Guidance for Understanding Climate Conditions and Climate Change, and Determining Physical Climate Risks in Operational Programming

Climate Change Knowledge Portal (CCKP)
2024

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Scope of this Document

There is a growing demand for climate science data to inform decisions such as investment, adaptation, resilience, and risk management across workstreams through tools such as climate assessments. However, these efforts require a foundational level of climate science literacy, which technical specialists and experts in other sectors may lack. This document provides practical guidance on interpreting climate data accurately and identifying and evaluating physical climate risks using the World Bank's (WB) Climate Change Knowledge Portal (CCKP). This guide's intended audience is the operational staff of the WB as well as the broader development community who need to undertake evaluations of historical and projected climates and potential changes for a country or region.

Additional supporting documents to the guidance provided here include CCKP's 'User Manual', 'Metadata', and 'Glossary'. The User Manual provides a comprehensive overview of CCKP functions and features by introducing key components, and step-by-step advice for assessing data and visualizations. The Metadata provides sources for historical and projected climate data, as well as the technical approaches and methodologies employed for CCKP's data processing and evaluation protocols. Finally, the glossary lists key terms and definitions useful for understanding CCKP pages and climate-related topics, with further elaboration in this document.

The intent of this operational guidance document, in conjunction with CCKP's User Manual, Metadata and supplementary resources, is to build foundational user knowledge on climate data and changing climate conditions and to provide guidance for how to define and understand: climate risks within mean climate conditions, climate trends versus natural variability, extreme event distributions, and contextually unique climate variables across both historical and projected contexts. This user guide presents an overview of:

- **Climate** and the basic foundations for understanding the physical processes involved in climate and climate change, and
- **CCKP**, including how it is designed to strategically fill a critical gap in accessing and using consistent and comparable global climate data by the development community.

The remainder of this document describes specific ***Stages*** (1-5) and underpinning ***Steps*** within each stage required to properly undertake a climate assessment using CCKP.

- **Stage 1.** *Identify scope* and unique assessment needs.
- **Stage 2.** *Identify context*, including relevant national documentation and specific climate classifications for a defined area of interest.
- **Stage 3.** *Understand historical climates and current climatology* through historical and observational data offerings, including how to define current climate contexts for unique areas of interest.
- **Stage 4.** *Understand future climates*, including the development and application of modeled climate data and scenarios, appropriate interpretation of modeled data, caveats for modeled data application in small vs. large spatial units, types of trends and variability, and appropriate interpretation of current and future climate variables to suit unique contexts.
- **Stage 5.** *Understand future extremes and risk conditions,* including key terms, appropriate interpretation of changes in extremes as well as attribution and assessment of other unique risk conditions such as coastal inundation risk due to sea level rise.

The stages in this document are designed to offer a roadmap for defining physical climate risks for both historical and projected climates, across various scenarios, for a designated focus area. Each stage of the guide provides a comprehensive set of tips and explanations, along with detailed examples on how to draw appropriate conclusions from data and unique contexts. Dedicated sidebar boxes additionally highlight examples with detailed technical information that may be particularly applicable for certain use cases.

It is neither plausible nor possible to address every question or define all applications of climate data for every location and its potential unique sectoral needs in this document. This document offers guidance to support your unique investigation with practical examples intended to support a grounded understanding and increased comfortability with climate data and its application.

Understanding ‘Climate’

Our climate is changing, which has resounding implications across ecosystems, economies, and communities. Since the beginning of the Industrial Revolution, people have burned increasing amounts of fossil fuels and altered landscapes, such as by converting vast areas of forested land into farmland, which affects the global concentration of greenhouse gases. These collective human activities are the primary causes of our changing climate today. The burning of fossil fuels produces carbon dioxide, a greenhouse gas, that results in the ‘greenhouse effect.’ In short, the greenhouse effect is a warming process in which incoming solar energy reradiated as heat by the Earth’s surface becomes absorbed by certain gases in the atmosphere, rather than escaping back into space. Our planet’s atmosphere, containing relatively small but powerful amounts of carbon dioxide and other similar gases, therefore acts like the glass of a greenhouse that traps heat and makes the air inside (or air closer to the earth’s surface) warmer than it otherwise would be. *Carbon dioxide is the primary cause of human-induced climate change and once in the atmosphere, remains there for multiple decades to thousands of years.* Other greenhouse gases, such as methane and nitrous oxide, also impact the Earth’s energy balance. For example, methane gas creates more significant warming effects (upwards of four times the warming of CO_2) but remains in the atmosphere for relatively shorter periods (roughly 12 years); nitrous oxide meanwhile can continue to warm the planet for about 120 years. It is also important to recognize that not all substances produce warming, and elaborating on those is beyond the scope of this document.[1]

Carbon dioxide and other substances are referred to as climate forcers as they force or push the climate towards warmer, cooler, wetter, drier states by affecting the flow of energy coming into and leaving the earth’s climate system. Small changes in the Sun’s energy reaching the earth, among other factors, can naturally force some climate change. Despite natural variation in the Sun’s radiance, the greenhouse gases accumulated since the Industrial Revolution are estimated to have had ~50 times the warming power than such natural variations in the Sun's radiance alone. *Future emissions of greenhouse gases, particularly carbon dioxide, will strongly determine how much more climate warming occurs.*

Weather and climate are not synonymous. While weather reflects short-term conditions of the atmosphere, climate refers to the long-term regional or global average of conditions such as temperature, humidity, precipitation, wind, and radiation, among others. While the weather can change in just a few hours, climate changes over longer timeframes. Climate events, like El Niño, (see *Stage 3, Step 3*), happen over several years, small-scale fluctuations happen over decades, and larger climate changes continue to occur over

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[1] In fact, certain aerosols that originate from human activities and pollute the air, have reflective properties that produce cooling rather than warming effects within the atmosphere. So ironically, the reduction in air pollution over the last few decades has accelerated climate change.

hundreds and thousands of years. Climate change is the significant variation of average weather conditions becoming, for example, warmer, wetter, or drier—over multiple decades or longer. *It is the longer-term trend that differentiates climate change from natural weather variability.*

Climate change can involve both changes in average conditions and changes in variability (see *Stage 3, Step 3*), including, for example, extreme events (further detailed in *Stage 5*). The Earth's climate is naturally variable across all time scales. However, its long-term state and average temperature are regulated by the net balance between incoming and outgoing energy. Any factor that causes a sustained change to the amount of incoming energy or the amount of outgoing energy can lead to climate change. Different factors operate on different time scales, and not all those factors have been responsible for changes in the Earth's climate. Changes in the distant past, identified and understood through paleoclimate research, can be relevant to contemporary climate change. Factors that cause climate change can be divided into two categories - those related to natural processes (changes internal to the climate system, such as variations) and those related to human activity. Ocean currents, atmospheric circulation, or volcanic eruptions can also influence the climate. Natural internal climate variability is superimposed on the long-term, forced climate change.

The climate research community relies on:

- **Historical and observational records** to understand historical climate epochs (paleoclimate), the recent past (change since the Industrial Revolution), and current climate conditions (present day climatologies); and
- **Modeled climate projections** to understand the Earth’s carbon cycle feedback in response to anthropogenic emissions, which change atmospheric concentrations of greenhouse gases and aerosol, and ultimately result in radiative forcings that drive the climate system changes.

Understanding climate conditions and potential changes at global, regional, and local scales is critical in the design and implementation of projects, investments, and policies.

The Climate Change Knowledge Portal (CCKP)

The Climate Change Knowledge Portal (CCKP) is the World Bank's (WB) designated climate data service. CCKP is designed as a global public good, to provide the WB, its operational teams, country clients, and the broader global development community with a comprehensive suite of climate and climate change resources that are both transparent and accessible. Policymakers and development practitioners require operational climate data products (as opposed to scientific research outputs) that are produced in a consistent and systematic manner to enable inter-comparable work across countries and sectors.

CCKP's user-centric platform is built on a systematic data archive[2] that provides *access to processed, operational climate data products derived from Primary Climate Data Collections*, producing outputs that are robust, science-driven, and consistent, supporting inter-comparable work. The standardized approach within CCKP ensures the systematic and consistent production of data offerings and use of the best available climate change information.[3] This ensures that users are provided with an appropriate, robust, trusted source of information that enables users to define, understand, and then communicate impacts of climate, natural variability, and future climate changes across contexts to meet climate change assessments, impact modeling, and corporate climate commitments. The climate products consist of basic climate variables as well as a large collection of more specialized climate indicators representing selected characteristics of climate with direct relevance to applications, such as evaluation of evolving risks. Products are *freely accessible and available for all countries*.

CCKP adheres to the same data distributions and technical approaches of the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports as well as internationally agreed standards set by the World Metrological Organization. The IPCC Assessment Reports and Working Groups identify data distributions appropriate for operational use and best practices for data processing, presentation, and interpretation. However, data is presented only at a global or regional scale, not by individual countries; note that this not a deficiency but by design.

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[2] CCKP's systematic data archives and flexible architecture enables efficient management of large and complex data volumes and the ability to respond quickly for new product generation to meet expressed needs from WBG teams.

[3] While public access to raw climate data is improving, widely distributed data archives commonly differ in formats, time spans, samples (models), and even strategies to synthesize data(ensembles). This requires specialized knowledge by each user to handle the data formats, to be aware of differences between collections, to themselves bridge inconsistent spatial and temporal resolutions, etc. CCKP adds value by: 1) offering a systematic way of pre-processing the raw observed and model-based projection data to enable inter-comparable use across a broad range of applications; 2) production of an expansive range of climates variables (70+) from which users can investigate the various, often nuanced, application-oriented aspects of climate across different scenarios; 3) gridded data (CF standard netCDF files) at global domain using a common grid; 4) precomputed data can be extracted per variables, select timeframes, climate projection scenarios, across ensembles or individual models, etc.

To fill this gap and support user operational needs, CCKP offers both global gridded climate data (available as netCDF format) as well as spatial aggregations per WB approved national, sub-national, watershed and Exclusive Economic Zone (EEZ) scales. For spatially aggregated data, we apply a weighting to each unique polygon (per each unique shapefile designating the various scales) to appropriately calculate the proportion of a grid-cell within a designated spatial unit. Maps, as represented on a digital platform, are a 2-D representation of the Earth. So, an additional latitudinal weighting is applied to all spatial units to accurately capture the curvature of the Earth and corresponding physical properties. For a detailed description of why we apply spatial and latitudinal weighting as opposed to zonal statistics (and why we do not recommend using zonal statistics to calculate spatially aggregated gridded climate data), see Annex. You will find detailed information on data sources, presentations, and methods for observed and projection data in *Stages 3-5* of this document.

Rationale for Using CCKP For Your Climate Data and Analysis

The WB's CCKP is a nexus between climate science, international development, and the operational application of climate change information. CCKP's standardized approaches result in products that are systematically produced resulting in comparable and consistent outputs. This results in climate data products (available for all countries) that support comparisons across different countries and sectors to understand conditions and potential change across both space and time. CCKP's data service platform provides a comprehensive suite of geospatial climate information, contextualization, and dynamic visualizations across the largest set of publicly available global climate indicators to support the widest range of use and application possible.

While there is no 'perfect solution' or 'silver bullet' for understanding and defining our future climate, we can rely on the latest science, and available data, information, and tools to help us identify current and potential future physical risk conditions and assess the robustness of data which tries to model these futures. CCKP works to provide users with access to the latest scientific understanding and available data necessary to garner a more complete picture of historical and current conditions, the potential for emergence or exacerbation of physical climate risks, and related impacts from future climates and development pathways. As our scientific knowledge as well as technical and computational capabilities continue to expand, we are ever able to more accurately understand critical areas of our world and better reflect these physical properties. However, it must also be recognized that for some geographies and physical processes, a clear picture of associated climate responses remains difficult to understand and model.

Currently CCKP data is:

1. used to support WB climate corporate commitments, including Country Climate and Development Reports (CCDRs), Paris Alignment, Climate and Disaster Risk

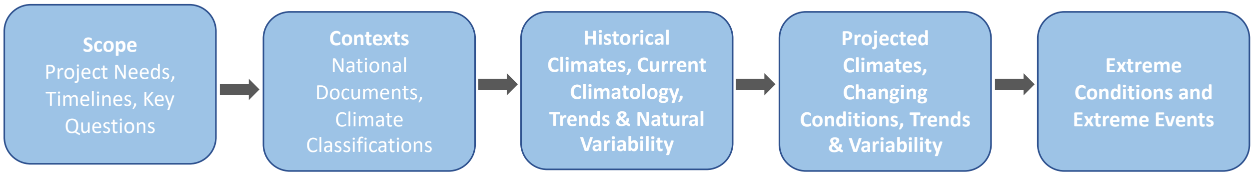
Screening (CDRS), sectoral vulnerability assessments (e.g., health), climate impact modeling at country and sectoral level, and climate risk screening and analytical efforts at the project level,

2. integrated directly across a wide range of World Bank Group data platforms to support specific analytical efforts, tools, and inter-sectoral workstreams,
3. used by client countries to support scientific efforts and distributed climate information of national-level hydro-met services and climate centers[4], and,
4. relied upon by the global development community, such as development practitioners, policymakers, civil societies, students, researchers, multilateral development banks, and international partners.

All data is freely available for download and accessible by public APIs. For a complete description of data sources, methods, and data collections used, see the Metadata Guide.

Overview of Climate Analysis Stages

The CCKP website is built to present data for users to iteratively move through each webpage to build knowledge of current climate contexts and natural variability for a designated area and to explore the different ways climate conditions and climate-driven events may be changing across space and time through future climate scenarios. The next sections of this guide present the five key stages necessary for undertaking a climate assessment, with each stage detailed through specific, recommended steps and rich examples for how to draw appropriate conclusions using data projections. The final section of this user guide summarizes key tips and best practices described in each of the stages below.



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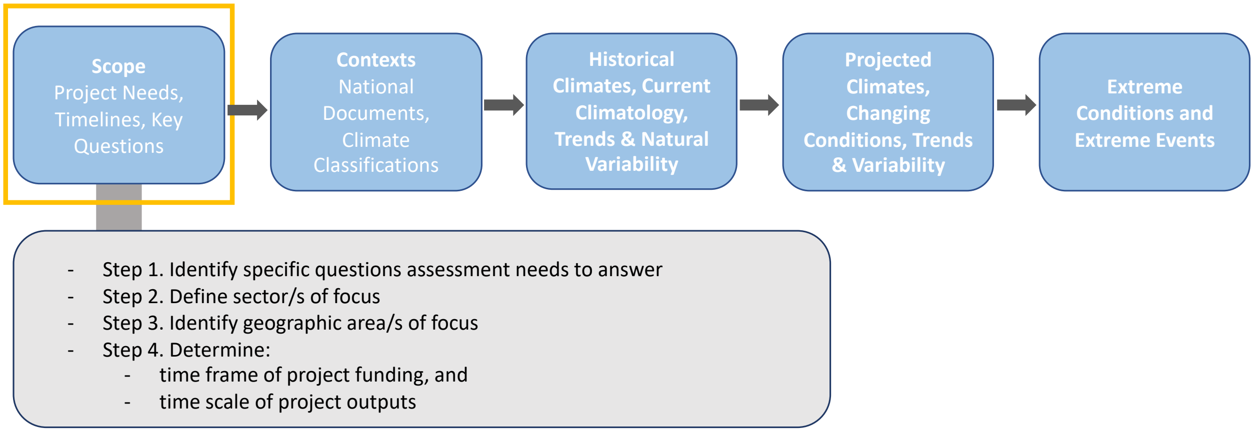
[4] Given the large data volumes and complexity of global climate model compilations, processing raw model outputs can be prohibitive for areas with limited technical, computational, and scientific capability. As such, processed climate data from CCKP is used directly for national programming and analysis.

Stage 1. Define Scope



- Step 1. Identify specific questions assessment needs to answer
- Step 2. Define sector/s of focus
- Step 3. Identify geographic area/s of focus
- Step 4. Determine:
  - time frame of project funding, and
  - time scale of project outputs

Step 1. Identify specific questions your assessment needs to answer, and the potential input data required.

Each assessment is unique and therefore, prior to searching for data sources or products, it is useful to ascertain the question(s) you are trying to answer and perhaps the level of depth of climate analysis that is required.

- *What are your objectives and parameters for conducting a physical risk assessment?*
- *What is the spatiotemporal granularity required?*
- *Has a physical risk assessment been conducted previously? If so, what were the main findings?*
- *Were there any gaps that needed to be addressed as part of future assessments?*
- *What additional work is needed to complement the new assessment?*
- *Are there sectors, regions, risks, or investment portfolios of greatest concern?*

You will likely discover multiple types of input data are required (i.e., observed climate data, modeled climate projections, remote sensing products, household survey data, socio-economic data, unique sector parameters, etc.), which are not all available from one website. CCKP offers data derived from multiple primary climate data archives, in addition to a growing offering of socio-economic datasets and other resources. Links to other datasets and tools from other providers are identified in General Resources tab.

