

EU-CIRCLE

A pan-European framework
for strengthening Critical
Infrastructure resilience to
climate change

D2.1 Report on Typology of Climate Related Hazards

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Statement

This deliverable provides an overview of available climate data (both observational and model simulated datasets), numerical weather prediction models and secondary effect models for the purpose of the EU-CIRCLE project. It is joint contribution of Task 2.1 Overview of existing climate information and metadata [Lead DHMZ] and Task 2.2 Secondary effect models and metadata [Lead CEREN] from the WP2 - Climatic Data Capture and Processing [Lead NCSR].

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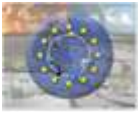
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D2.1 Report on Typology of Climate Related Hazards

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Executive summary

The goal of Task 2.1 Overview of existing climate information and metadata is to perform an assessment of the status and capabilities of climate and weather forecasting related models, their potential suitability and limitations in being utilized for assessing the climate related hazards on the operation of CI at different temporal and spatial scales.

Prediction of the atmospheric conditions in future time is classified by World Meteorological Organization (WMO) according to the forecast range, as follows:

- (1) Now-casting (0 -2 hours description of weather parameters)
- (2) Very-short range forecasting (up to 12 hours description of weather parameters)
- (3) Short-range weather forecasting (12 - 72 hours description of weather parameters)
- (4) Medium-range weather forecasting (72 hours - 240 hours description of weather parameters)
- (5) Extended-range weather forecasting (10 days - 30 days, description of weather parameters, usually averaged and expressed as a departure from climate values for that period)
- (6) Long-range forecasting (30 days – 2 years, description of averaged weather parameters expressed as a departure from climate values)
- (7) Climate forecasting (beyond 2 years, description of expected climate parameters due to climate variability and expected future climate due to both natural and human influences)

Numerical weather prediction (NWP) models are used for predictions of atmospheric conditions from 0 hours to several months ahead, while climate models are used for prediction and projections of the atmospheric conditions on longer forecast ranges. Nowadays, most NWP models and climate models are increasingly becoming components of a single so-called seamless modelling systems, whereby a single model family can be used for prediction across a range of time scales (from weather forecasting to climate change). In fact, all major NWP models in Europe have their counterparts in terms of the related climate models, but vice versa is not necessarily valid.

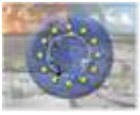
This contribution also summarizes:

- (1) observation and gridded environmental data availability,
- (2) relevant climate models' and reanalyses' products.

In terms of regional climate model, results of the PRUDENCE, ENSEMBLES, EURO-CORDEX and MED-CORDEX projects and initiatives are reviewed. Suggestion is given to use 12.5 km simulations available from the EURO-CORDEX initiative through the ESGF system for the purpose of the EU-CIRCLE estimates concerning the critical infrastructure and its sensitivity to possible climate change. The results of the EURO-CORDEX project cover the entire Europe (enabling the consistent analysis of all EU-CIRCLE European case studies) and typically cover period from 1971 up to 2100, where for the purpose of the climate projections (starting in December 2005) three emission and concentration scenarios are provided: RCP2.6, RCP4.5 and RCP8.5. In addition, in order to estimate the skill of EURO-CORDEX RCMs in reproducing specific observed weather and climate events, for each RCMs numerical experiments using boundary conditions from the ECMWF¹ ERA-Interim reanalysis are available through the ESGF² system. In order to systemically explore various options when using different climate and weather data, following links between EURO-CORDEX regional climate models and other climate data are suggested to be taken into account:

¹ECMWF: European Centre for Medium-Range Weather Forecasts

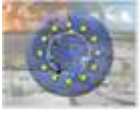
² ESGF: Earth System Grid Federation



- (1) EURO-CORDEX regional climate models are forced by the global climate models' simulations from the CMIP5 initiative. Comparisons between atmosphere-ocean coupled but low-resolution global climate models and corresponding atmosphere-only but high-resolution regional climate models can be made for the EU-CIRCLE case studies.
- (2) EURO-CORDEX regional climate models (RCMs) share some modelling elements with existing European NWP models and systems. For the study of the impacts of historical extreme weather events, NWP models enable higher spatial resolution (i.e., between 1 km and 10 km) needed for reproducing more details for the relevant events. At the same time, EURO-CORDEX RCMs are useful for examining the impacts of long-lasting extreme conditions over larger areas. In case when exact historical events are in focus, EURO-CORDEX RCMs forced by ECMWF reanalysis should be considered, while in case when statistics of historical and possible future extreme events are in focus, standard set of EURO-CORDEX RCMs forced by CMIP5 GCMs should be analysed.
- (3) Statistical downscaling methods can be applied directly to the CMIP5 GCMs or their downscaled EURO-CORDEX RCM partners. These options will be examined for the case of each EU-CIRCLE case study. The benefit of introducing the statistical downscaling step is by providing both spatial scale refinement and bias adjustment/correction in some applications.
- (4) The extensive use of the available observational datasets is advised in order to provide an estimate of the skill of EURO-CORDEX RCMs in reproducing the historical climate over the area of EU-CIRCLE case studies.
- (5) The dominant data format of various climate and weather data is NetCDF. CIRP system will be able to ingest data in the NetCDF format. For the purpose of some specific impact models where alternative format of the input data may be needed, offline and online (e.g. through CIRP) transformations are suggested.

The second part of D2.1 includes the contributions from the Task 2.2 Secondary effect models and metadata:

- (1) For each parameter describing the components of the hydrological cycle (rainfall, evaporation and evapotranspiration, river water level, river water speed, river discharge, water content in ground water, soil water content, water content in snow and ice, temperature of the surface water) and watershed information (2D and 3D information) definition, links with climate change impacts, existing databases and access to them, and current limits and constraints are reviewed and prepared for the purpose of D2.1.
- (2) The physical factors that perform an important role in the process of soil erosion are climate, topography and soil characteristics. Climate change is expected to impact soils through changes in both soil erosion and rainfall erosivity. Soil erosion is the actual loss of soil and can have substantial impacts on the availability of nutrients and organic matter in soil, on the other hand rainfall erosivity is a measure of the capacity of rainfall to cause erosion and is essentially a function of the amount of rainfall and the intensity of rainfall. Storm events will give rise to increased erosion, soil loss, and landslides. Much of the pollution and eroded soil will end up in the coastal environment. High velocity floods may cause erosion/scouring of embankments, slopes, levees, and building foundations. Overview of existing soil erosion models and datasets is prepared.
- (3) Overview of previous EU funded projects related to flood modelling and usually required datasets is in preparation.
- (4) Wildfires represent a substantial threat to Southern European forests and ecosystems and every year cause extensive losses to anthropic infrastructures and values. The overview of the fire danger evaluation, forest fire propagation models and forest fires in the context of EU-CIRCLE are made in D2.1.



D2.1 Report on Typology of Climate Related Hazards

In summary, D2.1 provides joined overview of both weather and climate based models and datasets, and EU-CIRCLE relevant impact models and datasets. This will provide starting reference for the subsequent analysis for specific EU-CIRCLE case studies.

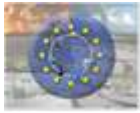
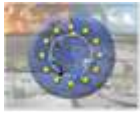


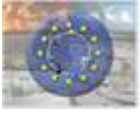
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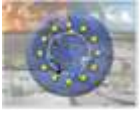


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1 Introduction

Deliverable D2.1 Report on Typology of Climate Related Hazards is result of Task 2.1 Overview of existing climate information and metadata and Task 2.2 Secondary effect models and metadata. Task 2.1 resulted in an assessment of the status and capabilities of climate and weather forecasting related models, their potential suitability and limitations is being utilized for assessing the climate related hazards on the operation of critical infrastructure at different temporal and spatial scales. Different types of climate information based on models are analysed (GCMs, RCMs, statistical– dynamically downscaled models, NWP models, global and regional reanalyses) categorised and assessed. Task 2.2 made an assessment of the climate information that will additionally be used to drive secondary effects models, that are inherently linked to climate. These include hydraulic models and flood simulators, forest fire spreading models, and soil erosion models. EU-CIRCLE is focused on establishing a generic interoperability framework which will provide these models initial driving conditions in a standardised manner.

The D2.1 (M20) deliverable will be followed by D2.2 Report on Climate related hazards information collection mechanisms (M24), D2.3 Tools for processing Climate Hazards Information and D2.4 EU-CIRCLE climate hazards metadata and standards. Further work between partners in WP2 Climatic Data Capture and Processing will lead to the development of the consolidated framework, with the main objective to establish a standard on producing climate related parameters that impact the critical infrastructure (operations and states), while aiming to expand current practices.

In summary, D2.1 provides a general overview of climate information that is needed for the EU-CIRCLE case studies and for the driving of the secondary hazard models in order to:

- (1) suggest the existing databases and the data (model based and observational) related to the needs of the EU-CIRCLE case studies,
- (2) decide the collection approach of required climate variables according to access policy of the selected databases,
- (3) develop or apply the existing processing tools for the initial processing of the data and the initial processing of risk assessment according to the examined hazard,
- (4) make an overview of the climate and impact related metadata standards description for climate information-hazards within the EU-CIRCLE.

Within each chapter in D2.1, general introduction provides an overview of the specific topic, lead by the relevant technical details at the level needed for the efficient implementation with the EU-CIRCLE.



2 Meteorological observations and gridded environmental data

2.1 Introduction

The main providers of in situ and satellite environmental data in Europe are the national meteorological services joined in EUMETNET, European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) (Tab. 1). There are several other organisations that facilitate free and unrestricted exchange of meteorological and other environmental data and information, products and services in real- or near-real time on a global and European scale, like World Meteorological Organisation (WMO), European Environmental Agency (EEA) and European Centre for Medium Range Weather Forecast (ECMWF).

Table 1.1: Overview of the potential producers and providers of observations and gridded data.

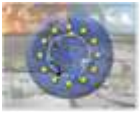
	Organisation / Project	data access
1.	National meteorological services	WMO-synop observations, www.ogimet.com EUMETNET-National meteorological services INSPIRE geoportal
2.	EC INSPIRE	INSPIRE geoportal
3.	COPERNICUS	http://www.copernicus.eu/main/data-access http://marine.copernicus.eu/
4.	EURO4M/UERRA(link to ESGF of EC/JRC)	http://www.euro4m.eu/datasets.html http://www.uerra.eu/outreach/data-and-products/data-services.html http://www.pcmdi.llnl.gov/
5.	EC/JRC MARS/Agri4Cast Data Portal	https://ec.europa.eu/jrc/en/mars https://ec.europa.eu/jrc/en/scientific-tools http://agri4cast.jrc.ec.europa.eu/DataPortal/Index.aspx?o=d
6.	JRC/European Flood Awareness System (EFAS)	https://www.efas.eu/
7.	JRC/European Drought Observatory (EDO)	http://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000
8.	JRC/The European Forest Fire Information System (EFFIS)	http://forest.jrc.ec.europa.eu/effis/
9.	Met Office Hadley Centre	http://www.metoffice.gov.uk/hadobs/hadex/index.html http://www.metoffice.gov.uk/hadobs/hadex/data/download.html
10.	WorldClim	http://www.worldclim.org/
11.	EEA	http://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-1/assessment

2.2 National Meteorological Services

National meteorological services can be reached through EUMETNET and INSPIRE web pages. They provide the most detailed data and service for their region, especially due to restricted data policies in most of the European meteorological services.

2.3 INSPIRE geoportal

EC is enhancing access to European spatial data through [INSPIRE geoportals](http://inspire.geoportals) that provide both access to the meta-data information and accesses to data. There are several spatial data themes of interest for the project, like Atmospheric conditions or Meteorological Geographical Features and topic categories of Climatology/Meteorology/Atmosphere. This is supposed to be a first insight into available spatial data and



their providers in EU. Nevertheless, this source of information is still not unified for all countries and types of data, depending on the engagement of the responsible data providers. Most of the meteorological data are still available primarily from responsible national meteorological services. This is related also with different data policies of the European meteorological services.

2.4 Copernicus

Recent EU efforts are focused on the European Programme for the establishment of a European capacity for Earth Observation-Copernicus, previously known as GMES (Global Monitoring for Environment and Security).

Copernicus system for monitoring the Earth collects data from multiple sources: earth observation satellites and in situ sensors (ground stations, airborne and sea-borne sensors). The data are processed and users are provided with reliable and up-to-date information. The services are related to environmental and security issues. New Sentinel satellite, launched in April 2016, offer all data with free and open data policy, that is predicted to be a breakthrough in the use of satellite data for specialised users, but also for the general public.

The services address six thematic areas: land, marine, atmosphere, climate change, emergency management and security.

Data are available through the web portals operated by the various Copernicus service lines:

- (1) Land-related data: <http://land.copernicus.eu> (land cover, land use, settlements, DEM)
- (2) Atmosphere-related data: <http://atmosphere.copernicus.eu> (air quality, atmospheric composition, greenhouse gas)
- (3) Marine-related data: <http://marine.copernicus.eu> (sea level, ocean temperature, currents, chemistry, biology)
- (4) Emergency-related data: <http://emergency.copernicus.eu> (Rapid Mapping, Risk and Recovery Mapping)
- (5) Climate change-related data: <http://climate.copernicus.eu> (in situ and satellite-based observations, re-analysis of the Earth climate and modelling scenarios)

The Copernicus programme provides users with free, full and open access to environmental data. The data can be obtained either from the Copernicus services or directly from the Copernicus satellites. No registration is required for discovery and view services while registration free of charge is a prerequisite to download Sentinel and other data.

For the Emergency Management service, data production can be requested only by "authorized users" while the maps produced by the service are available on the service web portal and can be downloaded without registering. Here is an example for the recent Ireland flood, (Fig. 1.1).

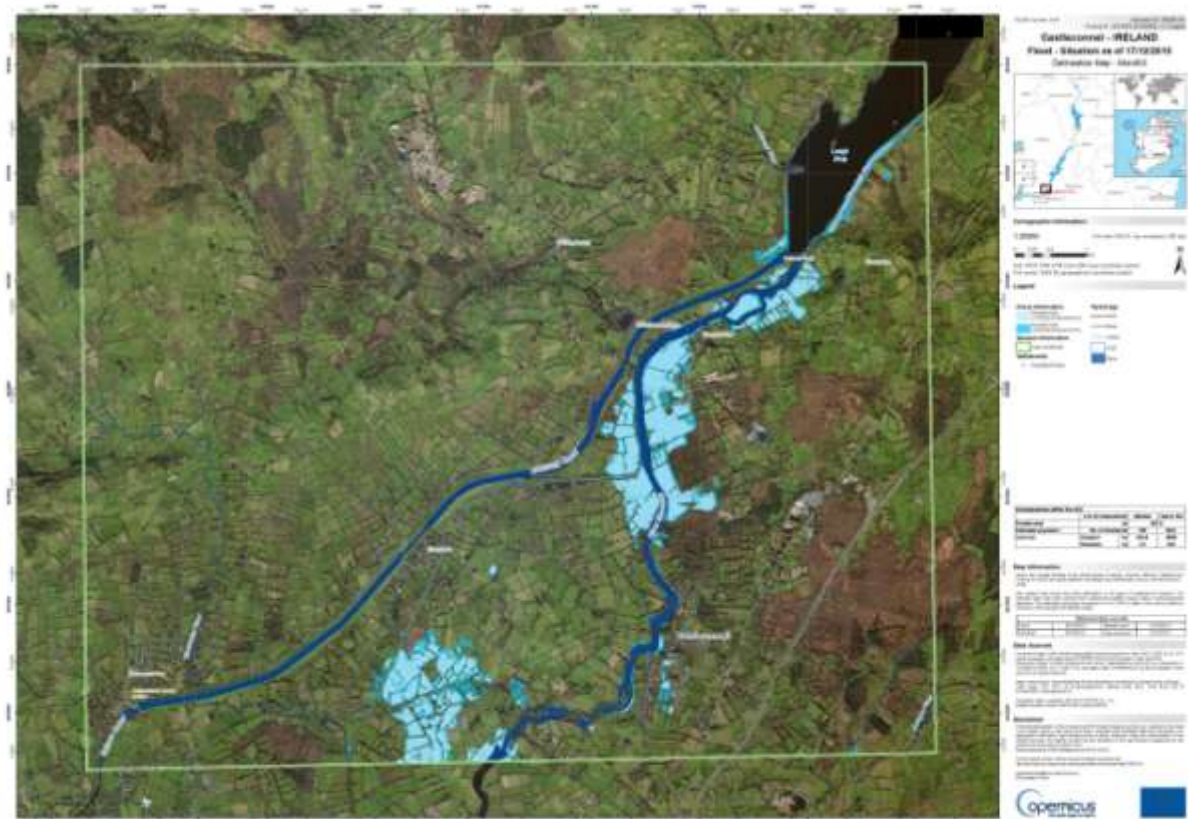
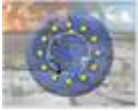


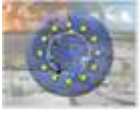
Figure 1.1: Copernicus emergency management service, (EMS - Mapping), Flood, Castleconnel, Ireland, 17.12.2015.

Besides Emergency related data, the second one important for the project is Climate change related data. The service will give access to information for monitoring and predicting climate change that will support adaptation and mitigation. The climate change service builds on a in situ and satellite-based observations, re-analysis of the Earth climate and modelling scenarios, based on a variety of climate projections.

The service will provide access to several climate indicators (e.g. temperature increase, sea level rise, ice sheet melting, warming up of the ocean) and climate indices (e.g. based on records of temperature, precipitation, drought event) for both the identified climate drivers (CO₂) and the expected climate impacts (e.g. reducing glaciers).

The implementation of the service started in November 2014, whit the European Commission signing a Delegation Agreement with ECMWF (European Centre for Medium-Range Weather Forecasts). The implementation started with the "proof of concept", meaning capacity building and testing of the overall architecture. The following will be a pre-operational stage, while it is expected that the operational capacity will be reached during the third year of operations. Currently, average surface air temperature maps are available based on ECMWF's ERA-Interim reanalysis, climate reanalysis is available from ERA5 Climate Reanalysis data and the current proof-of-concept phase of the development of the seasonal forecast is available.

We point out also to marine data from Copernicus data portal, where e.g. observed ocean temperature, salinity, heights and currents are available, together with forecasts. The catalogue is available in interactive format and in [pdf](#). This is potentially very interesting for the Baltic Case Study 2.



2.5 EURO4M/UERRA

The finished EURO4M project provided inventory of available observations, gridded products, satellite climate products and reanalysis on <http://www.euro4m.eu/datasets.html>

In the framework of successor UERRA project, the focus is on the availability of several Essential Climate Variables (ECVs) as defined by the WMO/Global Climate Observing System (GCOS): air temperature (TT), atmospheric pressure (SLP), wind speed and direction (WS and WD), relative humidity (RH), dew point temperature (DP), precipitation (RR), snow depth (SD) and snowfall (FS).

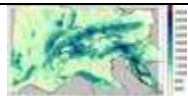


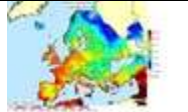
There are several tools necessary for smooth processing and maintenance of EURO4M/UERRA datasets listed below. Those tools are based on already existing technologies used for other TIGGE-like datasets in the past. However, many modifications have been necessary to make those tools fully compatible with EURO4M/UERRA data.

- (1) Data processing and archiving suite is the collection of Shell/C/python codes for data processing (retrieval, encoding, modifications, verification etc.) run under ECFLOW (ECMWF task monitor scheduler).
- (2) Data portal provides web interface to MARS, meteorological data repository at ECMWF, for easy data access.
- (3) ECMWF WEB-API provides batch data access to data archived in MARS.
- (4) METVIEW is the visualization and data handling software.
- (5) ECMWF GRIB-API is the application program interface accessible from C, Fortran and Python programs developed for encoding and decoding WMO GRIB edition 1 and edition 2 messages.

There are several observational and gridded data sets available through EURO4M data portal that we consider more important (Table 1.2). A pilot and demonstration website for visualization of a selection of EURO4M datasets is available at euro4mvis.knmi.nl.


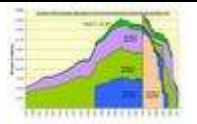

While EURO4M was mainly concerned with meteorological observations and increasing their availability, UERRA is a European reanalysis project of meteorological observations. It includes recovery of historical (last century) data, estimating uncertainties in the reanalysis and user friendly data services. It aims to prepare for and contribute to a future Copernicus climate change service. The data should be available through ECMWFs MARS catalogue and Earth System Grid Federation - ESGF. On ESGF are available already several model intercomparison project outputs like CMIP5 outputs (details further in the report).


Table 1.2: Datasets of essential climate variables available from EURO4M/UERRA project (based on <http://www.euro4m.eu/datasets.html>).

Essential Climate Variable	--	Datasets	Res. Inst.	Area	Spatial Res.	Temporal Res.	Period	Format
Precipitation		Alpine precipitation grid dataset (EURO4M-APGD)(D1.1)	MS	European Alps and adjacent flatland	5 km	daily	1971-2008	NetCDF
<u>Factsheet: Alpine Precipitation Grid Dataset.</u> <u>Isotta, F.A. et al., 2013: The climate of daily precipitation in the Alps: development and analysis of a high-resolution grid dataset from pan-Alpine rain-gauge data. Int. J. Climatol., 34 (5), 1657-1675.</u>								
Atmospheric surface variables		European Climate Assessment & Dataset (ECA&D).	KNMI	European, North Africa and the Middle East	point data	daily	1775-present	ASCII
<u>Factsheet: Daily station data - ECA&D (European Climate Assessment & Dataset).</u> <u>Klein Tank, A.M.G. and Coauthors, 2002. Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int. J. of Climatol., 22, 1441-1453.</u>								
Air temperature, pressure, precipitation		Updated and merged Mediterranean station dataset (D1.12, D1.13)	URV	All countries bordering the Mediterranean Sea	point data	daily	1850-1970	ASCII
<u>Factsheet: Merged climate dataset for the Mediterranean.</u>								
Air temperature, pressure, precipitation		E-OBS gridded dataset (D1.4).	KNMI	European, North Africa and the Middle East	25 km or 50 km	daily	1950-present	NetCDF
<u>Factsheet: E-OBS gridded dataset (D1.4).</u> <u>Haylock, M.R., N. Hofstra, A.M.G. Klein Tank, E.J. Klok, P.D. Jones and M. New. 2008: A European daily high-resolution gridded dataset of surface temperature and precipitation. J. Geophys. Res (Atmospheres), 113, D20119, doi:10.1029/2008JD10201</u> <u>Besselaar, E.J.M. van den, M.R. Haylock, A.M.G. Klein Tank en G. van der Schrier, A European Daily High-resolution Observational Gridded Data set of Sea Level Pressure J. Geophys.</u>								



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<u>Res., 2011, 116, D11110, doi:10.1029/2010JD015468</u>								
Air temperature, pressure, precipitation, water vapour		<u>CRU/UEA gridded data products (D1.6).</u>	UEA	Global (European window available)	0.5 degree	monthly	1901-2011	ASCII
<u>Factsheet: CRU/UEA Data Products</u>								
Precipitation		<u>Global Precipitation Climatology Centre (GPCC) full data reanalysis version 5 (D1.3).</u>	DWD	Global (European window available)	0.5 degree	monthly	1901-2009	ASCII
<u>Becker, A. et al., 2013: A description of the global land-surface precipitation data products of the Global Precipitation Climatology Centre with sample applications including centennial (trend) analysis from 1901-present. Earth Syst. Sci. Data, 5, 71-99.</u>								
Surface radiation budget		<u>Surface solar irradiance (SIS) gridded dataset (D1.7).</u>	DWD	Europe, North Africa and the Middle East	0.03 degree	monthly	1983-2005	NetCDF
<u>Factsheet: Surface solar irradiance (SIS).</u>								



2.6 EC Joint Research Centre, JRC

2.6.1 MARS/Agri4Cast Data Portal

Monitoring Agricultural ResourceS - MARS project provides scientific and technical support on EU Agriculture and Food Security policies (not to be confused with MARS at ECMWF). The project is supervised by two units of the European Commission's JRC in Ispra (Italy): Agri4Cast and Foodsec. The MARS-project is now running in an operational context what is called the MCYFS (Mars Crop Yield Forecast System). The Joint Research Centre of the European Commission has developed Interpolated Meteorological Datasets available on a regular 25x25km grid both to the scientific community and the general public (Biavetti et al., 2014). The Interpolated Meteorological Datasets include daily maximum/minimum temperature, cumulated daily precipitation, evapotranspiration and wind speed. These datasets can be accessed through a web interface Agri4Cast Data Portal. The temporal coverage of the datasets is more than 30 years starting from 1975 and the spatial coverage includes EU Member States, neighbouring European countries, and the Mediterranean countries. Through Agri4Cast Data Portal other datasets are available like Future daily weather data over Europe derived from climate change scenarios, gridded satellite data, etc. The Interpolated Meteorological Datasets also serve the Crop Growth Monitoring System (CGMS), the core of the MARS Crop Yield Forecast System (MCYFS), at European level.

2.6.2 European Flood Awareness System (EFAS)

Part of the JRC Hazards and risks of climate change impacts projects and portals are the EFAS, EDO, EFIS and Agri4Cast that are described here since the strong connection with the EU-CIRCLE project activities. The European Floods Awareness System (EFAS) is providing flood forecasts up to 10 days in advance to national and/or regional authorities responsible for flood forecasting. Any national, regional or local authority that is legally obliged to provide flood forecasting services or has a national role in flood risk management within its country and the European Commission Services can become an EFAS partner. EFAS forecasts are provided for free and are not limited to EU Member States. The portal provides observed in-situ and satellite data and forecast from ECMWF and DWD.

2.6.3 European Drought Observatory (EDO)

The EDO pages contain drought-relevant information such as maps of indicators derived from different data sources (e.g., precipitation measurements, satellite measurements, modelled soil moisture content). The national meteorological services are potential partners in the project. The portal uses temperature, precipitation, and soil moisture data to derive drought indicators on a European level.

2.6.4 The European Forest Fire Information System (EFFIS)

The European Forest Fire Information System (EFFIS) supports the services in charge of the protection of forests against fires in the EU countries and provides the European Commission services and the European Parliament with updated and reliable information on wild-land fires in Europe. A number of specific applications are available through EFFIS like current situation with today meteorological fire danger maps and forecast up to 6 days, daily updated maps of hot spots and fire perimeters.

A multi-hazard framework to map exposure to multiple climate extremes in Europe along the twenty-first century is presented in Forzieri et al. (2016). Using an ensemble of climate projections, changes in the frequency of heat and cold waves, river and coastal flooding, stream flow droughts, wildfires and wind storms are evaluated. Those weather and climate hazards are a key component of a risk assessment. Results show that Europe will likely face a progressive increase in overall climate hazard with a prominent spatial gradient towards south-western regions mainly driven by the rise of heat waves, droughts and wildfires (Fig. 1 in Forzieri et al., 2016.). Key hotspots emerge particularly along coastlines and in floodplains in southern and western Europe. Also we point out to the largest data base of natural disasters at CATDAT-



Damaging Natural Disaster Databases (Earthquakes, Floods, Volcanoes), spanning from 1900-today, operated at [KIT](#).

2.7 Met Office Hadley Centre

[HadEX](#) is a global land-based climate extremes dataset produced through the coordination of the Expert Team on Climate Change Detection and Indices (ETCCDI). The set includes 27 indices of temperature and precipitation on a 2.5° x 3.75° grid from 1951 to 2003. The indices represent seasonal and/or annual values derived from daily station data. 2500 temperature stations and 6000 precipitation stations are used to derive the data. Data are available from the download page without charge for the purposes of private study and scientific research, according to terms and conditions stated. European environment agency (EEA) used HedEX as a data source for the maps produced on their web page.

2.8 WorldClim

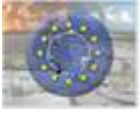
[WorldClim](#) is a set of global climate layers (climate grids) with a spatial resolution of about 1 square kilometre. The data can be used for mapping and spatial modelling in a GIS or with other computer programs. It is created from global observed meteorological data using geostatistical interpolation methods. The data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km²" resolution). Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables. The WorldClim interpolated climate layers were made using major climate databases compiled by the Global Historical Climatology Network (GHCN), the FAO, the WMO, the International Center for Tropical Agriculture (CIAT), R-HYdronet, and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru, Bolivia, among others. The SRTM elevation database (aggregated to 30 arc-seconds, "1 km") is used together with the ANUSPLIN software. ANUSPLIN is a program for interpolating noisy multi-variate data using thin plate smoothing splines. Latitude, longitude, and elevation are used as independent variables. New worldClim data set also serves WorldClim 1.4 downscaled (CMIP5) data, where GCM output was downscaled and calibrated (bias corrected) using WorldClim 1.4 as baseline 'current' climate

2.9 EEA

The European Environment Agency (EEA) is an agency of the European Union. The task of EEA is to provide a major information about the environment for the general public and also for those involved in developing, adopting, implementing and evaluating environmental policy. The EEA is not producing environmentally related data but uses different data sources to provide information for the reports, data, maps etc. Several examples of the products are in the Table 1.3. For those products, data from the numerous organisations and projects are used, like E-OBS from ENSAMBLES project, HedCRUT4 and HedEX from Met Office Hadley Centre, GISTEMP from NASA, soil erosion modelling from JRC, statistical data from EUROSTAT, [EM-DAT: The International Disaster Database](#) provided by Centre for Research on the Epidemiology of Disasters (CRED) etc., were used as data sources. Detailed information is provided on the web pages listed in Table 1.3.

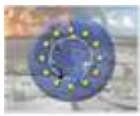
Table 1.3: EEA climate related information

Product	web link
Heavy precipitation	http://www.eea.europa.eu/data-and-maps/indicators/precipitation-extremes-in-europe-3/assessment
Wind storms	http://www.eea.europa.eu/data-and-maps/indicators/storms-2/assessment
Soil moisture	http://www.eea.europa.eu/data-and-maps/indicators/soil-moisture-1/assessment



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	maps/indicators/water-retention-4/assessment
Global and European sea level	http://www.eea.europa.eu/data-and-maps/indicators/sea-level-rise-4/assessment-2
Floods and health	http://www.eea.europa.eu/data-and-maps/indicators/floods-and-health-1/assessment
Forest fires	http://www.eea.europa.eu/data-and-maps/indicators/forest-fire-danger-2/assessment
River flow	http://www.eea.europa.eu/data-and-maps/indicators/river-flow-3/assessment
Soil erosion	http://www.eea.europa.eu/data-and-maps/indicators/soil-erosion-by-water-1/assessment



3 Climate models and reanalyses products

3.1 Introduction

The climate models' products include simulations of regional climate and global climate models (RCMs and GCMs). The relationship between RCMs and GCMs, are discussed in several review papers: Giorgi and Mearns (1991), McGregor (1997), Giorgi and Mearns (1999), Wang et al. (2004), Laprise et al. (2008) and Rummukainen (2010, 2015).

For the purpose of the EU-CIRCLE project, the use of the latest generation of the RCM simulations over Europe is suggested. These simulations are available on the approximately 12.5 km grid spacing and for the climate projection use the latest IPCC³ scenarios: RCP2.6, RCP4.5 and RCP8.5. They are available through the ESGF system and WCRP⁴ CORDEX⁵ project (EURO-CORDEX initiative) or alternative portals and ftp servers run by the specific RCM groups. Also, results and description of the several other projects and initiatives that provide access to corresponding climate model simulations are presented. We will shortly present technical details (e.g., model resolution, the availability of the GCM-RCM combinations, the use of specific GHG concentration scenarios) and scientific results relevant for the EU-CIRCLE project. Several specific improvements are documented over the course of time: (1) the increase of the RCM resolution from 50 km in PRUDENCE⁶, to 25 km in ENSEMBLES⁷, and finally to 12.5 km in EURO-CORDEX, (2) the increase in the number of GCMs providing boundary conditions, (3) the increase in the number of assumed GHG concentration scenarios from 1 in PRUDENCE (IPCC SRES A2) and 1 in ENSEMBLES (IPCC SRES A1B) to 3 in EURO-CORDEX (IPCC RCP2.6, RCP4.5 and RCP8.5)⁸, (4) the development of the regional atmosphere-ocean-hydrology coupled models in Med-CORDEX.

The dominant data format of all products is NetCDF (both NetCDF3, and NetCDF4 classical and compressed), and should be related with the CIRP platform accordingly.

3.2 Regional climate models

3.2.1 PRUDENCE

EU FP5 project Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects (PRUDENCE) lasted from November 2001 to October 2004. In this project simulations using four global climate models (GCMs) were applied to force ten different regional climate models (RCMs) for the historical periods 1961-1990 and future projection under the IPCC SRES A2 and B2 scenarios for the period 2071-2100. Horizontal resolutions of the RCMs over the large European domain were ~20 km (two PRUDENCE RCMs) and 50 km (all PRUDENCE RCMs). The list of the available simulations from the project web-page (i.e., <http://prudence.dmi.dk/>) is shown in Table 2.1.

Main scientific results of the PRUDENCE project included:

- (1) The interpretation of the 2003 summer heat wave over Europe in comparison to previous heat waves and potential future heat waves according to the PRUDENCE simulations (Beniston, 2004). Here, 2003 summer heat wave was shown to be distinct from the weaker heat waves recorded in 1947 and 1976, and more comparable to extreme climate events projected by the end of the 21st century under the IPCC SRES A2 scenario.
- (2) The summer 2003 heat wave was also interpreted in terms of interannual variability by Schär et al. (2004). Again, PRUDENCE RCM simulations were applied in order to demonstrate

³IPCC: Intergovernmental Panel on Climate Change

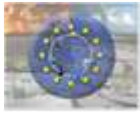
⁴WCRP: World Climate Research Programme

⁵CORDEX: A COordinated Regional climate Downscaling Experiment

⁶PRUDENCE: Prediction of Regional scenarios and Uncertainties for Defining European Climate change and Effects

⁷ENSEMBLES: ENSEMBLE-based Predictions of Climate Changes and their Impacts

⁸RCP: Reference Concentration Pathways



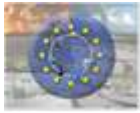
exception of the 2003 heat wave from the usual interannual variability. While changes in the mean climate over large parts of Europe are detectable in both observations and RCM projections, changes in the interannual variability are clearly present for only in RCM projections (as demonstrated by the PRUDENCE RCM ensemble). In this sense, summer 2003 heat wave was shown to represent typically conditions by the end of 21st century under the IPCC SRES A2 scenario.

