A Living Manual for Climate Information for Adaptation Planning

WEST AFRICA BIODIVERSITY AND CLIMATE CHANGE (WA BiCC) PROGRAM

About: This living manual is intended for those preparing National Adaptation Plans (NAPs) or specific adaptation interventions. It provides guidance on how to understand and use climate information in the context of adaptation planning. The material was developed in the context of a coastal adaptation project in West Africa—the USAID-funded West Africa Biodiversity and Climate Change project—but it has wide utility for anyone interested in the application of climate information for adaptation planning and development interventions. This web-based resource is called a "living manual" since the contents have been updated based on the needs and feedback of participants in a series of country workshops held in the West Africa region.

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Citation: West Africa Biodiversity and Climate Change (WA BiCC) Program (2020). A Living Manual for Climate Information for Adaptation Planning.

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Cover photo: A newly constructed embankment in the Momaya community, Sierra Leone. Credit: Thomas Lebbie

This document was made possible by the generous support of the American People through the United States Agency for International Development (USAID). The contents of this document are the sole responsibility of its authors and do not necessarily reflect the views of USAID or the United States Government.

The Material: The Living Manual has a number of sections. Users who are familiar with the basics of climate information may wish to skip to the Sectoral Information Needs section, which details information needs for various sectors. In Climate Data Types, the difference between climate information and climate data is discussed, and types of climate data are examined in detail. Examples of best practice from different countries are provided for those interested in using climate data to develop climate information products. A Guide to Online Climate Information Tools is also included, and directs users to external climate information resources.

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1. Climate Information Basics

Introduction

Climate information is needed to characterize climate risks and to inform decision-making for effective risk management. Climate information is information about the past, present, and future climate of an area, built on data from observations and models. Climate information comprises the statistical characteristics of climate variables over extended periods (months, seasons, years, or longer), while weather forecasts consist of predictions about the weather conditions in the near future. Climate information organizes climate data in a way that makes it useful for planners. Information about climate can therefore help practitioners make decisions on mid- and long-term timescales.

Climate information is needed to characterize climate risks and to inform decision-making for effective risk management. However, decision makers often have to make do with limited availability of climate data and limited capacity to apply information gleaned from the data. Moreover, the selection of future climate scenarios has become much richer and global climate model (GCM) outputs can now be used to create regional and local climate projections, providing new opportunities for adaptation practitioners to incorporate future climate information into their practice.

Several guides have been developed to help decision makers and information providers understand and utilize climate information required for adaptation planning. However, in many developing regions climate data are sparse and the provision of climate information does not follow well-established guidelines. Furthermore, to understand how the climate may change, it is first important to have a good understanding of baseline climatic conditions; spatial and temporal data gaps can make the development of information about future climate change challenging (see Section 3: Climate Data Types).

This section reviews key concepts necessary for better understanding available climate information and its limitations, and for more

Box 1: Weather and Climate

Weather: The state of the atmosphere at a given time and place with regard to temperature, air pressure, wind, humidity, cloudiness, and precipitation. The term weather is restricted to conditions over short periods of time. Weather is whatever is happening outdoors in a given place at a given time, and can change within a very short time.

Climate: The average condition of the atmosphere near the earth's surface over a long period of time, taking into account temperature, precipitation, humidity, wind, barometric pressure, and other phenomena. Climate also incorporates seasonality and the likelihood of extremes. Climate tells us what it's usually like in the place where you live.

"Weather is what you get; climate is what you expect"

effective communication with information producers. It draws on many of the articles and reports listed in the Resources section (Section 6).

External Link: What is climate change?

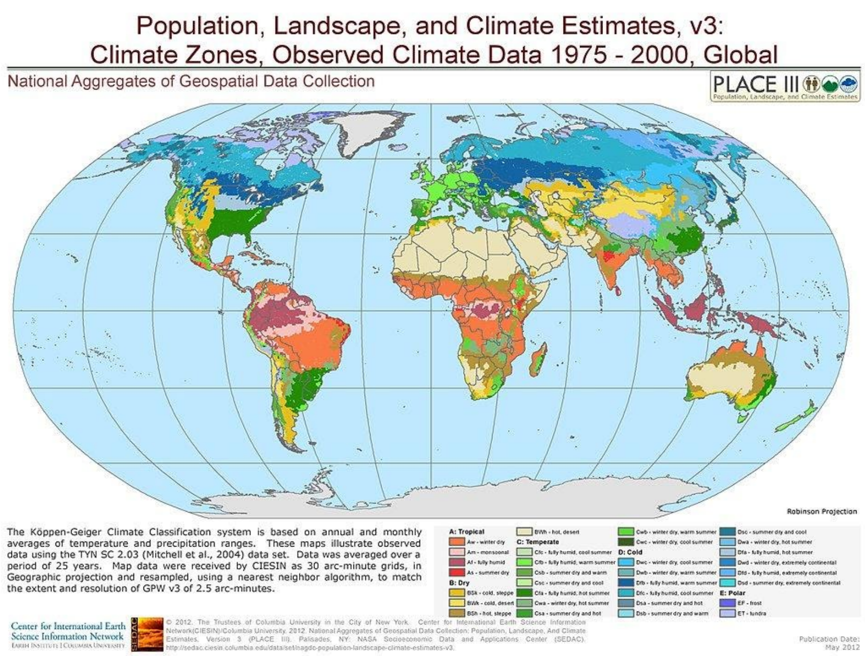
[Climate Change Basics - US EPA (2015)]

Framing Information Needs

In general, climate information needs will depend on the scope of the adaptation planning/analysis, ranging from initial risk screening and detailed risk analysis to assessing risk management options. There is also a need to clearly identify non-climate drivers. However, when seeking climate information, practitioners need to clearly understand the statistical nature of climate change, the fundamental difference between data and information as well as between climate vs. impact information, and the need to account for uncertainties in the projections. In addition, practitioners need to clearly articulate their needs around specific time horizons (periods of time) and temporal and spatial resolution.

Box 2: How is my local climate determined?

Scientists have characterized local climate "types" using a variety of systems., One system is the Köppen Climate Classification system, which divides the world into different climate zones based on seasonal temperature and precipitation patterns .

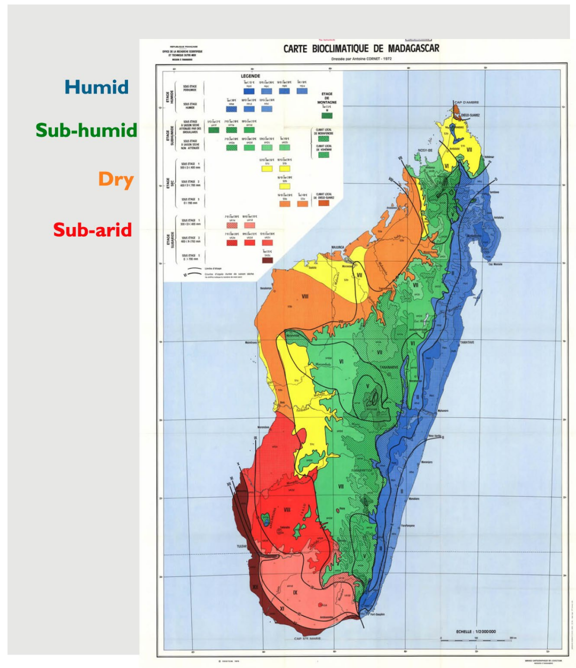


Source: NASA Socioeconomic Data and Applications Center (SEDAC)

Box 2: How is my local climate determined? (continued)

In Madagascar, for example, the country is divided into several different climate zones. These are determined by several factors:

1. Energy balance
2. Seasonality
3. Sea-land distribution
4. Circulation Patterns
5. Local topography



The Statistical Nature of Climate Change

While the concept of climate change may connote modifications to something steady and immutable, climate in fact varies on a number of scales. Human activities as well as natural systems evolve in response to such variations and can cope with a range of climatic conditions without serious damage. Figure 1 conceptualizes current climate variations and the coping range. Occasionally, climate variations exceed the coping range and the system is put under higher stress or severely damaged. If the frequency of such events is low, the system will progressively recover. When they become more frequent, the system may reach a new state. Within such a framework, climate change means that severe impact events may happen more frequently, and/or events of unprecedented magnitude may occur, putting the system under such stress that recovery is difficult if not impossible (Figure 1, right side).

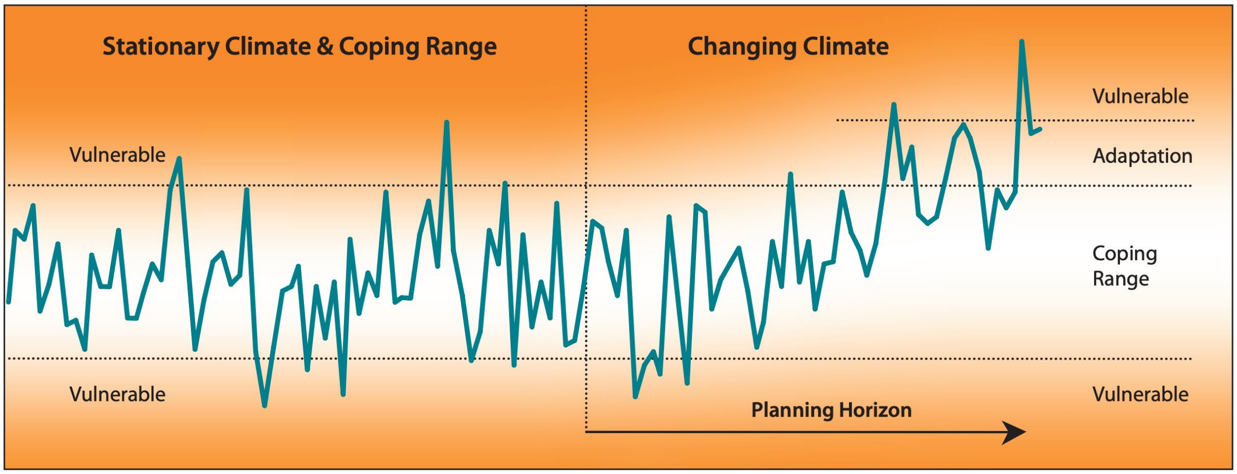


Figure 1. Conceptual illustration of historical and future climate, coping range and adaptation. Source: Lu, 2007, adapted from Carter et al. 2007.

Adaptation is aimed at limiting damage and speeding recovery from such damaging events. As seen in Figure 2, high impact events in the future can occur more frequently due to:

- Change in the average, keeping the amplitude of the variability the same (Fig. 2a)
- Change in the amplitude of the variability, keeping the average the same (Fig. 2b)
- Change in the frequency of rare events on one side of the distribution (Fig. 2c)
- Any combination of the above at the same time.

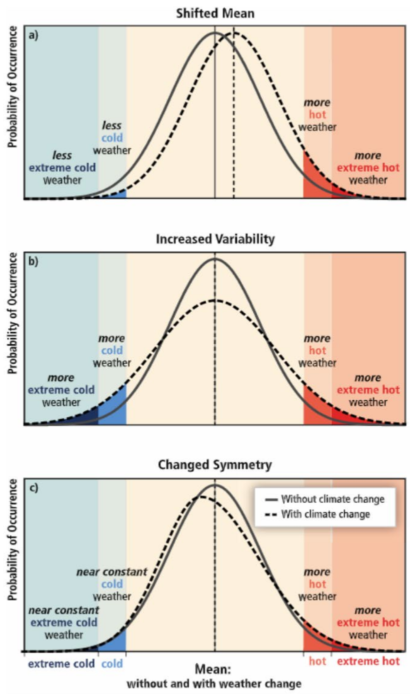


Figure 2. The effect of changes in temperature distribution on extremes. Different changes in temperature distributions between present and future climate and their effects on extreme values of the distributions: (a) effects of a simple shift of the entire distribution toward a warmer climate; (b) effects of an increase in temperature variability with no shift in the mean; (c) effects of an altered shape of the distribution, in this example a change in asymmetry toward the hotter part of the distribution. Source: IPCC (2012)

Data vs. Information

Decision makers needing climate information must understand the distinction between data and information. Very often requests are made for 'data' while what is needed is 'information.' Data is simply an array of numbers, most often recorded values of a meteorological variable in a given location with a given time-step; for example, daily rainfall recorded in Accra. As such, data may not be very useful to policymakers and practitioners, unless they are used in impact models or other types of data analyses.

