Actuarial Weather Extremes Series: Quarterly Global Warming Report

Catastrophe and Climate

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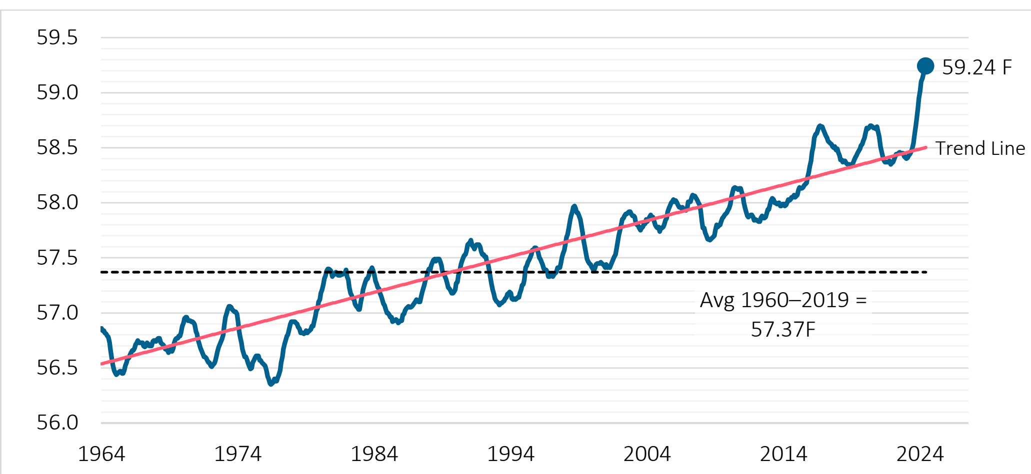
Global Warming Trends through June 2024

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. This update uses data from 1960 through the end of June 2024. The data source is ERA5, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). As depicted in Figure 1, July 2023 to June 2024 is the warmest 12-month period on record for air temperature averaged across the entire surface of the earth. Across this period, the global average temperature was 59.24F, which is 1.87F above the long-term average of 57.37F computed across the 60 years from 1960 to 2019.

Figure 1

12-MONTH TRAILING AVERAGE OF GLOBAL AIR TEMPERATURE (F)



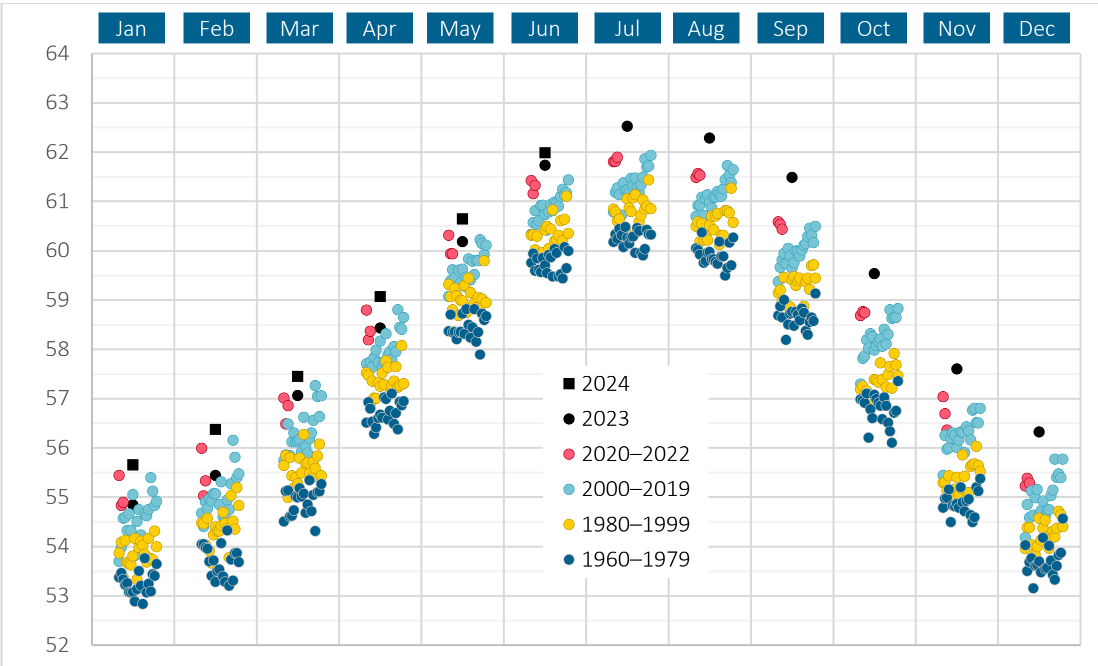
The average global air temperature from July 2023 through June 2024 was 59.24F.