- (3) The Central Europe flooding in summer 2002 was also examined in context of the present and future climate (Christensen and Christensen 2003). PRUDENCE RCM simulations suggest strong reduction of the summer total precipitation amount over most of the central and southern Europe. However, the frequency and amount of the extreme precipitation events may be expected to increase by the end of the 21st based on the same simulations and IPCC SRES A2 scenario.
- (4) The results of the future climate projections were also examined as the function of the boundary conditions based on the GCM simulations and applied to specific RCM (Räisänen et al., 2004). In terms of near-surface air temperature, PRUDENCE simulations indicate warming over the whole Europe (largest winter warming over the northern Europe, and largest summer warming over the southern Europe). In terms of the total precipitation amount, increase is expected over the northern Europe (especially in winter) and decrease is expected over the southern Europe (especially in summer). Also, sensitivity of the projected precipitation change on the use of different GCM boundary conditions is found.

The limitations of the PRUDENCE RCM simulations in context of the EU-CIRCLE needs include: (1) relatively coarse spatial resolution, (2) the use of relatively small number of GCM boundary conditions (this primarily has an impact on internal variability in each model simulations), and (3) focus on the ends of the 20th and 21st centuries. Some of this limitations will be addressed by the projects and initiatives described below. However, majority of the scientific results based on the PRUDENCE RCMs are mostly confirmed by the next generations of the climate simulations.

Table 2.1: Available PRUDENCE RCM simulations from the <http://prudence.dmi.dk/> database. Detailed explanation of the acronyms is available from: http://prudence.dmi.dk/public/DDC/compact_table.html.

Institute	Model	Driving data	Ensemble member	Experiment
DMI	HIRHAM	HadAM3H A2	1	Control
			1	Scenario
			2	Control
			2	Scenario
			3	Control
			3	Scenario
		HadAM3H A2	1	Scenario
		HadAM3H B2		Scenario
		ECHAM4/OPYC		Control
		ECHAM4/OPYC A2		Scenario
		ECHAM4/OPYC B2		Scenario
		ECHAM5 A2		Control
				Scenario
	HIRHAM High res.	HadAM3H A2	1	Control
			1	Scenario
	HIRHAM Extra High res.	HadAM3H A2	1	Control
			1	Scenario
HC	HadCM3 A2 (OAGCM)		1	Control



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			1	Scenario
			2	Control
			2	Scenario
			3	Control
			3	Scenario
	HadCM3 B2			Scenario
	HadRM3P	HadAM3P	1	Control
			1	Scenario
			2	Control
			2	Scenario
			3	Control
			3	Scenario
		HadAM3P B2		Scenario
ETHZ	CHRM	HadAM3H A2	1	Control
			1	Scenario
GKSS	CLM	HadAM3H A2	1	Control
			1	Scenario
	CLM (improved)		1	Control
			1	Scenario
MPI	REMO	HadAM3H A2	1	Control
			1	Scenario
SMHI	RCAO	HadAM3H A2	1	Control
			1	Scenario
		HadAM3H B2		Scenario
		ECHAM4/OPYC		Control
		ECHAM4/OPYC A2		Scenario
		ECHAM4/OPYC B2		Scenario
	RCAO High res.	HadAM3H A2	1	Control
			1	Scenario
UCML	PROMES	HadAM3H A2	1	Control
			1	Scenario
		HadAM3H B2		Scenario
ICTP	RegCM	HadAM3H A2	1	Control
			1	Scenario
		HadAM2H B2	1	Scenario
METNO	HIRHAM	HadAM3H A2	1	Control
			1	Scenario
KNMI	RACMO	HadAM3H A2	1	Control
			1	Scenario
Météo-France	Arpège	Observed SST	1	Control
			2	Control



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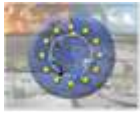
		HadCM3 A2	3	Control
			1	Scenario
			2	Scenario
			3	Scenario
		HadCM3 B2		Scenario
		Arpège/OPA A2		Scenario
		Arpège/OPA B2	1	Scenario
			2	Scenario
			3	Scenario
		SST of MRI-CGCM2.3 A1B	1	Control
MRI	MRI-20km-AGCM		1	Scenario

3.2.2 ENSEMBLES

EU FP6 project ENSEMBLES was a major research effort performed from September 2004 to December 2009. One of the main activities relevant for the EU-CIRCLE project was **Research Themes “RT3 Formulation of very-high resolution Regional Climate Model ensembles for Europe” and “RT2B Production of regional scenarios for impact assessment”**. **We shall refer to RCM simulations from this project in the rest of this report as “ENSEMBLES RCMs”**. **Two groups of the ENSEMBLES RCMs are performed in this project:** ERA40 reanalysis driven simulations for the period 1961-2000 (16 different RCMs; Table 2.2), and GCM driven simulations performed over the continuous **period from 1951 to 2050/2100 (so called “transient runs”; 15 different RCMs; Table 2.3)**. Two spatial resolutions are applied (25 km and 50 km), and majority of the projection runs were done under the assumption of the IPCC SRES A1B scenario. The results of the ENSEMBLES RCM simulations are available from the following URL address: <http://ensemblesrt3.dmi.dk/>.

Some of scientific results based on ENSEMBLES RCM simulations relevant for the EU-CIRCLE project include:

- (1) **ENSEMBLES RCMs’ simulations explored the impact of the horizontal resolution increase** from 50 km to 25 km. General results included the increase in the wet bias over locations and during season where already wet bias existed at the 50 km resolution, but also general improvement in simulating precipitation extremes (Rauscher et al. 2010).
- (2) Additional RCMs studies using ~2 km horizontal resolutions indicated improvements in reproducing the simulated daily precipitation cycle (Hohenegger et al. 2009).
- (3) ENSEMBLES enabled RCM simulations over the >100 yr periods, which enabled trends and regime shift analyses, and allowed many applications relevant for the climate change adaptation application.
- (4) Results of the ENSEMBLES RCM simulations provided opportunities to explore and improve models in term of reproducing specific weather and climate events (e.g., water and energy budgets over several regions and basins, extreme temperature events) but also several methodological aspects concerning the coupling between the RCM and boundary forcings provided by the GCMs (e.g., RCM domain size and location, the application of so called spectral nudging).
- (5) Information about systematic errors inherent to specific RCMs (this type of errors is expected to be reduced in the course of the model development) was used to adjust climate change projections (Boberg et al. 2010). This work showed reduction of the summer warming present in the raw model simulations. However, the science and practice of the bias correction or bias adjustment is still in progress and no general solutions are still available.
- (6) It was shown that no RCMs are best in terms of reproducing statistics of various climate variables (Christensen et al. 2010). Also, the model weighting was shown to be sensitive to the metric applied. Suggestion for the impact models (e.g., hydrological models, crop production



models, etc.) was made to include at least two or three different RCMs forced by at least two different GCM.

- (7) Although uncertainties related to different boundary forcing and RCM model formulations were well sampled in the ENSEMBLES RCM ensemble, this was not the case at that time for the uncertainties related to different scenarios and different internal variability (i.e., same RCM simulations forced by the same GCM, and under same scenario due to the chaotic nature of the climate system may have different temporal variability if started from slightly different initial conditions).

Table 2.2: ENSEMBLES RCM 40-year experiments driven by the ECMWF ERA40 reanalysis. Source: <http://ensemblesrt3.dmi.dk/>.

	Institute	Model	Resolution	Acronym
1	C4I	RCA3	25 km	C4IRCA3
2	CHMI	Aladin	50 km / 25 km	CHMIALADIN
3	CNRM	Aladin	50 km / 25 km	CNRM-RM4.5
4	DMI	HIRHAM	50 km / 25 km	DMI-HIRHAM
5	ETHZ	CLM	50 km / 25 km	ETHZ-CLM
6	GKSS	CLM	50 km	GKSSCLM
7	HC	HadRM3.0	50 km	METO-HC_HadRM3.0
		HadRM3Q0	25 km	METO-HC_HadRM3Q0
		HadRM3Q3	25 km	METO-HC_HadRM3Q3
		HadRM3Q16	25 km	METO-HC_HadRM3Q16
8	ICTP	RegCM	50 km / 25 km	ICTP-REGCM3
9	INM	RCA3	50 km / 25 km	INM-RCA3
10	KNMI	RACMO	50 km / 25 km	KNMI-RACMO2
11	METNO	HIRHAM	50 km / 25 km	METNOHIRHAM
12	MPI	REMO	50 km / 25 km	MPI-M-REMO
13	SMHI	RCA	50 km / 25 km	SMHIRCA
14	UCLM	PROMES	50 km / 25 km	UCLM-PROMES
15	OURANOS	CRCM	50km	OURANOSMRCC4.2.1
		CRCM	25km	OURANOSMRCC4.2.3
16	EC	GEMLAM	25km	RPN_GEMLAM

Table 2.3: ENSEMBLES RCM experiments driven by the CMIP3 GCMs for the period 1951-2050 or 1951-2100. Source: <http://ensemblesrt3.dmi.dk/>.

	Institute	Scen.	Driving GCM	Model	Res.	Acronym
1	C4I	A2	ECHAM5	RCA3	25km	C4IRCA3
2	CNRM	A1B	ARPEGE	Aladin	25km	CNRM-RM4.5
		A1B	ARPEGE_RM5.1	Aladin	25km	CNRM-RM5.1
3	KNMI	A1B	ECHAM5-r3	RACMO	25km	KNMI-RACMO2
		A1B	ECHAM5-r1	RACMO	50km	KNMI-RACMO2
		A1B	ECHAM5-r2	RACMO	50km	KNMI-RACMO2
		A1B	ECHAM5-r3	RACMO	50km	KNMI-RACMO2
		A1B	MIROC	RACMO	50km	KNMI-RACMO2
4	OURANOS	A1B	CGCM3	CRCM	25km	OURANOSMRCC4.2.1



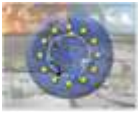
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5	SMHI	A1B	ECHAM5-r3	RCA	50km	SMHIRCA
		A1B	BCM	RCA	25km	SMHIRCA
		A1B	ECHAM5-r3	RCA	25km	SMHIRCA
		A1B	HadCM3Q3	RCA	25km	SMHIRCA
6	MPI	A1B	ECHAM5-r3	REMO	25km	MPI-M-REMO
7	METNO	A1B	BCM	HIRHAM	25km	METNOHIRHAM
		A1B	HadCM3Q0	HIRHAM	25km	METNOHIRHAM
8	C4I	A1B	HadCM3Q16	RCA3	25km	C4IRCA3
9	UCLM	A1B	HadCM3Q0	PROMES	25km	UCLM-PROMES
10	ETHZ	A1B	HadCM3Q0	CLM	25km	ETHZ-CLM
11	HC	A1B	HadCM3Q0	HadRM3Q0	25km	METO-HC_HadRM3Q0
		A1B	HadCM3Q3	HadRM3Q3	25km	METO-HC_HadRM3Q3
		A1B	HadCM3Q16	HadRM3Q16	25km	METO-HC_HadRM3Q16
		A1B	HadCM3Q0	HadCM3Q0	3.75°x2.5°	METO-HC_HadCM3Q0
		A1B	HadCM3Q3	HadCM3Q3	3.75°x2.5°	METO-HC_HadCM3Q3
		A1B	HadCM3Q16	HadCM3Q16	3.75°x2.5°	METO-HC_HadCM3Q16
12	DMI	A1B	ARPEGE	HIRHAM	25km	DMI-HIRHAM5
		A1B	ECHAM5-r3	DMI-HIRHAM5	25km	DMI-HIRHAM5
		A1B	BCM	DMI-HIRHAM5	25km	DMI-HIRHAM5
13	ICTP	A1B	ECHAM5-r3	RegCM	25km	ICTP-REGCM3
14	VMGO	A1B	HadCM3Q0	RRCM	25km	VMGO-RRCM
15	GKSS	A1B	IPSL	CLM	25km	GKSS-CCLM4.8

3.2.3 EURO-CORDEX

EURO-CORDEX is a major European initiative under the scope of the global CORDEX efforts (Giorgi and Gutowski 2015). The results of large number of RCM simulations on the 50-km and 12.5-km horizontal resolutions are available through the Earth System Grid Federation (ESGF) system, which consists of several data nodes. For example, one can explore the content of the entire database by accessing to e.g., <https://esg-dn1.nsc.liu.se/projects/esgf-liu/>. In addition, large number of new simulations are being performed and in the process of the postprocessing. As of the October 2016, status of the simulations over the European domain includes:

- (1) In total 61 (74) different RCM simulations at the approximate horizontal resolution of 12.5 km (50 km).
- (2) In total 10 different RCM have been applied, but in different combinations of boundary forcings and horizontal resolutions: ALADIN52 (3 different simulations), ALADIN53 (9), CCLM4-8-17 (17), HIRHAM5 (8), MOHC-HadGEM3-RA (1), MOHC-HadRM3P (1), RACMO22E (16), RCA4 (53), REMO2009 (18), RegCM4-2 (1), and WRF331F (8).



- (3) In total 10 different CMIP5 GCMs are applied to run different RCMs: CCCma-CanESM2 (applied in 3 different RCM simulations), CNRM-CERFACS-CNRM-CM5 (18), CSIRO-QCCCE-CSIRO-Mk3-6-0 (3), ICHEC-EC-EARTH (23), IPSL-IPSL-CM5A-MR (12), MIROC-MIROC5 (4), MOHC-HadGEM2-ES (18), MPI-M-MPI-ESM-LR (29), NCC-NorESM1-M (4) and NOAA-GFDL-GFDL-ESM2M (3). In addition, reanalysis ECMWF-ERA-Interim was downscaled 18 times by in total both 12.5-km and 50-km RCM models.
- (4) In total 18 evaluation (i.e., RCMs are forced over the historical period by the ECMWF ERA-Interim reanalysis) simulations are available, 35 historical simulations (i.e., RCMs are forced over the historical period by different CMIP5 GCMs, each having different internal variability and not correlated with the observed internal variability). In addition, future projections cover periods up to the end of the 21st century and include simulations where different GHG concentration scenarios are applied: RCP2.6 (13 different simulations), RCP4.5 (34) and RCP8.5 (35). At this stage there are no RCMs simulations using remaining RCP6.0 scenario.

Based on the research question at hand, different subset of the EURO-CORDEX simulation can be selected. In addition, various simulations are available for research or commercial applications (please check ESGF database for more information about specific simulation). A subset of these simulations are already interpolated from the default RCM grids to regular $0.44^\circ \times 0.44^\circ$ and $0.11^\circ \times 0.11^\circ$ grids (this may be relevant for some post-processing and visualization software).

In the rest of this subsection, several results based on the EURO-CORDEX simulations relevant for the EU-CIRCLE are discussed:

- (1) Skill of EURO-CORDEX RCMs forced by the ERA-Interim reanalysis in simulating heat waves, mean climate and climate variability was explored in Vautard et al. (2013) and Kotlarski et al. (2014). Both studies did not document substantial improvement in model performance when increasing the RCM horizontal resolution from 50 km to 12.5 km.
- (2) Several studies explore climate change signal and impacts based on the GCM historical and 21st century simulations. These include Jacob et al. (2013), Jerez et al. (2015), Dosio (2016), Giorgi et al. (2016), Smiatek et al. (2016) and Tobin et al. (2016). In terms of the mean climate change, EURO-CORDEX simulations confirm general results of the previous studies (warming in all seasons, but with variable amplitude over European regions; precipitation increase in the northern Europe and summer precipitation decrease over the southern Europe).
- (3) Simulated precipitation field compared to regional based gridded precipitation products is analysed in detail by Prein et al. (2015). This study finds added value of the 12.5 km simulation in simulating mean and extreme precipitation due to the better representation of the orographic forcing over European regions with complex orography, and due to the better representation of the convective events during the summer season.

Two issues may limit direct applicability of the EURO-CORDEX simulations for the purpose of the EU-CIRCLE project:

- (1) The existence of the systematic errors when comparing simulated and observed climatology (when available) motivates further model development. This task is beyond the scope of the EU-CIRCLE project, and can be replaced by the application of appropriate bias adjustment (or bias correction) technique, as a measure of the statistical post-processing before further use of the **RCMs' results in forcing different impact models**.
- (2) Model output for specific grid cell can be interpreted as an average value of the entire 12.5 km times 12.5 km area. The spatial/horizontal resolution of 12.5 km may be limited for some application, especially if focus is typical urban areas. Methodological framework developed inside EU-CIRCLE can be generalized to be applicable for the case of the higher resolution RCM simulations. This type of RCM simulations are already available in direct contact with specific research groups, and are expected to be available in the EURO-CORDEX style (i.e. large ensemble of



coordinated simulations over specific European region or the entire Europe) in the next 5 to 10 year period. In addition, EU-CIRCLE methodological framework should enable the use of the computationally cheaper climatological simulations with resolutions between e.g. 1 km and 10 km but only over specific domain of interest. In that case, care would be needed in securing the specific data naming and format conventions (e.g. CF convention, netcdf data format). An example of freely available access to RCM simulations at the 1km-10km resolution known to the authors of this report are results of the EXPRESS-Hydro project (Pieri et al. 2015). Here, WRF model at the 4 km resolution and forced by the ERA-Interim reanalysis simulated period 1979-2008 over Europe. The results of these simulations are available from the following database: <http://nextdatapoint.hpc.cineca.it/thredds/catalog/NextData/eurocdx/h1e4/catalog.html>.

Although there are no available simulations using the same model for the historical and future periods (forced by CMIP3 or CMIP5 model), the model domain in the EXPRESS-Hydro covers all European EU-CIRCLE case studies so historical weather events in the 1979-2008 period impacting critical infrastructure can be examined.

3.2.4 MED-CORDEX

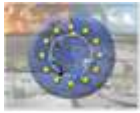
MED-CORDEX (<https://www.medcordex.eu/>) simulations follow CORDEX framework over the Mediterranean region, and include two general categories of simulations (we list below types of simulations relevant for the EU-CIRCLE project):

- (1) CORE simulations: 50 km atmosphere-only RCMs (similar to EURO-CORDEX but over smaller domain). These simulations differ in comparison to TIER-1 simulations (see below) in specific atmospheric or climatological conditions where interaction between processes in atmosphere and ocean is important.
- (2) TIER-1 simulations: 12.5 km atmosphere-only RCMs (similar to EURO-CORDEX but over small domain) and coupled RCM simulations (i.e., simulations having interaction between atmosphere and oceans) on a highest spatial resolution available to specific modelling group.

All MED-CORDEX experiments (i.e. ocean-only simulations, couple atmosphere-ocean simulations etc) are listed on the following URL: <https://www.medcordex.eu/simulations.php>. We limit in Table 2.4 only to archived atmosphere-only RCM simulations.

Table 2.4: MED-CORDEX RCM simulations available through www.medcordex.eu portal. In columns HIST, RCP8.5 and RCP4.5, period simulated and boundary conditions are stated. Empty cells indicate no specific simulations is performed/archived.

Institute	RCM	Res. (km)	ERA-Interim	HIST 1950-2005	RCP8.5 2006-2100	RCP4.5 2006-2100
ENEA	RegCM 3.1	30	1982-2010			
ICTP	RegCM4.3 v1	50	1979-2008	1970-2005: HadGEM2-ES		2006-2100: HadGEM2-ES
ICTP	RegCM4.3 v4	50	1979-2012			
ICTP	RegCM4.3 v7	50	1979-2008	1970-2005: MPI-ESM, HadGEM2-ES	2006-2100: MPI-ESM, HadGEM2-ES	
CNRM	ALADIN 5.2	50	1979-2012	1950-2005: CNRM-CM5	2006-2100 CNRM-CM5	
LMD	LMDZ	30	1979-2009			
U. Belgrade	EBU	50	1989-2008			



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IPSL	WRF 3.1.1 v1	50	1989-2008			
IPSL	WRF 3.1.1 v2	50	1989-2008			
UCLM	PROMES	50	1989-2008			
GUF	CCLM 4-8-11 v1	50	1989-2008			
GUF	CCLM 4-8-11 v2	50	1979-2008			
GUF	CCLM 4-8-18 v1	50	1979-2011	1950-2005: MPI-ESM	2006-2100: MPI-ESM	
GUF	CCLM 4-8-18 v2	50	1979-2011			
CMCC	CCLM 4-8-19 v1	50	1979-2012	1950-2005: CMCC-CCLM4-8-19	2006-2100: CMCC-CCLM4-8-19	2006-2100: CMCC-CCLM4-8-19
CMCC	CCLM 4-8-19 v2	50	1979-2012			
ICTP	RegCM4.3 v1	12	1979-2010	1970-2005: HadGEM2-ES	2006-2050: HadGEM2-ES	
CNRM	ALADIN5.2	12	1979-2012	1950-2005: CNRM-CM5	2006-2100: CNRM-CM5	2006-2100: CNRM-CM5
UCLM	PROMES	12	1989-2009			
GUF	CCLM4-8-18 v1	10	1989-2008			
GUF	CCLM4-8-18 v2	10	1989-2008			

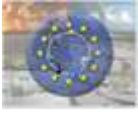
Scientific results of the MED-CORDEX initiative are recently presented in Ruti et al. (2016). At this stage, however, the use of MED-CORDEX simulations is suggested only in special cases because of the use of smaller domain not covering all European EU-CIRCLE case studies. Nevertheless, the results of the MED-CORDEX studies may be relevant when designing specific modelling studies where atmosphere-ocean effects are important, or if the use of the same modelling systems for different case studies in context of EU-CIRCLE is not a necessary condition.

3.2.5 Weather Research and Forecasting (WRF) Model

The Weather Research and Forecasting (WRF) Model is a state-of-the-art atmospheric mesoscale modeling system designed for both meteorological research and numerical weather prediction. It offers a host of options for atmospheric processes and can run on a variety of computing platforms. It features two dynamical cores, a data assimilation system, and a software architecture facilitating parallel computation and system extensibility. The model serves a wide range of meteorological applications across scales from tens of meters to thousands of kilometres. The effort to develop WRF began in the latter part of the 1990's and was a collaborative partnership principally among the National Centre for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by the National Centres for Environmental Prediction (NCEP) and the (then) Forecast Systems Laboratory (FSL)), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA).

WRF can generate atmospheric simulations using real data (observations, analyses) or idealized conditions. WRF offers operational forecasting a flexible and computationally-efficient platform, while providing recent advances in physics, numerics, and data assimilation contributed by developers across the very broad research community. WRF is currently in operational use at NCEP, AFWA, and other centres.

The WRF system contains two dynamical solvers, referred to as the ARW (Advanced Research WRF) core and the NMM (Non-hydrostatic Mesoscale Model) core. WRF model is increasingly used as an RCM,



because allows users to choose among a large combination of different parameterizations, according to the needs of each climate study. Various studies with even higher resolution simulations (10 to 7 km spatial resolution) have been carried out, focusing on countries domains to perform representations of climate patterns, extreme events, drought variability (Berg et al, 2013, Soares et al 2012, Argüeso et al 2012).

3.3 Reanalysis products

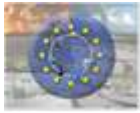
The use of the reanalysis in modern meteorology and climatology is enabled by the advanced combination of models and observations. Typical weather forecasts are performed using NWP models whose computer code changes over the course of time. For example, new numerical methods are implemented, new model physics are introduced, old model components are improved or developed, etc. In most modelling centres, these changes are done several times per year. The idea between the reanalysis is to use the frozen model code and simulate long periods (several decades or even a century). This enables to explore climatology and perform trend analysis in support to standard evaluation of pure observational records. We refer to following web-page with more references to specific (mostly global) reanalysis products: <http://reanalyses.org/>. In Table 2.5 we summarize several global reanalysis products, while in Table 2.6 similar is done for the regional reanalysis products openly available over Europe and relevant for the EU-CIRCLE project.

Table 2.5 State of the art global reanalyses. Summary of the main reanalysis products from <http://reanalyses.org/> relevant for EU-CIRCLE case studies and potential applicable through the CIRP platform.

Acronym	Institution	Spatial resolution	Period	References and comments	Data access
ERA-Interim	ECMWF	~80 km	1979-2016/present	Dee et al. (2011); (used to force EURO-CORDEX and MED-CORDEX RCMs)	http://apps.ecmwf.int/datasets/
ERA-20C	ECMWF	~125 km	1900-2010	Poli et al. (2016)	http://apps.ecmwf.int/datasets/
ERA-40	ECMWF	~125 km	1957-2002	Uppala et al. (2005); (used to force ENSEMBLES RCMs)	http://apps.ecmwf.int/datasets/
JRA-55	JMA	~125 km	1958-2016/present	Kobayashi et al. (2015); full observing system reanalysis)	http://jra.kishou.go.jp/JRA-55/index_en.html#download
MERRA-2	NASA	~ 50 km	1980-2016/present	Molod et al. (2015)	http://disc.sci.gsfc.nasa.gov/mdisc/
CFSR	NCEP	~ 38 km	1979-2016/present	Saha et al. (2010)	https://nomads.ncdc.noaa.gov/#cfsr
20CRv2c	NOAA-CIRES	~ 200 km	1851-2014	Compo et al. (2011)	http://portal.nersc.gov/project/20C_Reanalysis/

Table 2.6 State of the art regional reanalyses over Europe. Summary of the main reanalysis products relevant for EU-CIRCLE case studies and potential applicable through the CIRP platform.

Acronym	Institution/project	Spatial resolution	Period	References and comments	Data access
COSMO-REA6	MIUB, IGMAK	~ 6 km	1997-2014	Bollmeyer et al. (2014) (model domain covers the entire	ftp://ftp.meteo.uni-bonn.de/pub/reana



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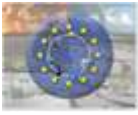
				Europe)	
COSMO-REA2	MIUB, IGMK	~ 2 km	2007-2013	Wahl et al. (2016; under review); (model domain covers central Europe)	ftp://ftp.meteo.uni-bonn.de/pub/reana
EURO4M MESAN	CLIPC	~5.5 km	1989-2010	Landelius et al. (2016)	https://esg-dn1.nsc.liu.se/search/esgf-liu/ (select "clipc" project)

3.4 Global climate models

Global climate models (GCMs) from the Coupled Model Intercomparison Project (CMIP) consist of atmosphere only and coupled ocean-atmosphere numerical models of the climate system. The idea of the CMIP initiative is to coordinate GCM intercomparisons and provision of comparable and consistent projections of the climate system for the entire Earth for the 21st century and beyond. Two most recent CMIP phases, CMIP3 (Meehl et al., 2007) and CMIP5 (Taylor et al., 2012), were basis for the IPCC report AR4 (IPCC, 2007) and AR5 (IPCC, 2013). Preparations for the next phase of GCM simulations and projections and for the next IPCC report (i.e. CMIP6 and AR6) are in progress. More details about the CMIP are available from <http://cmip-pcmdi.llnl.gov/>.

Some basic information about GCMs from CMIP3 and CMIP5 includes following:

- (1) CMIP3 included following models (http://www-pcmdi.llnl.gov/ipcc/data_status_tables.htm): BCC-CM1, BCCR-BCM2.0, CCSM3, CGCM3.1(T47), CGCM3.1(T63), CNRM-CM3, CSIRO-Mk3.0, CSIRO-Mk3.5, ECHAM5/MPI-OM, ECHO-G, FGOALS-g1.0, GFDL-CM2.0, GFDL-CM2.1, GISS-AOM, GISS-EH, GISS-ER, INGV-SXG, INM-CM3.0, IPSL-CM4, MIROC3.2(hires), MIROC3.2(medres), MRI-CGCM2.3.2, PCM, UKMO-HadCM3, UKMO-HadGEM1.
- (2) CMIP5 included following models (<http://cmip-pcmdi.llnl.gov/cmip5/availability.html>): BCC-CSM1.1, BCC-CSM1.1(m), CanAM4, CanCM4, CanESM2, CMCC-CESM, CMCC-CM, CMCC-CMS, CNRM-CM5, CNRM-CM5-2, CFSv2-2011, ACCESS1.0, ACCESS1.3, CSIRO-Mk3.6.0, EC-EARTH, FIO-ESM, BNU-ESM, INM-CM4, IPSL-CM5A-L, IPSL-CM5A-MR, IPSL-CM5B-LR, FGOALS-g2, FGOALS-gl, FGOALS-s2, MIROC4h, MIROC5, MIROC-ESM, HadCM3, HadCM3Q, HadGEM2-A, HadGEM2-CC, HadGEM2-ES, MPI-ESM-LR, MPI-ESM-MR, MPI-ESM-P, MRI-AGCM3.2H, MRI-AGCM3.2S, MRI-CGCM3, MRI-ESM1, GISS-E2-H, GISS-E2-H-CC, GISS-E2-R, GISS-E2-R-CC, GEOS-5, CCSM4, NorESM1-M, NorESM1-ME, NICAM.09, HadGEM2-AO, GFDL-CM2.1, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GFDL-HIRAM-C180, GFDL-HIRAM-C360, CESM1(BGC), CESM1(CAM5), CESM1(CAM5.1,FV2), CESM1(FASTCHEM), CESM1(WACCM).
- (3) CMIP3 GCMs applied IPCC Special Report on Emission Scenarios (SRES) for the projections for the 21st and beyond: B1, A1B, A2.
- (4) CMIP5 scenarios applied IPCC Representative Concentration Pathways (RCP) for the projections for the 21st and beyond: RCP2.6, RCP6.0, RCP4.5, RCP8.5.
- (5) CMIP3 GCMs have average horizontal resolution of ~250 km (e.g. Kusunoki and Arakawa 2015; their Table 1). CMIP3 GCMs have been used to force ENSEMBLES RCMs at horizontal resolutions of 25 km and 50 km.
- (6) CMIP5 GCMs have average horizontal resolution of ~200 km (e.g. Kusunoki and Arakawa 2015; their Table 2). CMIP5 GCMs have been used to force MED-CORDEX and EURO-CORDEX RCMs at horizontal resolutions of 12.5 km and 50 km.
- (7) **CMIP3 GCMs' simulations results can be accessed from** http://www-pcmdi.llnl.gov/ipcc/info_for_analysts.php or in a more user friendly way (for smaller amounts of data) from <https://climexp.knmi.nl>.
- (8) **CMIP5 GCMs' simulations results can be accessed from several nodes in the Earth System Federation (ESGF) Peer-to-Peer (P2P) system:** <https://pcmdi.llnl.gov/projects/esgf-llnl/>. From the



practical point of view, the ESGF system is in continuous development, and some functionalities may not be accessible 24/7. Partners of the EU-CIRCLE project may contact DHMZ in case if basic technical assistance in acquiring CMIP5 GCM and EURO-CORDEX RCMs from the ESGF is needed. DHMZ partners suggest following two specific ESGF nodes for the data search and data access needs for the purpose of the EU-CIRCLE case studies: <https://esgf-data.dkrz.de/projects/esgf-dkrz/> and <https://esg-dn1.nsc.liu.se/projects/esgf-liu/>.

Evaluation of CMIP5 GCMs over Europe in terms of their skill in reproducing basic climatology is given by e.g. Cattiaux et al. (2013), Kumar et al. (2014) and Jury et al. (2016).

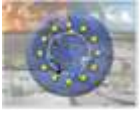
3.5 Statistical downscaling

The idea behind (empirical) statistical downscaling (ESD) is (1) to detect statistical relationships between simulated fields from GCMs or RCMs and real local observations in historical climate, and (2) to **apply these relationships on GCMs' or RCMs' future climate projections in order to reconstruct possible statistics of the local climate in future periods**. This means basically three ingredients are needed: (1) long time-series of high-quality local observations (e.g. time-series of total precipitation, 2m air temperature and/or 10m wind speed), (2) GCMs or RCMs projections of either same quantities as in (1) or of large-scale quantities than can strongly influence near-surface variables, and (3) development of statistical links between (1) and (2). The science of statistical downscaling is in progress and is often associated with the bias correction or bias adjustment methods (e.g. Piani et al., 2010, Themeßl et al. 2012). Bias adjustment is of particular concern when results of GCMs and RCMs are needed for force various impact models (e.g. forest fire spread model, detailed hydrological models, crop productivity models, etc.). For a quick introduction into this topic consider e.g. climate4impact.eu portal and Benestad et al. (2008). Comparison between dynamical downscaling approach used in and statistical downscaling is discussed in <https://climate4impact.eu/impactportal/documentation/backgroundandtopics.jsp?q=Downscaling>. In practice, both downscaling approach may be considered for specific case study (Ayar et al. 2015).

In the context of EU-CIRCLE project, partners and users of the CIRP platform may use already available results of the GCM- or RCM- based international projects and initiatives. In contrast, functionalities of several bias adjustment or empirical statistical downscaling methods could be implemented through the CIRP platform due to their cheaper implementation from the computational and data storage point of view. In addition, recently first results of the EU FP7 project CLIPC (<http://www.clipc.eu/>) and of the so called CORDEX-adjust initiative became available through the ESGF system. These can be accessed from <https://esg-dn1.nsc.liu.se/search/esgf-liu/> (select **"CORDEX-Adjust" project**). **As of January 2017, following bias adjusted RCM fields are available (only variables available at the 12.5 km resolution are listed here):** bias-adjusted near-surface wind speed, bias-adjusted daily maximum near-surface air temperature, bias-adjusted daily minimum near-surface air temperature, bias-adjusted near-surface air temperature, bias-adjusted precipitation and bias-adjusted surface downwelling shortwave radiation. For each variable, following information is provided: (1) underlying EURO-CORDEX RCM, (2) referent observational dataset and (3) bias adjustment method applied by the specific research group.

