Regional Climate Change Initiative Republic of Cyprus

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Report of the Task Force on

Enabling Technologies

Eastern Mediterranean and Middle East Climate Change Initiative

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Enabling Technologies

Eastern Mediterranean and Middle East Climate Change Initiative

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Abstract

Climate change and its effects pose substantial challenges for the countries of the Eastern Mediterranean and Middle East (EMME). Those challenges require well-designed adaptation and mitigation plans supported by enabling technologies such as Earth observation, geographic information systems, artificial intelligence, machine learning, visualisation, digitilisation, the Internet of Things and data-sharing systems. A system of advisory climate services conceived by and for the countries of the region will facilitate the design, implementation and monitoring of planned interventions for adaptation and mitigation.

Developments in enabling technologies are described, and their applicability examined through examples at the regional, national and municipal levels. Special attention is given to the preconditions for scalable deployment and adoption of enabling technologies in the region. The affordability of and access to enabling technologies are also explored.

Secondly, the report examines the potential of integrated systems known as climate services. Based on enabling technologies, climate services are designed to support 1) assessments of the spatial impacts of climate change now and in the future; 2) tailored products to address the links betweem climate change and sectors such as energy, agriculture and the urban environment; and 3) policies to mitigate and adapt to climate change. Climate services are ideally provided through a proposed Climate Services Hub consisting of several interconnected modules.

Acronyms

AI	artificial intelligence
CARE-C	The Climate and Atmosphere Research Centre
C3S	Copernicus Climate Change Service
CDKR	Climate Data and Knowledge Repository
EMME	Eastern Mediterranean and Middle East
ESA	European Space Agency
EU	European Union
GIS	geographic information systems
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
KTCP	Knowledge Transfer and Capacity Platform
MCM	Multi-scale Climate Modelling
MENA	Middle East and North Africa
ML	machine learning
NASA	National Aeronautics and Space Administration (United States)
NDC	Nationally Determined Contributions
NGO	non-governmental organisation
RCP	representative concentration pathway
SDG	Sustainable Development Goal
UNDRR	United Nations Office for Distaster Risk Reduction
UNFCCC	United Nations Framework Convention for Climate Change
WMO	World Meteorological Organization

Executive summary

This report examines the potential of enabling technologies such as Earth observation, geographic information systems, artificial intelligence (AI), machine learning, visualisation, digitilisation, and data-sharing systems to support the assessment and mitigation of climate change, as well as adaptations to its effects, in the Eastern Mediterranean and Middle East (EMME) region. The wide-ranging applications of these technologies include monitoring extreme weather events possibly linked to climate change, measuring thermal environments in urban areas, deploying climate and geospatial data to depict climate risks and assess vulnerability to those risks, predicting climate change's temporal and spatial effects, and assessing the links between climate change and energy production and consumption.

Developments in enabling technologies are described, and their applicability is examined through examples at the regional, national and municipal levels. Special attention is given to the preconditions for scalable deployment and adoption of enabling technologies in the region. The affordability of and access to enabling technologies are also explored.

The report recommends the development of a system of climate services in support of smart decisions that will enable the risks and opportunities of climate variability and change to be better managed in climate-sensitive productive sectors – including agriculture, energy, tourism and food security – as well as in the society as a whole. Such a system of climate services depends on the following tasks:

- Collection of knowledge about the past, present and future state of the climate system
- Identification of the necessary data – climate-related, environmental, geospatial and socioeconomic
- Identification of the climate risks facing the region
- Alignment of those risks with the circumstances of specific sectors, especially those most sensitive to climate variability and change
- Development and provision of a range of tools and products to support decisions about adaptation to and mitigation of climate change
- Identification of the enabling technologies needed to carry out the aforementioned tasks.

Based on its analysis of the characteristics of the EMME region and the needs of end users and stakeholders in the region, the task force proposes that the climate services system take the form of a Climate Services Hub having the capacity to:

- Organise data in a robust repository
- Deploy multi-scale climate modelling, including statistical and dynamic downscaling
- Develop a system of indicators for the early recognition of trends
- Support visualisation of the temporal and spatial effects of climate change
- Provide climate services in a multitude of sectors important for the EMME region
- Facilitate the development of adaptation and mitigation policies and plans using specially designed tools and indicators
- Promote the Hub's potential to support the needs of the public and private sectors in the EMME region
- Build a strong educational pillar
- Transfer knowledge and build capacity to achieve the desired outcomes.

The main findings of the task force concerning the use of enabling technologies to assess, mitigate and adapt to climate change in the EMME region are described below.

Several countries in the region already make advanced use of enabling technologies, especially Earth observation and artificial intelligence. However, substantial gaps exist in countries' knowledge and awareness of enabling technologies, resulting in the limited use of Earth observation data in public policy or AI in climate applications, as well as in drafting sectoral mitigation and adaptation plans. Poorer nations, in particular, may have difficulty accessing enabling technologies. Disparities can be traced to varying levels of economic development and degrees of integration of information technology.

But these essential technologies can be leveraged for the benefit of all through international cooperation for the exchange of technologies and innovation; for demonstrations of the potential of Earth observation, AI and other technologies to meet public sector needs; and for the establishment of open-access climate data repositories.

Moving from awareness of enabling technologies to understanding their practical applications is a priority issue to be addressed through capacity building and knowledge transfer, facilitated by regional and international cooperation. A policy environment that promotes open data and a culture of data integration and use is needed. The potential of enabling technologies' must be continually assessed so as to recognise developments that may be beneficial to assess, mitigate and adapt to climate change.

Ensuring the affordable and wide-scale deployment of enabling technologies will spur further advances and support their wider adoption in the broad field of climate change. Use by governments is critical to ensuring the progression of enabling technologies for combating climate change. Scalable deployment of enabling technologies is a critical part of resilience strategies at all levels.

Decision-support systems based on enabling technologies are needed to support 1) assessments of the spatial impacts of climate change now and in the future; 2) tailored products to address the links between climate change and sectors such as energy, agriculture and the urban environment; and 3) policies to mitigate and adapt to climate change.

The technologies covered by this report offer innovative solutions to meet the climate-related needs of the EMME region. Leveraging enabling technologies to provide climate services represents a significant opportunity to accelerate efforts to combat climate change and its impacts. The proposed Climate Services Hub would go far to meet the needs of the public and private sectors of the countries of the region to assess, mitigate and adapt to climate change.

1. Scope and purpose

This report focuses on the region of the Eastern Mediterranean and the Middle East (EMME), as illustrated by Figure 1. The socio-economic, cultural and political context varies considerably across the countries considered: Bahrain, Cyprus, Egypt, Greece, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, Turkey and the United Arab Emirates (UAE).

A diversity of climates and cultures characterise the densely populated region, whose population of 419 million is growing at an annual growth rate of 1.67%. The GDP of the EMME region is USD 3.6 trillion, with an average annual growth rate of 1.45%.

The objectives of the EMME Climate Change Initiative (EMME-CCI) are to develop a regional action plan to address the impacts of climate change in the region and to propose adaptation and mitigation options consistent with the Climate Convention and the 2015 Paris Agreement on Climate Change reached under the auspices of the United Nations Framework Convention for Climate Change (UNFCCC). That agreement set a goal of keeping the rise in global temperatures to no more than 2°C above the pre-industrial levels.

FIGURE 1. Countries included in the EMME Climate Change Initiative

To meet those objectives, EMME-CCI will develop solid projections of the processes and impacts of climate change in the region, identifying gaps in knowledge and proposing ways to address them. It will identify pathways for the most effective, rapid and economical ways to implement the Paris Agreement targets at the national level. It will assemble a policy "toolkit" for the alleviation of climate change's effects on various sectors. Finally, to enhance regional cooperation and capacity building in the most sustainable way, it will promote international mobility, joint educational programmes, advanced research and innovation, the sharing of good practices, and joint ventures and other projects likely to achieve the aforementioned goals.

Thirteen thematic task forces, including the one that produced this report, are pursuing the objectives of the Initiative. Each task force, consisting of ten to fifteen experts, will assess global knowledge in its area, identify policy needs and gaps in research, and provide a set of possible actions to address the region's climate challenges within its ambit. Each task force has been charged with producing a white paper. The thirteen white papers will form the basis of an overarching scientific report that will present technologically mature and economically affordable solutions to the climate change problem in various socioeconomic sectors.

The imperative behind EMME-CCI is this: The region is today one of the world regions most vulnerable to climate change. The 2013 report of the Intergovernmental Panel on Climate Change (IPCC) showed that most of the Mediterranean region faces significant climate risks, including heat waves, droughts, wildfires, coastal erosion, flooding and biodiversity loss. The effects of climate change are expected to be most intense in the eastern part of the Mediterranean, and particularly in the Middle East countries of the EMME region (MedEC, 2020).

The main drivers of change are climate (temperature, precipitation, atmospheric circulation, extreme events, sea-level rise, seawater temperature, salinity and acidification), population increase, air pollution, urbanisation and unsustainable land-use practices.

