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Report on the current status of availability and access to GFCS relevant data and products

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DRAFT

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Introduction

In 2009, the World Climate Conference-3 (WCC-3) established the Global Framework for Climate Services (GFCS), spearheaded by the World Meteorological Organization (WMO), to guide the development and application of science-based climate information and services in support of decision-making in climate-sensitive sectors (WMO, 2014a). For an effective delivery of climate information and its utilization, the GFCS includes the Climate Services Information System (CSIS), its core component that generates, exchanges, and disseminates climate information at global, regional and national scales, on an operational basis.

The implementation of the Framework relies on a strong commitment to the free and unrestricted exchange of data and products relevant to the GFCS. Towards this end, at its seventeenth session in 2015, the World Meteorological Congress adopted Resolution 60 (Cg-17) concerning the WMO policy for the international exchange of climate data and products to support the implementation of the GFCS. Through Resolution 60 (Cg-17), WMO Members are requested to provide GFCS relevant data and products required to support and sustain the CSIS and WMO initiatives at the global, regional and national levels and to enhance access to data and products deemed relevant to the implementation of the Framework in their countries (WMO, 2015a).

This paper attempts to provide a general overview of the current status of availability and access to meteorological, hydrological and climatological data and products, including related environmental data and products required to support the implementation of the GFCS, hereinafter referred to as GFCS relevant data and products. The first part provides the general context, by introducing the GFCS and Resolution 60 (Cg-17) endorsed by the World Meteorological Congress. The second part describes the type of climate data and products provided by the different institutions constituting the CSIS at global, regional and national levels. Finally, the third part outlines the major gaps underlined by the inventory, along with some recommendations to address the different issues.

1. General background

1.1. The Global Framework for Climate Services

Established in 2009, the GFCS is a United Nations-led initiative spearheaded by WMO which provides a worldwide mechanism for coordinated actions to enhance the quality, quantity and application of climate services (WMO, 2011a).

1.1.1. The vision

The vision of the GFCS is to enable society to better manage the risks and opportunities arising from climate variability and change, especially for those who are most vulnerable to climate-related hazards. This will be done through developing and incorporating science-based climate information and prediction into planning, policy and practice (WMO, 2011a).

1.1.2. The Principles

WMO had the responsibility of developing the GFCS Implementation Plan, following several principles in order to facilitate the more effective use of climate information to reduce vulnerability and manage climate-related risks.

The eight Principles of the Framework are (WMO, 2011a):

1. High priority for the needs of climate-vulnerable developing countries
2. Primary focus is the better access and use of climate information by users
3. Framework will address needs at three spatial scales: global, regional and national
4. Climate services must be operational and continuously updated
5. Climate information is primarily an international public good and governments will have a central role in the Framework
6. The Framework will encourage global, free and open exchange of climate-relevant data
7. The Framework will facilitate and strengthen - not duplicate
8. The Framework will be built through partnerships

1.1.3. The priority areas

The initial priority areas of GFCS are agriculture and food security, disaster risk reduction, health and water. However, given the importance of energy for global sustainable development, the seventeenth session of the World Meteorological Congress, in 2015, adopted energy as the new priority of the GFCS. The Framework has the potential to contribute to improve energy-related outcomes, in terms of promotion of renewable energy sources and through protection of energy infrastructure and delivery systems (WMO, 2015a).

1.1.4. The components

The Framework is built upon the following five pillars:

- Observations and Monitoring,
- Climate Services Information System,
- Research Modeling and Prediction,
- Capacity Development,
- User Interface Platform.

The CSIS component is the pillar the most concerned with the generation and dissemination of climate information.

1.2. The Climate Services Information System

The CSIS is the principal mechanism to routinely archive, store and process climate products and services that inform decision-making across a wide range of climate-sensitive applications. Climate data includes past, present data (e.g. historical data, climate monitoring), as well as future climate (forecasts, predictions and projections) for use in mitigation, planning and adaptation (Figure 1.1).

1.2.1. The data and products

1.2.1.1. Paleoclimate data

Paleoclimate data is derived from natural sources that record variations in past climate, such as pollen, tree rings, ices cores, corals, and ocean and lake sediments. These climate proxies are a very rich source of potential information and are particularly helpful in understanding climate variability before the pre-industrial period, thus enabling to extend the archive of weather and climate information hundreds to millions of years. The data include geophysical or biological measurement time series and reconstructed climate variables.

1.2.1.2. Historical data

Historical data mainly comes from instrumental and remote sensing sources. Historical data can be used *inter alia* for documenting the past behaviour of climate system, mapping hazards, detecting and assessing trends, changes and their causes, identifying the seasonality of climate, or providing initial boundary information for numerical models. Climate normals, reanalysis, hindcast forecast, return period of extremes are examples of historical products.

1.2.1.3. Climate monitoring

Current climate information is an important step in the identification of the early onset of severe conditions, and in combination with forecasting, it can provide advanced warning of imminent hazardous conditions. Therefore, climate monitoring may be of interest to the general public, environmental awareness groups, other government organizations and the private sectors.

1.2.1.4. Monthly, seasonal, decadal climate predictions

Forecasts, predictions and outlooks provide information about the expected or possible climate conditions in the future. They are instrumental for global decision-making and planning, since they can facilitate the risk assessment, preparation and adaptation to adverse conditions. Two crucial parameters are associated to them, the forecast period which is the validity period of a forecast and the lead time, the time between the issue of the forecast and the beginning of the forecast validity period (WMO, 2010).

A climate forecast can be issued under different formats:

- Deterministic forecasts provide only one possible outcome with no corresponding information regarding possible errors in the forecast.
- The interval indicates an explicit upper and lower limit between which the value is expected to occur.
- Probabilistic forecasts, with respect to a historical climatology, show the probability of one or more categories occur (commonly used in seasonal forecasts and climate outlook).

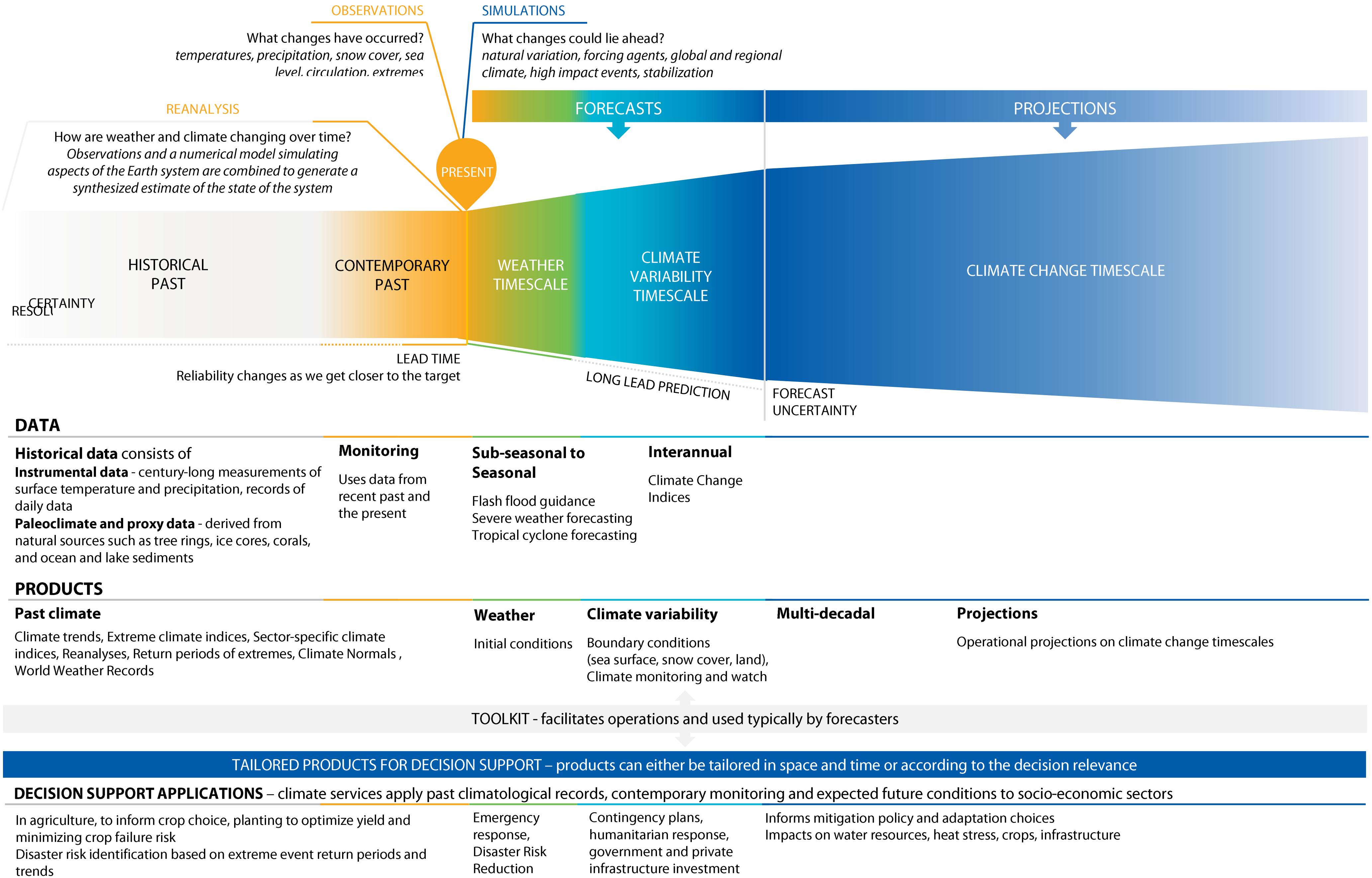

Figure 1.1: *CSIS data and products for climate services*

1.2.1.5. Climate projections and scenarios information

A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized (IPCC, 2013).

