



Global and Local Climate and our Future



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BREE Intern Orientation
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Outline

- **Science of climate change**
 - Global and local
 - What is happening to Vermont?
- **The transition we face**
 - How can we stabilize the climate?
 - What are scientists' responsibilities?

Discussion

Strategies for Resilience

- Understand technical/ecological issues
 - Don't build bridges with alternative facts
- Engineer for efficiency and resilience
 - Not “cost effective for today's bottom line”
- Spend \$1 trillion on climate resilience
 - saves \$60 trillion later this century
- If we ignore climate change
 - costs to human civilization and Earth's ecosystem catastrophic
- Community resilience!



Fundamentals

- ***Burning fossil fuels: transforming climate***
 - *Many water cycle amplifying feedbacks*
 - *Heading for high CO₂ “Carboniferous era climate”*
 - *Climate extremes increasing.*
 - *Severe weather costs: \$300B in US last year*
 - *Decadal to centennial - long timescales*
- **Avoidance of responsibility for decades**
 - Politicians, professionals, public
 - Climate change: Incompatible with business-as-usual
- **Linked to unmanaged technology**
 - Soluble by changing system guidelines
 - Create efficient society, based on renewable energy
- **Choices are value based**
 - Beyond science and economics
 - Community based

January 4, 2012: NASA

Earth's climate sustains life

- Increasing greenhouse gases reduces cooling to space
- **Climate is warming: ice is melting, extreme weather is increasing**
- Water plays crucial amplifying role



Hurricane season: 2017

- Earth is warming as greenhouse gases increase and reflective ice cover falls
- Oceans are storing 93% of heat
 - Warmer Atlantic, Caribbean, Gulf of Mexico and Gulf Stream means stronger hurricanes; when vertical shear is low
- *2017: Harvey, Irma, (Jose), Maria*

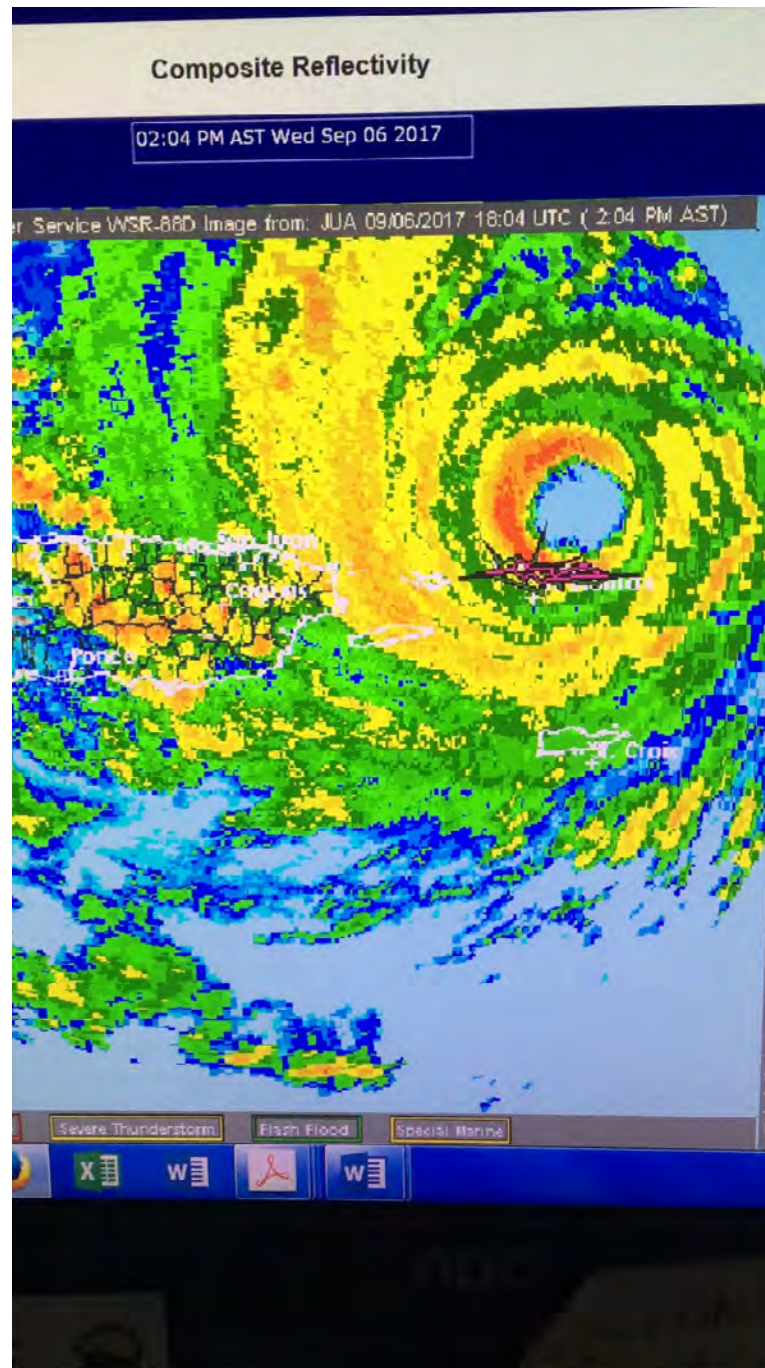
Why was Harvey so Damaging?

- Huge evaporation off warm ocean
- Category 4 hurricane developed
- Very heavy rain-rate: 10-12 inches per day
- Two stationary high pressure systems to the north **trapped** Harvey for 4 days over Houston
- Result **40+ inches** of rain & massive flooding

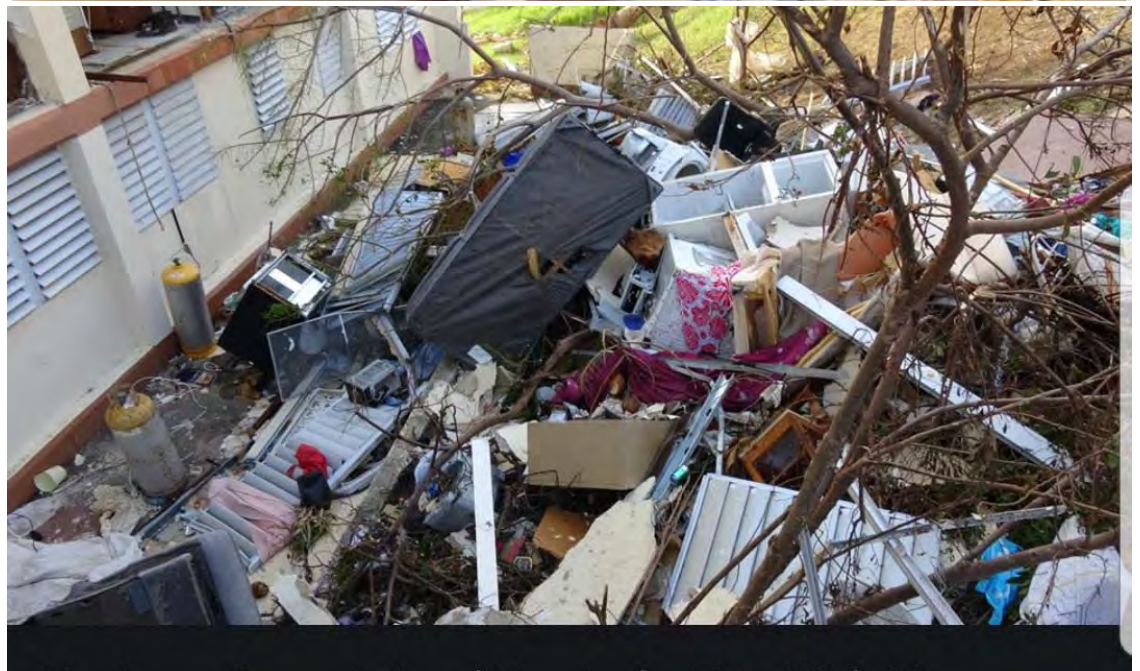


2pm Sept. 6
Category 5*
IRMA
grazing
St Thomas

****Cat 5 >155mph***
IRMA >180mph



Irma(Cat.5)
Sept. 6
St Thomas



Irma and Jose: Sept 7



After Jose passed; Catamaran to Puerto Rico on Sept 11

Maria: 5:30am Sept. 20

Category 4 hits Puerto Rico

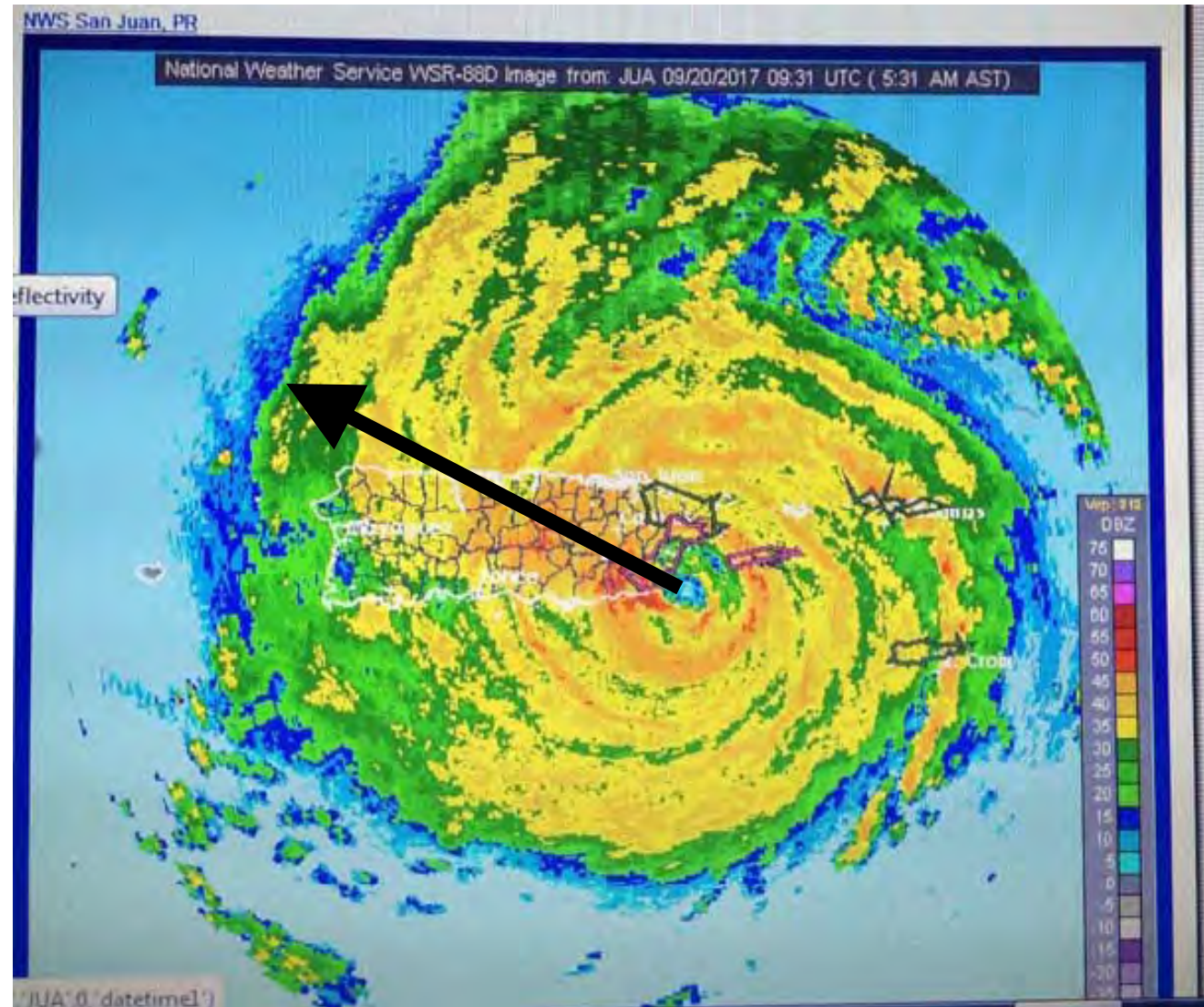
Cat 4

>130mph

Maria

>150mph

***Wiped cell
towers and
power grid
(90% back
after 6 mos!)***



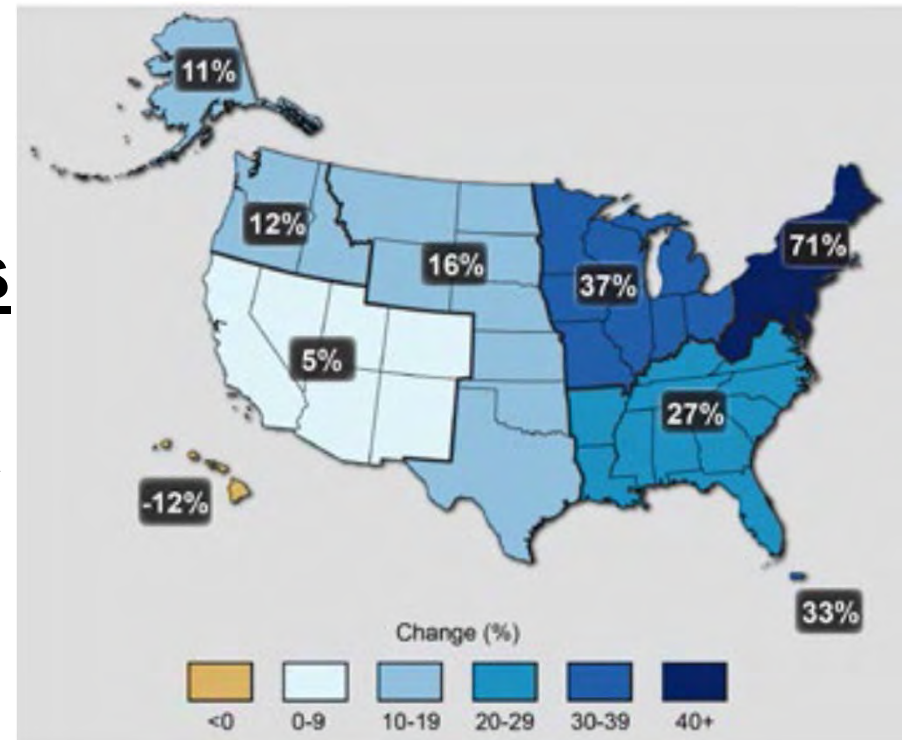
Two Severe Tropical Cyclones hit Mozambique

