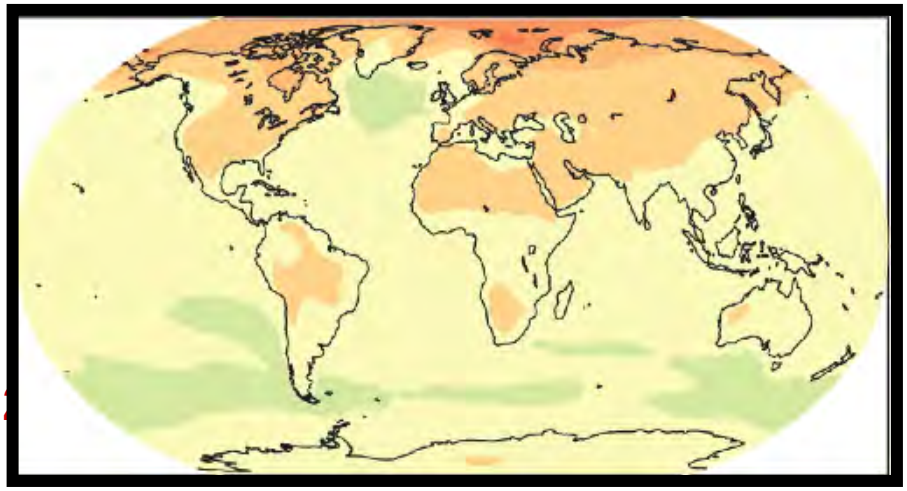
Decrease in:

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

Predicted Change in Temperature

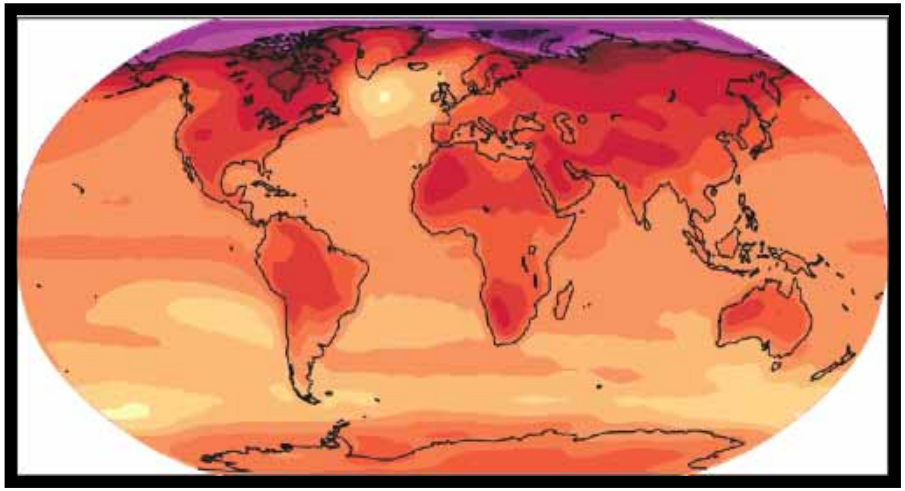
2020-2029 and 2090-2099, relative to 1980-1999 (ºC)

“Committed”

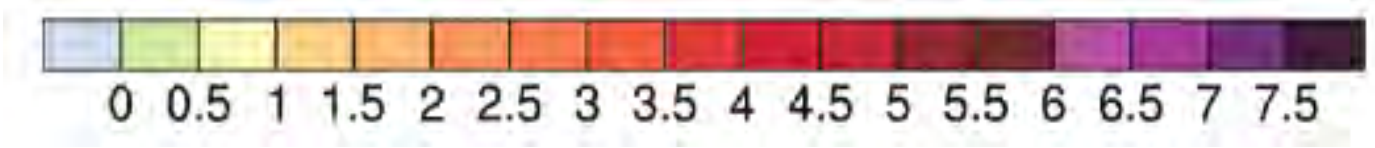


(We did nothing for the last 20 years)

Still up to us!



(We could halve this if we act now)