This graph captures ERA5 data through June 2024. The data for May and June 2024 is preliminary and could potentially be revised. Air temperature is measured two meters above the surface of the earth. The ERA5 dataset provides gridded data for over one million locations across the planet's entire surface. The final section of this report describes the methodology for averaging the gridded data to produce global average temperature.

The record-high average temperature for the 12 months ending in June 2024 is attributable to record-high monthly temperatures from July 2023 through June 2024, as illustrated in Figure 2 and Table 1. In addition, June 2023 was also a record high. Thus, global average air temperature has hit record-high levels for 13 consecutive months.

Figure 2

GLOBAL AVERAGE AIR TEMPERATURE (F) BY MONTH



Monthly air temperature has been at record-high levels from June 2023 through June 2024.

Table 1

GLOBAL AVERAGE AIR TEMPERATURE FOR THE MOST RECENT 12 MONTHS

1	2	3	4	5	6	7
Month	**Temp (F) In Recent Month**	**Monthly Average Temp (F) 1960 to 2019**	**Anomaly: Recent Temp Minus Historical Average (F)**	**Historical Standard Deviation (F)**	**Anomaly Divided by Standard Deviation**	**Percentile Ranking Against Data from 1960 to 2022**
2023-07	62.52	60.78	1.74	0.52	3.31	100.0%
2023-08	62.28	60.53	1.75	0.57	3.07	100.0%
2023-09	61.48	59.29	2.19	0.61	3.59	100.0%
2023-10	59.53	57.44	2.09	0.68	3.06	100.0%
2023-11	57.60	55.51	2.09	0.65	3.23	100.0%
2023-12	56.32	54.31	2.01	0.63	3.19	100.0%
2024-01	55.65	53.88	1.77	0.62	2.84	100.0%
2024-02	56.37	54.37	2.00	0.66	3.01	100.0%
2024-03	57.45	55.61	1.84	0.67	2.77	100.0%
2024-04	59.06	57.35	1.71	0.61	2.82	100.0%
2024-05	60.64	59.04	1.60	0.56	2.87	100.0%
2024-06	61.98	60.31	1.67	0.53	3.13	100.0%

In Figure 2, each circle represents the average global air temperature in a prior month. Black circles represent data for 2023, and black squares represent data for 2024. Table 1 provides greater detail for each of the most recent 12 months. Column 4 displays the monthly temperature "anomaly", equal to the difference between the temperature in 2023 or 2024 and the historical average (1960 through 2019) for the same calendar month. Column 6 presents "standardized anomalies", computed as the anomaly in column 4 divided by the historical standard deviation shown in column 5. Lastly, column 7 shows the 2023/2024 monthly temperature ranked against historical data for the corresponding calendar month.

