



Vermont's Climate and Climate Change



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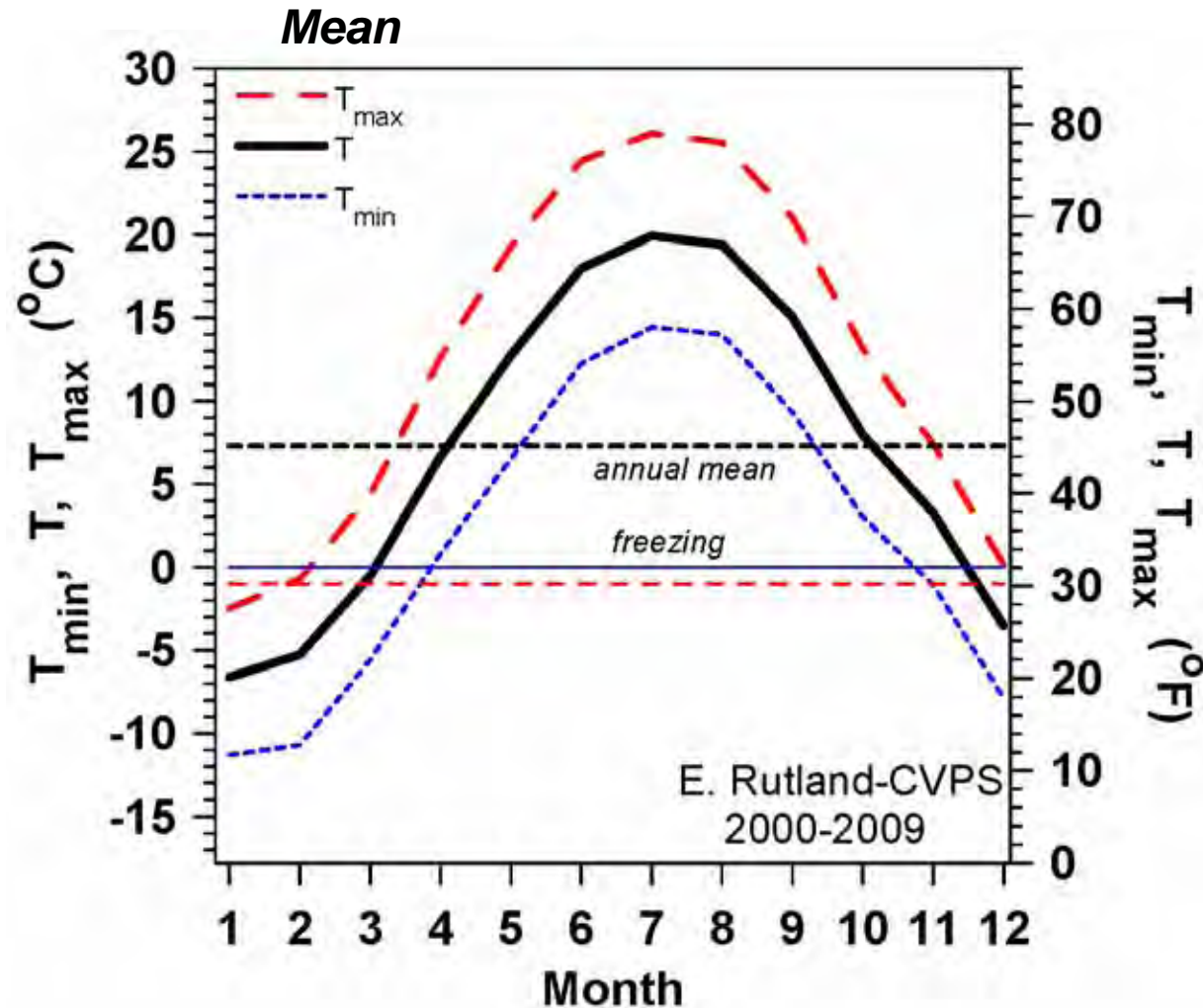
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High School Streams Project
VT EPSCoR RACC

June 26, 2012

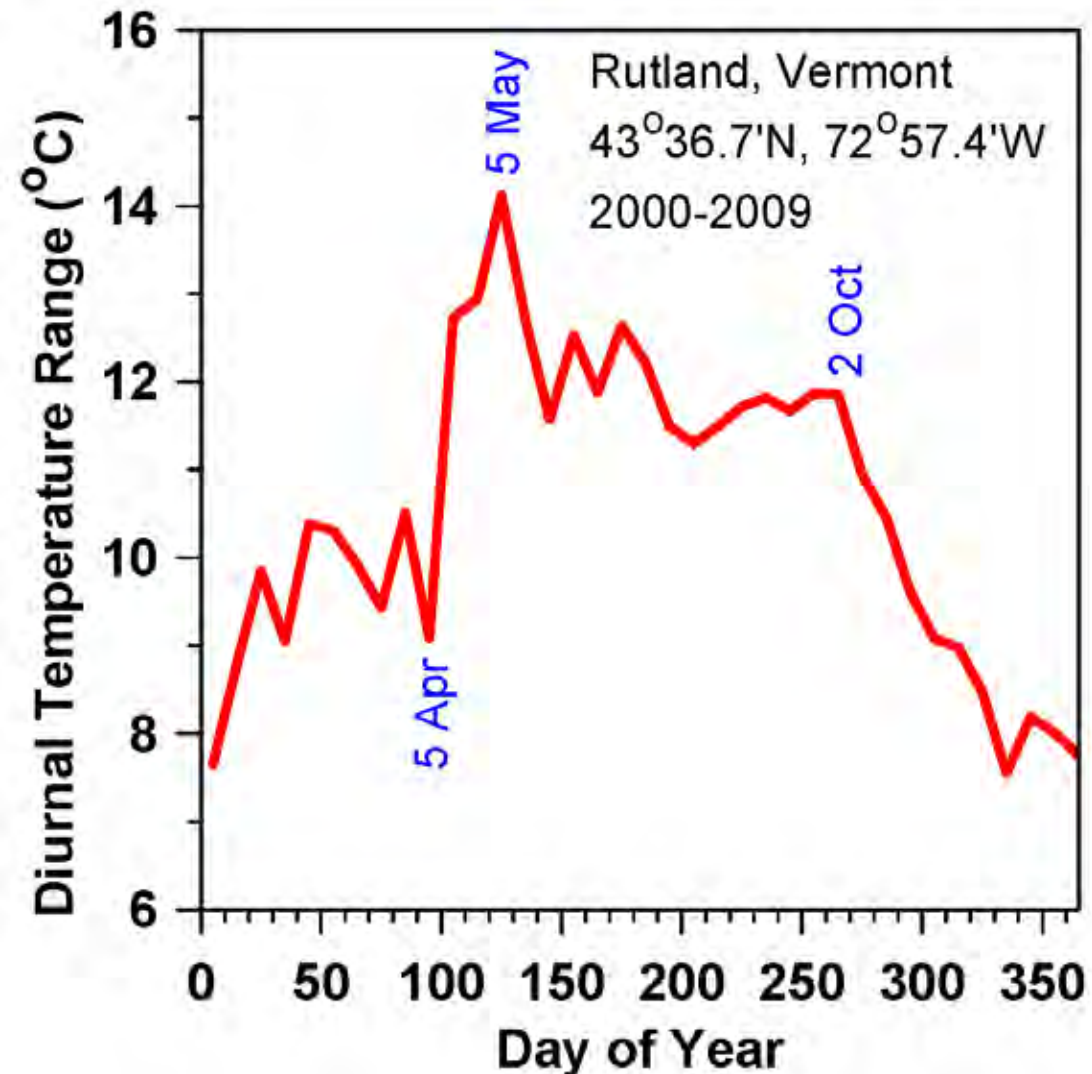
Climate of Vermont

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



Diurnal Temperature Range

- $T_{\max} - T_{\min}$
- Mean daily range of T **varies with season**



- 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: CO₂ and H₂O



January 2, 2012: NASA

What Is Happening to Vermont?

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

January Gardening, Pittsford, VT



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



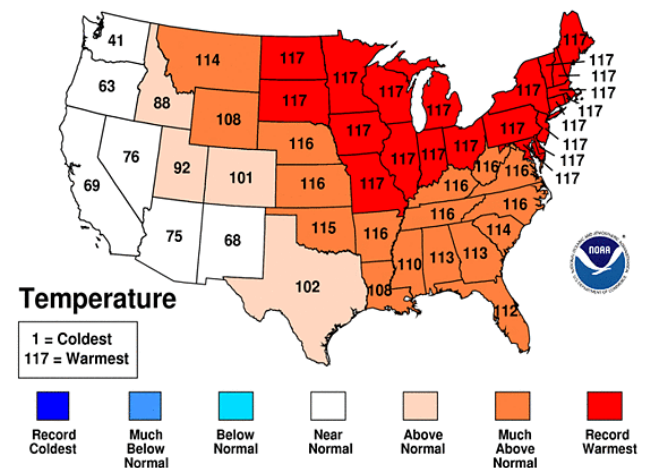
March 11, 2012



October 2011– March 2012

- **Warmest 6 months on record**
- **My garden frozen only 67 days**
- **Little snow cover**
- **Contrast snowy winter 2010-11**

