11 - FORECASTING THE IMPACT OF DROUGHT ON WATER RESOURCES USING SEASONAL RAINFALL FORECASTS

Brown, E.L[1], McBride, A.[1], Hodgson, R.[1], Counsell, C.[1], and Almond, S.[2]
[1] *Flood and Water Management Group, HR Wallingford Ltd, Howbery Park, Oxfordshire, OX10 8BA, UK*
[2] *European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading RG2 9AX, UK*

Abstract

Water is considered to be one of the main mechanisms through which people will experience climate change, with the number of people estimated to become exposed to water scarcity projected to increase sharply in the future (United Nations World Water Assessment Programme, 2011). Water resource managers in the UK have access to a range of meteorological and hydrological indicators of drought. However, these data are limited in their utility to directly forecast how systems should be managed to reduce impacts on water users. At present, forecasts are typically used in a qualitative manner, with seasonal forecasts not widely used to inform operational or planning decisions.

To increase uptake in the use of seasonal forecasts, water resources managers need concise visualisation of the data in a format which can readily be communicated and understood by both their management and customers. This requires inclusion of key historical information and metrics which are used across the industry to assess the current water resources status.

The European Centre for Medium-Range Weather Forecasts (ECMWF) implements the Copernicus Climate Change Service (C3S) on behalf of the European Union. At the heart of the C3S infrastructure is the Climate Data Store (CDS), which provides information on the past, present, and future climate. We have explored the potential of these data to support UK water companies manage their resources in periods of prolonged dry weather and droughts.

We combined C3S data with both operational practices and the latest UK water resources planning developments to provide metrics of value tailored to the needs of water resource managers. This analysis is presented via an app. Our app is currently operational and being updated with new forecast data as they are made available each month. It has been tested and trialled over the summer by three UK water company stakeholders.

The App allows users to view and analyse seasonal forecasts and explore how valuable these forecasts are in relation to predicting potential upcoming droughts based on historical performance. Forecasts are put into context against key industry metrics of value and meaning to water resources managers. Verification metrics are presented to help the users understand how well the forecasts have performed in the past. Visualisation of results has been developed in collaboration with industry stakeholders to ensure maximum value.

1 INTRODUCTION

Water is considered to be one of the main mechanisms through which people will experience climate change, with the number of people estimated to become exposed to water scarcity projected to increase sharply in the future (United Nations World Water Assessment Programme, 2011).

Water scarcity, or drought, has no universally accepted definition. Hydrologists, as distinct from economists or social scientists, define drought according to water deficits in some component of the hydrological cycle, or the impact on the level of service provided to the public (Tate & Gustard, 2000). Of the five main categories of drought, climatological drought, simply expressed in terms of a rainfall deficit, is used by the Environment Agency of England. The main merit of using such rainfall deficits to define droughts is the availability of long-term records. In England, the Environment Agency and water companies analyse water resources and prepare outlooks based upon long term average rainfall amounts, typically using 60% and 80% of this long term average as two key drought threshold indicators.

To support such water resources outlooks and related drought planning, the use of seasonal rainfall forecasts was considered pertinent, but at present, forecasts are typically used in a qualitative manner, with seasonal forecasts not widely used to inform operational or planning decisions.

To increase uptake in the use of seasonal forecasts, water resources managers need concise visualisation of the data in a format which can readily be communicated and understood by both their management and customers. This requires inclusion of key historical information and metrics which are used across the industry to assess the current water resources status.

1.1 Seasonal forecast data

The European Centre for Medium-Range Weather Forecasts (ECMWF) implements the Copernicus Climate Change Service (C3S) for the European Union. At the heart of the C3S infrastructure is the Climate Data Store (CDS), which provides information about the past, present and future climate. Users are able to access the CDS and download a wide range of freely available climate data from several suppliers and models.

1.2 Overview of the approach

The aim of this project was to demonstrate how seasonal forecasting data can be used to support water companies manage their resources in periods of prolonged dry weather and droughts. We have developed a web-based Application (the App) to demonstrate how this could work, with the involvement of three UK water companies and other national stakeholders.

