Exhibit GMP-RH-4

Climate Change – the Latest and Some Things Unforeseen…

Unitarian Church Montpelier

Facing the Climate Crisis - Series

6:30 PM January 14th 2020

Kellogg Hubbard Library

DISCLAIMERS AND ATTRIBUTION

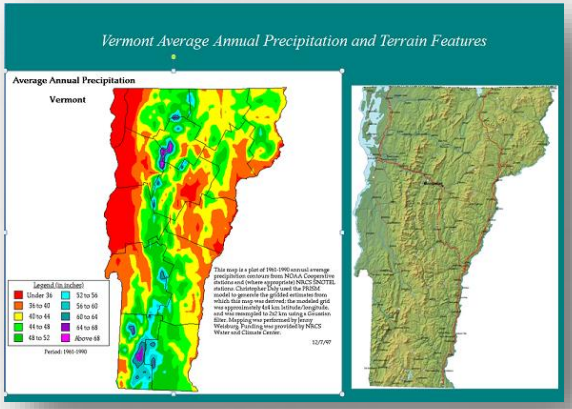
The content and conclusions are drawn upon 40 plus years in the field as an operational meteorologist weather forecaster.

The research presented is based on the following peer reviewed science; *Francis,Vavrus 2012, Jaiser et al 2012,2013 Cohen et al Nature Geosciences, 2014, Kim et al 2014, Feldstien and Lee 2014, the Vermont Climate Assessment 2014. Francis and Vavrus 2015, Kug et al 2015 Furtado et al 2015, Wu and Smith 2016, Zang et al 2016, Kretchmer et al 2016, Nakamura et al 2016, Vavrus et al 2017 Zou et al 2017 McKusker 2017 Cohen et al 2018.*

I'm conveying my observations/experiences in meteorology since the mid 1970s including various components of the climate system/climatology since the mid 1980s in Vermont.

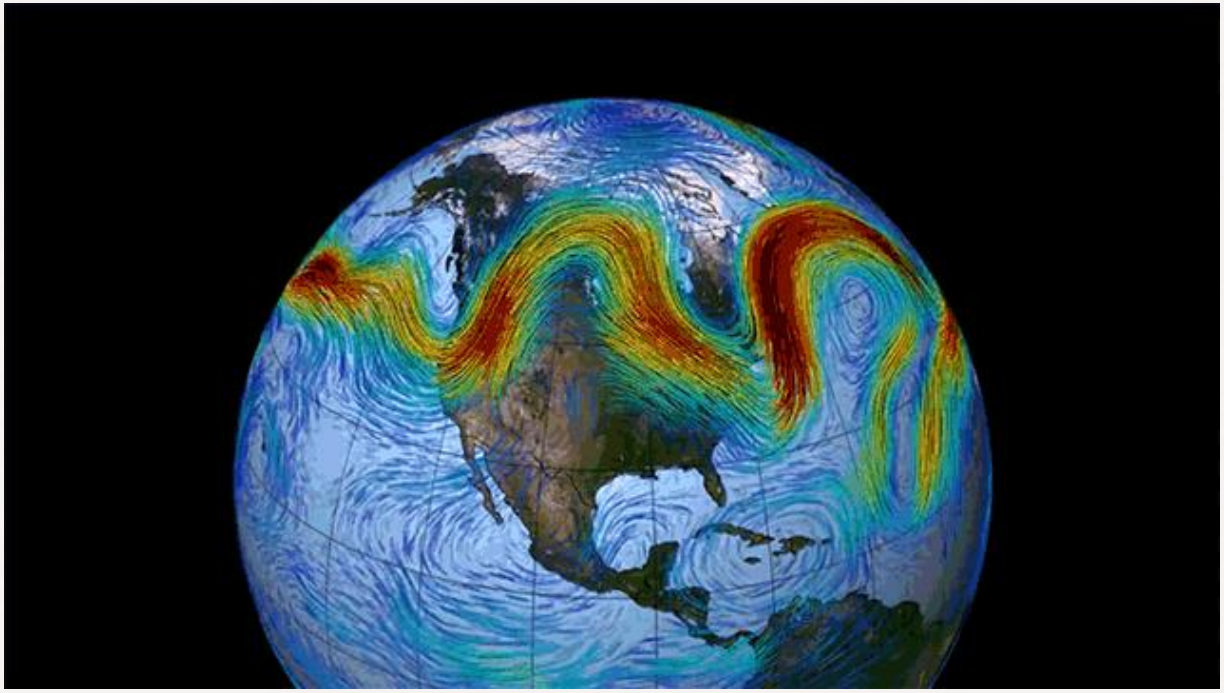
The presentation will discuss:

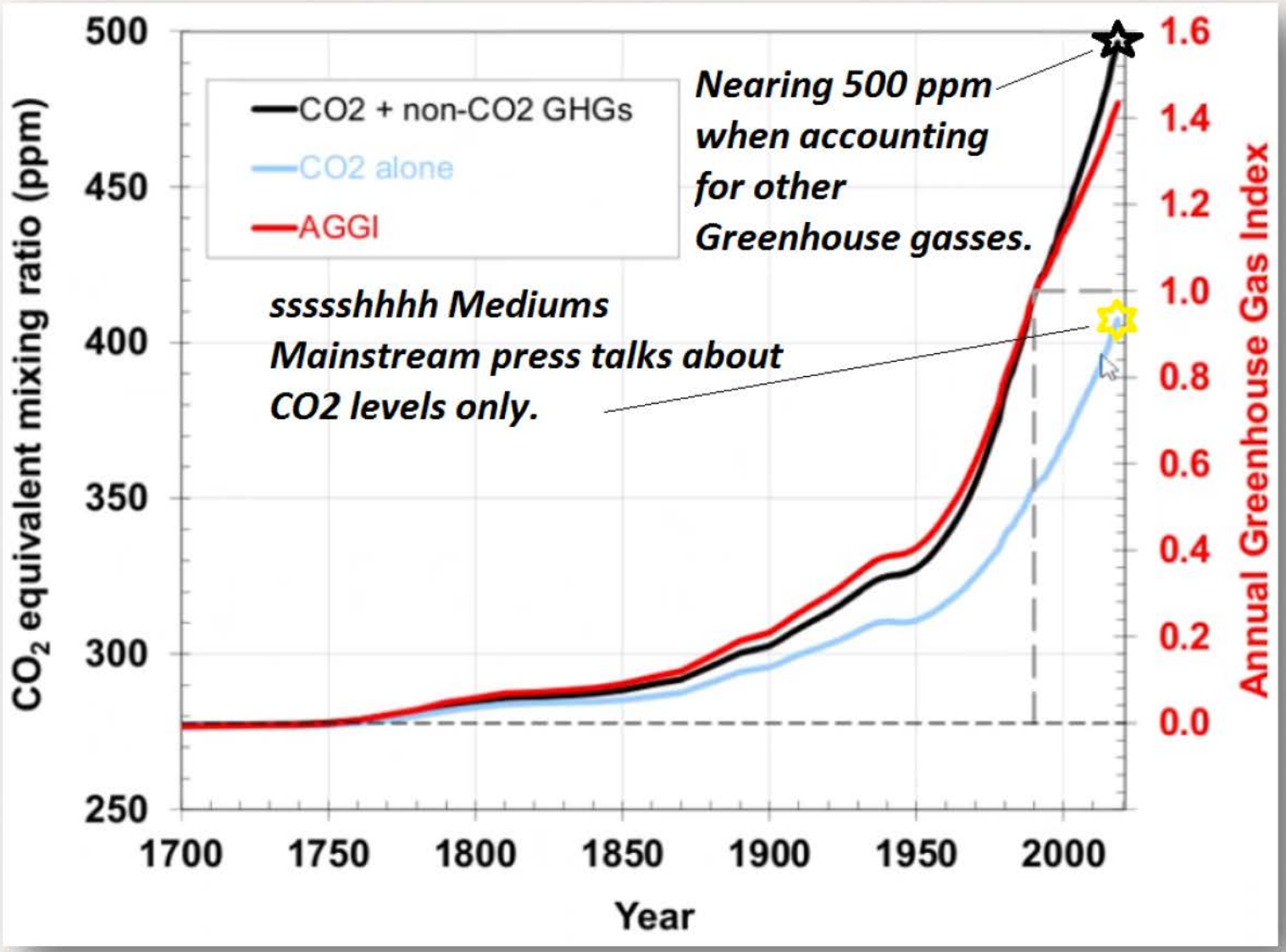
- Global Heating from Greenhouse gasses
- Climate shifting warmer not always in winter and spring & why
- Increasing trends in extreme weather
- Vermont Climate Trends and projections
- Recent Evolution of Heat Waves increasing
- Drought wild fire Association Contribution
- Positive (increasing) Feedback cycle
- All eyes to the north on the Arctic.

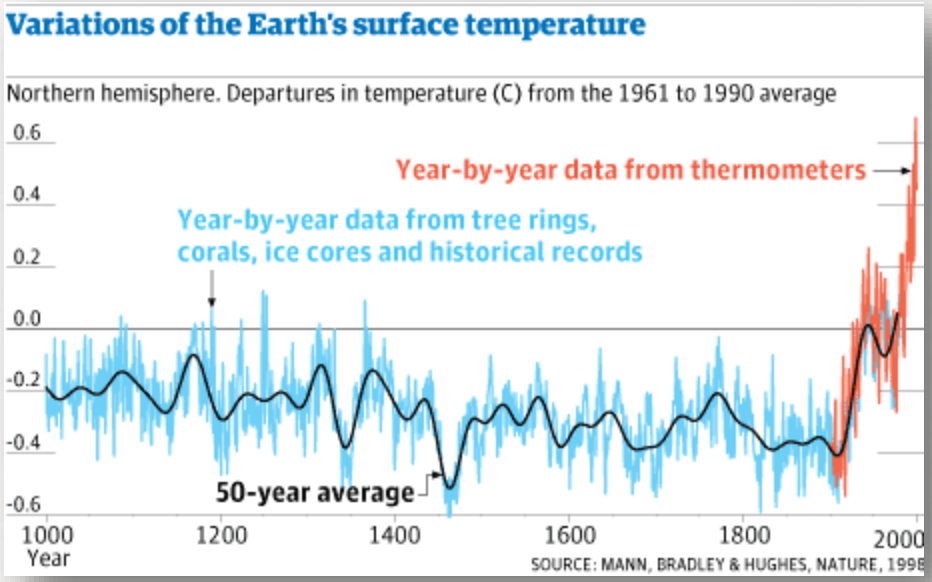


A New Normal?

- Increased evidence has linked extreme weather to loss of arctic sea ice and fall and spring snow cover
- (Francis-Vavrus 2012) Study says it's happening all over especially the Northern Hemisphere and many other papers have built on this since…

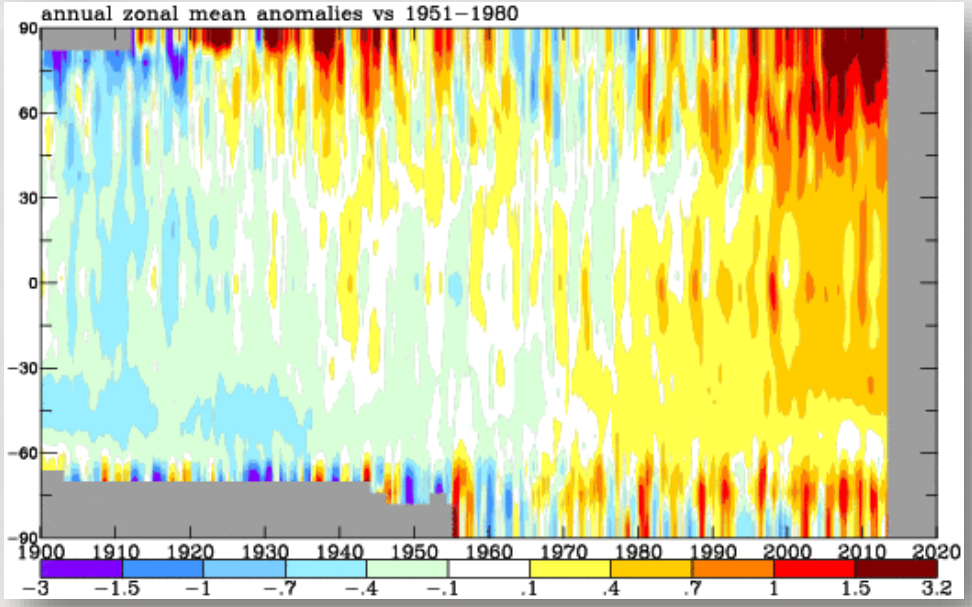



CO2 + non-CO2 GHGs
CO2 alone
AGGI
Nearing 500 ppm when accounting for other Greenhouse gasses.
ssssshhhh Mediums Mainstream press talks about CO2 levels only.
CO2 equivalent mixing ratio (ppm)
Annual Greenhouse Gas Index
Year
500
450
400
350
300
250
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1700
1750
1800
1850
1900
1950
2000



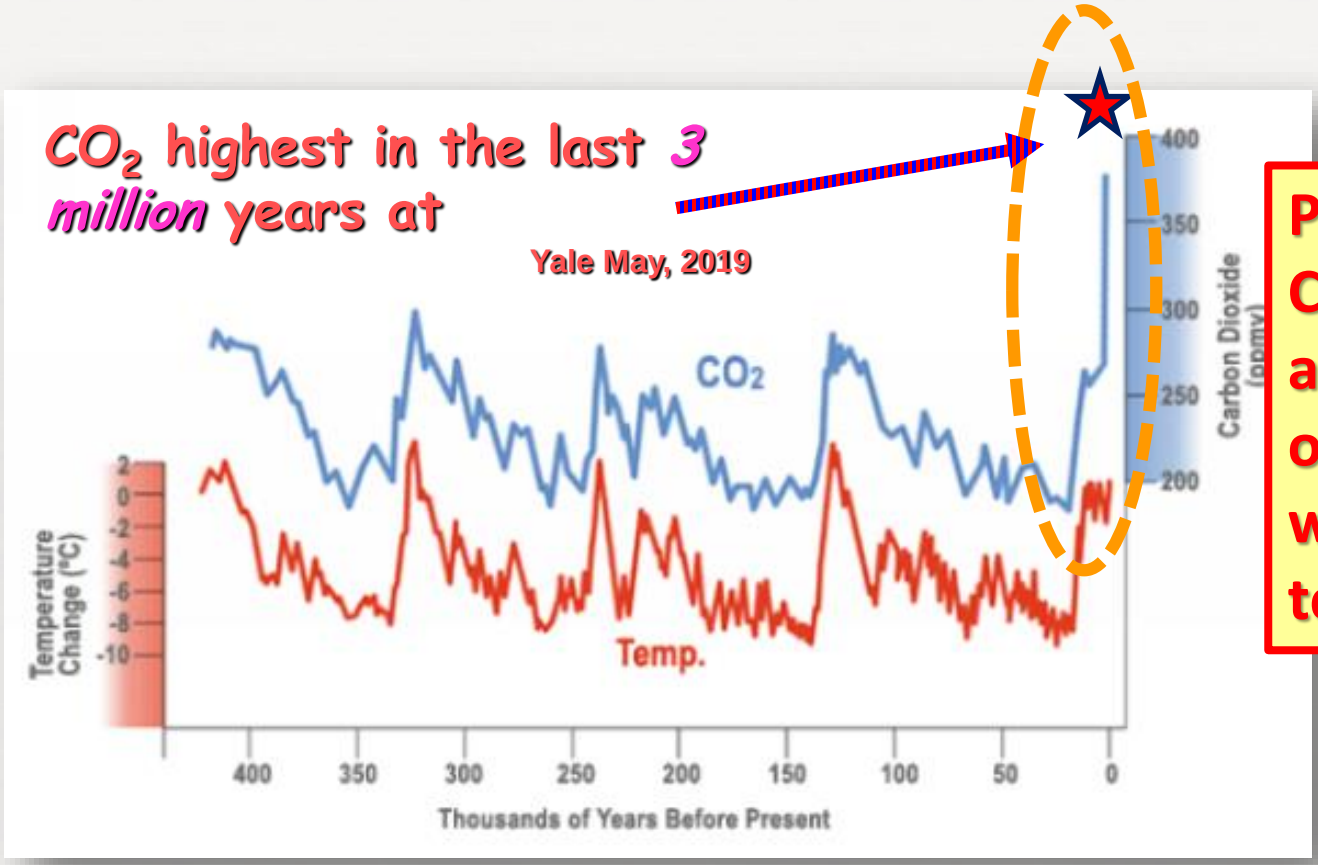
CO_2 levels are highest in 3 million years, and Earth's temperature is responding although not evenly around the globe.

January 2020 was the 420th *consecutive* month warmer than average



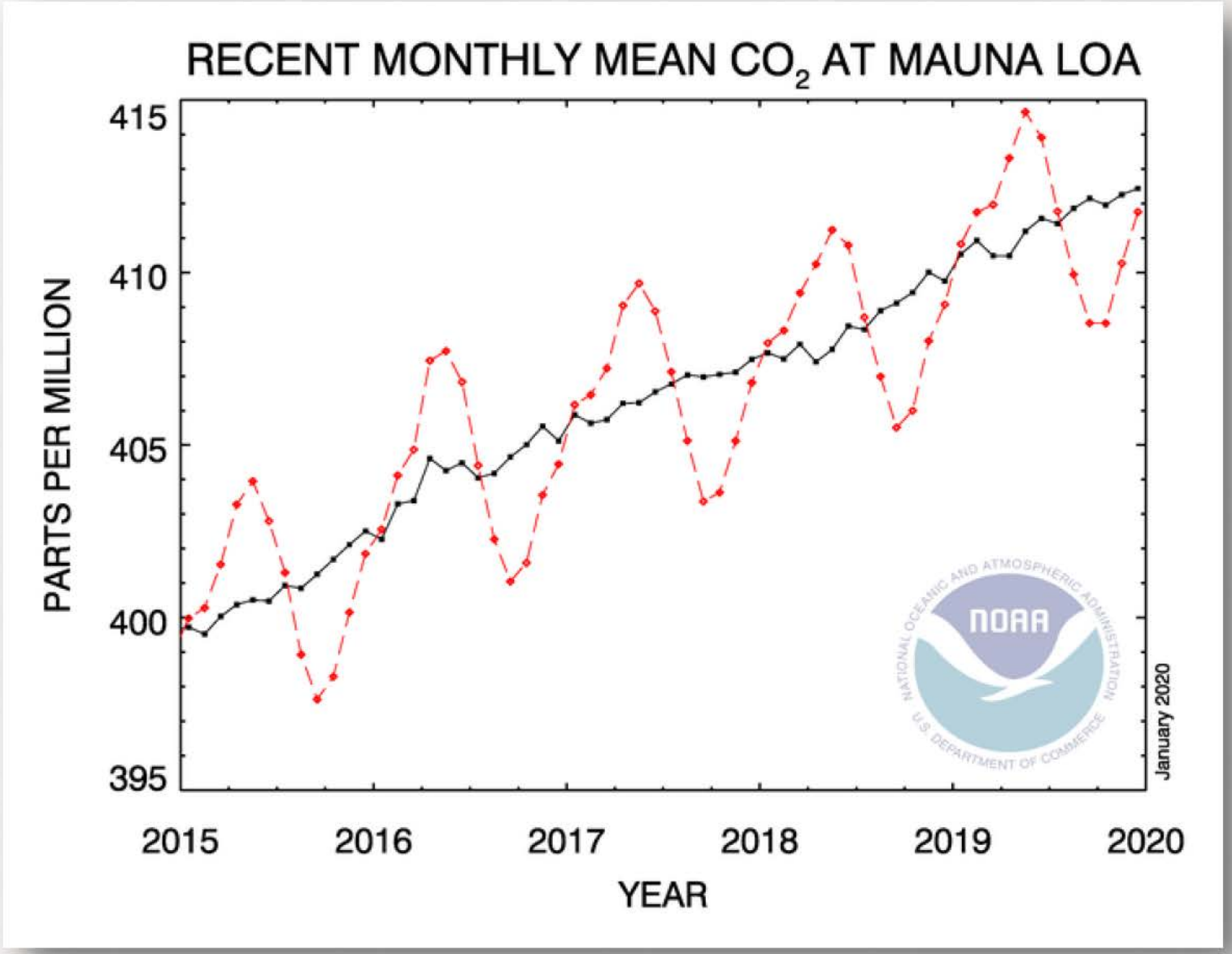
From NASA/GISS

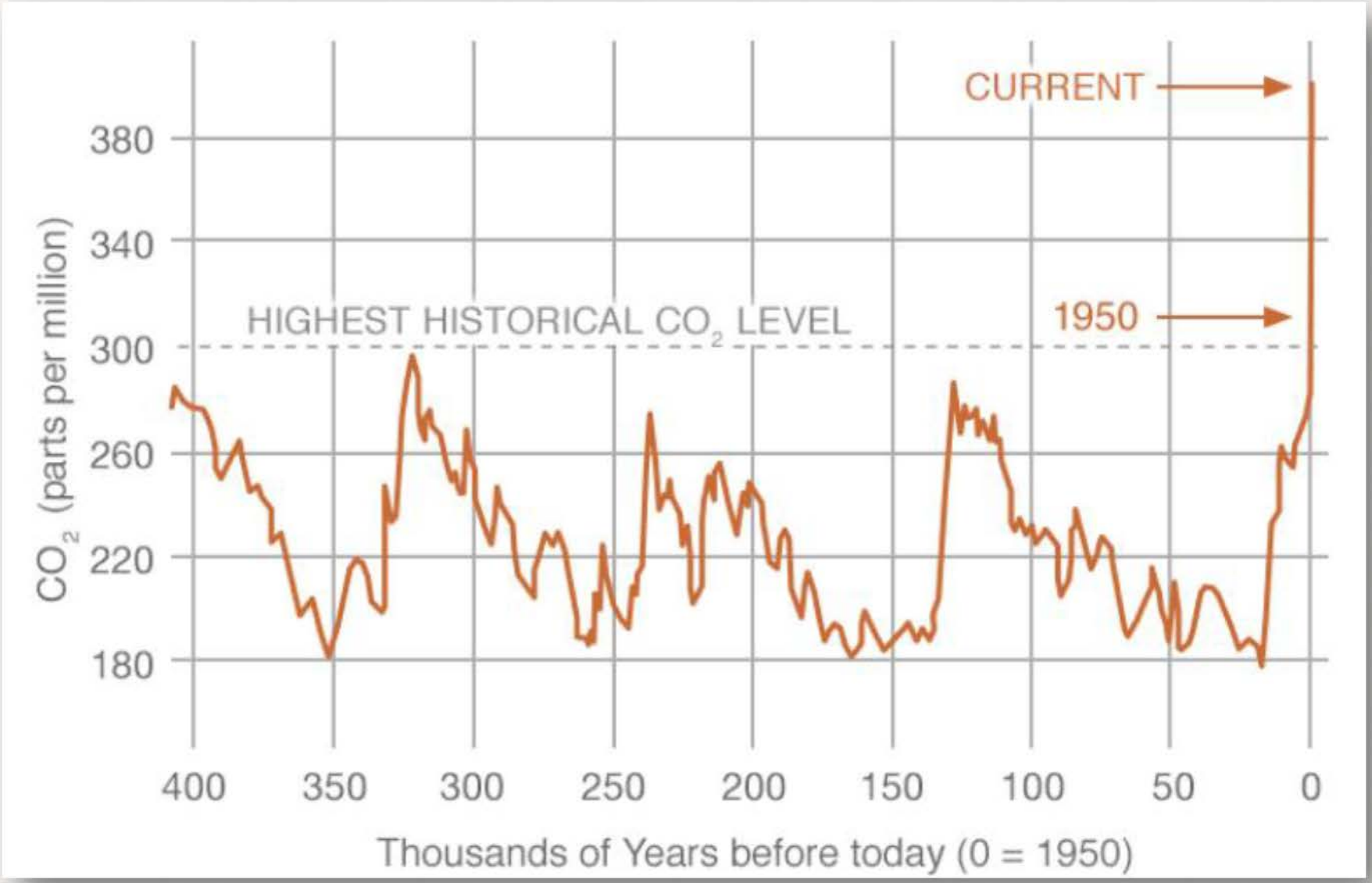
Let's look back a few hundred thousand years…

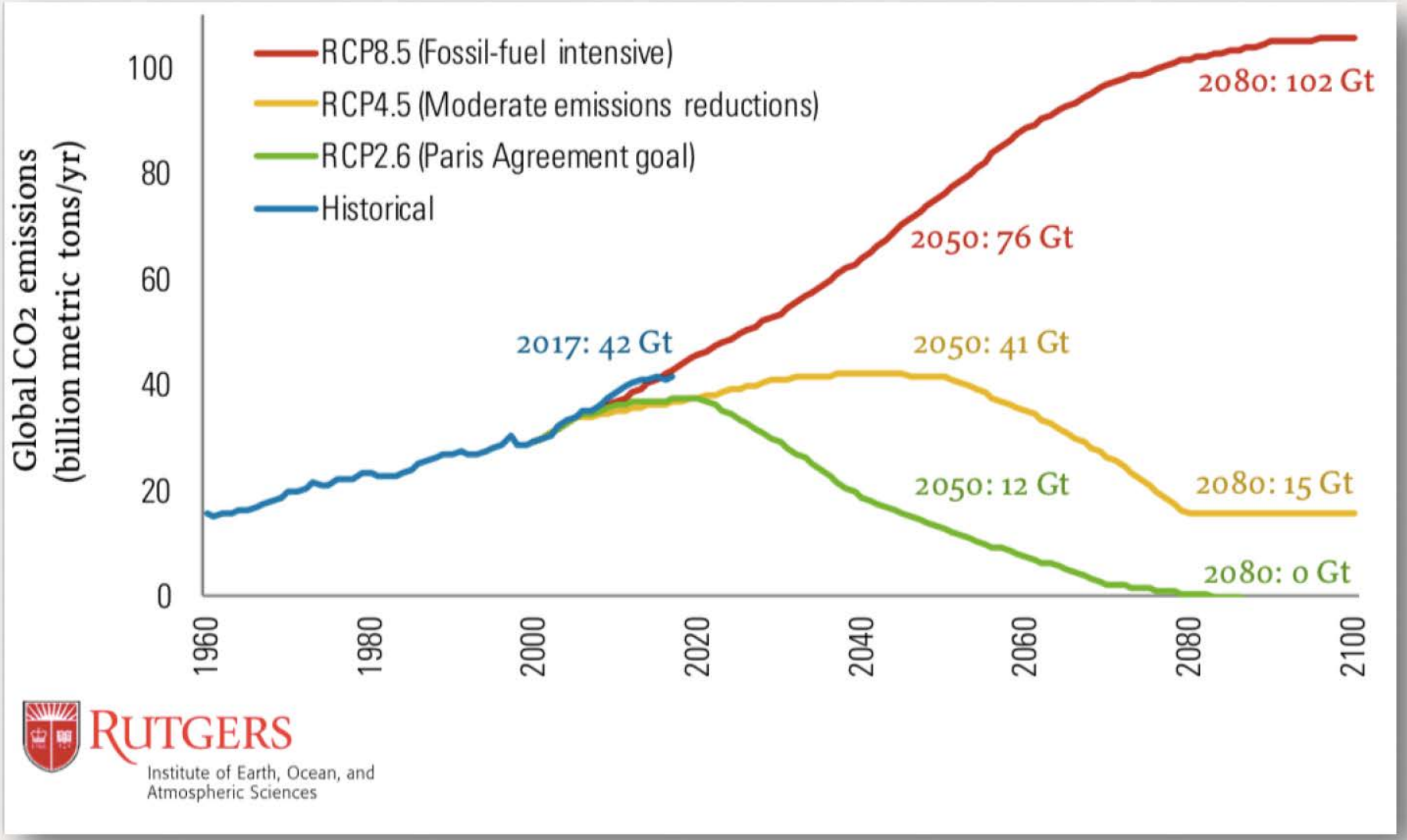


Present CO_2 levels are *WAY* out of whack with temperature

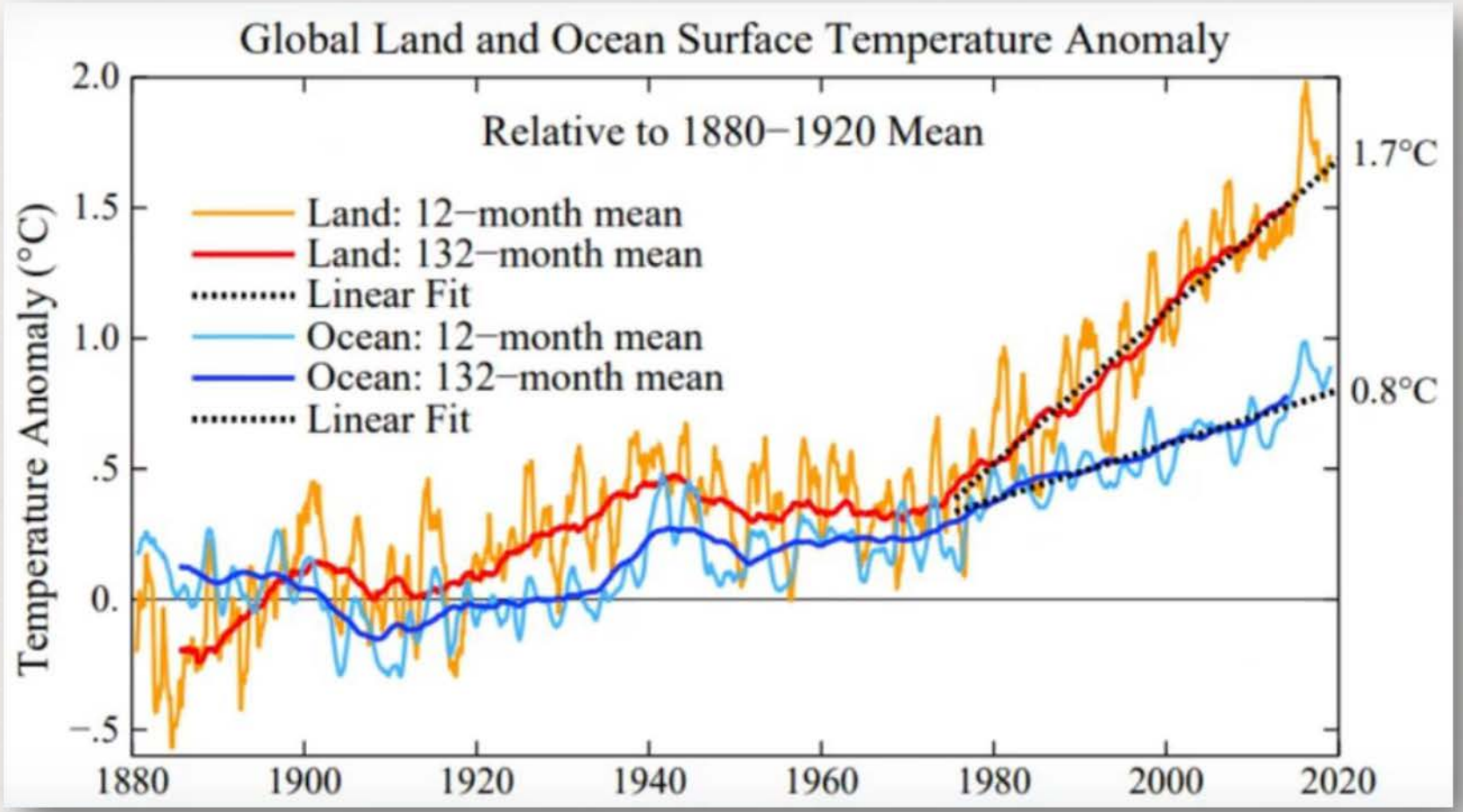
The last time CO2 levels were this high, the globe was several degrees warmer, sea level were tens of feet higher, and humans didn't exist.


RECENT MONTHLY MEAN CO_2 AT MAUNA LOA
PARTS PER MILLION
415
410
405
400
395
2015
2016
2017
2018
2019
2020
YEAR
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
January 2020


CURRENT
380
340
HIGHEST HISTORICAL CO_2 LEVEL
1950
300
260
220
180
CO_2 (parts per million)
400
350
300
250
200
150
100
50
0
Thousands of Years before today (0 = 1950)

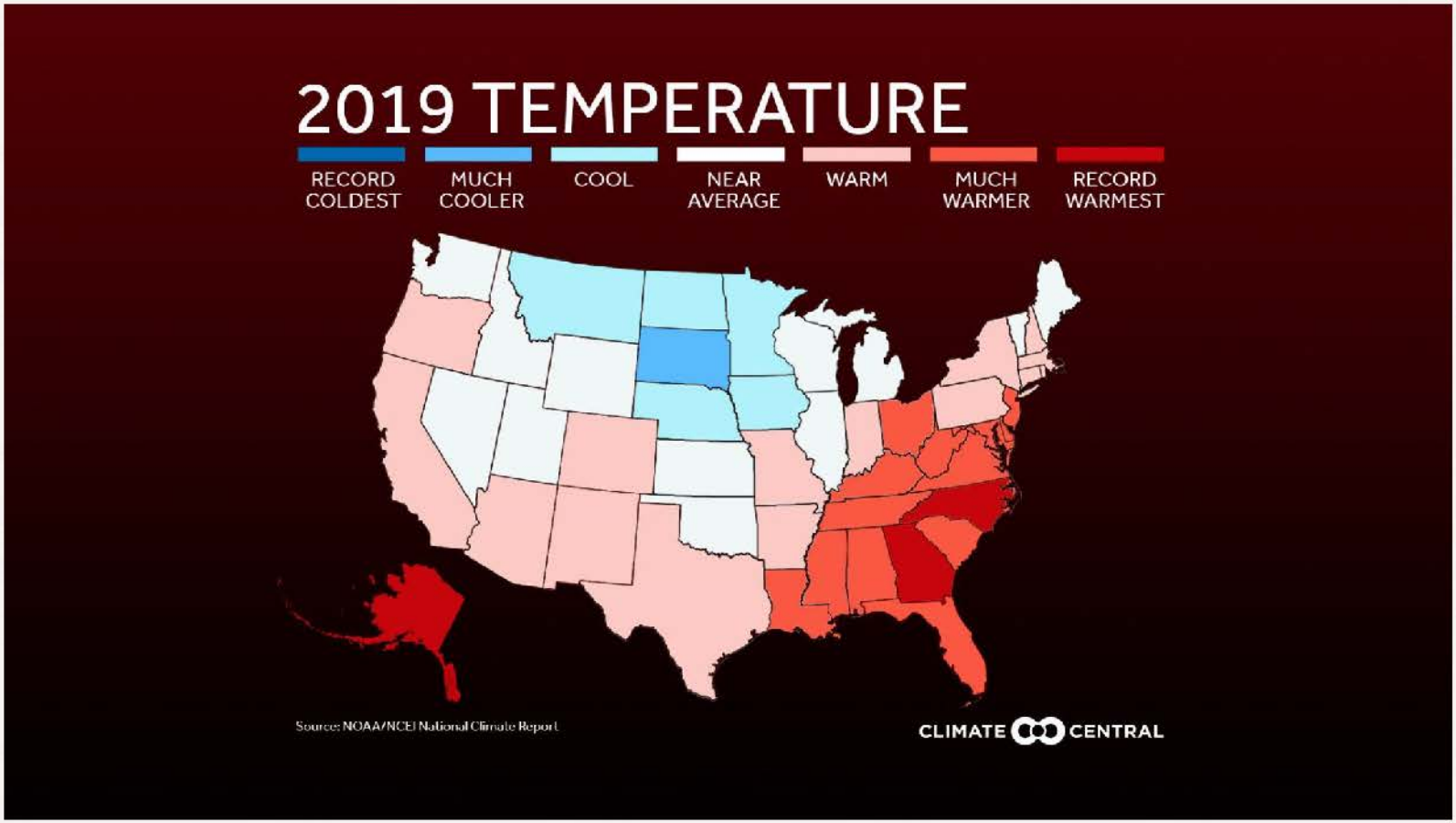


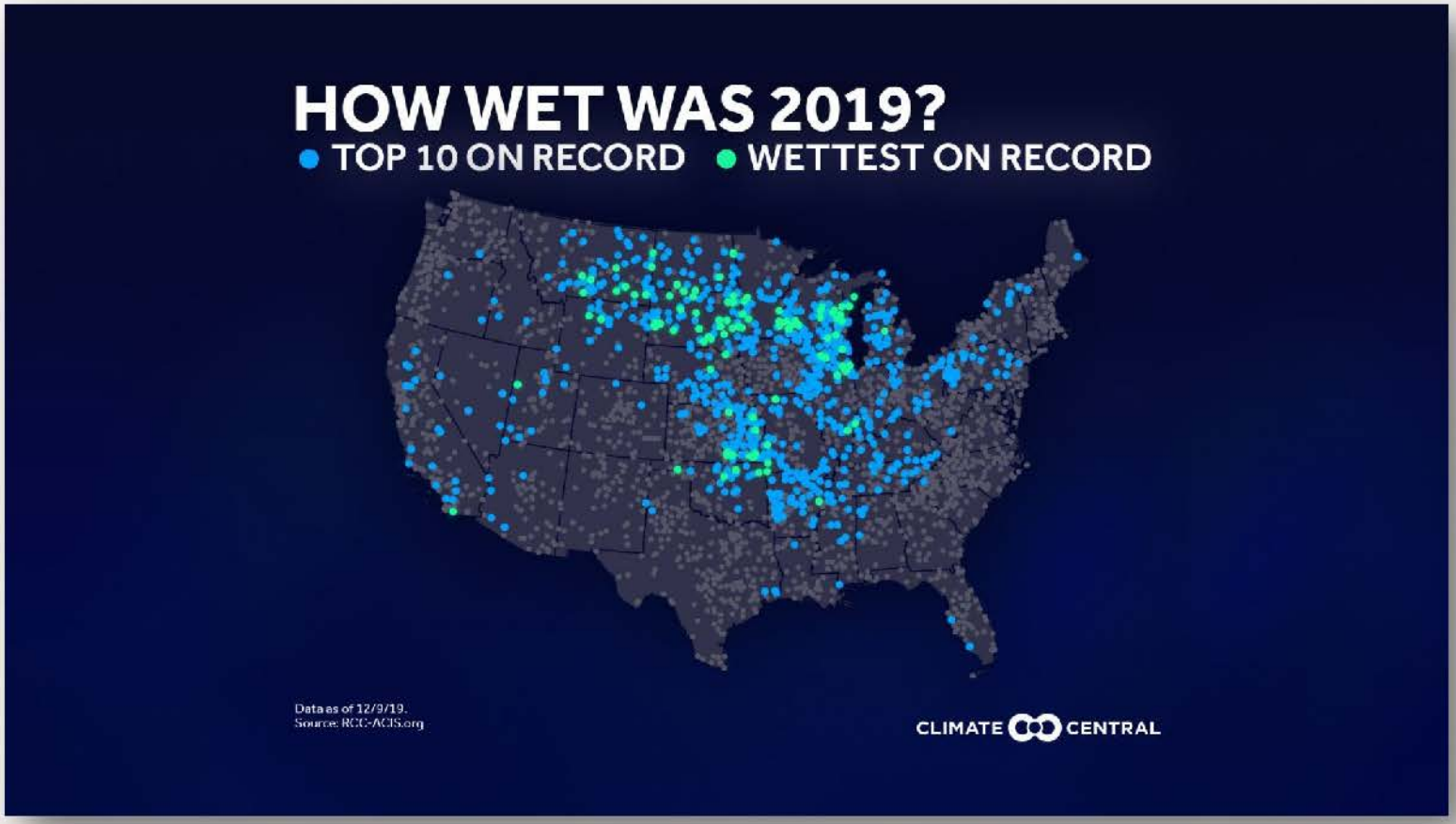
RUTGERS
Institute of Earth, Ocean, and Atmospheric Sciences

