GLOBAL CENTER ON ADAPTATION

GCA Learning from Practice

CLIMATE DATA FOR RISK ASSESSMENTS

2 - Climate Data Validation

This guidance note serves as a technical reference for practitioners conducting or supervising Climate Risk Assessments (CRAs).

It is part of a package of three complementary guidance notes on the use of climate data in CRAs, which outline minimum standards and recommended practices to enhance the consistency, credibility, scientific robustness, and usability of climate analytics—particularly in data-scarce environments.

The full package is structured around three complementary and foundational pillars available on the GCA website:

1. **Climate hazard indices**, used to characterize climate extremes and relevant metrics
2. **Climate data validation**, defining minimum requirements to assess the reliability of climate data and models;
3. **Uncertainty management**, providing approaches to interpret and communicate the range and confidence of possible outcomes.

This note focuses on **Climate Data Validation**.

2 - CLIMATE DATA VALIDATION

***Suggested Citation**: "GCA Learning from Practice, Climate Data Validation for Risk Assessments, Global Center on Adaptation, 2026"*

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Introduction

Validation is a critical step in climate risk assessment. It helps ensure that the data, models, and derived indices used in an assessment are appropriate for the conditions and scale of interest. Validation builds confidence in both historical and projected results and supports informed decision-making for infrastructure design, risk mitigation, and long-term planning.

What Does Validation Involve?

Validation generally involves assessing how well a candidate dataset or model represents observed conditions. Candidate data may include climate model outputs, downscaled data, satellite products, or other secondary datasets. Where suitable observations are available, in-situ measurements can provide an important reference for validation. Other observational or independently derived datasets may also be used, depending on the variable, spatial and temporal scales, and purpose of the assessment.

A simple approach is to compare candidate data with observations using graphical methods such as scatterplots or time-series plots. These can help identify systematic differences, including whether a dataset tends to over- or underestimate particular parts of the observed distribution. More formal statistical tests, such as the Kolmogorov–Smirnov test (GeeksforGeeks, 2025), can also be used to quantify agreement between datasets.

In general, if a model output or product line diverges substantially from in situ observations1, it suggests the product inaccurately reproduces the in-situ conditions and could therefore be unsuitable for the intended use. Practitioners should also consider whether the spatial and temporal resolution of the dataset is appropriate for the target area and application.

When Is Validation Needed?

Validation has two main components:

1. Validation of climate data and baseline conditions.

   Data validation is essential to ensure that the climate data used to characterize historial or baseline conditions are accurate and appropriate for the region of interest. It is particularly relevant when data are used as inputs to bias-correction, downscaling, or other processing steps.

2. Validation of climate projections.

[1] In situ observations, such as weather station measurements and local surveys, are generally considered the best available reference for validation. However, their quality, representativeness, and reliability should always be carefully assessed before they are used as validation data.

This involves assessing the credibility and robustness of the projected changed. This process generally requires expert judgment, including consideration of regional climate processes, comparison with large-scale projections such as those assessed by the Intergovernmental Panel on Climate Change (IPCC), and assessment of whether projected trends are broadly consistent with observed changes over recent decades. The objective is not to demonstrate that future projections are "correct", but to identify potential inconsistencies and better characterize the associated sources of uncertainty.

The need for validation depends on the type and scale of the assessment. It becomes particularly important when datasets are applied beyond their native spatial or temporal resolution (e.g., from regional to local scales or from monthly to daily time steps), or when statistical or dynamical downscaling or temporal disaggregation has been applied.

Which Types of Assessments Require Validation?

Validation should be considered for all climate risk assessments, but the level of scrutiny should reflect the intended use and potential consequences of error. It is particularly important for:

- **High-resolution, location-specific assessments** (e.g., for cities, towns, airports, or seaports), where local conditions can substantially influence climate hazards.
- **Future climate projections**, to ensure that baseline simulations are mostly aligned with historical observations before projecting future changes or carrying out bias-calibration of models.
- **Assessments involving climate extremes or locally sensitive hazards**, such as flood peaks, wind gusts, and short-duration precipitation extremes, which can be particularly sensitive to local topography and others characteristics that may not be well represented at coarse spatial scales.

Note: For location-specific assessments, direct observations from local monitoring stations should generally be prioritized where they are available and of sufficient quality. Gridded products remain valuable for spatial analysis and for areas where observations are sparse, but their suitability for point-specific applications should be assessed.

Which Indices Require Validation?

Not all indices demand the same level of validation. Indices that are sensitive to local conditions or extreme events, such as flood peaks, wind gusts, or short-duration rainfall, generally warrant more rigorous validation. Conversely, broad-scale indices, such as regional temperature trends, may require less extensive validation.