The App allows users to view and analyse seasonal rainfall forecasts and explore how valuable these forecasts are in relation to predicting potential for upcoming droughts based on historical performance. For the area of interest, rainfall data for the past six months and the forecast ensemble rainfall data for the coming six months are displayed. Traces showing the Long Term Average (LTA) rainfall values (plus the 60% and 80% LTA traces) are also displayed, which the water companies typically use as their drought threshold indicators. In this way, it puts into context the forecast data against thresholds with which the water resources planners are familiar. An assessment of the forecast skill is also presented. The analysis presents the proportion of the ensemble members below each threshold in each month.

The intended end users of the App are water resources planners in the UK. It is designed to build upon existing frameworks in the UK water industry, using long-established methods of considering and visualising system impacts, to enable water companies to identify areas with a potential risk to Levels of Service and the time frames over which these could develop. This in turn could inform the timely preparation of drought measures.

2 METHODS

The App was designed to communicate complex meteorological data and information in a manner that is understandable and easy-to-use by water resources planners. In addition, the App was designed to present information to enable users to assess the uncertainty in the seasonal forecasts.

There is growing use of uncertainty information in presenting forecast data, although this is still an area of concern with regard to the generalist's ability to understand what is being communicated. When uncertainty is communicated effectively, it can improve upon decision-making based upon deterministic forecasts (Joslyn and Savelli, 2020), and so it was considered an important aspect to include in the design.

2.1 Data

Seasonal forecast data are available from the Climate Data Store (CDS). The App requires data relating to observed and forecast precipitation. New forecast data become available on the 13th of each month and these are automatically downloaded.

The data listed below are the primary CDS inputs to the app.

Observed rainfall data: Recently observed rainfall data are downloaded from the CDS ERA5 dataset. ERA5 is the fifth generation ECMWF reanalysis for the global climate and weather for the past 4 to 7 decades. Currently data are available from 1979 to present. This dataset is used to display the previous six months of observed rainfall data. Recent rainfall observations provide context for the forecasts, and give users an idea of the initial conditions for those forecasts.

Seasonal rainfall forecasts: Seasonal rainfall forecast data are from the ECMWF SEAS5 dataset. This consists of an ensemble of 51 forecasts for each of the 1° grid cells. A sample forecast is shown in Figure 1.

Hindcast climatology: The hindcasts are retrospective forecasts which are used to define the model climatology, available as an ensemble of 25 members.

