Actuarial Weather Extremes Series Sea Level Rise – June 2025

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Introduction: Sea Level Rise

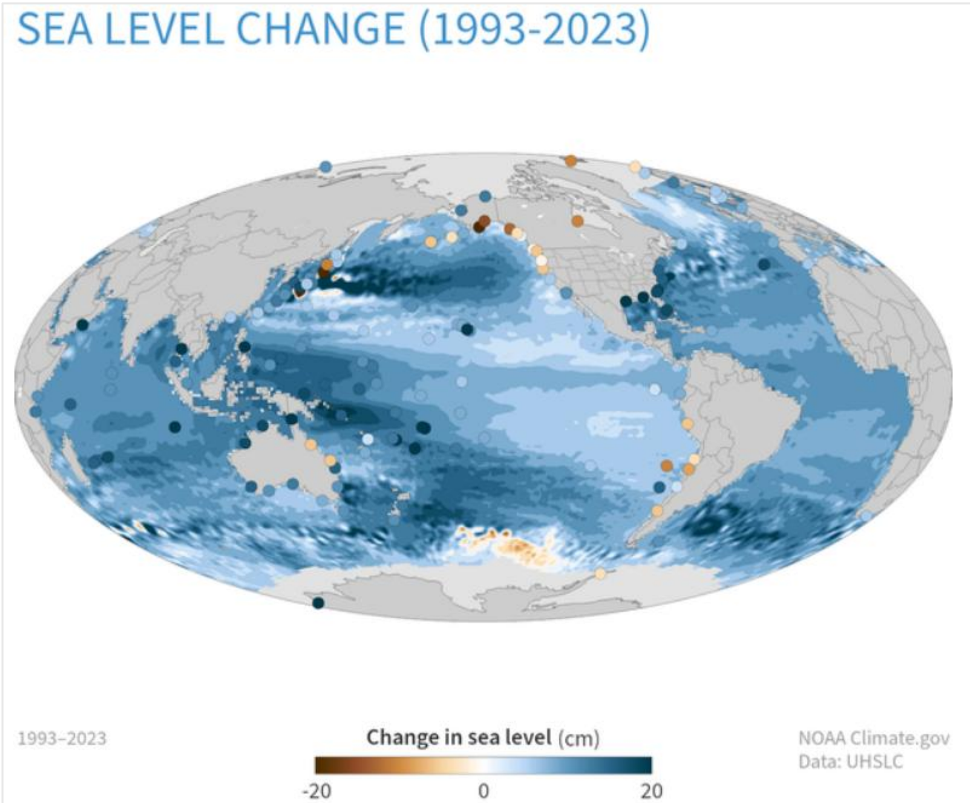
The actuarial profession has long been at the forefront of quantifying and mitigating financial risks. However, the advent of anthropogenic climate change presents a unique challenge, characterized by unprecedented scales, interconnected impacts, and significant uncertainties. Among these, sea level rise (SLR) stands out as a critical and often underestimated risk, particularly for coastal properties, infrastructure, and the livelihoods of millions. Unlike other perils that might manifest as discrete events, SLR is a pervasive, incremental threat that fundamentally alters the baseline risk profile for many assets and liabilities. This report will delve into the observed trends of sea level rise, the underlying drivers, and the methodologies used to understand and model these changes.

Understanding Sea Level Dynamics: Data and Trends

To fully appreciate the severity of sea level rise, it is essential to understand its components and the data that informs our understanding. Global mean sea level (GMSL) is influenced by two primary factors: thermal expansion of ocean water as it warms, and the melting of glaciers and ice sheets.[1] As shown in the figure below, produced by the National Oceanographic and Atmospheric Administration (NOAA), sea levels have not increased evenly across all oceans. We will look at both global sea levels and some key areas of the globe to see differences in how sea levels have changed over time.

[1] "Climate Change: Global Sea Level." *NOAA Climate.Gov*. 22 Aug. 2023, https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level.

Figure 1
SEA LEVEL CHANGE FROM 1993-2023[2]



