Climate Change, Vermont and the Future

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House Natural Resources and Energy Committee

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RACC
Research on Adaptation to Climate Change

Outline

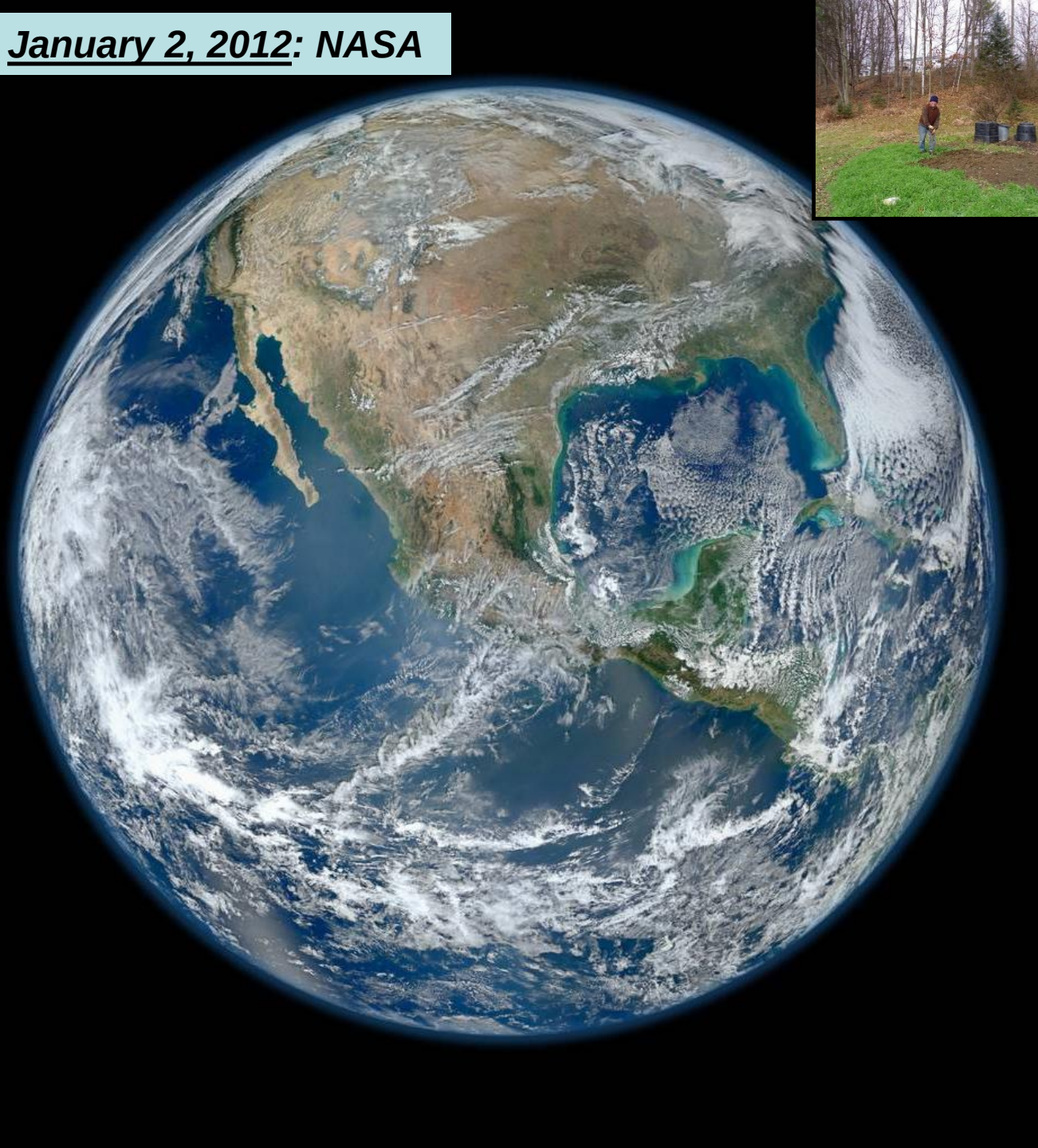
- **Science of climate change**
  - **Global and local**
  - **What is happening to Vermont?**
  - **Why is extreme weather increasing?**
- **The transition we face**
  - **Can we stabilize the climate?**
  - **Why has it become a moral issue?**

Discussion

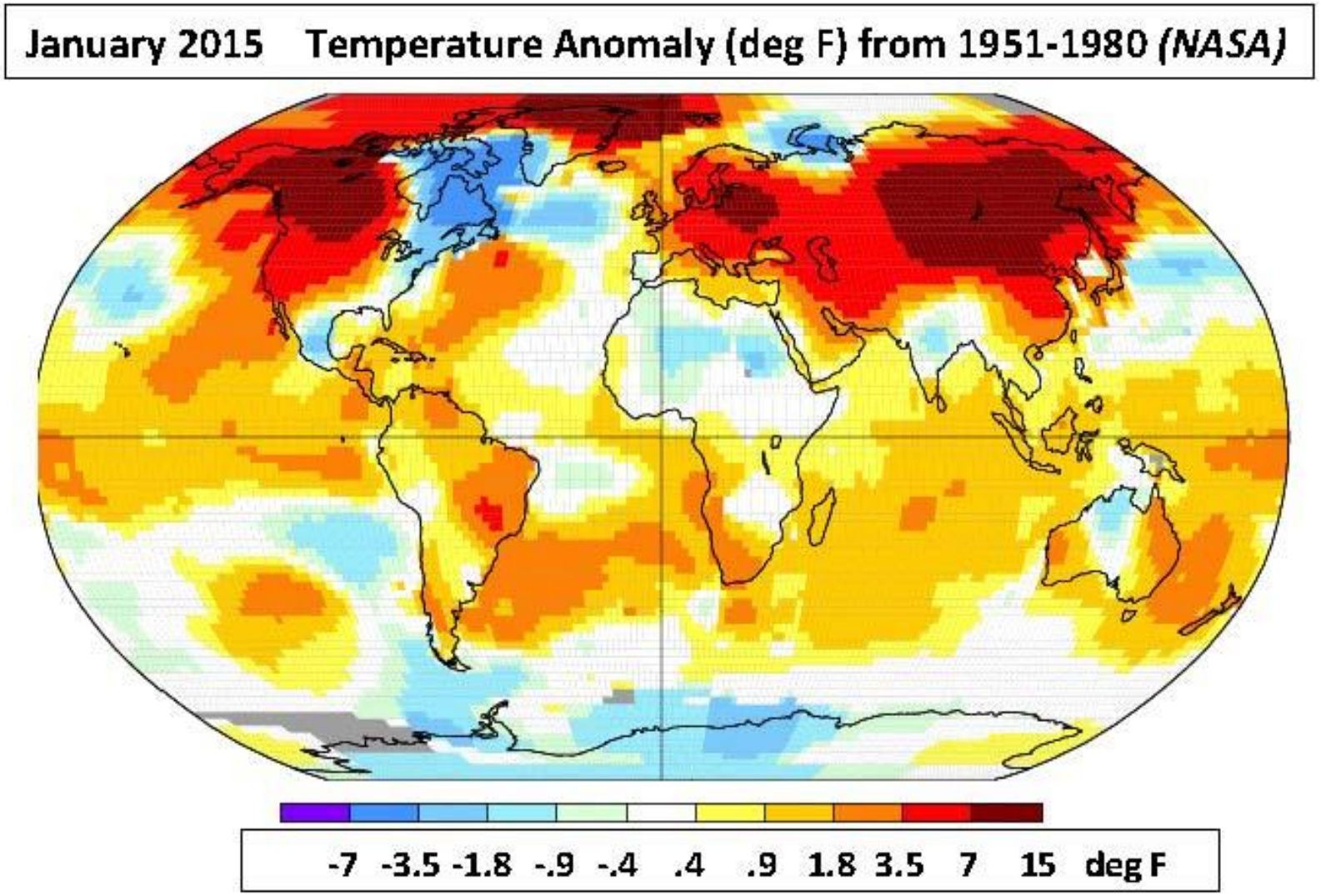
Earth's climate sustains life

- Burning fossil fuels is increasing greenhouse gases
- Climate is warming: ice is melting, extreme weather is increasing
- Water plays crucial amplifying role