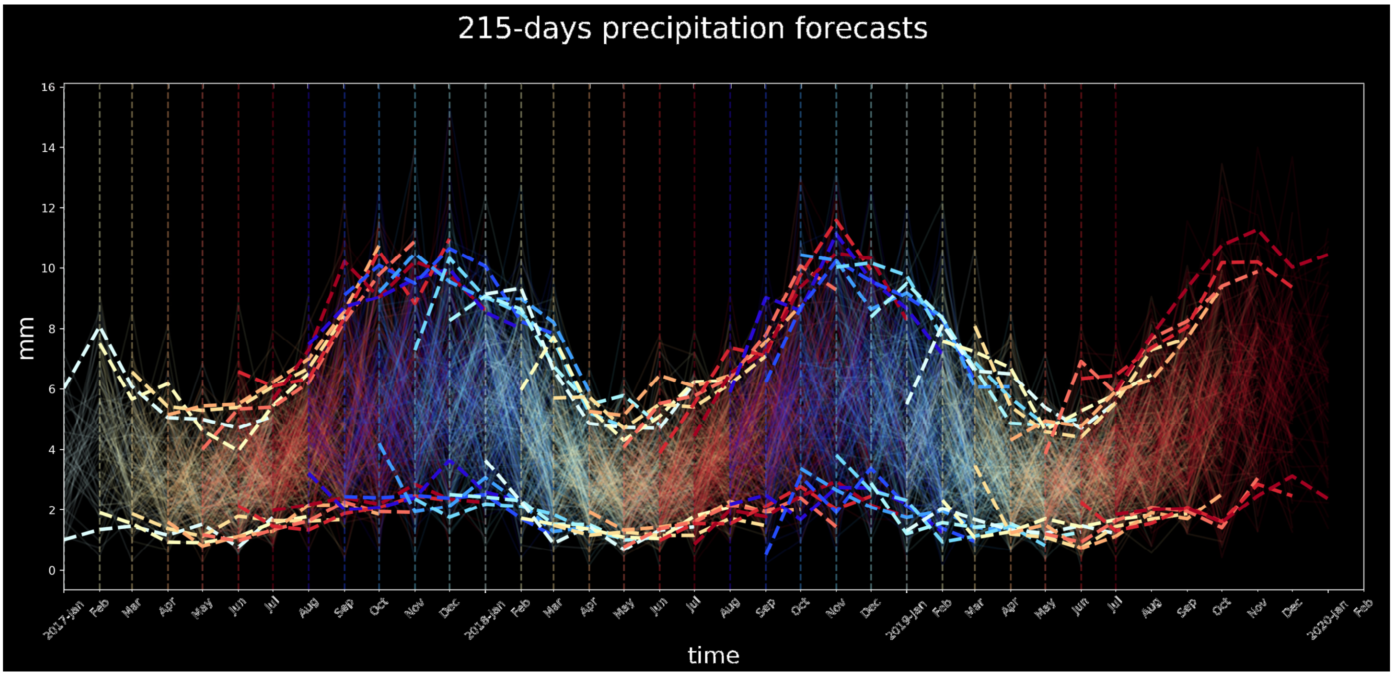

__Figure 1:__ Sample seasonal rainfall forecasts (2017 – 2019) where each colour represents a forecast initialised on a certain month. Solid lines are individual ensemble members and dashed lines represent the 5th and 95th percentiles. Source: Copernicus Climate Change Service

2.2 Bias correction

In addition to the random errors inherent in forecasts, which are quantified through the use of ensembles, there is typically a systematic difference between forecast model results and observations, due to limitations in the understanding of the physical processes, the representation of those processes in the models, and imperfect initialisation of climate models. For example, in the temperature graph of Figure 2, the difference between the actually observed climate (the blue line) and the modelled climate (the red line) clearly indicates a significant cold bias, and without correcting for this, the ensemble set of forecasts (numerous green lines) would also be biased.

Knowledge of this bias enables adjustment of data to make them more reliable. Therefore, bias correction was implemented in the App using an anomaly-based procedure, which compares the biased dataset with the model climatology to derive monthly anomalies. The anomalies are calculated as percentages of the average values, so that the procedure does not result in negative rainfall values. This procedure is applied to the 51 ensemble members of the forecast dataset, and the 25 ensemble members of the hindcast dataset. An additional potential benefit of bias correction is such that the data can then be compared sensibly with the outputs of other models, which may be of interest in the future.