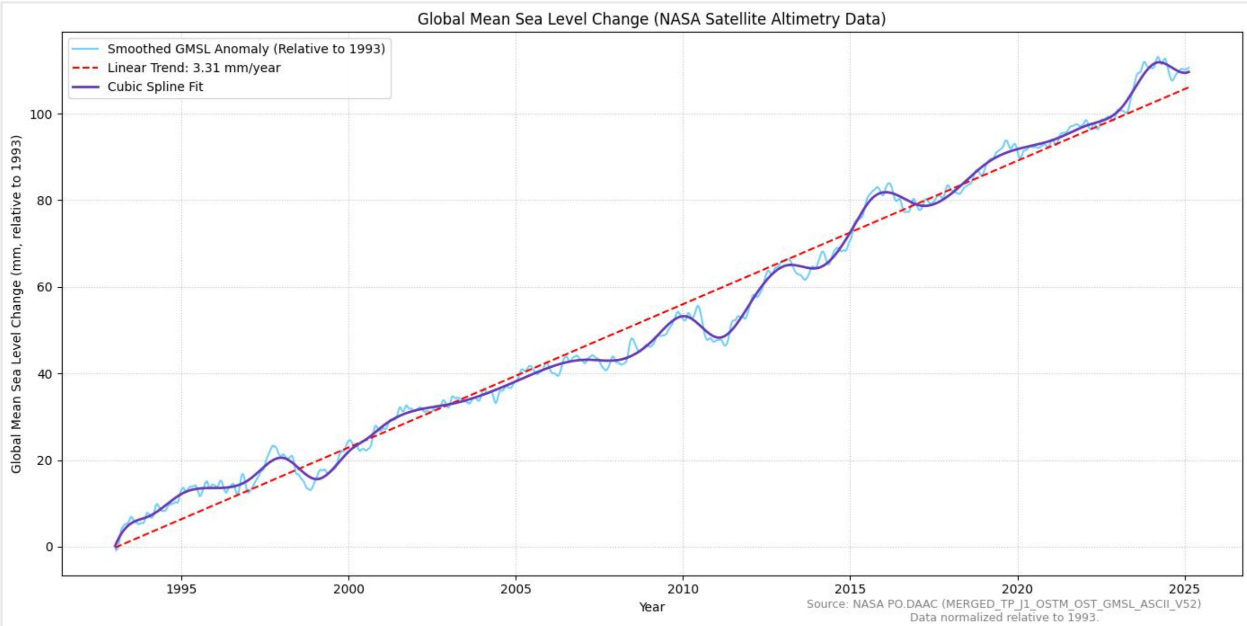
GLOBAL MEAN SEA LEVEL OVER TIME

Observational data reveals a clear and accelerating trend in global mean sea level. Satellite altimetry, combined with historical tide gauge records, provides a comprehensive picture of this rise.

[2] See footnote 1.

Figure 2

1993-2025 GLOBAL SEA LEVEL, FIT WITH A CUBIC SPLINE



The figure above shows the global sea level with a cubic spline fit through the seasonal variability. The graph shows a trend line of +3.31 mm/year. The data for global mean sea level is typically compiled from NASA PO.DAAC archive,[3] specifically the "MERGED_TP_J1_OSTM_OST_GMSL_ASCII_V52" dataset. Data is accessible from the NASA's Earthdata database, which is freely accessible with the creation of a user account. Data is fetched using Requests with .netrc authentication and then read into a Pandas DataFrame using pandas.read_csv, with columns such as "Decimal_Year" and "GMSL_GIA_Smoothed_NoSeasonal_mm" being central for plotting.

REGIONAL AND LOCAL SEA LEVEL VARIATIONS

While global mean sea level provides a critical overarching trend, local sea level rise can vary significantly due to factors such as ocean currents, land subsidence, or uplift (vertical land motion), and changes in Earth's gravity field due to ice melt redistribution. Areas chosen for local analysis are some key locations in the United States and other densely populated coastal cities from other parts of the world. Stations were chosen that had a long history and had limited missing data (Mumbai for example, has enough data points to see a trend despite missing decades in between). The data from Permanent Service for Mean Sea Level (PSMSL) includes hundreds of stations from around the world.

GENERAL PROCESS

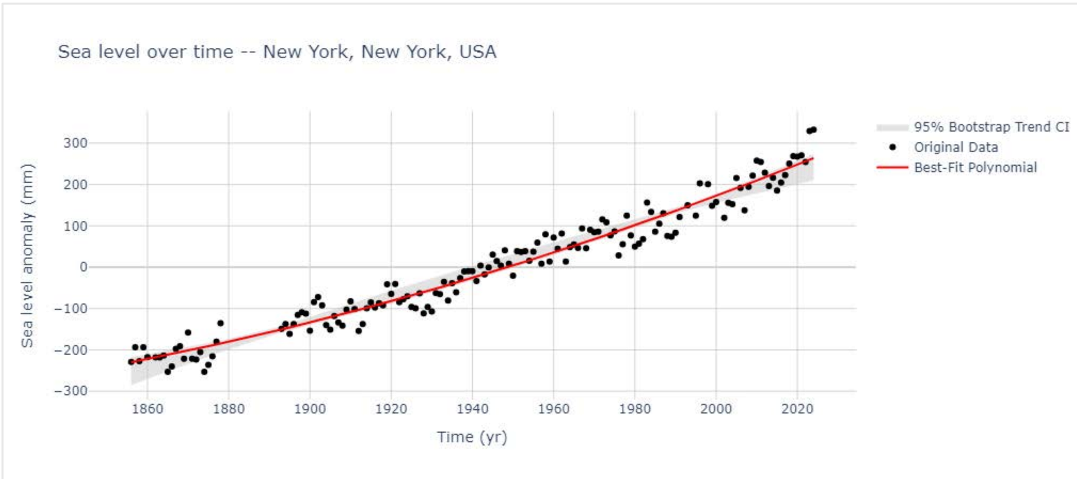
The steps below give a general outline of the process to produce these graphs:

