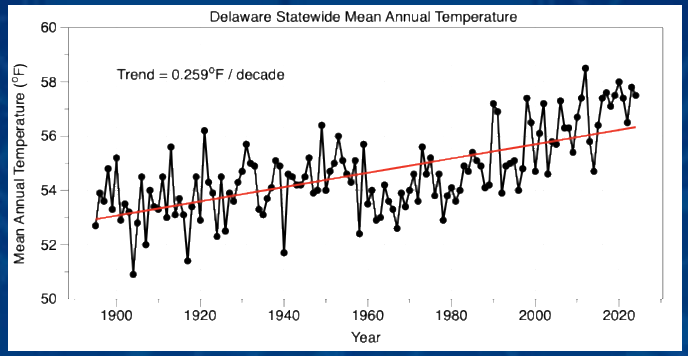
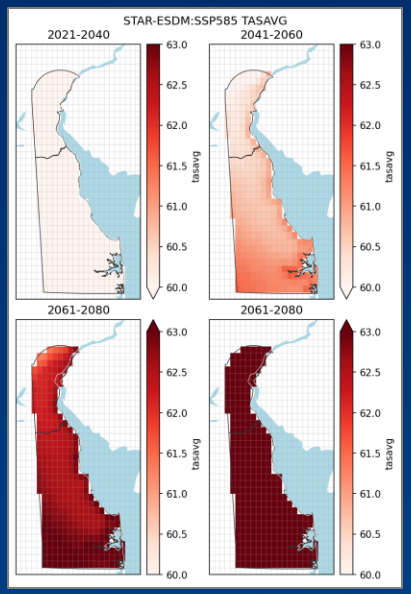
Delaware's Climate Through History and Into the Future

DE RASCL SUMMIT



March 5, 2025
Dover, DE



Kevin Brinson
Daniel J. Leathers
Tina Callahan

Delaware Climate Office
Center for Environmental Monitoring Analysis

CEMA

UNIVERSITY OF DELAWARE

DCO
DELAWARE CLIMATE OFFICE

Outline

- **The Delaware Climate Office (DCO) and CEMA**
  - Our Role in providing data and climate support services…
  - Delaware Climate in legislation/action…
- **Delaware's Climate in a Global Context**
  - Global temperature and precipitation changes…
  - United States temperature and precipitation changes…
  - Delaware's changing climate…
- **New Future Climate Scenarios for Delaware**
  - Future plans…

What is CEMA?

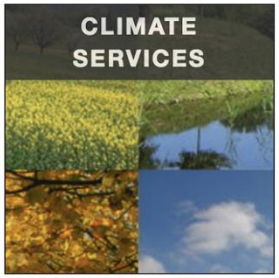
Service *and* Research Center located at:

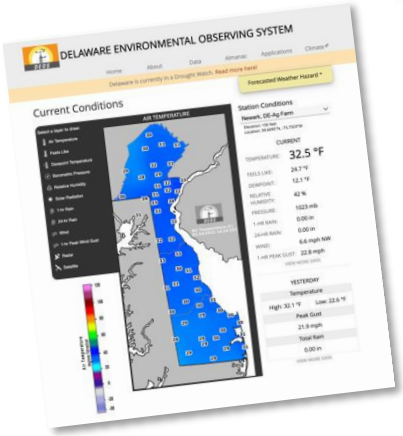
Funded by:

- DNREC
- DelDOT
- DEMA
- DGS

- NOAA
- FEMA (via state)
- EPA (via state)

What does CEMA do?





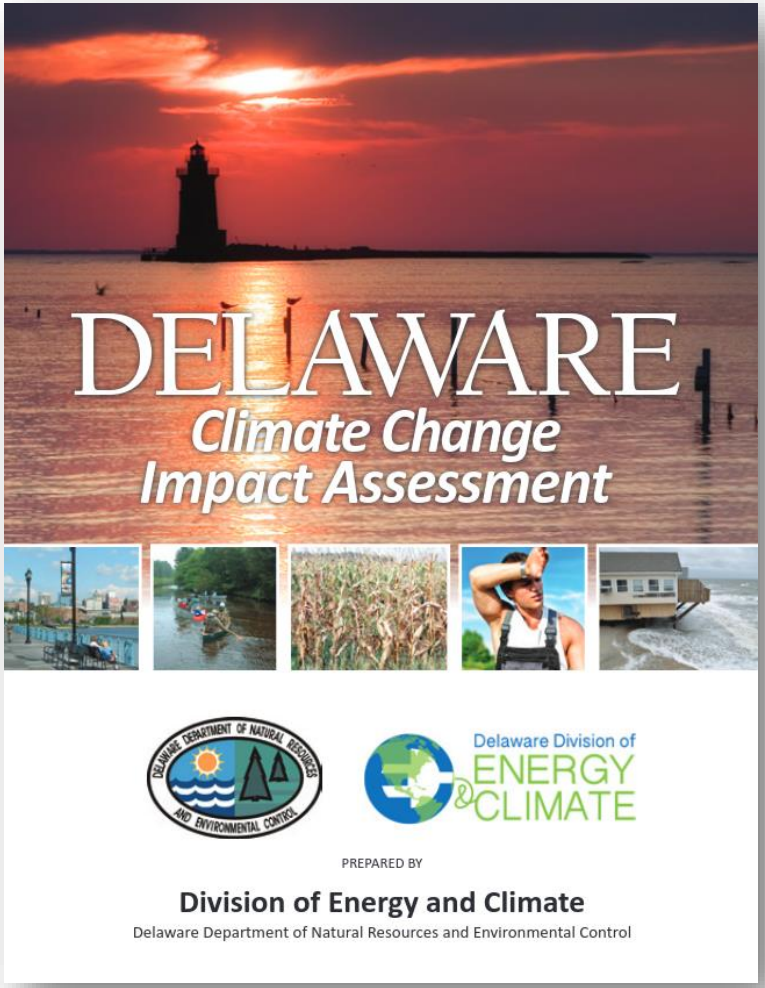
MISSION

- monitor the environment
- develop integrated applications
- provide climate & weather expertise

… to aid decision making and improve Delaware's ability to respond to extreme weather and climate events

What does the State Climate Office do?

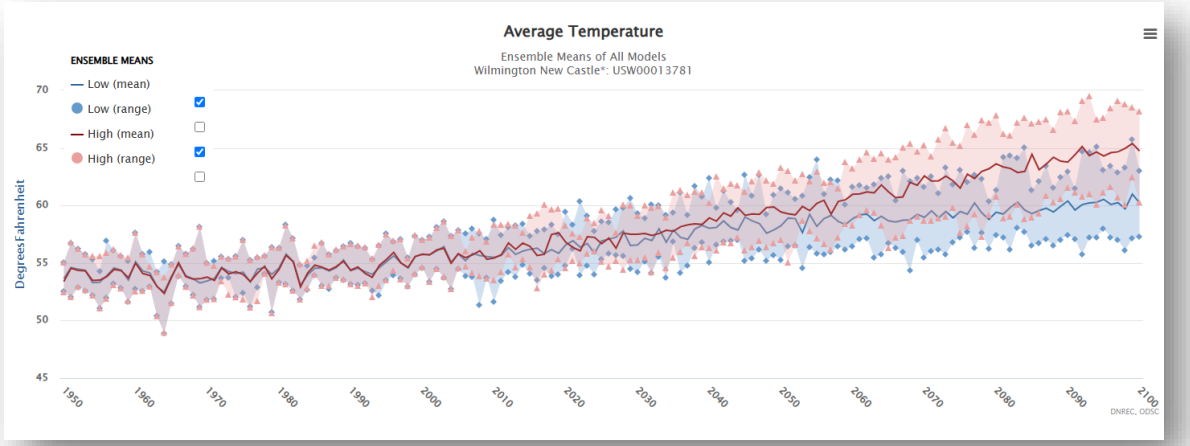
- Maintain climate records and datasets for Delaware
- Produce regular climate updates
- Emergency Weather Support
- Drought Monitoring
- Data Requests
- Applied Climate Research

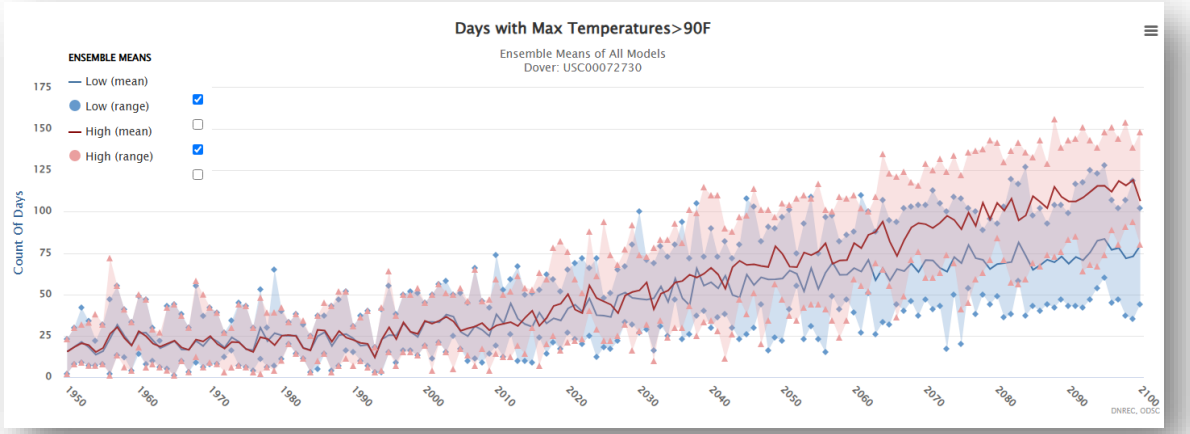


- Produced in **2014**
- Provided historical and future climate trends
- Used Global Climate Modem (GCM) data from CMIP5 models (9 models total)
- **Two** climate change scenarios considered/used
- Output for 14 locations in Delaware – ***no spatial coverage***

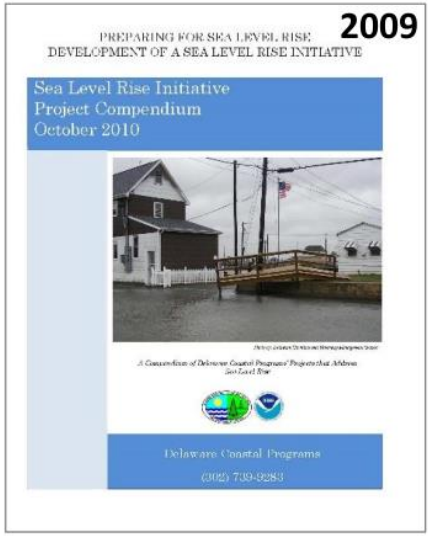
Delaware Climate Projections Portal

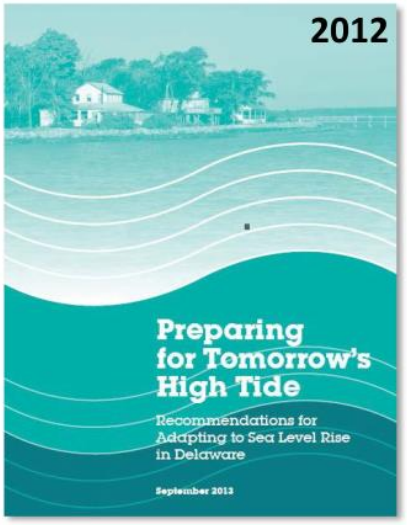
- Developed following release of DCCIA report
- Provides access to graphs and data from climate projections for all 14 stations

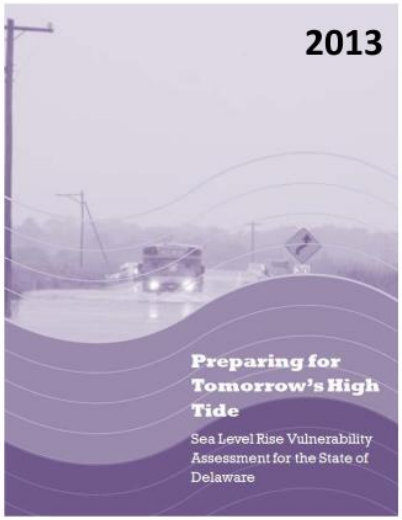


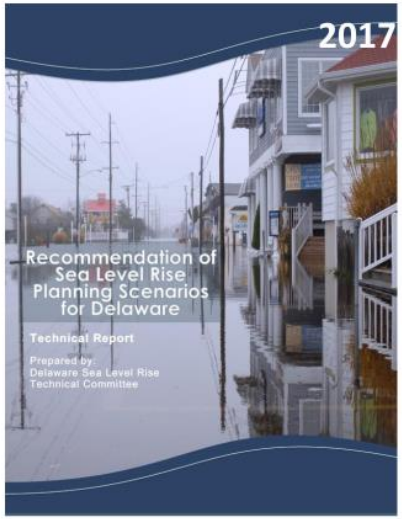


Previous Delaware Sea Level Rise Studies







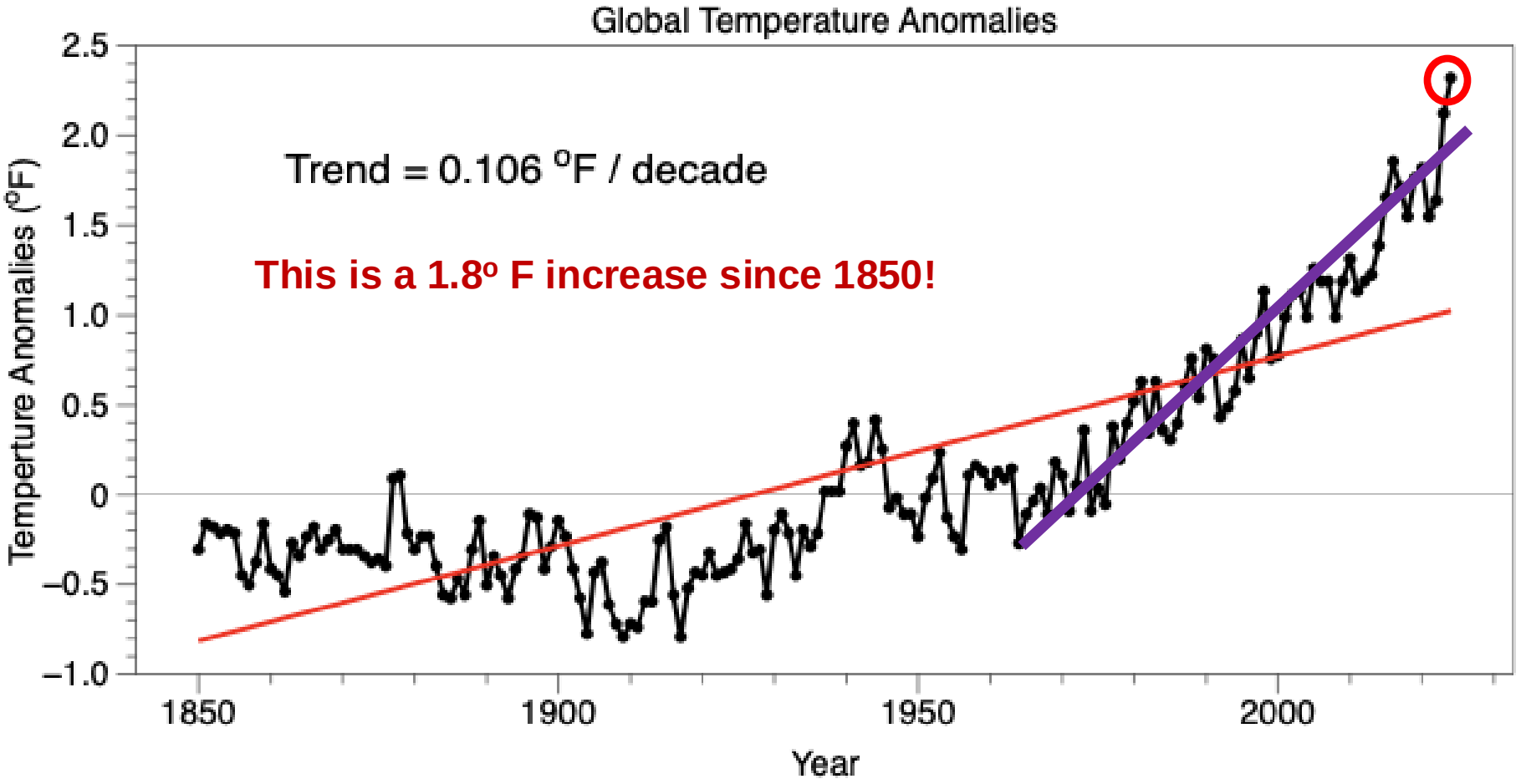


2023 Climate Change Solutions Act (HB 99)

- Creates a committee called Technical Climate Advisors
- Committee is responsible for:
  - Evaluating and updating the state's **sea level rise** projections
  - Evaluating and updating the state's **temperature** projections
  - Evaluating and updating the state's **precipitation** projections
- Projections shall be updated every **5 years** going forward

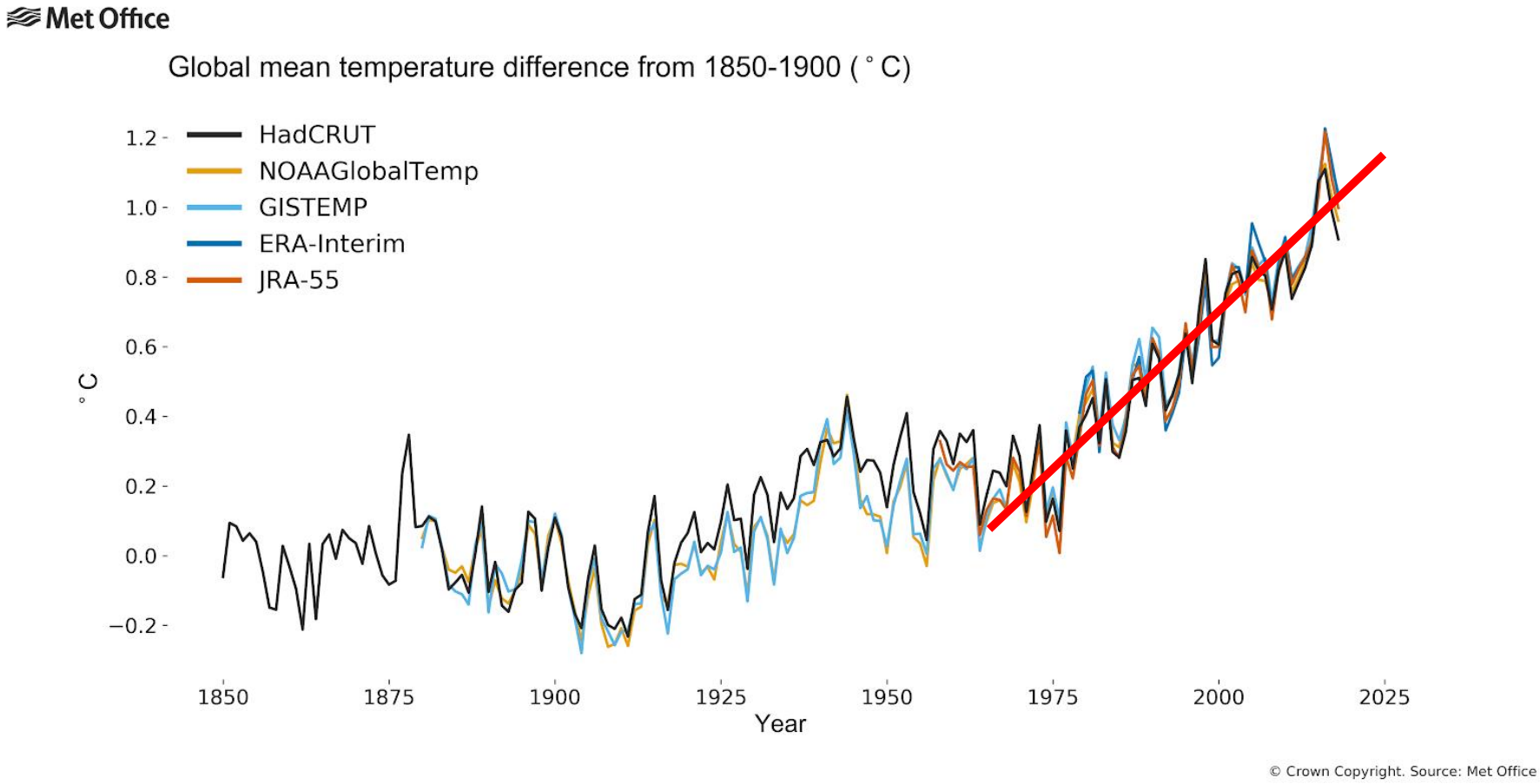
Delaware in the Context of Global Climate Change

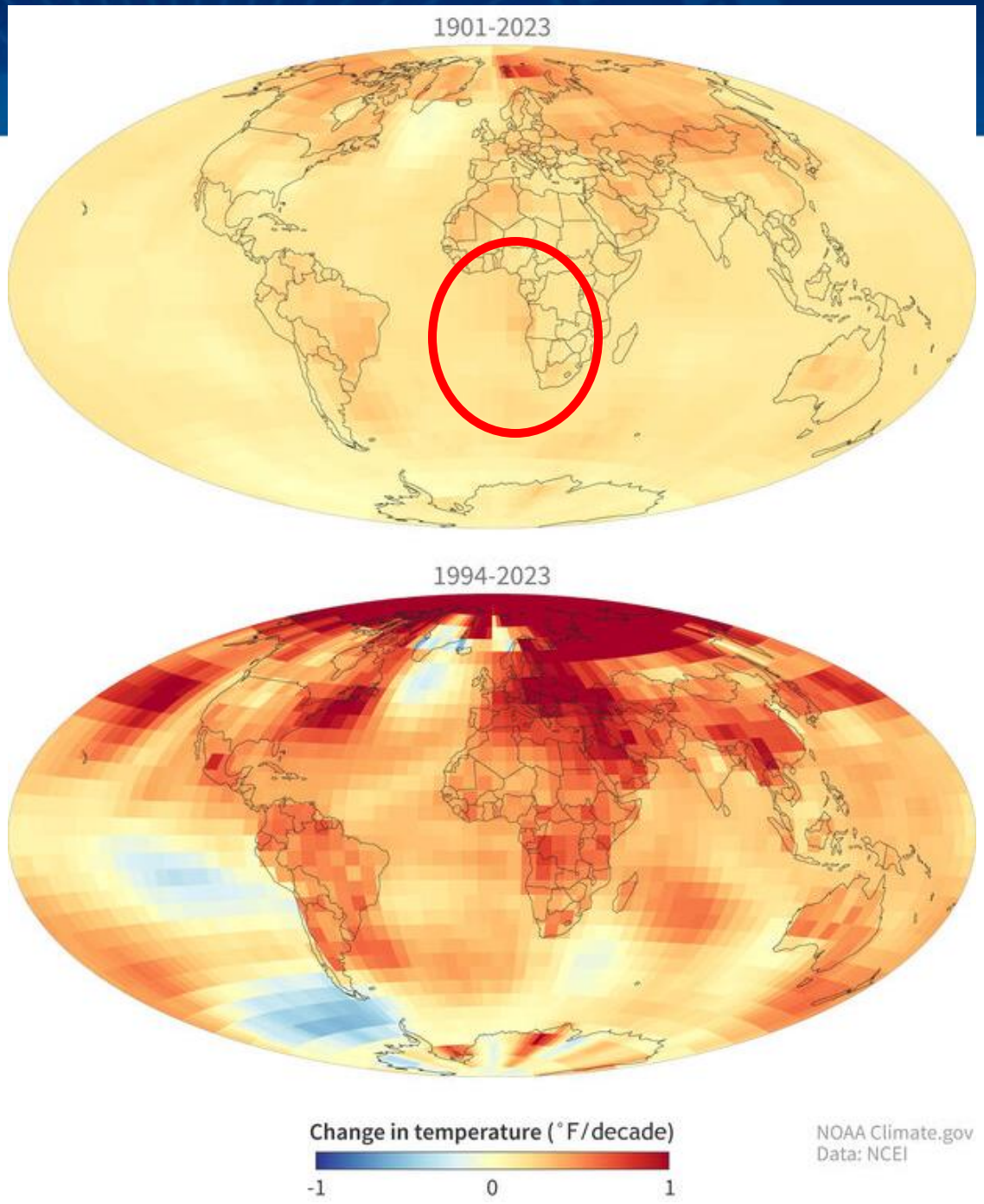
Global Temperature

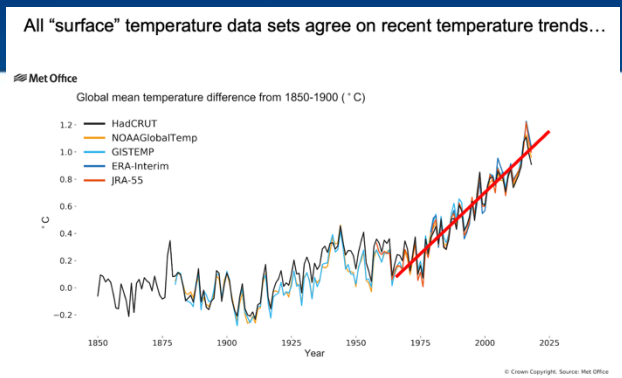


Anomalies are based on the 1901-2000 time period.

