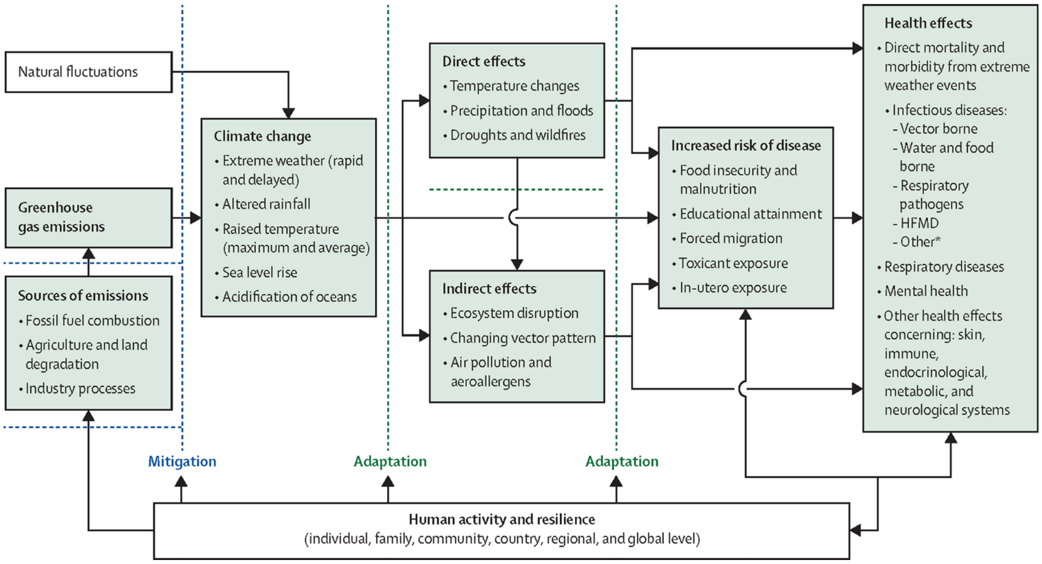
# Appendix A: Approach for Detailed Analyses

This appendix details the overarching analytic approach, methods, and uncertainties associated with the five detailed analyses included in the report. The report relies on a standardized approach to estimating and presenting risks of climate change on children's health and well-being, and to assessing the geographies and demographic groups that may experience these risks most acutely or disproportionately. The approach relies in part on methods and information developed previously and published in Appendix C of a recent EPA report, *Climate Change and Social Vulnerability in the United States*.[1] The below information is general to each of the detailed analyses; additionally, specific information related to implementing each analysis is highlighted in separate appendices.

## CLIMATE STRESSOR AND IMPACT SELECTION

A key step in developing this report was considering different types of climate stressors, and, subsequently, impacts that children are likely to experience. Figure 1 presents a framework found in Hellden et al., a recent synthesis literature review on the impacts of climate change on children's health, which maps climate change to its direct and indirect effects and ultimate health impacts.[2] This report examines five key aspects of climate change (referred to throughout as "climate stressors"), consistent with topics in the "direct effects" and "indirect effects" boxes in Figure 1, and provides an overview of how those stressors affect children. Each of the detailed analyses focus on one impact per stressor for which existing quantitative evidence is sufficiently available to support a detailed and spatially resolved projection of future conditions for children under different climate change scenarios. Each chapter closes with considerations for other important potential pathways of harm, and previews insights from new literature about those potential future impacts on children.

**Figure 1. Relationship Between Climate Stressors and Impacts on Children**



*Source: Figure 3 of Hellden et al. (2021).*

## How is mental health addressed in this report?

As described in Figure 1, mental health can be affected by various climate stressors. To the extent possible, this report describes any literature linking the climate stressors with mental health effects on children. As described in Chapter 8, quantitative evidence on the mental health impacts of climate change on children is generally lacking and remains a key area for future research.

An example of climate change impacts on child mental health is through the concept of “climate anxiety.” Essentially, this refers to generalized concern and worry pertaining to climate change and its effects on the future natural environment and human quality of life.[3] While the terms “eco-anxiety” and “climate change anxiety” have been used for nearly a decade,[4] the effects of climate change on mental health have been well-known for far longer.[5] Often, these sentiments arise in children upon experiencing poor environmental conditions, a severe weather event, or a series of such, but also upon having feelings of futility or despair about the future and the state of changing global conditions.[6] Even though adults also can experience climate anxiety, research demonstrates that children may be more predisposed to experiencing this specific type of anxiety and may experience it more intensely. For instance, older children, including pre-teenagers, adolescents, and young adults, understand the likelihood of experiencing climate change effects for the duration of their lives, which has been linked to feelings of hopelessness and trauma.[7] Additionally, these experiences are occurring at times of important psychological development when trauma may have longer-term mental health effects, as children are likely to maintain those memories with greater clarity.[8,9] Further, older children, including adolescents, are more likely to experience generalized depression or anxiety, irrespective of extrinsic factors, which can be compounded by these same bleak feelings.[10,11]

The sad fact remains that access to mental healthcare in the United States is not a given, and often is prohibitively expensive,[12,13] predominantly offered in English, or hard to access due to geographic location (e.g., difficult to reach without reliable access to a car or easy public transportation).[14,15] Many practitioners simply do not accept any type of insurance coverage, including private insurance or Medicaid, which would improve access to services.[16] Despite its relative effectiveness in helping to mitigate poor mental health,[17,18,19] child psychotherapy uptake in the United States is relatively limited,[20] especially among populations that are BIPOC, immigrants or children of immigrants, and individuals without private insurance.[21,22]

Finally, but no less significantly, there is limited research on how children who either identify as LGBTQIA+, or whose caregivers or family members are LGBTQIA+, are affected by climate change. What does exist, however, suggests that these individuals are at greater risk of experiencing more severe mental health outcomes due to climatic factors as well as implicit biases.[23,24] LGBTQIA+ youth statistically have higher rates of suicidality, depression, and homelessness, relative to their peers, and often face insecurity in their support from caregivers.[25] Therefore, in the face of climate change-related hazards, these children are left with a distinct predisposition for experiencing significant mental health outcomes.

## IMPACTS BY DEGREE APPROACH

As described in Chapter 2, this report conveys climate risk information using an "impacts-by-degree" framework that presents impacts to the health and well-being of children in the contiguous U.S. under different levels of future global temperature change. The impacts-by-degree framework builds on approaches employed in numerous published studies to produce physical and economic estimates of climate change impacts in the contiguous U.S. (CONUS), for a broad range of the most economically important impact sectors. The overall framework is based on a recently published conceptual paper and demonstration of the method by Sarofim et al.[26] The main objective of the framework is to provide estimates of the physical and economic impacts in the U.S. from 21st century trajectories of temperature and sea level rise. The methods adopt the same mainstream scenarios and projections used in the climate science community, but instead of estimating an impact at a specific period of time under an explicit greenhouse gas (GHG) emissions scenario, impacts are simulated during the years when future warming thresholds are reached. The framework is implemented using a set of underlying published studies, referred to as sectoral impact models and analyses, which relates climate change projections to:

1. Related environmental stressors (e.g., extreme temperatures, precipitation, floods, air quality) to assess exposure to vulnerable individuals and physical assets;
2. Physical impacts of climate-driven environmental stressors, such as property damage, health effects, or damaged infrastructure; and
3. Economic processes that are important to understand the relationship between physical impacts and economic outcomes, such as reduced economic welfare.

Using an impacts-by-degree approach aids in communicating risk information as it can provide a range of estimates expected for a given temperature change. The general steps and components in this approach are outlined below, with reference to more detailed information in this and other technical appendices that support this report.

### CLIMATE DATA

Consistent with guidance for the development of the Fourth National Climate Assessment,[27] this report uses representative concentration pathway 8.5 (RCP8.5) as a higher emission scenario and RCP4.5 as a lower emission scenario.[*] This selection is not an endorsement of either RCP8.5 or RCP4.5 and does not indicate any judgment regarding the likelihood of either scenario. Because this report estimates impacts under increasing degrees of future warming, the use of RCP8.5 allows for analysis of the widest potential temperature range in the modeling approaches, while limiting the number of total scenarios necessary for running through sectoral impact models. RCP8.5 provides

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[*] RCP8.5 and a lower emissions scenario (RCP4.5) were recommended for use in NCA4. The Sixth Assessment of the Intergovernmental Panel on Climate Change (IPCC; Working Group I), which was released in summer 2021, provided updated scenarios and temperature projections based on the Coupled Model Intercomparison Project Phase 6 (CMIP6). However, downscaled climate projections for the U.S. were not available in time for the development of this report.

projections for the full range of plausible 21st century temperatures, obviating the need to run multiple scenarios to address low, medium, and high impacts. Using multiple scenarios could provide insights into how a specific impact by degree warming level for RCP8.5 might differ from the same level of warming, with different timing (e.g., for RCP4.5), but these differences have been shown to be minimal once controls for socioeconomic inputs such as population and GDP are incorporated, as was done here.[28]

The analyses in this report use climate projections from the fifth phase of the Coupled Model Intercomparison Project (CMIP5).[29] For most sectors, six climate models are used: the Geophysical Fluid Dynamics Laboratory coupled general circulation model (GFDL_CM3), the Canadian Earth System Model (CanESM2), the Community Climate System Model (CCSM4), the Goddard Institute for Space Studies model (GISS_E2_R), the Hadley Centre Global Environmental Model (HadGEM2_ES), and the Model for Interdisciplinary Research on Climate (MIROC5). These six GCMs are listed in Table 1. In the case of the air quality analysis (see Chapter 4), only two of the six GCMs (GFDL_CM3 and CCSM4) were used due to computational constraints of the dynamic downscaling and atmospheric chemistry modeling steps.