***To Note:** When considering what types of input data are required for addressing your client's needs, a common practice involves reverting to climate variables used by pre-defined sector-modeling, impact calculations, damage functions, or economic models. We must recognize that these models' input data often comprise a limited range of available climate variables (i.e., mean, min, max temperatures, and precipitation,* *typically at annual timescale), which does not offer an adequate picture of risk. While average mean annual temperature, for example, is often used as a basic proxy indicator for 'climate change', it does not actually tell us much about the magnitudes of physical climate risks and potential adverse impacts. Additionally, the use of annual data obscures one's ability to understand seasonal differences, natural variability within the climate system, and a broad range of more nuanced climate responses that present a more accurate risk condition. See Stage 3, Step 2 for further detail.*

Furthermore, the atmospheric response within complex models can become muted with greater amounts of input data. To create a more complete 'risk picture' that can help inform comprehensive adaptation, resilience, or financing plans, one should consider the variables included and excluded in impact modeling efforts. An assessment may need to account for data needs driven by the impact model's capabilities, but one can add value by also including a broader recognition of climate variables in the assessment's narrative and potential compounded risk elements (further detailed in Stages 4 and 5).

Step 2. Define sector(s) of interest.

Understanding sectors or sub-sectors of focus helps to provide the appropriate lens for interpreting climate data. While changing climate conditions are important for all countries and all sectors, conditions may be viewed differently depending on acute requirements.

***Example**: A health assessment investigating extreme heat impacts on the elderly population may consider the implications of future climate conditions differently than an energy assessment investigating infrastructure generation and supply capabilities for future peak summer seasons. Both efforts may use the same threshold-based temperature metrics but will likely interpret risks and the ensuing adaptation required differently, depending on their unique needs. Equally, each assessment may also require different variables, i.e., the energy assessment in this example would benefit from use of 'Cooling Degree Day' data to inform energy demand and supply requirements, whereas the health assessment would benefit from heat thresholds focused on the biophysiological limits of the human body.*

Step 3. Define geographic area(s) of focus.

Different geographies and topographies exhibit differing physical relationships with the climate system. As such, the specific area of an assessment is important for not only understanding how the climate responds, but how to interpret the climate signal.

- *Are you focused on a national scale, a specific zone within a country, or a regional assessment?*

- *Are you looking at a national picture or just a specific area of a country where a project is located? Does your assessment cover a low-lying, tropical coastal zone, a high-elevation, arid plateau, or a cold and snow-packed mountainous zone?*

Assessing a climate at a national scale for a country with a vast and diverse topography can result in a ‘muted’ climate signal, as it represents the national average across the dissimilar areas and their corresponding climates, particularly for highly heterogenous country geographies. One should consider this risk when analyzing data offerings. If you are only focused on a specific area of a country, it may be more appropriate to focus analysis on that specific region or subregion, as opposed to the national picture.

Step 4. Define *timeframe of project funding* and *timescale of project output* – and understand the important difference.

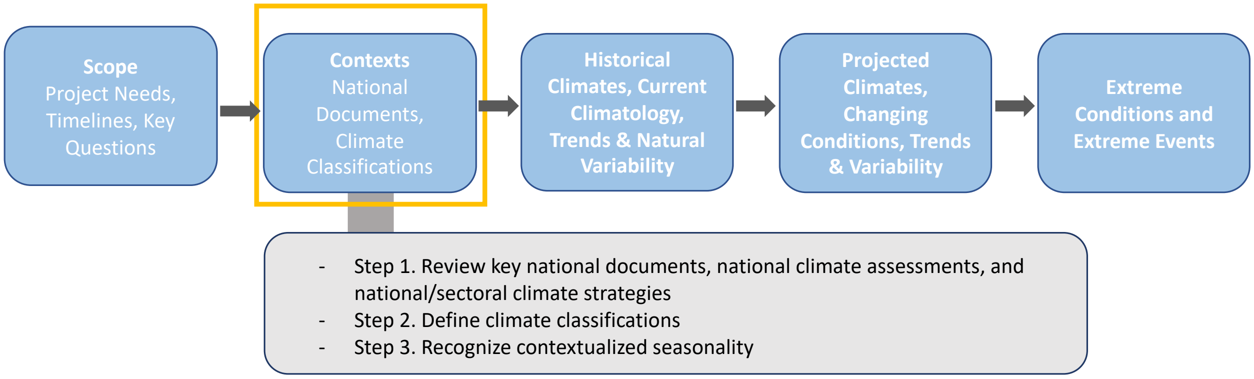
Assessments are often used to inform a particular investment by evaluating potential risks, usually over a specific and relatively short timeframe, i.e., two to five years. However, the finite timeframe of funding for the project should not define the timescale for assessing and determining climate risks related to the investment decision for the “asset life”. Instead, one should identify project targets (see examples below). *The lifetime of this funded output should dictate the timescale for the risk assessment.*

Example A*: An assessment for funding mangrove reforestation as a strategy to increase coastal resilience to flooding and coastal erosion should base its project timescale on the potential lifespan of the mangroves and not the limited funding timeframe by which mangroves are planted. If the mangroves have a life expectancy of 50 years, the climate assessment should use a projected climate horizon of 50 years into the future to assess potential conditions that the area may experience. What temperature thresholds and what changing precipitation dynamics will the mangroves need to withstand? This approach prompts the user to identify whether a more suitable (i.e., heat tolerant, drought resistant) varietal should be planted to achieve the most durable and effective project outcomes.*

Example B*: The construction of physical infrastructure, such as a bridge or road network, requires that an assessment account for the maximum possible precipitation events that could occur over the assets’ lifetime. If a bridge or road network is expected to perform its function for 80-100 years, this dictates an assessment that considers climate conditions at the end of the century, since risk estimates focusing only on near-term climate conditions can dangerously underestimate the potential risks of extreme events and their changing frequency of occurrence.*

Example C*: If your goal is to evaluate the upcoming seasonal conditions for planting a crop in a country and you are only concerned with very near-term, immediate time* *horizons, longer-term climate trends may not be appropriate for your assessment. In this case, understanding historical trends of the latest climatology, a seasonal forecast and/ or sub-seasonal outlook may offer more appropriate insights.*

Stage 2. Identify Context



- Step 1. Review key national documents, national climate assessments, and national/sectoral climate strategies
- Step 2. Define climate classifications
- Step 3. Recognize contextualized seasonality

Step 1. Review national documents.

Before beginning a climate evaluation, users are strongly recommended to review the existing documentation for their area of focus, since understanding existing national strategies may inform how one frames subsequent evaluation steps. Teams are advised to review the most recent National Climate Assessments and national commitments, such as Nationally Determined Contributions (NDCs), Long-term Strategies (LTSs), and National Adaptation Plans (NAPs). Identifying relevant sectoral or sub-national climate change strategies detailed in these documents could highlight past climate impacts, important policy goals, and state actions already undertaken that could help shape an assessment's inquiries and desired outputs. National-level documents may also provide important insight into how influences from global phenomena (such as the Intertropical Convergence Zone or ITCZ, El-Niño Southern Oscillation or ENSO, Indian Ocean Dipole or IOD, and the North Atlantic Oscillation or NAO) can impact one's area of focus. CCKP offers a library of national documents and resources, available through the General Resources tab.

Evaluation of historic and projected climate trends (*Stage 3*) and their influence on future socio-economic and wider risks will vary according to one's country, subregion, or sector of focus as well as ongoing vulnerability, adaptation, and/or mitigation strategies. However, after reviewing key national-level climate strategies, one can then select specific climate variables and shed light on topics or areas where further evaluation beyond the scope of this assessment may be necessary. This review can further provide insight into an area's perceived vulnerability and existing adaptive capacity[5], since adaptive capacities between

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[5] According to the IPCC's 6th Assessment Report, vulnerability is defined as 'the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.' Such adaptive capacity refers to 'the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences.'

and within populations vary and are important for understanding contextual and potential vulnerability to climate impacts.

***Example**: Very hot areas, projected to experience longer lasting and more intense hot seasons, face significant future risks to human health. If the area affected is a wealthy community with full-scale access to 24-hour active cooling mechanisms (i.e., air condition or evaporative cooling), these factors serve as an indication of the group's high degree of adaptive capacity and thus lower relative vulnerability*[6]*. However, if households in a community lack sufficient access to electricity (i.e., adequate power to operate an air conditioning unit) or do not have the purchasing power to pay the increasing energy costs of running an air conditioner, these communities are at higher relative vulnerability to extreme heat risks given their limited adaptive capacity. If a society without access to active cooling adapts to extreme heat conditions through strategies such as sleeping outdoors or on roofs to benefit from cooler night temperatures, these actions may no longer offer benefits in hotter projected extreme heat conditions. See Stage 5 for data interpretation examples of extreme heat risk.*

One must recognize that national-level plans may utilize different data sources and/or different processing methods than those of CCKP. As such, the user should not be surprised if data outputs between national documents, WB documents, and CCKP data do not 'match'.

Step 2. Define an area's climate context.

When assessing 'risk', change magnitudes, or the emergence of new climate conditions, a broad understanding of localized context is critical. When users try to understand change, and specifically, climate *change* – they should specify: *change of what? from what?*

An area's climate depends on several factors, including the amount of annual sunlight it receives, its topography, and its distance from the ocean or other major bodies of water. As a result, climate (and the specific physical responses of the climate system to increased atmospheric concentrations) can vary substantially within regions and often, within countries. Assessments must give due consideration to the unique climate characteristics of the area of interest. As a result, presenting only national-level statistics conceals important variations in temperature and precipitation patterns at the sub-national level, with critical implications for ongoing development. Determining a project area's climate context should therefore include the area's climate zone classification(s) and associated seasonality, described below.

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[6] Of course, there may be individuals in society without these benefits who experience a higher risk of heat exposure, lower adaptive capacity, and thus vulnerability to extreme heat conditions.

Step 3: Recognize seasonality

Climate Zone Classification

Climate zones are areas that possess distinct climate factors or combinations of factors. Each climate zone exhibits marked differences in temperature and precipitation patterns, which directly influence plant, animal, and human organisms. Many countries encompass more than one climate zone, therefore making it important to determine all the climate zones of an assessment area to adequately understand and track dynamic conditions across near-, medium- and longer-term futures.

One of the most widely used climate classification systems is the Köppen-Geiger Climate Classification System. The Köppen system divides the world's climates into five distinct climate zones based on the seasonal precipitation and temperature patterns needed to sustain locally suited vegetative growth. Each zone is further subdivided according to ranges of temperature and dryness. The major climate types of the Köppen-Geiger climate classification system are as follows:

Zone A: Tropical or equatorial zones
Zone B: Arid or dry zones
Zone C: Warm/mild temperate zones
Zone D: Continental zones
Zone E: Polar zones

CCKP presents global Köppen Classifications, as seen in **Figure A** below, using data derived from the CRU observational dataset (see *Stage 3, Step 1*). Classifications are calculated from the current climatology, 1991-2020. Thus, data presentations are consistent across Köppen classifications and CCKP's available observational data.

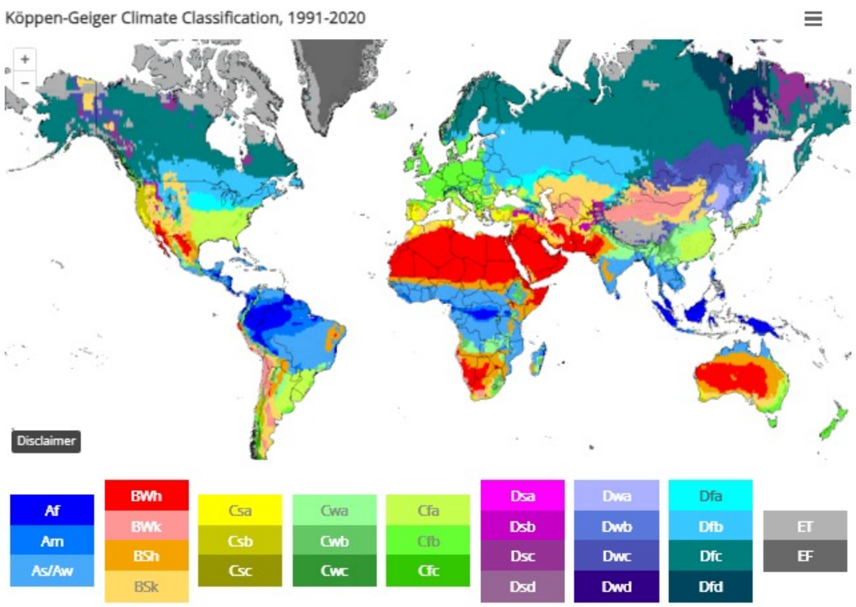
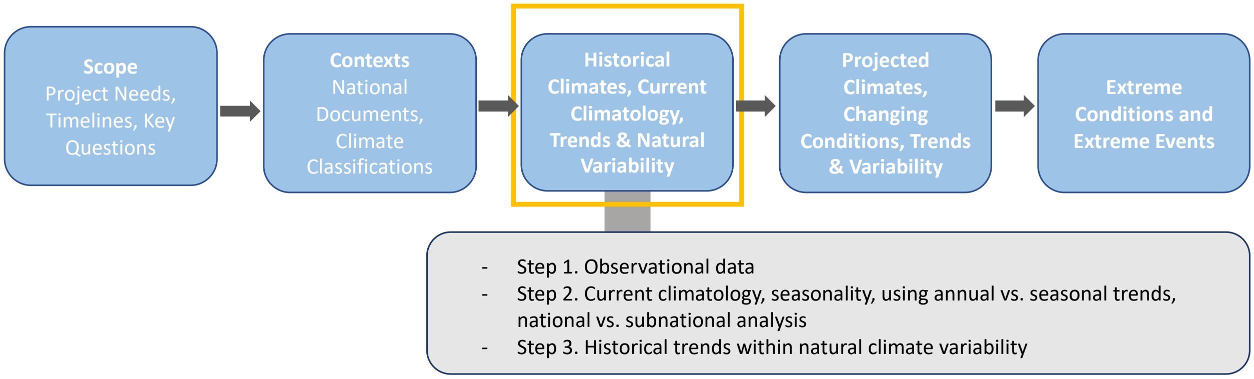


Figure A. World Map of the Köppen-Geiger Climate Classification System.

***Example**: When investigating a specific area, users should familiarize themselves with the area's current climate classifications and characteristic conditions. Does the area encompass a hot and humid coastline? Cold, high elevation mountainous terrain? A dry, warm plateau? Understanding an area's classifications can prepare you for better interpreting climate conditions, its seasonalities (see Stage 3, Step 2), and effects of changing conditions on the area.*

Users should access CCKP's ***Country Summary tab*** to explore the focus area's climate zones and potential differing classifications across the area.

Stage 3. Understanding Historical Climates, the Current Climatology, Historical Trends, and Natural Variability



- Step 1. Observational data
- Step 2. Current climatology, seasonality, using annual vs. seasonal trends, national vs. subnational analysis
- Step 3. Historical trends within natural climate variability

Step 1. Understand observational data.

Observational datasets, which can span long periods of time, are cornerstones of climate research. Observations, including those from satellites, field campaigns, and ground-based networks, provide the scientific basis of knowledge necessary for understanding changes occurring in the Earth's climate system across multiple temporal and spatial scales. These observations also inform the development, calibration, and evaluation of numerical models, including dynamical understandings of the physical, chemical, and biological processes that help explain past climate conditions and guide future projections. Long-running observational collections worldwide provide the climate research community with long-term records necessary for investigating climate change and its impacts. These include essential climate variables such as surface temperature, sea ice extent, sea level rise, and streamflow.

Observed data is a critical element for understanding the specific and unique climates of a designated area. By establishing a proper foundation of historical trends (both the pace and magnitudes of change overtime) and current climate contexts, scientists can better determine the potential for current and future risk within mean climates, natural climate variability, and extreme events.

CCKP offers two datasets for users to investigate recent, historical climate:

1. **CRU.** Observed, station-based data presented on CCKP is produced by the Climatic Research Unit (CRU) of the University of East Anglia[7]. CCKP derives its products using CRU TS (Climatic Research Unit gridded Time Series) dataset, one of the most widely used observational climate datasets available. Data are presented on a 0.5°

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[7] University of East Anglia. 2020: Climatic Research Unit. URL: http://www.cru.uea.ac.uk/about-cru

latitude by 0.5° longitude grid over all land domains except for Antarctica. It is derived by the interpolation of monthly climate anomalies from extensive networks of weather station observations and is available from 1901 to the present month.

This data is useful to understand mean climate conditions across the Essential Climate Variables (ECV): mean temperature, minimum temperature, maximum temperature, and precipitation. These are presented across designated 30-year climatologies: 1901-1930, 1931-1960, 1961-1990, and 1991-2020, the current climatology. Data is available as monthly, seasonal, or annual, from 1901-2022 (data is updated annually). On CCKP, CRU data visualizations can be found on the **Current Climate → Climatology tab,** or via Data Download.

2. **ERA5.** Satellite-derived, climate reanalysis products combine past observations with models to generate consistent time series of multiple climate variables. These are among the most-used datasets in the geophysical sciences. Reanalysis data provide a comprehensive description of the historical climate as it has evolved during recent decades (1950 to present). ERA5 provides sub-daily to daily estimates of several atmospheric, land, and oceanic climate variables on a 0.25° by 0.25° grid.

   In addition to understanding mean climate conditions, it is important to consider how a climate can differ from season-to-season, year-to-year, or even decade-to-decade. Given its sub-monthly presentation, CCKP's reanalysis data is helpful for understanding naturally occurring variability (intra-annual to decadal) and the changing trends within the variability of our climate system (see *Stage 3, Step 3*). Daily data can also help identify trends of 'extreme weather events' within climate variability (see Part II). Data is offered from 1950 to 2020 and is presented across a variety of timescales. On CCKP, ERA5 data visualizations can be found on the **Current Climate → Trends & Variability tab**, or via Data Download.

