ECMWF COPERNICUS REPORT

Copernicus Climate Change Service

End-to-end Demonstrator for improved decision making in the water sector in Europe (EDgE)

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EDgE User Guide

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Contributors

CENTRE FOR ECOLOGY & HYDROLOGY
K. Smith
L. Barker
S. Turner

ENVIRONMENT AGENCY
M. Gawith

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Introduction

This document contains the EDgE User Guidance, taken from the EDgE website (www.edge.climate.copernicus.eu), so it can be made available as an offline resource. It is divided into sections that provide details about:

- The EDgE project,
- The structure of the stakeholder engagement mechanism that was applied throughout the project,
- The EDgE modelling chain,
- Information on the Case Studies that were undertaken during the project, and
- The EDgE market analysis.

It also provides:

- Guidance on how to use the EDgE Map Viewers,
- A list of EDgE outputs and publications,
- A glossary, and
- A list of Frequently Asked Questions.

1. EDgE Project Summary

EDgE is a proof-of-concept project which combines climate data and state-of-the-art hydrological modelling to deliver a demonstration water-oriented information system implemented through a web application (Figure 1).

EDgE is working with key European stakeholders representative of private and public sectors to jointly develop and tailor approaches and techniques to assist them in using this improved climate information in decision-making, and support development of climate change adaptation and mitigation policies.

EDgE stands for "**E**nd-to-end **D**emonstrator for improved decision-making in the water sector in **E**urope".

By placing stakeholders at the heart of the research, EDgE bridges the gap between the data generated by climatological and hydrological models, and the information needed by decision-makers. EDgE will:

- Survey stakeholders' needs in seasonal forecasting and long-term projections for water management and planning
- Understand current barriers in the use of such information for decision-making
- Design an interface that can be used by users with different scientific and technical knowledge
- Enable robust assessment of the uncertainty and skill in the derived products

1.1 What will EDgE deliver?

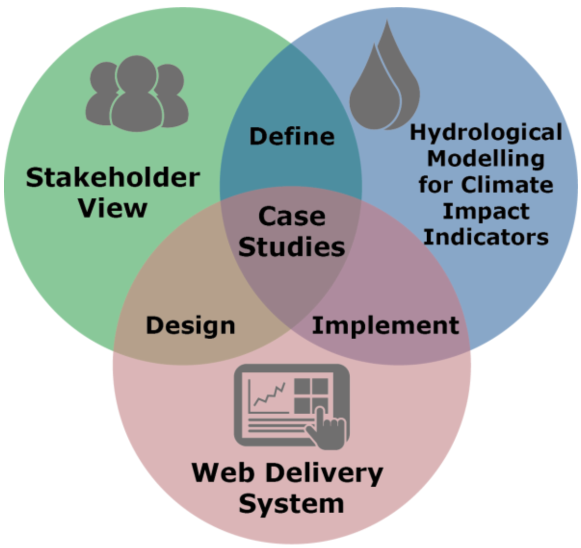


Figure 1: Structure of the EDgE project

EDgE's outputs will contribute to building a stronger capacity to incorporate climate information in decision-making across Europe. EDgE's deliverables include:

- An open-access, plug-in end-to-end modelling chain including state-of-the-art pan-European hydrological models, climate downscaling techniques and bias correction methods where new models and data can be easily added for a flexible multi-model ensemble modelling capacity. This will be accompanied by a protocol stating the technical requirements to follow for integration within the modelling chain.

- A range of hydrological seasonal re-forecasts and climate change impact projections based on latest C3S and CMIP5 climate modelling experiments, provided with different level of complexity through specific indicators including on drought and flood; different variables such as runoff or Potential Evapotranspiration; and different formats such as shape files, csv files or netCDF gridded time series for advanced users.

- A web-interface to display the information as graphics and maps and provide flexible downloading tools, co-designed with the users to reach users from different technical and scientific backgrounds.

- User guidance, in plain language, helping users to understand the data outputs and how to use them.

- Case Study fact-sheets of real-world examples of how to use the water information and the web-interface generated by EDgE, as well as market analyses of the value of a Sectoral Information System.

An overview of EDgE is given on the EDgE flyer

EDgE is funded by the European Centre for Medium-range Weather Forecasts (ECMWF) Copernicus Climate Change Service C3S.

1.2 Project Partners

EDgE is delivered by a pan-European consortium, coordinated by the Centre for Ecology & Hydrology (UK), the consortium is comprised of the following institutions:

Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL	Centre for Ecology & Hydrology (CEH), UK	CEH are providing scientific leadership and management of EDgE and are leading the development of the EDgE Map Viewer
CETAQUA WATER TECHNOLOGY CENTRE	Centro Tecnológico del Agua (Cetaqua), Spain	Cetaqua are leading the EDgE market analysis for each of the Case Studies
CLIMATE PARTNERSHIP, LLC	Climate Partnership LLC (CPL), Princeton, USA	CPL are contributing to the hydrological modelling underlying the EDgE Seasonal Forecasts and EDgE Climate Projections and leading the work on EDgE modelled uncertainty assessment
Environment Agency	Environment Agency (EA), UK	The EA are leading the stakeholder aspects of EDgE, including the Focus Groups and Case Studies - they are also leading the UK EDgE Case Study
HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ	Helmholtz Centre for Environmental Research (UFZ), Germany	UFZ are leading the hydrological modelling underlying the EDgE Seasonal Forecasts and EDgE Climate Projections
	Mediterranean Network of Basin Organisations (MENBO), Spain	MENBO are leading the Spanish Focus Group and Case Studies
NVE	Norwegian Water Resources & Energy Directorate (NVE), Norway	NVE are leading the Norwegian Focus Groups and Case Study

2. Stakeholder Engagement

Within EDgE we are actively engaging with a broad range of stakeholders and end-users in the water sector to understand how climate-related decisions are made and to identify the information needs of prospective European users. We are working with Focus Groups in three European countries to identify these needs.

2.1 Focus Groups

The project has established Focus Groups in each of the project countries (Norway, Spain and the United Kingdom), chosen to represent different hydro-climatic regions and user audience:

Norway

Snow dominated region with much hydropower use

Spain

Mediterranean region with many water allocation issues

UK

Range of weather conditions and water use pressures

Each Focus Group has met a minimum of three times during the project to:

- Discuss information needs including hydrological indicators
- Test a prototype of the Map Viewer
- Support the development of user guidance and implementation of the final Map Viewer

Together the groups represent users with varying levels of experience of applying a range of climate and hydrological information to inform their decision-making. The tasks that they are looking to perform, and the information they need to support them, compare well with the user categories summarised in Figure 2.

2.2 How has EDgE engaged across Europe?

EDgE stakeholder engagement activity has not been restricted to the Focus Groups. There are many other water-dependent industries across Europe and a targeted programme of wider stakeholder engagement has been undertaken. This was achieved through interviews with users identified through appropriate networks and literature. This wider European engagement provided an opportunity to test the relevance of our hydro-meteorological indicators and metrics to a broader range of users and consider where they might need to be refined to meet the needs of a wider range of water users throughout Europe. Examples included engagement with the agricultural sector, the European Environment Agency and the consultancy service sector, both large multi-national and

Small and Medium-sized Enterprises (SMEs). EDgE also explored the information needs of geographical settings that are different from those of our Focus Groups, for example large, trans-border river basins.

2.3 How stakeholder needs are used in EDgE

EDgE has worked closely with its Focus Groups throughout the project. A large amount of information on user requirements was gathered from stakeholders in the initial phase of the project. Common requirements were identified and condensed into a specification for the metrics and requirements for the interface, directly informing the modelling and web interface development work in EDgE. Users have tested and provided feedback on developing products at regular intervals in the project, helping to shape and refine work in the following phase.

There have been some hydro-meteorological indicators and metrics that users would like, but which could not be produced within the scope of EDgE (e.g. information on water temperature). This information and other needs identified by users that cannot be delivered within the existing project will be included in the roadmap for integration of EDgE with C3S to inform future research needs.

Organisation type / capacity	Simple Low capacity	Simple Medium low capacity	Medium complex Medium high capacity	Large complex High capacity
Task	Do I need to worry about this?	Tell me what the impacts will be and what I need to do	Doing first risk assessment - want tailored, sector specific information and advice	Doing quantitative assessments of risks and options; taking action; influencing and leading
Product needs	- Screening tool - Weather info	- Top-tips - Case studies - Simple tools - Headline messages - Present and future	- Tools and guidance - UKCP09 maps and key findings - Data and information - Present and future	- Specialist data and information to do, or commission, assessments - Present and future

Figure 2: Example of climate services user needs summary. Source: Climate Ready, Environment Agency, UK

2.4 Focus Group Meetings

2.4.1 Focus Group 1

The first round of EDgE Focus Group meetings were held in Oslo in February 2016 and London and Valencia in March 2016.

The aim of the meetings was to:

- Introduce EDgE, showing the kinds of outputs that might be produced in the project
- Find out what information stakeholders currently use to make decisions and its strengths and weaknesses
- Find out what information they would prefer to use in the future

Country	Main outcomes
	• Information about model skill (for seasonal forecasts) is very important. This could be provided as maps that show where forecasts have skill, or where there is uncertainty about the level of skill • Access to European level information is of considerable interest to some of the stakeholders. Having consistent information between Norway and other European countries, both in terms of spatial scales, variables produced, and climate scenarios covered, would be extremely helpful for decision-making in relation to energy prices and investments • Many stakeholders run their own hydrological models, and so access to driving data is important
	• It is very important to ensure that data generated can be downloaded • It is very important that the information generated by EDgE is translated into Spanish; otherwise its added-value would be very limited • Depending on the users, short (seasonal), medium and long-term predictions are needed; planning decisions need information/indicators at the local level
	• Downloadable data in simple file formats is essential, as is accompanying metadata • Seasonal disaggregations would be more useful for some metrics than monthly data (e.g. groundwater recharge) • Information on how hydrological extremes (floods and droughts) will change under climate change would be really useful • Interactive maps are very useful for exploring and understanding data as well as illustrating the issues to non-specialists

2.4.2 Focus Group 2

The second round of EDgE Focus Group meetings were held in Oslo, London and Valencia in October 2016.

The aim of the meetings was to:

- Demonstrate and test the EDgE Map Viewer
- Agree priorities for the next phase of the Map Viewer development
- Plan the Case Study work

Figure 3: EDgE Focus Group 2 in Oslo

Metrics
Users agreed that the suite of metrics provided by EDgE met their needs. They were particularly interested in temperature, precipitation, river flow, recharge, potential evapotranspiration, a soil moisture index and snow metrics. They suggested additional metrics that they would like to see available in future, which are beyond the scope of the EDgE proof-of-concept project. For example, the UK group highlighted a need for water quality information and all three groups had an interest in water temperature. The UK group suggested that seasonal disaggregations would be more useful for some metrics (groundwater recharge) than monthly. The UK and Spanish groups advised that it would be useful to have absolute values as well as change factors.

Map Viewer interface
Users were impressed with the maps and graphs and found the presentation of information visually very appealing. All three groups stressed the importance of ensuring users understand the data behind the outputs, and were keen to learn more about the uncertainties associated with the mapped outputs. Collectively, the groups provided a number of clear and specific suggestions on how to improve the interface in the next phase of EDgE, many of which have now been taken forwards and implemented in the EDgE Map Viewer.

Priorities for next development phase
Priorities for the development of the EDgE Map Viewer were identified across all three groups as being:

- Interactive maps (with data for selected grid cells)
- Interaction between the maps and graphs
- Downloadable maps and graphs

2.4.3 Focus Group 3

The third round of EDgE Focus Group meetings were held in London and Oslo in March 2017.

The aim of the meetings was to:

- Understand users' application of skill and uncertainty information
- Review different ways of visualising that information
- Explore user preferences for the content of, and the means of delivering, user guidance in order to inform both the next stage of the EDgE project and the wider Copernicus programme

Figure 4: EDgE Focus Group 3 in London

A presentation on seasonal forecast skill and uncertainty in the EDgE project was given and a facilitated discussion held on users' understanding and consideration of these concepts in their present modelling and decision-making. Two interactive sessions then followed, one on visualisation methods and another on user guidance. In each, a short presentation was followed by an interactive session in which users were asked to vote for and explain their preferences for different visualisation methods, and for the content and means of delivery of user guidance. The meeting concluded with a brief update on the Case Study work and an overview of the next phase of the project.

Country	Main outcomes
	• A consistent, trustworthy dataset (for seasonal forecasts and climate projections) across Europe becomes increasingly important with increasing power exchange across countries • A quantification or assessment about when the seasonal forecast is skillful or not would be valuable
	• Skill and uncertainty information is important both to decision-makers and intermediaries • Limited availability of skill and uncertainty information does not get in the way of decision-making, but does have a bearing on the decision-making approach • End-users are influenced by pragmatism and market norms in their consideration of uncertainty

2.4.4 Focus Group 4

The fourth round of Focus Group meetings took place in London and Oslo in September 2017 and Valencia in October 2017.

The aim of the meetings was to:

- Show the near-final Map Viewer and get users' responses to it
- Share the Case Studies that have been conducted using EDgE data
- Ask for feedback on the website and initial user guidance
- Reflect on the user experience of the EDgE project

All three Focus Groups were very impressed with the EDgE Map Viewer. They considered it easy to navigate and understand and they liked the way the data had been visualised. They were particularly pleased at the extent to which their comments and suggestions on the Map Viewer had been acted on: it was clear to them how their input had shaped the project. Users stressed the importance though of being able to understand and trust the data behind the Map Viewer, particularly because the Map Viewer is so accessible and user friendly. Specific suggestions were made on final revisions that they would like to see if possible.

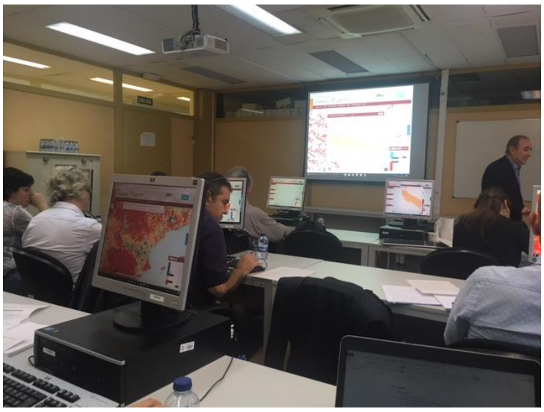


Figure 5: EDgE Focus Group 4 in Valencia

There was good interest in the Case Studies that had been conducted, particularly where results showed some comparison with those obtained from other national data that they were more familiar with.

Some very helpful suggestions were made on the emerging website content and user guidance. Some in the UK Focus Group felt that the early guidance assumed too much prior knowledge on modelling, forecasting and climate change for a high level end user and noted that simpler language would be desirable. Specific suggestions were made on questions to address in the FAQs.

The Spanish and Norwegian groups reiterated the importance of core guidance being made available in their own languages. Uptake of a future operational service will have limited if guidance and information is only available in English.

User's reflections on their experience of being involved in EDgE were very positive. They were pleased to have had a chance to take part in the project and identified specific benefits including:

- Having access to science and information that they may not have had otherwise
- Excellent discussions around understanding and visualising skill and uncertainty in modelling
- Networking with researchers, consultants and other decision-makers
- An opportunity to gain technical and precise knowledge on climate change impacts, water resources management and the use of tools for improved planning and forecasting

3. The EDgE Modelling Chain

EDgE has produced a range of data outputs to meet the needs of water users across Europe, identified through our Focus Groups. The project has modelled hydrology across Europe using a state-of-the-art modelling chain at a high spatial resolution of 5km and at two timescales for seasonal forecasting and climate projections.

A range of climate models and several hydrological models have been used to capture uncertainty in the modelling process.

EDgE provides Sectoral Climate Impact Indicators (SCIIs) that have been defined with stakeholders at Focus Group meetings in the UK, Spain and Norway. The SCIIs have been defined to provide the most useful indicators to meet water users' needs, being appropriate for use in areas such as drought, flooding, hydropower, etc.

The spatial domain of the EDgE project includes the current EU-28 member countries, Switzerland, Norway, Albania, the former Yugoslav Republic of Macedonia, Montenegro, Serbia, Bosnia and Herzegovina, Kosovo, Andorra, Monaco, San Marino, and the Vatican. The boundary of the domain is extended to include cells that flow within the EU region to maintain the consistency of river flows.

3.1 Seasonal Forecasting

Seasonal Forecasting attempts to provide information about the 'climate' that may be expected to occur in the next few months. Seasonal Forecasts provide a range of possible climate changes that are likely to happen in the upcoming season. Due to the chaotic nature of atmospheric circulation, it is not possible to predict the daily weather variations at a specific location months in advance.

You can read more about seasonal forecasting here.

EDgE provides Seasonal Forecasts of Sectoral Climate Impact Indicators (SCIIs) that are relevant to the water sector in Europe. As EDgE is a proof-of-concept project, the forecasts provided in the Seasonal Forecast Map Viewer are *hindcasts* (forecasts run over a historic period) from 1993-2011. Figure 6 summarises the EDgE Seasonal Forecasting modelling chain from the Seasonal Prediction Models, through Hydrological Models, to the derivation of the SCIIs.

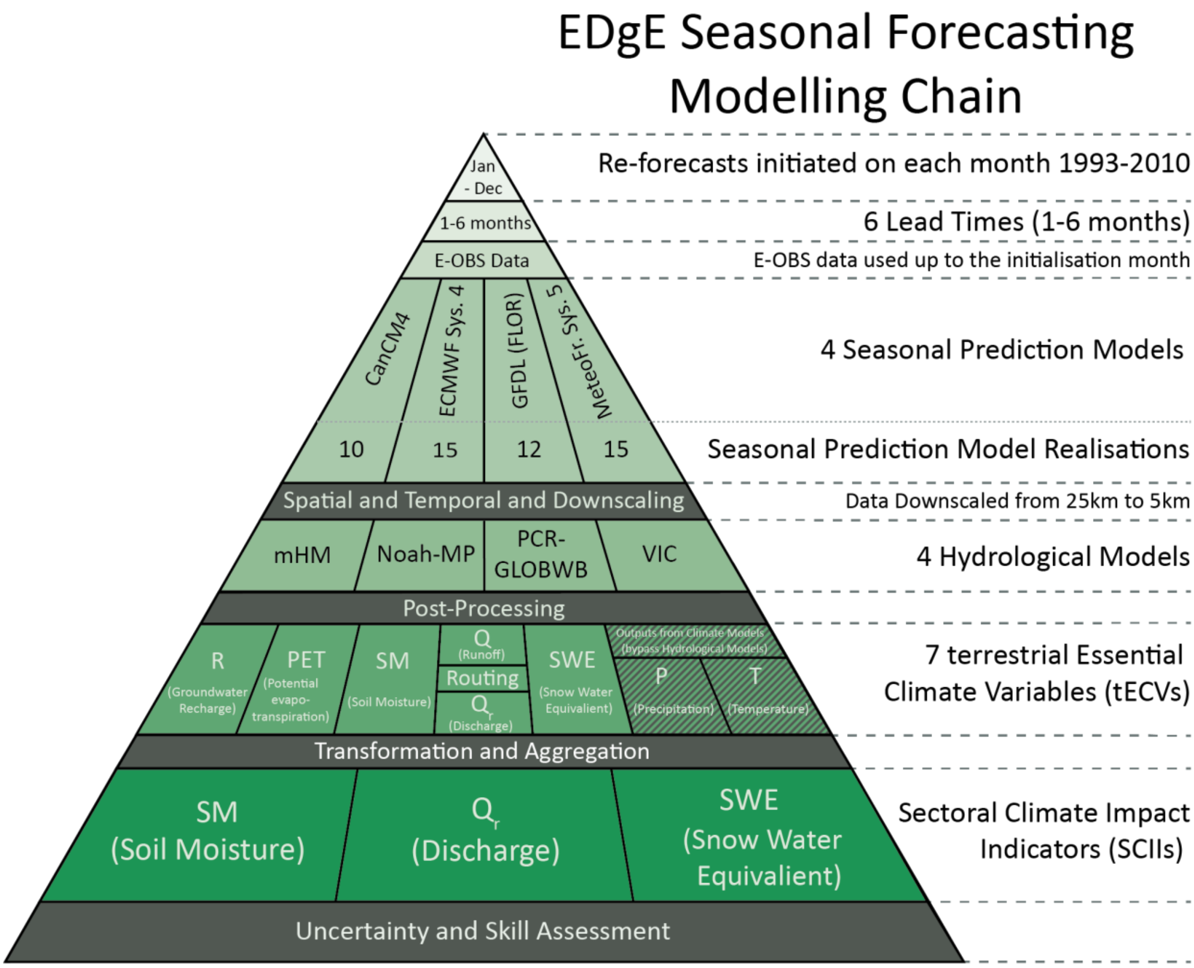


Figure 6: Overview of the EDgE Seasonal Forecasting Modelling Chain

3.1.1 Pre-Processing Methods

The pre-processing encompasses the preparation of static data required for the hydrological models and the processing of the meteorological forcing variables from different sources into the required format for each model.

The freely available E-OBS data (v12; Haylock et al. 2008) were used to drive the hydrological models up to the initalisation month. E-OBS is a European land-only daily high-resolution gridded data set for precipitation and minimum, maximum, and mean surface temperature for the period 1950–2015. The daily precipitation and temperature data from this dataset have been downscaled from their native 25km to 5km resolution using External Drift Kriging (EDK).

Reference model runs with the E-OBS data also provided the statistical basis for the calculation of the SCIIs. Meteorological data obtained from the North American Multi-Model Ensemble (NMME) and the ECMWF Seasonal Forecasting System are used for the seasonal hindcasting of hydrological variables.

3.1.2 Seasonal Prediction Models

The EDgE modelling chain begins with climate variables from seasonal prediction models. These climate variables (e.g. precipitation and temperature) were used to derive the variables needed as inputs to the hydrological models. Four seasonal prediction models have been used in EDgE: CanCM4, GFDL (FLOR), MétéoFrance System 5 and ECMWF System 4. Several model realisations have been applied for each model; 10 for CanCM4 and GFDL (FLOR), and 15 for LFPW and ECMWF System4. These model realisations account for some of the uncertainty that originates from unknown variables in the climate models (initial and boundary conditions).

Read more about skill and uncertainty here

3.1.2.1 CanCM4

CGCM4/CanCM4 originates from the Canadian Centre for Climate Modelling and Analysis. The atmospheric component of CanCM4 is the Fourth Generation Atmospheric General Circulation Model and its oceanic component is the Fourth Generation Ocean General Circulation Model (OGCM4/CanOM4). OGCM4 uses a z-level vertical coordinate, with horizontal differencings formulated on an Arakawa B-Grid. It was developed from the NCAR CSM Ocean Model (NCOM). There are 40 vertical levels with spacings ranging from 10m near the surface (there are 16 levels in the upper 200m) to nearly 400m in the deep ocean. Horizontal coordinates are spherical with grid spacings approximately 1.41 degrees in longitude and 0.94 degrees in latitude. Computational instabilities due to convergence of meridians near the North Pole are suppressed via Fourier filtering, and there is a column of special tracer grid cells centred on the North Pole as described by Gent et al. (1998).

3.1.2.2 GFDL (FLOR)

The NOAA Geophysical Fluid Dynamics Laboratory (GFDL) Forecast-oriented Low Ocean Resolution version of CM2.5 (CM2.5-FLOR, or FLOR) model (Vecchi et al. 2014) is a descendant of the CM2.5 model (Delworth et al., 2012) and CM2.1 model (Delworth et al., 2006). The FLOR model incorporates the higher horizontal resolution in the atmosphere and land, higher vertical resolution in the atmosphere, and significantly improved land model (LM3; Milly et al. 2014) from CM2.5. The FLOR model also uses the relatively low-resolution ocean and sea ice components of CM2.1. These choices create a coupled model that is relatively computationally efficient but can be used to address problems of regional climate and extremes.

3.1.2.3 MétéoFrance System 5

MétéoFrance System 5 is based on the integrated atmosphere/ocean/sea/ice-land surface model CNRM-CM. The global ensemble system uses a lag-averaged and a stochastic scheme to simulate initial state and model uncertainties using a lagged-average scheme. The atmosphere component has a 1.5° horizontal resolution and 91 vertical levels, while the ocean one has a 1° horizontal resolution and 42 vertical levels.

The EDgE project uses the 15 hindcast ensemble members that are available from 1991 to 2014. These hindcasts were built with one ocean initial state combined with 15 different sets of perturbations for stochastic dynamics.

3.1.2.4 ECMWF System 4

ECMWF System 4 is based on a more recent atmospheric model version (IFS model cycle 36r4) with higher resolution forecasts with and a higher top of the atmosphere, more members, and a larger hindcast data set. System 4 initial perturbations are defined (as in System 3) with a combination of atmospheric singular vectors and an ensemble of ocean analyses. Atmosphere model uncertainties are simulated using the 3-time level stochastically perturbed parameterized tendency (SPPT) scheme and the stochastic back-scatter scheme (SPBS) operational in the EPS (System 3 used only a 1-time version of SPPT). System 4 uses NEMO instead of HOPE as its ocean component (with the same resolution), with initial conditions generated by the Near Real Time (NRT) NEMOVAR suite instead of HOPE/OI. In February, May, August and November, 15 of the 51 members are extended to 13 months.

More detailed information about the seasonal prediction models used in EDgE can be found here

3.1.3 Hydrological Models

In the second step of the modelling chain, the meteorological tECVs (potential evapotranspiration (PET), precipitation (P) and temperature (T)) were used to force four hydrological models: mHM, NOAH-MP, and VIC and PCR- GLOBWB. These models were used to derive the hydrological tECVs: soil moisture (SM), groundwater recharge (R) and snow water equivalent (SWE). Finally, runoff (Q) was routed through the routing model, mRM, to obtain streamflow (Qr).

More detailed information about the Hydrological Models used in EDgE can be found here

3.1.3.1 Mesoscale Hydrological Model (mHM)

The mHM is a spatially distributed, grid-based mesoscale hydrologic model (mHM; Samaniego et al. 2010, Kumar et al 2013a) that accounts for the following main hydrologic processes: canopy interception, snow accumulation and melt, root zone soil moisture and evapotranspiration, infiltration, surface and subsurface runoff, percolation, baseflow and flood routing.

3.1.3.2 Noah-MP

The land surface model Noah-MP calculates fluxes and state variables within the energy and water cycles on the terrestrial land surface. It is the successor of the Noah model with the inclusion of multiple process parameterisation (hence Noah-MP) and is currently used as the land surface scheme for the atmosphere Weather Research and Forecasting Model (WRF).

3.1.3.3 VIC

The Variable Infiltration Capacity (VIC) model (Liang et al., 1994, 1996; Cherkauer et al., 2002) simulates the terrestrial water and energy balances and distinguishes itself from other land surface schemes through the representation of sub-grid variability in soil storage capacity as a spatial probability distribution, to which surface runoff is derived, and baseflow from parameterising a deeper soil moisture zone as a non-linear recession.

3.1.3.4 PCR-GLOBWB

PCR-GLOBWB is a large-scale hydrological model intended for global to regional studies (Van Beek et al., 2010). For each grid cell, PCR-GLOBWB uses process-based equations to compute moisture storage in three vertically stacked soil layers as well as the water exchange between the soil and the atmosphere and the underlying groundwater reservoir.

3.1.4 Downscaling Methods

Daily values of precipitation (P), daily average temperature (Tmean), daily maximum and minimum temperature (Tmax and Tmin, respectively) have been downscaled for both seasonal forecasts and climate projections from their native resolution to 25 km E-OBS resolution. The obtained daily fields at a 25km resolution were then downscaled to the 5km resolution using the same procedure that was used for the reference dataset E-OBS (i.e., external drift Kriging, EDK). In a second step, the daily values were further disaggregated to 3-hourly values using methods described in Bohn et al. (2013) to provide the representation of the diurnal cycle needed by the hydrological models.

3.1.5 Sectoral Climate Impact Indicators

The EDgE outputs are in the form of Sectoral Climate Impact Indicators (SCIIs), which have been derived from the terrestrial Essential Climate Variable (tECV) timeseries. For the EDgE Seasonal Forecasts the SCIIs represent model predictions of three variables; streamflow, soil moisture, and groundwater recharge.

These predictions are presented in "quintiles" compared to the E-OBS reference data. Five reference quintile categories are used to denote the probabilistic quintile distribution, defined as:

1. Q_forecast <= Qref_quantile_level_20
2. Qref_quantile_level_20 < Q_forecast <= Qref_quantile_level_40
3. Qref_quantile_level_40 < Q_forecast <= Qref_quantile_level_60
4. Qref_quantile_level_60 < Q_forecast <= Qref_quantile_level_80
5. Q_forecast > ref_quantile_level_80

Where Q_forecast is monthly forecasted values and the ref_quantile_level_20, 40, 60, and 80 denotes reference quantile levels. The reference levels are estimated for each calendar month, separately from the (E-OBS forced) datasets of the period 1993-01 to 2011-12. For a given month and lead-time, these categorical values are estimated for each realization and then finally the percentage of model ensemble members falling within each of the five reference quantile category are calculated. The forecasts run up to 6 months ahead from each forecast start month, with forecasts starting at 01/1993 and ending 12/2011.

Find out more about the EDgE SCIIs here

3.1.6 Uncertainty and Skill Assessment

Click here for a full description of the concepts of uncertainty and skill, and how they have been applied in the EDgE Seasonal Forecasts and the Climate Predictions

Uncertainty within the EDgE Seasonal Forecasts is estimated using an ensemble approach. The Seasonal Prediction Models (SPMs) have multiple realisations to account for different initial conditions: ECMWF-System 4 (15 realisations), MétéoFrance System 5 (15 realisations), CanCM3 (10 realisations), and GFDL-FLOR (12 realisations). Each of these model realisations has been forced through the four hydrological models (HMs), so for each forecast and lead time, the uncertainty in an SCII is computed from the 208 ensemble members (52 SPM ensembles x 4 HMs). Note that this ensemble approach does not account for all possible aspects of uncertainty, for example, the uncertainty in the observational data is not considered.

The (un)certainty in the Seasonal Forecast Map Viewer is presented with a slider. This slider uses data on the percentage of models within the ensemble that agree on the dominant quintile, and can be set to the users' preference to mask out areas with low certainty. The graph in the map viewer also shows how the models' predictions are distributed across the quintiles.

The models' skill is assessed using the Brier Score (BS), a measure of how well the forecast ensemble predicts an observed event (e.g. streamflow was below normal). It is calculated as the difference between the event happening (1) or not (0), and the probability of the forecast. The probability of the forecast is calculated as the fraction of the ensemble of forecasts that predict the event. This score is then averaged over all years for each month at each grid cell to give the Brier Score.

In the EDgE Seasonal Forecast Map Viewer, the BS score for each month in the forecast is presented in blocks at the bottom of the graph. The blocks are coloured green for a "good" score (BS<0.33), amber for a "medium" score (0.33<BS<0.66), and red for a "poor" score (BS>0.66).

