Global and Local Climate Change

- Complex Challenge

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BREE
Basin Resilience to Extreme Events
in the Lake Champlain Basin

Outline

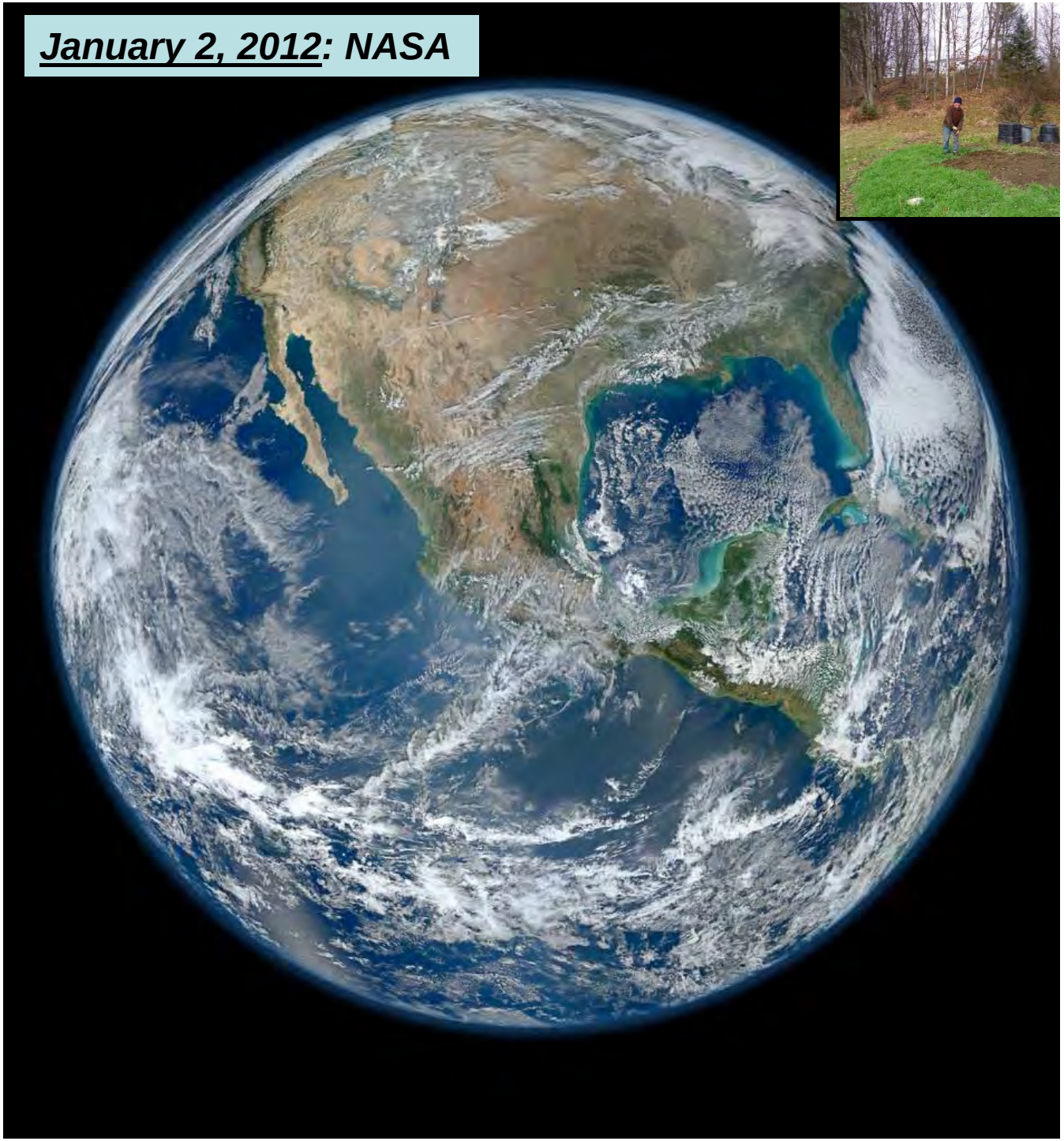
- **Science of climate change**
  - **What is driving global climate change?**
  - **What is happening to Vermont?**
  - **Why is extreme weather increasing?**

    Discussion
- **The transition we face**
  - **Can we stabilize the climate?**
  - **Why is it difficult?**
  - **What are our responsibilities?**

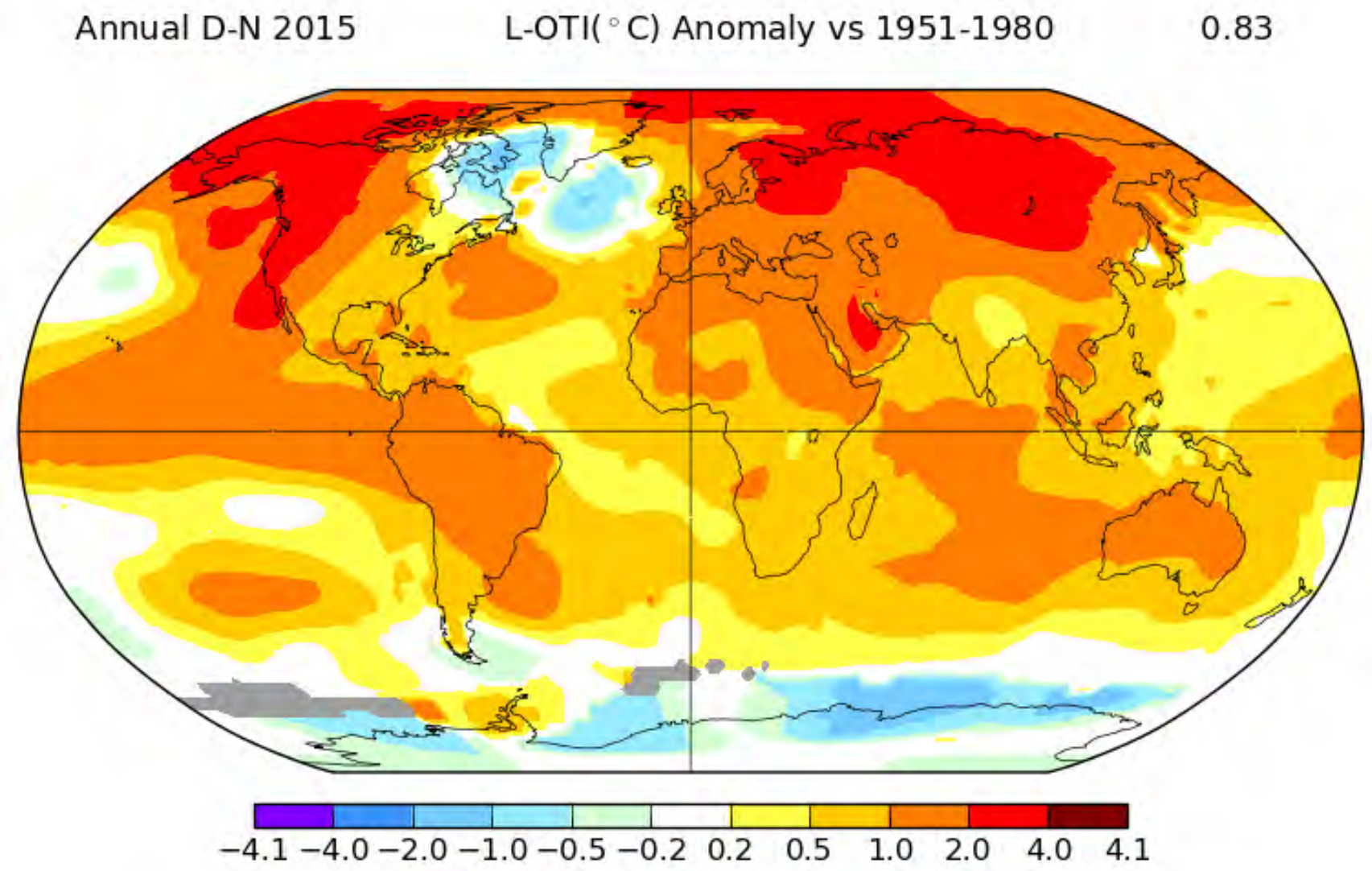
    Discussion

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**

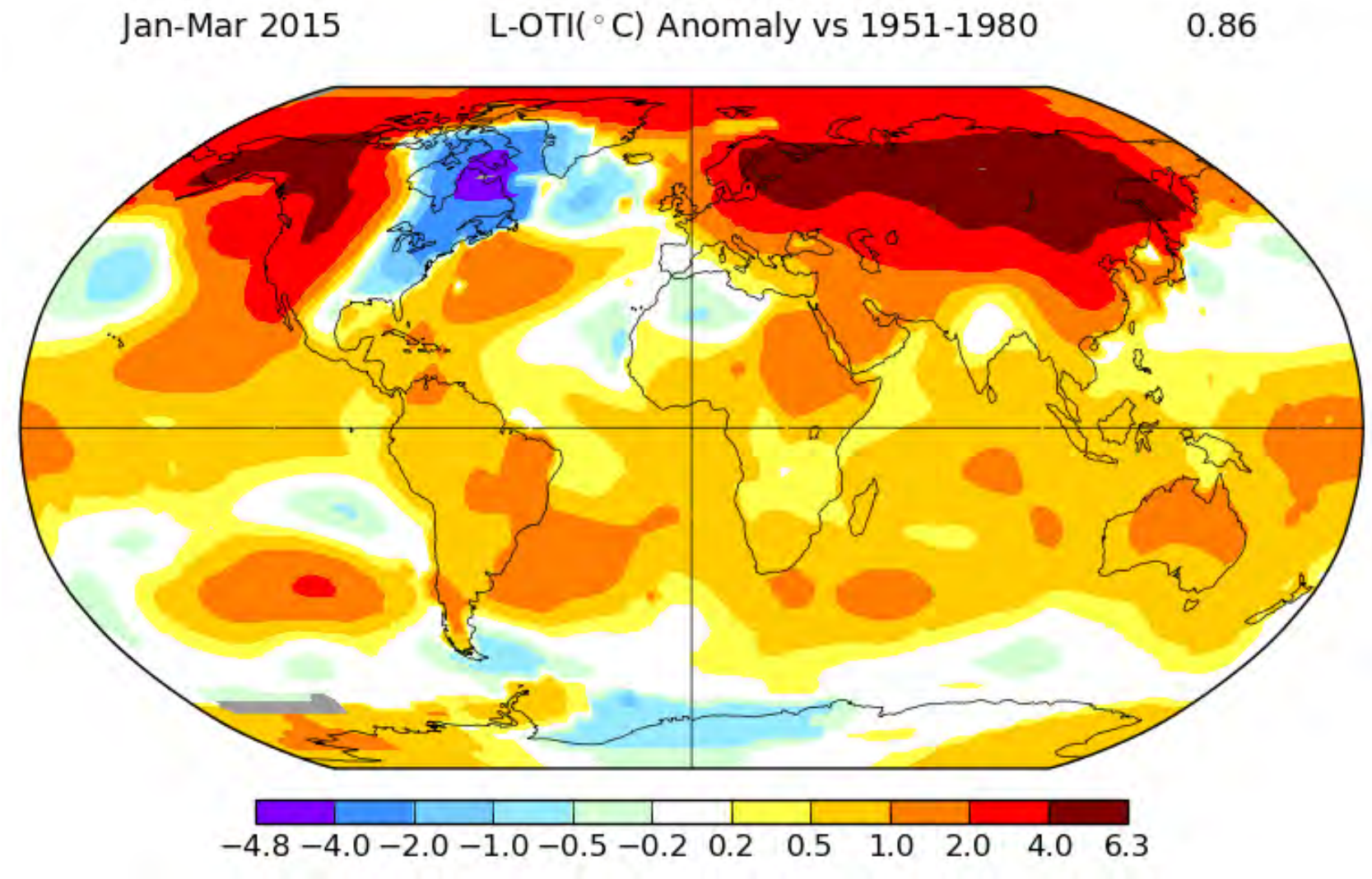


2015: Record Temperature
Note Northern Hemisphere!