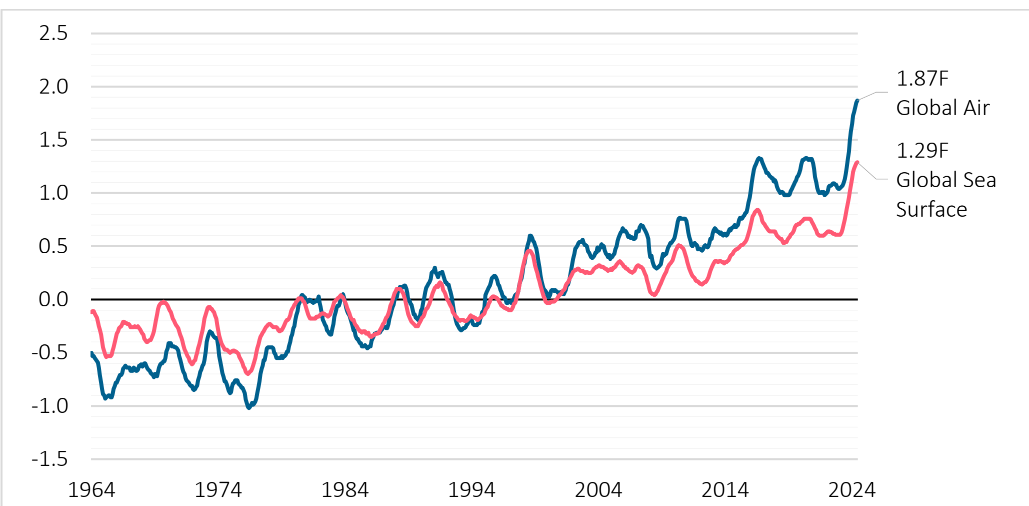
It is worthwhile to briefly explain the seasonal cycle of global average temperature that is apparent in Table 1 and Figure 2. This seasonality may seem counterintuitive given that, on a global level, the earth receives about the same total amount of solar energy per day throughout the year. When the 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.

Record-High Sea-Surface Temperatures

The recent record-high air temperatures have been accompanied by record-high sea-surface temperatures. As depicted in Figure 3, the 12-month average global sea-surface temperature (SST) from July 2023 through June 2024 was 1.29F above its 1960–2019 average, and global average air temperature was 1.87F above its 1960–2019 average. These are record highs relative to historical ERA5 data back to 1940. Note that to compute global average SST, climate scientists typically exclude latitudes north of 60N and south of 60S. This report uses the same approach.

Figure 3

12-MONTH TRAILING AVERAGE OF AIR TEMPERATURE AND SEA-SURFACE TEMPERATURE ANOMALIES (F)



Both global air and sea surface temperatures are at record-high levels.

In the parlance of climate scientists, temperatures defined relative to their corresponding long-term averages are termed "temperature anomalies". The anomalies in this graph are defined relative to 1960–2019 averages. The anomalies of 1.87F (air) and 1.29F (sea surface) reflect data averaged across the 12-month period from July 2023 through June 2024.

Global sea-surface temperature has been at record-high levels since April of 2023. Table 2 focuses on the most recent 12 months, from July 2023 through June 2024.

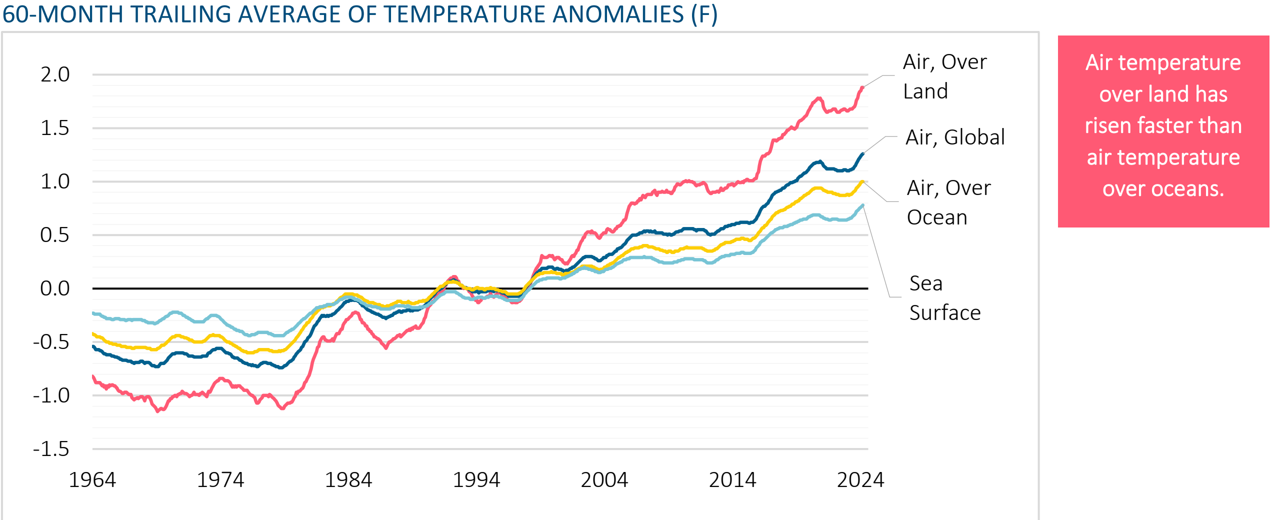
Table 2
GLOBAL AVERAGE SEA SURFACE TEMPERATURE FOR JULY 2023 TO JUNE 2024

