

Technical Documentation

Overview

This document provides technical details and background for *Climate Change Indicators in the United States: Fifth Edition*, including criteria used for evaluating and selecting indicators highlighted in the report.

Introduction

The Earth's climate is changing, and multiple lines of evidence reveal the far-reaching impacts of climate change on the people and environment of the United States. The U.S. Environmental Protection Agency (EPA) developed a set of key climate change indicators, based on long-term observational, data sets to understand these changes. This report uses a subset of EPA's indicators as well as an extensive review of relevant scientific literature to document how climate change has affected and continues to affect the United States; the magnitude of these changes; and their potential consequences for people, the environment, and society. For more information on EPA's indicators, see *Climate Change Indicators in the United States* at: www.epa.gov/climate-indicators.

The climate change indicators and the conclusions drawn from them are illustrative. The choice of indicators in the report is not intended to include all observed changes related to climate; it provides a review of some of the changes that are happening in the United States and, for context, around the world. The report does not present the comprehensive state of the science related to climate change trends and impacts—rather, it summarizes key historical trends elucidated through indicator data sets and other existing sources of information.

The sections below provide information on the climate change indicators used in this report, including criteria for their selection, data sources and derivation, and a discussion of limitations and uncertainty.

Evaluation of Indicators

EPA uses a set of 10 criteria to select climate change indicators, which are described in more detail in the “Information Quality and Peer Review Procedures” section below. These criteria are:

- Indicator data are available to show trends over time.
- Indicator data consist of actual measurements, observations, and derivations thereof.
- Indicator data have broad national coverage or significance.
- Indicator data are peer reviewed and published.
- Information on uncertainty associated with indicator data is available.
- The indicator informs issues of national importance associated with human or natural systems.
- The relationship between the indicator and climate change is supported by published, peer-reviewed science and data.
- Indicator data, methods, and analysis are scientifically objective and transparent.
- Indicator data and analysis are understandable to the public.
- The indicator is feasible to construct within a reasonable timeframe.

In choosing and developing indicators, EPA:

1. Identifies candidate indicators.
2. Conducts initial research and screens candidates against a subset of indicator criteria.
3. Conducts detailed research and screen candidates against the full set of indicator criteria.
4. Chooses indicators for development.
5. Develops draft indicators.

6. Facilitates expert review of draft indicators.
7. Periodically re-evaluates indicators.

To ensure that each indicator is fully transparent and peer reviewed, EPA follows an established framework to identify data sets, choose indicators, obtain independent expert review, and publish indicators in reports and on its website.

Details on the data sources and methods EPA uses to identify, develop, and maintain indicators is available online at: www.epa.gov/climate-indicators/data-sources-and-methods.

All of EPA’s climate change indicators address either causes or effects of climate change. While each indicator has a science-based relationship to climate change, EPA acknowledges that some indicators more closely correspond to climate than others. Indicators generally consider large spatial and time scales (e.g., regional observations spanning decades) to show patterns relevant to climate change. In addition, EPA has developed a handful of indicators labeled either “Community Connection” or “A Closer Look” (e.g., Cherry Blossom Bloom Dates in Washington, D.C.) that address topics of specific interest to particular regions or locations.

Indicator Selection for This Report

This report presents a subset of EPA’s climate change indicators across eight chapters to tell the story of what is happening to the nation’s climate and why the observed trends matter to people and the environment. The report features 39 of EPA’s total of 57 indicators. EPA chose these indicators based on their relevance to the eight illustrative chapter themes and their spatial coverage and temporal currency. Selection generally favored indicators with broader geographic coverage, longer periods of record, and more recent data. For space reasons, EPA tended to omit indicators that overlap conceptually. For example, Freeze-Thaw Conditions is excluded because indicators such as U.S. and Global Temperature, Seasonal Temperature, Snowfall, and Length of Growing Season collectively present much of the same story. Where additional choices needed to be made, EPA generally favored indicators and figures that are more straightforward to present and explain. For example, EPA elected to present greenhouse gas emissions and concentrations because the Climate Forcing indicator would have needed a longer accompanying technical explanation. Table 1 shows the indicators featured in each chapter.