To Note*: In some cases, user access to an observational record's specific time period or individual station data, may be necessary. However, if users consider data just from a selected time period, without calibration, they should recognize the potential for bias in analyzing data results. For example, if a user analyzes observed data for only a 5-year time period, how relevant is this for broader contextual analysis and trends? Was that 5-year period part of a warming cycle? A drier or wetter period influenced by an El Niño or La Niña event? If so, ensuing calculations built from this small sample size can be skewed with outcome calculations that incorrectly present drier or wetter outlooks. This is one of the reasons users are encouraged to review data across longer time periods and to understand the potential influences of the natural cycle within a long-term climate signal.*

Step 2. Current climatology, seasonality, using annual vs. seasonal trends, national vs. subnational

Current Climatology

When assessing climate conditions, scientists identify trends across the variation of individual daily and monthly data over a longer period. *Climatology* refers to conditions which are averaged over a multi-year period; data is typically presented in 20-year, 30-year, or 50-year climatologies. Analyzing historical climatologies allows scientists to understand a trend or climate signal through the 'noise' of hourly or daily data, or an individual month, both influenced by natural variability. To understand current climate conditions, the climate community relies on the latest 30-year climatology derived from observational data. In line with common climate science approaches, CCKP offers current climatology, 1991-2020.

Seasonality

Seasonality refers to predictable changes in temperature and precipitation patterns over a one-year period. Meteorologists and climate scientists generally group seasons into three-month periods based on temperature patterns and the Gregorian calendar: Winter, Spring, Summer, and Fall. Importantly, however, not all areas of the world experience temperature and precipitation conditions that neatly align with these four seasons. Some experience more seasonal shifts, while others experience fewer (i.e., does an area experience a single rainy and dry season, or a bimodal precipitation pattern containing two rainy and dry seasons annually?). Seasonal dynamics often have a large influence over local economies, livelihood structures, and cultures, with changes in seasonality causing potentially widespread implications across sectors. Factors that one must consider when assessing an area's seasonality include the number of seasons typically experienced, when a given season's typical onset occurs (i.e., month), and the average length of each season.

***Example A**: An earlier or later onset of summer temperatures can affect crop cycles with important repercussions on the supply and distribution systems for agricultural food products. How has seasonal change over time affected local livelihoods, broader export dependencies, or the nutrition profiles of communities? How might these effects further change given future climate projections?*

***Example B**: Are vector-borne disease transmission and infection periods 'aligned' with specific seasons? Are local adaptation efforts and distribution of resources (i.e., bed nets) oriented towards a specific seasonal onset? Has this trend changed or expanded over time? How might seasonal timings change in the future and what expanded adaptation efforts might they entail?*

Seasonal cycles are a common way to present monthly data, which depict seasonality. Users can evaluate an area's seasonal cycle, presenting historic monthly climatologies of temperature and precipitation through CCKP's '**Current Climate > Climatology'** tab.

Figure B provides an example of how the data and graphs from CCKP can be summarized to provide necessary information on historic seasonality. It depicts an annual seasonal cycle. With an understanding of an area's climate, one can analyze the graph's seasonal characteristics. *Winter* (December to February) conditions are cool and dry, *Spring* (March to May) conditions are hot and dry; *Summer* (June to September) conditions are rainy and humid with the highest temperatures, and *Fall* (October and November) conditions are warmer and drier.

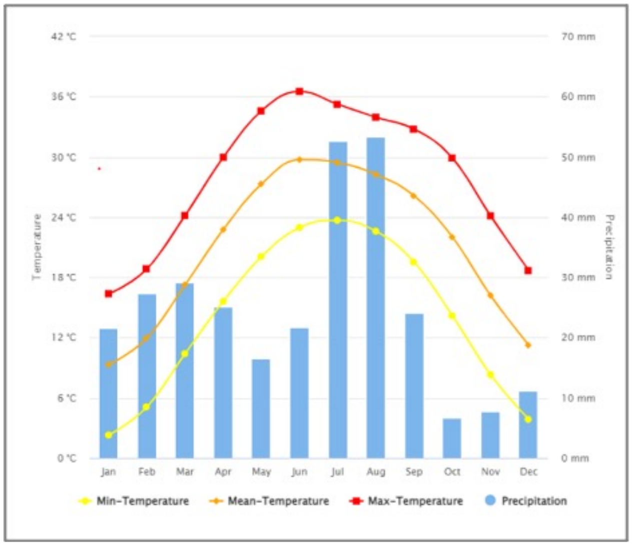


Figure B: Current and Projected Seasonal Cycles Showing Mean, Min, and Max Temperatures and Precipitation, 1991-2020.

> ***To Note:*** *Seasonal cycles calculated across a climatology represent the averages of each season's months across the period. Thus, the above seasonal cycle, 1991-2020, presents the average of 30 Januarys, 30 Februarys, etc. for each specific variable presented. This is important in allowing users to identify different climate conditions and possible changing trends over time.*

Annual vs. Seasonal Trends

Identifying appropriate *time* scales is a necessary step to bound one's analysis. An annual value represents the average conditions across its 12 constitutive months. For large countries and areas with diverse topographies, multiple climate zones, or more variable climates (i.e., the mid and higher latitudes experience broad annual changes, from colder winters to hotter summers), annual time scales produce more muted climate conditions between colder and warmer seasons. Similarly, threshold-based variables can provide information as to the number of days in a year surpassing a given threshold. However, we do not know *when* in the year variables are likely to surpass their thresholds. It is therefore recommended to review data on both annual and seasonal time scales. Reviewing monthly data may also be required to ensure that seasonal classifications fit a specific area's context and seasonality. This practice can provide a foundation for understanding when and where projected seasonal changes occur under future climate scenarios and assessing how they differ.

National vs. Sub-National Climate Signal

Recognizing the appropriate *spatial* scales needed for your analysis is another important step in properly assessing the climate conditions for your area of focus. Like the variations apparent when comparing annual, seasonal, or monthly data presentations, one must recognize how spatial variations can also influence outputs for interpretation. Analysis of large countries, areas with diverse topographies, or multiple climate zones at a national scale can therefore result in a more muted climate signal.

Example: *A country such as Argentina offers an interesting case for understanding and using national and sub-national data aggregations. Argentina has a highly diverse geophysical landscape, ranging from tropical climates in the north to the dry and cold tundra in the far south. Cerro Aconcagua is the Western Hemisphere's tallest mountain, while Laguna del Carbon is the lowest point in the Western Hemisphere.*

While most of the country experiences sub-tropical climates, some of its regions experience extreme thermal conditions, which vary from hot in the north to very cold in the extreme south and at the heights of the Sierras and Andes Mountains. The montane Andean region extends from the dry north to the heavily glaciated and ice-covered mountains of Patagonia. Patagonia is a region of arid, windswept plateaus, covering approximately 300,000 square miles. This region experiences very low rainfall, except in the strip of land adjacent to the Andes Mountains as well as in the southern end of the provinces of Santa Cruz and Tierra del Fuego. Humid lowlands are present in eastern Argentina, especially along the rivers of the Rio de la Plata system. In the north lie the savannas and swamps of the Chaco region. The alluvial plain of the Chaco in the north possesses a subtropical climate with dry winters and humid summers. Rainfall decreases from 150 to 50 cm, and temperatures reach 120°F. The humid plains in the west give way to rangeland and finally to desert, that is broken only by irrigated oases. The contiguous strip of the Andes Mountains has abundant forests, glaciers and permanent snows, at the eastern end of this region there is abundant rainfall, which decreases towards the west and desert areas with very scarce vegetation.

In this case, obviously, an annual average across the entire country will obscure many important factors and characteristics which are regionally important and meaningful to local climates. As such, it is recommended that analysis consider sub-national data presentations concerning specific areas of interest, in addition to national averages. One must also recognize that often, political and administrative boundaries determine sub-national (i.e., state, province, municipality) extents, not necessarily 'climate zones'. Users should appropriately consider this dynamic when interpreting climate conditions across spatial areas and administrative boundaries.

Step 3. Historical trends within natural climate variability.

Step 2-Current Climatology discussed presentation of observational data over 20 to 50-year climatologies as a means of identifying climate trends and broader climate conditions (as opposed to daily weather). Trends in climate — past, present and future — always need to be understood in the context of naturally occurring variability. CCKP refers to climate variability as the ways climate conditions (e.g., temperature and precipitation) 'flicker' from year to year within their respective, typical 'range of variability'. Scientists attribute one major cause of this natural variability to quasi-random internal variability of the coupled atmosphere-ocean-land-ice system. A prime example of this type of variability is the El Niño Southern Oscillation (ENSO) phenomenon. Other causes of natural variability include the non-human influence of periodic 'forcing' events, such as explosive volcanic eruptions. These natural factors (internal as well as natural forcing) comprise 'internal climate variability'. Internal climate variability is always present – sometimes a bit more exaggerated, sometimes a bit less. One must therefore imagine a climatology as a mean with variability around it. Variability can be very large from year to year (i.e., in the high latitudes) and for specific variables, variability can be small (i.e., temperatures in the tropics).

In contrast to natural variability, anthropogenic emissions of greenhouse gases and resulting changes in atmospheric concentrations (i.e., CO_2, methane), together with land surface changes and aerosols, impose a different forcing on the climate system. Scientific investigation of climate change signals tries to separate anthropogenic effects from the natural background variability. That signal can show as changes in the magnitude of variability as well as through a systematic trend over time. **Figure C** offers an example data presentation, showing annual mean temperature against the climatological trendlines of 30-year periods. Once can clearly see from this graph that both the pace and magnitude of change, within a natural state of climate variability, is increasing.

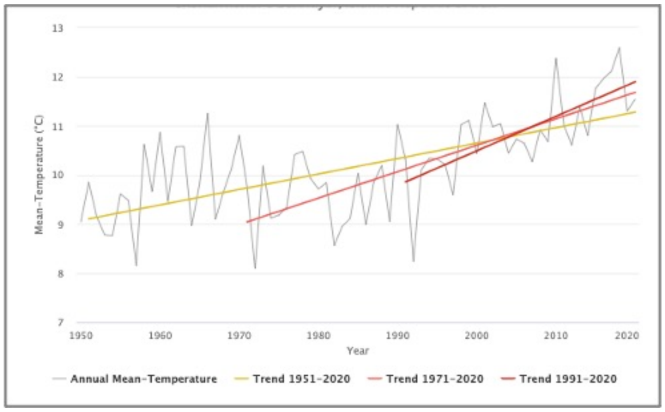
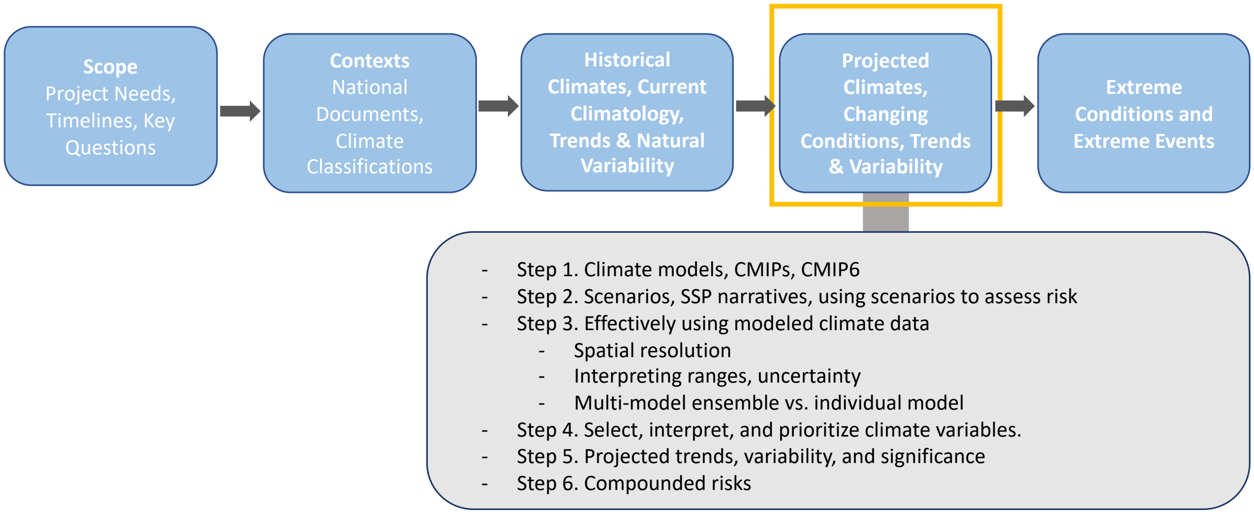


Figure C: Average Annual Mean Temperatures and Trends, 1991-2020.

CCKP's presentation of historical trends and variability, provides users with the ability to explore and understand differences in variability, trends, and significance of change across the last 70-, 50- and 30-year periods. This information is meant to augment the information from the Climatology page. Data presented is derived from ERA5 (see *Stage 3, Step 1*) and can be found from the **Current Climate → Trends & Variability tab**.

Stage 4. Understanding Climate Futures, Changing Conditions, Projected Trends, and Natural Variability within ‘Climate Change’



- Step 1. Climate models, CMIPs, CMIP6
- Step 2. Scenarios, SSP narratives, using scenarios to assess risk
- Step 3. Effectively using modeled climate data
    - Spatial resolution
    - Interpreting ranges, uncertainty
    - Multi-model ensemble vs. individual model
- Step 4. Select, interpret, and prioritize climate variables.
- Step 5. Projected trends, variability, and significance
- Step 6. Compounded risks

Step 1. Understand climate models, Coupled Model Intercomparison Projects (CMIPs), CMIP6

Understanding Climate Models

Climate models allow scientists to understand the processes and interactions shaping the earth’s climate system. A climate model is a complex computer code that creates a digital analogue of the earth. Models mimic the processes and interactions between the primary elements of the planet’s climate system: the atmosphere, ocean, land surface, cryosphere, and biosphere. The climate science community relies on models to understand carbon cycle feedbacks in response to anthropogenic emissions, which lead to changes in atmospheric concentrations of greenhouse gases and aerosols, and ultimately, radiative forcings that drive climate system changes. While model outputs can be used to estimate consequences of further changes in our climate, users should note that computational limitations do exist, as scientists are unable to precisely model every physical, biogeochemical, and societal process. However, overtime, and with scientific, technical, and computational advancements, the climate science community has improved representation of these processes with higher resolution and greater complexity, producing more realistic and relevant climate simulations of possible futures. Model results serve as the basis for climate research around the world. As we do not know for certain what our future holds, models are run against designated scenarios to offer insight into potential changes in climate magnitudes based on an increase or decrease of atmospheric concentrations and radiative forcings and corresponding plausible socio-economic development. These issues are discussed in greater detail in the *Scenarios* section (*Step 2*) below.

Overview of the Coupled Model Intercomparison Projects: CMIPs

Fully understanding our current and future climate is too large and complex for a single country, institution, or scientific discipline to tackle. Through international scientific cooperation and partnerships, the World Climate Research Program, established in 1995, supports the coordination of partners and modeling groups around the world participating in the Coupled Model Intercomparison Projects, or CMIPs. The best available, modeled climate data is derived from the CMIP outputs. Each CMIP is a result of years of scientific effort and new CMIP iterations are completed and released every ~5-7 years.

As the coordinating framework for a suite of coupled atmosphere-ocean general circulation and earth system model experiments, the CMIPs advance our understanding of the multi-scale dynamic interactions between natural and social systems affecting climate. This framework establishes standards and specifies experimental protocols, and a common infrastructure for collecting, organizing, and distributing outputs for enabling collective analysis of climate outputs. This not only creates a unifying structure for which to evaluate climate models, but also leads to improvements in model simulations, providing better understanding of past, present, and future climates.

CMIP's strength lies in its global infrastructure, gathering data and providing access for the growing global research community. The CMIP framework represents of one of society's most important sources of high quality and reliable climate information. For more detailed information on CMIP design and CCKP's use of CMIP6 outputs, see CCKP's Metadata Document.

The CMIP model results have become standard reference inputs for work concerning climate change science, impacts, vulnerability, adaptation, and mitigation. While independent of the regularly produced IPCC Assessment Reports, CMIP results are used to directly inform these Assessments. CMIP Phase 5 (CMIP5) provided the foundation for the 5th Assessment Reports released in 2013 and 2014, and the 6th Assessment Reports released in 2021 and 2022 used CMIP6, the latest collection of simulations done by the global climate science community. These reports are considered the world's most authoritative overviews of climate science.

CMIP6

The Coupled Model Intercomparison Project Phase 6 (CMIP6) represents the most advanced scientific, technical, and computational capabilities available from which to understand our past, present, and future climate. CMIP6 included more than 50 international modeling centers, over 100 contributing models, and thousands of researchers around the world. This work is estimated to have produced outputs upwards of ~40 petabytes of data. Models of CMIP6 included additional processes and account for more advanced scientific understandings of the physical processes and properties of climate system responses than models participating in previous CMIPs.