3.5.1 Application of the ESD in EU-CIRCLE case studies

Risk management emphasising consequences of climate change on critical infrastructure needs to build on information about changes at a local level. Global climate models (GCMs) are our main tools for exploring a future climate change, however, they are designed to represent large-scale features and do not provide sufficient details for local consequences. It is nevertheless possible to infer local changes from large-scale changes because the local climate is dependent on large-scale circulation. This is known as



downscaling, and may involve different approaches such as empirical-statistical downscaling (ESD) and nested high-resolution regional climate models (RCMs). It is also important to adapt the type of information from the modelling and downscaling to suit the type of risk analysis on a case-by-case basis, and place in the context of the specific situation. This requires an analysis of the information about past events to get an appreciation of potential hazards. The greenhouse effect has increased until now due to heightened levels of CO₂ over time, and a global warming has been observed. Historical observations already indicate trends in the past, and we can expect these trends to become more pronounced in the future unless there are physical reasons for a non-linear response. Hence, the analysis needs to include the analysis of historical observations (data), and it is essential to build the analysis on information that has been used in the past for safeguarding the infrastructure. Neither climate models nor downscaling provide a perfect representation of the real world, and it is also important to validate the results that are used for the risk analysis. An important point is for the climate modellers and those who carry out the downscaling to understand exactly how the data is being used in the decision making, or how the numbers representing climatic conditions enter the 'equation' used for planning. In many cases, local authorities need to follow national guidelines according to law.

In EU-CIRCLE, there were five pilot case studies for

- I- The risk of wildfires in southern France. Roads and power are lines closed when there are wildfires, and the wildfire hazard is strongest during summer and is exacerbated by droughts and heat waves. An initial analysis has been carried out to get an idea about past and present conditions concerning rainfall and dry spells. There were not abundance of data readily available, but there were some rain gauge data from the ECA&D dataset and E-OBS grids. The initial analysis⁹ included a trend analysis concerning the mean duration of dry spells, as it was assumed that the spell length statistics follows a geometric distribution. There has been a decreasing trend in the wet-day frequency for the locations with the longest records, although one station further inland with shorter record suggested an increase. A slight increasing trend was found for the mean dry spell duration in Marseilles over the period 1900-2013, which then suggests an increasing probability for longer droughts. A trend analysis applied to gridded rainfall (E-OBS) suggested greatest increasing trends in the dry spell duration near the Mediterranean coast. For future projections, ESD will be used to try to identify systematic dependencies between the dry-spell statistics and large-scale predictors. Some candidate predictors include mean sea-level pressure (SLP) and surface temperatures. ESD can also take wildfire data as predictors to try to downscale the area affected.
- II- The case study concerning storms and sea surge at sea port Gdynia in Poland. **Pipe lines authorities** needs information about wind and waves to make risk analysis for pipe operation and spill hazards. Wind measurements have traditionally been difficult to make with high accuracy and a good representation of the conditions in the wider vicinity. The wind speed is often very local and the measurements are often inhomogeneous over time due to changed surrounding environment. The barometric pressure has often been used to infer wind statistics over time, as the measurements are made with higher quality. Furthermore, tidal gauges can give some indication about storm activity, which affect the wave height and give rise to storm surges. Synoptic storms, or low pressure systems, are responsible for high winds and precipitation which are relevant for this case study there are some analyses of storm tracks which can be related to synoptic mean sea-level pressure patterns (Hov et al., 2013). An assessment of future risks needs to involve the present storm tracks and their dependency on large-scale conditions such as sea surface temperature, meridional temperature gradient, and the Arctic sea ice. ESD has been used to downscale storm track statistics for the Barents Sea region (Benestad et al., 2016), and similar assessment can be carried out for the Baltic Sea.

⁹ https://github.com/metno/esd_Rmarkdown/blob/master/EU-Circle/eu-circle_case-study-1.pdf

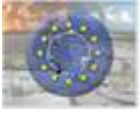
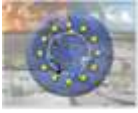


Figure 2.1 Stormtracks over the Baltic Sea. Source:
https://github.com/metno/esd_Rmarkdown/blob/master/EU-Circle/eu-circle_case-study-2.pdf

- III- Critical infrastructures such as power relays are exposed to flooding in Torbay, and waves, wind, heavy precipitation, and encroaching sea level height represent a problem. Planning has used national intensity-duration-frequency (IDF) curves for handling heavy precipitation and drainage of excess water, and the municipal has access to local wave measurements. Climate change adaptation will be based on recommended climate change factors compared to a given baseline as provided by UKCP09. UKCP09 also provide maps, probabilities and plume plots. ESD can provide additional information in terms of downscaled results based on large multi-model ensembles and for the statistics of synoptic storm tracks. An analysis of past trends suggest a modest increase the precipitation intensity for most rain gauge records in the vicinity of southwestern England, although with some exceptions. Increased mean precipitation intensity translates to increased probability of extreme precipitation, and downscaling attempts based on 108 RCP 4.5 CMIP5 simulations indicate a slight increase also in the future. Other aspects include inundation from high seas. Local sea level measurements for Torbay are lacking, however, there are tidal stations along the southwestern



coast of England and the northern coast of France in the English channel. A sea level rise is expected to exhibit a large-scale character which varies smoothly from place to place, and a comparison between sea level variations (PCA) supports this assumption. The local sea level is also expected to depend on the global mean sea level, and therefore it is possible to calibrate a model for the local sea level which uses the global mean as input. There are also more statistically sophisticated approaches, which have been explored in the Nordic research project eSACP. Storm surges from synoptic storms may affect critical infrastructure by flooding the electric power grid (relay stations), and a systematic displacement or shift in the storm statistics will have a strong influence since southern England is located within the region with North Atlantic storm tracks.

- IV- Winter flooding in Dresden may require evacuation from urban areas near the Elbe river. There are also severe floods during summer, but winter is more difficult to cope with because it requires the provision of shelter during cold conditions. The river levels are affected by heavy rain higher up in the catchment and rapid snow melting. Data of interest include Elbe river level¹⁰ that covers a long period, for instance daily maximum. There is a dense network of German rain gauge stations available from the ECA&D data set, and the E-OBS data provides gridded representation. There is a possibility that the river level statistics may lend itself to ESD analysis, in addition to the obvious candidates such as precipitation and temperature. The timing of past flooding events may be used together with the analogue method and synoptic weather charts to understand the connection between these extremes and the large-scale situation. The task is to find dependencies of the risk of heavy precipitation or snow melt (extremely high winter temperatures) to large-scale conditions that can be reproduced realistically by GCMs. A downscaling analysis could potentially provide probabilities for certain events, however, it is not yet clear exactly what type of numbers that are used in the climate change adaptation and planning.
- V- An important hazard in Bangladesh and its critical infrastructure is the consequence of tropical cyclones and heavy precipitation which cause flooding and storm surges. The data from Bangladesh is limited, although the Bangladesh Meteorological Department (BMD) has some daily data on precipitation and temperature. Tropical cyclones are large-scale phenomena, and their effect on precipitation can be crudely represented through an index that aggregates the daily precipitation across the country. Tidal gauge data¹¹ from PSMSL can provide information when it comes to storm surges, although it is important to beware of the limitation of non-certified data quality. Data is available from five tide gauges in Bangladesh with measurements back to the 1970s. The presence of several parallel and independent time series may be useful for evaluating the data quality. Although the time series are short, the historical analysis should involve trend estimation and the attempt to identify dependencies to tropical cyclone activity. Storm tracks from the IMILAST project may be explored, although it is not yet known whether they provide useful information in the Tropics.

¹⁰ There is data, but only a very limited selection is available: <http://www.bafg.de/php/DRESDENELBEW.bfg>.

¹¹ <http://www.psmsl.org/data/obtaining/stations/1451.php>

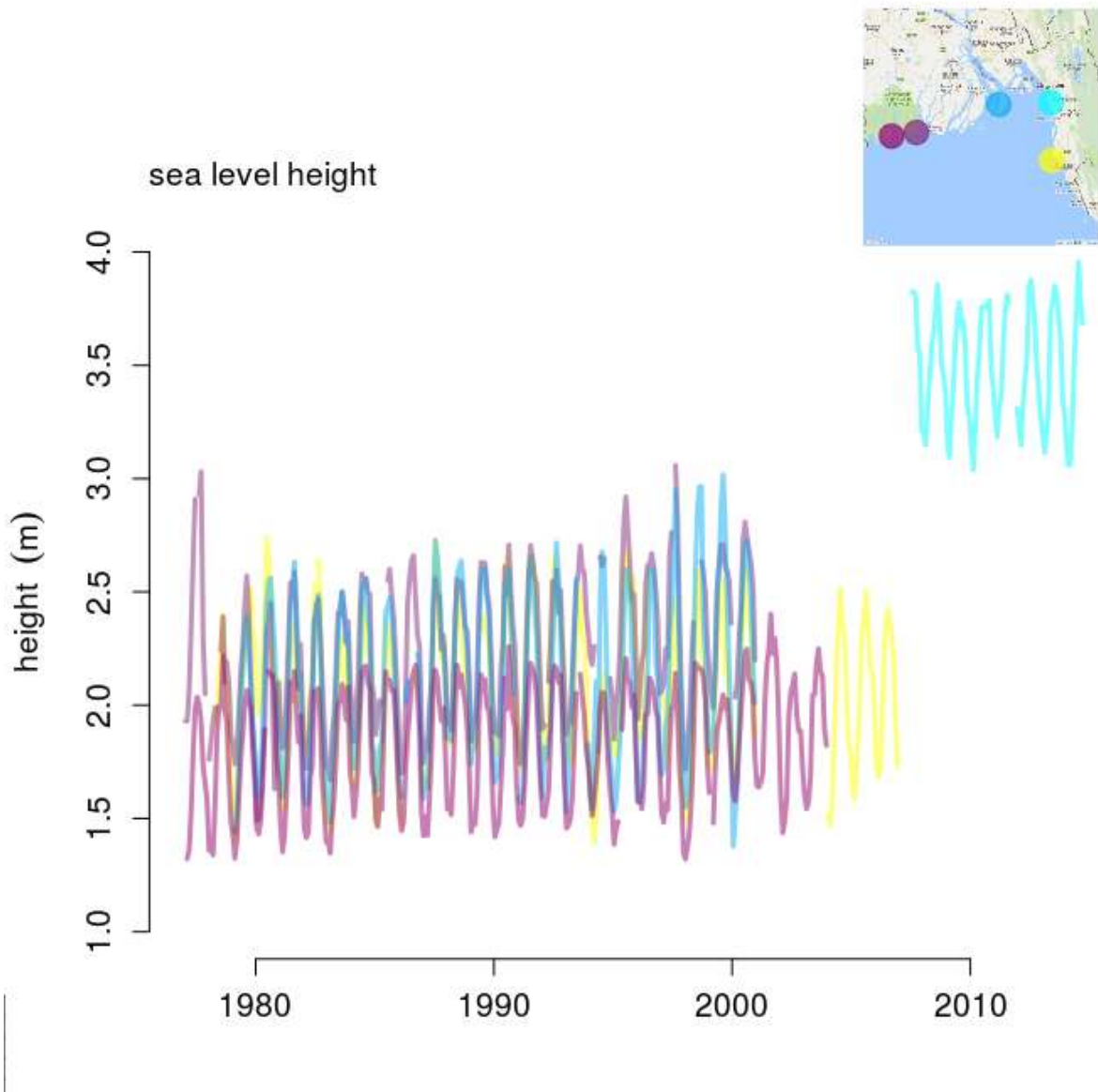
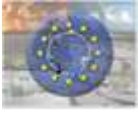
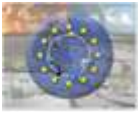


Figure 2.2 Sea level height for the tidal stations in Bangladesh. Based on https://github.com/metno/esd_Rmarkdown/blob/master/EU-Circle/eu-circle_case-study-4.pdf



4 Numerical weather prediction in Europe

4.1 Introduction

National weather services group their activities related to numerical weather prediction (NWP) into international consortia. Currently, there are four (4) NWP consortia in Europe focusing on short-range forecasting, that is forecasting weather and weather extremes up to several days ahead (Figure 3.1). In addition, those consortia develop forecasting models for medium-range and extended-range forecasting. Furthermore, European intergovernmental organization established European Centre for Medium-Range Weather Forecasts (ECMWF) which is established by the European Commission focuses also on medium- and extended-range forecasting. Thus, there are five main NWP stakeholder groups in Europe, as listed:

- (1) ECMWF (European Centre for Medium-Range Weather Forecasts) (<http://www.ecmwf.int/en/research/modelling-and-prediction>)
- (2) ALADIN (Aire Limitée Adaptation dynamique Développement InterNational) (<http://www.cnrm.meteo.fr/aladin/>)
- (3) HIRLAM (High Resolution Limited Area Model) (www.hirlam.org/)
- (4) COSMO (The Consortium for Small-scale MOdeling) (www.cosmo-model.org/)
- (5) MetUM (Met Office Unified Model) (<http://www.metoffice.gov.uk/research/modelling-systems/unified-model>)

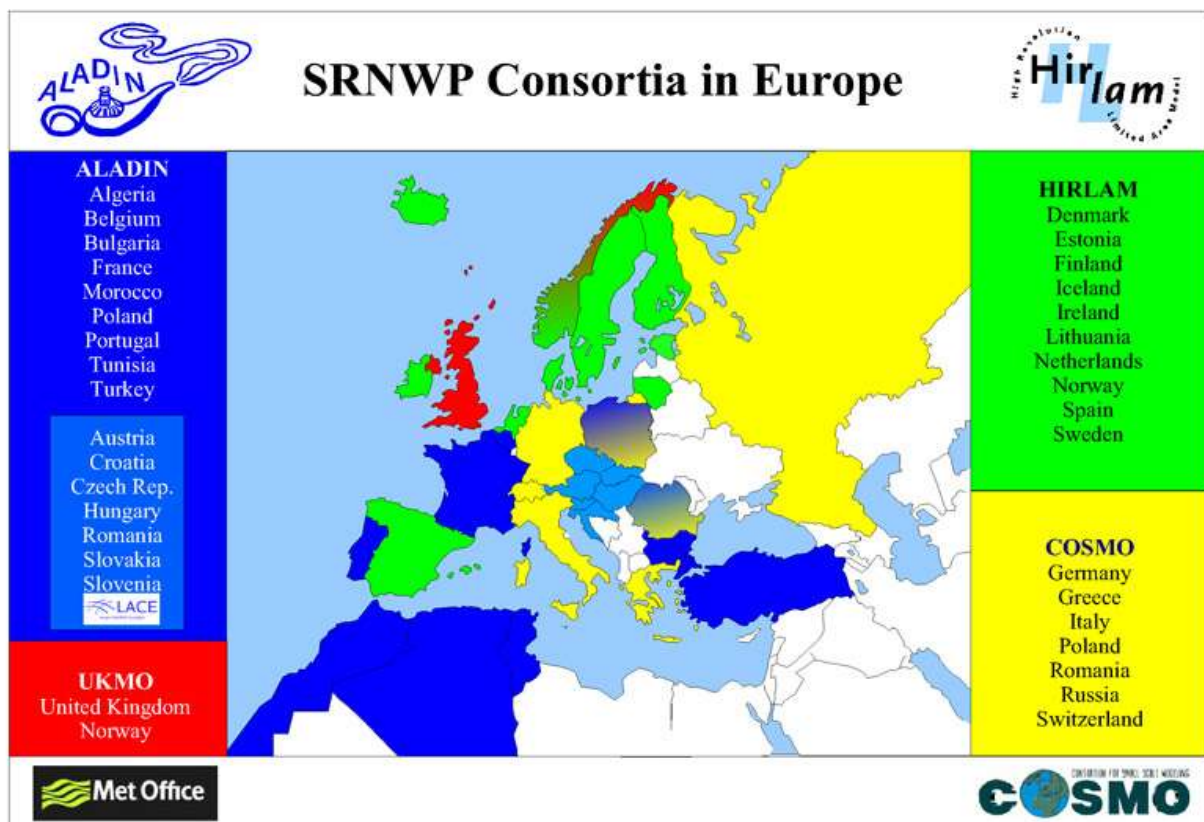
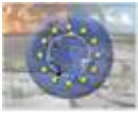


Figure 3.1: Short-range numerical weather prediction consortia in Europe.

These consortia have more or less intensive mutual collaboration. For example, ALADIN and HIRLAM jointly develop certain aspects of their NWP models. National weather services also support directly developments in ECMWF, and vice versa. A few remaining countries not members of these consortia are using other models such as the WRF (Weather Research and Forecasting) model.



The following overview covers operational deterministic and probabilistic NWP systems in European countries. Deterministic systems are typically used at higher resolutions and provide more detailed information on a single representation of the forecasted weather conditions. Probabilistic prediction systems provide lower resolution multiple, yet equally likely, realizations of the forecasted weather conditions. Both of those approaches are useful for prediction of weather extremes.

Both deterministic and probabilistic prediction systems may be configured using global models or so-called limited-area models (LAMs). Global model provide forecasts on the entire globe with coarser resolution, while LAMs provide forecasts on the selected area (domain) over the region of interest. LAMs are typically configured on higher resolution than global models.

4.2 Overview of deterministic NWP systems within major consortia

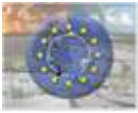
4.2.1 ECMWF-IFS

Integrated Forecast System (IFS) is an operational global forecasting model and data assimilation system developed and maintained by ECMWF in co-operation with Météo-France. The dynamical core of the IFS model is hydrostatic, two-time-level, semi-implicit, semi-Lagrangian and applies spectral transformation between grid-point space (physical parameterizations and advection are calculated there) and spectral space. By using this type of core, stability and accuracy are ensured, while very large time-steps can be used to perform the computation of the forecast within the acceptable time. IFS model has 137 vertical levels and is discretised using a finite-element scheme, while a reduced Gaussian grid is used in the horizontal. For research experiments, which are not used operationally, the non-hydrostatic dynamical core may also be used. Typical size of resolved processes is approximately 4-6 grid cells, which are at nominal resolution of 9 km. The sub-grid scale features and unresolved processes are described in a statistical way by atmospheric physical parameterizations. Namely, these are: radiative transfer, convection, clouds and stratiform precipitation, surface exchange, turbulent mixing, sub-grid scale orographic drag and non-orographic gravity wave drag. Model is initiated four times daily (00, 06, 12 and 18 UTC) and run through forecasting period of 10 days (15 days for 51 member Ensemble – Atmospheric Model (EMS), with coarser horizontal grid spacing of 18 km and 91 vertical levels). IFS uses four-dimensional variational data assimilation (4D-Var) to create a sequences of model states which fit as closely as possible with the available observations and background. 4D-Var analysis is performed on 12 hours assimilation window; 21 - 09 UTC (for the 00 and 06 UTC analyses) or 09 - 21 UTC (for the 12 and 18 UTC analyses). More information about the IFS model may be found on its home page.

4.2.2 ALADIN

Within the ALADIN (Aire Limitée Adaptation dynamique Développement InterNational) consortia there are several Numerical Weather Prediction (NWP) systems used over limited geographic areas, e.g. ALADIN, ALARO-0, ALARO-1 and AROME. Most of these models use either ARPEGE (Action de Recherche Petite Echelle Grande Echelle) or IFS global model data as Lateral Boundary Conditions (LBC) with typical update interval of 1-3 hours. ARPEGE model is a part of ARPEGE-IFS prediction system and it shares a major part of the code with IFS model, although it uses different set of physical parameterizations and different vertical discretization method.

ALADIN model has been developed by a group of scientists from 13 Central and Eastern European countries, joint by 3 North African countries (Figure 3.1.). It shares a considerable part of the code with the global models IFS and ARPEGE. ALADIN has the same vertical discretization (based on finite differences method), dynamics and physics as ARPEGE, except for the fact that shallow-water model and the 4D-VAR assimilation scheme are not coded within it. ALADIN uses spectral representation of horizontal fields by using the 2D Fourier transformation limited with elliptical truncation, while ARPEGE uses Legendre polynomials in one horizontal direction and Fourier transformation in the other. ALADIN lateral forcing from ARPEGE is done according to a Davies relaxation scheme. Primitive prognostic equations are solved for same variable in both

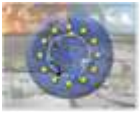


models and those are: horizontal wind components, temperature, specific humidity, and mean sea level pressure. ARPEGE is initialized four times daily (00, 06, 12 and 18 UTC) and depending on the time of initialization, it covers 60-102 hours forecasting range. Its horizontal grid spacing varies from 10 km over France to 60 km near antipode point. Depending on the needs and computing capabilities of member countries, ALADIN is initialized mostly two or four times daily (eight times in Slovenia) and is run through forecasting period of 36-84 hours. Typical horizontal grid spacing varies between 2 and 9 km. In vertical it has 70 levels (with spacing increasing from distance above the ground level) like ARPEGE or less, except for Czech and Slovenian versions which have 87 levels.

AROME (Applications of Research to Operations at MEsoscale) is a limited-area model designed for fine-scale weather forecasting (horizontal mesh-size around 1 to 2.5 km). It was designed to improve short-range forecasts of severe events such as intense Mediterranean precipitations (Cévenole events), severe storms, fog and urban heat during heat waves. AROME is based on the dynamical kernel of the non-hydrostatic version of ALADIN model and the physical parameterization package of the Meso-NH research model. AROME is used operationally at Météo-France, as well as in Austria, Hungary and Portugal. It is initialized two to eight times daily from data assimilation derived from the ARPEGE-IFS 3D-Var assimilation system and adapted to the AROME finer resolution. Operational version of AROME has horizontal grid spacing of 2.5 km and is run over 30-48 hours forecasting range on 60-90 vertical levels. As the AROME software is extremely expensive to run, in particular for real-time weather forecasting, a framework for the transition called ALARO has been developed. ALARO is based on the ALADIN model with a refined formulation of the physical parameterizations. Through the time, the starting version named ALARO-0 has been replaced with ALARO-1 in some countries like Czech Republic and Poland. Main characteristics of ALARO-0 setup are: (i) multi-scale; parameterizations being as scale-independent as possible and giving physically consistent results over a wide range of model resolutions, (ii) consistency of all formulation; in particular within the 3MT framework for the macro physical parameterization of precipitation, (iii) a prognostic character of parameterizations, while they share the same information, approaches and level of complexity and (iv) code stability, numerical efficiency and modularization. ALARO-1 introduced improvements and adaptations of parameterizations for higher resolutions, near the grey zone, i.e. convection permitting scale. The focus is put on radiation, turbulence, convection, clouds and microphysics. ALARO is typically run through 36-72 hours forecasting period. Its horizontal grid spacing varies between 2 and 8 km. For more details on ALADIN consortium models and activities please check its official web site.

4.2.3 HIRLAM

Within the international research programme HIRLAM (High Resolution Limited Area Model), two models for both synoptic-scale (HIRLAM model) and meso-scale (HARMONIE model) prediction have been developed. The HIRLAM model is a hydrostatic grid-point model, which shares part of a code with ALADIN. Its dynamical core is based on a semi-implicit semi-Lagrangian discretisation of the multi-level primitive equations, using a hybrid coordinate in the vertical. However, Eulerian dynamics can optionally be included as well. Model prognostic variables including horizontal wind components, temperature, specific humidity and linearized geopotential height are defined at full model levels, while pressure, geopotential height and vertical wind velocity are calculated at half-levels. For horizontal discretization an Arakawa C-grid is used. Equations are written for general map projection, but in practice normally a rotated longitude-latitude grid projection is adopted. Unresolved sub-grid scale processes include: radiation, clouds and condensation, turbulence, surface and soil processes, as well as mean and sub-grid scale orography. In majority of member states, HIRLAM is initialized four times daily (00, 06, 12 and 18 UTC) from either 3D-Var or 4D-Var assimilation data derived from IFS model or HIRLAM model of higher horizontal grid spacing. Depending on the setup and horizontal grid spacing, which may vary between 3 and 17 km, the model is typically run over 24-74 hours forecasting range. LBCs are refreshed every 1-6 hours. Besides the standard NWP setup, a chemistry component has also been developed and integrated into fully coupled atmospheric-chemistry transport system, including a passive tracer transport.



HARMONIE is a non-hydrostatic convection-permitting model, which is developed in cooperation with Météo-France and ALADIN. It builds-up on model components that have been developed in these two communities. At default horizontal grid spacing ≤ 2.5 km the forecast model and analysis system are basically those of the AROME model, while at coarser grid ALARO or ECMWF physical parameterisations can be used, as well as the ones from hydrostatic versions of ALADIN and HIRLAM. Besides standard physics package, HARMONIE also uses externalized surface scheme named SURFEX which distinguishes different surface types. Dynamical core of HARMONIE model is based on a two-time level semi-implicit semi-Lagrangian discretisation of the fully elastic equations, using a hybrid coordinate in the vertical. Optionally, for larger domains and coarser resolutions the hydrostatic version of this semi-Lagrangian scheme can be used. HARMONIE is initialized four to eight times daily either from 3D-Var data assimilation derived from HIRLAM/ALADIN models or from surface analysis. It is typically run over 6-66 hours forecast range on 60-65 model levels, and at default 2.5 km horizontal grid spacing. LBCs are refreshed every 1-3 hours. More details may be found on official HIRLAM/HARMONIE web page.

4.2.4 COSMO

Besides its major purpose related to small-scale modelling, within COSMO (Consortium for Small-Scale Modelling; Figure 3.1.) consortia, German meteorological service i.e. Deutscher Wetterdienst (DWD) was developing global NWP hydrostatic GEM model in collaboration with Max-Planck-Institut für Meteorologie. GME was recently replaced with ICOSahedral Non-hydrostatic model (ICON). The non-hydrostatic dynamical core of the ICON model is formulated on an icosahedral-triangular Arakawa C-grid and uses the edge-normal wind component, the vertical wind speed, density and virtual potential temperature as prognostic variables. Horizontal discretization is performed by using the finite volume method on triangular volumes. In the vertical, a generalized z-type terrain-following coordinate is used to allow for a rapid decay of topographic structures with height, thereby reducing the numerical discretization errors over steep mountains. Time integration is accomplished with a two-time-level predictor-corrector scheme, which is explicit, except for the terms describing vertical sound-wave propagation. Physical parameterizations are partly taken from IFS and COSMO models, while some like saturation adjustment had to be rewritten for ICON itself. ICON was developed to have flexible grid nesting, in order to replace both GME and COSMO-EU 7 km regional model at DWD. Compared to GME, ICON has finer horizontal grid spacing of 13 km (20 km) and vertical extent of 75 km (36 km), while the number of vertical levels is also increased to 90 (60 for GME). ICON is initialized eight times daily (every 3 hours from 00 UTC) by using 3D-Var data assimilation and run over 30, 120 or 180 hours forecasting range.

Small-scale COSMO Model is a non-hydrostatic limited-area model developed within the framework of the Consortium for Small-Scale Modelling (COSMO; Figure 3.1.). It has been designed for both operational NWP and various scientific applications on the meso- β and meso- γ scale. COSMO model is based on the primitive thermo-hydrodynamical equations describing compressible flow in a moist atmosphere. Model equations are formulated in rotated geographical coordinates and a generalized terrain following height coordinate is used in vertical. Basic set of equations is numerically solved using the traditional finite differences method.

Basic version of the COSMO model (formerly known as Lokal Modell (LM)) has been developed at the DWD. As a limited-area model, the COSMO model needs LBCs from a driving model. Today it is possible to nest the COSMO model into the global models ICON (from DWD) and IFS (from ECMWF). It is also possible to nest the COSMO-Model into itself. Lateral forcing from driver model is done according to Davies relaxation scheme as for the ALADIN model. LBCs are usually updated every 1-3 hours. Unresolved, sub-grid scale physical processes are taken into account by parameterization schemes. Part of physical parameterizations has been taken from LM, GME and IFS models, while the rest have been developed only for COSMO. Included physical processes are: vertical diffusion, cloud and precipitation formation, convection, radiation, and finally soil processes in a soil model.

Depending on the member country needs and capabilities, COSMO model is initialized one to eight times daily from four-dimensional data assimilation based on observation nudging or without data assimilation for



some setups (see Table 3.1 for details). This nudging or Newtonian relaxation relaxes the model's prognostic variables (i.e., pressure, temperature, wind, and mass fractions of different water species) towards the observations within a predetermined space and time window. The model is typically run over 24-78 h forecasting period on horizontal grid spacing which varies between 2 and 14 km. Besides operational forecasting, COSMO model is also used for regional climate and air pollution modelling, as well as for research case studies.

4.2.5 Met Office Unified Model

The Met Office Unified Model (MetUM) is a NWP and climate modelling system originally developed and used at the United Kingdom Met Office. However, nowadays it is both used and developed by many weather-forecasting agencies around the world (e.g. Australian Bureau of Meteorology and South Korea **Meteorological Administration**). **MetUM is a 'seamless' system in a sense that different configurations of the same model are used across all temporal and spatial scales.** Different configurations are each designed to best represent the processes which have the most influence on the timescale(s) of interest. For example, for accurate climate predictions the use of a coupled atmosphere-ocean model is essential, while for short-range weather forecasting a higher resolution atmospheric model may be more beneficial than running a costly ocean component.

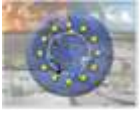
The latest version of the atmospheric model uses non-hydrostatic dynamics with semi-Lagrangian advection and semi-implicit time stepping. It is a grid point model with the ability to run with a rotated pole and variable horizontal grid. A number of sub-grid scale processes are represented, including convection, turbulent diffusion, radiation, clouds, microphysics and orographic drag. MetUM can be run as a global model, or a limited area model and can also be coupled to land surface, ocean models, wave models, chemistry and Earth system components. Global configuration, which was recently refined from 25 km horizontal grid spacing to 17 km, provides a medium-range weather forecast and also supports the nested higher resolution regional models with LBCs. It is initialized four times daily (00, 06, 12 and 18 UTC) from hybrid Incremental 4D-Var data assimilation with MOGREPS Ensemble and run over 48 (06 and 18 UTC runs)-144 hours forecasting range (00 and 12 UTC runs) on 70 vertical levels. Until recently, within MetUM system there were several progressively finer regional models which have provided more accurate short-range forecasts, e.g. North Atlantic and European model (NAE), EURO4 (Downscaler) and UK4 (Table 3.1). With the latest addition of variable resolution UK model (UKV), these are either retired or suspended.

UKV is initialized four times daily (03, 09, 15 and 21 UTC) from hybrid 3D-Var data assimilation derived from global configuration and run over 36 hours forecasting range on 70 vertical levels. LBCs are refreshed every 1 hour. UKV has a high resolution inner domain (1.5 km horizontal grid spacing) over the area of interest, separated from a coarser grid (4 km) near the boundaries by a variable resolution transition zone. This variable resolution approach allows the boundaries to be moved further away from the region of interest, reducing unwanted boundary effects on the forecasts.

UK Met Office also has the capability to relocate regional models to any area of interest worldwide. These Crisis Area Models (CAMs) with horizontal grid spacing of 12 km are often used as a military support or in case of natural hazards. Hadley Centre of UK Met Office has developed several configurations suitable for climate predictions from seasonal to centennial scales. These are of lower resolution than NWP models, and include ocean and sea-ice components coupled to the atmosphere model in order to represent the full coupled climate system. More information on both NWP and climate configurations of MetUM system may be found on its home page.

4.2.6 Other data

Only few European countries do not participate in the development of NWP models within major consortia, but rather use their own setups of ETA, WRF and NMMB models (Table 3.1). Except Serbian global NMMB model, all other are regional models. These models are initialized one to four times daily, using either global models (e.g. NCEP, IFS, GME and NMMB) as lateral forcing or coarser versions of their own regional models.



D2.1 Report on Typology of Climate Related Hazards

Forecasting range of these models varies between 48 and 216 hours, while horizontal grid spacing is between 4 and 30 km. Except for few Bosnian configurations based on nudging technique, data assimilation is not employed.



Table 3.1: Overview of deterministic prediction systems in Europe as listed in EUMETNET (as of Dec 2015).