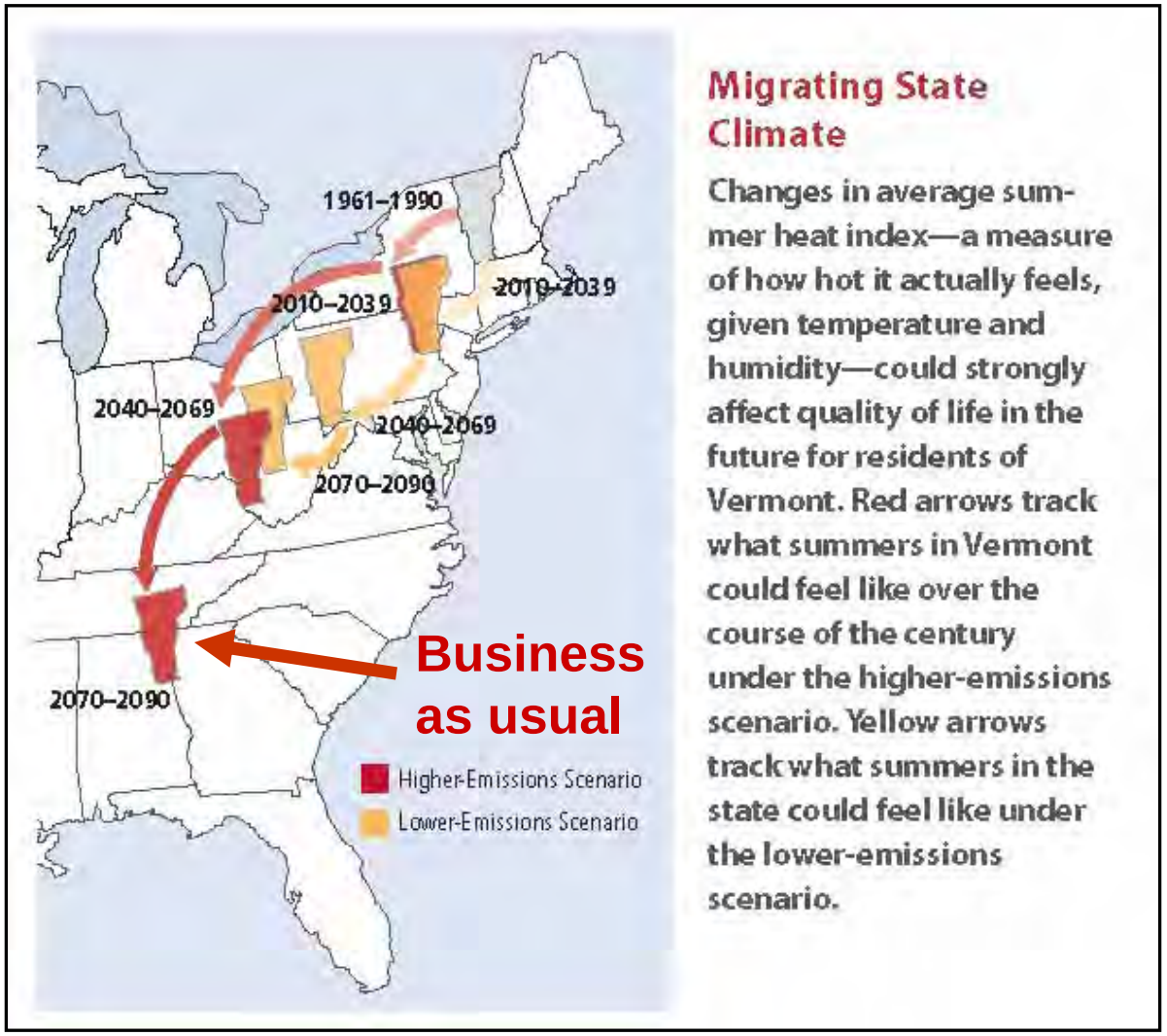


[ºC]

Vermont's Future with High and Low GHG Emissions

What about skiing?

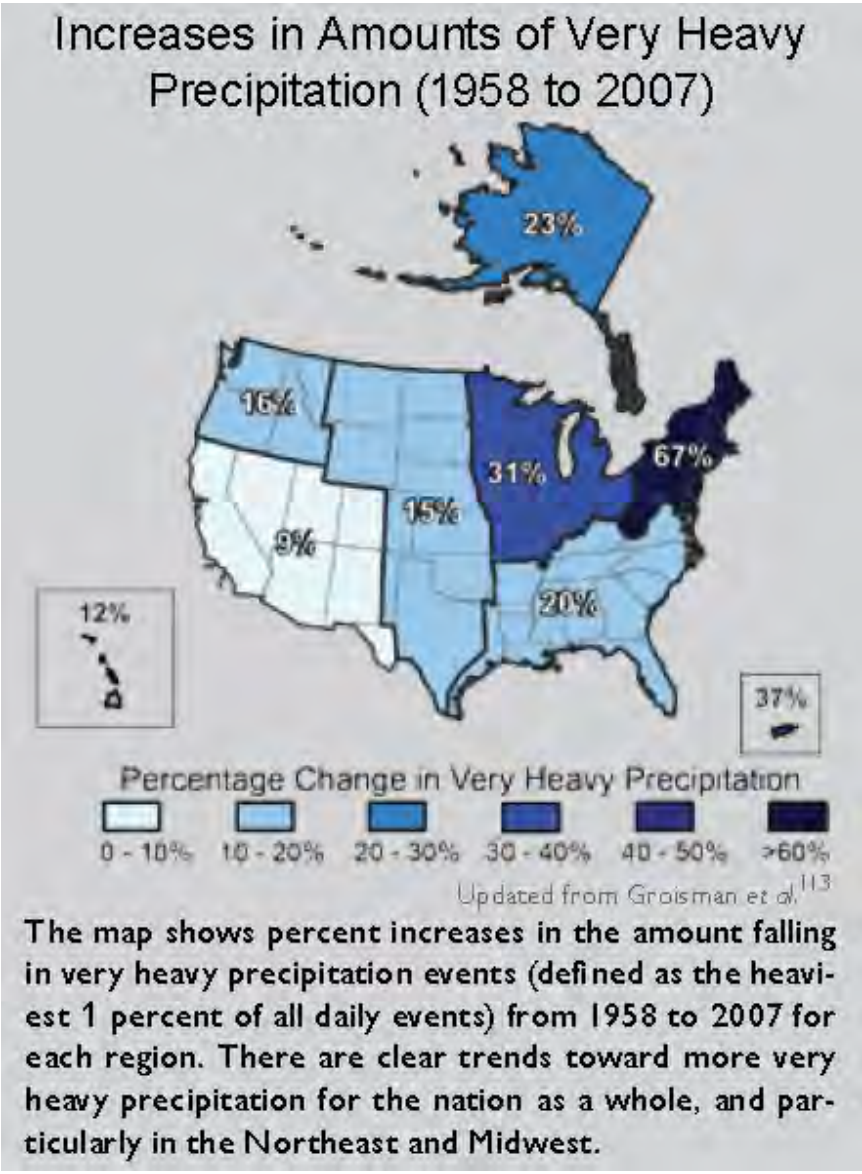
What about tropics?



NECIA, 2007

Very Heavy Precipitation Is Increasing

- **Precipitation Extremes**
- **Most of the observed increase in precipitation during the last 50 years has come from the increasing frequency and intensity of heavy downpours.**
- **67% increase in Northeast**
- **Little change or a decrease in the frequency of light and moderate precipitation**
- **NE stormflow increasing** ***(Lent, USGS, 2010)***



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.

