# Global Temperature Changes

Process Book
DS 4630/CS 5630
Dr. Paul Rosen

Github Repository

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# Background:

Climate change is one of the largest challenges facing the human race in the 21st century[1]. Rising global temperatures, food scarcity, and impacts on infrastructure are changing the world we live in. Though the issue affects all of us, there is still much debate around the subject, preventing actionable steps from being taken to address it. For the last half century[2], the conversation around climate change and global surface temperatures has been growing, but with that growth, public skepticism has grown as well. The public's skepticism can be tied to a misunderstanding of how the data is collected and analyzed, misinformation being pushed for political gain, and/or a general ignorance of the details surrounding the climate change issue[3].

By creating data-based, easy-to-understand visualizations of surface temperatures from across the country and the globe, we hope to make the data clearer and more accessible. The U.S. is both a leading emitter of greenhouse gases and highly vulnerable to climate-related risks, including heatwaves, hurricanes, and droughts. Looking at U.S. climate trends gives a closer view of how global warming shows up at a national scale. By analyzing the raw temperature data, we can see whether long-term changes match what mainstream claims about climate change suggest, while also highlighting the impacts that communities in the U.S. are already facing[4].

# Objectives:

Our first objective is to track how average temperatures in the United States have changed from the 19th century through today. Looking this far back lets us contextualize recent warming in the broader scope of history, rather than just the last few decades. By extending the timeline to the early 1800s, we capture key historical periods: the Industrial Revolution, the Second Industrial Revolution, and even the tail end of the Little Ice Age, when cooler conditions still shaped much of the Northern Hemisphere[5]. This longer view makes it possible to see whether the shifts of the past century stand apart from natural variations or fit into a broader global trend. Using the Berkeley Earth dataset, which brings together millions of historical temperature records, we can trace those changes with enough resolution to show how today's climate compares with that of the earlier baseline.

The second objective is to take what we find and make it understandable to people outside of climate science. A lot of climate graphs are either overly technical or stripped down to the point of being unclear. We want to avoid both of those extremes. Our plan is to build straightforward visuals such as line charts, heat maps, and trend plots that show the main story without overwhelming the viewer. The idea is that someone looking at our charts should walk away with a clearer picture of how U.S. temperatures have shifted without needing to dig through a scientific paper to get there.

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[1] Intergovernmental Panel on Climate Change, Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report (Cambridge: Cambridge University Press, 2021), https://www.ipcc.ch/report/ar6/wg1/

[2] Kieran Mulvaney, "4 Key Moments That Forced Americans to Confront Climate Change," HISTORY, A&E Television Networks, April 19, 2022, updated May 28, 2025, https://www.history.com/articles/climate-change-global-warming-events

[3] John Cook et al., "Consensus on Consensus: A Synthesis of Consensus Estimates on Human-Caused Global Warming," Environmental Research Letters 11, no. 4 (2016): 048002, IOP Publishing, https://repository.library.noaa.gov/view/noaa/62111

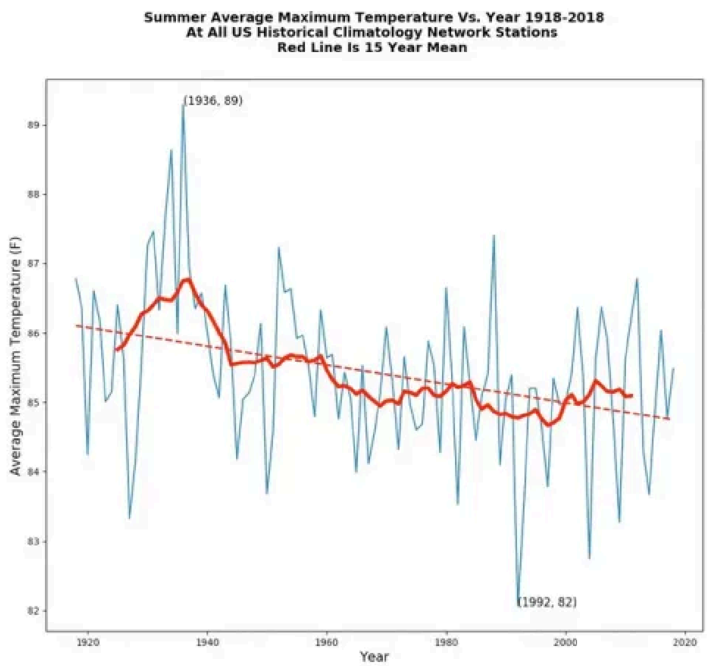
[4] U.S. Global Change Research Program, Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II (Washington, DC: U.S. Government Publishing Office, 2018), https://repository.library.noaa.gov/view/noaa/19487

[5] Emmanuel Le Roy Ladurie, Times of Feast, Times of Famine: A History of Climate Since the Year 1000, trans. Barbara Bray (Garden City, NY: Doubleday, 1971).

# Related Work:

USA Temperature: Can I sucker you?- This article was included in one of the optional readings for the course. It highlights how you can manipulate data to make it look like the overall temperature in the US is going down instead of increasing with global warming. It was motivating for us because it shows how misinformation about climate change continues to persist due to misleading visualizations. From the article:

*"There's a graph going around the internet from Steve Goddard a.k.a. Tony Heller, claiming to show that temperature in the U.S. has been declining, using only high temperatures, using only summertime temperatures, using only data since 1918, based on a simple average without taking into account new stations coming online or old stations retiring or area-weighting or any of that*




*"expert" stuff."*

# Data:

- Data set sources:
  - Kaggle: Climate Change: Earth Surface Temperature Data
    - This data set contains monthly data on Earth temperatures. It offers two CSV files that will be used. One is for state data and the other for city.
  - Kaggle: Average Monthly Temperature by US State
    - Covers the average monthly temperatures of each US state from January 1950 to August 2022.
    - Might use to fill in any missing data points

For the data visualizations, we need three different data sets outputted as CSV files:

1. State Monthly Averages (1800-2013)
    a. Use: This data set is going to be used on the national map for the US when the user wants to filter the map by the monthly temperature average instead of the yearly average.
    b. Missing data & Cleanup, data set: Climate Change: Earth Surface Temp
        i. From 1850 to 2013, only Alaska and Hawaii are missing monthly temperatures.
        ii. All of the NaN values are in the columns for average temperature and average temperature uncertainty. Most of those values and the most incomplete states are from western states that were sparsely populated in the early 1800s

```
na_counts = us_modern_ds['AverageTemperature'].isna().groupby(us_modern_ds['State']).sum()
print(na_counts)
```

```
State
Alabama                  0
Alaska                  76
Arizona                  1
Arkansas                 0
California               0
Colorado                 1
Connecticut              0
Delaware                 0
District Of Columbia     0
Florida                  0
Georgia (State)          0
Hawaii                   2
Idaho                   25
Illinois                 0
Indiana                  0
Iowa                     0
Kansas                 166
Kentucky                 0
Louisiana              180
Maine                    0
Maryland                 0
Massachusetts            0
Michigan                 0
Minnesota                0
Mississippi              0
Missouri                 0
Montana                166
Nebraska               166
Nevada                  59
New Hampshire            0
New Jersey               0
New Mexico              10
New York                 0
North Carolina           0
North Dakota           166
Ohio                     0
Oklahoma               240
Oregon                  47
Pennsylvania             0
Rhode Island             0
South Carolina           0
South Dakota           166
Tennessee                0
Texas                    0
Utah                    95
Vermont                  0
Virginia                 0
Washington              47
West Virginia            0
Wisconsin                0
Wyoming                221
Name: AverageTemperature, dtype: int64
```

        iii. After trimming the original data set to just temperature for the United States from 1800-2013, we have a remaining 126,213 data points and 1,824 null values for the average temperatures and average temperature uncertainty. For the 214 years in the range we're using for 51 states, there should be 2568 months for each location and 130,968 rows overall. To fill in those missing points, see the code below, and the confirmation that after running it, we had the correct number of rows.

```python
#Create full monthly date range from Jan 1800 to Dec 2013
full_dates = pd.date_range(
    start='1800-01-01',
    end='2013-12-31',
    freq='MS'
)

#Reindex for each state, without the warning
stateds_filled = (
    us_modern_ds
    .groupby('State', group_keys=False)
    .apply(lambda g: (
        g.set_index('dt')
         .reindex(full_dates)
         .assign(State=g['State'].iloc[0])
         .reset_index()
         .rename(columns={'index': 'dt'})
    ))
)
```

Show hidden output

```python
print(stateds_filled.count())
```

```
dt                               130968
AverageTemperature               124379
AverageTemperatureUncertainty    124379
State                            130968
Country                          126213
dtype: int64
```

iv. The average temperature in the original data was recorded in Celsius, so we added a new column with the temperatures in Fahrenheit.

```python
stateds_filled['AverageTemperature_F']=stateds_filled['AverageTemperature']*(9/5)+32
```