Country	Model		Mesh size (km)	Number of gridpoints	Number of levels	Initial times & Forecast ranges (h)		Type of data assimilation	Model providing LBC data	LBC update interval (h)	Computer
Denmark	HIRLAM	T15	16	610 × 568	40	00/06/12/18	+60h	3D-VAR	ECMWF/IFS	3h	Cray XT5
		K05	5.5	874 × 534	40	00/06/12/18	+48h	3D-VAR	ECMWF/IFS	3h	
		SKA	3.3	874 × 658	65	00/06/12/18	+54h	3D-VAR	ECMWF/IFS	3h	
	HARMONIE	DKA	2.5	800 × 600	65	00/06/12/18	+36h	Surf-ana only	ECMWF/IFS	3h	
		GLA	2.0	200 × 400	65	00/06/12/18	+36h	Surf-ana only	ECMWF/IFS	3h	
Estonia	HIRLAM	ETA II	11	366 × 280	60	00/06/12/18	+54h	3D-VAR fgat	ECMWF/IFS	3h	Linux Cluster
		ETB II	3.3	306 × 306	60	00/12	+36h	3D-VAR fgat	ETA II	1h	
Finland	HIRLAM		7.5	1030 × 816	65	00/06/12/18	+54h	4D-VAR	ECMWF/IFS	3h	Cray XC30
	HARMONIE		2.5	720 × 800	65	00/03/06/09/12/15/18/21	+54h	3D-VAR	ECMWF/IFS	3h	
Iceland	HARMONIE		2.5	300 × 240	65	00/06/12/18	+48h	Surf-ana only	ECMWF/IFS	3h	Cray @ ECMWF
Ireland	HIRLAM		11	654 × 424	60	00/06/12/18	+54h	4D-VAR	ECMWF/IFS	3h	SGI Altix ICE X at ICHEC
	HARMONIE		2.5	540 × 500	60	00/06/12/18	+54h	Surf-ana only	ECMWF/IFS	1h	
Netherlands	HIRLAM	CIS (7.2)	11	726 × 550	60	00/06/12/18	+48h	3D-VAR	ECMWF/IFS	3h	BullX B500
		E11 (7.2)	11	306 × 290	40	00/03/06/..../18/21	+60h	3D-VAR	ECMWF/IFS	1h	
		C11 (7.2)	11	306 × 290	40	00/03/06/..../18/21	+24h	3D-VAR	HIRLAM/CIS	3h	
		H11 (7.4)	11	306 × 290	40	00/01/02/..../22/23	+24h	3D-VAR	ECMWF/IFS	1h	
	BES (7.4)		7.7	438 × 301	65	00/06/12/18	+48h	3D-VAR	ECMWF/IFS	1h	
	HARMONIE	HA36 (36h1.4)	2.5	800 × 800	60	00/03/06/..../18/21	+48h	3D-VAR	HIRLAM E11	1h	
		HA38 (38h1.2)	2.5	800 × 800	65	00/03/06/..../18/21	+48h	3D-VAR	ECMWF/IFS	1h	
		MALI (38h1.2)	3	600 × 1080	65	00/03/06/..../18/21	+48h	3D-VAR	ECMWF/IFS	1h	
		VAR-test (36h1.4)	2.5	300 × 300	60	00/12/06/18	+24h +6h	3D-VAR	ECMWF/IFS	3h	at ECMWF
Norway	HIRLAM		12	864 × 698	60	00/06/12/18	+66h	3D-VAR fgat	ECMWF/IFS	3h	SGI ALTIX ICE X HPC
			8	344 × 555	60	00/06/12/18	+66h	3D-VAR fgat	ECMWF/IFS	3h	
	HARMONIE Arctic		2.5	800 × 900	65	00/12/06/18	+42h	none	ECMWF/IFS	3h	
	HARMONIE MetCoop		2.5	1875 × 2400	65	00/12/06/18	+66h	3D-VAR	ECMWF/IFS	3h	



D2.1 Report on Typology of Climate Related Hazards

Country	Model	Mesh size (km)	Number of gridpoints	Number of levels	Initial times & Forecast ranges (h)		Type of data assimilation	Model providing LBC data	LBC update interval (h)	Computer
Spain	HIRLAM	17	582 × 424	40	00/06/12/18	+72h	3D-VAR	ECMWF/IFS	6h	Cray X1e
		5.5	606 × 430	40	00/06/12/18	+36h	3D-VAR	ECMWF/IFS	6h	
	HARMONIE Aladin	11	384 × 400	40	00/06/12/18	+36h	3D-VAR	ECMWF/IFS	3h	
	HARMONIE Arome	2.5	576 × 480	65	00/06/12/18	+30h	only SFC analysis	ECMWF/IFS	1h	IBM @ ECMWF
Sweden	HIRLAM	11	606 × 606	60	00/06/12/18	+66h	4D-VAR	ECMWF/IFS	3h	Linux Cluster ClusterVision Intel Xeon E5-2640v3 (Sweden) + Linux Cluster SGI Intel Xeon E5-2670 (Norway)
		5.5	506 × 574	65	00/06/12/18	+48h	3D-VAR	ECMWF/IFS	3h	
	HARMONIE-Arome	2.5	750 × 960	65	00/06/12/18	+60h	3D-VAR-3h-RUC	ECMWF/IFS	3h	
Austria	ALARO	4.8	600 × 540	60	00/06/12/18	+72h	surface analysis (OI)	ECMWF/IFS	3h	SGI ICE-X
	AROME	2.5	600 × 432	90	00/03/06/09/12/15/18/21	+48h	surface OI upper-air 3D-Var	ECMWF/IFS	1h	
Belgium	ALARO	7	240 × 240	46	00/06/12/18	+60h	none	ARPEGE	3h	SGI Altix 4700
		4	192 × 192	46	00/06/12/18	+60h	none	ARPEGE	3h	
Bulgaria	ALADIN	7	180 × 144	70	06/18	+72h	none	ARPEGE	3h	Linux Cluster
Croatia	ALADIN	8	229 × 205	37	00/06/12/18	+72h	surface OI upper-air 3D-Var	ECMWF/IFS	3h	SGI UV 2000 38 Intel Xeon E5 6-core 2,9GHz CPUs with 228 cores 608GB RAM
	ALADIN	4	469 × 421	73	00	+72h	surface OI	ECMWF/IFS	3h	
Czech Rep.	ALARO	1	529 × 421	87	00/06/12/18	+54h	Blend Var (Digital filter blending + 3D-VAR)	ARPEGE	3h	NEC SX-9
France	ARPEGE	7.5- France 37- Antipode	global	105	00 06 12 18	+114h +72h +84h +60h	4D-VAR; 6h	-	-	BULL Intel Ivy Br.
	ALADIN-France-CEP	7.5	389 × 389	105	00 12	+54h +42h	Dynamical Adaptation coupled with IFS	ECMWF/IFS	3h	
	AROME-France	1.3	1440 × 1536	90	00/12 03 06/18 09/15/21	+42h +39h +36h +7h	3D-VAR	ARPEGE	1h	



D2.1 Report on Typology of Climate Related Hazards

Country	Model		Mesh size (km)	Number of gridpoints	Number of levels	Initial times & Forecast ranges (h)		Type of data assimilation	Model providing LBC data	LBC update interval (h)	Computer			
France Overseas	ALADIN	Réunion	8	489 × 799	70	00/12	+84h	3D-VAR	ARPEGE	3h				
		Polynesia		475 × 529		06/18	+54h		ECMWF/IFS					
		Caledonia		349 × 277										
		Ant. Guayana		501 × 439										
Hungary	ALARO		8	349 × 309	49	00 06 12 18	+54h +48h +48h +36h	3D-VAR	ECMWF/IFS	3h	IBM iDataPlex Cluster			
	AROME		2.5	490 × 310	60	00 06 12 18	+48h +36h +48h +36h	3D-VAR	ECMWF/IFS	1h				
Poland	ALARO		4	789 × 789	60	00/06/12 18	+66h +60h	none	ARPEGE	3h	Linux cluster (194xIntel Xeon E5-2690 CPUs)			
	AROME		2.55	637 × 637	60	00/06/12/18	+30h	none	ALARO (4km)	1h				
Portugal	ALADIN		9	277 × 439	46	00/12	+72h	none	ARPEGE	3h	IBM Power7+ (8+1 nodes)			
	AROME	Mainland	2.5	540 × 480	46	00/12	+48h	none	ARPEGE	3h				
		Azores	2.5	259 × 349	46	00/12	+48h	none	ARPEGE	3h				
		Madeira	2.5	189 × 181	46	00/12	+48h	none	ARPEGE	3h				
Romania	ALADIN		6.5	240 × 240	60	00 06 12 18	+78h +54h +66h +54h	none	ARPEGE	3h	IBM Linux Cluster			
Slovakia	ALADIN		4.5	625 × 576	63	00 06/18 12	+78h +36h +72h	upper-air digital filter blending CANARI surface analysis	ARPEGE	3h	IBM p755 10 nodes			
Slovenia	ALADIN		4.4	421 × 421	87	00/06/12/18 03/09/15/21	+72h +36h	surface OI, 3DVAR, 3h RUC	ECMWF/IFS	3h	SGI Altix ICE 8200			
Turkey	ALARO		4.5	439 × 705	60	12 00/06/18	+60h +72h	none	ARPEGE	3h	SGI Altix 4700			
	AROME		2.5	501 × 989	60	00	+48h	none	ARPEGE	3h	SGI UV2000			



D2.1 Report on Typology of Climate Related Hazards

Country	Model		Mesh size (km)	Number of gridpoints	Number of levels	Initial times & Forecast ranges (h)		Type of data assimilation	Model providing LBC data	LBC update interval (h)	Computer
Germany	ICON ¹²		13	global	90	00/12 06/18	+180h +120h	3D-VAR, 3h	-	-	Cray XC30/40
	COSMO	EU	7	665 × 657	40	00/12/06/18	+78h	Nudging	GME	1h	
		DE	2.8	421 × 461	50	00/03/06/.../18/21	+27h	Nudging	COSMO-EU	1h	
Greece	COSMO	GR7	7	649 × 393	60	00/12	+72h	none	ECMWF/IFS	3h	IBM @ ECMWF
		GR2	2.8	501 × 401	60	00/12	+48h	none	COSMO-GR	1h	
Italy	HRM		10	577 × 347	40	Ensemble FG	+9h	LETKF, 6h	ECMWF/IFS	3h	IBM @ ECMWF
	COSMO	ME	7	779 × 401	40	00/12	+78h	LETKF (interp)	ECMWF/IFS	3h	HP Linux Cluster
		IT	2.8	542 × 604	50	00/12	+24h	Nudging	COSMO-ME	1h	
		I7	7	297 × 313	40	00/12	+72h	Nudging	ECMWF/IFS	3h	plx Linux Cluster
		I2	2.8	447 × 532	45	00/12	+48h	Nudging	COSMO-I7	1h	
Poland	COSMO	PL14	14	193 × 161	35	00/12	+78h	none	ICON	3h	HP Xeon Cluster
		PL7	7	385 × 321	40	00/12 06/18	+78h +48h	Nudging	ICON	3h	
		PL2	2.8	285 × 255	50	00/12	+36h	none	COSMO-PL7	3h	
Romania	COSMO	RO7	7	201 × 177	40	00/12	+78h	Nudging	GME	3h	IBM Cluster (Blade Server)
		RO2	2.8	361 × 291	50	00	+30h	none	COSMO-RO7	1h	
Russia	Global		70	global	31	00/12	+174h	3D-VAR, 6h	-	-	SGI Altix 4700 SGI ICE 8200
	COSMO	RU-SIB	14	360 × 250	40	00/12 06/18	+78h +48h	none	GME	3h	
		RU7	7	700 × 620	40	00/12 06/18	+78h +48h	Nudging	GME	3h	
		RU2 Moscow	2.2	420 × 470	50	00/06/12/18	+24h	Nudging	COSMO-RU7	1h	
		RU2 Sochi	2.2	420 × 470	50	00/06/12/18	+24h	Nudging	COSMO-RU7	1h	
Switzerland	COSMO	7	6.6	393 × 338	60	00/06/12	+72h	Nudging	ECMWF/IFS	1h	CRAY XE6



D2.1 Report on Typology of Climate Related Hazards

Country	Model		Mesh size (km)	Number of gridpoints	Number of levels	Initial times & Forecast ranges (h)		Type of data assimilation	Model providing LBC data	LBC update interval (h)	Computer
		2	2.2	520 × 350	60	03 00/06/09/12/15/18/21	+45h +33h	Nudging	COSMO-7	1h	
United Kingdom	UM		25	global	70 (top 80km)	00/12 06/18	+144h +48h	4D-VAR	-	-	IBM P7
		NAE ¹³	12	600 × 360	70 (top 80km)	00/06/12/18	+48h	4D-VAR	UM (Global)	3h	
		UK4	4	360 × 288	70 (top 40km)	03/09/15/21	+36h	3D-VAR	UM (Global)	1h	
		Downscaler ¹⁴	4	360 × 288	70 (top 40km)	00/12 06/18	+120h +60h	none	UM (Global)	3h	
		UKV	1.5	744 × 928	70 (top 40km)	00/03/06/.../18/21	+36h	3D-VAR	UM (Global)	1h	

¹³ Model is retired, just as UK4 is.

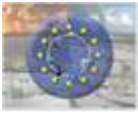
¹⁴ Model is superseded by UKV in many applications.



D2.1 Report on Typology of Climate Related Hazards

Country	Model	Mesh size (km)	Number of gridpoints	Number of levels	Initial times & Forecast ranges (h)		Type of data assimilation	Model providing LBC data	LBC update interval (h)	Computer
Bosnia-Herzegovina	HRM	14	161 × 161	40	00/12	+72h	none	GME	3h	Linux PC
	WRF-NMM	D1	30	74 × 98	35	00	+48h	none	NCEP/GFS(0.5deg)	3h
		D2	10	40 × 58	35	00	+48h	Nudging	WRF-NMM(D1)	1h
	WRF-ARW	D1	18	100 × 68	35	00	+72h	none	NCEP/GFS(0.5deg)	3h
		D2	6	58 × 61	35	00	+72h	Nudging	WRF-ARW(D1)	1h
Montenegro	NMM-HIRES	7	100 × 151	38	00/12	+96h	none	ECMWF/GFS	3h	Linux Cluster (32 node)
	WRF-NMM	12	196 × 216	38	00	+144h	none	ECMWF/GFS	3h	Linux PC (4 core)
		5	110 × 170	40	00/12	+144h	none	ECMWF/GFS	3h	
		1	100 × 250	60	00/12	+144h	none	WRF-NMM (5 km)	3h	
		10	100 × 170	40	00/12	+120h	none	NCEP/GFS (0.5deg)	3h	
		5	110 × 170	40	00/12	+120h	none	WRF-NMM (10 km)	3h	
Serbia	ETA	26	145 × 241	32	00/12	+120h	none	GME	6h	Linux PC
	WRF-NMM	4	220 × 290	45	00/12	+72h	none	ECMWF/IFS	3h	HP XC 256 Xeon
		12	260 × 500	38	00/12	+120h	none	GME	3h	HP XC 128 Xeon
		12	260 × 500	38	00/12	+120h	none	GFS	3h	
	NMMB	30	global	64	00	+216h	none	none (global)	-	HP Proliant DL380 G7, 384 Intel Xeon
		10	394 × 326	64	00	+120h	none	NMMB global	3h	
Cyprus	WRF-ARW	2	88 × 55	37	00/12	+120h	none	NCEP/GFS	3h	IBM iDataPlex dx360 M3 (Cyprus Institute Cy-Tera HPC Facility)
ECMWF	IFS ¹⁵	16	global	137	00/12 06/18	+240h +90h	4D-VAR; using error estimates from EDA	-	-	IBM/CRAY

¹⁵ Model is updated. Some of the changes are mentioned within subchapter 3.2.1.1, for more details check the IFS model official web site.



4.3 Overview of probabilistic NWP systems

In order to obtain perfect weather forecast we would need precise knowledge of every process in the atmosphere and this knowledge should be perfectly implemented into the forecasting system. However, set of prognostic equations used to obtain deterministic weather forecast represents only an approximation of the actual state of the atmosphere. Measurements, which quantify the initial state of atmosphere and are the first step towards the weather forecast, are neither perfect nor complete. Hence, every single forecast is, to some extent, uncertain. As atmosphere is chaotic system, small uncertainties in initial conditions (IC) can result in large errors in the prediction, especially with the growth of forecast time. For the purpose of assessment of forecast confidence due to imperfect IC, Ensemble Prediction Systems (EPS) were developed. EPSes are composed of large number of deterministic forecasts, where each of these forecasts (ensemble members) is based on a slightly different, but realistic, configuration of the IC. Typically, the EPS members move apart with increasing forecast time. They convey an idea of the predictability of weather conditions, and provide the basis for probabilistic forecasts.

Although they are usually based on simplified deterministic forecasts with coarser grid spacing, EPSes are computationally very expensive and each member state of specific consortia cannot afford to run them. Hence, they are usually limited to one EPS based on global deterministic model forecasts per consortia plus one or more EPSes based on regional deterministic model forecasts (Table 3.2).

4.3.1 ECMWF VAR-EPS

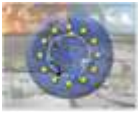
ECMWF was among pioneers in the development of the EPS. Their first EPS became operational in 1992. In 2008, ECMWF EPS was merged with the monthly prediction system and has been coupled to a dynamical ocean model. Since then it has been producing 15-day probabilistic forecasts initialized at 00 and 12UTC each day. Currently operational EPS probabilistic forecast is based on 52 integrations at approximately 18 km horizontal grid spacing up to forecast day 10 and 36 km thereafter. Vertical resolution is also coarser compared to the deterministic model, as here they have only 92 levels (Table 3.2).

One of the EPS members is at a higher spatial resolution than the other members (HRES). Its initial state is the most accurate estimate of the current conditions and it uses the currently best description of the model physics. Averaged over many forecasts HRES is the most accurate forecast for a certain period, which is currently estimated as 10 days for large-scale properties of the atmosphere. However, for any particular forecast it may not be the most skilful member of the EPS. ECMWF VAR-EPS has one more specific member (CNTL, i.e. control forecast) which is at a lower spatial resolution than the HRES, but at that specific resolution it utilises the most accurate estimate of the weather conditions and the currently best description of the model physics. Its significance for the EPS is that it provides the unperturbed member to which the perturbations for the remainder of the ensemble members are applied. The perturbed members (50 of them) are similar to the CNTL, but their initial states and model physics have been perturbed to explore the currently understood range of uncertainty in the observations and the model. When averaged over many forecasts, they have lower skill than HRES or CNTL (not valid for any single forecast). However, they do provide an estimate of the forecast uncertainty or confidence. For more information about ECMWF VAR-EPS and detailed list of available probabilistic outputs, please check official ECMWF web page.

4.3.2 PEARP (ARPEGE EPS), ALADIN-LAEF and ALARO-EPS

Within the ALADIN consortia some weather centres or minor sub-groups have developed and operationally use their own EPSes based either on global or regional models. Brief overview is given in the following paragraphs.

PEARP (Prévision d'Ensemble ARPEGE) is a global short-range 35 member (34 plus control) EPS developed at Météo-France and operationally used since 2004. It is run twice daily (06 and 18 UTC) and produces



probabilistic forecast with forecast range up to 108 hours (72 hours for 06 UTC run). PEARP uses almost the same configuration of the operational deterministic global numerical weather prediction model ARPEGE. The main difference is in slightly coarser horizontal grid spacing and reduced number of vertical levels. Perturbations to the ICs are computed by combining an Ensemble Data Assimilation (EDA) system with singular vectors. Singular vectors are computed over seven different areas around the globe, with different optimization times and norms. **Model uncertainties are represented through a 'multi-physics' approach with the set of 10 different physical parameterizations.**

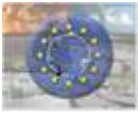
ALADN-LAEF (Aire Limitée Adaptation Dynamique Développement InterNational – Limited Area Ensemble Forecasting) is an EPS developed within the framework of the international cooperation of LACE (Limited Area modelling in Central Europe). The main goal of ALADIN-LAEF is to add value to probabilistic mesoscale short-range forecasts compared to global ensemble systems. It is running operationally from 2009 and produces probabilistic forecast twice daily (00 and 12 UTC) on a grid with horizontal spacing of 11 km and with 45 vertical levels. Integration is performed over 72 hours forecast range for totally 17 EPS members (16 plus control driven by ECMWF VAR-EPS control run). The 16 perturbed members differ in their IC, LBC (interpolated from first 16 ECMWF VAR-EPS members) and in the ALADIN model configuration. Generation of initial perturbations for the ALADIN-LAEF is done separately for upper level and surface fields. For the initial perturbation of upper level fields, so-called Breeding-Blending method is used. It combines large scale perturbations from ECMWF VAR-EPS with small scale perturbations from 12h forecasts from the previous ALADIN-LAEF forecasts by using the digital filtering method. The surface initial perturbations are generated from 12h forecast of ALADIN-LAEF, where in the initial fields ECMWF-EPS surface fields are exchanged with the current ARPEGE analysis. To account for model uncertainties every forecast-integration uses a different ALADIN configuration. The configurations differ in ALADIN model cycles and different combinations of parameterization schemes including: radiation, turbulent diffusion, cloud physics, deep convection and shallow convection. The results of ALADIN-LAEF are archived in the MARS-archiving system at ECMWF with an output frequency of one hour.

Hungarian Meteorological Service (HMS) developed EPS based on the hydrostatic version of ALARO model which produces probabilistic forecasts once daily (18 UTC) on a grid with horizontal spacing of 8 km and with 49 vertical levels. Forecast covers entire central Europe, as well as some parts of eastern and southern Europe. The system is based on a simple dynamical downscaling of first 11 members from PEARP EPS, i.e. there is no generation of local perturbations or data assimilation. Integration with ALARO model is performed through 60 hours forecasting range, with LBCs update interval of 6 hours. Operationally available products include majority of surface parameters, as well as vertical profiles (both at model and standard pressure levels) of temperature, geopotential, wind and relative humidity.

Besides above mentioned EPSes used within the ALADIN consortia, Météo-France is working on the development of convection-permitting EPS based on the AROME-France model. Current experimental setup of AROME-EPS includes 12 members. Integration is performed twice daily (09 and 21 UTC) through the forecast range of 45 hours. Perturbations of initial conditions include uncertainty due to: IC, LBC, surface conditions and the model (Stochastic Perturbation of Physics Tendencies - SPPT). LBCs are provided from PEARP EPS by selection process based on the clustering algorithm. It is expected that the AROME-EPS will be operational by the end of 2016. For more details on ALADIN consortium EPSes please check its official web site.

4.3.3 LAMEPS, HIRLAM-E05 and MMSREPS

Within the HIRLAM consortia, some of the member countries develop regional, short-scale targeted EPSes. Namely, these are: (i) LAMEPS (Limited Area Model Ensemble Prediction System) of Norwegian Meteorological Institute (NMI), (ii) HIRLAM-E05 of Danish Meteorological Institute (DMI) and (iii) MMSREPS (Multi-model-Multi-boundaries Short Range Ensemble Prediction System) of Spanish Meteorological Institute (SMI).



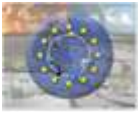
LAMEPS is a regional short-scale targeted EPS run with the Norwegian version of the HIRLAM model at 12 km horizontal grid spacing, with 60 vertical levels. It is driven by members of the ECMWF VAR-EPS which are targeted to produce maximum spread among ensemble members after 48 hours in the northern Europe and adjacent sea (Targeted EPS or TEPS). A multi-model EPS (NORLAMEPS) is also produced by combining all LAMEPS and TEPS members simultaneously. Even though the combined system is to some extent an auto-duplication, the ensemble spread is larger for two reasons: (i) there are uncorrelated differences between fields from the different models and (ii) the LAMEPS control forecast with HIRLAM can deviate considerably from the TEPS control with the ECMWF. TEPS uses the same model version and the same setup as used for the operational EPS at ECMWF. Only 20 ensemble members plus the control one are computed opposed to 52 for ECMWF VAR-EPS. The TEPS forecast length is 96 hours and it is run on ECMWF computer once daily at 12 UTC. LAMEPS is produced by applying 21 TEPS ensemble members both as LBCs (every 3 hours) and to perturb the IC for the limited-area model. The LAMEPS initial perturbations are the TEPS perturbations (difference between TEPS control and individual members) valid at forecast lead time increased by 6h. The LAMEPS control run is made from the HIRLAM 3D-Var analysis valid at 06 and 18 UTC and its forecast length is 60 hours. When interpreting the results of joint NORLAMEPS system, one has to keep in mind that its two sets of members (TEPS and LAMEPS) are not fully independent, and the model differences probably underestimate the actual model uncertainties.

HIRLAM-E05 is a 25 member high resolution limited-area EPS developed at DMI. Its members combine 5 different IC, 2 different clouds schemes, stochastic physics and perturbed roughness lengths for selected vegetation types. EPS members are obtained from S05 model, which is slightly modified version of deterministic K05 configuration. Small-scale S05 model (covers northern and western Europe) is nested into large-scale T15 HIRLAM model (covers large part of northern hemisphere), which is nested into global IFS model. T15 model is run from 3D-Var analysis, while S05 uses T15 analysis interpolated to the S05 grid with additional surface analysis used as a first guess. Model is initialized four times daily (00, 06, 12 and 18 UTC) and integrated through 36 hours forecasting period. LBCs are updated every 3 hours. Perturbations of IC are obtained by using so-called Scaled Lagged Average Forecasts method (SLAF), i.e. old forecasts of small-scale model are rather used than current forecasts from the larger-scale EPS. The basis of SLAF method is scaling of forecast error (difference between old forecast and recent analysis) in a way that relatively large forecast errors of older forecasts are damped more than relatively small forecast errors of recent forecasts. Perturbations of LBCs are obtained similarly as for IC, while physics stochastics is taken from ECMWF.

MMSREPS is a regional, short-scale targeted EPS which uses a Multi-model Multi-boundaries (MM) technique. MM technique consists of running several numerical models initialized with several different global models. Five different models which are run within MMSREPS are: HIRLAM, HRM (High resolution Regional Model) from DWD, MM5 (Mesoscale Model version 5) from Penn State University, MetUM and COSMO. LBCs and ICs are taken from four different deterministic global models: IFS, MetUM, GFS of NCEP (National Centers for Environmental Prediction) and GME. MMSREPS is consisted of 72 hours long forecasts from five numerical models, mixed with ICs and LBCs from four global models. The integration process is repeated four times daily (00, 06, 12 and 18 UTC) in order to build an 80 member super-ensemble. MMSREPS based probabilistic forecasts are obtained from four closest 20 member ensembles (constitute one super-ensemble) two times daily (00 and 12 UTC). SMI is currently developing new convection permitting EPS named g-SREPS which should replace MMSREPS and produce probabilistic forecasts at 2.5 km horizontal grid spacing. It will be based on integration of HARMONIE and WRF models four times daily (00, 06, 12 and 18 UTC) with ICs and LBCs from a bit changed set of global models compared to MMSREPS. For more details on HIRLAM consortia EPSes you may check its official web page.

4.3.4 COSMO-DE-EPS and COSMO-LEPS

Within the framework of COSMO consortium there are currently two groups which develop EPS based forecasts. DWD develops COSMO-DE-EPS, while ARPA-SIMC from Bologna develops COSMO-LEPS. COSMO-DE-EPS is a 20 member EPS based on the regional NWP model COSMO-DE, with horizontal grid spacing of



2.8 km and 50 vertical levels. It is operationally used since 2012. The forecast range of COSMO-DE-EPS is 27 hours, starting every 3 hours. This rapid update cycle allows for the frequent use of the most recent radar observations in the data assimilation, which is essential for the short-range forecast of precipitation. The LBCs for COSMO-DE-EPS are provided by BCEPS (Boundary Condition EPS), which is a multi-model approach based on forecasts of four global models (IFS, ICON, GFS, and GSM of Japanese Meteorological Agency (JMA)). The uncertainty in the ICs is estimated using BCEPS as well, i.e. the forecasts of the global models valid at the start time of COSMO-DE-EPS provide perturbations to the operational COSMO-DE analysis. The model uncertainty is quantified by different configurations of the standard parametrization schemes and by perturbations in the soil moisture.

COSMO-LEPS is a Limited-area Ensemble Prediction System developed by ARPA-SIMC in order to improve the short-to-medium range forecast of extreme and localised weather events. It is made up of 16 integrations of COSMO model, which is nested on selected members of ECMWF VAR-EPS. Selection process includes clustering of similar global EPS members and selection of representative member of each group. It is assumed herein that the majority of information from global EPS will be retained, while the number of LAM integrations will be significantly reduced. COSMO-LEPS is currently running twice daily (00 and 12 UTC) on a grid with 7 km horizontal spacing and 40 vertical levels. It provides forecast for central and southern Europe with 132 hours forecast range. Detailed list of its products can be seen at official COSMO web page.

Besides above mentioned EPS systems, DWD currently prepares its global EPS system based on the ICON model. ICON-EPS should cover entire globe with 72-hours forecast range. Moreover, it will provide additional boundary conditions for the high resolution COSMO-DE-EPS. The ICON ensemble is planned to be operational in 2017. Major scientific goals are to construct fast-growing perturbations based on analysis ensembles from EDA, and the simulation of model error using dynamically consistent perturbations of model tendencies.

4.3.5 UKMO MOGREPS

The Met Office Global and Regional Ensemble Prediction System (MOGREPS) is a 24 member EPS designed specifically for a short-range weather forecasting. It focuses on aiding the forecasting of rapid storm development, wind, rain, snow and fog. The global ensemble (MOGREPS-G) produces forecasts for the entire globe for a period up to one week (extended from previous 72 hours when horizontal grid spacing was around 60 km) and its outputs are used as LBCs for the regional ensemble (MOGREPS-UK). The regional ensemble produces forecasts for an area covering the UK for the next 36 hours. In the UK ensemble the model parameters (temperature, pressure, wind, humidity, etc.) are forecasted at model grid with 2.2 km horizontal spacing and on 70 vertical levels. The UK ensemble covers a limited area, so the global ensemble provides information on the weather entering the UK model domain through the boundaries. Because the global ensemble covers a much larger area, it is run at a lower resolution with grid points separated by about 33 km. Both global and regional EPSes are run four times daily, starting from 00 UTC for global EPS and from 03 UTC for regional EPS. Until recently, UKMO also produced another version of regional EPS which covered entire North Atlantic region on a grid where adjacent grid points were separated by about 18 km (MOGREPS-R).

Initial condition perturbations for MOGREPS EPS are calculated using the Ensemble Transform Kalman Filter (ETKF). The perturbations are rescaled to ensure they are consistent with forecast errors using a variable inflation factor. The ETKF produces a set of perturbations which are added to the Met Office 4D-Var analysis to provide the initial state for ensemble members. For more details on MOGREPS EPS please check Met-Office official web page.



D2.1 Report on Typology of Climate Related Hazards

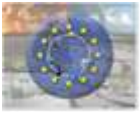
Table 3.2: Overview of probabilistic prediction systems in Europe as listed in EUMETNET (as of Dec 2015)

Country	Model	Mesh size (km)	Number of gridpoints	Number of levels	Initial times & Forecast ranges (h)		Type of data assimilation	Model providing LBC data	LBC update interval (h)	Number of EPS members
Denmark	HIRLAM-E05	5	496 × 372	40	00/06/12/18	+??h	SLAF, stoch. Physics; 2 physics packages	ECMWF	3h	25
Norway	LAMEPS / HIRLAM	12	232 × 371	60	06/18	+60h	EDA perturbations + initial ECMWF EPS SVs	ECMWF EPS	3h	20 + 1
Spain	HIRLAM, HRM, COSMO, MM5, UM	28	366 × 272	40	00/12	+72h	Downscaling of ECMWF GFS, GME, UM, CMC	ECMWF, GFS, GME, UM, CMC	3h	25
Austria (for ALADIN/LACE)	ALADIN-LAEF	11	600 × 500	45	00/12	+72h	Blending ECMWF SV and ALADIN Breeding Ensemble Land Surface Analysis	ECMWF EPS	6h	16+1
France	PEARP (ARPEGE EPS)	10 - France 60 - Antipode	global	90	06/18	+90h +108h	SV initial perturbation; coupling with global ensemble D.A.	-	-	35
Hungary (for ALADIN)	ALARO	8	349 × 309	49	18	+60h	SV initial perturbation in PEARP	PEARP	6h	10+1
Germany	COSMO-DE-EPS	2.8	421 × 461	50	00/03/06/.../18/21	+27h	IC from deterministic COSMO-DE perturbed by data from BCEPS	Boundary Condition EPS	1h	20
Italy (for COSMO)	COSMO-LEPS	7	511 × 415	40	00/12	+132h	Interpolation from ECMWF EPS + soil analysis fields from COSMO_EU	ECMWF EPS	3h	16
United Kingdom	MOGREPS-G ¹⁶	60	432 × 325	70	00/06/12/18	+72h	Local ETKF	-	-	24 (lagged)
	MOGREPS-R ¹⁷	18	400 × 240	70	00/06/12/18	+54h	Downscaled MOGREPS-G	MOGREPS-G	3h	24 (lagged)
	MOGREPS-UK	2.2	532 × 654	70	03/09/15/21	+36h	Downscaled MOGREPS-R	MOGREPS-R	1h	24 (lagged)
ECMWF	IFS VAR-EPS ¹⁸	31	TL639 (d0 - d10)	62	00/12	+360h	SV initial perturbation + Ensemble Data Assimilation	-	-	50+1
		62	TL319 (d10 - d15)							

¹⁶ Horizontal grid spacing of individual members is refined to around 33 km, i.e. total number of grid points is increased to 800 x 600. Forecast range is increased to 168 hours.

¹⁷ This part of MOGREPS system is not produced anymore.

¹⁸ In fact, the number of EPS members is not 50+1, but 50+2. Horizontal and vertical resolution have been improved too (follow the text in subchapter 3.2.4.).



4.4 Overview of output data formats

Each weather forecast service stores its real-time and historic NWP data in a predefined data format over the area of interest typically a domain of the model integration. NWP data having spatial coverage over a certain domain of interest (e.g. used for spatial analysis, mapping etc.) in Europe may be typically available in the following formats:

- (1) GRIB
- (2) NetCDF
- (3) FA

The formats of NWP spatial data are described in the sections below.

For point based forecasts, many other formats are available (.csv, xml, ascii). Formats for point based forecasts will not be described here further.

4.4.1 GRIB

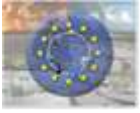
GRIB (GRIdded Binary or General Regularly-distributed Information in Binary form) is a concise data format used for storage and transport of gridded meteorological data, such as those from NWP or climate models. It is designed to be self-describing, compact and portable across computer architectures, which is facilitated by the fact that the size of GRIB files is typically 1/2 to 1/3 of the size of normal binary files (floats). The GRIB standard was designed and maintained by the WMO^[A]. A GRIB file contains one or more data records, arranged as a sequential bit stream. Each record begins with a header, followed by packed binary data. The header is composed of unsigned 8-bit numbers (octets). It contains information about: (i) the qualitative nature of the data (field, level, date of production, forecast valid time, etc.), (ii) the header itself (meta-information on header length, header byte usage, presence of optional sub-headers), (iii) the method and parameters to be used to decode the packed data, and (iv) the layout and geographical characteristics of the grid the data is to be plotted on.

Over the years, the WMO issued three editions of the GRIB standard: GRIB0, GRIB1 and GRIB2. GRIB0 was used to a limited extent by some projects, but now is outdated, unsupported and very rarely used. GRIB1 is used operationally worldwide by most meteorological centers for NWP outputs. Its future development is suspended, and there is a medium term plan to replace it completely by newer and advanced GRIB2 format. Unlike GRIB1 which needs separate parameter table to unpack the data, GRIB2 improves upon the standard with the compression and the inclusion of mentioned parameter table. Compression is ensured by using the same compression software used for images which gains in a roughly 50% reduction in file size over GRIB1.

4.4.2 NetCDF

NetCDF (Network Common Data Form) is a file format designed to support the creation, access, and sharing of array-oriented scientific data in a form that is self-describing (contains information defining the data within the file) and portable (data are in the form which can be accessed by computers with different ways of storing integers, characters, and floating-point numbers)^[B]. It is used extensively in the atmospheric and oceanographic communities to store variables, such as temperature, pressure, wind speed, etc. Array values may be accessed directly, without knowing the details of how the data are stored. Auxiliary information about the data, such as what units are used, may be stored with the data. Generic utilities and application programs can access netCDF datasets and transform, combine, analyse, or display specified fields of the data. The development of such applications has led to improved accessibility of data and improved re-usability of software for array-oriented data management, analysis, and display. NetCDF format was developed and is updated by the Unidata program at the University Corporation for Atmospheric Research (UCAR).