All “surface” temperature data sets agree on recent temperature trends…



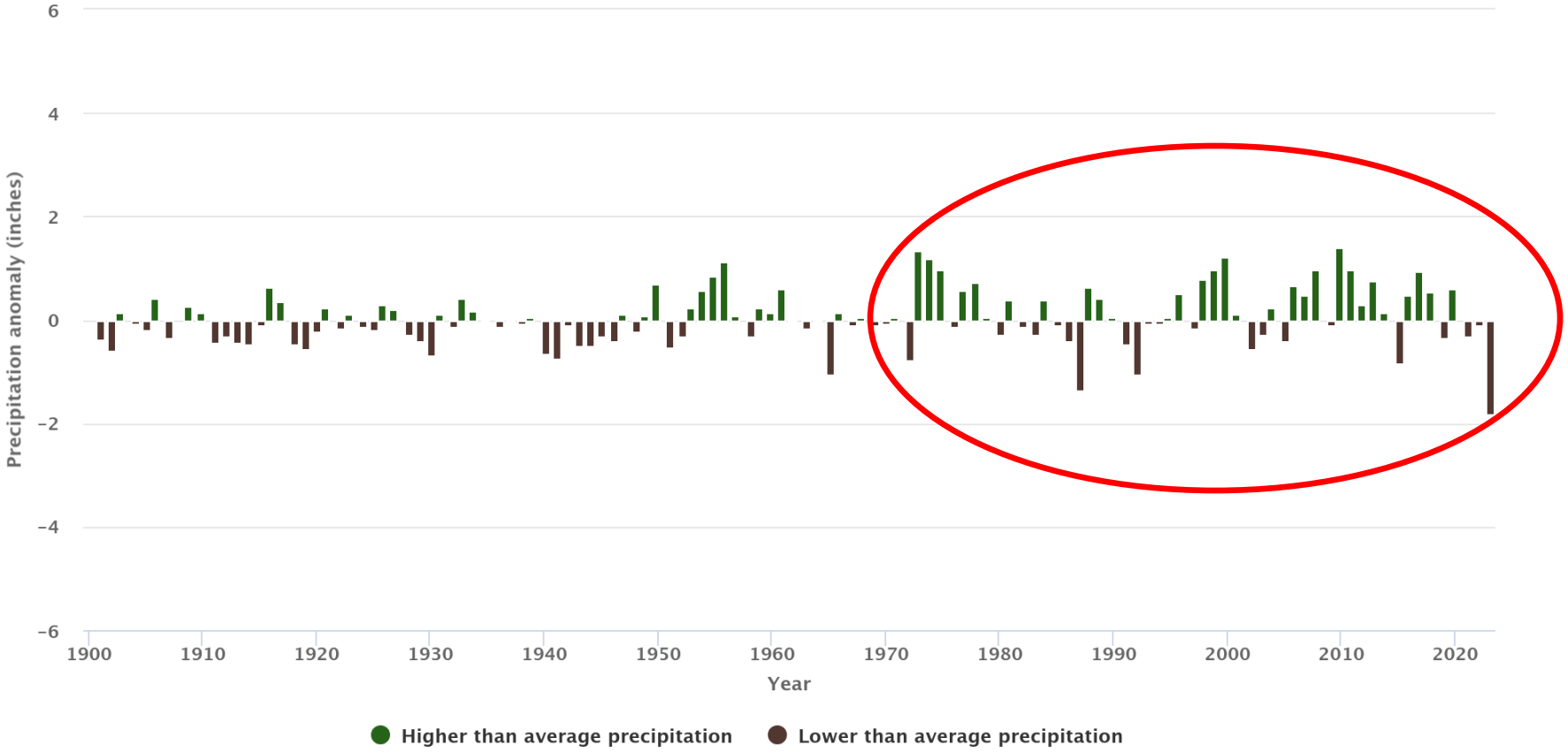




Warming over the last 30 years is much greater than the long-term trend!

Global Precipitation

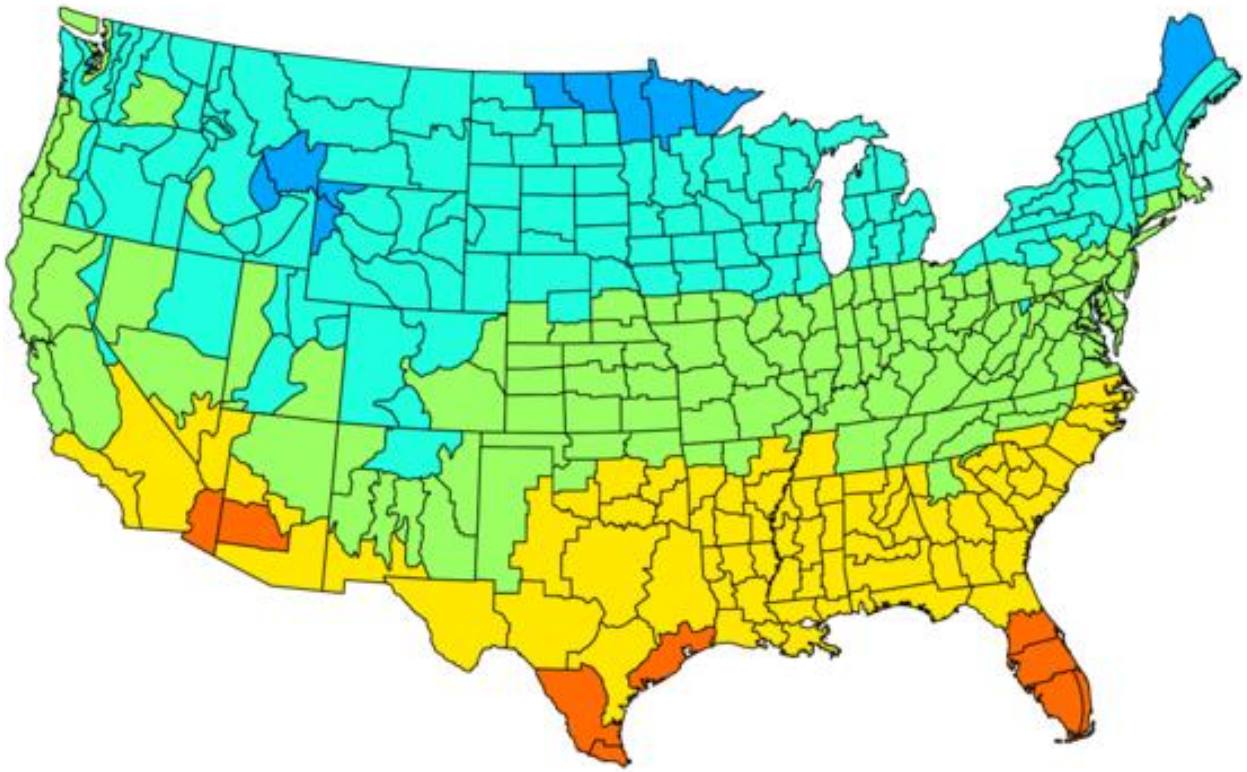
Precipitation Worldwide, 1901–2023



Data source: NOAA (National Oceanic and Atmospheric Administration). (2024). Extended version of GPCC dataset originally published in Blunden, J., Boyer, T., & Bartow-Gillies, E. (2023). State of the climate in 2022. *Bulletin of the American Meteorological Society*, *104*(9), S1–S516. https://doi.org/10.1175/2023BAMSStateoftheClimate.1
Web update: June 2024

For more information, visit www.epa.gov/climate-indicators.

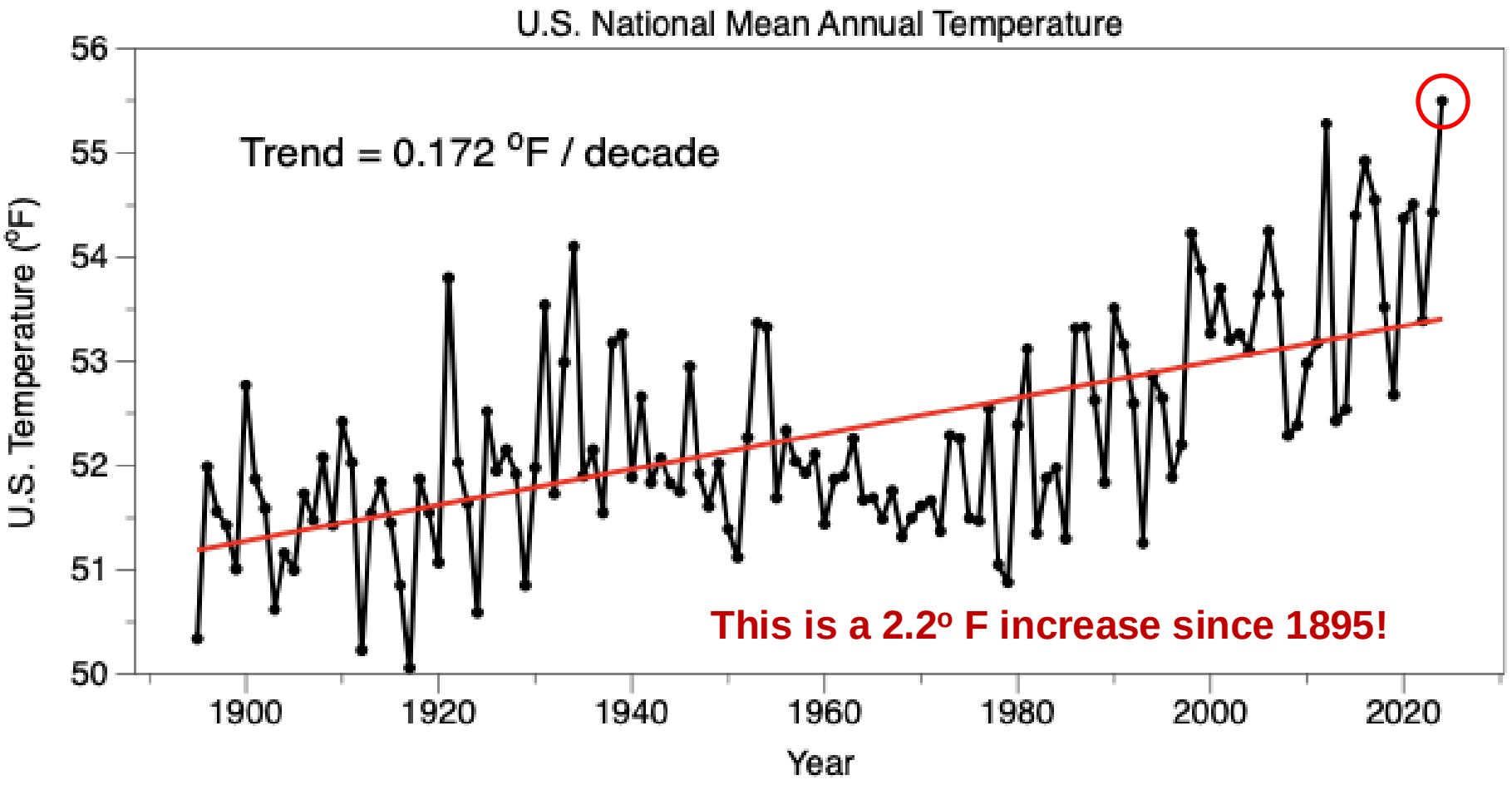
U.S. Temperature

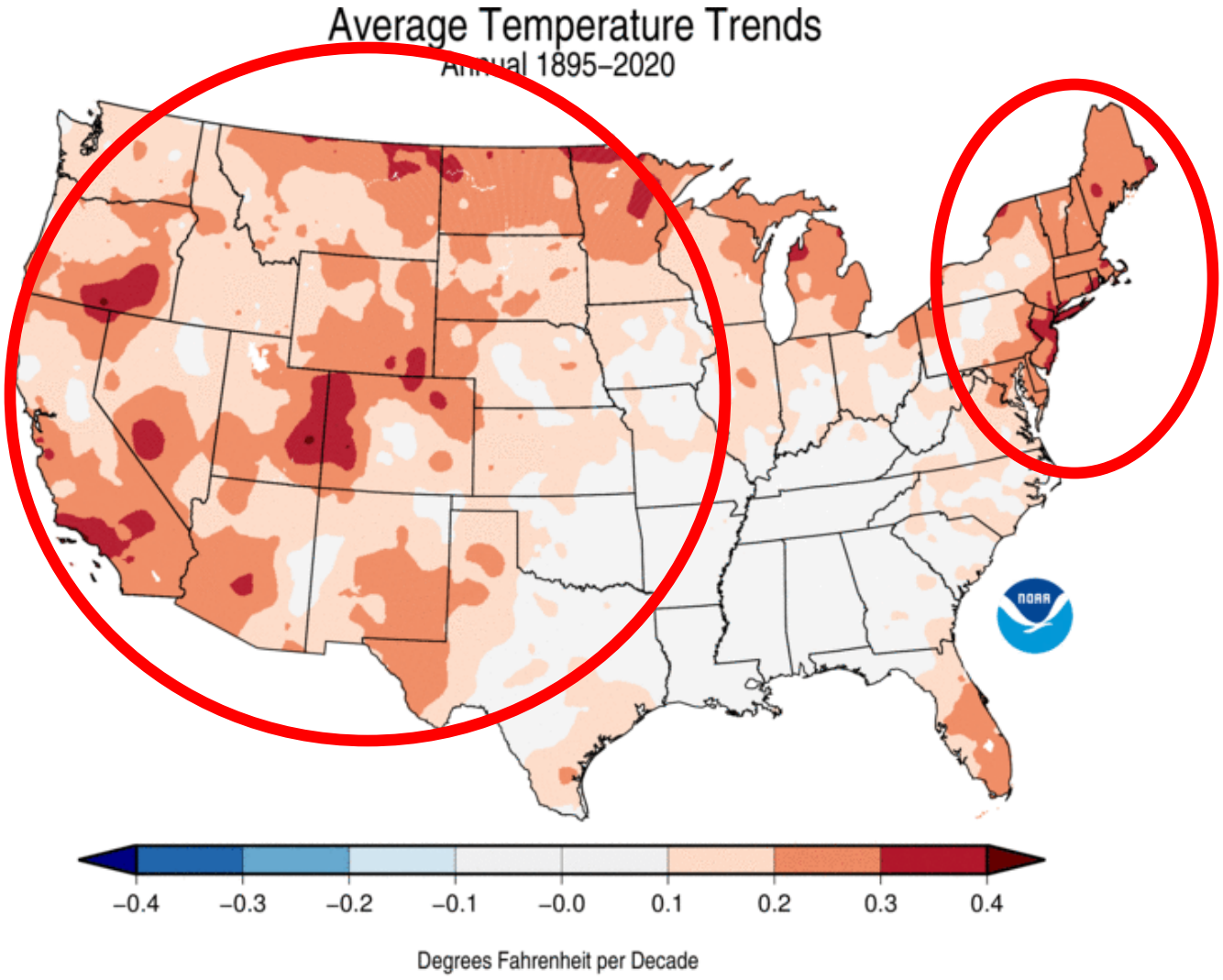


Mean Annual Temperature (F)

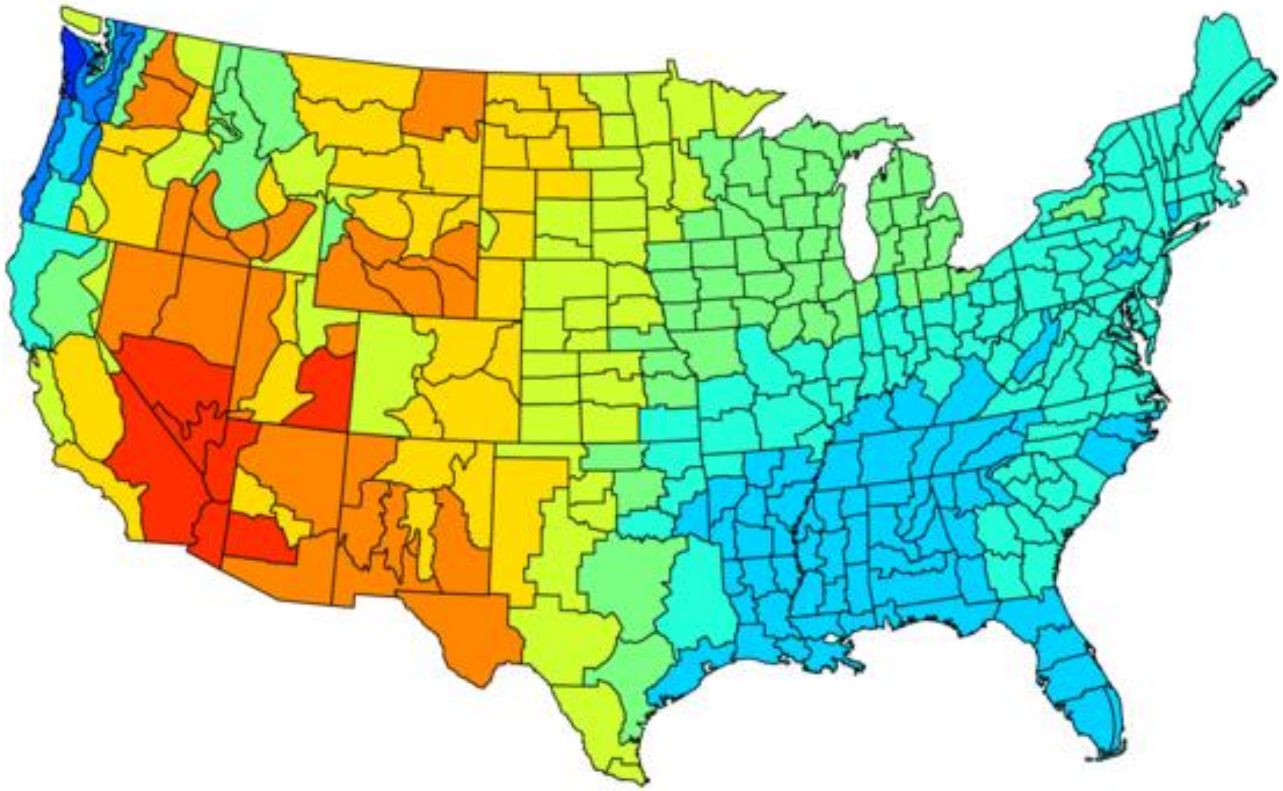
NOAA PSL and CIRES–CU

30. 40. 50. 60. 70. 80.