Find out more about EDgE skill and uncertainty here

3.1.7 Operationalisation

To operationalise the EDgE Seasonal Forecasting modelling system, six key operations would be required for each forecast initialisation time (e.g., per month), as well as occasional operations required to update to the operational system (Figure 7). The six key operations are to:

1. Update the initial states – this means running the models up to the date of forecast initialisation with newly available observational data (e.g. from the previous month)
2. Get seasonal forecasts and Ensemble Streamflow Prediction (ESP) – obtain the seasonal forecast climate data (precipitation and temperature) for the hydrological models; create the ESP input data (resampling the historic climate data)
3. Run the hydrological models to generate terrestrial Essential Climate Variables (tECVs)
4. Use the tECVSs to calculate Sectoral Climate Impact Indicators (SCIIs)
5. Calculate the forecast uncertainty (spread of model results), and update the skill (comparison with observations) with the previous months' data
6. Create visualisation – produce maps and graphs for the Seasonal Forecast Map Viewer

Occasional operations include: creating the longer term historical states; updating the operational system with new seasonal forecast of hydrological models; updating the system with new user requirements (e.g. new SCIIs) and updating the Seasonal Forecast Map Viewer.

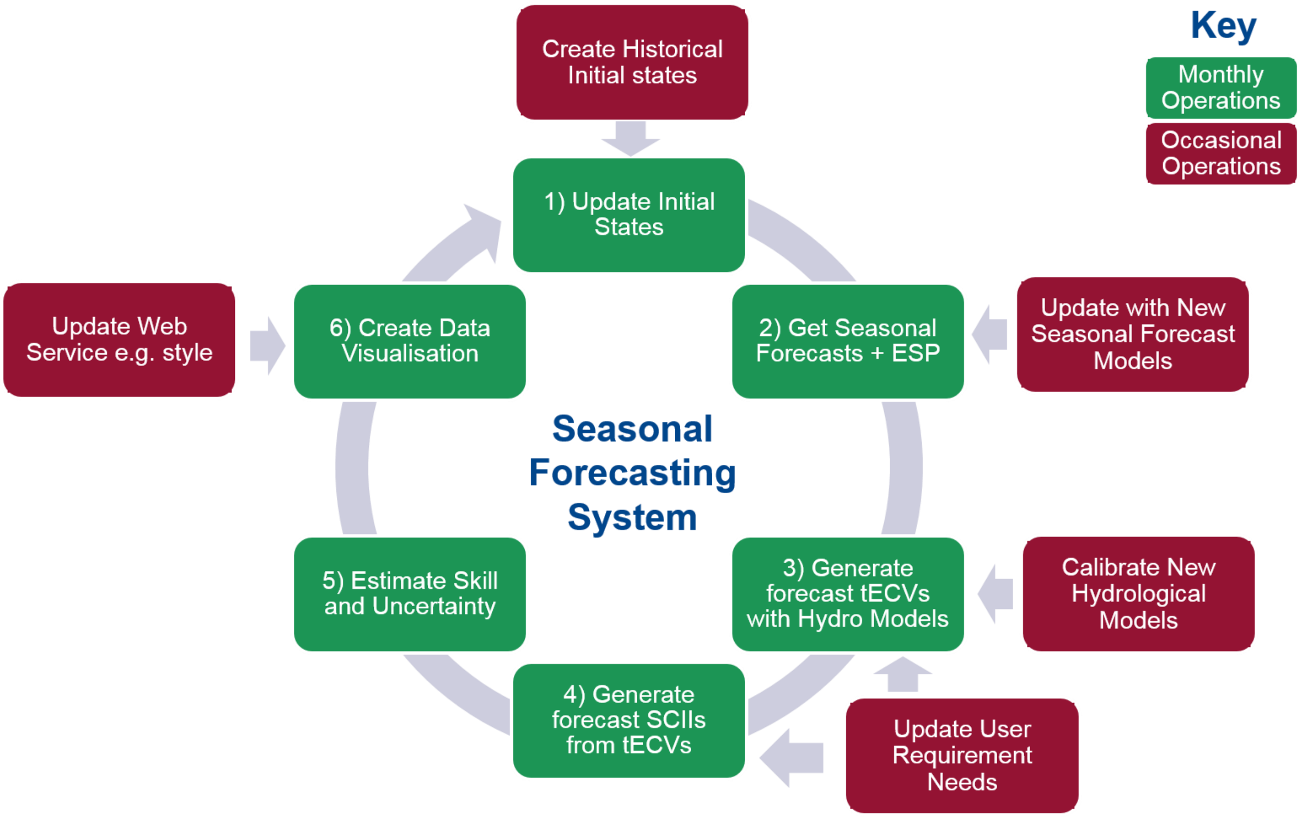


Figure 7: Overview of an operational EDgE Seasonal Forecasting System

3.2 Climate Projections

Climate projections provide estimates of environmental response to different greenhouse gas emissions throughout the 21st century. Projections are based upon Representative Concentration Pathways (RCPs) that provide scenarios of the emissions of four greenhouse gasses. Climate models then provide estimates of the impact of these emissions on climatic variables such as temperature and precipitation, which can then be used to drive impacts models such as hydrological models.

EDgE provides climate projections of Sectoral Climate Impact Indicators (SCIIs) that are relevant to the water sector in Europe, averaged over 30-year time windows on a five-year timestep from 2025 to 2080. The pyramid diagram in Figure 8 summarises the EDgE Climate Projections modelling chain from emissions scenario, through the General Circulation Models and Hydrological Models, to the derivation of the SCIIs.

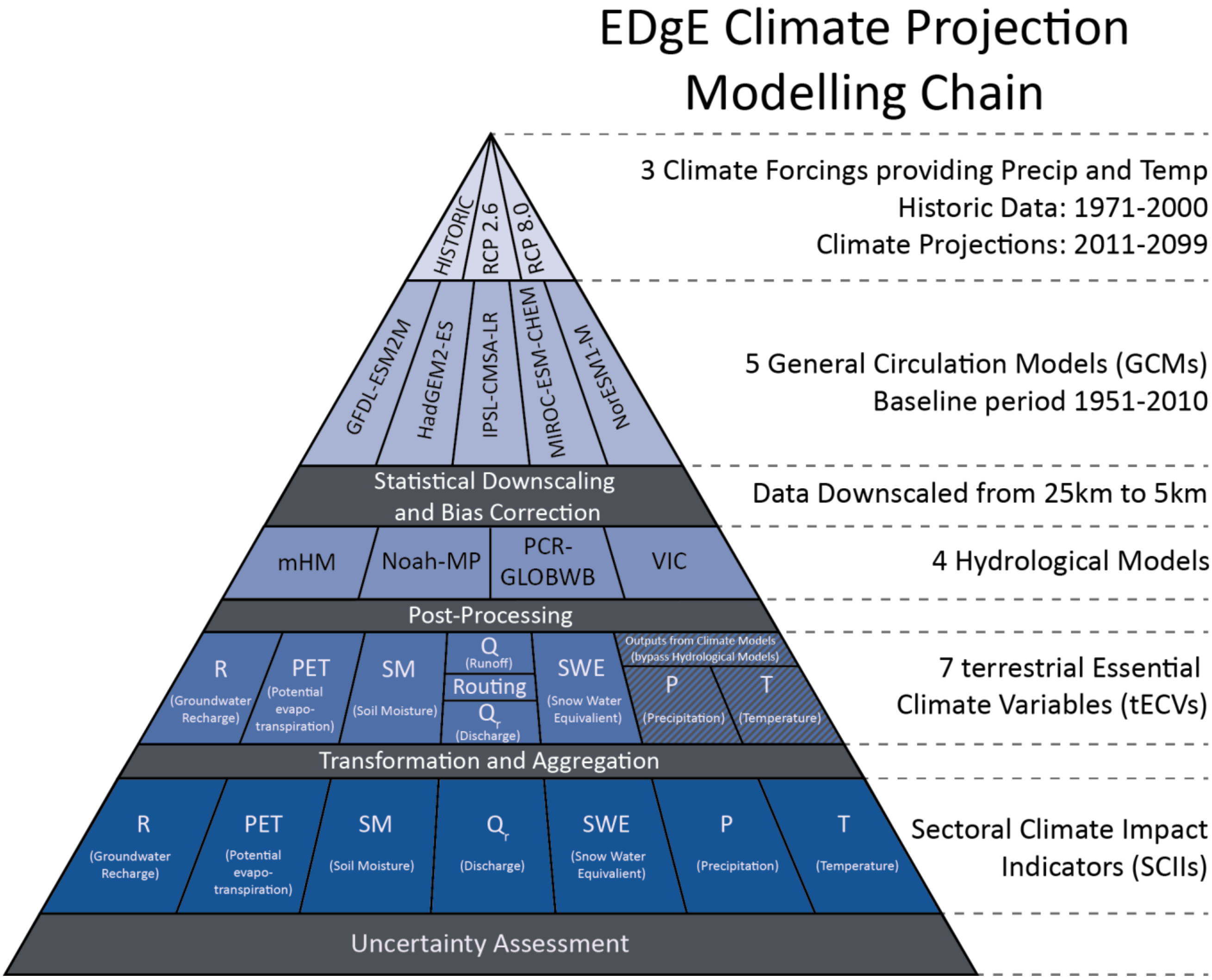


Figure 8: Overview of the EDgE Climate Projections Modelling Chain

3.2.1 Pre-Processing Methods

The pre-processing encompasses the preparation of static data required for the hydrological models and the processing of the meteorological forcing variables from different sources into the required format for each model.

The freely available E-OBS data (v12; Haylock et al. 2008) were used to drive the hydrological models up to the initalisation month. E-OBS is a European land-only daily high-resolution gridded data set for precipitation and minimum, maximum, and mean surface temperature for the period 1950–2015. The daily precipitation and temperature data from this dataset have been downscaled from their native 25km to 5km resolution using External Drift Kriging (EDK).

Reference model runs with the E-OBS data also provided the statistical basis for the calculation of the SCIIs. Meteorological data obtained from the North American Multi-Model Ensemble (NMME) and the ECMWF Seasonal Forecasting System are used for the seasonal hindcasting of hydrological variables.

3.2.2 Climate Models

The EDgE modelling chain begins with climate variables from General Circulation Models (GCMs). These climate variables (e.g. precipitation and temperature) were used to derive the variables needed as inputs to the hydrological models. Five GCMs have been used in EDgE: GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NOR-ESM1M. These models were chosen as they are the models from CMIP5 that were chosen for implementation in the Inter-Sectoral Impacts Model Intercomparison Project (ISI-MIP).

More detailed information on the climate models can be found here

3.2.2.1 GFDL-ESM2M

The Geophysical Fluid Dynamics Laboratory (GFDL) constructed NOAA's first Earth System Models (ESMs) (Dunne et al. 2012, 2013) to advance understanding of how the Earth's biogeochemical cycles, including human actions, interact with the climate system. ESM2M evolved from GFDL's CM2.1 climate model, and building on this GFDL produced two new models representing ocean physics with alternative numerical frameworks to explore the implications of some of the fundamental assumptions embedded in these models. In ESM2M, pressure-based vertical coordinates are used along the developmental path of GFDL's Modular Ocean Model version 4.1.

3.2.2.2 HadGEM2-ES

The HadGEM2 family of climate models represents the second generation of HadGEM configurations, with additional functionality including a well-resolved stratosphere and Earth System components.

HadGEM2 stands for the Hadley Centre Global Environment Model version 2. The HadGEM2 family of models comprises a range of specific model configurations incorporating different levels of complexity but with a common physical framework. The HadGEM2 family includes a coupled atmosphere-ocean configuration, with or without a vertical extension in the atmosphere to include a well-resolved stratosphere, and an Earth-System configuration which includes dynamic vegetation, ocean biology and atmospheric chemistry.

3.2.2.3 IPSL-CM5A LR

The ICMC (IPSL Climate Modelling Center) continuously develops and improves the climate model and its various components. The IPSL CM5 is the last version of the IPSL model and is a full earth system model. In addition to the physical atmosphere-land-ocean-sea ice model, it also includes a representation of the carbon cycle, the stratospheric chemistry and the tropospheric chemistry with aerosols.

3.2.2.4 MIROC ESM CHEM

MIROC-ESM is based on a global climate model MIROC (Model for Interdisciplinary Research on Climate). A comprehensive atmospheric general circulation model (MIROC-AGCM 2010) including an on-line aerosol component (SPRINTARS 5.00), an ocean GCM with sea-ice component (COCO 3.4), and a land surface model (MATSIRO) are interactively coupled in MIROC.

3.2.2.5 NorESM1M

The Norwegian Earth System (NorESM) family of models are based on the Community Climate System Model version 4 (CCSM4) of the University Corporation for Atmospheric Research, but differs from the latter by, in particular, an isopycnic coordinate ocean model and advanced chemistry-aerosol-cloud-radiation interaction schemes. NorESM1-M has a horizontal resolution of approximately 2° for the atmosphere and land components and 1° for the ocean and ice components.

3.2.3 Hydrological Models

In the second step of the modelling chain the meteorological tECVs: potential evapotranspiration (PET), precipitation (P) and temperature (T) were used to force four hydrological models: mHM, NOAH-MP, and VIC and PCR-GLOBWB. These models were used to derive the hydrological tECVs: soil moisture (SM), groundwater recharge (R) and snow water equivalent (SWE). Finally, runoff (Q) is routed through the routing model mRM to obtain streamflow (Qr).

More detailed information about the Hydrological Models used in the EDgE domain can be found here.

3.2.3.1 Mesoscale Hydrological Model (mHM)

The mHM is a spatially distributed, grid-based mesoscale hydrologic model (mHM; Samaniego et al. 2010, Kumar et al 2013a) that accounts for the following main hydrologic processes: canopy interception, snow accumulation and melt, root zone soil moisture and evapotranspiration, infiltration, surface and subsurface runoff, percolation, baseflow and flood routing.

3.2.3.2 Noah-MP

The land surface model Noah-MP calculates fluxes and state variables within the energy and water cycles on the terrestrial land surface. It is the successor of the Noah model with the inclusion of multiple process parameterisation (hence Noah-MP) and is currently used as the land surface scheme for the atmosphere Weather Research and Forecasting Model (WRF).

3.2.3.3 VIC

The Variable Infiltration Capacity (VIC) model (Liang et al., 1994, 1996; Cherkauer et al., 2002) simulates the terrestrial water and energy balances and distinguishes itself from other land surface schemes through the representation of sub-grid variability in soil storage capacity as a spatial probability distribution, to which surface runoff is derived, and baseflow from parameterising a deeper soil moisture zone as a non-linear recession.

3.2.3.4 PCR-GLOBWB

PCR-GLOBWB is a large-scale hydrological model intended for global to regional studies (Van Beek et al., 2010). For each grid cell, PCR-GLOBWB uses process-based equations to compute moisture storage in three vertically stacked soil layers as well as the water exchange between the soil and the atmosphere and the underlying groundwater reservoir.

3.2.4 Downscaling Methods

Daily values of precipitation (P), daily average temperature (Tmean), daily maximum and minimum temperature (Tmax and Tmin, respectively) have been downscaled for both seasonal forecasts and climate projections from their native resolution to 25 km E-OBS resolution. The obtained daily fields at a 25km resolution were then downscaled to the 5km resolution using the same procedure that was used for the reference dataset E-OBS (i.e., external drift Kriging, EDK). In a second step, the daily values were further disaggregated to 3-hourly values using methods described in Bohn et al. (2013) to provide the representation of the diurnal cycle needed by the hydrological models.

3.2.5 Sectoral Climate Impact Indicators

The EDgE outputs are in the form of Sectoral Climate Impact Indicators (SCIIs), which have been derived from the terrestrial Essential Climate Variable (tECV) timeseries. For Climate Projections, EDgE provides the following SCIIs; streamflow, soil moisture, groundwater recharge, Potential Evapotranspiration, precipitation, snow water equivalent and temperature.

The Climate Projection SCIIs are given as relative changes for a given 30-year projection window with respect to the reference period estimates of 1971-2010 for Representative Concentration Pathways (RCP) 2.6 and 8.5. For each SCII, the relative changes are given for each grid cell. The one exception to this is the soil moisture drought extent SCII, the monthly values are estimated as a percentage of basin area enduring drought conditions, and are provided for specified basin boundaries (WFD basins).

For each variable except the soil moisture, the SCIIs are provided in annual, seasonal and monthly averages over the 30 year period, compared to the reference period. Indicators of annual high (Q10), low (Q90) and drought (Q95) streamflow and groundwater recharge are provided, and an indicator for the maximum daily streamflow (flood) is also given. Seasonal averages are given as March to May, June to August, September to November, and December to February.

More detailed information about the SCIIs can be found here

3.2.6 Uncertainty Assessment

The assessment of climate projections SCII uncertainty was done using the inter-quantile distance for the individual GCM–Hydro Model combinations. For each SCII, we computed the Q10, Q25, Q50, Q75 and Q90 percentiles for all combinations for both RCP scenarios. The algorithm computes the quantiles and determines the uncertainty in the projections using the Q10-Q90 range.

The combinations are determined by the data availability and can be modified by the user “on the fly” in the web-based EDgE Map Viewer. This allows users to select custom sets of GCM-HM combinations, enabling them to fully understand the uncertainty and customise the output.

Find out more about EDgE skill and uncertainty here

3.2.7 Operationalisation

To operationalise the EDgE Climate Projections modelling system (Figure 9), the following five operations must be run both the first time the projections are produced, and when new climate projection data are available:

1. Downscale the climate projection data
2. Generate the projected terrestrial Essential Climate Variables (tECVs) with the hydrological models
3. Generate the Sectoral Climate Impact Indicators (SCIIs) from the tECVs
4. Estimate the uncertainty in the tECVs and SCIIs
5. Create visualisation – produce maps and graphs for the Climate Projections Map Viewer

Occasional operations include: obtaining new climate projection data; calibrating new hydrological models; updating the system with new user requirements (e.g. new SCIIs) and updating the Climate Projections Map Viewer.

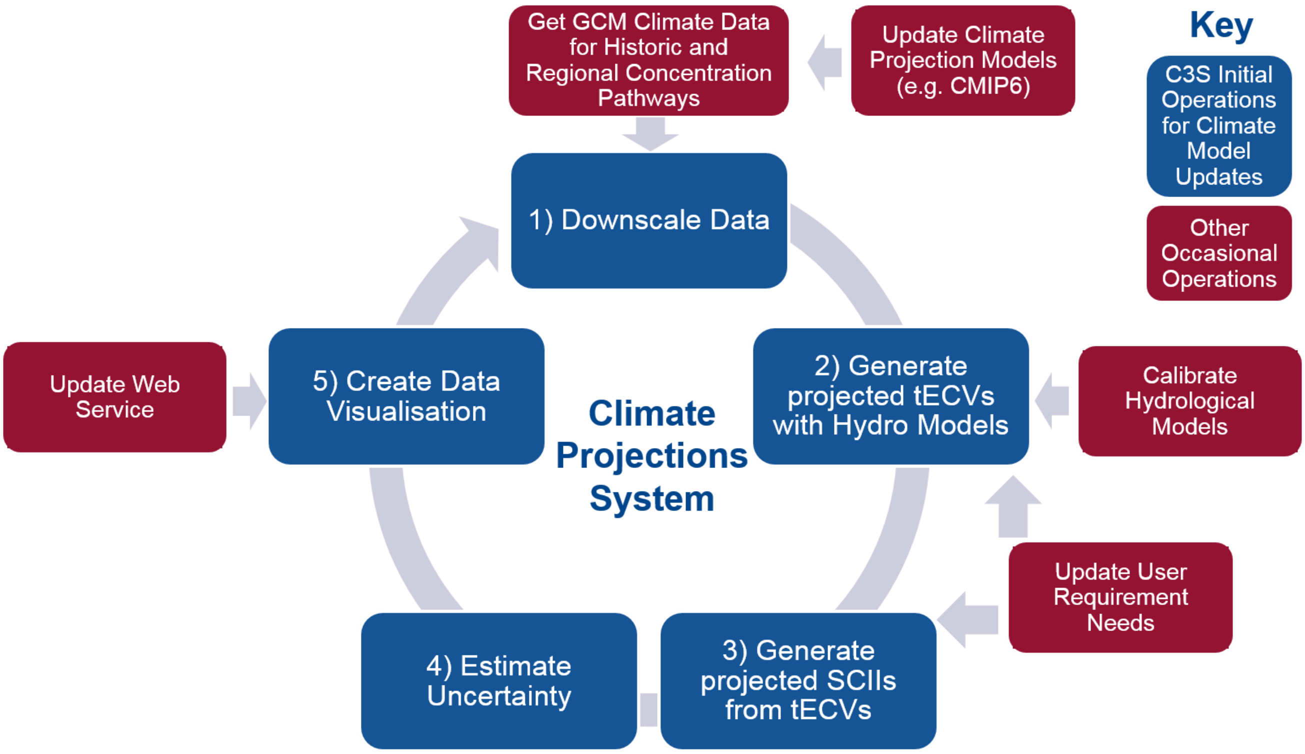


Figure 9: Overview of an operational EDgE Climate Projections System

3.3 Details on Skill and Uncertainty Estimation

3.3.1 What is Model Uncertainty?

Despite improvements in weather and climate forecasts over the past decades, there is an element of uncertainty in forecasting, and projecting the future. This uncertainty can come from: uncertainties in the data that goes into the forecast models, and uncertainties in how the models represent the physical processes (e.g. clouds, rainfall). Also the weather is an inherently chaotic/random process, even if we have a model that represents the climate system perfectly, uncertainties in the data will lead to uncertainties in the forecasts.

Figure 10 below shows two sources of uncertainty in modelling studies. The first (left) represents differences in the initial conditions of the model, for example small changes in the temperature or humidity of a certain grid cell. We don't necessarily know the values of all of these starting variables, and the same model, starting with different sets of initial conditions will evolve to provide different responses. The second (right) example represents the uncertainties that originate from using different models. There are numerous climate and hydrology models available and they all represent their respective systems in different ways. Starting with the same initial conditions, but using different models, also results in different responses.

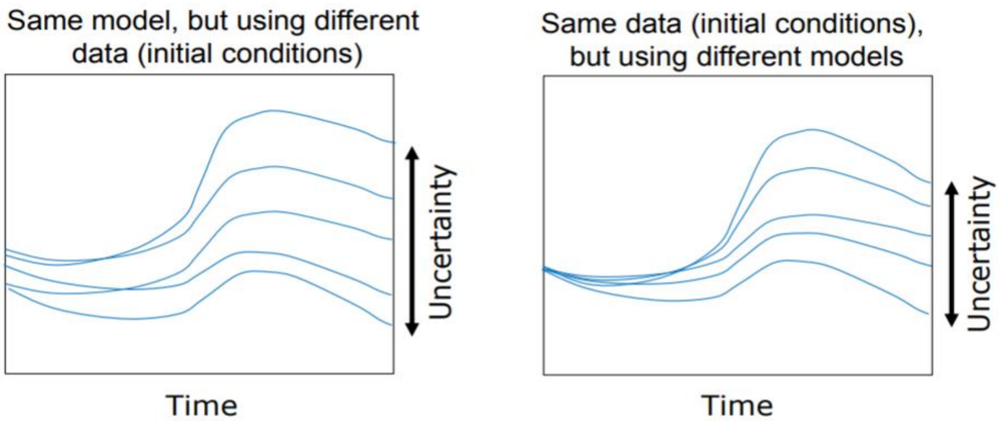


Figure 10: Example sources of uncertainty

3.3.2 What is Skill?

Skill is how well, on average, a model represents what has actually happened. Skill can be measured by comparing a set of model results against historic data. We may be interested in different aspects when assessing a model's skill, such as the magnitude, or the timing of an event. There are many mathematical equations that can be used to compare model results with observations, and the choice of equation (or skill metric) will depend on the aspect of the model results that the user is most interested in (Figure 11).

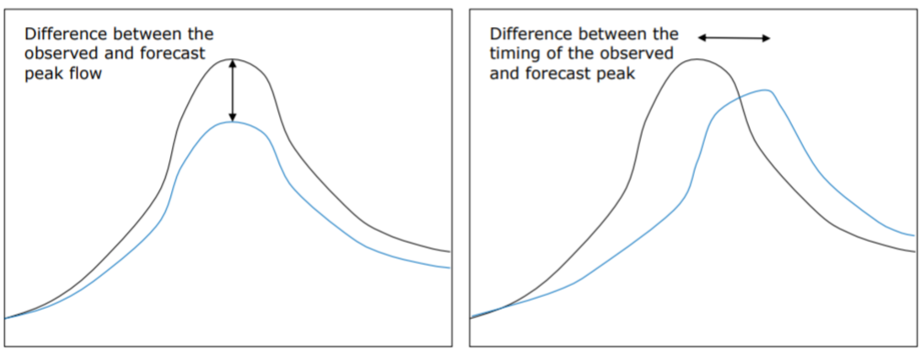


Figure 11: Sources of model skill

3.3.3 Comparing Skill and Uncertainty

Skill and uncertainty are often confused, but they are two distinct concepts. In modelling studies, uncertainty refers to a range or spread of the models results, whereas skill refers to the accuracy of the models compared to observations. Figure 12 below helps to explain this distinction with three examples. In these graphs, the blue lines indicate the results from a model ensemble, the black line represents the observations, and the vertical lines represents point in time that we are trying to simulate. In the left hand graph, the members of the model ensemble (the blue lines) show a wide spread at the point we are interested in; they exhibit a high level of uncertainty. However, this range of model results is centered on the observation, meaning the models together show high skill. In the middle graph, the spread of the models is much narrower, which shows a low level of uncertainty. The models are also centered on the observation, so here they have high skill. High skill and low uncertainty is ideal. In the right hand graph, the models show quite a wide spread, so they have a high level of uncertainty. They also are not centered on the observation, meaning they have low skill. This is a very poor result.

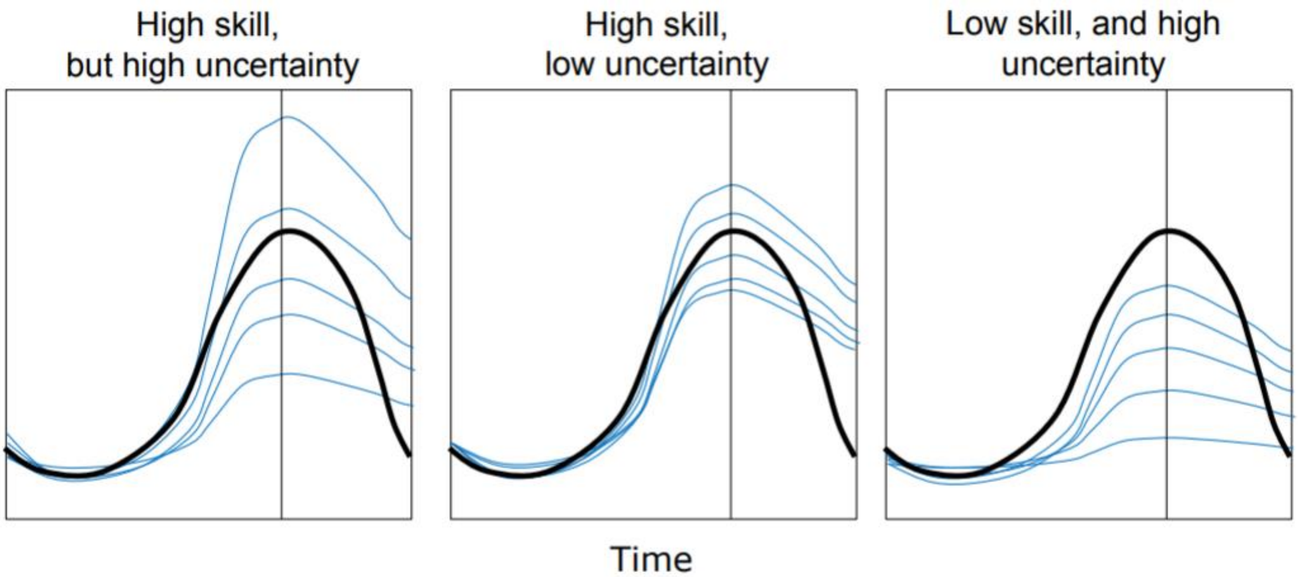


Figure 12: Differentiating skill and uncertainty

3.3.3.1 Uncertainty in EDgE Seasonal Forecasts

The uncertainty within the EDgE Seasonal Forecasts is estimated using an ensemble approach. The Seasonal Prediction Models (SPMs) have multiple realisations to account for different initial conditions: ECMWF-System 4 (15 realisations), MétéoFrance System 5 (15 realisations), CanCM3 (10 realisations), and GFDL-FLOR (12 realisations). Each of these model realisations has been forced through the four hydrological models (HMs), so for each forecast and lead time, the uncertainty in an SCII is computed from the 208 ensemble members (52 Seasonal Prediction Models ensembles x 4 Hydrological Models). Note that this ensemble approach does not account for all possible aspects of uncertainty, for example, the uncertainty in the observational data is not considered.

In the EDgE Seasonal Forecast Map Viewer, the map displays the colour of the dominant quintile for that forecast month in each grid cell. The (un)certainty in the Seasonal Forecast Map Viewer is presented with a slider (see Figure 13 below). This slider uses data on the percentage of models within the ensemble that agree on the dominant quintile, and can be set to the users' preference to mask out areas with low certainty. For example, in the image below the user has set the certainty slider to 35%, meaning only cells where more than 35% of the models agree on the dominant quintile are shown. When a cell is selected, the graph in the map viewer also shows how the models' predictions are distributed across the quintiles. In the example image below, the forecast for January shows that nearly 60% of the models agree that this location will be low, which provides some certainty. In June however, approximately 35% of the models indicate the streamflow will be low, yet approximately 30% indicate that streamflow will be high. This demonstrates a bimodal response, which leads to uncertainty in the model results.