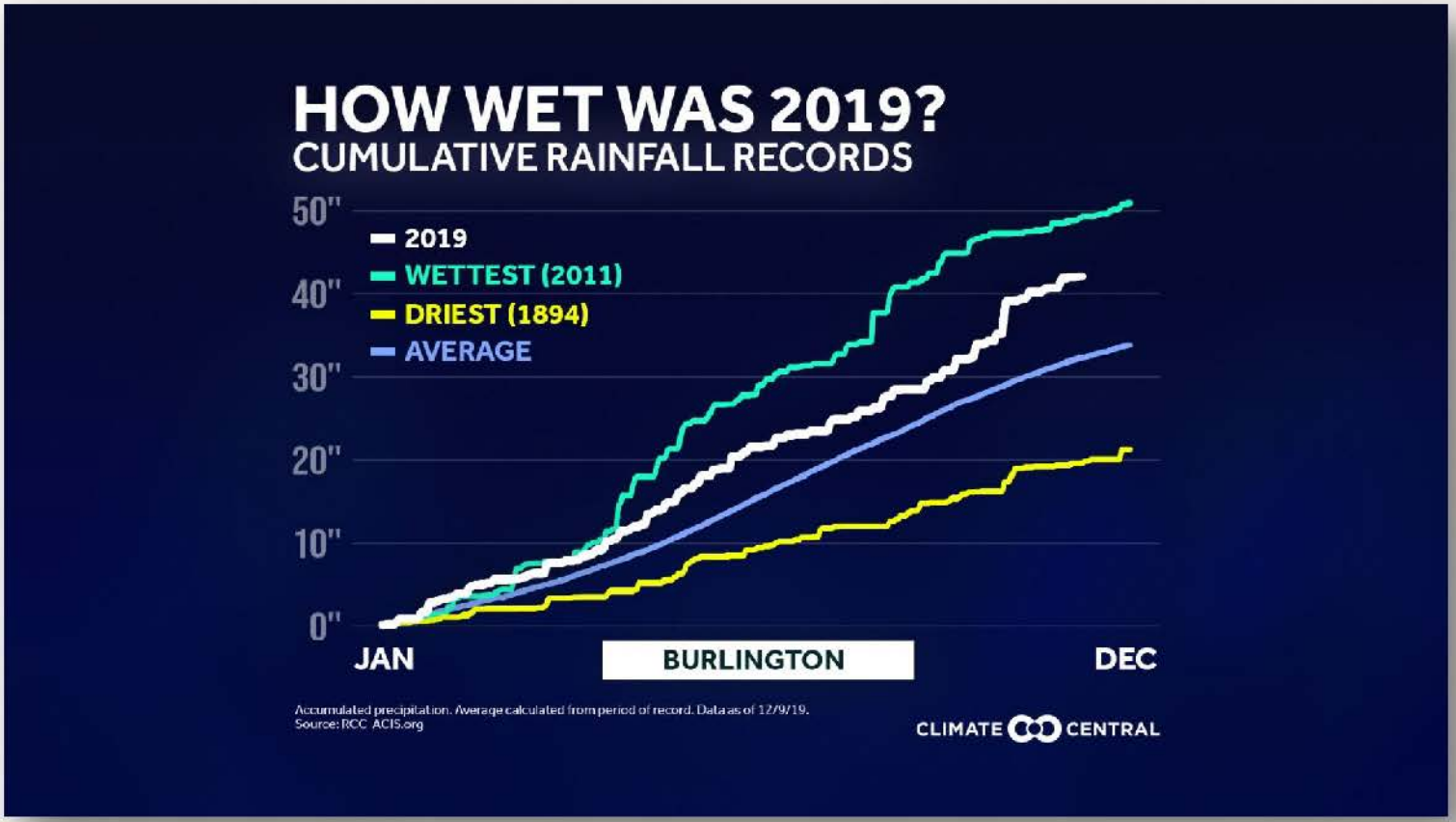

Global Land and Ocean Surface Temperature Anomaly
Relative to 1880–1920 Mean
Land: 12–month mean
Land: 132–month mean
Linear Fit
Ocean: 12–month mean
Ocean: 132–month mean
Linear Fit
1.7°C
0.8°C
Temperature Anomaly (°C)
2.0
1.5
1.0
.5
0.
–.5
1880
1900
1920
1940
1960
1980
2000
2020

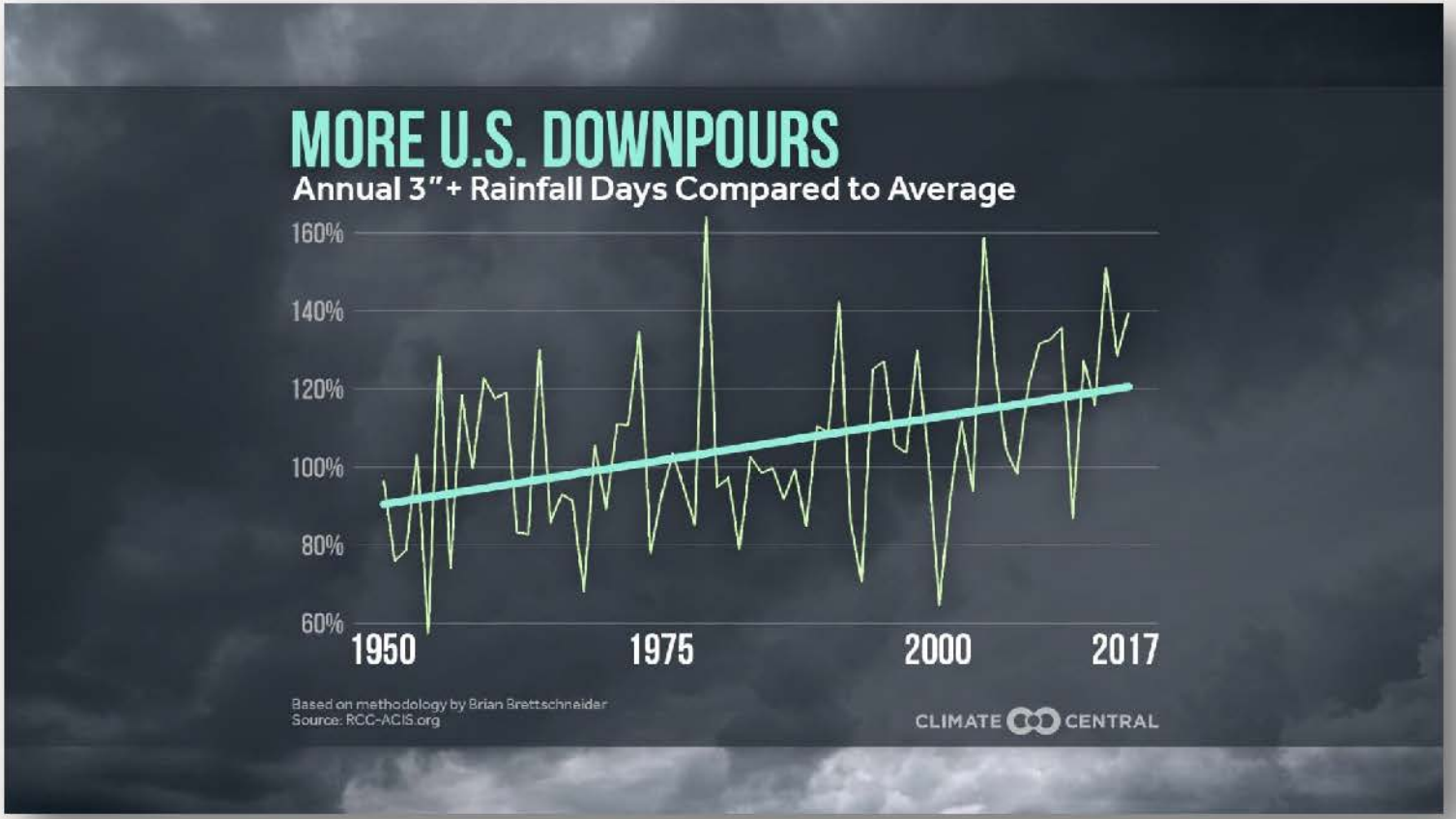
Look Back at 2019

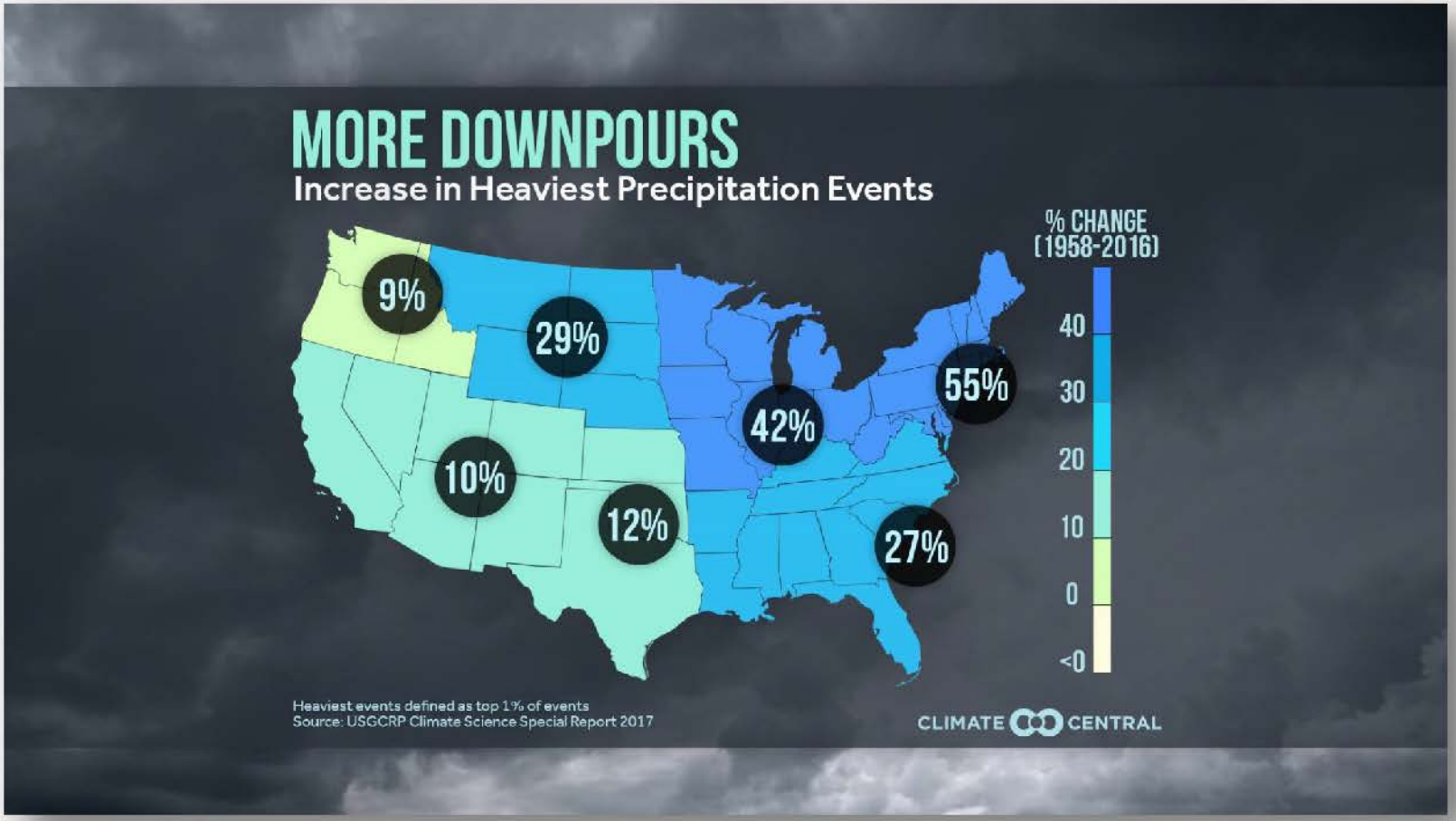
- **2019 was the second-wettest year on record in the U.S., and temperatures were above average despite regions that were among the only cool spots on the planet.**
- **2019 also concluded the warmest decade on record—the 2010s were the warmest of the past five decades for 87% of the 244 cities analyzed.**
- **Here's a recap of the year's U.S. climate rankings, before global statistics are released next week.**

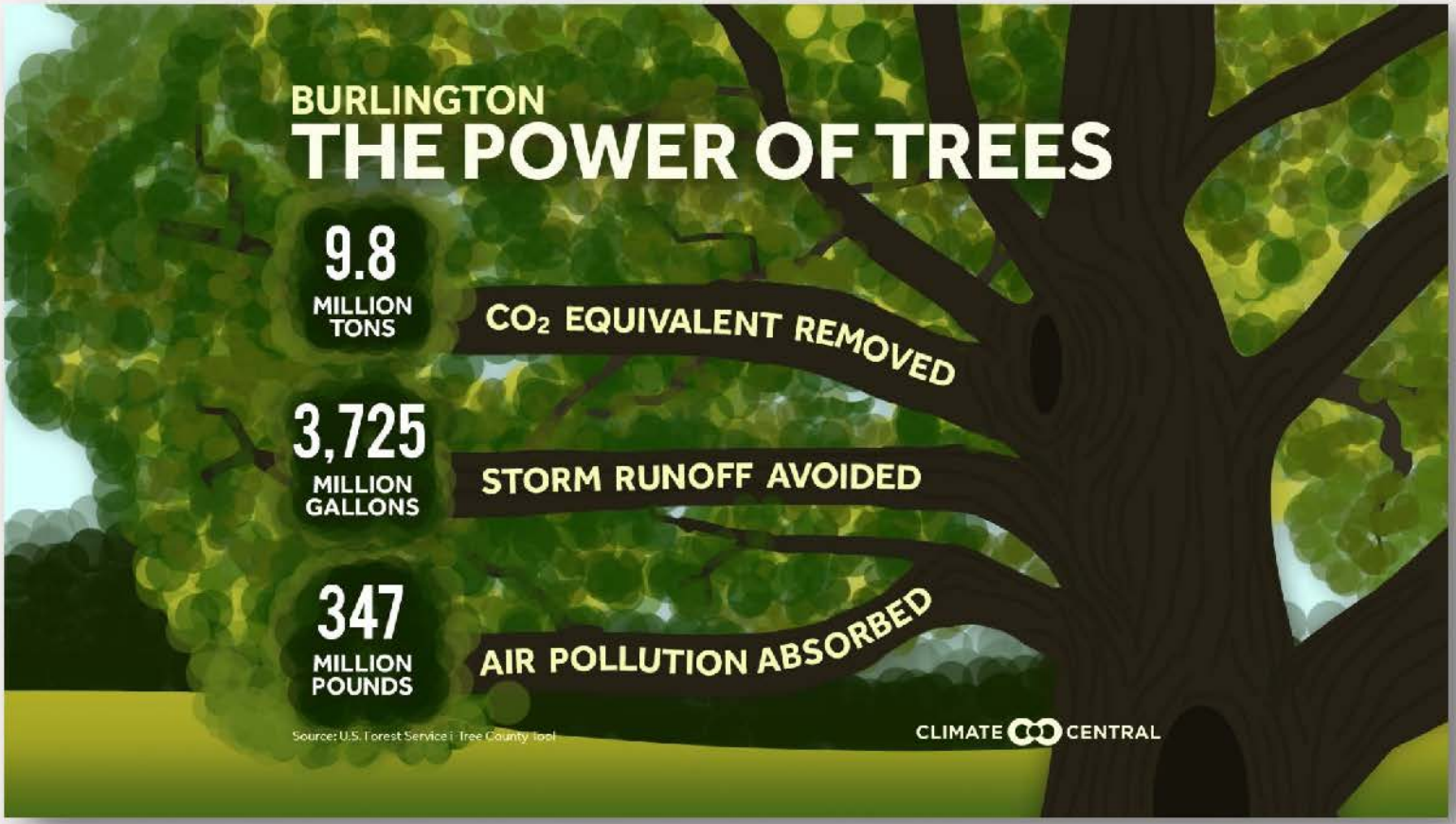

2019 TEMPERATURE
RECORD COLDEST
MUCH COOLER
COOL
NEAR AVERAGE
WARM
MUCH WARMER
RECORD WARMEST
Source: NOAA/NCEI National Climate Report
CLIMATE CENTRAL


HOW WET WAS 2019?
TOP 10 ON RECORD
WETTEST ON RECORD
Data as of 12/9/19.
Source: RCC-ACIS.org
CLIMATE CENTRAL

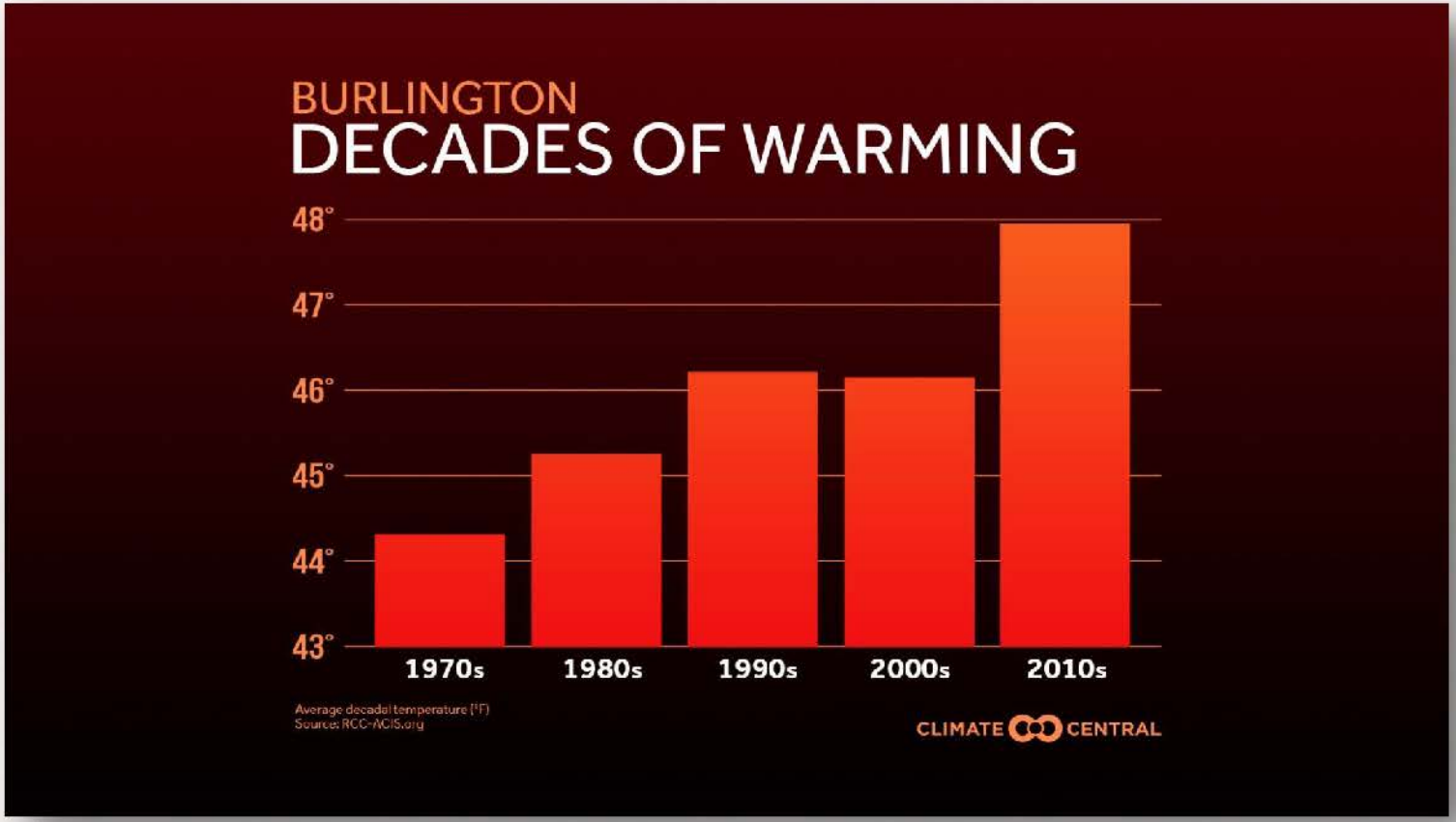

HOW WET WAS 2019?
CUMULATIVE RAINFALL RECORDS
50"
40"
30"
20"
10"
0"
2019
WETTEST (2011)
DRIEST (1894)
AVERAGE
JAN
BURLINGTON
DEC
Accumulated precipitation. Average calculated from period of record. Data as of 12/9/19.
Source: RCC ACIS.org
CLIMATE CENTRAL

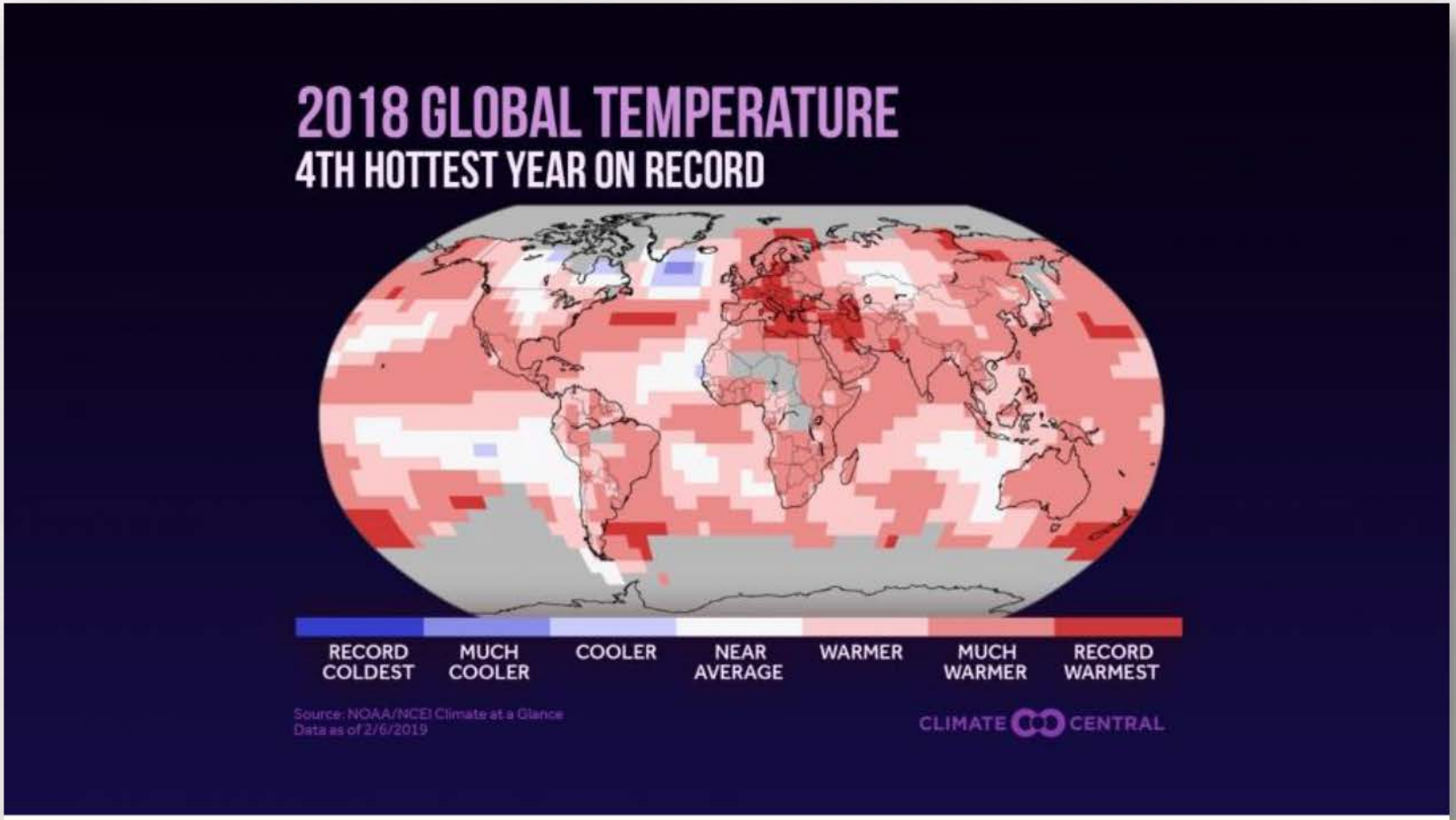

MORE U.S. DOWNPOURS
Annual 3"+ Rainfall Days Compared to Average
160%
140%
120%
100%
80%
60%
1950
1975
2000
2017
Based on methodology by Brian Brettschneider
Source: RCC-ACIS.org
CLIMATE CENTRAL

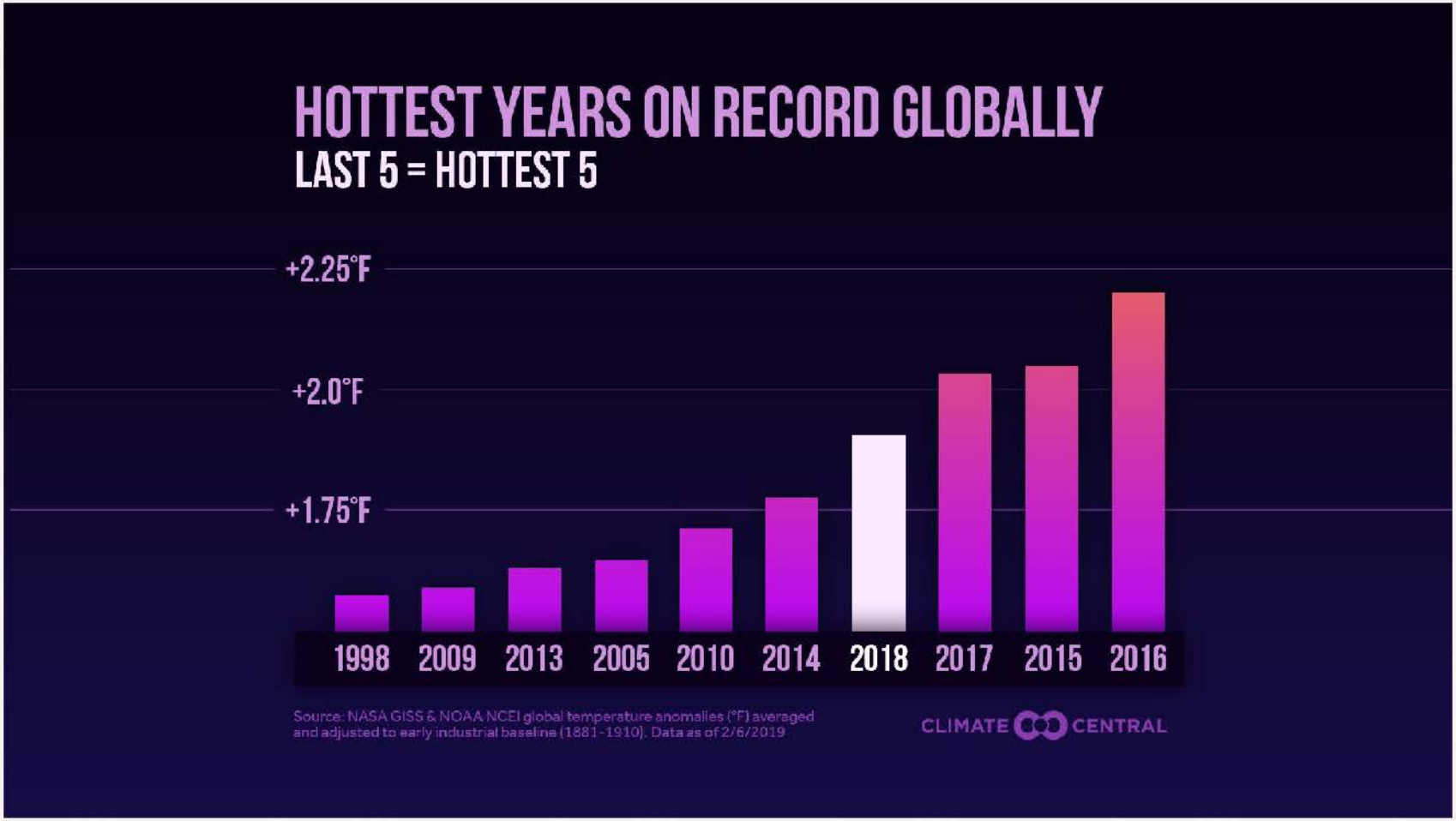

MORE DOWNPOURS
Increase in Heaviest Precipitation Events
% CHANGE (1958-2016)
40
30
20
10
0
<0
9%
29%
55%
42%
10%
12%
27%
Heaviest events defined as top 1% of events
Source: USGCRP Climate Science Special Report 2017
CLIMATE CENTRAL


BURLINGTON
THE POWER OF TREES
9.8
MILLION
TONS
CO2 EQUIVALENT REMOVED
3,725
MILLION
GALLONS
STORM RUNOFF AVOIDED
347
MILLION
POUNDS
AIR POLLUTION ABSORBED
Source: U.S. Forest Service i-Tree County tool
CLIMATE CENTRAL


RUNOFF AVOIDED BY TREES
Millions of Gallons Per Year
5
10
20
40
80
160+
Annual avoided runoff
USFS i-Tree County tool
CLIMATE CENTRAL


BURLINGTON
DECADES OF WARMING
48°
47°
46°
45°
44°
43°
1970s
1980s
1990s
2000s
2010s
Average decadal temperature (°F)
Source: RCC-ACIS.org
CLIMATE CENTRAL


2018 GLOBAL TEMPERATURE
4TH HOTTEST YEAR ON RECORD
RECORD COLDEST
MUCH COOLER
COOLER
NEAR AVERAGE
WARMER
MUCH WARMER
RECORD WARMEST
Source: NOAA/NCEI Climate at a Glance
Data as of 2/6/2019
CLIMATE CENTRAL

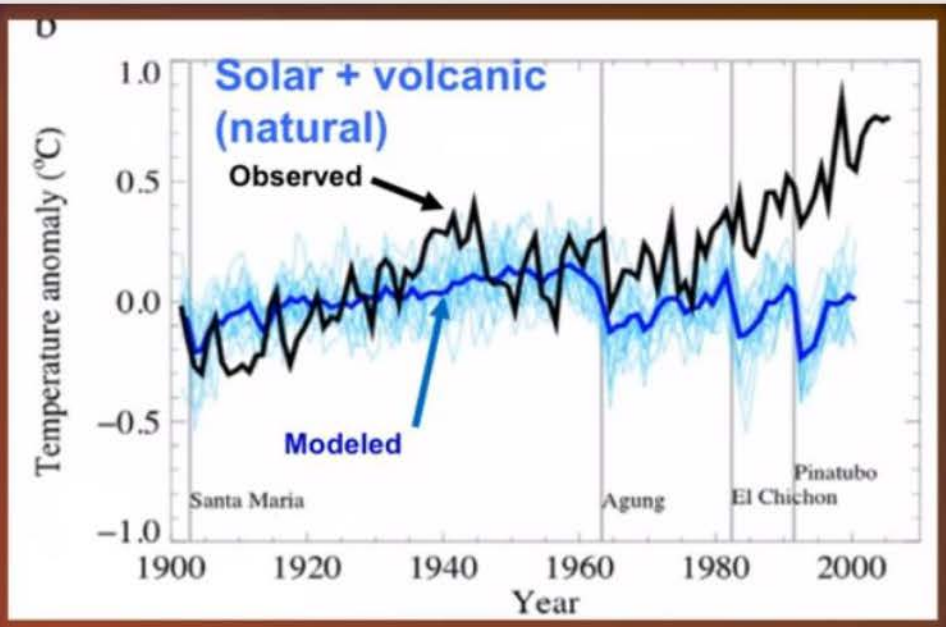

HOTTEST YEARS ON RECORD GLOBALLY
LAST 5 = HOTTEST 5
+2.25°F
+2.0°F
+1.75°F
1998
2009
2013
2005
2010
2014
2018
2017
2015
2016
Source: NASA GISS & NOAA NCEI global temperature anomalies (°F) averaged and adjusted to early industrial baseline (1881-1910). Data as of 2/6/2019
CLIMATE CENTRAL

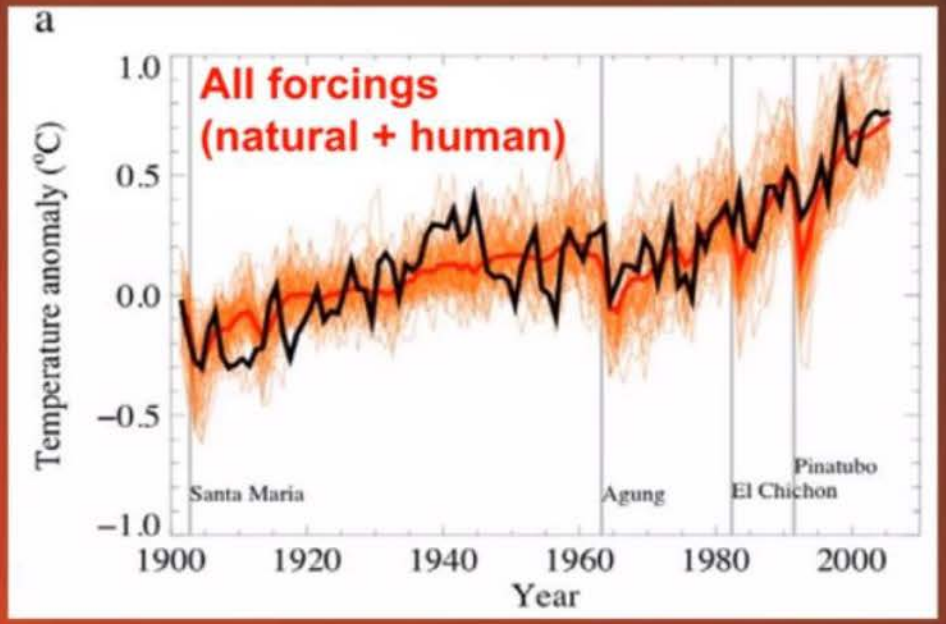
Evidence implicating humans

One of our best tools: computer programs

- climate models -

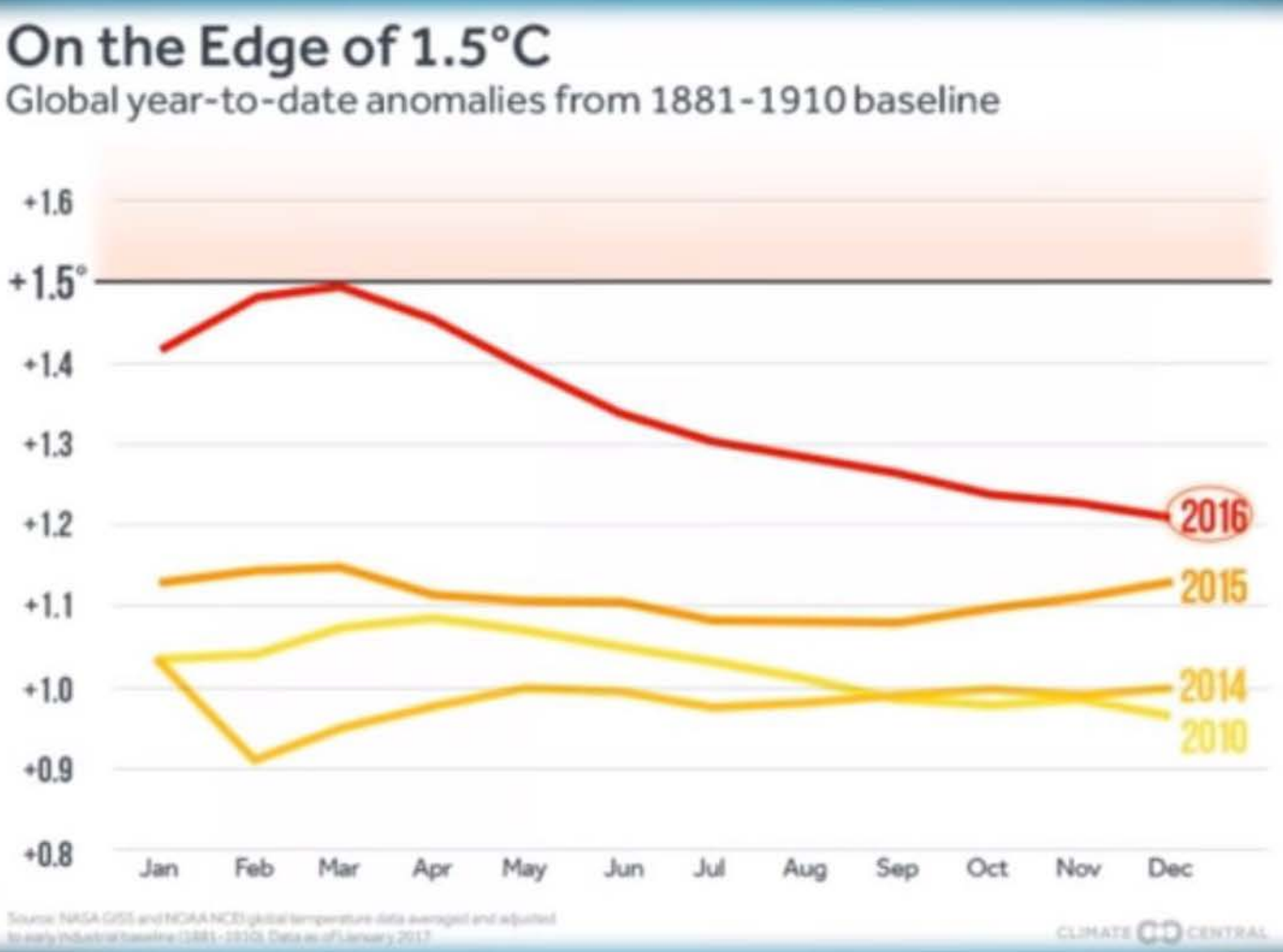
that simulate the complex physics of the atmosphere, ocean, snow, ice, and land and all the forces acting on them.