Winter 2015 was extreme

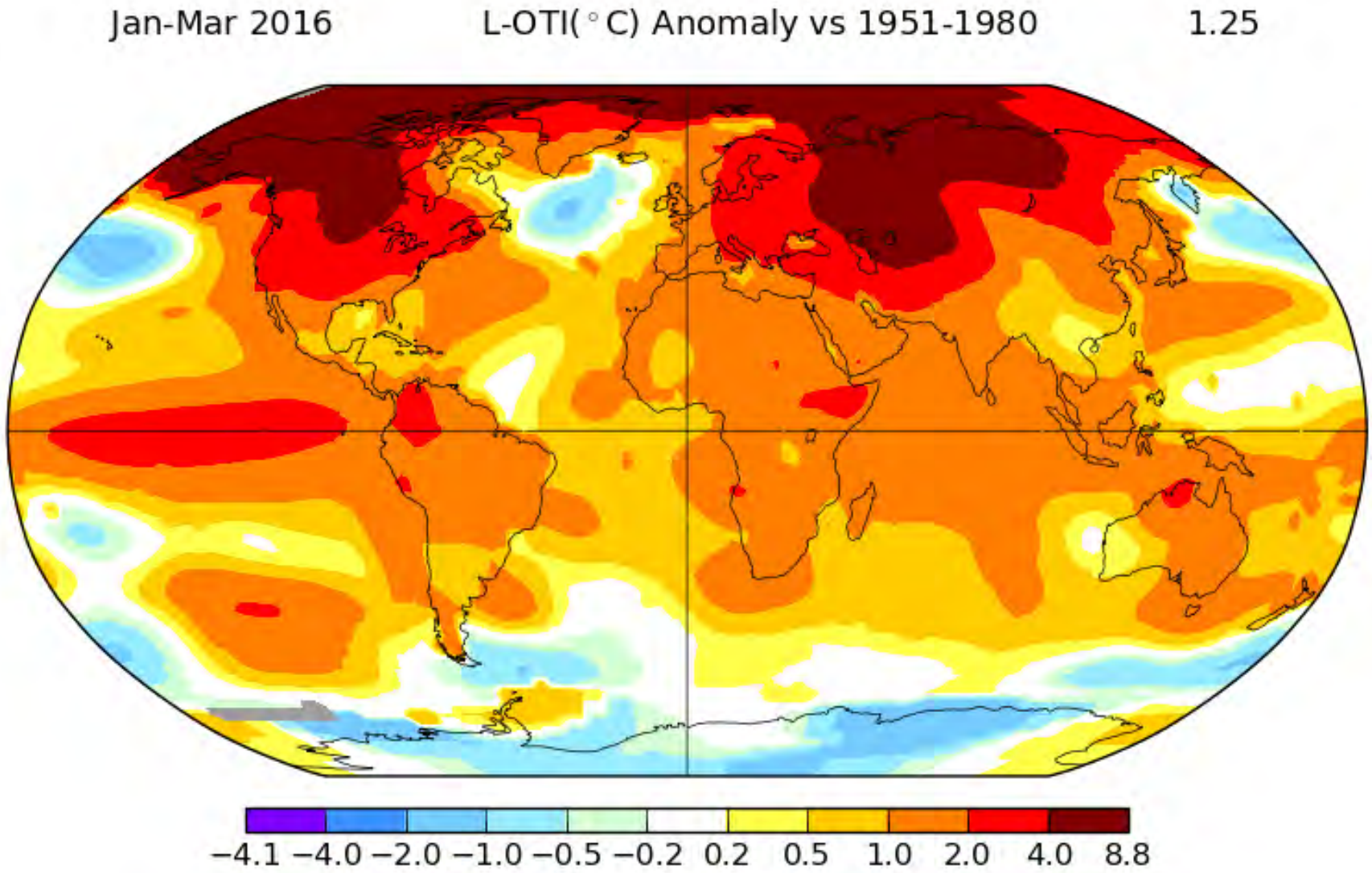
- Pattern stationary: Jan, Feb, Mar



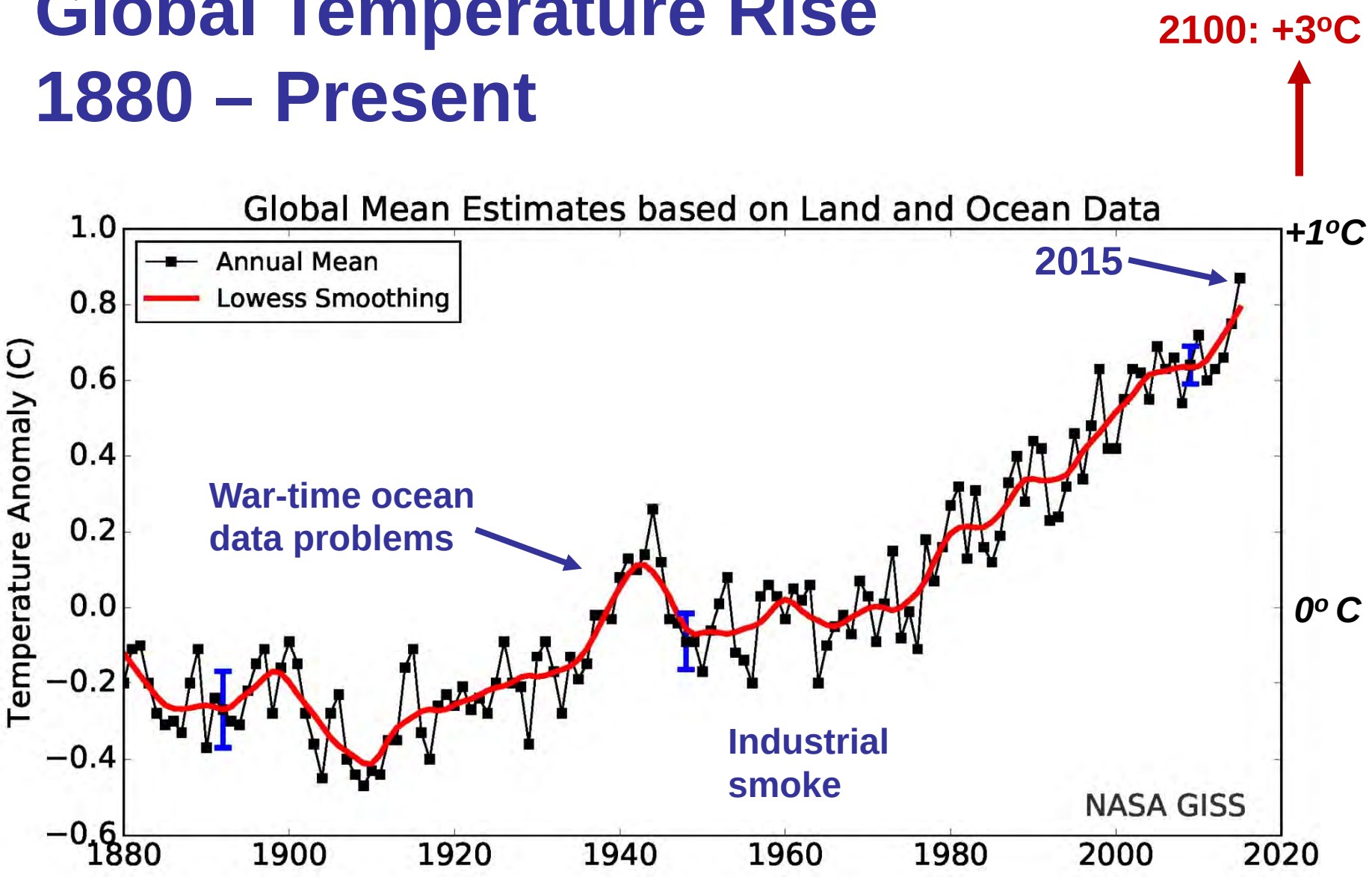
Warm Atlantic, Cold NE, strong coastal storms - Boston record snow

Winter 2016 again extreme

Pattern stationary for 3 months



Global Temperature Rise 1880 – Present



NASA-GISS, 2015

Why is Planet Warming?

- **Greenhouse gases are increasing from burning fossil fuels**
- **It isn't warming, just look at how cold it is today!**
- **The temperature of the earth has gone up and down for millions of years: just wait and it will go away**
- **This is just a conspiracy by climate scientists to increase their funding**
- **Global regulation and carbon taxes are an attack on our free-market values**
- **I don't believe in climate change**

(Why is Planet Warming?)

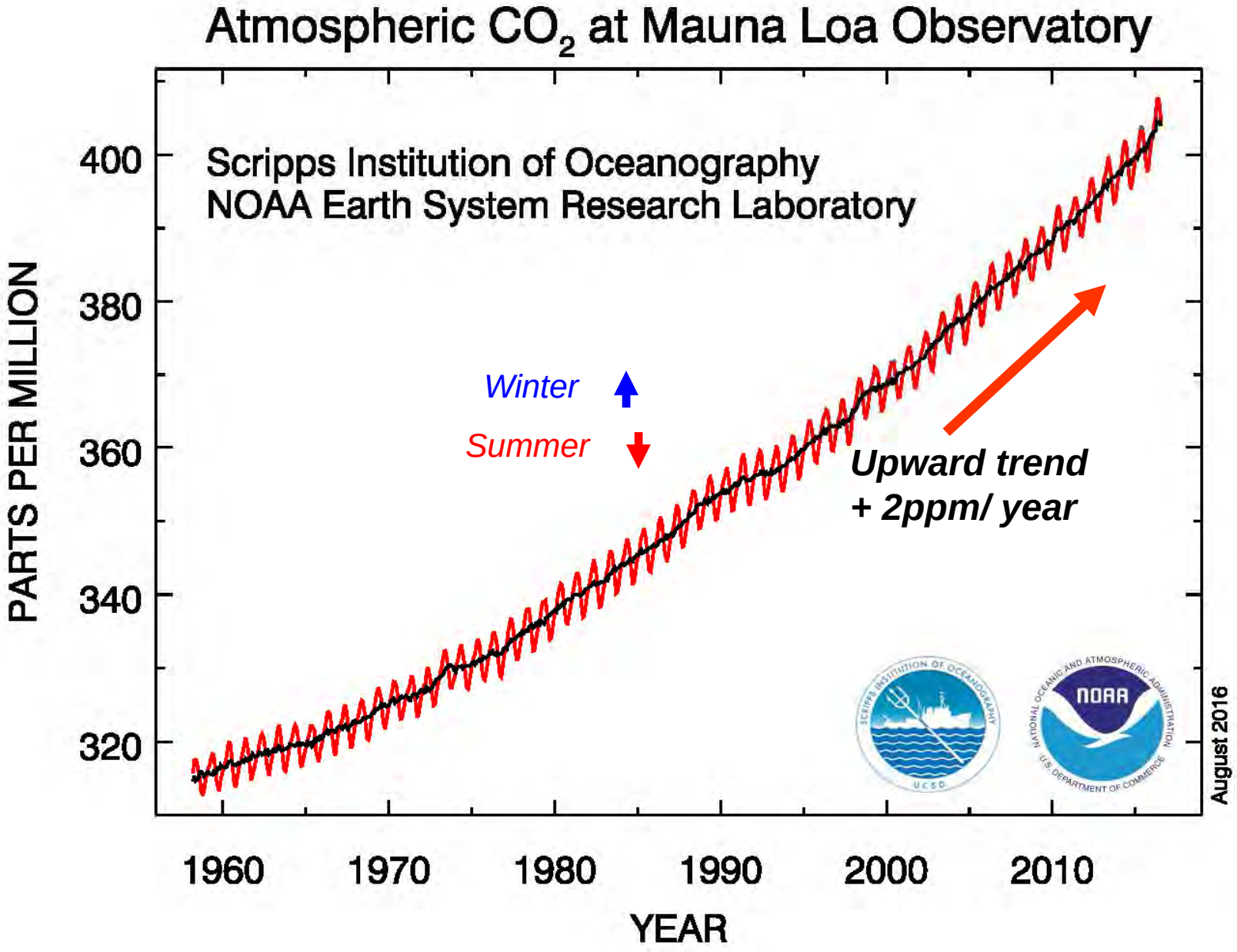
How does Earth keep its mean temperature at 15 C (60F) ?