Climate models are intended to be used for much more than climate research. They constitute a strong contribution for decision-making to help society to adapt to climate change and variability and to guide the implementation of possible mitigation measures.

1.2.2. The CSIS infrastructure

The CSIS is designated for producing and operationally delivering authoritative climate information data and products through appropriate operational mechanisms, data exchange, technical standards, authentication, communication and products delivery.

The implementation strategy of the CSIS is based on a three-tiered structure that includes the Global Producing Centres for Long-Range Forecasts (GPCLRFs) delivering global scale information and services, the Regional Climate Centres (RCCs) providing sub-regional, continent-wide climate information and services and the National Meteorological and Hydrological Services (NMHSs) acting on a national scale (Figure 1.2).

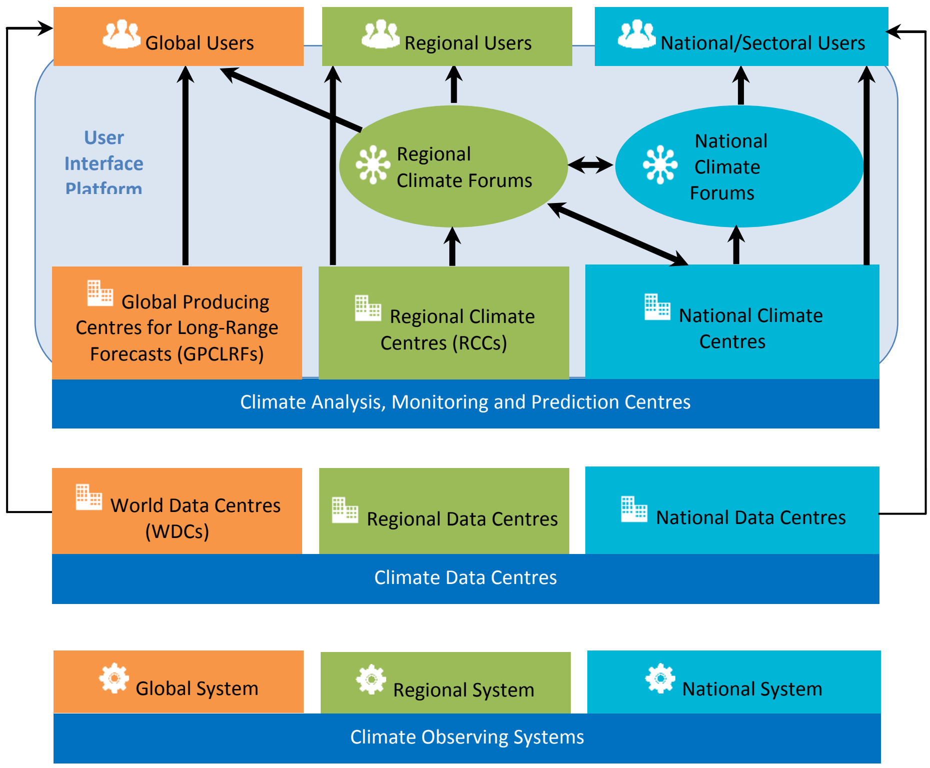

Figure 1.2: *The CSIS structure. Global, regional and national institutions, defined and designated under the GDPFS, constitute the key operational entities of the CSIS. The thin arrows depict data flows, while thick arrows illustrate value-added information flows. The CSIS generates and provides climate information and products to users at three levels, global, regional and national, with CSIS practitioners frequently in direct liaison with users to facilitate a two-way information flow.*

1.2.3. The CSIS functions

A set of initial high priority minimum functions of CSIS includes:

- Climate data rescue,
- Management and mining,
- Climate analysis and monitoring,
- Climate prediction,
- Climate projection.

These functions comprise processes of data retrieval, analysis and assessment, re-analysis, diagnostics, interpretation, assessment, attribution, generation and verification of predictions and projections and communication that will be carried out over a global-regional-national system of inter-linked producers and providers (WMO, 2014b).

1.3. Resolution 60 (Cg-17)

Over the past two decades, the World Meteorological Congress has adopted key policies on the free and unrestricted international exchange of data and products. In 1995, Congress adopted Resolution 40 (Cg-XII), committing Members to broadening and enhancing the free and unrestricted exchange of meteorological and related products (WMO, 1995). In 1999, Congress enacted Resolution 25 (Cg-XIII), extending its commitment to the open international exchange of hydrological data and products (WMO, 1999). Following the establishment of GFCS and the adoption of its implementation plan, Resolution 60 (Cg-17) was adopted by Congress in 2015, calling for increased access to data and products relevant to the implementation of the Framework.

Resolution 60 (Cg-17) adopts the policies, practices and guidelines of Resolutions 40 (Cg-XII) and Resolution 25 (Cg-XIII), for the exchange of GFCS relevant data and products. Resolutions 40 (Cg-XII) and Resolution 25 (Cg-XIII) will continue to be in force, including GFCS relevant aspects implicitly covered by them. Annex A presents the Annex to Resolution 60 (Cg-17) which identifies a set of data and products considered as relevant for the implementation of the GFCS.

Through Resolution 60 (Cg-17), the World Meteorological Congress decided that the GFCS relevant data and products from the WMO World Data Centres (WDCs), GPCLRFs, RCCs, Regional Climate Outlook Forums (RCOFs) and International Council of Scientific Unions World Data System (ICSU WDS), as well as from the framework of the Global Climate Observing System (GCOS) Essential Climate Variables (ECVs) (see Annex B) will constitute an essential contribution to the Framework and therefore should be made accessible among WMO Members, in particular through the CSIS, on a free and unrestricted basis. Annex 4 to Resolution 40 (Cg-XII) defined the term “free and unrestricted” as non-discriminatory and without charge (WMO, 1995). In the context of Resolution 40 (Cg-XII), “without charge” means at no more than the cost of reproduction and delivery, without charge for the data and products themselves.

1.4. The motivation of the inventory for GFCS relevant data and products

Mindful that the CSIS stands for the operational core of the GFCS and that this system needs to collect, process and distribute climate data and information according to the need of users and the procedures agreed by governments and other data providers as proposed by the High-Level Taskforce, the sixty-eighth WMO Executive Council requests the entities within CSIS to increase and harmonize the exchange of historical, current and forecast-related climate data and products called by Resolution 60 (Cg-17), in support of the CSIS implementation (WMO, 2016).

The WMO Executive Council also requests the WMO Commission for Climatology (CCl), in close collaboration with the Commission for Basic Systems (CBS) and other technical commissions, the GCOS and the World Climate Research Programme (WCRP) “to lead a review of the GFCS relevant data and products to be provided by the global and regional climate centres, with a view to increasing their access and availability" (WMO, 2016).

For that purpose, an upstream work consists in developing an inventory of data and products relevant for the GFCS implementation and currently available from the CSIS institutions. The inventory will allow a proper grasp of the types of data and products available among the entities within the CSIS and to assess their accessibility. Major gaps in term of availability and access, along with recommendations, will be identified and raised to the sixty-ninth session of the Executive Council. The inventory will serve as support to determine and itemize specific data and products considered necessary for the implementation of the Framework.

Besides, the inventory will also constitute an essential basis to identify the specific datasets and products needed to populate a suitably consolidated CSIS portal and to take into account into the Climate Services Toolkit (CST). The CST is conceived as a suite of software tools, training resources, guidance, but also a site of data which is considered to be a major enabling factor for CSIS implementation, particularly at national level.

2. Current status of availability and access to data and products from CSIS infrastructure

Against the backdrop of Resolution 60 (Cg-17), it is urgent to ensure that the large number of advanced centres, comprising the CSIS, makes available and gives access to data and products, deemed the most relevant for the GFCS implementation. For that purpose, more than 30 CSIS entities, operating at global, regional and national levels, have been investigated to know the different data and products delivered in historical past, recent past, climate variability timescale and climate change timescales.

2.1. The different CSIS entities screened

It is important to notice that this paper provides a non-comprehensive list of the CSIS entities and an indicative list of data and products.

2.1.1. The WMO global and regional centres and programmes

At global level, the inventory considers the twelve GPCLRFs officially WMO-designated centres, namely:

- Beijing: China Meteorological Administration (CMA)/Beijing Climate Center (BCC)
- Center for Weather Forecasts and Climate Studies (CPTEC)/National Institute for Space Research (INPE), Brazil
- European Centre for Medium-Range Weather Forecasts (ECMWF)
- Exeter: Met Office, United Kingdom
- Melbourne: Bureau of Meteorology (BOM), Australia
- Montreal: Meteorological Service of Canada (MSC)
- Moscow: Hydrometeorological Centre of Russia
- Pretoria: South African Weather Services (SAWS)
- Seoul: Korea Meteorological Administration (KMA)
- Tokyo: Japan Meteorological Agency (JMA)/Tokyo Climate Centre (TCC)
- Toulouse: Météo-France
- Washington: Climate Prediction Center (CPC)/National Oceanic and Atmospheric Administration (NOAA), United States.