Most of the time, these audiences need information extracted from the data: average annual rainfall, rainfall seasonality, trends in temperature, frequency of dry spells lasting longer than a given threshold, or frequency of temperature exceeding a threshold. Information is extracted from the data with a given objective in mind and will differ from sector to sector and from hazard to hazard. Average temperature in a location as well as the frequency of heat waves are both derived from the same data, applying different statistical analyses. However, while it may seem desirable for each sector and practitioner to derive their own information from the data, in practice, it is best to ask data holders (Meteorological Services) to provide this information because they are most aware of data limitations. For example, the quality of rainfall data in a given location might be sufficient to estimate the average annual rainfall but not good enough to estimate the frequency of extreme rains. Therefore, it is best to approach information producers to directly obtain the information rather than ask for the raw data. This also avoids duplication of datasets as well as issues with dataset versions and updates.

Climate Information vs. Impacts Information

Another useful distinction to keep in mind is between climate and impact information. Diverse past and projected statistics of meteorological data, as cited above and applied to rainfall, temperature, atmospheric moisture, solar radiation, and wind are climate information and should be available from Meteorological Services. Changes in crop yields due to variations in temperature, forecasts of areas flooded in a flash flood after heavy rain or changes in vector-borne disease incidence due to variations in temperature and rainfall, are usually beyond the mandate of climate information producers. Such impact information is usually developed by scientists in collaboration with sectoral decision makers (e.g., disaster managers, agricultural or health ministries) using impact models (e.g., crop models, hydrological or flood models, vector and disease models). In addition to many local or regionally calibrated models, a wide range of global impact models are now available through the Inter-Sectoral Impacts Model Intercomparison Project (ISI-MIP).

Uncertainty

Adaptation practitioners need to accept that information about future climate is provided with a certain level of uncertainty. This is inherent to any model of the real world, and especially to projections of the future. Uncertainty needs to be factored in the decision process. Uncertainty does not mean that future climate is totally unknown or that projections are false. Moreover, uncertainty can be quantified and decisions can still be made.[1] There are four main sources of uncertainty in climate projections:

1. Future levels of anthropogenic emissions and occurrence of natural phenomena (e.g. volcanic eruptions);
2. Imperfections of the climate models used to project changes in climate;
3. Imperfect knowledge of current climate that serves as starting point for the projections; and
4. Difficulty in representing, thus reliably projecting, interannual and decadal variations in climate.

Decision theory is a field that offers strategies to help practitioners quantify the value of different choices under uncertainty. While detailed descriptions of how such valuations are completed is beyond the scope of this manual, strategies practitioners may want to consider include:

1) Estimated Monetary Value: considers the value of a particular outcome weighted against the probability of that outcome occurring

2) Expected Utility: considers the value of a particular outcome weighted against both the probability of that outcome occurring and stakeholder's tolerance for risk

3) Value of perfect and imperfect information: a way of assessing the monetary value of perfect information in an uncertain environment

[1] Decisions are routinely made in the context of military operations and financial investments where uncertainty is greater than that of climate projections.

Time Horizon

The type of information needed will depend on the type of adaptation intervention or investment and, among others, on how far into the future the return on investment is expected. Figure 3 presents examples of different decision types as a function of their time horizon. Larger infrastructure investments (irrigation, transportation network, dams, etc.) usually have longer time horizons than individual decisions/investments such as cropping portfolios or farm planning. The time horizon of the intervention or investments will impact the precision with which the information can be provided. While the amounts of rainfall or the probability of long dry spell in the coming rainy season can be predicted with a higher degree of accuracy, only general tendencies in rainfall, with a wide uncertainty, can be provided for a horizon of 30 to 50 years. In addition, farming systems 50 years from now will most probably result from successive adaptation stages rather than from changes planned 50 years ahead of time. Not all of these changes will be driven by climate; changes in technology, seed stocks, global and local markets and economy, and customer preferences will all play significant roles.

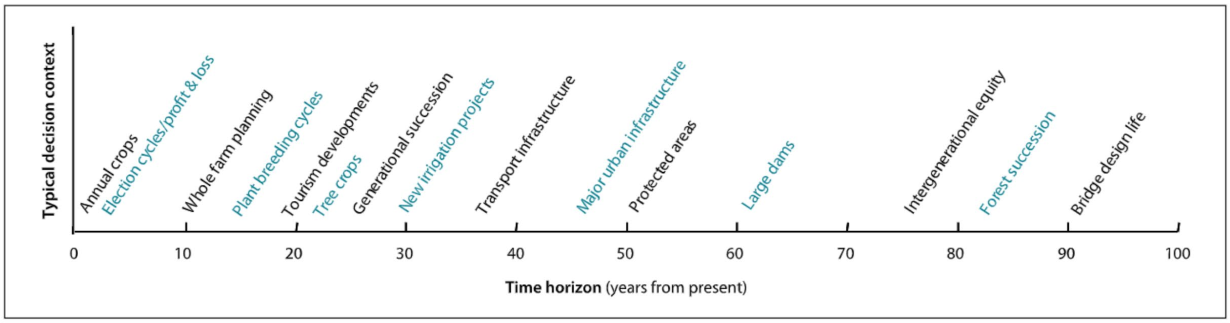


Figure 3. Adaptation decision contexts and their associated time horizons. Source: Lu, 2007

Thus, in a lot of cases interventions other than large scale infrastructure investments will focus on much shorter time horizons, more compatible with decisions at individual and community levels and project cycles. At such horizons, changes in climate might be less important than interannual variability, and even not significant. In addition, IPCC (2012) recommends focusing on measures that provide benefits both for future climate conditions and for current levels of climate variability, since current extremes are often a foretaste of future climate characteristics. These so-called "no regret strategies" have the potential to offer benefits now and lay the foundation for addressing changes in the future. With respect to Figure 1, such approaches expand the current coping range, irrespective of the direction that climate change is going to take.

Figure 4 presents a more complete continuum of horizons, including shorter time scales, and related adaptation applications. Note that the ability to provide climate information ahead of time for horizons shorter than several decades derives from drivers that are different from anthropogenic emissions, and that different time-scales have different drivers and different data needs. Thus, the issue of adaptation to climate change requires focusing on data collection and climate information not only for the distant future. It is useful to differentiate between time-frames below.

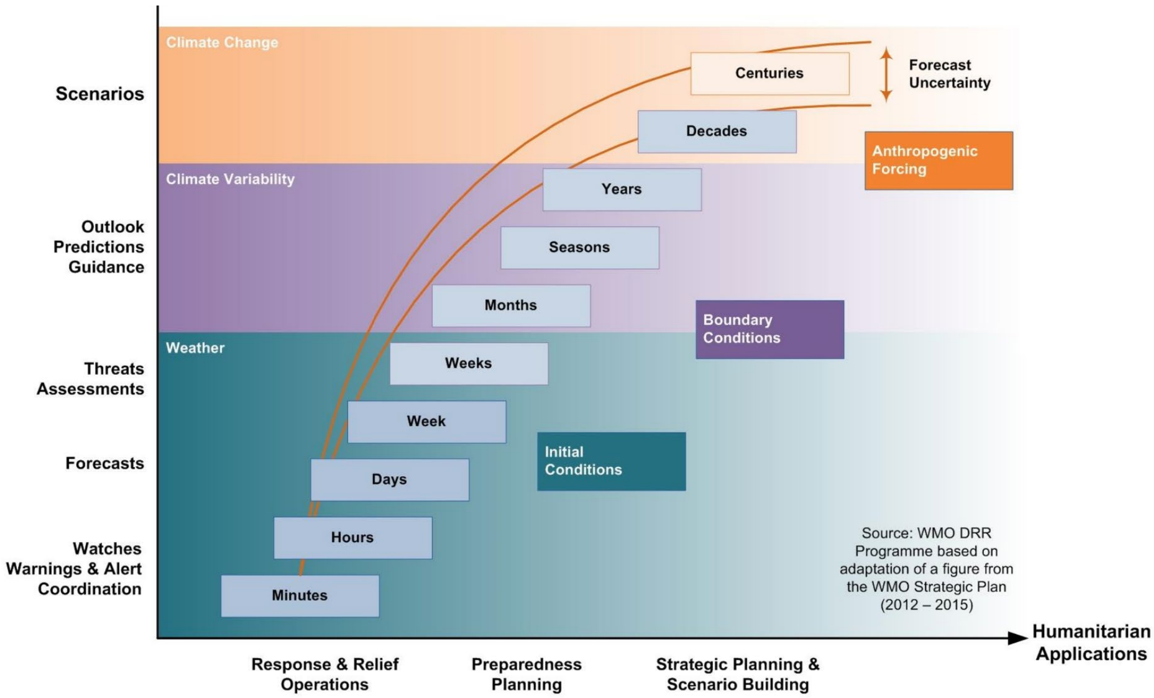


Figure 4. Schematic diagram showing the relationship between climate timescales, from weather to climate change, and emergency and adaptation mechanisms, from relief operations to climate change planning. Source: Mason et al. 2015, adapted from WMO (n.d)

Box 3: Different drivers underlying predictions / projections for different time horizons (boxes on the right of Fig. 4).

The most important factor in the predictions at weather time scales is the current state of the atmosphere; boundary conditions for predicting climate variability refers to components of the climate systems that influence the atmosphere, such as sea surface temperatures, that influence wind patterns and moisture content in the atmosphere and evolve more slowly than atmosphere; Anthropogenic forcing refers to the changes in the overall characteristics of the atmosphere due to greenhouse gas emissions linked with human activities. This in turn modifies the amount of energy in the climatic system thus distribution of temperature, rainfall and winds, leading to modification of global and local climate characteristics.

Time Frames

Most adaptation practitioners require information about climate patterns in the future in order to develop adaptation plans. However, climate information from the past and information on current climate variability are equally important for adaptation planning. Historical climate records allow practitioners to assess the frequency and magnitude of catastrophic events that negatively affect communities, livelihoods, and ecosystems. These assessments can constitute a baseline against which future changes in climate can be assessed. Conversely, current climate monitoring can facilitate the development of effective Early Warning Systems and support building resilience in communities.

Historical Climate Information

Historical climate analysis is a valuable component of adaptation assessments because it serves as a foundation for understanding current and future climate. Data on past conditions and trends can be used for mapping hazards, identifying relationships with past impacts (disease outbreaks, food crisis, etc.) and assessing relevant thresholds in climatic variables. It also provides a reference against which current and future conditions can be compared. Finally, an understanding of local climate characteristics such as seasonality and related disease or agricultural cycles or the coping range (Fig. 1) and patterns of natural variability can be built from historical observations.

It is particularly important to distinguish **three** different time-scales of climate variability and their relative importance to the given application.

- **Interannual variability**: changes in rainfall amounts and temperature for a given month or season from one year to the other. This is an intrinsic part of climate and such variations occur because of interactions between different components of the climate system. Socio-economic activities as well as ecosystems are usually adapted to a certain degree to such variations and it is only a few extreme years/seasons that lead to impacts beyond the coping range of human and natural systems (Fig. 5).
- **Decadal variability** refers to the occurrence of a sequence of drier than normal or wetter than normal years over periods of 10 to 30 years. Such sequences of repeated droughts for example have profound consequences on ecosystems and socio-economic activities as the systems often do not have time to recover before facing another event. The sequence of the Sahelian droughts in the 1970s and 1980s is the most notable example of such decadal variability in rainfall (Fig. 6, left). Decadal variability was also detected in East Africa, Atlantic hurricane activity and the Dust Bowl in the USA. It is critical to assess the importance of the decadal variability in the region of interest as it may impact the detection of longer term trends and may lead to an erroneous attribution of drier/wetter conditions to climate change (based on extrapolation of the trends).
- **Long-term trends** refer to climate shifts (beyond 30 years) with a new long-term mean and interannual variations occurring around that new mean, with possibly a different amplitude (cf. Fig. 1). The most important contributor to such shifts currently is anthropogenic climate change. However, it is important to note that such long-term trends are most easily detected in temperature while in rainfall long term changes or trends are often masked by interannual and decadal variability. Thus, in regions where water/rainfall are the limiting factors, reduction of vulnerabilities to interannual and decadal variations might be more important than adaptation to potential changes 50 to 80 years into the future.