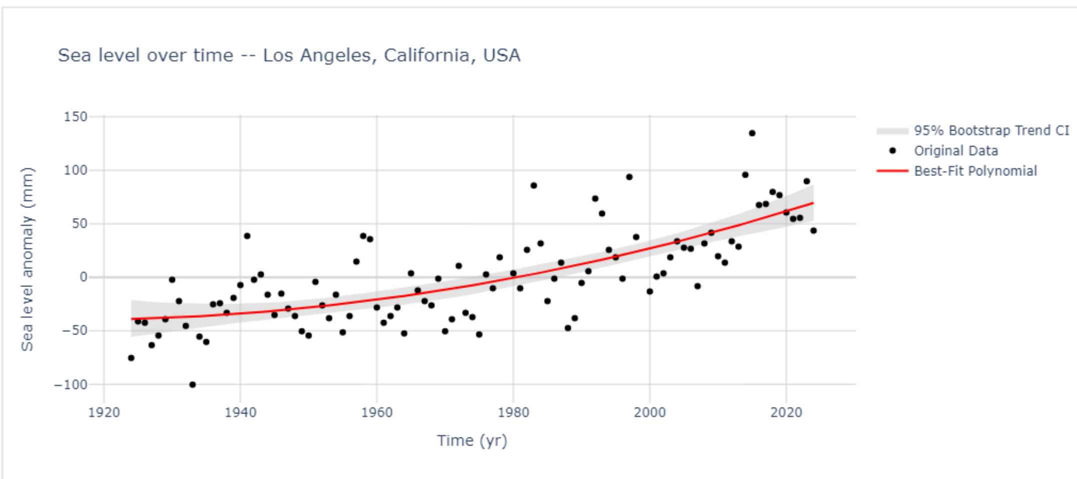
[3] Data source: https://archive.podaac.earthdata.nasa.gov/podaac-ops-cumulus-protected/MERGED_TP_J1_OSTM_OST_GMSL_ASCII_V52/GMSL_TPJAOS_5.2.txt

1. Sea level data for specific coastal cities is acquired from the PSMSL API (Application Programming Interface) and loaded into a Polars DataFrame, undergoing initial cleaning to handle missing values and quality flags. Codes corresponding to the cities can be found on the PSMSL website.
2. Sea level anomalies are calculated by subtracting the mean sea level from the observed readings, and any null values are filtered out.
3. A second-order polynomial is then fitted to this cleaned anomaly data to identify the long-term trend.
4. To quantify the uncertainty of this trend, a bootstrapping technique is applied, which involves resampling residuals from the initial fit to create multiple synthetic datasets and calculating a 95% confidence interval.
5. The Original data, the best-fit polynomial, and the bootstrap confidence interval are visualized using Plotly to effectively communicate the sea level trends and their associated uncertainty.

