Climate Change Projections & Scenario Update

District of Columbia

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Table of Contents

Executive Summary

The 2015 District of Columbia Climate Adaptation Plan provided an integrated analysis of existing climate change data, an assessment of the District's vulnerable assets, and a risk based, prioritized, plan for adaptation and resilience. Climate change projections used in the report, enabled the District to assess its vulnerabilities and risks today and into the future. **This report includes updated data points using the best available, publicly accessible climate projections** to provide District agencies a common set of climate indicators that can be used to inform decision-making.

This report utilizes the latest information on sea level rise (SLR), increasing precipitation, and extreme heat. This report considers data from a higher emissions scenario (RCP8.5, as defined by CMIP5) and lower emissions scenario (RCP4.5). Respectively, this report will refer to RCP8.5 as the worst-case scenario and RCP4.5 as the likely scenario. This report relies on publicly available, pre-processed indicators. Additionally, the initial planning horizon has shifted to the 2030s to allow the District time to incorporate near-term projections; previous planning horizons (2050s and 2080s) have been retained from the 2015 report.

Key findings in this report illuminate the following trends for the District:

- **Annual average and summer temperatures will continue to increase.**
    - During the historical baseline period 1991-2010, there were an average of ~9 days per year exceeding 95°F. Projections based on likely and worst-case climate scenarios range from 22-24 days per year with temperatures exceeding 95°F by 2030 to as much as 36-67 days per year by 2080.
    - During the historical baseline period, DC averaged less than one day above 100°F annually. By 2030, 5-6 days over 100°F are expected annually.

- **Heat waves will become more intense and will last for longer periods of time.**
    - In the coming decades, the frequency of extreme heat events is expected to nearly quadruple by the 2080s in the likely scenario and 75% of the summer could exceed 95°F in the worst-case scenario.
    - Heatwave intensities will grow, in 2000 the average temperature during a heatwave was 95°F, by 2080 the District will experience a heatwave average temperature range of 97-99°F.

- **The frequency and intensity of extreme precipitation events are expected to increase.**
    - More intense storms of shorter duration will add stress to natural, built, and social systems and will increase the likelihood of flooding.
    - Atlas 14, a record of precipitation frequency estimates for the United States produced by the National Weather Service (NWS) and the most widely-accepted national resource for determining stormwater design standards, is now regarded as out-of-date. Standards and codes based on this resource should be updated using the projections in this report.

- **Sea level rise will accelerate due to global ice sheet melting.**
    - Relative sea level rise projections for the District range from 1.1 to 1.7 feet by 2050 and 1.6 to 4.4 feet by 2080.

    - Relative sea level rise projections for the District through 2080 included in this report are between 19-60% higher than those included in the 2015 report.

- **Local sea level rise rates are higher than global rates, in part due to land subsidence** . The District is projected to sink half a foot or more in the next 100 years due to natural and human causes.

The report is organized into four key sections. The Background section explains why an update to the 2015 analysis is needed and how the District currently makes use of climate projections. The Methods section provides an overview of the project scope, planning horizons, scenarios, and constraints and limitations. The Updated Change Projections section provides a deep dive into the findings for three hazards that have significant impacts on the District: extreme heat, increasing precipitation, and sea level rise. Finally, the Future Updates section provides suggestions for ways District-specific climate indicators could be improved in future updates.

Acronyms

DOEE	District of Columbia Department of Energy and Environment
GSLR	Global Sea Level Rise
HMP	Hazard Mitigation Plan
HSEMA	DC Homeland Security and Emergency Management Agency
IDF	Intensity-Duration-Frequency
IPCC	Intergovernmental Panel on Climate Change
NCA	National Climate Assessment
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
RCP	Representative Concentration Pathways
RSLR	Relative Sea Level Rise
SLR	Sea Level Rise
USACE	United States Army Corp of Engineers

Definitions

Heat Waves	A prolonged period of unusually high temperatures. In this report a heat wave is defined as three or more consecutive days with a daily maximum heat index value above 95°F.
Net Zero	A target of completely negating the amount of greenhouse gasses produced by human activity. Achieved by reducing emissions and implementing methods of absorbing carbon dioxide from the atmosphere.
Planning Horizons	Planning horizons are the span of years over which climate change projections are analyzed.
Radiative Forcing	A measure of the Earth's energy balance. It is affected by greenhouse gas and aerosol concentrations, changes in land cover, and solar energy.
Representative Concentration Pathways	Representative concentration pathways (RCPs) are scenarios used to help characterize the uncertainty in emissions trajectories. Defined on the basis of radiative forcing pathways and level in 2100.
Climate Change	Climate change refers to long-term shifts in temperatures and weather patterns.
Sea Level Rise	The average increase in the water level of the Earth's oceans.
Greenhouse Gas Emissions	Gasses that trap heat in the atmosphere, which include carbon dioxide, methane, nitrous oxide, and fluorinated gasses.
Cooling Degree Day	A measure of how hot the temperature was on a given day or during a period of days. A day with a mean temperature of 80°F has 15 CDDs. If the next day has a mean temperature of 83°F, it has 18 CDDs. The total CDDs for the two days is 33 CDDs.

Introduction

Purpose

This report represents the best climate science using publicly accessible, freely-available resources, based on guidance from the District of Columbia. It is intended to serve as a benchmark for District agencies, partners, and decision-makers in their climate adaptation and resilience planning and implementation for the next five years.

Background

Scientists have continued to advance climate science knowledge at a variety of scales since the District first developed its own climate projections. New theoretical frameworks have been tested, new climate measurements have been collected from Earth observation networks, and new climate simulations are being conducted on supercomputers. These updates were recently distilled through a consensus process and documented in the sixth assessment report coordinated by the Intergovernmental Panel on Climate Change (IPCC). The IPCC's scientific working groups estimate that a worst-case end of century warming on the order of 4-5°C has a low chance of occurring, with likely peak warming now estimated to be between 2-3°C.[1] While estimates of peak warming have decreased, estimates of climate damages at all levels of warming have increased.[2] Recent climate observations continue to fall within the bounds of past climate model projections, underscoring their utility for short- and long-term planning.[3] Therefore, as climate science knowledge continues to accrue, planners and policy makers should integrate new and refined projections into projects, programs, and standards to ensure climate resilience.

It is now widely accepted that even 'low' warming levels of 1.5 or 2.0°C will be dangerous for all parts of the globe. If global warming reaches 2.0°C, NASA estimates that "more than 70 percent of Earth's coastlines will see sea-level rise greater than 0.66 feet, resulting in increased coastal flooding, beach erosion, salinization of water supplies and other impacts on humans and ecological systems."[4] Climate change is already exacerbating a variety of hazards, including extreme heat, extreme precipitation, flooding, drought, wildfire, sea level rise, tropical storms, and more at 1.3°C warming and will worsen for each fraction of a degree the planet warms.

Critical infrastructure such as drainage and sewer systems, transportation systems, and power supply were not designed for the projected wider variability of future climate conditions creating

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[1] IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*[Masson-Delmotte V, et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp., doi: 10.1017/9781009157896.

[2] IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Pörtner H-O, et al. (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi: 10.1017/9781009325844.

[3] Hausfather Z, Drake HF, Abbott T, & Schmidt GA (2020). Evaluating the performance of past climate model projections. *Geophysical Research Letters*, **47**, e2019GL085378. doi: 10.1029/2019GL085378.

[4] NASA, A Degree of Concern: Why Global Temperatures Matter. https://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/

a risk and opportunity to improve the resiliency of these systems. Extreme heat is projected to increase the risk of illness and death among older adults, pregnant women, and children. Changes in heat waves are expected to lead to significantly more premature deaths, hospitalizations, and emergency department visits. The Fourth National Climate Assessment provides a national and regional overview of the key impacts to the U.S. and the Northeast. See Appendix A for more information on projected impacts to the Northeast including its industries, infrastructure, and human wellbeing.

For the District, climate change is already having significant implications for its built, natural, social, and economic systems. Changing seasonal patterns are projected to impact key industries for the District including tourism, recreation, and urban agriculture.[5] Notably, these impacts are being disproportionately experienced by frontline communities (those impacted first and worst by a changing climate).[6] Frontline communities are often more exposed to climate hazards, are more sensitive to extreme events, and have a lower ability to bounce back.

The District's Climate Adaptation and Resilience Planning

There are over 80 District agencies that develop capital expenditure, operation, and performance plans on a regular basis. To help agencies incorporate climate projections into their plans, the District Department of Energy and Environment (DOEE) has published multiple reports and resources that identify key climate indices, risks, and adaptation strategies.

In 2016, the District of Columbia released their first Climate Adaptation Plan as part of a multi-phase project led by DOEE. Informed by the Vulnerability and Risk Assessment (2016) and Climate Projections & Scenario Development (2015) reports, the District of Columbia Climate Adaptation Plan was the first major step towards aligning strategic climate change preparedness priorities within programs, projects, and planning efforts across District agencies. The Climate Projections & Scenario Development report (2015) enabled agencies and local utilities to begin to use a common set of language, planning parameters, and climate hazard indicators in their near-, mid-, and long-term planning efforts. To date, the District of Columbia's key climate planning and implementation frameworks include:

- The 2015 Climate Projections & Scenario Development report identifies the likely impacts of climate change on the District of Columbia.
- The 2016 Vulnerability and Risk Assessment evaluates the vulnerability of District infrastructure, public facilities, and populations to those climate change impacts.

[5] USGCRP (2018) Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: [Reidmiller DR, et al. (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

[6] Frontline communities may include (but are not limited to) Black, brown, and Indigenous communities, immigrants, women, older adults, youth, those with and experiencing disabilities, individuals experiencing ongoing health issues, low-income communities, rural communities, LGBTQIA+ individuals, English as a Second Language (ESL) communities, the unhoused, individuals who do not have access to transportation, and individuals who lack access to television, radio, internet, and/or phone service.

- The 2016 District of Columbia Climate Adaptation Plan summarizes the analyses and recommendations for climate change adaptation that inform Climate Ready DC, the District of Columbia's Plan to Adapt to a Changing Climate.
- The 2016 Climate Ready DC Plan provides an overview of the District's climate change risk and adaptation strategy for improving resilience to climate change, with a focus on extreme heat, increasing precipitation, and sea level rise.
- The 2021 Resilient Design Guidelines provides a methodology for conducting a climate resilience needs assessment and suggests steps for planning, designing, and constructing projects to support resilient outcomes in the built environment.
- The 2022 Heat Sensitivity-Exposure Index Methodology Report provides a heat sensitivity and exposure indexing assessment including a series of heat risk index maps.
- The 2022 Keep Cool DC outlines the Districts adaptation strategy for extreme heat.
- The forthcoming 2023 District Hazard Mitigation Plan provides a guide for District agencies on how to identify risks within the District profile environments, communicate vulnerabilities, develop priorities, and inform decision-making for both the hazard mitigation plan and for other emergency management efforts.

In addition, the intersectionality of the climate crisis across a variety of issue areas requires that planners and policymakers take a holistic approach. Frameworks, guidelines, and planning documents that also inform the District's overarching climate adaptation and resilience planning include:

- The Resilient DC Strategy is a strategy to confront the complex challenges of the 21st century, including but not limited to climate change.
- The 2021 DOEE Equity Framework provides guidelines for how DOEE and partner agencies should incorporate equity considerations into key processes and equitably implement climate action; build resiliency; and provide national leadership on how equity can play a central role in climate and environment-focused project processes.
- The 2023-2025 District Racial Equity Action Plan maps out steps the District will take to reduce inequities and improve life for all residents.

Goals

The goal of this report is to assist District agencies in developing a common set of climate indicators based on the latest and best available science that can be used by the District agencies in future planning and implementation efforts. In addition, this report summarizes steps the District and its agencies can take to ensure the research organizations developing the metrics are taking the collective needs of the District agencies into account when developing future updates.