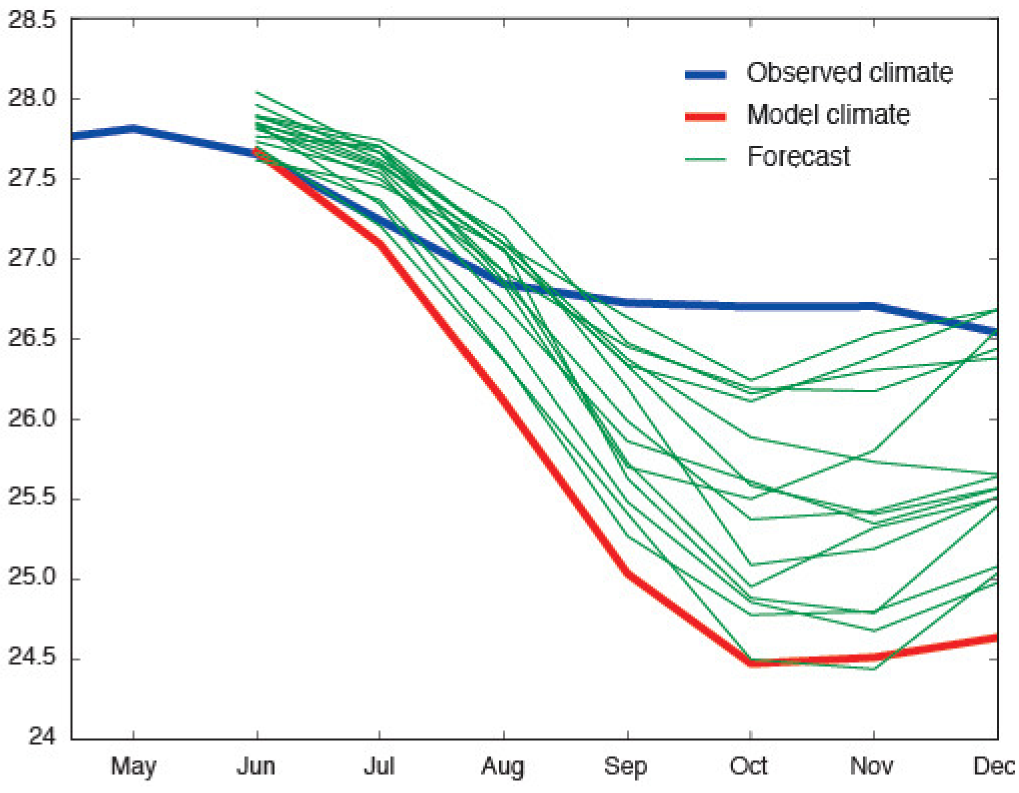

Figure 2: *Graph showing the difference between the actually observed climate (blue line) and the modelled climate (red line) alongside the ensemble set of forecasts (numerous green lines). Source: ECMWF website.*

2.3 Visualisation

Extensive and iterative stakeholder engagement was undertaken with three industry stakeholders to finalise the visualisation approach of seasonal forecasts. As quantitative seasonal forecasts are not routinely used by water resources planners or their managers, ensuring that the visuals produced were clear, concise, and of direct relevance to the decision making practices within the organisation were key.

The primary method of accessing data for a specific location is via a map-based user interface. The landing page contains a graph of Great Britain, with boundaries of the Water Resource Zones of each water company overlain by a 1-degree grid that represents the locations of the gridded data. In hovering the cursor over a grid cell, the user is informed of the area ("Water Resource Zone") and water company of relevance (Figure 3). The landing page also contains a descriptive methodology and user guide, for ready information on the data sources and the information presented.