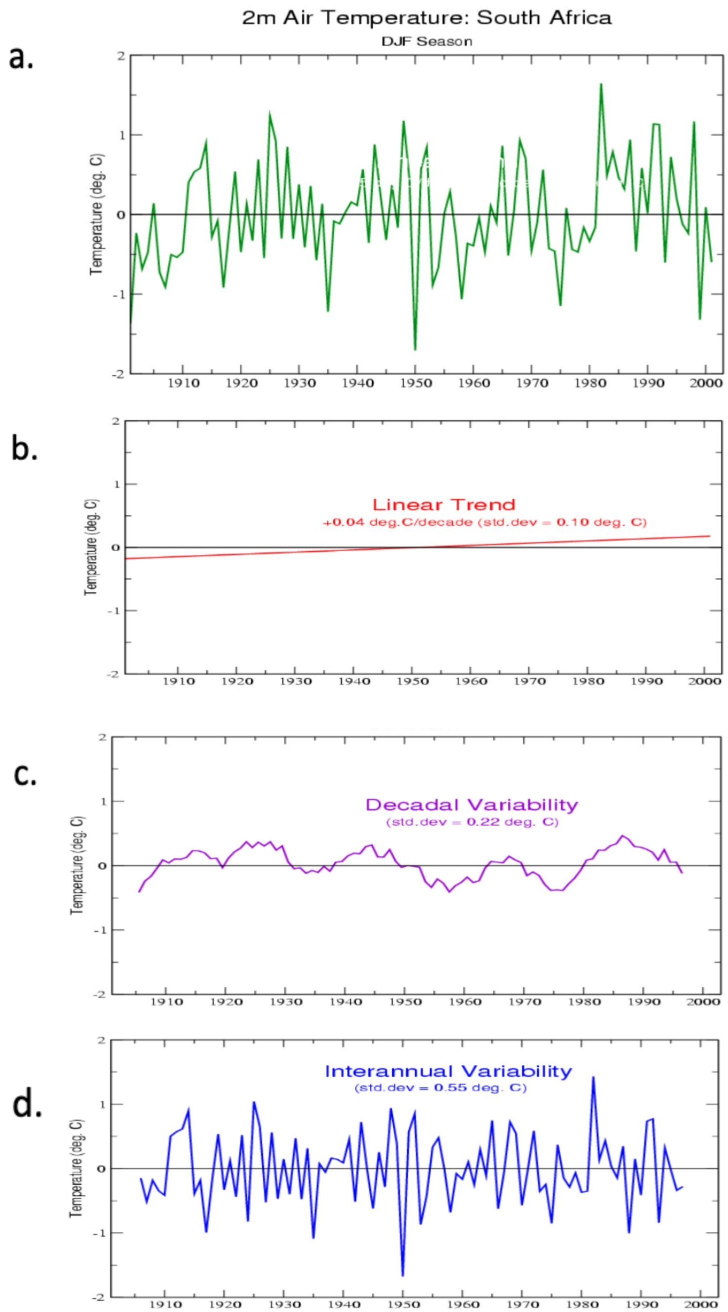


Figure 5. Different scales of variability in the climate system: (a) variability in temperature in South Africa, decomposed into (b) climate trend, (c) decadal variability, and (d) interannual variability.

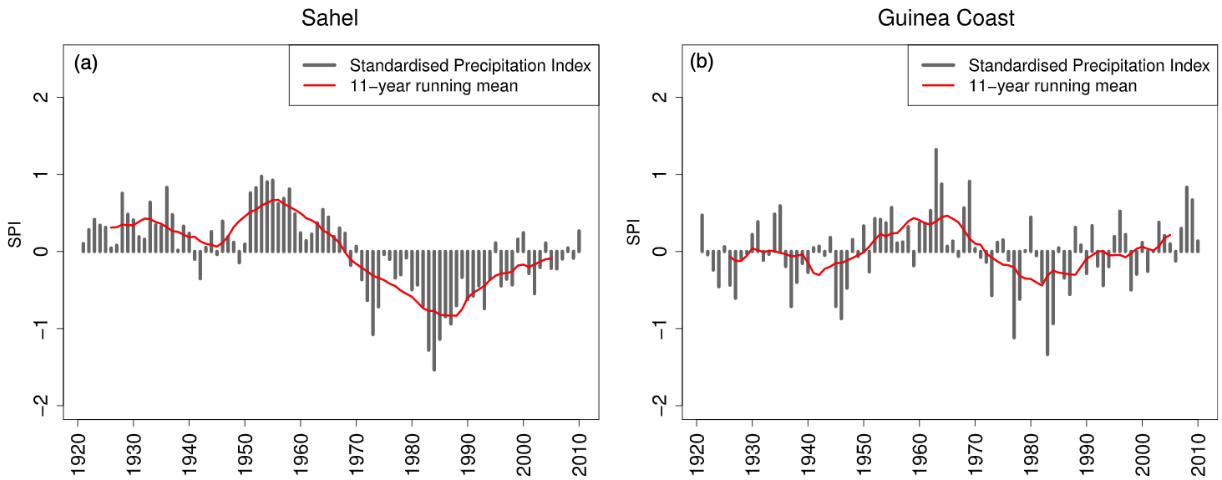


Figure 6. The Standardized Precipitation Index for 12 months (SPI-12) and its 11-year running mean for (a) the Sahel and (b) the Guinea Coast between 1921 and 2010, based on records in approximately 76 stations across West Africa for the period 1921-2010 and over 300 stations over the period 1980-2010 . Source: Sanogo et al., 2015.

Analysis of the historical climate can be performed at various spatial scales depending on data availability and the scope of the analysis. In an optimal scenario, long time-series of climate data from several meteorological (met) stations within a country should be used for the analysis. Met station data is the most accurate source of climate information and it reflects local conditions, capturing spatial variations within the country, which is important for national adaptation strategies. Historical climate analyses include long-term assessments of averages and variability, including statistics on extreme events and overall trends. They can also include change-point analysis (Lanzante, 1996) i.e., the detection of a point in time where the time series changes its characteristics (mean, distribution etc.). Figure 7 provides an illustrative example of a time series that has undergone change-point analysis. The change point is circled, and the two time periods are clearly distinguished by their differences in mean.

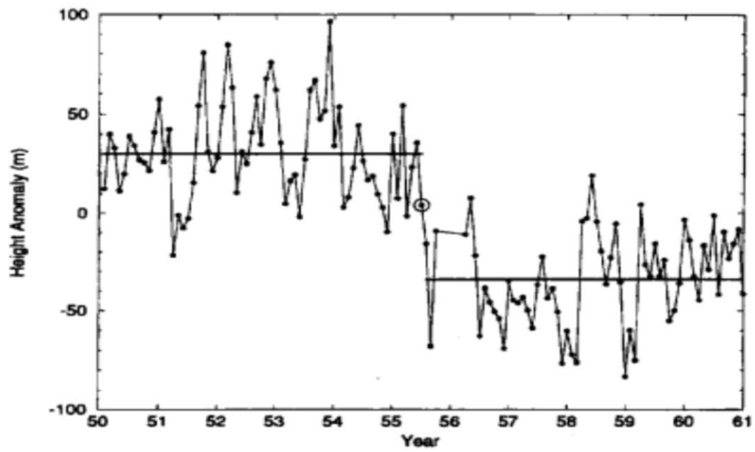


Figure 7. Time series anomaly of monthly 200 hPa geopotential height anomaly (m) at Hong Kong from 1950-1960. The monthly anomaly values are connected by a curve. The horizontal lines represent the biweight means of the two segments defined by the change-point (circled star). Source: Lanzante, 1996.

Current Climate Monitoring & Early Warning Systems

Box 4: Rapid and Slow Onset Disasters

Rapid-onset disasters are triggered by an instantaneous shock and often occur with no or little warning. The impact of such disasters may unfold over medium- or long- term, though most of their damaging effects occur within hours or days. Examples of rapid-onset disasters include earthquakes, tsunamis, volcanic eruptions, landslides, tornadoes, tropical cyclones and floods.

Slow-onset disasters take longer to unfold. They occur when the ability of agencies to support people's needs degrades over weeks or months. They emerge along with and within development processes. The hazard can be felt as an ongoing stress for many days, months or even years. Examples of slow-onset disasters include drought, famine, soil salinization, soil erosion, and AIDS epidemics.

- **Climate monitoring** is the assessment of near real-time climate information and comparison with historical information. Monitoring products will depend on the decisions they support but most frequently they include information on the previous ten days, previous month or previous three-month period. In addition to presenting values and anomalies they are also often presented in the context of historical information; e.g., with respect to standard deviation or thresholds of extreme events or in terms of return periods. While often used to qualify the amplitude of extreme events, such as extreme rainfall or a heat wave, climate monitoring is also instrumental in early identification of the slow-onset events. Climate monitoring is an essential element of Early Warning Systems. See Box 4.
- **Early Warning Systems** (EWS) enable timely responses to both short-term/rapid (e.g. cyclones, floods and storms) and long-term/slow (e.g. drought and long-term climate change) onset climatic hazards. An

EWS is an integrated method of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events (UNDP, 2015). Effective EWSs often require a joint effort among various national agencies to deliver early warnings in a timely and effective manner and their ultimate effectiveness and accuracy depend on climate information. They can be viewed as part of resilience building or adaptation strategies.

Predicting the Future: from Weather Forecasts to Climate Projections

Forecasts, projections and scenarios are useful for anticipating climate hazards, for planning humanitarian operations, and for long-term recovery and development planning.

- **Forecasts** are specific statements about the expected conditions for the immediate or very near future (up to a few months). Weather forecasts provide information about specific conditions in a specific place and time, typically up to a few days in advance. Conversely, climate forecasts are typically offered for the upcoming season and only give general tendencies of the climate over larger spatial scales (e.g., probabilities for above or below normal precipitation). These forecasts can be are incorporated into Early Warning Systems, and together with the weather and climate monitoring provide a basis for issuing alerts. Both weather and climate forecasts should be accompanied by an assessment of their accuracy in the past and present estimates of uncertainty.
- **Projections** are statements about climate conditions much further into the future, typically more than one year. Climate change projections usually target temporal scales of 30 to 50 years. Other projections can also be made—most notably to address decadal variations—though these are currently considered more theoretical than operational.

Forecasts and projections can be presented as:

- **Deterministic**: one possible outcome with no information about possible errors in forecast.
- A **range of values**: an upper and lower limit between which actual values are expected to occur. This format attempts to account for potential different outcomes but does not state the likelihood of each outcome. Graphs of the spread in projected temperature or rainfall are typical of this format (Fig. 8)
- **Probabilities**: different probabilities are given for different outcomes/values/ranges. Such a format accounts for known errors and uncertainties in the forecasts/projections.

Box 5: How are climate change projections elaborated?

Global climate change projections are developed via coordinated international modeling efforts to support the Intergovernmental Panel on Climate Change's (IPCC) assessment of the science of climate change. The main tools to produce information about future climate are **General Circulation Models (GCMs)** – computer programs that represent atmospheric, oceanic and biotic processes, and interactions between them, through a series of mathematical equations. They are able to incorporate changes in atmospheric composition due to human activities and produce global climate projections. Confidence in GCM projections at the global-scale is based on well-understood physical processes and laws, the ability of GCMs to accurately simulate recent and past climate, and the agreement in results across models. However, such models are only able to provide information about climate at the spatial resolutions of 100-200km and are more reliable in their projections of overall statistical characteristics of climate rather than exact values. Thus, GCM projections are more dependable at continental and larger spatial scales, which are oftentimes not useful for regional and local scale studies. Climate change information at scales more relevant to applications are often obtained through the process of downscaling**.** Downscaling can be performed by dynamical and/or statistical means. Dynamical downscaling refers to the use of a Regional Climate Model (RCM) that utilizes input from a GCM to numerically simulate climate at a finer resolution. In statistical downscaling, relationships between local- and large-scale climate variables are established based on observation and used to derive future local climate information from GCM projections (USAID, 2014).

