

CLIMATE SECURITY DATA AND ANALYSIS

Workshop Proceedings Report

La Spezia, Italy | 29-30 April 2025



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NATO Climate Change
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Climate Security Data and Analysis Workshop

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Workshop participants, April 29 2025, La Spezia, Italy (Photo credit: Ms Ilaria Saudella, NATO STO-CMRE)

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1. Introduction

Climate change is an increasingly present and tangible factor reshaping the security environment in which NATO operates. Higher temperatures, more frequent extreme weather, rising sea levels, and shifting ecological patterns are affecting where and how military missions take place. These same climate change effects impact the security of individuals, communities and regional groupings.

From the thawing Arctic, which opens new geopolitical and operational theatres, to the degradation of military infrastructure under heat stress, and the exacerbation of instability in fragile contexts, the implications of climate change are broad and interconnected. These impacts are not isolated; they converge in ways that can compromise mission success and challenge existing defence assumptions.

Recognizing this, NATO has formally identified climate change as a “threat multiplier” - a factor that amplifies existing security risks ([Source](#)). The Alliance has committed to integrating climate considerations into all areas of its core work, including strategic planning, operational effectiveness, infrastructure development, and capability delivery. This commitment is articulated in the NATO Climate Change and Security Impact Assessment ([Source](#)). To respond effectively, NATO needs reliable and relevant climate security data.

Climate security data encompass data coming from climate science disciplines (i.e., physical indicators, such as temperature readings) as well as data drawn from social science disciplines (i.e., socioeconomic indicators, such as food scarcity indices). Together, these sources provide the full picture needed to translate climate awareness into context-specific, informed action that supports planning, readiness, and resilience across the Alliance.

These data include more than just numbers and models. They span observed environmental conditions, forecasts, long-term projections, and integrated risk assessments, but also draw on qualitative insights including operational reports and local knowledge.

However, integration is not straightforward. It requires a structured approach that is grounded in evidence and informed by how climate information is produced, interpreted, and applied in practice. In this context, the concept of the climate security data lifecycle¹ can provide a useful way to make sense of these processes and support more consistent, informed decision-making (Figure 1).

Rather than treating climate security data as one-off inputs, the lifecycle perspective frames it as a continuous process that includes the generation of data, modelling, translation, application, and feedback. This approach highlights the technical, methodological, and epistemological choices that shape how climate and security information is used in practice. It also draws attention to the institutional mechanisms needed to ensure that insights are updated, shared, and incorporated into defence processes over time. Notably, these processes often differ from the respective fields involved: climate science data (or climate data, as will be referred to below) are often processed along paradigms developed in the physical and natural sciences, while security data are analyzed according to methodologies developed in social science disciplines. Particular to the climate security domain, then, is the incorporation of diverse approaches from these various fields and acknowledgment of these differing perspectives.

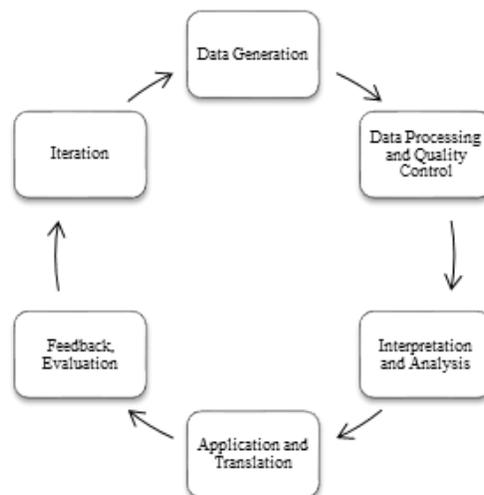


Figure 1. Data Lifecycle

¹The term climate security data lifecycle refers to the end-to-end process of generating, processing, interpreting, applying, and updating climate information to support decision-making. While not attributed to a single source, it reflects established practice in climate services and environmental data governance (WMO, 2014; USGCRP, 2015; Met Office, 2023). NATO's Climate Change and Security Impact Assessment (2023) aligns with this approach, emphasising the need for systematic, iterative integration of climate data into defence planning and operations. See also: [WMO Global Framework for Climate Services](#), [Copernicus Climate Data Store](#), [UK Met Office Climate Services](#), and the [US National Climate Assessment](#).

Subsequently, this proceedings report adopts the climate security data lifecycle as its core organizing principle to communicate insights from the Climate Data and Analysis Workshop, held in La Spezia, Italy, which brought together climate scientists, defence analysts, and strategic planners from across the Alliance.

The report is structured to reflect the key conversations held during the workshop, and mirror the steps in the climate security data lifecycle:

- Section 2: Data Generation: how and by which sources are climate security data being created
- Section 3: Data Processing and Quality Control: the treatment and transformation of these data to enable analysis
- Section 4: Interpretation and Analysis: the different methods of interpretation and analysis applied
- Section 5: Application and Translation: the application in defence and security contexts
- Section 6: Feedback Evaluation: the lessons learned from the process
- Section 7: Iterating a Common Approach

These proceedings offer a representative synopsis of current thinking and practice – not a final answer, but a marker of where we are now according to the consensus built from the workshop participants. They are intended to support a growing conversation across the Alliance, helping NATO build on what exists, reflect on what’s missing, and move forward with greater clarity and coordination as climate challenges continue to evolve.

The report includes observations from presentations delivered (including in-person and those presenting through the expert exchange sessions), discussions had and reflections from the authors of these proceedings.

2. Generation: Sources of Climate Security Data

The generation of data is the foundational step in the data lifecycle. As it comes to the climate security domain, there are two distinct types of data: the climate data and the security data. These both are necessarily tied in to the lifecycle in order to enable the follow-on steps (e.g., interpretation and analysis, application and translation). In this section, we will discuss both types of data. The exposition of the climate data, coming from the physical and environmental science disciplines, will necessarily be expansive due to its foundational basis for describing climate change effects. The summary of security data, coming from mainly social science disciplines, is still equally important when considering the analysis downstream in the lifecycle. Only a fair understanding and robust treatment of both kinds of data will enable robust and effective analyses for climate security applications.

2.1. *Climate Data*

The data coming from physical and environmental science disciplines shape the validity, resolution, and utility of all downstream analyses. For defence and security applications, understanding the characteristics, provenance, and limitations of different climate data sources is critical to developing robust evidence to inform insights.

This section of the proceedings is organised to capture the discussions of four major types of climate data discussed during the workshop. These different kinds of data are often referred to synonymously in climate security discourses, but the distinctions drawn here will help instruct on their differing sources, intentions and the resulting areas of relevance for downstream analysis. The final subsection will discuss the data considerations concerning the established climate emission pathway approaches (including representative concentration pathways, or RCPs, and Shared Socioeconomic Pathways, or SSPs).

- Section 2.1.1: Observational Data
- Section 2.1.2: Reanalysis Data
- Section 2.1.3: Traditional Climate Model Predictions
- Section 2.1.4: Near-Term Predictions
- Section 2.1.5: Climate Pathways

2.1.1. Observational Data: Ground Truth and Spatial Constraints

Climate observations are collected through a global network of meteorological systems that measure atmospheric, oceanic, and land-based variables. These include over 11,000 surface weather stations, as well as satellites, ships, and aircraft. The quality of observations varies, so each data point should be accompanied by metadata that records the conditions and methods of collection. This information is essential for accurate interpretation and comparison.

A widely used dataset is the Global Surface Summary of the Day (GSOD), managed by the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information. It provides daily summaries from over 9,000 stations worldwide, with historical records dating back to 1929. Coverage is more complete from 1973 onwards. The dataset includes up to 18 surface meteorological elements, aggregated from hourly observations.

Observational data are typically accessed using tools such as provider-based clients, and processed through software platforms including Python, R, Excel, and Power BI. Metadata are essential for analysing parameters such as precipitation, as they describe how measurements were taken and whether reporting was complete.

The **strengths** of observational data include high accuracy, detailed temporal resolution, and accessibility.

Limitations include missing values, inconsistent spatial and temporal coverage, and the need to homogenise data from stations that have moved or undergone changes over time.

An Example of an Observational System: The European Centre for Medium-Range Weather Forecasts (ECMWF) is an independent intergovernmental organisation supported by 35 European countries. It serves as both a world-leading research institute and an operational forecasting centre, delivering global weather predictions up to 15 days in advance and seasonal forecasts up to a year ahead.

ECMWF processes over 800 million daily observations - mostly from satellites -integrating around 60 million quality-controlled data points into its forecasts to support accurate, global weather prediction.

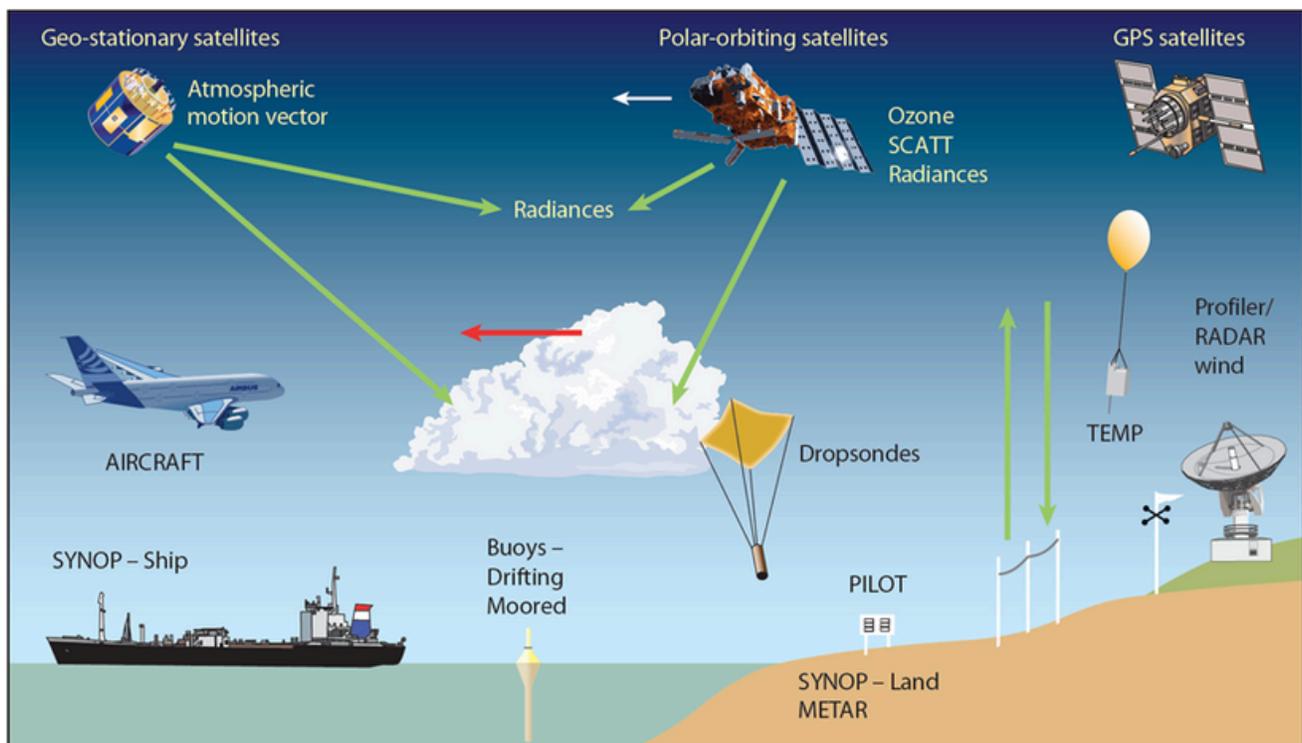


Figure 2. Observation Data [Source]

Using this observational system to obtain data, ECMWF runs one of the most advanced numerical weather prediction systems, the Integrated Forecasting System (IFS), and assimilates hundreds of millions of daily observations into its models. It also hosts two major EU Copernicus services: the Climate Change Service (C3S) and the Atmosphere Monitoring Service (CAMS), playing a central role in European climate monitoring and Earth system science.

2.1.2. Reanalysis Data: Spatially Complete, Model-Assimilated Observations

Reanalysis data provide a comprehensive and consistent reconstruction of past weather and climate by combining historical observations with modern weather forecasting models through data assimilation. In simple terms, reanalysis data provide a way to create a detailed picture by combining past weather and climate data (from observations) with modern computer models to make up for the missing values in observational data where weather stations or satellites were not existing to provide such data. For this reason, they are often called "maps without gaps," as they fill spatial and temporal holes in the observational record, enabling a clearer understanding of long-term climate trends and extreme events.

Reanalysis data are produced using the same model and assimilation system across the entire period, ensuring consistency. The process includes digitising old records, reprocessing satellite data, and applying quality controls to ensure accuracy. They blend observed data with physics-based models to fill in gaps and generate consistent datasets.

There are many available reanalysis products, with different sources, domains, resolutions and formats. Several provide global coverage and are produced by major meteorological organisations, for example:

- ECMWF datasets such as CERA-20C, ERA-20C, ERA Interim and ERA 5
- NASA provide the MERRA and MERRA2 datasets
- NCEP in collaboration with NCAR provide the NCEP-NCAR (R1) and CFSR
- JRA-55 is provided by the Japanese Meteorological Agency

Specialised regional reanalysis products include NCEP and NCAR's North American Regional Reanalysis (NARR) and the Arctic System Reanalysis product (ASR) which is produced by the Byrd Polar Research Centre at Ohio State University.

Key reanalysis datasets discussed during the workshop were:

- **ERA5** (ECMWF): A globally complete product with hourly data and ~30 km resolution, providing long-term continuity back to 1950.

ERA5, the latest comprehensive reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF), has replaced its predecessor ERA-Interim. It offers hourly data from 1940 to the present, covering the atmosphere, land surface, and ocean waves. ERA5 operates on a horizontal resolution of $0.25^{\circ} \times 0.25^{\circ}$ and spans 137 vertical levels from the surface up to 80 km. Its land surface component, ERA5-Land, provides enhanced spatial resolution at 9 km. ERA5 integrates updated sea surface temperature, sea ice concentration data, and radiative forcing from CMIP5, alongside numerous reprocessed observational datasets. Data are available via the Copernicus Climate Data Store **C3S**.