### Table 1. CMIP5 Global Climate Models (GCMs) Used in the Analyses of this Technical Report

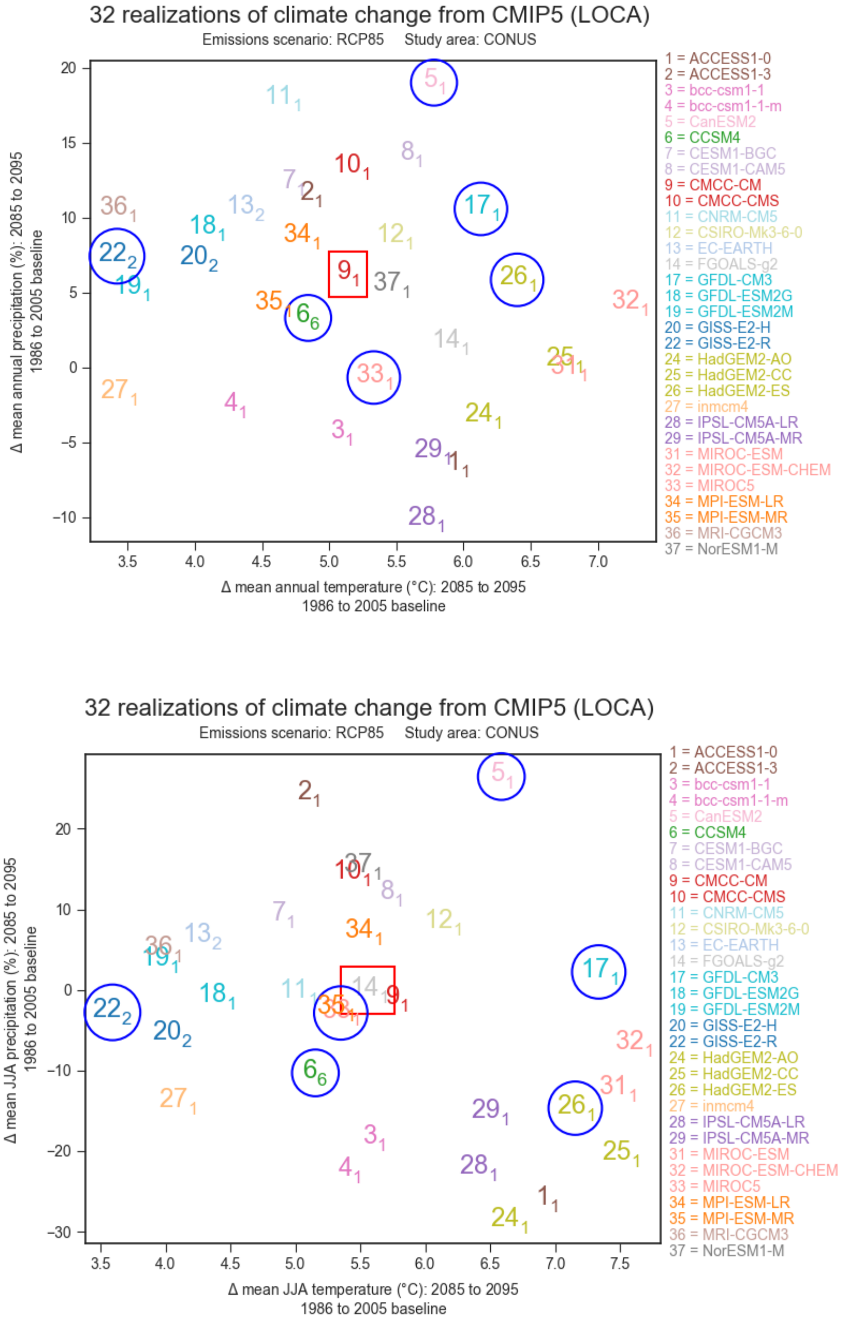
| Center (modelling group) | Model Acronym | References |
|---|---|---|
| Canadian Centre for Climate Modeling and Analysis | CanESM2 | Von Salzen et al. 2013[30] |
| Geophysical Fluid Dynamics Laboratory | GFDL-CM3 | Donner et al. 2011[31] |
| National Center for Atmospheric Research | CCSM4 | Gent et al. 2011[32]<br>Neale et al. 2013[33] |
| NASA Goddard Institute for Space Studies | GISS-E2-R | Schmidt et al. 2006[34] |
| Met Office Hadley Centre | HadGEM2-ES | Collins et al. 2011[35]<br>Davies et al. 2005[36] |
| Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology | MIROC5 | Watanabe et al. 2010[37] |

Five of the six GCMs (all but GFDL_CM3) were used in the second modeling phase of the impact-by-degree framework development, and the overall Climate Change Impact and Risk Assessment (CIRA) project.[38] These five GCMS were chosen based on a consideration of independence and skill at matching historical observed U.S. climate, and coverage of a wide range of future precipitation and temperature outcomes. GFDL_CM3 was added to that set with the most important criteria being the inclusion of an additional high temperature model that was different from other models already included, as evaluated by estimates of inter-model distance.[39] Other warm models considered included CESM1_CAM5, which was excluded based on similarity to CCSM4; ACCESS1_3, which has similarities to HadGEM2_ES; and CNRM_CM5, which was slightly cooler and slightly less skillful by the empirical metrics than GFDL_CM3.[40] GFDL_CM3 was added to the suite of climate models to include better coverage of the impacts-by-degree approach for higher levels of warming in the U.S., and that model's results are also considered in some of the impacts analyzed in this report. Sarofim et al. provides further justification for this rationale.[41]

Most sectoral analyses of this report require downscaled climate projections to reduce model bias and provide finer resolution. The approach presented here relies primarily on the LOCA (Localized Constructed Analog)[42,43] approach to produce daily temperature (maximum and minimum) and precipitation data at a 1/16-degree scale (approximately 6.25 km). The only detailed analysis in this report that did not use LOCA data is the coastal flooding analysis (Chapter 6), which relies on sea level rise and storm surge projections described below. Moreover, the air quality analysis utilizes dynamically downscaled climate projections (see Chapter 4).

To aid in the selection of specific GCMs, the LASSO[44] tool was used to produce scatter plots showing the variability across the CMIP5 ensemble for projected changes (2085-2095 compared to the 1986-2005 reference period) in annual and summertime temperature and precipitation. Figure 2 shows the range of temperature and precipitation outcomes across the CMIP5 ensemble. The GCMs used in the climate projections for this report are displayed with blue circles around them to highlight their location within the scatter plots. The model identified as the double median across temperature/precipitation outcomes is shown in a red rectangle.

**Figure 2. Variability of Projected Annual (top) and Summertime (bottom) Temperature and Precipitation Change across the CMIP5 Ensemble for the Continental U.S.**

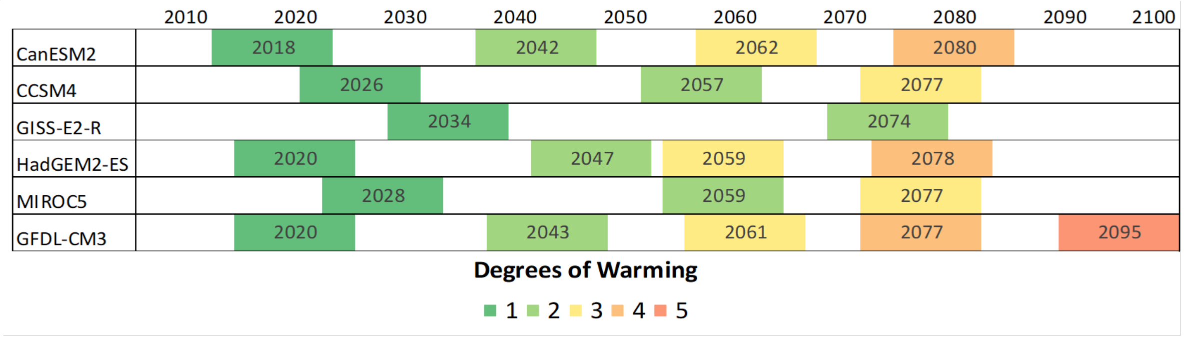


*Source: U.S. EPA (2017). Notes: Application of the LASSO tool (see text for reference) to produce scatter plots showing the variability across the CMIP5 ensemble for projected changes (2085-2095 compared to the 1986-2005 reference period) in annual (top panel) and summertime (bottom panel) temperature and precipitation. Numerals show individual GCM temperature and precipitation outcomes across the CMIP5 ensemble. GCMs used in this report are displayed with blue circles around them to highlight their location within the scatter plots. The red rectangle shows the model identified as the double median across temperature/precipitation outcomes.*

## ARRIVAL TIMES BY INTEGER WARMING

As part of the impacts-by-degree framework, the arrival times of global average temperature increases compared to the 1986-2005 baseline were identified from the GCMs described above. These arrival times represent the first 11-year period to have an average temperature equal to that of the warming degree. Figure 3 shows the year at which the 11-year moving average for when each of the GCMs first reached each degree above the baseline, and the 11-year window around that year (e.g., CanESM2 has an initial arrival year of 2018, and its 11-year "window" encompasses 2011-2022).