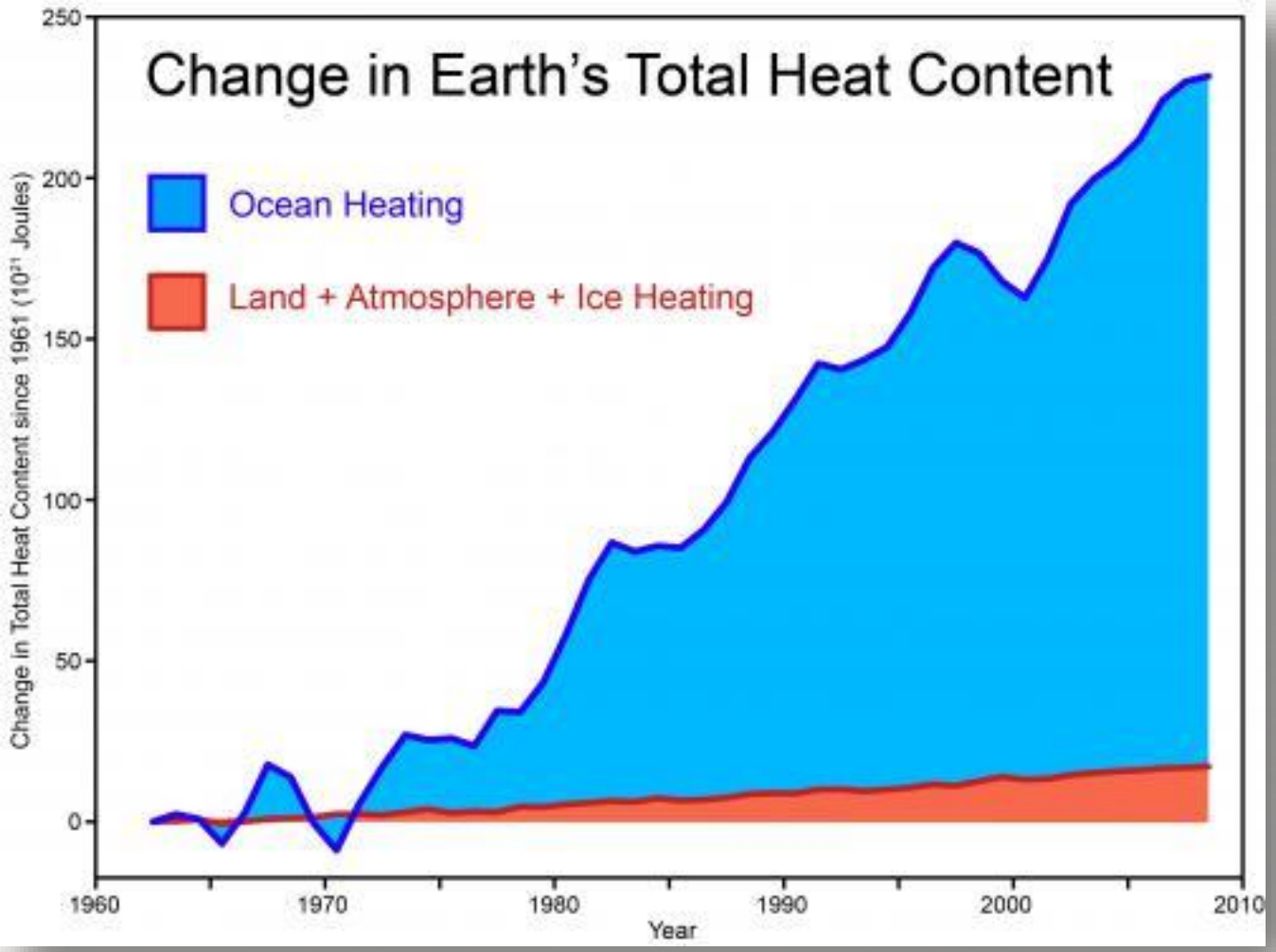
Is human-caused climate change playing a role?

Global temperature: *Warmest years*



ClimateCentral

EVEN MORE WORRISOME



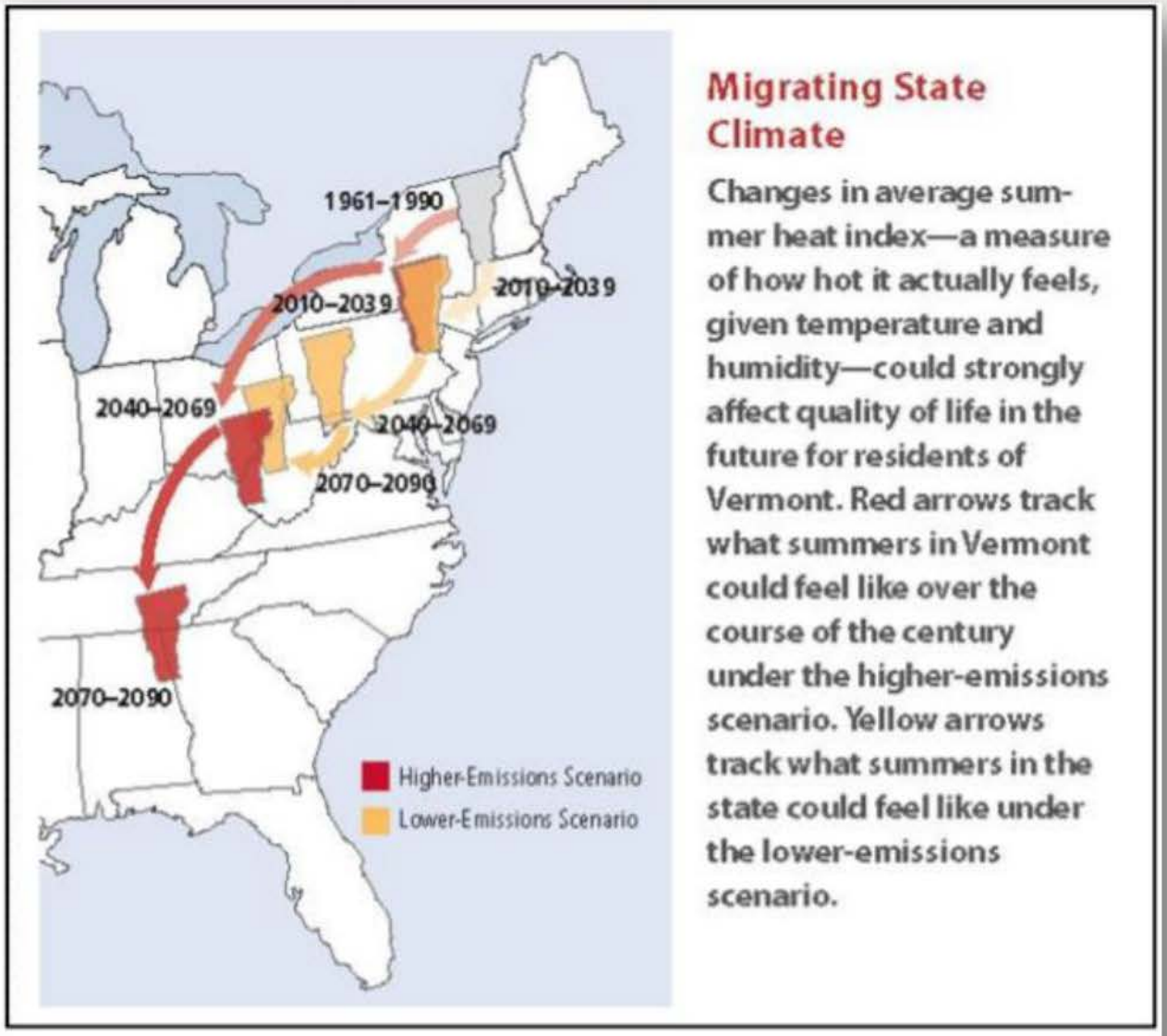
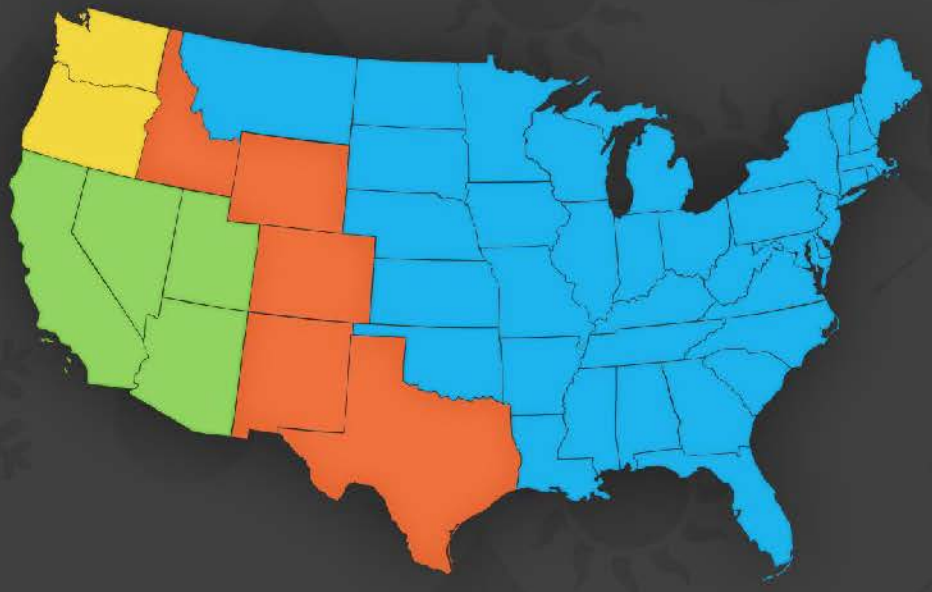


Figure 4. Schematic illustrating change of Vermont's summer climate by late-century with high and low emission scenarios

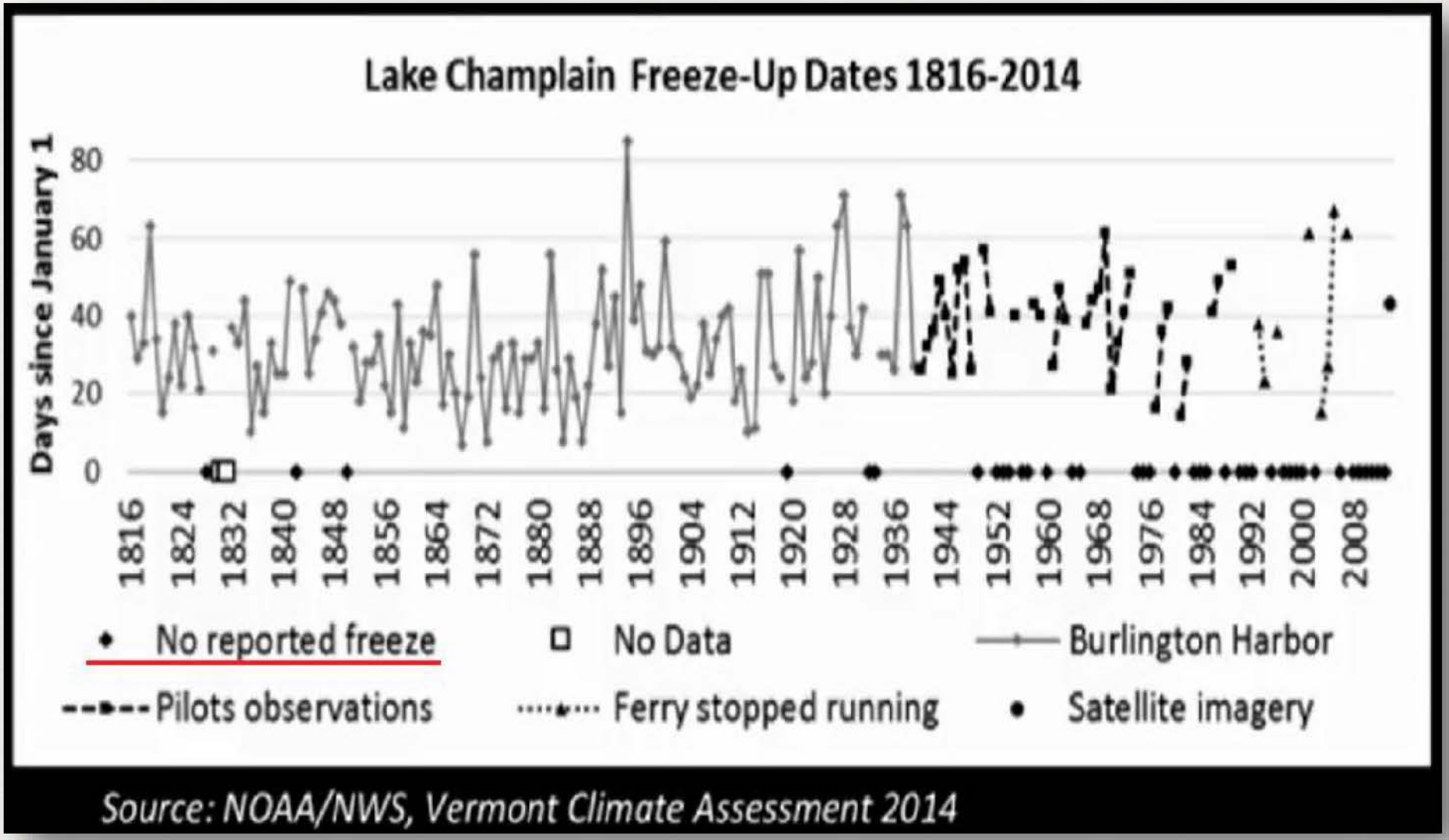
FASTEST WARMING SEASONS

WINTER SPRING SUMMER FALL



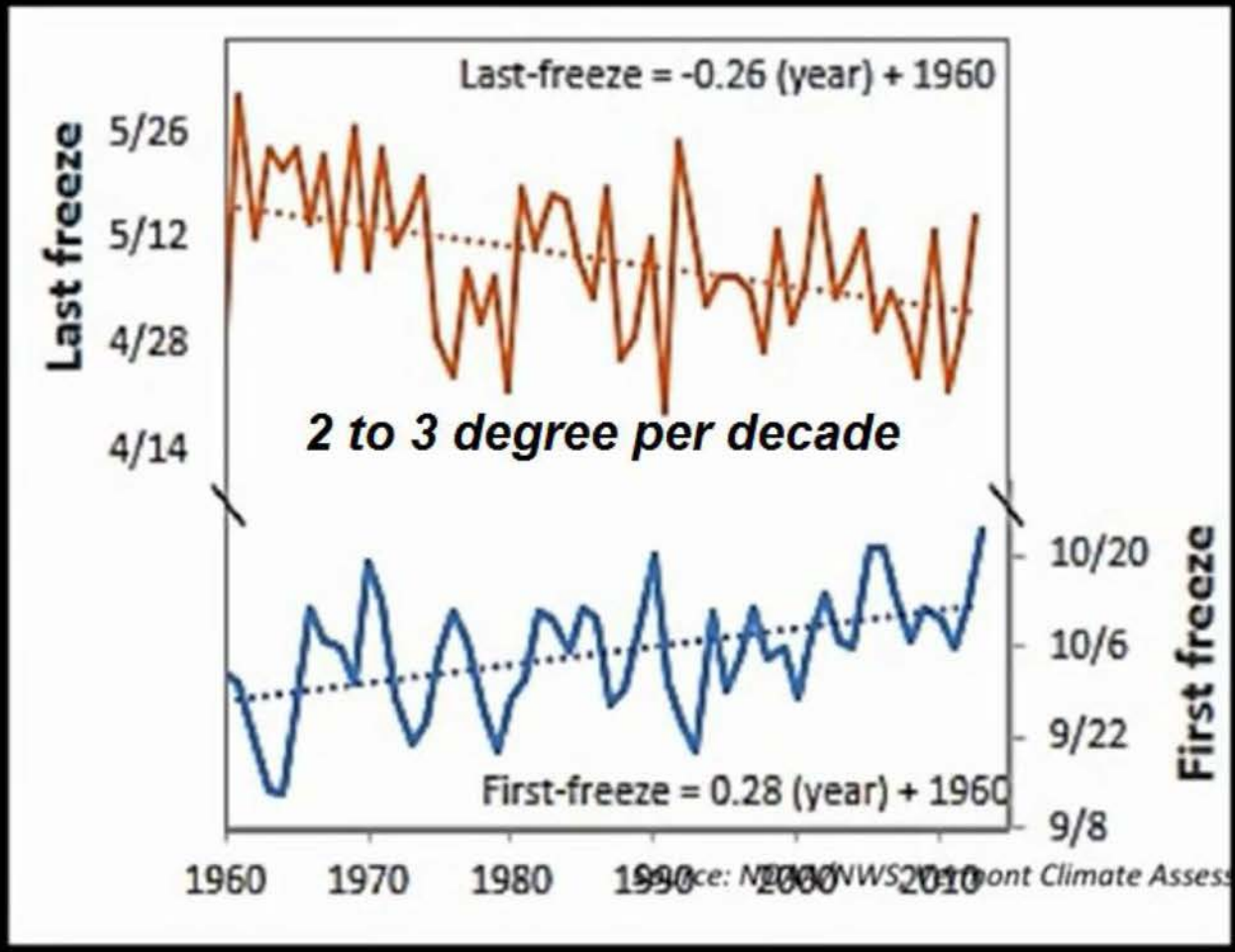
Linear seasonal trends fitted to 1970–2017 data
Source: NOAA/NCEI Climate at a Glance

CLIMATE CENTRAL



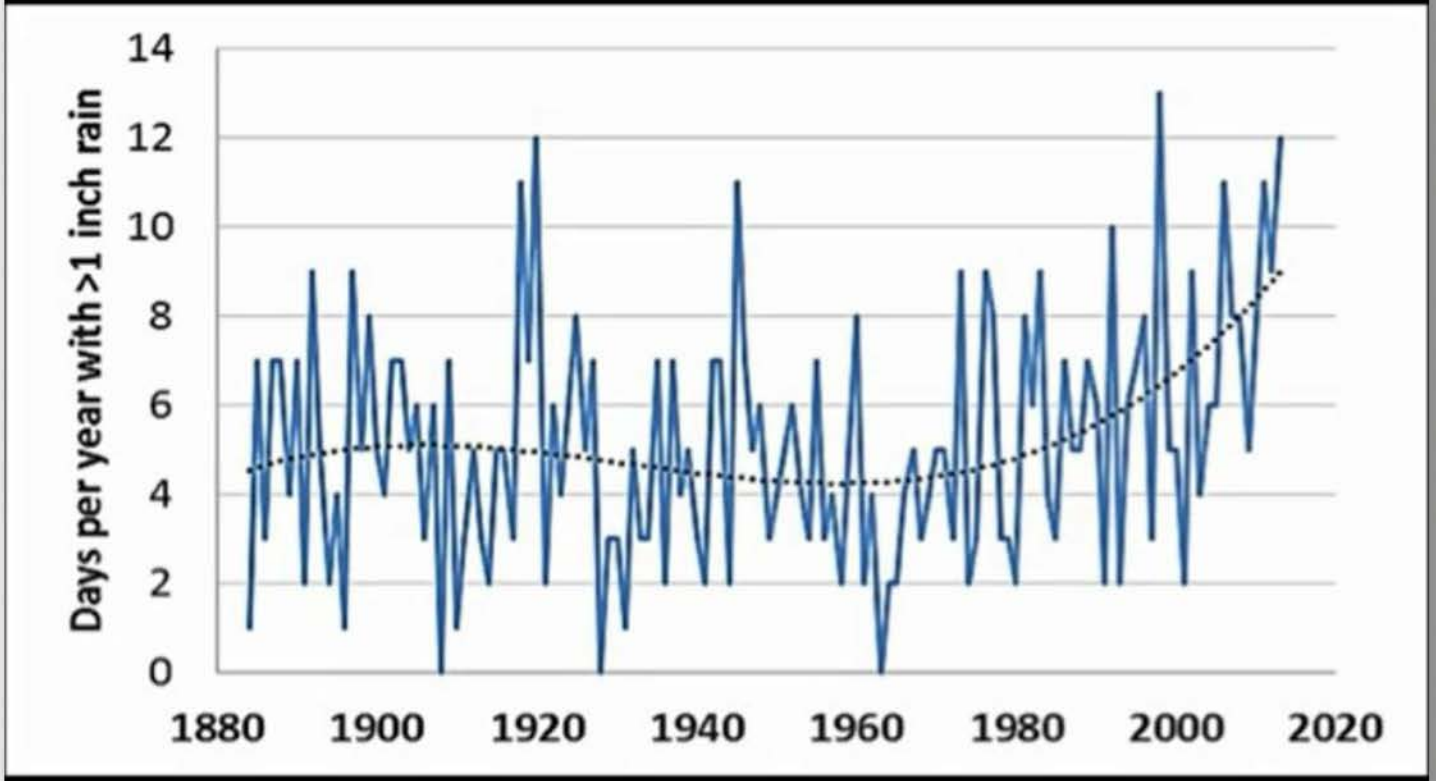
Source: NOAA/NWS, Vermont Climate Assessment 2014

Changes in the date of the first & last freeze dates

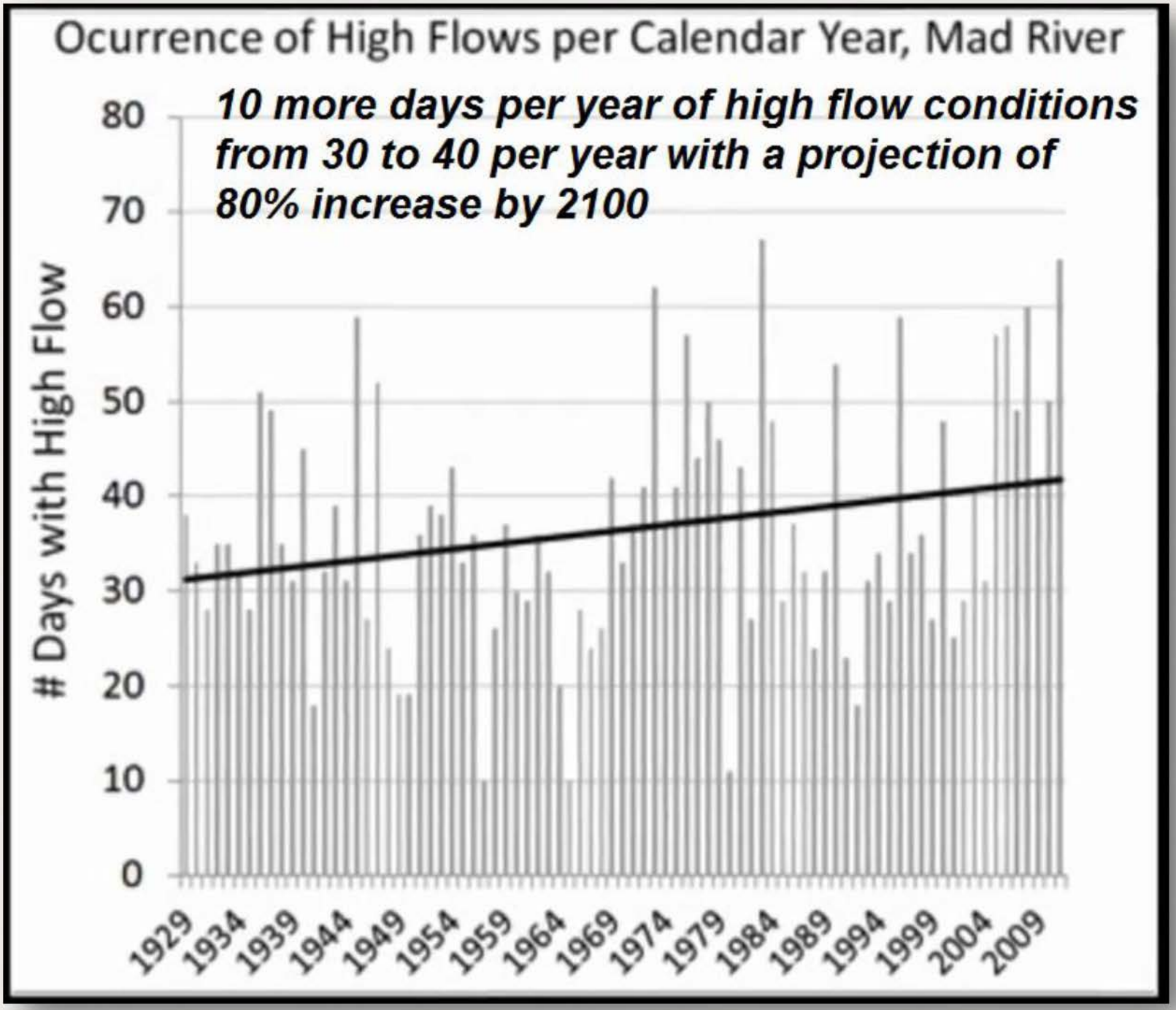


Source: NOAA/NWS, Vermont Climate Assessment 2014

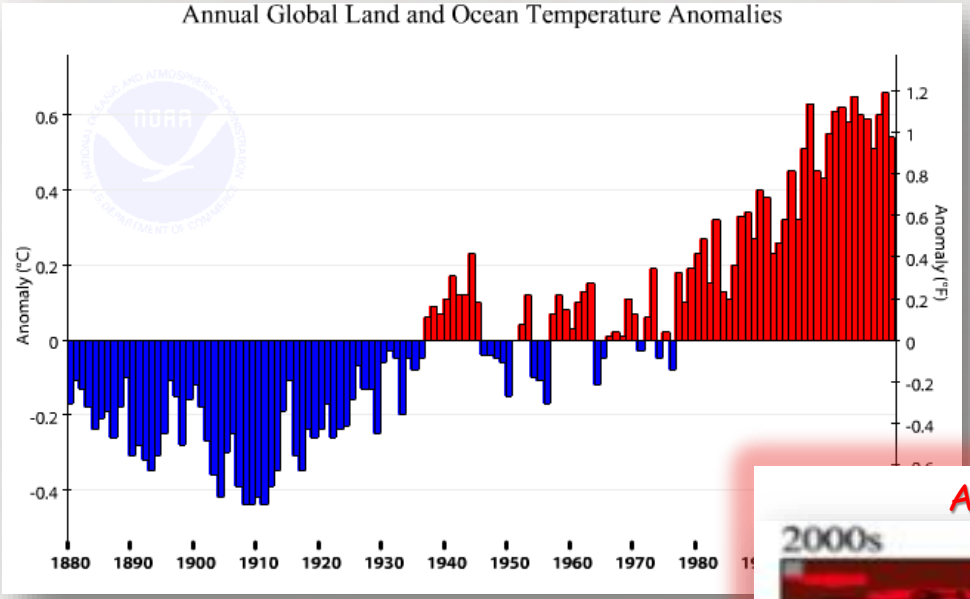
Number of days per year with greater than 1” of precipitation (BTV station)



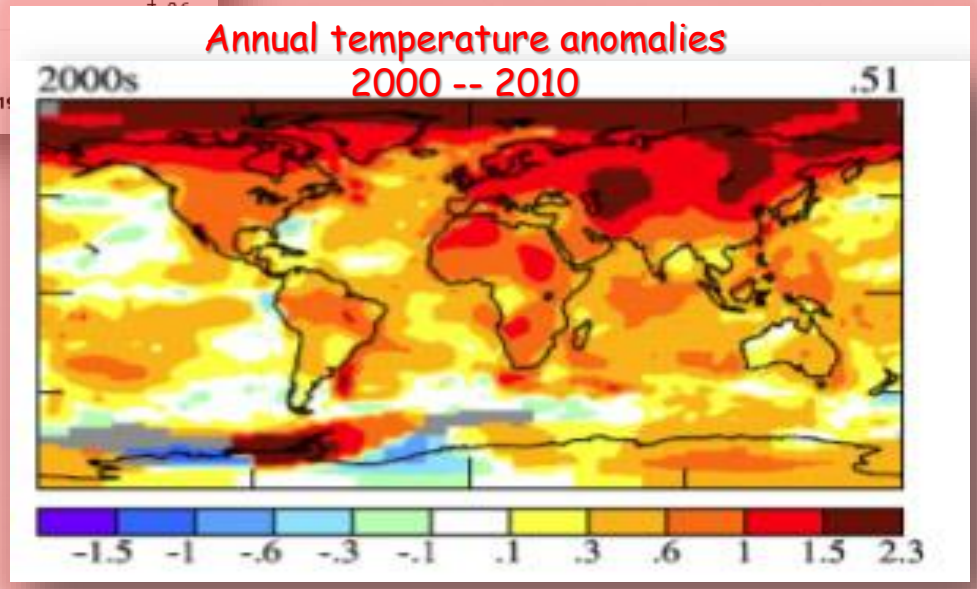
Source: NOAA/NWS, Vermont Climate Assessment 2014


Ocurrence of High Flows per Calendar Year, Mad River
10 more days per year of high flow conditions from 30 to 40 per year with a projection of 80% increase by 2100
Days with High Flow
80
70
60
50
40
30
20
10
0
1929
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009

The Earth's temperature is starting to catch up



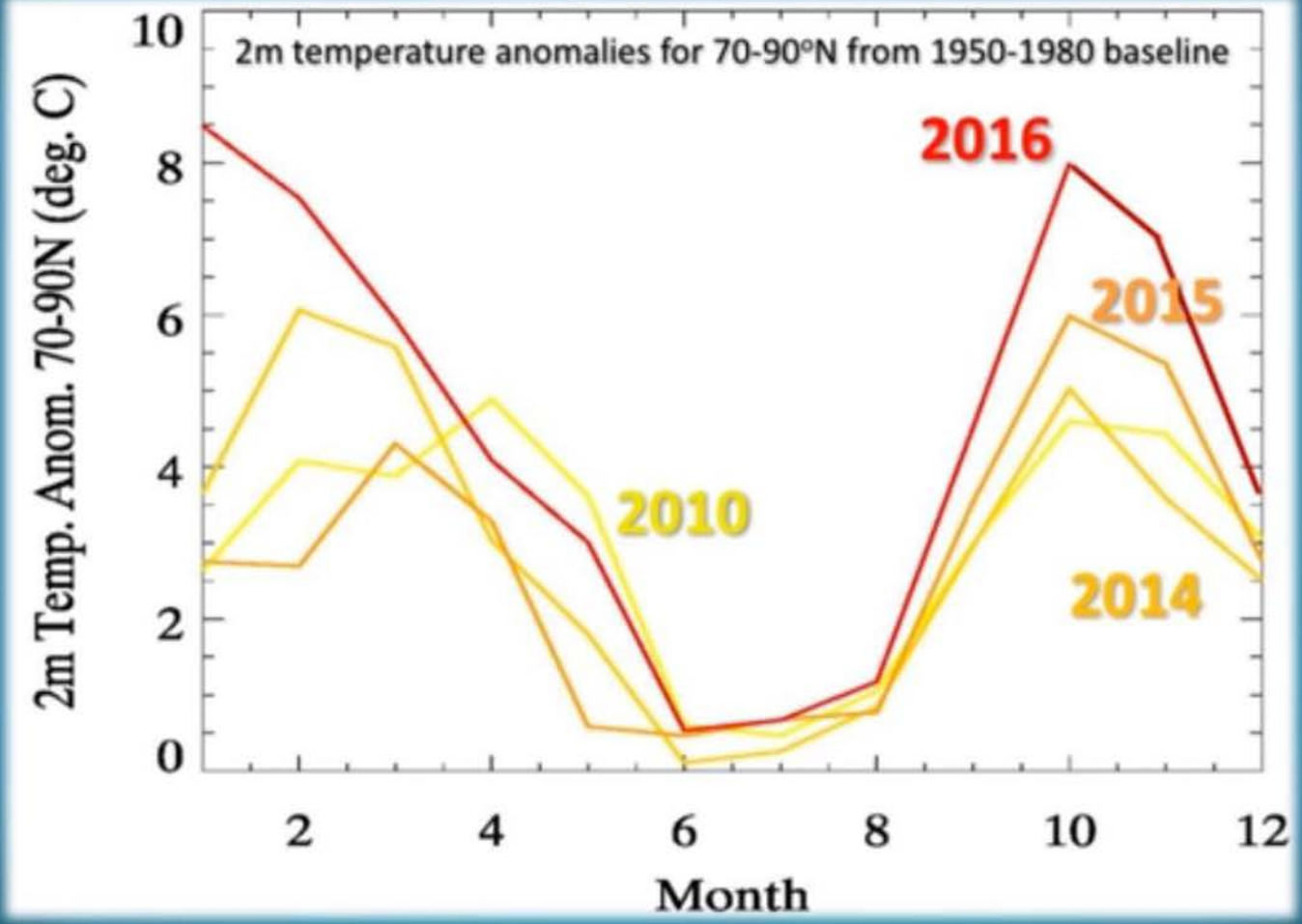
…although not evenly around the globe and in fits and starts



From NASA/GISS

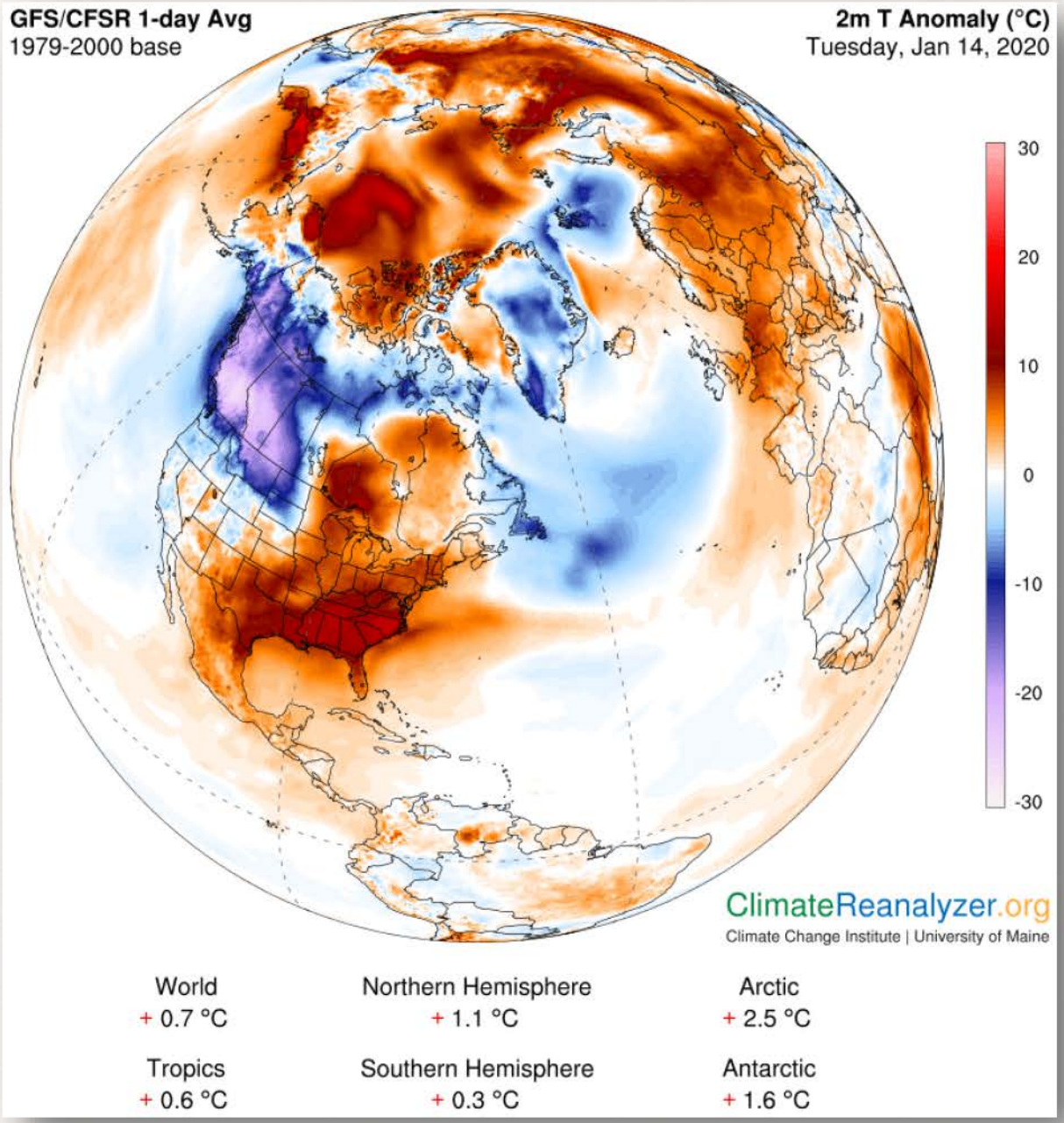
What happens in the arctic… doesn't stay in the arctic