- Southeast Africa cyclones were very rare
- *Idai* in March left 1000 dead from flooding
- Cat 4 *Kenneth* in April
 - 60 in of rain



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**

TS Irene

*Rte 131,
Cavendish
Sept, 2011*

Roads in valleys

Massive damage

**Some roads took
months to repair**

Wake-up call



TS Irene: 2011



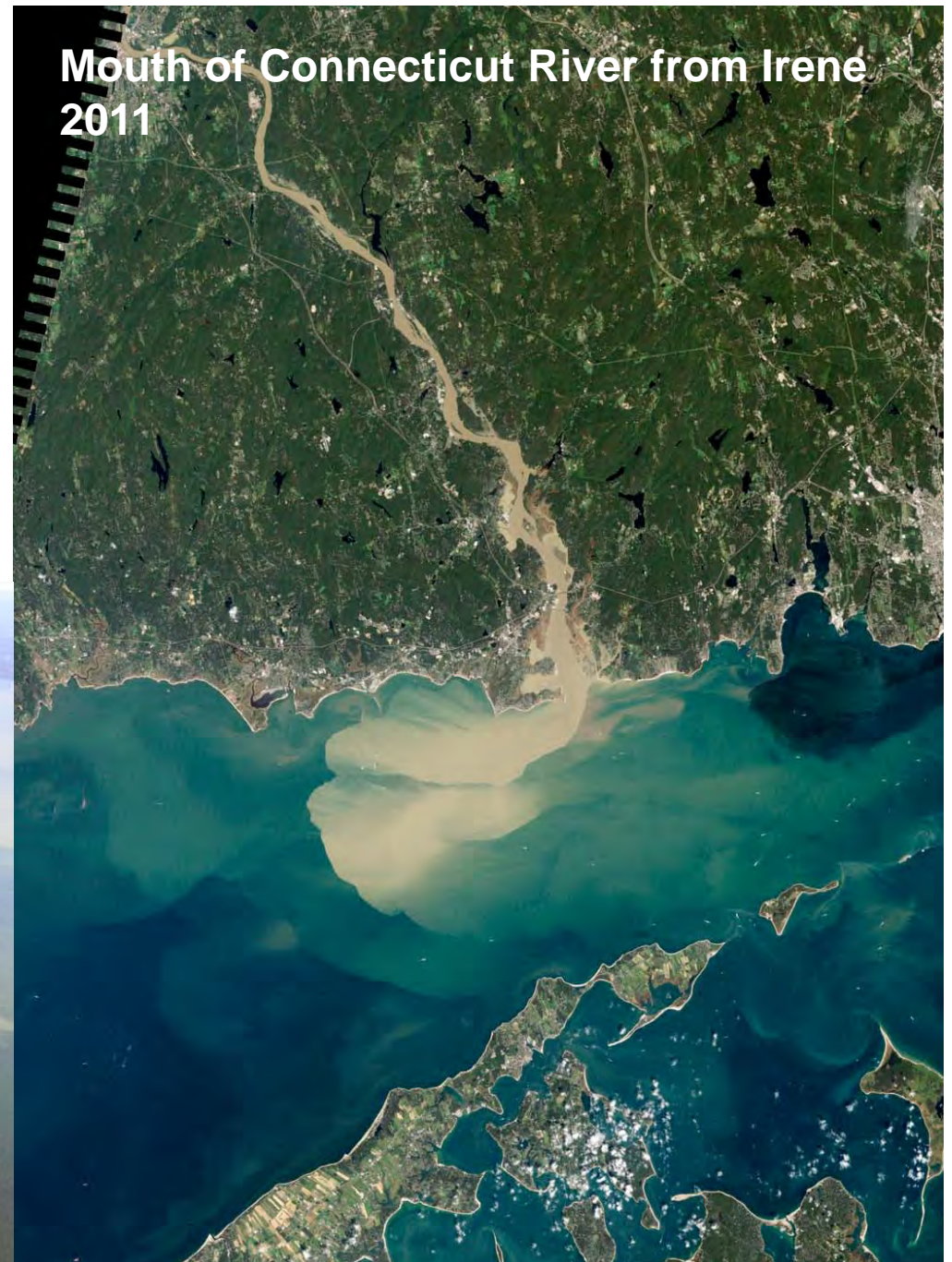
Brattleboro, VT, Courtesy of
Caleb Clark, CNN



Brattleboro, M. Reston



Wilmington, J. Cantore



Lake Champlain, Spring 2011, Courtesy LCBP

2011 Classic Flood Situations

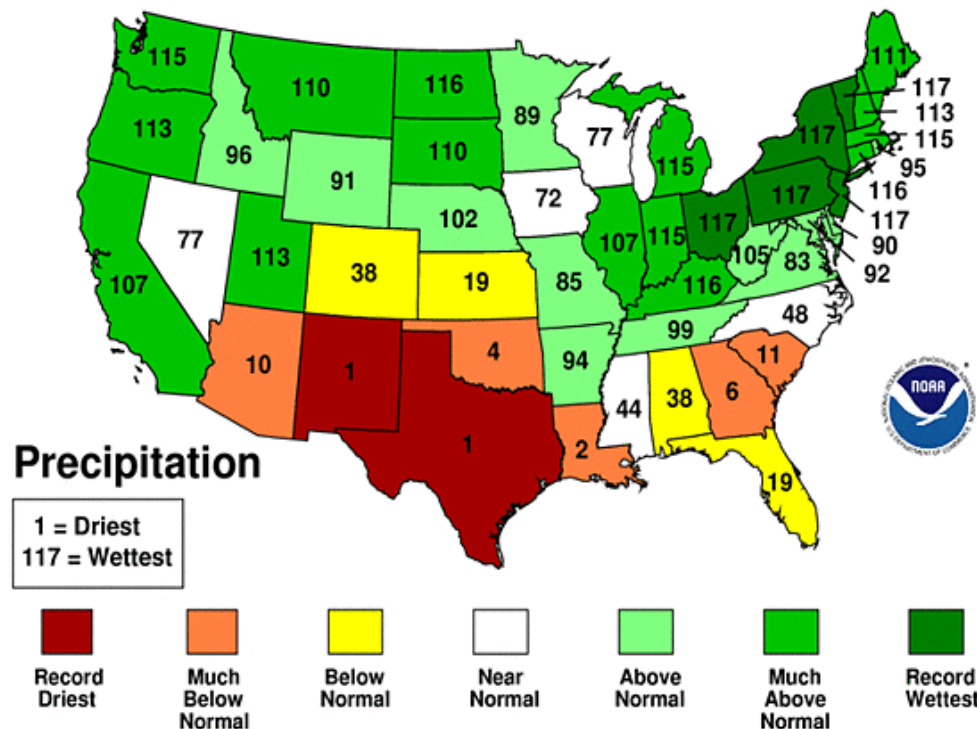
- **Spring flood:** heavy rain and warm weather, melting large snowpack from 2010-11 winter
 - 70F (April 11) and 80F(May 27) + heavy rain
 - record April, May rainfall: 3X at BTV
 - Severe floods on Winooski and Adirondack rivers
 - Lake Champlain record flood stage of 103ft
- **Irene flood: tropical storm** moved up east of Green Mountains and Catskills
 - dumped 6-10 ins rain
 - Extreme flooding

2011 Floods: VT and NY

- Record spring flood: Lake Champlain
- Record flood with Tropical Storm Irene

March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



March-August, 2011

- Record wet : OH to VT
- Record drought: TX & NM
- Pattern nearly stationary

Value of Flood Plains



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

Irene: Resilience

- 13 towns cut off overnight
- State emergency systems flooded
- FEMA: no road access
- Communities reorganized overnight
- Those with equipment stepped in
 - “Can fix this in 72 hrs”: will need engineer to check bridge (Brandon)
 - “We worked 120hrs last week...” (Wardsboro)
 - Social networks collected supplies; and rescue services across mountains
 - Communication networks critical

Flooding Issues

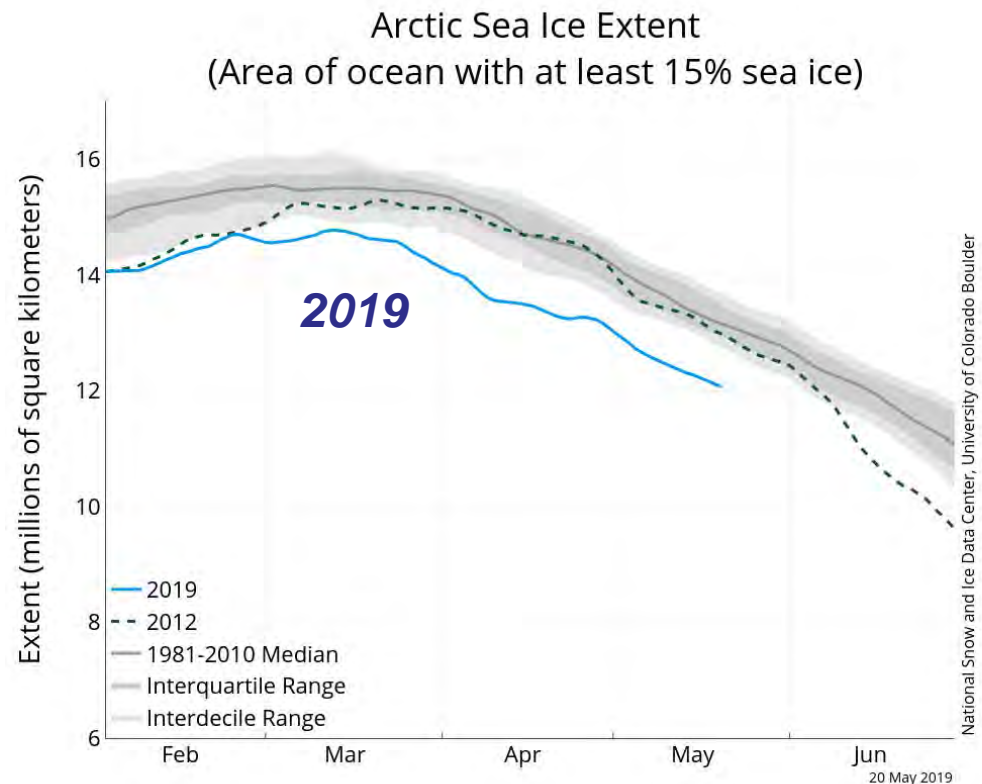
- **Maintain mountain forest cover**
 - Devastating floods in 1920's, 30's with reduced forest cover
- **Manage water/pollutants on landscape**
 - Maximize infiltration: urban and on farms
 - Don't wall-in rivers
- **Preserve flood plains**
 - Saves downstream towns (Middlebury)
 - Stop building houses and trailer parks in flood plains