In contrast, ERA-Interim, which was publicly available from 1979 to August 2019, had a coarser spatial resolution (79 km, 60 vertical levels) and used older model physics (IFS Cycle 31r2). ERA5 employs the more advanced IFS Cycle 41r2, offering hourly outputs and greater parameter coverage, including over 120 surface variables such as temperature, dew point, wind components, and soil moisture (**ECMWF**).

- **ORA5** (Ocean ReAnalysis): Provides insights into ocean heat content and salinity, crucial for understanding maritime and subsurface operational conditions.

ORA5 is ECMWF's global ocean reanalysis, combining observations and modelling to reconstruct past ocean states. It provides monthly updates covering key ocean variables like temperature, salinity, currents, heat content, and sea ice. With a horizontal resolution of 25 km and 75 vertical levels, ORA5 supports marine climate research and is accessible via the ECMWF ocean reanalysis portal.

- **CARRA** (Copernicus Arctic Regional Reanalysis): Focused on the Arctic region, offering high-resolution (2.5 km) data tailored to extreme environments.

The Copernicus Arctic Regional Reanalysis (CARRA) was developed in response to the urgent need for detailed climate data in the rapidly warming Arctic region. CARRA Phase 1 (CARRA-1) produced high-resolution (2.5 km) atmospheric reanalyses for European Arctic domains, including Greenland, Svalbard, Iceland, and Severny Island. Monthly updates are provided, and the reanalysis uses ERA5 as boundary forcing. The ongoing Phase 2 (CARRA-2), launched in April 2024, incorporates improvements in numerical weather prediction systems and is expected to be fully released by late 2026 ([Copernicus Arctic Reanalysis](#)).

Strengths are that reanalysis data are particularly useful for trend detection, anomaly identification, and initializing forecasts.

However, **limitations** include that these data inherit biases from the assimilated observations and the model physics, necessitating expert interpretation. Users must also be aware that reanalysis data are not purely empirical - errors in the underlying model or data assimilation technique can propagate through the datasets.

An Example of Reanalysis model: There is a growing need for high-resolution regional reanalysis in the Arctic to support military operations, planning, and situational awareness, as the region experiences warming at more than twice the global average.

Compared to ERA5, CARRA provides more precise spatial and temporal data for near-surface parameters over heterogeneous Arctic surfaces like sea ice and glaciers. This rapid environmental change, combined with rising geopolitical and economic interest, demands improved understanding of climate-related processes.

Whilst both systems produce consistent large-scale features such as pressure systems, with differences largely arising from local resolution and sea ice representation and accurate modelling is essential to capture complex Arctic terrain variables which influence mobility, infrastructure, and surveillance.

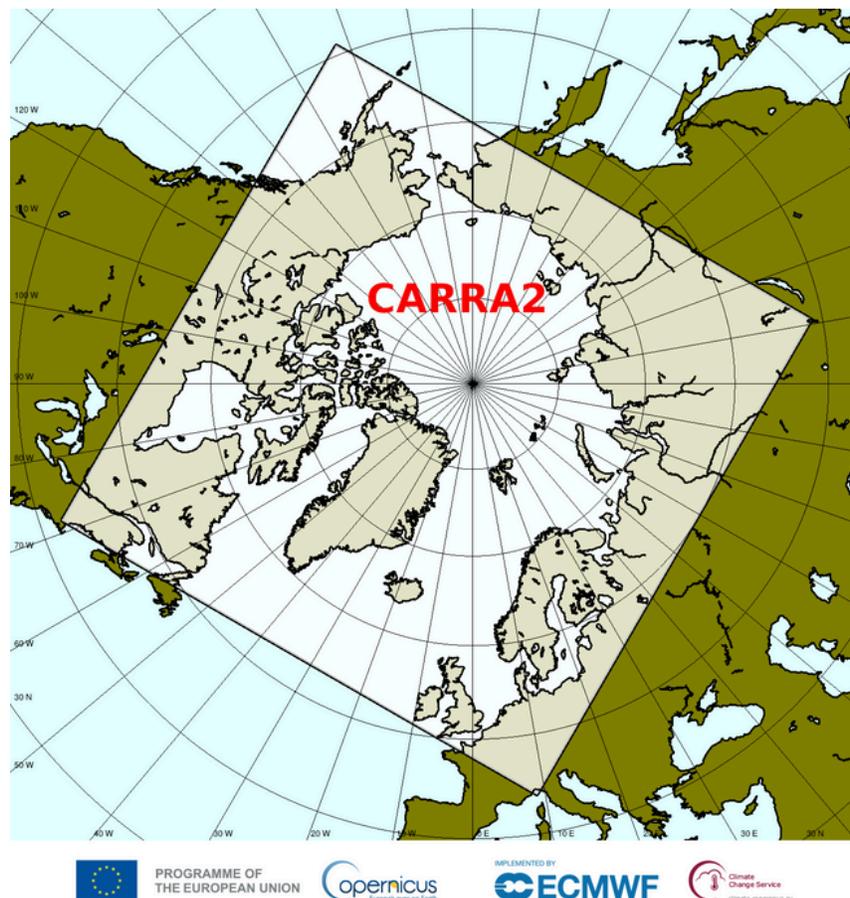


Figure 3. The pan-Arctic domain used for the second-generation Arctic regional reanalysis (CARRA2). [Source]

2.1.3. Climate Models: Projections of the Climate Future

Due to the complex and non-linear interactions between the individual components of the Earth system, climate models are the most suitable tools for long-range forecasting. Climate models simulate the climate system using physics and equations, they do not rely on past observations and instead use knowledge of current observations to simulate different future scenarios. To anticipate how climate change may affect NATO operations over coming decades, the use of modelled simulations is essential as they provide more than explanations of the past, they project into the future. Two types, **Global Climate Models** (GCMs) and **Regional Climate Models** (RCMs) are used to simulate the Earth's climate system based on varying emissions and policy scenarios.

Climate simulation and weather forecasting models are among the most complex types of scientific software, often involving millions of lines of code. These models typically simulate dependent variables such as pressure, density, humidity, temperature, and wind, across independent variables like spatial coordinates and time. Many of these models are written in FORTRAN, a long-standing scientific programming language, originally developed in the 1950s for scientific and engineering calculations. **FORTRAN** remains widely used in climate and weather modelling due to its efficiency in handling large-scale numerical operations and its established roots in scientific computing.

Figure 4 illustrates the components of global climate models and how each has improved over time. Advances in computing power have enabled increased resolution, significantly enhancing model performance. Additionally, the representation of physical processes has evolved; for example, models from the 1970s did not account for cloud feedbacks, whereas modern models now incorporate cloud microphysics and cloud-aerosol interactions, reflecting improved scientific understanding.

DATA GENERATION

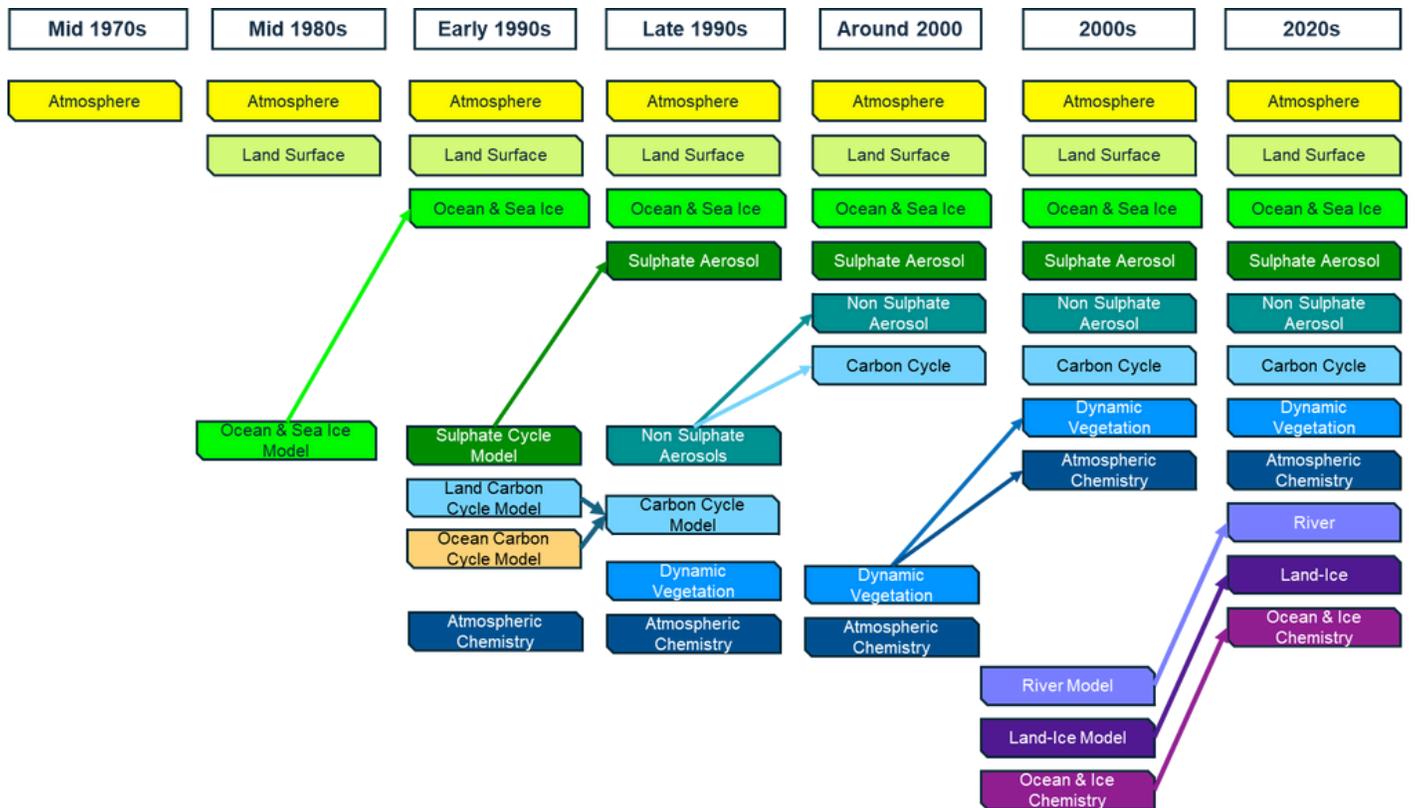


Figure 4. Components of global climate models and improvements to each over time.

To ensure consistency and robustness in climate modelling, large-scale collaborative projects have been established. The Coupled Model Intercomparison Project (CMIP), now in its sixth phase (CMIP6), is a flagship international initiative under the World Climate Research Programme. It coordinates the efforts of dozens of modelling centres worldwide, producing harmonised climate simulations used extensively in IPCC reports.

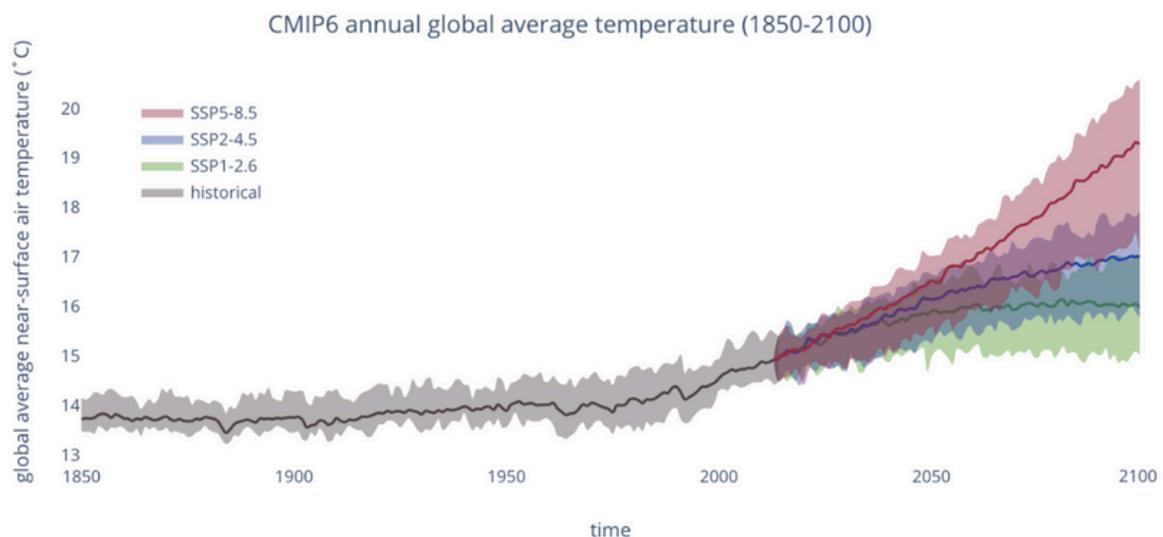


Figure 5. Projected global temperature change (1850–2100) from CMIP6 models [Source]

CMIP6 encompasses a wide range of variables and scenarios and provides comprehensive global coverage, though it operates at relatively coarse spatial resolutions (typically 80–250 km), which limits its ability to represent fine-scale features such as local extremes, terrain effects, and coastal dynamics.

To address these limitations, the Coordinated Regional Climate Downscaling Experiment (CORDEX) was launched. CORDEX refines global climate data using higher-resolution regional climate models (RCMs), better capturing local and extreme climate phenomena. With resolutions as fine as 12.5 km, CORDEX provides more detailed insights into region-specific changes, especially in relation to extreme events and land-atmosphere interactions. However, RCMs are dependent on the quality of the global models that drive them and often provide fewer oceanic parameters. Furthermore, most CORDEX projections are based on high-emission scenarios, limiting comparability across all emissions pathways (emission scenarios, including representative concentration pathways (RCPs), are outlined in detail in Section 2.1.5.)