- **The air is transparent to sunlight, which warms the Earth**
- ***Without an atmosphere the earth would cool to space so fast that we would freeze***
- **But some gases in the air trap the Earth's heat and keep the Earth from freezing**
- **We call them "greenhouse gases"**

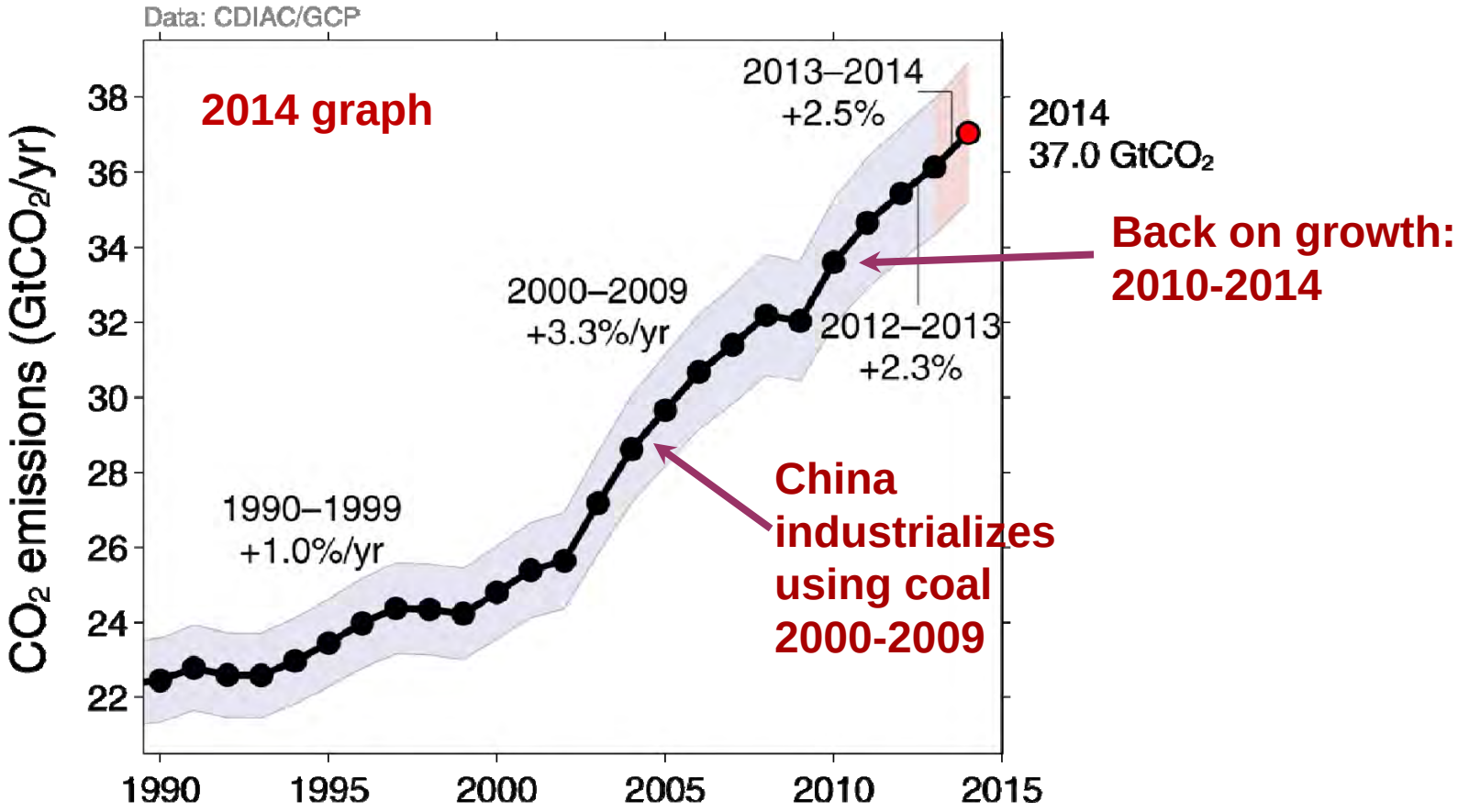
What are the greenhouse gases?

- **These "Greenhouse gases" are water vapor, carbon dioxide, ozone, methane (H_2O, CO_2, O_3, CH_4, CFCs…)**
- **CO_2 is rising fast: by itself only a small effect**
- **But water cycle processes amplify**
  - **More evaporation: water vapor, a strong greenhouse gas: triples warming of CO_2**
  - **Reflective snow and ice melt: doubles warming in Arctic and in winter**