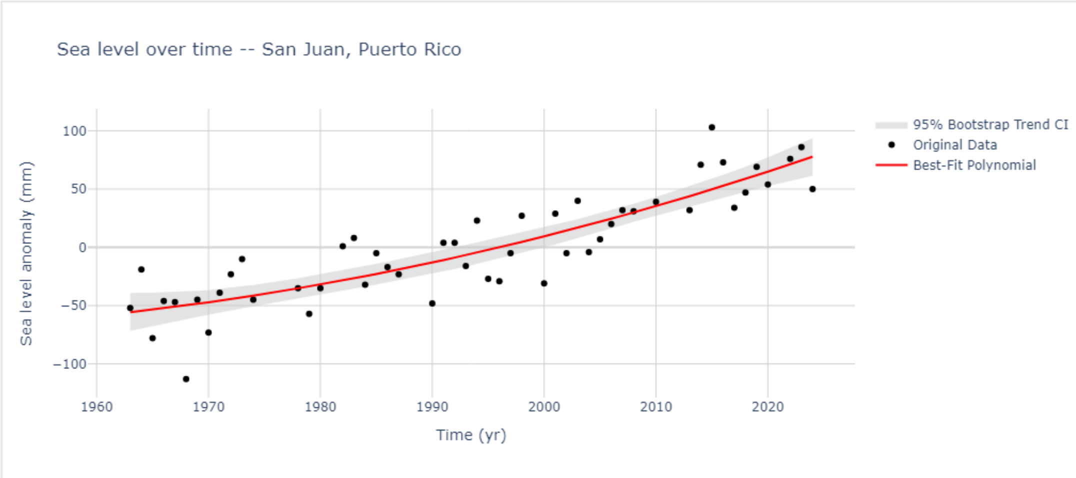
Figure 3

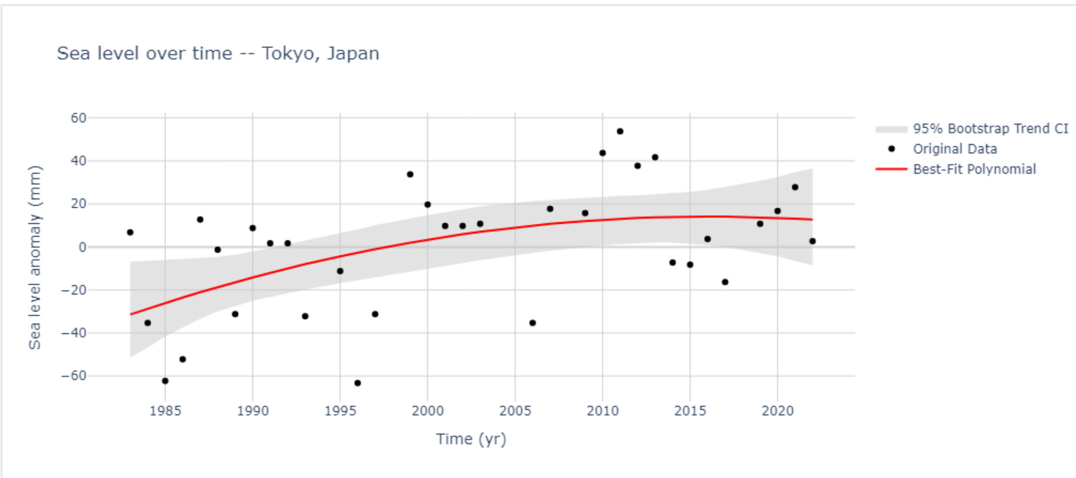
SEA LEVEL ANOMALIES COMPARED TO THE AVERAGE SEA LEVEL OVER THE YEARS DISPLAYED ON THE NEXT 10 REGIONAL GRAPHS[4]

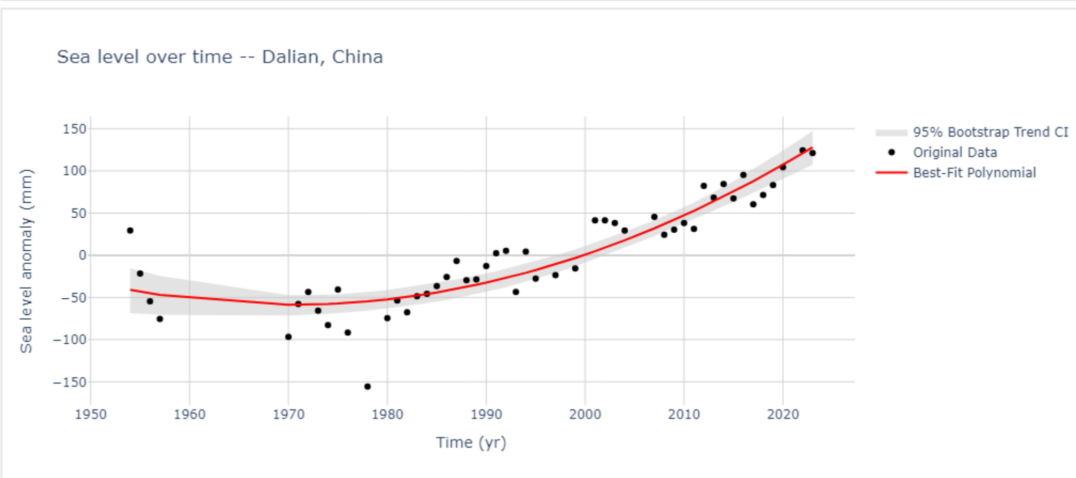




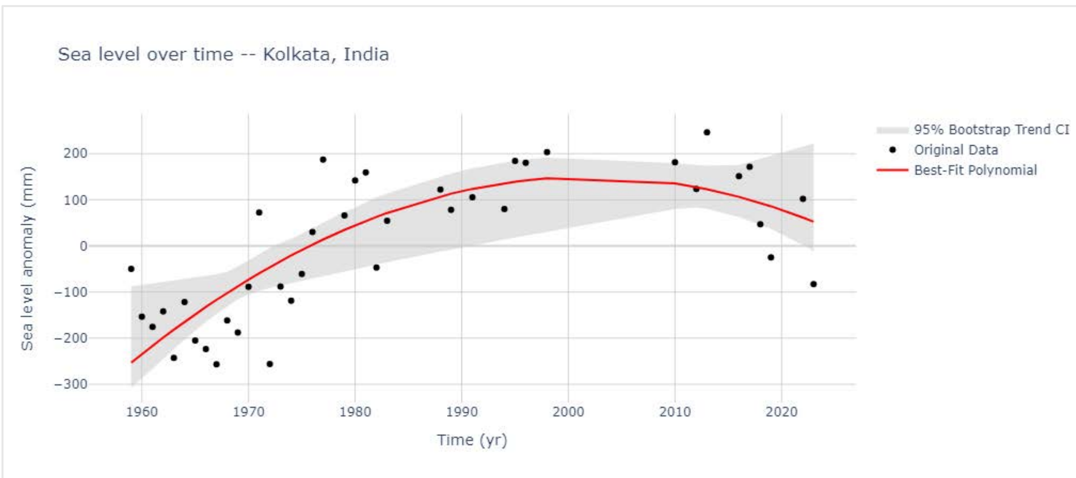
[4] Data sources:
New York: https://psmsl.org/data/obtaining/rlr.annual.data/12.rlrdata
Los Angeles: https://psmsl.org/data/obtaining/rlr.annual.data/245.rlrdata
San Juan: https://psmsl.org/data/obtaining/rlr.annual.data/1001.rlrdata
Tokyo: https://psmsl.org/data/obtaining/rlr.annual.data/1545.rlrdata
Dalian: https://psmsl.org/data/obtaining/rlr.annual.data/723.rlrdata
Sydney: https://psmsl.org/data/obtaining/rlr.annual.data/196.rlrdata
Kolkata: https://psmsl.org/data/obtaining/rlr.annual.data/369.rlrdata
Mumbai: https://psmsl.org/data/obtaining/rlr.annual.data/43.rlrdata
Takoradi: https://psmsl.org/data/obtaining/rlr.annual.data/331.rlrdata
Buenos Aires: https://psmsl.org/data/obtaining/rlr.annual.data/832.rlrdata


