

# 2017 Extreme Events

Water Utility Climate Alliance  
St. Simons, GA  
October 18, 2017

Brad Udall  
Colorado Water Institute  
Colorado State University  
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@bradudall

La Tuna Fire, 2017

# Extreme Events

- Hurricanes
- Heat Waves
- Fires
- Floods

Higher Temps cause

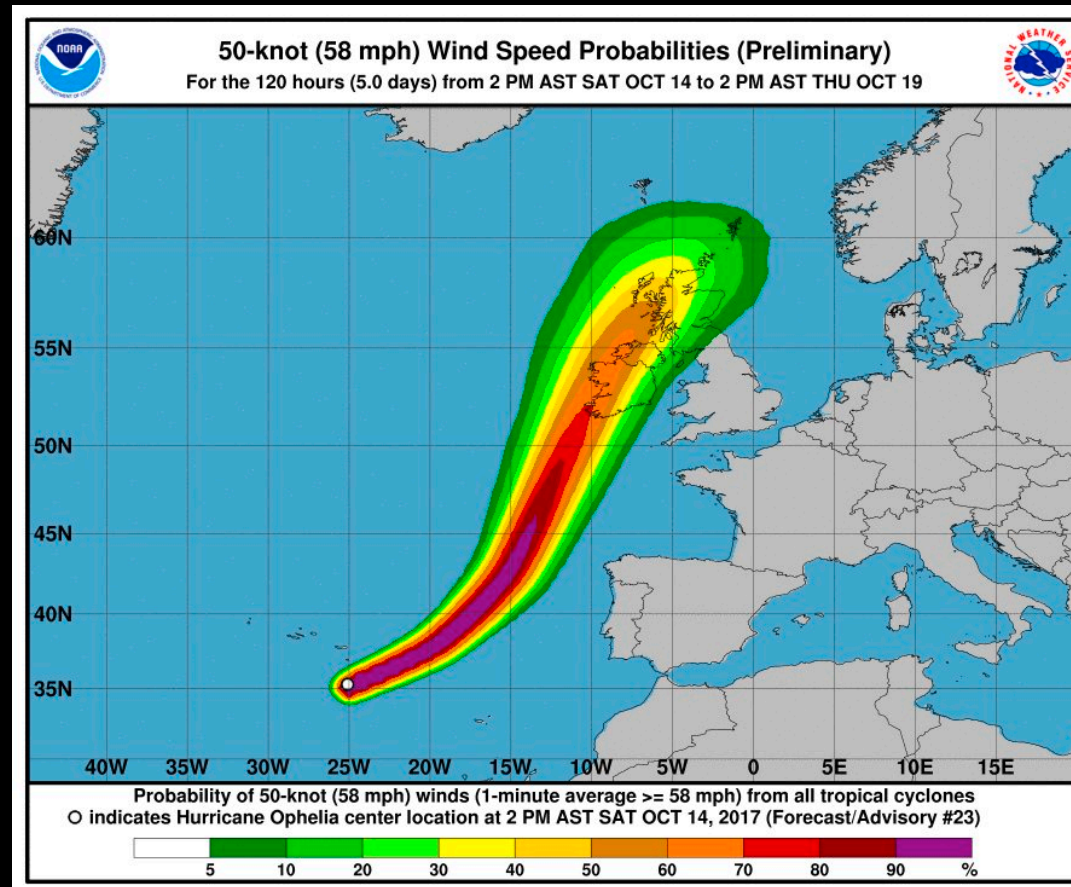
More drying (heat waves, fires)

More precipitation (floods, hurricanes)

Higher Sea Surface Temperatures (more intense hurricanes)

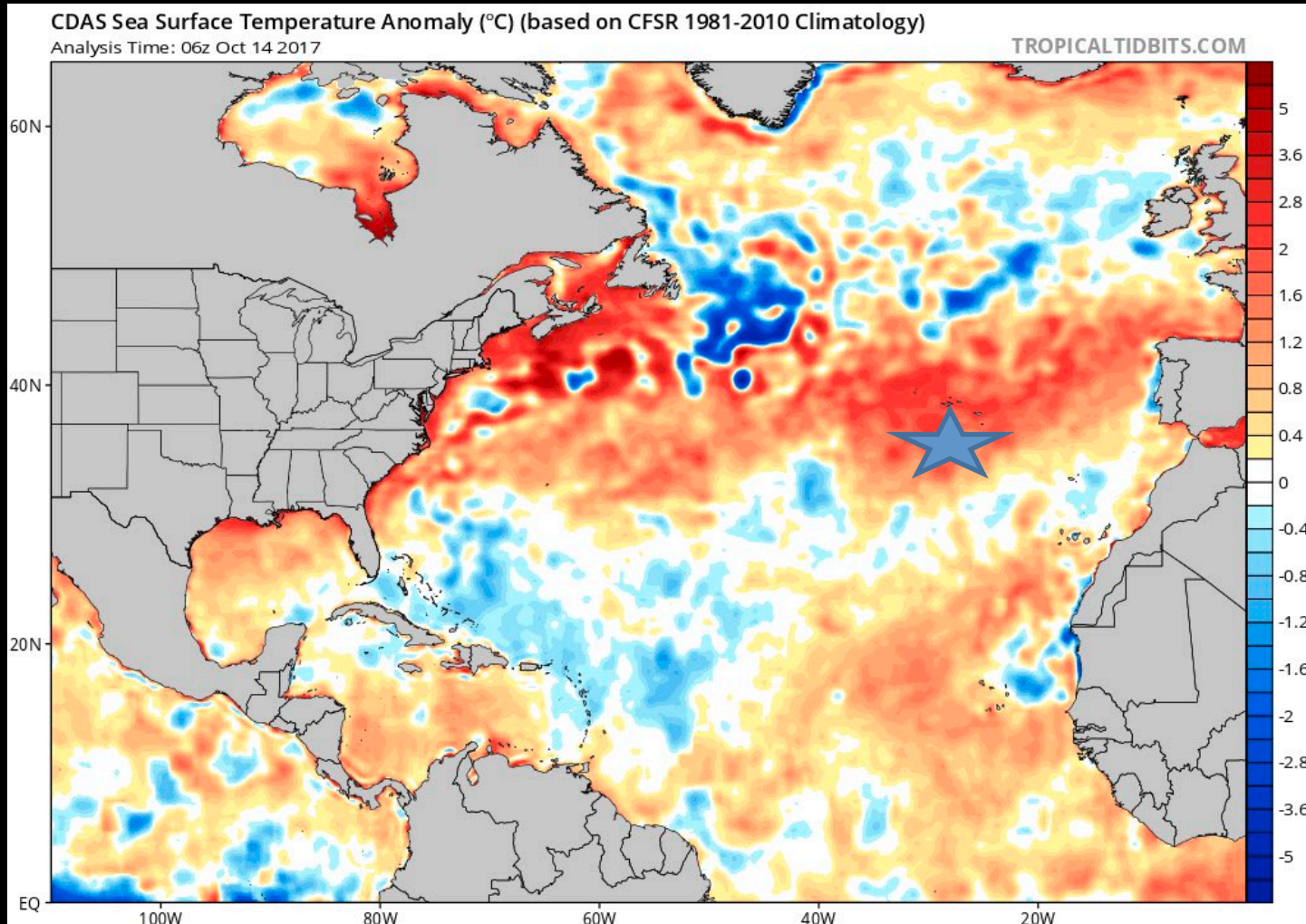
Changes in atmospheric circulation (heat waves, fires, floods)

## Hurricane Ophelia

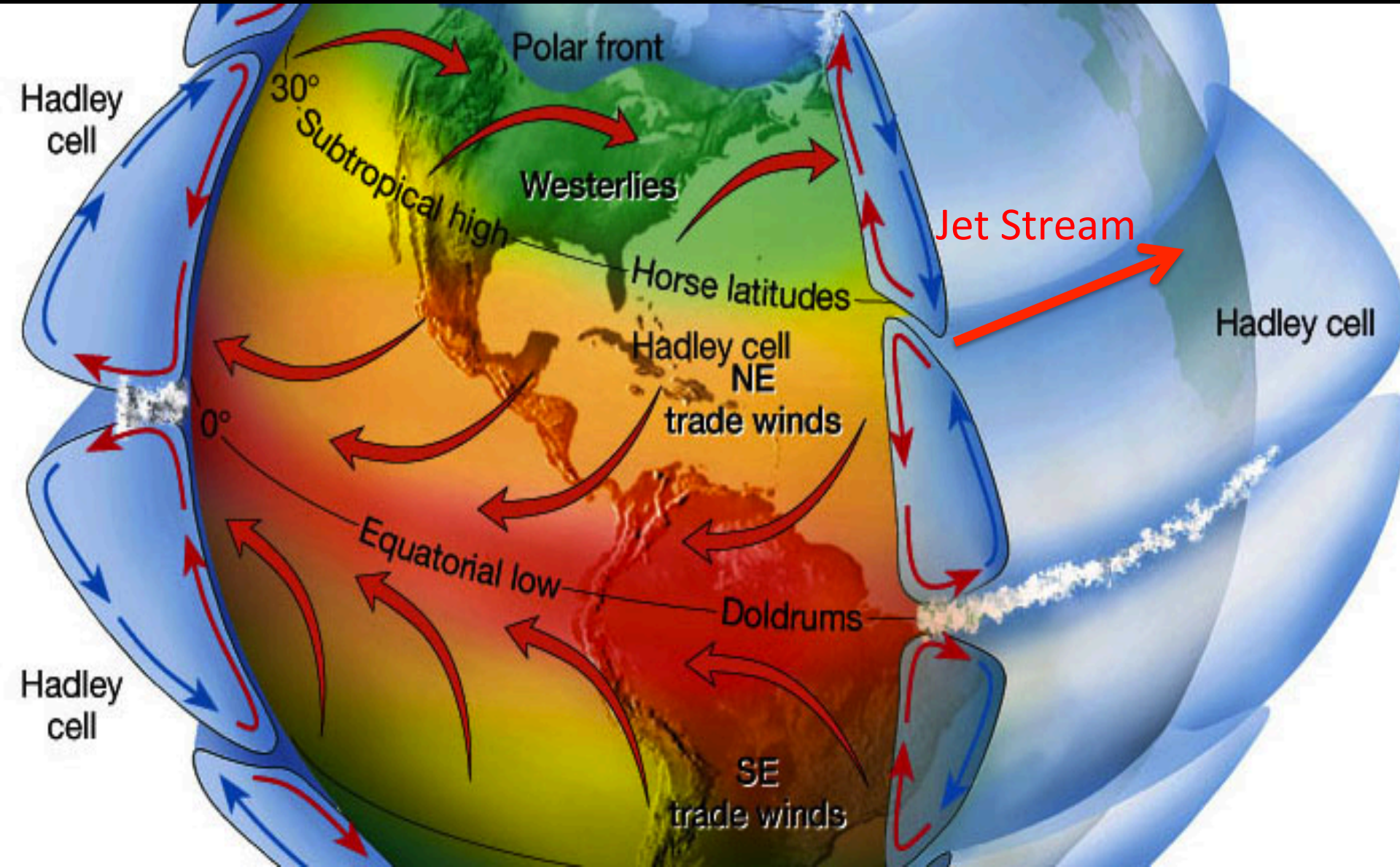




# Ophelia's High Sea Surface Temps



# Expanding Hadley Cells

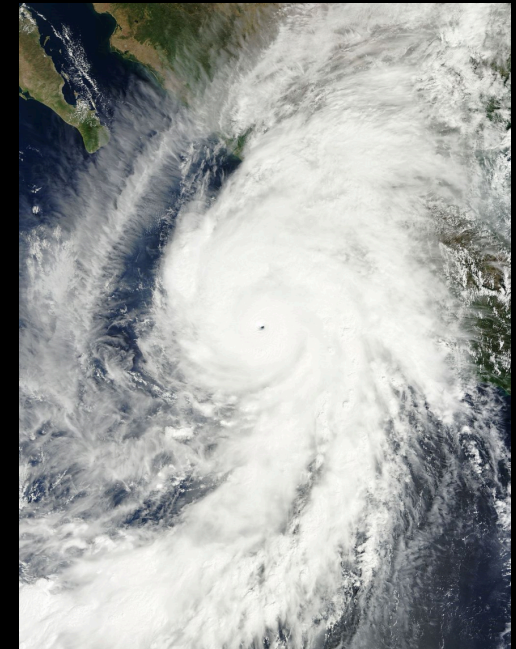




# Recent Hurricanes

- 2017 Season
  - 10 weeks of 10 hurricanes
- Matthew, 2016
  - October Records
- Patricia, 2015
  - 220 mph

Hurricane Patricia,  
October 2015  
215 mph winds



## 2017 Atlantic Hurricanes

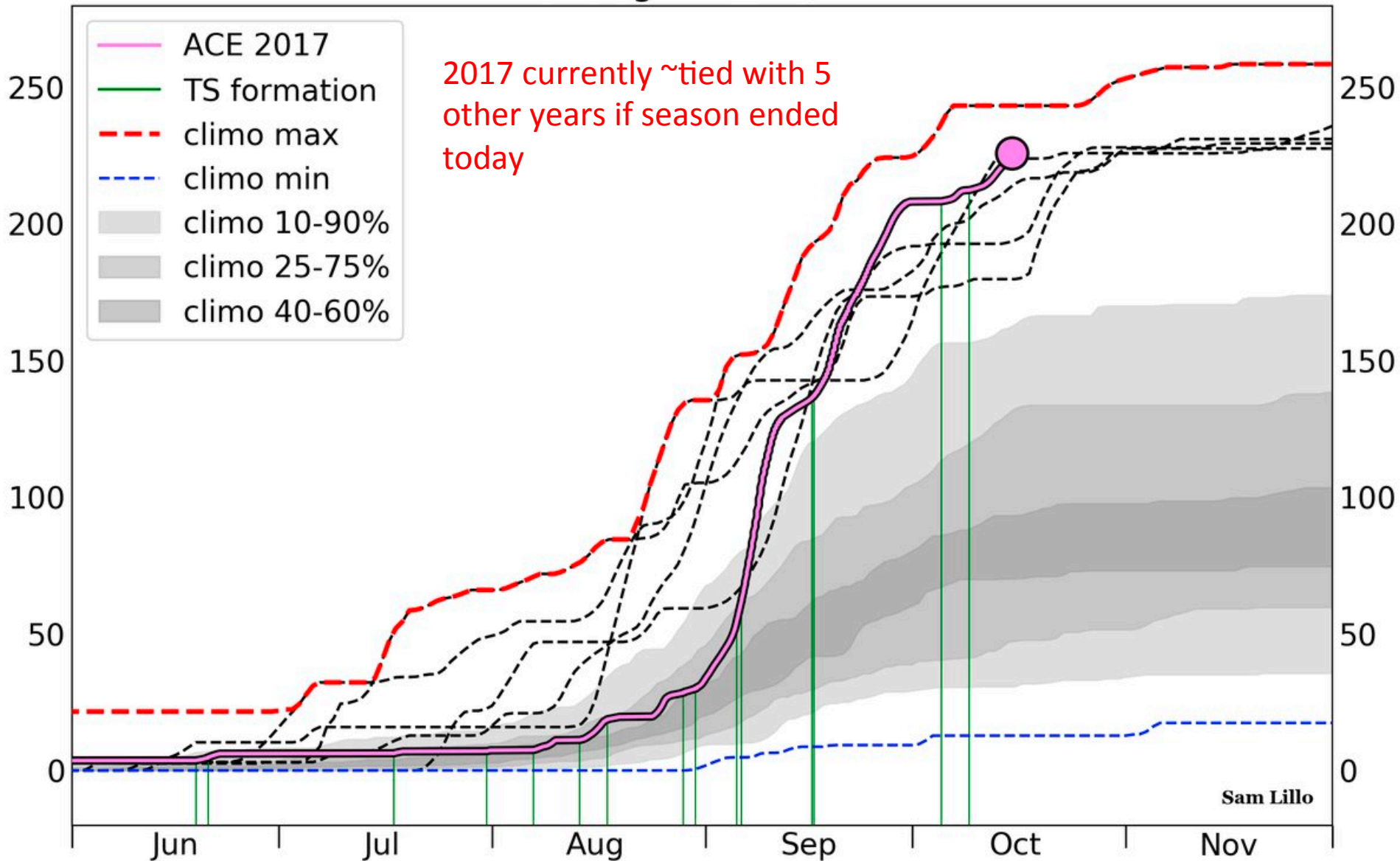
Category 1	Category 2	Category 3	Category 4	Category 5
Franklin (85 mph)	Gert (105 mph)	Lee (115 mph)	Harvey (130 mph)	Irma (185 mph)
Nate (90 mph)	Katia (105 mph)	Ophelia (115 mph)	Jose (155 mph)	Maria (175 mph)

# Hurricanes: Consensus Science

- Indisputable Science
  - Sea Level Rise
    - contributes to coastal flooding and storm surge
  - Warmer Sea Surface Temperatures
    - Strongest storms are getting stronger from higher sea surface temperatures
  - More moisture in the atmosphere
    - means more rainfall
    - more intense rainfall
- Under Consideration
  - Slow moving nature of Harvey might have been due to expanded High Pressure zone and further north Jet Stream
  - Rapid Intensification
  - Fewer Category 1-2 and more Category 3-5?
- Not Known
  - How storm frequency will change – more or fewer hurricanes?