Choosing between CMIP and CORDEX data depends on the research question. CMIP offers a broader, more varied set of future scenarios and is well-suited for analysing long-term global trends and uncertainties. In contrast, CORDEX adds considerable value when examining regional impacts or extreme weather patterns due to its higher spatial resolution. When used together, these datasets provide a powerful foundation for understanding the range and scale of potential climate futures, supporting evidence-based decision-making in both global and local contexts.

Ultimately, the **strengths** of climate models are in their ability to span long time frames to explore a range of future scenarios and provide insights at global and regional levels. The community efforts focused on their development have resulted in consensus models and sustained research programs that are intended to provide continually-updating GCMs and RCMs, leading to robust, widely-used models.

However, **limitations** include coarse resolution and a difficulty in determining the right models to use for the appropriate contexts without consulting external expertise. For example, local contexts (topography, sea/land interfaces) can be difficult to capture even with RCMs and require bespoke models.

An Example of a General Circulation Model: HadGEM3 UK Met Office. HadGEM3 (Hadley Centre Global Environment Model version 3) is the UK Met Office's state-of-the-art global climate model and a key component of the UK Earth System Model (UKESM1). It couples atmospheric (Unified Model), ocean (NEMO), and sea ice (CICE) systems via the OASIS coupler, supporting both standard (~130 km) and high-resolution (~25 km) configurations. HadGEM3 features improved representations of cloud processes, ocean-atmosphere interactions, and sea ice dynamics, making its simulations more consistent with observations. With a relatively high climate sensitivity (ECS ~5.5°C), it is used in major climate assessments, such as CMIP6 and IPCC reports, and is well-suited for studying long-term projections, regional impacts, and extreme weather events.

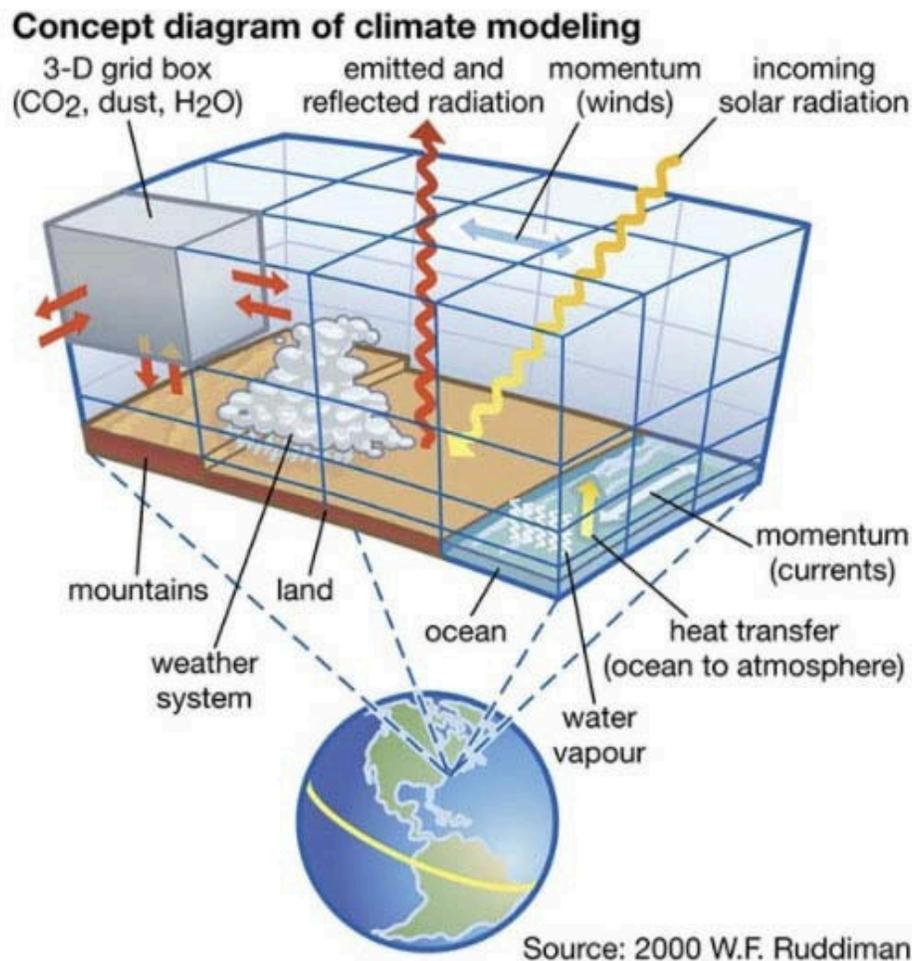


Figure 6. Schematic of a General Circulation Model [[Source](#)]

2.1.4. Near-Term Predictions: Seasonal and Decadal Data

Seasonal forecasting bridges the gap between short-term weather prediction and long-term climate modelling, providing insights into likely climate conditions over the coming months. Unlike weather forecasts, which offer snapshots of current atmospheric states, seasonal forecasts summarise weather patterns over a season. They highlight potential high-impact events such as tropical cyclones, floods, droughts, and heatwaves. These forecasts are influenced by large-scale climate phenomena like the El Niño-Southern Oscillation (ENSO), the dominant source of year-to-year climate variability. It is worth noting that traditional climate models, presented in the previous section, focus on longer-time horizons for predictions, commensurate with the usual 30+ year interval in time which represents the usual picture of climate (*contra* standard meteorology and the weather). Community efforts for climate modelling have been longstanding and productive, arriving at a quite remarkable research program built around consensus (e.g., the CMIP and CORDEX projects, feeding the IPCC Assessment Reports (ARs)). The shorter-term seasonal and decadal forecasts are relatively recent efforts, and accordingly do not have the institutional consensus and resultant credibility that the traditional climate models enjoy. Nonetheless, this field of research is growing, and its methods are important to understand given its place in bridging between traditional climate models and standard meteorology.

Figure 6 outlines how different forecast timescales, from daily weather to multi-decade climate projections, are influenced by distinct sources of predictability. At shorter ranges, forecasts are driven by current atmospheric observations. As forecasts extend into seasonal and decadal periods, they draw on slower-evolving climate components such as ocean conditions and large-scale variability patterns like ENSO. For projections beyond several decades, accuracy depends less on present conditions and more on assumed future changes in emissions and external forcing. The figure also identifies influential processes, including ocean-atmosphere interactions, and shows when they have the greatest impact on climate predictions.

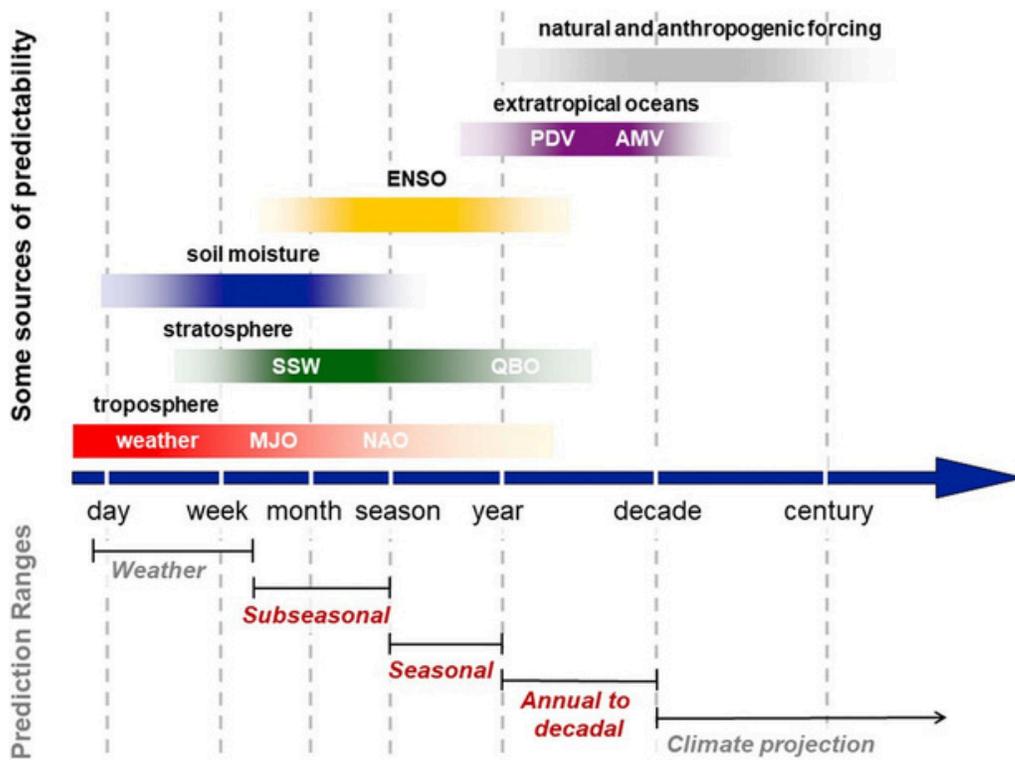


Figure 7. Forecast timescales and key sources of climate and weather predictability. [Source]

The Copernicus Climate Change Service (C3S) delivers seasonal forecast data via the Copernicus Data Store (CDS), including both graphical products and raw datasets. Forecasts are produced by institutions including ECMWF, the Met Office, Météo-France, DWD, CMCC, NCEP, JMA and ECCO. These systems provide forecasts using ensemble methods² up to six months ahead, covering over 30 parameters. Instead of single, deterministic estimates of each of the parameters, the forecasts are provided as probabilities of how likely parameter values will be much higher or much lower than expected values (i.e., how likely will the season be wetter, drier, warmer, colder compared to a seasonal average). The accuracy of seasonal forecasts is systematically improved through the use of methodologies which incorporate hindcasts: the tuning of models according to previous years' historical data.

²Forecasting using an ensemble means that several different simulations are conducted, varying in initial conditions or run properties – the output forecast is built from the probability distribution formed by the ‘ensemble’ of the simulation results.

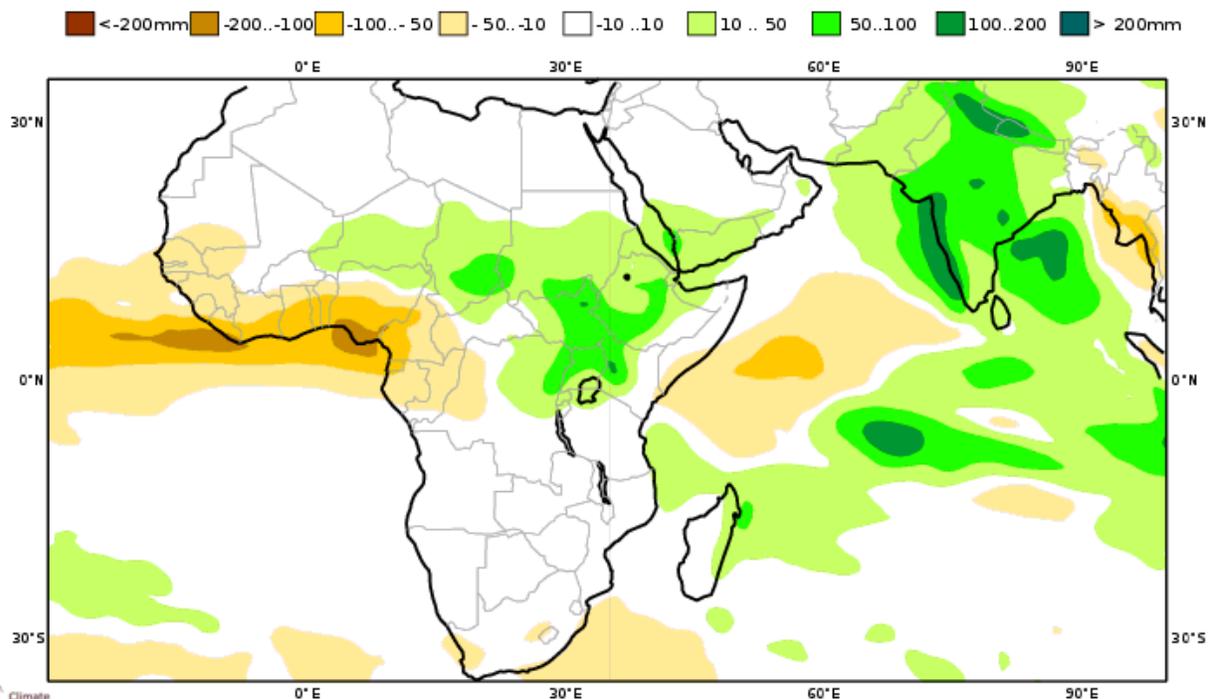
Decadal forecasting, also known as near-term climate prediction, focuses on the 1–10 year timescale. Although a newer field, it is increasingly important for informing climate policy and operational planning. These forecasts provide guidance on near-term global warming trends and help distinguish between natural variability and human-induced change.

Strengths include accuracy across specific timeframes and global coverage that can be improved through the use of multiple ensemble methods. Seasonal forecasts benefit from ensemble averaging, which helps address biases present in individual models, and are further strengthened by systematically refreshed forecasts and long-term hindcast records that support assessment of predictive skill. The datasets also offer accessible information on several climate parameters, supported by useful documentation to guide users.

Limitations are that some climate parameters vary in coverage and quality, affecting the overall fidelity of the data. In seasonal contexts, uncertainties in initial conditions and the substantial computational power required to apply bias corrections using hindcasts add to the complexity. Furthermore, the presence of model bias (explored in Section 3) and the probabilistic nature of forecasts can make interpretation challenging for end-users.

An Example of Seasonal Forecasts: Using data to predict variables such as those related to rainfall is particularly useful in supporting decisions in sectors like agriculture where rainfall controls planting and growth cycles. Seasonal forecasting can provide data on anomalies in precipitation values – that is, extremes (in excess or in dearth) relative to expected values. In addition, these forecasts provide likelihoods of these extremes, which can indicate expectations for flooding or drought conditions. Data from the Copernicus Climate Change Service show that seasonal models can predict such precipitation anomalies, offering more reliable guidance than historical averages and longer horizons of forecasts than traditional weather and meteorological approaches.

