# Climate Change and Vermont


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***BREE semina***
***November 13, 2018***

# Outline of this talk

- **What is happening to**
  - **Global climate**
  - **Climate of Vermont**
- **Broader issues**
  - **System issues**
  - **Social issues**

VERMONT EPSCoR

BREE Basin Resilience to Extreme Events in the Lake Champlain Basin

# Fundamentals

- ***Burning fossil fuels: transforming climate***
  - ***Many water cycle amplifying feedbacks***
  - ***Heading for high $CO_2$ "Carboniferous era climate"***
  - ***Oceans warming; Climate extremes increasing***
  - ***Decadal to centennial - long timescales***
- **Avoidance of responsibility for decades**
  - **Climate change*: Incompatible with business-as-usual***
  - **Soluble: using systems engineering**
  - **Create efficient society, based on renewable energy**
- **Choices are value-based**
  - **Science and economics need guidance**
  - **Market economy (mostly) maximizes current profit**

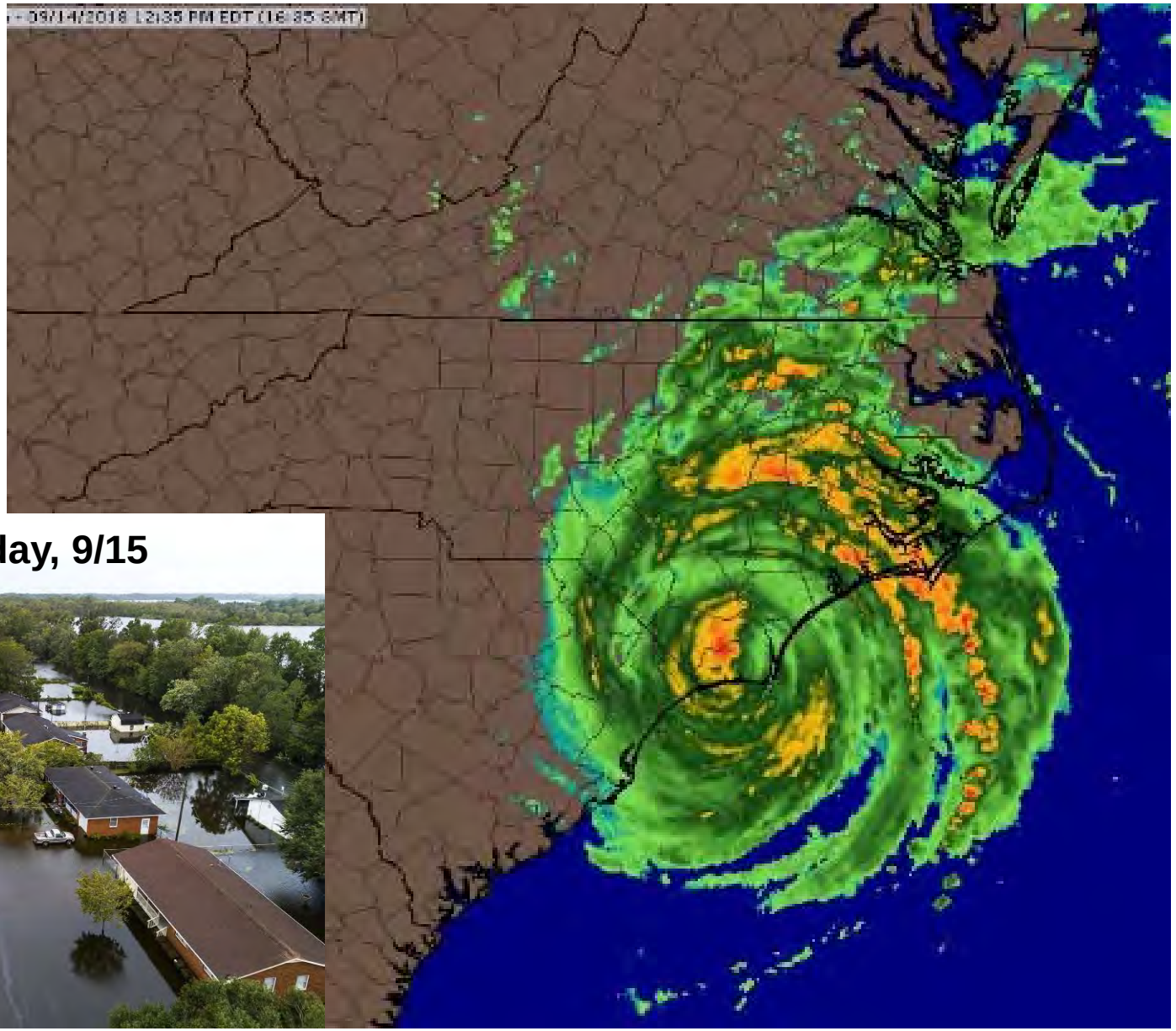
# Climate Drivers

- **Burning fossil fuels increases $CO_2$ and $CH_4$**
- **Amplified 3 times by water vapor increase, also strong greenhouse gas**
  - ***Reduce cooling to space, while solar heating increases as snow and ice decrease***
- ***93% of Earth's warming is stored in oceans, giving stronger storms, with more precip.***
  - ***Harvey, Irma, Maria, Florence, Michael***
- **Warming doubled in Arctic and winter by shrinking ice and snow**
  - **Changing mid-latitude weather; more stationary**

# Florence: N. Carolina Coast

**Friday, 9/14/18**
**12:35pm EDT**

**Warm ocean**
**Rain >24in**
**Major flooding**




**New Bern: Saturday, 9/15**

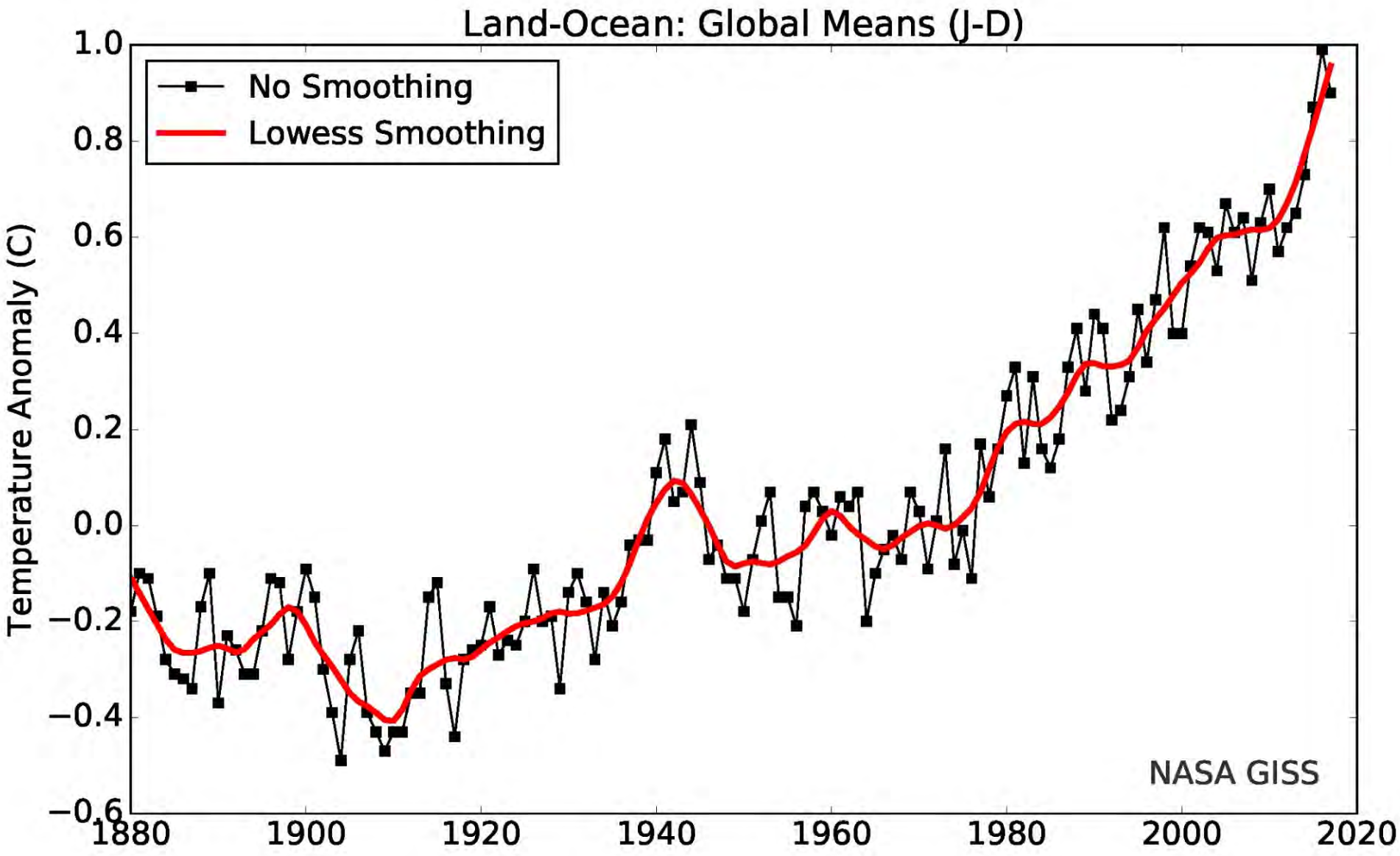
# System Problem

- **Human waste streams are transforming the Earth's climate, and human and natural ecosystems**
  - **This affecting climate, weather, water supplies, food system and human health**
  - ***Current financial interests vs Earth's future***
- **New strategies and mindset needed to mitigate, adapt and build resilience**
  - **Is this an efficient way of doing this?**
  - **Can we manage our waste streams better?**
  - ***Can we better manage our relation to the Earth?***