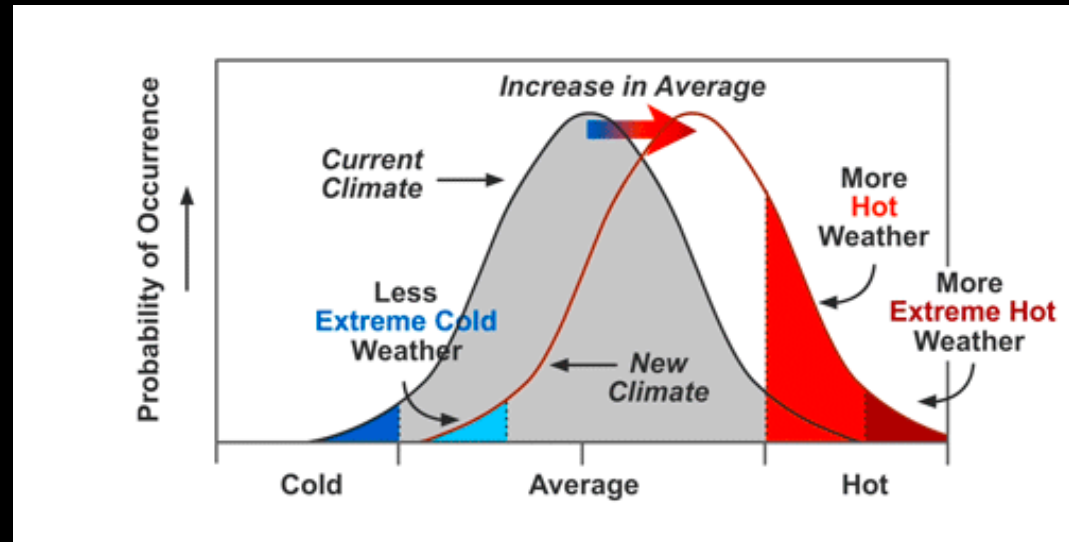


# 2017 Atlantic Accumulated Cyclone Energy through 12z 10/15



# Recent Heat Waves

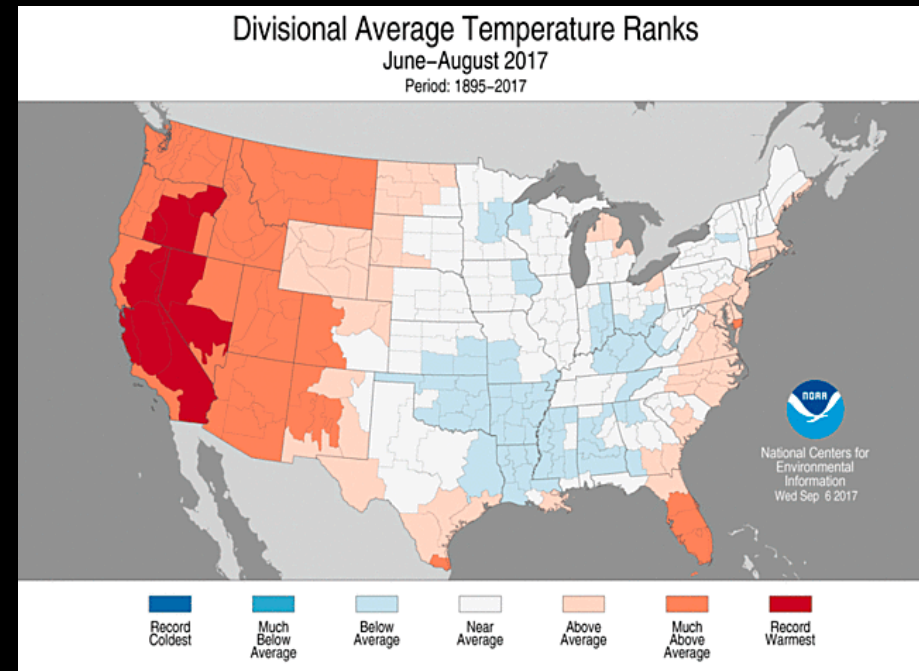
- Southwest, June 2017
- Pacific Northwest, August 2017
- Northeast, Fall 2017
- Colorado, March 2017



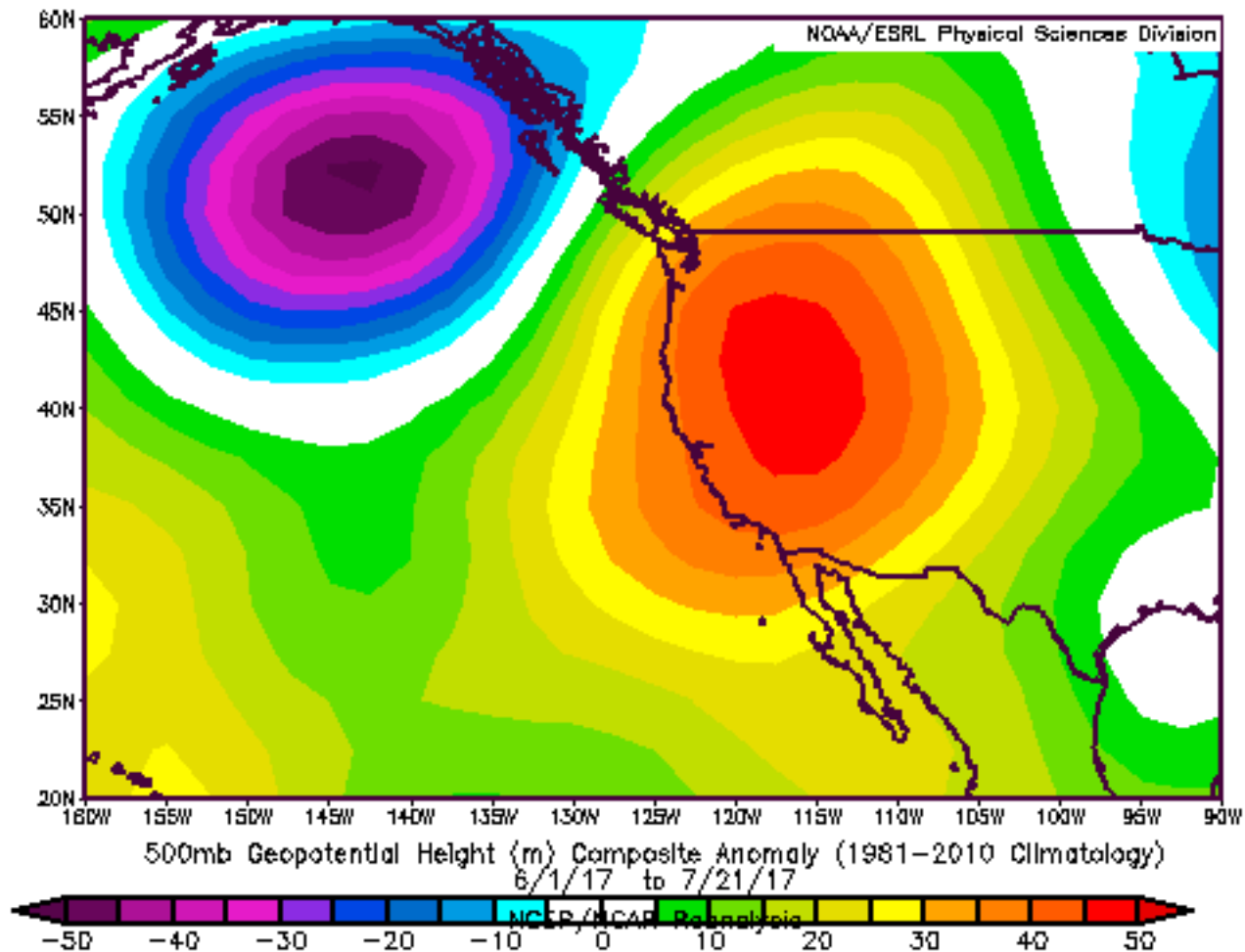


# Heat Waves – Consensus Science

- Easy tie to climate change
- Ridging/Blocking Events Important
- Soil Moisture Deficits Reinforce Heat
- Atmospheric Demand for Moisture dries land surface, then promotes heating
- Atmospheric moisture can reduce nighttime cooling
- Winds uncertain tie to CC