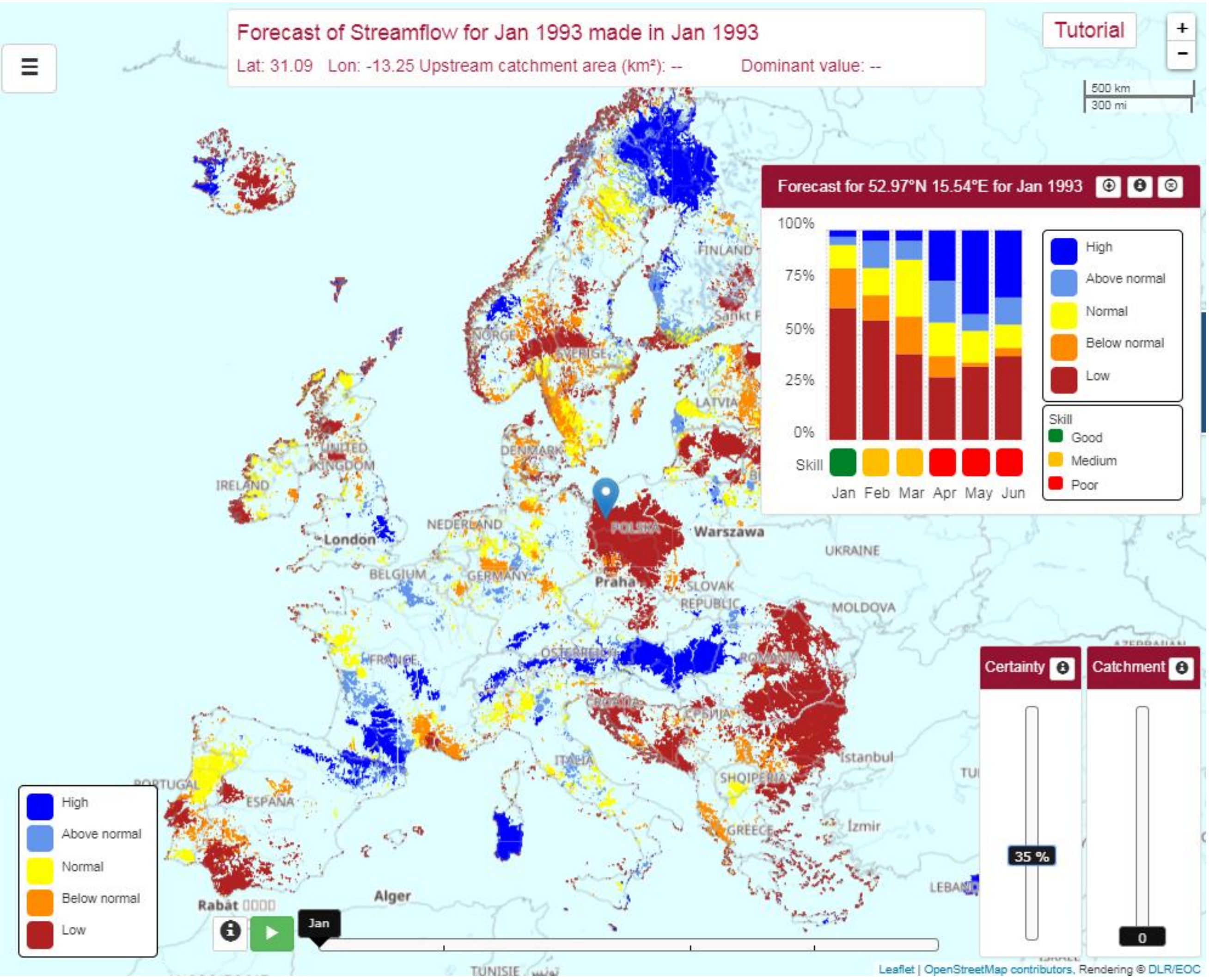


Figure 13: The EDgE Seasonal Forecast Map Viewer

3.3.4 Skill in EDgE Seasonal Forecasts

The models' skill is assessed using the Brier Score (BS), essentially the Mean Squared Error of the probability forecasts, considering that the observation is o1 = 1 if the event occurs, and that the observation is o2 = 0 if the event does not occur. The score averages the differences between pairs of forecast probabilities and the subsequent binary observations:

$$BS = \frac{1}{n}\sum_{k=1}^{n}(y_k - o_k)^2$$

where k denotes a numbering of the n forecast-event pairs.

As a mean-squared-error measure of accuracy, the Brier Score is negatively oriented, with perfect forecasts exhibiting BS = 0. Less accurate forecasts receive higher Brier Scores, but since individual forecasts and observations are both bounded by zero and one, the score can take on values only in the range 0 ≤ BS ≤ 1 (Wilks, 2011).

In the EDgE Seasonal Forecast Map Viewer, the BS score for each month in the forecast is presented in blocks at the bottom of the graph. The blocks are coloured green for a “good” score (BS<0.33), amber for a “medium” score (0.33<BS<0.66), and red for a “poor” score (BS>0.66).

3.3.5 Uncertainty in EDgE Climate Projections

The uncertainty within the EDgE Climate Projections is estimated using an ensemble approach. EDgE has applied five General Circulation Models (GCMs): GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M. These five models were made available by the ISI-MIP project (Warszawski et al.; 2014). It is worth noting that these GCMs only cover a fraction of the total uncertainty of the CMIP5 ensemble for temperature around 0.75 and 0.55 for precipitation (McSweeney and Jones, 2016). Each of these climate model outputs has been forced through the four hydrological models (HMs). Note that this ensemble approach does not account for all possible aspects of uncertainty, for example, the uncertainty in the observational data is not considered.

In the EDgE Climate Projections Map Viewer, the uncertainty is represented in the graph that is displayed when a cell is selected (see the image in Figure 14). The graph shows the range of model results within the ensemble for each timestep, and for RCP 2.6 and 8.5 (if both are selected in the selection panel). The graph shows both the range of the model ensemble that the user has selected, as well as the range of the full EDgE ensemble. This was implemented in order to avoid the misconception that selecting fewer models reduces the uncertainty in the projections. In the graph, the multi-model mean of the selected ensemble is shown as a solid line, and the multi-model mean of the full ensemble is shown as a dashed line. The 10th to 90th percentile range of the selected ensemble is shown in a darker colour, whilst the 10th and 90th percentile range of the full ensemble is shown in a paler colour. The grid cells on the map display the median of the selected ensemble members.

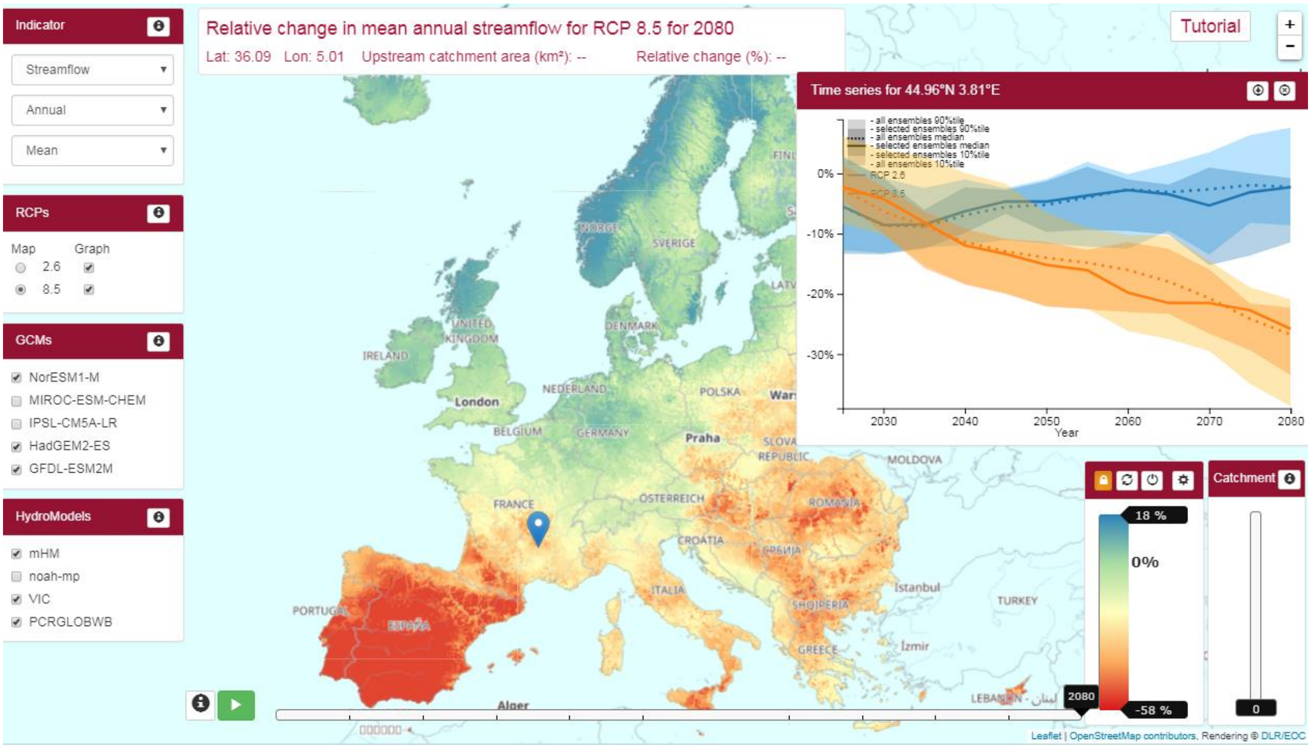


Figure 14: The EDgE Climate Projections Map Viewer

3.4 Details on the Sectoral Climate Impact Indicators

Sectoral Climate Impact Indicators (SCIIs) are hydro-meteorological metrics that represent change factors for some key variables that are useful for the water sector.

EDgE worked with stakeholders to identify which SCIIs are the most useful to make decisions, and prioritised those for delivery within the project. However, the choice of SCIIS also depended on the ability of the EDgE modelling chains to be able to calculate them accurately. For example, water temperature was suggested as an important variable for some sectors such as energy production or environmental protection, but was not included in the available hydrological models.

In EDgE, the following meteorological and hydrological variables are provided: **precipitation**, **temperature**, **potential evapotranspiration**, **streamflow**, **groundwater recharge**, **soil moisture** and **snow**. These variables are the results from a modelling chain that consists of climate models and hydrological models.

Read more about the EDgE Seasonal Forecasting and Climate Projection modelling chains here.

3.4.1 Seasonal Forecast SCIIs

3.4.1.1 What SCIIs are available?

Variable	Output Form	Time Scale	Values
Streamflow	Hydrological Model	Monthly, up to 6 months lead time	Mean
Soil moisture	Hydrological Model	Monthly, up to 6 months lead time	Mean
Groundwater recharge	Hydrological Model	Monthly, up to 6 months lead time	Mean

3.4.1.2 How are the Seasonal Forecast SCIIs calculated?

Across the EDgE pan-European domain, four [Seasonal Forecast models (CanCM4, GFDL(FLOR), MétéoFrance Sys5, ECMWF Sys 4) and four state-of-the-art hydrologic/land-surface models (mHM, NOAH-MP, PCR-GLOBWB and VIC) have been set-up at a spatial resolution of 5km. The Seasonal Forecasts are hindcasts run up to 6 months ahead from each forecast start month, starting at January 1993 and ending December 2011.

The EDgE Sectoral Climate Impact Indicators (SCIIs) have been derived from the raw outputs of the hydrological models (the terrestrial Essential Climate Variable (tECV) timeseries). These hindcasts are presented in "quintiles" compared to the E-OBS reference data. Five reference quintile categories are used to denote the probabilistic quintile distribution, defined as:

1. Q_forecast <= Qref_quantile_level_20
2. Qref_quantile_level_20 < Q_forecast <= Qref_quantile_level_40
3. Qref_quantile_level_40 < Q_forecast <= Qref_quantile_level_60
4. Qref_quantile_level_60 < Q_forecast <= Qref_quantile_level_80
5. Q_forecast > ref_quantile_level_80

Where Q_forecast is monthly forecasted values and the ref_quantile_level_20, 40, 60, and 80 denotes reference quantile levels. The reference levels are estimated for each calendar month, separately from the (E-OBS forced) datasets of the period 1993-01 to 2011-12. For a given month and lead-time, these categorical values are estimated for each realisation and then finally the percentage of model ensemble members falling within each of the five reference quantile category are calculated.

In the example graph shown in Figure 15, for the January 1993 forecast:

- 60% of the models predict the streamflow will fall into the low category (below the 20th percentile of the reference observations)
- 27% predict below normal (between the 20th and the 40th percentiles)
- 8% predict normal streamflow (between the 40th and 60th percentiles)
- 2% predict above normal streamflow (between the 60th and 80th percentiles), and
- 3% predict streamflow will be in the highest category (above the 80th percentile). On the map, this grid cell is coloured red for this forecast, to show that the majority of model ensemble members predict the streamflow will be low (the dominant quintile).

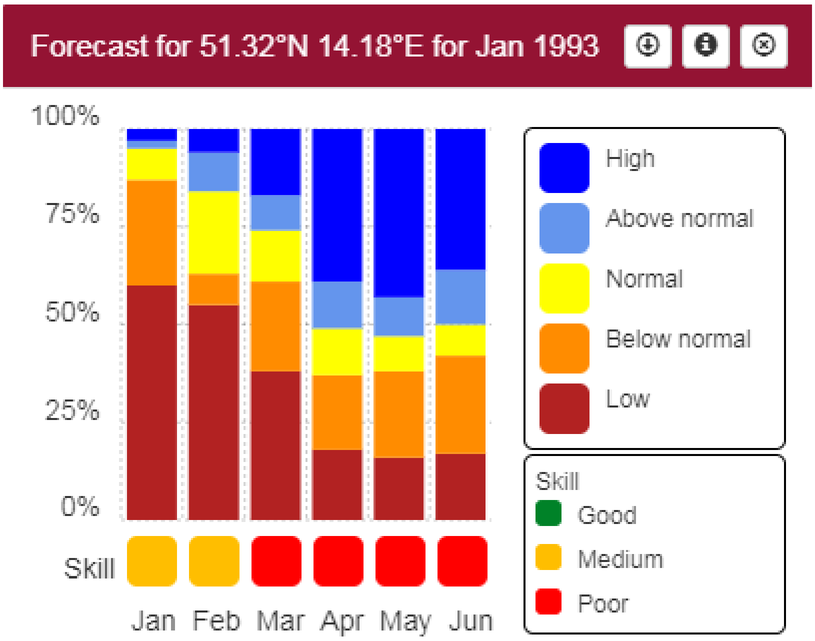


Figure 15: Example quintile plot from the EDgE Seasonal Forecast Map Viewer

3.4.2 Climate Projections SCIIS

3.4.2.1 What SCIIs are available?

Variable	Output Form	Time Scale	Values
Precipitation	Climate Model	• Annual • Seasonal • Monthly	Mean
Temperature	Climate Model	• Annual • Seasonal • Monthly	Mean
Potential Evapotranspiration (PET)	Hydrological Model	• Annual • Seasonal • Monthly	Mean
Streamflow	Hydrological Model	• Annual	• Mean • Flood (max daily flood) • High (Q10) • Low (Q90) • Drought (Q95)
		• Seasonal • Monthly	Mean

Variable	Output Form	Time Scale	Values
Groundwater Recharge	Hydrological Model	• Annual	• Mean • High (Q10) • Low (Q90) • Drought (Q95)
		• Seasonal • Monthly	Mean
Snow	Hydrological Model	• Annual • Seasonal • Monthly	Mean
Soil Moisture	Hydrological Model		• Drought Extent • Drought Duration

Where seasonal data are available, data are provided for each season:

- Spring (March, April, May)
- Summer (June, July, August)
- Autumn/Fall (September, October, November)
- Winter (December, January, February)

3.4.2.2 How are the Climate Projections SCIIs calculated?

Across the EDgE pan-European domain, five General Circulation Models (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NOR-ESM1M), and four state-of-the-art hydrologic/land-surface models (mHM, NOAH-MP, PCR-GLOBWB and VIC) have been set-up at a spatial resolution of 5km.

EDgE Climate Projections SCIIs are presented as percentage changes in the terrestrial Essential Climate Variables (tECVs) in the 2011-2099 projections from the baseline period 1951-2010, for two Representative Concentration Pathways (RCPs): 2.6 and 8.5. The SCIIs are calculated using 30 year averages on a five year timestep from 2025 to 2080. For example, the 2025 projections represent the 30 year average 2015 to 2040, and the 2080 projections represent 2065 to 2095.

In the EDgE Climate Projections Map Viewer (see example view in Figure 16 below), the map shows the median value of the selected model ensemble members. The graph then shows the median of the selected ensemble members, as well as the median of all ensemble members. The 10th and 90th percentiles of both the selected and all ensemble members are also shaded.

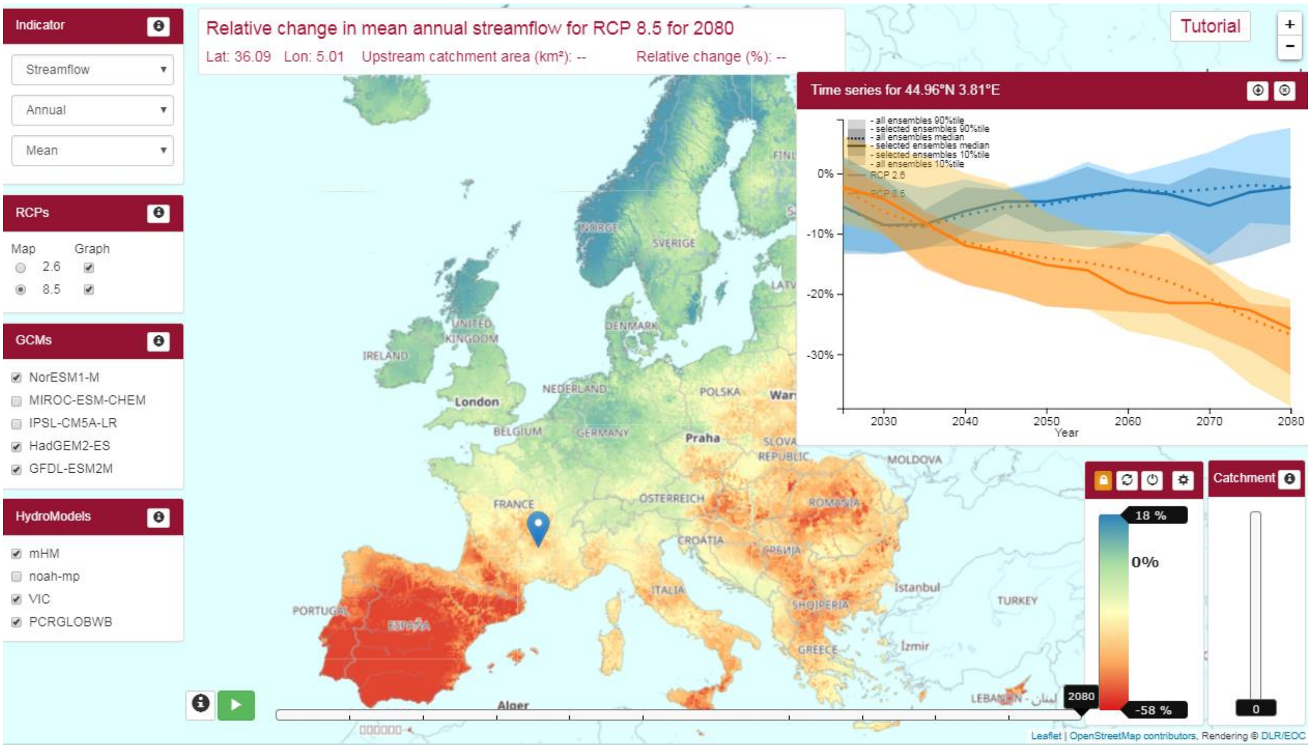


Figure 16: The EDgE Climate Projections Map Viewer

4. Using EDgE

EDgE has produced Case Studies in Norway, Spain and the UK to show how EDgE data and the Map Viewer can be used in decision-making by different sectors and over different time scales. Case Studies have been selected to address current water management and planning questions across Europe. The experiences from the Case Studies have been used to further refine the EDgE Map Viewer and to inform the development of user guidance (Figure 17).

The Case Studies have adopted transferable approaches that can be used elsewhere, so should be relevant and applicable to a wider audience and User Journeys have been created to illustrate pathways through the EDgE material.

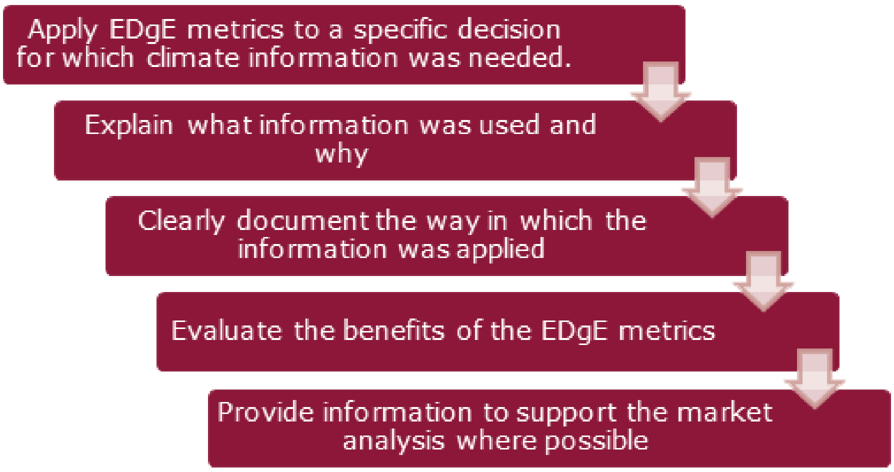


Figure 17: EDgE Case Study development process

4.1 Case Studies

EDgE is working on the following Case Studies:

Case Study	*Objective*	*Location*	*Time horizon*	*End users*	*Key issues*
Climate change adaptation in a snow-dominated region	Long-term water resource planning and adaptation measures		Multi-decadal	Public and private bodies at national, regional and local levels	Land use planning; infrastructure; hydropower; agriculture
Urban water management	Operation and planning of water supply		Seasonal to multi-decadal	Water operator (urban water supply)	Service continuity; safety of delivery; cost-effectiveness
Water resource management planning	Quantify the value of EDgE information compared to existing national services		Medium/long-term (25-50 years)	National regulator (Environment Agency)	Water resource management guidelines; operational work

Case Study	***Objective***	***Location***	***Time horizon***	***End users***	***Key issues***
Integrated water resource management	Evaluate the use of climate-derived water indicators for water resource management		Seasonal to medium term	River basin authorities	Frequency and severity of droughts and water scarcity episodes
Seasonal water resource planning	Evaluate the use of EDgE Seasonal Forecast information in a UK context		Seasonal (1-6 months)	National regulator (Environment Agency); water companies and their advisors	Informing seasonal water resource planning decisions
Improved hydropower production planning	Demonstrate how seasonal forecasts can assist production planning		Seasonal (1-6 months)	Public and private bodies at national, regional and local levels	Hydropower

4.1.1 Climate change adaptation in a snow-dominated region

Can EDgE data be used to predict future hydropower resources?

Location Glomma river basin (40,000km^2), Norway

Aim To demonstrate the use of EDgE hydrological projections to estimate changes in river flow (and therefore hydropower potential)

Exercise To compare EDgE data and Norwegian Centre for Climate Services (NCCS) data between a baseline and future period (2066-2095)

Results Most models indicate increases in the hydropower production potential because of increased river flows under a future climate

Products Case Study Fact Sheet

Market Analysis Summary

Summary

EDgE data have been used to determine the change in river flow at the outlet of the Glomma river basin under the high emission scenario (RCP8.5). The results were compared to those obtained by using the results from the NCCS.

The median projection shows an increase of more than 30% (EDgE) and approximately 7% (NCCS) for the 2080s, relative to baseline (1971-2000). The spread in the five EDgE projections was much larger than in the ten NCCS projections.

The Case Study has demonstrated that EDgE data can be successfully used to project future changes in the hydropower production potential. There is however, a need for information about the skill and a thorough understanding of the modelling process.

4.1.2 Urban water management

Can EDgE data be used by urban water managers?

Location	The cities of Barcelona, Alicante, Granada and Marbella
Aim	To demonstrate the use of tailored climate data to forecast urban water demand and local water availability
Exercise	Historical data were used to assess the correlation between water consumption and different climate variables. Seasonal forecast temperature data were validated for the coastal cities considered
Results	Summer water consumption was highly correlated to monthly average temperatures in some cities. Seasonal forecasts of temperature are, therefore, useful for urban water managers
Products	Case Study Fact Sheet Market Analysis Summary

Summary

This Case Study evaluates the potential in using tailored climate data and indicators to forecast urban water demand and availability. Historical data were used to evaluate the correlation between water consumption and climate variables and seasonal forecast temperature data were validated for the coastal cities considered.

4.1.3 Water resource management planning

Can EDgE data be used to estimate changes in deployable output?

Location	Grafham Water (SE England) and Wimbleball Reservoir (SW England)
Aim	To demonstrate the use of EDgE hydrological projections for estimating the source of deployable output within the UK water supply planning context
Exercise	To use EDgE data to compare reservoir deployable output under a range of future hydrological scenarios for the 2050s and 2080s
Results	Results are variable for Grafham but there is a clear trend towards reduced deployable output for Wimbleball by the 2080s
Products	Case Study Fact Sheet Report for Grafham Water Report for Wimbleball Reservoir Market Analysis Summary

Summary

EDgE data have been used to determine the change in deployable output for two reservoirs in England under different scenarios of future hydrological change. Thirty flow scenarios were considered for each reservoir for both the 2050s and 2080s. The contrasting reservoir systems responded differently - Wimbleball showed a clear decrease in deployable output by the 2080s whilst results for Grafham were mixed. EDgE Climate Projections can be applied to the water resource planning approach in England, but differences exist in modelled outcomes when compared with national data. However, EDgE data have potential advantages over national data as it has a greater spatial and temporal resolution, there is less pre-processing and the Map Viewer enables easier access to the data.

4.1.4 Integrated water resource management

Can EDgE data be used to predict reservoir failure?

Location	Basin of the Alarcón reservoir, Júcar system, Spain
Aim	To demonstrate the EDgE Seasonal Forecasts of precipitation have been used
Exercise	Compare the uncertainty of the EDgE precipitation Seasonal Forecast with the uncertainty associated with a statistical forecast based on observed data
Results	Two models significantly reduce uncertainty while the other two do not improve forecasts
Products	Case Study Fact Sheet Market Analysis Summary

Summary

EDgE data have been used to determine the precipitation of the Júcar basin that will occur in the following months and to be able to allocate water among the users of the basin which allows to have a lower uncertainty in what the status of water reserves will be at the end of the hydrological year. Of the four Seasonal Forecasting models used, two models significantly reduce uncertainty and two have the same uncertainty as a statistical forecast based on historical precipitation observations. When applying EDgE change factors to the historic flow record, four of the five hydrological models projected reservoir failure in the same year as the historic baseline (1944).

4.1.5 Seasonal water resource planning

Can the EDgE Seasonal Forecast inform UK water resource planning?

Location	Grafham Water (SE England) and Wimbleball Reservoir (SW England)
Aim	To determine how decision makers interpret and might use EDgE seasonal forecast information
Exercise	To consider how the availability of seasonal forecast information supports decision making
Results	Multiple lines of evidence are needed to support water sector decision making - seasonal forecast information would be a useful additional tool for highlighting a period of interest that requires closer examination
Products	Case Study Fact Sheet Seasonal Forecasting Report

Summary

EDgE Seasonal Forecasts have been blind tested with UK water resource planners, water companies, consultants and regulators to understand how they might be used to inform decision making and to assess the potential value of the seasonal forecasting viewer. A series of rolling forecasts of monthly probabilistic quintile streamflow were produced for two UK locations for January 1995-June 1997 (although they were not aware they were looking at data for this drought event at the time) and were discussed in an interview.

Respondents agreed that the seasonal forecasts were useful but need to be considered in the context of other information to be fully understood. The quintile plots produced were useful in highlighting developing situations that may require closer inspection. None of the interviewees would have made a decision on the basis of the seasonal forecast quintile plots alone. The interviews revealed that decision makers are more likely to trust existing methods above new seasonal forecasts (at least until such time as they are familiar with and trust the new information). Further research on the skill of seasonal forecasting is important in gaining the trust of users but research should be accompanied by programme of engagement with end-users to build confidence and explore the range of practical opportunities to apply the forecast information within the water industry.

4.1.6 Improved hydropower production planning

Can EDgE seasonal forecasts be used to improve production planning?

Location	Glomma river basin (40,000km^2), Norway
Aim	To demonstrate the use of EDgE seasonal forecasts to assist production planning
Exercise	To assess (qualitatively) the seasonal forecasts in 1995 and 1996 and the skill for the Glomma river basin
Results	Most months have poor skill in the Glomma basin. However, the wet months in 1995 and the dry year 1996 are to some extent captured by the seasonal forecast
Products	Case Study Fact Sheet

Summary

EDgE data have been used to assess if seasonal forecasts, with their current level of skill, will add information to existing approaches (climatology) to improve production planning.

The seasonal forecasts for the Glomma River in 1995 (a year with extreme river flows at the end of May and beginning of June) and 1996 (a dry year) were assessed.

The Case Study has demonstrated that EDgE seasonal forecasts do add some information in selected months with medium or good skill. In addition to the metrics, it would be beneficial to have the ability to download the precipitation and temperature seasonal forecasts that could then be used as inputs to the hydrological models for hydropower production planning.

4.1.7 Lessons learnt from Case Studies

The Case Studies show how the EDgE climate change indicators can successfully be used to address issues faced by water sector decision makers on a range of scales and contexts. The provision of indicators is welcomed, as it saves time and provides information not readily available elsewhere. Case Study participants see many additional potential applications for EDgE data, including informing water resources management decisions, scheduling maintenance of water infrastructure, comparing with outputs of national climate services, improving the timing and effectiveness of water conservation campaigns, allocating water resources, and informing the financial aspects of water management including estimating use and, therefore, expected revenue.

4.1.8 Remaining Challenges

Helpful insights were also provided into the remaining challenges and issues associated with the uptake and use of EDgE information.

Context matters In most cases, additional information was drawn on to fully understand the results generated by analysis of EDgE information, and to inform decisions on how to respond to the information and results. For example, it was noted that climate and hydrological projections are only some of the factors that influence decisions related to investments in new hydropower or upgrading old hydropower plants; additional information is needed to make properly informed decisions. Similarly, users of the EDgE Seasonal Forecast information in the UK and Spanish Case Studies called for observed temperature, precipitation, PET and discharge data to contextualise and make sense of the images presented in the forecasts. Hydrological impact information is important for influencing decisions, but water sector decision-making requires multiple lines of information and evidence. EDgE indicators are a very useful new addition, but alone they are not sufficient for decision-making.

Skill and uncertainty information is important to users This information needs to be presented with care to ensure it is properly understood. “Skill” in EDgE is taken as a measure of whether the models are right, while “uncertainty” is a measure of whether the models agree with one another. In some cases users perceived a reduction in the size of an ensemble to infer reduced uncertainty and therefore improved skill.

When asked what level of skill would be required to trust the seasonal forecast information enough to make a decision, users responded that they would like a “very good” level of skill. The Spanish urban water management case study suggested that with medium-good level of skill (e.g. a 60% level of skill) EDgE information could be taken into consideration in planning and investment decisions. With a good-very good level of skill (e.g. 80%-90%) information could be integrated into operational decisions.

For the climate change information, good model agreement – and the signal or direction of change – was considered important. Users noted that if all projections indicate an increase or decrease, a decision could be made more easily, and that they would want 60-80% of the ensemble members to agree to have confidence in the results.

Trust and familiarity are central to confidence In both the UK and Norway, EDgE Climate Projections information differed from that of their national projections. It is important that reasons for differences between climate projections from EDgE and national providers are understood and explained if EDgE results are to be used by decision-makers. UK users have indicated that, if there are significant differences between the data they know and trust and the new information they are receiving from EDgE, they will be more inclined to trust the information they know. A thorough explanation of the modelling chain and information on the robustness of the results is also needed. These findings highlight the importance of providing good guidance and support, and being transparent about the assumptions made, so users can fully understand and gain confidence in the information they are working with.