Summer stormflow increases 20-50%

Lent (2010) USGS, Me

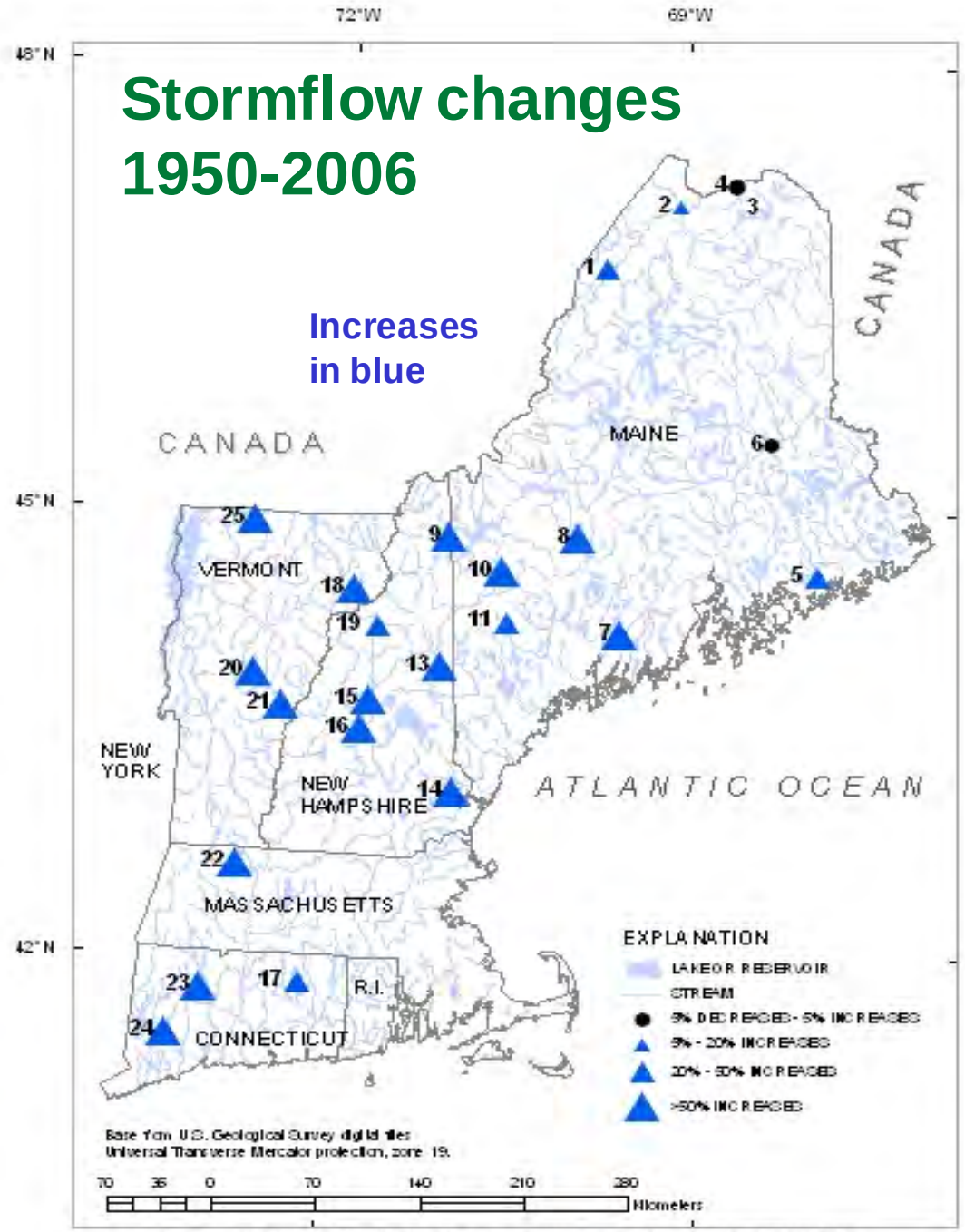
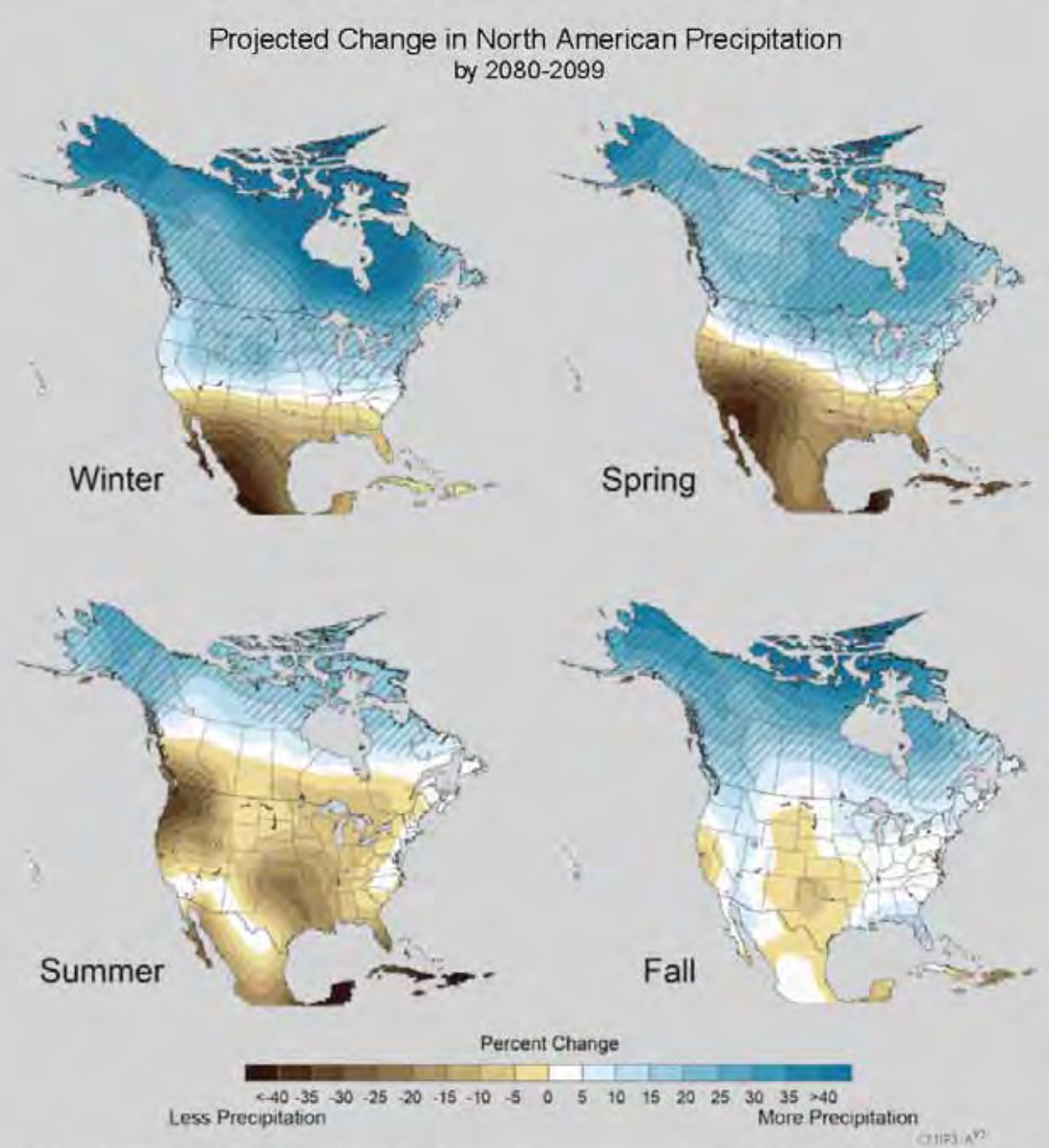