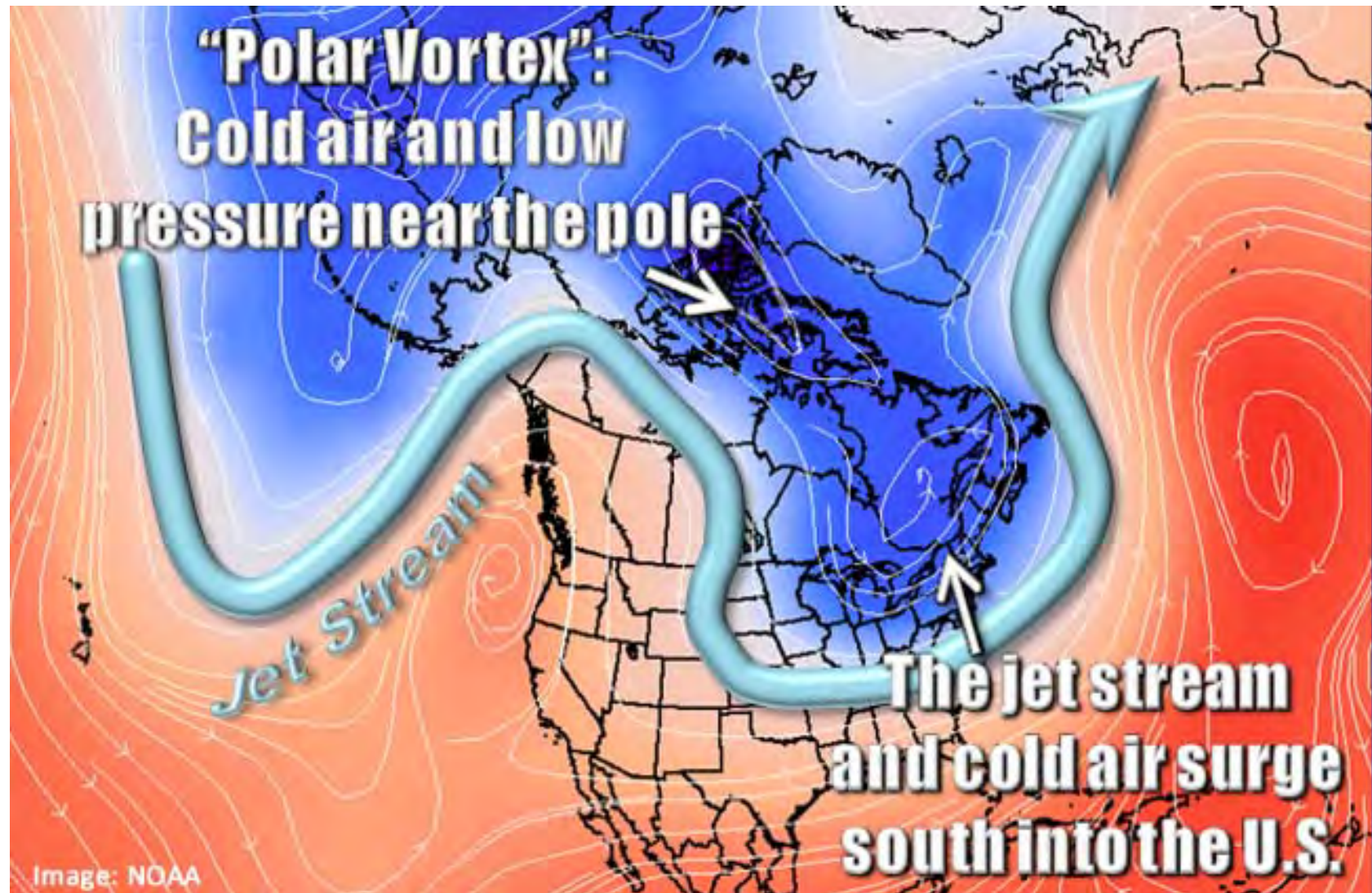
Winters are changing

- as Arctic warms and melts

- **Sea-ice minimum mid-September**

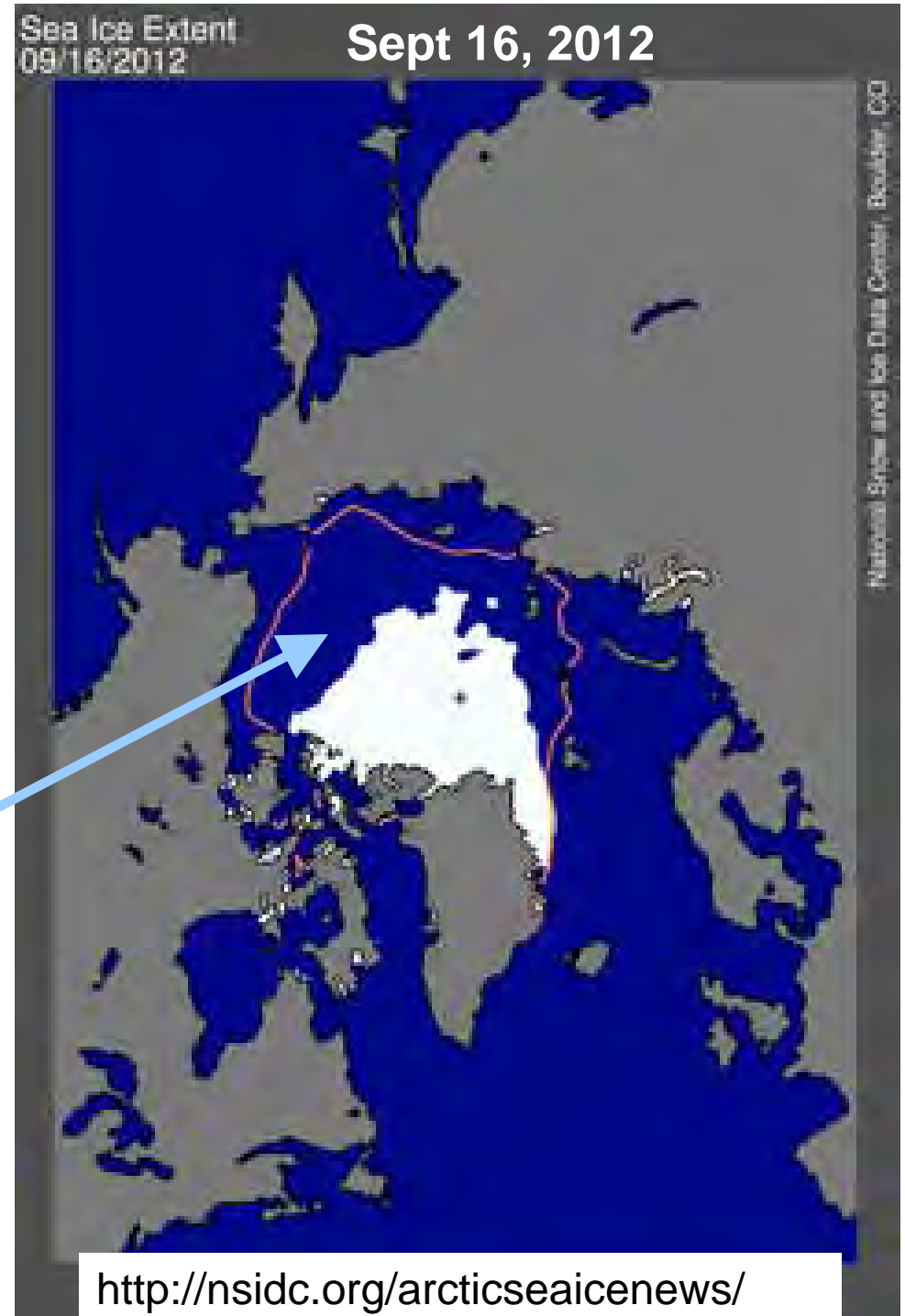
- **Winter sea-ice coverage falling**
- **Sea-ice thinning**
- **Polar vortex weakening**





- **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*





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)