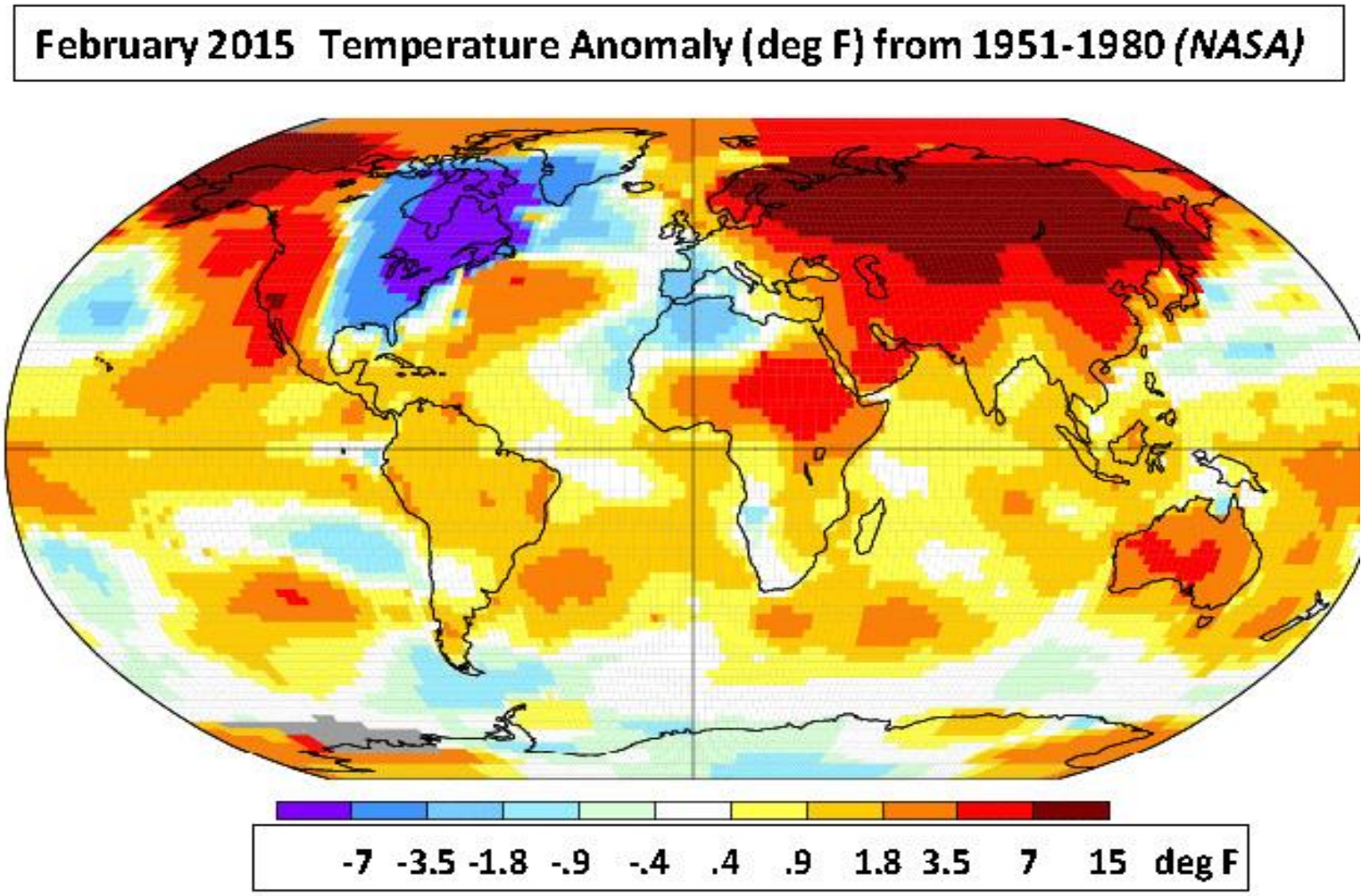
January 2, 2012: NASA



Chilly Winter Here - Look at the Rest of the Northern Hemisphere!



Extremes Larger in February
- Pattern stationary



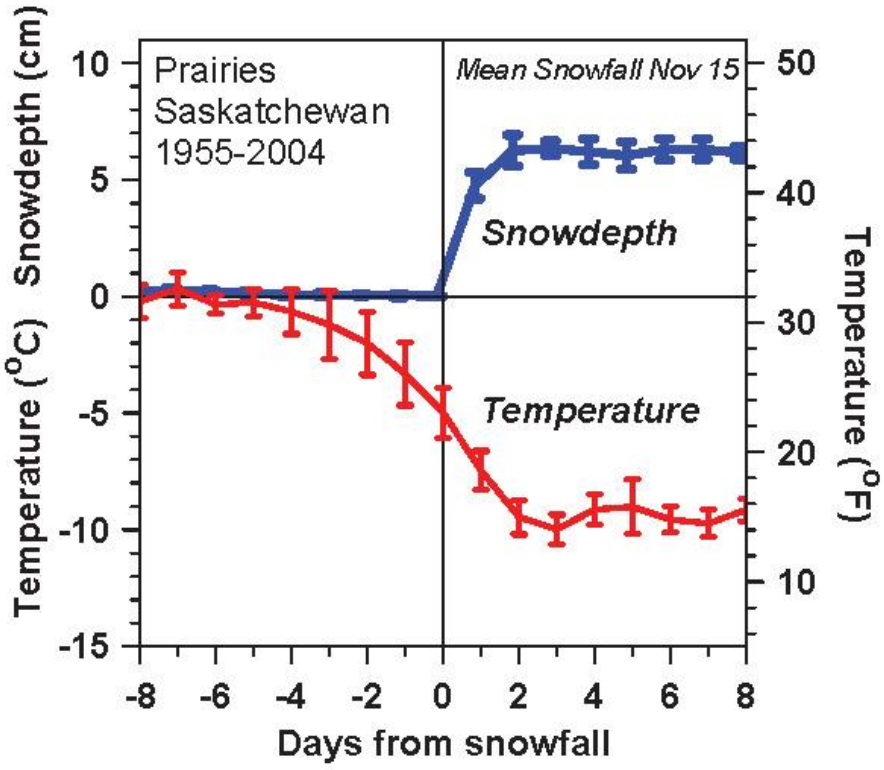
Warm Atlantic, Cold NE, strong coastal storms - Boston record snow

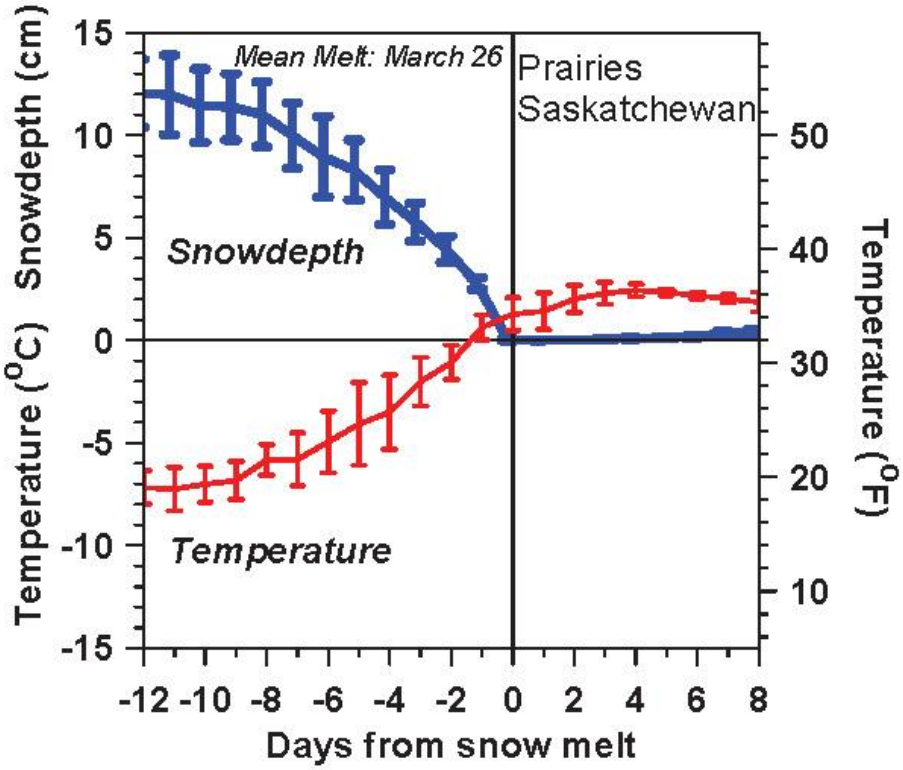
Winter Ice and Snow

Vermont Winter 2006

- **Snow reflects sunlight, except where trees shadow**
- **Cold; little evaporation, clear sky; earth cools to space**
- ***2011-12 warm winter, snow melts → positive feedback***
- ***2013-14 more snow and colder → positive feedback***

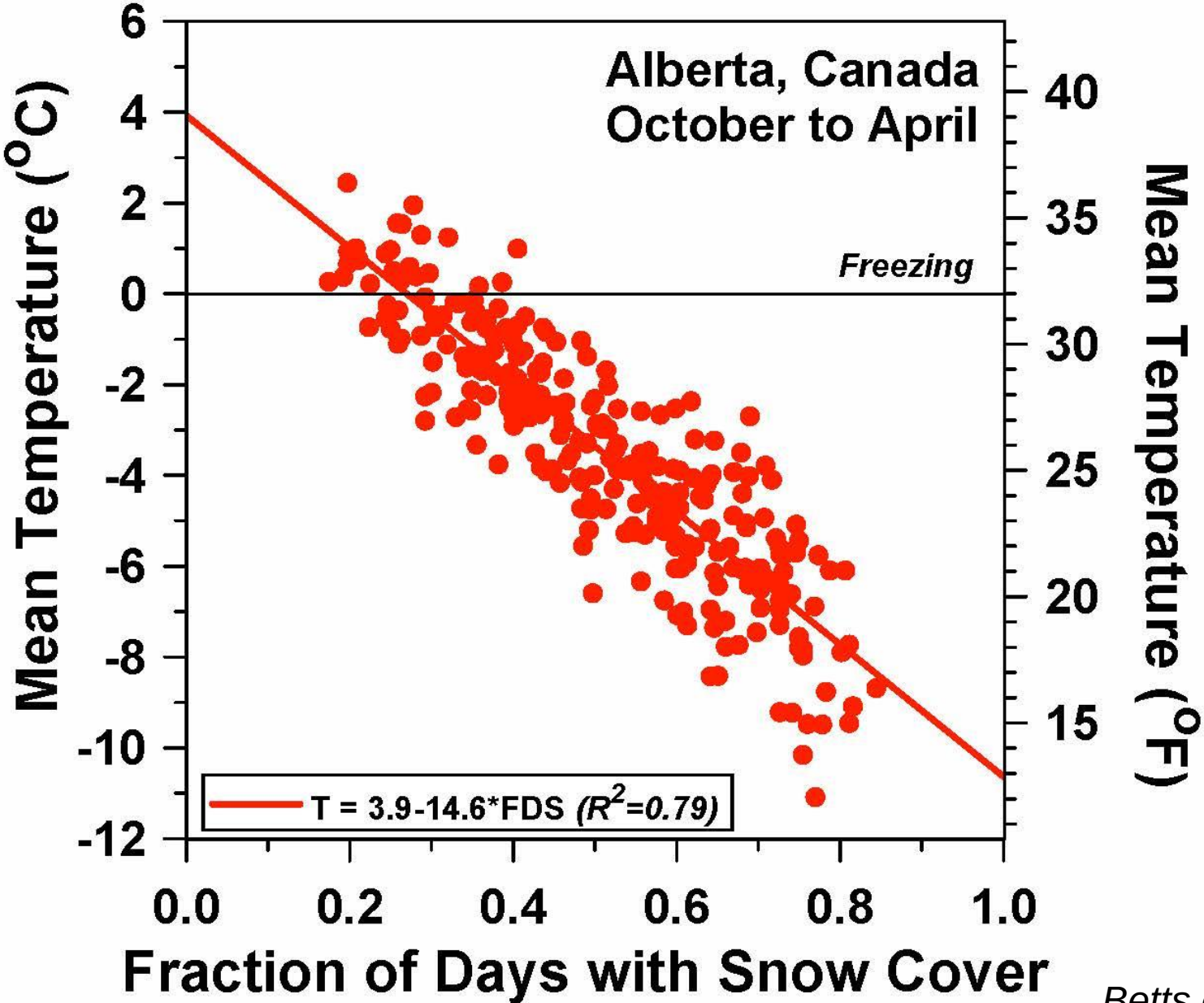
Snowfall and Snowmelt





- **Temperature falls 18F (10C) with first snowfall**
- **Reverse change with snowmelt**
- ***Fast transitions in 'local climate'***
  - ***Snow reflects sunlight***
  - ***Reduces evaporation and water vapor greenhouse***