Arctic temperature: *Record High*

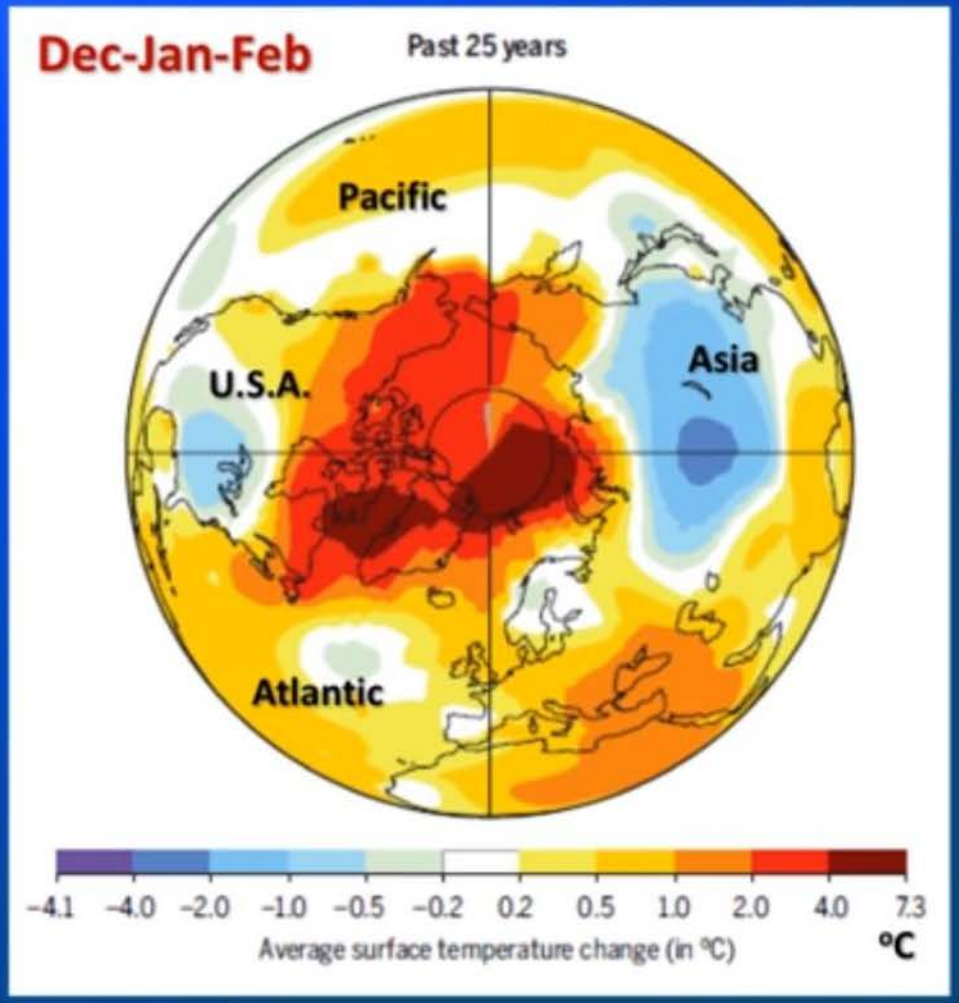


rancis@imcs.Rutgers.edu

data from NCEP reanalysis/ESRL

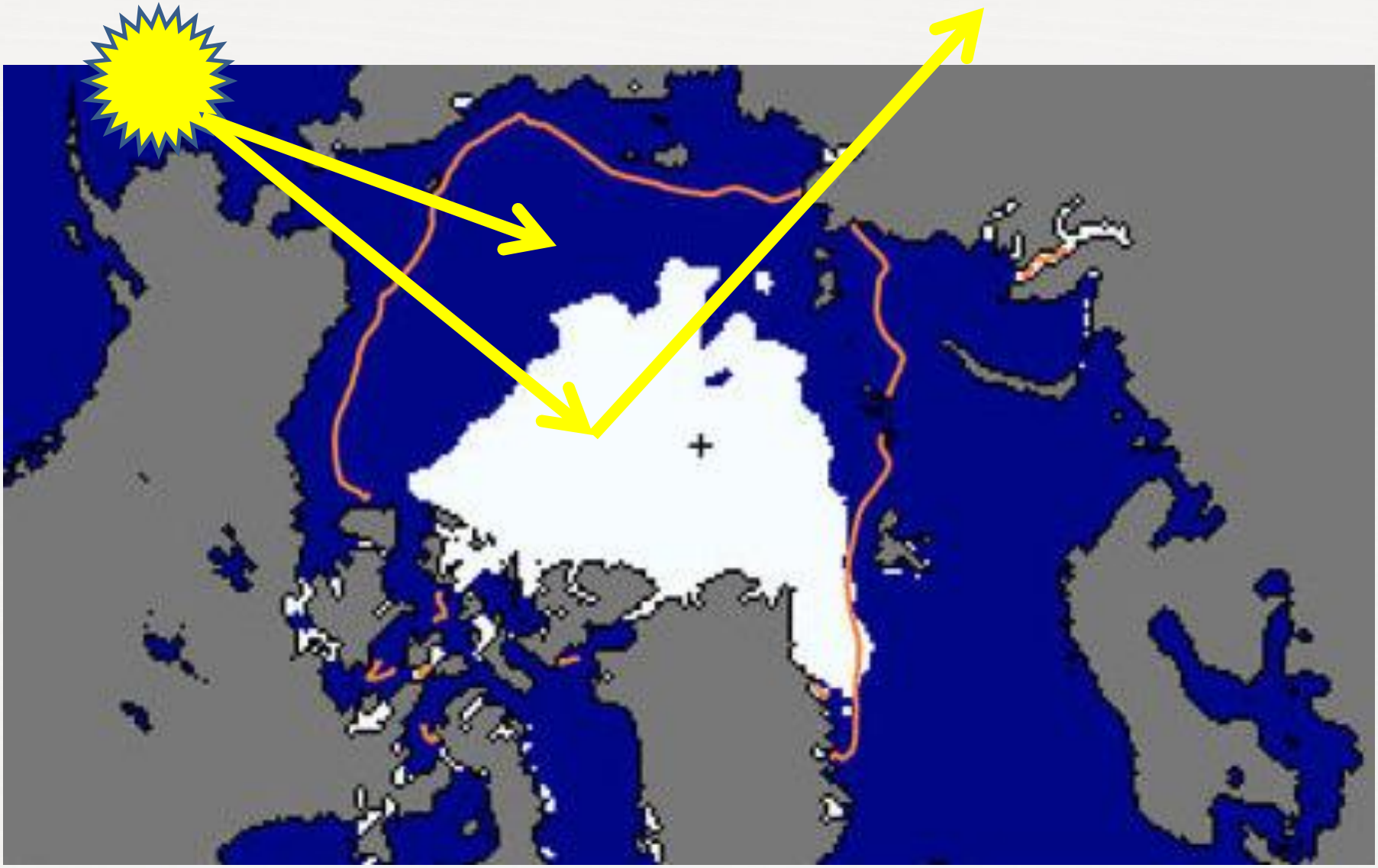

GFS/CFSR 1-day Avg
1979-2000 base
2m T Anomaly (°C)
Tuesday, Jan 14, 2020
30
20
10
0
-10
-20
-30
ClimateReanalyzer.org
Climate Change Institute | University of Maine
World
+ 0.7 °C
Northern Hemisphere
+ 1.1 °C
Arctic
+ 2.5 °C
Tropics
+ 0.6 °C
Southern Hemisphere
+ 0.3 °C
Antarctic
+ 1.6 °C

Air Temperature Anomaly



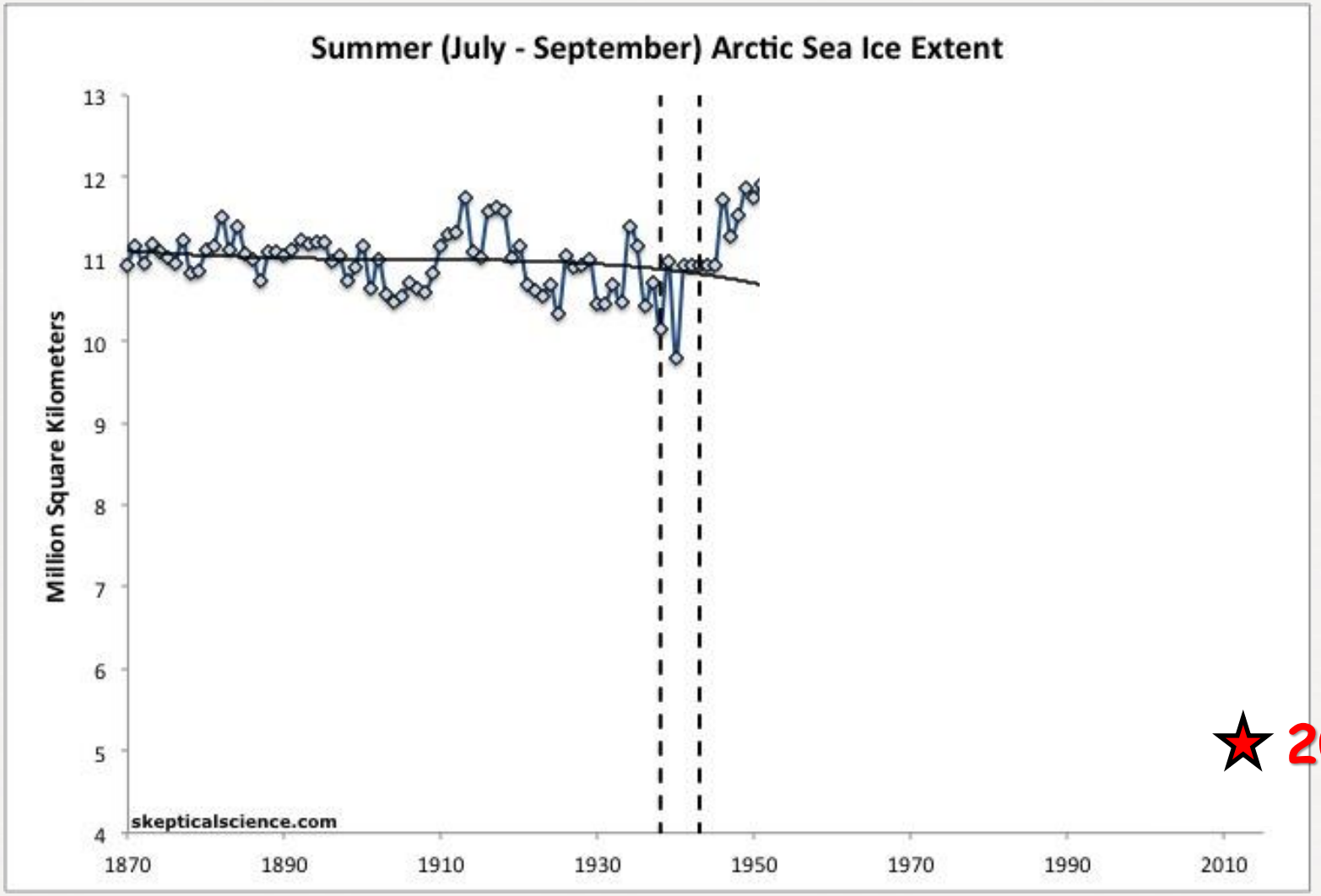
From Shepherd, *Science* 2016

J. Francis: *francis@imcs.Rutgers.edu*

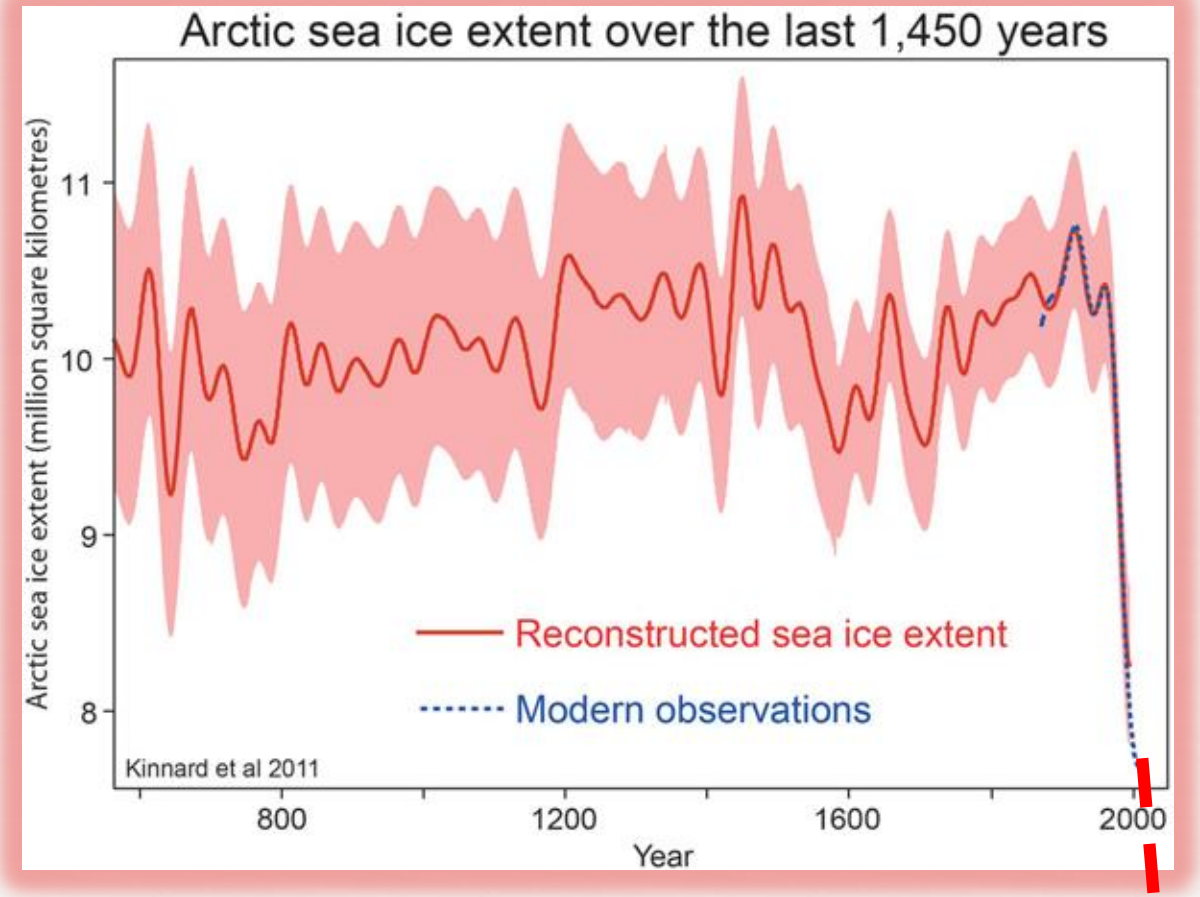


Extreme minimum Ice extent September 2012

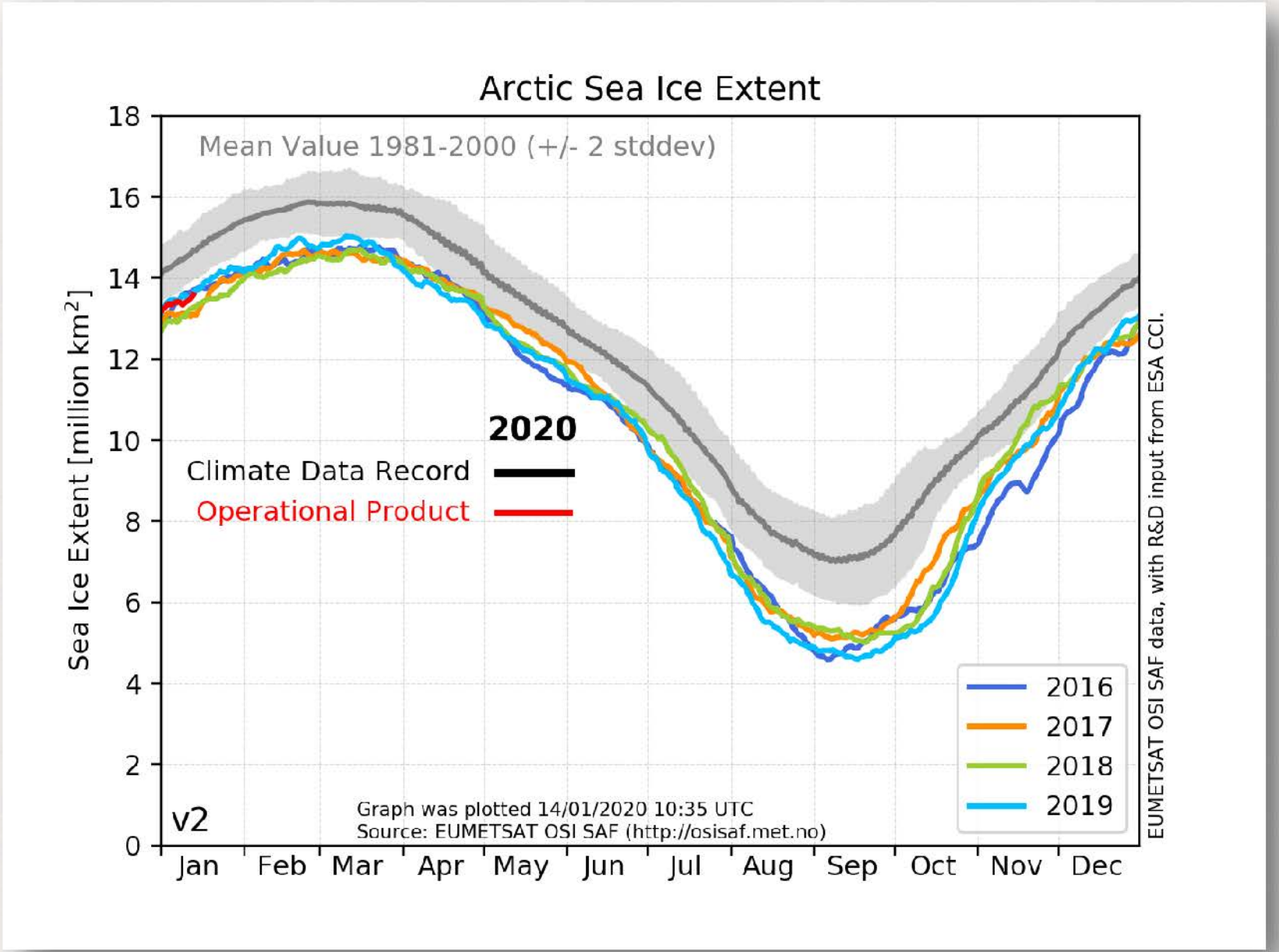
How unusual is this recent loss of Arctic sea ice?



Looking even farther back in time…

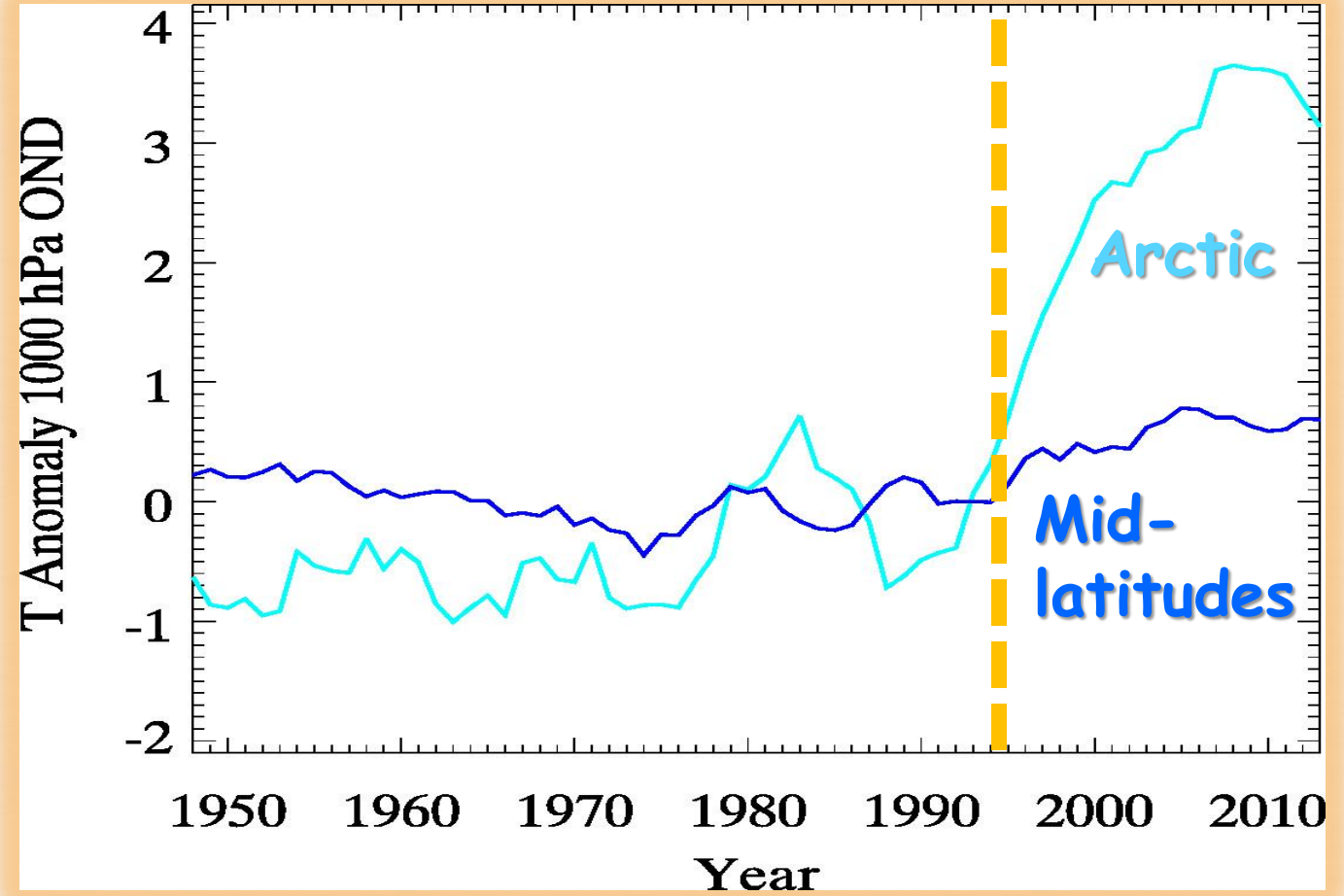


★ 2012


Arctic Sea Ice Extent
Mean Value 1981-2000 (+/- 2 stddev)
Sea Ice Extent [million km^2]
18
16
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2020
Climate Data Record
Operational Product
2016
2017
2018
2019
v2
Graph was plotted 14/01/2020 10:35 UTC
Source: EUMETSAT OSI SAF (http://osisaf.met.no)
EUMETSAT OSI SAF data, with R&D input from ESA CCI.

“Arctic Amplification”

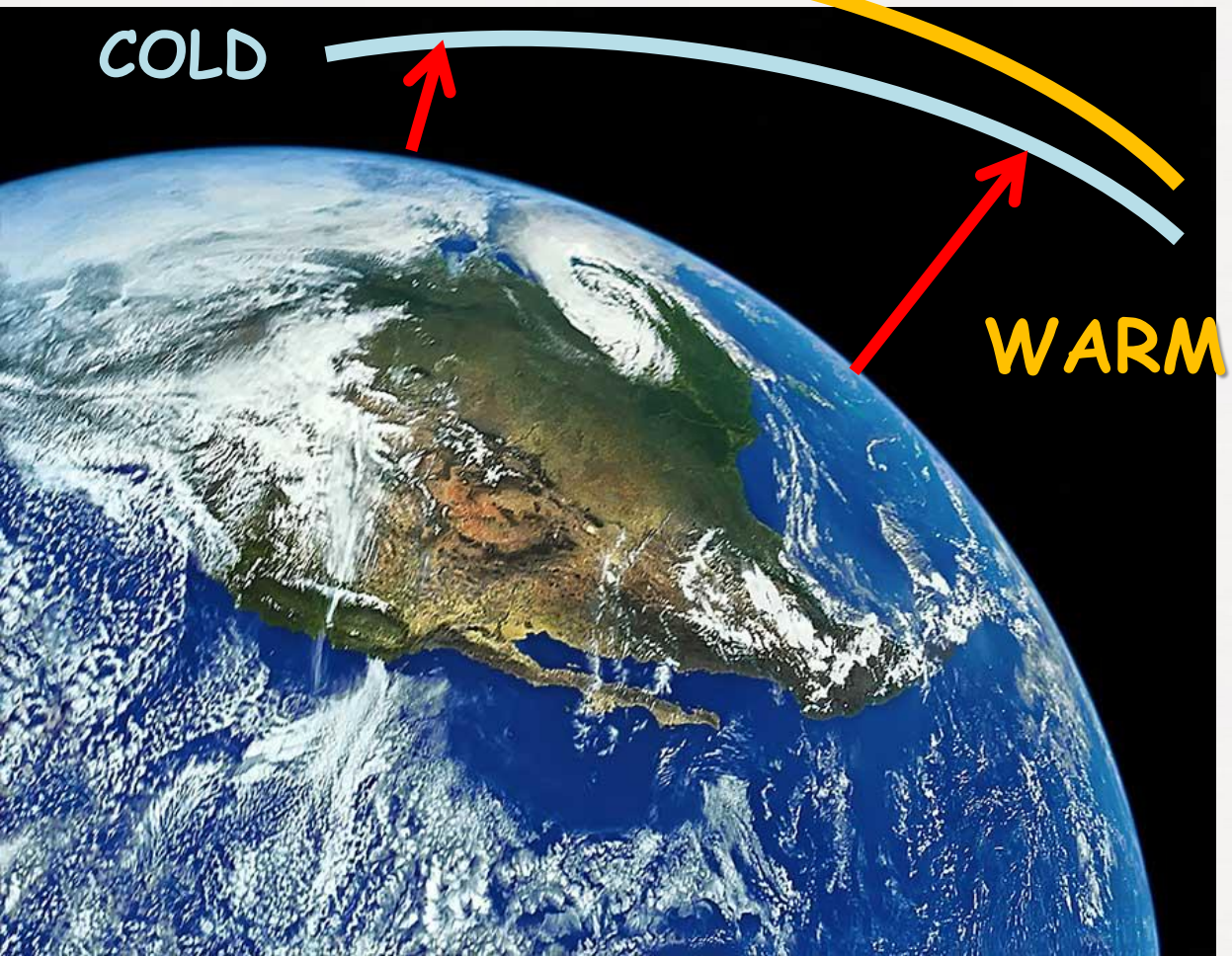
Near-surface air temperature (Fall)



Because warm air expands, the layer will be thicker here than it is in the Arctic

Consider a layer of atmosphere stretching from here (warm) to the Arctic (cold)

Air flows down this "hill", turns to the right as the Earth spins, and creates the Jet Stream

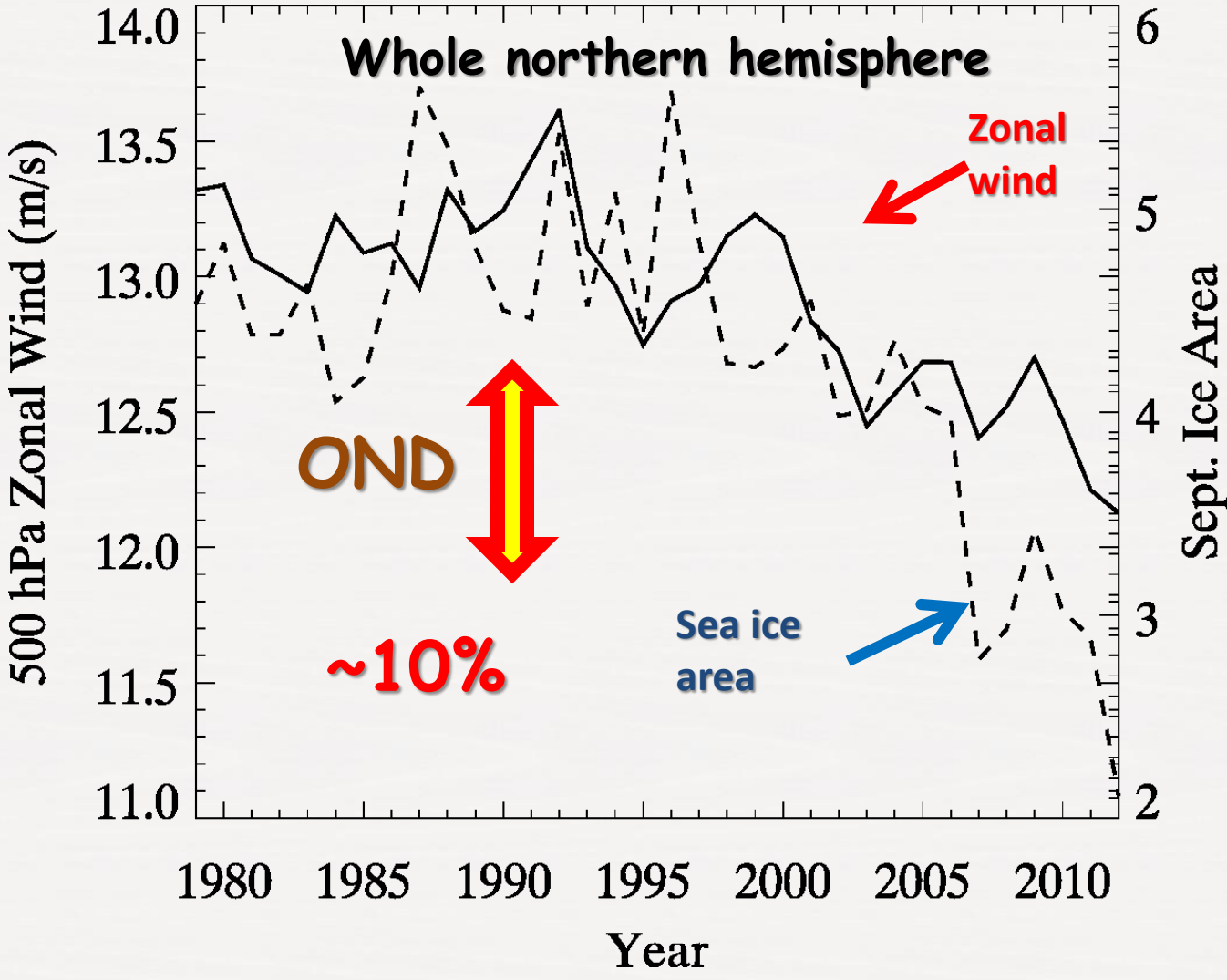


As the Arctic warms faster, the hill flattens, and the jet stream weakens

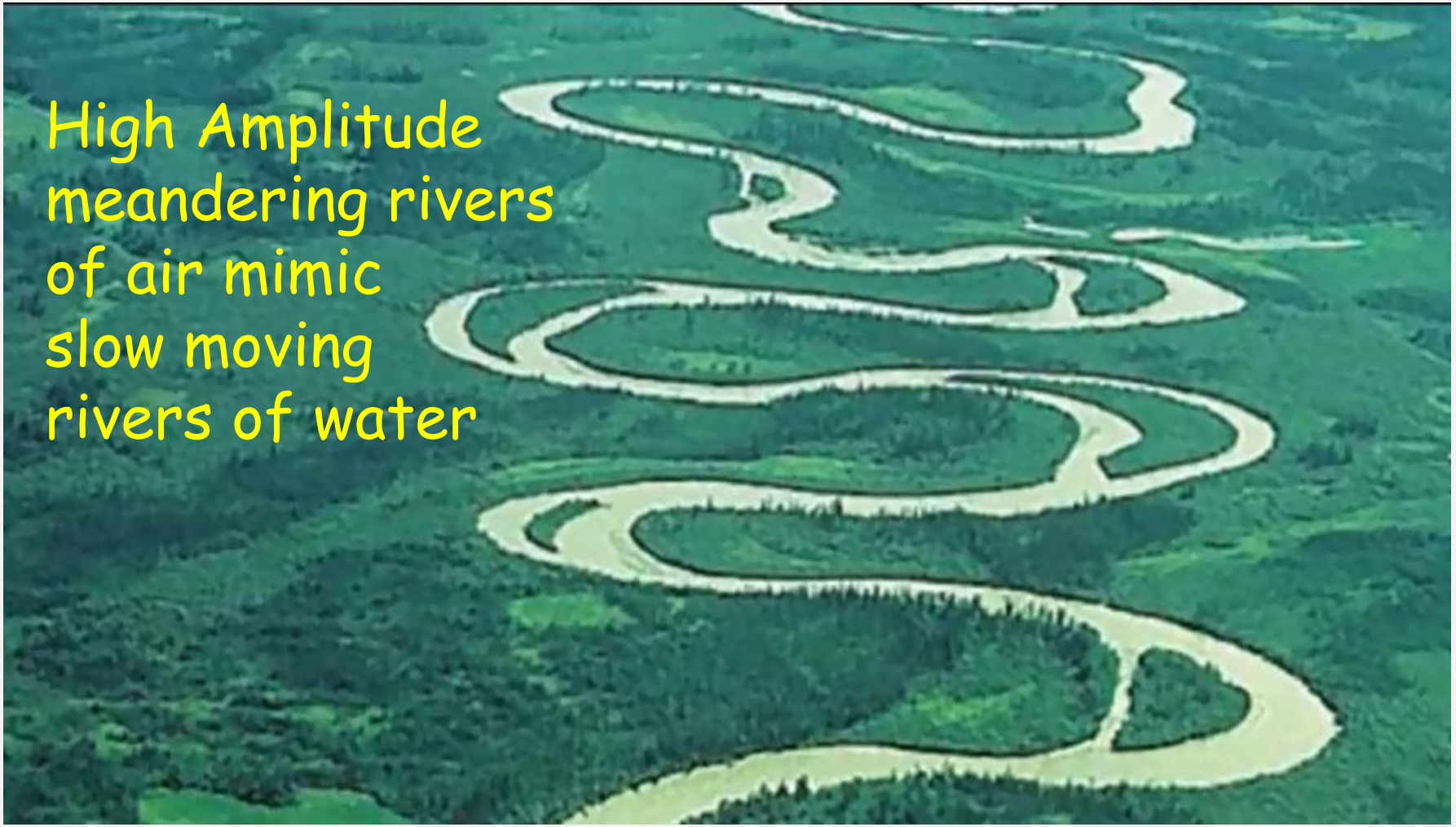
As the **HIGH** LATITUDES

warm faster than the

MIDDLE LATITUDES



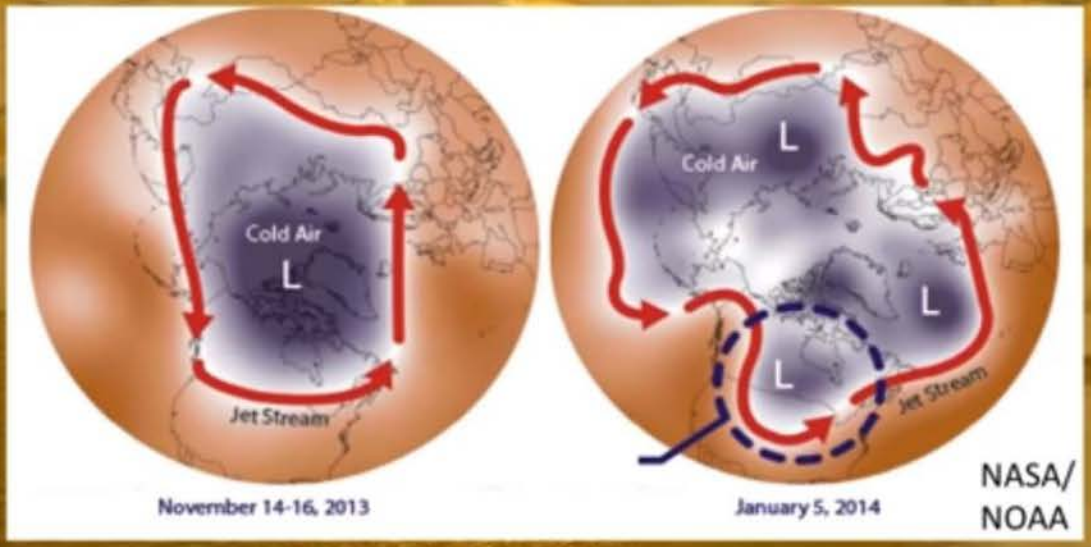
Rossby theory - weaker westerly flow favors more meandering pattern, slower eastward wave propagation.


High Amplitude
meandering rivers
of air mimic
slow moving
rivers of water

Two effects of AA

Weaker westerly winds

Intensified ridges



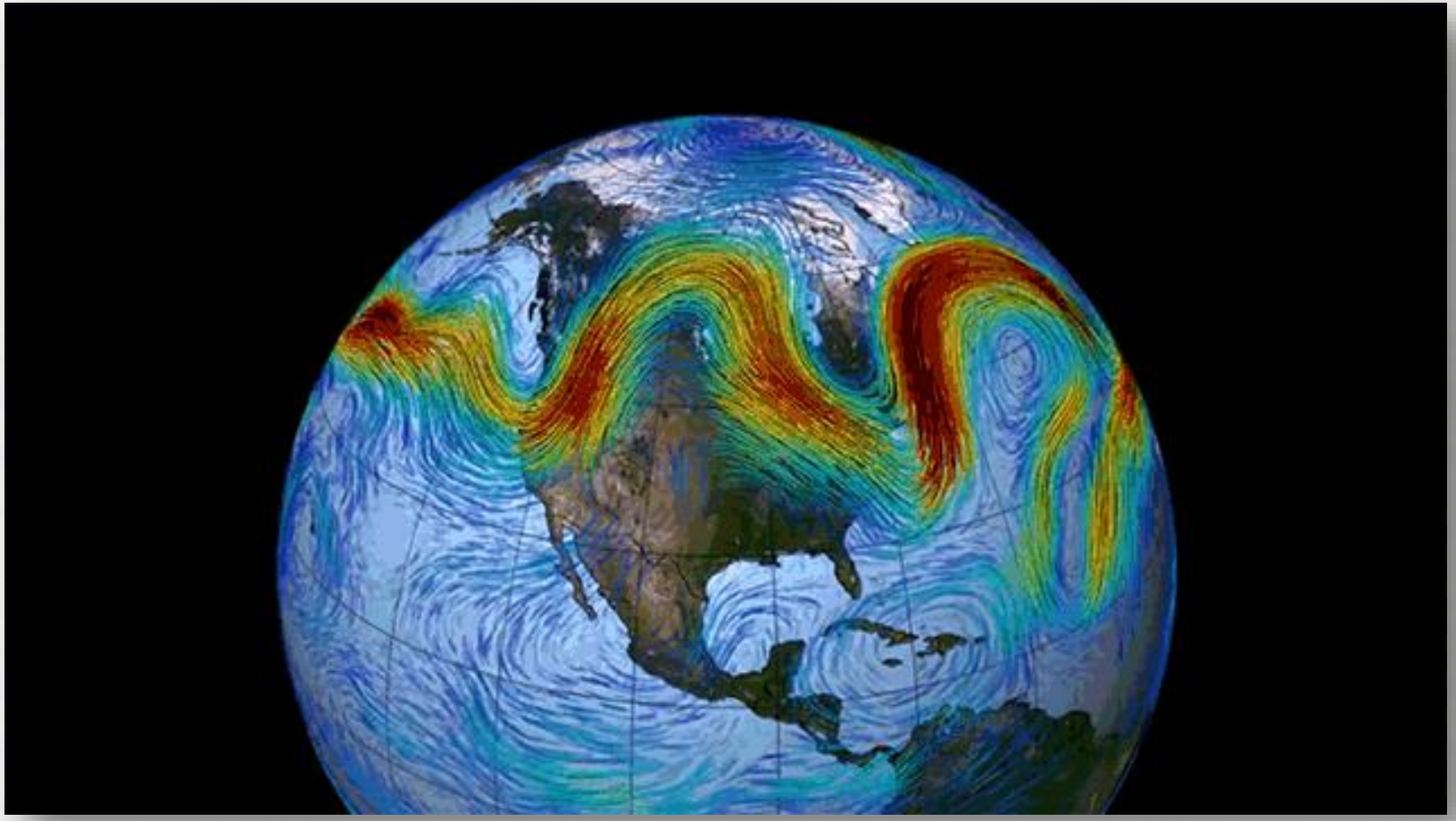
As the
HIGH
LATITUDES

warm faster
than the

MIDDLE
LATITUDES

from Francis and Vavrus, GRL 2012

Wavy jet stream High Amplitude Flow



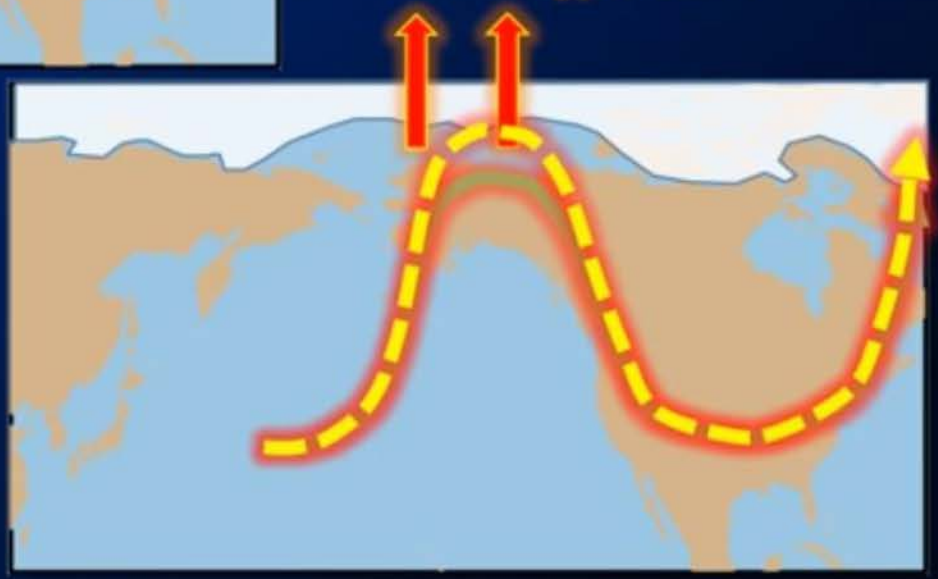
More intense ridges?