Methods

Scope

The project team reviewed the projected climate indicators, data sources, and baselines used to establish the District's 2015 climate change adaptation plan.[7] The team then proposed revised sources and metrics as appropriate in a memo titled 'District of Columbia's Climate Change Projections and Risk Assessments: Recommendations'. If the existing data source remained the best available per the latest scientific research, the team recommended the same source and indicator be used. However, if a more accurate or appropriate indicator, model, or time period had been identified between 2015 and 2023, the team recommended a revision to the source and/or indicator and provided justification for the revision. The scope of the evaluation included:

- Climate scenarios
- Data sources or models
- Baseline period
- Planning horizon
- Climate indicators

The team limited the evaluation to publicly available and easy to interpret data sources and models, knowing the District and its partner agencies may wish to access the sources in the future to update the metrics without external support. The scope climate hazards included:

- Extreme heat
- Increasing precipitation
- Sea level rise

These three hazards are fundamental in terms of causing impacts on people and infrastructure as well as driving other cascading hazards like sewer overflows and electrical grid stability. Other hazards that the District faces are covered in HSEMA's forthcoming District Hazard Mitigation Plan (e.g. flooding, hurricanes, severe storms, drought, extreme cold). DOEE is also currently completing the first District-wide Integrated Flood Model, which will identify future flood extent.

Scales of Analysis

Where available, this report references climate model outputs at the finest spatial scale focused on the District of Columbia [**Figure 1**]. Instrumental observations are intrinsically limited to one point in space representing the District as a whole (e.g. Washington Channel tide gauge, Reagan National airport). Gridded observations and downscaled climate model output referenced in this report have square grid cells 2.5 miles on a side, which results in 11 grid cells across the District. Because climate projections do not vary significantly within the District boundaries, gridded observations and climate model output are averaged spatially across the District (i.e. resulting in one spatial data point to represent the District as a whole).

[7] Climate Projections & Scenario Development: Climate Change Adaptation Plan for the District of Columbia. RFA: 2013-9-OPS. https://doee.dc.gov/publication/climate-projections-scenario-development

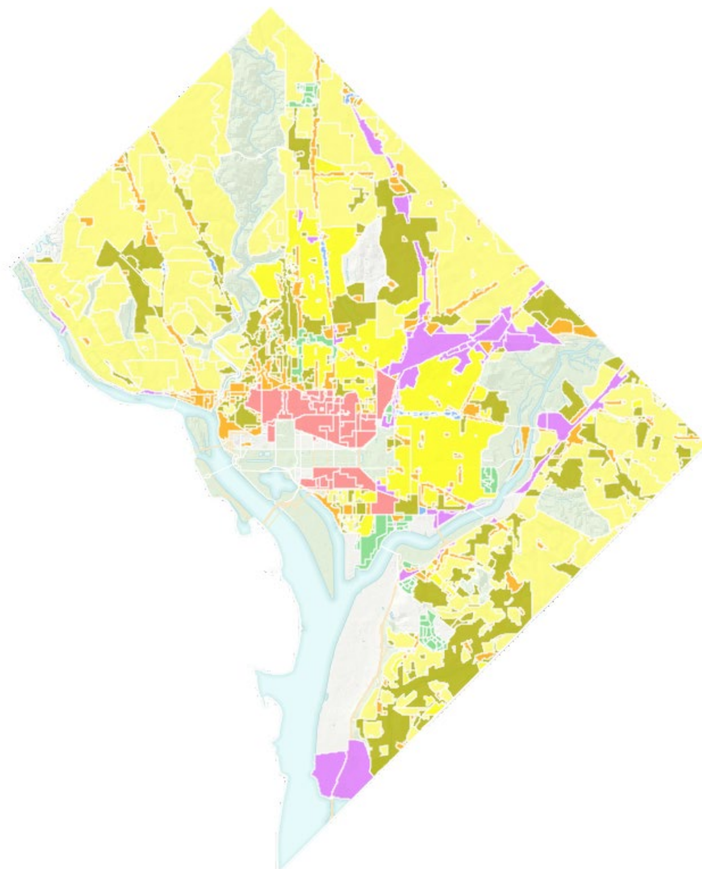

Figure 1. District of Columbia zoning map. Source: Washington DC Office of Zoning.

Planning Horizons and Historical Baseline

The 2015 Climate Projections & Scenarios report used a 20-year planning horizon across three timeframes, including the 2020s (2015 through 2034), the 2050s (2045 through 2064), and the 2080s (2075 through 2094). Planning horizons are the span of years over which climate change projections are analyzed. For storm projections, a 31-year planning horizon was used to match the methodology used previously by the District. Historical baselines allow future changes to be communicated relative to recent experience (e.g. 2°F warmer than the 1990s). The 2015 report used a 20-year historical baseline centered on 1990 (1981 through 2000) to represent future changes, except for the extreme heat projections, which used a different historical baseline due to data limitations associated with humidity observation.

The 2015 report used a 20-year averaging period in order to balance two competing needs. The first was the need for a shorter period to accurately capture the rate of climate change as well as the differences between conditions at the beginning versus the end of the same period. Too short of a period would result in an exaggerated influence of year-to-year variability. Too long of a period would result in muted differences between planning horizons. Therefore, 20 years was selected to balance these two competing needs. For this update the project team maintained the 20-year averaging period by shifting the historical reference period and the first planning horizon forward in time by ten years and left the remaining two planning horizons unchanged. Revised 20-year planning horizons center on the decades 2030s (2025 through 2044), 2050s (2045 through 2064), and 2080s (2075 through 2094). Future changes are calculated relative to a revised historical reference period centered on 2000 (1991 through 2010). For precipitation frequency projections, two 50-year planning horizons were used due to limitations in the publicly available resources. The precipitation frequency planning horizons centered on the year 2045 (2020 through 2070) and 2075 (2050 through 2100). Sea level rise projections have less variability within planning horizons so we list data for the years 2030, 2050, and 2080.

The 2020 timeframe is here, changes in climate are already apparent and adaptation is necessary. To better inform how action taken now can prepare for the immediate future, this report pushes the near-term horizon to the 2030s. Retaining the 2050s and 2080s as longer-term perspectives aligns well with the life expectancy of built infrastructure and the intrinsically long-range character of climate projections.

Scenarios

The exact amount of greenhouse gasses that humans will emit over the next century is unknown, therefore climate scientists create projections from models using a range of scenarios based on plausible societal responses to climate change (and other factors). These scenarios, also known as Representative Concentration Pathways (RCPs) describe potential future trajectories of GHG emissions to capture the complex relationships between policy decisions, human behavior, global population growth, economic factors, technological advancements, and global temperature changes. By exploring multiple scenarios with a range of climate forcings, scientists can provide a range of projected changes to climate hazards (e.g., # of projected extreme heat days per year, inches of extreme precipitation events, etc.) for the District.

The District's 2015 Climate Projections were based on two different climate scenarios that depict diverging choices by human society: one where annual global greenhouse gas emissions continue to increase through the year 2100 (worst case scenario) and one where annual global greenhouse gas emissions plateau by the year 2050 and decline thereafter (likely scenario).

The data points from the 2015 climate projections were drawn from simulations included in the Climate Model Intercomparison Project's fifth phase (CMIP5).[8] The report's authors included output from 9 different climate models. Whereas the previous report's authors did their own statistical downscaling of global climate model output to the District of Columbia, for this update the project team relied on datasets and tools that are publicly available. For details, see attachment #1 "District of Columbia's Climate Projections and Risk Assessments: Recommendations." In this 2023 update with new and revised climate projections, the number of models were increased to between 18 and 32 depending on climate indicator. This is because different indicators are determined from different climate data tools, each with their own methods.

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[8] See 'constraints and limitations' subsection below for information on CMIP6, the latest set of global climate projections at the time of this report's publication.

In this 2023 update, the use of both climate scenarios previously considered (likely and worst case) were retained. This choice was made because those scenarios have been widely adopted by publicly available climate data tools.

Uncertainty

Projections based on a range of climate scenarios capture a range of possible futures. This allows policymakers and planners to calibrate their policies, plans, and actions to differing risk levels. Whereas RCP8.5 was previously considered a default "business-as-usual" scenario, RCP8.5 is now widely considered to be a "worst case scenario" that society has likely avoided through investments in greenhouse gas emissions reductions across multiple economic sectors.[9] The project team recommends that planners use RCP4.5 as the most likely scenario and RCP8.5 as the worst-case scenario. In some cases, it may be most cost effective to plan around the most likely scenario, whereas in others it may be prudent to forge resilience for a worst-case scenario.

Even as certainty in higher climate damages at lower warming levels has increased, confidence has decreased that standard methods are properly capturing climate risk. This uncertainty comes from many sources:

- **Climate models–the main tools used to assess future climate change–simulate less intense thunderstorm rainfall than what is experienced in the real world.** This means climate model projections of future warming-enhanced extreme precipitation must be interpreted conservatively.
- **Knowledge of fundamental climate processes like ice-shelf dynamics, ecosystem- and soil-climate feedbacks, and deep ocean circulation continue to have large gaps.** The odds of sudden, dramatic shifts in regional and global climate, while small, cannot be ruled out.
- **Recent extreme weather events – e.g. the 2021 Pacific Northwest heatwave and the flooding rains of Hurricane Harvey in 2017 – have made scientists wonder if the risk of low-probability extreme weather events is being systematically underestimated.** It is possible that both climate models and common techniques used to evaluate climate risk do not fully capture singular extreme weather events. Cutting edge techniques are being developed to better quantify the risks of these "black swans", but it may be years before this research provides actionable analyses.

Within the planning horizons there are irreducible uncertainties in climate projections that can be assessed through the use of collections of climate simulations that scientists refer to as ensembles. The minimum to maximum range of climate change projections represented in ensembles should be scrutinized as closely as average or median estimates. Natural climate variability superimposed onto the global warming trend means that heat waves, storms, or droughts one might on average expect to occur much later this century could happen sooner as an extreme event. Extreme weather events from the past and in similar cities may provide warning that the modern climate exists in a rapidly evolving envelope of possibility.

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[9] Hausfather Z, and Peters GP (2020) Emissions–the 'business-as-usual' story is misleading. *Nature* **577**, 618-620 doi: 10.1038/d41586-020-00177-3

Constraints and Limitations

The projections described in this report represent the District of Columbia as a whole based on point data like gauge locations (e.g. Washington Channel tide gauge) or area-averages across District boundaries from gridded datasets that use uniformly sized grid cells to represent data. In other words, the projections do not represent spatial differences across the District. This is not a serious limitation because climate change is expected to be spatially consistent across the relatively small area of the District. Neighborhood to neighborhood differences in the average climate are driven less by global climate dynamics and more by local land use / land use change typically associated with the urban heat island effect.

For the 2015 climate projection and scenario development report a climate science consultant processed raw data into DC-specific climate indicators. For this update, the District preferred to use readily available climate indicators from public sources rather than indicators that require specialized processing. Therefore, proprietary or commercial options, which can provide more location-specific projections, were not utilized for the development of this report.

The sixth generation of climate model intercomparison (CMIP6) includes projections used in the IPCC's Sixth Assessment Report (AR6) published between 2021-2023. CMIP6 simulations were shared between 2019 and 2022 and were included in climate research studies beginning in 2020. Downscaling is a process that cannot start until model projections are available, so downscaled versions of CMIP6 did not appear until late 2022. The downscaling method used in Climate Explorer, LOCA, only made its CMIP6 dataset available in 2023 (called LOCAv2). Public data tools using downscaled CMIP6 data could be released in 1-3 years depending on funding.

New data tools based on CMIP6 data may show modest refinements over the versions based on CMIP5. Outside of the scenario nomenclature, CMIP6 is not radically different from CMIP5. Downscaling methods like LOCA have received significant upgrades since the CMIP5 cycle but it is unclear if that will make a significant improvement to climate model trends, extremes, and uncertainty at the local level. Incorporating CMIP6 data into District planning is nontrivial. The District could incorporate CMIP6 projections in one of three ways: (1) wait for a data tool like Climate Explorer to make a new version using CMIP6 data, (2) hire a company that can download and process existing downscaled data (like LOCAv2 or BCCAv2) or (3) hire a company to make a custom downscaled dataset as was done in the 2015 report. (1) is dependent on outside factors while (2) and (3) would require significantly more money and effort than this 2023 update.

Updating sea level rise projections will be simpler. Sea level rise projections are done in a significantly different way than extreme heat and precipitation metrics and are created more promptly relative to the CMIP cycle detailed above. This 2023 update used the 2022 Interagency Sea Level Rise Technical Report which will likely be updated before the end of this decade using the latest science. The District can monitor this process and incorporate the new projections when they are published.

