

Actuarial Weather Extremes Series: Quarterly Global Warming Report



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Global Warming Trends through September 2024

Every three months, the Society of Actuaries Research Institute performs a statistical analysis of global warming trends that incorporates the latest temperature data and issues an updated version of this report that summarizes the results. The data source is ERA5, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). For the period from January 1960 through September 2024, Figures 1A and 1B show the 12-month trailing average of global average air temperature and global average sea surface temperature (SST), respectively. Air temperature is averaged across the earth’s entire surface, while average SST excludes latitudes north of 60N and south of 60S (an approach that is commonly used by climate scientists to compute average SST).

12-MONTH TRAILING AVERAGE OF GLOBAL TEMPERATURE FROM JAN 1960 TO SEPT 2024

Figure 1A. Air Temperature (F)

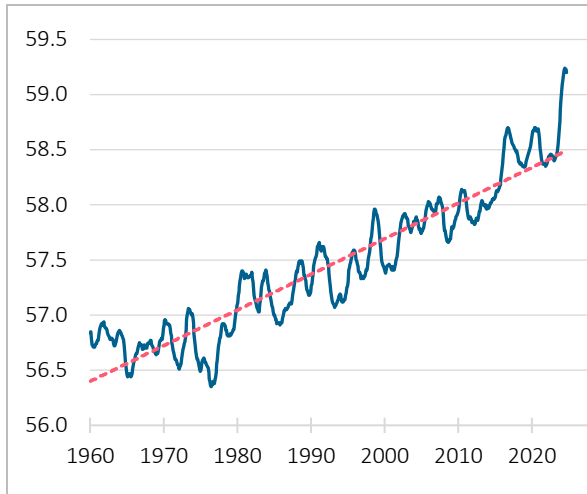
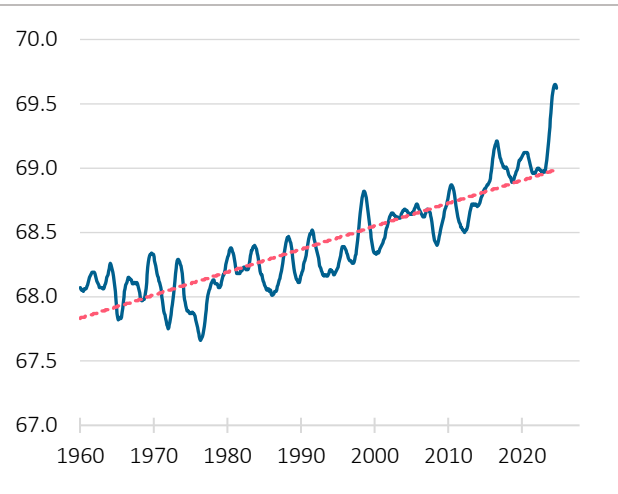


Figure 1B. Sea Surface Temperature (F)



Figures 1A and 1B reveal strong long-term warming trends, with recent global temperatures climbing to record-high levels. Using linear regression, the estimated long-term trend is +0.32F per decade for air temperature, and +0.18F per decade for SST.

Caveat and Disclaimer

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Figures 2A and 2B present the same data as in Figures 1A and 1B but focus solely on the time period from Jan 2022 to the present. The graphs reveal that the 12-month trailing averages of air temperature and SST rose steadily from January 2023 through June 2024. For both air temperature and SST, a peak was reached in June 2024 (reflecting data from July 2023 through June 2024). Since then, the 12-month trailing averages have declined slightly, but remain near their record highs.