Oct 2011-Mar 2012 Statewide Ranks
National Climatic Data Center/NESDIS/NOAA



Daffodils in Bloom

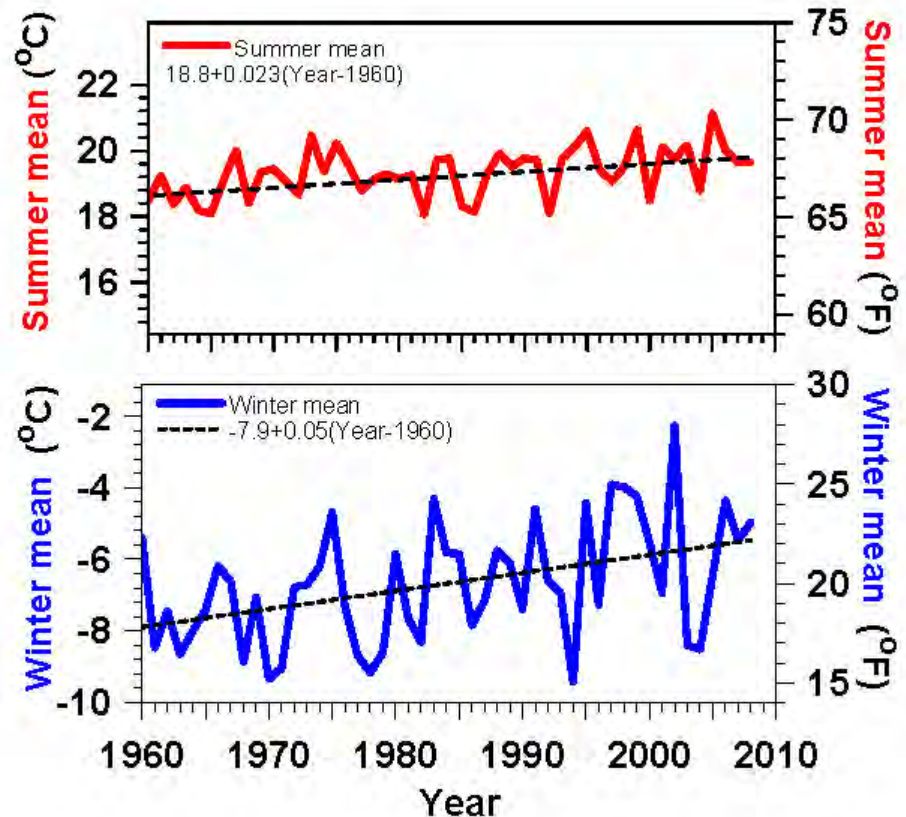
March 22 – 79°F



Pittsford
Vermont
3/22/12

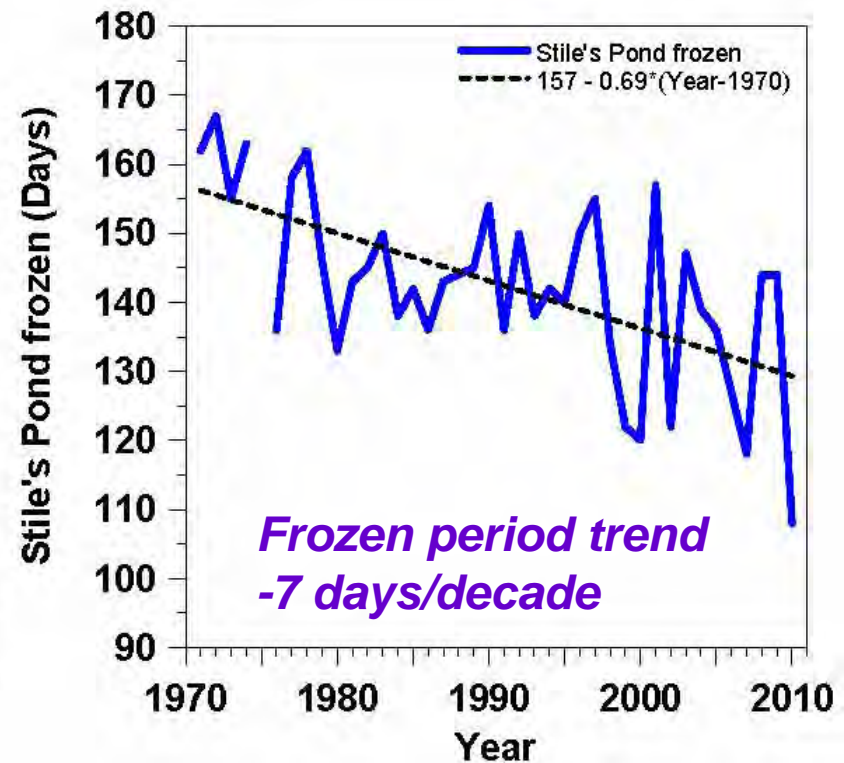
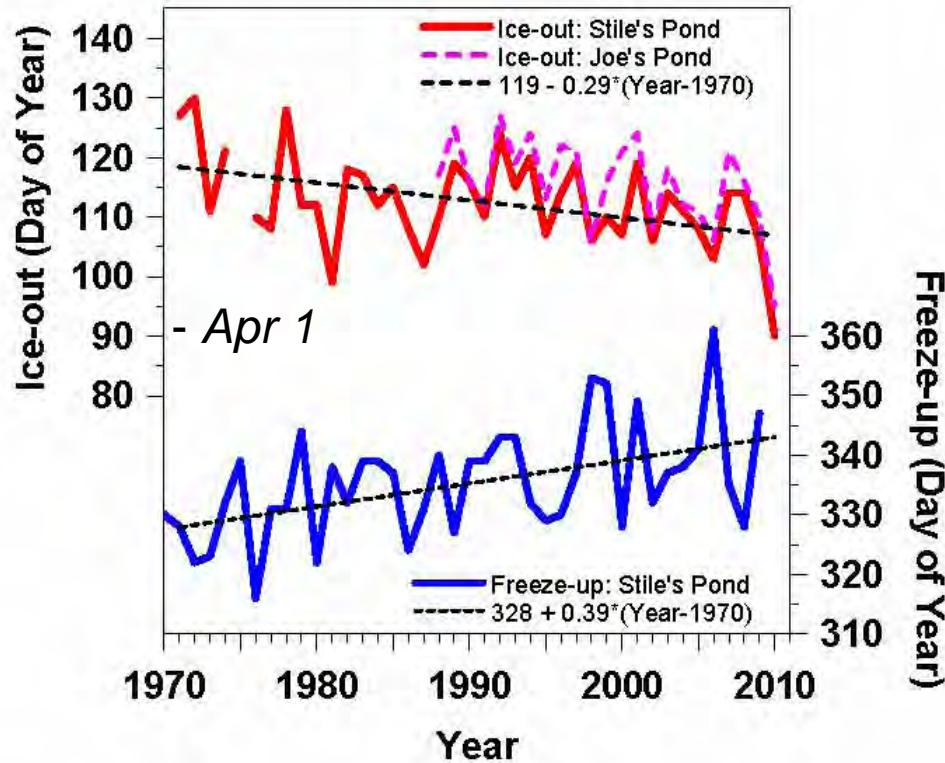
Vermont Temperature Trends

- **Summer $+0.4^{\circ}\text{F}$ / decade**
- **Winter $+0.9^{\circ}\text{F}$ / decade**
- ***Less snow (and increased water vapor) drive larger winter warming***



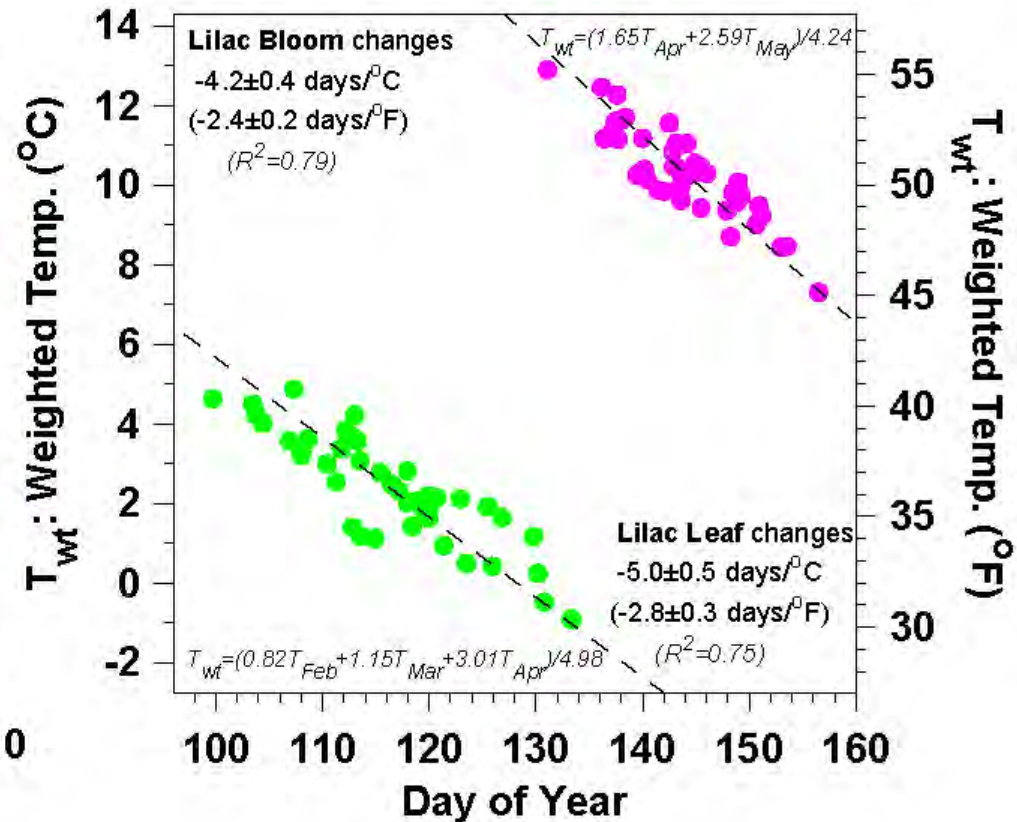
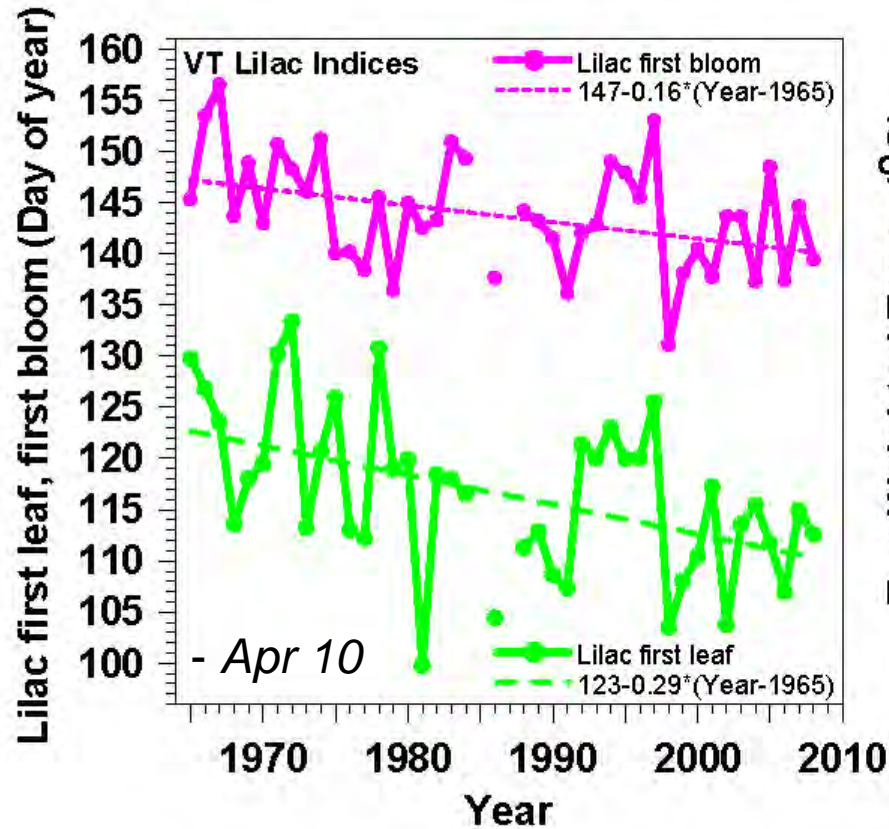
Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