March 3, 2017



January 10 and 12, 2018



January 10, 2018

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

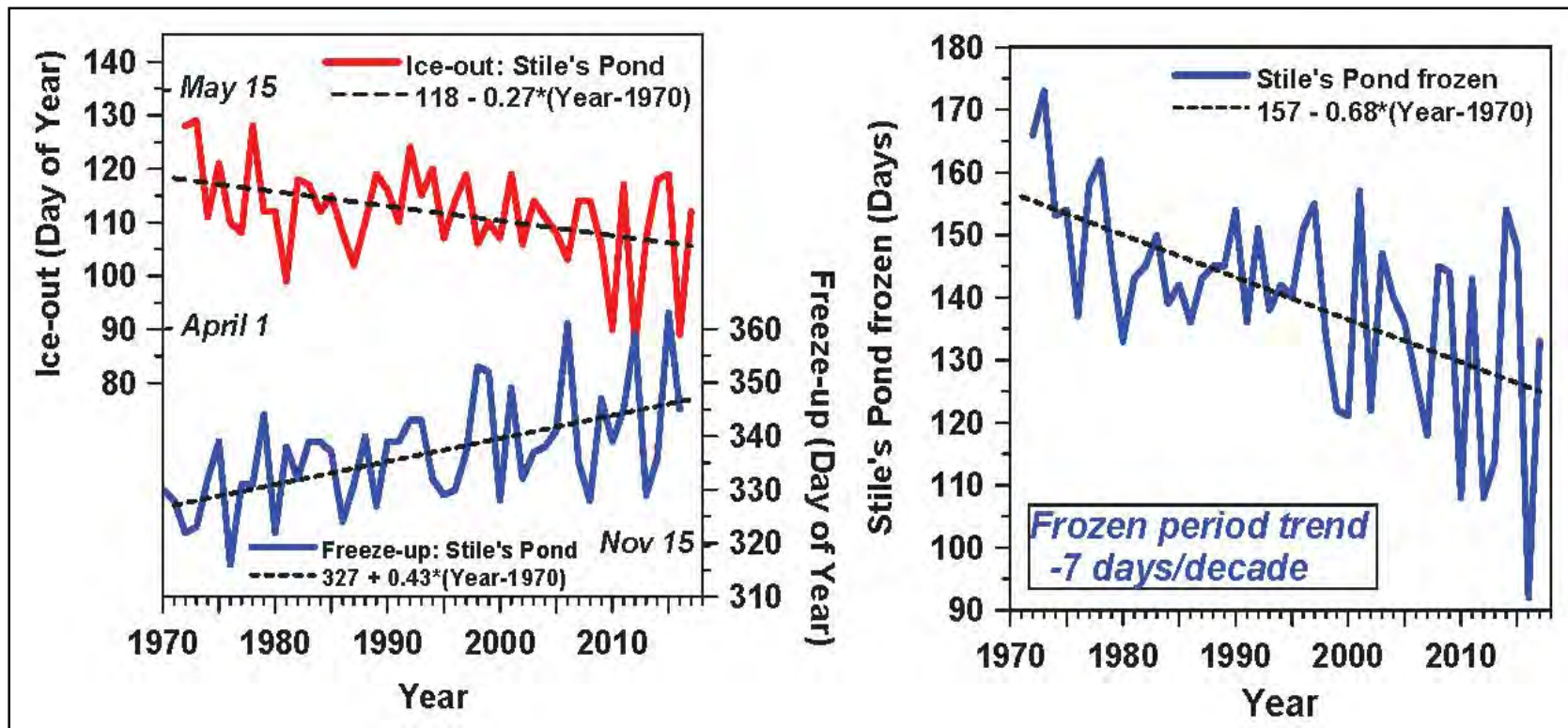


January 12, 2018

After T_{\max} up to 50F

Marker: Lake Freeze-up & Ice-out

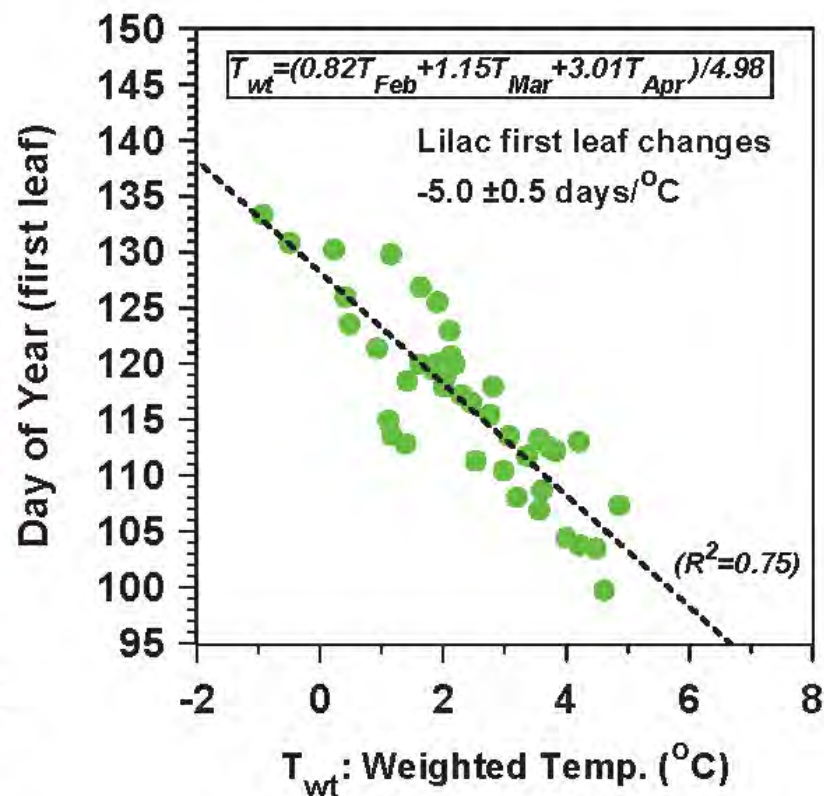
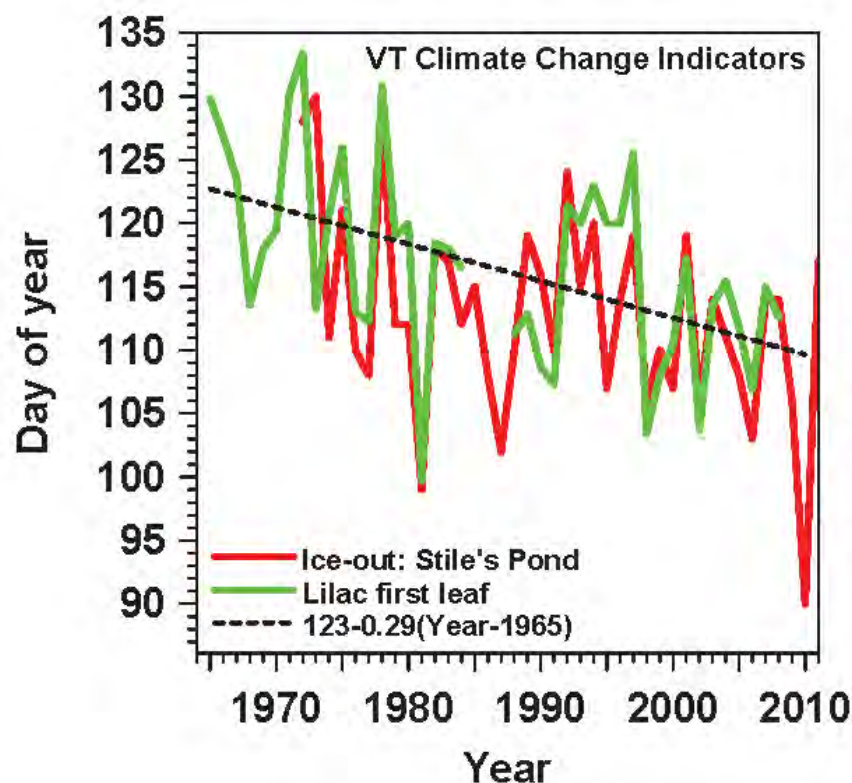
Frozen Period Shrinking: variability huge



- Freeze-up later by **+4 days / decade**
- Ice-out earlier by **-3 days / decade**
- Lake frozen period trend **- 7 days/decade**
- *Interannual variability \approx 40 yr trend*

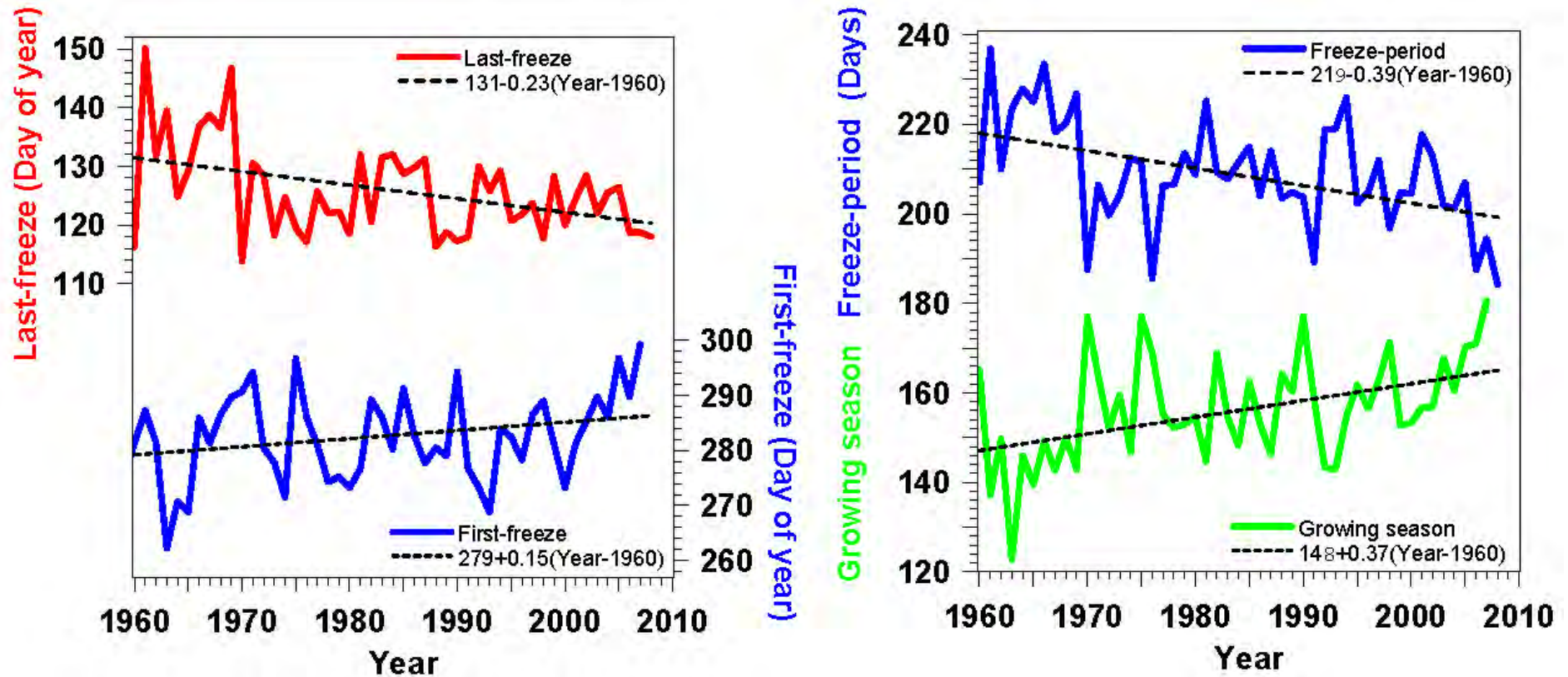
*Stiles Pond:
"Eye on the
Sky"*

Lilac First Leaf Earlier



- First leaf and ice-out changing: -3 days/decade
- Large variability linked to temperature: -5 days/ °C
- (No-snow – Snow) winter = 6*5 ≈ -30 days earlier leaf-out

First and Last Frosts Changing

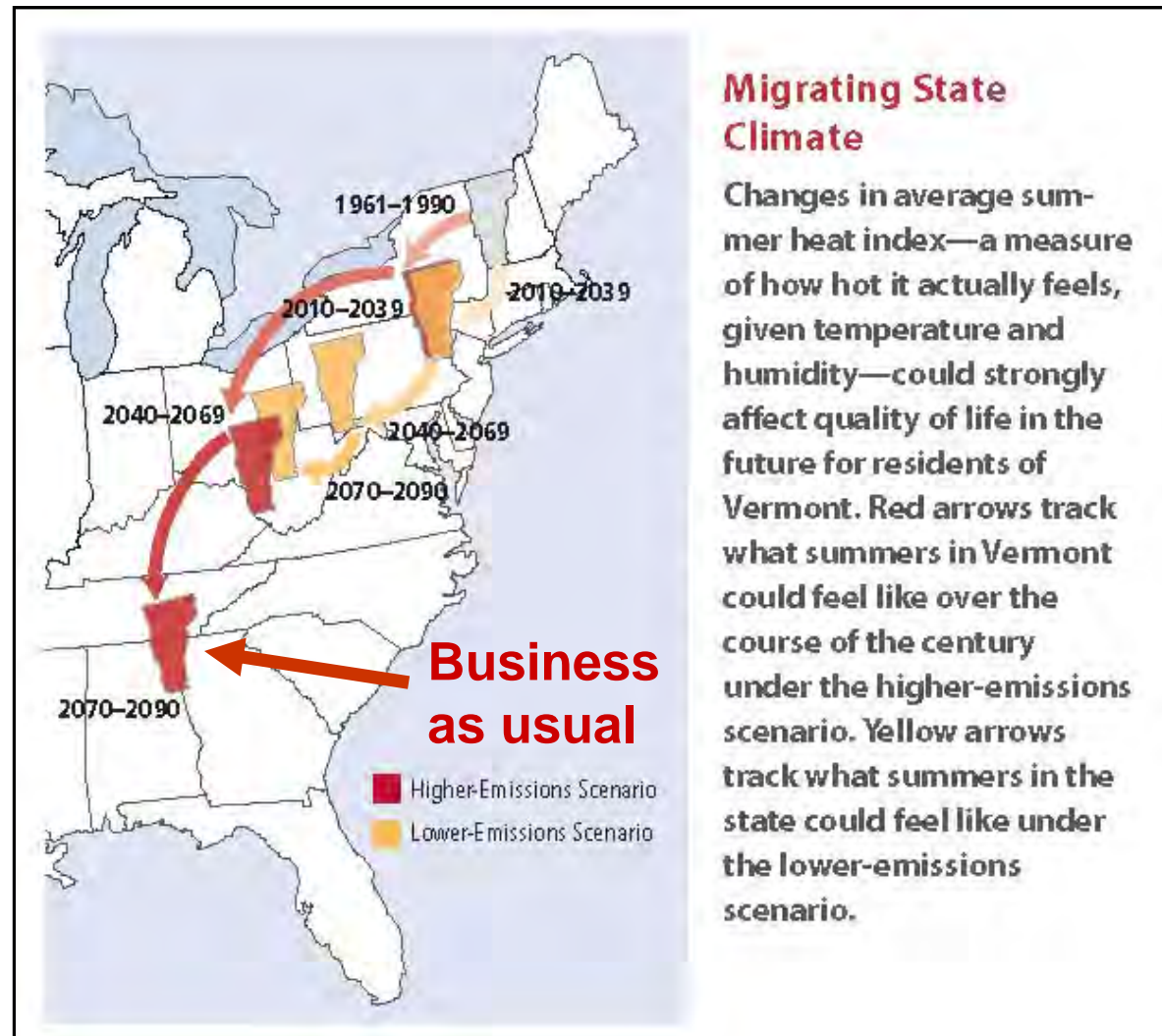


- Growing season for frost-sensitive plants increasing **3.7 days / decade**
- A help for growing “local food”

Vermont's Future with High and Low GHG Emissions

What
about VT
forests?