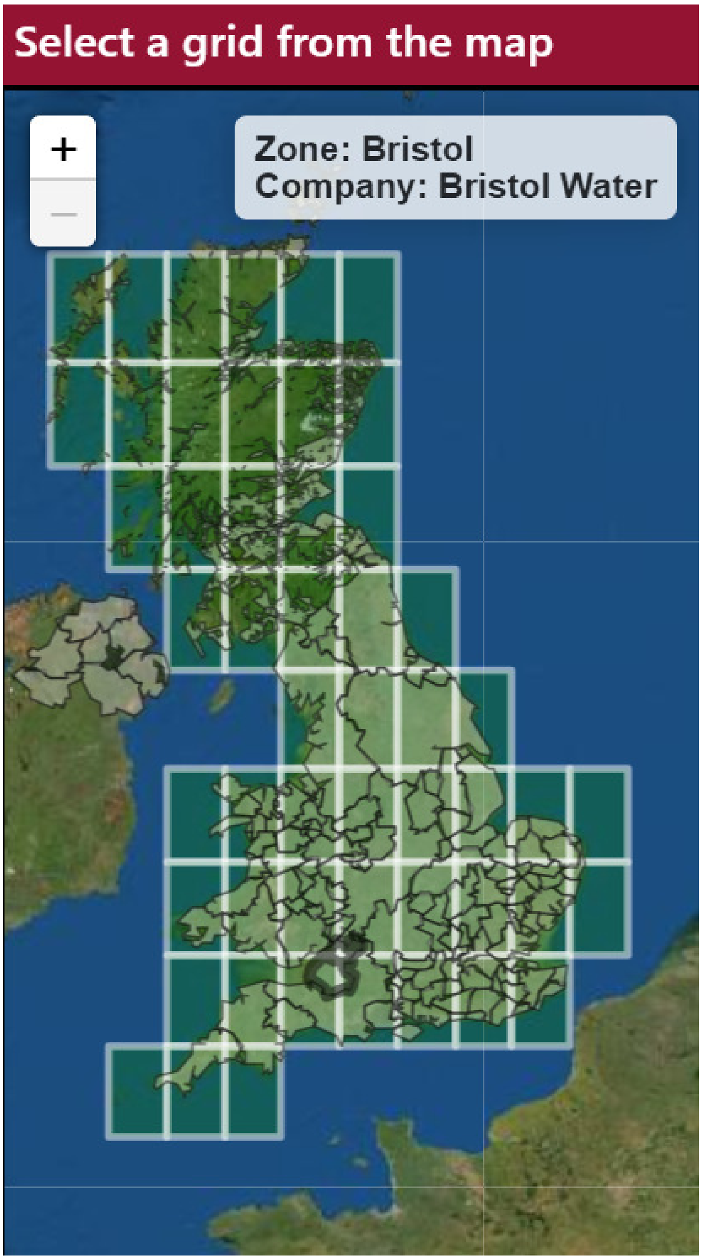

Figure 3: *Map showing Water Resource Zones and grid cells for selection, with Bristol Water's zone highlighted*

A mouse click on the grid cell generates a graph to the right-hand side. The graph summarises recently observed and upcoming rainfall forecast data alongside LTA rainfall (Figure 4).

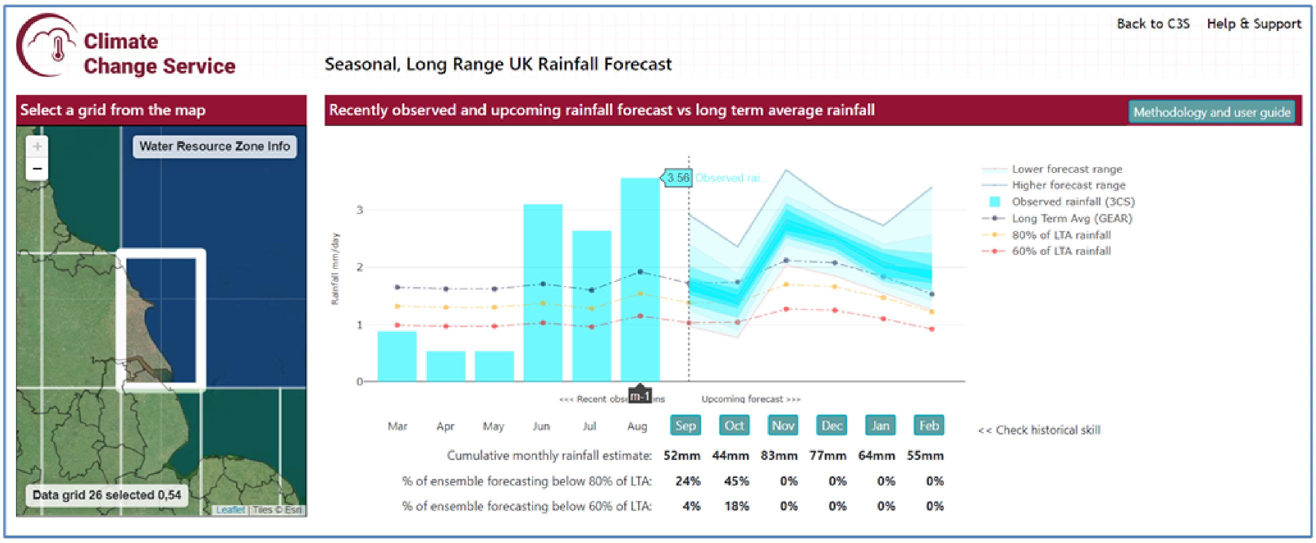

Figure 4: *Graph of recently observed and upcoming rainfall forecast data alongside LTA rainfall*

In order to provide some context for the forecasts, and to give an idea of the initial conditions for the forecast recently observed monthly rainfall values are presented on the graph (as vertical blue bars). An addition to the rainfall deficit, from a water resource availability perspective, the catchment wetness at a particular point in time is important to know, since it is key to determining how much of the total rainfall will infiltrate and how much will run off to become an available surface water resource.