C3S multi-system seasonal forecast ECMWF/Met Office/Météo-France/CMCC/DWD/NCEP/JMA/ECCC/BOM
 Mean precipitation anomaly JJA 2025
 Nominal forecast start: 01/05/25
 Variance-standardized mean



Seasonal forecast using the mean precipitation anomaly for a geographic region encompassing Africa and South Asia. The legend and colours represent the seasonal predictions relative to the expected precipitation (averaged over a reference season). Greener colours indicate regions of anomalously higher precipitation (more rainfall expected), while browner colours indicate region of anomalously lower precipitation (less rainfall expected). [[Source](#)]

2.1.5. Climate Pathways: RCPs, SSPs, and emissions scenarios

Understanding future climate change requires robust projections that account for both human influence and natural variability. Representative Concentration Pathways (RCPs) are one such framework, developed to explore potential futures based on differing greenhouse gas concentrations and their associated radiative forcing, essentially the energy imbalance in the Earth's system by the year 2100. These pathways range from low to high forcing levels (2.6, 4.5, 6.0, and 8.5 Watts per square metre), each corresponding to a projected global average temperature rise, from approximately 1.6°C to 4.3°C. RCPs are instrumental in helping scientists model how various emissions trajectories might influence the planet's climate system.

What Does “Radiative Forcing” Mean in Climate Science?

In climate science, radiative forcing is a measure of how much the Earth's energy balance is disturbed by changes such as increased greenhouse gas concentrations, aerosols, or land-use change. It is expressed in Watts per square metre (W/m^2)—a unit that tells us how much additional energy is being trapped or reflected across every square metre of the Earth's surface.

Think of it like adding a thin extra blanket to the planet: even a few extra Watts of retained energy per square metre, applied consistently across the globe, can significantly alter the climate over time.

The Representative Concentration Pathways (RCPs) - which underpin many climate models - are named after their radiative forcing targets by the year 2100. For instance, RCP4.5 refers to a scenario where greenhouse gas concentrations lead to 4.5 W/m^2 of additional energy retained in the Earth's system compared to pre-industrial levels. Higher radiative forcing means greater warming: under RCP8.5, the Earth could see over 4°C of average temperature rise by the end of the century.

Understanding radiative forcing helps us grasp how human activity is altering the Earth's natural energy flows—and why the scale of change matters.

Complementing the RCPs are Shared Socioeconomic Pathways (SSPs), a set of global narratives and quantitative projections that describe possible societal trends over the 21st century - ranging from sustainable development to fossil-fuelled expansion. The SSPs were introduced in the latest IPCC AR6 report as a natural follow-on to the RCPs, introduced in the prior IPCC AR5. These narratives do not assume mitigation actions but rather provide a basis for assessing how different policy or economic choices might shape emissions. By combining SSPs with RCPs, researchers create integrated scenarios that better reflect both human and environmental dimensions of climate change. We note that these scenarios and their resulting data are included in this climate data section, even though some of the considerations taken into account for estimating emission scenarios use some of the quantities natural to discuss in the security data space. This is because even though the input to these scenarios incorporate socioeconomic factors, the output of these scenarios are still the climate data: that is, the estimates of the physical indicators governing the climate science information. Five SSPs are recognized, each reflecting distinct global contexts such as high inequality, regional rivalry, or international cooperation toward sustainability.

- **SSP1 – Sustainability ("Taking the Green Road")**

A world making good progress toward sustainability, with low challenges to mitigation and adaptation.

- **SSP2 – Middle of the Road**

A continuation of historical trends, with moderate challenges to mitigation and adaptation.

- **SSP3 – Regional Rivalry ("A Rocky Road")**

A fragmented world with strong nationalism, limited global cooperation, and high challenges to both mitigation and adaptation.

- **SSP4 – Inequality ("A Road Divided")**

A world with high inequality both within and across countries, leading to unequal access to resources and technology.

- **SSP5 – Fossil-fuelled Development ("Taking the Highway")**

A world with rapid economic growth driven by intensive fossil fuel use and high greenhouse gas emissions.

Whilst the output data are still firmly in the climate science realm, the integration of socioeconomic factors as input into the development of these pathways – to ultimately generate climate projections – opens the door to assessing a wide range of human and ecological insecurities (e.g., food and water scarcity, migration, political instability, and conflict risk). Understanding how different futures shape vulnerability and resilience enables more informed decisions about where, when, and how to act in the face of climate-related threats. In the following section, we turn to the types of security data which must necessarily be incorporated into the overall climate security data lifecycle and analysis.

2.2. *Generation: Sources of Security Data*

Effective climate security analysis relies on an integration of climate data with sources of security data, that is, data that capture the dynamics and pressures that shape human and geopolitical vulnerabilities. This includes indicators of risks arising from environmental hazards, governance fragility, resource access and conflict risk.

Security data can come from a range of sources. This section of the proceedings is organised around the sources discussed in the workshop:

- Section 2.2.1: Conflict Event Data
- Section 2.2.2: Mission Specific Intelligence
- Section 2.2.3: Security Indicators

2.2.1. Conflict Event Data – Media and Open Source Data

Conflict data are systematically gathered by monitoring a wide range of political violence, protests, and armed conflict events. These datasets primarily rely on open-source information including media reports, official government and military statements, NGO and humanitarian updates, and social media content. The raw data are reviewed by trained analysts or by automated systems and coded into event formats, including details on date, location, actors involved, and event type.

Several conflict event databases exist, differing in coverage, conflict types and methodology³.

- Some sources are ‘researcher-based’, that is, events are systematically parsed and added to the database according to human/analyst intervention; others use automated techniques, such as web crawling, to automatically populate the database.
- Some projects perform retroactive validation, that is, event data for past dates are continually refreshed according to updated information.
- Certain databases focus on all conflict scopes, including fatal and nonfatal events, while others include conflicts with minimum number of fatalities.
- The scope also differs between conflict actors (e.g., governmental, militia, protestors, rioters).

³A comparison of some of the popular conflict event databases can be found in the following references:

- [In data we trust? A comparison of UCDP GED and ACLED conflict events datasets - Kristine Eck, 2012:](#)
- [Political instability patterns are obscured by conflict dataset scope conditions, sources, and coding choices | Humanities and Social Sciences Communications](#)

Unlike climate data from direct observations, conflict data are interpreted from these qualitative sources and geolocated to enable spatial and temporal analysis and accessed via structured databases or application programming interfaces (APIs). These datasets are commonly processed using GIS software for spatial mapping, and analytical platforms such as Python, R, or STATA for quantitative assessment. Data visualisation tools like Tableau or Power BI are used to identify trends, illustrate hotspots, and explore temporal or spatial correlations with other variables, including climatic or socioeconomic factors

The **strengths** are in the accessibility of the data in a consistent structure with (often) regular updates and global coverage. Widespread uses of the common databases generates continued evaluation and analysis in the literature.

Limitations stem from the interpretative nature of the collection, making it difficult to validate the data alongside bias in media coverage and over and under reporting. Furthermore, a lack of coordination between the major conflict event database projects makes it difficult to determine which should be used in which contexts.

An Example of a Conflict Event Database: The Armed Conflict Location & Event Data Project (ACLED) is an independent data initiative that collects, curates, and publishes disaggregated conflict event data from more than 150 countries. ACLED records incidents involving violence against civilians, battles, protests, and riots, among other categories. Each entry includes the date, location (with geocoordinates), actors involved, type of event, and source reference.

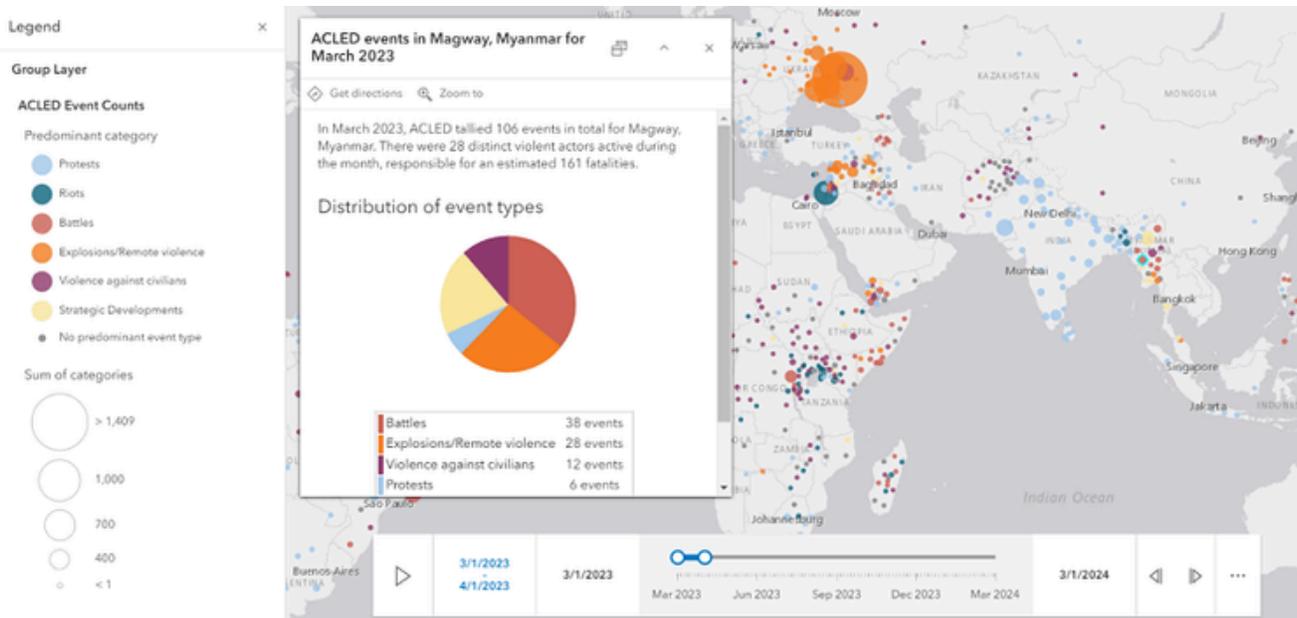


Figure 8. ACLED disaggregated data collection, analysis, and crisis mapping project [[Source](#)]

2.2.2. Mission Specific Intelligence

In addition to global datasets, security analysis often relies on mission-specific intelligence collected by organisations operating in complex environments. One example is the internal data generated by the United Nations Mission in South Sudan (UNMISS), which tracks security incidents such as killings, abductions, and conflict-related violence. These data are derived from field-based reporting, verified accounts, and structured analysis conducted by UNMISS personnel. While not publicly released in full, aggregated and anonymised findings are often shared in quarterly briefings or policy reports. These types of data provide timely, context-rich insights that are critical for understanding local dynamics, informing peacekeeping strategies, and guiding humanitarian response efforts.

Mission-specific intelligence data can be integral to detecting nuanced shifts in local dynamics and may provide early indicators of instability that may not yet be visible in broader datasets. The data are often geographically precise, with incidents geolocated at the village or neighbourhood level, making them especially useful for local-level threat assessments. Unlike many global conflict datasets, mission-specific sources include rich contextual narratives that capture actor motivations, cultural nuances, and evolving dynamics. Additionally, these data are tailored to the mission's mandate, meaning they may focus on specific security dimensions such as civilian protection, humanitarian access, infrastructure sabotage, or disputes over land and resources—providing sector-specific insights not found in broader datasets.

Strengths include a highly tailored collection of data that directly incorporates local context. Presumed accessibility, within the mission, to data providers and analysts ensures accurate interpretation.

Limitations are that these data sources are often restricted and not publicly available, due to mission contexts and commensurate releasability. Applicability to other geographic regions or other time scales is not straightforward.

An Example of Mission-Specific Intelligence: Within the SIPRI South Sudan Fact Sheet, the United Nations Mission in South Sudan (UNMISS) provides a critical layer of mission-specific security data ([Source](#)).

UNMISS is mandated to provide risk assessments on how the adverse effects of climate change affect the delivery of humanitarian assistance. During recent floods, it supported South Sudan’s state and county authorities in identifying high ground for communities to self-relocate, as well as in developing a conflict sensitivity database and activities to mitigate the risks of conflict. As the Fact Sheet explains: “Between April and June 2024, UNMISS documented 1062 victims of intercommunal and political violence; this represented a 32 per cent increase in violent incidents and a 16 per cent increase in the number of victims compared to the first quarter of 2024.”

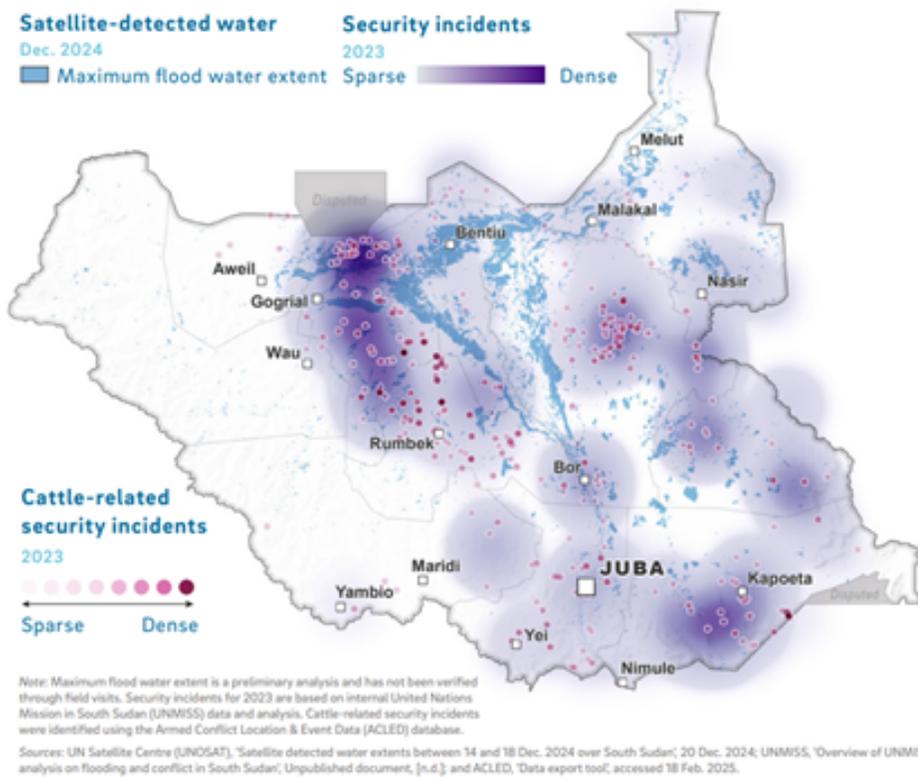


Figure 9. An example of overlaying climate data and security data through an analysis presenting the flooding and security incidents in South Sudan ([Source](#))

2.2.3. Security Indicators

Several security indicators have been defined for general human security metrics – quantities that describe the food, health, environmental, economic, or social situations of populations, at the community, regional, national or multinational levels.⁴ In these proceedings, we focus on those indicators that are commonly used in the analysis of climate security, i.e. those security indicators that are inherently tied to or directly impacted by climate change.