Sub-tropical
drought areas
moving into
southern US



**NECIA,
2007**

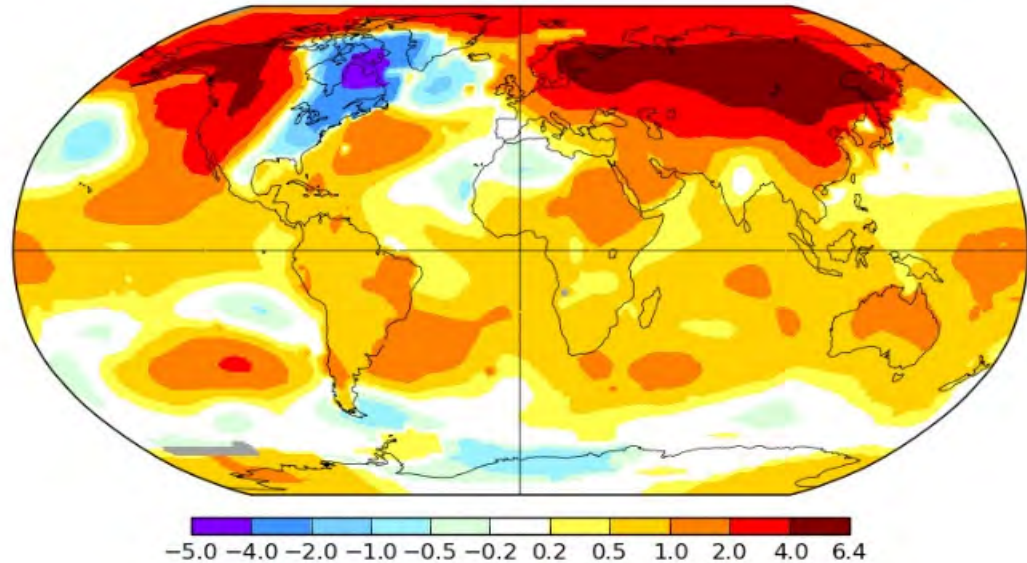
Jan-Feb-Mar 2015

Warm Atlantic, record temp in west;
cold NE, strong coastal storms - Boston record snow

Jan-Mar 2015

L-OTI(°C) Anomaly vs 1951-1980

0.86



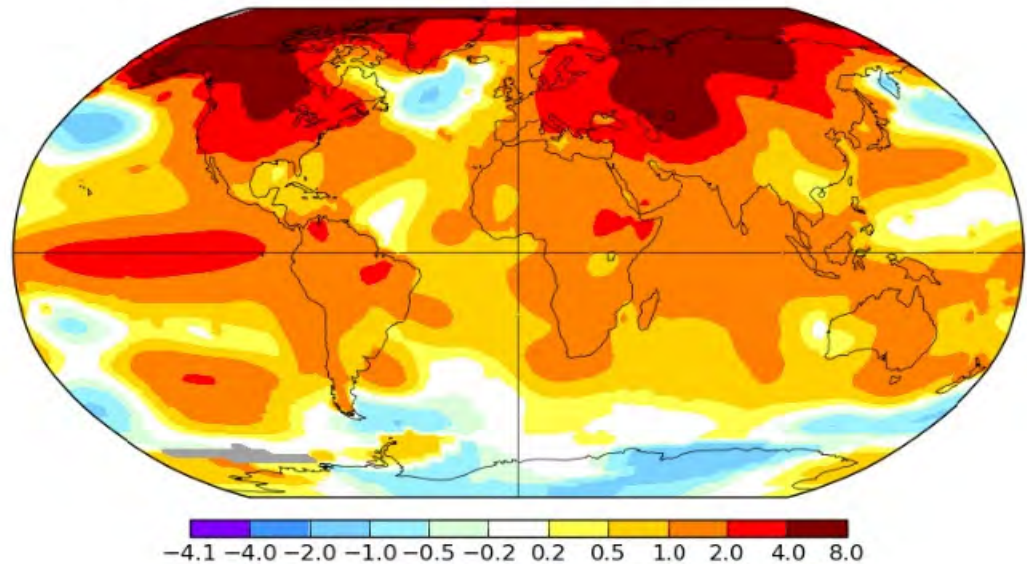
Jan-Feb-Mar 2016

Warm Atlantic, warm NE, little
snow, warm Arctic

Jan-Mar 2016

L-OTI(°C) Anomaly vs 1951-1980

1.24



April-2018

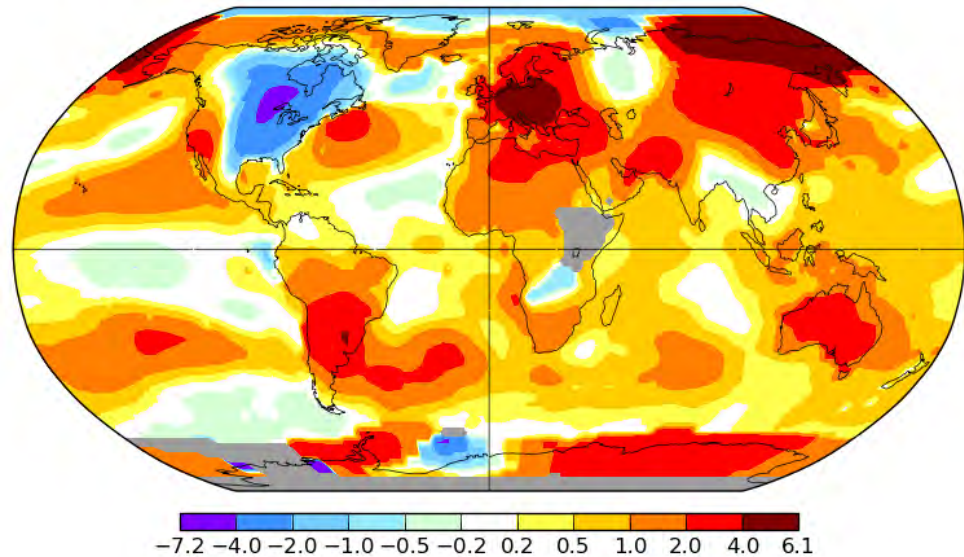
Warm Atlantic, (Record) cold NA;
warm Europe

Record coldest: Wisconsin, Iowa
2nd coldest: Minnesota, S.Dakota,
Nebraska, Kansas, Oklahoma,
Missouri, Michigan

April 2018

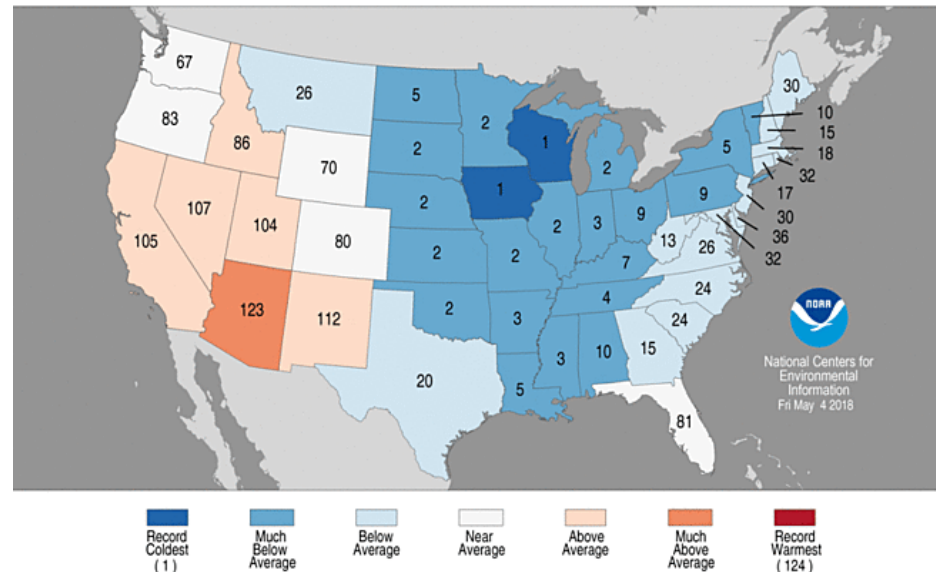
L-OTI(°C) Anomaly vs 1951-1980

0.86



Statewide Average Temperature Ranks

April 2018
Period: 1895-2018



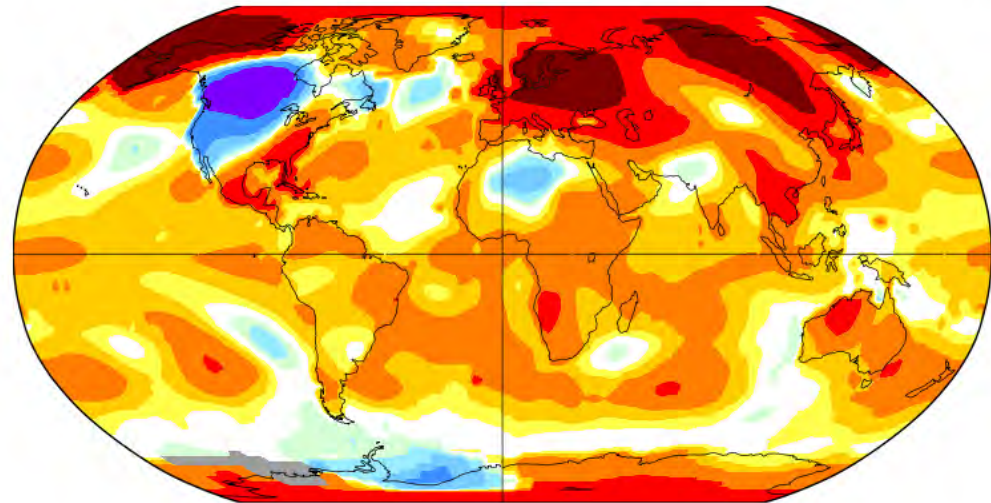
Feb-2019

**Extreme cold, central US, Canada
Extreme warmth UK, Europe, Asia,
NW Alaska**

February 2019

L-OTI(°C) Anomaly vs 1951-1980

0.94



-8.2 -4.0 -2.0 -1.0 -0.5 -0.2 0.2 0.5 1.0 2.0 4.0 12.4

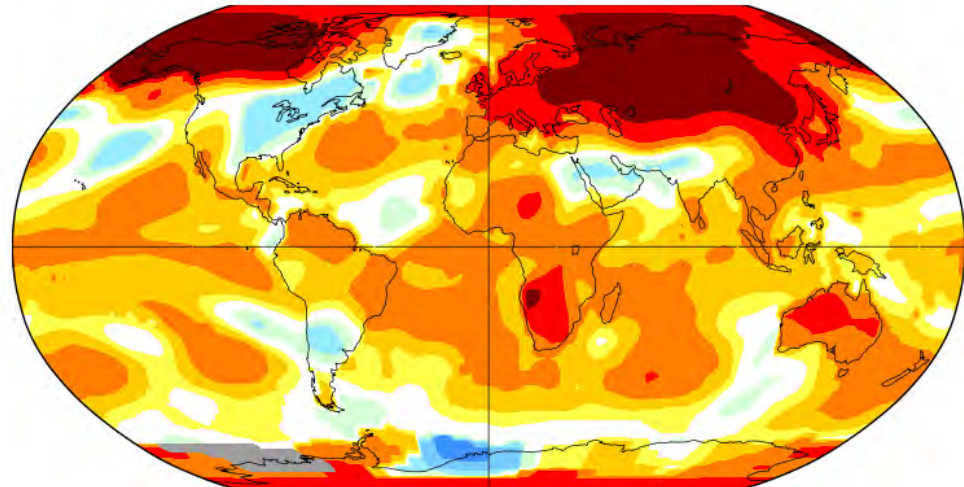
March-2019

**Cold eastern US, Canada
Extreme warmth UK, Europe, Asia
Alaska**

March 2019

L-OTI(°C) Anomaly vs 1951-1980

1.18



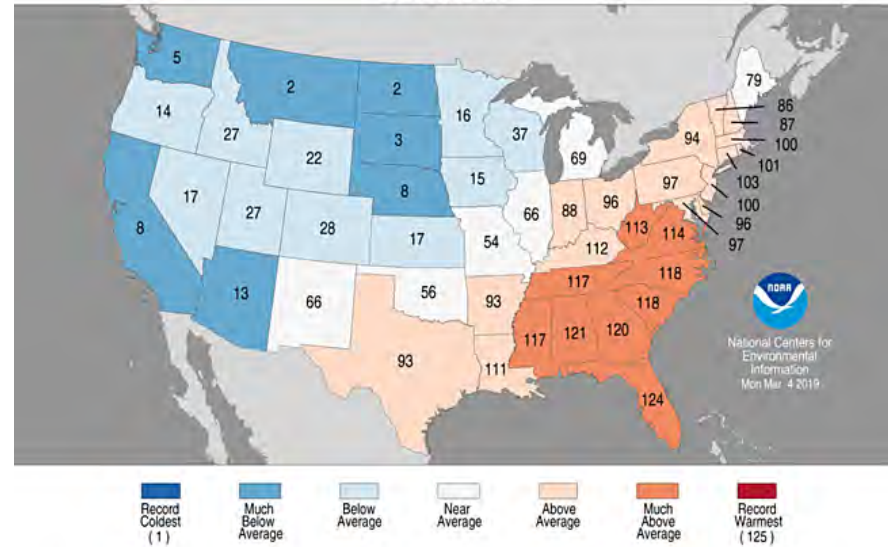
-4.1 -4.0 -2.0 -1.0 -0.5 -0.2 0.2 0.5 1.0 2.0 4.0 13.0