## Earth's climate sustains life

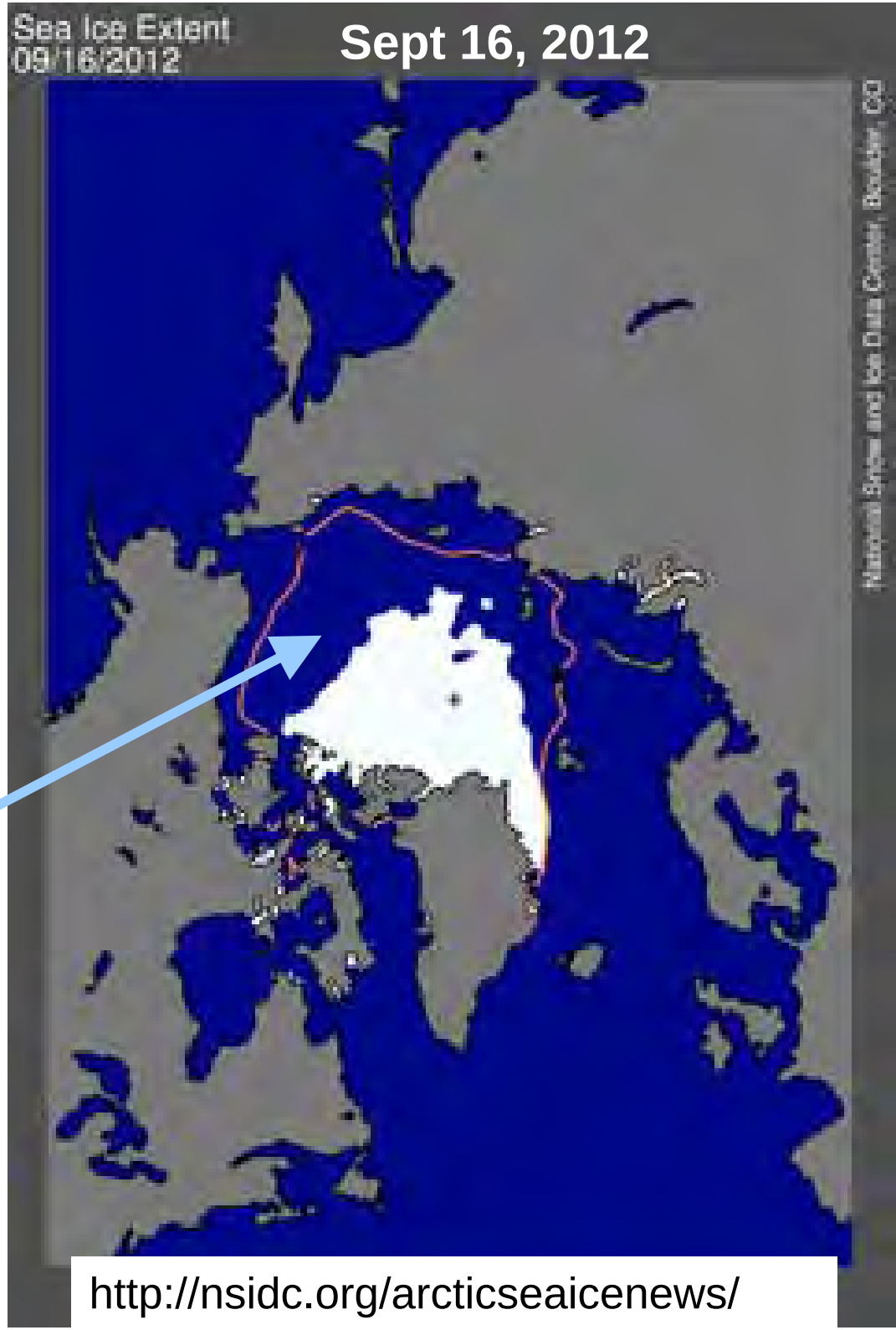
- Burning fossil fuels is increasing greenhouse gases
- Climate is warming: ice is melting, extreme weather is increasing
- Water plays crucial amplifying role
- Planetary modes: jet-streams changing

# Global Trend: 1880-2017



- **Arctic warming twice as fast as globe**
- **Half the Arctic Sea Ice Melted in 2012**
- **Open water gives warmer Fall in Northeast**

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



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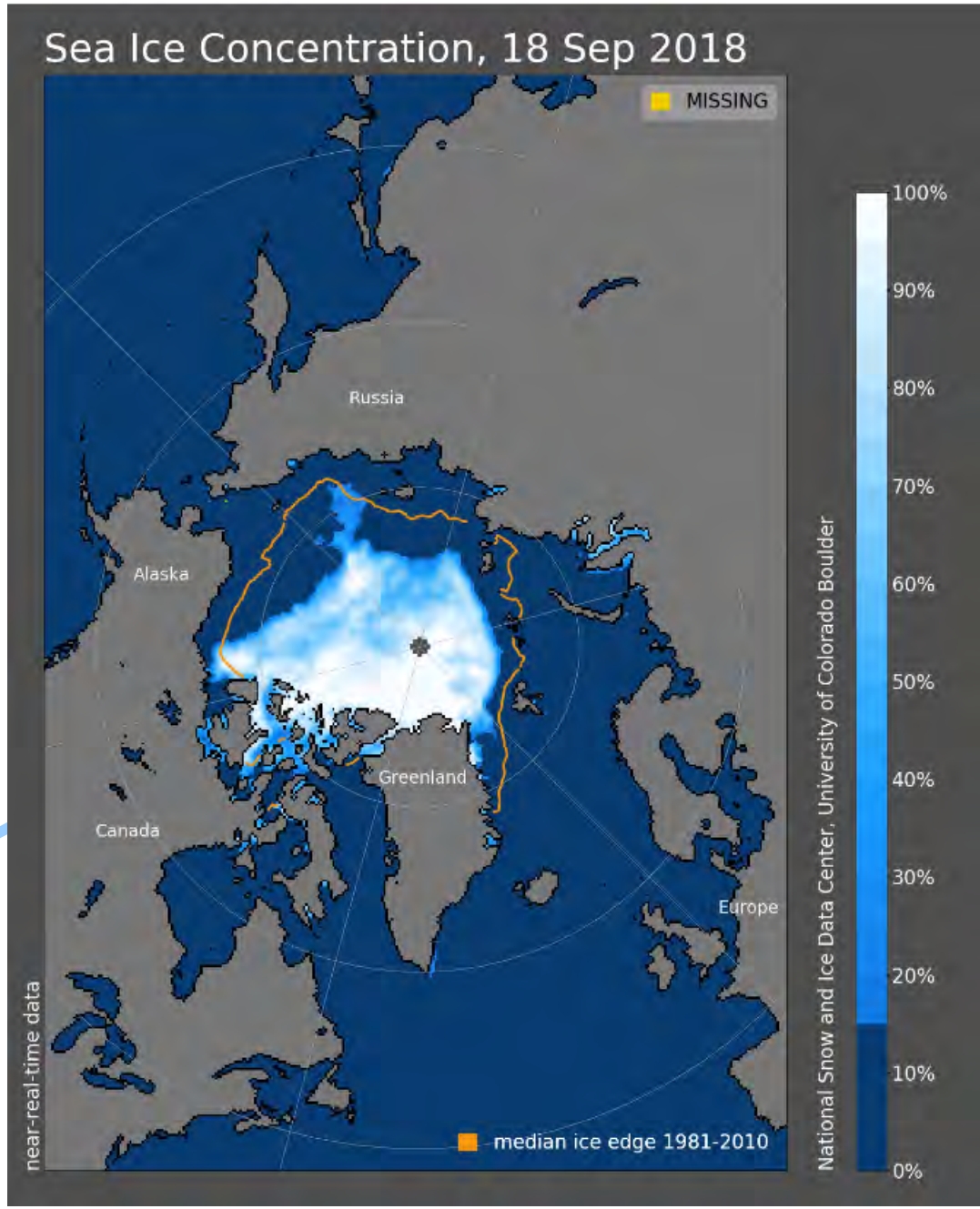
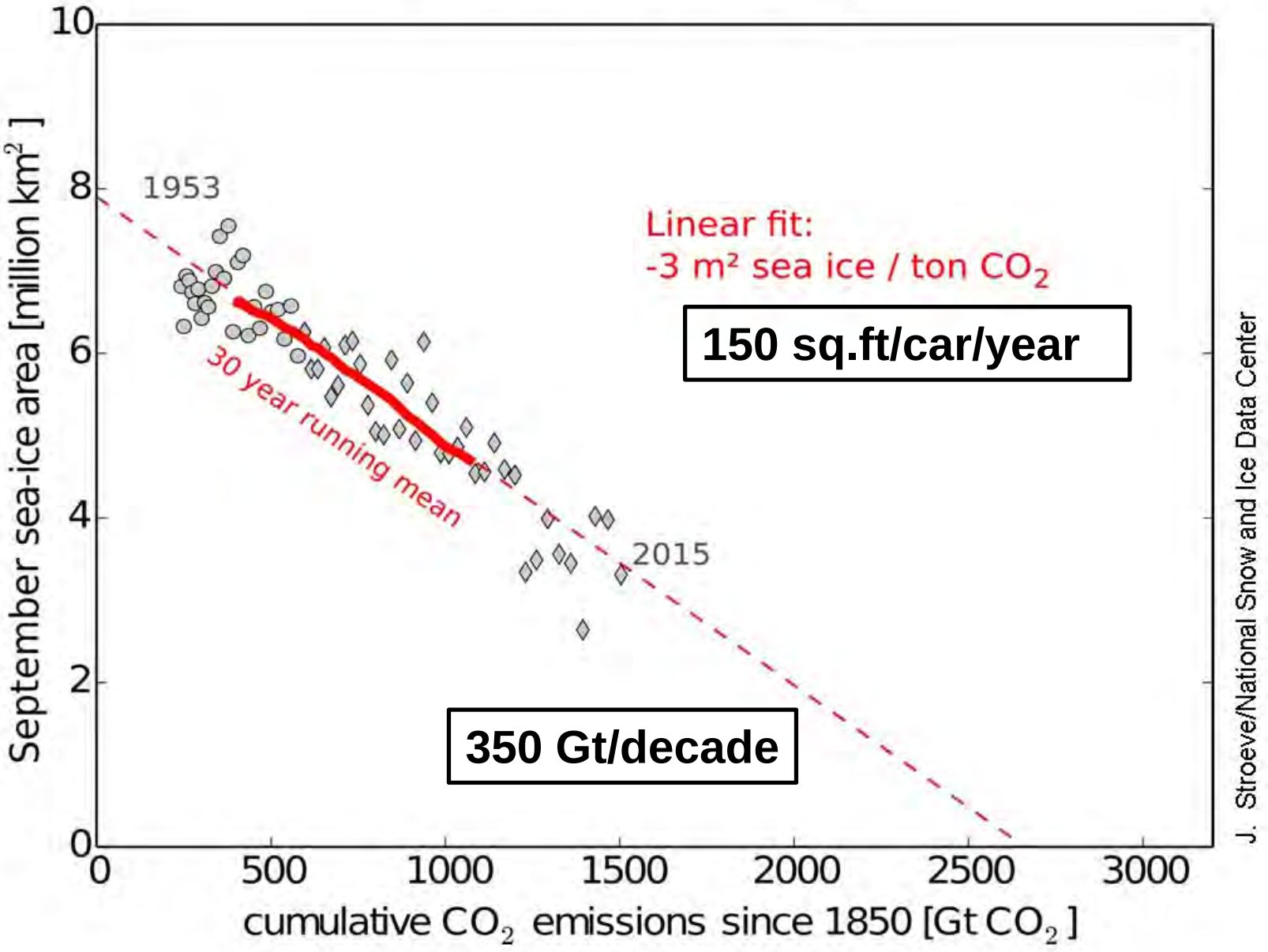