2. State Yearly Averages (1800-2013)
    a. Use: This data set will be used to generate the national map view of the US on our main page. In that visualization, each state will be color-coded by the average temperature for a whole year.
    b. Missing data, data set: Climate Change: Earth Surface Temp
        i. Starting where we left off on the data set for monthly averages by state, we extracted the monthly averages to get a yearly average for each state.

```python
# Step 1: make sure we have a 'Year' column
stateds_filled['Year'] = stateds_filled['dt'].dt.year

# Step 2: compute the yearly average temperature per state
yearly_avg = (
    stateds_filled
    .groupby(['State', 'Year'], as_index=False)['AverageTemperature_F']
    .mean()
    .rename(columns={'AverageTemperature_F': 'AvgTemp_F_Yearly'})
)

# Step 3: merge that yearly average back to your main DataFrame
stateds_filled = stateds_filled.merge(yearly_avg, on=['State', 'Year'], how='left')
```

| | | | | |
|---|---|---|---|---|
| 4 | Alabama | 1804 | 63.47480 | 17.486000 |

ii. After getting a yearly average, we created a new data set from the old one that only contains the year, the yearly average in F and C, and the state.

```python
state_year_avg = stateds_filled[['State', 'Year', 'AvgTemp_F_Yearly']].drop_duplicates()
state_year_avg['AvgTemp_C_Yearly'] = (state_year_avg['AvgTemp_F_Yearly'] - 32) * (5/9)
state_year_avg = state_year_avg.sort_values(['State', 'Year']).reset_index(drop=True)
state_year_avg.head()

#new DS for just the state yearly average
```

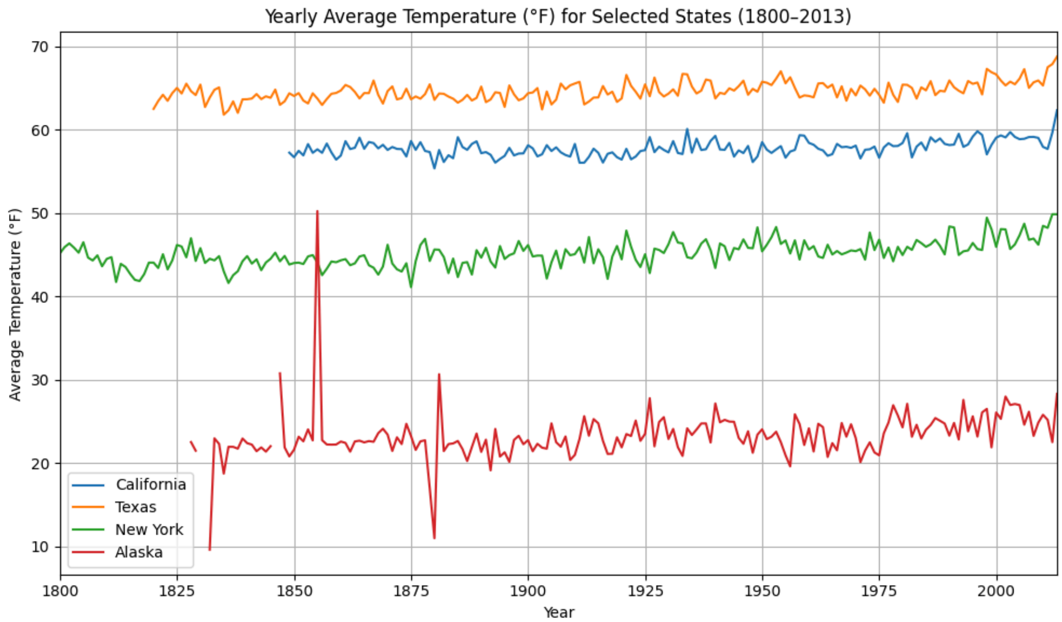
| | State | Year | AvgTemp_F_Yearly | AvgTemp_C_Yearly |
|---|---|---|---|---|
| 0 | Alabama | 1800 | 62.75210 | 17.084500 |
| 1 | Alabama | 1801 | 63.35000 | 17.416667 |
| 2 | Alabama | 1802 | 63.67145 | 17.595250 |
| 3 | Alabama | 1803 | 63.41330 | 17.451833 |
| 4 | Alabama | 1804 | 63.47480 | 17.486000 |

iii. Manually added the yearly average for Alaska and Hawaii for 2013 using data from the National Centers for Environmental Information: [ncei.noaa.gov/](ncei.noaa.gov/)

```python
state_year_avg.loc[
    (state_year_avg['State'] == 'Alaska') & (state_year_avg['Year'] == 2013),
    'AvgTemp_F_Yearly'
] = 26.2

state_year_avg.loc[
    (state_year_avg['State'] == 'Hawaii') & (state_year_avg['Year'] == 2013),
    'AvgTemp_F_Yearly'
] = 65.7
```

c. Initial Results:




i. As expected, some Western states did not have yearly data until much later, but there were some anomalies in Alaska. Looking back through how the yearly averages were calculated, we realized that the function .mean() ignores NaN values, so for 1855, Alaska's yearly average was based on the only two values recorded for that year.

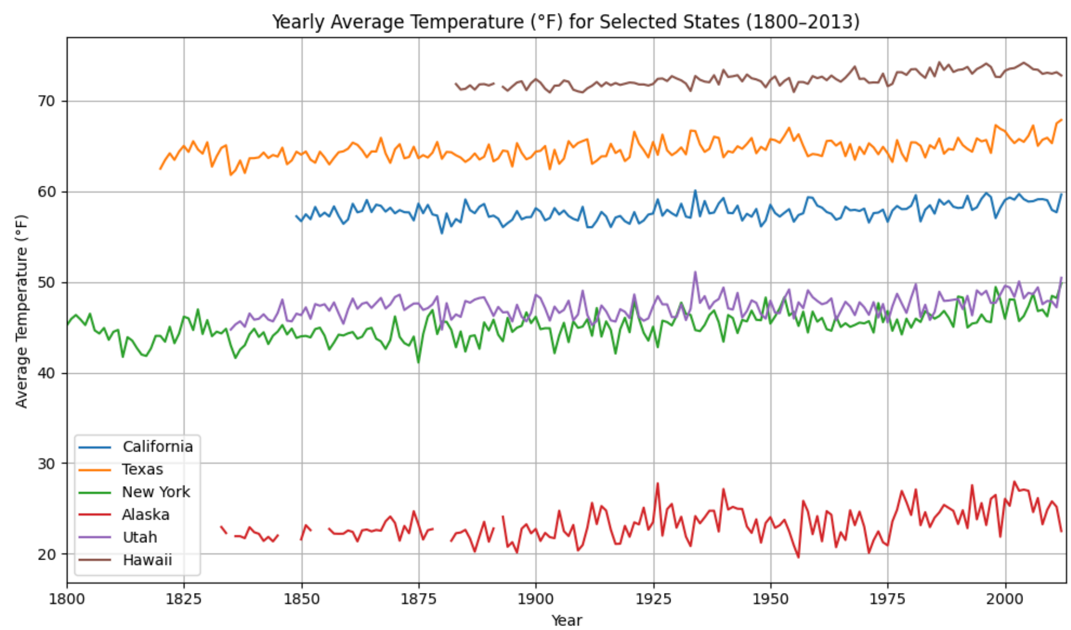
ii. To fix the issue, updated the code for calculating the yearly average to set the yearly average to NaN if there's missing data for that year.

```
# Step 1: make sure we have a 'Year' column
stateds_filled['Year'] = stateds_filled['dt'].dt.year

# Step 2: compute the yearly average temperature per state
yearly_avg_ds = (
    stateds_filled.groupby(['State', 'Year'], as_index=False)
    .agg({
        'AverageTemperature_F': lambda x: x.mean() if x.notna().all() else float('nan')
    })
    .rename(columns={'AverageTemperature_F': 'AvgTemp_F_Yearly'})
)

stateds_filled = stateds_filled.merge(yearly_avg_ds, on=['State', 'Year'], how='left')
```

iii. Final results:



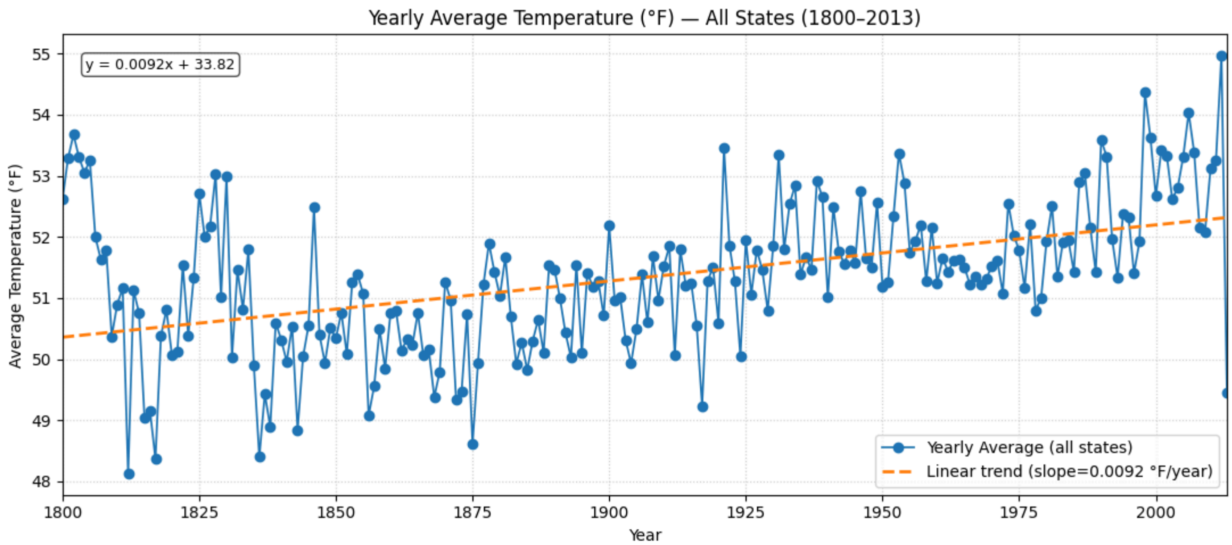

3. City Monthly Averages (1800-2013)
    a. Use: For use in the State page, shows the average temperatures of different cities throughout the US. Using the lat/ long data, map them directly to their location in the state.
    b. Missing data, Data cleaning: The dataset initially contained data for all major cities (and some smaller suburbs) globally, constituting over 8.5 million different temperature readings. As this project only contains analysis of US values after the year 1800, all non-US cities and readings dating prior to 1800 were culled. This produced a dataset of approximately 700k temperature readings.