The products developed by the GPCLRFs differ in format, uniformity and visualization techniques. To overcome these issues, two Lead Centres have been established; the Lead Centre for Long-Range Forecast Multi-Model Ensemble (LC-LRFMME), jointly managed by KMA and NOAA's National Centre for Environmental Prediction (NCEP) and the Lead Centre for Standard Verification System for Long-Range Forecasts (LC-SVSLRF), jointly managed by the Australian BOM and MSC.

The inventory also takes into account the WDCs collaborating with WMO, in the domains of meteorology and climatology, oceanography, paleoclimatology, solar radiation and radiation balance, glaciology, greenhouse gases, ozone and ultraviolet radiation, aerosols and remote sensing.

With the GPCLRFs, WMO RCCs and RCC-Networks constitute integral components of the WMO Global Data Processing and Forecasting System (GDPFS), by supporting regional and national activities in a given region to deliver the best climate services to national users. The RCOFs also play an important role at regional level and, albeit not belonging to WMO, are promoted by the Organization in partnership with the NMHSs, regional institutions and other international organizations. The RCOFs have completed more than twenty years of successful operations in several regions around the world.

The GCOS Surface Network (GSN) and the GCOS Upper-Air Network (GUAN) are essential benchmarks of observational data at global scale. The Regional Basic Synoptic Network (RBSN) and the Regional Basic Climatological Network (RBCN) meet regional needs.

The Climate Model Intercomparison Project (CMIP) and the Coordinated Regional Downscaling Experiment (CORDEX) are both projects under the umbrella of the WCRP providing global climate simulations and future scenarii.

2.1.2. Other global and regional centres

There are other international climate centres that cooperate closely with WMO structures and programs, but are not formally GPCLRFs or RCCs. Such centres carry out similar functions to those of WMO centers and deliver a wide range of climate products and services online. Among them, the International Research Institute (IRI) for Climate and Society at Columbia University and the Asia-Pacific Economic Cooperation (APEC) Climate Center (APCC) are centers providing global long-range forecasts and which are of prime interest for the inventory.

To these are added numerous of centres and institutions providing data and products, such as the Climatic Research Unit (CRU) of the University of East Anglia (UEA), the Global Precipitation Climatology Center (GPCC), the Global Precipitation Climatology Project (GPCP), the British Atmospheric Data Centre (BADC), ECMWF, the National Oceanic and Atmospheric Administration (NOAA), the National Center for Atmospheric Research (NCAR), The NOAA National Centers for Environmental Information (NCEI), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), the International Climate Assessment and Dataset (ICA&D), the Global Runoff Data Centre (GRDC) and the ICSU-WDS.

In addition to providing data, there are entities which can be considered as a tool for displaying climate products, such as ClimatView, the Enhancing National Climate Service (ENACTS), the Royal Netherlands Meteorological Institute (KNMI) Climate Explorer and the Partnership for Resilience and Preparedness (PREP).

2.1.3. National centres

At national level, the inventory takes into account some NMHSs and the National Climate Outlook Forum (NCOFs).

2.2. Availability of data and products from CSIS entities

The inventory enabled to put emphasis on the wealth of data and products, currently available among the CSIS. Data and products stem from a multitude of sources, such as proxies, observing stations, satellites, radars and model output. This section attempts to provide a general overview of data and products available among the CSIS entities, according to the different timescales.

2.2.1. Paleoclimate data

NOAA NCEI provides paleoclimatology proxies around the globe (like corals, insects, plant macros, pollen, tree rings, borehole, *etc.*) and makes available archives reconstructions of past climate conditions derived from these proxies. Reconstructed variables include past temperature, precipitation, vegetation, streamflow, sea surface temperature and other climate or climate-dependent conditions. They may extend from near present to several centuries or more into the past (back to 1000).

CRU also provides various datasets of reconstructed parameters derived from proxies used in publications (e.g. dataset of reconstructed temperature anomalies from 1000 to 2004 used in the chapter 6 ”Palaeoclimate” of the Intergovernmental Panel on Climate Change (IPCC) fourth Assessment Report (E. Jansen *et al.*, 2007)).

2.2.2. Historical and monitoring data

2.2.2.1. Climate normals

Climatological normals form a benchmark or reference against which conditions can be assessed and are widely used as indicator of the conditions likely to be experienced in a given location (WMO, 2007). ClimatView and WMO World Weather Information Service (WWIS) provide both station climate normals for precipitation and temperature (see section 2.2.2.7). However, while the former provide climatological normals on the period 1981-2010, the latter gives climatological normals for the period 1971-2000.

The probabilistic long-range forecasts or anomalies are computed with respect to a historical climatology which varies according to the centers. There is no common climatological reference period used among the CSIS entities for computing climate normals and performing anomalies.

2.2.2.2. In situ data

- *At global level*

The GCOS GSN provides a global reference network of more than 1000 land surface observation stations and mid-oceanic islands. It has been specifically designated to determine variability, including extremes, of surface air temperature over land. It also makes similar estimates for precipitation and pressure. Near real time data is available on a monthly basis.

The GCOS GUAN is a baseline network of about 150 stations selected from the full upper-air network on the basis of past performance and global representation. It provides measurements of large-scale temperature variations for heights up to 5 hPa for the detection of climate change. It also provides humidity and wind speed and direction.

Many efforts to produce long-term global climate database have been made (see Table 2.1), notably through the Global Historical Climatology Network (GHCN)-Daily dataset which delivers daily climate summaries from over 90 000 land-based stations across the globe; the Global Historical Climatology Network (GHCN)-Monthly with 7 280 stations providing temperature measurements; the Integrated Global Radiosonde Archive (IGRA) which consists of radiosonde and pilot balloon observations at over 2 700 stations globally distributed and the Integrated Surface Dataset (ISD) which comprises hourly global weather and climate observations over land areas.

	GHCN-Daily	GHCN-Monthly	IGRA	ISD
Temporal resolution	Daily	Monthly	Monthly	Hourly
Variable	maximum and minimum temperature, total daily precipitation, snowfall, and snow depth	mean temperature, maximum temperature and minimum temperature	vapour pressure, temperature, geopotential height, relative humidity, dew point depression, wind direction and speed, and elapsed time since launch	temperature, dew point, cloud data, visibility, wind speed and direction, precipitation, snow depth, etc.
Temporal coverage	~1900-present	~1900-present	~ 1905-present	~1900-present
Number of stations	~ 90 000	~ 7 280	~ 2 700	~ 35 000

Table 2.1: *Global station networks*

The GRDC is an international archive of river discharge data, up to 200 year old, collected at daily and monthly intervals from more than 9200 stations in 160 countries.

- *At regional level*

The Member countries of each of the six WMO Regional Associations (RAs) have committed to operate the RBSN. More than 4 000 stations belong to the six RBSNs and in the Antarctic Basic Synoptic Network (ABSN). They generate hourly meteorological parameters, measured at the surface and in vertical layers of the atmosphere, and exchanged globally via the Global Telecommunication System (GTS). Building on the concept of the RBSN, the RBCN initiative consists of more than 3 000 stations and provides support to regional-scale climate monitoring.

ICA&D serves as a web-portal for daily station data and derived indices brought together under regional cooperation. ICA&D is applied in the four regions, namely Europe (ECA&D), Latin America (LACA&D), Southeast Asia (SACA&D) and West Africa (WACA&D) (see Table 2.2). The data include many GCOS ECVs. There are blended and non-blended series. Blended series are series that are updated through a procedure that relies on the daily data from SYNOP messages distributed in near real-time over the GTS. In this procedure, the gaps in a daily series are also infilled with observations from nearby stations, provided that they are within 25 km distance and that height differences are less than 50 m.

	European Climate Assessment and Dataset (ECA&D)	Latin American Climate Assessment and Dataset (LACA&D)	Southeast Asian Climate Assessment and Dataset (SACA&D)	West African Climate Assessment & Dataset (WACA&D)
series of daily observations	43 176	1 778	5 979	First steps are being taken to set-up the WACA&D in collaboration with ACMAD. The database and website are currently under development.
number of variables	12	7	10	
number of meteorological stations	10 576	1 225	3 864	
number of climate extreme indices	72	53	43	
areas	Europe and the Mediterranean	Latin America	Southeast Asia	

Table 2.2: *Summarizing table of data and products provided by the four regions of the ICA&D*

- *At national level*

The Australian BOM provides access to a range of daily and monthly statistics, historical weather observations, rainfall, temperature and solar tables, graphs and data via the Climate Data Online (CDO). Dating back to the mid-1800s, the data represent more than 200 million records from a network of over 16 000 stations. The North African RCC-Network website proposes monthly temperature (maximum, minimum and mean) and monthly precipitation climate normals for the period 1981-2010 for different stations in Tunisia (17 stations), Morocco (17 stations), Libya (16 stations), Egypt (9 stations) and Algeria (29 stations).