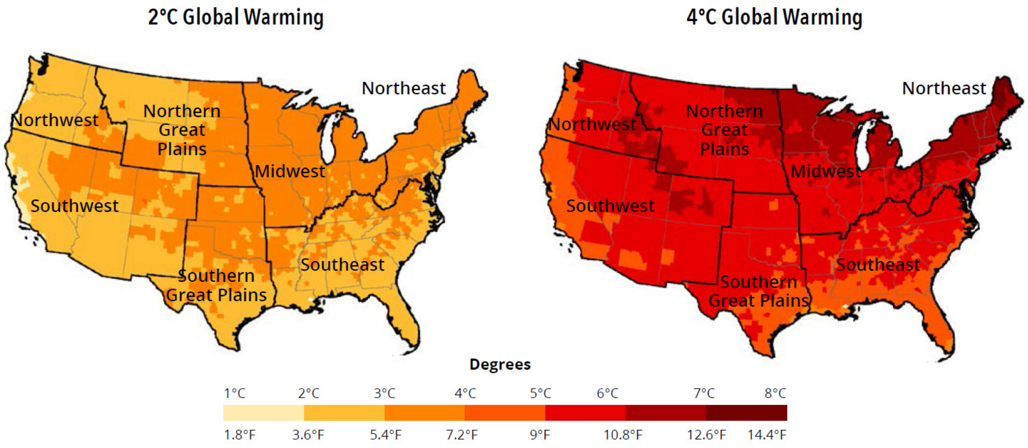
**Figure 3. Arrival Years of Global Increases in Temperature**



Notes: This graphic shows the 11-year windows assigned to each integer temperature by GCM under a higher emission scenario (RCP8.5). Values are calculated using a 1986-2005 baseline. Arrival years, or the year at which the 11-year moving average reaches the given integer, are listed in each bin. Source: Sarofim et al. (2021)

Temperature change is not uniform across the globe, and the projected global average temperature changes shown in Figure 4 manifest differently in the U.S. Figure 4 shows the projected county-level temperature changes that correspond to global warming of 2°C and 4°C. As shown, changes in global temperatures generally result in higher changes in average annual temperatures in the U.S.

**Figure 4. Projected Changes in Average Annual Temperatures Across the U.S.**



*Source: EPA (2021). These maps show the county-level average annual temperature changes associated with global average temperature changes of 2°C and 4°C relative to the 1986-2005 baseline.*

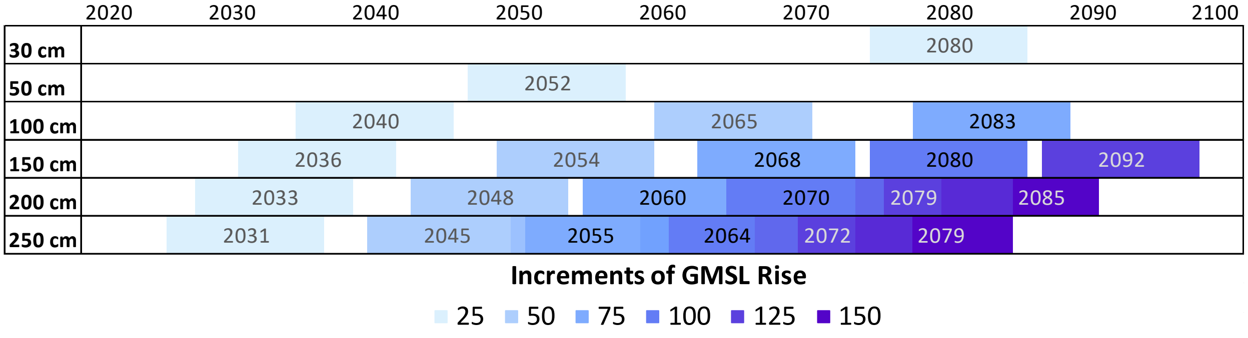
It is important to note that the 1986-2005 baseline is 0.61°C warmer than preindustrial (1850-1900) temperatures at the global scale.[45] Throughout the main report, results are presented for 2°C and 4°C of global warming. Impacts could be experienced between 2042-2074 (2056 average) and between 2077 and sometime after 2100 (2097 average) depending on the specific climate model. However, the risk and impact estimates are only available for 21st century years. As a result, measurements of the potential risks to children's health presented in this report for 4°C only include the three models with arrival years before 2100 (CanESM2, HadGEM2-ES, and GFDL-CM3). 2°C and 4°C of global warming were chosen for this report to provide a range of results that might be realized in the 21st century.

## SEA LEVEL RISE PROJECTIONS

This report projects impacts using future increases in global mean sea level (GMSL) in increments of 25 cm, up to 150 cm, relative to GMSL in 2000. Results in the main report convey impacts under 50 cm and 100 cm of global sea level rise. The underlying economic impact literature provides results for each year up to 2100, using six GMSL trajectories developed for the USGCRP's Fourth National Climate Assessment. The scenarios are categorized according to the future change in GMSL in 2100, relative to the year 2000 (e.g., 100 cm, 200 cm). Projections of location-specific differences in relative (or local) sea level change[46] account for land uplift or subsidence, oceanographic effects, and responses of the geoid and the lithosphere to shrinking land ice. Mean values for each tide gauge location are used. A distance weighting procedure for interpolating between tide gauge locations is employed to attribute tide gauge-level results to each coastal county. This procedure allows us to connect changes in GMSL with a) county-scale relative sea level rise (SLR) that considers these local scale factors, and b) data on the economic impacts of each increment in SLR for those localities.

Figure 5 shows the specific 11-year bins used to connect the underlying economic impact literature to GMSL increments in the NCA4 SLR trajectories. The SLR bins are based on the published NCA SLR trajectories and calculated using the temperature binning "arrival time" method adopted in supporting literature, adapted for GMSL arrival timing.[47]

**Figure 5. Arrival Years of Global Mean Sea Level (GMSL) Rise**



*Notes: This graphic shows the 11-year windows assigned to each 25 cm increment for results from each of the National Climate Scenario GMSL scenarios. Values are calculated using a year-2000 baseline. Arrival years, or the year at which the 11-year moving average reaches the given integer, are listed in each bin.*

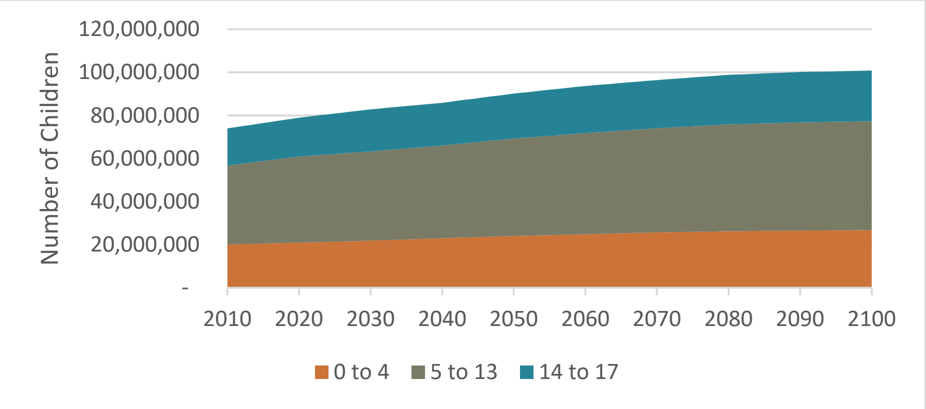
## POPULATION CONSIDERATIONS AND DATA

Ultimately, this report conveys the risk of the climate stressors and associated impacts to all children in the contiguous U.S. To do so, the detailed analyses incorporate projections for the future population of children. The analysis relies on U.S. Census data for 2010 as well as future projections published in EPA's Integrated Climate and Land Use Scenarios version 2 (ICLUSv2)[48] model through 2100. Given U.S. Census data for 2020 are available, the analysis evaluates how ICLUS compares with the U.S. Census data for that year and found only small differences. For consistency with other CIRA analyses, ICLUS is used for all years post-2010. The analysis takes the following approach:

- **Step 1:** Establish the baseline population of children by county using the 2010 U.S. Census.
- **Step 2:** Apply the growth rates at the county level calculated from ICLUS populations of children for each year between 2010 and 2100 to the 2010 population from Step 1.
- **Step 3:** Calculate percentage of children within each county by census tract and block group using 2015-2019 American Community Survey data (e.g., within county x, 10% of children live in census tract y).
- **Step 4:** Allocate population of children by census tract and block group for each year in ICLUS by multiplying percentages from Step 3 by total county population in Step 2.

While some of the detailed analyses focus on impacts across all children aged 0-17, some of the impact measures are specific to age ranges of children (i.e., 0-5 years, 14-17, etc.). The four steps above are performed for each relevant age category. Figure 6 below describes how the population of children is expected to change over the 21st century. Relative to 2010 levels, the total population of children is projected to increase by 22% by 2050 and 35% by 2090. To provide a better representation of the influence of climate specifically on the impacts measured in the report, the technical appendix for each detailed analysis also presents results assuming constant 2010 population, removing the influence of population growth on the results.

**Figure 6. Future Projections of Children's Population in the Contiguous U.S.**



*Notes: This figure presents the growth in population of children across the 21st century (x-axis shows 21st century years) using the 2010 U.S. Census data and projections from ICLUS. Specific age sub-groups are described using colors: aged 0-4 using orange, aged 5-13 using brown, and aged 14-17 using blue.*

## SOCIAL VULNERABILITY APPROACH

This report considers ways in which climate change impacts may be experienced disproportionately by overburdened populations, leveraging a previously published analytic approach to assess the likelihood of this occurring.[49] Across each relevant detailed analysis, this report uses a standard set of demographics: Black, Indigenous, and People of Color (BIPOC), low income, limited English speaking, and no health insurance. The specific data used to define each of these populations is identified below. For each analysis, children belonging to any of these four populations are first identified and are located within the spatial domain considered to be vulnerable to impacts for the analysis. For example, the coastal flooding analysis only considers children that live in coastal areas.