Figure 4. Geographic distribution of summer stormflow trends, 1950-2006.

Projected Mean Precipitation Increase by 2090

- ***Wetter - North***
- ***Drier - South***
- ***For NE***
  - **+15% in winter**
  - **+10% in spring**
  - **+5% in fall**
  - **No change summer**
  - **But heavier rain & more drought**
- **(Unshaded**
  - **less confident)**



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.[1] 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.

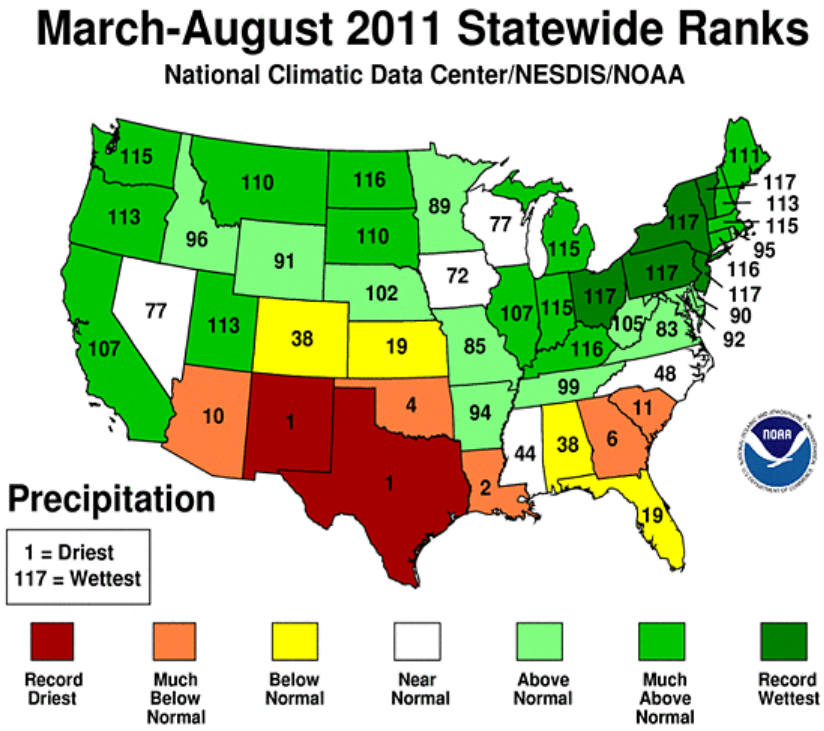
Extreme Weather (precip.)

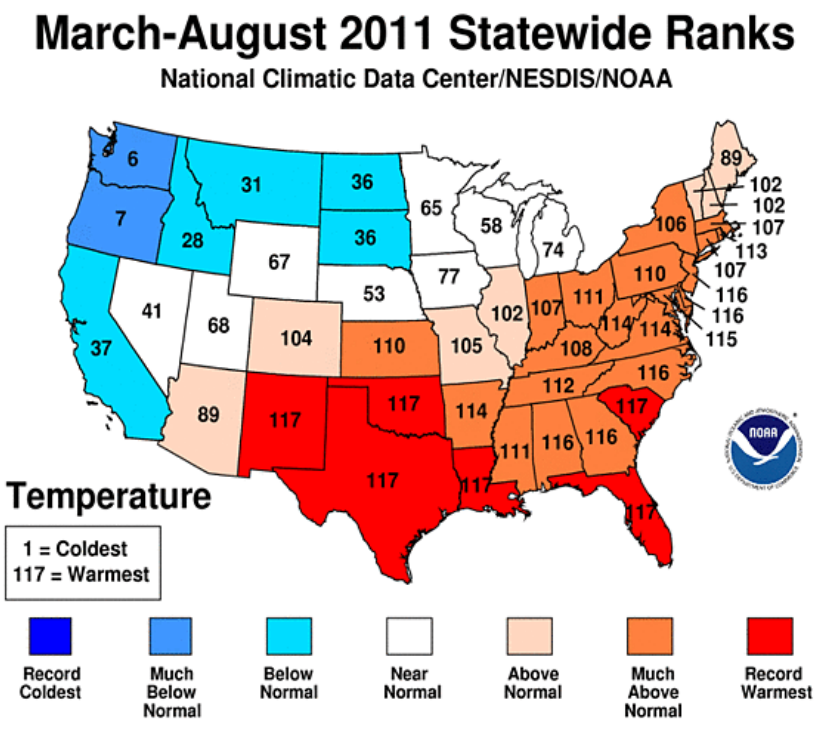
- **Precip. is condensation of atmospheric water vapor - large latent heat release drives storms**
- ***Saturation vapor pressure at cloud-base increases steeply with temperature (6%/^{o}C)***