Precipitation and temperature have a central position in the dataset of historical data and are extensively provided by the NMHSs. However, in historical archives, there are many more station years of monthly data available than daily data.

2.2.2.3. Gridded data and gridded merged data

CRU is a major data provider of gridded data for various meteorological parameters. The CRU Time-Series dataset is a long-term high-resolution gridded datasets with global coverage (all land areas, excluding Antarctica) containing the following parameters, cloud cover, diurnal temperature range, frost day frequency, potential evapotranspiration, precipitation, daily mean temperature, daily maximum temperature, daily minimum temperature, vapour pressure and wet day frequency. CRU acquires data from weather stations run by NMHSs around the world and updates the data series in

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near real-time via the CLIMAT network. The monthly average parameters are provided with a resolution of 0.5° in latitude and longitude from 1901 to 2015.

There are also gridded data for some regions of the world, for example, the ENSEMBLES Observations (E-OBS) from 1950 to 2015 provides daily temperature, precipitation and sea level pressure over the European sector, with a spatial resolution of 0.25° latitude and longitude.

Despite being a major climate variable, the measurement of precipitation is not as straightforward as the measurement of temperature. Many efforts have been made to produce gridded datasets of precipitation. These datasets are very useful to bridge the gap of the weak spatial coverage of data over some parts of the globe. Table 2.3 presents a non-exhaustive list of freely available global gridded dataset of precipitation.

The availability of data is enhanced by blending data from national observing networks with data from satellite and/or proxy climate reanalysis. The CPC Merged Analysis of Precipitation (CMAP) is a monthly and pentad global gridded precipitation means, in which observations from rain gauges are merged with precipitation estimates from several satellite-based algorithms and NCEP/NCAR reanalysis, with a spatial coverage of 2.5° in latitude and longitude. This data is provided with a spatial coverage of 2.5° in latitude and longitude, and extend back to 1979. It is comparable to the data from GPCP Global Precipitation Climatology Project which is a combination of satellites and station data, also with a spatial coverage of 2.5° x 2.5° (from 1979 to present).

2.2.2.4. Remote sensing data

- *Satellite-based data*

The use of meteorological and environmental satellites to observe Earth from space is one of the key tools in monitoring climate and hazards worldwide. Satellite data greatly assists in areas where in situ observational data are sparse or absent. Historical records of precipitation are derived from land-based measurements and observations and so do not provide any information regarding precipitation over oceans. To alleviate the dearth of observational data and to bridge gaps in historical data, satellites provide precipitation data across the entire globe. This 24-hour global coverage provides a never-ending stream of information critical for modelling and forecasting.

EUMETSAT provides a large number of variables which can be considered as GCOS ECVs (precipitation, cloud amount, radiation fluxes, radiation budget, albedo, upper oceanic biomass, ocean surface topography and wave height, sea-ice cover, sea surface temperature, ocean surface wind vectors and wind speed, atmospheric temperature, humidity, wind profiles, chemical constituents of the atmosphere, snow cover, ice sheet and glacier extent, vegetation and land cover and land surface topography).

The Satellite Application Facility on Climate Monitoring (CM SAF) is part of the EUMETSAT Satellite Application Network. It generates, archives and distributes widely high-quality satellite-derived parameters dataset suitable for climate monitoring and provides climatologies for the GCOS ECVs.

The World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT) also offers a growing collection of atmosphere-related satellite-based datasets (trace gas concentrations in the troposphere and the atmosphere, aerosols, atmospheric dynamics, radiation, mesopause temperatures, cloud physical parameters, sea and land surface temperatures and solar radiation).

The high spatial resolution of only few kilometres is the main asset of satellite data, contrary to the temporal resolution which is relatively short. The temporal resolution often ranges from 1960 to present and may not allow inferring long-term climate variability and change.

- *Radar data*

Baltic Sea Experiment's (BALTEX) Radar Data Centre collects data from several radars in or near the Baltic region. The NOAA NCEI also provides radar data in the USA with a typical range of 230 km from the radar site.

2.2.2.5. Reanalysis

Climate reanalysis are considered as robust historical datasets, through assimilation of available instrumental data into Global Climate Model (GCMs) predictions. They are therefore extensively useful for climate research and climate application studies, especially for study areas affected by a dearth of observational data.

- *Global reanalysis*

Global reanalysis are often presented on grids varying between 0.5° and 2.5° (commonly greater than 100 km grid size). Their main asset is their large spectrum of data covering the entire atmosphere in high temporal resolution (e.g. 6 hourly fields for ERA-40).

The widely used reanalysis dataset are provided by ECMWF, with the 40-year ECMWF Re-analysis (ERA-40) covering the period 1957-2002 and ERA-Interim covering the period from 1979 to current date; and by NCEP with the NCEP/NCAR reanalysis projects (1948 onwards) and NCEP Climate Forecast System Reanalysis (CFSR) (1979-2010). More than 10 global reanalysis are available and can be downloaded via Internet. Table 2.4 presents a non-exhaustive list of global reanalysis.

The global reanalysis mainly aim to understand long-term climate trends and their coarse resolution may preclude direct applications to assess climate variability and change impacts at local and regional scales. Two approaches exists to overcome this impediment:

- creation of high-resolution datasets by downscaling global reanalysis,
- development of high-resolution regional reanalysis.

- *Dynamical downscaling of global reanalysis*

In the case of dynamical downscaling of global reanalysis, Regional Climate Models (RCMs) are driven by boundary conditions from large-scale GCMs to generate detailed regional climate information. This approach enables to produce regional reanalysis at finer spatial resolution than global reanalysis data (~10-50 km).

Several studies have been conducted to downscale global reanalysis. The NCEP/NCAR reanalysis for the period 1948-2005 was dynamically downscaled to hourly, 10 km resolution over the state of California (CaRD10) in the study of Kanamitsu (Kanamitsu *et al.*, 2007). The NCAR Global Climate Four-Dimensional Data Assimilation (CFDDA) Hourly 40 km Reanalysis dataset is also a dynamically-downscaled dataset created using the NCAR's CFDDA. The dataset contains three-dimensional hourly analyses from 1985 to 2005 on a 40 km horizontal grid, with 28 vertical levels.

- *Regional reanalysis*

Regional reanalysis use global reanalysis as a lateral boundary forcing, along with regional data assimilation system to produce a high-resolution datasets. Unlike downscaling approach that assimilates only global analysis, but no additional observational data within the regional model domains to generate regional climate information, regional reanalysis assimilates observation data in regional models driven by global analysis.

Name	Source	Spatial resolution	Temporal resolution	Temporal coverage	Reference
CPC Unified Gauge-Based Analysis of Global Daily Precipitation	Gauge	0.5° x 0.5°	Daily	1979-present	P. Xie *et al.*, 2010
GPCC First Guess Product	Gauge	1.0° x 1.0°	Monthly	2004-present	M. Ziese *et al.*, 2011
GPCC First Guess Daily Product	Gauge	1.0° x 1.0°	Daily	2009-present	K. Schamm *et al.*, 2013
GPCC Monitoring Product	Gauge	1.0° x 1.0°	Monthly	1982-present	U. Schneider *et al.*, 2015a
GPCC Full Data Daily Product	Gauge	1.0° x 1.0°	Daily	1988-2013	K. Schamm *et al.*, 2015
VASClimO 50-Year Data	Gauge	0.5° x 0.5°	Monthly	1951-2000	C. Beck *et al.*, 2005
GPCC Climatology	Gauge	0.25° x 0.25°	Monthly	1951-2000	A. Meyer-Christoffer *et al.*, 2015
HOAPS/GPCC	Gauge, Satellite	1.0° x 1.0°	Daily	1988-2008	A. Andersson et al., 2016
GPCP Global Precipitation Climatology Project	Gauge, Satellite	2.5° x 2.5°	Monthly	1979-present	R. F. Adler *et al.*, 2003
GPCP One-Degree Daily Precipitation Data Set	Gauge, Satellite	1.0° x 1.0°	Daily	1996-present	G. J. Huffman *et al.*, 2013
Experimental GPCP Pentad Precipitation Analysis	Gauge, Satellite	1.0° x 1.0°	Pentad	1979-present	P. Xie *et al.*, 2002
CPC Merged Analysis of Precipitation	Gauge, Satellite, Reanalysis	2.5° x 2.5°	Pentad	1979-present	G. J. Huffman *et al.*, 1997