Table 1. Indicators Featured in This Report

Chapter	Featured Indicators
Greenhouse Gases	Global Greenhouse Gas Emissions, U.S. Greenhouse Gas Emissions, Atmospheric Concentrations of Greenhouse Gases
Heat on the Rise	U.S. and Global Temperature, High and Low Temperatures, Heat Waves, Heat-Related Deaths, A Closer Look: Heat-Related Workplace Deaths, Heating and Cooling Degree Days, Residential Energy Use
Extreme Events	Heavy Precipitation, Drought, Tropical Cyclone Activity, Wildfires
Water Resources at Risk	U.S. and Global Precipitation, Snowpack, Streamflow, A Closer Look: Temperature and Drought in the Southwest
Changing Seasons	Seasonal Temperature, Snowfall, Lake Ice, Leaf and Bloom Dates, Community Connection: Cherry Blossom Bloom Dates in Washington, D.C., Length of Growing Season, Growing Degree Days, Ragweed Pollen Season
Ocean Impacts	Ocean Heat, Sea Surface Temperature, Marine Species Distribution, Marine Heat Waves, Ocean Acidity
Rising Seas	Glaciers, Ice Sheets, Sea Level, Coastal Flooding
Alaska’s Warming Climate	U.S. and Global Temperature, Arctic Sea Ice, A Closer Look: The Black Guillemots of Cooper Island, Permafrost, Community Connection: Ice Breakup in Three Alaskan Rivers, Leaf and Bloom Dates

Technical Documentation for Indicators

EPA uses a standard format to document technical information for each climate change indicator. In doing so, EPA complies with the requirements of the Information Quality Act (also referred to as the Data Quality Act) and EPA’s *Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by the Environmental Protection Agency*.

Technical documentation accompanies each indicator to record the source(s) of the data, how each indicator was calculated, how accurately each indicator represents the intended environmental condition, and provides documentation of the history of all revisions and updates to the indicator. EPA’s technical documentation addresses 13 elements for each indicator:

1. Indicator description
2. Revision history
3. Data sources
4. Data availability
5. Data collection (methods)
6. Indicator derivation (calculation steps)
7. Quality assurance and quality control
8. Comparability over time and space
9. Data limitations
10. Sources of uncertainty (and quantitative estimates, if available)
11. Sources of variability (and quantitative estimates, if available)
12. Statistical/trend analysis (if any has been conducted)
13. References

Table 2 provides links to the technical documentation for each indicator featured in the report.

Table 2. Technical Documentation for Indicators Featured in This Report

Indicator	Link to technical documentation
A Closer Look: Heat-Related Workplace Deaths	www.epa.gov/system/files/documents/2024-06/heat-related-workplace-deaths_documentation.pdf
A Closer Look: Temperature and Drought in the Southwest	www.epa.gov/system/files/documents/2024-06/southwest_documentation.pdf
A Closer Look: The Black Guillemots of Cooper Island	www.epa.gov/system/files/documents/2024-06/blackguillemot_td.pdf
Arctic Sea Ice	www.epa.gov/system/files/documents/2023-11/arctic-sea-ice_tech-doc.pdf
Atmospheric Concentrations of Greenhouse Gases	www.epa.gov/system/files/documents/2024-06/ghg-concentrations_documentation.pdf
Coastal Flooding	www.epa.gov/system/files/documents/2024-06/coastal-flooding_documentation.pdf
Community Connection: Cherry Blossom Bloom Dates in Washington, D.C.	www.epa.gov/system/files/documents/2024-05/cherry-blossoms_documentation.pdf
Community Connection: Ice Breakup in Three Alaskan Rivers	www.epa.gov/sites/default/files/2021-03/documents/river-ice_td.pdf
Drought	www.epa.gov/system/files/documents/2024-06/drought_documentation.pdf
Glaciers	www.epa.gov/system/files/documents/2024-05/glaciers_documentation.pdf
Global Greenhouse Gas Emissions	www.epa.gov/system/files/documents/2024-05/global-ghg-emissions_documentation.pdf