1	2	3	4	5	6	7
Month	Temp (F) In Recent Month	Monthly Average Temp (F) 1960 to 2019	Anomaly: Recent Temp Minus Historical Average (F)	Historical Standard Deviation (F)	Anomaly Divided by Standard Deviation	Percentile Ranking Against Data from 1960 to 2022
2023-07	69.61	68.40	1.21	0.35	3.51	100%
2023-08	69.77	68.48	1.29	0.35	3.66	100%
2023-09	69.65	68.34	1.31	0.37	3.57	100%
2023-10	69.41	68.07	1.34	0.38	3.54	100%
2023-11	69.28	67.95	1.33	0.37	3.60	100%
2023-12	69.41	68.06	1.35	0.36	3.72	100%
2024-01	69.75	68.32	1.43	0.33	4.30	100%
2024-02	69.91	68.59	1.32	0.33	3.99	100%
2024-03	69.93	68.67	1.26	0.36	3.46	100%
2024-04	69.87	68.65	1.22	0.32	3.80	100%
2024-05	69.68	68.46	1.22	0.34	3.54	100%
2024-06	69.52	68.34	1.19	0.36	3.35	100%

Air Temperature Over Land versus Air Temperature Over the Oceans

Figure 3 reveals that average air temperature, computed across the entire surface of the earth, has risen at a faster rate in recent decades than has global average sea-surface temperature. Given this finding, it is worthwhile to disaggregate the air temperature data into areas over land versus areas over oceans. Figure 4 presents four series of temperature anomalies: (1) global air temperature, (2) air temperature over land areas, (3) air temperature over oceans, bays, and lakes; (4) and sea-surface temperature. To better illustrate long-term trends, Figure 4 shows anomalies averaged across the trailing 60 months rather than 12 months (as was used in Figure 3), revealing that air temperature over land has risen at a significantly faster rate compared to air temperature over the oceans.

Figure 4
60-MONTH TRAILING AVERAGE OF TEMPERATURE ANOMALIES (F)



This graph reflects temperature data through June 2024, with anomalies expressed relative to 1960–2019 average temperature.