The

"It Takes Two to Tango"

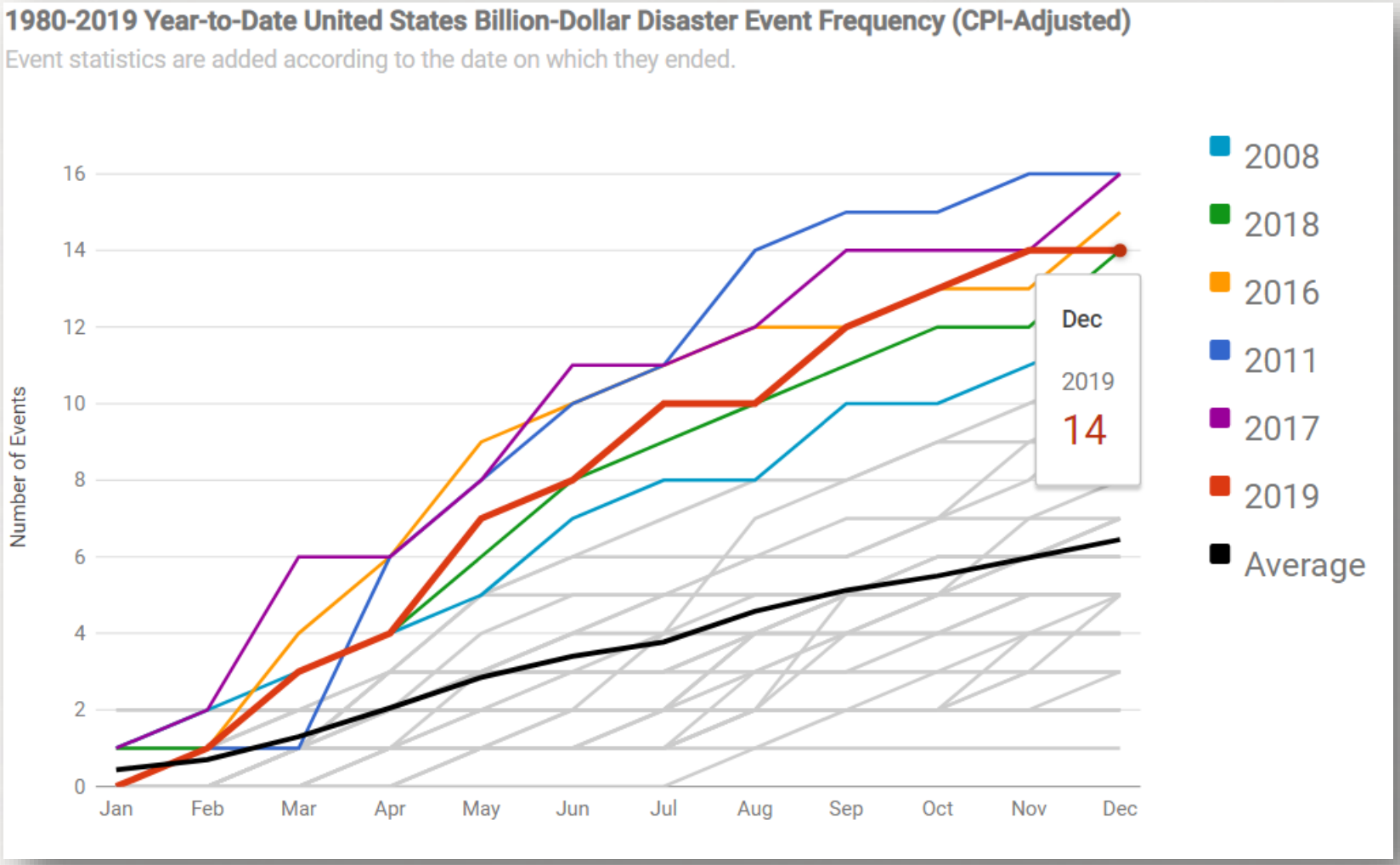
Hypothesis*

Extra heating intensifies ridge, making it more persistent.



*Francis et al, 2017

Nature's Carbon Tax



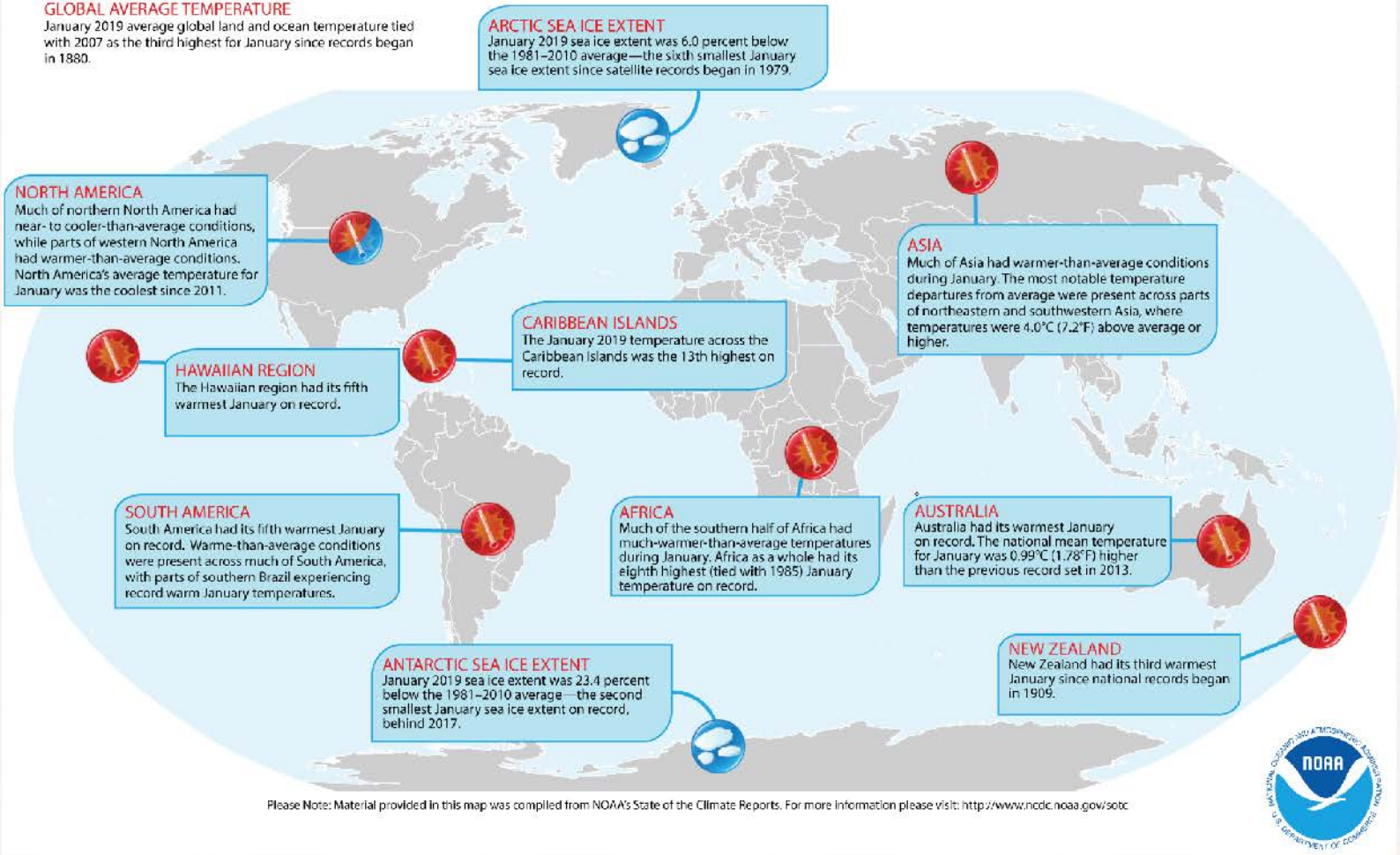
Courtesy: Green Mountain Power

An unusual "gravity wave" induced wind storm produced wind gusts of hurricane force in parts of western Vermont and eastern New York Friday afternoon. The unusual wind storm occurred suddenly in the late afternoon and appears to be driven by what is known as a gravity wave.

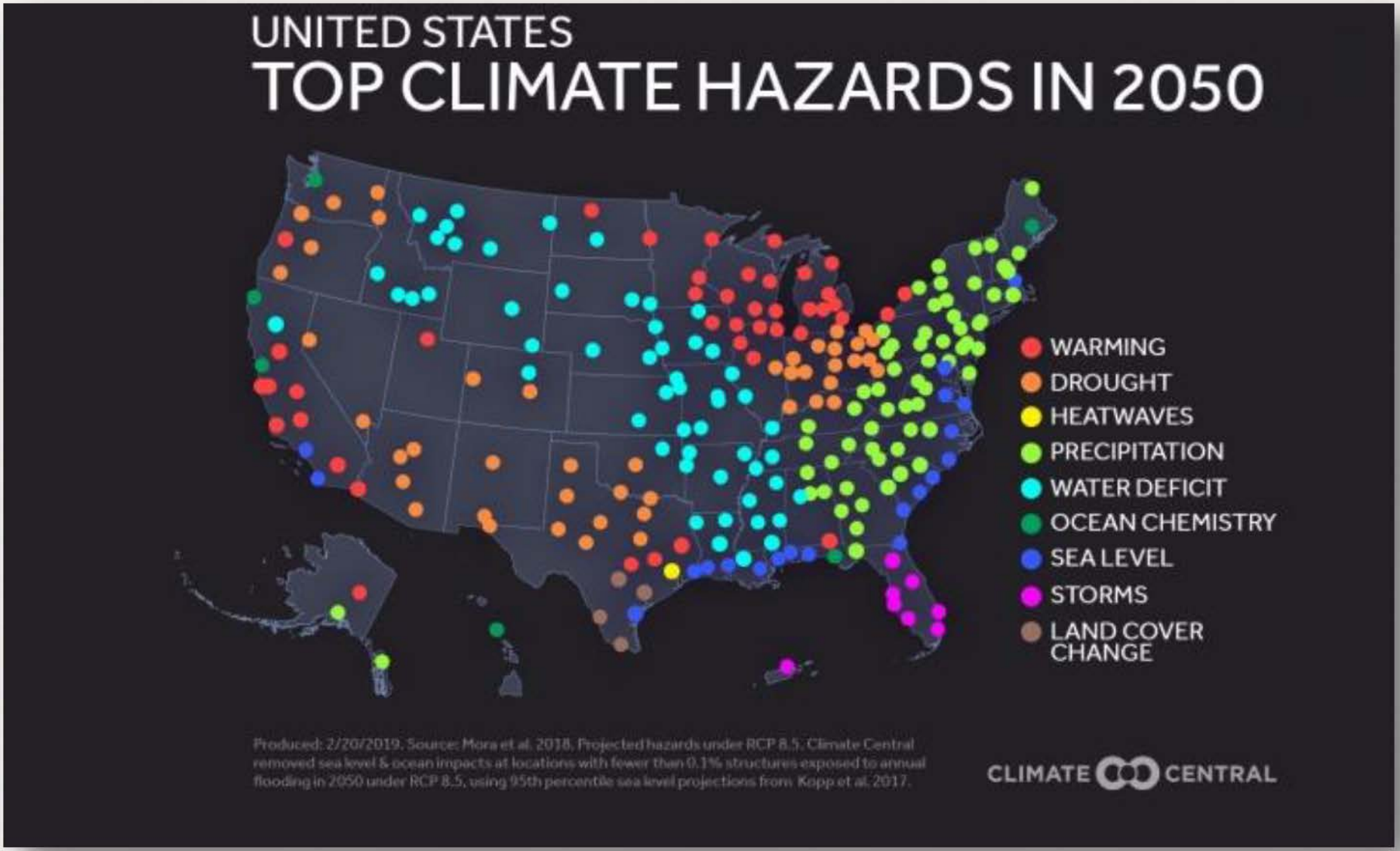
Summary of the Severe, High Wind, and Hydro Event on May 4, 2018

By Brooke Taber and Peter Banacos May 14 at 5:35 PM Email the authors

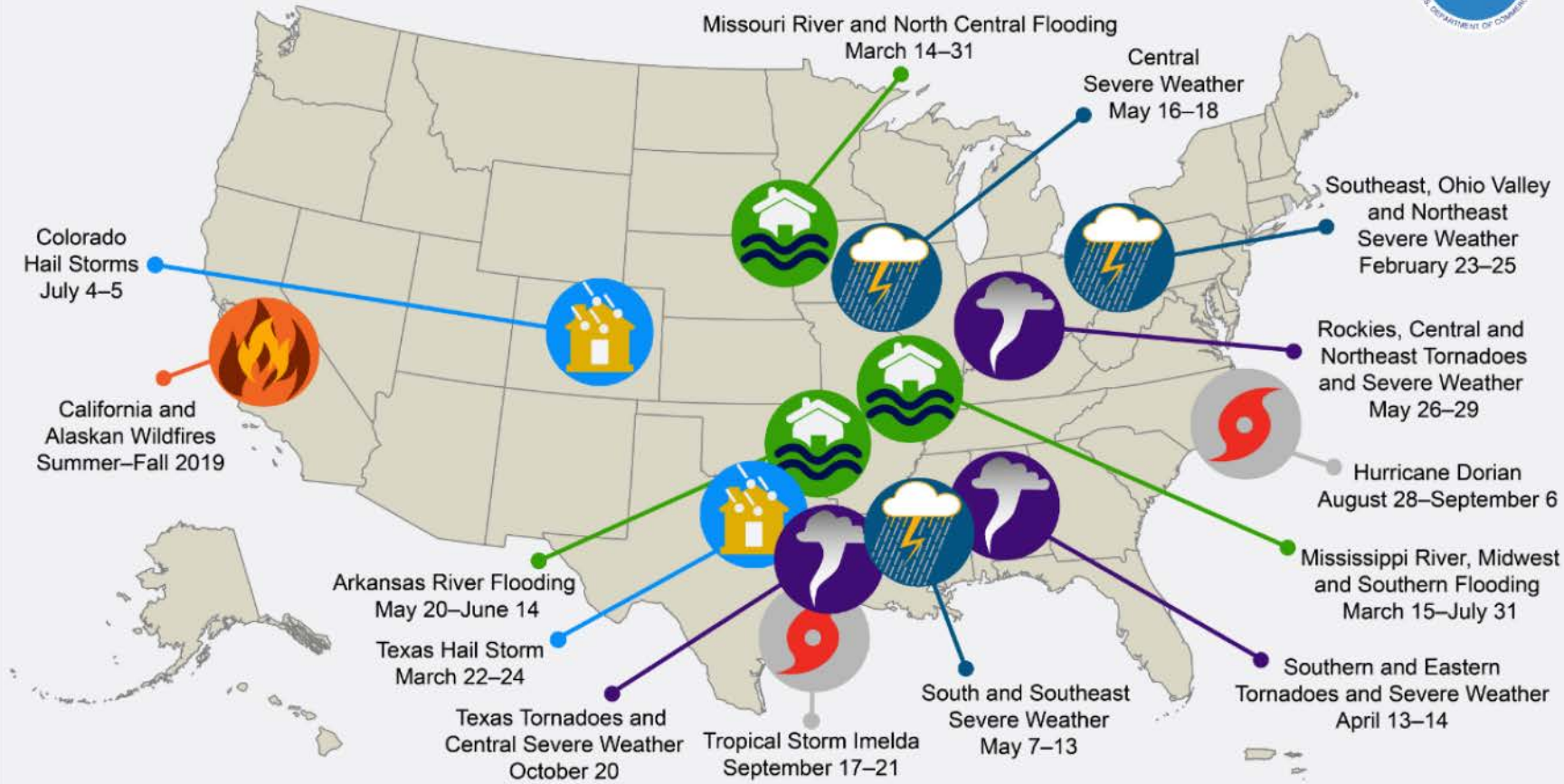
Selected Significant Climate Anomalies and Events
January 2019



Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

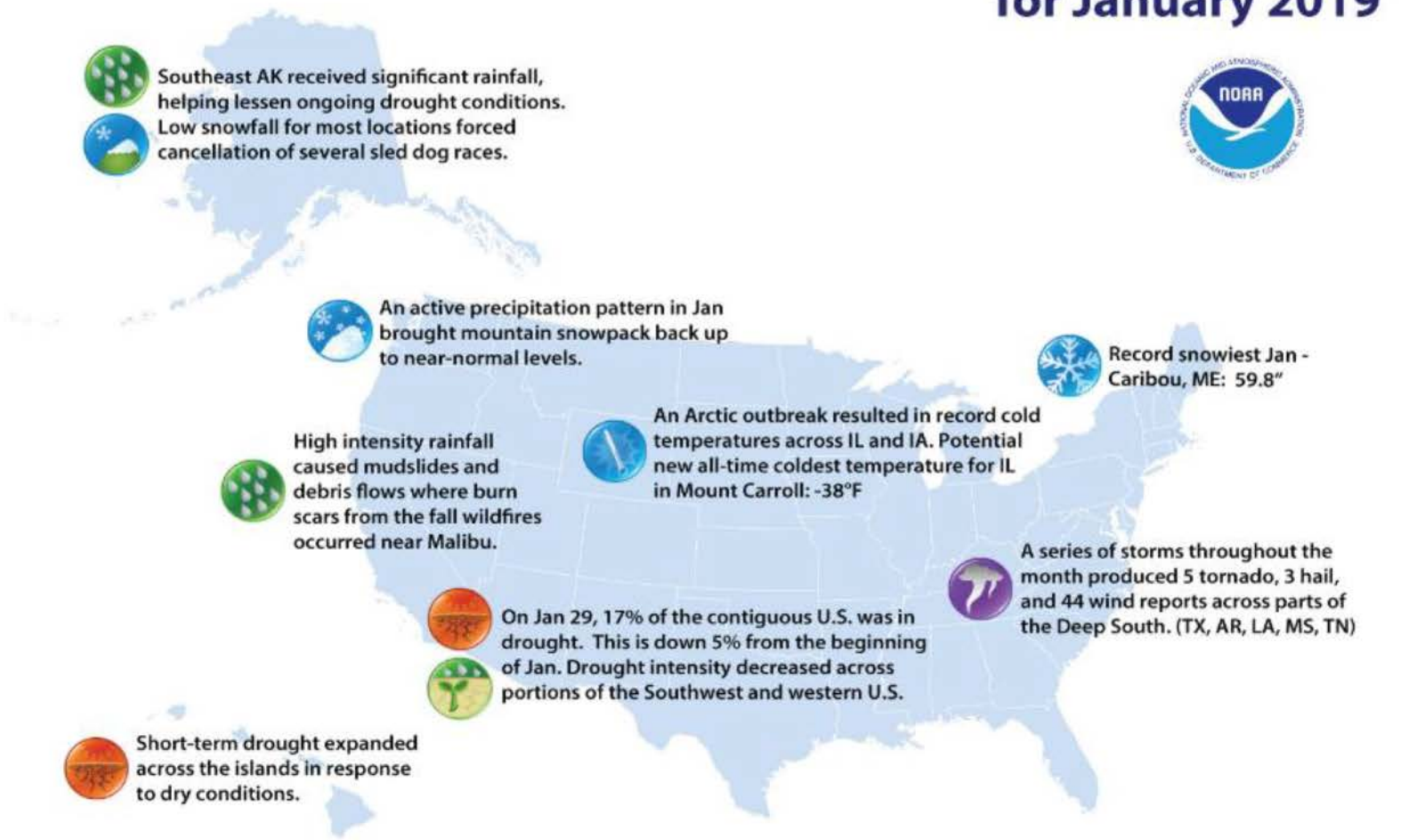

UNITED STATES
TOP CLIMATE HAZARDS IN 2050
WARMING
DROUGHT
HEATWAVES
PRECIPITATION
WATER DEFICIT
OCEAN CHEMISTRY
SEA LEVEL
STORMS
LAND COVER CHANGE
Produced: 2/20/2019. Source: Mora et al. 2018. Projected hazards under RCP 8.5. Climate Central removed sea level & ocean impacts at locations with fewer than 0.1% structures exposed to annual flooding in 2050 under RCP 8.5, using 95th percentile sea level projections from Kopp et al. 2017.
CLIMATE CENTRAL

U.S. 2019 Billion-Dollar Weather and Climate Disasters



*This map denotes the approximate location for each of the **14 separate billion-dollar weather and climate disasters** that impacted the United States **during 2019**.*

U.S. Selected Significant Climate Anomalies and Events for January 2019

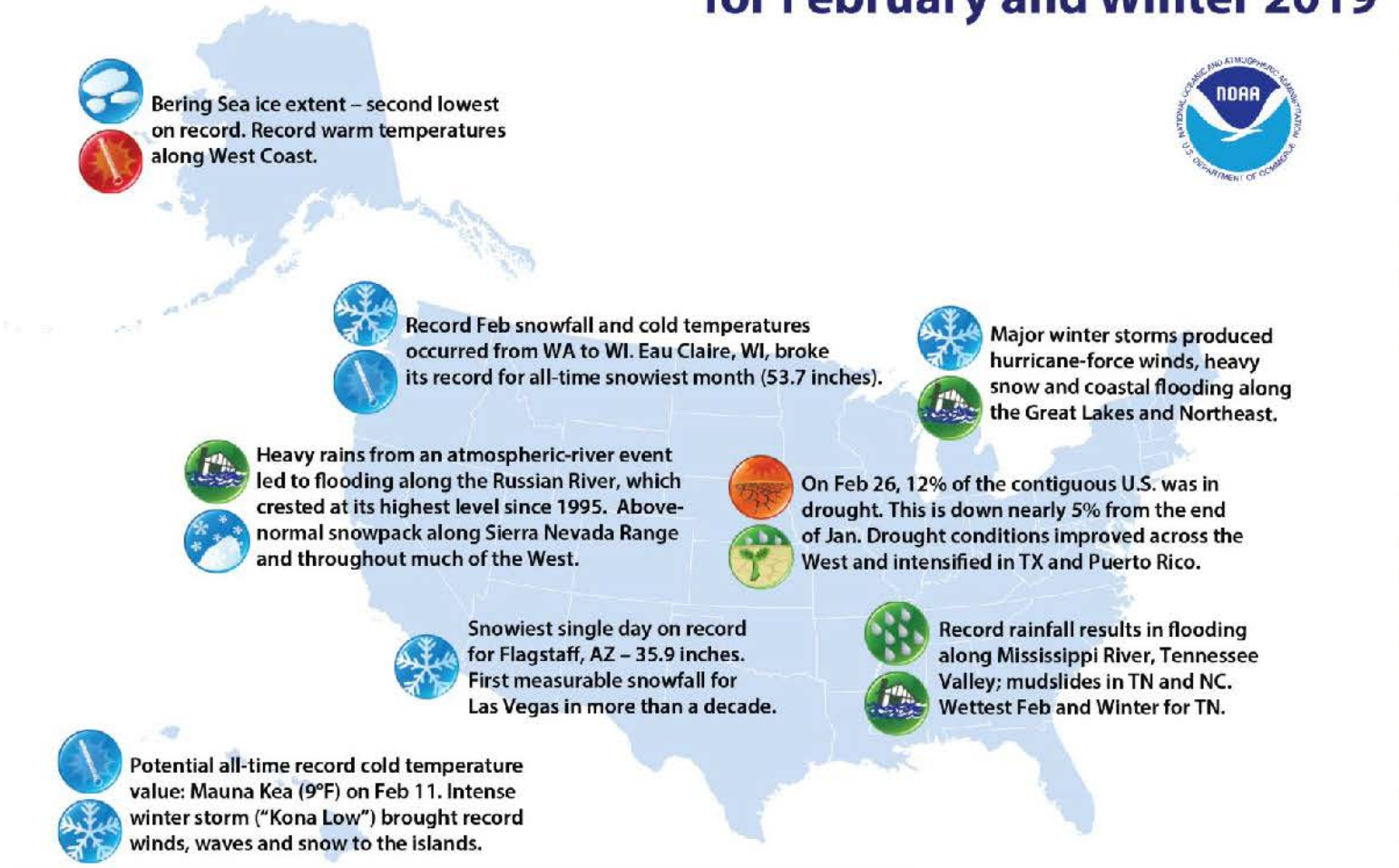


The average U.S. temperature for January was 32.7°F, 2.6°F above average, ranking in the warmest third of the 125-year record. The U.S. precipitation average for January was 2.49 inches, 0.18 inch above average, ranking in the wettest third of the record.

San Juan was slightly warmer and drier than normal. Despite it being warm, it was the coolest Jan since 2012 and precipitation was 56% of normal.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

U.S. Selected Significant Climate Anomalies and Events for February and Winter 2019

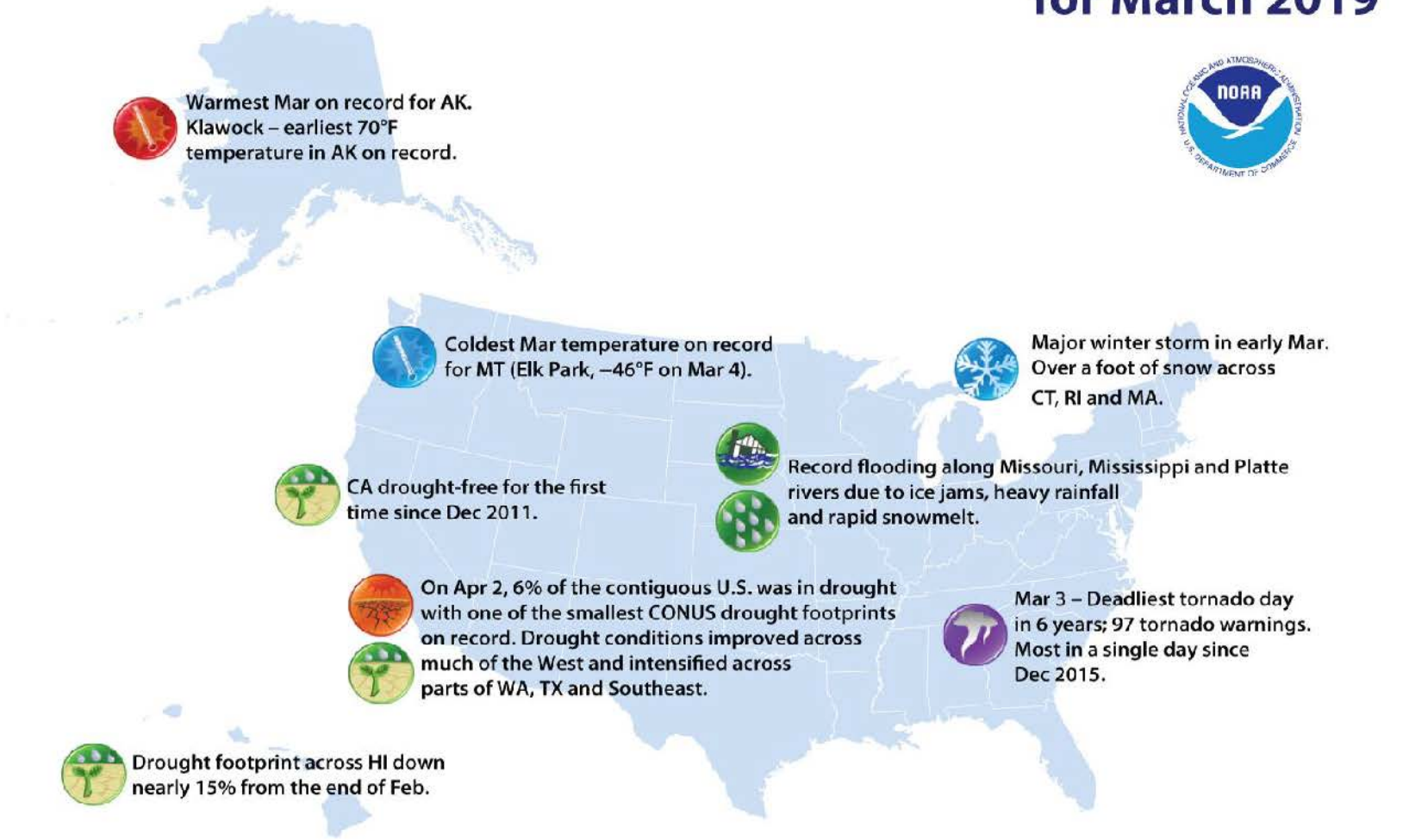


The average U.S. temperature for February was 32.0°F, 1.8°F below average, ranking in the coldest third of the 125-year record. The U.S. precipitation average for February was 3.22 inches, 1.09 inches above average, ranking second wettest on record. The winter average U.S. temperature was 33.4°F, 1.2°F above average. The winter precipitation total was 9.01 inches, 2.22 inch above average — wettest on record.

Moderate drought expands, covering nearly 33% of Puerto Rico.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

U.S. Selected Significant Climate Anomalies and Events for March 2019

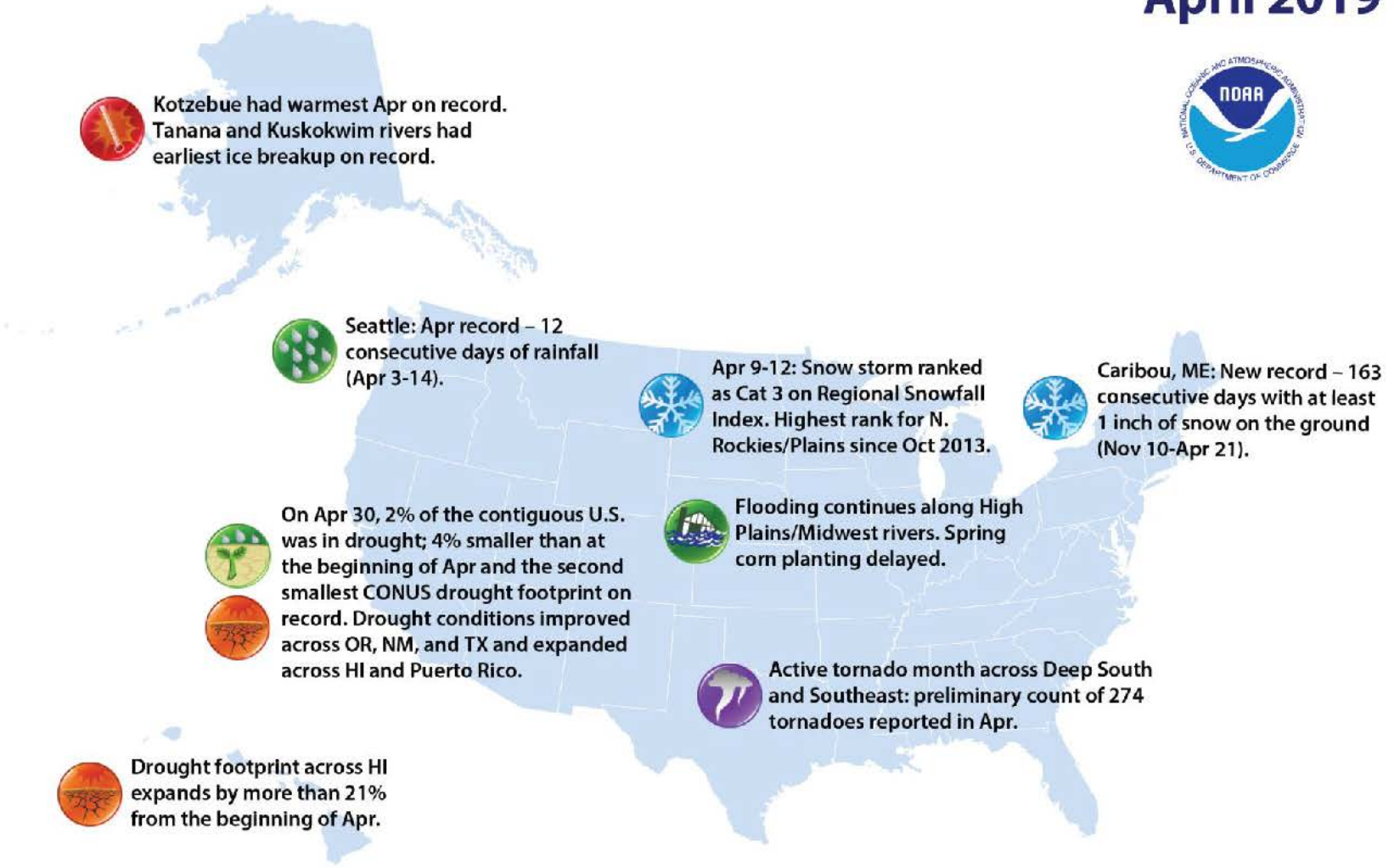


The average U.S. temperature for March was 40.68°F, 0.82°F below average, ranking in the middle third of the 125-year record. The U.S. precipitation average for March was 2.20 inches, 0.31 inches below average, ranking in the driest third of the record.

Moderate drought contracts, covering around 10% of Puerto Rico.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

U.S. Selected Significant Climate Anomalies and Events
April 2019



Kotzebue had warmest Apr on record. Tanana and Kuskokwim rivers had earliest ice breakup on record.

Seattle: Apr record – 12 consecutive days of rainfall (Apr 3-14).

Apr 9-12: Snow storm ranked as Cat 3 on Regional Snowfall Index. Highest rank for N. Rockies/Plains since Oct 2013.

Caribou, ME: New record – 163 consecutive days with at least 1 inch of snow on the ground (Nov 10-Apr 21).

On Apr 30, 2% of the contiguous U.S. was in drought; 4% smaller than at the beginning of Apr and the second smallest CONUS drought footprint on record. Drought conditions improved across OR, NM, and TX and expanded across HI and Puerto Rico.

Flooding continues along High Plains/Midwest rivers. Spring corn planting delayed.

Active tornado month across Deep South and Southeast: preliminary count of 274 tornadoes reported in Apr.

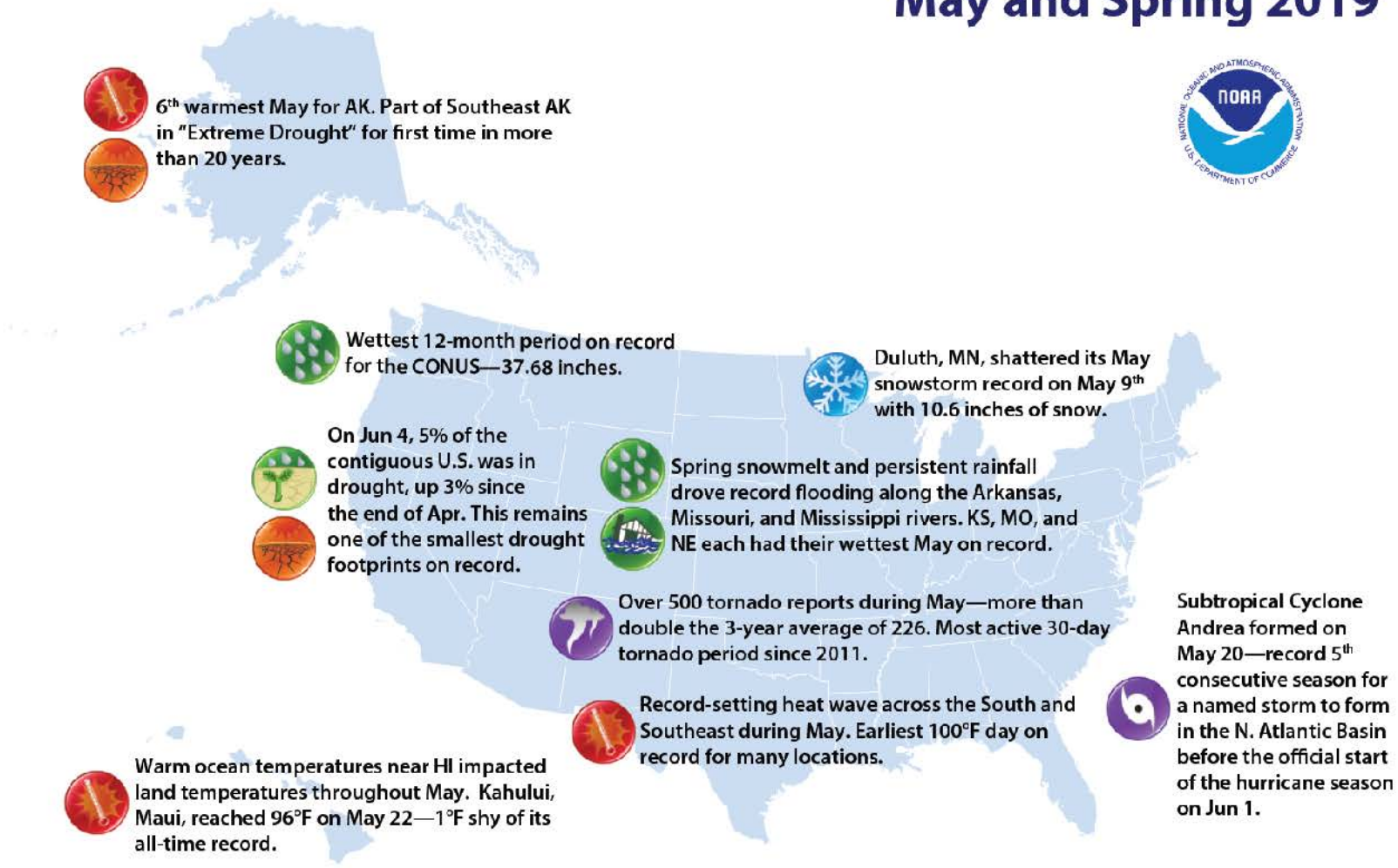
Drought footprint across HI expands by more than 21% from the beginning of Apr.

