Technical paper by the Adaptation Committee

Data for adaptation

at different spatial and temporal scales

United Nations
Climate Change

Data for adaptation

at different spatial and temporal scales

Technical paper by the Adaptation Committee

For further information contact:
Main office
UNFCCC secretariat
UN Campus
Platz der Vereinten Nationen 1
53113 Bonn
Germany
Telephone +49. 228. 815-10 00
Telefax +49. 228. 815-19 99
Email secretariat@unfccc.int
Website: https://unfccc.int

ISBN no. 978-92-9219-191-7

Contents

Executive summary

The demand for data for adaptation is growing in response to different political and practical needs. Through the Paris Agreement, Parties to the UNFCCC have called for a strengthening of global cooperation to ensure that adaptation action is based on and guided by the best available science. At national and associated sub-national scales, adaptation, following the process of formulating and implementing national adaptation plans (NAPs) or other plans and strategies, has entered the planning and implementation stage. This requires increasingly diversified and specialized data and related data products. The objective of the paper is to provide an overview of the categories of data that are required for effective adaptation, the forms in which these data are currently provided at different scales, remaining gaps and challenges and opportunities to enhance the provision and use of such data.

Effective adaptation to climate risks follows a continuous and iterative process consisting of the following stages: (i) assessing climate risks, (ii) planning adaptation, (iii) implementing adaptation measures, and (iv) monitoring and reviewing such measures. Implementing these stages requires different combinations of observational, projected, and historical data of both climate and socio-economic processes.

Observational data supports all stages of the adaptation process. It includes observations of the atmosphere, land and ocean as well as of socio-economic processes. Projected data is mainly required during the planning stage and is provided in the form of forecasts, predictions, and projections, which meet the needs for short-, medium-, and long-term planning, respectively. Historical data complements recent observations and outlooks to form the basis of understanding climate processes and their impacts at all scales from the past into the future.

Actors at different spatial scales contribute to the global provision of observational, historical and projected climate and socio-economic data. National Meteorological and Hydrological Services (NMHSs) play a central role in this regard and closely cooperate with international and regional data centres. The provision of climate data, in particular, guided by the vision of global sharing and open access, is facilitated through international coordination, the setting of quality standards and capacity building while socio-economic data is provided by a multitude of sources without global coordination under the climate regime. In most cases data is further processed into a variety of data products that meet different user needs across spatial and temporal scales and can also assist in closing gaps in observational coverage. Local-level stakeholders play an increasingly important role in complementing or validating top-down generated products with local knowledge and experience.

Important gaps and challenges remain with regard to all categories of adaptation data. In situ observation systems are still lacking in some regions of the world, most critically in regions where populations are at elevated risks, such as in coastal areas, or where local changes have global impacts, for example the melting of ice-sheet outlet glaciers and its contribution to sea-level rise. Modelled data is hardly downscaled to local levels where it is mostly needed. The interpretation of data is afflicted with major challenges that relate to rather technical issues around the measurements and models but also to deep uncertainties regarding future drivers of climate change, the response of the atmosphere and the effectiveness of adaptation measures in light of changing norms and values. Ensuring the quality of data is also becoming increasingly difficult as demands for the timeliness of data supply and its availability at various scales and for ever more specific adaptation situations are on the rise.

However, there are also important opportunities to further enhance data provision and use. Provision could be increased by focusing on three aspects: (i) exploiting the big data that is yet to be produced through innovative solutions like machine learning and cloud and edge computing; (ii) further ensuring open access to all existing data, including through the rescue of historical data and the lifting of restrictive data policies; and (iii) closing remaining data gaps through long-term funding of in situ observational systems and innovative ways of providing interdisciplinary data and information for local adaptation decision-making.

Capacity development of both providers and users of data in countries where it is needed would enhance both the provision and uptake of data. This would include the improvement of infrastructure required to transfer large amounts of data as well as the training of personnel for the

Photo: Gyan Shahane – Unsplash.

generation, downscaling, storage and management as well as the interpretation of high-quality data that is relevant to local contexts.

An indispensable aspect of encouraging data use is the provision of guidance in dealing with uncertainty that is an intrinsic part of data and its interpretation. There are various approaches and methods that can help in managing uncertainty, ranging from iterative risk management and participatory approaches to multi-criteria analysis and robust decision-making. Support in applying these tools should be an important component of the provision of climate services.

Climate services is a concept that is intended to build a bridge between scientifically generated data supply and the demand of end users for information that supports adaptation decision-making through a close interaction of data providers, service providers and end users. It is still a young field with mostly uncoordinated actors and activities but bears great potential once fully developed.

In conclusion, high-quality climate and socio-economic data are essential at all stages of the adaptation process and a great amount of data already exists or is underway in the form of big data. The global task is to make the information from this data available in a form and at scales that supports adaptation decision making at all levels and in all regions of the world. Meanwhile, uncertainties will remain an inherent part of using data for decision-making and will need to be managed, not tried to overcome.

Photo: NASA – Unsplash.

Background

The Adaptation Committee (AC) was established as the United Nations’ leading voice on adaptation. The sixteen-member body has offered expert guidance on a range of adaptation topics, helping countries, civil society and businesses to build resilience and adapt to the changing climate.

The AC prepared this paper in the context of its objective of providing guidance to the Parties on planning and implementing adaptation action. It expresses its thanks to the World Meteorological Organization’s Global Framework for Climate Services (WMO/GFCS), the Group on Earth Observation (GEO), and the World Adaptation Science Programme (WASP) for peer reviewing the paper.

Introduction

The demand for data for adaptation is growing due to different political and practical needs at various levels.

At the global level, the Paris Agreement includes several provisions which implicate increasing needs for adaptation-relevant data. In Article 7 of the Agreement, Parties acknowledged that adaptation action should be based on and guided by the best available science and that Parties should strengthen their cooperation in this regard.[1] These provisions build on those contained in the 2010 Cancun Adaptation Framework, through which Parties were invited to “[…] strengthen data, information and knowledge systems […] and “improving climate-related research and systematic observation for climate data collection, archiving, analysis and modelling in order to provide decision makers at the national and regional levels with improved climate-related data and information”.[2] They are also supported by ongoing work under UNFCCC Article 4, paragraphs 1 (g) and (h) and Article 5 and the agenda item on research and systematic observation under the Subsidiary Body for Scientific and Technological Advice.

At the national as well as regional and subnational levels, stakeholders have realized adaptation needs and have, to different degrees, entered into adaptation planning and implementation processes. The process to formulate and implement national adaptation plans (NAP process), established under the Cancun Adaptation Framework of the UNFCCC in 2010,[3] is increasingly being taken up by countries. These adaptation processes require data in order to be planned, implemented and monitored, and to be scaled up on the backing of evidence of their efficiency and effectiveness.

Considering these developments, the paper provides an overview of data required and provided for adaptation across different scales. It starts off by introducing key characteristics of climate risks and deriving different categories of data required at the iterative stages of the adaptation process (Overview of data categories to support adaptation). The following chapter describes the sources and processes through which these categories of data are provided across different spatial scales including remaining gaps and challenges. Finally, chapter 6 describes opportunities to further enhance data provision and use.

Overview of data categories to support adaptation

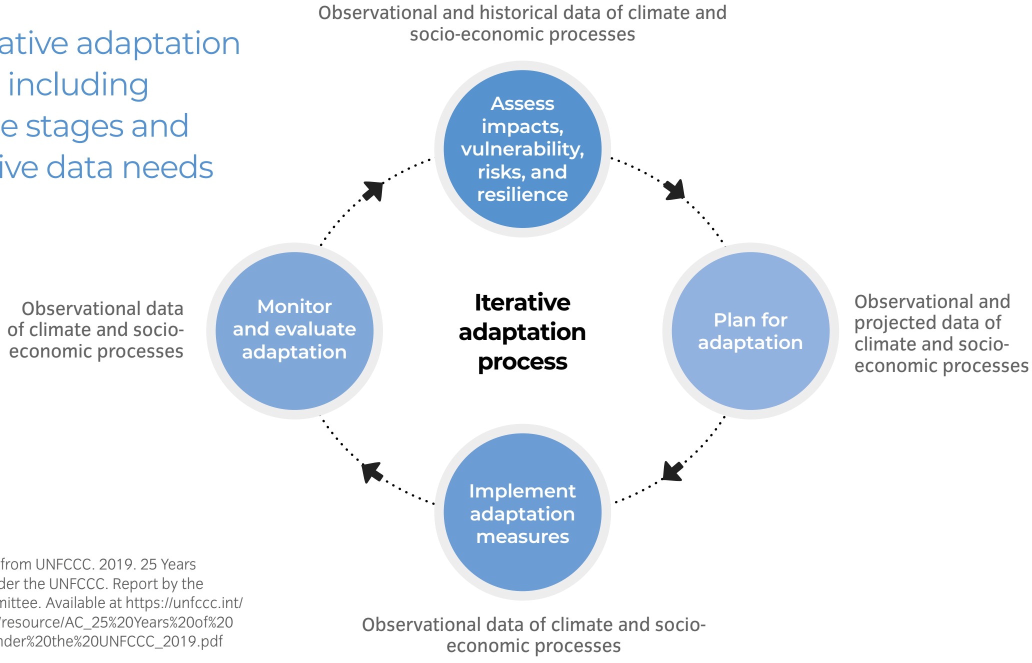
In its contribution to the Fifth Assessment Report (2014), Working Group II (WG II) of the Intergovernmental Panel on Climate Change (IPCC) describes two characteristics of climate risks that are key when deriving the categories of data required to adequately support adaptation to these risks.[4]

The first characteristic is the **composite nature of climate risks**: climate risks exist due to the interaction of climate-related hazards (including sudden-onset events and trends) with the exposure and vulnerability of human and natural systems. Hazards, exposure and vulnerability, in turn, are driven by climate and socio-economic processes. Taking adaptation decisions in order to reduce climate risks thus requires data and information on both climate as well as socio-economic aspects.[5]

The second characteristic is the **dynamic and complex nature of climate risks**: climate risks are evolving over time due to changes in both the climate and socio-economic systems. In order to account for these changes, adaptation to such risks must be a continuous, progressive and iterative process.[6] It is often described as containing four core and revolving stages: (i) assessing climate risks, (ii) planning adaptation, (iii) implementing adaptation measures, and (iv) monitoring and reviewing such measures (figure 1). Effective implementation of these stages requires information from observations and projections of climate and socio-economic processes as well as from experience with past climate impacts and respective socio-economic responses.

The composite, dynamic and complex nature of climate risks thus leads to the following categories of data required to support adaptation: observational, projected and historical data of climate and socio-economic processes. This data needs to be collected continuously and made available at spatial and temporal resolutions adequate to support the adaptation process at different spatial scales[7] and for different planning horizons.

FIGURE 1:
The iterative adaptation process including four core stages and respective data needs



Source: Adapted from UNFCCC. 2019. 25 Years of Adaptation under the UNFCCC. Report by the Adaptation Committee. Available at https://unfccc.int/sites/default/files/resource/AC_25%20Years%20of%20Adaptation%20Under%20the%20UNFCCC_2019.pdf

FIGURE 2:
The GCOS Essential Climate Variables to observe the atmosphere, land and ocean

Atmosphere

Surface
- Precipitation
- Pressure
- Radiation budget
- Temperature
- Water vapour
- Wind speed and direction

Upper-air
- Earth radiation budget
- Lightning
- Temperature
- Water vapor
- Wind speed and direction

Atmospheric Composition
- Aerosols
- Carbon dioxide, methane and other greenhouse gases
- Clouds
- Ozone
- Precursors for aerosols and ozone

Land

Hydrosphere
- Groundwater
- Lakes
- River discharge

Cryosphere
- Glaciers
- Ice sheets and ice shelves
- Permafrost
- Snow

Biosphere
- Above-ground biomass
- Albedo
- Evaporation from land
- Fire
- Fraction of absorbed photosynthetically active radiation (FAPAR)
- Land cover
- Land surface temperature
- Leaf area index
- Soil carbon
- Soil moisture

Anthroposphere
- Anthropogenic Greenhouse gas fluxes
- Anthropogenic water use

Ocean

Physical
- Ocean surface heat flux
- Sea ice
- Sea level
- Sea state
- Sea surface currents
- Sea surface salinity
- Sea surface stress
- Sea surface temperature
- Subsurface currents
- Subsurface salinity
- Subsurface temperature

Biogeochemical
- Inorganic carbon
- Nitrous oxide
- Nutrients
- Ocean colour
- Oxygen
- Transient tracers

Biological/ecosystems
- Marine habitats
- Plankton

Observational data

Observational data provides evidence of the recent or present-day situation of the climate as well as on environmental and socio-economic conditions. It thus helps to identify the climate vulnerability of a particular social or natural system (assessment stage of the adaptation process).[8] This data is also used to establish climate and socio-economic baselines when modelling future conditions and as references when evaluating adaptation options (planning stage). During the implementation of adaptation measures, observational data is compared to the prior projections and hence serves to monitor the effectiveness of the measures (implementation and monitoring stage). Observations therefore build the core of the data required to support the adaptation process.

In order to systematically observe changes in the climate system expert panels of the Global Climate Observing System (GCOS) have identified a set of 54 Essential Climate Variables (ECVs) (see figure 2).[9] Data on these are collected through real-time observations of the atmosphere, land and ocean via in situ or remote-sensing measurements.[10]

Examples of general and sector-specific observational socio-economic data include the following:[11]

a. **Population data** that reflects total number, distribution, structure and inequalities including, for example, total population, population density, urban population (including in coastal cities), age and gender structure, ethnic and religious affiliation;

b. **Economic data** that reflects wealth and its distribution including gross domestic product (GDP) per capita, GDP annual growth rate and GDP from climate-sensitive sectors like agriculture, industry and services;

c **Land cover/ land use data** that reflects the distribution of land use including total land area, arable and permanent cropland, permanent pasture, forest and woodland, other land;

d **Data on water** that reflects water resources and use including water resources per capita, annual withdrawal for domestic, industrial and agricultural use;

e **Data on agriculture/food** that reflects the socio-economic value of the agricultural sector including irrigated land, agricultural labour force, total labour force, stocks of different production animals.

Each adaptation context requires a particular combination of these observed climate and socio-economic data to implement the different stages of the adaptation process and might often need more specific data that would have to be collected for the individual adaptation activity.

Forecasts, predictions and projections

While observational climate and socio-economic data is required to assess current vulnerabilities and to monitor the implementation process, the planning of future adaptation activities requires estimations of how the climate and socio-economic future may unfold. In order to support the full range of adaptation activities across all temporal scales, from short-term implementation of evacuation plans to long-term policy planning, different kinds of weather, climate and socio-economic outlooks are required. The provision of these is sometimes called seamless hydro-meteorological and climate services (see figure 3).

The range of climate outlooks are produced by various climate models around the globe and can be summarized into the following three main categories:[12]

a **Weather forecasts** make use of enormous quantities of information on the observed state of the atmosphere and calculate, using the laws of physics, how this state will evolve during the next few days. Weather forecasts are particularly relevant in the case of extreme weather that requires the implementation of an evacuation plan or other safety measures. They provide the basis for issuing alerts.