# Persistent 7-Week Heat Dome / Ridge Summer 2017

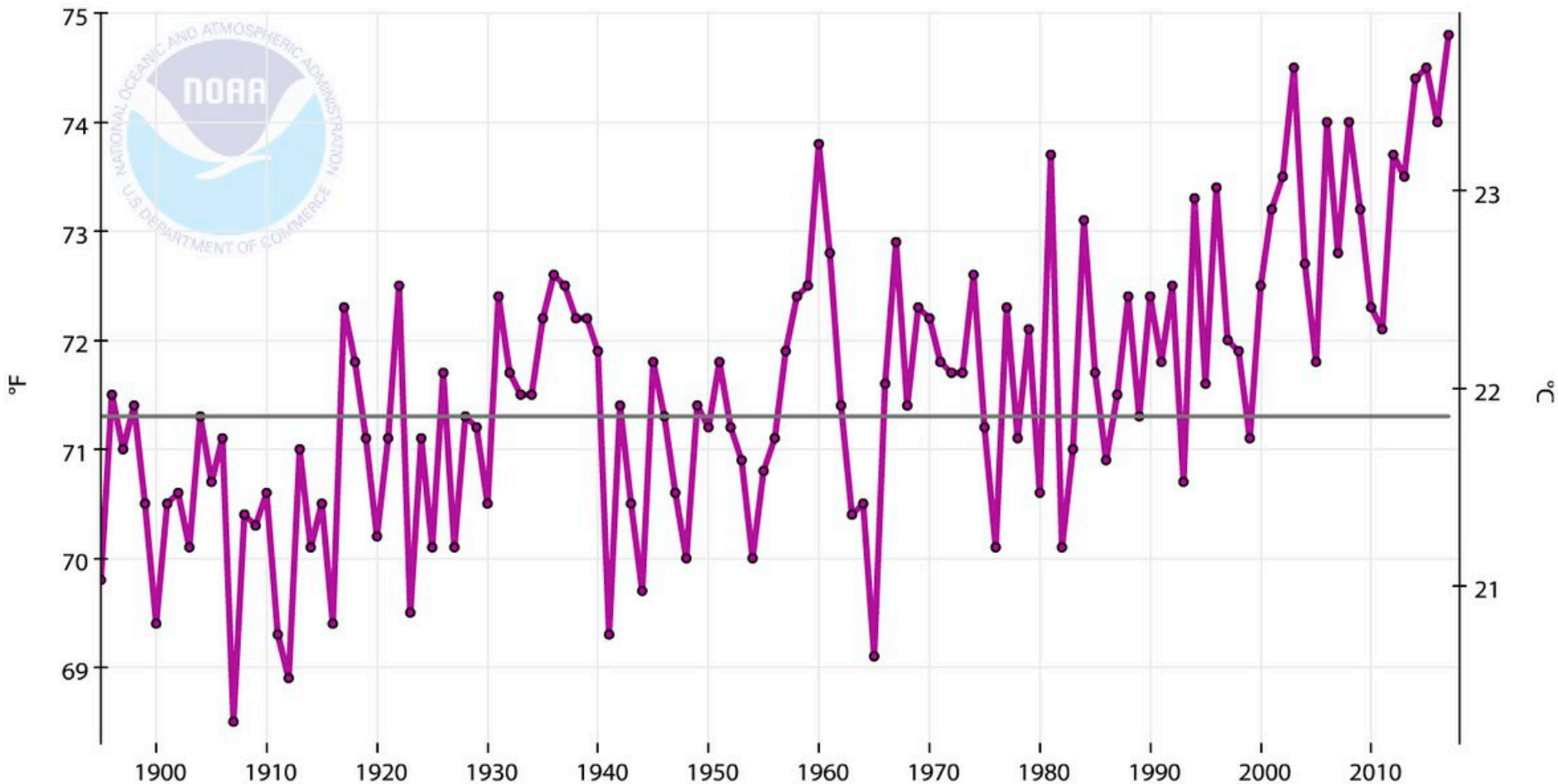


# Record Setting Temperatures in California, Summer 2017

California, Average Temperature, June-September

— 1901-2000  
Mean: 71.3°F

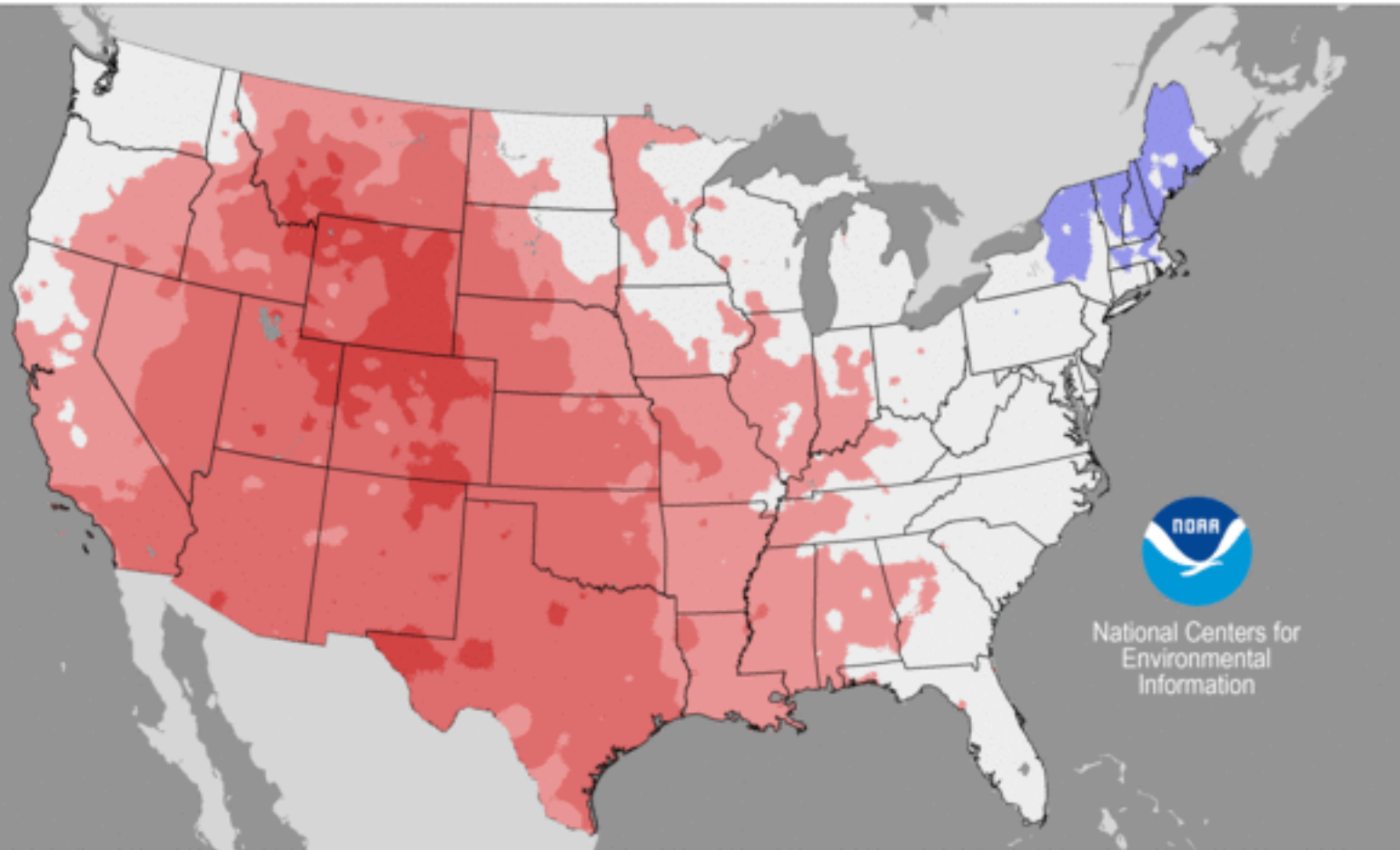
—●— Avg Temperature



# Mean Temperature Departures from Average

March 2017

Average Period: 20<sup>th</sup> Century



National Centers for  
Environmental  
Information



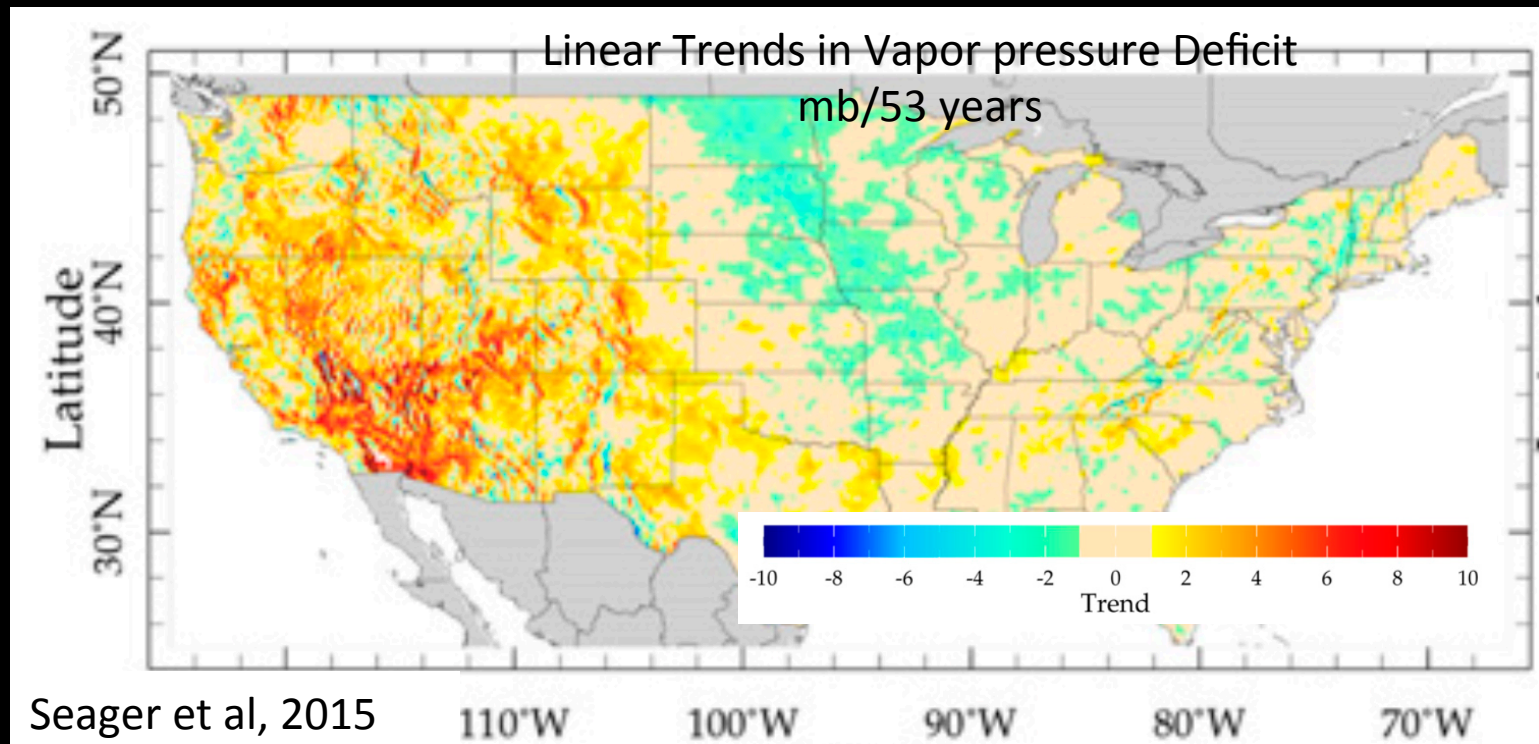
Created: Tue Apr 04 2017

Degrees Fahrenheit

Data Source: 5km Gridded (nClimGrid)

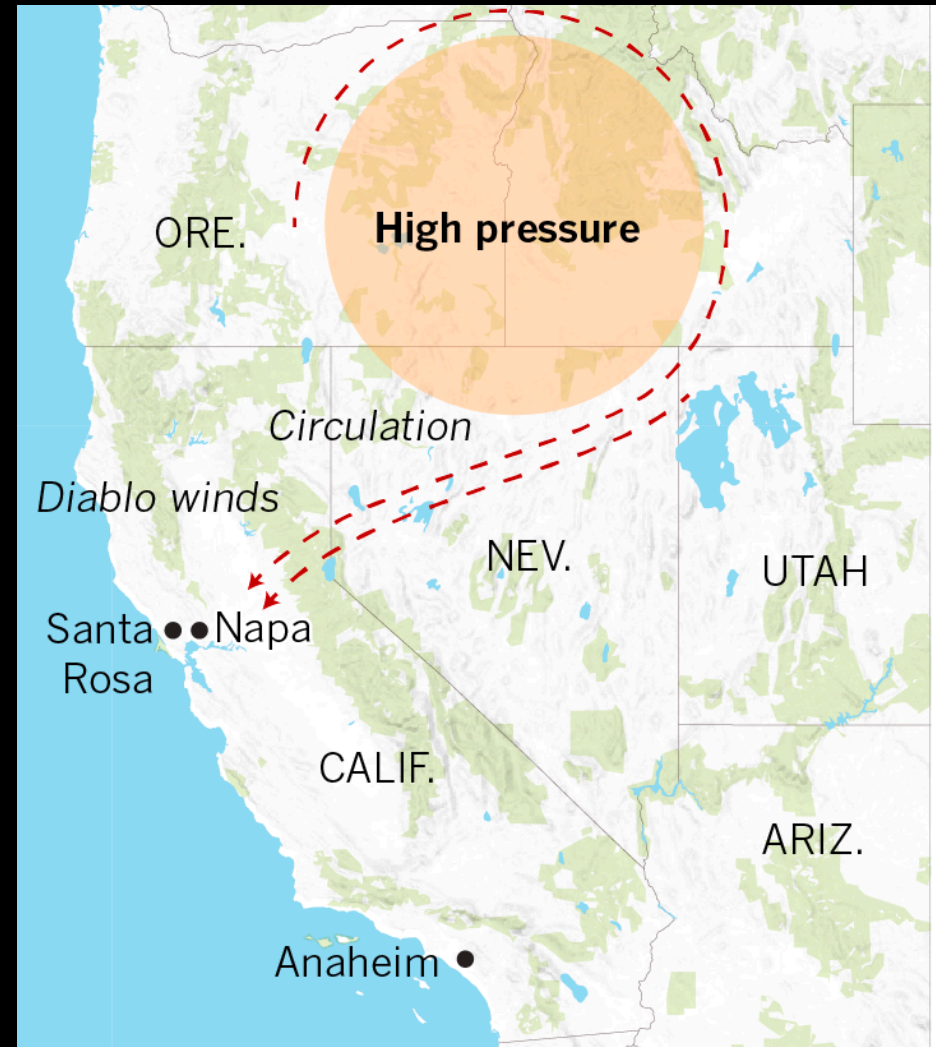


- Why do higher temps lead to less snowmelt runoff?
  - Longer Growing Season
  - More Warmth on Any Given Day
  - At some point, possibly more plants and growth upslope
  - More Evaporation from Soils
  - More opportunity for sublimation
  - More atmospheric demand



# Recent Extreme Fires

- California Fires, 2017
- British Columbia Fires, 2017
- Pacific Northwest, 2017
- Great Plains, 2017





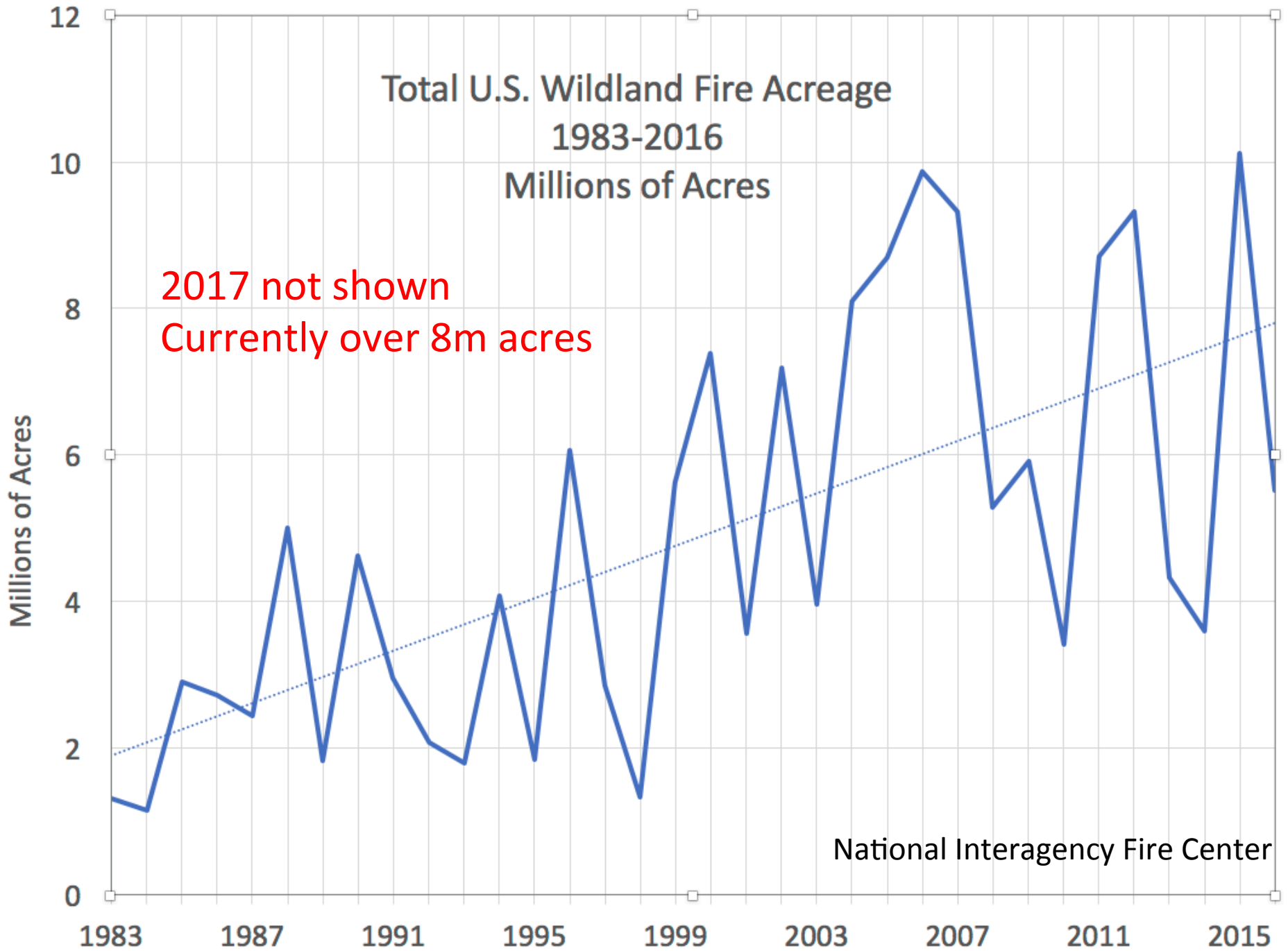
A satellite-style map of the Pacific Northwest region of the United States, showing the coastline, major cities, and mountain ranges. Numerous small red dots are scattered across the landmass, indicating the locations of fires. The map is overlaid with a grid of latitude and longitude lines. The text "Pacific Northwest Fires September 5, 2017" is overlaid in the lower right quadrant of the map.