An established and robust set of security indices can be found from the World Bank World Development Indicators. These provide widely-used and often-updated measure of socioeconomic data, including household incomes, poverty rates, etc. Other sources include the UN Integrated Food Security Phase Classification (IPC), which quantifies food security, and the Global Health Security Index which measures country capacity to prepare for epidemics and pandemics. The data are generated through a variety of methods including household surveys, government data and local missions and offices collecting and verifying data.

Built on top of these various indicators are aggregate indices, which combine these various lower-level indicators into combined measures of security. For example, the Notre Dame Global Adaptation Initiative (ND-GAIN) generates scores built on many of these indicators, resulting in single measures of security based on national climate readiness weighed against their respective climate vulnerability. Most often, the ND-GAIN is referenced in order to rank nations in terms of the impacts of climate change on an overall (human) security situation.

Security indicators provide quantitative measures of the human security situation, whether health, food, economic, social, or in aggregate.

Strengths of using security indicators for analysis include that quantitative measures can help inform decision-makers on development decisions and regional/temporal differences in the analysis of human security factors. **Limitations** of security indicators include the fact that they are inherently arbitrary and necessarily miss context-specific factors at the trade-off of generating higher-level comparative metrics of human security. Care should be taken to use established indicators generated by reputable organizations which are agreed-upon in the academic literature.

⁴The seven dimensions of human security as understood in the community are those outlined by the UNDP in the report: UNDP (United Nations Development Programme). 1994. Human Development Report 1994: New Dimensions of Human Security. New York. <https://hdr.undp.org/content/human-development-report-1994>"

Data Generation Conclusion

Gaining a clear understanding of where and how climate security data are generated provides a valuable foundational step for NATO's climate security analysis efforts. The examples presented offer only a snapshot of the diverse and complex data landscape that must be navigated. Recognising the variety of sources, each with its own strengths and limitations, helps build a more complete picture and it is this foundational knowledge that sets the stage for the next critical phase of processing and preparing these varied data streams to enable robust, actionable analysis.

3. Processing: Preparing Data for Analysis

The transformation of any data into a usable analytical format is an important part of the data lifecycle (i.e. the Data Processing and Quality Control step in Figure 1). When it comes to climate security data, this process is particularly complicated due to the approaches used in the different fields of study. Specifically, translating raw climate data into a usable analytical format is technically demanding due to the complexity of the models and the large amount of data. In parallel, ensuring quality control of security data can be challenging due to the differences in methodological approaches and the novelty of the incorporation of indicators into climate security analysis.

The utility and reliability of subsequent climate–security assessments depend on how well these data have been processed – cleaned, harmonized, corrected for bias, and structured into formats that can be queried and visualized effectively. This section outlines the key technical processes involved in climate security data processing, including bias correction, data formatting and structure, and the quality control approaches that comprise the climate data analysis ecosystem.

This section is organised around the main topics discussed in the workshop:

- Section 3.1: Bias Correction
- Section 3.2: Structuring Climate Data
- Section 3.3: Data Transformation and Quality Control of Security Data

3.1. *Bias Correction: Addressing Errors in Model Outputs*

Bias correction (BC) is a critical step when working with climate model outputs—particularly for impact assessments that require alignment with real-world observations. Climate models, by their nature, include simplifications, limited spatial resolution, and assumptions about Earth system processes. These lead to biases between model outputs and observed conditions, especially in regions with complex terrain, ocean-land contrasts, high degrees of stochasticity⁵, or sparse observational data. The bias correction methods discussed in this section are distinct from any treatment of systemic biases. The adjustment correction of these latter biases is a critical process that should precede the use of climate data.⁶

Bias correction methods aim to reconcile reference, or ‘default’ data sets (usually reanalysis or observational data) with output, or ‘target’ data sets (usually data generated from climate models). This reconciliation process, accomplished via statistical methods, aims to numerically provide the correction for the climate model shortcomings (evidenced in the target set) using credible information (drawn from the default set).

⁵Stochasticity describes the degree of randomness or uncertainty of a given quantity, where values are not distributed according to standard statistical distributions, for example precipitation-related quantities.

⁶Systematic biases can include measurement biases (data collection from single- or non-representative locations), experimental biases (experiment design discriminates perhaps inadvertently against demographics, geography, etc.), and human biases (errors in assumptions or non-representative samples collected and/or used for analysis).

What are Bias Correction Methods?

Bias correction methods are employed depending on the nature of the climate variables and the complexity of their interrelationships.

Univariate methods focus on correcting individual variables independently. Among these, Change Factor methods are commonly used for non-stochastic variables, that is those that exhibit less randomness, such as mean temperature. These include the Delta method, which adjusts future projections by applying the difference in mean values between the climate model outputs and reference observations, and the Scaling method, which uses the ratio between model estimates and observed data to modify projections. For more stochastic variables, such as precipitation, distributional methods like Empirical Quantile Mapping (EQM) are preferred. EQM aligns the statistical distribution of modelled data with observed data by adjusting each quantile individually, improving representation across the entire range of values. While univariate approaches are straightforward and effective for stable parameters and coarser temporal resolutions, they often struggle to accurately capture extremes and finer time scales.

Multivariate methods address limitations of univariate methods by considering the interdependencies between multiple climate variables simultaneously. This is essential for preserving physical consistency across the climate system, particularly when modelling phenomena like heat stress, floods, or droughts that arise from compound variables. Techniques such as copula-based mapping⁷ and multivariate quantile mapping enable the joint correction of related variables, thereby maintaining realistic correlation structures.

Recent advancements include multimethod and machine learning approaches, which combine traditional statistical techniques with computational algorithms to improve bias correction, especially for extreme events and high-frequency data such as hourly precipitation. Hybrid models like the Triangular Irregular Network: TIN-Copula integrate geometric approaches with statistical copulas, while others employ Generalized Additive Models (GAMs) or machine learning algorithms. These cutting-edge methods show promising improvements in performance but demand significant computational resources and require thorough validation to ensure robustness.

⁷A copula is a mathematical function that links different variables together to show how they are related or depend on each other. The term comes from the Latin word for “link” or “tie,” reflecting how copulas connect variables in a statistical model.

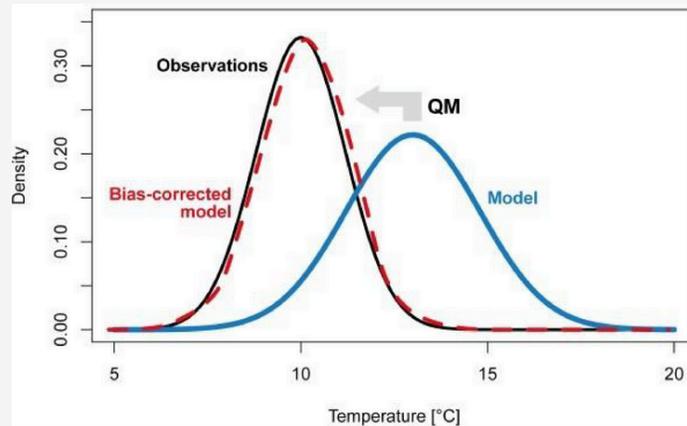
Overall, selecting an appropriate bias correction method depends on the variable characteristics, desired temporal resolution, and available computational capacity, making this a nuanced but vital process in climate data preparation.

A well-applied BC method can significantly enhance the realism of projections. The choice of method depends on the kinds of models (target data), the kinds of inputs (reference data) and the variables of interest. As a relatively advanced topic within climate science data and analysis, consultation with climate scientists is recommended before investigating and applying bias correction methods.

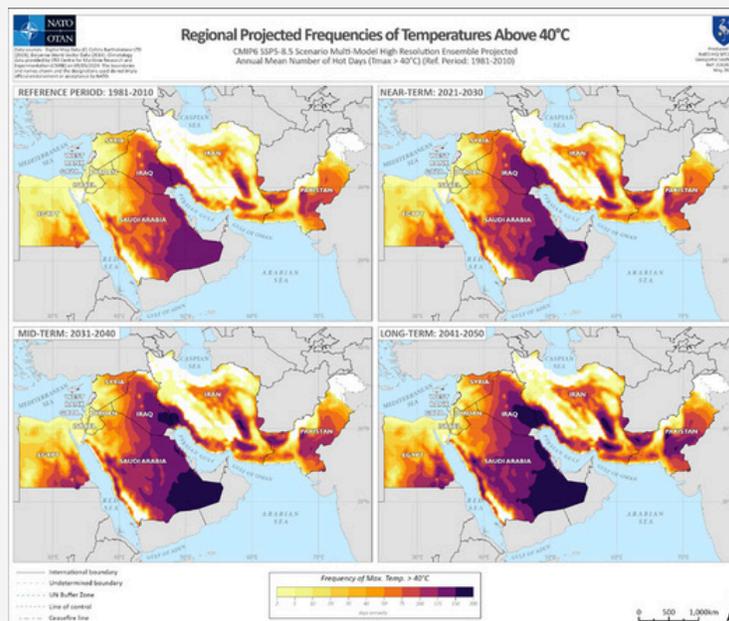
Bias Correction for Climate Models: Application

The CMRE investigated bias-correction methods for studying the climate data quantity: number of hot days (where the temperature is greater than 40°C). This analysis was provided as a case study in the latest NATO Climate Change and Security Impact Assessment [source: [link](#)], as a quantitative analysis informing the military operational capability of rotary-wing aircraft. Higher temperatures result in decreased air densities, which in turn reduce the lift capacity of these aircraft. As a result, operations involving these aircraft are affected when considering the platform standards relative to critical temperature thresholds.

The analysis focused on a specific geographic region (Middle East and North Africa, or MENA) motivated by the ongoing NATO Mission Iraq (a non-combat, advisory and capacity-building mission in the region). CMRE scientists determined that regional climate models with bias correction were required to inform an accurate picture of the estimated number of hot days projecting to 2050.



A schematic showing the effect of including bias correction (quartile mapping, or QM, red-dashed curve) on translating the temperature distribution of the original model (blue curve) relative to the real-world observations (black curve). Including bias correction successfully narrows the distribution of temperatures corresponding to the daily maximum temperature using the ERA5 dataset. (Source: CMRE Workshop Presentation)



The application of the bias-corrected models employed by the CMRE for analyzing the number of hot days in the MENA region. The various panels show the frequency of hot days as a density plot over successive time horizons, using the SSP5-8.5 scenario. (Source)

3.2. Structuring Climate Data

Effective use of climate data depends on its format, which governs how data can be accessed, queried, and analysed. The most common formats in climate science are NetCDF (Network Common Data Form) and **GRIB** (GRIdded Binary), each offering distinct benefits:

- **NetCDF** is widely used to store multi-dimensional gridded data (e.g., temperature over time, space, and altitude). It supports:
 - Detailed metadata embedding
 - Efficient slicing across time or space dimensions
 - Compatibility with computer programming tools (Python, R, MATLAB, etc.)
- GRIB is a binary format developed by the World Meteorological Organization, optimised for operational meteorological data (e.g., forecasts). It is highly compact and efficient for real-time applications but less accessible for custom analysis without specialised libraries.

With these formats, analysts can extract “slices” of **data** (e.g., temperature in Bahrain from 2030–2050) or “**layers**” (e.g., 2-metre temperature across Europe on a specific day) for use in spatial mapping or time-series analyses.

What is NetCDF and Why Is It Useful?

NetCDF stands for Network Common Data Form. It's a special kind of file used to store complex climate and environmental data - like temperature, rainfall, sea level, or wind - across space and time. Imagine a global weather map, but instead of just one snapshot, it stores thousands (or millions) of snapshots for different places and times in one organized file. Think of the Earth as a Grid. Imagine wrapping the Earth in a giant net or mesh made of small square cubes (like a 3-D chessboard). Each cube (or grid cell) represents a tiny area of the Earth's volume, identified by its latitude, longitude and altitude. Now, imagine storing a number in each box to represent something like the temperature in that place at a certain time. Do this for every hour, day, or month - and you start to get a picture of how NetCDF files work.

What's Inside a NetCDF File?

NetCDF files are like digital filing cabinets that contain:

- Dimensions - These define the shape of the data (for example, how many latitudes, longitudes, and time points there are).
- Coordinates - These say exactly where and when each data point is.
- Variables - These are the actual measurements, like temperature or rainfall.
- Attributes - These are notes or labels that describe what's in the file (e.g. "These data came from a satellite" or "These data were last updated in 2024").

So, instead of one spreadsheet for temperature and another for rainfall, NetCDF stores everything in one place, in a format that software tools can easily read.

Why Is It Powerful?

NetCDF allows scientists (and computers) to quickly pull out a slice of data programmatically, e.g.:

- All temperatures over Canada in January 2025.
- One spot in the ocean over the last 50 years.
- A global snapshot of precipitation on a specific day.

This makes NetCDF ideal for climate modelling, forecasting, and research.

How Is It Used?