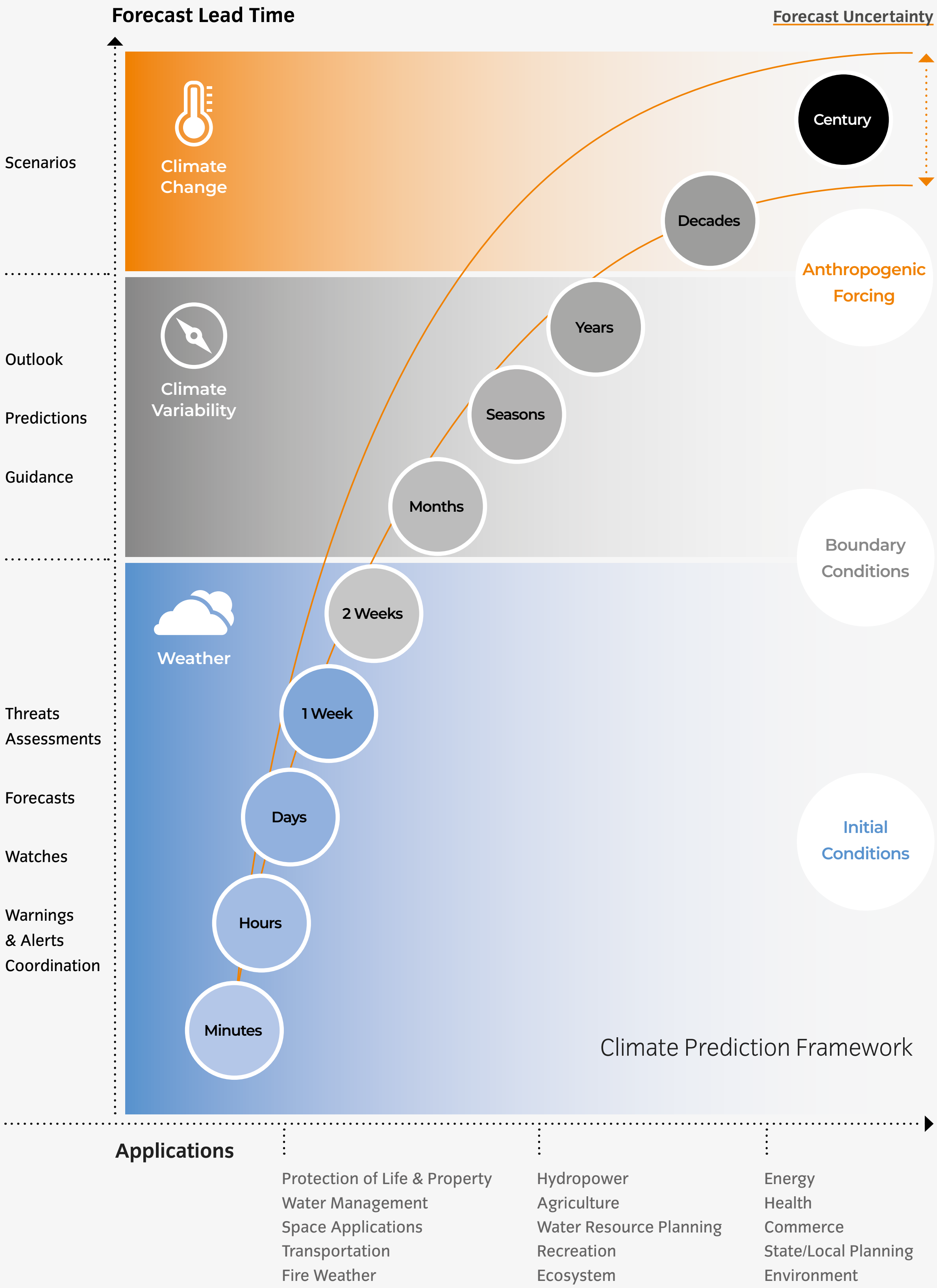
b **Climate predictions** are outputs of a model that computes the evolution of targeted parameters from initial conditions up to the final state at seasonal, annual or decadal timescales. They are most influenced by the current conditions that are known through observations (initial conditions) and the physical processes that will determine future evolutions of climate variability. They do not take into account assumptions or scenarios of human influence on the climate (forcings). This is due to the fact that projected levels of global mean temperature increase under different emission scenarios only begin to diverge after 2040 whereas they stay approximately the same before that year. The period until 2040 is therefore called the near-term era of committed climate change.[13] During this period, climate impacts can only be influenced by adaptation measures, which is an important information for decision makers. Most predictions are probabilistic, thus consisting of several individual forecasts from a climate model starting with slightly different initial conditions (both atmospheric and oceanic) and generating a set (or ensemble) of forecasts. This way, uncertainties linked to the prediction are accounted for. Predictions are produced at different time intervals (e.g. monthly or seasonally) and are useful for medium- to longer-term strategic adaptation planning, such as infrastructure planning and land zoning.

c **Climate projections** are statements about the likelihood that something will happen several decades to centuries in the future, if certain influential conditions develop (e.g. significant changes in the boundary conditions through human influence, for example the increase in greenhouse gas concentrations). Thus, climate projections provide indications to policy makers on how certain policy-driven action might influence future outcomes. For this, scenarios are developed containing certain (plausible) assumptions about future climate and socio-economic developments which then serve as the initial conditions in a climate model. The outputs of the model then provide information on the likely consequences of such developments in terms of climate change. By using different scenarios and different models, each with its own particular climate sensitivity, a range of reasonable possibilities of both societal development and climate behaviour is accounted for. These long-term projections are particularly relevant for climate negotiations and their implications for national adaptation policy making.

The climate elements typically forecasted in all categories of climate outlooks include surface air temperature and total precipitation, but increasingly also include objective seasonal to sub-seasonal predictions including other parameters such as the number of days with precipitation, snowfall, the frequency of tropical cyclones and the onset and cessation of monsoon seasons, which are needed for increasingly specific adaptation planning.

Socio-economic variables are not accounted for by weather forecasts and climate predictions. As such, these must be assessed and predicted separately when undertaking impact studies and planning adaptation for the short- to medium-term. Such predictions could include

FIGURE 3:
Seamless hydrometeorological and climate services



Source: WMO. Climate Services for Supporting Climate Change Adaptation. Supplement to the Technical Guidelines for the NAP Process. Available at https://www4.unfccc.int/sites/NAPC/Documents%20NAP/Supplements/WMO_climate%20change%20services%20for%20climate%20change%20adaptation.pdf

Photo: Kelly Sikkema – Unsplash.

those on population trends, land use scenarios, or income developments. Climate projections, however, do already include assumptions on socio-economic developments as these are contained in the global scenarios that form their basis. The same socio-economic assumptions should then be applied for long-term climate impact studies in order to ensure consistency in the data used.[14]

Historical data

Historical data forms part of observational data but has been recorded by in situ instruments before the digital revolution 40-50 years ago and is therefore stored on paper or other obsolete media. Access to historical data is nonetheless essential to understand the context of changes in climate and its extremes, and to frame the sensitivity of man-made and natural systems to climate variability and extremes as a guide to future adaptation. [15]

Historical climate data is used to reconstruct past climates, providing insights into the drivers of climate change, facilitating parameterization of climate processes in GCMs and the evaluation of the performance of global climate models, and thereby providing a basis for predicting the future climate. Long time series of data have also proved vital in demonstrating change and attributing this change to human and natural causes in IPCC Assessment Reports.

Historical data may also provide information on the way past climate events have impacted social systems, and thus on the vulnerability and adaptive capacity of such systems. This temporal analogue technique allows for the characterization of how human systems manage and experience climate risks, the identification of those processes and conditions which determine the efficacy, availability, and success of past and present adaptations, the development of a greater understanding of how social and biophysical processes shape vulnerability, and the establishment of a range of possible societal responses to future climate change.[16] If combined with effective short-term forecasting, this information might often suffice to derive useful coping strategies for similar future events, thus making costly climate predictions unnecessary.

Historical data thus supports the assessment, the planning and the implementation stages of the adaptation process and it is important that as much as practically possible of the considerable amount of early instrumental data on temperature, precipitation and other variables be recovered.

Quantitative and qualitative data

Under each category of data for adaptation – observational, projected and historical – quantitative and qualitative data can build useful complements.

Quantitative data is generated by observational systems, statistics, censuses and models and, if produced and shared transparently and according to international standards, can provide objective information that is relatively easy to compare in time and space and despite linguistic and/or cultural differences. With the aid of technology, huge amounts of such data can be generated, processed and stored with much lower levels of investment required in terms of time and workforce compared to qualitative data. However, both the generation and interpretation of quantitative data requires certain skills and data literacy and their application is accompanied by a certain level of uncertainty (see sections Remaining gaps and challenges and Managing uncertainty). In addition, important gaps remain in quantitative data regarding its coverage across regions and scales which can be an obstacle to effective adaptation planning.

In these cases, qualitative data and information, which are narrative descriptions of past, present and future conditions and their interactions, can form an important complement to quantitative data. It is mainly obtained through expert and other stakeholder consultations and dialogue using a variety of participatory methods such as surveys, interviews and group discussions. It can also take the form of process-based understanding, simulations and descriptive models.[17] Particularly in the case of historical data, it can be obtained via the analysis of newspaper articles and other types of archives.

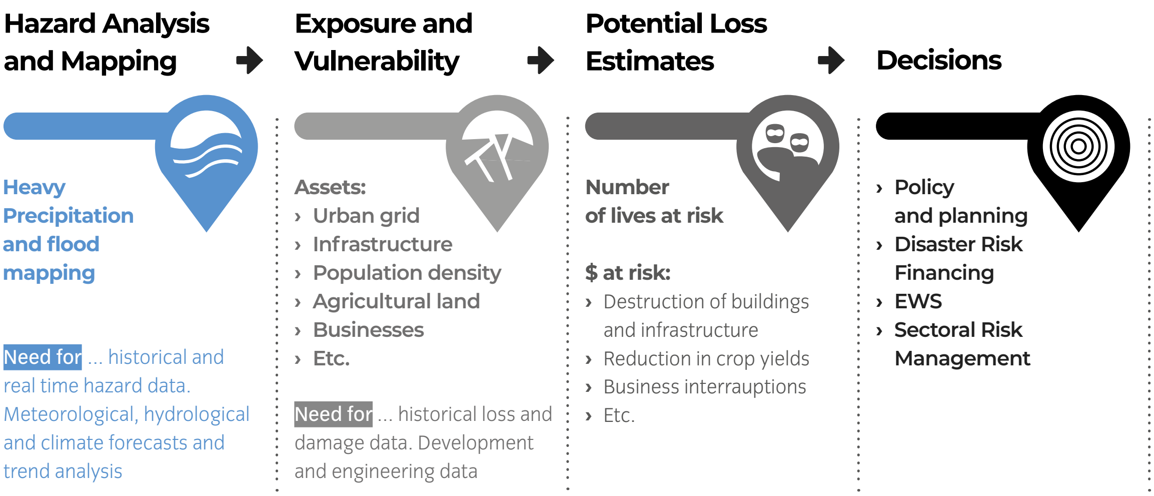
Alongside filling gaps in quantitative data, qualitative data helps in understanding aspects that are not quantifiable, including experience, judgements, priorities, emotions, behaviour, world views and non-monetary values.
The participatory nature of its generation enables the involvement of those with influence over the adaptation process or those affected by it, particularly also at local levels, and opens up opportunities of stimulating their interest, understanding and buy-in. It supports the "co-production" of knowledge among experts and users. Finally, qualitative data can be successful in conveying information to non-specialists and making quantitative data easier to understand, including addressing issues of uncertainty.[18] Thus, although more time-consuming and subjective, the involvement of qualitative data in adaptation planning processes, if generated skilfully, may lead to more effective and sustainable outcomes.

An example of using qualitative data for the planning of adaptation is the "bottom-up" approach to projections for climate impact studies. This approach involves local resource managers and decision-makers with access to local knowledge alongside quantitative observational and historical data when assessing how climate change might affect certain policy plans and goals. This involvement of local expertise in evaluating projections is increasingly recognized as being more effective than simply downscaling global model outputs (for a more detailed description of this approach see box 3).

Data requirements at different spatial scales

Adaptation planning and implementation occurs at various spatial scales including local, national, and regional. At each of these scales, various combinations of climate and socio-economic data at different spatial and temporal resolutions are required along the adaptation process and for increasingly specific adaptation contexts. Thereby, a matching of specific resolutions of data to specific levels of decision-making is not possible. Rather, decision-makers at different levels require the data that best describes the factors and processes that are relevant for their respective decision-making context.

FIGURE 4:
Example of hazard and vulnerability analyses related to flood risk and according data requirements for adaptation decision-making, as facilitated by the Global Framework for Climate Services



Source: WMO. Climate Services for Supporting Climate Change Adaptation. Supplement to the Technical Guidelines for the NAP Process. Available at https://www4.unfccc.int/sites/NAPC/Documents%20NAP/Supplements/WMO_climate%20change%20services%20for%20climate%20change%20adaptation.pdf

For example, a city manager whose city is located along a river that is prone to recurrent flooding, requires historical, observed and projected hazard and vulnerability data which allows him to take decisions regarding for example urban planning, protective infrastructure, resettlements, sectoral risk management, early warning and disaster risk financing (see figure 4). This data would need to be at rather high resolution to reflect the local topography as well as the social and economic particularities of the area. The same data would be important for a national adaptation planner who is responsible for national disaster risk financing. However, he would only be interested in the aggregated values at risk and evaluate that against other disaster risks in the country in order to plan total amounts and types of risk financing and their allocation. In case the river crossed several countries, the flood risk planning would at best be undertaken in a transboundary approach in order to estimate local stream flows as well as the likely impacts of such flows and respective adaptation measures on adjacent localities in the most efficient and effective manner. For this, the regional level would require regional climate data combined with socio-economic data from the different localities along the river. This information would allow for a regional adaptation approach or plan that could subsequently be implemented at each of the involved national and/or local levels.

Thus, in general, the **local level** is where high resolution and disaggregation of data is mostly needed. Climate data on maximum/minimum temperature and precipitation may be required for specific times of the day or periods of the year to identify the associated extremes, their frequency, intensity and changing trends. It may also be required at specific spatial resolution, e.g. urban environments where increasing parts of the world population reside, and climate impacts take particular shapes. Similarly, complementary socio-economic data is needed at these scales to allow for specific impact and vulnerability studies. General population trends for the national level, for example, may mask important trends in migration at local scales, e.g. from rural to urban, and nationally-averaged scenarios of per capita income may obscure local disparities between rich and poor or men and women.