Until version 3.6.0, all versions of netCDF employed only one binary data format, now referred to as netCDF classic format. In version 3.6.0 a new binary format was introduced, 64-bit offset format. Nearly identical to



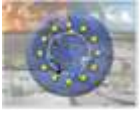
netCDF classic format, it uses 64-bit offsets, and allows users to create far larger datasets. In version 4.0.0 a third binary format was introduced, so-called HDF5 format. Starting with this version, the netCDF library can use HDF5 files as its base format. By default, netCDF uses the classic format. In order to use the 64-bit offset or netCDF-4/HDF5 format, one has to set the appropriate constant when creating the file.

4.4.3 FA

FA (Fichier ARPEGE) files are type of NWP output files used within the ALADIN and HIRLAM consortium. Essentially they are very similar to GRIB files, i.e. may be consisted of either grid-point data or spectral coefficients and can be compressed or uncompressed. Major difference between those two types of files is in fact that FA files cannot be split in multiple files each of whom would contain only one field with its own header. For more details look in [C]

Appendices

- A) WMO Code Form FM 92-IX Ext. GRIB (<http://www.wmo.int/pages/prog/www/WDM/Guides/Guide-binary-2.html>)
- B) NetCDF Users Guide (http://www.unidata.ucar.edu/software/netcdf/docs/user_guide.html)
- C) A Guide to the FA file format (<http://www.cnrm-game-meteo.fr/gmapdoc/spip.php?article42>)



5 Hydrological cycle and hydrological parameters

Hydrology has been a subject of investigation and engineering for millennia. Since the 1950s, hydrology has been approached with a more theoretical basis than in the past, facilitated by advances in the physical understanding of hydrological processes and by the advent of computers and especially [geographic information systems](#) (GIS).

The central theme of hydrology is that water circulates throughout the [Earth](#) through different pathways and at different rates. The most vivid image of this is in the evaporation of water from the ocean, which forms clouds. These clouds drift over the land and produce rain. The rainwater flows into lakes, rivers, or aquifers. The water in lakes, rivers, and aquifers then either evaporates back to the atmosphere or eventually flows back to the ocean, completing a cycle. Water changes its state of being several times throughout this cycle.

The areas of research within hydrology are concerning the movement of water between its various states, or within a given state, or simply quantifying the amounts in these states in a given region. Parts of hydrology are developing methods for directly measuring these flows or amounts of water, while others are modeling these processes either for scientific knowledge or for making prediction in practical applications.

The hydrology is also very sensitive to modification (climate change and anthropic modifications). Both influence it through different parameters.

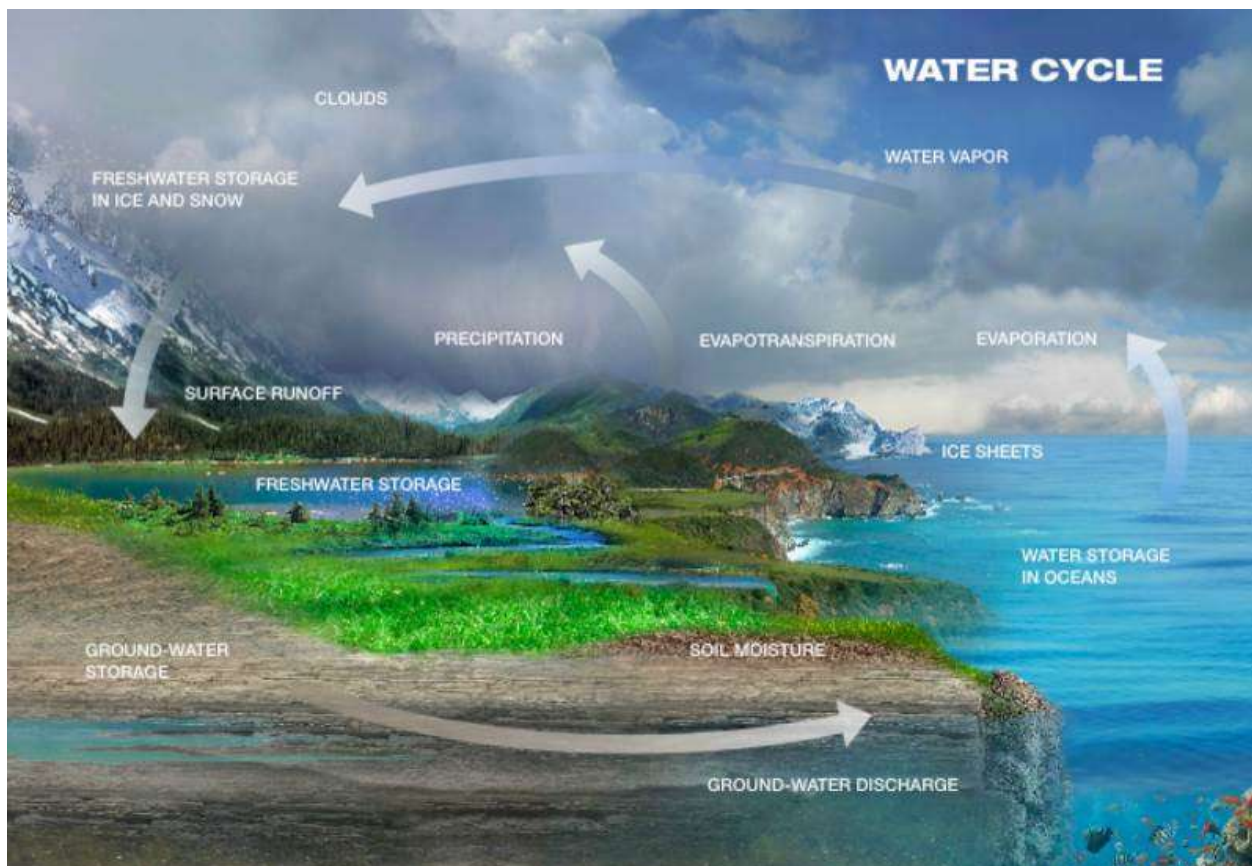


Figure 4.1 Water cycle. Based on <http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA18056>



D2.1 Report on Typology of Climate Related Hazards

	Hydrological parameters	Unit
1	Rainfall	mm
2	Evaporation and evapotranspiration	mm
3	River water level	m
4	River water speed	m/s
5	River discharge	m ³ /s
6	Water content in groundwater	m ³ or % or mm
7	Soil water content	% or g/cm ³ or m ³ /m ³
8	Water content in snow and ice	m ² (surface), m ³ or m ³ /s
9	Temperature of the surface water	°C
10	Watershed information (land use, soil types, landscape, rugosity, etc.) : 2D information	M and m ²
11	Topography (or bathymetry): 3D information	m



5.1 Rainfall

Key elements

Definition

The amount of water [falling](#) in [rain](#), snow, etc., within a given time and area.

Links with the climate change impacts

Changes in rainfall and other forms of precipitation will be one of the most critical factors determining the overall impact of [climate change](#). Rainfall is much more difficult to predict than temperature but there are some statements that scientists can make with confidence about the future.

A warmer atmosphere can hold more moisture, and globally water vapour increases by 7% for every degree centigrade of warming. How this will translate into changes in global precipitation is less clear cut but the total volume of precipitation is likely to increase by 1-2% per degree of warming.

There's evidence to show that regions that are already wet are likely to get wetter, but details on how much wetter and what impacts there will be on a local scale are more difficult to ascertain. The dry regions of the subtropics are likely to get drier and will shift towards the poles. For much of Europe, wetter winters are expected, but with drier summers over central and southern Europe.

It is the changes in weather patterns that make predicting rainfall particularly difficult. While different climate models are in broad agreement about future warming on a global scale, when it comes to predicting how these changes will impact weather – and consequently rainfall – there is less agreement at a detailed level.

It is likely that in a warmer climate heavy rainfall will increase and be produced by fewer more intense events. This could lead to longer dry spells and a higher risk of floods.

Data access

1. Meteorological service: provide data processed from in-situ measurements and model forecast information. This is good and high resolution data provided on regional areas. Radar observation data (Earth Observation data) can be added to improve the data.
2. Historical database of global data for average monthly rainfall from 1979 in the frame of GEWEX Global Precipitation Climatology Project (GPCP) from WRCP.
3. Projections of climate change effects on rainfall, using historical datasets and IPCC scenarios (RCP).
4. Two EU-CIRCLE partners – Meteorologisk Institutt (Norway) and Drzavni Hidrometeoroloski Zavod (Croatia) – have their own national rainfall databases.

The following platforms are providing information on (page bellow):



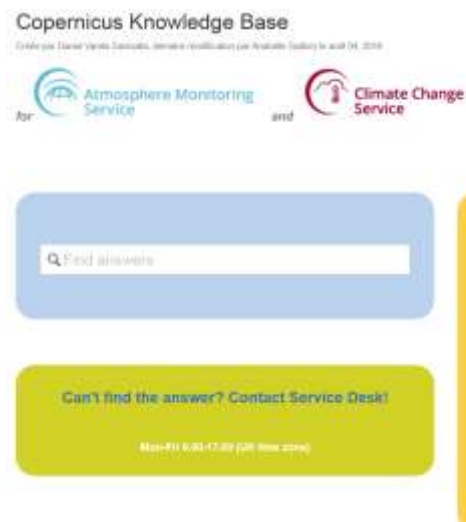
D2.1 Report on Typology of Climate Related Hazards

Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
French National Meteorological data platform	Meteo-France	mm	Precipitation	https://donneespubliques.meteofrance.fr/	French public meteorological data platform providing in situ and satellite data on precipitation parameters.	France			Hourly to annual
Earth2Observe (WCI portal)	Plymouth Marine Laboratory	mm	Various indicators	https://wci.earth2observe.eu/portal/	WCI portal is very user-friendly to find and visualize data: - Possibility to search data using different typologies (indicator type / data provider / region / interval / version / data type / etc.) - Possibility to produce a temporal graph to visualize a parameter evolution in a selecting geographic area.	World			
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	mm/d	Precipitation	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	For each 30-year analysis period, the available indicators for precipitation based on daily data are: - Mean: full period mean of all daily values. - Seasonality: expressed by the mean values of all Januaries, Februaries etc. that are part of the 30-year period. - Percentiles: 95th and 99th percentiles of all daily data in the 30-year period. - Variability: inter-annual variability of monthly mean values expressed as standard deviation of all monthly mean values that belong to the same month in the analysed period. - Daily: daily time series. This climate impact indicator is based on hydrological impact modelling performed within the EU FP7 project IMPACT2C (grant agreement 282746). The climate impact indicators are based on hydrological impact modelling using the hydrological model LISFLOOD.	European	Excel	5km	Projection of climate change effect on rainfall (RCP scenarios)
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	mm/d	Precipitation Intensity Maximum	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	The indicator "Precipitation Intensity Maximum" represents the average of all annual maximum hourly precipitation intensities within a period of 30 years.	European	Excel	Grid size: 650*390	Daily
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	mm / duration	Precipitation Intensity Duration	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	The Precipitation Intensity Duration indicator provides information about precipitation intensities at different levels of return periods (10, 50 and 100 year return period) and for different time resolutions (1, 2, 3, 6, 12 and 24 hourly data).	European	Excel	Grid size: 650*390	Depend of the duration
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	mm/d	Water runoff	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	Runoff is the sum of surface and subsurface runoff to streams for each grid cell. For each 30-year analysis period, the indicators for water runoff at catchment scale are: - Mean: full period mean of all daily values - Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period.	European	Excel	> Irregular catchment polygons, median catchment	Statistics over a long period (no temporal resolution)

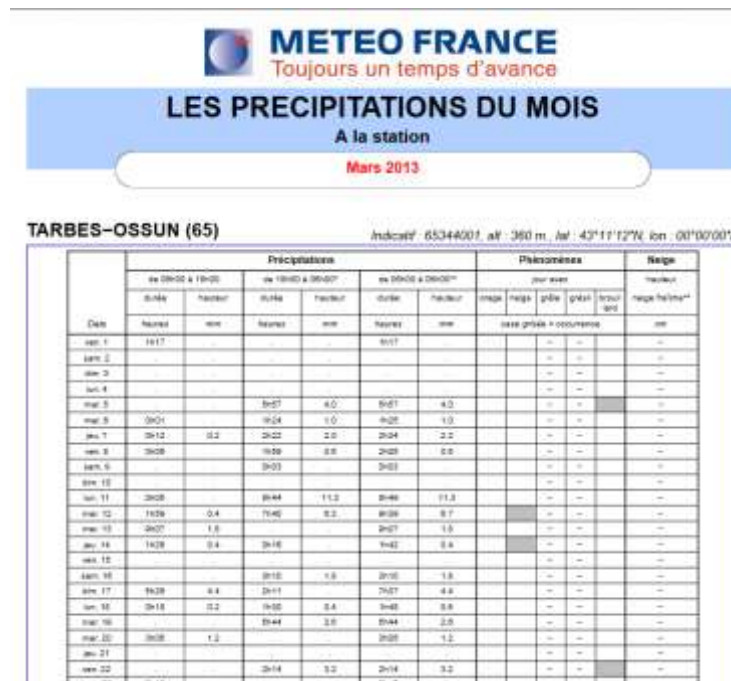


D2.1 Report on Typology of Climate Related Hazards

Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
								size 215km ² . > 0,5*0,5°	
JRC Water Portal	European Commission	mm/year	Annual precipitation for 1991-2010	http://water.jrc.ec.europa.eu/waterportal	Map shows the observed average annual precipitation between 1990 and 2010 obtained interpolation of the meteorological observations available at JRC.	European		5*5km	Annual
AQUAMAPS	FAO	mm/year	Global map of monthly precipitation - 10 arc minutes	http://www.fao.org/nr/water/aquamaps/	Grid with estimated precipitation per month with a spatial resolution of 10 arc minutes. This dataset has been constructed from 27 075 stations with 1961-1990 climatological normals. The dataset consists of 12 ASCII-grids with mean monthly data in mm/day * 10, and one ASCII-grid with yearly data in mm/year. In addition, 12 ASCII-grid with monthly values at 5 arc minutes resolution are made available as input data for a global water balance model (GlobWat).	Global		10 arc minutes	Monthly
EOSDIS	NASA		Various indicators and databases	https://search.earthdata.nasa.gov/	EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs. NASA network capabilities transport the EO data to the science operations facilities.	Global			



D2.1 Report on Typology of Climate Related Hazards



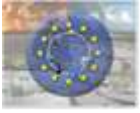
Copernicus Knowledge base relevant to download C3S (Copernicus Climate Change Service) data on rainfall (ERA5)

Data extraction from Meteo-France platform (monthly precipitation report for a meteorological station).

Limits and constraints

At the present time, the rainfall forecast from the satellite are not yet satisfactory for the numerical model at regional scale, as there are the only source of information for the ocean.

Program is in progress and their aims are to produce high resolution data (cf. The Program for the Evaluation of High Resolution Precipitation Products (PEHRPP)).



5.2 Evaporation and evapotranspiration

Key elements

Definitions

Evapotranspiration is the amount of total water transferred from the soil to the atmosphere through soil evaporation and plant transpiration.

It plays an important role in climates and microclimates, especially in cities. Very difficult to measure, it is the parameter that is generally lacking to complete a water balance.

For a given area (field, forest, region ...), we distinguish:

1. Potential evapotranspiration (PE): measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no control on water supply.
2. Actual evapotranspiration (AE): quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration.

As for rainfall measurement, the unit is the millimeter of water height: 1 mm corresponds to 1 liter per square meter or to 10 cubic meters per hectare. This amount of water is often referred to a time unit. Potential evapotranspiration or evaporation can reach 4-6 mm / day in summer in the European temperate zone and 6-8 mm / day in the Mediterranean zone.

Data use

1. Evapotranspiration measurements are important to understand the influence of vegetation cover on the water vapor content of the atmosphere and to estimate the growth rate of the plant.
2. Evaporation measurements make it possible to estimate the water losses of the surface water bodies.

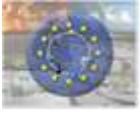
The ideal spatial resolution (if well measured) would be 1 / 10th of the size of the basin. The temporal resolution, for water resource studies, is daily (small watersheds).

Links with the climate change impacts

There are a whole host of factors that affect evapotranspiration:

Climate factors:

1. Temperature – As temperature increases, the rate of evapotranspiration increases. Evaporation increases because there is a higher amount of energy available to convert the liquid water to water vapor. Transpiration increases because at warmer temperatures plants open up their stomata and release more water vapor.
2. Humidity – If the air around the plant is too humid, the transpiration and evaporation rates drop. **It's the same reason sweat does not evaporate from our skin when it's too humid.**
3. Wind speed – If the air is moving, the rate of evaporation will increase. The wind will also clear the **air of any humidity produced by the plant's transpiration, so the plant will increase its rate of transpiration.**



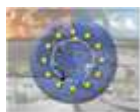
D2.1 Report on Typology of Climate Related Hazards

Hydrological factors:

1. Water availability – If the soil is dry and there is no standing water there will be no evaporation. If **plants can't get enough water they will conserve it instead of transpiring by closing their stoma.**
2. Soil type – Soil type determines how much water soil can hold and how easy it is for the water to be drawn out of it, either by a plant or by evaporation. For areas where the ground is covered by vegetation, the rate of transpiration is considerably higher than the rate of evaporation from the soil.

Plant type – Some plants, like **cacti and other succulents, naturally hold onto their water and don't** transpire as much. Trees and crops are on the other end of the spectrum and can release copious amounts of water vapor in a day.

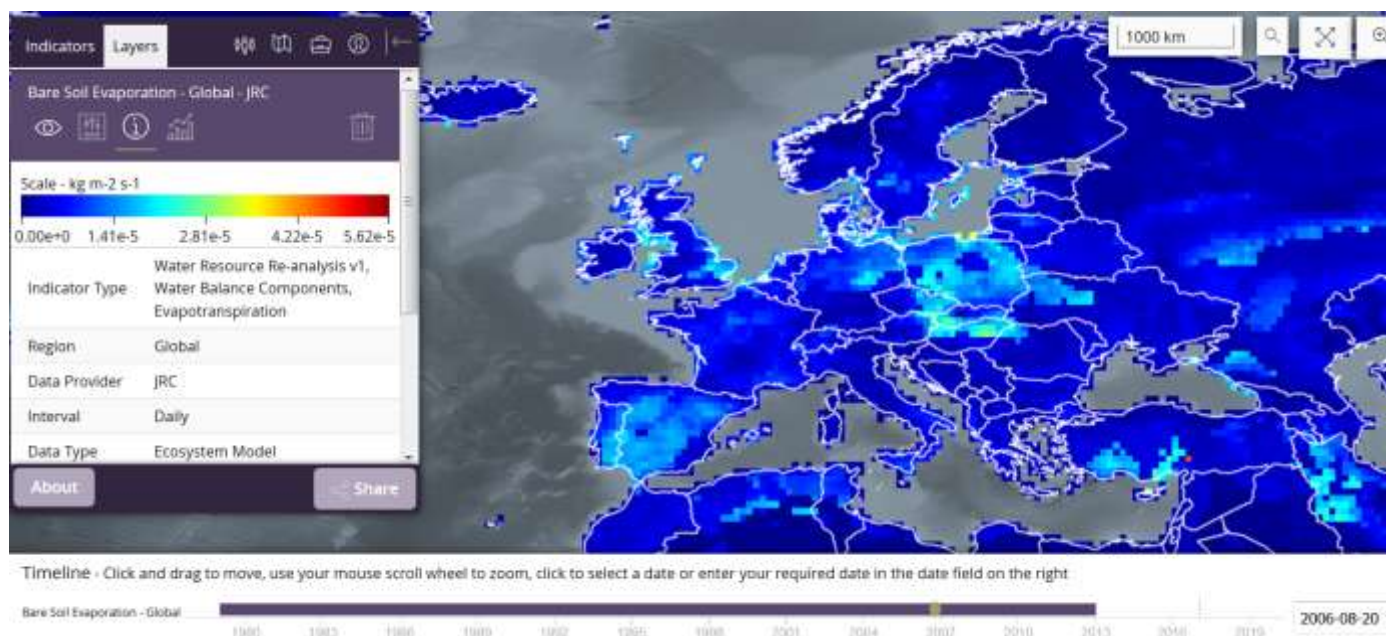
Climate change is thus affecting the evaporation and evapotranspiration processes with various impacts on agriculture, water resource availability, forest fires risks, etc.



D2.1 Report on Typology of Climate Related Hazards

Data access

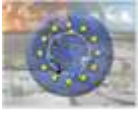
Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
Earth2Observe (WCI portal)	Plymouth Marine Laboratory	mm	Various indicators	https://wci.earth2observe.eu/portal/	WCI portal is very user-friendly to find and visualize data: . Possibility to search data using different typologies (indicator type / data provider / region / interval / version / data type / etc.) . Possibility to produce a temporal graph to visualize a parameter evolution in a selecting geographic area.	Global			
AQUAMAPS	FAO	mm/year	Global map of monthly reference evapotranspiration - 10 arc minutes	http://www.fao.org/nr/water/aquamaps/	Grid with estimated reference evapotranspiration per month with a spatial resolution of 10 arc minutes. The dataset contains mean monthly values for global land areas, excluding Antarctica, for the period 1961-1990. The dataset has been prepared according to the FAO Penman - Monteith method with limited climatic data as described in FAO Irrigation and Drainage Paper 56. The dataset consists of 12 ASCII-grids with mean monthly data in mm/day * 10, and one ASCII-grid with yearly data in mm/year.	Global		10 arc minutes	Monthly
EOSDIS	NASA		Various indicators and databases	https://search.earthdata.nasa.gov/	EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs. NASA network capabilities transport the EO data to the science operations facilities.	Global			



WCI platform (visualization of evapotranspiration parameter)

Limits and constraints

Evaporation and evapotranspiration are very complex parameters to measure. They are generally obtained by modeling, with large uncertainties, whereas these are key variables for the water cycle analysis.



5.3 River water level

Key elements

Definition

Measuring a water level (limnometry) or the variation of a water body is generally carried out discontinuously by reading a graduated scale (limnimetric scale)) fixed on a support on the river side. The limnigraph allows to follow the variations of a water body, providing a continuous recording of changes in water level as a function of time.

In addition to in-situ measurements, sometimes relayed by satellite, promising remote sensing techniques are already used. They are very expected in countries where implementing and maintenance of telemetry network are problematic.

Data use

- 1.** Water level for navigation.
- 2.** Water stocks management (lakes, reservoir...)
- 3.** Flood monitoring
- 4.** Drought monitoring.
- 5.** Biodiversity management
- 6.** Water level – discharge relations

Links with the climate change impacts

Lake and river levels reflect a balance between water inputs from precipitation and watershed runoff, and losses due to evaporation. Climate change is directly affecting these parameters (changing the precipitation regime; increasing temperatures and evaporation, etc.).



D2.1 Report on Typology of Climate Related Hazards

Data access

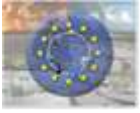
Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
French National Base HYDRO (Vigicrues network - Realtime datas)	SCHAPI	M	Water level	http://www.vigicrues.gouv.fr/	Real time database on water level and river discharge over 1 650 hydrological stations (French State monitoring). Each station have a reference code which allow everyone to download its data from four weeks ago.	National (France)	XML WMS / WFS		Hourly
French National database HYDRO (historical datas)	SCHAPI	M	Water level	http://www.hydro.eaufrance.fr/	The HYDRO database calculates for each hydrological station the instantaneous, daily, monthly and annual streamflows; based on the water height values and calibration curves (relationships between heights and flow rates). These data are regularly updated according to the information provided by the stations managers.	National (France)	XML WMS / WFS		
Hydroweb - OZCAR	Theia	m	Water level	http://hydroweb.theia-land.fr/?lang=en&	The database contains time series over water levels of large rivers, lakes and wetlands around the world. These time series are mainly based on altimetry data from Topex/Poseidon for rivers. ERS-1 & 2, Envisat, Jason-1 and GFO data are also used for lakes. Users of the data base can visualize the water level time series as well as Landsat images showing the geographic location of the site. Users can download the numerical values of the time series as well as associated errors. Temporal coverage: 1992 to present	Global	Text	100 to 500 m	10 to 35 days
Earth2Observe (WCI portal)	Plymouth Marine Laboratory	m	Various indicators	https://wci.earth2observe.eu/portal/	WCI portal is very user-friendly to find and visualize data: - Possibility to search data using different typologies (indicator type / data provider / region / interval / version / data type / etc.) - Possibility to produce a temporal graph to visualize a parameter evolution in a selecting geographic area.	Global			
EOSDIS	NASA	m	Various indicators and databases	https://search.earthdata.nasa.gov/	EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs. NASA network capabilities transport the EO data to the science operations facilities.	Global			



Realtime water level monitoring (Vigicrues visualization platform)

Limits and constraints

Large river level is quite easy to be evaluate thank to satellite, very convenient and accurate. The limits of the method is mainly link to the small river and also for those with high vegetation density on the river bed.



5.4 River water speed

Key element

Definitions

The flow velocity of a liquid or a fluid measures its movement. More specifically for water, it gives an indication on the water body movement.

Data use

- 1.** Free surfaces flow estimation.
- 2.** Navigation.
- 3.** Flood risk areas estimation.
- 4.** Ecosystems monitoring.
- 5.** River flow estimation.

Links with the climate change impacts

River water speed parameter depends on some climate parameter, particularly precipitations, evaporation and evapotranspiration; which are directly affected by climate change (changing of the precipitation regime; increasing of temperatures and evaporation, etc.).

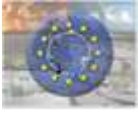


Data access

Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
Earth2Observe (WCI portal)	Plymouth Marine Laboratory	m/s	Various indicators	https://wci.earth2observe.eu/portal/	WCI portal is very user-friendly to find and visualize data: . Possibility to search data using different typologies (indicator type / data provider / region / interval / version / data type / etc.) . Possibility to produce a temporal graph to visualize a parameter evolution in a selecting geographic area.	World			
EOSDIS	NASA	m/s	Various indicators and databases	https://search.earthdata.nasa.gov/	EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs. NASA network capabilities transport the EO data to the science operations facilities.	Global			

Limits and constraints

This parameter is usually estimated thanks to model calculation and it is based on two other parameters: discharge and water level. So the accuracy of these parameters is link to the discharge and water level data accuracy and to the model approximation.



5.5 River discharge

Key elements

Definition

River discharge (Q , express with following units m^3/s or L/s) is the volume rate of water flow that is transported through a given cross-sectional area during a time unit. It is synonym to river flow or streamflow.

Generally, the direct and regular flow measurement is not available. More often, a recording of changes in water height in a given section (hydrometric station) is available. Then, the definition of a calibration curve $Q = f(H)$ allow to pass from the water heights curve as a function of time $H = f(t)$ (liminigram) to a flow curve $Q = f(t)$ (hydrograph).

The determination of the calibration curve is generally carried out by means of episodic flow measurement campaigns at several points in the hydrological cycle, distributed between the low and high waters. The calibration curve is often reproduced to take into account the possible changes in the watercourse section.

The most common method of flow measurement is based on the velocity field determined in a cross section of the river (at a number of points along vertices distributed over the river width). At the same time, the river cross-section is measured by measuring its width and performing depth measurements.

The flow rate $Q [m^3 / s]$ flowing in the river section $S [m^2]$ can be defined from the mean velocity $V [m / s]$ perpendicular to this section by the relation:

$$Q = V \cdot S.$$

The river section can be assessed measuring the water depth on various verticals points distributed regularly over the width. The flow velocity is generally measured on the various vertical points and at several depths in situ.

N.B.: there is a 20-30% uncertainties on flow rates estimation with classical methods in situ. Since last years, a notable research effort is being made to enhanced spatialization flow measurement, in order to overcome as much as possible in-situ observations, or at least to develop new estimation methodologies based on measurable parameters from space (Earth Observation data).

Data use

- 1.** Water resources estimation.
- 2.** Infrastructures sizing.
- 3.** Models calibration and validation

Links with the climate change impacts

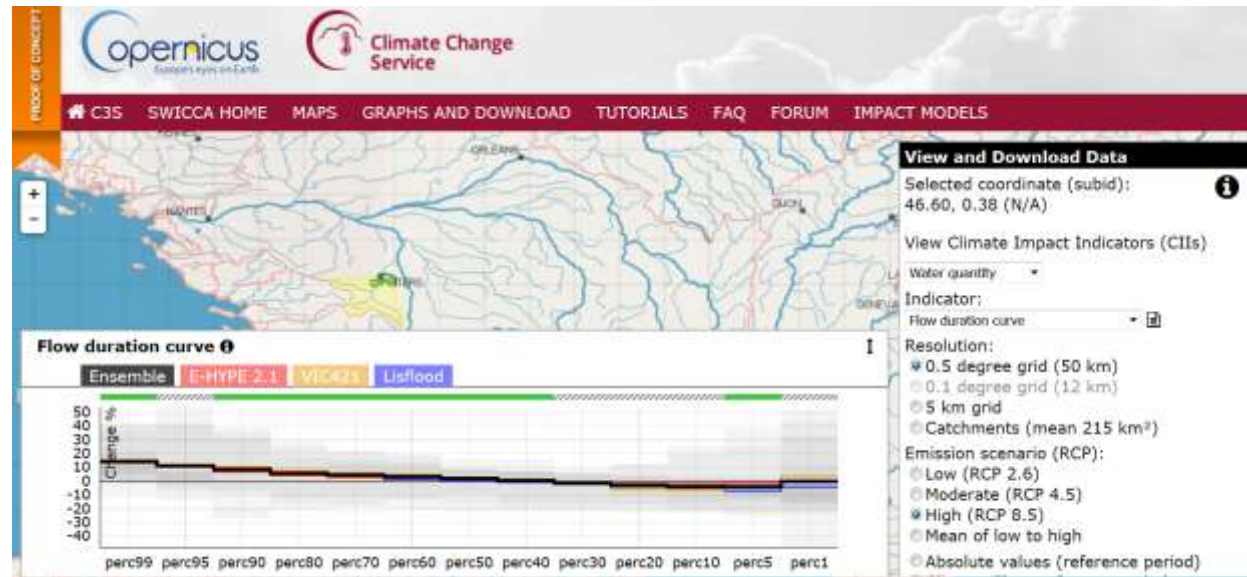
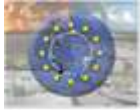
Changes in precipitation and evapotranspiration conditions with climate change have visible impacts on flows, therefore on ecosystems and on water users (agriculture, drinking water supply, energy production and industry).



D2.1 Report on Typology of Climate Related Hazards

Data access

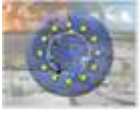
Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	m3/s	River Flow (daily, seasonality and mean)	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	River flow is the volume rate of water flow that is transported through a given cross-sectional area. It is synonym to river discharge or streamflow. For each 30-year analysis period, the indicators for river flow are: -Mean: full period mean of all daily values -Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period -Daily: daily time series	European	Excel	5km	Projection of climate change effect on rainfall (RCP scenarios)
	ESA / EEA / SMHI	m3/s	Flow duration curve	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	The flow duration curve (FDC) gives information about how frequently certain river flow rates occur. Here, the FDC is described through 13 percentiles of the distribution of daily river flows during a 30-year period: 1 %; 5 %; 10 % to 90 % in steps of 10 %; 95 %; 99 %	European	Excel	5km	Projection of climate change effect on rainfall (RCP scenarios)
	ESA / EEA / SMHI	m3/s	Flood recurrence	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	Flood recurrences are given as daily river flows that correspond to return periods of 2, 5, 10, 50, and 100 years. The return period values are calculated using a Gumbel distribution fitted to the yearly maximum river flows for a given 30-year period.	European	Excel	5km	Projection of climate change effect on rainfall (RCP scenarios)
JRC Water Portal	European Commission	m3/s	Various indicators	http://water.jrc.ec.europa.eu/waterportal	The Joint Research Centre (JRC) is the European Commission's science and knowledge service which employs scientists to carry out research in order to provide independent scientific advice and support to EU policy. It proposes some databases on flow measurement at the European scale.	European			
Scalgo Live Global	SCALGO	m3/s	SCALGO Live Flood Risk	scalgo.com/live	SCALGO Live Global provides a unique way of understanding the effect of global topography (mountains, valleys, etc.) on the flow of surface water and flood risk. It allow users to visualize flooding and surface water flow on a near-global elevation model (the SRTM-model from NASA).	Global			
Earth2Observe (WCI portal)	Plymouth Marine Laboratory	m3/s	Various indicators	https://wci.earth2observe.eu/portal/	WCI portal is very user-friendly to find and visualize data: . Possibility to search data using different typologies (indicator type / data provider / region / interval / version / data type / etc.) . Possibility to produce a temporal graph to visualize a parameter evolution in a selecting geographic area.	Global			
EOSDIS	NASA		Various indicators and databases	https://search.earthdata.nasa.gov/	EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs. NASA network capabilities transport the EO data to the science operations facilities.	Global			



Copernicus C3S (Copernicus Climate Change Service) visualization platform (indicator: Flow duration curve)

Limits and constraints

Same as water level issues.



5.6 Water content in groundwater (stocks and water table)

Key elements

Definitions

The groundwater stock is defined here as the water in the subsoil that flows more or less rapidly (day, month, year, century, millennium) into soil cracks and pores in saturated or non-saturated soil.

Water table: The level below which the ground is completely saturated with water.

Data use

1. Water resources management
2. Drinking water management
3. Water cycle modelisation.

Links with the climate change impacts

At the European level, groundwater is a significant economic resource (20% of the total water abstracted in Europe). These resources are threatened by over - abstraction and contamination from surface- derived pollutants. Climate changes exacerbate these pressures.

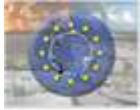
The interpretation of climate change on these important groundwater resources is difficult to predict but will be dependent on regional hydrogeological characteristics, as well as socio-economic conditions that will determine future water supply demand.