Table 2.3: *Gridded datasets of precipitation at global scale*

Name	Spatial resolution	Temporal coverage	Reference
NCEP CFSR	~38 km, with 64 levels from the surface to 0.26 hPa	1979-2010	S. Saha *et al.*, 2010
NCEP/DOE 2	~209 km, with 28 vertical levels	1979-present	M. Kanamitsu *et al.*, 2002
NCEP/NCAR	~209 km, with 28 vertical levels	1948-present	E. Kalnay *et al.*, 1996
ECMWF ERA-20C	~125 km, 91 model levels	1900-2010	P. Poli *et al.*, 2016
ECMWF ERA-20CM	~125 km, 91 model levels with the model top at 1 hPa	1900-2010	H. Hersbach *et al.*, 2013
ECMWF ERA-Interim	~80 km, 60 levels, with the model top at 0.1 hPa	1979-present	D. P. Dee *et al.*, 2011
ECMWF ERA-40	~125 km, 60 vertical levels, with the model top at 0.1 hPa	1957-2002	S. M. Uppala *et al.*, 2005
ECMWF ERA-15	~190 km, 31 vertical levels, with the model top at 10 hPa	1979-1993	J. K. Gibson *et al.*, 1999
JRA-25	~120 km, 40 vertical levels	1979-2004	K. Onogi *et al.*, 2005
JRA-55	~55 km, 60 vertical levels, with the model top at 0.1 hPa	1958-present	S. Kobayashi *et al.*, 2015
JRA-55AMIP	~55 km, 60 vertical levels, with the model top at 0.1 hPa	1958-2012	S. Kobayashi *et al.*, 2015
JRA-55C	~55 km, 60 vertical levels, with the model top at 0.1 hPa	1972-2012	S. Kobayashi *et al.*, 2014
MERRA	0.5° x 0.667°, 72 vertical levels, with the model top at 0.01 hPa	1979-present	M. Rienecker *et al.*, 2011
NOAA-CIRES (20CRv2)	2° x 2°, 28 vertical levels, with the model top at 0.2 hPa	1871-2012	G. P. Compo *et al.*, 2011
NOAA-CIRES (20CRv2c)	2° x 2°, 28 vertical levels, with the model top at 0.2 hPa	1850-2014	G. P. Compo *et al.*, 2011
GPCC Full Data Reanalysis	0.5° x 0.5°	1901-2013	U. Schneider *et al.*, 2015b

Table 2.4: *Non-exhaustive overview of freely available global reanalysis, with a sub-daily temporal resolution*

Several regional analysis have been attempts, including the North American Regional Reanalysis (NARR) project, which is an extension of the NCEP Global Reanalysis, and is run over the North America. This regional reanalysis covers 1979 to near present and includes 8 times daily, daily and monthly data, with a horizontal resolution of 32 km. The NCAR's Arctic System Reanalysis (ASR) also is a regional reanalysis across the mid- and high latitudes of the Northern Hemisphere spanning 2000-2012 with a high resolution of 15 km.

2.2.2.6. Climate extreme indices

Extreme indices are of prime importance for planning decisions and assessing impact analysis. The Expert Team on Climate Change Detection and Indices (ETCCDI) has defined a set of 27 core indices and computed these indices for several stations in 118 different countries. A gridded dataset version is also available in Met Office website (3.75° x 2.5° latitude and longitude). ICA&D also provides indices of extremes, whose many of them follow the definition of the ETCCDI indices. These indices are calculated for several stations in Europe (ECA&D), Latin America (LACA&D) and Southeast Asia (SACA&D) (see Table 2.2).

2.2.2.7. Graphical tools

KNMI Climate Explorer is an interesting tool, not only for historical or recent past, but also for climate variability timescales. It enables to plot graphics or maps, perform past climate analyses or climate change projections and download data for different time and spatial scales. There is a multitude of datasets available coming from numerous sources, such as CMIP, CORDEX, IRI, ECMWF, Météo-France, Met Office, *etc.*

The PREP is a public-private collaboration to empower data-driven approach to managing climate risk and building climate resilience. It develops platforms designated to help users access climate-relevant data and information and explore insights from those data. As KNMI Climate Explorer, the PREP provides data stemming from diverse sources and ranging different timescales (observed data, modelled historical data, modelled projections) at global, regional and national levels, in the domains of water, flood, energy, food resilience, health, transportation, ocean, ecosystem, *etc*.

ClimatView and the WMO WWIS are both tool for viewing through an interactive map monthly world climate data in a given station. The WMO WWIS presents not only official weather observations and weather forecasts, but also climatological information for selected cities supplied by NMHSs. To date, 1841 cities from 166 WMO Members have climatological data from 1971-2000. ClimatView enables to download data, from 1982 to current data, and give users access to statistics on monthly mean temperatures, monthly total precipitation amounts and related anomalies or ratios for more than 2 500 stations where data are available. The data are derived from CLIMAT messages reported via the GTS line from WMO Members around the world.

The Caribbean Regional Climate Centre provide daily and monthly temperature and rainfall statistics under the form of graphics for several countries in the Caribbean region, through the CariCOF Outlook Generator (CAROGEN).

The collection of a variety of data and products is important to establish a fully effective CSIS. Depending on the user's needs, the climate data and products may be combined with non-meteorological data, such as agricultural production, health trends, population distribution in high-risk areas to produce tailored climate products. Tailored climate products are a major contribution to improve the understanding risk assessments. IRI stands for an excellent example of provider of deriving tailored products, notably through its Climate Map Room and the ENACTS initiative. ENACTS focuses on the creation of over 30 years of reliable climate information (rainfall and temperature) suitable for both national and local decision-making, for every 4 km/5 km grid across each country. ENACTS has so far been implemented in Ethiopia, Madagascar, Tanzania, Rwanda, Kenya, Ghana, Mali, Uganda, Malawi, Zambia and The Gambia.

2.2.3. Sub-seasonal to seasonal climate predictions

2.2.3.1. At global level

Currently, twelve GPCLRFs, officially WMO-designated centres, are responsible for producing and disseminating long-range forecasts with global coverage, as input for the forecasting services of RCCs and NMHSs. They are mandated to provide, with a lead time between 0 and 4-month, forecast probabilities for tercile categories of 2 m temperature, precipitation and sea surface temperatures. Additionally, recommended provision includes forecasts for pressure at mean sea level, temperature at 850 hPa and 500 hPa geopotential height. Although GPCLRFs operate at global level, it is possible to zoom into already pre-set areas of interest.

The LC-LRFMME collects long-range forecast data from all GPCLRFs each month and maintains a central portal of GPCLRFs output in digital and graphical formats accessible to forecast users. It also develops and provides multi-model forecast products with improved skill and promotes research into techniques for combining predictions from different models. The LC-SVSLRF is responsible for collecting verification information from the GPCLRFs and displaying it in standardized format.

IRI and APCC also provide seasonal predictions at global scales. IRI provides probabilistic three-month predictions with a lead time between 1 and 4-month (for the next six-month period) for temperature, precipitation and sea surface temperatures. Besides, flexible format seasonal climate forecasts go further by granting users the options to specify probability or quantitative thresholds for mapping seasonal mean temperature and precipitation totals in order to predict the likelihood of exceeding this value. The flexible forecasts are also for a three-month season, with a lead time between 1 and 4-month. APCC provides probabilistic and deterministic monthly forecasts for precipitation, 2 m temperature, 850 hPa temperature, 500 hPa geopotential height and the sea surface temperatures, with a lead time of 1 to 6-month and seasonal forecasts for these same parameters with a lead time of 1 and 4-month.

The Global Seasonal Climate Update (GSCU) summarizes the current status and the expected future behaviour of the seasonal climate (three months), including major general circulation features and large-scale anomalies around the world (e.g. El Niño Southern Oscillation, North Atlantic Oscillation, Indian Ocean Dipole, *etc.*) and their likely impacts on continental-scale surface temperature and precipitation patterns. The GSCU is being designed to be used primarily by RCC, RCOFs and NMHSs, in order to elaborate regional and national climate updates and also by global user communities, as well as the general public. The GSCU is proposed to be regularly issued a few days ahead of the standard seasons (every three months).

The WMO El Niño/La Niña Update is prepared on a quasi-regular basis (approximately every three months) through a collaborative effort between WMO and the IRI. The Update is based on the contributions from the leading centres around the world monitoring and predicting this phenomenon and expert consensus facilitated by WMO and IRI.

2.2.3.2. At regional level

WMO RCCs and RCC-Networks, currently fully designated or in demonstration stage, cover five WMO RAs (RA I, RA II, RA III, RA IV and RA VI). They generate and deliver regionally-focused high-resolution data and products, including long-range forecasts that support regional and national activities and thereby strengthen capacity of WMO Members in a given region to deliver the best climate services to national users. Temperature at 2m and precipitation are the main parameters provided by the WMO RCCs and WMO RCC-Networks.

Given the multiple sources of information from global and regional entities within CSIS, the user needs to be assisted to identify robust climate signals and to understand inherent uncertainties. At regional level, the RCOFs stand for an effective mechanism for stimulating the development of such collaboration. Indeed, they are responsible for the production and the dissemination of regional assessment of climate for the upcoming season, with the aim of gaining substantial socio-economic benefits in climate-sensitive sectors. The RCOFs are held approximately once or twice a year. They produce probabilistic outlooks for temperature and precipitation anomalies along with a consensus statement. With 19 RCOFs, to date, conduced globally, the innovative RCOF concept plays a crucial role in implementing the GFCS, at regional level.

2.2.3.3. At national level

The generation of climate data at local and national levels is the responsibility of a country's NMHSs. These latter are mandated to continuously generate and disseminate weather and climate data across the country and develop and issue forecasts and warnings. NMHSs play a central role in producing and disseminating operational long-range forecasts, including through coordination of NCOFs.

As part of the programme for implementing GFCS at the national scale, NCOFs serve as national platforms for regular dialogue between climate information providers and users, in responding to natural hazards, climate variability, climate extremes and climate change. NCOFs are held around once or twice a year according to the country.