Apart from the appropriate resolution, the local level might require data in addition to what is required at the regional or national levels. This may include, for example, information on specific weather or air-quality variables such as on the frequency and intensity of fog, which is not included in global ECV observations.[19]

The **national level** usually operates from a more holistic viewpoint, trying to identify the various climate risks across the country and allocating respective resources by weighing different adaptation needs. Adaptation planners at this level thus not only need to take into account general climate and socio-economic patterns of their country as a whole, but also consider particular sectors or areas at risk from specific hazards or trends, such as floods, El Niño or sea level rise. In addition, they need to address regional interests which concern, for example, transboundary ecosystems. As such, they do not only require data at national resolution, but also data from local and regional scales (see box 1 for the types of required data and existing sources for national adaptation planning in St. Lucia as well as a list of further specific data needs). Thereby, the level of aggregation or disaggregation of the required data depends on the specific decision to be taken.

Adaptation planning at the **regional level** has two main objectives: preventing unintended trans-national effects of unilateral measures and increasing the efficiency and effectiveness of adaptation by sharing resources, information and experience among nations and locating measures where they yield optimum benefit. In order to meet these objectives, adaptation planning at this level depends not only on regional climate data, but also on climate as well as socio-economic data from the national to local levels, particularly from the key vulnerable sectors, of the involved countries.

In general, actors at any of these levels that operate across different scales and world regions, e.g. by being part of global supply chains, require data from different geographical regions and scales in order to effectively adapt to climate impacts.

A special case: data requirements at the global level

The global level is a special case regarding data requirements for adaptation since at this level data is not required to plan individual adaptation measures but to review the collective progress on adaptation by all countries.

Through Article 7 of the Paris Agreement, Parties to the UNFCCC have established the global goal on adaptation and tasked themselves with reviewing overall progress towards this goal as well as the adequacy and effectiveness of adaptation and support provided for adaptation at regular intervals as part of the global stocktake.[20] These reviews might need to be substantiated by the different categories and forms of climate and socio-economic data. Approaches and methodologies that could assist in undertaking these reviews are currently under development.[21]

BOX 1:

Data requirements and sources for assessing climate risks and vulnerabilities under Saint Lucia's NAP process

Required data	Sources
Socio-economic	2010 Population and Housing Census, Country Poverty Assessment (CPA) and UNDP's Human Development Index
Meteorological	St. Lucia's Meteorological Service which provides 24-hour meteorological forecasting and observations from two stations and rainfall records from 31 secondary stations
Climate change modelling	Projections from NGOs and research groups based on GCMs and RCMs, most comprehensively undertaken by CARIBSAVE for its Climate Change Risk Atlas
Land use, land cover and natural hazard mapping and assessment	Various risk assessment and national land use plans, with specific assessments for landslide risk and the agricultural sector
Information on natural resources and their management	Natural resource inventories and assessments e.g. website of the Government of St. Lucia's Biodiversity Resources
Sector-relevant information	For example, Assessment of the Economic Impact of Climate Change on the Agricultural Sector supported by ECLAC, Impact Assessment of Climate Risks to the Tourism Sector, Country Document for Disaster Risk Reduction

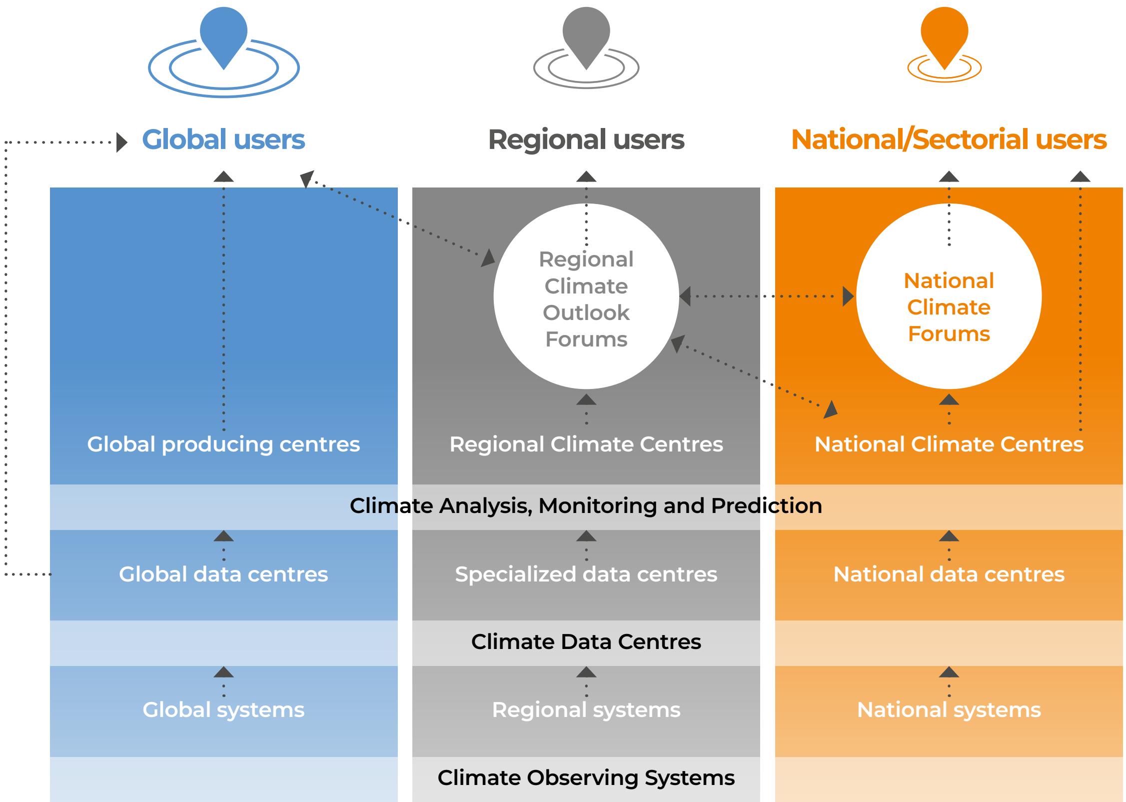
On the basis of its stocktake and vulnerability analysis, St. Lucia has identified a list of pressing data and information needs, including, for example, wind hazard information, local climate extreme indices, sea level rise modelling and coastal flood and erosion mapping, among others.

Further information on these activities can be found in St. Lucia's National Adaptation Plan Stocktaking, Climate Risk and Vulnerability Assessment Report available at https://www.climatechange.govt.lc/wp-content/uploads/2018/04/Saint-Lucia_Stocktaking-climate-report_FINAL.pdf.

Photo: Daniel Öberg – Unsplash.

Provision of data for adaptation across different spatial scales

FIGURE 5:
Data and information exchange as part of the Climate Service Information System (CSIS) of the Global Framework for Climate Services



Source: Presentation by the WMO on the CSIS available at https://gfcs.wmo.int//sites/default/files/Rupa%20Kumar%20Kolli%20CSIS.pdf

In parallel to the growing demand for data to support adaptation, the supply has also been increasing rapidly in the past years. Observational systems have been expanding and are providing data in near real-time, satellite data is contributing a wealth of complementary information on many of the Essential Climate Variables, and global climate models produce ever more detailed projections of the future climate and its impacts. This explosion of global data availability has been made possible through increased computer capacities and other technological developments on the one hand, and advances in global cooperation and coordination regarding research, systematic observation and modelling on the other hand. Figure 5 illustrates the exchange of data and information between the different spatial scales.

Observational data

Observational climate data

Observational climate data is produced by the climate observing systems composed of national, regional and global sub-systems. Thereby, the national level plays a central role. National-level bodies such as National Meteorological and Hydrological Services (NMHSs), oceanographic institutions and space agencies are the largest providers of climate observations.[22] Further sources may include other national agencies, commercial entities or development agencies.

The approximately 190 NMHSs around the world stand out since they are the official authoritative source, and often the single source, as well as guardians of weather and climate data obtained through networks of in situ measurement stations in their respective countries. In addition, they provide their data and products to regional and global data centres for archiving and further processing. According to the WMO Guide to Climatological Practice[23], an NMHS must be able to anticipate, investigate and understand the needs for climatological information among government departments, research institutions and academia, commerce, industry and the general public; promote and market the use of the information; make available its expertise to interpret the data; and advise on the use of the data. Thus, through their work, NMHSs form the basis of global climate monitoring and analysis.

National as well as regional observational systems provide their data to regional or specialized climate centres (RCCs). These are centres of excellence designated by WMO to strengthen the capacity of WMO Members in a given region to deliver better climate services to national users.[24] Examples include the Climate Services Centre of the Southern African Development Community in Botswana, the Beijing Climate Centre in China, the Regional Climate Centre for Western South America in Ecuador or the Caribbean Institute for Meteorology and Hydrology for the Caribbean.[25] The mandatory functions of RCCs include: (i) operational activities for long-range forecasting; (ii) operational activities for climate monitoring; (iii) operational data services; and (iv) training in the use of operational RCC products and services. RCCs are also encouraged to take up non-operational data services such as coordination, training and capacity building, and research and development.

In terms of observation from space over 40 countries worldwide have invested in space-based infrastructure with the capability to provide sophisticated, continuous, and sustained observations of the entire planet, and more investments are coming from the private sector and through public-private partnerships. Of the 54 ECVs, more than half have a major contribution from satellite observations.[26] The web-based inventory of existing and planned climate data records of the ECVs observable from space is updated annually and in 2019 it contained information for approximately 1300 datasets.[27]

Data from the different observing systems is usually submitted to global data centres which further process the data and make it publicly available. Such data centres hold basic archives of in situ observational data, for example relating to individual Essential Climate Variables or groups of them, and sometimes of satellite data. The scales for which this data is available range from near- real time to million-year-old proxy records and from global to sub-national and sector-specific scales.

Global data centres that collaborate with WMO include, for example, the World Data Center for Meteorology, Asheville in the US; the World Data Center for Meteorology, Obninsk in Russia; the China Meteorological Data Sharing Service System in China and the World Data Centre for Climate (WDCC) in Germany.[28]

Sub-national sources also contribute to the global provision of observational climate data. These include local public agencies, the private sector or international development projects. In addition, real-time observations on the environment are increasingly being collected through citizen science and crowdsourcing initiatives, as well as extracted from social media and smartphone activities, to complement official observational climate data.[29]

Altogether, the different observing systems and data centres hold a vast array of observational data. In order to make the data useful for their end users, including adaptation planners and decision-makers, climatologists at the various centres analyse and synthesize the data into a variety of data products. These products provide climate information at spatial scales and for time intervals that meet the requirements of specific adaptation contexts. A range of statistical methods is applied to arrive at these products, some of which also help in closing gaps in observational coverage.[30]

Climate data products may take the following formats:[31]

a. **Climate atlases:** publication for particular regions or the entire globe with several kinds of visualization and descriptive text;

b. **Online databases** with software tools that allow customers to produce statistics and visualization according to their needs;

Photo: ESA/Pierre Carril

c **Climatological data periodicals:** routinely (monthly or annually, sometimes weekly or seasonally) published bulletins containing data from a selection of stations within particular areas or a country and providing information on e.g. maximum and minimum temperature and total precipitation for each day, temperatures at fixed hours, together with the associated humidity values; daily mean wind speed and prevailing direction; duration of bright sunshine; or other locally important data (such as heating, cooling and growing degree-days); monthly averages and extremes and other statistical data, if available;

d **Occasional publications:** produced as the need arises, for example to support the planning of large, long-term investments or to explain unusual events, such as extreme weather or to describe and update an important predicted event such as a strong El Niño; they may also be published on long-term, continuous and homogeneous series of data (e.g. on temperature and precipitation) which are of great value for comparative climatological studies and for research on climatic fluctuations, trends and changes; historical climatological data series are sometimes summarized in yearbooks or annual bulletins;

e **Standard products:** fill the gap between the climate data periodicals and those tailored to individual users and are produced containing certain types of data (e.g. degree-day products) to satisfy the needs of various users, particularly at the local level; cost-sharing among users is an important aspect of standard products;

f **Specialized products:** transform the observations into a value-added product for particular recipients by analysing the data and presenting the information with a focus on the specifications that will enable the user to gain optimum benefit from the application of the information; the use of the product usually dictates the types of analysis and methods to generate the product;

g **Climate monitoring products:** summarized information on the current climate conditions, including local variations, of a country, put in context of the regional and/or global climate system, including the extremes and their impacts;

h **Indices:** characterize features of the climate at a particular station or for an area, usually combining several elements into characteristics of, for example, droughts, continentality, phenological plant phases, heating degree-days, large-scale circulation patterns and teleconnections; examples of indices include the El Niño Southern Oscillation (ENSO) Index; the North Atlantic Oscillation Index; descriptors such as the moisture availability index, used for deriving crop planning strategies; agrometeorological indices such as the Palmer Drought Severity Index, aridity index and leaf area index, which are used for describing and monitoring moisture availability; and the mean monsoon index, which summarizes areas of droughts and floods.[32]

The following are data products and statistical methods that assist in closing gaps in observational coverage:

a **Gridded data:** gridded climate data products are values of surface or upper-air climate variables (for example, air temperature, atmospheric moisture or sea surface temperature) or indices (for example, number of frost days), arranged on a regular grid with coverage ranging from the local to regional to global. Spatial resolution of gridded data varies from a few square metres in the case of sub-urban datasets to 200-300km as found in global scale datasets. Temporal resolution varies from the sub-hourly to annual timescale. Gridded data is derived from original observations (surface or satellite-based) using interpolation techniques or from the output of numerical or statistical climate models. They fill data gaps that arise due to an uneven geographical and temporal distribution of climate observations. Gridded datasets facilitate the spatial analysis of climate variables and the static or dynamic visualisation of climate patterns and trends;

b **Reanalysis:** process through which numerical weather prediction is done retroactively by using the same prediction model but incorporating a more complete set of observations that had not been available at the time of the original weather prediction. The output is on a uniform grid without any missing data. The result is an integrated historical record of the state of the atmospheric environment for which all the data have been processed in the same manner. The reanalysis values are not “real” data but estimates of real data based on unevenly distributed observational data. There are still challenges of localizing reanalysis to spatial and temporal scales finer than the reanalysis grid;

c **Reprocessing:** method through which data from different types of observations or different instruments is reprocessed in order to achieve homogenization or intercalibration; this method benefits from improved knowledge of instrument characteristics or better methods of generating gridded data products from the raw measurements.

In sum, great progress has been made through the global observing systems and data production methods, for example, in terms of global coverage of ECV data availability whereby in situ and space-based observing systems complement each other.[33]

<u>Observational socio-economic data</u>

Regarding the collection and management of, particularly quantitative, observational data of socio -economic processes, there is currently no international coordination under the climate regime comparable to that on climate data. In contrast, such data is collected and held by a wide variety of sources at all spatial scales that mainly collect the data for other purposes. This separate collection of socio-economic and climate data often makes an attribution of observed socio-economic changes to a cause, such as climate change, difficult. As long as more collocated time series of climate observations and socio-economic parameters are not available, quantitative socio-economic data for vulnerability assessments and adaptation planning, implementation and monitoring must be collected from the existing sources for each individual adaptation context and be complemented by qualitative information that is collected specifically for the adaptation activity.