http://nsidc.org/arcticseaicenews/

# September Arctic Sea Ice Loss



# Transport: big $CO_2$ source

- **High tech solution: convert all to electric cars**
  - **Means large investment in new infrastructure: good for economy!**
- ***Cheap solution: plug-in hybrids, which reduce fossil fuels use by 80% with no compromises***
- **Annual auto fuel efficiency in Vermont: 25mpg**
- ***Plug-in hybrid: 140 mpg: fixes problem, saves $***

## 2017 Prius Prime

***Cost $30000, less $4500 tax credit***

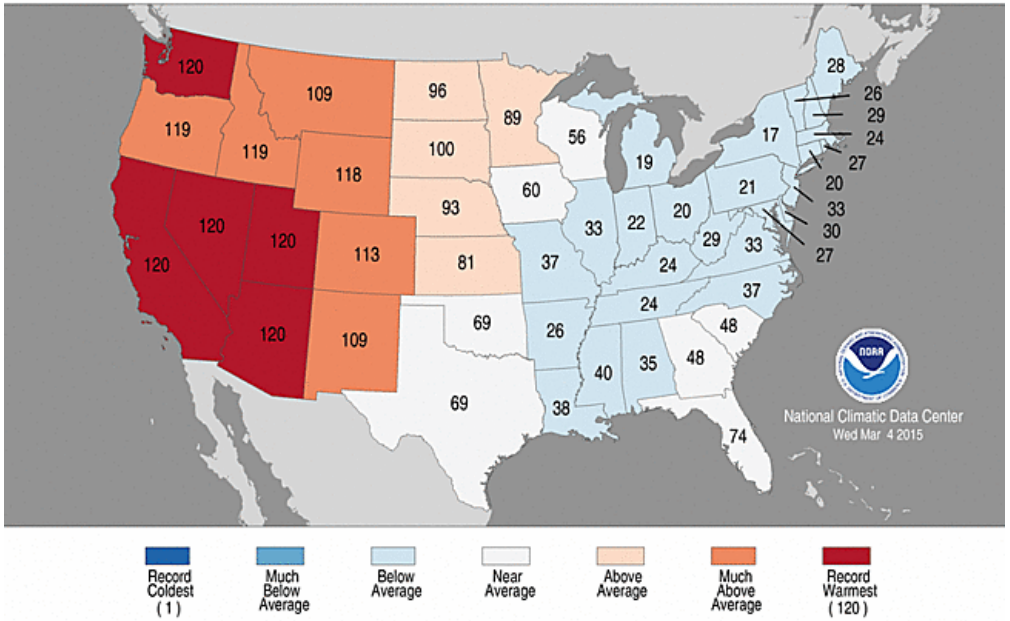
***All-electric range: 28 miles***

***Hybrid range: 600+ miles***

***(I am not a salesman!)***

- **23000 miles; 50% electric, 50% hybrid: 140 mpg**
  - **12000 miles/year: 88 gallons/year;1400 KWh/year**
  - **Compare 25 mpg car: 480 gals, cost $1344**
  - **Saves: $1344 – (246+252) = $846 annual savings**
- **Most efficient car on market *(better than Tesla!)***
  - **Running hybrid gets 68 mpg on VT roads at 50 mph**
  - **Long-trip: 2100 mile: avg 82 mpg (night plug-in)**
- ***So why doesn't Toyota advertise them?***

**DJF2015** Statewide Average Temperature Ranks
December 2014–February 2015
Period: 1895–2015




**DJF2016** Statewide Average Temperature Ranks
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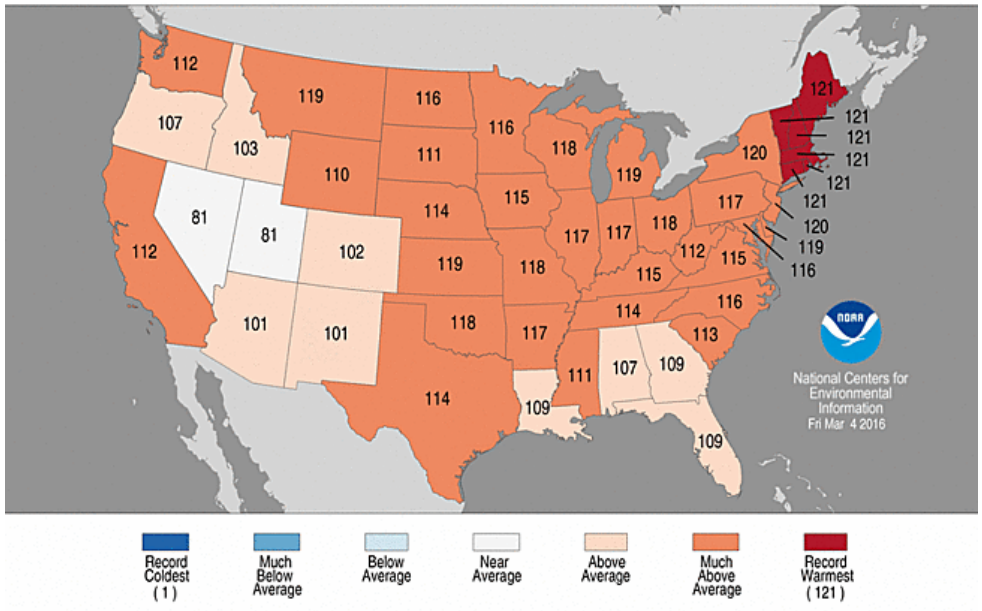


**DJF2017** Statewide Average Temperature Ranks
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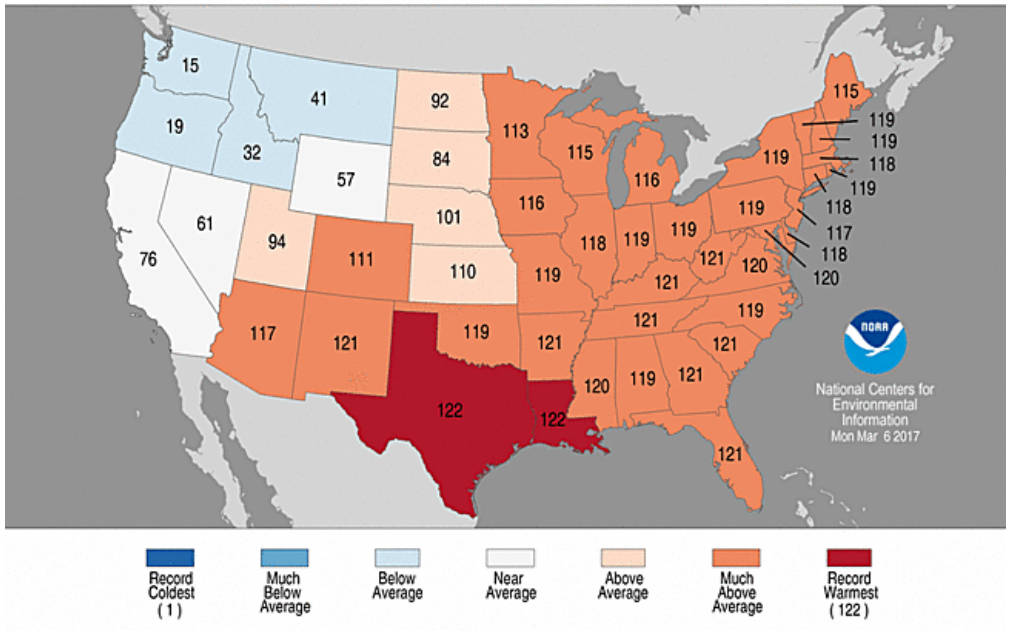
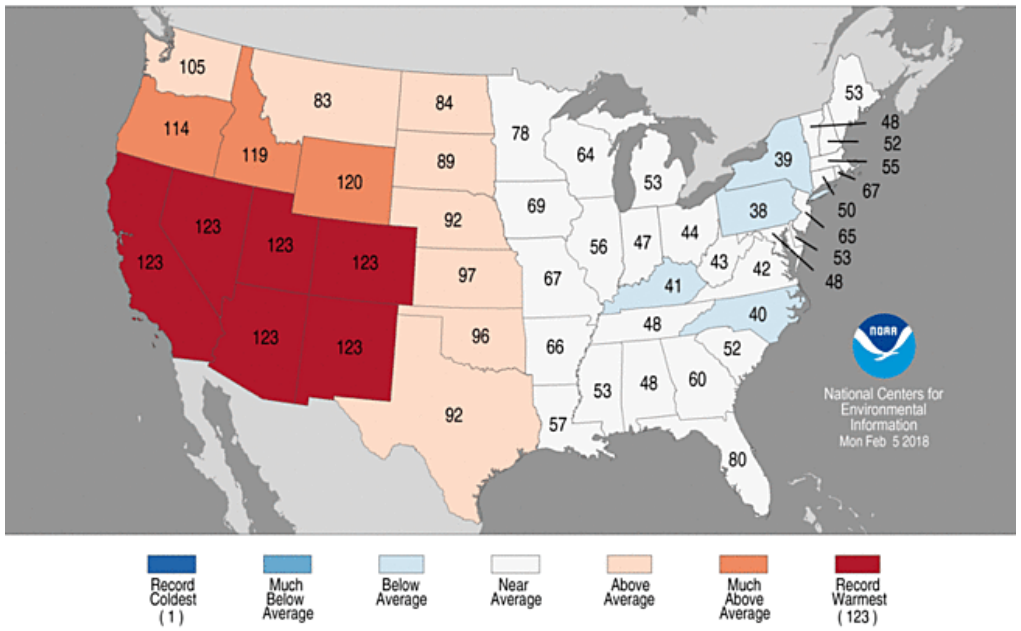
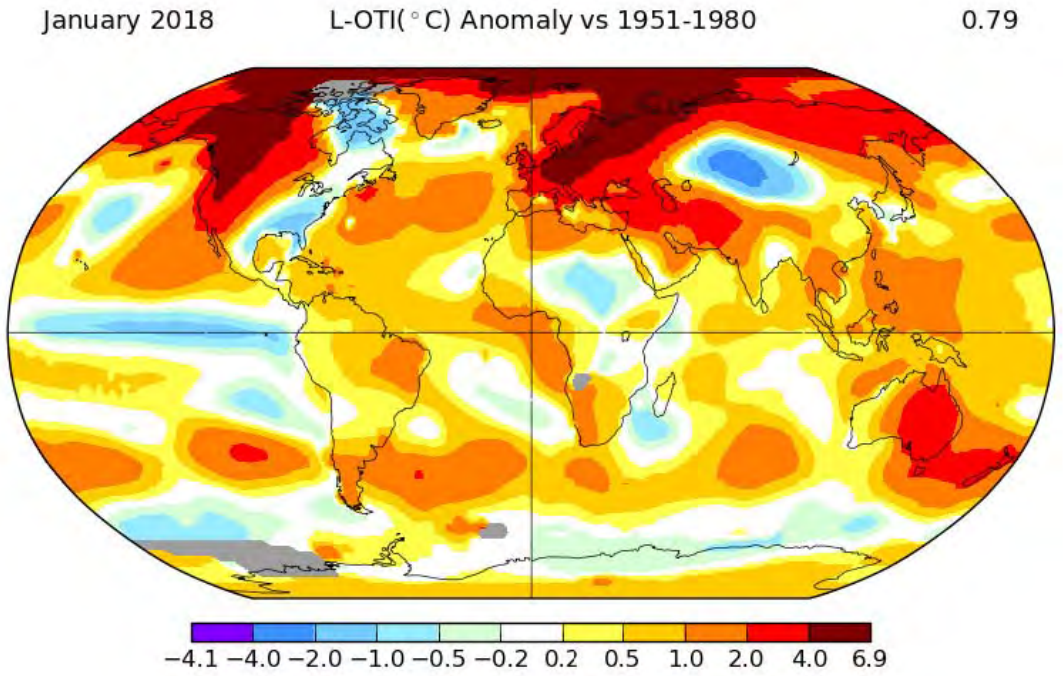