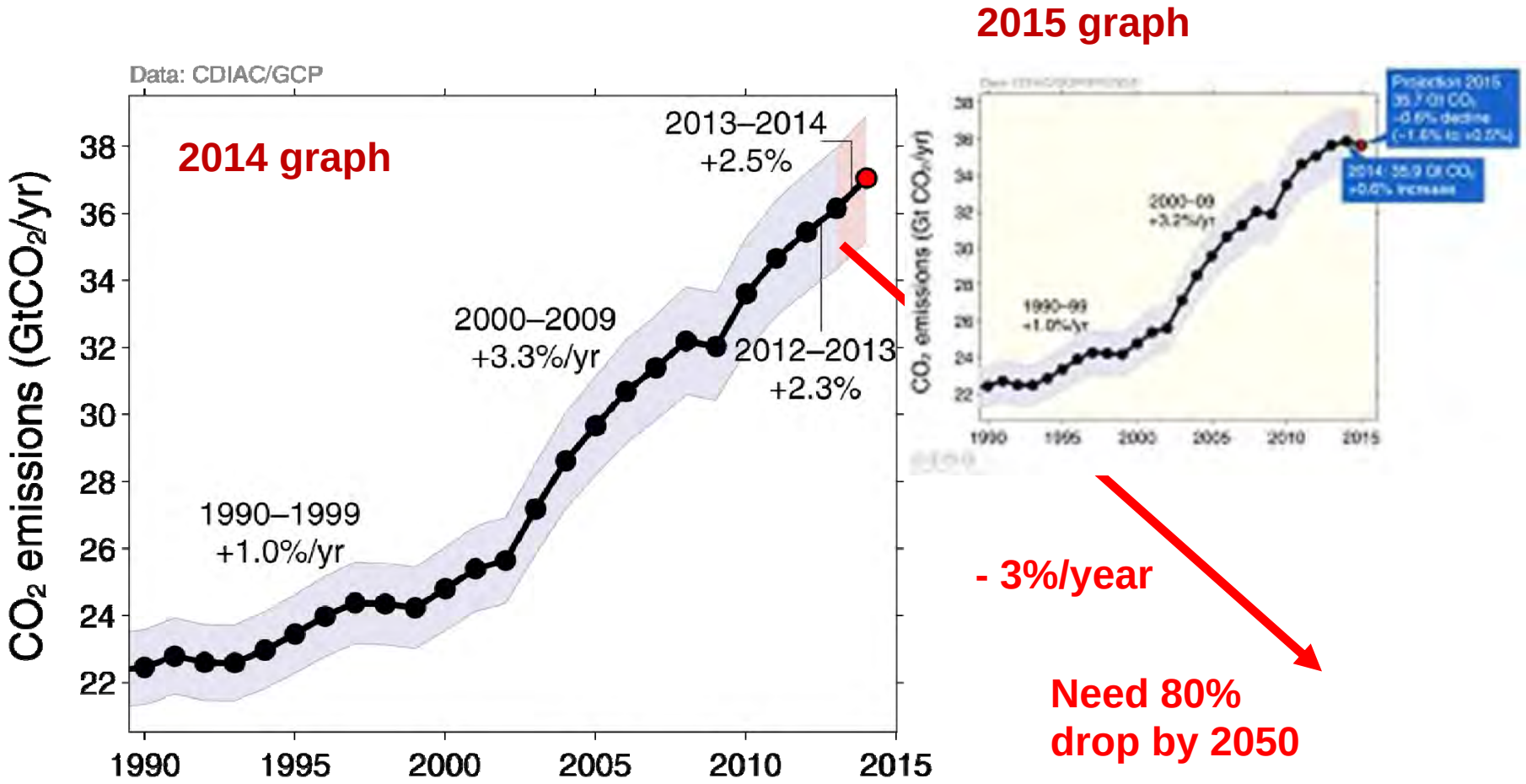
Carbon Dioxide Is Increasing



Growth of CO_2 Emissions



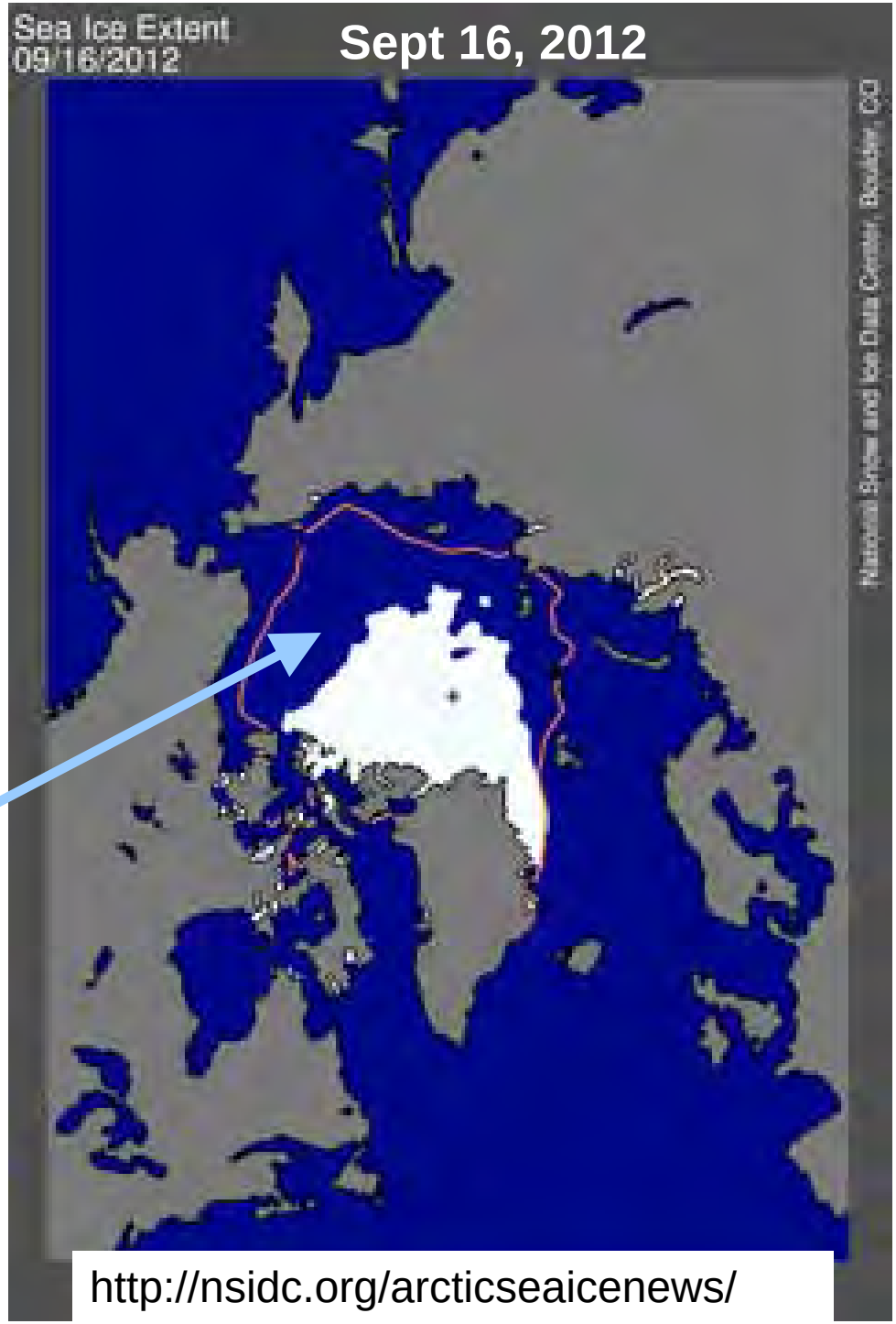
Growth of CO_2 Emissions Peaked



2014-2015 emissions PEAKED – shift from coal in China

- **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***



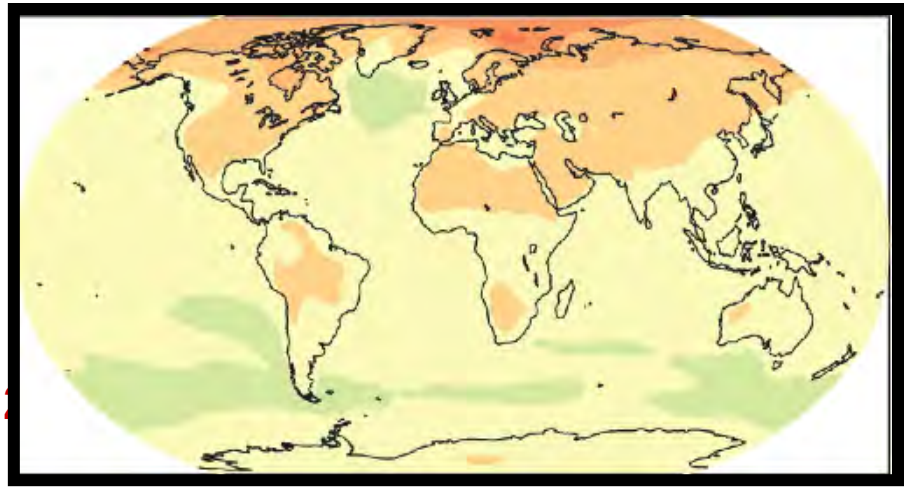
- **2016 is similar**
- **Open water in Oct. Nov. gives warmer Fall in Northeast**

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

Predicted Change in Temperature

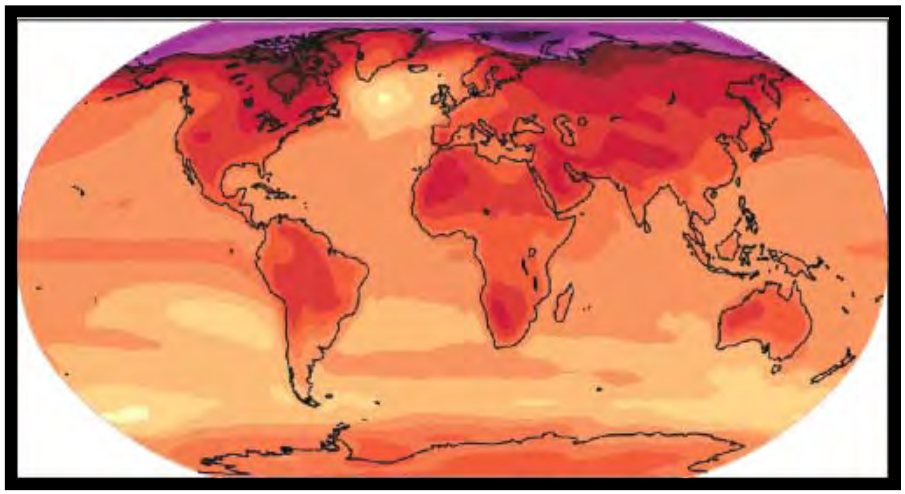
2020-2029 and 2090-2099, relative to 1980-1999 (ºC)

“Committed”



(We did nothing for the last 20 years)

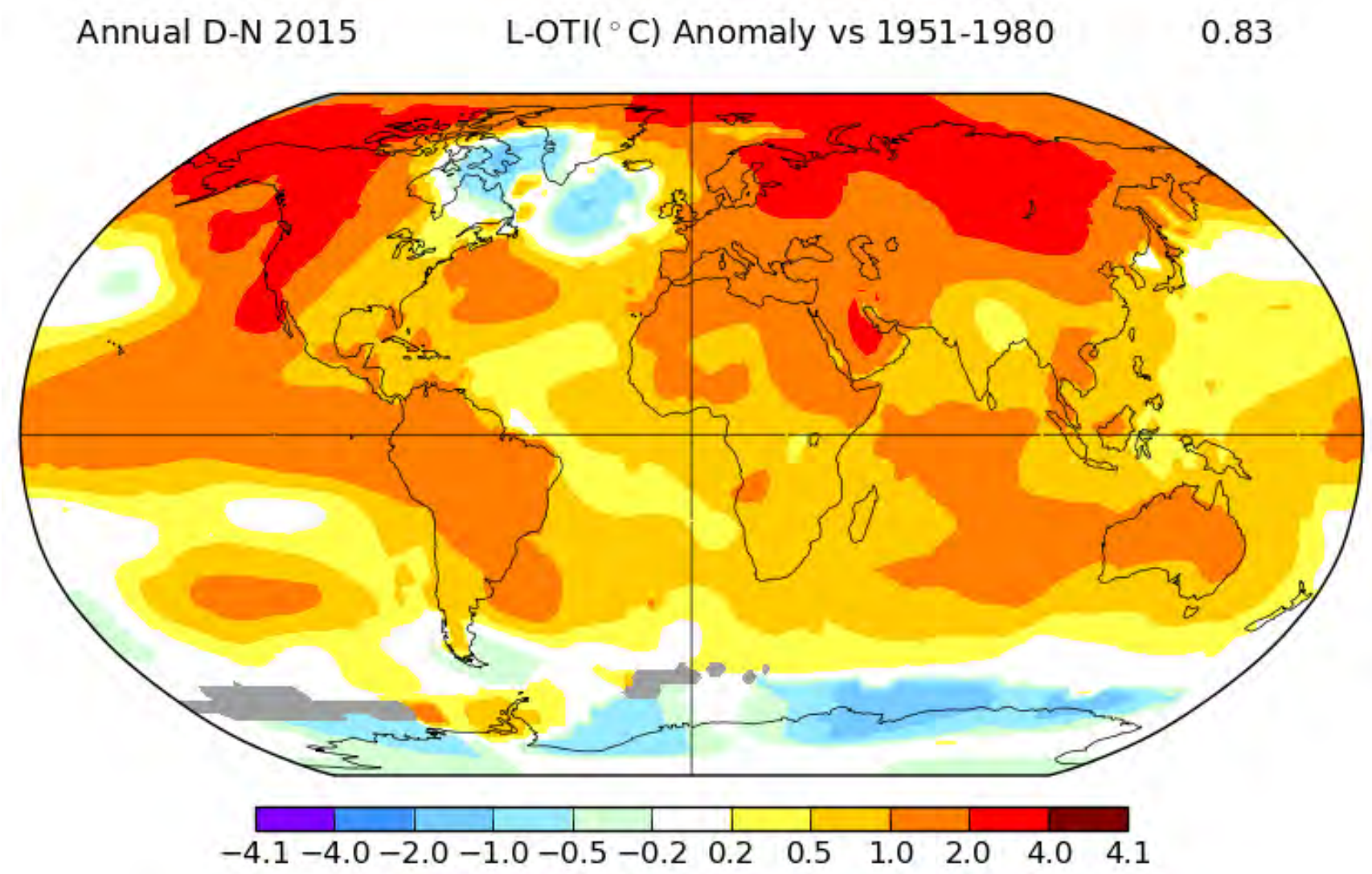
Still up to us!



