



I-CISK  
HUMAN CENTRED CLIMATE SERVICES

### Deliverable D3.3

Benchmarking tailored climate services for local applications using local knowledge and data

October 2024





Innovating Climate services through Integrating Scientific and local Knowledge

**Deliverable Title:** DL3.3 Benchmarking tailored climate services for local applications using local knowledge and data

**Author(s):** Lluís Pesquer (CREAF), Ilias Pechlivanidis (SMHI), Daniele Castellana (RC510), Vakho Chitishvili (CENN), Katherine Egan (ECWMF), Paolo Mazzoli (GECO), Alexandros Ziogas (ENVIS), Schalk Jan van Anandel (IHE), Amanda Batlle (CREAF), Ester Prat (CREAF), Micha Werner (IHE).

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## Executive Summary

The I-CISK project is focusing on the co-creation process of human-centred climate services (CS). The scientific work conducted in I-CISK aims to explore fit-for-purpose methodologies, tailored to address local needs. This document reviews the contribution of the tailored methods, local data, local knowledge and stakeholder feedback in order to achieve a higher usability of the I-CISK developed CS compared to the global and national ones (benchmarking). This analysis is done for all seven I-CISK Living Labs (LL), each with their own specific contexts and purposes.

Main conclusions of this work are:

- Most I-CISK CS developed high spatial resolution output models which are useful to understand the local impacts of climate change, and they allow to design better adaptation decisions and policy actions.
- Different downscaling techniques (specific for meteorological or hydrological applications) are applied in the specific tailored methods. The contribution of local data is totally relevant in these tailoring processes; the role of local knowledge is still low.
- Users demand several improvements on the visualization of the climate data (specially for uncertainty in prediction systems) to support a correct interpretation of climate information and to achieve the maximum usability to the sectors involved.

## Keywords

Climate Services, tailored information, usability, local data, local knowledge.

## About I-CISK

I-CISK's ambition is to innovate how climate information is used, interpreted and acted on through a next-generation of Climate Services that follow a human centred, social and behaviourally informed approach; integrating the knowledge, needs and perceptions of citizens, decision makers and stakeholders with climate information at spatial and temporal scale relevant to them.

Climate Services (CS) are crucial to empowering citizens, stakeholders and decision-makers in taking climate-smart decisions that are informed by a solid scientific evidence base, that contribute towards a sustainable European economy, lifestyle, environmental protection and resource use, and that are resilient to climate change and compatible with achieving climate neutrality. European and international collaborative research efforts, including Copernicus and GEOSS have established a solid scientific foundation for an effective CS value chain, including advanced scientific knowledge, monitoring and modelling of climate change and the impacts of climate extremes. However, several barriers challenge the current generation of CS in achieving the full opportunity of their value-proposition. These challenges include the failure to incorporate the social and behavioural factors and the local knowledge and customs of climate services users. Additionally, the effectiveness of climate services is challenged by; the still poorly developed understanding of the multi-temporal and multi-scalar dimension of climate-related impacts and actions; the translation of CS-provided data into actionable information; consideration of reinforcing or balancing feedback loops associated to users' decisions; and the lack of trans-disciplinary approaches across the full CS value chain.

I-CISK aims to seize these untaken opportunities through a human-centred framework for co-production of next generation CS that spans the full CS value chain taking the downstream part of the value chain as a starting point. The I-CISK framework realises the full potential of information provided through CS by empowering actors to take the impacts of extreme climatic events and climate change into account in their decisions.

## Table of Contents

1	Introduction.....	1
1.1	Purpose of this Document .....	1
1.2	Structure of this Deliverable .....	1
2	Integration of Local Data and Knowledge to Provide User-Tailored Information.....	3
2.1	Definitions .....	3
2.2	The I-CISK Living Labs and their challenges.....	3
2.3	Methods Followed to Transform Local Data / Knowledge in Tailored Information at each Living Lab5	
3	State-of-the-art in Tailoring Climate Services for Local Applications using Local Knowledge and Data.....	8
3.1	International Climate Services .....	8
3.2	National Climate Services.....	9
3.2.1	Climate Services in Spain .....	9
3.2.2	Climate Services in Georgia.....	10
3.2.3	Climate Services in Hungary.....	10
3.2.4	Climate Services in the Netherlands .....	10
3.2.5	Climate Services in Italy .....	10
3.2.6	Climate Services in Greece.....	11
3.2.7	Climate Services in Lesotho .....	11
3.3	Towards the Need for Tailored Climate Services.....	11
4	Benchmarking of the Implemented Climate Services across the Living Labs.....	13
4.1	Andalucía - Spain Living Lab .....	13
4.1.1	Climate Service description.....	13
4.1.2	Integration of local data and local knowledge.....	13
4.1.3	Usability of the tailored methods .....	14
4.1.4	Benchmarking .....	14
4.2	Alazani - Georgia Living Lab.....	15
4.2.1	Climate Service description.....	15
4.2.2	Integration of local data and local knowledge.....	16
4.2.3	Usability of the tailored methods .....	16
4.2.4	Benchmarking .....	16
4.3	Budapest – Hungary Living Lab .....	17
4.3.1	Climate Service description.....	17
4.3.2	Integration of local data and local knowledge.....	18
4.3.3	Usability of the tailored methods .....	18

4.3.4	Benchmarking .....	18
4.4	Rijnland - The Netherlands Living Lab.....	19
4.4.1	Climate Service description.....	19
4.4.2	Integration of local data and local knowledge.....	20
4.4.3	Usability of the tailored methods .....	20
4.4.4	Benchmarking .....	21
4.5	Emilia Romagna – Italy Living Lab .....	21
4.5.1	Climate Service description.....	21
4.5.2	Integration of local data and local knowledge.....	23
4.5.3	Usability of the tailored methods .....	23
4.5.4	Benchmarking .....	23
4.6	Crete – Greece Living Lab.....	23
4.6.1	Climate Service description.....	23
4.6.2	Integration of local data and local knowledge.....	24
4.6.3	Usability of the tailored methods .....	25
4.6.4	Benchmarking .....	25
4.7	Lesotho Living Lab .....	25
4.7.1	Climate Service description.....	26
4.7.2	Integration of local data and local knowledge.....	27
4.7.3	Usability of the tailored methods .....	27
4.7.4	Benchmarking .....	27
5	Summary of Lessons Learnt from the Local Applications.....	29
5.1	Lessons Learnt from the Local Applications at each Living Lab .....	29
5.2	Discussion and Moving Forward .....	31
	References .....	33

## List of Figures

Figure 1	Map of the seven I-CISK LL locations. ....	4
Figure 2	Screenshot of one (precipitation seasonal forecasts) of the implemented Spain LL climate services. It provides different percentiles of the ensembles results, median left upper figure and uncertainty/dispersion in the right upper. Plot of the 6 months forecasts of percentile ensembles of clicked location at the bottom. ....	13
Figure 3	Left: example of interactive survey about CS usability in bilateral meetings with LL stakeholders. Right: average feedback from all bilateral meetings.....	14
Figure 4	Left: Indicators selection legend of EDO and GDO. Right: Different experiment and model options in the Climate Data Store (CDS) of Copernicus. ....	15
Figure 5	Screenshot of forecast example of the Georgia LL pilot climate service.....	16
Figure 6	Urban heat map CS, Erzsébetváros district, Budapest.....	17
Figure 7	Drone controller (drones equipped with thermal cameras) for the Erzsébetváros campaign, Budapest. ....	18
Figure 8	Screenshot of LL Rijnland climate service component of seasonal river discharge forecast with low flow (drought) alert threshold indicated ( <a href="https://i-cisk.dev.52north.org/living-labs/rijnland-nl/app/">https://i-cisk.dev.52north.org/living-labs/rijnland-nl/app/</a> , last visited 2 October 2024) .....	19
Figure 9	Screenshot of Italy LL CS; left section – identifying the river station of interest. On the left side the user identifies the river station of interest using a map interface or a list, while on the right side (see next figures) river discharge forecasts are provided either as daily values for the incoming season (average and expected variability) or as monthly cumulate values, the latter is more interesting to the LL users with water storage capacity.....	21
Figure 10	Screenshot of Italy LL CS; right section – browsing the hydrological forecasts.....	22
Figure 11	Screenshot of Greece LL CS: (a) Seasonal forecasting of surface water availability at a basin level, including uncertainty information, and (b) seasonal forecast of landslide susceptibility locally and spatially variably covering the whole island.....	24
Figure 12	Screenshot of the Climate Service prototype for droughts, displaying drought risk levels across Lesotho districts for September and January based on user input. Additional layers can be accessed via the Layers menu. Please note that this is a prototype, and the final design may differ.....	27

## List of Tables

Table 1 Introduction to the living labs and the challenges address by I-CISK. ....	4
Table 2 Summary of the tailored methods and the usability of the local applications for each LL. ....	29

# 1 Introduction

## 1.1 Purpose of this Document

In the Description of Work of the I-CISK project it is stated that efforts will be targeted towards innovation and enhancement of existing climate services (CS) and downstream impact-based products, and consequently on the support of decisions and policies in multiple sectors accounting for their local trade-offs. In Work Package 3 (WP3), one of the aims is to address the local needs and sectoral gaps of existing CS, and therefore, various state-of-the-art methods will be used together with tools/methods to integrate local state-of-the-art observations and local knowledge. Both continental/global and local-scale process-based impact models, e.g. for the water and agriculture sectors, will be used to assess sub-seasonal, seasonal and centennial changes and impacts at the Living Lab (LL) scale. Therefore, a continuous dialogue with various WPs, e.g. WP1, WP2 and WP4, has been established to ensure a continuous exchange and feedback of information required to translate datasets into tailored information and indicators for local use.

The objectives of WP3 are:

- To advance local impact predictions and projections of climate change and future extremes by developing modelling chains that efficiently integrate existing CS while combining local data and knowledge for local tailoring.
- To explore different scientific state-of-the-art methods to bridge data and services currently separated on temporal and spatial scales (from forecasts to projections) and increase trust in local predictions.
- To evaluate the usefulness of the integrated impact predictions and assessments for local operations and decision-making from both a scientific and a user perspective.
- To unlock the benefits of transformation of data to information for and within the climate-sensitive LL regions and sectors by improving the confidence information of indicators while enhancing their usability.
- To develop user-driven visualisation tools that ensure robust and seamless transfer of produced information from CS, and communicate predictions, explicitly including uncertainty, for informed decision-making.
- To provide recommendations for product adaptations, extensions and CS improvements, and deliver fit-for-purpose tools, methods and products for user-tailored real-time operational services.

To achieve part of the objectives listed above, this document presents the currently ongoing work and reports on the advanced steps of the progress in WP3, while it addresses a series of specific objectives that include:

- Reviewing different approaches to the integration of local data and knowledge at the scale of the living lab to address the local user needs.
- Comparing the different usability of the existing international and national CS with the I-CISK dedicated CS.
- Describing the tailored methods to accomplish the user requirements in a co-design and co-develop process.
- Benchmarking the tailored CS over the spatial extent of the LLs.

## 1.2 Structure of this Deliverable

This deliverable is structured in 5 chapters:

- **Chapter 1** (current) is the introduction to the document presenting the scope.

- **Chapter 2** reflects on how local data and knowledge contribute to the creation of user-tailored information and presents the different methods followed at each LL.
- **Chapter 3** presents a summary of the state-of-the-art in tailoring Climate Services (CS) for local applications using local knowledge and data. It reviews major international initiatives and national climate services, offering a comparison of their key characteristics.
- **Chapter 4** is the main chapter of this deliverable and specifies the contribution of local data and knowledge for each LL and describes the usability of the tailored CS designed and implemented for all LL.
- **Chapter 5** provides the conclusions and a summary of the lessons learnt from the local applications within the LLs.

## 2 Integration of Local Data and Knowledge to Provide User-Tailored Information

### 2.1 Definitions

First, we revisit the general concepts of data, information and knowledge. **Data** refers to an unorganized collection of text, numbers, symbols and figures with no meaning. **Information** is the result of processing data; it is structured, becomes interpretable and gains significance. Finally, **knowledge** is information in context to produce an actionable understanding. Knowledge is the culmination of information and personal understanding; it is the use of information to solve problems (Frické 2018).

**Local data** refers to information which is collected, maintained, and stored within a specific (usually small scale) geographic area. There are different types: in-situ data, citizen observatories, earth observation (captured from multiple platforms: satellite, airborne, Unmanned Aerial Systems (UAS), etc.) in relation their typology sources.