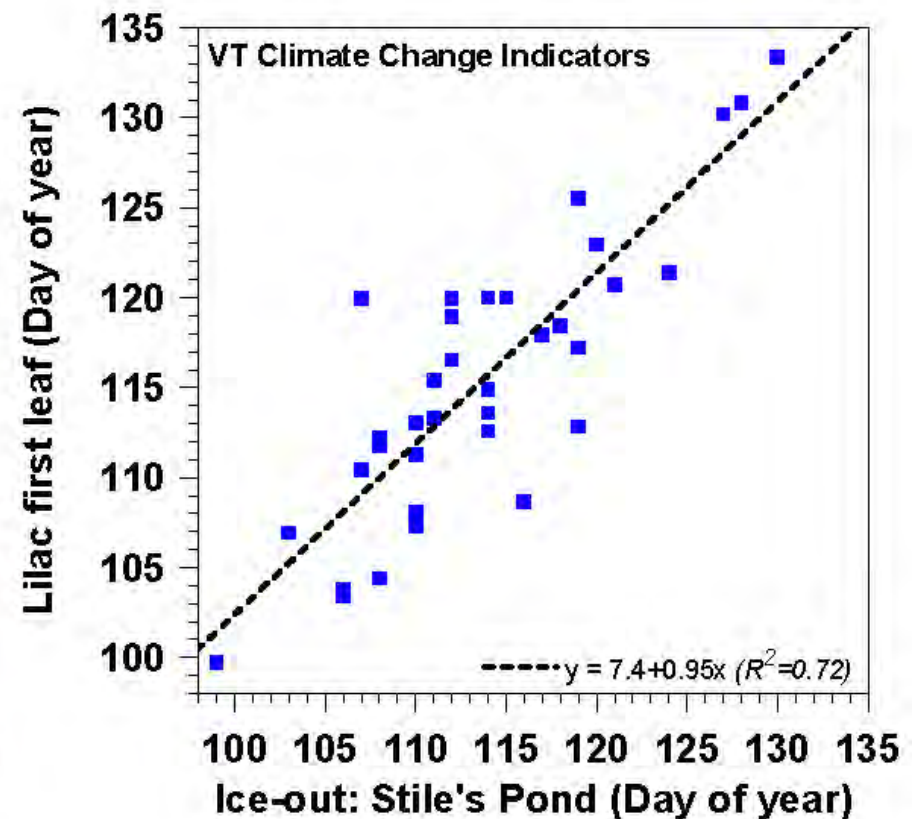
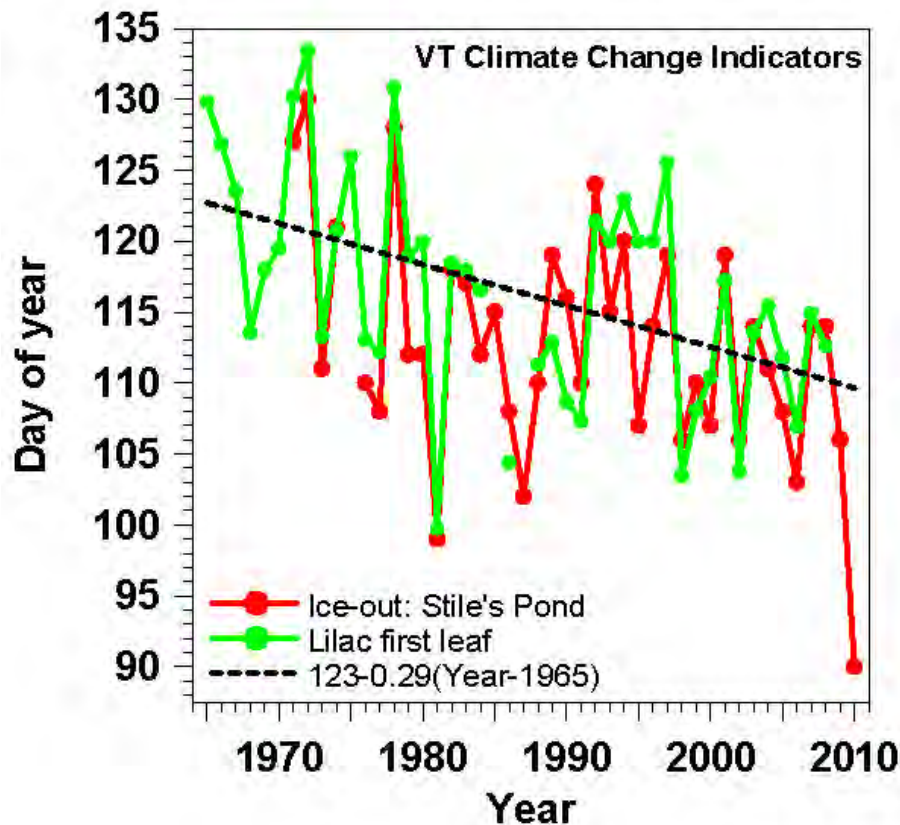
- Ice-out earlier **by 3 days / decade**
- Freeze-up later **by 4 days / decade**

