MAKING CLIMATE DATA ACCESSIBLE: METHODS FOR PRODUCING NEX-GDDP AND LOCA DOWNSCALED CLIMATE INDICATORS

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EXECUTIVE SUMMARY

The change in climate, fueled by the increase in global greenhouse gas concentrations, will alter our relationship with the planet, impacting agriculture, infrastructure, disaster management, and human conflict, among others. It is critical to anticipate these new trends so we can understand and adapt to variations in crop productivity, energy demand, disaster risk, and water resource management. Climate models provide projections of how weather patterns are expected to shift over time. But climate data are difficult to access, process, and utilize, and the information that can be derived from them is largely underused.

In this paper, we describe the process used to summarize global climate data into simple indicators and publish them as open datasets in common geospatial formats. We attempt to lower the barriers to using climate data so they can more easily be used to inform decisions on how to adapt to a changing climate. The climate data are visualized and available for download at <https://PREPdata.org> and <https://resourcewatch.org>. Source code to produce these data is available at <https://github.com/wri/process-gddp>.

INTRODUCTION

The increase in global greenhouse gas concentrations, and commensurate change in climate, is set to fundamentally alter our relationship with the planet, impacting agriculture, infrastructure, disaster management, and human conflict, among others. To anticipate and adapt to

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Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

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these changes, climate models provide projections of how weather patterns are likely to shift in the coming decades. This information can be used to understand weather-induced changes in crop productivity, energy demand, disaster risk, and water resource management.

The production of more accessible climate information is frequently cited as a necessary step toward systematically using climate information in decision-making (Jones et al. 2016). Many studies call for greater dialogue between climate scientists and end users, the iterative development of data products, and the utilization of boundary organizations or information brokers that can assist decision-makers in using science information (McNie 2012; Lemos et al. 2012; Dilling and Lemos 2011). Though these approaches may be effective in assisting individual end users and adapting information to their specific contexts, they all require interaction between end users and climate experts.

Here, we lower the barriers faced by resilience practitioners in using climate data by summarizing global climate information into indicators and publishing them as open datasets in common geospatial formats. This addresses several challenges: raw climate model outputs are too large to fit on desktop computers by several orders of magnitude, requiring specialized software expertise and computing resources to process; potential climate data users suffer from a paradox of choice when differentiating between individual models in an ensemble; and climate data often need to be analyzed in combination with other information to provide useful insights. In creating these indicators, we attempt to move agency from the domain of the climate scientist to the domain of the geographic information system (GIS) analyst to enable a much larger user group to consume climate data, and we provide a general-purpose product that can be used to understand and communicate the effects of climate change.

This document summarizes our approach and discusses cautions and limitations in using these data. Resulting data, listed in Table 1, are visualized and available for download at <https://PREPdata.org> and <https://resourcewatch.org>.

DATA SOURCES

Future climate data for these indicators are originally derived from the suite of Global Circulation Model (GCM) experiments that were produced for the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC 2014). These experiments, known as the Coupled Model Intercomparison Project phase 5 (CMIP5) (Taylor et al. 2011), were conducted by research institutions across the world, and include results from climate models designed to simulate climate under different levels of greenhouse gas concentrations.

We use results for two climate scenarios, known as representative concentration pathways (RCPs) (Moss et al. 2008, 2010)—a low emissions scenario (RCP 4.5), in which greenhouse gas emissions decline, limiting global average temperature increase to approximately 2–3 degrees Celsius (°C) by 2100, and a high emissions scenario (RCP 8.5), in which unconstrained greenhouse gas emissions lead to an increase of 3–6°C by end of century (Arora et al. 2011). From a policy perspective, RCP 4.5 corresponds to an aggressive pursuit of the 2015 Paris Agreement (UNFCCC n.d.), where countries rapidly decrease greenhouse gas emissions beyond current voluntary commitments.

Rather than using the CMIP5 GCM outputs directly, we use post-processed modeled temperature and precipitation data from two sources: NASA (National Aeronautics and Space Administration) Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) (Thrasher and Nemani 2015), available at <https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp>, for global indicators and Localized Constructed Analogs (LOCA) CMIP5 projections for the continental United States (Pierce et al. 2014; Maurer et al. 2007), available at https://gdo-dcp.ucllnl.org/dncs_downscaled_cmip_projections/.

These datasets are derived from the CMIP5 outputs through a statistical process known as downscaling, which increases their spatial resolution and statistically matches them to the historical record. NEX-GDDP uses the Sheffield et al. (2006) dataset as historical reference and LOCA uses Livneh et al. (2015). The relationship between these datasets and the resulting indicators, as well as the order of magnitude reductions in volume size, are shown in Figures 1 and 2.