Unlike scientific knowledge, which is developed through a formal and agreed methodology, **local knowledge** reflects the accumulated understanding of the environment by people living in close connection to it, such as farmers in rural areas, professionals in urban communities. They are acquired by the local people over a period of time through the accumulation of experiences over generations, society–nature relationships, and community practices and institutions' (Kniveton et al., 2014). In the context of climate predictions, local knowledge encompasses the native and intrinsic ways of making predictions based on the accumulation of knowledge by people who live in close ties with the natural environment (Hermans et al., 2022). The I-CISK deliverables [D3.1](#) "*Preliminary report on the skill assessment and comparison of state-of-the-art methods for forecasts and projections of extremes*" and D2.5 "*User Centred Validation of Climate Risk Knowledge Integration - Using Decision Timelines for Collecting, Understanding, and Integrating Local Knowledge*" explain in detail the concepts, types, roles and contributions of local knowledge and local data and their integration.

Various studies have highlighted that the climate information produced does not properly meet the user needs and requirements (Vincent et al., 2017; Singh et al., 2017) in some (or many) cases. This gap is sometimes referred to as the "valley of death" between climate information producers and users (Buontempo et al., 2014). **Tailored information** is that which has been specifically customised to meet these user preferences and needs, building a bridge between producers and users to reduce this gap.

### 2.2 The I-CISK Living Labs and their challenges

I-CISK selected seven LL in different geographic areas, at Europe and beyond (Figure 1). These LL are identified as climate change hotspots with a strong climate change signal and potential increased trend of multi-hazard events (Ridder et al., 2020). I-CISK LL have been established with a group of stakeholders who defined the needed functionalities and user requirements of the I-CISK CS in a co-generation process. These CS aim to respond the ambitions and needs of these stakeholders, multi-sectorial or specific to a sector (tourism, agriculture, water management, etc.) depending on the LL. The design, development and implementation of the tailored CS are big challenges for the project. Table 1 summarizes these challenges for each LL and the I-CISK approach to address them.



Figure 1 Map of the seven I-CISK LL locations.

Table 1 Introduction to the living labs and the challenges address by I-CISK.

Living Lab	Challenge	I-CISK approach
Andalucía - Spain	CS addressed to specific sectors and general purposes at same time. High resolution climate models.	Development of 2 sectorial CS + 3 general ones addressed to user requirements. Local data injection + downscaling methods.
Alazani - Georgia	Streamflow forecasts integrated in a water resources management system.	Tailored model of seasonal hydrological forecasting adjusted to sub-basin conditions.
Budapest – Hungary	Multi-source data integration. Support tool to implement heat island mitigation measures.	Data fusion techniques of heterogeneous sources of local data. Accurate representations of urban heat distribution.
Rijnland - The Netherlands	Increase awareness of short to long term drought risk and adaptation strategies.	CS drought alert service including impact of the climate change scenarios.
Emilia Romagna – Italy	Hydrological forecasts at sub-catchment level. Effectively communication of climate information.	Downscaling with the incorporation of local time series data (flow measurements). Co-design, user friendly interfaces, improvement in visualization functionalities.

Crete – Greece	CS addressed to the sectorial needs at different temporal and spatial scales. Supporting long-term planning adaptation measures	Seasonal forecasts of surface water availability and Landslide Susceptibility. To be defined.
Lesotho	Impact-based forecasts in a management. Centralized platform that consolidates information from spread local data.	Guidelines by a Vulnerability assessment Committee. Under discussion with stakeholders.

### 2.3 Methods Followed to Transform Local Data / Knowledge in Tailored Information at each Living Lab

Global Circulation Models (GCM) are mathematical representations of the Earth’s climate system to assess the impact of large-scale climate variations. These models simulate interactions between the atmosphere, land surface, oceans and ice surfaces at global scales. However, GCMs are not always adequate to address the interdisciplinary climate questions that stakeholders are concerned with. From the user requirements perspective, the strong preference is to obtain forecasts and climate projections at local scales (Jacobs et al., 2020). Therefore, some efforts should be towards overcoming some users’ distrust: “confidence in the data is highest at continental scales but lowest at the local scale” (Porter and Dessai 2017).

The demanded **spatial resolution, higher** than the existing state-of-the-art GCM outputs, is crucial for understanding the vulnerability and potential impacts of climate change. It also supports the design of better adaptation strategies and policy actions. Fine-scale climate information is derived by assuming that local climate is conditioned by interactions between large-scale atmospheric characteristics (circulation, temperature, moisture, etc.) and local features (topographic features, water bodies, land surface properties, etc.). Downscaling methods are the primary techniques used to increase spatial resolution. There are three types of downscaling: statistical, dynamical (high-resolution regional simulations) and deep learning downscaling. Trzaska and Schnarr (2014) compare statistical and dynamical downscaling, noting that high quality observational data is the main requirement for statistical downscaling, thus we need the contribution of **local data**. On the other hand, the main requirement for dynamical downscaling is high computational resources to run complex physical models.

Andalucía LL: Particularly in the context of I-CISK, statistical downscaling is the preferred method for the challenge of the generation of high spatial resolution models, tailored CS **meteorological** variables and the derived products in this LL. For the statistical downscaling, the relationship between present large-scale circulation and local climate remains valid under different forcing conditions of possible future climates (stationary assumption; Dixon et al., 2016). The statistical downscaling can be combined with **bias correction** (or bias adjustment). The Bias Correction (BC) approach corrects the predicted model outputs by accounting for differences in mean and variability between model projections and reference observations over a reference period. Two bias correction methods that have been used within I-CISK, the Distribution Based Scaling (DBS) and Multi-scale bias AdjuStment (MidAS) (Berg et al., 2022) belong to the Empirical Quantile mapping (EQM) family of methods. Here, biases are calculated for each percentile in the cumulative distribution function (CDF) of the present simulation. Finally, the calculated biases are applied to future simulations to correct the biases of each percentile. The accuracy of this process relies heavily on the quality of the observational data in the reference period, making **local data** crucial to the success of the BC. In addition, local knowledge helps select and weight the contribution of local features such as elevation, aspect, potential radiation, and distance to the coastline in the statistically downscaling method (multilinear regression with residual interpolation; Ninyerola et al., 2007). Local data is also essential to make an

independent evaluation of the downscaling process and to complement the finer spatial variability of the uncertainty.

Alazani, Rijnland and Emilia Romagna LLs: The I-CISK downscaling methods for seasonal **hydrological** forecasting aim to address discrepancies of the CS outputs at the locations that decisions are made due to the coarser discretization of the hydrological model or even due to mismatches in the delineation. The method involves calculating a scaling factor for each Point of Interest (POI) within their river basin. The scaling factor for each Point of Interest (POI) has been calculated by dividing the sub-basin watershed area of each POI by the watershed area at the outlet of the European Hydrological Predictions for the Environment (E-HYPE) (by Swedish Meteorological and Hydrological Institute (SMHI)) basin model, where the seasonal forecast data is available. This scaling factor is then applied to the forecasted flow rate for each POI. HYPE model is a semi-distributed, physically based catchment model, which simulates water flow and substances (Lindström et al., 2010). The WWH and E-HYPE model setups over the globe and Europe respectively, are used in most LLs within the project (see [I-CISK deliverable D3.2 “Skill assessment and comparison of state-of-the-art methods for forecasts and projections of extreme”](#)), and these models are implemented as CS in the Alazani LL, Rijnland LL and Emilia Romagna LL in collaboration with the SMHI. This approach ensures that the forecasted flow rates are adjusted to reflect the specific characteristics of each POI. By applying this scaling factor, the forecasts become more localized and relevant to sub-basin conditions.

Budapest LL: The tailored methods in the Hungary LL constitutes an integrated approach of a multi-layered analysis that captures the thermal properties and the visible characteristics of urban areas. Their goal is to generate accurate representations of **urban heat distribution**, enhancing our understanding of urban environmental dynamics. The contribution of local data in form of orthophotos, thermal infrared (TIR) remote sensing and images and citizen science observations is crucial for these purposes. Local datasets are transformed in tailored information through data fusion techniques of drone TIR images with satellite data, enhanced heat pattern recognition by convolutional neural network (CNN; Yoo et al., 2019) and orthophoto aided vegetation indexing for correlation analysis of green spaces with temperature variations.

Crete LL: With the aim of providing specific hazard severity indicators to the LL sectorial needs, the I-CISK tailored method is a seasonal **Landslide Susceptibility** forecast, based on precipitation seasonal forecasts. It is a hybrid implementation of the Rock Engineering System method (Tavoularis et al., 2021) based on static data, with incorporation of dynamic data in the analysis. It uses a model produced by the statistical correlation of ten parameters, selected as controlling factors for the landslide occurrence: distance from roads, slope, aspect, lithology, hydrogeological conditions, rainfall, land use, distance from streams, distance from tectonic elements, and elevation. Static information is collected from local data (as implemented in the Crete LL). The original method is modified by incorporating rainfall, sourced from Copernicus EU, as a dynamic parameter. This method provides seasonal forecasts of Landslide Susceptibility for the whole island of Crete at a resolution of 1km x 1km.

Lesotho LL: Here, data used to inform early actions to mitigate the impact of **droughts** is sourced from local providers. Lesotho Meteorological Services (LMS) and the Lesotho Disaster Management Authority (DMA) are the key stakeholders, offering expertise in rainfall forecasting, observations, and **vulnerability assessments**. This collaboration is formalized within the Anticipatory Action protocol, which ensures a structured and proactive response to potential droughts. The use of **local expertise** is intended to promote sustainability and build national capacity. Rainfall forecasts are generated using meteorological data from global centres such as the National Oceanic and Atmospheric Administration (NOAA) and the European Centre for Medium-Range Weather Forecasts (ECMWF). LMS downscales these global forecasts using station data and reanalysis information. Rainfall observations, collected from monitoring stations, support real-time assessments. Seasonal forecasts are issued in September, with an additional assessment in January following observations

made throughout the rainy season. Vulnerability assessments are conducted by the Lesotho Vulnerability Assessment Committee (LVAC), a group of government entities and humanitarian partners, with DMA as key partner. LVAC provides essential data on food and nutrition security, livelihoods, and socio-economic vulnerability, guiding both early action and emergency response efforts. Since 2017, LVAC has produced assessments on International Food Phase Classification and food insecurity projected for the next consumption year, and it releases key data during the rainy season.

### 3 State-of-the-art in Tailoring Climate Services for Local Applications using Local Knowledge and Data

In this chapter, we review the main international initiatives which develop global CS, along with national initiatives for the countries involved in the seven LL. Chapter 3 is important to set the scene of existing benchmarks and justify the importance of tailored climate services. Later in Chapter 4, the existing international and national CS will be addressed and compared with the CS developed within I-CISK.

Climate services can be described as the generation, provision, and contextualisation of consistent, authoritative, and timely climate information to support decision-making. The main task is to transform climate-related data into customised products, advise on best practices, and develop and evaluate solutions that may be useful for society (Street 2014). They generally involve tools, products, websites, or bulletins. (Vaughan and Dessai, 2014). They can be global, regional or local, and for general purposes, multidisciplinary or focused on a specific sector (health, tourism, agriculture, water management, etc.) or dedicated to concrete hazards (floods, droughts, forest fires, urban heat waves, etc.). They can be multitemporal or addressed to specific timescale, including hindcast, sub-seasonal or seasonal forecasts, decadal or centennial climate projections. The tailored information provided by the corresponding CS should consider all these aspects.

#### 3.1 International Climate Services

A number of global and continental climate services are available being able to meet the requirements of I-CISK LL users. These are described in detail in the I-CISK deliverable D3.1 *“Preliminary report on the skill assessment and comparison of state-of-the-art methods for forecasts and projections of extremes”* and summarized below:

- **Copernicus:** Copernicus is the European Union’s Earth Observation Programme ([www.copernicus.eu](http://www.copernicus.eu)). It provides a range of services covering the atmosphere, oceans, land, climate change, security and emergency services. Most of the Copernicus CS, which could be potential solutions to I-CISK goals and activities, are hosted in the C3S (Copernicus Climate Change Service) <https://climate.copernicus.eu/>. In addition, the Copernicus Emergency Management Service (CEMS) is of high relevance for some of the project’s LLs (see Chapter 4), particularly the Copernicus Drought Observatories for Europe (EDO) and the globe (GDO); see <https://drought.emergency.copernicus.eu/>.
- **European Climate Data Explore:** This CS is in the frame of a European Climate-ADAPT (<https://climate-adapt.eea.europa.eu>) initiative. The most relevant is the Agriculture CS, which provides a set of agroclimatic variables at 0.25 degree spatial resolution (<https://climate-adapt.eea.europa.eu/en/knowledge/european-climate-data-explorer/agriculture>). Also, the Water and coastal CSs collect hydrological and marine datasets at 0.25 degree spatial resolution <https://climate-adapt.eea.europa.eu/en/knowledge/european-climate-data-explorer/water-and-coastal>.
- **FAO:** The Food and Agriculture Organization (FAO) hosts the Agricultural Stress Index System (ASIS; <https://asis.apps.fao.org/>). It monitors agricultural areas with a high likelihood of water stress/drought on a global scale using satellite technology (Rojas et al., 2013). ASIS provides all raster datasets through the FAO Hand-in-Hand Geospatial Portal and the Google Earth Engine (GEE). The AQUAMAPS (<https://data.apps.fao.org/aquamaps/>) is AQUASTAT’s online geospatial (regional and global) database on water resources and agriculture with geospatial modelling and analytics functionalities for water management.