12-MONTH TRAILING AVERAGE OF GLOBAL TEMPERATURE FROM JAN 2022 TO SEPT 2024

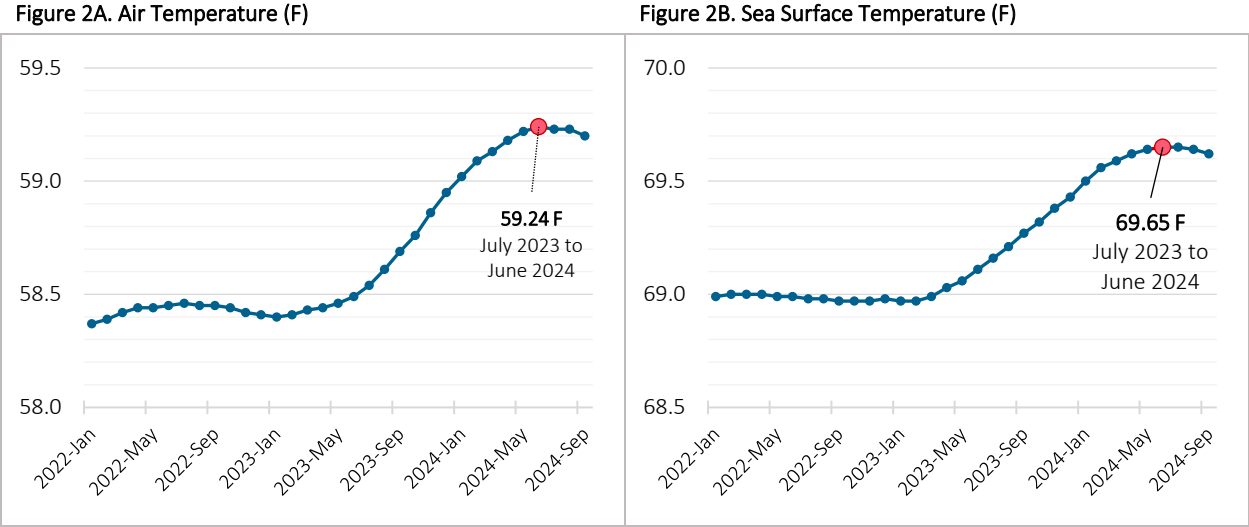
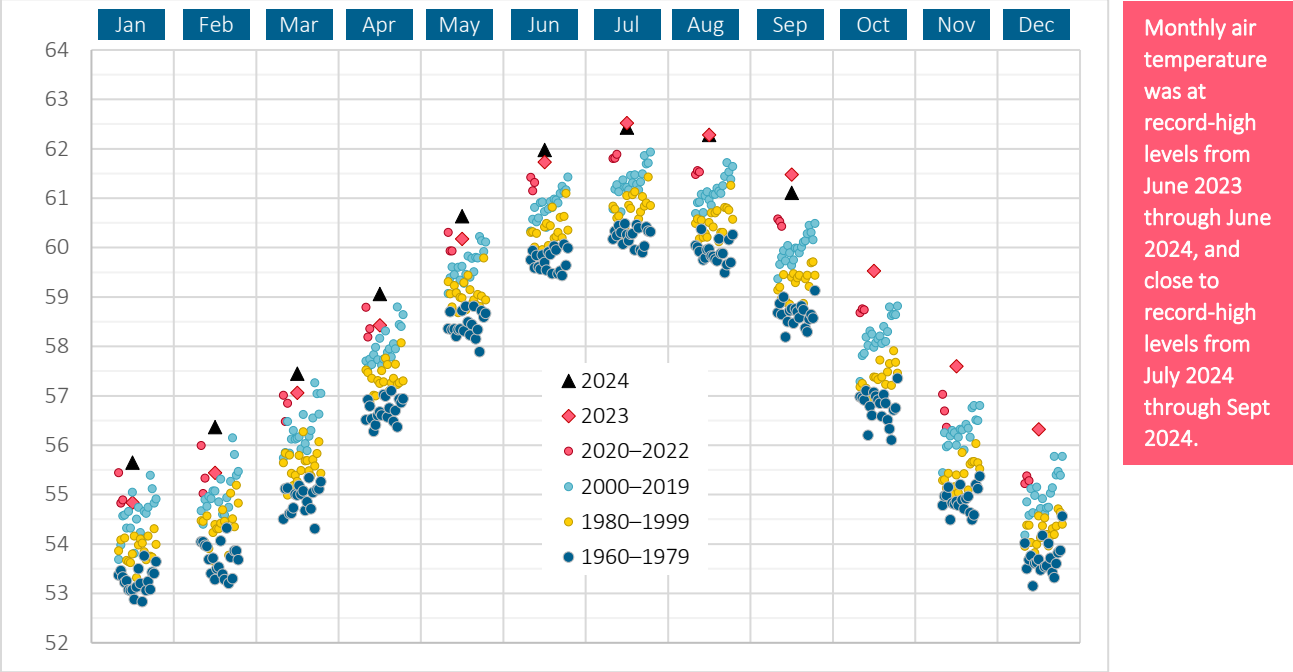


Figure 3 shows global average air temperature for each separate month (as opposed to the rolling 12-month averages show in Figures 1 and 2). The red diamonds reveal record-high monthly temperatures from June 2023 through December 2023. The black triangles indicate that record-high temperatures continued from January 2024 through June 2024. From July 2024 through September 2024, the global average temperature was slightly lower than the record-high levels observed in 2023.