To Note: *Data from CMIP5 and CMIP6 should not be 'mixed' within an assessment as the models used in CMIP5 and CMIP6 are distinctly different, even if produced by the same modeling groups. CCKP users are encouraged to use data and presentations from CMIP6, as it represents our best available scientific understandings. If an assessment is underway that started using data derived from CMIP5, it may not be feasible to 'update' all assessment inputs with CMIP6-derived data and thus should continue assessment using CMIP5 data. It should not be interpreted that because CMIP6 was released, CMIP5 data should no longer be used.*

Step 2. Understand scenarios, the best available means to assess our possible futures.

Scenarios are used by the climate community to characterize the range of plausible climate futures and illustrate the consequences of different pathways (policy choices, technological changes, etc.). *Scientists use scenarios to span a wide range of outcomes without any tie to likelihood; scenarios are meant to serve as 'what if' cases.* Over more than three decades, the approach to formulate future scenarios has evolved from a climate-centric concept to an increasingly societal development-centric concept, albeit with the same underlying goal of providing insight into a range of plausible climate outcomes. To distinguish the magnitude of climate forcing, the concept of *Representative Concentration Pathways* (RCPs) was adopted in the two most recent iterations (CMIP Phases 5 and 6). The numbering reflects a designated amount of radiative forcing (RF)[8] measured in watts per square meter (W/m^2) reached by 2100 (i.e., 2.6, 4.5, 6.0, 7.0, and 8.5 W/m^2 of change over pre-industrial levels). In the most recent CMIP6 release, an RF of 1.9 W/m^2 was added to offer insight into the climate response reflective of the Paris Accord target of keeping a global mean annual temperature increase below 1.5°C by 2100[9]. An RF of 7.0 W/m^2 was also added to represent another feasible response to high-emission pathways.

It must be realized that there are many plausible paths to achieve the same forcing levels based on various emission contribution, technological, societal, and mitigation combinations. While some scientific concerns call attention to an overly high climate change magnitude in *some* models of CMIP6, projections and particularly nearer term projections are still considered highly robust. Uncertainties associated with the high-end climate system scenario response are due to potential feedback processes that are still not fully understood. These include the so-called indirect aerosol effect on cloud optical properties and lifetime, as well as potential releases of methane and other greenhouse

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[8] A radiative forcing is reflective of the additional amount of energy entering the earth's climate system.

[9] For comparison, the present day anthropogenic radiative forcing since 1750 is estimated at ~2.5 W/m^2.

gases from melting permafrost regions. Feedback processes speeding up ice melt (or even ice sheet 'collapse') in Greenland and Antarctica could further enhance sea level rise. While not 'likely', such accelerations remain possible.

To Note: *The socio-economic narrative associated with an RF of 8.5W/m^2 presents a highly aggressive use of coal. However, this description serves as merely a proxy for one of the more than 100 different simulations (and thus combinations of different emission contributions) run, which reach the same level of forcing by 2100. The descriptions across plausible simulations used to reach 8.5W/m^2 of radiative forcing by 2100 are not the driving factors for emission or climate response and were only meant as an example descriptor[10]. It is the cumulative emissions and resulting atmospheric concentrations that influence the climate system. The actual source behind the emissions is relatively inconsequential.*

Shared Socioeconomic Pathways (SSPs) – Socio-economic narratives introduced with CMIP6

Introduced in CMIP6, *Shared Socio-economic Pathways* (SSPs) reflect the most advanced iteration of socio-economic narratives associated with each RF. The SSPs represent *possible* societal development and policy paths for meeting the designated radiative forcing by the end of the century (i.e., 1.9, 2.6, 4.5, 7.0 and 8.5 W/m^2)[11]. The CMIP6 SSP scenarios are the most complex to date and span a range from very ambitious mitigation actions to ongoing emission growth to describe the different, plausible 21st century pathways of emissions and atmospheric concentrations (including air pollutant emissions, aerosol emissions, and land use timeseries), consistent with socioeconomic developments. Socioeconomic developments include projections of societal wealth, disparity, and population growth, aligned with each SSP storyline. Additional details on scenarios and the different socio-economic growth paths and projections can be reviewed starting on CCKP's 'Climate Change Overview' page.

The standard CMIP6 pathways commonly used by scientific and development communities represent SSPs1, 2, 3, 5 and are paired with the designated RF suitable with each socio-economic pathway. Thus SSP3-7.0 represents: SSP3 pathway + 7.0 W/m^2 Radiative Forcing by 2100. The full suite of RFs and SSPs and Tier 1 and Tier 2 combination used by the modeling community[12] are seen below in **Figure D**. CCKP presents Tier 1 Scenarios plus a Tier 2 scenario, SSP1-1.9.

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[10] Changes across these simulations do not meet a threshold to substantially degrade the similarity between total cumulative CO_2 emissions and policies to mid-century.

[11] CMIP6 also contains alternatives to the main scenarios, such as Overshoot Scenarios.

12 O'Neill, B. C., Tebaldi, C., van Vuuren, D. P., Eyring, V., Friedlingstein, P., Hurtt, G., Knutti, R., Kriegler, E., Lamarque, J.-C., Lowe, J., Meehl, G. A., Moss, R., Riahi, K., & Sanderson, B. M. (2016). The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6. Geoscientific Model Development, 9(9), 3461–3482. https://doi.org/10.5194/gmd-9-3461-2016.

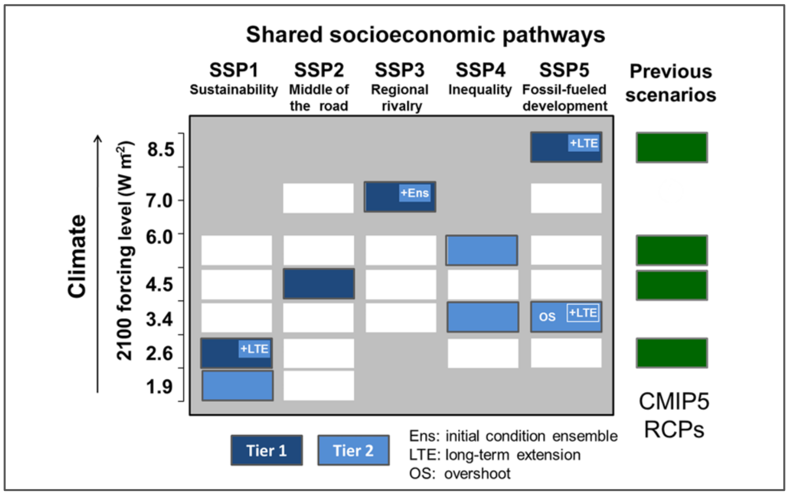

Figure D. SSP-RCP scenario matrix presenting ScenarioMIP simulations.

SSPs are not directly aimed at decision makers but at climate change analysts preparing climate policy analysis based on the SSPs. As the SSPs span a range of plausible futures, CMIP6 includes scenarios with high and very high GHG emissions (SSP3-7.0 and SSP5-8.5) and CO_2 emissions that roughly double from current levels by 2100 and 2050, respectively, scenarios with intermediate GHG emissions (SSP2-4.5) and CO_2 emissions remaining around current levels until the middle of the century, and scenarios with very low and low GHG emissions and CO_2 emissions declining to net zero around or after 2050, followed by varying levels of net negative CO_2 emissions (SSP1-1.9 and SSP1-2.6). Emissions vary between scenarios depending on socio-economic assumptions, levels of climate change mitigation and, for aerosols and non-methane ozone precursors, air pollution controls.

Figure E shows global average temperature rise for the primary Scenarios presented in IPCC AR6. The amount of ‘climate change’ by the end of the century depends on decisions we make today. If the international community reduces CO_2 amounts to stop increasing after 2050, global average temperature will increase from 1-1.5°C, and this is considered a best-case scenario (blue line in graph). If they don’t reduce CO_2 and the amounts continue to increase, the worst-case scenario warming will be 4.5-5°C (red line and shading in graph)[13].

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[13] IPCC Working Group I, 2021.

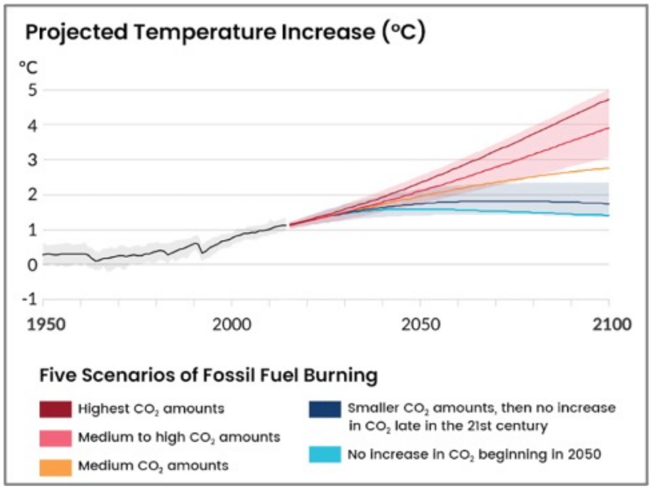

Figure E: Projected Temperature Increase According to Five Global Emission Scenarios Through 2100.

SSP1 and **SSP5** envision relatively optimistic trends for human development, with ‘substantial investments in education and health, rapid economic growth, and well-functioning institutions.’ However, they differ in that **SSP5** assumes this will be driven by an energy-intensive, fossil fuel-based economy, while in **SSP1** there is an increasing shift toward sustainable practices.

SSP3 and **SSP4**[14] are more pessimistic in their future economic and social development, with little investment in education or health in poorer countries coupled with a fast-growing population and increasing inequalities.

SSP2 represents a “middle of the road” scenario in which historical patterns of development are continued throughout the 21st century. [15]

Using Scenarios to Assess Risk – Which scenario should I use?

One should imagine Scenarios as *‘what-ifs’* designed to provide insight into the extent of future climate change magnitude and related climate signals. As such, users can apply these tools to help understand the characteristics and magnitude of emerging climate signals to inform their decision-making. In evaluating or contrasting scenarios, however, it is important to note that *scenarios are fundamentally not predictions and are not associated with likelihoods*.

Focusing solely on end-of-century outcomes is an inadequate way to evaluate the usefulness of a given RF and related SSP. For purposes of informing societal decisions, shorter time horizons are highly relevant. With regards to ‘choosing’ the most appropriate

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[14] SSP4 is not a commonly used pathway and model experiments reflect Tier 2 only. Thus, it is not used in the suite of SSPs for standard decision-making.

[15] Narrative descriptions from AR6 WG1 Technical Summary, TS1.3 and 1.6 and Cross-Chapter Box 1.4 of the Working Group 1 contribution. For a complete description of SSP Narratives, see O'Neill et al. 2017.

Scenario for nearer-term time horizons, cumulative greenhouse gas emissions are an important metric to assess scenario ‘usefulness’ and climate system feedbacks. By this metric, higher emission scenarios agree most closely with our existing levels of total cumulative emissions. Recognizing our current atmospheric concentration of ~420 parts per million CO_2,[16] the scale of current CO_2 drawdown and/or sequestration capabilities, current atmospheric concentrations, and the existing/evolving global political will and action addressing emissions can also help to guide appropriate selection of scenario and related near to mid- term risk outlook.

Due to the relatively long lag of the climate system response to *cumulative* emissions, scenarios produce highly similar outputs for near term (2020s, 2030s) and even much of mid-term (2040s) time horizons. The radiative forcing, and to an even larger degree the climate system response projected within SSP multi-model ensembles, exhibit a significant amount of overlap across nearly all scenarios for these time horizons. Divergence may start to appear between the pathways by the ~2050s, and the separation becomes drastic in the following decades (**Figure F**)[17]. It is important to recognize that distinguishing the climate system response to different SSPs in the near-term is made challenging by the influence of natural variability. Smoothed averages might be deceptive and the variability range around these ‘median’ response signals need to be considered.

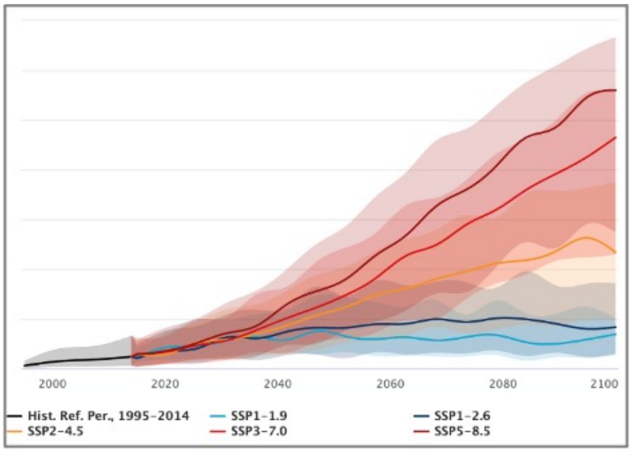

Figure F: Projected Average Mean Temperature Increase According to Multi-model Ensemble Scenarios (Ref. Period 1995-2014).

When analyzing risk, users should take a more conservative approach to risk projections, to avoid dangerously underestimating potential climate impacts. Current Nationally Determined Contributions (NDCs) align with a climate future between SSP2-4.5 and SSP3-

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[16] NOAA Mauna Loa Atmospheric Baseline Observatory, June 2021. https://research.noaa.gov/2021/06/07/coronavirus-response-barely-slows-rising-carbon-dioxide/

[17] Context matters. One may begin to recognize ‘divergence’ more clearly in the ~2040s in the high-latitudes due to greater extent of the region’s natural climate variability. Similarly, areas in the low-latitudes, with much more limited natural variability, will recognize ‘divergence’ later.

7.0. An approach of compare/contrast is beneficial when discussing potential futures and projected physical climate risk.

To Note: *The 'selection' of an optimistic vs. pessimistic scenario may create somewhat of a false choice, particularly for the next few decades, given the long-lag of the climate response and existing amounts of atmospheric concentrations (as discussed above) and as we continue to remain on an emission pathway closer to the higher emission scenarios (SSP3-7.0 and SSP5-8.5). Framing projected risks with regards to* ***avoided impacts*** *can be effective for supporting necessary mitigation actions, presenting effective rationales for meeting the Paris Agreement and enhancing Nationally Determined Contributions.*

The comparison of the most realistic presentation of projected climate through mid to late-century (SSP-7.0)[18] with a lower emission scenario (i.e., SSP1-2.6 or SSP1-1.9) is recommended as an effective means to identify potential risks and contrast with 'avoided impacts.'

Step 3. Effectively interpret modeled climate data, large and small spatial domains, multi-model ensembles vs individual models.

Scientists model data on global grids and outputs can be assessed as gridded data or aggregated for a designated spatial unit. When analyzing data, either from the multi-model ensemble or from an individual model, users should take care to appropriately gather robust outcomes for large and small spatial domains.

For small spatially aggregated units, the 'noise' from natural variability is very large relative to the actual climate signal. Rwanda presents a useful example (see **Figure G**). The number of grid cells factored into the Rwanda country average is small, not to mention the data used for sub-national level spatial aggregation. One might only expect the median of the multi-model ensemble to be reasonably 'smooth', but this would not be the case for the individual model when looking at a tiny spatial domain. Smaller spatial areas might not be representative as they are less able to account for topography or specific climate processes. Larger areas provide a better opportunity to understand these responses and guard against biases existing in the models. In this respect, conducting analysis only using a single grid cell (e.g., to locate a specific potential infrastructure site) is not recommended.

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[18] SSP3-7.0 is recommended as appropriate for presenting the most accurate state of our current emissions, and the projected physical climate risks.

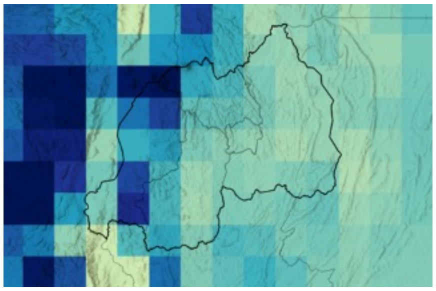
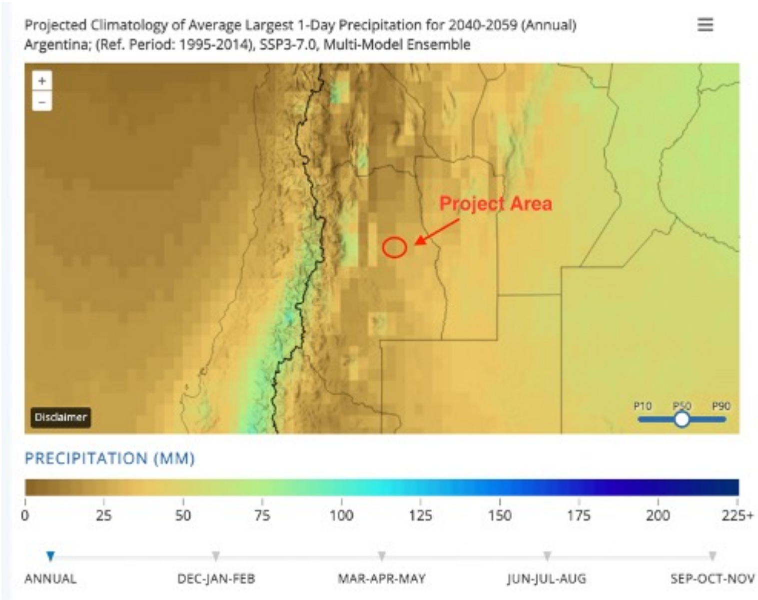


Figure G. Projected Annual Average Mean Precipitation (multi-model ensemble median) for 2080-2099, SSP5-8.5 at 0.25° x 0.25° Spatial Resolution.