- **GEOSS:** The Global Earth Observation System of Systems (GEOSS) has developed several CSs under different specific initiatives such as the Global Water Sustainability (GEOGLoWS; <https://www.geogloWS.org/pages/geogloWS-service>), the Global Drought Information System (GDIS; <https://earthobservations.org/organization/work-programme/global-drought-information-system>), the Crop Monitor by GEOGLAM (<https://cropmonitortools.org/tools/cmet/>) and AquaWatch (<https://www.aquawatchsolutions.com/>).
- **WMO:** The World Meteorological Organization (WMO) developed the Climate Services Information System (CSIS) as the core of the Global Framework for Climate Services (GFCS). Some selected specific CSs which could fit to the needs of the I-CISK LL users, are: the Integrated Drought Management HelpDesk (<https://www.droughtmanagement.info/>), the Global Data-processing and Forecasting System (GDPFS, <https://community.wmo.int/en/activity-areas/global-data-processing-and-forecasting-system-gdpfs>) and the Public Weather Services (PWS) with the World Weather Information Service (WWIS) (Ritterbush 2006).

All these global CSs are useful and relevant for many purposes, but they do not benefit from the contribution of local data and local knowledge at LL level. As discussed in the previous section, increasing the spatial resolution of these global datasets —which are visualized and delivered by these international CSs— is one of the most demanded features. The Coordinated Regional Climate Downscaling Experiment (CORDEX, <https://cordex.org/about/>) is a relevant international initiative of the World Climate Research Program (WCRP) specifically aimed at achieving this goal. CORDEX and its different domains, such as EuroCORDEX, MedCorDEX, etc., seek to advance and coordinate the science and application of regional climate downscaling through global partnerships. The CORDEX goals are: 1) better understanding of regional/local climate phenomena, their variability and changes, 2) improvement of regional climate downscaling models, 3) generation of coordinated sets of regional downscaled projections, and 4) communication and knowledge exchange with users of regional climate information. Currently, CORDEX leads the experiment design for the dynamical downscaling of CMIP-6 (Gutowski et al., 2016).

## 3.2 National Climate Services

### 3.2.1 Climate Services in Spain

AEMET (the public Spanish Meteorological Agency) provides a set of different CS for all of Spain, including seasonal forecasts, climate projections, and a drought observatory. The associated climate information is available through different map browsers: the AdapteCCa platform ([https://www.aemet.es/es/serviciosclimat\\*icos/cambio\\_climat/visor-AdapteCCa](https://www.aemet.es/es/serviciosclimat*icos/cambio_climat/visor-AdapteCCa)) shows the EuroCORDEX (CORDEX at European Domain, Jacob et al., 2014) climate projections maps, the drought monitor (<https://monitordesequia.aemet.es/>) is a palette of monthly drought indices' maps (historical available in <https://monitordesequia.csic.es/historico>) and a time series plot of a chosen location, the [https://www.aemet.es/es/portal/serviciosclimaticos/prediccion\\_estacional](https://www.aemet.es/es/portal/serviciosclimaticos/prediccion_estacional), current hydrological variables are available in [https://www.aemet.es/es/serviciosclimaticos/vigilancia\\_clima/balancehidrico](https://www.aemet.es/es/serviciosclimaticos/vigilancia_clima/balancehidrico).

El Tiempo (<https://www.eltiempo.es/>), an unofficial yet popular CS platform, is a private digital media channel owned by Pelmorex Corp, and is specialized in short-mid range weather forecasts, however it does not cover seasonal forecasts nor climate projections.

The LCSC Climatology and Climate Services Laboratory (<https://lsc.csic.es/>) contributes to the study of climatic droughts, their causes, changes, and impacts. It also develops free-access software, databases and climate services for drought quantification. The spatial resolutions of most products are: 1 degree for global, 0.125 degrees for European and 1.1 km for national (Spain).

### 3.2.2 Climate Services in Georgia

In Georgia, preparations are underway through various projects, such as GRAIL (<https://projects.worldbank.org/en/projects-operations/project-detail/P175629>) and the Multi-Hazard Early Warning System (<https://www.undp.org/georgia/projects/early-warning-climate-information>), however until today (September 2024) nothing has been fully established yet.

### 3.2.3 Climate Services in Hungary

The CS implemented by the Hungarian Meteorological Service (<https://www.met.hu/en/idojaras/>) provide essential meteorological variables in short recent past time series and short-term forecasts.

### 3.2.4 Climate Services in the Netherlands

The national level drought information available to the LL Rijnland at the start of I-CISK, and still to-date (September 2024) are the main national services used are two drought monitoring websites, one from the national meteorological office (KNMI; <https://www.knmi.nl/nederland-nu/klimatologie/droogtemonitor>), and another from the national agency for water resources management (RWS; <https://waterberichtgeving.rws.nl/owb/droogtemonitor>).

The KNMI service provides country-average potential precipitation deficit in timeseries graphs and in map format. The precipitation deficit is calculated as a cumulative difference between precipitation and potential evapotranspiration from 1st of April onward. The map only shows the most recent observed cumulative precipitation deficit. The timeseries graph shows the observed, but also a forecast for the coming 14 days based on ECMWF Integrated Forecasting System (IFS) Ensemble Prediction System (EPS). The KNMI drought monitor does refer to further information, such as Standardised Precipitation Index (SPI), which contains an interactive map with gridded information, also with a maximum 2-week lead time. The Rijnland water authority is interested in using this information in their local drought monitor as well, and are building up experience with using this data, but local decision guidelines with alert thresholds for SPI have not yet been developed.

The RWS drought monitor's key information used in the LL Rijnland is the observed river discharge at Lobith station, together with a 14-day streamflow prediction. National low (and high) flow alert levels are indicated. The Rijnland water authority uses these for their local drought pre-alert as well, because low flows in the Rhine increase salinity intrusion from the sea towards the main freshwater intake point. The national level RWS drought monitoring does refer to an ensemble prediction for the same streamflow station, which are used by the Rijnland water authority, but also these forecasts displayed are with a maximum 2-week lead time.

### 3.2.5 Climate Services in Italy

In Italy, national climate services are primarily provided by the Meteorological Service of the Italian Air Force (MeteoAM), which offers a wide range of forecasts and climate data, including both short-term and long-term projections of meteorological variables. These services are accessible through the official portal of MeteoAM (<https://www.meteoam.it/it/>).

Additionally, the Meteo Italian Supercomputing Portal (MISTRAL; <https://www.mistralportal.it/it/mistral-open-services-it/>) provides open access to climate data, including near-term weather forecasts and environmental monitoring. These tools are essential for various sectors and are closer to the needs of the Italian LL by providing meteorological forecast that could potentially be linked to the requested hydrological forecast of the local service. However, the most relevant services for the current context are the regional rather than national ones. For instance, the monthly maps with drought indicators provided by Agenzia Prevenzione Ambiente Energia Emilia-Romagna (ARPAE; <https://www.arpae.it/it/temi-ambientali/meteo>) and the seasonal forecasts are closer in scale and focus on drought season, to the specific needs of the LL.

ARPAE produces and distributes climatic, meteorological and hydrological data: climate projection summary reports and bulletins, historical data and data from monitoring. It is important to note that none of these tools currently offer seasonal flow forecasts for rivers, which is a significant gap. Such forecasts are provided, albeit without precise downscaling and thus with limited reflection of local hydrology, by the CEMS - GloFAS Forecast (<https://cds-beta.climate.copernicus.eu/datasets/cems-glofas-forecast>) as mentioned in the international section above.

#### 3.2.6 Climate Services in Greece

The National Meteorological Service of Greece (Hellenic National Meteorological Service, HNMR; <http://emy.gr/emy/en>) is the official provider of CSs in Greece. These CSs include informative maps, tables and reports for short- and medium-range weather forecasts for all of Greece, localised at regional, and city level, as well as for the entire European region. Additionally, HNMR provides extreme weather warnings, climatological data, and seasonal forecast short reports based on ECMWF seasonal forecast reporting. However, it does not include regional or localised information on seasonal data, nor does it include climatic projections.

In addition to official services, there are several unofficial yet popular national and local climate services. Meteo ([www.meteo.gr](http://www.meteo.gr)) is an additional weather forecasting service provided by the National Observatory of Athens (Research Institute). It offers short-range forecasting through intuitive maps, tables and diagrams, weather warnings, and meteorological measurements across Greece. Other similar services, but less interactive and with limited information, include FreeMeteo.gr (<https://freemeteo.gr/>), K24.net (<https://gr.k24.net/m/>), and local services such as CretaWeather.gr (<https://cretaweather.gr/>).

In the thematic area of climatic projections, a national hub was developed recently in 2023 by the Hellenic Ministry of Environment and Energy. This hub can be accessed through [http://mapsportal.yopen.gr/thema\\_climatechange](http://mapsportal.yopen.gr/thema_climatechange) or <https://adaptivegreecehub.gr/>. It provides climatic projections data organised in interactive maps and raster data with a resolution of 5km for approximately 25 climatic variables and indices, as well as information on climate change adaptation.

#### 3.2.7 Climate Services in Lesotho

The main national initiatives that provide Climate Services are:

- The Lesotho Meteorological Services (LMS) delivers seasonal precipitation outlooks to national stakeholders primarily through presentations at national round table meetings. LMS prepares its seasonal forecast using the North American Multi-Model Ensemble (NMME), which is downscaled with reanalysis products (Climate Hazards Group InfraRed Precipitation with Station data; CHIRPS) and data from local weather stations. They then refine this forecast by comparing it to the regional seasonal outlook produced by the Southern Africa Regional Climate Outlook Forum (SARCOF). Based on this comparison, LMS finalizes its seasonal outlook. They also provide updates throughout the season via email to keep stakeholders informed. Additionally, delivers daily temperature forecast via email and bulletins.
- The Lesotho Vulnerability Assessment Committee (LVAC) provides assessments using the Integrated Food Security Phase Classification, reporting on both current and projected food insecurity for the upcoming consumption year, at the administrative level 1. The analysis is shared in the form of a report with national stakeholders.

### 3.3 Towards the Need for Tailored Climate Services

The benchmark of the tailored CS can be measured by their usability, particularly concerning solutions designed to address the existing *usability gap* (Raaphorst et al., 2020). Usability depends on the level and

quality of interaction between information producers and users. It can provide insights into the gap between the potential usefulness of climate information perceived by scientists and what users find usable in their decision-making process (Lemos et al., 2012). Moreover, a disconnection between climate data production and its application can exacerbate this gap (Sing et al., 2018).

It is important to note that the I-CISK CS implementation is still under development or, at least, with a limited testing period for usability validation by end users. Therefore, it is premature to conduct a comprehensive benchmark evaluation by a representative group of I-CISK stakeholders at different LLs. Instead, we will approach usability by analysing the solutions designed to overcome the most common and particular barriers that impact user effectiveness and satisfaction (Pimentel et al., 2022; Brasseur and Gallardo, 2016) to improve CS usability:

- low level of user engagement in the co-development process
- low spatial resolution in CS information and lack of appropriate method for tailoring
- misunderstanding the provided climate information (e.g. uncertainty)
- lack of a CS evaluation phase (note that the CS evaluation is the scope of the oncoming I-CISK D3.4 deliverable)
- information is not actionable for management and decision-making.

Given that the usability is difficult to evaluate by quantitative metric, given that “different actors perceive the usefulness of scientific information differently” (Porter and Dessai 2017), therefore the next chapter qualitatively compares the usefulness of the I-CISK CSs versus existing international and national CSs which were briefly described in the previous subsection. We aim to highlight the success of the I-CISK CSs in overcoming the identified barriers and highlighting the added value and benefits they provide for the LLs.