More snow cover - Colder temperatures



Betts et al. 2014

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

- ***Positive feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Same feedbacks as in our winters***

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 60ºF**
- **Rise of CO_2 alone has only a small warming effect**

BUT…

Water, Snow & Ice Give Positive Radiative Feedbacks

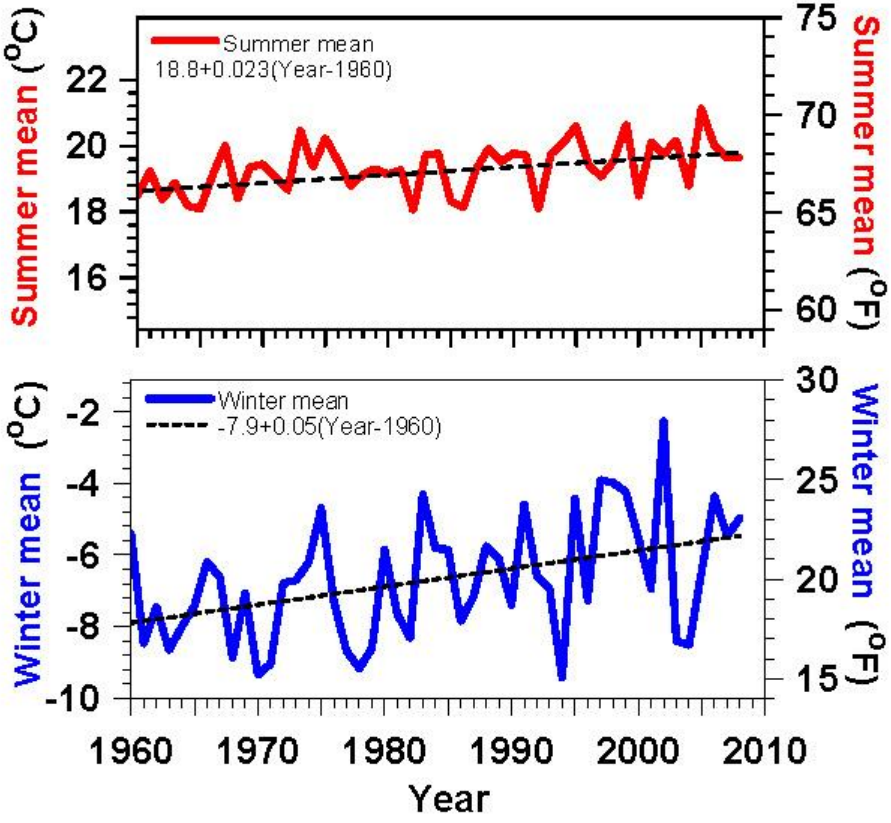
- **As Earth warms, evaporation and water vapor increase and this is 3X amplifier on CO_2 rise**
- **As Earth warms, snow & ice decrease and reduced solar reflection amplifies warming in Arctic in summer and mid-latitudes in winter**
- **Doubling CO_2 will warm globe about 5°F (3°C)**
  - **Much more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

What Is Happening to Vermont?

- **Warming twice as fast in winter than summer**
- **Winter minimums increasing even faster**
- **Lakes frozen less by 7 days / decade**
  - **Winter variability increasing**
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**
- **Extreme weather increasing**
- ***Evaporation increases with T***
- ***More 'quasi-stationary weather patterns'***

Vermont Temperature Trends 1961-2008

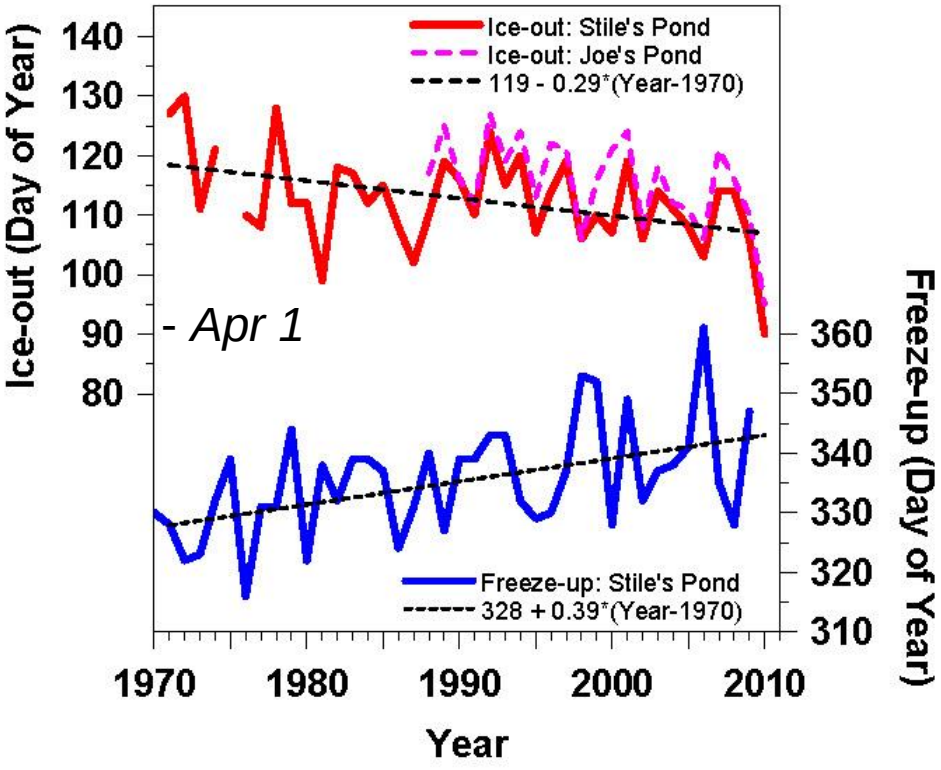
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***

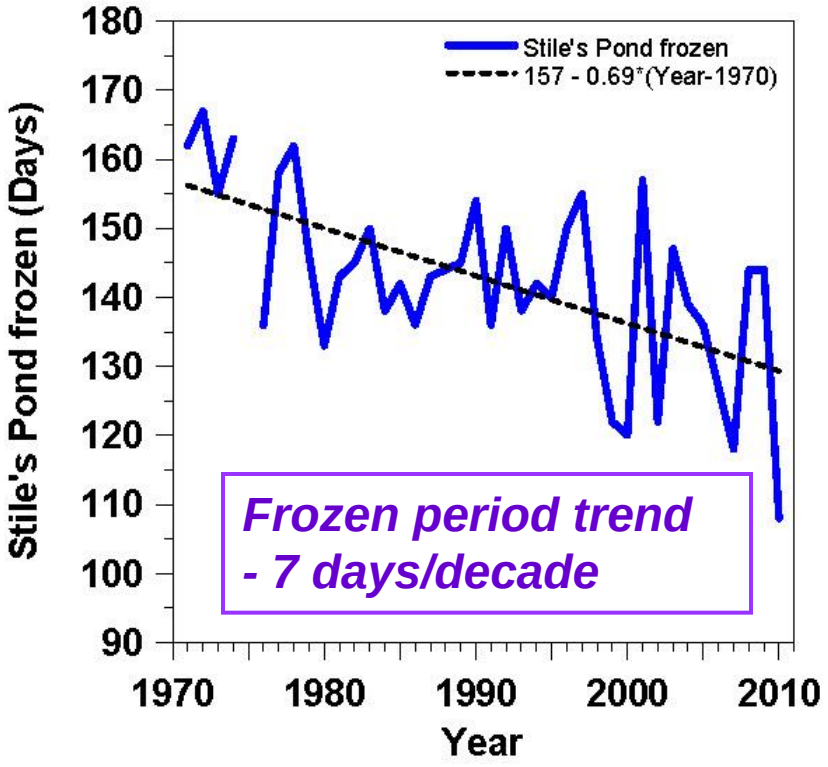


(Betts 2011)

Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



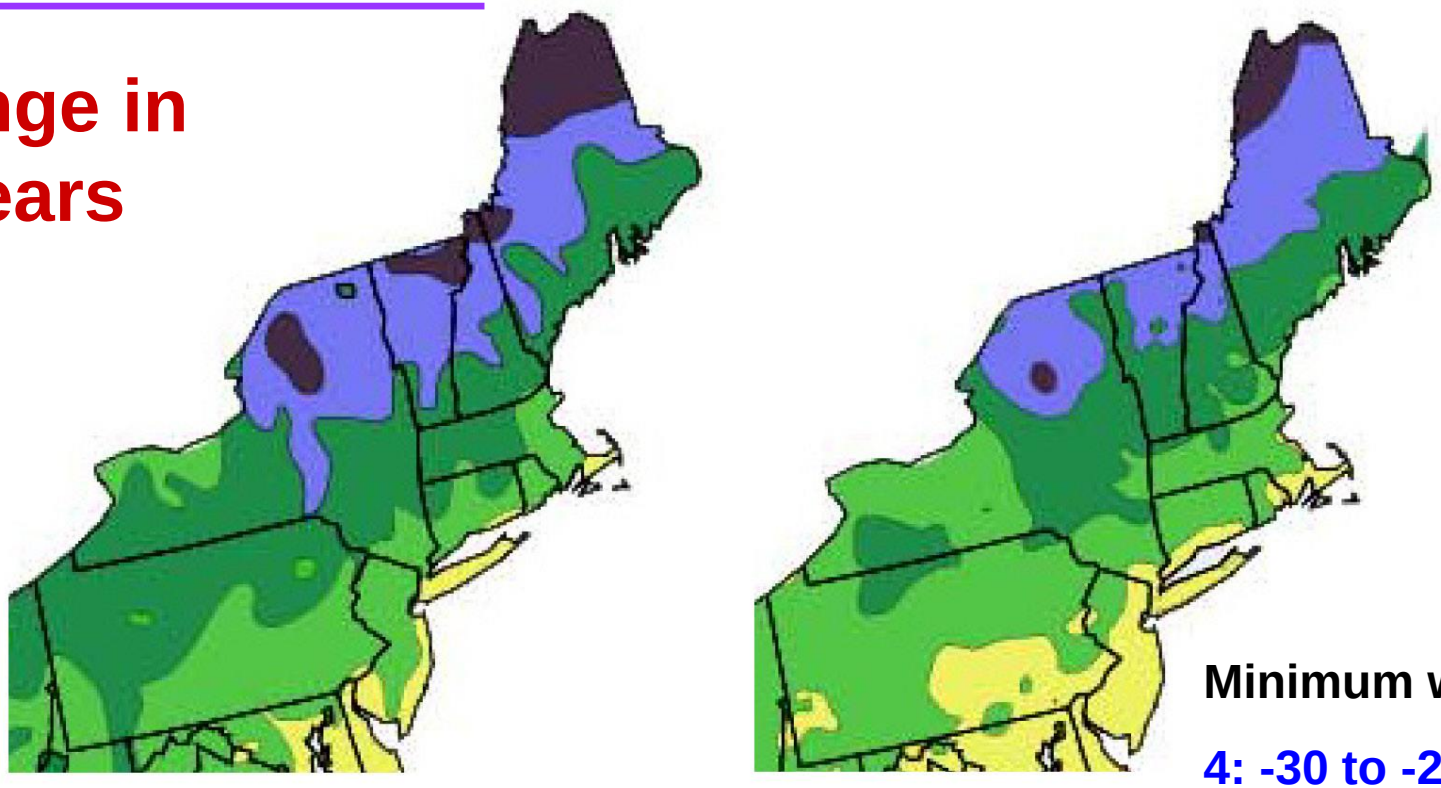


- **Ice-out earlier by 3 days / decade**
- **Freeze-up later by 4 days / decade**
- ***Soil ice probably similar***