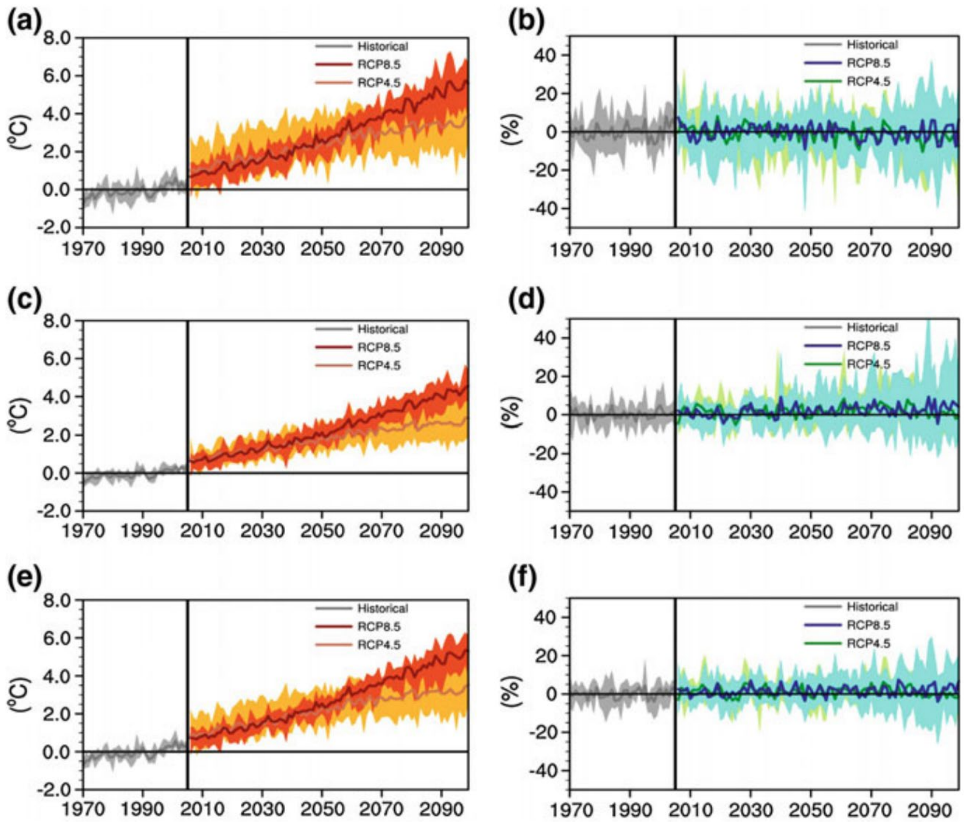


Figure 8. Long-term time series (1970-2100) of seasonal (May-September) mean temperature (left panels) and precipitation (right panels) anomalies for the Sahel (upper panels), the Gulf of Guinea (middle panels) and the West Africa (lower panels) and for both RCP4.5 and RCP8.5 based on multimodel CORDEX simulations. The anomalies are calculated with respect to the seasonal mean of the period 1976-2005. The shaded areas denote ensemble maxima and minima. (a) Sahel temperature change. (b) Sahel precipitation change. (c) Guinea temperature change. (d) Guinea precipitation change. (e) West Africa temperature change. (f) West Africa precipitation change.

Time and Space Resolution

Temporal Resolution

It is important to understand that for some assessments or sectors average climatic conditions, such as average annual or seasonal rainfall, are sufficient while for others—especially the ones dealing with extreme weather events—analysis of daily records is necessary. The data acquisition process and data quality make different time resolutions more or less reliable. For example, if large gaps in daily rainfall records exist, it may still be possible to derive a reliable estimate of the average annual rainfall while a reliable analysis of the extreme rainfall may not be possible.

Spatial Resolution

The spatial resolution of the information needed is defined by the purpose of the assessment. A global assessment of food security can rely on global coarse resolution gridded data and model outputs, on the order of several hundreds of kilometers. If the information is needed to design localized land use plans or delineate flood prone areas, then information at much finer scale (a few hundreds of meters) is needed. Similarly, climate information might be required for a variety of spatial extents, from regional to country to water basin to individual farm, and addressing those different extents involves using data at different spatial resolutions. Coarser resolution information is usually more easily available but will not capture climate variability or differences over short distances over heterogeneous landscapes (e.g., mountain areas).

2. Sectoral Information Needs

In order to use climate information for adaptation planning, identifying which climate variables are needed for different planning needs is critical. Although some overlap in variables exists between sectors, the precise variables needed may vary widely. Table 1 presents examples of potential impacts of climate change and the climatic variables relevant to different sectors. Some of the variables might be more easily available (e.g. temperature or rainfall) than others (solar radiation or sea level).

Table 1: Common climatic variables used for climate impact and risk assessment (Source: Lu 2007).

Sector/system	Areas of potential impacts	Relevant climatic variables
Agriculture	Pest and disease outbreaks Soil properties Crop yields Livestock herds	Temperature Rainfall Solar radiation
Water resources	Water availability and supply Water resources reliant on snow melt	Temperature Rainfall
Coasts	Coastal erosion Coastal flooding Storm surge return periods and area inundated	Temperature Rainfall Sea level Wind Pressure
Human health	Heat stress and related mortality Infectious disease	Temperature Rainfall Humidity
Infrastructure	Road and rail maintenance costs Building	Temperature Rainfall Radiation Winds Sea level
Energy	Energy Demand Energy Supply Hydropower Renewables	Temperature Precipitation Solar radiation
Biodiversity	Primary production Abundance and distribution of species Coral bleaching and mortality	Temperature Rainfall Radiation Sea surface temperature

Agriculture

Agricultural production is affected by seasonal and sub-seasonal temperature and precipitation patterns, and solar radiation (the amount of incoming radiation from the sun). Temperature and precipitation also affect evapotranspiration (the rate at which water evaporates from the soil and leaves of plants), which is also an important factor in the productivity of agricultural systems. In addition to the direct effects of climate change, the productivity of agricultural systems is also affected by the indirect effects of socially and ecologically-mediated responses to climate change, including changing soil properties, pest and disease outbreaks, and planting decisions. More broadly, the effects of climate change on agricultural systems occur within a context of other large-scale trends, such as a shift towards increased use of irrigation. Although a review of the impacts of these non-climate-related trends is beyond the scope of this manual, it is important to consider that their effects may be substantial, and may amplify or mitigate the effects of climate change in complex and non-linear ways.

Changes in precipitation, temperature, and evapotranspiration can affect the quantity and quality of crop yields. In the tropics, many crops show decreased productivity with increasing temperatures (Figure 2.1). Temperature data, in contrast to precipitation data, show less spatial variability. Agricultural planners concerned with general temperature trends may find relatively coarse projections useful. Those concerned with identifying specific thresholds, especially in areas with varied orography, may need to consider tradeoffs between higher resolution models and increased uncertainty.

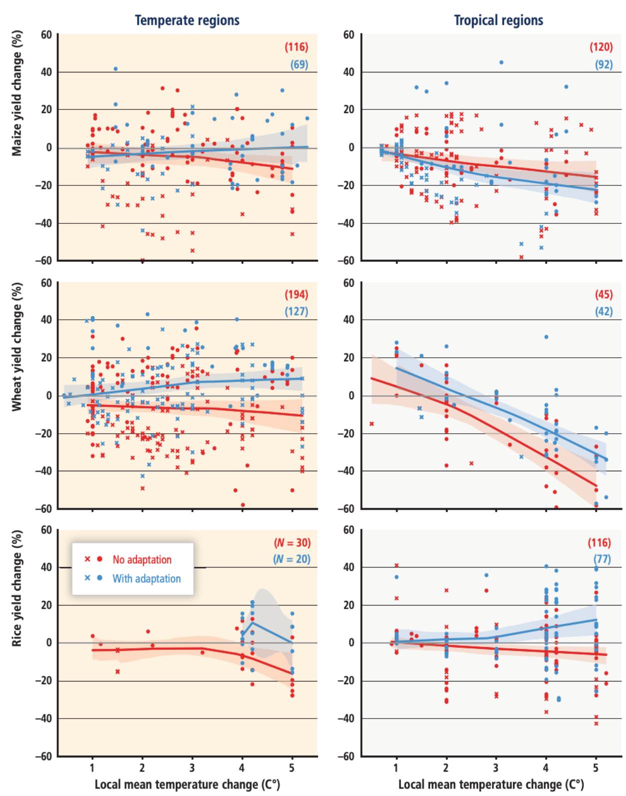


Figure 2.1 (Reprinted from IPCC AR5 WG II) The percentage change in yield for three crops in tropical and temperate regions, as a function of local temperature change. Note that adaptation measures mitigate some, but not all, losses.

Agricultural impact assessments should consider not only the total quantity of precipitation, but also the variability of precipitation. Precipitation indices such as the length of dry spells, the intensity of rainfall on rainy days, and seasonal patterns can help to inform adaptation practices within the agricultural sector. However, daily precipitation is poorly modeled by both GCMs and RCMs. Models tend to project more days with light rain, while observations show fewer rainy days but more intense precipitation. This discrepancy makes accurate projections of precipitation variability indices difficult, and accounting for this uncertainty in crop models is crucial.

Changes in cloud cover can also affect the amount of solar insolation an area receives. Whether or how clouds will change in the future remains one of the greatest outstanding sources of uncertainty in climate projections. While projections of future solar radiation in the region remain unsettled, agriculturalists should consider the consequences of this uncertainty.

Evapotranspiration rates are determined by temperature, surface winds, plant characteristics, and air moisture content. Higher evapotranspiration rates decrease available soil moisture and crops' water use efficiency, affecting agricultural productivity. Even in cases where models project increases in precipitation, soil moisture may remain unchanged or even decline if the increased evaporation expected with rising temperatures outweighs the effects of increased precipitation. Planting decisions, including what crops to plant, should consider the effect of evapotranspiration rates on water availability. Changes in temperature and soil moisture content can also affect the rate of plant decomposition, which may alter soil nutrient composition. Increases in intense rainfall episodes can also cause increased runoff and soil erosion, which can affect crop productivity as well as the quality of neighboring water resources.

The frequency and intensity of insect and disease outbreaks can also be affected by changes in temperature and precipitation. In some locations, pest outbreaks are tempered by the exceedance of certain low-temperature extremes; many pest populations cannot survive below specific temperature thresholds, and so an increase in mean temperatures could increase the probability that insect outbreaks occur. Agriculturalists concerned with pest and disease incidence may find tools focusing on climate extremes particularly useful.

Livestock productivity is affected by the availability of grazing land, and the presence of parasites and pathogens. In general, higher temperature and humidity leads to increased rates of parasitism and pathogenesis. Indirect climate impacts, such as the disruption of traditional trade pathways, may also increase the risk of the introduction of new diseases to an area. Alterations to local vegetation from changes in precipitation, temperature, solar radiation, and evapotranspiration affect the availability of suitable grazing land, which in turn affects livestock productivity.

Water Resources

Water resource managers are concerned with water availability, accessibility, and potability. Changes to surface and groundwater levels are determined by the balance between water inflow and outflow, and impact assessments should be wary of uncertainties in precipitation projections and future human use patterns. Responses to climate change by other sectors can also indirectly affect the availability of potable water in a region. For example, changes in agricultural practices can lead to increased runoff, affecting water quality; impacts to the energy sector, such as increased frequency of electricity outages and disruption of fuel supply chains, can affect groundwater accessibility. Water resource managers are familiar with other impacts on the water supply, such as changes in human populations or the impacts of new industries on water use, and should consider how climate impacts on different sectors may affect water availability.

Water flows to an area are determined by precipitation and surface runoff, and below-ground movement of water from one location to another. Water flow paths are determined by surface topography and the structure and features below ground. In mountainous areas a substantial portion of rainfall is provided by orographic precipitation. In these areas, coarse-resolution GCMs may be inadequate to project future rainfall and therefore surface water availability. On the other hand, spatial precision may be less necessary when considering water supply over a large watershed, and so the type of data used may depend on the size of the geographic area of interest.

The best data for precipitation are derived from station measurements. However, these provide little insight into future precipitation trends. Precipitation tends to show considerable spatial variability, so interpolated or reanalysis data should be used with caution, particularly over areas with sparse meteorological stations or variable topography. GCM simulations of precipitation also poorly replicate daily precipitation. Models tend to project more days with light rain, while observations typically show fewer rainy days with more intense precipitation. High rainfall intensity can increase surface runoff (and reduce soil moisture recharge), so local hydrologists should consider that GCM and RCM projections of rainfall likely underestimate the daily variability of precipitation and may overestimate soil moisture recharge.