Climate change impacts are modeled using the methods developed for each analysis to identify high impact areas. "High impact" is defined as areas in the highest tercile of impacts *per capita*. Note that the spatial resolution of analysis varies by sector (e.g., county, census tract, census block group), but is consistent within each analysis. Once high impact areas are identified, the number of socially vulnerable children, and the "reference" non-socially vulnerable children in those areas, are tabulated (see details below on definitions of socially vulnerable and reference populations for each specific population). From this, the likelihood of living in a high impact location is calculated for both populations, relative to the reference domain. The relative likelihoods described in this report are the result of comparing likelihoods of living in high impact areas for populations that are and are not socially vulnerable. This standardized approach allows us to present relative likelihoods of high impacts at regional and national scales, in which regional-level relative likelihoods are based on regional spatial domains and populations.

In standardized form, the difference in risk is calculated as:

$$\Delta R = \left(\frac{\sum P_{vh}}{\sum P_v}\right) \Big/ \left(\frac{\sum P_{rh}}{\sum P_r}\right) - 1$$

where $\Delta R$ is the risk difference, expressed as a percent; $P_{vh}$ is the sum of the socially vulnerable population in all "high impact" areas; $P_v$ is the total socially vulnerable population; $P_{rh}$ is the sum of the reference population in "high impact" areas; and $P_r$ is the total reference population. As an example, the details of an illustrative calculation for the impact of air quality on new cases of asthma for BIPOC children are presented in Table 2.

**Table 2. Example Calculation of Disproportionate Impacts on BIPOC Children – New Asthma Cases Associated with Air Quality**

| Variables | Calculation and interpretation |
|---|---|
| $P_v$= 12 million BIPOC children across CONUS<br>$P_r$= 11 million non-BIPOC children across CONUS<br>$P_{vh}$= 4 million BIPOC children in high impact census tracts<br>$P_{rh}$= 2 million non-BIPOC children in high impact census tracts | $83\% = \left(\frac{4}{12}\right) / \left(\frac{2}{11}\right) - 1$<br>BIPOC children are 83% more likely than non-BIPOC children to live in areas with the highest rates per capita of new asthma diagnoses linked with degrading air quality. |

## DEMOGRAPHIC CONSIDERATIONS AND DATA

This report relies on a contemporaneous picture of demographics across CONUS to assess the likelihood of disproportionate impacts on particular demographic groups of children. This is a departure from the health risk assessment analyses that project impacts to children while taking into consideration future changes in population. Projecting the future distribution of children across demographic groups is less certain, especially for specific variables such as those who are uninsured. Thus, these distributions generally are unavailable at the level of detail necessary for the social vulnerability analyses described in this report. However, shifting demographics and socioeconomic change will affect the spatial distribution and magnitude of vulnerability to climate change. Multi-sector assessments have demonstrated compounding effects of population growth and climate change impacts, particularly with regards to health-related effects.[50] Therefore, the results of this report should be interpreted with this limitation in mind, as actual impacts could be larger or smaller based on potentially changing demographics.

The report examines disproportionate impacts of climate change on children of various demographic groups by relying on ACS data, averaged across 2015-2019. Where available, data are collected at the block group level, or if necessary, at the census tract level. This analysis relied on the IPUMS[†] platform to download ACS data through its National Historical Geographic Information System (NHGIS). The NGHIS codes for data this report relies upon are provided in Table 3.[51]

## SOCIALLY VULNERABLE GROUPS CONSIDERED

This analysis considers four groups of socially vulnerable children. These variables were chosen primarily because the literature suggests children in these categories are disproportionately vulnerable to the specific climate stressors and impacts analyzed.

- **BIPOC:** The term BIPOC used in this report refers to individuals identifying as Black or African American; American Indian or Alaska Native; Asian; Native Hawaiian or Other Pacific Islander; and/or Hispanic or Latino. The BIPOC children included herein also only include those living in the CONUS. The ACS provides race and ethnicity data at the census block group level. This report relies on total population as well as White, non-Hispanic population to calculate the BIPOC population at the census block group and census tract spatial scales. Age-stratified demographic information is available at the census tract level, so these estimates are specific to children aged 0-17. Age-stratified race and ethnicity information is not available from the ACS at the block group level employed in the coastal flooding health risk analysis, so all-age demographic information is combined with block group-level age distributions to estimate the distribution of children for racial components within the BIPOC category. For calculations of disproportionate effects on socially vulnerable BIPOC populations, the White non-Hispanic population is used as the reference population. Across CONUS, the ACS 2015-2019 identifies 31 million BIPOC children and 42 million non-BIPOC children.

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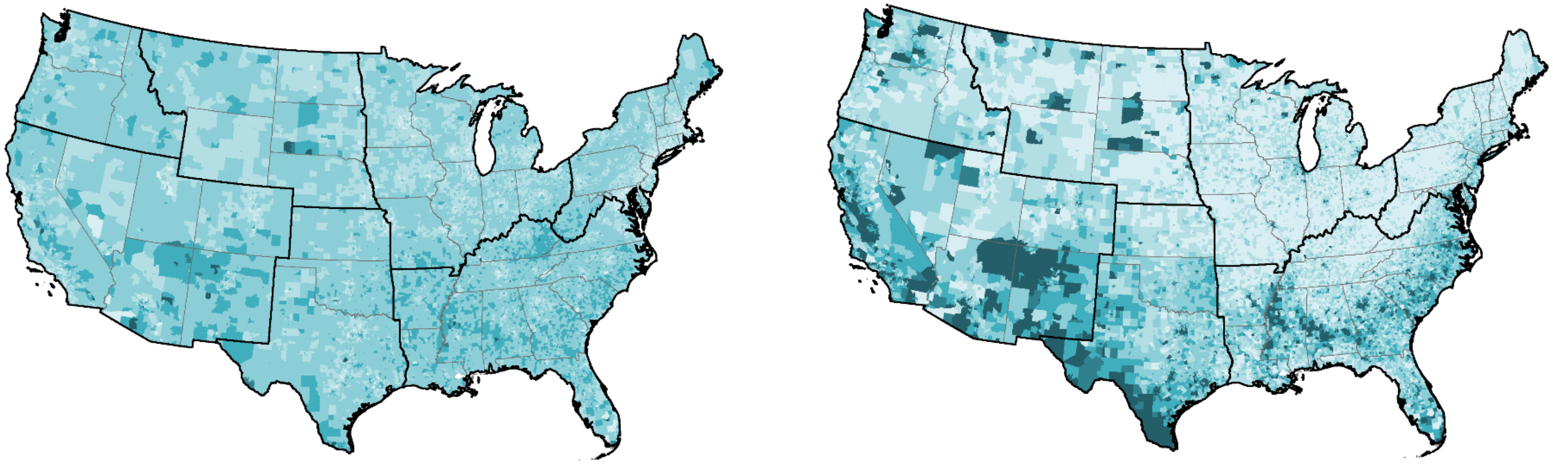
[†] IPUMS had previously been an acronym for Integrated Public Use Microdata Series, but not all of the data it accesses is public, or is microdata, so since 2016 it has been known only by its acronym.

- **Low income:** "Low income" at the individual level is defined as children living in households that have an aggregate income that is no more than twice the poverty threshold. This variable is not age-stratified, so this report relies on an all-ages poverty estimate. Additional information on the definition of poverty thresholds can be found on the U.S. Census website.[52] In this report, the estimates of households that fall into income-to-poverty threshold ratios below two times the poverty threshold are aggregated. The reference population is individuals living in households with income greater than two times the poverty threshold. Across CONUS, the ACS 2015-2019 identifies 24 million low-income children and 49 million children living above two times the poverty threshold.
- **Limited English speaking:** Children are considered "limited English speaking" in the ACS if those 14 years old and older have at least some difficulties with speaking English. This variable is not age-stratified in the ACS, so this report relies on an all-ages estimate of language isolation and assumes the proportion of children who are linguistically isolated is consistent with that of the rest of the population. In this report, the estimates of populations who live in limited English-speaking households are aggregated by primary language spoken at home. The reference population is individuals who do not live in a limited English-speaking household. Across CONUS, the ACS 2015-2019 identifies 4 million children who fall into the U.S. Census-defined category of "Limited English speaking" and 69 million children who are not considered to be in this category.
- **No health insurance:** The ACS provides age-stratified estimates of children with and without health insurance at the block group level. In this report, children of both sexes younger than 6 years old and between the ages of 6 and 18 years old who have no health insurance are aggregated, so the estimate is specific to all children aged 0-18 years. The reference population is children who have health insurance. Across CONUS, the ACS 2015-2019 identifies 4 million children lacking health insurance and 69 million children with insurance.

Introductory sections of each chapter summarize the literature and/or the conceptual links between impacts and vulnerability of these populations. There are additional dimensions of social vulnerability not considered in this report (e.g., disability, household composition, and others), warranting further analysis. Additional disproportionate risks may be present when evaluating the interconnections between social vulnerability measures, connections that are not explored in this report.