The average U.S. temperature for April was 52.88°F, 1.83°F above average, ranking in the upper third of the 125-year record. The U.S. precipitation average for April was 3.17 inches, 0.65 inches above average, ranking in the top 10% of the record.

Moderate drought expands, covering nearly 16% of Puerto Rico.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

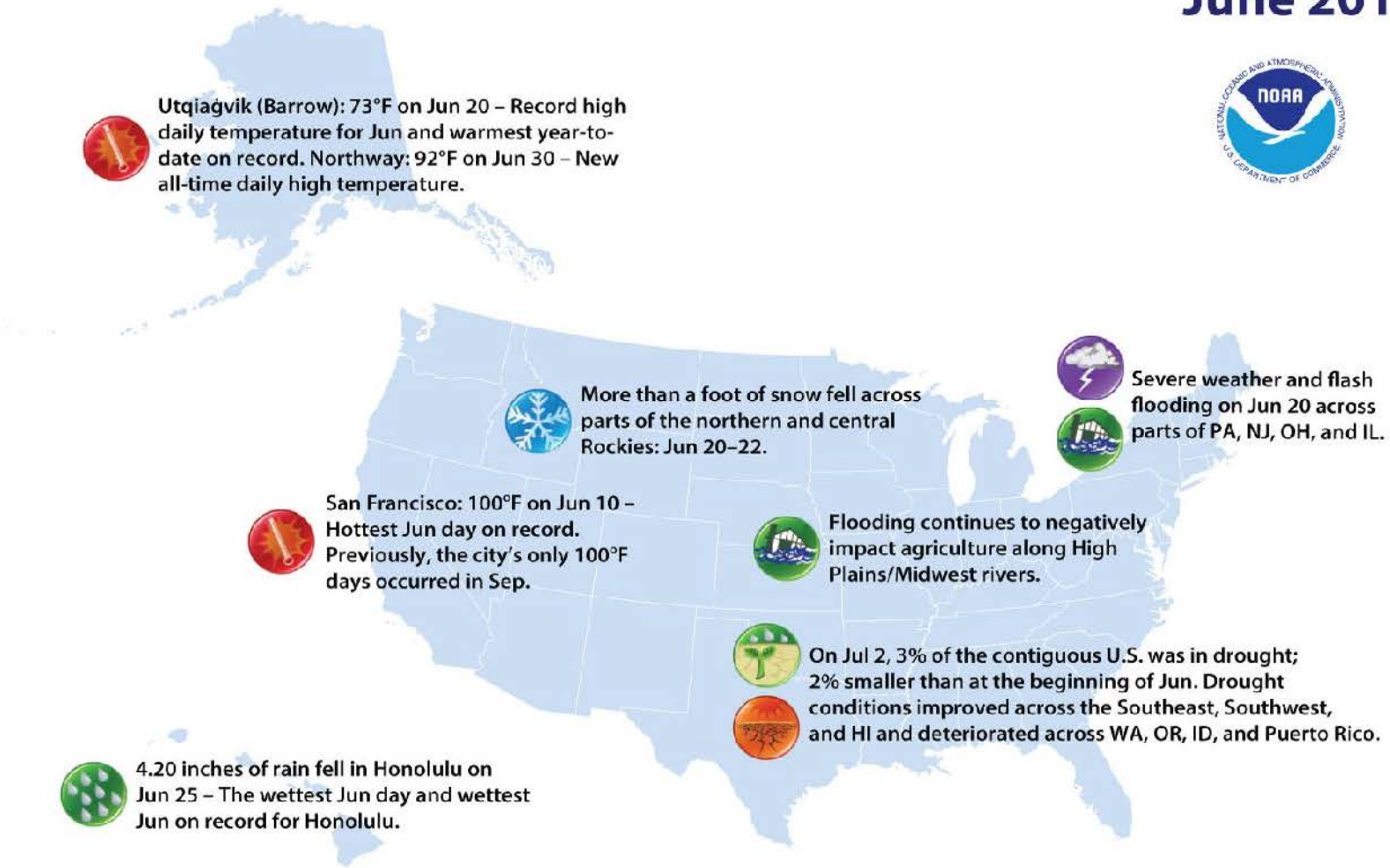
U.S. Selected Significant Climate Anomalies and Events
May and Spring 2019



The average U.S. temperature during May was 59.5°F, 0.7°F below average, ranking in the bottom third of the 125-year record. The spring average U.S. temperature was 50.9°F, 0.1°F below average, ranking near the mean. The May U.S. precipitation was 4.41 inches, 1.50 inches above average, ranking second wettest month on record. The spring average U.S. precipitation was 9.85 inches, 1.91 inches above average, ranking it the 6th wettest spring on record.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

U.S. Selected Significant Climate Anomalies and Events
June 2019

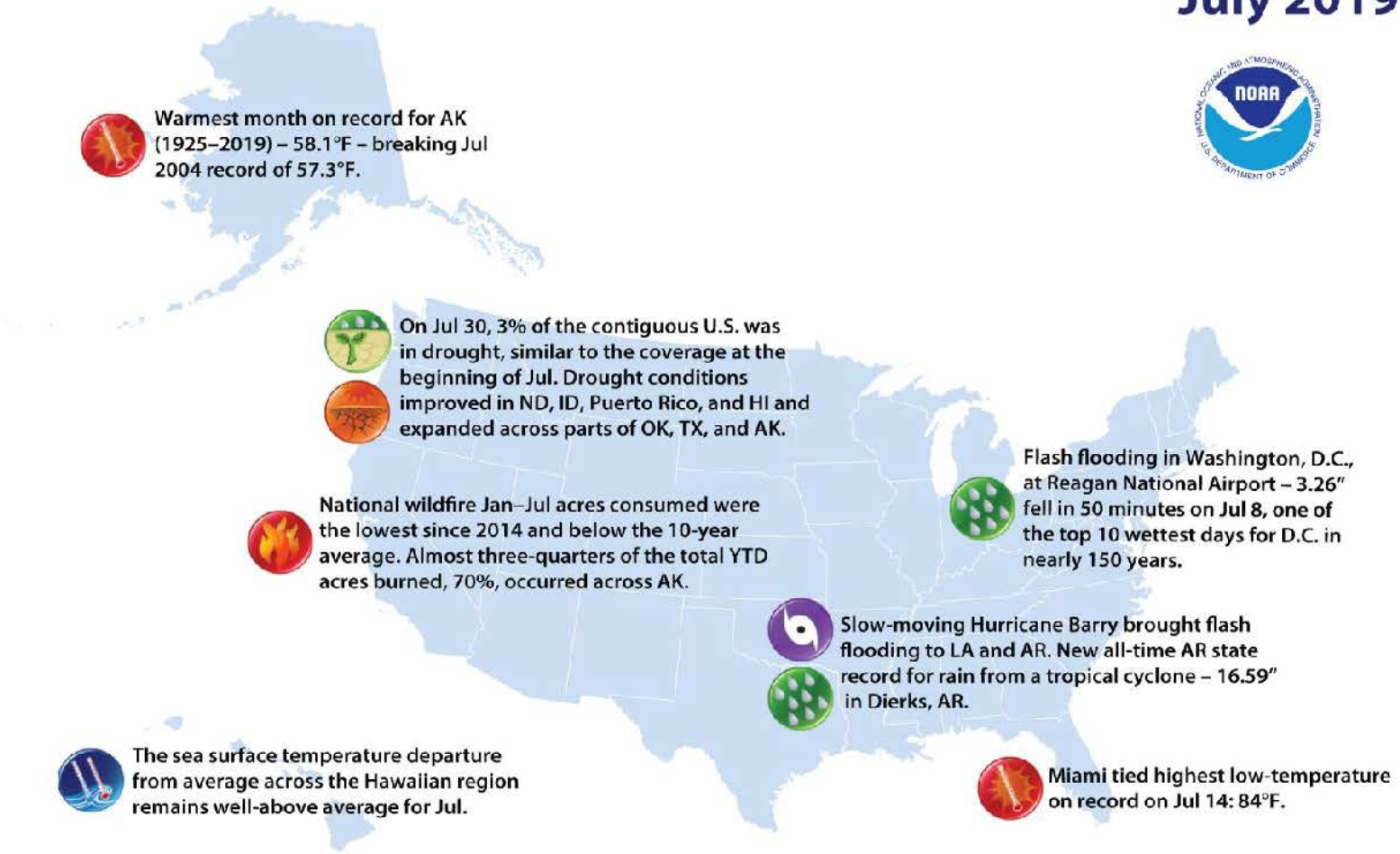


The average U.S. temperature for June was 68.7°F, 0.2°F above average, ranking in the middle third of the 125-year record. The U.S. precipitation average for June was 3.30 inches, 0.37 inch above average, ranking in the upper third of the record.

Moderate and severe drought expands, covering nearly 32% of Puerto Rico.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

U.S. Selected Significant Climate Anomalies and Events
July 2019



Warmest month on record for AK (1925–2019) – 58.1°F – breaking Jul 2004 record of 57.3°F.

On Jul 30, 3% of the contiguous U.S. was in drought, similar to the coverage at the beginning of Jul. Drought conditions improved in ND, ID, Puerto Rico, and HI and expanded across parts of OK, TX, and AK.

National wildfire Jan–Jul acres consumed were the lowest since 2014 and below the 10-year average. Almost three-quarters of the total YTD acres burned, 70%, occurred across AK.

Flash flooding in Washington, D.C., at Reagan National Airport – 3.26" fell in 50 minutes on Jul 8, one of the top 10 wettest days for D.C. in nearly 150 years.

Slow-moving Hurricane Barry brought flash flooding to LA and AR. New all-time AR state record for rain from a tropical cyclone – 16.59" in Dierks, AR.

The sea surface temperature departure from average across the Hawaiian region remains well-above average for Jul.

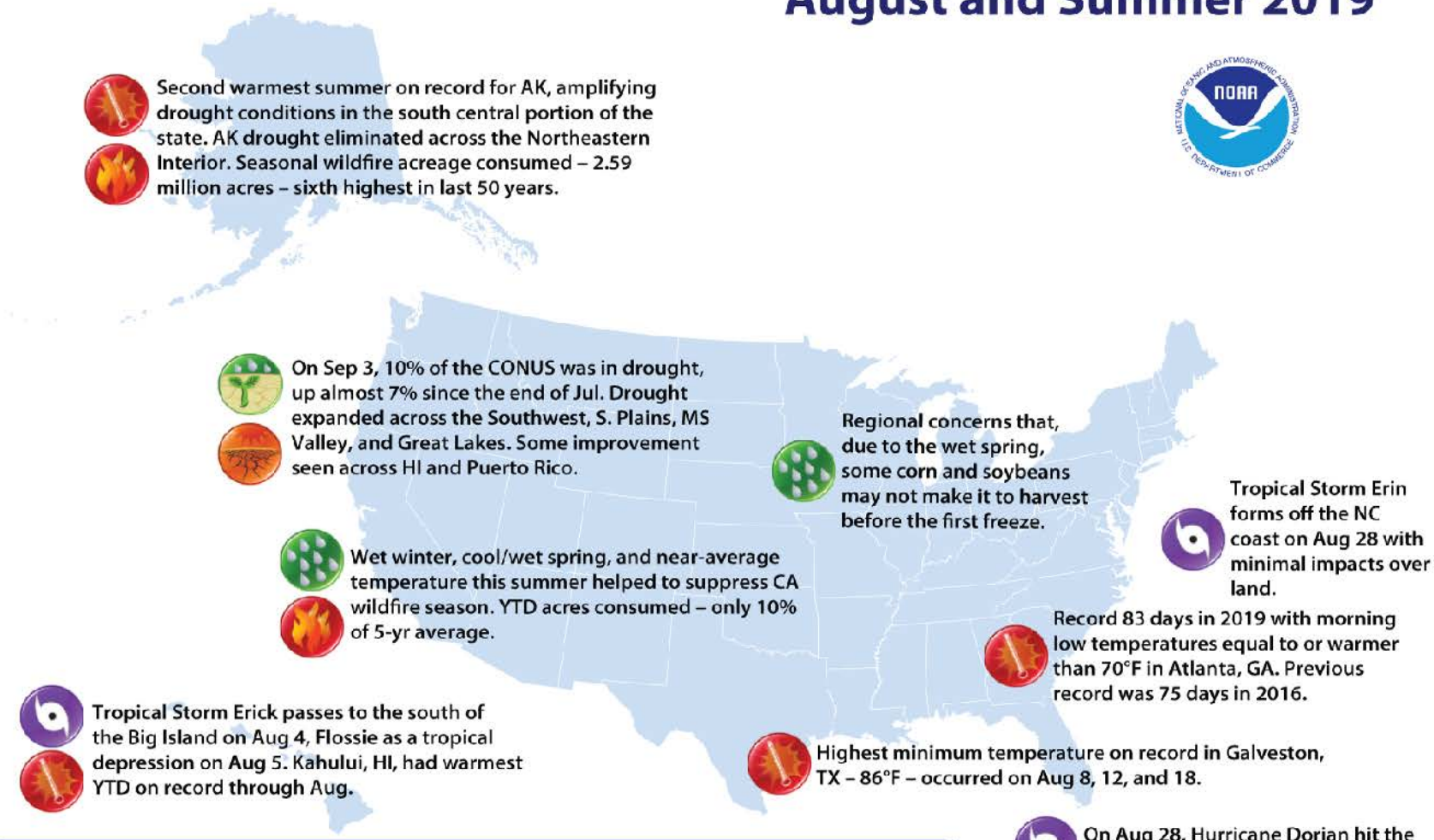
Miami tied highest low-temperature on record on Jul 14: 84°F.

The average U.S. temperature for July was 74.6°F, 1.0°F above average, ranking in the upper third of the 125-year record. The U.S. precipitation average for July was 2.69 inches, 0.09 inch below average, ranking in the middle third of the record.

Moderate and severe drought improves, covering nearly 24% of Puerto Rico.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

U.S. Selected Significant Climate Anomalies and Events
August and Summer 2019



Second warmest summer on record for AK, amplifying drought conditions in the south central portion of the state. AK drought eliminated across the Northeastern Interior. Seasonal wildfire acreage consumed – 2.59 million acres – sixth highest in last 50 years.

On Sep 3, 10% of the CONUS was in drought, up almost 7% since the end of Jul. Drought expanded across the Southwest, S. Plains, MS Valley, and Great Lakes. Some improvement seen across HI and Puerto Rico.

Regional concerns that, due to the wet spring, some corn and soybeans may not make it to harvest before the first freeze.

Tropical Storm Erin forms off the NC coast on Aug 28 with minimal impacts over land.

Wet winter, cool/wet spring, and near-average temperature this summer helped to suppress CA wildfire season. YTD acres consumed – only 10% of 5-yr average.

Record 83 days in 2019 with morning low temperatures equal to or warmer than 70°F in Atlanta, GA. Previous record was 75 days in 2016.

Tropical Storm Erick passes to the south of the Big Island on Aug 4, Flossie as a tropical depression on Aug 5. Kahului, HI, had warmest YTD on record through Aug.

Highest minimum temperature on record in Galveston, TX – 86°F – occurred on Aug 8, 12, and 18.

On Aug 28, Hurricane Dorian hit the U.S. Virgin Islands and Puerto Rico with 75 mph winds and heavy rain, then intensified to a Cat 5 storm by Sep 1, striking the Bahamas.

The average U.S. temperature for Aug was 73.9°F, 1.8°F above average, tying with 1955 as the 13th warmest Aug in the 125-year record. The U.S. precipitation average for Aug was 2.74", 0.12" above average, ranking in the middle third of the record. The summer average U.S. temperature was 72.4°F, 1.0°F above average, ranking in the upper third of the historical record. The summer precipitation total was 8.83", 0.51" above average, also ranking in the upper third of the record.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

U.S. Selected Significant Climate Anomalies and Events
September 2019

Wet weather across southwest and south-central AK in Sep diminished the wildfire threat & reduced drought. Warmest Sep on record for Utqiaġvik and Cold Bay.

A significant winter storm brought up to 4 feet of snow and blizzard conditions to parts of ID, MT, and WY during Sep 28–30.

On Oct 1, 19% of the CONUS was in drought; up almost 9% since the beginning of Sep. Drought expanded across the Southwest, South, and Southeast. Improvements were seen across AK, Puerto Rico, HI, and the Pacific Northwest.

Several EF2 tornadoes struck Sioux Falls, SD, on Sep 10, collapsing buildings and causing significant damage.

During Sep 3–6, Hurricane Dorian grazed the U.S. East Coast from FL to NC; made landfall near Cape Hatteras, NC.

Moisture from remnants of Tropical Storm Lorena caused flash flooding in AZ on Sep 23.

Tropical Storm Imelda and its remnants pummelled southeast TX from Sep 17–21 with more than 40 inches of rainfall in some locations, resulting in deadly flooding.

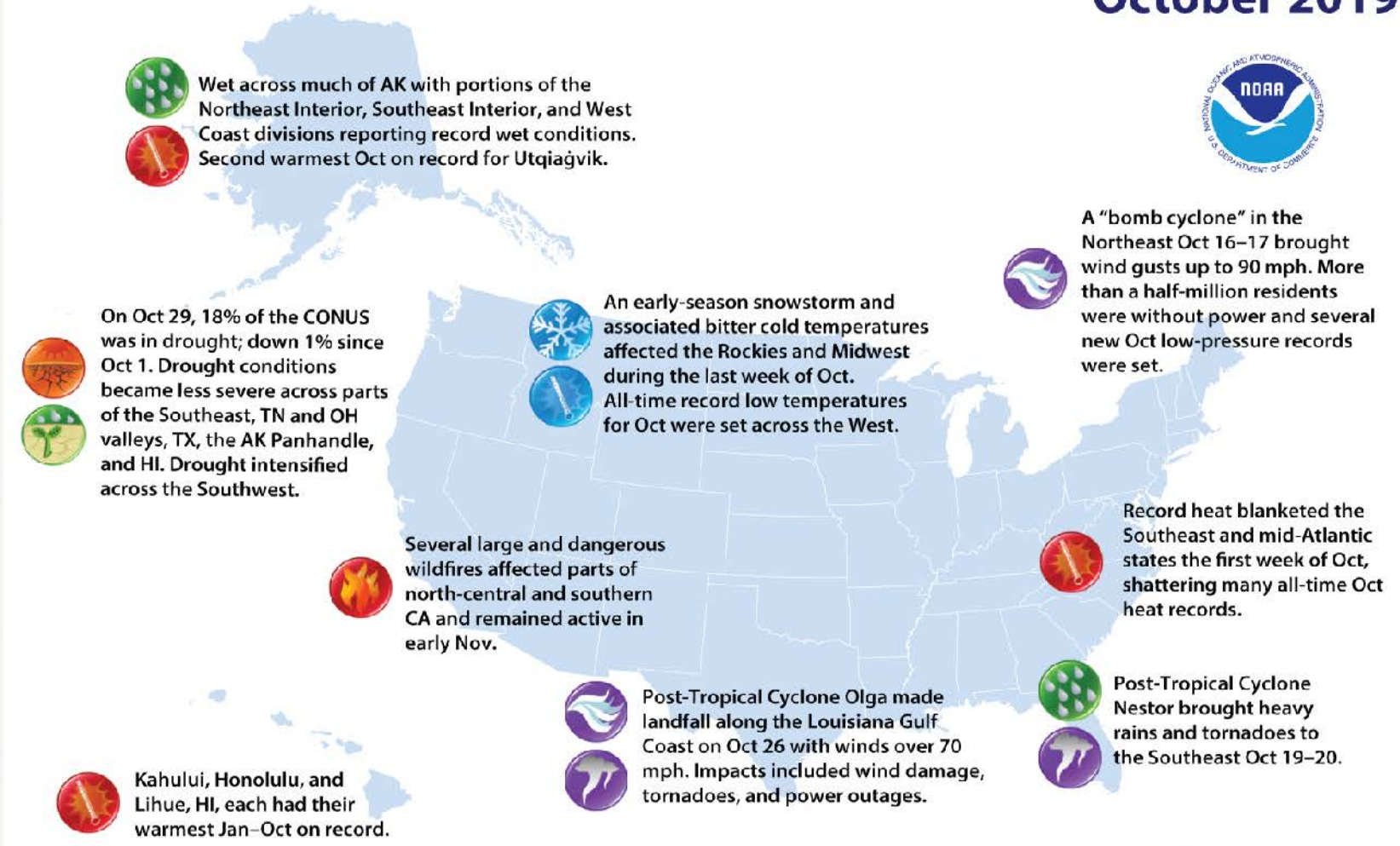
Kahului, HI, had warmest Jan–Sep on record. Warmest Sep on record for Hilo, Lihue, Kahului, and Molokai.

Tropical Storm Karen impacted Puerto Rico and the Virgin Islands Sep 24–25 with heavy rain, flooding, and landslides.

The average U.S. temperature for September was 68.5°F, 3.7°F above average, tying with 2015 for the second warmest September in the 125-year record. The U.S. precipitation average for September was 2.42", 0.07" below average, ranking in the middle third of the record.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

U.S. Selected Significant Climate Anomalies and Events
October 2019



Wet across much of AK with portions of the Northeast Interior, Southeast Interior, and West Coast divisions reporting record wet conditions. Second warmest Oct on record for Utqiaġvik.

A "bomb cyclone" in the Northeast Oct 16–17 brought wind gusts up to 90 mph. More than a half-million residents were without power and several new Oct low-pressure records were set.

On Oct 29, 18% of the CONUS was in drought; down 1% since Oct 1. Drought conditions became less severe across parts of the Southeast, TN and OH valleys, TX, the AK Panhandle, and HI. Drought intensified across the Southwest.

An early-season snowstorm and associated bitter cold temperatures affected the Rockies and Midwest during the last week of Oct. All-time record low temperatures for Oct were set across the West.

Several large and dangerous wildfires affected parts of north-central and southern CA and remained active in early Nov.

Record heat blanketed the Southeast and mid-Atlantic states the first week of Oct, shattering many all-time Oct heat records.

Post-Tropical Cyclone Olga made landfall along the Louisiana Gulf Coast on Oct 26 with winds over 70 mph. Impacts included wind damage, tornadoes, and power outages.

Post-Tropical Cyclone Nestor brought heavy rains and tornadoes to the Southeast Oct 19–20.

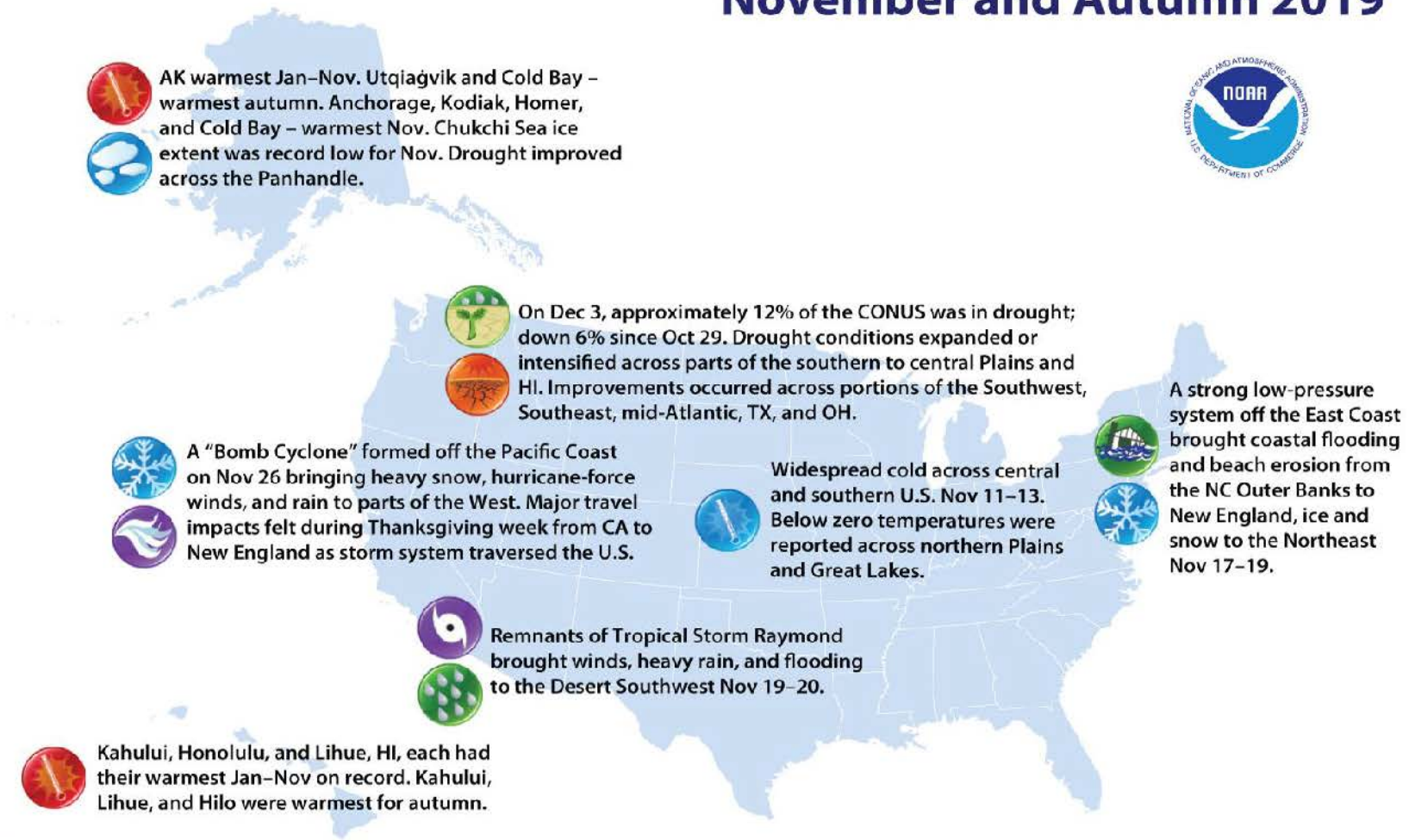
Kahului, Honolulu, and Lihue, HI, each had their warmest Jan–Oct on record.

The average U.S. temperature for October was 52.3°F, 1.8°F below average, ranking in the lowest third of the 125-year record and was the coolest October since 2009. The U.S. precipitation average for October was 3.14", 0.98" above average, ranking as the eighth wettest October on record.

Drought eradicated across Puerto Rico.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

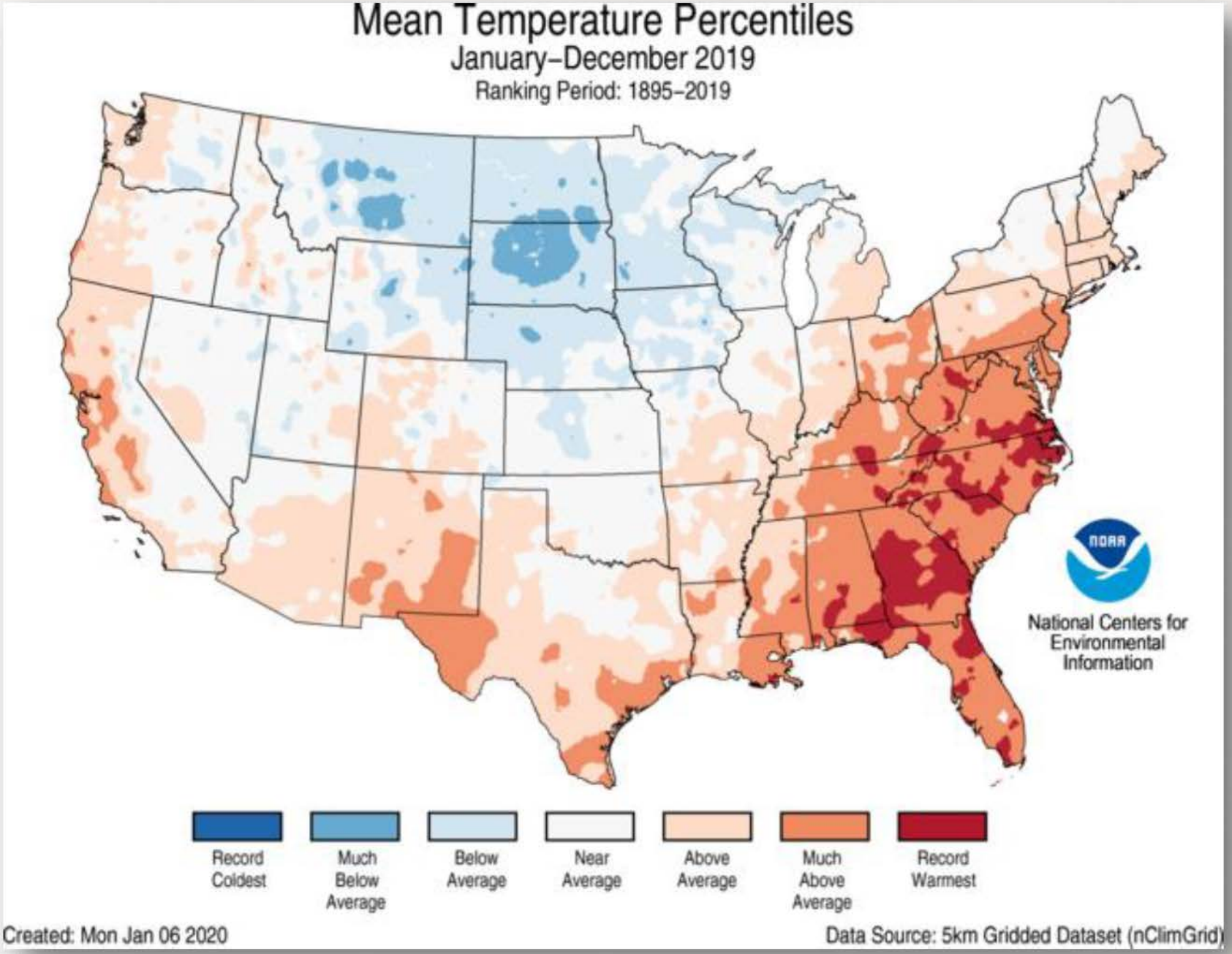
U.S. Selected Significant Climate Anomalies and Events
November and Autumn 2019

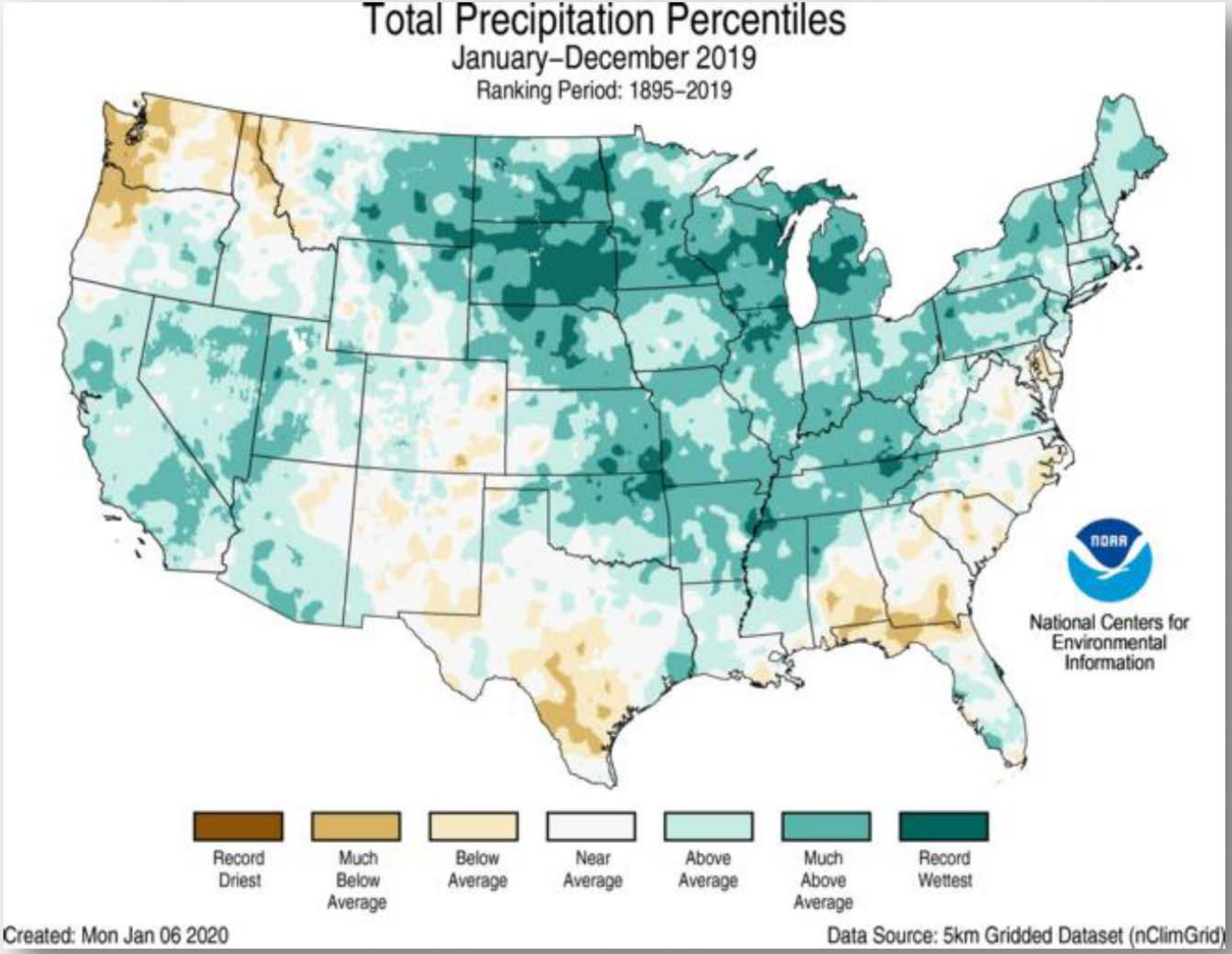


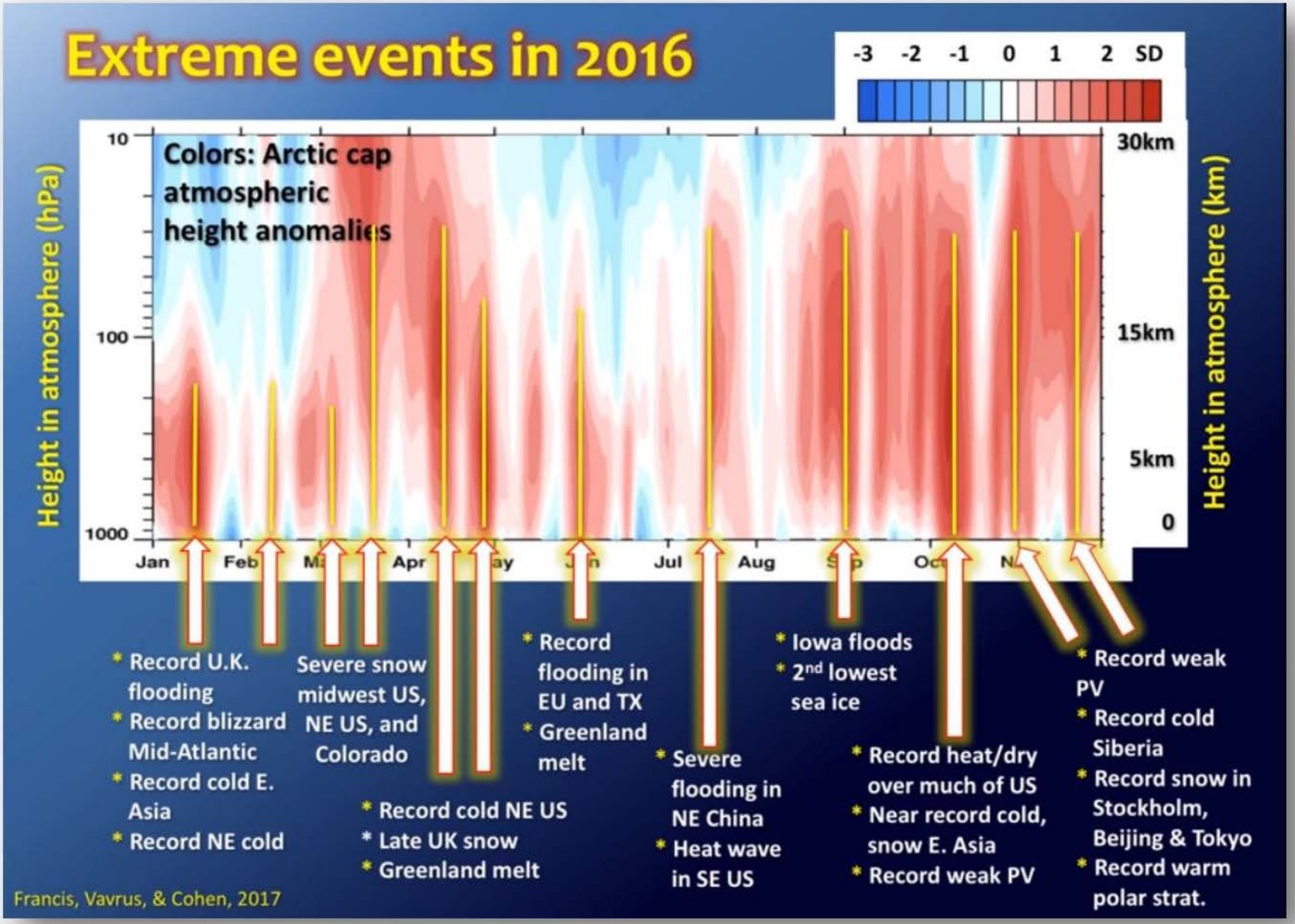
The average U.S. temperature for November was 41.2°F, 0.5°F below average, ranking in the middle third of the 125-year record. The U.S. precipitation average for November was 1.86", 0.37" below average, ranking in the driest third of the November record. The autumn average U.S. temperature was 53.9°F, 0.4°F above average, ranking in the middle third of the historical record. The autumn precipitation total was 7.46", 0.58" above average, ranking in the upper third of the record.