At the global level, the sources for quantitative data include UN organizations, such as the Department of Economic and Social Affairs (e.g. UN Statistics Division, population division and databases[34], division for economic analysis), the World Bank, the Organisation for Economic Co-operation and Development (OECD) and specialized research institutions, such as the Socioeconomic Data and Applications Center of NASA and the International Institute for Applied Systems Analysis (IIASA) in Austria, to name just a few.

At the regional level, such data is provided, among others, by UN regional economic commissions or regional development banks.

Socio-economic data at the national level can be obtained primarily from national statistical offices or from line ministries, civil society organizations, academia or private institutions. For data on smaller spatial scales within a country, agencies, universities or other archives at local levels may be consulted. Socio-economic microdata, including on individuals, households, or firms may also be obtained from surveys or company details. In addition, qualitative and anecdotal information from local resource managers, policy makers and other stakeholders can provide very useful supplementary materials.

Despite the current absence of a globally coordinated approach to collecting socio-economic data for adaptation, several international efforts are underway that might contribute to an increased systematization of the collection and provision of such data.

One is the 2030 Agenda for Sustainable Development, which, with its 17 Sustainable Development Goals, related targets and the national, regional and global, indicator-based review processes, will enhance the collection of socio-economic data in many fields which are also relevant for adaptation to climate change.[35] Although national reviews are voluntary and country-led, UN Member States have developed a common indicator framework[36] and national reviews should be consistent with the voluntary common reporting guidelines proposed by the UN Secretary-General, among others to facilitate the global review process. In order to enhance such consistency, the United Nations system, including through its Regional Commissions and country teams is offering coherent support to the conduct of national reviews in the context of the SDGs, including through building the capacity of national statistical offices, data systems and evaluation bodies.[37] As such, enhanced standardization, coordination and comparability of nationally collected socio-economic data that is also relevant for climate adaptation may be expected.[38]

In addition, the United Nations Economic Commission for Europe (UNECE) plays a leading role in global efforts to advance the development of official statistics for climate analysis and global reporting, including for adaptation. In this context, it has produced Recommendations on Climate Change-Related Statistics in 2014 (see box 6),[39] and since 2015 has organized an annual Expert Forum on Climate Change Statistics which provides a key international platform to support this work.[40]

In general, socio-economic data is often provided in the form of specific products such as statistical yearbooks, online databases which provide the opportunity of customization, or region-specific atlases. Taking into account the difference in the way climate impacts may affect different groups of society, disaggregation of the data according to sex, age, income, race, ethnicity, migration status, disability, geographic location and other nationally relevant criteria is desirable.

Projected data

Using observational data as a basis, the different spatial levels also interact in providing weather and climate forecasts, predictions and projections for different spatial and temporal scales.

Regarding long-range forecasts and predictions, the WMO Global Data-processing and Forecasting System produces seasonal forecasts on a monthly or at least quarterly basis including for the following variables: 2m temperature, precipitation, Sea Surface Temperature (SST), Mean Sea-Level Pressure (MSLP), 500hPa height, 850hPa temperature.[41] The system is composed of thirteen Global Producing Centres for Long-range Forecasts (GPCLRFs),[42] Regional Specialized Meteorological (Climate) Centres and NMHSs. The three interact in such a way that forecasts and predictions generated from a global climate model are downscaled to the regional level (for a limited area and up to a resolution of a few kilometres) and further to the national level (see figure 5 above). The downscaling methods can be either dynamical (using the larger-scale information from a GCM to simulate a regional climate) or statistical (creating statistical relationships between the large-scale variables and observed regional and local variables), or a combination of the two. NMHSs produce different forms of national climate outlooks, such as 8–14-day probabilistic outlooks, monthly, seasonal and annual climate outlooks or specific outlooks such as monthly and seasonal drought outlooks or weekly regional hazards outlooks for food security.[43]

WMO Regional Climate Outlook Forums play a particularly important role in the provision of climate outlooks and their distribution.[44] They produce consensus-based, user-relevant climate outlook products in real time for the coming season in sectors of critical socio-economic significance for the region in question. Forums bring together national, regional and international climate experts, on an operational basis, to produce regional climate outlooks based on climate predictions from all participants. By bringing together countries with common climatological characteristics, the Forums ensure consistency in the access to, and interpretation of, climate information. Through interaction with users in the key economic sectors of each region, extension agencies and policymakers, the Forums assess the likely implications of the outlooks on the most pertinent socio-economic sectors in the given region and explore the ways these outlooks could be used by them. They also offer training workshops on seasonal climate prediction to strengthen the capacity of national and regional climate scientists. Based on the needs of specific sectors, specialized, sector-oriented outlook forums, such as the Malaria Outlook Forums (MALOFs) in Africa, are being held in conjunction with the regional forums. The regional forums are usually followed by national forums to develop detailed national-scale climate outlooks and risk information, including warnings for communication to decision-makers and the public (see figure 5 above). NHMSs are key participants in these forums through which they provide their products and services and enter into a dialogue with end users. Local and sectoral stakeholders, in turn, may use this platform to raise awareness for their particular data needs.

Photo: Qinghong Shen – Unsplash.

Forecasts and predictions of socio-economic data that are required for short- to medium-term adaptation planning at regional, national or local scales are usually produced by those entities that also monitor socio-economic developments and provide the respective observational data (see section Observational socio-economic data). As examples at the global level may serve the UN Department of Economic and Social Affairs (UNDESA), which produces the annual flagship report "World Economic Situation and Prospects", in collaboration with the UN Conference on Trade and Development (UNCTAD) and each of the five UN Regional Commissions, containing a global economic outlook as well as regional ones for the different UN geographical regions for the subsequent year.[45] Its population division also regularly updates the World Population Prospects[46] as well as the World Urbanization Prospects,[47] describing trends in population and urbanization, respectively, for all countries in the world as well as additional sub-regions. The International Monetary Fund (IMF) publishes usually twice a year the World Economic Outlook reports, which present IMF staff economists' analyses of global economic developments during the near and medium term, including for major regions and individual countries.[48] Twice a year, the OECD produces the OECD Economic Outlook which is an analysis of the major economic trends and prospects for the next two years, covering all OECD member countries as well as selected non-member countries.[49] The OECD also makes available population projections for each OECD country and selected non-OECD countries up to the year 2030.[50]

Regarding long-term climate projections these are also produced by different climate centres around the world using Global Climate Models. Global centres that provide such projections include the Hadley Centre of the UK Met Office[51] or the European Copernicus Climate Change Service.[52] While formerly emission scenarios were used to arrive at climate projections, Representative Concentration Pathways (RCPs) have been applied under the IPCC's Fifth Assessment Report (2014). The different pathways describe possible radiative forcing trajectories resulting from different combinations of economic, technological, demographic, policy and institutional futures to arrive at four pre-defined radiative forcing levels in the year 2100.[53] The key difference between the two scenario processes is that while the former applied a sequential approach (developing socio-economic storylines to generate emission scenarios and then climate scenarios), the RCP process develops emissions and socio-economic scenarios in parallel, building on the different RCPs. In this context, Shared Socio-Economic Pathways (SSPs) are used alongside the RCPs to analyse the feedbacks between climate change and socioeconomic factors, such as world population growth, economic development and technological progress.[54] The integration of RCPs and SSPs, in turn, has allowed for improved climate impact studies, such as those undertaken by the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) which aims to improve global and regional risk management by advancing knowledge of the risks of climate change through integrating climate impacts across sectors and scales in a multi-impact model framework.[55]

Global Climate Model Outputs, based on the RCPs, need to be downscaled to regional and national levels in order to be useful for adaptation planning at these scales (see case study in box 2). They then need to be viewed in conjunction with projected socio-economic data when assessing localized climate risks and vulnerabilities. To this end, the IPCC Data Distribution Centre makes freely available a number of recent global data sets of baseline and scenario information on climatic, environmental and socio-economic conditions.[56]

As illustrated in box 3, there are usually two approaches when applying projections for climate impact studies and adaptation planning: a “top-down” and a “bottom-up” approach. The latter is increasingly recognized as being more practical since it uses the knowledge of local experts and decision-makers on the prevailing vulnerability and adaptation contexts and assesses how climate change might affect related policy plans and goals. In fact, both approaches are complementary, and their combined application allows local experts to evaluate the plausibility and credibility of national climate projections that are downscaled from global scenarios. The new approach of using Representative Concentration Pathways is assumed to better address both the top –down and the bottom-up methodologies.

BOX 2:

Sudan’s approach to develop regional climate projections

At the time Sudan conducted its NAP process (2011-2014), no regional climate projections had been available. In order to undertake effective vulnerability assessments and adaptation planning, the Sudanese government decided that such projections were required and undertook the following steps as part of the NAP process:

1. Building technical capacity by establishing a collaborative relationship between Sudanese meteorologists and international experts, as well as convening on-site and remote capacity strengthening programmes;

2. Defining current climate trends by summarizing observed precipitation and temperature characteristics from six stations over Sudan for the period 1961-2010;

3. Obtaining most recent GCM outputs from IPCC AR5 model runs for a region including Sudan and for the four Representative Concentration Pathways (RCPs) used in AR5;

4. Developing future regional climatic projections by applying statistical downscaling techniques to define future climate at a finer spatial resolution (12-km) and correlate these with historical regional climate (using also proxy data if required) to arrive at monthly, gridded (50km) time series of precipitation and minimum and maximum temperature for the period 1950 – 2100;

5. Producing maps and charts that illustrate how climate change would unfold in Sudan at the six stations (plotted for annual average temperature and annual total precipitation for the period 2006 – 2100);

6. Addressing uncertainty by characterizing the multiple contributors to uncertainty, including future climate drivers such as greenhouse gas emissions, choice of climate models, and choice of downscaling method.

Further information on these activities can be found in Sudan’s National Adaptation Plan (2016), available at https://www4.unfccc.int/sites/NAPC/Pages/national-adaptation-plans.aspx.

BOX 3:

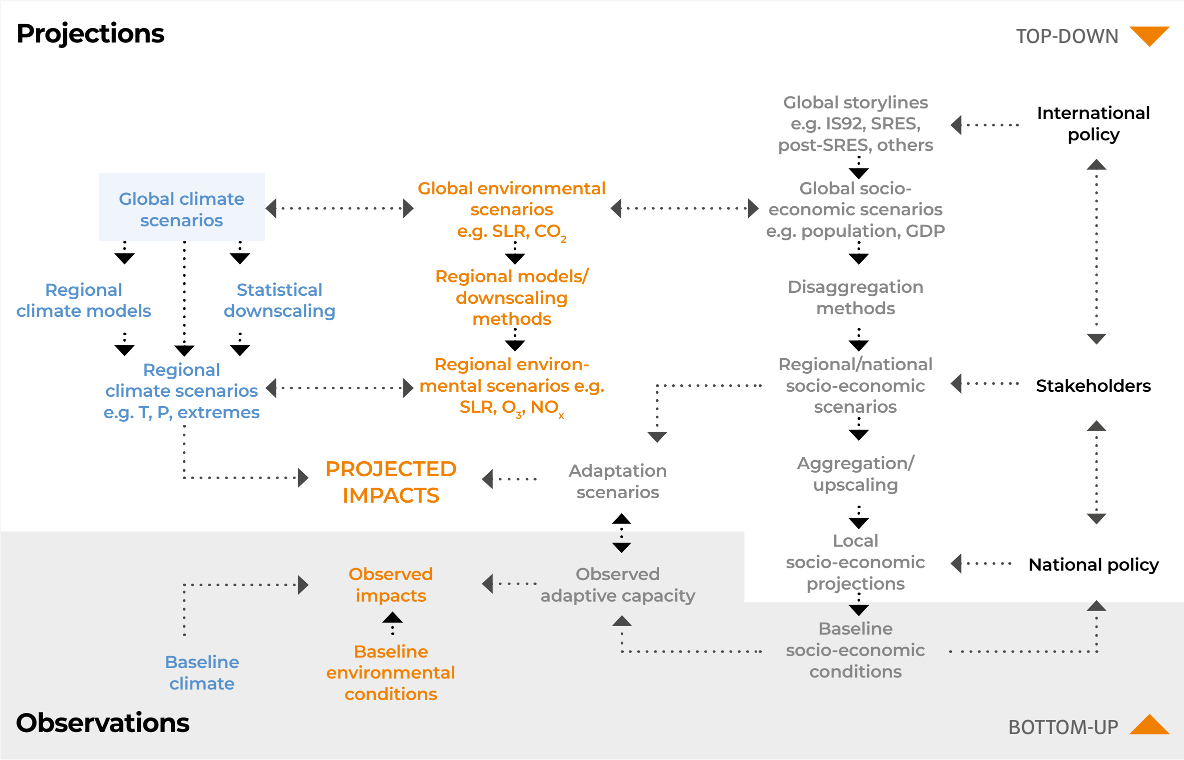
Top-down and bottom-up approaches to projections for climate impact studies

If applying projections for climate impact studies and adaptation planning, there are generally two pathways for carrying out scenario-based assessments: a “top-down” or “predict-then-act” approach and a “bottom-up” or “assess-risk-of-policy” approach (see figure below). The “top down” approach involves the interpretation and downscaling of global-scale climate and socio-economic scenarios to lower levels. These are then applied to assess which impacts they might have on particular systems of interest, followed by the formulation of adaptation strategies and options.

The “bottom-up” approach builds scenarios by aggregating from the local to higher scales. It starts with the vulnerability and adaptation decision-making context and then assesses how climate change might affect certain policy plans and goals. It uses observational or even historical data and closely involves local resource managers and decision-makers with access to local knowledge whereas the top-down approach predominantly applies projected data to different contexts.

In the past, most vulnerability and impact assessments have applied the top-down approach, typically for defining major projected climate change impacts and prioritizing interventions. However, the bottom-up approach is increasingly recognised to be more practical. In fact, these two approaches are complementary. The political scale at, and specific purpose for which an adaptation decision is taken will determine how much of a “top-down” or “bottom-up” approach is applied. The Representative Concentration Pathway (RCP) scenarios, succeeding the SRES scenarios in IPCC reports, are most likely better able to address both approaches.

Top-down and bottom-up approaches to climate projections. Source: IPCC Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA). 2007. General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Version 2. Available at: http://www.ipcc-data.org/guidelines/index.html#general.



Further information on these approaches is available in: IPCC Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA). 2007. General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Version 2. Available at: http://www.ipcc-data.org/guidelines/index.html#general and in Field, C.B. et al. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Available at https://www.ipcc.ch/report/ar5/wg2/

Historical data

As outlined in section Historical data, historical data can play an important role in evaluating projections and validating the output of global and regional climate models (see box 4). The storage and provision of historical data is also a shared responsibility among stakeholders working at different spatial levels. Many global data centres have a vital stake in archiving and redistributing historical data. In addition, the International Data Rescue Portal (I-DARE) of WMO and the Global Framework for Climate Services (GFCS) serves as a global centre of excellence in recovering climate heritage and making it available in the state of art and digital format for research, applications and climate services before, in some cases, it might be lost forever.[57] It particularly focuses on filling gaps, and extending time-series, of the GCOS Essential Climate Variables. It provides a single-entry point for accessing information on the status of historical climate data being digitized or in need of recovery and digitization so that support can be found to accelerate data rescue. Data rescue also remains a high priority of the WMO Commission for Climatology, as well as the Global Climate Observing System (GCOS) programme (for further information on the Commission and GCOS, see section Enabling data provision through international coordination, quality standards and capacity-building).