Updated Climate Change Projections for the District

Extreme Heat

Overview

The increasing severity, duration, and frequency of extreme heat events in the District of Columbia due to climate change represents a pressing public health and infrastructure challenge that requires immediate, near-, mid-, and long-term action. Rising global temperatures are expected to substantially amplify the frequency, duration, and intensity of heatwaves in the region. These extreme heat conditions pose serious safety and health risks to frontline communities, strain electrical grids due to increased demand for air conditioning, and can result in economic losses across economic sectors, among other things. Furthermore, the "urban heat island" effect—whereby more densely developed areas trap more heat than surrounding rural and more vegetated areas—creates spatial disparities across the District, making localized strategies essential for mitigation and adaptation. Given the multi-dimensional implications of extreme heat events, it's crucial to adopt holistic approaches to adaptation and resilience that integrate scientific research, technology deployment, policy reform, and community engagement to build resilience against extreme heat.

Seven indicators were used in the District's 2015 climate projections report to characterize extreme heat, of which only one (no. 3) was able to be replicated from publicly available climate tools. For the remainder, publicly available substitutes were found or were derived directly from downscaled datasets.

1. Average summertime maximum temperature
2. Average summertime minimum temperature
3. Days per year with a maximum temperature above 95°F
4. Days per year with a maximum heat index above 95°F
5. Heat waves per year lasting at least 3 days
6. Average heat wave length
7. Heat waves per year as or more extreme than the 2012 District of Columbia heatwave

Method

For extreme heat indicators 1-3, NOAA's Climate Explorer is recommended. While average summertime temperatures are unavailable, Climate Explorer does have average annual temperatures, an indicator that conveys similar information.

Three indicators produced by Climate Explorer that did not appear in the 2015 report are included in this update. Days per year over 100°F, nights per year with a minimum temperature above 80°F, annual cooling degree days, and days per year below 32°F. Annual cooling degree days (CDDs) are the sum of average temperatures above 65°F. Cooling degree days are correlated with the energy demand of air conditioning, with more cooling degree days being associated with higher temperatures and higher electricity bills.[10] Days per year above 100°F measures a different type of risk than days above 95°F: even in the past multiple days over 95°F were expected every year. Ten to twenty days a year over 100°F were not. Nights over 80°F are a measure of dangerous nighttime heat, a cause of mortality even absent extreme daytime temperatures.[11] Days per year below 32°F are a measure of dangerous cold exposure, a risk that is expected to decrease in the future.

Extreme heat indicators 4-7 were not available in public climate tools. Tools like Climate Explorer are built to be universally useful and in doing so miss these types of detailed District-specific indicators. While the authors of the 2015 report created their own downscaled climate data from scratch, there are now multiple publicly available downscaled datasets to choose from. Cadmus and Two Degrees Adapt used two publicly available climate datasets, Multivariate Adaptive Constructed Analogs Version 2 (MACAv2) and gridMET to update these indicators.[12,13] Time series of daily maximum temperature, minimum temperature, relative humidity, and wind speed for Washington, D.C. were constructed by averaging the 11 grid cells covering the District. A heat wave is defined as at least 3 consecutive days with a heat index above 95°F. A "severe heatwave" is defined as at least 5 consecutive days with daily maximum temperature above 100°F–a threshold that was crossed only once in the historical gridMET dataset during the summer of 2012. The changing character of heatwaves is evaluated through four indicators: number of heatwaves per year, average length of heatwaves, daily maximum temperature during heat waves, and daily minimum temperature during heat waves.

Climate Change Indicators

Average Temperatures

By the 2050s, the District will experience an annual average temperature increase by 3-5°F from 2000 average temperatures. A consistent baseline period was used for each extreme heat indicator. For baseline conditions (1991-2010), the annual average maximum temperature in the District was 67°F and the annual average minimum temperature in the District was 47°F [**Table 1**]. These are both expected to rise with global warming [**Figure 2**] at different rates depending on which emissions scenario is being used. The likely scenario shows a gradual slowing of the warming trend, assuming emissions peak and decrease after mid-century. The worst-case scenario shows steady warming through the end of the century. Projections show that annual average temperatures are expected to rise by between 5-9°F between circa 2000 and 2080s [**Table 1**]. This update is consistent with the 2015 projections.

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[10] U.S. Energy Information Administration: "Degree Days." Accessed September 2023.

[11] Kim SE, et al. (2023) Mortality Risk of Hot Nights: A Nationwide Population-Based Retrospective Study in Japan *Env. Heal. Per.* **131** 057005 doi: 10.1289/EHP11444

[12] Abatzoglou JT (2013) Development of gridded surface meteorological data for ecological applications and modeling *Int. J. Climatol*. **33** 121–131 doi: 10.1002/joc.3413

[13] Abatzoglou JT, and Brown TJ (2012) A comparison of statistical downscaling methods suited for wildfire applications *Int. J. Climatol.* **32** 772–780 doi: 10.1002/joc.2312

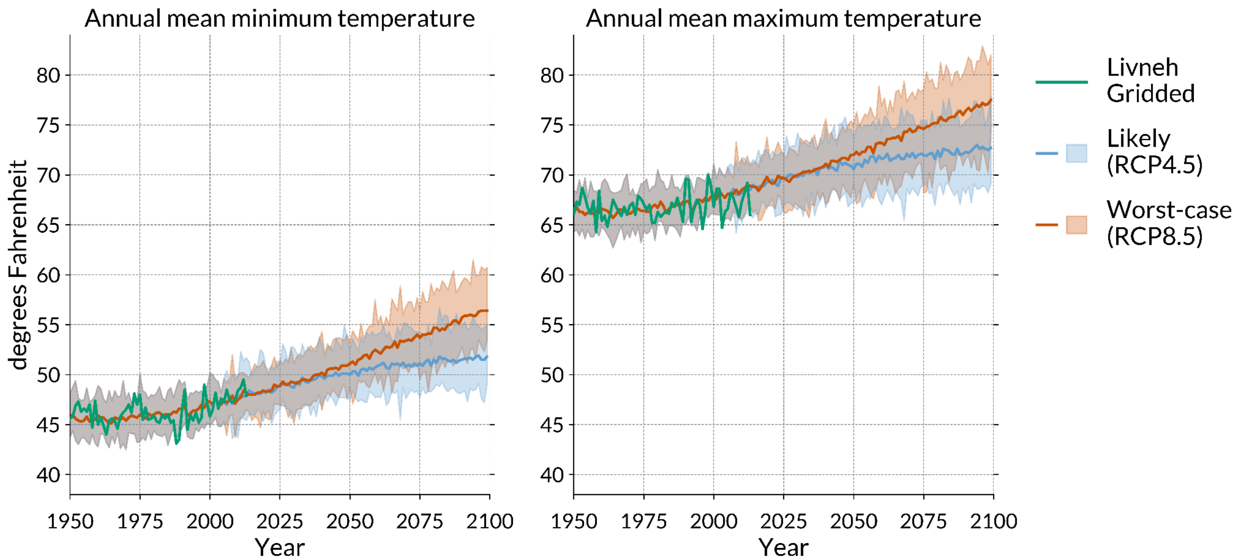


Figure 2. Annual mean minimum temperature ***[left]*** and maximum temperature ***[right]*** for gridded observations (green), a likely scenario in blue (line denotes multi-model mean, shading denotes minimum and maximum model values), and a worst-case scenario in red (line denotes multi-model mean, shading denotes minimum and maximum model values).

Extreme Temperatures

By the 2050s, the District will experience between 30 and 40 days per year of heat over 95°F. Beyond average temperature, temperature extremes also respond to global warming. Days above 95°F [**Figure 3**], 100°F [**Figure 4**], and nights above 80°F [**Figure 5**] all point to an increasing frequency of extreme heat in the District.

The District is already known for sweltering heat, with about 10 days above 95°F annually [**Table 1**]. In the coming decades, the frequency of extreme heat events is expected to increase, doubling by the 2030s and nearly quadrupling by the 2080s in the likely scenario. In the worst-case scenario, nearly 20% of the year or nearly 75% of the summer could exceed 95°F. Time series show this metric increasing in a manner similar to average temperatures for both scenarios [**Figure 2**].

Days above 100°F and nights above 80°F have historically been rare, occurring less than once per year [**Table 1**]. However, under the likely and worst-case scenario, extreme daytime and nighttime heat are both projected to occur multiple days a year. Under the worst-case scenario, more than 30 days of the year reach these extreme temperatures during the day. If such a reality materializes, significant public health measures would be necessary to forestall negative impacts.

Table 1. Climate Explorer heat indicators for District of Columbia, averaged across historical baseline circa 2000 (1991-2010) and 20-year planning horizons centered on the 2030s, 2050s, and 2080s.

Indicator	Baseline	Likely Scenario (RCP4.5)			Worst-case Scenario (RCP8.5)		
	ca. 2000	2030s	2050s	2080s	2030s	2050s	2080s
Annual minimum temp.	47.0°F	49.4°F	50.4°F	51.4°F	49.6°F	51.7°F	54.9°F
Annual maximum temp.	67.0°F	70.2°F	71.4°F	72.2°F	70.4°F	72.5°F	75.8°F
Annual days above 95°F	8.9 days	22.2 days	29.3 days	35.8 days	24.4 days	39.8 days	66.7 days
Annual days above 100°F	0.6 days	4.7 days	7.6 days	11.1 days	5.6 days	12.7 days	31.9 days
Annual nights above 80°F	0.1 nights	1.1 nights	2.0 nights	3.8 nights	1.4 nights	4.5 nights	18.9 nights
Annual cooling degree days	1405 CDDs	1820 CDDs	2015 CDDs	2150 CDDs	1875 CDDs	2235 CDDs	2875 CDDs
Annual days below 32°F	83.0 days	67.8 days	62.3 days	55.9 days	67.2 days	55.6 days	38.3 days