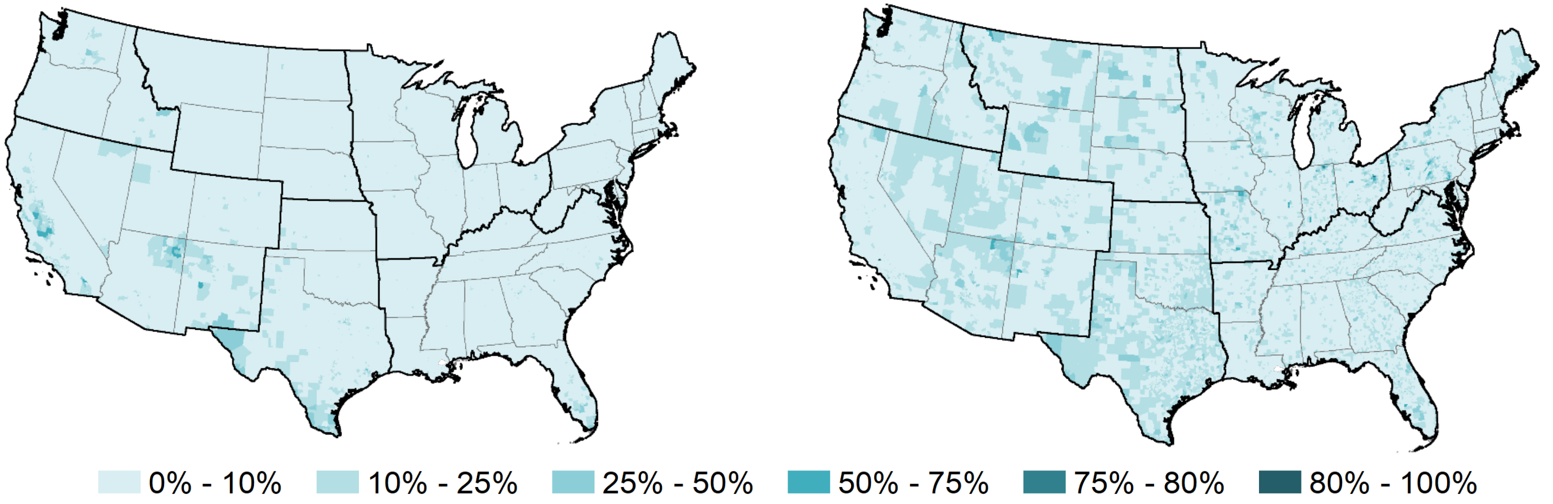
As illustrated in Figure 7, the demographic groups described above are spatially correlated with each other. The key disproportionality results, however, do not necessarily exhibit the same degree of correlation nationally or by region that are shown in the full ACS dataset, as each impact examines a different spatial domain based on the specific locations of the high impact terciles. Many individuals also may meet the ACS definition for inclusion in multiple categories from among the four chosen. Supplemental analyses were considered regarding disproportionate effects for individuals included in multiple categories of social vulnerability; however, ACS data support only limited versions of analyses that aggregate characteristics and are not stratified by age. For example, available low income cross-tabulations are focused on individuals with income below the poverty line, rather than below twice the poverty line, but do not reflect age-related effects.

**Figure 7. Spatial Distribution of Select Groups of Overburdened Children (Aged 0-17)**



**Low Income**

**BIPOC**



**Limited English Speaking**

**No Health Insurance**

*Notes: This graphic shows the spatial distribution of four groups of overburdened children by census tracts based on the U.S. Census Bureau's American Community Survey 2015-2019 (specific data tables are documented in Table 3). The percentages convey the portion of children living in each census tract that meet the definition. NCA regions are outlined in black.*

## Table 3. Underlying Demographic Data from U.S. Census Bureau's American Community Survey 2015-2019

| Data table | NHGIS Field Code | ACS Source Table | Spatial Scale | Description | Use |
|---|---|---|---|---|---|
| Sex by Age | ALTOE003; 004; 005; 006; 027; 028; 029; 030 | B01001 | Block Group; Census Tract | Total population of individuals by age (<5, 5-9, 10-14, 15-17) and sex (male, female) | BIPOC; Low Income; No health insurance |
| Race | ALUCE002 | B02001 | Block Group | White Alone | BIPOC |
| Race | ALUCE003 | B02001 | Block Group | Black or African-American Alone | BIPOC |
| Race | ALUCE004 | B02001 | Block Group | American Indian and Alaska Native Alone | BIPOC |
| Race | ALUCE005 | B02001 | Block Group | Asian Alone | BIPOC |
| Race | ALUCE006 | B02001 | Block Group | Native Hawaiian and Other Pacific Islander Alone | BIPOC |
| Race | ALUCE007 | B02001 | Block Group | Some Other Race Alone | BIPOC |
| Race | ALUCE008 | B02001 | Block Group | Two or More Races | BIPOC |
| Hispanic or Latino Origin by Race | ALUKE003 | B03002 | Block Group | White Alone, Not Hispanic or Latino | BIPOC |
| Hispanic or Latino Origin by Race | ALUKE012 | B03002 | Block Group | Hispanic or Latino (all races) | BIPOC |
| Sex by Age (White Alone) | AL4FE003; 004; 005; 006; 018; 019; 020; 021 | B01001A | Census Tract | Population of white individuals by age (<5, 5-9, 10-14, 15-17 years) and sex (male, female) | BIPOC |
| Sex by Age (Black or African American Alone) | AL4GE003; 004; 005; 006; 018; 019; 020; 021 | B01001B | Census Tract | Population of Black or African American individuals by age (<5, 5-9, 10-14, 15-17 years) and sex (male, female) | BIPOC |
| Sex by Age (American Indian and Alaska Native Alone) | AL4HE003; 004; 005; 006; 018; 019; 020; 021 | B01001C | Census Tract | Population of American Indian and Alaska native individuals by age (<5, 5-9, 10-14, 15-17 years) and sex (male, female) | BIPOC |
| Sex by Age (Asian Alone) | AL4IE003; 004; 005; 006; 018; 019; 020; 021 | B01001D | Census Tract | Population of Asian individuals by age (<5, 5-9, 10-14, 15-17 years) and sex (male, female) | BIPOC |
| Sex by Age (Native Hawaiian and Other Pacific Islander Alone) | AL4JE003; 004; 005; 006; 018; 019; 020; 021 | B01001E | Census Tract | Population of Native Hawaiian and other Pacific Islander individuals by age (<5, 5-9, 10-14, 15-17 years) and sex (male, female) | BIPOC |
| Sex by Age (Some Other Race Alone) | AL4KE003; 004; 005; 006; 018; 019; 020; 021 | B01001F | Census Tract | Population of individuals of some other race by age (<5, 5-9, 10-14, 15-17 years) and sex (male, female) | BIPOC |

| Data table | NHGIS Field Code | ACS Source Table | Spatial Scale | Description | Use |
|---|---|---|---|---|---|
| Sex by Age (Two or More Races) | AL4LE003; 004; 005; 006; 018; 019; 020; 021 | B01001G | Census Tract | Population of individuals of two or more races by age (<5, 5-9, 10-14, 15-17 years) and sex (male, female) | BIPOC |
| Sex by Age (White Alone, Not Hispanic or Latino) | AL4ME003; 004; 005; 006; 018; 019; 020; 021 | B01001H | Census Tract | Population of white non-Hispanic individuals by age (<5, 5-9, 10-14, 15-17 years) and sex (male, female) | BIPOC |
| Sex by Age (Hispanic or Latino) | AL4NE003; 004; 005; 006; 018; 019; 020; 021 | B01001I | Census Tract | Population of Hispanic or Latino individuals by age (<5, 5-9, 10-14, 15-17 years) and sex (male, female) | BIPOC |
| Ratio of Income to Poverty Level in the Past 12 Months | ALWVE001 | C17002 | Block Group; Census Tract | Total Population | Low Income |
| Ratio of Income to Poverty Level in the Past 12 Months | ALWVE002 | C17002 | Block Group; Census Tract | Under .50 | Low Income |
| Ratio of Income to Poverty Level in the Past 12 Months | ALWVE003 | C17002 | Block Group; Census Tract | .50 to .99 | Low Income |
| Ratio of Income to Poverty Level in the Past 12 Months | ALWVE004 | C17002 | Block Group; Census Tract | 1.00 to 1.24 | Low Income |
| Ratio of Income to Poverty Level in the Past 12 Months | ALWVE005 | C17002 | Block Group; Census Tract | 1.25 to 1.49 | Low Income |
| Ratio of Income to Poverty Level in the Past 12 Months | ALWVE006 | C17002 | Block Group; Census Tract | 1.50 to 1.84 | Low Income |
| Ratio of Income to Poverty Level in the Past 12 Months | ALWVE007 | C17002 | Block Group; Census Tract | 1.85 to 1.99 | Low Income |
| Ratio of Income to Poverty Level in the Past 12 Months | ALWVE008 | C17002 | Block Group; Census Tract | 2.00 and over | Low Income |
| Health Insurance Coverage Status by Sex and Age | AMLLE004 | B27001 | Census Tract | Male: Under 6 years: With health insurance coverage | No health insurance |
| Health Insurance Coverage Status by Sex and Age | AMLLE005 | B27001 | Census Tract | Male: Under 6 years: No health insurance coverage | No health insurance |
| Health Insurance Coverage Status by Sex and Age | AMLLE007 | B27001 | Census Tract | Male: 6 to 18 years: With health insurance coverage | No health insurance |
| Health Insurance Coverage Status by Sex and Age | AMLLE008 | B27001 | Census Tract | Male: 6 to 18 years: No health insurance coverage | No health insurance |
| Health Insurance Coverage Status by Sex and Age | AMLLE032 | B27001 | Census Tract | Female: Under 6 years: With health insurance coverage | No health insurance |