However, all climate datasets and derived indices should be assessed for suitability for their intended application. Where direct validation is not possible because of limited observations, the use of a dataset should at a minimum be supported by a review of relevant literature and documentation of its known limitations.

General Rules for Validation

The extent and rigor of validation should be proportionate to the purpose of the assessment and the consequences of potential errors:

- **For engineering design or regulatory compliance**, rigorous validation is required, using appropriate observations and/or well-established models to ensure reliability at local scales. While remote sources such as satellite data can provide a good basis for understanding, this information should be reviewed and validated by experts whenever possible.
- **For broader climate risk assessments** aimed at understanding general trends or spatial patterns, simplified validation may be sufficient, focusing primarily on the reliability of input data (e.g., precipitation, temperature) and on ensuring that baseline projections align with historical observations.
- When dealing with derived or composite indices (e.g., fire weather index, drought severity index), it is essential to ensure that all input variables are individually validated to maintain model credibility.

Illustrative Example

Figure 1 provides an illustrative example of a simple validation approach. It compares annual maximum daily precipitation from four candidate products - one reanalysis product and three satellite products - with in-situ observations at São Tomé International Airport.

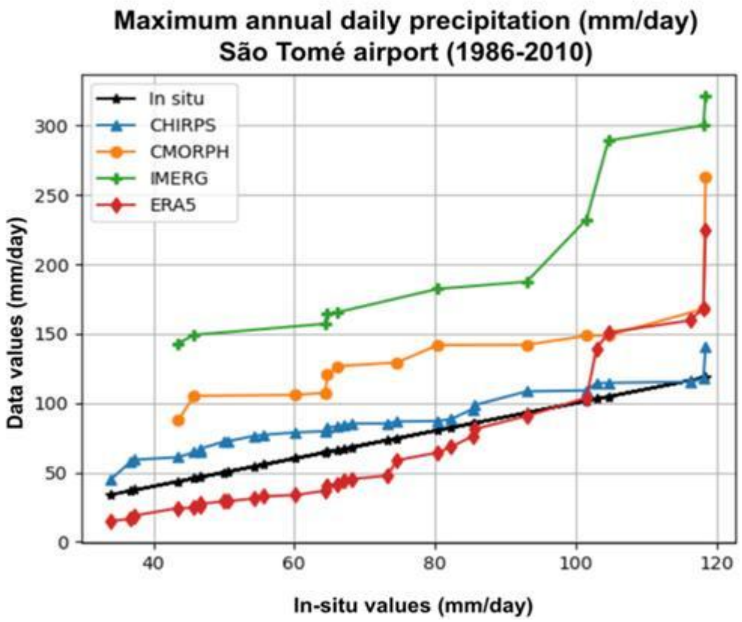

Figure 1: Example of validation for the annual maximum daily precipitation in São Tomé airport[2]

The product values are plotted against in situ observations, ordered by increasing annual maximum values in the historical record. The diagonal reference line represents perfect agreement between the candidate product and the observations. Products that remain close to this line show better agreement, while systematic deviations can indicate a tendency to over- or underestimate precipitation, particularly at specific points in the distribution. In this case, the blue and red products show acceptable performance, as their lines stay relatively close to the diagonal. By contrast, the CMORPH3 (yellow line) and IMERG4 (green line) precipitation products deviate significantly from the diagonal, indicating poor performance.

The example illustrates how graphical comparisons can help identify differences between candidate products and inform decisions about their suitability for a particular application. Such comparisons should, however, be interpreted alongside other evidence, including statistical performance measures, data quality, spatial and temporal resolution, and knowledge of the product's limitations.

Note: In-situ observations, such as weather station measurements and local surveys, can provide an important reference for validation. However, their quality, representativeness, and reliability should be assessed before they are used as validation data.

[2] São Tomé International Airport (TMS / FPST), WMO Station 61931 / ICAO FPST. It is located 10 m above mean sea level (33 ft) at the coordinates 0.378° N, 6.712° E.
[3] CMORPH is a satellite-based precipitation product developed by NOAA's Climate Prediction Center (CPC). It estimates rainfall by combining passive microwave satellite observations with infrared imagery, using a "morphing" technique to propagate rainfall features in time.
[4] IMERG is the primary global precipitation product of NASA's Global Precipitation Measurement (GPM) mission.

Validation guidance by hazard type

This document outlines validation guidance by hazard type, helping to determine when and how to validate climate data based on the intended application and available resources.

Temperature

Validation requirement: Light

Most temperature indices, such as annual mean temperature, monthly averages, and seasonal extremes, generally do not require extensive validation due to their relatively stable spatial patterns and well-understood physical drivers. However, certain cases may warrant additional attention, particularly in urban areas affected by the urban heat island effect or in regions where local geographic features amplify extreme temperatures.