- **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***
  - ***Cause may be Arctic warming***

2011 Vermont Floods

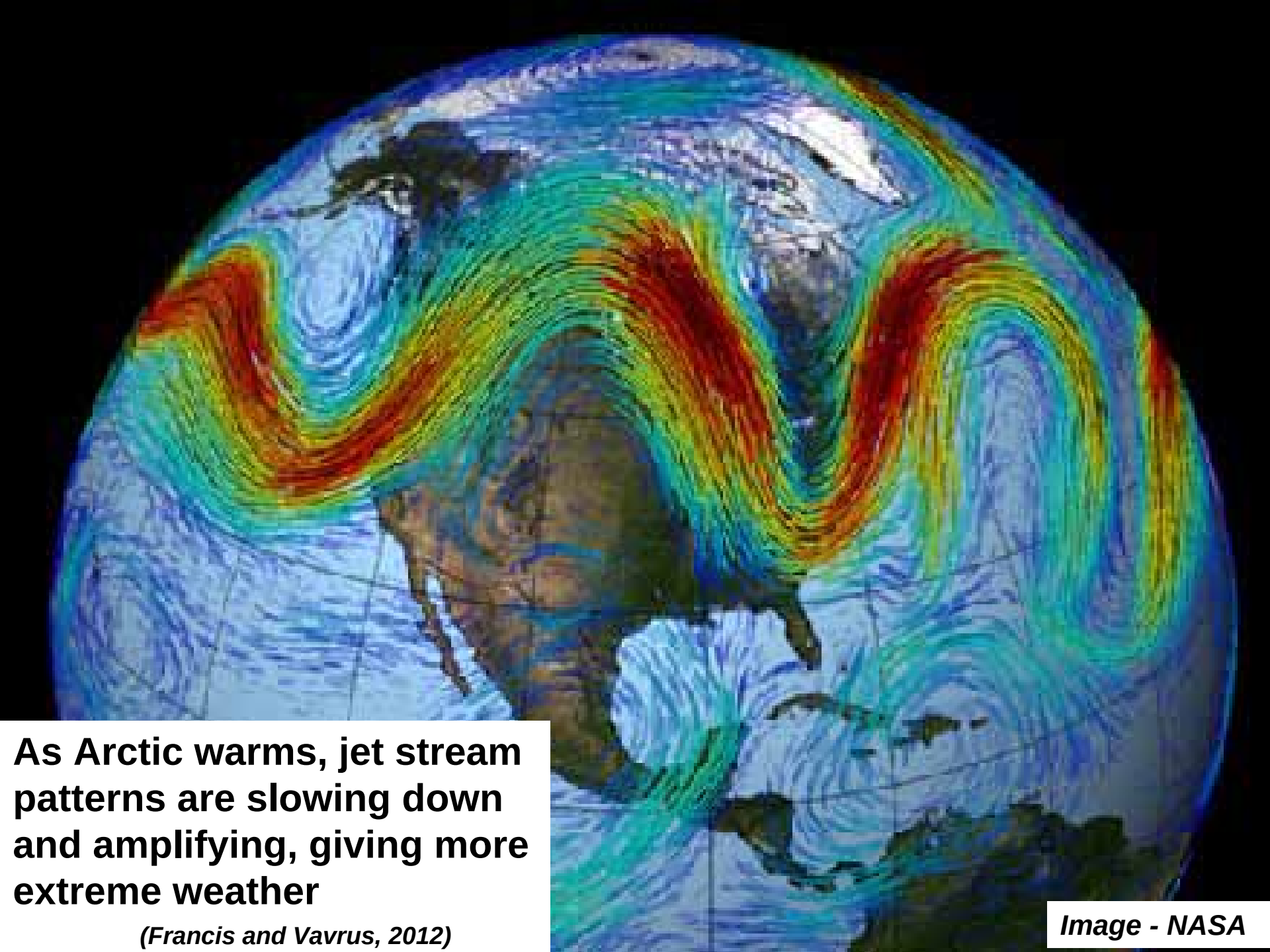
- **Record spring flood on Lake Champlain**
- **Record floods following TS Irene**
- **Record wet March-August, 2011: OH to VT**
  (but record drought in TX & NM)
- ***Quasi-stationary pattern for 6 mos***





2011 Classic VT Flood Situations

- **Spring flood: heavy rain and warm weather, melting large snowpack from 2010 winter**
  - **70F (4/11) and 80F(5/27) + heavy rain**
  - **record April, May rainfall: 3X at BTV**
  - **Severe Winooski flood**
  - **Lake Champlain record flood stage of 103ft**
- **Irene flood: tropical storm moved up east of Green Mountains**
  - **dumped 6-8 ins rain on wet soils**
  - **Extreme flooding**
  - **(Floyd on 9/17/1999 had similar rain - but with dry soils there was less flooding)**