| Data table | NHGIS Field Code | ACS Source Table | Spatial Scale | Description | Use |
|---|---|---|---|---|---|
| Health Insurance Coverage Status by Sex and Age | AMLLE033 | B27001 | Census Tract | Female: Under 6 years: No health insurance coverage | No health insurance |
| Health Insurance Coverage Status by Sex and Age | AMLLE035 | B27001 | Census Tract | Female: 6 to 18 years: With health insurance coverage | No health insurance |
| Health Insurance Coverage Status by Sex and Age | AMLLE036 | B27001 | Census Tract | Female: 6 to 18 years: No health insurance coverage | No health insurance |
| Household Language by Household Limited English Speaking Status | ALWTE001 | C16002 | Block Group; Census Tract | Total Households | Limited English speaking |
| Household Language by Household Limited English Speaking Status | ALWTE004 | C16002 | Block Group; Census Tract | Spanish: Limited English-Speaking Household | Limited English speaking |
| Household Language by Household Limited English Speaking Status | ALWTE007 | C16002 | Block Group; Census Tract | Other Indo-European Languages: Limited English-Speaking Household | Limited English speaking |
| Household Language by Household Limited English Speaking Status | ALWTE010 | C16002 | Block Group; Census Tract | Asian and Pacific Island Languages: Limited English-Speaking Household | Limited English speaking |
| Household Language by Household Limited English Speaking Status | ALWTE013 | C16002 | Block Group; Census Tract | Other Languages: Limited English-Speaking Household | Limited English speaking |

## SOURCES OF UNCERTAINTY AND LIMITATIONS

This section describes some of the main sources of uncertainty inherent across the detailed analyses. Limitations specific to each individual detailed analysis are described in those sections of this report and appendices.

### PROJECTIONS OF FUTURE CLIMATE

With the goal of presenting a consistent set of climate change impact analyses across sectors, this report presents results using an impacts-by-degree approach. Arrival windows for integral levels of future warming were identified from each climate model, and these years were used in the simulations for each sectoral impact analysis. Due to the level of effort necessary to run each scenario through the sectoral models of this report, only six climate models were chosen. While these models were chosen to capture a large range of the variability observed across the entire ensemble, this subset is not a perfect representation of climate models. However, even the full set of GCMs is not likely to span the entire range of potential physical responses of the climate system to changes in the concentration of atmospheric GHGs. Previous literature demonstrates the importance of climate sensitivity assumptions in understanding a wide range of potential changes to the climate system,[53,54] as well as the effect of natural variability on timing and magnitude of impacts.[55,56] The Sixth Assessment of the IPCC provides updated scenarios and temperature projections based on the CMIP6 project. However, these newer projections and the widely accepted downscaled and bias-corrected projections of the results of CMIP6 GCMs were not available in time for use in this report.

### COVERAGE OF CLIMATE STRESSORS AND IMPACTS

The analyses presented in this report cover just a handful of potential impacts of climate change in the U.S. The five stressors included were chosen because of the availability of robust methods and data for analysis that offered information specific to children or were easily extrapolated to younger populations. There are a number of additional impacts of climate change that likely will affect children, but which are not included in this report. The literature reviews that open each chapter provide some perspective on the broad range of possible impacts on all children and those disproportionately affected.

### COMPARISON ACROSS IMPACT MEASURES

Unlike previous CIRA reports that primarily focused on the presentation of economic results across sectors, this report contains limited monetization of impacts. The one exception is the analysis that projects lost future income associated with heat-induced learning losses, which aggregates impacts across students graduating each year. While the lack of a common economic metric makes comparisons across impacts more challenging, a focus on *physical impacts* (e.g., cases of asthma, number of children affected by flooding) is more appropriate in this context because the results are not dependent on the details of a specific economic valuation approach. In addition, some metrics used in this report have not yet been valued in economic terms, such as the mental stress of children losing a home to coastal flooding. It should be noted that even the physical measures used here cannot convey how climate effects and health outcomes experienced in childhood may prevail throughout an individual's life, including leading to future serious health effects. In either circumstance, these are likely to differ across the impacts considered.

However, to provide perspective on the costs associated with the physical impacts projected in this report, the report conveys direct medical costs and indirect productivity losses provided by available research. A major research gap is that these costs are infrequently described specific to children, and research (where it does exist) clearly shows that the costs differ between children and adults.[57] The unit costs offered in the report are merely to provide perspective on order of magnitude.

## IMPACT MODELING

The impact estimates presented in this report were developed using discrete impact models. These models are complex analytical tools, and choices regarding the structure and parameter values of the model can create important assumptions that affect the estimation of impacts. Ongoing studies such as the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) are investigating the influence of structural uncertainties across sectoral impact models.[58] The use of additional models for each analysis of this report would help improve the understanding of potential impacts in the future.

## JOINT IMPACTS ACROSS CLIMATE STRESSORS

The results presented for each detailed analysis primarily were developed independently of one another. As a result, the estimated impacts may omit important cumulative or interactive effects or outcomes. For example, the air quality and heat analyses do not examine the compounding health risks that individuals could suffer during heat waves with high ozone concentrations in the air. First-order connectivity was achieved in limited cases, such as with the coastal flooding analysis, which includes projected installation of coastal defenses and provides information on location and timing to inform where coastal properties may receive ancillary protection; however, improved connectivity between models would aid in gaining a more complete understanding of climate change impacts on children in the U.S.

## PROJECTIONS OF FUTURE POPULATION OF CHILDREN

Disaggregated population projections were produced at the county level using EPA's ICLUSv2 model. The spatial pattern of population change in ICLUS is dependent upon underlying assumptions regarding fertility, migration rate, and international immigration. These assumptions were parameterized using the storyline of SSP2, which suggests medium levels of fertility, mortality, and international immigration. The choice of this population scenario versus another could significantly influence the estimated impacts across sectors, particularly those most affected by changes in population and economic growth. Recent demographic trends in the U.S. suggest that population growth lies closer to the mid-range scenarios consistent with SSP2 (less than 0.5% per year—contrasted with SSP5, which projects population increases over 1% per year).[59] These choices for future population represent a reasonable central case, but use of other population projections would affect the results reported. The purpose of this analysis is to focus on understanding the differences between impacts under multiple climate scenarios. As a result, the exploration of uncertainty surrounding the use of the central case population projection is deferred to future work and the robust literature exploring the differences amongst scenarios.

## SOCIOECONOMIC AND DEMOGRAPHIC CHANGE

This report isolates the effects of climate change on socially vulnerable children by using current demographics to develop projections. The primary rationale for this approach is that long-term assumptions and forecasts for national changes in demographics have a high degree of uncertainty, and therefore are unavailable. Shifting demographics and changes to the socioeconomic statuses and characteristics of populations will alter the spatial distributions of effects and magnitude of population sensitivity and vulnerability to climate change. Therefore, the results of the social vulnerability analyses should be interpreted with this limitation in mind, as actual impacts could be larger or smaller based on changing demographics.

## CONSIDERATION OF ADAPTATION

Populations are likely to adapt to climate change in many ways, with some actions limiting the impact of climatic exposure, and other actions likely exacerbating impacts. Many of the same factors that contribute to exposure to climate hazards also influence the ability of individuals and communities to adapt to climate variability and change. Socioeconomic status, the condition and accessibility of infrastructure, the accessibility of healthcare, specific demographic characteristics, and other institutional resources all contribute to the timeliness and effectiveness of adaptive capacity.[60]

The detailed analyses of this report treat adaptation in unique ways, with some sectors directly modeling the implications of adaptation responses, and others implicitly incorporating well-established pathways for adapting to climate stress. For example, most analyses incorporate empirically-based accounting of individual, community, and infrastructure adaptation in estimating a climate stressor-response function (i.e., they reflect historical responses to these stressors). As climate stress worsens and expands geographically, historical adaptation actions implicitly are incorporated in the estimated response function, and by extension in the estimates presented here, but do not include new adaptive actions. The heat analysis explicitly holds baseline air conditioning use constant to underscore the risks associated with no further investment in cooling systems in schools and homes. The coastal flooding analysis employs a simulation modeling approach that allows for incorporation of baseline adaptation actions; as an example, continuing and expanding beach nourishment projects. These simulation modeling approaches also facilitate future adoption of more complex and extensive adaptive actions, such as changing maintenance practices and extending seawall protections, which constitute new adaptation scenarios. To the extent that future adaptation actions beyond those considered are implemented in response to ongoing climate change, future impacts would likely be lower than estimated in this report.

Adaptation actions that extend beyond historically implemented practices and baseline infrastructure investments require planning, potentially complex financing, maintenance costs, and efficacy evaluations with consideration for the specific human and natural environment contexts. Adaptation plans, therefore, typically are developed and implemented at local scales. The general adaptation scenarios considered in the analyses of this report do not capture the complex issues driving adaptation decision-making at local and regional scales. For example, the coastal flooding chapter considers the cost effectiveness of adaptive responses to sea level rise inundation and storm surge damages by comparing the costs of protection to the value of properties at risk of destruction. While many factors at the property, community, regional, and national levels will determine adaptive responses to coastal risks, this sectoral analysis uses the simplistic cost/benefit metric to enable consistent comparisons for the entire coastline. That said, the adaptation scenarios and estimates presented in all sections of this report should not be construed as recommending any specific policy or adaptive action.