Sea level over time -- San Juan, Puerto Rico
95% Bootstrap Trend CI
Original Data
Best-Fit Polynomial
Sea level anomaly (mm)
Time (yr)

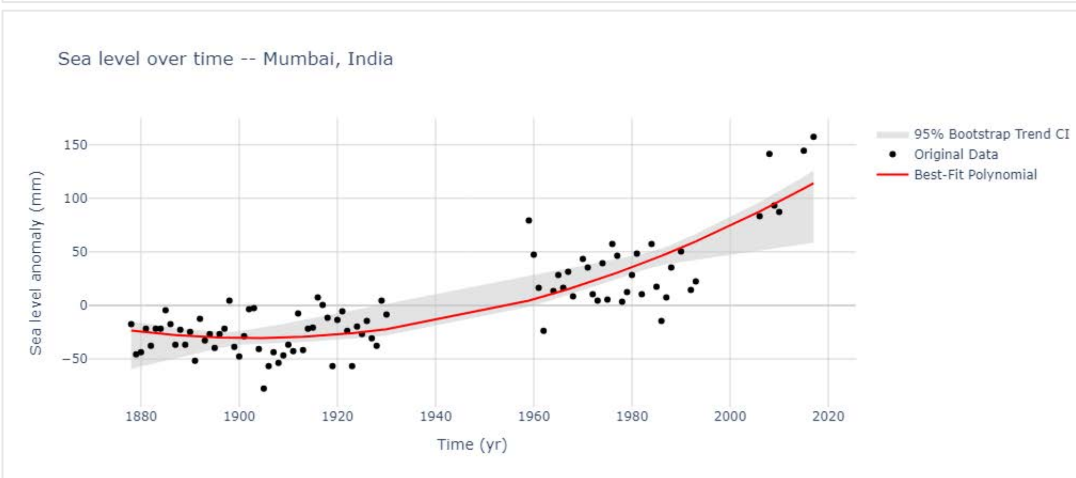

Sea level over time -- Tokyo, Japan
95% Bootstrap Trend CI
Original Data
Best-Fit Polynomial
Sea level anomaly (mm)
Time (yr)


Sea level over time -- Dalian, China
95% Bootstrap Trend CI
Original Data
Best-Fit Polynomial
Sea level anomaly (mm)
Time (yr)

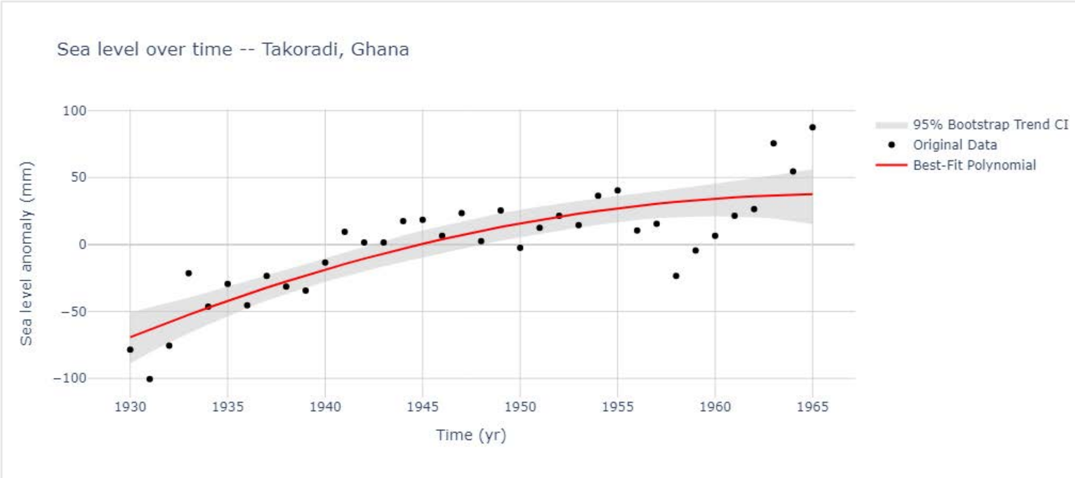
Sea level over time -- Sydney, Australia
95% Bootstrap Trend CI
Original Data
Best-Fit Polynomial
Sea level anomaly (mm)
100
50
0
−50
−100
1920
1940
1960
1980
2000
2020
Time (yr)