Loss from a watershed is determined by evaporation rates, human usage, and outflow rates. Evaporation rates increase with higher temperatures and faster surface winds. However, they decrease with increased humidity. Temperatures in target countries are expected to increase over the next century. While humidity may also increase in some areas, an overall trend towards increased evaporation is expected. Accessibility and potability can also be affected by water storage patterns. Groundwater (water stored in aquifers below ground) can be more difficult to access than surface water (water stored in lakes or rivers). However, groundwater, which is filtered by layers of rock and soil, is also less susceptible to contamination.

Coasts

The concerns of coastal adaptation practitioners likely overlap with other sectors, particularly infrastructure, biodiversity, and water resource management. Coastal zones are particularly sensitive to sea level rise and storm surge, which increases the probability of flooding and saltwater incursion. Because of their detailed topography, coasts are poorly represented by coarse-resolution models. Downscaled regional models with precise topographical mapping are often necessary to assess coastal impacts.

Coastal erosion is often driven by wave activity. Changes in sea level, wind, and atmospheric pressure can drive changes in coastal wave patterns, affecting coastal erosion. Changes to the frequency and intensity of precipitation, together with human alterations to the landscape, can alter runoff patterns and impact erosive processes. Wind can also transport sediment, and changes in wind patterns can be an important factor in the erosion of sandy beaches or coastal dunes. Erosion can reshape coastal topography, which in turn affects coastal inundation patterns.

Coastal flooding is heavily impacted by sea level rise, storm surge, and inland rainfall. An increase in the intensity of rain events—something that will become more common in a warming climate—can also lead to heightened flood risk, even absent an overall increase in precipitation. Assessments of coastal flood risk should consider changes in sea level, precipitation patterns (cumulative precipitation and precipitation intensity) as well as topographical changes such as coastal subsidence.

The storm surge return period refers to the average length of time between storm surges of a particular height. With sea level rise, areas that may once have experienced storm surge every 100 years may now experience saltwater inundation more frequently. An increase in the frequency of saltwater inundation can affect coastal ecosystems and infrastructure. Projections of storm surge return periods require information on sea level rise, local topography and bathymetry, and expected changes in storm patterns and frequency.

While beyond the scope of this manual, increasing carbon-dioxide concentrations leads to ocean acidification, which can have important impacts on ocean biodiversity and fisheries.

Human Health

Higher temperatures can have direct impacts on human health, increasing the incidence of heat stroke and heat-related respiratory illnesses. Heat stress occurs when the body is not able to cool itself fast enough to maintain a healthy temperature. Left untreated, heat stress can result in heat stroke and eventually death. Children, the elderly, and people with certain cardiovascular or respiratory conditions are particularly vulnerable to heat-related death.

Higher temperatures and increased humidity substantially impact the human body's ability to maintain a healthy temperature. Evaporative cooling (cooling effect from the evaporation of a liquid from a surface) from sweat is one of the human body's primary methods of thermoregulation (processes that enable organisms to maintain steady core temperatures). High environmental temperatures and/or physical exertion lead to increases in body temperature. When humidity increases, the rate at which sweat can evaporate decreases, and cooling occurs less efficiently. Together, these effects can lead to increased potential for heat stress and heat stroke. In assessing the probability of heat related illnesses, healthcare practitioners and public health officials should consider a heat index, like wet bulb global temperature, that accounts for both temperature and humidity (see figure 2.2).

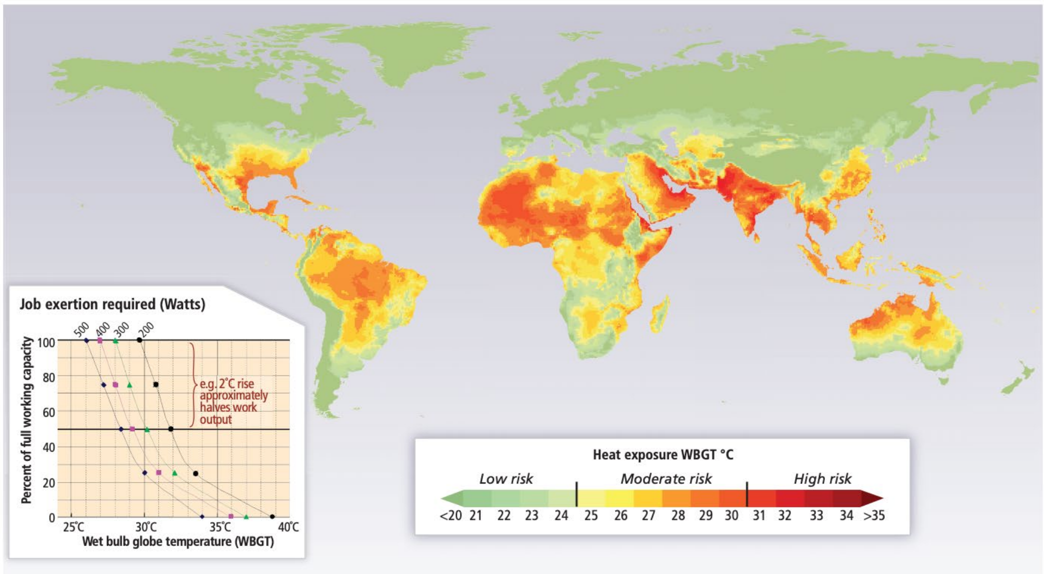


Figure 2.2 (Reprinted from IPCC AR5 WG II) The 1980-2009 average of the Wet Bulb Global Temperature for the hottest month. WBGT combines temperature, humidity, and other factors into a single index of the impact on work capacity and threat of heat exhaustion. Note that WBGT measures above 30 ℃ are considered very dangerous, while WGBT measures above 35 ℃ are generally lethal without artificial cooling.

With mean temperatures in West Africa expected to increase, public health officials should also consider projections related to the length and intensity of heat waves, as well as other factors that could influence heat, such as increases in impervious surfaces associated with urbanization, and the exacerbation of the urban heat island effect. This climate information should be considered alongside population characteristics, such as the age and health status of the general population.

The incidence of infectious diseases can also be affected by changes in climate. Vector-borne diseases such as malaria and dengue depend on climatic conditions (temperature, water availability) suitable for vector populations. As temperatures increase, malaria zones are expected to shift or expand. In particular, many communities at higher elevations, which historically have had little exposure to malaria, are expected to see the encroachment of malaria endemism. Public health officials should consider that these human populations likely have less resistance to the disease than their low-lying counterparts, who are more likely to have some native immunity from generations of exposure.

GCMs provide coarse resolution projections that may not capture the level of topographical detail necessary to represent precise temperatures in mountainous regions. However, using projected temperature anomalies, practitioners can consider shifts in temperature thresholds and anticipate the migration of malaria zones.

Waterborne diseases like cholera may also be impacted by changing precipitation patterns, especially increases in high-impact rain events. Increases in the incidence of natural hazards, particularly flooding, can lead to contamination of surface water sources. Public health officials should collaborate with practitioners focused on water resources and natural hazards to determine the likelihood of contamination. Recent progress in disease early warning systems may also allow the deployment of preventative and early intervention measures.

Infrastructure

Civil engineers and urban and regional planners are concerned with how changes in climate will affect the construction and maintenance of hard infrastructure. Infrastructure planning can occur at varied spatial scales; projects can range from regional rail systems to a single building. Accordingly, climate projections from regional to local scales may be relevant to infrastructure adaptation. Tradeoffs between spatial precision and the increase in uncertainty in downscaled models should be considered by sectoral practitioners.

Sea level rise and changes in the intensity of rainfall can increase the probability of flooding over bridges and roads. Builders should consider sea level rise, storm surge, and changes in flow regimes when determining the height and pitch of bridges that cross coastal waterways. Further inland, an expected increase in precipitation intensity should be considered. With heavier rainstorms, flash flooding is expected to occur more often. Unpaved roads are particularly vulnerable to increasingly intense precipitation, which can result in washout. Changes in flood patterns are also affected by other sectors. For example, coastal erosion and water management policies can affect flow regimes and hence the vulnerability of infrastructure projects to flooding. In addition to climate information, infrastructure managers will likely require input from other relevant sectors.

Construction of new buildings and retrofitting of existing structures should also consider the impacts of increased temperatures. Increases in temperature and humidity will require more airflow within buildings, which may necessitate improvements to fans or air-conditioning systems. Climate change can also affect the weathering of infrastructure. At higher temperatures transportation infrastructure softens and expands, which can cause permanent structural damage. Saltwater incursion can also enhance weathering of both transportation infrastructure and buildings, leading to higher maintenance costs.

Energy

Climate change can directly affect the demand for energy. As temperatures rise, air-conditioning use, especially in summer, is expected to increase. While this will contribute to heightened energy demand, economic development is projected to be the primary driver of rising energy use in low-income, warm-climate countries. Projections of air-conditioning usage over the next century estimate that 25% of the expected increase will be attributable to climate change, while 75% will be attributable to higher incomes.

On the supply side, higher temperatures reduce the efficiency of electricity production and distribution. An increased probability of extreme events also poses a high risk to facilities for hydro, thermal, and renewable energy production, as flooding and debris from high winds can damage production facilities and power grids. Droughts or floods can also hinder fuel supply chains, especially those that rely on barges or rail, hence disrupting distribution. It should be noted that energy supplied from hydropower is particularly sensitive to changes in the hydrological cycle. Whether the mean annual precipitation in the West Africa region will increase or decrease remains uncertain, and professionals in the energy sector should account for this uncertainty when developing energy plans. Changes in precipitation intensity and seasonality can also affect the efficiency of hydropower production; seasonal shifts in inflow and increases in extreme precipitation can result in higher peak flows, which in turn can result in lost output, as the use of bypass channels will result in lost productivity while extreme water volumes increase the likelihood that damage to dams and turbines will occur. As temperatures increase, evaporation will also increase, reducing surface water availability absent comparable increases in precipitation. The effects of droughts on hydropower facilities will be enhanced under warmer climates, as increased evaporation will further reduce the storage buffer and, as a result, lessen the productivity of hydropower stations. Countries with energy sectors highly reliant on hydropower will need to prepare for future uncertainty. Increases in hydropower storage capacity can help offset the potential loss due to changes in peak flows, while investment in other renewable energy sources can help to mitigate against potential reductions in water availability.

As interest in other forms of renewable energy grows, value assessments should consider projected regional changes to relevant climate variables. Biofuel is produced from agricultural products, and like all agricultural products biofuel crops are highly vulnerable to increases in the frequency and intensity of drought. Sea level rise and extreme rainfall can also damage biofuel crops, as can reductions in the availability of water. Increases in mean temperatures are expected to stress biofuel production moderately. Solar and wind energy remain relatively resilient to drought, changes in the variability of water flow, and rising temperatures. Changes in surface winds can affect the productivity of wind turbines, as a reduction in mean wind velocity can reduce productivity while extremely high winds can damage wind energy infrastructure. Sea level rise and storm surge can cause flooding and thus pose a moderate threat to all forms of renewables, as saltwater incursion can damage cropland and solar and wind energy infrastructure. An increase in extreme rainfall and flooding poses a high threat to all forms of energy production, including all forms of renewable energy, which can damage production infrastructure, and power grids, and disturb distribution paths. However, decentralized systems, such as solar micro-grids, can increase energy sector resilience to natural hazards, and may be particularly appealing in remote regions where connections to larger grids are more costly.

TABLE 1. SUMMARY OF RELATIVE RISK OF CLIMATE STRESSORS TO GHANA'S POWER SYSTEM.

Climate Stressor	Generation			Transmission & Distribution	Demand
	Hydro	Thermal	Renewables		
Extreme Rainfall, Flooding, & Sedimentation	High	High	High	High	Low
Drought	High	Med	High / Low*	Med	High
Sea Level Rise & Storm Surge	Low	High	Med	High	Low
Temperature	Med	Med	Med / Low**	Med	High
Water Flow, Volume, & Timing	High	Low	High / Low*	Low	Low

*Biomass is highly sensitive to drought and rainfall/flow variability/timing, while solar and wind have lower sensitivity
**Biomass has a higher level of sensitivity to temperature than solar and wind

Biodiversity

In its simplest term, biodiversity refers to the variety of living things in an area. Biodiversity loss is of concern to conservationists, farmers, and natural resource managers. Ecosystems are complex systems, making assessments of the impact of climate change on biodiversity complicated. The same change in a climate variable in one area may yield different results in another. Adaptation practitioners interested in biodiversity require knowledge of the local ecosystem sensitivities to different climate variables.