## 4 Benchmarking of the Implemented Climate Services across the Living Labs

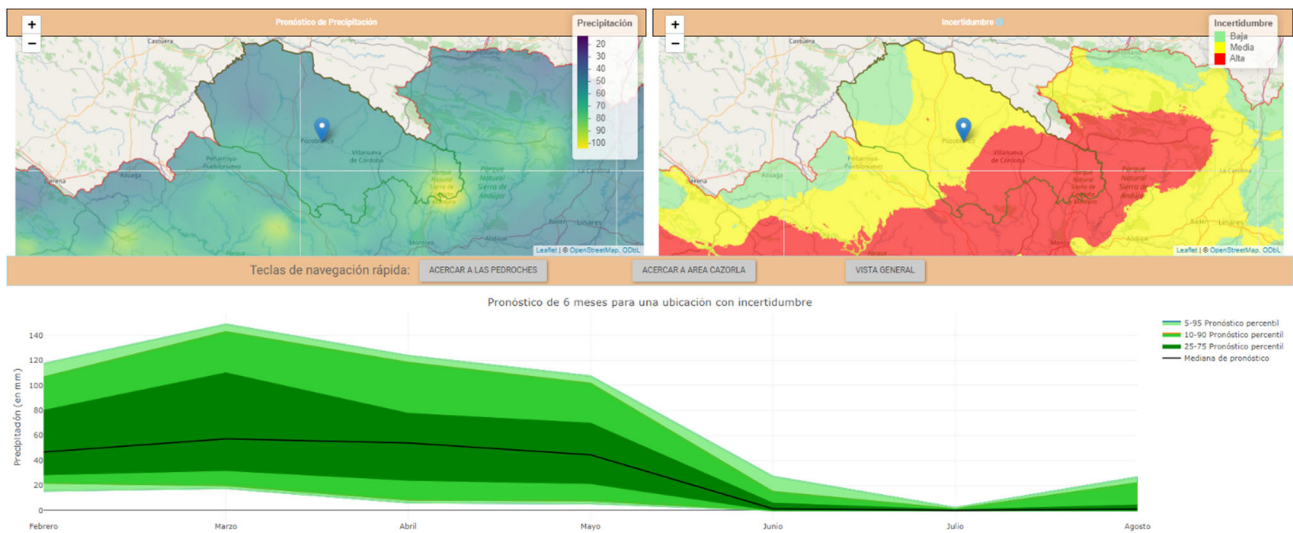
This chapter reviews the seven I-CISK LLs in order to understand the designed and/or implemented improvements applied to their corresponding tailored CS for overcoming the main barriers and increasing their usability. We recommend additional reading of the I-CISK deliverables *D1.1 “Characterization of the I-CISK Living Labs”*, for a more detailed information of the Living Labs characteristics, and *D2.1 (Preliminary report)* and *D2.4 (final) “Information on Climate Service Needs and Gaps”* for extended explanations of the main barriers to the CS usability in each LL.

### 4.1 Andalucía - Spain Living Lab

The Andalucía LL is mainly located in the Guadalquivir River Basin District (RBD), plus a small part of the Guadiana RBD. It mainly focuses in the *comarca* (region) of Los Pedroches, a primarily agricultural area located in the north of the province of Córdoba, in the autonomous region of Andalucía, Spain. It also includes the Sierra de Cazorla, Segura and Las Villas Natural Park in the upper Guadalquivir RBD as a complementary site for testing the developed CS for forestry landscapes.

#### 4.1.1 Climate Service description

This CS available in <https://i-cisk.dev.52north.org/living-labs/guadalquivir--es/> is an Agricultural and Forestry Planning Service and is composed by a set of products: historical climate information, seasonal climate forecasts, climate projections, agroclimatic information and groundwater characterization. Their goals are the reduction of the vulnerability to climate risks to (1) support sustainable agricultural and environmental management, (2) build societal resilience to multiple risks, (3) counter rural exodus and abandoning of agricultural activities, (4) build a culture of decision making based on up-to-date and evidence-based information and scientific data, and (5) strength the adoption of European climate change policies.



**Figure 2** Screenshot of one (precipitation seasonal forecasts) of the implemented Spain LL climate services. It provides different percentiles of the ensembles results, median left upper figure and uncertainty/dispersion in the right upper. Plot of the 6 months forecasts of percentile ensembles of clicked location at the bottom.

#### 4.1.2 Integration of local data and local knowledge

The contribution of local data is totally relevant for the historical and predictions CS in this LL. Historical records from AEMET, time series (1975-2022) of monthly, and daily in a reference subperiod (1993-2007), of mean temperature and precipitation allowed to generate a high spatial resolution monthly maps (250m) as well for drought indicators: Standardised Precipitation Index (SPI), Standardised Precipitation Evapotranspiration

Index (SPEI). We also considered auxiliary local datasets (SAIH, CAPDR, PAART, etc., Trojer et al., 2024) for testing/evaluation purposes, their times series are not still enough large for a contribution to the robust climate modelling methodologies.

The contribution of local knowledge is specially very relevant in this LL in two CSs:

- Agroclimatic CS: the experience of local farmers guided the selection of variables, such as aggregated spring precipitation and mean temperature in May and June, to be introduced as independent explanatory variables in the multiple linear regression model for annual oil production.
- Hydrogeologic characterization CS: the local farmers and local public managers suggested the locations of field campaigns and review and validate the characterization reports with their expertise.

#### 4.1.3 Usability of the tailored methods

After stakeholder consultation in form of live questionnaires in bilateral and sectorial online meetings, the main barriers of CS collected in this LL about the CS usability are:

- the lack of tailored information with two relevant aspects: insufficient spatio-temporal resolution (they prioritized the spatial resolution) and lack of access to historical meteorological time series.
- effective dissemination to target audiences.
- misunderstanding of forecast uncertainty.

Most efforts in this LL to develop CSs using tailored methods focused on downscaling techniques. These efforts aimed to generate high-resolution (HR) historical maps, HR seasonal forecasts, and mid/high resolution climate projections, all applied to monthly precipitation and mean temperature.

In general, we collected good evaluations in terms of usability (Figure 3) from the LL users (see MAP composition in [D1.1 Characterization of the I-CISK Living Labs](#)) about the CS based on the developed downscaling methods. Some refinements on visualization and time-respond are requested and we are working to solve them, but they totally agree with the spatial and temporal resolution of the provided climate information. Regarding uncertainty, users interested in risk management often ask for reliable predictions.

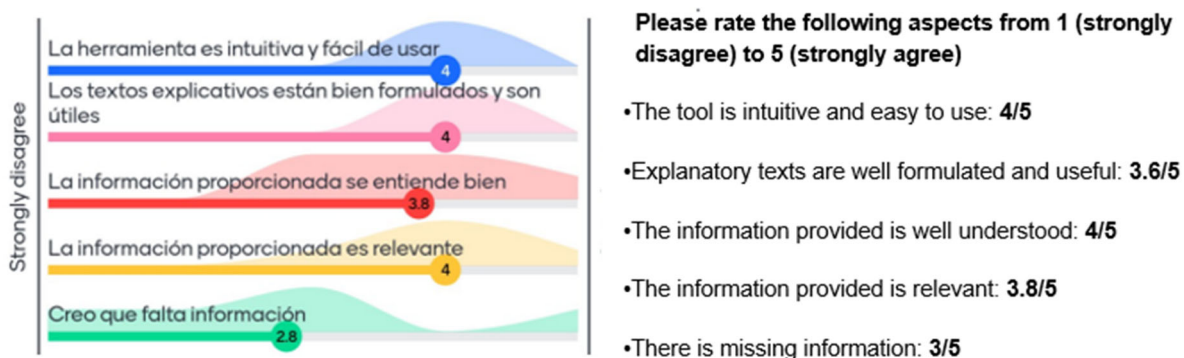


Figure 3 Left: example of interactive survey about CS usability in bilateral meetings with LL stakeholders. Right: average feedback from all bilateral meetings.

#### 4.1.4 Benchmarking

A comparison with existing CSs from international initiatives with similar to I-CISK objectives reveals that Copernicus C3S and CEMS (GDO and EDO) provide valuable climate information, but do not accomplish two main requirements for most of the Spain LL end users: finer spatial resolution and clear understandable information. Figure 4 shows the different options and indicators in drought CS and climate projections' downloading service. During the CS co-creation process, we selected (and simplified) the main information

following the users' demand. In addition, the language is a barrier to properly understand the climate information.

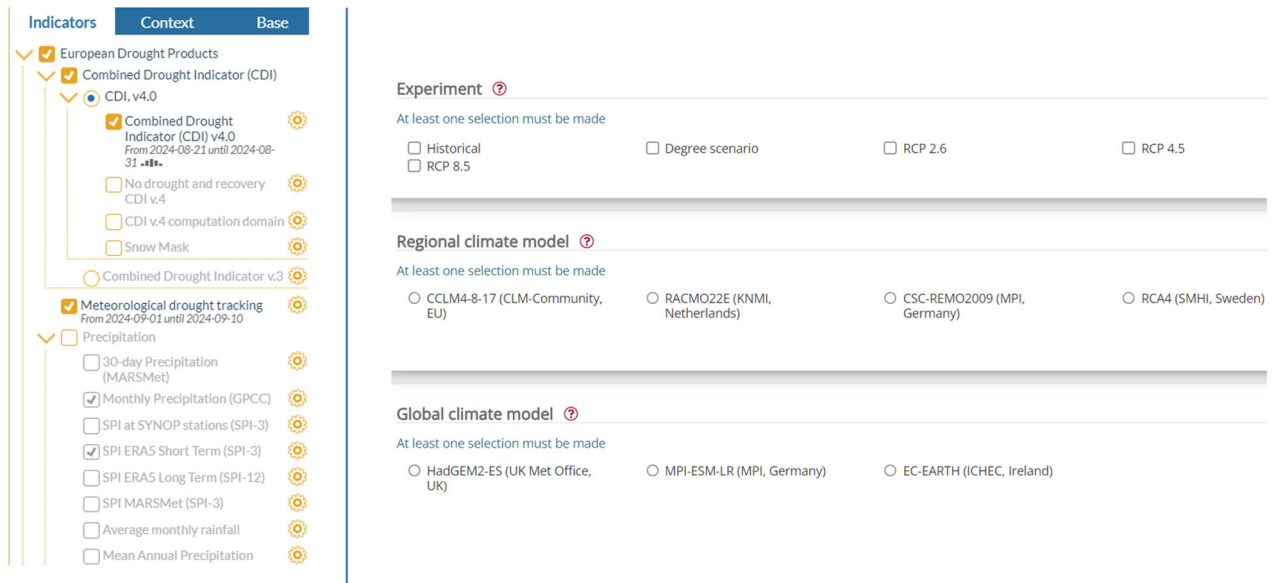


Figure 4 Left: Indicators selection legend of EDO and GDO. Right: Different experiment and model options in the Climate Data Store (CDS) of Copernicus.

The comparison with national CS exhibits that even there are several existing downscaled datasets, such as <http://www.meteo.unican.es/datasets/spain02> at 20km (Herrera et al., 2012) or 5km (Hernanz et al., 2022) these may not fit the demands of most LL stakeholders. In this case, the language (Spanish) makes easy the understanding of the interfaces, options and climate information by users, however the dedicated development to their local needs increases the I-CISK CS usability. Finally, the dedicated visual functionalities to allow comparison of conditions between different month/year (see Figure 2), or different locations are appreciated by the users.

## 4.2 Alazani - Georgia Living Lab

The Alazani River Basin LL is located within the territory of Georgia. Due to the complex mountainous topography and highly diverse climate settings, Georgia is subject to climate-related hazards such as floods, flash floods, landslides, debris flow/mudflow snow avalanches, hailstorms, windstorms and droughts.

### 4.2.1 Climate Service description

The I-CISK CS (<https://i-cisk.dev.52north.org/living-labs/alazani--ge/>) is a Water Resource Management Service (integrated management to EU Water Framework Directive) with the main goals: (1) to improve resilience through increased food production and water resource management for drinking water and irrigation, and (2) to achieve greater exploitation of renewable energy (hydropower) through improved management, policy making, supply and demand balancing and energy saving.