       The dataset did not contain state information, only date, city, country, latitude, and longitude, the latter two being approximations, where the values were rounded to two significant figures. This meant the state names and abbreviations needed to be mapped to each of the values. Initially, the state names mapping was attempted using a geospatial approach, where the longitude and latitude were used to assign state values. After this approach was implemented, errors were found due to the aforementioned rounding of the geographic coordinates, and the mapping method was scrapped. Next, a manual mapping option was chosen. Since there were fewer than 300 US cities represented in the dataset, with no duplicate cities (cities with the same name as other cities in different states), each city was mapped to its corresponding state, with the help of OpenAI's ChatGPT.

# Exploratory Data Analysis:

Initially, we used a line graph to look at the average yearly and monthly temperatures. From the line graphs of different states, we learned when records for temperatures started being recorded. Some states had data all the way back to 1800, but California didn't start until the 1850s. Hawaii didn't start until after 1875. For our design, this gave us some insight into what additional information we needed to include in the state pages.

After looking at the averages for the individual states, we created a line graph for the average yearly temperatures for the whole country. By adding a trend line to the data, it was easier to see the overall trend in average temperatures. From this, we learned the slope was a 0.0092 ℉ increase per year. Since this visualization made the trend much easier to see, we decided to add a trend line to all of the line graphs on the finished visualizations.




# **Design Evolution:**

Our design had two main components: A national map view of the whole U.S. and individual state views.

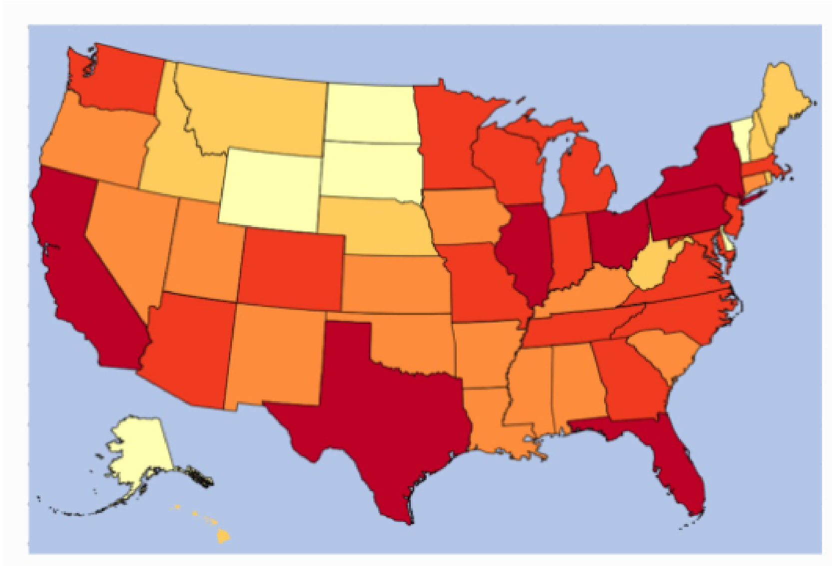
## **National View:**

For the national view, we proposed a heat map of the whole U.S. with each state color-coded for the average temperature. The purpose of this project was to show changes in average temperature across the US, so using a heat map was the most natural approach. This method allows users to quickly compare different states using a sequential color scale. To cut down on the amount of color and to create sufficient luminance contrast, we placed the map on a solid, neutral background. The colorscale we used was also limited to a smaller range to make each color more distinguishable.

We proposed a few interactive features to give the user the ability to filter between yearly and monthly data using a sliding scale that updates the map in real time. Giving the user more freedom to explore the visualization helps with both engagement and comprehension of the data being shown. To provide more granular information on the temperatures, we planned to include a tool tip, so users can hover over a state to get the exact average. This will also make the map more accessible for people with degrees of color blindness.

NOTE: Update throughout the project as we deviate from the original proposal

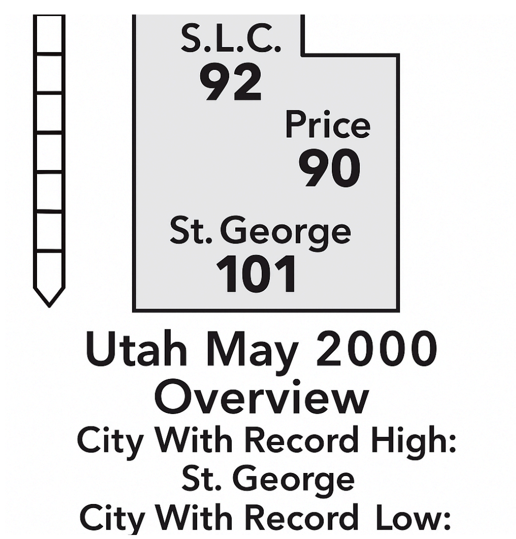
Proposed Map:



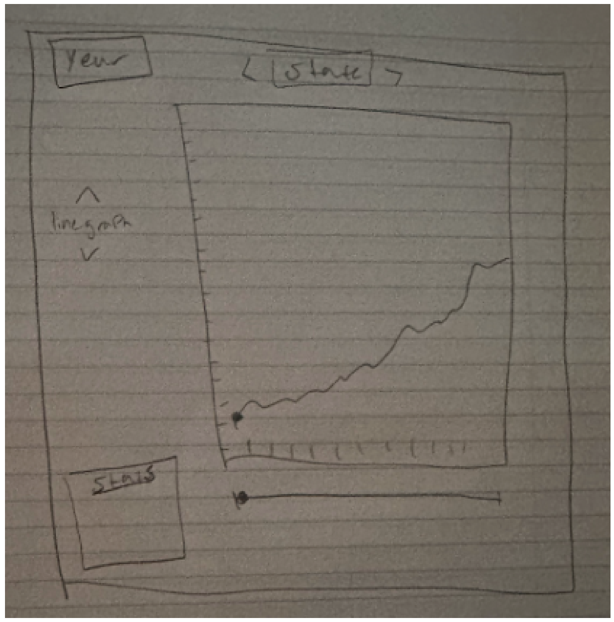
**State View:**

The proposed state view provides a mini-map for an individual state. The colors are consistent with the national map, so the colors have the same meaning for the two pages. We plan to include extra data on the state maps with the average temperature for major cities and their locations on the map. The cities will not be color-coded to cut down on the amount of color used on the map. In addition to the map, we plan to include a line graph to provide an easy way for the user to see how the state's monthly or yearly averages change over time. A line graph was ideal because it allows for a clear representation of changes over time. An additional trend line in the graph also shows the user how the temperatures have been steadily increasing.

Proposed Map:



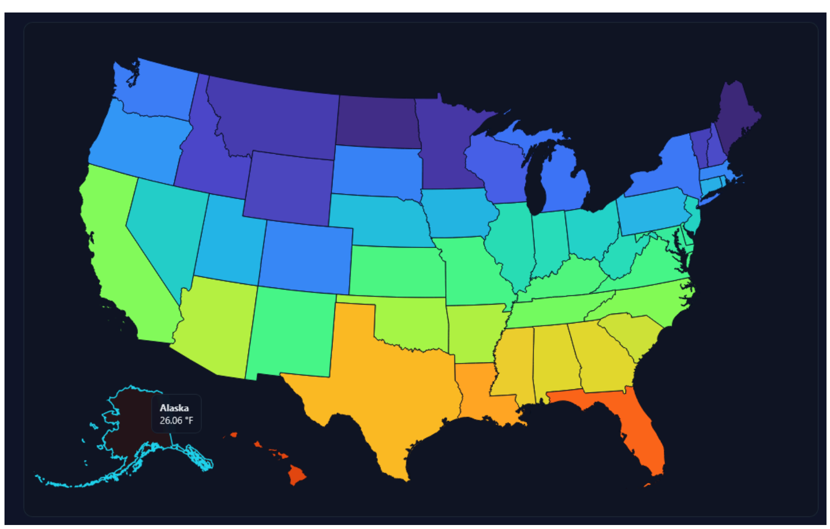
Proposed Line Graph:



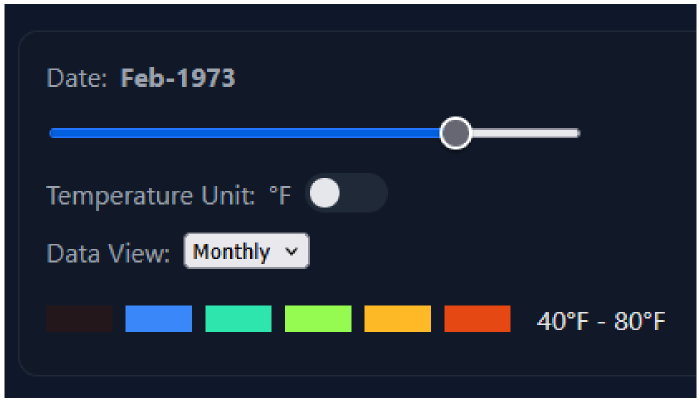

# Implementation:

## Landing Page - National View:

For our initial setup, we started with the landing page. The landing page shows temperature changes for the whole U.S. in one map. Before worrying about the data sets, we began with a rough outline of the map with a few made-up data points. To draw the map, we used geographic from D3, geoAlbersUsa, and geoPath to render each state as an SVG path. Once the map was working correctly, we linked it to the actual data sets. For more information on how the data sets were acquired and cleaned, see the data section. For our initial findings, see the exploratory analysis section. While linking the data to the map, we found that the data for Georgia was not being found. After inspecting the CSV files, we learned that the original data set had labeled the state of Georgia as Georgia (state), likely as a means of differentiating it from the country of Georgia. In VS Code, we use *Find All* and replace to fix all the entries for Georgia in the monthly and yearly averages data sets. The final version is pictured below:

