

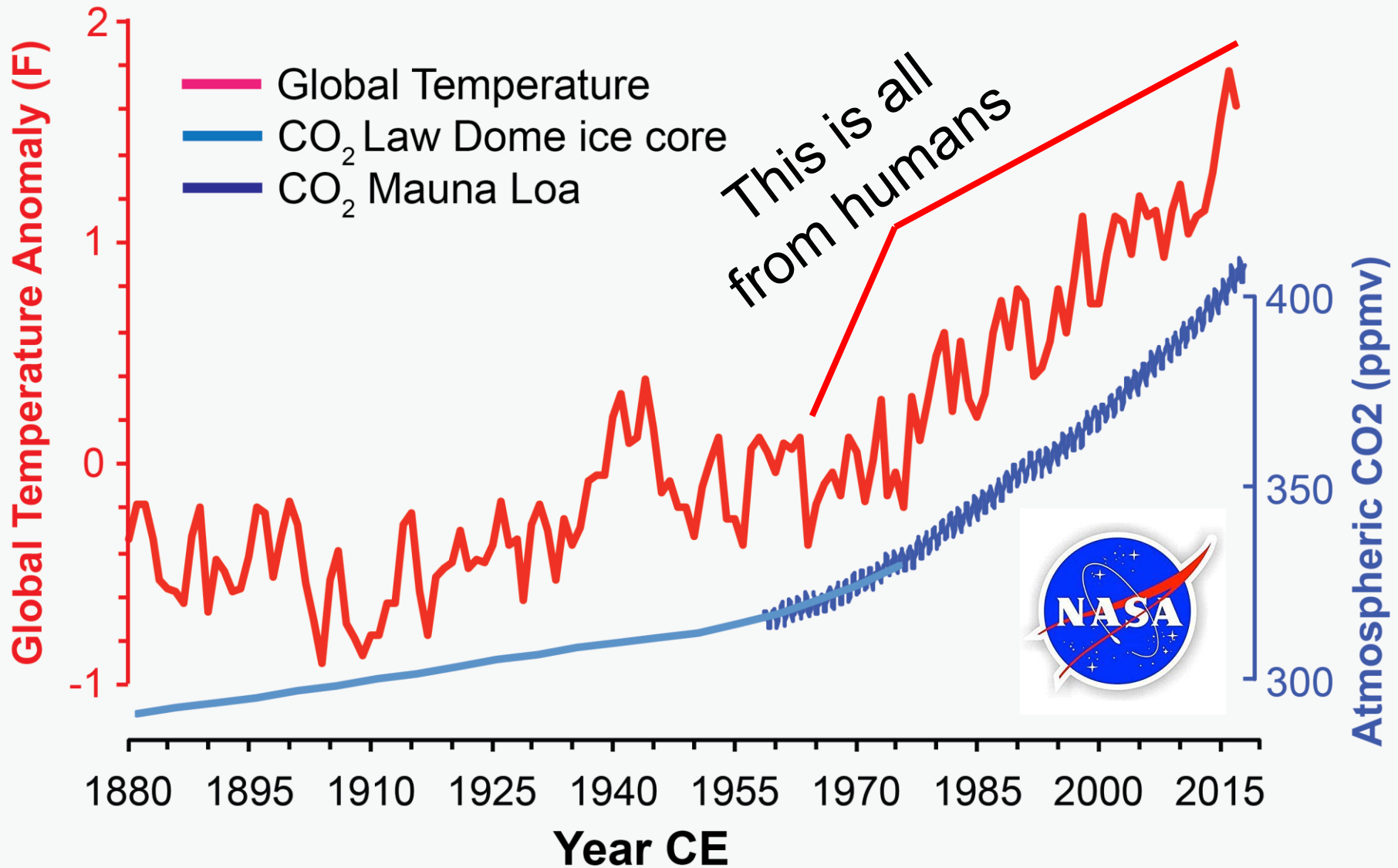
Downpours and Droughts: Changing Extremes in a Warming World



Dr. Erich Osterberg
Dartmouth College Earth Sciences



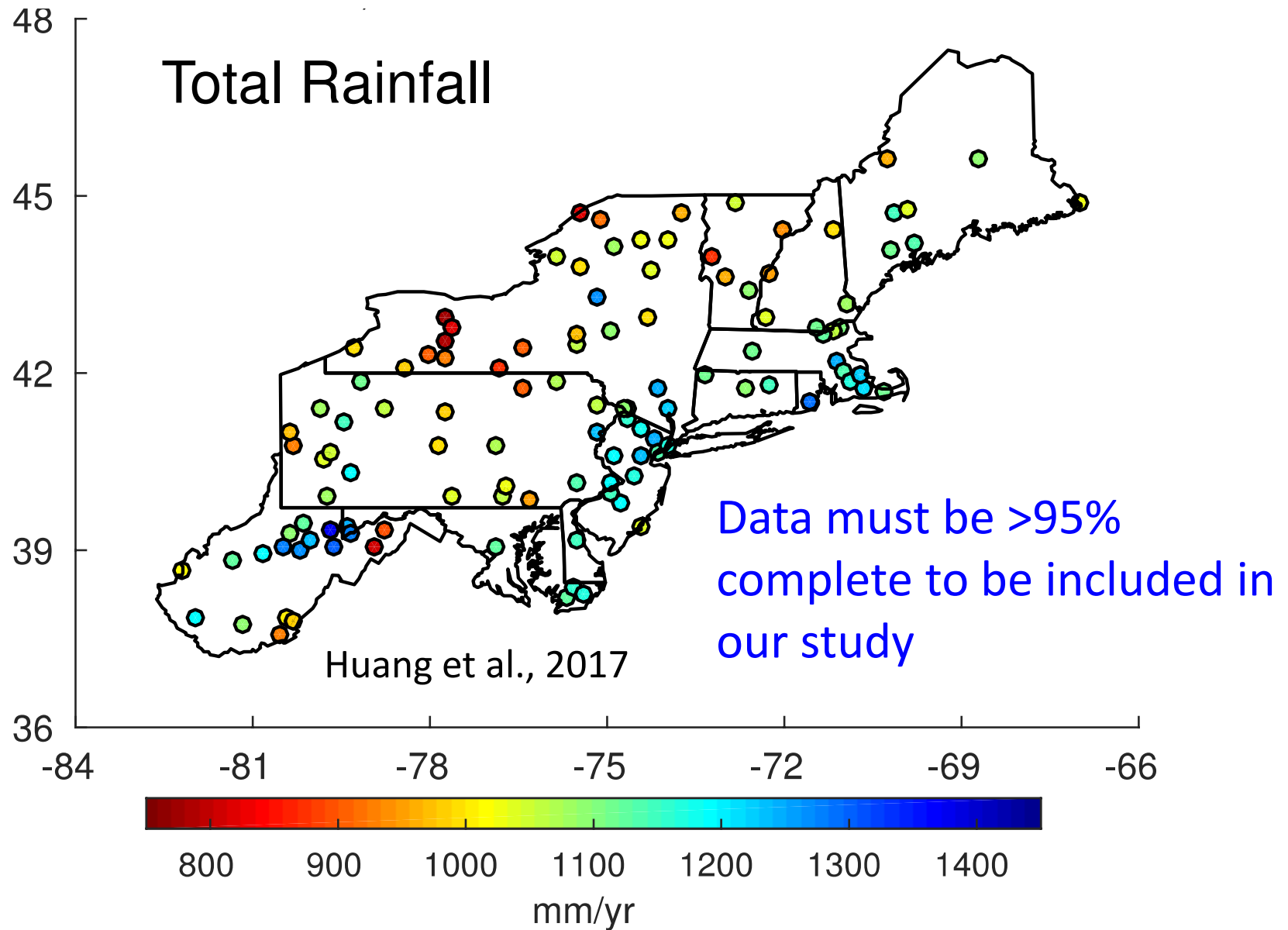
The Earth Has Warmed ~2°F since 1900



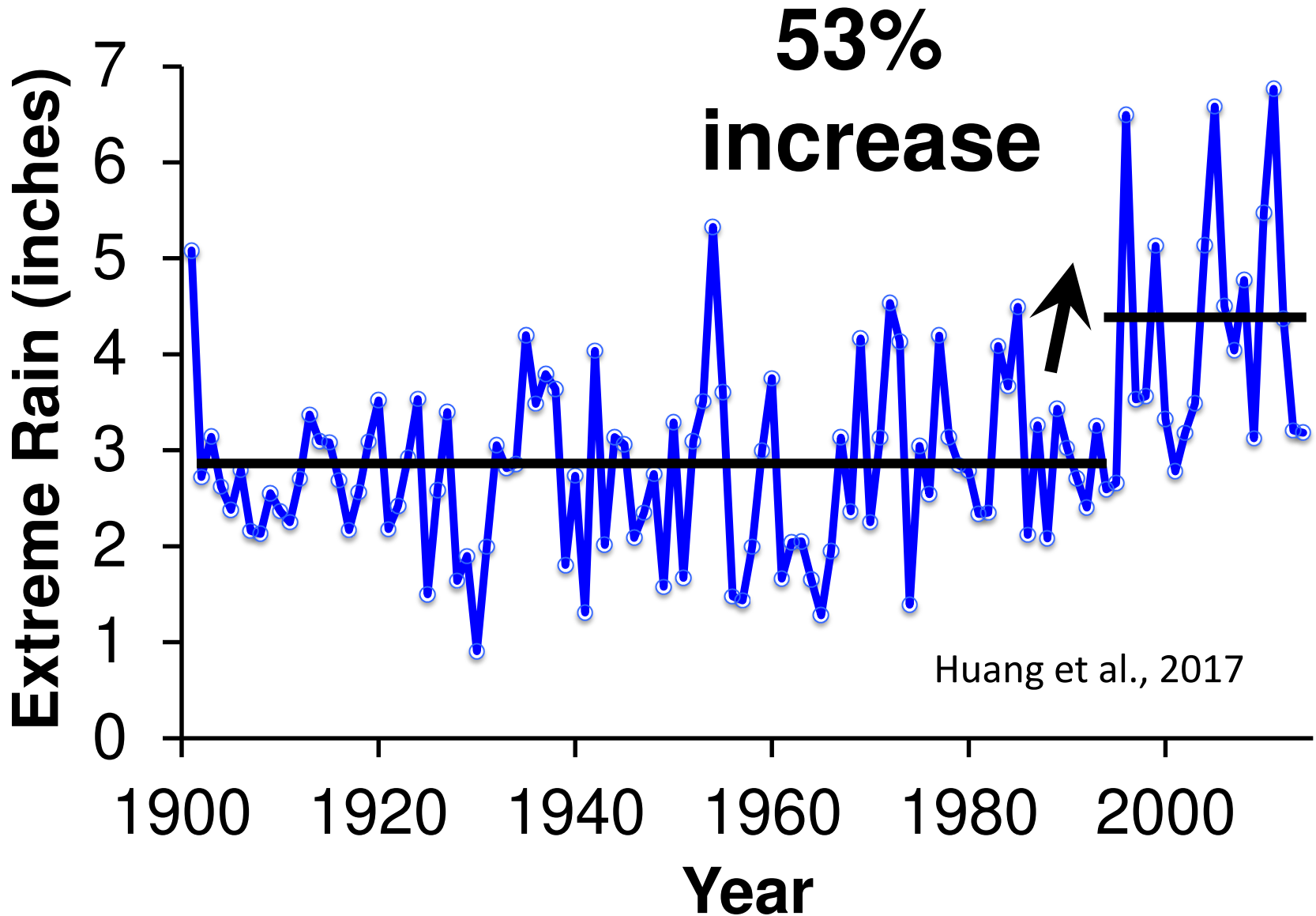
Take Home Messages

- Downpours (extreme rainfall) jumped up 50% in 1996
 - Caused by Hurricanes, Nor'easters and thunderstorms
- Drought is more frequent in NH & VT than you may think and has real impacts
- The future:
 - More downpours likely
 - More summer drought?

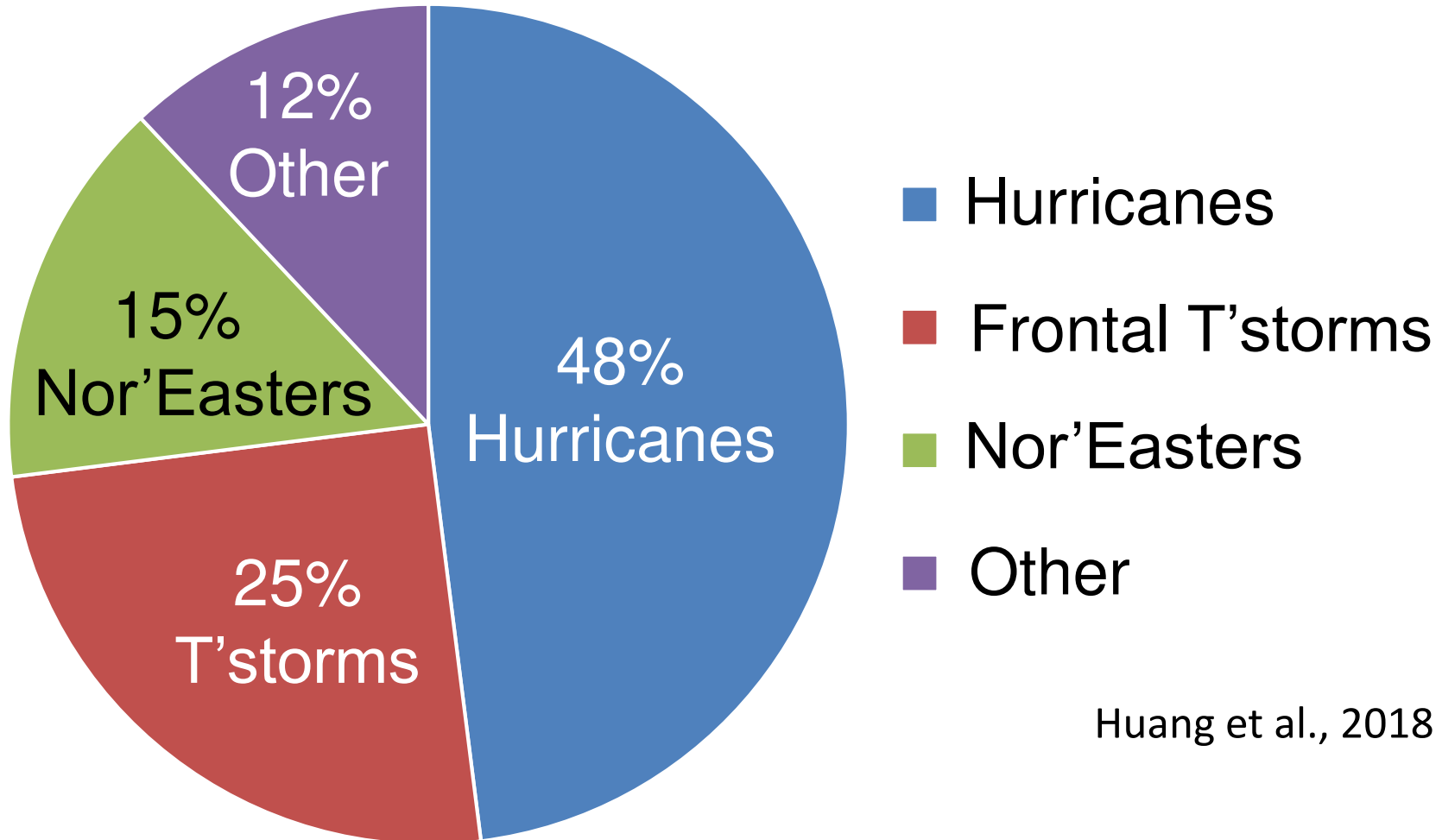
We Studied Rainfall Data from the Best 116 Weather Stations spanning 1900-2014



Extreme Rainfall Jumped 53% in 1996



Which Storms are More Extreme since 1996?



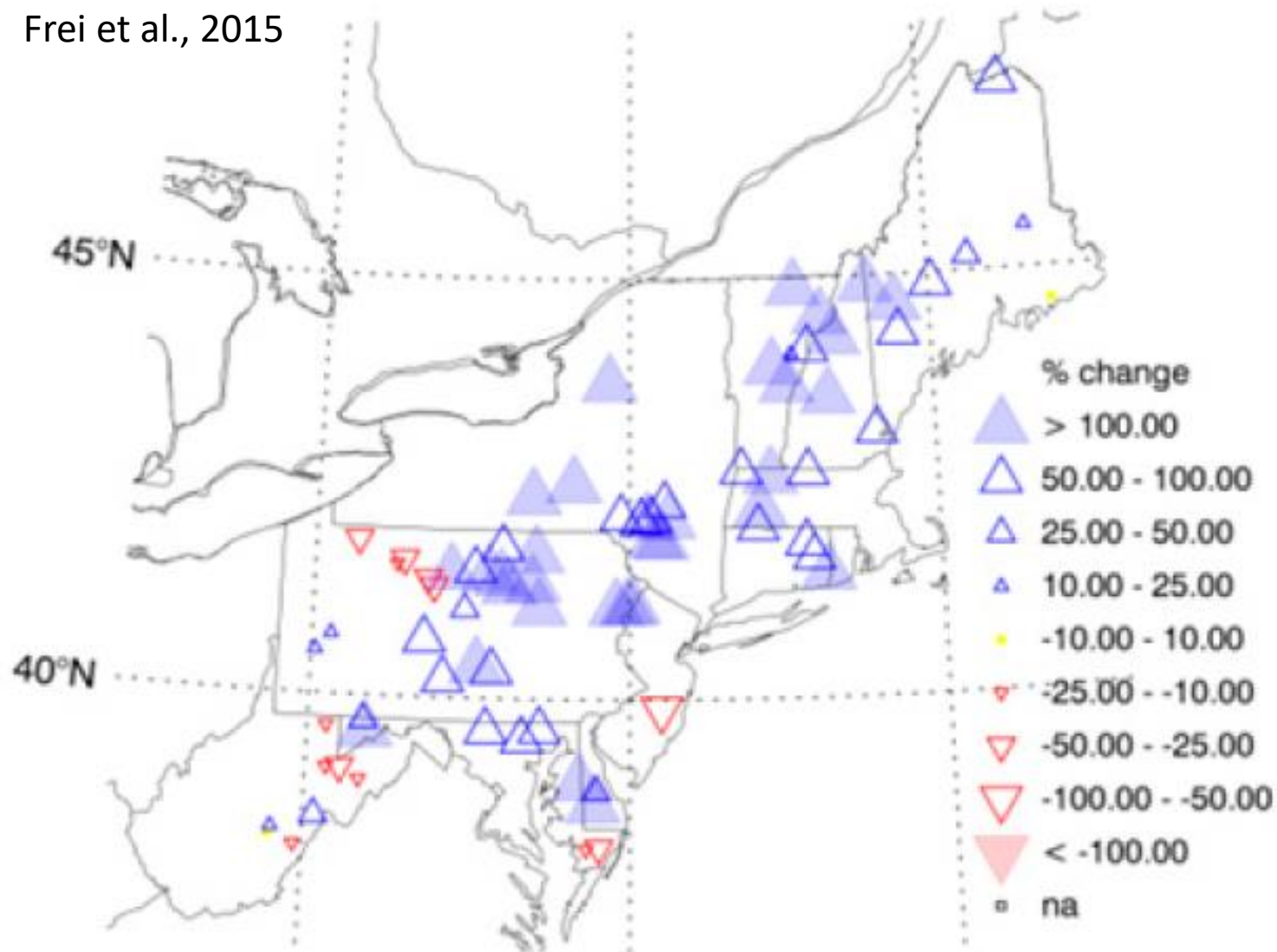
Huang et al., 2018

- Hurricanes are the biggest driver (48%)
- T'storms (25%) and Nor'Easters (15%) also causing more extreme rainfall

Summer Flooding is Increasing in Response

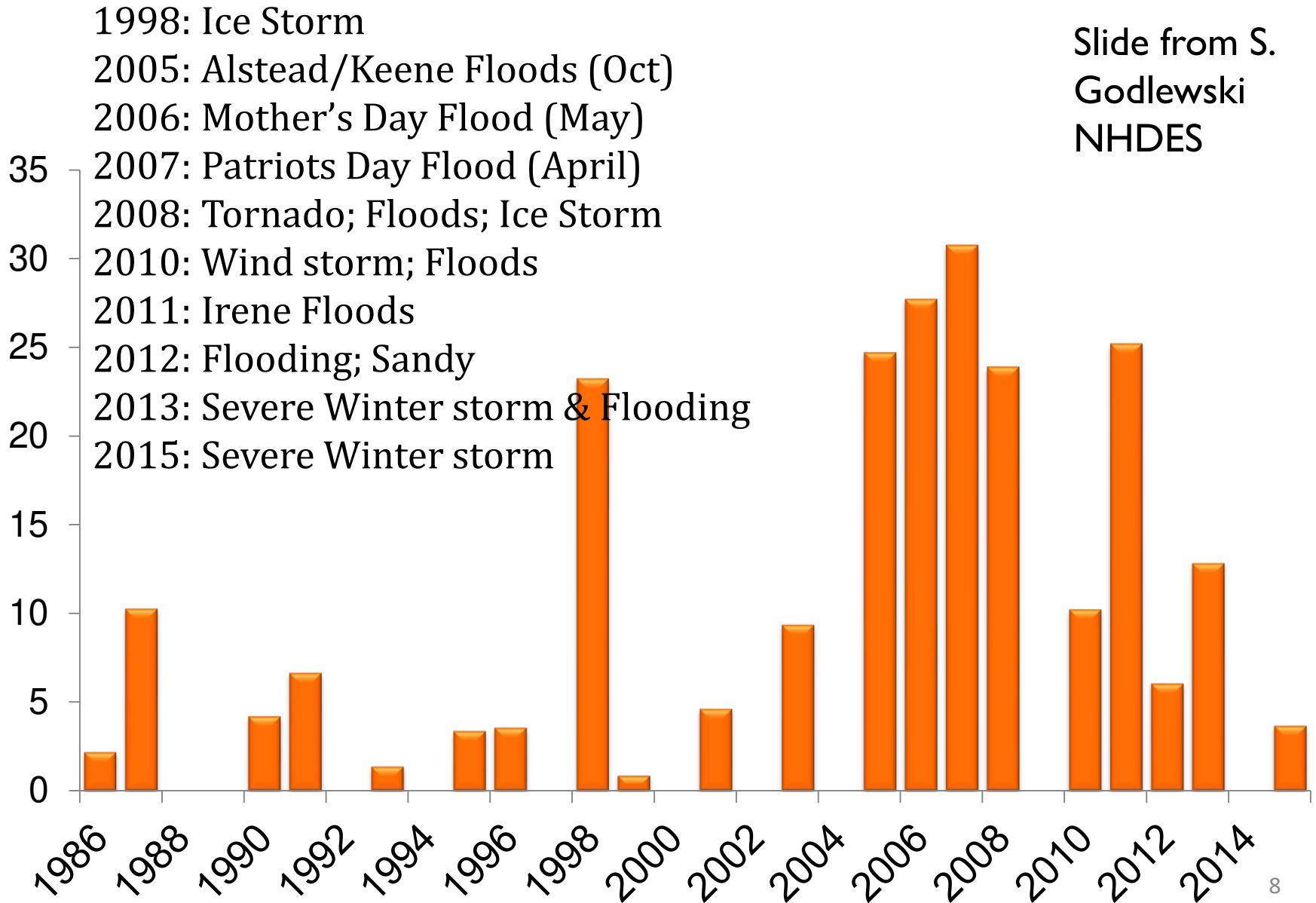
% Change in Summer Extreme Streamflow Events
in 2001-2012 compared to 1977-1988