Pacific Northwest Fires  
September 5, 2017



Total U.S. Wildland Fire Acreage  
1983-2016  
Millions of Acres

2017 not shown  
Currently over 8m acres



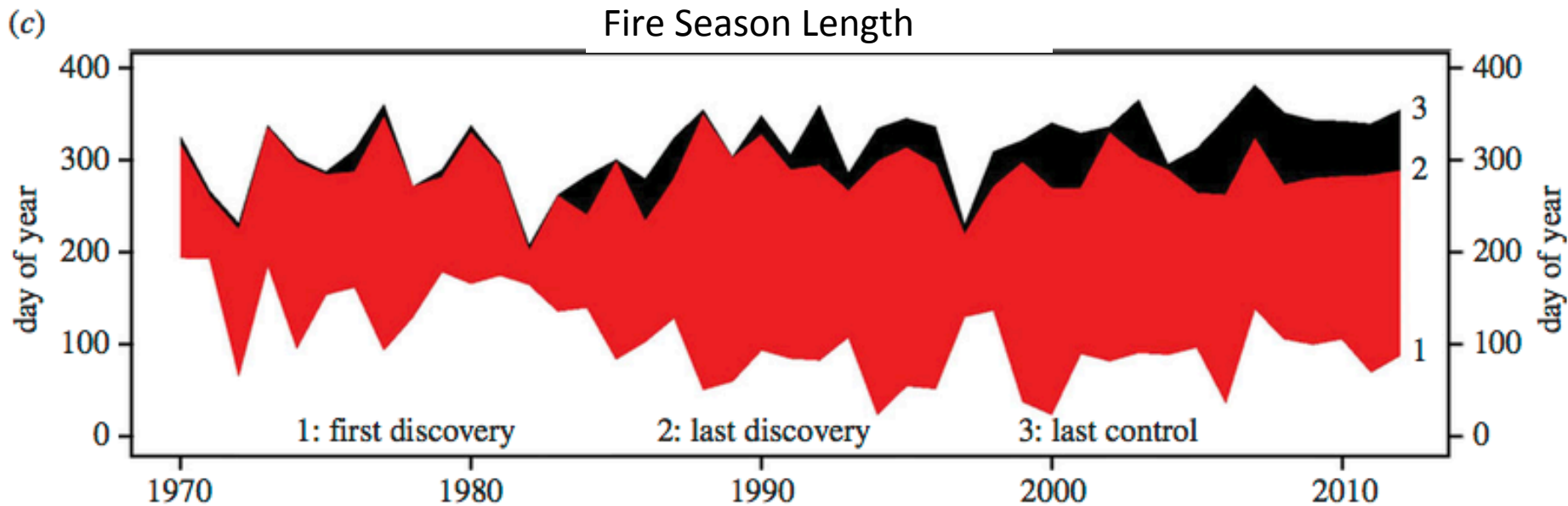
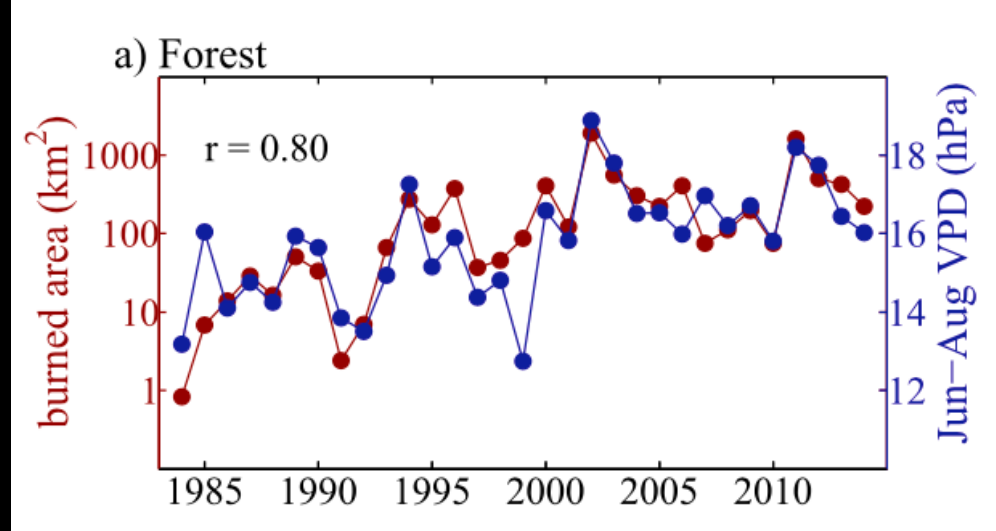
National Interagency Fire Center



# Fires: Consensus Science

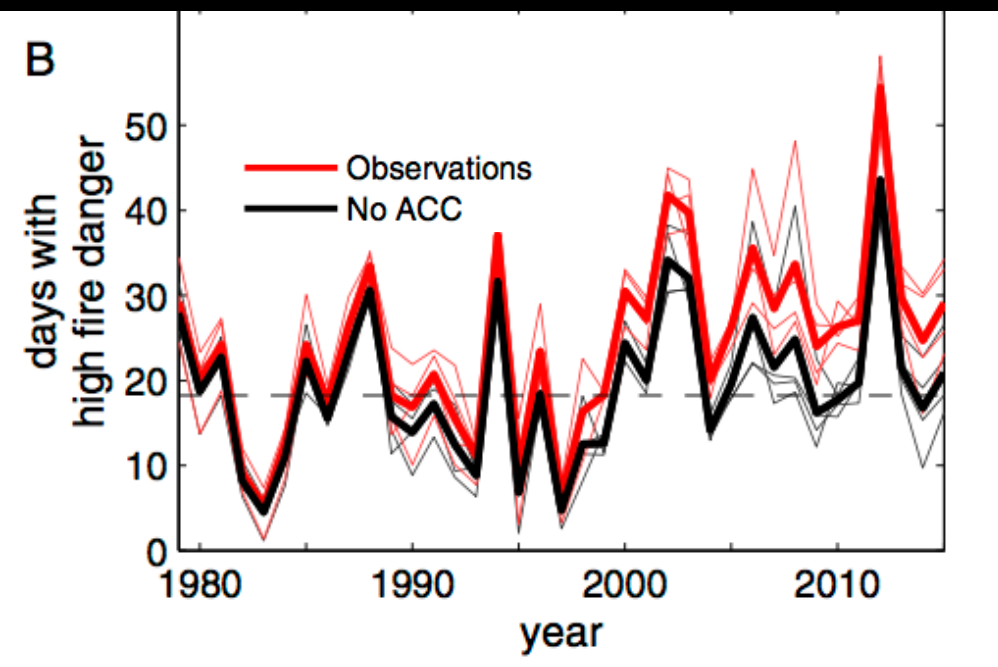
- Longer Fire Seasons
- Bigger Fires
- More Intense Fires
- Contributing Factors
  - Increased Aridity
  - Wet winters with hot summers
  - Early Runoff

Southwest US Area Burned and Vapor Pressure deficit



# Climate Change Blamed for Half of Increased Forest Fire Danger

By TATIANA SCHLOSSBERG OCT. 10, 2016



## Significance

Increased forest fire activity across the western United States in recent decades has contributed to widespread forest mortality, carbon emissions, periods of degraded air quality, and substantial fire suppression expenditures. Although numerous factors aided the recent rise in fire activity, observed warming and drying have significantly increased fire-season fuel aridity, fostering a more favorable fire environment across forested systems. We demonstrate that human-caused climate change caused over half of the documented increases in fuel aridity since the 1970s and doubled the cumulative forest fire area since 1984. This analysis suggests that anthropogenic climate change will continue to chronically enhance the potential for western US forest fire activity while fuels are not limiting.

## Impact of anthropogenic climate change on wildfire across western US forests

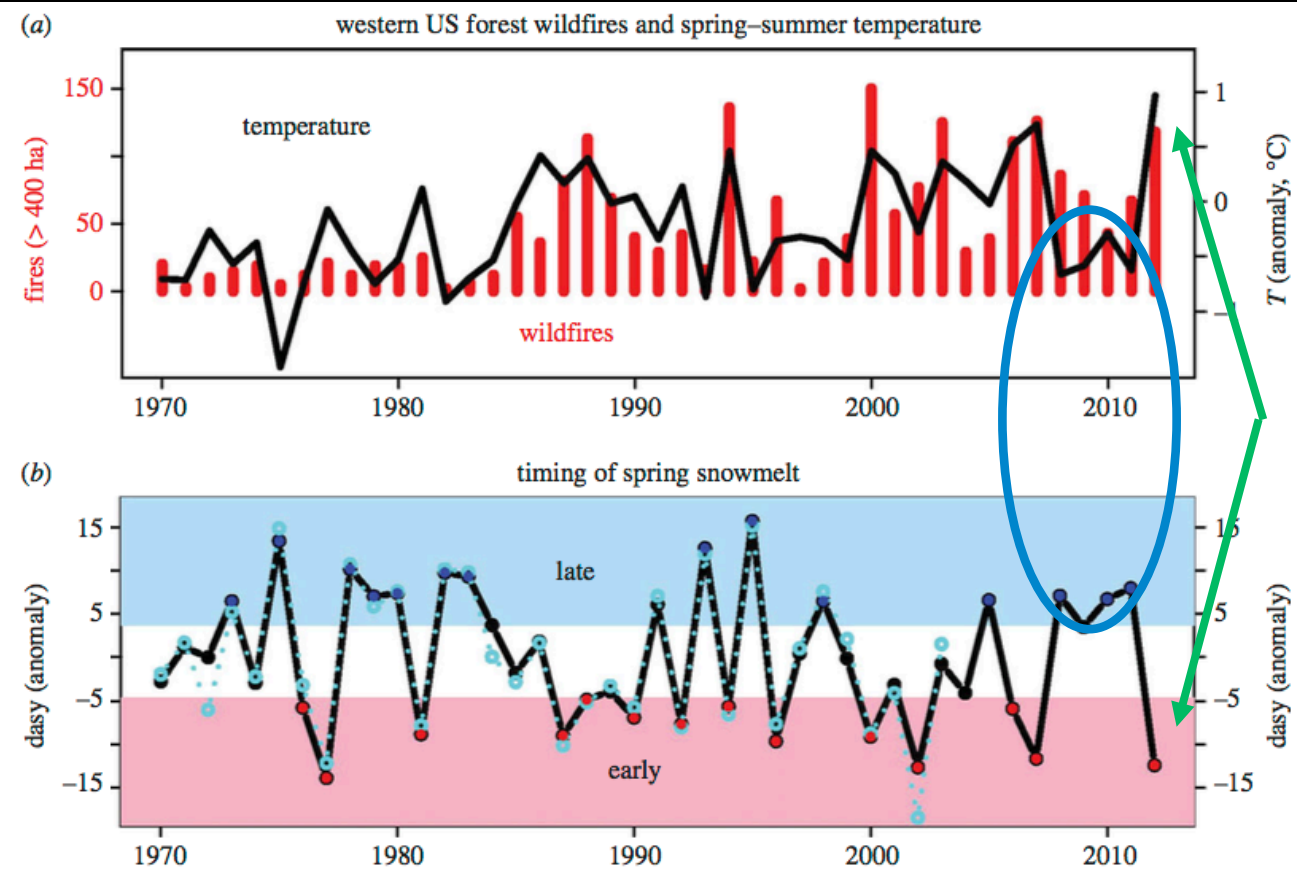
John T. Abatzoglou<sup>a,1</sup> and A. Park Williams<sup>b</sup>

# Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring

Anthony LeRoy Westerling

Early Snowmelt means more fires – green arrows

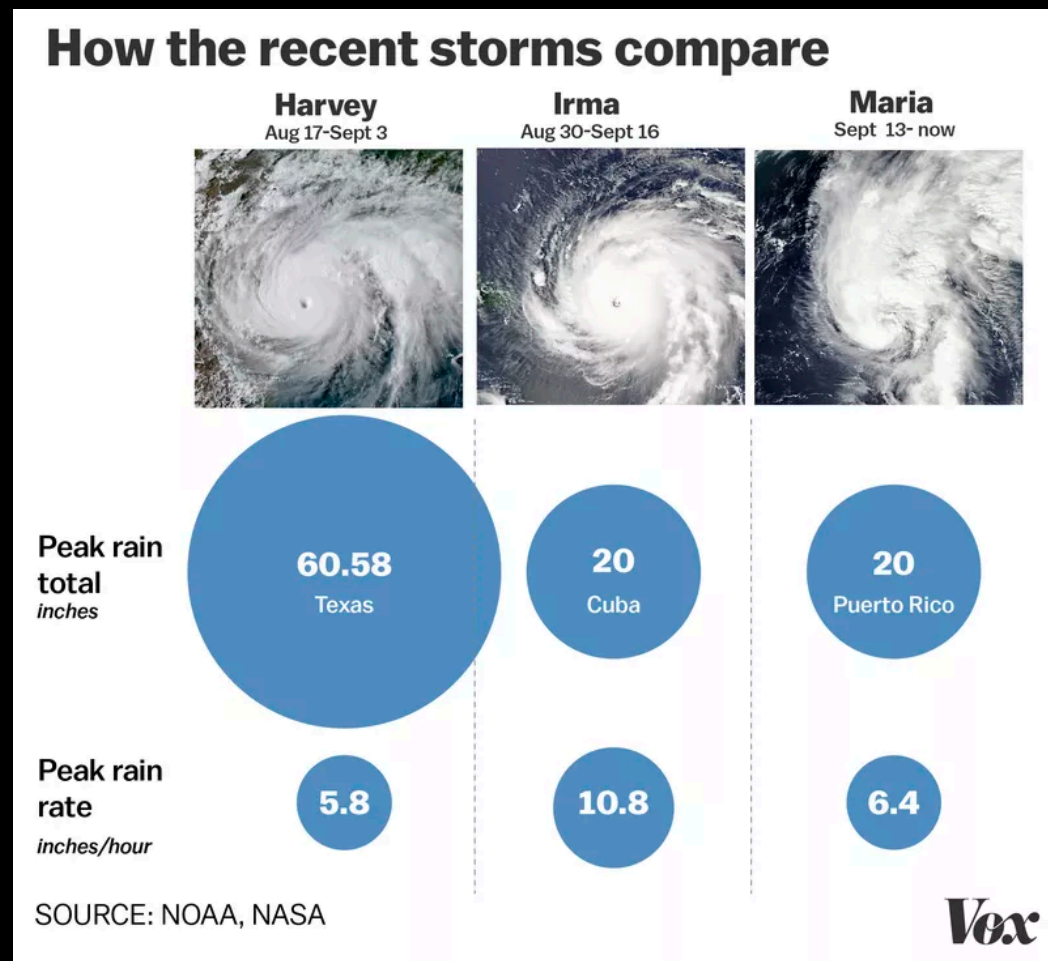
Late snowmelt means fewer fires – blue circle