Most NMHSs also hold historical data. Many NMHSs carry out significant digitization and quality control of their data records, particularly regarding monthly data on temperature and precipitation, called climatological normal. Other records have at least been scanned. In addition, historical data can in some cases be obtained from other national agencies or extracted from newspapers, farmers' diaries, other government documents and observatory reports.

Regional Climate Centres are encouraged to take up non-operational data services which include data rescue and data homogenization.

Photo: L.W. – Unsplash.

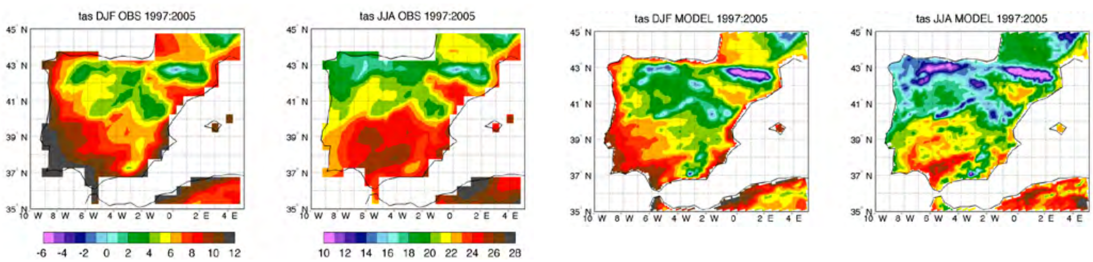
BOX 4:

Using historical data to assess the validity of regional climate model outputs

The EU research project “Bottom-Up Climate Adaptation Strategies Towards a Sustainable Europe” (BASE), which was carried out between 2012-2016 under the EU’s 7th Research Framework Programme, aimed at making experiential and scientific information on adaptation meaningful, transferable and easily accessible to decision-makers at all levels.

An important component of the project was the development of several case studies across Europe which were designed to gather interdisciplinary insights from the local level on costs, benefits, effectiveness, challenges and opportunities of adaptation across sectors.

Five of these case studies (located in Aveiro Coast, Cascais and Alentejo (Spain), Copenhagen and Prague) provided insights into the working of baseline climate change assessments, impacts and adaptation scenarios. For this assessment the case studies used socio-economic (SSP2 and SSP5) and the associated climate (RCP4.5 and RCP8.5) scenarios (up to 2100), considering temperature and precipitation, downscaled to two regions – the Iberian Peninsula and Northern Europe – through a high resolution Regional Climate Model (RCM). The horizontal resolution of this RCM is about 15km.



In order to evaluate the ability of the regional model to reproduce the observed recent climate in terms of 2-meter temperature and precipitation, the model outputs were compared to observations in the case study areas.

Observational data for temperature was obtained from the Climatic Research Unit at the University of East Anglia[58] which provides information on month-by-month variation in climate over the last century or so via time-series datasets. These are based on an archive of monthly mean temperature provided by more than 4000 weather stations distributed around the world and calculated on high-resolution (0.5x0.5 degree) grids. The latest time series generated by the Climatic Research Unit covers the period 1901 – 2017.

Observational data for precipitation was obtained from the daily gridded observational dataset for precipitation, temperature and sea level pressure in Europe (E-OBS),[59] which is a very high resolution data set with a 0.22° regular latitude-longitude resolution. The precipitation observational dataset covered the period 1850-2005.

The outcome of the assessment was that the regional model was able to capture the main features of the observed spatial patterns of temperature and precipitation in both regions (Iberian Peninsula and Northern Europe).

For further information on the BASE case studies refer to https://baseadaptation.eu/sites/default/files/BASE_Deliverable_5_1_0.pdf.

Enabling data provision through international coordination, quality standards and capacity-building

The generation and sharing of increasingly large amounts of adaptation-relevant data by a diversity of actors across scales and cultural backgrounds are only being made possible through a range of international efforts regarding coordination, quality standards and capacity-building, particularly with regard to climate data.

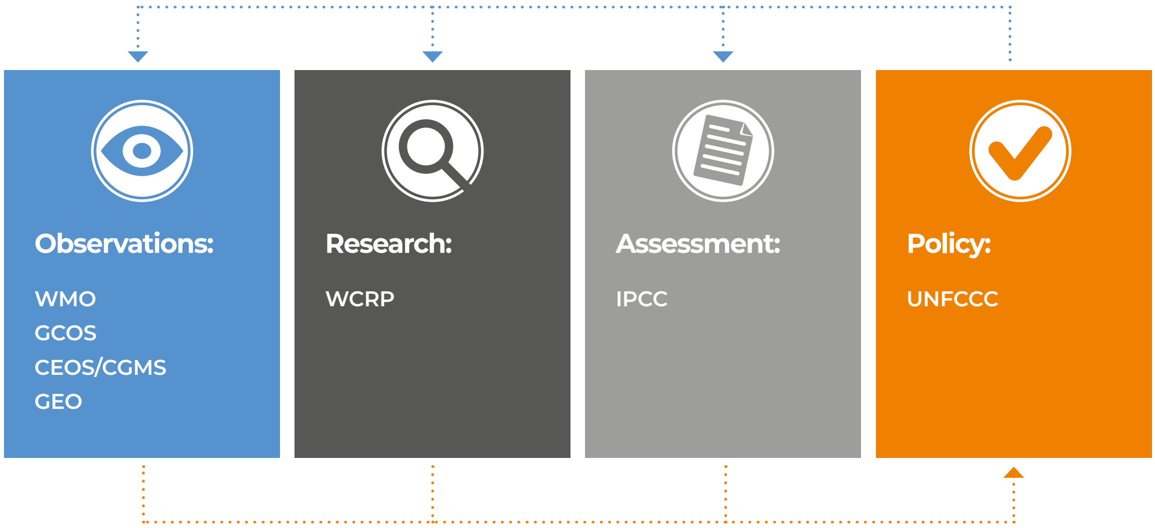
International coordination

A major contribution to the global provision of climate data and derived products are international arrangements for coordination and collaboration. These arrangements have been established under the understanding that no single nation is able to generate the data and information required to understand the global climate system. In contrast, it is to the benefit of all countries and increasingly diversified user needs to consolidate the myriad of local, national and international observing systems into a global observing system and to join forces in improving climate scenarios, models and projections. This requires coordination in terms of interoperability of the systems and compatibility of climate data and products. The international arrangements promote the free and open exchange of climate-relevant data and set standards for data collection, archiving and exchange. They also maintain publicly available databases and promote further research and collaboration in areas where they identify gaps or see opportunities (for example, see box 5 to learn more about the opportunity to exploit big data). Finally, they provide financial and technical support to developing countries in order to enhance their data management capacity.

The arrangements can be grouped into those that primarily contribute to the global observation of climate variables, those that stimulate and coordinate further science in this regard, and those that assess the meaning of observed data for further policy making. Figure 6 depicts the relationship between these areas of work as well as their main representative arrangements. In general, the arrangements are manifold and often overlap in terms of membership, sponsors or joint programmes. The World Meteorological Organization (WMO) stands out as a key driver of many of these arrangements and the coordinator of the data centres that are active in climate analysis, monitoring and prediction (see sections Observational data and Historical data above).

The following is a brief introduction to some of the main arrangements regarding climate observation, science and assessment. Further information on each of them is available in the annex.

FIGURE 6:
The relationship between observations, science, assessment and policy making and the main representative arrangements of these areas of work



Source: Adapted from GCOS Poster on its new implementation plan and its relationship with the UNFCCC Paris Agreement. Available at https://unfccc.int/files/science/workstreams/research/application/pdf/part1_gcos_richter_poster.pdf

Observations

The **Global Climate Observing System (GCOS)** programme, established in 1992, promotes the taking of needed observations by national or international organizations for their own interests as well as for common goals (e.g. under the UNFCCC). The GCOS programme does not directly make observations nor generates data products. In contrast, its overarching aim is to ensure that the observations and information needed to address climate-related issues (e.g. data, climate services and climate indicators) are obtained and made available to all potential users.

The **Working Group on Climate of the Committee on Earth Observation Satellites (CEOS)/Coordination Group for Meteorological Satellites (CGMS)**, established in 2010, is the centre-piece of GEOS' contribution to climate change monitoring. It coordinates and encourages collaboration activities between the world's major space agencies in the area of climate monitoring, particularly regarding the implementation and exploitation of Essential Climate Variable (ECV) time-series.

The **Group on Earth Observation (GEO)** established in 2005, is a partnership of more than 110 national governments and more than 110 participating organizations that improves the availability, access and use of Earth observations to support climate action, disaster risk reduction, and sustainable development. In addition to over 60 Work Programmes,[60] activities and initiatives that address global needs, coordination and knowledge gaps, the GEO community is creating a Global Earth Observation System of Systems (GEOSS). This is to better integrate observing systems and share data by connecting existing infrastructures and using common standards, which has already made accessible more than 400 million open Earth observation data and information resources.[61]

The **Copernicus Climate Change Service (C3S)**, established in 2014, is a component of the Copernicus Earth Observation Programme of the European Union and provides authoritative information about the past, present and future climate in Europe and the rest of the world. It offers free and open access to climate data and information on impacts on a range of topics and sectoral areas as well as tools to transform data into relevant products based on best available science that support adaptation and mitigation policies.

Science

The **World Climate Research Programme (WCRP)** established in 1980, aims at determining the predictability of the climate and the effect of human activities on it. Through the past 40 years, it has implemented a large number of major research and Coupled Model Intercomparison Projects through which it has addressed frontier scientific questions related to the coupled climate system which would have been too large and too complex to be tackled by a single nation, agency or scientific discipline. Through international science coordination and partnership, the WCRP contributes to advancing the understanding of the multi-scale dynamic interactions between natural and social systems that affect climate.

The **World Adaptation Science Programme (WASP)**, which succeeded the **Global Programme of Research on Climate Change Vulnerability, Impacts and Adaptations (PROVIA)** in 2018, facilitates the information exchange and usage amongst stakeholders to advance the science-policy-practice interface in the context of adaptation. It focuses primarily on the provision of climate science and policy products and services to support the UNFCCC, the Intergovernmental Panel on Climate Change (IPCC) and the Green Climate Fund. The WASP joins forces to identify knowledge gaps and leading-edge research priorities and mobilizes and coordinates the broader adaptation community through regular activities like its biennial international conferences.

The **World Climate Services Programme (WCSP)** established in 2011, contributes to improving the availability and access to reliable data, the advancement of knowledge in the area of climate data management and climate analysis, the definition of technical and scientific standards, and the development of activities to support them in countries.

Assessment

The **Intergovernmental Panel on Climate Change (IPCC)** established in 1988, is the UN body for assessing the science related to climate change. It does not conduct its own research but determines the state of knowledge on climate change, its impacts and future risks, and options for adaptation and mitigation through its assessment reports. The next Assessment Report, expected in 2021 and subsequent years, will contain chapters that focus on regional aspects of climate change, including on regional impact and risk assessments and regional projections, but also on the most recent scientific knowledge on impacts, risks and adaptation strategies, both at the global and regional scales. The IPCC has established a Data Distribution Centre (DDC) which provides climate, socio-economic and environmental data, both from the past and also in scenarios projected to the future.

Many of the global arrangements have created regional sub-programmes or initiatives that focus on the particular regional needs. For example, the Group on Earth Observation has four regional initiatives which provide regional data resources and promote collaboration and

BOX 5:

The opportunity of exploiting big data and the data revolution under the Sustainable Development Goal (SDG) process

Big Data refers to a collection of very large and complex data sets, both structured and unstructured, which are difficult to process using traditional data software applications or management tools.[63]

The large-scale availability of big data from diverse sources and new technologies provides grand opportunities to serve many, not few, which is an important component of the "data revolution" which has been called for by the Secretary General to meet the data demands under the Sustainable Development Goal process.[64] Big data is also part of one of the five proposed lighthouse activities of the World Climate Research Programme (WCRP) which is called "Digital Earths". The WCRP lighthouse activities identify the key scientific outcomes that are required from WCRP to ensure climate science is meeting societal needs for robust and actionable regional to local climate information.[65]

There are various innovative solutions to harness big data, particularly climate data, and make it useful for application along the adaptation process. Some of these include the following:

- Cloud computing refers to an on-demand availability of computer system resources, especially data storage and computing power without direct active management by the user. The cloud computing model is becoming the dominant mode of work for most medium and large-scale Earth observation applications;
- Machine learning are methods that make predictions and classifications based on patterns and relations in the input data. Machine learning methods have emerged as the best way to classify Earth observation images for providing e.g. land information;
- Data cubes are organised collections of remote sensing images covering a geographical area, in regular temporal intervals. Data cubes are thus an efficient way to explore satellite image archives spanning years or even decades. Most successful applications of large-scale land classification using machine learning rely on data cubes.

The Secretary-General's Independent Expert Advisory Group on the Data Revolution proposed "a programme for experimenting with how traditional and new data sources (including big data) can be brought together for better and faster data on sustainable development, developing new infrastructures for data development and sharing (such as a 'world statistics cloud'), and supporting innovations that improve the quality and reduce the costs of producing public data."[64]

Several transformative actions would be needed to move the data revolution forward which are also relevant within the climate regime. These include:

- Improving how data are produced and used;
- Closing data gaps to prevent discrimination;
- Building capacity and data literacy in "small data" (or traditional data) and "big data" analytics;
- Modernizing systems of data collection;
- Liberating data to promote transparency and accountability;
- Fostering collection of perception data from people and citizen empowerment, including the right to understand and review how taxpayer money or public sector finances are spent;
- Protecting data rights; and
- Developing new targets and indicators.

coordination among the GEO members of the particular region. The World Climate Research Programme has established a particular framework to evaluate regional climate model performance through a set of experiments aiming at producing regional climate projections through climate downscaling.[62]

Quality standards

As the global cooperation on data generation and use requires the open sharing of data between the many component systems and institutions, standard setting has become indispensable to ensure the highest quality of the data as well as to enable the interoperability of systems and the compatibility of data and products. This ultimately allows the end users to have confidence in the data and to adequately deal with the uncertainties naturally associated with them.

The WMO has adopted a range of global standards, technical regulations and supplementary guides for carrying out observations and providing the required metadata in order to make observations transparent and reduce uncertainties. The principal areas of standardization include: (i) instruments and methods of observation across all components, including surface-based and space-based elements (observations and their metadata); (ii) WMO Information System (WIS) exchange as well as discovery, access and retrieval services; and (iii) data management (data processing, quality control, monitoring and archiving).[66] From time to time, WMO publishes the Guide to Climatological Practices,[67] which describes, in a convenient form, the practices, procedures and specifications that WMO Members are expected to follow when developing climate services. Member countries and organizations of the WMO, in their own interest, have committed to adhere to these standards and to follow the guidelines when establishing and maintaining observing systems and generating, archiving and sharing data. The global observation of the GCOS Essential Climate Variables is also quality controlled according to these standards.