Frei et al., 2015



Federal Disaster Spending in New Hampshire

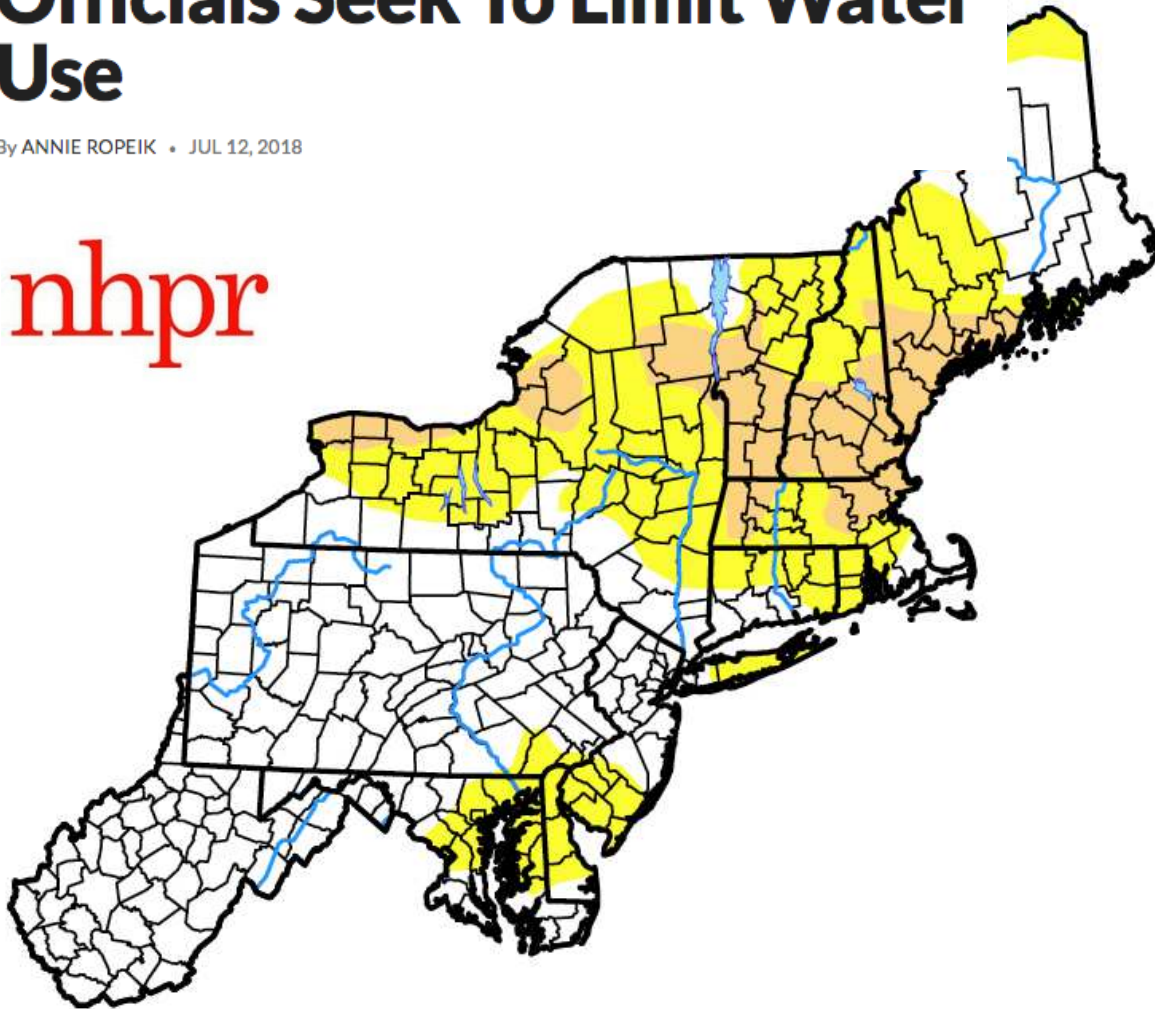
Slide from S.
Godlewski
NHDES








As N.H. Drought Spreads, Officials Seek To Limit Water Use

By ANNIE ROPEIK • JUL 12, 2018

nhpr



Intensity:

-  D0 Abnormally Dry
-  D1 Moderate Drought
-  D2 Severe Drought
-  D3 Extreme Drought
-  D4 Exceptional Drought

Author:

Eric Luebehusen
U.S. Department of Agriculture



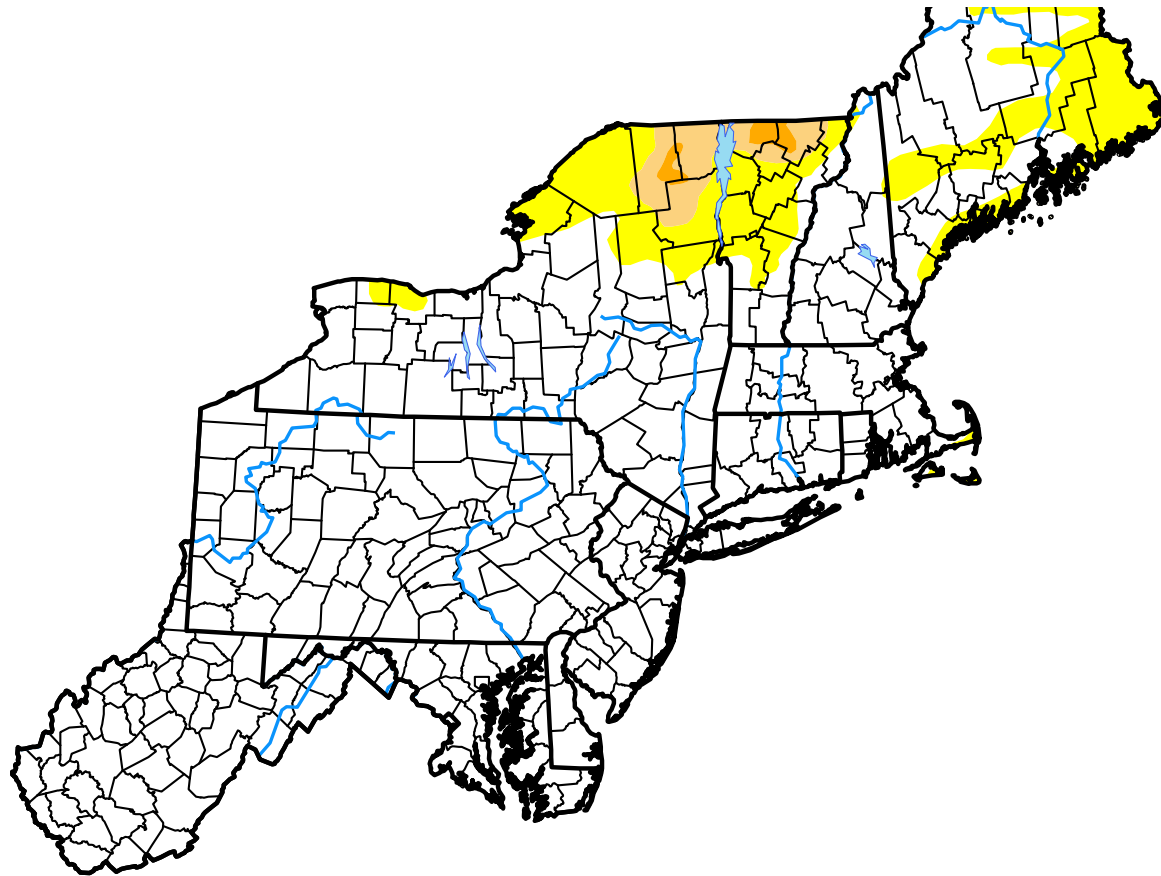
<http://droughtmonitor.unl.edu/>

U.S. Drought Monitor Northeast






October 23, 2018
(Released Thursday, Oct. 25, 2018)
Valid 8 a.m. EDT

Drought continues to plague northern Vermont, leaving farms and wells dry

By Elizabeth Gribkoff | VTDigger.org Oct 18, 2018



Intensity:

-  D0 Abnormally Dry
-  D1 Moderate Drought
-  D2 Severe Drought
-  D3 Extreme Drought
-  D4 Exceptional Drought

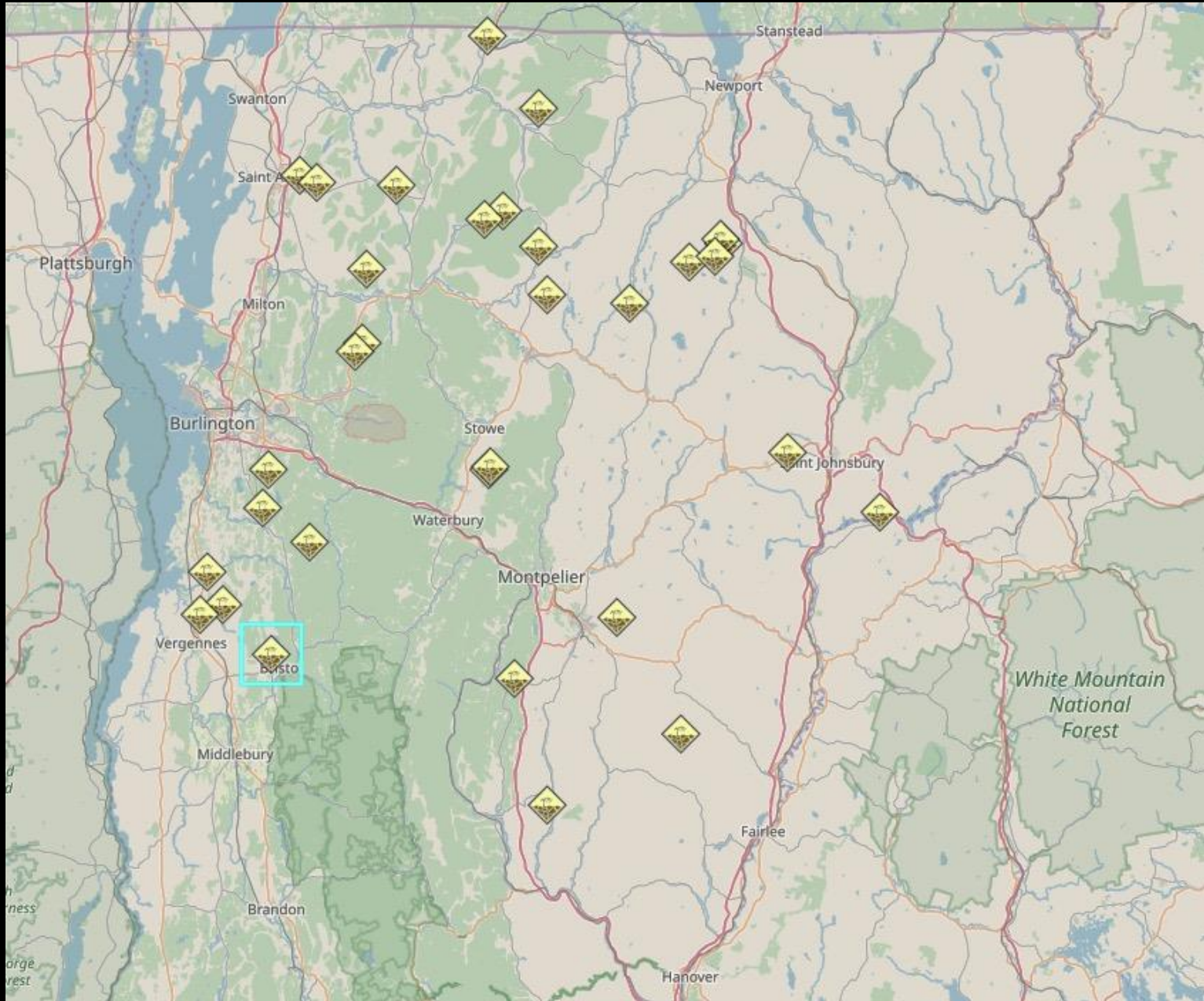
Author:

Eric Luebehusen
U.S. Department of Agriculture



<http://droughtmonitor.unl.edu/>

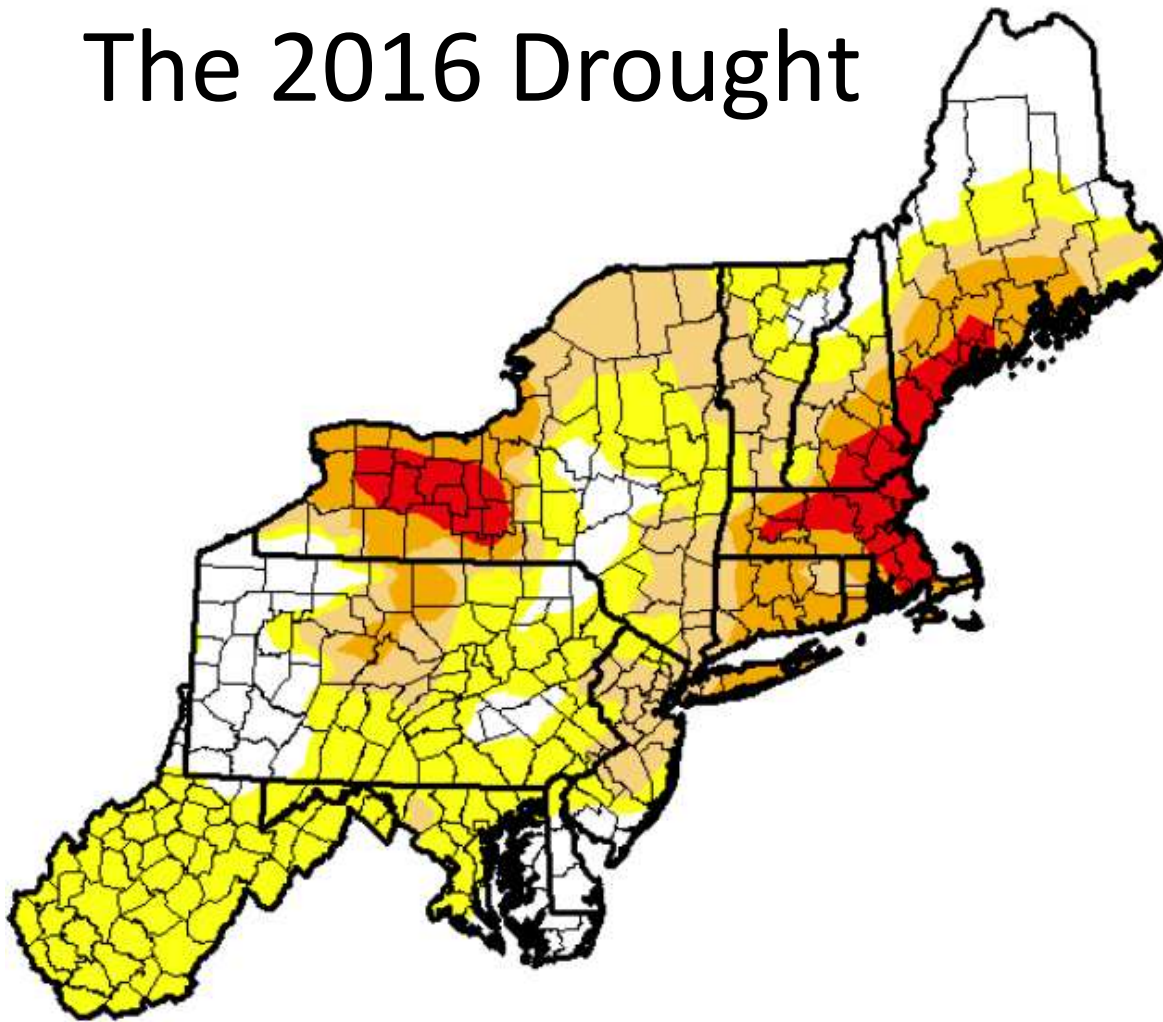
Some Wells in Northern VT are Currently Failing








U.S. Drought Monitor
Northeast

September 27, 2016
(Released Thursday, Sep. 29, 2016)
Valid 8 a.m. EDT

The 2016 Drought



Intensity:

-  D0 Abnormally Dry
-  D1 Moderate Drought
-  D2 Severe Drought
-  D3 Extreme Drought
-  D4 Exceptional Drought

Author:

Eric Luebehusen
U.S. Department of Agriculture



<http://droughtmonitor.unl.edu/>

Drought causes wells to dry up across NH

By Breanna Edelstein bedelstein@eagletribune.com Oct 4, 2016

**The Eagle-Tribune**

Wells Across New England Coming Up Dry Amid Drought

By Michael Casey
Associated Press

Thursday, September 22, 2016

**VALLEY NEWS**



The Boston Globe

Drought continues to spread across Mass.,






2016 Drought: Water Use Restrictions and Bans

Legend

-  County Boundary
-  Town Boundary

Municipality or Water System Status

-  Outdoor Use Ban
-  Restriction
-  Voluntary Restriction or Ban

Drought Condition

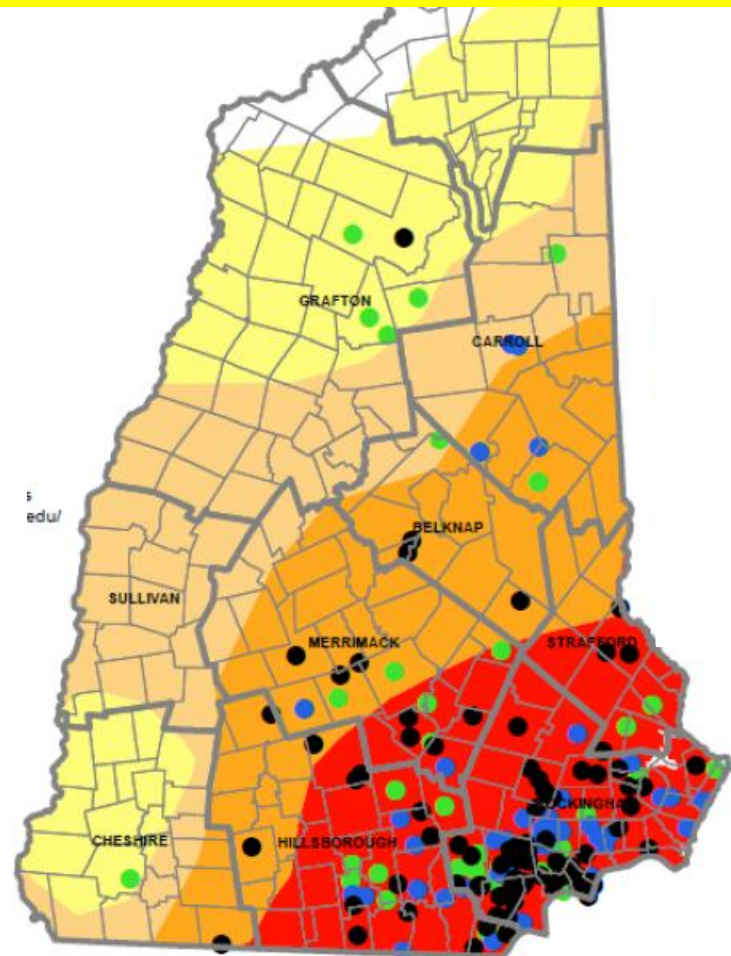
-  Abnormally Dry
-  Moderate Drought
-  Severe Drought
-  Extreme Drought



0 5 10 20
Miles








- 166 community restrictions or bans
- 12 towns setup emergency water sites
- 450 wells replaced or deepened