Lilac Leaf and Bloom



- 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

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**

January 2, 2012



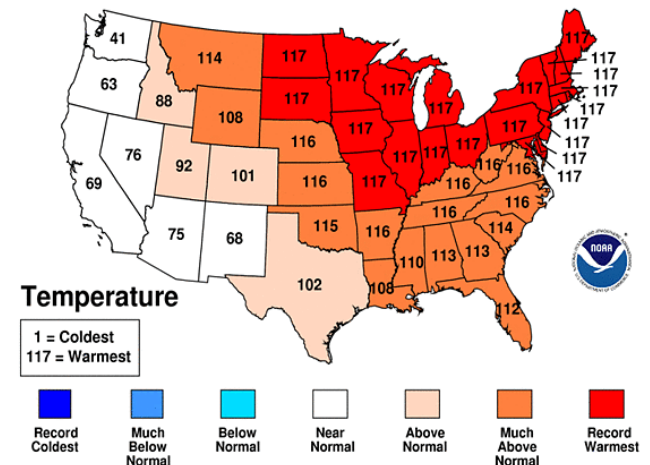
March 11, 2012



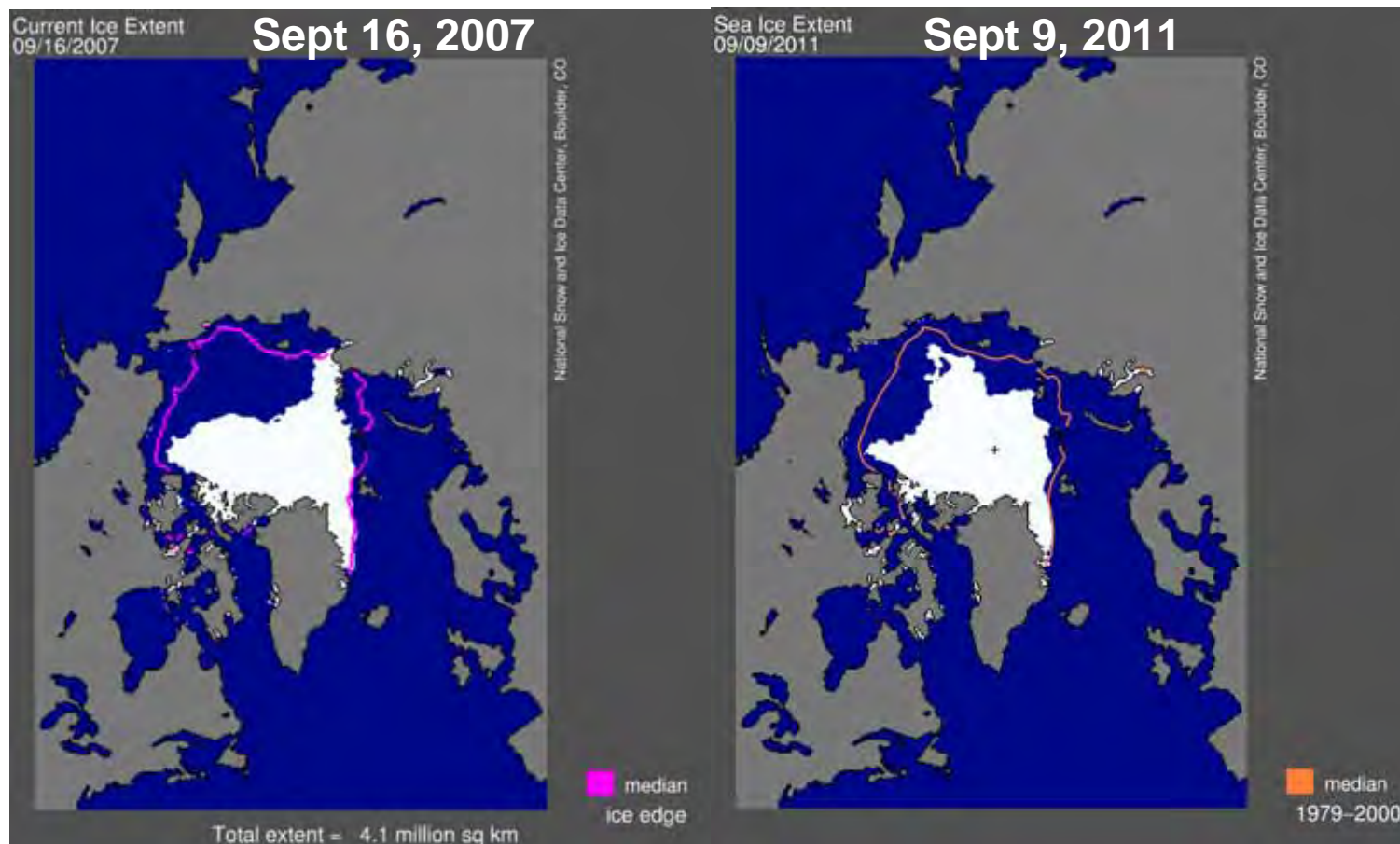
No permanent snow cover west of Green Mountains

- Warmest 6 months on record
- Dry winter, little snow
- Less reflection → Warmer, so snow melts faster

Oct 2011-Mar 2012 Statewide Ranks
National Climatic Data Center/NESDIS/NOAA



Arctic Sea Ice Loss Has Accelerated



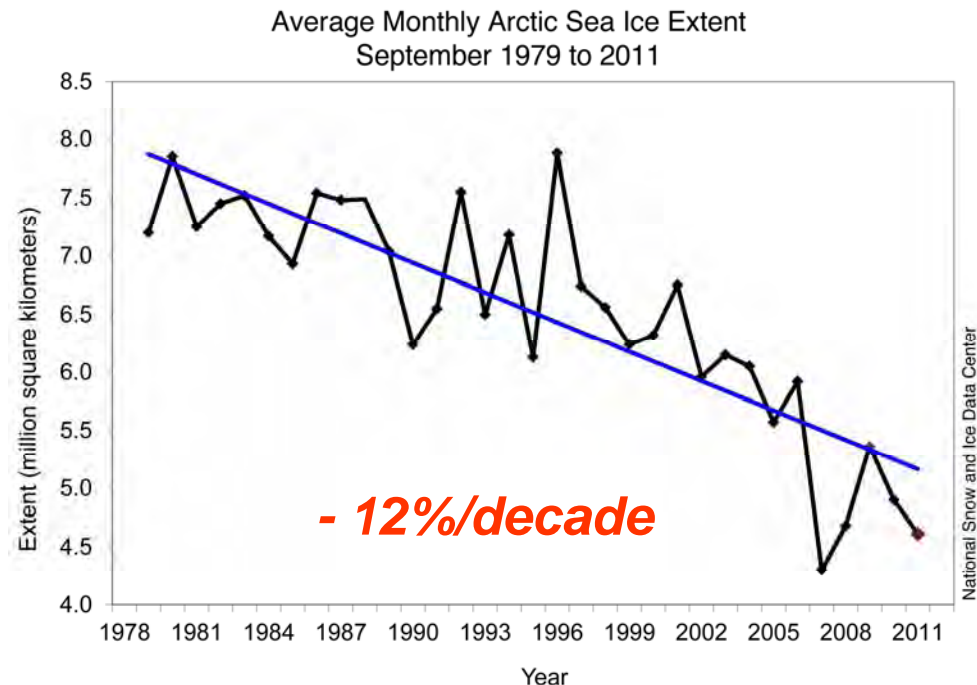
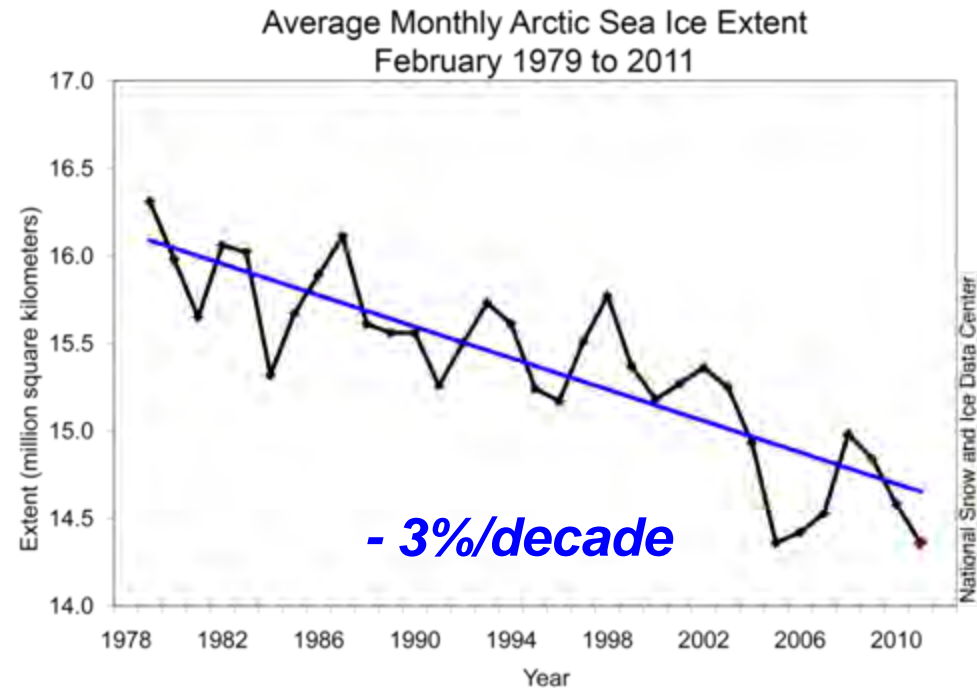
- **Positive feedbacks speed melting**
- **Less ice, less sunlight reflected**
- **More evaporation, larger water vapor greenhouse effect**

(www.nsidc.org)