Example: *If a user is interested in understanding the climate conditions for the City of Sydney, selecting just a single grid point, would likely not account for conditions such as winds from Sydney Harbor. What data projections or tools should one use for the most meaningful results in this situation? It would be more appropriate to consider aggregated conditions for a larger spatial domain to present a more robust picture of climate conditions for the area.*

To Note: *Model behavior across a specific geographic location can be highly spurious. Therefore, using just single grid cell may not be representative of more realistic model presentation. All individual models include inherent biases and underlying assumptions. As a result, unless users have high understanding of a specific model's individual biases and underlying assumptions of potential model responses for an area of interest, it is highly recommended that users apply multi-model ensembles (see **Figure H**).*



Projected Climatology of Average Largest 1-Day Precipitation for 2040-2059 (Annual)
Argentina; (Ref. Period: 1995-2014), SSP3-7.0, Multi-Model Ensemble

Figure H. Projected Average Largest 1-Day Precipitation (multi-model ensemble median) for 2040-2059, SSP3-7.0 at 0.25° x 0.25° Spatial Resolution Overlayed with a Prospective Project Area.

Users should exercise caution when calculating statistics over small geographies. CCKP recommends users apply the precomputed statistics for the closest available administrative unit offered by CCKP where a project area is located. In this example, statistics for the project area may be calculated from a single grid cell value but outcomes may not be representative nor robust, given the relatively high degree of variability for precipitation conditions and large range of uncertainty.

Multi-Model Ensemble Ranges

Not every model is used to calculate every climate indicator. For example, some models do not account for humidity and thus cannot calculate a Heat Index (the combination of surface air temperature and relative humidity). A multi-model ensemble represents the combination of multiple models appropriate for calculating a specific variable. Multi-model ensembles enable the production of more robust products. CCKP provides ensemble ranges for the 10th, median (or 50th), and 90th percentile of the multi-model ensemble. By identifying the 10th and 90th percentiles, the presented ensemble removes the most extreme model presentation for a variable calculation, likely results of highly spurious model behavior, and thus present a more robust, more meaningful output. It is not appropriate to present a single value for a projected climate condition over a future period. Best practice dictates presenting projections using the range of data: median (10th percentile, 90th percentile). Users may likely be interested in the possible 'highest,' 'lowest,' 'wettest,' and 'driest' possible conditions over future time periods. In this case, it is most robust to use the 10th and 90th percentiles of the ensemble range, as opposed to a single model. By default, there will be individual model responses 'outside' of the ensemble range and these represent the most extreme outcomes neither deemed as particularly meaningful nor useful to an assessment. If relying on a single model for an analysis, a skill assessment of the individual model should be performed prior to use.

To Note: *CCKP enables users to look at an individual model and compare it against the range (10th, 90th) of the multi-model ensemble to provide an educational tool for how an individual model simulation compares relative to that ensemble range. An individual model is not plotted with a range, the range (shown on CCKP presentations as shaded area around the median) is from the ensemble. To estimate the internal variability of a model requires the individual annual values (timeseries). CCKP offers users the capability to turn on/ off Ensemble Range only when an individual model is selected, precisely for this reason.*

Step 4. Select, interpret, and prioritize climate variables.

To properly understand the intricacies of future climate projections, scientists measure changing conditions using suites of individual metrics or variables. Temperature and precipitation metrics, especially over 30-year climatologies and longer-term periods, act as indicators of broader climate dynamics, with the following climate variables frequently referenced as 'essential': Average Mean Surface Air Temperature, Average Minimum

Surface Air Temperature, Average Maximum Surface Air Temperature, and Precipitation (sum). Users evaluating CCKP's menu of climate variables often ask how to appropriately analyze and apply metrics listed[19].

- *How should you decide which variables are most relevant for your desired assessment?*
- *How should you appropriately analyze and interpret climate projections for individual variables?*
- *How do you synthesize your review and analysis of future projections across multiple variables without misstating or misrepresenting scientific uncertainties?*

Effectively answering these questions requires integrating relevant data and considerations from previous stages while you interpret metrics both independently and collectively. The following extended analysis examples provide a systematic way for selecting, interpreting, and prioritizing first temperature-related, then precipitation-related climate variables. Sequential guidelines for this process include the following:

- Recall key conclusions from earlier stages before attempting to identify relevant climate variables.
- Then, assess spatial and temporal patterns for essential climate variables to understand big-picture projected changes.
- Next, preliminarily identify broad as well as relative extreme patterns across areas and timescales for different temperature-related variables.
- Select variables for full analysis and interpretation based on relevance to key assessment questions and goals.
- Finally, prioritize and synthesize analysis across variables by considering high and low ranges of probability, key thresholds, and combinations of projected conditions with relevance to assessment questions and goals.

Example A: *A user seeks to identify and analyze climate variables to understand changing temperature conditions in Colombia, with implications for agriculture and other key economic sectors.*

First, ***Identify Context (*****Stage 2).** *Colombia possesses diverse topographic regions roughly organized into five main regions: the heavily forested lowland Amazon plains in the south and the Orinoco plains in the east, the warmer Caribbean coast in the north and the cooler Pacific coast in the west, and the extensive Andes highlands and valleys along the country's central spine. Different agricultural yields and major cities can be*

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[19] For a full list of CCKP's climate variables available for user analysis, navigate to the **Climate Projections → Mean Projections** tab on a given country page and click on the dropdown menu for 'Variable.' Alternatively, users will be prompted with the full list of variables available for download according to customized data parameters when they follow instructions on the Download Data page. For further details, consult CCKP's Metadata Guide.

found in all these regions, with the country's climate temperature classifications ranging from tropical in the lowlands to subtropical, temperature, and even polar areas as one traverses higher in altitude across the Andes region. The average timing, duration, and temperature characteristics of seasons in Colombia highly depend on geographic distance from the Equator, localized topography, and proximity to the coast or coastal-facing slopes.

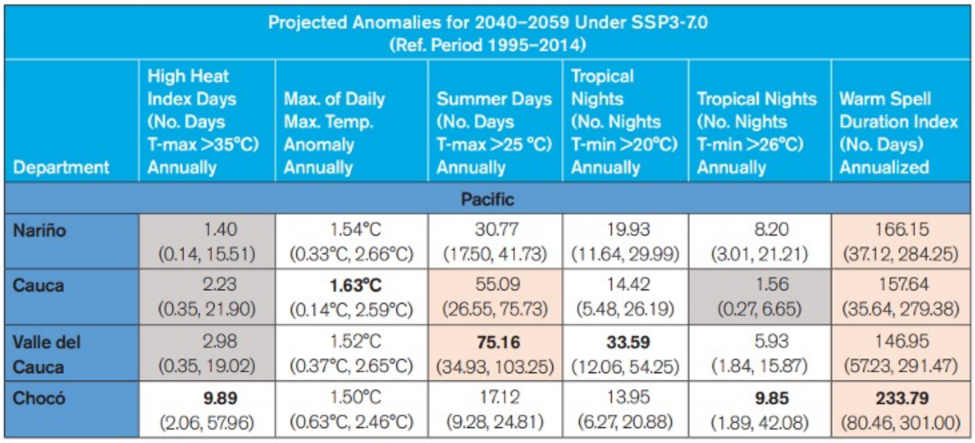
Some subnational units, or departments, possess one rainy and dry season, some possess two rainy and two dry seasons, and others possess average seasonal conditions somewhere in between or even lacking defined seasons on average. This is important because each subnational department's warmest month generally corresponds with the period before the onset of the year's first rainy season (ranging from January in the south to July in the north) and the coolest month with the end of the primary rainy season (generally summer months in the south and east, fall or winter months elsewhere). Given the diversity of Colombia's topo-geographic, climate, and seasonal conditions – and the fact that key locations of agricultural production and urban economic activities are scattered throughout parts of each region – ***the user will likely have to analyze temperature metrics within and across each of the country's major geographic and climatic regions (i.e., tropical, temperature, and cold alpine zones)****.*

*Upon reviewing observed spatial and temporal trends over the historical climatology of 1971-2020 (****Stage 3 – Understand Historical Climates****), Colombia's mean annual temperature increased by 0.22°C per decade. The Caribbean and Northern Andes regions observed the greatest changes over this period during the winter months, while the Amazon region observed temperature increases below the national average. However, Colombia's interannual variability is strongly influenced by El Niño Southern Oscillation (ENSO). During El Niño, dry seasons can become more intense and longer, affecting seasonal onset and leading to droughts and warmer weather. During La Niña, wet seasons can become more intense and longer, affecting seasonal onset and leading to floods and cooler weather, particularly between June and August.* ***The user can begin assessing future climate projections by evaluating whether these historical observed trends persist, intensify, or become regionally divergent****.*

Proceeding with ***Stage 4 – Understand Climate Futures, the user will likely begin assessing spatial and temporal patterns of essential climate variables – mean, minimum, and maximum temperatures.*** *After choosing a scenario (e.g., the higher emission SSP3-7.0 ensemble) and projected timeframe (2040-2059 for midcentury), the user may note subnational or regional spatial patterns at each annual, seasonal, or monthly interval compared to the national-level average. Projected temperature changes tend to display more homogeneous spatial patterns than precipitation. Using calculated anomalies under the specified parameters, Colombia's annual mean temperatures nationwide are homogeneously projected to increase by an anomaly of roughly 1.50°C compared to the historical reference period, with a positive 10th percentile anomaly value above the historical average, indicating a relatively high confidence in a warming trend. At* *the subnational level, the largest seasonal change occurs during winter months in the Eastern Andes and Orinoco regions, where Norte de Santander's mean temperature increases 1.83°C (median) from the reference period by midcentury, and the smallest seasonal change increases 1.14°C (median) in the Caribbean islands of San Andrés y Providencia. Projected annual minimum and maximum annual temperatures increase homogeneously nationwide and by roughly the same amount of change as the projected annual mean nationwide. But during winter months, there is a large increase in maximum temperatures across the Caribbean, Central and Northern Andes, and Orinoco regions. By midcentury under SSP3-7.0, Boyacá (Eastern Andes) is projected to experience a 1.87°C (median) increase in its median maximum temperature during winter months compared to 1.15°C (median) in San Andrés y Providencia. Analysis so far provides a framework for evaluating changes in other climate variables.*

However, due to the number of Colombia's climate zones at different altitudes, each with characteristic range of temperatures associated with historical observed conditions, ***it is important to assess mean projected temperature changes past certain threshold levels.*** *In fact, several departments in the Andes region are expected to endure conditions characteristic of different climatic zones by midcentury under SSP3-7.0. Using mean annual temperatures as thresholds for each climatic zone (18°C for temperate zone's lower threshold and 24°C for the tropical zone's lower threshold), median projected temperatures for midcentury according to SSP3-7.0 show that two departments mostly comprising of area in the alpine cold zone transition to areas with temperature conditions associated with the temperate zone. Meanwhile, one key department mostly comprising of temperate areas on average transitions to areas with temperature conditions associated with the hot tropical zone. While the user should note that these average temperature conditions apply to entire subnational areas, not necessarily specific sites within each area that may vary above or below the unit's average, mean temperature provides a general indication of areas where agriculture and living conditions exceed critical threshold levels of change. As discussed further below, the user should further analyze the range of likely variability (10th to 90th percentiles), not just the medians, to more fully understand the scope of future possibilities for specific sector activities.*

Upon preliminary interpretation of available temperature indicators, several appear to present important patterns (see ***Figure I****), while others (e.g., number of ice days) either broadly do not apply, show weak signals for conditions less relevant to the assessment, or duplicate findings from another variable. Colombia's diverse topo-geographic regions and climatic zones possess different relevant thresholds for appropriately revealing projected temperature conditions. For example, the number of tropical nights with a minimum temperature >20°C, a lower threshold, is projected to increase under SSP3-7.0 by midcentury across parts of each region across all four seasons. Projected anomalies increase the most year-round in the Andes region and areas of higher elevation, as average minimum temperatures elsewhere already exceed this discrete and relatively low threshold for much of the year and therefore cannot increase much further. However,* *the number of tropical nights with a minimum temperature >26°C, an even higher minimum threshold, is projected to increase most in departments along the Caribbean coast year-round, while resulting in lower annual totals in higher-altitude areas. Similarly, during the daytime, the number of summer days with a maximum temperature >25°C increase year-round in the portions of each region with the highest elevations. For other regions, high atmospheric moisture content means the number of projected days surpassing the Heat Index >35°C, an indicator of very hot and dangerous conditions, increase by midcentury over certain areas seasonally (the Caribbean region during the summer and fall months, and the Amazon and Orinoco lowlands during the spring and fall months). In sum, the combination of increases in High Heat Index Days or summer days, coupled with the rise in the number of tropical nights with high minimum temperature thresholds, magnify human health risks. This not only exacerbates human health concerns (i.e., for elderly, pregnant women, children and newborns, people with chronic illnesses and disabilities, outdoor workers, low-wage earners, and people living in areas with poorly equipped and ill-prepared health services), but also presents risks to water resources and food and agriculture sectors.*



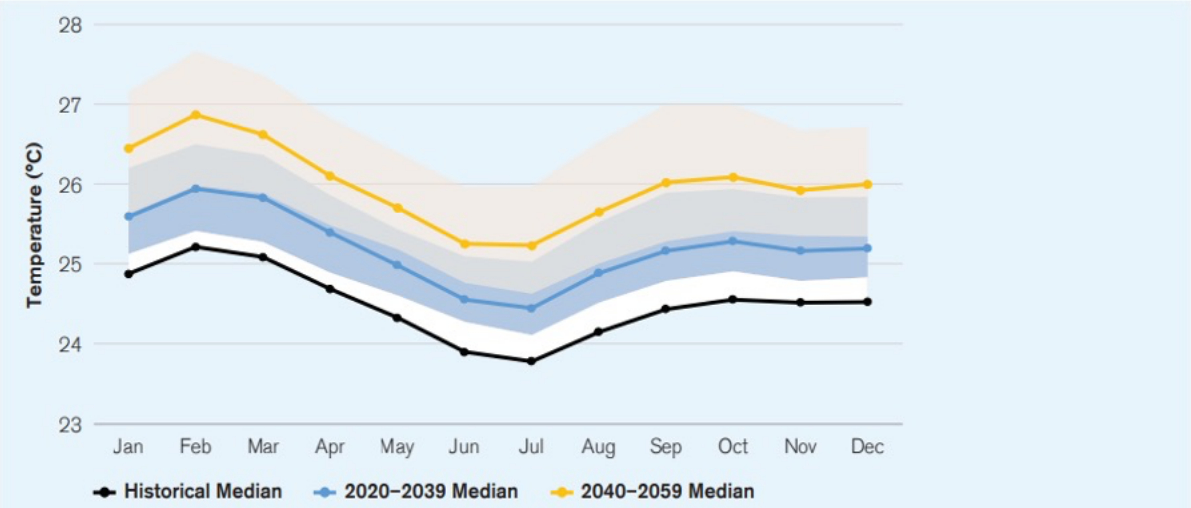
Projected Anomalies for 2040–2059 Under SSP3-7.0
(Ref. Period 1995–2014)

Department	High Heat Index Days (No. Days T-max >35°C) Annually	Max. of Daily Max. Temp. Anomaly Annually	Summer Days (No. Days T-max >25 °C) Annually	Tropical Nights (No. Nights T-min >20°C) Annually	Tropical Nights (No. Nights T-min >26°C) Annually	Warm Spell Duration Index (No. Days) Annualized
Pacific						
Nariño	1.40 (0.14, 15.51)	1.54°C (0.33°C, 2.66°C)	30.77 (17.50, 41.73)	19.93 (11.64, 29.99)	8.20 (3.01, 21.21)	166.15 (37.12, 284.25)
Cauca	2.23 (0.35, 21.90)	**1.63°C** (0.14°C, 2.59°C)	55.09 (26.55, 75.73)	14.42 (5.48, 26.19)	1.56 (0.27, 6.65)	157.64 (35.64, 279.38)
Valle del Cauca	2.98 (0.35, 19.02)	1.52°C (0.37°C, 2.65°C)	**75.16** (34.93, 103.25)	**33.59** (12.06, 54.25)	5.93 (1.84, 15.87)	146.95 (57.23, 291.47)
Chocó	**9.89** (2.06, 57.96)	1.50°C (0.63°C, 2.46°C)	17.12 (9.28, 24.81)	13.95 (6.27, 20.88)	**9.85** (1.89, 42.08)	**233.79** (80.46, 301.00)

10th percentile and 90th percentile values shown in parentheses. Largest anomalies (>50 days or >1.80°C) are shaded orange and smallest relative anomalies from the reference period are shaded gray. The largest anomaly in each region is bolded. Note that the maximum of daily maximum anomalies apply least to the coasts, High Heat Index anomalies apply most to the eastern lowlands and Caribbean, and summer day anomalies apply most to the Andes. High Heat Index day and warm spell anomalies use 1.00° × 1.00° (100km × 100km) data resolution and consider Distrito Capital as part of Cundinamarca. See text for interpretation.

Figure I. Projected Anomalies for 2040-2059 (Ref. Period 1995-2014) Under SSP3-7.0 in Pacific Region Departments of Colombia, with Relevant Metrics and Values Identified.