# Recent Extreme Floods

- Houston, Harvey 2017
- Houston, 2016
- Louisiana, 2016

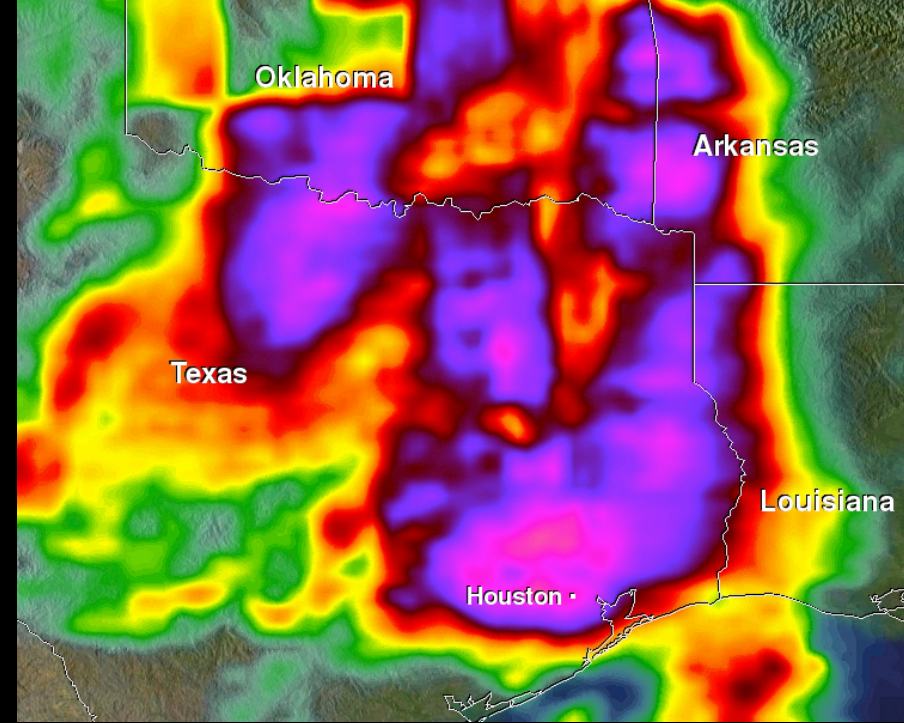


# Floods – Consensus Science

- Heavy Precipitation Increasing
  - Regional Differences Important
- Additional Atmospheric Moisture
  - 4% / Degree F
- Higher Sea Levels contribute to storm/tide surge and delay draining
  - 6 inches to a foot, lots more to come
- Stationary Storms are key element in recent floods
  - Tie to climate change unclear



# Texas Floods April 15-19, 2016

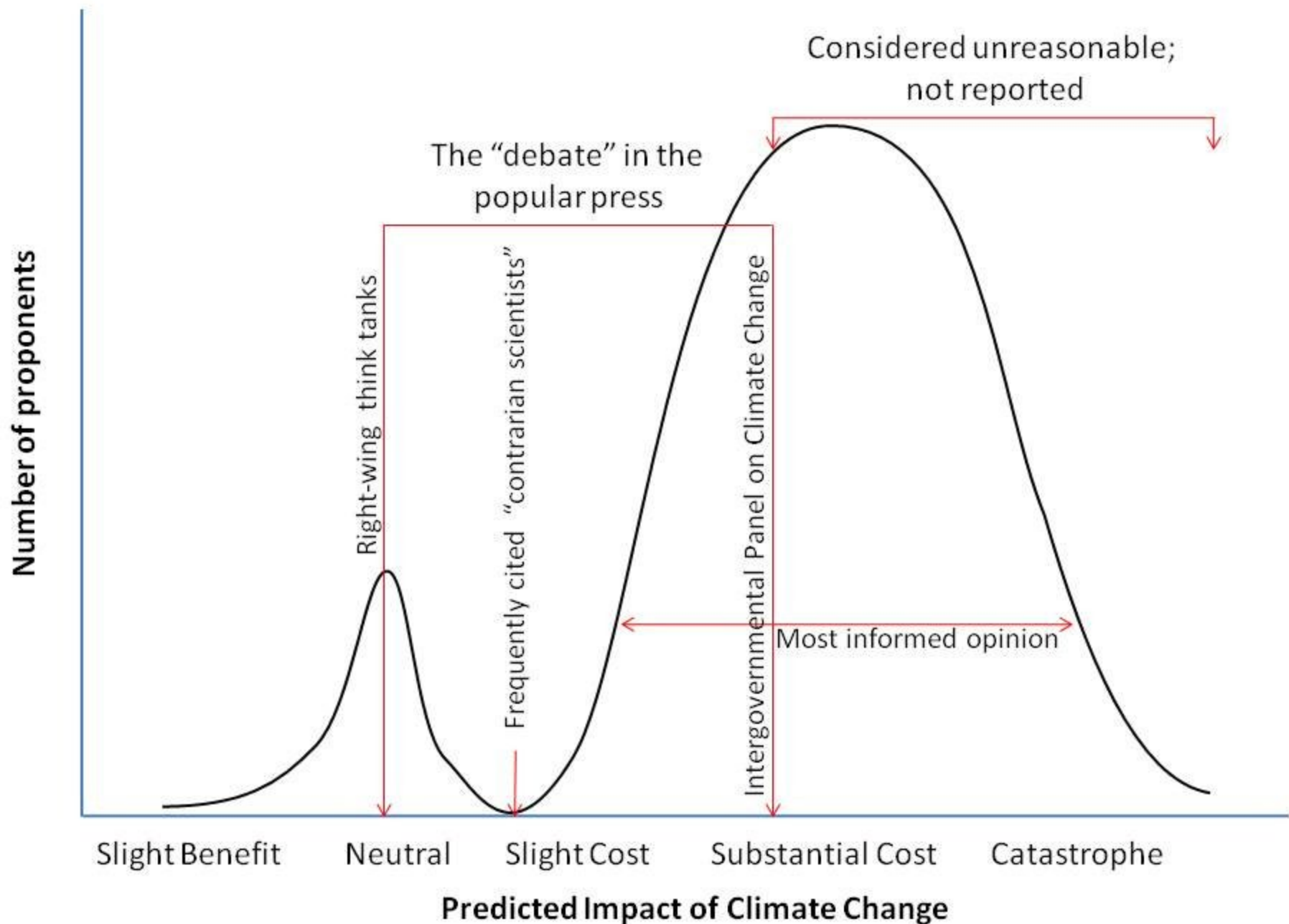


# Louisiana Floods August 8-14, 2016



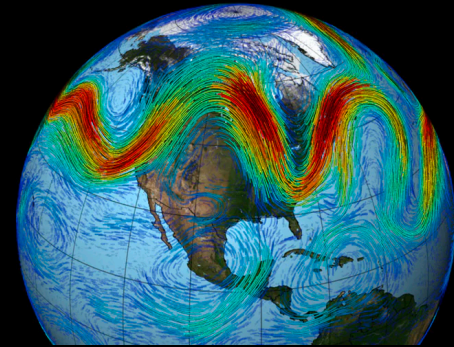


# Distribution of professional opinion on anthropogenic climate change



# Concluding Thoughts

- Extreme Events seem to be occurring more frequently
  - at only 1C Warming
- Warming Leads to...
  - Maritime Snowpack Reduction
  - Increases in co-occurring Drought
  - More Intense Precipitation
  - More Intense Hurricanes
  - Drier conditions leading to more fires
  - Changes in Atmospheric Circulation, e.g. Hadley and Polar
- Hadley Cell Expansion
  - More Northerly Hurricanes ?
  - Blocking Patterns that lead to Drought ?
  - Larger dry areas during drought
- Polar Amplification ?
  - In some cases, Colder winters in the East, Drier in the West



Rossby/Planetary Waves

*NEW YORK*

# The Uninhabitable Earth

Famine, economic collapse, a sun that cooks us: What climate change could wreak — sooner than you think.

By David Wallace-Wells

Read David Roberts on this

July 9, 2017  
9:00 pm



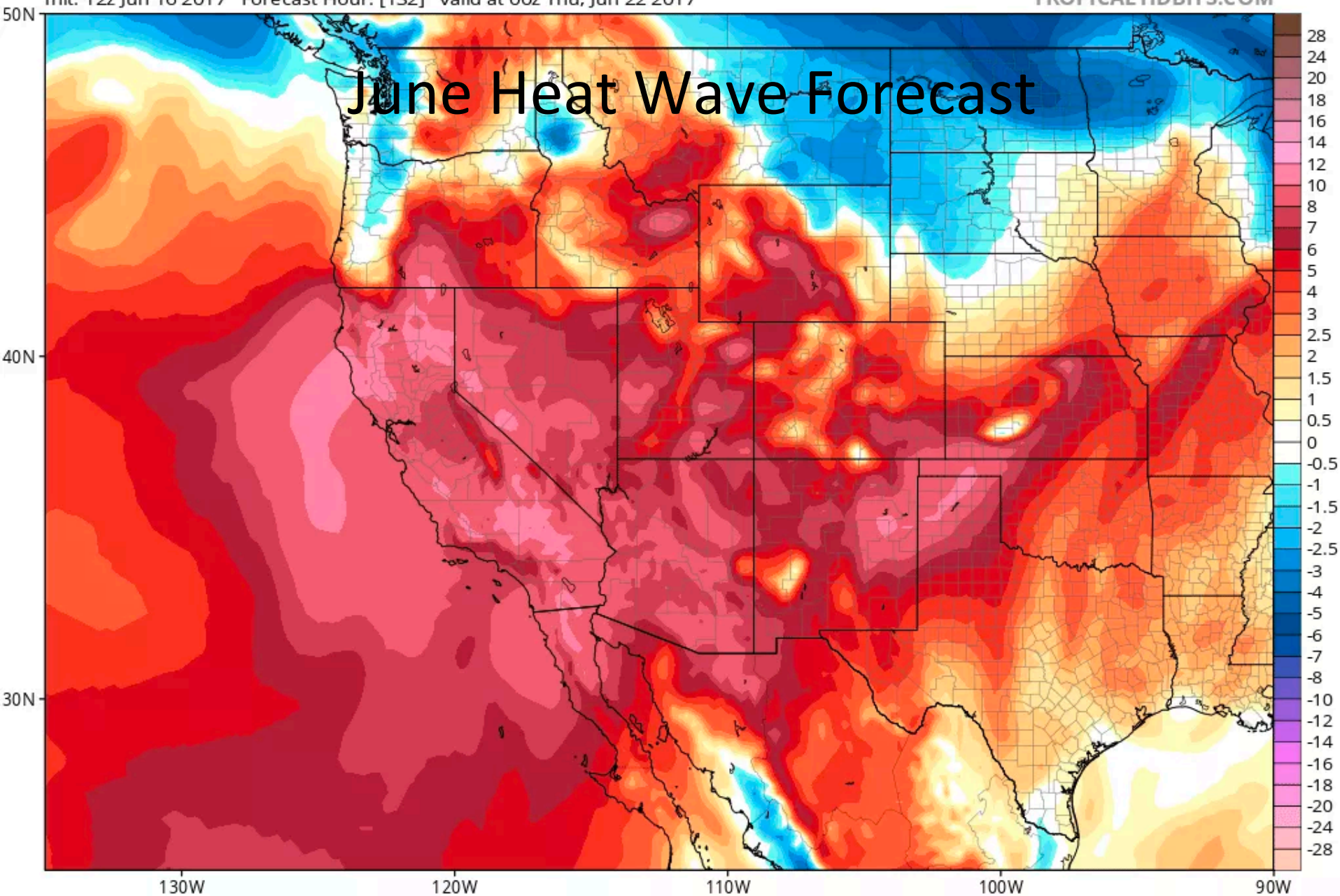


GFS 850 hPa Temperature Anomaly (°C) (based on CFSR 1981-2010 Climatology)

Init: 12z Jun 16 2017 Forecast Hour: [132] valid at 00z Thu, Jun 22 2017

TROPICALTIDBITS.COM

# June Heat Wave Forecast



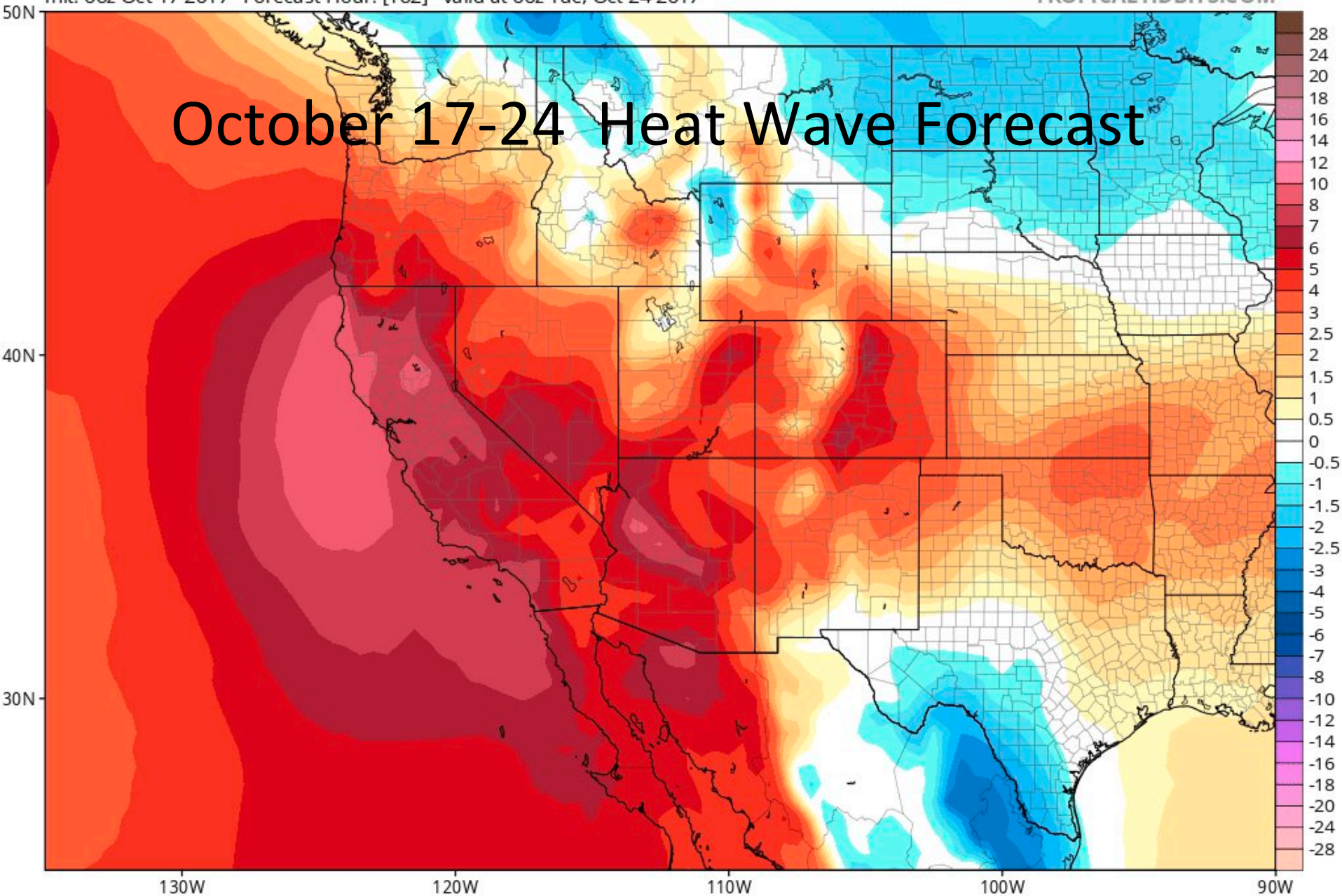


GEFS 850 hPa Temperature Anomaly (°C) (based on CFSR 1981-2010 Climatology)

Init: 06z Oct 17 2017 Forecast Hour: [162] valid at 00z Tue, Oct 24 2017

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# October 17-24 Heat Wave Forecast