Figure 1 | Relationship between CMIP5, Downscaled Climate Datasets, and PREP Indicators

Note: *Data size estimates assume internal file compression. CMIP5 data size estimate from Easterbrook (2012). "Layers" refer to the number of two-dimensional slices (i.e., maps) one would need to display the entire dataset. Abbreviations: CMIP5: Coupled Model Intercomparison Project phase 5; PREP: Partnership for Resilience and Preparedness; NEX-GDDP: NASA (National Aeronautics and Space Administration) Earth Exchange Global Daily Downscaled Projections; LOCA: Localized Constructed Analogs; hr: hour; yr: year.

Source: Authors

Figure 2 | **Illustration of Database Sizes**

Note: 1 petabyte = 1,000 terabytes = 1,000,000 gigabytes.

Source: Authors.

Downscaling

GCMs operate by modeling the physics of the atmosphere, ocean, and land. A model run may start several decades in the past and end a century into the future. GCMs re-create large-scale climatic patterns such as air and ocean currents, monsoons, and cyclonic storms, but will deviate from what actually occurred. Due to computational cost, GCMs are typically run at a relatively coarse spatial resolution that may not capture local variations in climate. In addition, different GCMs use different spatial resolutions (between one and three degrees) and may not use a regular cartesian grid. Downscaling addresses both of these issues: Values are resampled onto a regular grid, and localized variation is reintroduced using higher-resolution historical data.

Techniques for downscaling vary by dataset. Temporal matching is typically achieved via cumulative distribution function mapping. This works by shifting modeled values such that the frequency of their occurrences matches the frequency in a reference dataset. For example, in NEX-GDDP, for any given location over the period 1950–2005, the frequency for which there were 5 millimeters (mm) of rainfall on each calendar day of the year (± 15 days) will match the observed frequency. Downscaling also maps the coarse-resolution data onto the finer-resolution reference dataset. In its simplest form, spatial downscaling takes the

value of each coarse-resolution cell in the modeled dataset and divides it into finer-resolution cells to match the spatial distribution within that area in the reference dataset.

LOCA uses a more in-depth downscaling method (“LOCA” refers to the method: Localized Constructed Analogs). This method attempts to find days in the fine-resolution reference data that best match each day in the coarse-resolution model output (Bracken 2016). In contrast to NEX-GDDP, which uses the average historical distribution for the day of the year as the fine-resolution counterpart, for each modeled day, LOCA searches for historical days that have matching broad-scale (~1,000 kilometer [km]) and local-scale (~100 km) weather patterns. In addition, LOCA applies an additional frequency-based bias correction procedure to every location, matching variability on daily to decadal timescales with the historical record. LOCA’s downscaling procedure allows it to more exactly match the historical record, in terms of both localized weather patterns and seasonal and interannual variation. For applications where these characteristics matter, such as hydrological modeling, LOCA may perform substantially better.

The downscaling procedures for both LOCA and NEX-GDDP linearly shift temperature values while multiplicatively scaling precipitation values. This preserves the modeled linear change for temperature (e.g., $+1^\circ$) while preserving multiplicative change for precipitation (e.g., $1.1\times$ mm/year). Although downscaling does not increase the overall accuracy of the data, it can increase the accuracy of applications where spatial distribution matters. For example, the amount of precipitation that occurs on one side of a mountain range versus the other will affect river discharge calculations.

INDICATOR SELECTION

Indicator selection was conducted in consultation with the Partnership for Resilience and Preparedness (PREP), a consortium of U.S. federal agency representatives, as well as private sector and nongovernmental organizations (NGOs). The full list of PREP partners can be found at <https://prepdata.org/partners>. Our set of indicators in large part follows work done by the Cooperative Institute for Climate and Satellites – North Carolina for the U.S. Third National Climate Assessment (Kunkel and Buddenberg 2014).

First, to understand the data needs of individuals working in climate adaptation and resilience planning, representatives from the PREP Engagement Workgroup, led by World Resources Institute and Future Earth, conducted structured interviews from January to April 2017 with 42 potential end users. Interviewees were identified through the partnership network and covered 6 continents and 27 countries. Sixty percent of respondents were located in the United States. There was a mix of sector representation, with 43 percent working in the NGO sector, 31 percent in the public sector, 20 percent in the private sector, and 6 percent in the academic sector. Seventy percent of respondents identified as “analysts.”