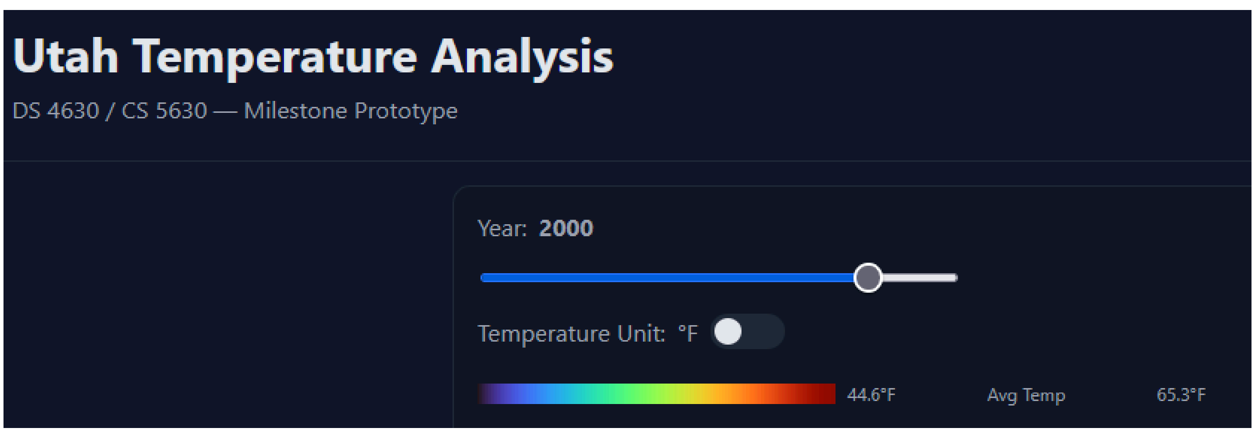


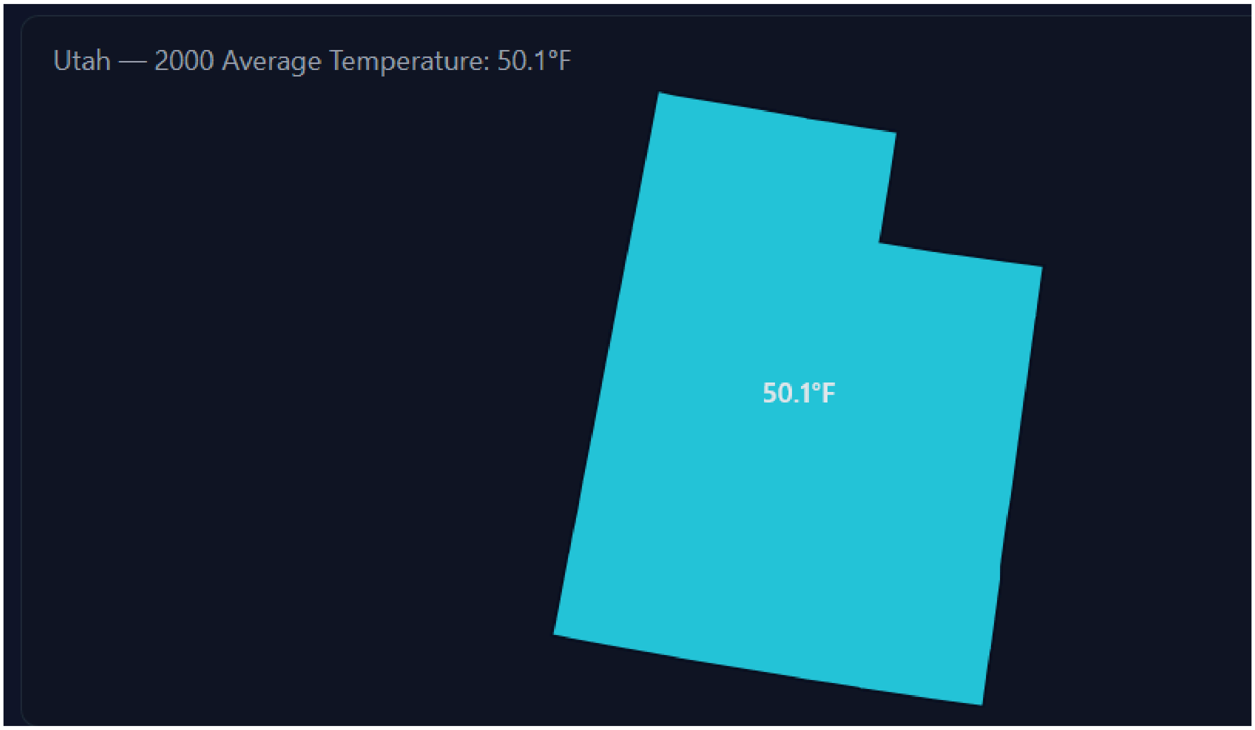
To give users more information about the temperature, we added a tool tip, so they can see the exact average for the state when they hover over the map. Above the map, we provided a legend with the color scale. We included a slider to allow users to easily navigate the map over time, from 1800 to 2013. There is a drop-down to switch between a map should the average temperature for a whole year or the average temperature for each month. An additional toggle allows them to switch between Fahrenheit and Celsius.



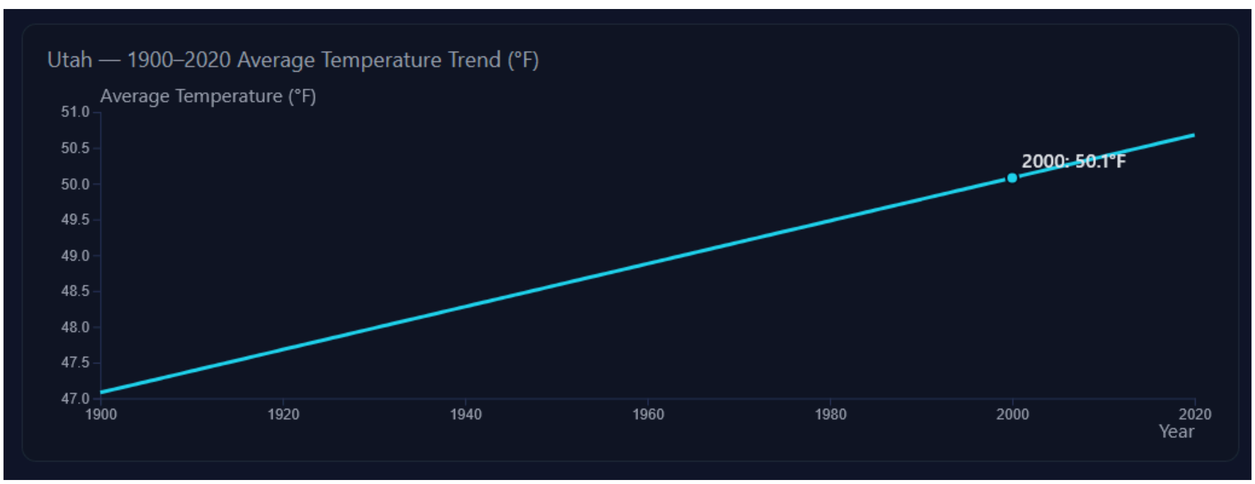

## **Landing Page - State View:**

At first, we had the state view on the same page as the national, but then we split it into its own page. Our next step is to link the two pages so that when a user clicks on a state, they are redirected to the state view page. We also need to link it to the data set for the city averages and then add those cities to the map. At this stage, the state page highlights the selected state in a map view of just that state. Above the map, we've included a slider for the user to change the year and a toggle to go between Fahrenheit and Celsius.






Below the map view, we've started with a simple line graph that shows the trend in temperatures for the selected state. On the line, we've included a point of interest, so the user can see the selected year.