The nature of available data Some users would like to have had access to data on a finer spatial resolution than were available from EDgE. Provision of higher resolution data was out of scope of the EDgE project and this was made clear to end-users, but the desire from some users for high resolution data suggests that availability of these data in future would be attractive. Those who manage small, responsive catchments were particularly interested in such data.

4.2 User Journeys

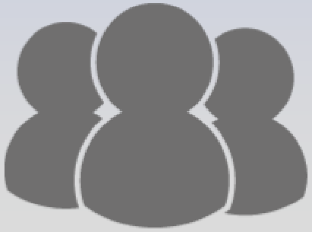
We have developed a sample of user journeys to help users quickly find the information they need from the EDgE website.

The user journeys start with a description of the user and their particular decision or information requirement. They show the route that different kinds of users should take to find the information that will help them address their particular problem, and point them to our additional EDgE resources that will be most useful to them.

4.2.1 Seasonal Forecasting User Journeys

I am a …

water resource planner developing management plans for the next 6 months



I want to …

…find out if the **dry conditions** being experienced now are likely to **improve** or **worsen** over the **next 6 months**

Go to …

- The **EDgE Seasonal Forecast** Map Viewer
- Select the forecast period and metric of interest (e.g. streamflow)
- Select the seasonal prediction and hydrological models of interest
- Click on the map to get a seasonal forecast for your selected location

Other considerations

- You might want to refer to your own historical **records** & **recent observations** to place the EDgE seasonal forecast in **context**
- You may wish to take a **screenshot** of the graph and **download the data** for further analysis

More EDgE resources

- See the **Seasonal Water Resource Planning** case study
- Find out more about how the EDgE Seasonal Forecasts are produced on the **Seasonal Forecasting** pages

I am a …

public communications planner in a **Non-Governmental Organisation**

I want to …

…access **reliable information at the right scale** to intervene in political and scientific debates, and to support our work raising public awareness of water resource issues and challenges

Go to …

- The **EDgE Seasonal Forecast** Map Viewer or the **EDgE Climate Projections** Map Viewer, depending on the timescale of interest
- Select the variable, time scale & metrics of interest
- Click on the map viewer to get a graph of projected changes for your chosen location

Further analysis

- Take a **screenshot** of the graph and save to separately for use in presentations and documents
- Click on '**download data**' to access the data and use in any further analysis

More EDgE resources

- For help and support, visit the **Help** pages
- The **EDgE Glossary** might be of particularly useful to help explain some of the terms used in EDgE to a wider audience

I am a …

manager of a **large agricultural business** that relies on irrigation during the summer months

I want to …

…have **reliable forecasts** of water resources to correctly calculate **irrigation requirements** for the **next growing season**

Go to …

- The **EDgE Seasonal Forecast** Map Viewer
- Select the forecast period of interest
- Select the variable you are interested in (e.g. streamflow, or groundwater recharge)
- Select the weather prediction & hydro models that you want to be included
- Click on your area of interest in the map to get a seasonal forecast for your selected location

Other considerations

- You may wish to use the **uncertainty slider** to screen out results below a certain confidence levels
- Use the **catchment slider** to screen out those cells that are not on a river network; this helps to show the river networks more clearly

More EDgE resources

- For information on how water resources might change in future, go to the **EDgE Climate Projections** Map Viewer
- Follow the steps set out in the **Seasonal Water Resource Planning** case study
- See the **Integrated Water Resource Management** case study

4.2.2 Climate Projections User Journeys

I am a …

hydropower manager upgrading existing hydropower infrastructure

I want to …

…assess whether **climate change** will influence the **hydropower production** potential of my hydropower system

Go to …

- The **EDgE Climate Projections** Map Viewer
- Select the indicator of interest
- Chose the emission scenario (RCP) climate model (GCM) hydrological models
- Click or zoom on the map to your area of interest
- Advance the time bar

Other considerations

- Be aware that for catchments of less than ~1000km^2 the streamflow indicators are unreliable
- Use the **catchment slider** to select the catchment size of interest
- Click on '**download data**' to access the data
- Use the **info icons** for more information

More EDgE resources

- See the **Climate Change Adaptation in a Snow-Dominated Region** case study
- Find out more about how the EDgE Climate Projections are produced on the **Climate Projections** pages
- For help and support, visit the **Help** pages

I am a …

consultant working on behalf of hydropower company that is planning a new pan-European hydropower development spanning several countries

I want to …

…assess whether **climate change** will influence the **hydropower production** potential differently across Europe

Go to …

- The **EDgE Climate Projections** Map Viewer
- Select your indicator
- Choose the emission scenario(s) (RCP), climate model(s) (GCM) & hydrological model(s)
- Use the catchment bar to exclude small catchments
- Advance the time bar
- Click at the river basin outlet to see a graph of the modelled change for that river

Other considerations

- Use the **info icons** for more information
- Click on '**download data**' to access the data

More EDgE resources

- Find out more about the **EDgE** project
- Find out more about how the EDgE Climate Projections are produced on the **Climate Projections** pages
- For help and support, visit the **Help** pages

I am a …

water resource planner developing long term water resource management plans

I want to …

…explore how **climate change** will impact the **deployable output** from my reservoir

Go to …

- The **EDgE Climate Projections** Map Viewer
- Select your variable, time scale and metric
- Select your time period, emission scenario and ensemble members
- Click on the map to view the projections for your selected location
- Download data for your analysis

Further analysis

- Derive naturalised flow series for observations from the nearest gauging station
- Perturb observations according to the EDgE Climate Projections change factors
- Run water resources model with perturbed data for each scenario until the reservoir empties

More EDgE resources

- See the **Long-Term Water Resources Management** case study
- For help and support, visit the **Help** pages
- For guidance on how to apply this approach in small catchments visit the **FAQs**

5. Market Analysis

An important consideration for this proof-of-concept project has been to assess the potential demand for and benefits that might accrue from the provision of hydrological impacts information to the European market.

In addition to identifying the climate information needs of end users, the EDgE project has completed a high level review of existing climate services in Europe to identify gaps in information provision. A market analysis was then undertaken to assess the value of the EDgE Map Viewer to the European water sector.

Some of the questions addressed in the market analysis were:

- Who are the potential target users of the service?
- What is the added-value of the service?
- How could the service be adjusted to provide higher economic value to Europe?

5.1 Market Analysis Methodology

The market analysis component of the EDgE project was split in two stages. The first provided general recommendations on the service development. In the second stage, the market analysis methodology was applied to the four case-studies to quantify the economic value of the service and product offered by SCII and visualisation prototypes.

The market analysis adopted a five step approach commonly used in market analyses shown in Figure 18.

Figure 18: Five step market analysis approach adopted in EDgE

A qualitative and quantitative analysis was performed in Stage 1:

- The qualitative analysis was based on the findings from Focus Group discussions in Norway, UK and Spain and provided information on the current use of climate services, the potential benefits that a new SIS for each market segment could bring, and the entry barriers.
- The quantitative analysis reviewed available data and literature to quantify potential users and benefits of the service at the European level.

5.2 Findings

5.2.1 Stage 1: Pan-European market evaluation

The findings from the pan-European market evaluation are summarised here.

Existing data use:

- All users currently use tailored climate-related data to perform decision-making either for operational purpose (day to day decision) and planning purpose (strategic planning, etc.). These platforms used are generally specific to a decision making process (e.g. flood protection, irrigation) and provide information at different spatial coverage (local, national and European). Most of the platforms provide past information and forecast for the next days. Recently developed prototypes also provide information at seasonal scale.

Barriers to uptake of a new service:

- The main barriers concern the reliability and usability of the data. Most of the end-users would decline using the service if reliability was poor, especially for seasonal forecast information. Users currently use data platforms that are adapted to their needs and/or have pre-defined decision processes. This would limit their ability to readily introduce and use new indicators.
- The reliability issue could be better addressed if the project prioritised resources on the areas with major potential outcomes (e.g. provide seasonal forecast of inflow to reservoir in the areas with major hydropower production).
- The issue of usability could be addressed through the project Case Studies, which provide some reference business cases for their market segments.

Benefits of the service:

- One of the main benefits identified by the potential users of the Copernicus Sectoral Information System (SIS) will be the access to ready-to-use seasonal forecasts. They are willing to use the SIS to get an outlook of the indicators currently considered (e.g. water needs for irrigation, water availability, etc.).

Potential size of the market:

- The market analysis focused on the three sub-sectors considered in the EDgE Case Studies: regulators and planners, dam managers and downstream water suppliers.
- The target uses identified are of great economic importance for Europe, now and in the future (with climate change). There is great potential for a high benefit to cost ratio for the service. Details for specific sub-sectors follow.
    - **Regulators and Planners and Dam managers**: Both flood and drought risk represent a current annual damage of more than €6 billion for Europe which would increase in the future (e.g. €46 billion EAD in 2050 for flood risk). Eastern and Central European countries are particularly affected.
    - **Dam managers**: Hydropower production contributes €38 billion to European GDP, and the countries with the highest hydropower production are Norway, France, Sweden, Italy and Spain. The production might decrease in the future.

- **Downstream water supplier**: The farming and food sectors generate 6% of European GDP (around €800 billion). Suitability of rain-fed agriculture is projected to decrease. Irrigation accounts for 80% of water use in southern Europe so irrigation requirements are expected to increase.
- **Downstream water supplier**: Enterprises engaged in water collection, treatment and supply count for a turnover of €60 billion in Europe and are affected by the impact of climate on water demand, water quantity and quality

Findings for the detailed qualitative and quantitative market analyses for those sub-sectors considered in the EDgE Case Studies are provided here for:

- Regulators and Planners
- Dam Managers
- Downstream water suppliers

5.2.2 Stage 2: Case Study analysis

In the second stage, the market analysis method used for the pan-European assessment was applied in each Case Study to quantify the economic value of the service and product offered by SCII and visualisation prototypes.

The market analysis has focused specifically on the “climate services” tested in each Case Study, rather than on the Case Studies themselves.

The application of the 5-step market analysis methodology to the Case Studies is described in Figure 19.

Structured interviews with users provided detailed information to support the tailored market analysis within the Case Study applications. For a summary of the market analysis of each Case Study, please see the relevant EDgE Case Study.

Conclusions on the climate services developed in each of the EDgE Case Studies, and about the potential of Copernicus C3S for being the base platform for European climate services are available in the project report.

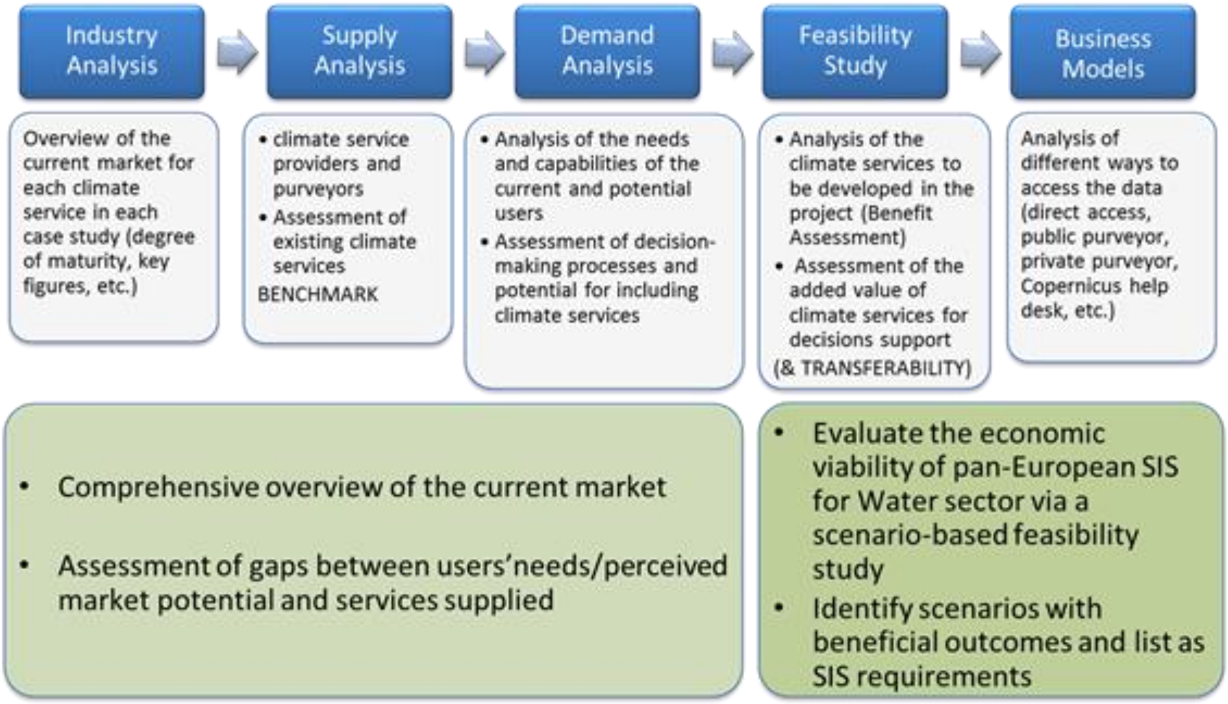


Figure 19: Application of the five step market analysis approach to EDgE Case Studies

6. How to Use the EDgE Map Viewers

6.1 Pictorial Guides

6.1.1 Seasonal Forecasting Map Viewer

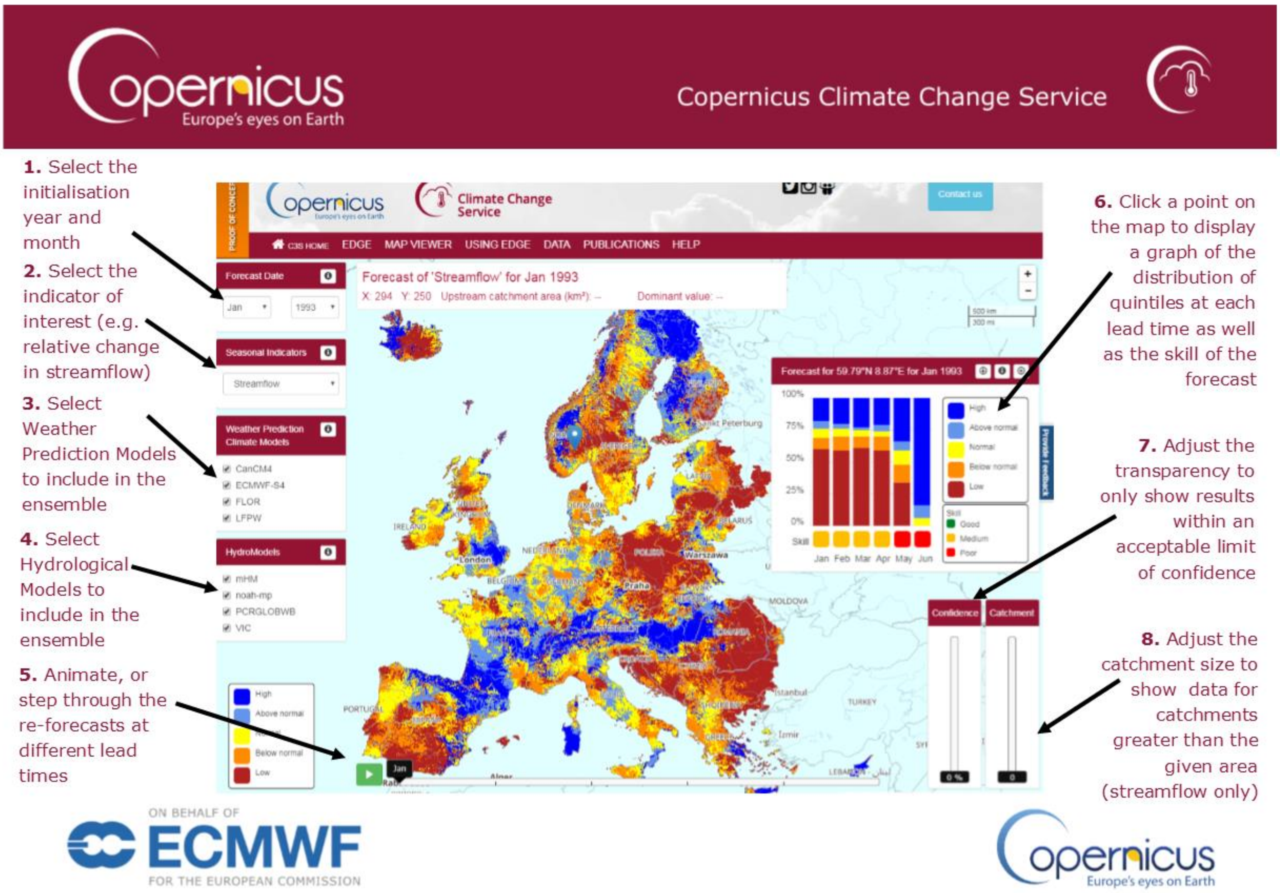


Figure 20: Pictorial guide to the EDgE Seasonal Forecasting Map Viewer

6.1.2 Climate Projections Map Viewer

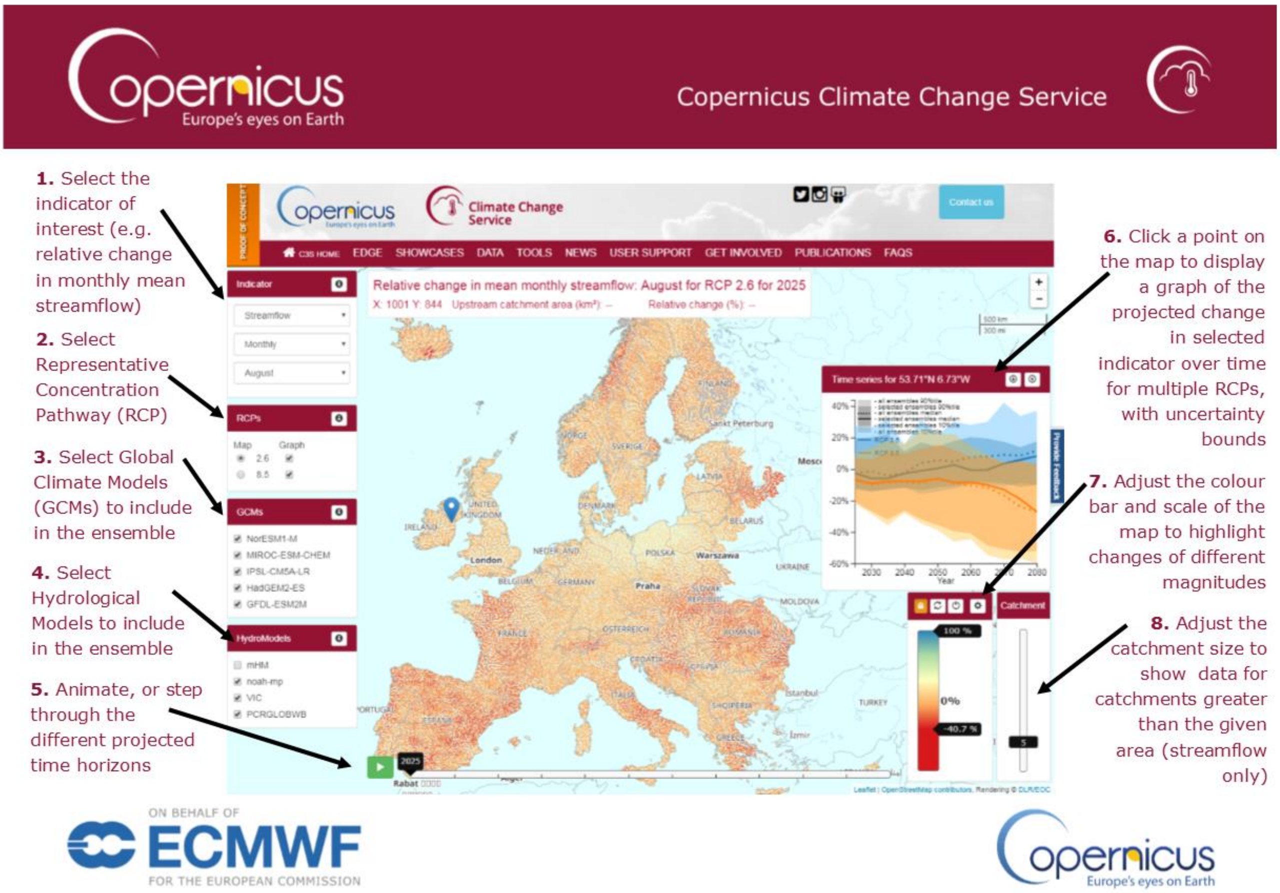


Figure 21: Pictorial guide to the EDgE Climate Projections Map Viewer

6.2 Video Tutorials

Short video clips were made explaining how to use the EDgE Map Viewers. The videos can be viewed online here:

- EDgE Seasonal Forecast Map Viewer Video Tutorial
- EDgE Climate Projections Map Viewer Video Tutorial

For static versions of the Tutorials in this User Guide, see:

- Section 10.4.1 for the Seasonal Forecast Map Viewer Tutorial
- Section 10.4.2 for the Climate Projections Map Viewer Tutorial

7. EDgE Outputs and Publications

7.1 EDgE Flyer

The EDgE Flyer (Figure 22) was produced to give an overview of the EDgE work packages including the following aspects of the project: stakeholder engagement, modelling chains (for both the seasonal forecasts and climate projections) and the Map Viewers. It was published in August 2017.

The Flyer can be viewed here

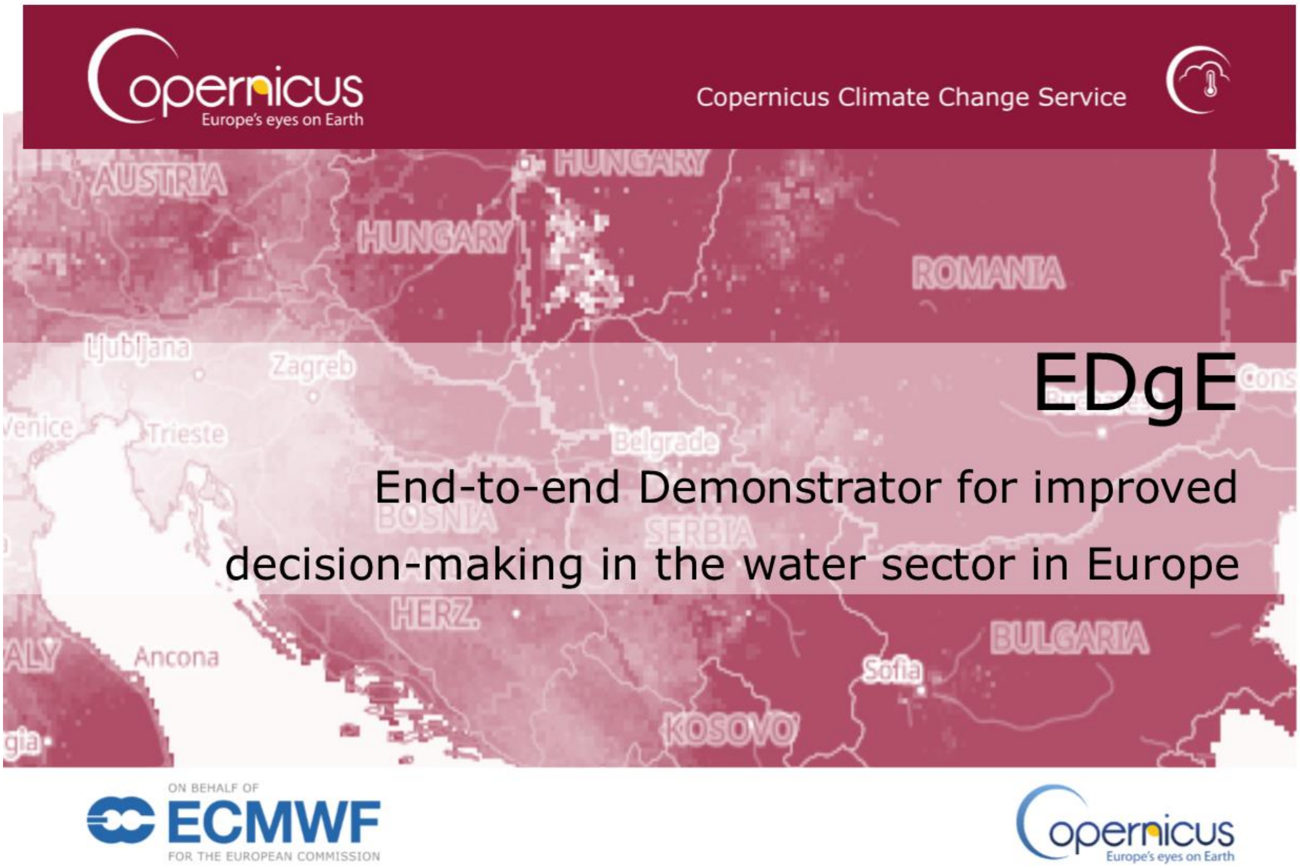


Figure 22: The EDgE flyer

7.2 EDgE Poster

The EDgE Poster (Figure 23) was produced for the Copernicus C3S General Assembly in Toulouse March 2017. It aims to give an overview of the EDgE work packages and their interactions, including stakeholder engagement, modelling chains (for both the seasonal forecasts and climate projections) and the Map Viewers. It was published in March 2017. Find out more about the C3S General Assembly here.

The Poster can be viewed here

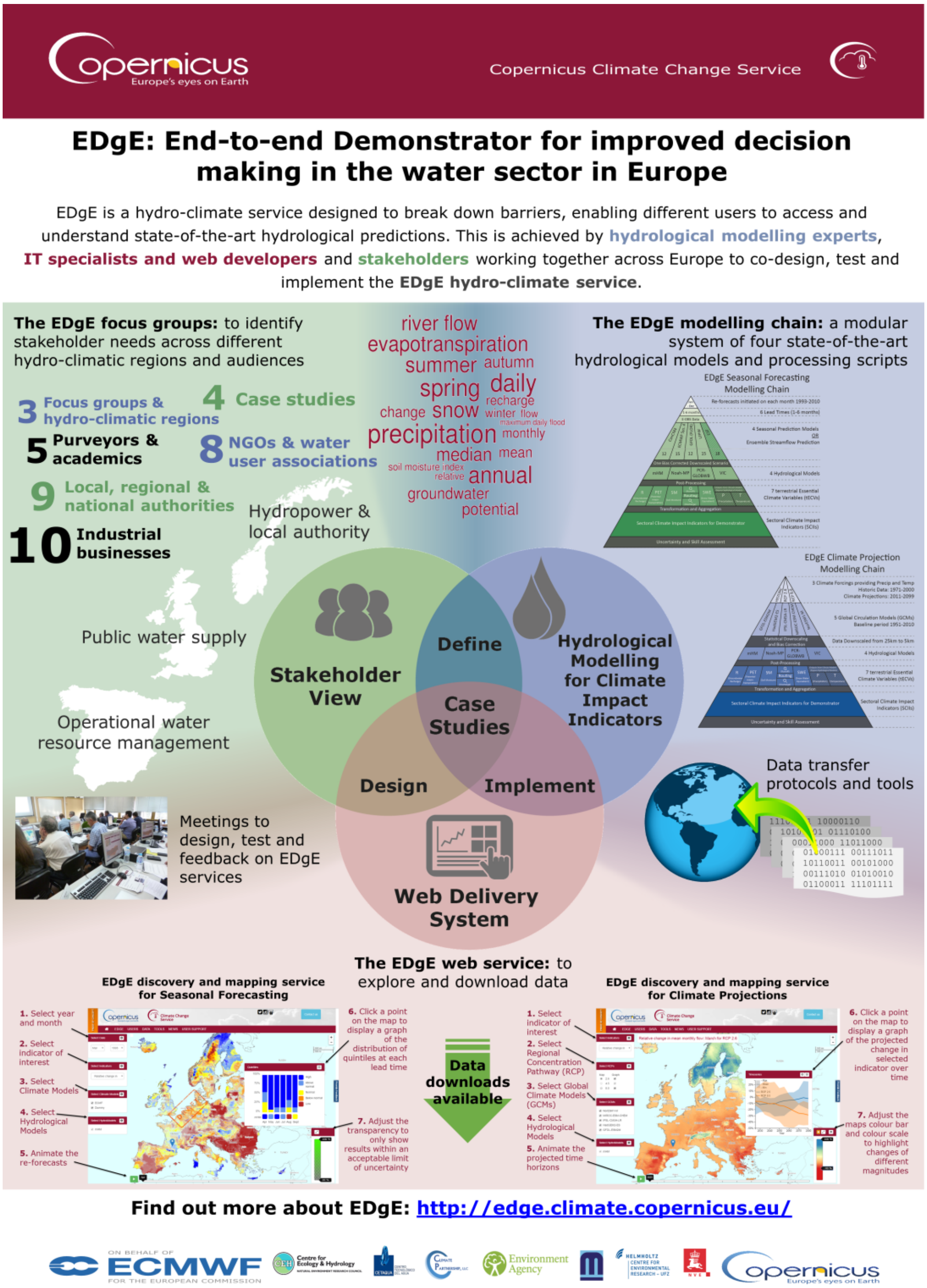


Figure 23: The EDgE Poster

7.3 Other EDgE Publications

Other EDgE publications including papers presented at international conferences and EDgE project reports can be viewed online at http://edge.climate.copernicus.eu/Publications/.