Puerto Rico remained drought free during Nov. A small area of moderate drought emerged in early Dec.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc


Mean Temperature Percentiles
January–December 2019
Ranking Period: 1895–2019
NOAA
National Centers for Environmental Information
Record Coldest
Much Below Average
Below Average
Near Average
Above Average
Much Above Average
Record Warmest
Created: Mon Jan 06 2020
Data Source: 5km Gridded Dataset (nClimGrid)

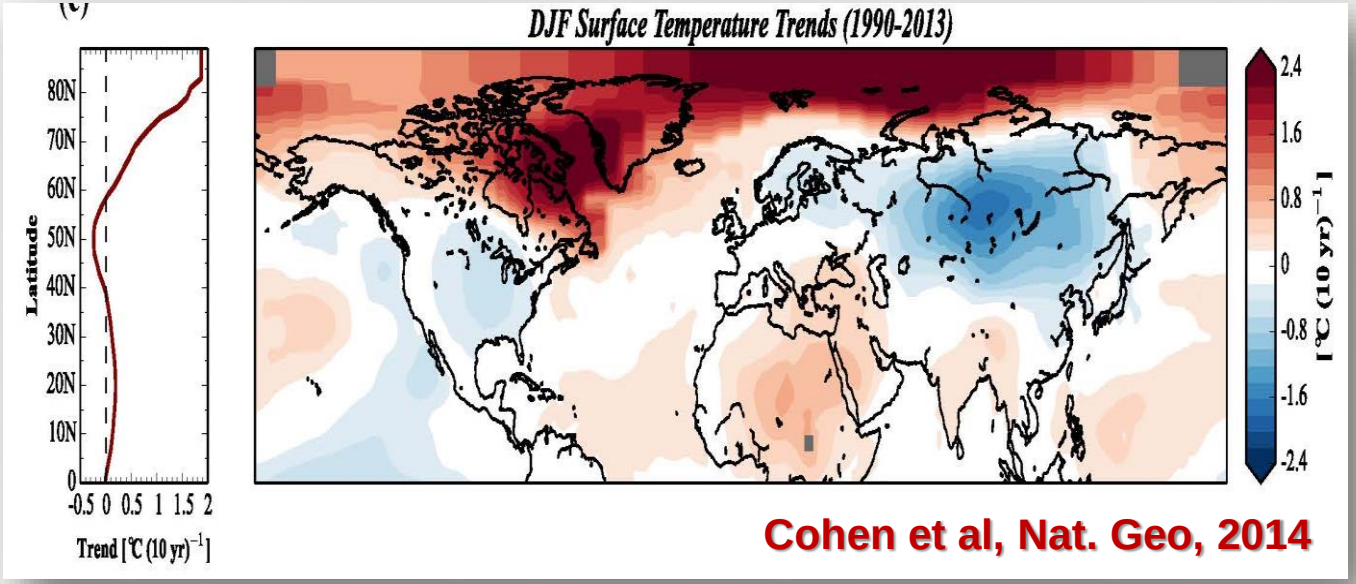

Total Precipitation Percentiles
January–December 2019
Ranking Period: 1895–2019
NOAA
National Centers for Environmental Information
Record Driest
Much Below Average
Below Average
Near Average
Above Average
Much Above Average
Record Wettest
Created: Mon Jan 06 2020
Data Source: 5km Gridded Dataset (nClimGrid)


Extreme events in 2016
-3 -2 -1 0 1 2 SD
Colors: Arctic cap atmospheric height anomalies
Height in atmosphere (hPa)
10
100
1000
Jan
Feb
Apr
Jul
Aug
30km
15km
5km
0
Height in atmosphere (km)
* Record U.K. flooding
* Record blizzard Mid-Atlantic
* Record cold E. Asia
* Record NE cold
Severe snow midwest US, NE US, and Colorado
* Record cold NE US
* Late UK snow
* Greenland melt
* Record flooding in EU and TX
* Greenland melt
* Severe flooding in NE China
* Heat wave in SE US
* Iowa floods
* 2nd lowest sea ice
* Record heat/dry over much of US
* Near record cold, snow E. Asia
* Record weak PV
* Record weak PV
* Record cold Siberia
* Record snow in Stockholm, Beijing & Tokyo
* Record warm polar strat.
Francis, Vavrus, & Cohen, 2017

Emerging mechanisms

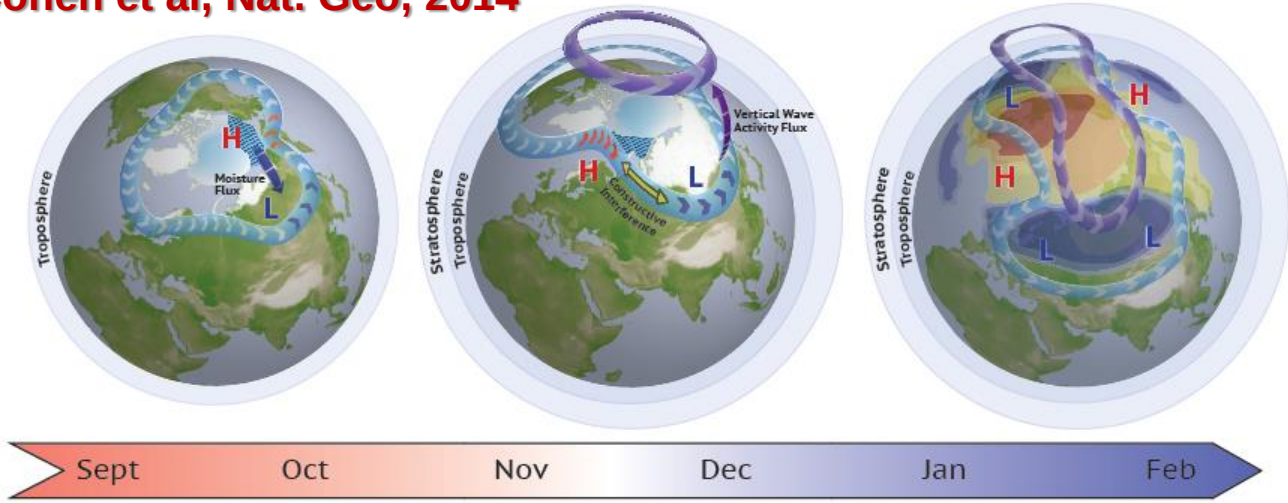
- Sea ice loss, AA over Barents/Kara creates ridge
- Earlier snowfall along coast promotes trough
- Wave energy transferred to stratosphere
- Polar vortex weakens
- Wavier jet stream
- Cold continents

Cohen et al, 2014
Kim et al, 2014
Feldstein & Lee, 2014



Cohen et al, Nat. Geo, 2014

Cohen et al, Nat. Geo, 2014




MARCH 1
2019

Arctic Amplification is alive and well:

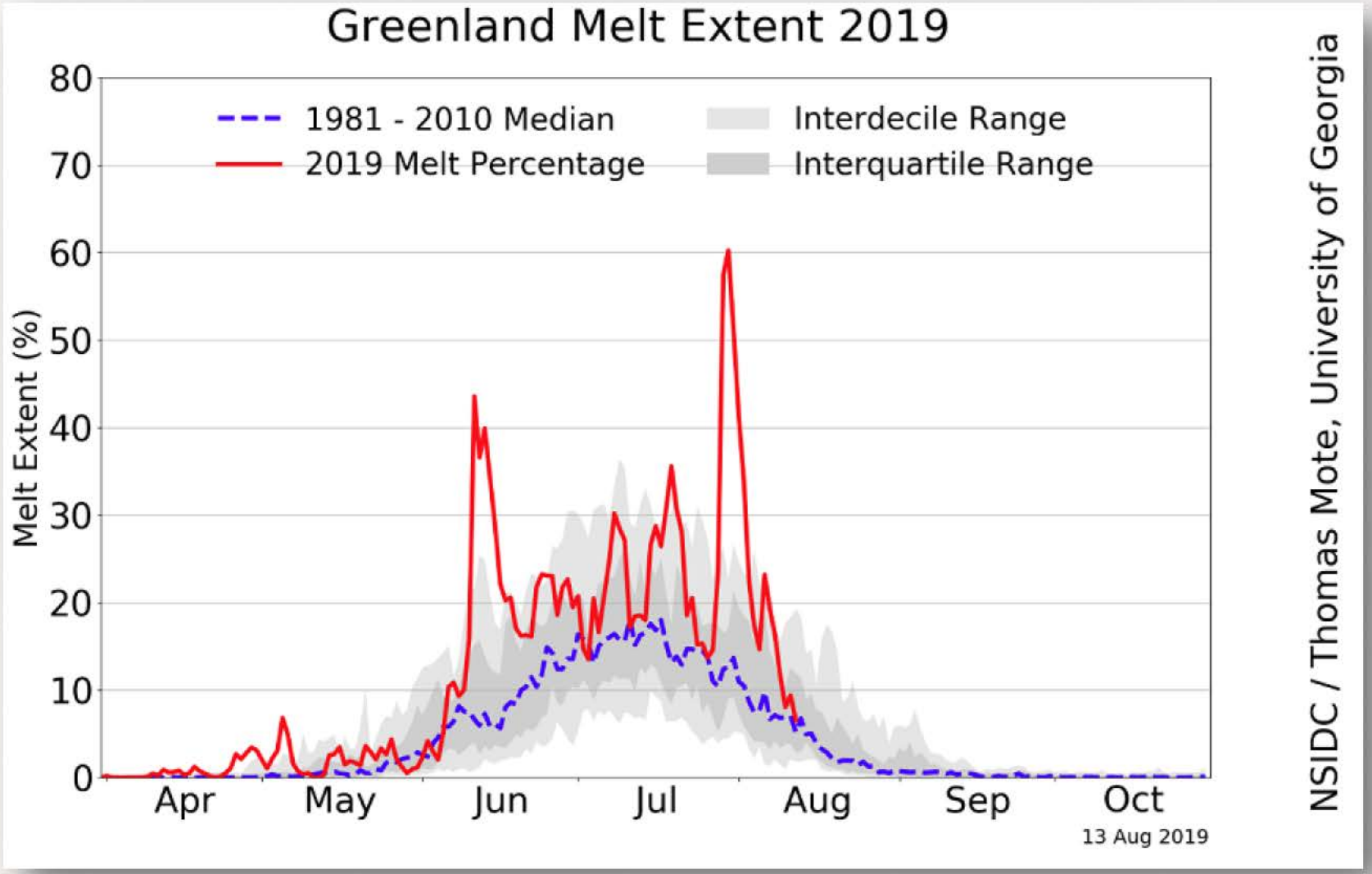
High latitudes are warming much faster than mid-latitudes, especially in fall and winter

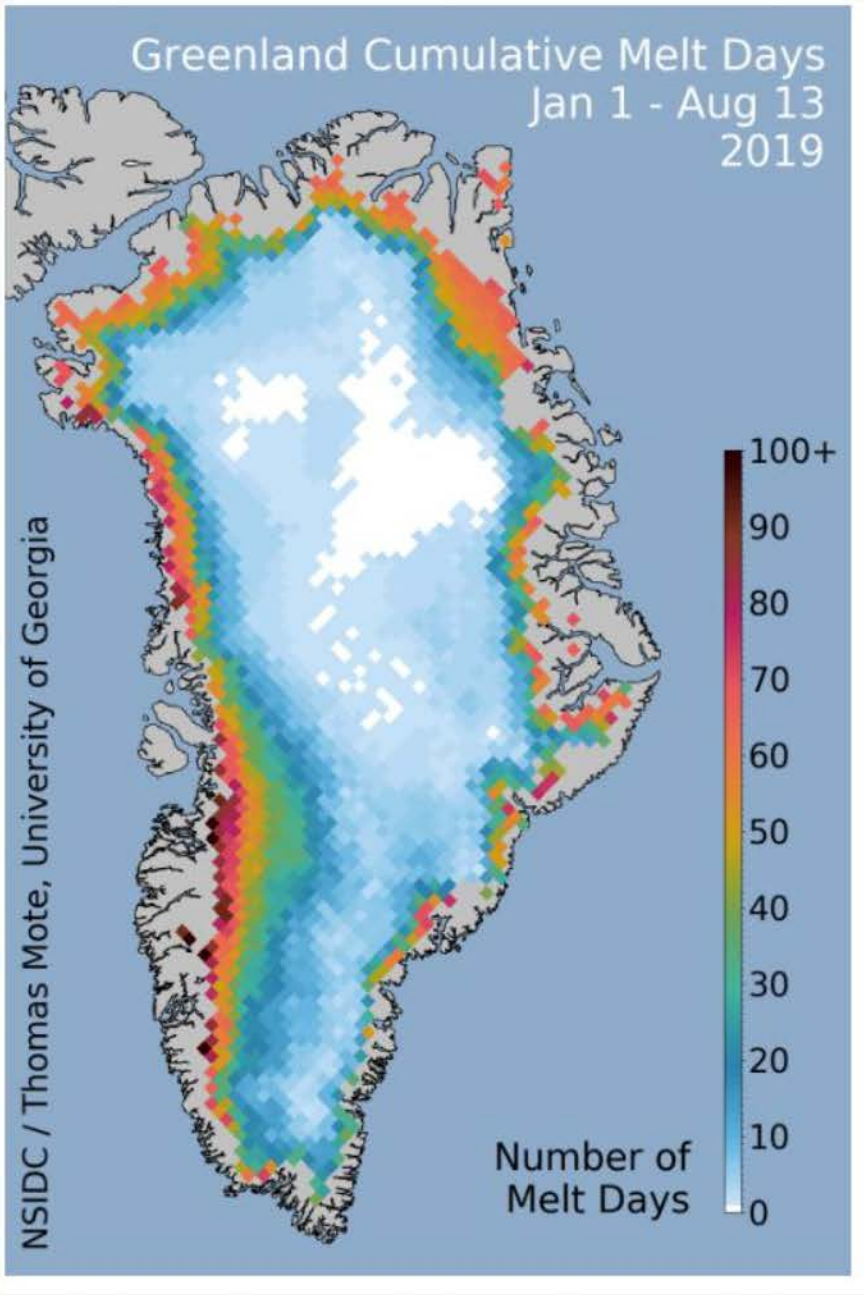
Poleward thickness gradient is weakening

Zonal-mean flow @500mb is weakening, flow meanders more

Peaks of ridges are elongating northward, wave amplitude is increasing

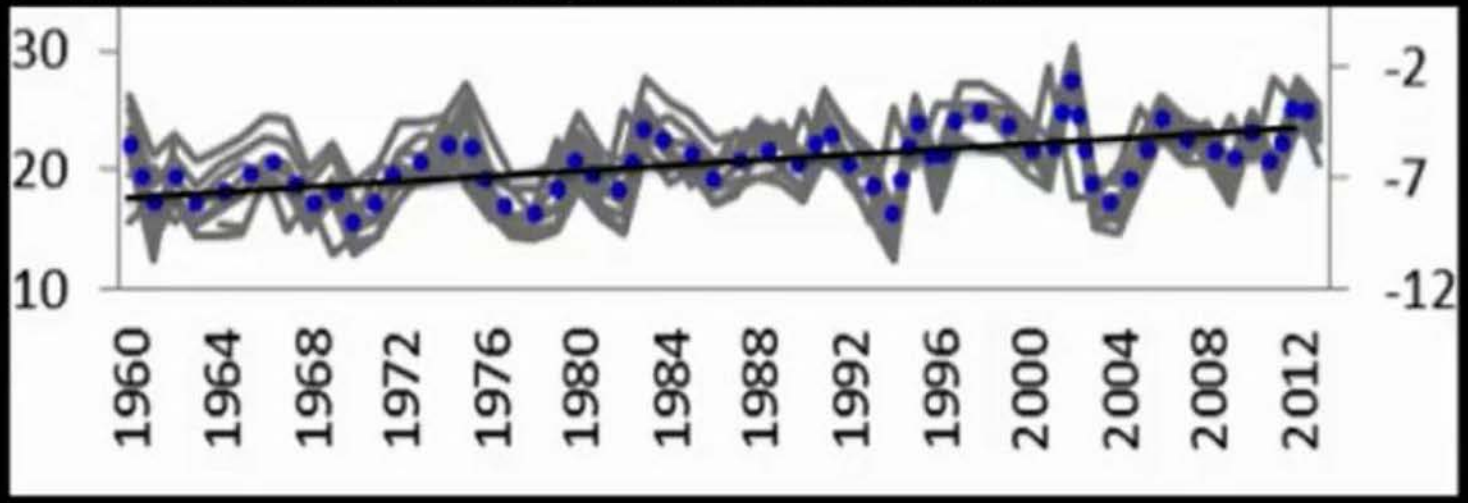
- **More amplified Rossby waves *should* progress eastward more slowly and increase likelihood of blocking**
- **Weather conditions more persistent**
- ***Increased probability of extremes: cold spells, heat waves, flooding, prolonged snowfall, and drought***


Greenland Melt Extent 2019
1981 - 2010 Median
2019 Melt Percentage
Interdecile Range
Interquartile Range
Melt Extent (%)
80
70
60
50
40
30
20
10
0
Apr
May
Jun
Jul
Aug
Sep
Oct
13 Aug 2019
NSIDC / Thomas Mote, University of Georgia

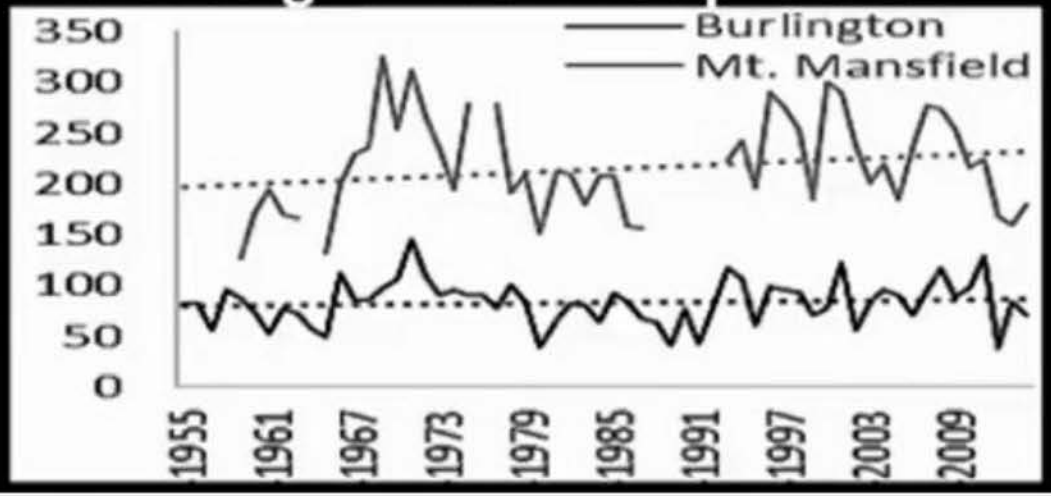

Greenland Cumulative Melt Days
Jan 1 - Aug 13
2019
NSIDC / Thomas Mote, University of Georgia
Number of
Melt Days
100+
90
80
70
60
50
40
30
20
10
0

Measurement
Station
Greenland
ice sheet

2015-2040: A Climate Change "Sweet Spot" for those of us who love snow…

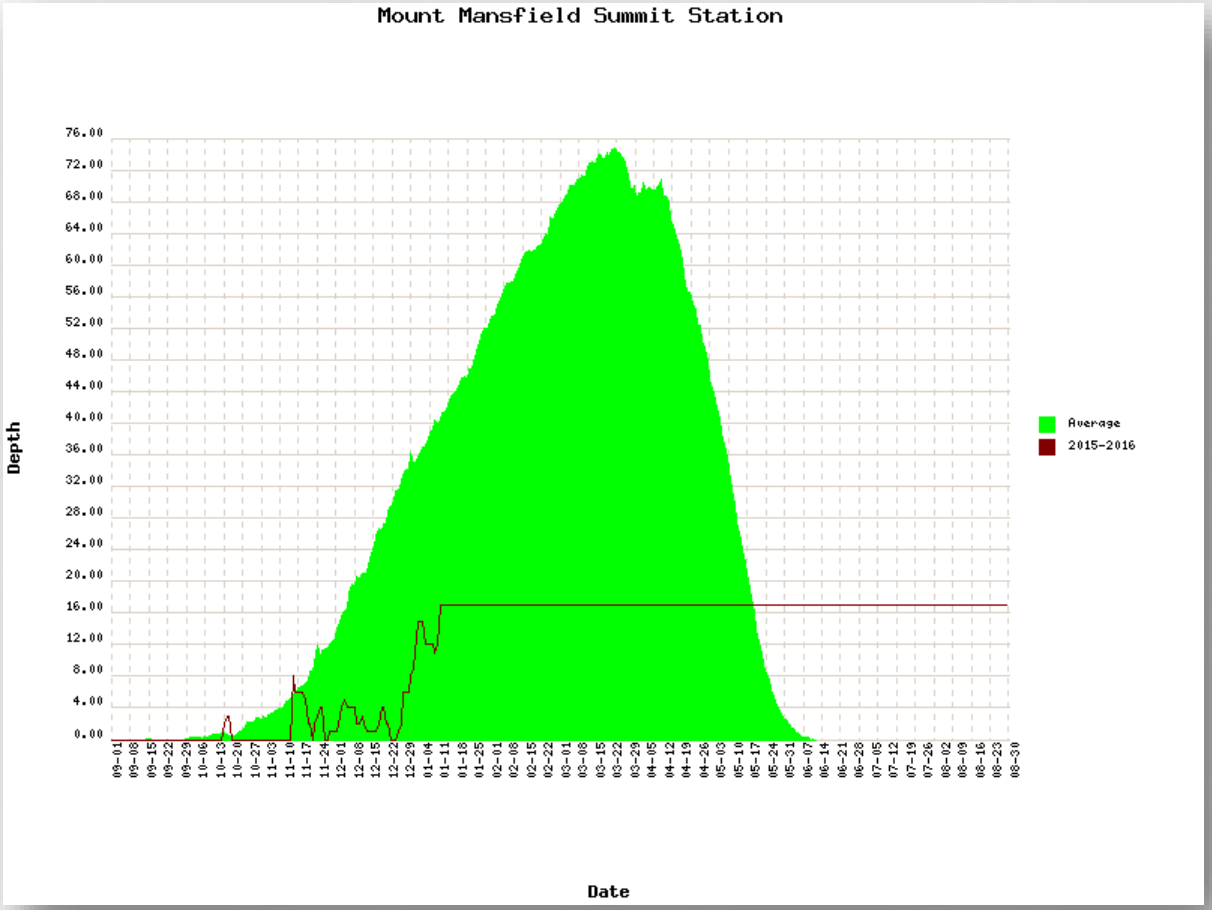


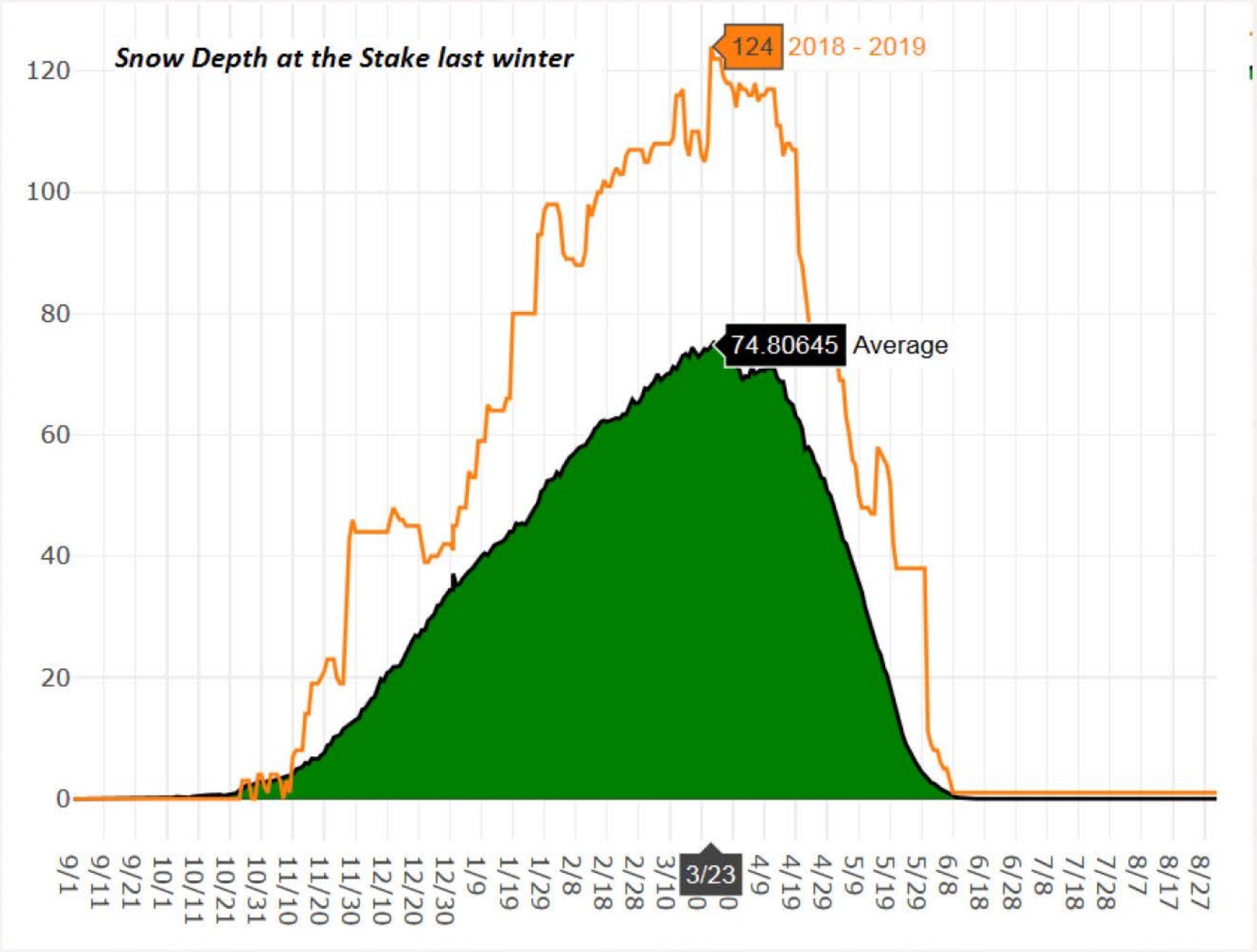
Increasing Winter Precipitation

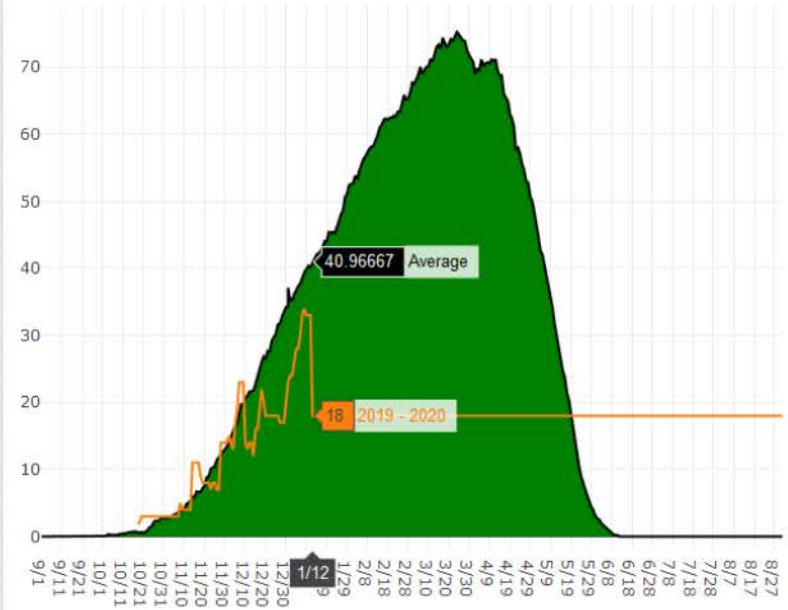


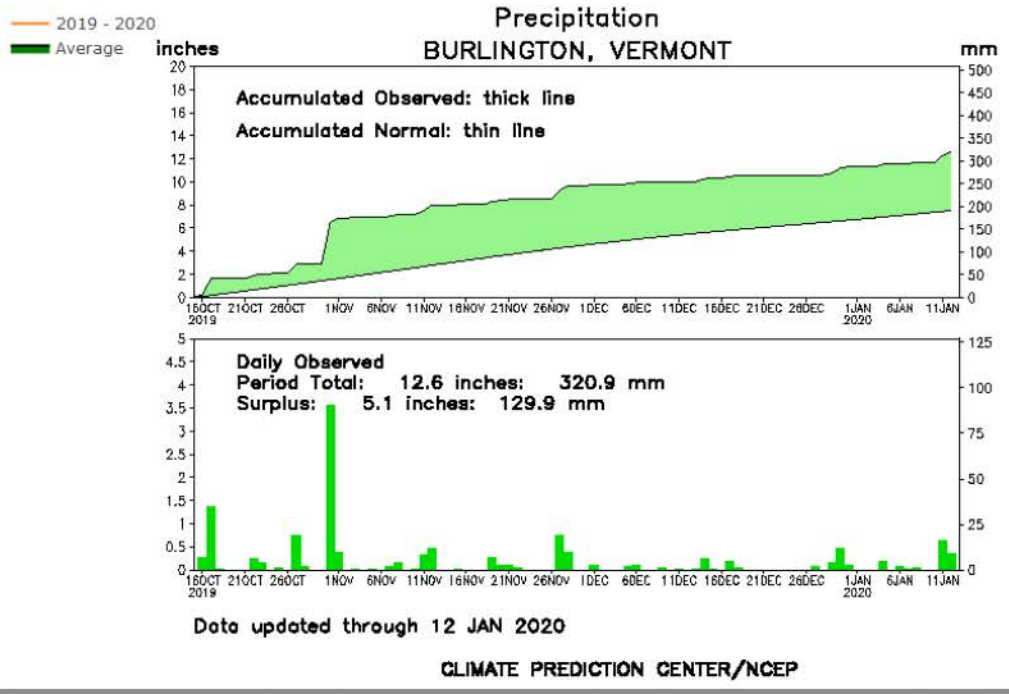
Source: NOAA/NWS, Vermont Climate Assessment 2014

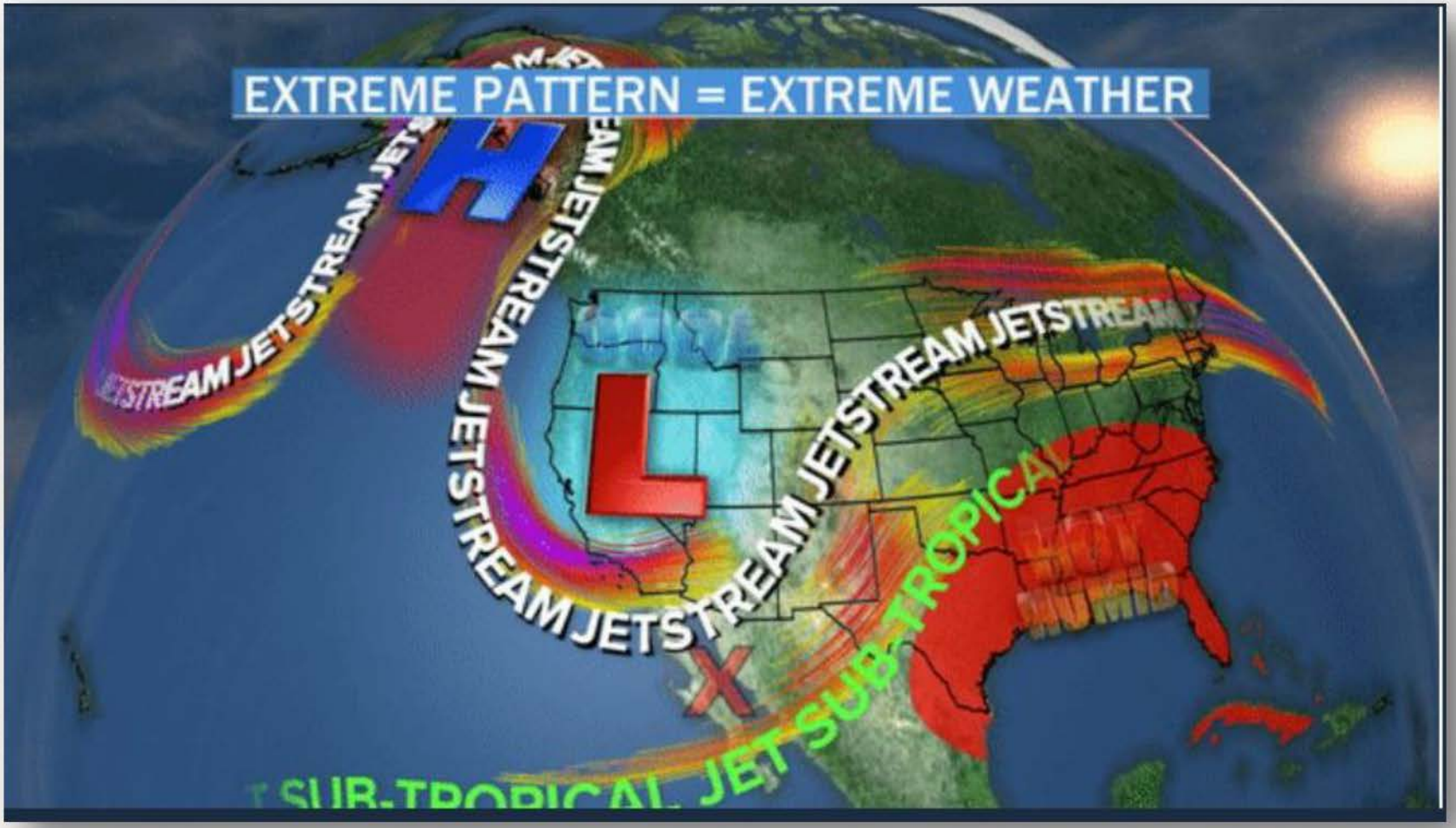
First Half of Winter 2015-2016



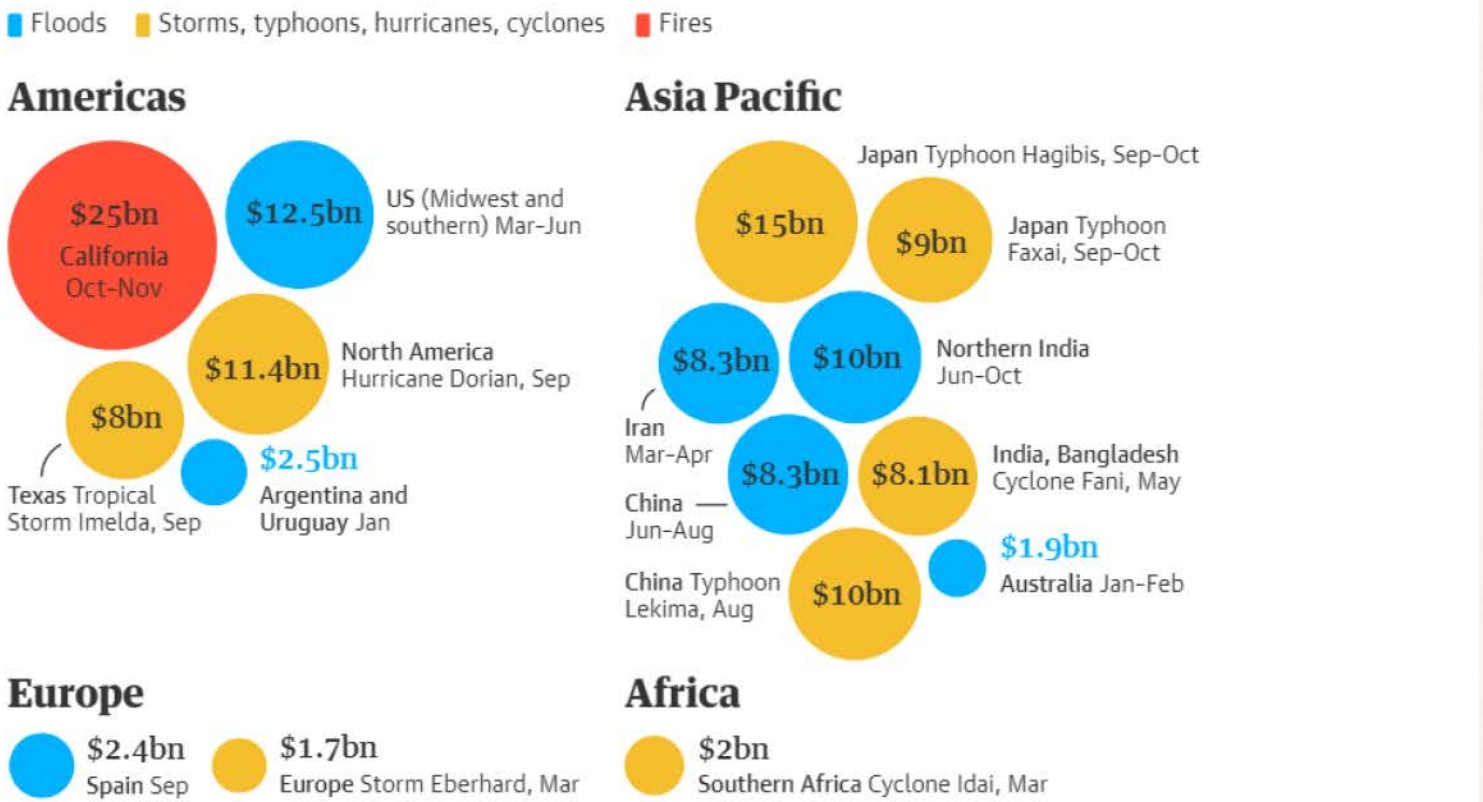

Snow Depth at the Stake last winter
124
2018 - 2019
74.80645
Average
120
100
80
60
40
20
0
9/1
9/11
9/21
10/1
10/11
10/21
10/31
11/10
11/20
11/30
12/10
12/20
12/30
1/9
1/19
1/29
2/8
2/18
2/28
3/10
3/23
4/9
4/19
4/29
5/9
5/19
5/29
6/8
6/18
6/28
7/8
7/18
7/28
8/7
8/17
8/27


70
60
50
40
30
20
10
0
40.96667
Average
18
2019 - 2020
1/12
9/1
9/11
9/21
10/1
10/11
10/21
10/31
11/10
11/20
11/30
12/10
12/20
12/30
1/29
2/8
2/18
2/28
3/10
3/20
3/30
4/9
4/19
4/29
5/9
5/19
5/29
6/8
6/18
6/28
7/8
7/18
7/28
8/7
8/17
8/27


2019 - 2020
Average
Precipitation
BURLINGTON, VERMONT
inches
mm
Accumulated Observed: thick line
Accumulated Normal: thin line
Daily Observed
Period Total: 12.6 inches: 320.9 mm
Surplus: 5.1 inches: 129.9 mm
15OCT 2019
21OCT
26OCT
1NOV
6NOV
11NOV
16NOV
21NOV
26NOV
1DEC
6DEC
11DEC
16DEC
21DEC
26DEC
1JAN 2020
6JAN
11JAN
Data updated through 12 JAN 2020
CLIMATE PREDICTION CENTER/NCEP


EXTREME PATTERN = EXTREME WEATHER
H
L
JETSTREAM JETSTREAM JETSTREAM
JETSTREAM JETSTREAM JETSTREAM
JETSTREAM JETSTREAM
SUB-TROPICAL JET