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

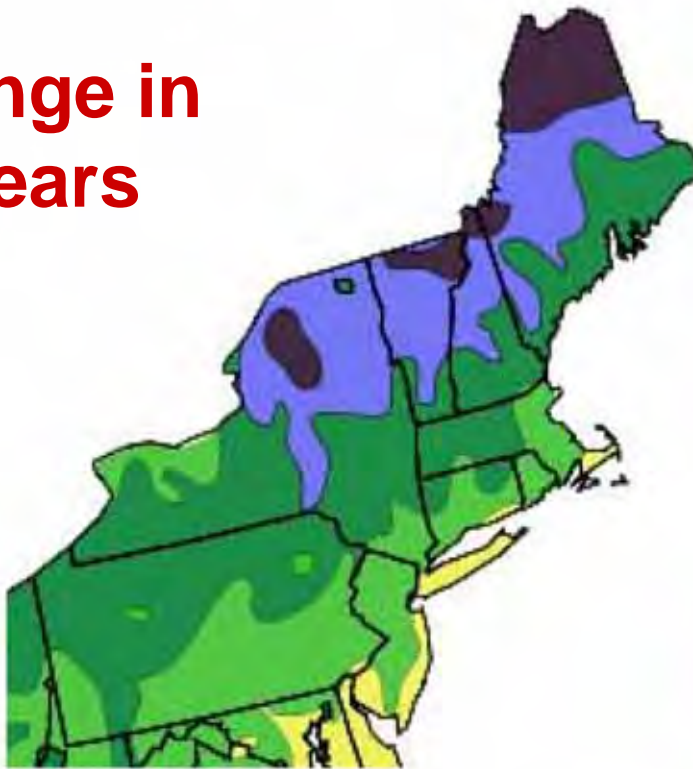
Sea Ice Trends

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

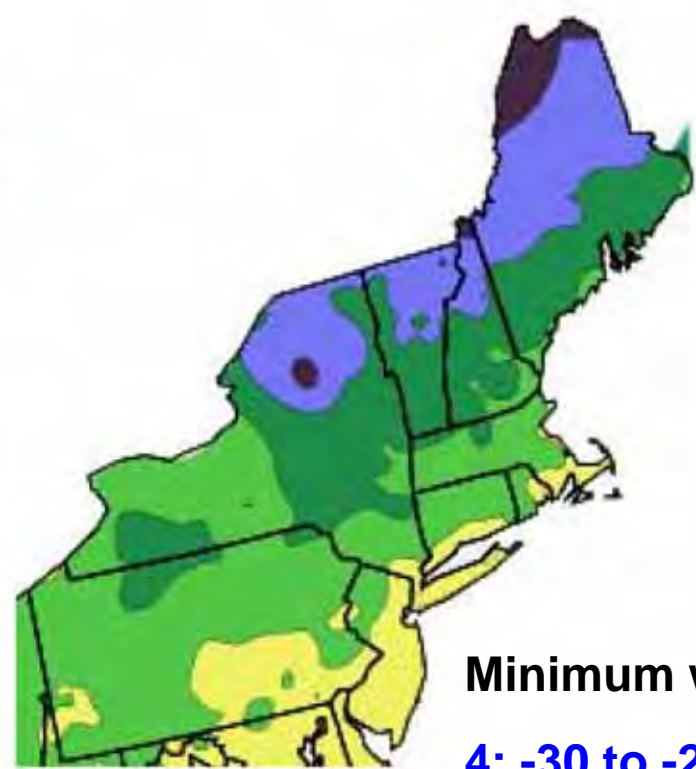


USDA Hardiness Zones - Northeast

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



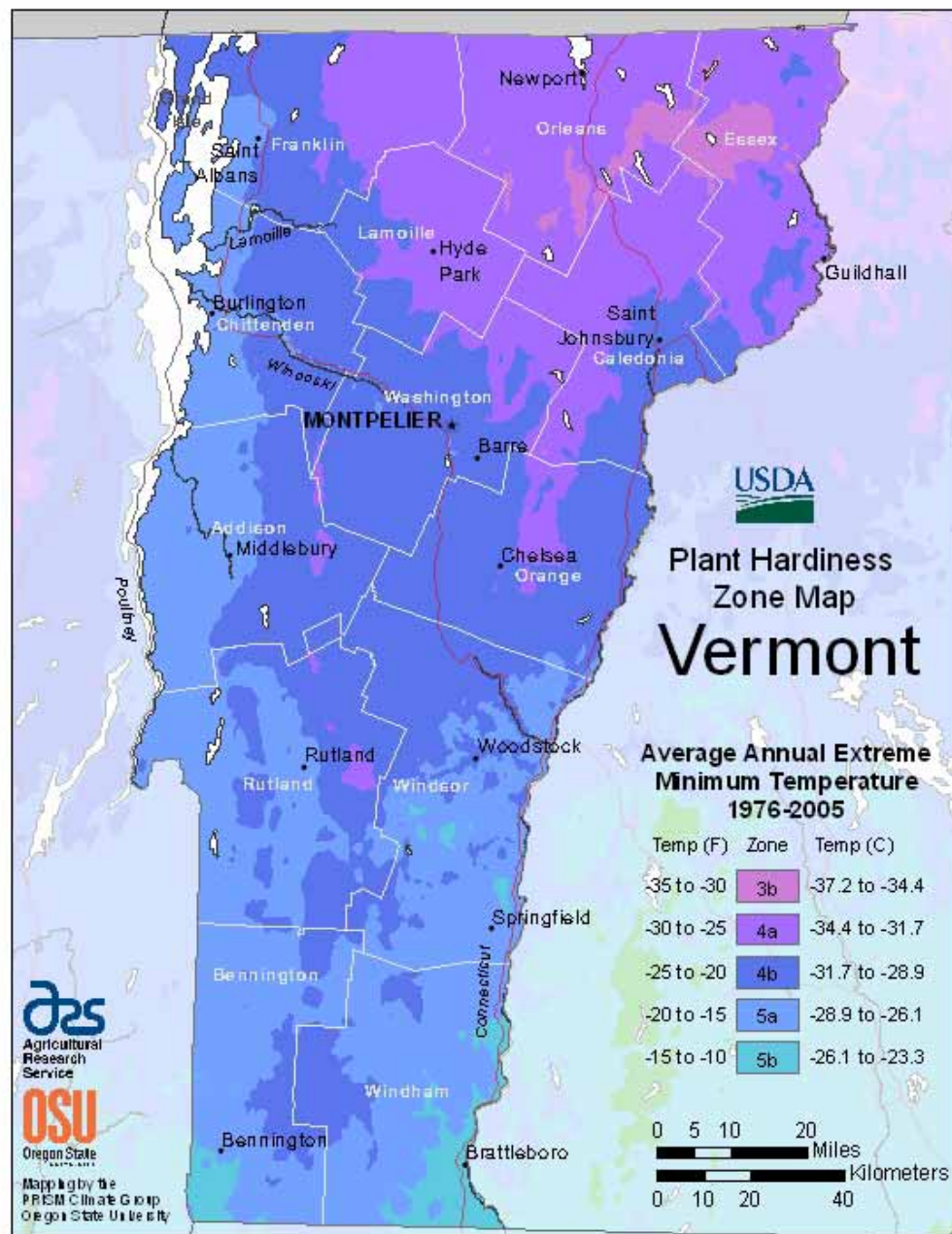
USDA Hardiness Zones

© 2006 by The National Arbor Day Foundation®

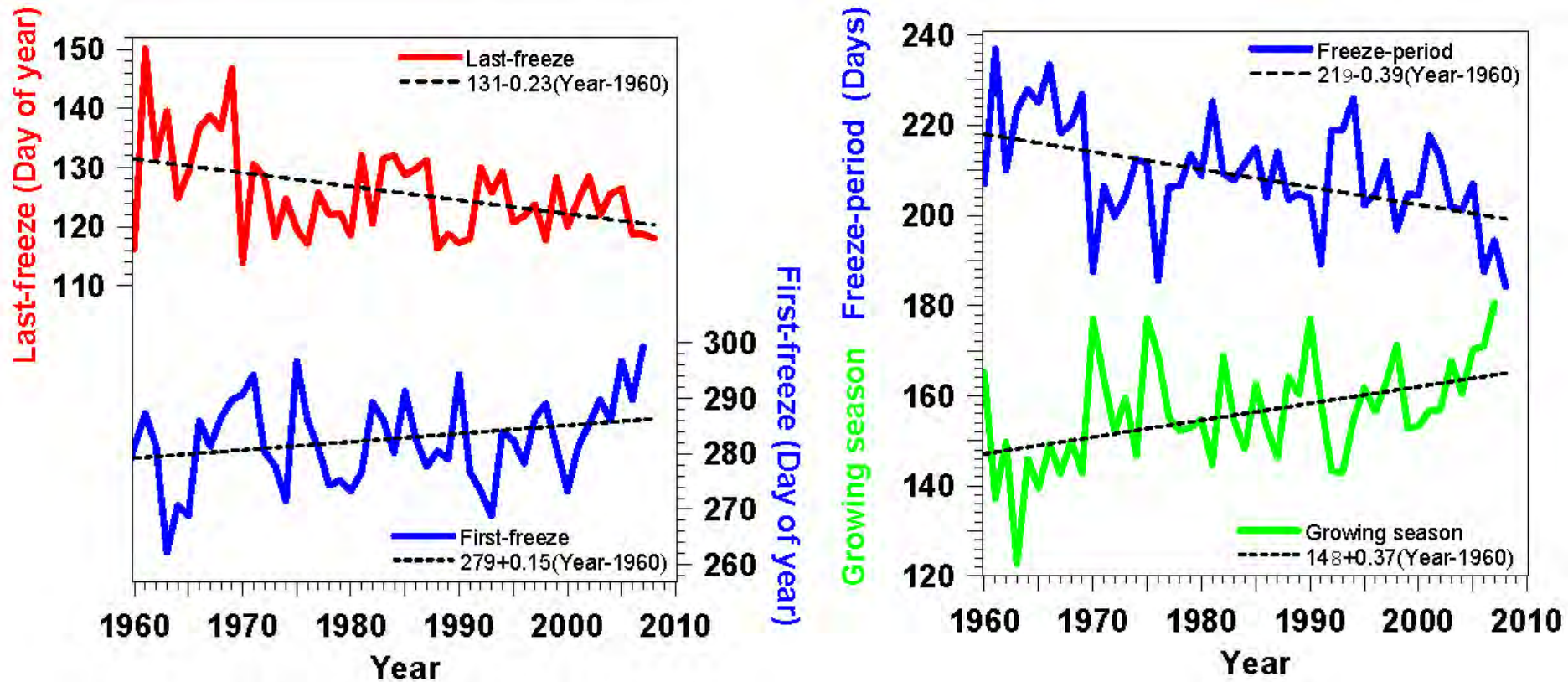
Latest detailed map

- **USDA : VT Hardiness Zone Map 1976-2005**

- <http://planthardiness.ars.usda.gov/PHZMWeb/>



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***

Wet summers



- Both 2008 and 2009 were wet
- Direct fast evaporation off wet canopies
- Positive evaporation-precipitation feedback

Summer dry-down

- Wet in spring
- Soil moisture falls: summer dry-down
- Low humidity & no rain
- Drought may lock-in