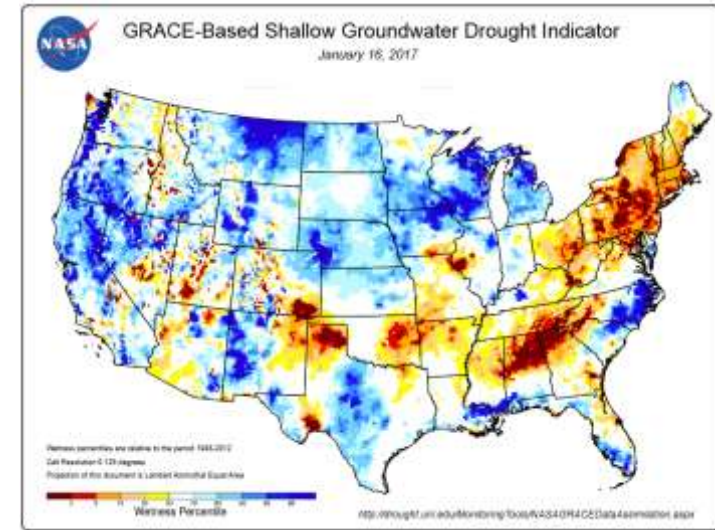
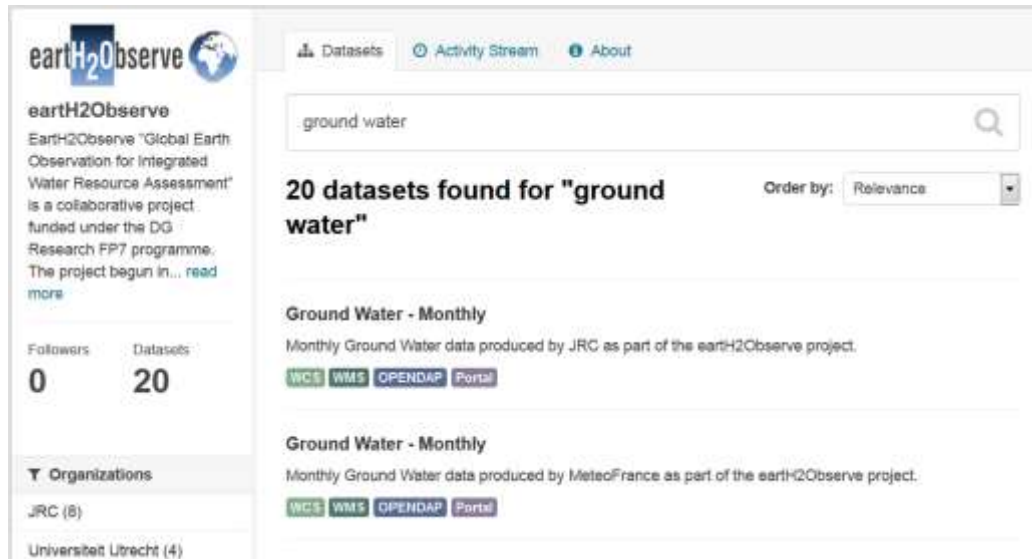
D2.1 Report on Typology of Climate Related Hazards

Data access

Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
ADES	BRGM	m	Piezometry	http://www.ades.eaufrance.fr/	French National database on ground water bodies (quality and quantity parameters). Regularly updated data are available by measurement point or network, by watershed, region, department or water body. ADES also allows to manage and process data making available some softwares, like "Piez'eau" (for processing piezometric data).	National (France)			Annual
Earth2Observe (WCI portal)	Plymouth Marine Laboratory	m	Various indicators	https://wci.earth2observe.eu/portal/	WCI portal is very user-friendly to find and visualize data: .Possibility to search data using different typologies (indicator type / data provider / region / interval / version / data type / etc.) . Possibility to produce a temporal graph to visualize a parameter evolution in a selecting geographic area. Results from five models are proposed (W3RA / LISFLOOD / HBV-SIMREG / Surfex-Trip / PCR-GLOBWB) provided by 4 operators (CSIRO / JRC / Meteo France / Utrecht University).	Global			
JRC Water Portal	European Commission	m	Various indicators	http://water.jrc.ec.europa.eu/waterportal	The Joint Research Centre (JRC) is the European Commission's science and knowledge service which employs scientists to carry out research in order to provide independent scientific advice and support to EU policy. It proposes some databases on flow measurement at the European scale.	European			
GRACE	NASA / DLR	cm	Ground Water level	http://grace.jpl.nasa.gov/mission/grace/	NASA's Gravity Recovery and Climate Experiment (GRACE) has measured significant groundwater depletion around the world in recent years.	World	Raster		Monthly / Annual



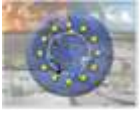
D2.1 Report on Typology of Climate Related Hazards



Earth2Observe data search platform, relevant to find hydrological datasets Visualization of groundwater data from GRACE satellite (example on groundwater)

Limits and constraints

This parameter is mainly derived from in situ measurement (piezometric data) or from mathematical models. The only spatial data is provided by GRACE satellites.



5.7 Soil water content

Key element

Definitions

The soil water content or soil moisture defines the soil saturation state. This parameter determine the soil propensity to flow more or less during a downpour (thus to produce flood); and to impact the evaporation mechanisms and the water soil infiltration.

The water content near root zone influence the vegetation water stress and so the water needs to irrigate the cultures. This soil water content can be measured by tensiometer (for agriculture) or neutron sensors.

We distinguish the surface soil moisture (the first 4-5 cm) and the deeper moisture, in the root zone and below (groundwater – see above).

Soil moisture is generally express in gravimetric (g/cm^3) or volumetric (m^3/m^3) units; or with index (%) relative to the soil saturation capacity.

To characterize a watershed, the minimum resolution needs is 1/100 of the watershed size. For agriculture is used the scale of the plot (100m). For meteorology or climatology issues, the resolution is respectively of the order of 25-50 km and 100-250 km.

Utilisation

- 1.** Water resources management.
- 2.** Agriculture and Irrigation management.
- 3.** Flood forecasting.
- 4.** Water cycle modelization.

Links with the climate change impacts

Soil moisture content is already being affected by rising temperatures and changes in precipitation amounts, both of which are evidence of changes in climate. Since 1951, modeled soil moisture content significantly increased in parts of northern Europe and decreased in the Mediterranean region.

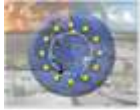
Projections for 2021–2050 show a general change in summer soil moisture content over most of Europe, including significant decreases in the Mediterranean region and increases in the northeastern part of Europe. Maintaining water-retention capacity and porosity are important to reduce the impacts of intense rainfall and droughts, which are projected to become more frequent and severe.



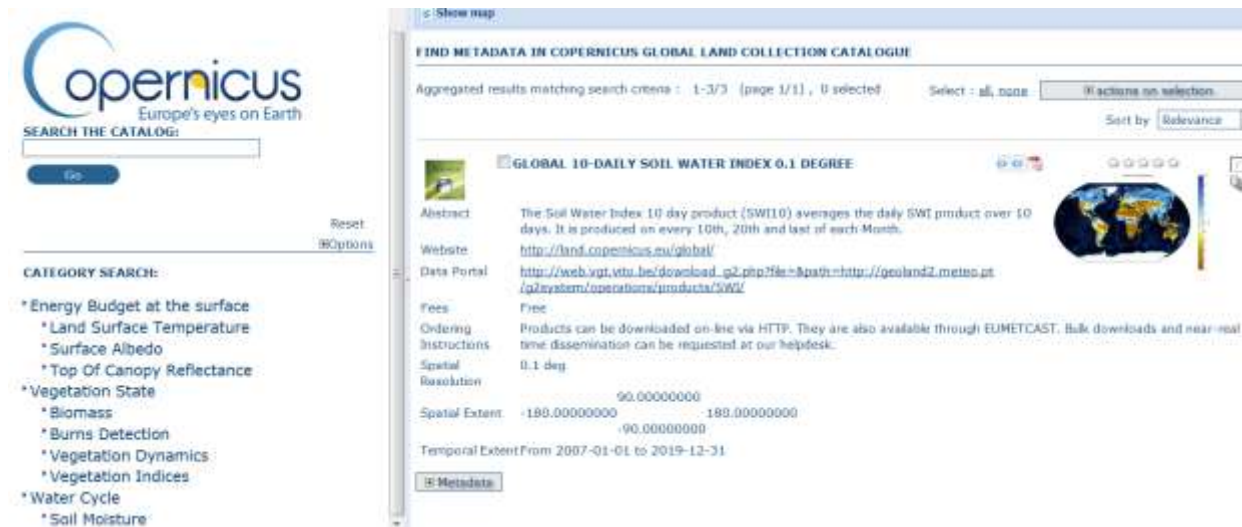
D2.1 Report on Typology of Climate Related Hazards

Data access

Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
Copernicus Land Use Service	ESA / EEA	m3	Soil Water Index (SWI) product	http://land.copernicus.vgt.vito.be/geonetwork/srv/eng/main.home?any=79407e56-e2e2-11e1-ba49-0019995d2a56	The Soil Water Index quantifies the moisture condition at various depths in the soil. It is mainly driven by the precipitation via the process of infiltration. The Surface Soil Moisture L2 product is derived from the Advanced SCATterometer (ASCAT) data and given in swath geometry. This product provides an estimate of the water saturation of the 5 cm topsoil layer, in relative units between 0 and 100 [%].	Global		25km	Daily
Earth2Observe (WCI portal)	Plymouth Marine Laboratory	m3	Soil Moisture	ftp://wci.earth2observe.eu/data/primary/public/tuwien/	WCI portal is very user-friendly to find and visualize data: - Possibility to search data using different typologies (indicator type / data provider / region / interval / version / data type / etc.) - Possibility to produce a temporal graph to visualize a parameter evolution in a selecting geographic area. Data provided by TU Wien.	Global		30km	Daily
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	%	Soil water content: 10 days, seasonality and mean	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	The soil water content represents the volume fraction of soil occupied by water, averaged over those soil layers that provide moisture for plant transpiration. This term includes all phases of water. - Mean: full period mean of all daily values - Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period - 10 days: means over all days that fall into the same 10-day window when counting the days from the first day of each year	European	Excel	0,5*0,5°	Projection of climate change effect on rainfall (RCP scenarios)
JRC Water Portal	European Commission	d/year	Soil Moisture Stress map	http://data.jrc.ec.europa.eu/dataset/e4de34cd3-71f5-49ef-bc02-67feb49dccc	Map shows the average number of days in a year on which soil moisture levels are not sufficient to meet the vegetation water demand.	European	TIF	5*5km	Annual
EOSDIS	NASA	m3	Various indicators and databases	https://search.earthdata.nasa.gov/	EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs. NASA network capabilities transport the EO data to the science operations facilities.	Global			



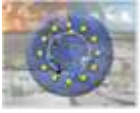
D2.1 Report on Typology of Climate Related Hazards



Copernicus data search platform relevant to find the datasets available (example on soil moisture)

Limits and constraints

The main limited factor is that this parameter value is changing very quickly (from hours to days). Apart from the automatic in situ measurements (provided by tensiometers), the relevance of the other measurements (satellite or in situ) are limited by their updating frequency.



5.8 Water content in snow and ice

Key elements

Definitions

The water content in snow and ice and its seasonal evolution are important water circle parameters. It determines indeed the rivers regime supplied by snow and ice melt. It increase flows and flood risk during intensive snowmelt and reduces low-water during drought periods.

The water content knowledge allows to anticipate watersheds supply downstream.

Data use

1. Water resources management.
2. Water storage in mountain reservoir
3. Hydraulics energy management
4. Water cycle modelisation.
5. Navigation and prediction of break-up for frozen water bodies.

Links with the climate change impacts

Water is collected and stored as snow and ice in glaciers, lakes, groundwater bodies and soil in the European mountain during winter. It is then slowly released as the ice and snow melt throughout spring and summer, feeding the main European rivers (Danube, Rhine, etc.). This makes water available when supply is dropping in the lowlands, and when demand is highest.

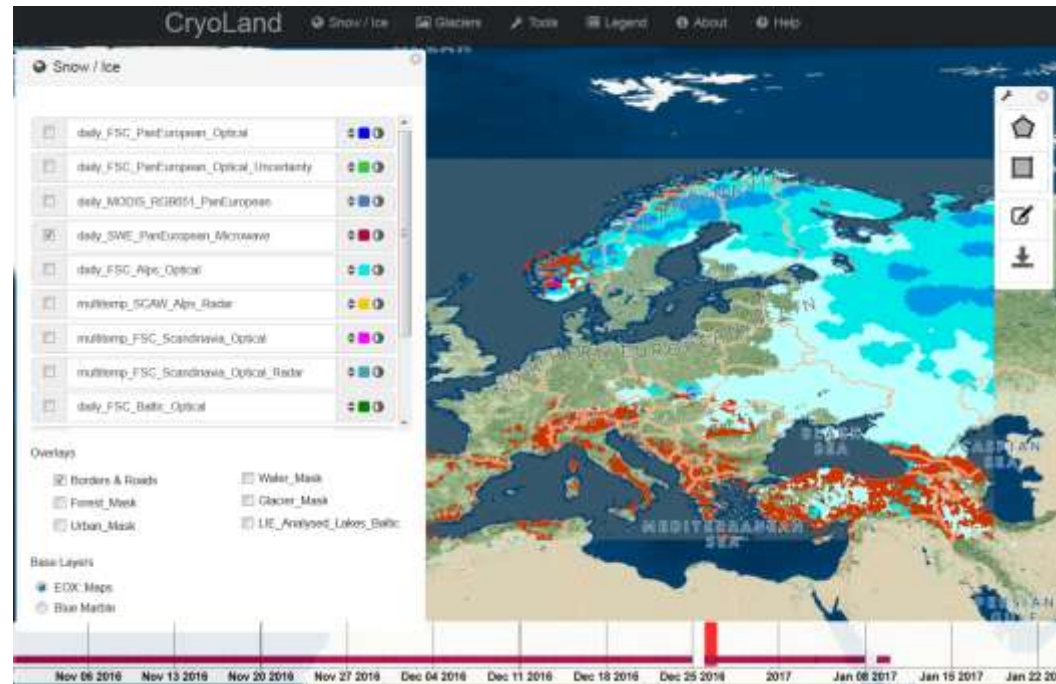
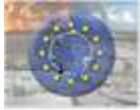
Climate change threatens to alter this 'water cycle' drastically. Changes in precipitation, snow-cover patterns and glacier storage are expected to alter the way water is transported. That means more droughts in summer, floods and landslides in winter, and greater variability in the water supply throughout the year. Water quality will also be affected.



D2.1 Report on Typology of Climate Related Hazards

Data access

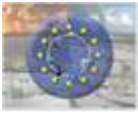
Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	mm	Snow Water Equivalent: seasonality and mean	http://swicca.climate.copernicus.eu/interface/graphs-and-download/	The snow water equivalent is a measure of the amount of water contained in the snow pack. It can be considered as the depth of water that theoretically would result if the whole snow pack instantaneously melts. Snow water equivalent is the product of snow depth and snow density. For each 30-year analysis period, the indicators for water runoff at catchment scale are: -Mean: full period mean of all daily values -Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period.	European	Excel	0,5*0,5°	Projection of climate change effect on rainfall (RCP scenarios)
CryoLand (Copernicus Service Snow and Land Ice)	ESA / EEA	mm SWE	Snow Water Equivalent for Pan-Europe	http://cryoland.eu/	This product provides an estimate on the snow mass of dry snow. The product is derived from satellite microwave radiometry blended by snow-measurements from meteorological stations. Data Base: Passive Microwave Satellite Data and Mountain mask	European	Raster file	10 to 20km	Daily
EOSDIS	NASA	m	Snow cover	https://search.earthdata.nasa.gov/	Daily maps of snow covers with a 500m spatial resolution (MODIS).	Global		500m	Daily



CryoLand (Copernicus Service Snow and Land Ice) visualization platform (example on Snow Water Content Equivalent indicator)

Limits and constraints

The available data is complex to interpret: water content value measured in the surface is not necessary the same in the total snow column. The high spatial and temporal distribution of the snow over the mountains is also a major limit.



5.9 Surface water temperature

Key elements

Definitions

The water temperature is a critical parameter of water quality, due to its links with the other quality parameters. The surface water temperature monitoring allows to characterise the exchanges between different water environment (for example: rising of underground cold water).

Temperature also conditions the micro-organisms and fishes survival. During low-water period (and/or warm period), this parameter need to be watching carefully because the water level decrease may cause a rapid and lethal increase in temperature.

Data use

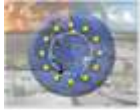
1. Water resources and aquatic environment quality.
2. Characterization of the exchanges between surface water and groundwater bodies in a watershed.

Links with the climate change impacts

Climate change will affect thermal regimes of rivers, having a direct impact on freshwater ecosystems and human water use.

Global mean and high (95th percentile) river water temperatures are projected to increase on average by 0.8–1.6 (1.0–2.2) °C for the SRES B1–A2 scenario for 2071–2100 relative to 1971–2000. The largest water temperature increases are projected for the United States, Europe, eastern China, and parts of southern Africa and Australia. In these regions, the sensitivities are exacerbated by projected decreases in low flows (resulting in a reduced thermal capacity).

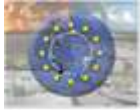
For strongly seasonal rivers with highest water temperatures during the low flow period, up to 26% of the increases in high (95th percentile) water temperature can be attributed indirectly to low flow changes, and the largest fraction is attributable directly to increased atmospheric energy input. A combination of large increases in river temperature and decreases in low flows are projected for the southeastern United States, Europe, eastern China, southern Africa and southern Australia. These regions could potentially be affected by increased deterioration of water quality and freshwater habitats, and reduced water available for human uses such as thermoelectric power and drinking water production.



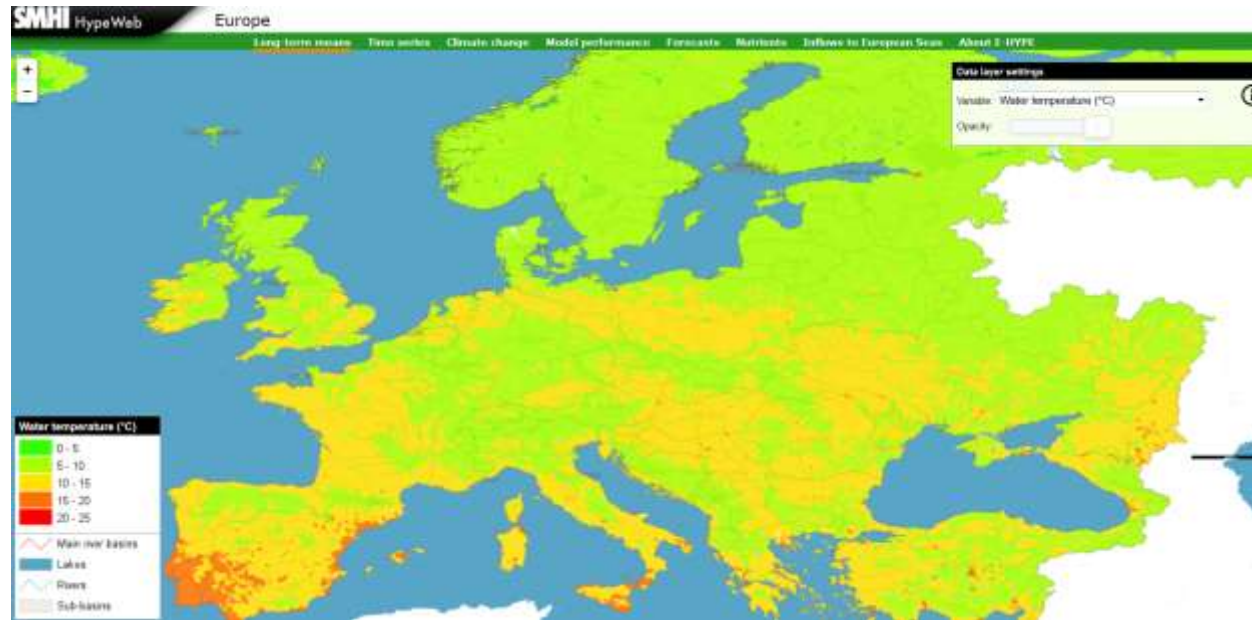
D2.1 Report on Typology of Climate Related Hazards

Data access

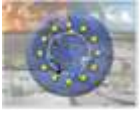
Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	°C	Water Temperature: mean and seasonality	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	Water temperature is the in-stream temperature. For each 30-year analysis period, the indicators for water temperature are: -Mean: full period mean of all daily values. -Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period	European	Excel	Irregular catchment polygons, median catchment size 215km².	Projection of climate change effect on rainfall (RCP scenarios)
HYPEweb	SMHI	°C	Water Temperature	http://hypeweb.smhi.se/	SMHI proposes an open data portal for free download from multi-basin and large-scale applications of the HYPE model world-wide, including an indicator on water temperature.	Global			
EOSDIS	NASA	°C	Various indicators and databases	https://search.earthdata.nasa.gov/	EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs. NASA network capabilities transport the EO data to the science operations facilities.	Global			



D2.1 Report on Typology of Climate Related Hazards



HYPEweb (SMHI) visualization platform (example on Water Temperature indicator)



5.10 Watershed information (land use, soil types, landscape, rugosity...) : 2D information

Key elements

Definition

The watersheds mapping aims to describe the hydrological processes determining the water cycle: distribution of infiltration into groundwater and runoff to rivers, watershed reactivity to a downpour, possibility of soil water recovery by evapotranspiration, etc.

For finest scale than watershed, water bodies (rivers, lakes, canals, wetlands) are characterized: hydrographic network location, delimitation of the riverbed and flood river plain, characterization of drying up areas.

These parameters are generally not very evolutive over time. Thus, the passage time of a satellite is not a determinant factor (if we try to obtain spatial data on a watershed). The minimum required resolution is about 1/100 of the watershed size for its overall characterization. The resolution must be more precise to work on the water bodies or drying up areas location (of the order of the river width).

Data use

1. Water resource analysis.
2. Water cycle modelisation (ground water recharge, runoff, etc.).
3. Surface and groundwater monitoring.
4. Wetlands monitoring.
5. Flooding analysis.
6. Forest fire analysis.
7. Coastline analysis (for coastal watersheds).
8. Monitoring on agriculture issues: cultures state, water stress, water needs and water pressures estimation, etc.

Links with the climate change impacts

Climate change won't directly impact this parameter, but will lead to changes in land use and landscape with consequences on watersheds hydrological characteristics (runoff, flow, etc.).



D2.1 Report on Typology of Climate Related Hazards

Data access

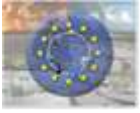
Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
Carthage database	French National Geographic Institute	m and m ²	French hydrological network map	https://www.data.gouv.fr/fr/datasets/bd-carthage-onm/	The Carthage database describes the French hydrological network. It is yearly updated by the French regional French Agencies.	National (France)	ESRI		Annual
Copernicus Land Use Service	ESA / EEA	m and m ²	Corine Land Cover (CLC)	http://land.copernicus.eu/pan-european/corine-land-cover/view	The CORINE Land Cover (CLC) inventory consists of an inventory of land cover in 44 classes. It cover the EEA39 countries. There are two types of database: > Complete database: polygons > 25 ha. > Changes database: identification of land use change > 5ha. Recommended Use Scale: 1/100 000	European	SHP; WMS GeoTIFF	25ha for the complete database 5 ha for changed database	Single occurrence
Copernicus Land Use Service	ESA / EEA	m and m ²	EU-Hydro	http://land.copernicus.eu/pan-european/satellite-derived-products/eu-hydro/view	Pan-European hydrographic reference datasets covering the EEA39 countries. Integrated EU-Hydro database (hydrographic and drainage database) is available in geodatabase format and contains: - hydrographic nodes, lines, and polygons; - drainage network elements (basins, catchments, drainage lines and nodes); - dams; - coastlines and land polygons.	European	Geodatabase format	2,5m	Single occurrence
AQUAMAPS	FAO	m and m ²	Rivers in Europe	http://www.fao.org/nr/water/aquamaps/	Dataset derived from HydroSHEDS (WWF) drainage direction layer and a stream network layer. The drainage direction layer was created from NASA's Shuttle Radar Topographic Mission (SRTM) 15-second Digital Elevation Model (DEM). The raster stream network was determined by using the HydroSHEDS flow accumulation grid, with a threshold of about 100 km ² upstream area.	European	Raster and vector layer (ArcGis)		
AQUAMAPS	FAO	m and m ²	Hydrological basins in Europe	http://www.fao.org/nr/water/aquamaps/	Major hydrological basins and their sub-basins. This dataset divides the European continent according to its hydrological characteristics (Dataset derived from HydroSHEDS (WWF)).	European	Raster and vector layers (ArcGis)		
EOSDIS	NASA	m and m ²	Various indicators and databases	https://search.earthdata.nasa.gov/	EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs. NASA network capabilities transport the EO data to the science operations facilities.	Global			



D2.1 Report on Typology of Climate Related Hazards



Corine Land Cover (2012) visualization on Copernicus Global Land Service Platform



5.11 Bathymetry & topography

Key elements

Definition

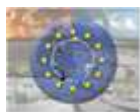
The watershed topography and the river topography (riverbed and flood plain topography), as well as the water bodies bathymetry; are the basis of any hydrological and/or hydraulic activity. This topographic analysis will allow to determine the flows, the water storage capabilities and the rivers characteristics.

Data use

1. Hydrological network characterisation.
2. Watershed reactivity characterisation.
3. Flooding areas identification and characterisation.
4. Water storage and drought characterisation.

Links with the climate change impacts

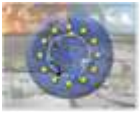
Climate change won't directly impact this parameter.



D2.1 Report on Typology of Climate Related Hazards

Data access

Platform	Operator	Unit	Name	Link	General description	Scale	Format	Spatial resolution	Temporal resolution
Copernicus Land Use Service	ESA / EEA	m	EU-DEM	http://land.copernicus.eu/pan-european/satellite-derived-products/eu-dem	Pan-European elevation reference datasets covering the EEA39 countries.	European	Geotiff	25m (+/-7m for the vertical accuracy)	Single occurrence
French National topography database	IGN	m	BD TOPO ®	http://professionnels.ign.fr/bdtopo	The BD TOPO® database is a 3D vector description of the French territory and its infrastructures, exploitable on scales ranging from 1: 5,000 to 1: 50,000.	France	Shapefile 3D	Metric scale from 1: 5,000 to 1: 50,000	Continuous updating
Copernicus Land Use Service	ESA / EEA	m and m²	Water Bodies product	http://land.copernicus.eu/global/products/wb	The Water Bodies product maps the areas covered by inland water along the year providing the maximum and the minimum extent of the water surface as well as the seasonal dynamics (the area of water bodies is identified as an Essential Climate Variable by the Global Climate Observing System).	Global	.zip archive (Geotiff, xml, xls)	Global, 10°x10° tiles, continental tile, 1km	The Water Bodies product is a 10-days composite.
EOSDIS	NASA	M and m²	Various indicators and databases	https://search.earthdata.nasa.gov/	EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs. NASA network capabilities transport the EO data to the science operations facilities.	Global			



5.12 Exchange of hydrological data

At its fourteenth session in 2012, the Commission for Hydrology (CHy-14) examined the issue of data access and exchange, particularly the need for standards to improve the interoperability of data and information systems.

This examination took place following a concern stated in the 2008 edition of the WMO Guide to Hydrological Practices that **“There are currently no standards for data exchange formats for hydrological data”**.

The Commission noted that the World Meteorological Organization (WMO) had signed a Memorandum of Understanding with the Open Geospatial Consortium (OGC) in 2009 to enhance the development and use of geospatial standards. Moreover, in conjunction with the Memorandum, WMO and OGC had jointly formed a Hydrology Domain Working Group (HDWG) specifically to address the issue of hydrological data exchange formats.

Through the activities of the HDWG, WaterML 2.0 was adopted by the OGC as an official standard in 2012. WaterML 2.0 is a standard information model for the representation of water observations data, developed to enable the exchange of hydrological data between information systems. It provides an interoperable hydrological exchange format that may be used to address a wide range of user needs. These include the exchange of data relating to:

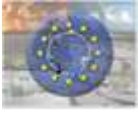
- (1) In situ observations at hydrological (gauges, reservoirs) or climatological stations;
- (2) Forecast products (probabilistic or deterministic time series) at forecast locations;
- (3) Emergency or operator-oriented alerts (of threshold exceedance) and reports;
- (4) Time series of planned intake and release/discharge; and
- (5) Groundwater observations of water level within wells.

Using WaterML 2.0, the linking of local, national, regional and global water information sources is possible as part of global water information networks.

In response to this development, the Commission for Hydrology adopted Resolution 3 at CHy-14 recommending that WMO Members test, through pilot projects during 2013-16, the use of WaterML 2.0 for the exchange of hydrological data, with a view to possibly adopting WaterML 2.0 as a joint WMO/ISO standard. The Commission also noted the importance of WaterML 2.0 and other emerging OGC standards to improve service delivery of key CHy programmes including the WMO's World Hydrological Cycle Observing System (WHYCOS) and the WMO Flood Forecasting Initiative.

Through the CHy Data Operations and Management thematic activity, the Commission has undertaken several pilot projects that demonstrate the use of WaterML 2.0 for exchange of hydrological data at global, national or state/provincial levels. The results of these demonstrations will be reported at CHy-15 in November 2016, along with a recommendation as to whether CHy should support the adoption of WaterML 2.0 as a joint WMO/ISO standard.

In conjunction with this effort, and in response to the need for CHy to more closely align its data activities with the WMO Integrated Global Observing System (WIGOS) and the WMO Information System (WIS), the CHy Advisory Working Group has endorsed the development of a “WMO Hydrological Observing System (WHOS)” as the hydrological component of WIGOS.



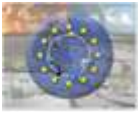
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It is proposed that WHOS be designed to provide access to the data holdings of those National Hydrological Services (NHSs) that make their data freely available online. It is being developed in stages. The first stage is the establishment of a simple map-based interface to the websites of NHSs that currently serve their data online. The second stage would be a more sophisticated implementation of data access and exchange that will employ an interoperable portal through which the data services of National Hydrological Services can be accessed. Initially, there will likely be a limited number of NHSs that will be accessible through this interoperable portal. Through time, however, services and training will become increasingly available to build data exchange capabilities in NHSs wishing to make use of them. The stage one map interface will be operating in mid-2015, and a demonstration version of the second stage will be presented at CHy-15 in late 2016. If approved by CHy-15, an operational version of the second stage WHOS portal will be implemented during the intersessional period following CHy-15.

To learn more about the various aspects of data access and exchange see **the report entitled "WMO Data Operations and Management: Global initiatives in hydrological data sharing"**¹⁹.

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<http://www.wmo.int/pages/prog/hwrrp/chy/data-access-exchange.php>



6 Soil erosion and landslide risks

6.1 Introduction

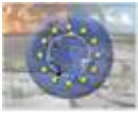
6.1.1 Climate Change and Soil Erosion Risk

During the past decade, the European Commission's Soil Thematic Strategy has recognized the occurrence of soil erosion as a relevant issue for the European Union, due to its impacts on food production, water quality, ecosystem services, floods, (Boardman and Poesen, 2006) and as well as the operation of critical infrastructures, therefore has proposed various methodologies to monitor soil erosion. Furthermore, **the sector's infrastructure is often concentrated along the coast and riverside ports due to its considerable reliance on maritime logistics and pipeline infrastructure. This exposes the sector's infrastructure to coastal erosion (leading to a degradation of coastal barriers) and flooding by sea level rise, tidal and storm surges (Acclimatise, 2010).** The physical factors that perform an important role in the process of soil erosion are climate, topography and soil characteristics.

Climate change is expected to impact soils through changes in both soil erosion and rainfall erosivity. Soil erosion is the actual loss of soil and can have substantial impacts on the availability of nutrients and organic matter in soil, on the other hand rainfall erosivity is a measure of the capacity of rainfall to cause erosion and is essentially a function of the amount of rainfall and the intensity of rainfall. Storm events will give rise to increased erosion, soil loss, and landslides. Much of the pollution and eroded soil will end up in the coastal environment. High velocity floods may cause erosion/scouring of embankments, slopes, levees, and building foundations.

Soil erosion by water accounts for the greatest loss of soil in Europe compared to other erosion processes (Panagos et al., 2015) and occurs through rills, inter-rills and gullies, as a result of rainfall, snowmelt and slumping of banks alongside rivers and lakes. An overview of the various methods that can be used to assess soil erosion risk, involves various approaches with the distinction to: expert based methods, (e.g. factorial scoring, Morgan 1995) and model-based methods that can be classified in a number of ways. Soil erosion models broadly fit into two groups: empirical and process-based models. The main factors affecting the degrees of soil erosion by water are precipitation, soil type, topography, land use/land cover and land management.

Climate change can also cause landslides, with significant impacts on affecting the stability of natural and engineered slopes at different temporal and geographical scales. Landslides are caused by the sudden detachment of rock and debris from a slope and can be relatively small or catastrophic in their magnitude and impact. Landslides have in the past damaged infrastructures, such as drilling pads and pipelines, and cut off transportation networks. These events can disrupt or shut down operations, cause loss of containment and result in increased costs for maintenance, rebuilding and pollution remediation. Landslides are related to increasing air temperatures, higher intensity and more frequent heavy rain events, decreasing summer precipitation, snow melting and sea level rise. Specifically, heavy rain events could result in greater erosion, higher sediment transport in rivers and streams, and a higher likelihood of landslides, primarily as a result of higher soil water content or a considerable flooding. Increasing air temperatures raise the risk of wildfire which can affect the rates of erosion on soil erosion and cause changes in land use and land cover that can dramatically affect the likelihood of a landslide. Coastal landslides frequently occur during low tides through a mechanism similar to the rapid drawdown condition in earth dams or of failure at delta fronts.



6.2 Soil Erosion Risk

6.2.1 Soil Erosion Models

The availability of input data is a critical selection criterion when assessing soil erosion risk at the regional, national or continental scale. The most known and under development soil erosion models are RUSLE2015, PESERA, MESALES and G2.