As the user now synthesizes analysis across variables, it is important to properly represent the full range of likely or probable conditions in future projections. The probability ranges for essential and other key temperature variables provide enough certainty to conclude that nationwide, Colombia will experience higher minimum and maximum temperatures, and hotter apparent conditions due to high atmospheric moisture content in most regions under the SSP3-7.0 scenario for the period of 2040–2059. For example, the 10th percentile ranges projected for essential temperature variables (e.g., see ***Figure J*** *for average mean projections) already exceeded the average median values over the reference period. This increase is very likely, considering that* *projected 10th percentile values for essential temperature variables additionally exceed the average median values over the reference period in the near-term (2020-2039) period and across lower-emission scenarios, though the extent of the increase is tempered compared to SSP3-7.0. Furthermore, other variables such as the Warm Spell Duration Index, reflect dramatic median and 10th percentile increases across all regions by midcentury, indicating a sustained shift in daily maximum temperatures to a different climate state. However, the same level of certainty does not apply everywhere, especially for surpassing the highest temperature thresholds in the near-term and under the lowest emission scenarios. As an example, the annual projected number of tropical nights with a maximum temperature >26°C under SSP1-2.6 by end of century is 13.14 nationwide (median), with a 10th percentile of 2.80 and a 90th percentile of 45.37. The median average change is relatively small on average, negligible at the 10th percentile, and higher – the equivalent of one and a half months annually – at the 90th percentile. Due to the range of probable outcomes as well as the nationwide spatial and annual temporal focus, which may mask important regional or seasonal changes, the user should deprioritize further interpretation of the metric under these parameters.*



Areas shaded yellow indicate 10th and 90th percentiles for 2040–2059, while areas shaded blue indicate 10th and 90th percentiles for 2020–2039. The projected climatology of mean temperature countrywide for each month (2040–2059 period) increases more than two times the projected climatology for 2020–2039 above the reference period.

Figure J. Projected Climatology of Mean Temperature in Colombia Countrywide for 2020-2039 and 2040-2059 (Ref. Period 1995-2015) Under SSP3-7.0, with Probability Ranges Above Historical Median Overlain.

***To note:** CCKP allows users to view future projections calculated two different ways. First, users can assess future projections for a variable as medians with their 10th to 90th percentile distribution, compared with the medians of the historical reference period climatology (i.e., 1995-2014). Second, users can assess future projections calculated as anomalies. This second method may be more relevant when distinguishing future trends, whereas the former method may be more relevant when focusing on future averages surpassing discrete critical thresholds. Users should note that a positive temperature* *anomaly indicates a warmer temperature than the reference value, while a negative temperature anomaly indicates a cooler temperature than the reference value.*

CCKP provides an array of temperature-related variables that offer insight into different aspects of climate change conditions and lend themselves to application in particular contexts or towards specific sectors. The maximum of daily maximum and minimum of daily minimum temperature per month or year inform seasonal extremes, relevant for crop cultivation and outdoor heat exposure. Cooling and heating degree days pertain to critical energy infrastructure needs, while the Cold Spell and Warm Spell Duration Index measures prolonged durations of extreme temperature conditions annually that could affect human health[20]. Many indices measure the number of days above or below certain threshold levels, which allow for detailed evaluation of changing annual and seasonal temperature patterns. In addition to the number of frost days (minimum temperature < 0°C) and number of ice days (maximum temperature < 0°C), users can analyze the number of hot days at various thresholds (maximum temperature >30°C, >35°C, >40°C, >42°C, and >45°C) and number of summer days (maximum temperature >25°C). But when analyzing temperature conditions, *users should remember to consider daytime versus nighttime temperatures, as well as the effect of humidity on heat, extreme heat and compounded heat conditions, as these indicate conditions that can threaten human health, plant and animal life, and cross-sector activities.* Hot days can become dangerously hot with high moisture levels in the air, measured as Heat Index Days (maximum temperature >35°C, >37°C, >39°C, or >41°C). Similarly, the number of Tropical Nights measures daily minimum temperature thresholds >20°C, >23°C, >26°C, and >29°C, which prevents human body temperature from maintaining restful levels of sleep. The combination of hot and especially hot and humid days with tropical nights exacerbates extreme heat exposure conditions detailed further in Stage 5. *Such interactions illustrate the benefit and need for considering suites of climate variables rather than a single indicator for comprehensive assessment.*

To note: *Projected temperature conditions do not always follow linear or even rates of change across spatial and temporal scales. Users should not assume projected conditions are linear and homogeneous without further comprehensive analysis.*

Example B: *A user seeks to identify and analyze climate variables to understand changing precipitation conditions in Bangladesh, with implications for disaster risk management and human health.*

According to **Stage 2 – Identify Context**, *Bangladesh consists mostly of low-lying deltaic floodplains between the Bay of Bengal and the Himalayan Mountains. Its hydrological*

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[20] Cooling degree days refer to the number of degrees that a day's average temperature is above 18.3°C, while heating degree days refer to the number of degrees that a day's average temperature is below 18.3°C. Cold Spell Duration Index measures the number of days that are part of a sequence of 6 or more days in which the daily minimum temperature exceeds the 10th percentile of the reference period. Warm Spell Duration Index measures the number of days that are part of a sequence of 6 or more days in which the daily maximum temperature exceeds the 90th percentile of the reference period.

terrain acts as important geographic context for understanding flood and drought impacts, constituting five major river systems and extensive tributaries. The country's climate is tropical moist in the floodplains and subtropical in the highest altitude areas along its north and east border with India. Observations over the current climatology (1991-2020) illustrate four distinct seasons (one main rainy and dry season) on average per year, heavily influenced by monsoon conditions. Tropical monsoons are associated with seasonal shifts in wind, partly due to differential heating of land and water, and precipitation. A hot pre-monsoon season (March to May) has the highest average maximum temperatures and northwesterly winds that can produce tropical cyclones. By June, a shift to southwesterly winds that carry warm moist air from the Indian Ocean drive the wet monsoon season until October. Precipitation volumes peak during July nationally (478.48 mm on average); however, the extent of monthly totals account for variations in annual precipitation. Compared to the subnational divisions located closest to the Himalayas, which trap in moisture and result in monthly rainfall peaks above 600 mm on average, the western floodplains exhibited monthly rainfall peaks between 300–400 mm, except for the south. As the Intertropical Convergence Zone (ITCZ) – a global band of converging trade winds – migrates according to seasonal changes in direct solar exposure, a warm and drier transitional post-monsoon period begins across Bangladesh. This post-monsoon season registers the greatest number of tropical cyclones on average under unstable atmospheric conditions. Winds predominantly blow from the north-northeast interior during the colder dry season beginning in December, resulting in the lowest monthly precipitation totals. From this assessment stage, the user concludes that ***analyzing the timing, duration, and intensity of Bangladesh's four seasonal stages will largely structure interpretation of future precipitation projections.***

Upon reviewing observed spatial and temporal trends over the historical climatology of 1971-2020 (**Stage 3 – Understand Historical Climates**)*, Bangladesh experienced significant decreases in precipitation per decade across the eastern subnational divisions (with the strongest effects during spring pre-monsoon months), but significant increases per decade across the western divisions (especially during fall monsoon and post-monsoon months). The geographically central divisions observed a significant but weaker decline in precipitation per decade, with the greatest drying during the summer wet monsoon months. Anomalously warm sea surface temperatures in the central and eastern Pacific and consequently weaker easterly winds characterize an El Niño phase, which tend to result in drier conditions over the northern Indian subcontinent during the wet monsoon summer months and raise the risk of poor agricultural yields and famine. Anomalously cool sea surface temperatures in the same locations result in the stronger easterly winds that characterize a La Niña phase, producing heavier flooding as well as tropical cyclone occurrence over the northern Indian subcontinent. The IOD modulates these effects if it occurs simultaneously with ENSO*[21]*. However, the phenomena produce*

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[21] Anomalously warm sea surface temperatures in the western Indian Ocean and strengthened equatorial easterly winds correspond with a positive IOD phase, while the opposite set of features characterize a negative IOD phase.

heterogeneous effects across the major Ganges, Brahmaputra, and Meghna River basins. Therefore, the user concludes the ***assessment must either expand its scope to the watershed level to adequately account for flood and water resource considerations, or transparently limit analysis to Bangladesh without accounting for key contributors to flood and water resources.***

Proceeding with **Stage 4 – Understand Climate Futures***, the user assesses spatial and temporal patterns of average mean precipitation totals, the essential climate variables. After choosing a scenario (e.g., the higher emission SSP3-7.0 ensemble) and projected timeframe (2020-2039 and 2040-2059), the user may note subnational or regional spatial patterns at each annual, seasonal, or monthly interval compared to the national-level average. Projected precipitation volumes under SSP3-7.0 nationally signal annual increases by midcentury, but seasonal and regional shifts with a wide range of uncertainty. Southern divisions over this timeframe are projected to experience declines in annual precipitation, northern divisions are projected to experience the greatest increases in annual precipitation, while central Dhaka is not projected to change much in yearly volume. By regionally tracking projected monthly and annual precipitation volumes and anomalies, the greatest precipitation increases by midcentury occur during the end of the wet monsoon season and extend into the pre-monsoon season for the wetter northern divisions. Meanwhile, the decreases in southern divisions during the pre-monsoon spring months over the 2020–2039 period become less extreme by midcentury. However, 10th and 90th percentile ranges across divisions for mean precipitation remain wide annually and monthly, potentially increasing or decreasing even if median values point relatively strongly in one direction. Additionally, while SSP3-7.0 predicts the driest annual precipitation nationally by midcentury compared to SSP1-2.6 and SSP2-4.5, it predicts the wettest annual precipitation by the end of the century (see* ***Figure K****). The user preliminarily concludes that national and regional precipitation signals maintain levels of uncertainty that require further investigation of potential driving factors. Changes in monsoon timing and duration also require further interannual investigation. See* ***Stage 5*** *for examples of interpreting precipitation intensity.*

To note: *Flood and drought considerations (further elaborated in Stage 5) do not solely depend on hydrometeorological factors. For example, climate variables such as precipitation amount during wettest days and annual SPEI drought index can inform future flood and drought conditions, respectively. But such precipitation indicators cannot fully account for other factors essential for comprehensively assessing flood and drought risk (e.g., riparian and coastal flood protections, soil and groundwater conditions, food and water supplies not dependent on local precipitation, etc.). Users should be mindful of appropriately bounding their analysis* (Stage 1 Scope) *and generalizing interpretation of single climate indicators to broader conditions and phenomena influenced by complex biophysical, socioeconomic, and technical drivers.*

To note: *Precipitation projections generally involve complex and uncertain processes and dynamics across scales that make them more difficult to model than temperature* *conditions. In effect, users should aim to highlight ranges of uncertainty, significance (see next section), and emerging trends to investigate further with additional metrics.*

CCKP precipitation-related variables offer insight into aspects such as frequency, duration, and intensity for specific contexts as well as sectors. Precipitation Percent Change measures anomalies as percentages from a reference period, which provide insight into relative precipitation change. Average largest 1-day, 5-day cumulative, and month cumulative precipitation metrics measure precipitation intensity over different time periods; Precipitation Amount During Wettest Days focuses on extreme volumes monthly or annually[22]; and number of days with precipitation > 20 mm and > 50 mm focus on surpassing smaller daily precipitation volumes. Finally, maximum number of consecutive dry days (< 1 mm) and maximum number of consecutive wet days (> 1 mm) highlight precipitation duration, as does the annual SPEI Drought Index[23].

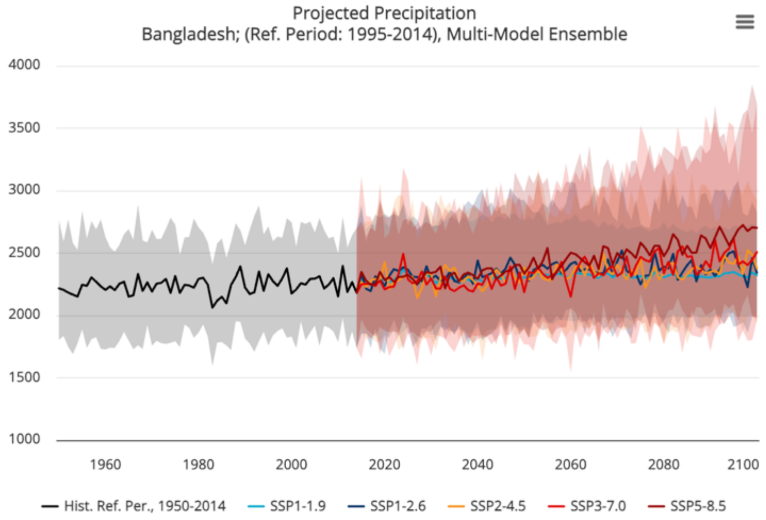

Figure K. Projected Precipitation in Millimeters for Bangladesh Countrywide Under Multiple Scenarios.

Step 5. Projected trends, variability, and significance.

Appropriately projecting and interpreting future climate trends requires a clear understanding of interannual variability (see Stage 3, Step 3). As illustrated in **Figure L**, projected climate conditions may display trends across future climatological periods

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[22] Precipitation amount during wettest days specifies a monthly or annual sum of precipitation when the daily precipitation rate exceeds the local 95th percentile of daily precipitation intensity.

[23] The annual probability of experiencing severe medium-term drought, determined by the Standardized Precipitation Evaporation Index (using 12-month window, where SPEI is computed over the full period, with threshold for severe drought at -2).

(while also considering influences from phenomena such as ENSO and IOD along with other internal natural variability).

For example, compared to Madagascar’s most recent historical reference period (1995-2014), the near-term (2020-2039) projected mean temperature distribution shifts to center on a higher temperature. This distribution has a narrower probability range of temperatures (length of base) and higher likelihood of occurring near the median. However, the future projected mean distributions for the next three climatological periods feature a persistent trend, different from the shift over 2020-2039. These projected mean distributions continue to shift to higher median temperatures (centers shift further to the right), but the range of potential mean temperatures widen (at the base) compared to previous distributions. The probability range of encountering a mean temperature therefore increases, but the shift from the center of the reference period distribution does not follow a smooth linear transition to the center of the 2080-2099 distribution. Rather, projected mean temperatures observed year to year will vary (e.g., depending on the ENSO phase) as they gradually become more probable to increase compared to previous climatologies. At the same time, they will also become more likely to deviate further from the climatology’s median average. For a further discussion of changes in variability, see *Stage 5 – Understanding Extremes*.

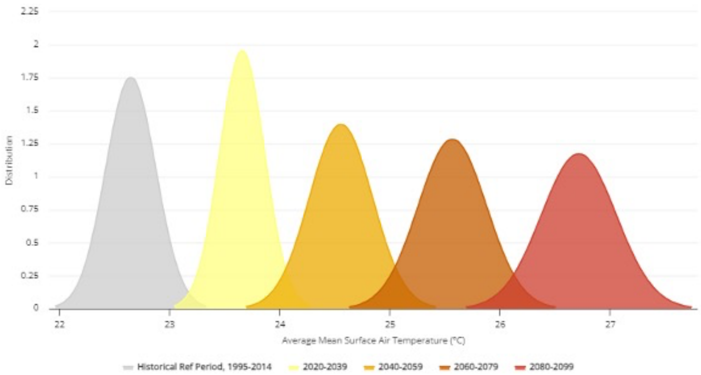

Figure L. Projected Change in Distribution for Average Mean Temperature Under SSP5-8.5 Across Climatologies by End of Century.

To note: *Statistical* significance *adds critical scientific context to understanding whether an observed or forecasted condition is not due to chance variation. For example, a mean temperature value that would occur in a sample climatology more than 95% of the time yields a statistically significant result, indicating a shift not due to chance (i.e., due to greenhouse gas forcing).*

Step 6. Compounded risk.

Example: Interpret Compounded Heat Risk Using Risk Categorizations

While increased greenhouse gas concentrations in the atmosphere are the primary factor associated with increased frequency and intensity of extreme hot events and decreased frequency and intensity in extreme cold events, extreme temperature changes at regional and local levels do not display homogeneous shifts. Changes may occur due to factors such as atmospheric circulation patterns, effects of soil moisture and reflectivity of snow and ice, as well as land use changes[24].

High heat conditions do not happen in a vacuum and individuals, households and communities must often contend with multiple conditions and changing threshold throughout a 24-hr cycle. CCKP offers capability to look further into compounded heat conditions and potential for associated risks, based on projected population densities for an area of interest. Compounded Heat Risk Categorization provides a simplified method for tabulating multiple types of heat conditions and indicate exposure and potential vulnerability through population-related data. If the ensemble climatology number of days for any month was >0.5 days, then it passed the scoring threshold. Each category (0-4) indicates the highest threshold passed for hot day, tropical night, and heat index thresholds across various temperature thresholds for comparison to population characteristics (see **Figure M**). An example of projected compounded seasonal heat risk for Djibouti categorization is shown in **Figure N**.