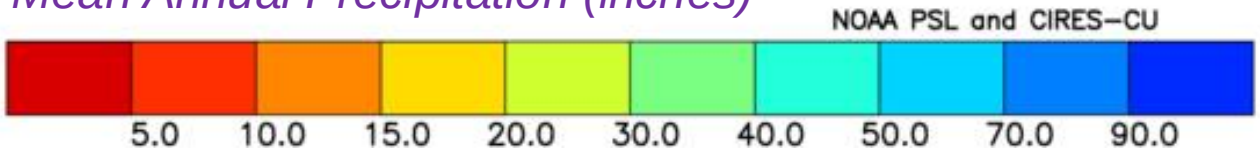

U.S. National Mean Annual Temperature
Trend = 0.172 °F / decade
This is a 2.2° F increase since 1895!
U.S. Temperature (°F)
56
55
54
53
52
51
50
1900
1920
1940
1960
1980
2000
2020
Year

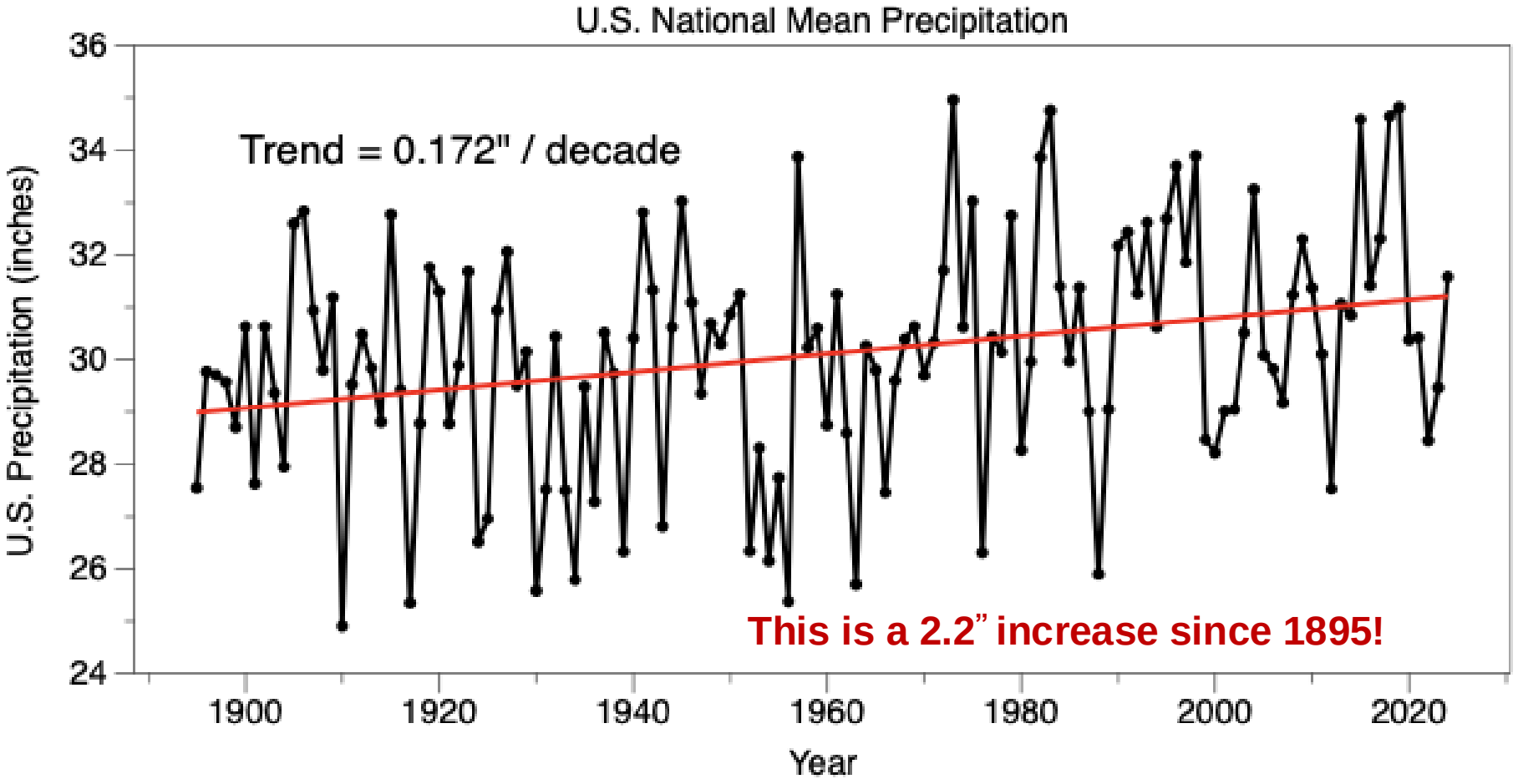

Average Temperature Trends
Annual 1895–2020
−0.4
−0.3
−0.2
−0.1
−0.0
0.1
0.2
0.3
0.4
Degrees Fahrenheit per Decade
Data Source: 5km Gridded Dataset (nClimGrid)
National Centers for Environmental Information

U.S. Precipitation

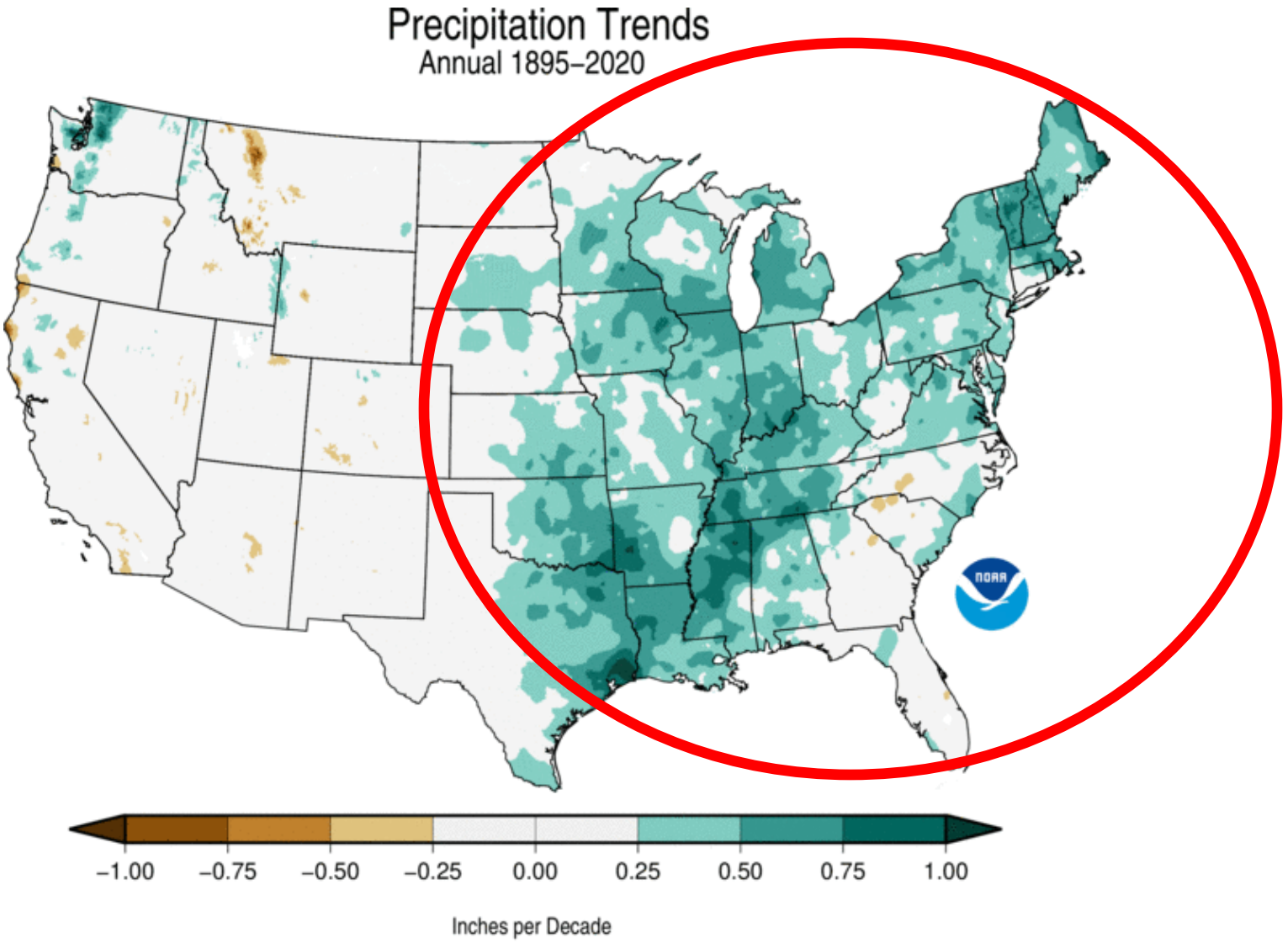


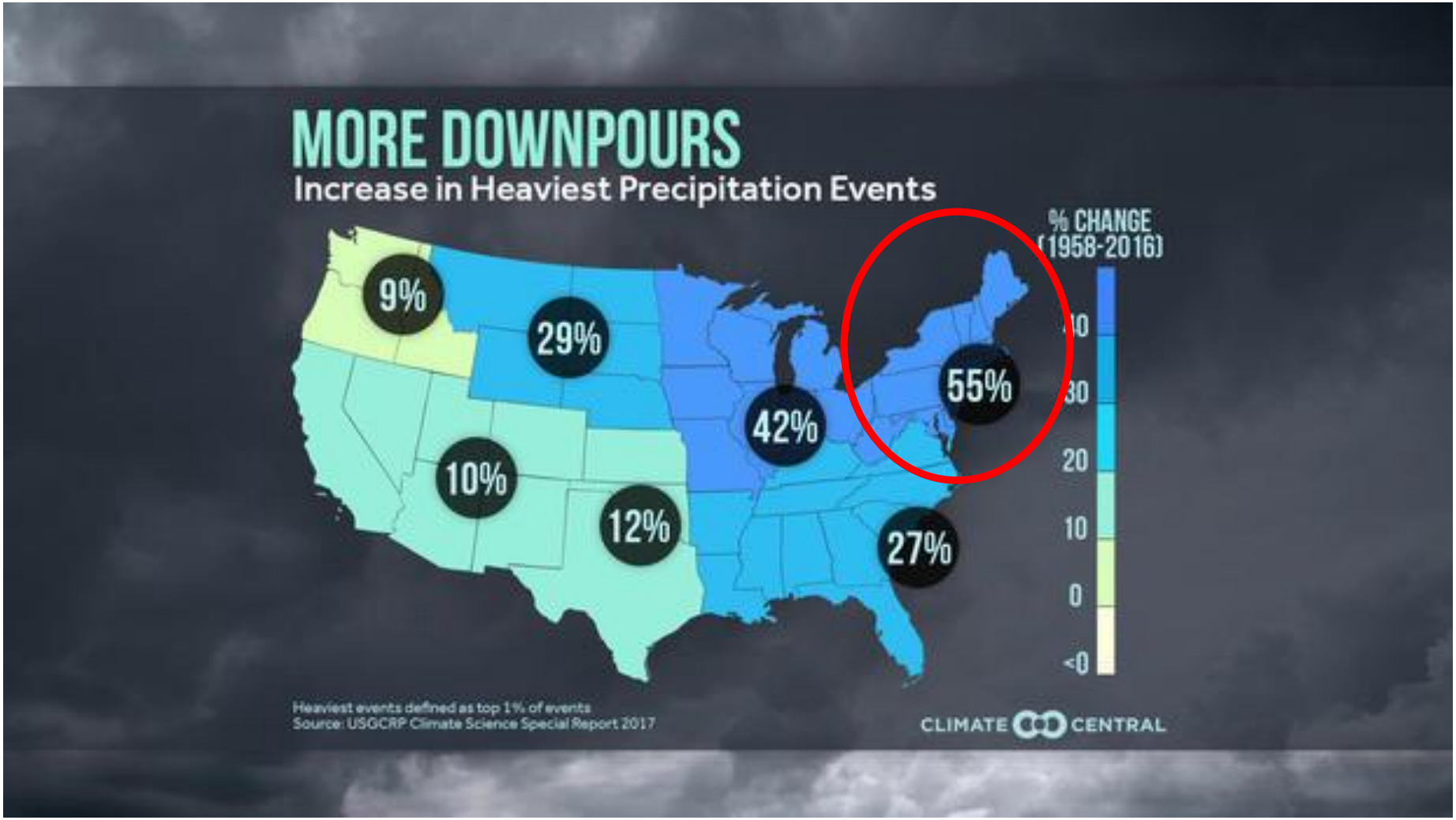
Mean Annual Precipitation (inches)



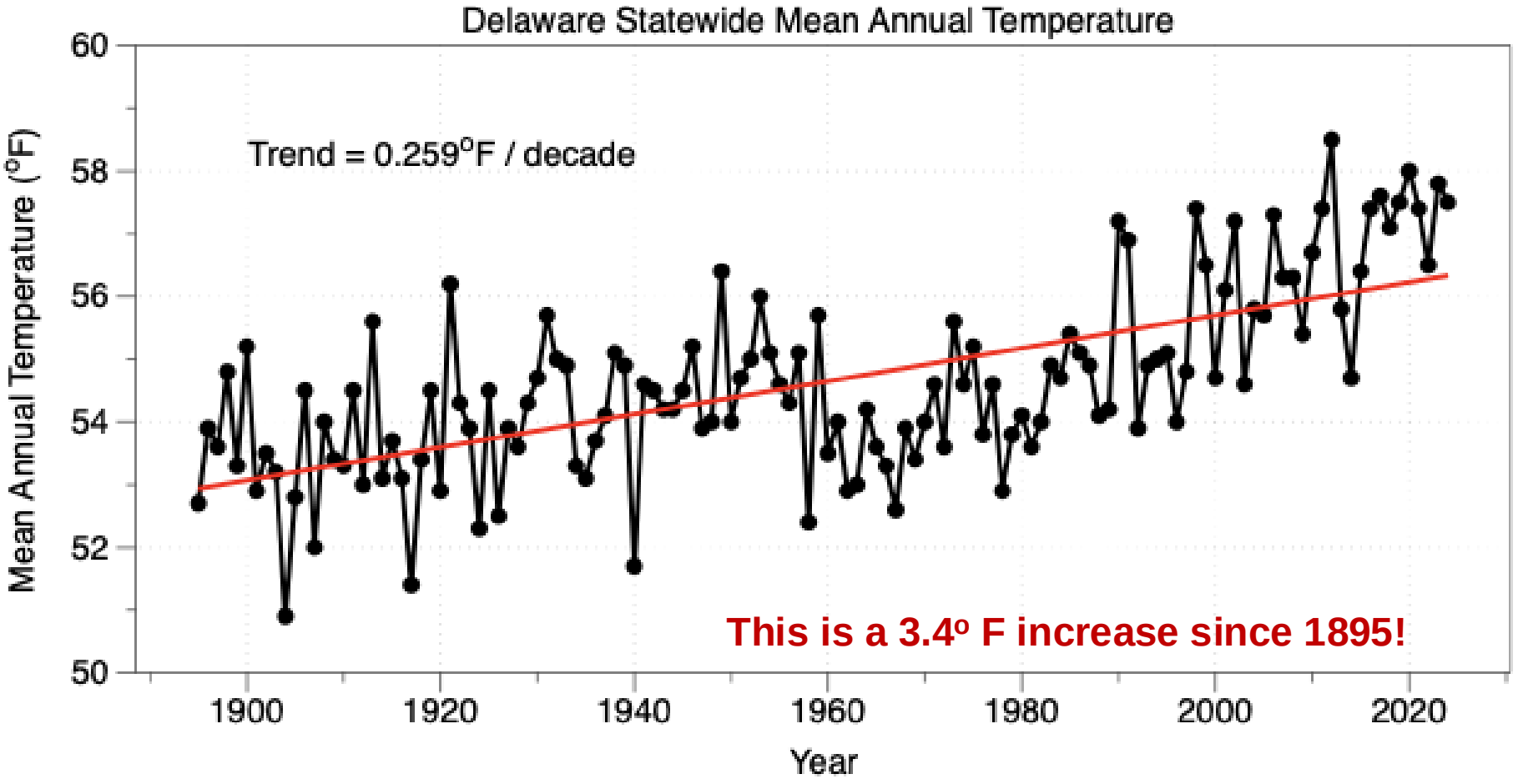


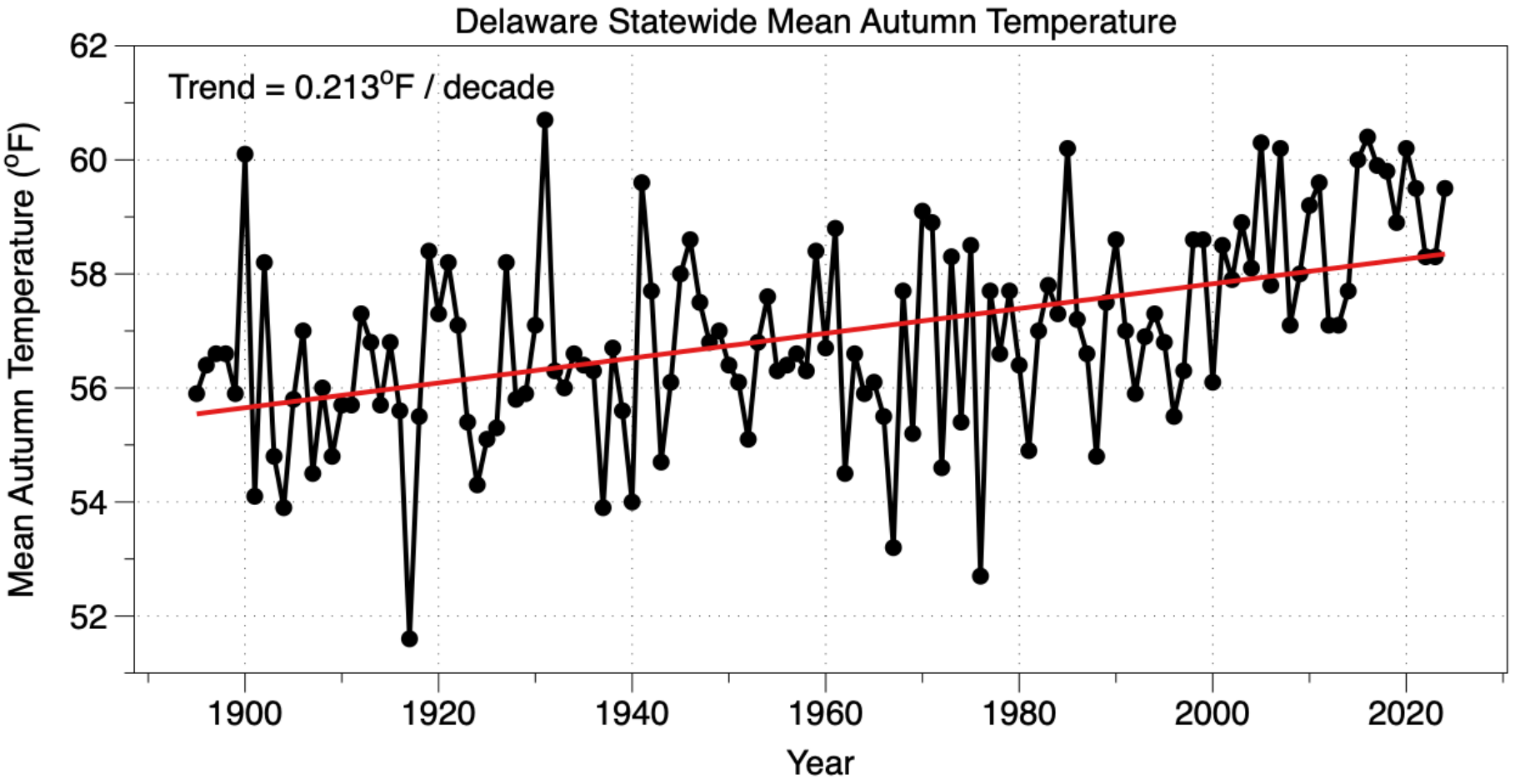
Since 1895 the United States has become warmer and wetter!


Precipitation Trends
Annual 1895–2020
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
Inches per Decade
Data Source: 5km Gridded Dataset (nClimGrid)
National Centers for Environmental Information


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

Delaware Temperature Changes

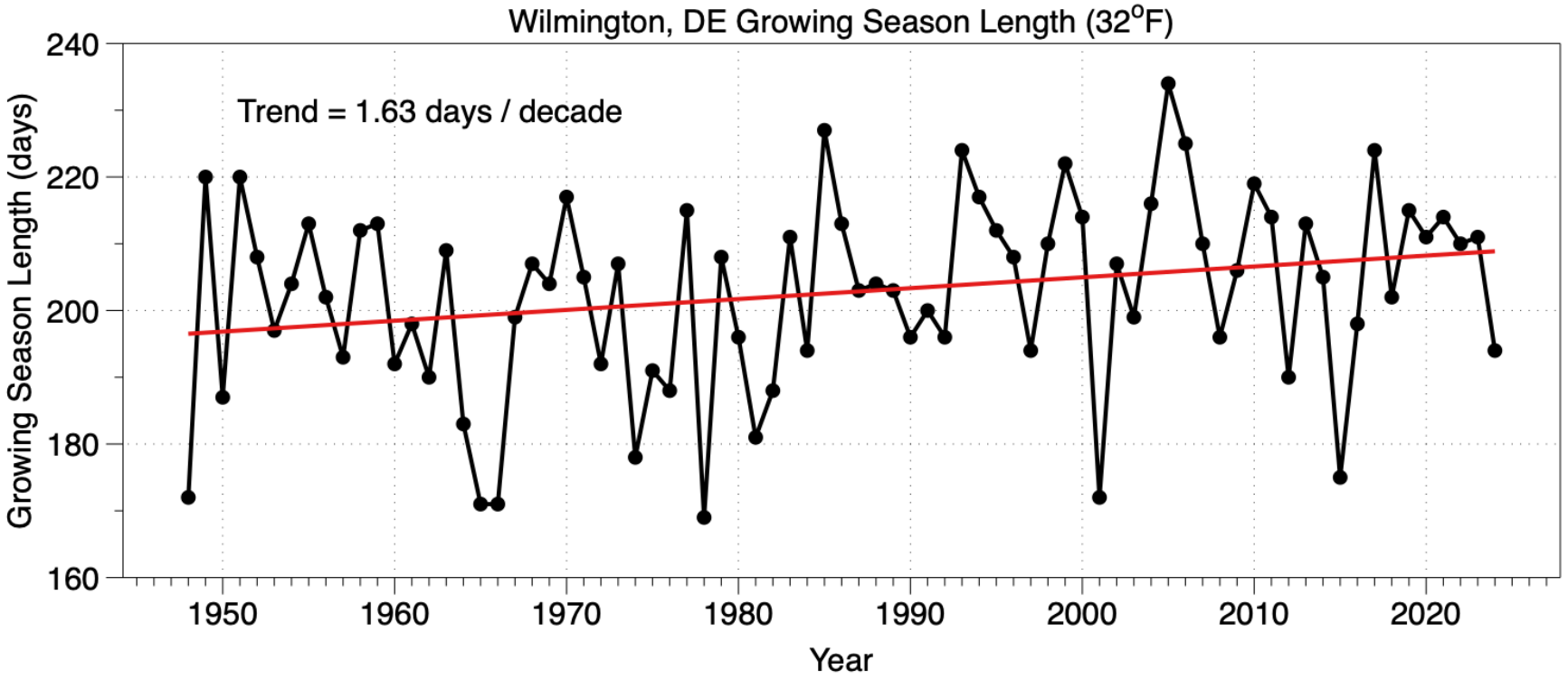

Delaware Statewide Mean Annual Temperature
Trend = 0.259°F / decade
Mean Annual Temperature (°F)
60
58
56
54
52
50
1900
1920
1940
1960
1980
2000
2020
Year
This is a 3.4° F increase since 1895!



All seasons have seen a 3° F to 4° F warming since 1895!