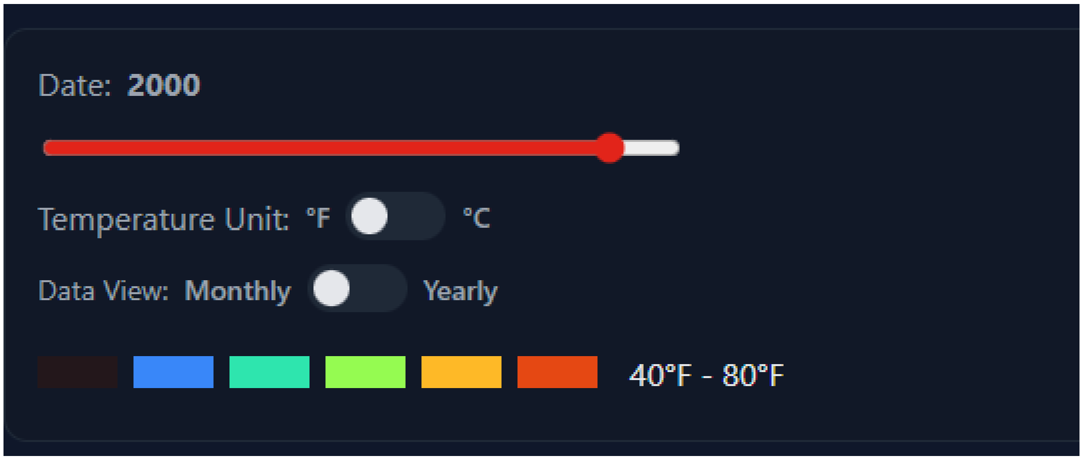


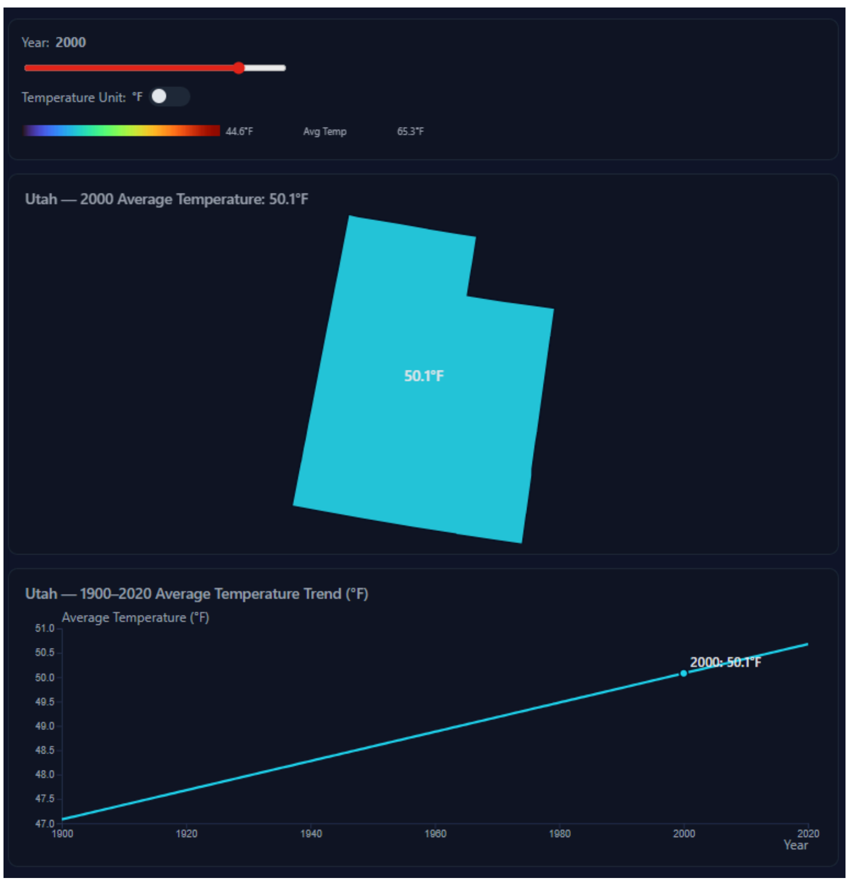

## Refining Page Structure and User Flow:

After the prototype was functional, much of the work turned toward improving how users move through the interface. The initial landing page and early state view existed mostly as functional placeholders, but lacked the organizational clarity needed for a polished analytical tool. The November development phase focused on strengthening this structure and ensuring each page guided users toward meaningful exploration.

A major part of this process involved rethinking spacing and visual rhythm. Earlier versions placed elements very close together, which made the interface feel dense. Adjusting margins and realigning components gave each element enough room to be read comfortably. The updated layout also anticipated future additions such as analytics tools, descriptive text, and navigation items. By making the structural changes early, the project avoided design conflicts later on.

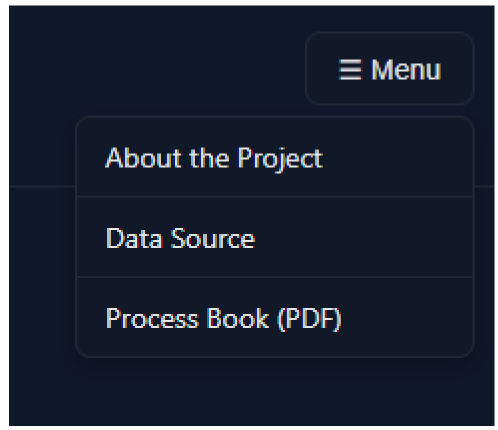
This structural refinement also ensured that the national and state views shared a consistent framework. Even though each page serves a different analytical purpose, a shared visual vocabulary, headings, spacing, and control placement help users transition smoothly between them. Small details, like aligning the map container widths and standardizing control spacing, made the system feel cohesive without drawing attention to itself.



## Navigation Menu and Header Enhancements:

Once the broader layout was stable, the next step was creating a reliable navigation system. In early prototypes, users had limited access to the project's supporting materials. To resolve this, a dedicated header was introduced with a compact menu button that opened a clean dropdown. This menu provided direct access to the About section, Data Source notes, and the Process Book, giving the site a structured framework similar to traditional analytical dashboards.




Behind the scenes, the dropdown required careful event handling to prevent unexpected behavior. For instance, clicking outside the menu now closes it, preserving a sense of polish. Positioning the menu required balancing the header's title weight with the functional needs of the right-aligned dropdown. Small adjustments to line height, padding, and hitbox size made the control feel more predictable during interaction.

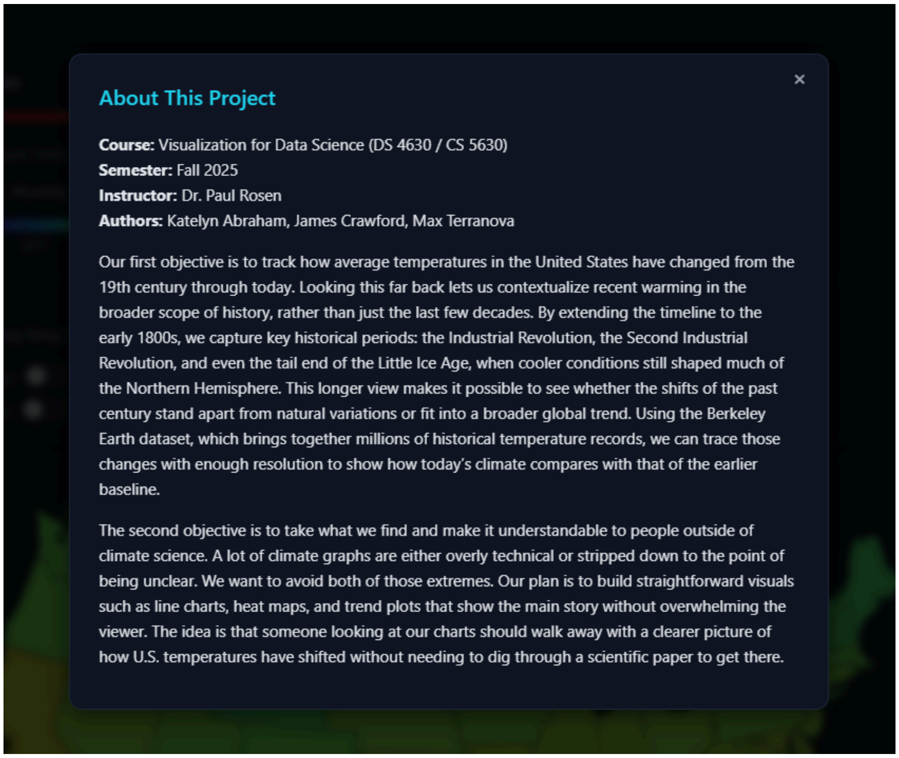
One subtle feature added during this stage was the fade-in timing of the dropdown. While slight, this smoothing helps the menu feel less abrupt, particularly when users open and close it frequently. Even though the animation is nearly imperceptible in the code, it contributes to a calmer, more professional feel across the interface.

The addition of this menu marked a transition from a prototype to a fully navigable application. It also set the stage for the modal windows that would later provide deeper context without pulling users away from their current view.

## Modal Information Windows and Supporting Logic:

To help viewers understand the purpose and origin of the data without leaving the main visualization, modal windows were introduced for the About section and the Data Source explanation. These overlays keep users grounded in the interface while revealing important background information in a focused space. The decision to use modals instead of separate pages helped maintain flow and kept the system feeling compact.

Stylistically, the modals were designed to match the site's existing card-like components, which created an immediate sense of consistency. They used familiar colors, rounded corners, and soft shadows to blend with the dark dashboard theme. Their placement centered on the screen to draw attention without overwhelming the map underneath.




A major technical improvement occurred during this stage. Early attempts to open the modals failed because event listeners were attached before the elements existed in the DOM. Wrapping all modal logic inside a *DOMContentLoaded* handler solved the problem and prevented intermittent behavior that could have appeared depending on browser load timing. This fix also established a pattern for future components that rely on dynamic elements.

A small, easily overlooked detail is that the modal backgrounds were calibrated to the same translucency used in the tooltip tint. This consistency helps the overlays feel integrated even though they serve different purposes.

## Script Stabilization and Event Flow Improvements:

As interactive elements multiplied, the underlying script required a more predictable structure. Early versions included scattered inline handlers and separate blocks of logic that didn't always fire in a controlled order. This became more noticeable as new elements such as the menu, modals, and tooltip logic were introduced.