Long-Term Warming Trends

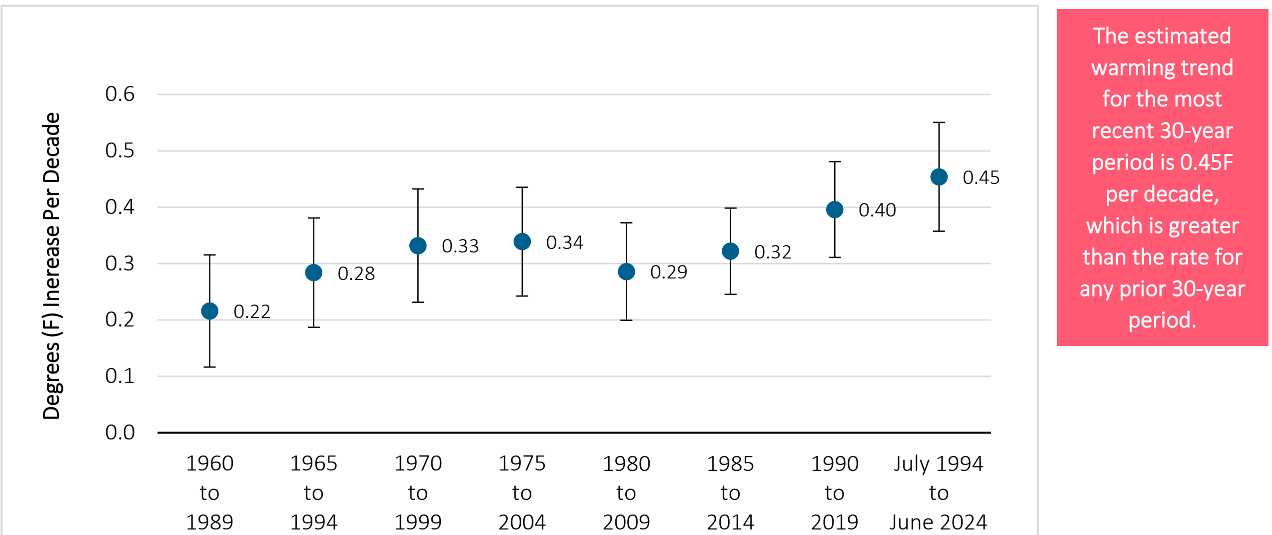
Figures 1, 3, and 4 reveal strong upward trends for both air temperature and sea-surface temperature. To estimate the trend for global average air temperature, and to assess whether it is changing across time, linear regressions were run across the following overlapping 30-year periods: 1960 to 1989, 1965 to 1994, 1970 to 1999, 1975 to 2004, 1980 to 2009, 1985 to 2014, 1990 to 2019, and July 1994 to June 2024. Because the data for 2024 is partial, extending only through June, and because the use of a partial year of data could introduce seasonal bias into the regression, the final 30-year period runs from July 1994 through June 2024, providing 30 complete 12-month cycles. The other 30-year periods begin in January of the first year and end in December of the final year (e.g., January 1960 to December 1989).

The slope of each regression line provides an estimate of the rate-of-warming across the associated 30-year period. A period of 30 years is long enough cancel-out short-term climate cycles such as El Nino and La Nina which can influence global temperatures, but short enough to provide insight into potential changes in the rate of global warming.[1]

Figure 5 shows the estimated 30-year trends and their 95% confidence intervals. 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 5

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



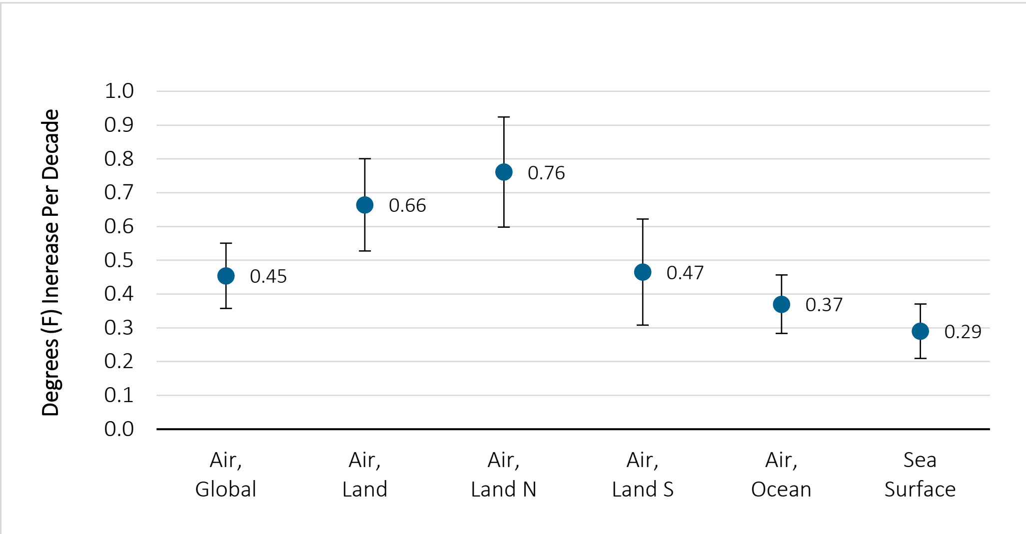
The graph's vertical bars represent 95% confidence intervals for the warming trend. The blue dot at the center of each vertical bar indicates the "best" estimate produced by the regression.