Feb-2019

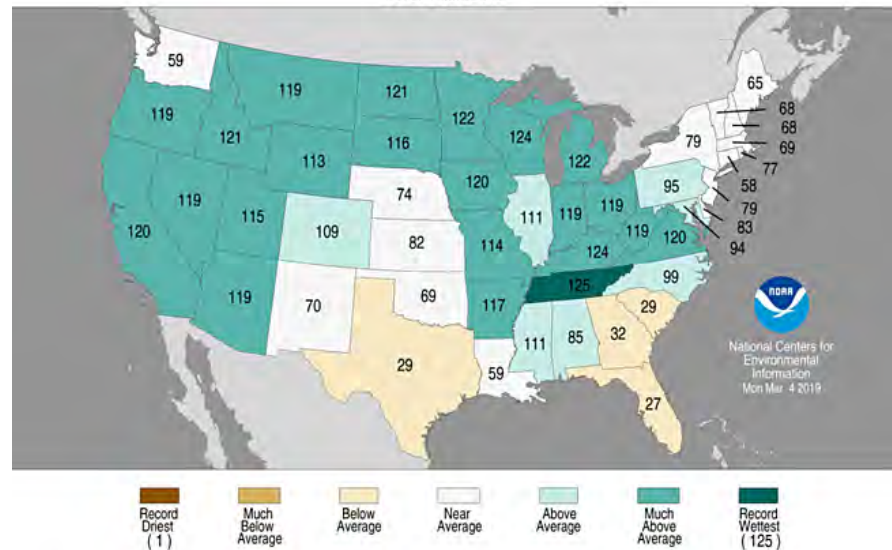
*Second warmest
in South-east*

*Second coldest
in north-central*

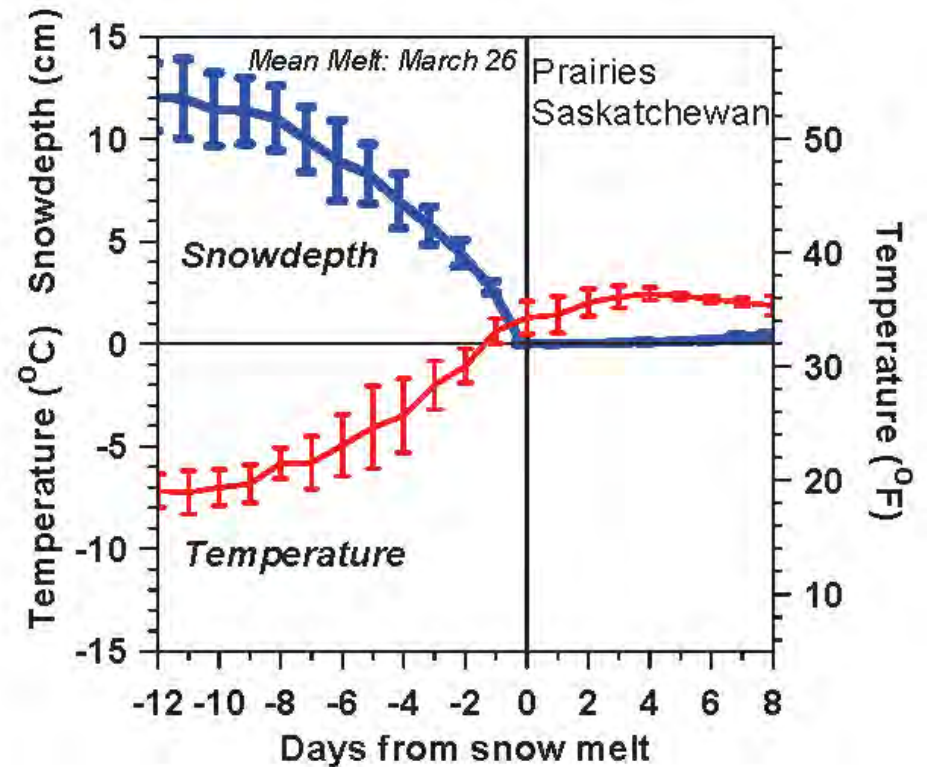
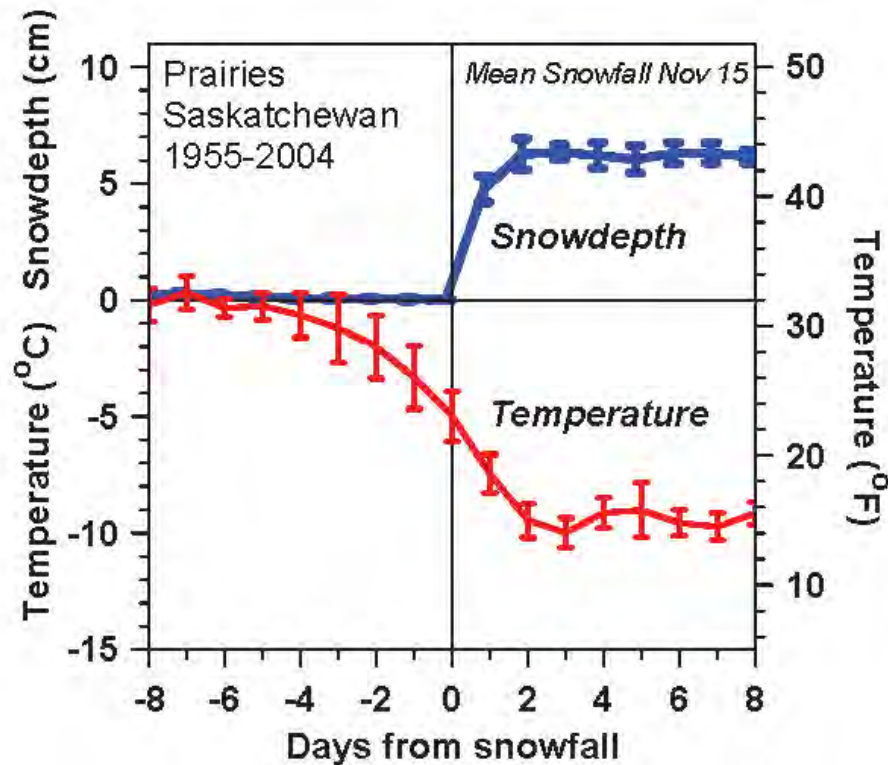
Statewide Average Temperature Ranks
February 2019
Period: 1895–2019



Statewide Precipitation Ranks
February 2019
Period: 1895–2019

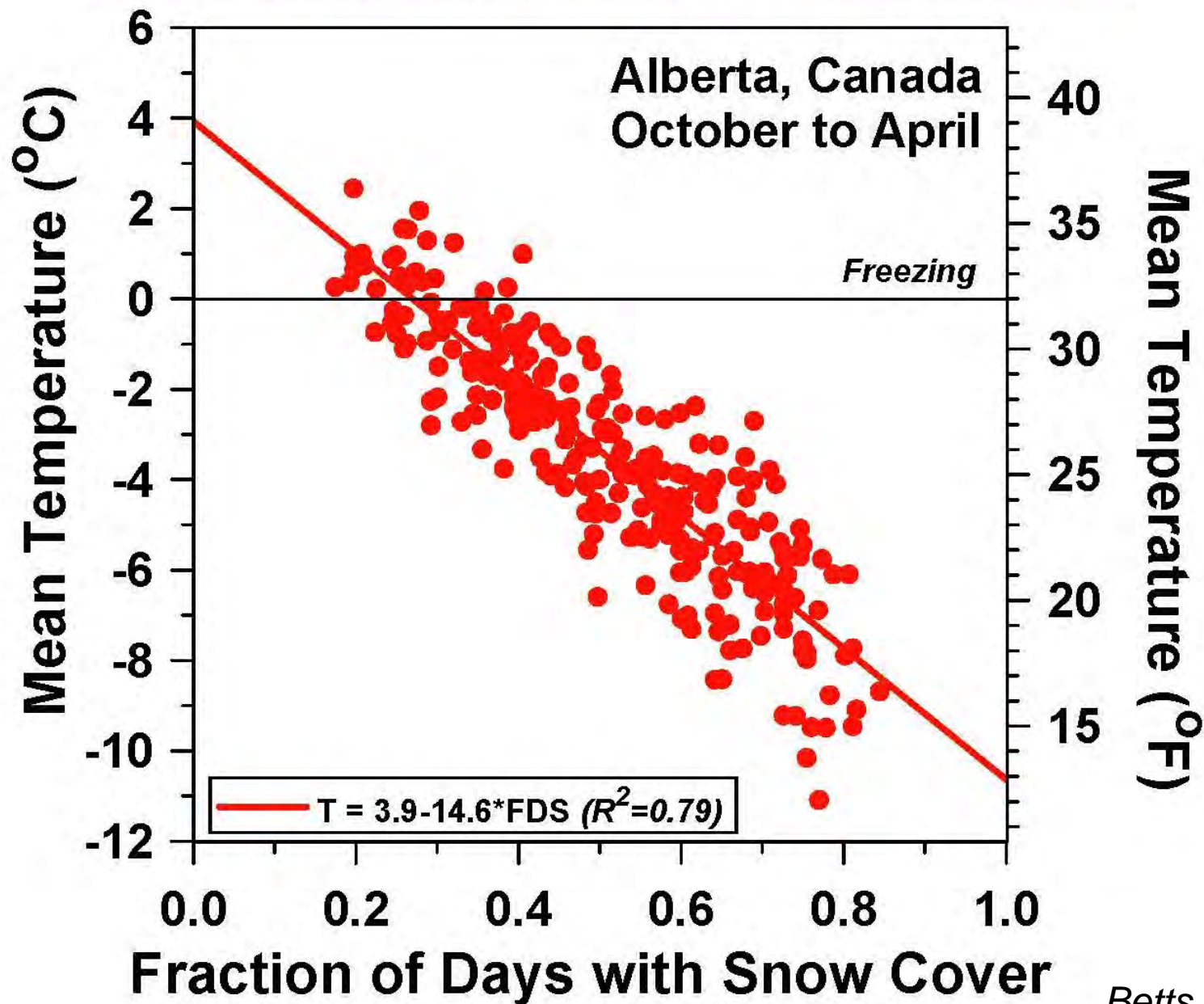


Snowfall and Snowmelt

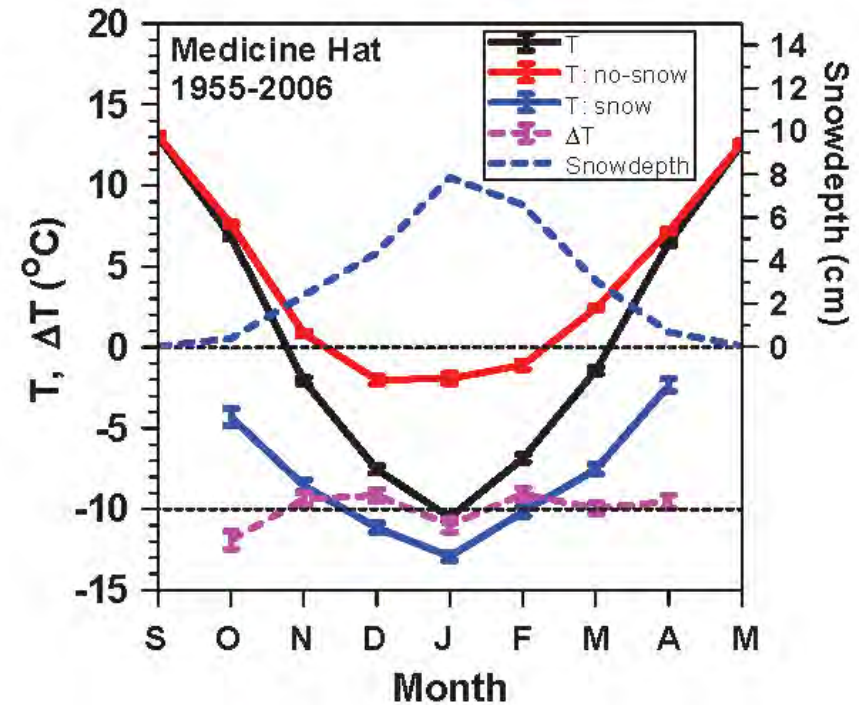
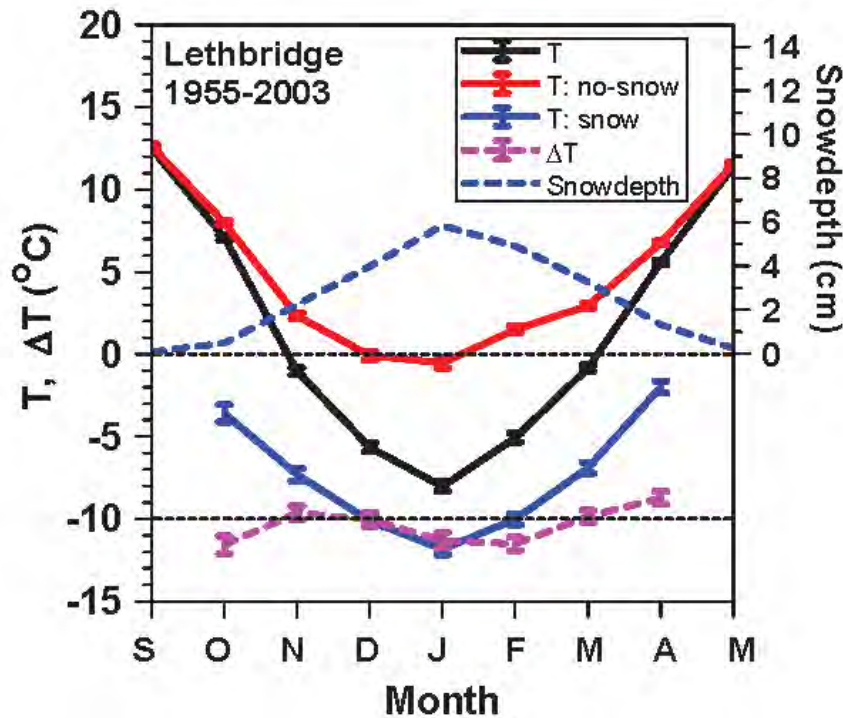