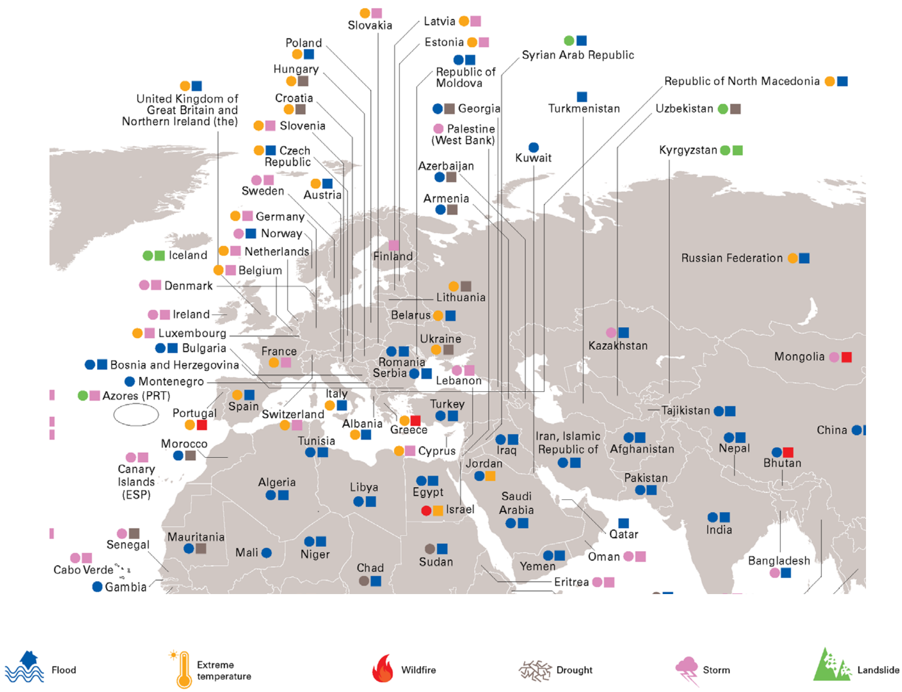
Impacts are expected to intensify in the coming decades, especially if global warming exceeds 1.5-2°C above the pre-industrial level. Annual mean temperatures across the Mediterranean Basin are already 1.5°C higher than during pre-industrial era. They are projected to rise until 2100 by an additional 3.8-6.5°C under a scenario of high greenhouse gas concentrations (RCP 8.5) and by 0.5-2.0°C under a scenario compatible with the long-term goal of the Paris Agreement (RCP 2.6).[1]

1. RCPs, or "representative concentration pathways", are greenhouse gas concentration trajectories defined by the IPCC.

Heat waves will intensify in their peaks and duration and summer precipitation will likely be 10-30% less in some regions, thus aggravating existing water shortages, advancing desertification and decreasing agricultural productivity. It is virtually certain that sea surface warming will continue during the 21st century by 1-4°C depending on the scenario (low or high greenhouse gas emissions), altering marine ecosystems and even altering circulation patterns over the long term. The Mediterranean mean sea level has risen by 6 centimetres (cm) over the past 20 years, approximately 3.6 millimetres (mm)/year for the Arabian Gulf (Siddig et al., 2019) and 2.8 mm/year for the Red Sea and Gulf of Aden (Alawad et al., 2019). These trends are likely to accelerate (with regional differences) toward the global rate of 43-84 cm until 2100 (MedEC, 2020), with severe implications for low-lying coastal areas.

FIGURE 2. Deadliest and most costly weather, water and climate-related hazards, by country

Circles refer to hazards likely to cause the greatest number of deaths; squares, to those likely to cause the greatest economic damage



Source: WMO analysis of 1970-2019 data from the Emergency Events Database of the Centre for Research on the Epidemiology of Disasters. From the 2020 State of Climate Services – Risk information and Early Warning Systems, WMO 1252.

Note: Not all of the countries shown here are part of the EMME region. See Figure 1 for the countries of the EMME region.

Significantly enhanced efforts are needed to adapt to inevitable changes, to mitigate the drivers of change and to increase resilience. Effective policies must be adopted to counteract climate and environmental changes, reinforce mitigation of the drivers of environmental change (such as greenhouse gas emissions), and enhance adaptation to impacts. Ways must also be found to address emergency events and climate-related hazards (such as floods) in the region (Figure 2). Current and evolving technologies will be key parts of the necessary policies.

2. Enabling technologies and policies to mitigate climate change

This section opens with a discussion of a set of technologies useful in slowing, mitigating, and adapting to climate change, with a focus on artificial intelligence (AI) and machine learning. Six examples from the EMME region are offered. The section then moves to a short review of national and regional policies in the EMME region in the overall area of climate change and preparation for the risks imposed by disasters.

2.1. Technologies

The enabling technologies needed to master the climate crisis are cutting-edge, innovative, and often disruptive. They include AI, machine learning, the Internet of Things, Earth observation and geographic information systems (GIS), cloud computing, augmented and virtual reality, digitalisation and Big Data.

These and other technologies offer significant potential to address the drivers and impacts of climate change. Many are inter-related, notably the Internet of Things, AI and Big Data. Even in instances where existing enabling technologies may not yet offer solutions to the complex challenges associated with climate change, the rapid advance of overall technology trajectories will likely result in new or more effective solutions in the future. In particular, the continuous increase in Internet speed (e.g. through 5G networks) and computational developments that will allow faster transmission and analysis of data.

TABLE 1. Use of enabling technologies in the EMME region

Enabling technology	Average degree of use for climate research and applications
Artificial intelligence and machine learning	Limited
Internet of Things	Limited
Earth observation	Satisfactory; strong potential is recognised
Geospatial information visualisation and GIS-based climate change strategy tools	Extensive
Digitalisation and big data	Very limited

Note: GIS = geographic information systems.

Several countries in the EMME region show an advanced use of enabling technologies to address climate change (Table 1). But substantial gaps exist in countries' knowledge and awareness of enabling technologies, resulting in the limited use of Earth observation data in public policy or AI in climate applications, as well as in drafting sectoral mitigation and adaptation plans.[2] Poorer nations, in particular, may have difficulty accessing enabling technologies.

Disparities in rates of use can be traced to varying levels of economic development and degrees of integration of information technology. Poorer nations, in particular, may have difficulty accessing enabling technologies. However, those technologies can be leveraged for the benefit of all through international cooperation for the exchange of technologies and innovation; for demonstrations of the potential of Earth observation, AI and other technologies to meet public sector needs; and for the establishment of open-access climate data repositories.

Moving from awareness of enabling technologies to understanding the full potential of their practical applications is a priority issue to be addressed through capacity building and knowledge transfer, facilitated by regional and international cooperation and by demonstration projects aimed specifically at the public sector. A policy environment that promotes open data and a culture of data integration and use is needed. The potential of enabling technologies' must be continually assessed so as to recognise developments that may be beneficial to assess, mitigate and adapt to climate change.

Ensuring the affordable and wide-scale deployment of enabling technologies will spur further advances and support their wider adoption in the broad field of climate change. Use by governments is critical to ensuring the progression of enabling technologies for combating climate change. Scalable deployment of enabling technologies is a critical part of resilience strategies at all levels.

Artificial intelligence (AI) algorithms will increasingly help to mitigate and manage climate change–related risk in the future, including extreme weather events, by improving the accuracy of regional climate models and climate forecasts. Some of the applications of AI are detailed in Table 2.

Machine learning, as a broad subfield of AI, is concerned with algorithms and techniques that allow computers to "learn by example". The major focus of machine learning is to extract information from data automatically using computational and statistical methods.

2. Mitigation refers to measures and activities aimed at reducing emissions of greenhouse gases or enhancing sinks for such gases. Adaptation refers to system adjustments in response to actual or projected climate change, including changes in socio-environmental processes and practices to reduce potential risks and damages.

TABLE 2. Areas of application of various types of artificial intelligence

Artificial intelligence	Areas of application
Automated detection and monitoring	Emissions, renewable energy potential, climate-related hazards (including extreme weather events)
Predictive analytics, forecasting and decision support	Solar energy potential, clouds, temperature, agriculture, water and air quality
Risk assessment and impact modelling	Hazards, migration, energy consumption, building emissions, ecosystem distribution, insurance
Optimisation of energy and materials use	Smart cities, smart electric grids, carbon intensity and footprint
New fields	Precision agriculture, small scale

Note: GIS = geographic information systems.

Over the last decade considerable progress has been made in developing machine learning for a variety of applications related to earth science and climate.

AI and machine learning are already used to resolve smaller-scale atmospheric processes and to reduce the uncertainties inherent in current climate models. Nevertheless, a reliable representation of climate processes driven by AI and machine learning is still lacking, in the EMME region.

The **Internet of Things** enables advanced services by interconnecting physical and virtual things based on existing and evolving interoperable information and communication technologies. It is essentially about measuring and remotely controlling previously unconnected “things”.

Satellite technology has, over the decades, provided unequivocal evidence of the changes taking place on Earth as a result of climate change. Satellite measurements of the Earth’s changing temperature, sea levels, atmospheric gases, and declining ice and forest cover are some of the key ways of obtaining the data needed to understand Earth as a geological system and predict its climatological future. The benefits of **Earth observation** include the provision of synoptic views of the Earth’s surface in a multitude of spectral regions, regular and repeatable observations, multi-annual time series of observations, and cost-effective means for monitoring remote and inaccessible areas. At the same time, data from next-generation satellites will help improve uncertain forecasts for sea-level rise, as well as improving our understanding of climate patterns. Between 2016 and 2019, 419 satellites (>50 kilogrammes) were placed in orbit, a massive increase over the 163 sent up between 2006 and 2015. As a result, data volumes are increasing, exceeding 22 petabytes by 2020 for the European Space Agency’s archives alone. CubeSats, the new generation of miniature satellites, will provide more petabytes of Earth observation data each year.

Geospatial information visualisation and GIS-based climate change strategy tools make it possible to analyse climate indices at regional scale. In general, in climate or systems modelling, the value of geographic analysis and spatial visualisation is well recognised, as it enables users to improve on the interpretation of modelling outcomes across an area or region. This spatial analysis enhances the limited applicability of single-site simulation. For these reasons, the use of geographic information system (GIS) software is widespread. The development of stand-alone GIS functionality involves four major steps: map projection, boundary allocation, data interpolation, and graphical display of the spatial data.

Digitalisation refers to enabling or improving processes by leveraging digital technologies and digitised data. But the challenge is not just to make existing data digital. Digitalisation also embraces the ability of digital technology to collect data, establish trends and make better decisions. This represents a clear shift from the traditional discovery of computational patterns inherent in data mining to data-driven modelling and inference.

With this shift, **Big Data** is opening new ground for scientific and statistical analyses. Big Data based on satellite imagery relies on the processing, analysis and fusion of multiple images and other data sources to create intelligence not previously available.