# Extra Slides



Hayman, 2002



Black Forest Fire, 2013



Fourmile Canyon, 2010



Waldo Canyon, 2012



High Park Fire, 2012

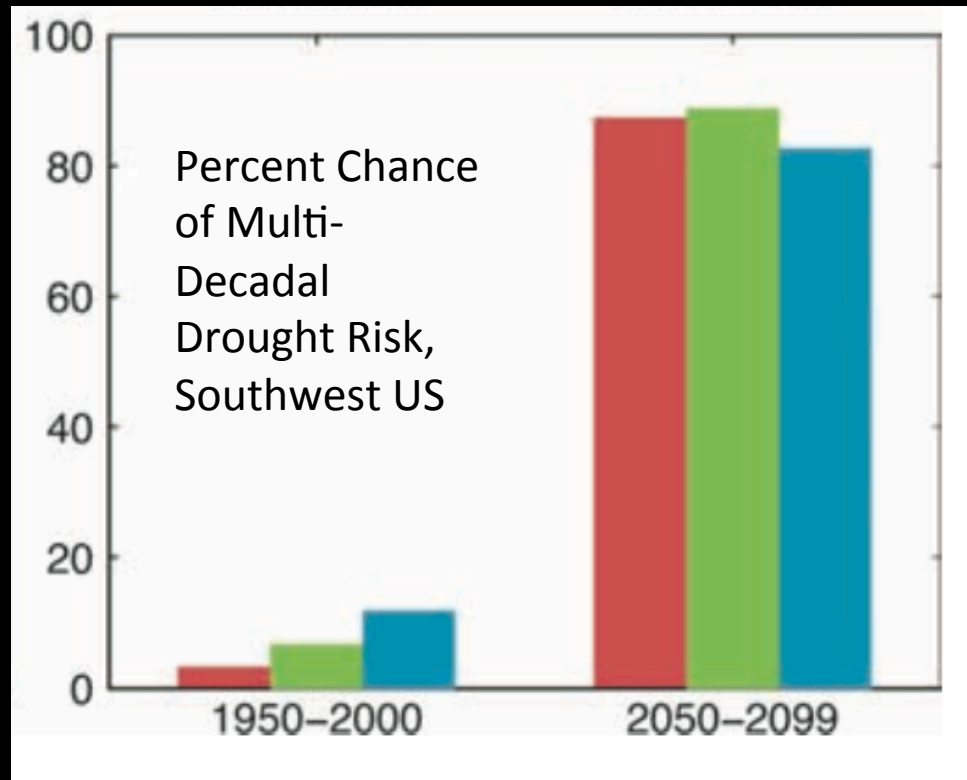


# Unprecedented 21st century drought risk in the American Southwest and Central Plains

Benjamin I. Cook,<sup>1,2\*</sup> Toby R. Ault,<sup>3</sup> Jason E. Smerdon<sup>2</sup>

In both Central Plains and Southwest, Multi-decadal Drought Risk\* exceeds 80% in 21<sup>st</sup> Century

\* Defined as Drought lasting 35 or more years

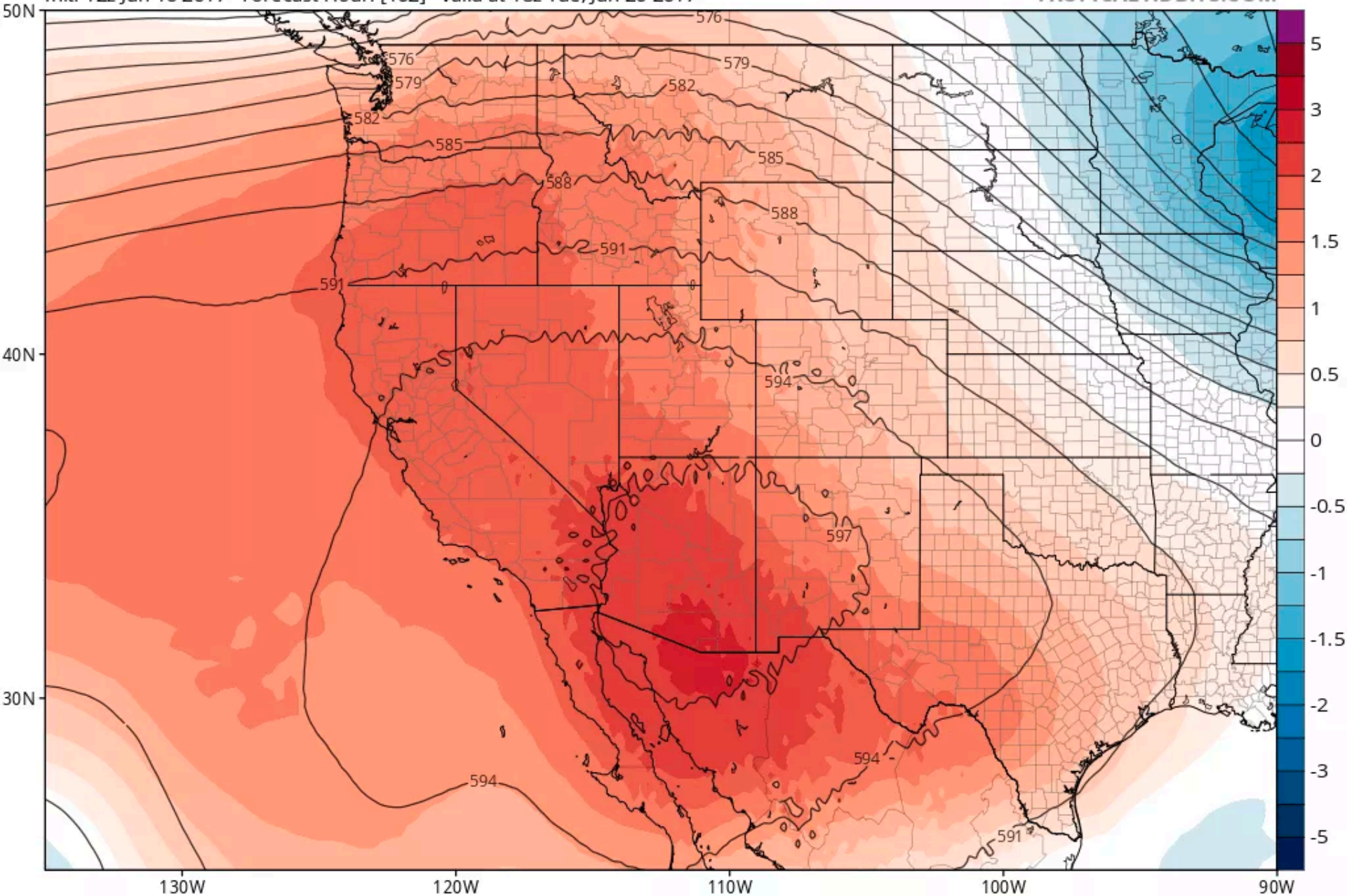




# GFS 500mb Geopotential Height & Normalized Anomaly (based on CFSR 1981-2010 Climatology)

Init: 12z Jun 16 2017 Forecast Hour: [102] valid at 18z Tue, Jun 20 2017

TROPICALTIDBITS.COM





Front Range Floods, September 2013



Jamestown  
Colorado Public Radio



# Fires

## Ice and fire: large blaze burns in Greenland for two weeks

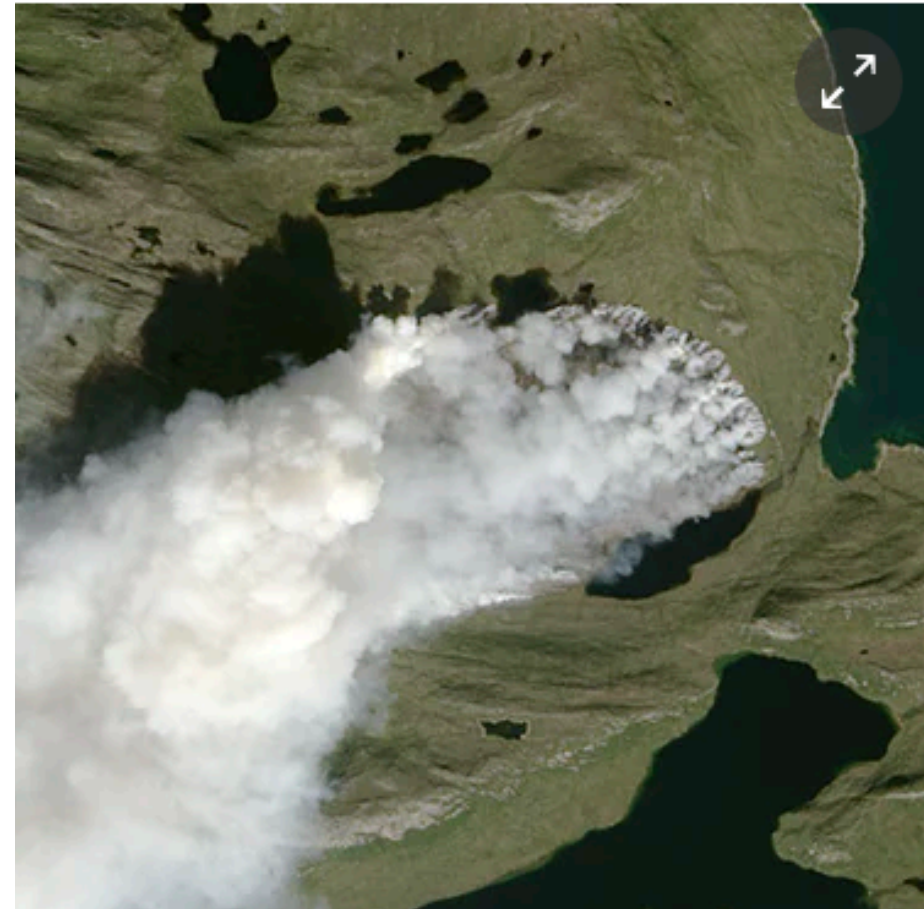
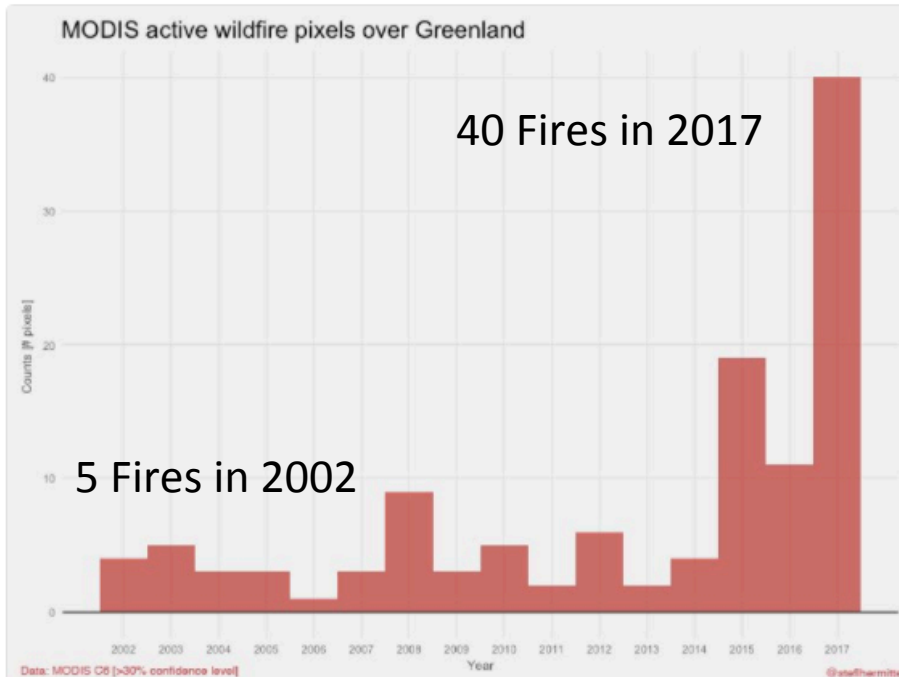
Scientists perplexed by wildfire that has been burning since July in grassland just 40 miles from the ice sheet

 **Stef Lhermitte**  
@StefLhermitte

Following

Replying to @StefLhermitte @ruth\_mottram and 7 others

To wrap up: wildfires have occurred in the past over Greenland but 2017 is exceptional in number of active fire detections by MODIS



len, using Landsat data from the US Geological Survey, shows a /Jesse Allen/NASA

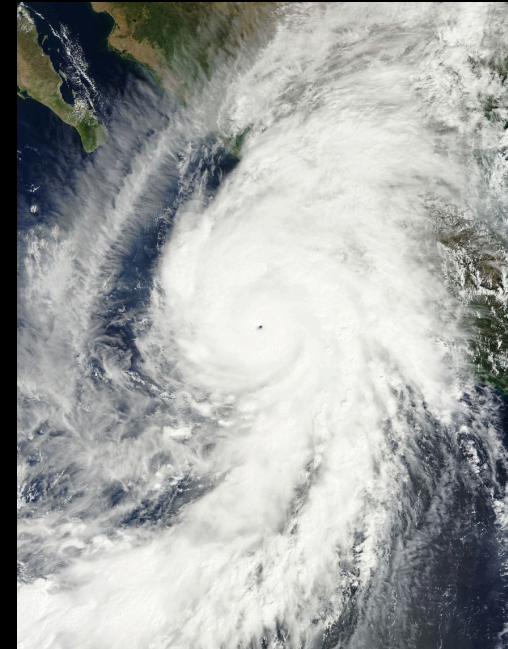
# 2017 Hurricane Records

- Number of Major Storms
  - 6, tied for 2nd
- Major Storm Days
- Accumulated Cyclone Energy 'ACE' Energy
- 10 Consecutive Hurricanes from Tropical Storms
- Ophelia
  - No Major Hurricane ever in region

# Hurricane Changes

- Warmer Ocean Waters have more Energy
- High Sea Level means more Storm Surge
- Warmer Atmosphere generates more rain, and more intense rain
  
- All of these changes lead to more powerful and damaging hurricanes

Hurricane Patricia,  
October 2015  
220 mph winds



## September 2017 Hurricane Records

Metric	2017 September	Previous Monthly Record
Named Storm Days	53.5	52.25 (September 2004)
Hurricane Days	40.25	34.50 (September 1926)
Major Hurricane Days	18	17.25 (September 1961)
Accumulated Cyclone Energy	175	155 (September 2004)