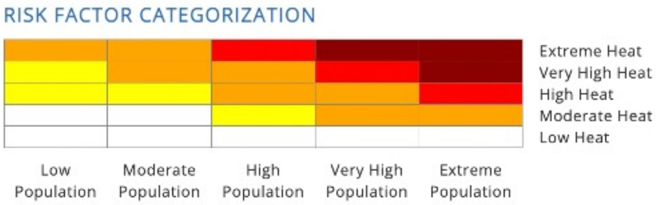

Figure M. Risk Categorization

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[24] Seneviratne, S.I., et al., 2021 Weather and Climate Extreme Events in a Changing Climate. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change pp. 1513–1766, doi: 10.1017/9781009157896.013.

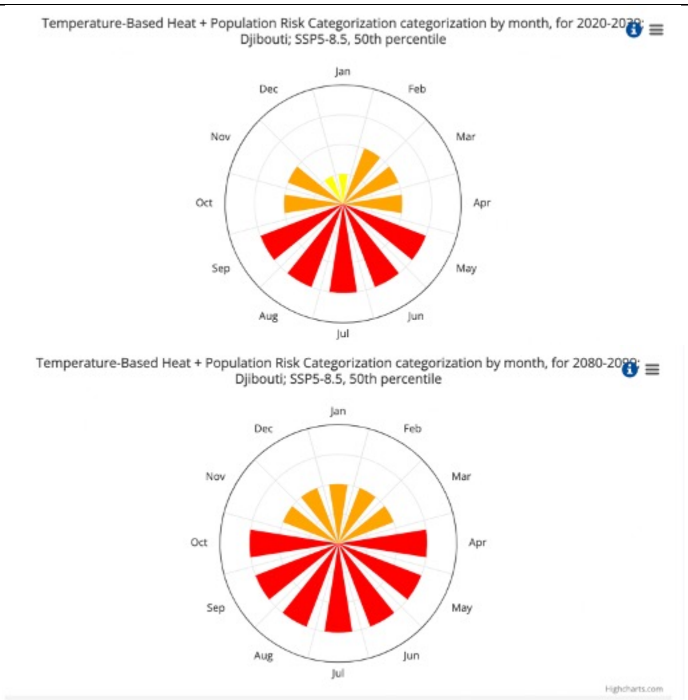


Figure N. Projected seasonal compounded risk categorization for Djibouti, comparing 2020-2039 and 2080-2099, SSP5-8.5, multi-model ensemble median.

The extreme heat risk plot below (see **Figure O**) for Cambodia identifies compounded heat conditions for the combination of hot and humid days and nights in the month of March starting by around midcentury. Very high heat conditions in April and May begin to emerge during the current decade and gradually expand to include the entire year by the end of the century, illustrating a different state of seasonal heat risk. Users can view risk scores spatially across national and subnational units along with population density and socioeconomic characteristics to inform strategic decision-making.

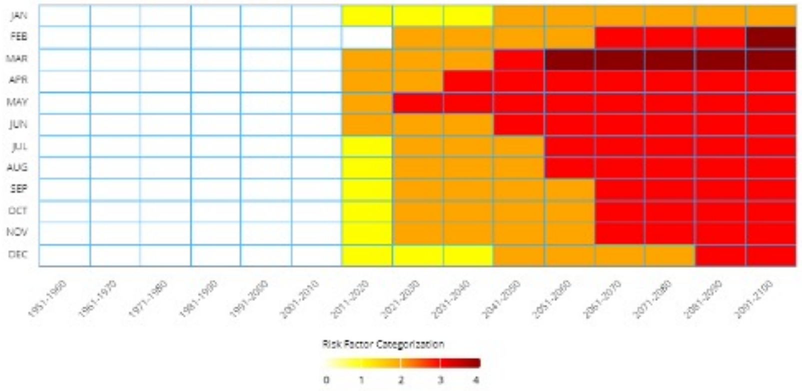
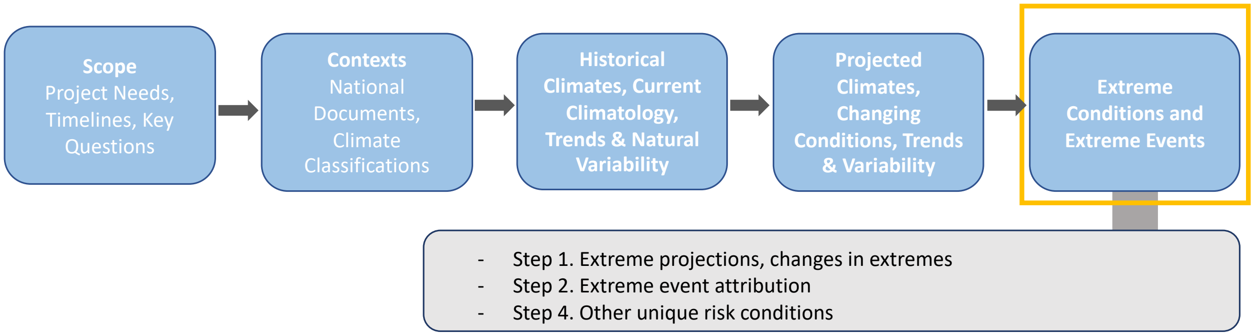


Figure O. Number of Hot Days and Tropical Nights with Humidity in Cambodia Under SSP3-7.0 (50th Percentile).

CCKP’s Compounded Heat Risk products can be found via **Risk → Heat Risk** tab

***To note**: Projected extreme temperature changes are not necessarily the same as changes in average mean warming for the same region. Changes in the magnitude of extreme temperatures are often magnitudes larger than the average mean surface temperature globally because of faster warming on land than ocean.*

Stage 5. Understanding Contextually Unique Risk Conditions



Step 1. Understanding extreme precipitation events and interpret associated data tables.

Extremes are often related to different physical processes than those that govern long-term means. While an average change in precipitation, for example, is primarily due to circulation changes, extremes are much more sensitive to the thermodynamic state and conditions during specific days. Therefore, it is important to compare trends and projections in means against those of rare events.

Extremes events only occur when several preconditions are met. For example, extreme rainfall requires maximized (“potential”) moisture transport into the region, high temperatures (or large temperature gradients) and significant instability of the atmosphere. An alignment of these “ingredients” is relatively rare. Under climate change, however, some of these conditions might see a systematic increase in occurrence, which is particularly true for temperatures across the globe. If that one condition – higher temperatures – is more often fulfilled, then the chance for a combined occurrence can also increase. Warmer temperatures are especially important for precipitation because the Clausius-Clapeyron relationship dictates that for every 1°C of increase in temperature, air’s potential to carry moisture increases by 7%. Thus, the warmer the air, the much more moisture it “can” carry, and therefore if rain were to form, much more water could be tapped into.

Scientists can measure changes in extremes according to five key dimensions, which are essential for comprehensive interpretation under climate change:

1. frequency,
2. magnitude,
3. timing,
4. location, and
5. compound risks

To describe the first two dimensions, scientists use the terms ‘return period’ and ‘return level,’ respectively. A return period estimates the interval of time between two extreme event occurrences at a fixed threshold of intensity. Comparing historical return periods of extreme events (measured in years) with projected (future) return periods over the same geographic area, for instance, yields insights into potentially changing frequencies. Alternatively, one can also examine annual exceedance probability or the expected number of events above a certain threshold magnitude annually. The change in annual exceedance probability associated with a certain magnitude can be expressed as a change factor or the likelihood that an event with a historical return period will occur in the future. While the return period indicates an event’s frequency, a return level indicates an event’s magnitude at a fixed frequency. Changes in return levels associated with the same frequency do not necessarily follow the same trends as changes in annual exceedance probability. Therefore, when discussing extremes, precise language is necessary to differentiate changes in extreme intensity at a fixed frequency from changes in extreme frequency at a fixed intensity (see example).

The third dimension of extreme timing could imply changes in seasonality or the onset and remission periods of certain phenomena. The fourth dimension of where extremes are located may change due to shifts in large-scale climate patterns or localized conditions. Lastly, the combination of multiple weather or climate events could produce amplified or uniquely extreme risks.

Where exactly the extreme events might happen is also somewhat uncertain as current local conditions over a broader region can dictate the dynamical process of triggering an event, although sometimes physical settings (e.g., topography) can lead to areas with higher likelihood of occurrence. Overall, extreme events must be seen as requiring a set of pre-conditions tied with a probabilistic element of initiation. This is why extreme thunderstorms can affect one place, while a few kilometers away there is hardly any precipitation registered.

To Note: It is important to recognize that (1) extreme precipitation events might show different signs and commonly larger magnitudes of change when compared to mean precipitation. (2) In a warmer world, the potential of air to carry moisture goes up exponentially, and thus the potential for heavier precipitation goes up. This means that intense events will likely recur more frequently, which can negatively affect the flooding risk. Only in areas where the occurrence of precipitation goes down significantly can the trend towards heavier rainfall be overcome and return periods of large events increase rather than decrease.

The Generalized Extreme Value (GEV) Distribution

The Generalized Extreme Value (GEV) distribution is an essential statistical tool in understanding and predicting extreme events linked to climate change. As climate change intensifies, the frequency and severity of extreme weather events—such as heatwaves, heavy rainfall, and intense storms—are expected to increase. The GEV distribution helps scientists and policymakers assess these risks by focusing on the tails of data distributions, which represent the most extreme occurrences.

By analyzing historical data on extreme weather events, the GEV distribution can estimate the probability and magnitude of future events. This is particularly important for projecting changes in climate patterns and preparing for their impacts. For instance, GEV models can predict the likelihood of unprecedented heatwaves, which are becoming more common due to global warming. These predictions are crucial for public health planning, agriculture, and energy management.

In hydrology, the GEV distribution is used to model extreme rainfall and flood events, which are expected to become more frequent and severe with climate change. This helps in designing infrastructure such as dams, levees, and drainage systems to withstand future extremes.

Example: *To analyze future trends in the largest 1-day precipitation amount in Colombia nationally, the tables in* ***Figure P*** *below identify historical return levels (mm) for a 20-year interval has a median of 83.88 mm. The return period of a 100 mm event had a median of 73.28 years over the historical period, or a 0.03 median annual exceedance probability.*

Return Levels, Historical: 1985-2014 (center 2000) (mm)

10-yr			20-yr			25-yr	
10th	median	90th	10th	median	90th	10th	median
41.50	74.33	150.66	46.00	83.88	174.28	47.45	86.99

Return Period, Historical: 1985-2014 (center 2000) (years)

50mm			100mm			
10th	median	90th	10th	median	90th	10th
0.39	1.78	53.43	2.73	73.28	7562.04	14.38

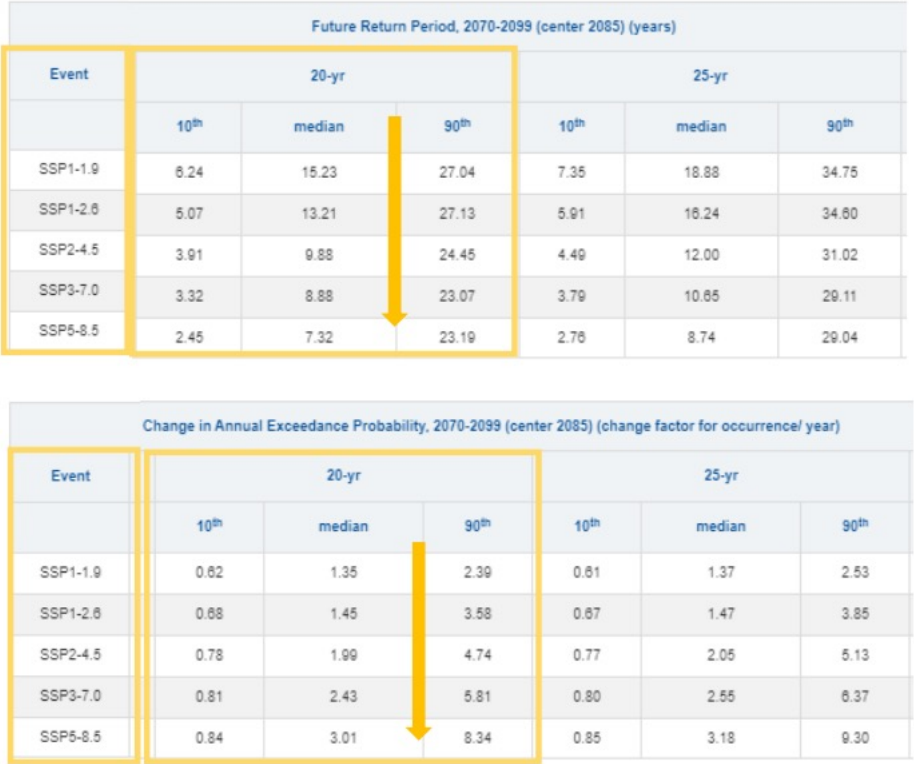
Annual Exceedance Probability, Historical: 1985-2014 (center 2000) (occurrence/year)

	50mm			100mm		
90th	10th	median	90th	10th	median	90th
7.28	0.05	0.67	3.07	0.00	0.03	0.59

Figure P. Probability Tables for Largest 1-Day Precipitation for Colombia (1985-2014, center 2000).

By contrast (see ***Figure Q****), the projected future return period for a 20-year interval event by 2070-2099 (center 2085) becomes much more frequent. The median future return period for a 20-year interval event decreases to 15.23 years under SSP1-1.9 and 7.32 years under SSP5-8.5, and therefore equivalent events from the reference period become more frequent. This translates into change factors of increasing frequency – a median of 1.35 times more likely under SSP1-1.9 and 3.01 times more likely under SSP5-*

8.5. The spatial extent of this shift is generally greater for scenarios with higher emissions and larger event intervals (e.g., 100-year events).



Future Return Period, 2070-2099 (center 2085) (years)

Event	20-yr			25-yr		
	10th	median	90th	10th	median	90th
SSP1-1.9	6.24	15.23	27.04	7.35	18.88	34.75
SSP1-2.6	5.07	13.21	27.13	5.91	16.24	34.60
SSP2-4.5	3.91	9.88	24.45	4.49	12.00	31.02
SSP3-7.0	3.32	8.88	23.07	3.79	10.65	29.11
SSP5-8.5	2.45	7.32	23.19	2.76	8.74	29.04

Change in Annual Exceedance Probability, 2070-2099 (center 2085) (change factor for occurrence/ year)

Event	20-yr			25-yr		
	10th	median	90th	10th	median	90th
SSP1-1.9	0.62	1.35	2.39	0.61	1.37	2.53
SSP1-2.6	0.68	1.45	3.58	0.67	1.47	3.85
SSP2-4.5	0.78	1.99	4.74	0.77	2.05	5.13
SSP3-7.0	0.81	2.43	5.81	0.80	2.55	6.37
SSP5-8.5	0.84	3.01	8.34	0.85	3.18	9.30

Figure Q. Probability Tables for Largest 1-Day Precipitation for Colombia (2070-2099, center 2085).

Example: *Djibouti's average highest precipitation amount over a cumulative 5-day period annually across its historical reference period has a mean of 19.90 mm (−26.79 mm, 10th percentile, 88.58 mm, 90th percentile). Under SSP3-7.0, the magnitude (historical return level) associated with this cumulative 5-day timeframe is projected to rise to a mean of 46.41 mm (23.62 mm, 10th percentile, 107.69 mm, 90th percentile) by midcentury. Changes in the frequency of the highest precipitation amount over a cumulative 5-day period annually do not neatly follow the increase in projected intensity across subnational units. In Djibouti's case, precipitation events associated with a 50-year return period have a change factor of less than 2 in the north and greater than 2 in the south. In other words, a precipitation event with a 50-year historical return period is less or more than 2 times likelier to occur, respectively, in the future under SSP3-7.0 by midcentury. This difference could have important implications for disaster risk management, food security, and water, sanitation, and hygiene.*

However, since probable ranges of future precipitation estimates vary much more than projected probability ranges for temperature, it is important to plan for multiple types of scenarios and understand underlying drivers of precipitation locally and regionally. For *example, the 10th and 90th percentile probabilities under various scenarios for Djibouti forecast precipitation decreases and precipitation increases, respectively, compared to the historical reference. Dynamic variables (e.g., increases in local temperature or evaporation rate) that influence changes in extreme precipitation magnitude at fixed frequencies may lead to certain conclusions, while variables that affect the frequency of extreme events at a fixed intensities (e.g., interannual El Niño patterns driven by sea surface temperature anomalies) may lead to alternative planning strategies. Timing and duration of rainy seasons annually, shifts in location of tropical cyclone patterns, and combination of more frequent extreme storm events following more frequent extreme drought events all pose different risks for policy sectors such as flood management and do not always coincide with changes in total projected mean average precipitation volumes. Given the greater uncertainty involved in making extreme precipitation projections, it is important to note the range of potential outcomes between the 10th and 90th percentile likelihoods and the potential effects of changes to each major driver of local precipitation.*

To Note: Individual, household, or community measures to adapt to climate change impacts may influence the tolerability levels of events considered ‘extreme’ over time, especially as unprecedented events become more common. Such adaptation activities underscore the importance of a multidimensional contextual understanding of extremes and merit ongoing monitoring and reassessment.

Step 2. Attribution of extreme events

According to the IPCC’s 6th Assessment Report[25], ‘it is an established fact that human-induced greenhouse gas emissions have led to an increased frequency and/or intensity of some weather and climate extremes since pre-industrial time.’ The frequency of extreme, once rare, or unrecorded events also become increasingly more probable for large regions globally under climate change – especially for extreme temperatures (very likely) and extreme precipitation magnitude (high confidence). However, the trends, dynamics, contributing factors, and levels of confidence vary between extreme temperatures, precipitation, and other phenomena.