This phase focused on reorganizing functions, consolidating event listeners, and ensuring all elements were initialized in the correct sequence. The *DOMContentLoaded* wrapper became a cornerstone of this process, eliminating race conditions that previously caused inconsistent behavior. With this structure in place, interactions across the page responded cleanly and predictably.

Another improvement involved refining event delegation. Rather than binding listeners to each individual element, several controls now rely on parent-level listeners that track specific targets. This reduces redundancy in the script and prevents failures if new elements are inserted or replaced later.

These refinements established a dependable backbone for the system and prepared the platform for more complex features such as city markers and zoom interactions.

## Early State Map Behavior and Structural Issues:

Before refinement, the state map worked mainly as a placeholder to demonstrate the intended layout. The map lacked city markers, interactive tooltips, and a clear connection between the state's geometry and the temperature data driving the visualization. The line graph below the map was also unlinked and acted more like a visual suggestion than an analytical tool.

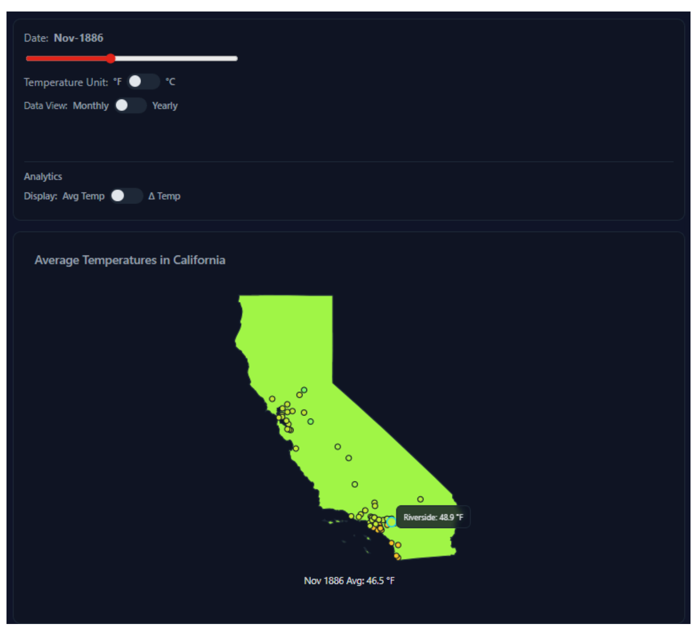
During this stage, several problems surfaced. The most persistent issue involved data alignment. Because the project had used multiple drafts of the dataset, field names in the script no longer matched the cleaned CSV. As a result, every city marker attempted to display temperature values that did not exist, defaulting to the scripted fallback text. This wasn't obvious until markers were introduced.

Another issue involved the SVG projection. Tall states such as California or Indiana were clipped at the top or bottom because the projection fit tightly to the container without padding. Earlier CSS rules also compressed the view slightly, amplifying the clipping. These issues guided the next development stage, which focused on accuracy and visual balance.

The early state map did, however, provide a clear testing environment for identifying these shortcomings. Its simplicity made it easier to isolate the problems that needed attention.

## City Data Linking and Coordinate Accuracy Fixes:

Once city-level visualization began, the first major issue was clear: every tooltip reported "No data," revealing a systematic mismatch between the data source and the script. Updating the references to the actual field names restored proper values. To ensure accuracy, several test cities were cross-checked by comparing tooltip values to the CSV entries.




The next challenge involved the coordinate precision of the original dataset. Many latitude and longitude values were rounded to two decimals, causing some cities to fall slightly outside their states. This misplaced markers along borders or coastlines, producing confusing visuals.

Replacing these values with high-precision coordinates corrected the city positions and made the spatial relationships far more reliable.

As an additional safeguard, a small tolerance was added when filtering city coordinates relative to state shapes. This helped prevent borderline cities from triggering “outside state” conditions during hit testing. Although subtle, this adjustment improved robustness when rendering states with irregular boundaries.

Together, these fixes strengthened the data pipeline and ensured that the map could support richer interaction.

## Marker Hover and Zoom Interaction Refinement:

With accurate city data in place, focus shifted to making interactions feel natural. The earliest marker behavior simply enlarged a dot on hover. When zooming was introduced, this caused conflicts: enlarged dots stayed inflated, or markers scaled unpredictably when zoom levels changed.

Introducing a dedicated hovered class allowed the system to track which marker was actively highlighted. The zoom handler now skips resizing hovered markers, preserving their appearance until the cursor moves away. When hover ends, the marker resets to its correct size based on the current zoom.

Testing across several states helped fine-tune this behavior. Dense urban clusters, such as California’s coastal regions, benefited most from the refinement because the interaction no longer obscured nearby cities. The improvement created smoother transitions and helped establish consistency between the national and state views.

A subtle feature added during this stage was a short delay before shrinking markers back to their normal size. This prevented jitter when the cursor briefly slipped off the marker, especially during slow zoom interactions.

## Projection Padding and Boundary Corrections:

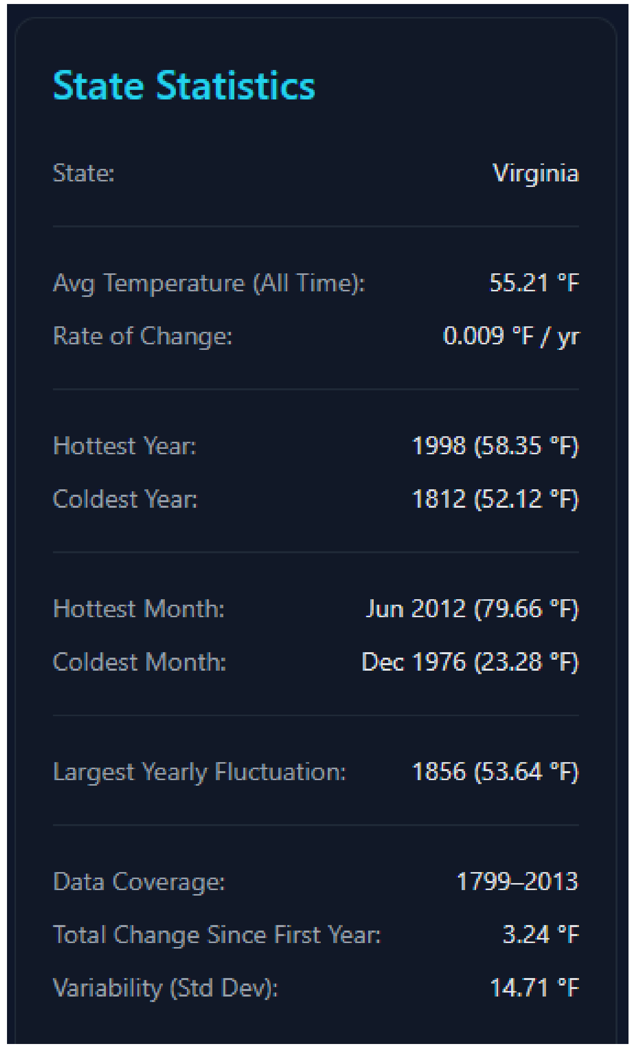
To resolve the recurring clipping issue, projection padding was introduced around the state geometry. Earlier versions fit the state precisely to the container, which worked for mid-sized states but failed for taller or unusually shaped ones. Slight increases to the projection’s top and bottom boundaries ensured states were rendered fully without distortion.

Several rounds of testing helped determine the appropriate padding values. Vertical padding had the greatest impact, while horizontal padding required only minimal adjustment. The goal was to preserve scale while giving the map enough breathing room to avoid edge collisions.

The new padding also improved marker readability. With slightly more space around the map, city markers no longer rubbed against the edges or felt compressed. The entire state view appeared more balanced, preparing the layout for future enhancements such as expanded legends or interactive overlays.

## Addition of the State Statistics Panel:

As the state view matured, a significant enhancement came with the introduction of a dedicated statistics panel. This panel summarizes long-term climate characteristics for the selected state and provides users with a richer context than the map and line graph alone can offer. It displays all-time averages, the long-term rate of change, historically hottest and coldest years and months, and the largest observed yearly fluctuation. It also includes dataset coverage information and cumulative change since the first recorded measurement. All values are calculated from the complete dataset rather than the selected year, giving viewers a stable reference frame as they navigate through time.




Positioned along the right side of the interface, the panel remains fixed as users interact with the slider, unit toggles, or tooltips. This anchored placement allows the statistical summary to act as a companion to the map without shifting as the layout changes. Because the project is designed for desktop viewing, the panel does not collapse or reflow on smaller screens. This decision kept the design straightforward and made it easier to maintain consistent alignment with the map and graph.