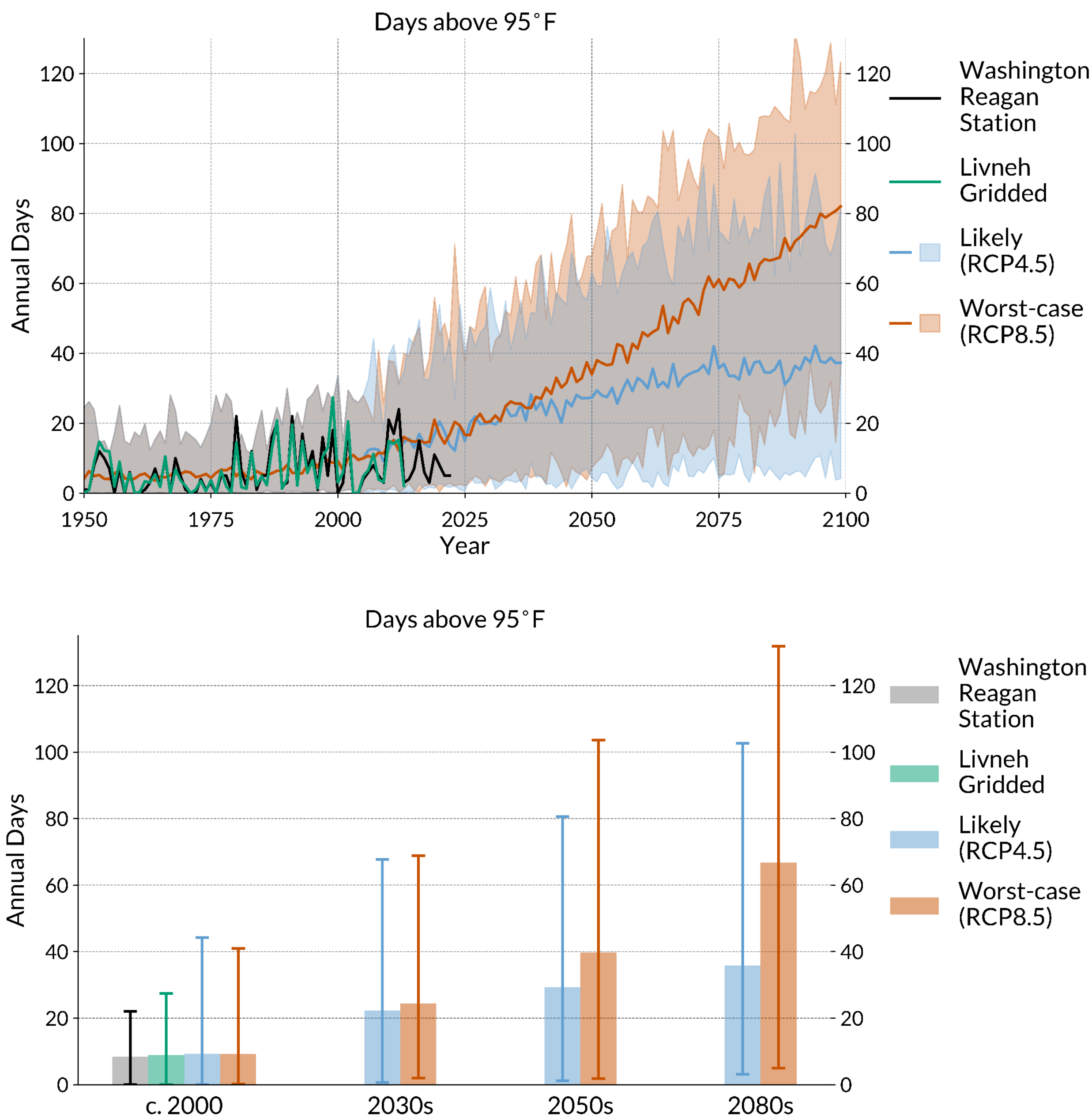
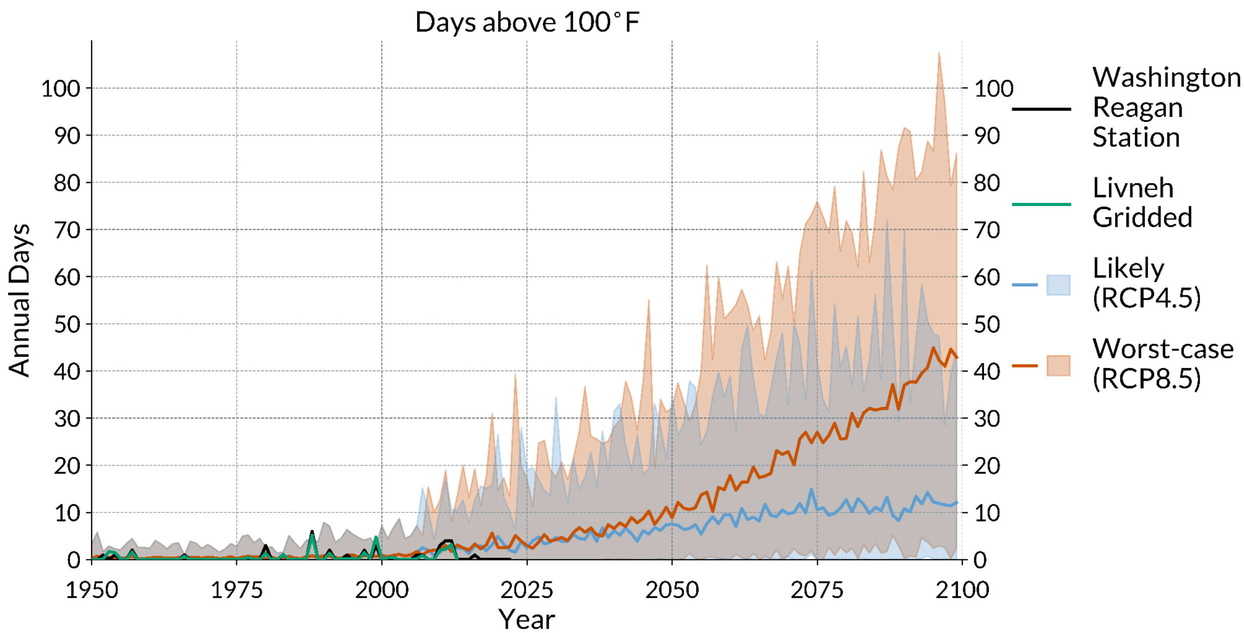


Figure 3. [*top*] Annual mean number of days at or above 95°F for gridded observations (green), Washington Reagan National Airport weather station (black), a likely warming scenario (RCP4.5) in blue (line denotes multi-model mean, shading denotes minimum and maximum model values), and a worst-case warming scenario (RCP8.5) in red (line denotes multi-model mean, shading denotes minimum and maximum model values). **[*bottom*]** As in the top panel, but averaged across the historical baseline (1991-2010) and the three 20-year planning horizons centered on the 2030s, 2050s, and 2080s.



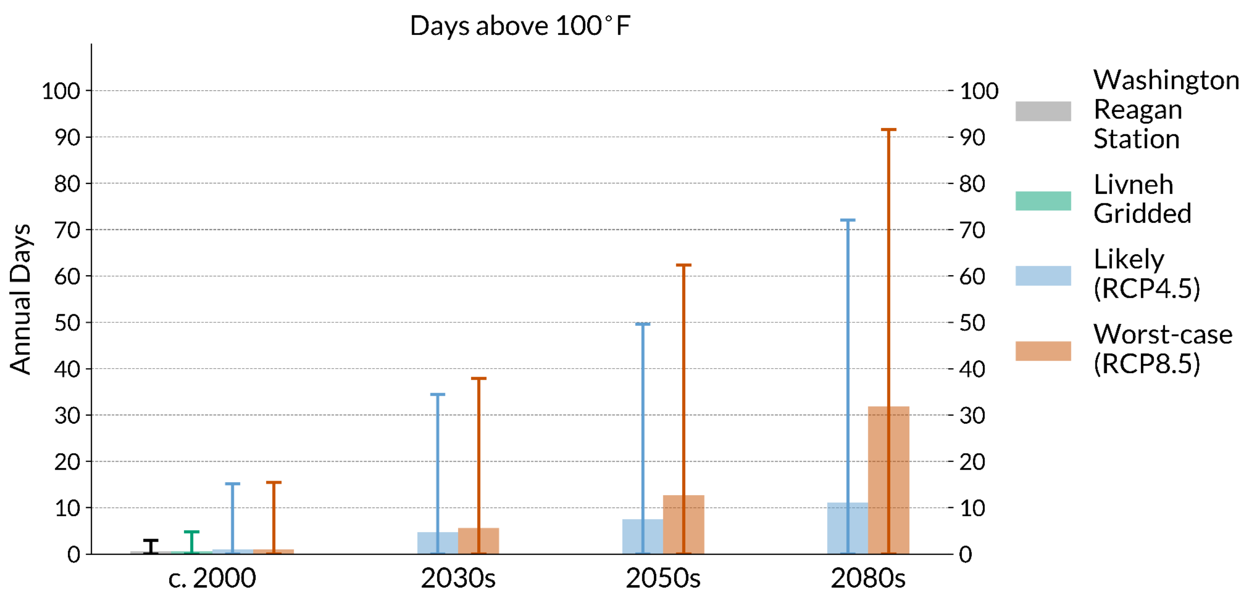


Figure 4. [***top***] Annual mean number of days at or above 100°F for gridded observations (green), Washington Reagan National Airport weather station (black), a likely warming scenario (RCP4.5) in blue (line denotes multi-model mean, shading denotes minimum and maximum model values), and a worst-case warming scenario (RCP8.5) in red (line denotes multi-model mean, shading denotes minimum and maximum model values). [***bottom***] As in the top panel, but averaged across the historical baseline (1991-2010) and the three 20-year planning horizons centered on the 2030s, 2050s, and 2080s.

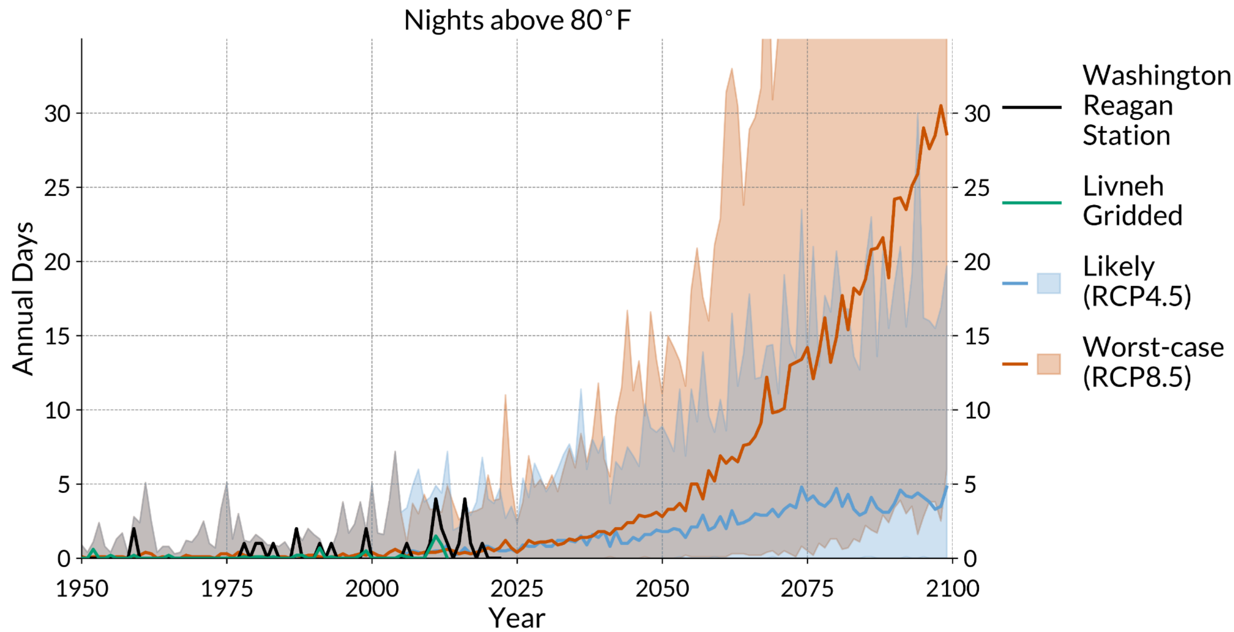


Figure 5. As in the top panel of Figure 4 but for the annual mean number of nights where the temperature does not drop below 80°F.

Heat Waves

The length of heatwaves will increase from an average of 5 days in 2000 to 7-8 days by 2050. By 2080, that number will grow to a range of 8-11 days. In that time period, the average temperature during a heatwave will grow from 95°F to 97-99°F.

Projected changes in heatwaves are shown in [**Table 2**]. In the future, heat waves will be more frequent, longer in duration, and more intense. By the 2030s, the District is expected to experience an extra 2-3 heat waves per year. That expands to an extra 3-4 by the 2050s and an extra 3.5-4.5 by the 2080s. Heatwaves get longer as warming increases: heatwaves are projected to be about a day longer in the 2030s, 2-3 days longer in the 2050s, and 2.5-6 days longer in the 2080s. By the 2050s half of any given summer will be spent within a heat wave. Not only are heat waves projected to become more frequent and last longer, they are also projected to become more intense. The average daytime maximum temperature is projected to be 1°F higher by the 2030s, 1-2°F higher by the 2050s, and 2-4°F higher by the 2080s. The average nighttime minimum temperature is projected to be 1-1.5°F higher by the 2030s, 1.5-2.5°F higher by the 2050s, and 2-4.5°F higher by the 2080s.

Severe heat waves (at least 5 consecutive days with daily maximum temperature above 100.0°F) will also increase in frequency and duration. By definition, severe heat waves are exceptionally rare in the historic record, only occurring in 2012. By the 2030s about 3 severe heat waves per decade are expected, by the 2050s 5-8 severe heat waves per decade, and by the 2080s 7-21 are expected. Severe heat waves will become significantly longer in the future, with an average severe heatwave event in the 2050s lasting longer than a week.

Table 2. Custom heat wave indicators for the District based on gridded climate observations (gridMET) and downscaled climate projections (MACA).