In open-ended responses, “access to data” was the most frequently reported barrier in trying to find and acquire data and information for climate adaptation and resilience planning, mentioned by 12 respondents. In cases where data are available and are able to be acquired, more than half of respondents identified finding and obtaining data at the correct spatial scale or resolution as a barrier. Asked about which data they find most useful, the three most frequent responses were “temperature” (19), “precipitation” (16), and “projections” (11). Information on “asset” (6) exposure and “vulnerability” (4) were also frequently cited.

Results from these interviews and the following criteria were used to inform the selection of a preliminary set of indicators:

- **User need:** Potential users indicate desire for these data.
- **Coverage:** Indicators cover a range of climate change effects, including changes in both average conditions as well as at the extremes.
- **Relevance:** Indicators can be used to understand potential climate change impacts on agriculture, energy, disaster risk, and water resources.
- **Transparency:** Indicators are simple, such that others can readily verify or re-create them.
- **Robustness:** Indicators attempt to minimize sources of bias and variation.

In addition, we sought to minimize the total number of individual data layers and overall size of the output dataset. The final set of indicators, listed in Table 1, was selected following feedback from the partnership.

Table 1 | **Selected Indicators and Descriptions**

Indicator	Description
Temperature indicators	
Average low temperature	Annual average daily minimum temperature.
Average high temperature	Annual average daily maximum temperature.
Average temperature	Annual average temperature.
Heating degree days	The annual sum of the number of degrees that each day's mean temperature is below 65°F (18.3°C). Heating degree days are often used to estimate heating needs in buildings.
Cooling degree days	The annual sum of the number of degrees that each day's mean temperature is above 65°F (18.3°C). Cooling degree days are often used to estimate cooling needs in buildings.
Frost free season	Annual average longest run of days with minimum daily temperatures above freezing.
Precipitation indicators	
Cumulative precipitation	Annual average total precipitation.
Dry spells	Annual average count of five-day periods without precipitation. For dry periods lasting more than five days, each additional day without precipitation counts as a fractional (1/5) dry period.
Extreme events	
Extreme heat days	Annual average count of days with high temperatures greater than the 99th percentile high temperature during the baseline period of 1960–90.
Extreme precipitation days	99th percentile precipitation during the baseline period of 1960–90.

Notes: Abbreviations: F: Fahrenheit; C: Celsius. Source: Authors.

INDICATOR CALCULATIONS

All indicators are calculated for each year, climate model, and scenario on a per-pixel basis (Figure 3, A). We then construct 31-year averages for each model (e.g., “ACCESS1-o” and “MIROC5” in the figure) and scenario for a baseline period (1960–90) and nine periods centered on each decade from 2000 to 2080 (Figure 3, B). The 31-year averages minimize the effects of annual and decadal variation and highlight the long-term climate signal. Finally, we compute ensemble medians, 25th and 75th percentiles, and interquartile ranges across the ensemble; that is, the set of 21 and 32 climate models in NEX-GDDP and LOCA, respectively (Figure 3, C). Indicators are converted from the original units (Kelvin and kilograms per square meter per second [$\text{kg}/\text{m}^2/\text{s}$]) to degrees Celsius and millimeters per year for temperature and precipitation, respectively.

In addition, we produce additive difference layers for temperature indicators and multiplicative change layers for precipitation indicators, which show the change between each future period and the baseline (1960–90) period. The baseline period was selected to align with long-standing guidance from the World Meteorological Organization (WMO 2017); however, we use a 31-year period so that periods are centered on calendar years.

Figure 3. Illustrative Example of Ensemble Indicator Calculation Using Average High Temperature (tmax)

RESULTS

Figures 4 and 5 show projected increases in temperature and precipitation indicators as derived from NEX-GDDP. Widespread increases in temperature are projected, with greater increases in high-latitude regions. By 2050 (middle of the 2035–65 period), high temperatures that are historically seen only three to four days each year may become the norm for more than two months each year across much of temperate and tropical zones. Higher temperatures will increase cooling energy demand and decrease heating energy demand, while substantially increasing growing-season lengths in temperate regions.

Precipitation changes are projected to be more varied across the world, generally showing increases in mean precipitation in high-latitude regions and a poleward shift of subtropical arid regions. In addition, precipitation is projected to occur in fewer, but more intense, events. Except in the few areas that are projected to see

Figure 3 | Illustrative Example of Ensemble Indicator Calculation Using Average High Temperature (tmax)

Notes: Part A starts with daily maximum temperature data for one of the climate models; one year of data is extracted and then averaged to calculate an annual indicator. In Part B, the annual indicators for each year are then summarized into a 31-year average. In Part C, the 31-year averages for each climate model are combined into the final ensemble indicators. Abbreviations: tmax: maximum temperature; ACCESS1-0 and MIROC5 are the names of climate models.
Source: Authors.