Winter Hardiness Zones

– *winter cold extremes*

Change in 16 years



Minimum winter T

4: -30 to -20ºF

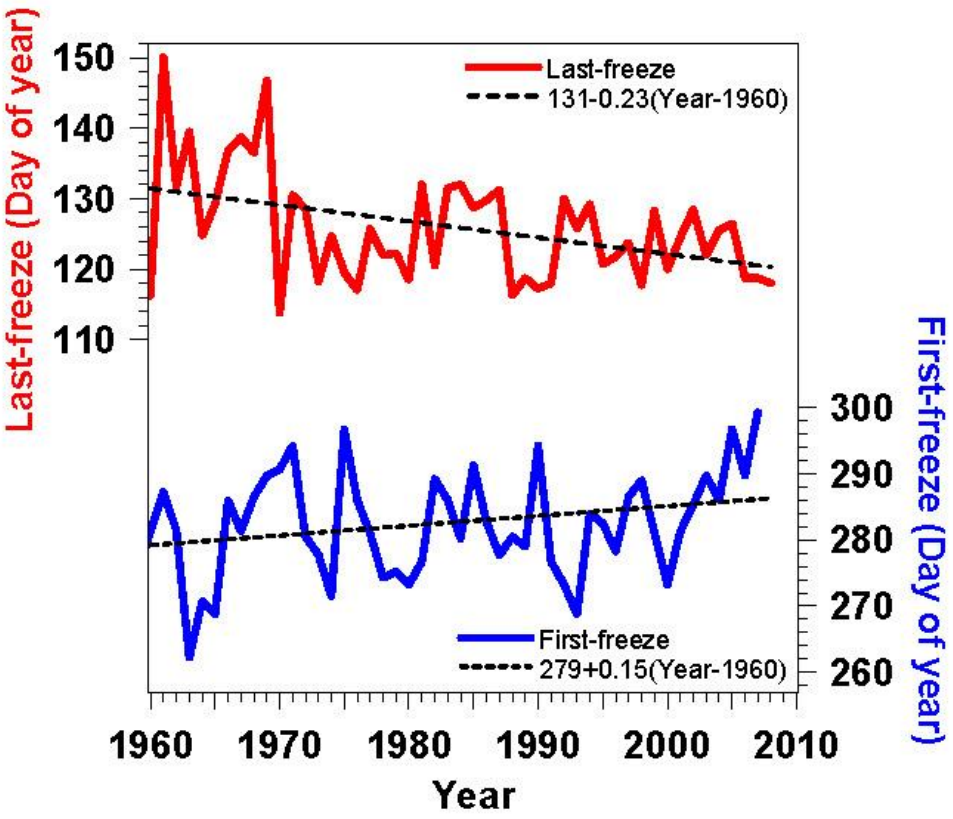
5: -20 to -10ºF

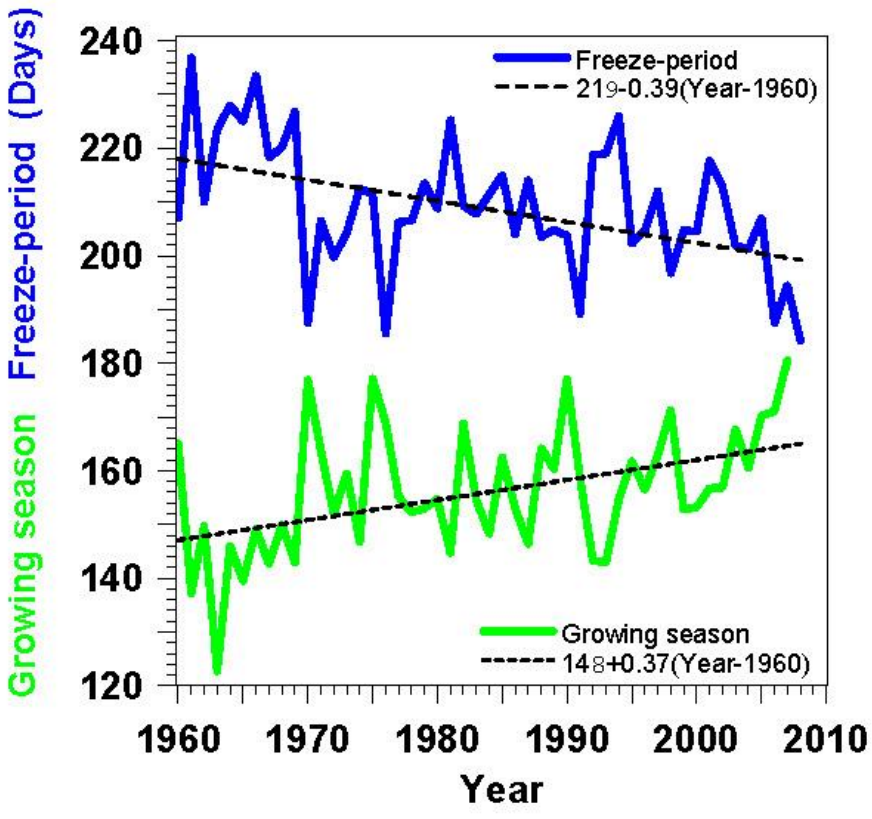
6: -10 to 0ºF

USDA Hardiness Zones

But winter variability getting larger

First and Last Frosts Changing





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

January 2, 2012

March 11, 2012

October 2011– March 2012

- **Warmest 6 months on record**
- **My garden frozen only 67 days**

- **January 15, 2013**
- **but 2014, 2015 frozen!**

Warm winter with little snow
Early Spring: *79ºF on March 22, 2012*

Pittsford Vermont

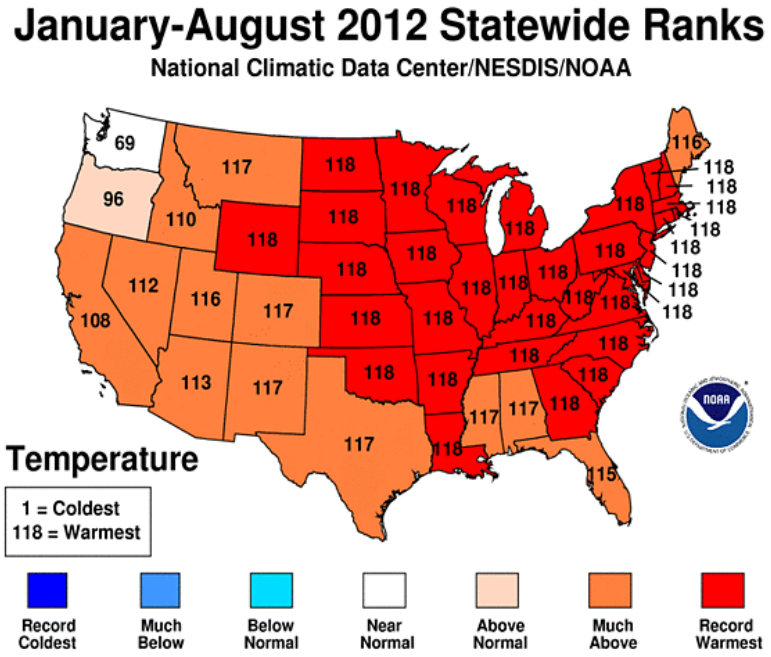
3/22/12

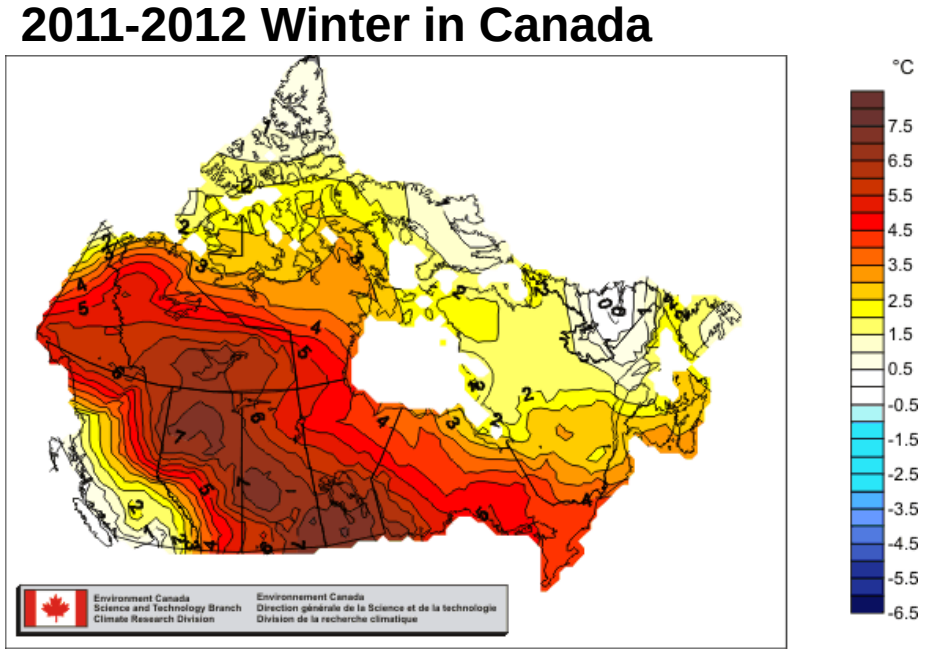
Pittsford Vermont

3/24/12

Daffodils, Forsythia in bloom

2012 Exceptionally Warm

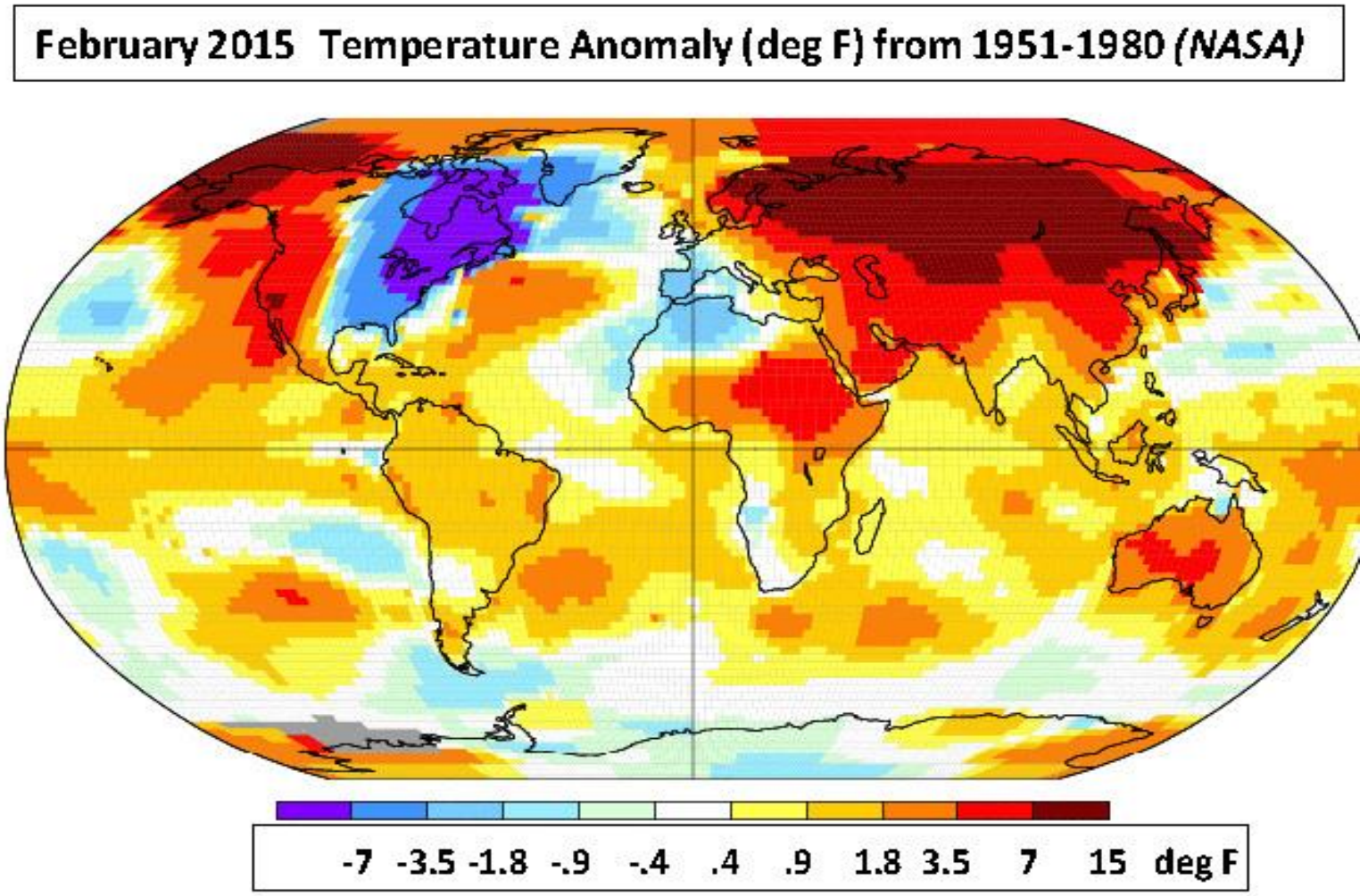




Little snow in Vermont winter 2011-12 – very warm
Record temperatures Jan-Aug 2012
Record Arctic ice melt

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

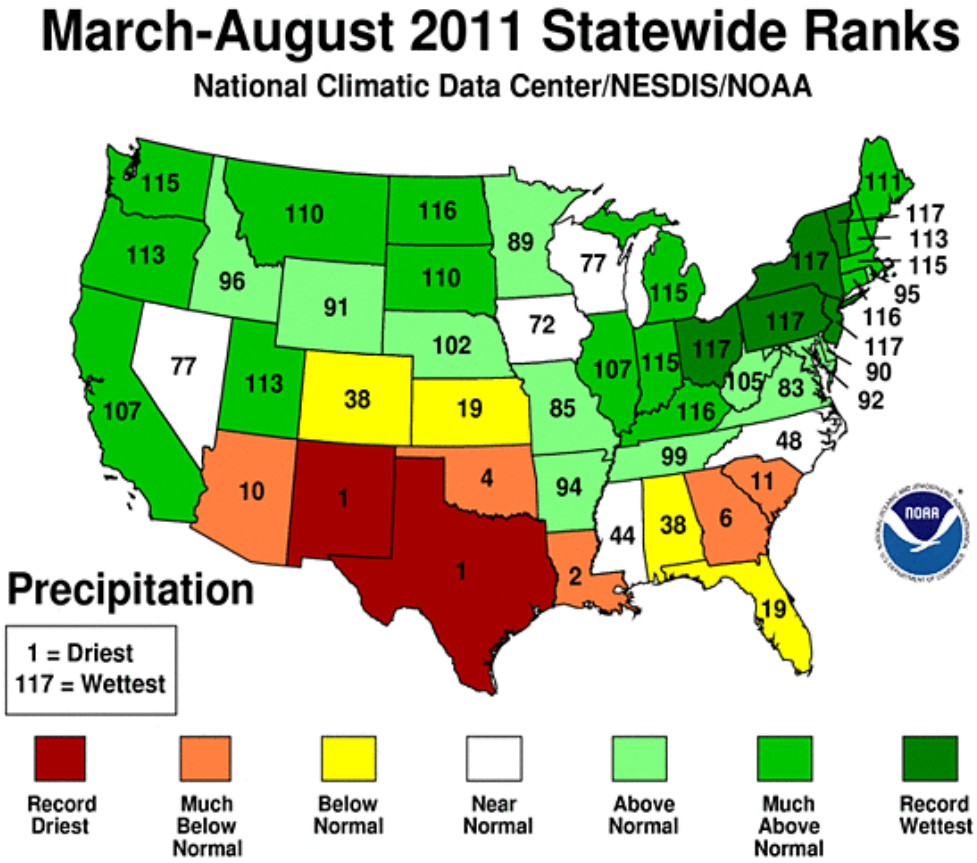
Jan., Feb. 'Frozen' Pattern gives Extremes



Warm Atlantic, Cold NE, strong coastal storms - Boston record snow

2011 Floods: VT and NY

- **Record spring flood: Lake Champlain**
- **Record flood with tropical storm Irene**