The IPCC Data Distribution Centre (DDC) provides technical guidelines on the selection and use of different types of climate and socio-economic data and scenarios in research as well as climate impact and adaptation assessments with the aim of improving consistency in this regard.[68]

Photo: USGS – Unsplash.

Capacity-building

The generation of data in accordance with the quality standards as well as their interpretation and use requires capacity on the part of data producers as well as end users. This capacity is often lacking, particularly in developing and least developed countries. Many of the international arrangements therefore offer capacity development programmes. These include, for example:

a. The WMO Education and Training Programme with a focus on capacity-building necessary for well-functioning meteorological, hydrological and climate services; [69]

b. The GCOS Cooperation Mechanism which involves focused capacity-building and improvement of infrastructure in least developed countries and small island developing States in order to support critical networks. In some cases, this programme also includes funding of operating expenses. [70]

c. GEO's flagships, initiatives and regional GEOs which focus primarily on institutional strengthening, through online and local training, webinars and other mechanisms. The goal is to help share new knowledge, skills and insights to assist developed and developing countries and regions to make full use of Earth observations for research, policy development, decision making and action.[71]

d. The IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) contributes to building capacity in the use of data and scenarios for climate-related research in developing and transition-economy regions and countries. It does this through the data and guidance provided via the Data Distribution Centre, by convening expert meetings on an as-needed basis, and by maintaining and updating a global list of networks for outreach.[72]

Remaining gaps and challenges

Despite great progress in international collaboration and technologies for data generation, some important gaps and challenges remain regarding the provision and use of data and related products. These include:[73]

a Increasing requirements for adaptation data in terms of timeliness of data supply, availability at various scales, length and stability of data records, and data product generation aggravate compliance with quality standards (e.g. automation increases timeliness of supply, but often reduces quality);

b International arrangements for the coordination of data collection and management mainly focus on data required to describe and understand the climate system, whereby such arrangements are lacking in terms of (socio-economic) data required to assess climate impacts and associated vulnerabilities.

Observational data

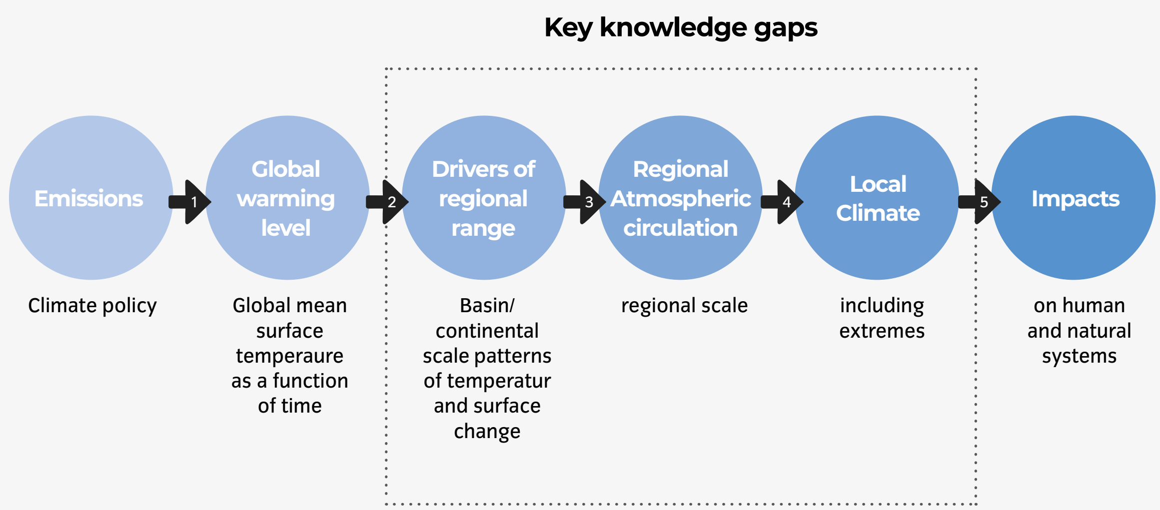
a Coverage of in situ observation systems is insufficient in some regions of the world, particularly in Africa, Asia, and South America.[74] These gaps are most critical in areas where populations are at elevated risks (e.g. small islands, coastal areas) and where local changes have global impacts (e.g. melting of ice-sheet outlet glaciers and its contribution to sea-level rise), but also in least developed countries and remote areas such as the southern ocean and mountainous regions;

b Satellite-based data products can help in increasing observational coverage, but are not always available in the spatial resolution required, i.e. often the spatial resolution is too coarse;

c Downscaling, reanalysis and gridded data techniques assist in closing some of the gaps regarding satellite-based observations. However, they need in situ stations for reference purposes at minimum density and with minimum time series of data which, in some regions, are not available;

d Challenges related to the interpretation of observational data are attributed to, for example, measurement uncertainties, differences in the length of time series, insufficient density of networks, unreliable access to metadata and insufficient samples of extreme events. These challenges lead to uncertainties when using such data;

FIGURE 7:
The global-to-regional knowledge gap (R. Sutton, NCAS. U. Reading, July 2018)



Source: World Climate Research Programme. 2020. WCRP High-level Science Questions and Flagship Workshop, 24 — 26 February 2020, Hamburg, Germany

e. Observations of socio-economic variables are only available independent from climate observations and often lack required quality and continuity due to major deficiencies in national statistical systems.[75] Long and collocated time series of climate observations and socio-economic parameters would be required to identify risks and attribute changes.

Photo: Hidayat Abisena – Unsplash.

Forecast, predictions and projections

a. Outputs of GCMs are often not downscaled to spatial scales relevant for adaptation planning at the local levels (see figure 7);[76]

b. Downscaling through multi-sector impact models that would enable multi-sector/ multi-purpose adaptation measures (e.g. modelling impacts on food security or on coastal areas) is lacking;

c. Deficiencies in local capacity that relate to infrastructural problems, e.g. limited or prohibitively expensive bandwidth that makes data transfers extremely problematic and/or a limited number of trained personnel, are one reason for the lack in downscaled data;

d. Top-down and bottom-up approaches to climate projections for climate impact studies and adaptation planning are not yet being sufficiently integrated;

e. Major challenges remain with regard to the interpretation of projections by the end user which include: inter-model projection scatters, the unforced variability of the climate system that needs to be accounted for, individual model discrimination (weighting) within multi-model ensembles, the optimal sizes of model (super-) ensembles, the added value of different downscaling techniques (dynamical, statistical) as well as related uncertainties, and the different credibility of the climate variables (characteristics) projected by the models. Model projections, if used improperly, may be misleading for climate risk and impact assessments;

f. Projections are also associated with even larger or "deep" uncertainties which relate to future climate drivers, the response of the atmosphere to them considering its chaotic nature, and the effectiveness of adaptation and development measures in terms of reducing vulnerability, considering that different norms and values are at play that might even change within and across generations.

Historical data

a. Recovered datasets of early year observations only cover sparse areas of the globe and reanalysis can only in part be used to make up for remaining gaps;[77]

b. Digitization has mostly been undertaken only for monthly station averages, whereas daily or sub daily station and marine data would also be important to serve several purposes, including better understanding of processes, capturing extremes, sea surface temperature analysis and reanalysis, and development of climate services;[78]

c. Uncertainties with regard to historical data are linked to their quality in terms of standards of measurement, processing and storage, particularly in cases where appropriate metadata is missing.

Opportunities to further enhance data provision and use

A number of opportunities exist to overcome some of the gaps and challenges and to further enhance data provision and use for effective adaptation.

Enhancing provision

There is great potential to enhance the provision and harnessing of data for adaptation by focusing on the following three issues: (a) exploiting the potential of big data and future-oriented technologies; (b) ensuring open access to existing data; and (c) closing remaining data gaps.

Exploiting big data

Great potential lies in exploiting the opportunities being provided by the big data generated by satellite observations, climate models and climate reanalysis, as well as by national statistical systems, through intelligent and innovative solutions such as artificial intelligence, machine learning, internet of things, data cubes, computational modelling and cloud and edge computing (see box 5). If algorithms, tools, methods and knowledge were shared in addition to sharing data, the world could move from open data to open science which would particularly benefit developing countries. They should be supported in applying these technologies including as one way of closing existing gaps in, for example, observational data coverage.

Ensuring open access

Open international data exchange and access to all existing data is key for understanding climate processes and impacts and finding effective responses without duplicating efforts.

For this to happen, countries, institutions and commercial or development organizations should be encouraged to lift any restrictive data policies particularly concerning historical data series, transboundary or local data. In addition, approaches to recover historical data at large scale in a coordinated, cost-effective manner should be further enhanced.

Regarding socio-economic data, national statistical offices and systems could be encouraged to facilitate access to existing adaptation-relevant statistics through following the recommendations described in box 6.

Ensuring the interoperability of observing systems and compatibility of climate data despite the multiplicity of national institutional arrangements for making the required measurements would be another way of contributing to the global data exchange.

Finally, international processes such as those under the climate change, disaster risk reduction and sustainable development regimes as well as sectors should be encouraged to closely cooperate regarding data generation and sharing, including with regard to socio-economic data, which could avoid duplicating efforts and encourage the exchange of experience.

Closing data gaps

A three-fold approach could help in closing persisting data gaps, particularly at the regional to local levels, which still hinder systematic observation of the climate system and understanding its impacts in some areas of the world:

a. First, satellite-based observation systems, reanalyses and global circulation models need to move towards generating higher spatial resolution products;

b. Second, in-situ observational coverage needs to be expanded to close gaps that can neither be filled by satellite observations nor by reanalysis or other innovative techniques. For this, further investments are needed to improve the in-situ observations made by a range of parties: NMHSs, non-NMHS agencies such as agricultural departments, and even the general public (citizen scientists). Long-term funding flows should be generated from a combination of national and international sources that would allow for the installation of new in situ observing systems and the proper and sustainable management of existing systems. In this context, the discontinuation of observing systems in situations where short-term research funding is exhausted, but the systems are not yet ready to be transferred to operational institutions with more sustainable financial flows, should be avoided;

C Finally, co-producing and bringing together data and information from different disciplines and scales as well as through all available approaches and methods could be an opportunity to close key knowledge gaps at the regional to local levels.[79] This could be enabled through e.g. the development of new adaptation-relevant official statistics (see box 6) and the development of local capacity needed to enable long and collocated time series of climate observations and socio-economic parameters which would allow for local and long-term impact studies.

Enhancing capacity

In countries where appropriate capacity is lacking, enhancing the capacity of those that generate and manage data as well as of those that need to interpret and use it, would greatly contribute to the provision of high-quality, locally relevant data and its effective application.

As a starting point, if the communication to and in countries on the value of observations as well as statistics and derived data products for adaptation was improved, the uptake of data that is already available could be increased.

On the generation and management side, overcoming infrastructural problems, e.g. limited or prohibitively expensive bandwidth, would facilitate the generation of locally relevant data products and the international sharing of data. Increasing the number of trained personnel in NMHSs and national statistical centres regarding the correct generation, downscaling, storage and management of climate and socio-economic data would improve the amount and quality of data available for local adaptation planning as well as international studies. Adopting a more holistic vision on capacity development, involving the co-design and co-production of capacity development efforts, could assist in better matching supply and demand. The exchange of experience through South-South cooperation also bears great potential in this regard and should be encouraged. These could add value to the capacity development programmes offered by some of the international arrangements as described in section Capacity-building.

On the user side, enhancing data literacy is as much needed as support in effectively managing the uncertainty that is related to the interpretation of the various data and their products. Approaches as discussed in section Managing uncertainty as well as the provision of climate services play important roles in this regard. In addition, national or sub-national dialogues with all relevant stakeholders on the interpretation of the data, which take into account different values and perspectives, are essential for taking sustainable adaptation decisions and their conduct should be encouraged and trained.

Managing uncertainty

Section Remaining gaps and challenges has summarized existing gaps and challenges in the provision and use of data for adaptation. As mentioned, these often lead to great uncertainties among end users of adaptation data.

Most of these types of uncertainty, particularly those related to climate scenarios, will persist despite great improvements in terms of standardization of data generation and management. However, such uncertainties do not need to delay adaptation action since a variety of approaches exists that help in taking wise and timely decisions in a setting where complete knowledge is impossible. The device is to manage uncertainty, not to try to overcome it and end users should receive support in doing so.[81]

The IPCC recommends **iterative risk management** as a general approach to decision-making in complex situations, where multiple climatic and non-climatic influences are changing over long timeframes. This approach is characterized by ongoing iterations of assessment, action, reassessment, and response, and continuous monitoring and learning.[82]

The use of **scenarios** helps to describe various ways in which the future may unfold. It contributes to learning and discussion and facilitates knowledge exchange which assists in exploring the solutions space involving strategic actions as well as options planning and governance.[83]

Participatory approaches are valuable tools to evaluate the plausibility of projections (top-down information) by acquiring complementary, mostly qualitative, information from climate experts, (sector) experts and stakeholders at the local level (bottom-up) (see box 3 and section Quantitative and qualitative data). This is particularly advisable in cases where deep uncertainties are involved.

An often-recommended method to appraise adaptation options and to deal with gaps in quantitative data is **multi-criteria analysis** (MCA). This is a systematic method for assessing and scoring options against a range of decision criteria, some of which are expressed in physical or monetary units, and some are qualitative. The various criteria can then be weighted to provide an overall ranking of options. These steps are undertaken using stakeholder consultation and/or expert input. Specific criteria can be included that address uncertainty.[84]

BOX 6:

UNECE's recommendations on climate change related statistics

As part of its leading role in global efforts to advance the development of official statistics for climate analysis and global reporting, the United Nations Economic Commission for Europe (UNECE) has published the first ever Recommendations on Climate Change-Related Statistics in 2014.[80] These contain recommendations on how to improve the access to and utility of existing national environmental, social and economic statistics as well as on how to develop new ones that would support the measuring of climate impacts as well as mitigation and adaptation efforts.

Regarding the facilitation of access to existing statistics the recommendations include:

› Creating national forums or events for producers and users of climate change-related statistics which would allow for the identification of relevant existing statistics as well as further needs;

› Promoting the use of existing official statistics which would avoid duplication of data collection activities;

› Providing access to climate change-related statistics using National Statistical Offices' dissemination channels, e.g. by combining official statistics with climate data held by other organizations or by creating "portals" for climate-related statistics in cooperation with, for example, scientific organizations;

› Improving access to microdata for researchers working on climate change through approaches that would enable access whilst preserving confidentiality of respondent's data.