(We could halve this if we act now)

[ºC]

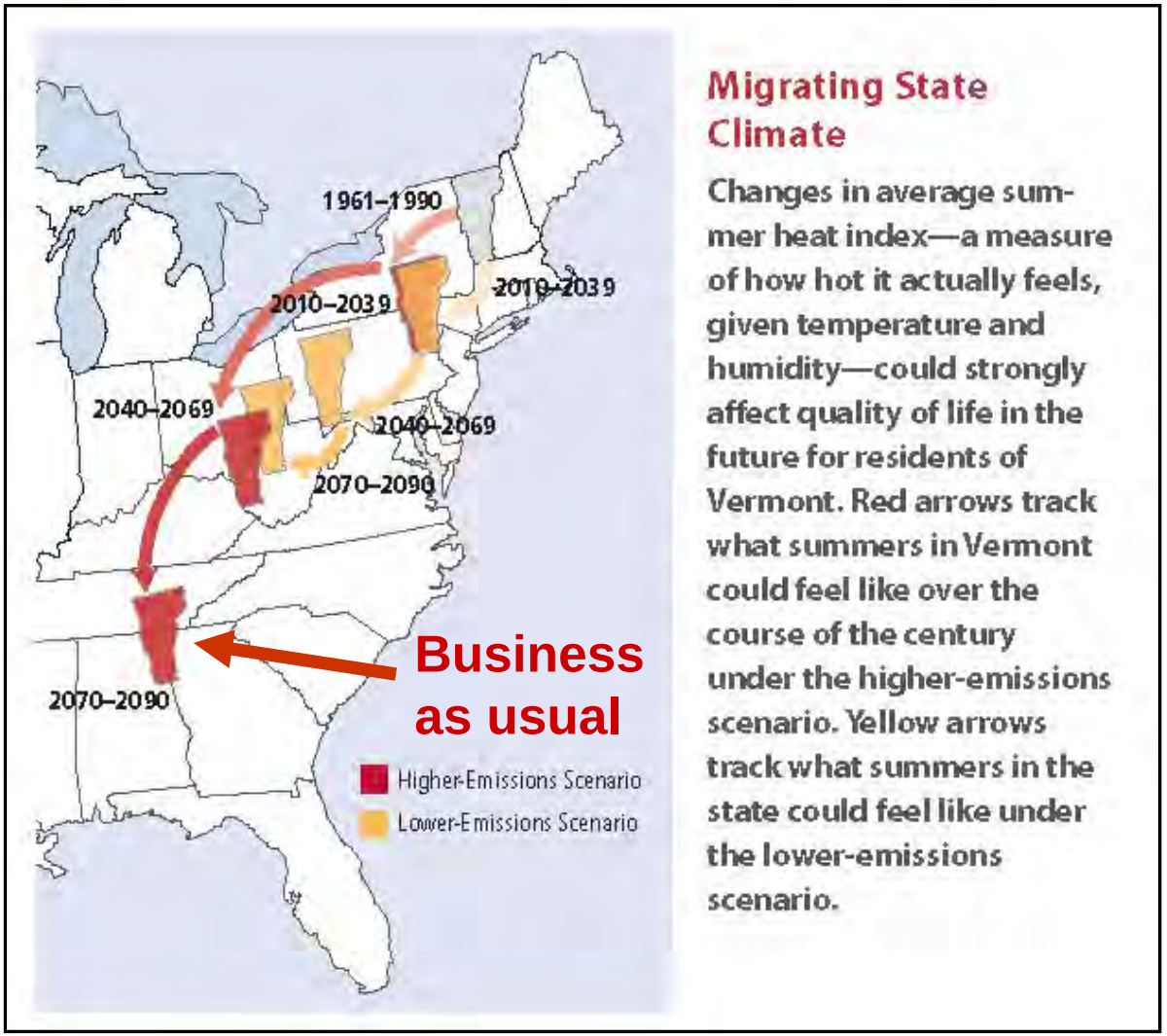
2015: Record Temperature



Vermont's Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US

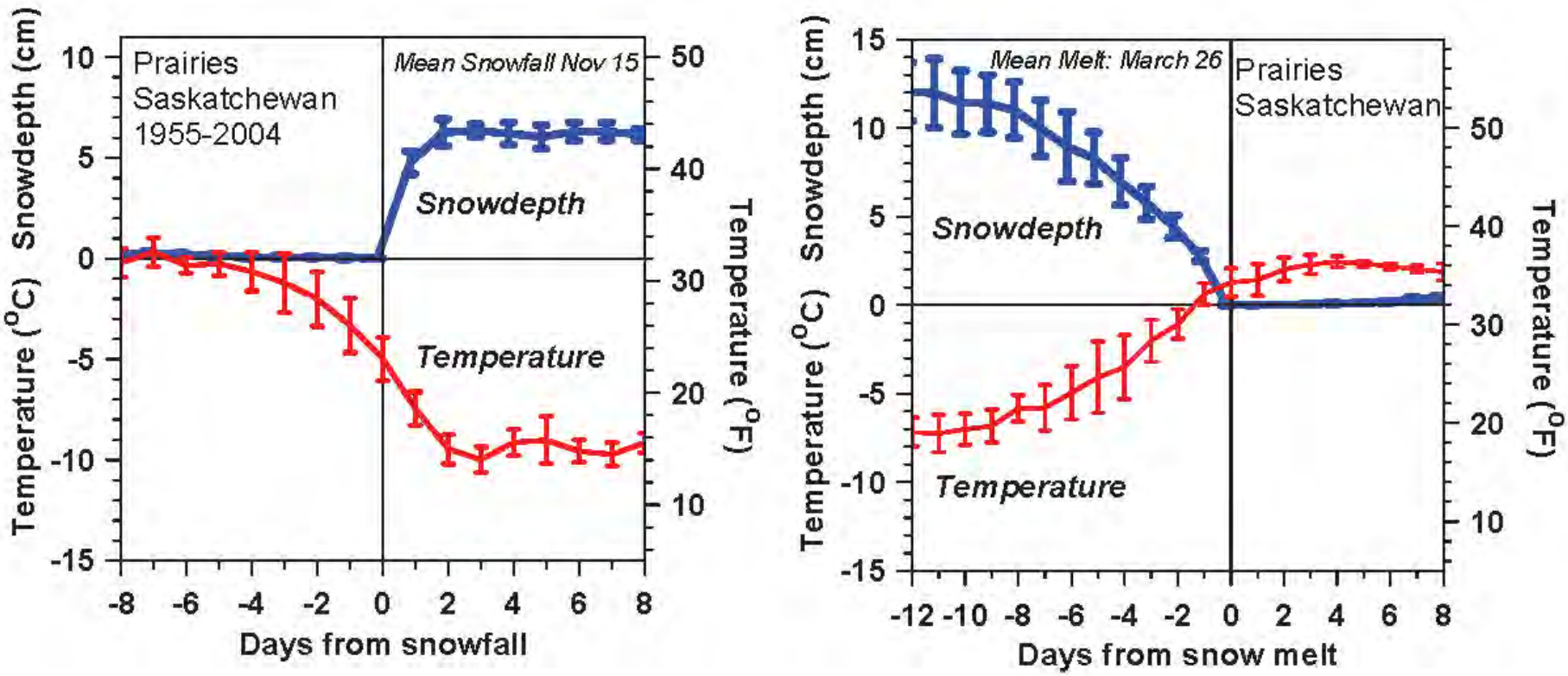


NECIA, 2007

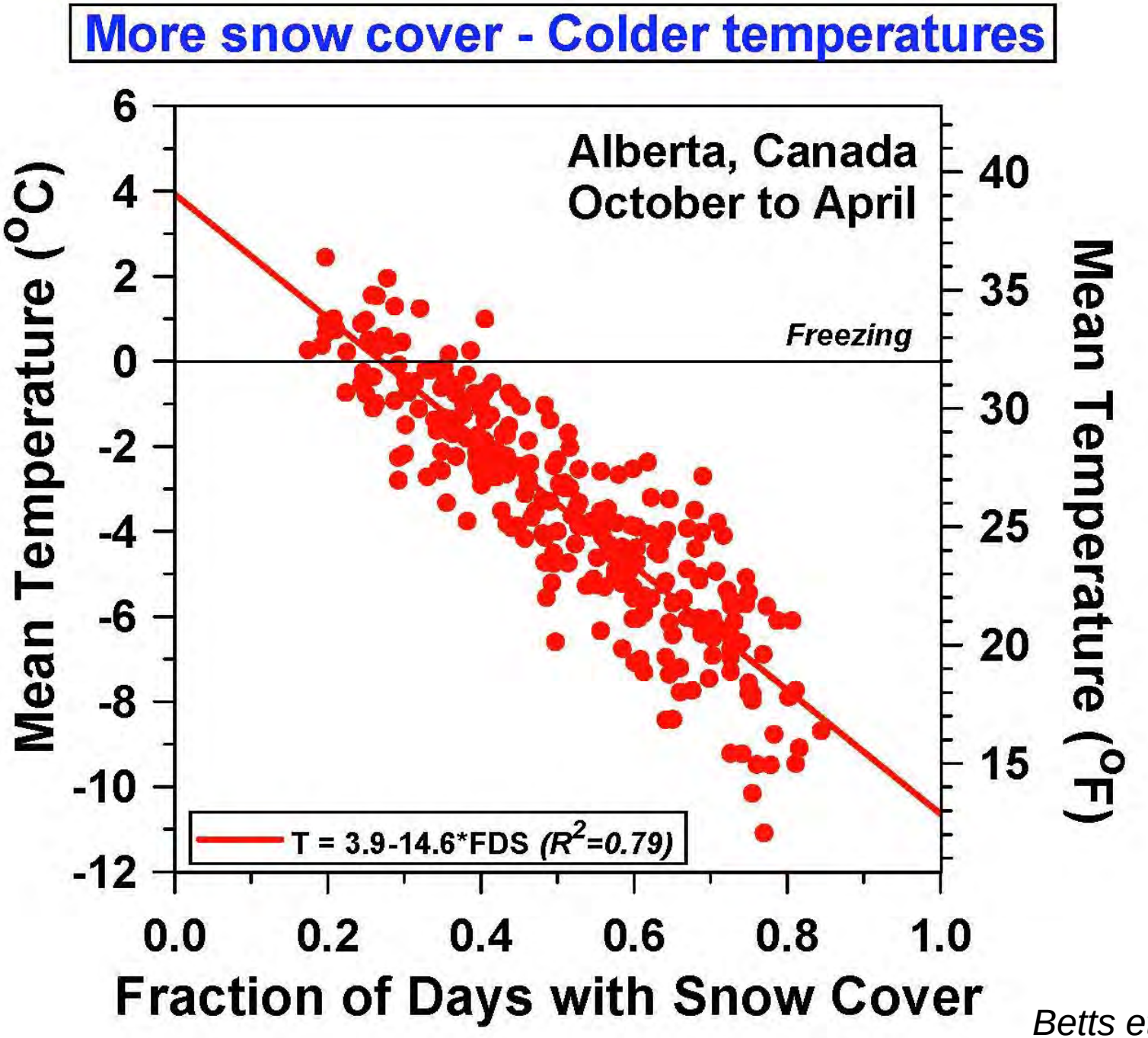
Vermont Winter 2015, 2016

- **Snow reflects sunlight, except where trees shadow**
- **Cold; little evaporation, clear sky; earth cools to space**
- ***2014-15 snowy winter: stays colder***
- ***2015-16 warm winter, little snow: 6C (10F) warmer***