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!*



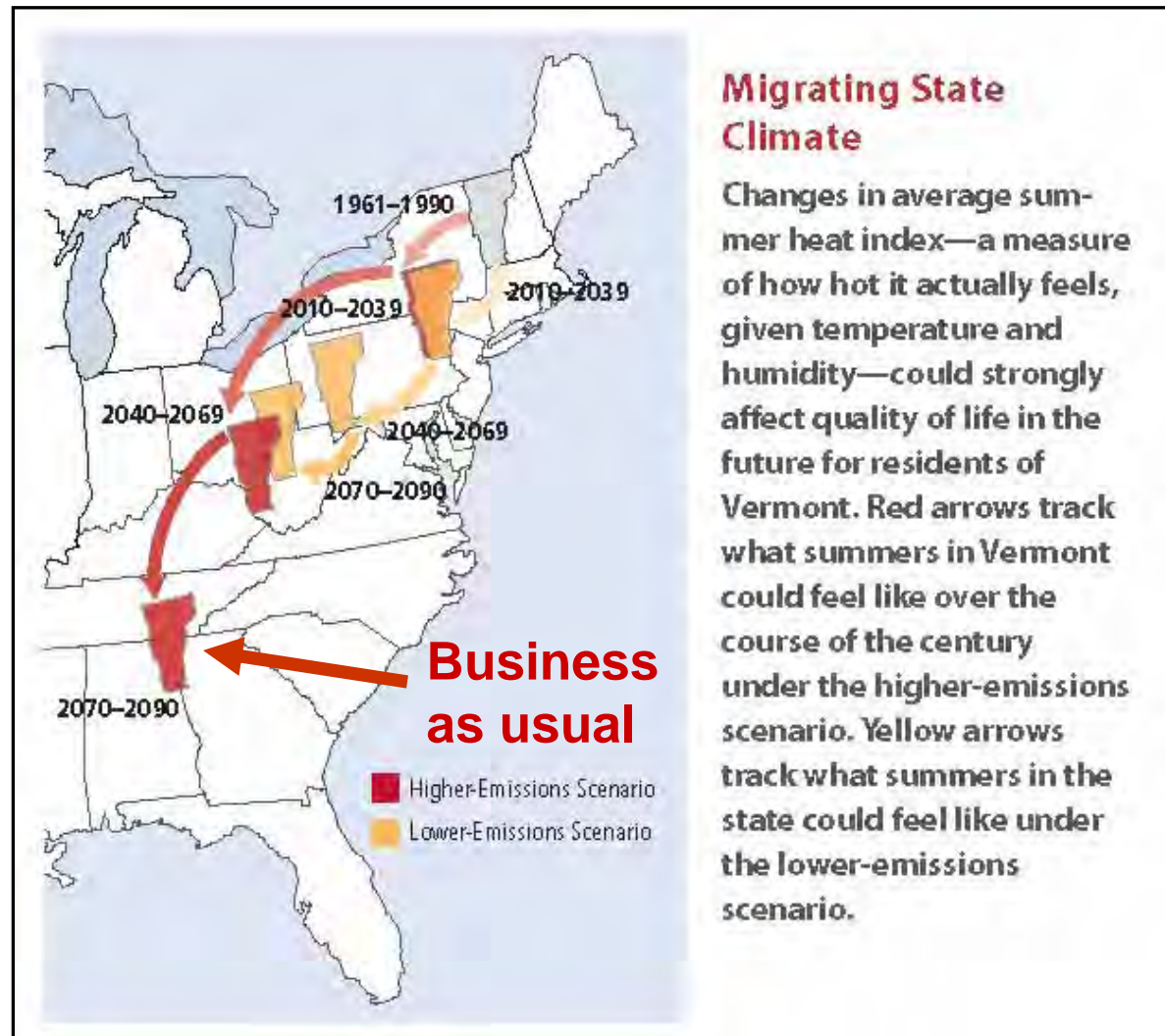
Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

Later frost: Growing season getting longer

Vermont's Future with High and Low GHG Emissions

What
about
skiing?

What
about
tropics?



NECIA,
2007

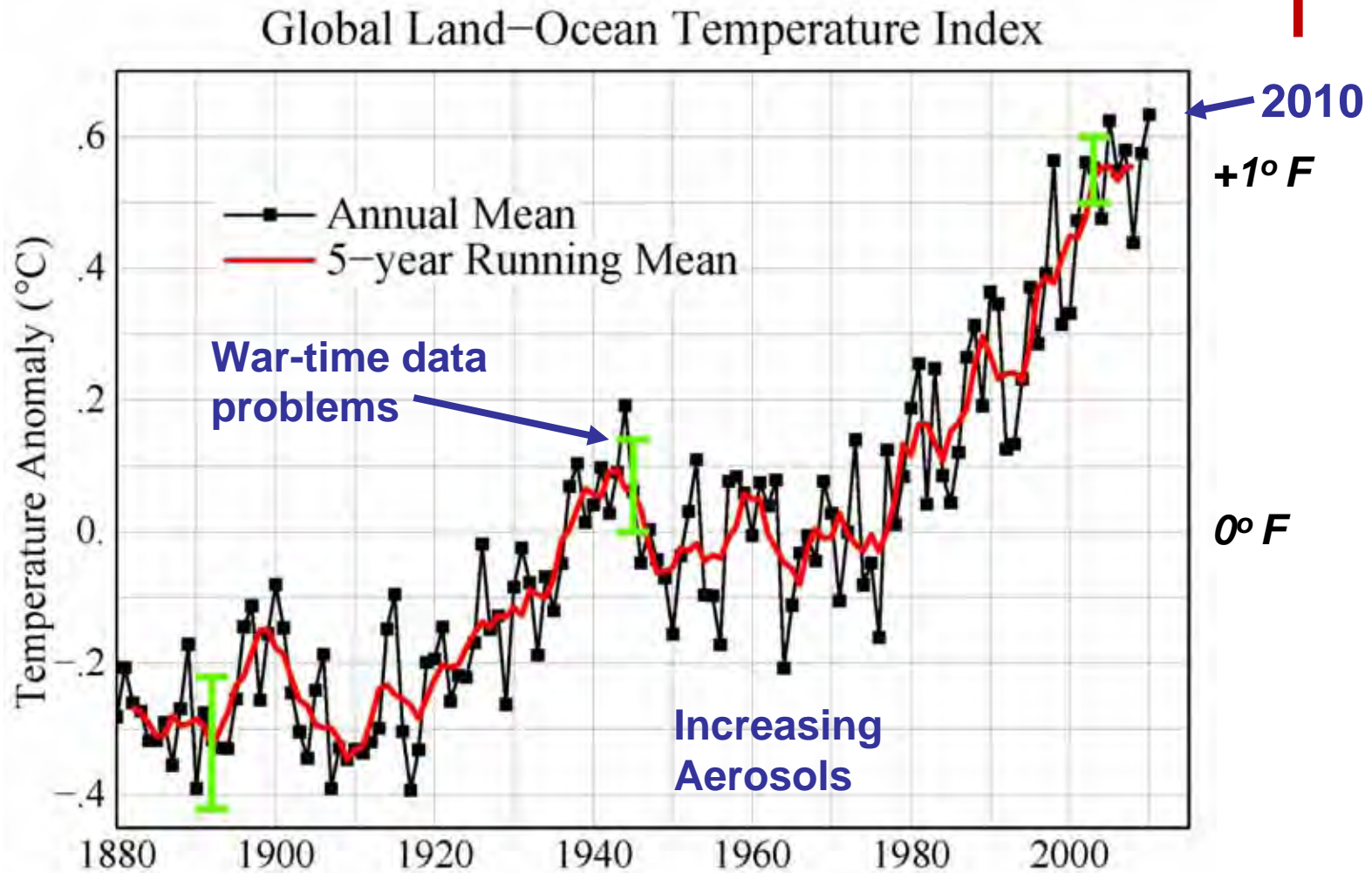
Global Climate Change

- One of the many great challenges for the 21st century - present path is unsustainable
- Known it would be a problem for 4 decades

J. S. Sawyer (1972): Man-made CO₂ and the “greenhouse” effect
- Earth science conflicts with historic values (and vested interests in fossil fuel economy)
- It is a global issue & a local issue