Figure 3
GLOBAL AVERAGE AIR TEMPERATURE (F) BY MONTH



It is worthwhile to briefly explain the seasonal cycle of global average air temperature that is apparent in Figure 3. This seasonality may seem counterintuitive given that, on a global level, the earth receives about the same total amount of solar energy per day throughout the year. When the northern hemisphere experiences fall and winter, the southern hemisphere experiences spring and summer, and vice versa. Less daylight in one hemisphere is counterbalanced by more daylight in the opposing hemisphere. This suggests that the global average temperature should remain roughly constant from one month to the next. However, the northern hemisphere contains over two-thirds of the earth’s land mass, and, in general, land heats up more quickly than does water in response to a given influx of solar energy. Consequently, global average temperature carries a strong signature of the northern hemisphere’s seasonal temperature changes.

Air and Sea-Surface Temperature Anomalies

In the parlance of climate scientists, temperatures defined relative to their corresponding long-term averages are termed “temperature anomalies”. The anomalies in Figures 4A and 4B are defined relative to 1960–2019 averages. The figures present anomalies of four temperature metrics: (1) air temperature averaged across the entire surface of the earth, (2) air temperature over land areas, (3) air temperature over oceans, bays, and lakes; (4) and sea surface temperature (SST). To better illustrate long-term trends, Figure 4A shows anomalies averaged across trailing 60-month periods, from 1960 to the present. The final 60-month period runs from October 2019 through September 2024. Figure 4B focuses solely on the period from January 2022 to the present and uses a 12-month averaging period rather than 60 months. The final 12-month period captured in Figure 4B runs from October 2023 to September 2024.

TRAILING AVERAGE OF GLOBAL TEMPERATURE ANOMALIES

Figure 4A. Anomalies Averaged Across Trailing 60 Months (F)

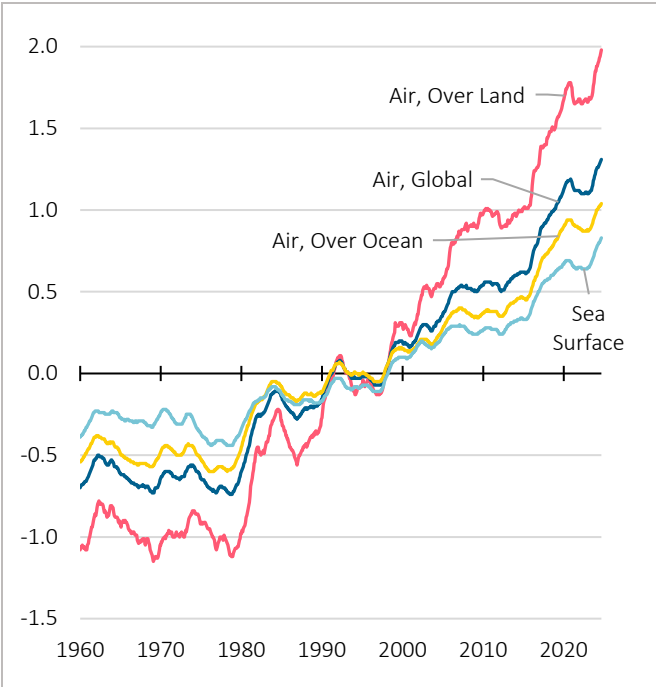


Figure 4B. Anomalies Averaged Across Trailing 12 Months (F)