Indicator	Link to technical documentation
Growing Degree Days	www.epa.gov/system/files/documents/2024-06/growing-degree-days_documentation.pdf
Heat Waves	www.epa.gov/system/files/documents/2024-06/heat-waves_documentation.pdf
Heating and Cooling Degree Days	www.epa.gov/system/files/documents/2024-06/heating-cooling_documentation.pdf
Heat-Related Deaths	www.epa.gov/system/files/documents/2024-06/heat-deaths_documentation.pdf
Heavy Precipitation	www.epa.gov/system/files/documents/2024-06/heavy-precip_documentation.pdf
High and Low Temperatures	www.epa.gov/system/files/documents/2024-06/high-low-temps_documentation.pdf
Ice Sheets	www.epa.gov/system/files/documents/2024-06/ice-sheets_documentation.pdf
Lake Ice	www.epa.gov/system/files/documents/2024-06/lake-ice_documentation.pdf
Leaf and Bloom Dates	www.epa.gov/system/files/documents/2024-06/leaf-bloom-dates_documentation.pdf
Length of Growing Season	www.epa.gov/system/files/documents/2024-06/growing-season_documentation.pdf
Marine Heat Waves	www.epa.gov/system/files/documents/2024-06/marine-heat-waves_documentation.pdf
Marine Species Distribution	www.epa.gov/system/files/documents/2024-06/marine-species_documentation.pdf
Ocean Acidity	www.epa.gov/system/files/documents/2024-06/acidity_documentation.pdf
Ocean Heat	www.epa.gov/system/files/documents/2024-06/ocean-heat_documentation.pdf
Permafrost	www.epa.gov/system/files/documents/2024-05/permafrost_documentation.pdf
Ragweed Pollen Season	www.epa.gov/system/files/documents/2024-06/ragweed_documentation.pdf
Residential Energy Use	www.epa.gov/system/files/documents/2024-06/residential-energy_documentation.pdf
Sea Level	www.epa.gov/system/files/documents/2024-06/sea-level_documentation.pdf
Sea Surface Temperature	www.epa.gov/system/files/documents/2024-06/sea-surface-temp_documentation.pdf
Seasonal Temperature	www.epa.gov/system/files/documents/2024-06/seasonal-temperature_documentation.pdf
Snowfall	www.epa.gov/system/files/documents/2024-06/snowfall_documentation.pdf
Snowpack	www.epa.gov/system/files/documents/2024-06/snowpack_documentation.pdf
Streamflow	www.epa.gov/system/files/documents/2024-05/streamflow_documentation.pdf
Tropical Cyclone Activity	www.epa.gov/system/files/documents/2024-06/cyclones_documentation.pdf

Indicator	Link to technical documentation
U.S. and Global Precipitation	www.epa.gov/system/files/documents/2024-06/precipitation_documentation.pdf
U.S. and Global Temperature	www.epa.gov/system/files/documents/2024-06/temperature_documentation.pdf
U.S. Greenhouse Gas Emissions	www.epa.gov/system/files/documents/2024-06/us-ghg-emissions_documentation.pdf
Wildfires	www.epa.gov/system/files/documents/2024-06/ocean-heat_documentation.pdf

Information Quality and Peer Review Procedures

This section describes the quality assurance and peer review process for the report.

Ensuring Information Quality

The report and underlying indicators were developed in accordance with EPA’s *Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by the Environmental Protection Agency*,¹ which follows Office of Management and Budget (OMB) guidelines² and implements the Information Quality Act (IQA) (Section 515 of Public Law 106–554).³

In keeping with OMB definitions, EPA defines “information quality” in terms of four standards: objectivity, integrity, utility, and transparency. EPA has established various processes (e.g., the Quality System, peer review requirements and processes) to ensure that its products meet these standards, considering the intended use of the information and the resources available.

Objectivity focuses on whether the disseminated information is being presented in an accurate, clear, complete, and unbiased way—and whether the substance of it is accurate, reliable, and unbiased. To ensure that this report is objective, EPA determined that:

- The information disseminated is complete, accurate, and reliable, according to internal quality control measures adopted by the expert modeling teams. This included quality checks throughout the chain of analytic steps, including developing and processing data, and checks on data to ensure that no errors occurred as results were compiled and summarized.
- The information disseminated is clear, complete, and unbiased, according to multiple rounds of independent review. The underlying indicators were independently peer reviewed; the report was also subject to an independent, external peer review to ensure that the information EPA summarized was

¹ U.S. EPA (Environmental Protection Agency). (2002). *Guidelines for ensuring and maximizing the quality, objectivity, utility, and integrity of information disseminated by the Environmental Protection Agency* (EPA/260R-02-008). https://www.epa.gov/sites/default/files/2020-02/documents/epa-info-quality-guidelines_pdf_version.pdf

² OMB (Office of Management and Budget). (2002). *Guidelines for ensuring and maximizing the quality, objectivity, utility, and integrity of information disseminated by federal agencies; notice; republication*. https://www.epa.gov/sites/default/files/2021-03/documents/omb_iqgs.pdf

³ The IQA requires OMB and federal agencies to issue guidelines that “ensur[e] and maximiz[e] the quality, objectivity, utility, and integrity of information (including statistical information) disseminated by Federal agencies” (Public Law 106-554; 44 U.S.C. 3516, note). The IQA does not impose its own standard of “quality” on agency information; instead, it requires only that an agency “issue guidelines” ensuring data quality. Following guidelines issued by OMB, EPA released its own guidelines—cited above—to implement the IQA.

technically supported, properly documented, consistent with established quality criteria, and communicated clearly.