8. Glossary and FAQs

8.1 Glossary

Term	Definition
Catchment	In EDgE the term 'Catchment' refers to the upstream drainage area of a cell on the 5km grid used in EDgE. When exploring streamflow indicators in the EDgE Seasonal Forecasts or Climate Projections Map Viewer the catchment slider will appear. This is to help users visualise the river network at their scale of interest. The slider can be adjusted to only show grid cells where the upstream area is greater than the selected value. As the slider is moved upwards, only data for larger catchments are shown on the map. This not only helps to view the river network (and ensure that the selected cell is on a river) but also helps to show how the river network is distributed on a 5km grid.
Climate Projection Uncertainty	The uncertainty in the climate projections is the total combination of the Sectoral Climate Impact Indicator (SCII) spread from all five Global Circulation Models forcing the four Hydrological Models. It is important to note that the presentation of uncertainties within the EDgE results are not a full quantification of all possible uncertainties in the climate projections; however they do represent some of the uncertainty that is derived from choice of different models. Read more about skill and uncertainty in EDgE here
Ensemble	A model ensemble is a selection of multiple models (for example, climate models or hydrological models) used to explore the range of possible results for a modelled scenario, whether this is the range of possible seasonal forecasts or climate projections.
Ensemble Streamflow Prediction (ESP)	Ensemble Streamflow Prediction is a forecasting method in which models are driven by climate forcings that are resampled from the historical record. ESP is a fairly simple forecasting method, and is often therefore used as a benchmark to assess the skill of more complex forecasting methods. In EDgE, the seasonal forecasts are benchmarked against "climatological skill", the skill of a forecast that simply consists of the long-term average of the selected indicator.
External Drift Kriging (EDK)	External Drift Kriging is the algorithm used to downscale the driving climate data used in EDgE.
General Circulation Models (GCMs)	General Circulation Models are mathematical models used to simulate atmospheric, oceanic, cryospheric and land surface processes in order to investigate the response of the global climate to increasing greenhouse gas concentrations. In EDgE, five GCMs are used to model climate indicators (precipitation and temperature) in the 2020 to 2080 period, and these in turn are used to drive the hydrological models that derive the other Sectoral Climate Impact Indicators (SCIIs). You can read about the GCMs used in EDgE here and about GCMs more generally here

Term	Definition
Hydrological Models (HMs) & Land Surface Models (LSMs)	Hydrological Models are conceptual numerical models that simulate hydrological processes. At the minimum, HMs need precipitation and potential evapotranspiration data to derive runoff or streamflow. Land Surface Models are more complex, and couple the land surface with the atmosphere to simulate the exchange of surface water and energy fluxes between the land and the atmosphere. HMs and LSMs are used in EDgE to produce seasonal forecasts and climate projections of hydrological indicators across Europe. Read about the HMs and LSMs used in EDgE here
Land Surface Models (LSMs) & Hydrological Models (HMs)	Hydrological Models are conceptual numerical models that simulate hydrological processes. At the minimum, HMs need precipitation and potential evapotranspiration data to derive runoff or streamflow. Land Surface Models are more complex, and couple the land surface with the atmosphere to simulate the exchange of surface water and energy fluxes between the land and the atmosphere. HMs and LSMs are used in EDgE to produce seasonal forecasts and climate projections of hydrological indicators across Europe. Read about the HMs and LSMs used in EDgE here
Regional Concentration Pathways (RCPs)	Regional Concentration Pathways are emissions scenarios for climate projections describing the possible future climate. EDgE has produced climate projections for two RCPs: RCP2.6 and RCP8.5.RCP2.6 describes a future where emissions of greenhouse gases peak between 2010 and 2020 and decline thereafter whilst RCP8.5 describes a future where emissions continue to rise throughout the 21st Century. You can read more about RCPs here
Seasonal Forecast Skill	The skill of a seasonal forecast indicates how well the prediction system does compared to observations, i.e. a forecast would be considered skilful if monthly mean streamflow was predicted to be high in a given month and was also high in observed data. Read more about skill and uncertainty in EDgE here
Seasonal Forecast Uncertainty (or Confidence)	In the EDgE data, the uncertainty of the seasonal forecast indicates the agreement within the multi-model ensemble. If all models agree the indicator will be in the “high” quintile, then the confidence is high and data would be displayed on the map even if the confidence slider is set to 100. If the confidence slider was set to 50%, for example, then only grid cells where at least 50% of models agree on the dominant quintile will be displayed. Read more about skill and uncertainty in EDgE here
Sectoral Climate Impact Indicators (SCIIs)	EDgE uses Sectoral Climate Impact Indicators (SCIIs) to show how variables like streamflow are expected to change in the short-term (Seasonal Forecasts) and long-term (Climate Projections). An example of an SCII used in EDgE is the relative change in mean annual streamflow. Read about the EDgE Sectoral Climate Impact Indicators (SCIIs) here
Snow Water Equivalent (SWE)	Snow Water Equivalent is the amount of water within the snow pack i.e. the depth of water if the snow were to be melted.

Term	Definition
terrestrial Essential Climate Variables (tECVs)	terrestrial Essential Climate Variables are the raw outputs from the climate, hydrological and land surface models used in EDgE. tECVS are then used to produce the Sectoral Climate Impact Indicators (SCIIs) for the Seasonal Forecasts and Climate Projections that are presented in the Map Viewers. tECV data are not available to download from the Map Viewers, but may potentially be available in the Copernicus Climate Data Store in future.

8.2 FAQs

8.2.1 About the EDgE Project

What does EDgE stand for?

The EDgE project is an "**E**nd-to-end **D**emonstrator for improved decision-making in the water sector in **E**urope"

8.2.2 About Downloading EDgE Data

How can I download EDgE data?

To download data for a grid cell in either the Climate Projections or Seasonal Forecasts Map Viewer:

- Go to the Seasonal Forecast or Climate Projections Map Viewer
- Select your chosen indicator, time step and model ensemble
- Click a cell on the map to display a time series graph
- Click the download button at the top of the graph window

An FTP page for downloading larger amounts of data from the EDgE archive is being set up. In the meantime, please email edge@ceh.ac.uk for other data download enquiries.

Find out more about exploring and downloading EDgE Seasonal Forecasts and Climate Projections on the Help pages.

Can I download all the data for my catchment of interest (e.g. the River Thames)?

When exploring streamflow indicators, you can use the catchment slider in the bottom right of the Map Viewer window to mask out cells with a small upstream area - this will help to identify cells which are part of the main river network. You can then click on a cell to download data for that cell (whether these are seasonal forecasts or climate projections). It is then possible to change the variable in the map options on the left and the graph will update and you will be able to download the data for the same point - however, the data are the mean for that individual cell.

8.2.3 About EDgE Modelling

What observational datasets are used in the modelling framework?

The E-OBS gridded dataset - European Climate Assessment & Dataset is used.
See here for more information on E-OBS

What is the resolution of the EDgE products?
The spatial resolution is 5km. The hydrological models are run at a daily resolution and the SCII's are computed monthly.

How many and which hydrological models are included in the EDgE model ensembles?
The five hydrological models included in the project are: NOAH-MP, mHM, PCRGLOBWB, and VIC.
Find out more about the hydrological models used in EDgE here

Which downscaling method is used for the climate forcing dataset?
The downscaling of climate datasets (e.g., from 50 km to 5km) is conducted using the External Drift Kriging (EDK) algorithm; wherein the elevation is taken as external drift and variograms are derived based on the historical point scale data-set.

What model is used for river routing?
The river routing model is mRm from UFZ.

What PET method is used in EDgE?
The daily PET are estimated based on the modified FAO Penman-Monteith (Allen et al., 1998, Stagge et al., 2015) equation using the daily average, maximum and minimum air temperature, land surface albedo (taken from the NOAH-MP default look-up table values) and the monthly mean wind speed (from the EFAS forcing data). These estimates are used as forcings for mHM and PCR-GLOBWB, while the NOAH-MP and VIC model internally derives the PET estimates.

8.2.4 About EDgE Climate Projections

Which GCMs are included in the Climate Projections for the EDgE project?
EDgE has used data from five Global Circulation Models (GCMs) for its climate projections: NorESM1-M, MIROC-ESM-CHEM, IPSL CM5, HadGEM2-ES and GFDL-ESM2M
Find out more about EDgE Climate Projections here and about the Climate Models used in EDgE here

How are the EDgE Climate Projection Indicators calculated?
Climate Projection indicators compare the 30-year mean over a future period against the value over the 30-year baseline period, with differences generally expressed as a percentage change. Indicators are calculated for 30-year periods at 5-year intervals over the 21st Century, centred on the years 2025 [2010 - 2040], 2030 [2015 - 2045] and 2080 [2065 - 2095] etc.

8.2.5 About EDgE Map Viewers

How do I save copies of the maps and graphs for use in reports and presentations?
Please save your chosen maps and graphs using your computers Print Screen or Screenshot capabilities as the EDgE proof-of-concept map viewer does not include a tool for downloading maps and graphs. Such a tool will be provided with the final Copernicus Climate Change Service.

What data are shown on the map for each grid cell?
Seasonal Forecasts Map Viewer: The dominant quintile from the selected ensemble is shown for each grid cell. View the distribution of the ensemble members (not just the dominant quintile) for one to six month lead times for the by clicking on the grid cell of interest.

Climate Projections Map Viewer: The median of the selected ensemble is shown for each grid cell. View the 10th-90th percentile range of the full and selected ensemble throughout the 21st Century by clicking on the grid cell of interest.

What area foes the streamflow indicator for a given cell represent?
Streamflow indicators represent the aggregated routed streamflow for all upstream grid cells. The upstream grid cells and the representation of the river network within the 5km gridded model can be understood using the catchment slider which is visible when viewing streamflow indicators in either the Seasonal Forecasts Map Viewer or the Climate Projections Map Viewer.

Can the range of legend colours automatically fit the range of the data shown on the map when I change indicator or the ensemble (i.e. the selected climate or hydrological models)?
Yes, in the legend slider click on the 'Lock' icon in the top left to change it from locked to unlocked. When it is locked the range of the legend is fixed as you change any of the map options. When it is unlocked, the legend will fit the range of the data shown on the map.

Find out more about changing the legend in the Seasonal Forecasts Map Viewer and Climate Projections Map Viewer on the Help pages.

Is it possible to change the base map in the EDgE Map Viewers?
Unfortunately it is not possible to change the basemap in the EDgE proof-of-concept Seasonal Forecasts or Climate Projections Map Viewer. It is hoped such a tool will be provided with the final Copernicus Climate Change Service. The basemap used in the EDgE Map Viewers is the EOC Basemap.

Note that in the EOC Basemap national parks are shaded in green and should not be mistaken for river catchment boundaries.

8.2.6 About using EDgE for Catchment Analysis

What does upstream area mean?
When exploring streamflow indicators, the catchment slider will appear in the bottom right of the Map Viewer window. This allows you to view data for catchments at your scale of interest. The slider masks out data from the map where the upstream area of the cell is less than your selected value. The upstream area of a cell is the area of the catchment at that cell.

How can I use EDgE with small catchments?
Hydrological assessments in small catchments can be difficult because of a lack of data. One way of over-coming this is to use relative change information taken from the larger catchment/geographic area of which the smaller catchment is a part. The method has been used in several climate change studies but is equally applicable to other analyses including seasonal forecasts.

When using relative changes, we advise the following steps:

1. Confirm that the catchment of interest has similar characteristics and behaves in a similar way as the larger catchment/geographic area of which it is a part and for which there is data available (for example similar rainfall, geology, base flow/run-off contribution, hydrograph).
2. Identify the location of interest. This may be the grid cell nearest the outlet or the value for the wider basin. Double-check the location is correct (for example, correct grid square and/or correct upstream catchment area).
3. Extract the monthly relative changes for the chosen future time period at the location of interest.
4. Apply the monthly relative changes to observed naturalised flow data from the location of interest for the full period of record available. Each month in the observed data should be perturbed using the equivalent month's relative change value (for example all Januarys should be perturbed with the January change value, all Februarys with February).
5. Either analyse the perturbed data directly or use as input to further modelling (for example stream inflows to a reservoir model)

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10. Appendix

10.1 Further information on Seasonal Prediction Models

10.1.1 CanCM4

The atmospheric component of CGCM4/CanCM4 is The Fourth Generation Atmospheric General Circulation Model and its oceanic component is the Fourth Generation Ocean General Circulation Model (OGCM4/CanOM4).

OGCM4 uses a z-level vertical coordinate, with horizontal differencings formulated on an Arakawa B-Grid. It was developed from the NCAR CSM Ocean Model (NCOM). There are 40 vertical levels with spacings ranging from 10m near the surface (there are 16 levels in the upper 200m) to nearly 400m in the deep ocean. Horizontal coordinates are spherical with grid spacings approximately 1.41 degrees in longitude and 0.94 degrees in latitude. Computational instabilities due to convergence of meridians near the North Pole are suppressed via Fourier filtering, and there is a column of special tracer grid cells centred on the North Pole as described by Gent at al. (1998).

The OGCM4 grid and associated coastlines are congruent with that of the overlying AGCM, with six OGCM grid cells (two in longitude vs three in latitude) situated beneath each AGCM cell. Coupling is once per day, although in the ESM version of the model a simulated position-dependent diurnal cycle in incident shortwave radiation is employed.

Vertical mixing is via the K-profile parameterization (KPP) scheme of Large et al. (1994), to which is added an energetically constrained, bottom intensified vertical tracer diffusivity to represent effects of tidally-induced mixing; the latter is computed in a manner similar to Simmons et al. (2004). Horizontal friction is treated using the anisotropic viscosity parameterization of Large et al. (2001). Isoneutral mixing is according to the parameterization of Gent and McWilliams as described in Gent et al. (1995), with layer thickness diffusion coefficients optionally determined according to the formulation in Gnanadesikan et al. (2006). The model incorporates the equation of state for seawater of McDougall et al. (2003).

In treating shortwave penetration, a fraction 0.45 of the incident radiation is photosynthetically active (Baker and Frouin,1987) and penetrates according to an attenuation coefficient which is the sum of a clear-water term and a term that varies linearly with chlorophyll concentration as in Lima and Doney (2004). Chlorophyll concentrations in the physical version of the model are specified from a seasonally varying climatology constructed from SeaWiFS observations, and in the ESM version are a prognostic variable. The remaining (red) incident shortwave flux is absorbed in the topmost layer.
The Strait of Gibraltar, Hudson Strait and pathways through the Canadian Archipelago that are unresolved are treated by mixing water properties instantaneously between the nearest ocean cells bordering intervening land. To prevent excessive accumulation of freshwater adjacent to river mouths, half of runoff from each modelled river is distributed across the AGCM cell (encompassing six OGCM cells) into which the river drains, with the remaining half distributed among all adjoining ocean-coupled AGCM cells.

10.1.2 GFDL (FLOR)

The GFDL Forecast-oriented Low Ocean Resolution version of CM2.5 (CM2.5-FLOR, or FLOR) model (Vecchi et al. 2014) is a descendent of the CM2.5 model (Delworth et al., 2012) and CM2.1 model (Delworth et al., 2006). The FLOR model incorporates the higher horizontal resolution in the atmosphere and land, higher vertical resolution in the atmosphere, and significantly improved land model (LM3; Milly et al. 2014) from CM2.5. The FLOR model also uses the relatively low resolution ocean and sea ice components of CM2.1. These choices create a coupled model that is relatively computationally efficient, but can be used to address problems of regional climate and extremes.

The enhanced resolution in the CM2.5 model has a significantly improved simulation of many aspects of climate, particularly hydroclimate over continental regions (Delworth et al., 2012, Figures 5,6,7 and 9); many of the improvements in simulation of near-surface climate in CM2.5 are recovered in FLOR (e.g., Jia et al. 2015). The FLOR model has been used extensively to understand predictability, change and mechanisms of tropical cyclones (Vecchi et al. 2014), Arctic sea ice (Msadek et al. 2014), precipitation and temperature over land (Jia et al. 2015), drought (Delworth et al., 2015), extratropical storms (Yang et al. 2015), the Great Plains Low Level Jet (Krishnamurthy et al. 2015), and the global response to increasing greenhouse gases (Winton et al. 2014).

FLOR is used in real time seasonal predictions, contributing to the North American Multi-Model Ensemble for seasonal prediction (NMME; Kirtman et al. 2014). Retrospective prediction output from FLOR is available from the GFDL data server: www.nomads.gfdl.noaa.gov/dods-data/NMME/

The atmospheric component of CM2.5-FLOR has similar physics as CM2.1, but uses a cubed-sphere dynamical core (Putnam and Lin 2007) with grid box cells that are 50 Km on a side, versus approximately 200 Km in CM2.1. The atmospheric component also increases the number of vertical levels from 24 to 32. The ocean component has the same horizontal resolution of CM2.1, which is approximately 1o (with meridional resolution of 1/3o near the Equator). The model uses increasing levels of parallelism to run efficiently on modern supercomputers. For example, the model was able to simulate 18(12) model years per day when using approximately 4000(2600) processors on the NOAA Research Supercomputer (GAEA) located at the Oak Ridge National Laboratory.

10.1.3 Météo-France System 5

As any long-range forecast system, Météo-France system 5 consists in an ensemble forecast operational production together with an ensemble re-forecast dataset, also called hindcast. Both ensembles come from integrations of the global coupled atmosphere/ocean/sea-ice/land-surface model CNRM-CM.

In this system, the ensemble members are generated by small differences in their initial conditions but also during the integration, in order to take into account uncertainties in the initial state as well as model errors.

More specifically, the 51 members of the forecast come from a combination of 2 sets of lagged average runs differing by their start date with either 25 or 26 distinct sets of perturbations applied during the integration as part of the stochastic dynamics procedure (Batté and Déqué, 2012).

The hindcast is fixed – as opposed to 'on the fly hindcasts'. It accounts for 15 members and spans 22 years from 1991 until 2014. It was built with one ocean initial state combined with 15 distinct sets of perturbations for stochastic dynamics.

The former system 4 has been running operationally since September 2012. It consists in a 51 member forecast based on ARPEGE-Climat version 5.2 coupled with NEMO3.2. The atmosphere component has a 1.5° horizontal resolution and 31 vertical levels, while the ocean one has a 1° horizontal resolution and 42 vertical levels. The ensemble is generated by 51 distinct initial conditions and slightly different start dates (lagged average technique). The main upgrades in system 5 are listed here:

1. ARPEGE-Climat version moves to Arpege-IFS cycle 37 with a finer horizontal resolution of 0.75° (Tl255 truncation)
2. Vertical resolution is increased to 91 levels allowing an explicit representation of the stratosphere (ozone, non-orographic gravity wave drag
3. Surface processes are managed by the dedicated SURFEX 7.3 modelling platform
4. Sea-ice is computed by a dedicated model: GELATO v5
5. Ensemble spread is generated by a stochastic dynamics technique in addition to using a lagged initialisation.

10.1.4 ECMWF System 4

The resolution of the ECMWF System 4 atmosphere model is increased from TL159 with 62 vertical levels to TL255 with 91 vertical levels. The model top is increased from 5 hPa to 0.01 hPa.

The NEMO ocean model replaces the previous HOPE ocean model. NEMO is used in the ORCA1 configuration, which has an approximate 1 deg x 1 deg resolution with equatorial refinement. The ORCA1 grid has a somewhat complex structure that cannot yet be described in GRIB. NEMO output is in netCDF, and the netCDF files are archived in ECFS. There are no plans at present to make System 4 ocean data available in MARS.

The ensemble sizes are slightly increased. The real-time forecasts will now have 51 members (previously 41). The re-forecasts will have 15 members uniformly for all start months (previously 11 members).

The period of the re-forecasts has been extended to include the last 5 years of operational running of System 3, and covers the 30 years from 1981 to 2010. This is longer than the 1981-2005 25 year period of the previous system, and should allow slightly better calibration of the forecasts and better assessment of their skill. It also means that anomalies will be relative to a standard 30 year period. The re-forecasts have also been created for January to April 2011 to bridge the gap to the start of the real-time forecasts.

The standard forecast length (for both forecasts and back integrations) remains at 7 months. However, the issue date of the forecasts will be brought forward from the 15th to the 8th of the month. This gives a forecast range of 6.75 months from the release date of the forecasts.

Four times a year, from the Feb, May, Aug and Nov starts, 15 members (out of 51) of the forecast ensemble will run to 13 months. This will allow an "ENSO outlook" to be given. The re-forecasts for these start months also have 15 ensemble members that extend to 13 months. Note that these extended runs remain classed as experimental rather than operational, and data from them will not be available via dissemination.

Major scientific changes for System 4

- A new ocean model (NEMO) and ocean data assimilation system (NEMOVAR). These changes give improvements to the mean state and to SST forecast skill in the East Pacific and Tropical Atlantic oceans.
- Change from IFS cycle 31r1 to 36r4, including many improvements to the model physics, and giving a generally much improved model climate (although not for equatorial Pacific winds).
- Improved representation of the stratosphere and processes such as the QBO, including volcanic aerosol and radiatively interactive ozone.
- Improved land surface model (HTESSEL) and land surface initialization methodology.
- Revision of stochastic physics, with the new SPPT3 scheme giving substantially bigger spread to the SST forecasts.
- Tests show that the prediction skill for Pacific equatorial SSTs (i.e. El Niño variability) is measurably improved in S4 in the East Pacific, but fractionally degraded in the west Pacific. Prediction skill in the Atlantic is notably improved. Changes in skill for atmospheric variables are less precisely measurable with the limited test samples available. However, ACC skill measures show substantial and consistent improvement in tropical scores. NH scores (poleward of 30N) do not seem to be improved in winter, but show noticeable improvements in other seasons, based on analysis of the first 18 years of re-forecast. Full information on skill will be available prior to operational implementation.

System 4 performance

Preliminary information on the performance of System 4 is available in the presentation to the Forecast Products Users' Meeting. More comprehensive documentation of the performance is in preparation.

10.2 Further information on Climate Models

10.2.1 GFDL-ESM2M

GFDL has constructed NOAA's first Earth System Models (ESMs) (Dunne et al. 2012, 2013) to advance our understanding of how the Earth's biogeochemical cycles, including human actions, interact with the climate system. Like GFDL's physical climate models, these simulation tools are based on an atmospheric circulation model coupled with an oceanic circulation model, with representations of land, sea ice and iceberg dynamics. ESMs incorporate interactive biogeochemistry, including the carbon cycle. Building the ESMs has been a large collaborative effort involving scientists from GFDL, Princeton University, Department of Interior and other institutions, to study climate and ecosystem interactions and their potential changes, from both natural and anthropogenic causes.

The atmospheric component of the ESMs includes physical features such as aerosols (both natural and anthropogenic), cloud physics, and precipitation. The land component includes precipitation and evaporation, streams, lakes, rivers, and runoff as well as a terrestrial ecology component to simulate dynamic reservoirs of carbon and other tracers. The oceanic component includes features such as free surface to capture wave processes; water fluxes, or flow; currents; sea ice dynamics; iceberg transport of freshwater; and a state-of-the-art representation of ocean mixing as well as marine biogeochemistry and ecology.

While carbon is necessarily included as the basic building block of ecosystems undergoing terrestrial and oceanic chemistry, associated chemical and ecological tracers which control nutrient limitation, plant biomass, productivity, and functional composition are also included. Chemical tracers are also tracked in the atmosphere. ESMs capture numerous types of emissions, variations of land surface albedo due to both natural vegetation changes and land use history such as agriculture and forestry, and aerosol chemistry. Adding these different components to the ESM represents a major step forward in simulating the Earth's ecological systems in a comprehensive and internally consistent context.

Their first prototype model, ESM2.1, evolved directly from GFDL's successful CM2.1 climate model (Delworth et al. 2006). Building on this, they produced two new models representing ocean physics with alternative numerical frameworks to explore the implications of some of the fundamental assumptions embedded in these models.

The models differ mainly in the physical ocean component. In ESM2M, pressure-based vertical coordinates are used along the developmental path of GFDL's Modular Ocean Model version 4.1. ESM2M utilizes a more advanced land model, LM3, than was available in ESM2.1 including a variety of enhancements (Milly et al., in prep).

10.2.2 HadGEM2-ES

The HadGEM2 family of climate models represents the second generation of HadGEM configurations, with additional functionality including a well-resolved stratosphere and Earth System components.

HadGEM2 stands for the Hadley Centre Global Environment Model version 2. The HadGEM2 family of models comprises a range of specific model configurations incorporating different levels of complexity but with a common physical framework. The HadGEM2 family includes a coupled atmosphere-ocean configuration, with or without a vertical extension in the atmosphere to include a well-resolved stratosphere, and an Earth-System configuration which includes dynamic vegetation, ocean biology and atmospheric chemistry.

Members of the HadGEM2 family will be used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. The ENSEMBLES project also uses members of this model family.

The standard atmospheric component has 38 levels extending to ~40km height, with a horizontal resolution of 1.25 degrees of latitude by 1.875 degrees of longitude, which produces a global grid of 192 x 145 grid cells. This is equivalent to a surface resolution of about 208 km x 139 km at the Equator, reducing to 120 km x 139 km at 55 degrees of latitude. A vertically-extended version, with 60 levels extending to 85km height, is also used for investigating stratospheric processes and their influence on global climate.

The oceanic component utilizes a latitude-longitude grid with a longitudinal resolution of 1 degree, and latitudinal resolution of 1 degree between the poles and 30 degrees North/South, from which it increases smoothly to one third of a degree at the equator, giving 360 x 216 grid points in total, and 40 unevenly spaced levels in the vertical (a resolution of 10m near the surface).

10.2.3 IPSL-CM5A LR

The IPSL Climate Modelling Centre (IPSL-CMC) continuously develops and improves its climate model IPSL-CM and its various components. The IPSL-CM5 is the fifth version of the IPSL model and is a full earth system model. In addition to the physical atmosphere-land-ocean-sea ice model, it also includes a representation of the carbon cycle, the stratospheric chemistry and the tropospheric chemistry with aerosols.

The IPSL-CM5A is an extension of IPSL-CM4 and has been updated to form the IPSL-CM5A2 model with the aim of having a fast version for long simulations. The model is based on the LMDZ atmospheric model that has two standard resolutions: the low resolution (IPSL-CM5A-LR) is 1.9°x3.75° (96x96xL39) and the mid-resolution (IPSL-CM5A-MR) is 1.25°x2.5° (144x143xL39). The NEMO oceanic model has a resolution of about 2°, with a meridional increased resolution of 0.5° near the Equator (149x182L31). The ORCHIDEE model is used for continental surfaces including the carbon cycle, and the INCA model is used for the chemistry of aerosols with the LMDz-REPROBUS coupled chemistry-climate model.

10.2.4 MIROC ESM CHEM

MIROC-ESM is based on the University of Tokyo's global climate model MIROC (Model for Interdisciplinary Research on Climate). A comprehensive atmospheric general circulation model (MIROC-AGCM 2010) including an on-line aerosol component (SPRINTARS 5.00), an ocean GCM with sea-ice component (COCO 3.4), and a land surface model (MATSIRO) are interactively coupled in MIROC. The atmosphere, ocean, and land surface components, as well as a river routing scheme are coupled by a flux computer. On the basis of MIROC, MIROC-ESM further includes an atmospheric chemistry component, a nutrient-phytoplankton-zooplankton-detritus (NPZD) type ocean ecosystem component, and a terrestrial ecosystem component dealing with dynamic vegetation (SEIB-DGVM). Due to given large uncertainty in coupling processed, the present version of MIROC-ESM includes some limited processed, only e.g. effects of vegetation changes on dust emission, and effects of deposition of black carbon (BC) and dust on snow albedo. Many coupling processes, which are potentially important in the Earth system are not included at present. MIROC-ESM-CHEM were runs using the CHASER-coupled version of MIROC-ESM.

10.2.5 NorESM1M

The Norwegian Earth System (NorESM) family of models are based on the Community Climate System Model version 4 (CCSM4) of the University Corporation for Atmospheric Research. NorESM utilises an isopycnic coordinate ocean general circulation model developed in Bergen during the last decade (e.g. Bentsen et al., 2004; Drange et al., 2005b; Lohman et al., 2009; Orre et al., 2010), originating from the Miami Isopycnic Coordinate Ocean Model (MICOM) (Bleck et al., 1992). The atmospheric module is modified with chemistry-aerosol-cloud-radiation interaction schemes developed for the Oslo version of the Community Atmosphere Model (CAM4-Oslo; Kirkevag et al., 2012). Finally, the HAMburg Ocean Carbon Cycle (HAMOCC) model developed at the MaxPlank-Institute for Meteorology, Hamburg (Maier-Reimer, 1993), adapted to an isopycnic ocean model framework, constitutes the core of the biogeochemical ocean module 15 in NorESM (Tjiputra et al., 2010). In this way NorESM adds to the much desired climate model diversity, and thus to the hierarchy of models participating in phase 5 of the Climate Model Intercomparison Project (CMIP5; Moss et al., 2010; Taylor et al., 2012). NorESM1-M has a horizontal resolution of approximately 2° for the atmosphere and land components and 1° for the ocean and ice components.

10.3 Further information on Hydrological Models

Details of the hydrological models used in EDgE are given below.

10.3.1 Mesoscale Hydrologic Model (mHM)

The mHM is a spatially distributed, grid-based mesoscale hydrologic model (mHM; Samaniego et al. 2010, Kumar et al 2013a) that accounts for the following main hydrologic processes: canopy interception, snow accumulation and melt, root zone soil moisture and evapotranspiration, infiltration, surface and subsurface runoff, percolation, baseflow and flood routing.

The conceptualization of hydrologic processes in mHM is similar to these of other existing large scale models such as the HBV, the WaterGAP, or the VIC models. mHM uses a novel multiscale parameter regionalization (MPR) scheme to account for the sub-grid variability of fine scale physiographical characteristics (e.g., terrain, soil, vegetation characteristics) that facilitates the model to run efficiently across a range of spatial resolutions and locations other than those used in calibration. The source code of mHM is available freely at the www.ufz.de/mhm. The model has been successfully applied to several river basins in Germany, North America and Europe, and other parts of world (Samaniego et al. 2010, 2013; Kumar et al. 2013a,b; Thober et al. 2015, Rakovec et al., 2016). The model is set up over the EDgE domain at a spatial resolution of 5km. It utilises high resolution land (sub-)surface properties on terrain, soil, vegetation, and geological characteristics to derive effective parameters using the MPR technology. These static land surface characteristics are based on multiple data sources including EU-DEM (EEA) and GTOPO30-DEM, ISRIC SoilGrids1km, CORINE and GLOBCOVER land cover dataset, and IHME1500 Hydrogeological Map of Europe. These datasets are processed, resampled and mapped on to a common resolution of 500m. During the historical period of 1950-2014, the model is forced with the daily gridded fields of precipitation, air temperature, and potential evapotranspiration - all derived based on the publicly available, free, E-OBS dataset.

The source code of mHM is available freely at www.ufz.de/mhm

10.3.2 Noah-MP

The land surface model (LSM) Noah-MP calculates fluxes and state variables within the energy and water cycles on the terrestrial land surface. It is the successor of the Noah LSM with the inclusion of multiple process parametrization (hence Noah-MP) and can be used as the land surface scheme for the atmosphere Weather Research and Forecasting Model (WRF).

Noah-MP incorporates a large number of process descriptions with a plenitude of parameters. Processes included, among others, are a two-stream radiation transfer model considering canopy gaps, a Ball-Berry type stomatal resistance scheme, a physically based three-layer snow model and different runoff generation schemes. It distinguishes between surface energy fluxes and states for the canopy and for the ground. Within the EDgE project, the parameters of Noah-MP are calibrated for selected catchments to guarantee a reliable simulation of tECVs. Only the most sensitive parameters, which have been identified in a previous study (Cuntz et al. 2016), are considered in the calibration because the parameter space of Noah-MP is highly-dimensional with a total of 150 parameters. The setup of the Noah-MP LSM over the EDgE modelling domain uses the same static data information employed for the mesoscale Hydrologic Model (mHM) when appropriate. These static data encompasses the ISRIC SoilGrids1km soil database and the CORINE land cover dataset. Both of these are given at a spatial resolution that is higher than 5km. The predominant soil and land cover class are then taken for each 5km grid cell, which is in line with the model requirements. The vegetation and soil parameters are obtained from standard parameter files for the STATSGO soil dataset and IGBP-MODIS vegetation classes. Additionally, monthly climatological greenness fractions are derived from the JRC fapar dataset.