Primary productivity refers to the amount of photosynthetically driven biological activity in an area. It may be generated by land or aquatic plants (i.e., algae), and ultimately forms the foundation of all ecosystem activity. Changes in incoming solar radiation (e.g., from changes in cloud cover) can impact the amount of primary productivity. Where temperatures are moderate, increases in temperature can increase plant productivity. Where temperatures are already high, further increases may have deleterious effects on productivity. Similarly, increases in rainfall may in many cases lead to an increase in primary productivity, yet flooding or intense rainfall can damage plants and reduce productivity.

Many species prefer specific climates, and alterations in temperature and precipitation in a region can affect species abundance and distribution. This is especially true for land species. Higher temperatures may cause temperature-sensitive organisms to migrate to cooler locations, such as higher elevations. Changes in precipitation may affect some species more than others; physiological adaptations allow some plants to use water more efficiently, making these species more resistant to decreased precipitation. Changes in the variability of temperature or precipitation can also affect biodiversity, even when the mean for each variable remains steady. Many organisms have temperature or precipitation thresholds that they cannot exceed, and when these thresholds are exceeded species may migrate to more suitable climate zones (if they are able) or risk extinction. Additionally, changes in climate can alter the distribution of disease and pests.

Finally, the departure or one species can have secondary effects on the prevalence of others. Organisms that depend on the others (i.e. predators on prey) will likely respond similarly to the same climate variables. In contrast, organisms that compete with one another (i.e., plant species that compete for space) may increase if their competitors prove more sensitive to climate change. Understanding ecosystem responses to climate change requires knowledge of climate sensitivities and local ecosystem dynamics in addition to predictions regarding climate variables.

Coral reefs exist along the coasts of Ghana, Côte d'Ivoire, and Guinea. They serve as tourist attractions and essential habitats for many economically important marine species. Reef-building coral species enjoy symbiotic relationships with single-cell plankton species called zooxanthellae that are sensitive to temperature changes. The presence of zooxanthellae is what gives coral its vibrant color. Increases in Sea Surface Temperatures (SSTs) can lead to the departure of these zooxanthellae, referred to as "coral bleaching." Without this relationship most hard coral species struggle to survive. Absent reef-building hard coral, reef structures become degraded and other marine organisms may lose an important habitat.

Natural Hazards and Impacts

Beyond the information needs for sectoral assessments, because adaptation assessments often originate from the need to understand and address changes in natural hazards and climate impact, we focus here on climate information requirements to better characterize the frequency and intensity of natural hazards. For example, an analysis of changes in the length of dry spells over a historical period for a particular region would enable understanding of the severity and extent of drought conditions. Of course, not all climate-related disasters are caused by climate change; for example, flooding may be due to changes in land cover, and the impact on society that makes it a "disaster" depends on the exposure of things that humans value (e.g. buildings, infrastructures, farms). However, understanding the role of climate change in exacerbating these impacts is vital for adaptation. Through the identification of climate analyses that help explain historical, current and future changes in natural hazards/climate impacts, stakeholders can focus their efforts on understanding a specified subset of climate information.

Severe Drought

The greatest contributing climatic factor in the duration and spatial extent of severe drought is precipitation. Temperature, human-induced land use change, agricultural practices, and soil quality and moisture can also contribute. Analysis of extremely low rainfall amounts over a historical time-period can demonstrate the anticipated duration of a drought event, while monitoring and forecasting of seasonal rainfall can provide an early drought warning, and projected changes in precipitation can show worsening or alleviating drought conditions over the course of the 21st century. Table 2 provides a summary of climate analyses that are needed to understand severe drought at various timescales.

Table 2. Examples of climate analyses to understand severe drought at different timescales.

Typical variables	Time Frame		
	Historical Climate	Monitoring & EWS	Projections
• Cumulative rainfall amounts • Dry spells (number of days with rainfall below a certain dependable amount) • Evapotranspiration	• Historical variability and trends of cumulative rainfall; • Historical length and distribution of dry spell lengths.	• Standardized Precipitation Index (SPI) • Length of current dry spell • Water satisfaction index (WRSI) • Seasonal rainfall forecast	• Seasonal rainfall and temperature • Daily rainfall distribution • Daily maximal and minimal temperature • Changes in distribution of length of dry spells • Probability distribution of WRSI

Changes in Rainfall Patterns and General Drought Conditions

Changes in rainfall patterns (i.e. the spatial distribution of rainfall, its seasonal onset, and general drought conditions) can be understood through analysis of average precipitation. Since it is vital for the agricultural sector to know about changes in the onset of the rainy season and how much rainfall is expected, investigation of total annual and seasonal precipitation is necessary. Unlike severe drought, which involves analysis of extreme precipitation, understanding changes in rainfall patterns and general drought conditions requires analysis of changes in average precipitation. Deviations from average precipitation are referred to as anomalies and can be calculated for each year and/or season. Table 3 provides a summary of climate analyses that are needed to understand potential changes in rainfall patterns and general drought conditions at various timescales.

Table 3. Examples of climate analyses to understand potential changes in rainfall patterns and general drought conditions.

Typical variables	Time Frame		
	Historical Climate	Monitoring & EWS	Projections
Climate Analysis	• Historical changes in average seasonal or annual precipitation	• Cumulative rainfall • Seasonal probabilistic rainfall forecast	• Downscaled projections of changes in average seasonal

	• historical changes in average daily precipitation, dry spell duration		or annual precipitation • changes in the amplitude of variability

Flash Floods

In contrast to severe drought, understanding flash floods requires analysis of extreme precipitation events. Rapid flooding of low-lying areas is often associated with heavy rain and severe storms. Soil moisture is also an important non-climatic influencer. Historical analysis of extreme high precipitation events can help to understand the probability of a rare flood event and the chances of one happening in the future. Flood early warning systems are essential for disaster preparedness and evacuation. Regional projections of extreme high precipitation events are needed since climate change might `affect the frequency and intensity of such events. Furthermore, hydrological, infrastructural, and adaptation planning processes require this type of information. Table 4 provides a summary of climate analyses that are needed to understand flash flood events at various timescales.

Table 4. Examples of climate analyses to understand flash flood events.

Typical variables	Time Frame		
	Historical Climate	**Monitoring & EWS**	**Projections**
• Hourly or daily rainfall or rainfall intensities	• Historical variability and trends in extreme high precipitation • Thresholds based on past events	• Weather forecast • 10-day Climate Bulletin-Dekadal probabilistic rainfall forecast	• Downscaled projections of extreme precipitation, using thresholds based on historical climate analysis.

Seasonal Flooding

Most West African countries experience seasonal flooding during the rainy season, which can vary in intensity depending on the West African Monsoon and other large-scale convective processes. Seasonal rainfall is a natural phenomenon that occurs due the north-south movement of the Intertropical Convergence Zone (ITCZ). Predictors with the greatest correlation to seasonal flooding include total seasonal rainfall and seasonal rainfall intensity, defined as total precipitation divided by the number of rainy days (de Perez et al., 2017). Understanding such predictors has become increasingly important due to observed changes in the rainy season and increased flooding intensity in certain areas as a possible impact of climate change. Additionally, sea level rise is another important climate change impact that should be investigated locally since it may exacerbate seasonal flooding.

Table 5. Examples of climate analyses to understand potential changes in seasonal flooding.

Typical variables	Time Frame		
	Historical Climate	Monitoring & EWS	Projections
• Average daily precipitation • Consecutive number of rainy days	• Historical changes in average precipitation and length of wet sequences	• Seasonal probabilistic rainfall forecast	• Downscaled projections of changes in average precipitation and length of wet sequences

Extreme Heat Events

An extreme heat event refers to an extended period of time (several days or more) with unusually hot weather conditions that can potentially harm human health. Increases in average global temperature are projected to make heat events last longer and occur more frequently. Both average and extreme temperature can be analyzed to better understand extreme heat events at various time scales. As shown in Figure 8, an increase in average future temperature results in more "hot weather".

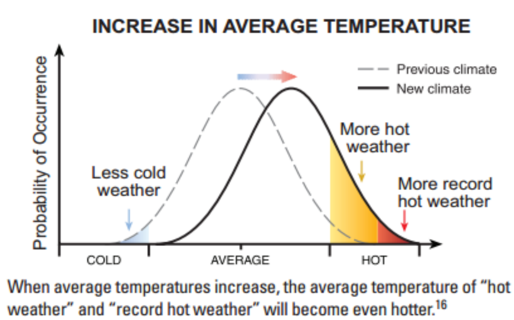


Figure 8. Graph of probability of occurrence of temperature conditions, demonstrating that an increase in average temperature results in more "hot weather" and "record hot weather". Source: CDC, no date.

In addition to average temperature analysis, projections using GCMs and RCMs for number of days above a certain temperature threshold can also be made to specifically analyze changes to extreme heat events. Temperature monitoring is needed for short-term forecasting and early warning in preparation for such extreme events. Although there is emphasis on rainfall early warning systems for agricultural purposes, temperature early warning systems are just as important for human health and survival. Table 6 provides a summary of climate analyses that are needed to understand extreme heat events at various timescales.

Table 6. Examples of climate analyses to understand extreme heat events.

Typical variables	Time Frame		
	Historical Climate	Monitoring & EWS	Projections
• Number of consecutive days with high maximum temperature • Maximum temperature	• Historical changes in maximum temperature, • Maximum temperature thresholds • Duration of high temperature sequences (above a certain critical threshold) .	• High temperature sequence monitoring • Weather/ extended weather forecast • Seasonal probabilistic temperature forecast;	• Downscaled projections of changes in maximum temperature: magnitude, duration; • Probabilities of exceeding high temperature sequences

Disease Outbreaks

Appropriate climate and weather conditions are necessary for the survival, reproduction, distribution, and transmission of disease pathogens, vectors, and hosts. Therefore, changes in climate or weather conditions impact the ability of infectious diseases to survive and proliferate. Particularly, excessive heat can increase mortality rates for some pathogens; rising temperatures can influence their reproduction and extrinsic incubation period; and extended periods of hot weather can raise the average temperature of water bodies and food environments, which may provide an agreeable environment for microorganism reproduction and algal blooms. With increased precipitation there is often an associated increase in fecal pathogens during the rainy season; droughts/low rainfall lead to slow river flows, causing a concentration of effluent water-borne pathogens. Humidity, sunshine, and wind also impact the survival, reproduction, distribution, and environment of disease pathogens and hosts (Wu et al., 2016). Due to the variety of climatic factors and interactions that influence disease outbreaks, it is difficult to model disease outbreaks. However, there are disease monitoring resources available, including the Malaria Early Warning System (MEWS), developed by the International Research Institute for Climate and Society (IRI) and National Malaria Control Program (NMCP).

3. Climate Data Types

The generation of climate data at local and national levels is typically the responsibility of a country's national meteorological service (NMS). NMS are mandated to generate weather and climate data and issue forecasts and warnings. Generating the data requires a functioning, well-maintained and well-distributed network of stations as well as the capacity to store and analyze the data and use it to model future conditions. Through strong climate data and information and analytical capacity, a country can see improvements in its adaptive capacity as well as its capacity to manage water resources, food security and disaster risks.. More and more data can also be accessed online, and it is important to understand the advantages and limitations of each type of data, and select data and information that is the best compromise between intended use and ease of access.

Historical/Current Data

Station Data

Station data capture local conditions best as they are in situ ("in position") measurements of meteorological variables. Station data, or information based on such data, can be obtained from the National Meteorological Services but is not always free of charge. In addition, in most of African countries spatial (and often temporal) coverage of such data may not be sufficient to meaningfully capture local details important for adaptation projects. In a lot of countries, a systematic drop in the number of operating and reporting stations has been observed since the 1980s (Figure 9). The quality of the data may also vary, and quality checks are always necessary. Additional data may have been collected by businesses, farmers' associations, agricultural extension services and academic institutions but may not be integrated in the main database. A subset of station data is available online through the GTS system, but the completeness of that data and their spatial and temporal coverage are usually less extensive than the data archived at the NMS.