Figure 6 focuses on the most recent 30-year period, from July 1994 to June 2024, presenting trends for global average air temperature and global average sea surface temperature. In addition, warming trends are displayed for air temperature across land areas ("Air, Land"), air temperature across oceans and other bodies of water ("Air, Ocean"), air temperature across land areas in the northern hemisphere ("Air, Land N"), and air temperature across land areas in the southern hemisphere ("Air, Land S"). Best estimates as displayed as blue dots, and 95% confidence intervals are represented by vertical bars.

[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

The results in Figure 6 indicate that average air temperature is increasing at a significantly faster rate than average sea surface temperature, 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.

Figure 6
ESTIMATED WARMING TRENDS FOR THE 30-YEAR PERIOD FROM JULY 1994 TO JUNE 2024



Average air temperature is increasing at a faster rate than sea surface temperature, and the northern hemisphere is warming at a faster rate than the southern hemisphere.

Note: "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.

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:

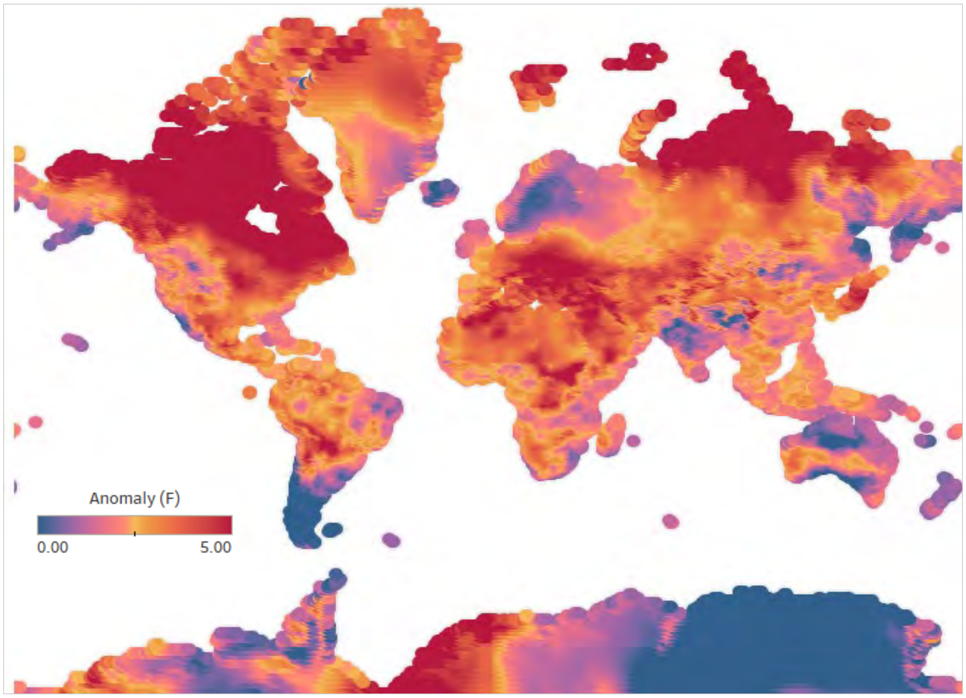
https://public.tableau.com/views/TemperatureAnomalies_17135526296080/Map?:langu age=en-US&publish=yes&:sid=&:display_count=n&:origin=viz_share_link

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 July 2023 to June 2024. In addition, the interactive map can also show anomalies calculated across the following periods: the 3-year period from July 2021 through June 2024, the 5-year period from July 2019 through June 2024, and the 10-year period from July 2014 through June 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 July 2023 to June 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 July 2023 to June 2024, its average temperature was 59.07F, which equates to an anomaly of 3.05F (the difference between 59.07F and 56.02F).

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



During July 2023 to June 2024, most of Canada, much of Russia, and some of Antarctica were more than 5F above the corresponding average temperatures from 1960–2019.

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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