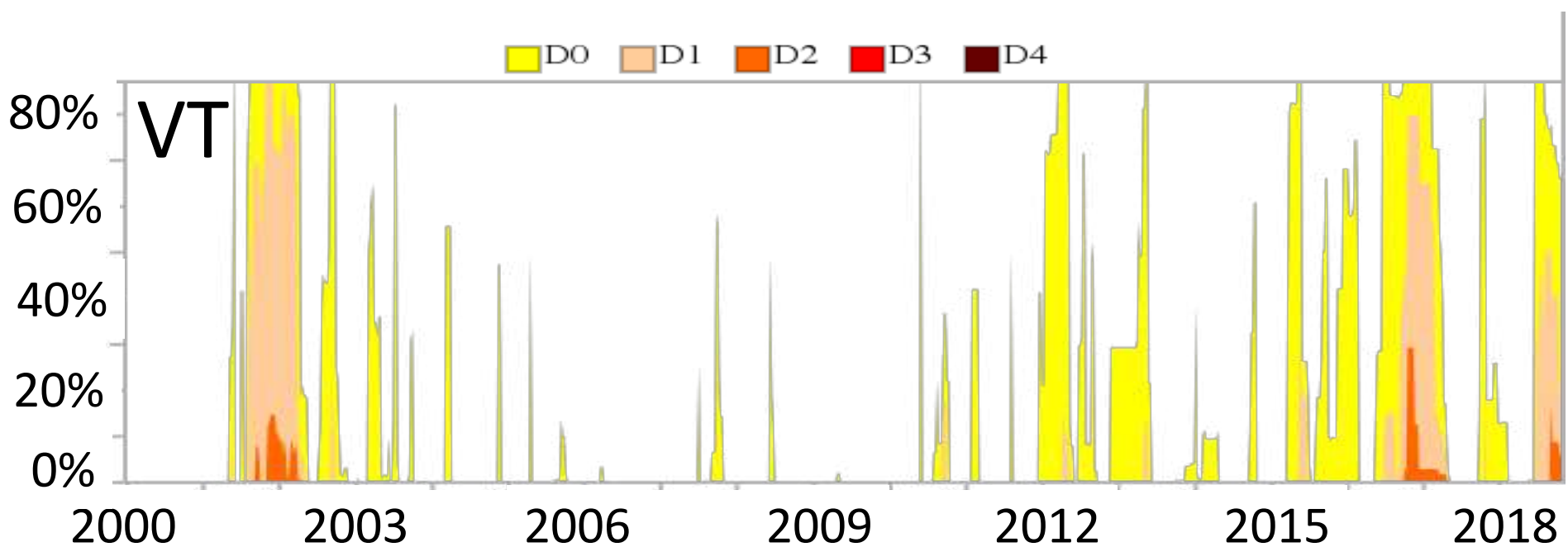
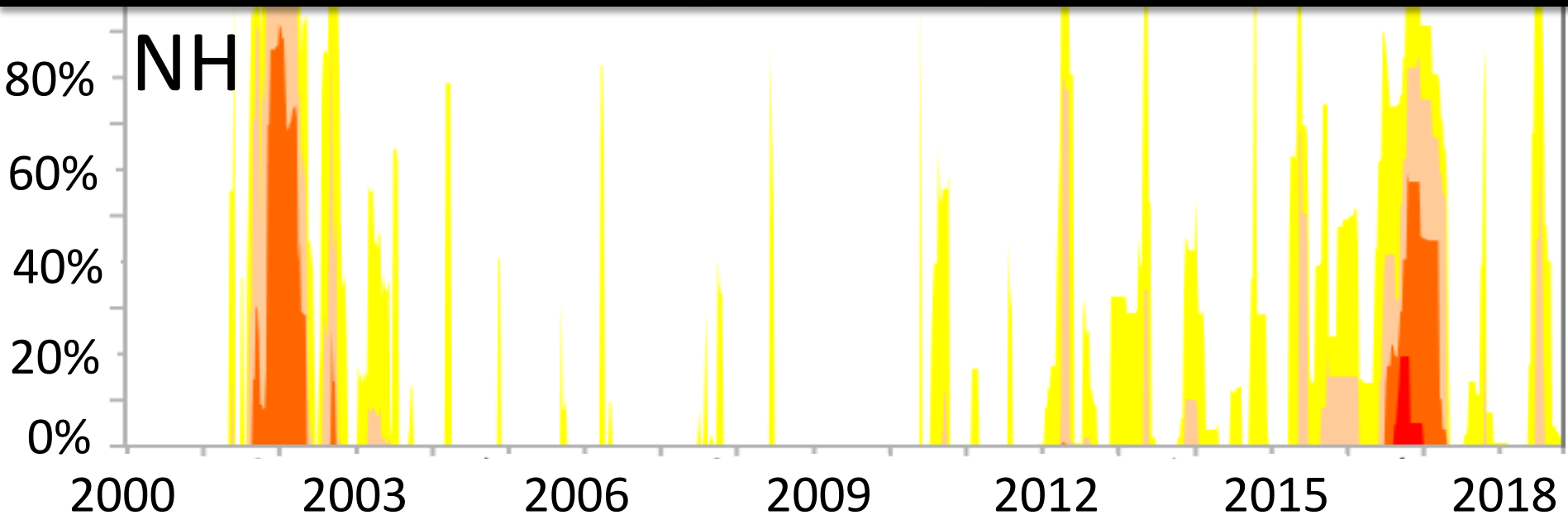


What do These Drought Classifications Mean?

Intensity:

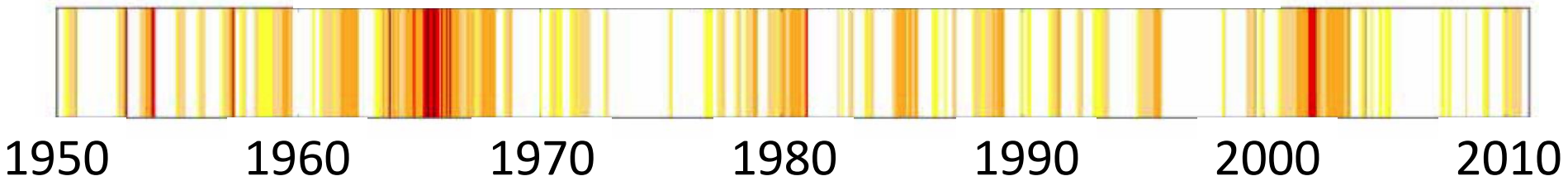
	D0 Abnormally Dry	Occurs every 6-9 months
	D1 Moderate Drought	Occurs every year
	D2 Severe Drought	Occurs every 3 years
	D3 Extreme Drought	Occurs every 10 years
	D4 Exceptional Drought	Occurs every 50-100 years

NH and VT Drought History: 2000-Today

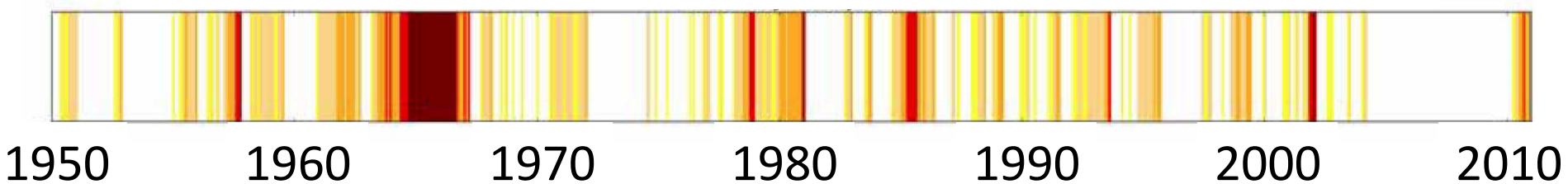


New Hampshire Drought History

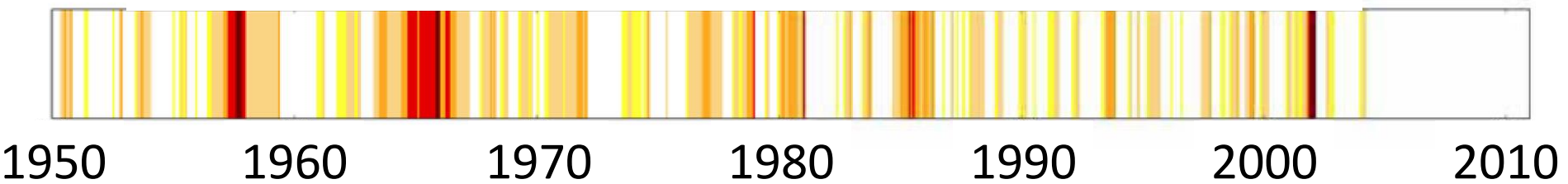
Grafton & Carroll Counties



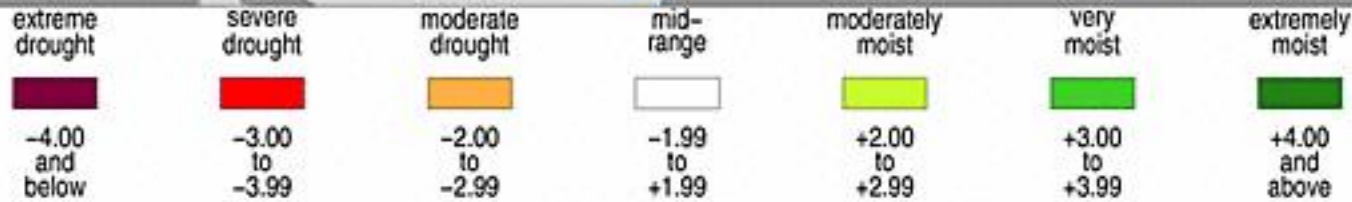
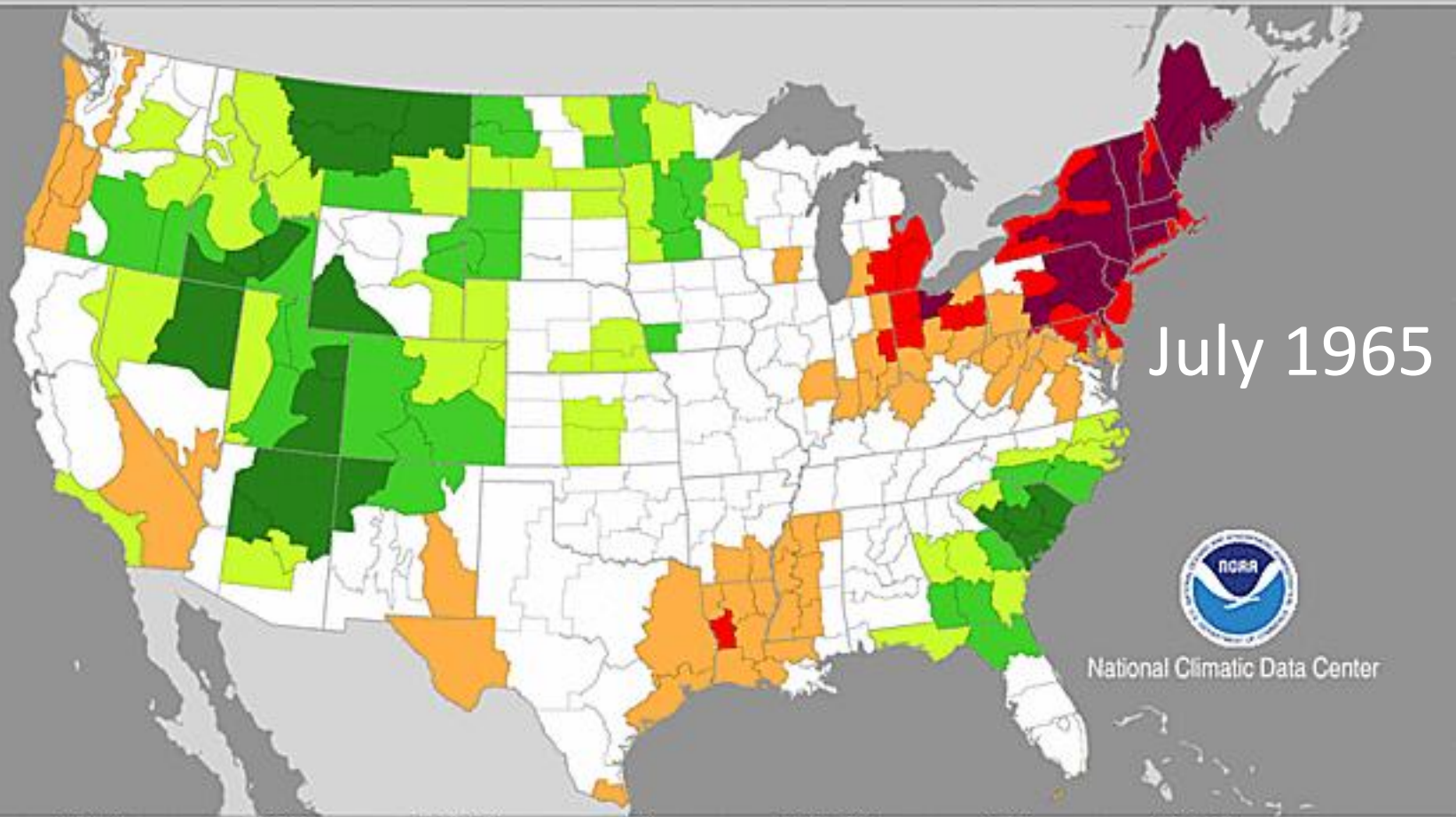
Hillsborough, Merrimack & Belknap



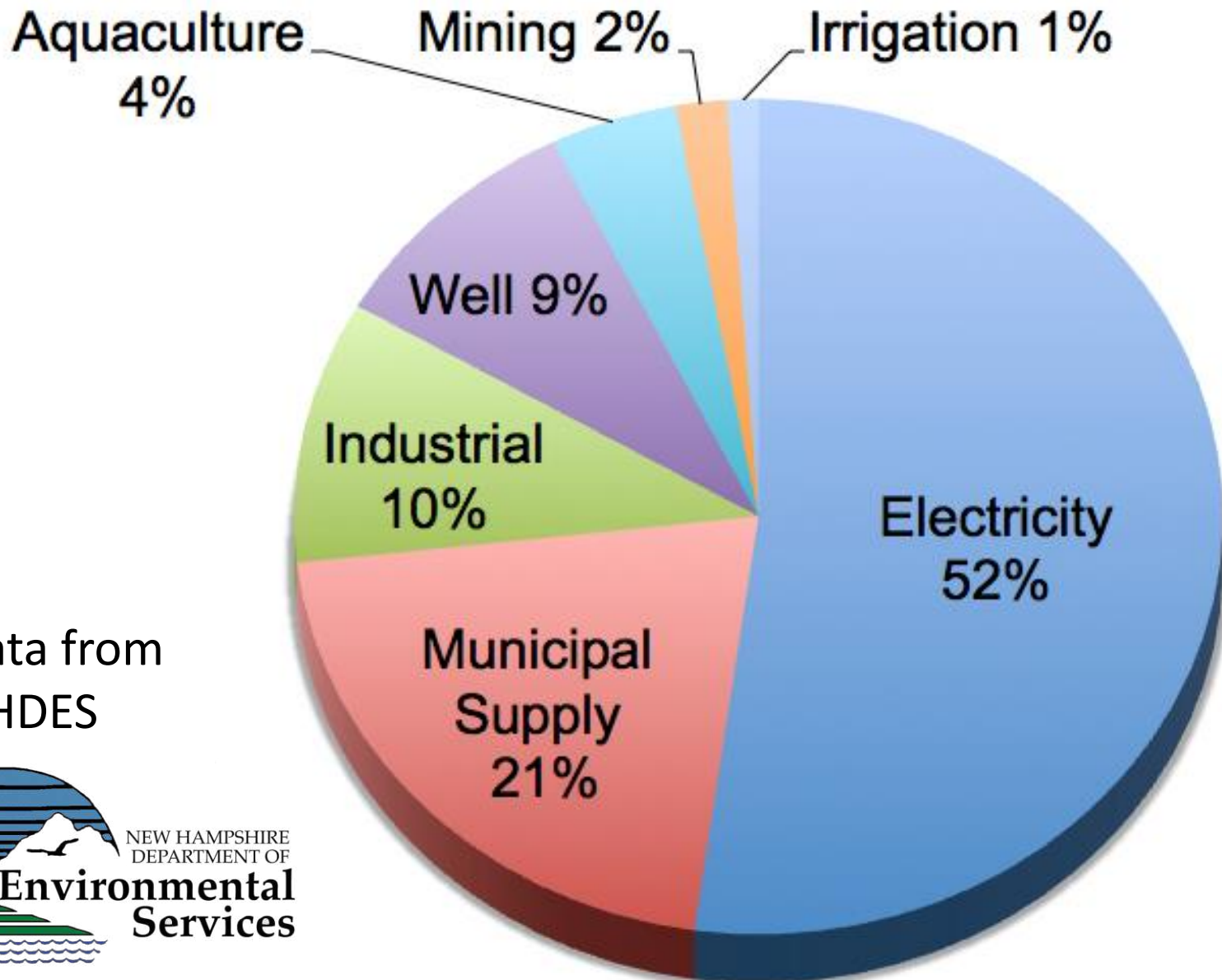
Stratford & Rockingham Counties



Historic Northeast Drought of 1963-1966



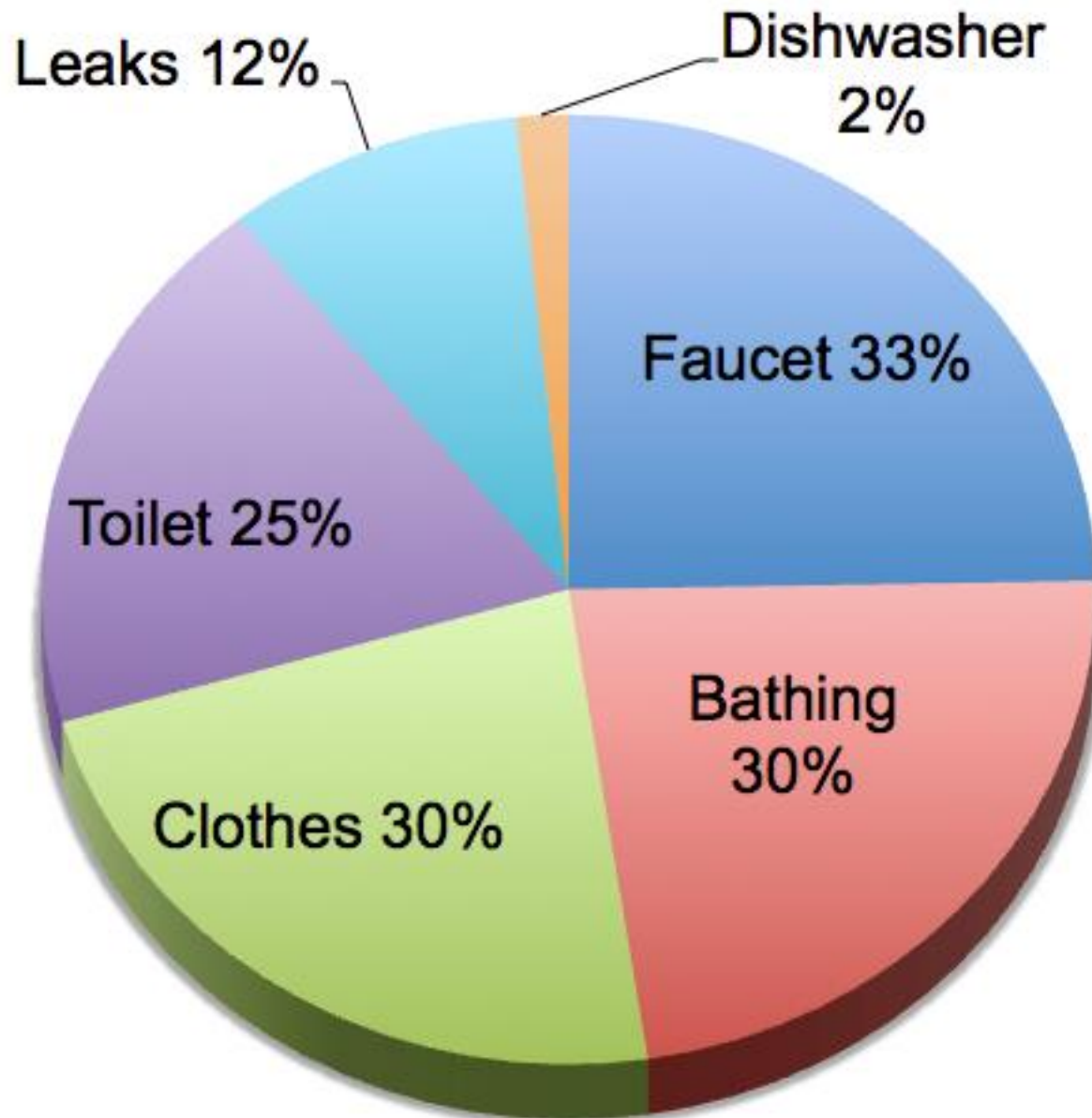
New Hampshire Water Use Statistics



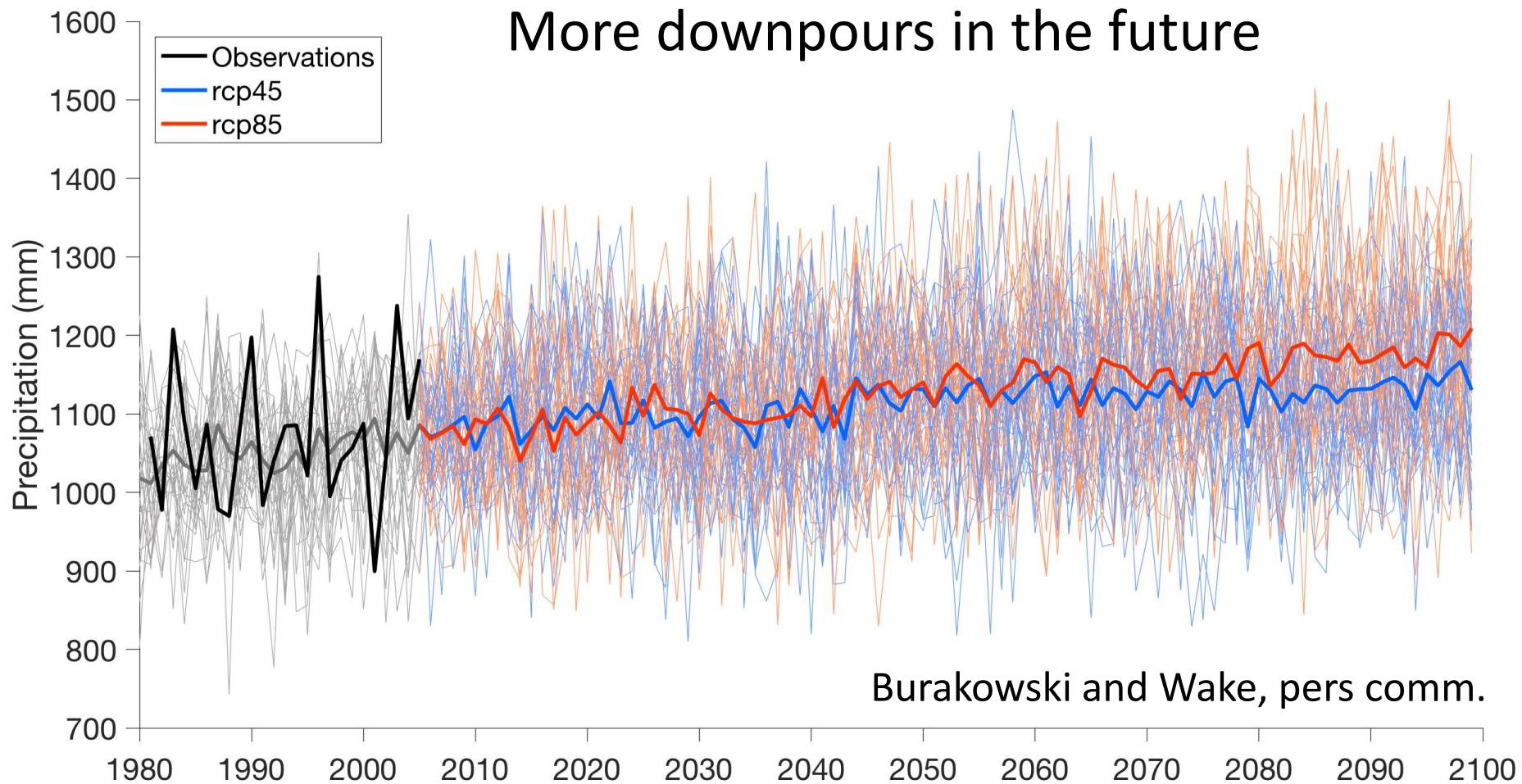
Data from
NHDES



How Do We Use Our Water at Home?