# How the recent storms compare

## Harvey

Aug 17-Sept 3



## Irma

Aug 30-Sept 16



## Maria

Sept 13- now



Peak rain  
total  
*inches*

**60.58**

Texas

**20**

Cuba

**20**

Puerto Rico

Peak rain  
rate

*inches/hour*

**5.8**

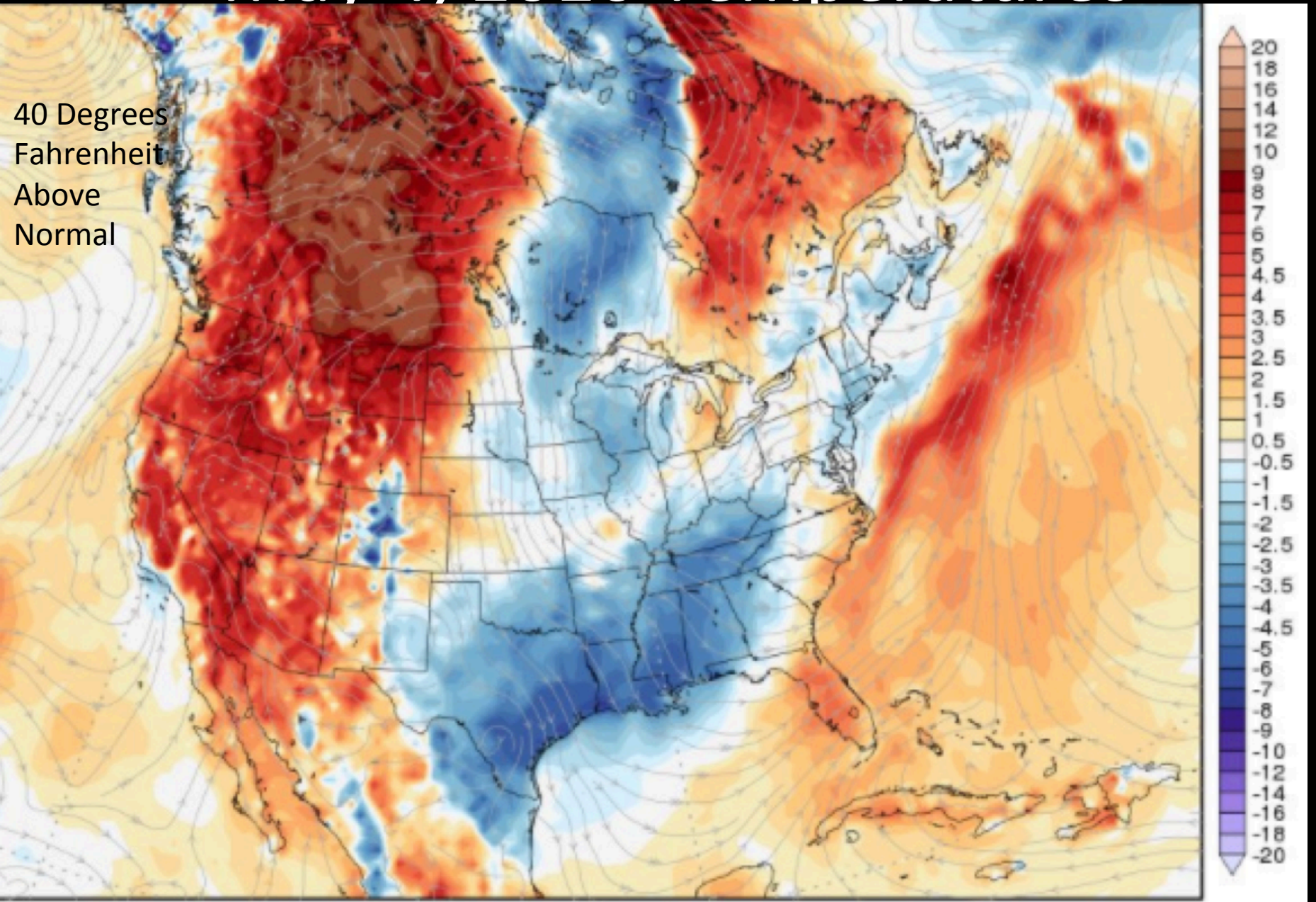
**10.8**

**6.4**

SOURCE: NOAA, NASA

**Vox**

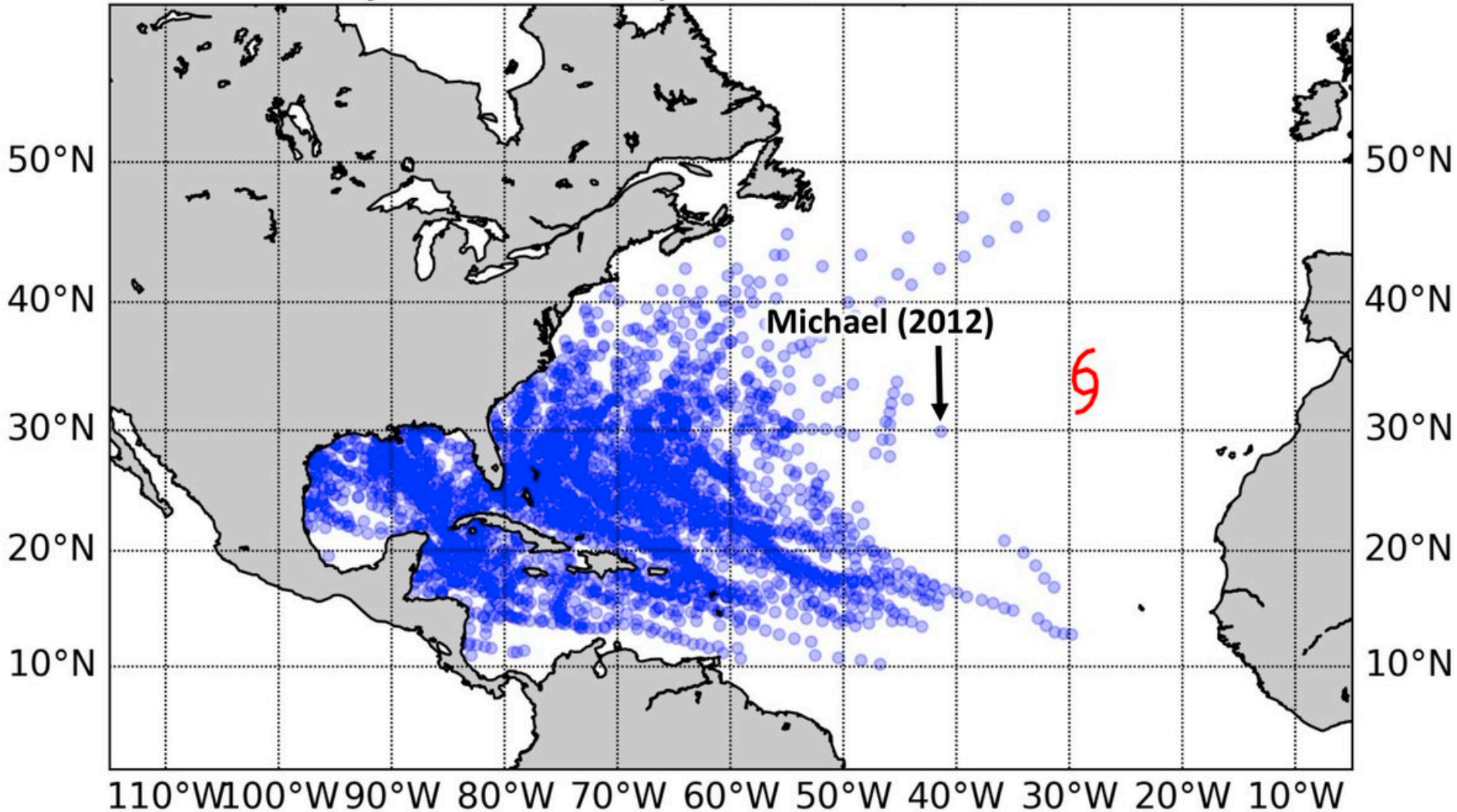
# May 4, 2016 Temperatures





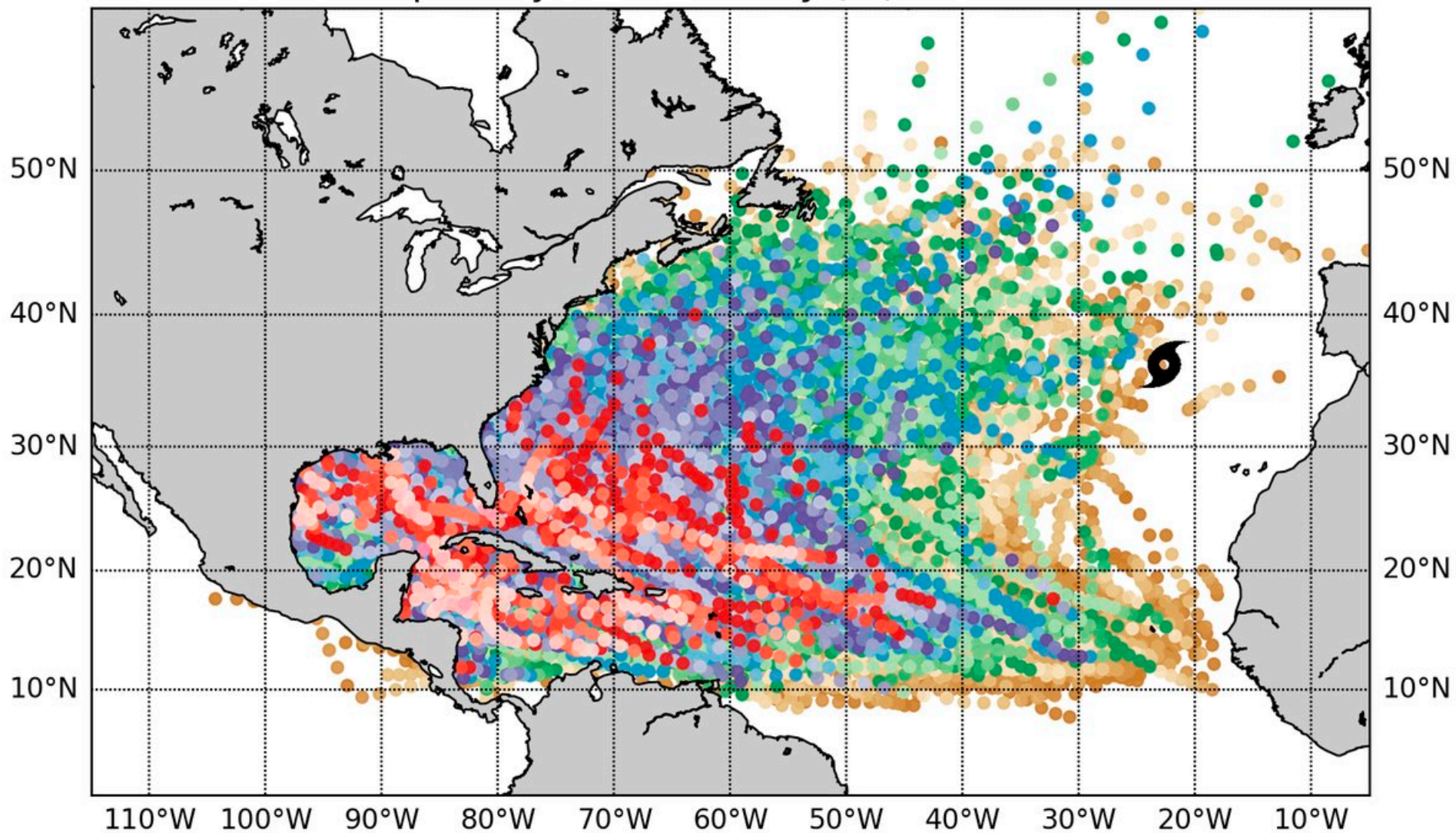
# Ophelia's Unprecedented Location

All major hurricane points ( $\geq 96kt$ ) 1851-2016





# Tropical cyclone intensity (kt) 1851-2016



# California 2014-15 Snowpack

5% of normal  
snowpack  
despite near  
normal  
precipitation in  
many places



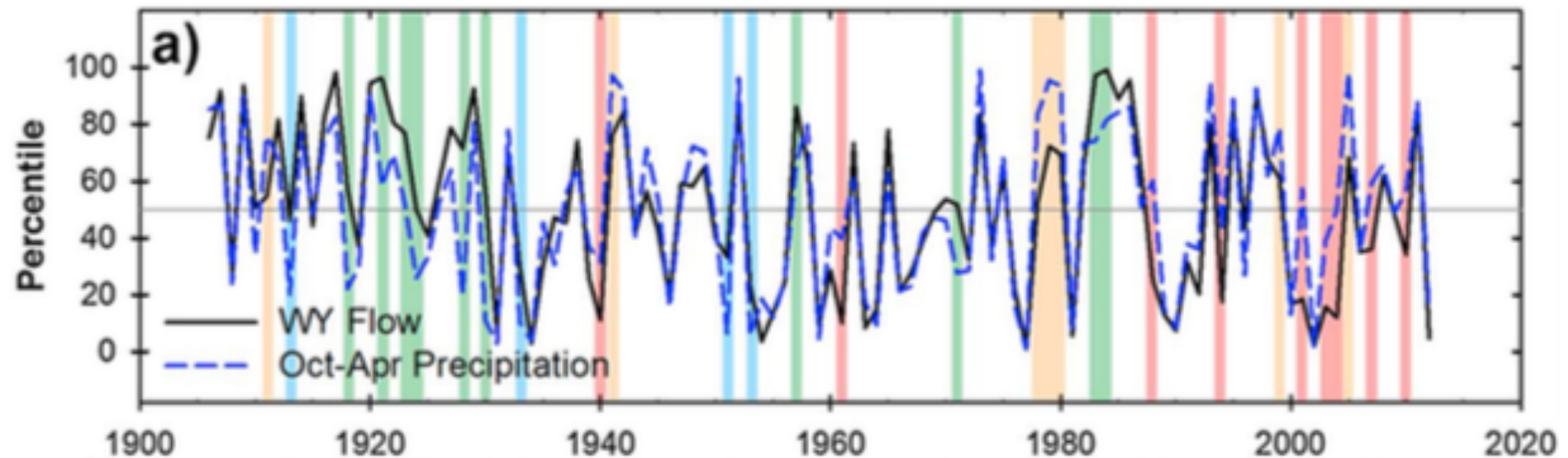


# Increasing influence of air temperature on upper Colorado River streamflow

Connie A. Woodhouse<sup>1,2</sup>, Gregory T. Pederson<sup>3</sup>, Kiyomi Morino<sup>2</sup>, Stephanie A. McAfee<sup>4</sup>, and Gregory J. McCabe<sup>5</sup>