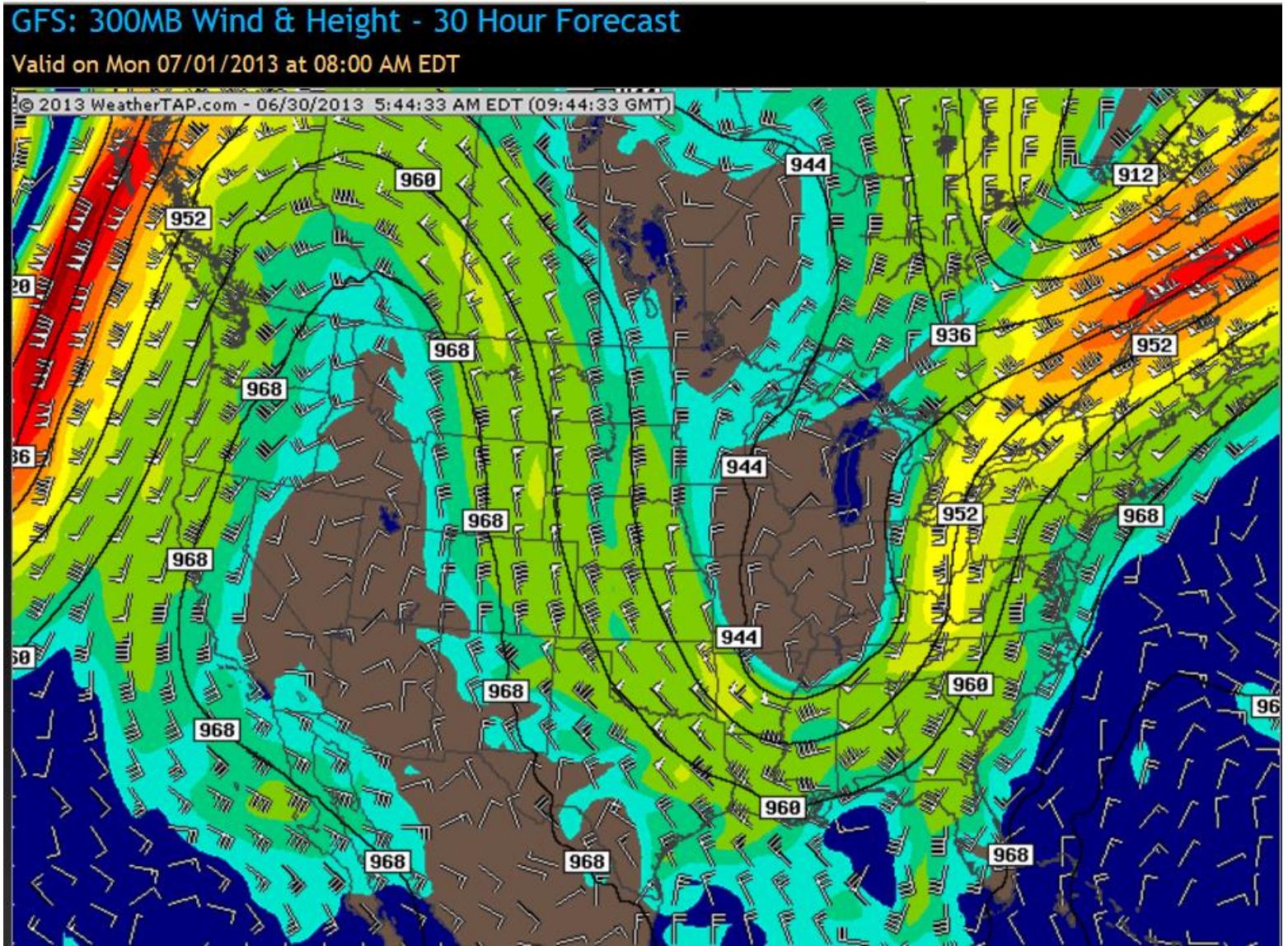


March-August, 2011

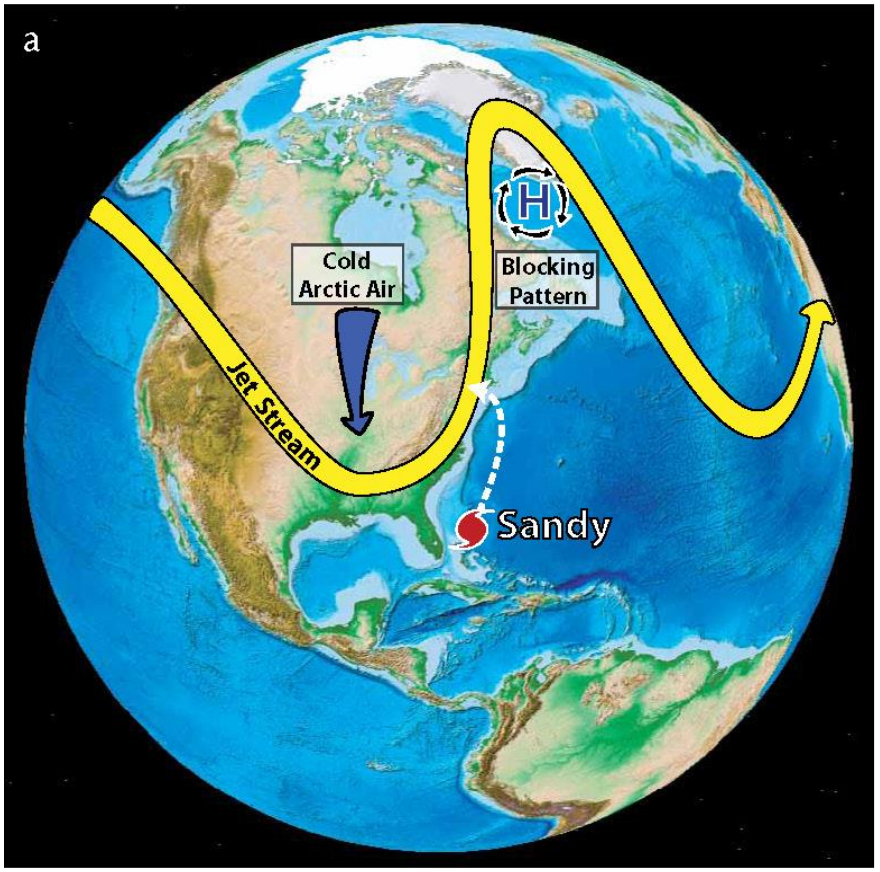
- **Record wet : OH to VT**
- **Record drought: TX & NM**
- **'Quasi-stationary' pattern**

Jet Stream Patterns Slowing Down and Amplifying, Giving More Extreme Weather

(Francis and Vavrus, 2012)



Blocking Pattern - Unique track



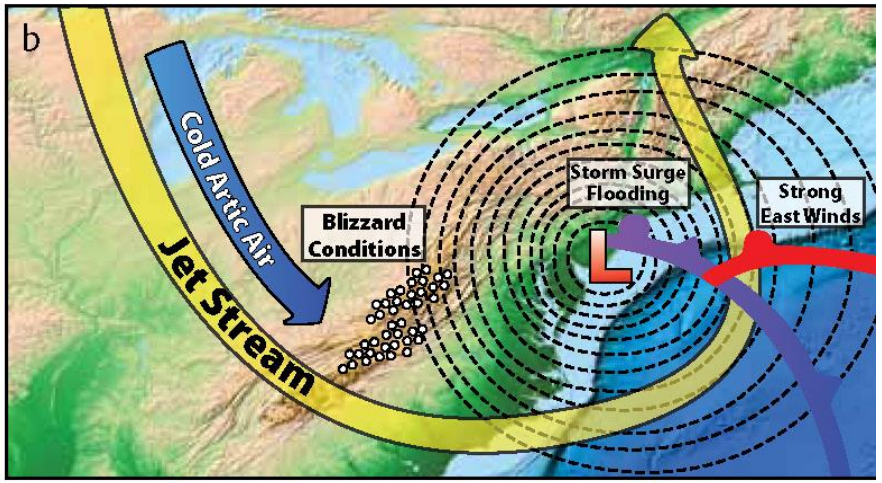


Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical and extra-tropical storm systems, the hybrid Superstorm Sandy made landfall in New Jersey and New York, bringing strong winds, storm surge, and flooding to areas near the coast and blizzard conditions to Appalachia.

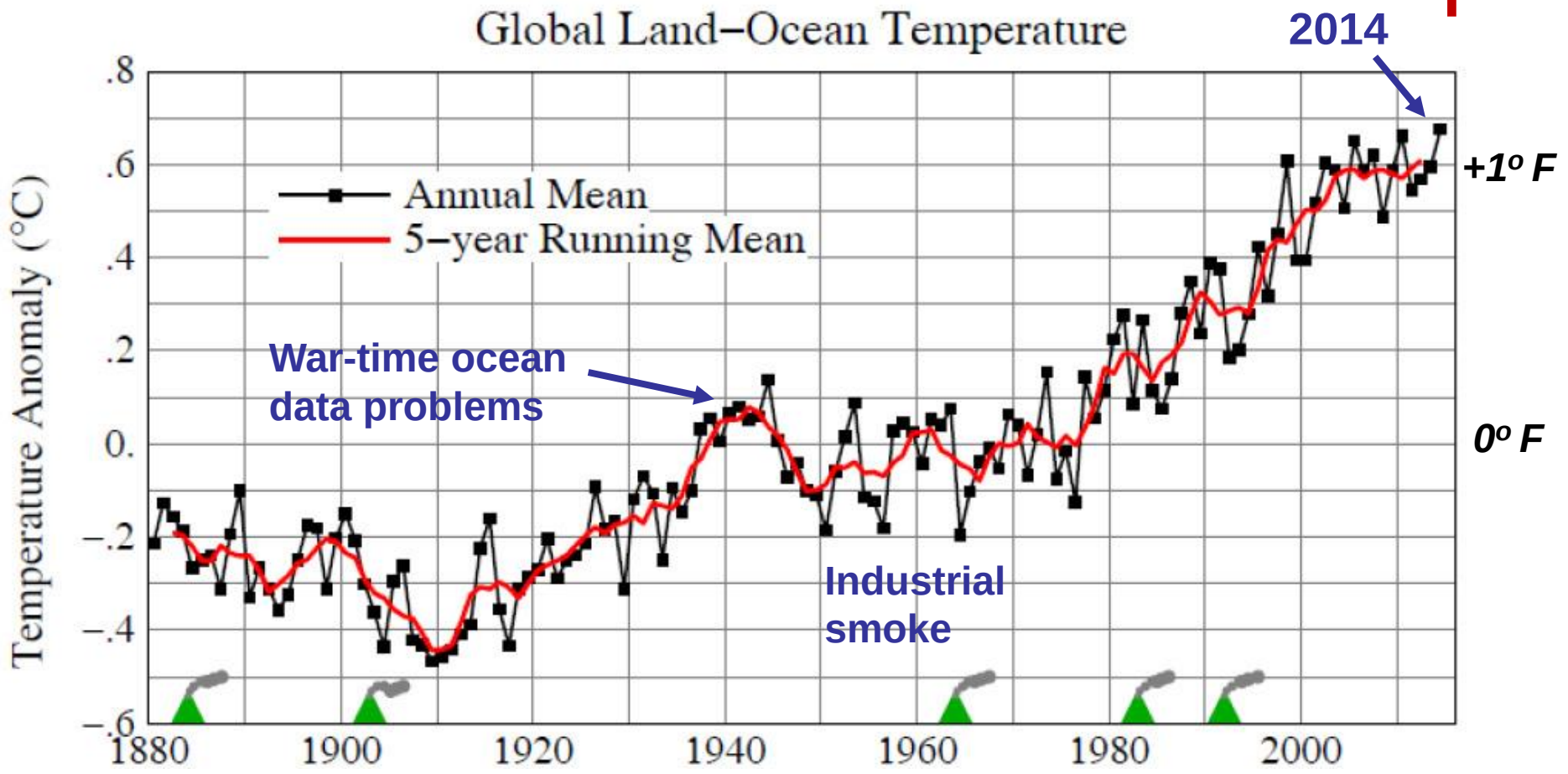
- **High amplitude jet-stream + blocking pattern + strong cyclone + hurricane winds + full moon high tide = record storm surge = disaster**