Digitalisation and Big Data already enable policymakers to build strategies to address climate change. The digitalisation of climate data, for example, preserves historical observations and provides the basis for understanding and assessing climate variability, predicting extreme climate events and designing adaptation and mitigation plans. In particular, small-scale, cost-effective digitalisation projects can help inform local climate adaptation policies and yield significant benefits for local communities. Information from observations with geographic, oceanographic and scientific data and making data available to multiple players across the public and private sectors will support new services and provide space for innovations based on Big Data. At the same time, non-technical users and decision makers will have to move from awareness of Big Data to understanding its practical applications.

2.2. Six examples

2.2.1. Three new AI-powered tools

The Ministry of Climate Change and Environment of the UAE has developed three AI-powered prototype tools in collaboration with Khalifa University and the International Renewable Energy Agency (MOCCAE, 2018)

- The solar energy tool is used to identify areas of concentrated solar energy highly suitable for the installation of solar panels.

- Using satellite data and AI-based algorithms, the air quality tool monitors and predicts air quality across the country.
- The water tool uses data generated by NASA and ESA satellites to produce a daily assessment of water quality in the UAE. The system also tracks ocean currents and marine pollution, including oil leaks, and provides information to optimise tanker routes in the region.

2.2.2. Innovative machine-learning applications

Specific applications of climate system models driven by Machine Learning (ML) include 1) cloud physics simulation, where deep neural networks can be combined with thermodynamics to reduce uncertainty related to clouds, with climate model components replaced with ML models; 2) prediction of changes in the extent of sea ice using Earth observation imagery and data; 3) forecasting of extreme events at sub-seasonal scale; 4) identification of extreme events using ML models such as deep learning approaches (e.g., to track storms); and 5) localised forecasts, such as flood risk estimates.

2.2.3. Adapting to urban climate change

ML models can be useful in adapting to urban climate change – for example, to model building energy based on a building's physical structure. Intelligent control systems in smart buildings can shrink their carbon footprint. ML models can be used in urban planning to forecast energy consumption based on features (e.g. location, geometries, building footprint, usage, material, roof type, immediate surroundings) and to assess buildings' retrofit potential. For purposes of gathering infrastructure data, remote sensing can be used to cluster buildings by type. High-resolution satellite images can generate building footprints and 3D reconstruction of cities.

2.2.4. CoastalDEM

CoastalDEM is a digital terrain model that uses machine learning techniques to improve estimates of coastal flood risks (Kulp and Strauss, 2018). The product focuses on improving land topography and elevation, as represented by satellite-based Digital Elevetion Models (DEM) such as the Shuttle Radar Topography Mission (SRTM). A neural network is used to perform a nonlinear, nonparametric regression analysis of SRTM error in which a multi-layer perceptron is used to predict the vertical error present in any SRTM pixel sample. The results are extended to assess population exposure.

2.3.5. GEO-CRADLE

The GEO-CRADLE project promotes the use of Earth observation services to coordinate and integrate state-of-the-art Earth observation activities in North Africa, the Middle East and the Balkans. A solar atlas of Egypt based on a 15-year compilation of direct normal and global horizontal irradiances was produced; data were downloaded from EUMETSAT's Surface Solar Radiation Data Set. Solar surface irradiance and normalised surface direct irradiance were derived from satellite observations of the MVIRI and SEVIRI instruments on Meteosat (Kosmopoulos et al., 2018)..

2.3.6. Exploitation of geospatial information visualisation

Quantitative assessments of climate change – its impact, the vulnerabilities it creates, and ways to adapt to it – can use geospatial information visualisation drawn from national reports on climate change submitted to UNFCCC. Results are based on past, present and future climate scenarios and their impacts on key human and natural systems such as the water, agriculture, biodiversity, coastal areas, urban areas and health. A representative case study dealing with biodiversity and ecosystems is related to Jordan's third national communication on climate change (Figure 3). Another on water resources and desertification relies on Saudi Arabia's third national communication report on climate change impacts (Figure 4).

2.3. Policies

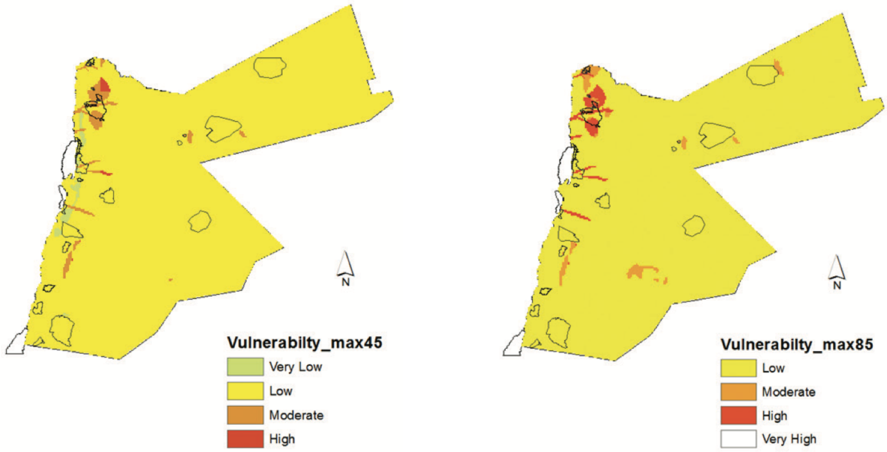
For this report, the task force examined national and regional policies in the EMME region pertaining to climate change and disaster risks. The list of policies begins with the Paris Agreement and the National Determined Contributions (NDCs) of the countries in the EMME region, as well as related national climate change action plans. It continues with the Arab Framework Action Plan on Climate Change, RICCAR (Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region), the Arab Strategy for Disaster Risk Reduction, and the Arab Climate Resilience Initiative of the United Nations Development Programme, along with other Arab strategies for sustainable development and water security. The task force also scrutinised the SDG Climate Nexus Facility; the World Bank's action plan for the Middle East and North Africa region; and the climate change profiles on Egypt, Iran, Jordan, Lebanon, Palestinian Territories produced by the Netherlands Ministry of Foreign Affairs.

Almost all EMME countries have submitted their NDCs to UNFCCC, as detailed in the NDC registry. Early warning systems are a top adaptation priority in most of the NDCs, but gaps in data collection and archiving are recognised. To close those gaps, countries must create a policy environment that promotes open data and a culture of data integration, use, innovation and governance to deliver tangible benefits to their citizens.

FIGURE 3. Vulnerability of Jordan's biodiversity and ecosystems in the year 2100 under two representative concentration pathways as defined by IPCC

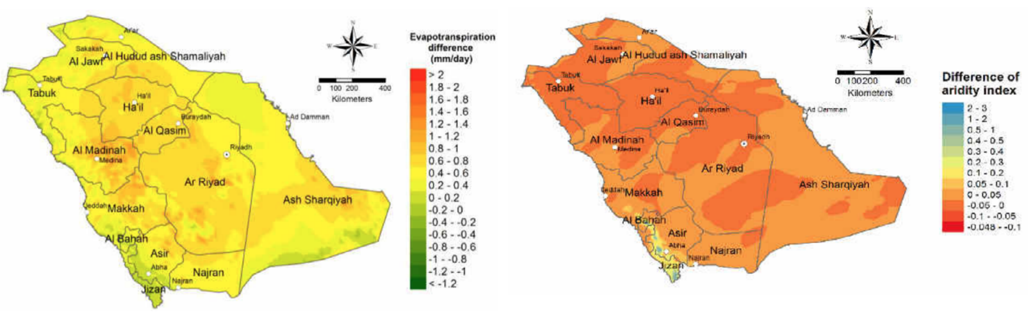
RCP 4.5 (global warming at a global average of 4.5 Watts per square metre)

RCP 8.5 (global warming at a global average of 8.5 Watts per square metre)



Source: UNFCCC, 2014.

FIGURE 4. Change in Saudi Arabia's evapotranspiration and aridity index from 2030 to 2080



Source: UNFCCC, 2016.

Environmental organisations should adopt common data strategies, assigning specific leadership roles to different actors and agreeing on the core global data sets that are needed to monitor the health of the planet and progress under global agreements. There is a need to build on and leverage existing partnerships and practitioner communities to ensure that the environment's digital ecosystem is inclusive and does not overlap with or duplicate existing activities.

It is equally imperative to curate and release global data analytics on environmental risks that have the power to influence global markets and investments in sustainable resource-management solutions. Public-private partnerships are needed to leverage private sector expertise and infrastructure in data science, cloud computing and AI, to share data and to promote the use of technology for global public goods.

Finally, integrated systems based on enabling technologies are needed to support 1) studies on the assessment of the spatial impacts of climate change, now and into the future; 2) tailored products addressing the links between climate change and energy, agriculture, the urban environment, and other sectors; and 3) policies to mitigate and adapt to climate change. These systems can be rolled out as climate services, as discussed in the next section.

3. Climate services and the proposed EMME Climate Services Hub

A climate service is a decision aid derived from climate information that help individuals and organisations make better decisions. A climate service requires appropriate and iterative engagement to produce timely advice that is comprehensibe to end users and can support decision-making, early action and preparedness. Climate services work by integrating high-quality meteorological and climate data (temperature, rainfall, wind, soil moisture and marine conditions) as well as maps, risk and vulnerability analyses, assessments, and long-term projections and scenarios that respond directly to users' needs.

3.1. Typology and examples of providers of climate services

Various climate services have been developed with public or private funding to provide data, data products, reports and guidelines. Table 3 offers a typology of providers of climate services, with their strengths and weaknesses.

3.1.1. Global Framework for Climate Services

At the 2009 World Climate Conference, 155 nations endorsed the Global Framework for Climate Services "to strengthen the production, availability, delivery and application of science-based climate prediction and services" (WMO, 2018).

The Global Framework aims to bridge the gap between the climate information being developed by scientists and service providers and the practical needs of end users and to enable "better management of the risks of climate variability and change and adaptation to climate change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scale" (WMO, 2011).