Downscaling

Minimum validation requirement: Light

Temperature is typically more homogeneous across regions (except in mountainous areas), and advances in physical understanding have enabled high-accuracy reproduction of temperature data. When downscaling from low-resolution to higher-resolution datasets, performance is generally reliable. Validation may be helpful, but it is usually not critical.

Future Projections

Minimum validation requirement: Light

While extensive validation is not usually required, it is recommended to compare future model projections with historical observations over the same baseline period. For example, validating whether projected annual or seasonal mean temperatures during the baseline period align with observed values can help confirm model reliability. Overall, temperature projections are typically robust, even with minimal validation. It is generally preferable to apply bias correction to each climate model using historical observations, rather than relying solely on comparisons of mean values over the baseline period. A minimum level of validation or consistency checking against historical observations should still be performed (i.e., Ensemble mean anomaly plots can be a useful validation).

Precipitation

Validation requirement: Strong

Due to the high spatial and temporal variability of precipitation, rigorous validation of precipitation indices is essential. Key indices requiring validation include annual and seasonal mean precipitation, as well as extreme indices such as Rx1day, Rx5day, R95p, and R99p5.

Note: Climate models generally exhibit lower skill and higher uncertainty in simulating precipitation, particularly at regional scales and for extremes, compared to temperature. This further reinforces the need for careful validation and bias correction of precipitation-related indices.

Downscaling

Minimum validation requirement: Compare the downscaled seasonal total precipitation with data from nearby gauges.

Because precipitation is highly unevenly distributed across space, and given the limited physical understanding of rainfall mechanisms, downscaling low-resolution precipitation data to higher resolutions requires careful validation. This typically involves comparing downscaled indices with gauge observations or other relatively reliable measurements (e.g., satellite products) at or near the project site to ensure accuracy.

Future Projections

Minimum validation requirement: Compare projected seasonal total precipitation with historical reanalysis data, satellite observations, or ground-based measurements over the same baseline period.

To ensure the reliability of the datasets used, validation is an essential step for future precipitation projections. It is important to compare projected indices with historical reanalysis data, satellite observations, or ground-based measurements over the same baseline period. Bias calibration of models is recommended.

[5] Often requires extreme outlier and value analysis. As in projection validation, anomalies (errors between the ensemble mean and individual realizations) can be useful here. Pinpointing usable data is particularly important for relative indicators.

Flooding

Validation Requirement: Varies

Flood-related indices like peak discharge, flood return periods, and annual maximum daily flow require rigorous validation due to the complex interactions among climate, hydrology, and catchment characteristics. However, for broader climate risk assessments, where the emphasis is on general trends and spatial patterns rather than exact flow values, validating precipitation inputs alone may suffice, especially when streamflow data is limited.

Note: For hazards that are strongly influenced by local environmental and physical conditions (e.g., flooding and landslides), validation can benefit from an impact-based approach. This involves comparing the spatial footprint or extent of past events (e.g., flood inundation areas) with the corresponding values of relevant hazard indices using satellite imagery, historical records, or impact reports. Such validation provides a more meaningful assessment of how well the indices represent real-world hazard occurrence and impacts than evaluating the indices in isolation.

Rainfall, Runoff Modeling

Minimum validation requirement:

- *For engineering design purposes: Validate the rainfall-runoff model using observed streamflow data from nearby locations.*
- *For broader climate risk assessments: Validate only the precipitation input data, following the same validation requirements outlined for precipitation.*

Ungauged streamflow indices are typically derived from rainfall and runoff models. The accuracy of these indices depends heavily on the quality of the hydrological models used. For engineering design purposes, this requires careful calibration and validation of the model against historical streamflow observations to ensure it reliably reflects local catchment responses. In contrast, for broader climate risk assessments, simplified validation focusing on the quality of precipitation inputs can provide sufficient confidence, especially in areas where streamflow data is unavailable and where specific past flooding events can be linked to magnitude-specific precipitation events.

Flood Modeling or Hydraulic models

Minimum validation requirement:

- *For engineering design purposes, validate the flood-prone areas produced by the model against independent observed data—such as documented flood marks, gauges, recorded water levels, or satellite-derived flood extents from past events.*
- *For broader climate risk assessments, perform at least a qualitative review of historical records or anecdotal evidence, and document key assumptions and uncertainties to ensure the results are reasonable and transparent.*

The validation helps ensure that the model can realistically capture past flooding, building confidence in its projections of future events. For engineering design, more precise validation against measured water levels or mapped extents is critical to inform robust infrastructure decisions. In broader climate risk assessments, where data may be limited, qualitative checks and transparent documentation of assumptions help users understand the reliability and limitations of the results.

