METHODOLOGY

Climate Projections

*Temperature data*

The climate projection methodology is described in full in Rasmussen et al. (2016). The climate projections shown are based on Representative Concentration Pathway (RCP) 4.5 and 8.5 (van Vuuren et al., 2012) experiments run by global climate models participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5) exercise (Taylor et al., 2012). RCP 4.5 represents a moderate scenario, in which countries achieve their current pledges to the Paris Agreement and global greenhouse gas emissions peak around mid-century, while RCP 8.5 represents a scenario in which global emissions continue to climb to high levels for the rest of the century. The Climate Impact Lab used downscaled CMIP5 climate projections prepared by the US Bureau of Reclamation (Brekke et al., 2013). This dataset is bias-corrected and downscaled using the Bias-Correction Spatial Disaggregation (BCSD) method (Thrasher et al., 2012).

CMIP5 projections do not inherently constitute a probability distribution; rather, they are an ensemble of runs conducted by climate modeling teams participating on a voluntary basis and running models that roughly represent ‘best-estimate’ projections of climate behavior. To produce a probabilistic ensemble that captures the full range of climate responses to greenhouse gas emissions, the Climate Impact Lab used the Surrogate Model/Mixed Ensemble (SMME) method of Rasmussen et al. (2016). This method weights projections by comparing their global mean surface temperature projections to those of a probabilistic simple climate model, in this case (as in Rasmussen et al., 2016) the MAGICC6 model (Meinshausen et al., 2011). The target global mean temperature distributions for 2080-2099 used were identical to those of Rasmussen et al. (2016). As in that paper, potential temperature outcomes produced by the probabilistic simple climate model but not represented within the downscaled CMIP5 dataset were represented by simulated ‘model surrogates’, produced using linear pattern scaling. Pattern scaling involves computing a statistical relationship between global average temperature change and local temperature change around the globe in select global climate models, which is used to develop a distribution of high-resolution daily climate variables.

The gridded projections were aggregated to regional estimates by first transforming the daily min, average, or maximum temperature at the grid scale, then aggregating to regions using a weighted average. Annual average temperatures are weighted using the shares of each region’s land area within each grid cell; estimates of days above 95°F/35°C and below 32°F/0°C are weighted using the shares of each region’s population within each grid cell.

The Climate Impact Lab’s future research priorities include updating this climate information to be consistent with the most recent cycle of the Coupled Model Intercomparison Project (CMIP6). As part of CMIP6, the Intergovernmental Panel on Climate Change developed a novel
tool for flexible spatial and temporal analyses of much of the observed and projected climate change information underpinning its Sixth Assessment Report. Visit the Interactive Atlas and explore the latest CMIP6 climate data: https://interactive-atlas.ipcc.ch/

Sea level rise data

The sea level rise projections presented here are based on three emissions scenarios used in the Sixth Coupled Model Intercomparison Project (CMIP6) modeling effort (SSP1-2.6, SSP2-4.5, SSP5-8.5). These emissions scenarios drive probabilistic sea level projections using the Framework for Assessing Changes To Sea Level (FACTS, Kopp et al., 2023) model. The sea level rise projections utilized here are sourced from the publicly available repository of the Intergovernmental Panel on Climate Change’s Sixth Assessment Report (AR6) (Garner et al., 2021), which provides a foundation for the sea level rise forecasts in AR6 (Fox-Kemper et al., 2021). Given the deep uncertainty surrounding the physical processes influencing future sea level rise, multiple probabilistic projections are generated from FACTS for each emissions scenario. These projections reflect different assumptions about the underlying physical processes affecting sea levels. The IPCC classifies these diverse distributions into two categories: low confidence and medium confidence, reflecting scientists’ relative confidence in the assumptions of underlying physical processes.