Its implementation plan targets gaps in the climate services supporting four climate-sensitive sectors: – agriculture, health, disaster reduction and water – with a focus on the most vulnerable. This is achieved by developing and incorporating science-based climate information and predictions into planning, policy and practical decision-making.

Effective climate services facilitate climate-smart decisions that will, for example, mitigate the impacts of climate-related disasters, improve food security and health outcomes, enhance water resources management, and bring better outcomes in disaster risk reduction. As climate services continue to rise in prominence on national, regional and global agendas, it is important to re-examine the opportunities and challenges they pose. These are apparent from the following profiles of three providers of climate services

3.1.2. The Copernicus Climate Change Service

The Copernicus Climate Change Service (C3S) provides authoritative information about past, present and future climate in Europe and the rest of the world. It is one of six thematic information services provided by the European Union's Copernicus Earth Observation Programme (https://climate.copernicus.eu/). Its mission is to support the adaptation and mitigation policies of the European Union by providing consistent, reliable information about climate change. Relying on climate research conducted under the auspices of the World Climate Research Programme, C3S responds to the needs of scientists, consultants, planners and policy makers, and other users, as defined by the Global Climate Observing

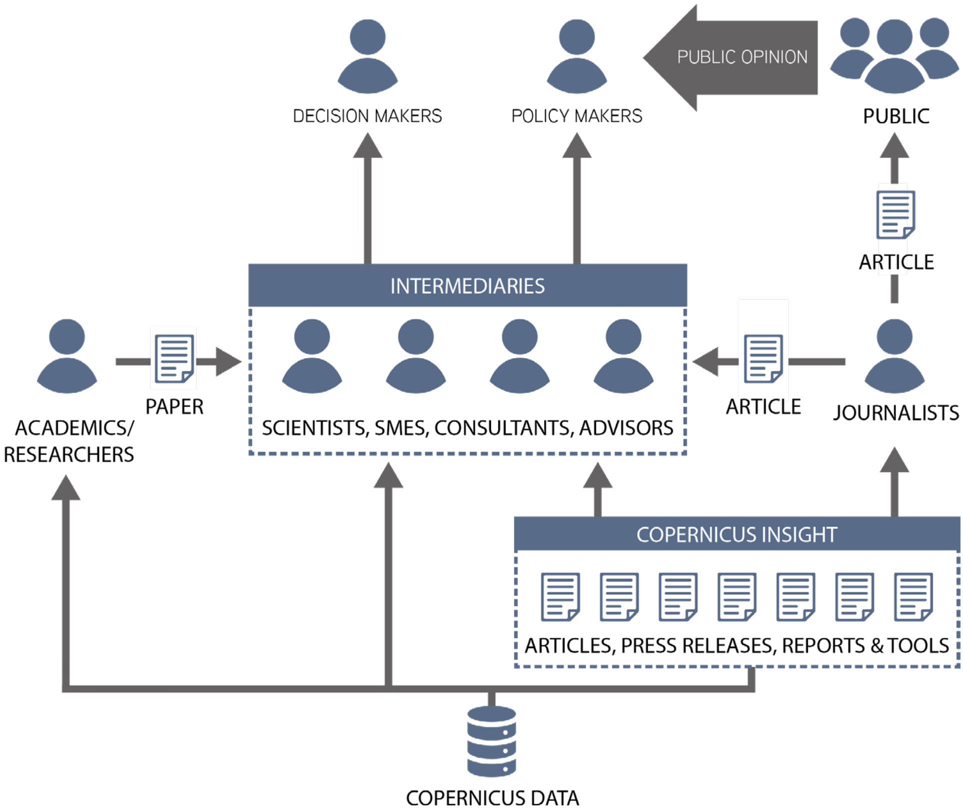
TABLE 3. Types of climate services providers, including a qualitative analysis on strengths and weaknesses

Type of climate services providers	Strengths	Weaknesses
Extension of meteorological services	Strong infrastructure; solid experience; supportive of disaster risk management	Main focus on physical data; limited field of climate services and products
Services offered by the European Commission or other international organisations	Strong infrastructure and support; wide mix of services; extended networking; good knowledge of users' needs; link to other operational programmes (e.g. Copernicus)	Few tailored products at local scale
Services offered by a university or a research centre (or groups)	Research orientation; use of state of the art methodologies	Limited knowledge of users' needs and limited mix of climate services
Private firms	Business orientation, good knowledge of users' needs	Little climate knowledge

System. It also supplies information to the media and the public. Its user model is illustrated in Figure 5.

C3S is implemented by the European Centre for Medium-Range Weather Forecasts on behalf of the European Commission. The centre is an independent intergovernmental organisation serving its EU member states and the broader community. C3S service components are used by about 200 companies and organisations across Europe. C3S provides climate data and information on impacts through the Climate Data Store, which is designed to enable users to tailor services to their particular needs.

FIGURE 5. The user model of the Copernicus Climate Change Service



Source: Copernicus Climate Change Service.

3.1.3. The Euro-Mediterranean Centre (CLARA project)

The aim of the EU's CLARA project (https://www.clara-project.eu/) is to develop a set of leading-edge climate services building on near-term forecasts and sectoral information from C3S –and to sustain their marketability and value. The main objectives of the project are:

- To facilitate the development of new climate services and enhance existing services by drawing on seasonal projections, including those of C3S.
- To analyse and demonstrate the economic and social value unleashed by forecast-enabled climate services – for example, by corroborating the direct and indirect benefits that various end users and customers gained from climate services (reduced risk, more efficient resource management, improved resilience to climate variability and change).

3.1.4. The Climate and Atmosphere Research Centre of Excellence

Capitalising on a research division with ten years of experience, the Cyprus Institute launched the EMME Climate and Atmosphere Research Centre (CARE-C) in January 2020 in cooperation with the Max Planck Institute for Chemistry in Germany, the Alternative Energies and Atomic Energy Commission in France, and the University of Helsinki in Finland. CARE-C is a centre of excellence within the framework of the European Commission's Horizon-2020 project.

The Centre focuses on environmental and climate change research and the development of sustainable solutions to address societal challenges in the EMME region, which has been identified as a climate change "hotspot".

Its sustainability- and user-driven research has been embedded at the policy-making level through strong collaboration with Cyprus government units responsible for agriculture and rural development; the environment; labour, welfare and social insurance; and health – as well as with the national funding agency in Cyprus for the research and innovation. CARE-C also works in close collaboration with high-level partners, institutions and organisations in Cyprus and the region.

CARE-C operates four research departments: Environmental Observations; Environmental Predictions; Impact and Policy; and Innovation. It has also upgraded several cutting-edge environmental monitoring facilities within its research units. Emphases include air pollution and climate services oriented to the needs of end users, such as: mitigation and adaptation strategies to downscale climate effects; the development of high-spatial-resolution climate projections and forecasting; observation, monitoring, and surveillance solutions using customised sensors and platforms; environmental chemical analyses; and assessments of risk and impacts on human health, ecosystems, water availability, agriculture, and vector-borne diseases spreading; energy generation; and tourism.

CARE-C is making a special effort in three specific areas:

- Science and research on climate change and air pollution in the EMME region
- Innovation in early warning systems for dust storms and extreme weather events; new cost-effective atmospheric sensors; and unmanned aerial vehicles for use in meteorology for measuring and forecasting air quality; and for gauging the region's carbon footprint
- Education and training (MSc, PhD, hands-on training) in atmospheric science and climate change.

3.2. Planning the Hub

Only if users and their needs are recognised and the scientific community becomes involved in the development, distribution and use of climate-informed services can a climate-resilient society be built.

A principal goal of EMME-CCI is to propose scientifically sound policies and initiatives to alleviate the effects of climate change in the region and accelerate mitigation efforts and adherence to the Paris Agreement. Concerned by the adverse impacts of climate variability and change, decision makers are demanding better climate services. The EMME Climate Services Hub will meet that demand, thereby advancing the goals of EMME-CCI.

To this end, the Task Force on Enabling Technologies has proposed the development of an EMME Climate Services Hub. The proposal, which has been endorsed by EMME-CCI, engages all task forces of the initiative. Input from each will be solicited using the questionnaire in the Appendix. The purpose of the questionnaire is to solicit suggestions on the climate services to be provided through the Hub.

The Hub will be developed over several years. Following an initial assessment by EMME-CCI, the task force will draft a timeline for its development, a recommended legal structure and an operating budget.

Once established, the EMME Climate Services Hub will provide climate data, information, products and services to help public and private entities make climate-smart decisions and define essential policies and plans. The data and information collected will be transformed into customised products such as projections, trends, economic analyses and services. The demands for such services are wide-ranging. Examples include water management, disaster risk reduction and response, energy production, and the protection of cultural heritage. Appropriate services must be developed for a wide range of spatial and time scales and conditions.

The Hub will demonstrate the importance of strong links between climate monitoring, analysis, application and use in various climate-sensitive sectors. It will provide comprehensive climate information covering a wide range of components of the EMME system (atmosphere, land, ocean, carbon), maximising the use of past, current and future Earth observations in conjunction with modelling, the generation of essential climate variables, and the establishment of key indicators for relevant economic sectors, such as energy, water, agriculture, biodiversity and disaster risk. Indicators include CO2 and temperature trends, energy consumption, changes in land cover, wind statistics, drought conditions, and growing seasons.

The steps in the development of the EMME Climate Service Hub are described below.

3.2.1. Step 1. Understand the trends in climate services

Manifold trends are shaping the design and provision of climate services. Users and their demands are becoming more diverse. The boundaries between research and operations projects are blurring. These trends point to the imperative of co-producing climate services with the end user and keying publicly funded science to societal needs.

Adapting to climate change and building resilience will require seasonal to decadal climate predictions; early warning systems; better spatial resolution for climate modelling; and statistical and dynamic downscaling of regional climate models.

Data must be treated as a service, sourced, managed and delivered in an immediately consumable format. Data must be open: Government policies must ensure that this clear demand of users is met and that users gain wider access to data and tools.