Future Projections

Minimum validation requirement:

- *For engineering design purposes: Compare the projected seasonal total discharge with the historical observation over the same baseline period*
- *For broader climate risk assessments: The only requirement to validate the precipitation projection is to follow the same validation requirements outlined for precipitation*.

Validation of future flood projections should follow the same context-specific approach. For detailed design work, projected streamflow indices should be validated against historical streamflow data over the baseline period. For broader climate risk assessments, it is acceptable to assess the reliability of flood projections based on the validation of the underlying precipitation projection and model behavior over the baseline period.

Wind Speed

Validation Requirement: Moderate to Strong

Wind speed data requires moderate to strong validation due to its spatial variability and sensitivity to local topography and land surface conditions. Key indices include mean wind speed, maximum daily wind speed, and extreme gust events.

Note: Regions exposed to tropical or extratropical cyclones may require dedicated consideration during the validation process. In these cases, standard climate indices may not be representative of the associated hazards, therefore demanding the integration of cyclone-specific datasets (e.g., storm track and intensity data) or specialized modelling approaches, such as stochastic cyclone modelling, to improve the assessment of hazard patterns.

Downscaling

Minimum validation requirement: Compare downscaled mean wind speed with observations from nearby weather stations.

Wind speed exhibits higher spatial variability than temperature, especially near coastlines, over complex terrain, and in urban areas. While statistical or dynamical downscaling can improve spatial resolution, validation is needed to ensure that the spatial and temporal patterns of wind speed reflect observed local conditions. Validation typically involves comparing downscaled or modeled data against gauge measurements or reanalysis datasets near areas of interest, such as wind farms or coastal infrastructure. Additionally, using local wind roses can help validate whether downscaled or modeled data correctly capture the prevailing wind directions at the site.

Future Projections

Minimum validation requirement: Compare projected seasonal mean wind speed with historical reanalysis or ground-based observations over the same baseline period.

Validating wind speed projections during the baseline period is essential to assessing model reliability. However, wind speed projections remain more uncertain than those for temperature or precipitation, due to the complex influence of atmospheric dynamics, larger inter-model spread, and boundary layer processes. For broader climate risk assessments, validating mean wind speed may be sufficient, with a focus on analyzing relative changes or trends. In contrast, engineering or infrastructure applications require more detailed validation of extreme wind indices using high-quality observational data or high-resolution model outputs.

Other Hazards

General Validation Guidance

For climate-related hazards beyond temperature, precipitation, flooding, and wind, such as droughts, heatwaves, cold spells, landslides, or wildfires, the validation requirements depend on the nature of the indices, data availability, and intended use.

Additionally, while climate model validation and projections typically focus on individual climate variables and hazard indices, climate hazards can interact to produce cascading or complex impacts.

Validation Across the Project Cycle

Project sponsors should consider model validation when framing TORs, evaluating proposals, and during project implementation:

i. **RFP / TOR stage**
   a. Specify the minimum level of validation expected for each hazard (e.g., strong validation for precipitation), whether any project-specific or locally sourced data will be made available to bidders, or whether there is an expectation that bidders obtain such data independently.
   b. If the expectation is that bidders obtain the data, then require them to describe how they will obtain it and compare local observations with model outputs.

ii. **Proposal review**
   a. Evaluate whether the proposed validation plan meets the hazard requirements.
   b. Preference should be given to proposals that demonstrate access to local data (e.g., gauge records) and clear validation methodologies.

iii. **Inception report**
   a. Ensure the consultant presents preliminary validation results or a schedule for acquiring necessary observations.
   b. Any limitations (e.g., lack of gauges) should be flagged early so that alternative data sources or sensitivity analyses can be planned.

iv. **Final output review**
   a. Check that validation results are clearly presented (scatter plots, bias statistics, etc.) and that they are used to justify confidence in hazard indices and projections.
   b. Unvalidated data or models should be explicitly flagged as such, with a discussion of the implications for decision-making.

References

Example of validation for the annual maximum daily precipitation in São Tomé airport (1986-2010). São Tomé International Airport (TMS / FPST), WMO Station 61931 / ICAO FPST.

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The Global Center on Adaptation (GCA) is an international organization, hosted by the Netherlands, which works as a solutions broker to accelerate action and support for adaptation solutions from the international to the local, in partnership with the public and private sector, to ensure we learn each other and work together for a climate resilient future

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Lobelia Earth specializes in high-resolution climate risk assessment, combining satellite data, climate modelling and computational intelligence. As an international expert in the generation of precise and highly relevant observational datasets from geophysical features, the company is grounded in Earth observation science and pioneers new software technologies that integrate climate analysis into public and private sector strategies.

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