Fifth National Climate Assessment: Appendix 3

# Scenarios and Datasets

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# A3.1. Scenarios and Climate Model Output

Scenarios are descriptions of how conditions may develop over time based on clear and consistent assumptions about key drivers of change.[1] For example, scenarios can describe future emissions, population, energy, and land use to answer questions such as How much more greenhouse gases will humans emit? How will populations grow or move? How will we use land for agriculture, forestry, or cities?

Climate models use scenarios to describe the plausible evolution of human and natural factors that affect the future of Earth's climate system. Climate model output is neither a forecast nor prediction but is referred to as a projection. Climate projections are conditional: when or if we reach a particular outcome is dependent on both human choices and the complex ways in which the climate system responds to those choices. Scenarios and climate model projections allow us to explore how we answer questions about the future and the potential implications of choices made over time. These tools have evolved and improved over time, but they are limited by the current state of knowledge and the necessary simplifications models make in representing Earth's complex climate system.

The state of the science represented in the National Climate Assessment (NCA) is always evolving, often at different paces in different fields. No one set of models, scenarios, or climate projections was implemented across NCA5. Authors could assess and reference any climate scenarios that met legally required evidence quality standards (App. 2). These included, but were not limited to, the Representative Concentration Pathways (RCPs), which were used in Phase 5 of the Coupled Model Intercomparison Project (CMIP5), and a more recent set of scenarios that integrated Shared Socioeconomic Pathways (SSPs).[2,3,4] A set of SSP-RCP combinations was used in CMIP Phase 6 (CMIP6) international model experiments.[3,4,5] In NCA5, Chapter 3 provides a description of SSPs along with a graphic representation of scenario development (Figure 3.4), and the Guide to the Report provides a list of descriptive terms for the RCP and SSP scenarios that are commonly referenced in the report text (Table 3). For certain topics or impact studies, scenarios that preceded the RCPs may be relevant, such as those from the Special Report on Emissions Scenarios (SRES).[6] Similar to the RCPs and SSPs, the SRES scenarios include a set of consistent assumptions that translate into a range of carbon emissions and carbon dioxide concentrations; however, the SRES do not include a net-negative emissions scenario (Figure 33.19 in Walsh et al. 2014[7]). For a more in-depth discussion of emissions scenarios, RCPs, and SSPs, see Chapter 4 of Volume I of the *Fourth National Climate Assessment*.[8]

Overall, CMIP6 models show some specific improvements over CMIP5 in their representation of Earth system processes—mainly due to the fact that more models include biological and chemical interactions as well as higher resolution (Figure TS.2, Section TS.1.2.2 in Arias et al. 2021[9]).[10] Importantly, projections can vary based on the particular climate models and scenarios used, assumptions or parameters employed within those models and scenarios, and methods used to analyze or interpret model outputs. For instance, some CMIP6 models show a particularly large global temperature response to increasing atmospheric carbon dioxide concentrations—a response that is not considered to be realistic (KM 3.1; e.g., Meehl et al. 2020;[11] Nijsse et al. 2020[12]). Scientists can use different methods to account for potential model biases in the temperature response and other climate system changes.[13,14] When comparing projections across NCA5 or with another assessment, it is critical to understand how the methodologies underlying the findings may differ. Supporting information for NCA5 findings can be found in the chapter text, cited references, Traceable Accounts, or figure captions and metadata—all available via the report website.

## Box A3.1. Projecting Climate Impacts Beyond 100 Years Into the Future

Climate change will not end in 2100. However, there is currently a limited number of climate studies with projections that extend past the year 2100. The lack of scenarios for emissions or land use that extend past 2100 constrains the NCA5 authors' ability to present or assess projections 100 years in the future as mandated by the Global Change Research Act of 1990.[15,16] One notable exception is the sea level rise (SLR) scenarios described in this appendix and in Chapter 9, which do extend past 2100 for the contiguous United States. To understand impacts at the century scale and beyond, authors could evaluate potential climate system changes based on applied laws of physics, Earth system dynamics, and extrapolation of climate system change indicators. Additionally, very high climate scenarios, such as RCP8.5 and SSP5-8.5, can be useful tools when considering a range of plausible greenhouse gas concentrations past 2100.[17,18]