NetCDF files can be opened and analysed using tools like:

- Python or R for programming
- Excel or MATLAB for analysis
- GIS software like ArcGIS for mapping
- Panoply or IDV for visualizing

These tools help turn the complex raw data in NetCDF files into maps, graphs, and insights.

Metadata and Homogenization: Ensuring Data Quality and Integrity

Metadata represents the contextual information about how data were collected and processed, and is essential for transparency, repeatability, and quality control. The general principles of robust and usable metadata apply to ensure climate security data quality and integrity.

High-quality metadata enables:

- Identification of data collection methods, for example:
- For *climate data* sources: satellite collection, direct measurements;
- For *security data* sources: survey collection, inferred indicators from governments;
- Correction for known errors or changes in observation procedures;
- Documentation of fundamental properties, for example:
- For *climate data*: information on spatial resolution, time steps, parameter definitions;
- For *security data*: information on survey sample sizes, geographic/date properties.

Workshop participants emphasised the need for homogenization – that is, a consistency in data collection and reporting – which is borne out by what is reported in the metadata. For example:

- Weather stations may relocate over time or upgrade their equipment;
- Observational gaps and inconsistencies may exist due to political or logistical factors;
- Household survey data may be outdated or not relevant due to inadequate collection methods;
- Different analyses may rely on different sources for food/health/economic security indicators.

For the *climate data*, uncorrected variations can create spurious trends or inconsistencies in historical baselines used for bias correction or scenario validation.

For the *security data*, inconsistencies in collection efforts can lead to systemic biases and incorrect baselines used for follow-on analyses.

3.3. Data Transformation and Quality Control of Security Data

The development and application of security data is a necessarily subjective exercise, as ground truth observations will always be complicated by local contexts, research methods and ultimately the current, in-vogue paradigms used for analysis. Nonetheless, empirical methods have their place in informing decision-makers with quantifiable data that can be used for evidenced-based decision making.

One main theme in the workshop discussions was surrounding the novelty of these methods in the burgeoning domain of climate security. Accordingly, it falls to analysts and experts to discuss and develop principles to ensure robust development of new, or application of existing security data, such as indicators and indices like those presented in Section 2.2.3. The workshop covered the following non-exhaustive list of assumptions often used when applying security data:

- **Interpolation:** Indicators for specific geographic regions (e.g., countries) are often assumed to be constant or applicable across subdivisional levels (e.g., counties, municipalities) without the fine-grained data actually collected
- **Aggregation:** Combining separate indicators (e.g., food scarcity with health access) requires a choice of relative weightings and a choice of how to average different quantities (e.g., arithmetic vs geometric mean)
- **Transformation:** The choice of scale can dampen or exaggerate differences between different data coming from the same set (e.g., along geographic regions or different populations)
- **Truncation:** Removing outliers can be arbitrary, for example including (or not) climate data from extreme weather events, or including (or not) conflict events deemed irrelevant to the security metrics used

- **Normalization:** Combining different kinds of metrics, like climate-based (precipitation levels) with security-based (drought indicators) necessitates choices in how to scale the disparate quantities onto a similar scale (e.g., ordinal scores)
- **Sampling:** Indices built on models often are trained against reference sets, and there can be inconsistencies in the validity or applicability of that data (e.g., conflict event data)
- **Benchmarking:** The impossibility of generating gold-standard data everywhere (geographically) and with consensus (expert review) leads to serious challenges in validation and verification
- **Cascade of assumptions:** The non-exhaustive list of assumptions above all must be incorporated behind the scenes, and the accumulation of each of these presents its own important assumption as standard approaches do not accumulate uncertainty systematically

While many of these assumptions are technical and under the purview of the developers of security data indicators and indices, these proceedings highlight this list in order to underscore the choices and nuances underpinning these kinds of security data. Where possible, harmonizing efforts should be encouraged in the community: for example, by determining common assumptions around subsets of security data which overlap in common areas, and through systematic multi-researcher validation efforts. Increased transparency can ensure robust and trusted security data, and research programs can complement similar efforts from the climate data community, particularly with the development of industry-standard climate models.

What is an Index for Climate Security?

Climate security indices attempt to assign scores, ranks or measures to describe a combined climate and security risk. The goal of constructing such indices is to provide decision-makers and policy-makers with a quantitative indication of how the compound climate and security risks vary across different regions, nations or broader multinational groupings.

One common framework used to define the combined climate and security risk is the formulation developed in the IPCC AR6 report ([Source](#)) as shown in the schematic below. Climatic drivers (i.e., the effects of climate change) impact or amplify hazards which contribute to an overall risk, mediated by community vulnerability, population exposure and societal response mechanisms.



What information is included in climate security indices?

Information from both *climate data* and *security data* is usually incorporated into climate security indices. Quantities from the former can include risks associated with extreme weather events, or forecasts of other physical indicators. The latter contributions can include conflict data as well as indicators describing food security, health security or other socioeconomic data.

What is important to keep in mind when using climate security indices?

These indices are by construction arbitrary: that is, there is no ground truth quantity that can perfectly describe the complex risks associated with climate change and security. Therefore, any developed scores should be scrutinized for their validation protocols, interrogated for their comparisons to other similar indices and researched for their uptake and reception in the academic community. Special attention should be paid to efforts made to project or forecast from these quantities.

Examples of climate security indices

The workshop discussed two main examples of climate security indices: the NATO Risk Management Framework (follow the [NATO topic page for updates](#)) and the Climate Conflict Vulnerability Index ([Source](#)).

Conclusion: Transparency Builds Confidence

Getting climate data into a usable form is a technical task, but how we do it matters just as much as what we do. The workshop highlighted the importance of making data processing steps visible and understandable. When approaches for cleaning, correcting, and formatting data are clearly explained and openly shared, it helps others trust the results, test the assumptions, and reuse the work effectively. Encouraging this openness across the climate-security community will make it easier to collaborate, spot inconsistencies early, and reduce duplication.

4. Interpretation: Analytical Approaches and Methodologies

Once climate data have been generated, processed, and quality-controlled, it must be interpreted, that is, transformed into insight to support decision-making. This interpretive phase involves selecting and applying analytical methods that are not only technically sound but also appropriate for the specific context of defence and security planning. Workshop discussions made clear that no single methodology is sufficient. Instead, a pluralistic, problem-driven approach is required, one that combines quantitative and qualitative rigour systems with scenario imagination and strategic relevance.

This section of the report is organised around four broad methodological families used across NATO and partner institutions:. Each is illustrated with examples from the workshop to highlight their application, strengths, and limitations.

- Section 4.1: Quantitative Methods
- Section 4.2: Qualitative Methods
- Section 4.3: Mixed Methods
- Section 4.4: Case-based Modelling

4.1. Quantitative Methods

Quantitative methods support NATO's ability to interpret complex climate security data and inform strategic decisions in a structured, reproducible way.

- **Ensemble Modelling (e.g., CMIP6):** Multi-model ensembles capture a range of plausible climate futures based on different emissions pathways (see Section 2.1.5). These ensembles provide both central estimates (e.g., median temperature change) and variability bounds. For example, temperature projections in the Mediterranean under SSP5-8.5 have been used to define potential thresholds for operational heat stress risks.
- **Statistical Downscaling:** Because global models typically operate at coarse resolutions, downscaling techniques, ranging from simple linear regression to more complex machine learning algorithms, translate large-scale model outputs into locally relevant information. This is essential for assessing infrastructure resilience or base-level impacts in specific geographies.
- **Extreme Value Analysis:** This method focuses on understanding the frequency and magnitude of rare but severe events, such as floods, heatwaves, and extreme wind, using long-term observational data. These analyses are critical for identifying climate thresholds that could affect operational capability or force readiness.
- **Interpreting Uncertainty:** Uncertainty is an inherent part of climate analysis, especially when projecting decades into the future. NATO's climate-security community increasingly draws on conventions from the IPCC to express uncertainty in a way that is transparent and decision-relevant. This includes the use of:
 - **Confidence levels** based on evidence and expert agreement (e.g., medium confidence in projected sea level rise at regional scales); and
 - **Likelihood terms** that express the probability of an outcome (e.g., very likely that heat extremes will become more frequent under high-emissions scenarios).

These methods allow analysts to articulate not only what might happen, but how confident we are in those outcomes. Figure 8 demonstrates the latest recommendations from the IPCC AR6 for conveying this kind of uncertainty, using colours and patterns.⁸ Still, the effectiveness of these approaches depends on input data quality, model structure, and the nature of the climate variable under consideration – especially in data-scarce regions or where human factors interact with environmental trends.

Cross-Chapter Box Atlas.1, Table 1 | Approaches for representing robustness (uncertainty) in maps of observed (approach A) and projected (approaches B and C) climate changes.

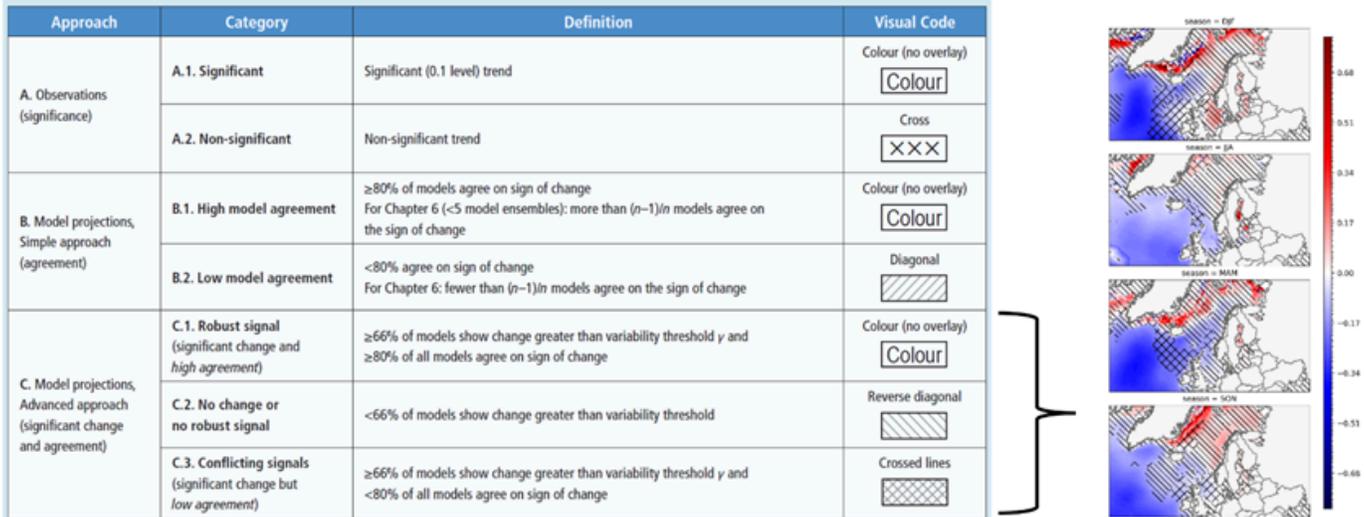


Figure 10. Approaches adopted by the IPCC Sixth Assessment Report ([Source](#))

⁸These techniques have yet to be widely adopted in the quantitative visualizations presented by the NATO community in their climate science analysis (e.g., the climate security impact assessment reports), but future reporting should begin to incorporate these latest IPCC recommendations wherever possible.

4.2. Qualitative Methods

Qualitative approaches are essential for understanding complex systems where data are sparse, contested, or inherently uncertain. These methods are particularly useful in foresight, conceptual modelling, and participatory scenario development. Key approaches discussed at the workshop included:

- **Systems Thinking and Causal Loop Diagrams (CLDs):** Used to visualise and diagnose interdependencies between climate variables and security outcomes (e.g., infrastructure degradation leading to readiness degradation and increased geopolitical risk). For example, NATO’s foresight teams and TNO use CLDs to inform strategic gaming exercises and early warning indicators.

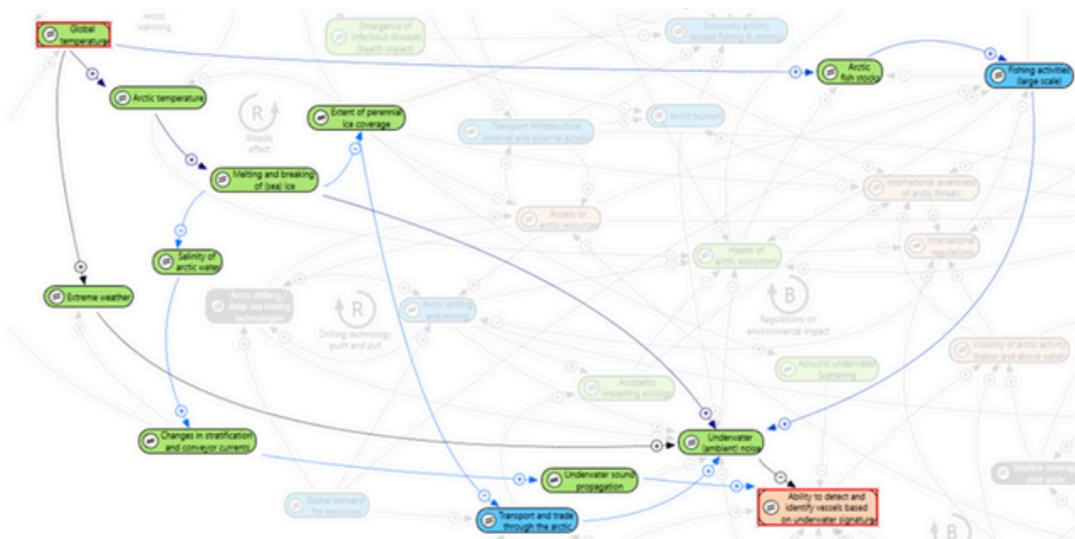


Figure 11. Effects (Source: TNO Workshop Presentation)

- **Strategic Foresight (VISTA):** A methodology used by TNO to develop exploratory scenarios incorporating both climate trends and sociopolitical developments. VISTA allows analysts to explore multiple plausible futures and stress-test strategies against a range of uncertainties.
- **Qualitative Wargaming:** TNO, Dstl and NATO have used facilitated games to explore how climate shocks (e.g., Arctic base isolation or regional heatwaves) could cascade through NATO command and control structures. These games surface institutional blind spots, decision bottlenecks, and adaptive capacity.