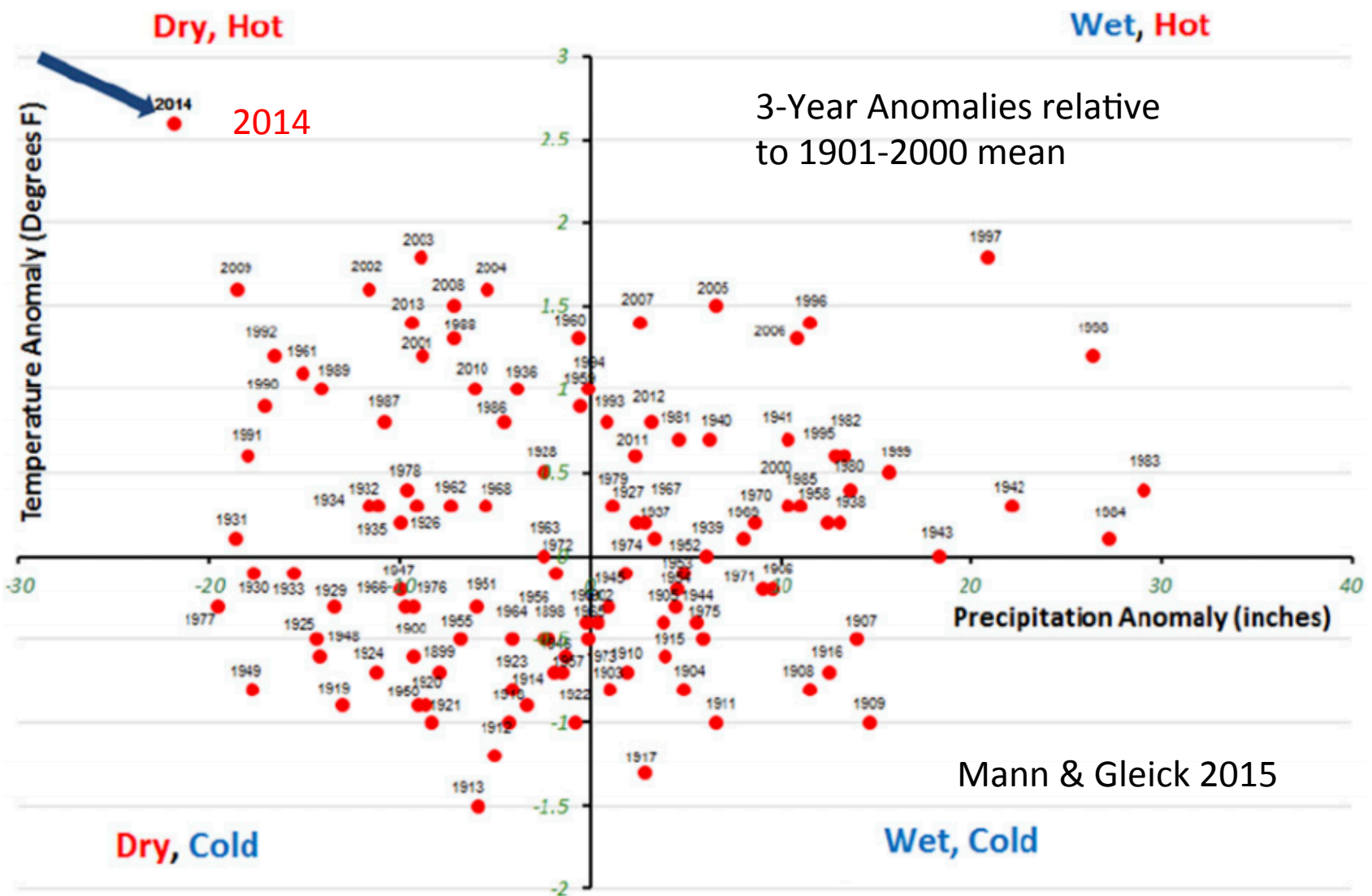
## Key Points:

- When UCRB flow departs from precipitation, temperature is a major forcing
- Since 1988, flows have often been less than expected given winter precipitation
- Warm temperatures exacerbated modest precipitation deficits in the 2000s drought

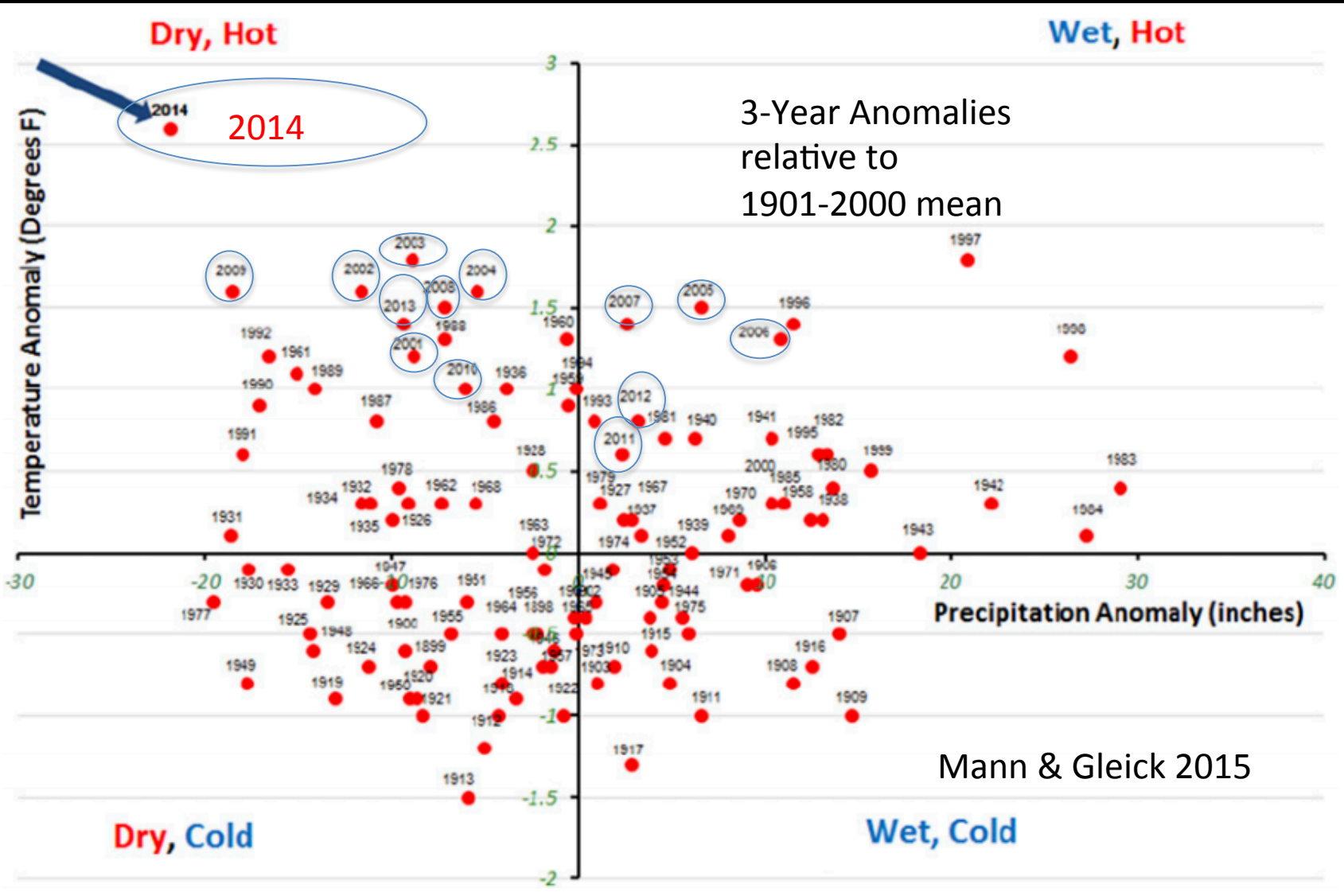




# CA 2012-2014 Precip+Temp



# CA Precipitation and Temperature



# California 2014-2015 Drought

- Winter Temperatures
  - Sierra Winter Above 32 F,
  - (1<sup>st</sup> time >32F in 120 years)
- Sierra Precipitation
  - Rain, not Snow
  - Not the driest!
  - (40% to 90% of normal)
- Snowpack
  - Lowest Ever - 5% on April 1
  - (1977 at 25%)
  - 500-Year (?) Return Period
- Drought
  - Worst in 1200 (?) Years
- Water Deliveries
  - Record Low to CVP Contractors





# Perspectives on the causes of exceptionally low 2015 snowpack in the western United States

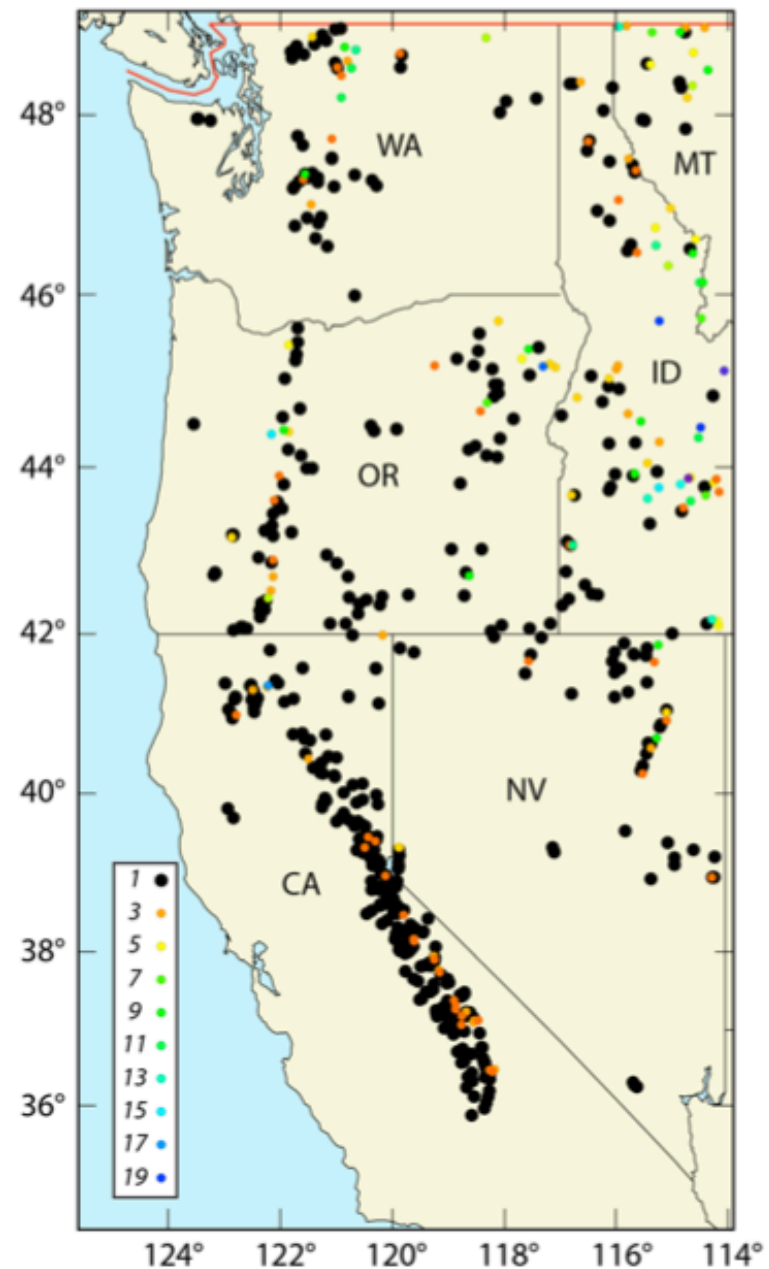
Philip W. Mote<sup>1</sup>, David E. Rupp<sup>1</sup>, Sihan Li<sup>1</sup>, Darrin J. Sharp<sup>1</sup>, Friederike Otto<sup>2</sup>, Peter F. Dennis P. Lettenmaier<sup>4</sup>, Heidi Cullen<sup>5</sup>, and Myles R. Allen<sup>2,6</sup>

AGU PUBLICATIONS

Geophysical Research Letters

## Key Points:

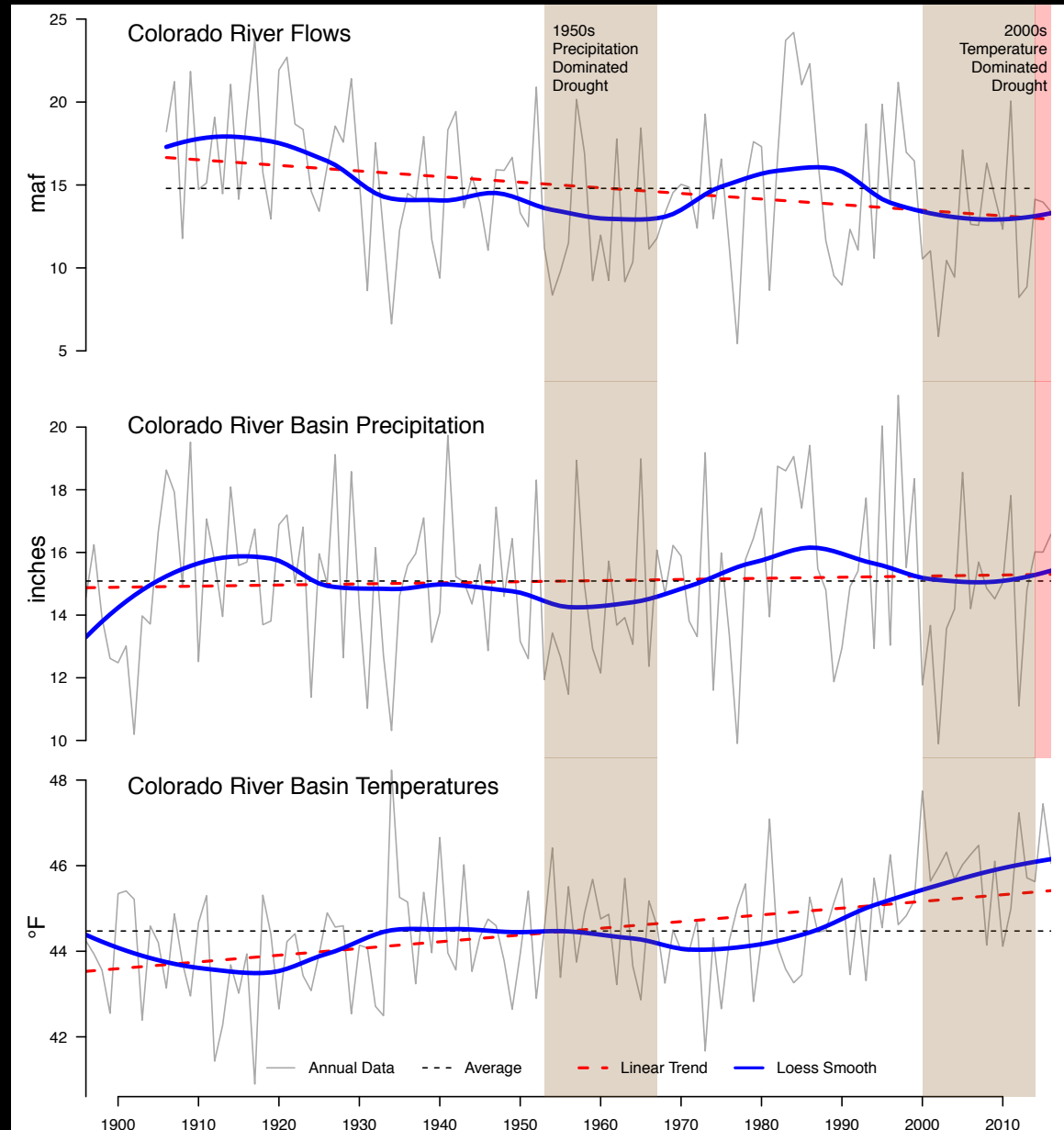
- In the 2012-2015 west coast drought, unusually high temperatures played a prominent role in reducing snow accumulation and causing drought
- In much of the westernmost U.S., April snowpack was at its lowest ever in 2015
- Crowd-sourced climate modeling shows that greenhouse gases and SST patterns did more to cause drought in the Northwest than in California



**Figure 1.** Locations of snow courses with data back to at least 1976 indicating the rank of 2015 against all available years, for 1 April SWE. Symbols and color indicate rank (including ties); filled circle indicates lowest ever.

# Colorado River Drought 2000-2014

- 2000-2014 Worst Drought in Colorado River Gage Record
- ~ 1/3 of the Decline due to Higher Temperatures
- 20% Loss by 2050 Possible due to higher temperatures
- Increases in precipitation may counteract losses somewhat
- Increased risk of megadrought in 21<sup>st</sup> century reinforces loss potential



Sources: Udall and Overpeck, 2017; Woodhouse et al., 2016

The last time carbon dioxide concentrations were this high ...

Pliocene 2.6 to 5.3 mya

2C to 3C Warmer

10C to 20C Warmer in  
the Arctic

15m to 25m higher Sea  
Levels

Carbon Dioxide Concentration