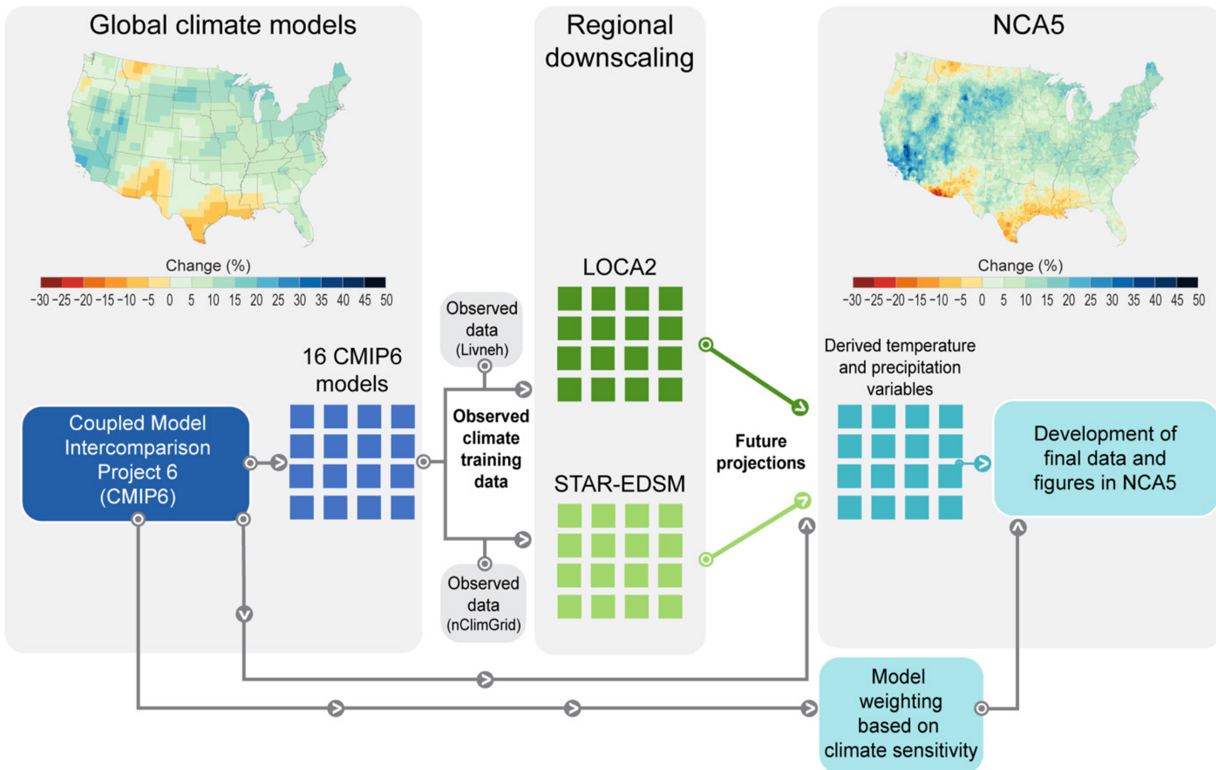
# A3.2. Projected Climate Variables

The NOAA Technical Support Unit (TSU) provided authors with projected climate variable information from 43 CMIP6 models using a set of five SSP-RCP scenarios, which were described in a reference guide provided to authors to ensure consistent terminology throughout NCA5 (see Guide to the Report). Depending on author team requests and variable availability, in some circumstances the TSU selected a smaller number of CMIP6 models and scenarios from the larger ensemble (global climate models box in Figure A3.1).

To provide higher-resolution projections at national or subnational scales, 16 global CMIP6 models were downscaled using historically trained computer algorithms (statistical downscaling) and model weighting based on equilibrium climate sensitivity (Figure A3.1). Two datasets that employed different statistical downscaling methods were used to develop gridded temperature and precipitation datasets for NCA5: the Localized Constructed Analogs Version 2 (LOCA2)[19] and Seasonal Trends and Analysis of Residuals, Empirical-Statistical Downscaling Model (STAR-ESDM)[20,21] (regional downscaling box in Figure A3.1). A collection (ensemble) of models is often used to show an uncertainty range. LOCA2 and STAR-ESDM were applied to 16 CMIP6 models, and downscaled outputs were weighted based on CMIP6 climate sensitivity through Bayesian model averaging.[22,23,24,25] Projections of changes in average and extreme temperature and precipitation were made available to NCA5 authors for national and subnational scales spanning the entire 21st century (NCA5 box in Figure A3.1).

Development of NCA5 overlapped with CMIP6 data releases, limiting the availability of downscaled CMIP6 climate projections. While STAR-ESDM also provided downscaled data for selected individual weather stations, there remains an overall gap in climate projections for geographies outside the contiguous United States, including the regions covered by the Alaska, US Caribbean, and Hawaiʻi and the US-affiliated Pacific Islands chapters. Authors were also provided guidance on how to access regional datasets or dynamically downscaled data from the CMIP5 Coordinated Regional Climate Downscaling Experiment to include data for these regions where available.[26,27]