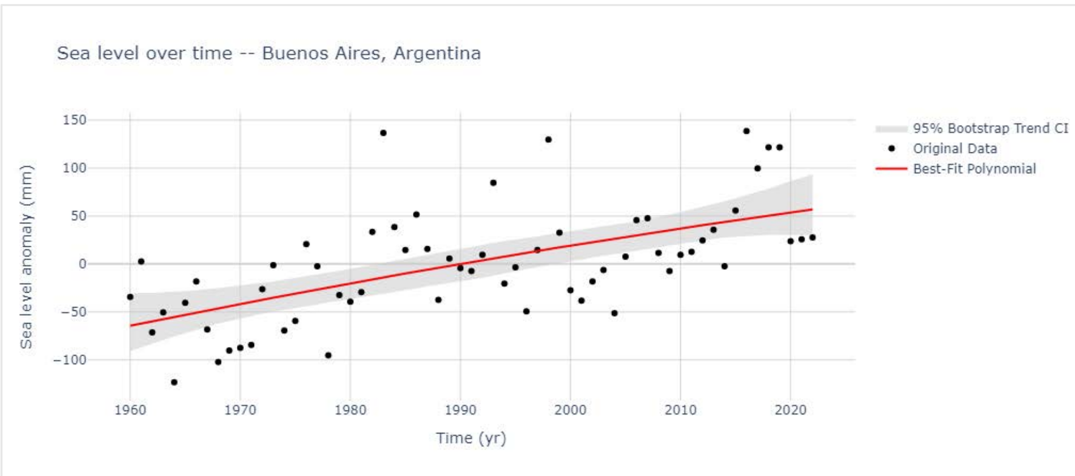


Sea level over time -- Kolkata, India
95% Bootstrap Trend CI
Original Data
Best-Fit Polynomial
Sea level anomaly (mm)
200
100
0
−100
−200
−300
1960
1970
1980
1990
2000
2010
2020
Time (yr)



Sea level over time -- Mumbai, India
95% Bootstrap Trend CI
Original Data
Best-Fit Polynomial
Sea level anomaly (mm)
150
100
50
0
−50
1880
1900
1920
1940
1960
1980
2000
2020
Time (yr)





The data for the regional sea level data for specific coastal cities is obtained from PSMSL. The notebook uses Requests to fetch data from this source, processing it with Polars for efficient data manipulation. Graphs visualizing sea level anomalies over time are generated using Plotly. Monthly data was considered, but sea level contains a fair amount of seasonality—so yearly data looks much more stable. The trend is bootstrapped by using the best fit line residuals to find a 95% confidence interval around the trend.

As can be seen from the charts, while most charts have a clear upward trend, this trend varies from place to place. When a major city (like Beijing) failed to have sufficient data, a nearby city was chosen to try to grab data that would give similar values.

CONTRIBUTIONS FROM ICE SHEETS: GREENLAND AND ANTARCTICA

The melting of the Earth's major ice sheets, Greenland and Antarctica, represents a significant and increasingly dominant contributor to global sea level rise. The sheer volume of ice contained within these sheets means that even a fraction of their melt could have catastrophic implications for coastal regions.

The below figures show the loss of sea ice for both Greenland and Antarctica, respectively. The data is sourced from NASA GRACE/GRACE-FO satellite data which tracks the ice melt over time. The data files provide the “Decimal_Year” and corresponding mass change in Gigatons (Gt), along with uncertainty. Similar to global sea level data, Requests is used to fetch the data, and Pandas is used to read and process the tabular data. Visualizations of ice sheet mass change over time are then created using matplotlib, including linear and cubic spline fits to highlight trends.

When looking at the graphs, it is important to keep in mind that around 360 Gt of ice translates to 1 mm of increase in the global sea level.[5]

[5] "Vital Signs: Greenland." *NASA Sea Level Change Portal*, https://sealevel.nasa.gov/understanding-sea-level/key-indicators/greenland. Accessed 5 June 2025.