While scientists cannot definitively link human or environmental triggers as direct causes of a single extreme event (i.e., human-generated climate changed caused a specific observed extreme event) due to natural variability, new methods allow them to calculate the contribution of human activities to specific events. By assessing the probability that the extreme event would have otherwise occurred in a climate with preindustrial levels of

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[25] Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change pp. 1513–1766, doi: 10.1017/9781009157896.013.

greenhouse gases, scientists can quantify the difference between the probability of the extreme event occurring in today's climate.[26]

Step 3. Appreciating contextually driven 'extreme' conditions

Adequate context is needed to properly appreciate the factors qualifying a condition identified within common nomenclature as 'extreme', such as the region's geography or characteristics specific to a weather or climate phenomenon. Thresholds are used by scientists to determine whether a condition may be relative or absolute, with important implications for what conclusions one can draw. These are detailed in the following example using metrics to measure extreme heat. Users must recognize common use 'extremes' to describe contextual conditions, which are different to specific events that are identified in data distributions as extreme events.

Example: To determine a region's most excessive or 'extreme' temperature records from the indicator maximum of daily maximum temperatures over a given time period, one could set a *relative threshold* for data at the 90th percentile or higher. The 90th percentile of maximum of daily maximum temperatures projected for summer seasons under SSP5-8.5 in southwest Pakistan between 2040-2059 is 47.5°C, relative to a mean average maximum temperature over the same time period of 39°C. However, the 90th percentile of maximum of daily maximum temperatures projected for summer seasons under SSP5-8.5 in central Panama by midcentury of 34°C, may also be considered relatively extreme for its region compared to a mean average maximum temperature over the same time period of 30°C. In these cases, the rarity of temperature events compared to the local mean averages (which vary significantly from place to place) determine whether an event is extreme.

By contrast, one could determine excessive or 'extreme heat conditions' using the *absolute threshold,* or number of days above a discrete temperature. For instance, the projected number of tropical nights (with a minimum temperature >26°C) is a useful metric for monitoring human health effects from prolonged heat exposure. (Note, the biophysiological risk limit is established at 20°C) Southwest Pakistan is expected to experience an average number (90th percentile) of 59 nights above 26°C during summer months with the parameters mentioned above. Under the same projected time range and conditions, the number of tropical nights with temperatures greater than 26°C in central Panama is 35 nights (90th percentile). The absolute number of tropical nights in southwest Pakistan is therefore more extreme compared to central Panama using a fixed mean threshold. Notably, accounting for other contextual factors could result in different conclusions. The anomaly or change between the projected time period and historical

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[26] Seneviratne, S.I., et al., 2021 Weather and Climate Extreme Events in a Changing Climate. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change pp. 1513–1766, doi: 10.1017/9781009157896.013.

baseline for tropical nights was actually higher in central Panama (a difference of roughly 30 nights) compared to southwest Pakistan (a difference of roughly 20 nights). By this metric, climate conditions considered ‘extreme’ in central Panama during the historical reference period would become more common and persistent. Accounting for both high temperature and humidity may further reveal different spatial and temporal patterns that one could qualify as ‘extreme conditions’ depending on implications for human health, biodiversity, or energy systems. These differences demonstrate the necessity of understanding not only the local context and historical climate conditions, but also which characteristics or criteria may qualify locally as extreme to appropriately prepare for and address locally distinct conditions.

Conclusion

The Climate Change Knowledge Portal (CCKP) serves as the World Bank's designated climate data service, acting as a comprehensive, global public good. Designed to meet the needs of the World Bank's operational teams, country clients, and the broader global development community, the CCKP provides a robust suite of climate and climate change resources that are transparent, accessible, and systematically structured. Policymakers and development practitioners require operational climate data products that are reliable and inter-comparable across countries and sectors. The CCKP addresses this need by offering processed operational climate data derived from primary climate data collections, ensuring outputs are consistent, science-driven, and capable of supporting rigorous climate change assessments, impact modeling, and corporate climate commitments.

CCKP's user-centric platform is built on a systematic data archive that ensures the standardized production and presentation of climate data. This approach guarantees that users can define, understand, and communicate the impacts of climate, natural variability, and future climate changes across various contexts. The platform adheres to internationally agreed standards set by the World Meteorological Organization and the IPCC Assessment Reports, ensuring that data is presented at a global or regional scale and is appropriate for operational use. By providing global gridded climate data and spatial aggregations at national, sub-national, watershed, and Exclusive Economic Zone scales, the CCKP enables precise climate assessments tailored to specific needs. The data is freely accessible and available for download, making it an invaluable resource for a wide range of stakeholders, including development practitioners, policymakers, researchers, and the global development community.

This guidance note is structured around a detailed framework encompassing five stages, each with specific steps designed to facilitate comprehensive climate assessments.

In **Stage 1**, users begin by defining the scope of their project, including identifying specific questions that the assessment needs to answer, defining the sectors of focus, and identifying the geographic areas of interest. This stage also involves determining the time frame of project funding and the time scale of project outputs. This initial stage is crucial for setting the parameters and objectives of the climate assessment, ensuring that the subsequent stages are aligned with the project's needs and goals.

Stage 2 focuses on understanding specific context/s of interest by reviewing key national documents, such as National Climate Assessments and National/Sector Climate Strategies, to define climate classifications and recognize contextualized seasonality. This stage ensures that the climate assessment is grounded in relevant national and sectoral contexts, providing a comprehensive understanding of the existing climate landscape and strategic priorities.

In **Stage 3**, users delve into historical climates, current climatology, trends, and natural variability. This involves analyzing observational data to understand historical climate conditions, current climatology, and seasonality. Users also examine historical trends within natural climate variability, providing a baseline understanding of past and present climate conditions that is essential for contextualizing future projections.

Stage 4 is dedicated to understanding projected climates, changing conditions, trends, and variability. This stage involves utilizing climate models, such as those from CMIP6, to explore future climate scenarios and assess risks. Users learn how to effectively use modeled climate data, considering factors such as spatial resolution, uncertainty, and multi-model ensembles. This stage also covers the analysis of variables, projected trends, variability, and significance, as well as compounded risks. By understanding these elements, users can make informed predictions about future climate conditions and their potential impacts.

Stage 5 addresses extreme climate conditions and extreme events, helping users understand localized conditions that may be considered 'extreme' for a given context and the projection of extreme events and potential for change in extremes. This stage includes the attribution of extreme events, the use of probability tables to assess extreme precipitation risk, and the identification of other unique risk conditions. This stage is critical for assessing the potential for extreme events and their implications, providing a comprehensive understanding of future risk conditions.

We believe that the Climate Change Knowledge Portal is an essential tool that bridges the gap between climate science and its operational application in international development. Its standardized approaches and comprehensive data offerings enable users to conduct rigorous climate assessments that are consistent and comparable across different contexts. The detailed framework provided in this guidance note equips users with the knowledge and tools needed to effectively evaluate historical and projected climates, understand climate risks, and support informed decision-making in the face of climate change. CCKP considered this Guidance Note to be a living document and as new, updated datasets and products are added to the website, this document will be updated to reflect new additions and updates.

The CCKP's role as a nexus between climate science, development, and operational application cannot be overstated. By providing access to reliable, science-driven climate data and supporting materials, the CCKP empowers users to make informed decisions that enhance resilience, adaptation, and risk management. As our understanding of climate science continues to evolve, the CCKP will remain a vital resource for navigating the complexities of climate change and its impacts on our world.

Annex. Calculating Statistics over Geographies

Climate data is produced on a grid, with grids representing latitude/ longitude. All CCKP data is available as global, gridded raster files in NetCDF format. CCKP derives spatially aggregated units at national, sub-national, watershed and Exclusive Economic Zone scales.[27] For spatial aggregations, CCKP applies both a shapefile weighting, per each unique polygon to appropriately calculate the proportion of a grid-cell within a designated spatial unit. Additionally, a latitudinal weight is applied to properly reflect the physical properties and changing climate responses of the Earth's curvature.[28]

While perhaps an easier approach, CCKP does not advise applying zonal statistics to gridded climate data to calculate spatial aggregations as key fractions of a grid within a polygon may not be properly captured or reflected. **Figure R** represents approach for zonal statistics, presenting visually where proportions of a grid cell are missed, or not properly captured. This is additionally shown through **Figure S**, which demonstrated the fraction of grid cells that must be accounted for given a specific project area or administrative boundary. By using a latitudinal weighting, CCKP address the dual concerns of properly accounting for the Earth's curvature and including values of fractions of grid cells due to unique overlay of zones.

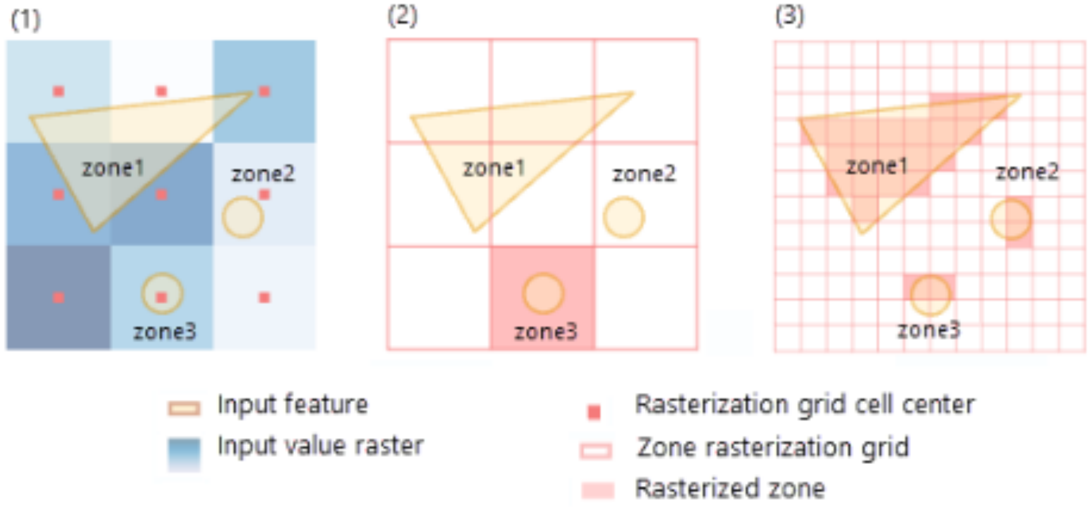

Figure R. Zonal Statistics: Calculating statistics on cell values of a raster (netCDF) within the zone defined by another dataset

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[27] Shapefiles are per World Bank recognized legal boundaries.

[28] Latitudinal weights are per Earth System Grid Federation. https://esgf.llnl.gov/

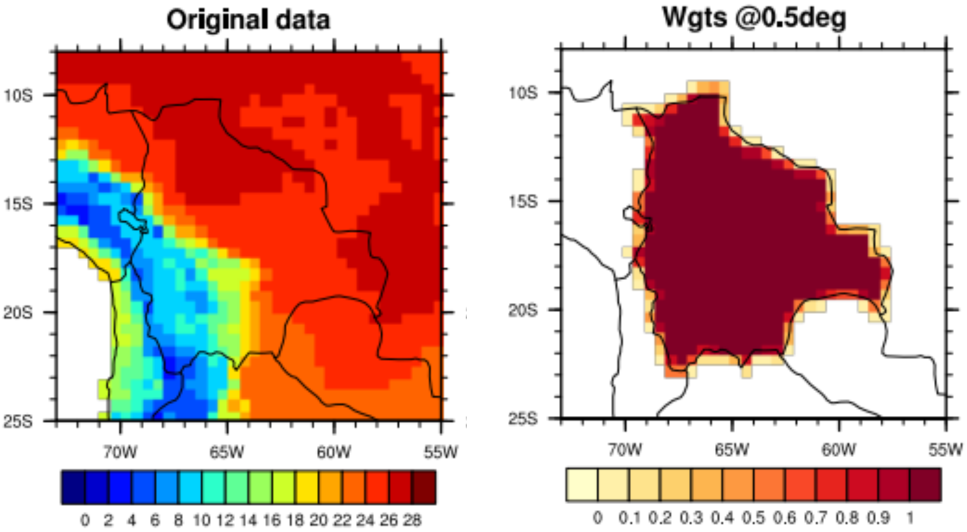
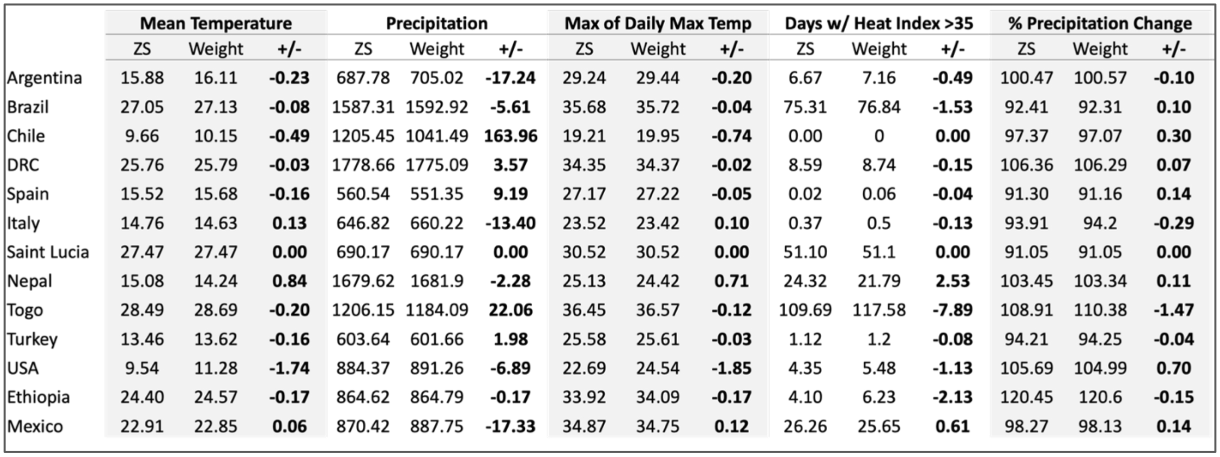


Figure S. Original data compared to the value of fractional pixels caused by the overlay of feature zones (e.g. project areas, administrative boundaries)

Finally, when running the calculations for each approach across a variety of different indicators for both relatively large and small nationally-designated spatial units, output differences can clearly be seen in **Figure T**. Differences are non-trivial.



	Mean Temperature			Precipitation			Max of Daily Max Temp			Days w/ Heat Index >35			% Precipitation Change		
	ZS	Weight	+/-	ZS	Weight	+/-	ZS	Weight	+/-	ZS	Weight	+/-	ZS	Weight	+/-
Argentina	15.88	16.11	**-0.23**	687.78	705.02	**-17.24**	29.24	29.44	**-0.20**	6.67	7.16	**-0.49**	100.47	100.57	**-0.10**
Brazil	27.05	27.13	**-0.08**	1587.31	1592.92	**-5.61**	35.68	35.72	**-0.04**	75.31	76.84	**-1.53**	92.41	92.31	**0.10**
Chile	9.66	10.15	**-0.49**	1205.45	1041.49	**163.96**	19.21	19.95	**-0.74**	0.00	0	**0.00**	97.37	97.07	**0.30**
DRC	25.76	25.79	**-0.03**	1778.66	1775.09	**3.57**	34.35	34.37	**-0.02**	8.59	8.74	**-0.15**	106.36	106.29	**0.07**
Spain	15.52	15.68	**-0.16**	560.54	551.35	**9.19**	27.17	27.22	**-0.05**	0.02	0.06	**-0.04**	91.30	91.16	**0.14**
Italy	14.76	14.63	**0.13**	646.82	660.22	**-13.40**	23.52	23.42	**0.10**	0.37	0.5	**-0.13**	93.91	94.2	**-0.29**
Saint Lucia	27.47	27.47	**0.00**	690.17	690.17	**0.00**	30.52	30.52	**0.00**	51.10	51.1	**0.00**	91.05	91.05	**0.00**
Nepal	15.08	14.24	**0.84**	1679.62	1681.9	**-2.28**	25.13	24.42	**0.71**	24.32	21.79	**2.53**	103.45	103.34	**0.11**
Togo	28.49	28.69	**-0.20**	1206.15	1184.09	**22.06**	36.45	36.57	**-0.12**	109.69	117.58	**-7.89**	108.91	110.38	**-1.47**
Turkey	13.46	13.62	**-0.16**	603.64	601.66	**1.98**	25.58	25.61	**-0.03**	1.12	1.2	**-0.08**	94.21	94.25	**-0.04**
USA	9.54	11.28	**-1.74**	884.37	891.26	**-6.89**	22.69	24.54	**-1.85**	4.35	5.48	**-1.13**	105.69	104.99	**0.70**
Ethiopia	24.40	24.57	**-0.17**	864.62	864.79	**-0.17**	33.92	34.09	**-0.17**	4.10	6.23	**-2.13**	120.45	120.6	**-0.15**
Mexico	22.91	22.85	**0.06**	870.42	887.75	**-17.33**	34.87	34.75	**0.12**	26.26	25.65	**0.61**	98.27	98.13	**0.14**

Figure T. Comparison of spatial aggregations derived by zonal statistics (ZS) and by latitudinal weighting (Weight). Statistics calculated from global gridded NetCDF files.