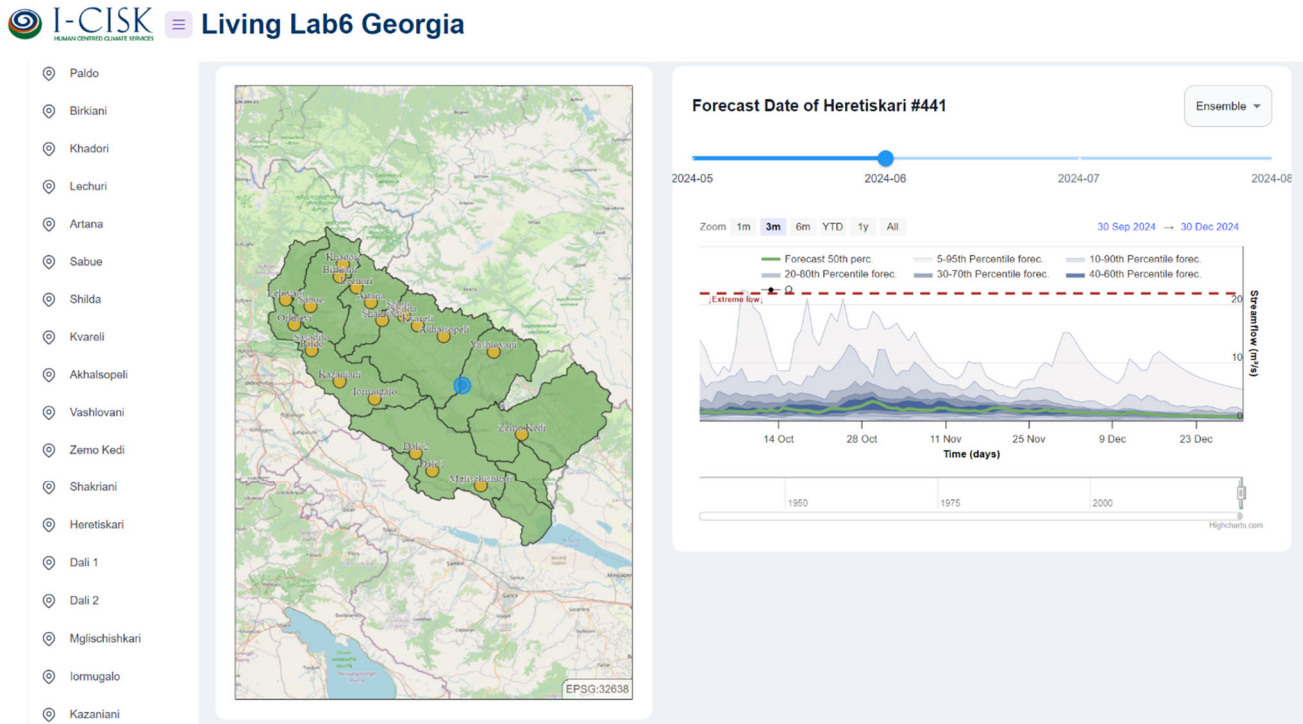


Figure 5 Screenshot of forecast example of the Georgia LL pilot climate service.

#### 4.2.2 Integration of local data and local knowledge

The National Environmental Agency (NEA) is the main hydrological agency in Georgia, and operates the network of hydrological and meteorological stations. Observed discharge data at stations in the Alazani and Iori basins is provided to evaluate and bias-adjust the seasonal streamflow forecasts. This includes historical data, as well as real time data. The latter is available only at a limited number of sites, as the hydrological network is still being reconstructed following its virtual collapse after the soviet period. Local past experience of farmers' associations contributes to the impact farming decisions' planning.

#### 4.2.3 Usability of the tailored methods

The tailored methods that are being implemented in the CS of this LL are:

- Sub-seasonal and Seasonal drought forecasts based on drought indicators to display expected drought conditions across the Alazani and Iori basins (displayed at sub-basin level).
- Hydrological forecasts at key locations, downscaled to single sub-catchment and specific point locations of interest.

The specific barriers detected in the national CS of this LL are:

- Service discontinuity (on-demand as opposed to regular production).
- Lack of long-term national strategy.
- Demands on sector-tailored information for agriculture planning.

The main barriers for the usability of the international CSs are the language for some of the local decision-makers and end users.

#### 4.2.4 Benchmarking

There is currently no provision of streamflow forecasts in Georgia, and users instead rely on weather forecasts of for instance precipitation, which is mainly sources from weather apps.

It is not possible to compare the I-CISK CS with the national CS, because as explained in subsection 3.3.2 these are currently under development at the national level, in collaboration with the Rural Development Agency,

NEA, UNEP and other partners. Seasonal streamflow forecasts are not included in those developing capabilities. The benefits versus International CS that are currently available of the CS developed in the Georgia LL are:

- Integration of basin management (EU Water Framework Directive).
- Improved resilience through increased food production and water resource management for drinking and irrigation.
- Greater exploitation of renewable energy through improved management, policy making, supply and demand balancing and energy saving.
- Wider range of variables related to heatwaves.

### 4.3 Budapest – Hungary Living Lab

The Budapest LL is located in the Erzsébetváros district, an inner-city area of Budapest (the capital and most populous city of Hungary). The area is densely constructed with many protected-heritage buildings mostly from the late 19<sup>th</sup> and early 20<sup>th</sup> centuries.

This district has a low percentage of green spaces, with a high density of buildings, and therefore is particularly exposed to heat waves, which are already causing issues for a range of sectors in the city. The focus of the Living Lab is on urban heat islands in the tourism and public health sectors.

#### 4.3.1 Climate Service description

The I-CISK CS (<https://i-cisk.dev.52north.org/living-labs/budapest--hu/>) is an Urban Heat Planning Service with two specific tools:

- Time-series analysis: Utilizing orthophotos as a high-resolution baseline for time-series analysis of thermal data. This method allows for tracking changes in urban heat over time with a clear reference to the physical changes in the urban landscape.
- Energy balance modelling with detailed surface information: Applying energy balance models that use detailed surface information from orthophotos, combined with thermal data, to interpret urban heat dynamics more accurately.



Figure 6 Urban heat map CS, Erzsébetváros district, Budapest.

#### 4.3.2 Integration of local data and local knowledge

Two types of relevant local data are provided in this LL:

- HR airborne thermal images generated by flight campaigns of small UAS flights with a thermal camera on-board.
- Contribution of the Volunteered Geographic Information with citizen measurements (Figure 7). Simultaneously with the aerial measurements, ground-based data were collected, aided by a team of enthusiastic volunteers. The team mapped the temperature of the streets using heat cameras.



Figure 7 Drone controller (drones equipped with thermal cameras) for the Erzsébetváros campaign, Budapest.

#### 4.3.3 Usability of the tailored methods

The tailored methods planned to implement in the CS of this LL are:

- Data fusion techniques of drone TIR images with satellite data.
- CNN for enhanced pattern recognition.
- Orthophoto aided vegetation indexing.
- Time-series analysis and energy balance modelling, considering physical changes in the urban landscape.

The specific barriers detected in the national and international CS of this LL are:

- Lack of specific variables related to heatwaves and health impacts.
- Limited information on green infrastructure.

#### 4.3.4 Benchmarking

There are not National CS specifically addressed to provide climate information to understand urban heat distribution and of urban environmental dynamics; the I-CISK contribution covers this missing topic.

The I-CISK's added value for the Budapest CS is:

- Improved understanding of urban heat island exposure leading to improved adaptation policies and behaviour.
- Decreased heatwave impacts (death, illness, discomfort and economic loss).

#### 4.4 Rijnland - The Netherlands Living Lab

The Rijnland LL is located on the Western coast of the Netherlands, between The Hague and Amsterdam. The LL region is mostly flat and below sea level. The water authority would like to pilot a local drought alert service to share with stakeholders first affected by droughts as well as operational water management decisions that are taken to counter the impacts these droughts have. The main stakeholders considered in this LL are the water tourism and agricultural sectors. Next to timely drought alerts, the objective for the water authority is also for the service to increase awareness of climate change and foster an active discussion on drought mitigation among stakeholders.

##### 4.4.1 Climate Service description

The I-CISK CS (<https://i-cisk.dev.52north.org/living-labs/rijnland-nl/app/>) is a drought alert service with the aim to increase awareness of short to long term drought risk and adaptation strategies by sector and across multiple sectors. The service is to feature four key components:

- Sub-seasonal to seasonal (S2S) lead time drought alerts with expected operational water management measures.
- S2S forecasts of cumulative precipitation deficit starting from 1 April, up to 31 October (currently considered as the drought season in the Netherlands (NL), because of longer daylight and higher temperatures during these months as compared to the other months and thus higher potential evapotranspiration and higher water demand due to agricultural and nature growth season).
- S2S forecasts of Rhine river discharge at Lobith (too low discharge at Lobith is an indicator for possible salt intrusion from the North Sea up to the freshwater intake point of the Rijnland water system) (Figure 8).
- Climate change projections and expected impact on drought hazards.

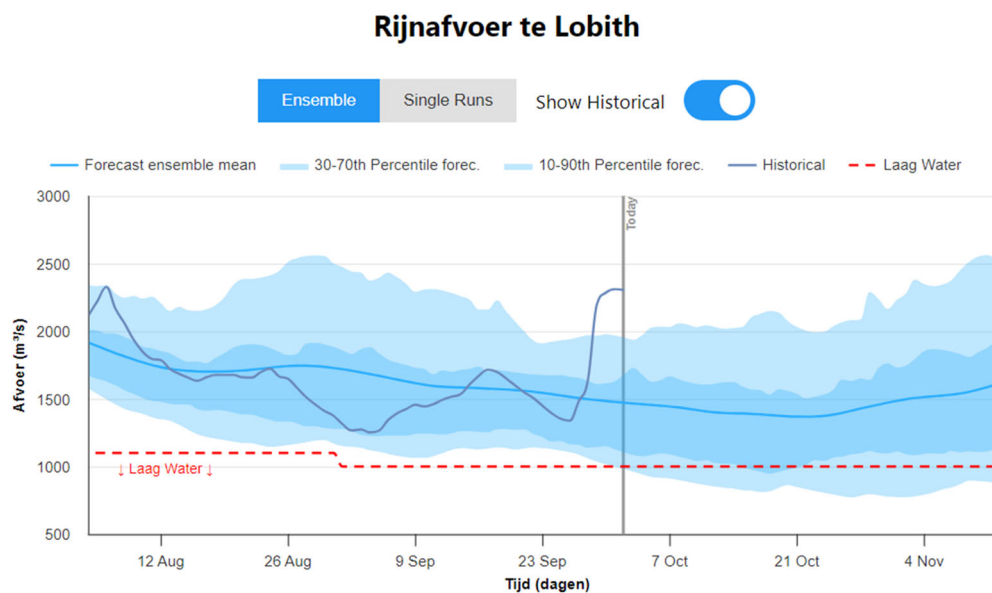


Figure 8 Screenshot of LL Rijnland climate service component of seasonal river discharge forecast with low flow (drought) alert threshold indicated (<https://i-cisk.dev.52north.org/living-labs/rijnland-nl/app/>, last visited 2 October 2024)

#### 4.4.2 Integration of local data and local knowledge

Local data is used in the cumulative potential precipitation deficit forecast service, using the most recent available observations in combination with each newly available meteorological forecast. The observed river discharge at Lobith is also displayed.

Local knowledge is integrated in the multi-level dynamic drought alert thresholds applied in the app, and in the generation of alert text message pointing at possible water management counter measures and sector-specific impact.

#### 4.4.3 Usability of the tailored methods

Two main methods have been tailored in this LL: S2S forecasts (precipitation and river discharge) and drought climate projections and they are the base methodology for the four components described in subsection 4.4.1.

In one-to-one sessions with Multi actor Platform (MAP) members feedback on and preferences for different options for platform, functionality, structure, and visualisation of the drought alert service has been collected. Options included whether to focus on smartphone or desktop, traffic light options for alerts, and how to link from operational forecast to climate change impact on droughts information. Examples of the envisaged design of the drought alert service are presented in Figure 9. Alert texts for the measures the water authority is planning to take, will be customised for each stakeholder group.

The alert service aims to provide users with more time to decide on, prepare, and implement operational mitigation measures in case of an eminent drought. By prominently referring to the information on climate change impact on future drought hazards, the drought alert aims to foster discussion on, developing, and deciding on strategic long-term adaptation measures.