Figure 4

GREENLAND ICE MASS ANOMALY FROM START OF DATA (2002)[6]

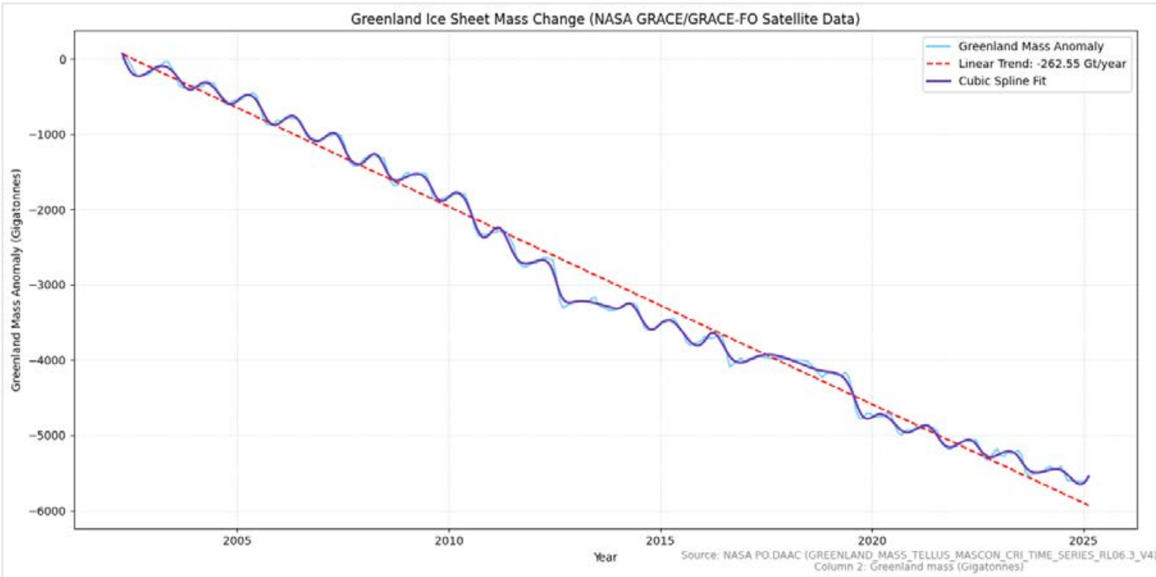
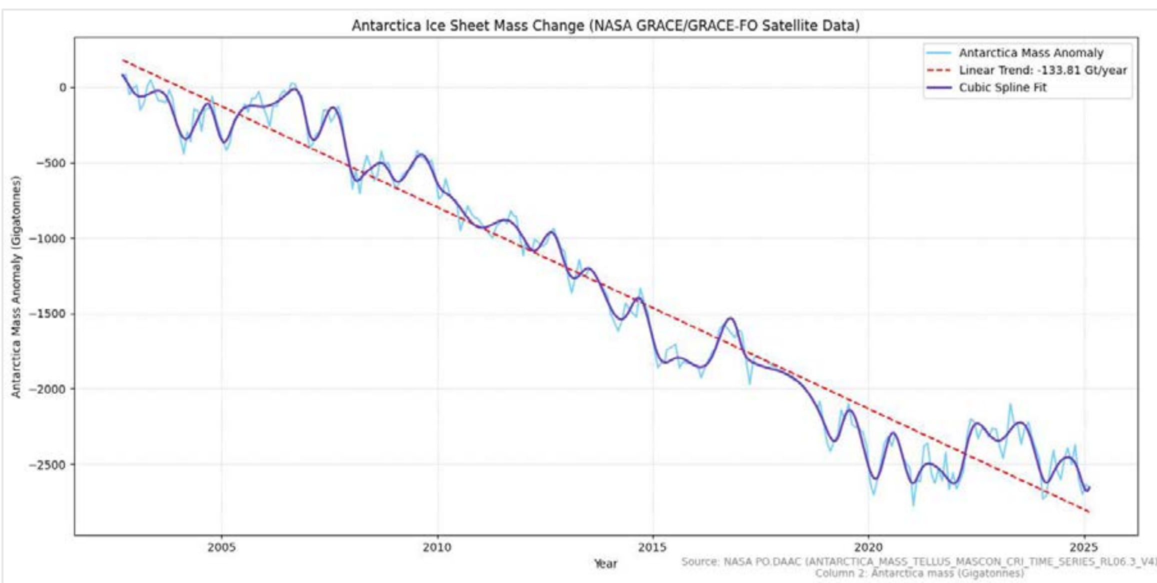


Figure 5

ANTARCTIC ICE MASS ANOMALY FROM START OF DATA (2002)[7]



[6] Data source: https://archive.podaac.earthdata.nasa.gov/podaac-ops-cumulus-protected/GREENLAND_MASS_TELLUS_MASCON_CRI_TIME_SERIES_RL06.3_V4/greenland_mass_200204_202502.txt

[7] Data source: https://archive.podaac.earthdata.nasa.gov/podaac-ops-cumulus-protected/ANTARCTICA_MASS_TELLUS_MASCON_CRI_TIME_SERIES_RL06.3_V4/antarctica_mass_200204_202502.txt

The two charts show a significant downward trend in ice mass since 2002. Greenland is showing a trend of -265.55Gt / year while Antarctica is showing a trend of -133.81Gt / year. This is in line with what is seen in the sea level data—as the ice sheets are melting, the sea level is continuing to rise.