Table 2 | Calculations for Selected Indicators

Indicator	Variable Name	Annual Indicator Calculation	Calculation Explanation
Temperature indicators			
Average low temperature	tmin	mean (tmin)	Mean of minimum temperature
Average high temperature	tmax	mean (tmax)	Mean of maximum temperature
Average temperature	tavg	mean ((tmax + tmin) / 2)	Mean of temperature
Heating degree days	hdds	sum (max ((18.33°C – tavg), 0))	Sum of the number of degrees the average temperature is below 18.33°C (65°F); if the average temperature is above 18.33°C, it is counted as zero
Cooling degree days	cdds	sum (max ((tavg – 18.33°C), 0))	Sum of the number of degrees the average temperature is above 18.33°C (65°F); if the average temperature is below 18.33°C, it is counted as zero
Frost free season	ffs	max (runs (tmin > 0°C))	Maximum run of days where minimum temperature exceeds 0°C (32°F)
Precipitation indicators			
Cumulative precipitation	pr	sum (pr)	Sum of precipitation
Dry spells	dry	sum ((if run ≥ 5 then run / 5 else 0) for run in runs (pr < 1 mm))	Sum of 5-day periods with less than 1 mm of precipitation; if a run exceeds 5 days, we count it as the number of days divided by 5 (so each additional day counts for 1/5 of a 5-day period)
Extreme events			
Extreme heat days	xs	count (tmax > baseline_q99tmax)	Count of days where the maximum temperature exceeds the 99th percentile of the baseline of 1960-90
Extreme precipitation days	xpr	count (pr > baseline_q99pr)	Count of days where the maximum precipitation exceeds the 99th percentile of the baseline of 1960-90

Notes: Calculations are performed on daily data for each year, model, and scenario to generate annual indicators. When calculating runs of consecutive days, we append each year to itself to include runs that cross New Year's Day. Abbreviations: °F: degrees Fahrenheit; °C: degrees Celsius; mm: millimeter; t: temperature; pr: precipitation.

Source: Authors.

substantial drying, historically extreme precipitation events are expected to become more frequent worldwide. Even as precipitation increases, dry periods are projected to increase in length and frequency.

Figures 6 and 7 show the same indicators for the continental United States as derived from LOCA. Results are largely consistent among NEX-GDDP and LOCA

indicators. However, LOCA indicators show reduced banding and increased model agreement, particularly for indicators that depend on threshold exceedance (e.g., dry spells, frost free seasons). This is likely because LOCA's downscaling methodology is better able to match statistical patterns over seasonal time scales and results in less spurious precipitation (Pierce et al. 2014).

Figure 4 | **Ensemble Median Change in NEX-GDDP-Derived Temperature Indicators from 1960-90 Baseline to 2035-65 Projection under High Emissions Scenario (RCP 8.5)**

Notes: Left column shows the difference between future and baseline periods. Right column shows model agreement as measured by the interquartile range (IQR) for the future period. Scales are aligned such that each tick on the right side corresponds to a half-tick on the left side. NEX-GDDP data also cover oceans but these data are masked in this figure. Abbreviations: NEX-GDDP: NASA (National Aeronautics and Space Administration) Earth Exchange Global Daily Downscaled Projections; RCP: representative concentration pathway; °C: degrees Celsius.

Source: Authors.

Figure 5 | Ensemble Median Change in NEX-GDDP-Derived Precipitation Indicators from 1960-90 Baseline to 2035-65 Projection for High-Emissions Scenario (RCP 8.5)

Notes: Left column shows the ratio between future and baseline periods. Right column shows model agreement as measured by the interquartile range (IQR) divided by the median for the future period. Scales are aligned such that each tick on the right side corresponds to a half-tick on the left side. NEX-GDDP data also cover oceans but these data are masked in this figure. Abbreviations: NEX-GDDP: NASA (National Aeronautics and Space Administration) Earth Exchange Global Daily Downscaled Projections; RCP: representative concentration pathway; mm/yr: millimeters per year.

Source: Authors.

Figure 6 | **Ensemble Median Change in LOCA-Derived Temperature Indicators from 1960-90 Baseline to 2035-65 Projection under High-Emissions Scenario (RCP 8.5)**

Notes: Left column shows the difference between future and baseline periods. Right column shows ensemble agreement as measured by the interquartile range (IQR) for the future period. Scales are aligned such that each tick on the right side corresponds to a half-tick on the left side. Abbreviations: LOCA: Localized Constructed Analogs; RCP: representative concentration pathway; °C: degrees Celsius. Source: Authors.