Research in data analytics and information retrieval, information visualisation, data mining, and the fusion of in situ data with geospatial information offer opportunities to create value that must not be ignored. Earth observation must be increasingly conducted in the Big Data context.

3.2.2. Step 2. Recognise the end users

The end user's perspective is the key to tailoring climate services. End users are a heterogeneous mix of stakeholders at the national, subnational and community levels. End users do not need climate data, but rather a finished service or product they can feed into their decision-making.

An additional category of end users are intermediaries. These recipients of climate information (such as trend projections and predictions of climate parameters) analyse and process that information to produce a useable, tailored and integrated climate service that can be sold or given to end users. For example, urban experts may receive climate predictions (climate information) for a time period in the future; to those predictions they link information on the urban form and functions of a city (sector-specific knowledge) in order to produce tailored urban advisories (climate services).

Bessembinder et al. (2012) recognises users in research and education; politics, policy-making and non-governmental action; consulting services and expertise; the media; and the public.

Researchers who work on impacts, adaptation and mitigation plans can be further subdivided by where they are housed (e.g. an academic institution or a private institution) and by their discipline. Educators develop educational curricula and materials.

Policy makers are a diverse group (consultancy companies may also have many of the roles of policy makers). NGOs and other stakeholder groups communicate information about climate and climate change. NGOs often apply that information to solve problems within their remit.

Consulting firms perform impact and adaptation studies; develop adaptation and mitigation plans; provide information on climate change; support the implementation of adaptation and mitigation plans. Some of these firms can be considered providers of climate services or even as policy makers (when they are hired to draft policies).

Experts, too, are a diverse group. They include spatial and urban planners, energy engineers, and investment portfolio managers in local government, industry, and business and finance.

3.2.3. Step 3. Understand the demand side

Communicating with end users on what they need is often either underestimated or overlooked in the design phase of projects that aim to deliver climate services in support of local, national or regional plans. However, end-user participation in the assessment of their needs for climate services is a prerequisite to the success of any programme aiming to build resilience to climate change. A critical requirement is the continuous involvement of end users in production, delivery and evaluation. This requirement is satisfied through specially designed interfaces facilitating the end user's interaction with the climate service provided.

3.2.4. Step 4. Foster systems thinking

Gaining a better understanding of the context of hazard, exposure and vulnerability is the goal of this step. It involves probabilistic modelling, expert opinion, bow-tie analysis, stochastic simulation, among other techniques, as well as ways to incorporate them into the Hub's operations.

In the course of this step, the Hub is aligned to the Paris Agreement of UNFCCC, the Sendai Framework for Disaster Risk Reduction 2015-2030 of UNDRR, the European Green Deal and the Strategy for transforming the EU into a competitive, low-carbon economy by 2050. The social, ecological, financial and political drivers of risk are identified, in parallel with opportunities for systemic innovation and positive impact (e.g. through interdisciplinary applications).

3.2.5. Step 5. Define the fundamental pillars of the Hub

A climate-resilient society stands or falls on whether its policies and actions are based on the latest internationally recognised knowledge and the most encompassing and accurate data available.

Because the scientific community must be involved in the development, distribution and use of climate-informed services, it is necessary to promote scientific networking, establish links between the scientific world and policy makers, and eliminate the barriers to access and analysis of good climate data.

An operational structure to embed data in analytical and modelling schemes is needed to ensure that the resulting climate services will be of sufficiently high quality. Tools and models visualise data, model climate change impacts, and provide knowledge and experience for the development of customised products are essential. Knowledge transfer and capacity building are needed to sustain the structure.

3.2.6. Step 6. Recognise the links

The Hub will rely on the strong links between climate monitoring, analysis, application and use in various climate-sensitive sectors. Those links must encompass a wide range of components of the EMME system (atmosphere, land, ocean, and carbon), and maximise the use of past, current and future Earth observations.

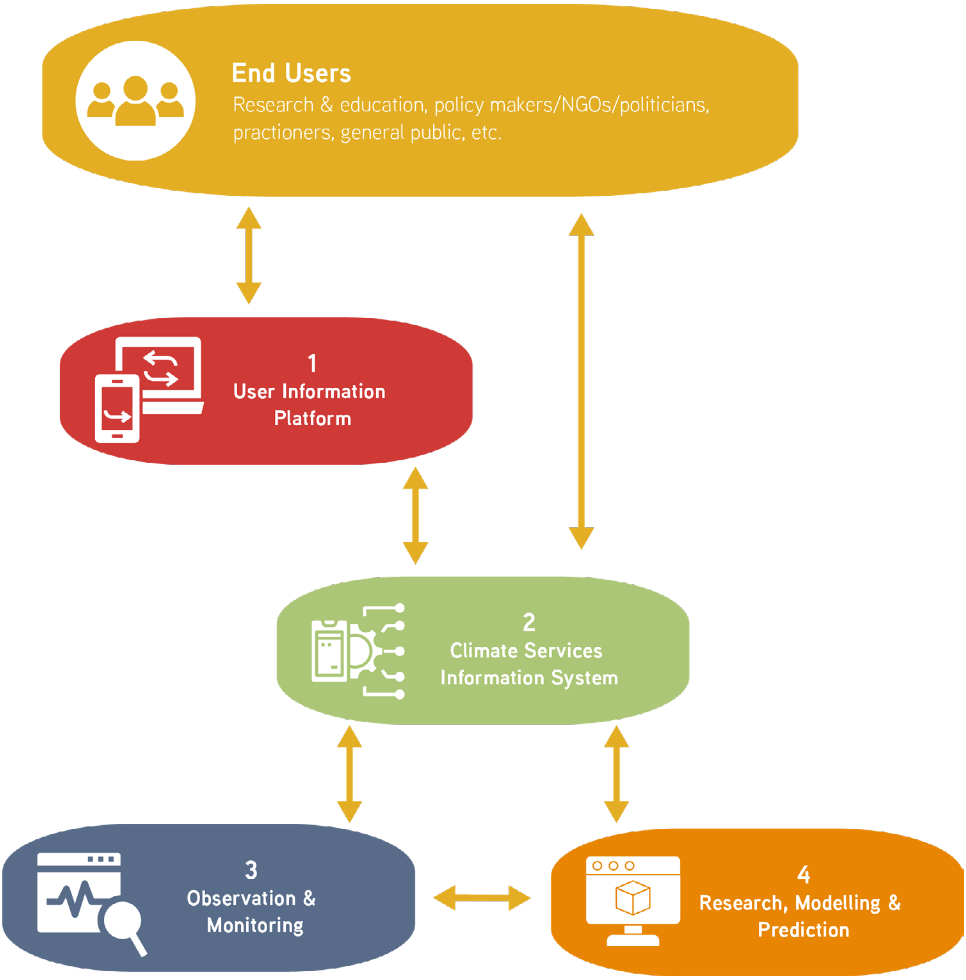
Vertical links among players should lead to the creation of integrated value chains, starting with the climate service supplier and proceeding through the developer and end user, which may reside within the Hub itself. These interactions allow hubs to bring together experts from different fields and disciplines, and to facilitate public-private partnerships.

Horizontal links within the Hub will help actors in the same thematic area but from different sectors to interact in a complementary way – for example, to ensure compatibility of methodologies and products.

3.2.7. Step 7. From climate data to climate services

The EMME Climate Services Hub will provide services by integrating high-quality meteorological and climate data (temperature, rainfall, wind, soil moisture and marine conditions) as well as maps, risk and vulnerability analyses, assessments, and long-term projections and scenarios. The data and information collected will be transformed into customised thematic products such as projections, trends, economic analyses and services. As noted in the introduction to this section, the demands for such services are wide-ranging – for water management, for disaster risk reduction and response, for energy production, for the protection of cultural heritage, and so on.

FIGURE 6. The architecture of the EMME Climate Services Hub



The aim is to support decision makers, as well as public and privates entities in the climate-sensitive EMME region, with high-quality information to advance climate-related decision-making and planning.

3.2.8. Step 8. Define the architecture of the Hub

The EMME Climate Services Hub has four main elements (Figure 6).

The **user interface platform** is a structure that allows users, scientists, climate researchers, climate information providers, stakeholders and end users to interact at all levels.

The **climate services information system** is a mechanism through which information about the climate is collected, organised, stored and processed to generate products and services.

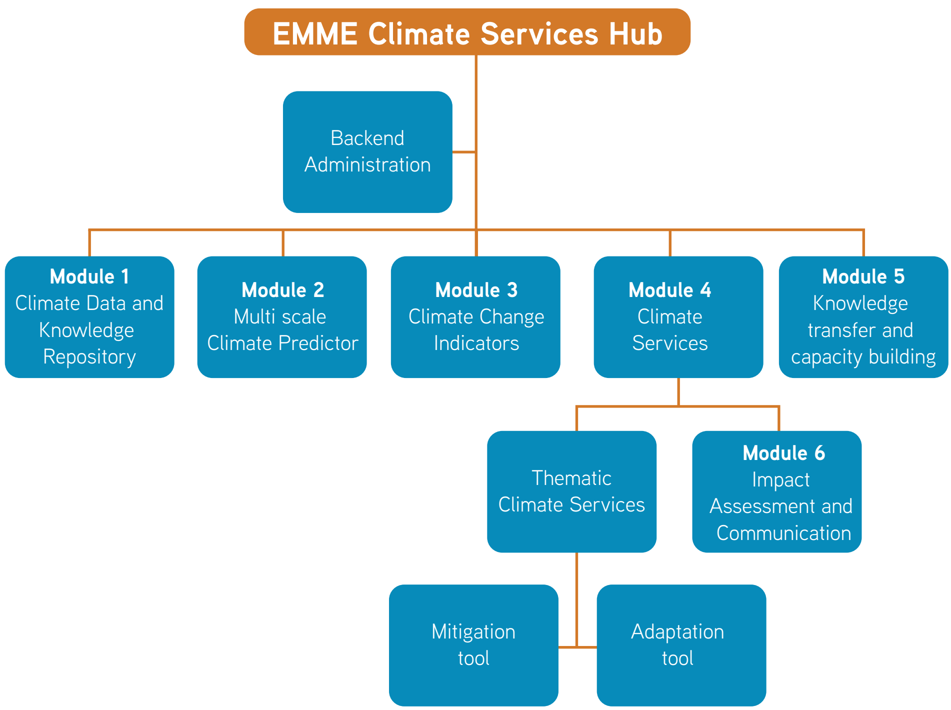
A **system for observation and monitoring** ensures that climate observations (including Earth observation) and other data (including metadata) are collected, managed and disseminated to meet the needs of end users.