The seasonal forecast dataset is an ensemble of 51 ensemble members, represented by a contoured, shaded blue polygon to the right of the vertical black dotted line, with contours at every 10th percentile of the forecast range. Traditional forecasts were deterministic, giving one prediction of the likely future state of the climate; by contrast, probabilistic forecasting creates a set of ensemble members that represent the uncertainty of the forecast, each of which reflects the uncertainty in the initial conditions of the forecasting model, and the errors in the forecast model formulation.

The long-term average rainfall threshold is represented as a blue dashed line. This threshold is derived from the Centre for Ecology and Hydrology's Gridded Estimates of Areal Rainfall (GEAR) dataset (Tanguy, et al., 2019). GEAR is a gridded 1km product derived from the interpolation of observed rainfall at all of the available daily and monthly rain gauges in the UK. Related to this are two key drought indicator thresholds, as advised by the Environment Agency, namely 80% LTA rainfall (yellow dashed line) and 60% LTA rainfall (red dashed line).

In addition, cumulative forecasted rainfall depth for specific months is indicated below the graph. The proportion of the ensemble members below each of the two drought thresholds is indicated, as a percentage. This gives users not only a visual feel for the likelihood of a drought, but also a numerical value upon which to base their decisions for management of the water resource. For instance, where the large majority of the forecast ensemble members lie below one or both of the thresholds, the end user can say with some certainty that a drought will manifest itself during that period.

2.4 Verification of forecasts

In order to give the user some idea of the quality of the forecasts, there are several attributes that can be examined. In turn, such verification of the forecasts can provide some idea of their value, that is, the degree to which the forecasts can help the decision maker (in this case, the water resources manager) to realise a benefit (in this case, to support water resources managers to manage their resources in dry weather and droughts). The main approach used here was the contingency score.

Contingency scoring

Contingency scores and associated tables are highly flexible methods that can be used to estimate the quality of a forecast and indicate its ability to anticipate correctly the occurrence or non-occurrence of predefined events. They are widely used in meteorological and hydrological applications, notably for flood forecasting (see: Environment Agency, 2009; Bartholmes et al., 2009).

In this case, the historical forecast ensemble dataset was compared with the drought thresholds derived from the historical observed rainfall data (from GEAR); the comparison was made specifically with the 80% and 60% LTA data. The information shows the Hit Rate as the colour-coded percentage of time that the hindcasts correctly forecasted rainfall below the 60% and 80% LTA thresholds. An accompanying bar graph shows the historical observed data (from 1993 to 2016), with a trace indicating the hindcast ensemble mean.

Since the forecast verification depends upon the location, lead time and the time of year, the user can select to perform the analysis for any cell, for any month, and for lead times of zero to six months (Figure 5). This is a useful tool for appreciation of the months of the year when the forecasts perform best for different parts of the country, and to see how the performance tends to fall with increasing lead time. This is useful information so that end users can see whether forecasts for particular months of interest (such as April in the UK) have value for their drought planning over the summer months.