Integrity refers to security of information (such as protection from unauthorized access or revision) to ensure that it is not compromised through corruption or falsification. The report and underlying indicators meet the standard for integrity due to the steps taken to ensure that the data and information remained secure. These steps included the use of password-protected data storage repositories, password-protected data transfer technology, and multiple layers of data validation checks.

Utility is the usefulness of the information to the intended users. The report and underlying indicators meet the standard for utility because they provide data relevant to observed changes in the climate system in the United States. Understanding the risks posed by climate change can inform federal, state, and community mitigation and adaptation actions designed to address these risks.

For products meeting a higher standard of quality, the agency requires an appropriate level of transparency for data and methods to facilitate the reproducibility of information by qualified third parties. Transparency ensures access to and description of the source of the data, the assumptions made, the analytic methods applied, and the statistical procedures used. EPA compiles and makes public technical documentation for every indicator to ensure that it is fully transparent—so readers can learn where the data come from, how each indicator was calculated, and how accurately each indicator represents the intended environmental condition. EPA uses a standard technical documentation format that includes 13 elements described in the “Technical Documentation for Indicators” section above.

Additional Quality Assurance

When evaluating the quality, objectivity, and relevance of scientific and technical information, EPA’s considerations can be put into five general assessment categories, as found in *A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information*⁴ and the *Guidance for Evaluating and Documenting the Quality of Existing Scientific and Technical Information*.⁵ The five factors are:

- **Soundness**, defined as the extent to which the scientific and technical procedures, measures, methods, or models employed to generate the information are reasonable for and consistent with the intended application. EPA follows an established framework to identify data, select indicators, obtain independent expert review, and publish indicators. For each proposed indicator, EPA carefully considers 10 criteria (see Table 3) to evaluate and select data for indicator development. EPA evaluates the scientific and technical procedures, measures, and methods employed to generate the data that underpin each indicator. If a proposed indicator and associated data meet all the criteria, EPA determines they are reasonable for, and consistent with, use as an indicator for this report.
- **Applicability and utility**, defined as the extent to which the information is relevant for the Agency’s intended use. Considerations related to this assessment factor include the relevance of the indicator’s purpose, design, outcome measures, results, and conditions to the Agency’s intended use. EPA carefully considers the relevance or usefulness of an indicator during development. EPA ensured that this report and the underlying indicators are relevant to their intended use so that the information disseminated provides insights and data for communicating trends in the climate-relevant impacts in the United States.
- **Clarity and completeness**, defined as the degree of clarity and completeness with which the data, assumptions, methods, quality assurance, sponsoring organizations, and analyses employed to generate the information are documented. For each indicator, EPA investigates the underlying data, assumptions, methods, and analyses used to generate the information and records these factors clearly, completely, and

⁴ U.S. EPA (Environmental Protection Agency). (2003). *A summary of general assessment factors for evaluating the quality of scientific and technical information* (EPA 100/B-03/001). <https://www.epa.gov/risk/summary-general-assessment-factors-evaluating-quality-scientific-and-technical-information>

⁵ U.S. EPA (Environmental Protection Agency). (2012). *Guidance for evaluating and documenting the quality of existing scientific and technical information*. <https://www.epa.gov/risk/guidance-evaluating-and-documenting-quality-existing-scientific-and-technical-information>

transparently in publicly available technical documentation. The underlying data and methods for analyses are peer reviewed and/or published by federal agencies and in scientific journals. These publications provide additional documentation of assumptions, methods, and analyses.

- **Uncertainty and variability**, defined as the extent to which the variability and uncertainty (quantitative and qualitative) in the information or in the procedures, measures, methods, or models are evaluated and characterized. EPA considers this carefully for each indicator’s underlying data, based on the documentation and source publications for those data. In the technical documentation, EPA also describes known sources of uncertainty and variability, as well as data limitations.
- **Evaluation and review**, defined as the extent of independent verification, validation, and peer review of the information or of the procedures, measures, methods, or models. EPA carefully considers the extent to which the data underlying each indicator are independently verified, validated, and peer reviewed. One of EPA’s criteria for choosing indicators to develop relates to peer review of the associated data and methods. EPA also ensures that each edition of the report is independently peer reviewed.