Regarding the improvement of the utility of existing statistics the recommendations include:

› Reviewing statistical programmes and data collections from the viewpoint of the data needs of climate change analysis, e.g. with regard to their level of detail, within regular periodic reviews of the statistical systems;

› Addressing challenges in matching data from different statistical domains and regarding the lack of coherence among data sets by e.g. increased methodological and operational harmonization between socio-economic and environmental data;

› Geo-referencing all relevant data to support analysis of the spatial dimension of data linked to climate change;

› Producing statistics for new geographical areas, such as coastal and urban areas or areas prone to flooding or drought, particularly in developing countries, e.g. by obtaining data from administrative sources that might provide information at finer levels of resolution than is possible through sample surveys.

Regarding the development of new statistics the recommendations include:

› Improving data for analysing drivers of climate change by connecting economic and climate change-related information, e.g. through the implementation of a System of Environmental-Economic Accounting Central Framework (SEEA-CF) which should be an important strategic goal for National Statistical Offices and be supported by international statistical organizations;

› Developing specific statistics to address climate change adaptation and adaptive capacity, for example those that can measure resilience, risks and vulnerability of population groups and societal preparedness to withstand the adverse impacts of climate change – e.g. populations at risk from natural disasters or from climate change-related poverty;

› Considering how to contribute to the on-going efforts to monitor biodiversity and ecosystems, e.g. through the establishment of baseline estimates of ecosystems in cooperation with environmental protection agencies.

Since 2015, UNECE has organized an annual Expert Forum on Climate Change Statistics which provides a key international platform to further support this work.

Further information on these activities is available at http://www.unece.org/stats/climate.html

Another widespread tool to deal with deep uncertainties is **robust decision-making** (RDM) which aims at identifying robust, instead of optimal, options or strategies which perform well over a wide range of futures. This tool is particularly useful for mid- to long-term decision-making when little or no probabilistic information is available.[85] In general, it is advisable to concentrate on tangible impacts (e.g. hard protective infrastructures) when the level of uncertainty is low and to opt for increasing general adaptive capacities (e.g. diversifying income strategies, increasing efficiency of water usage), when facing higher levels of uncertainty.[86]

Finally, **spatial and temporal analogues** (see also section Historical data) are methods that can help decision-makers in learning from other regions with similar characteristics or from past events in order to evaluate the climatic conditions predicted or projected for their own region.[87]

Across all of these approaches and tools, a transparent **communication** of the levels and types of uncertainty as well as the provision of metadata for all types of generated data and their products remains essential to support realistic decision-making. Decision makers are commended to take this information into account.

Providing climate services

Observational, projected and historical data provide a solid scientific basis for the adaptation process. However, as previous sections have pointed out, they are meaningless without being interpreted to derive decision-relevant information for policy makers and those people potentially affected by the risks. Responding to the need for a bridge between scientifically generated data supply and the demand of end users for information that supports decision-making in their particular adaptation context has led to the establishment of the concept of climate services.

Climate services connect natural and socio-economic data and modelling with practice by transforming climate-related data – together with socio-economic variables, e.g. on agricultural production, health trends, population distribution in high-risk areas– into customised products such as projections, trends, economic analysis and services to the user communities.[88] They help users to identify from the vast array of available datasets those that meet their needs, interpret the various data products and clearly communicate the uncertainties related to them.

The provision and use of climate services requires the cooperation of many different actors as well as related skills and capacity in order to translate petabytes of available data into useful end products. Data providers need to be able to adhere to global quality standards in order to provide data that is authoritative, service providers such as regional organizations must be able to transform these data into products that meet increasingly specific user needs; and end users such as consultancies and local decision-makers need to be able to interpret the data with the help of their local knowledge as a basis for decision-making.

The **Global Framework for Climate Services (GFCS)**, established in 2009 is a UN-led initiative spearheaded by WMO to guide the development and application of science-based climate information and services. Through its five components, the GFCS provides, among others, observational and projected climate data from national and international databases, combined with socio-economic variables, as needed, and related products such as vulnerability and risk assessments, maps, and long-term projections.[89]

One of its components is a user interface platform, through which users can communicate their needs and ensure that climate services respond to them, thus promoting the co-production of knowledge between providers and end users. Another important component is capacity development which will support the systematic development of the institutions, infrastructure and human resources needed for effective climate services. Priority is thereby given to climate-vulnerable developing countries. Capacity is aimed to be built in the areas of governance, management, human resources development, education and training, leadership, partnership creation, science communication, service delivery, resource mobilization and infrastructure.[90]

The GFCS also facilitates regional workshops that address gaps and needs related to the development and application of climate services at the regional level, and defines respective implementation priorities.[91] Besides the Regional Climate Centres designated by WMO, other regional organizations and research centres play an important role in contributing adaptation data and services to the countries of a region (see case study in box 7).[92]

National Meteorological and Hydrological Services also act as implementers of the GFCS, for example, by mainstreaming their services into national processes such as the process to formulate and implement NAPs. For this, they are encouraged to develop National Frameworks for Climate Services (NFCS) as complements to NAPs.[93]

Despite its great potential, climate services is still a young field with mostly uncoordinated actors and activities. Better coordination of research and programming on climate services and appropriate funding are required to increase their effectiveness in enhancing the use of adaptation data. Once fully developed, climate services could form the required bridge between the data supply of the scientific community and the increasing demands for specific adaptation information from decision makers.

BOX 7:

Providing climate services by connecting space to village in the Hindu Kush Himalaya region

SERVIR is a partnership of the NASA, the US Agency for International Development (USAID) and leading technical organizations which helps developing countries in all regions of the world use satellite data to address challenges in food security, land use and natural disasters. The International Centre for Integrated Mountain Development (ICIMOD) implements the initiative in the Hindu Kush Himalaya (HKH) region (Afghanistan, Bangladesh, Myanmar, Nepal, and Pakistan).

SERVIR-HKH activities include:

- Using data from a collection of Earth observation satellites, ground-based data and advanced geospatial information technology in innovative ways to support evidence-based decision-making in four thematic areas: agriculture and food security; land cover, land use change and ecosystems; water resources and hydro-climatic disasters; and weather and climate services;
- Regarding weather and climate services: implementing weather research and long-and short-term forecasting models and deploying climate services for consumption across other service areas (agriculture and droughts); monitoring extreme weather in the HKH;
- Building and institutionalizing technical capacity of decision makers, partner institutions and individuals to integrate Earth observation information and geospatial analysis into their decision-making, planning, and communication processes;
- Making available all data, tools and applications online on the SERVIR-HKH website (servir.icimod.org) and on the Mountain Geoportal (geoportal.icimod.org);
- Leveraging partnerships by engaging stakeholders in data sharing and management, developing and adopting standards of practice and developing or strengthening platforms for sustained upscaling and product uptake; strategic private sector partnerships with technology companies that provide access to cutting-edge technologies;
- Supporting the integration of gender concerns in its design and implementation as well as its monitoring and evaluation processes across its services.

More information on the initiative is available at servir.icimod.org or the global SERVIR website servirglobal.net.

Conclusions

High-quality climate and socio-economic data are essential at all stages of the adaptation process. A great amount of data already exists and innovative solutions are underway to exploit the big data that is yet to be produced. The global task is to make the information from this data available in a form and at scales that supports adaptation decision making at all levels and in all regions of the world. Meanwhile, uncertainties will remain an inherent part of using data for decision-making and will need to be managed, not tried to overcome.

Photo: Joel Vodell – Unsplash.

Annex:

International arrangements for coordination and collaboration on the provision of climate data and services

International arrangements for the coordination and collaboration on the provision of climate data can be grouped into those that primarily contribute to the global observation of climate variables, those that stimulate and coordinate further science in this regard, those that assess the meaning of observed data for further policy making, and those that enhance the provision of climate services.

Observations

World Climate Services Programme (WCSP)[94]

The WCSP, established in 2011 following a restructuring of the components of the World Climate Programme[95], contributes to improving the availability and access to reliable data, advancement of the knowledge in the area of climate data management and climate analysis, definition of the technical and scientific standards, and development of activities to support them in countries. Climate data management will include data rescue, development and coordination of a global climate data management system compatible with the WMO Information System (WIS). The WCSP coordinates (i) the development of high-quality climate datasets and related data management systems; (ii) systems, tools and products for monitoring and analysis of the climate system at various scales; (iii) methods and tools for operational climate predictions; and (iv) consensus-based climate updates and climate watches including the Statements on the State of the Global Climate. It facilitates (i) interactions between operational and research communities; (ii) the development of networks of global, regional and national climate centres; and the definition and standardization of operational climate prediction products. It also aims at developing and implementing climate services at the national level.

Global Climate Observing System (GCOS)[96]

The GCOS, established in 1992, stimulates, encourages, coordinates and facilitates the taking of needed observations by national or international organizations to support their own requirements as well as common goals (e.g. under the UNFCCC). Its expert panels have defined 54 Essential Climate Variables (ECVs) which are required to systematically observe Earth's changing climate. GCOS provides an operational framework for integrating and enhancing the observational systems of participating countries and organizations into a comprehensive system focused on the requirements for climate issues, including data, climate services and climate indicators. The GCOS programme does not directly make observations nor generate data products. In contrast, its overarching aim is to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. It regularly publishes status reports of the global climate observing system as well as implementation plans containing detailed recommendations for its improvement, in particular regarding the ECVs and in consideration of the monitoring needs of the UNFCCC, other conventions and multilateral agreements. For each ECV, a factsheet is available which includes a list of openly accessible data sets with worldwide coverage.

Working Group on Climate of the Committee on Earth Observation Satellites (CEOS)/Coordination Group for Meteorological Satellites (CGMS)[97]

The CEOS/CGMS Working Group on Climate, established in 2010, is the centre-piece of GEOS' contribution to climate change monitoring. It coordinates and encourages collaboration activities between the world's major space agencies in the area of climate monitoring, particularly regarding the implementation and exploitation of Essential Climate Variable (ECV) time-series. It also supports the work of GCOS in defining and delivering the ECVs required by the UNFCCC and supports the overall relation of CEOS to the UNFCCC, its subsidiary bodies, and to the Intergovernmental Panel on Climate Change (IPCC). WGClimate promotes openness, traceability, and access to climate data, codes, and products. The WG also pays utmost attention to the quality control and uncertainty assessment of the resulting products. Finally, the group coordinates with existing in situ networks to integrate complementary measurements and observations.

Group on Earth Observation (GEO)[98]

The CEOS/CGMS Working Group on Climate, established in 2010, is the centre-piece of GEOS' contribution to climate change monitoring. It coordinates and encourages collaboration activities between the world's major space agencies in the area of climate monitoring, particularly regarding the implementation and exploitation of Essential Climate Variable (ECV) time-series. It also supports the work of GCOS in defining and delivering the ECVs required by the UNFCCC and supports the overall relation of CEOS to the UNFCCC, its subsidiary bodies, and to the Intergovernmental Panel on Climate Change (IPCC). WGClimate promotes openness, traceability, and access to climate data, codes, and products. The WG also pays utmost attention to the quality control and uncertainty assessment of the resulting products. Finally, the group coordinates with existing in situ networks to integrate complementary measurements and observations.

Copernicus Climate Change Service (C3S)[99]

The C3S, established in 2014, is a component of the Copernicus Earth Observation Programme of the European Union and provides authoritative information about the past, present and future climate in Europe and the rest of the World. It offers free and open access to climate data and information on impacts on a range of topics and sectoral areas as well as tools to transform data into relevant products based on best available science that support adaptation and mitigation policies. Its data and information are offered through a Climate Data Store which is designed to enable users to tailor services to more specific public or commercial needs. C3S relies on climate research carried out within the World Climate Research Programme (WCRP) and responds to user requirements defined by the Global Climate Observing System (GCOS). C3S provides an important resource to the Global Framework for Climate Services (GFCS). It is implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Commission. The majority of C3S service elements are implemented by about 260 companies and organisations across Europe, which are selected based on competitive Invitations To Tender (ITTs). The programme derives maximum benefit from the existing infrastructure and knowledge of meteorological and environmental services across European countries and closely cooperates with them.

Science

World Climate Research Programme (WCRP)[100]

The WCRP, established in 1980 as part of the World Climate Programme, facilitates the analysis and prediction of Earth system variability and change for use in an increasing range of practical applications, including the design of adaptation and mitigation strategies. The two overarching objectives of the WCRP are (i) to determine the predictability of climate; and (ii) to determine the effect of human activities on climate. Three of its five focus areas are of great relevance to adaptation and include the observation of changes in the components of the Earth system, the assessment and attribution of significant trends in global and regional climates and the development and improvement of numerical models that are capable of simulating and assessing the climate system for a wide range of space and time scales. Through international science coordination and partnership, the WCRP contributes to advancing the understanding of the multi-scale dynamic interactions between natural and social systems that affect climate. During the past 40 years, the WCRP has implemented a large number of major research and Coupled Model Intercomparison Projects and thus addressed frontier scientific questions related to the coupled climate system which would have been too large and too complex to be tackled by a single nation, agency or scientific discipline.

World Adaptation Science Programme (WASP)[101]

The WASP, which succeeded the Global Programme of Research on Climate Change Vulnerability, Impacts and Adaptations (PROVIA) in 2018, is hosted by the UN Environment Programme. It focuses primarily on the provision of climate science and policy services to support UNFCCC, Intergovernmental Panel on Climate Change (IPCC) and the Green Climate Fund. The WASP's aim is to promote science for climate change adaptation policy and action by (i) advancing the adaptation research to bridge knowledge gaps for decision making and action; (ii) facilitating knowledge transfer and sharing, and (iii) better linking the science to policy, finance and actions.

Assessment

Intergovernmental Panel on Climate Change (IPCC)[102]

The IPCC, established in 1988, is the UN body for assessing the science related to climate change. It does not conduct its own research but determines the state of knowledge on climate change, its impacts and future risks, and options for adaptation and mitigation through its assessment reports. The next Assessment Report, expected in 2021 and subsequent years, will contain chapters that focus on regional aspects of climate change, including on regional impact and risk assessments and regional projections, but also on the most recent scientific knowledge on impacts, risks and adaptation strategies, both at the global and regional scales. The IPCC has established a Data Distribution Centre (DDC) which provides climate, socio-economic and environmental data, both from the past and also in scenarios projected to the future. These datasets are generated by different research groups and then supplied to the DDC where they undergo a quality check before being provided to the general public. One of the clear objectives of the DDC is to provide a consistent set of up-to-date scenarios of changes in climate and related environmental and socio-economic factors and, through their wide accessibility, encourage their application by new studies so that these may feed easier into the IPCC assessment process.

Service

Global Framework for Climate Services (GFCS)[103]

The GFCS, established in 2009, is a UN-led initiative spearheaded by WMO to guide the development and application of science-based climate information and services in support of decision-making in climate sensitive sectors at national, regional and global levels. With its various components and contributing programmes, it may serve as the primary go-to framework that may support adaptation decision-making at global to national levels, once fully implemented.[104] The services which are coordinated under the framework involve high-quality data from national and international databases on a selection of climate variables[105] as well as maps, risk and vulnerability analyses, assessments, and long-term projections and scenarios. Depending on the user's needs, these data and information products may be combined with socio-economic variables, such as agricultural production, health trends, population distributions in high-risk areas, and road and infrastructure maps for the delivery of goods.