The Extreme Nature of Sea Level Rise: Beyond Incremental Change

While global mean sea level has risen about 8–9 inches (21–24 centimeters) since 1880,[8] primarily due to meltwater from glaciers and ice sheets and the thermal expansion of warming seawater, the true severity lies in the accelerating rate and the implications of its future trajectory.

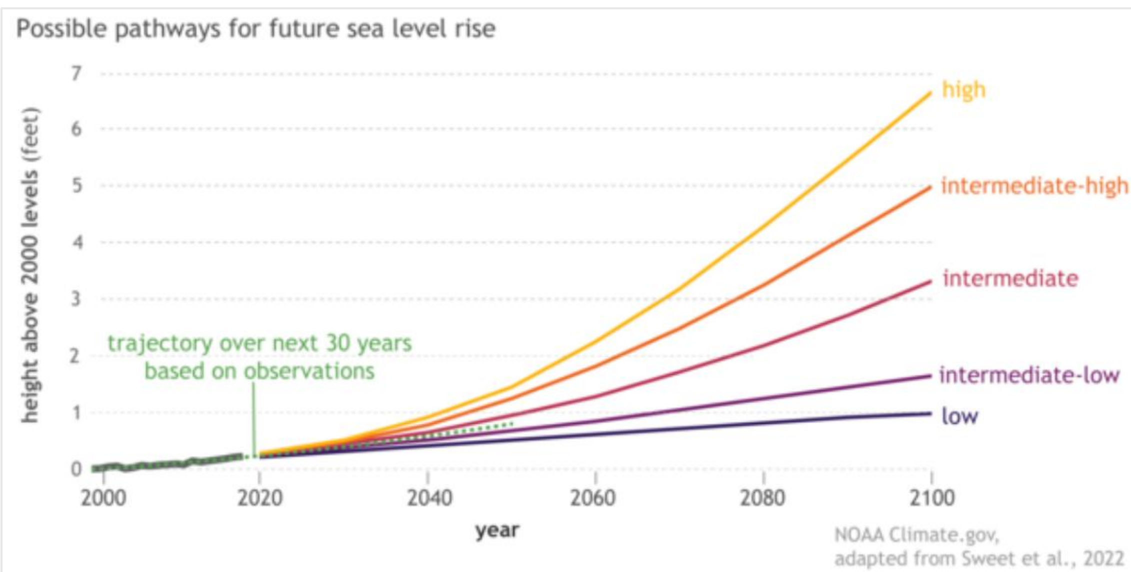
ACCELERATION AND AMPLIFIED COASTAL FLOODING

The rate of global sea level rise has more than doubled, from 0.06 inches (1.4 millimeters) per year throughout most of the twentieth century to 0.14 inches (3.6 millimeters) per year from 2006–2015.[9] This acceleration means that in many coastal areas, the frequency of "nuisance flooding"—or high-tide flooding—has increased by 300% to over 900% compared to 50 years ago.[10] This rising baseline poses an escalating threat to vital coastal infrastructure, including transportation networks, water supplies, and power systems.

EXTREME FUTURE PROJECTIONS

Figure 6

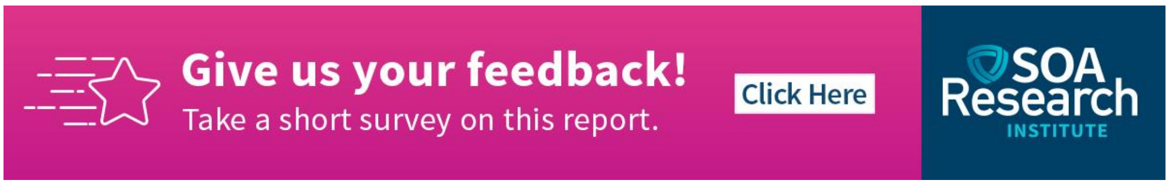
NOAA CLIMATE.GOV PROJECTIONS OF SEA LEVEL RISE UNDER VARIOUS EMISSION PATHWAYS [11]



Looking forward, the global mean sea level is likely to rise at least one foot (0.3 meters) above 2000 levels by 2100, even under lower emissions scenarios.[12] However, more extreme possibilities exist. Projections indicate that under

[8] See footnote 1.
[9] See footnote 1.
[10] See footnote 1.
[11] See footnote 1.
[12] See footnote 1.

high greenhouse gas emissions pathways, combined with rapid ice sheet collapse, average sea level rise for the contiguous United States could reach 2.2 meters (7.2 feet) by 2100 and a staggering 3.9 meters (13 feet) by 2150.[13] These higher emission scenarios highlight significant tail risks, emphasizing the critical need to consider non-linear and high-impact future events that extend far beyond historical observations.



[13] See footnote 1.

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