2.2.4. Decadal climate predictions

Decadal forecasts seem to be still in their infancy and are not widely available. The Lead Center for Near Term Climate Prediction (LC-NTCP), led by UK Met Office, is producing experimental multi-model decadal predictions. The predictions are for a one-year period or for an average 5-year period and currently concern surface air temperature, precipitation, sea level pressure and Atlantic Meridional Overturning Circulation (MOC).

2.2.5. Climate projections

2.2.5.1. Coupled Model Intercomparison Project

The objective of WCRP CMIP is to better understand past, present and future climate change arising from natural, unforced variability or in response to changes in radiative forcings in a multi-model context. CMIP has evolved over five phases into a major international multi-model research activity.

The fifth phase of CIMP provides an unprecedented set of climate model output data using around 61 GCMs, for two time scales, near term (10 to 30 years) and long-term (out to 2100 and beyond).The resolution of the CMIP5 models is highly variable. The model MRI-AGCM3-2S, from the Meteorological Research Institute (MRI), has the higher resolution (0.188° × 0.1875°), while the model FGOALS-gl, from the Laboratory of Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, has a resolution of 4.1026° × 5°. The fifth phase of CMIP was used in support of the fifth Assessment Report of the IPCC.

The outputs from CMIP are available through the IPCC and its Data Distribution Centre, and the Program for Climate Model Diagnosis and Intercomparison (PCMDI) archives much of the CMIP data.

Simulating climate change at regional and national levels is essential for policy-making. However, the coarse resolution of GCMs is not suitable for the sound understanding of climate and its impact and for decision-making at a smaller scale. Therefore, another initiative under the aegis of WCRP has been conducted for downscaling the CMIP output.

2.2.5.2. Coordinated Regional Climate Downscaling Experiment

CORDEX essentially has the two-fold purpose to provide a framework to evaluate and benchmark model performance and provide regionally downscaled climate projections for most land regions of the globe, as a compliment to the global climate model projections performed within the CMIP (F. Giorgi *et al.*, 2009). Multiple domains have been selected, namely South America, Central America, North America, Europe, Africa, South Asia, East Asia, Central Asia, Australasia, Antarctica, Arctic, Mediterranean, Middle East North Africa and South East Asia.

The first stream consists in the evaluation of multiple RCMs for a 20-year hindcast period with the lateral boundary forcing obtained from ERA-Interim reanalysis. These evaluations are critical to characterizing the strengths and the weaknesses of the models for their use in producing future projections. For the second stream (projections), the RCMs are run with boundary conditions from GCMs participating to the CMIP program for the period 1950-2100 under different greenhouse gas emission scenarii. The resolutions of the projections is between 0.11° and 0.44° (approximately between 12km and 50 km).

2.3. Accessibility and conditions of use of data and products

Data availability may not necessary lead to data access. Whilst the previous section informs on the status of data and products availability, this section deals with their accessibility within the CSIS entities and their usage.

2.3.1. Access to data and products

2.3.1.1. A large volume of data and products available in the public domain

The inventory enabled to highlight a huge quantity of information made available in the public domain which is generated and archived by a growing number of centres around the world and which can benefit the GFCS implementation. Available in the public domain means accessible via Internet without registration or agreement.

Generally, important information on meteorological data provided as deriving products in table, maps or animations form are totally accessible to public. These are excellent tools for visual examinations, especially for identifying spatial patterns.

2.3.1.2. A controlled access by a user registration

To control the access to their data, some entities require a user registration. Data can be accessible via a simple registration from a lambda user by entering an email and a password (e.g. ECMWF's reanalysis, WMO Lead Centres products, E-OBS gridded datasets), or a registration solely reserved to NMHSs (e.g. seasonal forecasts from RA VI RCC-Network Node on Long-Range Forecasts, gridded data from RA VI RCC-Network Node on Climate Monitoring, hindcast gridded data from TCC, *etc.*) with a login and a password provided by the institution itself.

The registration procedure may be longer and involve a form to fill. The user has to inform on the purpose of the research and the use of the data. For example, to access to some data from BADC, the user needs to fill a form with his contact details, as well as the purpose of the research, how are his intentions regarding the data for which he are applying for access to, what are the publication prospects, what is the nature of the funding of the research, if there is any commercial aspect to the research, *etc*. The application can be delayed or rejected if the user does not provide all relevant details. CMIP also put in place a similar subscription procedure by requesting the user about the statement of its work.

Data suppliers impose these access restrictions in order to monitor the use of their data and obtain an acknowledgement of the data source in any publication. Intellectual property issues compromise open access to data and incentivize a restricted data sharing through an acknowledgement.

2.3.1.3. Free access but limited by NMHSs

Data can be collected by meteorological offices and the access of some data, notably station data may be limited by the national policies governing data sharing. This is the case, particularly for station data which are not always free of charge and subject to commercial restrictions or just limited to NMHSs.

In Europe, the station network for near-surface climate observations is managed by a large number of (predominantly) NMHSs, each of which has its own data archive and distribution policy. For instance, the ICA&D system relies on the data providers in the specific regions which decide which of their stations will be available in ICA&D and which will not (E. J. M. Van Den Besselaar *et al.*, 2015). Thus, only part of the dataset is freely available for non-commercial and educational research.The ECA&D does not make available all the original daily data series available because of restrictions imposed by some of the data providers. Currently it makes publicly available about 76% of the station data series it uses. In the same way, the GPCC provides only gridded precipitation datasets, without restricted access, but due to restrictions imposed by data providers, the GPCC is not able to provide access to any of the station monthly precipitation totals.

2.3.1.4. Charges applied

The data the most submitted to charges concerns the raw data. Many NMHSs charge a fee for access. They are reluctant to provide free public access, because the sale of data enables to recoup the costs of generating observations.

Charges are levied particularly for long runs of station records and daily data (e.g. station data from Météo-France, Australian BOM, *etc.*). Furthermore, the inventory enabled to point out that the access to gridded data is easier than that for raw data. The inclusion of historical data in gridded regional and global climate datasets allows the free exchange of information contained within the data in ways that remains consistent with national data policies.

2.3.2. Conditions of use of data and products

Although accessible, data can be subject to a restriction of use. This section considers the different types of policy applied by the CSIS entities.

2.3.2.1. Free and unrestricted use

Regarding Resolution 40 (Cg-XII), some entities defined a set of products considered as “essential” and make it available in a free and unrestricted basis. For instance, EUMETSAT applies the distinction between “essential” and “additional” data in providing data to organizations outside the NMHSs of Member states. The “essential” data and products are available on a free and unrestricted basis in accordance with WMO Resolution 40 (Cg-XII). Users wishing to access EUMETSAT’s “non-essential” data can do so under a licence agreement. The payment of licence fee applies for commercial use of EUMETSAT’s “non-essential” data (EUMETSAT, 2016).

2.3.2.2. Restricted use for non-commercial research and educational purposes

Most of the time, the datasets are freely available for “non-commercial research and educational purposes” (for example, ICA&D datasets, ECMWF data). This term means that the results obtained from non-commercial research are expected to be made openly available at delivery costs only, without any delay linked to commercial objectives and that the research itself should be submitted for open publication and not considered proprietary. Results from educational purposes cannot be sold.

2.3.2.3. Unrestricted use for commercial purposes

In the case of CMIP and CORDEX data, all users need to sign the “Research” or “Commercial” group formula. Users in the “Research” group can download all the simulations for non-commercial research and educational purposes. Users in the “Commercial” group can download only output from a subset of the models for an unrestricted use.

3. Major gaps and recommendations

This section emphasizes major gaps and strives to provide some recommendation to address these issues raised during the inventory.

3.1. A poor organization of dataset and products and a lack of awareness about the important magnitude of available information

As mentioned in section 2.4.1, a large volume of data and products is generated by the CSIS entities and made available in their respective websites. However, easy access to such information is not guarantee. The lack of organization of archived information renders the navigation difficult through the bewildering number of websites, often offering the similar information, and search a dataset or visualize a parameter can become daunting. It is thus difficult to judge which dataset to choose and which dataset will be the most appropriate according to the study.

Potential users are not always aware of the plethora of information available among the different CSIS infrastructure and the poor organization of datasets does nothing to redress the issue. This lack of awareness on the part of potential users results in under-utilized data and products.

The CSIS institutions need to develop a simple and effective access environment showing the whole list of available data (with the spatial and temporal resolution) which can be downloaded. An organization according to the timescale (in the domain of historical and recent past, long-range forecasts and projections) would facilitate access to data. A good example of data organization according to the different timescales is the Australian BOM (http://www.bom.gov.au/climate/data-services/). A user-friendly and easy-to access database system is the key to serve equally all potential users, scientists and non-scientists alike (scientist community, government, academia, general public, as well as decision-makers), with an abiding interest in data and products.

In addition to sharing the information in a readily form, the CSIS entities have to ensure that the data and products are as useful as possible and understandable to a broader user, as well as kept updated to serve as a sustainable source of information, i.e. a systematic, regular and reliable flow of information.