**NDJ2018** Statewide Average Temperature Ranks
November 2017–January 2018
Period: 1895–2018



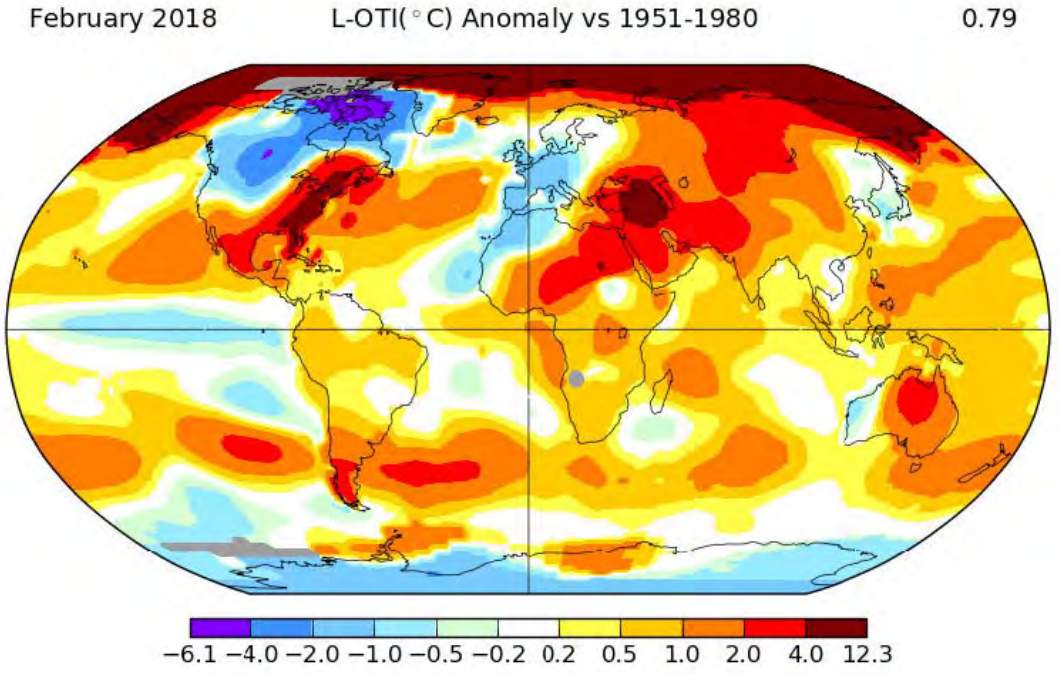
# *Jan-2018*

**Warm Atlantic, Warm Arctic, west-NA; cold east-NA; warm Europe**




# *Feb-2018*

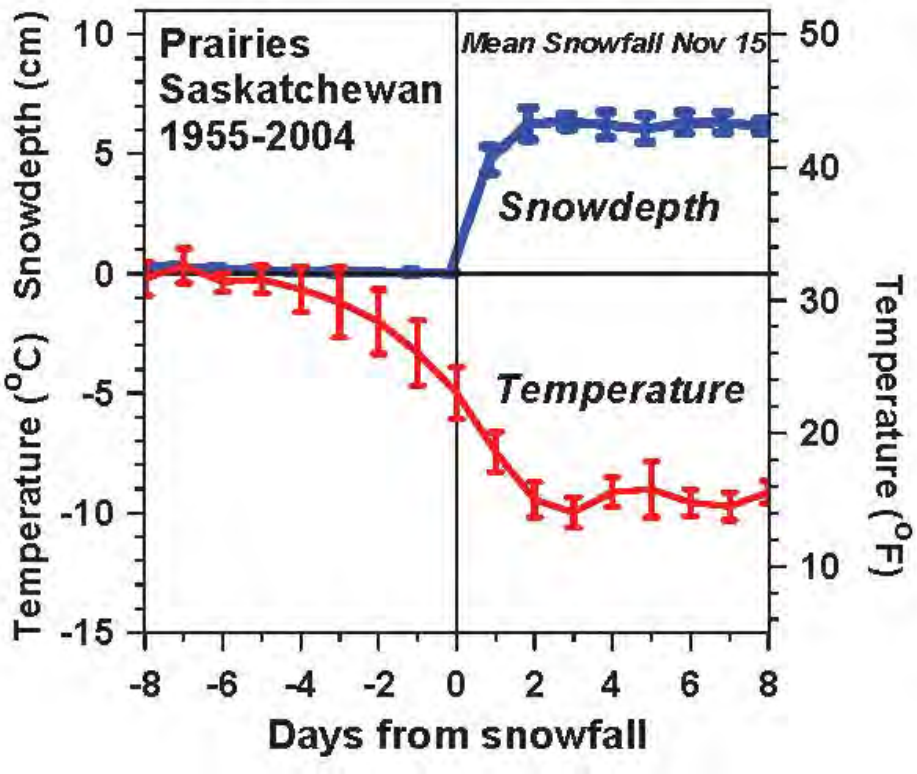
**Warm Atlantic, Warm Arctic, east-NA; cold west-NA and Europe**