Indicator	Baseline		Likely Scenario (RCP4.5)			Worst-case Scenario (RCP8.5)		
	Observed	Modeled						
	ca. 2000		2030s	2050s	2080s	2030s	2050s	2080s
Annual days with heat index above 95°F	20.6 days	26.1 days	44.4 days	54.6 days	60.8 days	47.2 days	65.2 days	91.5 days
Annual number of heat waves	2.7 per year	3.2 per year	5.7 per year	6.6 per year	6.9 per year	5.9 per year	7.1 per year	7.9 per year
Average length of heat waves	4.3 days	5.0 days	6.1 days	6.8 days	7.6 days	6.4 days	8.0 days	11.3 days
Average overnight low during heat waves	72.1°F	72.6°F	73.6°F	74.3°F	74.8°F	74.1°F	75.2°F	77.2°F
Average high temp. during heat waves	94.8°F	95.5°F	96.3°F	96.6°F	97.2°F	96.4°F	97.5°F	99.3°F
Average number of severe heat waves per year	0.0 per year	0.0 per year	0.3 per year	0.5 per year	0.7 per year	0.3 per year	0.8 per year	2.1 per year
Average length of severe heat waves	-	5.9 days	6.9 days	7.4 days	7.6 days	7.1 days	7.8 days	9.6 days

Implications

Average temperatures and days above 95°F are projected to increase in the coming decades. Extreme heat is the leading cause of climate-related deaths in the United States[14] and has been conclusively linked to risk of illness and death among older adults, pregnant women, and

[14] U.S. National Weather Service, "Weather related fatality and injury statistics." Accessed June 23, 2022.

children.[15] Increases in temperature have also been linked to premature deaths, hospitalizations, and emergency department visits during heat waves. The increasing temperatures, heat waves, and consequently adverse health impacts present a dire need for the District to expand strategies that protect residents from extreme heat.

This updated report adds new metrics related to elevated nighttime temperatures. While daytime maximum temperatures are headline grabbing, the District should closely monitor periods of elevated nighttime temperatures (e.g. >70°F, >80°F, even the very rare >90°F). These temperatures are particularly hazardous to people without access to air conditioning, individuals experiencing homelessness, and outdoor workers.

The District Hazard Mitigation Plan includes projections of average temperatures, days above 95°F, average heat wave durations, and average heat wave events per year. The average temperature and days above 95°F can be updated using Climate Explorer as shown in the earlier sections. However, the Climate Explorer does not provide heat wave metrics. Therefore, for this report, gridMET and MACA gridded climate datasets were used to fill in The Climate Explorer's gaps.

Projections show that in the near future heat waves will become more frequent, longer lasting, and more intense. It can be misleading to only look at heatwave frequency as a measure of how heat waves will change; it is important to also look at heatwave characteristics. By the 2050s, heatwave frequency and duration are projected to increase to the point where essentially half of the days within an average summer will be classified as heatwave days. These heat waves will be hotter during both the daytime and nighttime, greatly increasing health risks and air conditioning needs. Severe heat waves that were exceedingly rare in the historical record will become regular events by midcentury. A heatwave event as extreme as the 2012 heatwave is on average expected to occur every other year by the 2050s, even under the lower warming scenario. Severe heat waves and more extreme (longer and with higher daytime and nighttime temperatures) than the 2012 event should be expected.

The District has created several resources that provide information on the risk of extreme heat in District of Columbia including this report. There are multiple sources for climate projections, scenarios, and horizons to consider. These projections are used in several planning frameworks. Using an inconsistent set of metrics could result in differing plans across the Agencies, therefore, the District has created this report to ensure a consistent set of metrics and indicators are used across agencies moving forward. In addition, the District's Heat Emergency Plan governs the District's response to heat events. In 2022, the District published Keep Cool DC, a comprehensive strategy to adapt to hotter days by reducing the drivers of extreme heat and protecting District residents from the dangers of high temperatures. The 2022 Keep Cool DC report includes a projection for the 2020s, 2050s, and 2080s days above 95°F. The projections in this report align with those included in the 2022 Keep Cool DC plan.

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[15] USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: [Reidmiller DR, et al. (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

Increasing Precipitation

Overview

Driven by an intensifying hydrologic cycle, climate models project an uptick in both the frequency and severity of extreme precipitation events. These shifts could exacerbate urban flooding, water pollution, and infrastructure strain while also introducing new dynamics into the local hydrological cycle.

At a basic level, the capacity of the atmosphere to hold moisture increases exponentially with temperature. Shifting atmospheric circulation patterns—such as the jet stream and storm tracks—can lead to more frequent and intense precipitation events. Climate change also contributes to changes in oceanic cycles, affecting phenomena like El Niño and La Niña, which in turn influence weather patterns globally. Changes in land use, such as deforestation and urbanization, can further modify local climate and exacerbate the effects of increased precipitation. The cumulative impact of these factors creates a more variable and intense precipitation regime, making the prediction and management of these events increasingly complex and urgent.

Four types of indicators were used to characterize extreme precipitation in the District's 2015 climate projections:[16]

1. Days per year with rainfall at or above 1" or 2"
2. 24-hour storm amount: 1-year, 2-year, 15-year, 25-year, 100-year, 200-year recurrence
3. 6-hour storm amount: 2-year, 15-year, 100-year, 200-year recurrence
4. 24-hour storm: 80th percentile, 90th percentile, 95th percentile

Method

For precipitation indicator 1 NOAA's Climate Explorer is recommended,[17] which additionally includes days per year at or above 3" of rain.

For precipitation indicator 2-4 we recommend the Mid-Atlantic Intensity-Duration-Frequency (IDF) Curve Tool.[18] While the IDF Curve Tool misses a few data points explored in the 2015 report (namely the 200-year return period, and 95th percentile statistics) it is based on a much larger climate dataset and calculates statistics of sub-hourly rainfall rates down to 5-minute events. We worked with MARISA to compute additional statistics using the Mid-Atlantic IDF tool and Atlas-14. The 15-year return period was computed by interpolation and the 500-year return period was computed by extrapolation, both using a power law or log law functional relationship, whichever was a better fit to the data.[19]

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[16] See Attachment #1: District of Columbia's Climate Change Projections and Risk Assessments: Recommendations

[17] https://crt-climate-explorer.nemac.org/

[18] https://midatlantic-idf.rcc-acis.org/; Miro M et al. (2021) Developing Future Projected Intensity-Duration-Frequency (IDF) Curves: A Technical Report on Data, Methods, and IDF Curves for the Chesapeake Bay Watershed and Virginia. CA: RAND Corporation. doi: 10.7249/TLA1365-1

[19] A power law functional basis was a better fit to the data in all but one case.

Planning requirements around changing severe weather may require data and analysis not found in the publicly accessible climate tools used to write this report.[20] While sophisticated methods like downscaling can make up for some of this weakness, projections of future extreme rainfall should be viewed conservatively. Recent history provides a stark example. In 2018 Washington Reagan National Airport saw 24 days with at least 1” of rainfall, while the most extreme climate model projection through the end of this century is 21 days with at least 1” of rainfall. Consequently extreme precipitation analyses using downscaled climate data should only be interpreted as a single imperfect view into the future of extreme precipitation.

Other data sources can provide useful context. It may be appropriate to look at non-model sources of extreme rainfall information like historic weather observations, local paleoclimate proxies, or oral history and archival newspaper reports. These sources are not as easy to quantify as downscaled climate model data but go back much farther in time and give a fuller picture of the District’s climate. Since climate change will worsen extreme precipitation, future extreme flood events will have an increasingly good chance to be worse than any floods that have ever occurred in the District’s recorded history. Global warming means the worst flood and heatwave in the District’s history will very likely happen not once but multiple times this century. History provides a floor for just how bad those events could be, information that downscaled climate data may not always provide reliably.

Similar to extreme precipitation, climate models also fail to fully capture the dynamics of severe weather: damaging winds, hail, and tornadoes. Projections of future severe weather are so complex they can even disagree in sign (e.g. more severe weather vs. less severe weather) and should at this time be mostly interpreted qualitatively.

Climate Change Indicators

Average annual precipitation

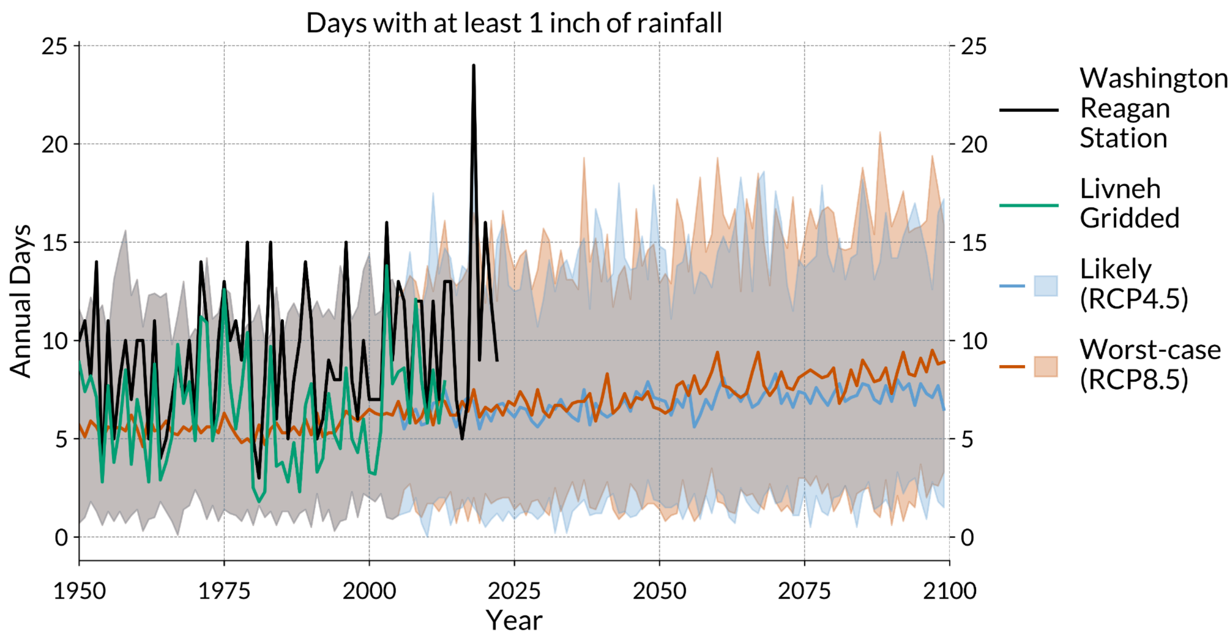
Annual precipitation is projected to rise slightly in the District [**Table 3**], from a historic average of 43.6” to around 46” by midcentury and 46”-49” by end of the century, with the worst-case scenario projected to have greater annual rainfall.

Days with at least 1 or 2 inches of precipitation

Days with extreme precipitation are projected to increase for likely and worst-case warming scenarios [**Table 3; Figures 6, 7**]. Median estimates of projections have the District experiencing 1-2 extra days with an inch of rain and 0.5 extra days with two inches of rain by the end of the century. For this precipitation indicator it is crucial to compare historical values to present and future modeled values. Comparing the gridded observations and station observations in [**Figures 6, 7**] to the historical modeled values, observed rainfall shows much greater extremes than modeled rainfall. The shading in [**Figures 6**] and the whiskers in [**Figures 7**] denote minima and

[20] Allen J (2018) Climate Change and Severe Thunderstorms. *Oxford Research Encyclopedia of Climate Science*. Retrieved 09-23-2023. doi: 10.1093/acrefore/9780190228620.013.62

maxima in the observational record and the projections. 2018, the wettest year in observed District history, received 24 days with at least one inch of rain. This exceeds even the maximum of the worst-case warming scenario projections by the year 2100 [**Figures 6, 7**].