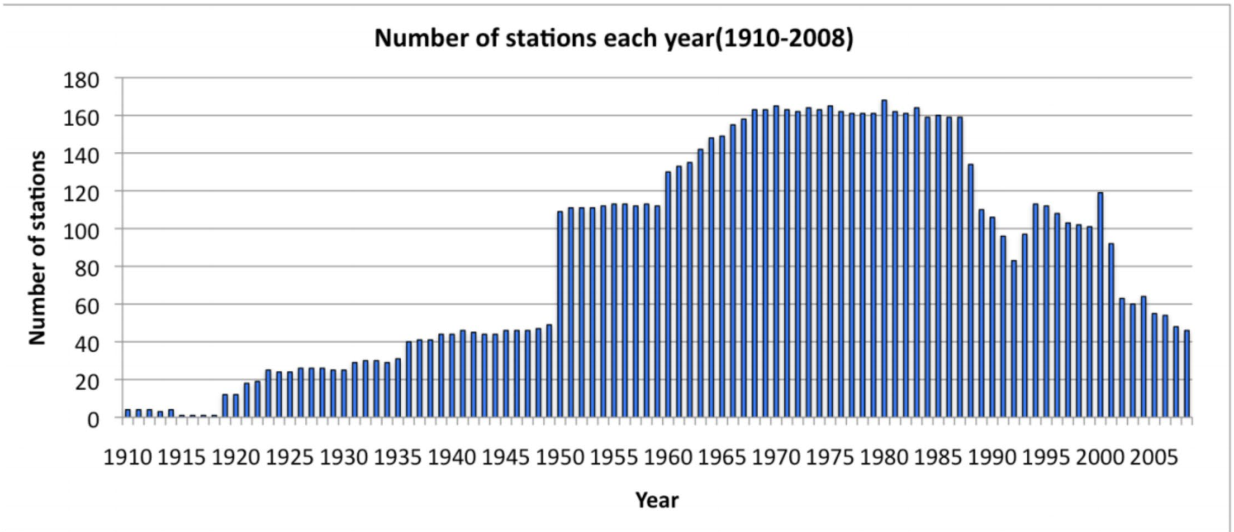


Figure 9: Number of rainfall stations operating in Mali since early 20th century. Source: Samake (AGRHYMET)

Satellite Data

Since the early 1980s satellites have been recording some meteorological variables at high spatial and temporal resolution and these archives are now long enough for climatic analyses. Satellite-based estimates of rainfall and temperature can be accessed online in different data repositories and have continuous spatial coverage in the form of a grid of values. They are usually global in nature. However, those data rely on indirect measurements (proxies) of rainfall quantities and temperature, and thus can present a biased vision of the conditions on the ground. For example, satellite rainfall estimates are based on the temperature at the top of the clouds, which is then correlated to temperature and rainfall records from stations on the ground. In the tropics, this relationship is strongly affected by the availability of in-situ data, while in the extratropic estimates are closer to reality.

Rainfall and temperature estimated from satellite recordings are available from the following datasets:

- CPC Morphing Technique (CMORPH) – a high spatial and temporal resolution dataset in real time. Only available since 2002.
- Tropical Rainfall Measurement Mission (TRMM) focuses on rainfall estimates in the Tropics and is available since 1998. There is however a delay of about a month in data availability and monthly aggregates are more accurate than higher temporal resolution products.
- Land Surface Temperature (LST) provides land-surface estimates for Africa and Latin America and is available since July 2002 for Africa.

In addition to meteorological variables, satellites also capture useful indicators such as vegetation cover with the Global Normalized Difference Vegetation Index (NDVI), available for 1981-2006 period and the TERRA-MODIS NDVI and Enhanced Vegetation Index (EVI) since

2000. More recently, soil moisture data have also become available. When using satellite rainfall data, it is important to remember that precipitation estimates have different validity in different regions, and thus need to be validated with in-situ observations for local applications.

Gridded Data

Another class of data providing continuous spatial coverage are so called 'gridded data.' From a user's perspective they are similar to satellite data in that data are available on a regular grid and for a given period of time. Most of these datasets are based on in-situ (station) information interpolated to a regular grid. Some datasets merge in-situ observations with satellite records to compensate for biases in satellite data. The quality of these merged products depends on the quantity of the in-situ data incorporated. Gridded datasets are usually global in nature and their spatial resolution is variable. Among the gridded datasets are:

- Global Precipitation Climatology Project (GPCP), combined satellite and station data; this product is available since 1979 for monthly rainfall data and since 1996 for daily rainfall data, but has a low spatial resolution.
- Climate Prediction Center Merged Analysis of Precipitation (CMAP) is similar to GPCP and the differences mainly come from different algorithms used.
- African Rainfall Estimate (RFE) combines satellite and station data for Africa. It has high spatial resolution and is available since 2001 but only with 10 day temporal resolution.
- Enhancing National Climate Service (ENACTS) program combines in situ observations retrieved from various Met Services with satellite data to provide a merged product with greater weight assigned to in-situ observations. The product is available since 1983 but on a country-by-country basis as data is provided by the countries themselves.
- Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) uses both station-data and satellite imagery to create 30+ year (1981-present) rainfall datasets.
- Climate Research Unit (CRU), gridded dataset for rainfall and temperature based solely on station data; has relatively high spatial and temporal resolution.

Another class of gridded data is called 'reanalysis' data, which uses observations from sources at the surface and higher in the atmosphere (planes, radio soundings, etc.) to interpolate meteorological variables using physical models, ensuring stronger consistency between variables and values. It provides a wider array of meteorological variables, including atmospheric measurements above the surface. Reanalysis products are usually high-resolution and date further back in time than other data types. However, this method relies strongly on dynamical models and some variable types are more reliable than others; for example, wind and pressure are fairly accurately captured through reanalysis while rainfall data are often biased. It is most useful for researchers studying the causes of climatic phenomena rather than for direct applications in adaptation.

Forecasts and Projections

Weather forecasts are the most widely known class of future information and are usually provided by the NMS. They are used in EWS and other short term (a few days) outlooks. In the last two decades additional forecast systems have been implemented by the WMO to make predictions over longer time scales. The most advanced systems currently available provide seasonal climate forecasts in the tropics.

Seasonal Forecasts

Seasonal forecasts take advantage of the fact that Sea Surface Temperatures (SSTs) influence moisture and atmospheric circulation in the tropics, but tend to evolve more slowly than the atmosphere by several months. As a result, SSTs can be used to predict the overall state of the atmosphere in a given region/climatic system in the coming months. A number of regions have been running seasonal forecasts over past decades and, in Africa, most notable seasonal forecasts are elaborated during the Climate Outlook Fora organized by ACMAD and ICPAC. During such fora the general tendencies of the season are predicted and presented in probabilistic format (Figure 10). These predictions can be helpful in planning water resource and on-farm management at national, subnational and individual levels.

Climate projections

A wide range of regional and international initiatives allow access to climate change projection data. Some of the portals giving access to projections are listed below:

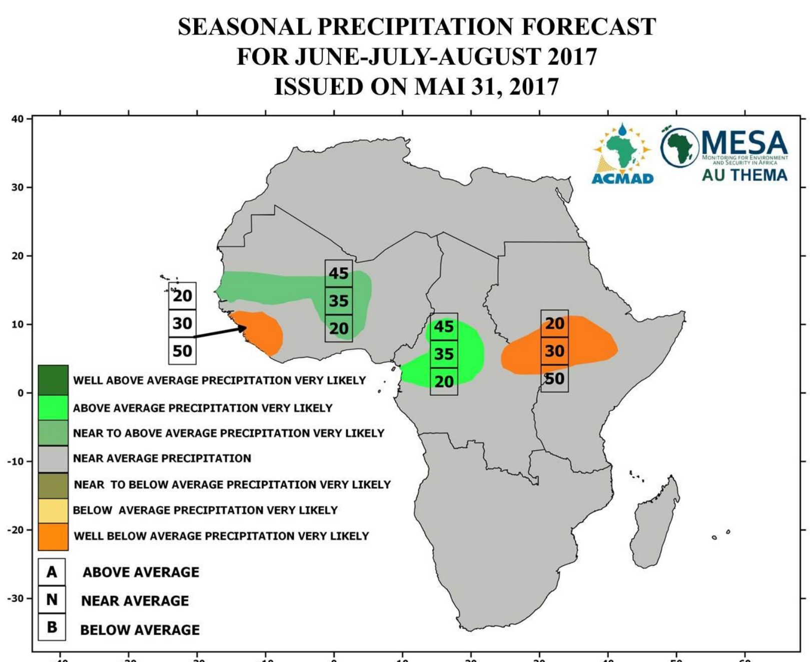


Figure 10: Probabilistic seasonal forecast for the Julne-August 2-17 Season in West Africa issued by ACMAD.

However, to make best use of the available data and information, the following needs to be considered:

- **Scope of the study** – how much climate information is really needed. E.g., general tendencies vs. precise high-resolution data for further impact modeling
- **Accuracy of climate models over the region of interest** – at local scale GCMs can present strong biases (e.g., precipitation can be strongly underestimated and using direct raw data may lead to biased conclusions with respect to future conditions); a thorough literature review is needed to assess such biases and eventually correct them
- **Uncertainty** – is usually assessed through the use of a variety of models and assessment of minimum vs. maximum changes projected
- **Documentation about data source** – sufficient explanations with respect to how the data were processed; this is particularly important when working with downscaled data.

Downscaled

Downscaled Information

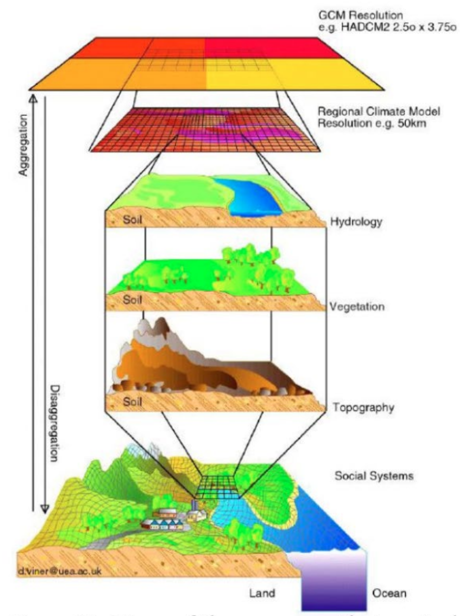


Figure 11: Many of the processes that control local climate, e.g., topography, vegetation, and hydrology, are not included in coarse-resolution GCMs. The development of statistical relationships between the local and large scales may include some of these processes implicitly. Source: Viner, 2012

Although GCMs are valuable predictive tools, they cannot account for fine-scale heterogeneity of climate variability and change due to their coarse resolution. Numerous landscape features such as mountains, water bodies, infrastructure, land-cover characteristics, and components of the climate system such as convective clouds and coastal breezes, have scales that are much finer than 100–500 kilometers. Such heterogeneities are important for decision makers who require information on potential impacts on crop production, hydrology, species distribution, etc. at scales of 10–50 kilometers.

Various methods have been developed to bridge the gap between what GCMs can deliver and what stakeholders require for decision-making. The derivation of fine-scale climate information is based on the assumption that the local climate is conditioned by interactions between large-scale atmospheric characteristics (circulation, temperature, moisture, etc.) and local features (water bodies, mountain ranges, land surface properties, etc.). It is possible to model these interactions and establish relationships between present-day local climate and atmospheric conditions through the downscaling process. It is important to understand that the downscaling process adds information to coarse GCM outputs so that information is more realistic at a finer scale, capturing sub-grid scale contrasts and inhomogeneities. Figure 11 presents a visual representation of the concept of downscaling.

Downscaling can be used to increase spatial or temporal resolution. There are two principal downscaling methods:

- **Dynamical**: Similar to GCMs, this method involves incorporating additional data and physical processes in regional- or local-scale models, at a much higher resolution than is seen in GCMs. This method has numerous advantages but is computationally intensive and requires large volumes of data and a high level of expertise to implement and interpret. The resources required place this method beyond the capacities of most institutions in developing countries.
- **Statistical**: This method involves establishing statistical relationships between large-scale GCM-modelled climate features and local climate characteristics. In contrast to the dynamical method, statistical methods are easy to implement and interpret. They require minimal computing resources but rely heavily on historical climate observations and the assumption that currently observed relationships will carry into the future. However, high quality historical records often are not available in developing countries.