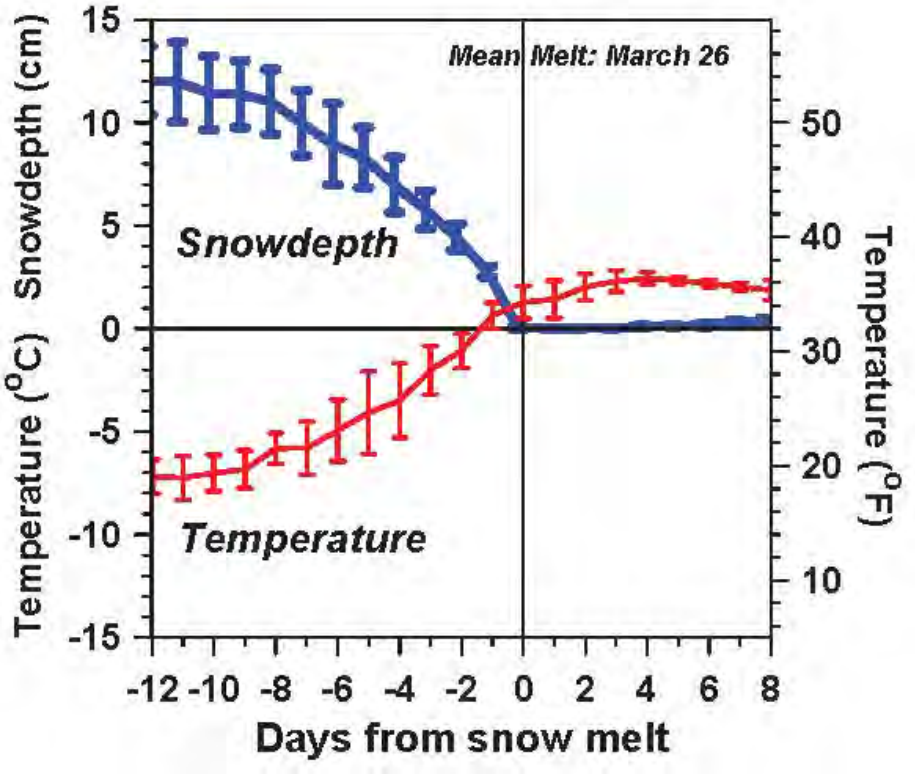



***March 2018: 4 Nor'Easter snowstorms***

# Snowfall and Snowmelt

## *Winter and Spring transitions*

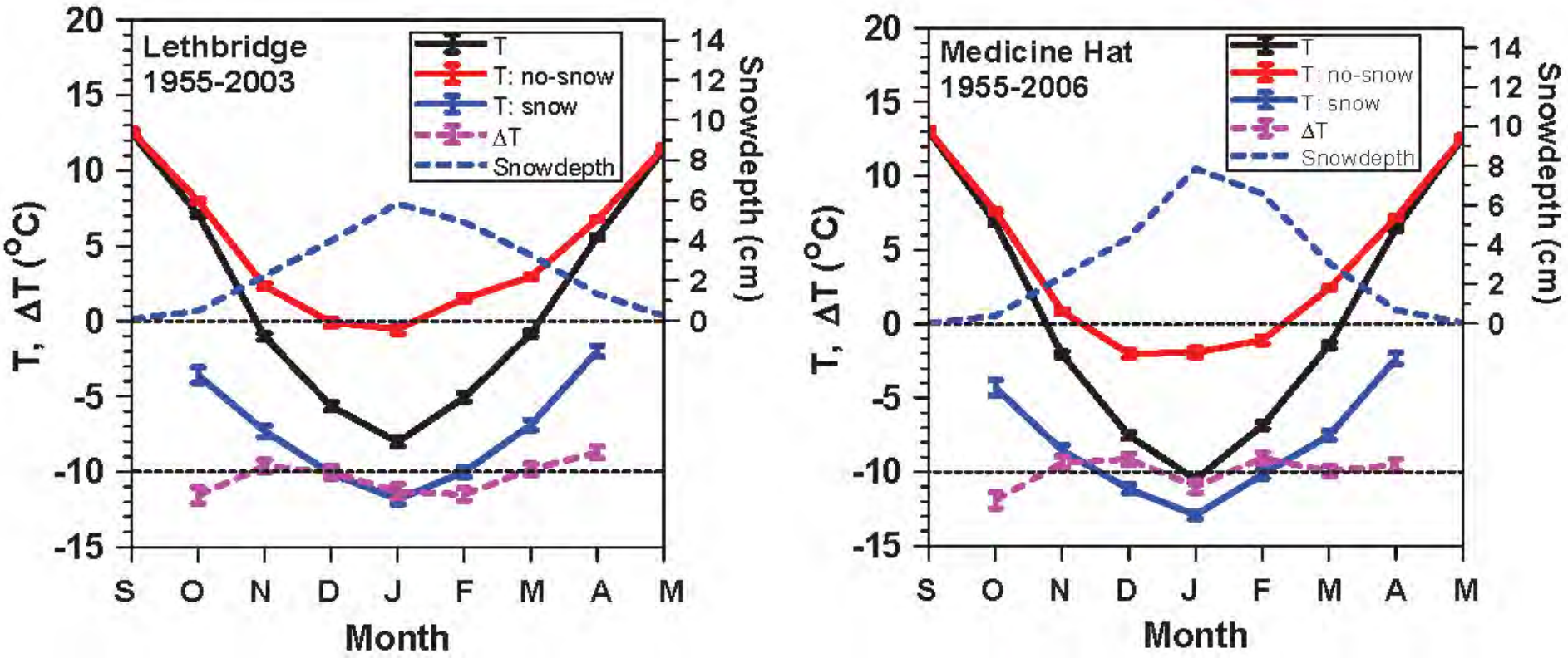



- **Temperature falls/rises about 18F with first snowfall/snowmelt**
- ***Snow reflects sunlight; shift to cold stable boundary layer***
  - ***Local climate switch between warm and cold seasons***
  - ***Winter comes fast with snow***

*(Betts et al. 2014a)*

# Impact of Snow on Climate

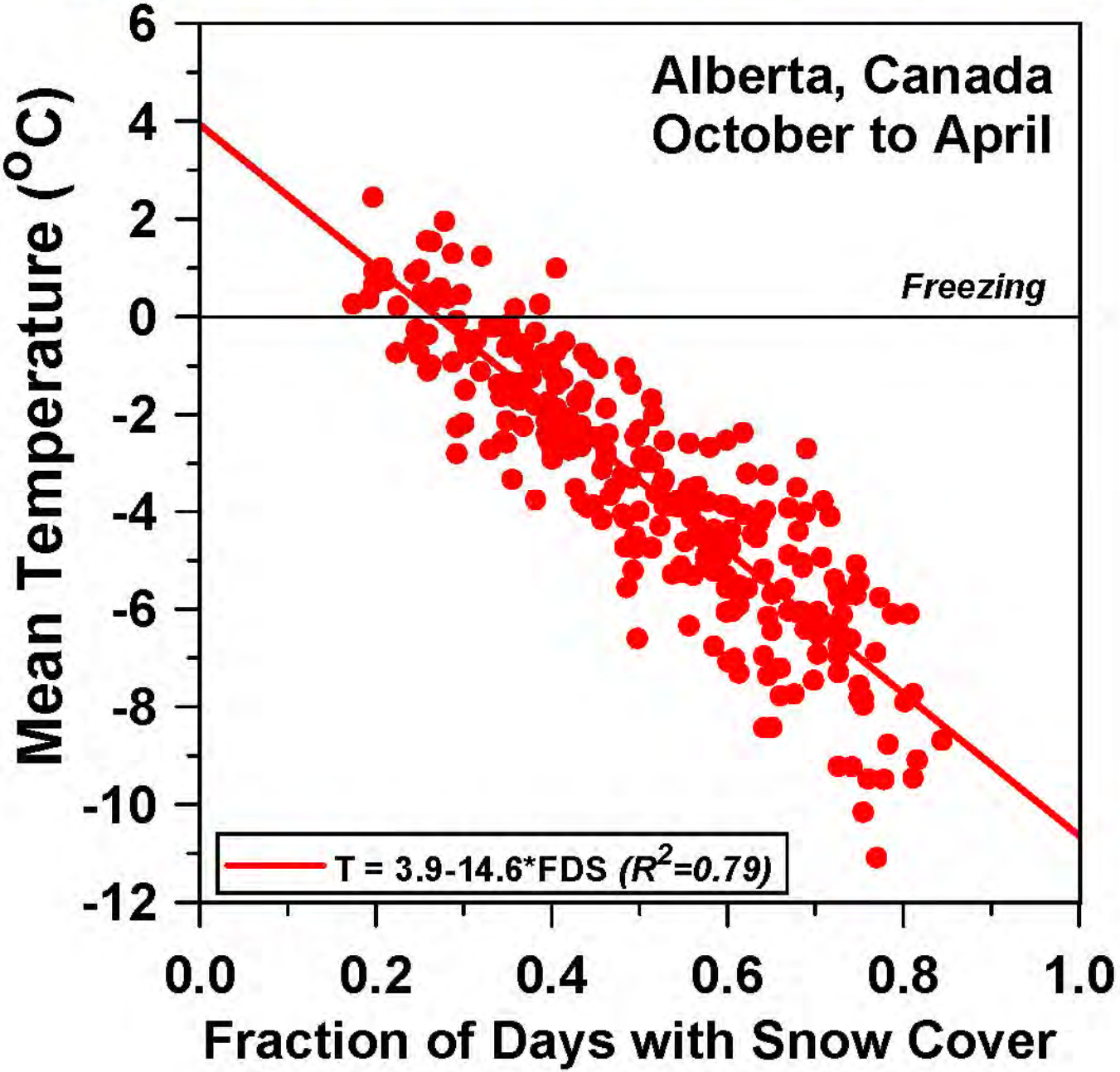



**Separate mean climatology into days with no-snow and Snowdepth >0**

**$\Delta T$ = T:no-snow –T:snow = -10.2(±1.1)ºC**

*Betts et al. (2016)*

## More snow cover - Colder temperatures




***Winter is colder if more snow cover***

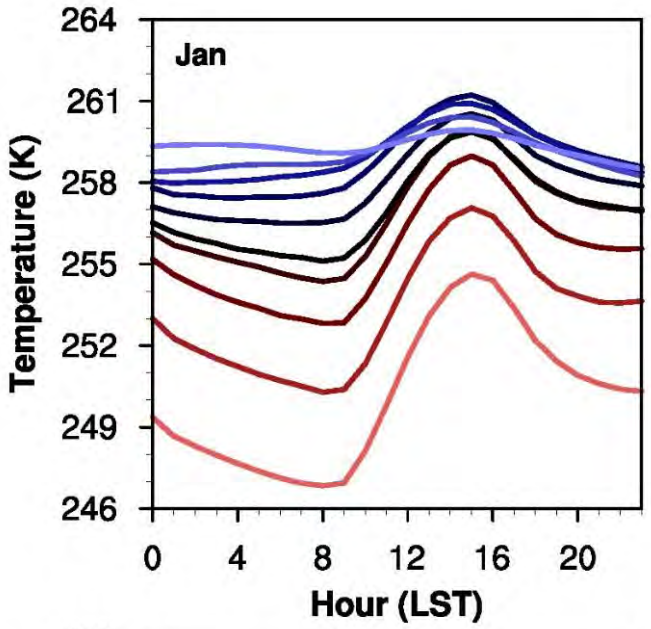
# Diurnal cycle: Clouds & Snow

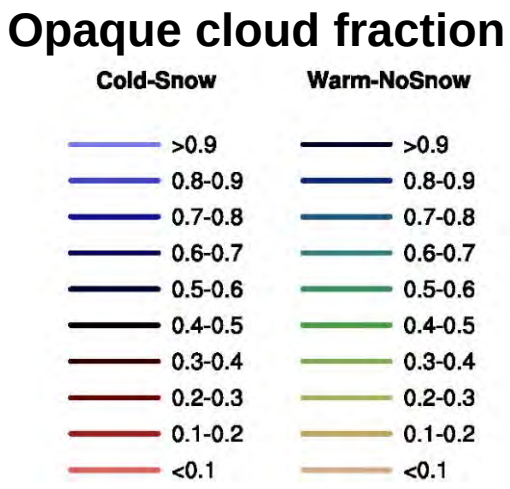
**Canadian Prairies**
**660 station-years of data**