(Oct 29, 2012) *[Greene et al., Oceanography, 2013]*

Global Climate Change

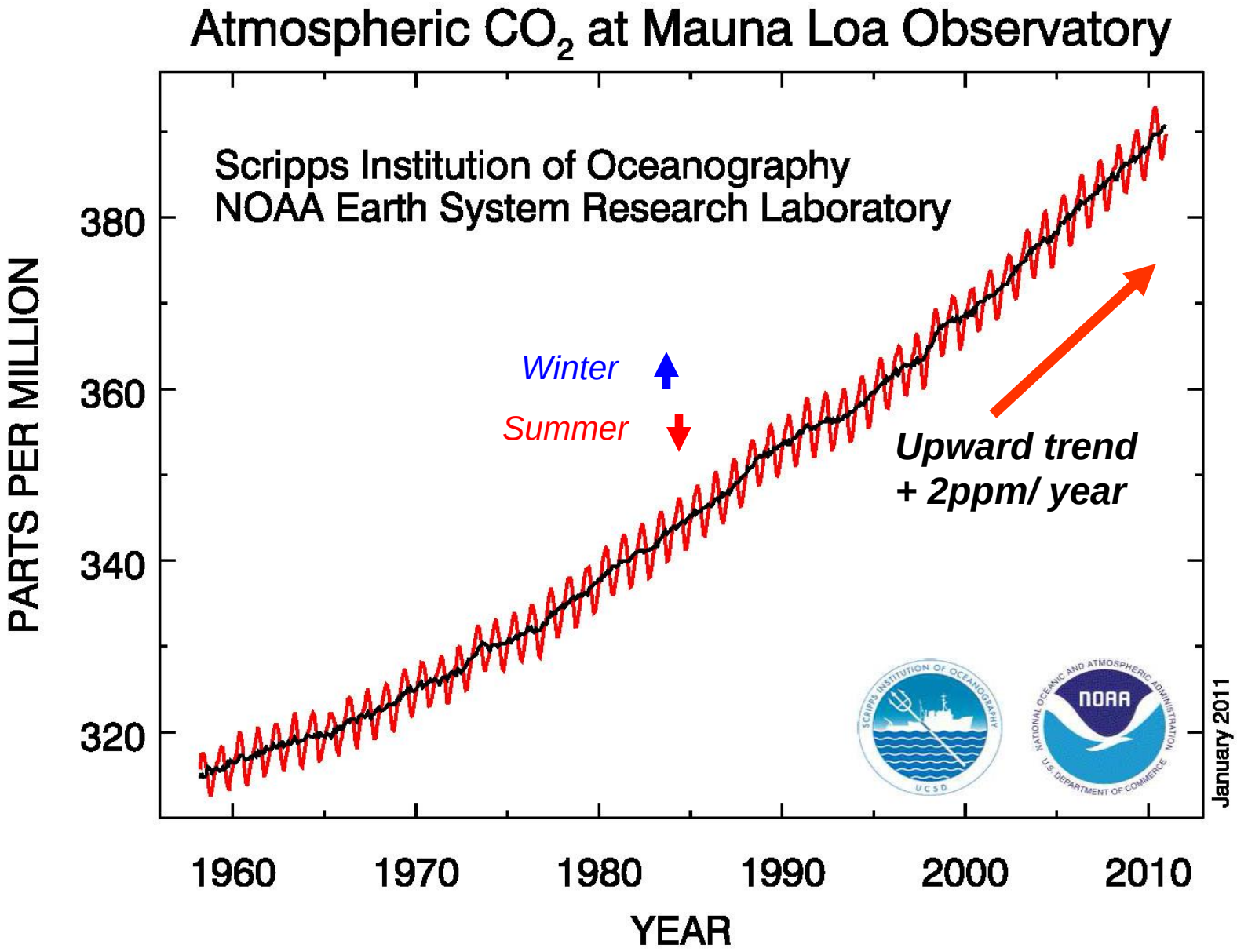
- **One of the many great challenges for the 21st century - present path is unsustainable**
- **Known about it for 35 years:**
  - *First National Academy of Science Report in 1979*
- **Earth science conflicts with political values (and vested interests in fossil fuel economy)**
- **It is a global issue and local issue**