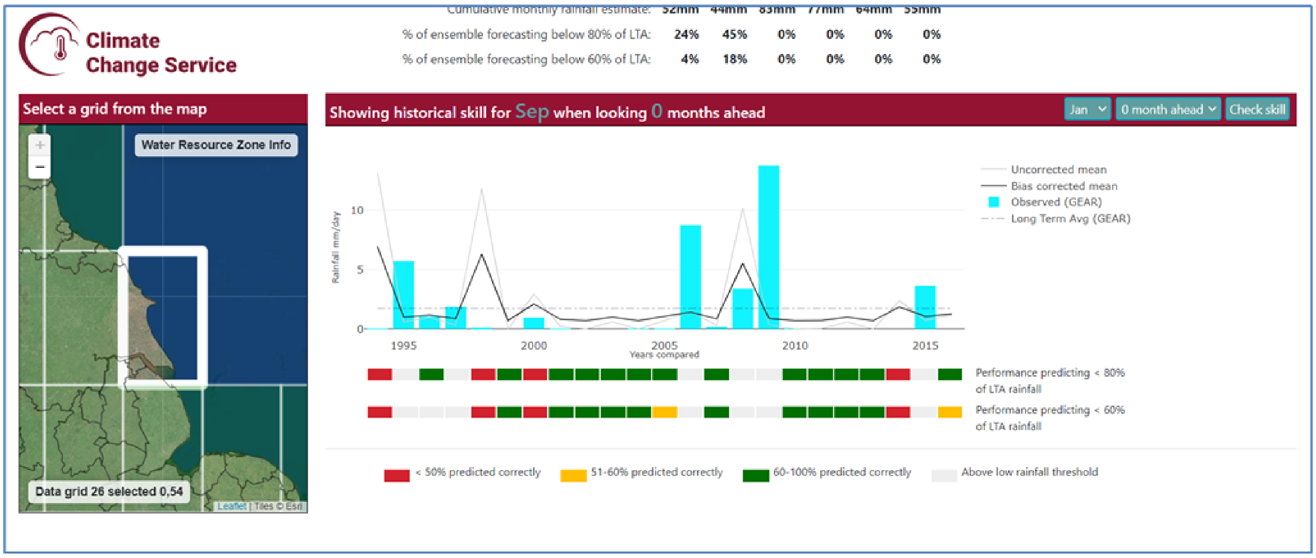

Figure 5: *Graph of verification metrics for September for a grid cell in east England*

3 CONCLUSIONS

Through engagement with our water company and national stakeholders, as well as with the Forecasting and Communications Teams at ECMWF, a number of refinements to the App were able to be made to ensure accuracy of the methods, and the use of appropriate and helpful communication techniques. A full set of feedback was gathered, and a clear appetite for continued use of the App emerged, with some ideas for further developments and enhancements, including the use of temperature data as another key metric and driver for droughts.

One key benefit of an App such as this is the increased familiarity of the industry stakeholders with the C3S products and their potential for use in their operations and planning. It promotes familiarity with the concept of probabilistic forecasts and their communication.

4 REFERENCES

Bartholmes, J.C., Thielen, J., Ramos, M.H., and Gentilini, S. (2009) The European Flood Alert System EFAS – Part 2: Statistical skill assessment of probabilistic and deterministic operational forecasts. *Hydrol. Earth Syst. Sci.* 13, 141-153.

Environment Agency (2009) *Risk-based probabilistic fluvial flood forecasting for integrated catchment models – Phase 1 Report*. Science Report: SC080030/SR1. ISBN: 978-1-84911-097-6.

Joslyn, S. and Savelli, S. (2020) Communicating forecast uncertainty: public perception of weather forecast uncertainty. *Meteorological Applications, Journal of the Royal Met. Soc, 17(2), Special Issue: Communicating weather information and impacts*. June 2020.

Tanguy, M., Dixon, H., Prosdocimi, I., Morris, D.G., and Keller, V.D.J. (2019) *Gridded estimates of daily and monthly areal rainfall for the United Kingdom (1890-2017) [CEH-GEAR].* NERC Environmental Information Data Centre. https://doi.org/10.5285/ee9ab43d-a4fe-4e73-afd5-cd4fc4c82556

Tate, E.L. and Gustard, A. (2000) Drought definition: a hydrological perspective. In: *Drought and Drought Mitigation in Europe*, ed. J.V. Vogt and F. Somma. Kluwer academic publishers.

United Nations World Water Assessment Programme (2011) *Water and climate dialogue: adapting to climate change: why we need broader and 'out-of-the-box' approaches*. UNESCO Briefing Note. ISBN 978-92-3-001004-1