Snowfall and Snowmelt

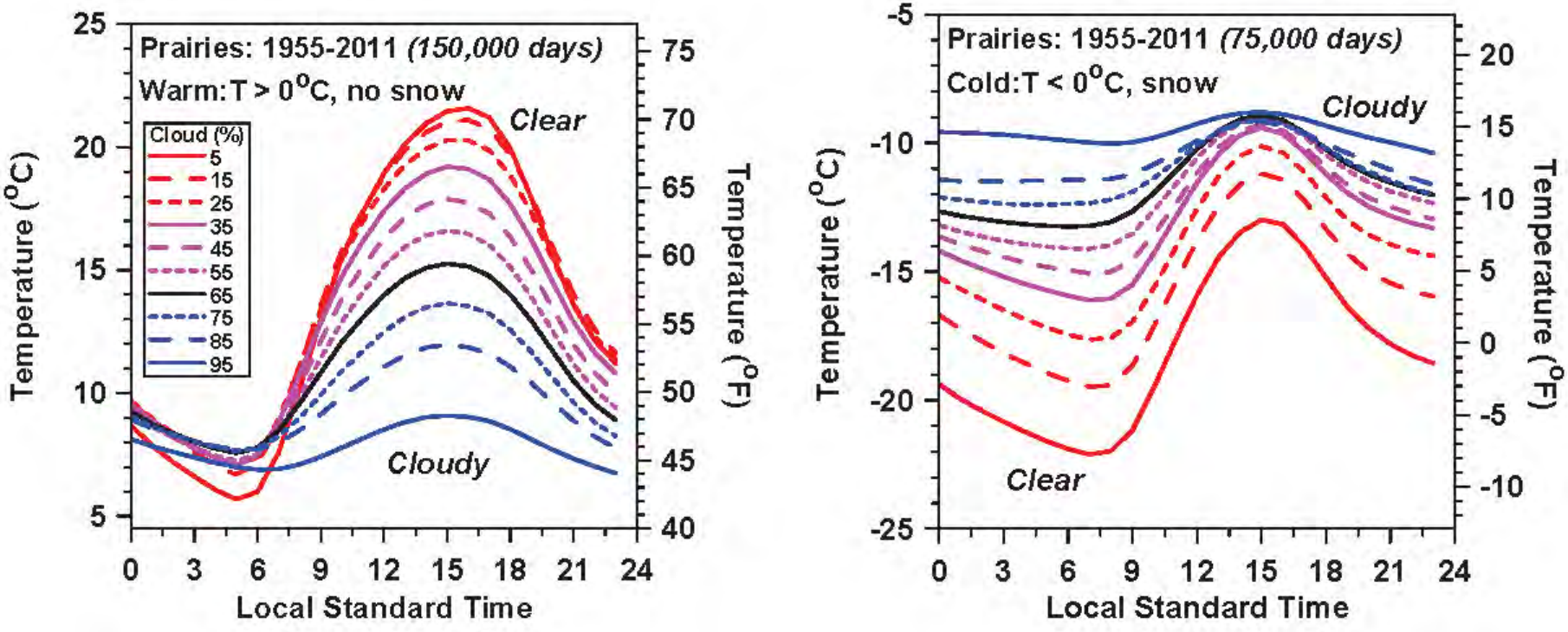


- **Temperature falls 18F (10C) with first snowfall**
- **Reverse change with snowmelt**
- ***Fast transitions in 'local climate'***
  - ***Snow reflects sunlight***
  - ***Reduces evaporation and water vapor greenhouse***



Betts et al. 2014

Clouds and Climate



- ***Above freezing:* Clouds reflect sunlight**
  - ***Less cloud, much warmer in afternoon***
- ***Below freezing:* Clouds are greenhouse (snow reflects sun)**
  - ***Less cloud, temperatures fall at night, very cold at sunrise***

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**

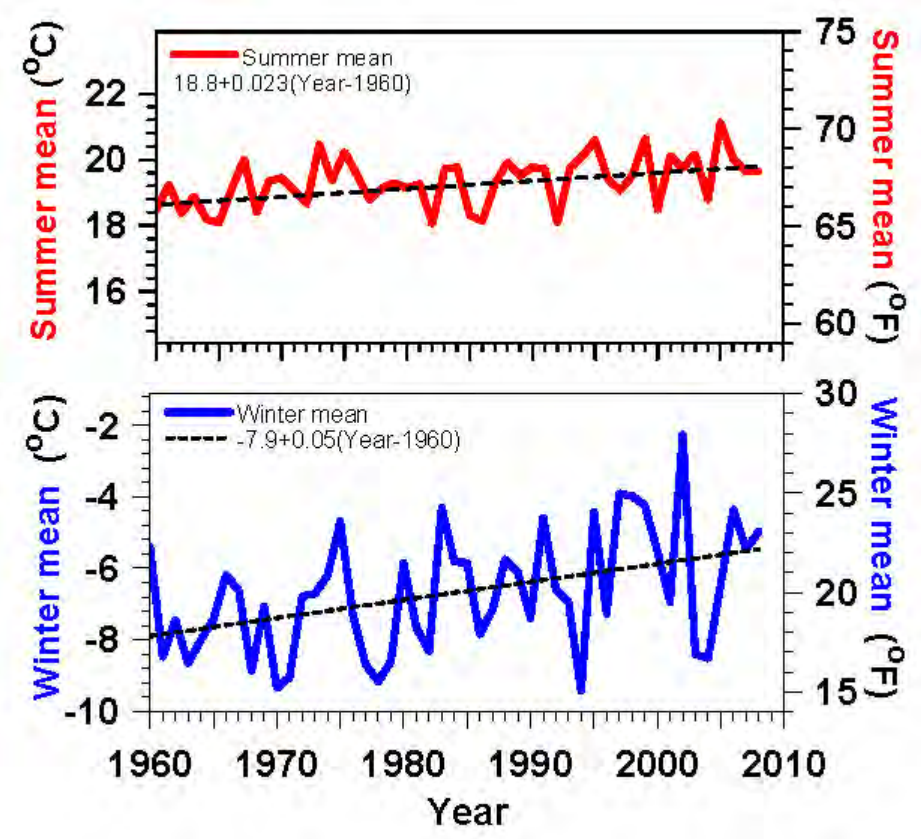
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**

(Betts, 2011)

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

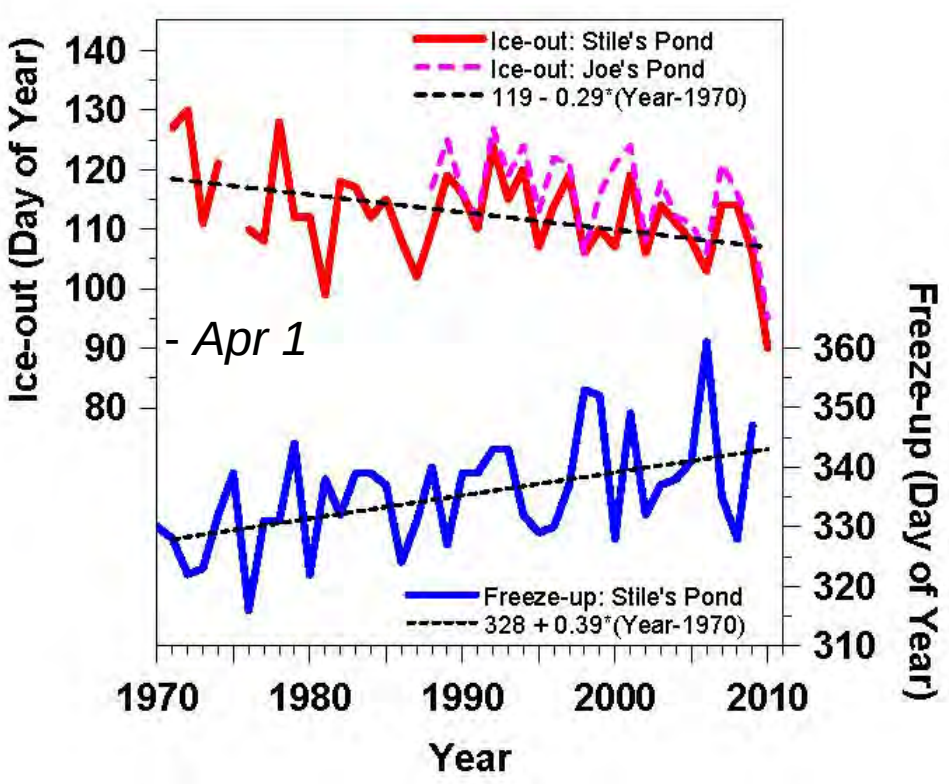
Vermont Temperature Trends
1961-2008

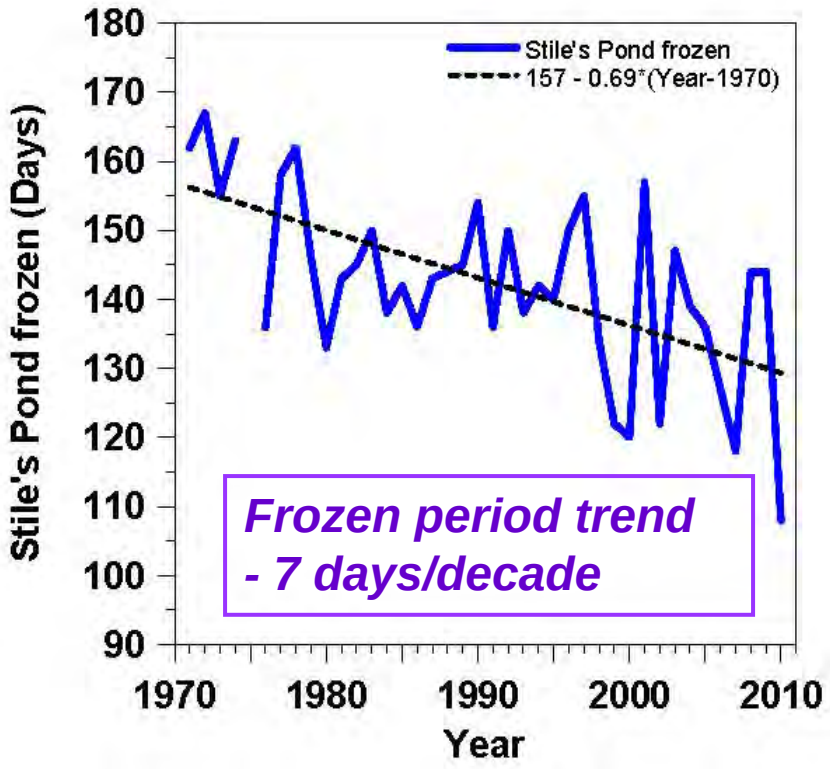
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow/more water vapor give warmer winters***



Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



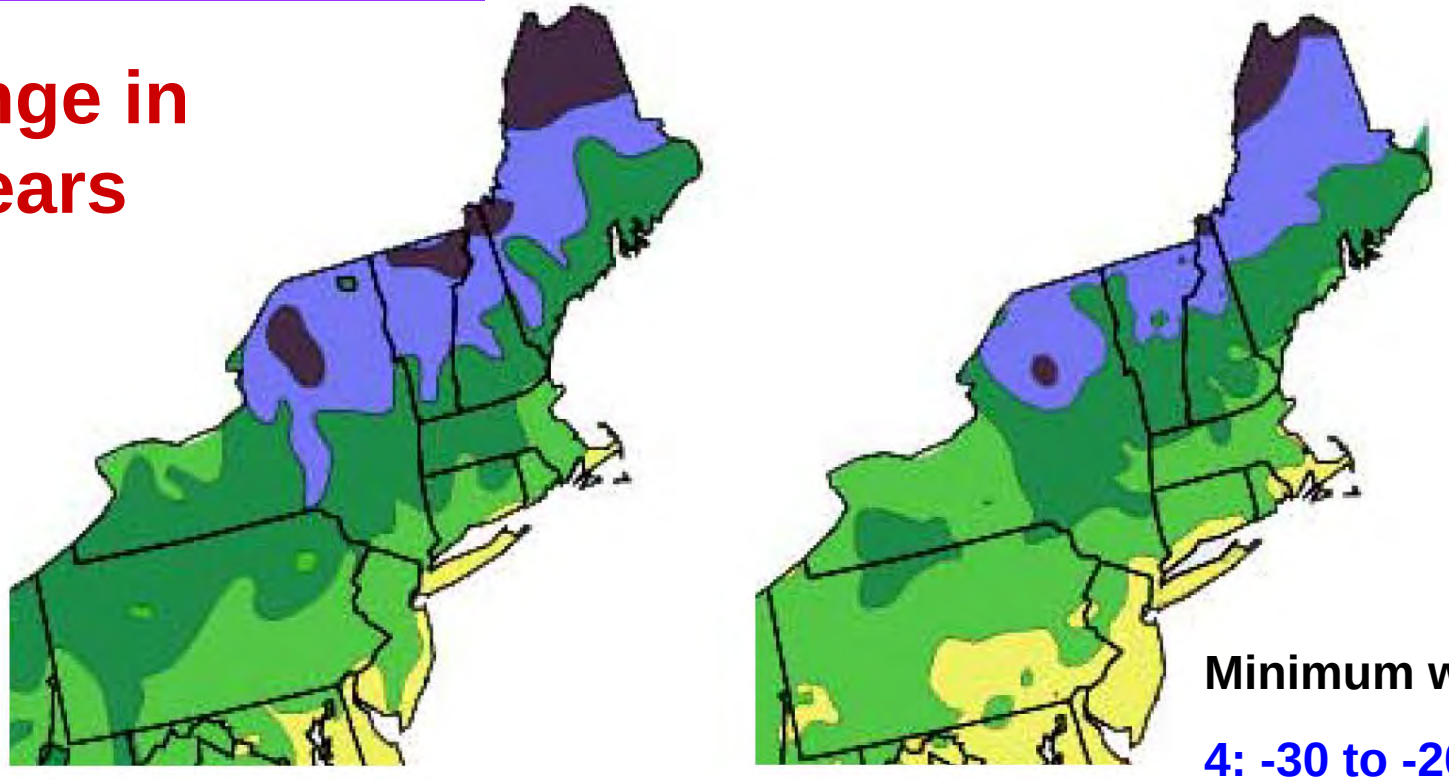


- **Ice-out earlier by 3 days / decade**
- **Freeze-up later by 4 days / decade**
- ***Soil ice probably similar***

Winter Hardiness Zones

– ***winter cold extremes***

Change in 16 years



Minimum winter T

4: -30 to -20ºF

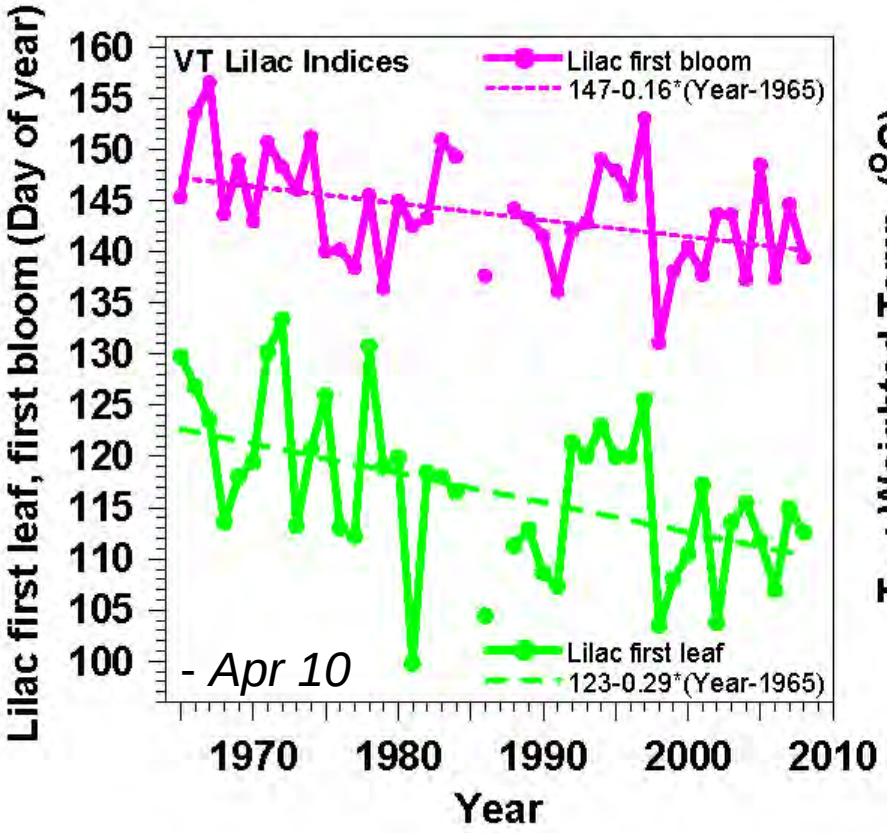
5: -20 to -10ºF

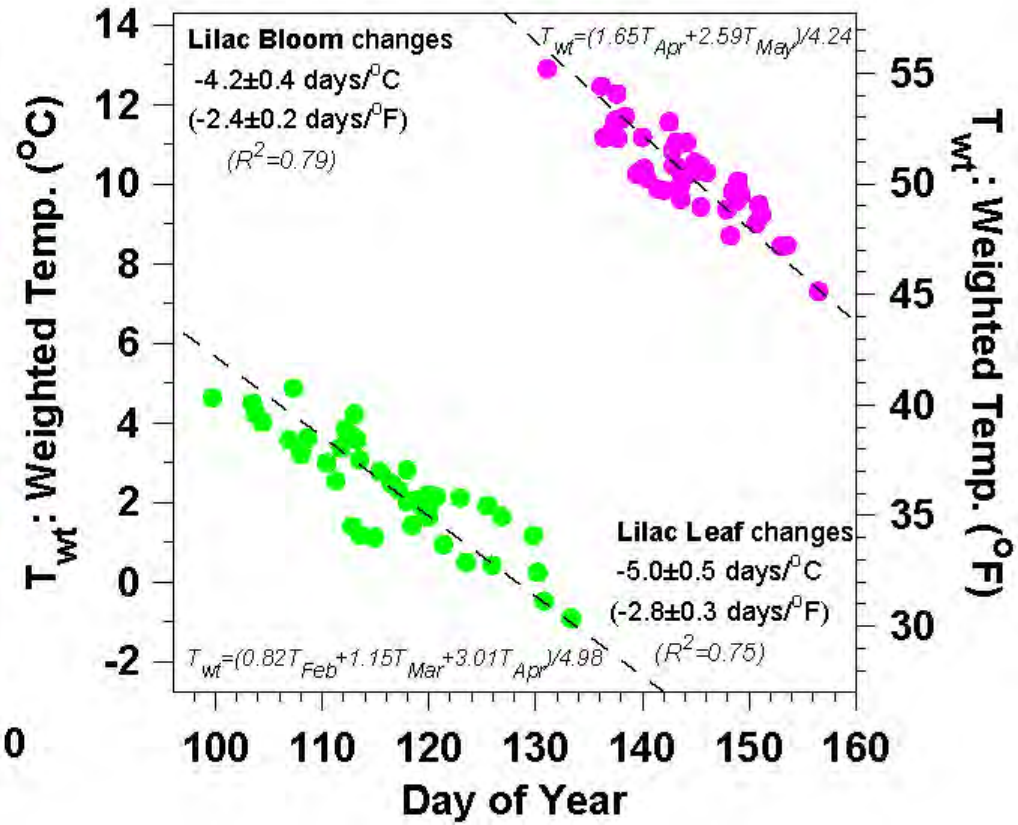
6: -10 to 0ºF

USDA Hardiness Zones

But winter variability getting larger

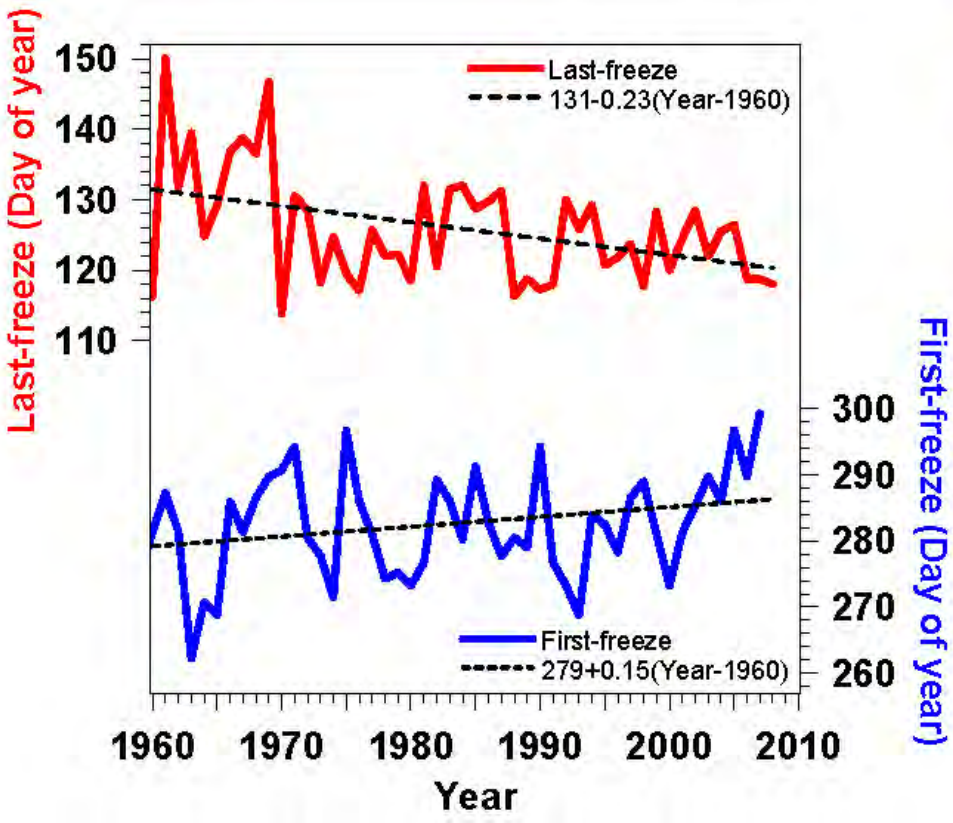
Lilac Leaf and Bloom

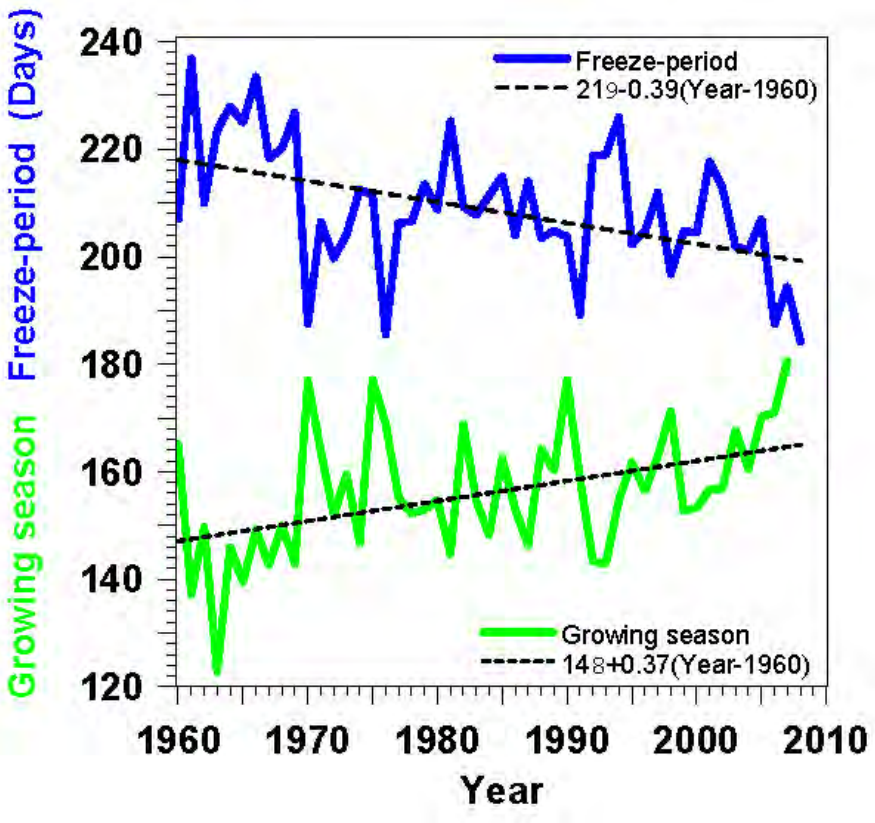




- **Leaf-out -2.9 days/decade; Bloom -1.6 days/decade**
- **Large year-to-year variation related to temperature: 2 to 3 days/ °F**