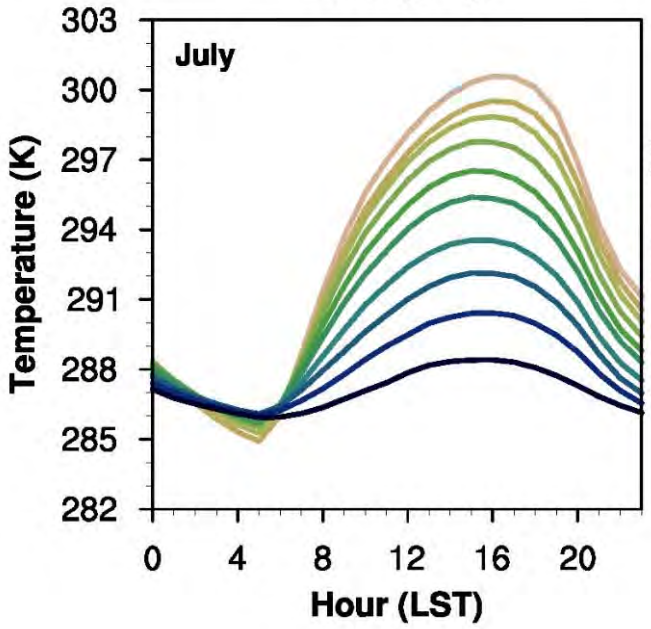
**Winter climatology**
- Colder when clear
- LWCF dominant with snow
- Stable BL

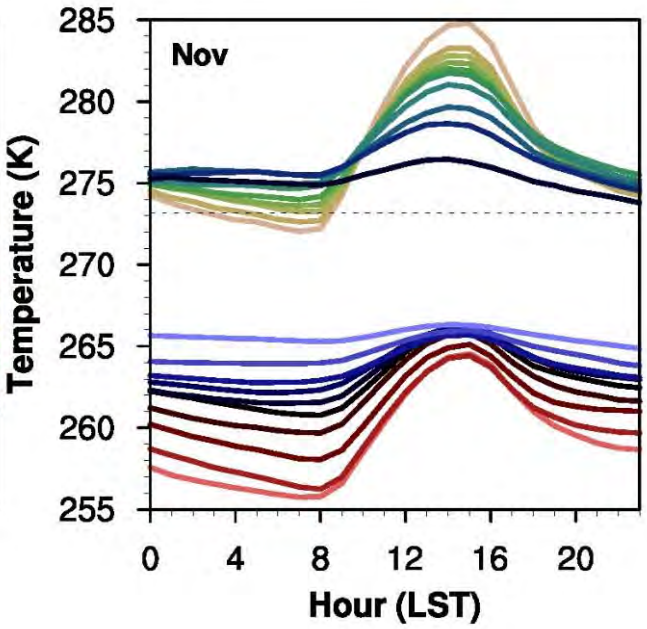
**Summer climatology**
- Warmer when clear
- SWCF dominant: no snow
- Unstable daytime BL

**Transition months:**
- Show both climatologies
- With 11K separation
- Fast transitions with snow
- Snow is “Climate switch”



# Impact of Snow

- **Distinct warm and cold season states**
- **Snow cover is the "climate switch"**

**With snow**

- **Prairies: Temperature falls 18°F**
  - **snow reflects 70%**
- **Vermont: Temperature falls 10°F**
  - **snow reflects 35% (because more forest)**

# Gardening in Pittsford, Vermont in January

**January 7, 2007**

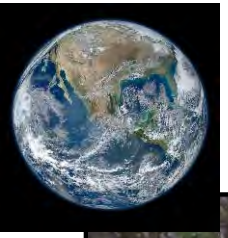
**December 2006:**

- **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

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

# January 10 and 12, 2018

**January 10, 2018**

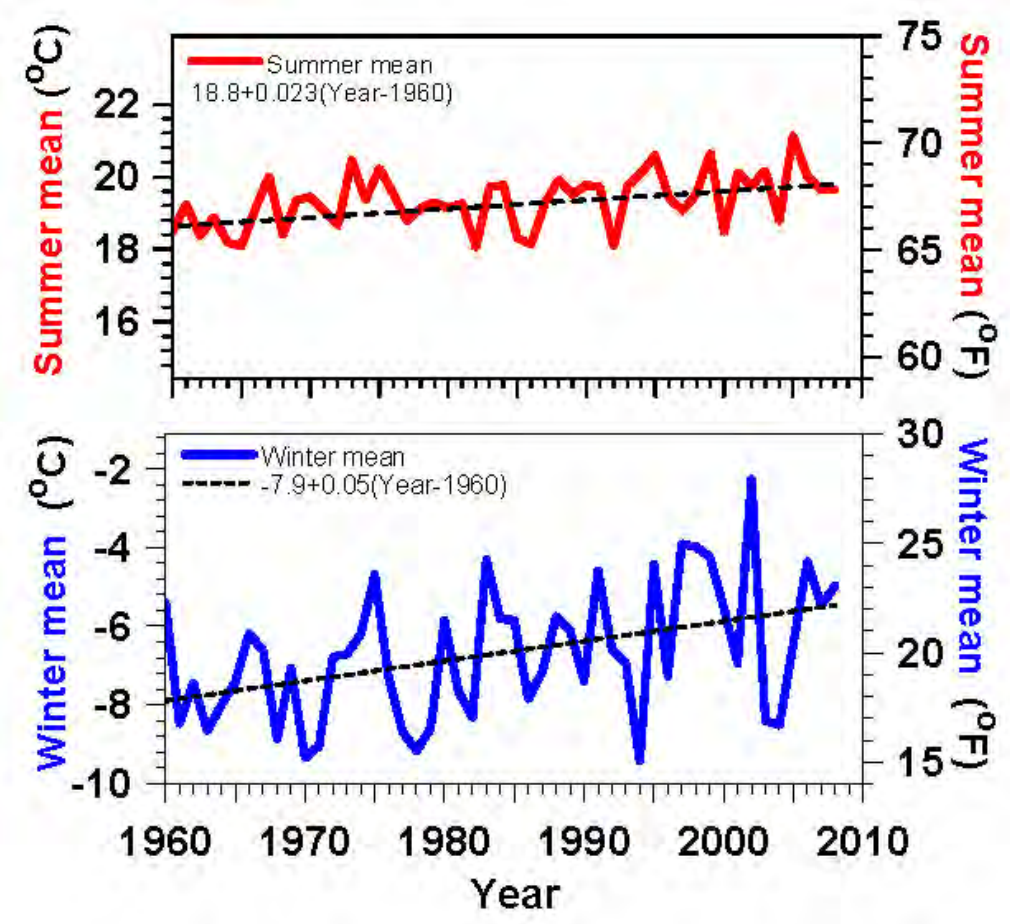
**After cold snowy period**
**$T_{min}$ down to -10 to -20F**