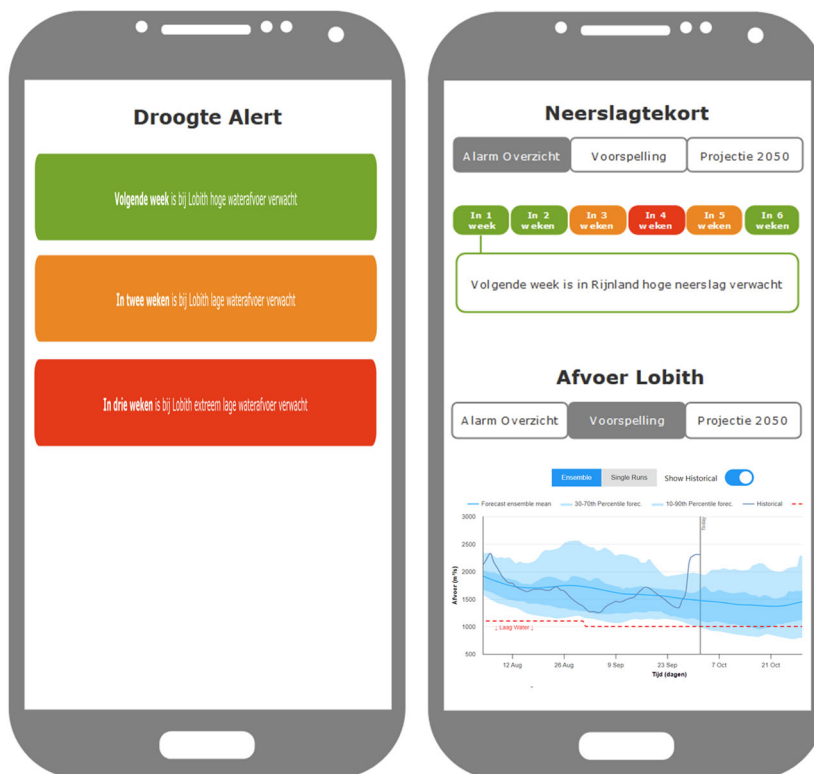


Figure 9. Mock-ups for LL Rijnland drought alert service.

#### 4.4.4 Benchmarking

As compared to the national drought monitoring and forecast services as described in Section 3.3.4, the I-CISK LL Rijnland drought alert service will provide operational drought forecasts and customised alerts per sector for lead times beyond 14 days, and prominently present the impact of climate change scenarios on drought hazards in the NL. Both RWS (streamflow) and KNMI (meteorological information) already have operational forecasts for sub-seasonal to seasonal and seasonal lead times, but these are not yet presented in the central public drought monitoring services and are therefore not yet used by the Rijnland MAP members. Additionally, the national drought monitors of KNMI and RWS do not contain or refer to climate change scenarios and the impact these have on expected drought hazards in the NL.

#### 4.5 Emilia Romagna – Italy Living Lab

The Emilia Romagna LL is located in the upper part of Secchia rivers, in Modena and Reggio Emilia provinces. The area is vulnerable to droughts and floods, due to a change in precipitation seasonal patterns and increase in temperature. Drought is the focus of the Lab activity. The sectors affected by droughts and the resulting water shortage are mainly agriculture, infrastructure, energy, manufacturing and production sectors, as well as environment (the river ecosystem itself). These compete for water and energy, especially during the warmer season.

##### 4.5.1 Climate Service description

The I-CISK CS (<https://i-cisk.dev.52north.org/living-labs/emilia-romagna-it/>) is a Water Resource Management Service for aiming to improve the water allocation decisions and reduced water shortages, to obtain a better agricultural and industrial activity planning and to reduce the agricultural production loss, plus reducing administrative burden for the region in authorizing exceptional measures during drought, once supported by the sound forecast.

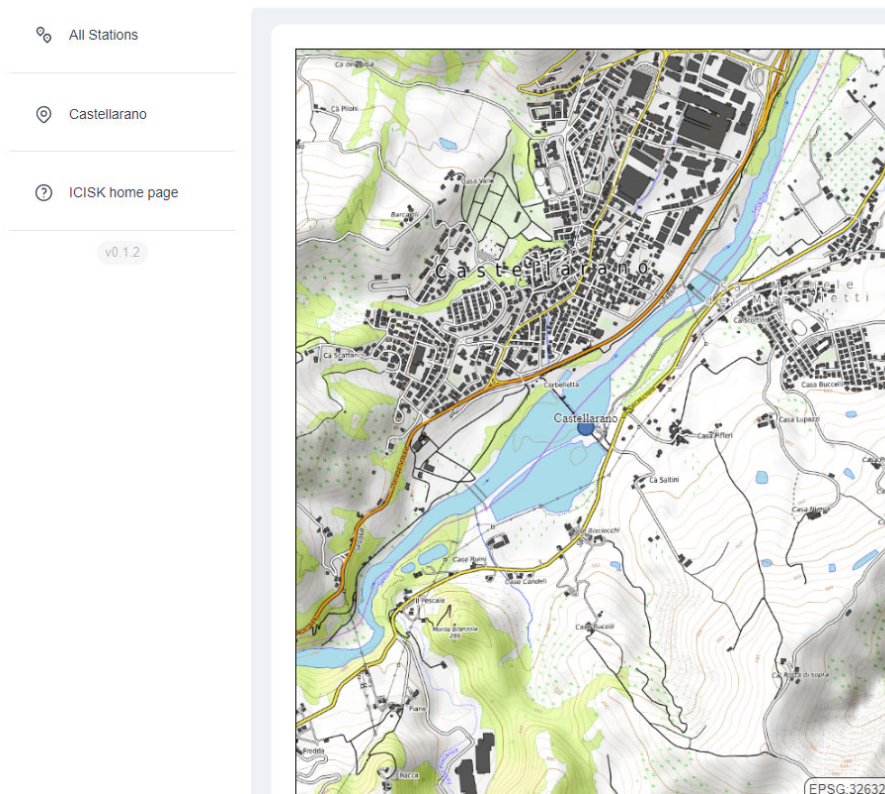


Figure 9 Screenshot of Italy LL CS; left section – identifying the river station of interest. On the left side the user identifies the river station of interest using a map interface or a list, while on the right side (see next

figures) river discharge forecasts are provided either as daily values for the incoming season (average and expected variability) or as monthly cumulate values, the latter is more interesting to the LL users with water storage capacity.

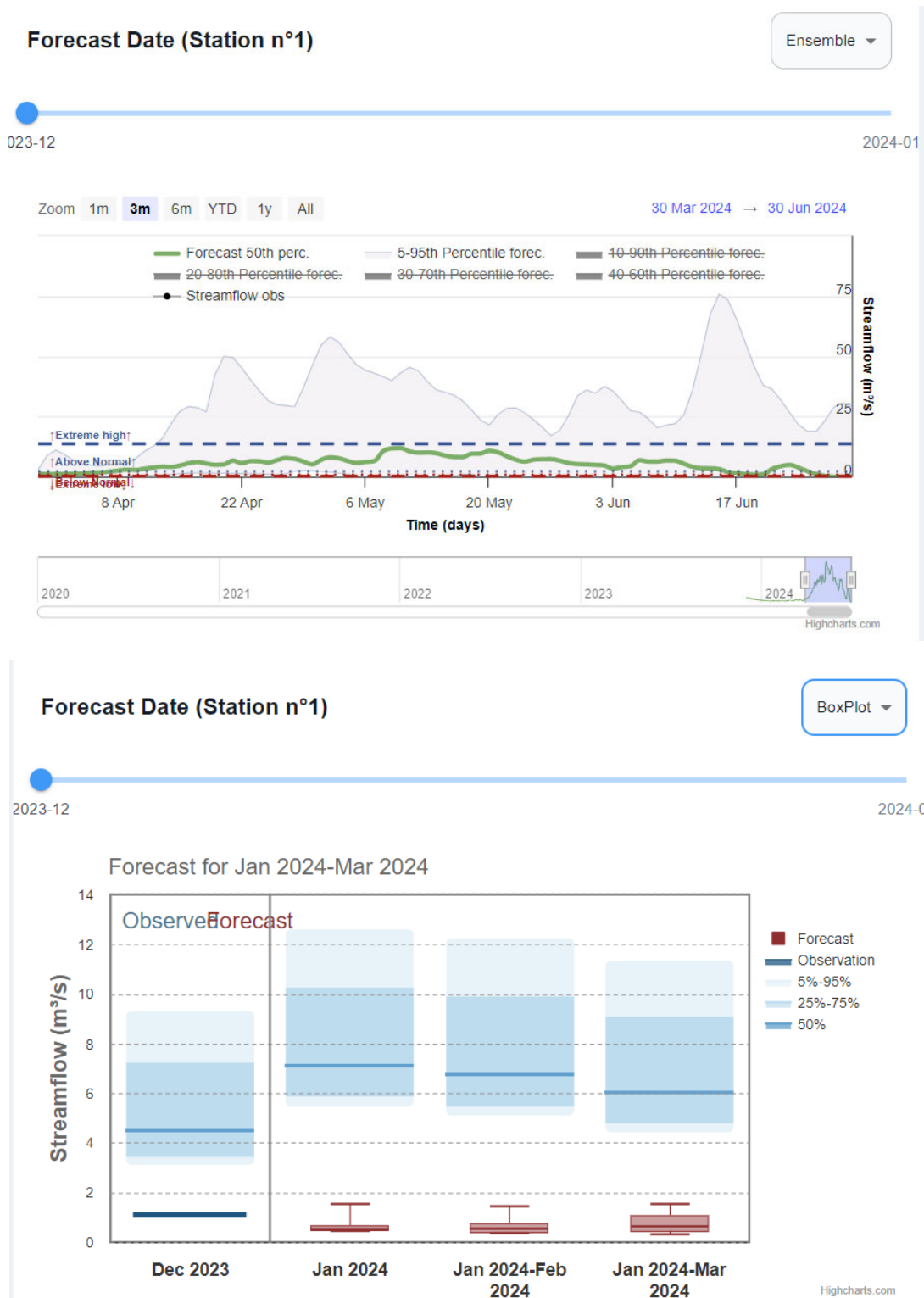


Figure 10 Screenshot of Italy LL CS; right section – browsing the hydrological forecasts.

#### 4.5.2 Integration of local data and local knowledge

In terms of local technical data integration, the primary focus is on incorporating time series data of flow measurements from the Lugo station on the Secchia River. This data is crucial for improving the accuracy of hydrological flow forecasts. Currently, this data is in the process of being made available to the I-CISK FTP server for the integration into the service. Local insights and experience from past play a crucial role in adapting to variability, thus local knowledge contributes to 1) long-term adaptation strategies in infrastructures such as distribution network modifications and new storage solutions 2) establish emergency protocols from their experience in past drought episodes.

#### 4.5.3 Usability of the tailored methods

The high-resolution seasonal hydrological forecasts, expected to be downscaled to single sub-catchments, are the key information for the Emilia Romagna Living Lab. While provision of such forecasts is still pending, stakeholders' interaction has emphasized that they shall make locally relevant predictions that reflect the unique hydrological conditions of the area. These forecasts should be comparable to the real-time and historical data recorded in Lugo hydrologic station, and offer sufficient temporal resolution (daily) to support both short-term and long-term decision-making. Users have also highlighted several key areas for improvement, such as visualization enhancements, including feedback on map usage and optimization of forecast graphs. Additionally, there have been suggestions to refine graphical elements like legends and to integrate underlying data from the Regional Environmental Agency to improve the overall usefulness of the service. Part of the feedback also addresses the role of the CS in supporting decision-making, particularly in activating protocols to reduce water withdrawals. Finally, the forecasts should be presented in a user-friendly format, with clear visualizations and easily interpretable uncertainty measures, to ensure they are actionable for local stakeholders.

#### 4.5.4 Benchmarking

The added value of the Emilia Romagna CSs lay in the ability to lead to better decisions before and during drought, including:

- Improved water allocation decisions and reduced water shortages.
- Better agricultural and industrial activity planning.
- Reduction of agricultural production loss.
- Reduction of administrative burdens for the region to authorize emergency measures.
- Enhanced resilience plans supported by innovative tools like the developed CS.

### 4.6 Crete – Greece Living Lab

The Island of Crete is situated at the southern boundary of Greece, in the eastern Mediterranean. Being a large island, Crete has a thriving tourism sector and concentrates a significant and variable economic activity. Tourism plays an important economic role for the country. Crete is among regions of Greece that are most vulnerable to climate change with droughts and reduced surface water availability as critical hazards affecting the tourism and transportation sector, followed by health, agriculture and water resources.

#### 4.6.1 Climate Service description

The developing I-CISK climate service (<https://i-cisk.dev.52north.org/living-labs/crete--gr/>) aims at supporting the adaptation and development of the tourism sector, primarily. However, it does so through an intra-sectorial approach, by addressing informational needs of other sectors as well, i.e. water management, transportation and energy. Water availability can impact tourism as an economic activity since it is directly associated with the guest experience (surface water availability at basin level, see Figure 11.a). Further, energy

demand, especially for cooling needs during the hot summer days and nights, is an important consideration for the tourism industry. Extreme weather events (e.g. heavy precipitation events, high winds) and flood impacts (coastal and river) are primarily related to transportation infrastructure (mainly ports and roads), which supports the economic activity as well as tourism-related infrastructure (landslide potential due, among others, to heavy rain, see Figure 11.b). As such, the main end users of the CS include tourism enterprises, tourists, citizens and users from the water supply, transportation and energy sectors.