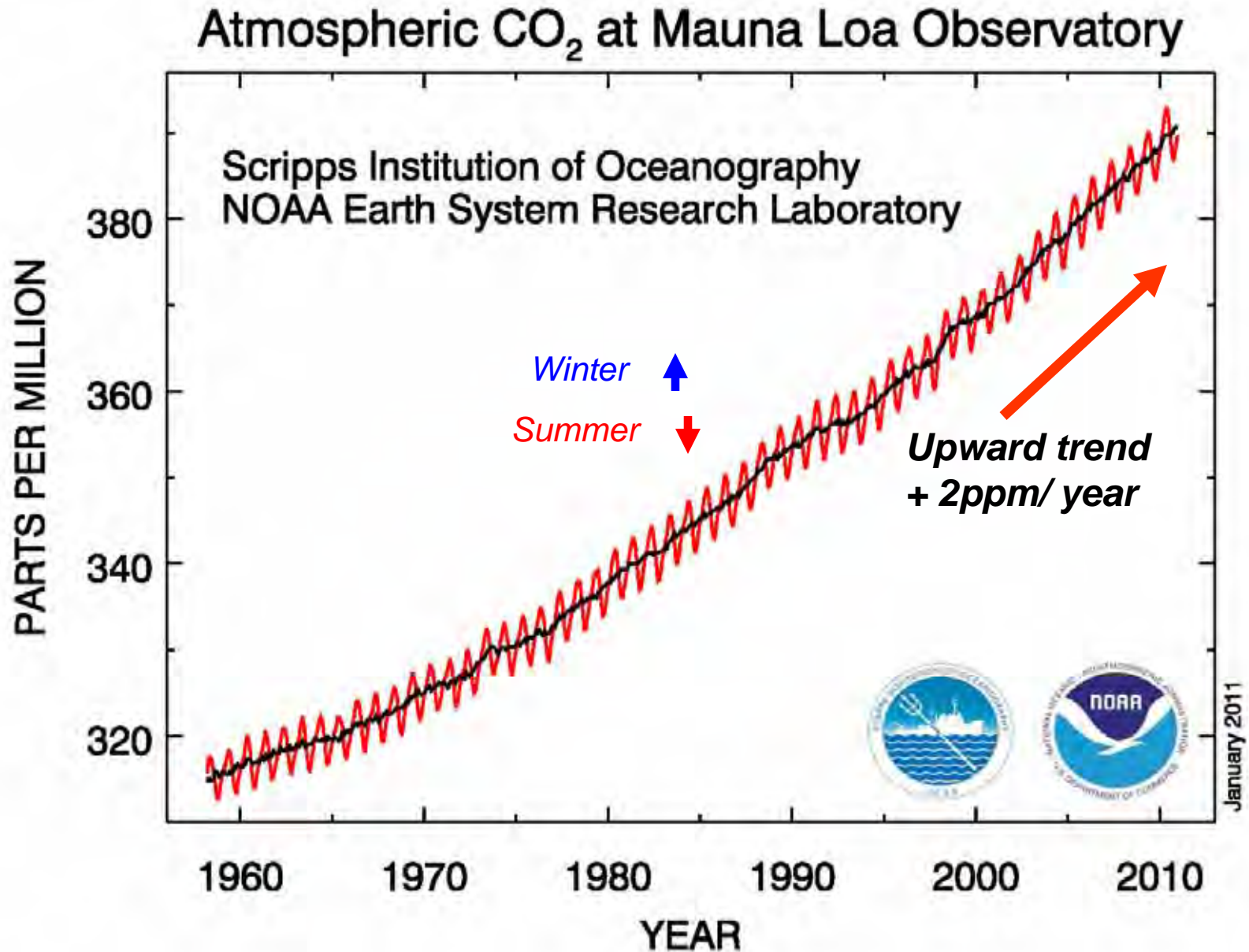
Global Temperature Rise 1880 – Present

2100: +5°F



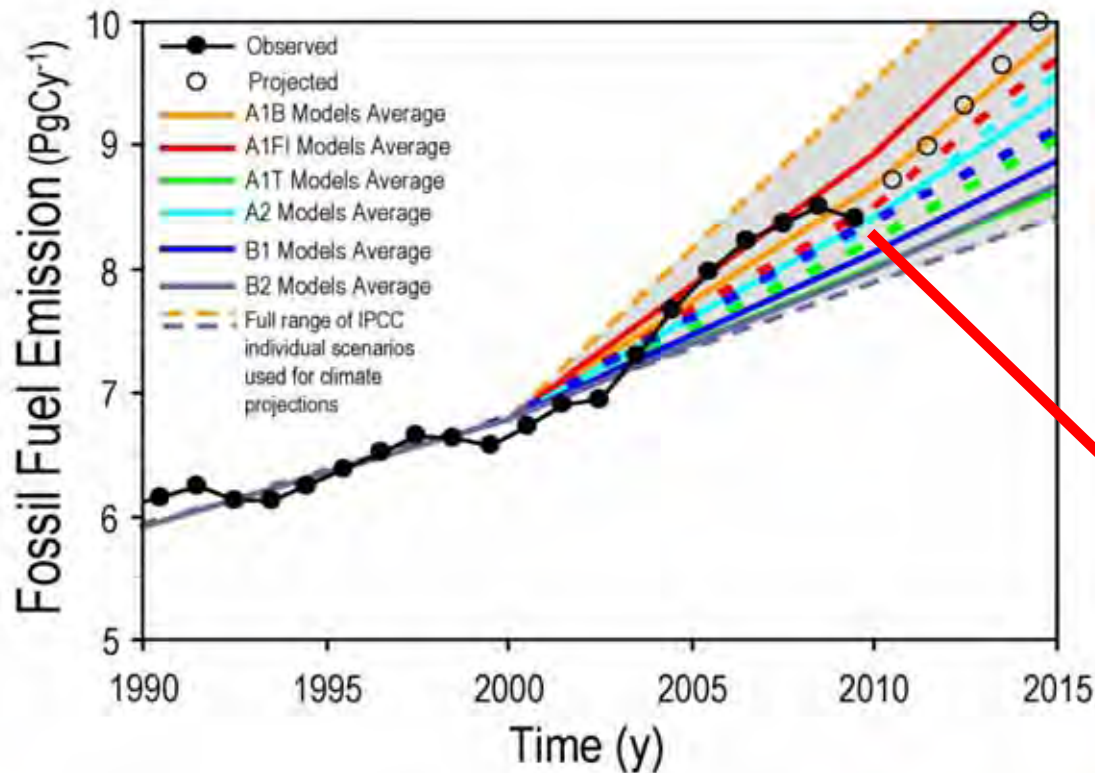
NASA-GISS, 2011

Carbon Dioxide Is Increasing



2009 Was “Good” for the Earth

Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Emission
Scenarios

- 4%/year

Why Is the Rise of Atmospheric CO₂ a Problem?

- The atmosphere is transparent to light from the sun, but not to infrared radiation from the earth
- Greenhouse gases: H₂O, CO₂, CH₄
 - trap the earth's heat, giving pleasant climate
- CO₂ rise alone has a small warming effect

BUT...



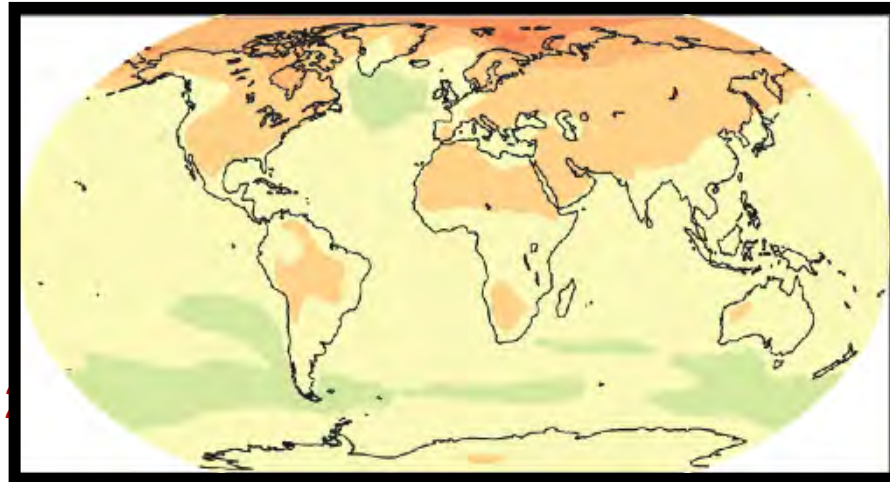
Why Is the Rise of Atmospheric CO₂ a Problem?

- As Earth warms, **evaporation and water vapor increase** and this amplifies warming a lot **(3X)**
- As Earth warms, **snow and ice decrease** and this amplifies warming in winter and northern latitudes, because less sunlight is reflected
- Doubling CO₂ will warm Earth about 5°F (3°C)
 - **much more in the North and over land**

Predicted Change in Temperature

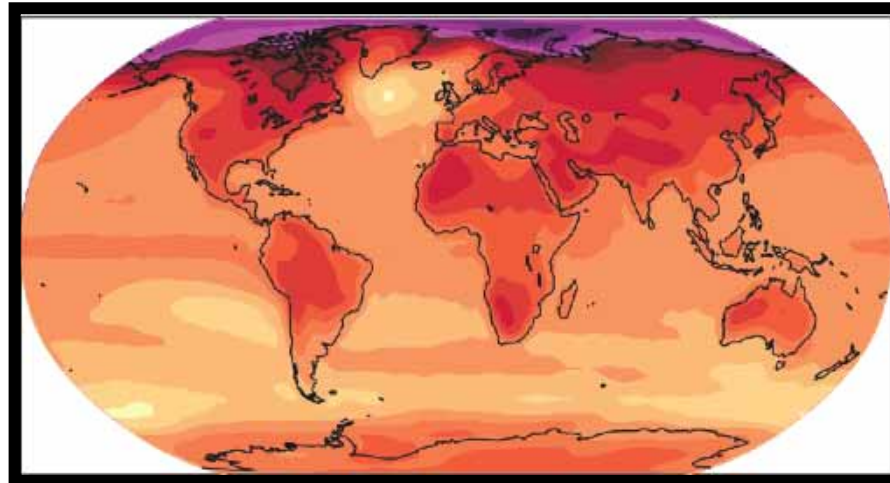
2020-2029 and 2090-2099, relative to 1980-1999 (°C)

“Committed”



**(We did
nothing for
the last 20
years)**

Still up to us!