10.3.3 Variable Infiltration Capacity (VIC)

The Variable Infiltration Capacity (VIC) model (Liang et al., 1994, 1996; Cherkauer et al., 2002) simulates the terrestrial water and energy balances. It distinguishes itself from other land surface schemes through the representation of sub-grid variability in soil storage capacity as a spatial probability distribution, to which surface runoff is derived, and base flow from parameterising a deeper soil moisture zone as a nonlinear recession.

Horizontally, VIC represents the land surface by a number of tiled land cover classes. Evapotranspiration is calculated using a Penman-Monteith formulation with adjustments to canopy conductance to account for environmental factors. The subsurface is discretized into multiple soil layers. Movement of moisture between the soil layers is modelled as gravity drainage, with the unsaturated hydraulic conductivity a function of the degree of saturation of the soil. Cold land processes in the form of canopy and ground snow pack storage, seasonally and permanently frozen soils and sub-grid distribution of snow based on elevation banding are represented. Soil temperatures are calculated from the heat diffusion equation and ice content is estimated based on temperatures; infiltration and baseflow are restricted based on the reduced liquid soil moisture capacity. The VIC model has been implemented in applications from catchment to global scales for understanding catchment behaviour, extreme hydrological events, hydrological predictability, and climate change impacts (e.g. Sheffield and Wood, 2008; Clark et al, 2015; Sheffield et al., 2014; Yuan et al., 2015). The VIC model is setup for the EDgE modelling domain similar to the other models. Soil parameter values are derived from the ISRIC SoilGrids1km database and adjusted to be consistent with large-scale calibrated values derived from global scale simulations. Land cover spatial variability and associated leaf area index values are taken from AVHRR satellite observations, which are regridded to 5km.

10.3.4 PCR-GLOBWB

PCR-GLOBWB is a large-scale hydrological model intended for global to regional studies. For each grid cell, PCR-GLOBWB uses process-based equations to compute moisture storage in three vertically stacked soil layers as well as the water exchange between the soil and the atmosphere and the underlying groundwater reservoir.

Exchange to the atmosphere comprises precipitation, evapotranspiration and snow accumulation and melt, which are all modified by the presence of the canopy and snow cover. Sub-grid variability within PCR-GLOBWB takes into account the vegetation, glacier coverage, snow elevation bands and soil type distribution. The sub-grid soil type distribution affects the soil hydrological properties and distribution of water-holding capacity of the soil resulting in variable saturation excess overland flow (Improved Arno Scheme, Hagemann and Gates, 2003) as a result of variations in soil depth, effective porosity and elevation distribution. Saturation-excess overland flow is one of the three specific runoff components, along with interflow along hillslopes and baseflow from the groundwater reservoir. The model is able to simulate dynamic water demand, groundwater abstraction and irrigation, allowing for human interaction with the water cycle. PCR-GLOBWB is implemented in the PCRaster-Python environment and has been applied in many studies with regard to simulations of discharge (van Beek et al., 2011), water demand (Wada et al., 2011), drought (Wada et al., 2013) and seasonal predictions (Wanders and Wada, 2015). For EDgE, the PCR-GLOBWB model has been adjusted to simulate the EDgE domain similarly to the other models.

10.4 EDgE Map Viewer Tutorials

10.4.1 EDgE Seasonal Forecast Map Viewer Video Tutorial

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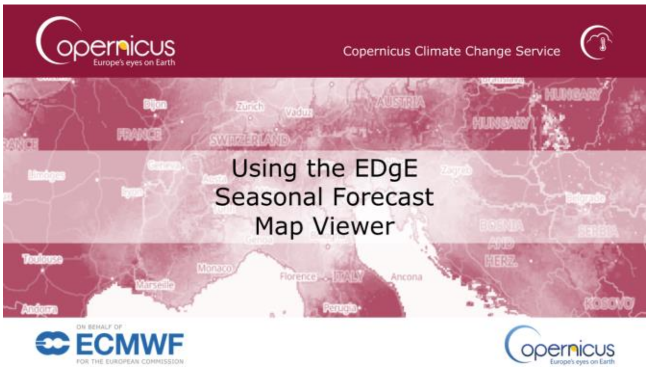

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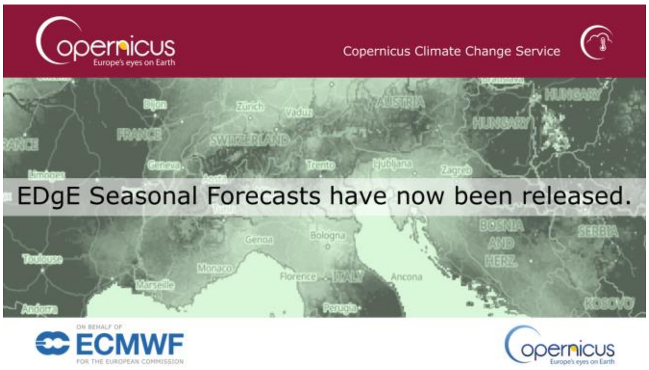

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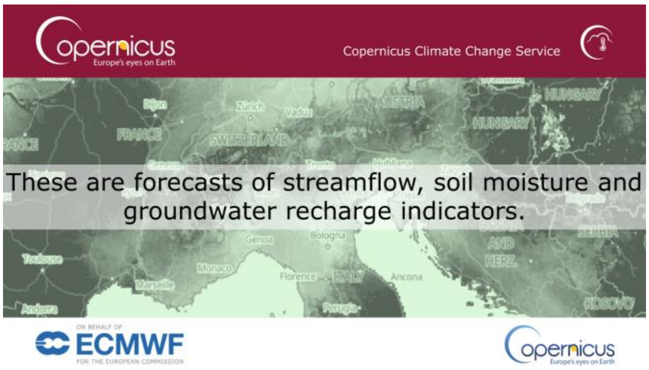

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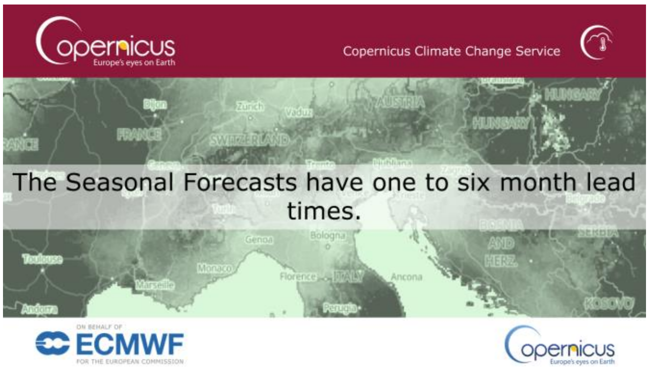

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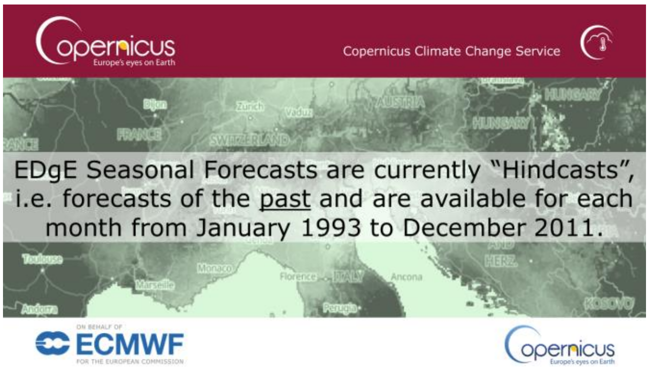

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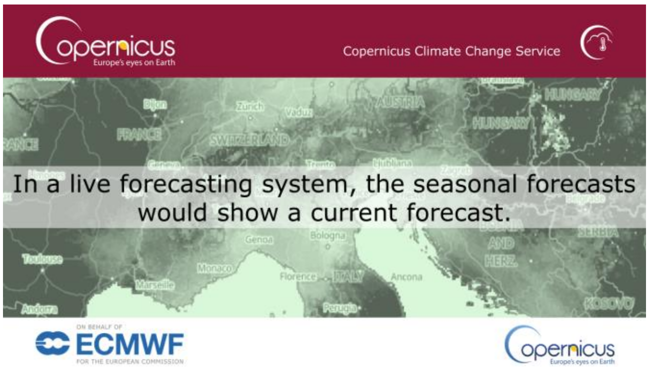

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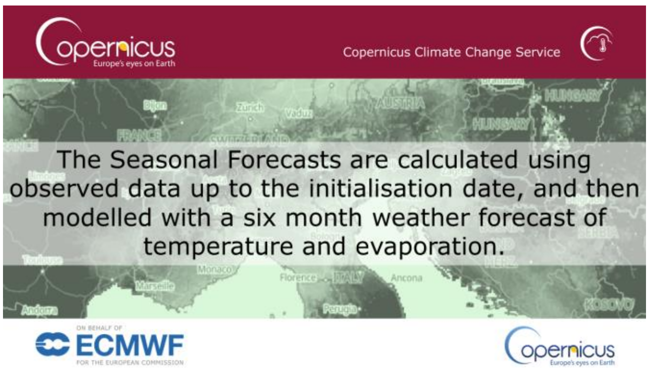

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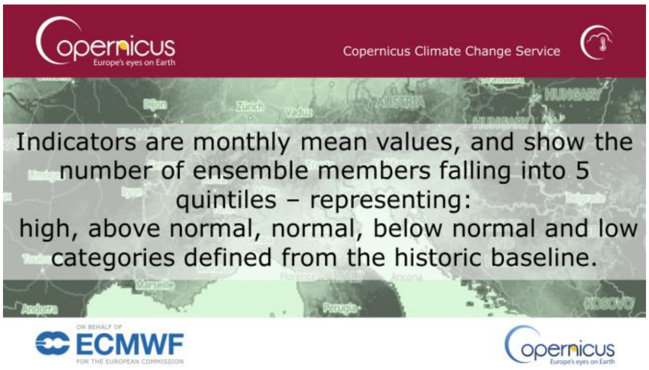

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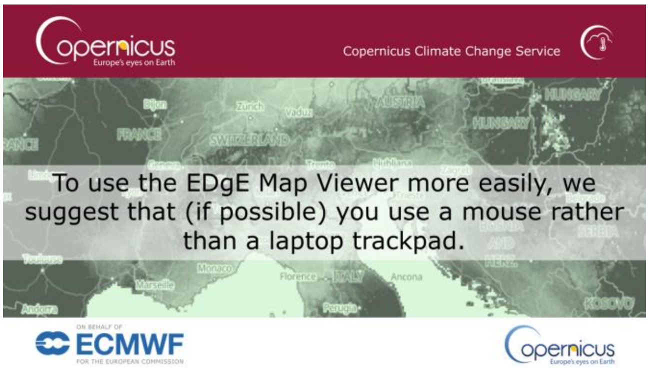

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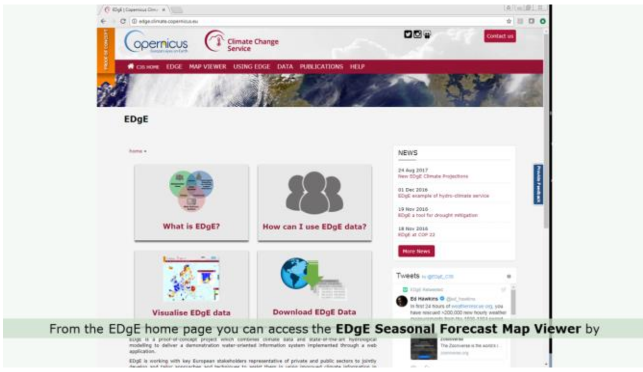

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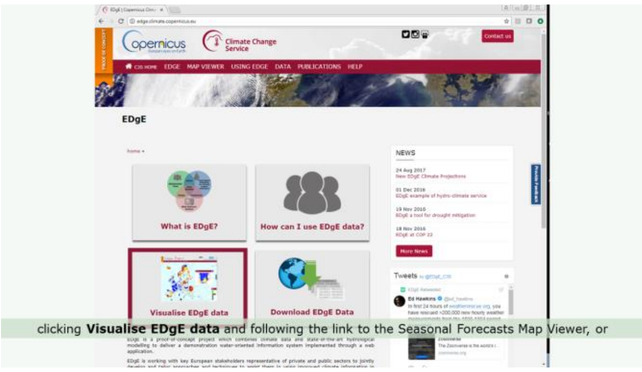

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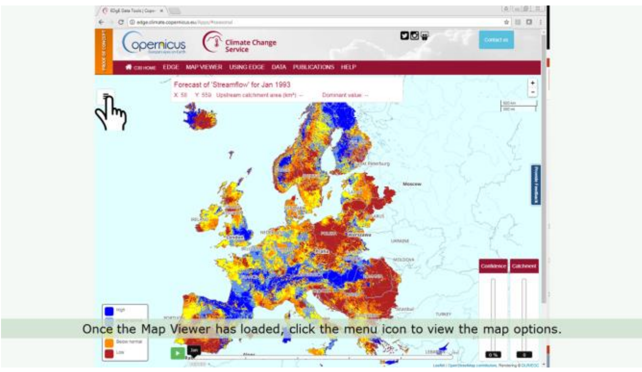

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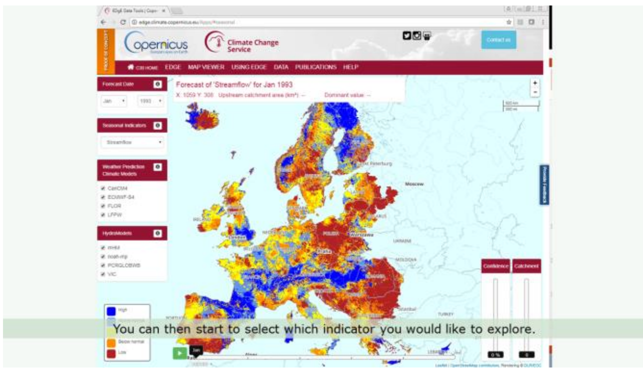

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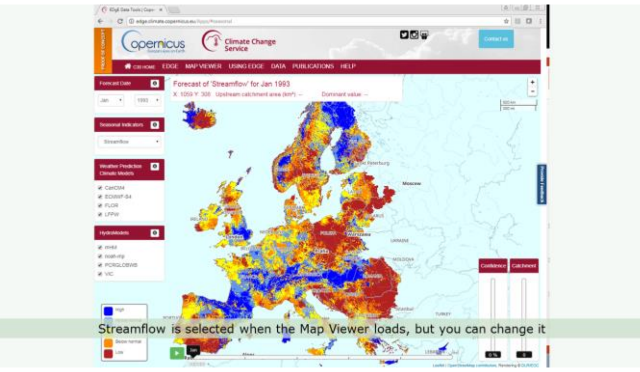

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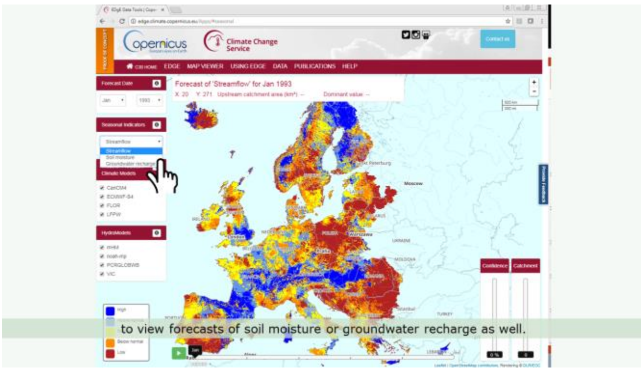

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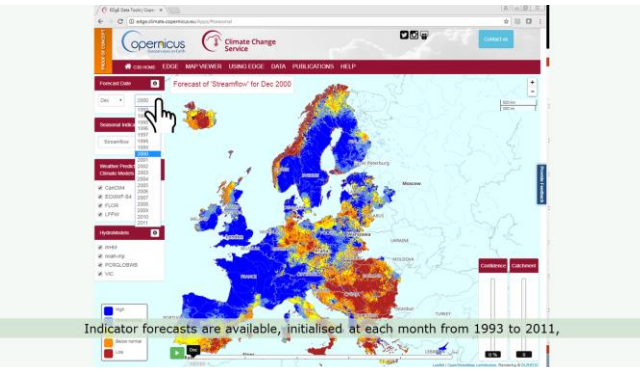

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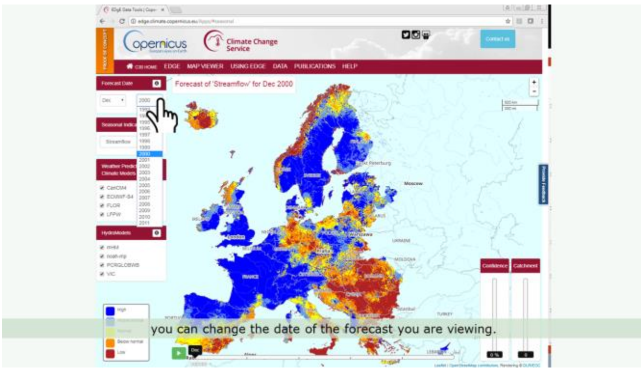

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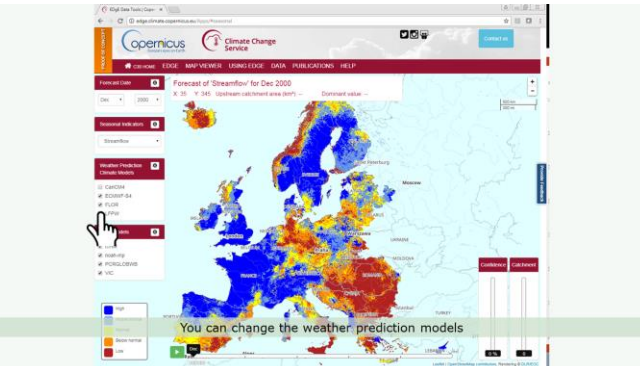

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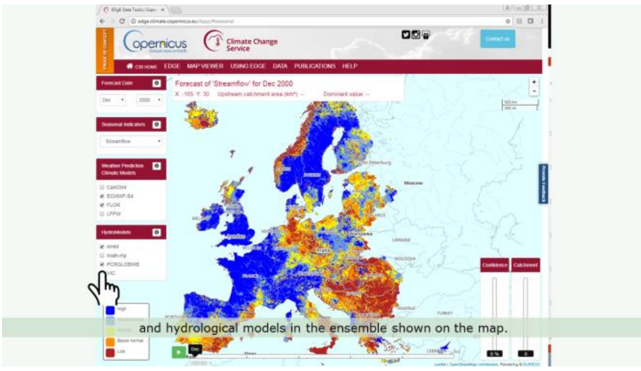

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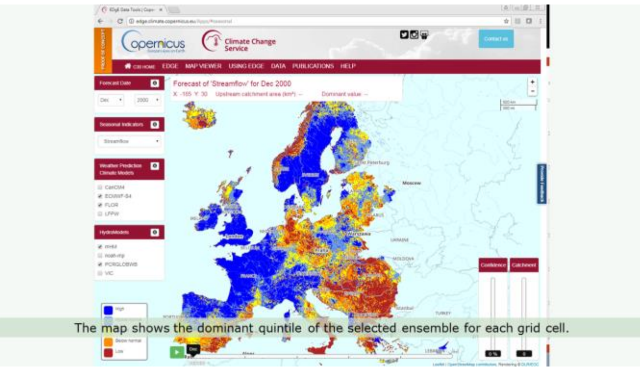

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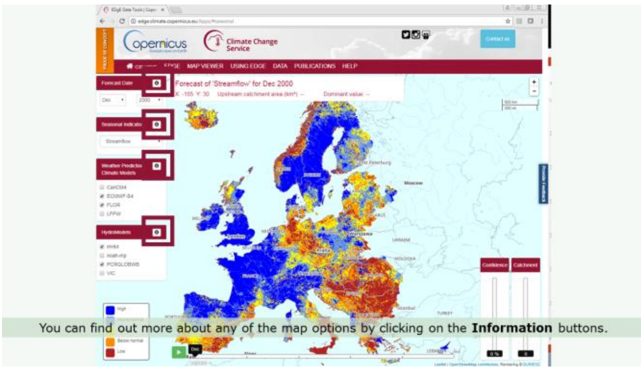

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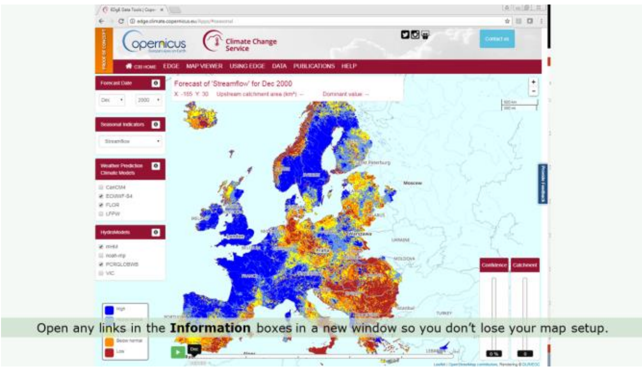

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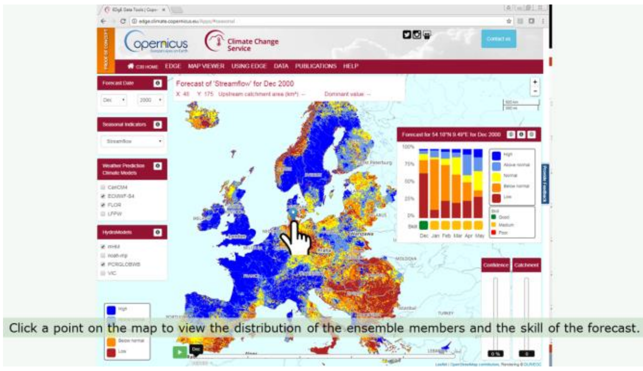

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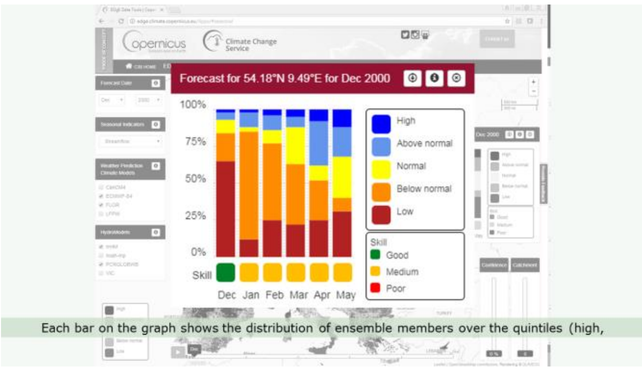

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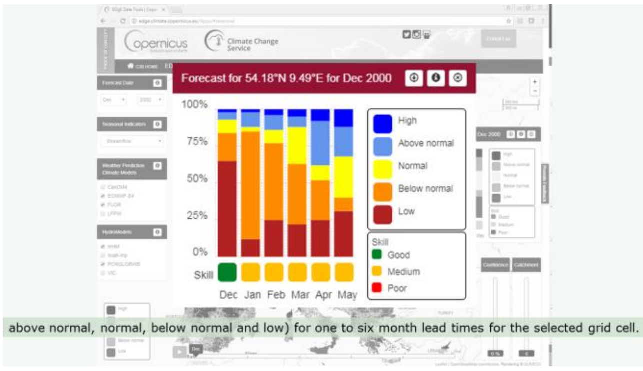

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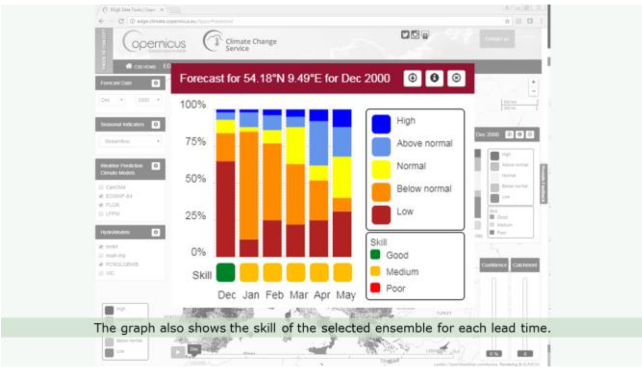

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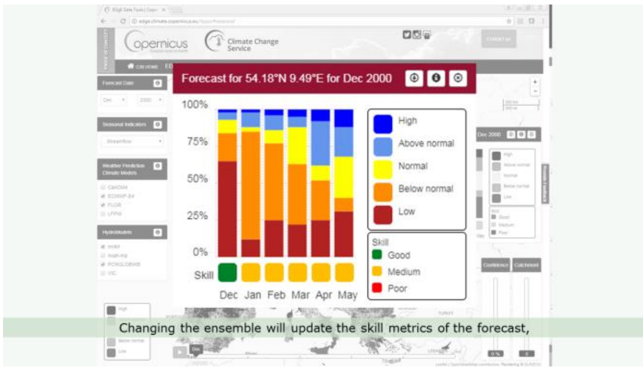

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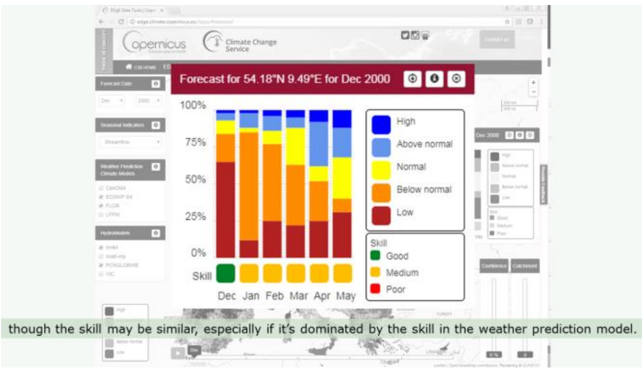

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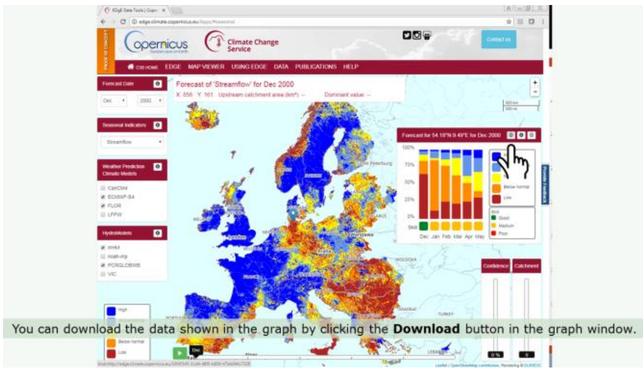

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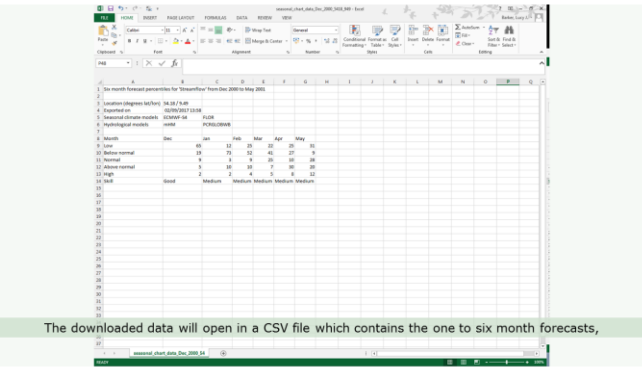

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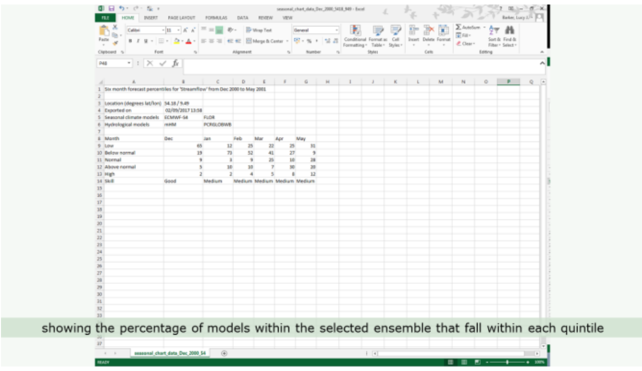

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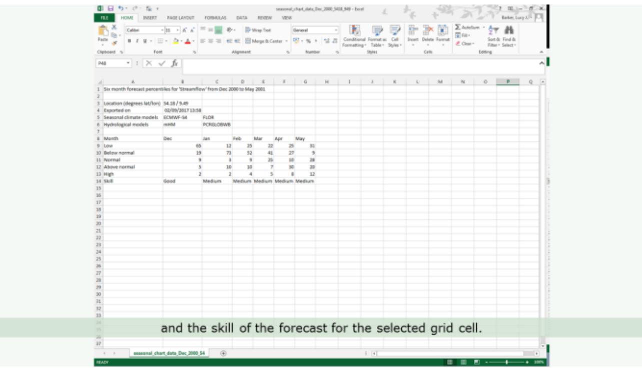

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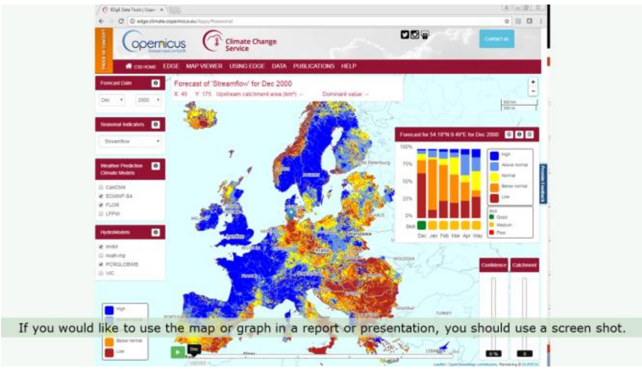

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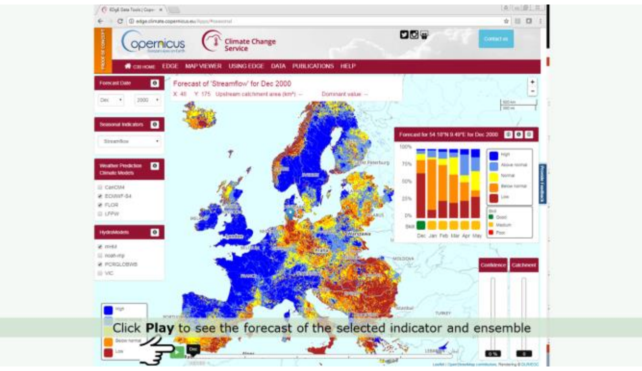

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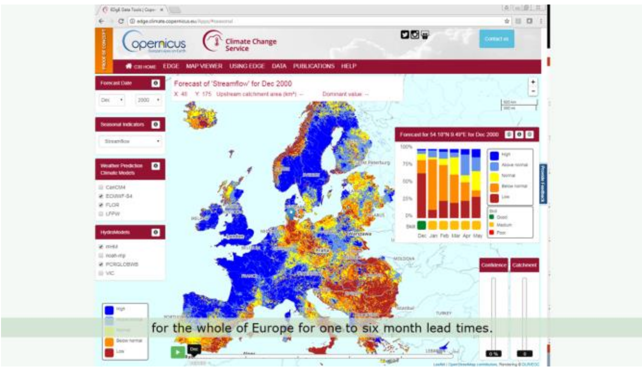