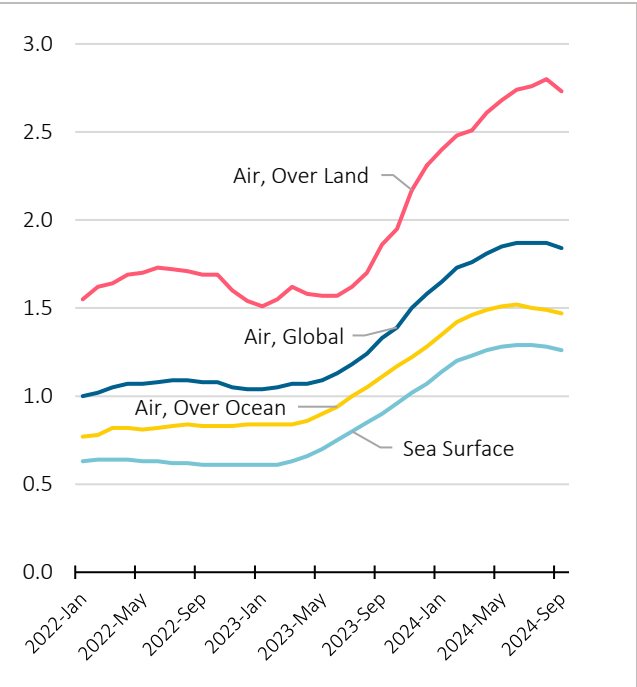
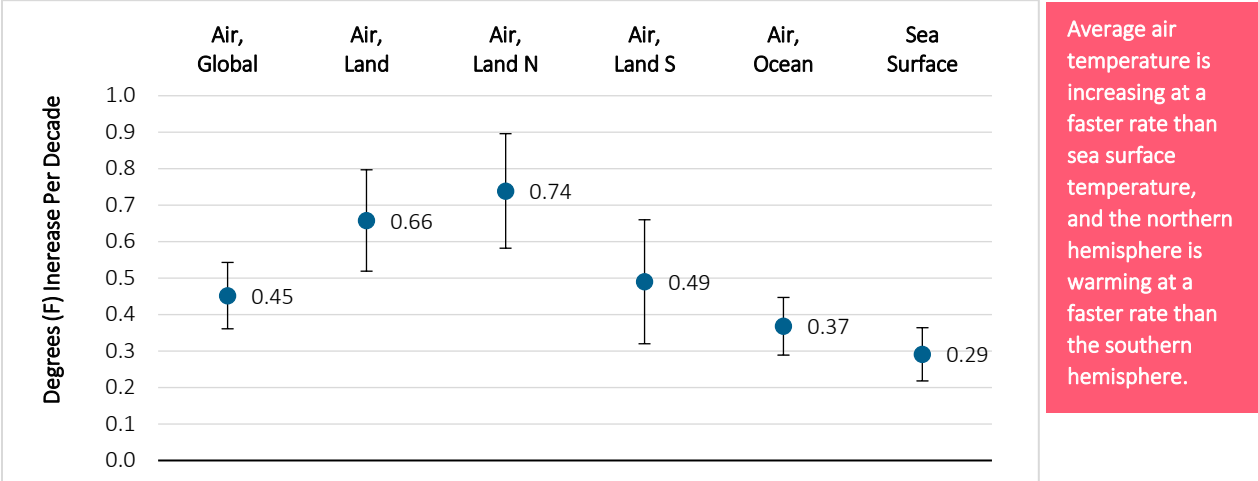


Figure 4A reveals that global average air temperature has risen faster than average SST, and air temperature over land has risen faster than air temperature over oceans. Figure 4B reveals that 12-month trailing average anomalies climbed steadily upwards from June 2023 to June 2024, before declining slightly from July to September 2024.

Warming Trends Estimated Using the Most Recent 30 Years of Data

To estimate warming trends for air temperature and SST, linear regressions were run across the most recent 30 years of data. A period of 30 years is long enough to cancel-out short-term climate cycles such as El Nino and La Nina which can influence global temperatures¹. Because the data for 2024 is partial, extending only through September, and because the use of a partial year of data could introduce seasonal bias into the regression, data was used from October 1994 through September 2024, providing 30 complete 12-month periods. The slope of each regression line provides an estimate of the rate-of-warming. Figure 5 shows the best estimate for each slope, as well as the 95% confidence interval.

Figure 5
ESTIMATED WARMING TREND FOR THE 30-YEAR PERIOD FROM OCT 1994 TO SEPT 2024



Note: Best estimates for trends are represented by blue dots, while the vertical bars represent 95% confidence intervals. “Air, Land” is air temperature averaged across all land areas, while “Air, Land N” and “Air, Land S” capture solely the land areas in the northern and southern hemispheres, respectively. “Air, Ocean” is air temperature across all bodies of water. “Sea surface” is the average water temperature across the surface of oceans and other bodies of water.

The results in Figure 5 indicate that average air temperature is increasing at a significantly faster rate than SST, and that air temperature over land is increasing at a faster rate than air temperature over water. Lastly, with respect to air temperature over land, the northern hemisphere is warming at a faster rate than the southern hemisphere.