**January 12, 2018**

**After $T_{max}$ up to 50F**

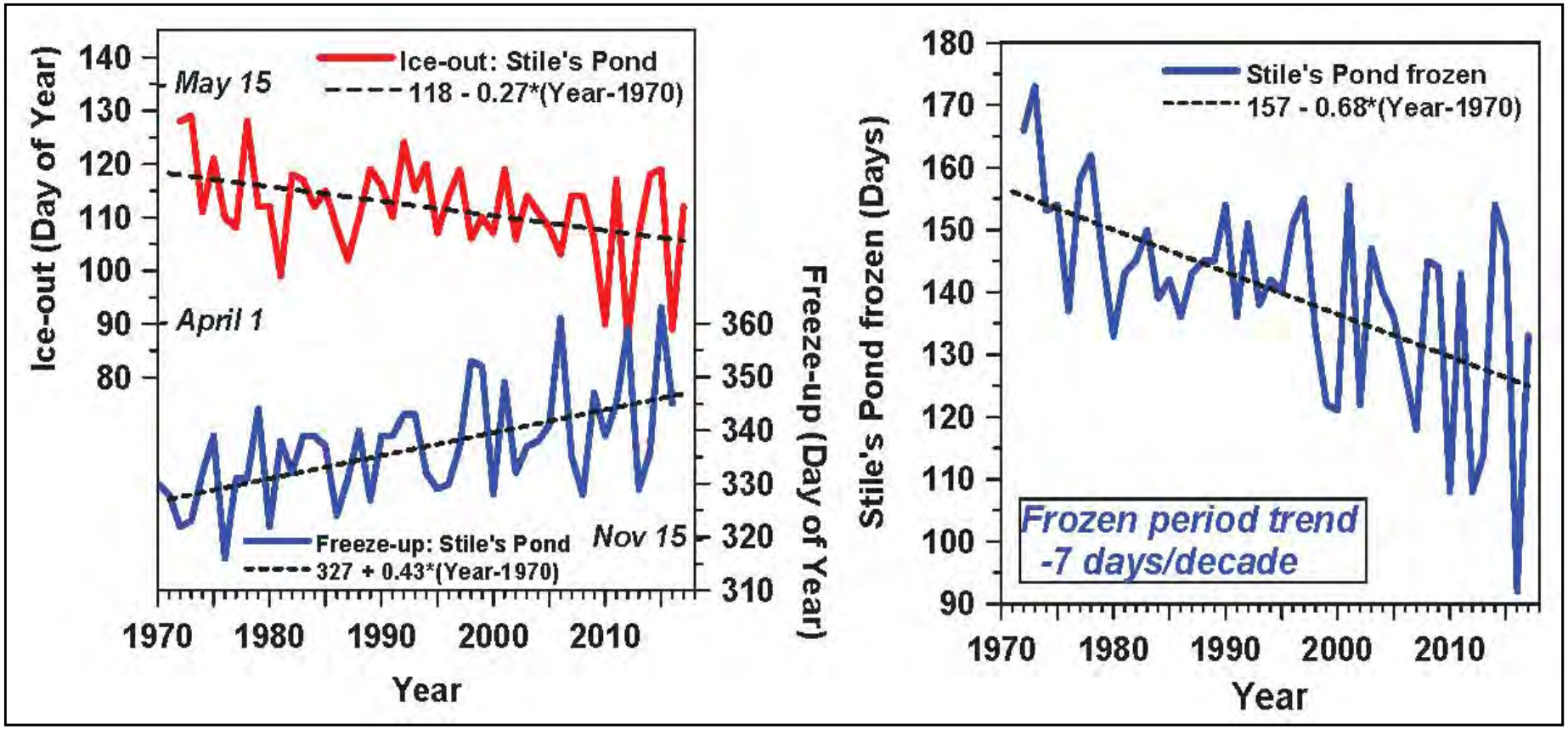
# Vermont Temperature Trends 1961-2008

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



# Marker: Lake Freeze-up & Ice-out

## Frozen Period Shrinking: variability huge



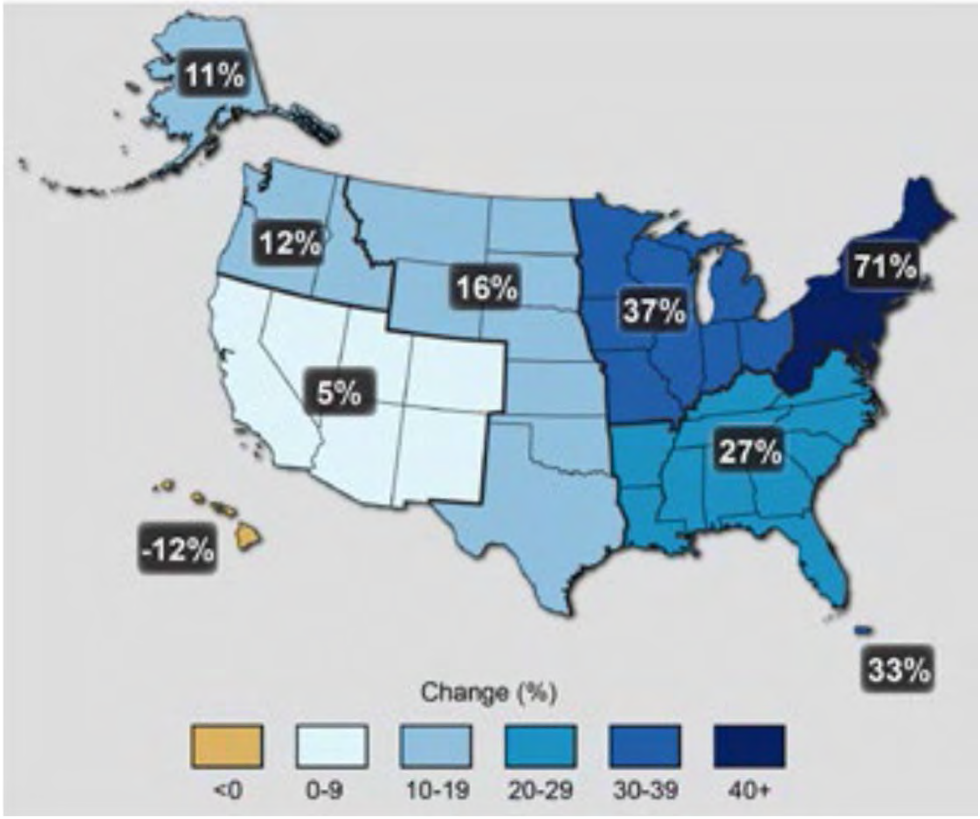

- **Freeze-up later by +4 days / decade**
- **Ice-out earlier by -3 days / decade**
- **Lake frozen period trend - 7 days/decade**
- ***Interannual variability ≈ 50 yr trend***

***Stiles Pond:***
***"Eye on the Sky"***

# Very Heavy Precipitation Is Increasing

- **Precipitation Extremes**

- **Most of the observed precipitation increase during the last 50 years has come from the increasing frequency & intensity of heavy downpours.**




*(Walsh et al., 2014)*

- **71% increase in Northeast**

Brattleboro, VT, Courtesy of Caleb Clark, CNN

Brattleboro, M. Reston

Wilmington, J. Cantore

# TS Irene

**Roads in valleys**

**Massive damage**

**Some roads took months to repair**

***Rte 131, Cavendish***

***Sept, 2011***

# Value of Flood Plains

- **Otter Creek after Irene on August 30, 2011**
  - **River rose ten feet: flood plain saved Middlebury**

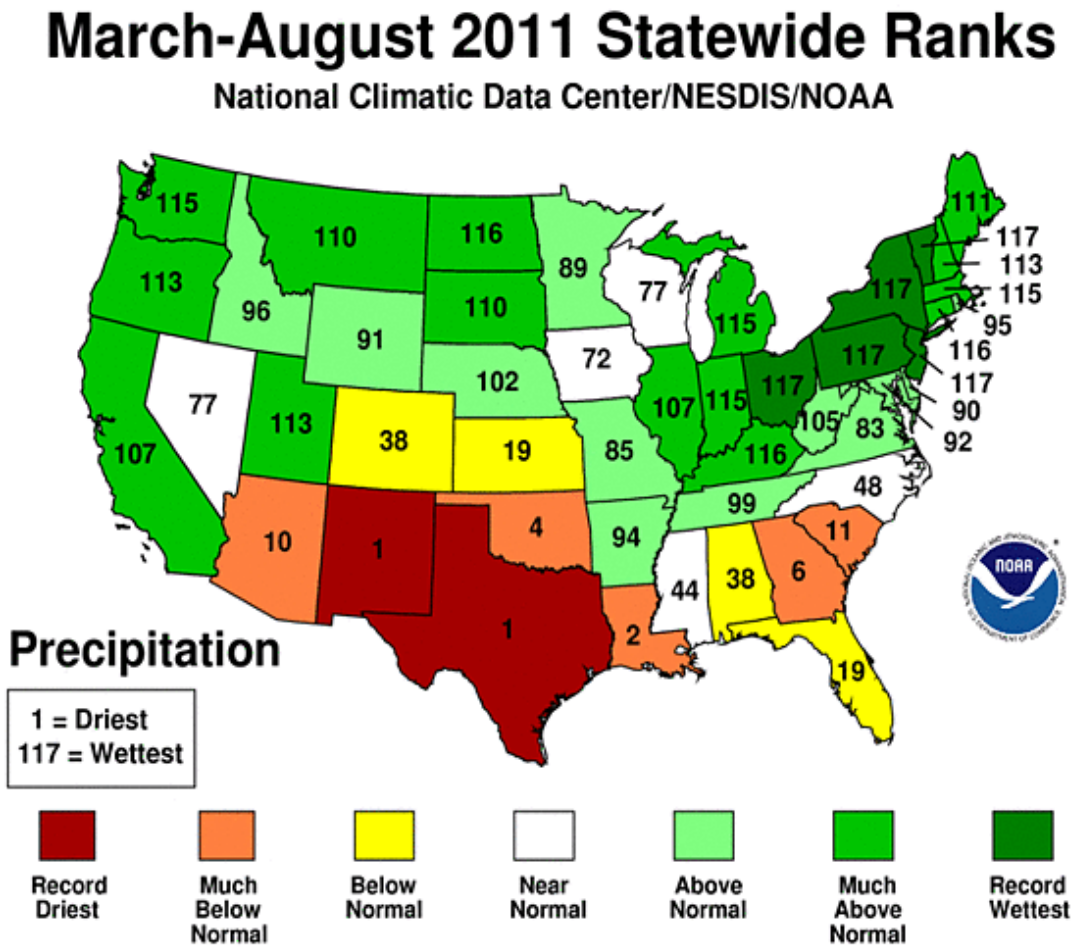
# 2011 Classic Flood Situations

- **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 floods on Winooski and Adirondack rivers**
  - **Lake Champlain record flood stage of 103ft**

- **Irene flood: tropical storm moved up east of Green Mountains and Catskills**
  - **dumped 6-8 ins rain on wet soils**
  - **Extreme flooding**

# 2011 Floods: VT and NY

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




**March-August, 2011**

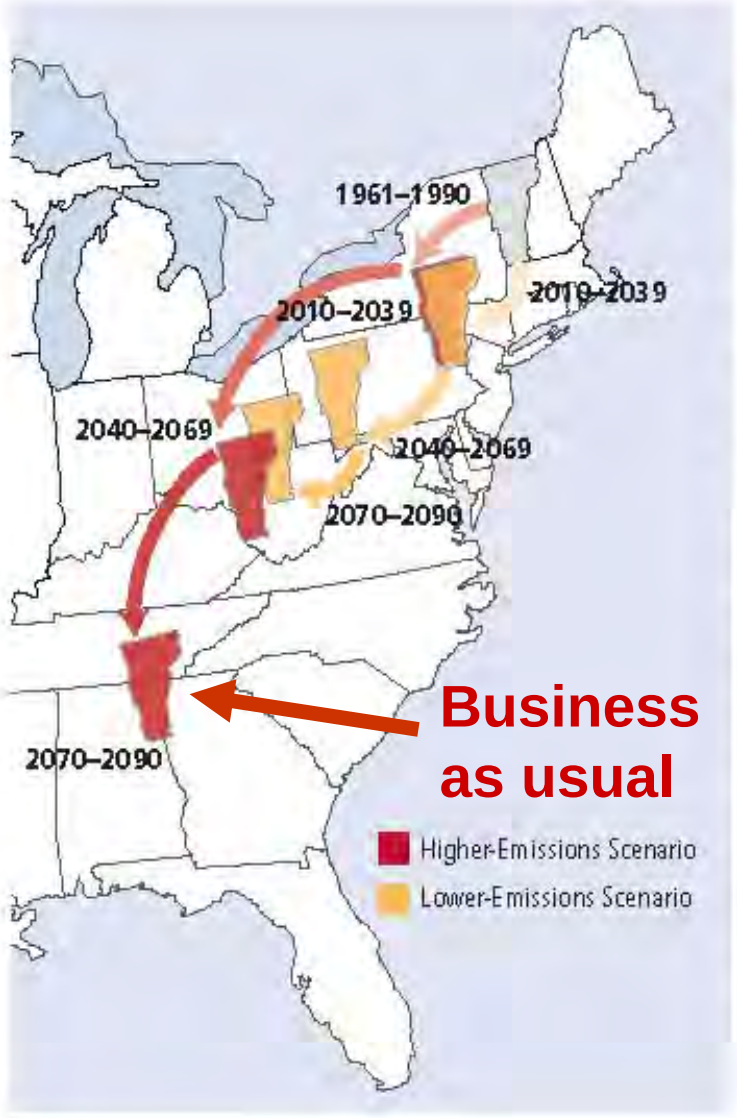
- **Record wet : OH to VT**
- **Record drought: TX & NM**