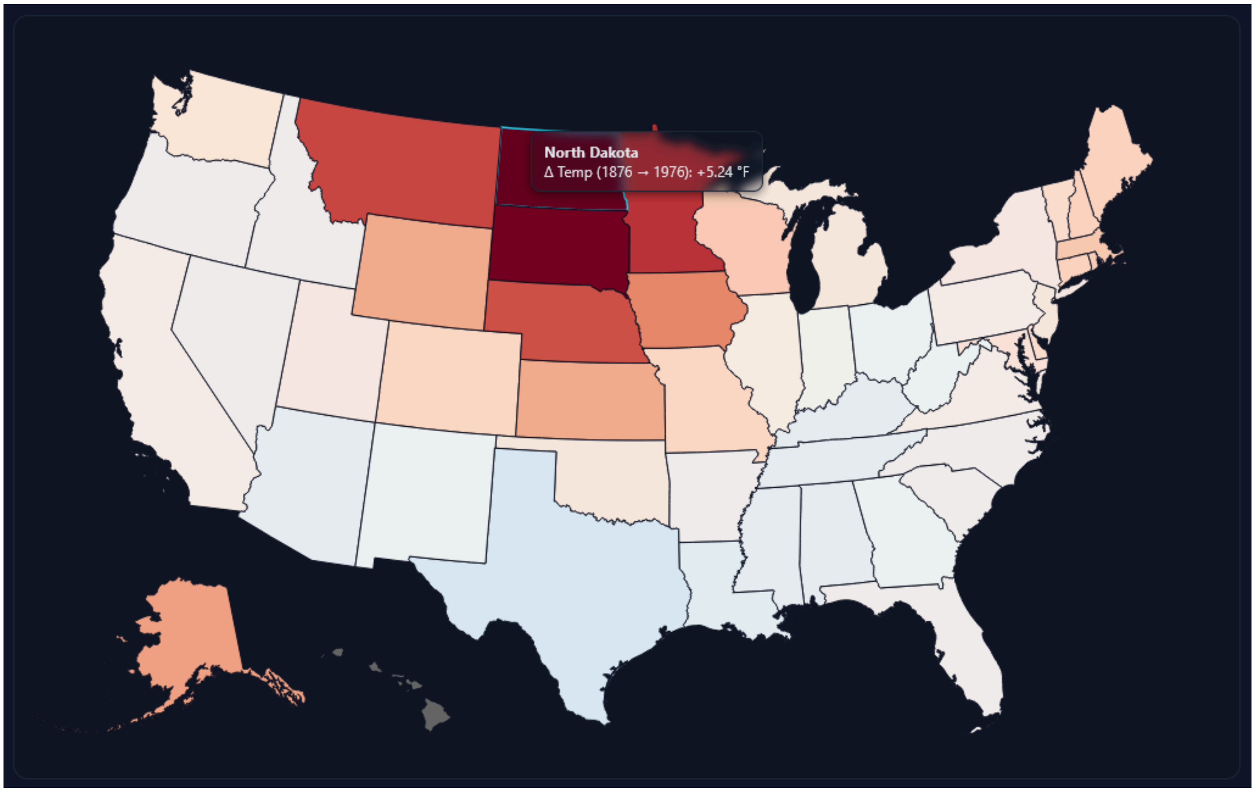
One subtle detail in its implementation is the standardized formatting of its numerical fields. Temperatures, fluctuations, and regression values follow a uniform precision rule, which avoids visual noise and makes comparison easier. Another detail is the dividing rules placed between sections, which guide the eye and help viewers navigate the long list of metrics. Although simple, these touches improve readability and help frame the statistics as a coherent unit rather than a loose collection of numbers.

Together, the map, graph, and statistics panel create a three-layered view of each state. They allow users to examine the present year, the long-term trend, and the state's overall climate profile at the same time.

## National Delta Comparison View:

To help viewers interpret how temperature has shifted across the country, the national map was expanded with a delta comparison mode. Instead of showing absolute temperatures, this mode displays how much each state has changed relative to a chosen baseline year. By anchoring the map around a reference point, the visualization makes broad national trends easier to see and compare. This mode became one of the project's strongest analytical tools because it emphasizes structural warming patterns rather than isolated temperatures.

The design preserves all core interactions—hover tooltips, color scaling, and unit switching—while substituting absolute values for deltas. The color scale adapts to highlight both positive and negative deviations, and state hover labels update to show the amount of change. The slider continues to function, allowing users to animate warming trends over time without losing the delta context.




An interesting behavioral detail is that delta mode influences portions of the system beyond the map itself. Although the state-level and multi-state trend tools remain independent, their date ranges update to reflect the baseline used in the delta calculation. This gives viewers a coherent narrative as they move between views. The map anchors the story spatially, while the charts and panels echo the temporal window that delta mode implies.

Adding delta mode helped unify the analytical framing of the entire application and created a bridge between spatial and temporal interpretations of warming.

## **Two-Way State Comparison Tool:**

To extend the analytical depth of the state page, a comparison tool was added directly within the line-graph section. This tool allows viewers to select a second state and view both temperature histories on the same chart. The intention was to provide a simple, direct method for comparing regional behavior without switching between multiple pages or interrupting the user's exploration.

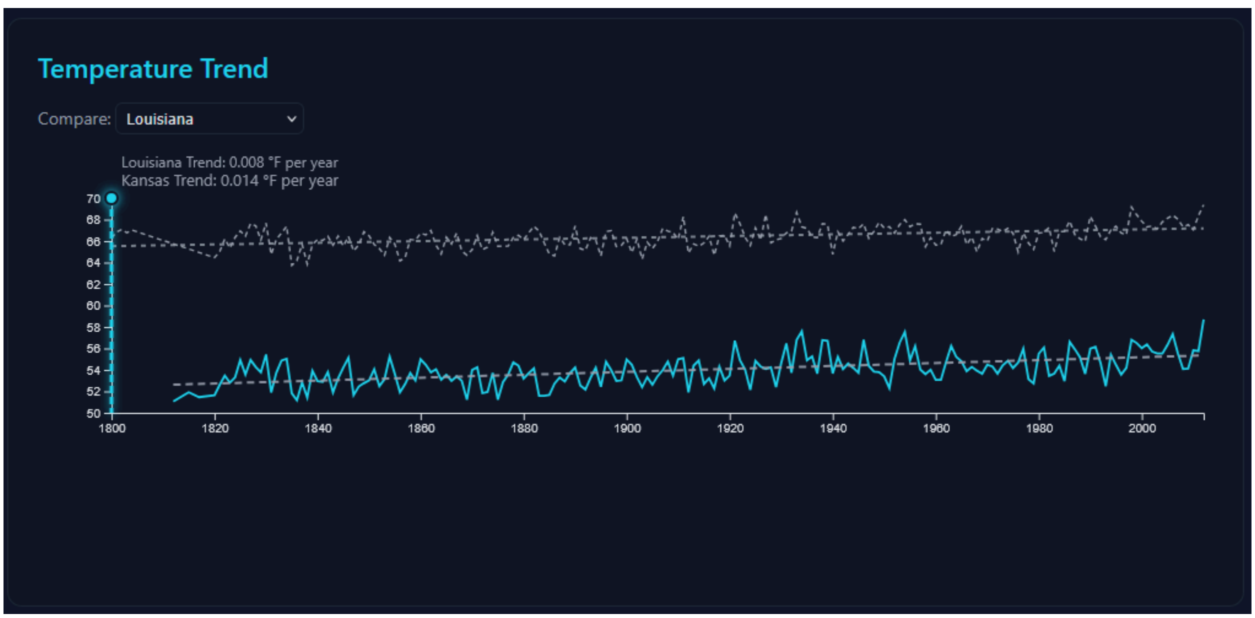
The interaction is handled through a single dropdown placed above the graph. When the user selects a second state, the graph redraws with two full temperature histories, each with its own color and corresponding regression line. The point-of-interest marker continues to track the primary state's selected year, but the tooltip updates to reflect values for both states at that moment. This ensures that the comparison remains grounded in the timeline structure of the state page.

The comparison tool is deliberately confined to the graph area. No extra panels or tables were added, which keeps the state view lightweight and focused. This decision also helps maintain a clear separation between the state-level analysis and the broader multi-state trend tool on the national page.

A subtle refinement is that regression lines for both states retain consistent styling regardless of their order or which state is primary. This decision prevents the graph from developing a visual hierarchy that might imply one state is more important than the other.

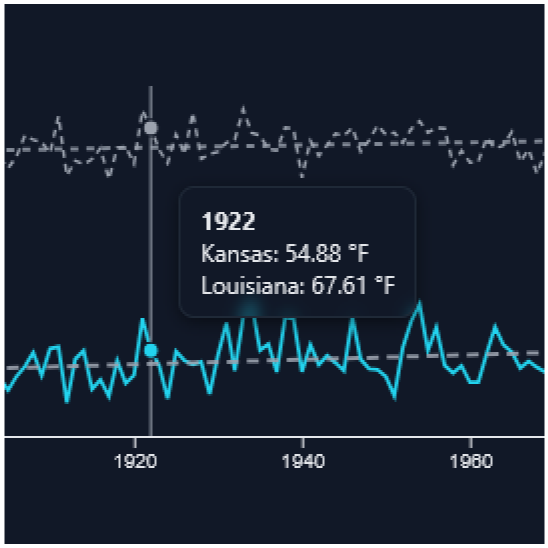
## Regression Trendlines in the State Line Graph:

As the state line graph became more central to the state view, it became important to give users a clearer sense of long-term behavior. A linear regression trendline was added to the graph to provide that clarity. This regression updates automatically based on the selected units and time span, giving viewers an immediate sense of whether temperatures are rising, how quickly, and how that rate compares to the descriptive statistics shown in the side panel.




The trendline behaves consistently whether the user is viewing a single state or engaging the comparison tool. Each state receives its own regression line, drawn with a light transparency to distinguish it from the raw data without overpowering the graph. This dual-line behavior allows users to compare long-term trajectories at a glance, revealing differences in slope and overall stability between two states.

A small but thoughtful feature is the persistence of the point-of-interest marker. Even when the regression lines are present, the selected-year indicator remains on top of all drawn elements, preventing the trendline from visually competing with the user's active focus point. This detail ensures the graph remains approachable, even when multiple layers of information are displayed.