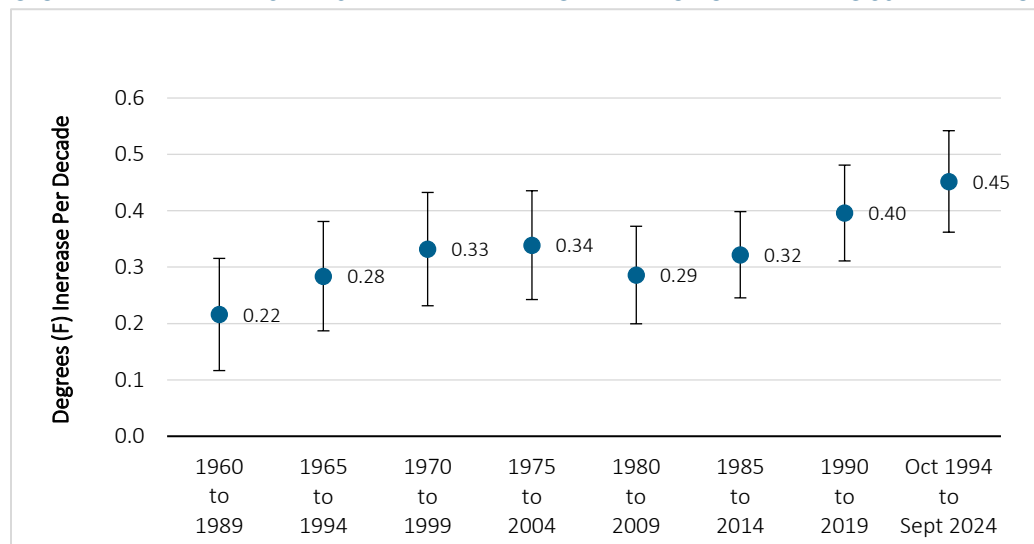
¹ El Nino and La Nina are components of an a climate osillation that is associated with variations in wind speed and sea-surface temperature over the topical Pacific Ocean. These variations, in turn, can affect global weather. A summary of this phenomenon is available here: https://en.wikipedia.org/wiki/El_Ni%C3%B1o%E2%80%93Southern_Oscillation

Is Global Warming Accelerating?

To assess whether the rate of global warming is changing across time, linear regressions were run across the following overlapping 30-year periods: 1960 to 1989, 1965 to 1994, 1970 to 1999, 1975 to 2004, 1980 to 2009, 1985 to 2014, 1990 to 2019, and October 1994 to September 2024. Focusing on global air temperature, the estimated warming trend for the most recent 30-year period is 0.45F per decade, which is greater than the rate for any prior 30-year period.

Figure 6

GLOBAL AIR TEMPERATURE: ESTIMATED WARMING TREND FOR OVERLAPPING 30-YEAR PERIODS



The estimated warming trend for the most recent 30-year period is 0.45F per decade, which is greater than the rate for any prior 30-year period.

The graph's vertical bars represent 95% confidence intervals for the warming trend. The blue dot at the center of each vertical bar indicates the "best" estimate produced by the regression.

Interactive Temperature Maps Are Available Online

The analysis presented thus far in this report has focused on global average temperatures. The results summarize the macro-level state of the planet but provide no information about temperature in specific regions. Therefore, a Tableau map was created to visualize air temperature data for each ERA5 grid point, and is accessible online:

https://public.tableau.com/views/TemperatureAnomalies_17135526296080/Map?:language=en-US&publish=yes&:sid=&:display_count=n&:origin=viz_share_link