3.2. Data and products restricted to the scientific community

The restriction to an internal use of data within NMHSs, the restriction of data usage for research and educational purpose, as well as an online registration requesting the study purpose are all examples showing a data usage exclusively reserved to the scientific community.

This is in contradiction with the non-discriminatory nature of the access to data advocated by Annex 4 to Resolution 40 (Cg-XII). CSIS needs to democratize the access to their data and products to a broader user target.

3.3. Need for increasing the availability of some variables

Basic atmospheric variables such as air temperature, precipitation, wind, air pressure and humidity are extensively available among the CSIS entities and through diverse types of data (observational, satellite, gridded data, *etc*.). However, gaps in observational data have been raised during the inventory. Many hydrometeorological variables, such as streamflow, soil moisture, surface evaporation and evapotranspiration are not well available and not even measured on regular basis. These parameters may be very useful for agricultural forecasting model, for example.

3.4. Need for long-term records, daily and higher resolution data

Historical records and daily data are the most difficult data to access, particularly because many NMHSs attach a commercial value to them and do not make them publicly available. The former may be very useful *inter alia*, for assessing past climate, while the latter may contribute to monitor extreme events (tropical cyclone, storm surges, heat waves, frost, hail, flood, drought, *etc*.) and consequently be beneficial for the well-being of society.

To improve understanding of knowledge of climate and its future evolution, as well as high impact events, CSIS should increase access to longer-term records, daily and even higher resolution data.

3.5. Unequal spatial and temporal coverage of observational data among WMO Members

The availability of observational data is disparate throughout the world. Observational data coverage is highly dense in developed areas, particularly in United States and in Europe, and very sparse or insufficient in Africa, South America, in the Arab region and in Pacific Islands. While some records extend back more than 100 years in Europe and North Africa, in developing countries, least developed countries and Small Island Developing States (SIDS), the length records do not extend back more than 50 years. In these regions, many historical records have a limited period of time (in the GHCN-Daily or ICA&D) or have gaps (maybe resulting from conflict, lack of resources which limits the collection and dissemination of data, *etc.*). Longevity, sustainability and completeness are imperatives for *in situ* observations to effectively support climate monitoring, climate services provisions and climate research (the Guide to Climatological Practices recommends at least 30 years of homogenous records for rainfall to adequately describe the mean and variability (WMO, 2011b)).

Relative short records may not reveal the full extent of natural variability and confound detection studies. The spatial and temporal resolution is inadequate to effectively support monitoring, climate services provision and climate research in these regions whose the vulnerability to hydro-meteorological hazards is much higher than in other areas and hampers the socio-economic development of already fragile economy.

Observations capture small-scale geographic variability in variables (e.g. precipitation and temperature) that can have a significant impact on the development of outcomes and the design of adaptation responses. Climate information produced at the global level does not fully exploit information from national observational data. Satellite data are a good alternative to address the spatial and temporal gaps in station data, as well as the lack of quality-controlled data. However, despite significant advances, even the highest-definition satellite data may not provide the level of details required for the smaller scales of government decision-making. The spatial coverage they offer makes them complementary to, but not a substitute for, the observing networks. Moreover, it is important to recall that satellites are not able to measure precipitation. A correct measurement of precipitation can only be made through rain gauges. This supports the importance of observational data around the world.

In addition to be essential for ensuring robust climate data for national decision-making, ground observations are crucial to analyse past and current climate and constitute a major contribution to improve early warning system, local forecasts and simulate the future evolutions of the climate. In a bid to increase and strengthen the resilience to the adverse impacts of climate change and variability to "the most vulnerable" countries, CSIS should adopt a notion of seamlessness to deliver data at all time and space scales. An integrated body of services spanning all timeframes and a CSIS-defined space-scale is the ideal mechanism.

3.6. Need for a standardization of metadata

Metadata, both intrinsic and extrinsic, is descriptive data providing information about the data or the products. While intrinsic metadata refers to the quality of the datasets (e.g. history of the stations), the extrinsic metadata refers to the context of the dataset (e.g. access, conditions of use, cost, *etc.*).

Metadata refers to information on the units used, the special codes employed, the corrections made to the data, the procedures of quality control applied, the adjustments made to ensure its homogeneity and the data estimated and filled in, after applying the interpolation procedure selected.

Besides, metadata has a critical role in the process of creating datasets, as the knowledge of the station history determine the confidence in the statistical techniques to ensure that climate variations in a climate time series are due to actual climate variability and change. Inherent uncertainties may arise around the sensitivity of the chosen gridding method or the density of stations in or around a grid box, in the case of gridded datasets.

Unfortunately, the metadata associated to data or products is not systematically reported and does not follow formatting standards. Quality control and homogenization are not uniformly available. The standardization of metadata would be a means of maintaining a comprehensive and always up-to-date documentation to ensure high-quality datasets and their proper use.

3.7. Clarification on the definition of GCOS ECVs in the context of the GFCS

GCOS ECVs are endorsed as an essential contribution to the implementation of the Framework and are considered as "GFCS relevant" variables under Resolution 60 (Cg-17). GCOS ECVs are not a select group of stand-alone variable, but a group of linked variables that needs an appropriate and detailed definition, addressed within the remit of the GFCS. GCOS ECVs are expected to bring an immediate information regarding the management of risks and opportunities arising from climate variability and change.

Last but not least, there is a genuine need of prioritization among the GCOS ECVs in term of relevance regarding climate services. It would be recommended to make a selection of significant variables among the GCOS ECVs, likely to better target the issue of implementing GFCS.

3.8. Guidance for interpretation and use of data and products

One of the CSIS functions includes providing data, deriving products and deriving tailored products and information, along with advice on their interpretation and use (WMO, 2014b). This role of guiding mechanism is an important aspect of the CSIS, notably when the products aim to inform complex decision-making processes across a wide range of climate-sensitive activities.

In the case of a climate projection, the simulated climate approximately represents a period spanning a nominal time scale, and individual model years do not correspond to any specific years or events in this period. Indeed, a future projection for a particular year (e.g. 2050) does not refer to a single year, but the climate averaged over a number of years (e.g. 2040-2060) for which this year is the central year. Consequently, a projection relates to an average climate and should not be construed as a forecast of a particular year. This is an important aspect to underline to the users to avoid any misinterpretation.

With regard to reanalysis, a useful distinction needs to be raised in the reliability of the output variables. Reanalysis can be classified into four classes, depending on the relative influence of the observational data and the relative influence of the model (E. Kalnay *et al.*, 1996):

- Class A: The analysis variable is strongly influenced by observed data (e.g. upper-air temperature, sea level pressure and wind). It is the most reliable class.
- Class B: Although observational data affects the value of the variable, the model also has a very strong influence on the analysis value (e.g. humidity and surface temperature).

- Class C: No observation directly affects the variable (e.g. clouds, precipitation and surface fluxes). The variable is completely determined by the model and subject to the largest uncertainties.
- Class D: The field is obtained from climatological values and does not depend on the model (e.g. plant resistance and land-sea mask).

Although this classification is somewhat subjective, CSIS entities should state the strengths and limitation of reanalysis and warn the user of the precautions to be taken concerning the interpretation of the results.

To conclude, the CSIS should provide guidance for the interpretation and use of data in an appropriate way. Given the escalating pace of progress, the user often fraught with data which dramatically increases in volume (see section 3.1) and in complexity, it is important to guide the user to grasp the different aspects of data and products available to assess the robustness of the model results or other data and the confidence to put in them.

Conclusion

To address the infrastructural capacity needs of the GFCS, WMO has fostered the establishment of infrastructure within the GDPFS to improve access to climate information for its 191 Members. For that purpose, the CSIS, based on a three-tiered worldwide structure of collaborating institutions, has been implemented to ensure the generation, exchange and dissemination of climate information and products, globally through a range of advanced centres such as the GPCLRFs, regionally through entities and network entities such as the RCCs and RCC-Networks, and nationally and locally by the NMHSs and, through national institutional arrangements, with partners.

To support the implementation of the GFCS, the seventeenth session of the World Meteorological Congress adopted Resolution 60 (Cg-17) in favour of the international exchange of GFCS relevant data and products among WMO Members. At the request of the WMO Executive Council, the WMO CCl, in close collaboration with CBS and other relevant technical commissions, GCOS, and WCRP, needs to lead a review of GFCS relevant data and products to be provided by the global and regional climate centers, with a view to increasing their availability and access, and present the results of the review along with recommendations to the sixty-ninth session of the Executive Council (WMO, 2016).

A first work consists in developing an inventory of the current status on the availability and access to the GFCS relevant data and products from the existing network of designated entities within the CSIS. For that purpose, more than 30 CSIS entities, operating at global, regional and national scales, have been screened to know the types of data and products they provide and to know their level of accessibility.

The inventory unveiled an impressive volume of data and products available in the public domain. This huge quantity of information is comprising a multitude of sources; paleoclimatology proxies, *in situ* data, remote sensing data and model output; covering all timescales, from prehistorical period to climate change timescales. The issue of data availability regarding long-term records and daily data has come to the fore during the inventory. Data availability is generally greater in developed countries than in developing countries, where resources sometimes may limit the collection and dissemination of daily meteorological observations, although restricted data access also remains a problem in some developed countries. Indeed, data policy and restrictions of use of data are prime concerns of many NMHSs, notably in Europe where data restrictions are perceived as a means of enhancing commercial value.