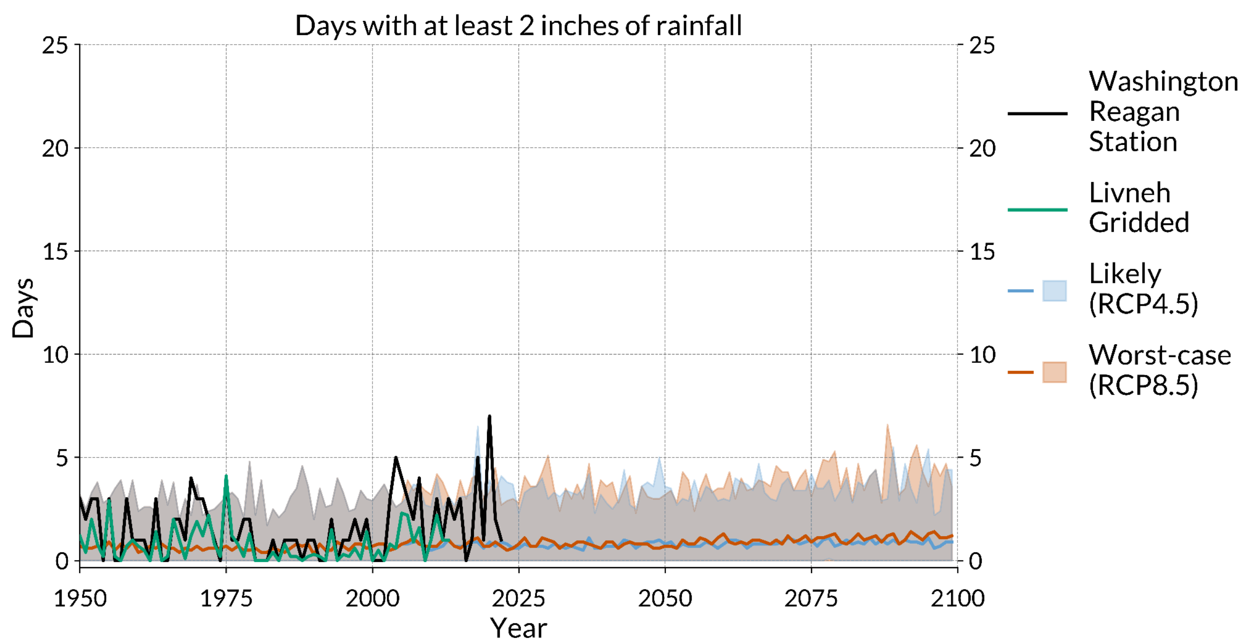


Figure 6. [***top***] Annual mean number of days with at least 1 inch of rain for gridded observations (green), Washington Reagan National Airport weather station (black), a likely warming scenario (RCP4.5) in blue (line denotes multi-model mean, shading denotes minimum and maximum model values), and a worst-case warming scenario (RCP8.5) in red (line denotes multi-model mean, shading denotes minimum and maximum model values). [***bottom***] as in top, but for days with at least 2 inches of rain.

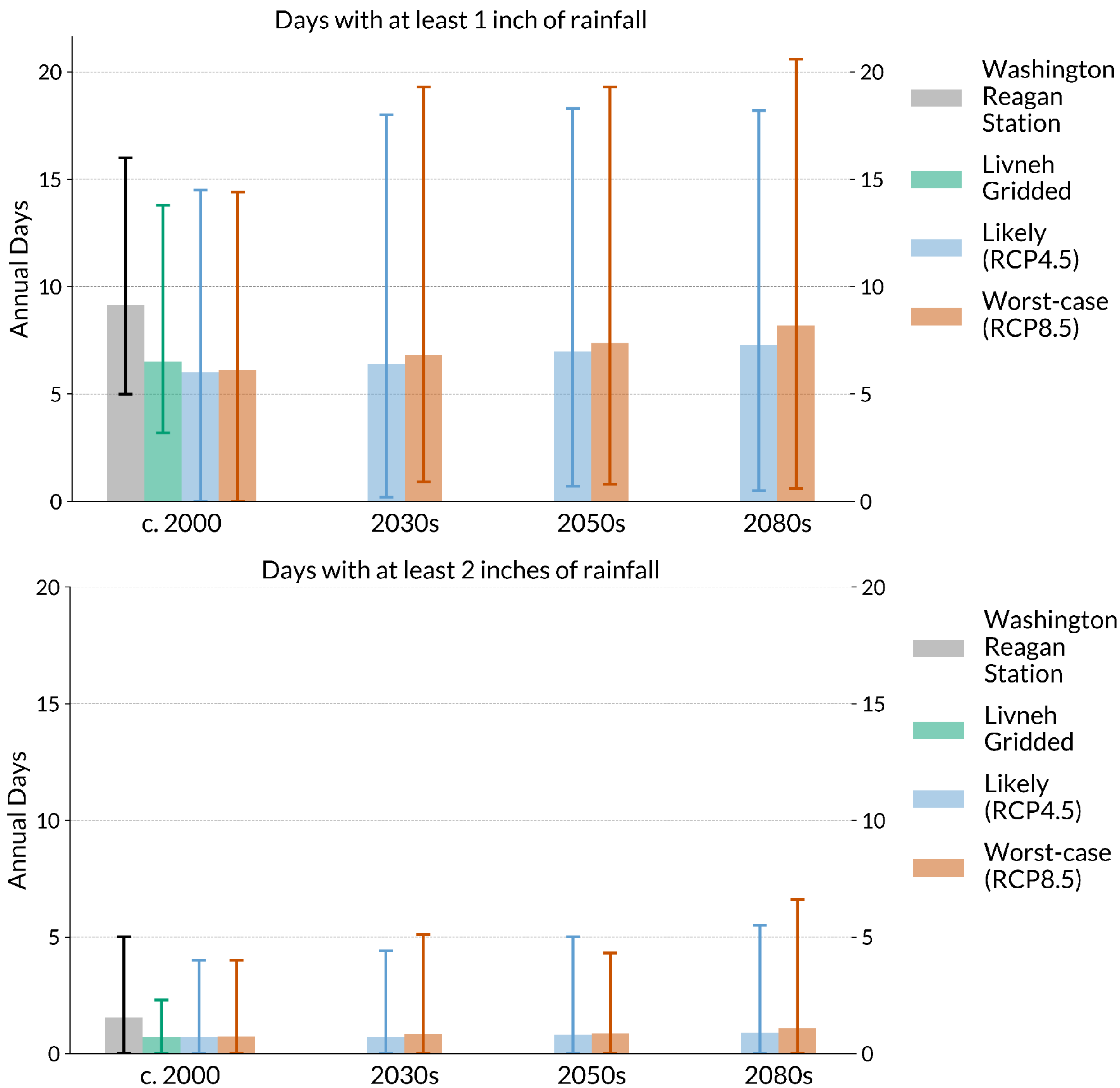


Figure 7. [***top***] Annual mean number of days with at least 1 inch of rain for gridded observations (green), Washington Reagan National Airport weather station (black), a likely warming scenario (RCP4.5) in blue, and a worst-case warming scenario (RCP8.5) in red. Bars denote averages, whiskers denote minimum and maximum values. [***bottom***] as in top, but for days with at least 2 inches of rain.

In 2020 the District experienced 7 days with two inches of rain, once again higher than the highest value found in the worst-case scenario projections. The trend is more significant than the actual values shown here. Models and theory both predict that significantly more extreme rainfalls will occur in the future, but as long as historical values are poorly captured by projections future values should be interpreted conservatively.

Table 3. Precipitation indicators for the District of Columbia based on data from The Climate Explorer.

Indicator	Baseline	Likely Scenario (RCP4.5)			Worst-case Scenario (RCP8.5)		
	ca. 2000	2030s	2050s	2080s	2030s	2050s	2080s
Annual precip. (inches)	43.6 inches	44.4 inches	45.7 inches	46.3 inches	45.4 inches	45.9 inches	47.8 inches
Days with at least 1"	6.5 days	6.4 days	7.0 days	7.3 days	6.8 days	7.4 days	8.2 days
Days with at least 2"	0.7 days	0.7 days	0.8 days	0.9 days	0.8 days	0.8 days	1.1 days
Days with at least 3"	0.3 days	0.2 days	0.2 days	0.2 days	0.2 days	0.2 days	0.3 days

Table 4. Precipitation records set at Ronald Reagan Washington National Airport weather station (1941-2023).[21,22,23,24]

Record	Amount	Date
Annual Maximum	66.28 inches	2018
Monthly Maximum	14.31 inches	August 1955
24-hour Maximum	7.94 inches	25-26 June 2006
Hourly Maximum	3.30 inches	8 July 2019
Days with 1" rain	24 days per year	2018
Days with 2" rain	7 days per year	2020

[21] National Weather Service: https://www.weather.gov/media/lwx/climate/dcaprecip.pdf. Accessed September 2023. Annual maximum rainfall.

[22] National Centers for Environmental Information: https://www.ncdc.noaa.gov/IPS/lcd/lcd.html. Accessed September 2023. Monthly and 24-hour maximum rainfall.

[23] Iowa Environmental Mesonet: https://mesonet.agron.iastate.edu/plotting/auto/. Accessed September 2023. Hourly maximum rainfall.

[24] The Climate Explorer: https://crt-climate-explorer.nemac.org/. Accessed September 2023. Days with 1" and 2" rain.

Intensity-Duration-Frequency Statistics

Intensity-Duration-Frequency (IDF) statistics were taken from the Projected Intensity-Duration-Frequency (IDF) Curve Data Tool for the Chesapeake Bay Watershed and Virginia.[25] This data tool provides IDF statistics over two periods, mid-century (2020-2070), and late-century (2050-2100). Additional statistics not offered by the data tool were computed by the research team in collaboration with MARISA, as described in the methods subsection above.

Storms of all durations and return intervals are expected to get more intense in the future **[Table 5]**. All projected future intensity statistics are greater than historic Atlas 14 values, even in the mid-century period. Multi-day extreme rainfall (48 hr. event, 500 year return period) increases by inches for the median estimate. The 90th percentile exceeds 20 inches for both scenarios and time horizons. Daily extreme rainfalls are projected to be significantly more intense, with a 25-yr 24 hr. event producing 19% (1.15 in.) more rain and a 100-yr 24 hr. event producing 11% (0.92 in.) more by the late 21st century under the likely warming scenario. Extreme hourly and sub-hourly rainfall events will also quickly grow in intensity, with a 100 yr. 1 hr. event projected to have 11% (0.35 in.) more rain under a likely warming scenario than in the past.

Implications

Of all the hazards assessed in this update report, precipitation has the largest range of variability across timescales from minutes to hours and days to years. This means that small climate changes (i.e., signals) are often dwarfed by climate variability (i.e., noise). In other words, large year-to-year variations in precipitation can obscure relatively small precipitation trends. At the same time, the physical causes of changing extreme precipitation are beginning to be understood and documented.[26] Climate model projections from low to high warming consistently call for more days of extreme precipitation. However, challenges in simulating historic extreme precipitation means that these projections should be interpreted conservatively (i.e., as low-end estimates). It is possible that even end-of-century projections for many of the extreme precipitation indicators discussed here will be exceeded in the near future.

The District is highly susceptible to flooding given its location at the intersection of the Potomac and Anacostia Rivers, and its footprint over a network of buried waterways. Given its vulnerability to flooding, much of the District Hazard Mitigation Plan is dedicated to assessing the flood risk including riverine flooding, coastal flooding, interior flooding, hidden streams and combined sewer system failure, and levee failure.

Much of the District's mitigation plan for flooding will be informed by the Integrated Flood Model project. The updated extreme precipitation metrics discussed in this section will be integrated into the District Integrated Flood Model assessing future flood risk throughout the District.

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[25] MARISA: Projected Intensity-Duration-Frequency (IDF) Curve Data Tool for the Chesapeake Bay Watershed and Virginia. https://midatlantic-idf.rcc-acis.org/, accessed September 2023.

[26] Fowler, H.J., Lenderink, G., Prein, A.F. et al. Anthropogenic intensification of short-duration rainfall extremes. *Nat Rev Earth Environ* **2**, 107–122 (2021). doi: 10.1038/s43017-020-00128-6

Table 5. MARISA IDF precipitation indicators (median; 10-90 percentile estimates in parentheses). Statistics were averaged between 3 District locations: Washington Reagan National Airport, Dalecarlia Reservoir, and National Arboretum. Dashes denote data not available for this report. All units are inches.