The diversity of existing downscaling methods reflects the diversity of goals of and resources for each downscaling exercise. Thus, there is no single best downscaling approach, and downscaling methods will depend on the desired spatial and temporal resolution as well as the impacts being assessed. In most cases, a sequence of different methods is needed to obtain results at the desired resolution.

When working with downscaled information the following needs to be kept in mind:

- Information on downscaling and the limitations of the results need to be understood and taken into account. Any results at resolutions higher than the native resolution of the GCMs has undergone downscaling and may mislead the user that the results are automatically more accurate because of their finer scale.
- Downscaling processes usually adds uncertainty to projections. Additional uncertainty should be factored into the interpretation of the results or indeed into the decision of whether downscaling is appropriate.
- Downscaling methods should be validated first on historical data to assess their potential biases and uncertainties.

In summary, downscaling is not a trivial process and requires some expertise. It may require significant investment in time, tools and capacity. The user should not believe that the results are automatically more true or valid because they are presented at higher resolution. The need for downscaling and the tradeoff between higher-resolution and increased uncertainty need to be carefully assessed.

4. Climate Variables

Climate entails the statistical characteristics of weather conditions in a given area. Climate zones are characterized by different combinations of climate variables, such as temperature, precipitation, humidity, and wind. When assessing the impacts of climate change on a region, it is important to consider the statistical characteristics of each climate variable, and the indices that are most useful for measuring that variable.

For example, in a given season daily temperature measures are often distributed normally around a mean temperature (Figure 4.1), meaning that very cold days are just as likely as very warm days. However, in many places rain occurs on only a fraction of the days in a season, meaning that the number of days with little or no rainfall is very high (Figure 4.1). This difference in the distributions of temperature and rainfall is one characteristic that influences the indices most useful for talking about each variable, as well as our ability to make predictions about each variable. Additional characteristics of each variable, and indices useful for assessing each variable, are described below.

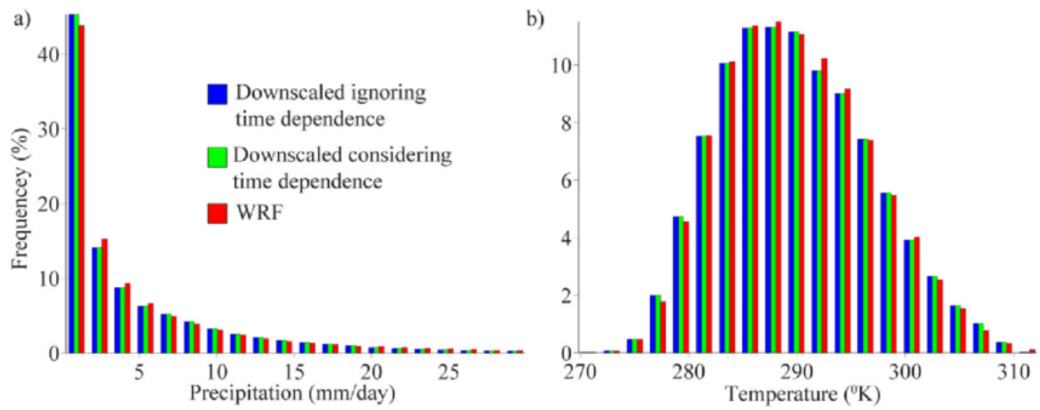


Figure 4.1 Probability distribution function of precipitation and temperature. Source: Jha et. al.

Temperature

Unlike precipitation, temperature is more easily interpolated across larger geographic areas. Even where topography varies, an increase in temperature in one location typically signals an increase in neighboring locations, even if the temperature in one area tends to be cooler than the other. For this reason, it is easier to interpolate temperature across a region.

Depending on the topic of study, different temperature indices may be more useful than others. Those concerned with whether temperatures surpass a particular threshold may consider the number of days in a season surpassing a given temperature, or the temperature on the coldest or warmest day of the year. Those concerned more with seasonal averages may consider the mean daily high and low temperatures over a three-month period.

Some temperature indices of interest may include:

- Highest high temperature in a year
- Lowest low temperature in a year

- Average daily high temperature in a month
- Average daily low temperature in a month
- Number of days in a season when temperature exceeds 30 °C
- Number of days in a season when temperature is below 0 °C
- Average length of heat waves
- The temperature at which a day is in 95th percentile
- The temperature at which a day is in the 99th percentile

Precipitation

In situ measures of precipitation are typically collected using a rain gauge. The frequency with which gauges are checked can determine what information may be available. At some stations, gauges are checked only once a month, providing information on total rainfall but no information on the intensity, length, or frequency of individual rainfall episodes. Stations that check rain gauges daily or hourly may be able to provide additional information important to end-users, such as the intensity of individual rainfall episodes and the length of time between rainfall episodes. Some precipitation indices of interest may include:

Greatest total precipitation over a 1-day period

Greatest total precipitation over a 5-day period

Average rainfall amount on rainy days (also called Simple Precipitation Daily Index)

Number of days when Precipitation exceeds 10mm

Number of days when precipitation exceeds 20mm

Maximum length of a dry spell

Maximum length of a wet spell

The precipitation amount when the year is in the 95th percentile

The precipitation amount when the year is in the 99th percentile

While station data on precipitation can provide very accurate information for the location from which it was collected, because precipitation varies considerably with topography, station measures may not provide much information about even very close locations without weather stations. . While temperature fluctuations are relatively homogeneous across space, high precipitation in one location may not indicate an increase in rainfall in neighboring locations. For this reason, interpolating precipitation measures across space can prove challenging. Where there is considerable topographic variation, interpolation may be less reliable over even smaller distances.

5. Best Practice Examples

This section was created from an analysis of National Adaptation Program of Action (NAPAs) for Sierra Leone, Liberia, Guinea, Côte d'Ivoire, Ghana, and Togo, hereafter referred to as "focus countries." The analysis compared NAPAs from the focus countries to those from more information-rich countries, such as South Africa and the United States. Key takeaways from the analysis are presented below, and are intended to provide guidelines for the development of future climate analyses. Since NAPAs are national-level adaptation planning reports, they should aim to achieve the highest caliber climate information and analysis. This section is intended to guide focus countries towards that goal.

Key Takeaways

Based on the findings of the present review and critique of climate analyses in national-level planning reports, it is clear that the majority of focus countries can benefit from improved explanations and analyses of their climate information. Quantitatively robust analysis is needed to accurately and truthfully assess the state of the climate, make projections, and understand natural hazards/impacts. Supplementing local knowledge and input with data and statistics will prove valuable. Reasons for shortcomings in climate analyses may be numerous and complex, but there is great opportunity for improvement. The following steps can be taken to ensure robust and thorough analysis of climate information:

For each focus country:

1. Create a time series histogram of the number of met stations in operation.
2. Determine the percentage of missing data for each met station, from the earliest consistently recorded measurement to the present, for temperature and precipitation.
3. If percentage of missing data is below 20% (ideal percentage), perform some or a variation of the following climate analyses based on what is deemed most important:

Historical Climate

- Monthly mean temperature and rainfall climatology for various locations within the country.
- Time series of average annual temperature and rainfall anomalies, showing 11-year running means and either a change-point analysis or linear trend with test for statistical significance for various regions as well as the national level.
- Trend test for high and low temperature extremes, possibly defined as the annual and seasonal number of days above the 90th percentile maximum temperature and the 10th percentile minimum temperature for each station.
- Trend test for changes in heavy precipitation, defined as the heaviest 1% of all daily events for each year over a long time series.
- Discussion and analysis of the drivers of rainfall variability at intra-seasonal and inter-annual time scales. Some examples include ENSO, AAO, IOS, MJO, and SOI.

Monitoring & Early Warning Systems

- Seasonal probabilistic temperature forecast.
- Heatwave forecast.
- Seasonal probabilistic total rainfall forecast.
- Standardized Precipitation Index (SPI).
- Forecast of total seasonal rainfall divided by number of rainy days.
- 10-Day Climate Bulletin: Dekadal probabilistic rainfall forecast.

Climate Projections

- Projected changes in average annual and seasonal temperature and rainfall generated by GCMs or downscaling. For larger countries, an ensemble of GCMs may be sufficient. However, at the local level, downscaling via an ensemble of RCMs or statistical methods is needed.
- Projected changes in extreme temperature and rainfall.
- For all projections, various emissions scenarios should be used as well as shorter and longer time horizons.
- For stations with >20% of missing data, perform as many of the above-mentioned climate analyses as possible, with identified caveats and constraints.

A review of the climate analyses in NAPAs suggests that focus countries can improve climate analysis capabilities. Climate data exploration tools provide access to additional climate information in the region, and can be used to supplement locally or nationally available data. The use of these resources, and attention to the guidelines laid out in this manual, should greatly improve the quality of NAPA climate analyses.

6. Guide to Online Climate Data Exploration Tools

This page contains a list of online climate information sources. A brief description of each tool or climate information source is included in the page, along with an explanation of how the resource may be used by practitioners.

World Bank Climate Change Knowledge Portal: This resource provides temperature and precipitation information at the national and regional levels. It also organizes climate information by watershed, which water resource managers will find helpful. Information is available for historical and future projections. It also permits users to download the climate data. Country profiles, with detailed information on climate change impacts and vulnerability to natural hazards, are also available for some countries in the region.

Climdex: This resource allows users to explore multiple indices for precipitation and temperature extremes (e.g. highest high temperature, greatest precipitation over a five-day period). Users can select information from individual stations or from gridded datasets. This tool is useful for practitioners interested in extremes, including agricultural and ecosystems managers, public health practitioners, and infrastructure and energy sector specialists. The tool also provides detailed descriptions of different indices, and in some cases allows users to set index thresholds (i.e. number of times a variable exceeds a particular threshold). The tool also provides for user-defined thresholds (that is, you can look up information on how many times a variable exceeded a particular threshold you set).

IRI Maproom: This resource allows users to explore multiple indices for precipitation and temperature extremes (e.g. highest high temperature, greatest precipitation over a five-day period). Users can select information from individual stations or from gridded datasets throughout the world. This tool is useful for practitioners interested in extremes, including agricultural and ecosystems managers, public health practitioners, and infrastructure and energy sector specialists. The tool also provides detailed descriptions of the different indices. The tool also provides for user-defined thresholds (that is, you can look up information on how many times a variable exceeded a particular threshold you set).

IPCC Data Distribution Center: This resource is from the IPCC, the intergovernmental group tasked with producing global climate assessments. The resource contains modelled data from the most recent assessment report, including regional information on temperature and precipitation. The resource also contains a guide on how to use the data and tools for visualizing climate variables.

NCAR Climate Inspector: This guide allows users to visualize temperature and precipitation changes on interactive online maps.

Climate Scenarios: This tool allows users to explore the climate change scenarios, and learn about how they're constructed.

Climate Engine by Google: This online mapping tool based on google maps allows users to visualize changing risks for wildfire, drought, and impacts on agriculture & ecosystems. It allows users access to remotely sensed and reanalysis data.

Aqueduct by WRI: This resource maps water resource availability, allowing users to explore changes to water availability at regional levels.

Climate Inspector: This resource uses climate datasets to create interactive online maps that allow users to explore local and regional changes to temperature and precipitation under different emissions scenarios.

GFDL AR5 Repository: This resource provides modelled climate data from the GFDL climate model. In addition to projections of climate variables, the resource also provides information related to ecosystem impacts, including vegetation and soil.

CCAF Data Portal: This resource provides downscaled data for multiple regions, using various downscaling techniques. The modelled datasets are also accompanied by detailed descriptions of the specific downscaling techniques used.

CMIP5 Data Center: In order to use this resource, you first need to create a user profile. This resource provides access to modeled data from multiple models in the CMIP5 ensemble, with options to select data focusing on different variables or realms (i.e. land, ocean, sea ice). The resource also provides data from the ongoing work for the CMIP6—the next phase of the project that compares GCM outputs.

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