The GCOS ECVs are of prime concern for characterizing Earth's climate, but they need to be complimented with a clarification on their definitions and their measurements. The definitions should reflect the relevance of the variable in the context of the GFCS, i.e. by stressing their interest regarding the management of risks and opportunities arising from climate variability and change.

To achieve the most effective access and improve usability of their data and products, and respond to Principle 2 of the GFCS, the CSIS entities should develop a user-friendly and easy-to access database system serving all potential users. CSIS should adopt a notion of seamlessness by providing data and products at global, regional and national levels and at all time and spatial scales. Fulfilling the needs of all types of interdisciplinary users should constitute a metric of success of the CSIS. Considering the ever-widening user target, the role of guiding mechanism of the CSIS cannot be overemphasized. Finally, CSIS should serve as a sustainable source of information, ensuring relevant and high-quality datasets to support the implementation of the GFCS.

The data and products, deemed necessary for the provision of climate services, in support of the protection of life and property, as well as the well-being of people, could be integrated into the CST, a major enabling factor for the implementation of the CSIS, particularly at national level. To better meet the expectations of countries, the CST should provide proper tools depending on the capacity of the country to assess climate variability and change in regional and national context.

Acronyms

ABSN	Antarctic Basic Synoptic Network
ACMAD	African Centre of Meteorological Application for Development
APCC	APEC Climate Center
APEC	Asia-Pacific Economic Cooperation
BALTEX	Baltic Sea Experiment
BADC	British Atmospheric Data Centre
BCC	Beijing Climate Center
BOM	Bureau of Meteorology
BRDC	BALTEX Radar Data Centre
CAROGEN	CariCOF Outlook Generator
CBS	Commission for Basic Systems
CCl	Commission for Climatology
CDO	Climate Data Online
CFDDA	Climate Four-Dimensional Data Assimilation
CFSR	Climate Forecast System Reanalysis
Cg	World Meteorological Congress
CIIFEN	Centro Internacional para la Investigación del Fenómeno de El Niño
CMA	China Meteorological Administration
CMAP	CPC Merged Analysis of Precipitation
CMIP	Climate Model Intercomparison Project
CM SAF	Satellite Application Facility on Climate Monitoring
CORDEX	Coordinated Regional Downscaling Experiment
CPC	Climate Prediction Center
CPTEC	Center for Weather Forecasts and Climate Studies
CRU	Climatic Research Unit
CSIS	Climate Services Information System
CST	Climate Services Toolkit
ECA&D	European Climate Assessment & Dataset
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
ENACTS	Enhancing National Climate Service Initiative
E-OBS	ENSEMBLES Observations gridded dataset
ETCCDI	Expert Team on Climate Change Detection and Indices
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
GCM	Global Climate Models
GCOS	Global Climate Observing System
GDPFS	Global Data-Processing and Forecasting System
GFCS	Global Framework for Climate Services
GHCN	Global Historical Climatology Network
GPCC	Global Precipitation Climatology Centre
GPCLRF	Global Producing Centre for Long-Range Forecast
GPCP	Global Precipitation Climate Project
GRDC	Global Runoff Data Centre
GSCU	Global Seasonal Climate Update
GSN	GCOS Surface Network
GTS	Global Telecommunication System
GUAN	GCOS Upper-Air Network

ICA&D	International Climate Assessment and Dataset
ICPAC	IGAD Climate Prediction and Application Centre
ICSU-WDS	International Council for Science - World Data System
ICT-CSIS	Implementation Coordination Team on Climate Services Information System
IGAD	Inter-Governmental Authority on Development
IGRA	Integrated Global Radiosonde Archive
INPE	National Institute for Space Research
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
ISD	Integrated Surface Dataset
JMA	Japan Meteorological Agency
KMA	Korea Meteorological Administration
KNMI	The Royal Netherlands Meteorological Institute
LACA&D	Latin American Climate Assessment and Dataset
LAI	Leaf Area Index
LASG	Laboratory of Atmospheric Sciences and Geophysical Fluid Dynamics
LC-LRFMME	Lead Center for Long-Range Forecast Multi-Model Ensemble
LC-NTCP	Lead Center for Near Term Climate Prediction
LC-SVSLRF	Lead Center for Standard Verification System of Long-Range Forecasts
MOC	Meridional Overturning Circulation
MRI	Meteorological Research Institute
MSC	Meteorological Service of Canada
NARR	North American Regional Reanalysis
NCEI	National Centers for Environmental Information
NCEP	National Centre for Environmental Prediction
NCOF	National Climate Outlook Forum
NMHS	National Meteorological and Hydrological Service
NOAA	National Oceanic and Atmospheric Administration
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PREP	Partnership for Resilience and Preparedness
RA	Regional Association
RBCN	Regional Basic Climatological Network
RBSN	Regional Basic Synoptic Network
RCC	Regional Climate Center
RCM	Regional Climate Models
RCOF	Regional Climate Outlook Forum
SAWS	South African Weather Services
SIDS	Small Island Developing States
SST	Sea Surface Temperature
TCC	Tokyo Climate Center
UEA	University of East Anglia
VASClimO	Variability Analyses of Surface Climate Observations
WACA&D	West African Climate Assessment & Dataset
WCC-3	World Climate Conference-3
WCRP	World Climate Research Programme
WDC	World Data Centre
WDC-RSAT	World Data Centre for Remote Sensing of the Atmosphere
WMO	World Meteorological Organization
WWIS	World Weather Information Service

Annex A: Annex to Resolution 60 (Cg-17)

Global Framework for Climate Services relevant data and products that should be exchanged among Members to support the implementation of the Framework

Purpose

The purpose of this listing of GFCS relevant data and products is to identify a set of data and products which Congress considers necessary to enable society to manage better the risks and opportunities arising from climate variability and change for all nations, especially for those who are most vulnerable to climate-related hazards.

Contents

In addition to the climate data and products provided under Annex 1 to Resolution 40 (Cg-XII), as well as the GFCS relevant data and products subsumed within the general designation of hydrological data and products in Resolution 25 (Cg-XIII), and in addition to all data and products that are already available on a free and unrestricted basis, the following types of data and products are considered necessary for the implementation of GFCS:

(1) Historical climate time-series from the Regional Basic Climate Networks (RBCNs), the GCOS Upper-Air Network and GCOS Surface Network at a temporal and spatial resolution necessary to resolve the statistics of climate, including trends and extremes;

(2) Essential climate variables for the ocean (full depth) (as defined by the GCOS Implementation Plan);

(3) Climate relevant coastal interface data, in particular sea level, waves and storm surges;

(4) Data on the composition of the atmosphere including aerosols;

(5) Climate relevant satellite data and products;

(6) Climate relevant cryospheric data, in particular snow cover, snow depth, glacial monitoring, permafrost and lake and river ice.

Annex B: The GCOS Essential Climate Variables

The Global Climate Observing System (GCOS) has elaborated a set of 50 Essential Climate Variables (ECVs) which describes climate change and variability in three physical domains (atmosphere, oceans and land), and in the cross-cutting fields such as cryosphere, hydrosphere and carbon cycle. All ECVs are technically and economically feasible for systematic observation. The international exchange is required for these variables, for both current and historical observation.

Domain	GCOS ECVs
Atmospheric (over land, sea and ice)	**Surface**[1]: air temperature, wind speed and direction, water vapour, pressure, precipitation, surface radiation budget **Upper air**[2]: temperature, wind speed and direction, water vapour, cloud properties, earth radiation budget (including solar irradiance) **Composition**: carbon dioxide, methane, and other long-lived greenhouse gases[3], ozone and aerosol, supported by their precursors[4]
Oceanic	**Surface**[5]: sea surface temperature, sea-surface salinity, sea level, sea state, sea ice, surface current, ocean colour, carbon dioxide partial pressure, ocean acidity, phytoplankton **Sub-surface**: temperature, salinity, current, nutrients, carbon dioxide partial pressure, ocean acidity, oxygen, tracers
Terrestrial	river discharge, water use, groundwater, lakes, snow cover, glaciers and ice caps, ice sheets, permafrost, albedo, land cover (including vegetation type), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Leaf Area Index (LAI), above-ground biomass, soil carbon, fire disturbance, soil moisture

Table 1: *GCOS ECVs divided in three domains, atmospheric, oceanic and terrestrial. (source: WMO, 2015b)*

1: Including measurements at standardized, but globally varying heights in close proximity to the surface
2: Up to the stratopause
3: Including nitrous oxide (N_2O), chlorofluorocarbons ($CFCs$), hydrochlorofluorocarbons ($HCFCs$), hydrofluorocarbons ($HFCs$), sulphur hexafluoride (SF_6), and perfluorocarbons ($PFCs$)
4: In particular nitrogen dioxide (NO_2), sulphur dioxide (SO_2), formaldehyde ($HCHO$) and carbon monoxide (CO)
5: Including measurements within the surface mixed layer, usually within the upper $15\ m$

Annex C: Inventory for GFCS relevant data and products currently available from WMO global, regional and national centres and other major institutions

Please visit this link: Inventory for GFCS relevant data and products

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