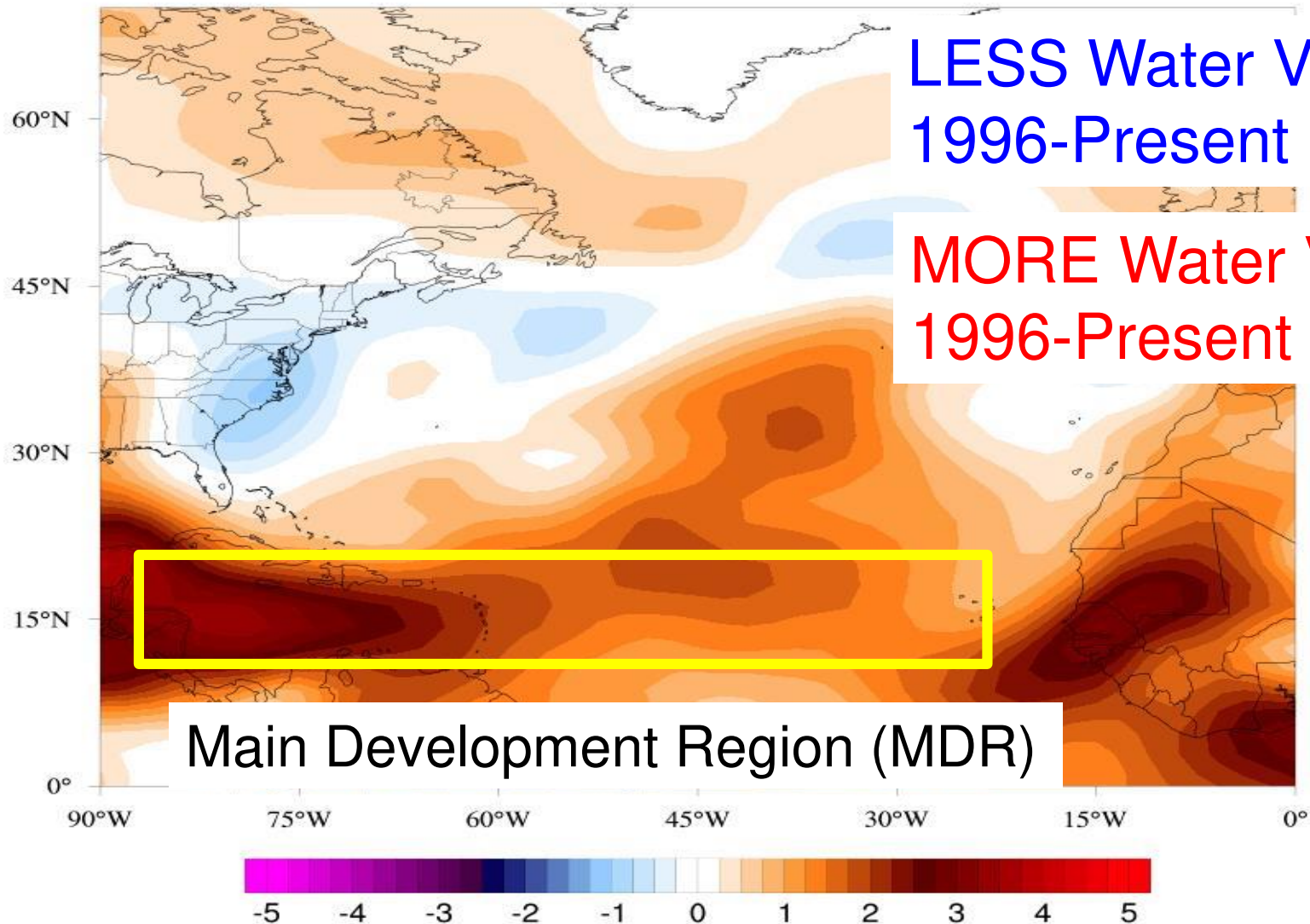
Climate Models Show the Northeast Getting Wetter Overall in the Future



More Frequent Extreme Rainfall Events from Hurricanes due to Warmer Ocean and More Vapor

Precipitable Water Anomaly (kg m⁻²)
20CR V2

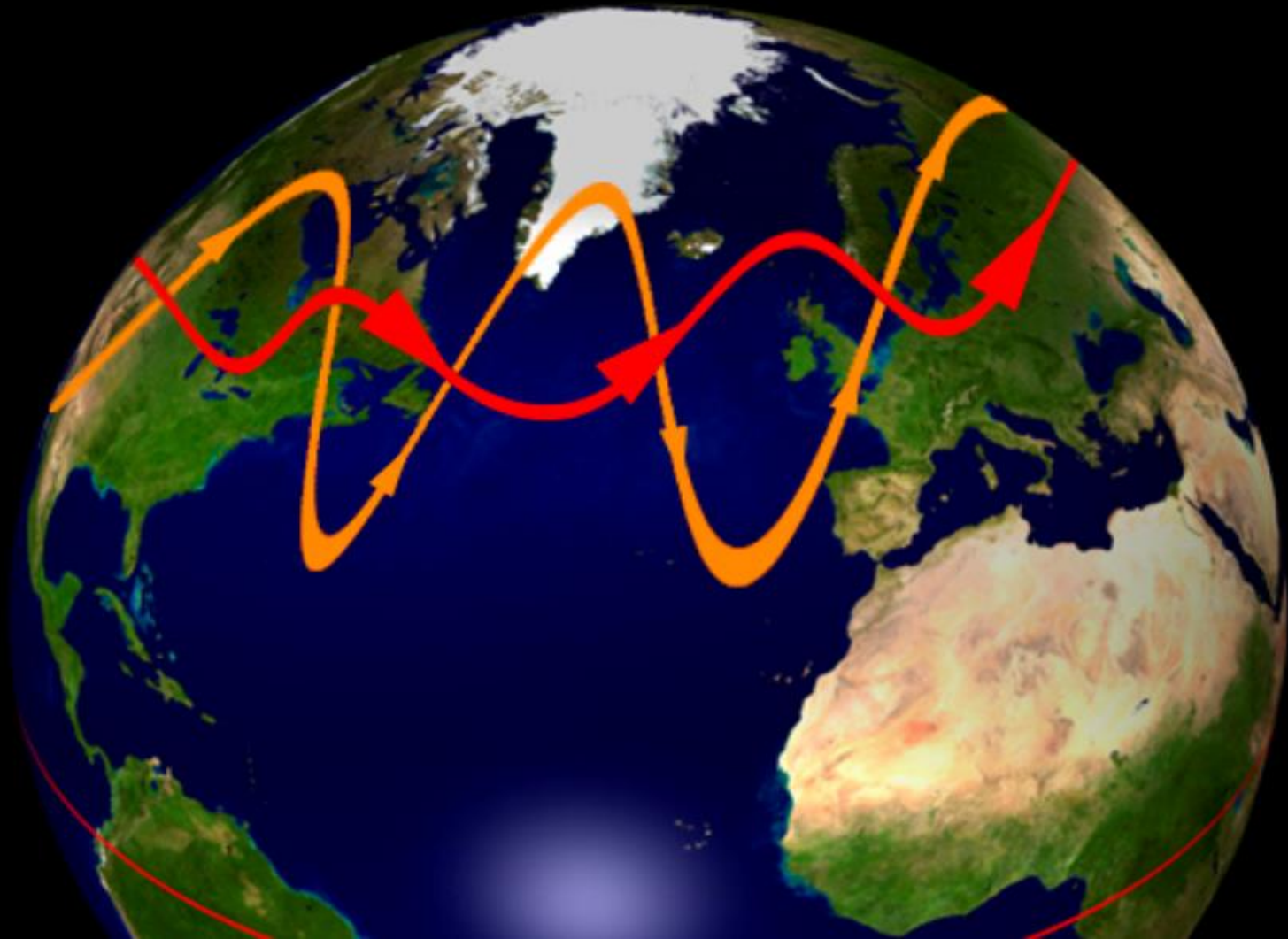
SON 1996-2010 minus 1928-1962



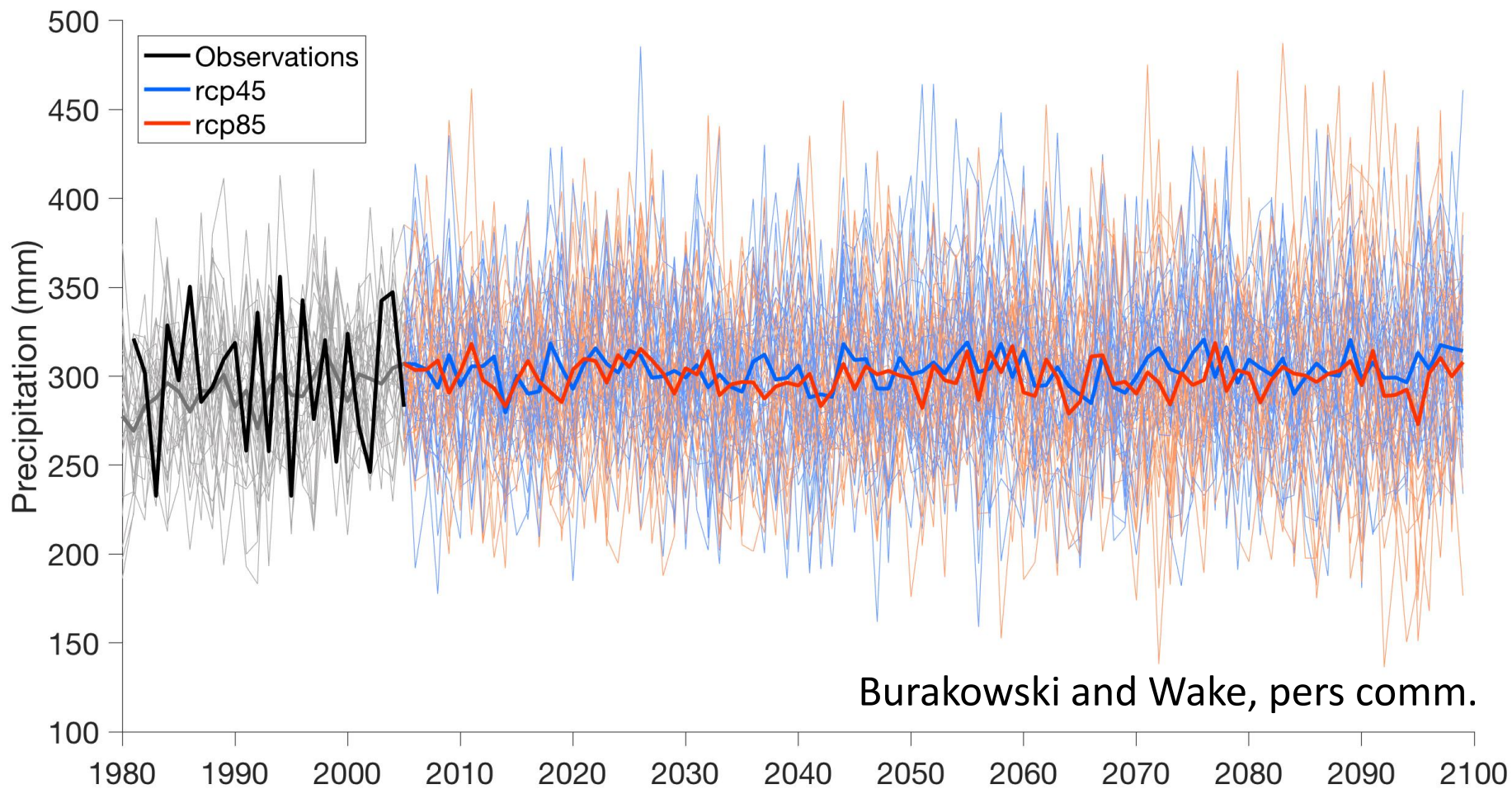
More Frequent T'Storms from Wavier Jet

→ = zonal flow

→ = meridional flow

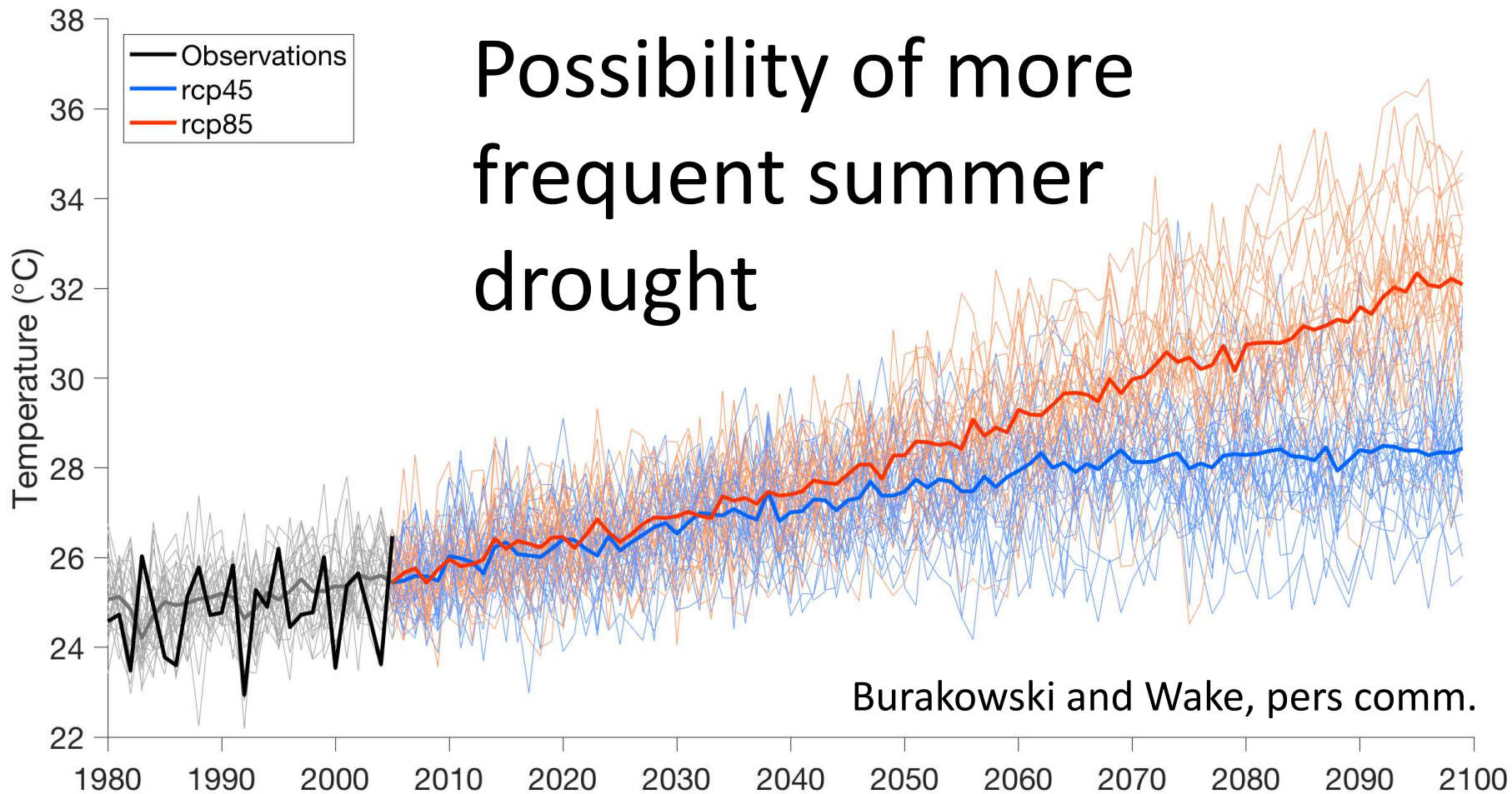


Summer Rain is Projected to Remain Steady in the Future



And Summer Temperatures are Projected to Increase 5-12°F!

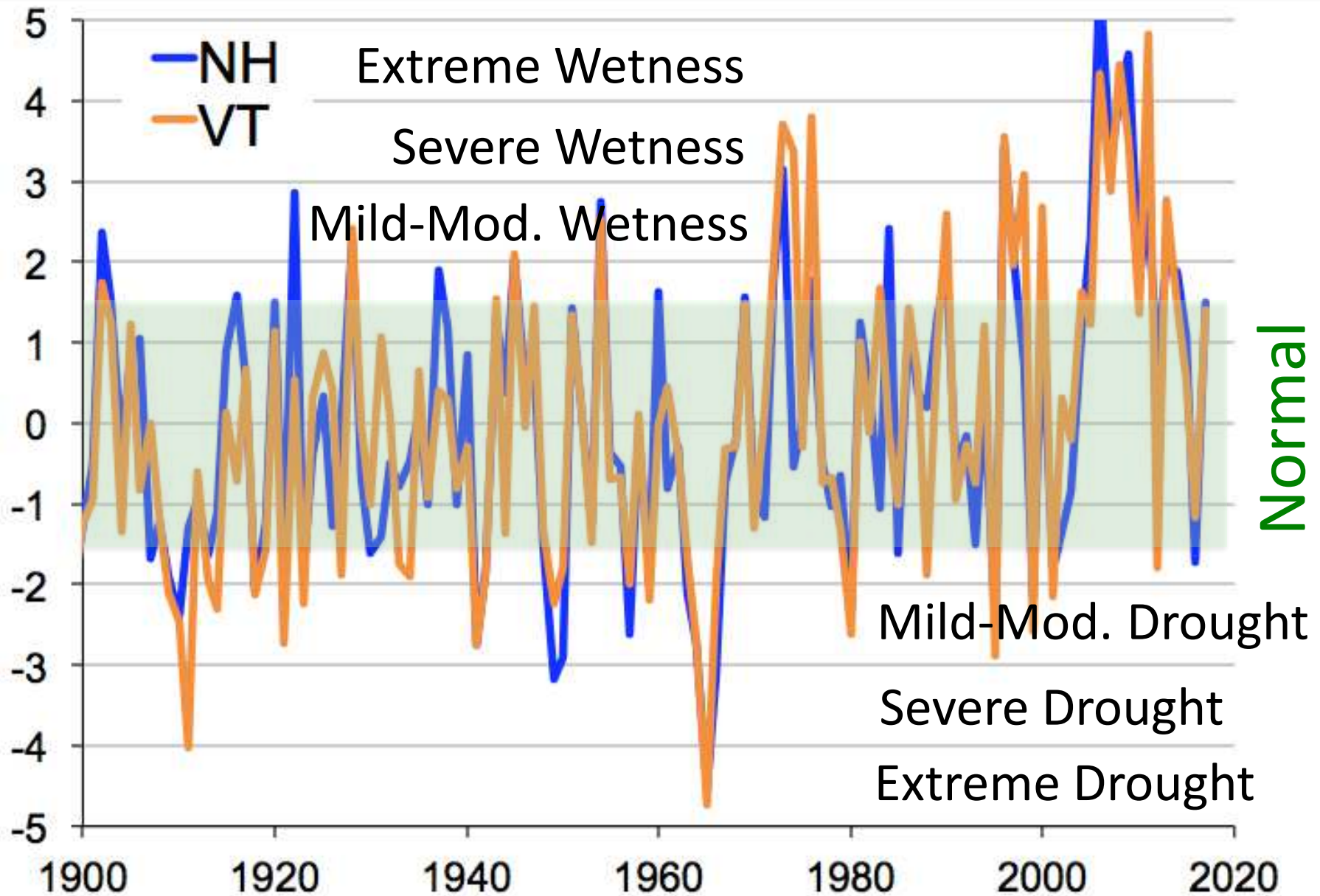
Possibility of more frequent summer drought



Take Home Messages

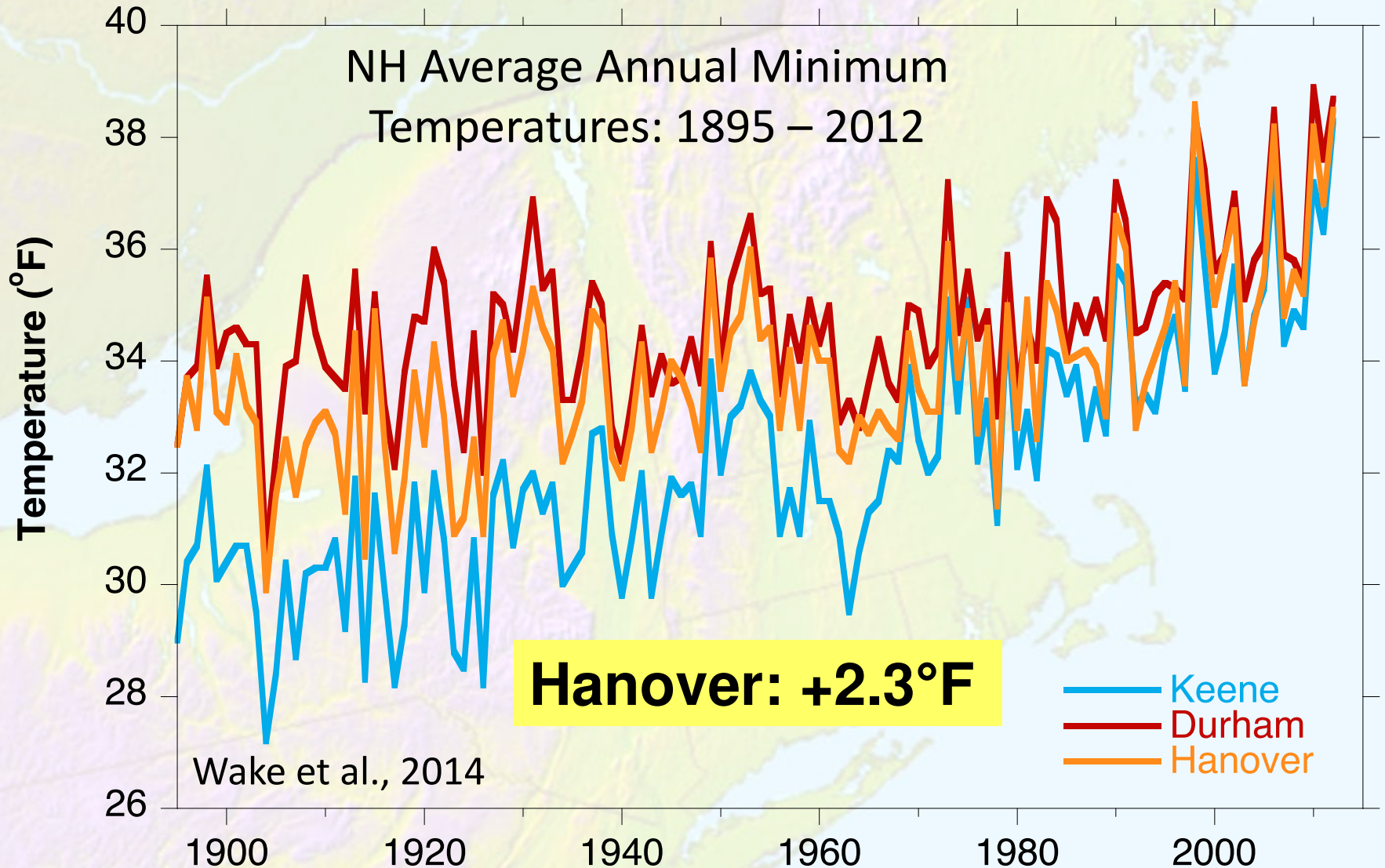
- Downpours (extreme rainfall) jumped up 50% in 1996
 - Caused by Hurricanes, Nor'easters and thunderstorms
- Drought is more frequent in NH & VT than you may think and has real impacts
- The future:
 - More downpours likely
 - More summer drought is possible