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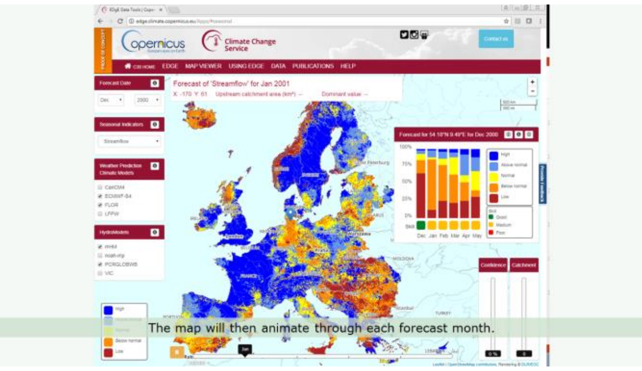

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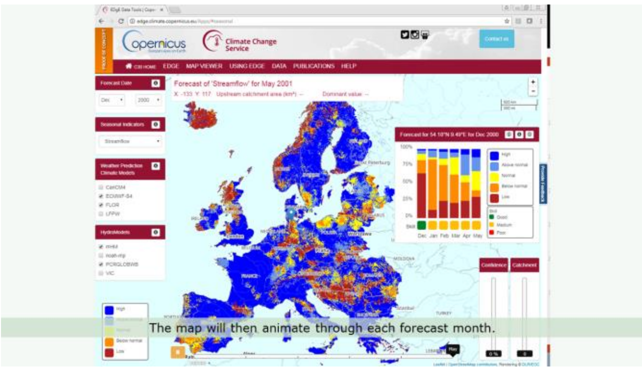

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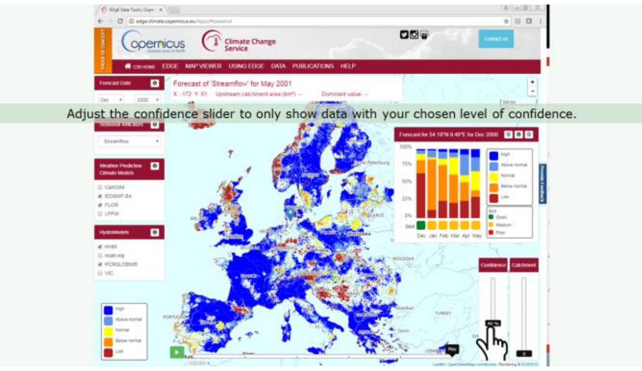

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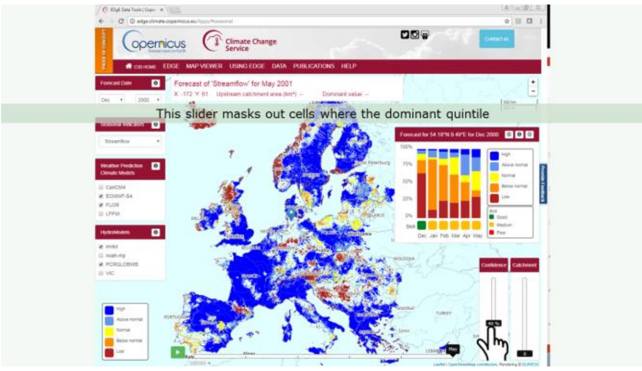

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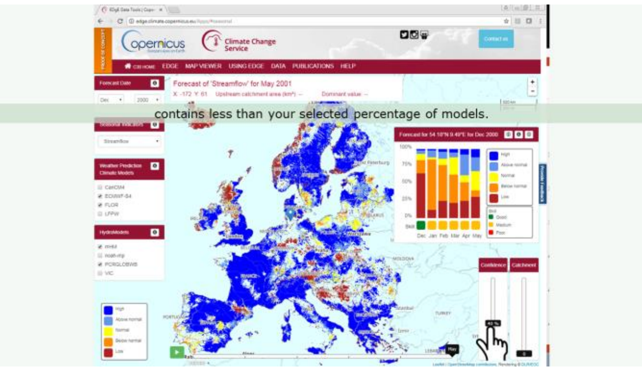

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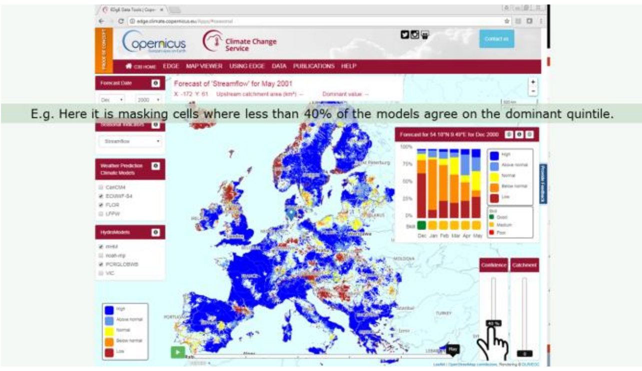

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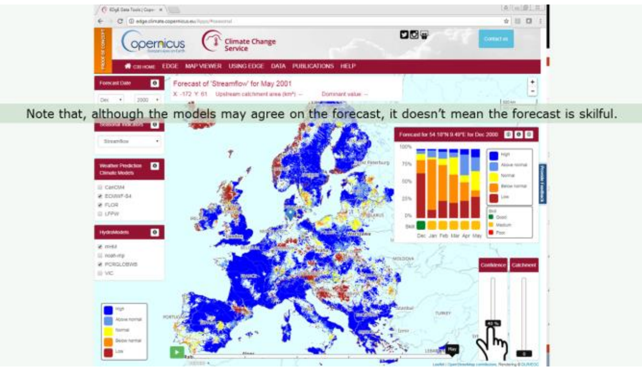

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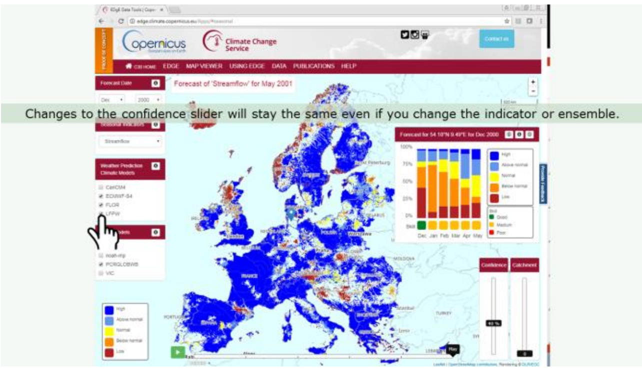

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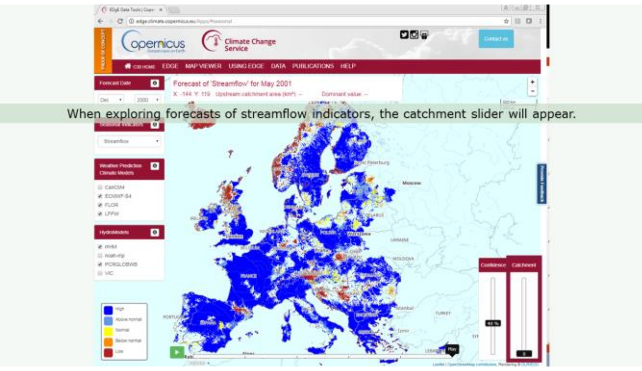

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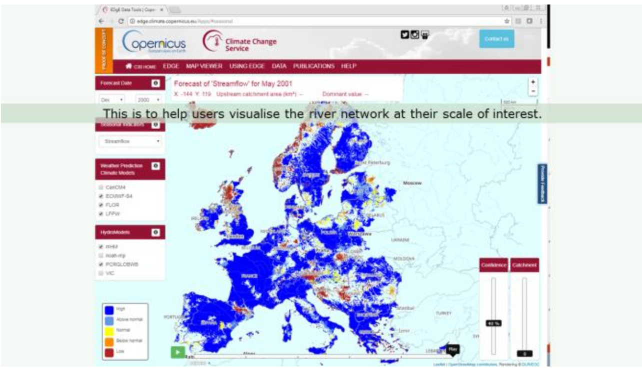

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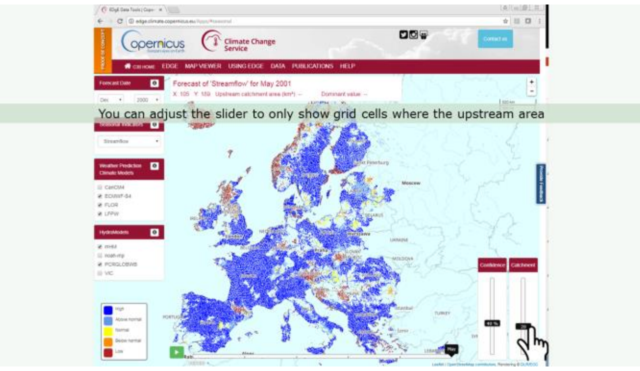

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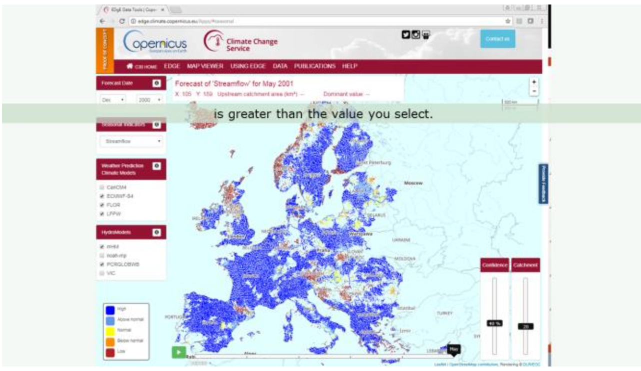

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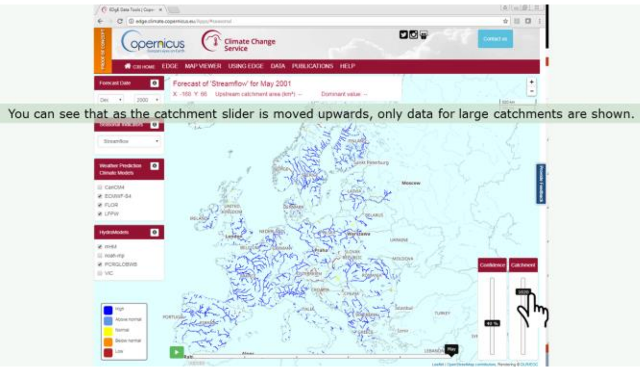

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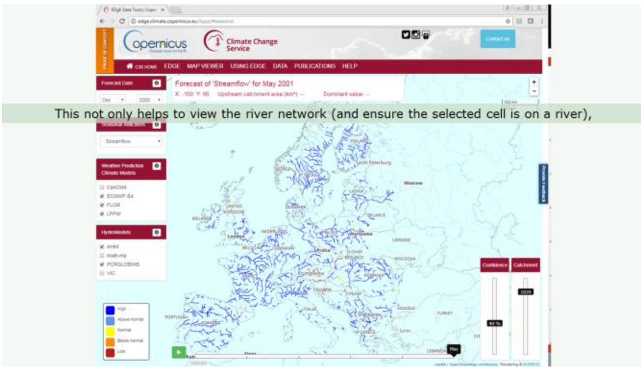

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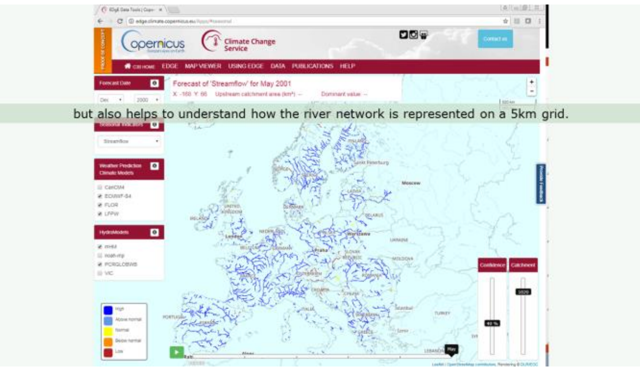

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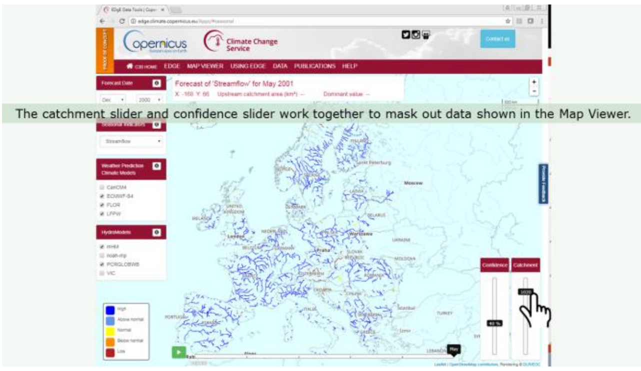

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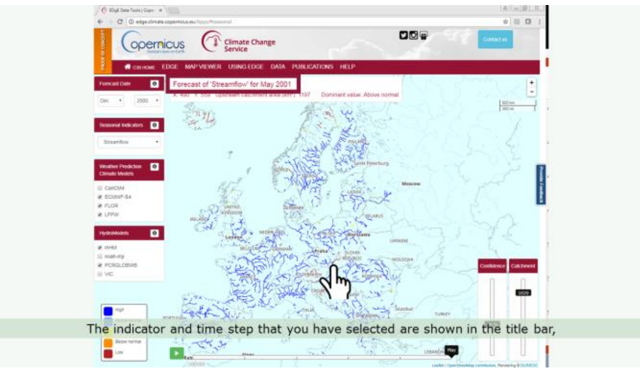

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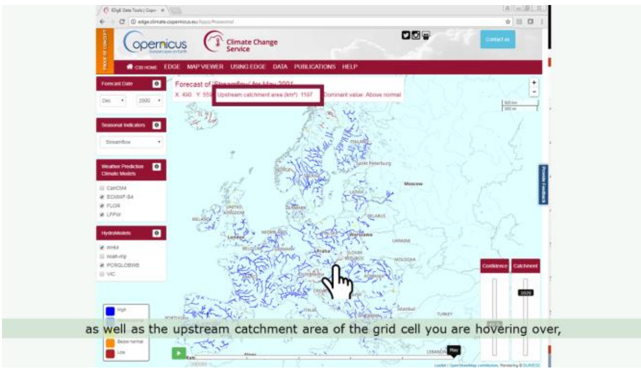

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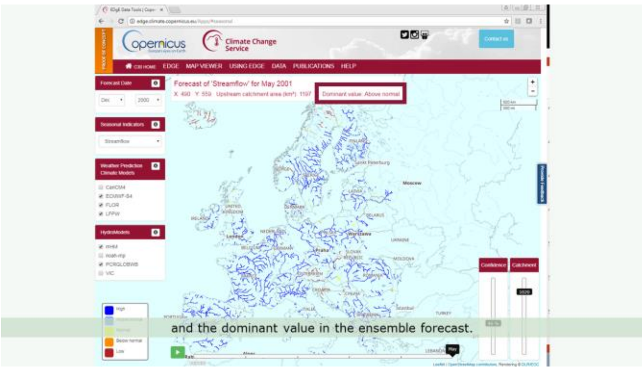

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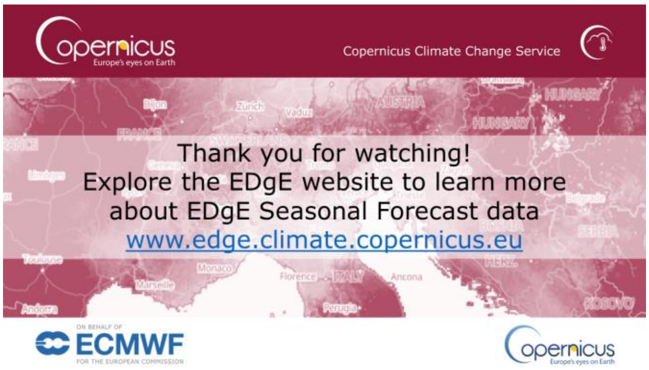

10.4.2 EDgE Climate Projections Map Viewer Video Tutorial

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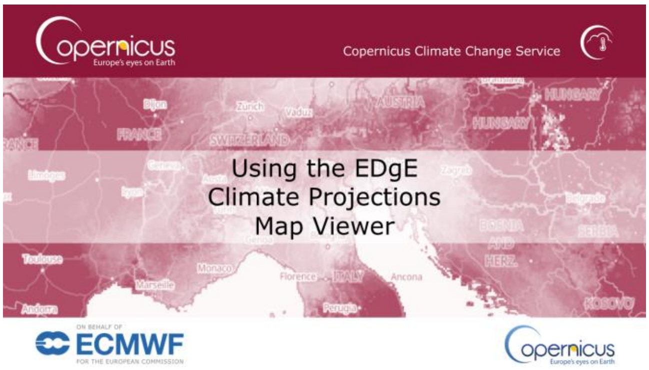

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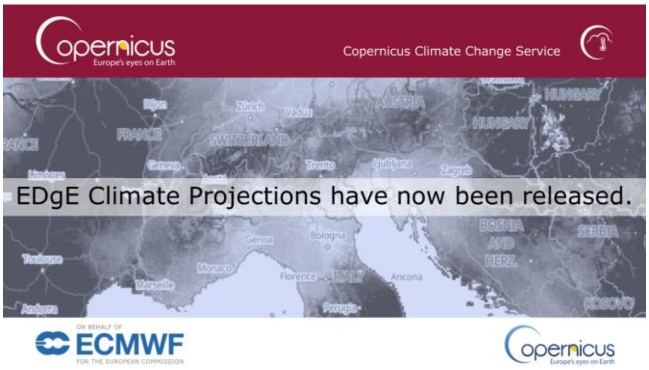

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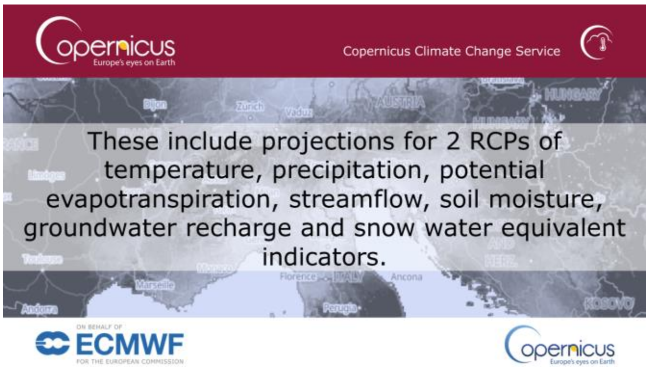

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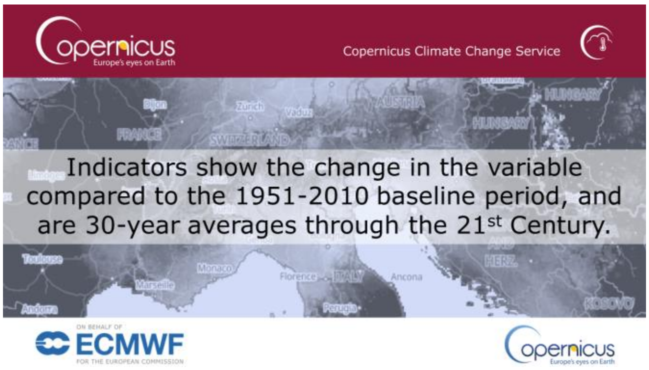

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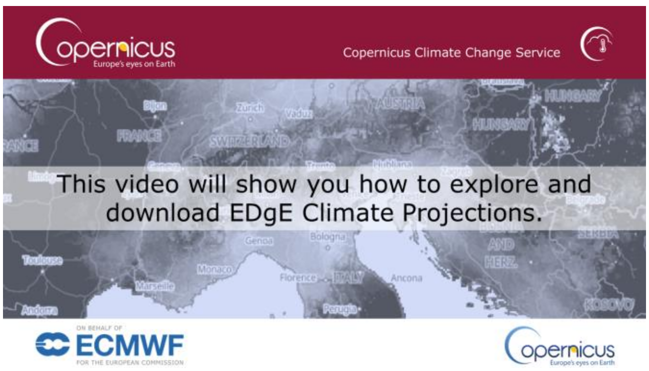

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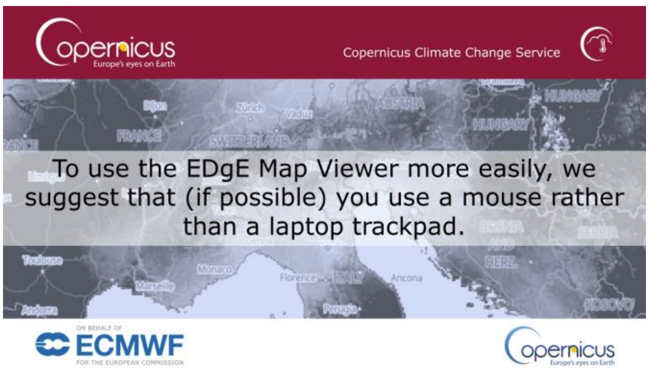

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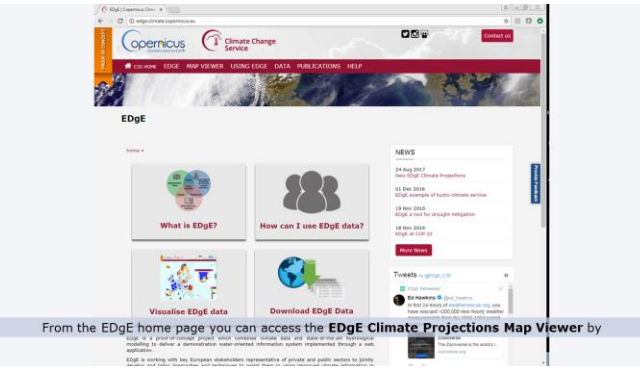

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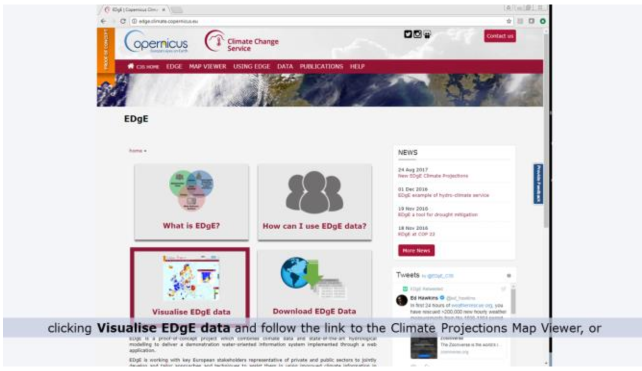

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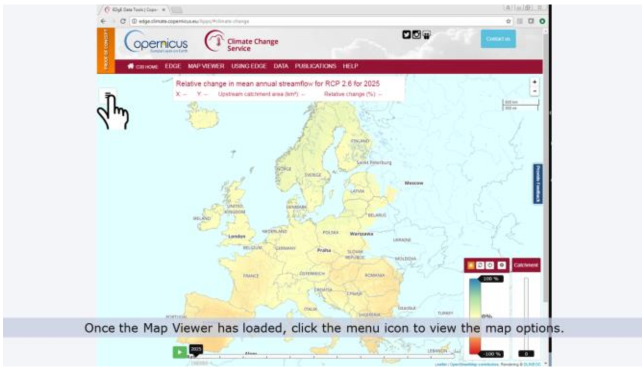

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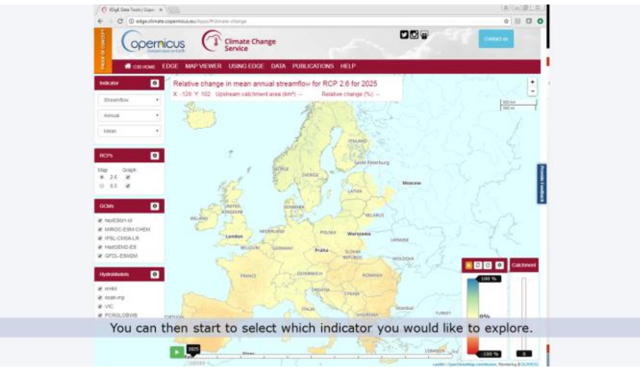

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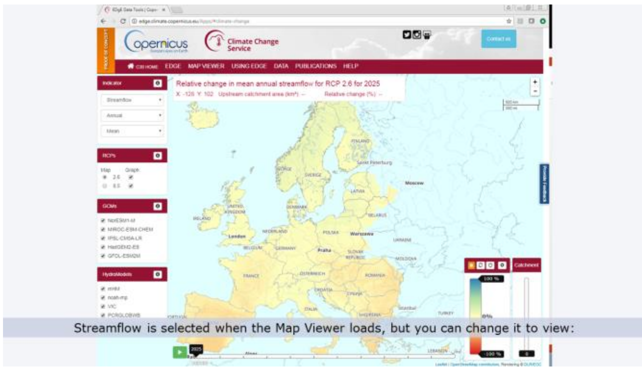

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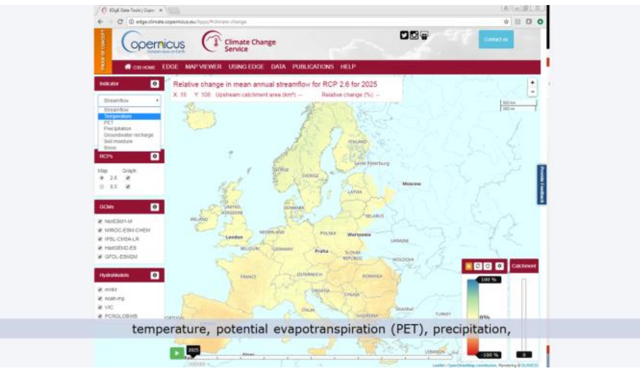

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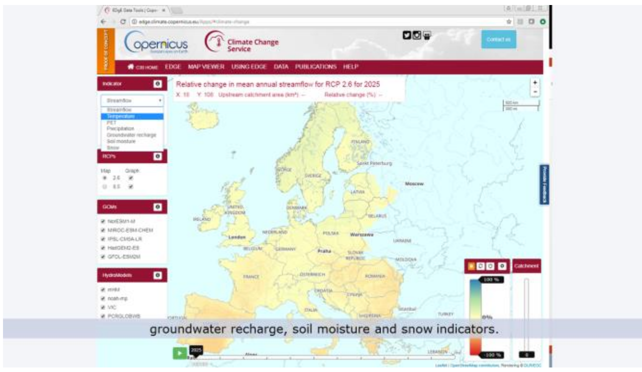

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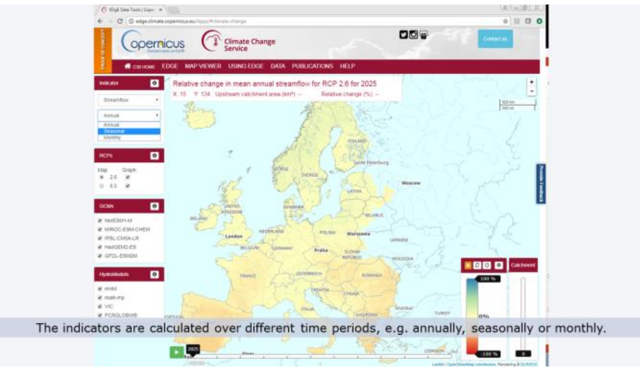

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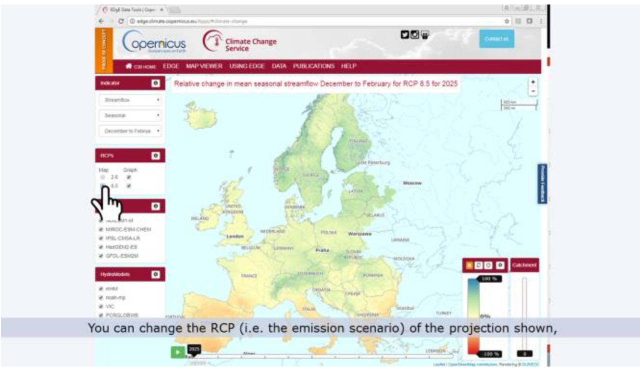

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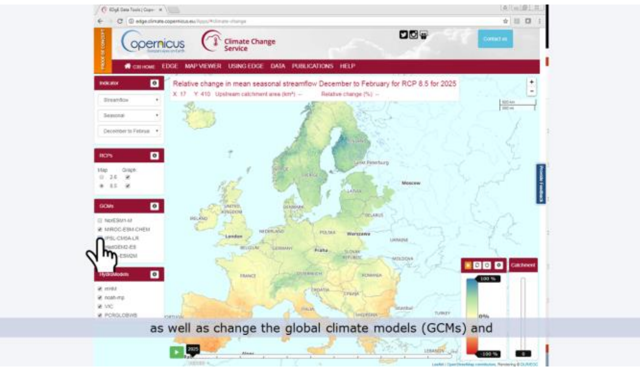

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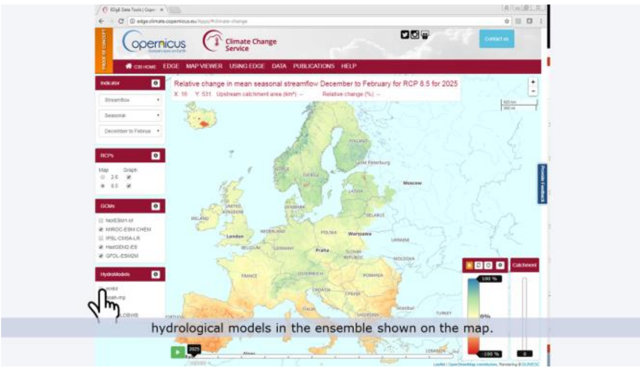

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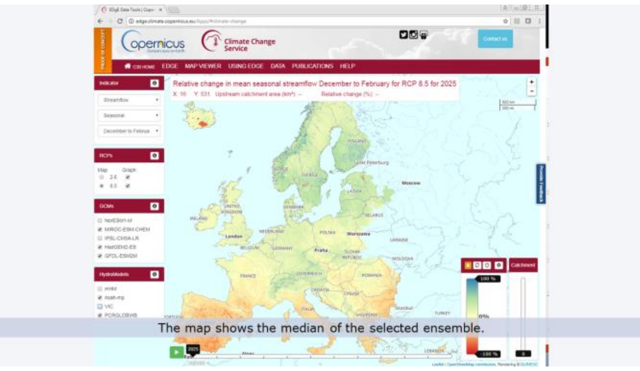