- Temperature changes 10°C with snow cover
- Snow cover is a 'climate switch'
- *Fast transitions in 'local climate'*
 - *Snow reflects sunlight*
 - *Reduces evaporation and water vapor greenhouse*

More snow cover - Colder temperatures



Impact of Snow on Climate



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

$$\Delta T = T:\text{no-snow} - T:\text{snow} = -10.2(\pm 1.1)^{\circ}\text{C}$$

Betts et al. (2016)

Impact of Snow

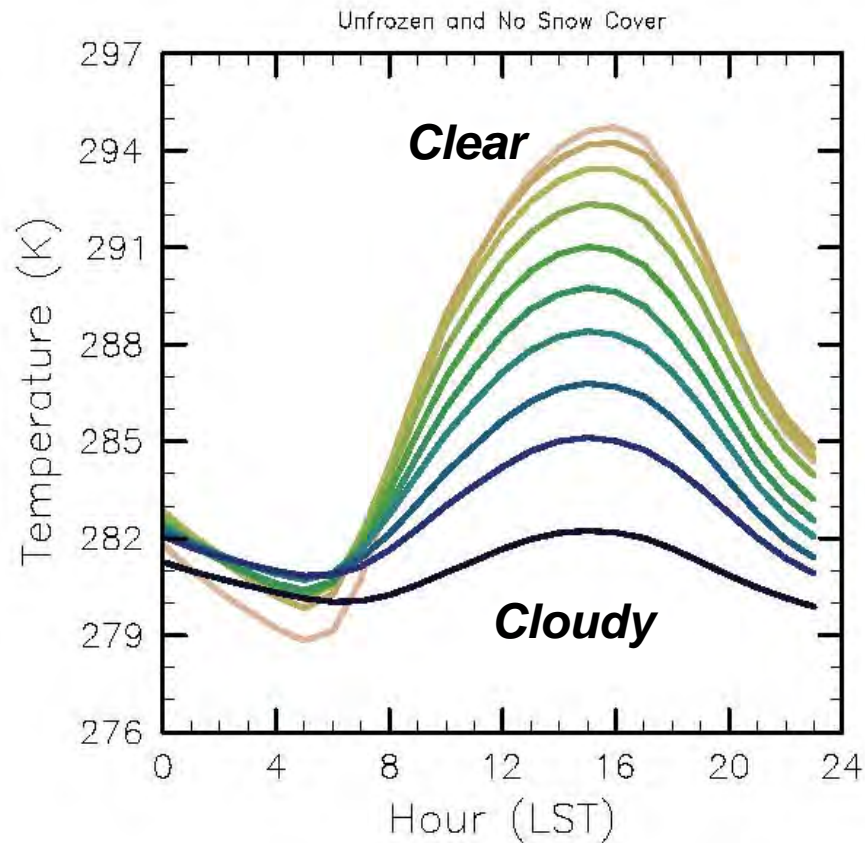
- **Distinct warm and cold season states**
- **Snow cover is the “climate switch”**

With snow

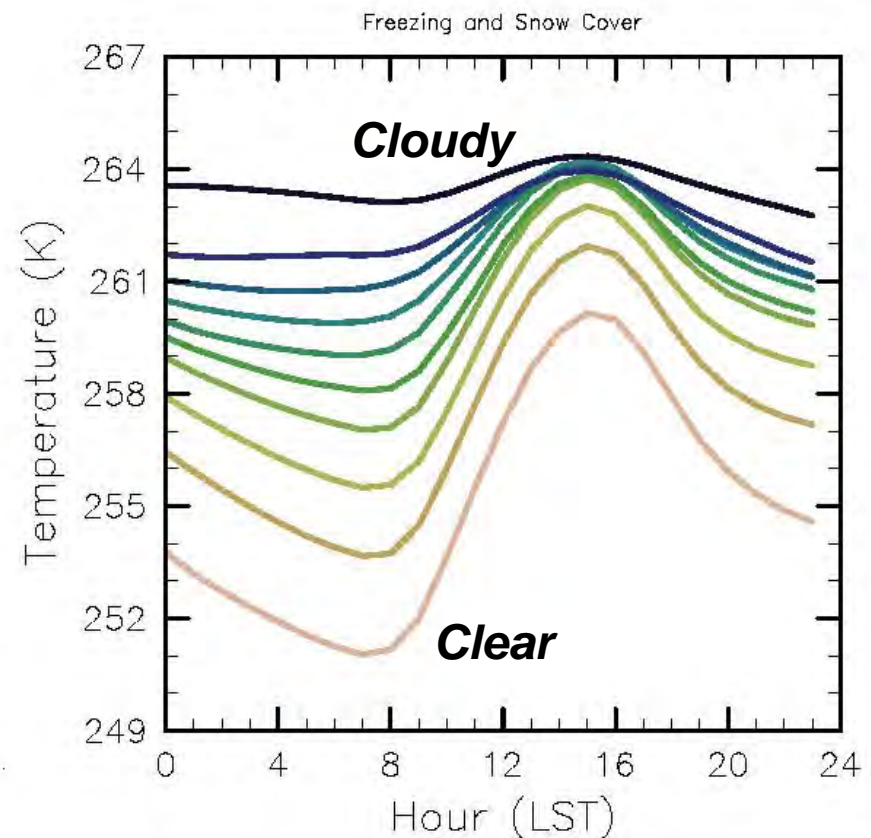
- Prairies: Temperature falls 10°C (18°F)
 - snow reflects 70%
- Vermont: Temperature falls 6°C (10°F)
 - snow reflects 35% (because more forest)

Warm & Cold Climates: $T > < 0^{\circ}\text{C}$

$T_m > 0^{\circ}\text{C}$: no snow: 150,000 days



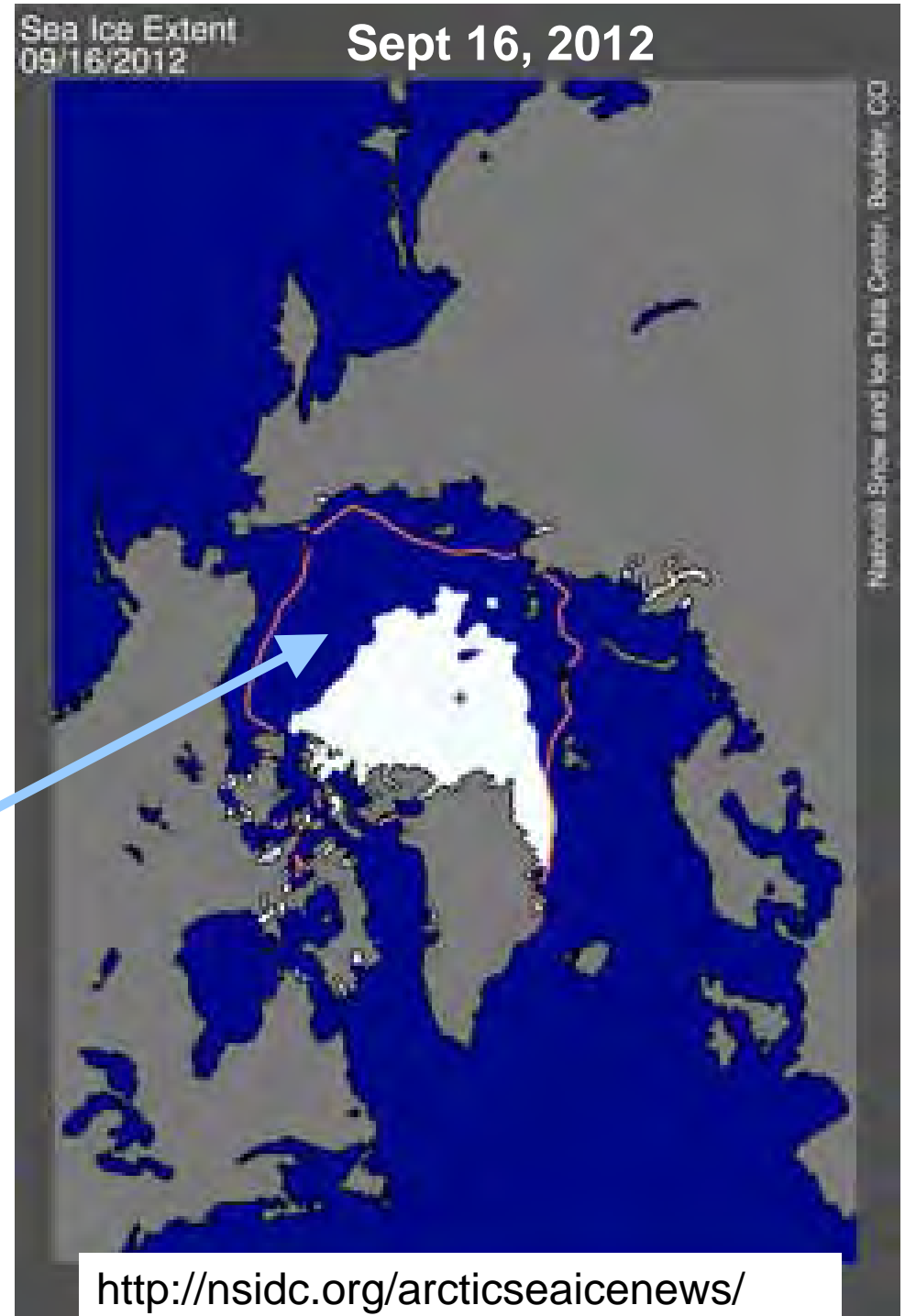
$T_m < 0^{\circ}\text{C}$: snow: 75,000 days



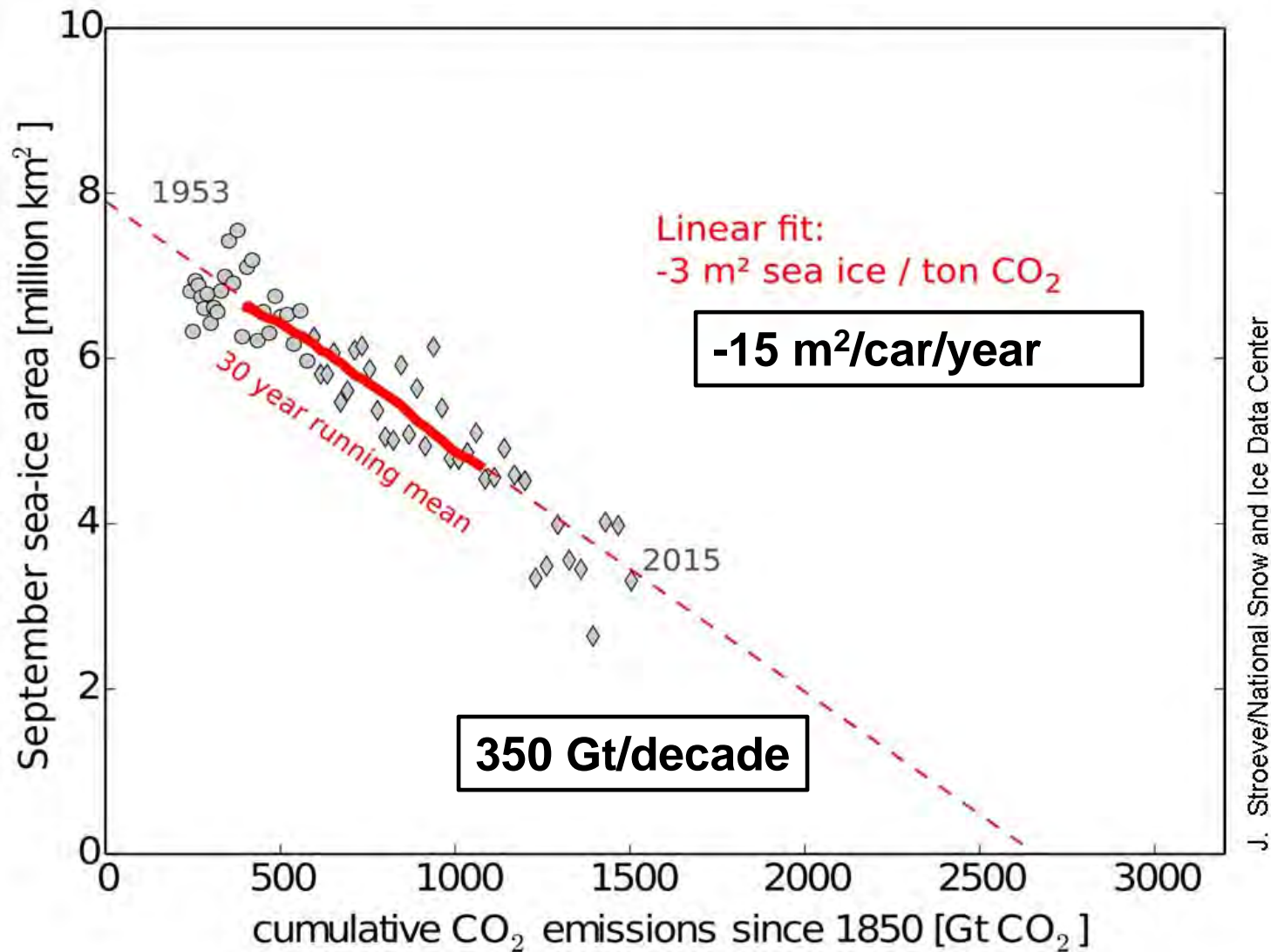
- **Warm $> 0^{\circ}\text{C}$: Clouds reflect sunlight**
- **Cold $< 0^{\circ}\text{C}$: Clouds are greenhouse & snow reflects sun**