## GEOGRAPHIC COVERAGE

This report does not examine impacts and damages occurring outside of U.S. borders. Aside from the inherent value of people and ecosystems around the world, these impacts could affect the U.S. through changes in migration, impacts on trade, and concerns for conflict and national security. In addition, the geographic focus of this report is on CONUS, with the detailed analyses excluding Hawai’i, Alaska, and the U.S. territories (although the District of Columbia is included). The main reason is that the underlying literature for this report (that is, the sectoral impact models referred to at the beginning of this Appendix, and in each of the other sector- and climate stressor-specific Technical Appendices) limits the spatial domain to CONUS. This omission may be particularly important given the unique climate change vulnerabilities of these locales, socioeconomic characteristics that often define them, and the subsequent effects on their populations.

## SUMMARY

The influence of the sources of uncertainty on the risks of climate change impacting children’s health is difficult to estimate. In theory, a quantitative estimate of the influence of different GCMs in the climate impact step can be performed to estimate the sensitivity of results to this source of variation in climate outcomes. Further, the influence of different socioeconomic inputs, sampling margins of error for the ACS data, or statistical measurement error from certain exposure-response relationships, or perhaps other sources of uncertainty as well, might be estimated quantitatively. Many of the underlying peer-reviewed studies relied on within this report perform these types of analyses to inform readers of the uncertainty associated with each estimate presented. For this report and the analyses, attempting to combine any quantitative results on uncertainty across analytic steps would necessarily involve mixing estimates of variability (e.g., across GCMs) with estimates of statistical uncertainty (e.g., for ACS margins of error, or the impacts that rely on statistically estimated exposure-response relationships). Moreover, a combined estimate of uncertainty would ignore other sources of uncertainty that cannot be easily quantified, such as structural uncertainty associated with the choice of a single sector impacts model, and potential correlations in sources of uncertainty that may not be fully independent, such as many GCMs sharing a common structural foundation. Consequently, this report relies on an approach of identifying the key sources of uncertainty and attempting to qualitatively characterize the potential influence of each source of uncertainty on the overall results.

# REFERENCES

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[1] U.S. Environmental Protection Agency. 2021. "Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. U.S. Environmental Protection Agency." EPA 430-R-21-003. Available at: https://www.epa.gov/cira/social-vulnerability-report

[2] Helldén, D., Andersson, C., Nilsson, M., Ebi, K.L., Friberg, P. and Alfvén, T., 2021. Climate change and child health: a scoping review and an expanded conceptual framework. *The Lancet Planetary Health*, *5*(3), pp.e164-e175.

[3] Wu, J., Snell, G. and Samji, H., 2020. Climate anxiety in young people: a call to action. *The Lancet Planetary Health*, *4*(10), pp.e435-e436.

[4] Clayton, S., Manning, C.M., Krygsman, K., and Speiser, M., 2017. "Mental health and our changing climate: Impacts, implications, and guidance." Washington, D.C.: American Psychological Association, and ecoAmerica.

[5] Fritze, J.G., Blashki, G.A., Burke, S. and Wiseman, J., 2008. Hope, despair and transformation: Climate change and the promotion of mental health and wellbeing. *International journal of mental health systems*, *2*(1), pp.1-10.

[6] Crandon, T.J., Scott, J.G., Charlson, F.J. and Thomas, H.J., 2022. A social–ecological perspective on climate anxiety in children and adolescents. *Nature Climate Change*, *12*(2), pp.123-131.

[7] Hickman, C., Marks, E., Pihkala, P., Clayton, S., Lewandowski, R.E., Mayall, E.E., Wray, B., Mellor, C. and van Susteren, L., 2021. Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. *The Lancet Planetary Health*, *5*(12), pp.e863-e873.

[8] Felix, E., Rubens, S. and Hambrick, E., 2020. The relationship between physical and mental health outcomes in children exposed to disasters. *Current Psychiatry Reports*, *22*(7), pp.1-7.

[9] Fuchs, R., Glaude, M., Hansel, T., Osofsky, J. and Osofsky, H., 2021. Adolescent risk substance use behavior, posttraumatic stress, depression, and resilience: Innovative considerations for disaster recovery. *Substance Abuse*, *42*(3), pp.358-365.

[10] Knight, Z.G., 2017. A proposed model of psychodynamic psychotherapy linked to Erik Erikson's eight stages of psychosocial development. *Clinical Psychology & Psychotherapy*, *24*(5), pp.1047-1058.

[11] Dodgen, D., Donato, D., Kelly, N., La Greca, A., Morganstein, J., Reser, J., Ruzek, J., Schweitzer, S., Shimamoto, M.M., Tart, K.T. and Ursano, R., 2016. *Ch. 8: Mental Health and Well-Being* (pp. 217-246). US Global Change Research Program, Washington, DC.

[12] Gunter, R.W. and Whittal, M.L., 2010. Dissemination of cognitive-behavioral treatments for anxiety disorders: Overcoming barriers and improving patient access. *Clinical Psychology Review*, *30*(2), pp.194-202.

[13] Mojtabai, R., 2005. Trends in contacts with mental health professionals and cost barriers to mental health care among adults with significant psychological distress in the United States: 1997–2002. *American Journal of Public Health*, *95*(11), pp.2009-2014.

[14] Belova, A., Gould, C.A., Munson, K., Howell, M., Trevisan, C., Obradovich, N. and Martinich, J., 2022. Projecting the suicide burden of climate change in the United States. *GeoHealth*, p.e2021GH000580.

[15] Robinson, L.R., Holbrook, J.R., Bitsko, R.H., Hartwig, S.A., Kaminski, J.W., Ghandour, R.M., Peacock, G., Heggs, A. and Boyle, C.A., 2017. Differences in health care, family, and community factors associated with mental, behavioral, and developmental disorders among children aged 2–8 years in rural and urban areas—United States, 2011–2012. *MMWR Surveillance Summaries*, *66*(8), p.1.

[16] Chien, A.T., Leyenaar, J., Tomaino, M., Woloshin, S., Leininger, L., Barnett, E.R., McLaren, J.L. and Meara, E., 2022. Difficulty Obtaining Behavioral Health Services for Children: A National Survey of Multiphysician Practices. *The Annals of Family Medicine*, *20*(1), pp.42-50.

[17] Barnes, T.N., Smith, S.W. and Miller, M.D., 2014. School-based cognitive-behavioral interventions in the treatment of aggression in the United States: A meta-analysis. *Aggression and Violent Behavior*, *19*(4), pp.311-321.

[18] Dickerson, J.F., Lynch, F.L., Leo, M.C., DeBar, L.L., Pearson, J. and Clarke, G.N., 2018. Cost-effectiveness of cognitive behavioral therapy for depressed youth declining antidepressants. *Pediatrics*, *141*(2).

[19] Ross, E.L., Vijan, S., Miller, E.M., Valenstein, M. and Zivin, K., 2019. The cost-effectiveness of cognitive behavioral therapy versus second-generation antidepressants for initial treatment of major depressive disorder in the United States: a decision analytic model. *Annals of Internal Medicine*, *171*(11), pp.785-795.

---

[20] Fan, Q., DuPont-Reyes, M.J., Hossain, M.M., Chen, L.S., Lueck, J. and Ma, P., 2022. Racial and ethnic differences in major depressive episode, severe role impairment, and mental health service utilization in US adolescents. *Journal of Affective Disorders*, *306*, pp.190-199.

[21] Lindly, O., Eaves, M.C., Xu, Y., Tarazi, C.L., Rao, S.R. and Kuhlthau, K.A., 2022. Therapy use for US school-aged children with developmental disabilities: State variation and determinants. *Disability and Health Journal*, *15*(1), p.101198.

[22] Chien, A.T., Leyenaar, J., Tomaino, M., Woloshin, S., Leininger, L., Barnett, E.R., McLaren, J.L. and Meara, E., 2022. Difficulty Obtaining Behavioral Health Services for Children: A National Survey of Multiphysician Practices. *The Annals of Family Medicine*, *20*(1), pp.42-50.

[23] Goldsmith, L., Raditz, V. and Méndez, M., 2022. Queer and present danger: understanding the disparate impacts of disasters on LGBTQ+ communities. *Disasters*, *46*(4), pp.946-973.

[24] Simmonds, K.E., Jenkins, J., White, B., Nicholas, P.K. and Bell, J., 2022. Health impacts of climate change on gender diverse populations: A scoping review. *Journal of Nursing Scholarship*, *54*(1), pp.81-91.

[25] Rhoades, H., Rusow, J.A., Bond, D., Lanteigne, A., Fulginiti, A. and Goldbach, J.T., 2018. Homelessness, mental health and suicidality among LGBTQ youth accessing crisis services. *Child Psychiatry & Human Development*, *49*(4), pp.643-651.

[26] Sarofim, M.C., Martinich, J., Neumann, J.E., Willwerth, J., Kerrich, Z., Kolian, M., Fant, C. and Hartin, C., 2021. A temperature binning approach for multi-sector climate impact analysis. *Climatic Change*, *165*(1), pp.1-18.

[27] U.S. Global Change Research Program. 2015. U.S. Global Change Research Program General Decisions Regarding Climate-Related Scenarios for Framing the Fourth National Climate Assessment. USGCRP Scenarios and Interpretive Science Coordinating Group. Available online at https://scenarios.globalchange.gov/accouncement/1158

[28] Sarofim, M.C., Martinich, J., Neumann, J.E., Willwerth, J., Kerrich, Z., Kolian, M., Fant, C. and Hartin, C., 2021. A temperature binning approach for multi-sector climate impact analysis. *Climatic Change*, *165*(1), pp.1-18.