- ***Pattern nearly stationary***

# Vermont's Future with High and Low GHG Emissions

**What about VT forests?**

**Sub-tropical drought areas moving into southern US**




**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.

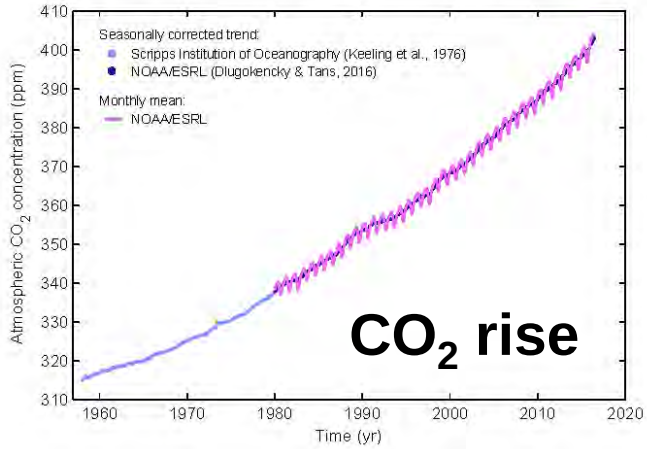
***NECIA, 2007***

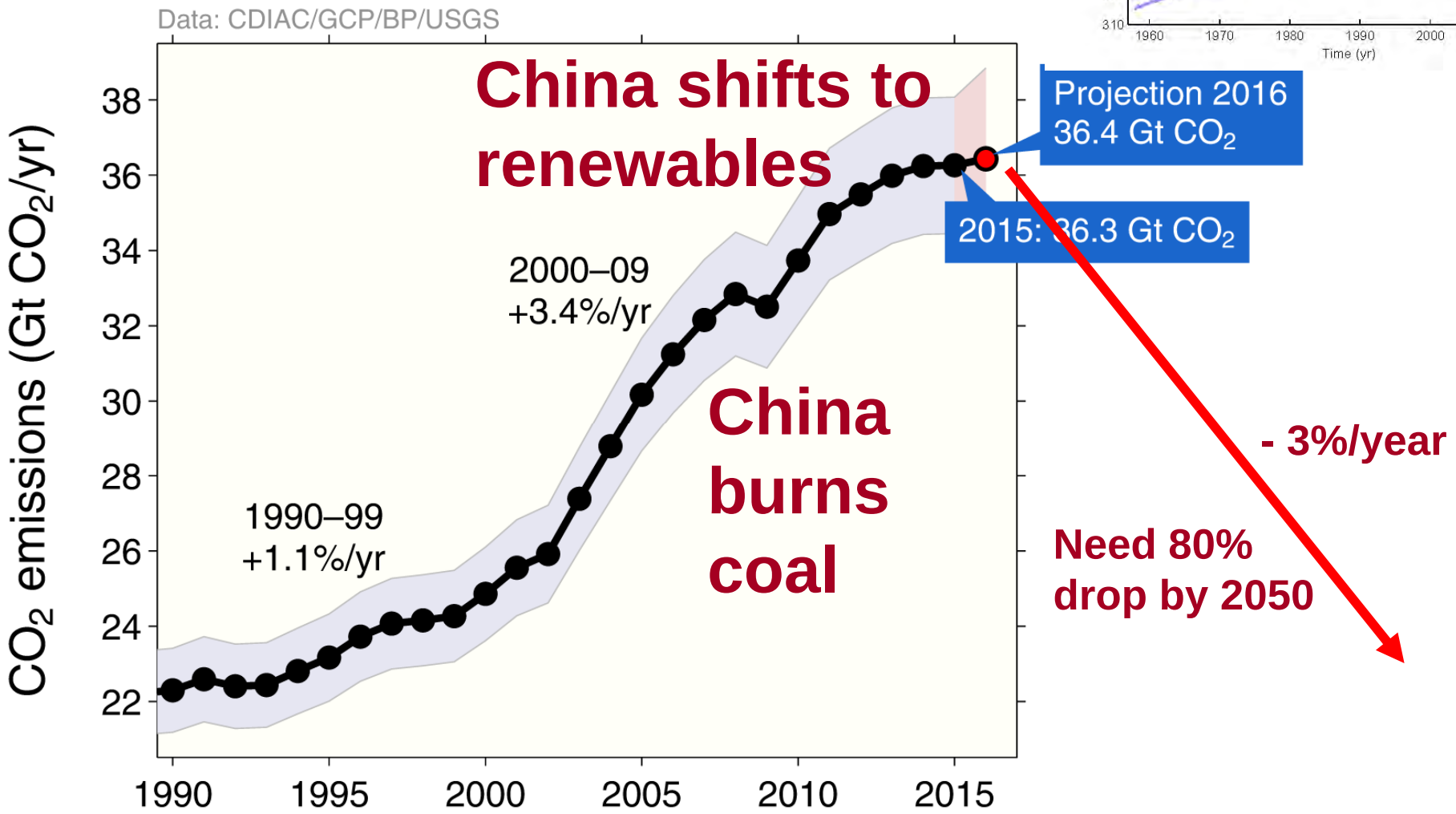
# Can We Stop "Dangerous Climate Change"?

*(UNFCCC 1992)*

- **Yes: Quickly stabilize atmospheric $CO_2$**
- **This means an 80% drop in $CO_2$ emissions!**
- **This is possible but very difficult**
  - **Fossil fuels have driven our industrial growth and population growth for 200 years**
  - **"Lifestyle" has become dependent on fossil fuels**
  - **Powerful vested interests: $trillions at stake**

# Growth of $CO_2$ Emissions Flat for 3 years



# What can we “safely” burn?

- **Only 750 Gt more for an even chance of keeping warming below 2ºC [3.8ºF]**
- ***Requires leaving 2/3 of remaining fossil fuels in ground***
- **Only 21 years left at 36 Gt/year**
- ***Rapid phase-down extends period***

# Efficiency Comes First

- **We need to double or triple our energy efficiency because…**
  - **We cannot replace current fossil fuel use with biofuels & renewable energy**
  - **Fossil fuel reserves are enough to push $CO_2$ to 1,000 ppm**
    - ***Radically change climate/wipe out many species***
    - ***Flood coastal cities as icecaps melt: and over centuries raise sea-level >100ft***

# 2015 was Transition Year

- **Climate meeting in Paris in December**
  - **188 Nations made ‘national commitments’**
- **Pope Francis 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**
- ***2017: US wants to avoid the commitments it made; China and Europe have to take lead***

# IPCC Special report (SR15) Oct. 2018

- **Paris agreement won't give 2°C warming**
  - **So promised to try: "study 1.5 °C"**
- **SR15: keeping warming below 1.5 °C has huge benefits to Earth**
- **But means massive effort before 2030**
  - ***Reduce emissions by 45% below 2010***
- **Or consequences large by 2040-2050**

# Powerful interests are threatened

- **Fossil fuels reserves are worth $20-30T**
  - **Big money: 'of course we will burn them'**
  - **Regulating or taxing emissions of $CO_2$ is an 'unfair cost to the free market'**
  - ***(Too bad if the Earth's ecosystems are destroyed: our kids can pay the price)***
- ***Our politics are facing collapse:***

  ***fantasy disconnected from real world***
  - ***We are all deeply embedded in system***

# Step back from dark side

- **Practical Local Solutions**
- **Vermont: some progress (< promised)**
  - **Large solar development**
  - **Battery storage coming**
    - **California installing 100MWh storage units**
  - **Energy efficiency for homes and businesses underway**
  - ***Need net-zero building codes***
  - ***Need transportation shift***

# Social and moral shift

- **The Future Is Not Our Past**
  - ***an economic, technological and financial system driven primarily by short-term profit***
- ***Collectively, we create the future***
  - ***Plan for a transition to a sustainable society***
  - ***Put community values and systems thinking above short-term profit***
  - ***Reconnect with the natural world***
- ***Will we turn the ship around?!***

# Outreach as scientists

- **We face many environmental catastrophes in your lifetime**
  - ***You need awareness, knowledge, vision, skills, resilience, community, grounding in the Earth***
  - ***You will be expected to guide in desperate times, so prepare with an open heart***
  - ***Realize the depth of our interconnections***

# Traditional Solutions…

- **More Science, more solid 'predictions'**
- ***Better communication of Science***
- **Hope that policy will catch up**
  - **But total mismatch of timescales, trends**
  - **In US, overt corruption increasing**
- ***Earth scientists have a responsibility for the Earth*** ***(Betts, BAMS 1976)***
  - ***Accept this moral responsibility as a global community of scientists***

# Paradigm shift for science

- **Great value of science is its honesty, integrity and its cooperative global vision**
  - **It deals with the measurable world**
  - **It communicates openly and globally**
  - **Priceless to societies lost in corruption & deceit**
- **Challenge is that humanity is embedded in a deeply interconnected living Earth system**
  - **That cannot be separated and objectified**
  - **In fact the incompatibility of our social frames with the Earth system is driving climate change**
  - ***Earth system limits need adaptive co-operative global governance that values the future***

# *alanbetts.com*

- **50 years of research papers**
- **10 years of newspaper articles**
  - **Written so a scientist will see them as accurate; transparent to public (art-form)**
- **10 years of talks to VT**
  - **Schools, citizen & business groups**
  - **I say “Yes” when asked**
- **I rely on ‘serendipity’**

# Discussion

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***(Research, talks & articles )***