Table 3. Criteria for Choosing and Developing Climate Change Indicators

Criterion	Description
Trends over time	Data are available to show trends over time. Ideally, these data will be long-term, covering enough years to support climatically relevant conclusions. Data collection must be comparable across time and space. Indicator trends have appropriate resolution for the data type.
Actual observations	The data consist of actual measurements (observations) or derivations thereof. These measurements are representative of the target population.
Broad geographic coverage	Indicator data are national in scale or have national significance. The spatial scale is adequately supported with data that are representative of the region/area.
Peer review status of indicator (and quality of underlying source data)	Indicator and underlying data are sound. The data are credible and reliable; they have been peer reviewed and published.
Uncertainty	Information on sources of uncertainty is available. Variability and limitations of the indicator are understood and have been evaluated.
Usefulness	The indicator informs issues of national importance and addresses issues important to human or natural systems. It complements existing indicators.
Connection to climate change	The relationship between the indicator and climate change is supported by published, peer-reviewed science and data. Climate may be among several factors/stressors driving the indicator, but the indicator’s relationship to climate change can be readily explained.
Transparent, reproducible, and objective	The data and analysis are scientifically objective, and methods are transparent. Biases, if known, are documented, minimal, or judged to be reasonable.
Understandable to the public	The data depict observations straightforwardly and are understandable to the average reader.
Feasible to construct	The indicator can be constructed or reproduced within the timeframe for developing the report. Data sources allow routine updates of the indicator for future reports.

Peer Review

Consistent with guidelines described in EPA's *Peer Review Handbook*,⁶ this report was subject to an independent, external peer review.⁷ The purpose of this peer review by independent, qualified, and objective experts was to ensure that EPA's presentation of indicator data is technically supported, competently performed, properly documented, consistent with established quality criteria, and communicated clearly. The underlying indicators were previously peer reviewed and published in EPA's online climate change indicator resource, so EPA was not seeking technical review of each individual metric presented in the report. Rather, the primary focus of the peer review was to ensure that EPA has presented the subset of climate change indicators in an easy-to-understand, unbiased way that effectively communicates the observed impacts to an educated but general audience.

The review was managed by a contractor (ICF) under the direction of a designated EPA peer review leader, who prepared a peer review plan, the scope of work for the review contract, and the charge for the reviewers. Importantly, the EPA peer review leader played no role in producing any portion of the report. The contractor identified, screened, and selected four reviewers who had no conflict of interest in performing the review, and who collectively met the technical selection criteria provided by EPA. Reviewers worked individually (i.e., without contact with other reviewers, colleagues, or EPA) to prepare written comments in response to the charge questions. The peer review charge directed reviewers to provide responses to the following questions:

1. Does the introduction clearly explain the purpose of the report, explain the relationship to EPA's climate change indicators website, and provide appropriate context for the chapters? If not, please provide recommendations for improvement.
2. The report has been written for an educated but non-technical audience. Are the writing level and graphics appropriate for this audience? If not, how can they be improved?
3. This report presents a subset of EPA's indicators organized by a theme for each chapter. Are the themes an effective way to organize and communicate the information in the report? If not, please provide recommendations for improvement.
4. Are the indicators within each chapter organized in a logical manner? If not, please provide suggestions for improvement.
5. The bulleted key points and accompanying figures are drawn from existing climate change indicators that were previously peer reviewed and are currently publicly available via the website. Has EPA accurately represented the indicators featured in the report? If not, please provide suggestions for improvement. Also, recognizing that EPA's indicators website contains additional information that does not appear in this draft report, please identify any such information that you feel is critical to add to the report to improve its quality.
6. Each chapter contains findings based on the individual and collective indicators presented within. Are these findings appropriate? Are there additional findings supported by the indicators that should be included?
7. Do the included indicator figures and maps adequately illustrate and support the information that is presented? If not, please provide recommendations for improvement.
8. The callout boxes are intended to help the readers connect the information presented on the indicators with action that EPA, individuals, and communities are taking. Do the callout boxes achieve this aim? Please provide suggestions for improvements, if any.
9. The appendix is intended to provide the reader with details related to the supporting evidence and climate change indicators provided in this report. It includes a summary of their selection and underlying

⁶ U.S. EPA (Environmental Protection Agency). (2015). *Peer review handbook* (4th ed.) <https://www.epa.gov/osa/peer-review-handbook-4th-edition-2015>

⁷ EPA has determined that this report falls under the classification of "Other Scientific and/or Technical Work Products." The report does not meet the criteria for "influential scientific information," as defined by OMB and further described in the EPA *Peer Review Handbook*, since it is not being used to support a regulatory program or policy position and does not meet one or more of the factors listed in Section 2.2.3 of the *Peer Review Handbook* for consideration as influential scientific information. As a corollary, the report also cannot be considered a "highly influential scientific assessment," as defined by OMB. This product is for science dissemination and communication purposes only and does not reflect analysis of, or recommendations on, any particular policy.

data sources, and it points the reader to full technical documentation available via the website. Has EPA provided an appropriate amount of information in the appendix about the indicators featured? If not, please identify other information that you feel would be important to include.