The CS developed addresses the sectorial needs at different temporal and spatial scales. The service is structured based on two main temporal scales: (a) seasonal and sub-seasonal information which address operational needs for informed and improved decision making, and (b) end-of-century climatic projections for supporting long-term planning adaptation measures.

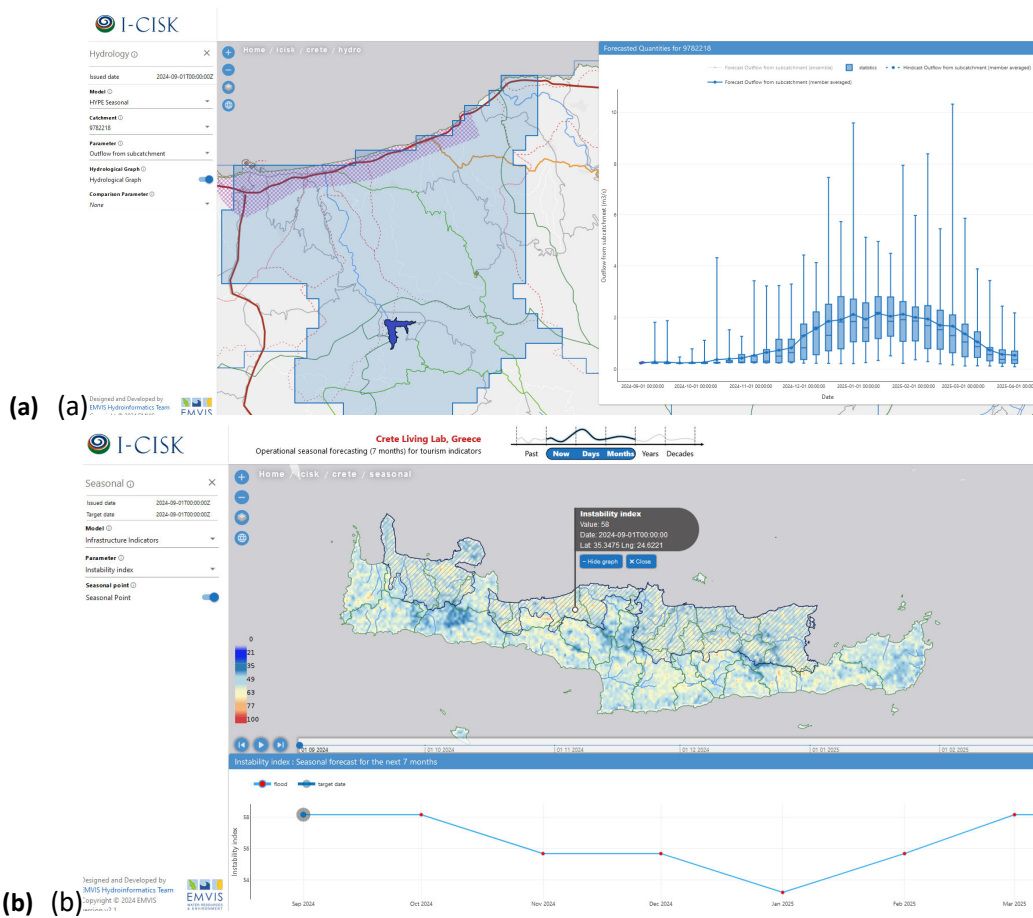


Figure 11 Screenshot of Greece LL CS: (a) Seasonal forecasting of surface water availability at a basin level, including uncertainty information, and (b) seasonal forecast of landslide susceptibility locally and spatially variably covering the whole island.

#### 4.6.2 Integration of local data and local knowledge

Local historical data (use of precipitation and temperature measurements throughout the island) have been used for the downscaling of meteorological variables to drive hydrological impact modelling and provide better, localized information.

Local information and local knowledge were crucial and actually shaped the developed services. This led to the design of the service to provide: (a) the information needed, (b) for the time needed, and (c) for the spatial scale needed:

- Water management sector: identification of specific needs (information needed, e.g. 4 months wet period surface water availability) for operational as well as long term planning (period of decision making – when the information is necessary, target period that the information covers – e.g. November to February, type of information required for better decision making, potential gains, etc.).
- Transportation: identification of specific needs for operational as well as long term planning (what type of information is required for each of the period addressed, what decisions are made addressing different periods of operations, climatic hazards identified, type of information required for better decision making, potential gains, etc.).
- Tourism, accommodation: identification of specific needs (information needed e.g. specific climatic indexes or variables) for operational as well as long term planning (period of decision making – when the information is necessary, target period that the information covers).

#### 4.6.3 Usability of the tailored methods

The tailored methods implemented in the CS of the Crete-Greece LL are:

- Seasonal forecasts of Landslide Susceptibility based on precipitation seasonal forecasts.
- Seasonal forecasts of surface water availability tailored to specific reservoir management needs.

The index produced was based on a collection of information from stakeholders (water management) regarding the decisions to be made, the problems to be addressed and the relevant timelines. It addresses water allocation and distribution seasonal planning based on the expected wet year surface water availability at a reservoir basin level. The information produced is based on seasonal forecasting of surface water discharge (information produced within the I-CISK project), when its availability covers the wet period in question. However, when this product (seasonal forecast of surface water availability) is not available for the desired period (e.g. early in the year), estimation of the index is provided based on comparison of current hydrological year with statistical analysis of historical data.

The specific barriers detected in the existing national and international CS of this LL are:

- Climate change services lack cross-sector links.
- Lack of sector-tailored information and sector-specific indicators.
- Lack of accessibility for non-expert users.
- Low spatio-temporal resolution.

#### 4.6.4 Benchmarking

The developed Climate Services are addressing data needs gaps under a cross-sectoral approach, providing information on high spatial (1km x 1km is the key feature for their usability) and temporal scales suitable for operational decision support (seasonal) and long-term planning. The new CS provide new information to support:

- Improved planning in the tourism sector, to support adaptation of products and destinations and widen the spatial distribution of tourism in the Mediterranean.
- Better informed and more agile planning of tourism policy and business activities (short and long term).
- Improved water resources planning and use efficiency in Crete (target SDG6–Clean water and sanitation).

### 4.7 Lesotho Living Lab

The Lesotho LL is spread in multiple locations throughout the country (Lesotho is a landlocked country in Southern Africa) focusing on areas at high risk of droughts and cold waves. The frequency of extreme events is likely to increase, with climate projections suggesting a hotter and drier conditions in the future, posing

higher and more frequent risk of food insecurity. The Living Lab focuses on the Disaster Management and as it is key in the preparation and response to such extreme events.

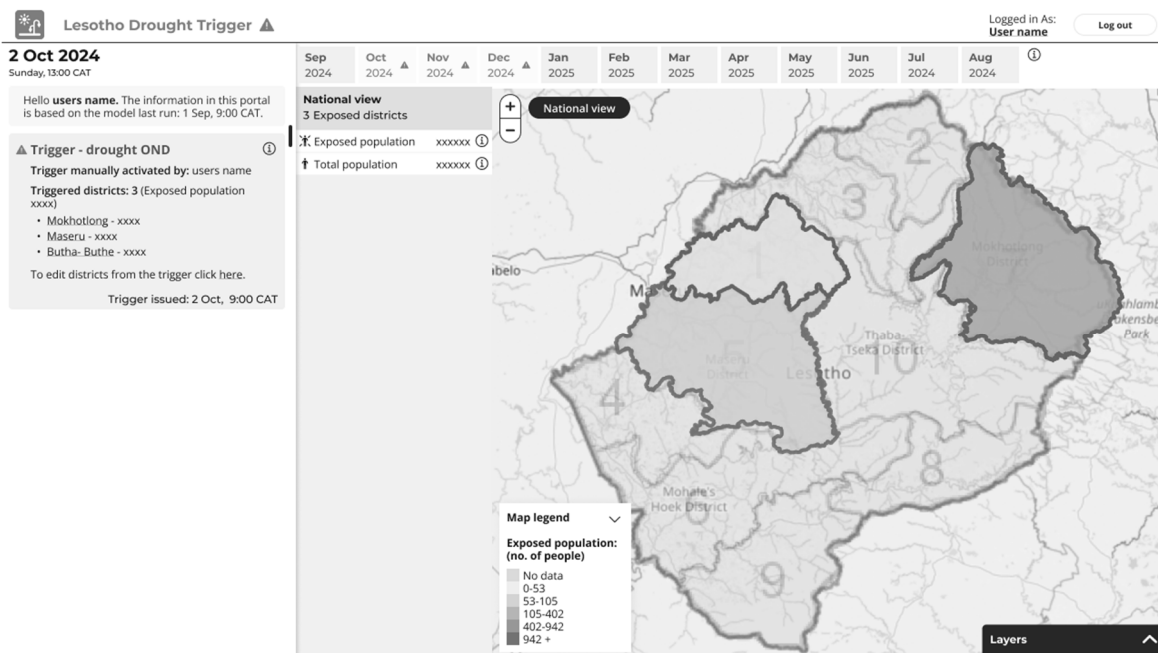
#### 4.7.1 Climate Service description

In Lesotho, two CSs are being implemented at Red Cross - Impact Based Forecasting portal, with the goal of enhancing the timely execution of anticipatory actions for cold waves and droughts, using impact-based forecasts.

However, there is currently no clear demand from users for a climate service information system (i.e., a platform) that visually delivers this service for cold waves. Instead, the support provided focuses on helping the Lesotho Meteorological Service improve the accuracy of their forecasts.

In contrast, the climate service for droughts will be an information system designed to monitor drought forecasts and support early action planning to mitigate drought impacts. These actions can be automatically triggered when linked to pre-approved plans and financing, as detailed in the Early Action Protocol agreed upon by relevant stakeholders.

Key actions are planned for October, marking the start of the rainy season, when early warning messages are disseminated to communities at risk, and January, when cash transfers are made to communities. The Climate Service will provide seasonal forecasts in September from the Lesotho Meteorological Service and information on precipitation observations and forecasted food insecurity in January. To support LRCS operations, additional data such as population density and livelihood zones will also be included.



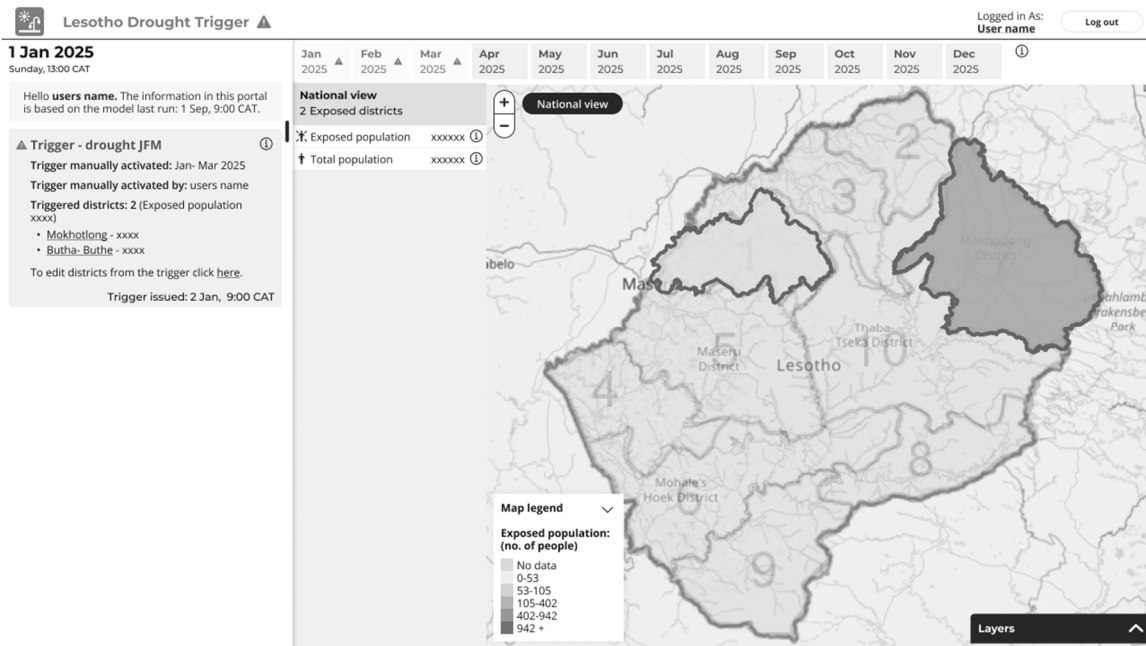


Figure 12 Screenshot of the Climate Service prototype for droughts, displaying drought risk levels across Lesotho districts for September and January based on user input. Additional layers can be accessed via the Layers menu. Please note that this is a prototype, and the final design may differ.