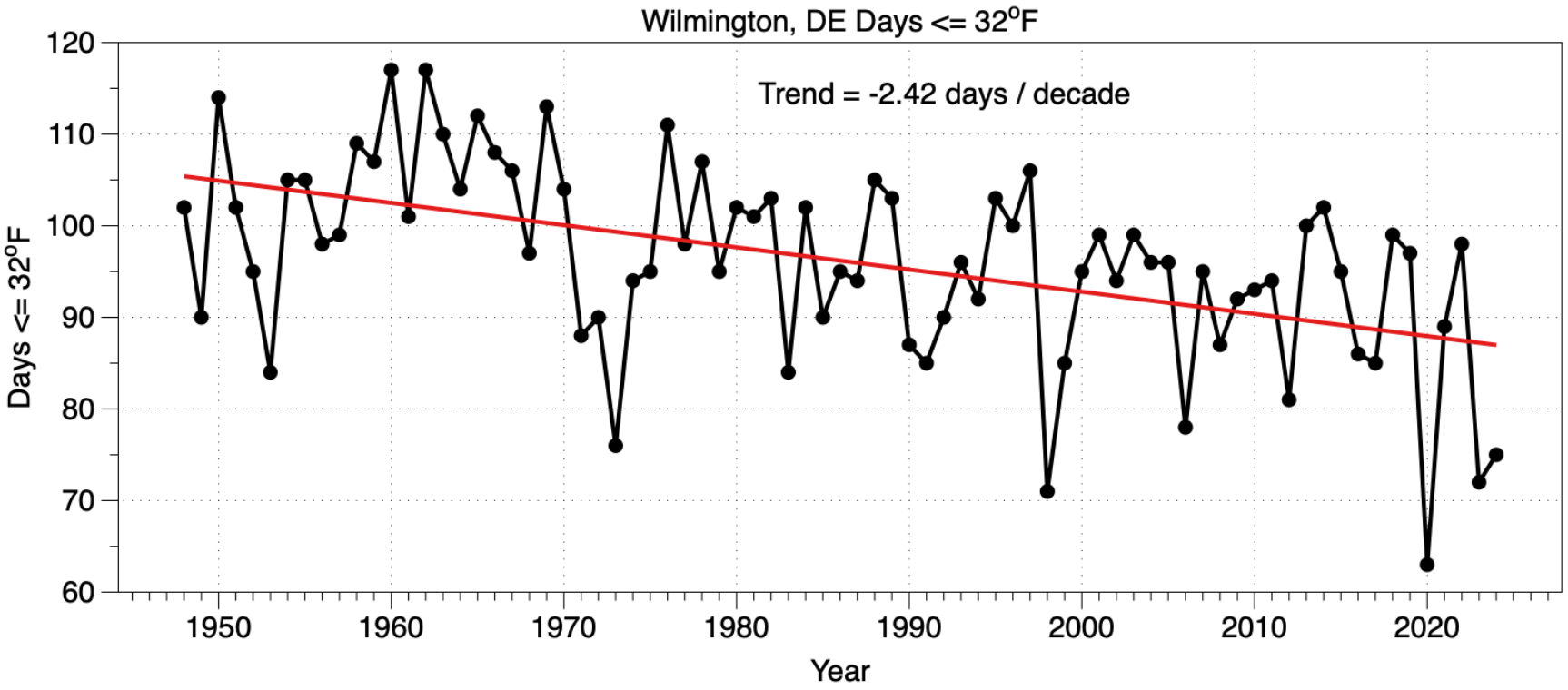
Impact of Temperature Changes

Increase in Growing Season Length

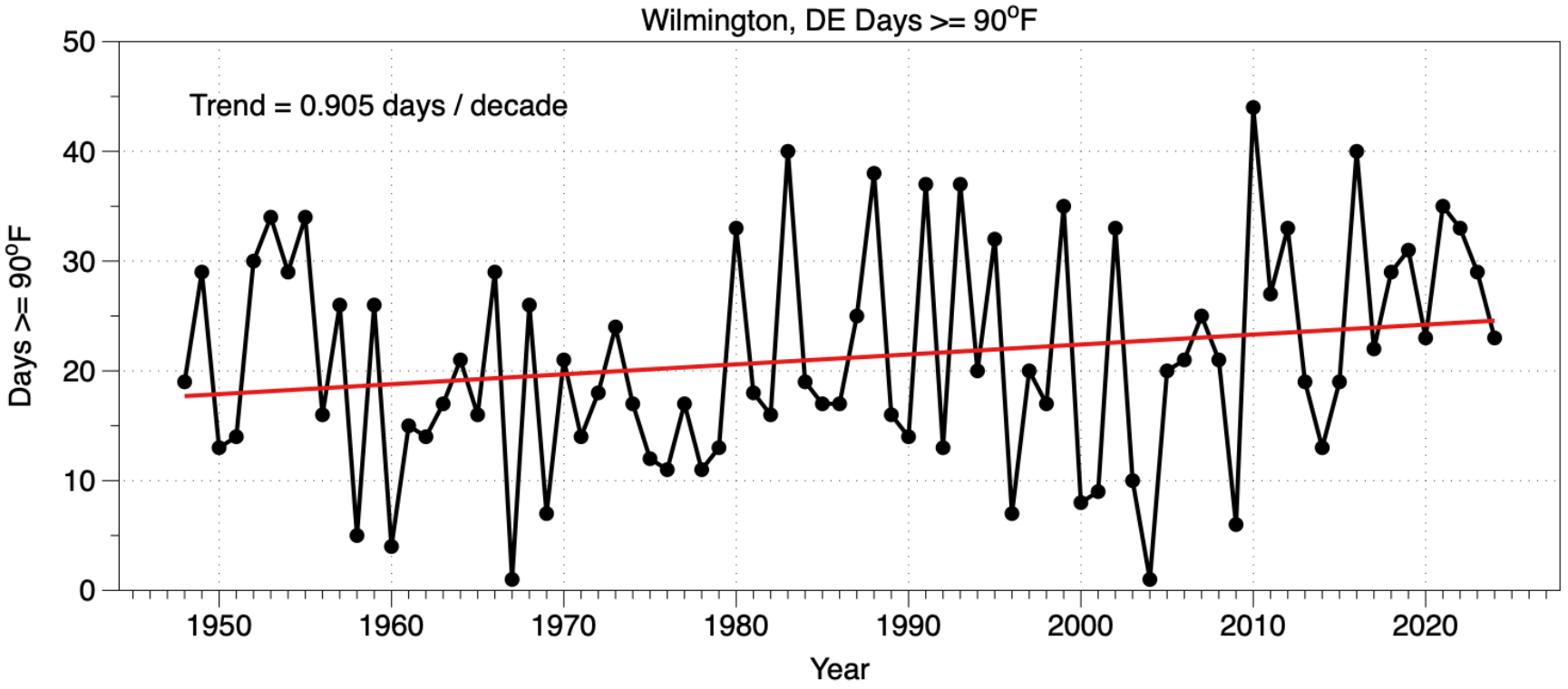


The growing season is defined as the number of days between the last spring freeze and the first autumn freeze.

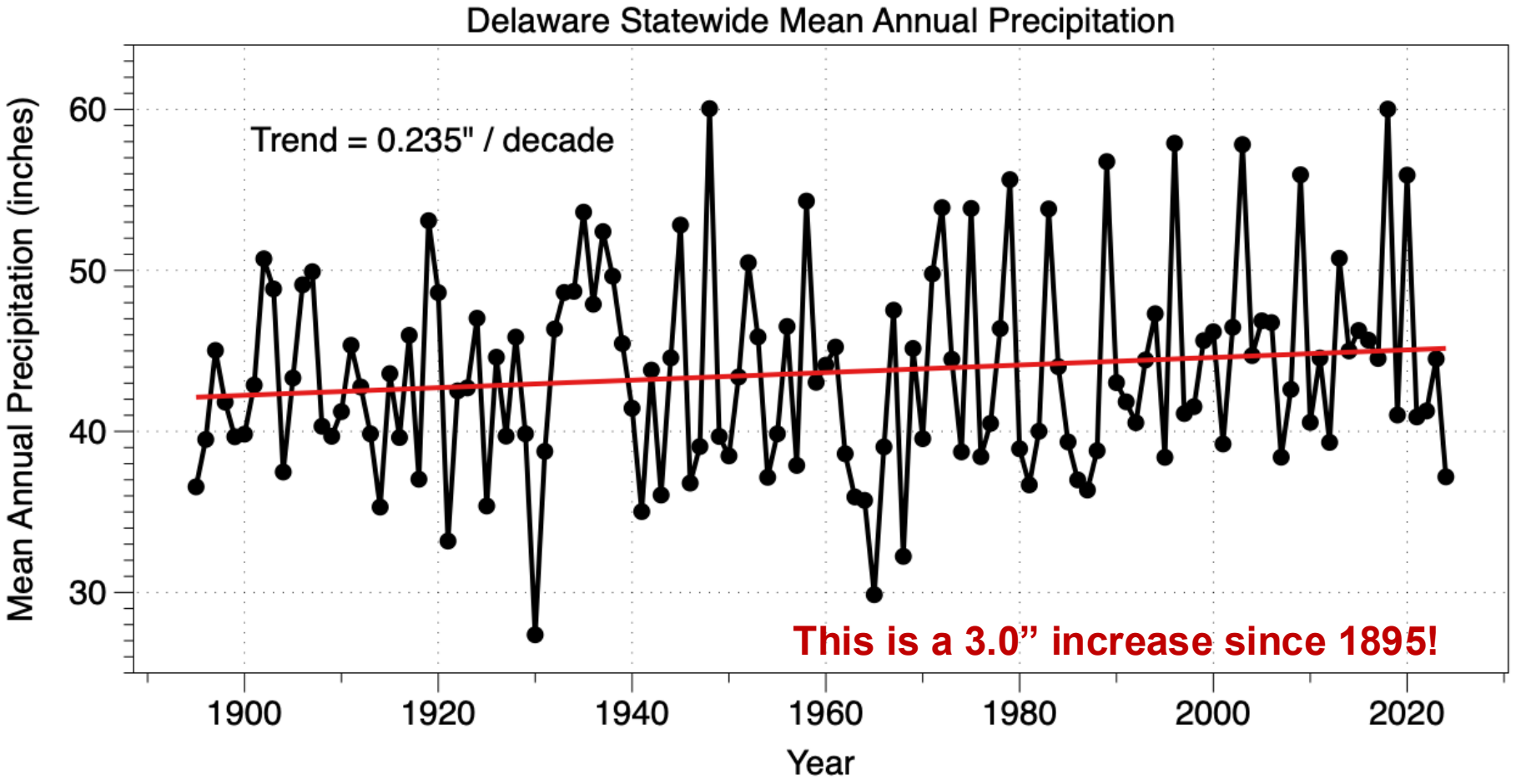
Number of days with Min Temps <= 32°

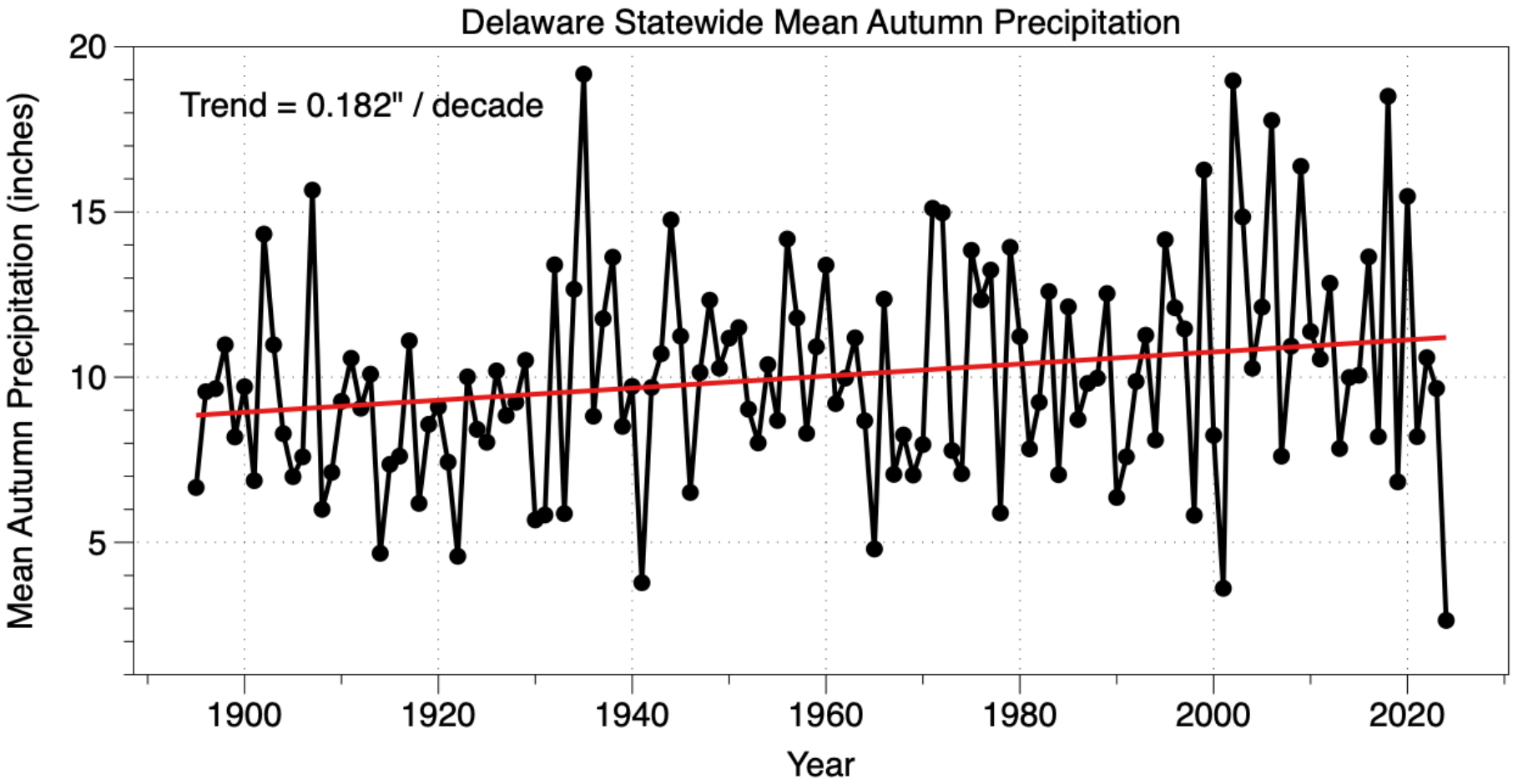


Number of days with Max Temps >= 90^{o}

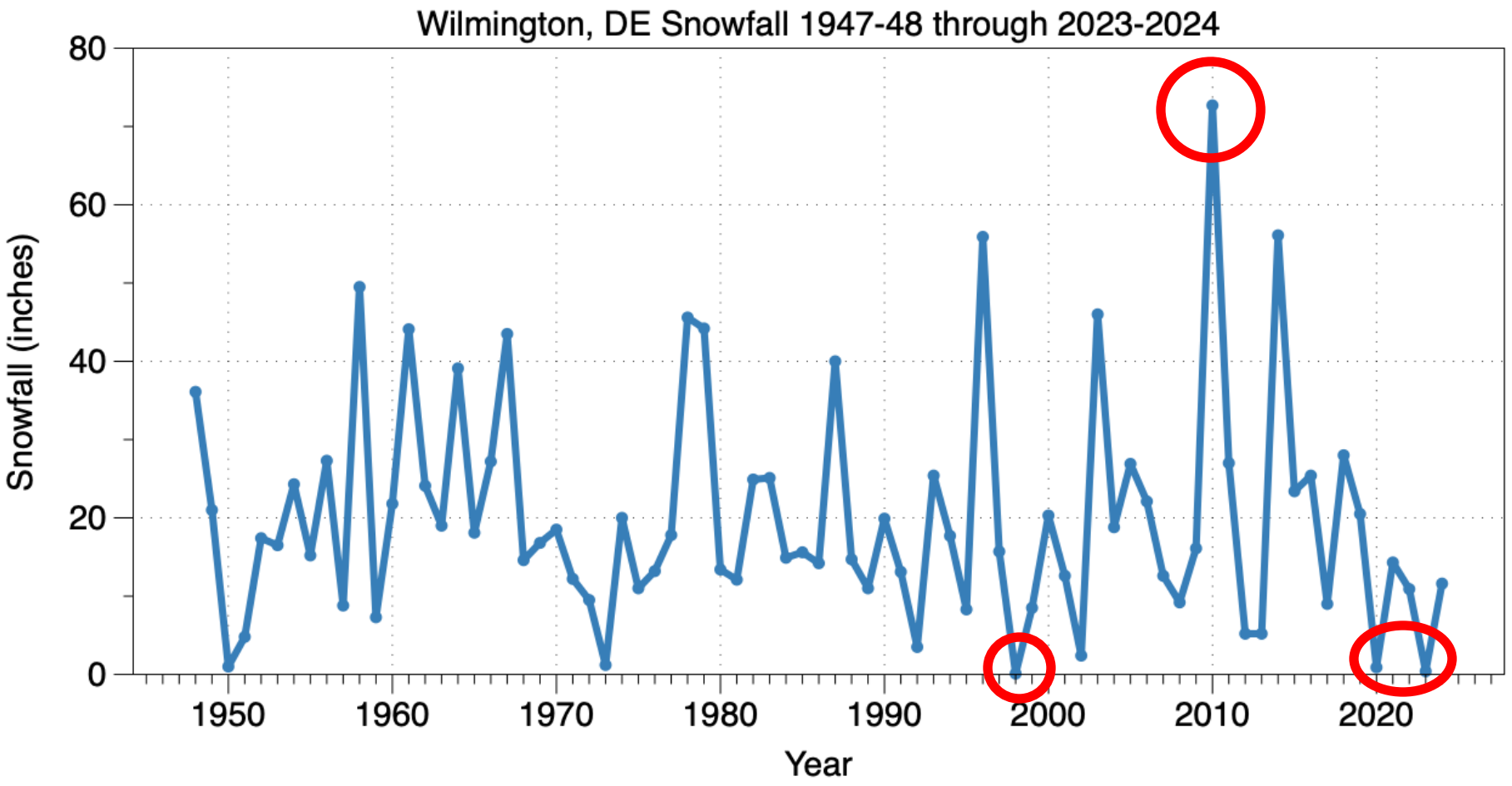


Delaware Precipitation Changes

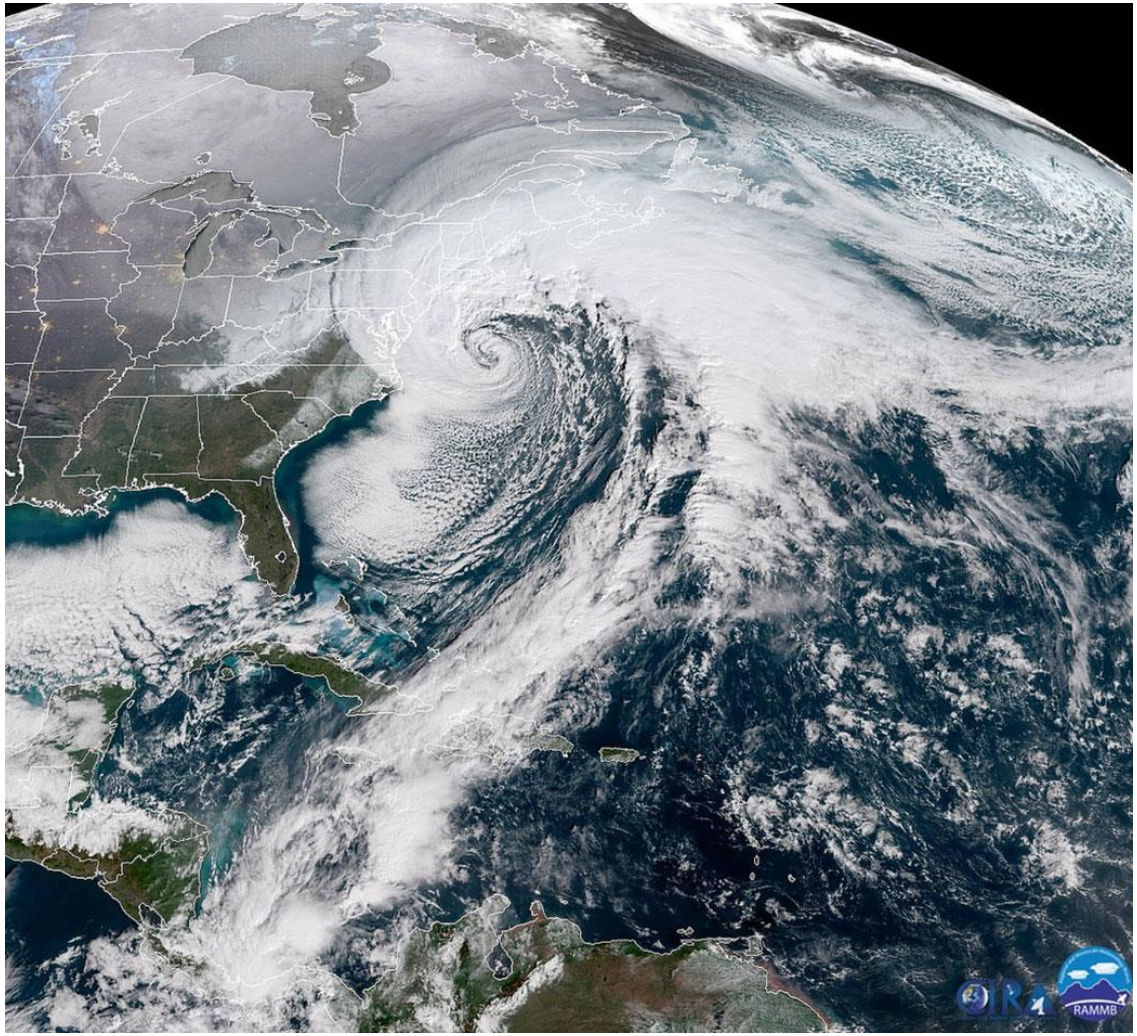

Delaware Statewide Mean Annual Precipitation
Trend = 0.235" / decade
This is a 3.0” increase since 1895!
Mean Annual Precipitation (inches)
60
50
40
30
1900
1920
1940
1960
1980
2000
2020
Year


Delaware Statewide Mean Autumn Precipitation
Trend = 0.182" / decade
Mean Autumn Precipitation (inches)
20
15
10
5
1900
1920
1940
1960
1980
2000
2020
Year

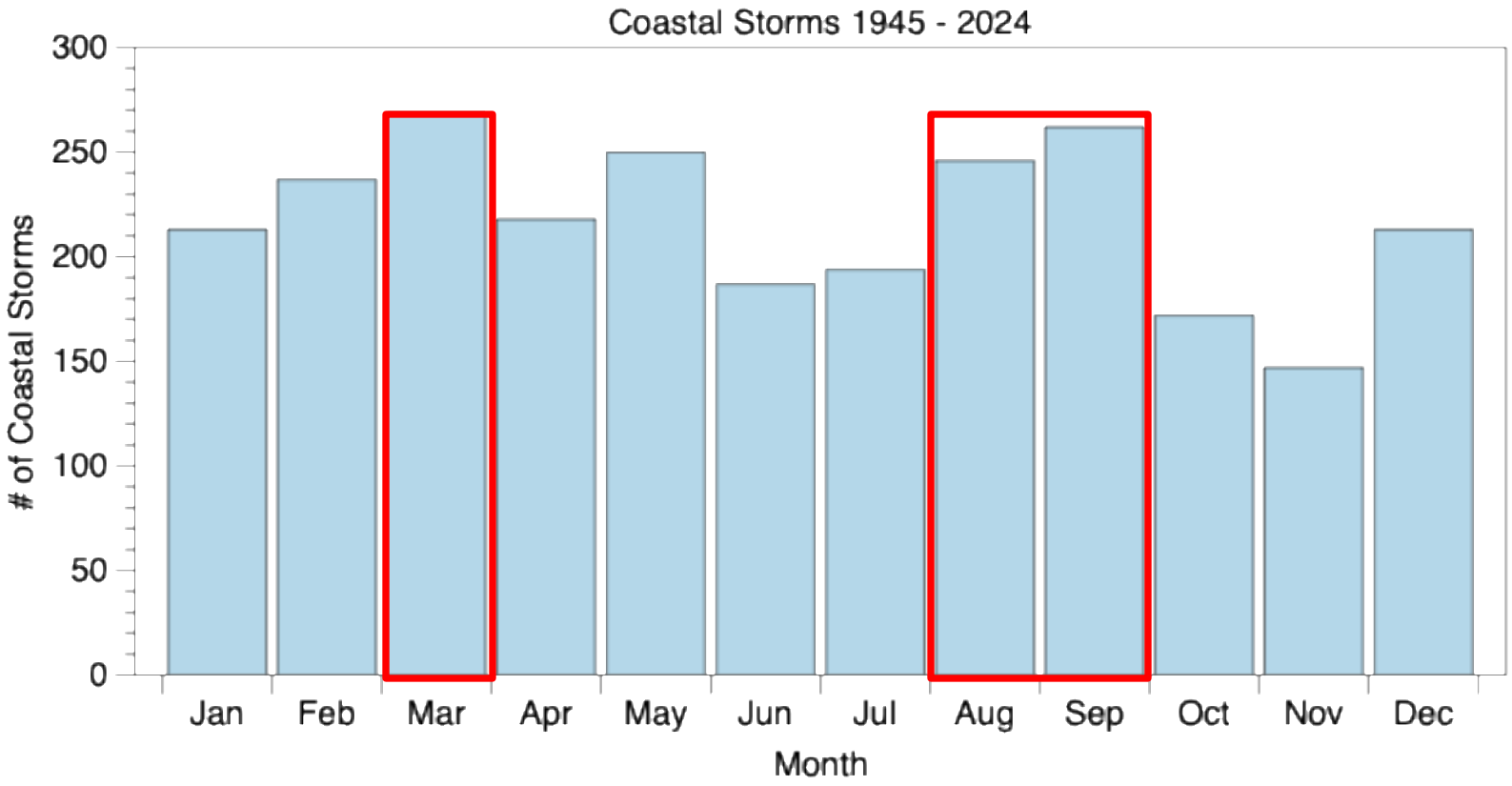
Snowfall?