We present results for the medium confidence group. These projections do not incorporate deeply uncertain physical processes, such as marine ice cliff instability, which could have substantial impacts on future sea levels, especially in higher-emission scenarios. The scientific community has limited consensus on these processes, and hence, they are represented in the low-confidence AR6 projections. These low-confidence projections forecast higher end-of-century global mean sea level rise compared to their medium-confidence counterparts, particularly for high emissions scenarios. For a comprehensive visualization of sea level rise projection data for both medium and low confidence scenarios, visit the NASA Sea Level Projection Tool: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool

Each sea level projection contains a Monte Carlo sampling of a distribution of local sea level rise projections, accounting for varied effects along coastlines due to ocean dynamics, the gravitational and rotational effects of changes in land ice and land water, and non-climate factors such land elevation changes due to tectonic activity or subsurface water extraction. Local sea level, as measured by tide stations, refers to the height of the water measured along the coast relative to a specific point on land. The platform illustrates a world where all regions experience the median projected relative sea level rise from the IPCC AR6 medium confidence probability distributions, aiming to highlight differences between emissions scenarios. However, realized trends will inevitably vary globally, with sea surfaces changing more or less than the median projection.
The Climate Impact Lab aggregated the IPCC sea level rise projections for a set of global coastal segments, described in Depsky et al. (2023), to coastal and low-lying regions. Reported sea level rise heights represent a coastline-length weighted average of projected sea level rise for each region. In reality, relative sea level change will vary within a region, especially in regions with long coastlines.

**Damage Projections**

**Mortality impacts**

The methodology for estimating the mortality impacts of future climate change is described in full in Carleton et al. (2022). This study uses comprehensive historical mortality records to quantify how death rates across the globe have been affected by observed weather variation. Carleton et al. (2022) compile the largest sub-national vital statistics database in the world, detailing hundreds of millions of deaths across 40 countries accounting for 38 percent of the global population. By combining these records with decades of daily and local temperature observations, the authors show that extreme cold and extreme heat have important effects on death rates, consistent with prior epidemiological and econometric evidence covering more limited regions. These relationships are then found to be strongly modified by the existing climate and income levels of the affected population. For example, higher incomes and warmer average climates correspond to lower death risks of heat. Carleton et al. (2022) use these results to develop a statistical model quantifying how observed levels of adaptation influence the sensitivity of a population to extreme temperatures.

Estimates of the mortality-temperature relationship are used to generate projections of the future impacts of climate change on mortality rates for areas across the globe, dividing the world into 24,378 distinct regions (each containing, on average, 300,000 people). Using a revealed preference technique to additionally measure the total cost of adaptive behaviors and technologies, these projections capture the full mortality risk of climate change, accounting for both adaptation costs and direct mortality impacts shown in the platform.

Here we present climate change’s estimated impact on mortality rates based on emissions scenarios RCP 4.5 and RCP 8.5, socioeconomic scenario SSP3 (from the IIASA Shared Socioeconomic Pathways database) and using climate model-weighted means over 33 climate models and 1,000 Monte Carlo simulation runs, allowing for an assessment of the uncertainty surrounding any particular projection. These estimates therefore reflect statistical uncertainty related to the underlying economic and health data as well as climatological uncertainty.

**Energy consumption impacts**

The methodology for estimating the energy consumption impacts of future climate change is fully described in Rode et al. (2021). This study uses comprehensive historical energy consumption data derived from International Energy Agency data files to quantify how a
population’s use of electricity and other fuels (for example, natural gas, oil, and coal) energy consumption responds to climate changes. The authors utilize the World Energy Balances dataset of the International Energy Agency, which describes electricity and direct fuel consumption across residential, commercial, industrial, and agricultural end-uses in 146 countries during 1971-2010.

By combining these records with decades of detailed daily and local temperature observations, the authors discover that extreme cold and extreme heat have important effects on energy consumption. These relationships differ by energy type (electricity, other fuels) and are modified by the income levels and climate of the affected population. The study uses these results to model how income growth and adaptation affect the sensitivity of energy consumption to extreme temperatures.

The authors then use these estimates of the energy-temperature relationship to generate projections of the future impacts of climate change on electricity and direct fuel consumption for areas across the globe, dividing the world into 24,378 distinct regions. Each region contains roughly 300,000 people. The projected impacts capture the effects of adaptive behaviors that populations undertake as they become richer and exposed to warmer climates.

Here we present climate change’s estimated impact on energy consumption based on emissions scenarios RCP 4.5 and RCP 8.5, socioeconomic scenario SSP3 (from the IIASA Shared Socioeconomic Pathways database) and using climate model-weighted means over 33 climate models and 1,000 Monte Carlo simulation runs, allowing for an assessment of the uncertainty surrounding any particular projection. These estimates therefore reflect statistical uncertainty related to the underlying economic and health data as well as climatological uncertainty.