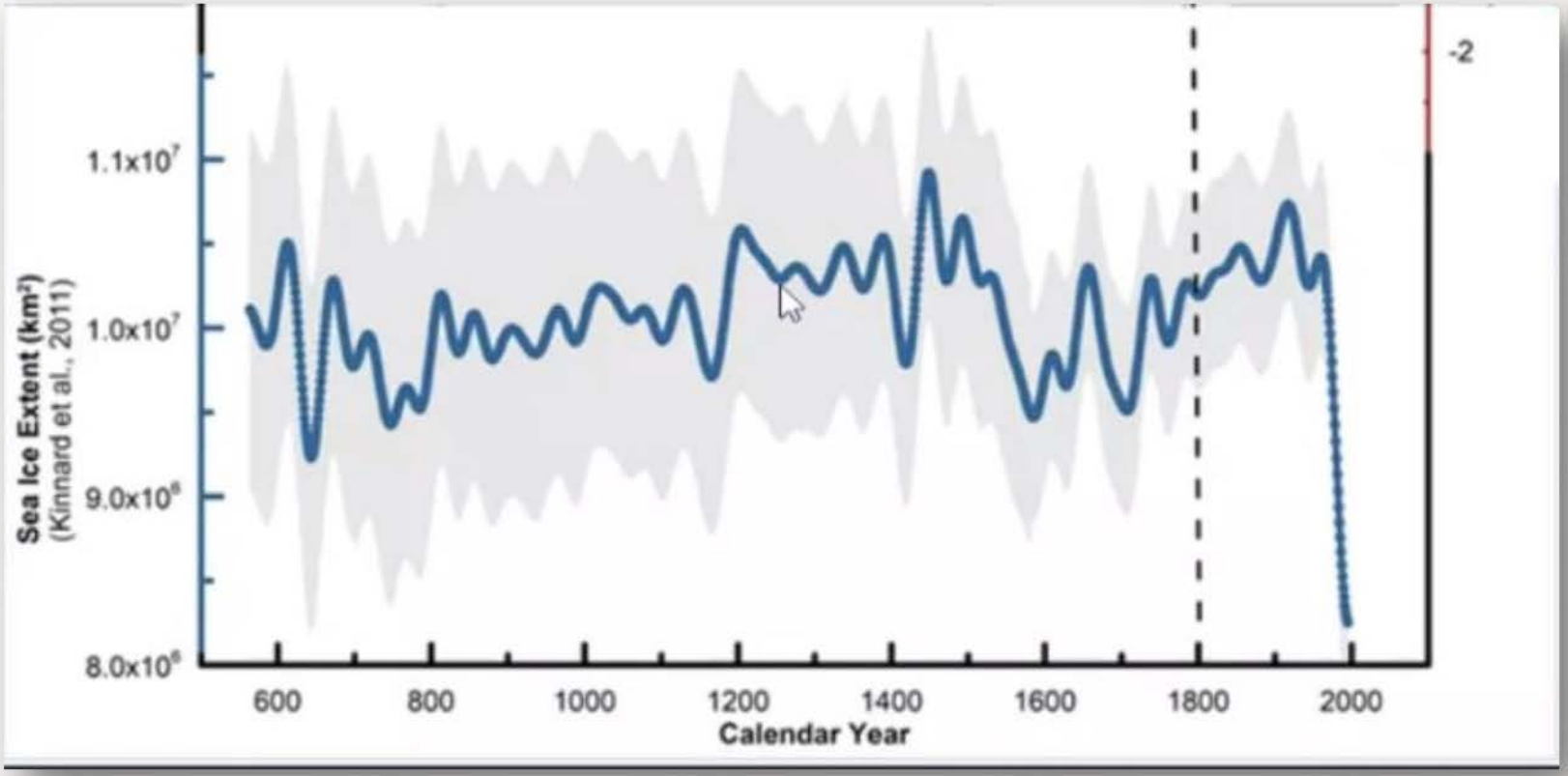
Extreme weather events across the world caused more than $100bn worth of damage in 2019

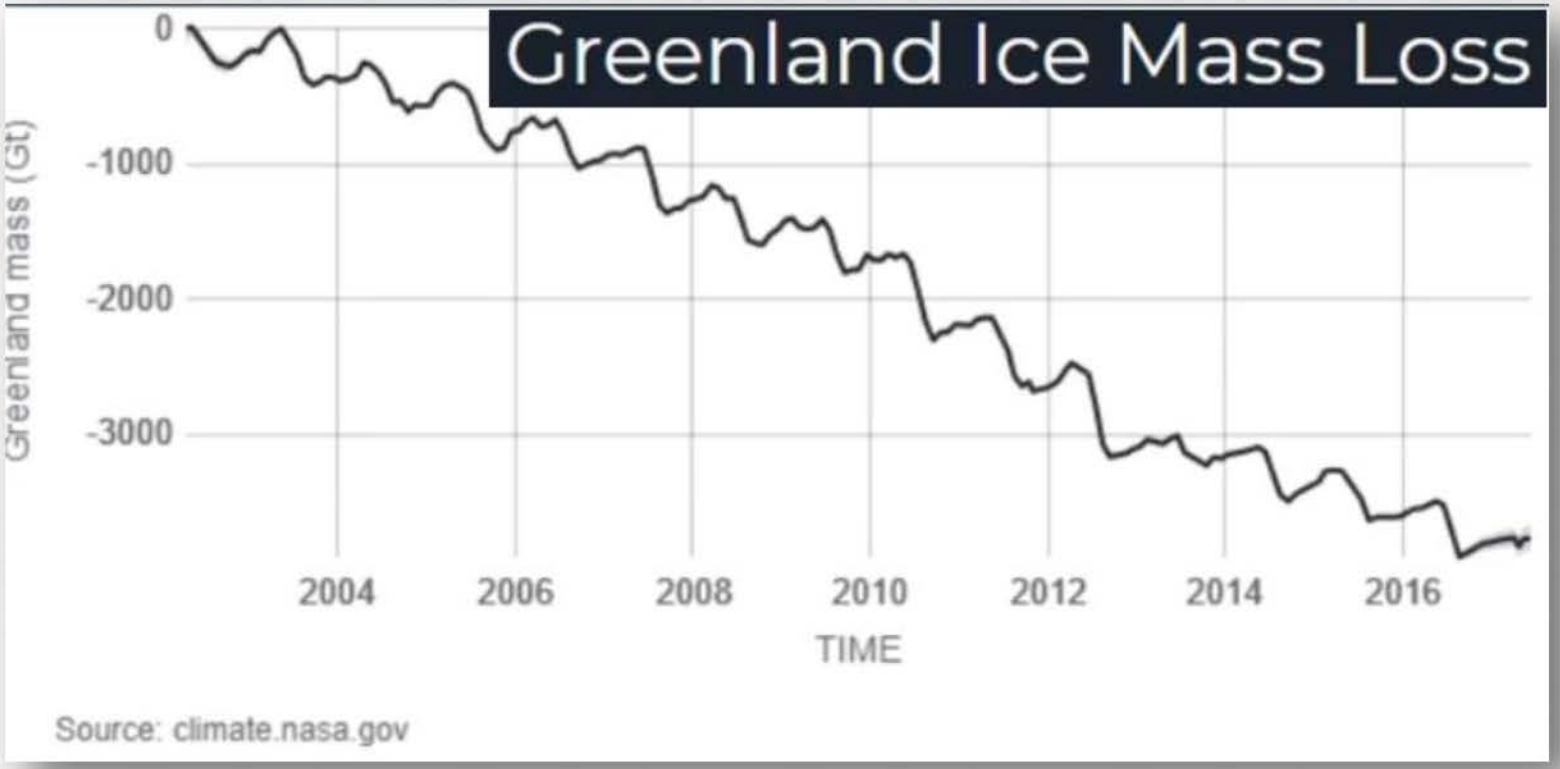


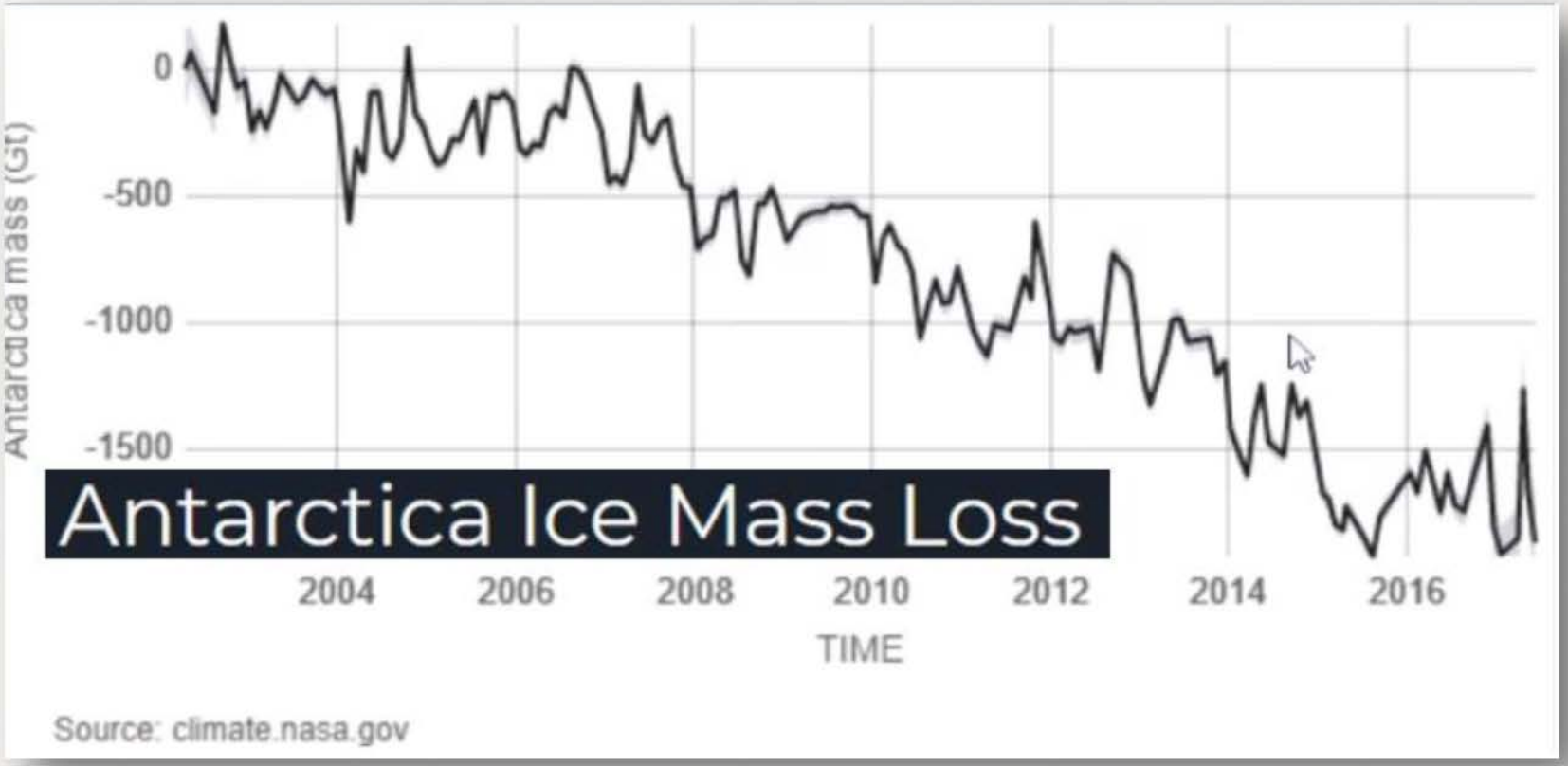
Guardian graphic. Source: Christian Aid

Past & Current Abrupt Climate Change

1. The Permian-Triassic Extinction 250 million years was geologically "instantaneous" (centuries). Included 10 C rise in near-surface ocean/ocean hypoxia (Penn et al., 2018).
2. The Paleocene-Eocene Thermal Maximum initial temperature rise of 5 C 56 million years ago may have been over less than two decades (Wright & Schaller, 2013). Deep-sea mass extinction and *very* rapid evolution/ecosystem havoc on land/sea.
3. An additional rise of 2-5 C is projected over next 80 yrs (IPCC, 2014). However, a much faster scenario is likely given trends and difficult to account feedback mechanisms...*a globally accelerating* climate change/global warming "event".


Sea Ice Extent (km²)
(Kinnard et al., 2011)
1.1x10⁷
1.0x10⁷
9.0x10⁶
8.0x10⁶
600
800
1000
1200
1400
1600
1800
2000
Calendar Year
-2


Greenland Ice Mass Loss
0
-1000
-2000
-3000
Greenland mass (Gt)
2004
2006
2008
2010
2012
2014
2016
TIME
Source: climate.nasa.gov


0
-500
-1000
-1500
Antarctica mass (Gt)
Antarctica Ice Mass Loss
2004
2006
2008
2010
2012
2014
2016
TIME
Source: climate.nasa.gov

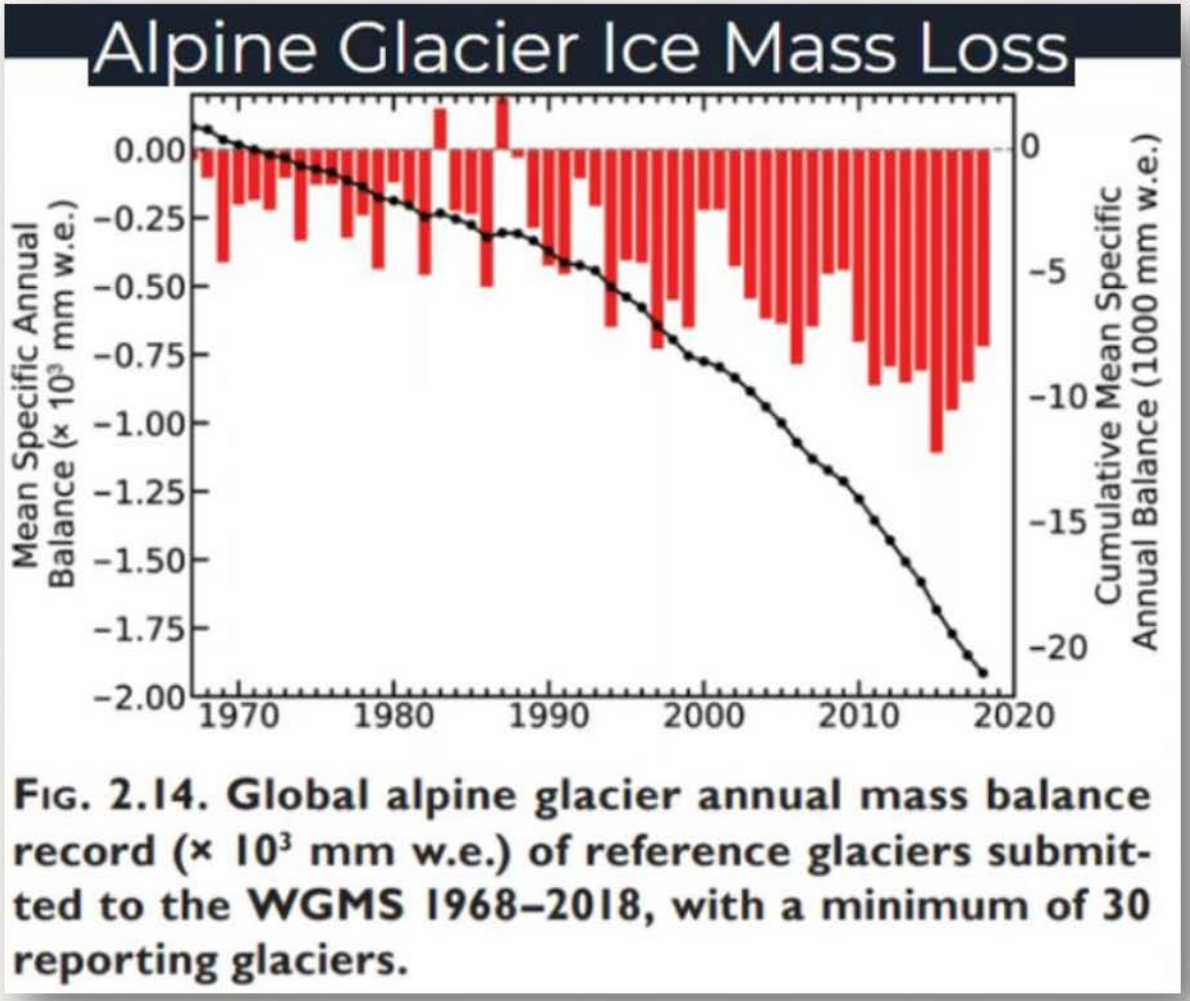
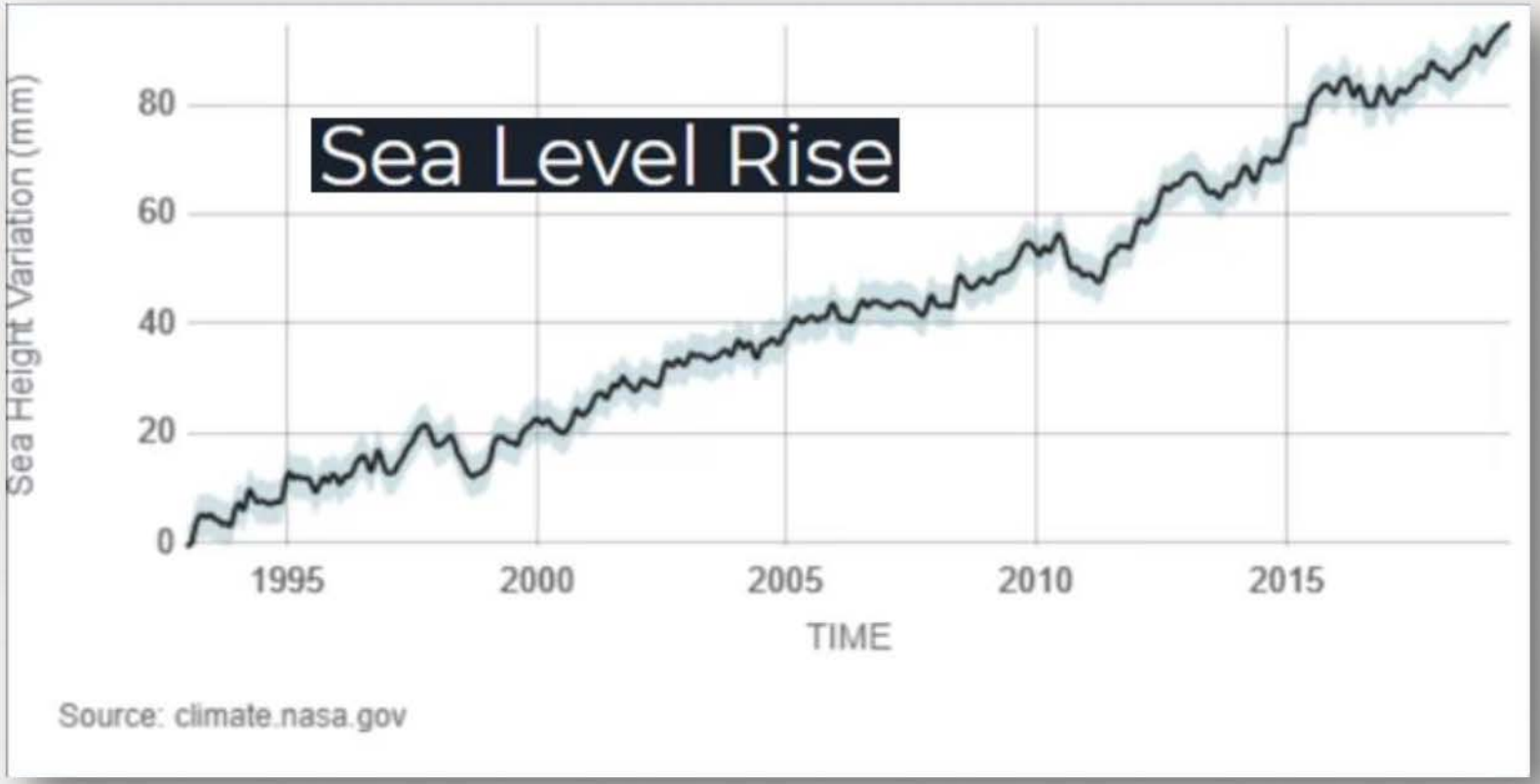


FIG. 2.14. Global alpine glacier annual mass balance record (× 10^3 mm w.e.) of reference glaciers submitted to the WGMS 1968–2018, with a minimum of 30 reporting glaciers.


Sea Level Rise
Sea Height Variation (mm)
80
60
40
20
0
1995
2000
2005
2010
2015
TIME
Source: climate.nasa.gov

Hurricane Dorian Grand Bahama Island

Tropical Cyclone Behavior Threat

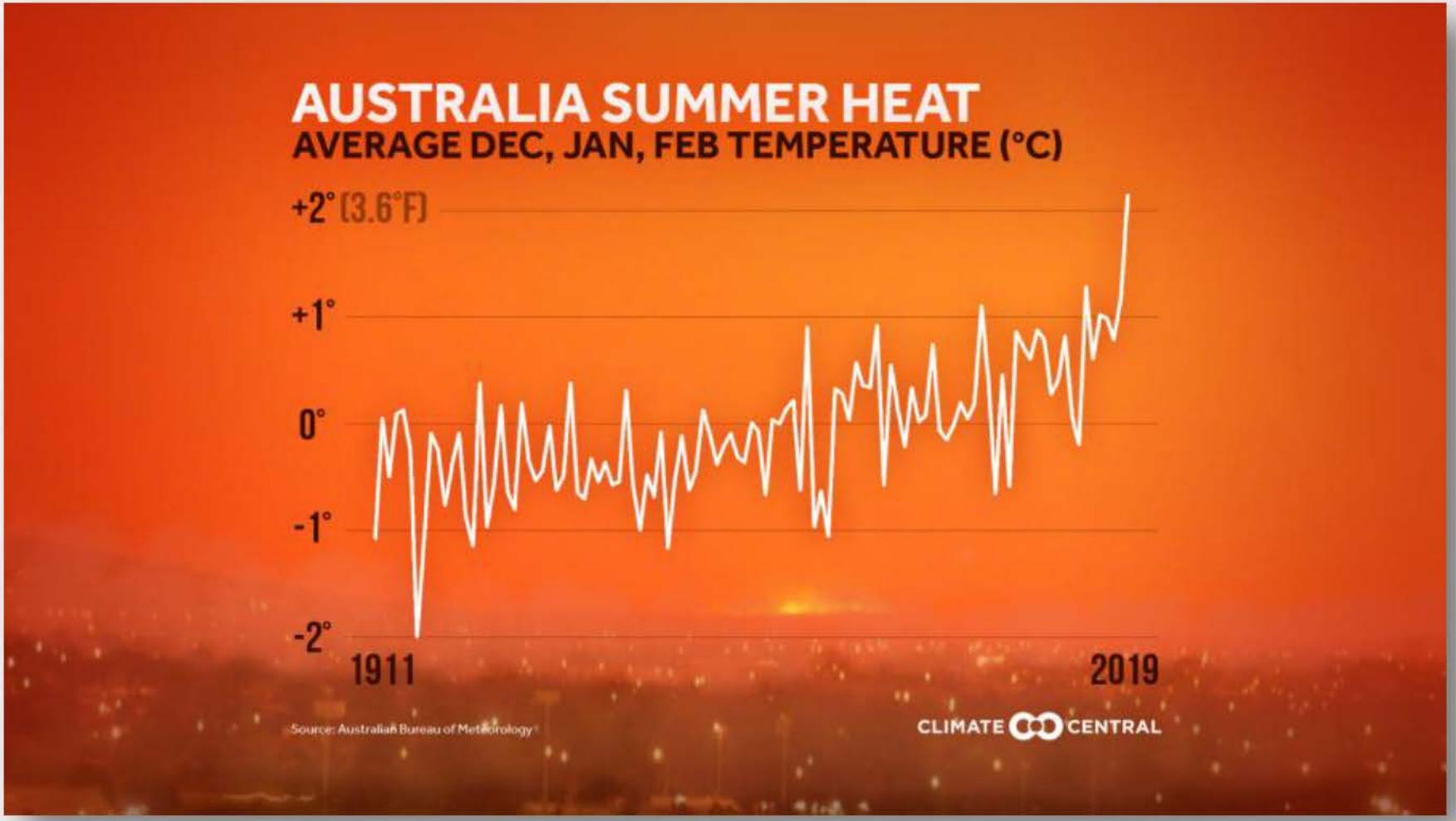
TC Projections for a 2°C global warming

1) **Storm Surge**: sea level rise will lead to higher storm inundation levels on average for TCs that occur, assuming all other factors are unchanged. (Not yet detected.)
2) **TC precipitation rates**: at least *medium-to-high* confidence in an increase at the global scale. About +14% for a 2°C global warming, or close to the rate of tropical water vapor increase expected for warming at constant relative humidity. (No detection.)
3) **TC intensity**: at least *medium-to-high confidence* in an increase at the global scale (10/11 authors). Magnitude about 5% (range 1 to 10%) for a 2°C global warming.
4) **Proportion of TCs that reach very intense (Category 4-5) levels:** at least *medium-to-high confidence* in an increase at the global scale. Median projection: +13%
5) **Poleward expansion of the latitude of maximum intensity in the western North Pacific?** (Mixed author opinion on projection; *low-to-medium confidence* in detection of past increase*)*
6) **TC frequency?** Mixed author opinion. 7 of 11 authors had *low-to-medium confidence* in a global decrease. Most modeling studies project a decrease, though mechanism not well known. Median estimate about -13% for 2°C global warming.
7) **Very intense TC frequency (Category 4-5)**? Mixed author opinion on whether this will increase globally or not

Beira Mozambique Cyclone Idai

A Reminder...Abrupt Climate Change is ONE Symptom of Ecological Overshoot

1. Abrupt Climate Change
2. Topsoil Loss
3. Natural Resource Depletion
4. Ocean Acidification
5. Mass Extinction
6. Global Toxicity (chemical/nuclear/plastic pollution)
7. Growing Socio-Economic Inequalities
8. Economic Instability
9. Political Instability/Rise of Authoritarianism
10. Symptom Cross-Feedbacks (symptoms amplify each other)

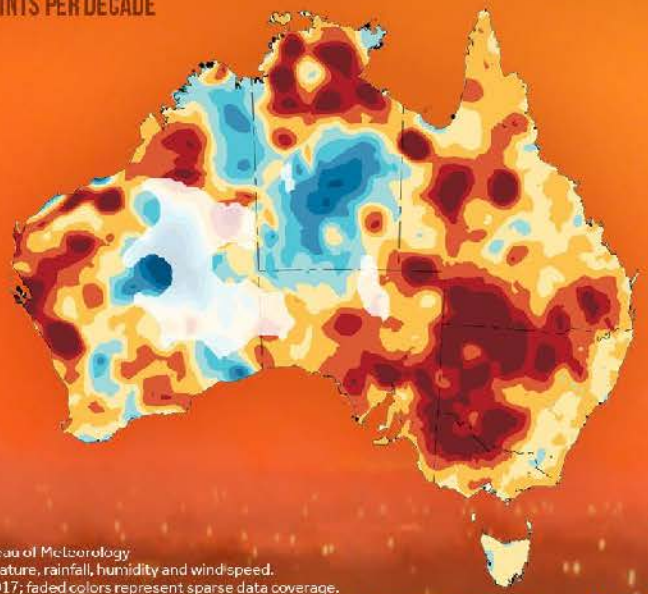

AUSTRALIA SUMMER HEAT
AVERAGE DEC, JAN, FEB TEMPERATURE (°C)
+2° (3.6°F)
+1°
0°
-1°
-2°
1911
2019
Source: Australian Bureau of Meteorology
CLIMATE CENTRAL

AUSTRALIA FIRE DANGER INDEX

CHANGE IN FIRE WEATHER RISK

-400 -300 -200 -100 0 +100 +200 +300 +400

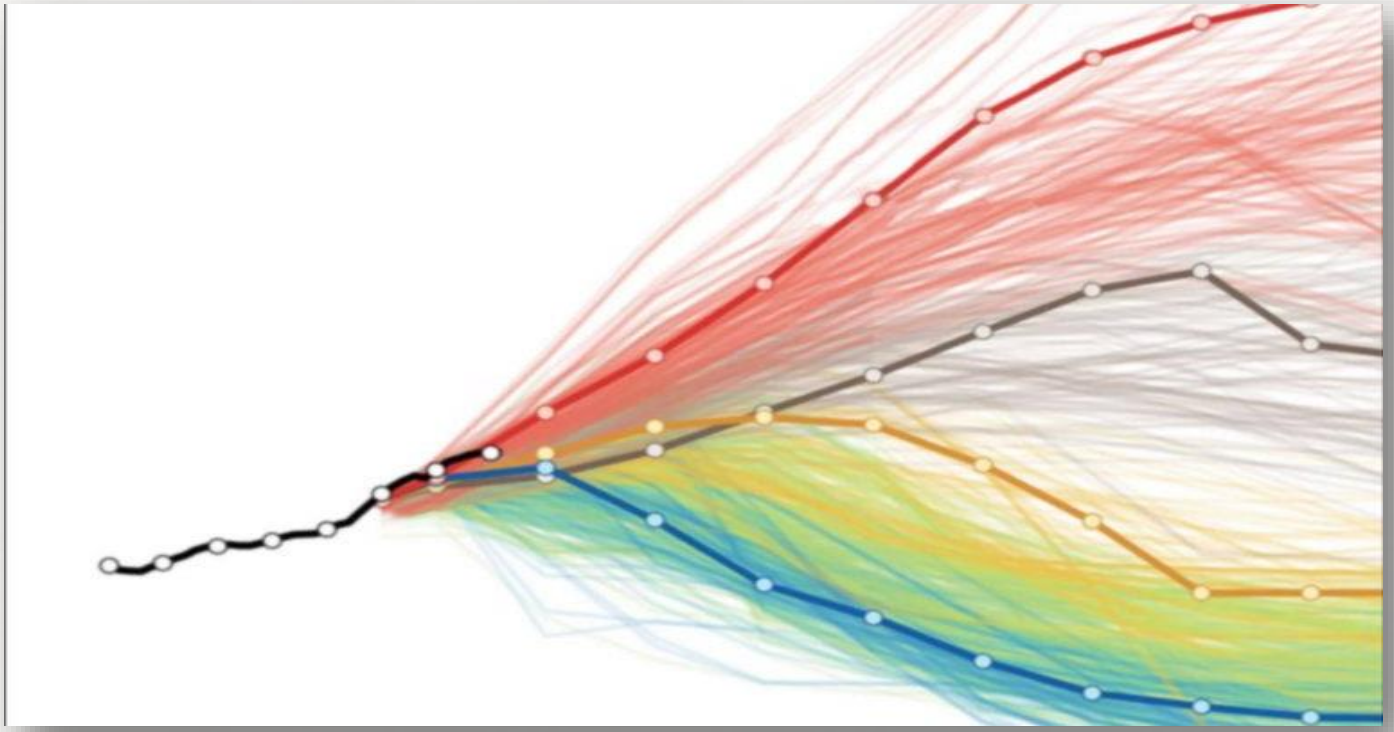
INDEX POINTS PER DECADE



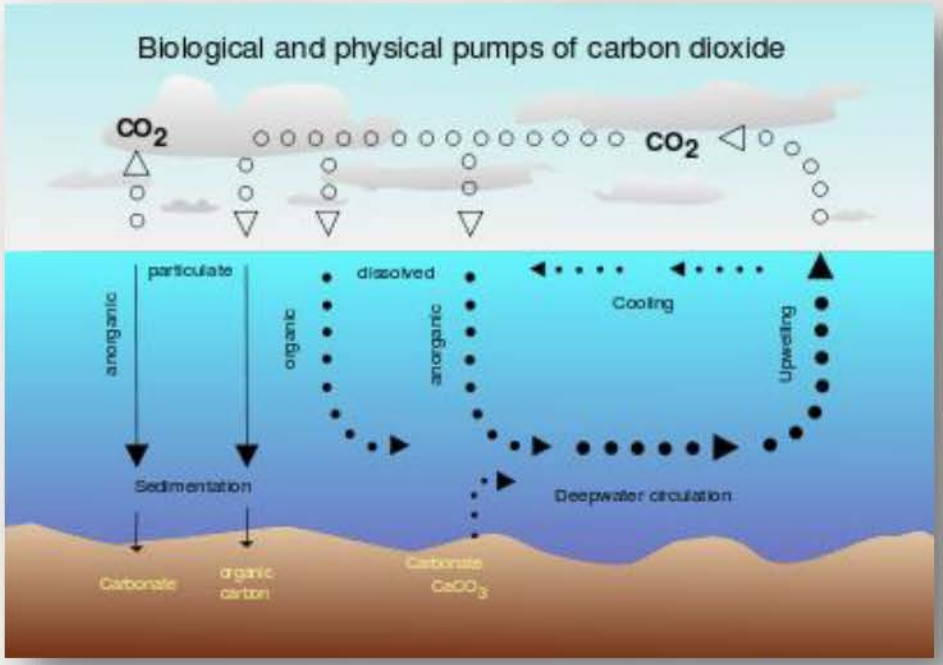
Source: Australian Bureau of Meteorology
Index based on temperature, rainfall, humidity and windspeed.
Trends from 1978 to 2017; faded colors represent sparse data coverage.
Positive (negative) numbers indicate increase (decrease) in length & intensity of fire weather season

CLIMATE CENTRAL

Climate Solutions



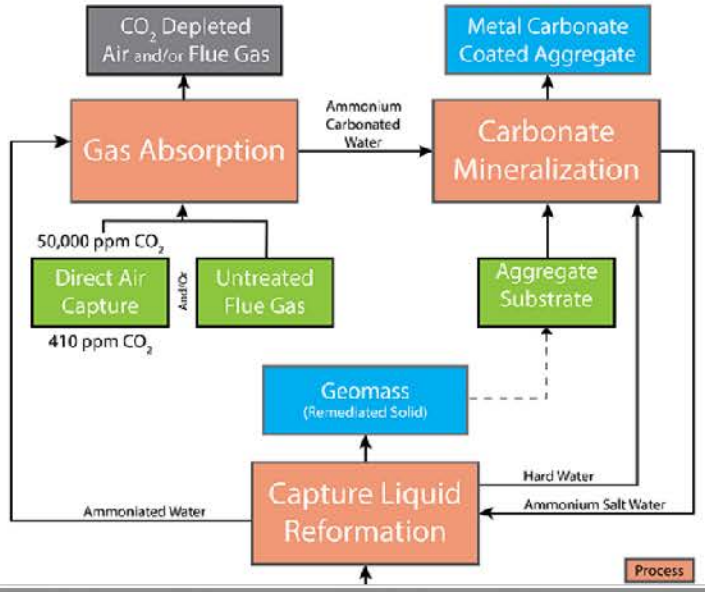
OCEAN SEEDING



Radical new technique promises a cheaper and more secure method of burying CO2 emissions underground instead of storing it as a gas

Blue Planet

Economically Sustainable Carbon Capture



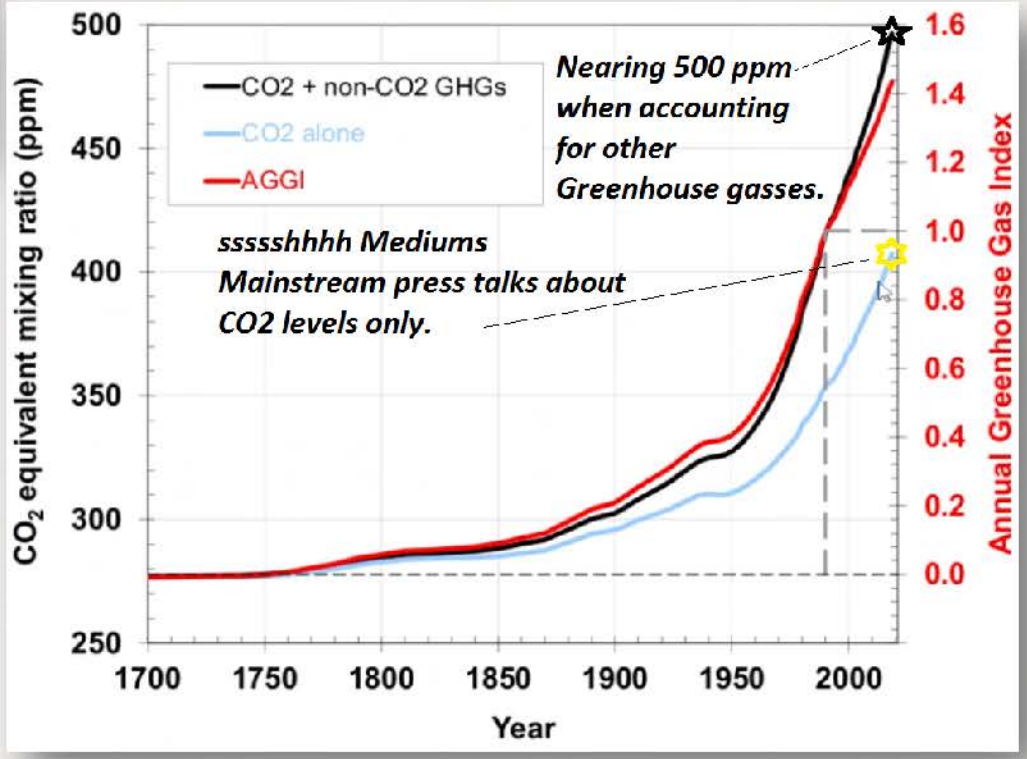
are released and combined with the carbonate solution to form the carbonate mineral coating.

Blue Planet Process is Similar to Ooid Formation in Nature

A rock particle is coated with our synthetic limestone, forming a carbon sequestering coating that is 44% by mass CO_2.The coating can contain residual fine particles from the capture solution regeneration.

44% (by mass) of $CaCO_3$ Coating is CO_2

CO2-Sequesterd Aggregate


CO2 + non-CO2 GHGs
CO2 alone
AGGI
Nearing 500 ppm when accounting for other Greenhouse gasses.
ssssshhhh Mediums Mainstream press talks about CO2 levels only.
CO2 equivalent mixing ratio (ppm)
Annual Greenhouse Gas Index
Year
500
450
400
350
300
250
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1700
1750
1800
1850
1900
1950
2000

QUESTIONS?


Chronicle HD
2004/05/14
New York
Green Mountains
WELCOME TO VERMONT
GREEN MOUNTAIN STATE
WELCOME CENTER
5 MILES
GREEN MOUNTAINS Mon Jul 2 17:46:47 2007
Glaciation or cirro-form fuzzy tops...
Low Topped Convection
Looks north from the Burlington International Airport, one of two waves of thunderstorms/showers moving toward the station late in the day
Dark Bases of the clouds
Cool Regime Thunderstorms crossed out of Canada July 2nd and brought gusty winds and sparse lightning.