Wilmington, DE Snowfall 1947-48 through 2023-2024
Snowfall (inches)
0
20
40
60
80
1950
1960
1970
1980
1990
2000
2010
2020
Year

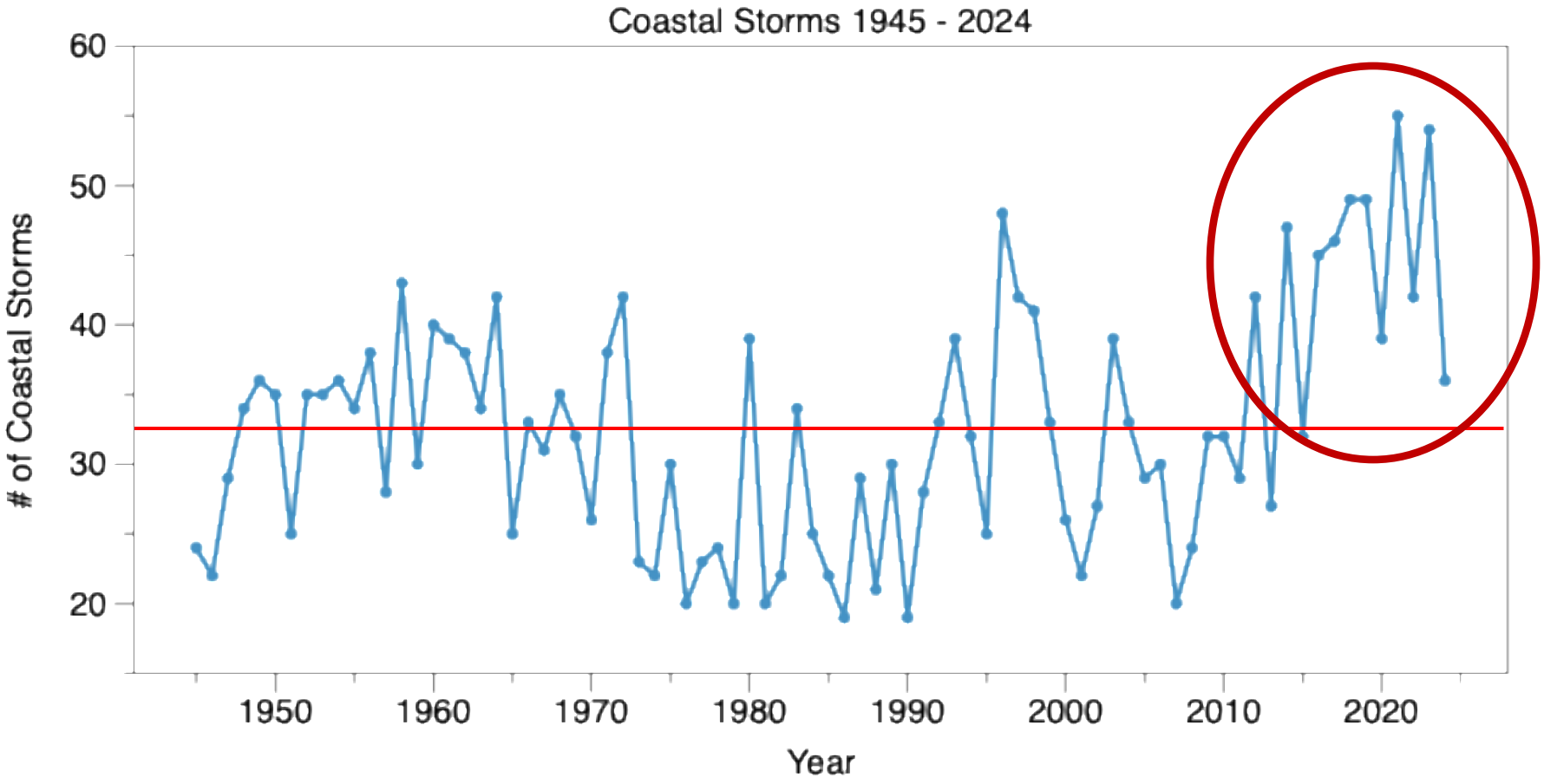
Delaware Coastal Storm Climatology 1945 - 2024



Annual Cycle of Delaware Coastal Storms 1945 - 2024

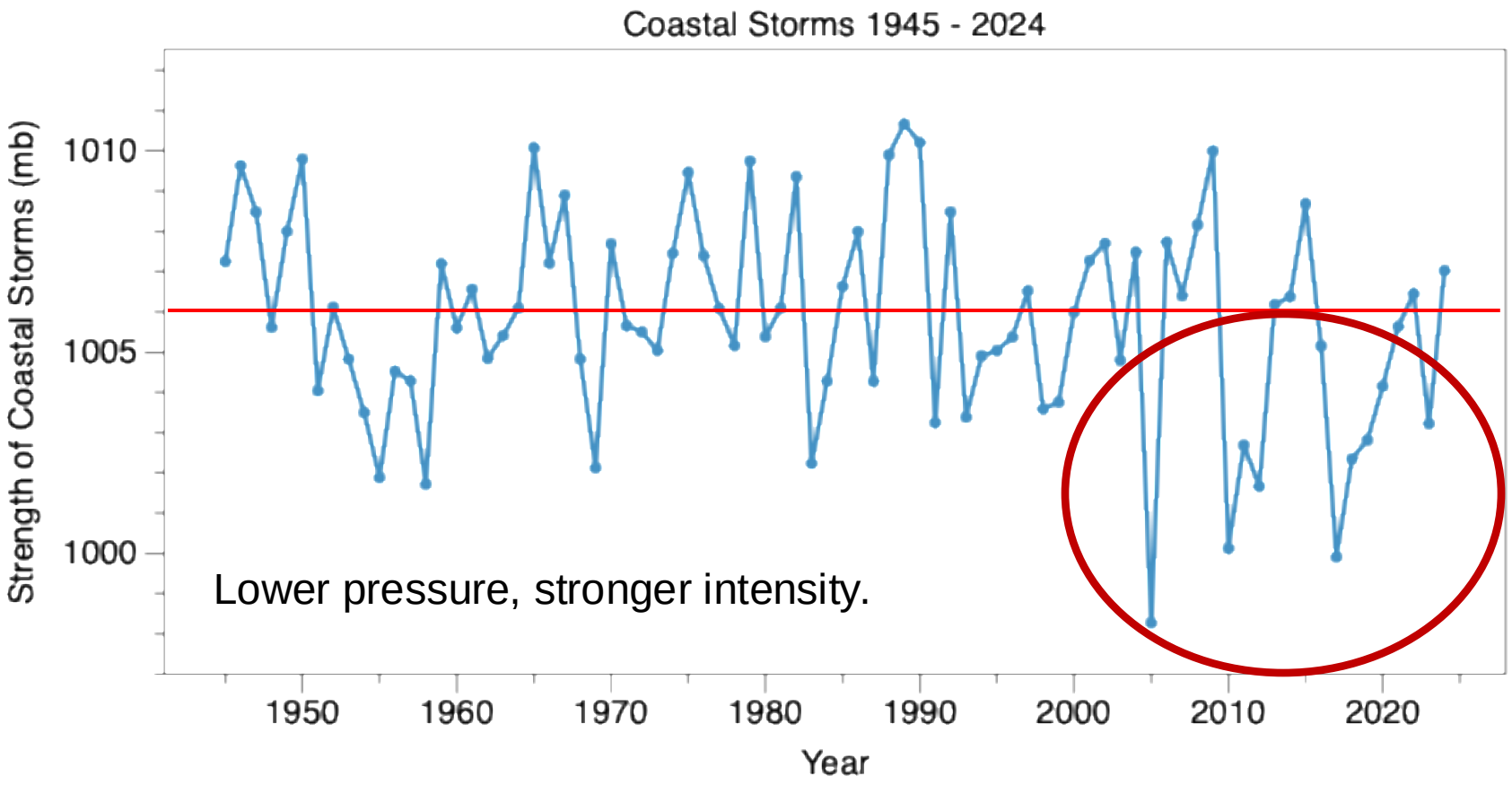


Coastal Storm Frequency 1945 - 2024



We average approximately 33 coastal storms each year.

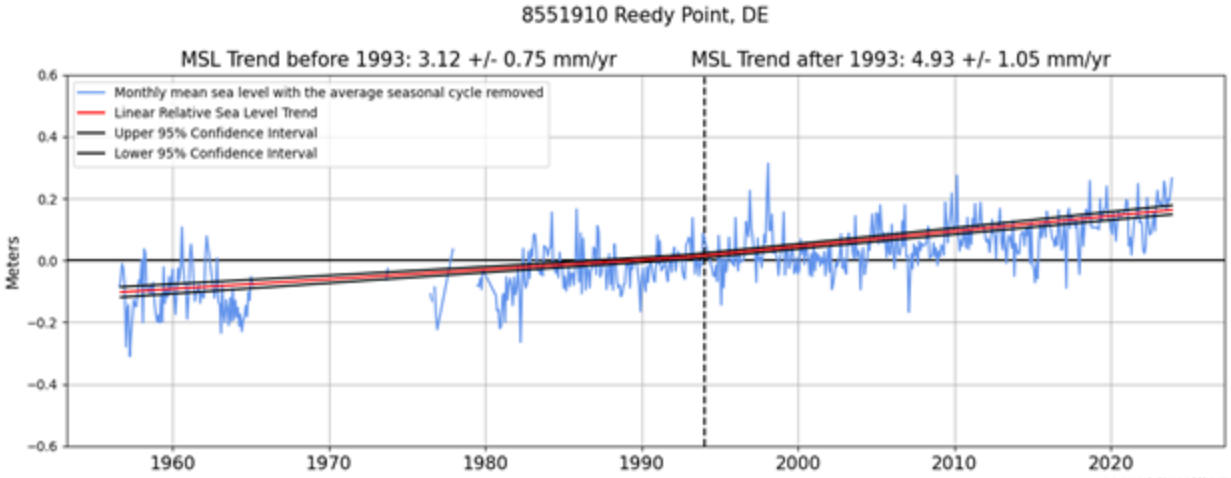
Coastal Storm Intensity 1945 - 2024



Since 2000 there has been a tendency toward more frequent and stronger coastal storms.

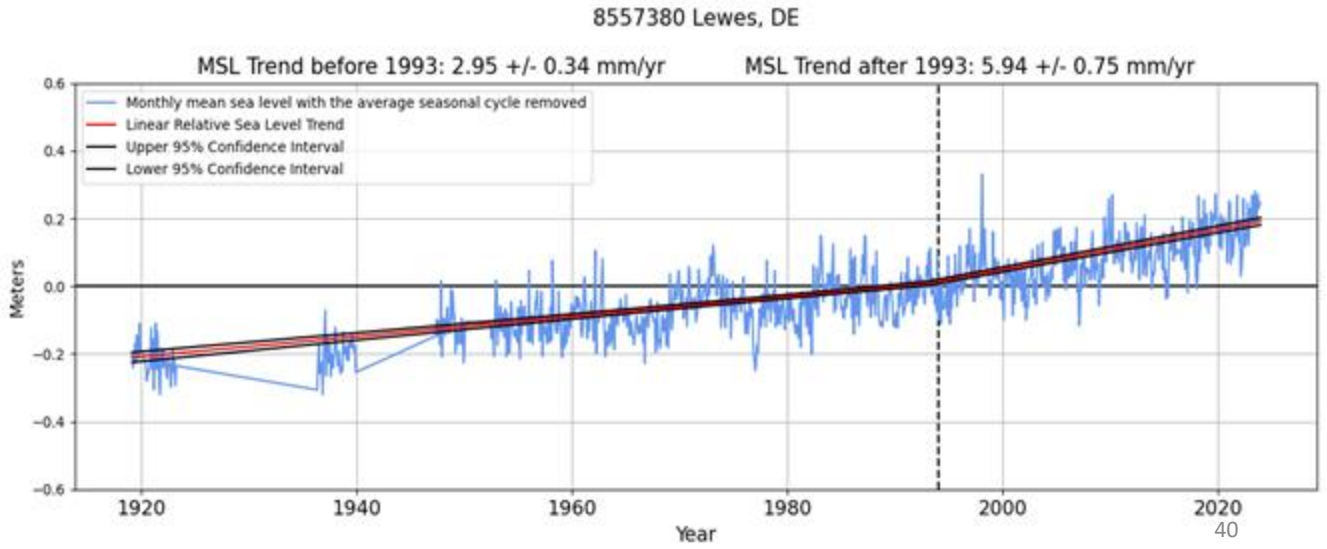
What About Sea Level Rise?

Mean Sea Level - Trends



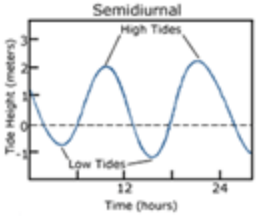
	Long-term Rate	Rate since 1993
Reedy Pt	3.91 mm/yr	**4.93 mm/yr**
Lewes	3.71 mm/yr	**5.94 mm/yr**

For Lewes that is a trend of 2.34” / decade

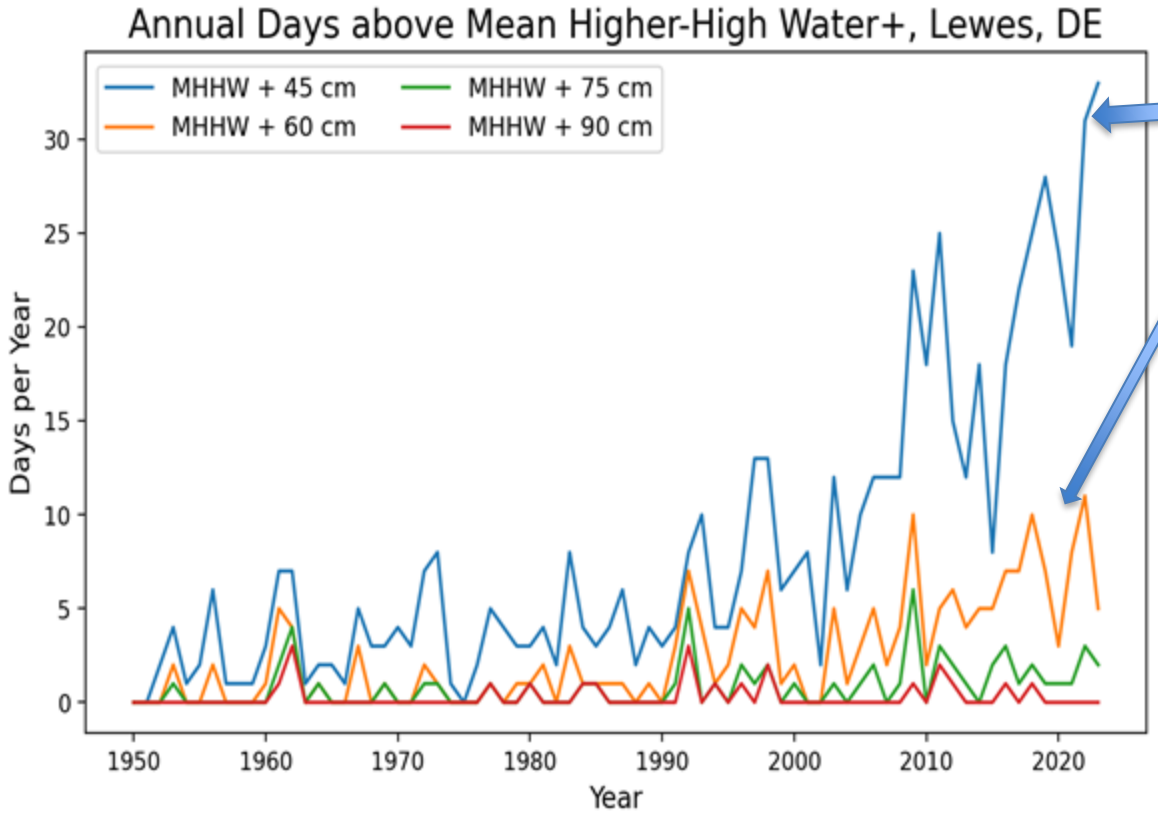


Coastal Flood Frequency – Observed Trends

MHHW = Mean Higher-High Water



15 cm ≈ ½ Foot



NWS Flood Advisory Levels

Closest level to Minor
41 cm / 1.35 ft

Closest level to Moderate
72 cm / 2.36 ft

Major = 1.02 m / 3.35 ft
(Very rarely occurs)

Values are above MHHW

Climate Change in our Region 1895 – 2020

	Temperature	Precipitation
Annual	+	+
Winter	+	N
Spring	+	N
Summer	+	N
Autumn	+	+

Looking at Delaware's Climate Future

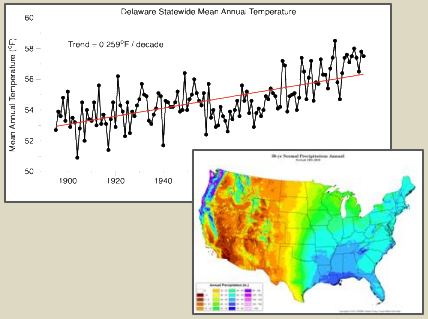
Historical Climate Analysis…

- Helps to identify and understand Delaware's climate challenges and overall environmental conditions.
- Provides the framework and context for a range of possible weather-related hazards and impacts, including:
  - Floods
  - Droughts
  - Heatwaves/Air Quality
  - Warm Night spells
  - Energy impacts (heating/cooling)
  - Severe Storms

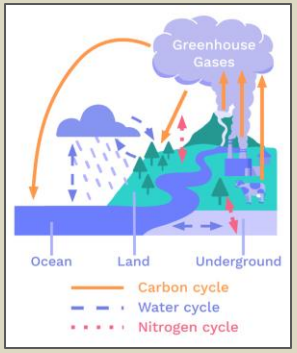
Planning for the Future…

- How do we plan for future?
  - Need data that show potential future risks

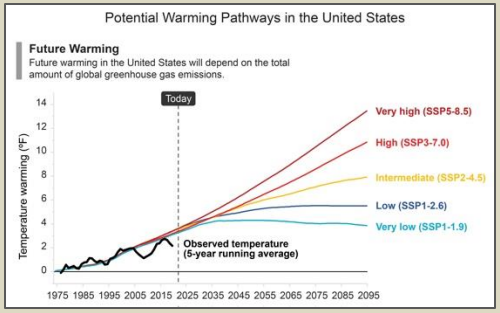
- Global Climate Models (GCMs)



Historical observation provides a basic framework.