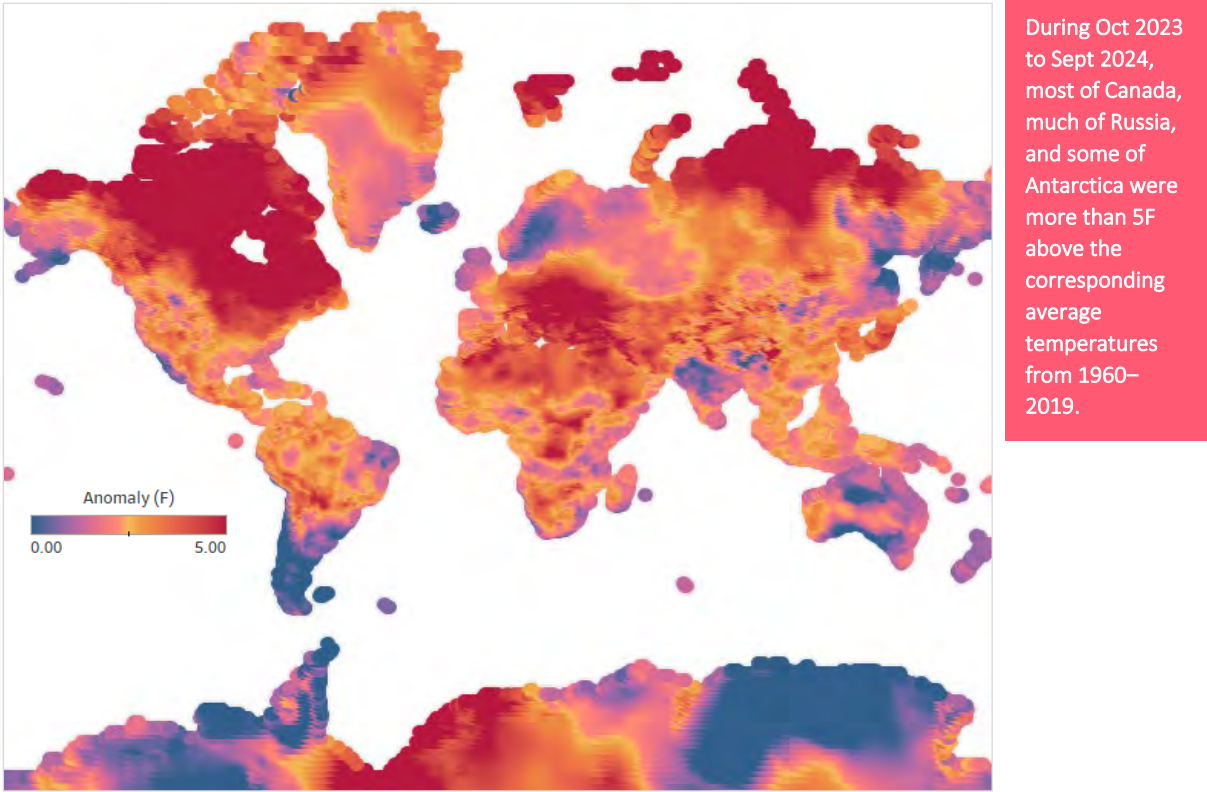
This map is focused solely on air-temperature over land areas and has interactive features for presenting temperature anomalies computed across various periods. For example, Figure 7 was produced from the Tableau map by selecting anomalies calculated across October 2023 to September 2024. In addition, the interactive map can also show anomalies calculated across the following periods: the 3-year period from October 2021 through September 2024, the 5-year period from October 2019 through September 2024, and the 10-year period from October 2014 through September 2024. A toggle switch is available to change the map display from one of these periods to another.

Figure 7 reveals that during the 12 months from October 2023 to September 2024, most of Canada, a large section of Russia, and some of Antarctica were more than 5F above the corresponding historical averages from 1960 to 2019.

Note that the anomalies in Figure 7 were calculated separately for each ERA5 grid point. For example, consider the grid point at 39N 77W, which is located just outside of Washington DC. During the 1960 to 2019 reference period, this location experienced an average temperature of 56.02F, according to ERA5 data. From October 2023 to



September 2024, its average temperature was 58.73F, which equates to an anomaly of 2.71F (the difference between 58.73F and 56.02F).

Figure 7
AVERAGE TEMPERATURE FROM OCT 2023 TO SEPT 2024, MINUS THE AVERAGE FROM 1960 TO 2019 (F)



Methodology for Computing the Worldwide Average Temperature

ERA5 grid points are evenly spaced with respect to degrees latitude and longitude, but they are not evenly spaced when measured in miles or kilometers. As one approaches the poles, lines of longitude converge, reducing the distance between grid points. Consequently, an unweighted global average across grid points would result in the overweighting of data near the north and south poles. The standard remedy used by climate scientists – and the approach used for the analysis presented in this report – is to weight each data point by the cosine of its latitude. At the equator, the resulting weight is 1.0; at 45 degrees north or south, the weight is 0.71; at 60 degrees north or south, the weight is 0.50, declining rapidly to zero as one approaches either pole. This decline counterbalances the increasing density of grid points near the poles, resulting in an even spatial weighting across the surface of the earth.

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