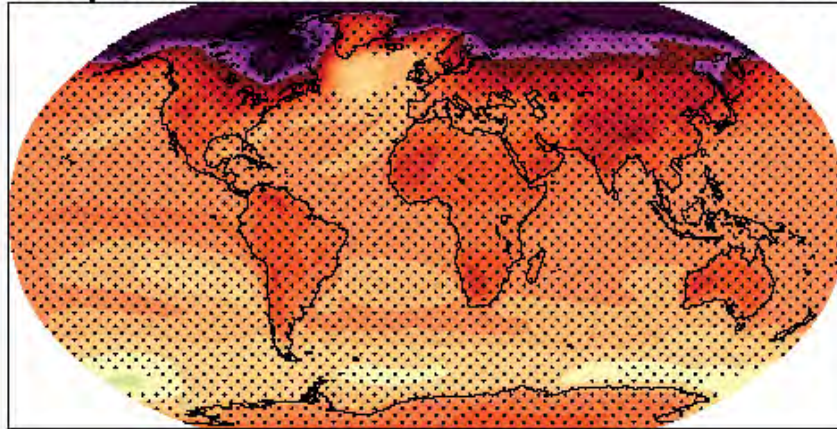
**(We could
halve this if
we act now)**



[°C]

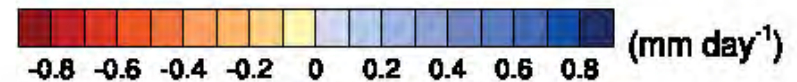
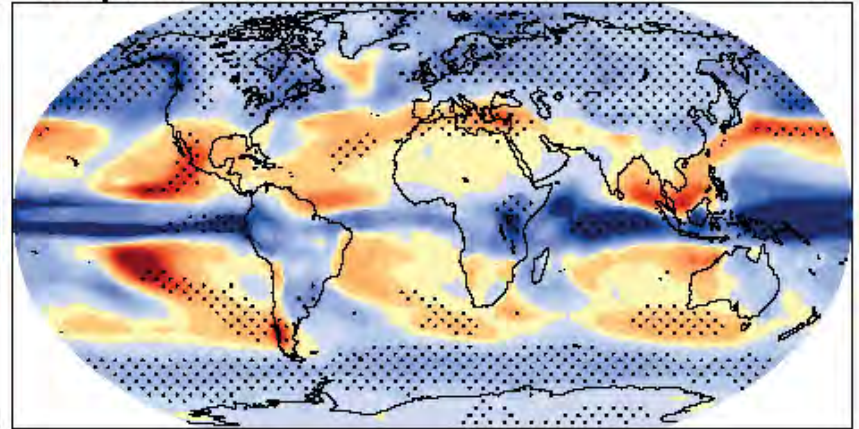
Climate Model Predictions

Temperature A1B: 2080-2099

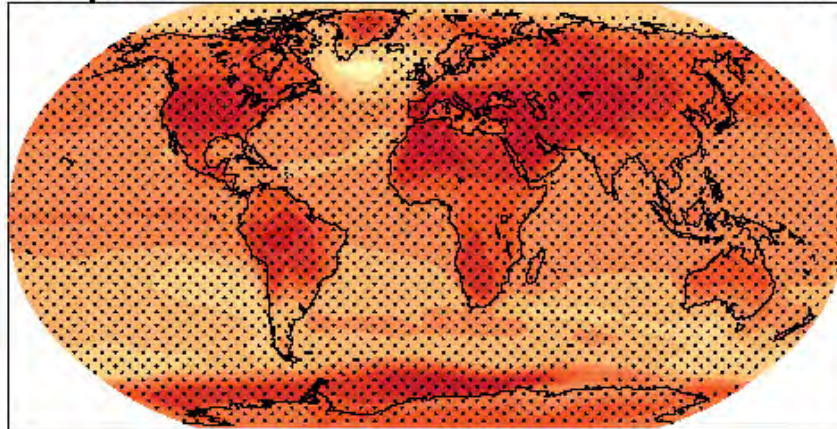


DJF Precipitation A1B: 2080-2099

DJF

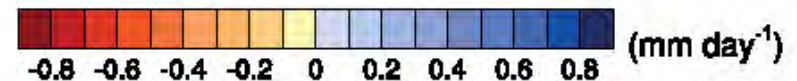
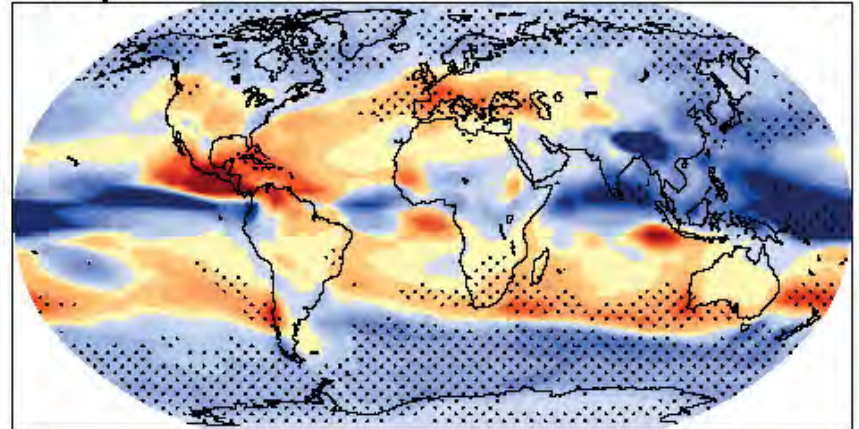


Temperature A1B: 2080-2099



JJA Precipitation A1B: 2080-2099

JJA



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
- Unless we drastically reduce burning of fossil fuels by 80% by 2050
- Sea-level rise will get our attention
 - But it will be too late!

Many Challenges Face Us

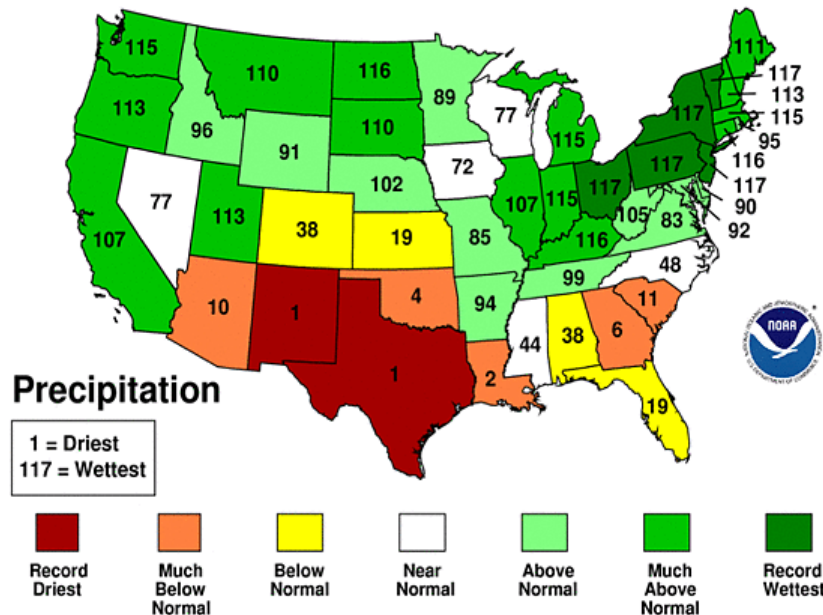
- **Extreme weather: Floods, fires, & drought**
 - **32 weather disasters >\$1B in 2011**
- **Melting Arctic and permafrost—methane release is positive feedback**
- **Ecosystem collapse, including perhaps forest and ocean ecosystems**
- **Collapse of unsustainable human population**

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)

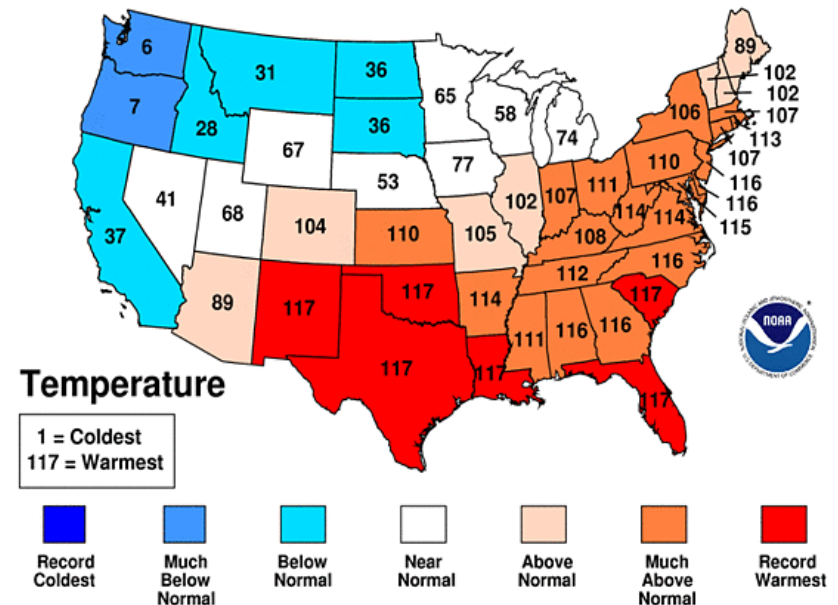
March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



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**

Will Attitudes Change?

- Irene changed Vermont's attitude
- **Changing climate and extreme weather will raise awareness (sea level rise will be too slow)**
- 'Managing' Lake Champlain is a microcosm for 'managing' the Earth

As Climate Changes....

- **Everything is interconnected**
- **Human society and waste streams: people's choices and actions**
- **Precipitation, seasons, streams, and forests; habitat and wildlife**
- **You have specific tasks in a large project**
- **But keep your eyes open to the big picture and draw connections**
- **Record more than the project lists/protocols**
- **Keep asking us for guidance**

[Continue on Friday]

Discussion

- <http://alanbetts.com>
 - this talk <http://alanbetts.com/talks>
 - articles at <http://alanbetts.com/writings>
 - **Sunday Environment page in Herald/
Times Argus: 2008-2012**
- *Vermont Climate Change Indicators*
- *Seasonal Climate Transitions in New England*