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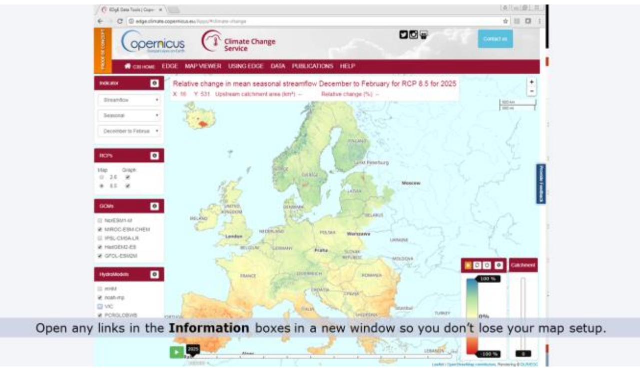

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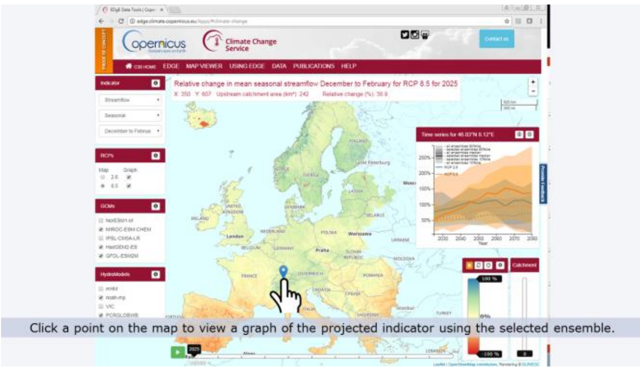

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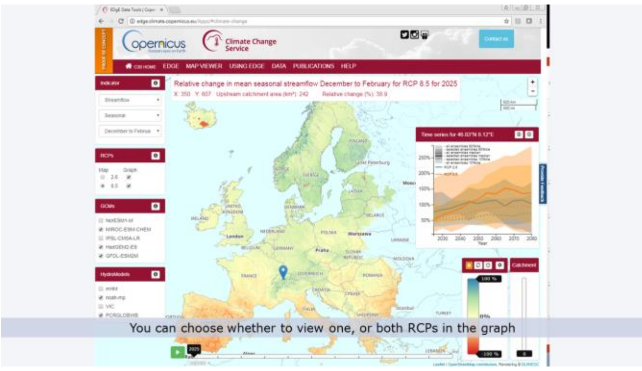

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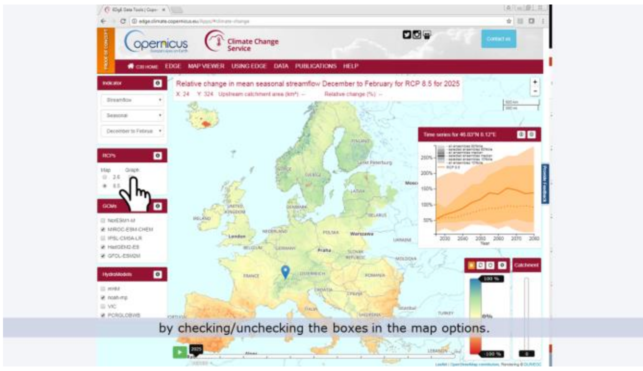

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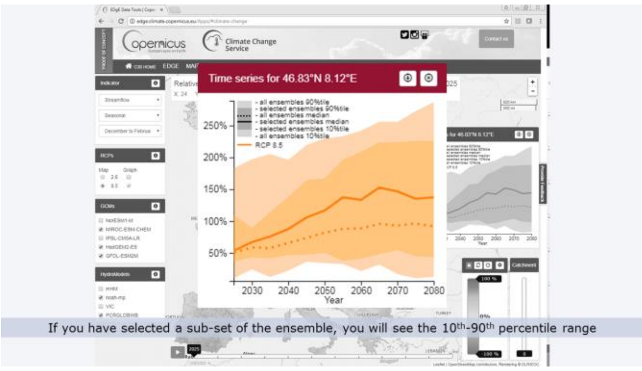

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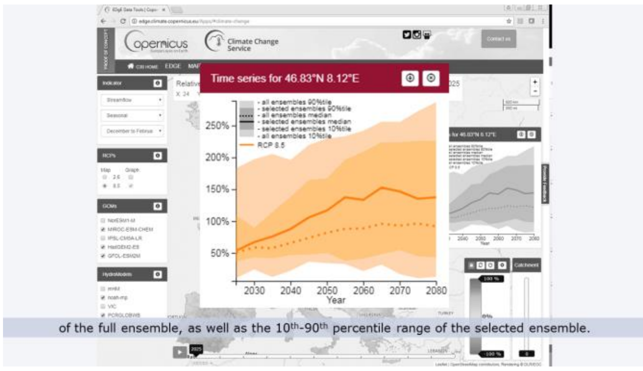

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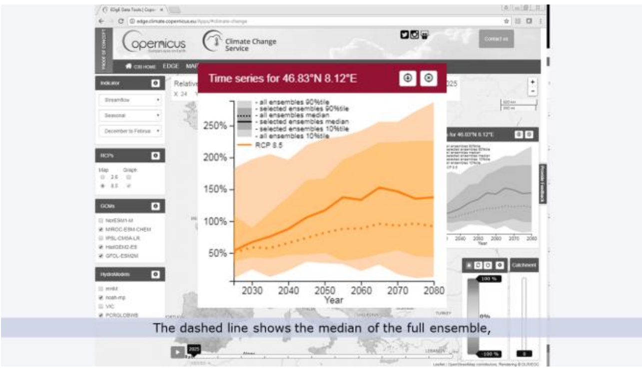

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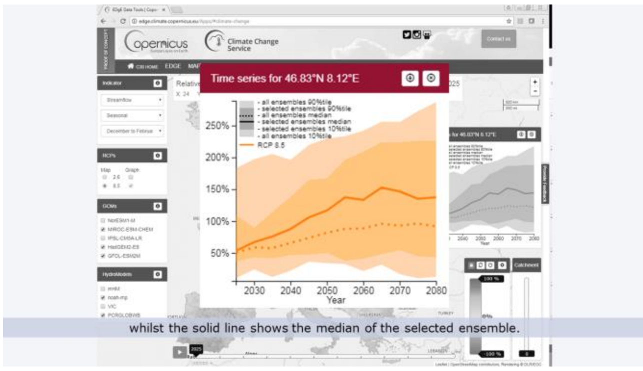

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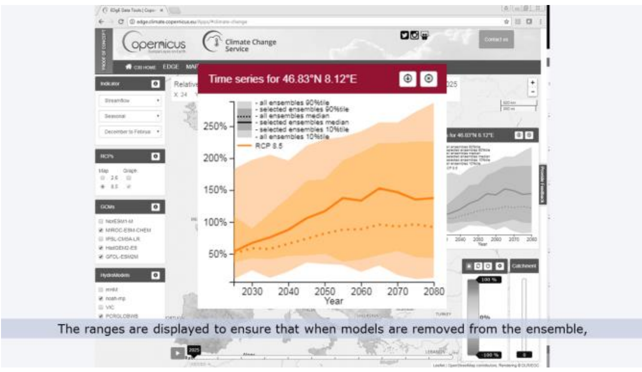

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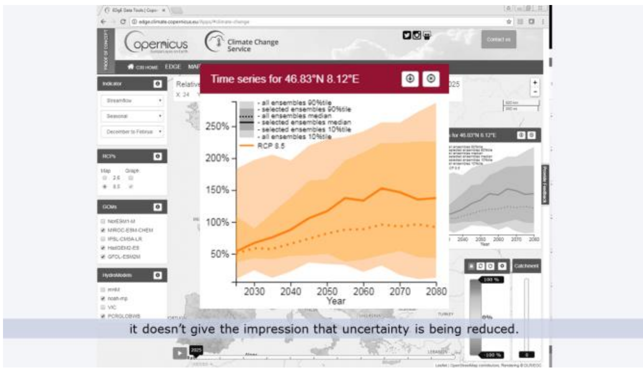

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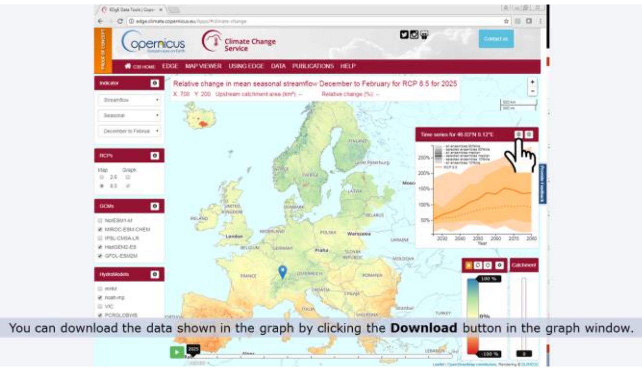

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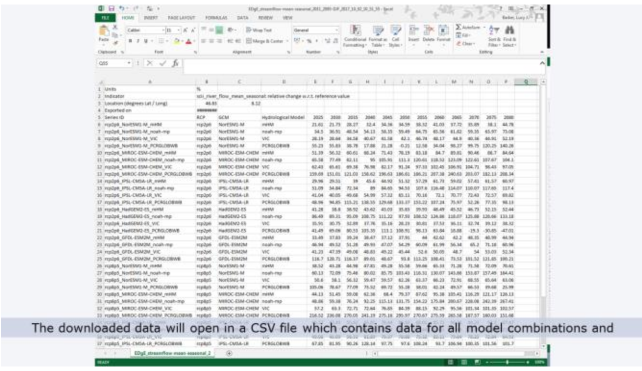

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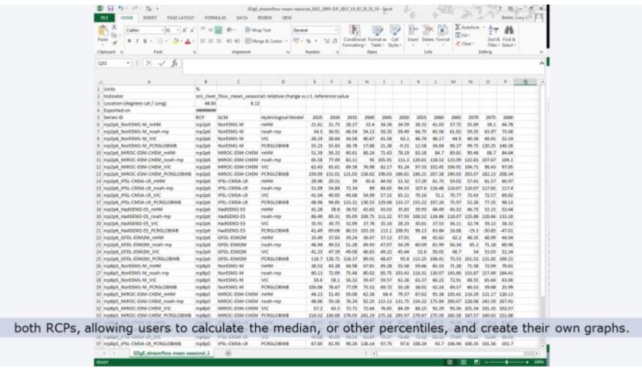

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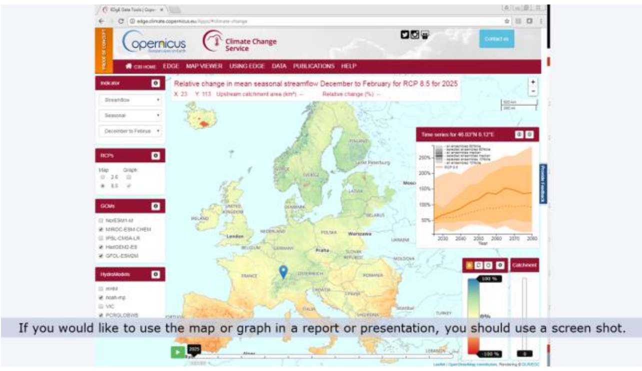

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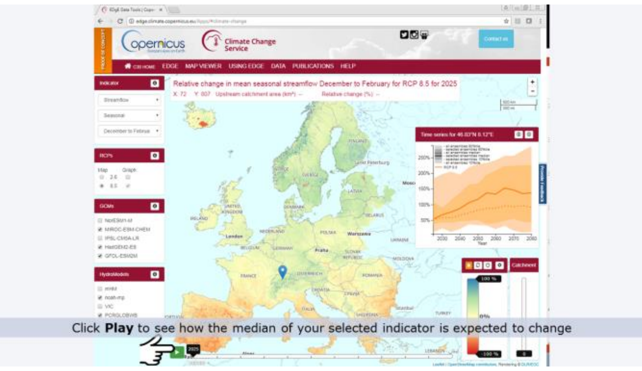

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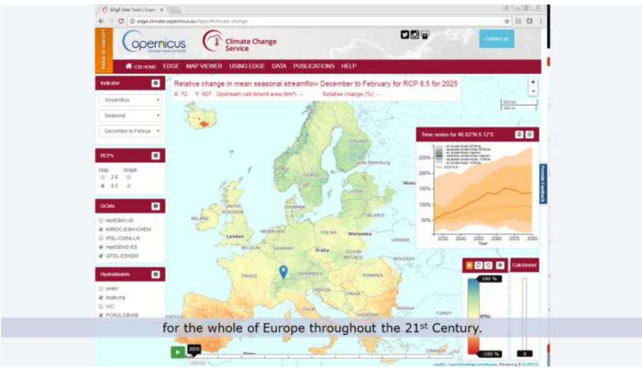

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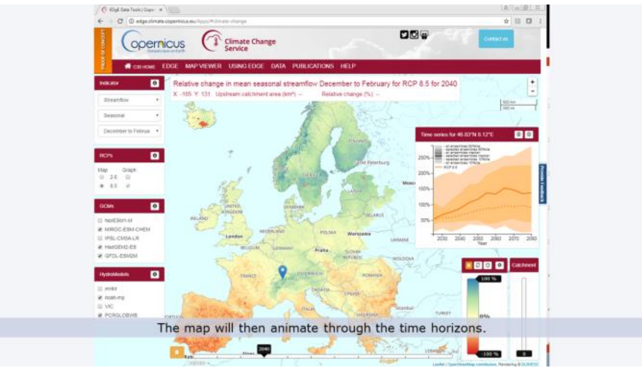

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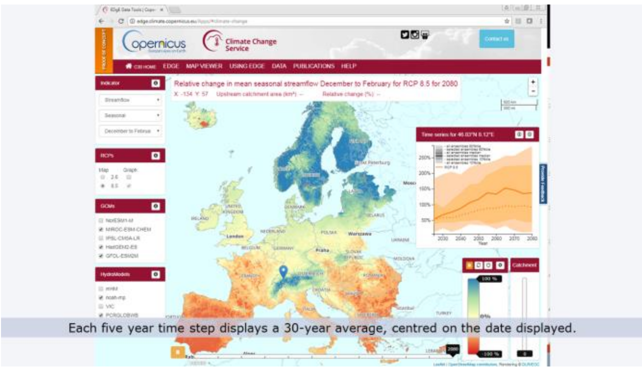

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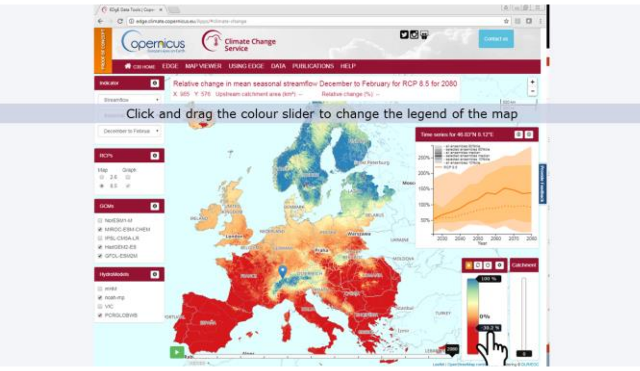

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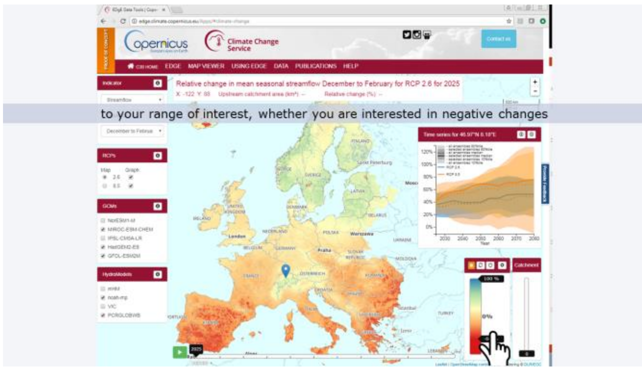

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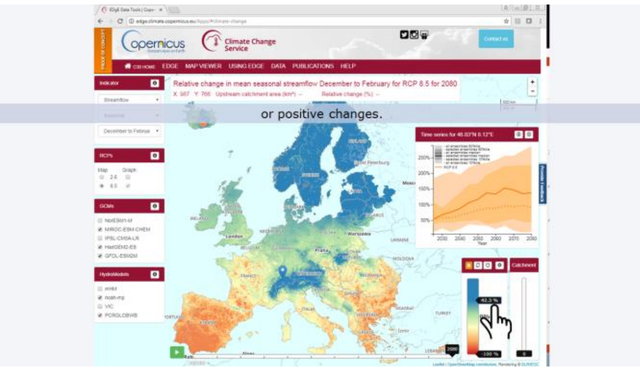

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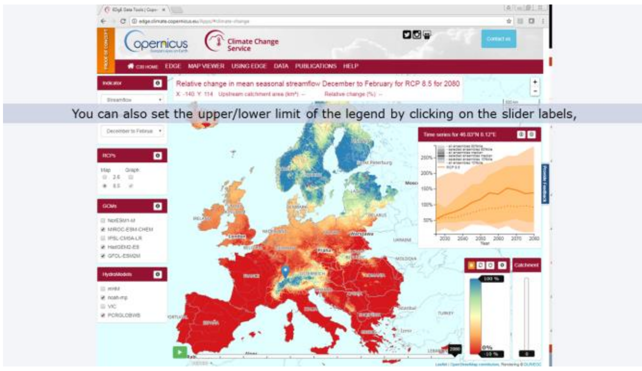

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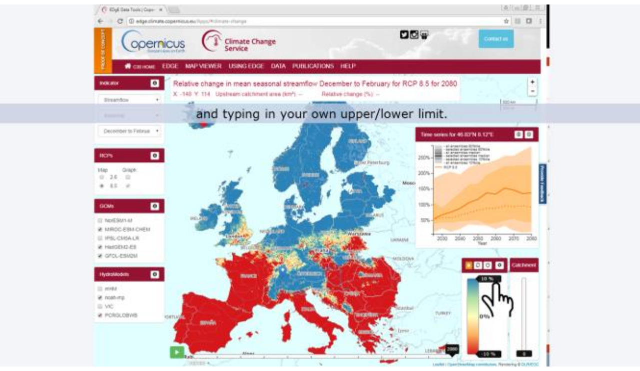

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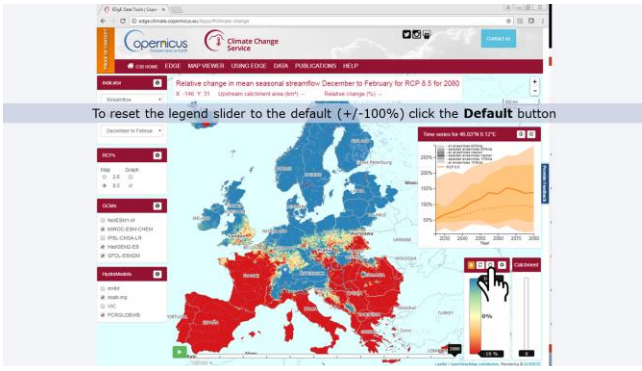

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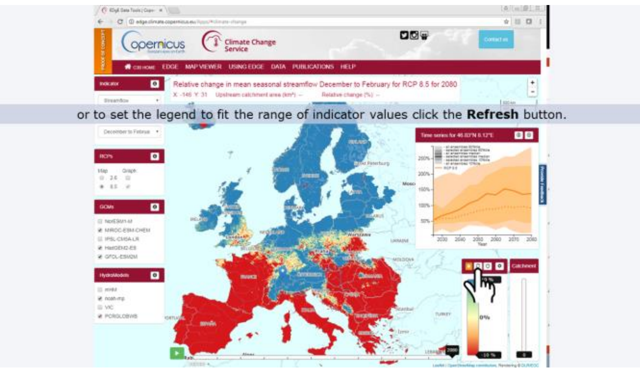

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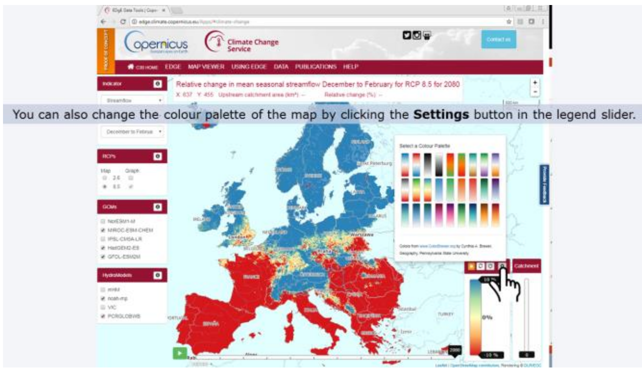

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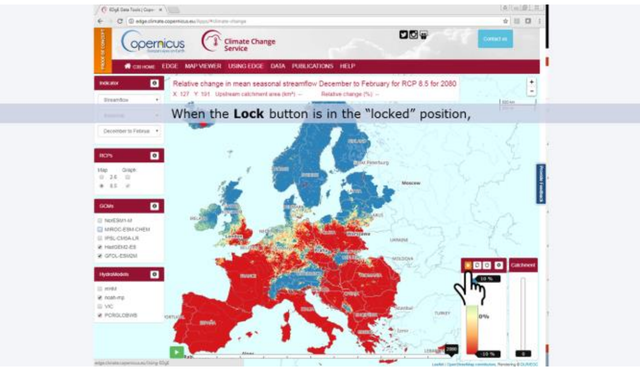

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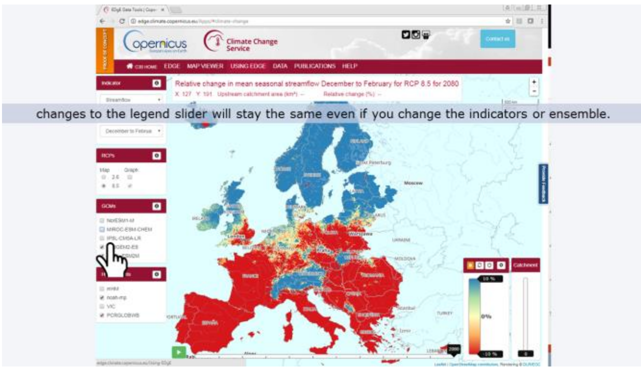

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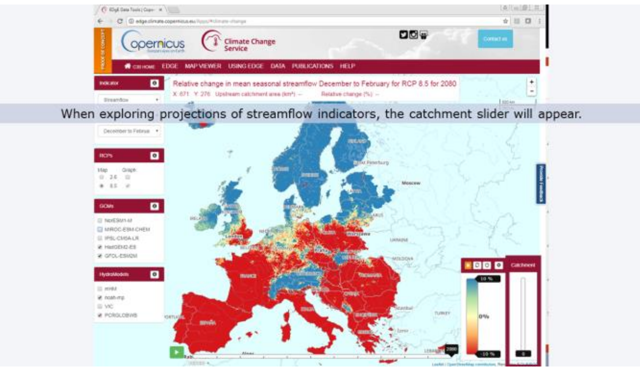

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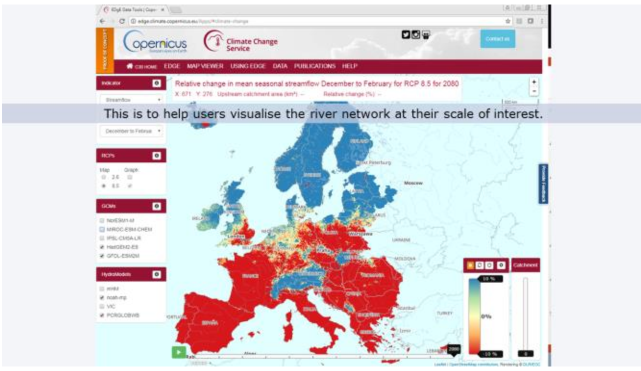

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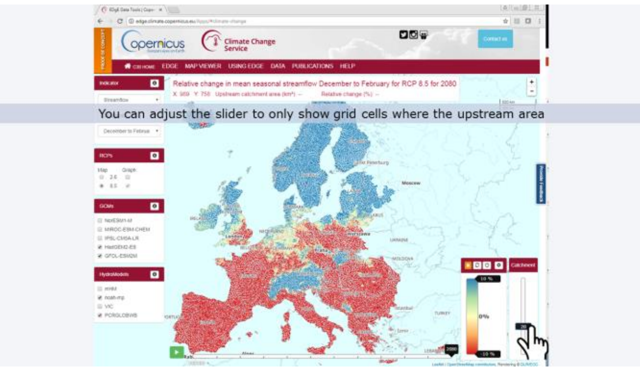

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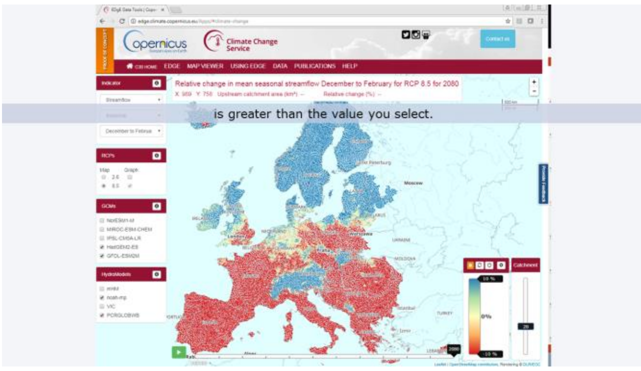

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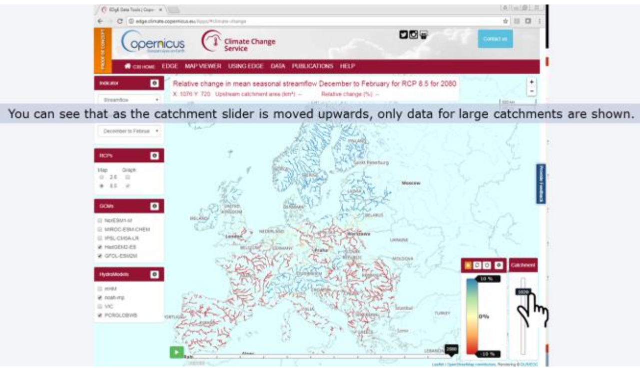

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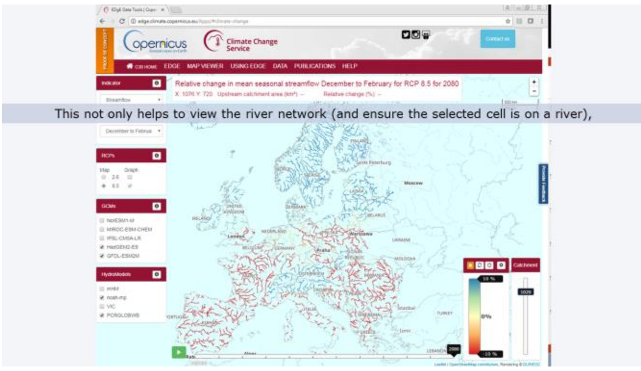

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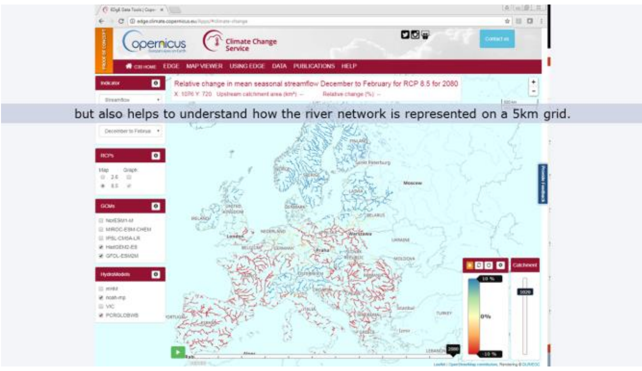
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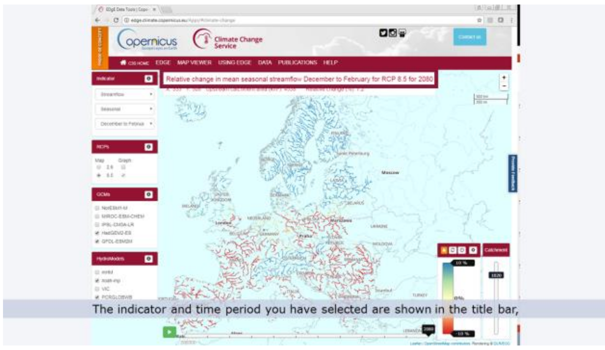
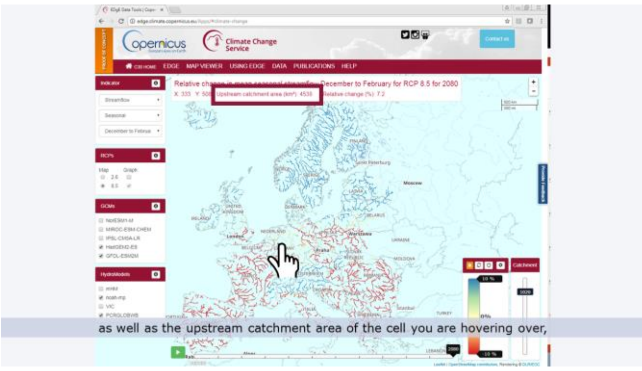
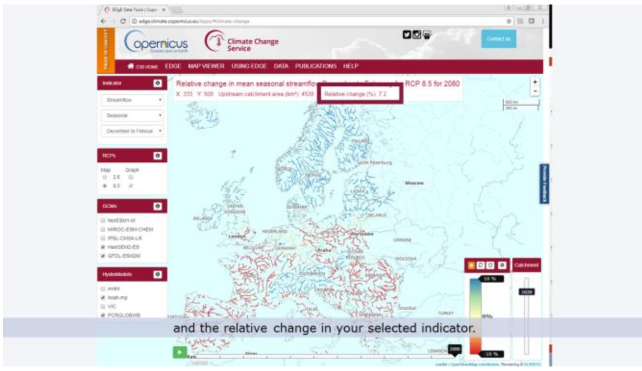

The indicator and time period you have selected are shown in the title bar,

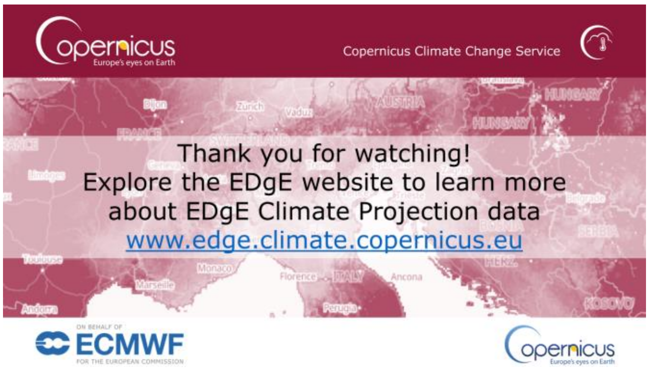
57


as well as the upstream catchment area of the cell you are hovering over,

58


and the relative change in your selected indicator.

59


Copernicus Climate Change Service
Thank you for watching!
Explore the EDgE website to learn more
about EDgE Climate Projection data
www.edge.climate.copernicus.eu

Copernicus Climate Change Service

ECMWF - Shinfield Park, Reading RG2 9AX, UK

Contact: info@copernicus-climate.eu