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

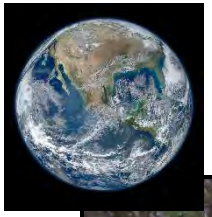
December 2006:

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

February 5, 2016
(Digging in Feb. first time ever)

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

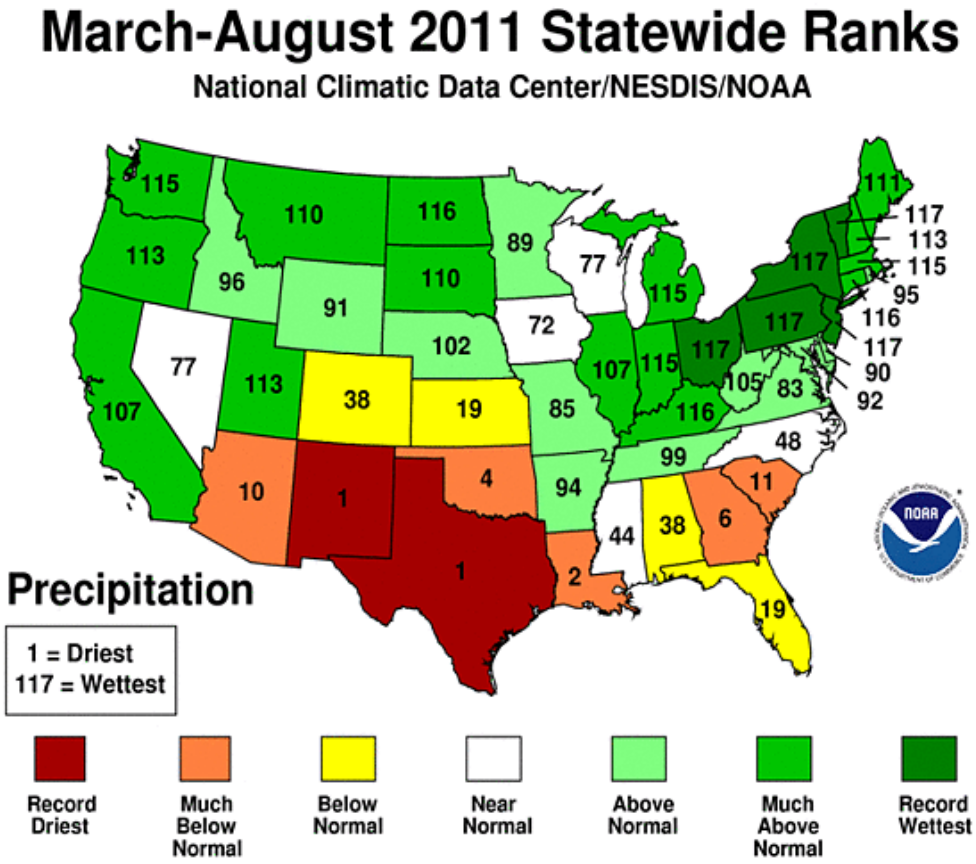
Climate, Seasons, Vegetation Connected

- **Upward temperature trend clear**
- **Winter extremes increasing**

- **Extreme precipitation and flooding increasing**

2011 Floods: VT and NY

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



March-August, 2011

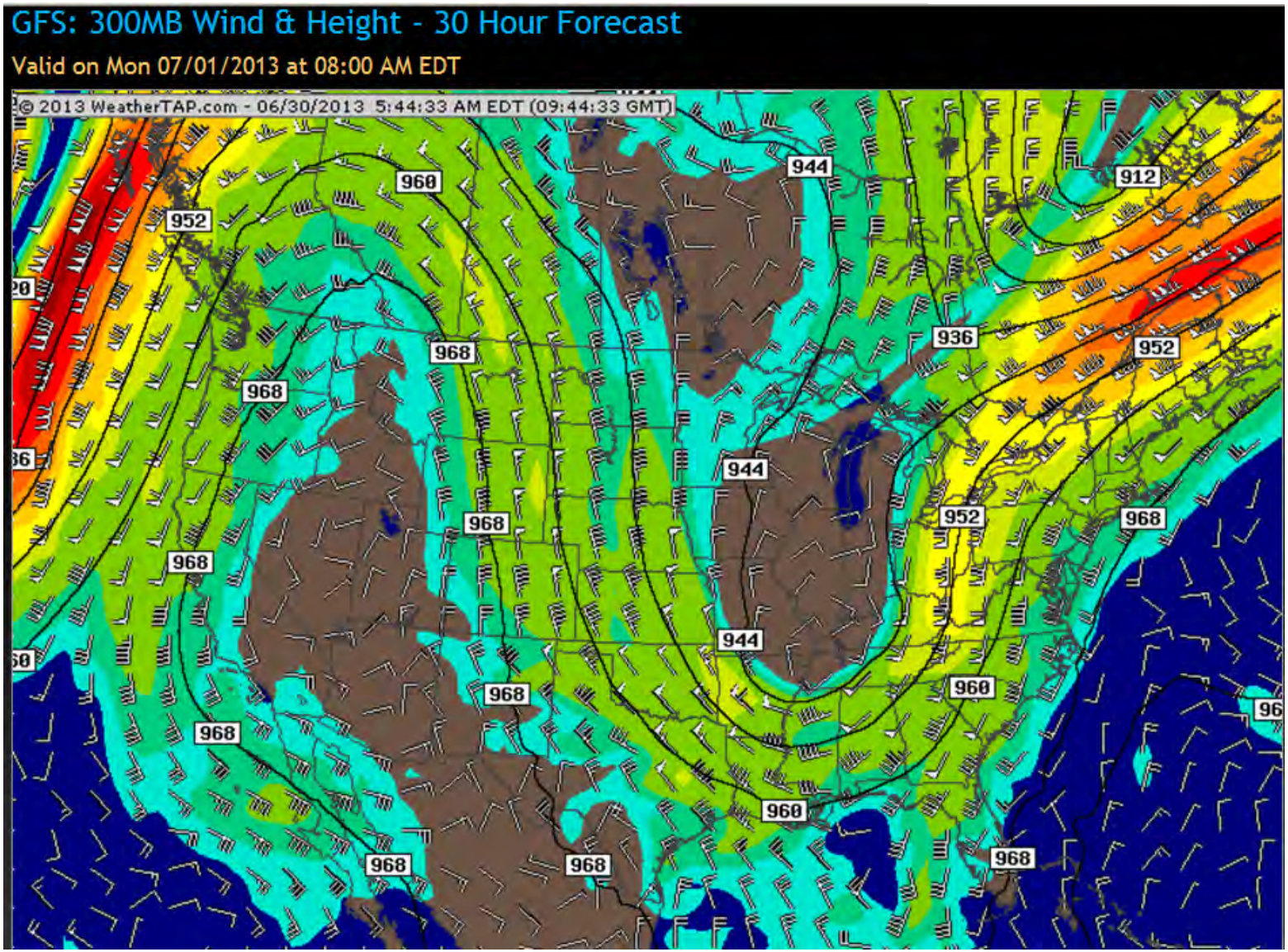
- **Record wet : OH to VT**
- **Record drought: TX & NM**
- **'Quasi-stationary' pattern**

2011 Classic VT Flood Situations

- **Spring flood: heavy rain and warm weather, melting large snowpack from 2010-11 winter**
  - **70F (4/11) and 80F(5/27) + heavy rain**
  - **record April, May rainfall: 3X at Burlington**
  - **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)**

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

(Francis and Vavrus, 2012)



Discussion

- **What is happening to the earth's climate?**
- **What do we know and what don't we know?**
- ***How much will sea-level rise this century? Next century? Next 500 years?***

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, a local issue and a moral issue**

“The difficulty is that with the rise of the modern sciences we began to think of the universe as a collection of objects rather than a communion of subjects”

The Great Work: Our Way into the Future

Thomas Berry, 1999

(“interconnected complex living system”)

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**
  - **Reserves of coal, oil and gas; shale-gas & shale-oil are sufficient to push CO_2 to 1,000 ppm—and in time melt icecaps**
    - **Need to leave 1/3 oil; 1/2 gas; 4/5 coal in ground**

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"**
  - **Carbon tax needed to change economics**
- **Politics lost in fantasy and deceipt**
  - **Ignoring Earth system and climate issues**
  - **Ignoring future costs**
    - **Manhattan within 1-ft of flooding with Irene**
    - **Did they put waterproof doors on tunnels? No**

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 tax to incentivize mitigation 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**

The Future Is Not Our Past

- **Collectively, we create the future, so we need to plan for a transition to a sustainable society**
- **In the face of a powerful economic and financial system driven by short-term profit**

- **Needs deep community discussion**
  - ***New values that respect the Earth***
  - ***Understanding to work with the Earth***

2015 was Transition Year

- **Climate meeting in Paris in December**
  - **188 Nations made commitments**
- **Pope Francis issued the first Papal Encyclical on the environment, climate change and our responsibilities to the Earth**
  - **Exploitation of the Earth and the poor are inseparable**
  - **Short-term profit as primary motive is immoral**
- ***New values that respect the Earth***

Discussion

- **This talk http://alanbetts.com/talks**

- **Rutland Herald articles at**
  http://alanbetts.com/writings
- **Interesting papers at**
  http://alanbetts.com/research

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**

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 guide has failed us**
- **We must manage our society better!**

Broad Guidelines or Rules to Minimize Impacts

- **Minimize the lifetime of 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**

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 limits**
  - **That accept our moral responsibilities**

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 +2-3^{o}F/decade**

- **More winter precipitation**
  - **Wetter snow; more mixed phase; more frequent melt**
- **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**

- **Strengths of science:**
  - **integrity, honesty and communication**
  - ***particularly valuable in a society lost in ignorance and deceit***

- **Limits of science:**
  - **tangible, measurable and communicable**
  - ***hard to deal with the complexity and interconnectedness of the living natural world***