## Downscaling Global Climate Model Data for NCA5




**Global model data were downscaled and weighted to generate higher-resolution climate projections.**

**Figure A3.1.** This flowchart shows the steps taken to downscale low-resolution global data from Phase 6 of the Coupled Model Intercomparison Project (CMIP6; **left side of the diagram**) to bias-adjusted high-resolution NCA5 products (**right side of the diagram**). Two downscaling algorithms (**center of the diagram**)—the Localized Constructed Analogs Version 2 (LOCA2) and Seasonal Trends and Analysis of Residuals, Empirical-Statistical Downscaling Model (STAR-ESDM)—were developed for each of the 16 selected global climate models (shown in dark blue) by training with two observational datasets (Livneh for LOCA2 and nClimGrid for STAR; shown in green). The resulting algorithms produce high-resolution bias-adjusted datasets of daily temperature and precipitation for the training dataset observational period. These model-specific algorithms are applied to global projections to produce high-resolution projections of temperature and precipitation in the United States for each model (shown in light blue). The individual model projections are averaged with model weights based on climate sensitivity to produce the final NCA5 datasets and graphics. LOCA2 and STAR provide gridded data for the 48 contiguous states. STAR additionally includes downscaled data for individual stations in Alaska, Hawai'i, and Puerto Rico. Figure credit: USGCRP/ICF, USGCRP, and North Carolina State University.

# A3.3. Sea Level Rise

NCA5 authors were provided with sea level rise scenarios produced by an Interagency Task Force for the 2022 Sea Level Rise Technical Report.[28] The technical report uses five SLR scenarios covering the time period from 2020 to 2150, constructed using the sea level projections from the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6)[29] and defined by global mean SLR target values in 2100 as follows: Low (0.3 m [1 foot]), Intermediate-Low (0.5 m [1.5 feet]), Intermediate (1 m [3 feet]), Intermediate-High (1.5 m [5 feet]), and High (2 m [6.5 feet]). Specifically, the AR6 projections across all possible warming levels and emissions are filtered to find ones that describe pathways that meet these five target values of global mean sea level rise. Near-term SLR estimates are derived from an extrapolation of observed rates and acceleration through 2050.

These five SLR scenarios are related to, but distinct from, the CMIP6 temperature and precipitation projections described above in Sections A3.1 and A3.2. Describing these five scenarios reduces the complexity of sea level projections that are conditional on future emissions and difficult-to-quantify physical processes. This supports decision-making in a number of ways, including providing a risk-based framing and allowing planners to compare the performance of different management strategies over time under different SLR scenarios. Chapter 2 introduces these five scenarios; Chapter 9 uses these scenarios and the IPCC projections to provide details about sea level rise dynamics and regional sea level rise.

While it is not possible to directly assign probabilities to each of the scenarios, additional assumptions about the future (e.g., global warming level above preindustrial conditions; see the Guide to the Report) allow for the assignment of a probability of exceeding a particular sea level scenario in that assumed future (Table A3.1). Although generated using global mean SLR, these exceedance probabilities are applicable to the US due to the construction of the sea level projections. At 2100 and beyond, the primary driver of the upper end of the SLR scenarios is the potential for rapid ice sheet loss; to account for this possibility, the far-right column of Table A3.1 represents a future with very high emissions, high warming, and significant contributions to SLR from these ice loss processes.

**Table A3.1. Sea Level Rise Exceedance Probabilities**

The table shows the probabilities of exceeding the amounts of sea level rise (SLR) projected for the five scenarios (Low, Intermediate-Low, Intermediate, Intermediate-High, and High) provided in the 2022 Sea Level Rise Technical Report. Probabilities are shown for the end of the century (2100) for five global warming levels (calculated as global mean surface temperature increases above preindustrial levels for the period 2081–2100) as well as for a possible future with very high emissions and rapid ice sheet loss processes, which are currently understood with only *low confidence*. The probabilities are based on IPCC projections. Adapted from Sweet et al. 2022.[28]

| Probability of exceeding the SLR scenario described below in 2100 at the global warming level described to the right | 1.5°C (2.7°F) | 2.0°C (3.6°F) | 3.0°C (5.4°F) | 4.0°C (7.2°F) | 5.0°C (9°F) | *Low Confidence* ice sheet loss processes, very high emissions |
|---|---|---|---|---|---|---|
| Low (0.3 m) | 92% | 98% | >99% | >99% | >99% | >99% |
| Intermediate-Low (0.5 m) | 37% | 50% | 82% | 97% | >99% | 96% |
| Intermediate (1.0 m) | <1% | 2% | 5% | 10% | 23% | 49% |
| Intermediate-High (1.5 m) | <1% | <1% | <1% | 1% | 2% | 20% |
| High (2.0 m) | <1% | <1% | <1% | <1% | <1% | 8% |

# A3.4. Tools and Applications

In addition to projections, the TSU developed historical climate information for NCA5 authors. Historical analyses are based on NOAA's nClimGrid and GHCN-Daily datasets,[30] and access was provided via an interactive visualization tool. Historical and projected climate variables from the TSU analysis include average annual and seasonal temperature and precipitation, extreme maximum and minimum quantities, threshold exceedances, and derived variables such as mean summer soil moisture and minimum annual temperature. The full suite of historical and future climate data and metadata records developed for NCA5 will be made publicly available via the NCA5 Atlas and through the Global Change Information System. The NCA5 Indicators Appendix provides more detail on observed trends for commonly used climate metrics (App. 4).

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