Return Interval, Duration	Baseline	Likely Scenario (RCP4.5)		Worst-case Scenario (RCP8.5)	
	Atlas 14	2020-2070	2050-2100	2020-2070	2050-2100
500-yr, 48 hr.	12.97	15.21 (12.06-20.08)	16.53 (10.8-22.3)	15.84 (10.01-21.05)	16.44 (11.12-21.44)
1-yr, 24 hr.	2.60	-	-	-	-
2-yr, 24 hr.	3.15	3.36 (3.10-3.62)	3.52 (3.23-4.02)	3.44 (3.20-3.79)	3.53 (3.25-3.87)
15-yr, 24 hr.	5.24	5.62 (4.96-6.49)	6.17 (4.81-7.32)	5.76 (5.05-6.72)	6.06 (5.28-7.07)
25-yr, 24 hr.	6.05	6.46 (5.61-7.48)	7.20 (5.17-8.78)	6.68 (5.67-7.85)	6.84 (5.85-8.05)
100-yr, 24 hr.	8.35	9.05 (7.49-11.41)	9.27 (7.54-11.94)	9.41 (7.40-11.99)	9.72 (7.66-12.14)
200-yr, 24 hr.	9.72	-	-	-	-
2-yr, 6 hr.	2.25	2.40 (2.21-2.58)	2.51 (2.31-2.87)	2.46 (2.28-2.70)	2.52 (2.32-2.76)
15-yr, 6 hr.	3.57	3.82 (3.35-4.38)	4.32 (3.25-5.19)	3.89 (3.37-4.54)	4.10 (3.53-4.78)
100-yr, 6 hr.	5.32	5.76 (4.77-7.27)	5.90 (4.80-7.60)	5.99 (4.71-7.64)	6.19 (4.85-7.73)
200-yr, 6 hr.	6.02	-	-	-	-
2-yr, 1 hr.	1.47	1.57 (1.45-1.70)	1.65 (1.51-1.88)	1.61 (1.5-1.78)	1.65 (1.52-1.81)
25-yr, 1 hr.	2.55	2.72 (2.36-3.15)	3.03 (2.17-3.68)	2.81 (2.39-3.30)	2.88 (2.46-3.39)
100-yr, 1 hr.	3.17	3.44 (2.84-4.33)	3.52 (2.87-4.54)	3.57 (2.81-4.56)	3.69 (2.91-4.61)
2-yr, 15 min.	0.85	0.91 (0.84-0.98)	0.95 (0.88-1.09)	0.93 (0.87-1.03)	0.96 (0.88-1.05)
25-yr, 15 min.	1.29	1.37 (1.19-1.59)	1.53 (1.10-1.86)	1.42 (1.20-1.67)	1.46 (1.24-1.71)
100-yr, 15 min.	1.50	1.63 (1.35-2.05)	1.67 (1.36-2.15)	1.69 (1.33-2.16)	1.75 (1.38-2.18)

Sea Level Rise

Overview

As sea water absorbs more of the heat from earth's atmosphere, it becomes increasingly hotter around the globe. A rise in sea water temperatures leads to a thermal expansion of water molecules, and this expansion is a main reason for rising global sea level rates over the past century. More than 90 percent of the heat trapped in the Earth's atmosphere over the past 50 years has been absorbed by the ocean.[27] In addition, land-based ice melt (e.g. glaciers, ice sheets), as observed in Greenland and Antarctica, has contributed to a rising global sea level. Local and regional processes like land sinking and water storage can introduce local variations in sea level rise rates. When including local variations, scientists refer to these metrics as relative sea level rise (RSLR). For example, land sinking in and around the District of Columbia tends to make RSLR larger than global sea level rise (GSLR). The District is interested in continuing to account for local and regional effects as it plans for sea level rise.

This report found that observed RSLR through 2023 is 8.8% higher than the 2015 report. RSLR projections for 2050 range from 1.1 to 1.7 feet, which is significantly higher on the low end than the projections for 2050 range in the 2015 report (0.7 to 1.7 feet). RSLR projections through 2080 are now 1.6 to 4.4 feet, higher than the 1.0 to 3.7 feet in the 2015 report.

Method

Newer resources are now available from USACE, NASA, and NOAA, which represent the best available science. USACE's Sea Level Tracker (https://climate.sec.usace.army.mil/slr_app/), NASA's Sea Level Change Portal (https://sealevel.nasa.gov/), and NOAA's Sea Level Rise Viewer (https://coast.noaa.gov/digitalcoast/tools/slr.html) all provide access to projections. NASA's Sea Level Change Portal and NOAA's Sea Level Rise Viewer are likely preferred for ease of use, however some agencies may prefer USACE's Sea Level Tracker for more advanced options.

Climate Change Indicators

The District's 2015 Climate Change Projections & Scenario Development report included SLR indicators based on the District waterfront (NOAA gauge 8594900 in Washington Channel: https://tidesandcurrents.noaa.gov). It reported that the RSLR at this location from 1924 to 2013 was 1.25 inches per decade (0.104 feet per decade). Extending the time series from 2013 to 2023 updates the 1924 to 2023 RSLR at this location to an increased 1.36 inches per decade (0.113 feet per decade) [**Figure 8**], which is 8.8% higher than reported in the 2015 report.

[27] Schuckmann KV, Cheng L, Palmer MD, Hansen J, Tassone C, Aich V, et al. (2020) Heat stored in the Earth system: where does the energy go? *Earth System Science Data* **12** 2013–2041 doi: 10.5194/essd-12-2013-2020

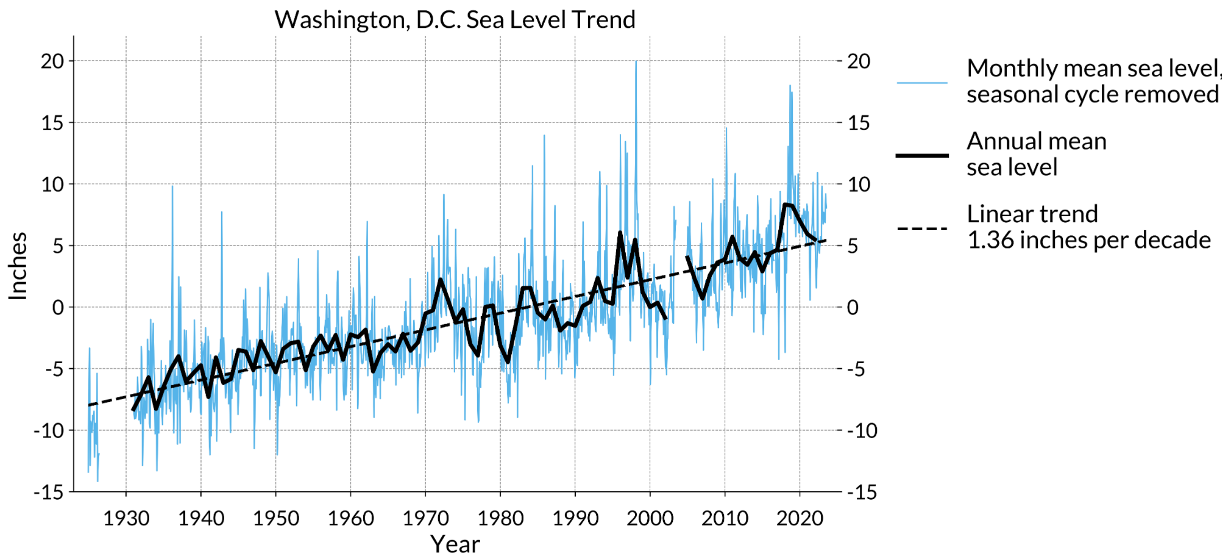

Figure 8. Historical monthly sea level and sea level linear trend for District of Columbia Values from NOAA Tides and Currents web interface, accessed September 2023.

The District's 2015 Climate Projections & Scenario Development report included three RSLR scenarios that accounted for local, regional, and global contributions to RSLR based on the US Army Corps of Engineers (USACE) 2014 low, intermediate, and high projections. These 2014 USACE projections are no longer considered the best available science.

The RSLR projections are updated based on the latest generation of global climate models and the sixth IPCC assessment report. They also incorporate multiple methods of projecting future ice-sheet changes, which are major contributors to future sea level rise and represent significant sources of uncertainty in projecting the pace and level of future sea level rise.

Global Sea Level Rise Scenarios

In this 2023 update, the Cadmus and Two Degrees Adapt team adopt the best available science in the form of the interagency 2022 Sea Level Rise Technical Report.[28] The interagency report presents relative sea level rise (RSLR) projections through 2150 with a baseline year of 2000. The RSLR projections are derived from five global sea level rise (GSLR) scenarios:

- **Low** - Based on the approximately 0.11 inches (3 mm) per year GSLR trend since the early 1990s, which implies 12 inches (1 ft) of 21st century GSLR.
- **Intermediate Low** - 19 inches (1.58 ft) of 21st century GSLR.
- **Intermediate** - 39 inches (3.25 ft) of 21st century GSLR.
- **Intermediate High** - 59 inches (4.91 ft) of 21st century GSLR.
- **High** - 79 inches (6.58 ft) of 21st century GSLR.

[28] Sweet WV, et al. (2022) Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf

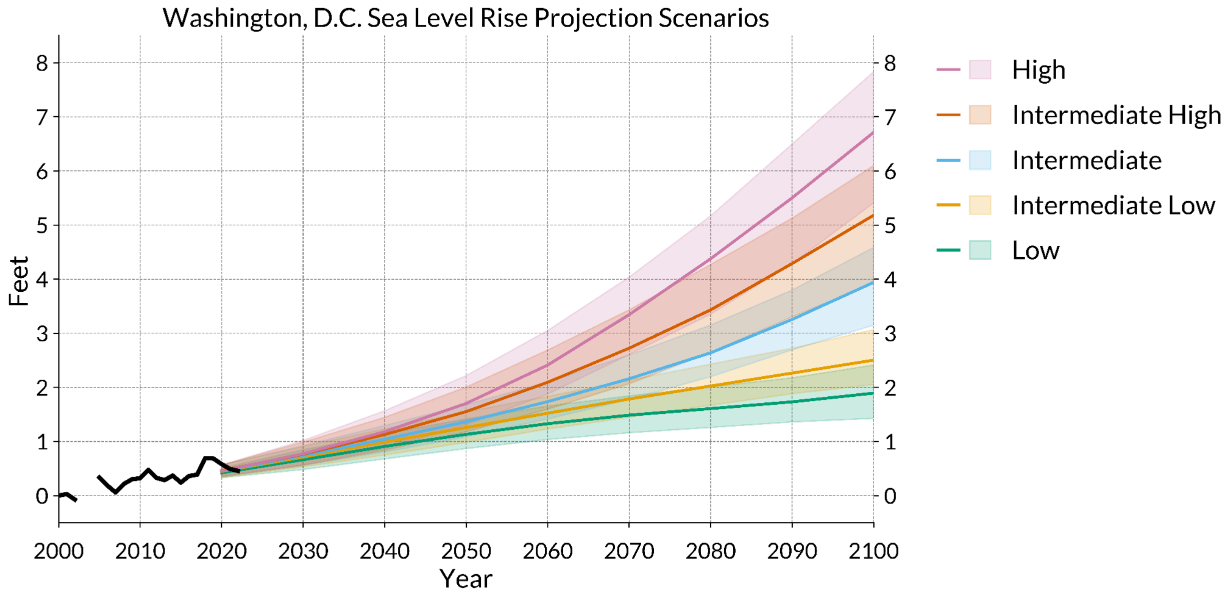

Figure 9. Historical and projected sea level rise scenarios for District of Columbia Median estimates (solid line) and 17-83 percentile estimate range (shading) for the five scenarios included in the report. Values from the 2022 Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force report.

Local RSLR projections for the District are shown graphically in **Figure 9**, including RSLR observations averaged to the annual timescale. All five scenarios show rises through 2100, and the intermediate, intermediate-high, and high scenarios show acceleration in RSLR after 2050. The scenarios show a spread of 1.89 to 6.71 feet of total RSLR in the District by 2100. This highlights the role that global processes play in determining the intensity of RSLR in the District.

Table 6 shows the data in tabular form, grouped by scenario and planning horizon (2030, 2050, 2080). It shows the median for each scenario, as well as a range based on the 17th and 83rd percentiles of estimates from the interagency 2022 technical report.

In the 2030s, the scenarios are fairly similar, however by the 2050s and 2080s the divergence between scenarios is clear. This is due to the differing contributions to each scenario from various physical processes. Those contributions are compared for the 2080s planning horizon in **Figure 10**. The Greenland and Antarctic Ice Sheets are the largest differing factors between scenarios.

Implications

Observed RSLR through 2023 is 8.8% higher than the 2015 report. RSLR projections through 2050 range from 1.13 to 1.70 feet, significantly higher on the low end than the 0.5 to 1.72 feet projected 2050 range in the 2015 report. Similarly for 2080, RSLR projections through 2080 are now 1.61 to 4.38 feet, higher than the 0.80 to 3.64 feet in the 2015 report. This is due to a combination of factors including: the observed acceleration in GSLR and RSLR in the District since 2013, the inclusion of newer climate model projections and understanding of physical processes such as contributions from Greenland and Antarctic Ice Sheets.