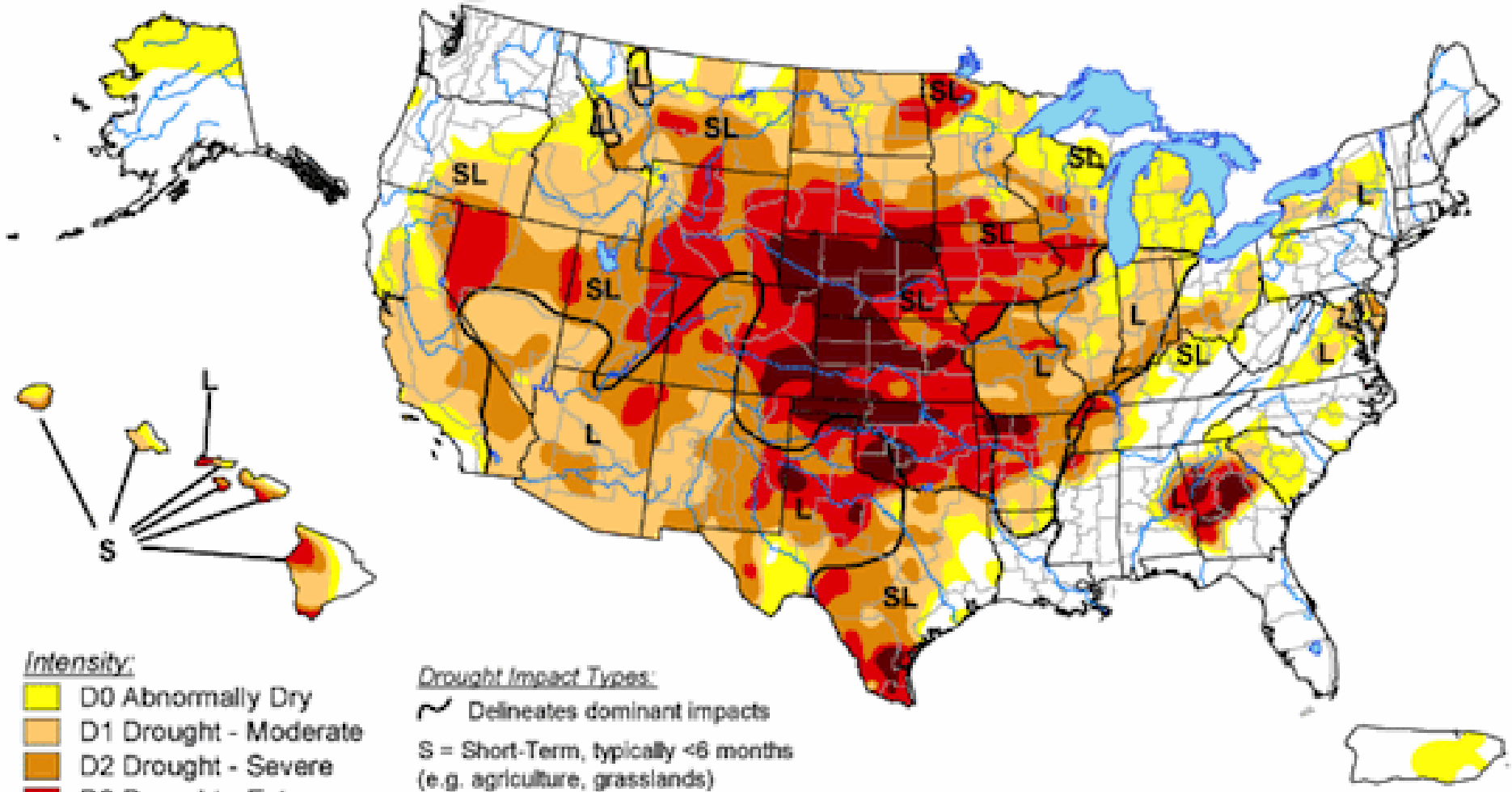
As Arctic warms, jet stream patterns are slowing down and amplifying, giving more extreme weather

(Francis and Vavrus, 2012)

Image - NASA

U.S. Drought Monitor

September 25, 2012
Valid 7 a.m. EDT



Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

~ Delineates dominant impacts

S = Short-Term, typically <6 months (e.g. agriculture, grasslands)

L = Long-Term, typically >6 months (e.g. hydrology, ecology)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

http://droughtmonitor.unl.edu/

Released Thursday, September 27, 2012

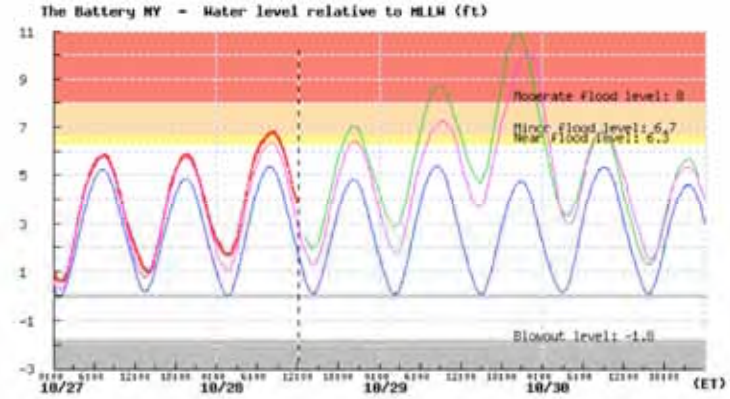
Author: Anthony Artusa, NOAA/NWS/NCEP/CPC

Three Successive Years of East-Coast Tropical Storm Disasters

- **September 21, 2010: Hurricane Igor with winds and record rainfall devastates eastern Newfoundland, isolating 150 communities as swollen rivers washed away the only roads into town and all connecting bridges. The worst storm ever in a province known for its storms.**
- **August 28, 2011: Tropical Storm Irene devastates Vermont, as heavy rain washes out roads and bridges, cutting off 20 towns**
- **October 29, 2012: Hurricane Sandy devastates New Jersey and New York City with winds and record storm surge flooding the subway tunnels, airports and shorelines**

Disasters Happen in Strong Storms

- **Hurricane Sandy hits NYC and floods subway tunnels: Oct 29 2012**
- **Extreme weather event + climate change = disaster**
  - **≈ 1ft rise of mean sea-level**
  - **Gulfstream warm + 5ºF**
  - **Blocking high: NE Canada**
  - **≈ 2ft extra storm surge**
  - **Extra 3ft = disaster**



Many Challenges Face Us

- **Sea-level rise: 3 - 5 feet / century likely**
- **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**

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 fuels**

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, shale-gas & shale-oil 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?