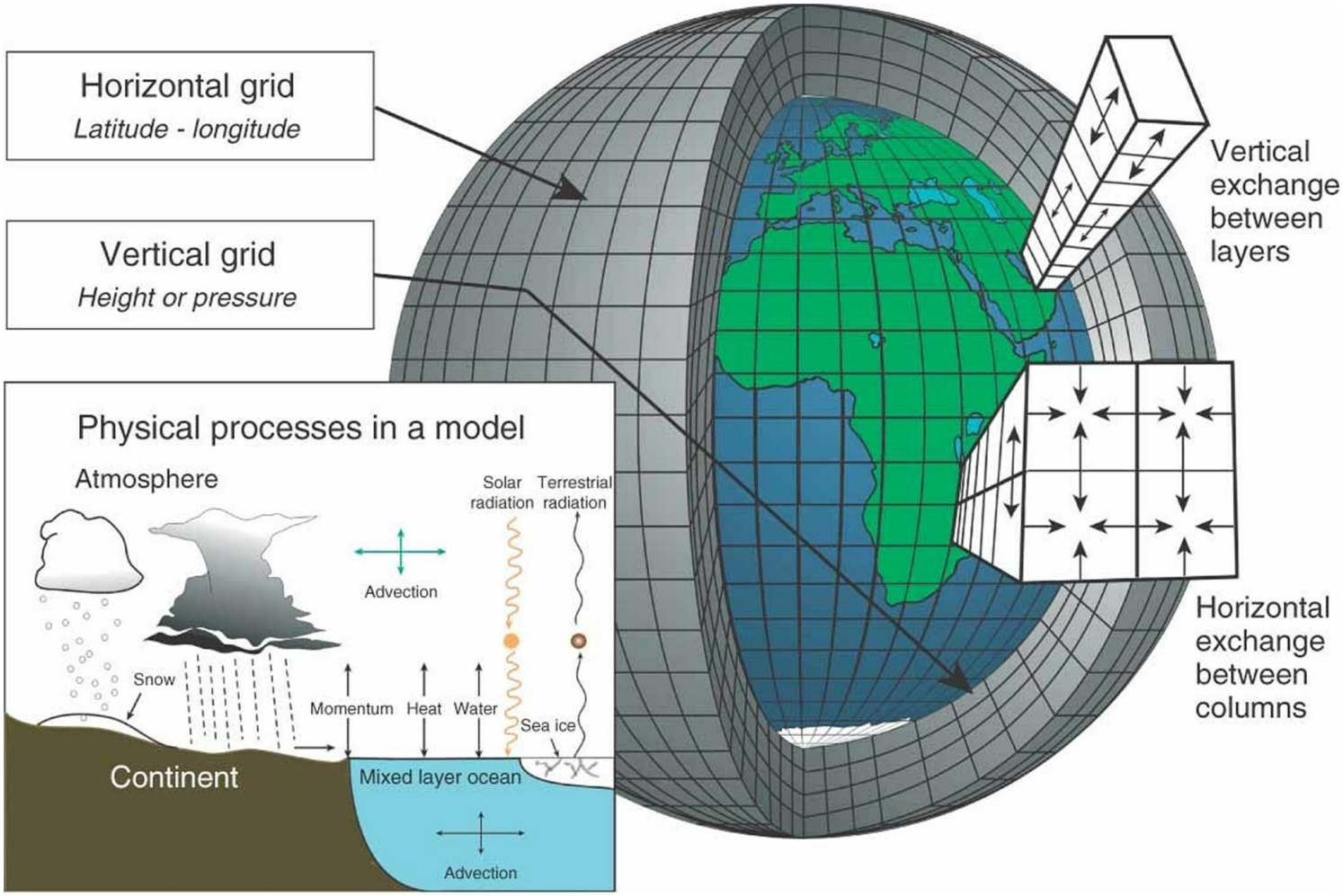


Physical processes, including land, ocean, atmosphere, ice.

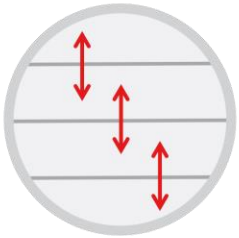


External forcings (ex. Solar, GHG, emissions) set framework for plausible futures

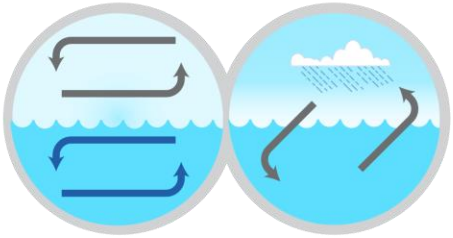
What is a Global Climate Model?



A Climate Modeling Timeline
(When Various Components Became Commonly Used)

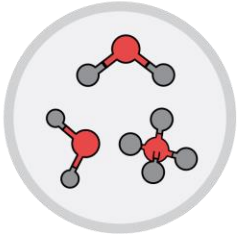


1890s
Radiative Transfer

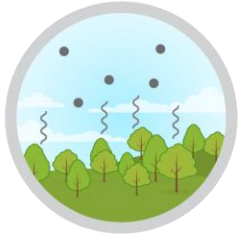


1960s
Non-Linear Fluid Dynamics
Hydrological Cycle

1970s
Sea Ice and Land Surface



1990s
Atmospheric Chemistry

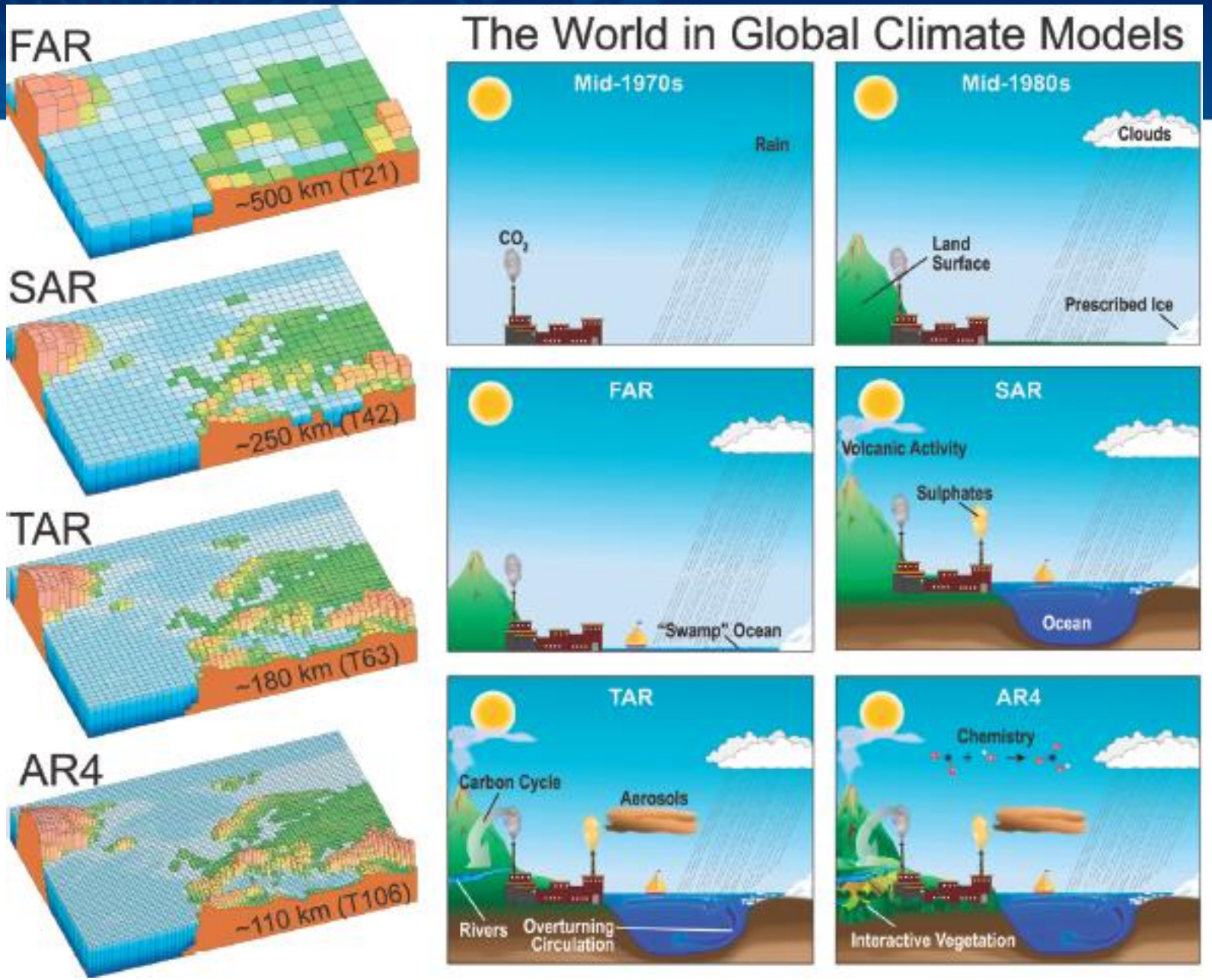


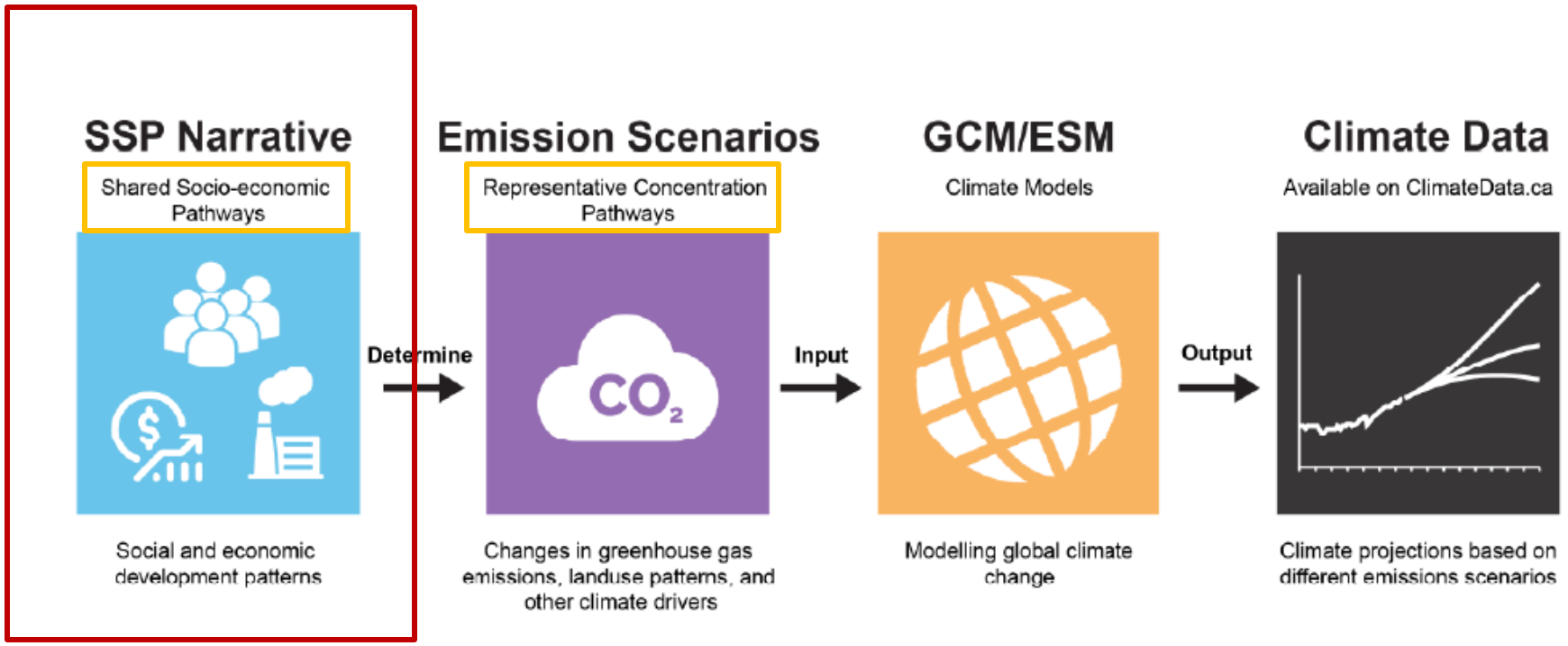
2000s
Aerosols and Vegetation

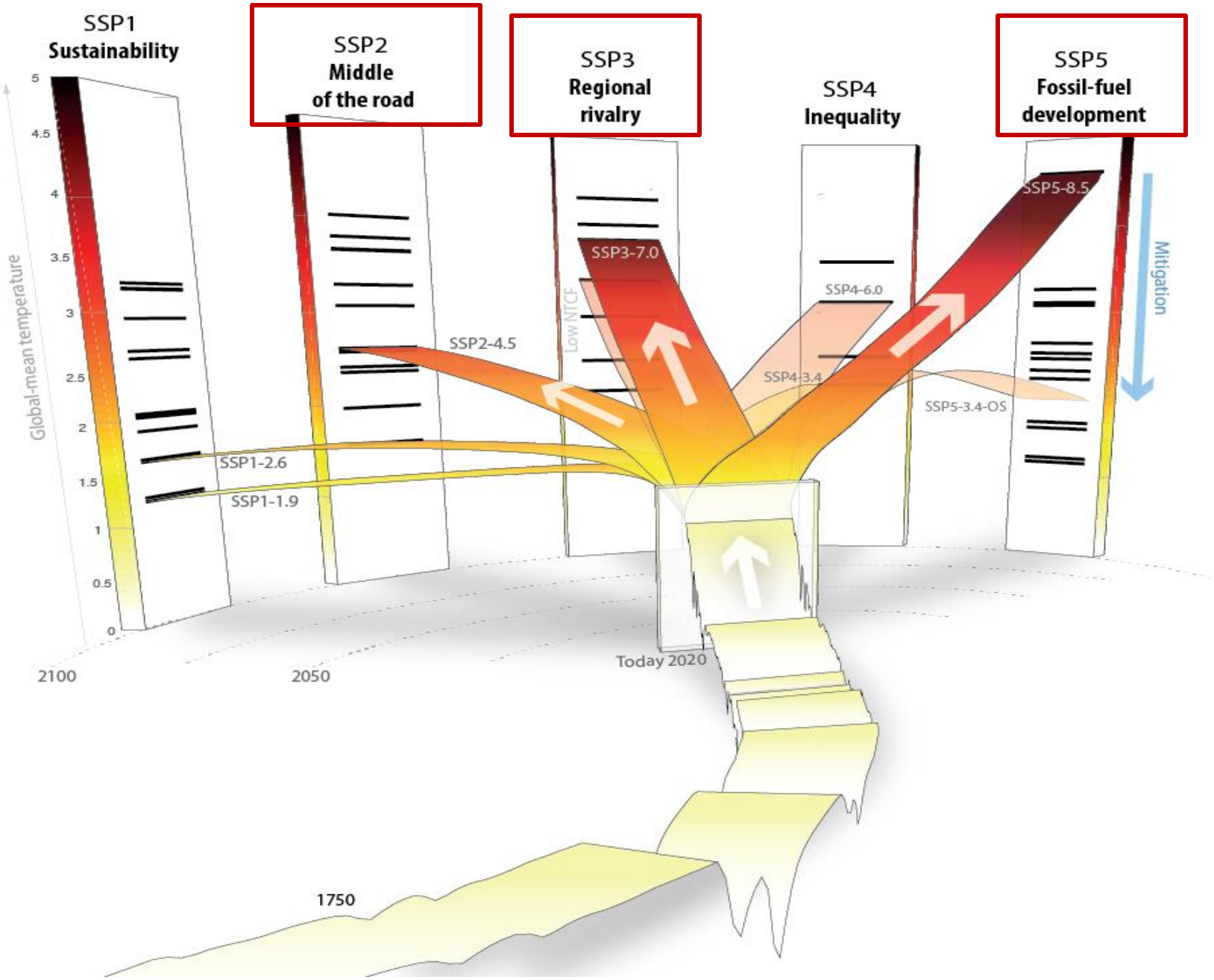
2010s
Biogeochemical Cycles and Carbon

Energy Balance Models → Atmosphere-Ocean General Circulation Models → Earth System Models

Computing Power Improvements


FAR
~500 km (T21)
SAR
~250 km (T42)
TAR
~180 km (T63)
AR4
~110 km (T106)
The World in Global Climate Models
Mid-1970s
Rain
CO_2
Mid-1980s
Clouds
Land Surface
Prescribed Ice
FAR
"Swamp" Ocean
SAR
Volcanic Activity
Sulphates
Ocean
TAR
Carbon Cycle
Aerosols
Rivers
Overturning Circulation
AR4
Chemistry
Interactive Vegetation


SSP Narrative
Shared Socio-economic Pathways
Social and economic development patterns
Determine
Emission Scenarios
Representative Concentration Pathways
CO2
Changes in greenhouse gas emissions, landuse patterns, and other climate drivers
Input
GCM/ESM
Climate Models
Modelling global climate change
Output
Climate Data
Available on ClimateData.ca
Climate projections based on different emissions scenarios

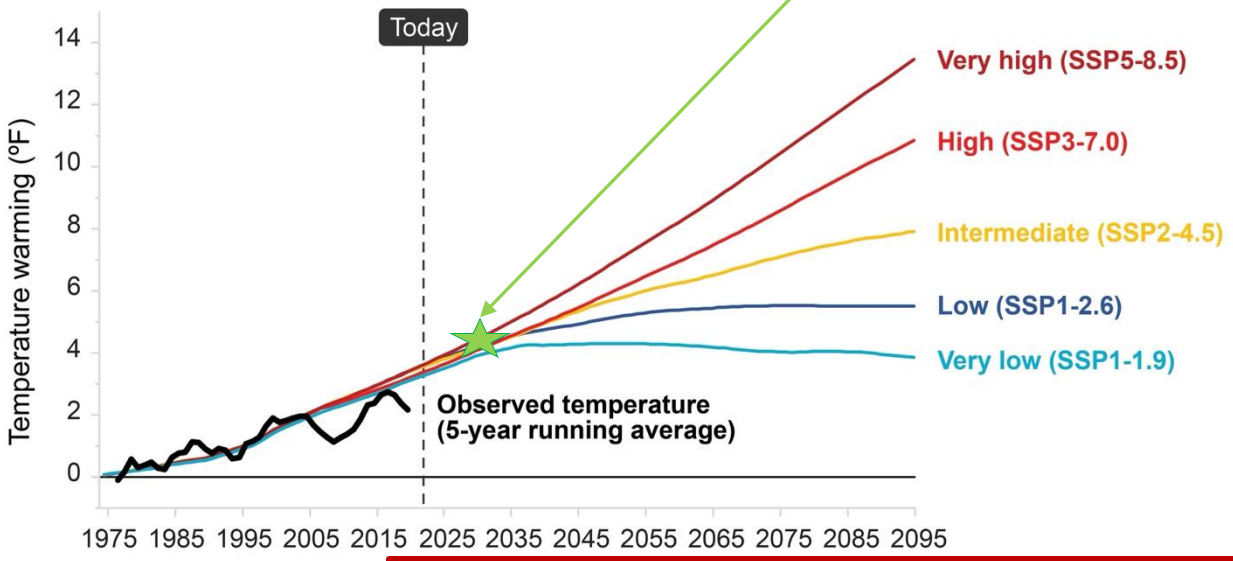

SSP1
Sustainability
SSP2
Middle
of the road
SSP3
Regional
rivalry
SSP4
Inequality
SSP5
Fossil-fuel
development
Global-mean temperature
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
SSP5-8.5
SSP3-7.0
SSP4-6.0
SSP2-4.5
SSP4-3.4
SSP5-3.4-OS
SSP1-2.6
SSP1-1.9
Low NTCF
Mitigation
2100
2050
Today 2020
1750

Potential Warming Pathways in the United States

Future Warming

Future warming in the United States will depend on the total amount of global greenhouse gas emissions.

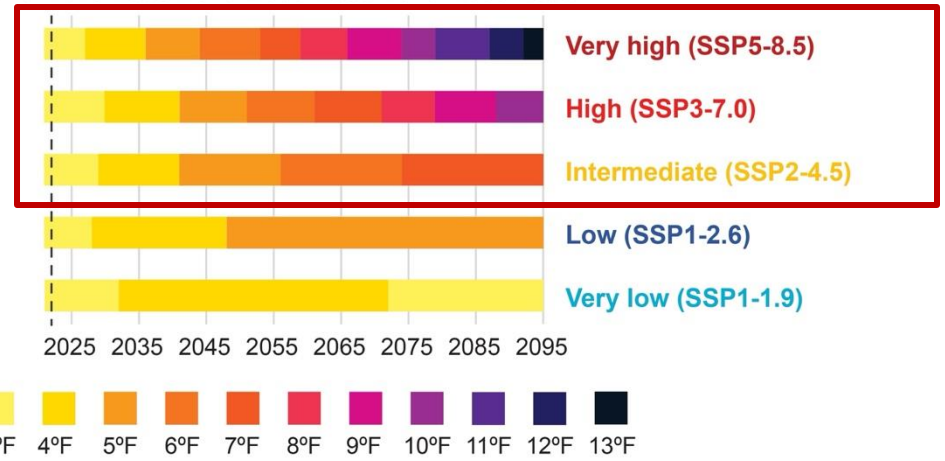
Reaching 1.5 C (2.7 F) by early 2030s



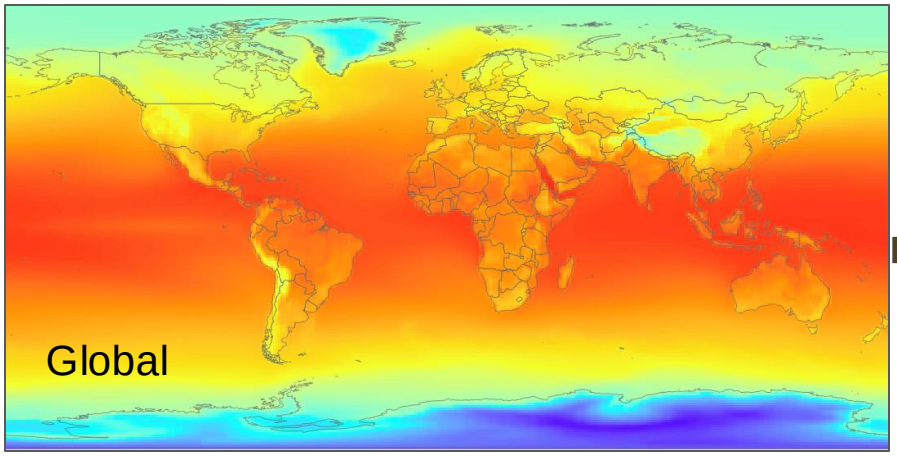
With no action could reach 5.5°F before mid century

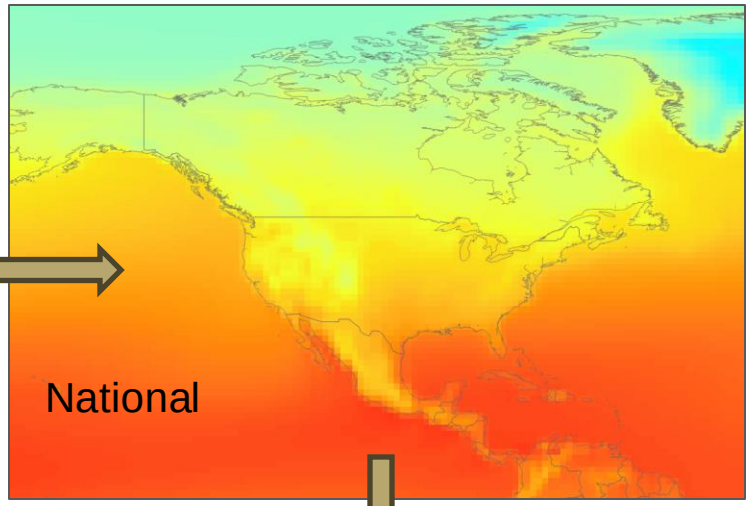
Crossing Times

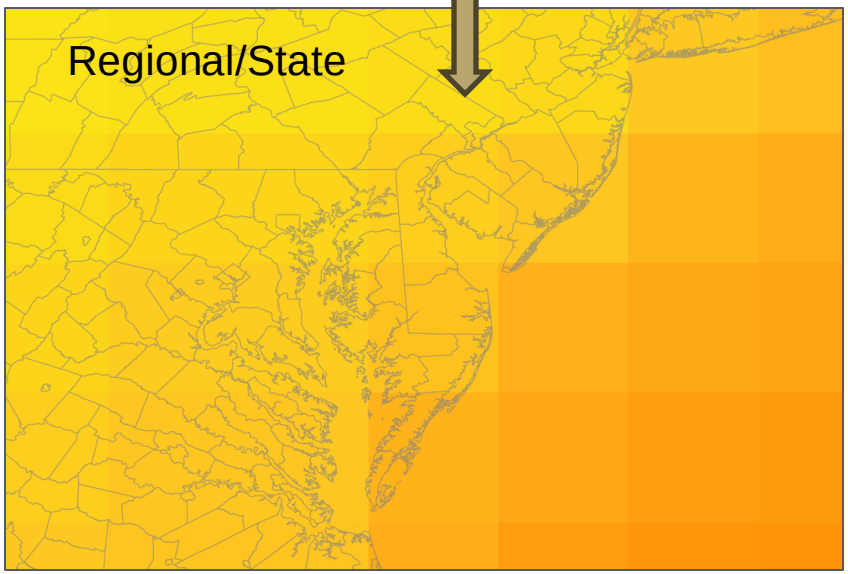
Whether–and when–a given temperature threshold is crossed depends on both the amount and rate of global greenhouse gas emissions.