Table 6. Projections for District of Columbia sea level rise. Values are median estimates in feet relative to year 2000 sea level. Values from the 2022 Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force report.

Total Relative Sea Level Rise From 2000 in feet	2030	2050	2080
Low	0.66'	1.13'	1.61'
Intermediate Low	0.71'	1.26'	2.02'
Intermediate	0.74'	1.37'	2.64'
Intermediate High	0.76'	1.55'	3.43'
High	0.77'	1.70'	4.38'

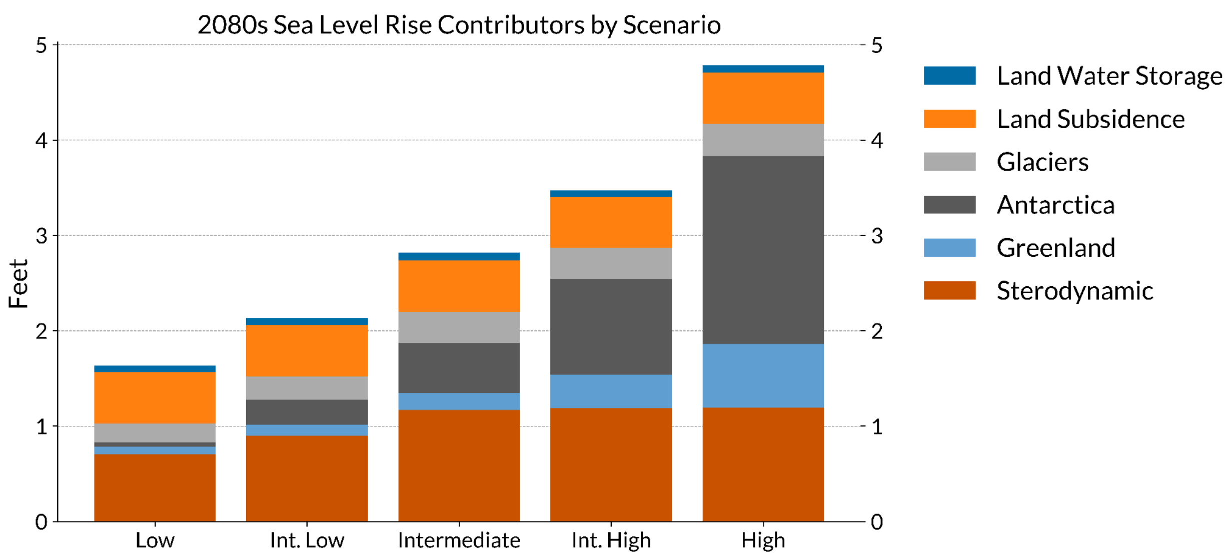

Figure 10. Contributors to 2080 median sea level rise projections. Values from the 2022 Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force report.

Future Updates

The District of Columbia should continue to keep its climate projections up-to-date so that projects, plans, and programs across the District accurately reflect the best and most up-to-date science. Climate change is a dynamic phenomenon; outdated models may not accurately capture the current risks covered by this report, including extreme temperatures, increasing precipitation, and rising sea level. Staff and decision-makers can make more informed decisions that support the District's broader adaptation and resilience goals by regularly updating these climate projections and ensuring consistency in the way that agency staff and leadership are using climate projection information in planning and operations. This proactive approach will save lives and reduce long-term costs by minimizing damage caused by climate hazards and by ensuring that the District's resources are being allocated effectively.

Below is a list of recommendations for ways District-specific climate indicators could be improved in future updates:

- **Continue to monitor climate tools** created by local, regional, and federal government agencies. The most recent generation of climate projections, CMIP6, was completed in 2022. As described in the 'constraints and limitations' subsection, online climate tools could see updates incorporating CMIP6 projections prior to 2026.

- **Try to influence developers of climate tools to incorporate climate analyses more relevant to District planning.** As it stands many climate tools are more useful as "first-pass" resources, but do not offer the kind of detailed information that would most benefit agencies. Most climate tools are hampered by their limited number of climate indicators and their inflexibility with averaging eras. Since climate model-based indicators are mostly time series analyses, adding a handful of climate indicators should be a relatively simple task for climate tool developers if input can be provided near the beginning of the development process. Hearing from end users of their products would likely be as fruitful for the climate tool developers as it would be for the District. It is to their advantage to learn that such important users exist and are relying on their product. Since many of these tools were developed during time-bound contracts from federal agencies, it may be necessary to identify funding mechanisms for future updates.

Drill down on what climate indicators are most useful for all agencies involved in climate planning. Many climate variables that climate scientists find useful may not be useful for adaptation planning. For example, "change in spring temperature" offers very little useful information for planners, while "change in number of freeze-thaw days" provides tangible information about how soils, cement, asphalt and infrastructure may respond to warming. As an example, an analysis of MACA finds that compared to the 1991-2010 baseline spring in the District will warm about 3°F by 2050 while the average number of daily freeze-thaw cycles in a year will drop 40 percent. All else held equal this dramatic reduction of freeze-thaw cycles may significantly increase the lifetime of cement and asphalt in the District, with complex implications for capital budgets and long-term planning. For decades climate visualization and communication have focused more on providing overwhelming proof (to spur decarbonization and convince skeptics) rather than actionable information. Agencies should feel empowered to push back on climate data analysts who do not provide useful climate indicators. The scientific community is still learning how to maximize the usefulness of climate data and with improved dialogue between scientists and planners more useful analyses can be created.

- **Standardize climate indicators across District agencies, programs, codes, and standards where possible.** This will allow more rapid and efficient updating of climate indicators as they are provided, and more consistency between agencies. Choosing climate indicators that are more frequently updated may be helpful, e.g. building flood risk planning around more commonly published 10- or 25-year storms rather than 15-year.
- **Begin to quantify "outside of climate data" climate risks.** There are dozens of climate risks that are related to but not captured by projected values of temperature, precipitation, and humidity. Some examples include wildfire smoke and air quality issues, post-flood mold risks, plant disease or pest spread, and disease vector spread. Unfortunately, much of this information lies in primary literature.
- **Hire a consultant to create a District-specific climate dataset as was done for the 2015 report.** ATMOS Research downscaled climate projections to create District-specific climate indicators for the 2015 climate projection and scenario development report. In 2023 there are now several open-source climate downscale products (at least three significantly different methods with public downloads available) so the effort required to replicate the analyses of the 2015 report would be significantly smaller. More importantly, the creation of a custom District dataset would allow for the creation of novel climate indicators. The biggest challenge is getting the data in the appropriate form. Once it is pre-processed it can be analyzed hundreds of ways. The benefit of hiring a consultant is that the District could specify what format the data should be stored in for ease of use by its agencies and partners.
- **Hire full-time staff climate scientists to stay current with research and provide continually updated climate analysis that best suits the District's needs.** Climate science is evolving quickly. There are many new ways of quantifying climate risk that are years away from being put into a climate planning tool like Climate Explorer but could greatly benefit the District today. Having an expert on staff would allow agencies to plan with the most modern tools. Climate science and climate planning is fractured between academia, government agencies, private sector firms, and NGOs in a way that is not always conducive to optimal transfers of information. Having local, full-time experts would reduce inefficiencies.

Conclusion

The goal of this report is to provide District agencies a common set of climate indicators based on the latest climate projections that can be used to inform current and future planning and implementation efforts across District agencies. The report provides updates to indicators previously published in the 2015 Climate Projections & Scenario Development using a new horizon for the near-term centered on the 2030s. The report maintains the mid- and long-term horizons centered on the 2050s and 2080s, providing District Agencies an opportunity to plan for the near-, mid-, and long-term impacts of climate change.

In addition to revising climate indices previously published, this report presents new indices and recommendations for how the Agencies can coordinate climate planning efforts in the future. For example, annual days over 100°F, annual nights with lows above 80°F, and sub-hourly intensity-duration-frequency statistics are new in this report.

Climate change poses risks to the District's residents, infrastructure, industry, and economy, however, with the projections presented in this report, a thoughtful and organized planning approach, and collaboration among the District Agencies, an opportunity exists to avoid the worst impacts of climate change. District Agencies are invited to use the climate projections in this report to ensure future plans are resilient to the ever-changing climate.

Appendix A: National Climate Assessment

One aspect of the U.S. federal government's response to climate change is its development of the National Climate Assessment (NCA), a comprehensive report that provides a detailed look at the current and projected impacts of climate change on the United States. The NCA is a collaborative effort involving multiple federal agencies and experts from various fields, encompassing topics like climate modeling, flood resilience and environmental justice. Typically the report is released every four years as mandated by Congress through the Global Change Research Act of 1990. Specifically the legal mandate requires "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." The previous iteration was released in 2021, known as the 4th National Climate Assessment (NCA4).[29,30] The latest iteration was released in 2023, known as the 5th National Climate Assessment (NCA5).[31]

NCA4 concludes that "the evidence of human-caused climate change is overwhelming and continues to strengthen, that the impacts of climate change are intensifying across the country, and that climate-related threats to Americans' physical, social, and economic well-being are rising." A direct connection is drawn between a warming climate and changes that will be experienced as a result of this atmospheric change. NCA4 consists of a set of response chapters that "assess the science of adaptation and mitigation, including benefits, trade offs, and best practices of ongoing adaptation measures and quantification of economic damages that can be avoided by reducing greenhouse gas emissions." It is important to note that the report does not evaluate or recommend specific policies. At the time of development the most recent climate projections were available under four Representative Concentration Pathways (RCPs), scenarios that depict a range of greenhouse gas emission trajectories through the year 2100. While all RCP scenarios are considered throughout the report, two are the report's core scenarios and provide consistency with the NCA3.[32]

Diving deeper into the chapters provides a look at regional perspectives on climate change with the District of Columbia designated as part of the Northeast region. NCA4 Chapter 18 calls out the impact of changing seasons, precipitation patterns, and sea level rise on commerce, historic sites, and adaptation efforts:

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[29] USGCRP (2017) *Climate Science Special Report: Fourth National Climate Assessment, Volume I* Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA, 470 pp, doi: 10.7930/J0J964J6.

[30] USGCRP (2018) *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, Eds. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

[31] USGCRP (2023) *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. doi: 10.7930/NCA5.2023

[32] RCP4.5 (lower emissions, likely scenario) and RCP8.5 (higher emissions, worst-case scenario).

- Milder winters and earlier spring are alerting ecosystems and impacting tourism, recreation, and urban agriculture. Earlier leaf-out and blooming has been observed in flowering trees such as the District's distinctive Cherry trees.
- Ocean warming is the largest contributor to sea level rise, and coupled with land sinking and storms enhances coastal flood risks.
- Critical infrastructure such as drainage and sewer systems, transportation systems, and power supply were not designed for the projected wider variability of future climate conditions like precipitation extremes, which creates an opportunity for future-climate informed planning.
- Heat has been conclusively linked to risk of illness and death among older adults, pregnant women, and children. Projected increases in temperature are expected to lead to significantly more premature deaths, hospitalizations, and emergency department visits during heat waves.

With all reports of this magnitude, gaps do exist within NCA4, they include topics such as incomplete regional coverage, failure to incorporate socio-economic factors, little integration of mitigation and adaptation plans, and lacking perspective on the global context of climate change. Regional uncertainties related to summer rainfall are highlighted. There is high confidence in temperature increases and increasing winter precipitation, as well as more atmospheric evaporative demand for surface moisture (due to temperature increases).

NCA5 was unveiled on November 14, 2023. A draft was released a year prior, open for public comment through January 2023. New chapters with relevance to the District include economics, social systems and justice, compound extreme events, COVID-19, and supply chains. A new appendix was developed around indicators, which may aid in standardization across planning activities. Compared to past National Climate Assessments, NCA5 was developed with more public engagement, a more diverse set of authors, more consideration of Indigenous Knowledge, a higher level of documentation, and new website functionality. Major themes of the draft assessment include "every degree counts," an emphasis on greenhouse gas emissions reduction and the societal choices that could drive them; "innovation in mitigation and adaptation," including novel responses to these dual climate imperatives; "climate change exacerbates inequality," highlighting the disproportionate impacts and compounding of existing inequities that results from climate change. The District's agencies should review NCA5 and incorporate the key messages into their planning.