NH & VT Drought and Wetness History

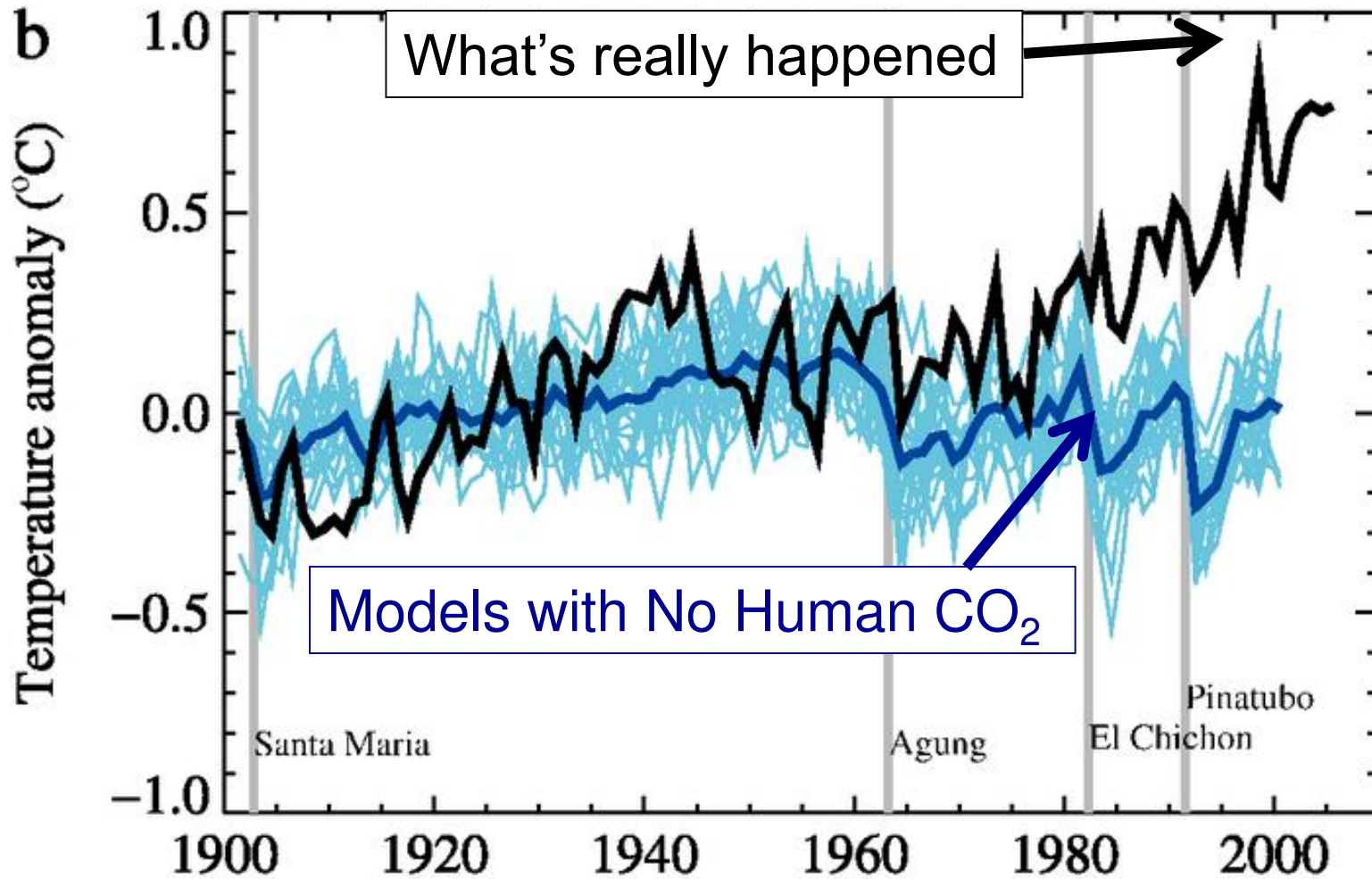


NH/VT has Warmed: 2-4°F since 1895

Winter is Warming the Fastest



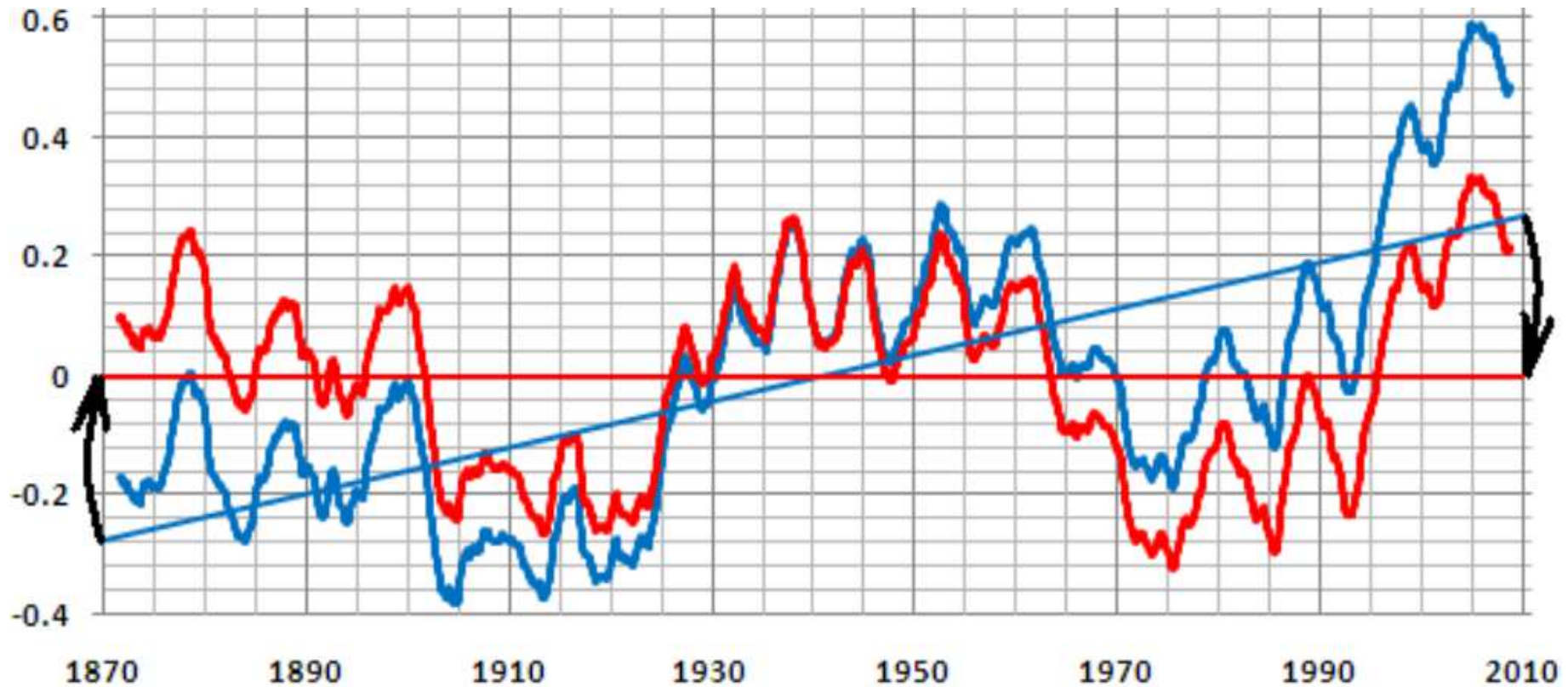
Warming since 1970 Can Only be Explained with Human Greenhouse Gases



Bottom Line: In order to explain temperature rise since ~ 1960 , one MUST include human CO_2 .

Not All the Atlantic Ocean Warming is from Human Activities

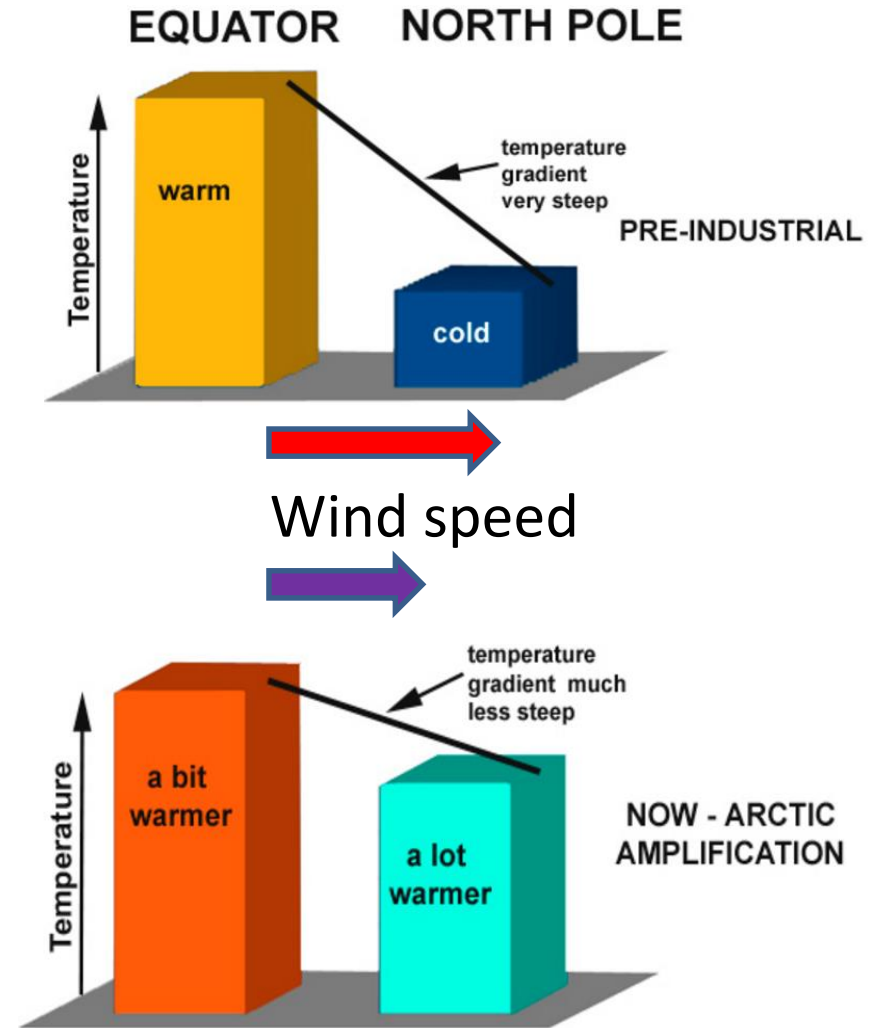
AMO vs. North Atlantic SST Anomalies



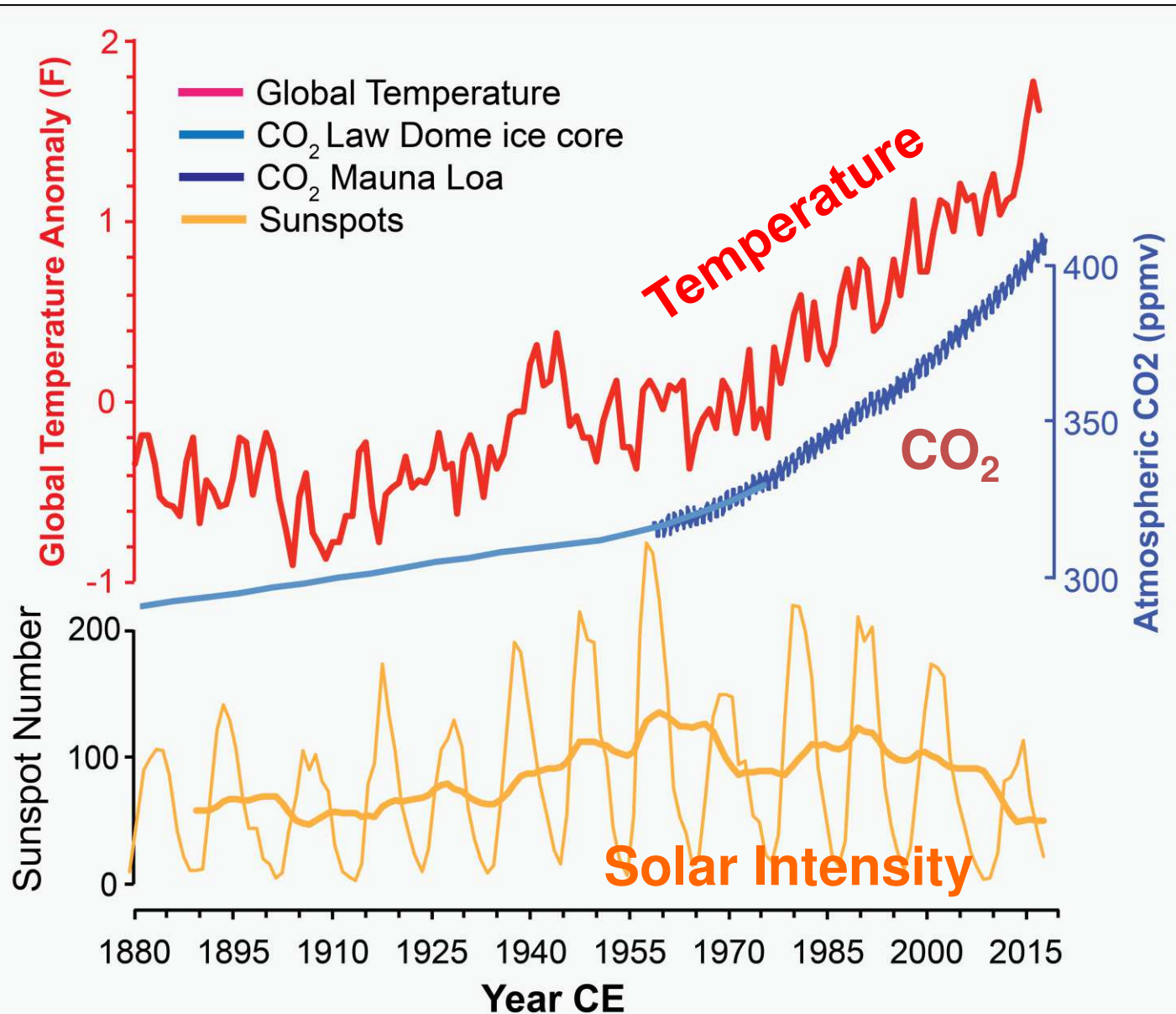
Arctic Amplification Causes Wavier Jet Stream?

Arctic Amplification(AA)
leads to decreased
pressure gradient and
weaker winds.

May cause wavier jet
stream and more
extreme thunderstorms
and Nor'Easters
(Francis and Vavrus 2012;
Cohen et al., 2018)



Solar Radiation Contributed to Early 20th Century Warming, but Sun has been Weakening since 1960



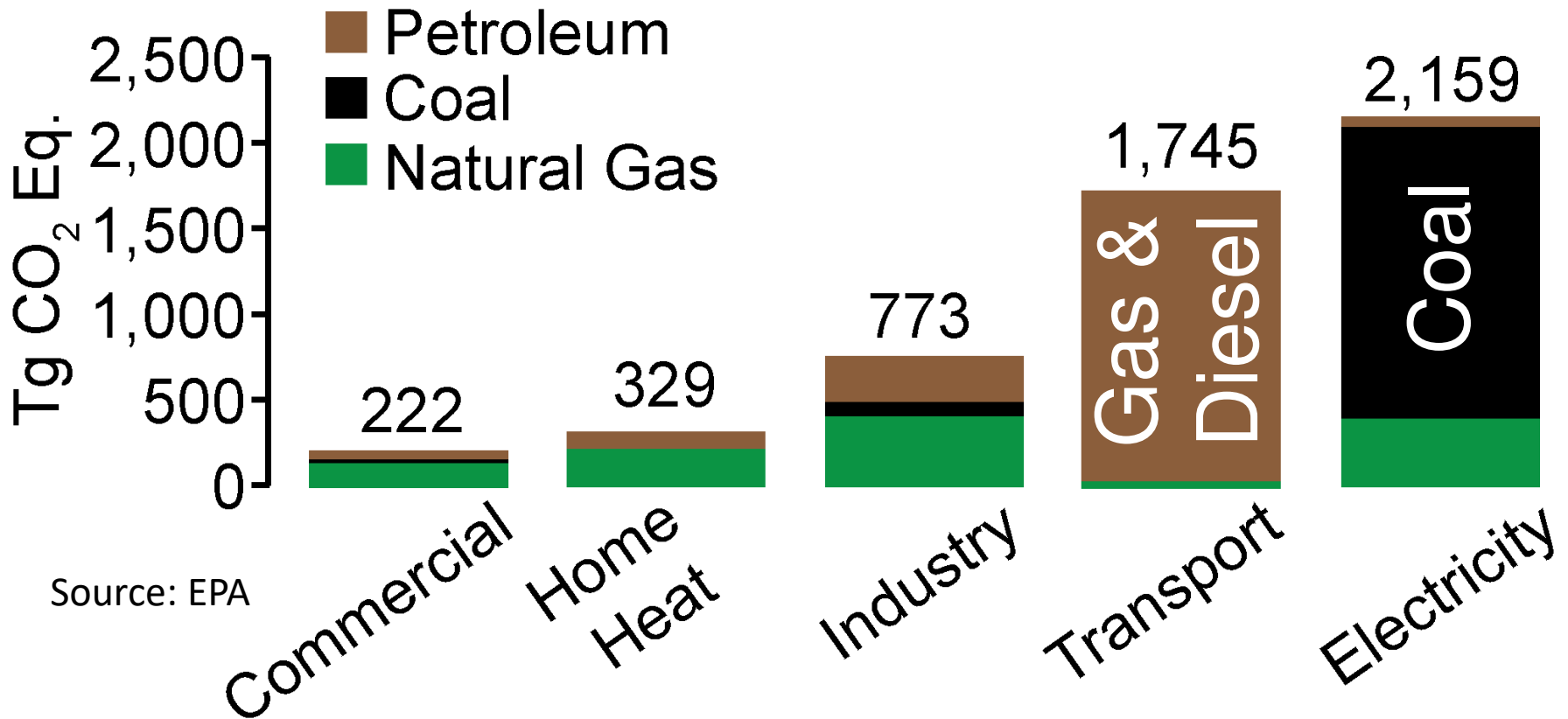
Warming since 1960 is NOT from the Sun!!