**Labor impacts**

The methodology for estimating the labor impacts of future climate change is fully described in Rode et al. (2022). Evidence shows that workers in agriculture, construction, manufacturing, transport, and utilities (i.e., high-risk sectors) reduce their hours worked when outdoor temperatures deviate from average temperatures. This study uses individual work hours data from time-use surveys and labor force surveys for seven countries, representing nearly one-third of the global population, and daily variation in the weather to econometrically evaluate the impact of daily temperature on labor supply. The labor response is estimated to be an inverted U-shaped relationship, with lost labor occurring at extreme hot and cold temperatures for high-risk, weather-exposed sectors. The relationship is similar, though the impacts are smaller in magnitude for low-risk sectors.

The authors then use these estimates of the labor supply-temperature relationship to generate projections of the future impacts of climate change on time spent working in high-risk and low-risk sectors for areas across the globe, dividing the world into 24,378 distinct regions. Each region contains roughly 300,000 people. The projected impacts capture predicted shifts in the
global workforce towards less weather-exposed industries as populations become richer and exposed to warmer climates.

Here we present climate change’s estimated impact on the labor supply based on emissions scenarios RCP 4.5 and RCP 8.5, socioeconomic scenario SSP3 (from the IIASA Shared Socioeconomic Pathways database) and using climate model-weighted means over 33 climate models and 1,000 Monte Carlo simulation runs, allowing for an assessment of the uncertainty surrounding any particular projection. These estimates therefore reflect statistical uncertainty related to the underlying economic and health data as well as climatological uncertainty.

**Sea level rise impacts**

The coastal modeling platform for estimating the sea level rise impacts of future climate change is fully described in Depsky et al. (2023). The platform integrates global data layers incorporating satellite-derived information on coastal land elevations, local sea levels, population distribution, and more. These data layers are projected onto nearly 10,000 unique map segments that span global coastlines and are then modeled independently to evaluate impacts.

Using the platform, the Climate Impact Lab generated projections of the future impacts of sea level rise under a range of climate change scenarios. Each coastal segment is paired to a specific region of coastal land or neighboring low-lying inland region. The impacts shown here are the median of the IPCC AR6 medium-confidence projections. For additional context on these projections, refer to the Sea level rise data section.

Estimates of the share of the population living on land at risk of flooding during extreme events are based on a ‘1-in-20 year flood’. This flood level has a 5% chance of being equaled or exceeded in any year and a nearly 65% chance of occurring during a 20-year period. Local sea level rise caused by climate change is assumed to raise the height of extreme sea levels during a ‘1-in-20 year flood,’ expanding the floodplain to expose a greater share of the population to the risk of flooding. Information about present-day spatial distribution of population along coasts comes from LandScan 2021 (Sims et al., 2022), which is overlaid on elevation data coming primarily from a digital elevation model with a horizontal resolution of 30 meters (Kulp and Strauss, 2021). Depsky et al. (2023) employs a hydraulic connectivity model to prevent erroneous flooding in low-lying inland regions that are protected by higher elevation. Nevertheless, certain low-elevation locations are treated as having no physical barrier between them and the open water, potentially overestimating the likelihood of flooding in these areas.

Estimates of how much land will be lost to permanent inundation are based on projections of local mean sea level along global coastlines. Local sea level refers to the height of the water as measured along the coast relative to a specific point on land, accounting for changes in both the vertical water and land that are caused by differences in geography and gravity. The projected mean sea level is computed over a 20-year period at a 1-degree spatial resolution.
Notably, projections of sea level rise impacts are made relative to a counterfactual scenario. In this scenario climate-driven sea level rise is absent but non-climatic local vertical land motion continues. The results displayed on the platform are obtained by subtracting the projections in this “no climate change” counterfactual world from those in the “with climate change” projections.

While the projections represent the best available observations and projections of sea levels at a global scale, the estimated impacts reflect some data limitations. They should be used as a guide for deeper investigation of local risks, which often require consideration of fine-scale socioeconomic and physical characteristics. For instance, existing coastal protections, such as seawalls, dams, or levees, are not directly considered, nor are a broader array of protection options, such as mangrove restoration and other nature-based solutions. Additionally, the model does not account for potential future coastal protections or relocation strategies in response to sea level rise.

References