Figure 7 | Ensemble Median Change in LOCA-Derived Precipitation Indicators from 1960–90 Baseline to 2035–65 Projection for High-Emissions Scenario (RCP 8.5)

Notes: Left column shows the ratio between future and baseline periods. Right column shows ensemble agreement as measured by the interquartile range (IQR) for the future period. Scales are aligned such that each tick on the right side corresponds to a half-tick on the left side. Abbreviations: LOCA: Localized Constructed Analogs; RCP: representative concentration pathway; mm/yr: millimeters per year.

Source: Authors.

Model agreement appears to be higher in temperature indicators than in precipitation indicators. For both datasets, it should be expected that the range between the high (75th percentile) and low (25th percentile) estimates of indicators is higher where projected change is higher.

In addition, model agreement is lower for indicators that depend on threshold exceedance, as a small absolute difference in projected values could result in values falling on the other side of the threshold.

Figure 8 | Indicator Display on PREPdata.org

Notes: This map shows the projected change in cumulative precipitation in millimeters of change, between 1960–90 and 2051–80. The areas in blue green are projected to have more precipitation, whereas the areas in brown are expected to have less. The chart below the map shows the projected change for a 25 square kilometer area in Algeria, indicated by the yellow dot on the map. In the chart, the dotted black line shows the ensemble mean of the 21 climate models and the gray shaded area shows the range between the 25th and 75th percentiles. Abbreviation: mm: millimeter.

Source: PREPdata.org.

These indicators are available for download and can be viewed on an interactive map at <https://prepdata.org>. Users can view ensemble median indicators on an interactive map, and overlay them with demographic, land use, and infrastructural data. They can also select specific locations to view changes over time, as well as see the 25th and 75th percentile estimates, as shown in Figure 8.

DISCUSSION

The indicators developed for this study provide a starting point for understanding and analyzing the likely effects of climate change. In particular, they are intended to provide a broad-scale indication of how climate change may affect agriculture, energy requirements, and other environmental and social factors.

We provide these data in several formats to enable users with varying levels of expertise to make use of the climate information. The interactive maps are most accessible, enabling lay users to answer simple climate questions. Are heating or cooling demands projected to increase in this city? Is precipitation expected to increase or decrease in my watershed? Is the growing season likely to change in my state's agricultural region? This visual analysis informs on the general magnitude and directionality of change. GIS datasets enable desktop analysis in combination with a wealth of other open data on infrastructure, demographic characteristics, and environmental characteristics. Finally, open source code enables others to re-create the same indicators, adjust thresholds, or produce new ensemble indicators on commodity hardware. This hierarchy of data products is intended to maximize the potential of this information.

As with all climate projections, there are limitations in how well these indicators can forecast the future. Users should keep in mind the following caveats:

- There remain areas of weakness in global circulation models. In particular, some models perform better than others in re-creating regional climate patterns such as monsoons in hindcasts. For specific applications, it may be appropriate to select individual models based on regional performance.

- The downscaling approaches used to produce these indicators inherently assume that the relative spatial patterns in temperature and precipitation will remain constant under future climate change. Dramatic shifts in global weather patterns, such as the slowing or reversal of major air and ocean currents, are possible but will not be captured in these indicators.
- The historical data used for downscaling vary in quality across the world. In particular, areas that have short records or sparse coverage of in-situ weather observations may have reduced accuracy.

Because these global circulation models are developed by independent research teams and incorporate different assumptions and mechanisms, it is likely that they cover a substantial range of probable futures. We provide both low and high estimates so that users can see and evaluate this likely range of outcomes. For example, ensemble median projections show a 10 percent decrease in precipitation in Southern California; however, the 25th and 75th percentiles range between approximately -20 percent and +10 percent annual average precipitation. At the same time, one of the primary challenges of working with and communicating climate projections is that, inherently, we can never achieve universal agreement about what will happen in the future. We provide ensemble medians (across the climate models) as a reasonable best guess of future conditions. Understanding the potential range of outcomes is essential to developing robust plans for the future, but a single best estimate more clearly communicates likely change.

LIST OF ABBREVIATIONS

CMIP: Coupled Model Intercomparison Project

GCM: Global Circulation Model

GIS: geographic information systems

LOCA: Localized Constructed Analogs

NEX-GDDP: NASA (National Aeronautics and Space Administration) Earth Exchange Global Daily Down-scaled Projections

PREP: Partnership for Resilience and Preparedness

RCP: representative concentration pathway

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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