Solar radiation has been *declining* since 1960

Most CO₂ is from Electricity and Transportation

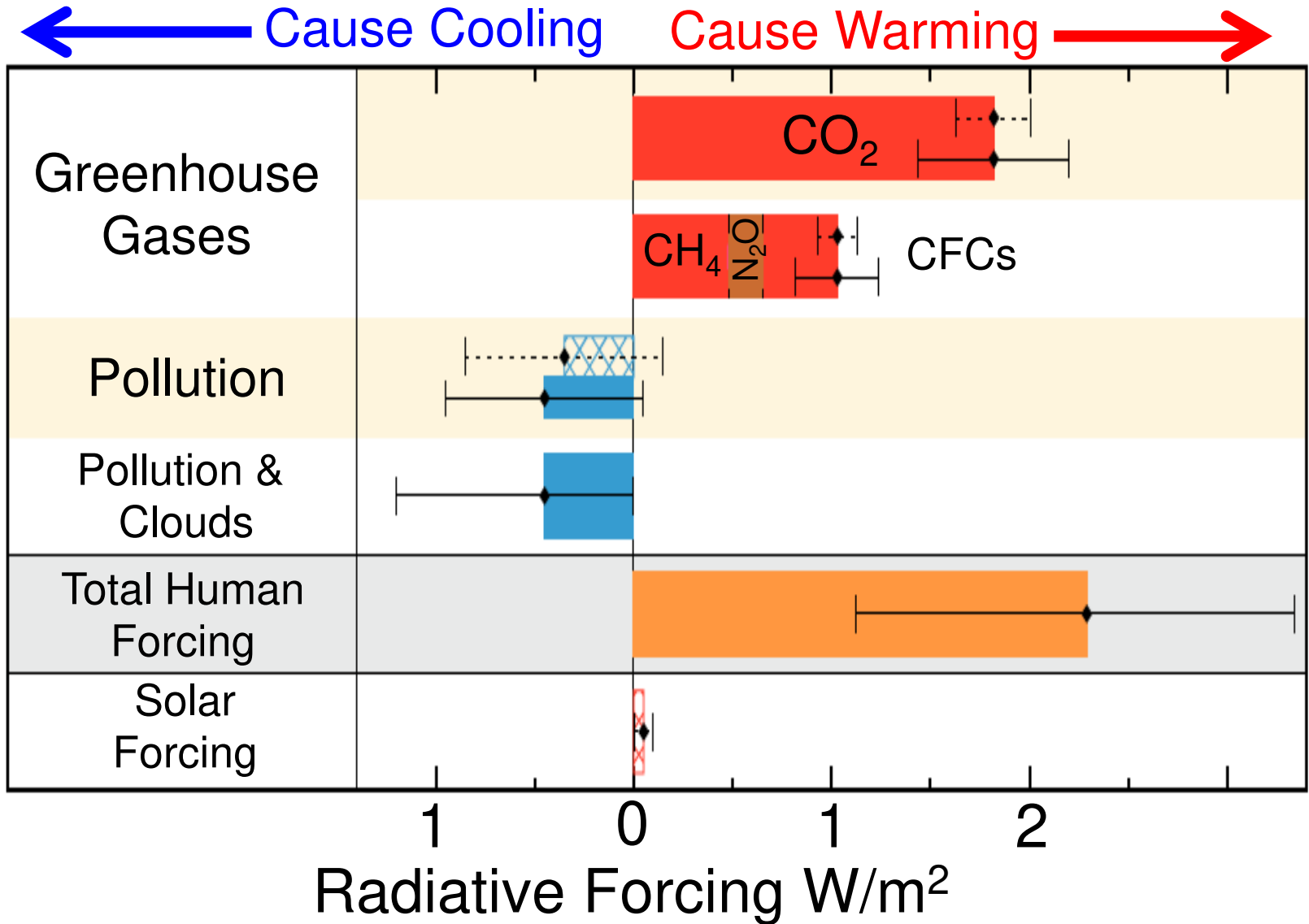
Coal produces 2x as much CO₂ per BTU as Natural Gas
Coal produces 1.5x as much CO₂ per BTU as Oil

US CO₂ Emissions by Source & Sector (2011)

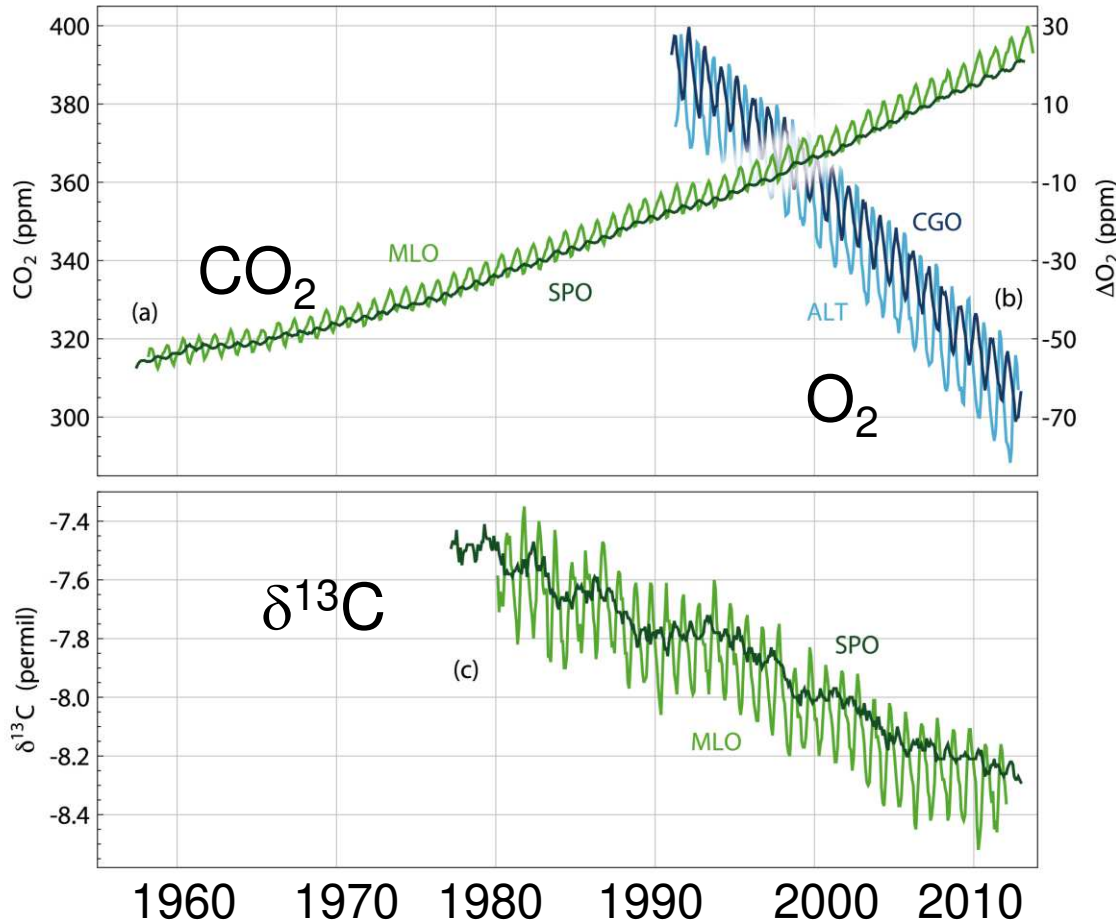


Source: EPA

Climate Forcing from 1750-2011



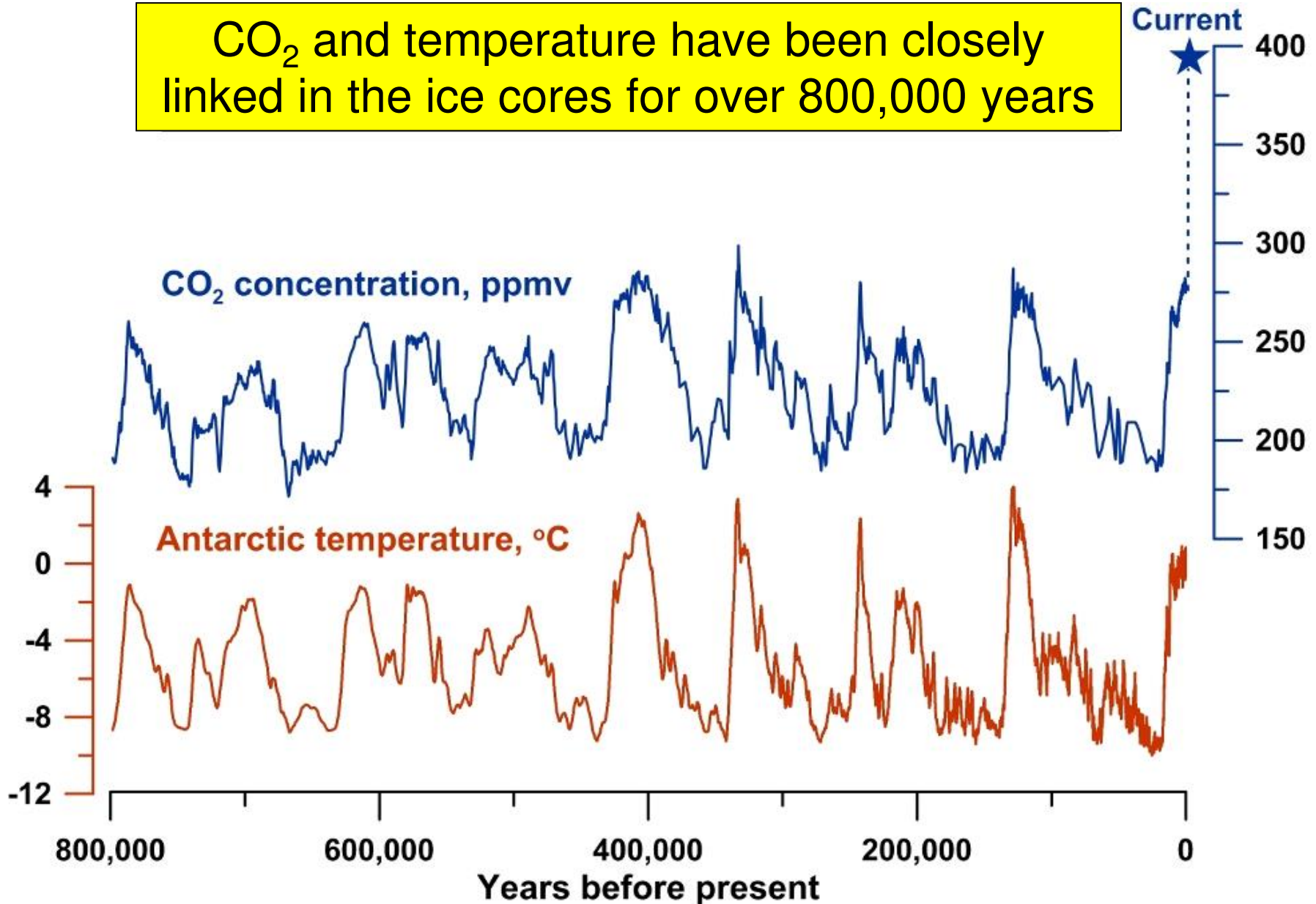
Some CO₂ Facts



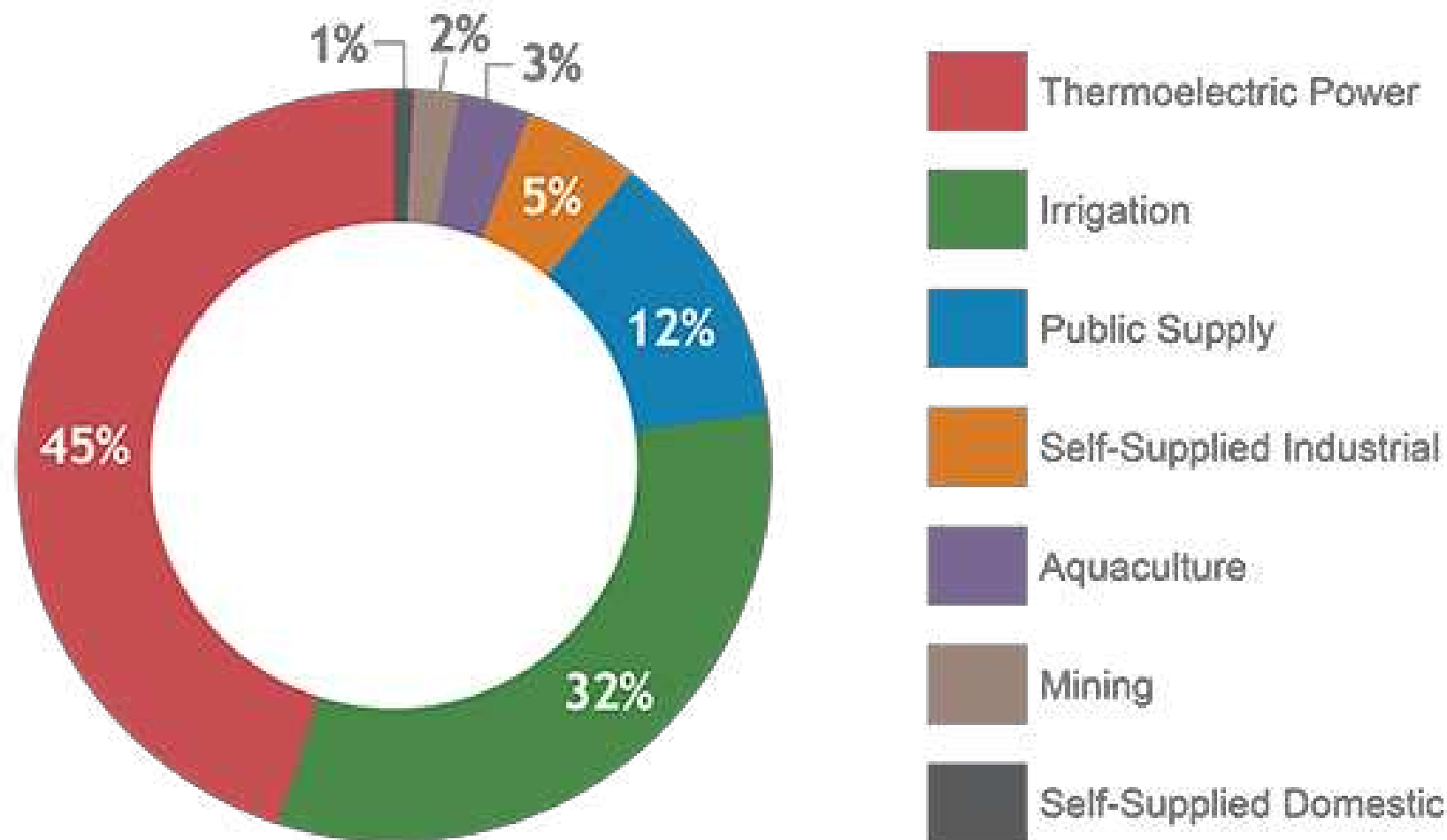
- Humans emit ***100+ TIMES*** more CO₂ than
- CO₂ has a fossil fuel chemical fingerprint
- CO₂ traps heat, raising temp.
- Without CO₂ Earth's average temp = -5°F!! (today = 57°F)

Temperature and CO₂ are Closely Linked

CO₂ and temperature have been closely linked in the ice cores for over 800,000 years



U.S. Freshwater Withdrawals (2010)



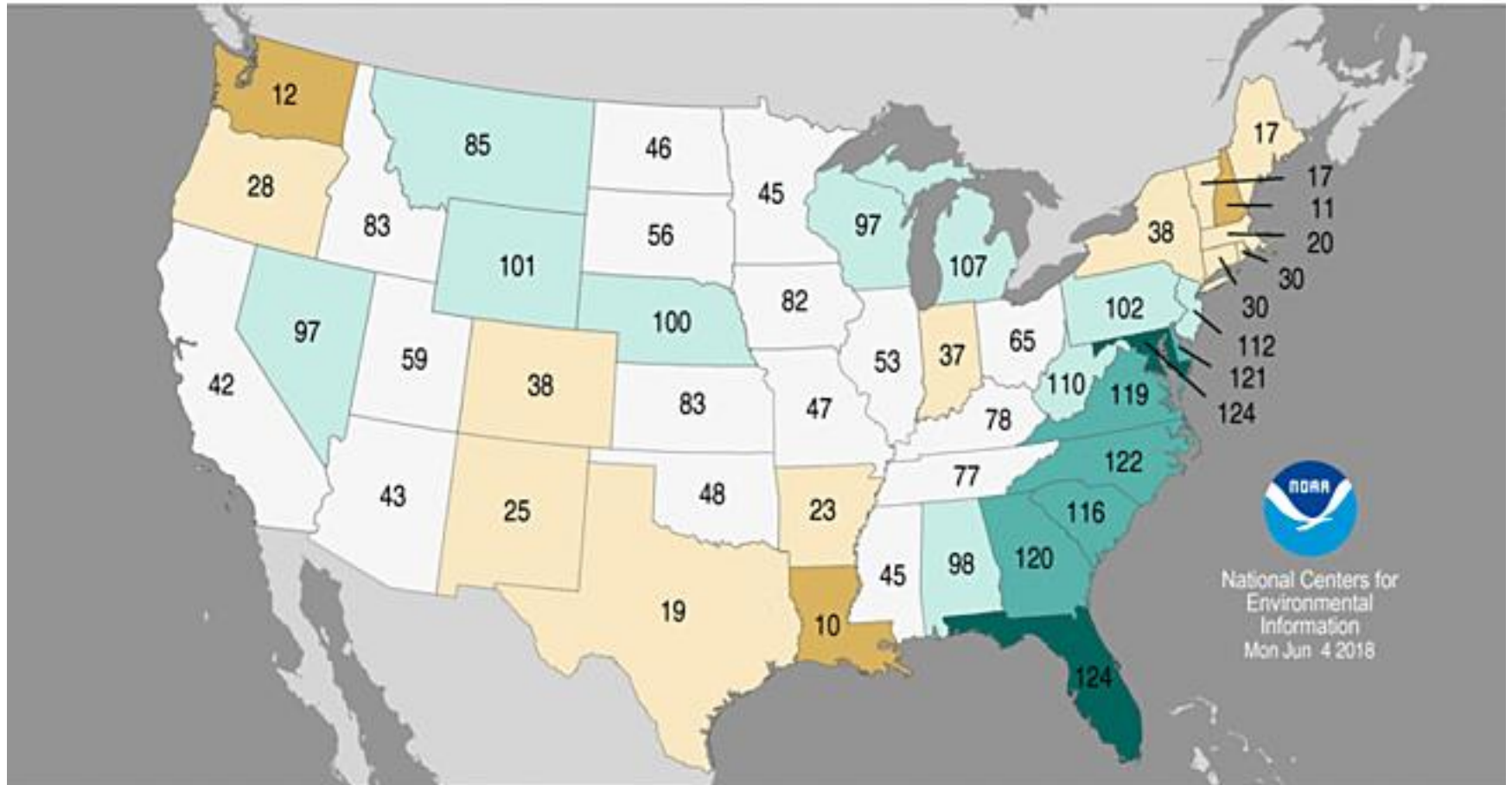
*Livestock is approximately less than 1% of total use and is not included.

*Data comes from Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2014, Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405, 56 p., <http://dx.doi.org/10.3133/cir1405>.

Statewide Precipitation Ranks

May 2018

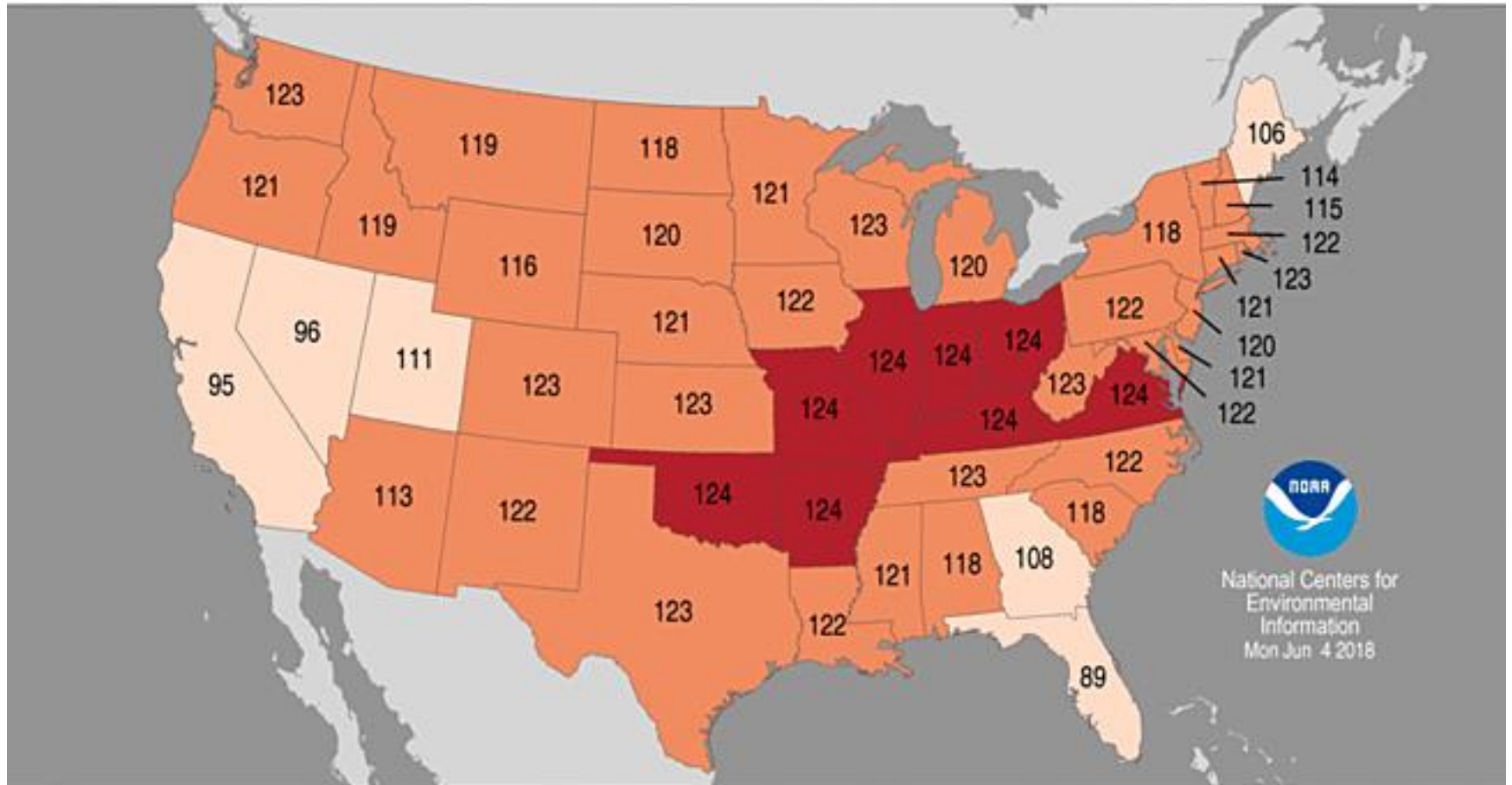
Period: 1895–2018



Statewide Average Temperature Ranks

May 2018

Period: 1895–2018



National Centers for
Environmental
Information
Mon Jun 4 2018

Record
Coldest
(1)