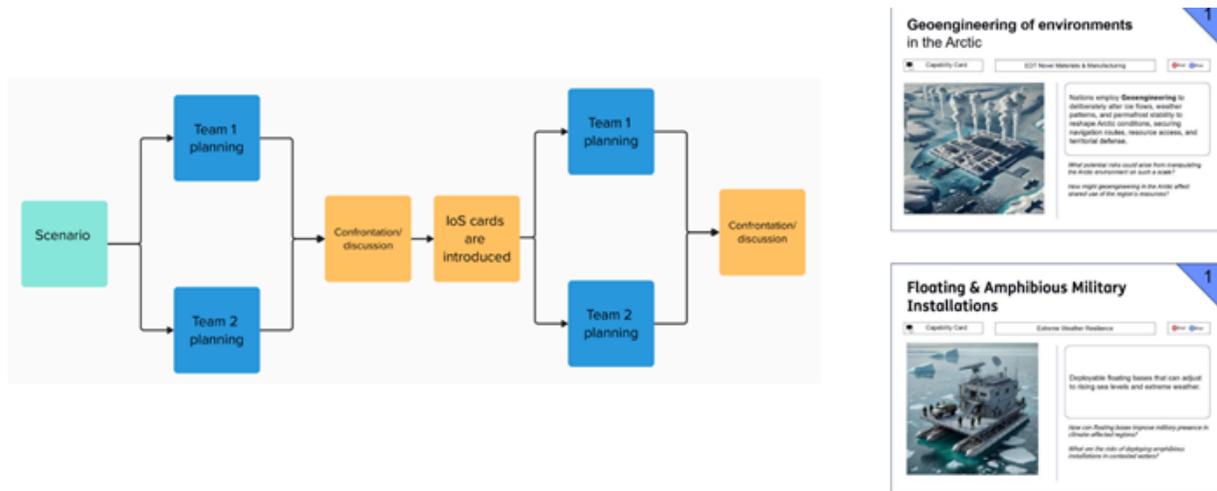


Figure 12. DTAG [Source: TNO Workshop Presentation]

- **Expert Elicitation and Structured Judgment:** Useful where data are unavailable or inadequate. This includes structured interviews, Delphi techniques, and prompt-based generative analysis, such as using LLMs to explore policy scenarios.

The strength of qualitative methods lies in their ability to reveal complexity, facilitate dialogue, and uncover hidden assumptions. However, they are sometimes seen as less rigorous or reproducible, underscoring the need for transparency.

4.3. Mixed Methods

The most effective climate–security analyses increasingly combine both quantitative and qualitative tools - an approach described throughout the workshop as essential to navigating uncertainty and complexity.

Mixed-method approaches allow users to model physical variables with high fidelity while integrating geopolitical, institutional, and behavioural dimensions that are not easily quantified. For instance, a scenario tool might start with CMIP6-derived temperature projections (quantitative), incorporate institutional capacity ratings (qualitative), and feed both into an impact matrix to support NATO resilience assessments.

TNO’s MACCID framework (Mapping the Adaptation Capability Chain to Climate Impact Domains) was cited as a successful example. It uses quantitative stressor profiles (e.g., thermal thresholds) and links them to qualitative capability domains (e.g., deployability, sustainment), producing actionable insights for defence planners.

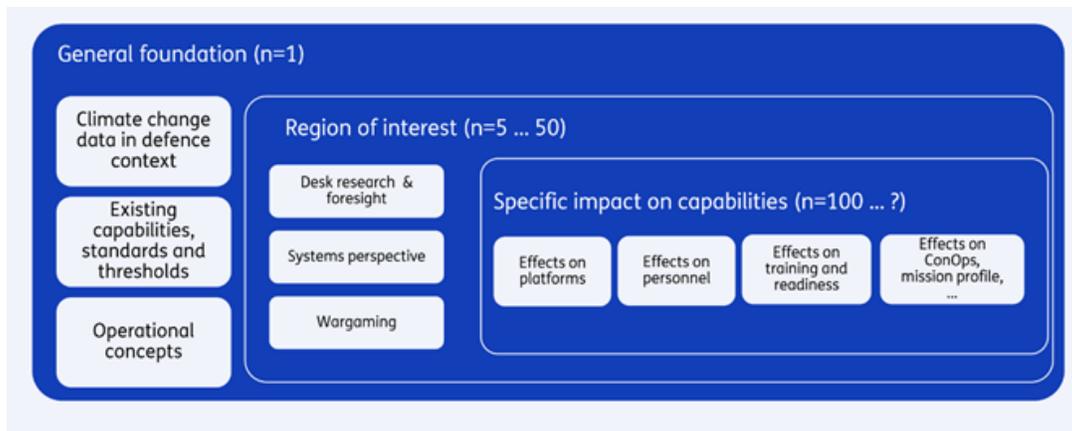


Figure 13. MACCID

Mixed methods also help to ground high-level projections in operational reality. By combining the statistical validity of models with the contextual nuance of human judgment, NATO can make better-informed decisions under conditions of uncertainty.

4.4. Case-based Modelling

Common examples from the workshop sessions and in the Expert Brief session illustrated the importance of place-based or case-based modelling: the development of analytical frameworks tailored to specific geographic, operational, or strategic contexts.

Key examples included:

- **Sigonella Air Base (NATO):** Used as a pilot site to model future “black flag” days (i.e., when heat conditions are unsafe for outdoor physical activity) under different warming scenarios. The results were used to test platform heat resilience, personnel endurance, and the performance of systems.
- **Arctic Sonar and Ice Melt (CMRE):** High-resolution reanalysis data combined with regional models to understand sonar signal propagation changes due to freshwater intrusion and sea ice reduction. This work directly informs undersea surveillance and maritime situational awareness.
- **Urban Flash Flooding in Northern Europe (FFI):** Leveraged CMIP6 ensemble outputs with historical impact data and urban drainage models to assess near-future risk to critical infrastructure.

Case-based approaches have high operational relevance, making them ideal for developing illustrative examples.

Conclusion: Embracing Analytical Pluralism

The interpretation of climate data in defence contexts demands an analytical pluralism: a deliberate combination of methods, guided by the problem at hand rather than disciplinary orthodoxy. The workshop emphasized that analysts should not be forced to choose between rigour and relevance, between data and judgment. Instead, NATO must build capacity for methodological integration, ensure clear documentation of assumptions, and share best practices from mixed method analyses.

5. Application: Translating Data into Defence Strategy and Practice

The ultimate purpose of climate data analysis is to enable informed adaptation. While the preceding stages in the climate security data lifecycle focus on creating, processing, and interpreting information, this phase – application – is where insight becomes impact. The workshop was restricted to unclassified examples; however, the varied and rich examples presented in the main sessions and in the Expert Brief Session demonstrated how climate security information is being used, and helped to direct attention to what still needs to be done.

This section is structured to follow the ways in which climate security data and analysis were discussed through example of operationalisation across five key defence domains:

- Section 5.1: Operations
- Section 5.2: Capabilities
- Section 5.3: Infrastructure
- Section 5.4: Early Warning Systems
- Section 5.5: Strategic Decision Support

5.1. Operations

Operational environments are already being altered by climate change. Workshop participants highlighted how heat stress, flooding, sea state changes, and extreme weather are already degrading mission readiness and reliability.

A key example was the use of CMIP6 ensemble projections to model “black flag days” at Sigonella Air Base. This analysis identified days when conditions exceeded safe thresholds for outdoor physical activity and training. These projections, refined through bias correction and downscaling, revealed a potential doubling or tripling of black flag days by 2050 under high emissions scenarios. The implications are profound: disrupted training schedules, reduced deployment capacity, and the need to reassess base-level health and safety protocols.

In maritime contexts, sea state and ice melt data from CMRE and reanalysis products are informing submarine and surface fleet operations, particularly in the Arctic, where sonar performance and transit windows are increasingly sensitive to freshwater layering and ice cover changes.

These examples show how forecast-informed planning, risk maps, and scenario-based stress testing are becoming essential tools for maintaining operational resilience under climate stress.

5.2. Capabilities

Climate change is expected to push defence platforms and systems beyond their design tolerances. Extreme heat, humidity, dust, and precipitation are affecting platform functionality, increasing wear and tear, and compromising mission effectiveness.

Dstl shared an unclassified example analysis of climate exposure thresholds and vulnerability assessments of specific UK capability platforms. By mapping temperature projections against known performance specifications it identified limitations (e.g. overheating of vehicle systems or degraded avionics at high wet-bulb temperatures), and projected when and where certain capabilities may no longer be viable without adaptation.⁹

Importantly, this kind of assessment goes beyond theoretical vulnerability: it supports procurement strategy, informs platform adaptation planning, and helps prioritise investment in resilient and climate-hardened technologies.

Workshop participants also noted that capability assessments need to be forward-looking – using projected and predictive data to inform design specifications for next-generation systems, rather than retrofitting legacy platforms after failure.

⁹A key point here is ‘without adaptation’ – it refers to the platform vulnerabilities without accounting for capability upgrades and technological innovation.

5.3. Infrastructure

Military installations, both fixed and deployed, face acute risks from sea-level rise, flooding, wildfires, and heatwaves. Several case studies discussed during the workshop addressed the vulnerabilities of fixed infrastructure and the need for risk-informed site management:

- Naval Station Norfolk, the largest naval base in the world, is already experiencing recurrent tidal flooding, posing threats to logistics, power supply, and force generation.
- Sigonella was again cited for its temperature envelope analysis, which also examined runway integrity and heat-driven equipment malfunction.

Using high-resolution regional climate models (e.g. CORDEX), combined with engineering specifications and GIS-based risk mapping, analysts can now identify “hotspots” for climate adaptation investments - reinforcing the resilience of barracks, runways, depots, and critical energy infrastructure.

Some participants proposed integrating climate risk into military infrastructure lifecycle assessments, making climate-informed design a baseline standard rather than a future add-on.

5.4. Early Warning Systems

Preventing, mitigating, and responding to climate-related crises requires anticipatory tools that fuse climate data with geopolitical, social, and economic indicators. A hazard only becomes a disaster when it intersects with human populations or vulnerable systems, turning potential threats into real-world impacts.

The workshop showcased several operational tools designed to support early warning functions¹⁰:

- DisasterAWARE – A global multi-hazard early warning system that integrates climate data with real-time alerts for natural disasters. Its modular dashboards are used by civil protection agencies and defence planners.
- CESDA Hub (Climate, Environment, and Security Data Analytics) – Developed by SatCen and partners, this platform aggregates climate indicators (e.g. precipitation anomalies, vegetation stress), socioeconomic vulnerability metrics, and conflict indicators to provide tailored warning products for defence users.

Such tools are not just for situational awareness; they support contingency planning, inform humanitarian deployments, and can trigger pre-positioning of assets in anticipation of climate-linked instability.

¹⁰The definition of early warning systems is different between the humanitarian sector and the disaster risk community. Here, it is used to refer to integrated frameworks that detect, monitor, and communicate potential climate-related hazards in advance, enabling timely actions that reduce exposure, vulnerability, and potential impacts on people and systems.

5.5. *Decision Support*

Strategic decisions, from force posture to long-term investment planning, must increasingly be climate-informed. A variety of tools and methods are being used to support decision-making in defence contexts:

- Scenario tools and foresight methods (e.g. VISTA) help planners explore multiple plausible climate futures and stress-test plans.
- AI-enabled decision support platforms (e.g. CESDA's use of large language models and prompt engineering) provide rapid synthesis of open-source climate-security intelligence.
- Wargaming applications – A growing number of allies are embedding climate scenarios into red-blue-green team exercises to explore cascading effects on command decisions, logistics chains, and alliance cohesion.
- Standard-setting initiatives – NATO's Climate Security Impact Assessment is being used to define shared risk assumptions, emissions scenarios, and baseline datasets that align diverse national efforts.

These tools are beginning to influence procurement strategies (e.g. environment-driven platform specifications), doctrine development, and to build alliances through data share agreements with civilian science and foresight partners.

Conclusion: Bridging Insight and Action

The workshop made it clear that climate-informed planning is happening – albeit unevenly. Mainstreaming climate security data into all levels of defence decision-making requires better integration, clearer standards, and sustained collaboration across scientific, operational, and strategic communities. The use of these tools and the application of these approaches still require a considered and careful examination of the data and methods underlying, as the Sections 2 and 3 described. Yet, as these applications show, the payoff is significant: a more resilient, adaptive, and forward-looking Alliance, equipped to operate in a climate-altered world.

6. Feedback: Lessons Learned and Systemic Challenges

Throughout the workshop, participants identified not only promising tools and methods, but also a shared set of challenges and structural barriers that currently limit the full integration of climate security data into defence analysis and planning. These systemic issues must be addressed to strengthen NATO's climate-security posture and to advance a more coherent, interoperable, and action-oriented approach.

This section synthesises the key lessons learned across sessions, focusing on challenges related to:

- Section 6.1: Data Accessibility, Interoperability, and Validation
- Section 6.2: Methodology
- Section 6.3: Usability
- Section 6.4: Epistemological Interoperability

6.1. Data Accessibility, Interoperability, and Validation

Despite the proliferation of climate datasets, access remains uneven and inconsistent, particularly across national and institutional boundaries. Several participants noted that while high-quality global datasets like ERA5 and CMIP6 are publicly available, downscaled or validated regional datasets are often locked behind paywalls, national firewalls, or bespoke data agreements. This creates significant disparities in what different NATO actors can access and apply.

Moreover, data interoperability remains a concern. Different institutions use incompatible formats, naming conventions, temporal resolutions, and spatial baselines, making it difficult to compare or integrate datasets.

Validation itself is often underdeveloped. There is no universally adopted standard for validating climate security tools - whether a dashboard, an index, or a modelled scenario. Without agreed benchmarks or performance metrics, there is a risk that different tools may yield contradictory results without a clear basis for comparison or adjudication.