What does this data look like?





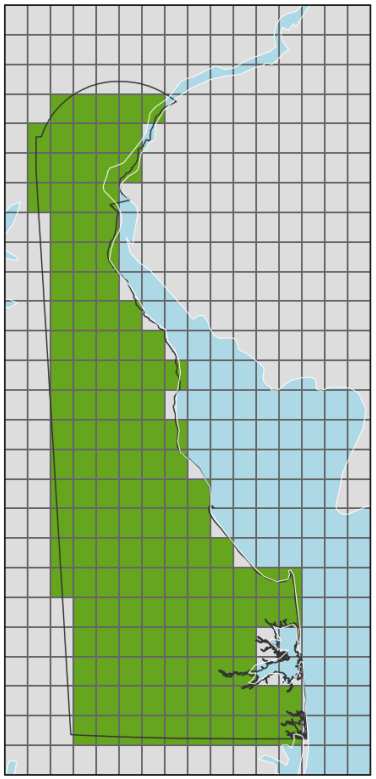


Example:
GFDL-CM4 Model

- 1 degree resolution (111km or 69 miles)
- Global-scale climate trends and patterns are captured

- However…
  - National/Local climate impacts are not captured.
  - For local planning use regional and **downscaled models**.

LOCA2 Full State Mask



LOCA2

LOCalized Analogs version 2

- Daily Tmin, Tmax, and Precipitation (working on humidity)
- Gridded with 6 km spatial resolution to **Livneh-Unsplit**
- 1950-2100
- SSP2-4.5, SSP3-7.0, and SSP5-8.5

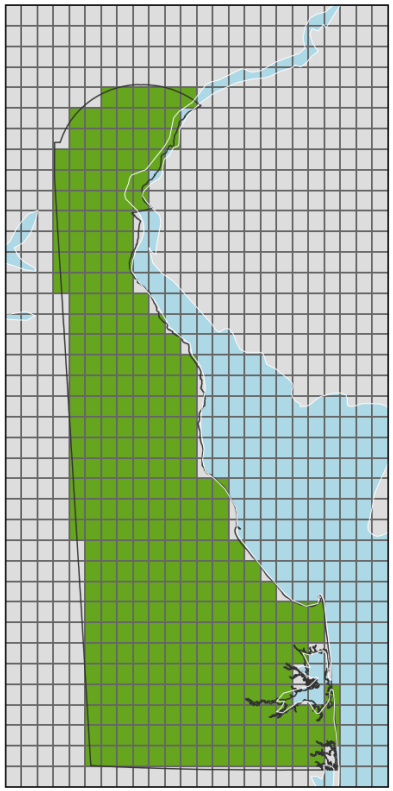
https://loca.ucsd.edu/loca-version-2-for-north-america-ca-jan-2023/

STAR-ESDM

Seasonal Trends and Analysis of Residuals Empirical-Statistical Downscaling Model

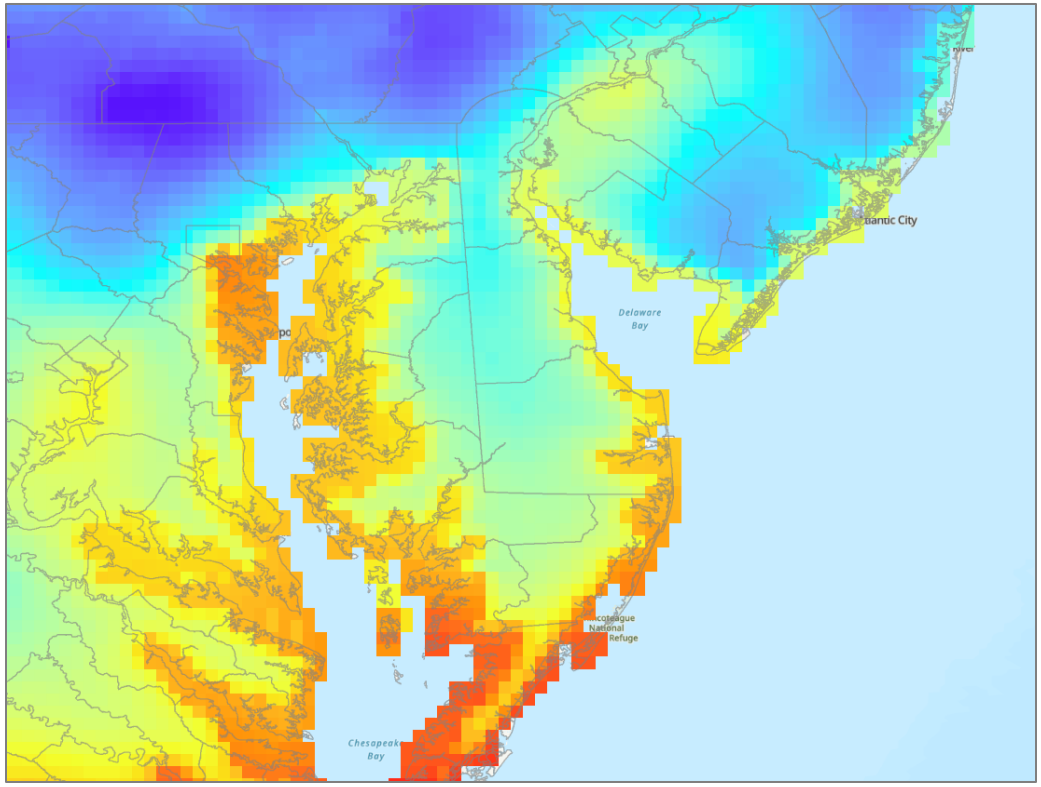
- Daily gridded and station data are available for Tmin, Tmax, and Precipitation
- Gridded to **NCEI's nClimgrid** (1/24th degree resolution; approximately 4 km)
- 1950-2100
- SSP2-4.5, SSP3-7.0, and SSP5-8.5
- Station data available for the Delmarva (approximately 27 stations)

STAR-ESDM Full State Mask



https://www.depts.ttu.edu/csc/data/

Minimum Temperature



- 1/24th degree resolution
- approximately 4 km

- Coastal and interior features are recognizable

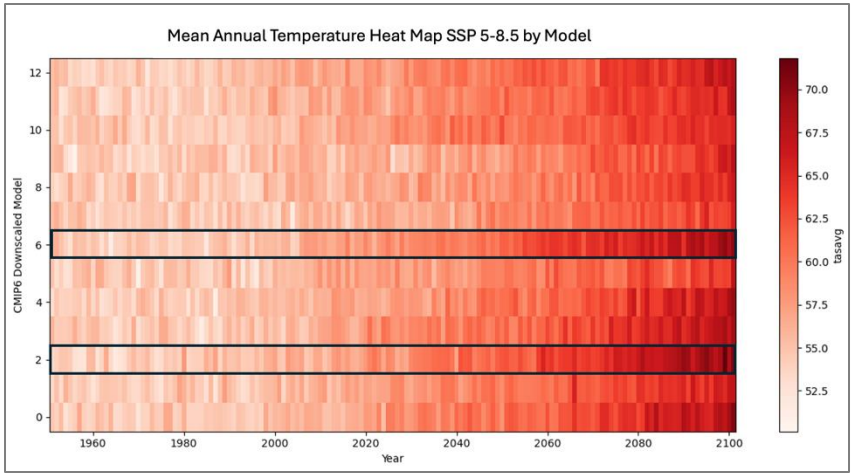
Models
ACCESS-CM2
BCC-CSM2-MR
CanESM5
EC-Earth3
EC-Earth3_Veg
FGOALS-g3
GFDL-CM4
GFDL-ESM4
MPI-ESM1-2-HR
MPI-ESM1-2-LR
MRI-ESM2-0
NORESM2-LM
NORESM2-MM

Temperature Indicators (Fahrenheit)

- Mean, Max, Min Temperature
- Annual Cooling/Heating Degree Days
- Growing Degree Days First/Last Frost
- Growing Season Length
- Longest Period of Days w/ Max Temp > 90, 95, 100, 105, 110
- Days w/ Max Temp > 90, 95, 100, 105, 110
- Day/Year Min Temp < 32, 20
- Nights w/ Min Temp > 70, 75, 80, 85, 90

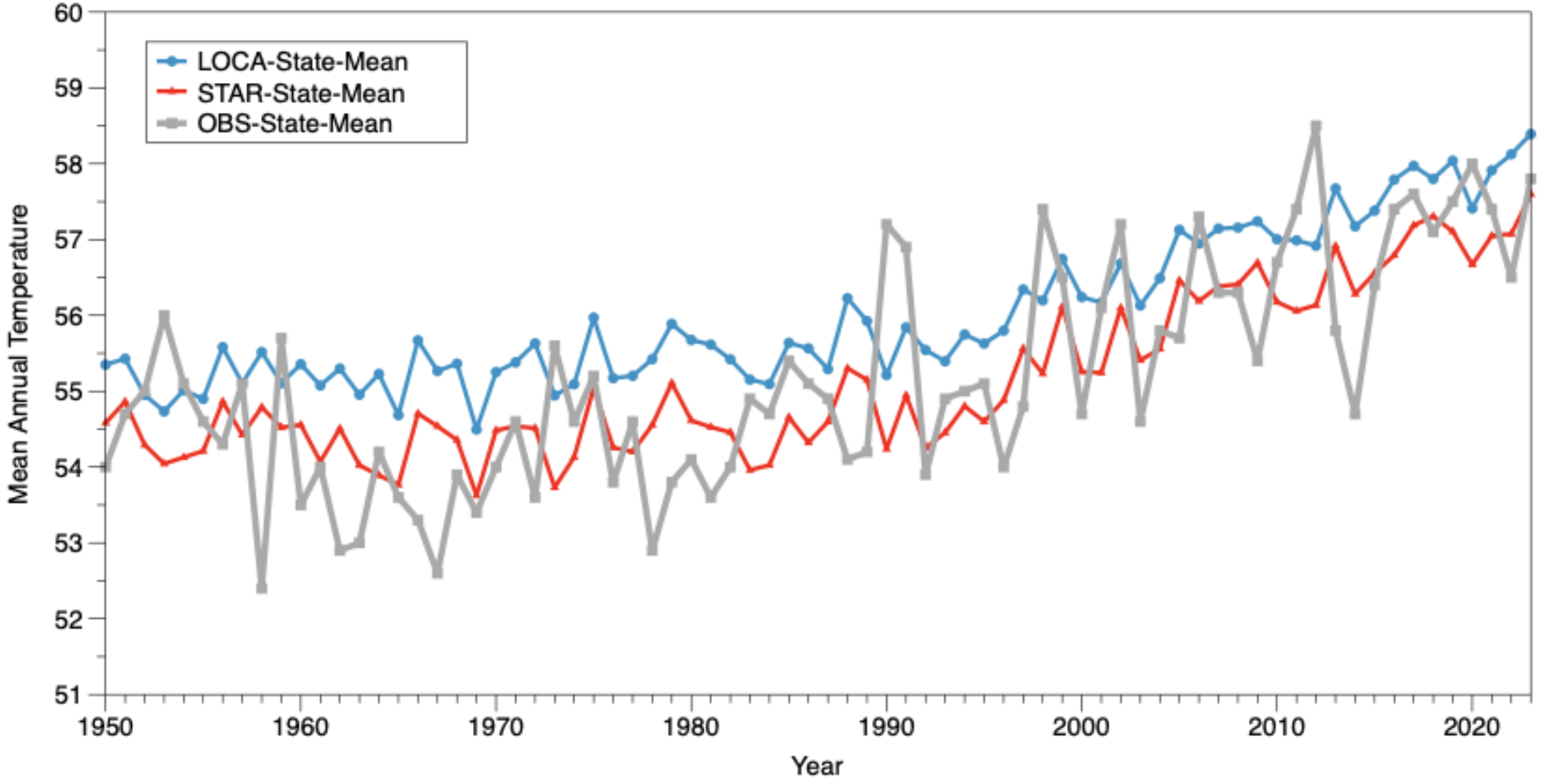
Times

- Day
- Month
- Seasonal
- Annual
- 10- and 20-year

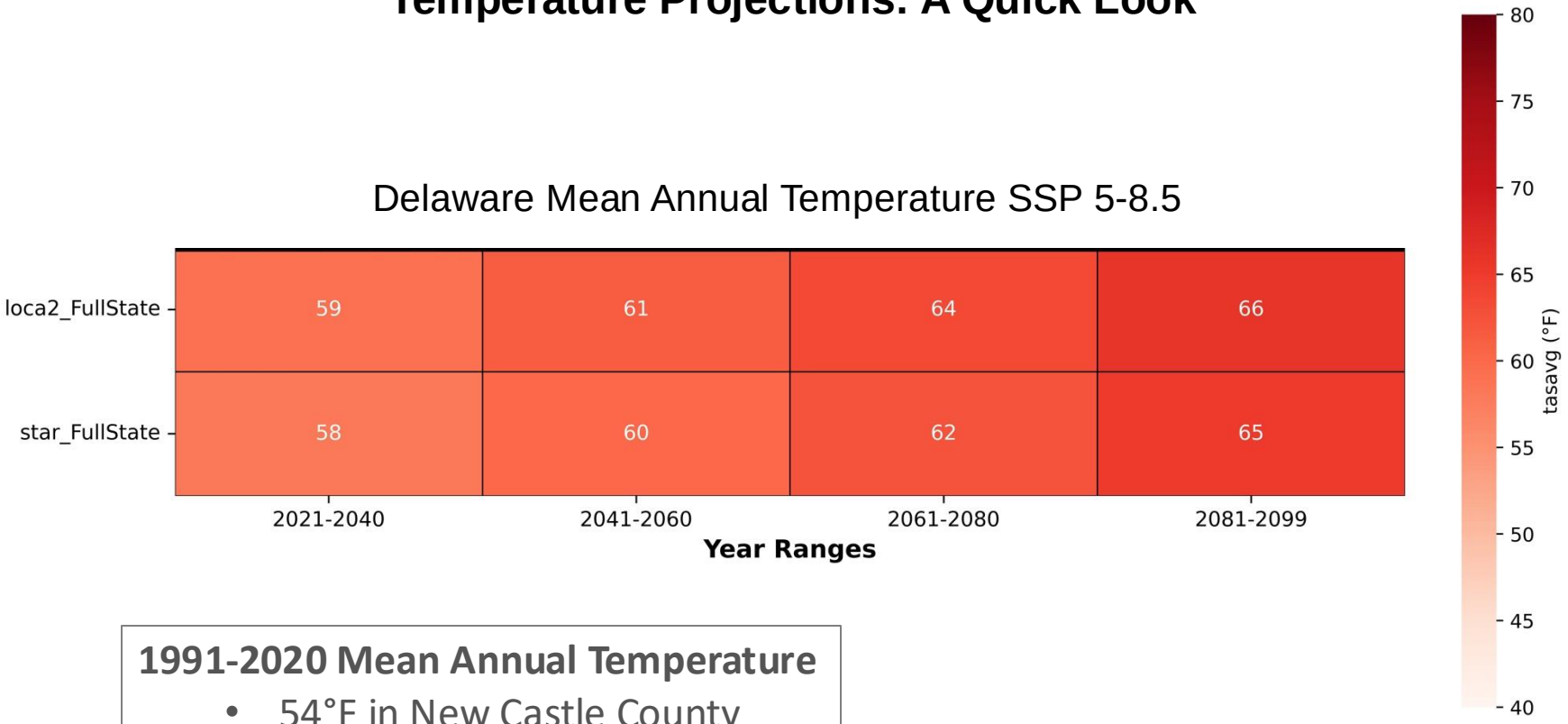


Historical Analysis: How do the modeled data match observed data?

*Statewide ensemble Mean Annual **Temperatures** (°F)*



Temperature Projections: A Quick Look



1991-2020 Mean Annual Temperature

- 54°F in New Castle County
- 58.1°F along the coast

Increasing Temperature under SSP 5-8.5

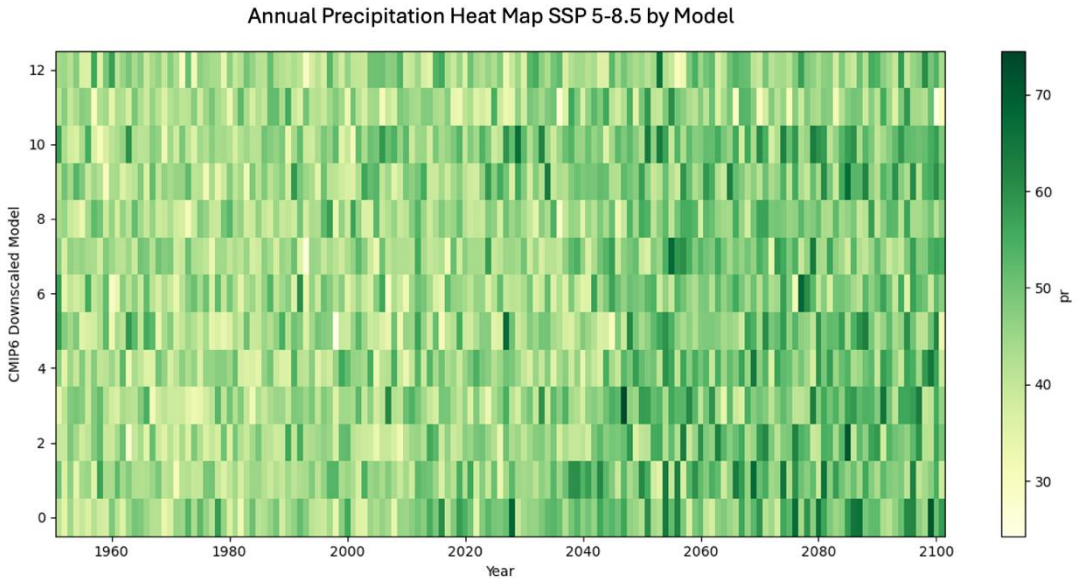
- 6°F by mid-century
- 11°F by end of century

Precipitation Indicators (inches)