- **Fossil fuels reserves are worth $20-30T**
  - **Regulating emissions of CO_2 is an "unfair cost" to the "free market"**
  - **Yet we are still subsidizing fossil fuels**
- **Politics lost in fantasy**
  - **Ignoring Earth system and climate issues**
  - **Ignoring future costs**
    - **So. Manhattan within 1-ft of flooding with Irene**
    - **Did they put waterproof doors on tunnels? No**

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 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

Discussion

- **This talk http://alanbetts.com/talks**
- **Rutland Herald articles at**

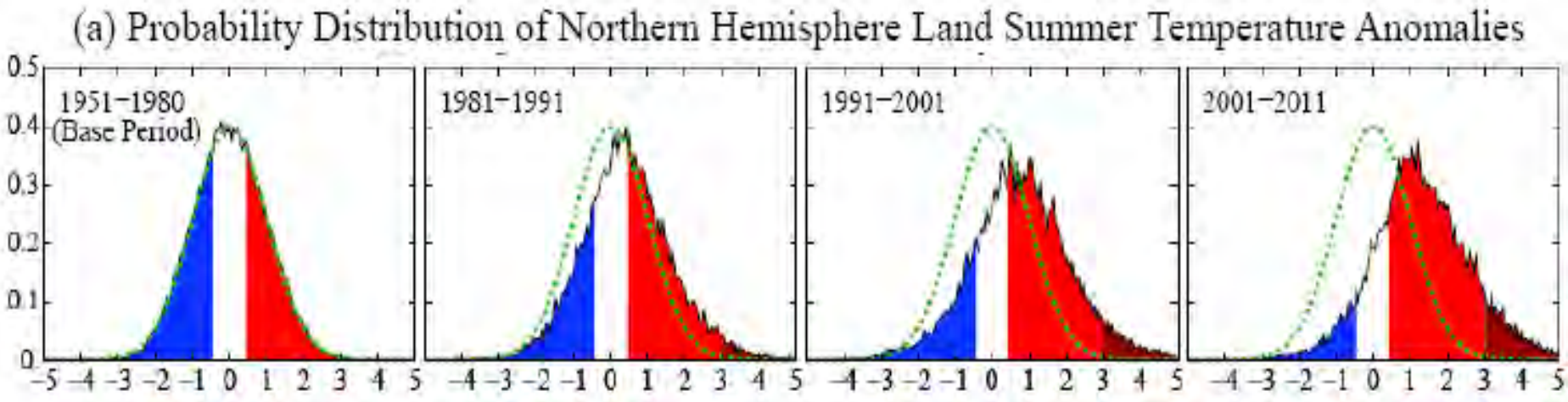
  http://alanbetts.com/writings
- **Interesting papers at**

  http://alanbetts.com/research

  – ***Vermont Climate Change Indicators***

  – ***Seasonal Climate Transitions in New England***

Increasing Temperature Extremes is "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**
  - **Increased from baseline 0.15% to 10% in 45 years**

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**

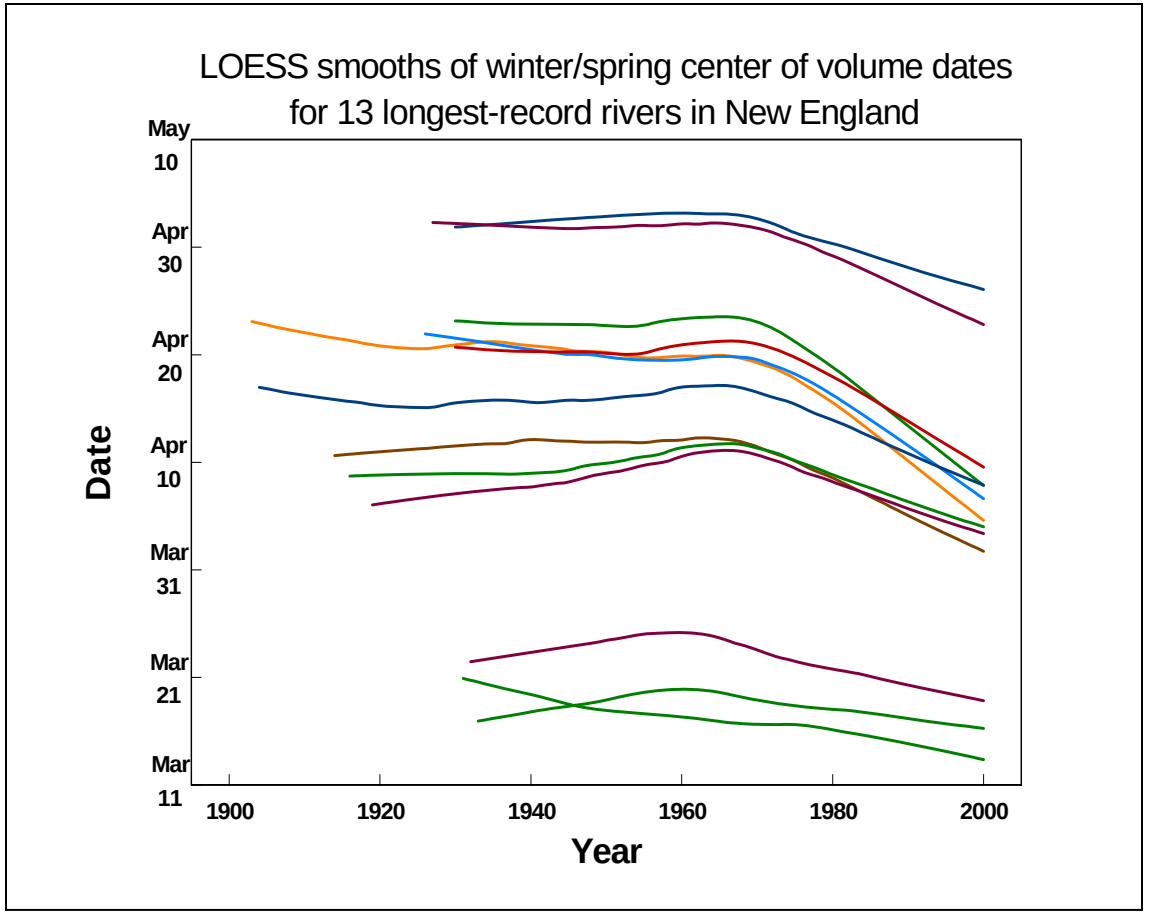
‘Anti-global warming’ tactics [*delay, confuse and deny*]