Global Temperature Rise 1880 – Present

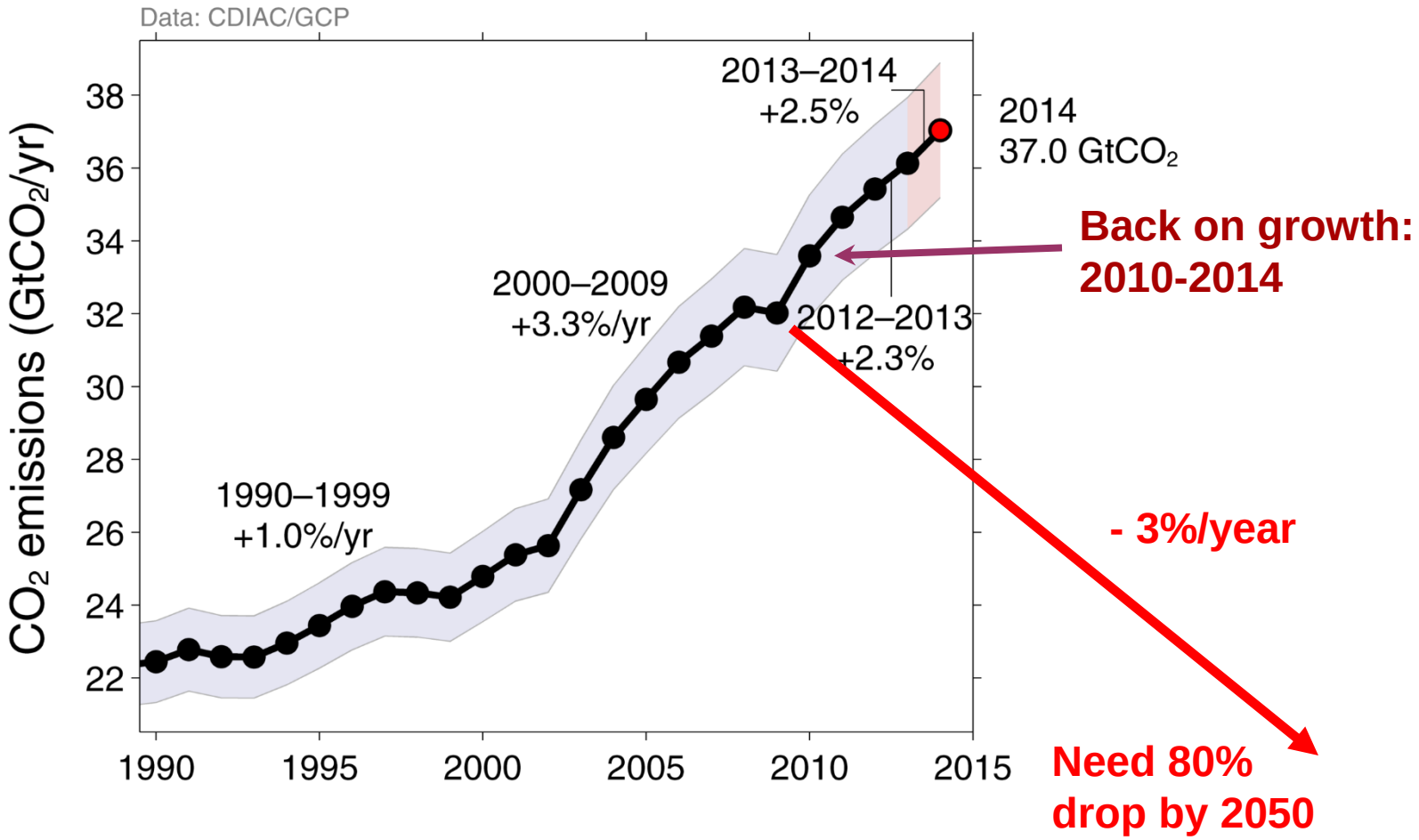


NASA-GISS, 2015

Carbon Dioxide Is Increasing



Growth of CO_2 Emissions Continues

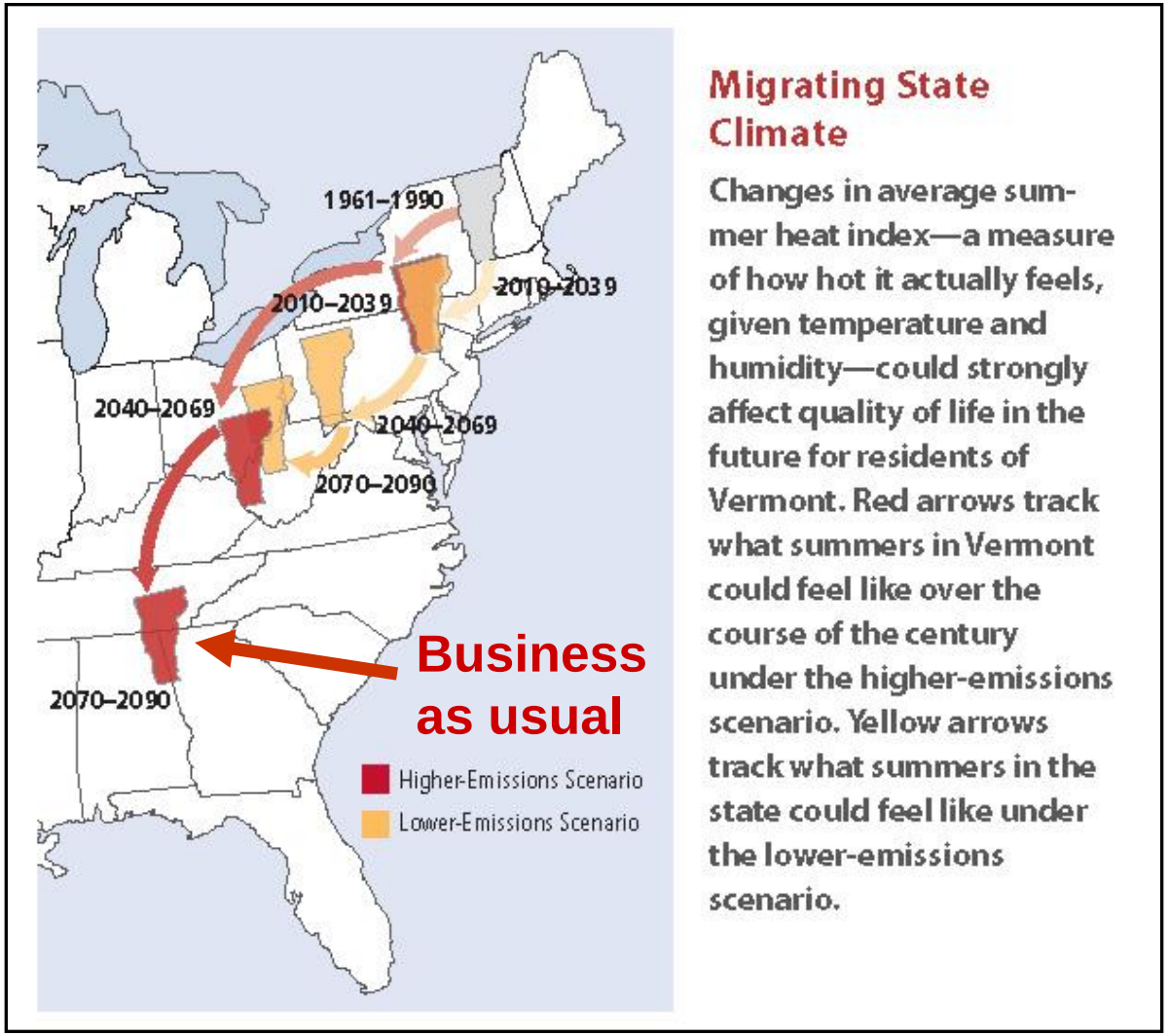


2014 emissions flat – shift from coal in China

Vermont's Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US



NECIA, 2007

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**
    - **<u>Need to leave 1/3 oil; 1/2 gas; 4/5 coal in ground</u>**

What Lies Ahead?

- Humanity's impact is now global
- Climate extremes increasing
- Environmental damage that will transform or destroy ecosystems

- Dumping waste streams into atmosphere, streams, lakes and oceans is unsustainable – long term costs likely to exceed $1000 trillion

- Will need fossil carbon pollution tax to incentivize change and pay for the long-term costs

Change of Attitude Needed?

- **Do we just exploit the Earth's wealth**
  - **For greater 'economic growth'**
  - **For a wealthy few**
  - **What will be left for our children?**
  - **What happens to the ecosystems we depend on?**
  - **How do we pay for the damage we are doing?**
- **Moral Issue**
  - **We need to care for and co-operate with the Earth**
  - **Shift in understanding and mind-set needed**

2015 is Transition Year

- **Climate meeting in Paris in November**
  - **Nations making commitments**
  - **33 countries have submitted plans so far**
- **Pope Francis will issue the first Papal Encyclical on the environment, climate change and our responsibilities to the Earth**
  - **Will shift the position of the Catholic church**
  - **Protestant traditions will follow his lead**
  - **Shift from short-term profit as primary motive**
- ***New values that respect the Earth***

Fitting that Vermont takes steps to change direction

- **Fossil carbon pollution tax will**
  - **Signal the economic system that CO_2 has a price (downstream of order $1000 trillion)**
  - **Build funds for adaptation costs, building new infrastructure, rebuilding after the next 'Irene' etc**
- **Other New England states will likely follow (and west coast)**

Discussion

- **More at http://alanbetts.com**
- **Papers at** **http://alanbetts.com/research**
  - ***Vermont Climate Change Indicators***
  - ***Seasonal Climate Transitions in New England***
  - ***Climate Change in Vermont. ANR Report***
  - ***Herald/Times-Argus columns since 2008***
  - ***Public talks***

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

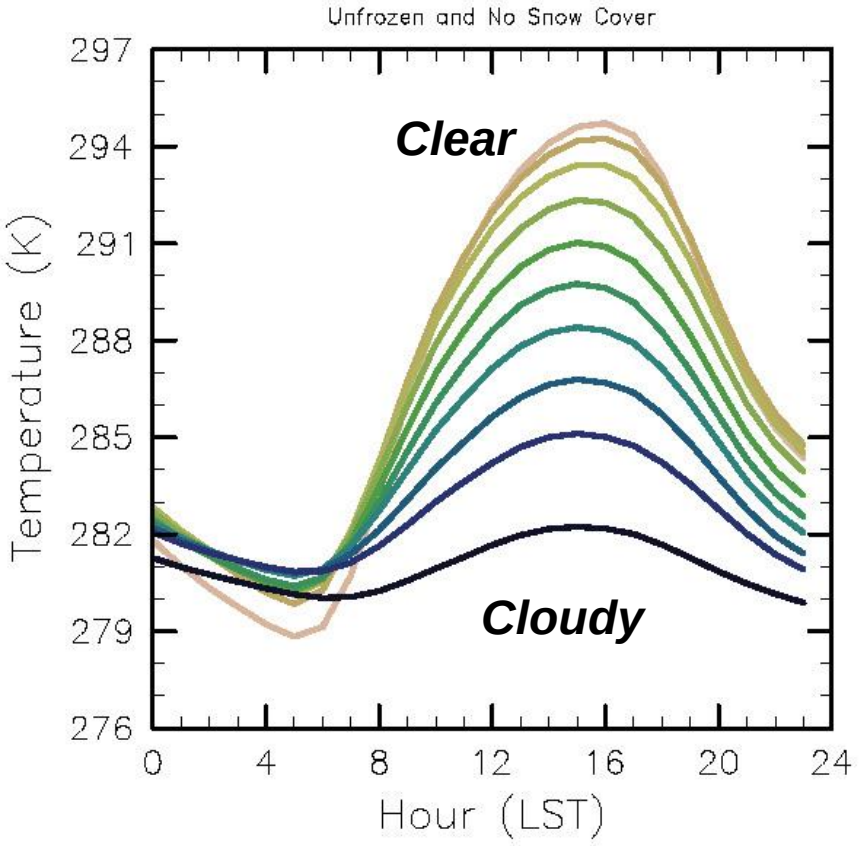
  - careful forest management

Agricultural planning

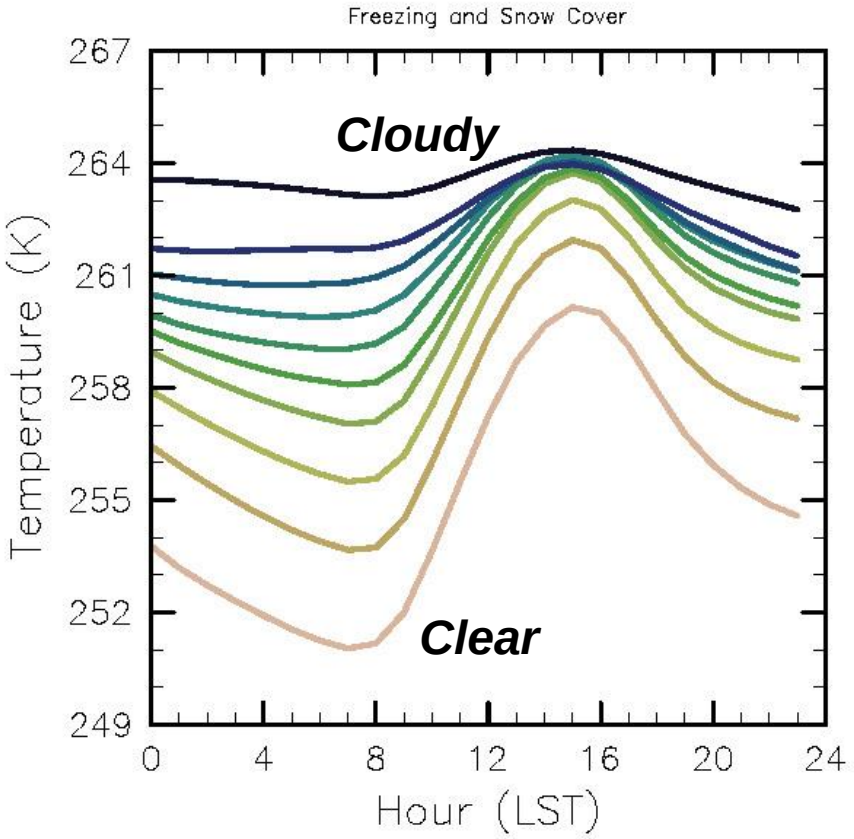
- **Frozen ground and lakes: -7d/decade**
- **Earlier melt, earlier spring leaf-out: - 3d/decade**
- **Frost-free growing season: +4d/decade**
  - **Greenhouse, row cover seasonal extenders**
- **Winter extremes increasing with variable snow**
  - **T_{min} extremes increasing +2-3ºF/decade**
- **More winter precipitation**
  - **Future decades: wetter snow; rain/snow mix**
- **Variable summer precipitation**
  - **Heavier rain-rates, longer storms, longer droughts**
  - **Maximize soil water infiltration; water storage**
  - **Manage to reduce soil erosion**
  - **Design infrastructure to handle larger runoff**
  - **Increase soil organic matter**

Warm & Cold Climates: T><0°C

T_m >0°C: no snow: 150,000 days



T_m <0°C: snow: 75,000 days



- **Warm >0°C: Clouds reflect sunlight**
- **Cold <0°C: Clouds are greenhouse & snow reflects sun**