Much
Below
Average

Below
Average

Near
Average

Above
Average

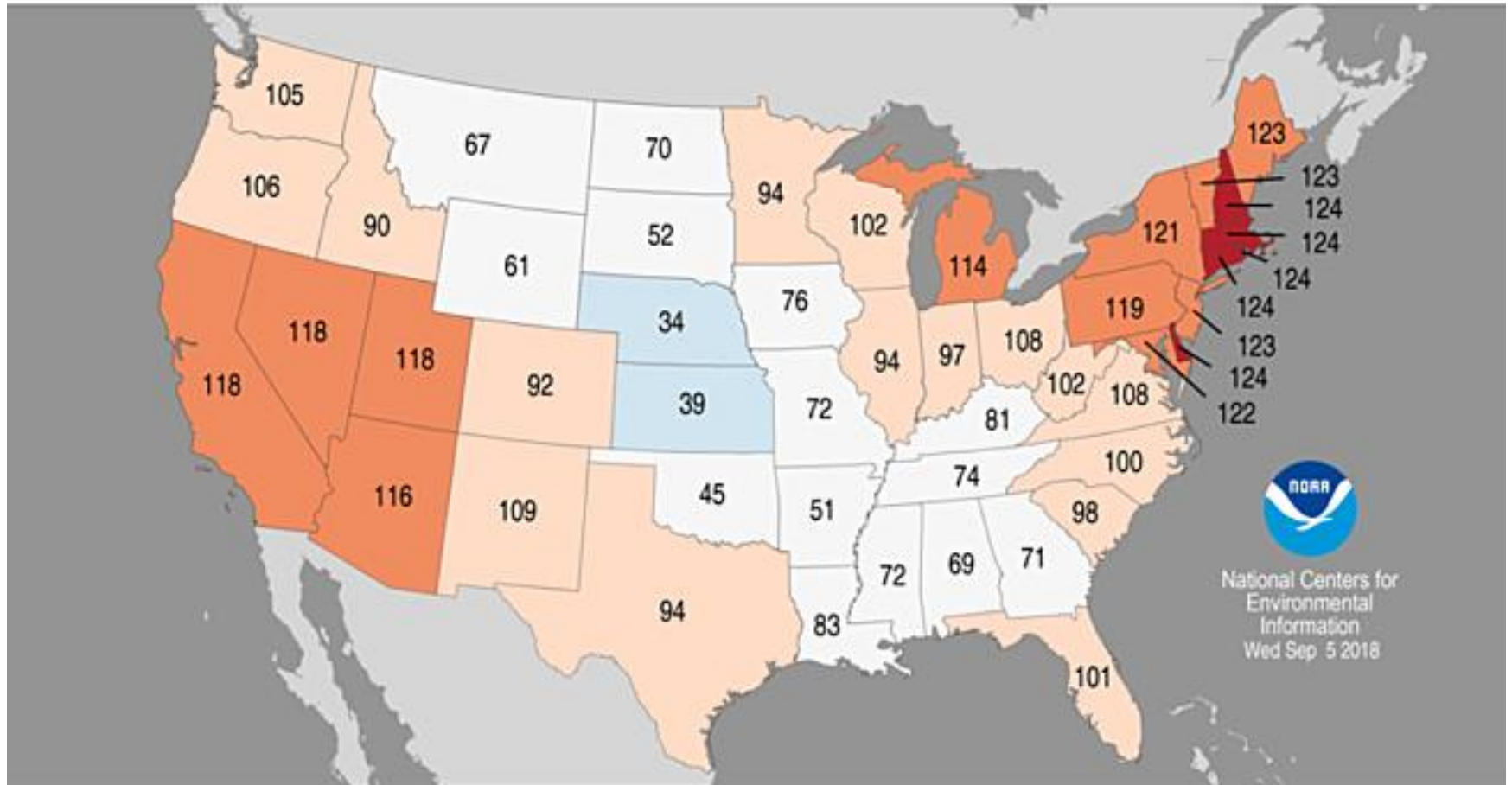
Much
Above
Average

Record
Warmest
(124)

Statewide Average Temperature Ranks

August 2018

Period: 1895-2018



National Centers for
Environmental
Information
Wed Sep 5 2018

Record
Coldest
(1)

Much
Below
Average

Below
Average

Near
Average

Above
Average

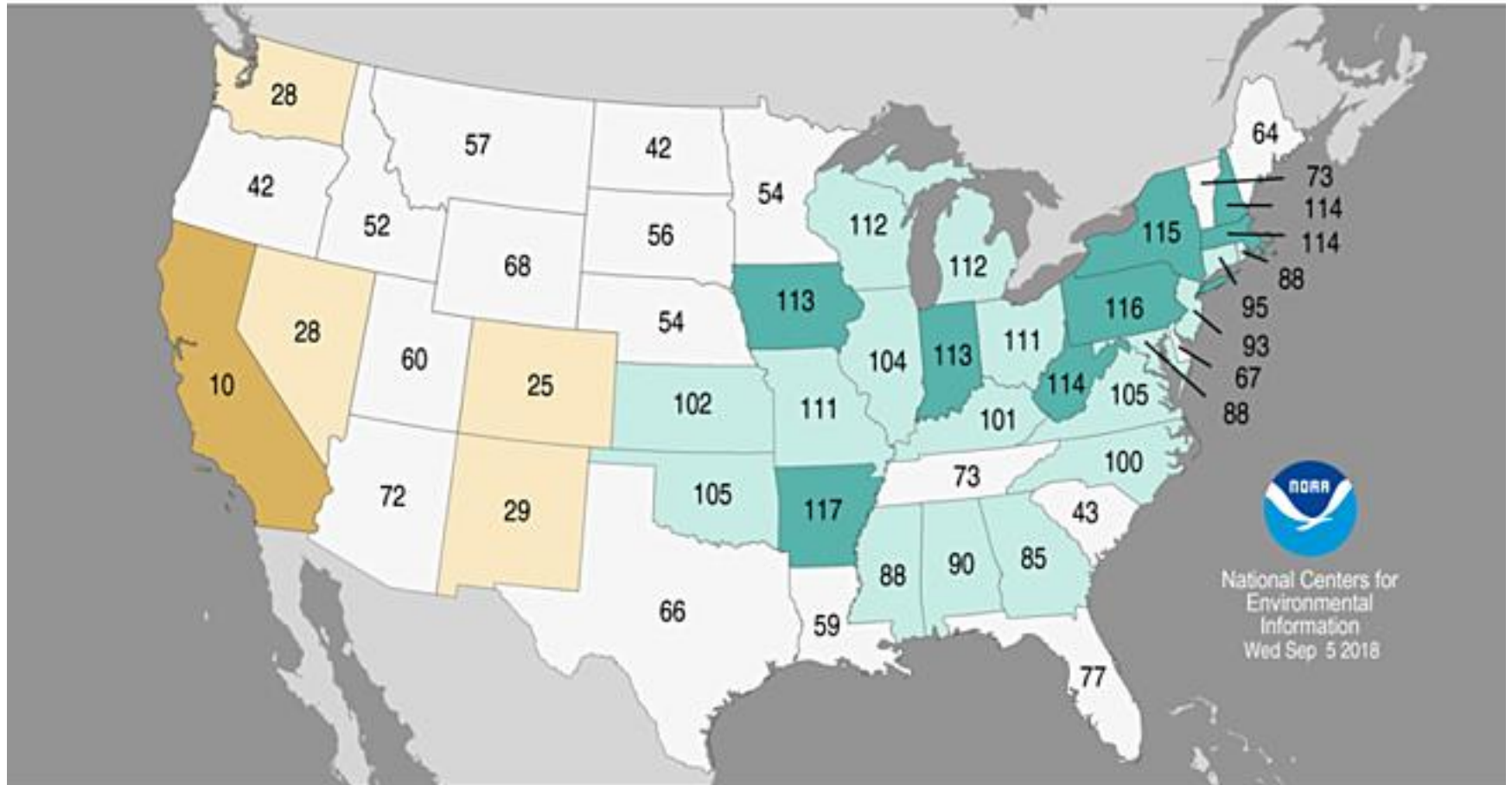
Much
Above
Average

Record
Warmest
(124)

Statewide Precipitation Ranks

August 2018

Period: 1895–2018

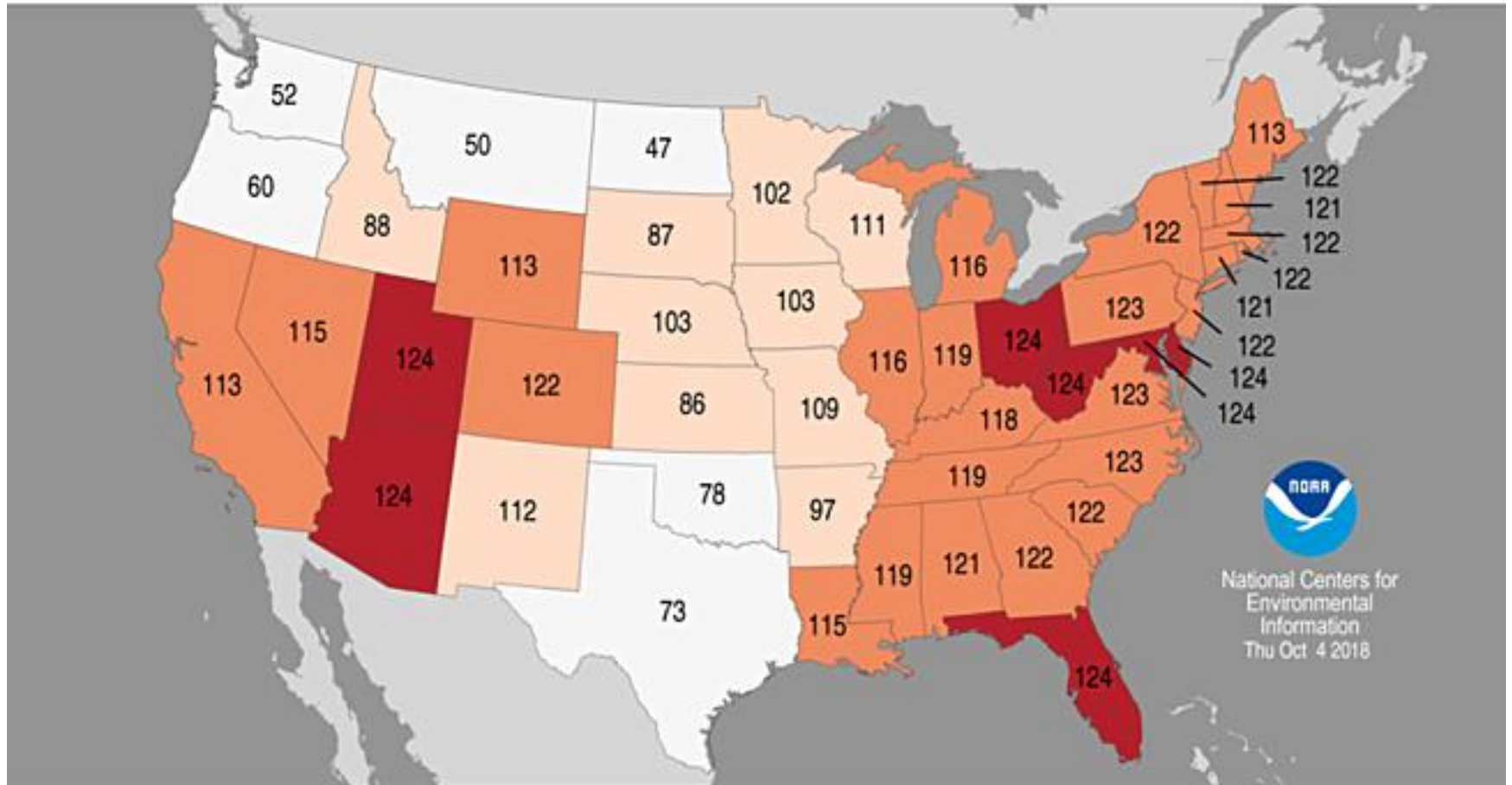


National Centers for
Environmental
Information
Wed Sep 5 2018

Statewide Average Temperature Ranks

September 2018

Period: 1895–2018



National Centers for
Environmental
Information
Thu Oct 4 2018

Record
Coldest
(1)

Much
Below
Average

Below
Average

Near
Average

Above
Average

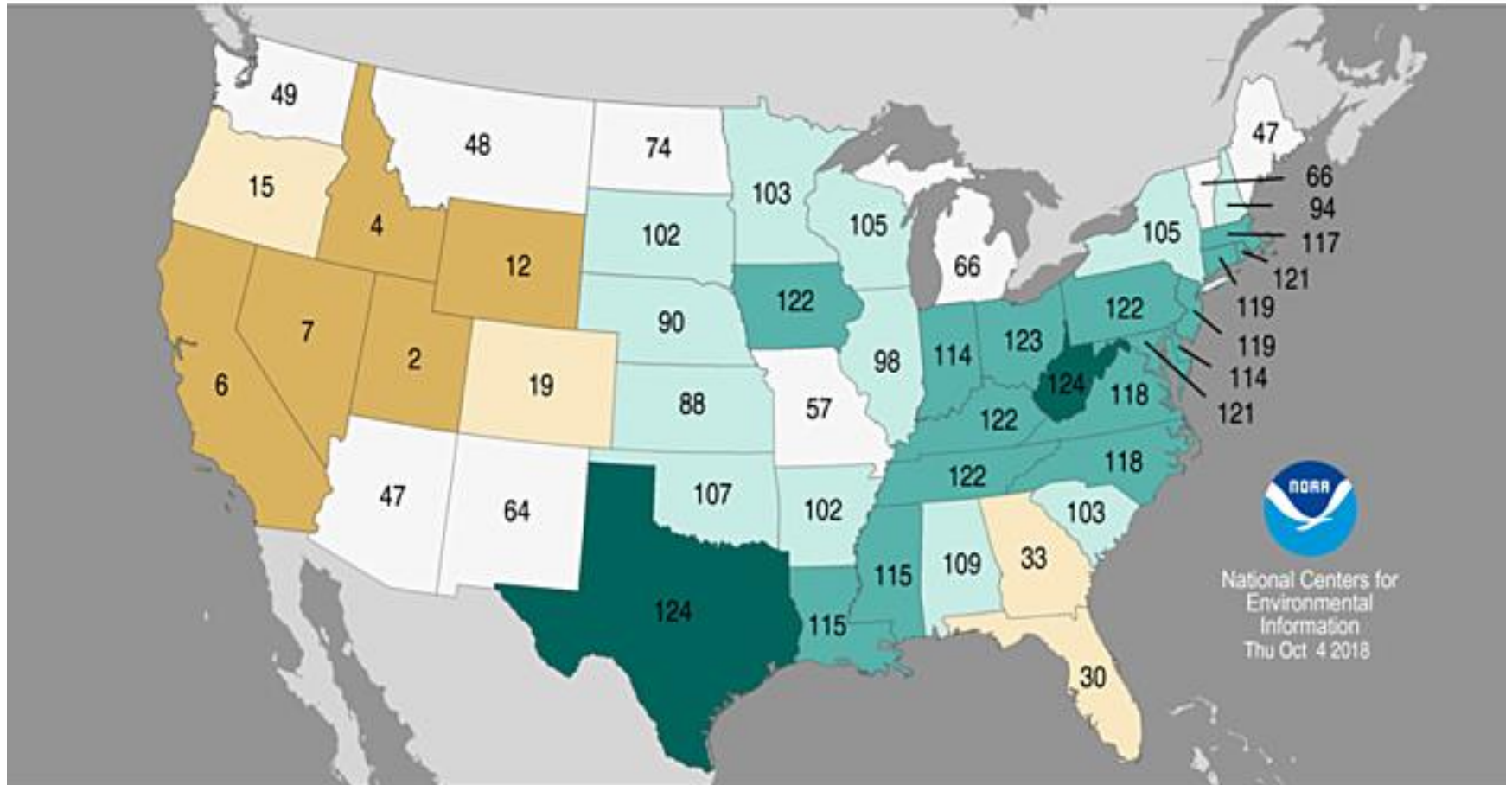
Much
Above
Average

Record
Warmest
(124)

Statewide Precipitation Ranks

September 2018

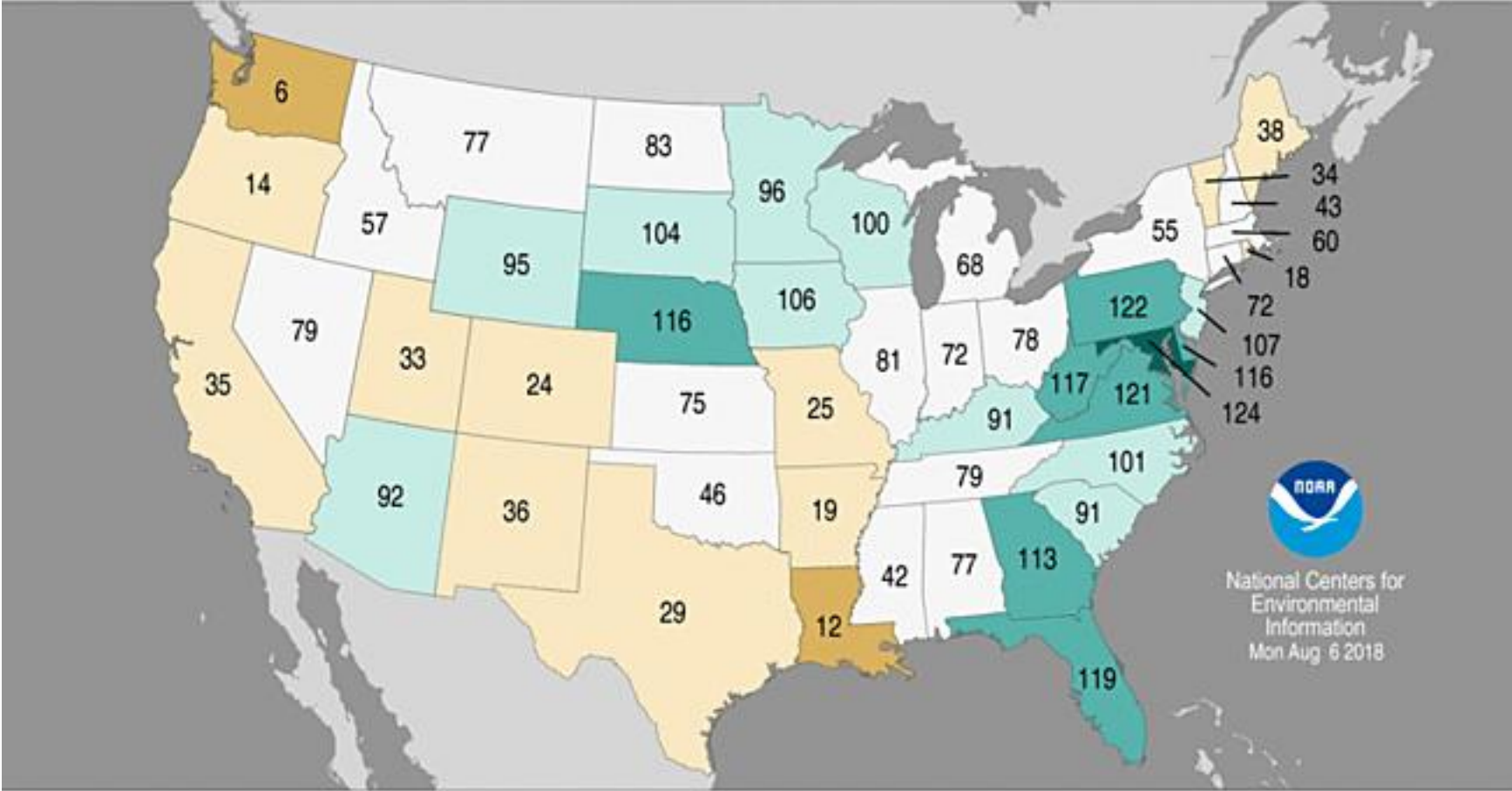
Period: 1895–2018



Statewide Precipitation Ranks

May–July 2018

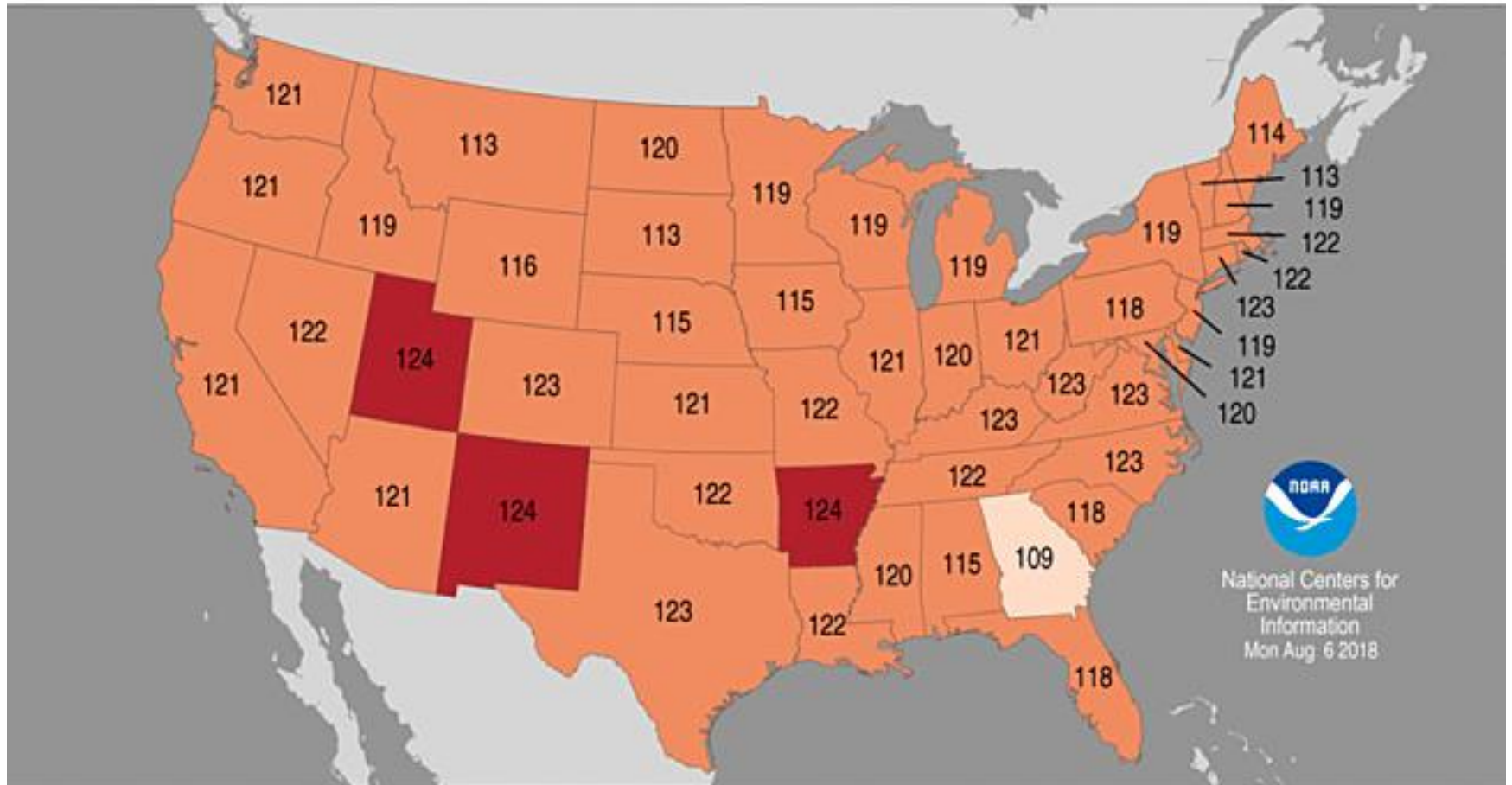
Period: 1895–2018



Statewide Average Temperature Ranks

May–July 2018

Period: 1895–2018



National Centers for
Environmental
Information
Mon Aug 6 2018

Record
Coldest
(1)