- **Fabricate ‘data’ or cherry-pick the science for unsolved issues and ignore the big picture. ‘This disproves global warming’ *or* ‘Science isn’t resolved; we need more science.’**
- **Models can’t predict the future with certainty, so the models are ‘unreliable’, ‘can’t be trusted’. Given this uncertainty, *we cannot be held responsible for the future*.**
- **If climate change were real, it would require collective government regulation of the ‘free market’, which we are opposed to; so *climate change must be a ‘hoax/conspiracy’***
- **It is too costly to make structural changes to our society, and it would affect profit margins.**
- **[We will wait till China and India take action]**
- **[The poor in Africa need energy]**

Hydrology is Sensitive to Climate

Lent (2010), USGS, Me

- **Spring runoff dominates the annual hydrograph**
- **Occurring significantly earlier in northern New England in recent years**
  - ***-3 days/decade***
- **Timing related to air temperatures**



Hodgkins and others, 2003

How Do We Manage the Earth?
(When there is so much we don't know)

- **We must manage our society better!**
- **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**

Broad Guidelines or Rules to Minimize Impacts

- **Minimize the lifetime of human waste products in the Earth system and eliminate waste with critical biosphere interactions**

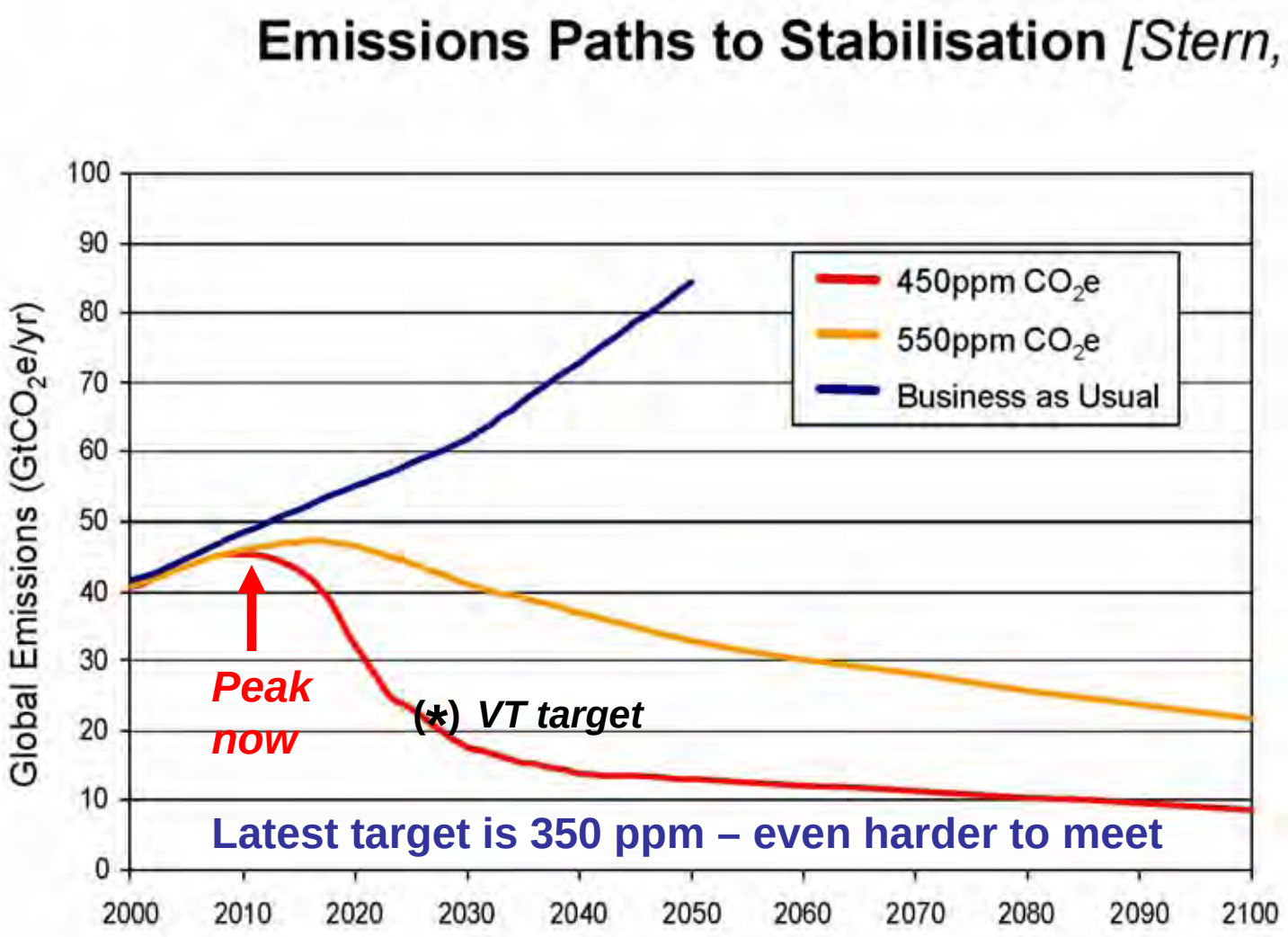
- **Minimize the use of non-renewable raw materials, and**
- **Maximize recycling and re-manufacturing**

- **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**

How Do We Avoid "Dangerous Climate Change"?



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**

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**

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**

But If Growth Can't Save Us, Surely Technology Can?

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

Ice-core history!

Last four ice-age cycles