- 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



September Arctic Sea Ice Loss



Efficient transport

- Gasoline to hybrid: 50% gain to 50mpg
- Hybrid to plug-in hybrid: now 130mpg
- Electricity from community solar array



>3000lbs and 130 mpg
Payload: 750 lbs at 60 mph



180lbs gets "1800 mpg"
Payload: 350lbs at 25mph

Can We Stop “Dangerous Climate Change”?

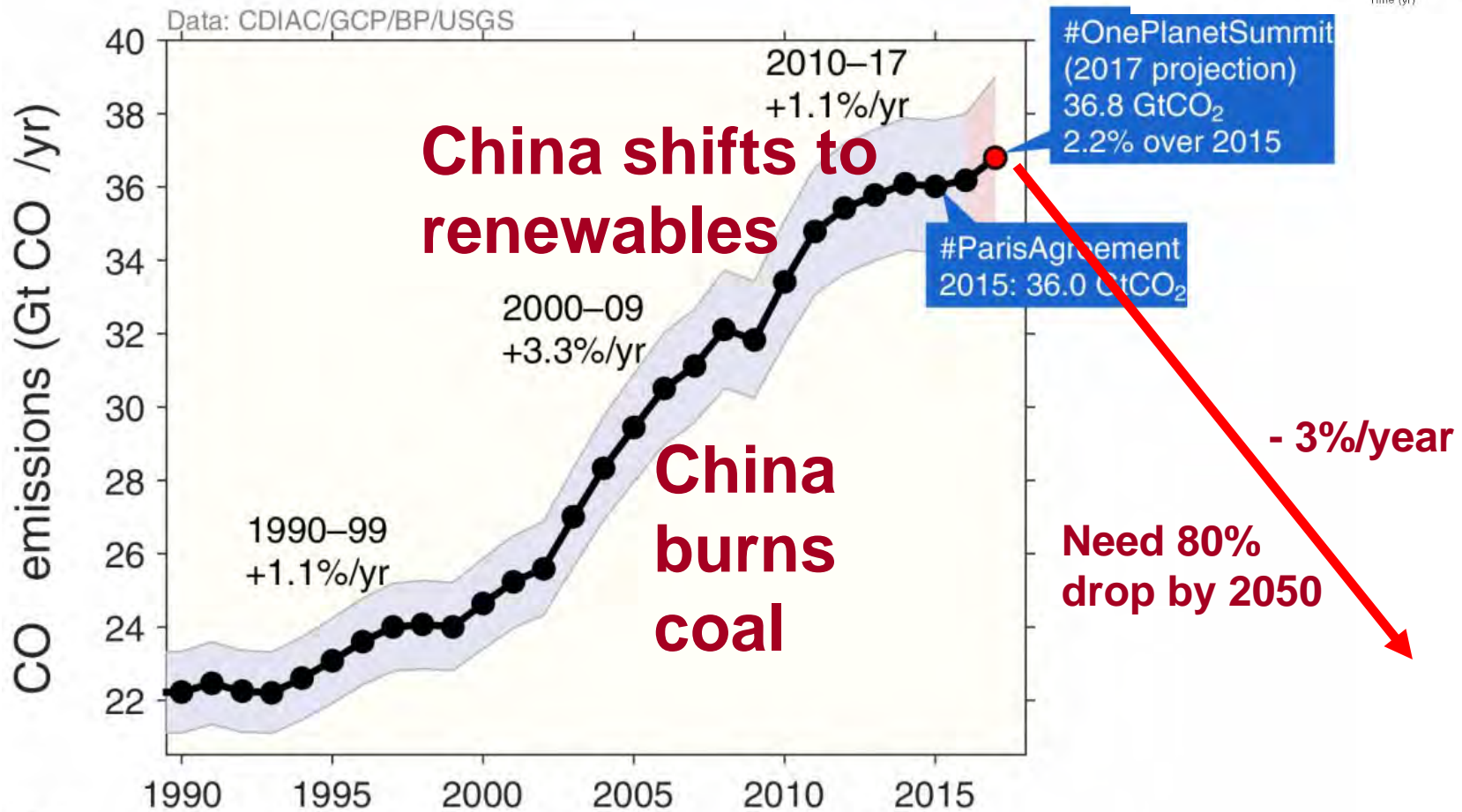
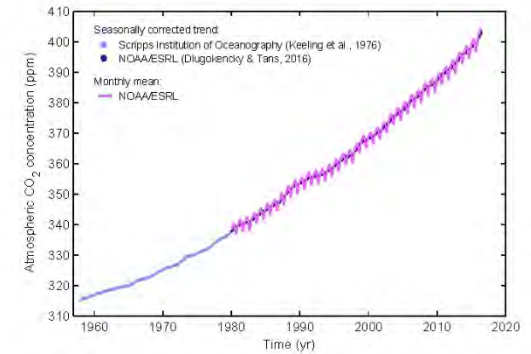
(UNFCCC 1992)

- **Yes:** Quickly stabilize atmospheric CO₂
- This means an 80% drop in CO₂ 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

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***
 - ***2019 UN report says one million species will be gone in the next decade or two from habitat loss and climate change***

Growth of CO₂ Emissions slowed – now increasing



What can we “safely” burn?

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

How do we do it?

Systems Engineering

- *Change the rule-book from Maximizing Profit*
- **Minimize the lifetime of human waste products** in the Earth system: remove dangerous wastes
- **Maximize the efficiency** with which our society uses energy and fresh water, and
- **Maximize the use of renewable energy**
- **Minimize the use of non-renewable raw materials, and**
- **Maximize recycling and re-manufacturing**

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 CO₂ to 1,000 ppm**
 - *Radically change climate/wipe out many species*
 - *In time melt icecaps, raise sea-level >100ft*

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

Powerful interests are threatened

- **Fossil fuels reserves are worth \$20-30T**
 - Big money: of course we will burn them
 - Regulating or taxing emissions of CO₂ is an 'unfair cost to the free market'
 - Too bad if the Earth's ecosystems are destroyed: others can pay the price
- ***Our politics are facing collapse:
fantasy disconnected from real world***
 - *We are deeply embedded in system!*

How do we plan/adapt?

- **Future needs creative approaches**
 - **Community support**
 - **Efficient society run on renewable energy**
- **We need to work with the Earth**
 - *People reconnected to landscape*
 - **Manage water on landscape**
 - **Manage forest diversity for a warmer climate**
 - **Manage diversified year-round agriculture**
 - **Manage energy crops and solar farms**

Scientific Integrity

- **What are the challenges scientists face?**
 - **Complex living systems: balanced, accurate assessment is always challenging**
 - **Social resistance to change**
 - **Political hostility/attempts to silence scientists**
 - **Corruption in the system at many levels**
- **Rapid change over your lifetime**
 - **Scientific, technical and social challenges**
 - **Climate refugees, internal and from overseas**

What are the Responsibilities of Environmental Scientists?

- Just do research
 - The research funded by society
 - Leave policy to ‘others’
 - Avoid public discussion, education and politics?
- Or accept that understanding brings responsibility
 - Climate change is existential issue for humanity
 - For the future of the Earth and its ecosystems
 - We need your skills to navigate the future

March 15, 2019

- School strikes, 123 countries, 1.6 million students, demanding climate action



Capetown

Greta Thunberg (born Jan 2, 2003)



On 20 August 2018, Greta Thunberg decided to not attend school until the 2018 Sweden general election on 9 September, after heat waves and wildfires in Sweden. Her demands were that the Swedish government reduce carbon emissions in accordance with the Paris agreement. She protested by sitting outside the Swedish parliament every day during school hours with the sign *Skolstrejk för klimatet* (school strike for the climate).

After the general elections, she continued to strike only on Fridays, gaining worldwide attention – prompting global ‘Friday’ protests by students who realized they and their children were to be sacrificed



“we can’t change the world by playing by the rules, because the rules have to be changed.”

Extinction Rebellion

- **Destruction of Earth now a Civil Rights issue**
 - Can only be checked by civil disobedience
 - To defend the rights of our children
 - To defend the rights of the Earth
- **Shut down London (4/16) till UK and Scottish governments declared “Climate Emergency”**
 - Government must act now to halt biodiversity loss and reduce greenhouse gas emissions to net zero by 2025
 - Government must create and be led by the decisions of a Citizens’ Assembly on climate and ecological justice.

<https://rebellion.earth>

***Do good work; discuss the
issues ahead***

(<http://alanbetts.com>)

What is a pollutant?

- **First it was the obvious hazards to health**
 - Smoke/smog from burning coal and exhausts
 - Toxic contaminants dumped in drinking water
 - These were regulated by the Clean Air and Clean Water legislation in 1980's & 1990's
- **But many of our waste products that look harmless to humans are hazards to life on Earth!**
 - CFCs that destroy the ozone layer that protects life
 - CO₂ from burning fossil fuels, driving climate change
 - Plastics dumped into the oceans
- *In our disconnected human world, these are harder for us to deal with*

Technical solutions

- **Electrical power**
 - Renewable: solar, wind, hydro
 - Storage: lithium batteries down to \$150/kWh
 - Electric car industry generating massive storage
- **New technologies: electricity to liquid fuels**
- **Net-zero housing**
- **Rethink transport**

Social, moral, spiritual shift

- **The Future Is Not Our Past**
 - *an economic, technological and financial system driven 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*
- *How do we turn the ship around?!*

Step back from dark side

- **Cannot be solved with mindset that created it**
 - **Oppose new fossil fuel “solutions”**
 - ***But stand for the Earth and ‘reality’***
- **Push practical solutions**
 - **Efficiency and renewables**
 - **And a fossil-carbon tax**
- **Social, moral, spiritual shift needed**
 - **Your personal role**
 - **Role of community**

The Cabal of Libertarian Billionaires

- **Aim: *purchase control of the Republican Party***
 - US Congress (“Freedom Party”); many state legislatures
- **Doctrine: *limited role for government***
 - protect wealth, property and the rule of law
- **Freedom to exploit the earth:**
 - Shall not be limited by environmental regulation
 - *Doctrine in direct conflict with Earth’s ecosystem*
- **Leading to**
 - *Climate science is a (fictitious) conspiracy*

(Dark Money, Jane Mayer, 2016)

Water, Snow & Ice Give Positive Radiative Feedbacks

- As Earth warms, evaporation and water vapor increase and this is 3X amplifier on CO₂ rise
- As Earth warms, snow & ice decrease and reduced SW reflection amplifies warming in Arctic in summer and mid-latitudes in winter
- Doubling CO₂ will warm globe about 5°F (3°C)
 - Much more in the cold regions and over land, which responds faster than oceans
 - Change the global circulation

Vermont Temperature Trends 1961-2008

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