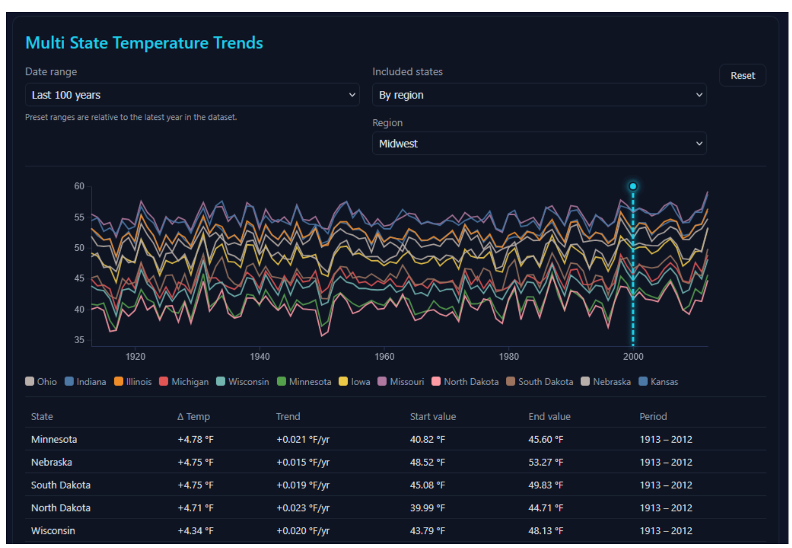



Trendlines brought the state analysis closer to the sophistication of the multi-state system and strengthened the connection between the various analytical components of the project.

## **Multi-State Trend Integration:**

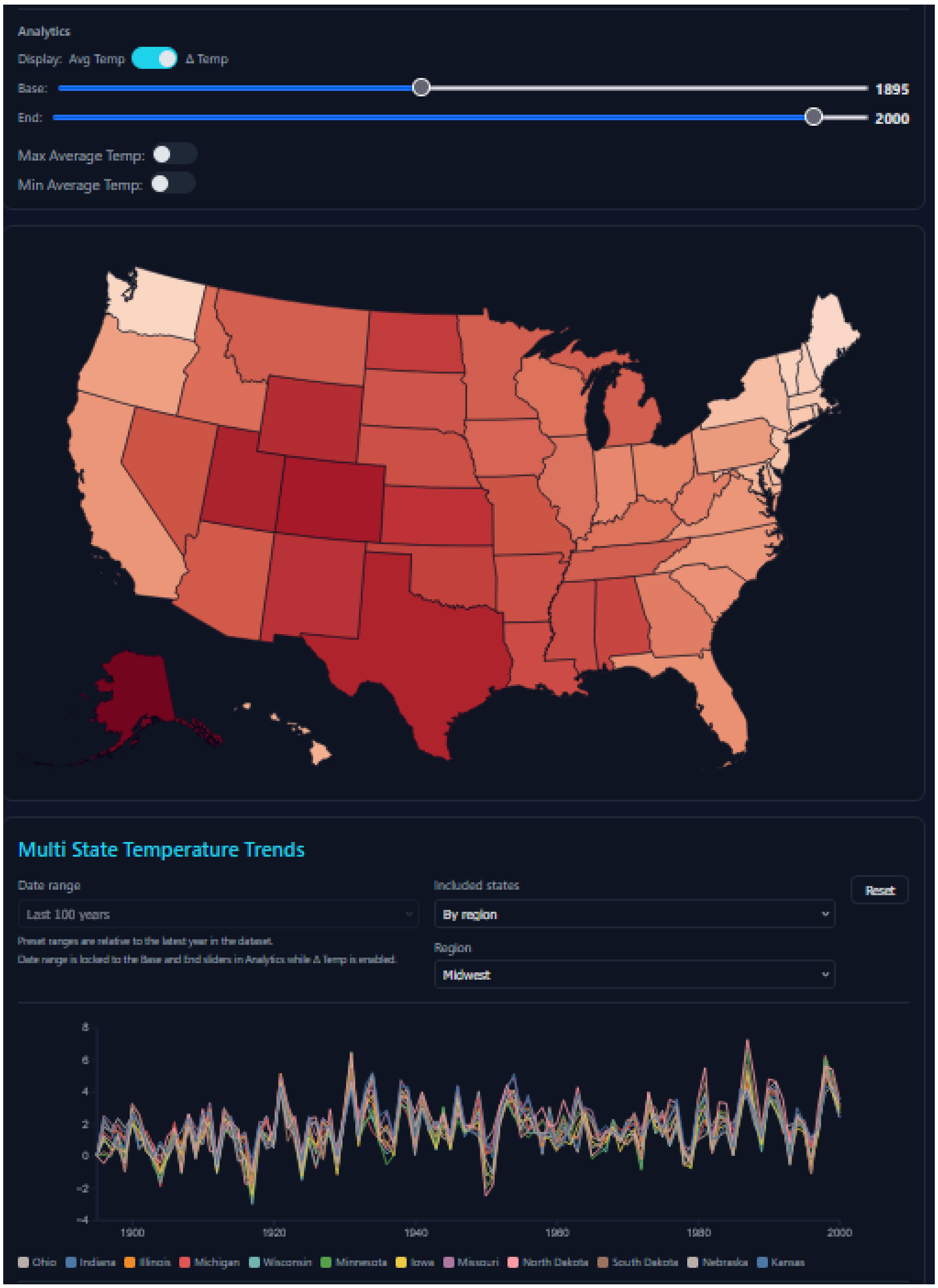
The Multi-State Temperature Trends view became one of the largest additions to the project and extended the analytical capabilities beyond individual states. While the map reveals spatial structure and the state page shows local detail, the multi-state trend panel displays long-term temporal relationships across multiple regions. Users can select preset groups—such as the hottest states, coldest states, or regional clusters—or define completely custom selections, allowing the panel to support both structured analysis and open exploration.

The chart renders multiple state lines simultaneously, each assigned a stable color from a controlled palette. As the user adjusts the date range or switches between units, the lines update instantly, maintaining alignment with the rest of the dashboard. The accompanying summary table below the chart lists starting values, ending values, total change, and per-year trend, and sorts automatically so the most significant warming appears first. This simple table communicates a great deal of structural information in a compact format.



Although delta mode does not control the multi-state tool directly, the panel stays synchronized with the timeline decisions made in the national view. This helps maintain consistency across views even when users transition frequently between them. A reset button returns the panel to a familiar configuration, easing navigation when users explore more complicated sets of states.

A small but meaningful refinement is the vertical highlight line on the chart. This line tracks mouse movement and reveals values for all states at a given timestamp. Its color and thickness were tuned so it remains visible even in dense clusters of lines without overwhelming the chart.



# Evaluation:

From the visualizations we built, we learned that all fifty of the United States have had an upward trend in average temperatures. We relied on two types of visualizations: heat maps for average temperatures and line graphs. We also included a section on our main page for users to explore the data with an interactive line graph that allowed for custom filtering of the data and printed summaries of the data shown. The heat maps of the whole country or the individual states didn't reveal as much as we had expected. This was due to the very gradual changes in temperature. These gradual changes, when represented in colors, were difficult to judge relative to each other and created a more difficult context than we hoped. Adding a play button gave us the ability to watch the temperatures change from the 1800s to 2012, but it was still difficult to get a good sense of the changes. The comparison tool, which allowed us to select a base year and another year for comparison, was more useful for comparing two years at a time, but overall the heat maps did not provide an easy context for long-term temperature patterns.

The line graphs told us more about the data and directly answered our key question. We let users switch between average yearly temperatures and average monthly temperatures. The yearly graphs were easier to read because the angles between each of the points were closer to 45 degrees. The line graphs of average monthly temperatures were not helpful for seeing trends unless the date was filtered to a smaller range. When all the months from 1800 to 2012 were included, the angles between points were so small, the graph was nearly unreadable. The most useful line graph was on the individual state page, which included a trend line. This made the change in temperatures easy to see visually.

In addition to the line graphs, the interactive feature on our main page that printed out the average temperature trends turned out to be especially helpful. This tool let users filter the dataset however they wanted including by state, year range, top five hottest, top five coldest, regions, or monthly versus yearly averages. It also included a numerical summary of the trend they were looking at. Having the trend displayed in text made it much easier to interpret the visualizations, especially when the graphs were dense or when the change wasn't visually obvious at first glance. It also gave users a quick way to confirm whether the temperatures were increasing, decreasing, or staying roughly the same without having to analyze the slopes themselves. This feature helped bridge the gap between the raw visual data and the conclusions we wanted users to take away.

Overall, some of our visualizations were more effective at answering our question regarding changing average temperatures in the United States. It was by printing out the trends for each state on our main page, so users can easily see the average trends listed numerically, and adding a trend line to the line graphs on our state pages that we were more clearly able to see the upward trend. If we were to improve the project, we would consider adding more global data or including more countries, since some regions might show more dramatic changes. Additional improvements would be to include different options for the color scale on the heat map, such as a uniform color scale, enhanced contrast modes, or giving the user the ability to adjust the color scale range. We could also have added annotations to the national map with significant events like industrialization milestones and explanations for data gaps as a lot of the western United States did not have average temperature data for much of the 19th century. Adding extra features, like a light mode or a colorblind friendly pallette, would also make the site more accessible. Altogether, these improvements would strengthen our ability to communicate the long-term changes in U.S. temperatures and make the project more usable, accessible, and informative for a wider range of audiences.