- Total Precipitation
- Day/Year > 0.5, 1, 2, 3, 4, 5

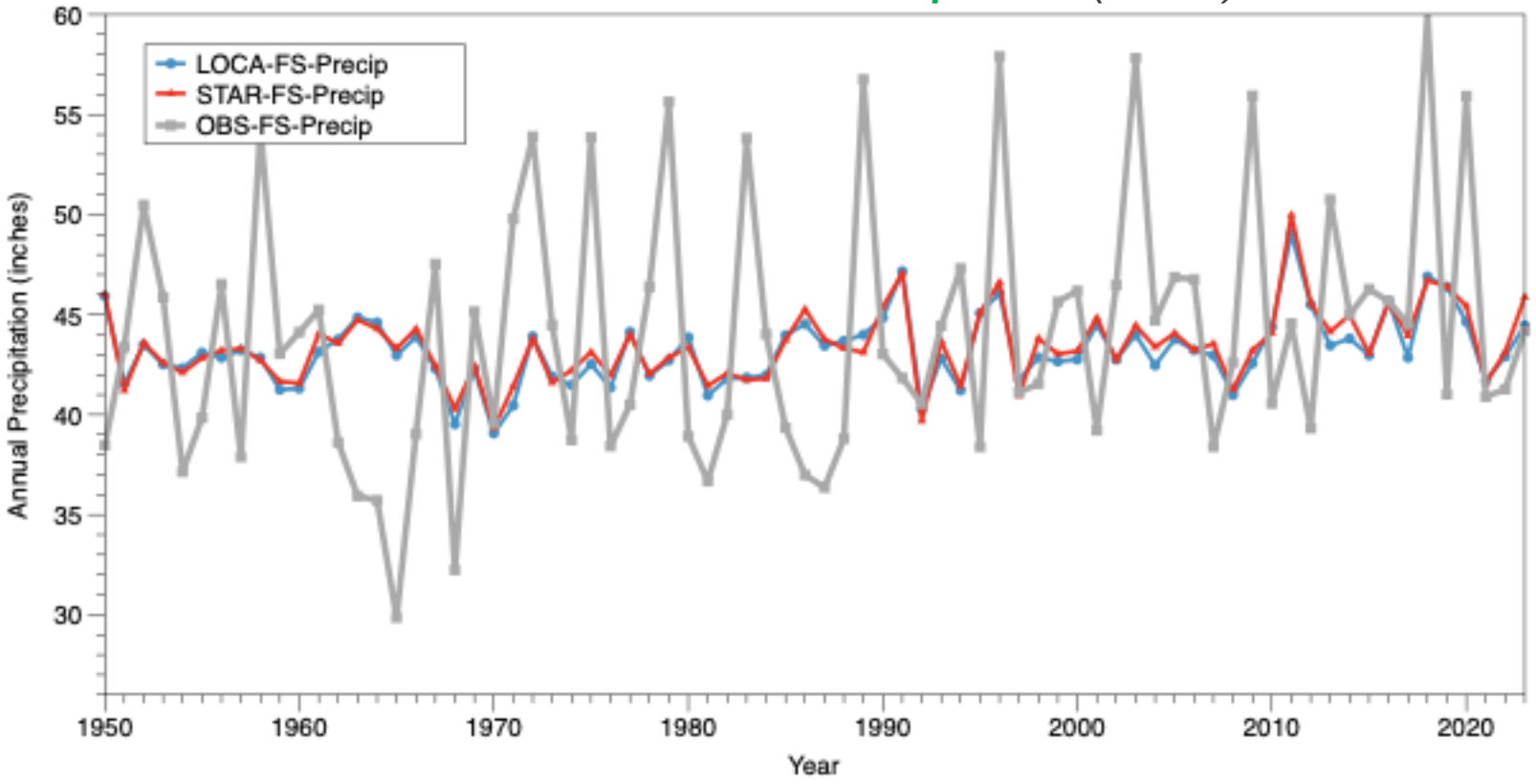
Times

- Day
- Month
- Seasonal
- Annual
- 10- and 20-year



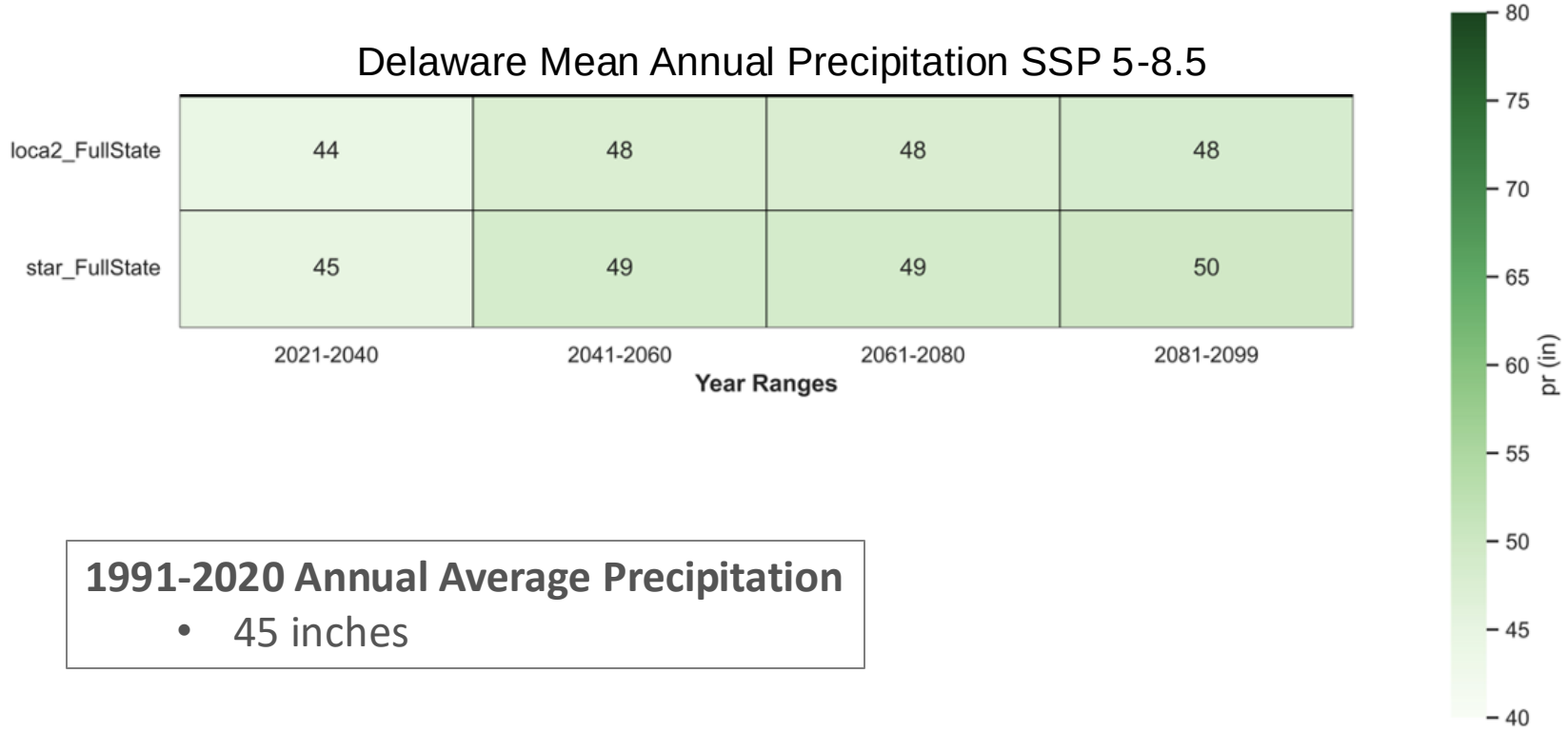
Historical Analysis: How do the modeled data match observed data?

*Statewide ensemble Mean **Precipitation** (inches)*



Models do not capture interannual precipitation variability!

Precipitation Projections: A Quick Look



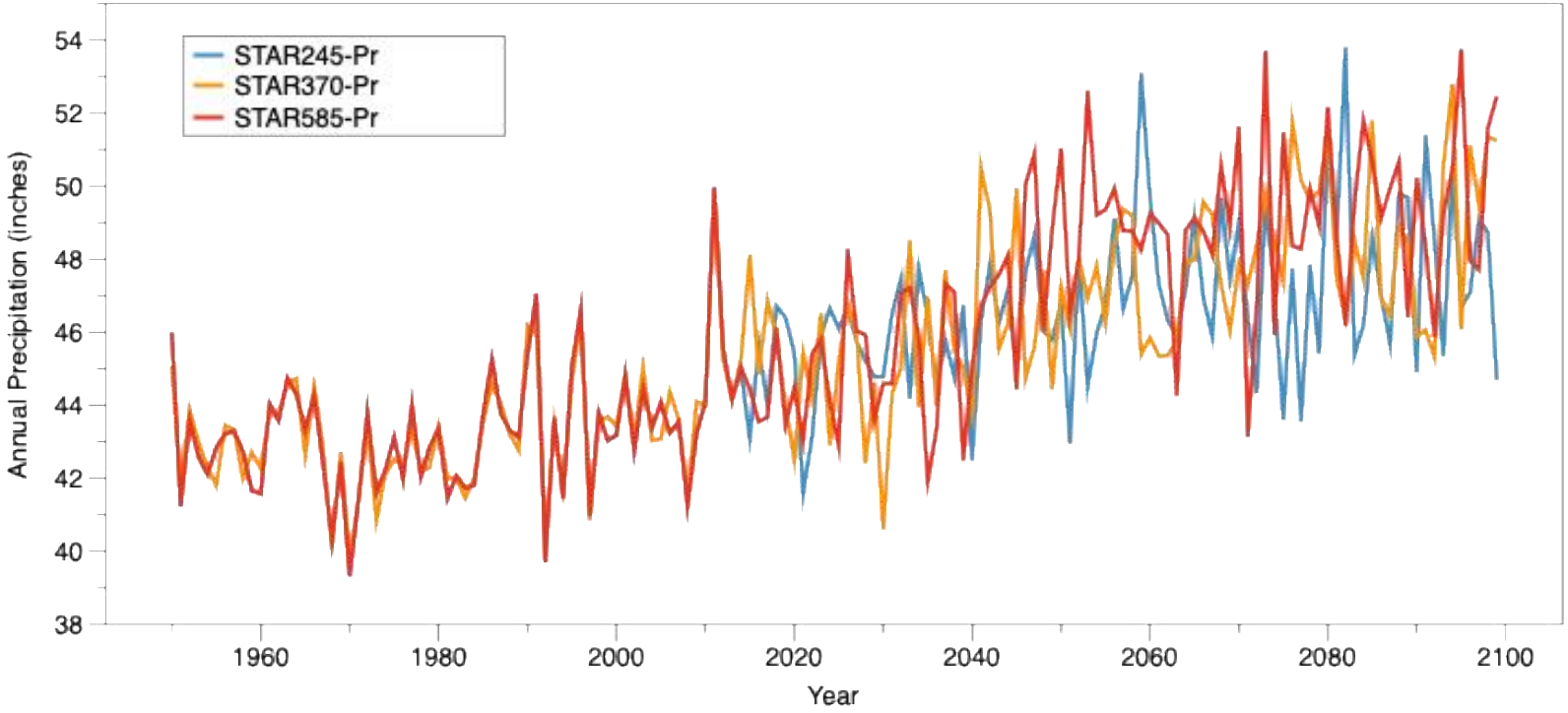
1991-2020 Annual Average Precipitation

- 45 inches

Increasing Precipitation under SSP 5-8.5

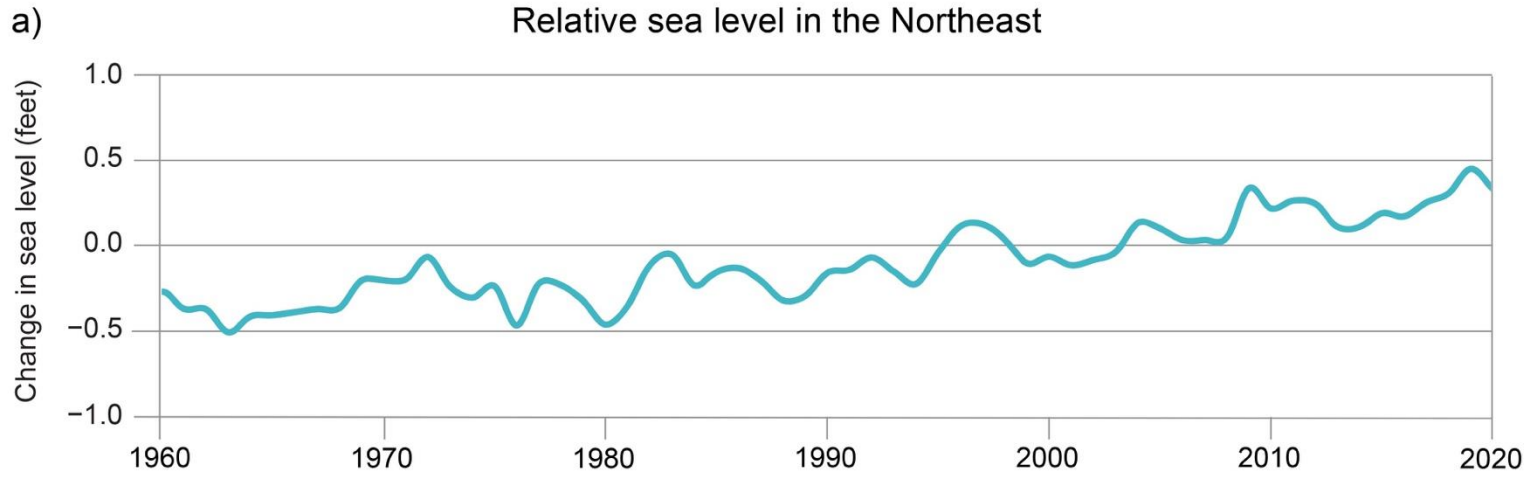
- 4” by mid-century
- 5” by end of century

Precipitation Projections: A Quick Look

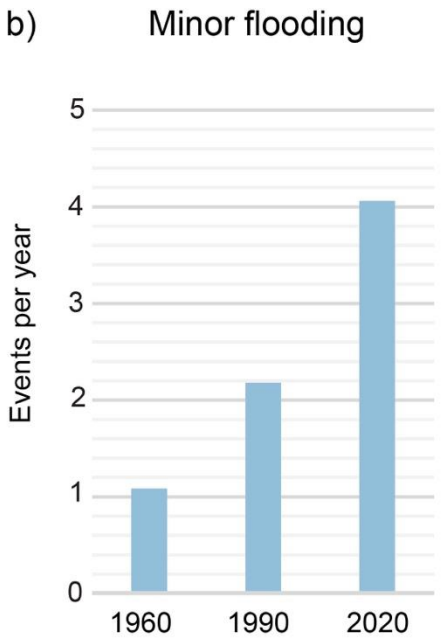


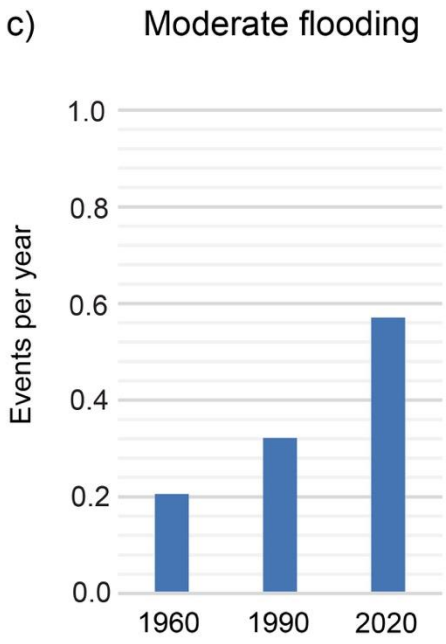
- Increasing Precipitation
- Increasing Intensities
- High Annual Variability

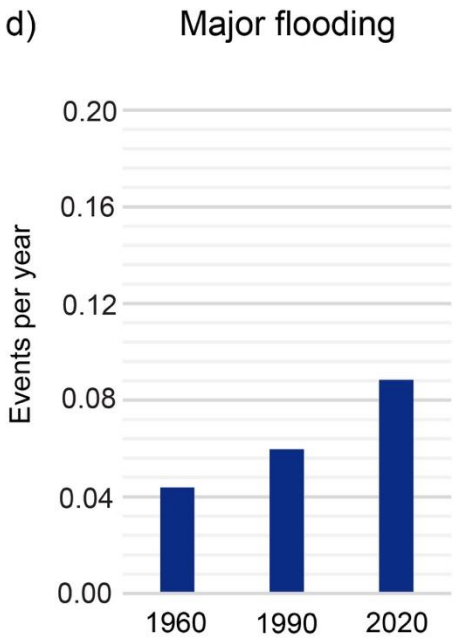
Sea Level and Coastal Flooding in the Northeast



High tide flooding event frequency in the Northeast by category



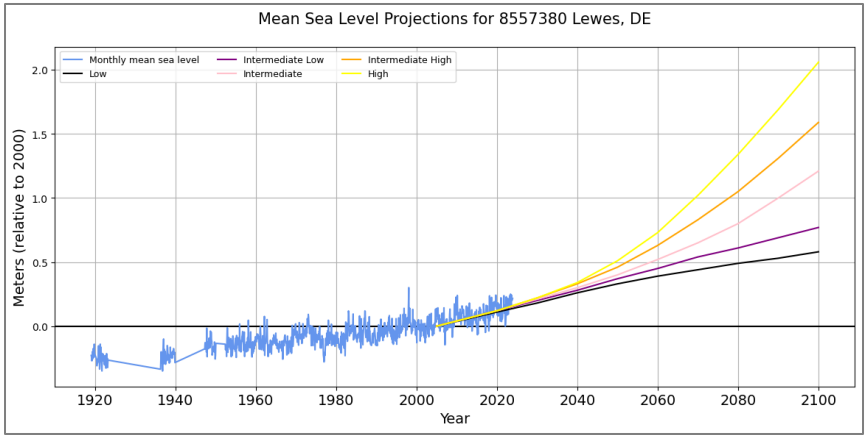


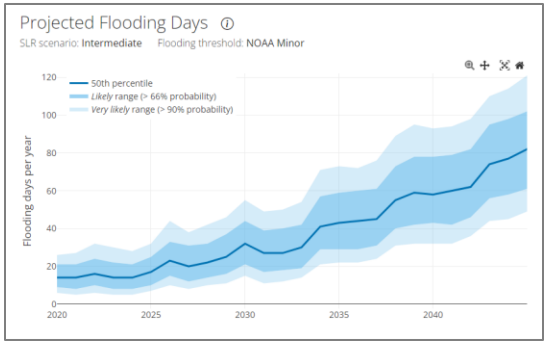


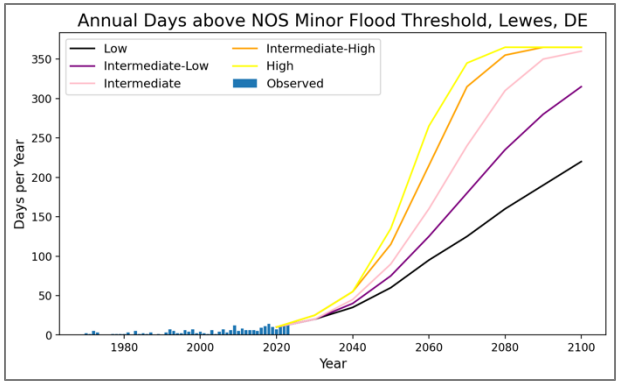
Sea Level Rise

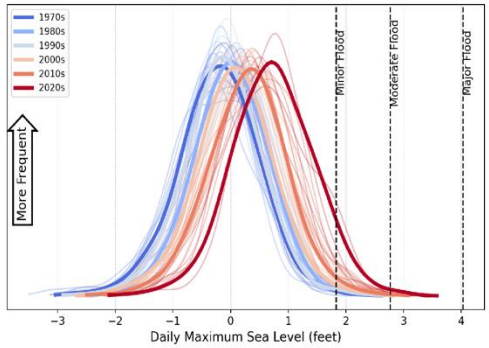
Mean Sea Level

- Trends
- Observation-based Trajectories
- Avg Seasonal Cycle
- High Tide Flood Frequency
- Coastal Flood Frequency
- Extreme Water Levels

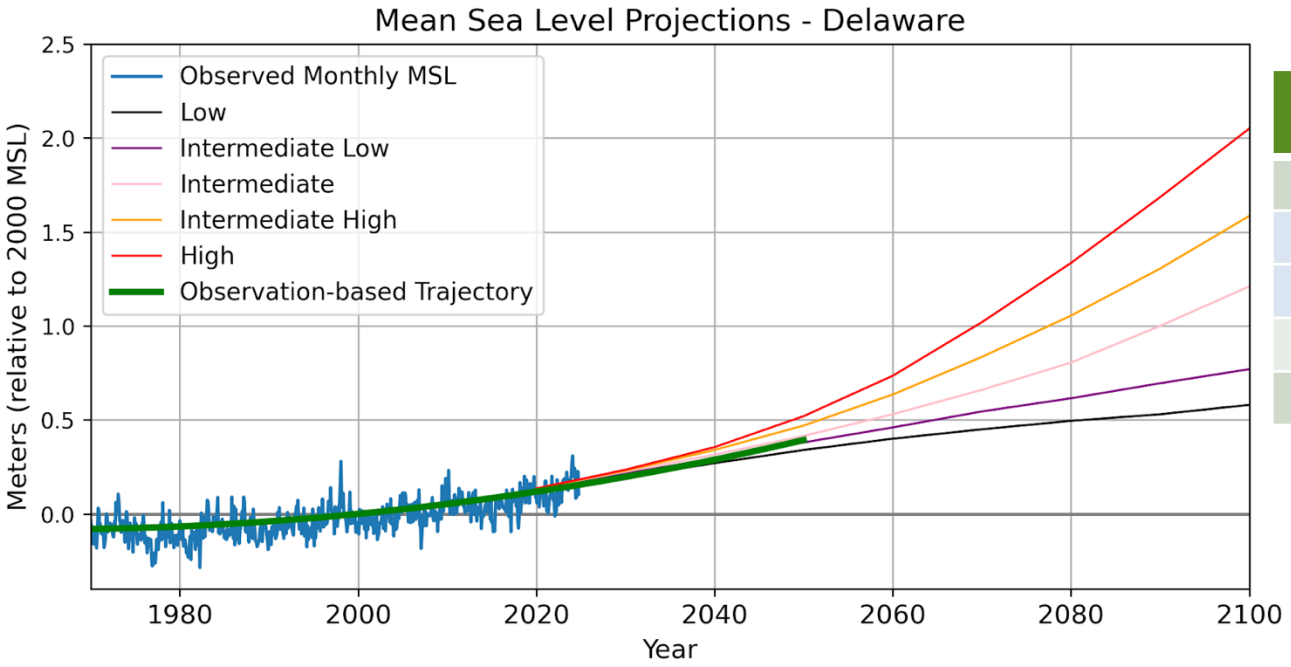








Delaware State MSL Projections



For near-term planning:
observation-based extrapolations

Scenario	Scenario Projections	Observation Extrapolation
Low	0.34 m / 1.12 ft	
Inter-Low	0.38 m / 1.25 ft	**0.39 m / 1.29 ft**
Intermediate	0.42 m / 1.36 ft	
Inter-High	0.47 m / 1.54 ft	
High	0.52 m / 1.71 ft	

For longer-term planning:
ensemble of model projections

Scenario	SLR by 2100*
Low	**0.58 m / 1.90 ft**
Inter-Low	0.77 m / 2.53 ft
Intermediate	**1.21 m / 3.97 ft**
Inter-High	1.59 m / 5.22 ft
High	**2.05 m / 6.73 ft**

*Relative to 2000 MSL

Key SLR/Flooding Takeaways

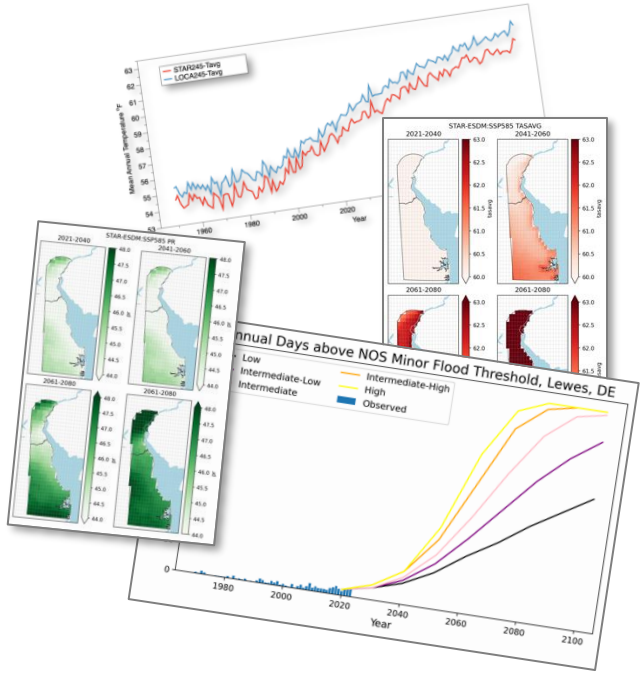
- Delaware SLR amounts by 2100 are generally **higher** than 2017 report
- Frequency of flooding and probability of extremes are **increasing**

Next Steps

Final Report and Data Delivery (June 2025)

Develop Additional Indicators
- Heat and Health
- Drought and Precipitation Frequency

Develop Web-based Delivery Tools
- Visualizations
- Messaging
- Data Dashboard



Each phase completion will be shared with Climate Change Tech Advisors to ensure a final product that is meaningful and useful in planning and policy over the next decade.

Questions or Comments?

DELAWARE CLIMATE OFFICE

climate.udel.edu

National Centers for Environmental Information
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

www.ncei.noaa.gov

CEMA

cema.udel.edu

Sea Level Projections research and graphics were created by John Callahan.

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