The workshop highlighted the need for a shared verification and validation framework within NATO that balances methodological flexibility with a minimally viable consensus set of quality standards.

6.2. Methodology

A consistent theme was the siloing of expertise and the persistence of tribal axioms. Climate scientists, defence analysts, foresight practitioners, modellers, and policy strategists often work in isolation from one another. This limits mutual understanding and reduces the opportunity to embrace quality insights that can be generated from interdisciplinary approaches.

For example, quantitative analysts may produce highly detailed models that are methodologically rigorous but conceptually narrow, missing broader sociopolitical dynamics. Conversely, qualitative foresight teams may develop rich scenarios that are narratively compelling but analytically ungrounded in climate data. The challenge, then, within climate security analysis is to integrate the two, too-often disparate approaches to enable a constructive and meaningful research program, developing a truly inter-disciplinary field.

Mixed-method approaches were widely endorsed as a solution, but they are still underutilised in practice. Barriers include differences in terminology, epistemological assumptions, and institutional culture. As one expert from a research agency put it: “That is, we need to build translation mechanisms between disciplines - people who are fluent in both climate statistics and operational planning.”

Several participants advocated for the creation of dedicated interdisciplinary workshops, training programs, and methodological guides that facilitate structured dialogue to support the co-development of integrated tools.

6.3. Usability

Different decision-makers—planners, military practitioners, analysts, policymakers—have different thresholds for evidence, complexity, and uncertainty tolerance. What is “credible” to a climatologist may be unintelligible to an operations planner; what is “usable” for a battalion commander may be too coarse or speculative for strategic resource allocation.

This creates a tension between scientific rigour and operational usability. Tools that are overly complex or opaque risk being ignored; tools that oversimplify may mislead. The workshop emphasized the need to design tools and outputs with the end-user in mind, incorporating principles from user-centered design, data storytelling, and risk communication.

Participants suggested developing tiered products (e.g., an executive dashboard for leadership, a scenario model for planners, and a technical annex for analysts) all derived from the same core datasets and analytical logic. This multi-layered approach can help bridge the gap between complexity and comprehension.

6.4. *The Complexity of Climate–Conflict Causality and Philosophical Paradigms*

One of the most intellectually challenging areas of discussion was the causal relationship between climate change conflict and (in)securities. Participants stressed that while climate is an amplifier of security risks, it is rarely a sole or proximate cause. Instead, it interacts with governance quality, socioeconomic inequality, state capacity, and identity politics in complex, often nonlinear ways.

This recognition challenges simplistic modelling approaches that assume direct, mechanistic causality. It also calls into question the philosophical assumptions behind different analytical methods. For instance:

- Systems dynamics sees causality as circular and emergent.
- Statistical modelling seeks probabilistic associations.
- Foresight and wargaming embrace deep uncertainty and narrative logic.

Each paradigm has value, but they imply different standards of evidence, validation, and decision utility.

Participants agreed on the need for greater methodological humility, transparency about assumptions, and careful framing of climate–security insights. Analysts must not only ask “What do the data say?” but also “What assumptions are we embedding in the way we interpret and apply data?”

Conclusion: Confronting the Barriers to Climate-Ready Defence Analysis

The path toward effective climate-security analysis within NATO is constrained not only by data or technical capacity but by systemic, institutional, and epistemological challenges.

Addressing these requires:

- Shared standards for data validation and interoperability;
- Structural incentives for interdisciplinary work;
- Investment in user-centred design of decision tools;
- Critical reflection on the assumptions behind our methods.

These challenges are not insurmountable, but neither are they easy. They must be purposely acknowledge explicitly and addressed collaboratively. The feedback gathered through this workshop represents a collective recognition of what must change for NATO to fully leverage climate security data in service of mission relevance, readiness and resilience.

7. Iteration: Building a Common NATO Climate Security Data Approach

Climate informed defence planning is not a one-time task but a continuous, adaptive process. As both the climate system and the security landscape evolve, so too must the frameworks, tools, and partnerships that NATO uses to assess risk and guide action. The workshop concluded with a strong consensus: NATO requires a living, iterative climate security data process that institutionalises best practices, fosters interdisciplinary collaboration, and ultimately leads to actionable insights that supports decision-makers at all levels.

This section outlines the initial building blocks of such an approach, drawing on workshop insights and participant recommendations. It is structured using four thematic insights:

- Section 7.1: Common Frameworks
- Section 7.2: Guidance Documents
- Section 7.3: Capacity Building
- Section 7.4: Collaborative Platforms

7.1. Common Frameworks: Shared Assumptions, Scenarios, and Standards

Participants emphasized the need for NATO to adopt common reference points to ensure coherence across national and institutional analyses. These include:

- **Baseline Scenarios:** Agreed-upon climate futures based on CMIP6 SSPs (e.g., SSP2-4.5 and SSP5-8.5) to anchor risk assessments.
- **Reference Time Horizons:** Common time windows (e.g., 2035, 2050, 2080) to support comparative analysis and capability development.
- **Shared Geographic Focus Areas:** Standard regions of interest (e.g., Arctic, Sahel, Mediterranean) to concentrate data processing and scenario work.
- **Climate Security Indicators:** A NATO-wide index or suite of indicators drawing from tools like the NATO RMF methodology, the CCVI and SatCen dashboards.

These shared assumptions will not limit creativity or national autonomy, but provide a coordinated starting point: a scaffold for collective analysis.

7.2. Guidance Documents: Codifying Best Practices

To translate workshop insights into institutional practice, it was recommended that NATO must produce and maintain a set of climate security guidance documents. Participants recommended the creation of:

- **A Climate Data Compendium:** Detailing approved datasets, bias correction protocols, and quality standards.
- **A Methodology Handbook:** Offering templates for mixed-method assessments, including case studies and tool selection criteria.
- **An “Aqua Book” for Climate Tools:** Inspired by HM Treasury's guide for modelling, this would define validation principles for climate security dashboards, indices, and scenario platforms.

Such guidance would enhance analytical credibility, consistency, and transparency, and support training and evaluation efforts across the Alliance.

7.3. Capacity Building: Training, Exchanges, and Communities of Practice

Human capacity is as critical as technical infrastructure. The workshop highlighted several avenues for strengthening climate data capabilities:

- NATO Short Courses and Fellowships: Programs like a CCASCOE Short Course, collaborative Climate Security Training Courses and exploration to develop initiatives linked to Nato Defence College and Nato School Oberammergau should include climate security analytics.
- Academic and Scientific Exchange: Bilateral and multilateral placements, especially among NATO research centres (e.g., CMRE, Dstl, TNO), can promote cross-pollination of methods and accelerate innovation.
- Communities of Practice: Online and in-person platforms to sustain practitioner networks, share use cases, and support peer review of tools and models.

The goal would be to normalise climate analysis as a defence skillset, not a niche specialism.

7.4. Collaborative Platforms: Digital and Institutional Hubs

Several existing tools and organisations offer strong foundations for a networked, iterative climate data architecture. These include:

- CMRE: Cloud Platform for Verified and Validate Climate Data. A potential backbone platform for hosting validated data layers, running scenario engines, and sharing analysis products across NATO entities.
- CCASCOE: Positioned to act as a curator of methods, supporting standardisation, cross-validation, and methodological innovation.
- Federally funded allied research organisations and meteorological centres: Anchors for scientific validation and operationalisation, linking theory to real-world defence contexts.
- NATO HQ: Strategic leadership and political endorsement of the climate security agenda.

Together, this would support a distributed but coordinated framework, ensuring that insights developed in La Spezia, Montreal, Brussels or other locations are accessible, comparable, and actionable across the Alliance.

8. Conclusion: Future-Proofing Allied Defence with Data

The Climate Data and Analysis Workshop held in La Spezia brought together a diverse and highly qualified group of practitioners, scientists, strategists, and analysts to begin longer, deeper conversations on the development and application of climate security data.

The insights captured in these proceedings form the foundation for a more coherent and impactful NATO climate data analysis process and roadmap. But insights are only as valuable as the actions they enable.

To future-proof Allied defence in an era of climate disruption, NATO must embed climate data and analysis throughout the defence enterprise, from early warning to strategic foresight, from platform procurement to infrastructure design, from operational planning to alliance cohesion.

This requires continued investment in:

- Validated, accessible, and interoperable datasets for both climate data and security data;
- Mixed-method analytical tools that embrace complexity;
- Cross-disciplinary communities of practice;
- Training, guidance, and governance mechanisms to mainstream it into defence strategy

The convening of this workshop, the publication of these proceedings and the follow-on conversations inspired to date have all indicated a strong appetite in shaping the best practices for climate data and analysis across the Alliance. Future events and engagements will build on these lessons to continue to inform defence analysis best practices in this ever-burgenoning field of research.

Whilst we can not respond to all enquires, we welcome hearing your views and contributions to the discussion. You can engage with the conversation by following the CCASCOE LinkedIn Page. In October, we intend to launch a community of practice and hold a second workshop in late 2025 to make progress in these areas.

Outcome

The primary outcome of this workshop is the establishment of a core community of practice, bringing together experts from across disciplines to collaborate on integrating climate data into defence planning. This emerging network, alongside the identification of priority areas for action, lays the groundwork for a NATO-specific roadmap and standards to support climate-informed decision-making across the Alliance.

The organisers of the Climate Data Analysis Workshop would like to extend their sincere thanks to all those who contributed to the success of this event.



CCASCOE
NATO Climate Change
and Security Centre
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TNO innovation
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Annex A: Acronyms

Acronym	Full Term		
BC	Bias Correction	HQ	Headquarters
CCASCOE	NATO Climate Change and Security Centre of Excellence	IDV	Integrated Data Viewer
CARRA	Copernicus Arctic Regional Reanalysis	MACCID	Mapping the Adaptation Capability Chain to Climate Impact Domains
CESDA	Climate, Environment, and Security Data Analytics	ML	Machine Learning
CLD	Causal Loop Diagram	NATO	North Atlantic Treaty Organization
CMIP	Coupled Model Intercomparison Project	NetCDF	Network Common Data Form
CMRE	NATO Centre for Maritime Research and Experimentation	NCL	NCAR Command Language
CORDEX	Coordinated Regional Downscaling Experiment	ORA5	Ocean ReAnalysis version 5
Dstl	Defence Science and Technology Laboratory (UK)	RCM	Regional Climate Model
ECCC	Environment and Climate Change Canada	SatCen	European Union Satellite Centre
ECMWF	European Centre for Medium-Range Weather Forecasts	SHAPE	Supreme Headquarters Allied Powers Europe
ENSO	El Niño–Southern Oscillation	S2S	Sub-seasonal to Seasonal Forecasting
GAM	Generalized Additive Model	SSP	Shared Socioeconomic Pathway
GIS	Geographic Information Systems	TIN	Triangulated Irregular Network
GCM	Global Climate Model	TNO	Netherlands Organisation for Applied Scientific Research
GRIB	GRIdded Binary	UQ	Uncertainty Quantification
		WMO	World Meteorological Organization

Annex B: Useful Resources

Climate Datasets & Modelling Frameworks

- ERA5 Reanalysis (ECMWF)

<https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5>

- CARRA – Copernicus Arctic Regional Reanalysis

<https://climate.copernicus.eu/copernicus-arctic-regional-reanalysis-service>

- ORA5 – Ocean ReAnalysis

<https://www.ecmwf.int/en/about/media-centre/news/2023/ecmwfs-new-ocean-reanalysis-dataset-ora5-now-available>

- CMIP6 – Coupled Model Intercomparison Project Phase 6

<https://esgf-node.llnl.gov/projects/cmip6/>

- CORDEX – Coordinated Regional Downscaling Experiment

<https://cordex.org/>

- Environment and Climate Change Canada – Climate Prediction Systems

<https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/climate-models.html>

- WMO Global Producing Centres for Long-Range Forecasts

<https://www.wmolc.org/>

Institutions and Centres

- NATO Climate Change and Security Centre of Excellence (CCASCOE)

<https://www.ccascoe.org>

- NATO Centre for Maritime Research and Experimentation (CMRE)

<https://www.cmre.nato.int/>

- Defence Science and Technology Laboratory (Dstl)

<https://www.gov.uk/government/organisations/defence-science-and-technology-laboratory>

- European Union Satellite Centre (SatCen)

<https://www.satcen.europa.eu/>

- European Centre for Medium-Range Weather Forecasts (ECMWF)

<https://www.ecmwf.int/>

- Netherlands Organisation for Applied Scientific Research (TNO)

<https://www.tno.nl/en/>

- World Meteorological Organization (WMO)

<https://public.wmo.int/en>

Analytical & Visualization Tools

- Climate Data Operators (CDO)

<https://code.mpimet.mpg.de/projects/cdo>

- Panoply – NetCDF Viewer (NASA)

<https://www.giss.nasa.gov/tools/panoply/>

- NCAR Command Language (NCL)

<https://www.ncl.ucar.edu/>

- GrADS – Grid Analysis and Display System

<http://cola.gmu.edu/grads/>

- Ferret (NOAA)

<https://ferret.pmel.noaa.gov/Ferret/>

- Integrated Data Viewer (IDV – Unidata)

<https://www.unidata.ucar.edu/software/idv/>

- ArcGIS (ESRI)

<https://www.esri.com/en-us/arcgis/about-arcgis/overview>

- R – Project for Statistical Computing

<https://www.r-project.org/>

- MATLAB – MathWorks

<https://www.mathworks.com/products/matlab.html>

Indices, Platforms, and Dashboards

- DisasterAWARE – Multi-Hazard Early Warning Platform

<https://www.pdc.org/disasteraware/>

- Climate Conflict Vulnerability Index (CCVI)

[Climate–Conflict–Vulnerability Index \(CCVI\)](#)

- SIPRI

<https://www.sipri.org/publications/2023/other-publications/climate-security-risk-assessment-index>

- Water, Peace And Security

[Water, Peace and Security](#)