A modified version of the Revised Universal Soil Loss Equation (RUSLE) model (RUSLE2015) estimates soil loss in Europe for the reference year 2010, within which the input factors (Rainfall erosivity, Soil erodibility, Cover-Management, Topography, Support practices) are modelled with the most recently available pan-European datasets. While RUSLE has been used before in Europe, RUSLE2015 improves the quality of estimation by introducing updated (2010), high-resolution (100 m), peer-reviewed input layers. **The mean soil loss rate in the European Union's erosion-prone lands (agricultural, forests and semi-natural areas) was found to be $2.46 \text{ t ha}^{-1} \text{ yr}^{-1}$, resulting in a total soil loss of 970 Mt annually.** A major benefit of RUSLE2015 is that it can incorporate the effects of policy scenarios based on land-use changes and support practices. The impact of the Good Agricultural and Environmental Condition (GAEC) requirements of the **Common Agricultural Policy (CAP) and the EU's guidelines for soil protection can be grouped under land management (reduced/no till, plant residues, cover crops) and support practices (contour farming, maintenance of stone walls and grass margins).** The policy interventions (GAEC, Soil Thematic Strategy) over the past decade have reduced the soil loss rate by 9.5% on average in Europe, and by 20% for arable lands. Special attention is given to the $4 \times 10^6 \text{ ha}$ of croplands which currently have unsustainable soil loss rates of more than $5 \text{ t ha}^{-1} \text{ yr}^{-1}$, and to which policy measures should be aimed to.

The new soil loss by water erosion map of Europe uses a modified version of the RUSLE model (RUSLE2015, based on Renard et al., 1997), which calculates mean annual soil loss rates by sheet and rill erosion according to the following equation: Soil erosion for RUSLE model, is estimated using the following empirical equation:

$$E = R * K * C * LS * P$$

Where:

E: annual average soil loss ($\text{t ha}^{-1} \text{ yr}^{-1}$),

R : Rainfall erosivity factor ($\text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ yr}^{-1}$),

K : Soil erodibility factor ($\text{t ha h ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$),

LS : Slope factor (dimensionless)

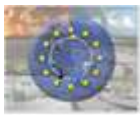
C : Cover management factor (dimensionless)

P: support practices factor (dimensionless).



Figure 5.1 Input datasets used for the estimation of soil loss factors for Europe in RUSLE2015 (source: <http://esdac.jrc.ec.europa.eu/themes/rusle2015>)

The soil erosion data (RUSLE2015) are available to the public user (ESDAC). According to future land use scenarios, RUSLE2015 estimates that rates of soil loss by water will fall slightly by 2050, mainly due to



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an increase in forest areas. Nevertheless, pressures to increase the amount of arable land for food and fuel could offset the reduction, unless more sustainable land management practices are applied. On the other hand, climate change scenarios estimate that the soil loss rates may increase by 10-15% by 2050 due to an analogous increase of rainfall erosivity in Europe.

Pan-European Soil Erosion Risk Assessment – PESERA - is a process-based model designed to estimate long-term average soil erosion rates at a 1-km resolution (Kirkby et al. 2008) and has been applied to most of the European territory. The PESERA uses a process-based and spatially distributed model to quantify soil erosion by water. The theoretical basis of the PESERA model can also be extended to include estimates of tillage and wind erosion. The model is anticipated as a regional diagnostic tool, replacing similar existing methods, such as the Universal Soil Loss Equation (USLE), which are less suitable for European conditions and lack compatibility with higher resolution models. The PESERA model combines the effects of topography, climate, vegetation (land cover) and soil into a single integrated calculation of soil erosion.

Table 5.1 Required data for the PESERA model

Climate Data	Land Use Data	Soil Parameters	Topographic Data
Mean monthly rainfall	Land cover type/management option	Sensitivity to surface crusting	Standard deviation of elevation
Mean monthly rainfall per rain day	Initial ground cover	Sensitivity to erosion	
Coefficient of variation of monthly rainfall	Initial surface storage	Effective soil water storage capacity	
Mean monthly temperature Corrected for altitude	Surface roughness reduction per month	Soil water available to plants in top 300mm	
Monthly temperature range (max-min)	Root depth	Soil water available to plants : (300mm and 1000mm depth)	
Mean monthly PET		Scale depth	

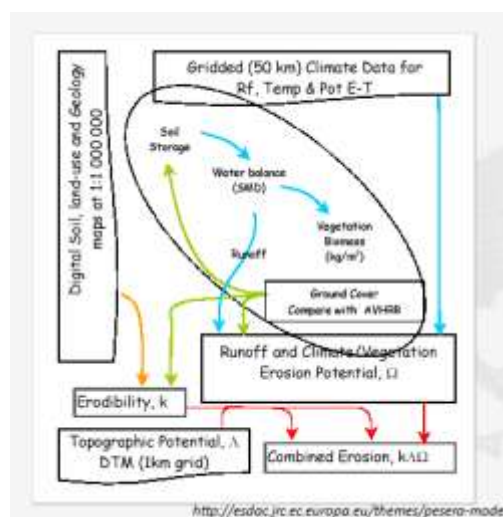
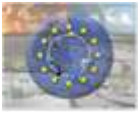


Figure 5.2 Model structure of PESERA and characteristics (source: http://eusoils.jrc.ec.europa.eu/Esdb_Archive/pesera/pesera_cd/sect_2_1.htm)

MESALES (Modèle d'Evaluation Spatiale de l'ALéa Erosion des Sols - Regional Modelling of Soil Erosion Risk) uses empirical rules to combine data on land use (CORINE Land Cover database), soil crusting



susceptibility, soil erodibility (determined by pedotransfer rules from the Soil Geographical Data Base of Europe at scale 1:1 Million), relief (USGS HYDRO1K digital elevation model), and meteorological data at a 1 x 1 km pixel size (Space Applications Institute, Ispra Joint Research Center). Spatial units for the presentation of results are defined using either administrative units or watershed catchment units.

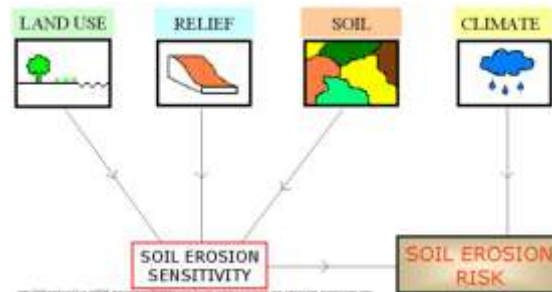


Figure 5.3. Model structure of MESALES and characteristics (source: http://h05-prod-vm15.jrc.it/ESDB_Archive/serae/GRIMM/erosion/inra/europe/analysis/maps_and_listings/web_erosion/index.html)

G2 model is a new model for erosion, resulted from the cooperation of JRC/IES/Land Resource Management Unit/SOIL and the Lab of Forest Management and Remote Sensing, School of Agriculture, Forestry and Natural Environment of the Aristotle University of Thessaloniki in the framework of geoland2 project. G2 allows for mapping estimates of soil loss (in t/ha) from sheet and interrill erosion caused by raindrop splash and surface runoff, on a month-time step on a local to regional scale. G2 inherits its fundamental equations from USLE, especially the estimation of rainfall erosivity and soil erodibility. However, it is innovative in the estimation of the vegetation coverage and management parameter, which is based on a combination of empirical tables from USLE and Gavrilovic (EPM) models. It also introduces a corrective factor to the topographic parameter. The formula of G2 is:

$$E=(R/V)*S*(T/I)$$

Where:

E: erosion (t ha⁻¹)

R: rainfall erosivity (original USLE formulas or alternatives developed by G2 or other authors) (MJ mm ha⁻¹ h⁻¹)

V: vegetation retention (developed by G2 using Biopar data or equivalent and land use/management databases, e.g. CORINE) (dimensionless; V>=1)

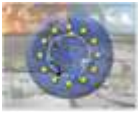
S: soil erodibility (original USLE formulas or modified USLE by JRC, 2012) (t ha h MJ⁻¹ ha⁻¹ mm⁻¹)

T: topographic influence (USLE modifications, 1996; strict implementation of USLE terms) (dimensionless; T>0)

I: slope intercept (developed by G2 using satellite data; corrective to T; partially analogous to P of USLE) (dimensionless; 1 =< I<=2)

G2 employs harmonized standard input data from European and global databases, such as the LUCAS soil database, the European Soil Database (ESDB), the Topsoil Organic Carbon (TOC), BioPar products of geoland2, Image 2006 imagery, CORINE LC, Landsat TM, the ASTER DEM datasets, and other large public datasets. As a data-oriented model, the cartographic scale of a G2 implementation is determined by the spatial resolution of the input data.

G2 is a dynamic, feasible, easy to run model, providing alternatives for the estimation of all erosion factors. Several published studies of G2 implementation, e.g. in the cross-borders basin of river Strymonas/Struma (Greece and Bulgaria), in the basin of rivers Ishmi and Erzeni (Albania), and in the Mediterranean island of Crete (Greece), have provided realistic results. Currently, the model is being implemented at the national scale (in the whole of Greece).



6.3 Landslide risk

At the regional scale, the impact of climate and its variation on the distribution, abundance, frequency, and types of landslides, is expressed considering the influence of climate on landslide hazard. In the following equation is described the probabilistic model for landslide hazard assessment (Guzzetti et al., 2005a):

$$H_L = p(A_L) \times p(N_L) \times S$$

H_L : Landslide hazard

$p(A_L)$: The joint probability of landslide size of landslide occurrence in a given period $p(N_L)$

S : Landslide spatial occurrence, known as landslide susceptibility.

This function is an expression of the space that landslides can occur, how frequently they will occur, and their magnitude or how damaging they will be.

Other factors that determine the risk of landslides include the type of geological material; fractures and joints, the angle of the slope, and the position of the water table.

However, according to Gariano and Guzzetti 2016, the type, extent, magnitudes, and direction of the changes in the stability conditions of the slopes, and on the location, abundance and frequency of the landslides, are not completely clear. The effects of the warming climate on landslide risk, and mostly the risk to the population, also remain difficult to quantify. Therefore it is very difficult to find good scales for expressing the hazard intensity of landslides. Attempts have been made to use velocity, impact (rockfall), depth (debris flow) or volume as hazard indicators, but still there is no universal hazard intensity scale that is applicable everywhere.

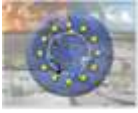
Mass movements very often result in collapse or burial of the buildings that are directly in the path or on top of a fast moving landslide, therefore very often a vulnerability of 1 is used. In practice most of the methods for landslide vulnerability assessment use an expert opinion approach.

Table 5.2 Common elements or criteria for risk area identification according to soil threats

COMMON ELEMENTS FOR THE IDENTIFICATION OF AREAS AT RISK OF LANDSLIDES	
Soil typological unit (STU) (soil type)	
Occurrence/density of existing landslides	
Bedrock	
Topography	
Land cover	
Land use (including land management, farming systems and forestry)	
Climate	

6.4 Projecting of soil erosion risk in a future scenario

Based on the aforementioned analysis of the erosion models, a brief summary of the procedure of soil erosion risk or landslide risk for future RCP scenario should include the following steps. Primarily, it is needed to choose the erosion model and then to collect all the necessary information, depending on the model input data. Climate information involves exclusively long-term precipitation and temperature data, provided from Meteorological Services or Climate Models Databases e.g. EURO-CORDEX 2.6 RCP scenario (2005-2050) to extract time-series or multivariate data of total precipitation, seasonal precipitation, precipitation of driest/wettest months, average temperature and other calculated climate drivers. High temporal resolution of precipitation data depend on the model that is used. Additionally, to download required soil parameters from the European Soil Data Centre (ESDAC), land use and vegetation types from CORINE database or the Land-use Harmonization (LUH1) project, provided harmonized land-use data for the



future years (). All the above data are used as an input in the erosion model equation to calculate the erosion risk for the area and the period of our interest.

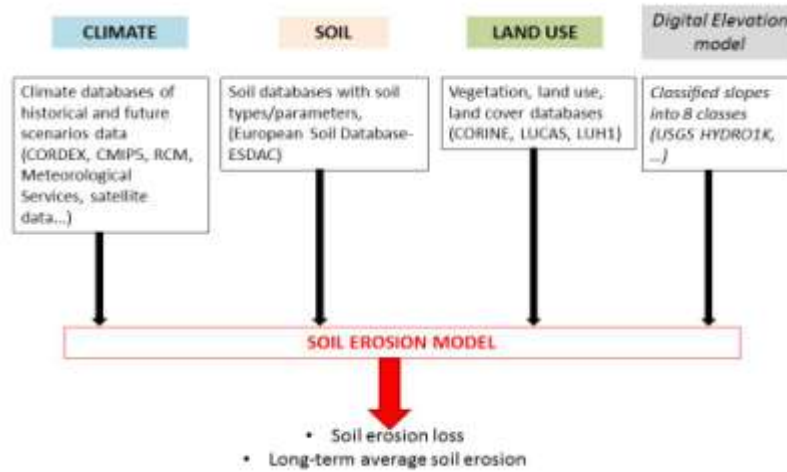
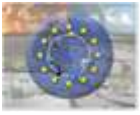


Figure 5.4 Flowchart for the calculation of erosion risk



7 Flood modelling

Flood modelling is usually classified into two main categories of modelling: hydrological and hydraulic approaches.

7.1 Hydrological modelling

Hydrological modelling investigates the rainfall-runoff response within a basin or sub-catchments using simplified lumped parameters. The solutions are based on the continuity equations for each modelling unit (basin or sub-catchment). The flow interactions between modelling units can only follow pre-defined flow paths to propagate, while the detailed flow dynamic with a unit is ignored and only reflected as a single value such as discharge or flood volume. Flow rating curves or flood volume spreading algorithms are then used to translate the runoff into flood depths or extents. The simplification allows the hydrological modelling to simulate flooding for a large domain with much lower computational resources requirement than hydraulic modelling. Therefore, the approach has been widely adopted to provide overall flood assessment for large areas (Arnold et al., 1998), uncertainty analysis (Beven, 1993) and flood forecasting (Cole et al., 2010), but is not suitable for specific geospatial flood modelling.

7.2 Hydraulic modelling

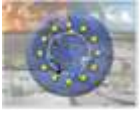
Hydraulic modelling considers spatial varied characteristics affecting the rainfall-runoff process and adopts partial differential equations such as Saint Venant equations or the dynamic wave equations to analyse flow dynamics. Therefore, it can provide more specific information regarding flood movements and geospatial results. Pender (2006) compared different hydraulic models and classified them based on dimensionality.

In general, one-dimensional (1D) approach focuses on the dynamic with a dominant flow direction **such as river channel or sewer pipe flows. The reduction of parameters also limits 1D models' ability to** describe the variation of flood depth in a wide floodplain that runoff does not necessarily move along the pre-defined flow paths. Additional data processing is often required for mapping 1D modelling results to a two-dimensional (2D) domain. The three-dimensional (3D) approach requires extraordinary computational cost to solve such that it is often only used for modelling local phenomena near hydraulic structures (e.g. **inlet (Djordjević et al., 2012)**), sediment transport (Wu et al., 2000) and flow-vegetation interaction (Marjoribanks et al., 2014).

The 2D approach lies between the over-simplification of the hydrologic and the 1D hydraulic approach, and the computationally expensive 3D approach. It can provide good representations of flow movements on the ground surface, with a reasonable computing cost. Together with the recently quick development of computing hardware and data surveying, 2D modelling is now an affordable option and has been widely applied to many flood modelling practices (Yu et al., 2016; Wolfs et al., 2016; Martins et al., 2016; Guidolin et al., 2016; Dimitriadis et al., 2016; Innovyze, 2014; DHI, 2014; Deltares, 2014; Néelz and Pender, 2013; Neal et al., 2011).

Domain extent, grid or mesh resolution, computing power and available lead time are the main factors that affect the performance of flood modelling. In most applications, the selections of above mentioned parameters are often a compromise between the accuracy and efficiency.

To reflect various attributes for different components within rainfall-runoff process, the above approaches are often combined or coupled together. For example, in urban pluvial flood modelling, a 1D sewer flow model can be combined or coupled with a 1D channel flow model (Leandro et al., 2011, 2009;



Djordjević et al., 2005) or a 2D overland flow model (Martins et al., 2016; Chen et al., 2016; Hsu et al., 2002, 2000) to describe the flow movement in the sewer pipe system and on the ground surface system, as well as the interactions between both systems. The other common example is the 1D river flow model coupled with a 2D overland flow model for fluvial flood modelling (Morales-Hernández et al., 2016).

Previous EU funded projects, such as PREPARED (Sušnik et al., 2015), FLOODSITE (Asselman, 2009) and CORFU (Chen et al., 2014), as well as the UK EPSRC funded FRMRC project (Pender, 2006), have reviewed the different approaches, applied flood modelling of various types and discussed about the results comparatively, their overall suitability for different Use Cases and the possible combinations/extensions with further modelling (e.g. for impact and/or risk assessment).

7.3 Usually required Datasets

Terrain data are essential to flood modelling. Nowadays, the NASA's Shuttle Radar Topography Mission (SRTM-2) Digital Elevation Model (DEM) covers most of the land surface globally (CEOS, 2015). Many countries such as the US and the UK have better DEM acquired by LiDAR with horizontal resolution as fine as 25 cm that improves the representation of topography in flood modelling and, consequently, offers better simulation results (EA, 2015).

Other information such as building layouts, land uses or soil type data are also necessary to set up the locations of structures that will significantly affect the flow movement, and to determine the roughness and infiltration parameters in modelling. These data at global scale are now publicly available from providers such as the Open Street Map Foundation (2015), Global Land Cover Facility (2015) and SoilGrid map (ISRIC - World Soil Information, 2015). More detailed information like the sewer pipe networks and river channel cross sections will further enhance the quality of modelling output but the availability of such data often varies in different countries and cities.

Rainfall, water levels in river channels and the sea levels are the main drivers that lead to flooding. The observations and statistical analysis of these data are the key inputs for flood forecasting and flood risk analyses, respectively. Observations can be obtained via gauge measurements, radar or remote sensing, and often archived in a national database such as NOAA (2017) and, CEDA (2017). Historical records of weather and flood information can be utilised for model calibration and verification.



8 Forest fires

8.1 State of the art

Wildfires represent a substantial threat to Southern European forests and ecosystems and every year cause extensive losses to anthropic infrastructures and values. On average more than 500,000 hectares of land burn every year in Europe, with large spatial and temporal variability, and with the largest area burned and impacts concentrated in Mediterranean countries. The potential effect of climate change on **forest fire risk is of significant concern around the world**. Climate change projections suggest substantial warming and increases in the number of droughts, heat waves and dry spells across most of the Mediterranean area and more generally in southern Europe. Greenhouse gas emissions, via the greenhouse effect, are causing the global temperature to increase and the climate to change. This enhances the likelihood of wildfires. As the climate warms, moisture and precipitation levels are changing, with wet areas becoming wetter and dry areas becoming drier. Higher spring and summer temperatures and earlier spring snow-melt typically cause soils to be drier for longer, increasing the likelihood of drought and a longer wildfire season. These hot, dry conditions also increase the likelihood that, once wildfires are started by lightning strikes or human error, they will be more intense and long-burning. These projected climate changes would increase the length and severity of the fire season, the area at risk and the probability of large fires. Climate change is expected to contribute to a dramatic increase in forest fire damage in Europe, but better forest management could mitigate the problem. By 2090, the area burned by forest fires in the European Union could increase by 200 percent, states the study published in the journal *Regional Environmental Change*. However, preventive fires could keep that increase at below 50 percent. An improved fire fighting response could provide additional protection against forest fires. To prevent fire ignition and fire propagation, actual prevention and suppression actions should be reinforced. Among them is the evaluation of the fire danger index.

The relationship between fire danger and weather parameters was demonstrated in several research works since the beginning of 20th century. Forest fire danger is characterized by various indicators.

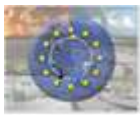
8.2 Fire danger evaluation

The Fire Weather Index (FWI) System is well known and applied worldwide for fire risk assessment, constituting a building block of the CFFDRS, established in Canada since the early 70's (Van Wagner, 1987; Stocks et al, 1989) and subsequently adopted in other regions of the world, like the Mediterranean (Viegas et al., 1999; Dimitrakopoulos et al., 2011).

Viegas et al. (1999) found that the FWI System components were well correlated with fire activity in southern Portugal, Spain, France and Italy, although the vegetation and dry Mediterranean climate were much different than those in Canada. As an example, it is used in all the French regions impacted by forest fires, especially in the Mediterranean area, since 1995. This choice was made succeeding the European research program MINERVE which showed that the FWI was very performing for the Mediterranean area. Its calculation of drought with three different components is unique and makes it closer to reality. It gives better results than other danger indexes for most situations.

Currently, the Joint Research Centre uses FWI as a reference index to produce fire risk maps at the European level (Camia et al., 2008, San-Miguel-Ayanz et al 2012).

Fire danger rating tries to answer the questions of when and where fires will occur, and should classify (or quantify) fire behaviour as objectively as possible (Alexander, 1994). Although it has not yet been clarified as to whether the meteorological conditions or the landscape pattern fundamentally determine fire risk and



spread (Moreira et al., 2011), it seems that the climatic and weather conditions in the Mediterranean region have a profound effect on fire occurrence (Koutsias et al., 2013). Therefore, understanding the links between weather, climate and fires is important for implementing effective fire prevention policies (Karali et al., 2014).

The classic use of the FWI is associated with the daily fire danger mapping, based on meteorological measurements, while in recent researches, e.g Giannakopoulos et al., (2009) and Good et al., (2008) this indicator has been used with forecasted climatic data for studying the changes in the occurrence and intensity of natural disasters.

In France, the real time fire weather danger monitoring is carried out by the forecaster at the EMIZ Meteo-France branch all throughout the day using weather parameters (wind, temperature, humidity...) and specific forest fire indexes: FWI, propagation indexes and Drouet ignition thresholds. This enables to update forecasted dangers) and meet immediate forecast needs during a fire. The forest fire indexes are used in the Fire Tactic propagation model that is described just after. In Canada the first component of the danger rating system was introduced in 1974 as the Fire Weather Index (FWI) system which tracks weather parameters into a series of indices to aid in the forecasting of fuel combustibility (Van Wagner 1974).

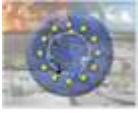
FWI is comprised of six components: three fuel moisture codes and three fire behaviour indices. This system accounts for the effects of fuel moisture and wind on fire behaviour and comprehends three levels of information: (i) fire weather observations, (ii) fuel moisture codes, and (iii) fire behaviour indices. Calculation of the components is based on daily observations made at noon of air temperature, relative humidity, 10-m open wind speed and 24-hour cumulative precipitation.

The calculation algorithm of FWI is quite complex and a full description of the calculations are available in the "Equations and FORTRAN Program for the Canadian Forest Fire Weather Index System" document of C.E. Van Wagner & T.L. Pickett, released by the Canadian Forest Service, Ottawa, 1985. FWI values range from 0 to above 100 and are categorized, for operational purposes, in four (4) to six (6) classes, depending on the application area, corresponding to the different fire danger levels. (Alexander M.E, 1994, JRC-EFFIS system, Dimitrakopoulos et al., 2011, Camia et al., 2000).

8.3 Forest fire propagation models

The behaviour of forest fires spreading depends on several parameters related to the fuel, the topography and the meteorological conditions. Several studies and European research projects were focused on forest fire propagation models development and validation as for example INFLAME, PROMETHEUS, SPREAD). In Europe, several models were developed based on BEHAVE system (Rothermel, 1983; Andrews, 1986) as for example FMIS (Eftichdis, 1998) developed by ALGOSYSTEM and suitably adapted to Mediterranean forest fuel types. Different type of propagation models have been developed, according to the aim they have been developed for. Fire growth simulation models have a multitude of uses that may be split into three broad categories: (i) operational fire fighting; (ii) wildfire preparedness; (iii) wildfire investigation. This section largely draws on work by Pearce (2009) who identifies a variety of wildfire growth simulation model applications. According to Weber (1991) , propagation model scan be classified in 3 groups: statistical, empirical and physical. Those models are often linked to fire danger rating system.

Empirical models are mainly used to help fire managers during prescribed burnings or during real fire fighting operations. They are based on the principle of energy conservation. The fire propagation velocity is evaluated from parameters characterizing the vegetation and the environment in which the fire propagates. The advantage is that they run faster than the real time on standard desktop computer.



The most famous system based on empirical models the FARSITE one (Finney 2004) which is widely used by the U.S. Forest Service, National Park Service, and other federal and state land management agencies to simulate the spread of wildfires and fire use for resource benefit across the landscape. FARSITE computes wildfire growth and behaviour for long time periods under heterogeneous conditions of terrain, fuels, and weather. It uses existing fire behaviour models for surface fire spread (Rothermel 1972), crown fire initiation (Van Wagner 1977), and crown fire spread (Rothermel 1991), post-frontal combustion (Albini and others 1995; Albini and Reinhardt 1995), and dead fuel moisture (Nelson 2000).

Physical models are based on fluid mechanics equations and take into account physical processes as **convection, radiation, combustion, pyrolysis, turbulence....** They allow the calculation of temperature, velocity, chemical composition fields. The calculation is time consuming but this fine description of the various components allows the knowledge and the comprehension of classical and specific fire behavior.

The cellular automata were invented by J. Von Neumann [21] in 1957. He proposed to study whether the laws of evolution in nature can come from simple logical rules. The first use of cellular automata to model the propagation of forest fires is due to Kourtz [10] in 1971. This type of model is sometimes called a contagion model. It has the interest of being two-dimensional, of requiring a small calculation time and of being able to model the propagation of the fire in a heterogeneous and with low density.

8.4 Forest fires and EU-CIRCLE

In the frame of the Eu-Circle project, it is proposed to use forest fire propagation models, and to evaluate the evolution of fire danger according to climate changes prevision. In France, in which the EU-CIRCLE forest fire study case will be developed, the forest fire propagation model (Drouet, 1972) used by the fire fighters is called FIRETACTIC. In this model, the fire propagation velocity is calculated with the following meteorological parameters: wind speed, soil water content, temperature and sunshine. The slope is considered through a digital terrain model. The vegetation is taken into account by the way of a corrective coefficient taking into account its flammability and its combustibility. To date, FIRETACTIC® distinguishes three types of vegetation dominant, which correspond to a modulating factor for propagation velocities: these are the dominant vegetation found in the South of France, namely dominant of Kermes Oak, dominant of Pines and dominant of green oak. This software is used in the context of the fight against forest fires and constitutes a decision-making aid in defining the tactics of fighting a fire.



Figure 7.1 Example of fire successive fire contours in South of France

As part of the EU-CIRCLE project, ignition points will be determined in the high-risk zones defined by the FWI calculation and fire contours obtained using the FireTactic software will be transformed into fire intensity and will allow the evaluation of the fire thermal impact on critical infrastructures assets.

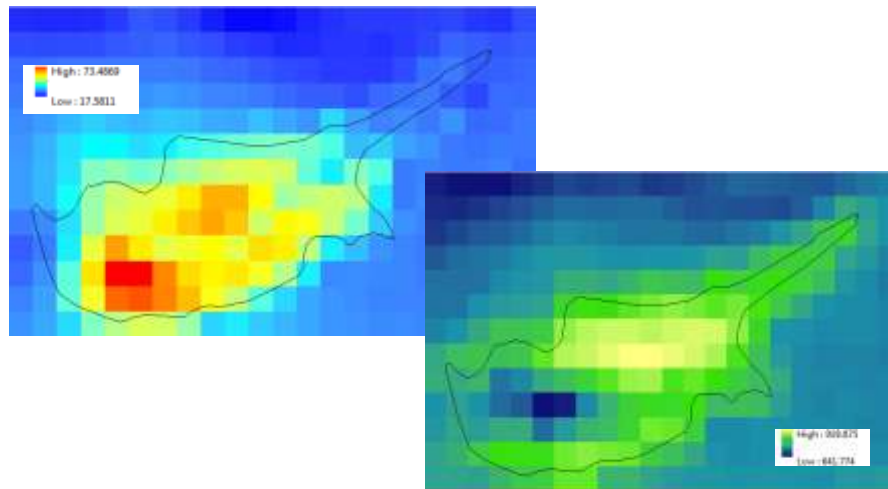
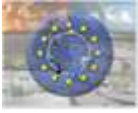
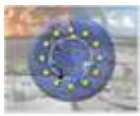


Figure 7.2 Example maps of FWI and DC values calculated for 23/07/2050 as derived from EU-CORDEX data, for the scenario RCP2.6 for Cyprus area.



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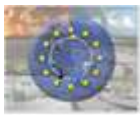
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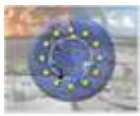
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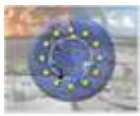
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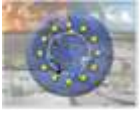
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Annex 1: The use of weather and climate data: example of Hellenic National Meteorological Service (HNMS).

Global weather prediction models (deterministic)

Hellenic National Meteorological Service – HNMS for its numerical weather prediction needs runs and uses three numerical weather models. One global, of European Medium Weather Forecasting Center – ECMWF, that runs for Europe for medium range forecasts (up to ten days ahead) and two very high resolution limited area models - LAM for short-range forecasts (for a few hours to a few days in the future). The latter models are in general using boundary condition data from ECMWF.

HNMS uses the outputs of the global deterministic weather prediction model of European Medium Weather Forecasting Center – ECMWF for Europe. This model has been developed by ECMWF and is available for its 34 Member states, to cover their requirements for the area of numerical weather prediction. The ECMWF produces global numerical weather forecasts for its users worldwide. These forecasts **are of “medium – range” and refer to time periods up to about two weeks ahead and are produced twice a day for weather services and businesses.** The last operational option of ECMWF deterministic model is the model named ECMWF HRES with horizontal resolution of 9 km (from 3/2016), while the previous one model had horizontal resolution of 16 km. Both models give forecasts for up to 240 hours.

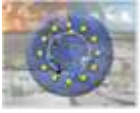
In addition, ECMWF produces extended forecasts for monthly and seasonal timescales. The weather **services of each Member state receive ECMWF’s numerical weather prediction data in real time – 24 hours a day, 7 days a week.** 40 million observations a day are used by ECMWF for its assimilation system and come from more than 50 different instruments on satellites, and from many ground-based and airborne observing measurement systems. ECMWF uses advanced computer modeling techniques to analyze observations and predict future weather.

ECMWF uses a system for archiving data, named MARS - Meteorological Data Archive System, which is the largest in the world. This archiving system contains tens of petabytes of operational and research data, with about 120 terabytes being added daily. In addition, reanalysis gridded data are available for decades for several meteorological parameters to represent the climate, to monitor the climate change, for research and education, and for commercial applications. Reanalysis data are produced by combining models data with archived observation data, involving the data assimilation systems in the production of estimates of **atmospheric parameters for all locations on earth. These estimates or “reanalysis data” span for a long time period that can be extend back by decades or more.**

Regional weather prediction models

The short range limited area numerical weather prediction models developed with joined efforts and used by HNMS are the following: The COSMO-GR model and the SKIRON/Eta model. These models consist of the regional weather forecasting systems of HNMS and are non-hydrostatic models.

The COSMO-GR (formerly known as LM) model runs for a domain with a longitude range of 45° and a latitude range of 24.5° with 35 vertical levels and a horizontal resolution of 0.0625° (~ 7km). This model runs named as COSMO – Mediterranean and gives forecasts for up to 72 hours with domain of Mediterranean. In addition nowadays, there is another operational option of COSMO – GR model named COSMO-Greece, which runs for a domain of Greece and gives forecasts for up to 48 hours with horizontal resolution of 3 km.



The SKIRON/Eta model is a non-hydrostatic model and its operational domain at HNMS is 26N – 56N and 20W – 40E with a spatial resolution of 0.060 (~ 7km). It runs and gives forecasts for up to 72 to 120 hours (depends on resolution). The SKIRON/Eta does not run operationally at present at HNMS, while it runs for research purposes at University of Athens / Physics department.

All the models (ECMWF – global, COSMO models) are simulated at ECMWF supercomputer (Gray Gray XC30 System).

Climate models

In terms of climate modeling, in addition to COSMO - GR model, there is the COSMO – CLM which is the COSMO model in climate mode. As it is known, the COSMO model is the non-hydrostatic operational weather prediction model applied and further developed by the national weather services joined in Consortium for Small scale Modeling (COSMO).

The COSMO-CLM is a regional climate model and since 2005 runs as climate model for the German climate research. The model has been used for simulations on time scales up to centuries and spatial resolutions between 1 and 50 km. There are thoughts and intention to begin to install a version of COSMO-CLM in near future, in HNMS for Greek climate research needs.

HNMS and climate data

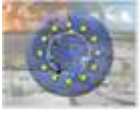
In terms of climatology, HNMS has developed a Climatological Database which contains climatological information of a series of meteorological parameters for several meteorological and climatological stations for the whole Greece.

The HNMS is responsible and updates a Greece data archive containing hourly and 3-hours (synoptic) and daily observations. These observations come from a network of meteorological stations that has changed over the years. This information has been used in order to derive a series of climate statistics which allows for climate descriptions spatial and temporal comparisons. First the meteorological data gathered at each station reach the HNMS headquarters in real time and in digital format. Then the data first are subject into primary checks and after that a semi-automatically quality control is applied in order to produce meteorological series of data, consistent in space and time. Changes in climate and trends can be investigated, using the long station based meteorological data. The spatial representativity is influenced by the missing data and inhomogeneities and depends on the nature of the variable and the number of stations providing information for an area.

Climate statistics are given for a number of meteorological variables and their departures from normals and several indices are provided for extreme temperature and rainfall phenomena.

In addition, the long – term averages for climate for Greece are available in a form of Climate Atlas for the period of 1971-1990 in digital form for the basic meteorological parameters (temperature and precipitation), while tabulated and graph data are available for the period of 1961-1990 for a greater number of meteorological parameters. In addition, there are similar data as for the period 1961-1990, for the period starting 1931 to 1960, but in paper format that means there is a need of digitizing these data and then produce the relative charts and graphs needed. Having available the climate data for the three mentioned periods, there is the possibility to investigate the climate variability or/and change.