The GFCS has five components: (i) a user interface platform, through which users can communicate their needs and ensure that climate services respond to them; (ii) a climate services information system (CSIS), forming the operational core of the framework, which produces and distributes climate data and information products that address user needs, initially in the five priority areas agriculture and food security, disaster risk reduction, energy, health and water; (iii) observations and monitoring which promotes and coordinates the essential infrastructure for generating the necessary climate data; (iv) research, modelling and prediction, through which the science that is needed for improved climate services will be advanced; and (v) capacity development which will support the systematic development of the institutions, infrastructure and human resources needed for effective climate services. The GFCS promotes the free and open exchange of climate-relevant observational data and has defined the building of capacity in climate vulnerable developing countries as one of its priorities.

Notes

1 Article 7, paragraphs 5, 7(a) and (c) of the Paris Agreement.
2 Decision 1/CP.16, paragraph 14 (h) and (i).
3 Decision 1/CP.16, paragraphs 15-18.
4 Field, C.B. et al. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Available at https://www.ipcc.ch/report/ar5/wg2/.
5 Note that this paper focuses primarily on climate and socio-economic data as opposed to information. Climate data, for example, is defined as "historical and real-time climate observations along with direct model outputs covering historical and future periods" (WMO. 2014. Implementation Plan of the Global Framework for Climate Services.). However, as raw observations and model outputs need to be processed into information in order to be useful for adaptation decision-making, the paper also touches upon data products and climate services which represent a fluent transition from pure data to climate information and knowledge.
6 As agreed by Parties to the UNFCCC in decision5/CP.17, paragraph 2.
7 Scales refer to analytical dimensions used to study adaptation and may include spatial, temporal, institutional, or jurisdictional scales. Each scale can be comprised of multiple levels. With regard to spatial scales these range from local to global. With regard to temporal scales these range from minutes to centuries. Source: Field, C.B. et al. 2014. Technical summary. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Available at https://www.ipcc.ch/report/ar5/wg2/.
8 Note that this paper will focus on data for the adaptation of socio-economic systems and will not include specific data requirements to assess climate risks for natural systems and their adaptation needs.
9 More information on GCOS and the ECVs is available at https://gcos.wmo.int/.
10 For a detailed overview of existing ECV data records see https://gcos.wmo.int/en/essential-climate-variables and http://climatemonitoring.info/ecvinventory/.
11 Based on IPCC TGICA, 2007, General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Available at http://www.ipcc-data.org/guidelines/index.html#general which disseminates socio-economic data and information describing the present-day situation which serves as the basis to derive socio-economic scenarios for the future.
12 The descriptions are based on the following sources: IPCC TGICA, 2007, General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Available at http://www.ipcc-data.org/guidelines/index.html#general and WMO. 2018. Guide to Climatological Practices (WMO-No. 100). Geneva. Available at http://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.php.
13 Field, C.B. et al. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Available at https://www.ipcc.ch/report/ar5/wg2/.
14 IPCC Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA). 2007. General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Version 2. Available at: http://www.ipcc-data.org/guidelines/index.html#general.
15 Website of the International Data Rescue Portal (I-DARE), available at https://idare-portal.org/content/importance-dare.
16 Ford, J.D. et al. 2010. Case study and analogue methodologies in climate change vulnerability research. Wiley Interdisciplinary Reviews: Climate Change, 1(3). 374–92.
17 Field, C.B. et al. 2014. Technical summary. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Available at https://www.ipcc.ch/report/ar5/wg2/.
18 UNEP. 2013. PROVIA Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change. Consultation Document.
19 GCOS, 195. Status of the Global Observing System for Climate. WMO, 2015. Available at https://library.wmo.int/doc_num.php?explnum_id=7213.
20 Article 7, paragraphs 1 and 14 (c) and (d) of the Paris Agreement.
21 The Adaptation Committee has been mandated to develop such approaches and methodologies. Further information on this ongoing work is available at the Committee's website (https://unfccc.int/Adaptation-Committee) and at https://unfccc.int/topics/adaptation-and-resilience/groups-committees/adaptation-committee/joint-ac-and-leg-mandates-in-support-of-the-paris-agreement.
22 GCOS: Status of the Global Observing System for Climate. WMO, 2015. Available at https://library.wmo.int/doc_num.php?explnum_id=7213.
23 WMO. 2018. Guide to Climatological Practices (WMO-No. 100). Geneva. Available at http://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.php.
24 https://public.wmo.int/en/our-mandate/climate/regional-climate-centres.
25 For a full list of designated centres refer to https://cpdb.wmo.int/regions/africa/regional_centres.
26 CEOS and ESA, 2015, Satellite Earth Observations In Support Of Climate Information Challenges – CEOS Earth Observation Handbook for Cop21. Available at <http://eohandbook.com/cop21/files/CEOS_EOHB_2015_COP21.pdf>.
27 Statement Reporting on Progress by the Committee on Earth Observation Satellites (CEOS) and the Coordination Group for Meteorological Satellites (CGMS) on Coordinated Response to UNFCCC Needs for Global Observations, 51st Session of the of the Subsidiary Body for Scientific and Technological Advice (SBSTA), 2-9 December 2019, Madrid, Spain. Available at https://www4.unfccc.int/sites/SubmissionsStaging/Documents/201911281201---CEOS-CGMS_Statement_for_SBSTA51_v1.1_20191023.pdf.
28 For a full list of global data centres refer to https://community.wmo.int/meetings/world-data-centres.
29 See the initiative ISeeChange, in collaboration with NASA's Orbiting Carbon Observatory Mission <http://crowdandcloud.org/iseechange.>
30 A detailed analysis of the potential of these products to fill gaps in global observations is beyond the scope of this paper and needs to be accessed in more specific literature that is published, for example, by the GCOS programme.
31 Further information on climate products is available at WMO. 2018. Guide to Climatological Practices (WMO-No. 100). Geneva. Available at http://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.php.
32 The construction and evaluation of indices specific to climate change detection, climate variability and climate extremes is discussed in Guidelines on Analysis of Extremes in a Changing Climate in Support of Informed Decisions for Adaptation (WMO/TD-No. 1500, WCDMP-No. 72).
33 GCOS, 195. Status of the Global Observing System for Climate. WMO, 2015. Available at https://library.wmo.int/doc_num.php?explnum_id=7213.
34 See, for example, the Demographic Explorer for Climate Adaptation (DECA) of the UN Population Fund, available at nijel.org/un_popclimate/deca.
35 For the goals, targets and global indicators see https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf.
36 https://unstats.un.org/sdgs/.
37 Report of the Secretary General on Follow up and Review of the 2030 Agenda. A/70/684.
38 UNDG. 2017. Guidelines to Support Country Reporting on the Sustainable Development Goals. Available at https://unsdg.un.org/resources/guidelines-support-country-reporting-sustainable-development-goals.
39 Available at http://www.unece.org/index.php?id=37166.
40 Further information on these activities is available at http://www.unece.org/stats/climate.html.
41 https://community.wmo.int/global-producing-centres-long-range-forecasts.
42 For a full list of GPCLRFs and the data products required from them refer to https://community.wmo.int/global-producing-centres-long-range-forecasts.
43 WMO. Climate Services for Supporting Climate Change Adaptation. Supplement to the Technical Guidelines for the NAP Process. Available at https://www4.unfccc.int/sites/NAPC/Documents%20NAP/Supplements/WMO_climate%20change%20services%20for%20climate%20change%20adaptation.pdf.
44 https://public.wmo.int/en/our-mandate/climate/regional-climate-outlook-products.
45 https://www.un.org/development/desa/dpad/publication/world-economic-situation-and-prospects-2019/.
46 Latest revision (2019) available at https://population.un.org/wpp/.
47 Latest revision (2018) available at https://population.un.org/wup/.
48 https://www.imf.org/en/Publications/WEO.
49 www.oecd-ilibrary.org/economics/oecd-economic-outlook_16097408.
50 https://stats.oecd.org/Index.aspx?DataSetCode=POPPROJ#.
51 https://www.metoffice.gov.uk/weather/climate-change/organisations-and-reports/met-office-hadley-centre/index.
52 https://climate.copernicus.eu/.
53 Further information on the RCP approach is available at https://www.nature.com/articles/nature08823 and a good description of models and scenarios is available at: https://www.climatescenarios.org/primer/.
54 More information on the SSPs is available at https://iiasa.ac.at/web/home/research/researchPrograms/Energy/SSP_Scenario_Database.html.
55 Further information on the ISIMIP is available at https://www.isimip.org/about/#mission.
56 http://www.ipcc-data.org/. For a good description of models and scenarios see also: https://www.climatescenarios.org/primer/.
57 https://idare-portal.org/.
58 https://catalogue.ceda.ac.uk/uuid/3f8944800cc48e1cbc29a5ee12d8542d

59 https://www.ecad.eu/download/ensembles/download.php
60 2020-2022 GEO Work Programme: http://www.earthobservations.org/geoss_wp.php.
61 GEOSS Portal: https://www.geoportal.org/?f:dataSource=dab.
62 https://www.cordex.org/about/what-is-regional-downscaling/.
63 Provost, F. and T. Fawcett. 2013. Data Science for Business.
64 UN. 2014. World that Counts: Mobilising the Data Revolution for Sustainable Development, a Report by the Secretary-General's Independent Expert Advisory Group on the Data Revolution.
65 World Climate Research Programme. 2020. WCRP High-level Science Questions and Flagship Workshop, 24 — 26 February 2020, Hamburg, Germany.
66 WMO Integrated Global Observing System (WIGOS) website. Available at https://public.wmo.int/en/resources/bulletin/wmo-integrated-global-observing-system-wigos.
674 Available at https://public.wmo.int/en/resources/library/guide-climatological-practices-wmo-100.
68 IPCC Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA). 2007. General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Version 2. Available at: http://www.ipcc-data.org/guidelines/index.html#general.
69 https://public.wmo.int/en/programmes/education-and-training-programme.
70 GCOS, 195. Status of the Global Observing System for Climate. WMO, 2015. Available at https://library.wmo.int/doc_num.php?explnum_id=7213.
71 https://www.earthobservations.org/cb.php.
72 IPCC TGICA website https://archive.ipcc.ch/activities/tgica.shtml.
73 The summary of the gaps and challenges is mainly based on GCOS, 195. Status of the Global Observing System for Climate. WMO, 2015 which contains further details on each of them. It is available at https://library.wmo.int/doc_num.php?explnum_id=7213.
74 GCOS-200. The Global Observing System for Climate: Implementation Needs. WMO, 2016. Available at https://library.wmo.int/doc_num.php?explnum_id=3417.
75 UNDG. 2017. Guidelines to Support Country Reporting on the Sustainable Development Goals. Available at https://unsdg.un.org/resources/guidelines-support-country-reporting-sustainable-development-goals.
76 Note that there are, however, several global initiatives that are focusing on advancing the science and application of regional climate downscaling, e.g. CORDEX of the World Climate Research Programme.
77 GCOS, 195. Status of the Global Observing System for Climate. WMO, 2015. Available at https://library.wmo.int/doc_num.php?explnum_id=7213.
78 Ibid.
79 This has also been identified as one of the lighthouse activities agreed upon by the World Climate Research Programme in 2020. WCRP lighthouse activities identify the key scientific outcomes that are required from WCRP to ensure climate science is meeting societal needs for robust and actionable regional to local climate information. More information is available in the following report: World Climate Research Programme. 2020. WCRP High-level Science Questions and Flagship Workshop, 24 to 26 February 2020, Hamburg, Germany.
80 United Nations Economic Commission for Europe. 2014. Conference of European Statisticians Recommendations on Climate Change-Related Statistics. Available at http://www.unece.org/fileadmin/DAM/stats/publications/2014/CES_CC_Recommendations.pdf.
81 Kropp, J. and M. Scholze. 2009. Climate Change Information for Effective Adaptation. A Practitioner's Guide. GIZ.
82 Field, C.B. et al. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Available at https://www.ipcc.ch/report/ar5/wg2/.
83 Field, C.B. et al. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Available at https://www.ipcc.ch/report/ar5/wg2/.
84 Van Ierland, E.C. , de Bruin, K. and Watkiss, P. 2013. Multi-Criteria Analysis: Decision Support Methods for Adaptation, MEDIATION Project, Briefing Note 6. Available at https://www.weadapt.org/sites/weadapt.org/files/legacy-new/knowledge-base/files/742/526a3d410cd11decision-support-methods-for-climate-change-adaptation-6-multi-criteria-analysis-summary-of-methods-and-case-study-examples-from-the-mediation-project.pdf.
85 Watkiss, P. and Dynzynski, J. 2013. Robust Decision Making: Decision Support Methods for Adaptation, MEDIATION Project, Briefing Note 3. Available at https://www.weadapt.org/sites/weadapt.org/files/legacy-new/knowledge-base/files/1201/5205005ecb3b5robust-decision-making.pdf.
86 Kropp, J. and M. Scholze. 2009. Climate Change Information for Effective Adaptation. A Practitioner's Guide. GIZ.
87 Ibid and Ford, J. D., et al. 2010. Case study and analogue methodologies in climate change vulnerability research. Wiley Interdisciplinary Reviews: Climate Change, 1(3). 374–92.
88 WMO. Climate Services for Supporting Climate Change Adaptation. Supplement to the Technical Guidelines for the NAP Process. Available at https://www4.unfccc.int/sites/NAPC/Documents%20NAP/Supplements/WMO_climate%20change%20services%20for%20climate%20change%20adaptation.pdf; website of the Global Framework for Climate Services available at http://www.gfcs-climate.org/what_are_climate_weather_services/.
89 Further details on the GFCS are provided in the annex and available at https://gfcs.wmo.int//.
90 https://gfcs.wmo.int//.
91 http://www.gfcs-climate.org/regional_workshops/.
92 Examples of such organizations include the International Centre for Integrated Mountain Development (ICIMOD) for the Hindu Kush Himalaya region, the Caribbean Community Climate Change Centre (CCCCC), and the Secretariat of the Pacific Regional Environment Programme (SPREP), among others.
93 https://gfcs.wmo.int/national-frameworks-for-climate-services.
94 https://public.wmo.int/en/programmes/world-climate-services-programme.
95 http://www.wmo.int/pages/prog/wcp/wcp.html.
96 https://gcos.wmo.int/en/home.
97 http://ceos.org/ourwork/workinggroups/climate/.
98 http://www.earthobservations.org/index.php.
99 https://climate.copernicus.eu/what-copernicus.
100 https://www.wcrp-climate.org/about-wcrp/wcrp-overview.
101 https://www.unenvironment.org/explore-topics/climate-change/what-we-do/climate-adaptation/world-adaptation-science-programme.
102 https://www.ipcc.ch/.
103 http://www.gfcs-climate.org/.
104 For its current implementation plan see WMO. 2014. Implementation Plan of the Global Framework for Climate Services. Available at https://gfcs.wmo.int/implementation-plan.
105 These include temperature, rainfall, wind, soil moisture and ocean conditions.

United Nations
Climate Change