Research, modelling and prediction functions promote research in the field of climate modelling, embracing statistical and dynamic downscaling and including decadal to seasonal predictions.

3.3. Deploying the Hub

The Hub will be organised as six interconnected modules (Figure 7). Each is described in turn.

FIGURE 7. The modules of the proposed EMME Climate Services Hub



Source: Modified from WMO, 2018.

3.3.1. Module 1: The EMME Climate Data and Knowledge Repository

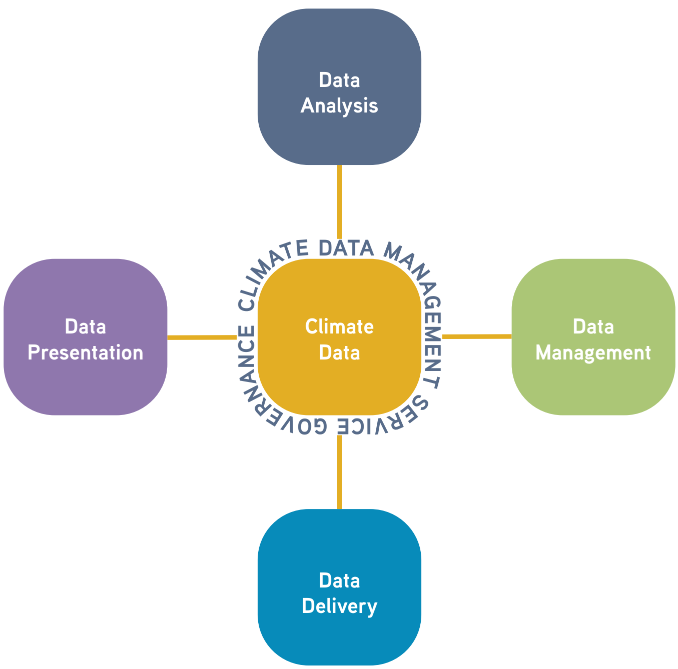
The EMME Climate Data and Knowledge Repository (EMME-CDKR) will provide easy access to a wide range of climate data sets relevant to the region via a searchable catalogue distributed in the cloud. An online toolbox will enable users to build workflows and applications suited to their needs. Access to curated and validated data will be, in most cases, open, free and unrestricted.

Data sets include observations, historical climate data records, estimates of essential climate variables derived from Earth observations, global and regional climate reanalyses of past observations, seasonal forecasts and climate projections, and geospatial data, among others. Open access will be provided to collections of scientific papers, reports, case studies and policies.

EMME-CDKR will support a wide range of users with different needs by facilitating the processing of large volumes of data and through visualisations based on multiple data sources.

Through a governance unit, EMME-CDKR will perform four data-related actions: analysis, management, presentation and delivery (Figure 8).

FIGURE 8. Data functions of the EMME-CDKR (modified from WMO, 2020)



The system will have linked modules referring to data, publications, codes, visualisation tools and big data analytics and impact analysis, as described below.

CDKR DATA is an open access scientific data repository (including geospatial data), offering data in various formats (asci, raster and vector data, netCDF, HDF, geoTIFF, GRIB, shapefile).

CDKR METADATA contains metadata on observations (time-series data describing how, when and where climate observations were made and the conditions under which they were made) and provenance (information relevant to climate data that permits data managers, scientists and the general public to develop trust in the integrity of the climate data).

CDKR PUBL offers collections of scientific papers, reports, and policies, while CDKR LAB makes it possible to create and share live interactive code and visualisations of scientific data.

CDKR VISUALISE and CDKR ANALYTICS focus on data visualisation and Big Data analytics and impacts analysis, respectively.

Some of the questions asked in the course of establishing EMME-CDKR appear in Box 1.

EMME-CDKR will be supported by a catalogue of software tools classified as 1) tools that perform basic operations on data, such as computation of statistics, sub-setting, smoothing, and value at points; 2) workflows that combine the output of tools and feed it into other tools to produce derived results; and 3) interactive web pages that allow users to exploit the repository through parameterisation and make use of the workflows and selected data and products it contains.

EMME-CDKR will benefit from the expanding volume of Earth observation data sent back by orbiting satellites and from improvements in sensor technology and spatial, temporal and spectral resolutions. To be considered are a common Earth observation data pool from all missions covering the EMME region and the possibilities of sharing resources and cloud services for processing Interlinked Earth observation data catalogues.

Finally, EMME-CDKR will provide a web portal allowing users to browse and search for data and products, retrieve data and publications, access the toolbox, and visualise or download results. The web portal will also provide a help desk facility, FAQs, and a user forum.

Box 1. Questions asked in planning EMME-CDKR

- What kinds of data (images, numeric, textual, series) will be collected?
- In what formats (jpeg, csv, open data cubes, compressed, encrypted)?
- How will the data be represented (data structures, data types, field-based vs. object-based modelling, interpolation)?
- What sorts of data transformation are needed (rectification, resampling, registration, resampling)?
- What will be the volume of data and how will that volume evolve?
- Where will the data be stored (central repository and/or distributed data repositories) and in what storage format (database such as PostgreSQL or more-flexible forms such as HDFS, Data Lake)?
- What are the requirements with respect to spatial and temporal scales, quality analysis and validation, and preprocessing?
- What formats and standards are need to ensure precision and accuracy in data transfers?
- Are there restrictions on the open use of data?
- Which models and structures will be used for the data (machine learning, neural networks, statistical models, big data analytics, Python, R, Matlab)?
- What will be the framework for the execution of the programmes used (Jupiter Notebook, Spark, SQL, Unix scripts)?
- What are the current and anticipated computer needs and requirements (multi-node clusters, HPC, central processing unit, memory, disk)?

3.3.2. Module 2. EMME Multi-scale Climate Modelling

EMME Multi-scale Climate Modelling (EMME-MCM) has three parts: 1) inputs of meteorological, Earth observation and surface information; 2) a modelling system (consisting of an independent model or an ensemble of models) to assess climate change and its impacts based on the IPCC scenarios; and 3) tools to analyse and downscale outputs to suit individual cases, including error analysis and indicators of uncertainty.

In particular, EMME-MCM will allow users to integrate atmospheric, Earth observation and surface data from multiple sources; employ reanalysis to validate climate modelling estimates; assemble multiple-model seasonal forecasts and climate projections at the global and regional levels; and compare and visualise results and scenarios for different climate indicators of interest.

3.3.3. Module 3. EMME Climate Change Indicators

The EMME Climate Change Indicators module will suggest customised and thematic indicators for monitoring climate change and for assessing the performance of climate adaptation and mitigation tools. Table 4 provides an example of climate change indicators for urban areas.

TABLE 4. Indicative climate indicators for urban areas

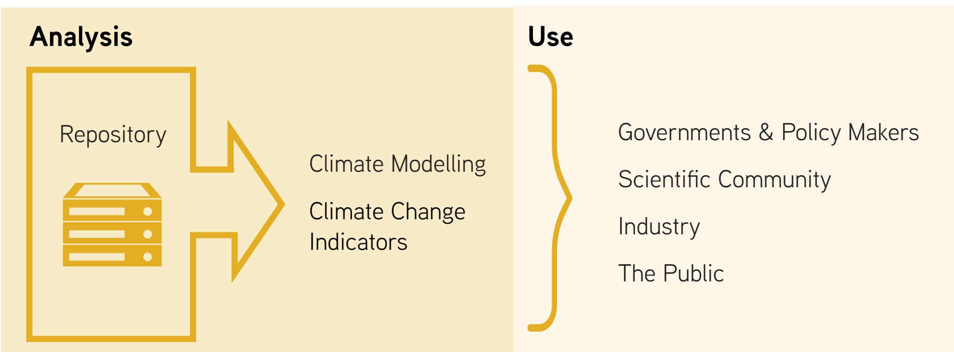
Tropical nights	Number of days when temperature exceeds 20°C	Days when minimum temperature exceeds 20 °C	Monthly/annual
Number of hot days	Fraction of days when temperature is in 90th percentile	Fraction of days with hot daytime temperatures	Percent
Consecutive dry days	Maximum number of consecutive dry days (when precipitation is less than 1.0 mm)	Longest dry spell	Monthly/annual
Heat wave number	Three or more days when temperature is in 90th percentile	Number of individual heatwaves	Monthly/annual

Source IPCC, 2013.

3.3.4. Module 4. EMME Climate Services

The architecture of this module takes advantage of the previously described elements of the EMME-Climate Services Hub to support governments and policy makers, the scientific community, industry and the public (Figure 9).

FIGURE 9. Conceptual structure of the EMME Climate Services Hub



Source: Modified from Copernicus Climate Services.

Submodule 4.1. EMME thematic climate services

This submodule aims to provide climate services in each of the following sectors: agriculture, biodiversity, coastal zones, cultural heritage, disaster risk, energy, tourism, urban areas and water management. Climate services may address spatial or temporal changes in biodiversity in the occurrence of heatwaves (especially in urban and tourist areas), or in the erosion occurring in cultural heritage sites, among others.

These services will be based on a compilation of reliable analytical models, tools, methods and procedures. They will inform options for sectoral, multi-sectoral and multi-stakeholder planning.