[29] Taylor, K.E., Stouffer, R.J. and Meehl, G.A., 2012. An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, *93*(4), pp.485-498.

[30] von Salzen, K., Scinocca, J.F., McFarlane, N.A., Li, J., Cole, J.N., Plummer, D., Verseghy, D., Reader, M.C., Ma, X., Lazare, M. and Solheim, L., 2013. The Canadian fourth generation atmospheric global climate model (CanAM4). Part I: representation of physical processes. *Atmosphere-Ocean*, *51*(1), pp.104-125.

[31] Donner, L.J., Wyman, B.L., Hemler, R.S., Horowitz, L.W., Ming, Y., Zhao, M., Golaz, J.C., Ginoux, P., Lin, S.J., Schwarzkopf, M.D. and Austin, J., 2011. The dynamical core, physical parameterizations, and basic simulation characteristics of the atmospheric component AM3 of the GFDL global coupled model CM3. *Journal of Climate*, *24*(13), pp.3484-3519.

[32] Gent, P.R., Danabasoglu, G., Donner, L.J., Holland, M.M., Hunke, E.C., Jayne, S.R., Lawrence, D.M., Neale, R.B., Rasch, P.J., Vertenstein, M. and Worley, P.H., 2011. The community climate system model version 4. *Journal of Climate*, *24*(19), pp.4973-4991.

[33] Neale, R.B., Richter, J., Park, S., Lauritzen, P.H., Vavrus, S.J., Rasch, P.J. and Zhang, M., 2013. The mean climate of the Community Atmosphere Model (CAM4) in forced SST and fully coupled experiments. *Journal of Climate*, *26*(14), pp.5150-5168.

[34] Schmidt, G.A., Ruedy, R., Hansen, J.E., Aleinov, I., Bell, N., Bauer, M., Bauer, S., Cairns, B., Canuto, V., Cheng, Y. and Del Genio, A., 2006. Present-day atmospheric simulations using GISS ModelE: Comparison to in situ, satellite, and reanalysis data. *Journal of Climate*, *19*(2), pp.153-192.

[35] Collins, W.J., Bellouin, N., Doutriaux-Boucher, M., Gedney, N., Halloran, P., Hinton, T., Hughes, J., Jones, C.D., Joshi, M., Liddicoat, S. and Martin, G., 2011. Development and evaluation of an Earth-System model–HadGEM2. *Geoscientific Model Development*, *4*(4), pp.1051-1075.

[36] Davies, T., Cullen, M.J., Malcolm, A.J., Mawson, M.H., Staniforth, A., White, A.A. and Wood, N., 2005. A new dynamical core for the Met Office's global and regional modelling of the atmosphere. *Quarterly Journal of the Royal Meteorological Society: A Journal of the Atmospheric Sciences, Applied Meteorology and Physical Oceanography*, *131*(608), pp.1759-1782.

---

[37] Watanabe, M., Suzuki, T., O'ishi, R., Komuro, Y., Watanabe, S., Emori, S., Takemura, T., Chikira, M., Ogura, T., Sekiguchi, M. and Takata, K., 2010. Improved climate simulation by MIROC5: mean states, variability, and climate sensitivity. *Journal of Climate*, *23*(23), pp.6312-6335.

[38] U.S. Environmental Protection Agency. 2017. Multi-model framework for quantitative sectoral impacts analysis: a technical report for the Fourth National Climate Assessment. U.S. Environmental Protection Agency, EPA 430-R-17-001. Available at: https://www.epa.gov/cira/multi-model-framework-quantitative-sectoral-impacts-analysis

[39] Sanderson, B.M., Wehner, M. and Knutti, R., 2017. Skill and independence weighting for multi-model assessments. *Geoscientific Model Development*, *10*(6), pp.2379-2395.

[40] Sanderson, B.M., Wehner, M. and Knutti, R., 2017. Skill and independence weighting for multi-model assessments. *Geoscientific Model Development*, *10*(6), pp.2379-2395.

[41] Sarofim, M.C., Martinich, J., Neumann, J.E., Willwerth, J., Kerrich, Z., Kolian, M., Fant, C. and Hartin, C., 2021. A temperature binning approach for multi-sector climate impact analysis. *Climatic Change*, *165*(1), pp.1-18.

[42] U.S. Bureau of Reclamation, Climate Analytics Group, Climate Central, Lawrence Livermore National Laboratory, Santa Clara University, Scripps Institution of Oceanography, U.S. Army Corps of Engineers, and U.S. Geological Survey, 2016: Downscaled CMIP3 and CMIP5 Climate Projections: Release of Downscaled CMIP5 Climate Projections, Comparison with Preceding Information, and Summary of User Needs. Available online at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/downscaled_climate.pdf. Data available at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/.

[43] University of California San Diego. 2017: LOCA statistical downscaling. Scripps Institution of Oceanography. Available online at http://loca.ucsd.edu/

[44] U.S. Environmental Protection Agency. 2019. Locating and Selecting Scenarios Online, https://lasso.epa.gov/

[45] Oppenheimer, M., Campos, M., Warren, R., Birkmann, J., Luber, G., O'Neill, B., Takahashi, K., Brklacich, M., Semenov, S., Licker, R. and Hsiang, S., 2015. Emergent risks and key vulnerabilities. In *Climate Change 2014 Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects* (pp. 1039-1100). Cambridge University Press.

[46] Sweet, W.V., Kopp, R.E., Weaver, C.P., Obeysekera, J., Horton, R.M., Thieler, E.R. and Zervas, C., 2017. *Global and Regional Sea Level Rise Scenarios for the United States* (No. CO-OPS 083).

[47] Sarofim, M.C., Martinich, J., Neumann, J.E., Willwerth, J., Kerrich, Z., Kolian, M., Fant, C. and Hartin, C., 2021. A temperature binning approach for multi-sector climate impact analysis. *Climatic Change*, *165*(1), pp.1-18.

[48] ICLUS v2 population estimates available at: https://www.epa.gov/gcx/iclus-fourth-national-climate-assessment

[49] U.S. Environmental Protection Agency. 2021. Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. U.S. Environmental Protection Agency, EPA 430-R-21-003.

[50] U.S. Environmental Protection Agency. 2017. Multi-model framework for quantitative sectoral impacts analysis: a technical report for the Fourth National Climate Assessment. U.S. Environmental Protection Agency, EPA 430-R-17-001. Available at: https://www.epa.gov/cira/multi-model-framework-quantitative-sectoral-impacts-analysis

[51] Manson S, Schroeder J, Van Riper D, Kugler T, and Ruggles S. IPUMS National Historical Geographic Information System: Version 15.0 American Community Survey 2014-2018a. Minneapolis, MN: IPUMS. 2020. Note that the NHGIS field codes in Table 3 are unique to IPUMS – ACS table numbers differ from the field codes shown here, but the data are identical.

[52] U.S. Census Bureau. "How the Census Bureau Measures Poverty." Available online at: https://www.census.gov/topics/income-poverty/poverty/guidance/poverty-measures.html

[53] Paltsev, S., Monier, E., Scott, J., Sokolov, A. and Reilly, J., 2015. Integrated economic and climate projections for impact assessment. *Climatic Change*, *131*(1), pp.21-33.

[54] Monier, E., Gao, X., Scott, J.R., Sokolov, A.P. and Schlosser, C.A., 2015. A framework for modeling uncertainty in regional climate change. *Climatic Change*, *131*(1), pp.51-66.

[55] Monier, E., Gao, X., Scott, J.R., Sokolov, A.P. and Schlosser, C.A., 2015. A framework for modeling uncertainty in regional climate change. *Climatic Change*, *131*(1), pp.51-66.

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[56] Mills, D., Jones, R., Carney, K., St Juliana, A., Ready, R., Crimmins, A., Martinich, J., Shouse, K., DeAngelo, B. and Monier, E., 2015. Quantifying and monetizing potential climate change policy impacts on terrestrial ecosystem carbon storage and wildfires in the United States. *Climatic Change*, *131*(1), pp.163-178.

[57] U.S. Environmental Protection Agency. 2003. "Children's Health Valuation Handbook." Available online at: https://www.epa.gov/environmental-economics/childrens-health-valuation-handbook-2003

[58] Huber, V., Schellnhuber, H.J., Arnell, N.W., Frieler, K., Friend, A.D., Gerten, D., Haddeland, I., Kabat, P., Lotze-Campen, H., Lucht, W. and Parry, M., 2014. Climate impact research: beyond patchwork. *Earth System Dynamics*, *5*(2), pp.399-408.

[59] Wear D.N., Prestemon J.P., 2019. Spatiotemporal downscaling of global population and income scenarios for the United States. *PLoS ONE* 14(7): e0219242. https://doi.org/10.1371/journal.pone.0219242 and William H. Frey analysis of U.S. Census Bureau historical population estimates, including 2020-2022 annual estimates released December 22, 2022, available at https://www.brookings.edu/research/new-census-estimates-show-a-tepid-rise-in-u-s-population-growth-buoyed-by-immigration/

[60] Gamble J.L., Balbus J., Berger M., Bouye K., Campbell V., Chief K., Conlon K., Crimmins A., Flanagan B., Gonzalez-Maddux C., Hallisey E., Hutchins S., Jantarasami L., Khoury S., Kiefer M., Kolling J., Lynn K., Manangan A., McDonald M., Morello-Frosch R., Redsteer M.H., Sheffield P., Thigpen Tart K., Watson J., Whyte K.P., and Wolkin A.F., 2016. Ch. 9: Populations of Concern. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* U.S. Global Change Research Program, Washington, DC, 247–286.