Much
Below
Average

Below
Average

Near
Average

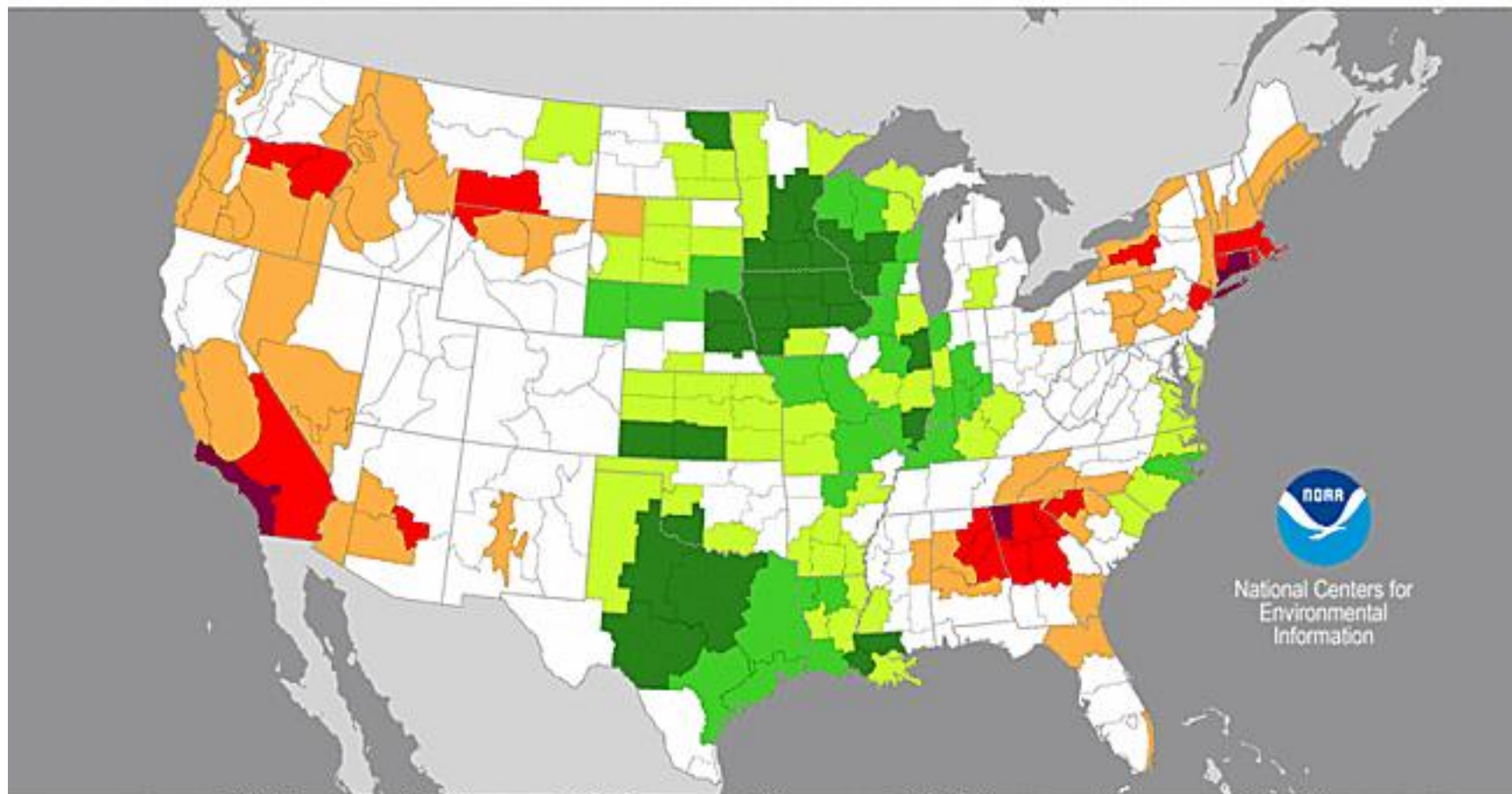
Above
Average

Much
Above
Average

Record
Warmest
(124)

Palmer Drought Severity Index

September, 2016



National Centers for
Environmental
Information

extreme
drought



-4.00
and
below

severe
drought



-3.00
to
-3.99

moderate
drought



-2.00
to
-2.99

mid-
range



-1.99
to
+1.99

moderately
moist



+2.00
to
+2.99

very
moist



+3.00
to
+3.99

extremely
moist

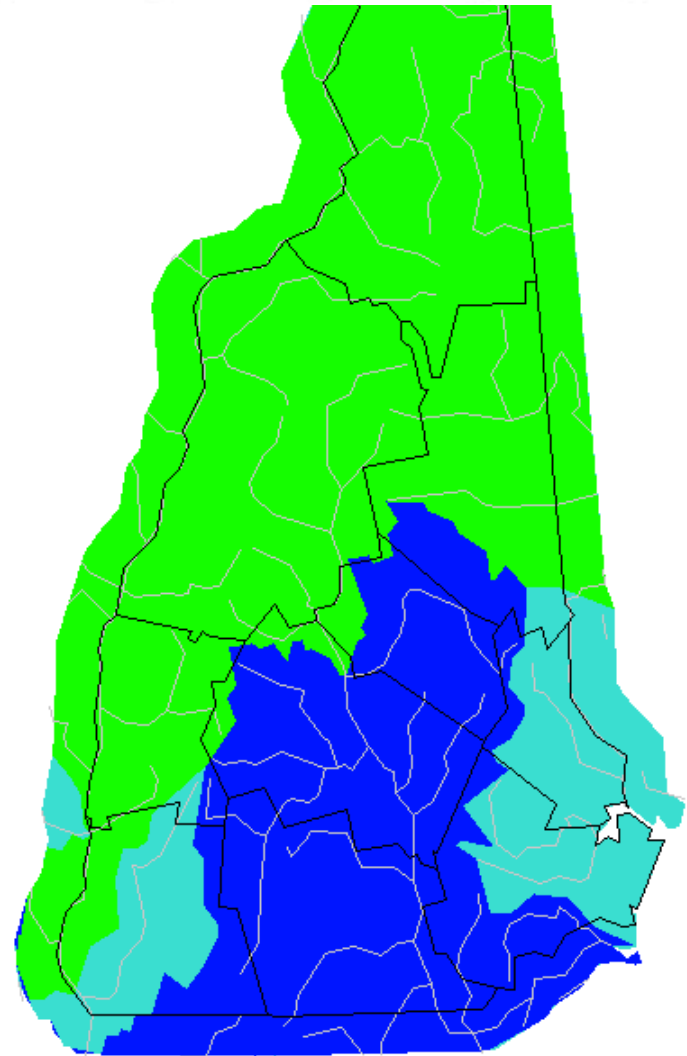
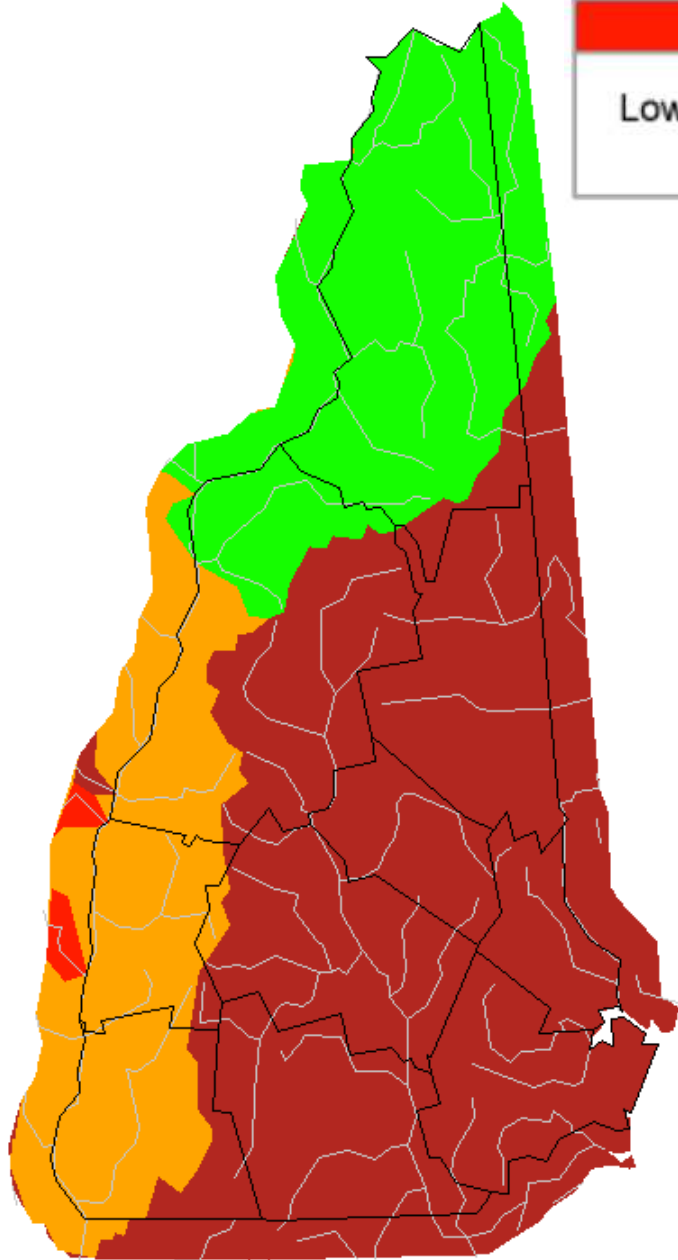


+4.00
and
above

September 2016

Explanation - Percentile classes

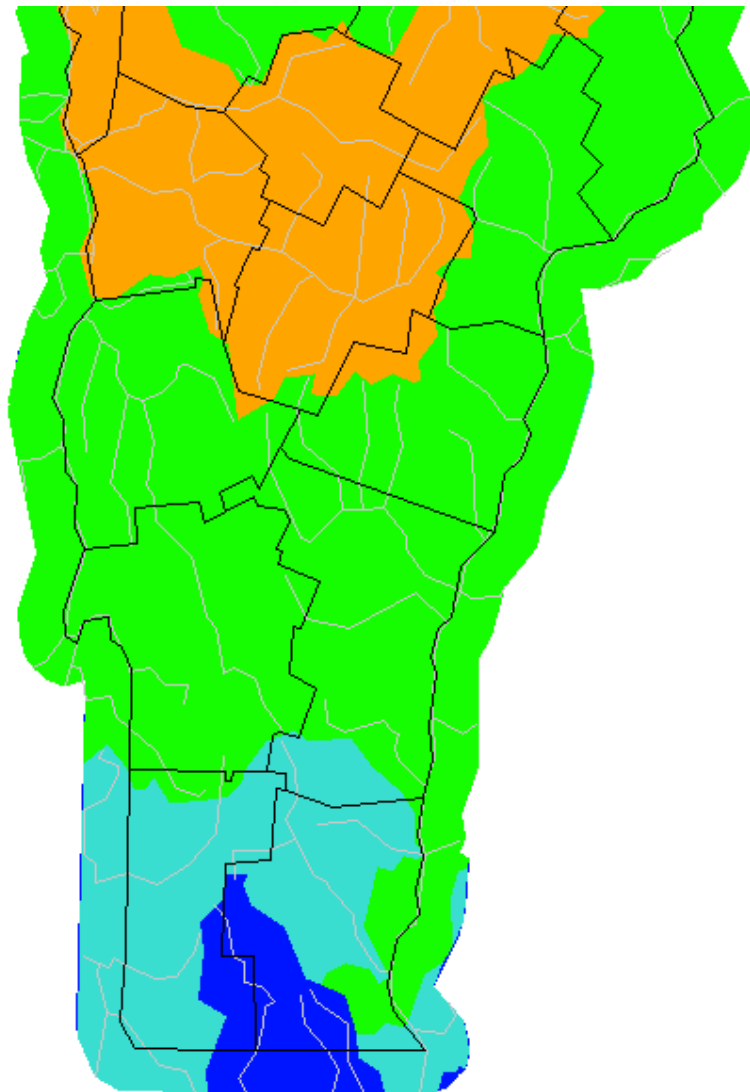
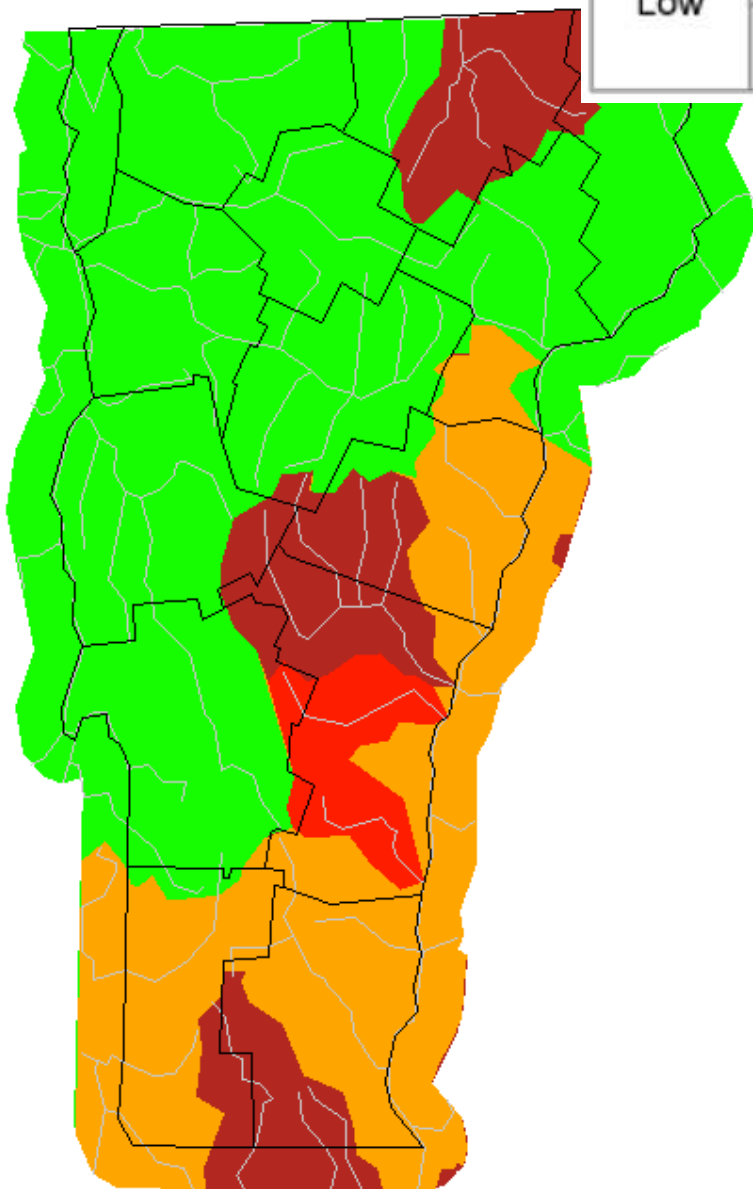
Low	<10	10-24	25-75	76-90	>90	High	No Data
	Much below normal	Below normal	Normal	Above normal	Much above normal		



September 2016

Explanation - Percentile classes

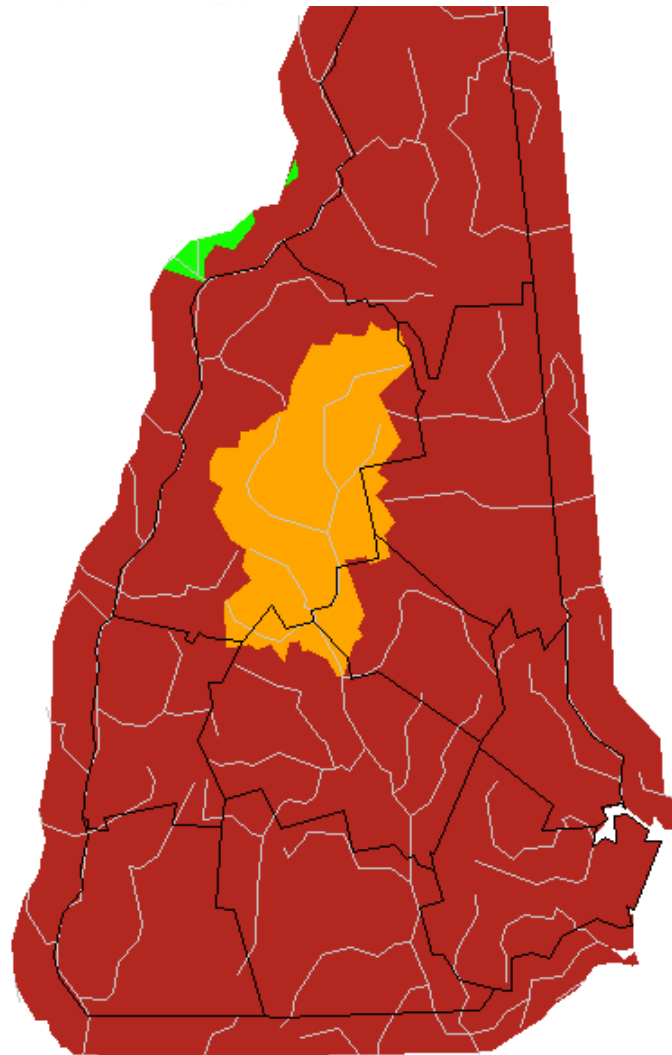
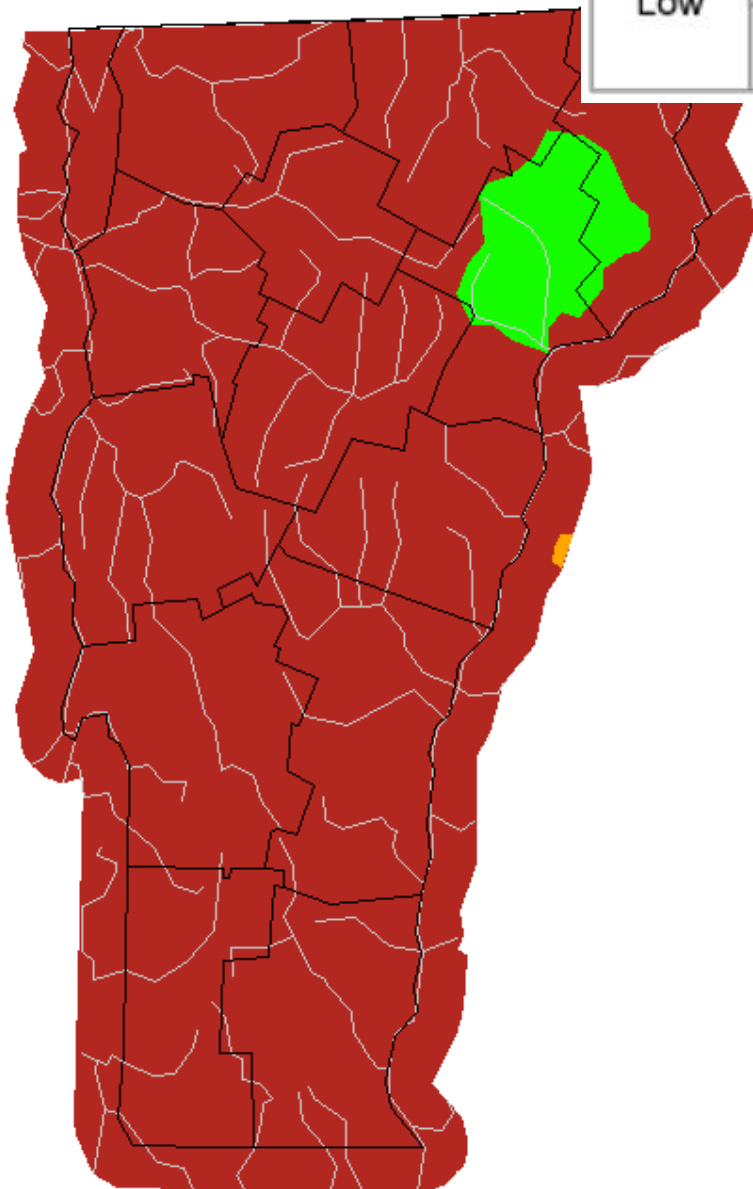
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	Much below normal	Below normal	Normal	Above normal	Much above normal		



July 1965

Explanation - Percentile classes

							
Low	<10	10-24	25-75	76-90	>90	High	No Data
	Much below normal	Below normal	Normal	Above normal	Much above normal		



Category	Description	Possible Impacts
D0	Abnormally Dry	<p>Going into drought:</p> <ul style="list-style-type: none"> ▪ short-term dryness slowing planting, growth of crops or pastures <p>Coming out of drought:</p> <ul style="list-style-type: none"> ▪ some lingering water deficits ▪ pastures or crops not fully recovered
D1	Moderate Drought	<ul style="list-style-type: none"> ▪ Some damage to crops, pastures ▪ Streams, reservoirs, or wells low, some water shortages developing or imminent ▪ Voluntary water-use restrictions requested
D2	Severe Drought	<ul style="list-style-type: none"> ▪ Crop or pasture losses likely ▪ Water shortages common ▪ Water restrictions imposed
D3	Extreme Drought	<ul style="list-style-type: none"> ▪ Major crop/pasture losses ▪ Widespread water shortages or restrictions
D4	Exceptional Drought	<ul style="list-style-type: none"> ▪ Exceptional and widespread crop/pasture losses ▪ Shortages of water in reservoirs, streams, and wells creating water emergencies

Hurricane Irene: August, 2011



~50% of the jump since 1996 is from MORE hurricane events with warmer ocean waters and higher water vapor

July 2013 & 2017 Thunderstorms

+3" Rain for Each Event

Route 25A • Orford, N.H.
July 1, 2017 • Courtesy Peter Bouchard



~25% of the jump
since 1996 is from
MORE T's storm evens
with wavier jetstream



Type of Use	Gallons per Capita	Percentage of Total Daily Use
Showers	8.8	19.5%
Clothes Washers	10.0	22.1%
Toilets	8.2	18.0%
Dishwashers	0.7	1.5%
Baths	1.2	2.7%
Leaks	4.0	8.8%
Faucets	10.8	23.9%
Other Domestic Uses	1.6	3.4%

Source: [Handbook of Water Use and Conservation](#), Amy Vickers