#### 4.7.2 Integration of local data and local knowledge

The I-CISK CS for droughts primarily relies on local data providers. Currently, there is no automated method to integrate this data seamlessly. The Anticipatory Action focal point at LRCS will manually update the local information into the CS. Global data may be included to offer preliminary insights into the rainy season before the local seasonal outlook is available.

In Lesotho LL, local knowledge contributes to farmers decision making and supports the Vulnerability Assessment Analysis reports. In addition, local knowledge is intended to incorporate the indigenous knowledge from communities, at this stage without success. This contribution is crucial in a collaborative process in CS co-designing, with the aim to achieve that the outcomes are not perceived as imposed.

#### 4.7.3 Usability of the tailored methods

The Climate Service for droughts is under development, with feedback on usability from the main user already incorporated into the design. This iterative process ensures that the service meets the needs of its users.

#### 4.7.4 Benchmarking

For cold waves, an Early Action Protocol (EAP) has been drafted by LRCS and is currently in the process of acceptance and review. However, questions remain around the action thresholds included for snow and temperature forecasts. For snow, the threshold is too loosely defined (occurrence of 'moderate' snow in the Lesotho highlands), whilst for temperature, although the threshold itself is more specific (maximum temperature  $\leq 2$  C for at least two consecutive days) its application in reality is not clear (for example spatially). A particular barrier to developing the action thresholds for snow was a lack of observed snow depth observations, which ideally would have helped define the thresholds through an analysis of how much snow fell during past cold wave events with known impacts. To aid threshold refinement, and additionally to understand forecast performance at those thresholds, user-centred evaluation of both thresholds and ECMWF forecasts is being conducted using ERA5 Land reanalysis data as a 'truth' proxy. Comparison of ERA5 Land temperature and snow 'records' to a database of impact cold/snow events is expected to provide valuable information for the refinement of EAP action thresholds. Once these thresholds have been thoroughly defined,

a user-centred, event-based assessment of ECMWF temperature and snow forecast can be undertaken. It is hoped that this will provide further information to the Lesotho Meteorological Service (LMS) on forecast performance, including for example, *are events typically too early or too late? How often do we see false alarms?* Taken together, this should support both LMS and LRCS in their cold wave anticipatory actions. Whilst this is not in itself new climate service, it supports and bolsters the current process for cold wave preparation and anticipatory action. Results will be presented in a follow-on I-CISK deliverable D3.4 *“Assessment of existing and tailored climate services using a range of user-driven evaluation metrics”*.

For droughts, no existing climate service offers a centralized visualization of multiple information sources tailored to user needs. Currently, users receive information from various stakeholders in table or list formats, often filled with technical jargon, making it challenging to interpret. There is a need for a centralized platform that consolidates information, making it easier to access and understand the relationships between different data sets. Additionally, internal communication within LRCS is currently inefficient, primarily occurring via email. The CS will make this better, by providing a platform easily accessible by users.

## 5 Summary of Lessons Learnt from the Local Applications

### 5.1 Lessons Learnt from the Local Applications at each Living Lab

Table 1 provides a comprehensive overview of the various aspects of the I-CISK CSs across the different LL implementations: applied domain, local data and local knowledge contribution, tailored methods implemented, main barriers from a user perspective, and the benefits and added value of these I-CISK CSs. From this summary, supported by the content of the previous chapters, we can conclude the following:

- Most tailored I-CISK CSs aim to generate outputs with higher spatial resolution than the available from global, regional, or national services.
- Downscaling techniques are widely applied as tailored methods across many LLs, with local data playing a crucial role in these efforts.
- Local data falls short of meeting FAIR (Findability, Accessibility, Interoperability and Reuse) data principles.
- Despite the extensive information collected during the co-creation processes, only a few LLs fully benefit from local knowledge contributions. This knowledge is primarily used to enhance the understanding of climate information, but not to build comprehensive climate knowledge.
- In some LLs, using the local language is a requirement for a complete understanding of the climate information, while in others, the technical terminology poses a barrier.
- The interpretation of the provided climate information (particularly, the uncertainty) is key for developing actions for water resources planning, tourism policy, climate adaptation and vulnerability reduction in different sectors at different LLs.
- Sector-tailored information and/or sector-specific indicators are repeatedly demanded in some LLs.

**Table 2** Summary of the tailored methods and the usability of the local applications for each LL.

Living Lab	Discipline	Local data contribution	Local knowledge contribution	I-CISK tailored methods	Barriers in the existing CSs	Added value from I-CISK tailored CSs
Andalucía - Spain	Meteorological	Long time series of temperature and precipitation dense network observations	Advisory on explanatory variables, potential correlations and design of agriculture adaptation strategies	Statistical downscaling, bias correction	Low spatial resolution, language, misunderstanding of forecast uncertainty, lack of sector-tailored information	High spatial resolution, language, visualization tools addressed to user needs
Alazani - Georgia	Hydrological	Time series of discharge, temperature and precipitation. Sparse network, with many	Past experience from farmers	Sub-seasonal and seasonal drought forecasts, hydrological downscaled forecasts	Service discontinuity, lack of long-term national strategy	Integration of basin management, improved water resource and renewable

		stations not operational				energy managements
Budapest – Hungary	Meteorological	HR airborne thermal images, VGI	No info. available	Data fusion techniques, CNN for enhanced pattern recognition, orthophoto aided vegetation indexing	Lack of specific heatwaves' variables, limited information on green infrastructure	Detailed urban heat mapping at the street and block level
Rijnland - The Netherlands	Hydro-meteorological	Ground station observations Precip., ETpot, and Q	Advisory for the multi-level dynamic drought alert thresholds	S2S drought forecasts and sector specific alerts, climate change information	Drought alert lead time limited to 14 days, no reference to climate change information	S2S drought forecasts Drought alerts with sector specific texts. Drought forecast and climate change info in one application
Emilia Romagna – Italy	Hydrological	Time series data of flow measurements	Experience from past drought episodes, design of adaptation strategies	HR seasonal hydrological forecasts	Visualization barriers, misunderstanding of graphical elements	Supporting decision-making, water resources planning
Crete – Greece	Hydrogeological	Historical time series of precipitation temperature measurements	Decisions related to climate hazards (droughts, wildfires and heatwaves) and energy demand	Seasonal forecasts of landslide susceptibility and surface water availability	Lack cross-sector links, lack of accessibility for non-expert users, low spatio-temporal resolution	Water resources planning, tourism policy
Lesotho	Meteorological	Rainfall observations	Support to vulnerability assessments	Drought forecasts, cold waves Early Action Protocol	Disconnected datasets in table or list formats, technical jargon	Impact-based forecasts, centralized platform, harmonized climate information

## 5.2 Discussion and Moving Forward

Currently, global and European organizations provide a wide range of CS based on high-quality climate data. These organizations generate and present various types of outputs, from hindcasts and sub-seasonal to seasonal forecasts to climate projections, using an ensemble of models and emission scenarios. They produce both essential meteorological variables (e.g., precipitation and temperature) as well as impact indicators, such as drought indices, bioclimatic indicators, and agroclimatic indicators, at different temporal and spatial scales.

The planned Copernicus CS evolution will focus to respond these main requirements:

- Climate prediction information at decadal timescales
- Linking extreme weather events to climate change

The action plan to develop, explained in *A European research and innovation Roadmap for Climate Services* (European Commission 2015) related to “Enhancing the quality and relevance of climate services” includes many actions with the centre on the local users and which are addressed to decision-making. It concludes with the recommendation of ensuring that stakeholders are involved throughout the process (CS development).

From the experience in I-CISK LLS, based on the needs expressed by stakeholders, the main recommendations from a usability perspective for improving climate information, within and beyond the I-CISK LLS, are:

**1) To increase the spatial resolution of climate (impact) information:**

Information from regional models is not adequate to understand the local impacts of climate change. Some I-CISK LLS feature heterogeneous landscapes with high topographic variability and the spatiotemporal patterns of meteorological and climate variables are very complex at a local scale; hence the need for increasing the spatial resolution.

**2) To increase the provision of hydrological forecasts:**

Meteorological forecasts are more widely available than hydrological, and those are high demanded in some I-CISK LLS. Note that the water sector has a great representation in the MAP composition on some I-CISK LL, and maybe other composition may call for more extension of bioclimatic or agroclimatic predictors.

**3) To enrich the in-situ component for enhancing local data:**

Local data should populate global (at least European) datasets. National Agencies should share their local observations to global / European initiatives. These datasets should be accessible in common repositories, and they should be used in the regional models in different processes (training, calibration, validation, etc.).

**4) To increase the provision of extremes:**

Modelling and predicting extreme events is very complex; however, the scientific community should intensify its research efforts in this area. Extreme events are of great interest to stakeholders, as they have a significant impact on both natural and human environments, as well as on their activities.

And the main recommendations from a usability perspective for the evolution to newly generated CSs are:

**1) To include (or maintain) the co-creation strategy:**

Stakeholder engagement in the I-CISK LLS has demonstrated significant benefits for the usability of CS. The involvement of local stakeholders in the design, development, delivery and evaluation of CSs adds clear value. The contribution of local knowledge and data is highly relevant and essential for the service uptake and improved decision-making.

**2) To add comparison tools between past and future:**

The inclusion of simple analysis/scenario tools, for instance, a comparison of predictions against a past benchmark event (with high impact) helps to understand future predictions and the potential impact of these predictions.

**3) To develop sectorial CSs with tailored climate information:**

The existing essential variables and their impact indicators available from Copernicus are useful for specific sectors; however new generation climate services should develop specific sectorial climate information to forestry, agriculture, urban planning, tourism, water management, etc. using tailored information, methods and tools.

**4) To reduce language and semantic barriers and to provide leaning materials:**

The right interpretation of climate information is a key point for the right decisions by local stakeholders. The reduction of climate vulnerability, the adaptation measures and the reduction of impacts in climate hazards depends on this interpretation. Barriers in this interpretation should be reduced, and constantly updated learning materials should be provided.

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## Appendix 1 Glossary

Acronym	Definition
AEMET	Agencia Estatal de Meteorología
ARPAE	Agencia Prevencione Ambiente Energia Emilia-Romagna
ASIS	Agricultural Stress Index System
BC	Bias Correction
CDS	Climate Data Store
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CEMS	Copernicus Emergency Management Service
CMIP	Climate Model Intercomparison Project
CNN	Convolutional neural network
CORDEX	Coordinated Regional Climate Downscaling Experiment
CS	Climate Service
CSIS	Climate Services Information System
C3S	Copernicus Climate Change Service
EAP	Early Action Protocol
E-HYPE	European HYPE
EPS	Ensemble Prediction System
EQM	Empirical Quantile mapping
EUROCORDEX	Coordinated Downscaling Experiment at European Domain
FAIR	Findability, Accessibility, Interoperability, and Reuse
FAO	Food and Agriculture Organization
GCM	Global Circulation Models
GEO	Group on Earth Observations
GEOGLAM	GEO Global Agricultural Monitoring
GEOSS	Global Earth Observation System of Systems
GFCS	Global Framework for Climate Services
GloFAS	Global Flood Awareness System
HR	High Resolution
HYPE	Hydrological Predictions for the Environment
IFS	Integrated Forecasting System
KNMI	Koninklijk Nederlands Meteorologisch Instituut
LCSC	Climatology and Climate Services Laboratory
LL	Living Lab
LRCS	Lesotho Red Cross Society
LVAC	Lesotho Vulnerability Assessment Committee
MAP	Multi actor Platform
MISTRAL	Meteo Italian Supercomputing Portal
NL	Netherlands
NMME	North American Multi-Model Ensemble
POI	Point of Interest
RBD	River Basin District
RWS	Rijkswaterstaat
SARCOF	Southern Africa Regional Climate Outlook Forum
SPEI	Standardised Precipitation Evapotranspiration Index
SPI	Standardised Precipitation Index
SMHI	Swedish Meteorological and Hydrological Institute
S2S	Sub-seasonal to seasonal
UAS	Unmanned Aerial Systems

TIR	Thermal infrared
VGI	Volunteered Geographic Information
WMO	World Meteorological Organization
WCRP	World Climate Research Program
WWH	World-Wide HYPE

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# I-CISK

HUMAN CENTRED CLIMATE SERVICES

## Colophon:

This report has been prepared by the H2020 Research Project “Innovating Climate services through Integrating Scientific and local Knowledge (I-CISK)”. This research project is a part of the European Union’s Horizon 2020 Framework Programme call, “Building a low-carbon, climate resilient future: Research and innovation in support of the European Green Deal (H2020-LC-GD-2020)”, and has been developed in response to the call topic “Developing end-user products and services for all stakeholders and citizens supporting climate adaptation and mitigation (LC-GD-9-2-2020)”. This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101037293.

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