A number of six representative (pilot) meteorological stations (Hellinikon, Mikra – Thessaloniki, Heraklion, Larisa, Kerkyra, Rodos) covering whole Greece have been selected in order to be available for the purposes and needs of EU-CIRCLE project. These stations provide long-term data on daily, monthly and yearly basis. The basic parameters are the following: temperature (min, max, mean), precipitation, relative humidity, winds and their frequencies, statistics on number of days with several phenomena, and other climatic statistics and indices.



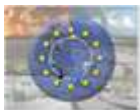
Annex 2: Analysis of data platforms providing hydrological data



Source	Operator	Website	Contact	Description	Observations (strengths and Weaknesses)
Hydrological Exploitation Platform - HEP	European Space Agency (ESA)	https://hydrology-tep.eo.esa.int/#/	hydrology-tep@esa.int	<p>Hydrology Thematic Exploitation platform project aim to facilitate the access and use of Earth Observation data to water community users:</p> <ul style="list-style-type: none"> > proposing a platform allowing users to access, process, visualise data. > providing EO services & products for hydrology applications (Flood monitoring and small Water bodies mapping, Water quality and level, Hydrological models). <p>It was thinking as a tool where the members of the community can rapidly and easily access to a large number of Earth Observation data, integrate their own data and tools (in-situ data, socioeconomic data, analysis tools...) and process their processors (service prototypes, hydrological models, meteorological models) within a user-friendly environment.</p>	<ul style="list-style-type: none"> > Scale: world > Access to the TEP Hydrology platform is currently restricted to invited early adopters.
Earth2Observe ("Global Earth Observation for Integrated Water Resource Assessment") WCI portal	Plymouth Marine Laboratory? (European research program with 27 partners and 4 associate partners)	http://www.earth2observe.eu/ https://wci.earth2observe.eu/portal/	bac@pml.ac.uk	<p>It is a collaborative project funded under the DG Research FP7 programme (2014-2017). The overall objective is to contribute to the assessment of global water resources through the use of new Earth Observation datasets and techniques. For this purpose, the project will integrate available earth observations, in-situ datasets and models, to construct a consistent global water resources reanalysis dataset of sufficient length (at least 30 years).</p> <p>The resulting datasets will be made available through an open Water Cycle Integrator data portal: the European contribution to the GEOSS/WCI approach.</p>	<ul style="list-style-type: none"> > Scale : world. > Case studies in the Mediterranean and Baltic Region and in Bangladesh. > Parameters (468 datasets --> https://wci.earth2observe.eu/data/group/earth2observe/): <ul style="list-style-type: none"> . EO data: soil moisture (m3 / daily / 1978-2015 / world / provider: TU Wien / resolution: 30 km) . In situ data: groundwater, surface water, water quality, soil moisture, precipitation and evaporation. > WCI portal: very user-friendly to find and visualize data: <ul style="list-style-type: none"> . Possibility to search data using different typologies (indicator type / data provider / region / interval / version / data type / etc.) . Possibility to produce a temporal graph to visualize a parameter evolution in a selecting geographic area.



Source	Operator	Website	Contact	Description	Observations (strengths and Weaknesses)
WOIS (Africa)	European Space Agency	http://www.tiger.esa.int/	walli@geo-ville.com	<p>TIGER initiative of the European Space Agency (ESA), whose main goal is the Support of the African Earth Observation Capacity for Water Resource Monitoring in close collaboration with African water authorities and experts.</p> <p>Development of an open-source Water Observation and Information System (WOIS) for monitoring, assessing and inventorying water resources in a cost-effective manner.</p> <p>WOIS 4.0 was released in 2016.</p>	<p>> Scale : Africa.</p> <p>> Free access to download the WOIS software by registration on the project website.</p> <p>> Parameters: proposition of different workflows (products) directly usable:</p> <ul style="list-style-type: none"> . Large Lakes Water Quality and levels monitoring (based on MERIS and AATSR data). . Medium resolution land degradation index (based on SPOT VGT NDVI time-series data). . Medium resolution full basin land cover characterization (based on MERIS and MODIS data and time series of biophysical SPOT VGT products). . High resolution land cover characterization (based on SPOT, RapidEye and Landsat data). . Water bodies mapping (based on index based classification). . Flood mapping (based on high resolution SAR data, including Sentinel-1 data). . Hydrological characterization (products from another models: Historical soil moisture at 1km resolution; historical and operational soil water index at 25km resolution; operational (daily) Evapotranspiration; historic and operational (daily) Precipitation). . Hydrological models (discharge)
Copernicus Program (previously known as GMES: Global Monitoring for Environment and Security)	European Space Agency / European Environment Agency (EU)	http://www.copernicus.eu/		<p>The Copernicus Program aim to capitalize existing datas (EO and in situ) on environment issues (six themes: land use / oceans / emergency / security / atmosphere / climate change). It have four components:</p> <ol style="list-style-type: none"> 1. EO data 2. In situ data 3. Standardization and harmonization of data 4. User services, developed by various projects funded by the European FP7: geoland2 (land use; quality and availability of water resources, climate change), MyOcean, MACC and MACC II 	<p>> Scale: world</p> <p>> Users: policymakers and public authorities</p>



D2.1 Report on Typology of Climate Related Hazards

Source	Operator	Website	Contact	Description	Observations (strengths and Weaknesses)
				(atmosphere).	
Copernicus Climate Change Service(C3S)	European Space Agency / European Environment Agency (EU)	http://climate.copernicus.eu/	http://climate.copernicus.eu/contact-us	<p>The service will give access to information for monitoring and predicting climate change and will, therefore, help to support adaptation and mitigation. It benefits from a sustained network of in situ and satellite-based observations, re-analysis of the Earth climate and modelling scenarios, based on a variety of climate projections.</p> <p>The service will provide access to several climate indicators (e.g. temperature increase, sea level rise, ice sheet melting, warming up of the ocean) and climate indices (e.g. based on records of temperature, precipitation, drought event) for both the identified climate drivers and the expected climate impacts.</p>	<p>> Data provided:</p> <ul style="list-style-type: none"> . Homogenised time series of in-situ observations and associated metadata . reprocessed climate data records from satellites, . output from global and regional reanalyses . seasonal forecasts . outputs from climate models including projections . searchable metadata relevant to provenance, traceability, use and applicability of all datasets. <p>> Users support with visualization tools.</p> <p>> Two projects are in progress on Water theme to product Sectoral Information Service (SIS) based on Sectoral Climate Impact Indicators (SCII) :</p> <ul style="list-style-type: none"> . EDgE: End-to-end Demonstrator for improved decision making in the water sector in Europe. . SWICCA: Service for Water Indicators in Climate Change Adaption (see below).



D2.1 Report on Typology of Climate Related Hazards

Source	Operator	Website	Contact	Description	Observations (strengths and Weaknesses)
SWICCA: Service for Water Indicators in Climate Change Adaption	Swedish Meteorological and Hydrological Institute (SMHI)	http://swicca.climate.copernicus.eu/start/climate-indicators/		<p>SWICCA offers readily available climate-impact data to speed up the workflow in climate-change adaptation of water management across Europe</p> <p>The SWICCA project is run from November 2015 to February 2018 by the Swedish Meteorological and Hydrological Institute (SMHI) together with 10 sub-contractors from across Europe and 3 in-kind partners.</p>	<p>> Scale: Europe.</p> <p>> Various parameters directly usable: each have a data description sheet (resolution, origin, Update frequency, etc.), with a link to visualize and another to download the datas.</p>
Copernicus Land Use Service	European Space Agency / European Environment Agency (EU)	http://land.copernicus.eu/	hans.dufourmont@eea.europa.eu	<p>The Copernicus land monitoring service provides geographical information on land cover/land use and on variables related to vegetation state and the water cycle. It supports applications in a variety of domains, such as spatial planning, forest management, water management and agriculture and consists of the following four main components.</p>	<p>> Scale: Europe.</p> <p>> Parameters: land use.</p> <ul style="list-style-type: none"> . Corine Land Cover (global land use database). . EU-Hydro (Pan-European hydrographic reference datasets covering the EEA39 countries). . EU-DEM (Pan-European elevation reference datasets covering the EEA39 countries). . Water Bodies product (maps the areas covered by inland water along the year providing the maximum and the minimum extent of the water surface as well as the seasonal dynamics). . Soil Water Index (SWI) product (quantifies the moisture condition at various depths in the soil).



Source	Operator	Website	Contact	Description	Observations (strengths and Weaknesses)
CryoLand (Copernicus Service Snow and Land Ice)	European Space Agency / European Environment Agency (EU)	http://www.cryoland.eu/	Online	<p>CryoLand developed, implemented and validated a standardized and sustainable service on snow and land ice monitoring as a Downstream Service within Copernicus.</p> <p>It provides geospatial products on the seasonal snow cover, glaciers, and lake / river ice derived from Earth observation satellite data.</p> <p>The CryoLand project (funded by the FP7 Program) was successfully completed in January 2016. Nevertheless, the near-real time services of selected products have been extended beyond the lifetime of the project, and are providing the continuity of near-real time information on snow and land ice for our users.</p>	<p>> Scale: European.</p> <p>> Parameters: snow and ice monitoring (data from EO).</p> <p>> CryoLand Geoportal: interactive maps / search and download functions.</p>



Source	Operator	Website	Contact	Description	Observations (strengths and Weaknesses)
JRC Water Portal	European Commission	http://water.jrc.ec.europa.eu/waterportal		<p>The Joint Research Centre (JRC) is the European Commission's science and knowledge service which employs scientists to carry out research in order to provide independent scientific advice and support to EU policy.</p> <p>The JRC water portal serves as the gateway to JRC's products on freshwater and marine water resources, providing access to water data, publications, and maps, as well as to water projects and events.</p>	<p>> Scale: Europe.</p> <p>> The Water Resources Datasets are available as a Web Map Service (WMS) in accordance with the Open Geospatial Consortium (OGC) specifications. The data layers can be incorporated to any web application.</p> <p>> Parameters: a catalog of datas allow users to visualize on the european map or to download it, with limited specifications access. Parameters available:</p> <ul style="list-style-type: none"> . Soil moisture stress map . Some indicators on water quantity (water availability, annual precipitation, etc.). . High Resolution Precipitation Datasets . Socioeconomic indicators on water use (water abstraction by sector, water cost, etc.). . Flow characteristics. <p>> Two type of request:</p> <ul style="list-style-type: none"> . GetCapabilities: produces the information about the layers contained in the service in the form of a descriptive XML document. . GetMap: using the result of the GetCapability request, it returns a raster map with the requested layer selected from all the available layers as define in the XML document.
HYPEweb (Regions with HYdrological Predictions for the Environment)	SMHI	http://hypeweb.smhi.se/	mailto:Hydro.fou@smhi.se	<p>The hydrological catchment model HYPE simulates water flow and substances on their way from precipitation through soil, river and lakes to the river outlet (Arheimer et al., 2008; Lindström et al., 2009). The catchment is divided into subbasins which in turn are divided into classes (calculation units) depending on land use, soil type and elevation</p>	<p>> SMHI proposes an open data portal for free download from multi-basin and large-scale applications of the HYPE model world-wide.</p> <p>> Scale: regional (swedish coast, baltic sea, coasts of continental Europe, coasts of sub-indian continent, etc.).</p> <p>> Parameters: astomsphere; river discharge; runoff from land; ETP; water temperature; snow), with the possibility to take into account climate change for ones of it (ETP, runoff, precipitation, snow and river discharge).</p>

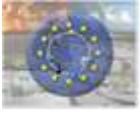


D2.1 Report on Typology of Climate Related Hazards

Source	Operator	Website	Contact	Description	Observations (strengths and Weaknesses)
AQUAMAPS	FAO	http://www.fao.org/nr/water/aquamaps/		<p>AquaMaps is the FAO global online spatial database on water and agriculture. It makes accessible through a simple interface regional and global spatial datasets on water resources and water management considered as a standard information resource, produced by FAO or by external data providers.</p> <p>AquaMaps is complementary to AQUASTAT, FAO's Information System on Water and Agriculture. While AQUASTAT focuses on collecting mainly statistical data and qualitative information on (sub)country level, AquaMaps concentrates on geographical information.</p>	<ul style="list-style-type: none"> > Scale: world. > Origin of the data: the FAO GeoNetwork data catalogue from which it retrieves a thematic collection of layers, data and metadata, allowing users to query, explore, and download spatial data in commonly used GIS format. > Parameters divided by themes: <ul style="list-style-type: none"> . River and water bodies: regional hydrographic networks derived from Hydrosheds . Irrigation and infrastructures: area equipped for irrigation, dams . Hydrological basins: global and regional layers of hydrological basins derived from Hydrosheds . Climate: Monthly grids of precipitation and reference evapotranspiration . Models: output grid of FAO global soil water balance model (GlobWat), including modeled actual evapotranspiration, runoff and infiltration . Analyses: examples of global analyses performed on the basis of the above mentioned dataset. > GIS portal: very user-friendly to find and visualize data: <ul style="list-style-type: none"> . Possibility to search data using the theme above mentioned. . Direct accessibility to datasets detailed specifications.
Scalgo Live Global	SCALGO	scalgo.com/live	mailto:info@scalgo.com	<p>SCALGO Live Global provides a unique way of understanding the effect of global topography (mountains, valleys, etc.) on the flow of surface water and flood risk. It allow users to visualize flooding and surface water flow on a near-global elevation model (the SRTM-model from NASA).</p> <p><i>NB: SCALGO also developed SCALGO Live Flood Risk in the same way.</i></p>	<ul style="list-style-type: none"> > Scale: world. > Parameters: topography (SRTM-model from NASA); Flow Accumulation; sea level rise; Watersheds. > No specifications about the datasets used on the platform. > Good tool to easily visualize simple hydrological parameters .



Source	Operator	Website	Contact	Description	Observations (strengths and Weaknesses)
Geoportail	IGN	https://www.geoportail.gouv.fr/		Geoportail is a French national portal (manage by the National Geographic Institute) that aims to facilitate the public access to reference geographic databases (2D and 3D). It propose a visualization platform allowing a good interoperability between various information layers. It propose various services for all.	<ul style="list-style-type: none"> > Scale: France. > User-friendly platform: easy visualization / access to data specifications. > Hydrological database available: hydrographic network (land use).
EOSDIS (Earth Observing System Data and Information System)	NASA	https://earthdata.nasa.gov/about		<p>EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs. NASA network capabilities transport the EO data to the science operations facilities.</p> <p>The remaining capabilities of EOSDIS constitute the EOSDIS Science Operations, which are managed by the Earth Science Data and Information System (ESDIS) Project. These capabilities include: generation of higher level (Level 1-4) science data products for EOS missions; archiving and distribution of data products from EOS and other satellite missions, as well as aircraft and field measurement campaigns.</p>	<ul style="list-style-type: none"> > Scale: world. > All data in EOSDIS are held on-line and accessed via ftp and http. > Data provides: <ul style="list-style-type: none"> . LANCE Near Real-Time Data: access near real-time products from the AIRS, AMSR2, MISR, MLS, MODIS, OMI and VIIRS instruments in less than 3 hours from observation from the Land, Atmosphere Near real-time Capability for EOS (LANCE). . Worldview: Interactively browse full-resolution, global, near real-time satellite imagery from 200+ data products from LANCE and other NASA data providers. . GCMD: The Global Change Master Directory (GCMD) is a directory to Earth science data and services. The GCMD database currently holds more than 25,000 Earth science data sets and services covering all aspects of Earth and environmental sciences. . Earthdata Search: it provides easy-to-use access to EOSDIS services for Earth science data discovery, filtering, visualization, and access. It also serves as a platform to feature planned EOSDIS services as they become available. . The CEOS WIGISS Integrated Catalog (CWIC) is being developed by the Committee on Earth Observation Satellites (CEOS) to provide a framework that allows for easier search and access of Earth Observation data via partnering of CEOS agency data systems. > Hydrological parameters available on Earthdata Search portal: atmosphere data (winds, precipitation, temperature, clouds, atmospheric water vapor); cryosphere data (snow, ice, sea ice); land data (land use, soils, topography); hydrosphere.



Annex 3: Analysis of data available by hydrological parameter



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
Copernicus Land Use Service	ESA / EEA	Watershed information (land use, soil types, landscape, rugosity...) : 2D information	m and m²	Corine Land Cover (CLC)	http://land.copernicus.eu/pan-european/corine-land-cover/view	<p>The CORINE Land Cover (CLC) inventory consists of an inventory of land cover in 44 classes. It cover the EEA39 countries. There are two types of database:</p> <p>> Complete database: polygons > 25 ha.</p> <p>> Changes database: identification of land use change > 5ha.</p> <p>Recommended Use Scale: 1/100 000</p>	Europe	Space	CLC1990: MSS/TM (single date) CLC 2000: ETM (single date) CLC2006: SPOT and LISS III (dual date) CLC 2012: LISS III and RapidEye (dual date)	CLC1990 : < 50m CLC2000 , 2006 & 2012 : < 25m	SHP; WMS GeoTIFF	25ha for the complete database 5 ha for changed database	Single occurrence	Interactive form	
Copernicus Land Use Service	ESA / EEA	Watershed information (land use, soil types, landscape, rugosity...) : 2D information	m and m²	EU-Hydro	http://land.copernicus.eu/pan-european/satellite-derived-products/eu-hydro/view	<p>Pan-European hydrographic reference datasets covering the EEA39 countries. Integrated EU-Hydro database (hydrographic and drainage database) is available in geodatabase format and contains:</p> <ul style="list-style-type: none">- hydrographic nodes, lines, and polygons;- drainage network elements (basins, catchments, drainage lines and nodes);- dams;- coastlines and land polygons.	Europe	Both space and in situ		20m	Geodata-base format	2,5m	Single occurrence	Interac-tive form	



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
Copernicus Land Use Service	ESA / EEA	Topography (or bathymetry): 3D information	m	EU-DEM	http://land.copernicus.eu/pan-european/satellite-derived-products/eu-dem	Pan-European elevation reference datasets covering the EEA39 countries.	Europe	Space	NASA ICESat satellite	Geoscience Laser Altimeter System (GLAS)	25m	Geotiff	25m (+/- 7m for the vertical accuracy)	Single occurrence	Interactive form
Copernicus Land Use Service	ESA / EEA	Topography (or bathymetry): 3D information	m and m ²	Water Bodies product	http://land.copernicus.eu/global/products/wb	The Water Bodies product maps the areas covered by inland water along the year providing the maximum and the minimum extent of the water surface as well as the seasonal dynamics (the area of water bodies is identified as an Essential Climate Variable by the Global Climate Observing System).	Global	Space		> PROBA-V > SPOT-VGT	0,009°	.zip archive (Geotiff, xml, xls)	Global, 10°x10° tiles, continental tile, 1km	The Water Bodies product is a 10-days composite.	Free by ftp and Eumetcast



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
Copernicus Land Use Service	ESA / EEA	Soil water content	m3	Soil Water Index (SWI) product	http://land.copernicus.vgt.vito.be/geonetwork/srv/eng/main.home?any=79407e56-e2e2-11e1-ba49-0019995d2a56	The Soil Water Index quantifies the moisture condition at various depths in the soil. It is mainly driven by the precipitation via the process of infiltration. The Surface Soil Moisture L2 product is derived from the Advanced SCATterometer (ASCAT) data and given in swath geometry. This product provides an estimate of the water saturation of the 5 cm topsoil layer, in relative units between 0 and 100 [%].	Global	Space	Metop	> ERS-2 AMI_WS between 1997 and 2003 > METOP-ASCAT from 2007 onwards	0,1°		25km	Daily	Products can be downloaded on-line via HTTP. They are also available through EUMETCAST. Bulk downloads and near-real time dissemination can be requested at our helpdesk.
Hydrological Exploitation Platform - HEP	ESA	River water level	m	Flood Monitoring	https://hydrology.tep.eo.es/a.int/geobrowser/?id=floodmonitoring#!&context=EOData%2FSentinel-1GRD	Historical analysis of large floods events at medium resolution using Sentinel-1 GRD data and archive MODIS data for results refinement. Flood monitoring detailed mapping of affected areas at high resolution.	Global	Space	Sentinel-1	> GRD					
Earth2Observed (WCI portal)	Plymouth Marine Laboratory	Soil water content	m3	Soil Moisture	ftp://wci.earth2observed.eu/data/primary/public/tuwien/	Data provided by TU Wien.	Global	Space					30km	Daily	ftp



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
Earth2Observe (WCI portal)	Plymouth Marine Laboratory	Water content in groundwater	mm	Water content in groundwater	https://wci.earth2observe.eu/portal/	5 models (W3RA / LISFLOOD / HBV-SIMREG / Surfex-Trip / PCR-GLOBWB) provided by 4 operators (CSIRO / JRC / Meteo France / Utrecht University)	Global	In situ						Daily and Monthly	
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Humidity	%	Relative Humidity	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	Relative humidity is a measure of the air's actual water vapour content in relation to the water vapour at saturation. For each 30-year analysis period, the available indicator for relative humidity is: - Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period Note that the data is based on uncorrected climate model data. For the reference period (1971-2000) absolute values are given, for the future period(s) relative change. The regional climate model simulations were performed as part of the CORDEX project.	European				0,1*0,1°	Excel	Grid size: 650*390	Projection of climate change effect on rainfall (RCP scenarios)	



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series			
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access	
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Rainfall	mm/d	Precipitation	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	<p>For each 30-year analysis period, the available indicators for precipitation based on daily data are:</p> <ul style="list-style-type: none">-Mean: full period mean of all daily values.-Seasonality: expressed by the mean values of all Januaries, Februaries etc. that are part of the 30-year period.-Percentiles: 95th and 99th percentiles of all daily data in the 30-year period.- Variability: inter-annual variability of monthly mean values expressed as standard deviation of all monthly mean values that belong to the same month in the analysed period.-Daily: daily time series. <p>This climate impact indicator is based on hydrological impact modelling performed within the EU FP7 project IMPACT2C (grant agreement 282746). The climate impact indicators are based on hydrological impact modelling using the hydrological model LISFLOOD.</p>	European						Excel	5km	Projection of climate change effect on rainfall (RCP scenarios)	



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Dryness	n° of days	Dry spells	http://swicca.climate.copernicus.eu/interface/graphs-and-download/	Two indicators are given to describe dry spells (periods with consecutive dry days) statistics during 30-year periods in the data: -Longest dry spell: the largest number of consecutive days during which the precipitation is less than 1 mm/day. -Number of dry spells: the number of dry spells with a length of more than 5 days during which precipitation is less than 1 mm/day. This climate impact indicator is based on hydrological impact modelling performed within the EU FP7 project IMPACT2C (grant agreement 282746). The climate impact indicators are based on hydrological impact modelling using the hydrological model LISFLOOD.	European					Excel	5km	Projection of climate change effect on rainfall (RCP scenarios)	
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Rainfall	mm/d	Precipitation Intensity Maximum	http://swicca.climate.copernicus.eu/interface/graphs-and-download/	The indicator "Precipitation Intensity Maximum" represents the average of all annual maximum hourly precipitation intensities within a period of 30 years.	European				0,1°0,1°	Excel	Grid size: 650*390	Projection of climate change effect on rainfall (RCP scenarios)	
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Rainfall	mm / duration	Precipitation Intensity Duration	http://swicca.climate.copernicus.eu/interface/graphs-and-download/	The Precipitation Intensity Duration indicator provides information about precipitation intensities at different levels of return periods (10, 50 and 100 year return period) and for	European				0,1°0,1°	Excel	Grid size: 650*390	Projection of climate change effect on	



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
					us.eu/indicator-interface/graphs-and-download/	different time resolutions (1, 2, 3, 6, 12 and 24 hourly data).								rainfall (RCP scenarios)	
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Temperature of the surface water	°C	Water Temperature: mean and seasonality	http://swi.cca.climate.copernicus.eu/indicator-interface/graphs-and-download/	Water temperature is the in-stream temperature. For each 30-year analysis period, the indicators for water temperature are: -Mean: full period mean of all daily values. -Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period	European					Excel	Irregular catchment polygons, median catchment size 215km².	Projection of climate change effect on rainfall (RCP scenarios)	
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Water quality (turbidity, eutrophication, total suspended matter (SM))	µg/l (concentration) kg (loads)	Phosphorous and Nitrogen loads and concentrations	http://swi.cca.climate.copernicus.eu/indicator-interface/graphs-and-download/	For each 30-year analysis period, the indicators for water temperature are: -Mean: full period mean of all daily values. -Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period	European					Excel	Irregular catchment polygons, median catchment size 215km².	Projection of climate change effect on rainfall (RCP scenarios)	



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Discharge	m ³ /s	River Flow (daily, seasonality and mean)	http://swi.cca.climate.copernicus.eu/indicator-interface/graphs-and-download/	River flow is the volume rate of water flow that is transported through a given cross-sectional area. It is synonym to river discharge or streamflow. For each 30-year analysis period, the indicators for river flow are: -Mean: full period mean of all daily values -Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period -Daily: daily time series	European				0,5*0,5	Excel	5km	Projection of climate change effect on rainfall (RCP scenarios)	
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Discharge	m ³ /s	Flow duration curve	http://swi.cca.climate.copernicus.eu/indicator-interface/graphs-and-download/	The flow duration curve (FDC) gives information about how frequently certain river flow rates occur. Here, the FDC is described through 13 percentiles of the distribution of daily river flows during a 30-year period: •1 % •5 % •10 % to 90 % in steps of 10 % •95 % •99 %	European				0,5*0,5	Excel	5km	Projection of climate change effect on rainfall (RCP scenarios)	
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Discharge	m ³ /s	Flood recurrence	http://swi.cca.climate.copernicus.eu/indicator-interface/graphs-and-download/	Flood recurrences are given as daily river flows that correspond to return periods of 2, 5, 10, 50, and 100 years. The return period values are calculated using a Gumbel distribution fitted to the yearly maximum river flows for a given 30-year period.	European				0,5*0,5	Excel	5km	Projection of climate change effect on rainfall (RCP scenarios)	



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Rainfall	mm/d	Water runoff	http://swi.cca.climate.copernicus.eu/indicator-interface/graphs-and-download/	Runoff is the sum of surface and subsurface runoff to streams for each grid cell. For each 30-year analysis period, the indicators for water runoff at catchment scale are: -Mean: full period mean of all daily values -Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period.	European					Excel	> Irregular catchment polygons, median catchment size 215km². > 0,5*0,5°	Projection of climate change effect on rainfall (RCP scenarios)	
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Soil water content	%	Soil water content: 10 days, seasonality and mean	http://swi.cca.climate.copernicus.eu/indicator-interface/graphs-and-download/	The soil water content represents the volume fraction of soil occupied by water, averaged over those soil layers that provide moisture for plant transpiration. This term includes all phases of water. -Mean: full period mean of all daily values -Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period -10 days: means over all days that fall into the same 10-day window when counting the days from the first day of each year	European					Excel	0,5*0,5°	Projection of climate change effect on rainfall (RCP scenarios)	



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
Copernicus Climate Change Service (C3S) - SWICCA	ESA / EEA / SMHI	Water content in snow and ice	mm	Snow Water Equivalent: seasonality and mean	http://swicca.climate.copernicus.eu/indicator-interface/graphs-and-download/	The snow water equivalent is a measure of the amount of water contained in the snow pack. It can be considered as the depth of water that theoretically would result if the whole snow pack instantaneously melts. Snow water equivalent is the product of snow depth and snow density. For each 30-year analysis period, the indicators for water runoff at catchment scale are: -Mean: full period mean of all daily values -Seasonality: mean values of all Januaries, Februaries etc. that are part of the 30-year period.	European					Excel	0,5*0,5°	Projection of climate change effect on rainfall (RCP scenarios)	
CryoLand (Copernicus Service Snow and Land Ice)	ESA / EEA	Water content in snow and ice	mm SWE	Snow Water Equivalent for Pan-Europe	http://cryoland.eu/	This product provides an estimate on the snow mass of dry snow. The product is derived from satellite microwave radiometry blended by snow-measurements from meteorological stations. Data Base: Passive Microwave Satellite Data and Mountain mask	European	Both space and in situ		SSM/I/S, AMSR2	10-25km	Raster file	10 to 20km	Daily	
JRC Water Portal	European Commission	Soil water content	d/year	Soil Moisture Stress map	http://data.jrc.ec.europa.eu/dataset/ede34cd3-71f5-49ef-bc02-67febf49dccc	Map shows the average number of days in a year on which soil moisture levels are not sufficient to meet the vegetation water demand.	European					TIF	5*5km	Annual	
JRC Water Portal	European Commission	Rainfall	mm/year	Annual precipitation for 1991-	http://water.jrc.ec.europa.eu/waterportal	Map shows the observed average annual precipitation between 1990 and 2010 obtained interpolation of the meteorological	European	In situ					5*5km	Annual	



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
				2010	al	observations available at JRC.									
JRC Water Portal	European Commission	Discharge	m ³ /s	Various indicators	http://water.jrc.ec.europa.eu/waterportal/	Map shows the different observed streamflows.	European								
AQUAMAPS	FAO	Watershed information (land use, soil types, landscape, rugosity...) : 2D information	m and m ²	Rivers in Europe	http://www.fao.org/nr/water/aquamaps/	Dataset derived from HydroSHEDS (WWF) drainage direction layer and a stream network layer. The drainage direction layer was created from NASA's Shuttle Radar Topographic Mission (SRTM) 15-second Digital Elevation Model (DEM). The raster stream network was determined by using the HydroSHEDS flow accumulation grid, with a threshold of about 100 km ² upstream area.	European	Both space and in situ		NASA radar		Raster and vector layer (ArcGis)			
AQUAMAPS	FAO	Watershed information (land use, soil types, landscape, rugosity...) : 2D information	m and m ²	Hydrological basins in Europe	http://www.fao.org/nr/water/aquamaps/	Major hydrological basins and their sub-basins. This dataset divides the European continent according to its hydrological characteristics (Dataset derived from HydroSHEDS (WWF)).	European	Both space and in situ		NASA radar		Raster and vector layer (ArcGis)			



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Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
AQUAMAP S	FAO	Evaporation and evapotranspiration	mm/year	Global map of monthly reference evapotranspiration - 10 arc minutes	http://www.fao.org/nr/water/aquamaps/	Grid with estimated reference evapotranspiration per month with a spatial resolution of 10 arc minutes. The dataset contains mean monthly values for global land areas, excluding Antarctica, for the period 1961-1990. The dataset has been prepared according to the FAO Penman - Monteith method with limited climatic data as described in FAO Irrigation and Drainage Paper 56. The dataset consists of 12 ASCII-grids with mean monthly data in mm/day * 10, and one ASCII-grid with yearly data in mm/year.	Global						10 arc minutes	Monthly	
AQUAMAP S	FAO	Rainfall	mm/year	Global map of monthly precipitation - 10 arc minutes	http://www.fao.org/nr/water/aquamaps/	Grid with estimated precipitation per month with a spatial resolution of 10 arc minutes. This dataset has been constructed from 27 075 stations with 1961-1990 climatological normals. The dataset consists of 12 ASCII-grids with mean monthly data in mm/day * 10, and one ASCII-grid with yearly data in mm/year. In addition, 12 ASCII-grid with monthly values at 5 arc minutes resolution are made available as input data for a global water balance model (GlobWat).	Global						10 arc minutes	Monthly	
AQUAMAP S	FAO	Dryness	%	Global map of aridity - 10 arc minutes	http://www.fao.org/nr/water/aquamaps/	Grid of estimated aridity with a spatial resolution of 10 arc minutes. This dataset represents average yearly precipitation divided by average yearly potential evapotranspiration, an aridity index defined by the United Nations Environmental Programme (UNEP).	Global						10 arc minutes	Monthly	



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Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
French National Base HYDRO (Vigicrues network - Realtime datas)	SCHAPI	River water level	m	Water level	http://www.vigicrues.gouv.fr/	Real time database on water level and river discharge over 1 650 hydrological stations (French State monitoring). Each station have a reference code which allow everyone to download its data from four weeks ago.	National (France)	In situ				XML WMS / WFS		Hourly	Opendata
French National Base HYDRO (Vigicrues network - Realtime datas)	SCHAPI	Discharge	m³/s	Discharge	http://www.vigicrues.gouv.fr/	Real time database on water level and river discharge over 1 650 hydrological stations (French State monitoring). Each station have a reference code which allow everyone to download its data from four weeks ago.	National (France)	In situ				XML WMS / WFS		Hourly	Opendata
French National database HYDRO (historical datas)	SCHAPI	River water level	m	Water level	http://www.hydro.eaufrance.fr/	The HYDRO database proposes water level measurements, at variable times) from about 5000 hydrological stations, located on French rivers and provides an access to the stations datas.	National (France)	In situ				XML WMS / WFS		Monthly	Obligation to sign a convention to download the data
French National database HYDRO (historical datas)	SCHAPI	Discharge	m³/s	Discharge	http://www.hydro.eaufrance.fr/	The HYDRO database calculate for each hydrological station the instantaneous, daily, monthly and annual streamflows; based on the water height values and calibration curves (relationships between heights and flow rates). These datas are regularly updated according to the information provided by the stations managers.	National (France)	In situ				XML WMS / WFS		Monthly	Obligation to sign a convention to download the data



D2.1 Report on Typology of Climate Related Hazards

Data location		Hydrological parameter		Database							Characteristics associated with the data		Characteristics of the data series		
Platform	Operator	Name	Unit	Name	Link	General description	Scale	Data from	Satellite name	Type of sensor	Spatial resolution	Format	Geographic	Temporal	Modalities of access
ADES	BRGM	Water content in groundwater	m	Piezometry	http://www.ades.eaufrance.fr/	French National database on ground water bodies (quality and quantity parameters). Regularly updated datas are available by measurement point or network, by watershed, region, department or water body. ADES also allows to manage and process data making available some softwares, like "Piez'eau" (for processing piezometric data).	National (France)	In situ						Variable (depend on the piezometric station)	Opendata
Carthage database	French National Geographic Institute	Watershed information (land use, soil types, landscape, rugosity...) : 2D information	m and m ²	French hydrological network map	https://www.data.gouv.fr/fr/datasets/bd-carthage-onm/	The Carthage database describe the french hydrological network. It is yearly updated by the French regional French Agencies.	National (France)					ESRI		Annual	Opendata