Submodule 4.2 Climate change mitigation and adaptation

The EMME Climate Mitigation Tool (EMME-CMT) will support the development of climate change mitigation plans to reduce emissions of greenhouse gases. To do so, inventories of greenhouse emissions will be compiled on the basis of energy use, transport modes, and urban form and functions, among others. The EMME Climate Adaptation Tool (EMME-CAT) will support the development of thematic adaptation plans on the basis of the recognition of climate risks and vulnerabilities. The steps in both processes appear in Table 5.

TABLE 5. Steps in the development of the EMME climate mitigation and climate adaptation tools

EMME Climate Mitigation Tool	EMME Climate Adaptation Tool
Step 1. Recognise sources of emissions of greenhouse gases	Step 1. Assessing exposure, sensitivity and adaptive capacity
Step 2. Develop emission inventories	Step 2. Assessing climate risks and vulnerabilities
Step 3. Identify mitigation options	Step 3. Identify adaptation options
Step 4. Communicate with stakeholders and local population	Step 4. Communicate with stakeholders and the local population
Step 5. Develop the mitigation plan	Step 5. Develop the adaptation plan
Step 6. Monitor and evaluate the plan	Step 6. Monitor and evaluate the plan
Step 7. Promote rectification measures	Step 7. Promote rectification measures

3.3.5. Module 5. EMME Knowledge Transfer and Capacity Platform

The EMME Knowledge Transfer and Capacity Platform (EMME-KTCP) will offer access to technical support in the form of technical courses, e-learning programmes, help-desk applications, multimedia training platforms, and other training material. Ideally, it will be linked to specialised graduate programmes offered by universities and research centres in the region.

A key objective of EMME-KTCP is to build capacity within the EMME countries to use the Hub's tools without external assistance – or at most limited assistance. In this way, it will help integrate climate-resilient and adaptive planning into national, regional and municipal decision making. To this end, the principal pillar of Module 5 is to demonstrate the potential of climate services to the entities of the EMME region through selected case studies, and to provide training to officials in state, regional and city administrations in the use of the Climate Services Hub.

EMME-KTCP will also promote cooperation among the countries of the region by 1) supporting higher education programmes in the broad field of climate services as related to adaptation and mitigation; and 2) fostering cooperation across world regions through joint educational initiatives.

To this end, one of the chief objectives of EMME-KTCP is to design and produce an e-learning master's programme on climate services related to adaptation and mitigation. The programme should be interactive, collaborative, and peer-to-peer; it should feature online material of the highest quality, such as lectures and other educational material, web tools, interactive maps with data overlays, tutorials with executable algorithms, and so on. In particular, the master's programme will:

- Offer courses on AI and machine learning, the Internet of Things, Big Data, Earth observation, data analysis, and other enabling technologies with a view to their utility in the development of climate services
- Assemble case studies on a wide range of climate services, with particular emphasis on their operational character
- Exploit the use of climate models and state-of-the-art software, with priority accorded to open-source software. Examples include WRF for hydrometeorological modelling, SNAP for satellite image processing, QGIS for organising information in a GIS environment, and IMAGE 3.0 for assessing the impacts of climate change on water resources
- Enable active learning, providing users with the ability to immediately implement what they have learned through exercises, tests and interactivity over various platforms (Web, mobile devices), with instant feedback through a help desk
- Use gamification to enable users to get hands-on experience with new concepts through interactive software and collaborative exercises.

The master's programme will be directly related to the environmental and climatic priorities of the EMME region, will be consistent international conventions and initiatives related to climate change (e.g. IPCC, UNFCCC, UNEP, EU) and will be aligned with the UN Sustainable Development Goals.

3.3.6. Module 6. Impact evaluation

The impact of the EMME Climate Services Hub will be evaluated against a set of criteria as described in Table 6.

TABLE 6. Criteria for evaluation of the impact of the EMME-Climate Services Hub

Impact evaluation criterion	Scope
Capabilities matching	Define Hub's capacity to address climate change risks and the balance between centralisation and decentralisation of data access
Cost of the options	Assess development and operation costs
Option implementation process	Assess complexity of implementation
	Estimate administrative burden
Advantages derived	Inventory partnerships achieved between EMME countries
	Assess revenues from commercial activities and/or financial gains for the public sector from mitigation and adaptation plans
	Address social impacts
Competitiveness	Define richness of climate data
	Assess user-friendliness
	Catalogue the variety of tools
Valorisation	Examine use of online access
	Assess number of derived products
	Assess visibility of climate change
Knowledge transfer and capacity building	Assess potential for knowledge transfer and capacity building

The following graphical representation summarizes the elements and functions of the Climate Services Hub.

EMME Climate Services Hub

Module 1

Climate Data & Knowledge Repository (EMME-CDKR)

- Easy access to a wide range of regionally relevant and validated climate data sets
- Searchable catalogue distributed in the cloud
- Online toolbox allows for customized workflows and applications
- Open access to scientific papers, reports, case studies and policies
- Facilitation of the processing of large volumes of data, including through visualisations
- Governance unit functions include data analysis, management, presentation and delivery
- Linked modules referring to data, publications, codes, visualisation tools and big data analytics and impact analysis
- Web portal allows for browsing and searching for data and products, retrieving data and publications, accessing the online toolbox, and visualising or downloading results
- Help desk facility, FAQs, and a user forum also available on web portal

Module 2

Multi-scale Climate Modelling (EMME-MCM)

- Inputs of meteorological, Earth observation and surface information
- Modelling system to assess climate change and its impacts based on IPCC scenarios
- Tools to analyse and downscale outputs to suit individual cases, including error analysis and indicators of uncertainty.

Users can:

- Integrate atmospheric, Earth observation and surface data from multiple sources
- Employ reanalysis to validate climate modelling estimates
- Assemble global- and regional-level multiple-model seasonal forecasts and climate projections
- Compare and visualise results and scenarios for different climate indicators of interest

Module 3

Climate Change Indicators

Provides recommendations for:

- Customised and thematic indicators to monitor climate change
- Assessing the performance of climate adaptation and mitigation tools

EMME Climate Services Hub, continued

Module 4
Climate Services

Provides support to governments and policy makers, the scientific community, industry, and the public

Submodule 4.1. Thematic Climate Services

- Provides climate services for the agriculture, biodiversity, coastal zones, cultural heritage, disaster risk, energy, tourism, urban areas and water management sectors
- May address spatial or temporal changes in biodiversity in the occurrence of heatwaves, especially in urban and tourist areas, or in the erosion occurring in cultural heritage and other sites
- Services based on a compilation of reliable analytical models, tools, methods and procedures to inform options for sectoral, multi-sectoral and multi-stakeholder planning

Submodule 4.2 Climate Change Mitigation and Adaptation

- Support for the development of climate change mitigation plans to reduce greenhouse gas emissions with the EMME Climate Mitigation Tool (EMME-CMT)
- Support for the development of thematic adaptation plans based on the recognition of climate risks and vulnerabilities with the EMME Climate Adaptation Tool (EMME-CAT)

Module 5
Knowledge Transfer & Capacity Platform (EMME-KTCP)

- Provides technical support, including courses, e-learning programmes, help-desk applications, and multimedia training platforms, ideally, linked to specialised graduate programmes at regional universities and research centres
- Builds capacity so users can utilize the Hub's tools with no or limited external assistance, which the aim of helping to integrate climate-resilient and adaptive planning into national, regional and municipal decision making
- Promotes cooperation among the countries of the region by supporting higher education programmes in adaptation- and mitigation-related climate services and fostering global cooperation through joint educational initiatives

Module 6
Impact Evaluation

The impact of the EMME Climate Services Hub will be evaluated against the following set of criteria

- Capabilities matching
- Cost of the options
- Option implementation process
- Advantages derived
- Competitiveness
- Valorisation
- Knowledge transfer and capacity building

4. Conclusions

Use of the enabling technologies examined in this report can support the assessment of climate change and its impacts, as well as the development of climate services sorely needed by the countries of the EMME region. For the foreseeable future, effective operational services will depend on sustained efforts in research and innovation. To move from climate information to climate services, there is a clear need to:

- Co-design and co-produce services with the users
- Compile climate intelligence from multiple data sources
- Exploit present and future climate modelling capabilities
- Establish appropriate data infrastructure
- Adhere to standards in data collection and categorisation
- Develop a quality assurance system for data
- Organise a thematically oriented system for the provision of data and services.

The report recommends the development of a Climate Services Hub for the EMME region and defines the architecture, characteristics and functions of the Hub. It links the Hub with education and training in order to develop a critical mass of users and providers in the region.

If the proposed Climate Services Hub is to succeed, a framework for regional cooperation will be needed. Coordination actions – regional and subregional assessments; networking; data sharing; training programmes; capacity building – are essential elements in the deployment of the Hub and in its wider adoption in the EMME region.

References and Bibliography

Adloff F et al. (2015) Mediterranean Sea response to climate change in an ensemble of twenty first century scenarios. Climate Dynamics, 45, 9.

Alawad, K.A.; Al-Subhi, A.M.; Alsaafani, M.A.; Alraddadi, T.M.; Ionita, M.; Lohmann, G. Large-Scale Mode Impacts on the Sea Level over the Red Sea and Gulf of Aden. *Remote Sens*. 2019, 11, 2224. https://doi.org/10.3390/rs11192224

Arias, Rodrigo, et al. 'The Effect of the Internet of Things on Sustainability.' World Economic Forum (WEF), 21 Jan. 2018, www .weforum .org/ agenda/ 2018/ 01/ effect -technology -sustainability -sdgs -internet -things -iot/

Banos de Ghisasola, E. Mapping of Climate Services Providers in Italy – Summary Report. Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), 2014. Research Paper Issue RP0213.

Baumann, P.; Mazzetti, P.; Ungar, J.; Barbera, R.; Barboni, D.; Beccati, A.; Bigagli, L.; Boldrini, E.; Bruno, R.; Calanducci, A.; et al. Big data analytics for earth sciences: The EarthServer approach. Int. J. Digit. Earth 2016, 9, 3–29.

Bessembinder, J., Street, R., Themessi, M., Baños de Guisasola, E., Delecluse, P., Benestad, R., (2012), Guidance to support the identification and assessment of users' requirements. Guidance document for inventories of users' requirements (first version), JPI Climate. http://www.climateservices.org/wp-content/uploads/2015/05/jpi2012_assessment_of_users_requirements.pdf.

Bessembinder J.J.E, Overbeek B.A., Jacobs C.G.W., Reidsma P., Schaap B.F., Delsman J., Verboom J., van Bodegom P., Witte J.P.M., (2012), Tailoring information about climate change and its impacts. KfC report number 52/2012.

Bojinski, S., Verstraete, M., Peterson, T.C., Richter, C., Simmons, A., Zemp, M., 2014. The concept of essential climate variables in support of climate research, applications, and policy. Bull. Am. Meteorol. Soc. 95 (9), 1431–1443.

CARE-C, https://www.cyi.ac.cy/index.php/care-c/about-the-center/care-c-center-overview.html

Camara, G.; Assis, L.F.; Ribeiro, G.; Ferreira, K.R.; Llapa, E.; Vinhas, L. Big Earth observation data analytics: Matching requirements to system architectures. In Proceedings of the 5th ACM SIGSPATIAL International Workshop On Analytics for Big Geospatial Data, Burlingame, CA, USA, 31 October 2016; ACM: New York, NY, USA, 2016; pp. 1–6.

Christel, I., Hemment, D., Bojovic, D., Cucchietti, F., Calvo, L., Stefaner, M., Buontempo, C., 2018. Introducing design in the development of effective climate services, Climate Services, 9, 111-121.

Copernicus. DIAS | Copernicus. 2020. Available online: https://www.copernicus.eu/en/access-data/dias/

Copernicus Climate Services, https://climate.copernicus.eu/

Cortekar, J., Lamich, K., Tart, S., 2018. MARCO. Development of a categorized database of EU-based climate services providers, European Commission.

Cramer W et al. (2018) Climate change and interconnected risks to sustainable development in the Mediterranean. Nature Climate Change, 8, 972-980

Hassani, H., Huang, Xu, Silva, E., 2019. Big Data and Climate Change, Big Data Cogn. Comput., 3, 12; doi:10.3390/bdcc3010012

Davis, M., Lowe, R., Steffen, S., Doblas-Reyes, F., Rodo, X., 2015. Barriers to using climate information: challenges in communicating probabilistic forecasts to decision makers. In: Drake, J.L. et al. (Eds.), Communicating Climate Change and Natural Hazard Risk and Cultivating Resilience: Case Studies for a Multidisciplinary Approach. Springer International Publishing. chap. 6.

Daron, J.D., Lorenz, S., Wolski, P., Blamey, R.C., Jack, C., 2015. Interpreting climate data visualisations to inform adaptation decisions. Clim. Risk Manage. 10, 17–26.

European Commission, 2019. COPERNICUS, Market report.

European Commission, 2015: A European research and innovation Roadmap for Climate Services. [online] Luxembourg: European Commission. Available at: http://europa.eu/sinapse/webservices/dsp_export_attachement.cfm?CMTY_ID=0C46BEEC-C689-9F80-54C7DD45358D29F-B&OBJECT_ID=552E851C-E1C6-AFE7-C9A99A92D4104F7E&DOC_ID=7805BB42-91F4-46A5-A8C87397412DBE00&type=CMTY_CAL

European Commission, 2011: The roadmap for transforming the EU into a competitive, low-carbon economy by 2050, https://ec.europa.eu/clima/sites/clima/files/2050_roadmap_en.pdf

European Environment Agency, 2012: Climate Change, Impacts and Vulnerability in Europe 2012, an Indicator-Based Report. EEA Report No. 12/2012, European Environment Agency (EEA), Copenhagen, Denmark, pp. 304.

Chethan Kumar GN. 'Artificial Intelligence: Definition, Types, Examples, Technologies.' Medium, Medium Corporation, 31 Aug. 2018, https:// medium .com/ @ chethankumargn/ artificial -intelligence -definition -types -examples -technologies -962ea75c7b9b

Guo, H.D, Zhang, Li and Zhu, L.W., 2015. Earth observation big data for climate change research, Advances in Climate Change Research, 6, 108-117

Herweijer, Celine, et al. 'Harnessing Artificial Intelligence for the Earth.' World Economic Forum (WEF), Jan. 2018, http:// www3 .weforum .org/ docs/ Harnessing _Artificial _Intelligence _for _the _Earth _report _2018 .pdf

Imran Sahifa, Philippa Biggs, Chris Ip, Cristina Bueti, Gulnara Roll, Amie Figueiredo, Guilherme Canela De Souza Godoi, Guillermo Anllo, Mijke Hertoghs, Simon Wahl, Sylvie Motard, Wondwosen Asnake Kibret, Motsomi Maletjane, David Oehmen, Julie Amoroso-Garbin, Patricia Purcell, Robert Lewis-Lettington, Marcus Mayr, Shipra Narang Suri, Keira Ives-Keeler, Klaus Tyrkko, Stephan Sicars, Alfredo Hernan Cueva Jacome, Helene Molinier, Verona Collantes and Sylvia Hordosch, 2020. Frontier Technologies to Protect the Environment and Tackle Climate Change, ITU.

IPCC (2013) Annex I: Atlas of Global and Regional Climate Projections [van Oldenborgh GJ et al. (eds.)]. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker TF et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Joint Programming Initiative, 2011. Connecting Climate Change Knowledge for Europe, http://www.jpi-climate.eu/media/default.aspx/emma/org/10826597/JPI-CLIMATE_Strategic_Research_Agenda-adopted_111109.pdf

Kosmopoulos P., Kazadzis S. and El-Askary H, (2018). The Solar Atlas of Egypt. Submitted as a book in the framework of the GEO-CRADLE project. http://www.nrea.gov.eg/Content/files/SOLAR%20ATLAS%202018%20digital1.pdf

Kovats RS et al. (2014) Europe. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros VR et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York.

Kulp, S.A.; Strauss, B.H. CoastalDEM: A global coastal digital elevation model improved from SRTM using a neural network. Remote Sens. Environ. 2018, 206, 231–239.

Liu, D.L., Timbal, B., Mo, J., Fairweather, H., 2011. A GIS-based climate change adaptation strategy tool, International Journal of Climate Change Strategies and Management, Vol. 3 No. 2, 140-155.

Mathieu, P.P., Aubrecth, C., 2018. Earth Observation Open Science and Innovation, ISSI Scientific Report Series, vol. 15, Springer Open.

MedECC (2020) Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report [Cramer, W., Guiot, J., Marini, K. (eds.)] Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 600pp.

Mills, Theadora. 'Enlisting Technologies in the Fight against Climate Change.' ITU News, 18 Dec. 2018, news .itu .int/ technologies -fight -against -climate -change/

MOCCAE, 2018. United Arab Emirates Ministry of Climate Change and Environment – AI Lab Tools; https://www.moccae.gov.ae/en/media-center/news/7/11/2018/ministry-of-climate-change-and-environment-showcases-ai-lab-tools.aspx#page=1.

Rolnick, David, et al. 'Tackling Climate Change with Machine Learning.' ArXiv.org, Cornell University, https:// arxiv .org/ pdf/ 1906 .05433 .pdf

Sedona, R.; Cavallaro, G.; Jitsev, J.; Strube, A.; Riedel, M.; Benediktsson, J.A. Remote sensing big data classification with high performance distributed deep learning. Remote Sens. 2019, 11, 3056.

Sentinel-Hub. Sentinel-Hub Documentation. 2020. Available online: https://docs.sentinel-hub.com/api/

Siddig, N.A.; Al-Subhi, A.M.; Alsaafani, M.A. Tide and mean sea level trend in the west coast of the Arabian Gulf from tide gauges and multi-missions satellite altimeter. Oceanologia 2019, 61, 401–411.

Soares, M.B., Alexander M., Dessai, S., 2018. Sectoral use of climate information in Europe: A synoptic overview, Climate Services, 9 (2018) 5–20

The European Green Deal, 2019: Communication from the Commission to the European Parliament,

the European Council, the European Economic and Social Committee and the Committee of the Regions, COM/2019/640 final.

UNDRR, 2015. https://www.undrr.org/implementing-sendai-framework/what-sendai-framework

UNFCCC, 2014. Jordan's third national communication report on Climate Change, https://unfccc.int/resource/docs/natc/jornc3.pdf

UNFCCC, 2015. https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/paris-agreement

UNFCCC, 2016. Third National Communication of the Kingdom of Saudi Arabia, https://unfccc.int/files/national_reports/non-annex_i_natcom/application/pdf/saudi_arabia_nc3_22_dec_2016.pdf

Vitor C. F. Gomes, Gilberto R. Queiroz and Karine R. Ferreira, An Overview of Platforms for Big Earth Observation Data Management and Analysis, Remote Sens. 2020, 12, 1253; doi:10.3390/rs12081253.

Weng, Q., 2010. Remote Sensing and GIS Integration – Theories and Applications, Mc Graw – Hill, ISBN: 978-0-07-160654-7

WMO, 2010a: WMO Position Paper on Global Framework for Climate Services. Geneva.

WMO, 2010b. Position Paper on Guidelines for National Meteorological Services in the Establishment of National Climate Services. Geneva.

WMO, 2011. Climate Knowledge for Action: A Global Framework for Climate Services – Empowering the Most Vulnerable (WMO-No. 1065). The Report of the High-level Taskforce for the Global Framework for Climate Services. Geneva.

WMO, 2014. Annex to the Implementation Plan of the Global Framework for Climate Services – User Interface Platform Component. Geneva.

WMO, 2014. Climate Data Management System Specifications, WMO-No. 1131.

WMO, 2018. Step-by-step Guidelines for Establishing a National Framework for Climate Services, WMO-No. 1206.

WMO, 2020. State of Climate Services. Risk Information and Early Warning Systems. WMO-No. 1262.